Vol. 49 • No. 6
June 2006

Microwave Journal

Semiconductors/ MMICs/RFICs

The Road from RFIC to SoC

UHF RFID and Tag Antenna Scattering

Power Amplifiers for RF and Microwave Applications

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Featured Products

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- EMI gasket or ground plane available
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- VSWR < 1.3:1 through 26.5GHz.

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- Single body construction
- Solid outer contacts
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- VSWR @ 2 GHz: 1.03:1
  @ 6 GHz: 1.17:1
  @ 11 GHz: 1.43:1

$4.25 ea (2500 pcs)

Low Loss Cable Assemblies

- VSWR through 18 GHz 1.20:1
  (Based on 3 ft flexible low loss cable terminated with 2 SMA plugs)

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RG 402/405 type cables with Anti-Torque SMAs

- .141 Hand-formable
- VSWR through 18 GHz 1.12:1

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To Provide Exce
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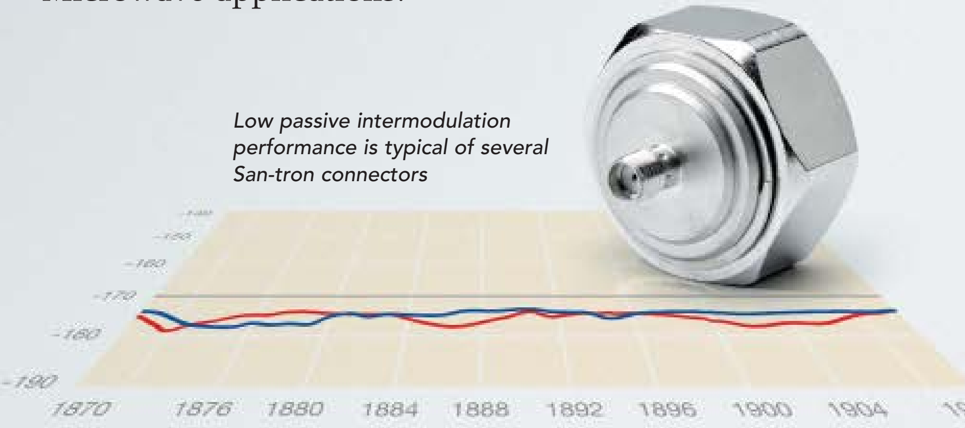
As a family owned business, San-tron is proud to be expanding upon a 50 year reputation as a premier RF coaxial connector manufacturer. We're bringing you more options, faster deliveries, higher performance and even greater levels of quality. Offering everything from the latest SMAs, turnkey cable assemblies and custom interconnects up to 34 GHz, San-tron is dedicated to becoming your end-to-end connector and cable assembly resource for a new generation of RF and Microwave applications.

Low passive intermodulation performance is typical of several San-tron connectors



Measuring Up

You can buy connectors from a variety of companies but no one delivers low passive intermodulation performance more consistently than San-tron. With five decades of engineering experience behind us, we've perfected the selection of components and materials and the design/manufacturing techniques that produce PIM performance below -170 dBc on even the most challenging designs.

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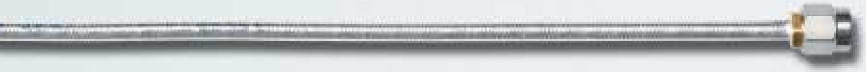

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With headquarters, engineering, and manufacturing in Ipswich, Massachusetts, and a wholly owned manufacturing facility in Suzhou, China, San-tron offers a balanced approach to meeting market demands. Our flexible manufacturing options allow us to provide solutions on a component-by-component basis and to meet every delivery, pricing and performance requirement of today's applications.

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Our company has been built on a reputation for providing precise solutions to the most challenging interconnection requirements. Our design/manufacturing expertise enables us to perfect your interfaces and impedance matching requirements, often resulting in improved system performance.

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From mobile battlefield radar terminals to tower connections in the arctic tundra, San-tron products have stood the test. Our connectors are trusted in high level military and homeland security programs, and in the most demanding wireless and medical applications in the world.

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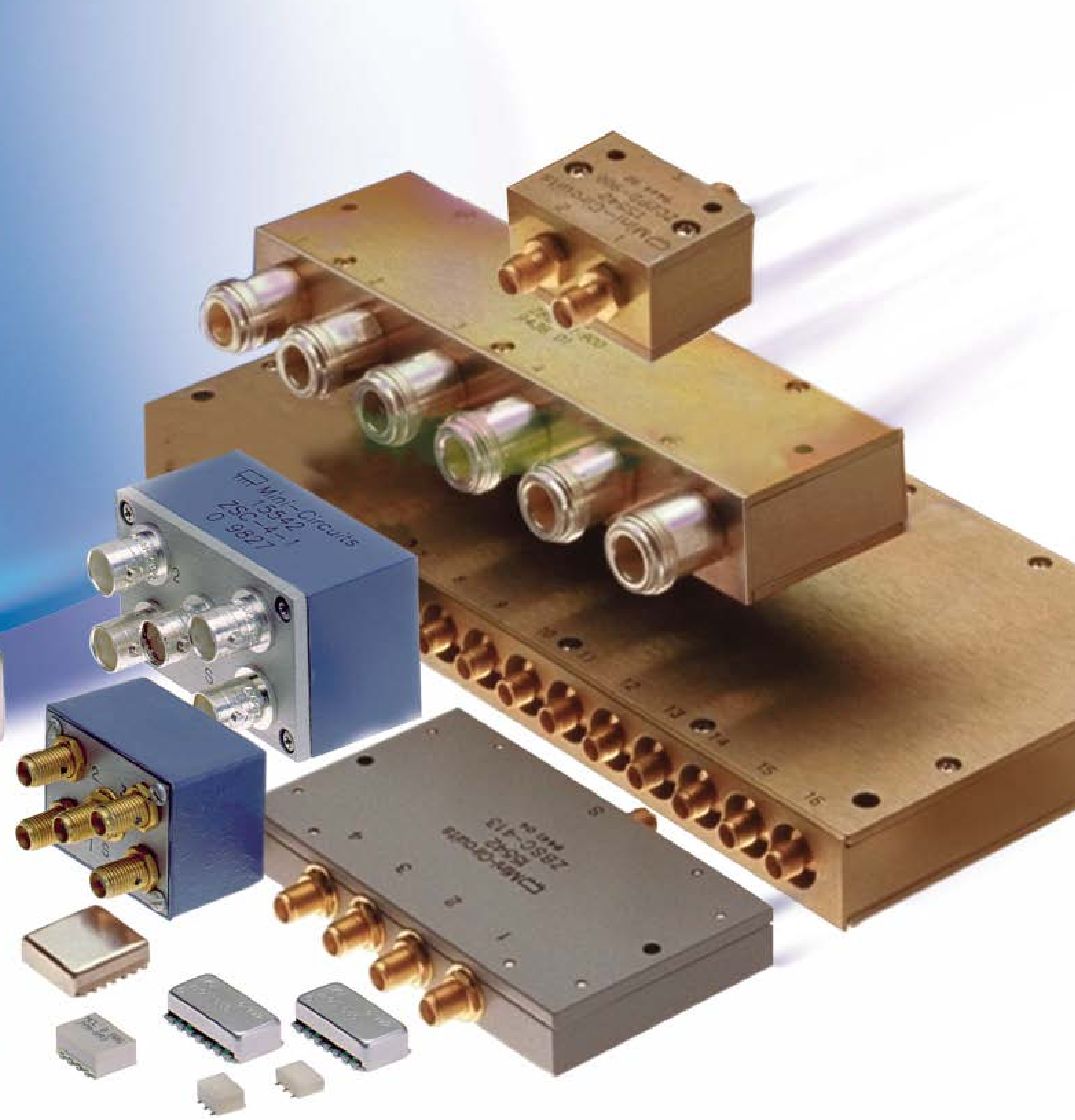

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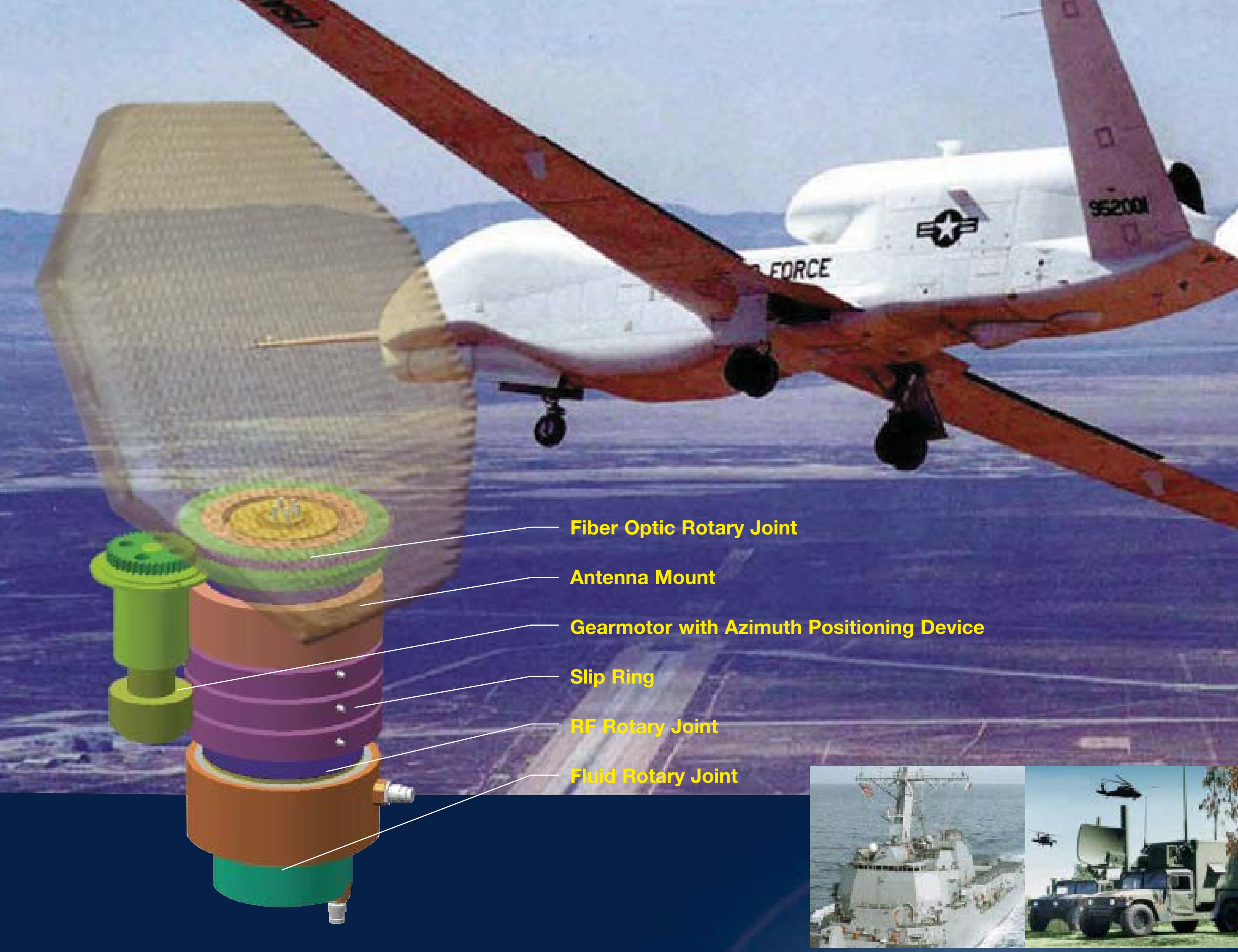

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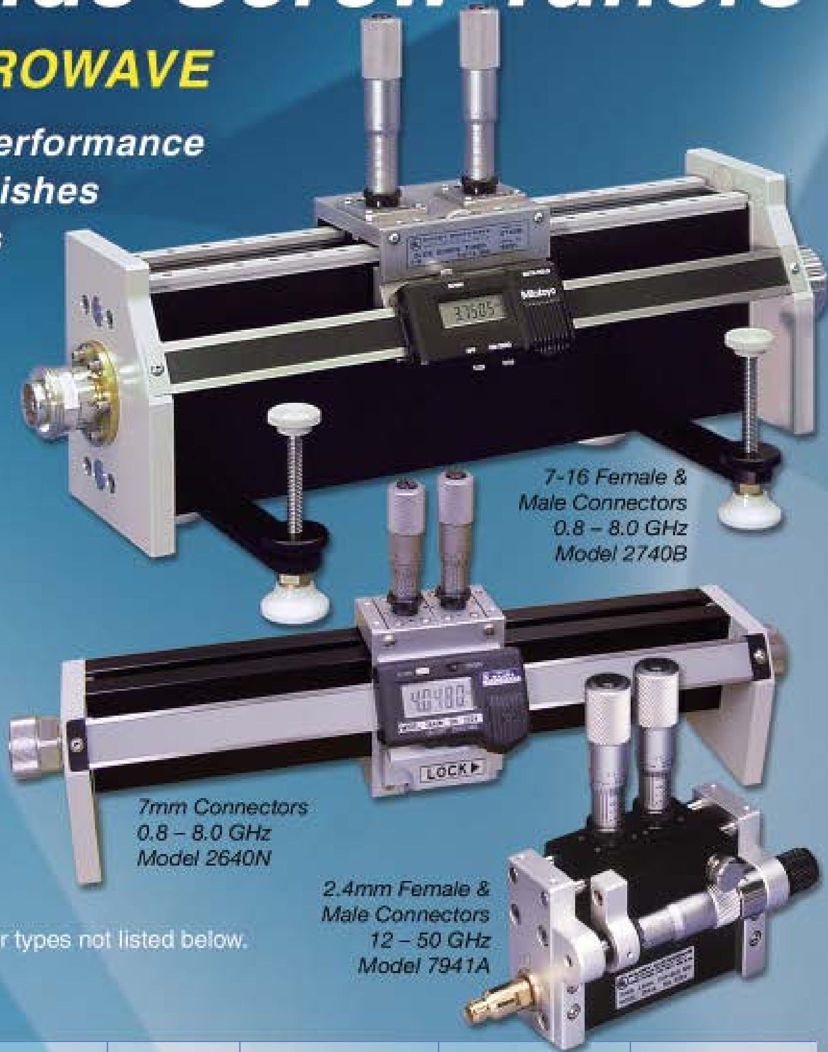

7-16 Female & Male Connectors 0.8 – 8.0 GHz Model 2740B

7mm Connectors 0.8 – 8.0 GHz Model 2640N

2.4mm Female & Male Connectors 12 – 50 GHz Model 7941A

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* Maury also makes adapters for connector types not listed below.

Available Models

MODEL	FREQUENCY RANGE (GHz)	CONNECTOR TYPE	VSWR MATCHING RANGE	MAXIMUM LOSS (PROBES RETRACTED)	PROBE CROSSOVER FREQUENCY	POWER [1] HANDLING (AVE./PK. WATTS)	CARRIAGE TRAVEL INCHES	(CM)	OVERALL LENGTH INCHES	(CM)
7941A	12.0 — 50.0	2.4mm	10:1	1.0 dB	21.5 GHz	15/150	0.417	(1.059)	4.62	(11.735)
8041C	12.0 — 34.0	3.5mm	10:1	0.7 dB	16.0 GHz	15/150	0.417	(1.059)	4.95	(12.573)
8045D1		3.5mm				25/250	3.4	(8.636)	8.94	(22.708)
2640D1	1.8 — 18.0	7mm	12:1	0.4 dB	5.5 GHz	50/500	3.4	(8.636)	8.88	(22.555)
1643D1		Type N				50/500	3.4	(8.636)	8.92	(22.657)
8045P		3.5mm				25/250	7.8	(19.812)	13.34	(33.884)
2640P	0.8 — 18.0	7mm	10:1	0.6 dB	4.6 GHz	50/500	7.8	(19.812)	13.28	(33.731)
1643P		Type N				50/500	7.8	(19.812)	13.32	(33.833)
1643N	0.8 — 2.5 2.5 — 8.0	Type N	25:1 18:1	0.5 dB	2.8 GHz	50/500	7.8	(19.812)	13.32	(33.833)
2640N	0.8 — 2.5 2.5 — 8.0	7mm	25:1 18:1	0.5 dB	2.8 GHz	50/500	7.8	(19.812)	13.28	(33.731)
8045N	0.8 — 2.5 2.5 — 8.0	3.5mm	25:1 18:1	0.5 dB	2.8 GHz	25/250	7.8	(19.812)	13.34	(33.884)
2740B	0.8 — 8.0	7-16	35:1	0.1 dB	2.8 GHz	100/1000	7.88	(20.015)	14.48	(36.779)
2440B		14mm					7.88	(20.015)	13.07	(33.198)
2740C	0.4 — 4.0	7-16	25:1	0.1 dB	1.4 GHz	100/1000	14.95	(37.973)	22.76	(57.810)
2440C		14mm					14.95	(37.973)	21.35	(54.229)

[1] Within rated matching range.

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Microwave Journal

JUNE 2006 VOL. 49 • NO. 6

FEATURES

COVER FEATURE

SPECIAL REPORT

TECHNICAL FEATURES

APPLICATION NOTE

Microwave Journal (USPS 396-250) (ISSN 0192-6225) is published monthly by Horizon House Publications Inc., 685 Canton St., Norwood, MA 02062. Periodicals postage paid at Norwood, MA 02062 and additional mailing offices.

POSTMASTER: Send address corrections to *Microwave Journal*, PO Box 3256, Northbrook, IL 60065-3256 or e-mail mwj@omeda.com. Subscription information: (847) 291-5216. This journal is issued without charge upon written request to qualified persons working in that part of the electronics industry, including governmental and university installation, that deal with VHF through light frequencies. Other subscriptions are: domestic, $120.00 per year, two-year subscriptions, $185.00; foreign, $200.00 per year, two-year subscriptions, $370.00; back issues (if available) and single copies, $10.00 domestic and $20.00 foreign. Claims for missing issues must be filed within 90 days of date of issue for complimentary replacement.

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Printed in the USA


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Ask Harlan

"Ask Harlan," a technical question and answer session with Harlan Howe, Jr., an industry veteran and long-time *Microwave Journal* editor, has been a regular part of our web site (www.mwjournal.com) for almost two years now. In an effort to better combine the editorial content of our magazine with our newly developed and retooled on-line presence, we have decided to develop Harlan's RF and microwave engineering advice into a monthly feature.

How it works: Harlan has selected one question from his "Ask Harlan" column to be featured in the magazine. Please visit www.mwjournal.com/askharlan to provide an answer to this month's featured question (see below). Harlan will be monitoring the responses and will ultimately choose the best answer to the question. Although all of the responses to the featured question will be posted on our web site, we plan to publish the winning answer in the August issue. All responses must be submitted by **July 7, 2006**, to be eligible for the participation of the June question.

The winning response will win a free book from Artech House, along with an "I Asked Harlan!" t-shirt. In addition, everyone who submits a legitimate response will be sent an "I Asked Harlan!" t-shirt.

April Question and Winning Response

The April question was submitted by Renuka Wekhande from RF Arrays Systems India Pvt. Ltd.:

Dear Harlan,

1. What are the various parasitics that should be considered when designing a monolithic microwave integrated circuit (MMIC) for standard quad flat no-lead (QFN) packages?
2. What are the advantages of using a gallium arsenide (GaAs) heterojunction bipolar transistor (HBT) over a pseudomorphic high electron mobility transistor (PHEMT)?

The winning response to the April question is from Bhavin Shah of Hittite Microwave Corp.:

1. The major parasitic component for a MMIC housed in a QFN package is the bondwire inductance.
2. GaAs HBT can be run at higher current densities thereby increasing their output power over the PHEMT. HBTs are inherently more linear compared to the PHEMT.

This Month's Question of the Month

(answer on-line at www.mwjournal.com/askharlan)

Charles Werner from Gamma Remote Sensing AG has submitted this month's question:

Dear Harlan,

1. How good are direct digital synthesizers at generating FMCW signals? I am looking at a system that uses a frequency translation loop Analog Devices AD9858 to get output in the range of 2.1 to 2.3 GHz for an FMCW radar.
2. What is the best way to get this signal heterodyned to the range of 4.1 to 4.3 GHz and what configuration of mixer/LO is recommended/required?

If your response is selected as the winner, you'll receive a free book of your choice from Artech House. Visit the Artech House on-line bookstore at www.artechhouse.com for details on hundreds of professional-level books in microwave engineering and related areas (maximum prize retail value $150).

RF & MICROWAVE
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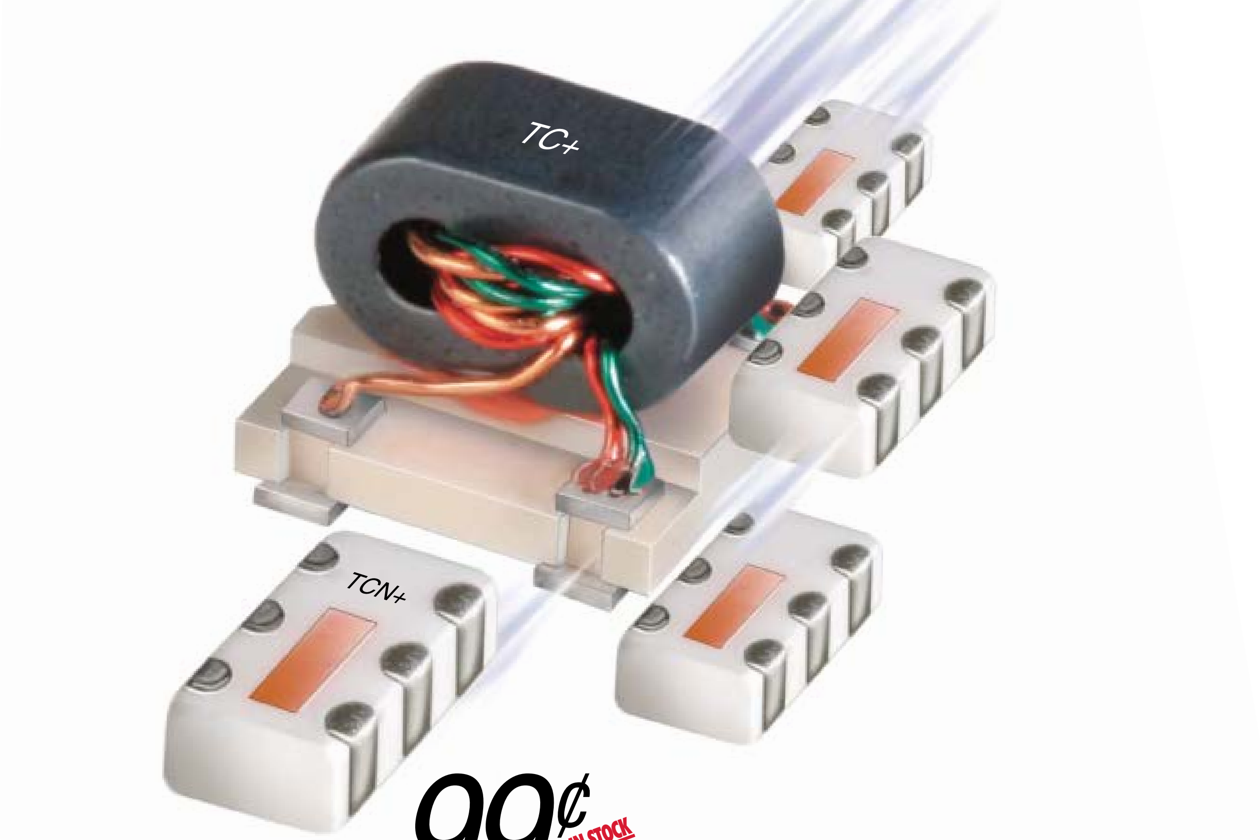

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TCL1-11+	1	G	600-1100	1.09
TCL1-19+	1	G	800-1900	1.09
TC1.5-1+	1.5	D	0.5-2200	1.59
TC2-1T+	2	A	3-300	1.29
TC3-1T+	3	A	5-300	1.29
TC4-14+	4	A	200-1400	1.29
TC4-19+	4	H	10-1900	1.09
TC4-1T+	4	A	0.5-300	1.19
TC4-1W+	4	A	3-800	1.19
TC4-25+	4	H	500-2500	1.09
TC4-6T+	4	A	1.5-600	1.19
TC8-1+	8	A	2-500	1.19
TC9-1+	9	A	2-200	1.29
TC16-1T+	16	A	20-300	1.59
*TC4-11+	50/12.5	D	2-1100	1.59
*TC9-1-75+	75/8	D	0.3-475	1.59

*Step down transformer.

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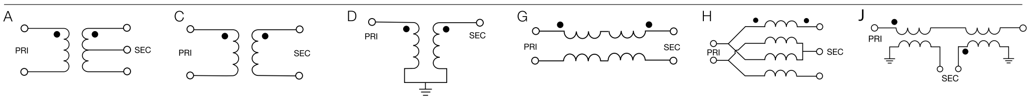

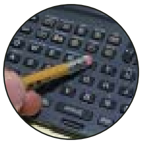

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by July 28, 2006
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by August 18, 2006
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by October 2, 2006

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WCA 2006
June 27–30, 2006 • Washington, DC
www.wcai.com

AUGUST

NIWeek 2006
August 8–10, 2006 • Austin, TX
www.ni.com/niweek

IEEE International Symposium on Electromagnetic Compatibility (EMC 2006)
August 14–18, 2006 • Portland, OR
www.emc2006.org

SEPTEMBER

Antenna Systems Co-located with Short-range Wireless 2006
September 6–7, 2006 • Vienna, VA
www.antennasonline.com

European Microwave Week 2006 (EuMW 2006)
September 10–15, 2006 • Manchester, UK
www.eumw2006.com

IRMMW-THz 2006
September 18–22, 2006 • Shanghai, China
www.sitp.ac.cn/irmmw-thz2006

IEEE International Conference on Ultra-wideband (ICUWB 2006)
September 24–27, 2006 • Waltham, MA
www.icuwb2006.org

OCTOBER

AMTA 2006
October 22–27, 2006 • Austin, TX
www.amta.org

NOVEMBER

electronica 2006
November 14–17, 2006 • Munich, Germany
www.electronica.de

MM-Wave Products and Technologies
November 16, 2006 • Savoy Place, London
www.iee.org/events/mmwave.cfm

JANUARY

IEEE Radio and Wireless Symposium (RWS 2007)
January 9–11, 2007 • Long Beach, CA
www.radiowireless.org

IEEE Topical Workshop on Power Amplifiers for Wireless Communications (PA Workshop)
January 8–9, 2007 • Long Beach, CA
http://paworkshop.ucsd.edu

7th Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF 2007)
January 10–12, 2007 • Long Beach, CA
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■ **Topics:** This intensive, five-day course provides acceleration through the RF design learning curve by presenting a comprehensive introduction to RF and microwave design theory, techniques and measurements. Although the course includes necessary theoretical aspects, great emphasis is placed upon the practicalities of RF engineering. For more information, visit www.conted.ox.ac.uk.
■ **Site:** Summertown, Oxford, UK
■ **Dates:** July 3–7, 2006
■ **Contact:** University of Oxford Continuing Education, 1 Wellington Square, Oxford, OX1 2JA UK +44 (0) 1865 286958 or e-mail: anthony.santiago@conted.ox.ac.uk.

ANTENNAS: PRINCIPLES, DESIGN AND MEASUREMENTS

■ **Topics:** This course will present antenna fundamentals, arrays, wire antennas, broadband antennas, horns, reflectors, antennas in systems, antennas for wireless communications and measurements. For more information, visit www.antennacourse.com.
■ **Site:** Albuquerque, NM
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■ **Contact:** Leanne Traver, Northeast Consortium for Engineering Education, PO Box 68, Port Royal, VA 22535 (804) 742-5611 or e-mail: edpub@crosslink.net.

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Gali 1	DC-8000	12.7	12.2	4.5	27	108	40	3.4	.99
Gali 21	DC-8000	14.3	12.6	4.0	27	128	40	3.5	.99
Gali 2	DC-8000	16.2	12.9	4.6	27	101	40	3.5	.99
Gali 33	DC-4000	19.3	13.4	3.9	28	110	40	4.3	.99
Gali S66	DC-3000	22	2.8	2.7	18	136	16	3.5	.99
Gali 3	DC-3000	22.4	12.5	3.5	25	127	35	3.3	.99
Gali 6F	DC-4000	12.1	15.8	4.5	35.5	93	50	4.8	1.29
Gali 4F	DC-4000	14.3	15.3	4.0	32	93	50	4.4	1.29
Gali 51F	DC-4000	18.0	15.9	3.5	32	78	50	4.4	1.29
Gali 5F	DC-4000	20.4	15.7	3.5	31.5	103	50	4.3	1.29
Gali 55	DC-4000	21.9	15.0	3.3	28.5	100	50	4.3	1.29
Gali 52	DC-2000	22.9	15.5	2.7	32	85	50	4.4	1.29
Gali 6	DC-4000	12.2	18.2	4.5	35.5	93	70	5.0	1.49
Gali 4	DC-4000	14.4	17.5	4.0	34	93	65	4.6	1.49
Gali 51	DC-4000	18.1	18.0	3.5	35	78	65	4.5	1.49
Gali 5	DC-4000	20.6	18.0	3.5	35	103	65	4.4	1.49
Gali 74+	DC-1000	25.1	18.3	2.7	38	120	80	4.8	2.35

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Model	Passband (MHz)	fco, Nom. Loss 3dB (MHz) Typ.	Stopband Loss >20dB (MHz) Min.	Model	Passband (MHz)	fco, Nom. Loss 3dB (MHz) Typ.	Stopband Loss >20dB (MHz) Min.
VLF-80	DC-80	145	200	VLF-1450	DC-1450	1825	2025
VLF-95	DC-95	165	220	VLF-1500	DC-1500	1825	2100
VLF-105	DC-105	180	250	VLF-1525	DC-1525	1750	2040
VLF-120	DC-120	195	280	VLF-1575	DC-1575	1875	2175
VLF-225	DC-225	350	460	VLF-1700	DC-1700	2050	2375
VLF-320	DC-320	460	560	VLF-1800	DC-1800	2125	2425
VLF-400	DC-400	560	660	VLF-2250	DC-2250	2575	2900
VLF-490	DC-490	650	800	VLF-2500	DC-2500	3075	3675
VLF-530	DC-530	700	820	VLF-2600	DC-2600	3125	3750
VLF-575	DC-575	770	900	VLF-2750	DC-2750	3150	4000
VLF-630	DC-630	830	1000	VLF-2850	DC-2800	3300	4000
VLF-800	DC-800	1075	1275	VLF-3000	DC-3000	3600	4550
VLF-1000	DC-1000	1300	1550	VLF-5000	DC-5000	5580	6850
VLF-1200	DC-1200	1530	1865	VLF-6000	DC-6000	6800	8500
VLF-1400	DC-1400	1700	2015	VLF-6700	DC-6700	7600	9300

U.S. Patent Numbers 6,790,049 & 6,943,646

High Pass *VHF Models $24.95 ea. (1-9)*

Model	Passband (MHz)	fco, Nom. Loss 3dB (MHz) Typ.	Stopband Loss >20dB (MHz) Min.	Model	Passband (MHz)	fco, Nom. Loss 3dB (MHz) Typ.	Stopband Loss >20dB (MHz) Min.
VHF-650	710-2490	650	480	VHF-1810	1900-4750	1810	1480
VHF-740	780-2800	740	550	VHF-1910	2000-5200	1910	1400
VHF-880	950-3200	880	640	VHF-2000	2260-6250	2000	1530
VHF-1200	1220-4600	1180	940	VHF-2100	2200-6000	2100	1530
VHF-1300	1400-5000	1300	930	VHF-2275	2450-7000	2275	1770
VHF-1320	1400-5000	1320	1060	VHF-2700	2650-6500	2500	1800
VHF-1500	1600-5500	1550	1250	VHF-3800	4250-10000	3800	3200
VHF-1600	1650-5000	1600	1290	VHF-5500	6000-11500	5500	4500
VHF-1760	1900-5500	1760	1230	VHF-8400	9000-13000	8400	6000

U.S. Patent Number 6,790,049

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RF/IF MICROWAVE COMPONENTS

INVITED PAPER

THE ROAD FROM RFIC TO SoC

Twenty years ago, the microwave semiconductor industry in the US and subsequently all over the world got a boost from the Defense Advanced Research Procurement Activity, DARPA's $600 M MIMIC (Microwave and Millimeter-wave Monolithic Integrated Circuits) program. Driven by an emphasis on production discipline, established through volume production, the industry transformed itself from a supplier of specialty diodes and transistors into a reliable supplier of microwave monolithic integrated circuits (MMIC). Gallium arsenide (GaAs) was the microwave material of choice, clearly superior to silicon for microwave applications due to its higher electron mobility and semi-insulating nature. Significant reviews of the development of this technology have been published, providing comprehensive overviews of the technology development from the days of molecular electronics to the creation of fully monolithic devices.[1,2]

Although many of the expectations of technical dominance and business riches for GaAs-based semiconductors have not materialized, this technology has enabled the introduction of many breakthrough products that in the last 20 years have changed the way that we live. GaAs transmit/receive (T/R) modules for long-range active array radars warn our troops of incoming threats from missiles or projectiles. GaAs low noise amplifiers (LNA) for direct broadcast satellite TV receivers or cable modems allow us to watch our favorite games wherever they take place. GaAs power amplifiers (PA) and switches for cellular phones connect us wirelessly to our families and our work. Our computers are constantly connected to the world. Whether in our offices or in the coffee shop, we have constant network access. RF semiconductors have enabled the development of disruptive technologies that impact all facets of our lives. This article will focus on some of the major milestones that drove the technical capability and cost of RF semiconductors, enabling this new world to become a reality.

At the beginning of the 1980s, the potential of monolithic integration of microwave functions on semi-insulating GaAs had been well recognized. Impressive demonstrations of the capability of MMIC technology were widely reported.[3] Although semiconductor fabrication discipline was established in silicon technology, this discipline was slow to adopt in GaAs processing. The strong commercial pull for silicon-based integrated circuits drove wafer volume, which in turn drove production discipline and learning. Wafer diameters, in silicon production, progressed from three inch to 100 to 150 mm, driven by ever-increasing fabrication (FAB) volume.

J.P. LANTERI AND D.J. CARLSON
M/A-COM Inc.
Lowell, MA

In GaAs-based technologies, the material was two inches in diameter. A debate was raging on the advantages of ion implantation versus epitaxy for active layer formation. Processing was dominated by hand dipping in magic solutions in wet chemical benches. Process control monitors (PCM), a key element of FAB control in silicon, were rarely applied. Test was challenging; instrumentation was primitive, methods manual and calibration procedures had not been standardized. Gate lengths were much shorter than in silicon, resulting in significant lithography challenges, but the transistor density for RF applications was very low, yet the MMICs were very large.

DARPA

Manufacturing discipline in GaAs IC fabrication received its first major push not from RF but from the digital world. In 1982 DARPA initiated the Advanced On-Board Signal Processing (AOSP)[4] program focused on high speed digital processing using GaAs. This program was based on the assumptions that state-of-the-art GaAs semi-insulating substrate material was adequate for some types of digital very large scale integration (VLSI) circuits; the low yield of GaAs LSI circuits was primarily driven by random processing defects, not lack of reproducibility in device parameters; strict process control, as practiced in silicon-based VLSI manufacturing, would result in achieving comparable ‘learning curve’ type yield improvements; and a minimum of 100 wafers/week throughput is necessary to achieve pilot manufacturing discipline.[4] Pilot lines were established in several companies, many of which were applying GaAs technology to both digital and RF applications. The program, for the first time, began to drive significant wafer volumes through GaAs processing lines.

Following closely on the heels of DARPA's digital GaAs effort, DARPA launched the MIMIC program with this objective:

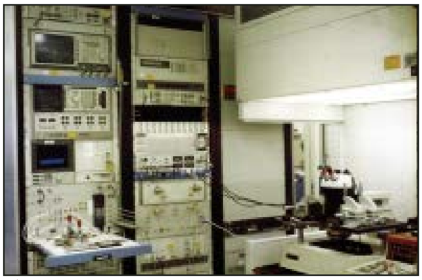
“Provide the needed microwave and millimeter-wave products at a price that will allow their use in fielded Department of Defense systems, that meet all required electrical, mechanical, and environmental parameters, and that continue to operate reliably for the time necessary to fulfill their intended application.”[5]

The MIMIC program, building upon the issues identified in AOSP, recognized that there were many areas that required attention to achieve the program goals. All aspects of MMIC fabrication, from materials, to device processing, to test, to design needed to be addressed. The MIMIC program was structured as a multiphase effort: Phase 0 – definition phase (1987); Phase I – first hardware development phase (1988); Phase II – second hardware development phase (1991); and Phase III – focusing on critical technology development. This comprehensive program, in an effort to drive down the cost of MMIC production and facilitate their use in systems, addressed: (1) the high cost of the starting materials; (2) the poor production control of active layer formation by ion implantation or epitaxial growth; (3) the lack of a comprehensive computer-aided-design systems with appropriate circuit models; (4) the lack of adequate production capabilities; (5) the absence of databases that could link design and processing parameters with test results; (6) inadequate and expensive MMIC packaging; and (7) the high cost of test.

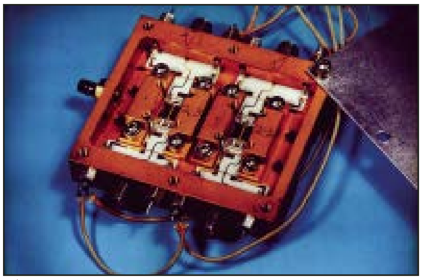
To achieve these goals, challenges were overcome on a number of technical fronts. Process control monitors were introduced across all FABs participating in the MIMIC program. The adoption of PCMs required the development of rapid on-wafer DC and RF test. Statistical process control (SPC) and PCM are terms that are very familiar today, but were very seldom present in the thinking in GaAs FABs of 1980 or 1985. Charts were generated, more to show that the number of wafers processed were in the 10s or 100s, rather than applying the results for process improvement or control. The ability to generate test data outstripped the engineers' ability to read the charts, understand their significance and take specific action. First, clear correlations had to be established though they were well hidden by variations in process, test and design. Ultimately, characterization of every wafer run resulted in several benefits: (1) FAB controls based on SPC could be put in place leading to more consistent process performance; (2) correlations between DC/RF parameters and process parameters could be established based on meaningful statistics; (3) statistically valid device models could be developed and used as the basis for MMIC CAD systems; (4) first-pass design success became a realistic possibility.[5] The simple introduction and utilization of meaningful PCM structures, on wafer, directed the industry on a path toward increased process control, improved device understanding, higher production yields and ultimately lower production costs.

The ability to test full MMICs on wafer was a key element in the learning process. One of the most challenging areas was the development of on-wafer power amplifier testing. Under a DARPA MIMIC Phase III program, we developed a pulsed power on-wafer test (see ***Figure 1***). This capability revolutionized power MMIC testing allowing one to gain meaningful amplifier data without going through the expense and difficulty of assembly prior to characterization. The development of this test technology was one of the last requirements to accomplish known-good-die (KGD) testing for phased-array radar T/R module assembly.

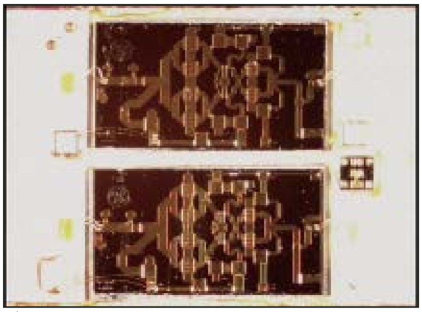
Over the course of the MIMIC program, the production cost dropped from $20/mm^2 to under $10/mm^2 by the end of Phase I, and under $1/mm^2 by the end of Phase II. Today's high volume commercial production of MMICs can achieve a cost on the order of $0.10/mm^2. The MIMIC programs focus on manufacturing coupled with its dual-use technology policy[6] placed US MMIC manufacturers in a dominant market position. The program's legacy persists today.



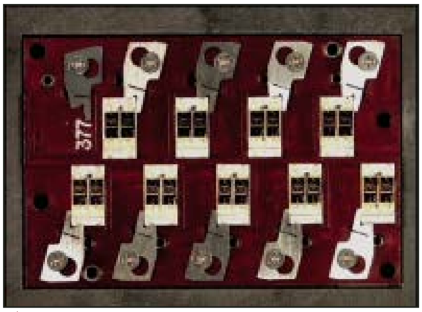
▲ *Fig. 1 On-wafer pulsed-power test system developed under MIMIC Phase III.*



▲ *Fig. 2 Reliability test fixture for COBRA PA assembly (each fixture contained two PA carrier assemblies).*



▲ *Fig. 3 COBRA program dual HPAs mounted on a carrier to facilitate RF test and burn in.*



▲ *Fig. 4 COBRA HPAs on carriers fixtured for RF test using on-wafer pulsed RF test equipment.*

▲ *Fig. 5 Fixtured MMICs being fed into an on-wafer test stand.*

PRODUCTION

While the MIMIC program was essential in establishing the foundation for MMIC manufacturing, volume production truly drove the technology forward. The first high volume insertions of MMIC technology were for defense applications. HARM (High Speed Anti-Radiation Missile) and COBRA (Counter Battery Radar) were two of the first MMIC insertions that benefited from the MIMIC program. In the case of COBRA, the system was a C-band phased-array radar that was initially developed by General Electric Electronics Lab in Syracuse, NY, and later produced in Moorestown, NJ. The T/R module contained six GaAs-based MMICs: a driver, two combined high power amplifiers, a phase shifter, a variable gain amplifier and a low noise amplifier. The program required delivery of 25,000 chip sets to very strict specifications. Given the maturity of the technology, the use of known-good-die in module assembly was essential to achieve practical yields at the module assembly level. Production drove learning. Issues from MMIC design, to fabrication, to test, to burn-in, to assembly all benefited from the demands of production.[7]

Visual inspection raised significant issues to overcome. MIL standards, derived from the silicon industry, were being applied. There was no statistically validated correlation between visual inspection defects and reliability. At 1000X, a one micron or less gate, covered by two layers of silicon nitride, is difficult to see on an optical microscope. Inspection yields were operator dependant and decreased as a function of repeat inspections. No correlation was found between many of the visual yield defects and yields at burn-in and/or life test. Production MMICs were subjected to extensive reliability testing in an effort to seek correlations between process and inspection data and long-term device performance (see ***Figure 2***). One hundred percent electrical test was also a critical area of focus. To assure high module yield, the MMICs were mounted on carriers which included decoupling networks, bias networks and stabilization networks to facilitate 100 percent RF test and, in the case of the PA and driver, burn-in. RF test was achieved by fixturing the MMICs, on carrier, in a multi-up format (see ***Figures 3*** and ***4***). The use of the multi-up format allowed for highly automated testing of a large number of HPA assemblies. The die were then probed using the testing capability established in MIMIC Phase 2 and Phase

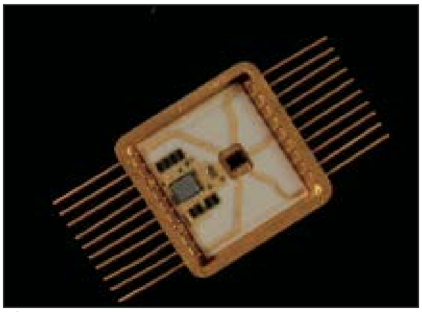
3 (pulsed power) (see ***Figure 5***). The use of on-wafer test equipment allowed for rapid, automated test of multiple parts. This known-good-die approach was credited as one of the major factors in the success of the program.

Most foundries were pursuing a dual-use strategy to fill their GaAs capacity. While defense insertions were critical in driving both the technology and the manufacturing capability, true high volume was to be found in the commercial market place. The first major volume drive from the commercial arena came from the emerging wireless communications market. GaAs FET MMIC switches, a relatively simple product, proved to be an ideal solution for the 900 MHz wireless handset. These switches were available in SOIC-8 packages and met the performance and cost expectations for the market. This market opportunity drove the number of MMICs delivered per year from tens of thousands to millions.[8] Moving from the military market, in which state-of-the-art device performance and characterization is paramount, to the commercial market, in which predictable, repeatable performance is considered a given and cost is the primary product differentiator, required a new level of manufacturing discipline. It was found that product test was a major cost driver.[9] Driving down the cost of test required a more sophisticated understanding of device performance, allowing correlations to be established between various device parameters, enabling a reduction in the number of parameters tested to assure performance. A focus on hardware and software was further required to reduce the test time. Gravity fed auto-handlers coupled with robust test interface boards were implemented to achieve rapid part insertion and accurate measurement (see ***Figure 6***). Efficient flow of data to and from test systems was also critical to improving throughput. Test times were reduced from 45 to 60 seconds per device to close to one second per device. These improvements drove down test cost and enabled high volume production.

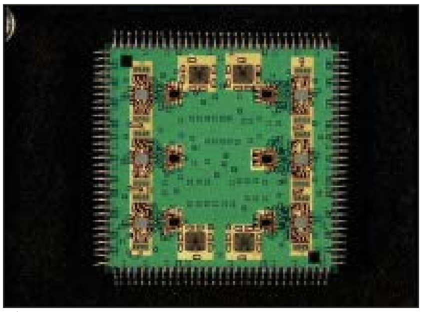
In addition to GaAs MMIC switches for handset applications, the wireless market drove a need for high power switches for base stations (see ***Figure 7***). Initial products, assembled in traditional metal and ceramic packages, were not amenable to low cost, high volume assembly and test. Evolution of base station technology and the demand for more complex switching functions drove more sophisticated solutions. Multi-chip modules for switch matrices drove the adoption of new assembly and packaging technology leading to cost-effective solutions. ***Figure 8*** shows a multi-chip 4 × 6 switch matrix module containing six single-pole four-throw switches, switch drivers and power dividers, encapsulated in epoxy.

The production capability demonstrated on switches for wireless base stations and handsets was used as a springboard to begin to address multifunction ICs in high volume. For defense applications, significant integration in GaAs had been demonstrated (see ***Figure 9***) in the form of complete transmit/receive functions for C-band radar on a single chip.

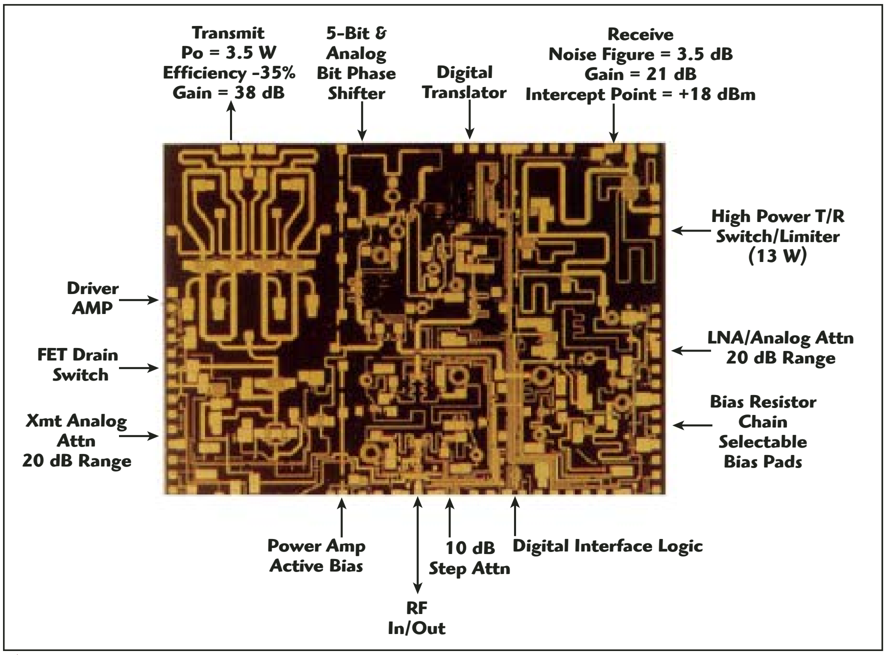
▲ *Fig. 6 Gravity-fed auto-handler used in initial high volume switch production.*



▲ *Fig. 7 Metal and ceramic-packaged high power GaAs MMIC switch with driver for base station applications.*



▲ *Fig. 8 Multi-chip module 4x6 switch matrix for base station applications on a six-level board.*



▲ *Fig. 9 C-band T/R module on a chip realized in the MSAG™ process.*

Commercial pull came from the evolution of the wireless market. A high performance RFIC chip set was developed for the Japanese Handy Phone System (PHS) at 1.9 GHz.[10] This work represented the most highly integrated chip set for the PHS application allowing the RF portion of the phone to be realized with less board space facilitating a smaller phone size. It became clear that to enter the high volume PHS market, the GaAs transceiver must be sold for less than $4. The only way this cost target could be met was to focus on minimizing the total area of the die. The need for compaction drove more efforts in electromagnetic (EM) simulation and tricks to reduce coupling between adjacent design elements. The transceiver IC was 3.5 mm^2, realized in an ion-implanted E/D process, encompassing Rx LNA, Rx mixer, LO switch, LO amp, Tx amplifier mixer, Tx amplifier and step attenuator functions. The output IC consisted of a driver amplifier, power amplifier and T/R switch realized in 1.5 mm^2. Similar parts, designed by a team of leading experts in the field but with a defense orientation, achieved similar results in 9 mm^2 of GaAs, a result which did not match the target market. The two-chip solution was plastic packaged in shrink small outline packages (SSOP) allowing standard pick and place machines to be used in mass production. The packaged parts were assembled with standard wire bonding and transfer molding techniques with a total cost of tens of cents. The use of standard plastic packaging enabled the adoption of mainstream, silicon IC, autohandlers to be used to perform functional RF testing.

The total volume of GaAs RFICs had grown to a point that dedicated RF handlers and test systems were becoming available. Further evolution of the wireless communications market led to highly integrated MMIC up-converters/drivers for cellular and PCS CDMA handsets.[11] This solution consisted of two multifunction ICs that operate in the 800 MHz (cellular) and 1900 MHz (PCS) frequency bands. Volume continued to grow as the wireless industry expanded.

During this time period, the market was also beginning to accept the GaAs heterojunction bipolar transistor (HBT) as a viable solution for the output power amplifier for handheld wireless applications. Offering distinct advantages over silicon in efficiency, gain and linearity, HBTs have become the technology of choice for this function. GaAs-based D-mode MESFETs and pHEMTs, both contenders of the PA socket, lost market share due to the negative gate voltage, which required a DC-DC converter, thus increasing cost. While E-mode devices were a possible solution, they were generally found to be difficult to manufacture. Wireless communications, as the largest consumer electronics market,[12] has driven volume applications for GaAs-based RFICs. This commercial pull resulted in improvement in processes, design, test and packaging.

INTEGRATION, SCALING AND THE IMPACT OF SILICON

The drive to reduce cost and increase functionality mandates greater and greater integration. In the case of the wireless handset, front-end modules (FEM) have been adopted as an integration path. Clearly, no advantage is gained from merely moving components from "on the board" to inside the FEM package.[13] What is limiting integration, in a cost-effective manner, is the large number of components realized in disparate technologies. Alternate technologies must be adopted for some of the key functions such as filtering and passive components.

Scaling, a driver of the silicon industry for over 30 years, does not really exist in RF semiconductor technologies. Although gate lengths are reduced to achieve higher frequency performance, the channel-to-channel pitch does not reduce much. This is due to thermal dissipation considerations as much as the fabrication tool set being used. Power devices are limited more by the substrate thickness then by the critical dimension of the transistor. The material set used in fabrication is essentially fixed: GaAs substrate, Si3N4 dielectric and gold interconnects; therefore, inductor and capacitor sizes remain fairly constant. Three-dimensional integration of passive components through the use of multiple metal layers is a possibility; implementation of this

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Width	55 mm
Height	18 mm

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concept in GaAs has been slow due to the limited numbers of metal layers and the absences of planarization as compared to silicon processing.

The capability of adding SiGe epitaxial layers to a standard CMOS or BiCMOS process so that high speed HBTs may be integrated with conventional Si circuits has revolutionized the course of microwave circuit design over the past few years. The ability to have denser functionality, and better control over system partitioning between RF and digital domains, coupled with the economies of scale and portability that conventional silicon fabrication offers, makes extending the design of both analog and mixed-signal ICs to microwave and millimeter-wave frequencies an obvious area to exploit. SiGe can offer the opportunity to provide very low cost microwave and millimeter-wave solutions with the potential to integrate digital and control functions together with RF. This results in great flexibility in system design and partitioning.

SiGe is not the magic bullet for RF semiconductors; there are a number of performance limitations where it is inferior to traditional III-V semiconductors. In particular, power output and noise figure are two critical areas of concern. Silicon-based technologies do offer a significant benefit in terms of integration and cost in applications in which the technical performance is appropriate.

System-on-a-chip (SoC) solutions based on silicon technologies are emerging for many RF applications. At lower frequencies and lower power levels, integration on silicon is a natural approach. For example, SoC solutions for Bluetooth[14] have been introduced which realize the full RF front end, baseband processor, microprocessor, memory and I/O functions in 0.25 μm silicon CMOS technology. Integration is resulting in silicon solutions consuming more and more of the functions that had been the domain of GaAs. All RF functions with the exception of the switch and the PA, the main components of the FEM, are being integrated into silicon.

As silicon CMOS technology continues to scale to shorter and shorter critical dimensions, higher frequency applications become within the reach of mainstream silicon processing technology.[15] Single chip solutions for WLAN and HIPERLAN systems are available. Through the use of SiGe technology, the millimeter-wave regime has become accessible to silicon technologies. Short-range, ultra-wideband radar sensors for the automotive market are an excellent example of the potential for SiGe technology to facilitate the integration of millimeter-wave and digital functions to create a highly integrated, compact, cost-effective solution for a very high volume commercial application.[16] The short-range radar operates in the 22 to 29 GHz band, a domain typically addressed with III-V solutions. Realized as a transmit IC and a receive IC, the SiGe solution in low cost QFN (quad flat-pack no-leads) plastic packaging provide full RF front-end functionality of the radar system. The receiver chip includes two LNAs, a switch, two mixers, two variable gain amplifiers and two integrators. The receiver has 45 dB (maximum) of conversion gain with 7.8 dB (including the plastic package) noise figure at 24 GHz.

IMPLICATIONS FOR THE FUTURE

The field of RF semiconductors is flourishing. The major commercial market driver, wireless communications, has become ubiquitous. The industry is expecting to pass the landmark of one billion handsets manufactured in one year. We communicate wirelessly, our computers communicate wirelessly and soon many of the appliances within our homes will communicate wirelessly. Defense applications remain demanding; on one hand very large aperture phased-array radars are driving unique requirements for very low power consumption at very low cost, on the other hand the desire to look farther with greater resolution is driving a need for ever-increasing power output and bandwidth.

The pronounced difference in volume between commercial and defense markets has, to a certain extent, driven a bifurcation in the RF semiconductor industry. More and more, companies that have focused on the commercial marketplace have done so to the exclusion of traditional defense business; while many of the FABs that benefited from the early push of the MIMIC program have either exited the market or turned primarily captive in nature. Few facilities continue to aggressively pursue a dual-use product strategy. The volume disparity between those FABs focused on commercial production and those focused on defense production is very wide. The cycles of learning with commensurate improvements in performance, yield and cost will favor those addressing higher volume applications.

Silicon CMOS and SiGe technologies are now addressing many applications that were viewed as owned by GaAs only a few years ago. Advanced electromagnetic modeling, multi-layer interconnects and short gate length active devices enable digital and RF integration of an unprecedented level. The silicon content of RF devices will only grow with time while GaAs works to maintain its grip on power and high frequency applications. Total semiconductor sales in 2005 were on the order of $225 B, of which GaAs MMIC devices represented less than $3 B. Silicon processed over six billion square inches of material, while the GaAs industry consumed 10 to 20 million square inches. GaAs RF semiconductor technology is clearly a niche of the broader semiconductor market. The GaAs niche can and must look to silicon to adopt their best practices and learn.

New RF semiconductor technologies are emerging: SiC and GaN to address high power applications; antimonide-based materials to address very low voltage applications. Significant government funding has helped move these technologies forward; impressive results have been achieved. Will the development time-line mirror that of GaAs? Are there significant applications on the horizon that will drive the learning required to mature these technologies?

Delivering high volume specification-compliant and repeatable ICs on time drove the maturation of GaAs MMIC technology. Real demand drove learning and progress in all aspects of the design and manufacturing process. Each major cycle of learning resulted in a major step forward in terms of product capability and cost. The continuation of this drive will bring RF semiconductors into applications that have yet to be dreamt. ■

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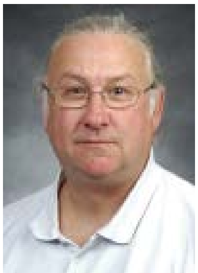
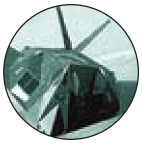
Jean-Pierre Lanteri *holds an MS degree in electronics and a PhD degree in semiconductor electronics. He has been with M/A-COM for over 20 years. He is presently vice president and technical director of M/A-COM's Strategic R&D group, with primary research interests in packaging and silicon-based system-on-chip (SoC) design for MW/mmW applications, such as automotive radar transceivers, military radar transceivers, baseband power amplifier linearization and broadband antennas. His personal focus and expertise is in low cost packaging of MW/mmW T/R modules and broadband circuits in plastic leadframes or laminate BGAs. He presently oversees an AFRL panel antenna program for space applications. A few years ago he was principal investigator for a DARPA/AFRL MAFET module program with chip-on-board components. He has extensive experience in MMIC fabrication, test and assembly, having led on-wafer test activities for DARPA's MIMIC program and pioneered on-wafer pulse power test of MMIC PAs extensively used in T/R modules. Later he established automated assembly and test facilities producing T/R subassemblies for the COBRA and GBR radars, 77 GHz cruise control sensors and large volume commercial RFICs.*



Douglas Carlson *received his Sc.B degree in electronic materials from Brown University in 1983 and his Sc.D degree in electronic materials from the Massachusetts Institute of Technology in 1989. He is chief technology officer for M/A-COM's Integrated Products Business Unit. He has been employed at M/A-COM for over 15 years working in various engineering and management positions involving GaAs materials and devices. He has been involved in compound semiconductor research and production for over 20 years.*



Internet Technology Improves Air Combat Capabilities

An Electronic System Center (ESC) capability, demonstrated in a "proof-of-concept" flight at Eglin AFB, FL, could translate into more effective information-sharing and better overall situation awareness. Flexible Access Secure Transfer, or FAST, is a technology concept managed by ESC's Global Information Grid Systems Group, which delivers critical near-term operational benefits.

"Through it, pilots could use imagery and video for positive target identification and battle damage assessment," said Lt. Col. Gary Zimmerman, Tactical Data Network Division director. "That means more accurate and more timely targeting for the war fighter." With FAST, aircraft equipped with Link 16 capability may soon have improved access to the airborne network and more up-to-date decision-making information. Link 16 is a backbone communications system and was first developed at ESC in the 1980s. FAST re-uses much of the Link 16 infrastructure of antennas, amplifiers and communications. Designers extended the system to eliminate many of Link 16's inherent problems. It improved its capability while adding Internet protocol connectivity for older platforms.

FAST removes limiting restrictions and reorganized the way distributed radios transmit and access information on the network — retaining compatibility with legacy radios — while simultaneously using FAST messages to pass imagery or TCP/IP transactions. That functionality was successfully demonstrated by the 46th Test Squadron at Eglin, using a four-node network: an F-15 eagle, a King Air small passenger plane and two ground stations. Several functions made possible through the protocol connection were tested during the demonstration. FAST allowed the King Air, acting as an intelligence, surveillance and reconnaissance asset, to send streaming video to the ground stations. It also enabled the F-15 with modified Link 16 radios to receive images from a ground station to the King Air through the F-15.

FAST will allow warfighters to perform missions that require a free flow of information and live updates to tasking orders and flight plans without pre-mission planning. "FAST is an evolutionary approach for moving current capabilities closer to network-centric combat operations," said Col. Anita Latin, commander of the Global Information Grid System Group. The upgrade would include only minor hardware and software adjustments with minimal integration impact on existing platforms.

The FAST team, which includes members of the test and contractor communities, will analyze the data gathered during the demonstration to assess the possibility of upgrading more than 2000 platforms. The analysis will be a key component in determining a fielding decision.

Raytheon Delivers First Aircraft Self Protection Security System

Raytheon Co. Integrated Defense System (IDS) business recently delivered to the Air Force the first prototype of an Aircraft Self Protection Security System (ASPSS). Using near object detection sensor (NODS) technology, the system provides electronic perimeter security for aircraft parked on the tarmac of an airfield or in a field location. Raytheon also has developed a system — the Vigilant Eagle Airport Protection System — that protects airplanes from man-portable air defense systems threats during takeoffs and landings. The two systems are complementary: Vigilant Eagle protects active aircraft and ASPSS protects parked aircraft. The four-sensor version of ASPSS is a low cost, portable system the Air Force recently accepted after tests at Eglin AFB, FL, under a $2.1 M cost-plus-fixed-fee contract administered by the Electronic System Center, Hanscom AFB, Bedford, MA. "This aircraft self protection security system warns of potential close proximity threats to aircraft parked on the ground," said Mark Russell, Raytheon IDS vice president of engineering. The NODS technology consists of three components: a near object detection sensor the size of a book, a communications module and a personal digital assistant (PDA)-like alarm and display device. The near object detection sensor and communications modules are mounted on a tripod and placed around the parked aircraft. The PDA-like display unit and another communications module, together known as an annunciator, are carried by security personnel. Each near object detection sensor covers approximately 120° arc and is able to detect the presence of people and vehicles out to 100 meter and beyond. Four sensors can provide overlapping coverage of a single aircraft and more sensors can be arranged to cover multiple aircraft parked together. According to Russell, Raytheon IDS will be delivering a three-sensor solution to the Air Force in the near future and a multiple aircraft version in late summer. In addition to aircraft protection, the technology shows promise for fence line, fixed facilities and commercial applications where cleared zone security is a consideration, Russell said.

Northrop Grumman and Digital Fountain to Provide Advanced Communications

Northrop Grumman Corp. has entered into a strategic alliance agreement with Digital Fountain Inc. to offer advanced communications technology to a wide range of US and allied government customers. Northrop Grumman provides world-class systems integration capabilities that can enable a variety of users to exchange real-time information on tactical ad-hoc networks. It specializes in offering new networking concepts to address its customers' technology gaps. These capabilities will be enhanced by Digital Fountain's expertise in fundamental technology and software components that dramatically improve the quality and performance of communications in the most challenging network conditions. "Northrop Grumman believes its longstanding commitment to seek innovation in non-traditional relationships with companies and incorporate state-of-the-art commercial technology in our products adds even more value to our customers," said Paul K. Meyer, sector vice president, Advanced Capabilities Development, Northrop Grumman Integrated Systems. "Integrating Digital Fountain capabilities will allow us to offer very near term network-centric solutions that better meet the digital communications requirements of current and future users." Northrop Grumman will incorporate the Digital Fountain technology in systems it develops for government customers or sublicense it to them or other contractors. Government customers covered in the agreement include defense, intelligence, homeland security and other federal agencies, as well as state and local agencies and governments of allied countries. Digital Fountain's technology — used for point-to-point communications and broadcast to multiple users simultaneously of data files and streaming video — provides more reliable delivery of data, which is especially important as tactical networks become part of the digital global information grid. Network-centric warfare today relies upon a mix of wired and wireless networks to deliver mission-critical information. Commanders and tactical war fighters depend on timely information to make informed battlefield decisions. However, network conditions within the tactical infosphere can suffer from extreme conditions such as limited bandwidth, high latency (delay time), fading and interference or jamming. The result is often poor communications performance that impairs the ability to share mission-critical information among tactical operation centers and individual war fighters. Digital Fountain's patented DF Raptor™ forward error correction technology addresses those problems. Adopted as a global standard for the wireless distribution of multimedia content over third-generation (3G) cellular networks, the technology improves the reliability of tactical communications links by protecting the transfer of large files and streaming data from "packet" (data) loss. This improvement in quality guarantees faster delivery of critical data over today's networks and allows more efficient use of network bandwidth. ■

Richard Mumford, European Editor

CORDA Centres on Maritime Research

A programme that could be instrumental in shaping military thinking over the next 20 years will be overseen by the Centre for Operational Research & Defence Analysis (CORDA). The wholly-owned subsidiary of BAE Systems has been awarded the enabling contract by the UK MoD Research Acquisition Organisation to lead the delivery of the Maritime Surface Effects research programme for Defence Equipment Capability (Above Water Effects) (DEC (AWE)).

The £5 M contract will involve CORDA leading the programme as the prime contractor and provide advice to inform future capability planning, including equipment procurement planning decisions and to de-risk technology to support early procurement activity.

The scope of this initial three-year enabling contract is to undertake research in the following areas: technology assessment and maturation for defensive and offensive surface warfare, military benefit assessment of coastal suppression options, the impact of Net enabled capability on surface warfare, operator involvement in effects-based surface warfare operations and unmanned surface vehicles.

CORDA will work closely with academia and 23 industrial partners. Joint teams involving members from all industrial partners will be developed for each research task and outputs delivered to the Research Acquisition Organisation with defined routes for exploitation of these outputs across MoD and the UK defence industrial base.

Wireless Design Centre Thinks Twice

Ember's Cambridge, UK-based IC design facility is set to double in size by the end of 2006, following the announcement of the company's development partnership with STMicroelectronics on ZigBee projects. Its 11-strong hardware design team has already developed two ICs at the site, including the ZigBee industry's first single chip solution integrating both radio and microcontroller. The company is now finalising the specifications for several new IC programs with STMicroelectronics and actively recruiting digital and analogue engineers for the development phases.

The IC design challenges that the partnership faces include finding ways to minimise the number of external components usually required to build a radio, the use of fine geometry semiconductor fabrication processes in a way that does not degrade radio performance, obtaining high radio sensitivity in close proximity to high clock rate digital circuits, and optimising operating modes and power management schemes to suit ultra-long lifetime operation from battery power. However, the rewards of getting these designs right promise to be market sizes that will dwarf all current wireless applications combined.

Excited by the venture, Nick Horne, director of IC Engineering at Ember Europe, commented, "We expect the UK design centre to be at least 20 strong by the end of 2006. Ember has an intellectual lead in this exciting new wireless semiconductor marketplace. We're capitalising on that by developing new generations of product in partnership with STMicroelectronics, who are providing semiconductor IP as well as access to advanced fabrication processes and semiconductor research."

Columbus Heads for US

At a ceremony to mark the delivery of the European laboratory for the International Space Station (ISS), Columbus, by EADS SPACE Transportation to the European Space Agency (ESA), German Chancellor Angela Merkel emphasised the international cooperation aspects of Columbus and the ISS, as an example for a world with less boundaries. The ceremony, held in Bremen, Germany, marked the final integration of the laboratory before it was shipped to Cape Canaveral from where it will be flown on a Space Shuttle to the ISS in the second half of 2007.

During its planned 10-year operational lifetime, scientific researchers in Europe, with the help of the astronauts onboard and a Europe-wide support infrastructure on the ground, will be able to conduct a vast programme of experiments in the areas of the life and physical sciences, materials science, fundamental physics and technology research.

The Columbus laboratory is Europe's cornerstone contribution to the ISS and is regarded as an important technology driver for European industry and as a basis for European researchers to perform world-class research in space.

Project MESA on Track

At a meeting of the MESA Project attended by over 50 participants from Europe, the US, Canada and China, important steps were taken to bring broadband mobile communications to the public safety communities in both Europe and North America with five new proposals by manufacturers being received. These technical contributions will now form the basis for specifications and standards that specify enhanced capability requirements for future Public Safety and Disaster Relief systems.

These latest proposals are just part of ongoing initiatives as Project MESA Organisational Partners, including European Telecommunications Standards Institute (ETSI) and Telecommunications Industry Association (TIA) members, continue to facilitate government and industry dialogue on next generation digital systems to be utilized by public safety, security and emergency users.

The chair of the meeting stated: "The vendor proposals included ways to coordinate and leverage the latest networking standards, to ensure that 'Incident Area Networking Technologies' can work seamlessly in these highly demanding situations. Examples of the technologies covered in the proposals are: cdma2000® EVDO, W-CDMA, variations of 802.11, 802.16 and satellite technologies."

It Pays to Integrate Toll Solutions

Within the scope of a large-scale test, the Siemens Industrial Solutions and Services (I&S) Group in Australia has proven that the previously separate technologies for the collection of road toll fees — microwave-based Dedicated Short Range Communication (DSRC) and satellite-based Global Navigation Satellite Systems (GNSS) — can be integrated into one single solution in the future with just a single hardware component.

These two separate toll collection technologies are proven at being able to function smoothly and reliably. Nevertheless, both systems exist in parallel and up until now it has not been possible to operate them simultaneously. However, in the field test in Melbourne and the New South Wales region, Siemens ITS, Transurban and the largest Australian mobile radio provider, Telstra, successfully tested a hybrid on-board unit (OBU) from Siemens VDO and a new software application with which both microwave-based and satellite-based toll solutions can be used by one single unit. The hybrid OBU, into which a DSRC microwave module is integrated, makes it possible to detect existing microwave signals from toll gantries in addition to normal satellite operation.

"Therefore, Siemens is the first manufacturer of a hybrid OBU which detects microwave signals from gantries and processes GPS signals," said Stefan Höpfel, responsible for toll solutions in the Intelligent Traffic Systems (ITS) Division of Siemens I&S. "Operators can keep using the existing infrastructure and, at the same time, also the advantages of satellite-based toll collection." ■

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LAVI-22VH+	425-2200	525-2400	100-700	+21	+31	+20	7.7	50	45	24.95
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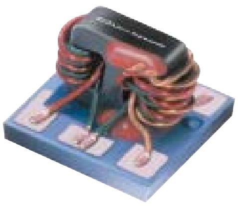

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SBTC-2-15-75+	500-1500	75Ω	3.49
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RF/IF MICROWAVE COMPONENTS

Wireless Regional Area Network Project Hits Major Milestone

The IEEE 802.22 working group has passed a major milestone in the development of the IEEE P802.22™ standard, which aims to use geographically unused TV channels to bridge the "digital divide" between rural and outer-suburban areas and major urban centers. The milestone involves the acceptance of a single, unified proposal derived from the 10 proposals originally submitted to the working group. The unified proposal will serve as a baseline for developing the standard. The future standard is intended to increase the efficiency of spectrum use by enabling the deployment of wireless regional area networks in the "white space" between the coverage areas of over-the-air broadcast VHF/UHF TV stations on a non-interfering basis. This will facilitate the provision of fixed wireless broadband access services within 40 km or more of a transmitter in locales that cannot be served economically by more traditional services, such as DSL and cable modem. The formal title of the IEEE P802.22 project is "Wireless Regional Area Networks (WRAN) — Specific Requirements — Part 22: Cognitive Wireless RAN Medium Access Control (MAC) and Physical Layer (PHY) Specifications: Policies and Procedures for Operation in the TV Bands." The creation of a unified proposal involved consolidating the 10 proposals initially presented in November 2005 to two at the beginning of March 2006. The two remaining proposal teams then agreed to merge their offerings into a unified proposal, which now forms the baseline for further development of the IEEE P802.22 standard. IEEE P802.22 is sponsored by the 802 Local and Metropolitan Standards Committee of the IEEE Computer Society.

GaAs Device Market Will Break Through $3 B in 2006

The Strategy Analytics annual five year outlook for the gallium arsenide microelectronics industry, "GaAs Industry Forecast: 2005–2010," predicts that GaAs device revenues will grow by 36 percent over 2005 to 2010, breaking the $3 B barrier in 2006. Overall market growth will continue to be derived from wireless markets, with cellular handsets as the primary driver, over the next five years. Cellular handset shipments that continue to grow will be characterized by multi-mode and multi-band operational requirements. The added complexity of multi-mode and multi-band handsets will increase GaAs device penetration in handsets, offsetting ASP erosion. "It's not just a case of increasing handset shipments which helps to increase GaAs device demand from the handset market over the next five years," observed Asif Anwar, director of the Strategy Analytics GaAs and Compound Semiconductors Technology services. "2006 and beyond will see the market shift toward EDGE/GPRS and WCDMA/EDGE multi-mode, multi-band architectures. This will actually increase the number of HBT and pHEMT die going into increasingly complex RF front-end module solutions." "Demand from other applications will augment GaAs device revenues as well," noted Stephen Entwistle, vice president of the Strategic Technologies Practice at Strategy Analytics. "We foresee increased demand from a whole host of markets in which GaAs is the enabling technology."

MEMS Revenue Slow in 2005 Despite Shipment Growth

Revenue growth for sales of MEMS devices worldwide slowed dramatically in 2005, despite the fact that unit shipments were very strong, reports In-Stat. Nearly 1.8 billion MEMS devices were shipped in 2005, generating revenues of just under $7 B, the high tech market research firm says. In-Stat found that inventory backlogs, weakness in key markets and lower average selling prices all clearly had an effect. Despite projected unit shipment growth exceeding 11 percent over the next five years, revenues are forecast to increase at a compound annual growth rate of just 6.8 percent through 2010 due to continued price reductions, as well as the introduction of new MEMS devices with commodity-like pricing.

Recent research by In-Stat found the following:

- The top 20 suppliers of MEMS devices maintained their dominance of the industry, accounting for more than 86 percent of total revenues in 2005.
- The automotive and computing segments, long mainstays of the MEMS industry in terms of both unit shipments and revenues, are projected to be displaced by the communications and industrial markets within the next five years.
- With optical networks finally emerging as a growth segment, as well as the rapid integration of RF MEMS and microphones in cell phones, the communications market will be a key driver of overall growth.

The research, "An Industry in Transition: 2006 MEMS Forecast," covers the global market for MEMS. It provides a snapshot of the state of the MEMS industry and looks at a variety of trends and issues that will impact its future growth. The research contains more than 50 tables and charts quantifying the growth of MEMS, including worldwide forecasts by major device category, device type and key markets through 2010. It also includes lists of the top 20 suppliers in 2005, by both unit shipments and revenues.

Scalability, Interoperability, Performance: RFID's New Mantra

RFID markets, increasingly concentrated on the Gen 2 specification, show signs of a healthy transition to the next phase of RFID implementation: full integration at the enterprise level, backed by deep management commitment. When Wal-Mart's new CEO, Rollin Ford, addressed his troops upon taking office recently, saying, "When Gen 2 was released, we planned to make it our standard at the beginning of the year. We have done that, and I can confirm that we will be sunsetting Gen 1 on June 30." That kind of dedication is echoed across the range of vertical markets in which RFID plays a role: transportation, pharmaceuticals, retail, consumer goods and defense. What is inspiring it?

ABI Research has released a new market update to its RFID Research Service, according to which the past quarter's new found confidence stems from two sources: RFID hardware and components and RFID's assimilation into business systems. Erik Michielsen, the firm's director of RFID research, points out that for hardware, "Standards and the maturity of the technology are beginning to have a significant effect. Components can now be sourced from a multiplicity of vendors, large and small. Many vendors have already released several generations of products and they are applying the lessons they have learned to each new release." All this is happening in a standard-driven environment. "Everybody is building around the common ground of Gen 2," says Michielsen. "Performance, scalability and interoperability are at the core of the new product designs." He cautions that these factors raise barriers to new component market entrants, driving development of industry- and application-specific environments. At the enterprise level, the platforms that are emerging across infrastructure are also showing sign of maturity. The data collected by RFID has to translate to more effective business processes. Early trials and compliance efforts did not really address those issues. But now, Michielsen observes, "Whether it is the FDA or Wal-Mart or Target or Metro or the Department of Defense, you are seeing commitment that is resonating through the industry: this is something that will be long-term, not short-term." Michielsen dismisses reports of an industry slowdown: "It is just that buying cycles are being extended," he says. "Companies are planning RFID and setting capital expenditure budgets with a longer-term mindset." ■

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SMV1405-107, SMV1206-107 SMV2019-107

Switch, Attenuator or Limiter Applications:
SMP1340-107, SMP1345-107, SMP1352-107, SMP1302-107, SMP1304-107,CLA4607-107

Mixer and Detector Applications:
SMS3923-107, SMS7621-107, SMS7630-107

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New Small Size, Low Profile, Green SPDT Switch

The SKY13268-344LF, SPDT 300 kHz- 3 GHz SPDT switch is packaged in the new SOT-666 package (1.65 x 1.65 x .4 mm). This new device delivers the RF performance of the industry standard AS179-92LF switch in a package which offers a 35 percent footprint reduction and a 40 percent height reduction. This low-loss switch is ideal for 802.11 b/g, ISM, WiBro, and Bluetooth transmit/receive applications which require low-voltage operation.

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High Linearity General Purpose Amplifiers

SKY65013, SKY65014, SKY65015, SKY65016 and SKY65017
These amplifiers are broadband devices with gain from 13 to 21 dB, and output power (P1 dB) from 14 to 20 dBm. Skyworks' gain blocks have the highest output third order intercept (IP3), gain compression points (P1dB) and wider bandwidth when compared to otherwise similar operating products. They are fully cascadable 50-Ohm impedance matched to provide excellent linearity and very low distortion making them ideal for many wide-ranging applications including, home satellite DBS, WLAN, Bluetooth, medical and test equipment.

They are manufactured using Skyworks' state-of-the-art InGaP HBT process and are available in several industry standard packages.

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INDUSTRY NEWS

■ **Murata Manufacturing Co. Ltd.** announced that it has acquired privately held US-based venture company **SyChip Inc.**, a leader in radio frequency chip scale modules (CSM). Murata Manufacturing Co. Ltd. is an innovator in electronics and a global supplier of passive components. Murata agreed to pay approximately $140 M as the total consideration for outstanding shares, stock options and warrants.

■ **Microsemi Corp.** announced that it has finalized its acquisition of **Advanced Power Technology** in a combined stock and cash transaction. With this acquisition, Microsemi provides customers with a broader range of high performance analog, high reliability and RF products.

■ **Andrew Corp.** has acquired **Precision Antennas Ltd.**, a Stratford, England-based provider of antennas for terrestrial and satellite communications systems. Under the agreement, Andrew paid approximately $26 M to acquire the subsidiary of UK-based Cobham plc. Precision Antennas designs and produces microwave antennas for use in carrying point-to-point radio signals, primarily for cellular network backhaul.

■ **Filtronic plc**, a global designer and manufacturer of customized microwave electronic subsystems for the wireless telecommunications and defense industries, and **Powerwave Technologies Inc.**, a global supplier of end-to-end wireless solutions for wireless networks, announced that the companies have entered into a period of exclusive negotiations for the disposal of Filtronic's filter-based transmit receive module and power amplifier businesses of its Wireless Infrastructure Division.

■ **EPCOS** closed the deal that transfers its tantalum capacitor business to US American capacitor manufacturer **KEMET**. The selling price for EPCOS' tantalum business is € 86.5 M. The sale will give EPCOS an expected cash inflow totaling € 70 M, the bulk of which will be paid in the current (third) quarter of fiscal 2006.

■ **Lytron Inc.**, a supplier of liquid cooling products to OEMs, announced the acquisition of **Lockhart Industries Inc.**, a subsidiary of Wakefield Thermal Solutions. Lytron designs and manufactures advanced aluminum-brazed cooling components for the military and electronics markets. Lytron plans to move and fully integrate the Lockhart business into its newly expanded Woburn, MA facility later this year.

■ The management team of **BFi OPTiLAS** has completed a management buyout of the company, which has been a wholly-owned subsidiary of the Avnet Corp. for over 10 years. The management team has acquired a majority stake in the company, with Avnet retaining a minority stake. It has stated that it will continue to expand its operation as a pan European distributor of products and services for the electronic and photonic market places, including RF and microwave components, systems and assemblies.

■ **Elcoteq SE**, a provider of electronics manufacturing services to the communications technology industry, has entered into an agreement with American-based **PCTEL Antenna Products Group Inc.**, a wholly-owned subsidiary of PCTEL Inc. According to the agreement, Elcoteq will manufacture integrated Variable Electrical Tilt (iVET) base station antennas along with certain land mobile radio antennas in Elcoteq's new St. Petersburg plant in Russia. The deliveries will begin in the second quarter of 2006.

■ **Park Electrochemical Corp.** announced a change in name for its advanced composite materials business from FiberCote Industries Inc. to **Nelcote Inc.** Consistent with this name change, Park's advanced composite materials product line will now be sold under the Nelcote™ trade name.

■ **M/A-COM** announced the opening of the M/A-COM–Shenzhen Engineering and Operations Center in Shenzhen, China. The new center is a fully capable facility that enables the company to rapidly create and manufacture derivative product designs, with local engineering resources available to support the company's customers who have manufacturing and engineering facilities in China. The new center is located at M/A-COM Shenzhen Office, 3/F, Block 1, Keji South Road, Vision Shenzhen Business Park, Shenzhen Hi-Tech Industrial Park, Shenzhen, P.R.C., +86 755 27620888 or fax: +86 755 26716058.

■ **Unity Wireless Corp.** announced that it has opened a sales and customer support office in the United Kingdom to service OEM, operator and distributor customers in the European, Middle Eastern and African (EMEA) regional markets.

■ **Aperto Networks**, a developer of WiMAX base stations and subscriber units, announced the establishment of an Aperto WiMAX development center in Bangalore, India, for the purpose of accelerating the engineering development and deployment of the company's WiMAX Forum Certified and WiMAX-class products.

■ **Kulicke & Soffa Industries Inc.** has relocated its corporate headquarters to a new location in Fort Washington, PA. The company will maintain its current telephone numbers and e-mail addresses. The new corporate address is located at 1005 Virginia Drive, Fort Washington, PA 19034.

■ **Modelithics** announced that it will now provide direct distribution and support of all model libraries and custom models for **Eagleware/Agilent** GENESYS and HARBEC simulation software, in the same way it continues to support Agilent ADS customer's needs for improved accuracy model libraries.

FEATURED MODELS

Model #	Frequency (MHz)	Typical Phase Noise (dBc/Hz)	
		@10 kHz	@100 kHz
FSW Series [Dual supply voltage +5 & +15 VDC]			
FSW511-50	50 to 115	-103	-120
FSW1125-50	110 to 250	-100	-122
FSW1536-50	150 to 360	-100	-120
FSW1847-50	180 to 470	-95	-120
FSW1847-100	180 to 470	-98	-120
FSW2462-50	230 to 620	-95	-119
FSW60160-50	600 to 1600	-90	-117
FSW150290-50	1500 to 2900	-85	-107
FSW190410-50	1900 to 4100	-82	-107
FSW Series [Dual supply voltage +5 & +24 VDC]			
FSW514-50	50 to 140	-103	-120
FSW1129-50	110 to 290	-100	-122
FSW1545-50	150 to 450	-100	-120
FSW1857-50	180 to 570	-95	-120
FSW1857-100	180 to 570	-98	-120
FSW2476-50	240 to 760	-95	-119
FSW60170-50	600 to 1700	-90	-117
FSW150320-50	1500 to 3200	-85	-107
FSH196225-50	1960 to 2250	-94	-119
LFSW Series [Single Supply voltage +5 VDC]			
LFSW514-50	50 to 140	-102	-120
LFSW1129-50	110 to 290	-99	-122
LFSW1545-50	150 to 450	-98	-120
LFSW1857-50	180 to 570	-94	-120
LFSW1857-100	180 to 570	-98	-120
LFSW2476-50	240 to 760	-94	-119
LFSW35105-50	350 to 1050	-108	-130
LFSW60170-50	600 to 1700	-90	-117
LFSW150320-50	1500 to 3200	-85	-107
LFSW190410-50	1900 to 4100	-82	-107
LFSH196225-50	1960 to 2250	-93	[illegible]

FEATURES:

- Exceptional Phase Noise Performance
- Interactive Communication
- Selectable Interface
- Standard Programming Interface
- Single or Dual Supply Options
- Small Size, Surface Mount
- Lead Free - RoHS Compliant
- Patent Pending REL-PRO® Technology

RoHS COMPLIANT

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i2S INTELLIGENT INTERACTIVE SYNTHESIZERS

■ **JEM Engineering**, a custom antenna design, manufacturing and testing services company, announced that it has co-engineered an artificially-evolved antenna with NASA, becoming the first of its type in space. The evolved antenna — mounted on three of NASA's Space Technology 5 (ST5) satellites — was launched into an Earth orbit on March 22nd.

■ **Ansoft Corp.** has joined the GEIA Compact Model Council (CMC), a group of 35 semiconductor and electronic design automation companies worldwide that promote the standardization of compact model formulations.

■ **The LXI Consortium** announced that **Geotest-Marvin Test Systems Inc.** has joined the standards organization as an advisory member. As a global supplier of PXI and PC-based test products, systems and solutions, Geotest expands the growing number of test and measurement companies supporting and promoting the LXI standard.

■ **ANADIGICS Inc.** announced five new patents covering innovations in the design and development of radio frequency integrated circuits. The patents strengthen the company's impressive intellectual property portfolio and extend its technological advantages across its wireless and broadband product families.

■ **Electron Energy Corp.**, a producer of rare earth magnets and magnet systems, assures that all EEC orders for magnets and magnet systems with a stated end use by the US Department of Defense are produced in compliance to US law Berry Amendment specialty metal provisions enacted in DFARS 252.225-7014 Alt 1. This is the specific mechanism in the Defense Federal Acquisitions Regulations Supplement by which "domestic source restrictions" are implemented by the Department of Defense. US law and its revisions known as the Berry Amendment enact "domestic source restrictions" provisions for national defense.

■ **EMA Design Automation**,™ a full-service provider of Electronic Design Automation (EDA) solutions, and **Ageus Solutions**, a leader in RoHS and WEEE compliance, have joined forces to provide environmental compliance solutions from design through manufacturing.

■ **Comarco Wireless Test Solutions** announced it has delivered 350 Prizm multi-band, multi-technology RF scanners to **ZK Celltest Inc.** for use in ZK's RMS real-time monitoring system.

CONTRACTS

■ **EMS Technologies Inc.** announced that its Defense and Space Systems Division has been awarded a contract by an undisclosed US prime contractor to build electronics for a US Department of Defense satellite program. The contract award calls for EMS to build an undisclosed quantity of units that will find a home in national security space applications. The 24-month contract was valued at approximately $9 M. Additional quantities, valued at approximately $4 M, are expected to be ordered later this year.

■ **Lockheed Martin** awarded **G.T. Microwave** a continuance contract after G.T. successfully completed and delivered 500 calibrated-for-true position vector modulators on time. G.T. Microwave, a designer and manufacturer of microwave integrated components, proposed the accepted plan to Lockheed Martin, an advance technology systems integrator. The vector modulators will be utilized to solve an antenna test application with 0.1-degree accuracy.

■ **Texas Instruments Inc.** announced that **Alvarion**, a provider of wireless broadband solutions and specialized mobile networks, has selected the company's portfolio of WiMAX infrastructure technologies as part of its mobile WiMAX solution, 4Motion. Alvarion's BreezeMAX system, the primary building block of 4Motion's radio access network, will leverage TI technology to address the growing demand for mobile broadband wireless technologies, including support for IEEE 802.16e standards, across a broad range of spectrum. These products enable carriers to offer high performance broadband data, voice and multimedia services over wider coverage areas.

■ **Cadence Design Systems Inc.** announced that **Saifun Semiconductors Ltd.**, a provider of non-volatile memory technology and solutions, has adopted the Cadence® Analog Mixed Signal (AMS) Methodology Kit. Leading semiconductor manufacturers use Saifun NROM technology to develop and manufacture a variety of Flash products for the wireless, consumer electronics, networking and automotive markets.

FINANCIAL NEWS

■ **Endwave Corp.** announced that it has entered into a Preferred Stock and Warrant Purchase Agreement with **Oak Investment Partners XI**, Limited Partnership. Pursuant to the purchase agreement, Oak has purchased 300,000 shares of Series B Preferred Stock for $150 per preferred share for gross proceeds of $45 M. The preferred shares are convertible into 3,000,000 shares of common stock, for an effective purchase price of $15 per common share equivalent and an approximate 12 percent premium to the closing price of Endwave's common stock on April 24, 2006. As part of the transaction, Endwave issued a three-year warrant granting Oak the right to purchase an additional 90,000 preferred shares at an exercise price of $150 per preferred share, which are convertible into 900,000 shares of common stock at $15 per share.

■ **WJ Communications Inc.** reports sales of $11.7 M for the fourth quarter ended December 31, 2005, compared to $7.9 M for the same period in 2004. Net loss for the quarter was $2.1 M ($0.03/per common share), compared to a net loss of $4 M ($0.07/per common share) for the fourth quarter of last year.

■ **Merrimac Industries Inc.** reports sales of $7 M for the fourth quarter ended December 31, 2005, compared to $7.8 M for the same period in 2004. Net income for the quarter was $117,000 ($0.04/per diluted share), compared to a net income of $209,000 ($0.07/per diluted share) for the fourth quarter of last year.

■ **VERTILAS GmbH**, a supplier of laser diodes, announced its successful third round financing results total-

ing € 3.6 M. The company plans to use the new capital to advance commercialization of its products.

■ **Jazz Semiconductor Inc.** announced that it has filed a registration statement with the Securities and Exchange Commission for the proposed initial public offering of its common stock.

NEW MARKET ENTRY

■ **FDK Corp.** announced its entry into the standard DC/DC converter market with the introduction of the Senpai series of non-isolated point of load converters. These DC/DC converters are designed for intermediate bus architecture and distributed power architecture applications that require high efficiency, tight regulation and high reliability in elevated temperature environments with low airflow.

PERSONNEL

■ Xceive® Corp. announced the appointment of **Jean-Louis Bories** as CEO. Bories brings more than 25 years of experience in the semiconductor industry, gained from high profile positions with companies such as National Semiconductor and LSI-Logic.

▲ *Bill Hartman*

■ **Bill Hartman** has joined The Micromanipulator Co. as president and CEO. Prior CEO, Kenneth Hollman, has retired from Micromanipulator to pursue other interests. Hartman was previously president of MesoSystems Technology. He has over 20 years of sales, business development and executive leadership experience in test equipment, telecommunications and other technology-related markets.

■ Mimix Broadband Inc. announced that it expanded its management team at the positions of chief technology officer (CTO), senior vice president sales and vice president operations. **Damian McCann** was promoted from vice president product development to the position of CTO. McCann has more than 20 years of experience in microwave and millimeter-wave component development, device modeling and design. Before joining Mimix, McCann was vice president of advanced marketing and technology for Celeritek Inc. Jim Harvey continues to play an instrumental role at Mimix as CTO Emeritus. **John McCarthy** joins Mimix as senior vice president sales, with extensive experience in semiconductor markets worldwide, and a background that includes analog, RF, wireless and custom/ASIC. McCarthy comes to Mimix from Peregrine Semiconductor. **Donald P. Mathes**, vice president operations, has over 30 years of experience managing a broad range of semiconductor and high tech manufacturing operations in the US and worldwide. From 2000 to 2003, Mathes designed, built and ramped to production a world-class semiconductor-manufacturing facility for a start-up wafer foundry in Taiwan.

■ Alereon Inc. announced it has selected **David Shoemaker** as vice president of engineering and operations. In this position, he will oversee the company's engineering operations and manufacturing relationships. He brings the company more than a decade of industry expertise in RF, analog and ASIC architectures, as well as software and system design.

■ Superconductor Technologies Inc. (STI), a provider of high performance infrastructure products for wireless voice and data applications, announced that **Adam Shelton** has joined the company as vice president of product management and marketing. Shelton will manage all aspects of STI's product management and marketing program. Prior to joining STI, Shelton was senior director of marketing for Motorola, where he was responsible for the marketing of Motorola Networks' products.

■ SiGe Semiconductor announced the appointment of **John Brewer** as vice president of marketing. Brewer brings 25 years of engineering, executive management and marketing experience in the wireless semiconductor industry. At SiGe Semiconductor, he will oversee global marketing and product line management for the company's WLAN, Bluetooth, GPS and WiMAX products together with driving new product initiatives.

■ picoChip has announced a significant expansion of its sales network in Europe with the appointment of **David Hutton** as vice president of sales Europe, and with the signing of a distribution agreement with UR Group under which Ultimate Renaissance will sell picoChip's products through its European network of sales offices. Hutton has over 22 years of experience in the semiconductor and wireless industries, having held senior sales and marketing positions at Texas Instruments, IDT and most recently Pericom.

■ California Eastern Laboratories announced that **Joe Larkins** has joined the company as director of major accounts. Larkins will be responsible for account planning, strategy and sales to CEL's major customers. He comes to CEL from Infineon Technologies where he led Infineon's worldwide sales efforts with Nortel and Cisco.

■ EDX Wireless is pleased to announce two new appointments to its management team. **Bob Shaw** was appointed director of sales and holds day-to-day responsibility for all sales activities. Shaw, a 20-year veteran of the wireless industry, brings a wealth of experience to EDX, including expertise in wireless broadband. Most recently, he was executive director of sales and marketing at Wytec Inc. In complement, **Jennifer Duncan** has been appointed to the key position of executive director, business development and strategy. Duncan, an 11-year veteran of EDX, will build upon the company's strength in Metropolitan Area Networks, such as WiMAX and WiFi, and expand the company's presence in other areas. In related news, **Kai Dietze** joins EDX's Product Management team after completing his doctorate in electrical engineering from Virginia Polytechnic Institute.

■ StratEdge announced that **Bob Solomon** has joined the company as senior account manager. Solomon has engineering, design and development, management and sales experience in the semiconductor, telecommunica-

Broadband Amplifiers by AML Communications

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Model	Frequency (GHz)	Gain (dB)	Flatness (dB) max	NF (dB) max	P1dB (dBm) min	VSWR (In/Out)	DC Current @ +12/+15VDC
Broadband Low Noise Amplifiers							
AML016L2802	0.1 – 6.0	28	±1.25	1.3*	+7	2.0:1	190
AML48L3001	4.0 – 8.0	30	±1.0	1.2	+10	1.8:1	150
AML412L3002	4.0 – 12.0	30	±1.5	1.5	+10	1.8:1	150
AML218L0901	2.0 – 18.0	9	±1.0	2.2	+5	2.5:1	60
AML0518L1601-LN	0.5 – 18.0	16	±1.0	2.7	+8	2.2:1	100
AML0126L2202	0.1 – 26.5	22	±2.25	3.5*	+8	2.2:1	170
AML1226L3301	12.0 – 26.5	33	±2.0	2.8	+8	2.5:1	200
Broadband Medium Power Amplifiers							
AML0016P2001	0.01 – 6.0	21	±1.25	3.2*	+23*	2.0:1	480
AML26P3001-2W	2.0 – 6.0	28	±2.5	6	+33	1.8:1	1500
AML28P3002-2W	2.0 – 8.0	30	±2.0	5.5	+33	2.0:1	2000
AML218P3203	2.0 – 18.0	32	±2.5	4	+25	2.0:1	450
AML618P3502-2W	6.0 – 18.0	35	±2.5	4	+33	2.0:1	1850
Narrow Band Low Noise Amplifiers							
AML23L2801	2.8 – 3.1	28	±0.75	0.7	+10	1.8:1	150
AML1414L2401	14.0 – 14.5	24	±0.75	1.5	+10	1.5:1	130
AML1718L2401	17.0 – 18.0	24	±0.75	1.6	+10	1.8:1	150

Low Phase Noise Amplifiers				Phase noise (dBc/Hz) at offset			
Part Number	Frequency (GHz)	Gain (dB)	Output Power (dBm)	100Hz	1KHz	10KHz	100KHz
AML811PN0908	8.5 – 11.0	9	17	-154	-159	-167	-170
AML811PN1808	8.5 – 11.0	18	18	-152.5	-157.5	-165.5	-168
AML811PN1508	8.5 – 11.0	15	28	-145.5	-153.5	-158.5	-164.5
AML26PN0904	2.0 – 6.0	9	20	-150	-165	-165	-178
AML26PN1201	2.0 – 6.0	11	15	-155	-160	-160	-175

High Dynamic Range Amplifiers

Part Number	Frequency (MHz)	Gain (dB)	P1dB (dBm)	OIP3 (dBm)	DC
AR01003251X	2 – 32	21	32	52	+28V @ 470mA
AFL30040125	50 – 500	23	28	53	+28V @ 700mA
BP60070024X	20 – 2000	32	30	43	+15V @ 1100mA

*Above 500MHz.

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Power Amplifiers by Microwave Power

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Model	Frequency (GHz)	Psat (dBm)	Psat (W)	P1dB (dBm)	Gain (dB)	DC Current(A) @ +12V or +15V
Broadband Microwave Power Amplifiers						
L0104-43	1 - 4	42.5	17.8	41.5	45	14
L0204-44	2 - 4	44	25	42.5	45	14
L0206-40	2 - 6	40	10	38.5	40	8.5
L0208-41	2 - 8	41	12	40	40	17
L0218-32	2 - 18	32	1.4	31	35	5
L0408-43	4 - 8	43	20	41.5	45	17
L0618-43	6 - 18	43	20	41.5	45	22
L0812-44	8 - 12	44	22	42	45	22
Millimeter-Wave Power Amplifiers						
L1826-34	18 - 26	34	2.5	33	35	4
L1840-27	18 - 40	27	0.5	26	30	2
L2240-28	22 - 40	28.5	0.7	27	30	3
L2630-39	26 - 30	39	8.0	38	40	15
L2632-37	26 - 32	37	5.0	36	38	10
L2640-31	26 - 40	31	1.2	30	30	5
L3040-33	30 - 40	33	2.0	32	33	9
L3337-36	33 - 37	36	4.0	35	40	12
L3640-36	36 - 40	36	4.0	35	40	10

High-Power Rack Mount Amplifiers

Model	Frequency (GHz)	Psat (dBm)	Psat (W)	P1dB (dBm)	Pac (kW)	Height (in)
C071077-52	7.1 - 7.7	52.5	170	51.5	1.8	10.25
C090105-50	9 - 10.5	50	100	49	1	8.75
C140145-50	14 - 14.5	50.5	110	49.5	2	10.25
C1416-46	14 - 16	46	40	45	0.35	5.25
C1820-43	18 - 20	43	20	41.5	0.25	5.25
C2326-40	23 - 26	40	10	39	0.25	5.25
C2630-45	26 - 30	45	30	44	0.45	5.25
C3236-40	32 - 36	40	10	39	0.25	5.25
C3640-39	36 - 40	39	8	38	0.24	5.25

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tions, medical, aerospace and defense industries. Solomon's responsibilities include new business development for the company's complete line of DC to 50+ GHz packages, stripline filters, and assembly and test services. Prior to joining StratEdge, Solomon was regional sales manager for Corning Gilbert, Microwave Division.

■ RFMW Ltd. welcomes **Steve Kim** to its sales team as regional sales engineer for the GA, AL, MS and TN territories. Kim has 16 years of experience in RF and wireless communications product development with various companies in Atlanta and is knowledgeable in system design for cell phones, pagers, spread spectrum radios, WLAN products, CATV amplifiers, CATV set tops and bi-directional amplifiers. **Russ Dahl** has also joined the RFMW sales team as the regional sales engineer for the Midwest. Dahl has worked at Arrow Electronics where he was director of RF technical marketing and Richardson Electronics as business unit manager for solid-state and components.

REP APPOINTMENTS

■ **Richardson Electronics** announced a global distribution partnership with **TeraVicta Technologies**, Austin, TX, to distribute its complete line of MEMS-based RF switching solutions. In related news, Richardson Electronics Ltd. announced a franchise distributor partnership agreement with **Radiotronix Inc.**, Oklahoma City, OK. Under terms of the agreement, Richardson will distribute, on a global basis, the entire line of Wi.232 DTS and frequency hopping spread-spectrum modules, as well as the Wi.M family of developer-controlled, spread-spectrum capable products developed by Radiotronix.

■ **LitePoint Corp.**, a manufacturer of high quality, high performance advanced wireless test solutions, announced a new partnership agreement with **TestMart Inc.** to provide a product catalog and government marketplace services to better serve and expand LitePoint's federal customer channel. The agreement authorizes TestMart to present LitePoint WLAN, MIMO and Bluetooth test solutions to the US government and military markets.

■ **Micro Lambda Wireless Inc.**, Fremont, CA, has appointed **GMB Partners** to represent the company's products in Korea. **Associated Technical Sales** will handle the company's products in Southern California.

WEB SITES

■ **Agilent Technologies Inc.** announced a web-based discussion forum for network analyzer customers to collaborate with peers and Agilent engineers around the world. Customers may use the forum to ask network analyzer questions, share perspectives or read about prior discussion topics. For more information, visit www.agilent.com/find/agilent_naforum.

■ **Rogers Corp.** announced the creation of its new web site for the Chinese market. This site can be accessed on the company's home page by visiting www.rogerscorporation.com and clicking on the Chinese Welcome message.

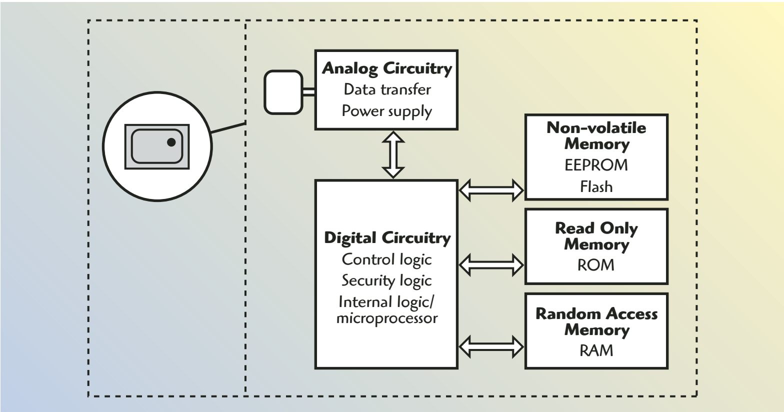
RADIO FREQUENCY IDENTIFICATION: EVOLUTION OF TRANSPONDER CIRCUIT DESIGN

A basic RFID system consists of three components: an antenna, a reader and a transponder, commonly called a tag. Tag designs are the most well researched over the years and different designs came about to suit their application in various fields. This article focuses on approaches, improvements and comparison of various transponder circuits. It is observed that the trend is toward the design of passive tags, as opposed to active tags. This article opens a way for researchers to obtain a good understanding of RFID transponder circuit design, which will help them to develop more powerful, flexible and efficient applications.

Radio frequency identification (RFID) is an area of automatic identification that has quietly been gaining momentum in recent years and is now being seen as a radical means of enhancing data handling processes, complementary in many ways to other data capture technologies such as bar coding. RFID systems involve the use of robust tags that permits the operator to collect data and manage it in a portable, changeable database. A basic RFID system consists of three components: an antenna, a reader and a transponder, widely known as a tag. The antennas, attached to the reader and the tags, are the conduits between the two, which control the system's data acquisition and communication. The tag contains an electronic microchip, as shown in ***Figure 1***, which is fabricated as a low power integrated circuit (IC). Depending on the device application, the tag memory may comprise ROM, RAM, non-volatile programmable memory (EEPROM, Flash) and data buffers.

Transponders are being developed and employed at different frequencies, ranging from

Fig. 1 The tag electronic microchip.



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Cyberjaya, Malaysia

Medium Power Amplifiers

FEATURES:

- High Efficiency
- Wideband Power up to 1 Watt
- HEMT Technology
- Temperature Stabilized
- Single Bias, Regulated and Protected

Model Number	Frequency (GHz)	Gain (dB, Min.)	Gain Flatness (±dB, Max.)	Noise Figure (dB, Max.)	Output Power (dBm, Min.)	VSWR In/Out (Max.)	DC Power @ +15V (mA, Nom.)
AMF-3D-00100200-60-27P	0.1–2	25	2	6	27	2:1/2.3:1	475
AMF-4D-00100200-40-27P	0.1–2	40	1.5	4	27	2:1/2.3:1	750
AMF-4D-00100800-40-28P	0.1–8	37	1.5	4	28	2:1	800
AMF-2B-02000800-70-27P	2–8	15	1.5	7	27	2:1	560
AMF-3B-02000800-55-27P	2–8	25	1.5	5.5	27	2:1	660
AMF-4B-02000800-45-27P	2–8	36	1.5	4.5	27	2:1	720
AMF-5B-08001800-80-27P	8–18	20	2	8	27	2:1	1200
AMF-6B-08001800-70-27P	8–18	25	2	7	27	2:1	1300
AMF-7B-08001800-60-27P	8–18	30	2	6	27	2:1	1400
AMF-9B-08001800-70-29P	8–18	30	2.5	7	29	2:1	3000
AMF-1B-01000200-40-25P	1–2	10	1	4	25	2:1	250
AMF-2B-01000200-13-25P	1–2	30	1	1.3	25	2:1	300
AMF-3B-01000200-10-25P	1–2	42	1	1	25	2:1	360
AMF-2B-02000400-30-25P	2–4	22	1	3	25	2:1	330
AMF-3B-02000400-15-25P	2–4	35	1	1.5	25	2:1	400
AMF-4B-02000400-13-25P	2–4	47	1	1.3	25	2:1	440
AMF-3B-04000800-25-25P	4–8	25	1	2.5	25	2:1	450
AMF-4B-04000800-15-25P	4–8	36	1	1.5	25	2:1	490
AMF-5B-04000800-15-25P	4–8	47	1	1.5	25	2:1	540
AMF-6B-12001800-45-25P	12–18	33	1.5	4.5	25	2:1	740
AMF-5B-12001800-60-28P	12–18	18	2	6	28	2:1	1600
AMF-6B-12001800-50-28P	12–18	24	2	5	28	2:1	1700
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the low frequency region of 125 kHz to the microwave region of 5.8 GHz to satisfy a wide range of applications. The applications include access control, automatic data collection, livestock tracking, inventory management and factory automation.

In the retail and pharmaceutical industries, losses arising from drug counterfeiting, overstocking or outdated products make RFID a sought after automatic identification system. Each year, retail and pharmaceutical markets are burdened by more than $2 B in product returns. In 2001 alone, the industry faced some 1300 recalls. To add more damage to the market, up to seven percent of all drugs in the international supply chain may be counterfeit.[1] Therefore, RFID technology's ability to track, trace, authenticate and uniquely identify each pharmaceutical product helps to improve inventory management through the reduction of out-of-stock items and increase the safety of the stock, more efficient product recalls, improvements in product quality and drug safety, and anti-counterfeiting. As the pharmaceutical industry relies upon the integrity of many forms of data throughout the process of drug trials, manufacturing, distribution and retail sale, RFID will prove to benefit the pharmaceutical industry beyond the fight against counterfeiting of drugs. Some studies estimate that RFID-based solutions could save the industry more than $8 B by the end of 2006. At the item level, RFID can provide 100 percent visibility of inventory no matter where it is in the supply chain, making it easier and quicker to move goods to the right place within the chain. The technology can improve productivity in shipping and receiving, reduce touch labor, increase the assurance of shipping and dispensing accuracy, and expand product availability at the retail store, thus reducing customer complaints and back charges. Therefore, the US Food and Drug Administration (FDA) recommends the widespread use of RFID in the pharmaceutical supply chain at the item level by 2007[2] to monitor the international drug supply from "manufacture to medicine cabinet," thus keeping the drug supply safe and secure. Pharmaceutical companies like Purdue Pharma LP, maker of the painkiller OxyContin, have begun using RFID technology. The OxyContin bottles with the tags can help authorities and the company to battle against theft as the stolen bottles can be traced back to the particular pharmacy, once the thieves are caught. The maker of one of the most counterfeited pharmaceutical products, Pfizer, had planned to add passive RFID chips to bottles of the impotency drug Viagra by the end of the year 2005. A third US pharmaceutical company, GlaxoSmithKline, said it will also begin using RFID on one of its products in the next 12 to 18 months. In the United Kingdom, six manufacturers are working together on a pharmaceutical RFID and bar-code pilot to see if the technologies can be used to detect dispensing errors and counterfeit drugs before they reach the patients.[3,4]

RFID can also be potentially used in library systems. The Rose Creek

branch of the Sequoyah Regional Library System has become the first public library in Georgia to adopt this advanced technology for materials management, employing RFID transponders to track books. With this system, patrons are enjoying self-checkout, shorter checkout lines and improved customer service, while the staff is spending more constructive time assisting patrons and less time with repetitive, clerical tasks. The system has a built-in security component that alerts the staff when items are removed from the library without authorization. Since RFID transponders need not be seen in order to be read, the library will be able to track its materials regularly by waving a portable RFID inventory wand-reader along the base of shelves. Besides, materials can be stacked up on the counter and can be identified simultaneously by the built-in RFID reader without having to scan it individually. In the same step, the security mechanism inside each tag is deactivated. It is anticipated that the system's speed and user-friendly features will mean that the vast majority of the branch's circulation will soon be handled without staff intervention. The Sequoyah Library System's state-of-the-art RFID was developed by Vernon Library Supplies Inc., a Norcross-based company, in partnership with Tagsys, a world leader in the manufacture of RFID tags and hardware for libraries.[5]

Other developing countries like Malaysia are also adopting this advanced technology in their automatic identification system. The Malaysian government bought the RFID 0.25 mm^2 chip, known as the MM chip,[6] designed by the Japanese R&D company FEC Inc. While the usage of the chip is not determined, it would most probably be used in national passports and currency notes, for example, to eliminate counterfeiting activities and to greatly prevent the possibility of terrorist acts. Further research and modifications can make the chip useful for a broad range of applications, from fighting forgery to killing cancer cells. The MM chip's potential has also attracted the attention of many countries that are looking forward to utilize the RFID technology in national applications. Government officials in China, Canada, Mexico and Australia were keen to explore the chip's usage in a variety of projects. According to the CEO of FEC Inc., Mexico had conveyed interest in using the chip as IDs for voters in elections, while Canada and Australia wanted to use it for national identity cards.[7,8]

The main purpose of this article is to review and discuss the various circuit designs of RFID transponders performed by various individuals and organizations, mainly in the last three years. The advances, approaches and improvements in the designs will be examined and, if possible, compared with one another.

ARCHITECTURES OF RFID TRANSPONDERS

Tags are either passive or active. Active tags are powered by an internal battery while passive tags derive the power supply from the field generated by the reader through the antenna. Active tags allow greater communication ranges, better noise immunity, higher data transmission rates and do not require a higher powered reader than passive devices. The trade-offs of active tags are greater size, greater cost and a finite lifetime, compared to the virtually unlimited operational lifetime of the passive tags.[1]

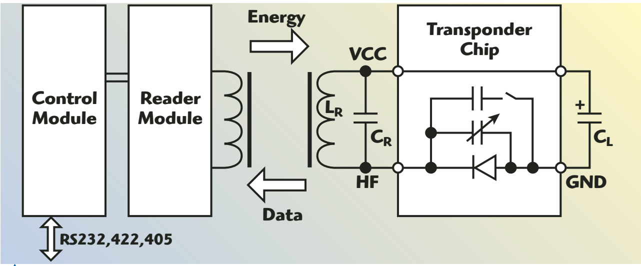
A tag is a data-carrying component to be attached on an item and needs to be robust so that the reader can easily track it. Tag designs are the most commonly explored area of RFID systems. Throughout the years, various RF researchers came up with different designs to suit different applications. Beginning from the year 1993, different ways to produce low cost and low power tags can be seen and, along the way, additional features are being added to the designs to make them more valuable.

Raymond Page, a design engineer for Wenzel Associates, emerged with the grand prize in the 1993 RF Design Awards Contest, with his winning design of a low cost and low power tag, applied to rail car tracking.[11] He uses an unusually simple method of converting the interrogating RF field into a data-modulated signal, which can be transmitted back to the reader. This contributes to the low manufacturing cost of the tag design. To achieve the lower power requirement from the reader, the tag design consists of only one inexpensive microwave semiconductor, a diode, and allows all parts to be mounted on an FR-4 printed circuit board with the patch antennas. In contrast, other design approaches using expensive microwave parts, including SAW devices, oscillators, mixers, filters and amplifiers, involve more RF circuitry and tend to be power hungry, which require higher RF interrogation fields. Besides that, the tag's efficiency in rectification, frequency doubling and modulation eliminates the need for higher power. One watt of power, transmitted with an antenna gain of 31.6 (16 dB) and received with an antenna gain of 2 (3 dB), allows the tag to function from as far as 20 feet away. This means that just over 1 mW is adequate to energize the tag.

In 1995, Pobanz and Itoh[12] designed a novel microwave RFID tag in the form of an ID card that has been developed for remote identification of personnel and articles. The tag is compatible with interrogation frequencies in the range of 4 to 7 GHz, which includes the 5.8 GHz ISM band. Based on a sub-harmonically pumped quasi-optical mixer, the tag is activated by a C-band interrogation beam to up-convert and radiate a digitally modulated identification tone at two X-band frequencies. The advantages of this scheme is that the new microwave frequencies of the response signal are created non-harmonically, an octave apart from the interrogation signal without a microwave oscillator, compared to the frequency doubling in the response signal by Page.[11] This scheme further avoids the interference of signals from the interrogation band and the problem of false detection resulting from an interrogator receiving reflections of its own transmitted harmonics is avoided. The quasi-optical structure consists of an anti-parallel Schottky diode pair mounted at the terminals of a planar bowtie (triangular dipole) antenna, allowing it to receive the interrogation signal and transmit the response an octave apart.

The same year, Kaiser and Steinhagen[13] designed a low power passive read/write tag, following the TIRIS specification, working at a carrier fre-

quency of 134.2 kHz. Kaiser and Steinhagen employed an LC tank, as shown in ***Figure 2***, for wireless communication purposes and to retrieve the power to supply the microchip. The LC tank consists of the antenna L_R and capacitor C_R to retrieve the energy from the reader unit during the charge-up phase and to send back data during the transmission phase. The supply capacitor C_L stores the energy during the charge-up phase and delivers the current to activate all circuits in the microchip when the data transmission phase begins. This technique of retrieving energy from the reader can be seen in many designs thereafter. The system works in half-duplex mode. Thus, the powering and data transmission phases are separated and this gives a superior performance at reading distances of up to two meters, depending on the size of the antenna and the allowable field strength.



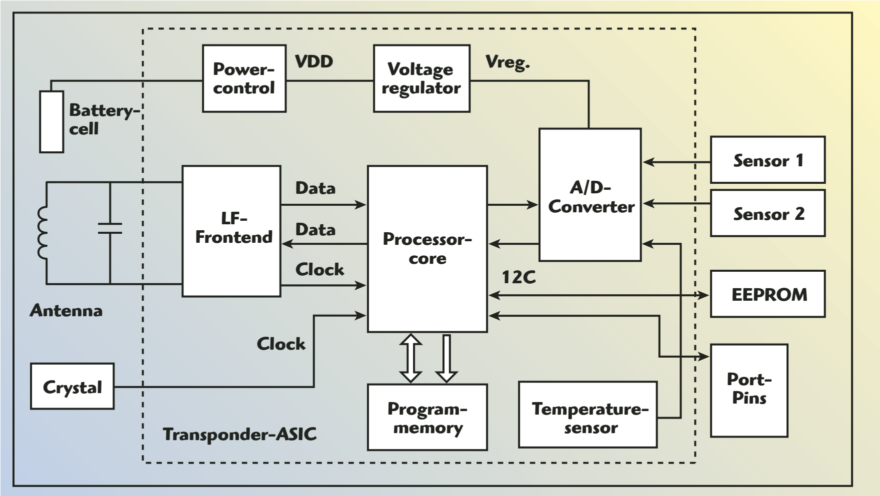
▲ *Fig. 2 Tag system using an LC tank circuit.*

Several building blocks included in the design are the 'end of burst' detector, RF limiter, a trimming block to allow optimal tuning of the LC tank with on chip capacitors so that the maximum possible transmission distance can be achieved, EEPROM with a shift register, a discharge circuit, a clock regenerator, a clock divider and a modulator. However, if more than one tag enters into the electromagnetic field at the same time, the one that is read is the one closest to the reader's antenna. This is not suitable for applications whereby many tags need to be read at the same time.

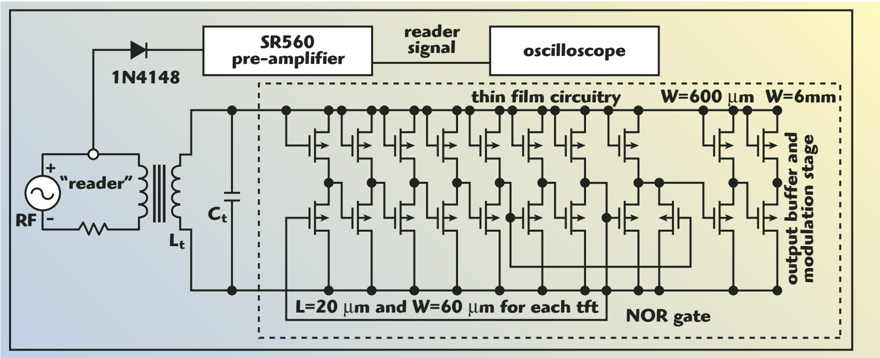
Using this design, Wu, Yang and Liu[14] presented a Texas Instruments compatible passive tag, operating at a frequency of 134.2 kHz. This design also has an LC tank. The differences in the design lie in the use of a digital CMOS circuit as the major part of the design and the output frequencies are implicitly determined, independent of the load of the antenna.

To overcome the problems caused by many tags entering the electromagnetic field at the same time, and to be able to read all of them at a time, an anti-collision scheme is employed into the tag design. This feature is described by Masui, Ishii, Iwawaki, Sugawara and Sawada.[15] The design is a read/write 13.56 MHz tag, which includes complex functions such as anti-collision and authentication, controlled by a dedicated central processing unit (CPU). As the addition of the complex functions increases power consumption, the CPU is there to control the power consumption, therefore retaining the tag chip's low power consumption and achieving a higher data rate, exceeding 100 kbps, than the previous work by Kaiser and Steinhagen.[13]


RFID SOLUTIONS



▲ *Fig. 3 Block diagram of a multifunction tag.*



▲ *Fig. 4 Schematic of the 1-bit pentacene-based tag circuit.*

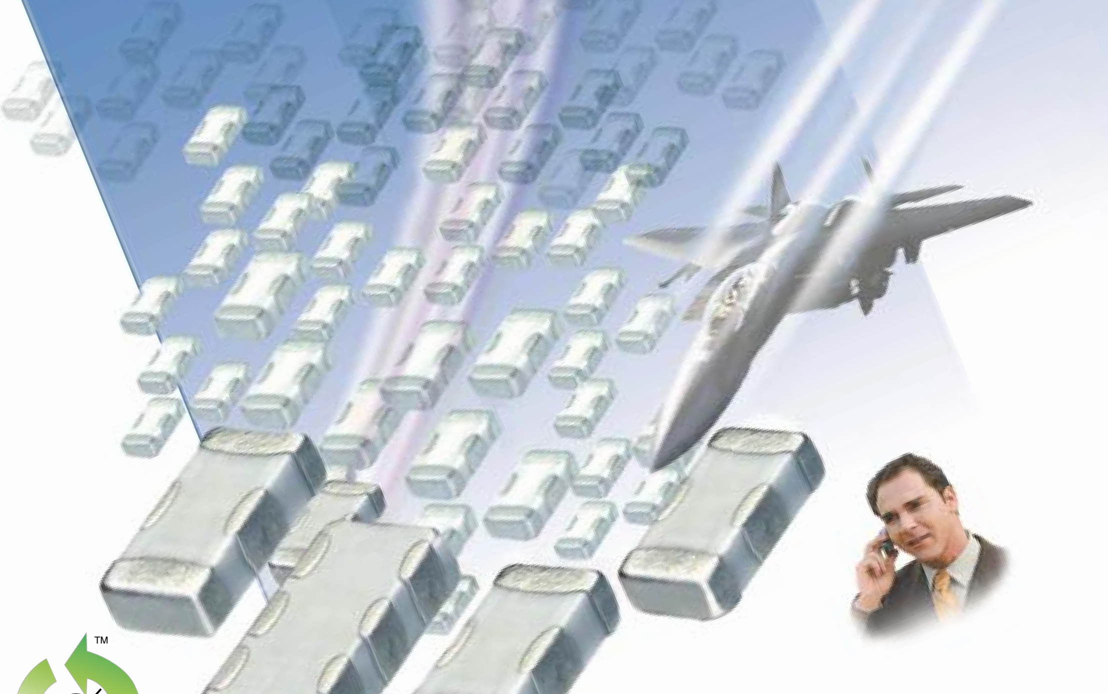
A multifunction tag, shown in ***Figure 3*** and operating at 125 kHz, was unveiled by the Fraunhofer Institute of Microelectronics Circuits and System (IMS) in November 2000.[16] This tag can be used either in the passive or active mode. In the passive mode, the LC tank formed by the inductor and capacitor serves as the RF interface to receive energy as described before. In the active mode, the tag is supplied with energy from a rechargeable battery or primary cell, which is built into the tag. The tag can also be added with an anti-collision feature and is capable to be read up to about 50 tags at a time.

In 2001, Panitantum, Yordthein, Noothong, Worapisher and Thamsirianunt[17] presented a passive read-only RFID tag, targeting applications such as animal and asset tracking. It operates at 13.56 MHz and employs a Zener-zap one-time programmable (OTP) ROM to store ID. The Zener-zap technology provides an opportunity for programming an OTP at the wafer probe or field programming after chip packaging. This tag also has an anti-collision feature but instead of adding a CPU to minimize power consumption, the anti-collision feature is separated from the main power circuitry and its power utilization is minimized by a clock extractor that is subsequently divided by a factor of 32. This design also employs an RF limiter, as seen in the design by Kaiser and Steinhagen,[13] to protect damages caused by CMOS gate-oxide breakdown due to excessive coupling voltage from the reader for a short distance operation. Besides that, an LC tank is used for powering and data communication purposes.

In mid-2001, Hitachi released one of the world's smallest IC chips, known as the μ-Chip,[18] which is only 0.4 × 0.4 mm in size. It is thin enough to be embedded in paper. The μ-Chip is integrated with a 2.45 GHz high frequency analog circuit and a 128-bit ROM. The chip data is recorded in its memory during the semiconductor production process, and therefore cannot be rewritten, thus providing high resistance to tampering and guaranteeing its authenticity.

In 2003, Baude, Ender, Kelley, Hasse, Muyres and Theiss of the 3M Co. in the US presented an organic semiconductor RFID tag.[19] An organic semiconductor offers a lower manufacturing cost compared to its silicon counterpart, which is in favor to the current need for lower cost to encourage RFID applications in the retail market. Another advantage of an organic semiconductor is its compatibility with flexible substrates. In this design, the chosen organic semiconductor is pentacene because of its relatively high mobility, of the order of 1 cm^2/V-sec. The tag is a 1-bit pentacene-based RFID tag. The tag circuitry is patterned entirely using flexible polymeric shadow masks with 20 μm gate lengths and 30 μm design rules. The tag operates at RF frequencies of 125 kHz and as high as 8.8 MHz. The circuits, fabricated on glass substrates, were optimized for AC powering. Unlike the other tag designs, this tag circuitry doesn't need a separate rectification stage as it is powered directly from the resonant LC tank. ***Figure 4*** shows the circuit schematic of the 1-bit pentacene-based tag. The circuit consists of a seven-stage ring oscillator, a NOR gate and two output buffers. The power is coupled into the circuit using inductive coupling from the reader loop to the tag loop. The ring oscillator and NOR gate were used to create a pulse signal that was in turn buffered and sent to a large inverter. This inverter was used to modulate the absorbed RF energy and the modulation was detected internally using simple peak-detection demodulation circuitry. In this design, the tag exhibited sufficient amplitude modulation of the absorbed RF to be detected externally with peak-detection demodulation.

In the same year, Applied Digital Solutions demonstrated its sub-dermal VeriChip personal verification microchip and its new, implantable, temperature-sensing microchip based on the former.[20] Each VeriChip product is about the size of a grain of rice and contains a unique verification number, which is captured and detected by a proprietary handheld scanner. The VeriChips are available in several forms, some of which will be able to be inserted under the skin.[21] The first sub-dermal VeriChip



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LFCN-1200	DC-1200	1530	1865	7	1.99
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LFCN-1525	DC-1525	1750	2040	7	2.99
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LFCN-1700	DC-1700	2050	2375	7	1.99
LFCN-1800	DC-1800	2125	2425	7	2.99
LFCN-2000	DC-2000	2275	3000	5	1.99
LFCN-2250	DC-2250	2575	2900	7	1.99
LFCN-2400	DC-2400	2800	3600	5	1.99
LFCN-2500	DC-2500	3075	3675	7	1.99
LFCN-2600	DC-2600	3125	3750	7	1.99
LFCN-2750	DC-2750	3150	4000	7	1.99
LFCN-2850	DC-2800	3300	4000	7	1.99
LFCN-3000	DC-3000	3600	4550	7	1.99
LFCN-3800	DC-3900	4850	6000	7	2.99
LFCN-4400	DC-4400	5290	6700	7	2.99
LFCN-5000	DC-5000	5580	6850	7	1.99
LFCN-6000	DC-6000	6800	8500	7	1.99
LFCN-6700	DC-6700	7600	9300	7	1.99
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HFCN-740	900-2800	740	550	7	1.99
HFCN-880	1060-3200	880	640	7	1.99
HFCN-1200	1380-4600	1180	940	7	1.99
HFCN-1300	1510-5000	1300	930	7	1.99
HFCN-1320	1700-5000	1320	1060	7	1.99
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chipping procedure was performed on September 24 of the same year, in New York City, at the Applied Digital Solutions lower Manhattan Authorized VeriChip Center.[22] The procedure to implant the tag under the skin is quick, simple and painless. The brief outpatient chipping procedure lasts just a few minutes and involves only local anesthetic. The standard location of the microchip is usually in the triceps area between the elbow and the shoulder of the right arm. Once inserted, the VeriChip is inconspicuous to the naked eye. Therefore, unlike traditional forms of identification, VeriChip cannot be lost, stolen, misplaced or counterfeited. VeriChips can be used in a variety of applications such as security, financial and emergency identification.

To achieve higher data rates, longer reading distances and smaller antenna size, Karthaus and Fischer designed a passive tag IC in the UHF band region (868/915 MHz and 2.45 GHz).[23] In order to increase the reading distance, they used a different voltage generator topology and employed a very well suited technology, which is the two metal, two-poly, 0.5 µm digital CMOS process, to support the EEPROM and Schottky diodes. The specially designed Schottky diodes, with low series resistance, allow a high efficiency conversion of the received RF input signal energy to DC supply voltage. Therefore, a low power of 16.7 µW is sufficient to power the tag. The IC's power supply is taken from the energy of the received RF electromagnetic field with the help of a Schottky diode voltage multiplier. The IC includes the power supply generation, phase shift keying backscatter modulator, pulse width modulation demodulator, EEPROM and logic circuitry including some finite state machines handling protocol, used for wireless write and read access to the IC's EEPROM and for the anti-collision procedure.

By the end of 2003, Trolley Scan had developed its new energy-efficient UHF RFID passive EcoTag that uses only 250 µW of energy to operate,[24] which is about one quarter of the energy needed by the previous version of the EcoTag. Although the power consumption is not as low as seen in the work done by Karthaus and Fischer, it is considered energy efficient compared to some other UHF tags in the market. The EcoTag can operate as far as nine meters, which is a significant distance. Trolley Scan achieved such low power consumption by working on improving the common problem of transferring the energy efficiently from the air to the electronic circuit due to incompatibilities between the microchip and the antenna in the UHF band. The improved performance comes from calculating and implementing the correct transfer network to match the antenna impedance to the equivalent load of the tag circuit as seen via the power rectification circuits of the tag. Trolley Scan has since been awarded a US patent for its work.

RFID adopters and those who are skeptical in using the RFID technology often raised the privacy issue concerning the used of the technology. This called for a blocking technique

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It's a new venue, a new location, and an extended format as the home city of Manchester United Football Club plays host to the 9th European Microwave Week. Now extended to SIX days the Week has ONE goal — to offer FOUR strong, responsive and challenging conferences, complemented by ONE established exhibition featuring international players, and a vibrant social agenda. Europe's premier RF and Microwave event kicks off at the G-Mex/MICC Complex on 10 September through to 15 September.

THE MUST GO SHOW

Concentrating on the needs of engineers the event showcases the latest trends and developments that are widening the field of application of microwaves. Pivotal to the week is the **European Microwave Exhibition**, which offers YOU the opportunity to see, first hand, the latest technological developments from global leaders in microwave technology, complemented by demonstrations and industrial workshops. Registration to the Exhibition is FREE!

- **International Companies** — catch up with the premier industry names from around the globe
- **Leading-edge Technology** — exhibitors will showcase the latest product innovations, offering demonstrations and the chance to talk technical with experts
- **The Venue** — with good international access, and in the heart of the city of Manchester, G-Mex/MICC offers first class facilities
- **Technical Workshops** — get first hand technical advice and guidance from the experts
- **Four Conferences** — The European Microwave Conference 2006, EuMIC 2006, Wireless Technology 2006 and the European Radar Conference 2006

BE THERE

Exhibition Dates	Opening Times
Tuesday 12th September	09.30 – 17.30
Wednesday 13th September	09.30 – 17.30
Thursday 14th September	09.30 – 16.30

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European Microwave Week Workshops and Short Courses

For a more detailed description of any events on this page, visit www.eumw2006.com

Sunday September 10

Time	Workshop	Title
All day	SC1 (EuMIC/EuMC/ECWT)	Fundamentals of Microwave Power Amplifier Design
Morning	WS1 (EuMIC/ EuMC)	RF Materials and Devices
Afternoon	WS2 (EuMIC/ EuMC)	SiGe C HBT: Device Technology and Applications
Morning	WS3 (EuMIC/EuMC)	Non-linear Device Noise Models and Low Phase-Noise Oscillator Design
Afternoon	SC2 (EuMC/EuMIC)	Microwave Oscillators and PLL Frequency Synthesisers
All day	WS4 (EuMC/EuMIC)	RF Device Modelling
Morning	WS5 (EuMC/EuMIC/ ECWT)	Circuit level Linearisation Techniques
All day	WS6 (EuMIC/EUMC)	Terahertz Devices, Design, Modelling and Characterisation
Morning	WS7 (EuMC)	Nanostructure Ferroelectric Films for Tuneable Microwave and Related Components
Afternoon	WS8 (EuMC)	Passive Microwave Devices using Advanced Materials
Morning	WS9 (ECWT)	Integration of Satellite Navigation and 3G Mobile Communications
Afternoon	WS10 (ECWT)	Modelling for TX System Analysis
All day	WS11 (ECWT)	Mobile Video and TV, Wireless Technologies and Circuits

Friday September 15

Time	Workshop	Title
All day	WS12 (EuRad)	New Horizons for Radio Astronomy Techniques (Talks and open forum in morning, trip to Jodrell Bank in afternoon)
Morning	WS13 (EuMC/EuRad)	Microwave Sensors and Imaging Systems
All day	WS14 (EuMC/EuMic/ECWT/EuRAD)	RF MEMS and RF Microsystem applications and development in Europe.

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Full Day WITHOUT conference registration	£140	£100	£160	£120
1/2 Day WITHOUT conference registration	£100	£70	£110	£80

that has been in its research stages at RSA Security since early 2004. Without any disruption to normal RFID operation, the RFID blocker tag[25] can prevent readers from performing unwanted scanning and tracking of people or goods. The blocker tag, similar in size and cost to a normal RFID tag, works by disrupting the transmission of information to any unauthorized RFID readers. When the blocker tag is removed from a product, the RFID tags would work normally, but when RFID tags are in the coverage area of a blocker tag, the RFID tag and its contents will be shielded from the reader.

In March 2004, Toppan Forms, a technology subsidiary of Japan's Toppan Printing, teamed with Kanazawa, a Japan-based integrated circuit manufacturer FEC Inc., to create the first multi-frequency RFID microchip, called the MM chip,[26] that can operate at all frequencies from 13.56 MHz to 2.45 GHz. The aim for this chip is to make it possible for companies to use tags that can be read anywhere, regardless of local regulations. The write-once passive chip is rather small, measuring 0.5 × 0.5 mm in size, and has 32 bytes of memory storage. The chip uses a proprietary method of communication between the tag and reader, so standard readers cannot read it. Unlike most RFID chips, which are tuned to one frequency for reading and writing, a special reader developed by Toppan, using any frequency, will be able to read the MM chip. The data is written on the chip, using the infrared portion of the electromagnetic spectrum. The MM chip can store a 64-bit or 86-bit EPC.

In December 2004, a startup company named Sandtracker came up with a new RFID technology that replaces silicon chips in the tags.[27] The proposed RFID tag uses a quartz crystal diode, instead of a silicon chip, for transmitting the signal from the tag to the reader. As a result, the signal is reportedly stronger and the tag offers a longer reading range and costs less to manufacture than tags using conventional RFID technology. About 4000 Sandtracker tags can be read simultaneously in any spatial orientation with read ranges of up to 18 meters. The tags can be passive or active. They contain prewritten RFID codes and can have numbers written to them at the point of use or can be written to more than once, depending upon the application and the type of Sandtracker tag that is used. The tags can operate at the recommended frequencies ranging from 100 MHz to 1 GHz or can be configured to operate at multi-frequencies. Their design hold the same data constructs, use the same frequencies and show the same signal characteristics as UHF tags based on existing EPCglobal standards. The tags also hold an EPC-compliant RFID number in the standard format.

Tag designs continue to evolve as the world is turning to new applications, performance improvement, cost reduction, low manufacturing cost and size reduction. The tag's key design goal is to include all the required components on a single IC and use inexpensive components for cost reduction purposes. The second design goal is to minimize the power consumption to enable operation at maximum range. This requires special low voltage and low current design techniques and a suitable low power process. The third design goal is to minimize the chip area, thus requiring a small geometry process for minimal cost. Other goals include improving the performance of the tag in terms of reducing errors in detection and adding anti-collision feature. Privacy and security concerns further encourage researchers to add more security features in the tags. The designs of tags vary based on their application, operating frequency, technology used and simplicity of the designs.

CONCLUSIONS AND RECOMMENDATIONS

Improvements in RFID are constantly taking place, and are clearly driven by the advances in RF technologies. These include the design and technology, manufacturing methods and the frequency spectrum allocation. Smaller chip surfaces will bring new assembly technologies, such as flip-chip technology.[28] A use-once-and-throw-away, low cost, read-only RFID tag will eventually be possible in the near future. Any environmentally friendly material is possible to receive today's RFID electronics. When recycled, the remains would consist of paper fibers, silicon (sand), copper and minute traces of aluminum. However, some fundamental changes in the existing RFID technology are required. These include the way the tags are manufactured and the process used.

As the demand for wireless communication and high speed mixed-signal systems continues to increase, providing sufficient electrostatic discharge (ESD) protection for the tags could be researched and implemented in the chip design. Currently, most of the existing tag chips do not contain an ESD protection circuit that is tailored towards mixed-signal circuits. ■

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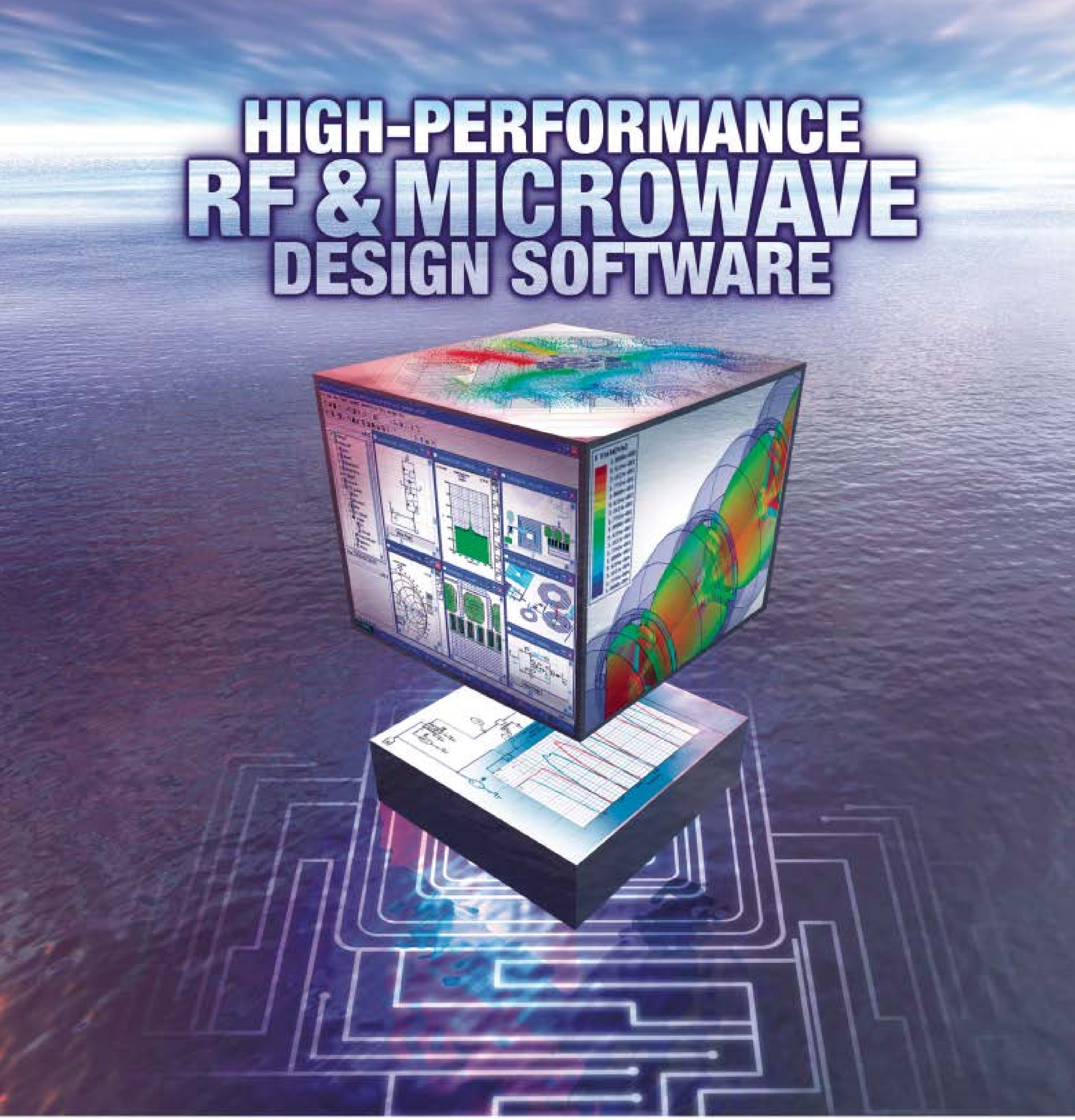
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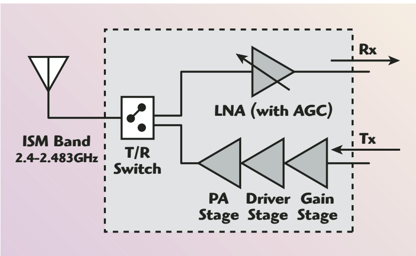
A 2.4 GHz CMOS Transceiver Single-chip RF Front-end for ISM-band Wireless Communications

A 2.4 GHz CMOS transceiver single-chip RF front-end for ISM-band wireless communications is presented. The CMOS RFIC contains a gain-controlled low noise amplifier (LNA), a series-type T/R switch and a power amplifier (PA) with diode linearizers, which are integrated on a single chip. The RFIC was fabricated with the 0.25 μm 1P5M standard CMOS process; the measurements of the RFIC were performed using an FR-4 PCB test fixture. In the receive mode, the CMOS transceiver RFIC exhibits a gain of 13 dB, a noise figure of 5.7 dB, an input P1dB of –5.3 dBm and an IIP3 of 1.5 dBm. In the transmit mode, the CMOS transceiver RFIC exhibits a linear gain of 28 dB, an output P1dB of 13.5 dBm and a PAE of 14.9 percent. The maximum allowable output power is 13.43 dBm for the IEEE 802.11b transmit spectrum mask test (data rate = 11 Mbps).

Due to the fast development of wireless communications, a low cost, high performance, highly integrated technology is needed for system-on-a-chip (SoC) implementations. The CMOS technology provides a good solution for SoC integration.[1] Recent improvements of the standard CMOS process make it possible to implement RF blocks, such as low noise amplifiers, mixers, voltage-controlled oscillators (VCO), power amplifiers and T/R switches,[2,3] for operation at frequencies in the 2.4 and 5 GHz bands. Also, a 2.4 GHz CMOS power amplifier with an output power of 20 dBm has recently been reported.[4] The goal of a single-chip transceiver radio or a radio-on-a-chip (RoC) with a medium-range transmitting power has become more feasible.

Fig. 1 Block diagram of a single chip 2.4 GHz CMOS transceiver RF front-end.



In this article, a 2.4 GHz single-chip CMOS transceiver RF front-end is presented (see **Figure 1**) for ISM-band wireless applications. The transceiver includes a three-stage power amplifier with a diode linearizer, a se-

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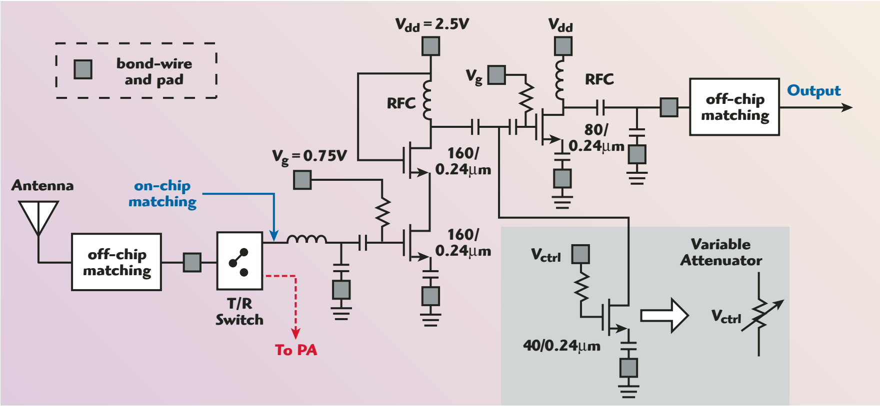
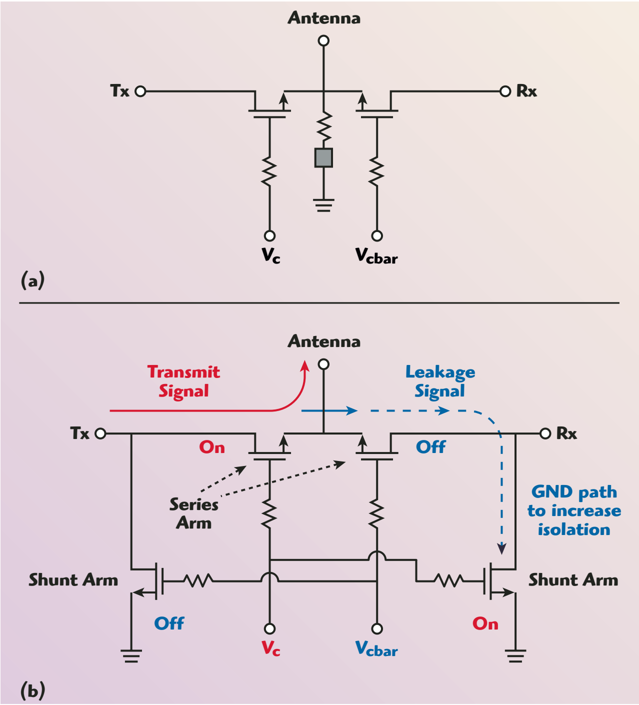
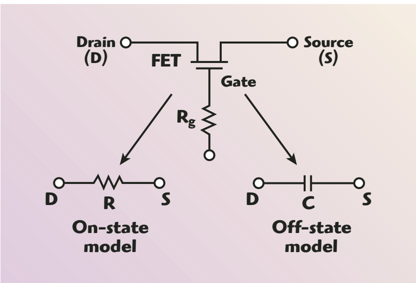
ries-type T/R switch and a gain-controlled LNA. The RFIC was fabricated with the 0.25 µm 1P5M standard CMOS process. Using an FR-4 PCB test fixture, extensive measurements were performed in the transmit and receive modes, including the IEEE 802.11b transmit spectrum mask test.



▲ *Fig. 2 Schematic of the 2.4 GHz CMOS two-stage, gain-controlled LNA (with a T/R switch).*



▲ *Fig. 3 T/R switches; (a) series-type and (b) shunt/series-type.*



▲ *Fig. 4 Transistor on/off equivalent model.*

RECEIVE CIRCUIT DESIGN

Gain-controlled LNA

The first and second stages of the LNA use a cascode and cascade topology to increase gain and isolation. The cascode configuration is used to reduce the Miller effect and to increase the 3 dB bandwidth of the amplifier. Owing to the high isolation of the input and output ports of the amplifier, the matching task can be easily done. The schematic of the designed 2.4 GHz CMOS, two-stage, gain-controlled LNA (with a T/R switch) is shown in ***Figure 2***. The design procedure is as follows:

- The most important procedure is to choose the right NMOS transistor channel width, which has the lower noise figure.[5] In accordance with the simulation results, the channel width of the first NMOS transistor was chosen to be 160 µm.
- On-chip spiral inductors were used for the RF chokes of the first and second stages. The RF chokes have been chosen from experience to provide a good inter-stage matching of the two stages.
- Due to the low Q-factor and the large size of the chip spiral inductors, off-chip lump elements are used to realize the output matching circuit.
- The input port of the LNA and the Rx port of the T/R switch are connected on chip. The interface between the T/R switch and LNA is designed to be conjugately matched.
- A gain control circuit is added by using a parallel variable resistance, which is implemented by using a NMOS transistor biased at V_{ds} = 0 V.[6]

Series-type T/R Switch

Two typical circuit configurations of the T/R switch, the series- and shunt/series-type switches, are shown in ***Figure 3***. Adding the two shunt arms to a series-type T/R switch forms the shunt/series-type T/R switch. The two shunt arms increase the isolation between the Tx and Rx ports of the shunt/series-type T/R switch over that of the series-type. Although a low isolation could possibly saturate the received signal with the transmit signal leaking when the PA is turned on, for WLAN applications (with a TDD duplex) when the Tx and Rx modes will not turn on simultaneously, the series-type T/R switch should be adequate. In addition, the series-type T/R switch has a lower insertion loss, a simpler architecture and no power consumption. Here the series-type T/R switch is used for integration into the designed 2.4 GHz transceiver RF front-end circuits. The design considerations are as follows:

- As shown in ***Figure 4***, when the transistor is turned on and off, it can be modeled as a resistor R and a capacitor C. The resistor R results in an insertion loss when a signal passes through the transistor; the capacitor C provides the isolation between the two ports of the transistor.
- When the transistor is turned on, as the transistor gate width is increased, the on-state resistance R becomes smaller and results in a lower insertion loss.
- When the transistor is turned off and the transistor gate width is increased, the off-state capacitance C becomes larger and results in a lower Tx/Rx port isolation.
- By using the above three rules, the most suitable transistor gate width is chosen according to the simulation results from the RF model.
- The interfaces between the T/R switch, LNA and PA are connected on chip and the antenna port uses an

off-chip matching circuit to assure the antenna port is matched to 50 Ω.

A series-type 2.4 GHz CMOS T/R switch is shown in ***Figure 5***. A 320/0.24 µm transistor gate width (Tx arm) and a 90/0.24 µm transistor gate width (Rx arm) are chosen for the series arms. In order to have a higher PA output power, a larger gate width is chosen for the Tx arm transistor. The control voltage is 2.5 V. Note that a resistance R_1 is needed to assure a DC ground-return path. A summary of the simulated characteristics is given in ***Table 1***.

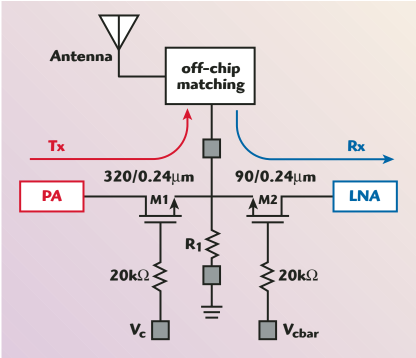
Receive Mode Test

Figure 6 illustrates the receiving mode test for the transceiver RF front-end. ***Figures 7***, ***8***, ***9*** and ***10*** and ***Table 2*** show the simulated and measured performance in the receiving mode. The receiving mode exhibits a gain of 12.9 dB. The noise figure is 5.7 dB. The input 1 dB compression point (P1dB) is approximately –5.3 dBm, and the IIP3 is approximately 1.5 dBm. The input (at the antenna-port of the T/R switch) and output return losses are approximately 12.5 and 23.3 dB. When the gain control circuit turns on at 2.44 GHz the gain tuning range is approximately 12.93 (V_{ctrl} = 0 V) to 2.24 dB (V_{ctrl} = 2.5 V) and the noise figure over the tuning range is approximately 5.7 (V_{ctrl} = 0 V) to 10.35 dB (V_{ctrl} = 2.5 V).

TRANSMIT CIRCUIT DESIGN

Power Amplifier with a Diode Linearizer

In order to decrease the output power required from the upconversion mixer, when the power amplifier

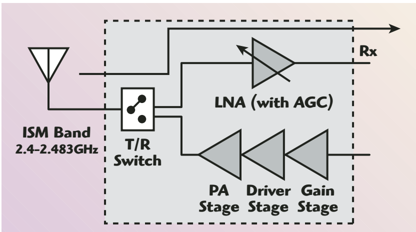


▲ *Fig. 5 Schematic of a series-type 2.4 GHz CMOS T/R switch.*

TABLE I

SIMULATED CHARACTERISTICS OF THE 2.4 GHz CMOS T/R SWITCH

Control voltage (V)	2.5
Input return loss (Tx/Rx ports) (dB)	> 16
Input return loss (ant port) (dB)	> 26
Insertion loss (dB)	< 1.6
Isolation (Tx/Rx mode) (dB)	> 20/> 13
Input P1dB (dBm)	> 19



▲ *Fig. 6 Receiving mode test for the 2.4 GHz CMOS transceiver RF front-end.*

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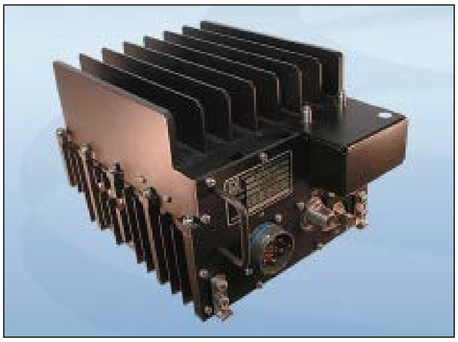

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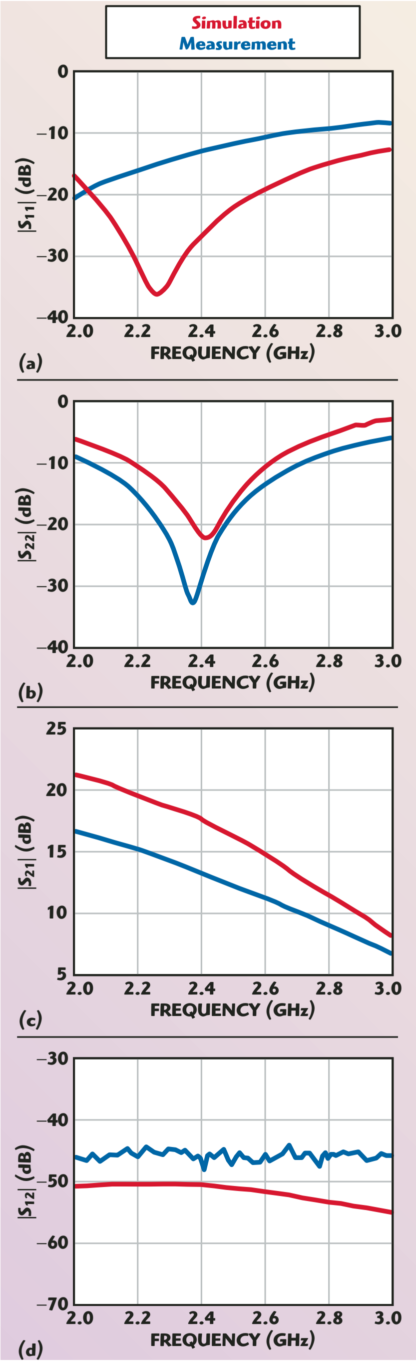
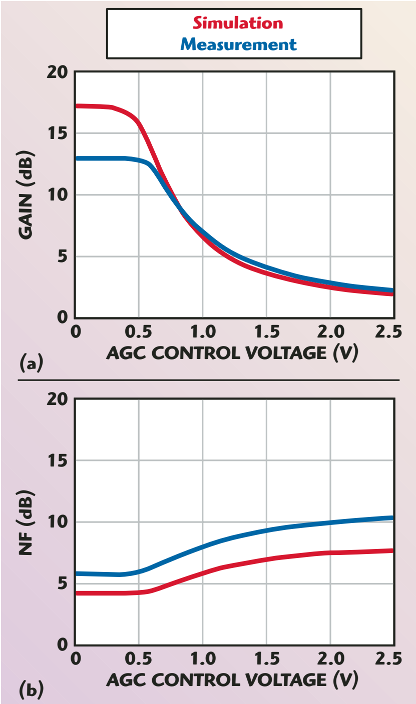


▲ *Fig. 7 Simulated (red) and measured (blue) S-parameters for the receiving mode of the 2.4 GHz CMOS transceiver front-end.*

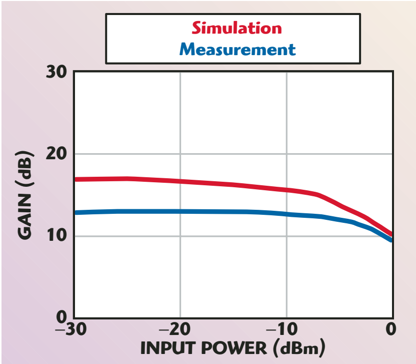
(PA) is operated at the maximum output power, the 2.4 GHz CMOS linearized PA requires a three-stage topology. Because of the need for enough linearity, the designed PA uses a class-AB topology and a diode linearizer at the output stage to increase the linearity of the PA.[7] Due to the low breakdown voltage and high knee voltage, the output power and efficiency of a CMOS PA is limited. The design goal of the 2.4 GHz



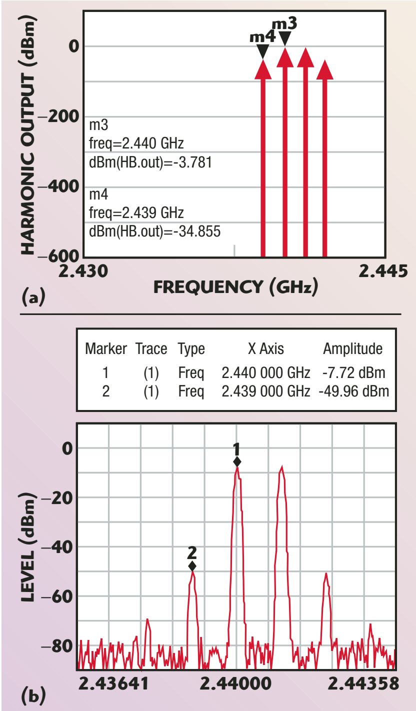
▲ *Fig. 8 Simulated and measured (a) gain and (b) noise figure for the receiving mode.*

CMOS linearized PA (with T/R switch) is: output P1dB > 13 dBm, linear gain > 25 dB, and PAE > 12 percent. The schematic of the designed 2.4 GHz CMOS three-stage, linearized PA (with T/R switch) is shown in ***Figure 11***. The following is the design procedure:

- A class-AB topology (V_g = 0.9 V) is used at the output stage to acquire enough linearity.
- The channel width of the output stage transistor is chosen to be 600 µm, using ADS load-pull software.
- The driver and gain stages are designed to drive the output stage to the desired output power, and the channel width of the gain and driver stages are chosen to be 90 and 320 µm, respectively.[8]
- A resistor is placed across the gate and drain of the transistors to increase the stability of each stage and assure that the PA is unconditionally stable.
- In order to prevent metal migra-



▲ *Fig. 9 Gain vs. input power for the receiving mode.*

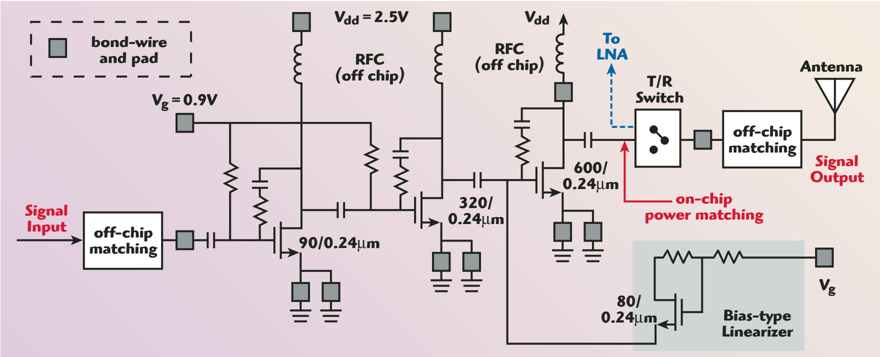


▲ *Fig. 10 The receiver mode (a) harmonic output and (b) two-tone IM test results.*

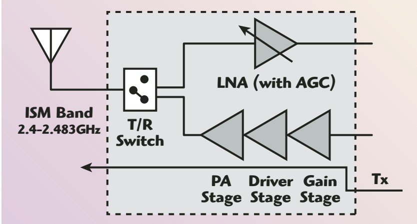
TABLE II

SIMULATED AND MEASURED CHARACTERISTICS OF THE RECEIVING MODE OF THE 2.4 GHz CMOS TRANSCEIVER FRONT-END

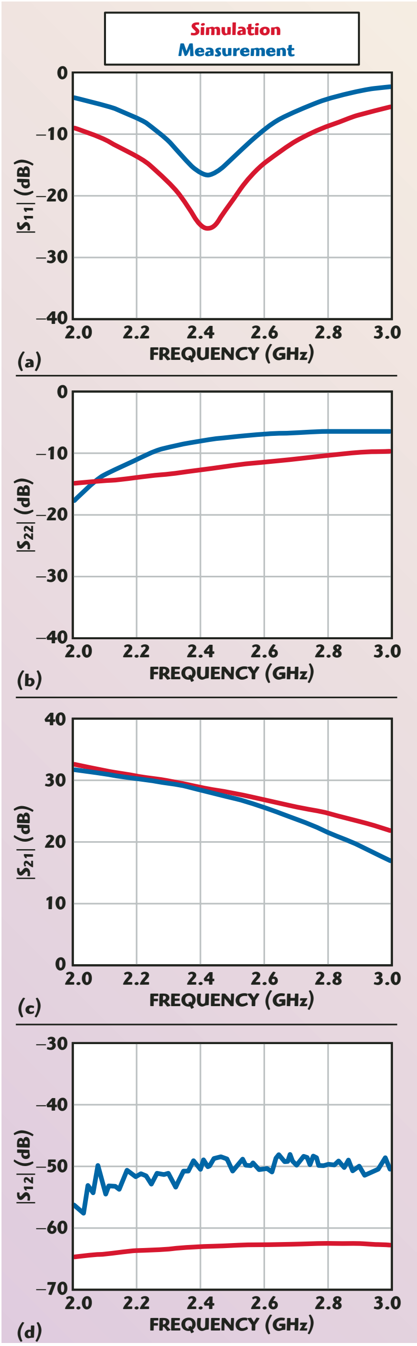
	Simulation	Measurement
V_{dd}/V_g (V)	2.5/0.75	2.5/0.75
Current/power consumption (mA/mW)	7.88/19.7	9/22.5
Input/output return loss (dB)	24.7/21.4	12.5/23.3
Gain (dB)	17.1	12.9
Noise figure (dB)	4.2	5.7
IIP3 (dBm)	–4.34	1.5
Input P1dB (dBm)	–15	–5.3
Gain tuning range (dB)	17.1–1.97	12.93–2.24
Noise figure tuning range (dB)	4.2–7.7	5.7–10.35



▲ *Fig. 11 Schematic of the 2.4 GHz CMOS three-stage linearized power amplifier with T/R switch.*



▲ *Fig. 12 Transmitting mode test for the 2.4 GHz CMOS transceiver RF front-end.*



▲ *Fig. 13 Simulated (red) and measured (blue) S-parameters of the transmit mode of the 2.4 GHz CMOS transceiver RF front-end.*

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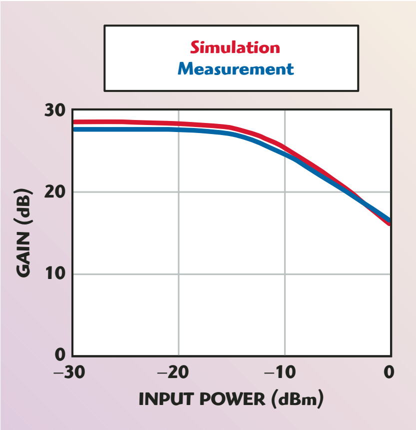
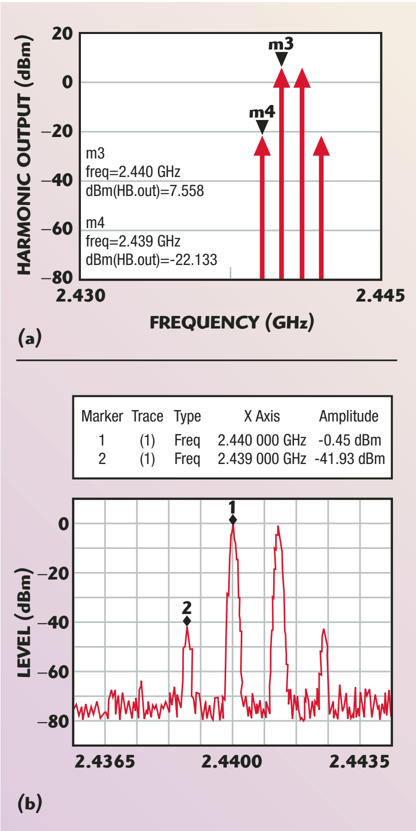


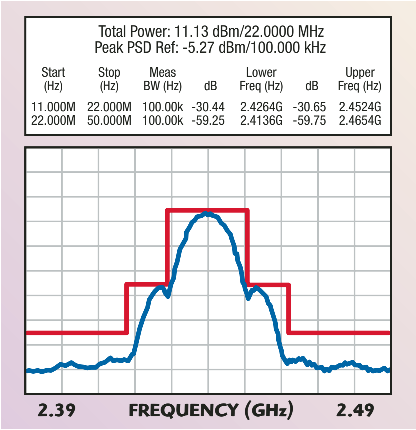
▲ *Fig. 14 Simulated and measured gain vs. input power for the transmit mode.*



▲ *Fig. 15 Transmit mode (a) harmonic output and (b) two-tone IM test results.*

tion of the on-chip spiral inductors, the RF chokes at each stage use off-chip inductors, and the three RF chokes have been experimentally chosen to provide a good power match of the three stages.

- The output port of the PA and the Tx port of the T/R switch are connected on chip, and the interface between the T/R switch and PA is designed to be power matched.
- The input port of the PA uses an off-chip matching circuit to assure the input impedance of the PA to be 50 Ω.



▲ *Fig. 16 802.11b transmit spectrum mask.*

TABLE III

SIMULATED AND MEASURED CHARACTERISTICS OF THE TRANSMITTING MODE OF THE 2.4 GHz CMOS TRANSCEIVER FRONT-END

	Simulation	*Measurement*
V_{dd}/V_g (V)	2.5/0.9	2.5/0.9
Current/power consumption (mA/mW)	60.3/150.8	60/150
Input/output return loss (dB)	25.1/12.5	16.5/7.8
Linear power gain (dB)	28.3	28.0
P_{out} @ 1dB compression point (dBm)	14.5	13.5
PAE @ 1dB compression point (%)	14.03	14.9
OIP3 (dBm)	20	20.3

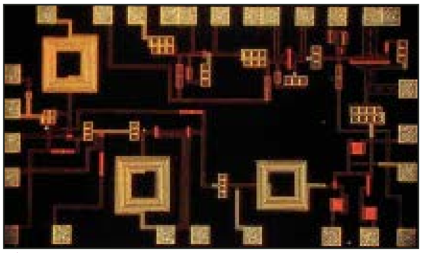
Transmit Mode Test

Figure 12 illustrates the transmitting mode test for the transceiver RF front-end. ***Figures 13***, ***14***, ***15*** and ***16*** and ***Table 3*** show the simulated and measured performance of the transmit mode. The transmit mode exhibits a gain of 28 dB, an output 1 dB compression point of approximately 13.5 dBm, an OIP3 of approximately 20.3 dBm and a PAE of 14.9 percent. The input and output return losses (at the antenna-port of the T/R switch) are approximately 16.5 and 7.8 dB, respectively. All the tests were made at 2.44 GHz. The maximum allowable output power is 13.4 dBm for the IEEE 802.11b transmit spectrum mask test (center frequency = 2.44 GHz, Gaussian filter BT = 0.4, data rate = 11 Mbps). ***Figure 17*** shows a micrograph of the 2.4 GHz CMOS transceiver RF front-end RFIC chip with a size of 1.92 × 1.10 mm².

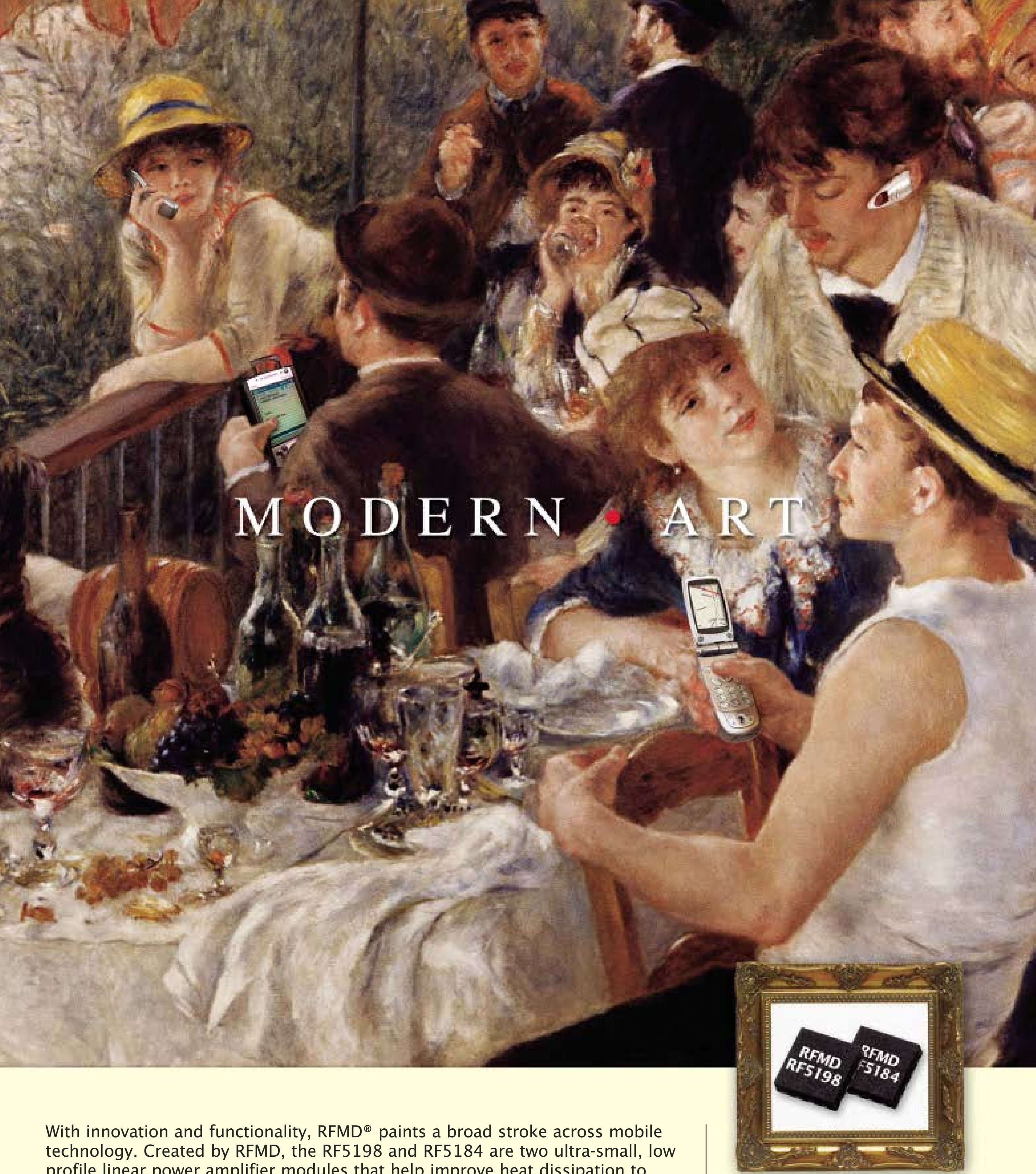
CONCLUSION

The design, fabrication and measurements of a 2.4 GHz CMOS transceiver single-chip RF front-end have been presented. The single-chip RFIC, with a chip size of 1.92 × 1.10 mm², is fabricated with the 0.25 μm 1P5M standard CMOS process. The transceiver RFIC consists of a series-type T/R switch, a gain-controlled LNA and a three-stage PA with a diode-linearizer. Using an FR-4 PCB test fixture, extensive measurements in the transmit and receive modes were performed, including an IEEE 802.11b transmit spectrum mask test.

For the receive mode, the CMOS transceiver RFIC exhibits a gain of 13 dB, a noise figure of 5.7 dB, an input P1dB of –5.3 dBm and an IIP3 of 1.5 dBm. The input (at the antenna-port of the T/R switch) and output return losses are approximately 12.5 and 23.3 dB, respectively. The gain tuning range is approximately 12.93 (V_{ctrl} = 0 V) to 2.24 dB (V_{ctrl} = 2.5 V) and the noise figure within the tuning range is approximately 5.7 (V_{ctrl} = 0 V) to 10.35 dB (V_{ctrl} = 2.5 V), respectively. For the transmit mode, the CMOS transceiver RFIC exhibits a gain of 28 dB, an output 1 dB compression point of approximately 13.5 dBm, an OIP3 of approximately 20.3 dBm and a PAE of 14.9 percent. The input and output return losses (at the antenna-port of the T/R switch) are approximately 16.5 and 7.8 dB, respectively. The maximum allowable output power is 13.4 dBm for the IEEE 802.11b transmit spectrum



▲ *Fig. 17 Micrograph of the 2.4 GHz CMOS transceiver RF front-end chip.*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mask test (center frequency = 2.44 GHz, Gaussian filter BT = 0.4, data rate = 11 Mbps). The CMOS transceiver RFIC performance demonstrates that the standard 0.25 µm CMOS process has a great potential in the transceivers for 2.4 GHz wireless communications. ■

ACKNOWLEDGMENTS

This work was supported by the National Science Council, Taiwan, ROC, under Grant NSC 92-2213-E-006-063. The authors would like to thank the Chip Implementation Center (CIC) of the National Science Council, Taiwan, ROC, for supporting the TSMC CMOS process.

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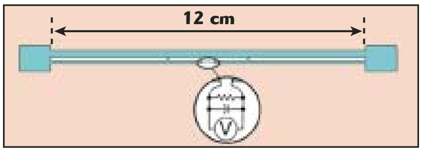
UHF RFID AND TAG ANTENNA SCATTERING, PART II: THEORY

In Part II of this work, a numerical solution, using a reasonable estimate for the tag IC impedance, is shown to provide accurate estimates of the scattering effects of tag antennas. A greatly simplified scattering theory for tag arrays is also presented, using an elaboration of the Floquet approximation after Hill and Cha and a simplified generic tag antenna model, allowing semi-quantitative results for complex arrays with elementary analytic expressions and no iteration. The results provide a qualitative confirmation that arrays of tag-like antennas produce sufficiently strong scattering to impact the ability to power and read a tag, particularly when end-fire illumination is employed.

In Part I of this article,[1] a number of experimental results were presented, suggesting that interactions in arrays of tag antennas play an important role in determining when a UHF RFID tag can be read, even when no other scattering is present in the environment. How can these effects be understood and predicted? It is first helpful to verify that, given the measured antenna geometry and reasonable values for the impedance of the integrated circuit loads, the observed behavior can be numerically reproduced from expected electromagnetic interactions. Such a demonstration both validates the interpretation of the measured data and limits the scope of physical effects that need to be considered to those incorporated in the numerical model. Guided by the results of numerical modeling, an attempt was also made to formulate a quasi-analytic model that is less accurate but computationally much less demanding, and thus easier to implement and scale to large arrays and complex geometries.

Fig. 1 Simulated geometry of an I-tag showing the lumped-element model of the IC.



NUMERICAL SIMULATIONS

An array of I-tag-like antennas was simulated using the full 3D field-solver CST Microwave Studio (Transient Solver), which uses the finite integration technique. The simulated antenna metal was assumed to be a perfect electric conductor. In the center of the antenna, where the RFID tag IC normally would be attached, a lumped load network was connected with a 1 kΩ resistor in parallel with a 1.6 pF capacitor. The simulated antenna geometry is shown in ***Figure 1***. ***Figure 2*** shows the

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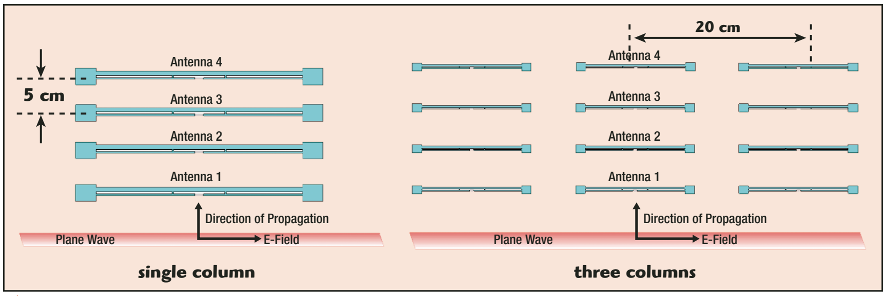

Fig. 2 *Simulated tag arrays.*

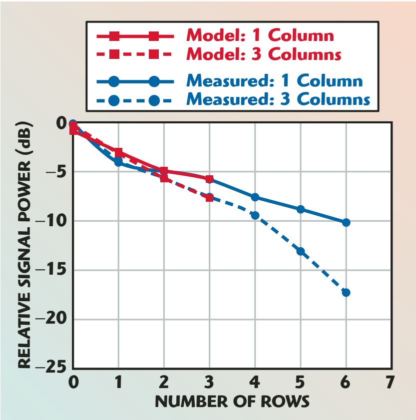

Fig. 3 *Comparison of the simulated and measured data for I-tag arrays.*

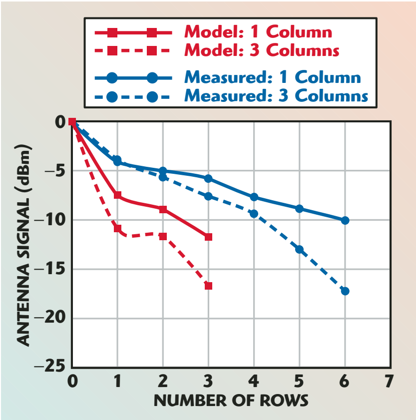

Fig. 4 *Same data as Figure 3 but with the shunt capacitance set at 0.8 pF.*

arrangement of antennas for the single- and three-column array cases.

To be able to determine the power delivered to the resistive load, which represents the real load of the tag IC, a voltmeter was connected in parallel with the resistor. The antenna calculation space was terminated with open boundary conditions except for along the symmetry line of the antenna where an electric boundary condition was used. Identifying a symmetry-plane in the set up helped cut the number of calculated mesh cells in half. In this simulation set up, no discrete or waveguide ports were defined. Thus, no S-parameters were calculated. Instead, a plane wave excitation source was used with linear polarization. The E-field vector was parallel to the I-tag antennas with broadside propagation orthogonal to the antennas. The amplitude of the electric field was set to be 1 V/m. The simulated results, using a shunt capacitance of 1.6 pF and a shunt resistance of 1 kΩ at 910 MHz (insignificantly different from the 915 MHz used in the measurement), are compared to the measured data in ***Figure 3***. Excellent agreement is obtained with the measured results for both a single column and three columns. Note that the model and measurement are of comparable rather than identical quantities: the numerical data are based on the voltage at successive elements of the center column of the array with all elements present, whereas the measured data is taken by adding successive rows to the array with a fixed receiving antenna (see Figure 18 in Part I). The close agreement between theory and experiment suggests that the strong effects of arrays of tag antennas on measured fields are real and expected for a typical array of tag antennas. The numerical results are quite sensitive to the load impedance value. For example, if the assumed capacitance is reduced to 0.8 pF, the effect of the array is considerably magnified (see ***Figure 4***). This sensitivity can be roughly understood by considering the radiating part of the antenna as predominantly capacitive, and treating the shunt central region as an inductor; in this case, the equivalent circuit of the system including IC is roughly a capacitance C_s in series with the shunt combination R, L and C of the simulated geometry. Thus, for fixed parameter values, a series resonance with maximum current flow is expected in the radiating portion (and maximum scattering), and a parallel resonance of L_p and C_p, typically at a slightly higher frequency, with large reactive currents in the shunt portion and minimal current flow in the series (radiating) part. Corresponding to these differing conditions, a differing voltage gain is expected from the impinging electric field to the IC contacts, affecting the ability of the IC to rectify the incoming RF power and turn on. The radar cross-section is proportional to the square of the current flow in the radiating portion of the antenna, so the measured variations in RCS (see Table 2 in Part I) suggest that array effects will vary with tag design and frequency.

SIMPLIFIED ANALYTIC MODEL FOR TAG ARRAYS

Numerical simulations of the type discussed, in which the detailed current distribution for each antenna element is self-consistently established, require specialized software, and are difficult to scale to large arrays. A considerable amount of work has been done on both numerical and analytic solutions to the problem of array fields for large but finite arrays.[2-6] In particular, many treatments assume the validity of the Floquet theorem, which states that the current on all elements of the array is of the same magnitude and varies only in phase from one element to the next. This theorem is valid for an infinite array, but is in serious error for a finite array illuminated near end-fire (that is, in the plane of the array). However, Hill and Cha[4] showed that reasonable results can often be obtained by applying Floquet's theorem individually during the calculation of the current on each individual element of the array, while allowing the current magnitude to vary when different element currents are calculated. This approach is roughly equivalent to assuming that the current magnitude varies slowly along the array so that the local currents on any given element are of similar magnitude and their relative phase dominates the determination of the total field strength. The numerical results also suggest a simplified approach to modeling the antenna currents and charges for typical RFID tag designs. ***Figure 5*** shows the simulated current magnitude for an I-tag antenna with a 1.6 pF shunt load capacitance at 915 MHz. Along the radiating portion of the antenna, the current varies from approximately 17 to 10 mA/m; that is, there is only approximately a 25 percent variation from the average value

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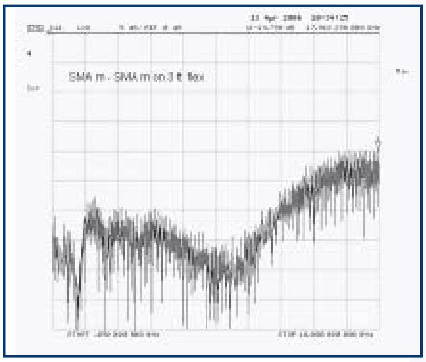

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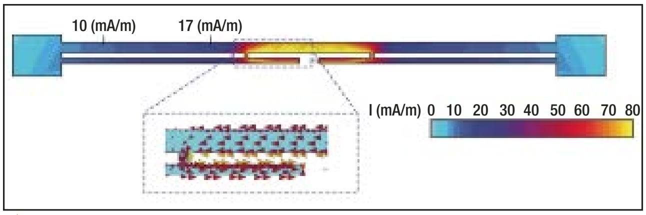
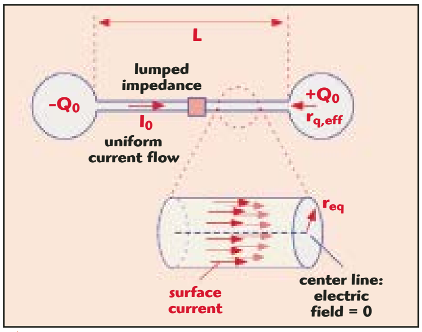


▲ *Fig. 5 Numerical model of the current distribution in an I-tag-like antenna at 915 MHz.*

of approximately 13.5 mA/m. Large gradients in current density, observed in the loading regions at the ends of the antenna, show that charge is stored in these regions. The inset is a close-up of the inductive shunt region, showing that the currents flowing on the two arms of the antenna are opposed and approximately cancel one another, leading to relatively little radiated power from the central region. Guided by these results, a simplified analytic model of element antennas appropriate for many RFID tags is proposed, consisting of a radiating region along which the current is constant, a charge storage region at the ends in which no current flows and a central lumped-element load (see ***Figure 6***). The radiating region is modeled as a cylinder with some equivalent radius r_{eq}; the end regions provide a capacitive charge storage with an equivalent size $r_{q,eff}$. The effect of the central lumped impedance is to reduce the value of the peak current flow. (This is a reasonable approximation as long as the impedance is comparable in magnitude to the radiation resistance of the remainder of the antenna; for large central impedances one must account for the change in current distribution along the radiating region.) A further simplification that should be valid for most tag designs within their intended frequency range is obtained by taking into account the fact that in most cases a tag antenna will be designed to provide a conjugate match to the load impedance presented by the IC. As a consequence, the current flow on an isolated antenna can be assumed to be in phase with the incident field. An example of the application of this analytic approach to an end-fire array will be provided. The last element of a linear array with J elements in the plane of propagation, offset from each other by a distance δy, is considered first. In the particular case of the last element of an end-fire array, the sum of the delay from the source to an earlier element, and from that element to the end is constant, so the contributions from preceding tag antennas can be added in phase in the Hill and Cha approximation. The effect of other elements can be split into a scalar (electric) po-



▲ *Fig. 6 Simplified model of an RFID tag antenna.*

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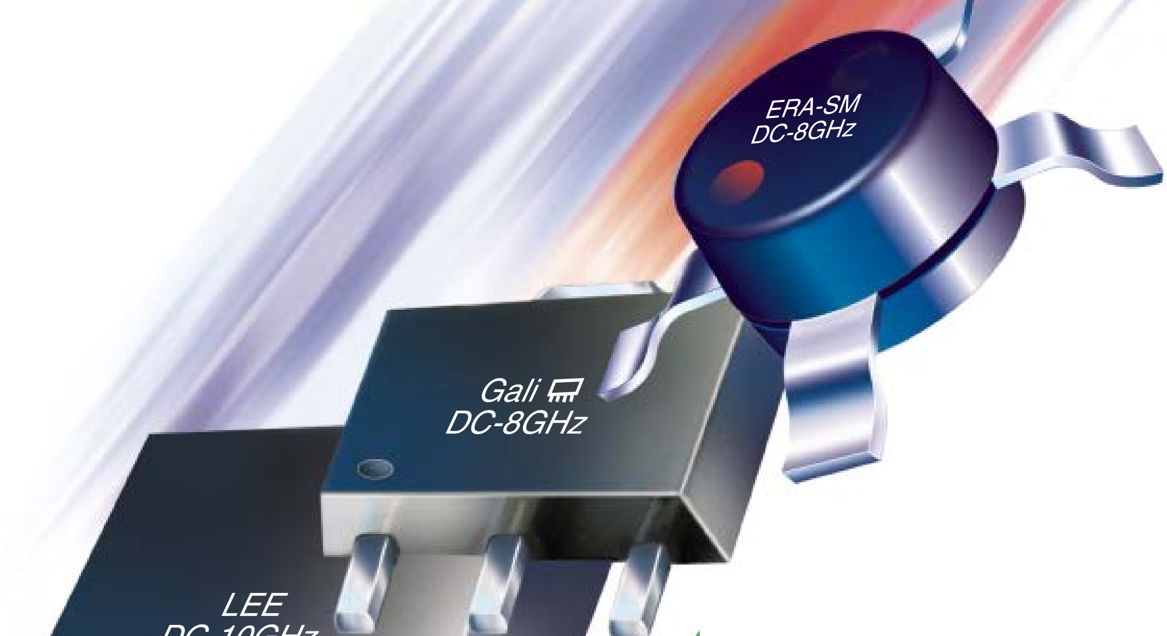

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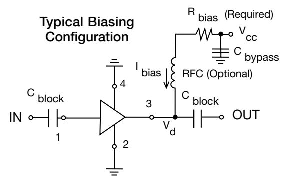

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tential and magnetic potential (mutual inductance). The scalar potential contribution is only significant from the nearest-neighbor antenna when the spacing is small compared to the antenna size. The vector potential contribution decreases approximately as 1/n δy and thus does not converge as the array grows larger. (The Hill and Cha approximation in this case ignores the phase shift along the array that would actually exist, and so slightly overestimates the contribution of distant antennas.) The boundary condition is the requirement that the scattered electric field E_{sc} due to the currents on all the antennas is the negative of the incident field E_{inc} at the last antenna, so that the total field within the wire is zero (see Figure 6). In integral form

$$V_{inc} = \int_{-L/2}^{L/2} E_{inc}dz = -V_{sc} = \int_{-L/2}^{L/2} E_{sc}dz \qquad (1)$$

The scattered voltage from the Jth tag antenna (self-voltage) is simply due to the radiation resistance and the series equivalent resistance of the IC

$$V_{sc,J} = 2I_0\left(R_{rad} + R_{ld}\right) \qquad (2)$$

where

I_0 = current along the antenna, presumed constant

The scalar potential contribution from the next-neighbor antenna (J-1) is approximately due only to the charge localized at the ends of the element. If δy is small compared to L

$$V_{sc,\phi,J-1} = -\frac{\mu_0 c^2}{2\pi}\left(\frac{I_0}{i\omega\delta y}\right) \qquad (3)$$

The scalar potential contribution from more distant antennas (J-2), etc. will generally be negligible. The magnetic contribution is obtained from the vector potential, in this case along the axis of the antenna (so that only the x component is considered). To a reasonable approximation

$$A_{sc,A,J-n} \approx \frac{\mu_0}{4\pi} I_0 L \frac{1}{n\delta y} \qquad (4)$$

Though for small δy, one should slightly modify the contribution from the nearest antenna

$$A_{sc,A,J-1} \approx \frac{\mu_0}{4\pi} I_0 L \frac{1}{\sqrt{(\delta y)^2 + \left(\frac{L}{4}\right)^2}} \qquad (5)$$

The electric field due to the vector potential is –iωA; this potential is approximately constant along the antenna, so the associated voltage is obtained by multiplying by L. Summing all the contributions

$$V_{sc,A,J\neq n} \approx -i\omega \frac{\mu_0}{4\pi} I_0 L^2 \left[\frac{1}{\sqrt{(\delta y)^2 + \left(\frac{L}{4}\right)^2}} + \sum_{n=2}^{J-1} \frac{1}{n\delta y}\right] \qquad (6)$$

The total scattered voltage, obtained by adding all the contributions above, is set equal to minus the incident voltage

$$V_{inc} = -V_{sc} = V_{sc,J} + V_{sc,\phi,J-1} + V_{sc,A,J\neq n} \qquad (7)$$

Since each contribution is proportional to the current on the antenna I_0, the resulting current is inversely proportional to the total impedance due to each contribution to the voltage. The power delivered to the end of the array relative to that incident on an isolated antenna in the same location is then

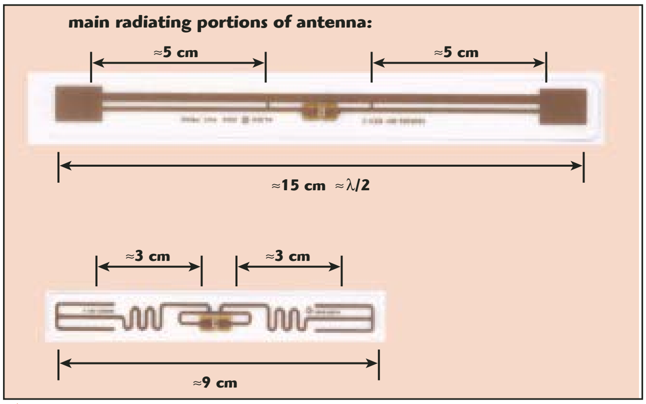


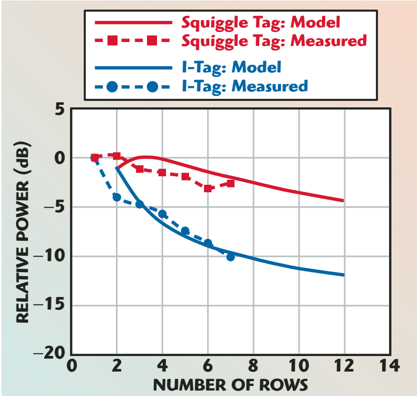
Fig. 7 Estimates of the radiating length of the I-tag and squiggle tag antenna designs.

$$I_{rel,J} = 20\log\left(\frac{I_{0,J}}{I_{0,J=1}}\right) \qquad (8)$$

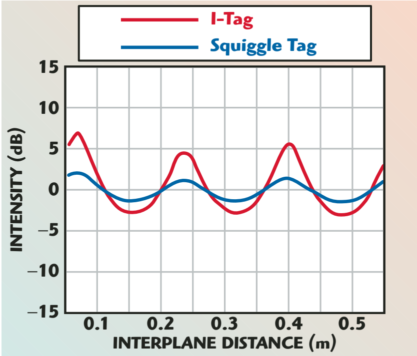
Because of the local Floquet assumption, no iteration is necessary: this model may readily be implemented in a spreadsheet or other general mathematical environment, and the computational time is negligible, even for large arrays. In order to apply the model, the fact that in general, the effective (radiating) length of a tag antenna is not the same as the physical end-to-end length, must be accounted for. Examples are shown in ***Figure 7*** for the I-tag and Squiggle tag; reasonable estimates of the radiating lengths of these antennas are approximately 10 and 6 cm, respectively.

In ***Figure 8***, the relative intensity for varying array sizes is shown, for two different values of the antenna length L, roughly corresponding to the I-tag and Squiggle tag, respectively, predicted from the simple model for a tag array. In all cases, the relative power is measured at the most distant tag (the far end of the array from the transmitting antenna). The model results are shown for a single column with a spacing of 5 cm in the propagation direction. Also shown is the experimental data for this configuration from Figure 19 in Part I. This very simple model provides a semi-quantitative agreement with the measured data, and explains the difference between the two types of tags primarily in terms of the difference in their effective radiating length. The simple analytic model is not nearly as accurate as the full numerical model, but can be scaled to large or complex arrays more readily than the numerical model.

When arrays other than a simple linear end-fire configuration are considered, both the phase offset between the element currents, due to the local Flocquet assumption, and the phase delay due to propagation from each remote element J to the el-



▲ *Fig. 8 Comparison of the simple analytic model with the measured data for a single column of tags.*



▲ *Fig. 9 Simulated intensity at the center of the rear array for two planes of 3x9 tags as the interplane distance is varied (924 Mz).*

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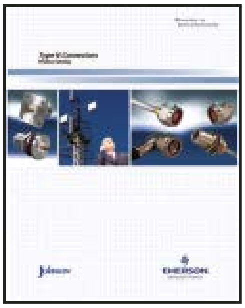

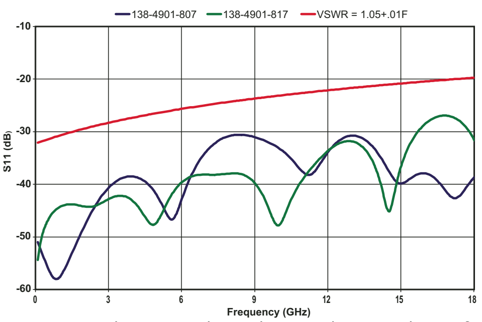

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ement of interest must be explicitly accounted for. Equations 3 to 6 become slightly more complex, as phase factors must be included, and a full complex number implementation is needed to perform model calculations, but otherwise the model is not significantly altered. An example of a result for a more complex geometry is shown in ***Figure 9***. Here a pair of plane arrays was modeled. Each plane contains a three by nine array of tag antennas, making this problem challenging to implement using a self-consistent numerical approach. The intensity in the center of the rear plane is plotted for parameters representing Squiggle and I-tag antennas. The expected half-wave periodicity can be observed and qualitative agreement with the data in Figures 10 and 12 in Part I is obtained.

In order to use this analytic approach as a systematic and accurate tool for general-purpose modeling of large RFID tag arrays, it will be necessary to establish a detailed correspondence with numerical simulations of various tag designs or measurements, obtained for example from radar cross-section data, so that appropriate parameters can be employed for each given combination of tag design and frequency of operation.

CONCLUSION

In this article, reasonable estimates of the load presented to the tag antenna by the integrated circuit have been shown permitting to reproduce the measured behavior of a simple array of single-dipole tags and providing theoretical confirmation that tags create substantial attenuation of incident signals in geometries reasonably representative of realistic commercial applications. Array effects are very sensitive to assumptions about the central IC impedance, and thus would be expected to vary with frequency and tag design. It is also shown that a simplified analytic theory for this interaction shows promise for providing a practical modeling tool, which can be implemented readily using general-purpose software tools and can deal with arrays much larger than those that are convenient to model using 3D simulation software. ■

ACKNOWLEDGMENTS

The authors would like to thank Jim Buckner, Kathy Radke, Titus Wandinger, Jose Hernandez, Don MacLean, Dan Kurtz and Walter Strifler for their assistance with this work.

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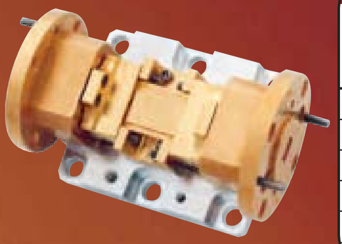

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JSW4-18004000-35-5A	18-40	21	2.5	3.5	2.5:1/2.5:1	5
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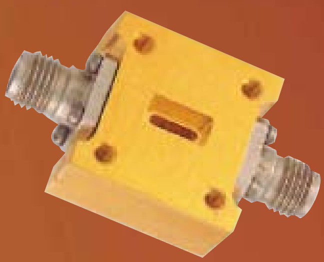

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MAX3M300300	10	30	10	10	60	160
MAX2M360500	18-25	36-50	10	10	18	160
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Up until a few years ago, it was only possible to fabricate radio frequency power amplifiers (RFPA) in the VHF band by using bipolar transistors, because the devices designed in vertical MOS technology (VMOS), which were the only MOS power devices available at that time, were not able to amplify signals of more than a few hundred megahertz. In fact, the old vertical geometry presents two types of parasitic parameters caused by the transistor layout: the source inductor and the feedback capacitor (gate-drain capacitor), which limit the frequency range to less than approximately 300 MHz. In RF power amplifiers, MOS transistors must be operated in the common-source configuration since the package flange to which the source is electrically connected must be attached to the cooling heat sink (that is the ground), because of thermal problems related to the dissipation of the heat generated. In the same way, BJT transistors are connected in the common-emitter configuration since, in fact, for them the emitter is attached to the flange. For MOS transistors, the common-source configuration (which is analogous to the common emitter of the bipolar transistors) magnifies the capacitance existing between the gate and the drain, because of the Miller effect. In BJT transistors, the capacitance is the one between the base and the collector (see ***Figure 1***). A small value of the capacitance C produces a strong feedback between the output and input, which decreases the gain. From the analysis of their performances, the main difference observed between bipolar and MOS transistors used in RF power applications is the gain: for the same output power level, a BJT has a typical gain value of approximately 8 to 9 dB, while an MOS transistor is able to provide a gain up to 14 dB. From what has been previously demonstrated, if bipolar devices are used as amplifiers between the up-converter and the antenna in the transmission channel, 8 or 9 amplifier stages are necessary. If it is possible to use MOS power transistors, two to three intermediate stages could be eliminated, thanks to their higher gain.

If the number of stages that make up the chain decrease, in addition to the active devices, it is possible to spare the power supply stages, protection circuits and heat sink, and generally decrease cost and size. In this way, it is possible to reduce the probability of failure because the system is made up of a series of several stages: if the number of stages that

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Information

Deadlines

Summary – at least 1000 words	**18 Aug. 2006**
Authors notified of acceptance	**29 Sept. 2006**
Full papers – 6 pages	**1 Dec. 2006**

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In addition to formal presentations, there will be poster presentations. Authors who believe their papers are better suited to a poster format are requested to so note on their summaries. The poster format provides authors the opportunity to display their paper and related equipment or visual aids and to discuss their information with the conference participants. Both oral presentation and poster presentation papers will be published in the proceedings. Poster paper authors will present a 2-minute oral summary of their work in suitable sessions.

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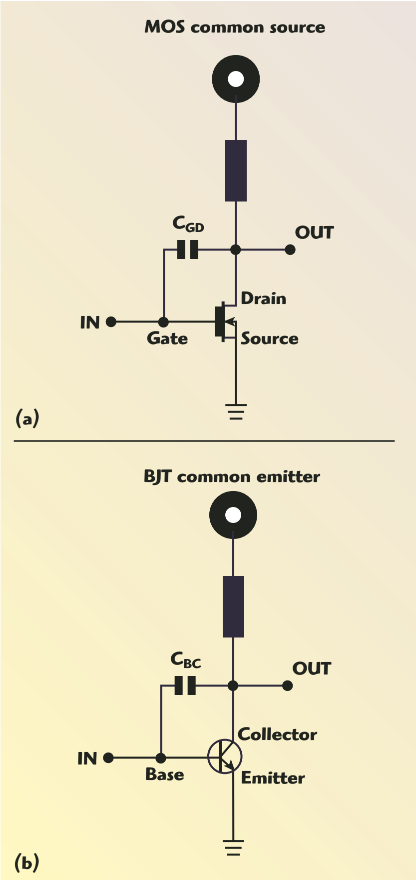

Fig. 1 *MOS transistor (a) and BJT (b) configurations.*

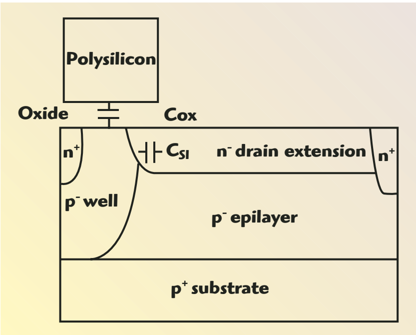

Fig. 2 *Gate-drain capacitor in the LDMOS transistor.*

make up the chain decreases, the reliability will increase because the number of the terms Pi is less (every term is less than or equal to 1), which represents the probability of work for the generic stage.

The unavailability of MOS power devices with high gain and able to work at frequencies in the VHF band has stimulated the research and development departments of the silicon foundries that were already producing RF bipolar transistors to design a new MOS power transistor able to work with good efficiency (over the

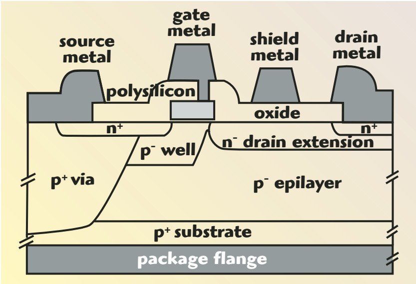

Fig. 3 *Cross-section of an LDMOS transistor.*

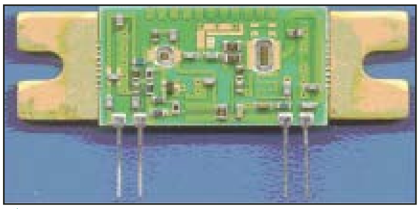

Fig. 4 *Layout of a high power LDMOS transistor.*

300 MHz to 3 GHz frequency range) that is from the UHF to low microwaves (L- and S-bands). The key push for this technological development was caused by the anticipation of a large number of mobile telecommunications sets, first at 900 MHz, then in the dual-band at 1.8 and 2.7 GHz.

Since their introduction in the market, the fields in which LDMOS transistors find application are increasing. The most important one is telecommunications, but many other applications such as military communications and avionics, radar transmitters and broadcasting have been interested by the arrival of the new power semiconductors and benefiting from their optimal performances that represent one important step in digital transmissions.

TECHNOLOGICAL DEVELOPMENT

It was possible to achieve the new LDMOS technology by combining lateral diffusion (LD) with the VMOS transistor (vertical) process in order to avoid the frequency limitations described previously. The reductions of the feedback capacitor and the source inductor have allowed the devices to support high power applications in the frequency range from approximately 300 MHz to 3 GHz. The new LDMOS has been the device of choice in the wireless telecommunications field.

There are two types of technological innovations in the layout of the transistors that have allowed improving the frequency performance of the devices. The first goal has been to reduce the feedback capacitor C_{gd}, made from the two series capacitors C_{ox} and C_{si}, where C_{ox} is the overlap capacitor between the gate and the diffused n-drain extension region. It is proportional to the area of such overlap and depends on the oxide thickness. C_{si} represents the transition capacitor associated with the junction p– well and n– drain extension: this capacitor depends on the depth of the junction and the doping of the n– drain extension region (see ***Figure 2***). The addition of the diffusion region n- drain extension has the effect of reducing the C_{si} capacitor, which is the larger of the two capacitors in the series, allowing the reduction of the total capacitor C_{gd}. It is possible to cancel the source inductor by means of the diffusion of one p+ via that forms the contact between the source of the device and its substrate, which has direct contact with the package flange. In such a way, the flange of the device represents the source contact that, in common-source configuration (the only one possible in RF and microwave power applications), must be connected directly to the ground, attaching the same flange of the transistor to the heat sink without electrical insulator, which would make the heat transfer worse. The technological development described, which avoids the use of a bond wire between source and the ground, allows cancelling the associated inductor responsible for the gain decrease that is proportional to the frequency. A cross-section of the LDMOS transistor is shown in ***Figure 3***. An example of the layout of a power amplifier using two LDMOS transistors is shown in ***Figure 4***. It is able to provide approximately 250 W of output power. In the layout, it is possible to observe that the realization of two devices (in push-pull) is made with interdigitated structures in order to optimise the matching. In the layout, it is also possible to observe the impedance matching networks (also called prematching networks) that are fundamental for the transformation of the input and output impedances in order to realize the external matching to the standard value of 50 Ω. ***Figure 5*** shows some of the LDMOS transistors that are available for use at frequencies up to 1 GHz.

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ZX60-1215LN	0.8-1.4	15.5	0.4	+27.5	12.5	12.0	50	149.95
ZX60-1614LN	1.217-1.620	14.0	0.5	+30.0	13.5	12.0	50	149.95
ZX60-2411BM	0.8-2.4	11.5	3.5	45.0	24.0	5.0	360	119.95
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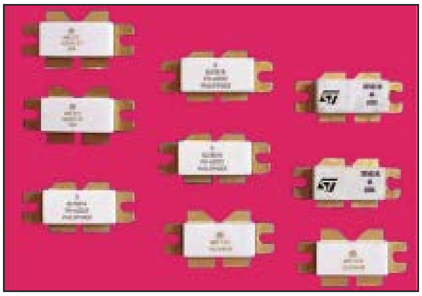

▲ *Fig. 5 Some LDMOS transistors for applications up to 1 GHz.*

ADVANTAGES COMPARED TO THE BIPOLAR TECHNOLOGY

The smaller intermodulation distortion and the better linearity in class A and class AB operations are characteristics that are intrinsic to MOS transistors compared to bipolars, especially if they are used in digital applications. LDMOS transistors have higher efficiency and superior thermal stability, particularly if the bias current for class A is next to the crossing point characteristics. The superior quality of such devices is their gain: its average value is approximately 4 to 5 dB higher than for bipolar transistors for equal output power levels. LDMOS transistors have a typical gain of 13 dB in wideband UHF applications; therefore, they could show gains of over 20 dB in narrowband conditions. It is normal to wait for the LDMOS technology to mature, because it is relatively young and remains subject to reviews and frequent upgrades in order to achieve a better reliability and more resistance to several types of failure. It is important to remember that the new LDMOS transistors, in the same way as the MOS, are intrinsically more delicate than the BJT for accidental electrostatic discharges, which, if induced on the gate, can have deleterious effects (and many times fatal) when they perforate the thin oxide layer present under the same control electrode. Several precautions have been adopted by MOS manufacturers for some time (for example, protection circuits made with diodes have been introduced in the devices in the same package). For the new LDMOS transistors, the most important application is in cell phone base stations.

Thanks to the lateral diffusion technology, it is possible to obtain RF power amplifiers able to provide from 5 to 250 W or more output power. These amplifiers require a very good linearity that is necessary to maximize the high data throughput in each channel. The main consideration to achieve that linearity is the DC biasing for optimal drain current for a given power output. Beyond this primary application, the LDMOS technology is finding many other applications in the telecommunications field, where the signal frequencies are extended into the low microwave bands and where the power output levels exceed some hundred watts. LDMOS transistors are used more and more in radar systems, in military communications and in the power amplifiers for TV broadcast. In this last field, only a few years have passed since the advent of these new LDMOS devices. Now, however, every possible co-existence with RF amplifiers using the old bipolar technology has already been excluded.

For broadcast applications, the LDMOS technology has clearly shown advanced characteristics compared to what is possible from equipment using BJT transistors, such as the linearity of the video parameters, and harmonic and intermodulation distortions, the main characteristics for the transformation of the actual transmission video systems to the digital signal systems of digital video broadcasting-terrestrial (DVB-T) type. Only by using amplifiers with LDMOS transistors is it possible to achieve a good minimization of the output power back-off, a representative parameter of the loss of power available due to the conversion of a traditional transmission system to the new standard DVB-T. Only with this innovative technology is it possible to exercise one good pre-correction on the digital signal in the pre-modulation stage. Thanks to this operation, which is very effective only with LDMOS technology, it is possible to contain the output back-off and therefore to have a reduction in the available output power f approximately 3 dB, an output power reduction that becomes approximately 7 dB if the conversion operation is made on equipment using bipolar transistors. ■


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ALL-IN-ONE PHASE NOISE TESTER AND SPECTRUM ANALYZER

Fig. 1 A typical phase noise measurement using the phase detector method, with the signal frequency, level and residual noise displayed. ▼

The characteristics of transmit and receive modules for radio transmissions are determined primarily by the phase noise of the oscillators in use. Therefore, the measurement of characteristics, particularly phase noise, is just as essential for effective communications and broadcast systems as it is for special high tech applications such as radar. For simple, commercial applications, a spectrum analyzer is usually sufficient but if the requirements for dynamic range, accuracy and flexibility are greater then a phase noise measurement using the phase-locked loop (PLL) method is preferred. The new R&S FSUP Signal Source Analyzer unifies both options in one device. It offers the user a high end spectrum analyzer (R&S FSU) up to a maximum frequency of 50 GHz, combined with a phase noise tester based on the PLL method.

THE PLL METHOD

The PLL method normally requires very complex set ups and the effort to calibrate the measurement is greater than for measurements using a spectrum analyzer. However, this new instrument simplifies the process by making phase noise measurements possible at the push of a button. It also offers the flexibility needed to adapt the test setup to special sit-

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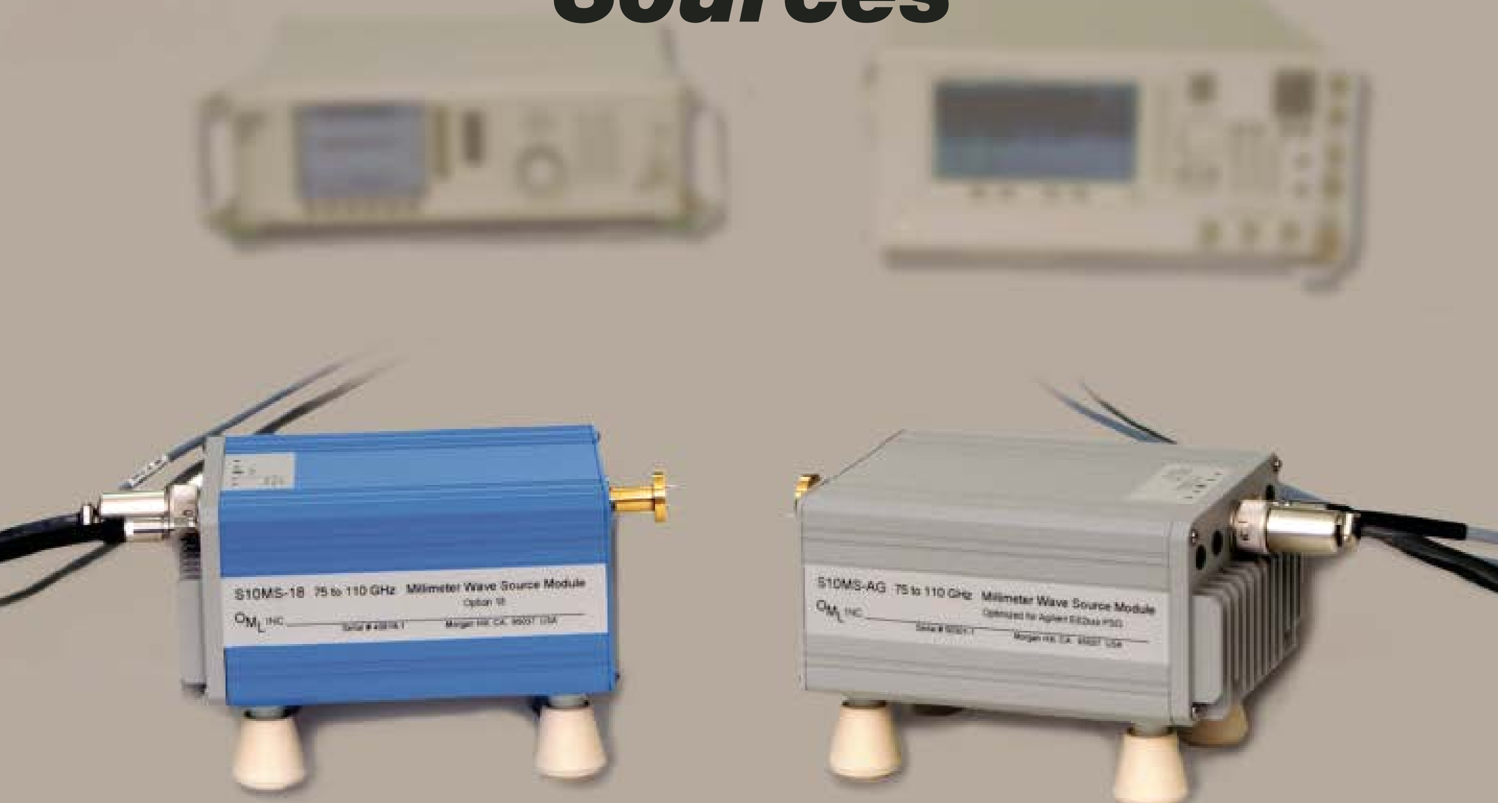

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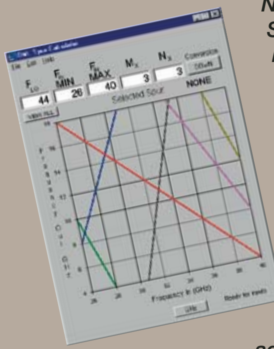

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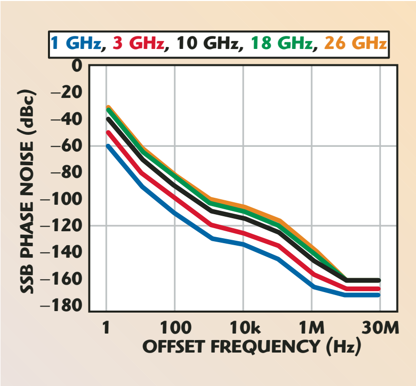
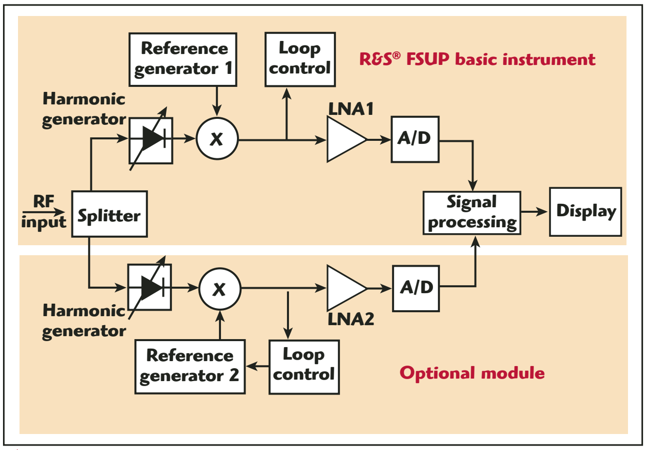
If a more complex test setup with an external reference is needed, there is graphical help. A wiring schematic displayed on the screen shows the user how to connect the various modules, while LEDs on the front panel show which outputs and inputs should be connected.

The premeasurement covers all important oscillator parameters such as power and tuning slope and the instrument then automatically selects the optimum parameters for the test. Depending on the input frequency, the device uses internal frequency multipliers to operate the internal reference within the optimum range. However, the user also has the option of changing the defined parameters.

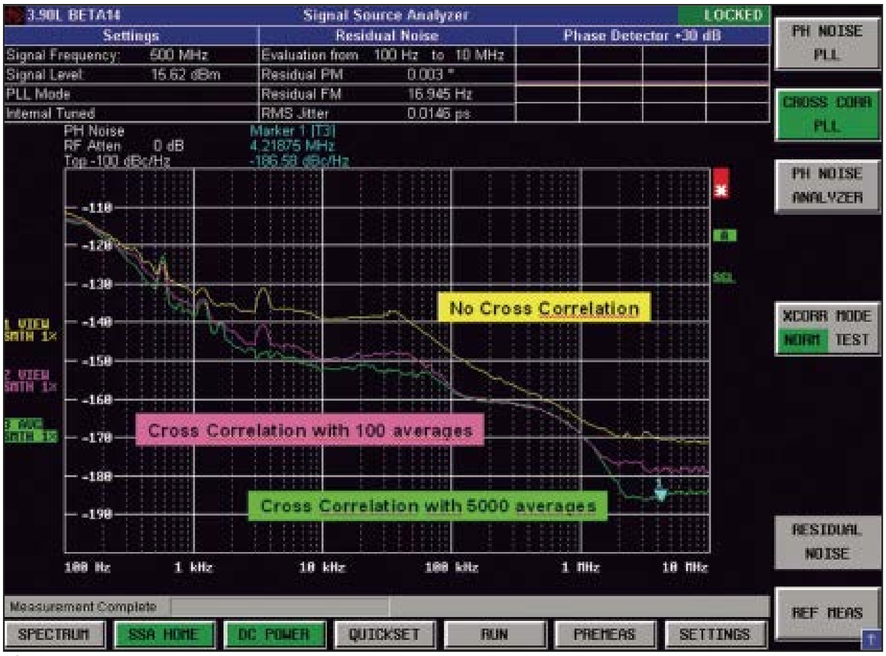
The offset range is easily set, as are the other measurement parameters such as bandwidth, filter type and number of averages. The menu set up is similar to that of R&S FS-K40 Application Firmware and makes operation very simple for the user, particularly when changing between different test modes. Predefined settings additionally simplify handling when a rapid or a very stable measurement is required.



▲ *Fig. 2 Phase noise of the internal reference source for various input frequencies.*



▲ *Fig. 3 An illustration of the principle of cross-correlation to increase sensitivity during phase noise measurements.*



▲ *Fig. 4 Measurement on an oscillator with a subsequent filter, illustrating the improvement in sensitivity achieved by cross-correlation.*

After the phase noise measurement starts, the display shows 'Locked' or 'Unlocked' to indicate whether the PLL is locked and a successful measurement can begin. The loop bandwidth can be adapted as needed, and the voltage on the phase detector can be displayed during the measurement. An efficient algorithm then allows the user to select one of the following options: display during the measurement of all spurious emissions caused, for example, by AC frequency interference or the phase detector frequency or suppress all or specific, clearly defined interference. Integral parameters such as residual FM/PM or RMS jitter are also displayed. The calculation applies to the entire test range and the user can define the integration limits.

Figure 1 shows a typical phase noise measurement using the phase detector method, with the signal frequency, level and residual noise being displayed. Unwanted spurious emissions are detected automatically and can be suppressed. It is also possible to obtain a listing of these spurious emissions (shown top right) and the exact frequency.

To ensure uncorrupted measurements on oscillators, the phase noise of the internal reference must be negligible when compared with the oscillator. The internal source of the R&S FSUP possesses good phase noise values for this application. At an input frequency of 640 MHz and a frequency offset of 10 kHz, the phase noise value is < –136 dBc (1 Hz); at a frequency offset of 10 MHz it is < –165 dBc (1 Hz). The phase noise of the internal reference source for various input frequencies is shown in ***Figure 2***.

CROSS-CORRELATION

With the R&S FSUP-B60 option, the signal source analyzer is equipped with two parallel receive paths. This symmetrical structure allows a cross-correlation between the two paths, al-

lowing the uncorrelated inherent noise of the two reference sources to be eliminated. Complex parts are eliminated by averaging so that only the correlated signal of the device under test (DUT) remains. As a result, sensitivity is no longer limited by the phase noise of the internal references. The degree of improvement depends on the number of averages and can be up to 20 dB. ***Figure 3*** shows the principle of cross-correlation to increase sensitivity during phase noise measurements.

Figure 4 shows the measurement on an oscillator with a subsequent filter, which illustrates the improvement in sensitivity achieved by cross-correlation. The yellow trace shows a measurement without cross-correlation, while cross-correlation was used with the two other measurements. It is clear how an improvement in sensitivity can be achieved, depending on the number of averages.

SPECTRUM ANALYZER FUNCTIONS

The new signal source analyzer is linked to a high end spectrum analyzer, which enables the measurement of the phase noise directly in the spectrum. This method determines the spectral power density in the sidebands. However, the disadvantages are obvious — it requires more time, sensitivity is lower because the carrier is not suppressed, and thus the dynamic range is severely limited. In addition, cross-correlation is not possible and there is no way to distinguish between amplitude noise and phase noise. The calculation or suppression of spurious emissions is also more complicated for the user. Conversely, the obvious advantage of measurements using the spectrum analyzer lies in the fact that significantly higher frequency offsets can be measured. As a result, the spectrum analyzer is clearly a necessary addition during phase noise measurements.

Even when measuring harmonics or interference, the instrument offers interesting options over and beyond the normal functions of a spectrum analyzer, such as the spurious emissions measurement function. It is possible to define a list of various sweep ranges with specific parameters in which the analyzer automatically searches for interference and spurious emissions. Up to 100,000 measurement points can be evaluated and the results listed in a table.

The measurement of the adjacent channel power is also an important function during characterization of signal sources. The instrument has simple measurement functions that allow rapid determination of power in the adjacent channels. Users can select from predefined default settings, or they can also separately define the channel widths and spacing. Also offered is a large dynamic range.

Finally, the device, like an FM/PM/AM demodulator, records the oscillator signal over time. Broadband resolution of transient effects or switching resulting from high frequency sources is thus possible.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OSCILLATOR CHARACTERIZATION

In order to record characteristics and to allow measurement of the phase noise using the PLL method, the user must set the supply and tuning voltage of the oscillator exactly. To this end, the R&S FSUP is equipped with two independent, very low noise DC ports and the supply voltage and tuning voltage can be individually defined for each port via a clear menu. The values will change based on the settings needed for the measurement application but the maximum and minimum values will not be exceeded. It is also possible to define the sequence in which the various voltages are applied at the start of the measurement. For special applications, a negative supply is additionally available.

To characterize a voltage-controlled oscillator the following typical measurements are applied. At a constant supply voltage, it is possible to change the tuning voltage (tuning characteristic) or the supply voltage while maintaining a constant tuning voltage (DC dependencies). A combination of the two variants (pushing) is also available. In addition, characteristic parameters can be measured not only for the fundamental, but also for the harmonics and the tuning voltage or the frequency can be selected to allow scaling of the X-axis. For these measurements the user can define the number of measurement points to optimize resolution for the application.

CONCLUSION

With the functionality of a phase noise tester and a spectrum analyzer combined into a single device and with a maximum input frequency of 50 GHz, the R&S FSUP is the optimum instrument for development and production. With this device, investments for signal source analysis drop significantly, test setups are easier and flexibility increases. All functions can also be remotely controlled via LAN or GPIB, so that the device can be easily integrated into production lines.

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AM-1607-1000	.01 – 1000	40	41	0.75	3	12	2:1	110
AM-1607-2000	.01 – 2000	40	41	1	3	9	2:1	110
AM-1607-2500	.01 – 2500	40	41	1.5	3.2	7	2:1	110
AM-1616-1000	.01 – 1000	20	21	.5	3.2	12	2:1	60
AM-1616-2000	.01 – 2000	20	21	.75	3.2	9	2:1	60
AM-1616-2500	.01 – 2500	20	21	1	3.2	7	2:1	60

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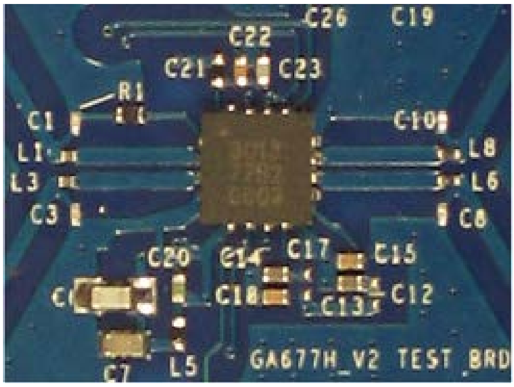
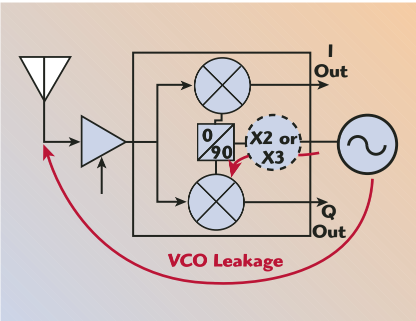


A New Solution for Direct Conversion System Integration

Direct conversion radio architectures offer the best compromise between radio performance (adjacent channel rejection and dynamic range), spurious response, versatility (easily allowing multiple modulation bandwidths), current consumption and cost. However, there are several classic issues that must be understood and mitigated before superheterodyne-level performance can be achieved with the convenience of direct conversion. Designed to address these issues is the new SKY73013 direct conversion (and low IF) front-end downconverter IC that enables very high performance operation in the 4.900 to 5.925 GHz frequency spectra.

Fig. 1 The common architecture of the SKY73013 downconverter IC.



In its development, careful attention has been paid to the relevant standards including WiMAX, WLAN and dedicated short-range communication (DSRC), to allow operation of even the most difficult modulation formats, such as 64-QAM OFDM and the stringent WiMAX adjacent channel requirements. Further, this level of intelligent integration in a standard product downconverter enables additional markets such as low cost, low current proprietary wireless data and radio frequency identification (RFID).

LO FREQUENCY PLANNING

The principal issues surrounding direct conversion relate to the fact that the most obvious implementation involves a synthesizer/voltage-controlled oscillator (VCO) that has an integer (or direct) relationship with the carrier frequency. This causes radiation coupling issues that can upset the phase-locked loops (PLL) and create a transient upon T/R (transmit/receive) mode change; transmit phase modulation can injection-pull the VCO; and local oscillator-radio frequency (LO-RF) leakage creates a DC offset that varies with the LO-RF coupling profile (that is, low noise amplifiers gain setting and antenna return loss). ***Figure 1*** shows this common architecture; ***Figure 2*** depicts the potential baseband transient response.

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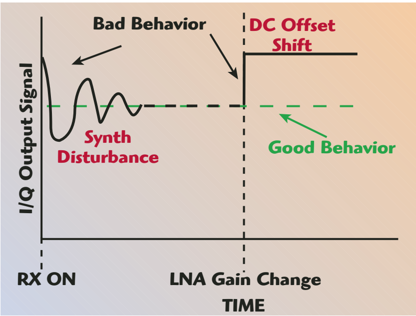
Common strategies, such as shielding and buffering, are usually impractical as their required cost/complexity often outweighs the intended benefits of direct conversion. One should consider that a VCO has an extremely high gain at its resonance frequency, as it is a sensitive radio receiver itself. Therefore, it is quite difficult to fully isolate a VCO, considering that much of the coupling and feedback is radiated rather than conducted. The similar transmitter architecture is even more vulnerable to VCO disturbances.

Another common isolation technique is to operate the VCO/synthesizer at one-half or one-third the carrier frequency, then apply a doubler or tripler in the LO chain, which also increases phase noise at a rate of 6 dB per octave. Although additional isolation is achieved, particularly when the one-half approach is combined with a differential architecture, the challenges still exist, since VCOs are still very susceptible to harmonics and the resultant harmonics still produce dynamic DC offsets.

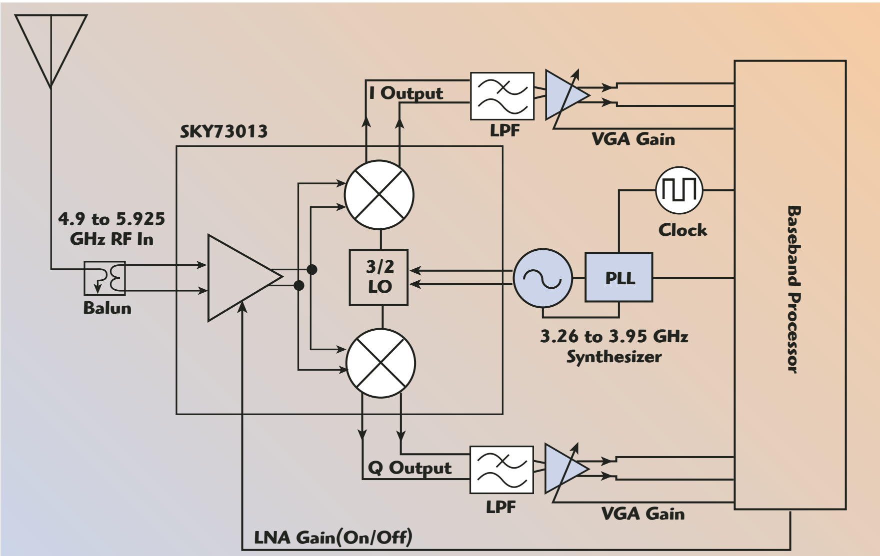


▲ *Fig. 2 Potential baseband transient response.*

Also, the 2X frequency planning technique, where the VCO would operate from 10 to 12 GHz, could be effective for the receiver, though still potentially problematic for the complementary transmitter since the second harmonic of the PA would be synchronous with the VCO. This synthesizer reference requirement, however, would simply be too difficult and expensive to achieve with conventional standard product devices.

In order to overcome such problems the SKY73013 IC utilizes a 3/2 LO architecture where the VCO/synthesizer operates at 2/3 of the carrier frequency. This eliminates VCO radiation pulling problems and dynamic DC offsets (especially important at an LNA gain change), while requiring an LO signal that is well within the frequency range of conventional PCB materials, and off-the-shelf synthesizers and VCOs (3.26 to 3.95 GHz). ***Figure 3*** shows the SKY73013 downconverter's functional block diagram.

The result is that only very high order products could even potentially produce harmonics that are synchronous to the VCO, while dynamic DC offsets are non-existent. This non-integer LO architecture provides a good solution to the conventional direct conversion frequency planning issues without adding to the complexity of the solution.



▲ *Fig. 3 The SKY73013-306 integrated receiver downconverter subsystem for the 4.900 to 5.925 GHz frequency band, featuring 'no-pull' local oscillator architecture and switchable LNA gain.*

QUADRATURE ACCURACY

Additional considerations with direct conversion relate to the fact that the RF signal is demodulated in quadrature, and that phase accuracy and amplitude balance must be maintained over a wide range of frequencies and post-quadrature gain settings, as opposed to splitting to quadrature at a fixed IF. The proprietary 3/2 LO architecture utilized allows extremely accurate quadrature phase/amplitude splitting over a very wide frequency range. Thus, the SKY73013 device produces an I/Q phase accuracy of better than 3° and an amplitude balance of 0.25 dB over the entire operating frequency range and temperature. The system integrator has the option to employ baseband calibration techniques such as I/Q cross-correlation (for phase error canceling) and I/Q averaging (for amplitude balancing) for better performance.

Also, the new downconverter IC, with its 100 MHz I/Q bandwidth, allows low IF image reject operation. This cousin of direct conversion, where the I/Q output is a low frequency IF that is converted to baseband in the digital domain, produces perfect quadrature accuracy at the expense of a higher sampling rate and an analog-domain image product, which is then suppressed by applying a Hilbert transform in the digital domain.

DC OFFSET CORRECTION

A DC offset is almost always present at the output of a mixer and is caused by various RF leakage products. This fact is especially pertinent to direct conversion receiver design because successive stages must be low frequency coupled, since the intermediate frequency is zero. Further, in order to achieve high linearity, which influences adjacent channel performance, it is necessary to place most of the receiver gain after the mixer, rather than before. Therefore, a large amount of DC-coupled post-mixer gain will easily saturate in the presence of an input-referred DC offset.

As long as the DC offset is quasi-static, however, it is possible to remove this offset without degrading communications performance. DC offsets are best mitigated via AC coupling or DC offset subtraction, which are equivalent signal processing operations. Such operations, of course,

should not excessively interfere with the in-band signaling content. Therefore, a slow-DC offset correction corner (that is, a low 3 dB high pass in the analog baseband path) should be less than a few percent of the total signaling bandwidth in order to negligibly interfere with the desired information content regardless of whether the modulation is OFDM or single carrier.

Unless the receiver is kept on all of the time, the resultant offset at the output of the mixers is really a step function rather than continuous DC. Therefore, the system integrator should be aware that a slow-DC correction circuit, or AC coupling, requires a finite amount of time to converge. While such convergence periods are acceptable in many communications standards, fast packet switching systems such as WLAN and WiMAX have relatively short T/R turnaround periods. An excellent strategy for these systems is to understand their specific medium access control (MAC) timing intervals such that a fast-settling DC offset initialization loop is enabled during periods where it is not possible to receive data.

In addition, low IF operation offers significant advantages with regards to DC offset correction. Since low IF demodulates the signal with a frequency offset greater than the modulation bandwidth, the entire double-sided signaling spectra appears within both the I and Q arms of the direct conversion output. Therefore, baseband DC offset correction affects frequencies that are above or below the modulation spectra, rather than in the middle. This means that low IF DC correction can always be accomplished with one simple correction loop, while avoiding having to compromise settling time versus signal performance degradation.

DYNAMIC RANGE AND ADJACENT CHANNEL PERFORMANCE

The SKY73013 downconverter IC has been architected to fully support the dynamic range requirements of unlicensed WiMAX and WLAN, which are two very stringent wireless data specifications. In particular, careful attention has been paid to both adjacent and non-adjacent channel performance — the entire chain, including ADCs, must remain linear in the presence of the combination of the desired signal and the adjacent/non-adjacent signal, whose pragmatic peak-to-average ratio approaches 10 dB. The downconverter IC supports sufficient linearity such that packet error rate (PER) requirements are met over the 802.11a and 802.16d (unlicensed 5 GHz OFDM PHY) adjacent/non-adjacent channel conditions.

Non-adjacent channel performance is also dependent upon even-order intermodulation products and many of these products fall about DC. Since direct conversion architectures utilize a zero IF, even-order products become a potential issue. Of particular concern is the fact that this causes an envelope demodulation product of non-adjacent carriers to fall within the IF range. The SKY73013 IC utilizes a differential architecture so even-order intermodulation products are rejected, providing the necessary immunity to envelope demodulation.

The necessary linearity/noise tradeoff was accomplished by properly distributing gain rather than placing a large gain before the mixers, while maintaining enough device gain to overcome even a significant amount of input-referred noise at the baseband VGA inputs. Overall, the downconverter IC is capable of demodulating 64-QAM signals at least as strong as –30 dBm, while maintaining adjacent/non-adjacent channel performance, and has a noise figure of 6.5 dB (high gain mode).

CONCLUSION

The SKY73013 direct conversion front-end downconverter IC has been developed to meet the most stringent standards. This has been achieved by producing a device that is reliable and exhibits high performance at a relatively low cost. Additional information may be obtained via e-mail at sales@skyworksinc.com.

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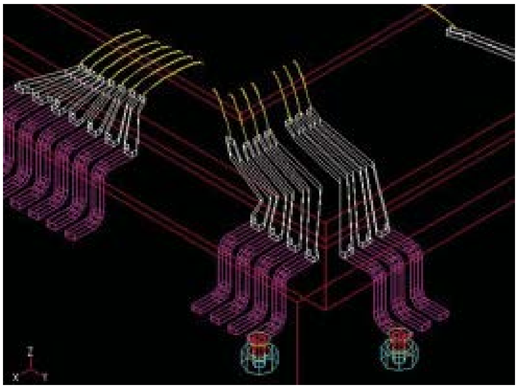
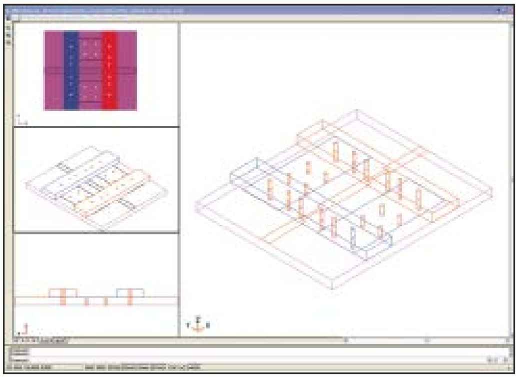


FULL 3D EM SIMULATION AND VERIFICATION FOR THE MASSES

With the ever-increasing complexity in today's high frequency and high speed circuit designs, designers appreciate the development time and cost savings that can come from accounting for electromagnetic (EM) effects up-front in designs. However, many designers still see EM point tools as an expensive luxury that is best left to EM gurus who exercise high end software to its fullest. What if practical, EM accuracy could be had for a fraction of the typical cost? What if EM simulation could be as common and accessible as circuit simulation?

The new Electromagnetic Design System (EMDS) 2006A (see ***Figure 1***), from Agilent Technologies' EEsof EDA division, seeks to fill this price performance gap, making full 3D EM simulation an attractive and economical option for designers working with RF circuits, MMICs, PC boards, modules and signal integrity applications. The software package provides the best price performance 3D EM simulator on the market, with a full 3D electromagnetic field solver, a modern solid modeling front-end, and fully automated meshing and convergence capabilities for modeling arbitrary 3D shapes such as connectors, machined parts, components, bond wires, antennas and packages.

Fig. 1 Example of the modern AutoCAD-based solid modeling system employed by EMDS.



BASED ON INDUSTRY-PROVEN FINITE ELEMENT METHOD SIMULATION TECHNOLOGY

The finite element method (FEM) divides the full problem space into smaller regions and represents the field in each sub-region, or element, with a local function. In EMDS, the geometric model is automatically divided into a number of tetrahedra, where a single tetrahedron is formed by four triangles. This collection of tetrahedra is referred to as the finite element mesh. ***Figure 2*** shows the finite element mesh that was created for a sample structure. The finite element mesh is an efficient and accurate way to divide and solve for EM effects in a wide variety of high frequency 3D geometries.

The finite element mesh can be tuned to meet the accuracy standards of the designer. The finer the mesh, the more accurate the 3D EM solution. The tradeoff is in simulation time. The designer has control over the fineness of the mesh.

AGILENT EESOF EDA
Santa Rosa, CA

EM DESIGN SYSTEM FEATURES

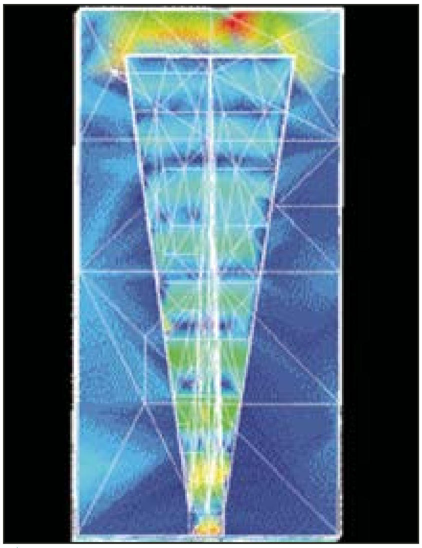
EMDS features include:

- Arbitrarily shaped 3D passive structures for generalized EM analysis
- Conductors, resistors, isotropic and anisotropic dielectrics, isotropic and anisotropic linear magnetic material modeling allow a wide range of application coverage
- An unlimited number of ports, which enables simulating multi-I/O design applications such as packages
- Electric and magnetic fields modeling, allowing visualization of EM fields in a design
- Absorbing boundary condition (free space), allowing antenna modeling
- Full-wave, EM-accuracy for first-pass design success
- Multi-mode impedance and propagation constants that overcome single-mode modeling limitations in many other EM modeling tools
- Antenna parameters (gain, directivity, polarization and so on), to allow better insight into antenna design
- An EMDS/ADS link, providing an integrated approach to EM/circuit design

INTEGRATION WITH LEADING RF AND MICROWAVE DESIGN FLOW VERSUS EXPENSIVE POINT TOOLS

Today's 3D EM modeling experts have been required to invest heavily in sophisticated 3D EM point tools that allow them to study the EM behavior of complex high frequency/high speed designs. However, these "experts" are few and far between. When the cost and complexity of 3D EM point tools prohibit their use, RF and microwave engineers may choose not to study EM effects. They may instead revert to rule-of-thumb methods and guesses to push a design forward, in hopes that the design will work after a few tries.

With Agilent's popular 3D planar tool, Momentum, fully integrated into the company's Advanced Design System (ADS), the new Electromagnetic Design System gives RF and microwave engineers access to the most comprehensive EM simulation tools in the industry-leading RF/microwave design flow. Agilent's circuit and system design tools include both the ADS EDA platform and the GENESYS RF and microwave design software. The EMDS roadmap includes increasingly tight integration with both ADS and GENESYS.



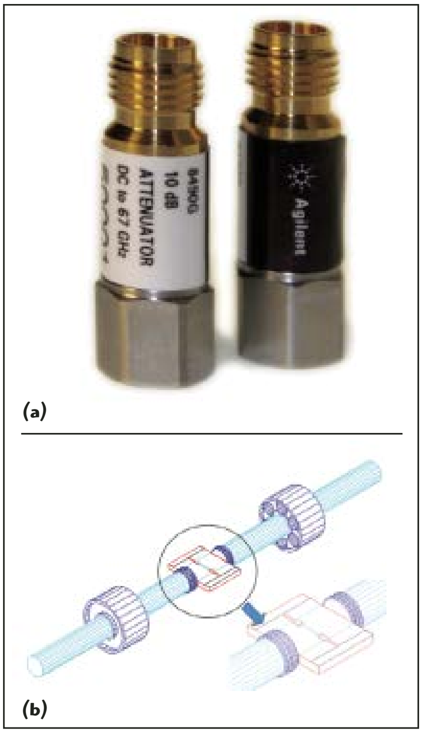
▲ *Fig. 2 The finite mesh created for a sample structure.*

USED TO DESIGN CUTTING EDGE PRODUCTS

Behind every EDA design tool is the accumulated knowledge and expertise of the people who not only build the software, but of those who use it and put it through its paces. Agilent is unique in the marketplace as an EDA company inside a test and measurement organization, actually using these EDA tools to design virtually all of the company's RF and microwave instruments and related products. For example, the technology in EMDS was recently used to design the company's 8490G precision coaxial fixed attenuators. These attenuators are used to maximize their users' operating frequency range up to 67 GHz with industry-leading attenuation accuracy, coupled with low SWR and a variety of attenuation options to suit users' application needs. ***Figure 3*** shows these precision attenuators and a solid model representation of the attenuators in EMDS.

CONCLUSION

The new Electromagnetic Design System occupies an important price performance niche for RF/microwave circuit designers. Its addition makes 3D EM simulation an attractive and economical option for designers who need to account for EM effects in today's increasingly high frequency and high speed designs. The simulation package offers full 3D EM modeling capabilities with integration into Agilent's industry-leading RF/microwave circuit design flow. It is a new tool that lowers the economic barrier and will find a way to desktops throughout the RF/microwave design community.



▲ *Fig. 3 The model 8490G precision coaxial fixed attenuator (a) designed using the 3D EM technology in EMDS and a solid model representation (b) of the attenuator.*

Agilent EMDS 2006A is expected to ship in July 2006, with prices starting at approximately $15K. For more information about EMDS and Agilent's other EDA offerings, visit www.agilent.com/find/eesof.

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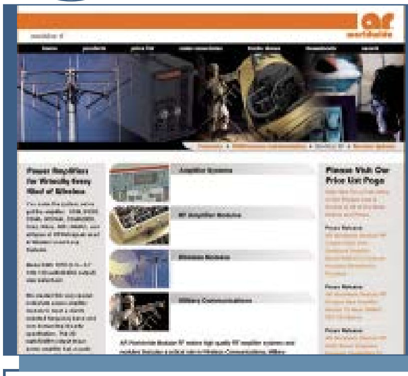

RF Amplifier Systems and Modules

This redesigned web site features a new search tool that allows users to search by keyword, power, power option and/or frequency. AR Worldwide Modular RF manufactures RF amplifier systems and modules for wireless communications, military communications, and a variety of medical, scientific and industrial applications.

AR Worldwide Modular RF,
11807 North Creek Parkway South,
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Bothell, WA 98011

www.ar-worldwide.com

Systems and Components

This web site features the company's RF and microwave products for the defense, space and communications industries for use in electronic countermeasures, missiles, radar, intelligence and guidance systems. The company specializes in mission critical, harsh environment products for air, sea, ground, space and missile applications.

Crane Aerospace and Electronics Microwave Systems, Electronics Group,
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Redmond, WA 98073

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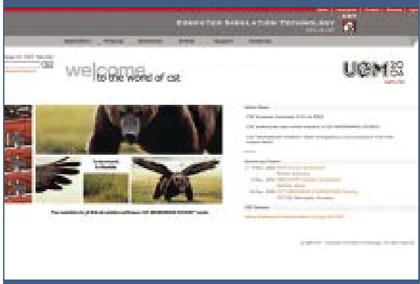

3D Electromagnetic Field Simulation Software

This recently updated web site features the company's 3D EM simulation software for high frequency applications. New additions to the site include: Web-based videos demonstrating the state-of-the-art 3D EM simulator CST MICROWAVE STUDIO® 2006, applications examples, technical support area and downloads.

CST of America® Inc.,
10 Laurel Avenue, Suite 300,
Wellesley Hills, MA 02481

www.cst.com

Amplifiers and Subassemblies

This web site has been upgraded and designed for engineers looking for RF and microwave amplifier solutions. Inside, users will find complete listings of the company's low noise, high and medium power amplifiers, special amplifiers and subassemblies for commercial and military applications. An easy-to-use product search section makes finding the right amplifiers simple. There is a new thin-film manufacturing services section, which describes the company's complete custom and build-to-print manufacturing offerings.

CTT Inc.,
241 East Java Drive,
Sunnyvale, CA 94089

www.cttinc.com

RF/Microwave Products

This redesigned web site features custom RF/microwave filters up to 40 GHz for military, commercial, wireless and space applications. The filter products are organized by cavity, lumped element, waveguide and wireless categories. Products are available in band pass, band reject, high pass, low pass, transmit, receive, and duplexer and multiplexer configurations. Utilize the site to submit an on-line request for quote or to find a local representative in your area.

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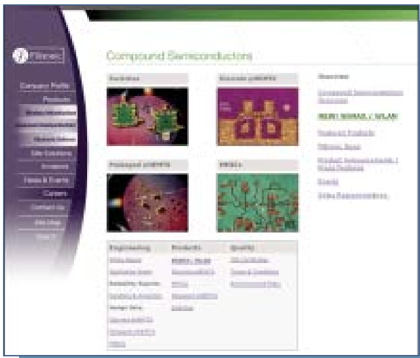

Components and Subsystems

Filtronic Compound Semiconductors Ltd. announces the merger of its web site with parent company, Filtronic plc. The Compound Semiconductor site features data sheets for the company's line of packaged PHEMT, discrete PHEMT, MMIC, power FET products and switch products. The site also offers product and site search capabilities allowing quick access to data sheets, design data such as S-parameters, application notes and device models.

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www.filtronic.co.uk/compound_semis

IC, Modules and Subsystems

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Hittite Microwave Corp.,
20 Alpha Road, Chelmsford, MA 01824

www.hittite.com

Microwave Components

New additions to the web site include new products in all categories for commercial communications and military applications. In addition, engineers have the ability to place on-line orders for coaxial isolators, MICA*PAC isolators, and drop-in isolators and circulators. Frequency ranges include 0.5 to 40 GHz. Price and delivery quotes are within 48 hours, on most on-line products. Have special requirements? This web site makes it easy to request those custom, hard to find solutions.

MICA Microwave,
1096 Mellon Avenue, Manteca, CA 95337

www.mica-mw.com

Cosite Mitigation Equipment

This recently updated web site illustrates the company's breadth of product offerings for RF interference mitigation. The site provides many useful features such as company information, application notes, product details, interface information and a catalog file that can be downloaded for reference in support of your next design program.

Pole/Zero Corp.,
5530 Union Centre Drive,
West Chester, OH 45069

www.polezero.com

The 7th Topical Meeting on
Silicon Monolithic Integrated Circuits in RF Systems

January 10-12, 2007
Long Beach, CA, USA

First Call for Papers

This 7th Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems (SiRF 2007) continues to be the only conference devoted to Si-based devices, passives, integrated circuits, and applications for high-frequency systems. Over three days, papers and sessions will highlight the significant technological advances of this dynamic field, as well as provide a unique forum for the presentation of new ideas and candid exchange on the emerging challenges and opportunities. Invited tutorial talks from international experts will be presented in key topical areas.

Technical papers are solicited in the following areas, but all papers related to Si-based RF systems are welcome:

- **Materials:** epitaxial growth, strain engineering, characterization methods, stability issues, defects
- **Devices:** physics, optimization, and scaling limits of SiGe HBTs, RF-CMOS, SOI CMOS, strained-Si CMOS, SiGe MOSFETs, Si-based MODFETs, diodes that are applicable to RF, microwave, and millimeter-wave circuits and systems
- **IC Technologies:** novel device structures, SiGe HBT and CMOS integration issues, heterogeneously integrated devices and circuits, interconnects, fabrication on high-resistivity Si and SOI, packaging issues
- **Circuits:** RF, microwave, and mm-wave building blocks (LNA, mixer, VCO, PA, switches, filters), integrated transceivers, high-speed DAC and ADC, analog/mixed-signal circuit blocks
- **Passives:** inductors, capacitors, thin film resistors, transmission lines, integrated antennae, transformers
- **MEMS:** RF MEMS, micro-machining for improved passives, integration with Si-based circuits and systems
- **Reliability Issues:** yield and reliability concerns in high-frequency Si-based devices, passives and circuits, digital/RF circuit integration challenges, signal isolation issues, interference, substrate noise, RF impedance mismatch robustness, cooling architecture for devices and circuits
- **Measurement and Modeling:** compact modeling of Si-based transistors, robust measurement and de-embedding techniques, methods of built-in-self-test and built-in-self-calibration, models to correlate high-frequency parameters with easy-to-measure DC/AC parameters
- **Applications:** system-on-a-chip (SoC) and system-in-a-package (SiP) solutions utilizing the low-cost and high-level integration advantages of Si technology for RF, microwave, and mm-wave sub-systems and systems, integration of Si-based photonic elements with electronic circuits
- **Emerging Technologies:** Nano, quantum, optical, and THz technology devices and circuits

Submission Deadline: July 28, 2006

PAPER SUBMISSION GUIDELINES

Authors must submit a **two-page abstract** in *pdf* format (one page text and one page figures) for consideration by the Technical Program Committee, and must clearly indicate how the work advances the-state-of-the-art. Papers should include: 1) the names of all authors and their affiliations, 2) whether this is a student paper, and 3) the mailing address, phone number, fax number, and email address of the corresponding author. See http://www.ece.wisc.edu/SiRF07 for further information.

MEETING DETAILS

This meeting will be held during the *Radio and Wireless* week (http://www.radiowireless.org/) in Long Beach, CA with joint sessions between *Radio and Wireless Symposium* and *PA Workshop for Wireless Communications*. Our popular single session format allows active interactions between all participants. A refereed IEEE Conference Proceeding will be published, and a best student paper competition will be held. Questions on the conference details and paper submission procedure may be found at the conference web site: http://www.ece.wisc.edu/SiRF07.

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University of Wisconsin
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Robert Plana
LAAS-CNRS
George Ponchak
NASA Glenn Research Center
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Korea University
Clemens Ruppel
EPCOS AG
Katsuyoshi Washio
Hitachi Ltd
Robert Weigel
University of Erlangen

Integrated Circuits and Solutions

This updated web site features a brand new look, more efficient web product database functionality, enhanced product content and documentation. A user can also access the latest RFMD news, request product samples, download design kit information or access reference design information, investor relations information and technical articles.

***RFMD*®**
7628 Thorndike Road,
Greensboro, NC 27409

www.rfmd.com

Green World

The "Green Leader" web site contains information on the company's environmentally friendly specialty materials and related subjects. The company's environmentally friendly product lines include: high frequency laminates; flexible circuit materials; BISCO® silicones; PORON® urethanes; and DUREL® EL lamps and drivers. Letters of Compliance and flowchart examples to determine if equipment is within the scope of directives are also provided.

Rogers Corp.,
One Technology Drive, PO Box 188,
Rogers, CT 06263

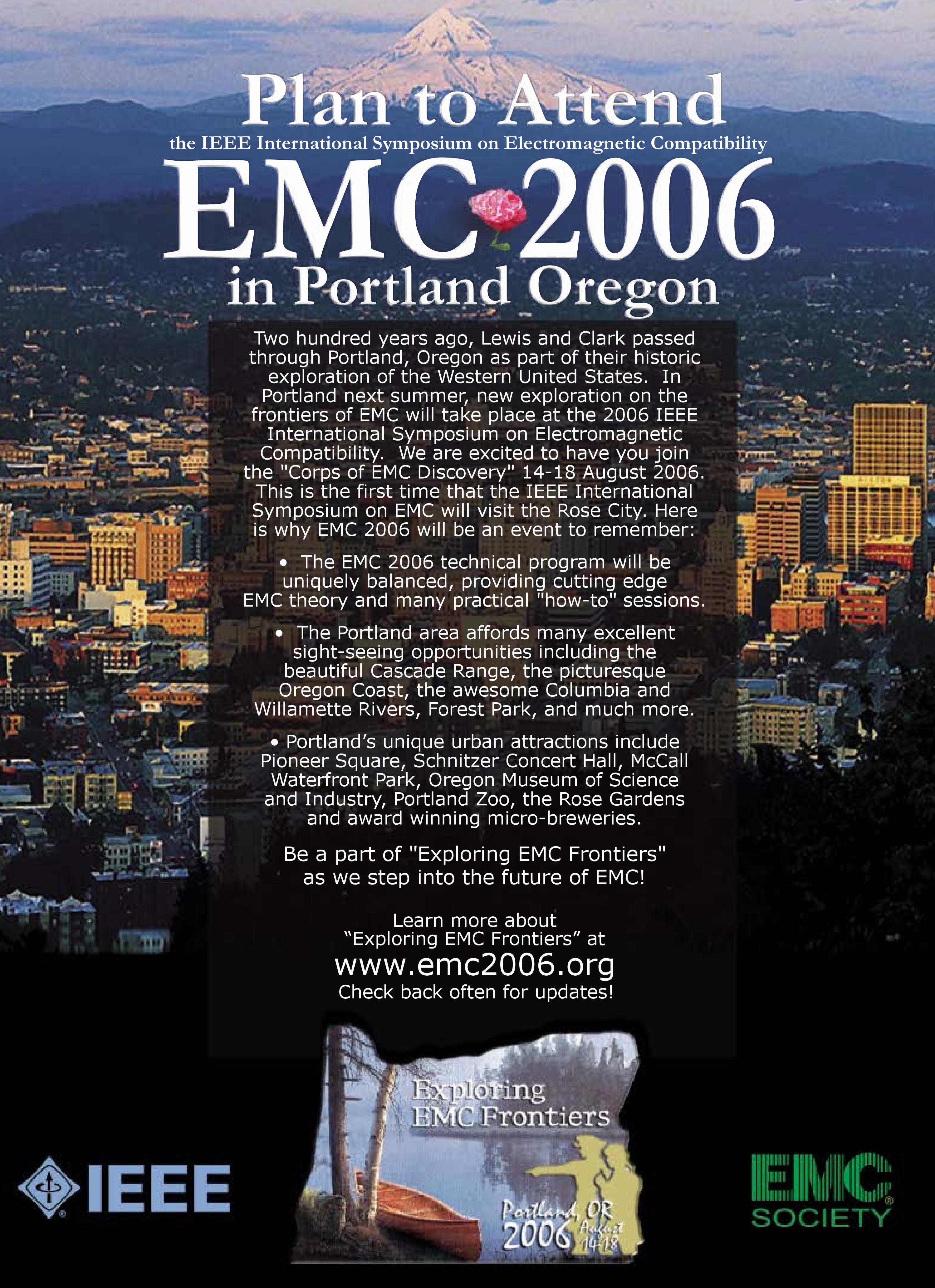
www.rogersgreen-world.com

EM Simulation Software

This web site features a comprehensive collection of technical and product information that concerns the use of high frequency electromagnetic (EM) simulation software. The site contains easy to understand content that explains how to choose the right type of EM tools to product information on Sonnet and CST Microwave Studio. Numerous technical papers can be found focusing on the theory of numerical electromagnetics.

Sonnet Software,
100 Elwood Davis Road,
North Syracuse, NY 13212

www.sonnetsoftware.com


Plan to Attend
the IEEE International Symposium on Electromagnetic Compatibility
EMC 2006
in Portland Oregon
Two hundred years ago, Lewis and Clark passed through Portland, Oregon as part of their historic exploration of the Western United States. In Portland next summer, new exploration on the frontiers of EMC will take place at the 2006 IEEE International Symposium on Electromagnetic Compatibility. We are excited to have you join the "Corps of EMC Discovery" 14-18 August 2006. This is the first time that the IEEE International Symposium on EMC will visit the Rose City. Here is why EMC 2006 will be an event to remember:
• The EMC 2006 technical program will be uniquely balanced, providing cutting edge EMC theory and many practical "how-to" sessions.
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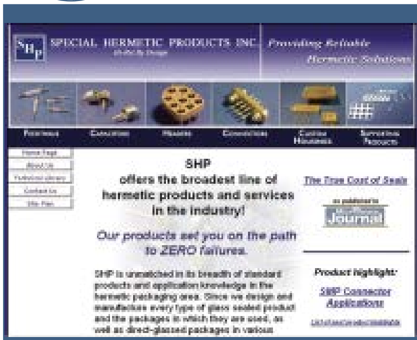


Hermetic Products and Services

This recently updated web site features the company's standard line of products and services, and related information including the Product Highlight. Newly added is the Technical Library, which includes design and process guidelines offering customers assistance in product application and troubleshooting based on many years of hands-on experience. The Technical Library and Product Highlight provide new information on a regular basis.

Special Hermetic Products Inc., 39 Souhegan Street, Wilton, NH 03086

www.shp-seals.com

Passive Electronic Components

This site recently had a major overhaul and boasts improved access to product information by reducing the number of clicks required for users to obtain the most desired product information. In addition to simpler product searches for over 250,000 part numbers, the site also offers improved navigation and consolidates information from several sites into one location.

Tyco Electronics Corp., PO Box 3608, MS 38-41, Harrisburg, PA 17105

www.tycoelectronics.com

Power Systems

This site provides users with up-to-date information on its power systems products. The homepage is designed to make searching for products easier and faster by offering easy navigation menus with recognizable industry standard category names. Users can click on these names and be linked to product family pages, where thumbnail images of product families, detailed product descriptions and product documentation are easily located.

Tyco Electronics Power Systems Inc., 3000 Skyline Drive, Mesquite, TX 75149

www.power.tycoelectronics.com

RF Power MOSFET

The model ARF475FL is a high voltage, flangeless packaged, RF power MOSFET that utilizes a newly-patented process and finer geometry to deliver high peak power and RF gain. These MOSFETs operate reliably at DC voltages up to 165 V. The ARF475FL utilizes two die, configured for push-pull operation, in the new T3 flangeless package and is capable of 1000 W pulsed output and 300 W CW at up to 150 MHz. Price: $81.25 (500 pieces).

Advanced Power Technology,
Bend, OR (541) 382-8028,
www.advancedpower.com.

RS No. 216

Low Phase Noise Amplifiers

These surface-mount amplifiers offer residual phase noise better than –155 dBc at 1 kHz offset. Frequency coverage is L-, S- and X-band with bandwidths of up to two octaves. Models offer gain between 10 and 20 dB and output powers of +20 dBm. DC current is nominally 100 mA at +15 VDC. Size: 0.45" × 0.45" square. Delivery is immediate.

AML Communications Inc.,
Camarillo, CA (805) 388-1345,
www.amlj.com.

RS No. 217

Measurement Platform

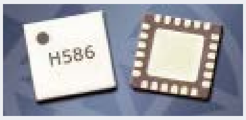
The M150 measurement platform delivers precision microwave measurement capability in a highly affordable and flexible platform. It supports 2 and 4 port RF measurements, load-pull and noise parameter test as well as DC and failure analysis applications. Highly affordable value packages include everything needed to start RF probing – prober, microscope, cables, RF probes, impedance standards, and WinCal 2006 VNA calibration software with its new advanced VNA automatic cal algorithms and monitoring-validation tools for enhanced accuracy.

Cascade Microtech Inc.,
Beaverton, OR (503) 601-1000,
www.cascademicrotech.com.

RS No. 218

MMIC Voltage-controlled Oscillator

The model HMC586LC4B is an SMT wideband GaAs InGaP HBT MMIC VCO that incorporates the resonator, negative resistance device and varactor diode. This fully integrated MMIC VCO offers a wide output frequency tuning range of 4 to 8 GHz, with +5 dBm output power and low SSB phase noise of –100 dBc/Hz at 100 kHz offset. Output power and phase noise performance are excellent over temperature due to the oscillator's monolithic construction.

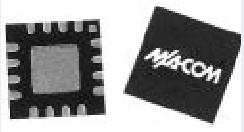


Hittite Microwave Corp.,
Chelmsford, MA (978) 250-3343,
www.hittite.com.

RS No. 219

Discrete Transistors

The model MAAP-003438-005PP0 is a 12 V GaAs PHEMT designed for WiMAX basestation and CPE applications up to 3.8 GHz. This transistor is also suited for multi-channel multi-point distribution system (MMDS), wireless local loop (WLL) or wideband code division multiple access (W-CDMA) driver applications from 2.1 GHz, providing 5 W (P1dB), ACPR –40 dBc at +27 dBm Pout (W-CDMA). It offers a typical 10 dB gain with lead-free 3 mm PQFN 16-lead surface-mount packaging.



M/A-COM Inc.,
Lowell, MA (800) 366-2266,
www.macom.com.

RS No. 220

High Dynamic Range Amplifier

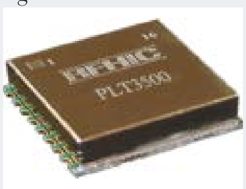
The model CMM6004-SC is a high dynamic range amplifier designed for applications operating within the 0.25 to 3 GHz frequency range. This amplifier achieves 41 dBm OIP3 and 2.1 dB noise figure, with a gain of 14.5 dB. The device is packaged in a low cost, space efficient, surface-mount SOT-89 package that provides good electrical stability and low thermal resistance. All devices are 100 percent RF and DC tested for guaranteed performance. This amplifier is an ideal solution for transmit and receive functions where high linearity is required.

Mimix Broadband Inc.,
Houston, TX (281) 988-4600,
www.mimixbroadband.com.

RS No. 221

PLL Synthesizer

This 3.5 GHz PLL synthesizer series is designed for the WiMAX and WiBRO wireless infrastructure markets. The PLV3500 operates in a frequency range from 3.45 to 3.55 GHz, is available in PS-16 (19 × 19 × 6.6 mm), or PS-32 (20 × 15 × 3.8 mm) package, and is lead-free/RoHS compliant. It also offers an output power of 0 dBm, with phase noise of 95 dBc/Hz at 10 kHz.



RFHIC,
Suwon, Korea +82-31-250-5011,
www.rfhic.com.

RS No. 222

Dual-band Front-end Modules

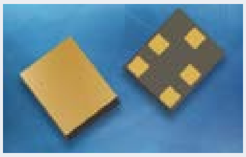
Models SKY77517 and SKY77518 are ultra-compact, dual-band transmit GSM/GPRS front-end modules designed for handsets targeted at emerging markets. Designed in low profile, compact form factor, these highly efficient 6 × 8 × 1.2 mm models offer a complete transmit VCO-to-antenna and antenna-to-receive SAW filter solution. The module also supports GPRS multi-slot operation and consists of impedance-matching circuitry for 50 Ω input and output impedances, transmit harmonics filtering, high linearity and low insertion loss PHEMT RF switches, diplexer and PAC block with internal current sense resistor.

Skyworks Solutions Inc.,
Woburn, MA (781) 376-3000,
www.skyworksinc.com.

RS No. 223

Surface Acoustic Wave Filters

These GSM and CDMA handset surface acoustic wave (SAW) filters are small in size measuring 1.4 × 1.2 × 0.5 mm^3. The filters are designed for next-generation handset designs. These SAWs are 40 percent smaller than the 2 × 1.4 mm filters, allowing phone designers to free-up circuit board space for new mobile device features and functionality.



TriQuint Semiconductor Inc.,
Hillsboro, OR (503) 615-9000,
www.triquint.com.

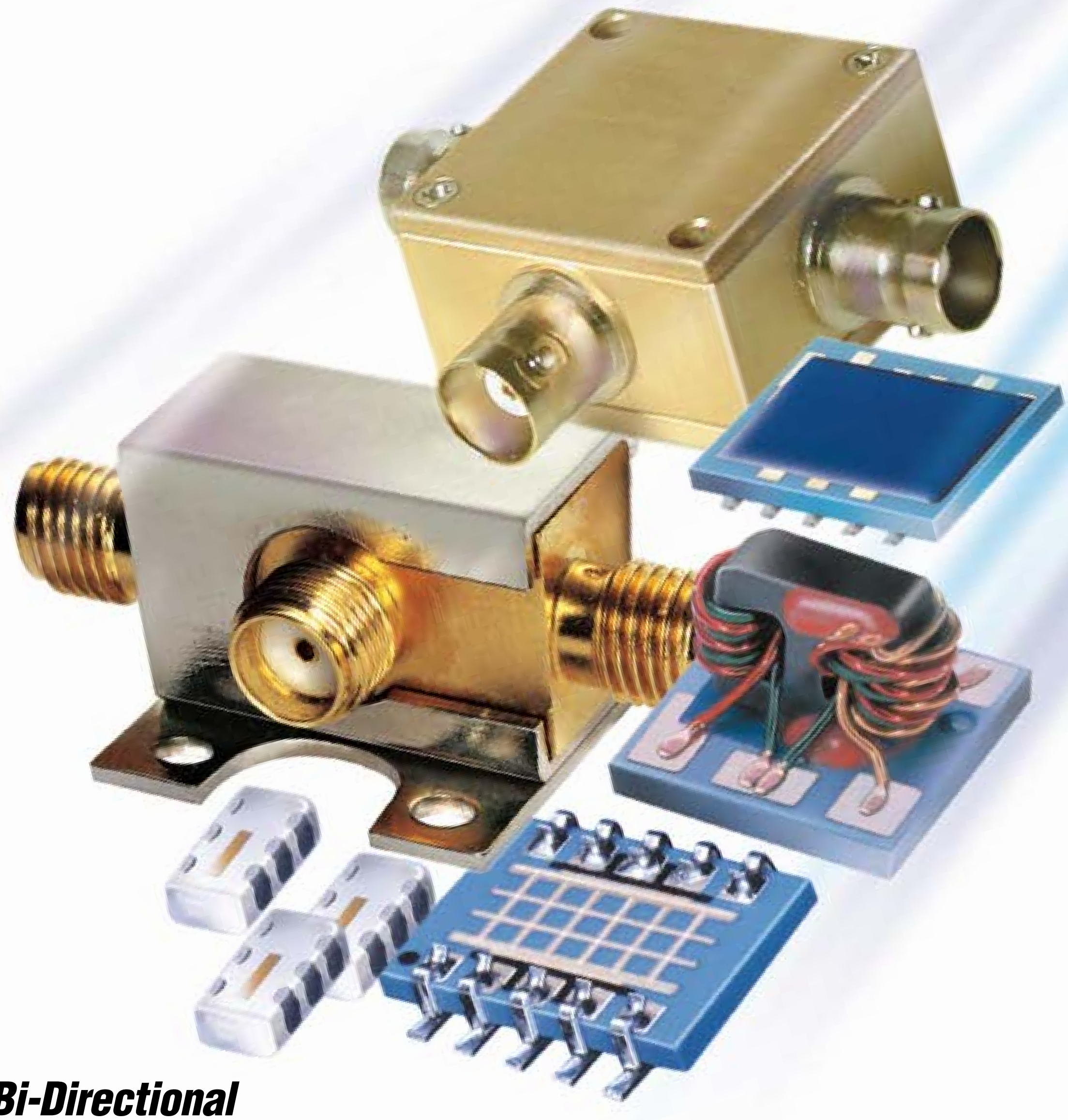
RS No. 224

Voltage-controlled Oscillator

The model CLV1630A-LF is a voltage-controlled oscillator (VCO) designed for demanding mobile communications systems. This RoHS compliant model utilizes patented design techniques to deliver single sideband (SSB) phase noise of –111 dBc/Hz at 10 kHz away from carrier with a second harmonic suppression better than –15 dBc. The CLV1630A-LF operating at 5 VDC supply and drawing only 25 mA (typical) generates frequencies between 1593 and 1654 MHz within 0.5 to 4.5 VDC of control voltage. Size: 0.50" × 0.50" × 0.16". Price: $24.95 (5 pcs. min.). Delivery: stock to four weeks.

Z-Communications Inc.,
San Diego, CA (858) 621-2700,
www.zcomm.com.

RS No. 225



Directional/Bi-Directional

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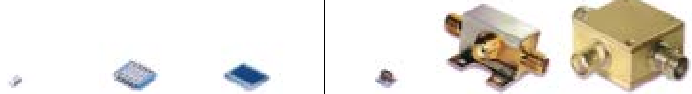

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See our 244 page RF/IF Designer's Guide in EEM (Electronic Engineers Master)

NEW PRODUCTS

COMPONENTS

SP10T Absorptive Switch

The model MSN-10DT-05-DEC-M options NE, 100M18, 3SS, 45004, is an SP10T absorptive switch that operates from 100 MHz to 18 GHz. Insertion loss is ≤ 2.25 dB at 100 MHz and ≤ 4.15 dB at 18 GHz. Isolation is ≥ 95 dB at 100 MHz and ≥60 dB at 18 GHz. Amplitude is ±0.5 dB between ports from 100 MHz to 18 GHz and VSWR is 2:1. Speed is ≤ 275 ns delay on and ≤ 75 ns delay off. Size: 5" × 1.5" × 0.4". Weight: ≤ 6 ounces typical.

American Microwave Corp., Frederick, MD (301) 662-4700, www.americanmicrowavecorp.com.

RS No. 226

Weather Resistant Power Divider

The model 152-014-002-W is a rugged power divider solution ideal for hostile field environments and designed to resist detrimental effects of weather. This model is a 50 Ω, 5 W unit that operates in a frequency range from 800 to 2200 MHz. The divider offers a 20 dB minimum isolation, ±0.3 dB amplitude tracking and N female RF connectors. Other configurations are available and delivery is from stock.

BroadWave Technologies Inc., Franklin, IN (317) 346-6101, www.broadwavetech.com.

RS No. 227

800 MHz Re-banding Duplexer

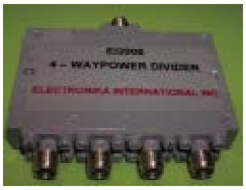
The model WSD-00420 is an 800 MHz re-banding duplexer that has been created in response to the recent Federal Communications Commission (FCC) mandate for signal spectrum separation among incompatible Enhanced Specialized Mobile Radio (ESMR) technologies. This duplexer provides signal interference protection among communications equipment used by emergency services providers. The WSD-00420 ESMR duplexer module operates between 817 to 824 MHz within its receive filter, while its transmit filter operates between 862 to 869 MHz. The downlink transmit filter enables a sharp roll-off into the guard and expansion bands below 862 MHz, thus mitigating the ESMR downlink out-of-band emission.

K&L Microwave Inc., Salisbury, MD (410) 749-2424, www.klmicrowave.com.

RS No. 229

Coaxial Power Divider

The EI2000 series of coaxial power dividers are available in two-, four-, eight- and twelve-way configurations from DC to 18 GHz. These dividers come with standard SMA (F) connectors; N (F) connectors are available upon request. VSWR is 1.50 maximum, 1.20 average on these models, insertion loss is 0.50 dB maximum and isolation is 20 dB. A majority of models are in stock or delivery is one week, ARO. Price: starts at $75.00 each.



Electronika International Inc., Cleveland, OH (440) 743-7034, www.electronikainc.com.

RS No. 228

Dual-band Reject Filter

The model 5DBR-1227/1575-X10-S is a GPS dual-band reject filter with bi-directional inputs. The filter features 1 dB maximum loss over the passband while achieving a typical notch depth attenuation of 50 dB at 1227 and 1575 MHz. Typically the 3 dB bandwidths are less than 50 MHz. The VSWR is 2.0 from DC to 1700 MHz, excluding the notch area. The physical size is 4.5 × 1.25 × 0.50, excluding SMA female connectors. If preferred, the filters can be sold as individual filters in separate 3" long boxes.

Lorch Microwave, Salisbury, MD (410) 860-5100, www.lorch.com.

RS No. 230

Solid-state SP4T Switch

The model 140-F106 is a high power SP4T switch that operates from 7.5 to 18 GHz and handles 150 W CW in a matched load or 100 W CW into a 2:1 load. Low loss and moderate isolation make this unit well suited for switching transmitters in EW applications.

RH Laboratories, Nashua, NH (603) 459-5900, www.rh-labs.com.

RS No. 239

RF Attenuators

These 5 and 10 W 7/16 DIN attenuators cover all wireless bands from DC to 2.5 GHz making them ideal for base station applications where there is a need to reduce signal levels. Standard attenuation values of 3, 6 and 10 are in stock ready for immediate shipment. Made in USA.

MECA Electronics Inc., Denville, NJ (973) 625-0661, www.e-meca.com.

RS No. 232

Power Dividers/Combiners

The RF solutions series of power dividers/combiners focuses on the frequency range of 0.8 to 2.5 GHz. This series will include two- through eight-way power dividers/combiners as well as directional couplers. SMA and Type N connectors are both available. MCLI offers a large warehouse that allows it to maintain large quantities of these components in stock. Orders received before 11:00 AM can be shipped out the same day.

Microwave Communications Laboratories Inc., Saint Petersburg, FL (727) 344-6254, www.mcli.com.

RS No. 233

High Power Fixed Attenuator

The model BW-40N100W is a 50 Ω, 40 dB, 100 W fixed attenuator that is excellent for testing high power components used in communication systems. The attenuator is ideal when testing high power amplifiers using low power test equipment. With 40 dB attenuation, it can be used as a termination for high power amplifiers. The BW-40N100W operates in a frequency range from DC to 4 GHz. Price: $249.95 each (1–9).

Mini-Circuits, Brooklyn, NY (718) 934-4500, www.minicircuits.com.

RS No. 234

30 kHz to 40 GHz Bias Tee

These multi-octave bias tees operate in a frequency range from 30 kHz to 40 GHz. Insertion loss and isolation are 3 and 40 dB, respectively. The unit can handle up to 500 mA at 25 V with a VSWR of 1.8. 2.92 mm connectors are utilized for the RF and RF+DC ports, while pins are used for the DC input.

Pulsar Microwave Corp., Clifton, NJ (800) 752-2790, www.pulsarmicrowave.com.

RS No. 237

Drop-in Isolators

These drop-in isolators and circulators are designed for 802.11a broadband systems that operate in the frequency range from 5.15 to 5.825 GHz. These ferrite devices offer 20 dB isolation over the whole frequency band of 5.15 to 5.825, which allows manufacturers to stock one device for all 12 of the 802.11a channels. The isolators and circulators feature small dimensions (0.375" × 0.500"),

and use ceramic magnets for reliability. Isolators include a termination rated at 10 W.
M2 Global Technology Ltd., San Antonio, TX (210) 561-4800, www.m2global.com.

RS No. 231

High Frequency Relay

The ARJ is a high frequency relay that offers a low insertion loss value of 0.5 dB at 5 GHz, minimizing signal loss between a contact and terminal when the circuit is closed.

Isolation of 35 dB and 1.25 VSWR at 5 GHz make the ARJ ideal for the demanding requirements of test equipment and mobile telecommunications markets. This 2 Form C relay offers an impedance of 50 Ω available in either surface-mount or through-hole style. Size: 14 × 9 × 8.2 mm.
Panasonic Electric Works Corp. of America, New Providence, NJ (800) 276-6289, www.pewa.panasonic.com.

RS No. 235

Fibre Channel Re-drivers

Models PI2EQX3201, PI2EQX3202, PI2EQX4501 and PI2EQX4502 are signal conditioning re-drivers designed specifically to manage high speed protocols such as SATA, SAS, XAUI, Fibre channel and PCI Express. These models offer solutions to solve high speed signal integrity problems either on PCB boards or through cables and multiple connector points while operating up to 4.5 Gbps bandwidth.
Pericom Semiconductor Corp., San Jose, CA (408) 435-0800, www.pericom.com.

RS No. 236

Coaxial Cables and Connectors

These HELI-FOIL™ ultra low loss phase stable DC to 18 GHz bulk coaxial cables and connectors are ideally suited for interconnect applications ranging from laboratory environments to demanding field commercial systems.

HELI-FOIL microwave coaxial cable and connectors offer low insertion loss; ultra stable insertion loss, phase and VSWR with flexing; good shielding effectiveness; temperature endurance up to 150°C; flexible, low minimum bend radius; and precision stainless steel connectors.
Times Microwave Systems, Wallingford, CT (203) 949-8400, www.timesmicrowave.com.

RS No. 240

Narrowband Waveguide Filter

The model 4W8-9.375G-X9FS1 is a narrowband waveguide filter centered at 9.375 GHz with a minimum 1 dB passband of 9 MHz. This 0.1 percent bandwidth filter only

has 1.75 dB of insertion loss and exhibits a VSWR of 1.5 or better. The unit takes up only 0.75" × 1.25" × 5.4" of space and can come with any combination of flange or coaxial connector options.
Reactel Inc., Gaithersburg, MD (301) 519-3660, www.reactel.com.

RS No. 238

2 W Fixed Attenuators

The XFP-18 series of precision 50 Ω fixed attenuators offers good performance over the DC to 18 GHz band, with input power of 2 W CW and a maximum VSWR of 1.35. Attenuation accuracy is ± 0.75 dB for 30 dB. The body and connector housings are passivated stainless steel with an operating temperature range of –65° to +125°C. Values of 1, 3, 6, 10, 20 and 30 dB are available from stock.

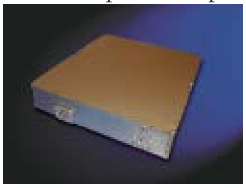
Trilithic Inc., Indianapolis, IN (317) 895-3600, www.trilithic.com.

RS No. 246

AMPLIFIERS

Solid-state RF Amplifier

The model SSPA 29.6-30.5-10 is a high power Ka-band amplifier that operates from 29.6 to 30.5 GHz minimum. This PA is ideal for broadband military platforms as well as commercial applications because it is robust and offers high power over a large bandwidth.



Waveguide combining is employed in the PA section of this unit. This amplifier offers a minimum P1dB of 10 W at room temperature. Saturated output power across the band is typically 12.5 W. Noise figure at room temperature is 12 dB typical. Size: 10" × 11" × 2".
Aethercomm Inc., San Marcos, CA (760) 598-4340, www.aethercomm.com.

RS No. 241

Cryogenic Low Noise Amplifier

The model APTC4-00101800-1910-D4 is a cryogenic low noise amplifier (LNA) designed to operate at extremely low temperatures (below the liquid helium temperature of 16 K) in order to take advantage of the decreased

noise figures at these levels. This model is an ultrawideband LNA that operates in a frequency range from 0.1 to 18 GHz. These amplifiers offer low DC power options (as low as +3 VDC), low current consumption and a lightweight, compact housing/design.
AmpliTech Inc., Hauppauge, NY (631) 435-0603, www.amplitechinc.com.

RS No. 242

Manpack Booster Amplifier

These man-packed or vehicle-mounted booster amplifiers offer capabilities to boost output signals of military radios from 5 W up to 20 or 40 W. The family includes a multi-band/manual band-switch version (model KMW1030M6, 20 W, 30 to 512 MHz), a multi-band/auto band-switch version (model KMW1031, 20 W, 30 to 512 MHz) and a SINCGARS only version (model KMW1032, 20 W, 30 to 108 MHz). The family also includes two dual-purpose high power units, one in a multi-band manual version (model KMW1030HP, 20/40 W, 30 to 512 MHz) and one for SINCGARS only (model KMW1032HP, 20/40 W, 30 to 108 MHz).

AR Worldwide Modular RF, Bothell, WA (425) 485-9000, www.ar-worldwide.com.

RS No. 243

VSAT Power Amplifier

The model SP172-30-35 is a compact power amplifier with greater than 35 dBm output power at 1 dB gain compression from 13 to 17.5 GHz. This model is primarily for Ku-band VSAT transmitter and point-to-point radio applications. The unit offers a

nominal gain of 35 dB with VSWR less than 2:1 at the input and 1.5 at the output. This amplifier requires a +10.5 VDC bias with 2.9A quiescent current and 3.4A at 1 dB gain compression. The amplifier is delivered with a heatsink and fan assembly to manage heat dissipation.
Spacek Labs Inc.,
Santa Barbara, CA (805) 564-4404, www.spaceklabs.com.
RS No. 245

20 W Broadband Amplifier

The model 20S4G11 is the latest addition in a family of broadband, solid-state amplifiers that satisfy the need for low power, high frequency

applications. Model 20S4G11 is a 20 W, 4 to 10.6 GHz amplifier that joins the 1, 5 and 10 W versions. Due to the frequency response, this new family of amplifiers gives users room to grow as EMC and wireless specifications and requirements demand higher frequencies.
AR Worldwide RF/Microwave Instrumentation,
Souderton, PA (215) 723-8181, www.ar-worldwide.com.
RS No. 244

ANTENNAS

High Performance Radome

These high performance nose radomes are designed for airborne applications. This particular radome is parabolic in shape, six feet in diameter,

and six feet long. This multi-layer composite radome has been optimized for the demanding electrical performance of advanced radar systems while also providing the high strength required for the rigors of a subsonic flight and landing on unimproved runways. Key features include low insertion loss, beam deflection, and sidelobe degradation, high strength to weight ratio, and rain erosion protection.
Cobham Defense Electronic Systems – Nurad Division,
Baltimore, MD (410) 542-1700, www.cheltonmicrowave.com.
RS No. 247

Optional RFID Tags

These RFID tags can be placed on microwave antenna boxes and allow customers the option to track finished goods. The RFID tags allow for

the latest in asset management and logistics management.
Radio Waves Inc.,
N. Billerica, MA
(978) 459-8800,
www.radiowavesinc.com.
RS No. 248

SOURCES

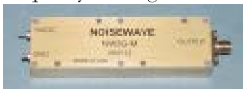
Voltage-controlled Crystal Oscillators

This line of low phase noise voltage-controlled crystal oscillators (VCXO) operates up to 130 MHz. These surface-mount RoHS compliant VCXOs

achieve noise figures as low as –120 dBc/Hz at 100 Hz, –145 dBc at 1 kHz and –155 dBc at 100 kHz offset (measured at 120 MHz).
BeckElec Inc.,
Phoenix, AZ (623) 435-6555,
www.beckelec.com.
RS No. 249

Amplified Noise Source

The model NW3G-M is an amplified noise source that features broadband frequency coverage from 10 MHz to 3 GHz. This model is ideal for wireless



test applications and covers all major wireless and CATV applications. The NW3G-M offers power out of 0 dBm, spectral flatness of ±2 dB, internal regulation and operates with +15 VDC at 300 mA. The NW3G-M comes standard with SMA connectors and is in a small low profile housing that measures 4" × 1" × 0.5".
NoiseWave Corp.,
East Hanover, NJ (973) 386-1119, www.noisewave.com.
RS No. 250

TEST EQUIPMENT

Analog Signal Generator

The E8663B analog signal generator provides a close-to-carrier phase noise performance available in an off-the-shelf signal generator that makes

it ideal for developing high resolution radar and electronic warfare systems and their components. Its good level accuracy ensures that all measurements are both repeatable and precise. The E8663B replaces the discontinued HP or Agilent 8662A and 8663A signal generators. The E8663B provides even lower phase noise than its predecessor, enhancements in level accuracy and harmonic distortion, and includes code compatibility to assure seamless operation in automated test equipment (ATE) applications.
Agilent Technologies Inc., Signal Sources Division,
Santa Rosa, CA (800) 829-4444, www.agilent.com.
RS No. 251

DTV Carrier-to-Noise Generators

The model CNG-DTV is a carrier-to-noise generator designed for IF loop-back testing (as called out in ATSC a80). This generator provides calibrated, accurate C/N ratios for generating BER performance of DTV modems. The CNG line features true Gaussian noise for accurate tests against BER curves based on the Gaussian PDF, self-calibration for accurate S/N ratios and a field calibration feature that reduces down time and total cost of ownership.

Micronetics Test Solutions Group, Hudson, NH (603) 883-2900, www.micronetics.com.

RS No. 252

Radar/Microwave Monitoring Receiver

The model RMR-818-77-NRL is an 8 to 18 GHz radar/microwave monitoring receiver designed for laboratory applications. The receiver uses an extended range detector log video amplifier (DLVA), a preamplifier and RF bandpass filtering. It also offers a dynamic range of 75 dB with a typical TSS of –80 dBm. It can be supplied with either individually removable bandpass filters or various switched filter bank options. The basic model shown above offers a log video output for analysis through external test equipment. These receivers are available in frequency ranges from 0.5 to 20 GHz as well as different sizes and capabilities.

Planar Monolithics Industries Inc., Frederick, MD (301) 631-1579, www.planarmonolithics.com.

RS No. 253

NEW LITERATURE

CAPABILITIES BROCHURE

This brochure highlights the company's design, development and manufacture of custom microwave hybrid circuits on ceramic, quartz, AlN, BeO, ferrite and glass. The hybrid circuits encompass resistor and conductor layers, plated-through holes, solid filled vias, multilayer circuits, air bridges and snapstrates.

Bandwidth Semiconductor LLC,
Hudson, NH (603) 595-8900,
www.bandwidthsemi.com.

RS No. 200

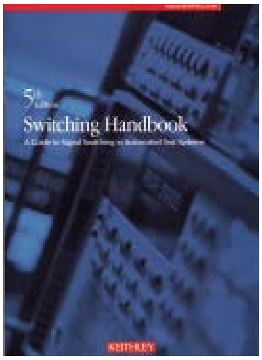
PRODUCT BROCHURE

This brochure highlights the company's narrowband frequency synthesizer products. Featured products include the MFS, DFS and WMFS series that offer reliable integrated system synthesizers. Also highlighted are the SPDRO, SFDRO and PSDRO series products that offer phase noise efficiency with broad performance features. The products are targeted for applications such as radar systems, EW, instrumentation, digital radio, military, fiber optics and SATCOM.

Elcom Technologies,
Rockleigh, NJ (201) 767-8030,
www.elcom-tech.com.

RS No. 201

SWITCHING HANDBOOK

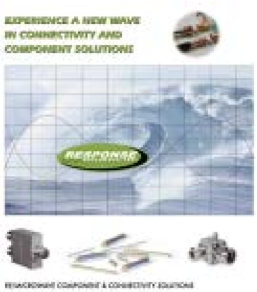


This 190-page handbook features the fundamentals of the switching function in test and measurement applications. The handbook is divided into seven sections and discusses topics that include: switching components, issues in switch system design, hardware implementation and applications. It also includes three appendices, including a glossary of commonly used switching terms and a discussion of safety considerations.

Keithley Instruments Inc.,
Cleveland, OH (440) 248-0400,
www.keithley.com.

RS No. 202

PRODUCT SELECTION GUIDE



The 24-page brochure provides an overview of corporate capabilities and selection tables of the company's passive component and connectivity product offering, which operates from DC to 40 GHz. The guide also offers application notes on the company's HYBRIDLINE series of drop-in quad hybrids and couplers. The guide provides a comprehensive outline to its web site and enhances data sheets and application notes.

Response Microwave Inc.,
Framingham, MA (978) 456-9184,
www.responsemicrowave.com.

RS No. 203

POWER AMPLIFIERS DATA SHEET

This data sheet provides complete detail on the company's 10 to 12 W Ka-band power amplifiers, the MPC2-1530 series. This series is ideal for SATCOM systems serving military and commercial airborne and mobile platforms. A product photograph, description, performance features, electrical and mechanical specifications, and outline drawings are also provided.

Sophia Wireless Inc.,
Chantilly, VA (703) 961-9573,
www.sophiawireless.com.

RS No. 204

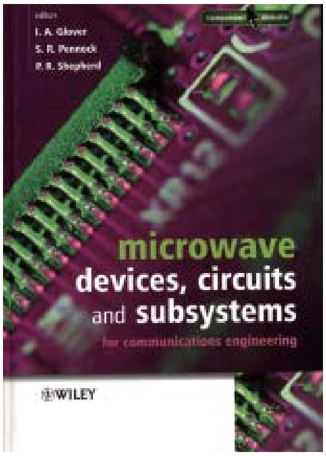
PASSIVE COMPONENTS CATALOG

The Summer 2006 edition of the passive components catalog has recently been released. This 25-page catalog contains comprehensive product information, pricing and data sheets. It is available for download on the company's web site or it can be requested on mini CD-ROM.

Vista RF Inc.,
Roseville, CA (916) 529-4799,
www.vistarf.com.

RS No. 205

Microwave Devices, Circuits and Subsystems for Communications Engineering



A. Glover, S.R. Pennock and P.R. Shepherd, Editors
John Wiley & Sons Ltd. • 549 pages; $119.95
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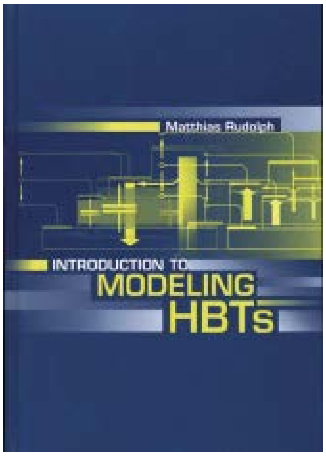
This book originated from a master's degree course in RF communications engineering offered by the University of Bradford, UK. As such, it reads like a textbook, with many problems to challenge the reader. The focus of this book is microwave communications and so, while much of the material offered is generic, the selection and presentation of the material are conditioned by this application. Chapter 2 is a review of semiconductors and their fundamental properties. The role of electrons and holes as charge carriers in intrinsic semiconductors is described and the related concepts of carrier mobility, drift velocity and drift current are presented. Semiconductor devices of all types are described in detail. Chapter 3 is a survey of practical transmission line structures, including those without conductors (dielectric waveguides), those with a single conductor (conventional waveguide) and those with two conductors (such as microstrip). Virtually all systems need amplifiers to increase the amplitude and power of a signal. Chapter 4 starts by defining the power and gain quantities. Amplifier requirements, such as power, low noise and stability are then considered. A mixer is a nonlinear circuit, which must be implemented using a nonlinear component. Chapter 5 outlines the operation of commonly used nonlinear devices. Chapter 6 provides the background and tools for designing filter circuits at microwave frequencies. The various filter characteristics are described as well as the various types of filter responses. Chapter 7 describes the fundamentals of microwave oscillator design, including simple active component realizations using diodes and transistors. The standard topology of transistor feedback oscillators is described and analyzed from a mathematical point of view. Examples of practical voltage-controlled oscillator designs complete this section.

Introduction to Modeling HBTs



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The aim of this book is not only to provide a reference of relevant HBT models, but also to discuss their background from a circuit designer's point of view. A second motivation comes from the fact that texts on transistors frequently give the reader the impression that a compact model is obtained for free as a by-product of understanding the device physics. However, it is not as simple, as one discovers quickly when attempting to understand how a specific compact model works. Chapters 1 and 2 give a general introduction to compact modeling. The treatment focuses on the circuit level, watching the physics through the equivalent circuit. This way, instead of developing the model from physics upwards, it enables a discussion of practical implementation issues, the possibilities that are provided by modern circuit simulators, and also shortcomings and pitfalls. Chapter 3 then discusses the physics and technology of III-V HBTs. This chapter does not comprehensively provide all aspects of semiconductor physics. It is focused on the effects that are of practical relevance in contemporary HBT devices. Chapter 4 combines the preceding chapters and discusses modeling issues specific to HBTs. It thereby provides an explanation of the building blocks needed for a dedicated HBT model. Since noise is a special topic, it receives its own development in Chapter 5. In Chapter 6, a discussion of the most recent HBT models available plus two widespread bipolar models, SPICE Gummel-Poon and VBIC, is provided. Finally, Chapter 7 addresses the most important issue of all: how to obtain the model parameters. It is, as everything in science, a fragment, since each technology calls for adjustments of the extraction procedures. However, the strategies presented in the book seem to be satisfactory for most transistors.

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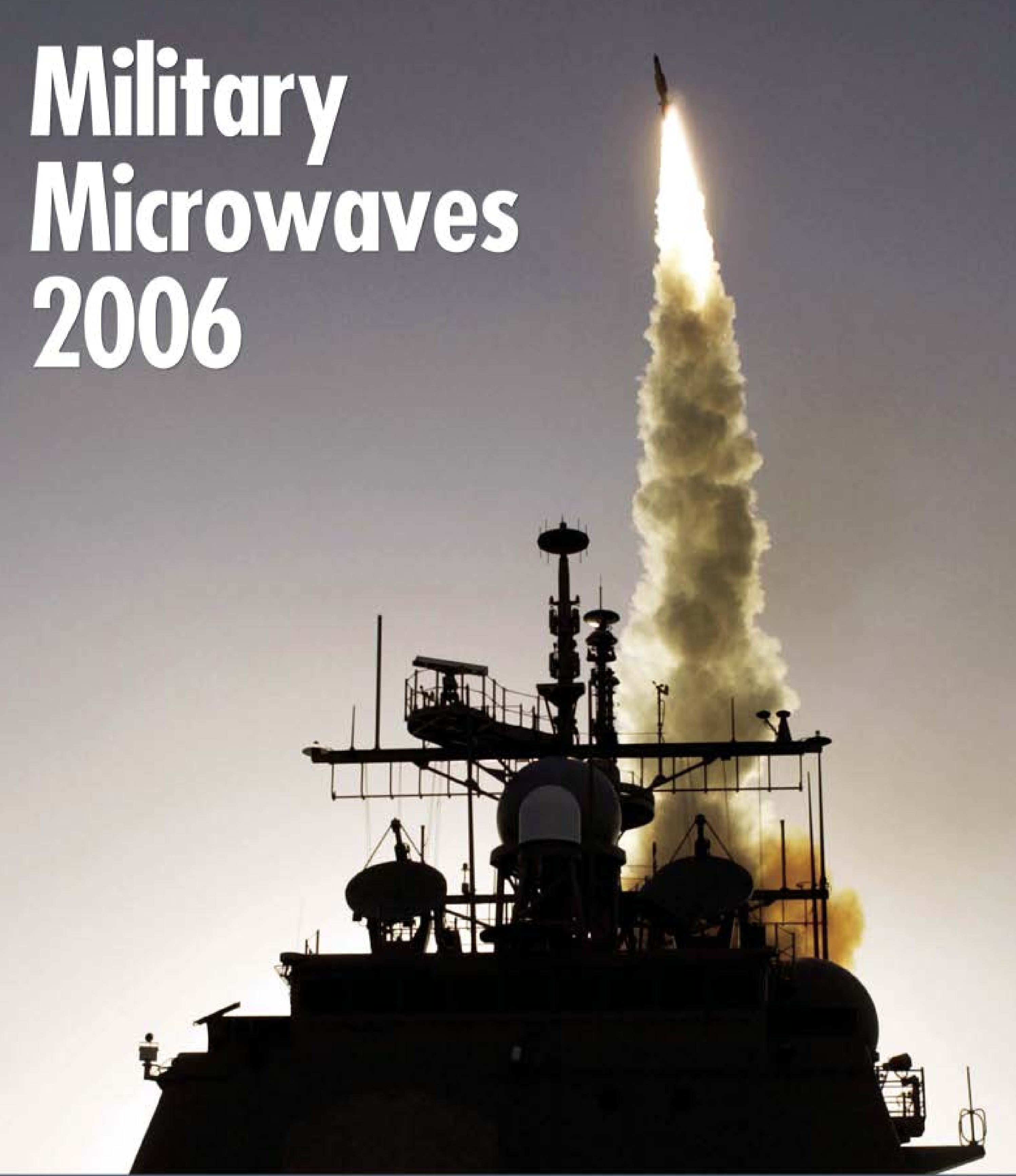

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Military Microwaves 2006 — Current Viewpoints on Air Defense Systems

Harlan Howe, Jr. – Editor, *Microwave Journal*
Richard Mumford – European Editor, *Microwave Journal*
Michael Puttré – Editor-in-Chief, *Journal of Electronic Defense*

The editors of *Microwave Journal* and *Journal of Electronic Defense* interviewed some key executive and military leaders in the markets that we serve, both in the US as well as in Europe. Selected questions and answers from those interviews are presented below. We would like to thank the participants who took the time and effort to present their views. As expected there are significant differences in the US and European approaches to system development. We hope you find the responses to be informative.

Mark Hebeisen
Vice President
Marketing & Business Development
Endwave Corp.

MWJ: *Looking at the air defense programs in Europe and the United States, what are the key areas of development?*

MH: Endwave Defense Systems is actively involved as an RF subsystem supplier on a number of current and future Air Defense Systems (ADS). These opportunities span a wide range of capabilities and platforms, from fighter jet aircraft, attack helicopters, unmanned aerial vehicles (UAV), and other airborne warning and surveillance applications. At a time when governments are struggling to dedicate the necessary funding required to secure the homeland and fight a long global war on terror, the Pentagon is pushing for "military transformation" — one that signals a shift away from large stove-piped defense platforms towards creating more agile, mobile forces that work in concert and are linked with advanced wireless communications networks. The fight today is, first and foremost, for communication superiority.

In the near-term, it is apparent from the QDR and US defense budget released earlier this year that major defense programs like F/A-22 Raptor, F-35 Joint Strike Fighter and Future Combat Systems are all continuing. Contracts favoring upgrades to extend the range or increase the payload of existing air defense platforms are more likely than replacing them with completely new systems — so adaptability is a common theme. Programs dedicated to only one military branch will be a distant memory as the resounding theme of interoperability within a joint "future force" is being voiced by the Pentagon. Key areas of development will shift the Department of

Defense's (DoD) attention from conventional fighting techniques to unconventional irregular warfare. Endwave sees tremendous opportunities for missiles and anti-missile systems, smart munitions, and UAVs for both surveillance and strike capability. Both manned and unmanned programs in Intelligence, Surveillance and Reconnaissance (ISR) applications abound. An excerpt from the QDR cited, "the ability of the future force to establish an 'unblinking eye' over the battlespace through persistent surveillance will be instrumental to conducting effective joint operations."

MWJ: *Describe how the development of wireless networking technology, such as data links, is making integrated ADS more effective and survivable.*

MH: Taking critical battlefield information from multiple sensors amongst a host of different platforms — and making that information available to all members of the joint future force, will create a "network-centric" military operation. As an example of the power of connectivity, many of the UAV missions conducted in the Middle East were flown remotely by pilots in Nevada, with real-time communications from forces on the battlefield to direct the mission. The enabler for such information connectivity lies in high capacity directional data links in order to put the right information real-time directly in the hands of combatant commanders. As such, these data links are deemed necessary in order for the United States' UAV strategy to pay off, which calls for a near doubling of the UAV coverage. Recently, tactical data links were used to demonstrate airborne interoperability between US Apache attack helicopters and Hunter UAVs, as further evidence that the network-centric military force is not so far away.

MWJ: *What changes in radar systems are needed to support the new generation of ADS?*

MH: Synthetic aperture radars (SAR) at millimeter-wave frequencies are being incorporated onto many UAV platforms in conjunction with optical imaging sensors to provide high resolution imaging around the clock or during harsh weather environments. Furthermore, phased-array radars are becoming an increasingly popular choice in ADS, due to their ability to steer the antenna beam in a near-instantaneous fashion — improving accuracy and precision, as well as the ability to track more targets simultaneously. These radars often use thousands of radiating antenna elements, each driven by a T/R module with precise control of gain and phase amongst elements.

There is certainly a trend towards the increased use of microwave and millimeter-wave frequencies — due in large part to their unique ability to carry large amounts of data, to provide higher resolution for radar systems, to penetrate certain structures and to provide solutions that are small, light-weight and high performance. In addition, we've seen numerous instances where millimeter-wave radars are necessary to see through sand storms in the Middle East for automatic landing guidance (ALG) systems on attack helicopters and other fighter aircraft in ADS.

MWJ: *Are there any applications for conventional antenna systems or will all new radars be phased array?*

MH: We see opportunities for both conventional and phased-array radars in future ADS. Given the DoD emphasis on budget trimming, each radar platform has a risk vs. reward analysis to be done. As a hardware supplier for a major development program in 2005, we witnessed a shift away from a phased-array approach used in the engineering development models to a more conventional radar-trading performance for a lower overall cost. But over time, as innovative technologies are introduced to lower the costs of these advanced radar systems, we believe phased arrays will be the predominant choice in the industry.

MWJ: *What advances in sensor fusion are required?*

MH: Sensor fusion refers to the ability to collect, distribute, process and quickly respond to intelligence data coming in from multiple sensors — all in an effort to aid decision-makers in battlefield coordination and to anticipate the actions of our adversaries. In future Air Defense Systems, the assimilation of sensor inputs will require access to intelligence data

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Parent Part ID	*Min.*	*Max.*	*Min.*	*Max.*	*Max.*	*Typ.*	*Max.*	*Min.*	*Typ.*	*Max.*	*Max.*	*Max.*
DBL-0102N305	.05	2.0	28.0	32.0	0.5	1.8	2.0	5.0	15.0	2.0	2.0	150
DBS-0102T412	0.5	2.0	29.0	35.0	1.5	3.2	3.8	12.0	22.0	2.0	2.0	250
DBS-0102N318	0.5	2.0	34.0	39.0	1.0	2.0	2.2	18.0	28.0	2.0	2.0	250
DBS-0112N210	0.5	12.0	20.0	26.0	1.5	5.5	6.5	10.0	20.0	2.0	2.0	270
DBS-0208N315	2.0	8.0	30.0	35.0	1.5	2.1	2.3	15.0	25.0	2.0	2.0	200
DBS-0208N320	2.0	8.0	32.0	38.0	1.5	2.5	3.0	20.0	30.0	2.0	2.0	300
DBS-0208N420	2.0	8.0	42.0	48.0	1.5	2.5	3.0	20.0	30.0	2.0	2.0	350
DBS-0208N323	2.0	8.0	32.0	38.0	1.5	2.5	3.0	23.0	33.0	2.0	2.0	350
DBS-0218N320	2.0	18.0	20.0	26.0	2.0	4.5	5.0	20.0	30.0	2.0	2.0	425
DBM-0218N627	2.0	18.0	34.0	41.0	2.0		6.5	27.0	35.0	2.0	2.5	1800 Typ
DBS-0408N318	4.0	8.0	30.0	35.0	1.5	2.3	2.5	18.0	28.0	2.0	2.0	230
DBS-0411N320	4.0	11.0	26.0	30.0	1.5	4.0	4.5	20.0	30.0	2.0	2.0	250
DBS-0411N630	4.0	11.0	39.0	45.0	1.5		7.5	30.0	40.0	2.0	2.0	1250
DBS-0513N215	5.0	13.0	20.0	24.0	1.5	2.2	2.5	15.0	25.0	2.0	2.0	140
DBS-0513N320	5.0	13.0	27.0	31.0	1.5	3.0	3.5	20.0	30.0	2.0	2.0	290
DBS-0612N210	6.0	12.0	20.0	24.0	1.5	2.2	2.5	10.0	20.0	2.0	2.0	150
DBS-0612N320	6.0	12.0	25.0	29.0	1.5	3.5	4.0	20.0	29.0	2.0	2.0	250
DBS-0612N420	6.0	12.0	34.0	38.0	1.5	3.5	4.0	20.0	29.0	2.0	2.0	300
DBL-0618N410	6.0	18.0	28.0	33.0	1.0	2.3	2.5	10.0	20.0	2.0	2.0	150
DBS-0618N315	6.0	18.0	26.0	30.0	1.5	2.7	3.0	15.0	25.0	2.0	2.0	260
DBL-0618T620	6.0	18.0	28.0	35.0	2.3	3.5	4.0	20.0	30.0	2.0	2.0	490
DBL-0618N420	6.0	18.0	30.0	34.0	1.5	2.3	2.5	20.0	30.0	2.0	2.0	370
DBS-0618N520	6.0	18.0	32.0	37.0	1.5	2.7	3.0	20.0	30.0	2.0	2.0	430
DBS-0712N315	7.0	12.4	28.0	32.0	1.5	2.3	2.5	15.0	25.0	2.0	2.0	190
DBS-0712N320	7.0	12.4	22.0	26.0	1.5	2.5	3.0	20.0	30.0	2.0	2.0	260
DBS-0910N420	9.0	10.0	30.0	35.0	1.0		1.7	20.0	30.0	2.0	2.0	350
DBS-0910N530	9.0	10.0	30.0	40.0	0.5		3.0	30.0	40.0	2.0	2.0	1200
DBS-1218N515	12.0	18.0	32.0	37.0	1.5	2.8	3.0	15.0	25.0	2.0	2.0	310
DBS-1218T718	12.0	18.0	36.0	44.0	1.5	3.7	4.0	18.0	28.0	2.0	2.0	510
NWL-0412N410	4.0	12.0	40.0	48.0	1.0	1.2	1.5	8.0	16.0	2.0	2.0	225
NWM-0218N630	2.0	18.0	45.0	52.0	2.0		6.5	30.0	38.0	2.0	2.0	3000 Typ

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originating from both inside and outside of the battlespace — so a seamless integration of inputs from tactical, terrestrial and satellite communications sources will be necessary. Imagine being able to simultaneously strike thousands of enemy targets at remote locations around the globe, or the ability to instantaneously re-target cruise missiles and bomber payloads mid-flight while moving allied troops out of harms way. That's what the future air defense capability looks like. Given the large amount of data to be shared amongst many mobile combatant commanders, and the speed in which that information needs to be pushed down to this large group of users, products and platforms that enable secure wireless broadband data distribution will be in high demand.

MWJ: *What technologies will fuel the growth of ADS over the next five to 10 years and to what extent?*

MH: New threats require new battlefield tactics, and new battlefield tactics will require "disruptive" technologies to break through previous cost vs. performance barriers and allow system designers to pack more complex hardware into tighter form-factors than ever before. In high frequency subsystems, consistency and cost are two of the most common challenges encountered. Advances in both MMIC and MMIC-alternative technologies are paving the way for tuneless low cost T/R modules that form the heart of future radars and communication links. Multilithic Microsystems® (MLMS) is an advanced circuit technology using flip-chip and electromagnetic coupling methods to minimize expensive semiconductor real estate while eliminating lengthy interconnects and their related variability. MLMS moves passive circuitry onto an inexpensive proprietary substrate that processes with the ease of silicon, yet works past 100 GHz. Only the discrete active devices remain, which are then flip-mounted on top of the MLMS substrate. Mixed device technologies like SiGe, GaAs and InP can be utilized to increase functionality and optimize performance. The result is a true "system on a chip" with no bondwires in the RF path — and at 30% less cost than a MMIC-based solution.

With phased-array radars often employing thousands of T/R modules, the mechanical packaging associated with high frequency electronics is often a major contributor to the overall cost of ADS platforms. Conventional millimeter-wave thinking is rooted in the belief that module housings have to be fabricated utilizing costly machining and plating techniques. In contrast, Epsilon® Packaging is a multi-layer substrate and module package, all in one. It replaces costly and heavy weight metal mechanicals with metallized FR-4 and injection molded metallized plastics. The Epsilon Packaging approach includes revolutionary mixed technology integration, allowing chip-on-board and surface-mount technology components to co-exist, thus easing assembly and reducing cost. The end

result is a package with no machined metal parts, making it light and mass producible, with efficient heat extraction.

In summary, the opportunities in fighter and surveillance aircraft, missiles, smart munitions and UAVs all demand technologies that aid the "lighter, cheaper, faster" requirements of these future Air Defense Systems. To learn more about Endwave's response to these challenges, please visit www.endwave.com.

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JED: *Looking at the air defense programs in Europe and the United States, what are the key areas of development?*

LOCK: Lockheed Martin's primary air defense programs impacting both the US and European markets include the Theater High-Altitude Area Defense (THAAD) system; the Medium Extended Air Defense System (MEADS); the Patriot PAC-3 and PAC-3 Missile Segment Enhancement (MSE); and the High-Altitude Airship (HAA) program, which will provide greater situational awareness against low-flying threats such as cruise missiles. Another important program is the US Army's Counter-Rocket, Artillery and Mortar (C-RAM) program [prime: Northrop Grumman], which ties a Firefinder counter-battery radar with a modified Phalanx gun system. This system has already been deployed to Iraq.

It is clear that defense against a wide range of missile and projectile threats, from ballistic missiles to mortars covering all altitudes and ranges are required to ensure coverage. Armed forces are working on protecting high-value assets and individual personnel from high-tech and low-tech threats.

JED: *Describe how the development of wireless networking technology, such as data links, is making integrated ADS more effective and survivable.*

LOCK: Air and missile defense (AMD) systems are moving to "plug-and-fight" architectures that integrate multiple sensors and shooters into distributed, survivable networks. Such an architecture is more survivable because individual components can be unplugged, moved and plugged back in without taking the whole network offline. The network is also more resistant to damage.

Technological advances have enabled a significant reduction in the size of equipment while at the same time providing increased capability, higher reliability and a reduced logistics burden. Technology has also taken us from the analog world to predominantly a digital world. This enables software-only upgrades and multiple modes of radar operation. The different modes could be looking for air-breathing targets or tactical ballistic missiles. The radar may be operating in a rotating 360-degree surveillance mode in one situation and in a sectorized, longer-range mode in another if the goal is to get high-range resolution data on a target. Phased-array radar technology seems to provide the versatility required for today's and tomorrow's AMD architectures.

Technology also enables the integration of a multitude of acquisition and fire control sensors. The ultimate goal is the creation of a single integrated air picture (SIAP).

JED: *What changes in radar systems are needed to support the new generation of ADS?*

LOCK: The capabilities of next generation air defense systems are driven by expanding missions, advanced threats and operation in hostile man-made environments. Radar system improvements required to support new Air Defense Systems include:

- Increased sensitivity to detect smaller targets at longer ranges
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CBL-3FT-SMNM+	SMA to N-Type	3	1.5	27	104.95
CBL-4FT-SMNM+	SMA to N-Type	4	1.6	27	112.95
CBL-6FT-SMNM+	SMA to N-Type	6	3.0	27	114.95
CBL-15FT-SMNM+	SMA to N-Type	15	7.3	27	156.95
CBL-2FT-NMNM+	N-Type	2	1.1	27	102.95
CBL-3FT-NMNM+	N-Type	3	1.5	27	105.95
CBL-6FT-NMNM+	N-Type	6	3.0	27	112.95
CBL-15FT-NMNM+	N-Type	15	7.3	27	164.95
CBL-20FT-NMNM+	N-Type	20	9.4	27	178.95
CBL-25FT-NMNM+	N-Type	25	11.7	27	199.95
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These radar system improvements provide increased capability to support next generation Air Defense Systems.

JED: *Are there any applications for conventional antenna systems or will all new radars be phased array?*

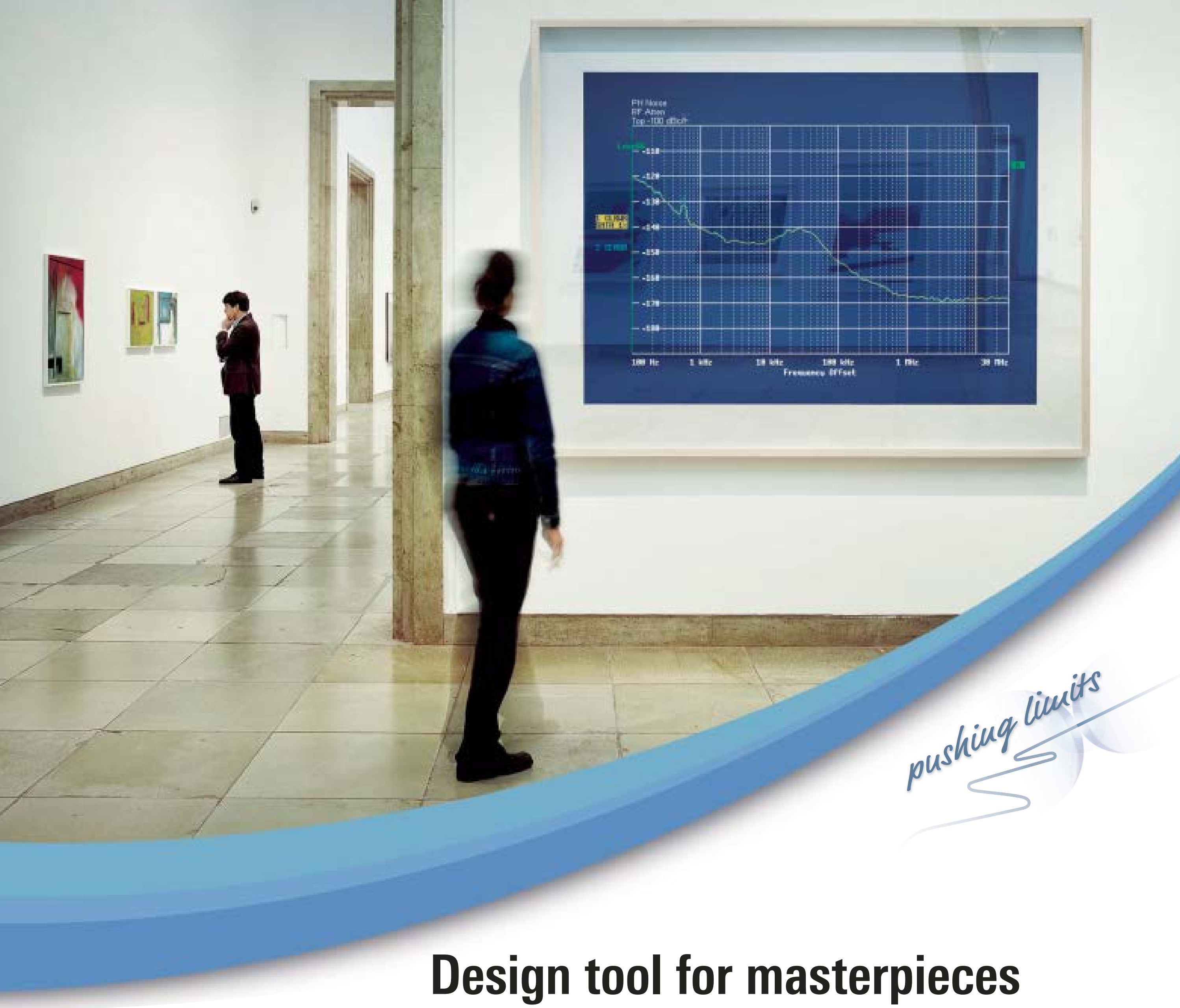
LOCK: As new radars operate in increasingly complex stressing environments, the advantages of phased-array radars will be required. Phased arrays provide an agile beam and enable multi-function radars. Phased arrays enable the dynamic control of radar time, allowing radar beams to be priority scheduled. This flexibility allows the application of radar resources and track update rates to vary based on target priority. In addition, phased arrays enable increased radar track capacities. The use of conventional antenna systems is limited to applications where an agile beam is not required or weight and cost are primary system constraints.

JED: *What advances in sensor fusion are required?*

LOCK: The ability to fuse sensor data from multiple sensors can increase the fidelity of the air defense picture. The advances required to improve sensor fusion performance are higher bandwidth sensor networks, improved sensor registration and track correlation capabilities. This is especially true with mobile sensors operating in target-rich high-clutter environments. Additionally, networks allow sharing of data from one sensor or weapon system with another system enabling engage on remote capabilities. Target registration and deconfliction along with robust target classification, discrimination, and identification are critical elements of any network-centric air defense system.

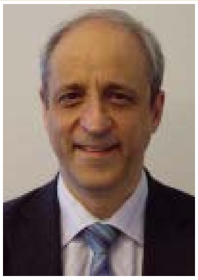
EUROPEAN PERSPECTIVE

Political, social, demographic and economic factors are key influences on the development and direction of European defence and security, with the challenge being to adapt and prosper within this changing environment. To meet these challenges both governments and commercial enterprise are tending towards a collective European approach. Particular European Union initiatives include the development of a European Security Research Programme (ESRP), as part of the 7th EU Research Framework Programme, a key element of which is the Preparatory Action for Security Research (PASR). This overview article specifically addresses the development of Air Defence Systems and here the Medium Extended Air Defence System (MEADS) is being designed to be effective against enemy aircraft, which will incorporate its own three-radar set, along with networked communications. Its broader goal being an open architecture system that


pushing limits

can plug into larger defensive systems along with shorter-range systems. Commercially, the AeroSpace and Defence Industries Association of Europe (ASD), formed in 2004, represents industry in Europe in all matters of common interest with the objective of promoting and supporting competitive development both on a European level and transnationally. The following interviews testify to the ongoing development work being carried out in Europe particularly concerning the changing operational needs of society and the increasing capabilities offered by technology. Asymmetric warfare, network-enabled capabilities and global security are all addressed with particular attention being paid to wireless networking technology, sensor fusion and phased-array radar.

Gilles Martin
Marketing Director
Chelton Telecom & Microwave – a Cobham Avionics & Surveillance Division company



MWJ: *Looking at the air defence programmes in Europe and the United States, what are the key areas of development?*

GM: From a European perspective I see the areas of development of air defence programmes as being active phased arrays, satellite data communications, UAVs, identification systems, missiles and antimissiles. There is unquestionably continuing progress towards phased arrays in general in the air defence market and as far as phased-array antennas are concerned several major European countries are becoming equipped. Their motivation being low power consumption and increased radar power.

Satellite data communications also play a key role in Air Defence Systems. Via integrated radio links, they are used for both localisation and observation, with information relayed from ground bases and aircraft creating a clear understanding of what is happening on the battlefield. Battlefield knowledge is also driven by the development of UAVs, drones and identification (IFF and BIF). We should also mention missiles and antimissiles – the Future Surface-to-Air Family (FSAF) programme for instance.

MWJ: *Describe how the development of wireless networking technology, such as data links, is making integrated ADS more effective and survivable?*

GM: ADS will certainly benefit from all of the major achievements made in the telecommunication sector, such as the processing and treatment of information, which can help secure military systems. Telecommunications are synonymous with efficiency and speed, which leads to a reduction in costs. The radio mobile (IF band) has also made important strides, such as the improvement in the security of data transmission based on low phase noise PLLs. As a major player in the telecommunications market we share our knowledge with other customers.

MWJ: *What changes in radar systems are needed to support the new generation of ADS?*

GM: Several areas of amelioration should be considered: mobility (smaller, lighter, reduced consumption), prices and delivery (COTS), the integration of components with regards to specific functions, for instance Circulator + Isolators + Limiter (CIL) assemblies in the RF head with passive and active components, and the optimisation of features. We can envisage an open architecture with standard components that is easy to install.

We should also consider mechanical ruggedness and higher RF EMP handling capability, lower intermodulation products (IM3) like in radio mobile applications, increased power and wider operating bands (higher than 20 percent). And in order to facilitate users in different countries and provide modularity for maintenance why not add a compatible protocol for all systems, which will consequently increase component reproducibility.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MWJ: *Are there any applications for conventional antenna systems or will all new radars be phased array?*

GM: Phased-array antennas are heading the market but specific applications will use conventional radars like mono-function types such as target radars for territory, area surveillance and control. This is because conventional radars offer invaluable advantages: low cost, easy installation and maintenance, countermeasure capability and network capacity as multiple sensors. Furthermore, if we consider the necessary time to get to market and the long heritage of conventional radars, we can bet they have a long life ahead.

MWJ: *What advances in sensor fusion are required?*

GM: Sensor fusion is a multi-domain awareness system that uses live information from various sources and as such creates a need for multiple database analysis. Depending of what is requested, various sensors will be designed according to the three modes: cooperative, competitive and complementary modes. Thus, the advances in sensor fusion are complex. Modern weapons platforms on land, at sea and in the air are heavily reliant upon massive computer capability, which continues to improve enormously. This may lead to a combining of sensor functions, which, in turn, may well drive multi-function components and subsystem needs throughout the market, in terms of both software and hardware.

The trend for European system manufacturers to buy black boxes for multifunction applications continues at pace, and it is clear that companies with a poor range of technologies will not be able to stand the natural evolution of the microwave component market into raw subsystem-based entities.

MWJ: *What technologies will fuel the growth of ADS over the next five to 10 years and to what extent?*

GM: From our point of view, elements or technologies that need to be developed are: integration of discreet elements under functions or modules, higher power capability, miniaturization, weight reduction, MMIC and MEMS in five to 10 years and the integration of new materials (that is, with better power and thermal handling capabilities).

Bernhard Gerwert
CEO
EADS Defence Electronics

MWJ: *Looking at the air defence programmes in Europe and the United States, what are the key areas of development?*

BG: As usual, the key drivers of development are two pronged — firstly, the changing operational needs of the customer and secondly the increasing capabilities offered by technology that are vital in order to meet these needs. On the customer side,

we are addressing the changing security needs related to asymmetric warfare, network-enabled capabilities and global security, which together extend the traditional scope of air defence.

This fits perfectly into our activities on the technology side. We are driving forward component technologies and thereby increasing the performance of sensors to meet the future operational threat, for example, MMIC technologies which also reduce the size, weight and power consumption of the HF radar elements. Also, digitization contributes greatly to increasing processing throughput and miniaturization of core components. Not forgetting the development of GaAs materials, enabling the employment of high density T/R modules. This, together with the refinement of algorithms and systems technology, leads to a new generation of radars offering unprecedented capabilities in detecting very small, fast moving objects, tracking individual targets while scanning vast volumes, not to mention automated IFF for avoiding friendly fire and operation modes such as data link.

To give just one example, we have encapsulated all these achievements in the production of thousands of T/R modules for the MEADS Active Electronically Scanning Array (AESA) fire control radar, which is a move towards a new dimension of air defence.

MWJ: *Describe how the development of wireless networking technology, such as data links, is making integrated ADS more effective and survivable?*

BG: This is basically the overall network-centric story — if you have the situational picture, target data, etc. available to all relevant players in real time then you are able to optimise the positioning of your resources as well as their deployment, thus protecting your forces and improving their overall mission effectiveness.

Apart from sensors gathering the necessary information with the right quality and sensor fusion systems processing it, data links are the cornerstone of this net-centricity. Good examples might be the Multifunctional Information Distribution (MIDS) system introduced in NATO or the increasing use of UAVs, which depend on data links for distribution of reconnaissance data as well as telecommand data uplinks. Also, you need high performance data links for missile mid-course guidance. To achieve sufficient transmission rates and jamming resistance, development is concentrating on high bandwidth microwave technologies, high speed digital signal processors, pencil-beam directional antennas with high precision stabilisation and the overall miniaturization of digital and microwave components.

MWJ: *What changes in radar systems are needed to support the new generation of ADS?*

BG: As mentioned earlier, radar technology is in a phase of breathtaking dynamism. Therefore, the idea is not to change individual features here and there, but to create a system ar-

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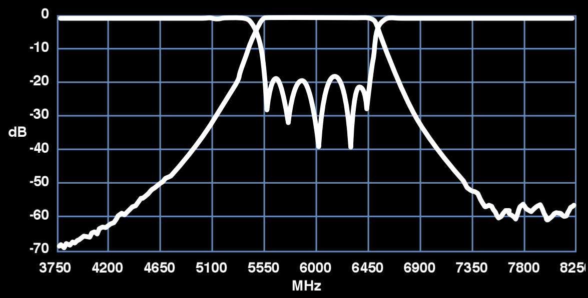

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chitecture, which enables the exploitation of all the new opportunities created by progress in component technologies as well as in system technology.

MWJ: *Are there any applications for conventional antenna systems or will all new radars be phased array?*

BG: Conventional antennas will always find their place alongside active E-scan arrays. This is a question of cost-efficiency relative to the requirements, as well as technical limitations such as size, weight, power consumption and power output. For example, naval radars with conventional antennas for ships below frigate size can very efficiently use existing and solid-state technology to fulfil complex operational requirements while remaining within the limits set by the ships' sizes and budgets.

MWJ: *What advances in sensor fusion are required?*

BG: Intelligent multi-source sensor fusion is the fundamental prerequisite for countering new complex threat scenarios with dwindling air defence resources. If you have less air defence units, the capability of the single unit must be higher and, ideally, the coordination between all existing assets must improve. That means sensor fusion systems have to be opened up to a multitude of intelligence sources, which affords increasing transmission and processing capabilities and, above all, highly refined algorithms.

MWJ: *What technologies will fuel the growth of ADS over the next five to 10 years and to what extent?*

BG: From the electronics point of view, Air Defence Systems will see tremendous progress in terms of component performance due to a combination of digital technologies, further miniaturization based on MMICs and micro-packaging, as well as new materials like GaAs and GaN and related automated production capabilities. To put it simply: Together with innovative systems design this will lead to a reduction of size and weight of radars while increasing tremendously the detection performance and multi-functional capabilities. Even if everybody is talking about 'new' threats, radar will remain the only truly all-weather and day/night capable source of intelligence for the foreseeable future with 3D or even 4D capability.

Paul Holbourn
Deputy Capability Director
SELEX Sensors and Airborne Systems

MWJ: *Looking at the air defence programmes in Europe and the United States, what are the key areas of development?*

PH: The key areas of development are not new but probably have received increased emphasis as a result of recent operational experience. As Air Deployable Systems become more complex, achieving interoperability with friendly forces has be-


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come a greater challenge. The need for modern ADS to be deployable, resilient and to integrate with other land and airborne assets has been reinforced by recent experience.

Effective and robust target identification is also a priority. Looking to the future, target threats will change — not only will an ADS have to contend with conventional fixed wing and rotary wing threats, but also handle increasingly 'difficult' targets such as low observable Unmanned Aerial Vehicles/Unmanned Combat Aerial Vehicles and long-range cruise missiles.

MWJ: *Describe how the development of wireless networking technology, such as data links, is making integrated ADS more effective and survivable?*

PH: Networking lies at the heart of an effective ADS. Such a system comprises a combination of weapons, sensors and computing resources. An optimal architecture will deliver battle-winning capability, through the effective integration of the various components and will endow the system with capabilities that would otherwise be unachievable. Networked sensor systems are more resilient and have better performance than the individual components.

Radio frequency data links have a particular importance for integrating the elements of a mobile ADS interacting with airborne assets, for example, Airborne Early Warning (AEW), and obviously for communication with missile systems. Increasingly important considerations for the data links are bandwidth, encryption and covertness.

MWJ: *What changes in radar systems are needed to support the new generation of ADS?*

PH: The introduction of active phased-array radar technology is the disrupter. This technology is now mature and should be regarded as product ready. It offers many interesting new degrees of freedom for the system designer. These encompass enhanced detection and tracking performance, including adaptive beam and energy management, increased Electronic Counter Counter-Measures (ECCM) resistance, covertness and high availability. The challenge for the system architect is to optimally exploit these new features within an integrated multiple sensor system.

MWJ: *Are there any applications for conventional antenna systems or will all new radar be phased arrays?*

PH: For the customer with demanding operational requirements phased-array-based systems should be considered. Phased-array technology is now mature, and for most applications is affordable and offers considerable performance and Life Cycle Cost advantages. For less demanding applications there is still a market niche for conventional antenna systems. However, over the next 10 years or so, conventional antenna systems will become increasingly marginalized and potentially obsolete in the market place, as phased-array technology becomes more available. Ultimately the cost of a conventional

antenna will overtake that of the phased-array equivalent.

MWJ: *What advances in sensor fusion are required?*

PH: Sensor fusion is a pretty mature technology. However, for it to see the light of day in the field will require ADS architectures to recognise the many benefits that sensor fusion can bring, that is, system resilience, system reconfigurability, graceful degradation, covertness and improved tactical data gathering. By planning for multi-sensor data fusion as an integral feature of the ADS system architecture, the appropriate provision of a flexible data network with distributed processing can be planned.

One active area of research that is of interest to the ADS community is the fusion of data from multiple sources to support high confidence target identification. Such a system would accept data from diverse sources including co-operative Identification Friend or Foe systems, and non-co-operative radar, Electronic Support Measures (ESM) and Electro Optic (EO) sensors to support robust and accurate target identification.

MWJ: *What technologies will fuel the growth of ADS over the next five to 10 years and to what extent?*

PH: The growth of ADS is not likely to be technology driven, rather it is likely to focus more on consolidating and implementing current technologies within open system architectures, using common standards, which recognise the value of sensor data fusion and the need for networking. Technologies, such as Gallium Arsenide (GaAs), which underpin active phased arrays, are already sufficiently mature to incorporate into product. Emerging III-V semiconductor materials such as Gallium Nitride (GaN) will offer some performance benefits. However, the focus is likely to be on incremental improvement, such as affordability, rather then breakthrough technology.

Thus the key technology is likely to be systems engineering to realise a step change in capability by integrating multiple sensors with distributed processing to deliver operationally effective complex systems. A particularly interesting technology that may come of age is bi-static radar operation using emitters of opportunity. ■


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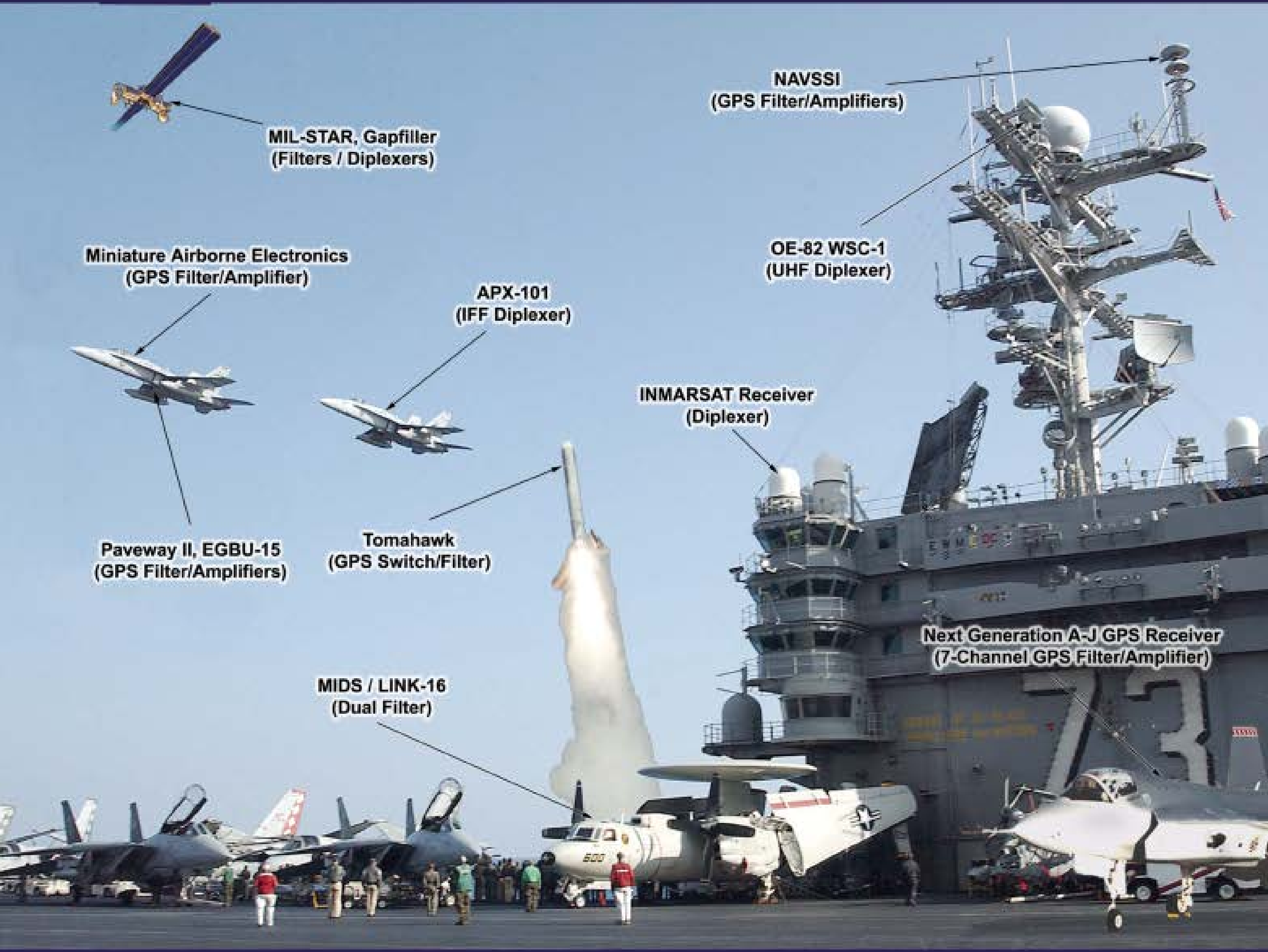
Name of the Roses

Russia's "joint" S-300 air defense system turned out to be nothing of the sort.

Michal Fiszer
Collegium Civitas, Warsaw, Poland

In the late 1960s, the highest authorities in the Soviet Union (read: the Politburo of the Communist Party) were concerned about the growing costs of armaments development programs. At that time, the Soviet Union undertook tremendous efforts to field a broad range of new weapons types, including new air defense systems, such as the S-200 Angara (SA-5), 2K11 Krug (SA-4), 2K12 Kub (SA-6), ZSU-23-4 Shilka and the 9M32 Strela-2 (SA-7). Simultaneously, there were efforts to improve deployed systems, such as the SA-75 Dvina (SA-2), S-75 Desna, S-75M Volkhov and the S-125/S-125M Neva (SA-3), which were then in mass production. Moreover, the Country Air Defense Forces (Voiska Protivovozdushnoi Oborony Strany, or PVO-Strany) issued a requirement for a new air defense system that would replace the two existing transportable systems it fielded: the S-75 and S-125. Both of these were so-called "single-channel" systems that could engage only one target at a time. The single-engagement capability was the price for being transportable, as opposed to fixed or semi-fixed systems, such as the S-25 (SA-1) and S-200 (SA-5), respectively. The new PVO-Strany system was to be transportable and have the ability to engage multiple targets. The transportability was to enable a change in fire positions, which would increase the system's survivability and combat effectiveness by countering an enemy's efforts to develop a carefully scripted suppression attack against it. In addition, the Soviet Army also desired a new medium- to long-range system with the ability to engage multiple targets that, by necessity, would also be mobile. The Soviet Navy also expressed some interest in such a system.

Upon hearing all of these requests and more (for example, a new infantry combat vehicle to replace the just developed BMP-1), the Politburo members became furious. The new Brezhnev administration generally supported strong military forces but, at the same time, it wanted to spend funds for military programs in a more rational way than the ill-fated Khrushchev's team had. Therefore, the Politburo started to seek ways of consolidating defense spending, although the effort was not even close to the extent that the US Secretary of Defense, Robert McNamara, tried in the United States during roughly the same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period. One seemingly obvious method (and one also pursued by McNamara) was to combine the similar requirements of different services into common programs to avoid what appeared to be duplications of efforts.

Thus, the Soviet Council of Ministers decided that fulfilling the requirements of all the services for new air defense systems would be just such a duplication of effort and, in December 1966, it directed the Voyenno-Promyslenny Komplex (VPK, the military-industrial complex) to organize the development of a single medium- to long-range mobile air defense system with the ability to engage multiple targets that would be common for three services: the Air Defense Forces (PVO-Strany, coded "P"), the Soviet Army (Sukhoputnoye Voiska, coded "S") and the Soviet Navy (Flot, coded "F").

THE FIRST CRACKS

This decision immediately sparked heated discussions among specialists from the military forces, industry, the Ministry of Defense and the Politburo. Most of the military and industry authorities strongly opposed a "joint" program. Only the Navy did not object vigorously, since it usually got versions of land systems anyway (there was only one pure naval air defense missile system ever developed in the Soviet Union: the M-11 Shtorm, or SA-N-3). The Army, however, was strongly against the idea. Army officers believed that a system developed for the Country Air Defense would first meet PVO-Strany's requirements, leaving the mobile forces with a cumbersome, heavy and complicated system. PVO-Strany was usually more powerful in the Soviet military hierarchy, and the Soviet Army was definitely sensitive about combining development efforts with this service. Army officers knew that they would not be able to change a decision that originated from the highest Communist Party authorities, so they started to sabotage the program in an effort to make it appear that separate systems were needed. (Their posture was somewhat similar to the US Navy's when it was forced to acquire the F-111B aircraft, a version of the US Air Force's F-111A fighter-bomber.) The Soviet Army wrote its requirements in such a way that PVO-Strany would not accept them. One of the primary features of the Army system was the ability to engage short- and medium-range ballistic missiles. The Army stated that it was absolutely essential to provide the land forces with effective protection against US Pershing 1A missiles with a range of 740 km. This requirement was set by Gen. Col. Pavel N. Kuleshov, then chief of Glavnoye Raketno-Artileriyske Upravleniye (GRAU, Main Missile-Artillery Directorate). Although desiring an anti-ballistic-missile (ABM) capability was rational, the firm statement that an ABM capability against medium-range missiles was absolutely essential immediately created a technological challenge. At the same time, it was clear that PVO-Strany would not demand any ABM capability, since its systems protected objects located well beyond the range of theater ballistic missile (TBM), and a strategic ABM capability was provided by a dedicated system deployed only around Moscow. (The Moscow ABM system, A-35 and A-135, requires a separate description and lies outside the scope of this article.) The other important requirement the Army laid down was the need for a lightly armored, tracked chassis. Again, it was obvious that tracked vehicles and light armor would be luxuries for PVO-Strany and that it would not want to pay for them. Both services, however, agreed that the range of the air defense system be at least 50 to 60 km (not less than the S-75M Volkhov or 2K11 Krug), that it have the ability to engage targets at altitudes from 25 to 25,000 m, that it have the capability to engage at least six targets at a time (to account for a four-ship formation in a single engagement sequence at a kill probability of 75 percent), and that the system also be able to engage small unmanned aerial vehicles (UAV) and cruise missiles flying at extremely low altitude at high subsonic speed. The Army also wanted the capability to engage hovering helicopters, but there was a willingness to be flexible on this point. As was expected, PVO-Strany wanted to downgrade the Army version: no ABM capability, no armor and a wheeled chassis (no cross-country mobility required).

In May 1969, the Central Committee of the Communist Party and the Council of Ministers, during a joint session, issued a decision regarding the development of a unified S-300 system. The document directed that a unified system, adapted to the needs of the three services, was to be developed cooperatively by the following organizations: MKB "Strela" would develop the S-300P version for PVO-Strany; VNII RE MSP would develop the S-300F version for the Navy; and NIEMI would develop the S-300V version for the Army. This decision was meaning-

ful. Theoretically, it demanded that all three versions be unified, but at the same time, separate organizations were responsible for their development, so the commonality was doubtful at best. Soviet authorities thought that a joint system would be developed. They were wrong.

The S-300P project for the air defense Forces was to be based on the earlier MKB "Strela" concept program. It was decided that the core of the system would consist of a dozen launchers that would carry single-stage solid-fuel missiles (SA-10 Grumble), a target-tracking and illumination radar, and a command post. The radar was to be based on modular solid-state electronics. The command post was to automatically control the radar and would be equipped with a digital computer. All of the system's electronics were to be digital and solid state. It is worth mentioning that the S-300F's core remained very similar, with the use of the same missile in a "navalized" form (5V55RM and later 48N6M — "M" for morskiy, or naval) and a similar radar with a slightly different, stabilized antenna, adapted for naval operations; some different radar electronics; and much different software.

As it might be expected, the Army version developed by NIEMI was based on the earlier S-500U conceptual model, and although called the S-300V, it did not develop into simply another version of the S-300 family. The S-300V became a very complicated and cumbersome system, with a few different types of complex radars, two types of missiles (SA-12a Gladiator and SA-12b Giant) and four types of launchers, all placed on tracked, lightly armored vehicles. The Army shot an "own goal" in setting such a wide range of challenging requirements. The resulting S-300V met all of these requirements as a system of impressive cost and complexity.

ROSE ONE: S-300P

During the development of the S-300P, it was assumed that the system would be fully automated, from the collection of information about a target to engagement. The system was divided into the fire unit: the fire-control radar, the battery command post, a dozen launchers and auxiliary equipment; and the command-and-control unit with an interface to the regiment's automated command-and-control system (the 5S99M Senezh). Rounding out the system was an acquisition radar (later it got two acquisition radars) and a battalion command post that controlled up to six fire batteries. Given that a battalion of S-300P (see ***Figure 1***) would be able to engage up to 36 targets a time, this represented a rather dramatic increase in capabilities over previous systems such as the S-75 and S-125, which had only a single fire battery in a battalion with the ability to engage just one target at a time.

The digital computer for the S-300P, called 5E26, was developed by the Moscow Institute for Precise Mechanics and Computing Technologies. The biggest problem in its development was a lack of software specialists, but MKB Strela solved the problem by undertaking cooperation with the Moscow Physical and Mathematical Institute (MFTI), drafting the best graduates and even students for

▲ *Fig. 1 The S-300P is among the world's foremost air defense systems. (Photo by Michal Fiszer)*


Global
response.

▲ *Fig. 2 The 5P85S main launcher of the S-300PS system. (Almaz photo)*

the effort. Such specialists were relatively rare in the early 1970s.

From the very beginning, it was assumed that the whole system would be mobile. But the main designer of the Minsk Automobile Factory (MAZ) in Belarus said that the chassis based on the MAZ-543 would not be ready within the timetable specified for the initial system production. Therefore, it was decided that the system would be built in two basic versions: S-300PT ("T" for transportiruyemiy, or transportable) and S-300PS ("S" for samokhodniy, or self-propelled).

The S-300P's 5N63S (Flap Lid A) fire-control radar was developed by MKB "Strela" and consists of the F20 chassis based on the MAZ-543M vehicle, the F1S module behind the truck's cabin that houses the 30N6 fire-control radar set with its phased array antenna, the F2K module with its 5E26 computer, communication equipment, the operators station and a 5S17 gas-turbine electrical power unit. The radar has a range of 250 km and can observe a 60° sector with the antenna fixed. The antenna can be quickly turned to change the observation sector towards any direction. The radar works at X-band, and its initial production version had 16,000 phased-array elements. The early radar can be recognized by the squarer shape of the antenna, which is wider than the later 30N6-1 version associated with the S-300PM. It could be easily recognized by the hydraulic telescopic servomotors that are attached to the bottom part of the antenna. In the S-300PM (Flap Lid B) version, the servomotors are attached to the sides of the antenna, which has a more rounded shape. The radar has the capability of electronic beam shaping and can engage up to six targets at a time with up to 12 missiles (two per target). The 5N63S and later 30N6-1 sets were produced by AOOT Moskovskiy Radiotekhnicheskiy Zavod (Moscow Radio-Technical Factory).

The 5N63S radar and battery command post with six launchers (two main and four auxiliary) formed a S-300PT battery, together with a crane and three 5T99 missile-transport vehicles. Technically, it was possible to associate as many as six main and six auxiliary launchers with a given fire-control radar, but this possibility was never pursued in front-line units. Three such batteries formed a battalion. Again, technically it was possible to attach six batteries to a battalion's command system, but this possibility also was not pursued in Soviet and Russian front-line units. The battalion command post was formed around the 83M6 command-and-control (C2) system, which consisted of the 54K6 C2 post and the 64N6 observation and target-acquisition radar. The latter was not developed on time, and early S-300PT and S-300PS (see ***Figure 2***) systems were issued with the "off-the-shelf" ST-68M (19Zh6; NATO: Tin Shield) radar. The radar was renamed 36D6 for the S-300PT/PS system. It works at S-band and has 3-D capability. It uses electronic scanning in elevation and mechanical scanning in azimuth. The detection range for a fighter-sized target is 147 to 175 km, flying between 2000 and 18000 m, 80 km for targets around 1000 m and 38 to 42 km against targets flying at 100 m. The radar could track up to 100 targets at a time. The ST-68M and 36D6 were accepted for service in 1981, together

▲ *Fig. 3 A 76N6 low altitude detection radar, an export version of the 5N66M. (Almaz photo)*


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with the first fielded S-300PT. It was developed and produced by Zaporozhskiy Kazenniy Electromashinostroitelniy Zavod "Iskra" from Zaporozhe, in Ukraine.

The other radar usually attached to the battalion's command post was initially the 5N66M (NATO: Clam Shell) radar for the detection of low flying targets (see ***Figure 3***). It was developed by KB "Lira" from Lianozovo (a part of NPO Uties from Moscow). The system was later produced by Lianozovo Electro-Mechanical Plant (LEMZ) in Lianozovo. This radar had a vertical parabolic antenna, similar to the antennas of altitude-finder radars. The range of the radar was 300 km, and it had the ability to detect targets flying at 100 m at a distance of 48 km. The antenna was placed on a special 24.4 m 40V6 mast.

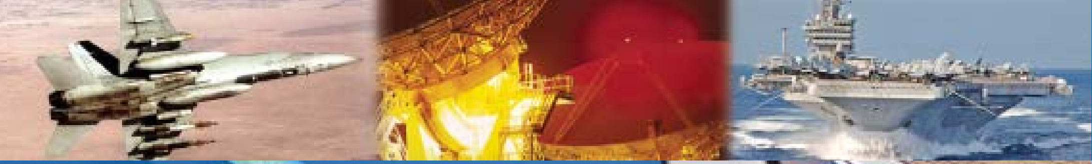
The 54K6 command system is a fully automated system, with the ability to track up to 100 targets in the vicinity of 500 km. The system controls the associated radars (initially, the 36D6 and 5N66M) and has interfaces to the Senezh (or Senezh-M) SAM brigade/regiment command system. The target tracks are a combination of the plots of targets detected by the battalion's organic radars and plots of targets tracked by the Senezh system, which are passed to 54K6 in real time. The latter system merges data from all sources into a single air-situation picture and sends information about targets tracked by the battalion's radar to the Senezh. Interestingly, the tracking data can be originated by passive detection systems and then fed through an automated C2 system to the 54K6 and further down to the S-300P batteries. With later systems (S-300PM/S-300PMU-1/2/S-400) (see ***Figure 4***), it is possible to launch a missile against a target tracked by passive systems with all the battalion's radars silent, just turning on the 30N6-1 radar for the final part of the engagement, a few seconds before a hit. Such a test with the use of Kolchuga-M stations (it is not known, however, whether it was Ukrainian Kolchuga-M or the much less known Russian Kolchuga-M) was conducted at the Sary-Shagan shooting range in September 2003.

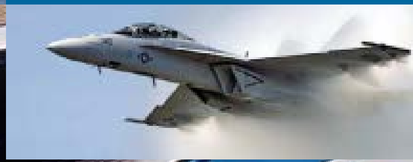
Despite being accepted into service, the S-300PT and PS did not meet the main requirement for a 140 km range. Therefore, in January 1983 Soviet authorities mandated that a new upgraded system called the S-300PM would be developed. Work started immediately, and soon the new upgraded 30N6-1 radar (see ***Figure 5***) was developed. It had a range of 300 km and could work in several modes: sector observation of 64° horizontally and 14° vertically (range: 160–240 km) as its primary mode, sector observation of 64° by 5° for long-range search (maximum range: 300 km), and 90° in azimuth and 1° in elevation for low level search (range of around 80–130 km below 1000 m of target altitude). The 30N6-1 radar received a new, narrower, rounder antenna (recognizable by a side attachment of hydraulic servo-mechanisms for antenna deployment and folding). The radar received the new 40U6 digital computer developed by the Moscow Institute for Precise Mechanics and Computing Technologies. The new digital computer enabled the introduction of new powerful software, which greatly increased the jamming resistance of the system. The modernized S-300PM system also received the 64N6 (NATO: Big Bird) observation radar and 5N66M (NATO: Clam Shell) low level observation radar (known better under its export designation of 76N6) and the new 48N6 missile.

The 64N6 observation radar was intended for the S-300P from the very beginning, but its prolonged development time forced the use of the 36D6 as a temporary solution. The 76N6 was a further developed version of the 5N66M used in earlier systems. The 64N6 radar was developed by Novosibirskiy NII Izmeritelnikh Priborov (Novosibirsk Research and Development Institute of Measurement Instruments) in Novosibirsk, which is presently also a part of the "Almaz" consortium. Production of the radar got underway at Novosibirskiy Zavod Imieni Kominterna (Novosibirsk Factory of Komintern) approximately in 1985. The radar has a large, double-sided, phased-array antenna and can work in a 360° observation mode (with revolutions) or in sector mode, observing a 75° sector. In elevation, the observation sector is 13.4° in detection mode and 55° when the target is tracked. The radar's range is 260 km against fighter-sized targets at medium altitude. The radar can track up to 200 targets at a time, with an accuracy of 30° in azimuth, 35° in elevation and 200 m in distance. In the closer zone of observation (out to 64 km), the radar is protected against jamming by frequent power-output adjustment. At greater ranges, it uses a special algorithm that stabilizes false signal levels. In addition, the radar employs frequency hopping and electronic beam shaping. It has been assessed that its jamming resistance is relatively high.

▲ *Fig. 4 A S-300PMU battery in launch position. (Photo by Miroslav Gyurosi)*

▲ *Fig. 5 A 30N6-1 (NATO: Flap Lid) fire-control radar for the S-300 system. (Rosoboron export photo)*





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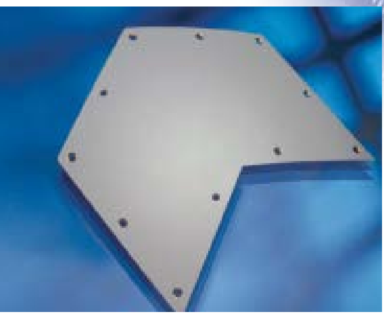

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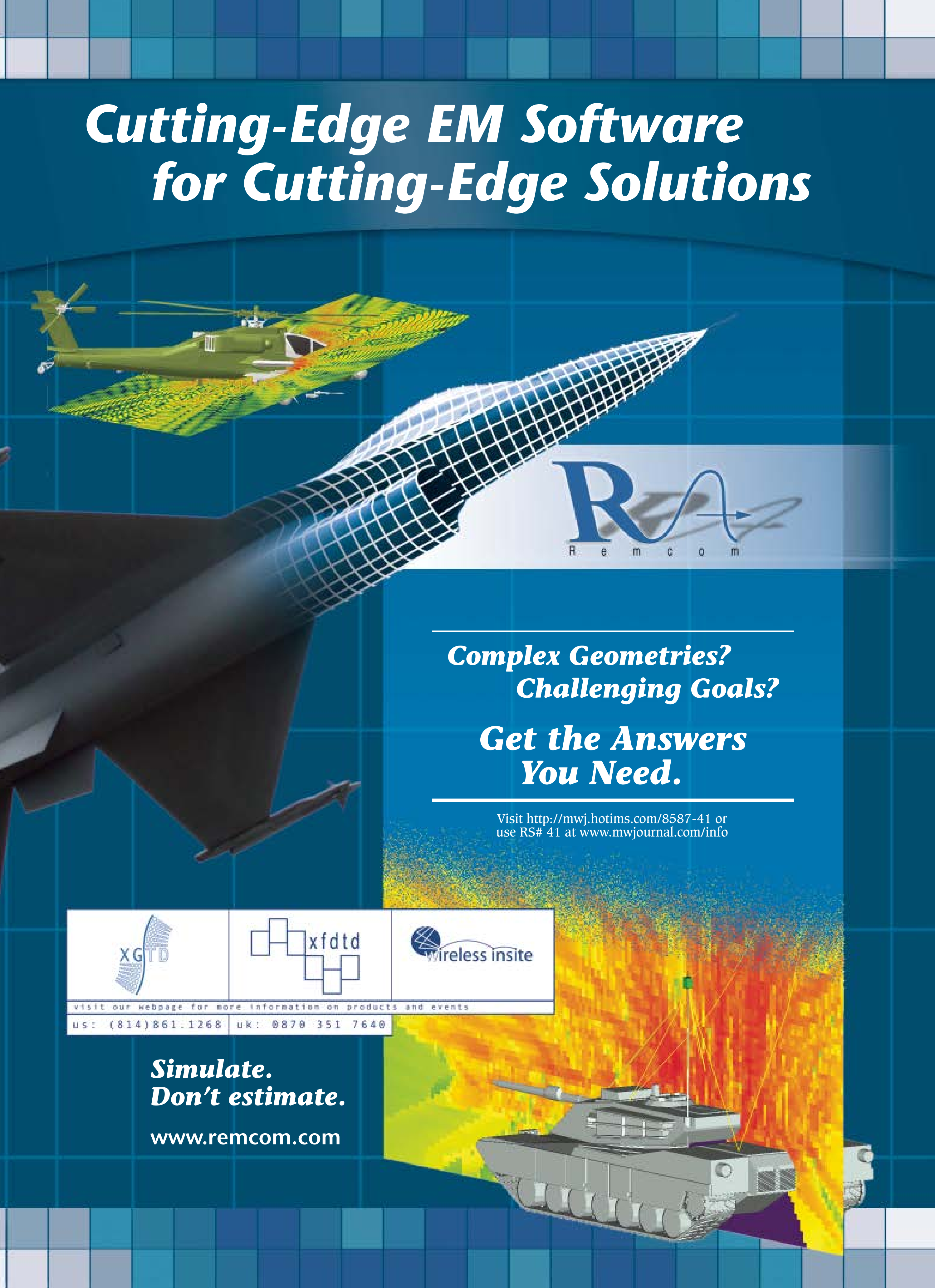

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The 5N66M radar, developed by KB "Lira" in Lianozovohas, has an antenna similar to its 5N66 predecessor. This is one of the most mysterious radars in the S-300P system, and not many of its technical parameters are known. The radar has a range of 300 km, and the antenna rotates very quickly — 20 revolutions per minute. The antenna is usually placed on the improved 39 m 40V6M mast, but doing so takes two hours.

The key for achieving the 150 km range was to develop a new missile with better energy characteristics, and such a missile — the 48N6 — was developed by MKB Fakel. The 48N6 missile is slightly bigger to accommodate a larger rocket engine. The missile's length was increased to 7.5 m and the diameter to 519 mm. The missile's weight was increased to 1850 kg, including a 143 kg warhead (slightly heavier than in previous missiles). The 48N6 missile's rocket engine burns for about 12 seconds, which enables the missile to reach a maximum speed of 2000 m/sec. The missile has a track-via-missile guidance mode and can maneuver at up to 20 G. The maximum range of the missile was increased to 150 km, and the minimum engagement altitude was lowered from 25 m to just 10 m. The maximum engagement altitude is probably around 30,000 m.

The first elements of the S-300PM system were tested at the shooting range in 1984. Factory trials ended in mid-1987, and the system was submitted to state trials, which were conducted in 1988. The S-300PM system was accepted into service in the autumn of that year.

ROSE TWO (AND THREE): S-300V

The S-300V system has four types of launchers and two types of missiles. The 9M82 (SA-12b Giant) missile is primarily designed to engage TBMs, although it has an anti-aircraft capability), while the 9M83 (SA-12a Gladiator) is designed to engage short-range TBMs and highly maneuvering aircraft. Both missiles can maneuver at up to 20 G.

A S-300V brigade typically consists of three battalions, the basic fire unit. A battalion consists of a headquarters company and four launch batteries. The headquarters has a 9S457 command post (CP) and two radar sets: a 9S15M Obzor-3 (Bill Board) and a 9S19M2 (High Screen). Each of the launch batteries consists of a 9S32 (Grill Pan) fire-control radar station; two 9A82 transporter-erector-launcher and radar (TELAR) vehicles for anti-TBM-capable 9M82 missiles (two missiles per launcher); one 9A84 reload/transporter-erector-launcher (TEL) vehicle for 9M82 missiles; four 9A83 TELARs for 9M83 missiles (four missiles per launcher); and two 9A85 reload/TELs for 9M83 missiles. All of the aforementioned equipment is fully mobile, mounted on a tracked chassis. The 9A82 and 9A83 launchers have an illumination radar for semi-active radar missile guidance. The

9A84 and 9A85 reloader/TELs have cranes to reload the other missiles on the TELARs as their primary function, but they could be also used as launchers in an emergency.

The mobile 9S457 CP receives information from the 9S15M and 9S19M2 radar sets, and from external sources via the Polyana-D4 C3 I system. The 9S457 command post is able to process information on approximately 200 targets and continuously track 70 of them. It can issue information on 24 targets to the batteries (six targets per battery). The command post also processes information uploaded from batteries about targets detected by their sensors, as well as combat and logistics status information, which is passed upwards to the brigade command center.

The 9S15M Obzor-3 is a 3-D phased-array radar, providing all-around surveillance, warning and target acquisition. It has three main modes of operation: long-range, 360° (12-second antenna rotation) surveillance; medium-range, 360° (six-second antenna rotation) surveillance; and anti-TBM surveillance in a 120° sector (four-seconds full-sector scan). In the first mode, the radar has a range of 330 km (large target) or 240 km (fighter or TBM), and it works with a 40° scan in elevation. In the second mode, the radar has a 150 km range (all targets), with 20° scan in elevation. In the third mode, the radar employs a 55° elevation scan, and the TBM-detection probability is greatly increased. It can detect a Scud-type TBM at 115 km and a Lance-type TBM at 95 km. The radar scans electro-mechanically in azimuth and electronically in elevation. It can track up to 200 targets.

The 9S19M2 Imbir radar set is designed for sector scan, with its main function being TBM warning. It has a fully phased-array antenna with an electronically scanned sector of ±45° in azimuth and +26° to +75° in elevation. The range is from 75 to 175 km (depending on TBM type). It is able to track up to 16 TBMs at a time. When tracking two or more TBMs simultaneously, the radar employs track-while-scan, with the whole sector scanned in 12.5 to 14 seconds. When small targets like SRAM missiles are to be tracked, the radar scans a sector of ±30° in azimuth and +9° to +50° in elevation. The range is up to 175 km, although ranges for a SRAM or similar missiles are much shorter. In a third mode, the radar searches for air-breathing targets in a sector ±30° in azimuth and 0° to +50° in elevation to a range of up to 150 km.

The 9S32 radar set in each launch battery can work together with the battalion command post or autonomously. It has a phased array, electronically scanned antenna in both azimuth and elevation. The observation sector is 5° in azimuth and 6° in elevation when working with the battalion command post, or ±30° in azimuth and 0° to 18° in elevation in autonomous mode. It can automatically track up to 12 targets and provide information on approximately six of them to all six launchers. It could also radio-command 12 missiles toward six targets at a time, out to the point when they reach illumination signals from the TELARs' radars, thus allowing lock-on after launch mode.

CONCLUSION

In practice, the joint concept of a multi-service S-300 air defense system was a complete failure, and both systems ended up having only one thing in common: the S-300 designation. This is not to say that the individual projects did not succeed on their own. However, a lot of wasted time, talent, resources and money were spent pursuing a dead-end joint system. Although some commonality of parts was achieved (well below 50 percent), the SA-10 (S-300P) and SA-12 (S-300V) were totally different systems, the former optimized for engaging cruise missile and low radar-cross-section targets, while the latter was optimized to engage TBMs. The S-300V was from the very beginning a self-propelled system on a tracked chassis, while the S-300P was developed as a re-deployable towed system on a wheeled chassis. Finally, in 1986, both programs were again separated and everything came back to the pre-1980 status. Only one serious development came out of the ill-fated merger: the S-300P adopted the semi-active guidance method developed from the outset for the S-300V. This was further developed into the track-via-missile (TVM) method. Although TVM was designed in the Soviet Union separately from the TVM capability of the US Patriot system, the general idea was copied. ■

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Metric Radars Win Reprieve in Hungary

Zord Gabor Laszlo

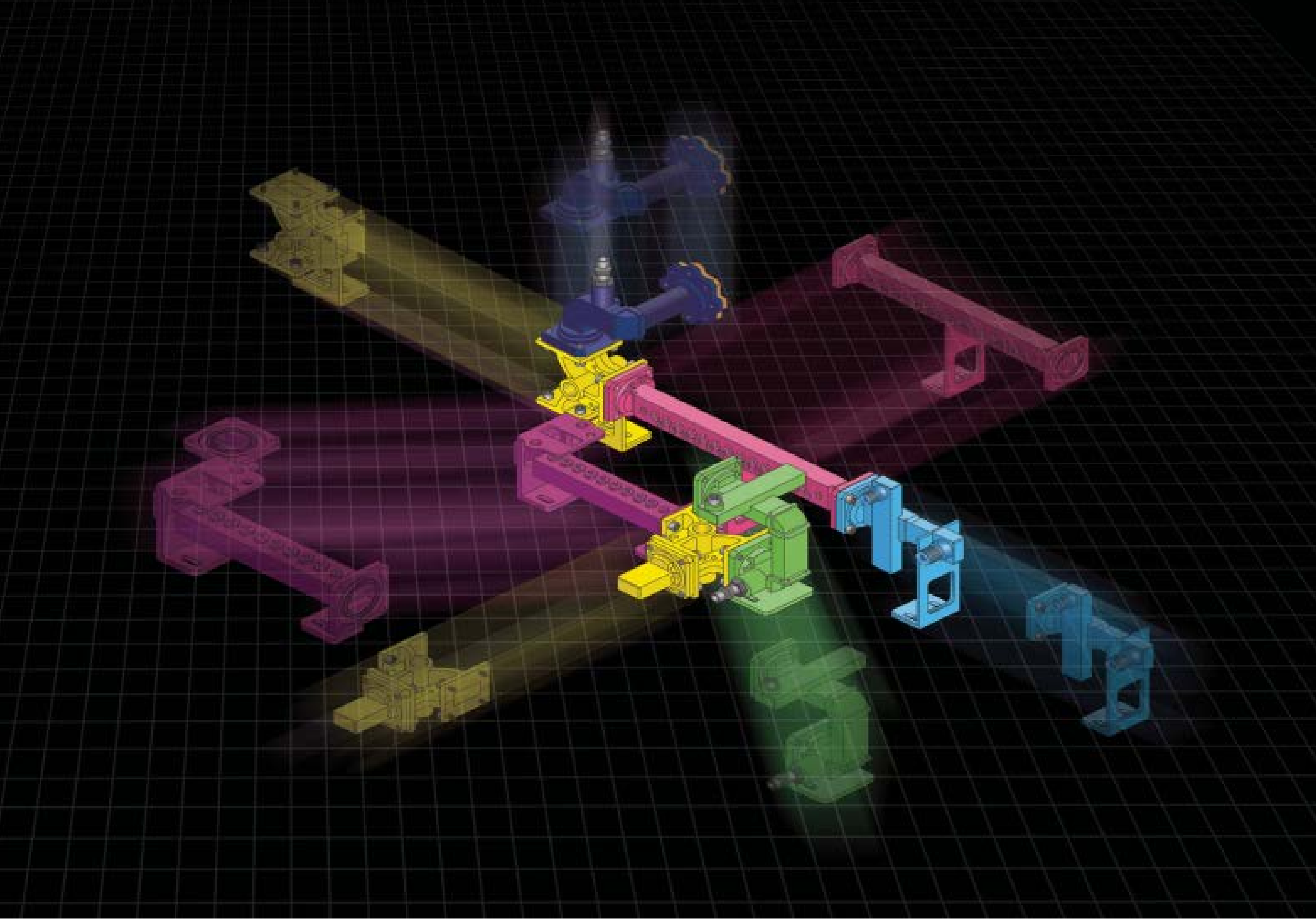
Decades ago, western defense industry contractors and armed forces downplayed the usefulness of meter-wavelength radars of Soviet/Russian origin, but they are still going strong in several countries around the globe. Although a member of NATO for nearly seven years now, Hungary not only still operates such radars, but also modernizes them with the clear aim of developing an indigenous design and using VHF frequencies for prospective bi- and multi-static systems (see ***Figure 1***).

Radar units of the former Warsaw Pact (WP) armed forces usually employed an array of radars operating in bands covering meter, decimeter and centimeter wavelengths. In addition to technological and manufacturing reasons (lower frequency radars were generally cheaper), the Soviet-model air defense systems retained this diversity to present a huge challenge for NATO electronic-warfare planners. The often-overlooked factor in maintaining this diversity, however, was the fact that different operating bands offered an opportunity to utilize the best properties associated with each of them. Being "high end" metric radars, the semi-fixed P-14 and the deployable Oborona (NATO: Tall King A and C), with their high gain parabolic antennas, acted as very long-range surveillance sensors for the contemporary integrated air defense system (IADS) at selected sites. They also served as target-acquisition radars for the S-200 (NATO: SA-5 Gammon) extra long-range surface-to-air missile (SAM) system. At the same time, much simpler and cheaper P-12 and P-18 radars (NATO: Spoon Rest), with their multiple Yagi arrays (see ***Figure 2***), were employed by all radar posts as their metric component, and SAM batteries (such as SA-3 and SA-2) used them as an embedded target-acquisition sensor (see ***Figure 3***).

Fig. 1 Hungary's modernized P-18 metric radars reappeared from the upgrade process. ▼

While not a well-known fact, these two classes of metric radars were also combined in a special project throughout the WP, unofficially known as the "P-13." Each country's radar engineers matched some of their P-12 equipment with the huge array of the P-14 to increase detection performance. Actual technical realization varied, but the Hungarian way of coupling the backend with the antennae earned respect as the most efficient solution.

Under the Soviet system, the role of metric radars proved to be enduring, but their importance was elevated by the developments in Western threat technologies beginning in the 1970s. Faced with the emergence of small targets like cruise missiles or targets with low



▲ *Fig. 2 Yagi antennas of the P-18 Spoon Rest.*

observable technologies — generally, targets with small radar cross-sections (RCS) — metric radars became clearly irreplaceable, as higher frequency radars could not handle such targets with sufficient efficiency. At the same time, it also became evident that these radars could not be targeted by anti-radar missiles (ARM), as those weapons do not have enough space to house a homing antenna big enough to fulfill their mission against radars operating at this wavelength. With the dissolution of the Warsaw Pact, this threat perception disappeared — at least in the Central and Eastern European countries that had just become independent from the Soviet Union. Along with joining Western institutions like NATO, large-scale downsizing of the armed forces was on the agenda. Radar communities focused on establishing new, much smaller structures offering a minimum of coverage to support peacetime air sovereignty. This general trend, however, was abated — at least for a short period — in Hungary, which had a serious security problem on its borders: the violent disintegration of Yugoslavia beginning in 1991. The experience of that conflict for the Hungarian Defense Forces (HDF) showed a continuing need for the detection of low level targets by easily deployable, simple, "wartime" gap-fillers.

Reflecting the philosophy of "frequency diversity," temporary radar posts deployed along the southern

▲ *Fig. 3 A Hungarian P-18 radar deployed in the field, supporting a Kub SAM unit.*

border of the country consisted of centimetric (ST-68U Tin Shield), decimetric (P-15 Flat Face and Kasta-2) and metric (P-18) radars, as well as PRV-16 (Thin Skin) altitude finders. Being the cheapest elements, both the P-18 and the P-15 were available to the HDF in rather large numbers for such tasks. However, while the metric radar survived the downsizing, the post-Cold War service of decimeter-band equipment was cut short by unexpected external developments. In addition to being described as "simply archaic" by 1990s-era operators, the fate of the P-15 Dzhigit was finally sealed by the increasing commercial utilization of the UHF band (300 MHz to 1 GHz), mostly for communications purposes. The lobbying power of the HDF in frequency allocation was not even enough to keep its brand-new successor, the pulse-compression Kasta-2 system, in service. In contrast, the P-18 earned a new lease of life, though it had and still has to fight similar threats to its existence. From the viewpoint of the HDF, relatively low operating costs and growth potential made it a perfect piece of equipment in the cost-cutting post-Cold War environment. "Human factors" also played a part in the continuation of Hungarian metric-radar operations, as several officers remained in charge whose thinking was influenced by the philosophy of "frequency diversity." While the wavelength question was being addressed, it was also decided that metric radars had to undergo modifications reflecting contemporary technology levels and the current Hungarian (that is NATO IADS) operational requirements — much like other legacy radars, such as the centimetric P-37 (Bar Lock). Before increasing actual radar perfor-

mance, however, priority was given to ensure radar-data compatibility with new command-and-control nodes, like the US-financed Air Sovereignty Operations Center (ASOC), which require certain digital input formats. For this task, special interfaces were developed that basically transformed the analog output of these radars into digital data, as required. After initial interfacing was achieved, concepts were developed to improve the biggest deficiencies in the radars themselves, such as high manpower requirements, low mean times between failures (MTBF) and unsophisticated signal processing. Though initial research and prioritization of tasks were conducted by the Ministry of Defense (MoD) Technology Agency, the actual modernization program for the P-18 started in 2000 at Arzenal stock company, a specialized defense firm located in Nyirtelek, in eastern Hungary.

While the modernization effort has not altered the transmitter, an integrated solid-state unit has replaced the entire receiver and signal-processing system. Being software-controlled, this unit has taken over the role of several original hardware units, which could then be taken out of the cabin, making it more spacious and comfortable (see ***Figure 4***). The use of new components and the decrease in the number of parts, in turn, improved the MTBF and shortened the time required to set up and test the equipment. Also worth noting is the VHF correction algorithm embedded in the tracker, which compensates for the signal-fragmentation phenomena characteristic of metric radars. In addition to the integrated PC-based control and display unit in the cabin, there is also a remote control and display unit that can be deployed away from the radar, connected via a single coaxial cable. The new receiver and signal-processing system also permits the supply of data in the required format to the ASOC and other currently operational command-and-control systems, as well as NATO's future Air Command and Control System (ACCS). Arzenal handed over the first modernized P-18 to the Hungarian Air Force in 2002, and additional upgraded systems have since been delivered to the 54th Airspace Control Wing and the 12th SAM battalion. With the arrival, beginning in 2006, of the new NATO-financed Selex (Alenia Marconi) RAT-31D long-range surveillance radars, the main task of the modernized P-18s will be to fill the gaps left in their coverage according to actual needs or as dictated by the threat situation. With the SAM unit, they will act as embedded target-acquisition sensors, sending data to modernized K-1P mobile command posts, which in turn cue the Kub and Mistral missile systems. Again, frequency diversity has prevailed, as the modernized P-18s are paired with modernized centimetric ST-68U radars.

While modernization efforts seems to have paid off already, the Technology Agency and a small private electronics firm went further by developing an indigenous radar — the first for Hungary since 1945. Although Budapest-based Sagax Ltd. had been mostly engaged in the development and manufacturing of radio-interception and direction-finding equipment, the company realized how useful its experience with software-radio technology could be in radar development. Designated the SRV-P-18, the 200 W model and the 3 kW prototype of the new radar utilizes the existing antenna mechanics of the P-18 but otherwise is an entirely new design. Using a sub-pulse modulated transmitter and a matched-filter pulse-compression receiver, it promises to overcome several limitations inherent in conventional VHF radars, while code-modulated pulses and random frequency-hopping modes are improving the system's resistance to electronic countermeasures (ECM). Engineers and university students involved in the program introduced their wholly commercial, off-the-shelf-based model to insiders last January,

▲ *Fig. 4 Redundant equipment from the original P-18 following the modernization.*

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▲ *Fig. 5 The 85 kg black box of the new Hungarian VHF radar.*

and several tests have since taken place at different locations in the country. Being a 60 × 60 × 50 cm, 85 kg "box," the new equipment can be transported easily by car (see ***Figure 5***). In addition to using the P-18 antennas, the HDF also allowed testing of the new system coupled to the only available high gain Oborona array that is still operational at one of Hungary's radar sites. In the future, a new antenna design allowing for monopulse measurement is likely to be developed to solve current azimuth-accuracy and resolution shortfalls.

Though results of the testing are encouraging — and even the NATO Research and Technology Organization has relayed good feedback to the developers — the modernization project does not currently have a dedicated funding from the Hungarian MoD. Ongoing work is being financed by the Technology Agency, Sagax, and by some general centralized research and development (R&D) funds. To date, total investment has not exceeded, as one developer put it, "a couple of million Hungarian Florints" — under $10,000. In parallel, the Technology Agency has a project for the development of bi- and multi-static radar systems that would use VHF radars as well. After drawing up the concept, evaluation will start in 2006. Again, researchers decided to use two trusty P-18s: one as a transmitter and the other as a receiver. A new synchronization unit controls the sector sweeps and the triggering of the radars based on highly accurate Global Positioning System relative-position data and timing. In the current phase, the project managers plan to use unmodified P-18s to confirm the overall feasibility of the concept, but in the longer term the new metric radar could be used — or at least the developers hope so. This would make it easier to connect these sensors into a highly efficient and redundant, multi-static network.

Whether these R&D efforts will ever come to fruition is an open question, as Hungarian defense spending was cut by a third in 2004 and the country ranks last among NATO countries in terms of percentage of gross domestic product spent on armed forces. The other big question is whether the Hungarian radar community has enough lobbying power to ensure VHF frequency allocation beyond 2008, when the currently valid license to radiate in the metric band will expire. ■

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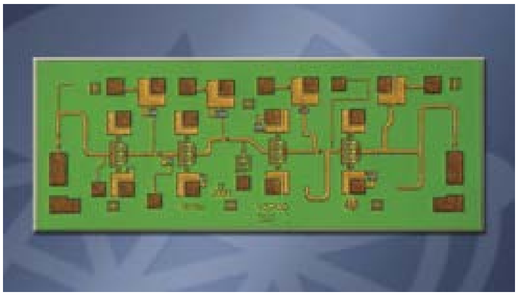
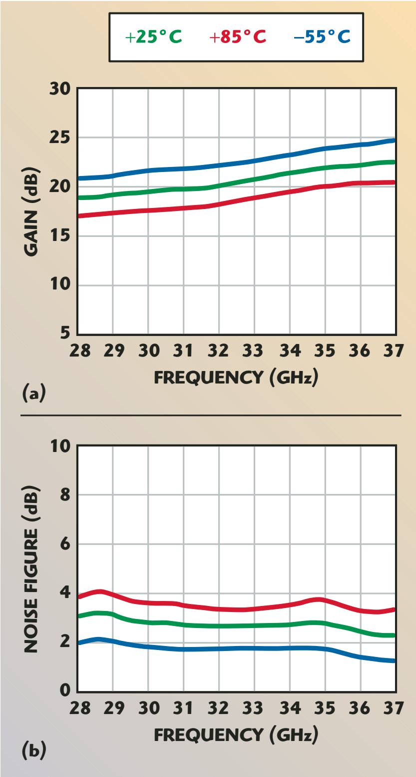


Hittite Microwave Corp.
Chelmsford, MA

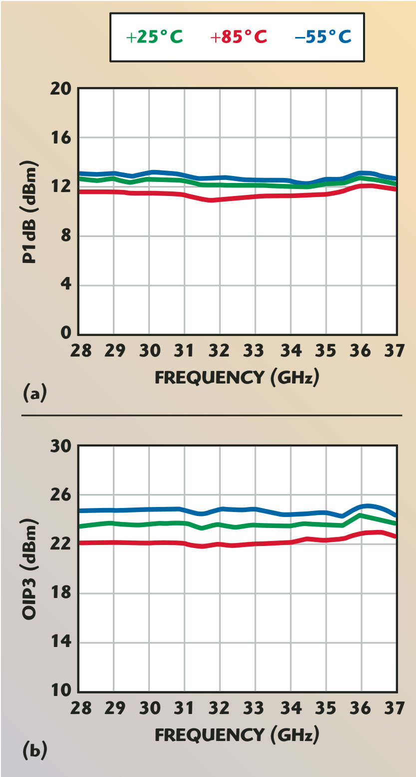
Over the past two decades, the military market has widely embraced the use of monolithic microwave integrated circuits (MMIC). The MMIC Program of the mid-1980s brought about significant advances in the design, manufacture and test capability of GaAs MMIC components. The advantages of using MMICs over their MIC/discrete hybrid counterparts include lower total cost, easier assembly and more consistent performance, and the impact of these advantages increases with the frequency of operation. Components used in today's military systems must exhibit very high performance, and be robust enough to operate in harsh land-, sea- and air-based environments. While a discrete solution generally provides the fewest sacrifices in electrical performance, achieving consistent results in volume production at Ka-band, without the use of MMICs, can be challenging.

While MMIC components and subsystems find use across the microwave and millimeter-wave spectrum, the Ka-band, and in particular the 29 to 36 GHz band, is home to many important applications for MMIC components. A relative null in the RF absorption of the atmosphere near the middle of this band drives the use of many military electronic warfare (EW) applications including radar, missile seekers and target acquisition. This same feature is also useful for other applications such as military/satellite communications, radio astronomy, radio navigation and of course the terrestrial point-to-point microwave radio band from 31.8 to 33.4 GHz. While it can be less expensive to build communications systems at lower frequencies, the shorter wavelengths associated with the millimeter-wave bands offers several system level advantages, including smaller antennas for a given beam width and more accurate target acquisition capabilities.

In order to address these applications specifically, Hittite Microwave has released the HMC566 GaAs pHEMT (pseudomorphic high electron mobility transistor) MMIC low noise amplifier (LNA). The HMC566 is a wide band LNA chip that is specified from 29 to 36 GHz.



▲ *Fig. 1 The HMC566 GaAs MMIC pHEMT LNA's (a) gain and (b) noise figure versus temperature.*



▲ *Fig. 2 The HMC566 LNA's (a) output P1dB and (b) output IP3 versus temperature.*

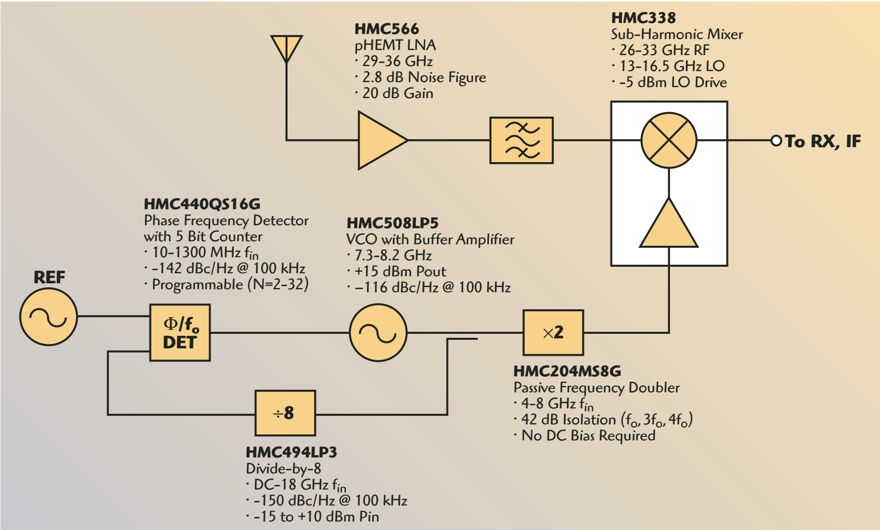
The device employs a four-stage single-ended topology where the first two input stages of the amplifier are optimized for lowest noise figure, while the output stage is matched to provide broad, flat output P1dB and output IP3 characteristics. Each of the four stages is independently self-biased. Bond pads for all drain bias lines (V_{dd1}, V_{dd2}, V_{dd3} and V_{dd4}) are presented on one side of the chip, and only a few bias decoupling capacitors are required to achieve unconditional stability. The HMC566 also features on-chip DC blocks on the RF input and output, and the amplifier is suitable for either epoxy or eutectic die attach.

The HMC566 LNA provides 20 dB of small-signal gain and 2.8 dB of noise figure at mid-band (see ***Figure 1***). The LNA also provides a positive gain slope across the operating band, which will be especially welcome in subsystem applications where the amplifier is operated over a wider band. This feature serves to counteract the inherent insertion loss roll-off versus frequency exhibited by microwave and millimeter-wave printed circuit substrates and interconnects. The small-signal gain level is generally monotonic versus temperature allowing for straightforward temperature compensation if required at the system level. The noise figure performance of the HMC566 is well behaved and generally increases by 1 dB or less from +25° to +85°C.

Another significant feature of the HMC566 amplifier is its single voltage supply operation. The device is self-biased and operates from a single +3 V supply, consuming only 60 mA. The linearity of this LNA is very consistent across its rated band, with output P1dB and the output IP3 performance of +12 and +24 dBm, respectively (see ***Figure 2***). Such performance enables the HMC566 to be used in various applications, including low noise, LO buffer and transmit gain block applications. Since the typical P1dB and IP3 values vary by less than 3 dB from –55° to +85°C, the designer does not have to overdesign the linearity of the RF chain, potentially driving up DC power consumption, in order to meet system level specifications at the operating temperature extremes.

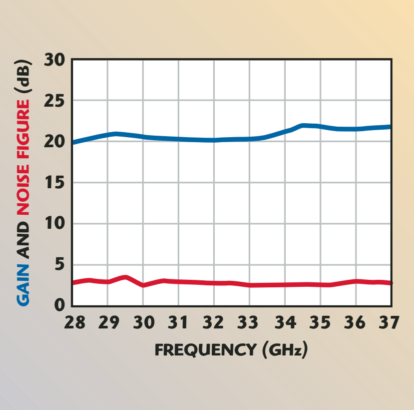
The HMC566 LNA is ideal for hybrid and multi-chip module (MCM) assembly applications due to its compact size, convenient layout and flexible mounting options. It is fabricated in a mature GaAs pHEMT process. This volume production fabrication process has been qualified by Hittite for use in various military and space programs.

Whether discrete or MMIC, the GaAs pHEMT device is the workhorse of the low noise receiver chain. Transceiver designers know that millimeter-wave LNAs fabricated in a sub-micron geometry GaAs pHEMT process can deliver low noise figure, high gain and high efficiency. The simplified block diagram, shown in ***Figure 3***, is an example of how the HMC566 GaAs pHEMT MMIC LNA may be combined with other Hittite components to construct a Ka-band receiver and LO generation chain.

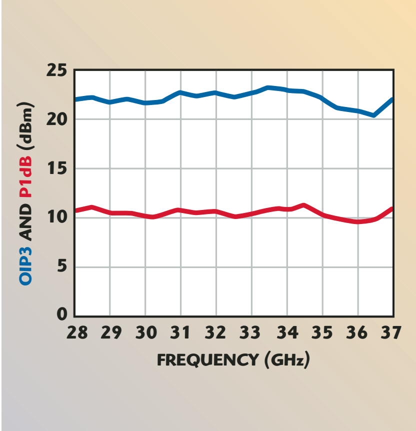


▲ *Fig. 3 Simplified block diagram of a Ka-band receiver and LO generation chain.*

▲ *Fig. 4 The HMC-C027 29 to 36 GHz LNA module.*



▲ *Fig. 5 The HMC-C027 pHEMT LNA module's gain and noise figure versus frequency.*



▲ *Fig. 6 The HMC-C027 LNA module's output P1dB and output IP3 vs. frequency.*

The company offers an extensive line of VCOs, mixers, dividers, multipliers and amplifiers, which are suitable for applications in this frequency range. This entire block diagram can be constructed without a negative voltage supply since all of these components are either passive, or operate from +3 or +5 V.

The HMC566 GaAs pHEMT MMIC LNA die and each of the products shown in the block diagram are available from stock and can be ordered via the company's e-commerce site or via direct purchase order. Released data sheets and S-parameter data are available on-line at www.hittite.com. The HMC566 GaAs pHEMT MMIC LNA will also be available in a RoHS-compliant, 4x4 mm surface-mount compatible package in late 2006.

The HMC-C027, shown in ***Figure 4***, is a 29 to 36 GHz low noise amplifier module and is intended for applications where a hermetic packaged module format is required. The HMC-C027 module incorporates the HMC566 and additional features not found in the die version, such as bias decoupling, over-voltage and ESD protection circuitry for added robustness. The hermetic module package also features field-replaceable 2.92 mm connectors, which are essential in test equipment and laboratory settings where numerous connector mating and unmating cycles may be required.

The small-signal and noise figure performance of the HMC-C027 is similar to the bare die version. ***Figure 5*** shows the small-signal gain and noise figure performance of the HMC-C027 versus frequency. As in the die version, the HMC-C027 exhibits a slightly positive gain slope, and a low, flat noise figure. As shown in ***Figure 6***, the linearity performance of the HMC-C027 is only slightly lower than the die version, exhibiting output P1dB and IP3 values of +10 and +22 dBm, respectively.

The HMC-C027 is unconditionally stable, and is rated for operation from –55° to +85°C. As with Hittite's other module products, the HMC-C027 is available from stock and can be assembled and screened for military and space applications. Released data sheets and S-parameter data are available on-line. ■

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www.hittite.com.

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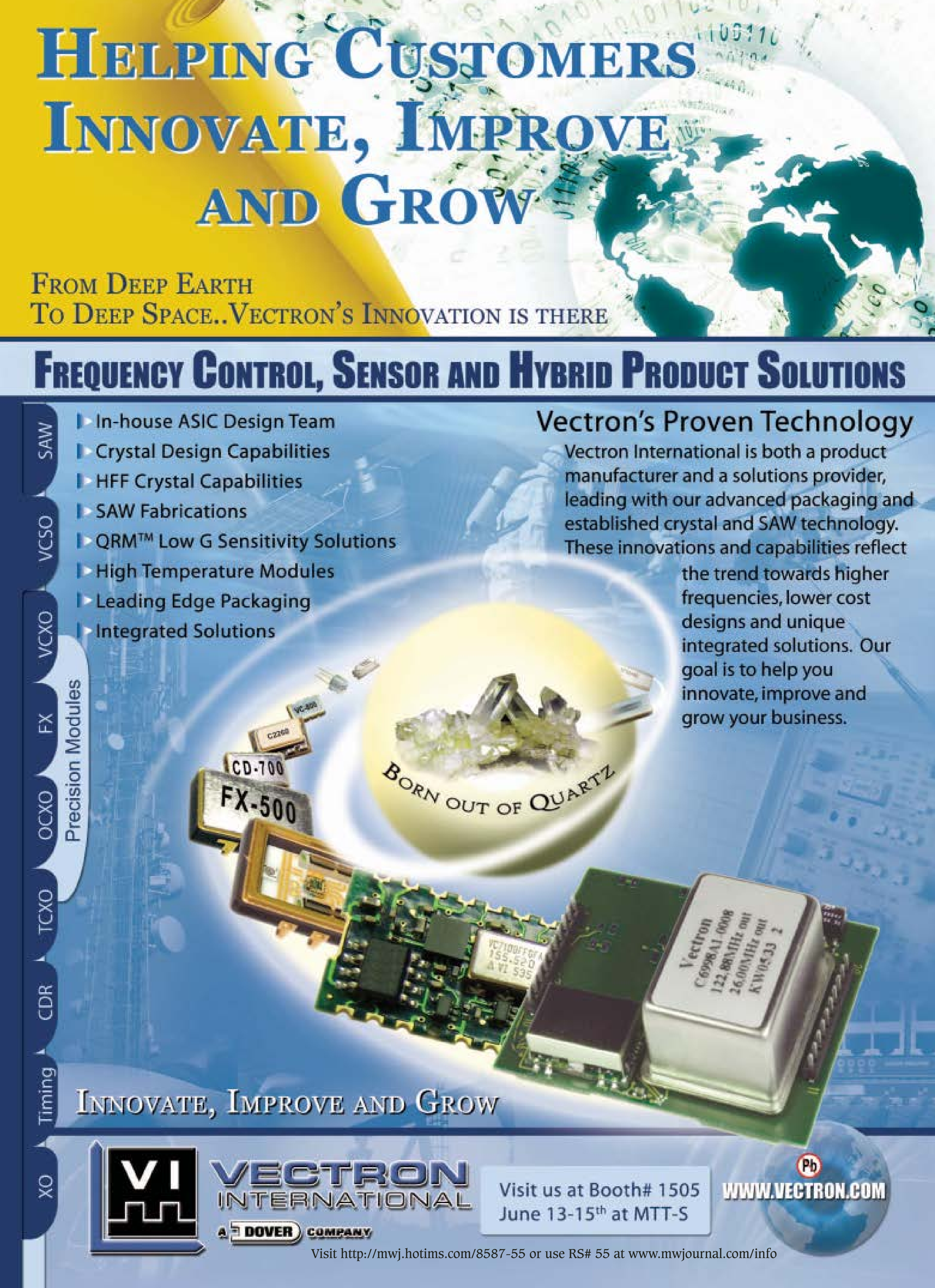
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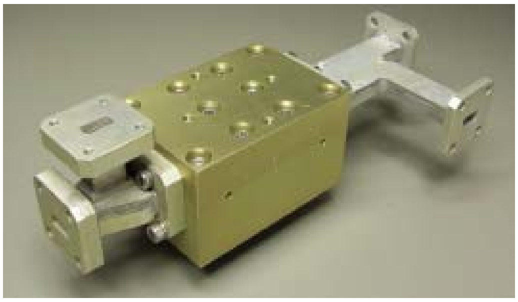
Ka-band Waveguide Ferrite Switches and Switch Matrices

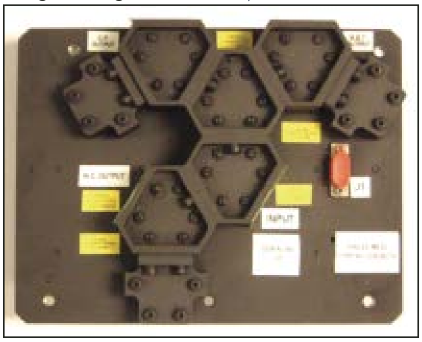


THALES MESL
Edinburgh, Scotland

The defence market has particular requirements for highly reliable, fast switching, high power handling switches and switch matrices in Ka-band. This is the sector targeted by Thales MESL when extending its portfolio of microwave switch products by developing Ka-band waveguide ferrite switches and switch matrices for short range air/sea defence systems. These switches use toroidal phase shifter technology to provide high power handling and fast switching as well as incorporating additional features, such as power splitting and selectable output polarization.

Typical applications are in fire control radar systems, as these radars, linked into command centres, can have multiple antennas for identification, tracking and ordinance uplinks. Therefore, using a switching network allows the radar designer to use one power source for multiple applications within the radar. A second common application at this frequency is for secure communications. In this application the switching networks can be used with the reverse function to that used for fire control radars — rather than one power source being switched between multiple antennas, several power sources can be switched to one output.

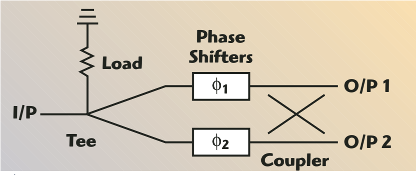
Fig. 1 SP3T switch matrix using latching circulators.



BACKGROUND

In order to get an insight into the development of the new products first consider that ferrite switches fill the gap between PIN diode switches (low power handling, fast switching speed) and rotary switches (high power handling, slow switching speed). Thales MESL produces two types of latching ferrite switches in WR28 waveguide: the switching junction circulator and the toroidal ferrite switch. The switching junction circulator is similar to the classic waveguide circulator that uses a ferrite resonator between permanent magnets.

In the switching circulator, the ferrite is magnetised by a current pulse fed through a wire threading the resonator, allowing the direction of circulation to be reversed. Without active cooling, this type of switch is limited to tens of watts of average power due to heat dissipation within the small ferrite resonator. ***Figure 1*** shows a matrix that is constructed



▲ *Fig. 2 Toroidal SP2T switch schematic.*

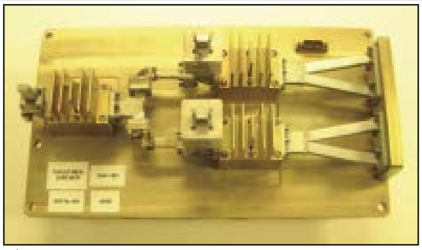
TABLE I EXAMPLE SPECIFICATION FOR A KA-BAND SWITCH	
Function	SP2T switch, non-reciprocal
Frequency (GHz)	35
Bandwidth (%)	10
Power handling (W)	1400 peak, 120 average (into load with 1.6 VSWR)
Switching time (μs)	< 2
Switching rate (kHz)	5
RF interface	waveguide WR28
Control	TTL interface
Power	+15 V, 100 mA; −15 V, 20 mA
Insertion loss (dB)	0.6 typ
VSWR	1.25 max
Isolation (dB)	> 25
Temperature range (°C)	−30 to +80

using five switching circulators and three high power loads. The driver electronics required to control the matrix are located on the rear side of the mounting plate.

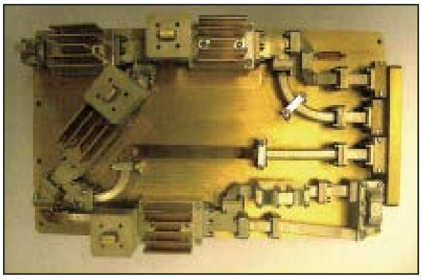
TOROIDAL SWITCH

The toroidal switch, in its simplest form, uses dual 90° toroidal ferrite phase shifters between a waveguide tee and coupler in a Butler matrix configuration, shown schematically in ***Figure 2***. The tee splits the input power into two signals of equal magnitude and phase. These pass through the phase shifters which introduce a relative phase shift of +90° or −90°, before being recombined in the coupler to either one of the output ports.

The magnetization of the ferrite elements is controlled through wires lacing the toroids. The ferrite elements are only partially magnetized, increasing the complexity of the driver circuit required to control the switch, but allowing compensation for changes in the properties of the ferrite over temperature, which is necessary to maintain good performance over a wide temperature range.



▲ *Fig. 3 An SP4T switch that can provide equal amplitude to the output ports.*



▲ *Fig. 4 An SP4T switch with square waveguide outputs that provides selectable polarization output from one port via an orthomode transducer.*

Careful choice of ferrite material is necessary to ensure optimum performance for the requirements of each particular application. Peak power handling is limited by the critical power level of the ferrite material, above which insertion loss increases due to excitation of spin-wave instabilities. Peak power handling can be extended at the expense of slightly increased insertion loss by the inclusion of rare earth element doping in the ferrite material.

Average power handling is governed by the thermal properties of the assembly and can be increased by modifying the phase shifter geometry to decrease the phase and insertion loss per unit length. The toroid is made longer to maintain the available differential phase, but the power is dissipated over a larger area, limiting the heating of the ferrite material.

DRIVER ELECTRONICS

The second key aspect of switch design is the driver electronics. The magnetisation of the ferrite toroids is controlled by applying short (1 to 2 μs) current pulses through wires lacing the toroids. No holding current is required. It is necessary to compensate for changes in the magnetic properties of the ferrite material with temperature by adjusting the lengths of the current pulses according to a signal from a temperature sensor mounted in the metalwork close to one of the toroids. The switch driver interface is typically the power supplies (±15 V, 100 mA), one or more control lines and a status line from the driver, which reports any faults. An example specification for a Ka-band switch is given in ***Table 1***.

The switch is non-reciprocal — it provides reverse isolation of 20 dB minimum. Reciprocal versions of the switch are also realizable using a different microwave circuit.

SWITCH MATRIX PRODUCTS

Several of the SP2T switches described above have been combined to produce two types of switch matrices that provide switching from one input to one of four outputs. The versatility of this switch element means that it can be used to provide additional features. ***Figure 3*** shows an SP4T switch that can also provide an equal amplitude, equal phase power split between the four output ports. ***Figure 4*** shows an SP4T switch with square waveguide outputs that also provides selectable polarization output from one port via an orthomode transducer. Other network topologies can be accommodated to suit particular system requirements.

CONCLUSION

These new products have been specifically developed to meet the defence market's requirements for switches and switch matrices in Ka-band that enable fast and reliable, high power switching between antennas or power sources. They can easily be configured into a network to provide switching between one input and multiple outputs, making them suitable for land, air and naval defence systems, particularly for fire control radar and secure communications applications. ■

Thales MESL,
Edinburgh, Scotland,
+44 131 333 2000,
www.thales-mesl.com.

RS No. 303

Military Microwaves

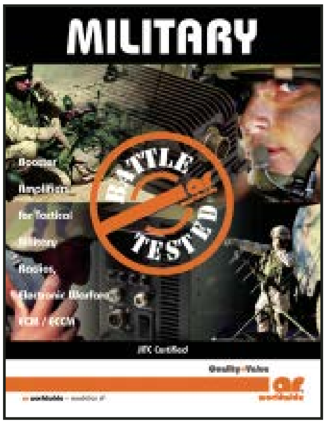
Literature Showcase

Capability Brochure

This eight-panel folding brochure highlights the products and capabilities of the American Microwave family of companies. Products include solid-state switches, attenuators, DLVAs, phase shifters, amplifiers, filters, switched filter banks and integrated assemblies. Machine shop and clean room facilities are also detailed. Handy pocket panel houses the latest product data sheets and company announcements.

American Microwave Corp., Frederick, MD (301) 662-4700, www.americanmicrowavecorp.com.

RS No. 310

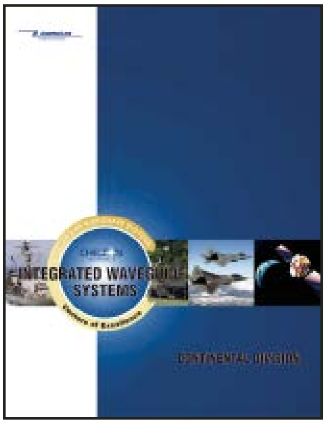


Military Brochure

This brochure highlights the company's booster amplifiers that are designed for tactical military radios, electronic warfare and ECM/ECCM. Designed for use with single- or multi-band tactical radios within the 30 to 512 MHz range, this family of amplifiers is compatible with virtually every military device worldwide. These amplifiers are adaptable to vehicular, fixed site, airborne and manportable configurations. The KMW2030 and KMW2050 are JITC certified.

AR Worldwide Modular RF, Bothell, WA (425) 485-9000, www.ar-worldwide.com.

RS No. 311



Product and Capabilities Brochure

This 12-page brochure highlights the product lines and capabilities of Chelton Microwave – Continental Division. From design and manufacture of waveguide components and complex integrated waveguide assemblies to repair and overhaul of the same, this division offers complete solutions for military and aerospace applications.

Chelton Microwave – Continental Division, Exeter, NH (603) 775-5200, www.cheltonmicrowave.com.

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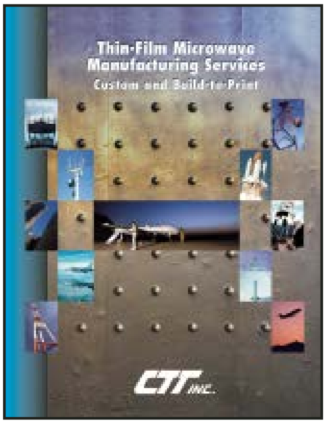
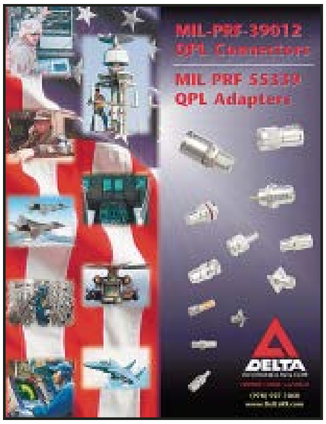


Product Brochure

This brochure highlights the company's new thin-film microwave manufacturing services including custom and build-to-print. CTT's facility was specifically designed to accommodate the unique requirements of hybrid microwave integrated circuit manufacturing conforming to MIL-PRF-38534C. The company has developed an automated and optimized thin-film hybrid manufacturing process especially suited to the production of microwave integrated circuits using chip and wire bond techniques.

CTT Inc., Sunnyvale, CA (408) 541-0596, www.cttinc.com.

RS No. 313



Product Brochure

This brochure presents the company's recently-expanded line of MIL-PRF-39012 QPL connectors and MIL-PRF-55339 adapters. This line now includes over 220 QPL configurations in the BNC, N, SMA and TNC series. The M39012 QPL connectors are available in a wide range of cable connector configurations with clamp, crimp and solder type cable attachments, as well as bulkhead- and panel-mounted receptacles. The company's M55339 QPL adapters include with- and between-series types in BNC and N interfaces.

Delta Electronics Manufacturing Corp., Beverly, MA (978) 927-1060, www.deltarf.com.

RS No. 314

Product Catalog

This catalog details the company's capabilities in the design and manufacture of RF microwave connectors and cable assemblies. The company is a provider of high quality, standard and special RF and microwave connectors, adapters, blindmate interconnecting components and cable assemblies for use in military applications and commercial microwave, RF and wireless industry components. Information on quote requests, ordering information and product warranty are also provided.

Dynawave Inc., Haverhill, MA (978) 469-0555, www.dynawave.com.

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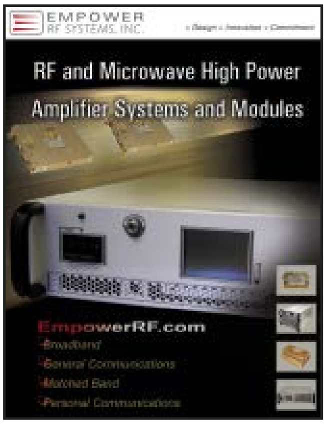
Literature Showcase

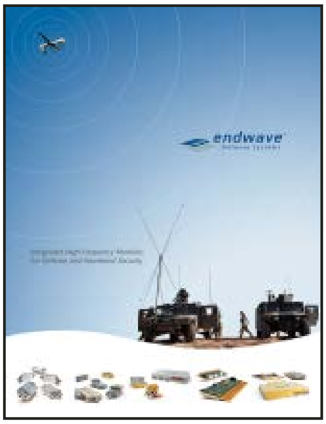


Amplifier Systems and Modules

This catalog contains RF and microwave solid-state amplifiers in module and rack-mount system configurations for the military, aerospace, medical and commercial markets worldwide. Depending on the configuration, frequencies range from 10 kHz to 24 GHz. Output power levels run from 1 to 2500 W. The Empower ISO 9001:2000 Quality Assurance Program assures consistent performance and high reliability.

Empower RF Systems,
Inglewood, CA (310) 412-8100, www.empowerrf.com.

RS No. 316



Defense Systems Brochure

As defense and homeland security systems move up in frequency and down in budget, companies turn to Endwave Defense Systems. Advanced technology, quick time-to-market and consistent, high quality manufacturing are the hallmarks of the company's business philosophy. The brochure features its library of circuit building blocks that can customize nearly any integrated assembly imaginable.

Endwave Defense Systems,
Sunnyvale, CA and Diamond Springs, CA
(408) 522-3170, www.endwave.com.

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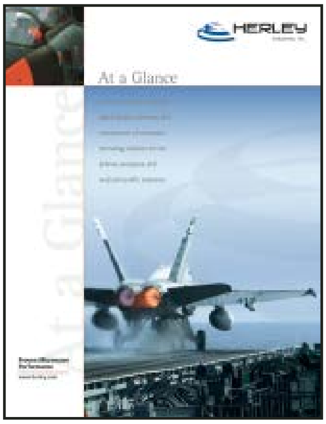
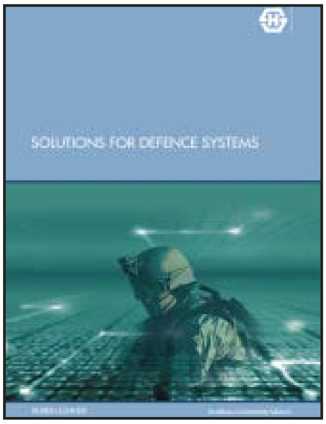


Product Catalog

This catalog displays the company's solid, innovative and sophisticated RF, microwave and millimeter-wave components and subsystems used by the defense and aerospace industries. Based in Lancaster, PA, the company has nine manufacturing facilities that offer design, development and manufacture of microwave technology solutions worldwide.

Herley Industries Inc.,
Lancaster, PA (717) 735-8117, www.herley.com.

RS No. 318

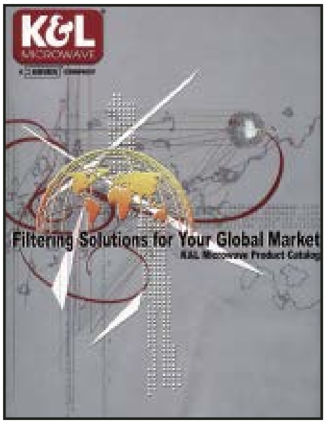


Defence Solutions

This brochure features the company's wide range of products and services that provide the platform to build modern defence systems. Uncertain conditions, extreme environments and challenging operational demand the highest quality. Many years of experience in development and production of cables, connectors and assembled cable systems guarantee optimized solutions – even for complex and ambitious projects.

HUBER+SUHNER AG,
Herisau, Switzerland +44 71 353 4111, www.hubersuhner.com.

RS No. 341



Product Catalog

This edition of the catalog features the latest information on the company's broad range of RF and microwave filter products for defense electronics and telecommunications, including integrated assemblies and a wide assortment of lumped component, cavity, ceramic and suspended substrate filters.

K&L Microwave,
Salisbury, MD (410) 749-2424, www.klmicrowave.com.

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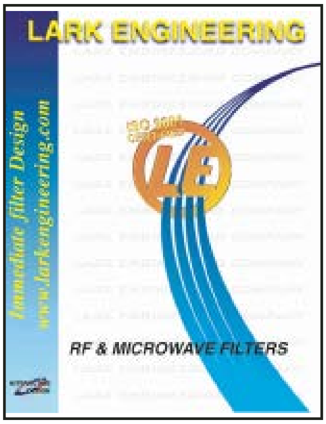


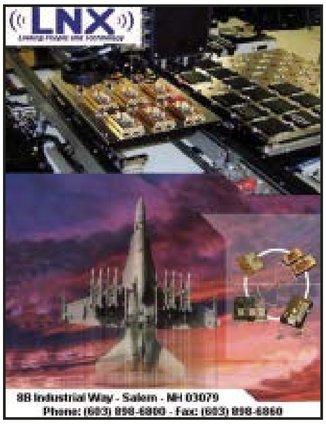
RF/Microwave Filters and Multiplexers Catalog

This 114-page catalog contains the company's ISO 9001-certified RF and microwave filters that offer an extensive product mix with filters and multiplexers ranging from 100 kHz to 18 GHz. These products are currently being used in digital and analog wireless communications systems, test equipment and military systems. Typically, samples can be shipped within 10 working days.

Lark Engineering Co.,
San Juan Capistrano, CA (949) 240-1233,
www.larkengineering.com.

RS No. 320

Literature Showcase



Product Catalog

This catalog features the company's design and manufacture of sophisticated defense related components and subsystems. The catalog displays microwave and digital design manufacturing from 20 MHz to 96 GHz. It utilizes and combines advanced concepts in the design and manufacturing of analog RF/microwave and digital signal processing. The catalog also highlights RF/microwave products and designs, analog and digital signal processing for EW and ECM applications, digital RF memory, and test and measurement.

LNX Corp.,
Salem, NH (603) 898-6800, www.lnxcorp.com.

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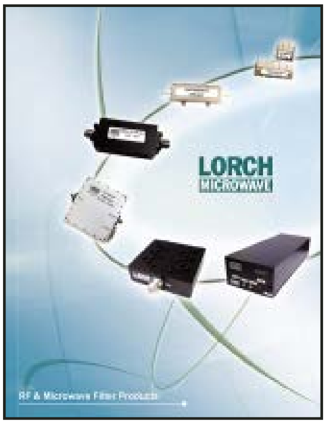


RF and Microwave Filter Catalog

This catalog includes the company's complete line of RF and microwave filter products. Also featured in this new edition are integrated filter assemblies, which include switched filters and filter amplifiers. Other RF products included are phase comparators, manual and digital phase shifters, voltage-controlled phase shifters, voltage-controlled attenuators and broadband mixers.

Lorch Microwave,
Salisbury, MD (410) 860-5100, www.lorch.com.

RS No. 322

Product Solutions Guide

This product solutions guide contains information on over 1000 standard microwave and RF products. It contains parameters for each part number organized by product category. RoHS-compliant products and off-the-shelf distribution products are noted for easy reference. Most standard products can be up-screened to meet defense and space applications or parts can be customized to meet certain specifications.

M/A-COM,
Lowell, MA (800) 366-2266, www.macom.com.

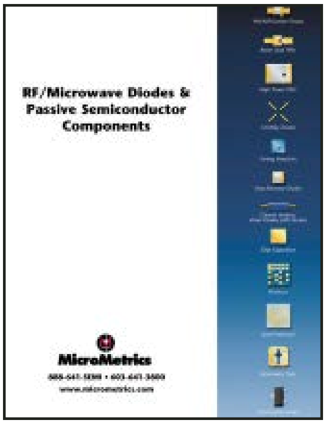
RS No. 323

Product Catalog

This redesigned catalog features the company's standard product data sheets and useful application notes. Standard products include RF/microwave mixers, doublers, multipliers and specialty components up to 65 GHz. Outline drawings, including information about new surface-mount packaging technology and performance specifications are provided for each component. E-mail: mixers@markimicrowave.com to request a copy.

Marki Microwave,
Morgan Hill, CA (408) 778-4200, www.markimicrowave.com.

RS No. 324



Product Introduction Guide

This new product introduction guide contains a wide variety of new information on JAN-Products, high power PIN diodes greater than 1200 V, new spice models for limiters, Schottky diodes featuring bridge quads, ZBD detector diodes, and P type Schottkys and mixers. Epi wafer capability for three, four and five inch wafers, as well as Polysilicon coating, is also highlighted.

MicroMetrics Inc.,
Londonderry, NH (603) 641-3800, www.micrometrics.com.

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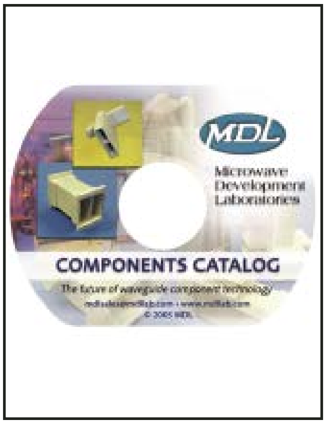


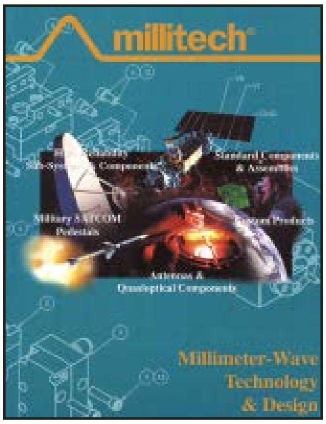
Components Catalog CD-ROM

This catalog CD-ROM features the company's cast components and other passive waveguide products. The CD also highlights the company's commitment to total control for perfection, engineering capabilities, quality manufacturing capabilities and guaranteed reliability.

Microwave Development Laboratories–MDL,
Needham Heights, MA (800) 383-8057, www.mdllab.com.

RS No. 326

Literature Showcase



Millimeter-wave Technology and Design

This catalog features the company's millimeter-wave technology and design products for applications that operate in the frequency range from 18 to 300 GHz. The MMW Product Division designs, develops and manufactures everything from individual components to complete systems for use in satellite, scientific, military and commercial applications. A wide variety of amplifiers, isolators, mixers, antennas, multipliers and switches make up the company's standard product catalog.

Millitech Inc.,
Northampton, MA (413) 582-9620, www.millitech.com.

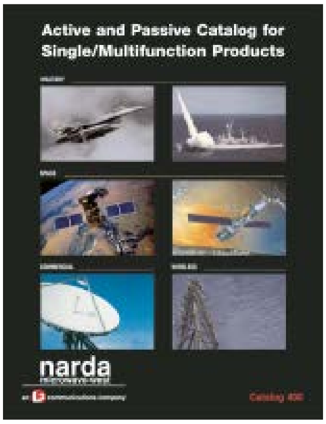
RS No. 327

Company and Range Brochure

This comprehensive brochure contains valuable information about the company and its design capabilities. Key advantages offered by the company's portfolio are explained including power density, the dual-band solution, five-year warranty, upgrade facility and the use of interface technologies and integrated Ethernet USB and RS-232 protocols. Application guidelines are covered and the Series 2000 design concept is explained.

MILMEGA Ltd.,
Isle of Wight, UK +44 1983 618004,
www.milmega.co.uk.

RS No. 328



Product Catalog

The Narda catalog 400 features the company's full line of active and passive products. This active product line includes both space and non-space amplifiers, multipliers and converters. Passive products include both space and non-space filters, diplexers, multiplexers, ferrite components and standard base station products, including band pass and duplex filters and integrated assemblies. Narda Microwave-West is ISO 9001 certified.

Narda Microwave-West, a division of L-3 Communications,
Folsom, CA (916) 351-4500, www.nardamicrowave.com.

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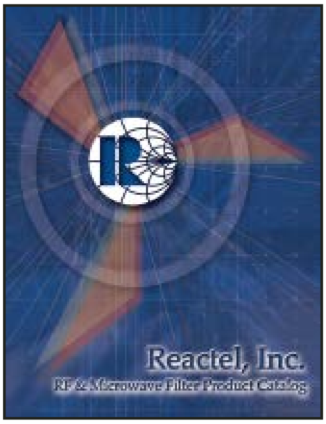


RF and Microwave Filters

This catalog features the company's full line of RF and microwave filter products. The catalog highlights high reliability filters, multiplexers and switched filter banks that cover DC to 50 GHz and are tailored to meet the military market. To request a complimentary copy, e-mail: catalog@reactel.com.

Reactel Inc.,
Gaithersburg, MD (301) 519-3660, www.reactel.com.

RS No. 330

Software Tools Brochure

This brochure features the company's wide range of electromagnetic simulation software tools. The product line includes: XFDTD, the finite difference time domain analysis package, Wireless Insite, a UTD-based urban and terrain propagation tool, and the XGTD software solution for more general UTD antenna and propagation analyses.

Remcom Inc.,
State College, PA (814) 861-1299, www.remcom.com.

RS No. 331

Product Brochure

The "Handset Solutions" product brochure showcases the company's wide range of specialty materials for handset applications. This literature features high performance foams, electroluminescent lighting and advanced circuit materials. These materials are used in a multitude of handheld device applications. For ease of use, each specialty material is color-coded to correspond to a table listing both its features and benefits.

Rogers Corp.,
Rogers, CT (860) 779-5597, www.rogerscorporation.com.

RS No. 332

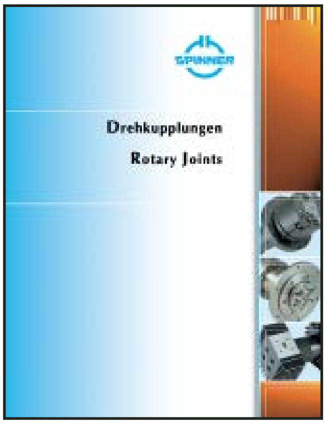
Literature Showcase

Radiocommunications Catalog 2006/2007

This brand-new catalog in CD-ROM format provides a comprehensive guide to all of the manufacturer's current equipment and systems. Reflecting the company's position as a leading supplier of professional radiocommunications equipment for mission-critical environments, included are: solutions for global communications, tactical communications, LOS communications and avionics equipment, together with system processor and software.

Rohde & Schwarz GmbH,
Munich, Germany +49 180 512 4242, www.rohde-schwarz.com.

RS No. 333



Product Catalog Rotary Joints

This catalog displays the company's wide product range that includes high quality RF rotary joints and slip rings mainly used in military and civilian radar systems. In addition to the company's standard products, it also offers customized designs to satisfy specific requirements. SPINNER is based in Munich and has subsidiaries and representatives in over 40 countries worldwide.

SPINNER GmbH,
Munich, Germany (+49) 89 / 12601-0, www.spinner.de.

RS No. 334

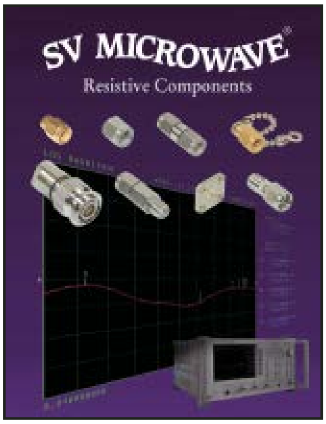
Literature Showcase

High Performance Solutions

This newly updated catalog covers high performance microwave interconnect solutions to 50 GHz for defense and aerospace applications: phase stable, low loss and miniature flexible assemblies; semi-rigid cable and assemblies; capabilities; custom applications and solutions; and case studies. Product selection grids, performance graphs, tables, charts, tutorials, photos, and ordering and service information are also included.

Storm Products–Microwave Group,
Woodridge, IL (630) 754-3300, www.stormproducts.com.

RS No. 335

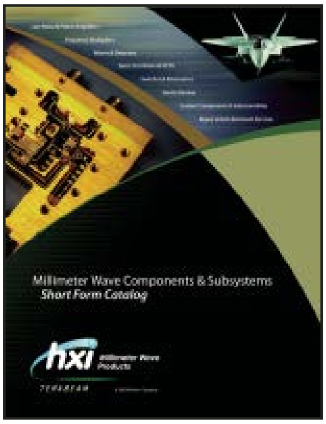


Resistive Components Catalog

This 24-page catalog provides specifications and outline drawings for some of the company's most popular fixed coaxial and chip attenuators as well as coaxial terminations. QPL attenuators to MIL-A-3933/14, /16, /18 and /25 are included, as well as QPL terminations to M39030/3. It also includes short circuit terminations and resistance cards.

SV Microwave Inc.,
West Palm Beach, FL (561) 840-1800, www.svmicrowave.com.

RS No. 336

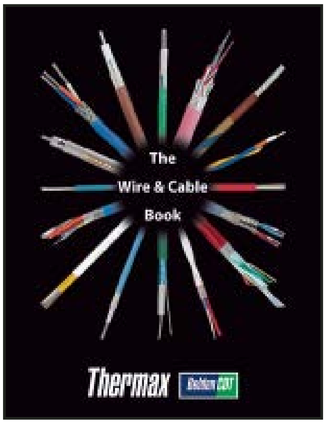


Short Form Catalog

This short form catalog highlights the company's millimeter-wave (MMW) products that include a complete line of components from 18 to 110 GHz. The millimeter-wave product availability includes low noise amplifiers, medium/high power amplifiers, mixers, detectors, Gunn oscillators and VCOs, frequency multipliers, pin switches and attenuators, isolators and circulators, and custom subassemblies.

Terabeam/HXI,
Haverhill, MA (978) 521-7300, www.terabeam-hxi.com.

RS No. 337



The Wire and Cable Book

Recently revised and expanded, The Wire and Cable Book showcases the company's extensive lines of MIL-qualified and commercial products, ranging from sophisticated, high performance coaxial cables to rugged, severe-environment aerospace wires and cables, including MaxFlite 100 Base-T Ethernet cable for inflight data systems.

Thermax,
Wallingford, CT (203) 284-9610, www.thermaxcdt.com.

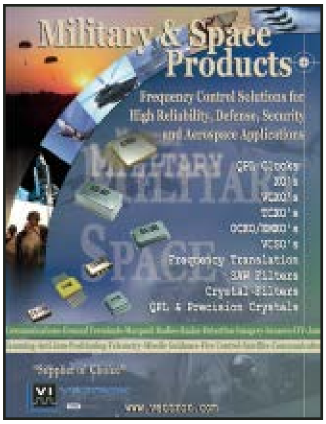
RS No. 338

Test Cable Brochure

This brochure features the company's heavy-duty armored *SilverLine™ TuffGrip™* test cable series for wireless infrastructure and wireless Internet cell site RF field testing applications. These test cables employ a robust hand grip at the system test end enabling the user to apply as much hand resistance as necessary to make or break heavily weatherproofed RF connections quickly and easily without the use of wrenches and without damaging the test cable.

Times Microwave Systems,
Wallingford, CT (203) 949-8400, www.timesmicrowave.com.

RS No. 339



Military and Space Products

This product brochure highlights the company's military and space products for high reliability, defense, security and aerospace applications. Products include: QPL clocks, crystal oscillators, voltage-controlled crystal oscillators, temperature-controlled crystal oscillators, oven-controlled crystal oscillators, voltage-controlled SAW filters, frequency translation, SAW filters, crystal filters, and QPL and precision crystals.

Vectron International,
Hudson, NH (888) 328-7661, www.vectron.com.

RS No. 340

Military Microwaves

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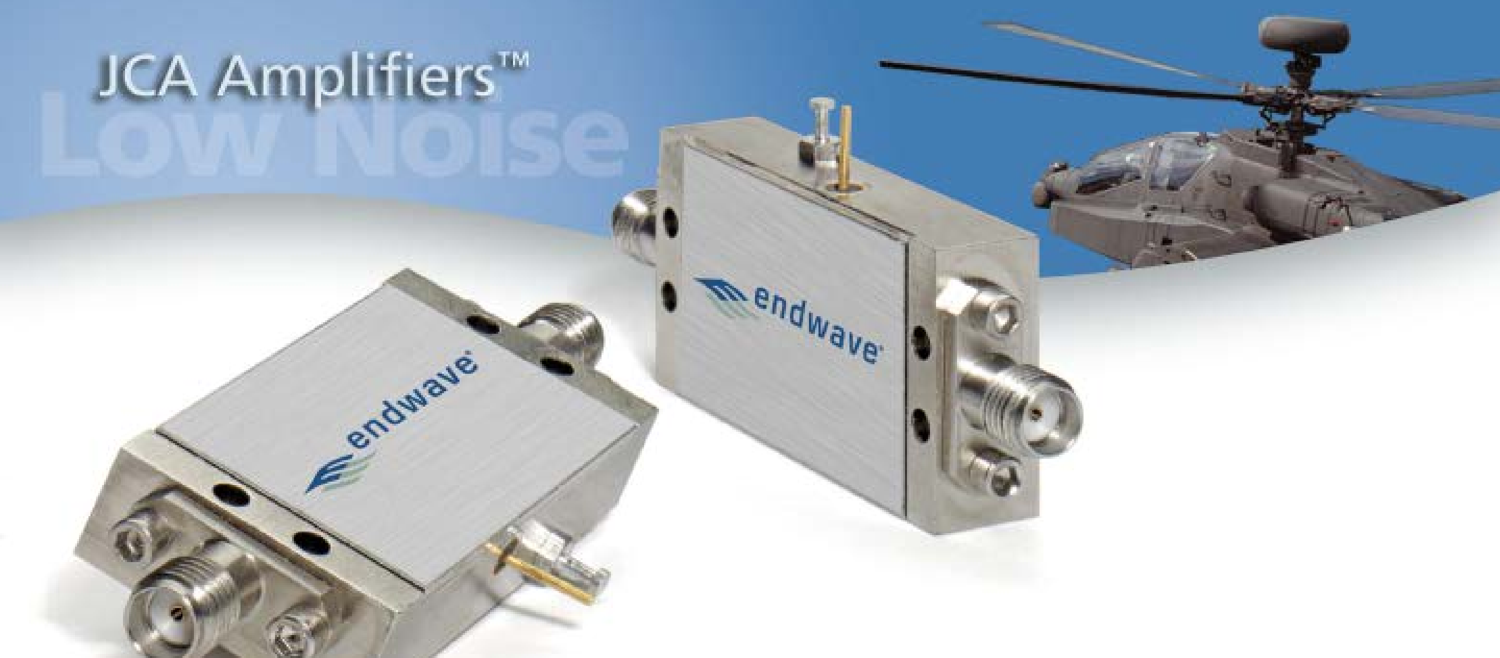
JCA Amplifiers™ Low Noise



NEW MODELS

You can see clearly now—the noise is gone

Endwave's latest JCA Amplifiers are the answer when you need to improve sensitivity, increase dynamic range, and lower reception thresholds. By combining standard JCA amplifier stages with an innovative circuit approach, we're able to optimize performance and cost, leaving you seeing clear.

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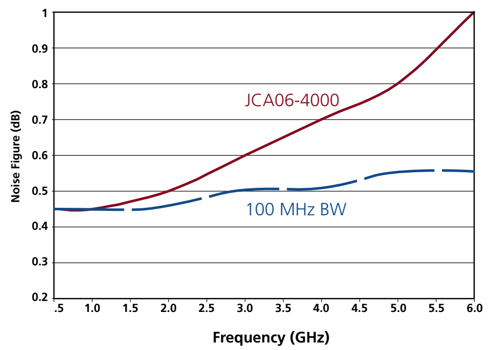
Noise Figure Capability



- ***Narrowband noise figure < 0.5 dB***
- ***Broadband noise figure < 1.0 dB***
- ***Unconditionally stable***
- ***2 to 4 weeks delivery***
- ***ISO9001 and AS9100 certified***

Model	Frequency GHz	Gain dB Min	Noise Figure dB Max	Gain Flatness +/- dB Max	P1dB dBm Min	VSWR In/Out Max	DC Current +15v, mA
LNAs							
JCA01-3041	0.50 to 0.60	40	**0.5**	1.00	15	2.0:1	250
JCA01-3042	0.60 to 0.70	40	**0.5**	1.00	15	2.0:1	250
JCA01-3043	0.70 to 0.80	40	**0.5**	1.00	15	2.0:1	250
JCA01-3044	0.80 to 0.90	40	**0.5**	1.00	15	2.0:1	250
JCA01-2034	0.80 to 0.90	30	**0.5**	1.00	10	2.0:1	200
JCA01-2035	0.90 to 1.00	30	**0.5**	1.00	10	2.0:1	200
JCA01-3045	0.90 to 1.00	40	**0.5**	1.00	15	2.0:1	250
JCA01-2001	0.50 to 1.00	30	**0.9**	2.00	10	2.0:1	200
JCA12-2000	1.00 to 2.00	30	**0.9**	1.50	10	2.0:1	200
JCA12-3000	1.00 to 2.00	40	**0.9**	1.50	15	2.0:1	250
JCA12-4000	1.00 to 2.00	50	**0.9**	1.50	15	2.0:1	300
JCA14-3001	1.00 to 4.00	40	**0.9**	2.00	15	2.5:1	250
JCA14-2001	1.00 to 4.00	30	**0.9**	2.00	10	2.5:1	200
JCA14-4001	1.00 to 4.00	50	**0.9**	2.00	15	2.5:1	300
JCA24-2000	2.00 to 4.00	30	**0.9**	1.50	10	2.0:1	200
JCA24-3000	2.00 to 4.00	40	**0.9**	1.50	15	2.0:1	250
JCA24-4000	2.00 to 4.00	50	**0.9**	1.50	15	2.0:1	300
JCA06-4000	0.50 to 6.00	30	**1.2**	2.00	10	2.5:1	300
JCA26-2001	2.00 to 6.00	30	**1.2**	2.00	10	2.0:1	200
JCA26-3001	2.00 to 6.00	40	**1.2**	2.00	15	2.0:1	250
JCA26-4001	2.00 to 6.00	50	**1.2**	2.00	15	2.0:1	300

OPTIONS

Variable Gain Control	TTL Switching	Temperature Compensation
Input/Output Isolators	Waveguide Interface	Detector Output
Input Limiters	Phase Tracking	Gain Matching
Limiting Amplifiers	Low Phase Noise	Hermetic Packages
Environmental Screening	K-Connectors	Bias-T Output

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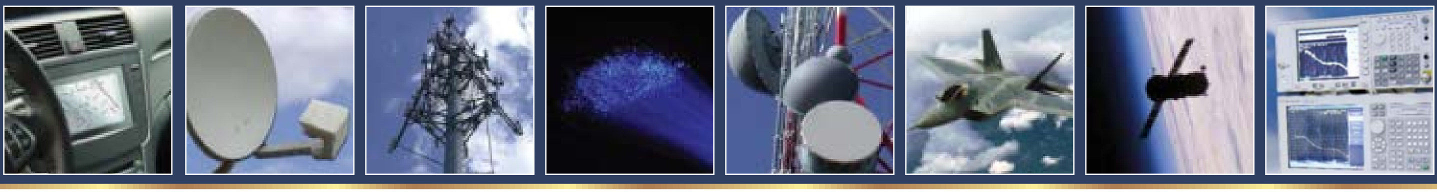
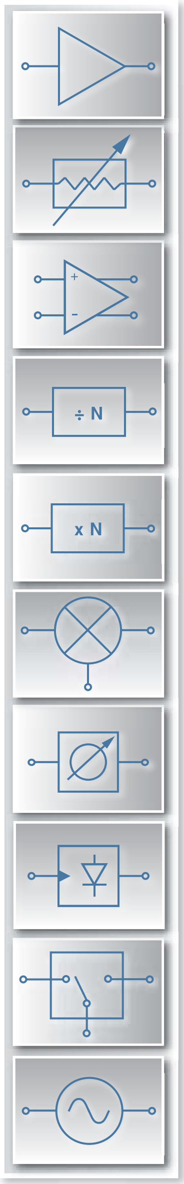
Product Selection Guide

Analog & Mixed-Signal ICs, Modules & Subsystems
DC - 110 GHz





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Phase Shifters ♦ Power Detectors ♦ Switches ♦ Synthesizers ♦ VCOs & PLOs ♦ Connectorized Modules**

Hittite MICROWAVE CORPORATION

June 2006

2 NEW PRODUCT LINES!

DATA CONVERTERS

Input Freq. (GHz)	Function	Single Tone THD/SFDR (dB)	Max. Clock Rate (GS/s)	Output Noise (mV RMS)	Hold Mode Feed-through Rejection (dB)	Package	Part Number
DC - 4.5	Track-and-Hold Amplifier	-66/67	3.0	0.95	>60	LC4B	HMC660LC4B

POWER DETECTORS

Frequency (GHz)	Function	± 3 dB Dynamic Range (dB)	RSSI Slope (mV / dB)	RF Threshold Level (dBm)	Bias Supply	Package	Part Number
0.05 - 4.0	Log Detector/Controller	75	19	-69	+2.7 to +5.5V @ 29mA	LP4	HMC600LP4 (E)

AMPLIFIERS

Frequency (GHz)	Function	Gain (dB)	OIP3 (dBm)	NF (dB)	P1dB (dBm)	Bias Supply	Package	Part Number
1.2 - 2.0	Low Noise	28	21	1.2	11	+5V @ 21mA	LP3	HMC548LP3 (E)
6 - 20	Low Noise	22	20	2.4	10	+3V @ 53mA	Chip	HMC565
7 - 13.5	Low Noise	17	24	1.8	12	+3V @ 51mA	Chip	HMC564
29 - 36	Low Noise	21	23.5	2.8	12	+3V @ 80mA	Chip	HMC566
29 - 36	Low Noise	20	22	2.9	11	+3V @ 80mA	Module	HMC-C027

ATTENUATORS

Frequency (GHz)	Function	Loss (dB)	Atten. Range (dB)	Input IP3 (dBm)	Control Input (Vdc)	Package	Part Number
DC - 3	6-Bit Digital, Serial Control	1.2	0.5 to 31.5	45	Serial TTL/CMOS	LP4	HMC542LP4 (E)
DC - 13	6-Bit Digital, Serial Control	3.6	0.5 to 31.5	32	Serial TTL/CMOS	Module	HMC-C018

FREQUENCY MULTIPLIERS - ACTIVE

Input Freq. (MHz)	Function	Output Frequency (GHz)	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Package	Part Number
2500 - 5000	Active x2	5 - 10	3	17	-140	LP4	HMC575LP4 (E)
9000 - 13500	Active x2	18 - 27	3	16	-132	Chip	HMC576
9000 - 13500	Active x2	18 - 27	3	17	-132	LC3B	HMC576LC3B
12000 - 16500	Active x2	24 - 33	3	16	-129	Chip	HMC578
12000 - 16500	Active x2	24 - 33	3	16	-129	LC3B	HMC578LC3B
14750 - 15000	Active x2	29.5 - 30	3	21	-128	LC4B	HMC577LC4B
16000 - 23000	Active x2	32 - 46	3	12	-127	Chip	HMC579

I/Q MIXERS / IRMs

RF/LO Freq. (GHz)	Function	IF Frequency (GHz)	Conversion Gain (dB)	Image Rejection (dB)	Input IP3 (dBm)	Package	Part Number
31 - 38	I/Q Mixer / IRM	DC - 3.5	-10.5	17	21	Chip	HMC555
36 - 41	I/Q Mixer / IRM	DC - 3.5	-11	18	23	Chip	HMC556

MIXERS

RF Freq. (GHz)	Function	IF Frequency (GHz)	Conversion Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
0.8 - 1.2	High IP3, DBL-BAL, 0 LO	DC - 0.3	-8	27	27	LP4	HMC551LP4 (E)
1.6 - 3.0	High IP3, DBL-BAL, 0 LO	DC - 1.0	-8	30	25	LP4	HMC552LP4 (E)
7 - 14	+13 LO, DBL-BAL	DC - 5	-7	48	22	Chip	HMC553
7 - 14	+13 LO, DBL-BAL	DC - 5	-7	50	22	LC3B	HMC553LC3B
11 - 20	+13 LO, DBL-BAL	DC - 6	-7	46	18	Chip	HMC554
11 - 20	+13 LO, DBL-BAL	DC - 6	-7	46	18	LC3B	HMC554LC3B
24 - 40	+13 LO, DBL-BAL	DC - 18	-8	35	21	Chip	HMC560
24 - 40	+13 LO, DBL-BAL	DC - 17	-10	35	21	LM3	HMC560LM3

SWITCHES

Frequency (GHz)	Function	Insertion Loss (dB)	Isolation (dB)	Input P1dB (dBm)	Control Input (Vdc)	Package	Part Number
DC - 6	SPST, Failsafe	0.7	25	27	0 / +2.2 to +5V	SOT26	HMC550 (E)
0.2 - 2.7	SPDT, 10W, Failsafe	0.4	35	40	0 / +3 to +8V	LP2	HMC546LP2 (E)
DC - 4	SPDT T/R	0.25	23	39	0 / +3 to +5V	SOT26	HMC544 (E)
DC - 20	SPST, High Isolation	3	100	23	0 / +5V	Module	HMC-C019

VOLTAGE CONTROLLED OSCILLATORS*

Output Freq. (GHz)	Function	Output Power (dBm)	10kHz SSB Phase Noise (dBc/Hz)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
4 - 8	Wideband VCO	5	-75	-100	+5V @ 55mA	LC4B	HMC586LC4B

AMPLIFIERS

Frequency (GHz)	Function	Gain (dB)	OIP3 (dBm)	NF (dB)	P1dB (dBm)	Bias Supply	Package	Part Number
Low Noise Amplifiers								
0.04 - 0.96	Low Noise, Dual Output	5	27	3.5	12	+5V @ 120mA	MS8G	HMC549MS8G (E)
0.3 - 3.0	Low Noise, High IP3	15	37	1.5	22	+5V @ 90mA	SOT26	HMC374 (E)
0.35 - 0.55	Low Noise	17	35	1	21	+5V @ 104mA	LP3	HMC356LP3 (E)
0.7 - 1.0	Low Noise	14.5	34	1	21	+5V @ 100mA	LP3	HMC372LP3 (E)
0.7 - 1.0	Low Noise	15	36	0.7	21	+5V @ 73mA	LP3	HMC376LP3 (E)
0.7 - 1.0	Low Noise w/ Bypass	14	35	0.9	21	+5V @ 90mA	LP3	HMC373LP3 (E)
NEW! 1.2 - 2.0	Low Noise	28	21	1.2	11	+5V @ 21mA	LP3	HMC548LP3 (E)
1.7 - 2.2	Low Noise	17.5	34	0.9	18	+5V @ 136mA	LP3	HMC375LP3 (E)
1.7 - 2.2	Low Noise	15	30	1	16	+5V @ 67mA	LP3	HMC382LP3 (E)
2.3 - 2.5	Low Noise	17	13	1.8	5	+3V @ 8.5mA	SOT26	HMC286 (E)
2.3 - 2.5	Low Noise	22	7	2.5	3	+3V @ 9mA	MS8	HMC287MS8 (E)
2.4 - 2.5	Transceiver, Front End	13	10	3	5	+3V @ 24mA	MS8G	HMC310MS8G (E)
3.4 - 3.8	Low Noise w/ Bypass	15	18	2	7	+3V @ 9mA	LP3	HMC491LP3 (E)
3.5 - 7.0	Low Noise	15.5	28	2.4	16	+5V @ 50mA	Chip	HMC392
5 - 6	Low Noise	9	13	2.5	2	+3V @ 6mA	MS8G	HMC318MS8G (E)
5 - 6	Low Noise	12	8	2.5	9	+3V @ 25mA	MS8G	HMC320MS8G (E)
NEW! 6 - 20	Low Noise	22	20	2.4	10	+3V @ 53mA	Chip	HMC565
NEW! 7 - 13.5	Low Noise	17	24	1.8	12	+3V @ 51mA	Chip	HMC564
7 - 17	Low Noise	21	20	1.8	15	+3V @ 65mA	Chip	HMC516
9 - 18	Low Noise	20	25	2	14	+3V @ 65mA	LC5	HMC516LC5
13 - 25	Low Noise	21	13	3.5	5	+3V @ 41mA	Chip	HMC342
13 - 25	Low Noise	22	20	3.5	9	+3V @ 43mA	LC4	HMC342LC4
17 - 26	Low Noise	19	24	2.2	11	+3V @ 65mA	Chip	HMC517
17 - 26	Low Noise	19	24	2.5	13	+3V @ 67mA	LC4	HMC517LC4
18 - 32	Low Noise	15	22	2.8	12	+3V @ 65mA	Chip	HMC519
20 - 32	Low Noise	14	24	2.8	12	+3V @ 65mA	Chip	HMC518
21 - 29	Low Noise	13	19	3	8	+3V @ 35mA	LC3B	HMC341LC3B
24 - 30	Low Noise	13	16	2.5	6	+3V @ 30mA	Chip	HMC341
24 - 36	Low Noise	23	13	2.3	6	+3V @ 58mA	Chip	HMC263
NEW! 29 - 36	Low Noise	21	23.5	2.8	12	+3V @ 80mA	Chip	HMC566
12 - 16	Medium Power LNA	23	34	2.5	25	+5V @ 200mA	LP5	HMC490LP5 (E)
12 - 17	Medium Power LNA	26	35	2.2	26	+5V @ 200mA	Chip	HMC490
***Broadband Gain Blocks** (Listed by P1dB Output Power)*								
DC - 6	SiGe Gain Block	15.5	22	3	8	+5V @ 25mA	MP86	HMC474MP86 (E)
DC - 6	SiGe Gain Block	20	25	2.5	12	+5V @ 35mA	MP86	HMC476MP86 (E)
DC - 10	HBT Gain Block	15	24	4.5	13	+5V @ 56mA	Chip	HMC397
DC - 10	HBT Gain Block	15	25	4	13	+5V @ 50mA	Chip	HMC405
DC - 6	HBT Gain Block	17	27	6.5	14	+5V @ 50mA	SOT26	HMC313 (E)
DC - 8	HBT Gain Block	12	30	6	14	+5V @ 56mA	Chip	HMC396
DC - 4	HBT Gain Block	15	28	4.5	15	+5V @ 54mA	Chip	HMC395
DC - 6	HBT Gain Block	14.5	30	4.5	15	+5V @ 56mA	LP3	HMC311LP3 (E)
DC - 6	HBT Gain Block	15	30	4.5	15	+5V @ 54mA	ST89	HMC311ST89 (E)
DC - 4	SiGe Gain Block, +5V	22	32	2	18	+5V @ 62mA	MP86	HMC478MP86 (E)
DC - 4	SiGe Gain Block, +5V	22	30	3	18	+5V @ 62mA	ST89	HMC478ST89 (E)
DC - 5	SiGe Gain Block	14	34	4	18	+8V @ 72mA	MP86	HMC479MP86 (E)
DC - 5	SiGe Gain Block	15	34	4	18	+8V @ 75mA	ST89	HMC479ST89 (E)
DC - 5	SiGe Gain Block	20	33	3.5	19	+8V @ 79mA	ST89	HMC481ST89 (E)
DC - 5	SiGe Gain Block	19	34	2.9	20	+8V @ 82mA	ST89	HMC480ST89 (E)
DC - 5	SiGe Gain Block	20	33	3.5	20	+8V @ 74mA	MP86	HMC481MP86 (E)
DC - 5	SiGe Gain Block	19	36	4	22.5	+8V @ 110mA	ST89	HMC482ST89 (E)
DC - 5	Dual SiGe Gain Block	15	34	4	18	+8V @ 75mA	MS8G	HMC469MS8G (E)

SELECTION GUIDE BY PRODUCT

AMPLIFIERS (Continued)

Frequency (GHz)	Function	Gain (dB)	OIP3 (dBm)	NF (dB)	P1dB (dBm)	Bias Supply	Package	Part Number
DC - 5	Dual SiGe Gain Block	20	34	3.2	20	+8V @ 80mA	MS8G	HMC471MS8G (E)
Driver Amplifiers								
0.8 - 3.8	Driver	18	30	7.5	17	+5V @ 53mA	SOT26	HMC308 (E)
3.0 - 4.5	HBT Driver	21	36	5	23.5	+5V @ 130mA	MS8G	HMC326MS8G (E)
Linear & Power Amplifiers								
0.4 - 2.5	High IP3 Amp, 1/2 Watt	12.5	42	6	27	+5V @ 150mA	ST89	HMC454ST89 (E)
1.7 - 2.5	High IP3 Amp, 1/2 Watt	13	42	6	27	+5V @ 150mA	LP3	HMC455LP3 (E)
0.8 - 1.0	Medium Power Amp	26	40	8	26	+4V @ 310mA	QS16G	HMC450QS16G (E)
1.6 - 2.2	Medium Power Amp	22	40	5.5	27	+3.6V @ 270mA	QS16G	HMC413QS16G (E)
4.9 - 5.9	Medium Power Amp	20	32	6	23	+3V @ 285mA	LP3	HMC415LP3 (E)
5 - 6	Medium Power Amp	18	38	6	26	+5V @ 300mA	MS8G	HMC406MS8G (E)
5 - 7	Medium Power Amp	15	40	5.5	25	+5V @ 230mA	MS8G	HMC407MS8G (E)
5 - 20	Medium Power Amp	22	30	6.5	20	+5V @ 127mA	Chip	HMC451
5 - 20	Medium Power Amp	19	30	7	19	+5V @ 127mA	LC3	HMC451LC3
6 - 18	Medium Power Amp	16	32	4.5	20	+5V @ 95mA	Chip	HMC441
6 - 18	Medium Power Amp	17	32	4.5	20	+5V @ 95mA	LC3B	HMC441LC3B
6.5 - 13.5	Medium Power Amp	14	29	4.5	18	+5V @ 95mA	LP3	HMC441LP3 (E)
7 - 15.5	Medium Power Amp	16	32	4.8	20	+5V @ 95mA	LH5 Hermetic	HMC441LH5
7 - 15.5	Medium Power Amp	16	30	4.5	19	+5V @ 95mA	LM1	HMC441LM1
12 - 30	Medium Power Amp	16	25	7	16	+5V @ 101mA	Chip	HMC383
12 - 30	Medium Power Amp	16	25	7.5	16.5	+5V @ 101mA	LC4	HMC383LC4
17 - 24	Medium Power Amp	24	34	4	25	+5V @ 250mA	Chip	HMC498
17 - 24	Medium Power Amp	22	36	4	25	+5V @ 250mA	LC4	HMC498LC4
17 - 40	Medium Power Amp	21	26	10	18	+3.5V @ 300mA	Chip	HMC283
17 - 40	Medium Power Amp	20	27	10	18	+3.5V @ 300mA	LM1	HMC283LM1
17.5 - 24	Medium Power Amp	14	27	6.5	21.5	+5V @ 85mA	LM1	HMC442LM1
17.5 - 25.5	Medium Power Amp	13	27	8	22	+5V @ 84mA	LC3B	HMC442LC3B
17.5 - 25.5	Medium Power Amp	15	28	5.5	22	+5V @ 85mA	Chip	HMC442
21 - 32	Medium Power Amp	16	33	5	24	+5V @ 200mA	Chip	HMC499
21 - 32	Medium Power Amp	15	33	5	24	+5V @ 200mA	LC4	HMC499LC4
0.4 - 2.2	Power Amp, 1 Watt	16	48	7	30	+5V @ 510mA	ST89	HMC452ST89 (E)
0.4 - 2.2	Power Amp, 1.6 Watt	14.5	50	7	32	+5V @ 725mA	ST89	HMC453ST89 (E)
0.45 - 2.2	Power Amp, 1 Watt	16	48	7	30	+5V @ 485mA	QS16G	HMC452QS16G (E)
0.45 - 2.2	Power Amp, 1.6 Watt	14.5	50	7	32	+5V @ 725mA	QS16G	HMC453QS16G (E)
1.7 - 2.2	Power Amp, 1 Watt	26	46	5.5	30.5	+5V @ 500mA	QS16G	HMC457QS16G (E)
1.7 - 2.2	Power Amp, 1 Watt	12	45	6	29.5	+5V @ 300mA	LP3	HMC461LP3 (E)
2.2 - 2.8	Power Amplifier, 1/2 Watt	20	39	7	27	+5V @ 300mA	MS8G	HMC414MS8G (E)
3 - 4	Power Amplifier, 1/2 Watt	21	40	5	27	+5V @ 250mA	MS8G	HMC327MS8G (E)
3.3 - 3.8	Power Amp, 1 Watt	31	45.5	5.8	30.5	+5V @ 615mA	LP4	HMC409LP4 (E)
5.1 - 5.9	Power Amplifier, 1 Watt	20	43	6	30	+5V @ 750mA	LP3	HMC408LP3 (E)
7 - 9	Power Amplifier, 2 Watt	26	40	6.5	33	+7V @ 1.3A	Chip	HMC486
7 - 9	Power Amplifier, 2 Watt	22	40	7	32	+7V @ 1.3A	LP5	HMC486LP5 (E)
9 - 12	Power Amplifier, 2 Watt	20	36	8	32	+7V @ 1.3A	LP5	HMC487LP5 (E)
12 - 16	Power Amplifier, 1 Watt	13	34	9	31	+7V @ 1.3A	LP5	HMC489LP5 (E)
Wideband (Distributed) Amplifiers								
2 - 20	Wideband LNA, Self Biased	15	26	2.5	15	+5V @ 63mA	Chip	HMC462
2 - 20	Wideband LNA, Self Biased	13	25	2.5	14	+5V @ 66mA	LP5	HMC462LP5 (E)
DC - 20	Wideband LNA	14	28	2.5	16	+8V @ 60mA	Chip	HMC460
2 - 20	Wideband LNA	14	28	2.5	16	+5V @ 60mA	Chip	HMC463
2 - 20	Wideband AGC LNA	13	26	3	18	+5V @ 60mA	LP5	HMC463LP5 (E)

AMPLIFIERS (Continued)

Frequency (GHz)	Function	Gain (dB)	OIP3 (dBm)	NF (dB)	P1dB (dBm)	Bias Supply	Package	Part Number
DC - 20	Wideband Driver	17	30	2.5	22	+8V @ 160mA	Chip	HMC465
DC - 20	Wideband Driver	15	28	3	23	+8V @ 160mA	LP5	HMC465LP5 (E)
2 - 35	Wideband Driver	12	25	4	17	+8V @ 80mA	Chip	HMC562
DC - 18	Wideband PA	17	32	3	25	+8V @ 290mA	Chip	HMC459
DC - 20	Wideband PA	14	36	4	28	+10V @ 400mA	Chip	HMC559
2 - 20	Wideband PA	16	30	4	26	+8V @ 290mA	Chip	HMC464
2 - 20	Wideband PA	14	30	4	26	+8V @ 290mA	LP5	HMC464LP5 (E)
Connectorized Amplifier Modules								
NEW! 29 - 36	Low Noise	20	22	2.9	11	+3V @ 80mA	Module	HMC-C027
2 - 20	Wideband LNA	15	24	2.2	14	+12V @ 65mA	Module	HMC-C001
2 - 20	Wideband LNA	14	26	2	18	+12V @ 60mA	Module	HMC-C002
2 - 20	Wideband LNA	14	27	2	16	+8V @ 75mA	Module	HMC-C022
7 - 17	Wideband LNA	22	25	2.5	14	+8V @ 93mA	Module	HMC-C016
17 - 27	Wideband LNA	18	25	3	14	+8V @ 96mA	Module	HMC-C017
0.01 - 20	Wideband Driver	16	33	3	23	+12V @ 195mA	Module	HMC-C004
0.01 - 20	Wideband Driver	15	30	3	23	+12V @ 225mA	Module	HMC-C024
2 - 20	Wideband PA	15	34	4	26	+12V @ 310mA	Module	HMC-C003
2 - 20	Wideband PA	14	30	4	24	+12V @ 310mA	Module	HMC-C023
2 - 20	Wideband PA	28	30	3	25	+12V @ 400mA	Module	HMC-C026
Connectorized Power Amplifier Modules - >10 Watts								
0.4 - 1.0	10 Watt PA	40	54	12	40	+12V @ 6.5A	Module	HMC-C012
0.8 - 2.0	10 Watt PA	43	56	12	40	+12V @ 6.5A	Module	HMC-C013
1.8 - 2.2	15 Watt PA	42	53	6	42	+14V @ 6.5A	Module	HMC-C008

ATTENUATORS

Frequency (GHz)	Function	Loss (dB)	Atten. Range (dB)	Input IP3 (dBm)	Control Input (Vdc)	Package	Part Number
Attenuators - Analog							
0.45 - 2.2	Analog VVA, +V	1.9	0 to 48	20	0 to +3V	MS8	HMC473MS8 (E)
1.5 - 2.3	Analog VVA, +V	3.3	0 to 40	15	0 to +2.5V	MS8	HMC210MS8 (E)
DC - 8	Analog VVA	1.5	0 to 32	10	0 to -3V	MS8G	HMC346MS8G (E)
DC - 8	Analog VVA	2	0 to 30	10	0 to -3V	C8	HMC346C8
DC - 8	Analog VVA	2	0 to 30	10	0 to -3V	G8 Hermetic	HMC346G8
DC - 14	Analog VVA	2	0 to 30	10	0 to -3V	LP3	HMC346LP3 (E)
DC - 18	Analog VVA	1.5	0 to 30	10	0 to -3V	LC3B	HMC346LC3B
DC - 20	Analog VVA	2.2	0 to 25	10	0 to -3V	Chip	HMC346
Attenuators - Digital							
DC - 5	1-Bit Digital	0.5	10	50	TTL/CMOS	LP3	HMC541LP3 (E)
0.7 - 4.0	2-Bit Digital	0.5	2 to 6	52	0 / +3V	SOT26	HMC290 (E)
0.7 - 4.0	2-Bit Digital	0.9	4 to 12	54	0 / +3V	SOT26	HMC291 (E)
DC - 6	2-Bit Digital	0.5	2 to 6	50	TTL/CMOS	LP3	HMC467LP3 (E)
0.75 - 2.0	3-Bit Digital	1.8	4 to 28	45	0 / +3V	MS8	HMC230MS8 (E)
0.7 - 3.7	3-Bit Digital	1.3	2 to 14	51	0 / +3V	MS8	HMC288MS8 (E)
DC - 6	3-Bit Digital	0.7	1 to 7	50	TTL/CMOS	LP3	HMC468LP3 (E)
DC - 5.5	4-Bit Digital	0.8	1 to 15	48	TTL/CMOS	LP3	HMC540LP3 (E)
0.7 - 2.7	5-Bit Digital	2.3	1 to 31	54	0 / +3V	QS16	HMC274QS16 (E)
0.7 - 3.0	5-Bit Digital	1.3	0.5 to 15.5	48	0 / +3V	MS10	HMC603MS10 (E)
0.7 - 3.0	5-Bit Digital	1.3	0.5 to 15.5	48	0 / +3V	QS16	HMC603QS16 (E)
0.7 - 3.7	5-Bit Digital, Serial Control	2.1	1 to 31	48	Serial TTL/CMOS	LP4	HMC271LP4 (E)
0.7 - 3.7	5-Bit Digital	2.1	1 to 31	48	0 / +3V	MS10G	HMC273MS10G (E)
0.7 - 3.8	5-Bit Digital, Serial Control	1.5	0.5 to 15.5	52	Serial TTL/CMOS	LP4	HMC305LP4 (E)
0.7 - 3.8	5-Bit Digital	1.5	0.5 to 15.5	52	0 / +3V	MS10	HMC306MS10 (E)

Selection Guide by Product

ATTENUATORS (Continued)

	Frequency (GHz)	Function	Loss (dB)	Atten. Range (dB)	Input IP3 (dBm)	Control Input (Vdc)	Package	Part Number
	DC - 3	5-Bit Digital	2.0	1 to 31	44	0 / -5V	G16 Hermetic	HMC335G16
	DC - 3	5-Bit Digital	1.3	1 to 31	45	TTL/CMOS	LP3	HMC470LP3 (E)
	DC - 4	5-Bit Digital	1.9	1 to 31	44	0 / -5V	QS16G	HMC307QS16G (E)
	DC - 4	5-Bit Digital	0.7	0.25 to 7.75	50	TTL/CMOS	LP3	HMC539LP3 (E)
	DC - 3	6-Bit Digital	1.5	0.5 to 31.5	45	TTL/CMOS	LP4	HMC472LP4 (E)
	DC - 3	6-Bit Digital	3.0	0.5 to 31.5	32	0 / -5V	G16 Hermetic	HMC424G16
NEW!	DC - 3	6-Bit Digital, Serial Control	1.2	0.5 to 31.5	45	Serial TTL/CMOS	LP4	HMC542LP4 (E)
	DC - 13	6-Bit Digital	4.0	0.5 to 31.5	32	0 / -5V	Chip	HMC424
	DC - 13	6-Bit Digital	3.2	0.5 to 31.5	32	0 / -5V	LH5 Hermetic	HMC424LH5
	DC - 13	6-Bit Digital	4.0	0.5 to 31.5	32	0 / -5V	LP3	HMC424LP3 (E)
	2.4 - 8.0	6-Bit Digital	3.5	0.5 to 31.5	40	0 / +5V	Chip	HMC425
	2.4 - 8.0	6-Bit Digital	3.2	0.5 to 31.5	40	0 / +5V	LP3	HMC425LP3 (E)

Connectorized Attenuator Modules

	Frequency (GHz)	Function	Loss (dB)	Atten. Range (dB)	Input IP3 (dBm)	Control Input (Vdc)	Package	Part Number
NEW!	DC - 13	6-Bit Digital, Serial Control	3.6	0.5 to 31.5	32	Serial TTL/CMOS	Module	HMC-C018
	DC - 13	6-Bit Digital	3.2	0.5 to 31.5	38	0 / +5V	Module	HMC-C025

DATA CONVERTERS

	Input Freq. (GHz)	Function	Single Tone THD/SFDR (dB)	Max. Clock Rate (GS/s)	Output Noise (mV RMS)	Hold Mode Feed-through Rejection (dB)	Package	Part Number
NEW!	DC - 4.5	Track-and-Hold Amplifier	-66/67	3.0	0.95	>60	LC4B	HMC660LC4B

FREQUENCY DIVIDERS (PRESCALERS) & PHASE / FREQUENCY DETECTORS

Input Freq. (GHz)	Function	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
DC - 8	Divide-by-2	-12 to +12	-6	-148	+3V @ 42mA	SOT26	HMC432 (E)
DC - 10	Divide-by-2	-15 to +10	0	-148	+5V @ 83mA	S8G	HMC361S8G (E)
DC - 11	Divide-by-2	-15 to +10	0	-148	+5V @ 105mA	Chip	HMC361
DC - 12.5	Divide-by-2	-15 to +10	2	-145	+5V @ 105mA	S8G	HMC364S8G (E)
DC - 13	Divide-by-2	-15 to +10	1	-145	+5V @ 105mA	Chip	HMC364
DC - 13	Divide-by-2	-15 to +10	5	-145	+5V @ 110mA	G8 Hermetic	HMC364G8
DC - 18	Divide-by-2	-15 to +10	-4	-150	+5V @ 77mA	LP3	HMC492LP3 (E)
DC - 8	Divide-by-3	-12 to +12	-2	-148	+5V @ 67mA	MS8G	HMC437MS8G (E)
0.1 - 3.0	Divide-by-4	-20 to +10	3.5	-146	+3V @ 13mA	MS8	HMC426MS8 (E)
DC - 8	Divide-by-4	-12 to +12	-3	-150	+3V @ 53mA	SOT26	HMC433
DC - 11	Divide-by-4	-15 to +10	-9	-149	+5V @ 68mA	Chip	HMC362
DC - 12	Divide-by-4	-15 to +10	-9	-149	+5V @ 68mA	S8G	HMC362S8G (E)
DC - 13	Divide-by-4	-15 to +10	2	-151	+5V @ 110mA	Chip	HMC365
DC - 13	Divide-by-4	-15 to +10	7	-151	+5V @ 120mA	G8 Hermetic	HMC365G8
DC - 13	Divide-by-4	-15 to +10	2	-151	+5V @ 110mA	S8G	HMC365S8G (E)
DC - 18	Divide-by-4	-15 to +10	-4	-150	+5V @ 96mA	LP3	HMC493LP3 (E)
10 - 26	Divide-by-4	-15 to +10	-4	-150	+5V @ 96mA	LC3	HMC447LC3
DC - 8	Divide-by-5	-12 to +12	-1	-150	+5V @ 80mA	MS8G	HMC438MS8G (E)
DC - 8	Divide-by-8	-5 to +12	-2	-150	+3V @ 62mA	SOT26	HMC434 (E)
DC - 12	Divide-by-8	-15 to +10	-9	-153	+5V @ 70mA	Chip	HMC363
DC - 12	Divide-by-8	-15 to +10	4	-153	+5V @ 90mA	G8 Hermetic	HMC363G8
DC - 12	Divide-by-8	-15 to +10	-9	-153	+5V @ 70mA	S8G	HMC363S8G (E)
DC - 18	Divide-by-8	-15 to +10	-4	-150	+5V @ 105mA	LP3	HMC494LP3 (E)

Connectorized Frequency Divider Modules

Input Freq. (GHz)	Function	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
DC - 18	Divide-by-2	-15 to +10	-4	-150	+5V @ 75mA	Module	HMC-C005
DC - 18	Divide-by-4	-15 to +10	-4	-150	+5V @ 93mA	Module	HMC-C006
DC - 18	Divide-by-8	-15 to +10	-4	-150	+5V @ 98mA	Module	HMC-C007

Phase / Frequency Detectors & Counters

Input Freq. (GHz)	Function	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
DC - 2.2	5-bit Counter, ÷2 to 32	-15 to +10	4	-153	+5V @ 194mA	LP4	HMC394LP4 (E)

FREQUENCY DIVIDERS (PRESCALERS) & PHASE / FREQUENCY DETECTORS (Continued)

Input Freq. (GHz)	Function	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
0.01 - 1.3	Phase Freq. Detector	-10 to +10	2 Vpk-pk	-153	+5V @ 96mA	QS16G	HMC439QS16G (E)
0.01 - 1.3	PFD / Counter	-10 to +10	2 Vpk-pk	-153	+5V @ 250mA	QS16G	HMC440QS16G (E)

FREQUENCY MULTIPLIERS - ACTIVE

Input Freq. (MHz)	Function	Output Freq. (GHz)	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Package	Part Number
4500 - 8000	Active X2	9 - 16	2	15	-140	LP4	HMC368LP4 (E)
4950 - 6350	Active X2	9.9 - 12.7	0	4	-142	LP3	HMC369LP3 (E)
NEW! 2500 - 5000	Active x2	5 - 10	3	17	-140	LP4	HMC575LP4 (E)
NEW! 9000 - 13500	Active x2	18 - 27	3	16	-132	Chip	HMC576
NEW! 9000 - 13500	Active x2	18 - 27	3	17	-132	LC3B	HMC576LC3B
9500 - 12500	Active X2	19 - 25	0	12	-135	Chip	HMC448
10000 - 12500	Active X2	20 - 25	0	11	-135	LC3B	HMC448LC3B
NEW! 12000 - 16500	Active x2	24 - 33	3	16	-129	Chip	HMC578
NEW! 12000 - 16500	Active x2	24 - 33	3	16	-129	LC3B	HMC578LC3B
13500 - 16500	Active X2	27 - 33	0	10	-132	Chip	HMC449
13500 - 15500	Active X2	27 - 31	0	10	-132	LC3B	HMC449LC3B
NEW! 14750 - 15000	Active x2	29.5 - 30	3	21	-128	LC4B	HMC577LC4B
NEW! 16000 - 23000	Active x2	32 - 46	3	12	-127	Chip	HMC579
2450 - 2800	Active X4	9.8 - 11.2	-15	3	-142	LP4	HMC443LP4 (E)
3600 - 4100	Active X4	14.4 - 16.4	-15	-2	-140	LP4	HMC370LP4 (E)
1237.5 - 1400	Active X8	9.9 - 11.2	-15	4	-136	LP4	HMC444LP4 (E)
618.75 - 687.5	Active X16	9.9 - 11.2	-15	6	-130	LP4	HMC445LP4 (E)

FREQUENCY MULTIPLIERS - PASSIVE

Input Freq. (GHz)	Function	Output Freq. (GHz)	Conv. Gain (dB)	1Fo / 4Fo Isolation (dBm)	Input Drive (dBm)	Package	Part Number
0.7 - 2.4	X2 Passive	1.4 - 4.8	-15	47 / 38	10 to 20	Chip	HMC156
0.7 - 2.4	X2 Passive	1.4 - 4.8	-15	47 / 38	10 to 20	C8	HMC156C8
0.85 - 2.0	X2 Passive	1.6 - 4.0	-15	45 / 40	10 to 20	MS8	HMC187MS8 (E)
1.25 - 3.0	X2 Passive	2.5 - 6.0	-15	45 / 45	10 to 20	MS8	HMC188MS8 (E)
1.3 - 4.0	X2 Passive	2.6 - 8.0	-15	45 / 40	10 to 20	Chip	HMC158
1.3 - 4.0	X2 Passive	2.6 - 8.0	-15	45 / 40	10 to 20	C8	HMC158C8
2 - 4	X2 Passive	4 - 8	-13	34 / 40	10 to 15	MS8	HMC189MS8 (E)
4 - 8	X2 Passive	8 - 16	-20	45 / 38	10 to 15	Chip	HMC204
4 - 8	X2 Passive	8 - 16	-17	41 / 40	10 to 15	C8	HMC204C8
4 - 8	X2 Passive	8 - 16	-17	42 / 50	10 to 15	MS8G	HMC204MS8G (E)
6 - 12	X2 Passive	12 - 24	-17	32 / 32	10 to 15	Chip	HMC205
12 - 18	X2 Passive	24 - 36	-14	50 / 60	11 to 15	Chip	HMC331

I/Q MIXERS / IRMs

RF/LO Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	Image Rejection (dB)	Input IP3 (dBm)	Package	Part Number
1.7 - 4.5	I/Q Mixer / IRM	DC - 1.5	-8	-	23	LP5	HMC340LP5 (E)
4 - 8.5	I/Q Mixer / IRM	DC - 3.5	-7.5	40	23	Chip	HMC525
4 - 8.5	I/Q Mixer / IRM	DC - 3.5	-7.5	40	23	LC4	HMC525LC4
5.9 - 12.0	I/Q Mixer / IRM	DC - 1.5	-8	30	18	Chip	HMC256
6 - 10	I/Q Mixer / IRM	DC - 3.5	-7	40	22	Chip	HMC520
6 - 10	I/Q Mixer / IRM	DC - 3.5	-7	40	23	LC4	HMC520LC4
6 - 10	I/Q Mixer / IRM	DC - 3.5	-7.5	40	28	Chip	HMC526
6 - 10	I/Q Mixer / IRM	DC - 3.5	-7.5	40	28	LC4	HMC526LC4
8.5 - 13.5	I/Q Mixer / IRM	DC - 3.5	-7.5	40	24	Chip	HMC521
8.5 - 13.5	I/Q Mixer / IRM	DC - 2	-7.5	35	28	Chip	HMC527
8.5 - 13.5	I/Q Mixer / IRM	DC - 2	-7.5	34	28	LC4	HMC527LC4
8.5 - 13.6	I/Q Mixer / IRM	DC - 3.5	-7.5	38	24	LC4	HMC521LC4

SELECTION GUIDE BY PRODUCT

I/Q MIXERS / IRMs (Continued)

	RF/LO Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	Image Rejection (dB)	Input IP3 (dBm)	Package	Part Number
	11 - 16	I/Q Mixer / IRM	DC - 3.5	-7.5	35	24	Chip	HMC522
	11 - 16	I/Q Mixer / IRM	DC - 3.5	-7.5	35	24	LC4	HMC522LC4
	11 - 16	I/Q Mixer / IRM	DC - 3.5	-8	35	27	Chip	HMC528
	11 - 16	I/Q Mixer / IRM	DC - 3.5	-8	35	26	LC4	HMC528LC4
	15 - 23	I/Q Mixer / IRM	DC - 3.5	-8	25	25	LC4	HMC523LC4
	15 - 23.6	I/Q Mixer / IRM	DC - 3.5	-8	27	25	Chip	HMC523
	22 - 32	I/Q Mixer / IRM	DC - 3.5	-10	23	20	Chip	HMC524
NEW!	31 - 38	I/Q Mixer / IRM	DC - 3.5	-10.5	17	21	Chip	HMC555
NEW!	36 - 41	I/Q Mixer / IRM	DC - 3.5	-11	18	23	Chip	HMC556
	26 - 33 RF	Sub-Harmonic I/Q Mixer / IRM	DC - 3	-11	22	16	Chip	HMC404
	Connectorized I/Q Mixer Modules							
	4 - 8.5	I/Q Mixer	DC - 3.5	-7.5	37	23	Module	HMC-C009

MIXERS

	RF Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
	High IP3 Mixers							
	0.45 - 0.5	High IP3, SGL-END	DC - 0.15	-9.5	20	32	MS8	HMC387MS8 (E)
	0.6 - 1.2	High IP3, DBL-BAL	DC - 0.3	-7.5	22	27	MS8	HMC350MS8 (E)
	0.7 - 1.2	High IP3, DBL-BAL	DC - 0.3	-10	42	26	S8	HMC351S8 (E)
	0.7 - 1.4	High IP3, 0 LO	DC - 0.35	-9	20	35	MS8G	HMC483MS8G (E)
	0.74 - 0.96	High IP3, SGL-END	DC - 0.25	-8.5	24	35	MS8	HMC399MS8 (E)
NEW!	0.8 - 1.2	High IP3, DBL-BAL, 0 LO	DC - 0.3	-8	27	27	LP4	HMC551LP4 (E)
	1.1 - 1.7	High IP3, DBL-BAL	DC - 0.7	-7	40	24	MS8	HMC296MS8 (E)
	1.3 - 2.5	High IP3, DBL-BAL	DC - 0.65	-9	30	25	MS8	HMC216MS8 (E)
	1.5 - 3.5	High IP3, DBL-BAL	DC - 1	-8	38	25	MS8	HMC316MS8 (E)
NEW!	1.6 - 3.0	High IP3, DBL-BAL, 0 LO	DC - 1	-8	30	25	LP4	HMC552LP4 (E)
	1.7 - 2.2	High IP3, SGL-END	DC - 0.3	-8.8	30	36	MS8	HMC400MS8 (E)
	1.7 - 2.2	High IP3, 0 LO	0.05 - 0.3	-9.2	-8	35	MS8G	HMC485MS8G (E)
	1.7 - 3.0	High IP3, SGL-BAL	DC - 0.8	-9	30	30	MS8	HMC304MS8 (E)
	1.8 - 2.2	High IP3, SGL-END	DC - 0.5	-8.5	25	31	MS8	HMC402MS8 (E)
	2.4 - 4.0	High IP3, SGL-END	DC - 1	-10	30	34	MS8	HMC214MS8 (E)
	9 - 15	High IP3, DBL-BAL	DC - 2.5	-7.5	40	24	MS8G	HMC410MS8G (E)
	Downconverter RFICs							
	0.7 - 1.0	Downconverter	0.05 - 0.25	12.5	25	15	QS16	HMC420QS16 (E)
	0.8 - 1.0	Hi-IP3 Downconverter	0.05 - 0.25	13.8	28	15	QS16G	HMC377QS16G (E)
	1.4 - 2.3	Hi-IP3 Downconverter	0.05 - 0.3	9	33	19	QS16G	HMC421QS16 (E)
	1.7 - 2.2	Hi-IP3 Downconverter	0.05 - 0.3	11	25	19	QS16G	HMC380QS16G (E)
	1.7 - 2.2	Hi-IP3 Dual Downconverter	50 - 300	9	10	27	LP6	HMC381LP6 (E)
	0 to +7 dBm LO Double & Single Balanced Mixers							
	0.6 - 1.3	Low LO, DBL-BAL	DC - 0.4	-8	35	15	MS8	HMC423MS8 (E)
	1.2 - 2.5	Low LO, DBL-BAL	DC - 1	-8	30	15	MS8	HMC422MS8 (E)
	2 - 2.8	Low LO, SGL-BAL	DC - 1	-8	20	10	SOT26	HMC332 (E)
	3 - 3.8	Low LO, SGL-BAL	DC - 1	-8.5	15	10	SOT26	HMC333 (E)
	4 - 7	0 LO, DBL-BAL	DC - 2.5	-7	32	15	MS8G	HMC488MS8G (E)
	4.5 - 6.0	+7 LO, DBL-BAL	DC - 1.6	-7	28	13	MS8	HMC218MS8 (E)
	+10 dBm LO Double & Single Balanced Mixers							
	0.7 - 2.0	+10 LO, DBL-BAL	DC - 0.3	-9	45	17	S8	HMC207S8 (E)
	0.7 - 2.0	+10 LO, DBL-BAL	DC - 0.5	-9	24	17	MS8	HMC208MS8 (E)
	1.5 - 4.5	+10 LO, DBL-BAL	DC - 1.5	-8.5	40	19	MS8	HMC213MS8 (E)
	1.7 - 3.0	+10 LO, SGL-BAL	DC - 0.8	-9	30	21	MS8	HMC272MS8 (E)

MIXERS (Continued)

RF Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
1.7 - 3.5	+10 LO, SGL-BAL	DC - 0.9	-9	30	21	SOT26	HMC285 (E)
4.5 - 8.0	+10 LO, DBL-BAL	DC - 2	-8.2	35	16	C8	HMC168C8
5 - 12	+10 LO, DBL-BAL	DC - 4	-7.5	25	17	MS8	HMC220MS8 (E)
7 - 10	+10 LO, DBL-BAL	DC - 2	-9	32	16	C8	HMC171C8

+13 dBm LO Double & Single Balanced Mixers

RF Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
1.7 - 4.5	+13 LO, DBL-BAL	DC - 1	-8	30	20	MS8	HMC175MS8 (E)
2.5 - 4.0	+13 LO, DBL-BAL	DC - 2	-9	45	18	C8	HMC170C8
4.5 - 9.0	+13 LO, DBL-BAL	DC - 2.5	-8.5	25	21	MS8	HMC219MS8 (E)
NEW! 7 - 14	+13 LO, DBL-BAL	DC - 5	-7	48	22	Chip	HMC553
NEW! 7 - 14	+13 LO, DBL-BAL	DC - 5	-7	50	22	LC3B	HMC553LC3B
9 - 15	+13 LO, DBL-BAL	DC - 2.5	-7.5	40 - 50	17	MS8G	HMC412MS8G (E)
10 - 15	+13 LO, SGL-BAL	DC - 3	-9	27	16	MS8G	HMC411MS8G (E)
NEW! 11 - 20	+13 LO, DBL-BAL	DC - 6	-7	46	18	Chip	HMC554
NEW! 11 - 20	+13 LO, DBL-BAL	DC - 6	-7	46	18	LC3B	HMC554LC3B
14 - 26	+13 LO, DBL-BAL	DC - 8	-7.5	39	20	Chip	HMC260
14 - 26	+13 LO, DBL-BAL	DC - 8	-7.5	38	20	LC3B	HMC260LC3B
16 - 30	+13 LO, DBL-BAL	DC - 8	-8	38	21	LC3B	HMC292LC3B
17 - 31	+13 LO, DBL-BAL	DC - 6	-8	32	19	LM3C	HMC292LM3C
20 - 30	+13 LO, DBL-BAL	DC - 8	-7.5	38	19	Chip	HMC292
24 - 32	+13 LO, DBL-BAL	DC - 8	-10	38	18	LC3B	HMC329LC3B
NEW! 24 - 40	+13 LO, DBL-BAL	DC - 18	-8	35	21	Chip	HMC560
NEW! 24 - 40	+13 LO, DBL-BAL	DC - 17	-10	35	21	LM3	HMC560LM3
25 - 40	+13 LO, DBL-BAL	DC - 8	-9.5	42	19	Chip	HMC329
26 - 40	+13 LO, DBL-BAL	DC - 8	-8	37	19	LM3	HMC329LM3

+15 to +20 dBm LO Double & Single Balanced Mixers

RF Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
1.8 - 5.0	+15 LO, DBL-BAL	DC - 3	-7	42	18	Chip	HMC128
1.8 - 5.0	+15 LO, DBL-BAL	DC - 2	-8	40	18	G8 Hermetic	HMC128G8
4 - 8	+15 LO, DBL-BAL	DC - 3	-7	40	17	Chip	HMC129
4 - 8	+15 LO, DBL-BAL	DC - 3	-7	30	17	G8 Hermetic	HMC129G8
4 - 8	+15 LO, DBL-BAL	DC - 3	-7	40	17	LC4	HMC129LC4
6 - 11	+15 LO, DBL-BAL	DC - 2	-7	40	17	Chip	HMC130
6 - 15	+15 LO, DBL-BAL	DC - 2	-8.5	35	20	C8	HMC141C8 / 142C8
6 - 18	+15 LO, DBL-BAL	DC - 6	-10	25	21	Chip	HMC141 / 142
7 - 14	+15 LO, DBL-BAL	DC - 2	-10	35	20	LH5 Hermetic	HMC141LH5
14 - 23	+15 LO, DBL-BAL	DC - 2	-10.5	38	18	Chip	HMC203
5 - 20	+20 LO, DBL-BAL	DC - 3	-10	30	21	Chip	HMC143 / 144
6 - 20	+20 LO, DBL-BAL	DC - 3	-10	30	21	LC4	HMC144LC4

Sub-Harmonic Mixers

RF Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
14 - 20 RF	Sub-Harmonic	DC - 3	-10	40	7	LM3	HMC258LM3
14 - 21 RF	Sub-Harmonic	DC - 3	-10	40	7	Chip	HMC258
17 - 25 RF	Sub-Harmonic	DC - 3	-9	25 - 30	10	Chip	HMC337
20 - 30 RF	Sub-Harmonic	DC - 6	-10	40	13	Chip	HMC264
21 - 31 RF	Sub-Harmonic	DC - 6	-9	40	13	LC3B	HMC264LC3B
20 - 30 RF	Sub-Harmonic	DC - 4	-9	30	10	LM3	HMC264LM3
20 - 31 RF	Sub-Harmonic	0.7 - 3.0	3	28	8	LM3	HMC265LM3
20 - 32 RF	Sub-Harmonic	0.7 - 3.0	3	20 - 40	10	Chip	HMC265
20 - 40 RF	Sub-Harmonic	1 - 3	-12	24	13	Chip	HMC266
26 - 33 RF	Sub-Harmonic	DC - 2.5	-9	33	11	Chip	HMC338
33 - 42 RF	Sub-Harmonic	DC - 3	-10	37	10	Chip	HMC339

Connectorized Mixer Modules

RF Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	LO/RF Isol. (dB)	Input IP3 (dBm)	Package	Part Number
16 - 32	+13 LO, DBL-BAL	DC - 8	-8	28	19	Module	HMC-C014
24 - 38	+13 LO, DBL-BAL	DC - 8	-8.5	35	20	Module	HMC-C015

MODULATORS - BI-PHASE

Input Freq. (GHz)	Function	Loss (dB)	Amp/Phase Balance (dB/Degree)	Carrier Supr. (dBc)	Bias Control (mA)	Package	Part Number
1.8 - 5.2	Bi-Phase	8	0.2 / 2.5	30	+/- 5	Chip	HMC135
4 - 8	Bi-Phase	8	0.1 / 4.0	30	+/- 5	Chip	HMC136
6 - 11	Bi-Phase	9	0.25 / 10.0	20	+/- 5	Chip	HMC137

MODULATORS - DIRECT QUADRATURE

Input Freq. (GHz)	Function	Output IP3 (dBm) / Carrier Supr. (dBc)	Modulation Bandwidth (MHz)	Output Noise Floor (dBc/Hz)	Bias Supply	Package	Part Number
0.1 - 4	Direct	23 / 42	DC - 700	-159	+5V @ 170mA	LP4	HMC497LP4 (E)
0.25 - 3.8	Direct	14 / 38	DC - 250	-158	+3.3V @ 108mA	LP3	HMC495LP3 (E)
4 - 7	Direct	17 / 34	DC - 250	-157	+3V @ 93mA	LP3	HMC496LP3 (E)

MODULATORS - VECTOR

Frequency (GHz)	Function	Gain Range (dB)	Continuous Phase Control (degrees)	IP3 / Noise Floor (Ratio)	Input IP3 @ Max. Gain (dBm)	Package	Part Number
1.8 - 2.2	Vector	-50 to -10	360	185	33	LP3	HMC500LP3 (E)

PHASE SHIFTERS - Analog

Frequency (GHz)	Function	Insertion Loss (dB)	Phase Range (deg)	2nd harmonic Pin = 10 dBm (dBc)	Control Voltage Range (Vdc)	Package	Part Number
5 - 18	Analog	4	500° @ 5 GHz 100° @ 18 GHz	80	0V to +10V	Chip	HMC247
6 - 15	Analog	7	750° @ 6 GHz 500° @ 15 GHz	40	0V to +5V	LP4	HMC538LP4 (E)
Connectorized Phase Shifter Modules							
6 - 15	Analog	7	750° @ 6 GHz 450° @ 15 GHz	40	0V to +5V	Module	HMC-C010

POWER DETECTORS

	Frequency (GHz)	Function	± 3 dB Dynamic Range (dB)	RSSI Slope (mV / dB)	RF Threshold Level (dBm)	Bias Supply	Package	Part Number
NEW!	0.05 - 4.0	Log Detector/Controller	75	19	-69	+2.7 to +5.5V @ 29mA	LP4	HMC600LP4 (E)

SWITCHES

	Frequency (GHz)	Function	Insertion Loss (dB)	Isolation (dB)	Input P1dB (dBm)	Control Input (Vdc)	Package	Part Number
	SPST Switches							
NEW!	DC - 6	SPST, Failsafe	0.7	25	27	0 / +2.2 to +5V	SOT26	HMC550 (E)
	DC - 6	SPST, Hi Isolation	1.4	52	27	0 / -5V	G7 Hermetic	HMC231G7
	SPDT Switches							
	DC - 2.5	SPDT, Reflective	0.4	36	29	0 / -5V	S8	HMC239S8 (E)
	DC - 3	SPDT, Reflective	0.4	28	30	0 / +3V	SOT26	HMC197 (E)
	DC - 3	SPDT, Reflective	0.4	28	30	0 / +3V	SOT26	HMC221 (E)
	DC - 3	SPDT, Reflective	0.4	27	30	0 / +3V	MS8	HMC190MS8 (E)
	DC - 3	SPDT, Reflective	0.3	31	34	0 / +3 to +8V	SOT26	HMC545 (E)
	DC - 4	SPDT, Reflective	0.5	28	29	0 / -5V or +5V / 0	Chip	HMC240
	DC - 2.5	SPDT, CATV	0.6	58	28	0 / +5V	LP3	HMC348LP3 (E)
	DC - 3	SPDT, Hi Isolation	0.7	50	23	0 / +5V	MS8	HMC194MS8 (E)
	DC - 3.5	SPDT, Hi Isolation	0.5	45	25	0 / +5V	MS8G	HMC284MS8G (E)
	DC - 4	SPDT, Hi Isolation	0.9	65	31	0 / +5V	LP4C	HMC349LP4C
	DC - 4	SPDT, Hi Isolation	0.9	57	31	0 / +5V	MS8G	HMC349MS8G (E)
	DC - 4	SPDT, Hi Isolation	1.1	47	31	0 / +5V	MS8G	HMC435MS8G (E)
	DC - 6	SPDT, Hi Isolation	1.4	50	26	0 / -5V	G7 Hermetic	HMC232G7
	DC - 6	SPDT, Hi Isolation	1.4	43	26	0 / -5V	G8 Hermetic	HMC232G8
	DC - 6	SPDT, Hi Isolation	1.4	43	26	0 / -5V	G8 Hermetic	HMC233G8
	DC - 6	SPDT, Hi Isolation	1.6	42	25	0 / +5V	MS8G	HMC336MS8G (E)

SWITCHES (Continued)

Frequency (GHz)	Function	Insertion Loss (dB)	Isolation (dB)	Input P1dB (dBm)	Control Input (Vdc)	Package	Part Number
DC - 8	SPDT, Hi Isolation	1.4	50	26	0 / -5V	C8	HMC232C8
DC - 8	SPDT, Hi Isolation	1.5	45	26	0 / -5V	C8	HMC234C8
DC - 8	SPDT, Hi Isolation	1.2	48	23	0 / -5V	MS8G	HMC270MS8G (E)
DC - 8	SPDT, Hi Isolation	2.0	44	23	0 / -5V	C8	HMC347C8
DC - 8	SPDT, Hi Isolation	2.2	35	23	0 / -5V	G8 Hermetic	HMC347G8
DC - 12	SPDT, Hi Isolation	1.5	55	27	0 / -5V	LP4	HMC232LP4 (E)
DC - 15	SPDT, Hi Isolation	1.4	50	26	0 / -5V	Chip	HMC232
DC - 15	SPDT, Hi Isolation	1.7	44	23	0 / -5V	LP3	HMC347LP3 (E)
DC - 20	SPDT, Hi Isolation	1.7	45	23	0 / -5V	Chip	HMC347
DC - 20	SPDT, Hi Isolation	1.8	47	23	0 / -5V	LP3	HMC547LP3 (E)
0.2 - 2.2	SPDT, 10W, Failsafe	0.4	40	> 40	0 / +3 to +8V	MS8G	HMC546MS8G (E)
NEW! 0.2 - 2.7	SPDT, 10W, Failsafe	0.4	35	40	0 / +3 to +8V	LP2	HMC546LP2 (E)
0.824 - 0.894	SPDT, 10W, T/R	0.6	22	> 40	0 / +5V	SOT26	HMC446 (E)
DC - 2	SPDT T/R	0.6	20	35	0 / +3V	SOT26	HMC226 (E)
DC - 3	SPDT, 3W, T/R	0.3	30	37	0 / +3 to +10V	SOT26	HMC595 (E)
DC - 3	SPDT, 5W, T/R	0.3	30	39	0 / +3 to +10V	MS8	HMC574MS8 (E)
DC - 3	SPDT, 10W, T/R	0.5	30	> 40	0 / +3 to +10V	MS8G	HMC484MS8G (E)
NEW! DC - 4	SPDT T/R	0.25	23	39	0 / +3 to +5V	SOT26	HMC544 (E)
DC - 6	SPDT T/R	0.5	27	37	0 / +3 to +5V	MS8G	HMC536MS8G (E)
5 - 6	SPDT T/R	1.2	31	33	TTL/CMOS	MS8	HMC224MS8 (E)
Multi-Throw Switches							
DC - 3.5	SP3T	0.5	44	26	TTL/CMOS	QS16	HMC245QS16 (E)
DC - 2	SP4T	0.8	32	24	0 / -5V	S14	HMC182S14 (E)
DC - 3.5	SP4T	0.6	45	25	TTL/CMOS	QS16	HMC241QS16 (E)
DC - 4	SP4T	0.6	47	26	TTL/CMOS	LP3	HMC241LP3 (E)
DC - 4	SP4T	0.7	40	25	TTL/CMOS	G16 Hermetic	HMC244G16
DC - 8	SP4T	1.8	42	21	0 / -5V	Chip	HMC344
DC - 12	SP4T	1.8	42	27	0 / -5V	LH5 Hermetic	HMC344LH5
DC - 8	SP4T	1.8	40	21	0 / -5V	LP3	HMC344LP3 (E)
DC - 8	SP4T	2	32	21	0 / 5V	LP3	HMC345LP3 (E)
DC - 3	SP6T	0.8	41	24	TTL/CMOS	QS24	HMC252QS24 (E)
DC - 2	SP8T	1.3	30	20	0 / -5V	QS24	HMC183QS24 (E)
DC - 2.5	SP8T	1.1	36	23	TTL/CMOS	QS24	HMC253QS24 (E)
DC - 8	SP8T	2.3	40	23	0 / 5V	LP4	HMC321LP4 (E)
DC - 10	SP8T	2	38	23	0 / -5V	Chip	HMC322
DC - 8	SP8T	2.5	25	23	0 / -5V	LP4	HMC322LP4 (E)
Bypass, Diversity, Matrix & Transfer Switches							
DC - 2.5	Bypass DPDT	0.3	25	23	0 / +5V	MS8	HMC199MS8 (E)
4.9 - 5.9	Diversity DPDT	1	23	30	0 / +3V	MS8G	HMC436MS8G (E)
5 - 6	Diversity DPDT	1.2	20	30	0 / +5V	MS8G	HMC393MS8G (E)
0.2 - 3.0	4x2 Matrix	6	44	26	0 / +5V	LP4	HMC276LP4 (E)
0.7 - 3.0	4x2 Matrix	5.8	33	26	0 / +5V	QS24	HMC276QS24 (E)
DC - 8.0	Transfer	1.2	42	26	0 / +5V	LP3	HMC427LP3 (E)
Connectorized Switch Modules							
NEW! DC - 20	SPST, Hi Isolation	3	100	23	0 / +5V	Module	HMC-C019
DC - 20	SPDT, Hi Isolation	2.0	40	23	0 / -5V	Module	HMC-C011

VOLTAGE CONTROLLED OSCILLATORS*

Frequency (GHz)	Function	Output Power (dBm)	10kHz SSB Phase Noise (dBc/Hz)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
2.05 - 2.25	VCO w/ Buffer	3.5	-89	-112	+3V @ 35mA	LP4	HMC384LP4 (E)
2.25 - 2.5	VCO w/ Buffer	4.5	-89	-115	+3V @ 35mA	LP4	HMC385LP4 (E)
2.6 - 2.8	VCO w/Buffer	5	-88	-115	+3V @ 35mA	LP4	HMC386LP4 (E)

Selection Guide by Product

VOLTAGE CONTROLLED OSCILLATORS* (Continued)

Frequency (GHz)	Function	Output Power (dBm)	10kHz SSB Phase Noise (dBc/Hz)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
2.75 - 3.0	VCO w/Buffer	4.5	-89	-114	+3V @ 37mA	LP4	HMC416LP4 (E)
3.15 - 3.4	VCO w/ Buffer	4.9	-88	-113	+3V @ 39mA	LP4	HMC388LP4 (E)
3.35 - 3.55	VCO w/ Buffer	4.7	-89	-112	+3V @ 41mA	LP4	HMC389LP4 (E)
3.55 - 3.9	VCO w/ Buffer	4.7	-87	-112	+3V @ 42mA	LP4	HMC390LP4 (E)
3.9 - 4.45	VCO w/ Buffer	5	-81	-106	+3V @ 30mA	LP4	HMC391LP4 (E)
4.45 - 5.0	VCO w/ Buffer	4	-79	-105	+3V @ 30mA	LP4	HMC429LP4 (E)
5.0 - 5.5	VCO w/ Buffer	2	-80	-103	+3V @ 27mA	LP4	HMC430LP4 (E)
5.5 - 6.1	VCO w/ Buffer	2	-80	-102	+3V @ 27mA	LP4	HMC431LP4 (E)
5.6 - 6.8	VCO w/ Buffer	10	-82	-105	+5V @ 83mA	MS8G	HMC358MS8G (E)
6.1 - 6.72	VCO w/ Buffer	4.5	-73	-101	+3V @ 31mA	LP4	HMC466LP4 (E)
6.8 - 7.3	VCO w/ Buffer	11	-82	-104	+3V @ 80mA	LP4	HMC505LP4 (E)
7.8 - 8.8	VCO w/ Buffer	14	-80	-103	+3V @ 77mA	LP4	HMC506LP4 (E)
13.2 -13.5	VCO w/ ÷8	-8	-83	-110	+5V @ 230mA	QS16G	HMC401QS16G (E)
14.0 - 15.0	VCO w/ ÷8	6	-75	-110	+5V @ 260mA	QS16G	HMC398QS16G (E)
23.8 - 24.8	VCO w/ ÷16	11	-70	-95	+5V @ 220mA	LP4	HMC533LP4 (E)
10.43 - 11.46 / 5.21 - 5.73	VCO with Fo/2 & ÷4	7	-85	-110	+3V @ 275mA	LP5	HMC513LP5 (E)
11.17 - 12.02 / 5.58 - 6.0	VCO with Fo/2 & ÷4	7	-85	-110	+3V @ 275mA	LP5	HMC514LP5 (E)
11.5 - 12.5	VCO with Fo/2 & ÷4	10	-85	-110	+5V @ 200mA	LP5	HMC515LP5 (E)
12.4 - 13.4	VCO with Fo/2 & ÷4	8	-85	-110	+5V @ 260mA	LP5	HMC529LP5 (E)
13.6 - 14.9	VCO with Fo/2 & ÷4	7	-82	-110	+5V @ 260mA	LP5	HMC531LP5 (E)
Wideband VCOs							
NEW! 4 - 8	Wideband VCO	5	-75	-100	+5V @ 55mA	LC4B	HMC586LC4B
5 - 10	Wideband VCO	5	-65	-95	+5V @ 55mA	LC4B	HMC587LC4B
8 - 12.5	Wideband VCO	5	-65	-93	+5V @ 55mA	LC4B	HMC588LC4B

***** *HMC VCOs integrate resonator, negative resistance generator and tuning varactor circuits on-chip. No external components are required.*

PHASE LOCKED OSCILLATOR

Frequency (GHz)	Function	Output Power (dBm)	10kHz SSB Phase Noise (dBc/Hz)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
14.7 - 15.4	Phase Locked Oscillator	9	-110	-110	+5V @ 340mA +12V @ 28mA	LP4	HMC535LP4 (E)

CONNECTORIZED MODULES

Robust, High Performance RF to Light Solutions

Our hermetic module product line is expanding with new wideband / power / low noise amplifiers, attenuators, mixers, phase shifters, prescalers & switches. Utilizing our standard MMIC products, we take advantage of our design, manufacturing and quality knowledge base. Contact us to discuss your custom module requirements.

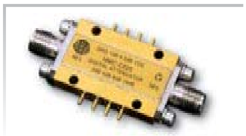
C-1
35.31 x 17.78 x 7.38 mm

C-2
38.1 x 17.78 x 7.38 mm

C-3
40.89 x 17.78 x 7.38 mm

C-4
41.66 x 36.32 x 8.50 mm

C-5
41.66 x 29.84 x 8.50 mm



C-6
45.34 x 17.27 x 8.50 mm

C-7
High Power Amplifiers

C-9
41.66 x 27.59 x 8.50 mm

C-10
41.66 x 27.59 x 8.50 mm

FEATURES:

- *Off-The-Shelf Availability*
- *Hermetically Sealed*
- *Internal DC Power Regulation*
- *Field Replacable Connectors*
- *Military & Space Upscreening*
- *Customization Offered*

AMPLIFIERS

	Frequency (GHz)	Function	Gain (dB)	OIP3 (dBm)	NF (dB)	P1dB (dBm)	Bias Supply	Package	Part Number
NEW!	29 - 36	Low Noise	20	22	2.9	11	+3V @ 80mA	Module	HMC-C027
	2 - 20	Wideband LNA	15	24	2.2	14	+12V @ 65mA	Module	HMC-C001
	2 - 20	Wideband LNA	14	26	2	18	+12V @ 60mA	Module	HMC-C002
	2 - 20	Wideband LNA	14	27	2	16	+8V @ 75mA	Module	HMC-C022
	7 - 17	Wideband LNA	22	25	2.5	14	+8V @ 93mA	Module	HMC-C016
	17 - 27	Wideband LNA	18	25	3	14	+8V @ 96mA	Module	HMC-C017
	0.01 - 20	Wideband Driver	16	33	3	23	+12V @ 195mA	Module	HMC-C004
	0.01 - 20	Wideband Driver	15	30	3	23	+12V @ 225mA	Module	HMC-C024
	2 - 20	Wideband PA	15	34	4	26	+12V @ 310mA	Module	HMC-C003
	2 - 20	Wideband PA	14	30	4	24	+12V @ 310mA	Module	HMC-C023
	2 - 20	Wideband PA	28	30	3	25	+12V @ 400mA	Module	HMC-C026
	Power Amplifier Modules: >10 Watts								
	0.4 - 1.0	10 Watt PA	40	50	13	40	+12V @ 6.6A	Module	HMC-C012
	0.8 - 2.0	10 Watt PA	40	50	11	40	+12V @ 6.6A	Module	HMC-C013
	1.8 - 2.2	15 Watt PA	42	53	6	42	+14V @ 6.5A	Module	HMC-C008

ATTENUATORS - Digital

	Frequency (GHz)	Function	Loss (dB)	Atten. Range (dB)	Input IP3 (dBm)	Control Input (Vdc)	Package	Part Number
NEW!	DC - 13	6-Bit Digital, Serial Control	3.6	0.5 to 31.5	32	Serial TTL/CMOS	Module	HMC-C018
	DC - 13	6-Bit Digital	3.2	0.5 to 31.5	38	0 / +5V	Module	HMC-C025

Connectorized Modules

Hittite MICROWAVE CORPORATION

Robust, High Performance RF to Light Solutions

FREQUENCY DIVIDERS (PRESCALERS)

Input Freq. (GHz)	Function	Input Power (dBm)	Output Power (dBm)	100kHz SSB Phase Noise (dBc/Hz)	Bias Supply	Package	Part Number
DC - 18	Divide-by-2	-15 to +10	-4	-150	+5V @ 75mA	Module	HMC-C005
DC - 18	Divide-by-4	-15 to +10	-4	-150	+5V @ 93mA	Module	HMC-C006
DC - 18	Divide-by-8	-15 to +10	-4	-150	+5V @ 98mA	Module	HMC-C007

I/Q MIXERS

RF/LO Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	Image Rejection (dB)	Input IP3 (dBm)	Package	Part Number
4 - 8.5	I/Q Mixer	DC - 3.5	-7.5	37	23	Module	HMC-C009

MIXERS

RF Freq. (GHz)	Function	IF Freq. (GHz)	Conv. Gain (dB)	LO/RF Isol. (dB)	IIP3 (dBm)	Package	Part Number
16 - 32	+13 LO, DBL-BAL	DC - 8	-8	28	19	Module	HMC-C014
24 - 38	+13 LO, DBL-BAL	DC - 8	-8.5	35	20	Module	HMC-C015

PHASE SHIFTERS - Analog

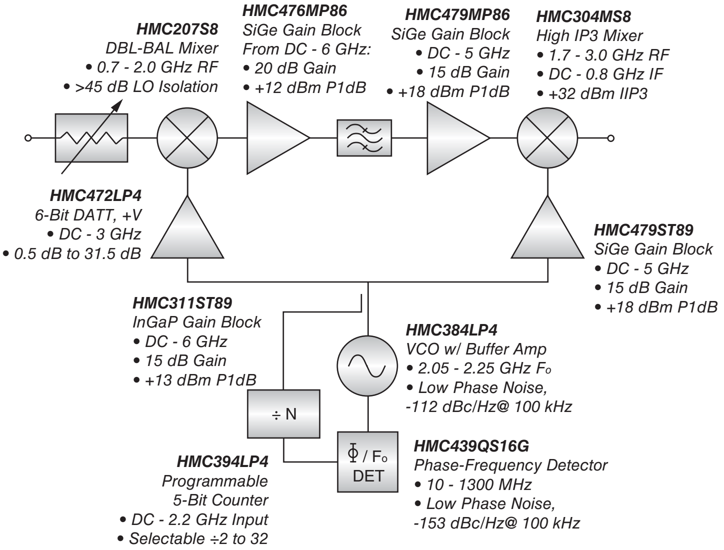
Frequency (GHz)	Function	Insertion Loss (dB)	Phase Range (Deg)	2nd Harmonic Pin= 0 dBm (dBc)	Control Voltage Range (Vdc)	Package	Part Number
6 - 15	Analog	7	750° @ 6 GHz 450° @ 15 GHz	40	+0V to +5V	Module	HMC-C010

SWITCHES

	Frequency (GHz)	Function	Insertion Loss (dB)	Isolation (dB)	Input P1dB (dBm)	Control Input (Vdc)	Package	Part Number
NEW!	DC - 20	SPST, Hi Isolation	3	100	23	0 / +5V	Module	HMC-C019
	DC - 20	SPDT, Hi Isolation	2.0	50	23	CMOS	Module	HMC-C011

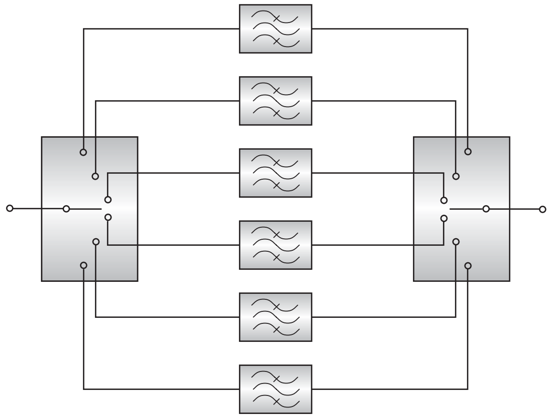
CABLE MODEM, CATV, DBS & VoIP SOLUTIONS, 5 - 2150 MHz

Cable Modem Termination System (CMTS)



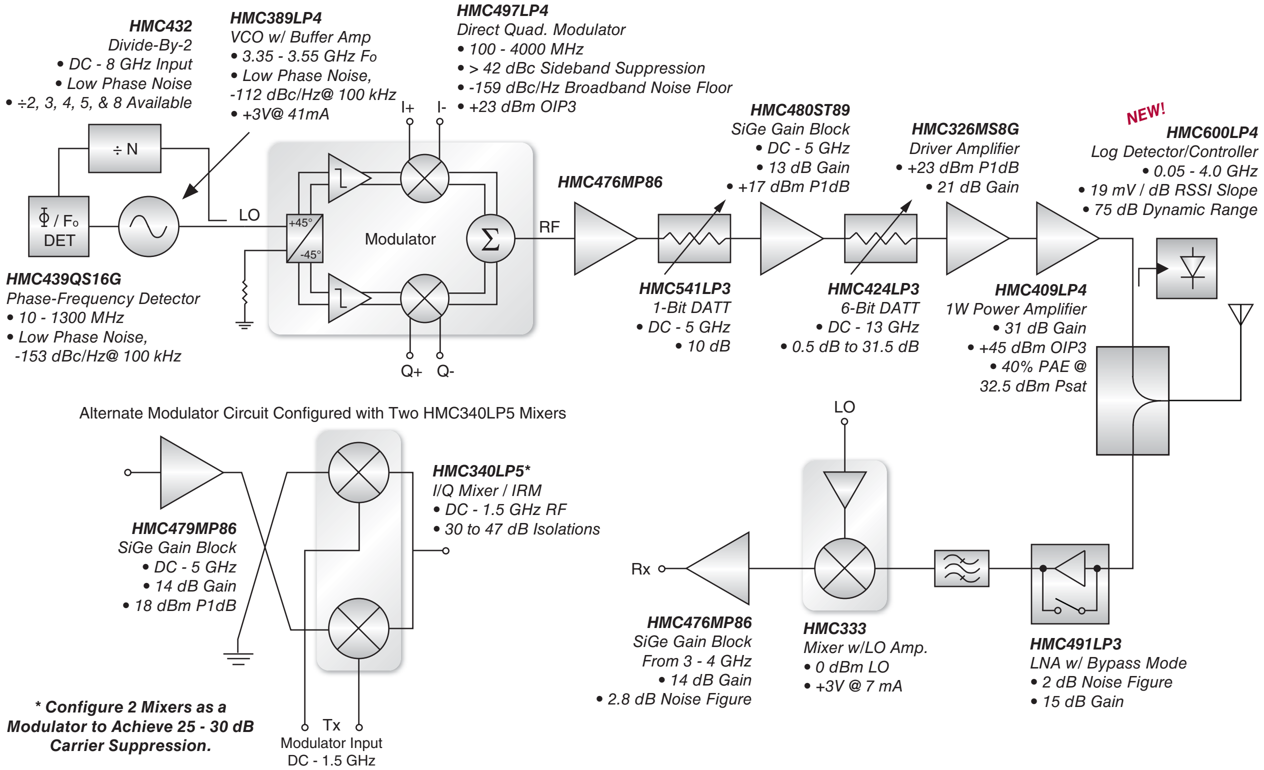
A Selection of SPNT Switches for CATV Filter & Signal Routing

Part Number	Frequency (GHz)	Function	1 GHz Loss / Isolation (dB)
HMC348LP3 (E)	DC - 2.5	SPDT, 75 Ω	0.6 / 58
HMC349LP4C (E)	DC - 4	SPDT	0.9 / 65
HMC347LP3 (E)	DC - 15	SPDT	1.4 / 65
HMC245QS16G (E)	DC - 3.5	SP3T	0.5 / 44
HMC345LP3 (E)	DC - 8	SP4T	2.0 / >50
HMC252QS24 (E)	DC - 3	SP6T	2.0 / >45
HMC321LP4 (E)	DC - 8	SP8T	2.0 / >45



Typical Broadband applications are illustrated. See the full product listing for alternatives to the select HMC products shown in each functional block.

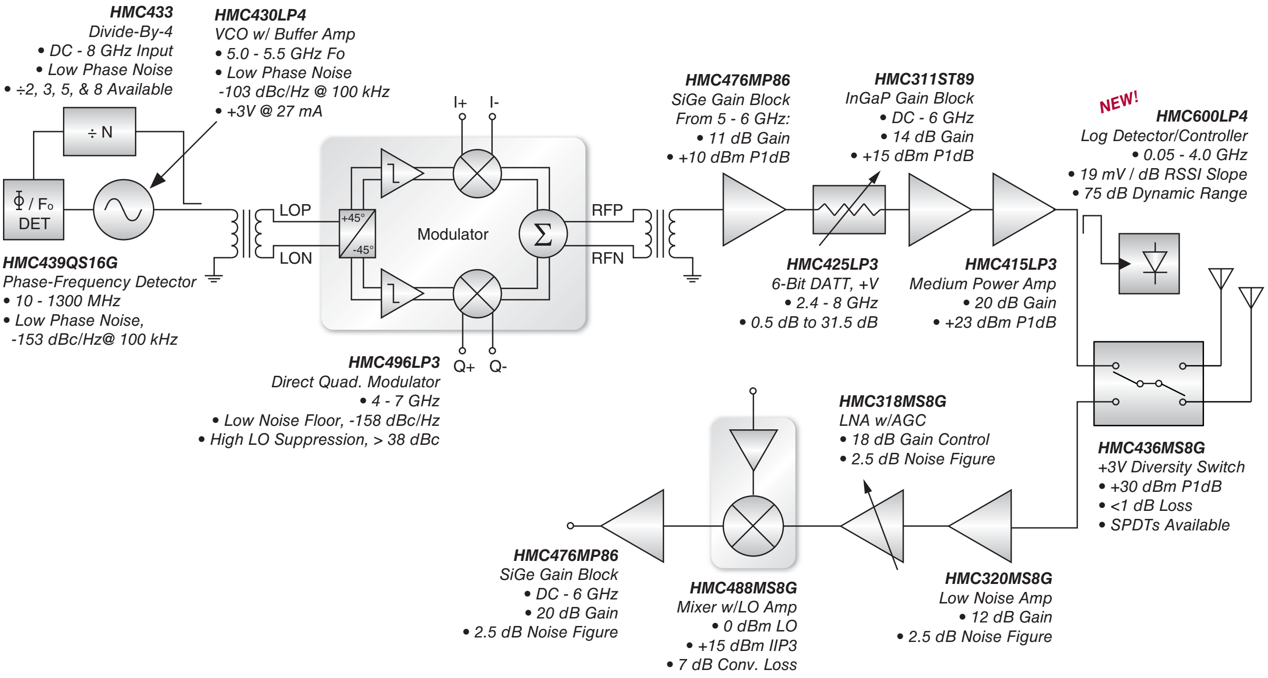
WiMAX & FIXED WIRELESS, 2 - 6 GHz



Typical WiMAX / FWA Transceiver is illustrated. See the full product listing for alternatives to the select HMC products shown in each functional block.

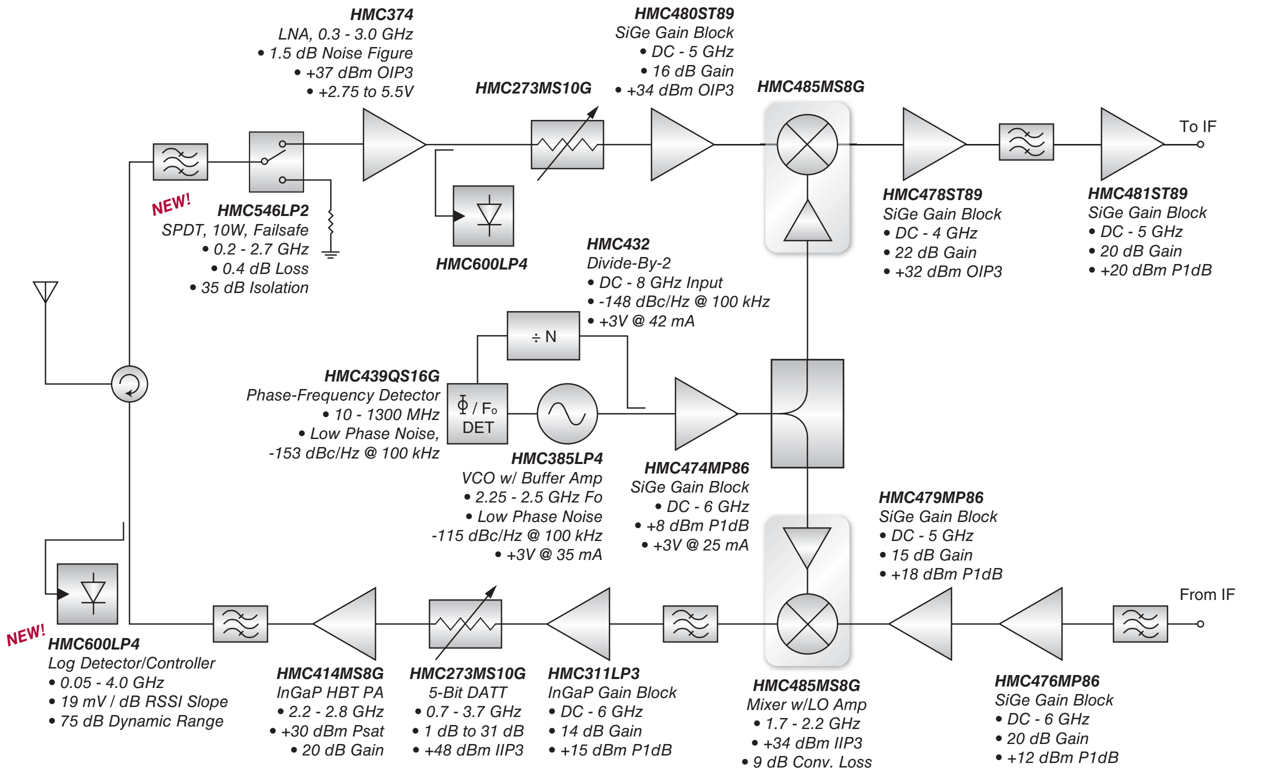
Broadband, DC - 11 GHz

WirelessLAN, UWB, UNII & ISM Solutions, 2.4, 4.9, 5.4, 5.8 & 3 - 11 GHz



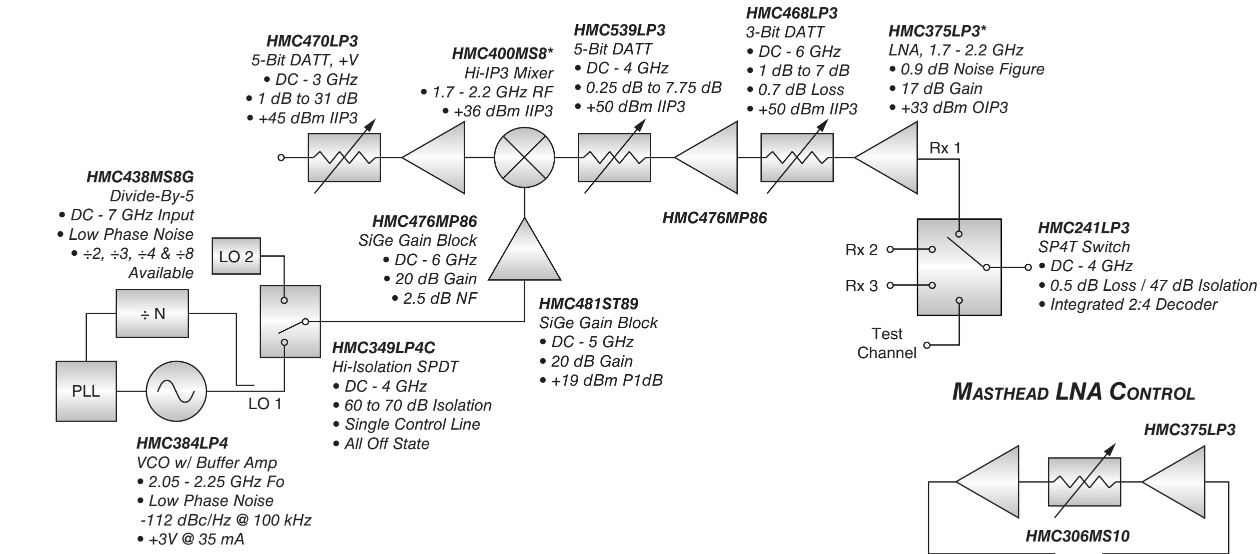
Typical 4.9 - 5.9 GHz Wi-Fi Access Point application is illustrated.
See the full product listing for alternatives to the select HMC products shown in each functional block.

WiBro "Wireless Broadband", 1.82 - 1.87, 2.3 - 2.5 & 3.48 - 3.52 GHz

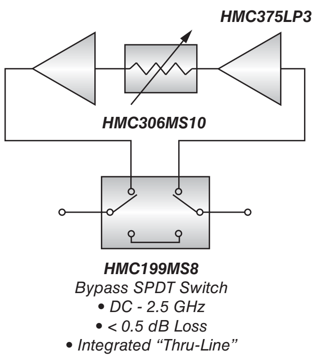


Typical WiBro application is illustrated. See the full product listing for alternatives to the select HMC products shown in each functional block.

BTS RECEIVER SOLUTIONS FEATURING HIGH IP3 MIXER



MASTHEAD LNA CONTROL



*** For 700 - 1000 MHz Systems Use:**

HMC399MS8
Hi-IP3 Mixer
- 700 - 1000 MHz RF
- +35 dBm IIP3

HMC372LP3
LNA, 700 - 1000 MHz
- 0.9 dB Noise Figure
- 15 dB Gain
- +35 dBm IIP3

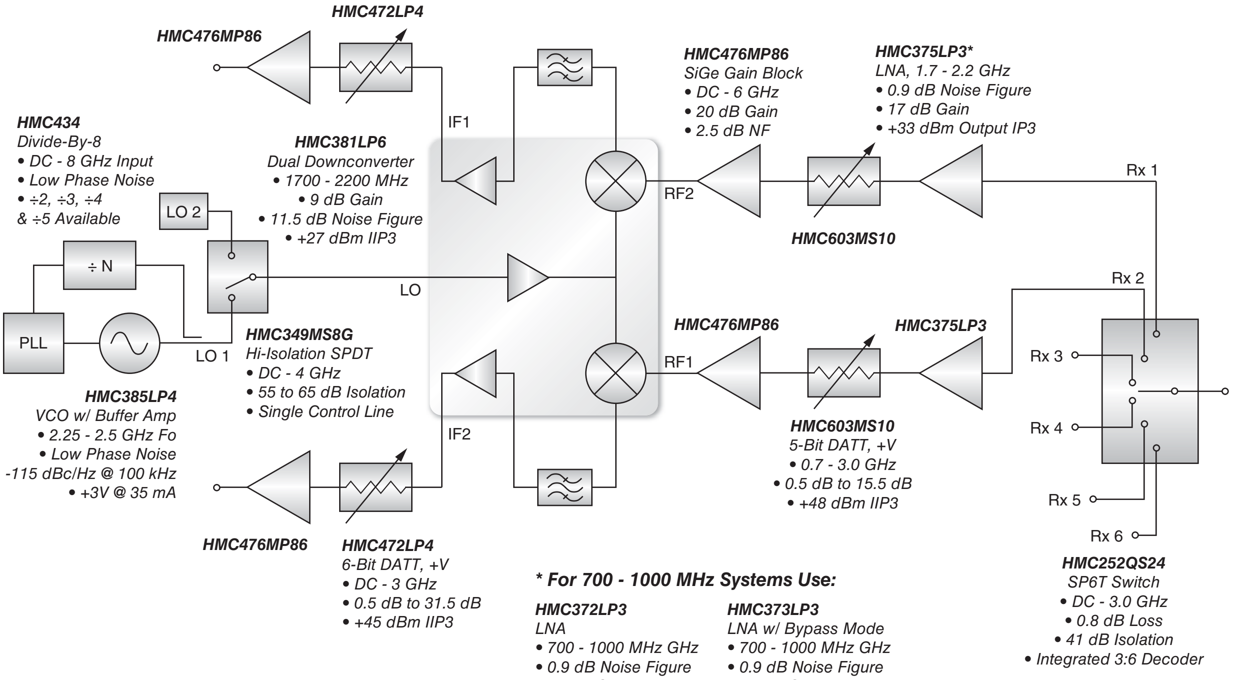
*** For 380 - 500 MHz Systems Use:**

HMC387MS8
Hi-IP3 Mixer
- 450 - 500 MHz RF
- +32 dBm IIP3

HMC356LP3
LNA, 350 - 550 MHz
- 1 dB Noise Figure
- 17 dB Gain
- +35 dBm IIP3

Ask About Our Custom VCO Capabilities!

BTS RECEIVER SOLUTIONS FEATURING DUAL RFIC DOWNCONVERTER



*** For 700 - 1000 MHz Systems Use:**

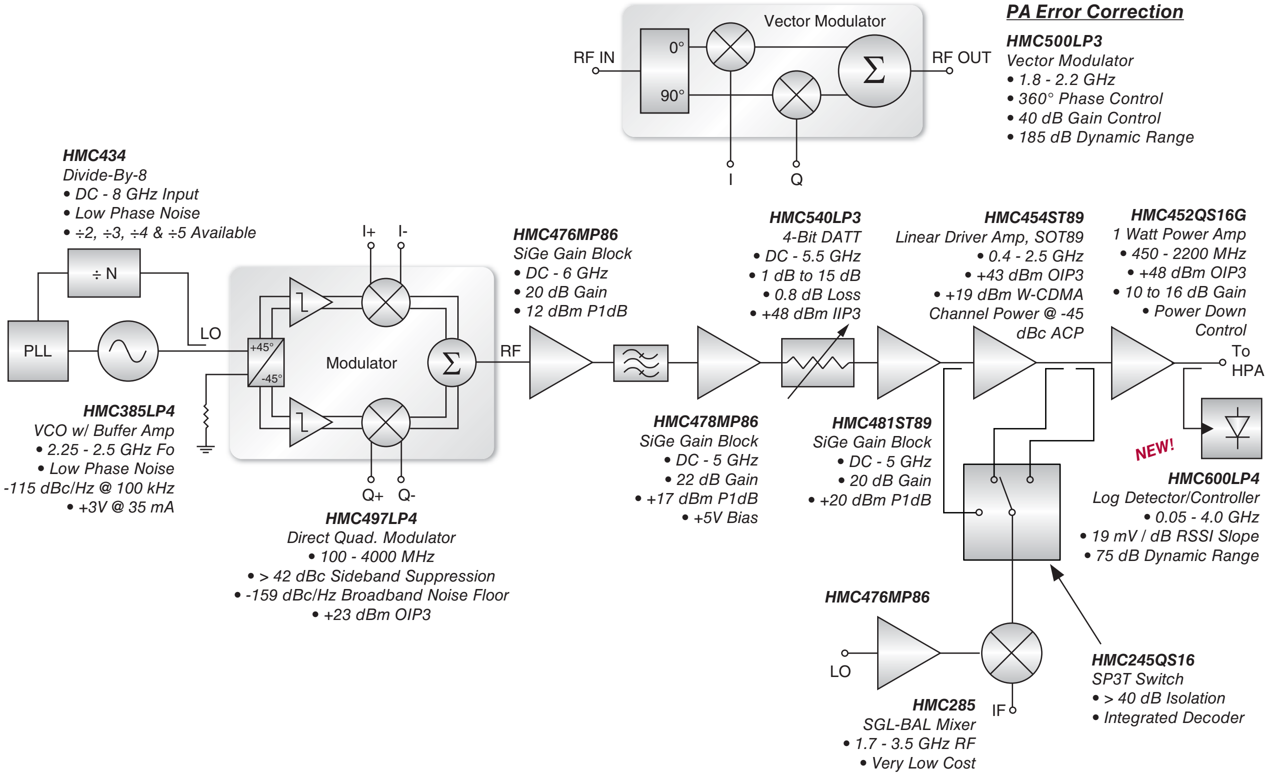
HMC372LP3
LNA
- 700 - 1000 MHz GHz
- 0.9 dB Noise Figure
- 15 dB Gain
- +35 dBm IIP3

HMC373LP3
LNA w/ Bypass Mode
- 700 - 1000 MHz GHz
- 0.9 dB Noise Figure
- 14 dB Gain
- < 2 dB Bypass IL

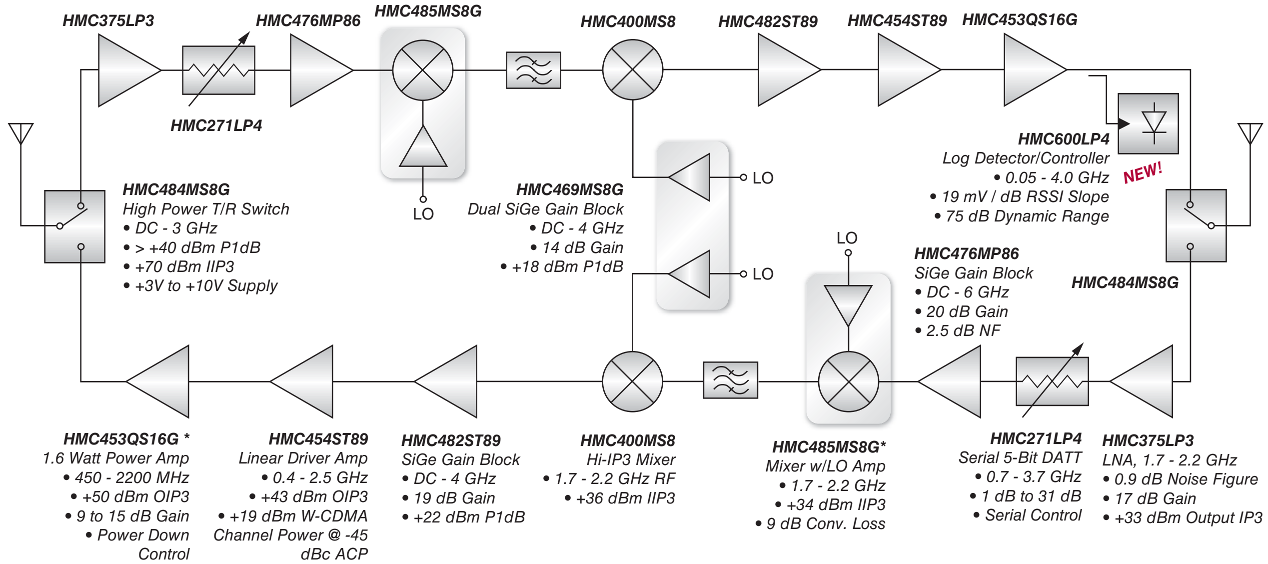
Typical Cellular/PCS/3G applications are illustrated.
See the full product listing for alternatives to the select HMC products shown in each functional block.

Cellular Infrastructure, 380 - 2200 MHz

BTS TRANSMITTER SOLUTIONS



CDMA / GSM REPEATER SOLUTIONS



*** High Gain Option:**

HMC457QS16G
1 Watt Power Amp
• 1.7 - 2.2 GHz
• +46 dBm OIP3
• 26 dB Gain

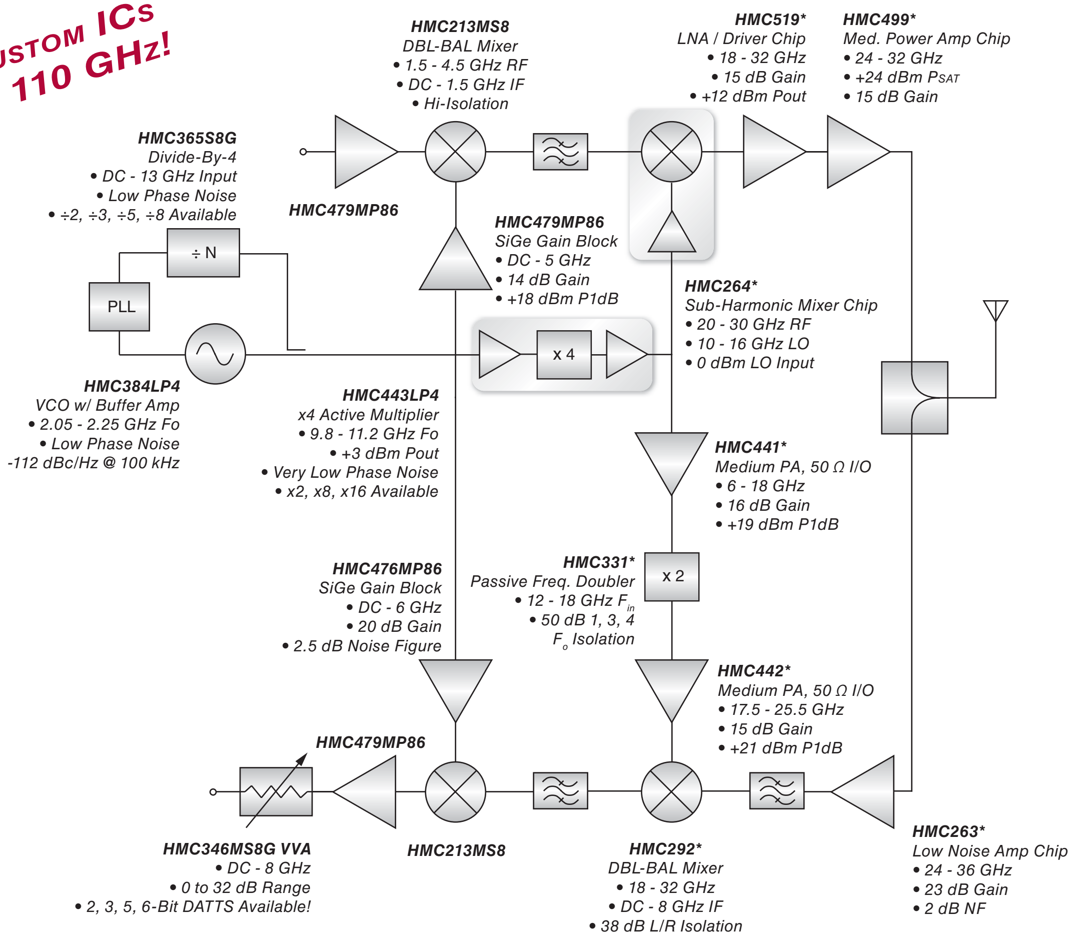
*** For 700 - 1000 MHz Systems Use:**

HMC483MS8G
Mixer w/LO Amp
• 0.7 - 1.4 GHz
• +35 dBm IIP3

Typical Cellular/PCS/3G applications are illustrated.
See the full product listing for alternatives to the select HMC products shown in each functional block.

DOUBLE UPCONVERSION & DOUBLE DOWNCONVERSION

CUSTOM ICs TO 110 GHz!



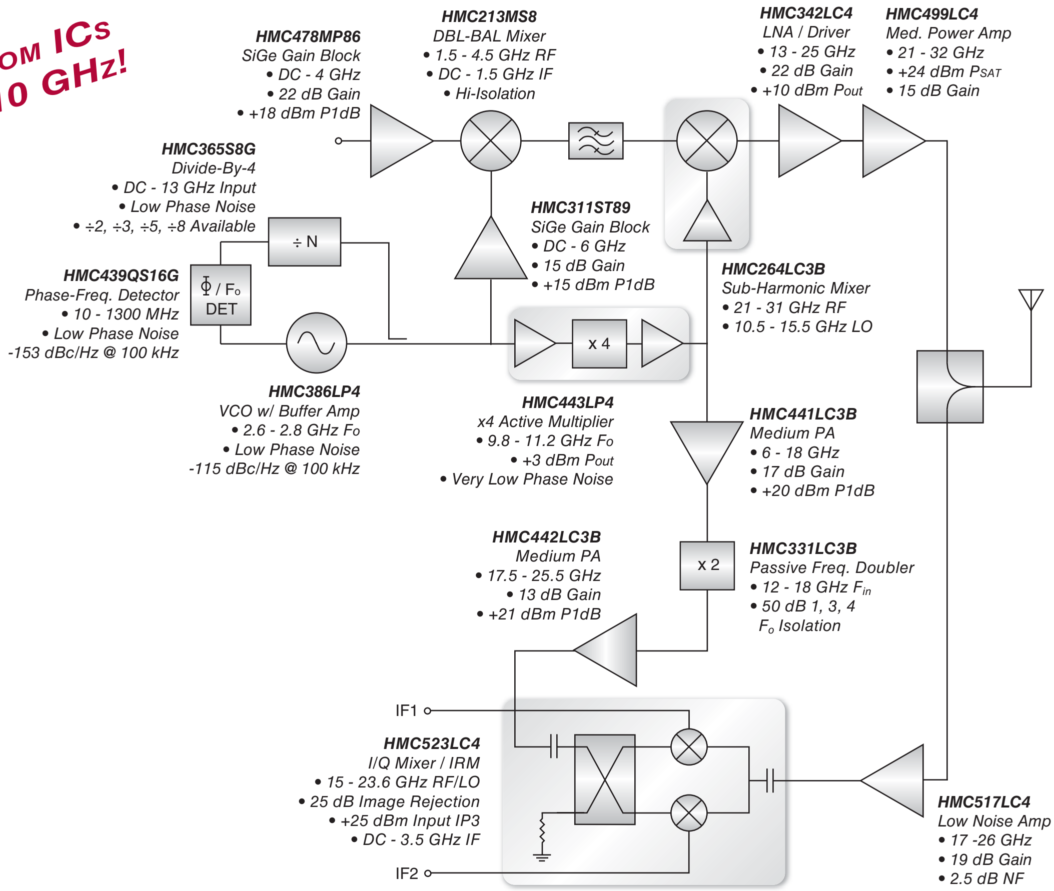
* PRODUCTS AVAILABLE IN DIE, SMT OR CONNECTORIZED PACKAGE FORM TO 60 GHz!

C-4	LC3 / LC3B	LC4 / LC4B	LC5	LM1 / LM3
41.66 x 36.32 x 8.50 mm	3.0 x 3.0 x 1.0 mm	4.0 x 4.0 x 1.0 / 1.2 mm	5.0 x 5.0 x 1.0 mm	5.1 x 5.1 x 1.1 mm

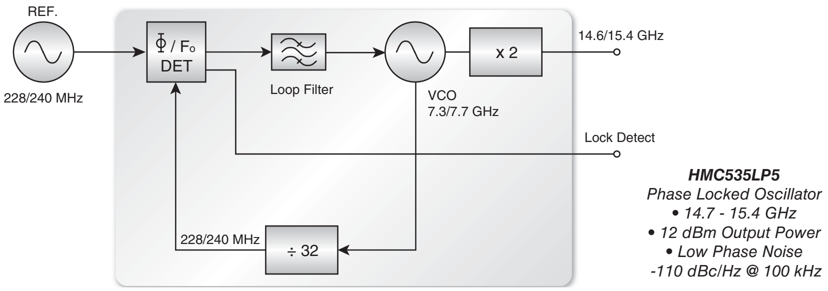
Typical Microwave / Millimeterwave transceiver application is illustrated.
See the full product listing for alternatives to the select HMC products shown in each functional block.

Double Upconversion & Direct Downconversion

Custom ICs to 110 GHz!



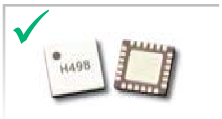
15 GHz Integrated PLO



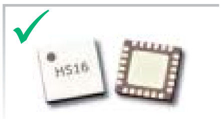
* Products Available in Die, SMT or Connectorized Package Form to 60 GHz!

C-4
41.66 x 36.32 x 8.50 mm

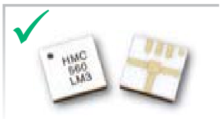
LC3 / LC3B
3.0 x 3.0 x 1.0 mm



LC4 / LC4B
4.0 x 4.0 x 1.0 / 1.2 mm



LC5
5.0 x 5.0 x 1.0 mm

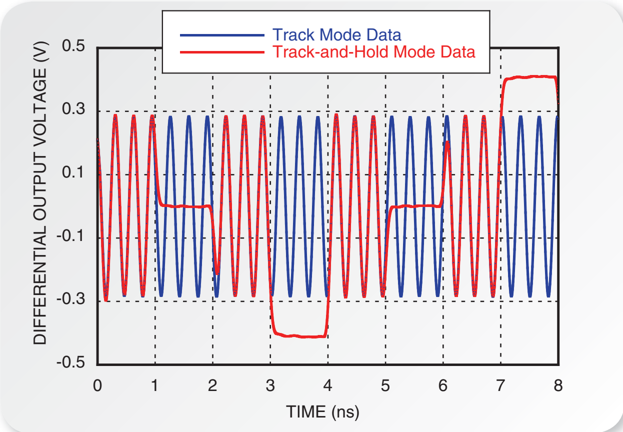


LM1 / LM3
5.1 x 5.1 x 1.1 mm

Typical Microwave / Millimeterwave transceiver application is illustrated.
See the full product listing for alternatives to the select HMC products shown in each functional block.

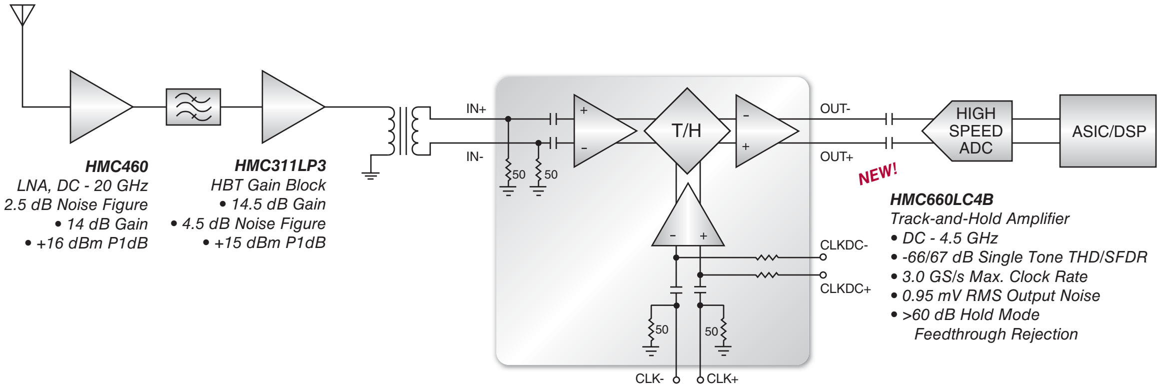
HMC660LC4B Wideband Track-and-Hold Amplifier

- ♦ *4.5 GHz Input Bandwidth (1 Vpp Full Scale)*
- ♦ *Single Tone THD/SFDR: -66/67 dB*
- ♦ *Maximum Clock Rate: 3 GS/s*
- ♦ *Extends High Speed ADC Performance*

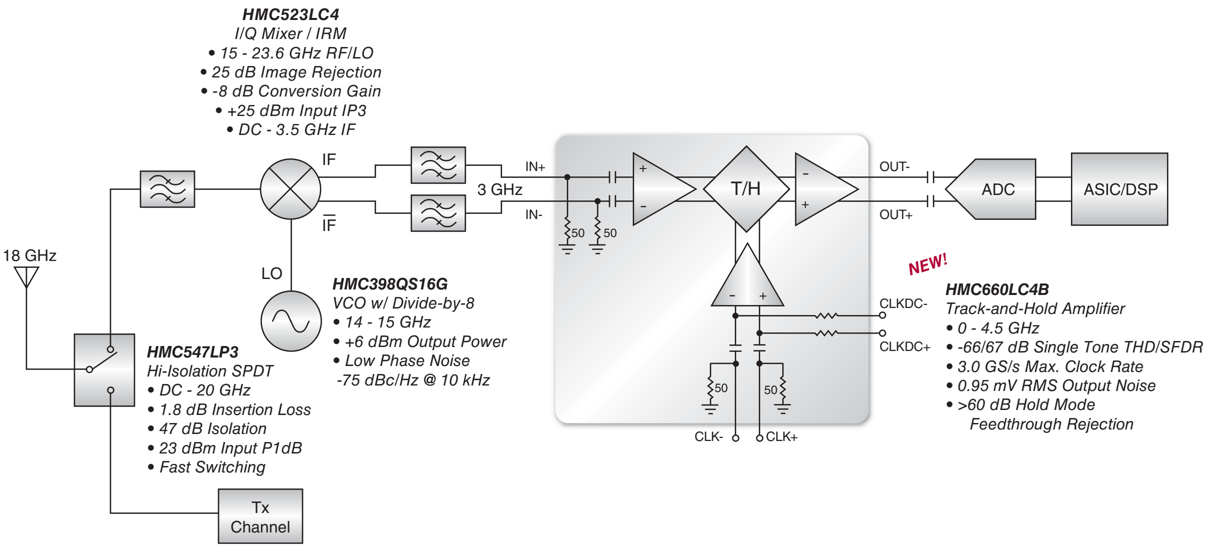


Measured time-domain ouput waveforms with a 3.125 GHz sinewave input signal sampled at 500 MSample / s

Direct Conversion Receiver Track-and-Hold Amplifier Application



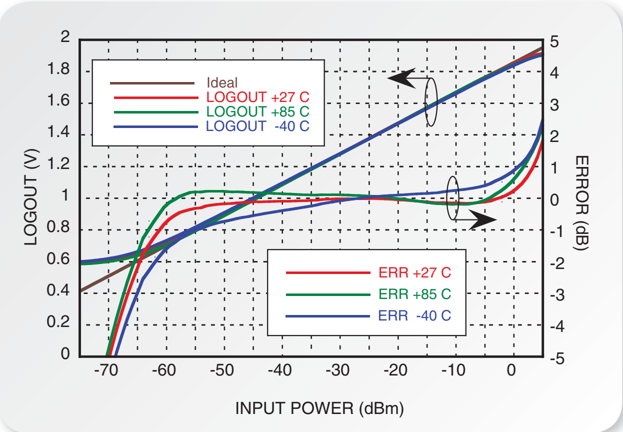
Generic Software Radio Track-and-Hold Amplifier Application



Power Detector Product Solutions

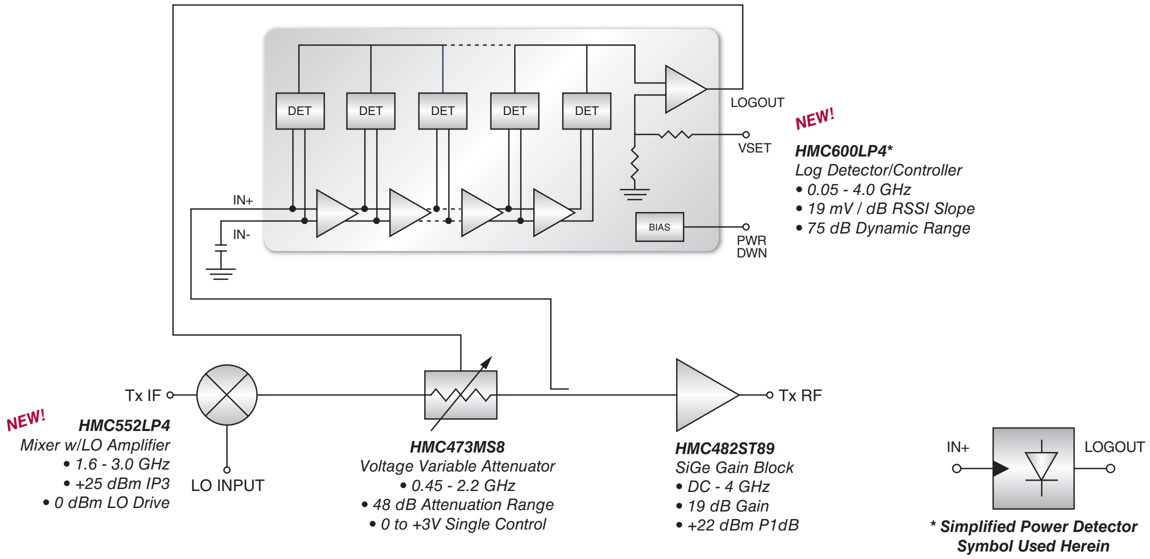
HMC600LP4 Logarithmic Detector / Controller

- ♦ ***50 - 4000 MHz Wide Bandwidth***
- ♦ ***Wide Dynamic Range: >70 dB***
- ♦ ***Excellent Stability vs. Temperature***
- ♦ ***Ideal for AGC & RSSI Applications***



Output Voltage and RSSI Error as a function of Input Power & Temperature (at 3.3 VDC) measured at 900 MHz

Automatic Gain Control (AGC) Log Detector/Controller Application



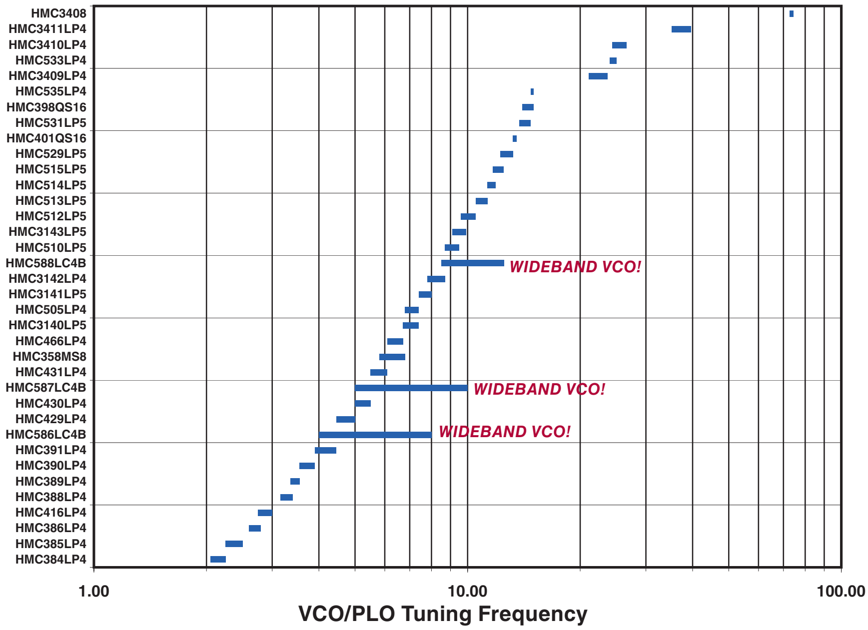
FREQUENCY GENERATION

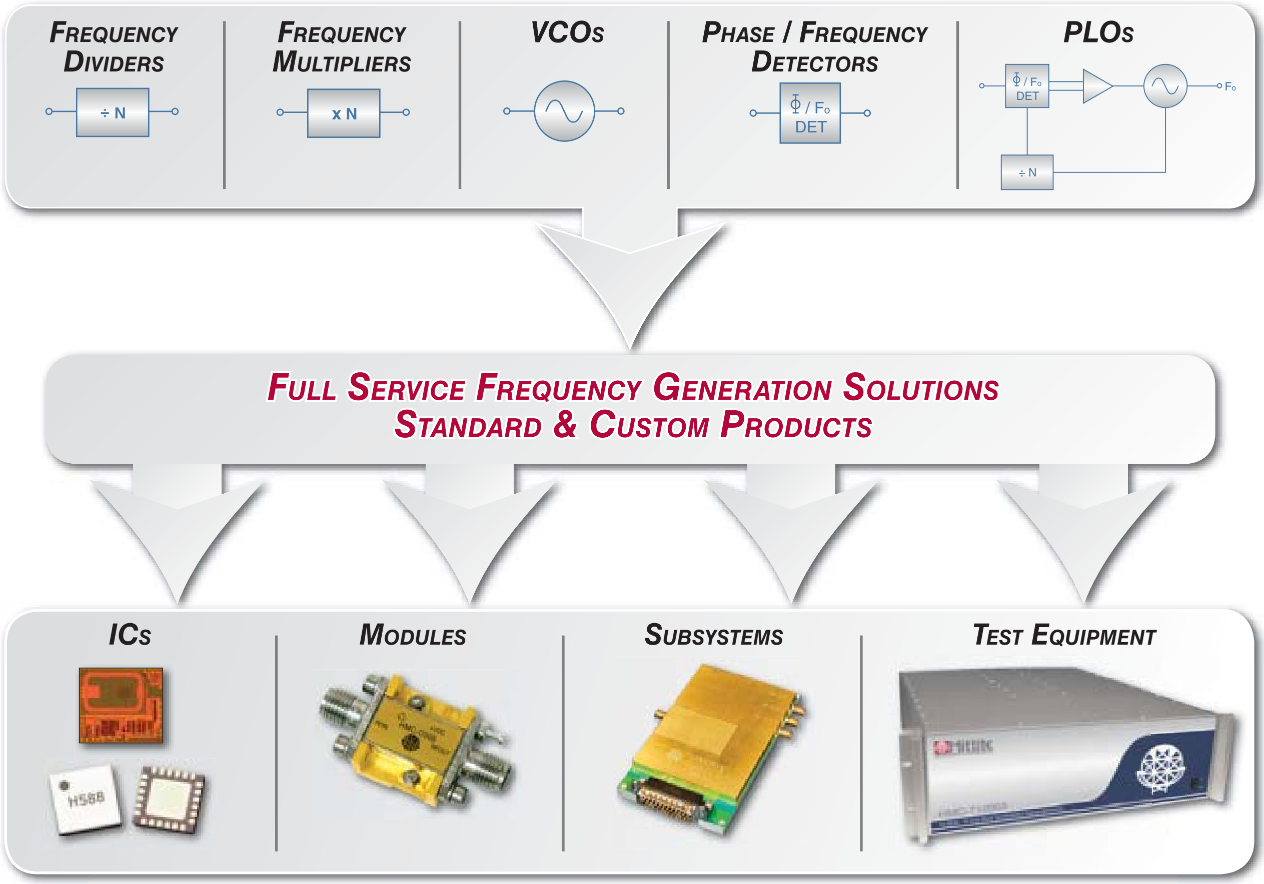
IC, Module, Subsystem & Test Equipment Solutions to 80 GHz

VCOs, PLOs, PLLs, DIVIDERS, DETECTORS, MULTIPLIERS & SYNTHESIZERS

Hittite Microwave offers standard and custom Freqency Generation products from DC to 80 GHz. Our MMIC VCOs integrate a resonator, negative resistance circuit & tuning varactor and/or dividers and buffer amplifiers. The accuracy & repeatability of MMIC wafer processing eliminates all tuning at our factory and yours.

A Sampling of MMIC VCOs & PLOs





New Commercial Synthesizer

Low Noise, High Power & Fast Switching

HMC-T1000A Dual Synthesized Signal Generator, 10 MHz to 8 GHz

- ***Two Independently Controllable / Programmable Synthesizers***
- ***-135 dBc/Hz SSB Phase Noise @ 100 kHz Offset @ 8 GHz***
- ***-75 dBc Spurious***
- ***10 µSec Switching Speed***
- ***Standard Rack Mountable 17" 3U Chassis***
- ***Ideal for ATE, Test & Measurement, and Communications***

Two Synthesizers Per Unit

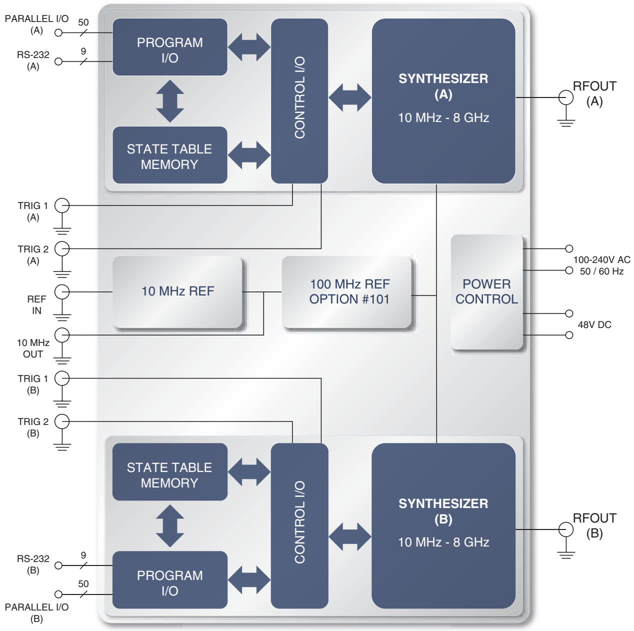
Introducing a new Synthesized Microwave Signal Generator from Hittite that delivers "best in class" ultra low phase noise performance coupled with fast 10 microsecond switching in a standard 17" 3U chassis. The HMC-T1000A integrates two, independently controllable / programmable, 10 MHz to 8 GHz synthesizers that provide high output power of up to +15 dBm each and excellent spectral purity of -75 dBc.

Innovative MMICs = Revolutionary Synthesizer

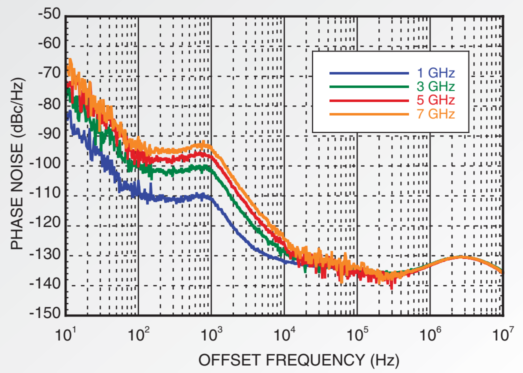
Based upon 20+ years of Hittite proprietary MMIC technology, packaging expertise and our unique synthesizer architecture, the HMC-T1000A achieves SSB phase noise performance of -135 dBc/Hz at 100 kHz offset that is 10 dB better than any microwave synthesizer in the same class. Our core MMIC technology delivers fast frequency switching while maintaining revolutionary phase noise performance.

Programmable & Flexible For All Applications

Both BCD-parallel and RS-232 interfaces enable independent control of each of the synthesizers. Power supply inputs include 100V to 240V 50/60 Hz AC or 48V DC. The HMC-T1000A is a flexible solution for all production test, R&D and communications applications. Hittite offers customization of the HMC-T1000A for specific electrical and environmental requirements.



HMC-T1000A SSB Phase Noise *



SYNTHESIZER PERFORMANCE						
Frequency	Range	10 MHz to 8 GHz				
	Resolution	0.001 Hz				
	Switching Speed	10 µSec				
Step Sweep	Operational Modes	Fully Programmable via State Table				
	Number of States	65,536 Maximum				
Output	General	2 Independently Controllable / Programmable RF Outputs				
	Power (dBm)	10 MHz to 3 GHz	+15 dBm			
		3 GHz to 8 GHz	+10 dBm			
Spectral Purity	Spurious	-75 dBc				
	Enhanced SSB Phase Noise (dBc/Hz) *	Offset From Carrier				
		100 Hz	1 kHz	10 kHz	100 kHz	1 MHz
	10 MHz to 1 GHz	-110	-112	-132	-135	-133
	>1 GHz to 3 GHz	-100	-102	-129	-135	-133
	>3 GHz to 5 GHz	-97	-97	-126	-135	-133
	>5 GHz to 7 GHz	-94	-95	-125	-135	-133
	8 GHz	-92	-94	-125	-135	-133

**** Utilizing Option #101, 100 MHz REF***

Contact Us to Discuss Your Requirements & Arrange a Demonstration!

BROADBAND, DC - 11 GHz – CATV, DBS, VoIP, WiMAX, WiBro & WLAN *

Function	0.005 - 2.15 GHz CATV & DBS	1.8 - 2.7 GHz WiMAX / WiBro	3.3 - 3.9 GHz WiMAX / WiBro	4.9 - 5.9 GHz WiMAX / Fixed
Low Noise Amplifier	HMC548LP3 HMC549MS8G	HMC286 HMC287MS8G	HMC491LP3	HMC318MS8G HMC320MS8G
Driver Amplifier	HMC454ST89	HMC308	HMC326MS8G HMC327MS8G	HMC406MS8G HMC407MS8G HM415LP3
Linear & Power Amplifier	HMC453QS16G	HMC454ST89	HMC409P4	HMC408LP3
Attenuator: Analog	HMC473MS8	HMC346MS8G	HMC346MS8G	HMC346MS8G
Attenuator: Digital	HMC467LP3 HMC468LP3 HMC541LP3	HMC305LP4 HMC467LP3 HMC540LP3	HMC271LP4 HMC467LP3 HMC539LP3	HMC425LP3 HMC467LP3 HMC468LP3
Mixer:	HMC207S8 HMC208MS8 HMC216MS8	HMC285 HMC316MS8 HMC332	HMC214MS8 HMC333 HMC340LP5	HMC220MS8 HMC218MS8 HMC488MS8G
Modulator	HMC495LP3 HMC497LP4	HMC495LP3 HMC497LP4	HMC495LP3 HMC497LP4	HMC496LP3
Power Detector	HMC600LP4	HMC600LP4	HMC600LP4	HMC600LP4
Switch: SPST & SPNT	HMC253QS24 HMC536MS8G HMC544 HMC550	HMC484MS8G HMC536MS8G HMC546LP2 HMC550	HMC349MS8G HMC536MS8G HMC544 HMC550	HMC224MS8 HMC321LP4 HMC536MS8G HMC550
Switch: Bypass, Diversity, Matrix & Transfer	HMC276LP4 HMC427LP3	HMC276LP4 HMC427LP3	HMC427LP3	HMC436MS8G HMC427LP3
VCO		HMC384LP4 HMC385LP4	HMC388LP4 HMC389LP4	HMC430LP4 HMC431LP4

CELLULAR INFRASTRUCTURE, 380 - 2200 MHz – GSM, GPRS, CDMA, WCDMA & UMTS *

Function	400 MHz	800 / 900 MHz	1800 / 1900 MHz	2100 / 2200 MHz
Low Noise Amplifier	HMC356LP3 HMC374	HMC372LP3 HMC376LP3	HMC375LP3 HMC382LP3	HMC375LP3 HMC382LP3
Driver Amplifier	HMC454ST89 HMC478ST89	HMC308 HMC454ST89	HMC308 HMC454ST89	HMC308 HMC454ST89
Linear & Power Amplifier	HMC452ST89 HMC453ST89	HMC450QS16G HMC452ST89 HMC453ST89	HMC452ST89 HMC453ST89 HMC457QS16G	HMC452ST89 HMC453ST89 HMC455LP3
Attenuator: Analog	HMC473MS8	HMC473MS8	HMC210MS8	HMC210MS8
Attenuator: Digital	HMC539LP3 HMC540LP3 HMC541LP3 HMC472LP4	HMC539LP3 HMC540LP3 HMC541LP3 HMC467LP3	HMC539LP3 HMC540LP3 HMC541LP3 HMC468LP3	HMC305LP4 HMC539LP3 HMC540LP3 HMC541LP3
Frequency Divider & Detector	HMC394LP4 HMC434 HMC439QS16G	HMC394LP4 HMC434 HMC439QS16G	HMC394LP4 HMC434 HMC439QS16G	HMC394LP4 HMC434 HMC439QS16G
Mixer:	HMC387MS8	HMC399MS8 HMC423MS8 HMC483MS8G HMC551LP4	HMC400MS8 HMC381LP6 HMC485MS8G HMC552LP4	HMC400MS8 HMC402MS8 HMC421QS16G HMC422MS8
Modulator	HMC495LP3 HMC497LP4	HMC495LP3 HMC497LP4	HMC495LP3 HMC497LP4	HMC495LP3 HMC497LP4
Power Detector	HMC600LP4	HMC600LP4	HMC600LP4	HMC600LP4
Switch: SPST & SPNT	HMC321LP4 HMC349MS8G HMC546MS8G HMC550	HMC349MS8G HMC546MS8G HMC550 HMC574MS8	HMC349MS8G HMC545 HMC546MS8G HMC550	HMC349MS8G HMC484MS8G HMC546MS8G HMC550
Switch: Bypass, Diversity, Matrix & Transfer	HMC199MS8 HMC427LP3	HMC199MS8 HMC427LP3	HMC199MS8 HMC427LP3	HMC199MS8 HMC427LP3

** A selection of components, see the full product listing starting on page 4.*

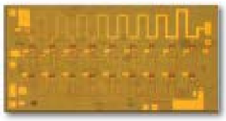
MICROWAVE & MILLIMETERWAVE RADIO *

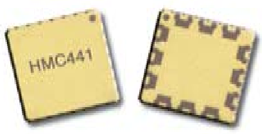
Function	7 / 8 GHz	11 GHz	13 GHz	15 GHz	18 GHz	23 GHz	26 GHz	28 GHz	32 / 38 GHz
Low Noise Amplifier	HMC564 HMC565	HMC516LC5 HMC564 HMC565	HMC516LC5 HMC565	HMC516LC5 HMC565	HMC517LC4 HMC565	HMC341LC3B HMC517LC4	HMC341LC3B HMC517LC4	HMC341LC3B HMC518	HMC263 HMC566
Driver Amplifier	HMC441LP3 HMC451LC3 HMC516LC5	HMC441LP3 HMC451LC3 HMC516LC5	HMC441LC3B HMC451LC3 HMC490LP5	HMC441LC3B HMC451LC3 HMC490LP5	HMC383LC4 HMC442LC3B HMC498LC4	HMC383LC4 HMC442LC3B HMC498LC4	HMC383LC4 HMC283LM1 HMC499LC4	HMC383LC4 HMC283LM1 HMC499LC4	HMC283LM1 HMC300LM1 HMC383LC4
Power Amplifier	HMC486LP5	HMC487LP5	HMC489LP5	HMC489LP5	HMC498LC4	HMC498LC4	HMC499LC4	HMC499LC4	HMC283LM1
Attenuator: Analog	HMC346LP3	HMC346LP3	HMC346LP3	HMC346LC3B	HMC346LC3B				
Divide-by-2	HMC361S8G	HMC364S8G	HMC492LP3	HMC492LP3	HMC492LP3				
Divide-by-4	HMC362S8G	HMC365S8G	HMC493LP3	HMC493LP3	HMC447LC3	HMC447LC3	HMC447LC3		
Divide-by-8	HMC363S8G	HMC363S8G	HMC494LP3	HMC494LP3					
Multiplier: Active X2	HMC368LP4 HMC575LP4	HMC368LP4	HMC368LP4	HMC368LP4	HMC448LC3B HMC576LC3B	HMC448LC3B HMC576LC3B	HMC448LC3B HMC578LC3B	HMC449LC3B HMC578LC3B	HMC449LC3B HMC578LC3B HMC579
Multiplier: Active X4		HMC443LP4	HMC370LP4	HMC370LP4					
Multiplier: Passive X2	HMC189MS8	HMC189MS8	HMC204MS8G	HMC204MS8G	HMC204MS8G	HMC205	HMC205	HMC331	HMC331
I/Q Mixer / IRM	HMC520LC4 HMC525LC4	HMC521LC4 HMC527LC4	HMC521LC4 HMC527LC4	HMC522LC4 HMC528LC4	HMC523LC4	HMC523LC4	HMC524LC4	HMC524LC4	HMC404 HMC524
Mixer: Fundamental	HMC129LC4 HMC144LC4 HMC219MS8 HMC220MS8	HMC144LC4 HMC411MS8G HMC412MS8G	HMC144LC4 HMC411MS8G HMC412MS8G	HMC144LC4 HMC260LC3B HMC412MS8G	HMC144LC4 HMC260LC3B HMC292LC3B	HMC260LC3B HMC292LC3B	HMC292LC3B HMC329LC3B	HMC292LC3B HMC329LC3B	HMC294 HMC329LM3
Mixer: Sub-Harmonic				HMC258LM3	HMC258LM3	HMC264LC3B	HMC264LC3B	HMC265LM3	HMC338 HMC339
Switch	HMC547LP3	HMC547LP3	HMC547LP3	HHMC547LP3	HMC547LP3				
VCO & PLO: *Requires X2 or X4	HMC466LP4 HMC505LP4 HMC506LP4 HMC587LC4B	HMC513LP4 HMC515LP5 HMC588LC4B	HMC513LP4 HMC529LP4	HMC529LP4 HMC531LP5	HMC429LP4	HMC431LP4	HMC515LP5	HMC531LP5	HMC505LP4 HMC512LP4

** A selection of components, see the full product listing starting on page 4.*

MILITARY LEVEL & HI-REL COMMERCIAL / INDUSTRIAL COMPONENTS & ASSEMBLIES

Hittite Microwave performs Class B screening on standard & custom product die and packaged die including SMT plastic encapsulated devices for COTS applications.

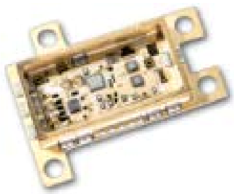


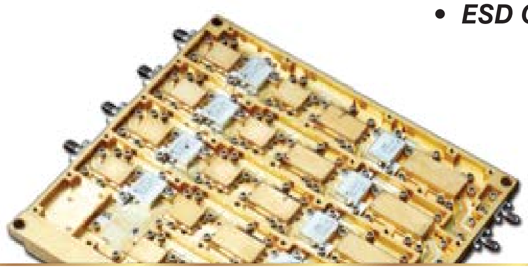


We design, produce and screen highly integrated MIC sub-assemblies for major defense OEMs.

Class B Screening MIL-PRF-38534 / 38535

- *VI to Method 2010B & 2017B*
- *Bond Pull & Die Shear Test*
- *Solderability Test*
- *High Temp Burn-In Test*
- *Vibration Stress Test*
- *Temp Cycle Stress Test*
- *Constant Acceleration Stress Test*
- *Fine & Gross Hermeticity Test*
- *Serialized Test Data*
- *ESD Characterization*





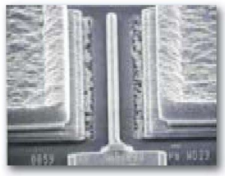
SPACE LEVEL COMPONENT & MODULE QUALIFICATION

Class S Screening & Qualification MIL-PRF-38534 / 38535

- *VI to Methods*
  2010A & 2017S
- *Temp Cycle Stress Test*
- *High Temp Burn-In & Life Test*
- *Wafer Lot Acceptance Test*
  Bond Pull & Die Shear Test
  SEM Inspection
  Metal & Glass Thicknesses
- *Serialized Test Data*
- *Qualification Report*

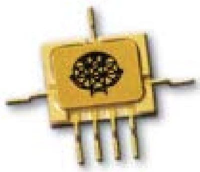
Hittite Microwave offers Class S screening on standard & custom product die and select hermetic packaged devices.

We are qualified by major spacecraft OEMs worldwide, shipping tens of thousands of S-Level components which are currently operational on dozens of commercial, scientific & military spacecraft.



FET Channel SEM

Serialized Die in GEL-PAK



Hermetic SMT Package

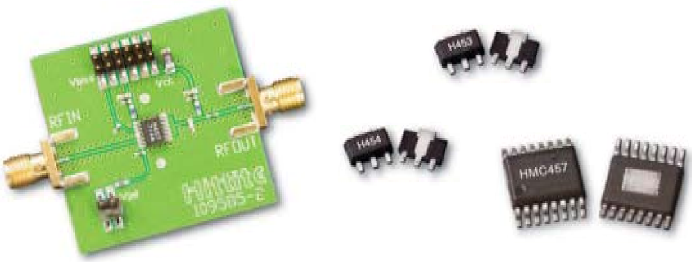
Hermetic Modules

Contact Us Today With Your High Reliability Mixed-Signal RF, Microwave & Millimeterwave Requirements!

Evaluation Boards & ICs Reduce Design Cycle Time

5 Designer Kits Available to Choose From!

- ♦ *Gain Blocks DC - 6 GHz, HMC-DK001*
- ♦ *Linear Driver Amplifiers 0.4 - 2.5 GHz, HMC-DK002*
- ♦ *High IP3 Mixers 0.45 - 4.0 GHz, HMC-DK003*
- ♦ *Digital Attenuators DC - 6 GHz, HMC-DK004*
- ♦ *SPDT Switches DC - 12 GHz, HMC-DK005*



Design engineers can now order pre-packaged MMIC Designer Kits which enable them to quickly assess which Hittite product is the best choice for their application. The end result is a design that goes to layout more quickly and with fewer subsequent changes.

Each Hittite Designer's Kit contains an assembled & tested connectorized evaluation board, 5 to 10 ICs of each part and the latest Hittite CD-Rom catalog.

IN STOCK DESIGNER KITS

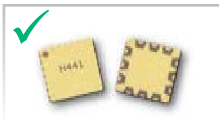
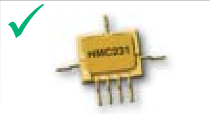
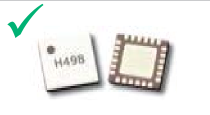
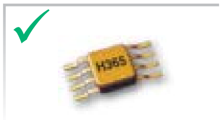
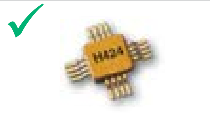
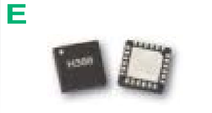
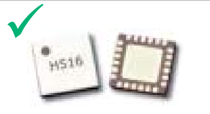
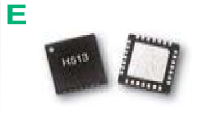
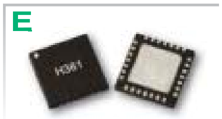
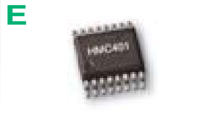
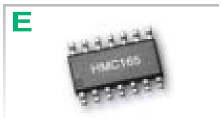
Kit Contents	Gain Blocks DC - 6 GHz HMC-DK001 *	Linear Driver Amps 0.4 - 2.5 GHz HMC-DK002 **	Hi-IP3 Mixers 0.45 - 4.0 GHz HMC-DK003 **	Digital Attenuators DC - 6 GHz HMC-DK004 **	SPDT Switches DC - 12 GHz HMC-DK005 **
ICs	HMC474MP86 HMC476MP86 HMC313 HMC311ST89 HMC478MP86 HMC478ST89 HMC479MP86 HMC479ST89 HMC481ST89 HMC480ST89 HMC481MP86 HMC482ST89	HMC454ST89 HMC450QS16G HMC413QS16G HMC452ST89 HMC453ST89 HMC457QS16G	HMC387MS8 HMC483MS8G HMC399MS8 HMC316MS8 HMC400MS8 HMC485MS8G HMC402MS8 HMC214MS8 HMC478ST89 HMC481ST89 HMC480ST89	HMC291 HMC468LP3 HMC274QS16 HMC271LP4 HMC273MS10G HMC305LP4 HMC306MS10 HMC470LP3 HMC472LP4	HMC221 HMC284MS8G HMC349MS8G HMC232LP4 HMC226 HMC595 HMC574MS8 HMC484MS8G HMC536MS8G
Eval Boards	104217 – HMC313 110161 – HMC478ST89 107490 – HMC481MP86	107749 – HMC454ST89 108349 – HMC450QS16G 105000 – HMC413QS16G 108712 – HMC452ST89 108718 – HMC453ST89 106043 – HMC457QS16G	110161 – HMC478ST89 105188 – HMC485MS8G 106334 – HMC399MS8 101830 – HMC400MS8	103372 – HMC291 107302 – HMC468LP3 104976 – HMC274QS16 108782 – HMC271LP4 103393 – HMC273MS10G 108782 – HMC305MS10 103393 – HMC306MS10 107006 – HMC470LP3 107010 – HMC472LP4	101675 – HMC221 107662 – HMC349MS8G 107723 – HMC232LP4 104124 – HMC574MS8 104124 – HMC484MS8G 105143 – HMC536MS8G

** 10 each IC and 1 each Eval Board per kit as listed.*
*** 5 each IC and 1 each Eval Board per kit as listed.*

See www.hittite.com To Order Your Designer's Kit!

Package Information

Available SMT & Module Packages

Plastic SMT	Plastic SMT	Ceramic SMT	Hermetic Ceramic SMT & Connectorized Modules	
E  **MP86 “Micro-P”** 5.21 x 5.08 x 1.57 mm	E  **LP2 “DFN”** 2.0 x 2.0 x 1.0 mm	✓  **LC3 / LC3B** 3.0 x 3.0 x 1.0 mm	✓  **LH5 Hermetic** 5.0 x 5.0 x 1.0 mm	✓  **G7 Hermetic** 16.1 x 17.3 x 1.7 mm
E  **SOT26** 2.8 x 2.9 x 1.2 mm	E  **LP3 “QFN”** 3.0 x 3.0 x 1.0 mm	✓  **LC4 / LC4B** 4.0 x 4.0 x 1.0 / 1.2 mm	✓  **G8 Hermetic** 10.2 x 4.6 x 1.8 mm	✓  **G16 Hermetic** 10.4 x 10.4 x 1.7 mm
E  **ST89** 4.50 x 4.14 x 1.54 mm	E  **LP4 / LP4C “QFN”** 4.0 x 4.0 x 1.0 mm	✓  **LC5** 5.0 x 5.0 x 1.0 mm	 **C-1** 35.31 x 17.78 x 7.38 mm	 **C-2** 38.1 x 17.78 x 7.38 mm
E  **MS8 / MS8G** 4.9 x 3.0 x 1.0 mm	E  **LP5 “QFN”** 5.0 x 5.0 x 1.0 mm	✓  **LM1 / LM3** 5.1 x 5.1 x 1.1 mm	 **C-3** 40.89 x 17.78 x 7.38 mm	 **C-4** 41.66 x 36.32 x 8.50 mm
E  **MS10 / MS10G** 4.9 x 3.0 x 1.0 mm	E  **LP6 “QFN”** 6.0 x 6.0 x 1.0 mm	✓  **C8** 7.4 x 5.1 x 2.4 mm	 **C-5** 41.66 x 29.84 x 8.50 mm	 **C-6** 45.34 x 17.27 x 8.50 mm
E  **S8 / S8G** 6.0 x 4.9 x 1.6 mm	E  **QS16 / QS16G** 6.0 x 4.9 x 1.5 mm		 **C-7** High Power Amplifiers	 **C-9** 41.66 x 27.59 x 8.50 mm
E  **S14** 6.0 x 8.7 x 1.6 mm	E  **QS24** 6.0 x 8.7 x 1.6 mm		 **C-10** 41.66 x 27.59 x 8.50 mm	

E = *Specify “E” suffix for RoHS Compliant packaging.*　　✓ = *These packages are RoHS Compliant.*

HMC “Green” Component Program

Hittite is committed to meeting the Restriction of Hazardous Substances (RoHS) European Union directive and has an active program in place to eliminate halogen compounds, antimony compounds and lead (Pb) from our products. HMC plastic package types are now qualified for both RoHS and JEDEC MSL1 (260 deg. C peak temperature) and their related products have been released to production. The lead plating is 100% matte tin (Sn) over copper alloy and is backwards compatible with the current standard SnPb solder as well as future higher temperature “Pb free” solders. RoHS Compliant “E” products are form, fit & functional replacements for their related, released non-RoHS HMC product. Products such as all bare die (chips) and ceramic based packages have always been RoHS Compliant, are released, are available from stock and do not require a “E” part number suffix designator.

Currently Hittite offers 385 RoHS Compliant RFIC & MMIC standard catalog products and will continue to offer the original non-RoHS versions of our plastic packaged products. Please contact earthfriendly@hittite.com for details on our RoHS Compliant products or see the RoHS Compliant Components link on our web site.

Customer Support

How to Buy:

Hittite Microwave Corporation offers many convenient ways to order products and/or receive pricing and delivery information. Our order entry/MRP system assures customer sample requests and orders will be entered quickly, tracked easily, and completed accurately on-time.

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  With our E-Commerce capability Hittite customers can enjoy the convenience of on-line ordering via a secure shopping cart interface. A minimum purchase of 10 pieces can be made for die and SMT products or one piece minimum for evaluation PCB and module products. Customers may also purchase volume tape & reel for SMT products.

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  You may contact Hittite Microwave directly at (978) 250-3343. Purchase orders can be faxed to (978) 250-3373 or sent via email to sales@hittite.com. There is a minimum purchase order charge of $250.00 (U.S. Dollars).

- **HMC Field Sales Offices:**

  You may contact our field sales offices listed to the right for assistance in purchasing Hittite products.

Worldwide Network of Sales Representatives

You may purchase our products through our network of manufacturer representatives. European customers may also purchase products in Euros directly from Hittite Microwave Deutschland GmbH.

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Hittite Microwave Corporation is Committed to:

- *Being a supplier of products of the highest quality.*
- *Advancing state-of-the-art technology to support our products.*
- *Enhancing our competitive position with superior products.*

Hittite's Quality Policy Recognizes Responsibilities for Every Individual to:

- *Take the initiative to promote quality.*
- *Create an environment where highest standards are maintained.*
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The Quality & Product Support Section of Our Web Site Includes:

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- *Product Reliability*
- *Qualification Test Reports*

Product Application Support

- *Application Engineering Support*
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- *Mixer Spur Chart Calculator & PLL Phase Noise Calculator*
- *Package & Layout Drawings - Product outline, PCB land pattern and tape & reel drawings.*
- *Parametric Product Search- Match desired performance parameters to HMC products.*
- *Product Cross Reference - Thousands of ICs cross-referenced to HMC products.*
- *Published Papers*
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Data Sheets

- *Complete product data sheets in PDF format can be found on our web site.*

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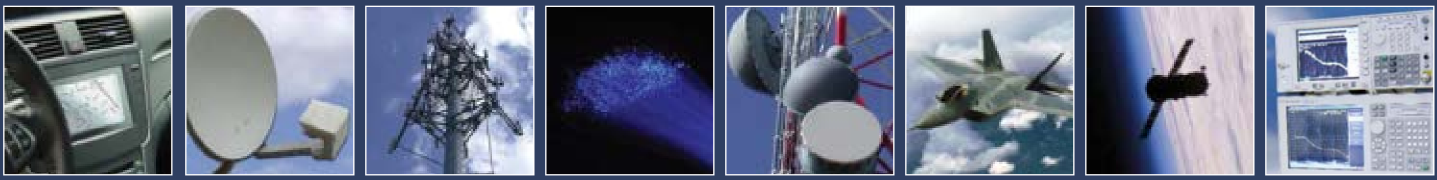

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