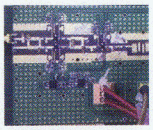
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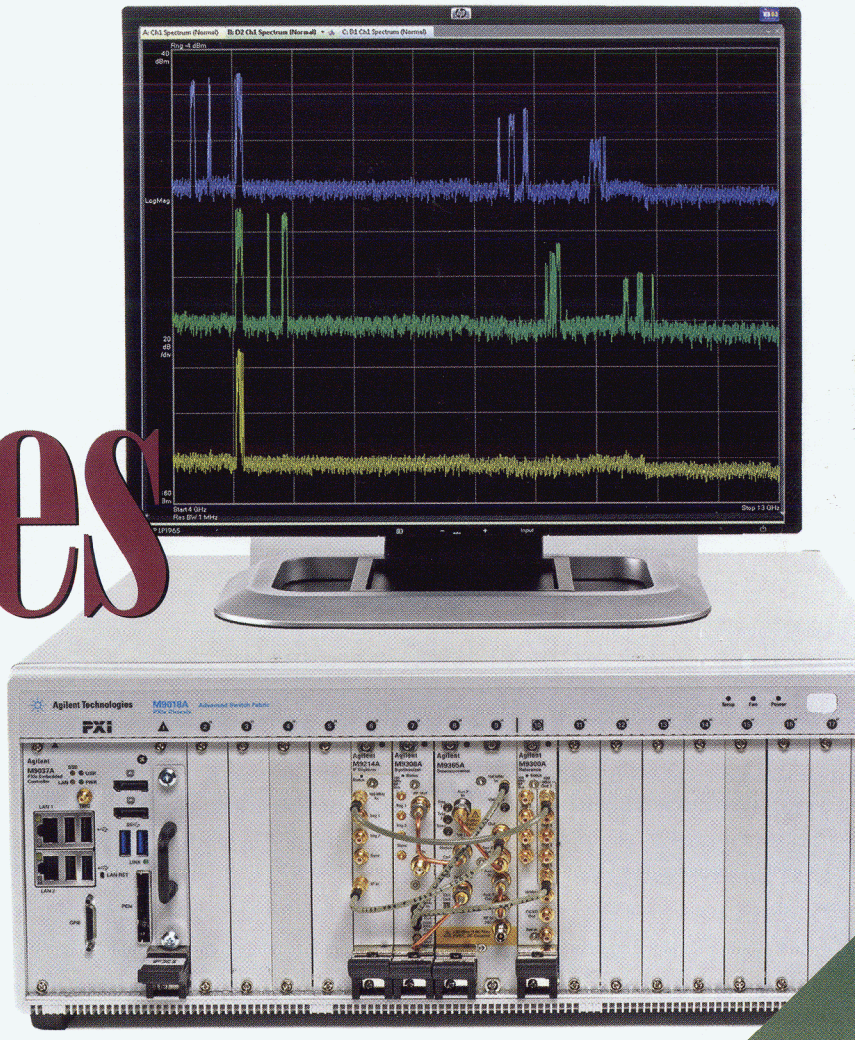
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WIRELESS TECHNOLOGIES ISSUE

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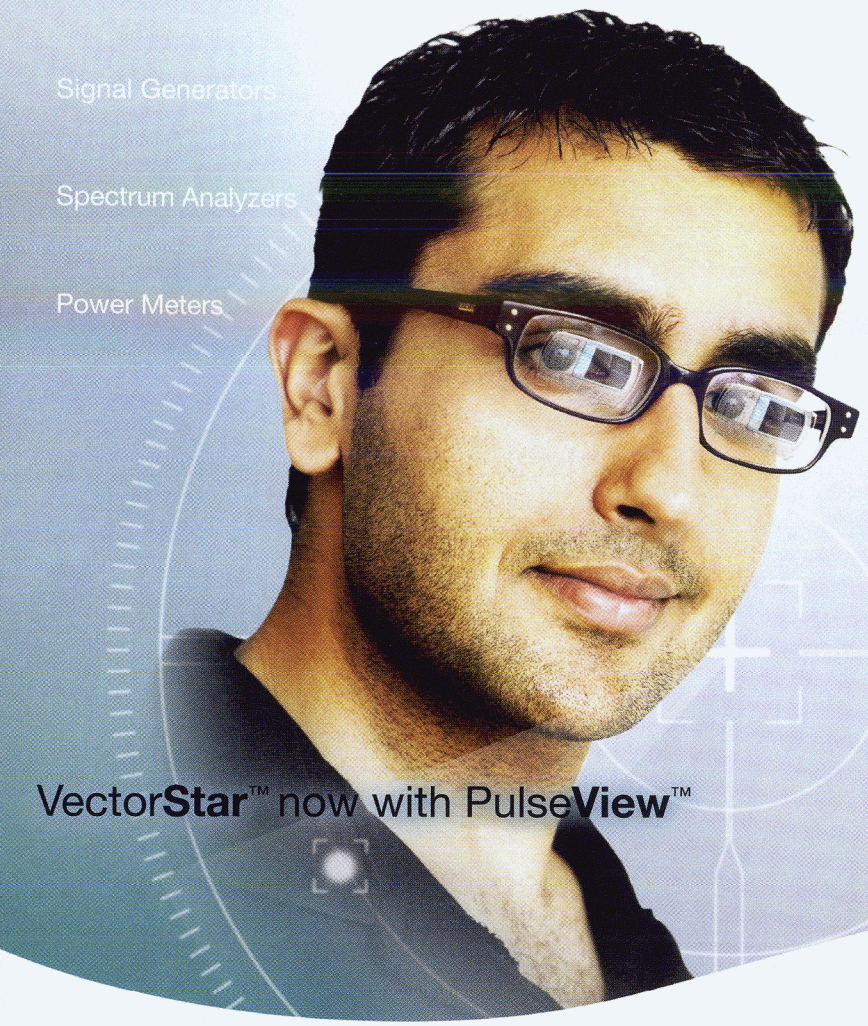
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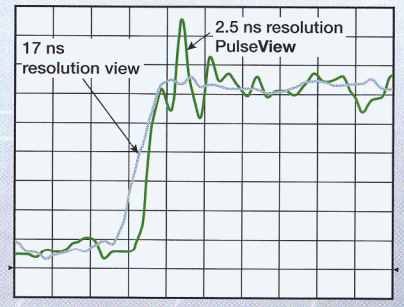
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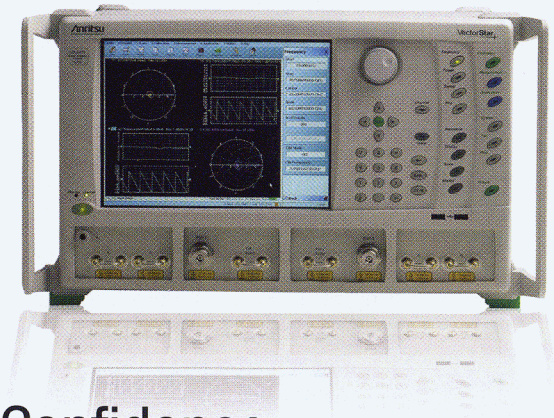
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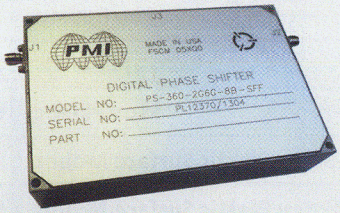
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8-BIT Digital Phase Shifter



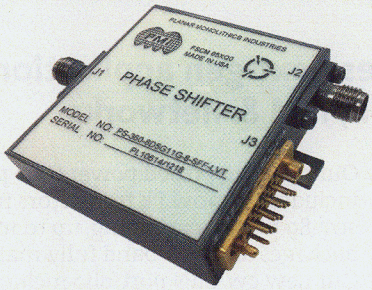
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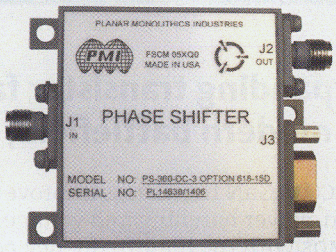
- 2.0 to 6.0GHz
- 10.5dB Insertion Loss
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- +/- 1.5dB PM/AM
- 285nsec Phase Shift Speed
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8.5 to 11.0GHz
8-BIT Digital Phase Shifter



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- +/- 4 Degrees Phase Flatness
- +/- 1.5dB PM/AM
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6.0 to 18.0GHz
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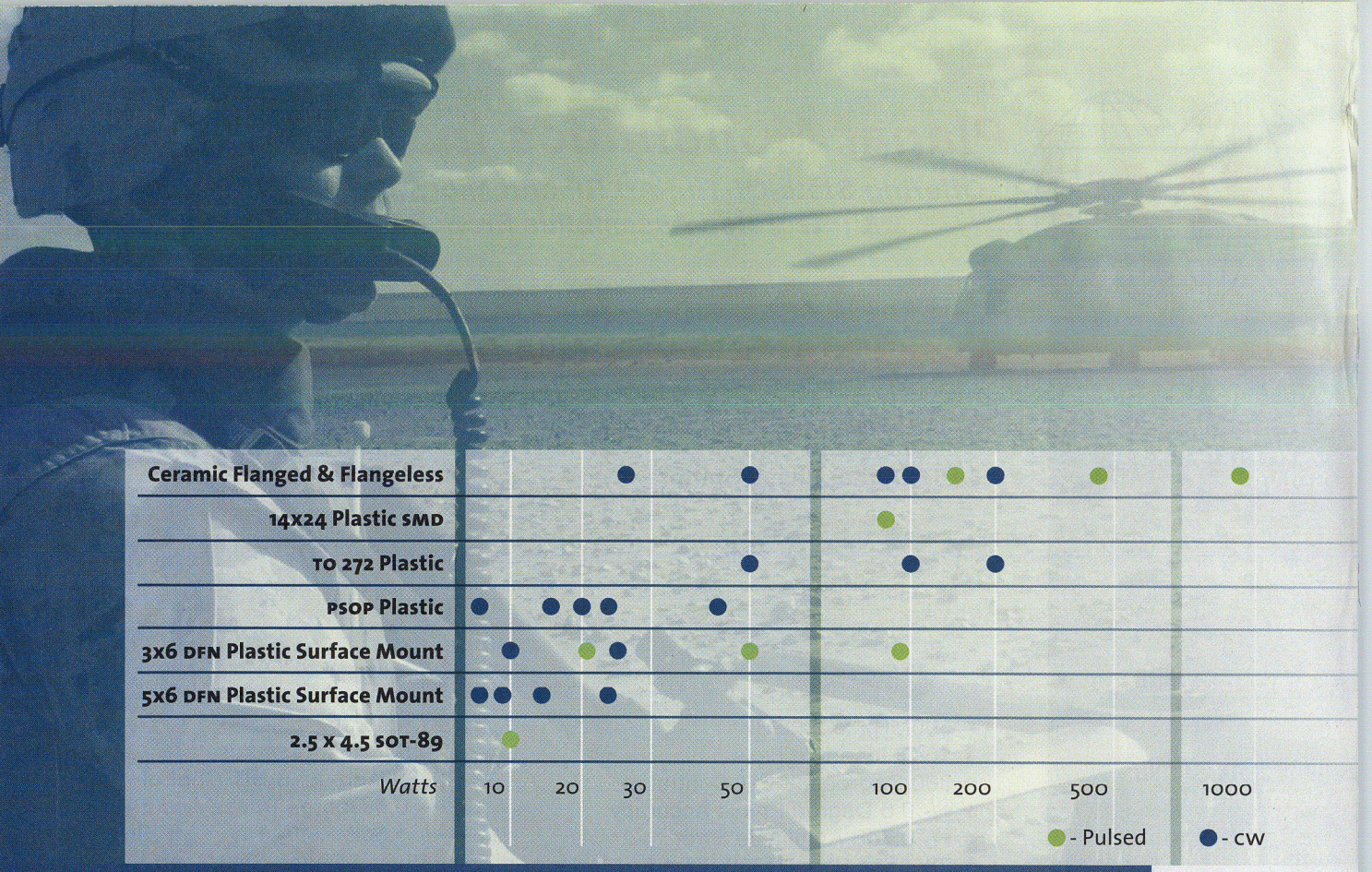
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- 10dB Insertion Loss
- 360 Degrees, 8-BIT Control
- +/- 5 Degree Phase Accuracy
- +/- 0.8dB PM/AM
- 500kHz Min. Translation Rate
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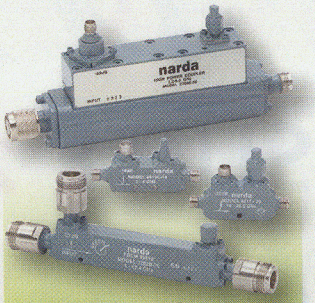
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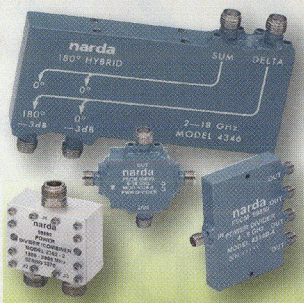
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- Fixed, Step, or Variable
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- DC to 40 GHz



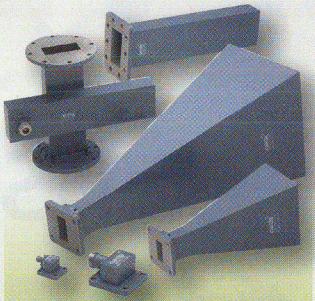
Directional Couplers

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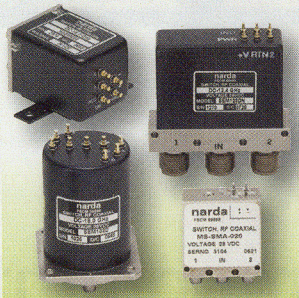
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- Newly Expanded Line, Including 130 New Products
- 1.7-40 GHz
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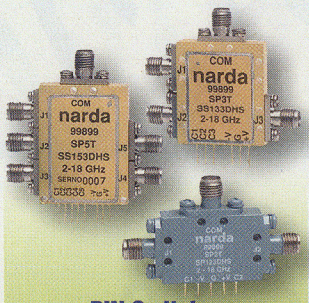
Terminations

- Low VSWR
- High Power (up to 500W CW)
- DC-40 GHz



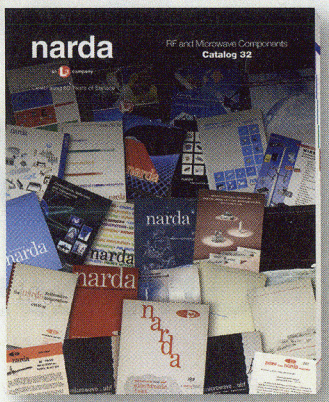
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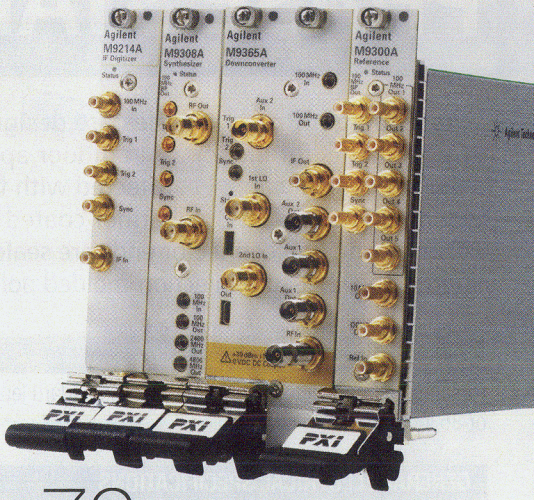
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PXIe Modules Pack Speedy 27-GHz VSA
Blazing frequency switching speed and unmatched accuracy have been packed into this broadband VSA and its compact, flexible PXIe form factor.

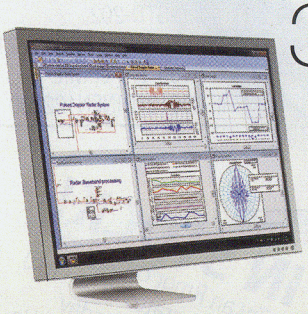
52 Five Trends Shaping 802.11 WLANs
WLAN technology continues to expand and evolve, with this wireless technology supporting personal and enterprise applications.

58 Low-Cost Front End Receives 9 GHz
This wideband, low-cost superheterodyne receiver front end employs GaAs HEMTs with a commercial mixer.

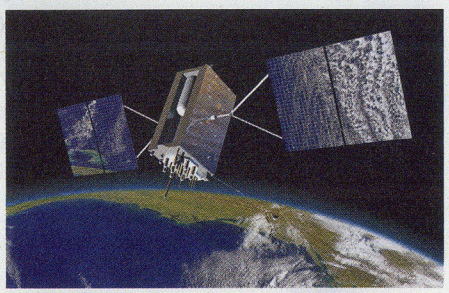
66 Radiometer Aids Fire Detection
This prototype Ku-band radar system can be instrumental in safety applications, such as for use in fire-detection radar equipment.



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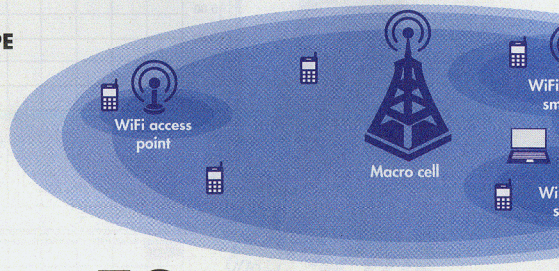
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Additional connector interfaces and armor/cable diameters are available on request.

DESCRIPTION

Rosenberger connectors, cable assembly, standard length 915mm or 36 inches

GENERAL ELECTRICAL SPECIFICATIONS

Impedance:	50 +/- 1 Ohms
Operating frequency:	DC to 70 GHz
Return loss:	14 dB minimum up to 70 GHz
Cable insertion loss:	.67 dB/ft @ 10.0 GHz
Velocity of propagation (%):	78 % nominal
Capacitance:	24.7 pf/ft. nominal
Shielding effectiveness:	< -90 dB
Dielectric withstand voltage:	1000 Vrms
Amplitude & phase stable:	+/- .03dB & +/- 1° @10GHz

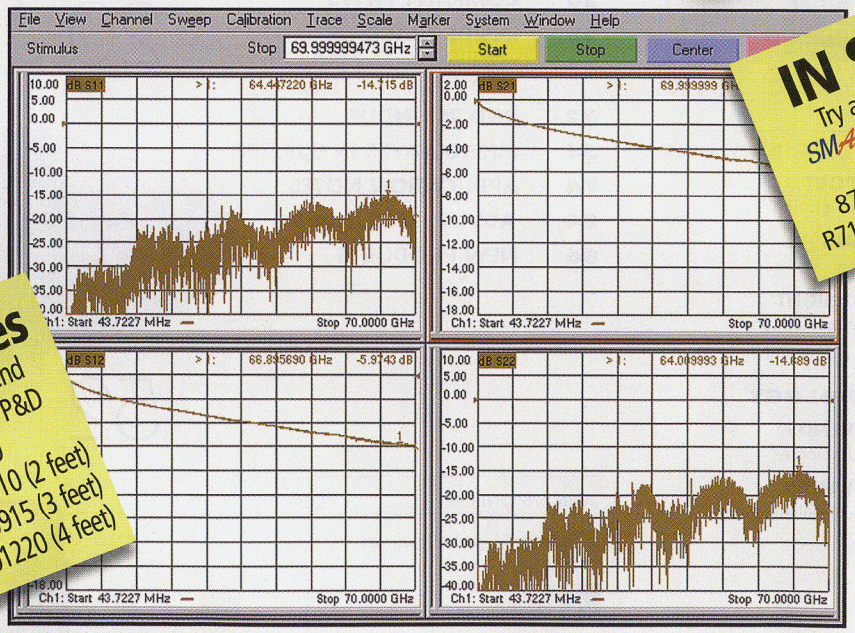
MECHANICAL SPECIFICATION

Cable jacket & armor outer diameter:	092 inches nominal & .250 inches nominal
Minimum bend radius:	.5 inches
Armor crush strength:	450 lbs/in (min)
Connector retention:	≥25 lbs.
Mating torque:	7-10 inch pounds

MATERIALS AND FINISHES

Armor type:	SPIRAL-wound 304 SS & Polyurethane blue jacket
Connector environmental testing:	Per MIL-STD-202, Meth 101,106,107,204 & 213
Connector interface dimension:	IEC 60169-17 Per MIL-PRF-39012 DINEN122200

Note: Cable assemblies also available with interfaces such as 1.85mm, 2.4mm, 2.92mm, SMA +, SMA, N.



Example of typical 36 inches assembly up to 70 GHz

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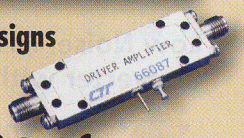
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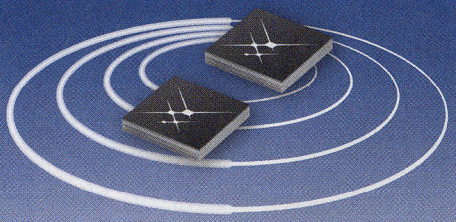




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- Output auto discharge when disabled
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- High efficiency: up to 98%
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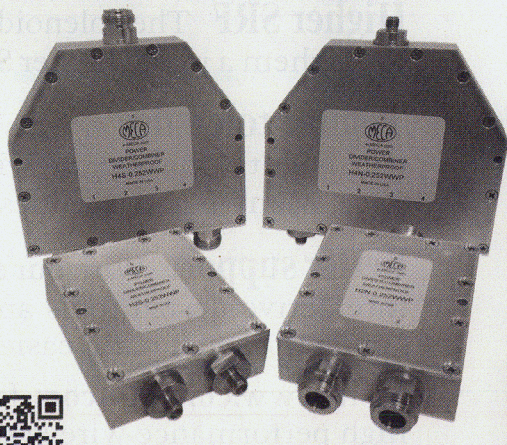
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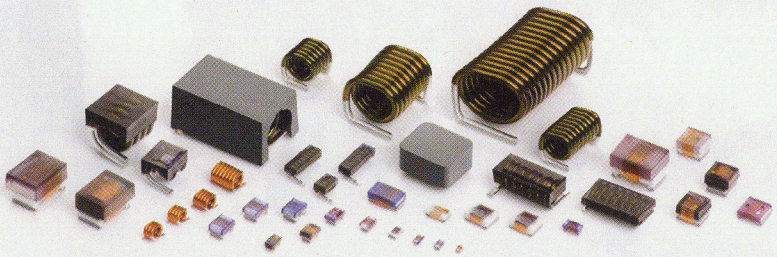
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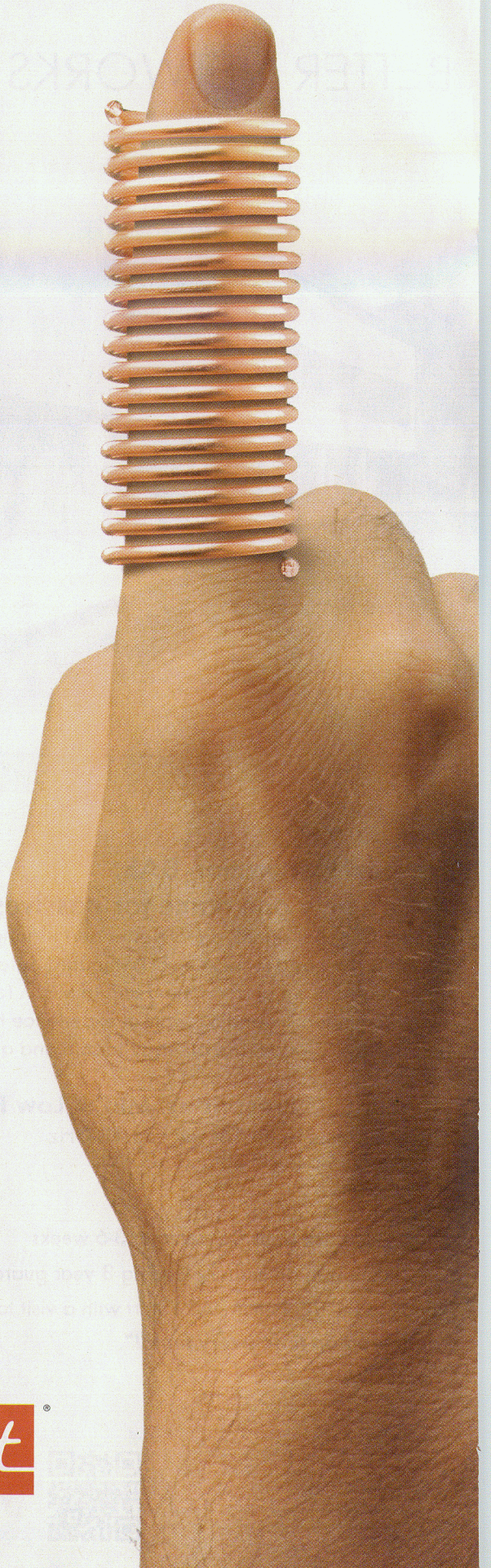
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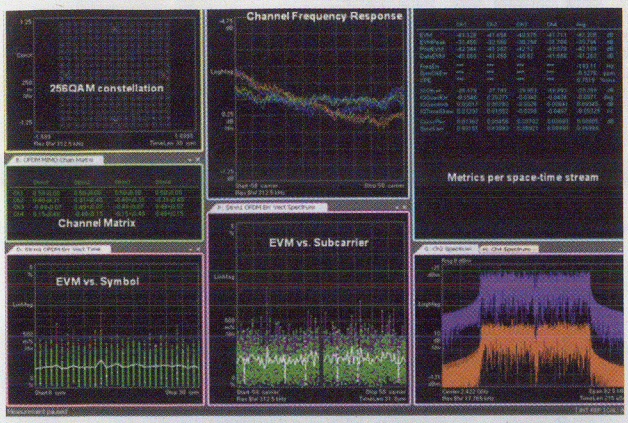


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WHAT'S THE DIFFERENCE BETWEEN IEEE 802.11AC AND 802.11AD?

The IEEE 802.11ac and 802.11ad specifications both promise to deliver increased capacity, speed, and performance in different ways, allowing users on-the-go to enjoy even their highest-data-rate applications. In this Web-exclusive report, Agilent Technologies' *Liz Ruetsch* breaks down the differences between the two.

To read the article in its entirety, go to *www.mwrf.com/test-amp-measurement/what-s-difference-between-ieee-80211ac-and-80211ad*

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• Microwave Meetings

News

Putting Software Through Its Paces

Jack Browne, Technical Contributor

In addition to offering demonstrations of its powerful computer-aided-engineering (CAE) software tools at booth No. 330, AWR will be sponsoring several social gatherings at the 2013 IMS.

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Corralling Materials For Microwave Circuits

Jack Browne, Technical Contributor

Engineers in need of a starting point for their high-frequency printed-circuit boards (PCBs) will find them by comparing notes with members of Rogers Corp.'s Advanced Circuit Materials division at IMS booth No. 1459. Visitors to the booth will learn about Rogers' next generation RO4000® circuit materials.

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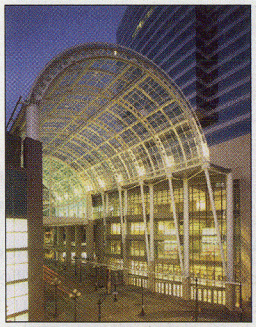
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BOB NELSON—*Product Support Engineer, Agilent Technologies*

REVISIT IMS2013



The 2013 installment of the RF/microwave industry's flagship event, the *International Microwave Symposium,* has come and gone. Luckily for you, it needn't live on just in memory. Visit *www.mwrf.com/ims-2013-microwaves-rf-reports-event* to check out our show coverage, as well as *www.engineering tv.com* to view videos from the event.

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ZHL-5W-1	5-500	44	8	11	995	970
• ZHL-100W-GAN+	20-500	42	79	100	2395	2320
• ZHL-50W-52	50-500	50	40	63	1395	1320
• ZHL-100W-52	50-500	50	63	79	1995	1920
LZY-1+	20-512	43	37	50	1995	1895
• ZHL-20W-13+	20-1000	50	13	20	1395	1320
• ZHL-20W-13SW+	20-1000	50	13	20	1445	1370
LZY-2+	500-1000	46	32	38	1995	1895
NEW ZHL-100W-13+	800-1000	50	79	100	2195	2095
ZHL-5W-2G+	800-2000	45	5	6	995	945
ZHL-10W-2G	800-2000	43	10	13	1295	1220
ZHL-30W-252+	700-2500	50	25	40	2995	2920
ZHL-30W-262+	2300-2550	50	20	32	1995	1920
ZHL-16W-43+	1800-4000	45	13	16	1595	1545
ZVE-3W-83+	2000-8000	36	2	3	1295	1220
ZVE-3W-183+	5900-18000	35	2	3	1295	1220

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** To order **without** heat sink, add **X** suffix to model number (example: LZY-22X+).*

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Editorial

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Satellites Prove Key To Search

The satellite market is moving forward at a dazzling rate, thanks to the myriad needs of today's world and subsequent technology developments. From GPS III to commercial, weather-monitoring, and otherwise-purposed satellites, advances are being driven forward daily. With so many "eyes in the sky," many have worried about loss of privacy. If the official story is true, the tragic loss of Malaysia Airlines' 370 jet has revealed that satellite systems and technology are indeed so numerous that they can provide at least some intelligence on anything within their "view."

As the world waited to find out what had happened to the missing jet, new satellite reports of ocean debris were produced frequently from various countries. Between bad weather and the delays in pinpointing potential debris, however, searches were delayed or postponed—only to discover that the sighted objects were most likely garbage floating in the ocean. In the process of figuring out how a jet could just "disappear," the world learned a lot about the 777's transponder and communications equipment and how—once those systems were disabled—the plane would simply cease to be tracked.

By tracking satellite "pings" and applying several math concepts to them, it was finally announced that the plane's path had been rather definitively plotted. One of Inmarsat's satellites had received regular "pings" from a plane that it could confidently identify as Flight 370. According to an article on CNN, titled "How 'groundbreaking' number crunching found path of Flight 370," Inmarsat officials and engineers were able to determine whether the plane was flying away or toward the Inmarsat satellite's location by expanding or compressing the satellite's signal.

Each ping was analyzed to determine the direction in which the plane was moving—a process reviewed by space-agency experts with contributions from Boeing. By adding trigonometry calculations, the engineers were able to determine angles of flight. According to these findings, the plane's final resting place was calculated as being in the southern Indian Ocean. As of the time of this writing, the plane has still not been found, leaving the story behind its fate a mystery. In addition to underscoring how tragedy can strike so unexpectedly, this story reveals how implicitly we have come to trust and depend on today's electronic communications systems. Whether or not their presence is welcome, today's satellites have hopefully provided some answers for the many relatives and loved ones in mourning. mw

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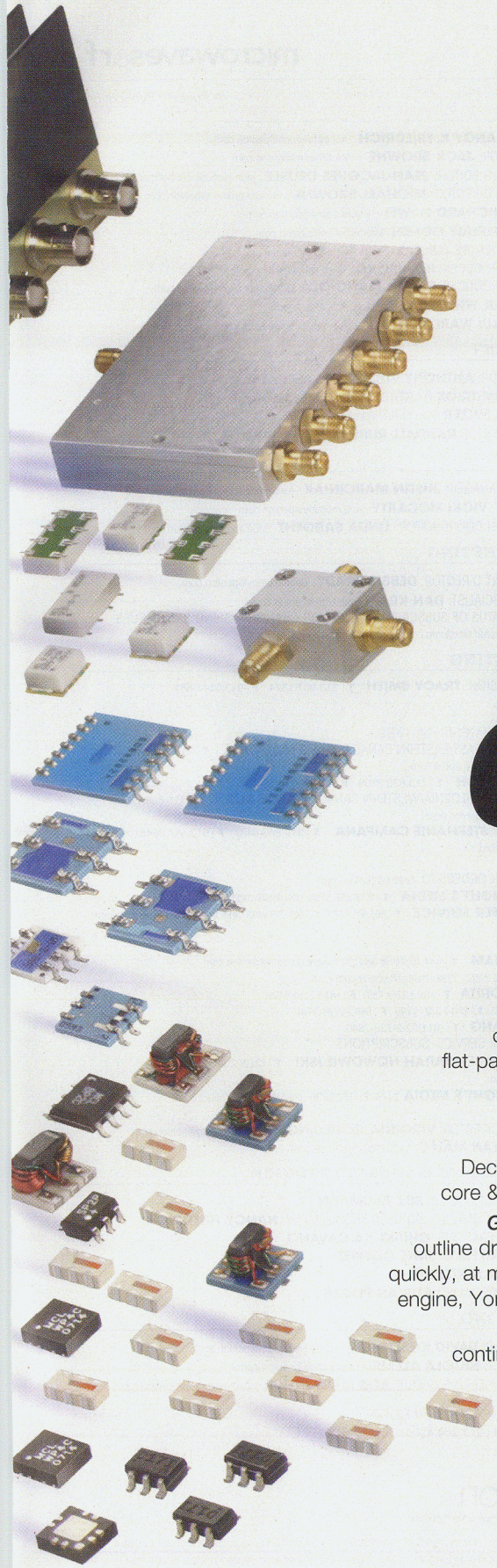
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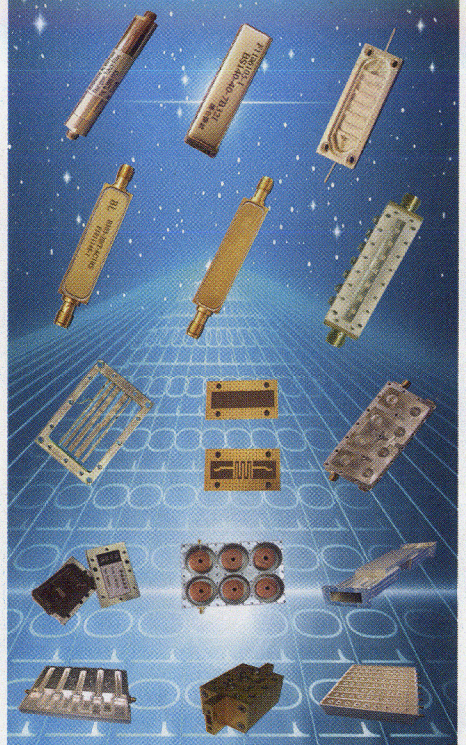
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CA01-2110	0.5-1.0	28	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA12-2110	1.0-2.0	30	1.0 MAX, 0.7 TYP	+10 MIN	+20 dBm	2.0:1
CA24-2111	2.0-4.0	29	1.1 MAX, 0.95 TYP	+10 MIN	+20 dBm	2.0:1
CA48-2111	4.0-8.0	29	1.3 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA812-3111	8.0-12.0	27	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA1218-4111	12.0-18.0	25	1.9 MAX, 1.7 TYP	+10 MIN	+20 dBm	2.0:1
CA1826-2110	18.0-26.5	32	3.0 MAX, 2.5 TYP	+10 MIN	+20 dBm	2.0:1

NARROW BAND LOW NOISE AND MEDIUM POWER AMPLIFIERS

CA01-2111	0.4 - 0.5	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA01-2113	0.8 - 1.0	28	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3117	1.2 - 1.6	25	0.6 MAX, 0.4 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3111	2.2 - 2.4	30	0.6 MAX, 0.45 TYP	+10 MIN	+20 dBm	2.0:1
CA23-3116	2.7 - 2.9	29	0.7 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA34-2110	3.7 - 4.2	28	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA56-3110	5.4 - 5.9	40	1.0 MAX, 0.5 TYP	+10 MIN	+20 dBm	2.0:1
CA78-4110	7.25 - 7.75	32	1.2 MAX, 1.0 TYP	+10 MIN	+20 dBm	2.0:1
CA910-3110	9.0 - 10.6	25	1.4 MAX, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA1315-3110	13.75 - 15.4	25	1.6 MAX, 1.4 TYP	+10 MIN	+20 dBm	2.0:1
CA12-3114	1.35 - 1.85	30	4.0 MAX, 3.0 TYP	+33 MIN	+41 dBm	2.0:1
CA34-6116	3.1 - 3.5	40	4.5 MAX, 3.5 TYP	+35 MIN	+43 dBm	2.0:1
CA56-5114	5.9 - 6.4	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6115	8.0 - 12.0	30	4.5 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA812-6116	8.0 - 12.0	30	5.0 MAX, 4.0 TYP	+33 MIN	+41 dBm	2.0:1
CA1213-7110	12.2 - 13.25	28	6.0 MAX, 5.5 TYP	+33 MIN	+42 dBm	2.0:1
CA1415-7110	14.0 - 15.0	30	5.0 MAX, 4.0 TYP	+30 MIN	+40 dBm	2.0:1
CA1722-4110	17.0 - 22.0	25	3.5 MAX, 2.8 TYP	+21 MIN	+31 dBm	2.0:1

ULTRA-BROADBAND & MULTI-OCTAVE BAND AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	3rd Order ICP	VSWR
CA0102-3111	0.1-2.0	28	1.6 Max, 1.2 TYP	+10 MIN	+20 dBm	2.0:1
CA0106-3111	0.1-6.0	28	1.9 Max, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-3110	0.1-8.0	26	2.2 Max, 1.8 TYP	+10 MIN	+20 dBm	2.0:1
CA0108-4112	0.1-8.0	32	3.0 MAX, 1.8 TYP	+22 MIN	+32 dBm	2.0:1
CA02-3112	0.5-2.0	36	4.5 MAX, 2.5 TYP	+30 MIN	+40 dBm	2.0:1
CA26-3110	2.0-6.0	26	2.0 MAX, 1.5 TYP	+10 MIN	+20 dBm	2.0:1
CA26-4114	2.0-6.0	22	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA618-4112	6.0-18.0	25	5.0 MAX, 3.5 TYP	+23 MIN	+33 dBm	2.0:1
CA618-6114	6.0-18.0	35	5.0 MAX, 3.5 TYP	+30 MIN	+40 dBm	2.0:1
CA218-4116	2.0-18.0	30	3.5 MAX, 2.8 TYP	+10 MIN	+20 dBm	2.0:1
CA218-4110	2.0-18.0	30	5.0 MAX, 3.5 TYP	+20 MIN	+30 dBm	2.0:1
CA218-4112	2.0-18.0	29	5.0 MAX, 3.5 TYP	+24 MIN	+34 dBm	2.0:1

LIMITING AMPLIFIERS

Model No.	Freq (GHz)	Input Dynamic Range	Output Power Range Psat	Power Flatness dB	VSWR
CLA24-4001	2.0 - 4.0	-28 to +10 dBm	+7 to +11 dBm	+/- 1.5 MAX	2.0:1
CLA26-8001	2.0 - 6.0	-50 to +20 dBm	+14 to +18 dBm	+/- 1.5 MAX	2.0:1
CLA712-5001	7.0 - 12.4	-21 to +10 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1
CLA618-1201	6.0 - 18.0	-50 to +20 dBm	+14 to +19 dBm	+/- 1.5 MAX	2.0:1

AMPLIFIERS WITH INTEGRATED GAIN ATTENUATION

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure (dB)	Power-out @ P1-dB	Gain Attenuation Range	VSWR
CA001-2511A	0.025-0.150	21	5.0 MAX, 3.5 TYP	+12 MIN	30 dB MIN	2.0:1
CA05-3110A	0.5-5.5	23	2.5 MAX, 1.5 TYP	+18 MIN	20 dB MIN	2.0:1
CA56-3110A	5.85-6.425	28	2.5 MAX, 1.5 TYP	+16 MIN	22 dB MIN	1.8:1
CA612-4110A	6.0-12.0	24	2.5 MAX, 1.5 TYP	+12 MIN	15 dB MIN	1.9:1
CA1315-4110A	13.75-15.4	25	2.2 MAX, 1.6 TYP	+16 MIN	20 dB MIN	1.8:1
CA1518-4110A	15.0-18.0	30	3.0 MAX, 2.0 TYP	+18 MIN	20 dB MIN	1.85:1

LOW FREQUENCY AMPLIFIERS

Model No.	Freq (GHz)	Gain (dB) MIN	Noise Figure dB	Power-out @ P1-dB	3rd Order ICP	VSWR
CA001-2110	0.01-0.10	18	4.0 MAX, 2.2 TYP	+10 MIN	+20 dBm	2.0:1
CA001-2211	0.04-0.15	24	3.5 MAX, 2.2 TYP	+13 MIN	+23 dBm	2.0:1
CA001-2215	0.04-0.15	23	4.0 MAX, 2.2 TYP	+23 MIN	+33 dBm	2.0:1
CA001-3113	0.01-1.0	28	4.0 MAX, 2.8 TYP	+17 MIN	+27 dBm	2.0:1
CA002-3114	0.01-2.0	27	4.0 MAX, 2.8 TYP	+20 MIN	+30 dBm	2.0:1
CA003-3116	0.01-3.0	18	4.0 MAX, 2.8 TYP	+25 MIN	+35 dBm	2.0:1
CA004-3112	0.01-4.0	32	4.0 MAX, 2.8 TYP	+15 MIN	+25 dBm	2.0:1

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MEASURING MODULAR TEST EFFECTIVENESS

In reading recent issues of *Microwaves & RF*, I have seen an increasing number of modular instruments being marketed for RF/microwave applications, both for commercial applications and military use. These instruments are designed as racks with plug-in modules (such as PXI and VXI modules), so a user can acquire or specify only the required functionality for a required series of measurements, then achieve that measurement capability by plugging those modules into a compact mainframe.

However, when I review the performance specifications for the majority of these modular measurement products, it always appears that traditional mainframe-type test instruments, although they may be larger and fixed in functionality, provide better performance. It would seem that a customer who is serious about performance would stick with the traditional measurement equipment and leave these modular instruments for less critical applications.

SIMON MAQUEDA

EDITOR'S NOTE

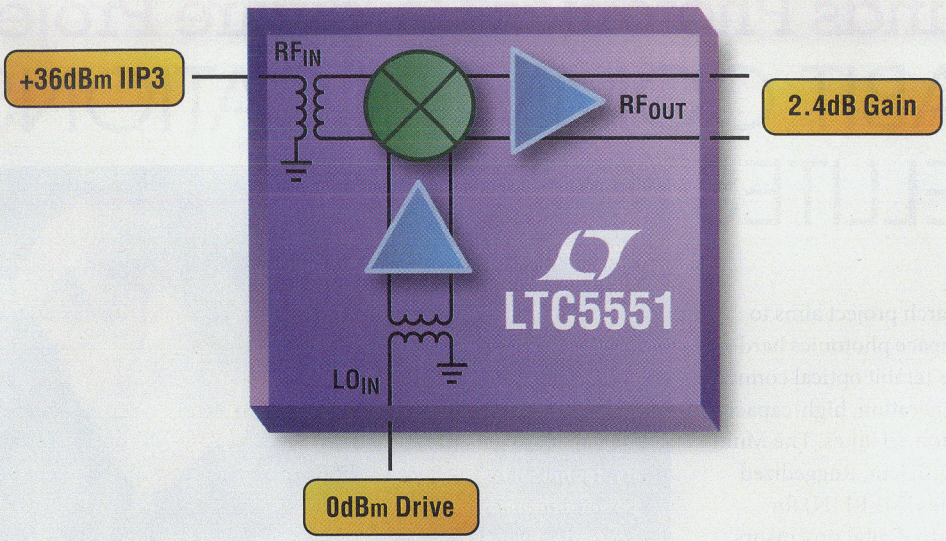
While it may have been true some years ago that modular measurement equipment was often viewed as "toys"—or at the very least, as test instruments that sacrificed modularity and portability for performance—many modular measurement instruments are now available with performance levels that match, and sometimes even exceed, traditional bench-top instruments.

A case in point is the M9393A PXIe vector signal analyzer (VSA) from Agilent Technologies (www.agilent.com), which is featured on p. 76. Admittedly, this is an instrument that offers performance levels that were simply not available in any type of modular instrument several years ago. It features a total bandwidth of 9 kHz to 27 GHz with 150-µs switching speed with measurement capabilities equally well suited for production and the research laboratory.

This is an instrument sure to capture the attention of many engineers working in high-frequency commercial and military/aerospace applications. It is available from a company that at one time was strongly associated with traditional, bench-top measurement equipment. But even with that background, Agilent (along with other high-frequency measurement firms) is well aware of the flexibility of a modular measurement format like PXIe. These companies are pushing to ensure that modularity does not translate into any sacrifice in performance.

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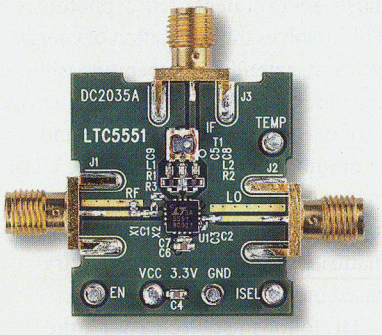
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LINEAR TECHNOLOGY

News

EU Funds Photonics Hardware Project for TERABIT COMMUNICATIONS SATELLITES



The latest terabit-capacity satellites will require a new approach to address digital on-board processors that rely on electronic technologies to combine scalability, technical feasibility, power-efficiency, and cost-effectiveness. (Image courtesy of DLR)

A new research project aims to develop space photonics hardware that enables terabit optical connectivity for next-generation, high-capacity telecommunication satellites. The Multi-gigabit, Energy-efficient, Ruggedized LIghtwave eNgines (MERLIN) for advanced on-board digital processors project is a collaborative mission set to run from November 2013 to October 2016. It is funded by the European Union's (EU) 7th Framework Program.

The latest terabit-capacity satellites will require a new approach to address digital on-board processors that rely on electronic technologies to combine scalability, technical feasibility, power-efficiency, and cost-effectiveness *(see photo)*. The MERLIN project outlines its plan through four main development objectives. The technologies will be integrated on a space-grade photonics platform to provide ruggedized transceiver modules with 150-Gb/s throughput and <10-mW/Gb/s energy consumption.

The first is an advanced electro/photonic vertical platform for harsh-environment embedded opto-electronic engines. It will be based on low-temperature-co-fired-ceramics (LTCC) circuit substrates. The novel LTCC structures, in combination with high-precision bonding and assembly, will be used to achieve the necessary micron-scale optical alignment for multicore optical fibers. The platform will be suitable for both stand-alone multi-channel optical transceivers and for application-specific-integrated-circuit/field-programmable-gate-array (ASIC/FPGA) packaging with embedded optical interconnects.

Next is the development of multi-core compatible and energy-efficient harsh-environment vertical photonics. This involves the fabrication of energy-efficient, extended-temperature gallium-arsenide (GaAs) 850-nm vertical-cavity surface-emitting laser (VCSEL) and photodiode arrays. GaAs and the ULM manufacturing process were chosen due to their radiation-hard performance, maturity, and readiness for foundry-based industrial mass fabrication.

The following objective is for the development of low-power multi-channel VCSEL drivers and transimpedance amplifier (TIA) integrated circuits (ICs). The multi-channel driver ASICs will be adapted for co-integration and RF interconnection with the active photonics on the LTCC platform. The ICs will be developed for operation as high as 25 Gb/s. A total chip throughput of 150 Gb/s will be reached through the integration of multi-channel ICs. They will be fabricated using an IHP Microelectronics silicon-germanium (SiGe) bipolar-complementary-metal-oxide-semiconductor (BiCMOS) process suitable for the production of electronics for aerospace applications.

The last objective is the development of radiation-hardened multicore, multimode fibers to be coupled with the opto-electronic chips. MERLIN will employ advanced-modified-chemical-vapor-deposition (MCVD) technology to accurately control the index of refraction of each fiber. This will help to enable 25-Gb/s multimode transmissions. OFS recently signed on to the project to help in the fabrication of the fibers. ■

LTE-TDD SMALL-CELL NETWORK Demonstrated at NASCAR Raceway

ALTHOUGH CONVENTIONAL MACRO-CELL towers provide excellent wide-area wireless-communications coverage, the deployment of small-cell networks offers a more cost-effective solution that delivers high levels of mobile data capacity to both indoor and outdoor venues. Qualcomm Technologies, in collaboration with Sprint and NASCAR, recently demonstrated the second phase of an over-the-air trial of a Long Term Evolution (LTE) time-division-duplex (TDD) hyper-dense small-cell network.

The Phoenix International Raceway was chosen as the venue for the demonstration because of its large fan attendance during NASCAR races and the challenging radio frequency (RF) conditions and high demand for mobile data during the events *(see photo)*. For the trial, Qualcomm installed 31 small-cell base stations in the garage area of the raceway to test density limits, measure network performance capabilities, and quantify the potential impact on users' mobile-communications experiences.

The hyper-dense network had an equivalent density of 1000 cells/km^2 and operated on Sprint's band 41 LTE-TDD spectrum. It was built with Airspan's AirSynergy 2000 LTE-Advanced Pico Base Stations, which are powered by Qualcomm's small-cell chipsets and UltraSON technology. The combination of technologies was previously demonstrated in November 2013 to show improvement of wireless data performance and quality of service (QoS) while reducing signaling load to the network. ■



The trial took place March 1-2, 2014 during the NASCAR Sprint Cup Series March Phoenix Race. (Photo courtesy of NASCAR)

MILCOM MARKET WILL Reach $30 Billion by 2022

THE INCREASING DEMAND for data-centric communications and net-centric capabilities will drive the military-communications market to reach $30 billion by 2022. The four areas that are expected to grow are ground, airborne, terrestrial-military-satellite, and shipborne communications. The new report by Strategy Analytics Advanced Defense Systems (ADS) includes information about all four of these markets and details their expected growth.



According to Strategy Analytics, the tactical-radio market will reach $4.5 billion in 2022 due to increasing demand.

Investments into ground-communications systems and components are expected to continue. The tactical-radio market is predicted to grow at a compound annual growth rate (CAGR) of 7.2%, reaching $4.5 billion in 2022 *(see photo)*. Handheld tactical radios will represent 94% of shipments, limiting the electronic component market to just over $721 million. The multiband sector will account for 78% of the total market by 2022.

The airborne-communications systems and components market will continue to grow at a CAGR of almost 2%, reaching $1.3 billion in 2022. The bulk will be represented by fast-jet platforms. The unmanned-aerial-vehicle (UAV) market will see the fastest growth with an emphasis on Ku-band and Ka-band frequencies. The electronic-components market will reach $79 million because of the emphasis on multiband radios. Gallium-arsenide (GaAs) and gallium-nitride (GaN) semiconductors also will see growth.

With their new satellite-communications platforms, terrestrial-military-satcom systems will accelerate demand for military very-small-aperture-terminal (VSAT) terminals. Shipments of Ka-band military VSAT terminals, as demand for voice and data-centric communications increases, will grow the most quickly through 2022. GaAs and GaN technologies will lead in the RF front end with the overall market for semiconductors predicted to grow at a CAGR of 7%. ■

PRECIPITATION RADAR EMPLOYS Variable Pulse Repetition

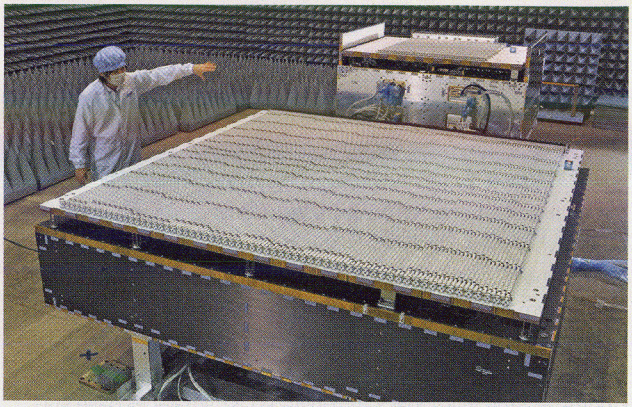
During space missions, long-range observation often causes delays between receiving and transmitting signals. But efficient sampling can be achieved by transmitting pulses successively. This method of variable pulse repetition frequency (VPRF) is currently being utilized by the dual-frequency precipitation radar (DPR) aboard the Global Precipitation Measurement (GPM) Core Observatory satellite. That mission seeks to better understand the Earth's weather and climate cycles by more accurately measuring precipitation.

The DPR was developed by the Japan Aerospace Exploration Agency (JAXA) and National Institute of Information and Communication Technology in Tokyo. Using emitted radar pulses, it makes detailed measurements of rainfall's three-dimensional structure and intensity. This approach allows researchers to improve estimates of how much water the precipitation holds.

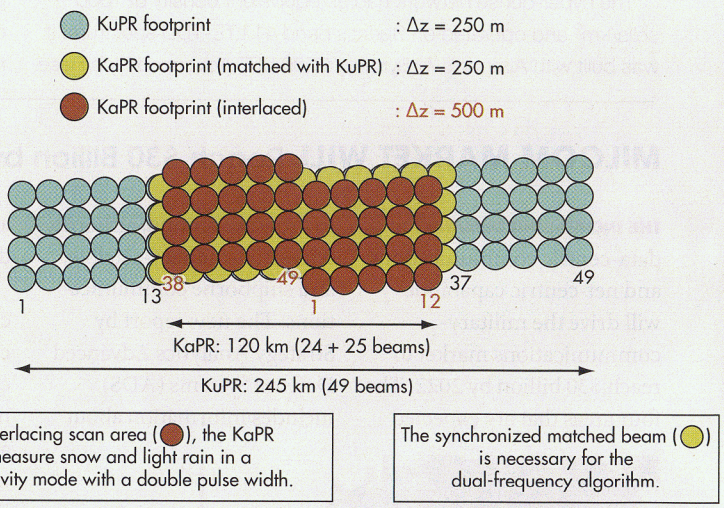
The instrument consists of two radars: a Ka-band precipitation radar (KaPR) at 35.5 GHz and a Ku-band precipitation radar (KuPR) at 13 GHz. The KaPR detects snow and light rain while the KuPR detects heavy rain. Combined, the DPR has 190-kb/s bandwidth over the 1553B spacecraft data bus.

The instrument has a vertical range resolution of 250 m, which provides vertical information at scales needed to resolve cloud structures. Both channels scan the beams in the cross-track direction to broaden observation areas. This effort is aided by the VPRF technique *(Figs. 1 and 2)*, which increases the number of samples at each instantaneous field of view (IFOV) and realizes 0.2-mm/h sensitivity. Such sensitivity allows for insight into the microphysical processes—evaporation, collision/coalescence, aggregation—that helps to distinguish regions of precipitation.

The satellite also houses a global microwave imager (GMI) that uses highly sensitive frequencies to discriminate between the noise and signatures of small particles of precipitation. Together, the instruments provide a three-dimensional view of the column of precipitation. The Core Observatory satellite was successfully launched from Tanegashima Space Center, Japan in February 2014. ■



1. The DPR consists of two radars: a Ka-band precipitation radar (KaPR) at 35.5 GHz and a Ku-band precipitation radar (KuPR) at 13 GHz. (Photo courtesy of NASA)



2. This image is courtesy of the JAXA presentation, "Draft plan of JAXA's GPM/DPR standard and research products."

PEOPLE


ABERLE

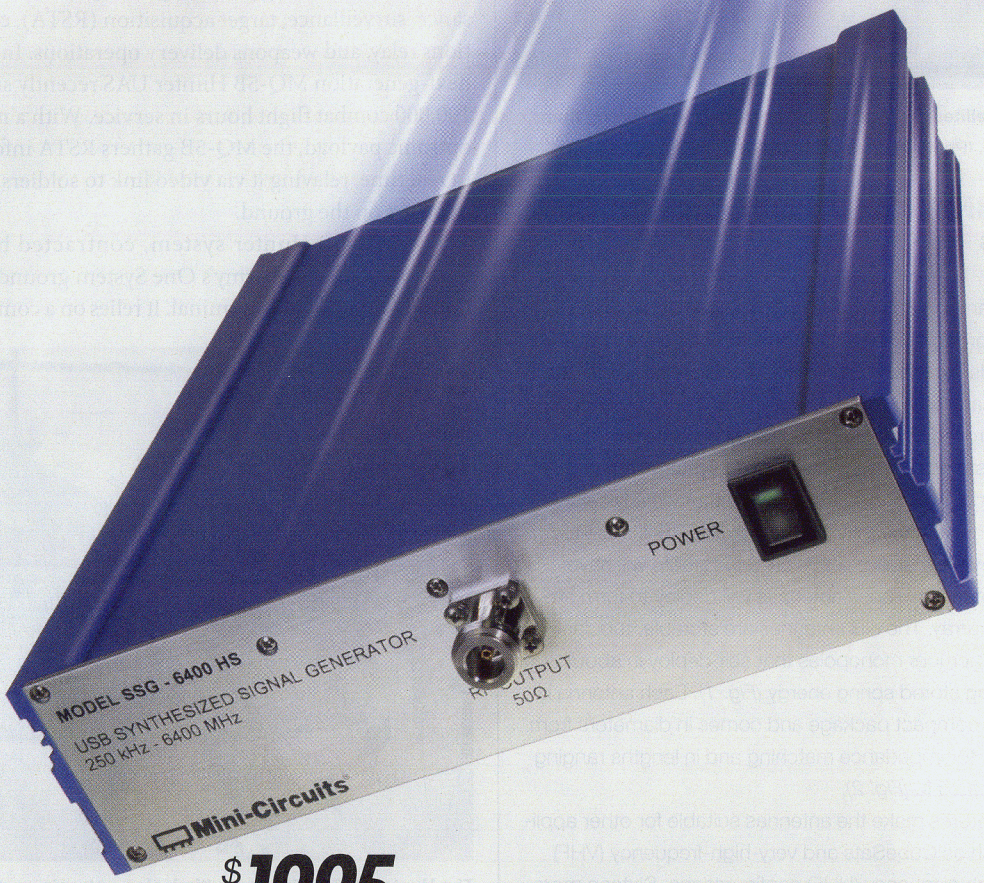
QUALCOMM INC.—Derek Aberle, executive vice president of Qualcomm Inc. and group president, has been promoted to president. In his new role, Aberle will have oversight for all business divisions across the organization as well as the company's global market development and marketing groups. He will also continue to formulate and drive key strategies for diversifying and growing the company, both in its core businesses as well as new business opportunities. Aberle will report to Steve Mollenkopf, who recently transitioned to the role of CEO of Qualcomm Inc.

NORTHROP GRUMMAN—Appointed Thomas P. Mendez, Jr., vice president and controller of its aerospace systems sector. In this role, Mendez will be responsible for financial planning and analysis; financial reporting and accounting; budgets, rates, and overhead management; government relations and compliance; resource management; and property administration for the sector.


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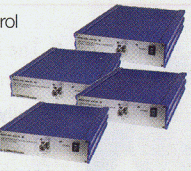
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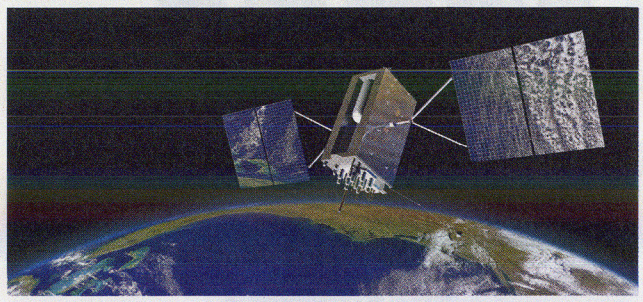
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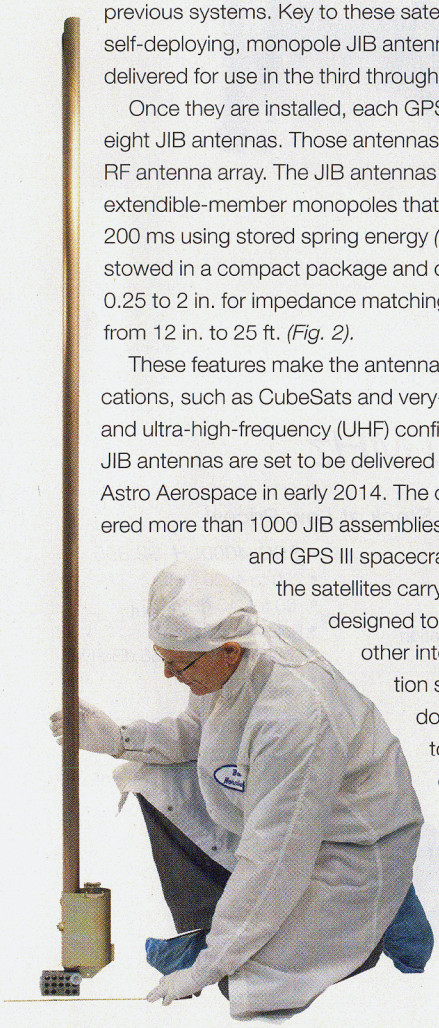
1. The GPS III satellites are said to deliver 3× better accuracy than previous systems. (Photo courtesy of Lockheed Martin)

JIB ANTENNAS WILL Form Array for GPS III Satellites

THE GPS III program's main objective is to replace dated GPS satellites in an affordable way while improving their capabilities. To meet the demands of military, commercial, and civilian users, the next-generation satellites are said to deliver 3× better accuracy and up to 8× improved anti-jamming capabilities compared to previous systems. Key to these satellite systems are the 32 self-deploying, monopole JIB antennas that were recently delivered for use in the third through sixth GPS III satellites.

Once they are installed, each GPS III satellite will have eight JIB antennas. Those antennas will deploy to form an RF antenna array. The JIB antennas are storable, tubular, extendible-member monopoles that self-deploy in about 200 ms using stored spring energy *(Fig. 1)*. Each antenna is stowed in a compact package and comes in diameters from 0.25 to 2 in. for impedance matching and in lengths ranging from 12 in. to 25 ft. *(Fig. 2)*.

These features make the antennas suitable for other applications, such as CubeSats and very-high-frequency (VHF) and ultra-high-frequency (UHF) configurations. Sixteen more JIB antennas are set to be delivered by Northrop Grumman Astro Aerospace in early 2014. The company has so far delivered more than 1000 JIB assemblies for GPS IIF, GPS IIR, and GPS III spacecraft. The antennas will help the satellites carry a new civil signal that is designed to be interoperable with other international global navigation satellite systems. In doing so, they promise to enhance civilian connectivity. ■

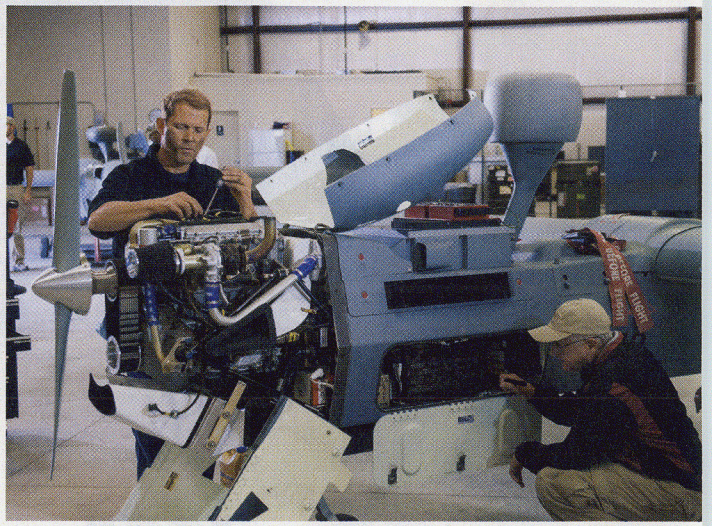


2. The GPS III JIB antenna assembly in its fully deployed configuration. (Photo courtesy of Northrop Grumman)

HUNTER UAS REACHES 100,000 Combat Flight Hours

In use since 1996, the RQ-5A Hunter was the US Army's first fielded unmanned aircraft system (UAS). In many ways, it set the bar by providing warfighters with reconnaissance, surveillance, target acquisition (RSTA), communications relay, and weapons delivery operations. In fact, the next-generation MQ-5B Hunter UAS recently surpassed 100,000 combat flight hours in service. With a multimission optronic payload, the MQ-5B gathers RSTA information in real time, relaying it via video link to soldiers and commanders on the ground.

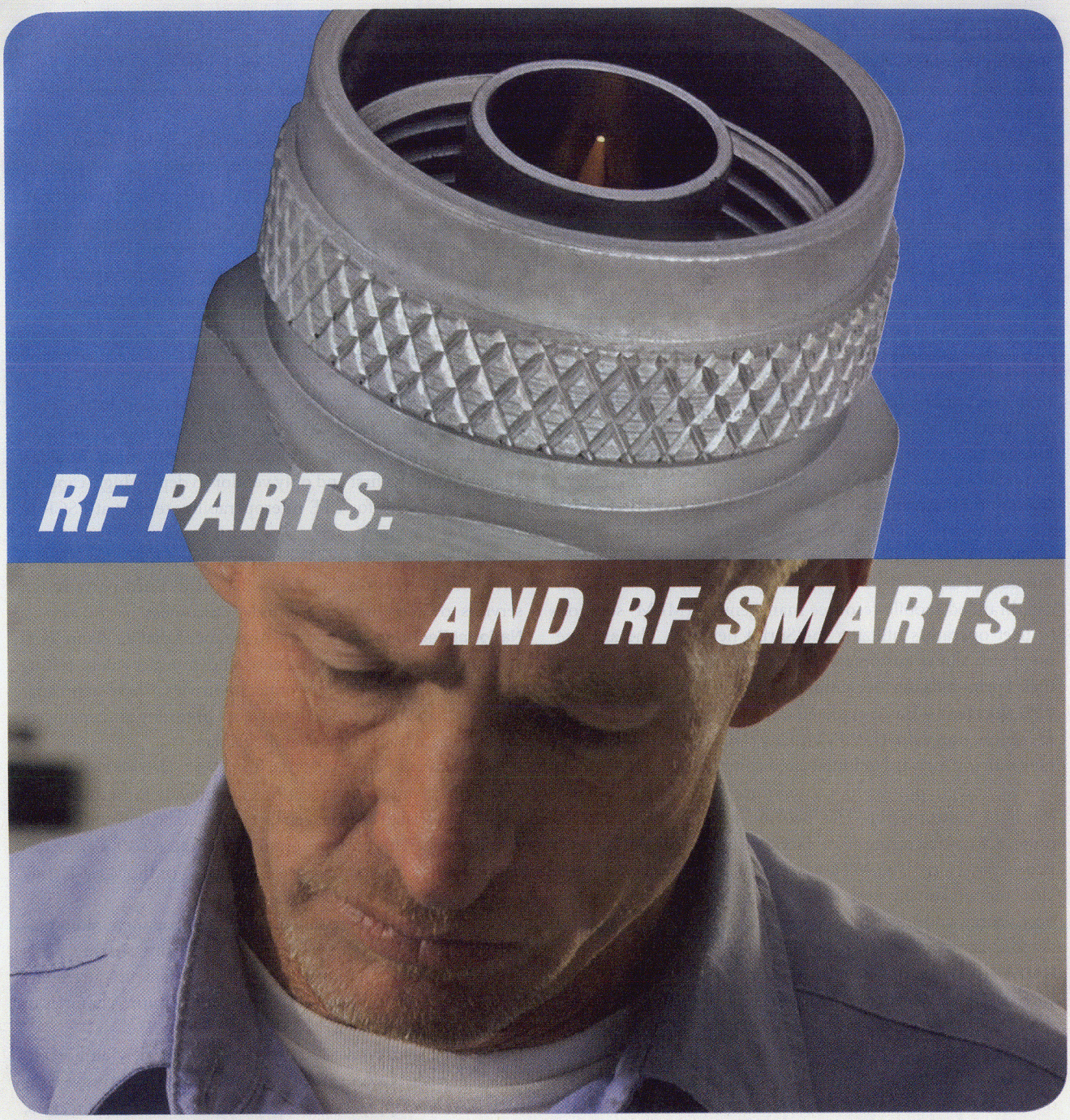
The MQ-5B Hunter system, contracted by Northrop Grumman, uses the Army's One System ground-control station and remote video terminal. It relies on a communications relay package to extend its radio range. Communications are sent over C-Band or tactical-common-data-link (TCDL) line-of-sight (LOS) data links. This aspect allows for the broadcasting of sensor data that enhances situational awareness. In doing so, it enables more proactive planning and the execution of decisive operations. A relay mode allows for the system to be controlled by other unmanned aerial vehicles (UAVs) at extended ranges or over difficult terrains.



The Hunter UAS utilizes a multimission optronic payload to relay real time information. (Photo courtesy of Northrop Grumman)

The UAS is equipped with a differential GPS automatic takeoff and landing system. It is easily distinguished by its heavy fuel engines—one serves to "push" the system while the other "pulls." The engines allow the Hunter to climb quickly, operate at high altitudes, and display endurance while reducing maintenance time and operation support costs. It also houses a "wet," or fuel-carrying, extended center wing with weapons-capable hard points and a modern avionics suite. ■

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CONTRACTS

Verizon Wireless—Will deploy Alcatel-Lucent's advanced data management platform throughout its network, helping to support the carrier's LTE expansion. The Alcatel-Lucent Subscriber Data Manager (SDM) will help support the expansion of Verizon's LTE services by centralizing multiple application databases.

SGS—Has selected the Rohde & Schwarz R&S TS-8980FTA-2 and R&S CMW500 wireless test platforms for industry conformance and carrier acceptance testing supporting key technologies, including LTE FDD and TDD Release 8, 9, and 10; carrier aggregation; and VoLTE/IMS and RCS.

VERIZON WIRELESS Deploys Alcatel-Lucent platform

SGS Selects R&S test solutions

General Communication, Inc.—Is eligible to receive $41.4 million from the Federal Communications Commission for rural 3G/4G wireless projects as part of the agency's Tribal Mobility Fund Phase I. More than 37,000 Alaskans across dozens of communities are expected to benefit from the fund, with GCI submitting winning bids to serve 48 communities.

FRESH STARTS

Knowles Capacitors—Brings leading specialty capacitor manufacturers Dielectric Laboratories (DLI), Novacap, Syfer Technology, and Voltronics under one roof as the newly formed company sets up shop at its headquarters in Norwich, UK.

Gowanda Electronics—Is teaming up with its recently acquired sister company, TTE Inc., to provide a broader range of electronic components to the global design engineering community.

Spireon—Partnered with Sprint to provide Spireon's FleetLocate-branded mobile resource management (MRM) solutions to fleet operators utilizing the Sprint network. The arrangement also allows customers to include FleetLocate services on their Sprint bills, further simplifying the offering.

WiFi Wireless—Has completed a final round of due diligence in conjunction with its WiFi My City program. The company is now moving forward to initiate and complete a designed, engineered, and operating proof of its concept City WiFi Network.

National Instruments—Has become the first vendor to execute a Manufacturing Test License (MTL) agreement with Broadcom Corp. The MTL agreement authorizes NI to provide manufacturing test solutions and modifiable application source code to Broadcom wireless LAN and Bluetooth device customers.

RADWIN—Will implement its FiberinMotion train-to-track wireless broadband solution in the Moscow metro, enabling the subway system to deliver 90 Mbps per train across distances of up to 900 meters. This throughput is used to provide broadband WiFi and paid advertising content to passengers on board trains.

ITC Global—Launched a new network over Sub-Saharan Africa, utilizing the Intelsat IS-25 spacecraft. Designed to provide high-performance voice, video, and data communications for remote mining and energy operations, the network covers most of the African continent, including both western and eastern coastal regions.

Alcatel-Lucent—Announced an agreement with Etisalat to extend that company's LTE coverage in the United Arab Emirates, one of the largest and fastest-growing markets for mobile data services.

Aviat Networks—Completed its LTE evaluation in the Public Safety Communications Research (PSCR) program at the Commerce Department's Boulder Laboratories in Boulder, Colo. Aviat is the first and only vendor to deploy high-capacity microwave radios for LTE interoperability testing at PSCR in licensed spectrum.

Plextek RF Integration—Has been selected by Cree as a preferred design resource. The firm will provide third-party design services to Cree's European foundry customers.

National Technical Systems—Announced that its Plano, Texas facility is now offering wireless and product safety testing services and international product approvals. These new capabilities enhance the comprehensive set of testing and engineering services already in place at the facility.

AT&T—Has proposed selecting the West Delray Beach area of Florida as one of two locations nationwide for a multi-year technology trial to be overseen by the Federal Communications Commission. This pilot program will shape AT&T's efforts to develop new products and processes, both in the West Delray Beach community and nationally.

xG Technology—Has been awarded a key cognitive radio patent for enabling high-performance spectrum sharing. This patent allows base stations to coordinate their measurements of spectrum usage and jointly determine optimum channels to use for communications.

East Coast Microwave Distributors—Has a new authorized franchise distribution agreement with Times Microwave Systems Inc. to supply the manufacturer's line of connectors, cable, and cable assemblies for high-performance reliable RF/microwave solutions.

TRM Microwave—Completed the acquisition of the high-power product line of Putnam RF Components of Manchester, N.H. The purchase of Putnam's high-power components line gives TRM a more competitive edge by offering a greater range of services, products, and added engineering talent. The company's first product introduction after the acquisition is the Model DDH 4016, a broadband dual-directional coupler, ready for quick-turn and volume production.

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455 rev H

Inside TRACK with James Klein,

VICE PRESIDENT OF INFRASTRUCTURE & DEFENSE PRODUCTS, *TriQuint*

Interview by JEAN-JACQUES DELISLE



JD: Given the recently announced merger of TriQuint and RFMD, what main technological capabilities would you say the two companies offer each other?

JK: Both TriQuint and RFMD have a long heritage as leaders in the RF solutions space. We look forward to merging TriQuint's advanced filter expertise and semiconductor capabilities with RFMD's strong background in semiconductors and internal packaging capabilities to create a market leader in products based on gallium-arsenide (GaAs), gallium-nitride (GaN), and CMOS technology.

By joining together, TriQuint and RFMD will consolidate their complementary capabilities to create a $2-billion RF powerhouse that offers a broad portfolio of enabling technologies with proven expertise in high-volume manufacturing. We'll be able to develop and commercialize tightly integrated solutions at record speeds for the world's top communications, defense, and aerospace companies.

JD: How will the R&D capabilities of the two companies benefit from the merger?

JK: One of the reasons the merger is advantageous to both companies is that there isn't a significant amount of overlap between TriQuint and RFMD in terms of our technology portfolios. This results in a much broader portfolio of technologies that will create value for our customers. It also provides the opportunity to enter into broader growth markets both today and in the future.

JD: How do you expect the merger to affect the GaN market?

JK: By bringing the capabilities of TriQuint and RFMD together, we're creating a new industry leader that can accelerate GaN technological development and more quickly deliver innovative products to the marketplace. The new combined company will expand its leadership in the GaN market beyond defense applications into infrastructure to drive widespread global adoption.

JD: Are there new goals/roadmaps for the GaN market based on this merger?

JK: It's really too early to provide a lot of details. We're diving much deeper now into detailed assessments of the respective capabilities of both companies. We'll align product and technology roadmaps to determine the best way to solve our customers' RF challenges and quickly realize the strategic benefits of the merger. If anything, the merger will strengthen our resolve around GaN and allow us to more quickly accelerate our technologies into broader markets.

JD: How will the combined company's aerospace and defense capabilities be enhanced?

JK: We have a long history of supporting defense technology and infrastructure development, and this merger reinforces our focus within that industry. For example, TriQuint has been a leading supplier of semiconductor technologies for military radar systems used on fast jets including the F-15, F-22, and F-35. We hold US Department of Defense (DoD) Trusted Source accreditation. RFMD also is active in the defense space with products targeting radar, communications, and electronic-warfare applications. The merger will broaden our collective capabilities, and we plan on bringing all those new products to our defense customers.

JD: How will TriQuint's fab be used to enhance the combined business?

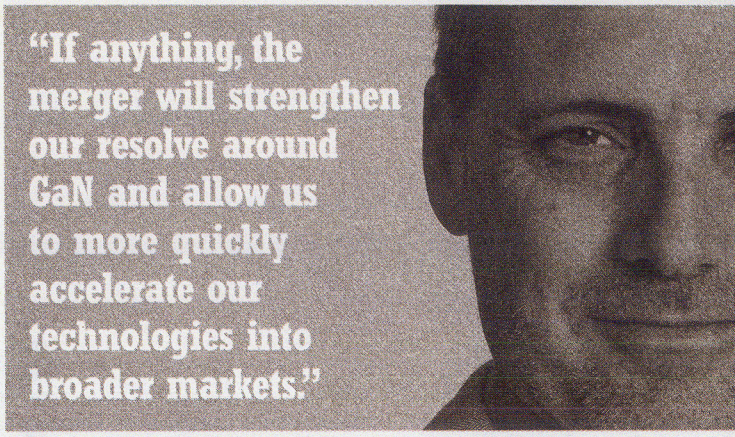
JK: Both TriQuint and RFMD have world-class fab capabilities. With its advanced technology portfolio, we expect the new company to enable the highest-performing, smallest, and most cost-effective RF products on the market. Over the next 24 months, we will be going through a process to streamline our efforts and fully rationalize our capacity needs.

JD: What impact do you predict the merger will have on mobile-device and network-infrastructure technology?

JK: With TriQuint's filtering capability and RFMD's advanced packaging and CMOS technology—coupled with our GaN and GaAs—we plan to deliver the industry's most comprehensive portfolio of critical RF technologies to mobile and infrastructure customers. We will leverage our collective integration expertise to pack more functionality and higher performance into single modules that are considerably smaller than discrete solutions. In addition, we will continue to drive innovation at the heart of the mobile data ecosystem and enable the worldwide transition to Long Term Evolution (LTE)—from base stations and optical fiber networks to highly integrated RF modules for today's increasingly complex mobile devices.

In the mobile-device space, the LTE buildout is expanding RF band counts in handsets dramatically. This trend, in turn, is driving increased demand for broadband power amplifiers (PAs) and high-performance filters. This has created a strong push toward integrated modules, which combine premium filters with highly efficient broadband PAs to reduce RF size and complexity for smartphones and other mobile devices. The company will be uniquely positioned with the technologies, integration know-how, and high-volume manufacturing expertise to address our customers' toughest LTE system and chipset challenges.

In the network infrastructure market, we'll harness those same capabilities to drive advancements in next-generation networks. The explosive increase in mobile data traffic is spurring service providers around the world to upgrade their networks. They must have sufficient capacity and coverage to meet customer demand. LTE deployments give those carriers more efficient ways to carry significantly more data traffic,



which drives a lot of the high-capacity requirements—from the base station through the backhaul connections to the data and switching centers and, ultimately, to the consumer. In China alone, more than 400,000 base stations are expected to be deployed. The ripple effect into optical networks and microwave radio links is already being felt across the industry.

Mobile carriers also are easing the strain on their overstretched networks by offloading an increasing amount of data traffic onto WiFi and small-cell networks, such as micro-, pico-, and femtocells. Our advanced filters and GaN and GaAs amplifiers enable these solutions to handle the interference, range, and capacity demands that we anticipate, as the utilization of high-bandwidth applications and crowded spectrum become more prevalent for consumers and businesses alike.

JD: How will the merger disrupt/enable technologies in the aerospace/defense industry?

JK: We'll be able to offer our long-time global customers a broader set of technologies that will continue our legacy of outstanding service and support. We remain committed to the defense market as a driver of innovative new technologies.

JD: What industries will become more accessible due to the merger?

JK: One of the great aspects of this merger is the limited amount of overlap in the markets we serve. RFMD has strong capabilities in cable television and WiFi, while TriQuint brings defense-industry knowledge and products as well as our proven optical and base-station technologies. It is really an ideal union and will quickly create a number of growth opportunities in three large, global markets: mobile devices, network infrastructure, and aerospace/defense.

We are in the very early stages of a deliberate strategic process to analyze our business and unleash our collective potential. As we have stated, however, we believe that there is at least $150 million in synergies that we can bring to bear as this process takes place over the next 24 months. mw



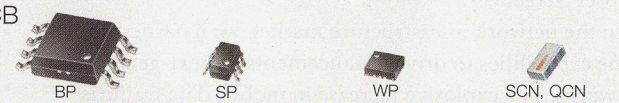
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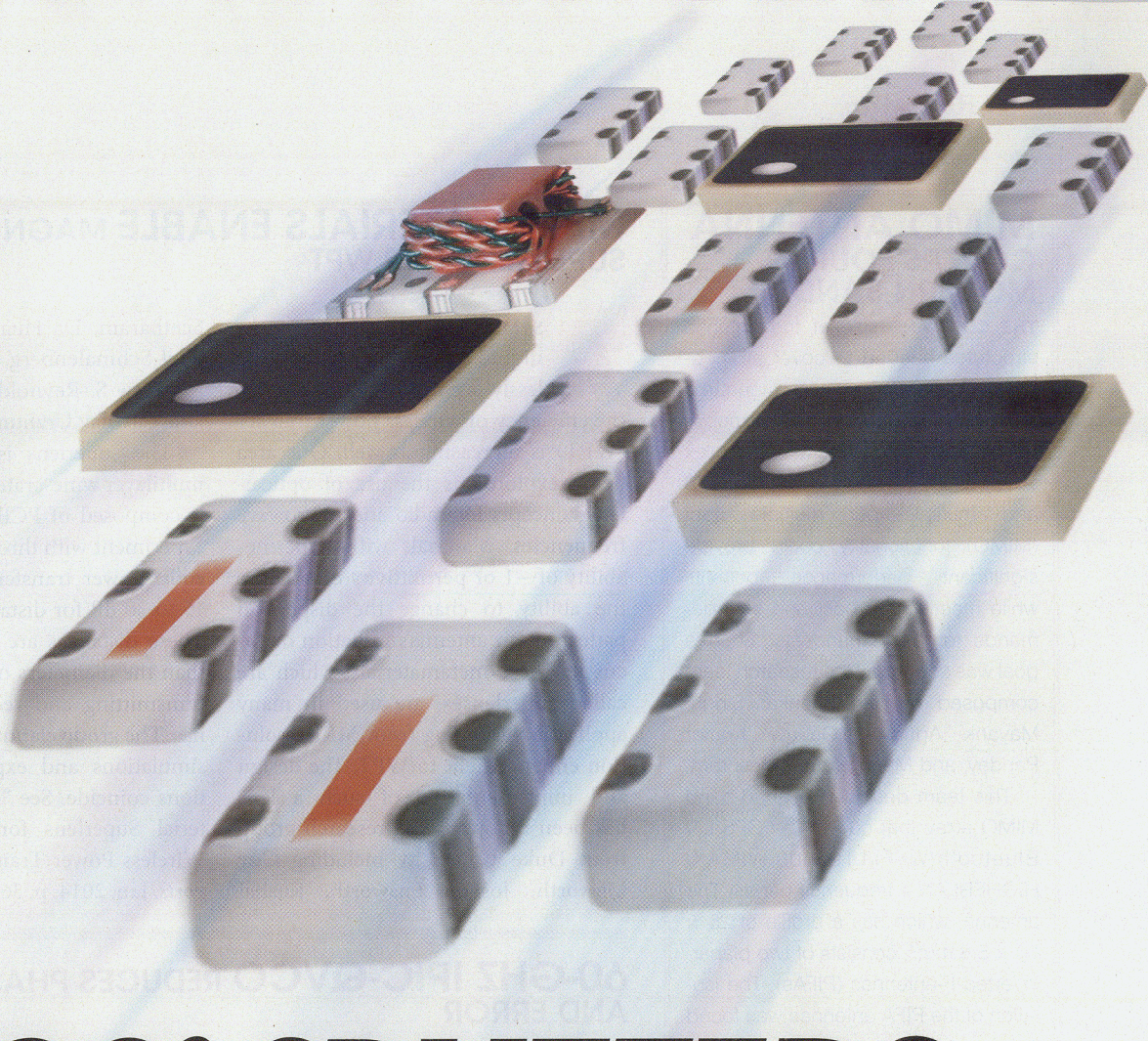
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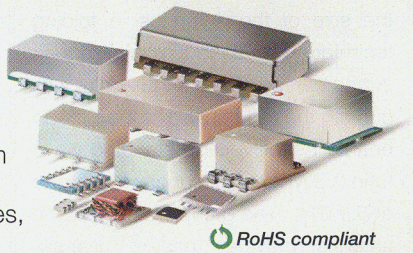
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MIMO ANTENNA COVERS FOUR MODERN BANDS

THE COST AND size of the antenna structures needed to cover all modern telecommunications standards are major considerations for mobile handset manufacturers. Complex antenna arrays that incorporate GPS and multiple-input multiple-output (MIMO) functionality could provide significant performance benefits while meeting the cost and size demands for these handsets. Such a goal was sought by the research team composed of Hari Shankar Singh, Mayank Agarwal, Gaurav Kumar Pandey, and Manoj Kumar Meshram.

This team designed a quad-band MIMO array that covers the GPS-L1/Bluetooth/Wi-Fi/LTE2500/WiMAX/HIGHERLAN 1 frequency bands. The antenna, which has a profile of 25 × 10 × 5.8 mm^3, consists of two planar-inverted F-antennas (PIFAs). The isolation of the PIFA antennas was found to be better than −15 dB with a correlation coefficient lower than 0.015 between the antenna elements.

The primary PIFA antennas are mirrors of each other and are thus mounted on the circuit-board corners. The antennas are configured for optimized functionality at 1.575 GHz. Because the optimization process increased the size of the antennas, a folding technique was used to minimize their surface areas. A rectangular slot was cut into the top surface of the PIFA to enable better voltage standing wave ratio (VSWR) in the higher-order mode at 5.1 GHz. The group claims that the antenna provides pattern diversity adequate for mobile communications and good isolation characteristics. See "A Quad-Band Compact Diversity Antenna for GPS L1/Wi-Fi/LTE2500/WiMAX/HIPERLAN1 Applications," *IEEE Antennas and Wireless Propagation Letters*, Feb. 2014, p. 249.

METAMATERIALS ENABLE MAGNETIC SUPERLENS FOR WPT

AS MORE IS invested in techniques for relaying power wirelessly, research into boosting the efficiency of wireless power transfer (WPT) is increasing as well. One area being explored is the use of optical-lens concepts for radio and microwave frequencies. Materials with a permeability of −1 or permittivity of −1 have the ability to change the dispersion pattern of an antenna's radiation or focus it. These metamaterials, which are called superlenses, are used in many applications ranging from MRI resolution enhancement to WPT. The design and implementation of such a lens has been reported by a research group from Duke University including Guy Lipworth, Joshua Ensworth, Kushal Seetharam, Da Huang, Jae Seung Lee, Paul Schmalenberg, Tsuyoshi Nomura, Matthew S. Reynolds, David R. Smith, and Yaroslav Urzhumov.

The superlens is constructed of a multilayer wine-crate-style lattice, which is composed of PCB-based coils. In an experiment with three layers of resonant coils, power transfer was increased by 15 to 30 dB for distances of 8 to 24 cm. These distances are 4× to 12× greater than the diameters of the non-resonant transmitting and receiving coil antennas. The group claims that the numerical simulations and experimental simulations coincide. See "Magnetic Metamaterial Superlens for Increased Range Wireless Power Transfer," *Scientific Reports*, Jan. 2014, p. 3642.

60-GHZ IPIC-QVCO REDUCES PHASE NOISE AND ERROR

DESIGNING A LOW-POWER CMOS phase-locked loop (PLL) operating at 60 GHz for a direct-conversion transceiver is quite tricky. For example, it is difficult to account for low phase noise/phase error and the wide-range operation necessary for high-data-rate wireless communications. A research group from Singapore has developed an integer-N, third-order, charge-pump PLL with a 135-MHz reference and an in-phase, injection-coupled (IPIC) quadrature voltage-controlled oscillator (QVCO). A paper describing the design of the IPIC-QVCO has been provided by Xiang Yi, Chirn Chye Boon, Hang Liu, Jia Fu Lin, and Wei Meng Lim.

A benefit of this design is that quadrature accuracy is not affected by the mismatches of the Q of the tank circuit and the current reference. But the mismatch of the coupling network does affect the quadrature accuracy as a function of phase error. Because the coupling network is composed of a symmetric design, the mismatches produced are minimal. In terms of phase error, this amounts to less than a 1-deg. error with a maximum 5% mismatch in the coupling network.

The circuit was simulated with 65-nm transistors, as they meet the frequency requirements of 60-GHz transmission. In a comparison with other simulated typologies of QVCOs, the IPIC-QVCO supposedly outperforms P-QVCOs, super-harmonic-coupled QVCOs, and magnetically coupled QVCOs when it comes to phase-noise and phase-error metrics. The experimental circuit in 65-nm CMOS covers 57.9 to 68.3 GHz while boasting phase noise from −89.8 to −91.0 dBc/Hz at 1-MHz offset from the carrier throughout the frequency of operation. See "A 57.9-to-68.3 GHz 24.6 mW Frequency Synthesizer With In-Phase Injection-Coupled QVCO in 65 nm CMOS Technology," *IEEE Journal Of Solid-State Circuits*, Feb. 2014, p. 347.

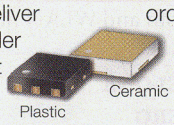


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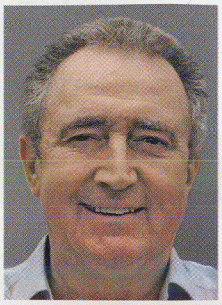
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PAUL WHYTOCK | European Editor



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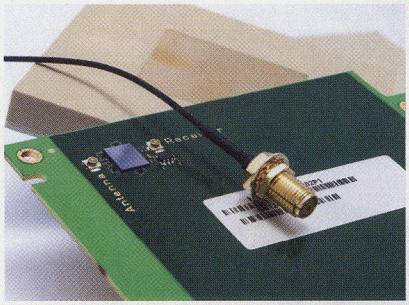
Tablet Sales May Be Declining, But Technology Launches Remain Strong

TABLET SALES are set to tumble, according to IDC. The market-research firm predicts that the substantial 51% market growth recorded in 2013 is likely to decline to around 20% this year. Even with the decline, that translates into 260 million units being shipped worldwide. Whether this situation should be called a downturn or merely market stabilization is debatable. But what is clear to analysts is that tablet users are becoming less inclined to upgrade to higher-performing models. Interestingly, this cooling was not reflected in the scores of corporate announcements at this year's Mobile World Congress (MWC) event in Barcelona.

Among these announcements, the collaborative result between research organization Imec and satellite-navigation specialist Septentrio is of particular interest. They have developed an integrated RF antenna element for a multi-frequency Global Navigation Satellite System (GNSS) antenna for GPS, GLONASS, BeiDou, and GALILEO *(see photo)*. Developed within the EU's Seventh Framework Programme, called HANDHELD, the antenna can be integrated into multi-frequency handheld GNSS devices that are designed for high-precision location applications (up to 1 cm).

Internationally, it is well known that the most prominent satellite navigation system is the United States' Global Positioning System (GPS). By comparison, however, first-generation GPS receivers provide accuracy of just a few meters when relying solely on the navigation satellites. With advances in technology and ever-increasing demands on the existing GPS, there was obvious motivation to develop new systems. In addition to GPS III, examples include Russia's GLONASS, Europe's GALILEO, and China's BeiDou.

To optimally serve these systems, Imec and Septentrio co-developed their compact antenna by integrating Imec's GNSS antenna and Septentrio's GNSS RF front end. According to Imec, its antenna design meets the demands of the high-accuracy GNSS market while remaining small enough to be used in handheld devices. The antenna simultaneously covers all GPS, GLONASS, and GALILEO bands. According to Septentrio, its GNSS RF front end provides very good out-of-band interference rejection. It can therefore avoid device self-interference with other radiation sources, such as Bluetooth and WLAN radios.



A recent technology partnership has resulted in the development of an antenna-RF integrated element for a multi-frequency Global Navigation Satellite System (GNSS) antenna for GPS, GLONASS, BeiDou, and GALILEO.

FROM BARCELONA TO NUREMBERG

At the same time that the MWC was convening in Spain, another event—Embedded World—was taking place in Nuremberg, Germany. There, wireless-connectivity specialist CSR reported that it has teamed up with ARM to use its mbed platform as a component partner. This industry venture is designed to nurture the growth of the Internet of Things (IoT). Thanks to this arrangement, the mbed community will have access to CSR Bluetooth, Bluetooth Smart, WiFi, and GPS connectivity solutions. This partnership also will facilitate the integration of those solutions into existing microcontroller projects.

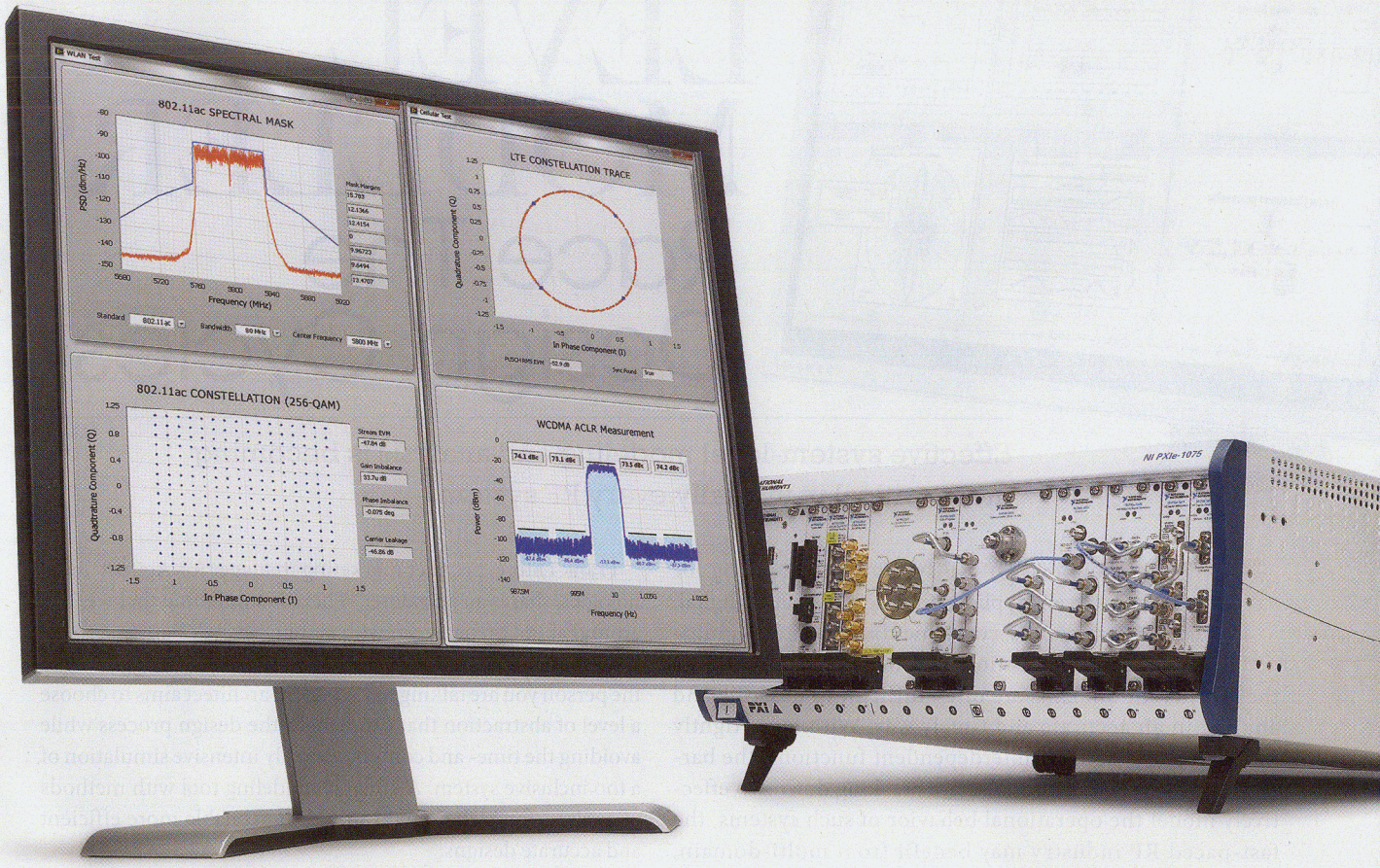
The ARM mbed IoT device development platform is an initiative that provides hardware and software building blocks to developers. In doing so, it lowers the barrier of entry for the rapid development of Internet-connected products and concepts based on ARM microcontrollers. The project also promises to ease the integration of connectivity and software components.

IoT TECHNOLOGY FIRST

In addition, CSR recently unveiled what it describes as a technically disruptive Bluetooth Smart solution, which is designed to place smartphones at the center of the IoT. Called CSR Mesh, it allows an almost infinite number of Bluetooth Smart-enabled devices to be networked and controlled from a single smartphone, tablet, or PC. The solution combines a configuration and control protocol with CSR's Bluetooth Smart devices including the CSR101x and CSR8811. As a result, consumers can control any Bluetooth Smart-enabled device in the home (including lighting, heating, appliances, and security systems) from wherever they are. mw

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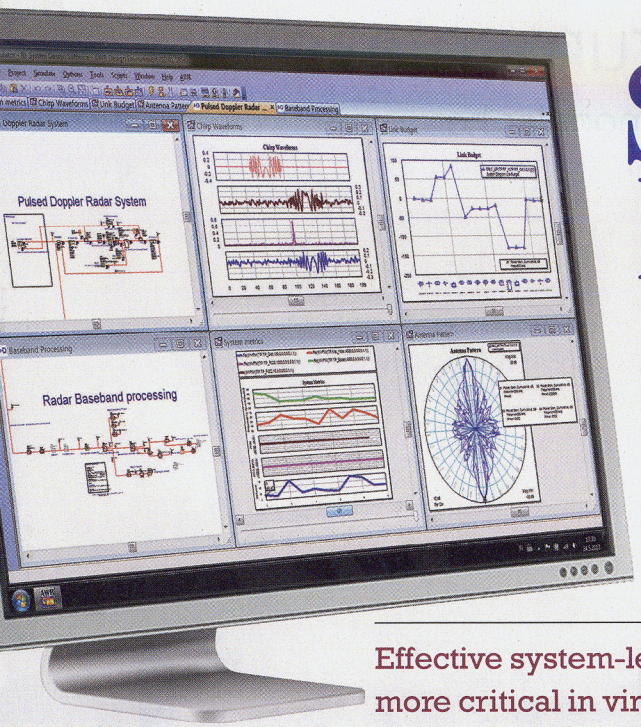
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SYSTEM-LEVEL MODELERS Race The Design Cycles

Effective system-level modeling and analysis is becoming more critical in virtually every RF system.

The complexity of RF systems is increasing for almost every application. The addition of digital, analog, and RF components necessitates multi-domain interactions. Yet the interfaces between these different domains are often difficult to describe and analyze in an accurate and timely way. With more tightly integrated and domain-interdependent functions, the barriers between the domains also are breaking down. To effectively model the operational behavior of such systems, the fast-paced RF industry may benefit from multi-domain, system-level modeling tools that can follow a design from conception to implementation.

By definition, system-level modeling is the functional block-level analysis of a system. There are levels of abstraction to consider when modeling a system. Micro-system-level modeling, such as transistor-level modeling, analyzes the interactions among the individual transistors based upon detailed device models. Conversely, macro-system-level modeling involves the interaction between a device and the much larger environment in which the device may operate. Different considerations exist at various levels of abstraction.

1. (See above.) Many system-modeling tools have the capability to support a multi-window interface to capture key aspects of a system and make them readily available to the system architect.

Frank Ditore, product marketing manager for Agilent Technologies, shares an anecdote: "There is something that we joke around about on our team with system-level design or system-level modeling. It's that the system is always one level higher than the person you are talking to." A system architect aims to choose a level of abstraction that can benefit the design process while avoiding the time- and computationally intensive simulation of a too inclusive system. A scalable modeling tool with methods of analysis for each domain would then enable more efficient and accurate designs.

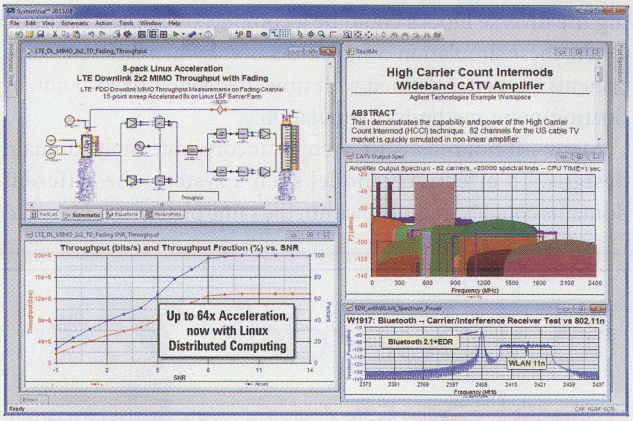
Until recently, office productivity tools like Microsoft Excel were the mainstay of the system architect. Spreadsheet-style tools provide a high level of flexibility and a mathematically open and definable environment. Yet spreadsheet tools often fall down when it comes to the effective incorporation of non-linear effects and multi-domain modeling. Ditore elaborates, "If you look at a filter as a mathematical representation, it is a polynomial. I can model that in a spreadsheet. But if I need to implement that in a DSP or FPGA, it becomes a fixed point or Z-domain representation of that polynomial. If my tool can't allow me to model in that domain very quickly, that tool becomes less effective."

Because the interfaces between various domains are often hard to detail mathematically, tools that can account for these issues may be best suited to enabling the latest designs.

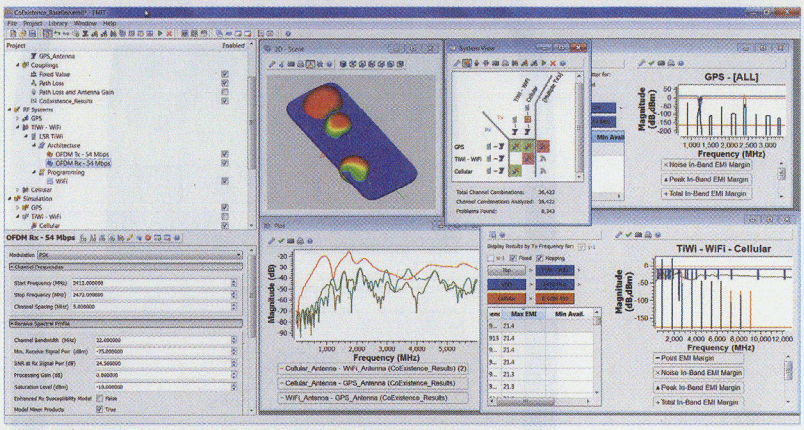
As RF systems are incorporated into more devices, specific tools for RF system-level modeling or RF-capable add-ons for EDA tools are becoming more available. Modern tools for system-level modeling are often integrated design suites, which allow for the functional block-level analysis of complex systems. Such software includes the Mathworks MATLAB/Simulink/SimRF, Agilent SystemVue, CST Design Studio, and AWR Visual System Simulator (VSS; *Figs. 1 and 2*).

An example of the recent advances in technology and industry collaboration is the development of the AD9364, a software-defined-radio (SDR) prototype module from Analog Devices. In this collaboration with the Mathworks, a fully integrated SDR was modeled—in detail—within the MATLAB, SimuLink, and SimRF environments. Reportedly, the model turned out to be highly consistent with the behavior models developed to enhance the prototyping platform. Such models can then be analyzed with the full capability of relevant MATLAB toolboxes and user-defined code.

The controls of the modeled and practical SDRs are supposedly the same, which could save significant time during product design. Another aspect of the prototyping system is that environmental and channel models can be imported into the simulation. This aspect adds another layer of model detail. It also could aid in preparing the design for market. In addition, an early prototype with a computerized test system could be deployed in real-world environments to confirm radio functions that the device is meant to perform. Other organizations, in contrast, would have to develop a custom system-level-modeling structure to enhance their design flow in such a way.



2. Modeling complex modulation schemes, such as LTE-Advanced, is a major challenge without advanced tools that integrate block-level schematics, parametric analysis, and equation-driven solutions.



3. Co-site analysis is becoming a more critical step in system-level analysis, as a variety of antennas is being incorporated into almost every platform.

RF Integration, for example, has developed its own system-level-modeling processes known as the System Accelerator Tool (SAX). In discussing the effective use of system-level-modeling tools, Finbarr McGrath, the firm's chief technologist, comments, "In the best case, it might save you a design cycle. What it certainly does is give you a much higher-quality design and a much better-understood design."

This design-enhancing process usually begins with an interpretation of customer specifications. Those specifications are broken down into individual block performance parameters. A system-level-modeling tool is used to cascade the system blocks into a functional model, in which early analysis is performed. Once the block-level definitions are refined, the optimized block parameters are given to the designers.

Using the system model to predict the system component specifications, the designers complete the internal block designs. The process of refining the block-level models with detailed component-level analysis is iterative. When the system blocks are adequately defined, the block performance metrics are fed into the SAX environment. If needed, the overall system is adjusted to account for the enhanced block-level information. McGrath notes, "This process partitions the design in such a way that the block-level model is contained and precise. The design engineer doesn't have moving specifications, so changes come back to them less often."

If performed well, this type of process could prevent the over-designing of systems and enable much faster design-cycle turnaround. Ideally, the same test methods used with the software also would be used to test the physical device. In that case, troubleshooting, error correction, and design refinement could be dramatically decreased.

A critical step in this process is the description of the block-level parameters. As stated by John Broderick, director of systems engineering for RF integration, "Sometimes, we come up with how good a parameter needs to be from experience or estimates...we have to build off those behavior modules." Broderick further explains that depending upon the tool used, simulat-

ing the diverse blocks could be a complex or canned solution. Often, these simulation complexities occur when different components are better defined with time, frequency, fixed-point, or floating-point methods of simulation.

Many—if not most—RF systems incorporate multi-domain designs. To effectively model such a system, the different domains could be handled within the same platform. This could prevent time-intensive and potentially error-prone interfacing caused by multiple tool use and custom generation. Ditore shares, "The best way to solve this is by providing different methods of computation that are well integrated. So you could take a fixed-point model, floating model, time-domain RF model, and frequency-domain RF model and combine them all together into one simulation."

System-level-modeling tools, such as SystemVue, provide different methods of computation to allow different computation models to run efficiently. The ability to neatly interface the different computation methods enables simulations of an entire system to be performed more rapidly than single methods of computation. This class of tools offers frequency- and time-domain computation for both analog and RF. It also provides floating- and fixed-point methods for the digital domain.

With this approach, the method of computation can be tailored to the type of model that is optimal for each individual block within the system. Ditore shares an analog/RF example: To model an amplifier that has a gain and noise figure as well as input and output impedance matching, a frequency-domain simulation would be adequate in terms of speed. Yet a time-domain envelope simulator could be a viable option—if it was not critical to model the impedance matching and only the gain and noise figures. The time-domain simulation would run faster with the tradeoff of losing the impedance-matching resolution.

For example, Ditore points to a digital representation using a digital-signal-processing (DSP) finite-impulse-response (FIR) filter. A floating-point simulation would produce the FIR filter coefficients. If finite precision is desired, a set number of bits of resolution could be determined for each coefficient. Using a floating-point simulation with 10 bits of resolution for the coefficients, and using 2's complement format for numeric precision, it may not be possible to run such a system in a reasonable amount of time. A fixed-point simulation could potentially run the same DSP FIR-filter model at a higher rate.





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Armored (APC)	DC-18	N	6.0-15	-55/+105
Low Loss (KBL-LOW)	DC-40	2.92	1.5-6.6	-55/+85
Phase Stable (KBL-PHS)	DC-40	2.92	1.5-6.6	-55/+85

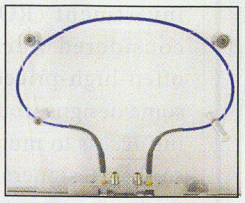
All models 50Ω except as noted.

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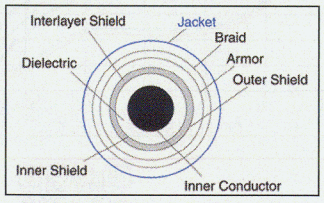
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Beyond the system-level-modeling tools that enhance the design flow from the block level, the design of robust devices can be aided by tools that account for environmental factors and other RF systems. For example, RF co-site analysis predicts the interactions between various antenna and radio systems. This step is critical in ensuring that the behavior of antenna and radio systems do not interact and create interference.

Software offerings like Delcross's EMIT use asymptotic electromagnetic (EM) analysis to acquire a superposition of currents stimulated across a multi-radio platform. This analysis involves the combining of physical-optics and EM-analysis techniques. First, rays are shot at the geometries of the platform. The circulation currents that were created are analyzed. An observer is then created spatially. It integrates the generated currents, which are transformed into an approximation of far-field contributions at some combination of angles.

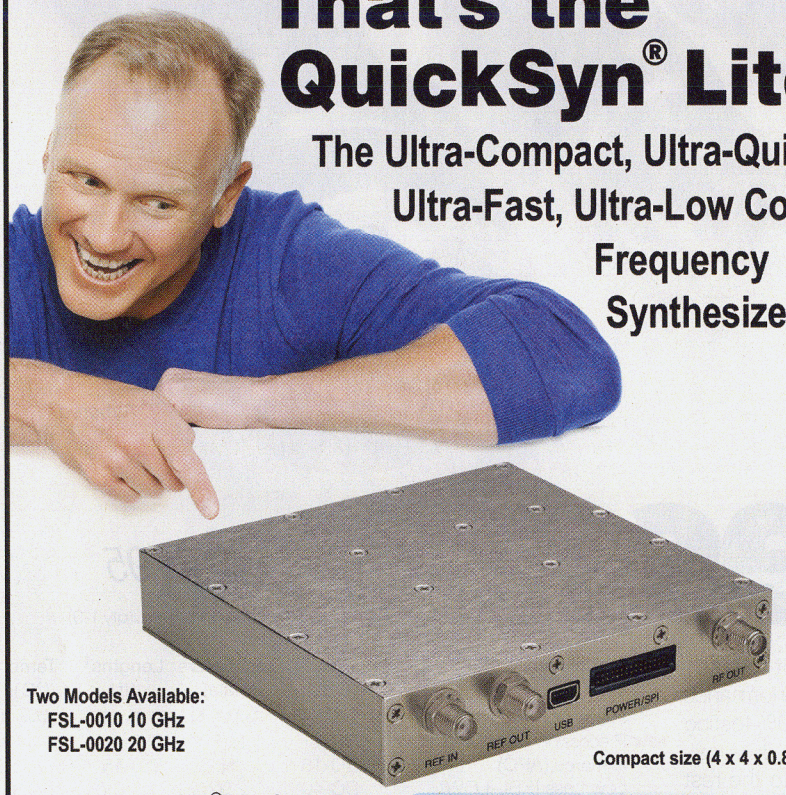
Next, the software integrates the antenna, radio, cable, and filter models to define the interaction of these different radios. This can be done channel by channel, component by component, or in complete simulation mode. The goal of the software is to follow the design of a radio system that is intended to operate in a multi-radio platform—from early conception to final design. Such a process could indicate whether certain design decisions will produce interference and compromise the functionality of the various radio systems.

From antenna interference to chip-level component analysis, advanced system-level-modeling and analysis tools can provide valuable insight throughout the design process. If a system model is well defined and iteratively improved throughout the cycle, costly redesigns can be avoided. The test/verification process can be minimized as well. Thanks to the development of multi-domain tools and the improvements in those tools' computational efficiency, more refined simulations of complex systems are now possible.

Of course, cost and return-on-investment (ROI) always must be considered when evaluating these often-high-priced tools. In addition, some designs would benefit from having access to multiple modeling tools so that designers could compare and contrast performance. So far, there are no complete start-to-finish tools that account for every aspect of a design. As a result, much weight is still placed on the experience and diligent planning of system architects. mw

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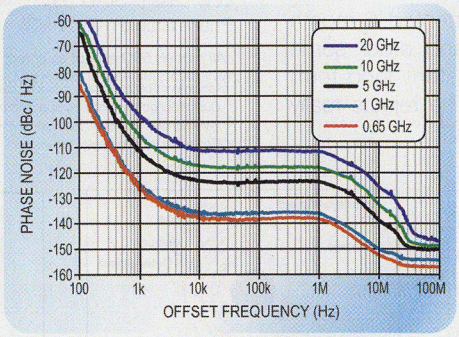
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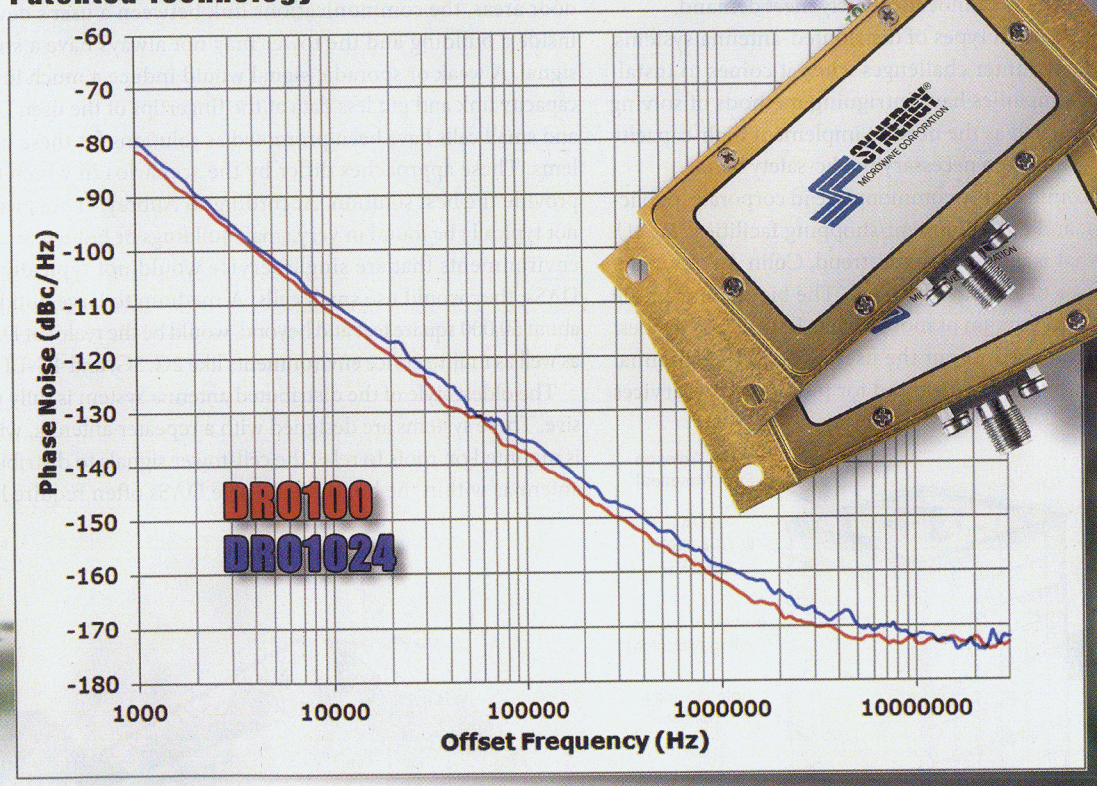
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JEAN-JACQUES DELISLE | Technical Engineering Editor

DASs Bring Capacity Both Indoors And Outdoors

To solve the demands of high data rates in buildings, in stadiums, and on public transportation, distributed antenna systems are bringing the antennas to the people.

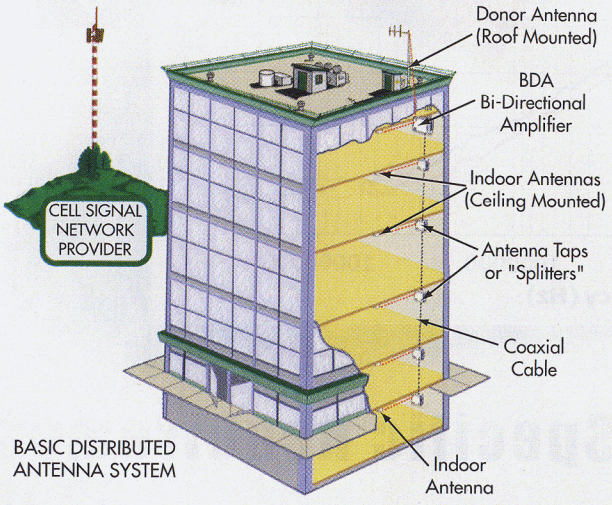
INCREASINGLY, DISTRIBUTED ANTENNA systems (DASs) have been providing much-needed wireless service in locations ranging from sports stadiums to private yachts. The term "DAS" describes a network of antennas and interconnects that route telecommunications signals throughout a localized environment. The goal of a DAS is to bring wireless connectivity to areas where macrocells cannot adequately meet demand.

There are three main types of distributed-antenna systems, yet all of them encounter challenges when it comes to installation. Several companies have intriguing methods of solving those challenges, such as the need to implement high-capacity data links alongside often necessary public-safety bands.

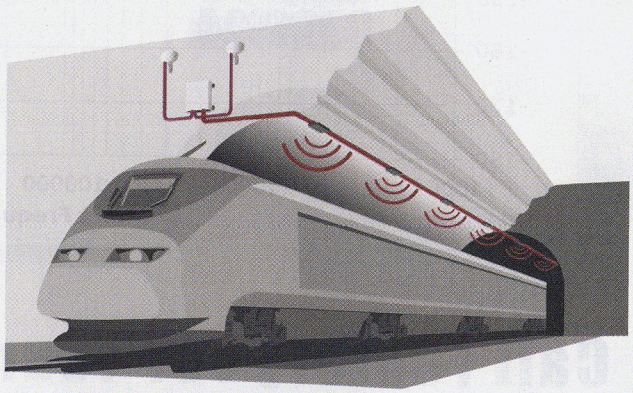
DASs are becoming more commonplace in corporate, public-transportation, and entertainment/shopping facilities *(Fig. 1)*. When asked what is influencing this trend, Colin Aubrey, chief marketing officer of Zinwave, replies, "The biggest one at the moment is the proliferation of mobile data. To generate the best performance, you need to put the user close to the antenna. There is also an increasing demand for public-safety services to be available inside a building." Wireless network operators have an incentive to provide coverage wherever their customers require network access. This demand for coverage precipitates a need for solutions that can maintain connectivity indoors, outdoors, and on the go *(Fig. 2)*.

Because macrocells are designed for coverage over large outdoor areas, the communications link between a user's devices inside a building and the tower may not always have a strong signal. A weak or sporadic signal would induce a much lower-capacity link and put less data at the fingertips of the user. DASs and small cells have been promoted as solutions for these problems. These approaches differ by the scenarios in which they provide the best solution. According to Aubrey, "DASs would not typically be found in very small buildings or homes. Smaller environments that are single service would not typically use DASs; they would use small cells. A medium to large building, about 50,000 square feet and beyond, would be the realm of DASs, as well as multi-service environments like 2G, 3G, and 4G-LTE."

The oldest style of the distributed antenna system is fully passive. These systems are designed with a repeater antenna, which is mounted on roofs to relay the cell-tower signals to distributed antennas within the building. Passive DASs often require long

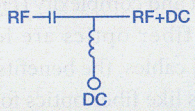


1. An in-building DAS can be implemented by routing a high-speed wireless link from a cell tower indoors with an externally mounted antenna.



2. The demand for constant connectivity to high-capacity links is driving network operators to seek indoor routing solutions in train tunnels and other public-transit systems.





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TCBT-6G+	50-6000	0.7	28	200	9.95
TCBT-14+	10-10,000	0.35	33	200	8.45

TCBT: LTCC, Actual Size .15" x.15", U.S. Patent 7,012,486.

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JEBT-4R2G+	10-4200	0.6	40	500	39.95
JEBT-4R2GW+	0.1-4200	0.6	40	500	59.95
PBTC-1G+	10-1000	0.3	33	500	25.95
PBTC-3G+	10-3000	0.3	30	500	35.95
PBTC-1GW+	0.1-1000	0.3	33	500	35.95
PBTC-3GW+	0.1-3000	0.3	30	500	46.95
ZFBT-4R2G+	10-4200	0.6	40	500	59.95
ZFBT-6G+	10-6000	0.6	40	500	79.95
ZFBT-4R2GW+	0.1-4200	0.6	40	500	79.95
ZFBT-6GW+	0.1-6000	0.6	40	500	89.95
ZFBT-4R2G-FT+	10-4200	0.6	N/A	500	59.95
ZFBT-6G-FT+	10-6000	0.6	N/A	500	79.95
ZFBT-4R2GW-FT+	0.1-4200	0.6	N/A	500	79.95
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Note: Isolation dB applies to DC to (RF) and DC to (RF+DC) ports.

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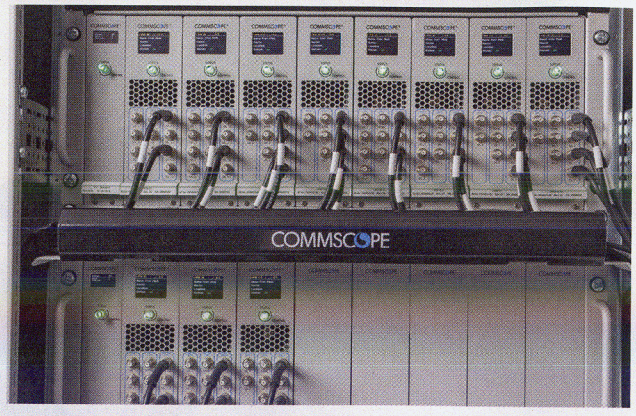
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runs of coaxial cables and repeaters, which are necessary for signal integrity considering the losses of the cable. Such systems may not be suited for all environments when considering costs and in-building routing.

Though wideband, this style of fully passive DAS is limited to the capacity of the repeater channel. It is therefore not suited to high-capacity links. The challenges of passive DAS include coexistence, passive intermodulation (PIM), and other types of interference. Among the solutions that can help mitigate these problems are quasi-omnidirectional antennas and antenna test sweeps with PIM equipment throughout the location. As most of these performance issues are derived from signal-routing problems, fiber-optic and unshielded-twisted-pair (UTP) cabling solutions have found a place in the market.

Hybrid DASs rely on a fusion of passive and active systems. The passive portion of the hybrid DAS includes the last few meters of coaxial cabling and the electronics that convert optical signals into RF signals. The active portion of the system is usually a fiber-optic signal path that connects directly with a base station and is routed to hubs distributed throughout a building.

The goal of all DASs is to offer operation on all frequencies that benefit the end user. This includes common cellular, public-safety, and even WiFi bands. Mike Williamson, Director of DAS



3. Compact DAS distribution methods are common to ensure that the system can meet capacity demands while maintaining a scalable platform.

Product Line Management for CommScope, shares, "Distributed antenna systems should be designed to support any technology today and in the future. There may be some technical challenges with the systems when new frequency bands are released." Williamson notes that DASs often have frequency-selective circuitry. Using amplifiers and filters as an example, a system will not be able to provide service if the amplifier or filters used in the DAS do not operate across the frequencies of interest. Such an approach would require adding new components to the system—potentially increasing cost and complexity *(Fig. 3)*.

Because fiber optics are less lossy than coaxial cables, the benefits of using technologies like fiber optics for routing include lower-cost cabling, easier routing paths through complex building structures, and lower power. Hybrid and passive DASs require amplification technology to increase the power levels in the sections preceding the lossy passive-cabling parts. Yet hybrid systems still suffer from interference issues, as the impact of the interference is directly related to the strength of the signals in the system.

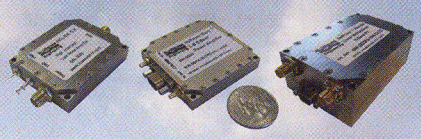
A fully active DAS is a solution that distributes low-power points throughout the system and minimizes routing complexities. These DASs use optical routing that is similar to what is used by hybrid-DAS systems. But the fiber-optics and power infrastructure is routed directly to the point of antenna delivery *(Fig. 4)*. In a large building, the wireless operators will generally have a room devoted to housing the operators' various base stations, known as a base-station hotel.

In such a "hotel," one or more main active DAS hubs will be connected to the operator's base stations. To adjust the base-station signals to a nominal level

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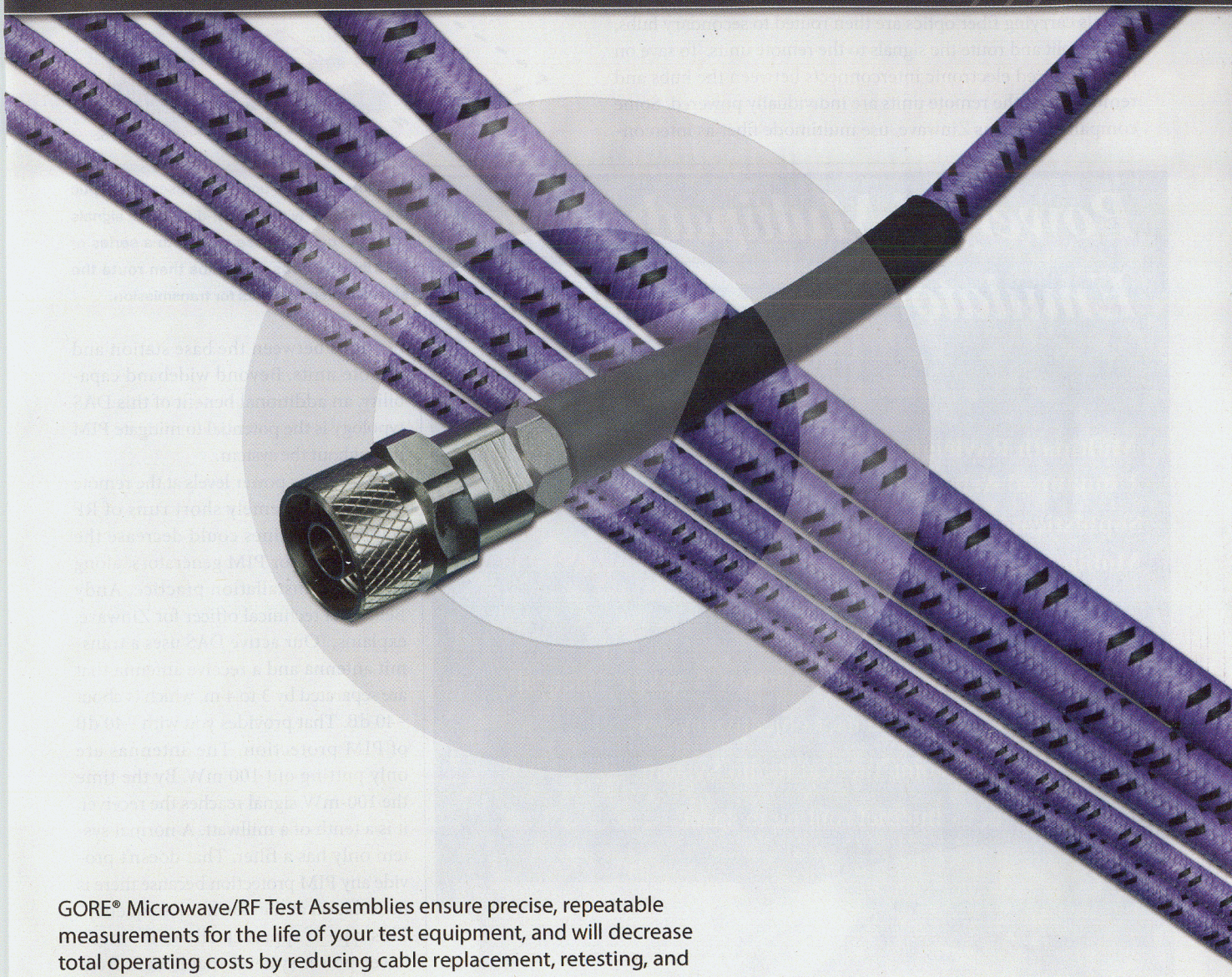
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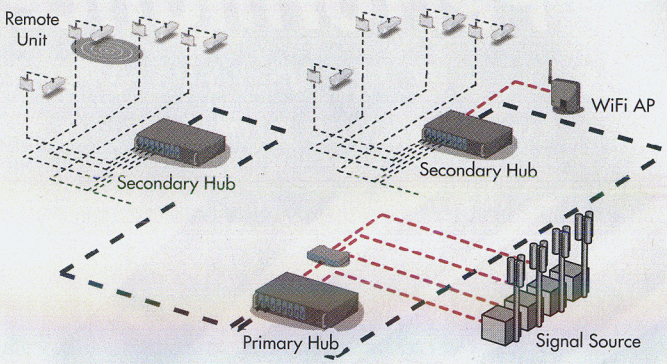
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4. A fiber-optics or active DAS uses fiber-optic links to route wideband bi-directional signals from the cellular base station to a series of distribution hubs. The hubs then route the signals to remote units for transmission.

and convert the signals from RF to optical signals, the necessary conversion electronics are contained within the main hubs. The signals carrying fiber optics are then routed to secondary hubs, which split and route the signals to the remote units. To save on high-powered electronic interconnects between the hubs and remote units, the remote units are individually powered. Some companies, such as Zinwave, use multimode fiber as interconnections between the base station and remote units. Beyond wideband capability, an additional benefit of this DAS typology is the potential to mitigate PIM throughout the system.

Having low power levels at the remote units and extremely short runs of RF transmission lines could decrease the opportunity for PIM generators, along with good installation practice. Andy Bell, chief technical officer for Zinwave, explains, "Our active DAS uses a transmit antenna and a receive antenna that are separated by 3 to 4 m, which is about −40 dB. That provides you with −40 dB of PIM protection. The antennas are only putting out 100 mW. By the time the 100-mW signal reaches the receiver, it is a tenth of a millwatt. A normal system only has a filter. That doesn't provide any PIM protection because there is no isolation at the downlink frequency." This type of approach allows for much lower-power systems that benefit from a less lossy cabling structure and a much wider-bandwidth. Additional cost savings from requiring less PIM-stringent components is also a consideration.

Advances in DAS, including wideband multi-technology solutions, have gone a long way in expanding the scope of environments in which these systems can be found. Innately wideband interconnects within DAS enable more system flexibility while offering the potential to reduce failure modes. They could ensure future-proof platforms that can support the latest frequency bands and standards. mw



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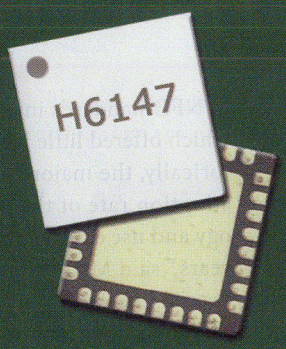
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9 - 12	I/Q Downconverter/Receiver	DC - 3.5	11	2.2	25	+2	LC5	HMC908LC5
17 - 20	I/Q Downconverter/Receiver	DC - 3.5	14	2.5	40	0	LP4	HMC966LP4E
17 - 24	I/Q Downconverter/Receiver	DC - 3.5	12	3	30	0	LC5	HMC904LC5
21 - 24	I/Q Downconverter/Receiver	DC - 3.5	15	2.5	25	+1	LP4	HMC967LP4E
20 - 28	I/Q Downconverter/Receiver	DC - 3.5	14	2.5	21	+1	LP4	HMC977LP4E
27 - 34	I/Q Downconverter	DC - 4	12	3	17	+2	LP4	HMC1065LP4E
37 - 44	I/Q Downconverter	DC - 4	13	3.5	25	+2	LC5A	HMC6147ALC5A

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JEAN-JACQUES DELISLE | Technical Engineering Editor

NFC Gets Ready For Wide Adoption

The inclusion of NFC chips in mobile phones is rapidly increasing the opportunities for companies to enhance user experiences with the latest in digital customer interaction.

THE RECENT EXPLOSION of smartphone users has left many industries scrambling to find ways to best take advantage of the compact computers in everyone's pocket. With the ability to engage with end users in interactive, consumer-driven media, the smartphone-equipped consumer is a hot topic for the commercial industry. There are very few technologies as well suited to enabling this desired interaction with high-tech consumers as near-field communications (NFC).

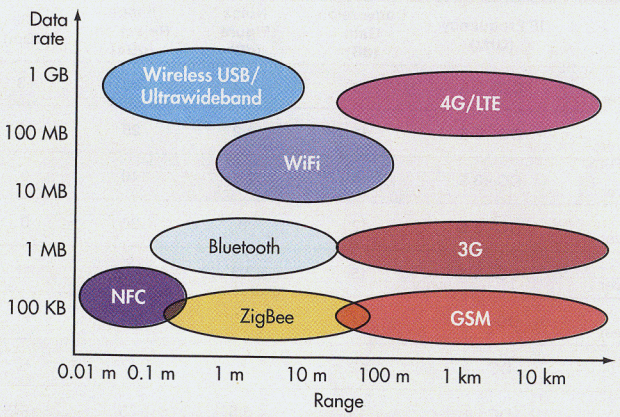
NFC technology is a very-short-range, fast, low-power, and secure method of communicating between two devices. From within 4 to 8 cm, it is rather well known that a secure communications link can be established between two devices, such as a smartphone and contactless pay-service. But that explanation only scratches the surface of what is possible with this trending technology. Because NFC services can only be activated within close physical proximity of the devices, NFC enables a tangible interaction with a variety of media and consumer infrastructure systems.

The footwear retailer Bonton, for example, embeds NFC tags within its shoes. The NFC-enabled shoe can then be scanned with a curious shopper's smartphone. An order could be placed with the right shoe size and shipped immediately to the customer's home. Other retail examples include accessing a video or song through the Web when NFC touches a certain product. Even the simple act of scanning a product on an NFC-tagged shelf could give a consumer access to a range of other recommended products at a variety of price points while plugging the latest deals.

These types of uses have led to the inclusion and adoption of NFC standards in an increasing number of environments, which offered little NFC support only a few years ago. "Historically, the major barrier to market growth had been the adoption rate of the NFC feature in phones. The technology and use cases have been very interesting for a number of years," said Matthew Bright, chair of the NFC Forum Retail Special Interest Group and director of technical marketing for Thin Film Electronics.

"But it has only been in the last two to three years that we reached an inflection point in terms of NFC penetration into mobile devices. This is due to the fact that a wide variety of stakeholders within the NFC ecosystem have seen value in the technology and encouraged its adoption," he added.

ABI Research is predicting the number of NFC smartphones shipped worldwide to reach 500 million by the end of 2014. Seeing this growth, more industries are looking to benefit logistically from this technology. Mass-transit systems like buses, trains, and airports may soon be allowing NFC-based boarding passes to help increase the throughput and ease of travelers. Another, more recent NFC application is the fast pairing of devices.



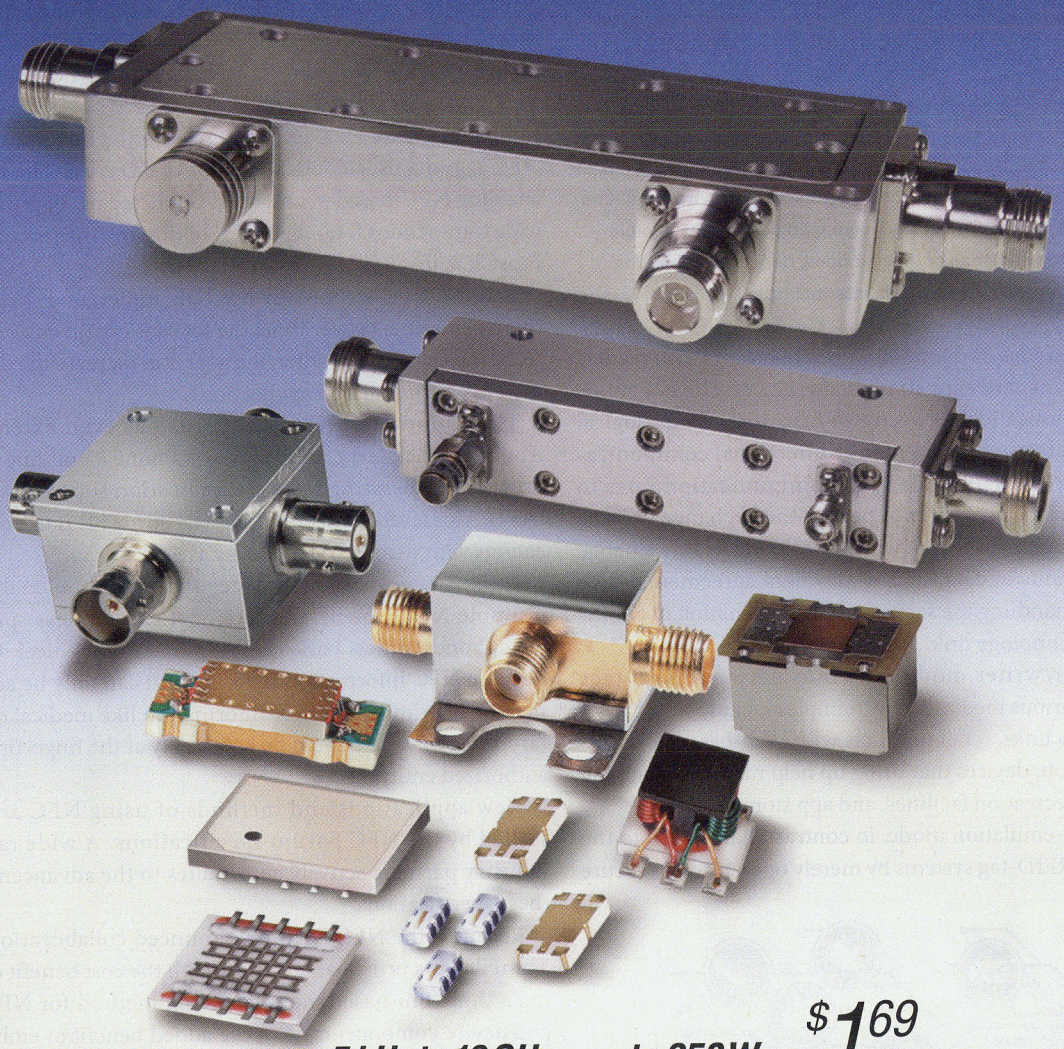
1. NFC operates as a companion technology to the mid-range wireless-communications technologies. It can rapidly enable links between devices with WiFi, Bluetooth, ZigBee, and future wireless technologies.

With the ability to identify oneself with a personal NFC device like a smart card or smartphone, users could have access to their automobile, home, hotel room, or even secure information through the postal system.

Additionally, two smart devices could use the NFC protocols to establish the optimal method of linking. Higher-data-rate communications could be enabled using other wireless technologies like Bluetooth or WiFi *(Fig. 1)*. This is done in one of

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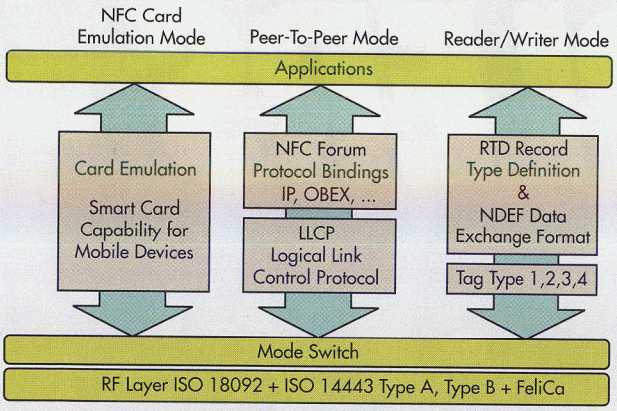
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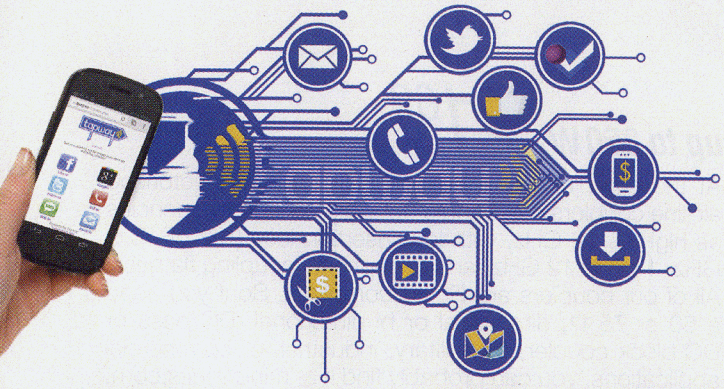


2. NFC devices can operate in three different modes: card emulation, P2P mode, and R/W mode. An NFC-equipped device may be able to operate in only one or all of those modes, depending upon the technology with which the device is interfacing.

NFC's three modes of operation: peer-to-peer (P2P), reader/writer (R/W), or card emulation mode *(Fig. 2)*. The P2P mode allows communication between two machines using a logical link control protocol (LLCP) for bi-directional communication. As the NFC standards limit communication rates to 424 kb/s, the P2P link will not permit the exchange of large amounts of data. But the link will allow the very fast exchange of small amounts of data, such as payment agreements, URL sharing, and handling the security and coordination of another wireless technology link.

The reader/writer mode functions between NFC tags installed in various media. A few examples include smart posters with video links, retail products with Web-based advertising information, devices that bring up help manuals, mapping functions in recreation facilities, and app store links.

NFC's card-emulation mode, in contrast, harks back to the operation of RFID-tag systems by merely operating as a secure identifier. This mode is predominantly designed for access control, identification, and payment. Examples for applications include access control for automobiles, rail/public transit-fare redemption, building access, and credit/bank-card replacement. As this information requires sensitive information to be held on the device, highly secure memory-access systems are necessary.



3. The collaboration between standards bodies for SD cards, SIM cards, and NFC devices is geared toward empowering non-native NFC devices to have NFC capabilities. In doing so, they can increase NFC adoption rates and use.

The need for secure memory access has piqued the interest of groups behind the SIM and SD card standards to create secure channels between the memory and NFC device *(Fig. 3)*. Additionally, mobile devices that are not NFC enabled can benefit from NFC technology with the integration of an NFC tag in a user-controlled SIM or SD card. The trend of enabling NFC-based payments is predicted to support worldwide transactions totaling $151.7 billion by 2015, according to Frost & Sullivan.

Because NFC technology has only undergone small iterative advancements over time, the focus is not on enhancing its technical capability. Rather, the goal is to increase the development of market-driven applications.

The adoption of NFC standards has even extended to Android, BlackBerry, and Windows Phone 8 building in support at the operating system's application support interface (API). This level of integration opens up a wide range of applications with wearable technology as well.

Among the wearable devices that could be enabled by a simple NFC "touch" interconnect are wireless speakers, headphones, fitness bands, and a variety of medical devices. Because NFC information is secure and can only be accessed in close proximity, sensitive information like medical or military-personnel data could be kept safely at the fingertips of an authorized entity.

New applications and methods of using NFC are controlled by the NFC Forum specifications. A wide range of industry partners actively contributes to the advancement of these specifications.

Recently, the NFC Forum announced collaboration with ThinFilm as a principal member. With the cost benefit of having a thin-film-based manufacturing method for NFC tags and device components, with the added benefit of embedded thin-film memory, the development of NFC systems could be significantly reduced. Additionally, companies like Broadcom and Qualcomm have announced their latest chipsets that integrate NFC in addition to the other wireless technologies that they traditionally support.

With its broad adoption, NFC has increased the depth of interaction between mobile device users and their work, retail, travel, medical, and information-driven lifestyles. Although there haven't been many breakthroughs with NFC technology from a device perspective, the potential applications of an NFC interactive environment are tremendous. The next few years will witness an ever-increasing NFC-enabled world. mw

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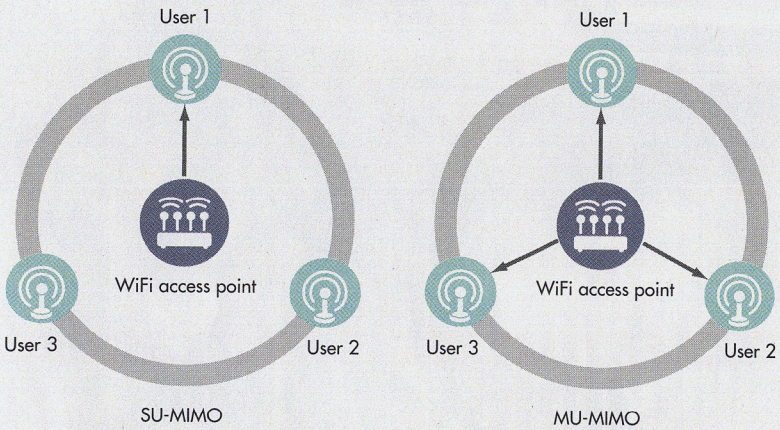
Five Trends Shaping 802.11 WLANs

WLAN technology continues to expand and evolve, with this wireless technology supporting personal and enterprise applications and reaching millimeter-wave frequencies.

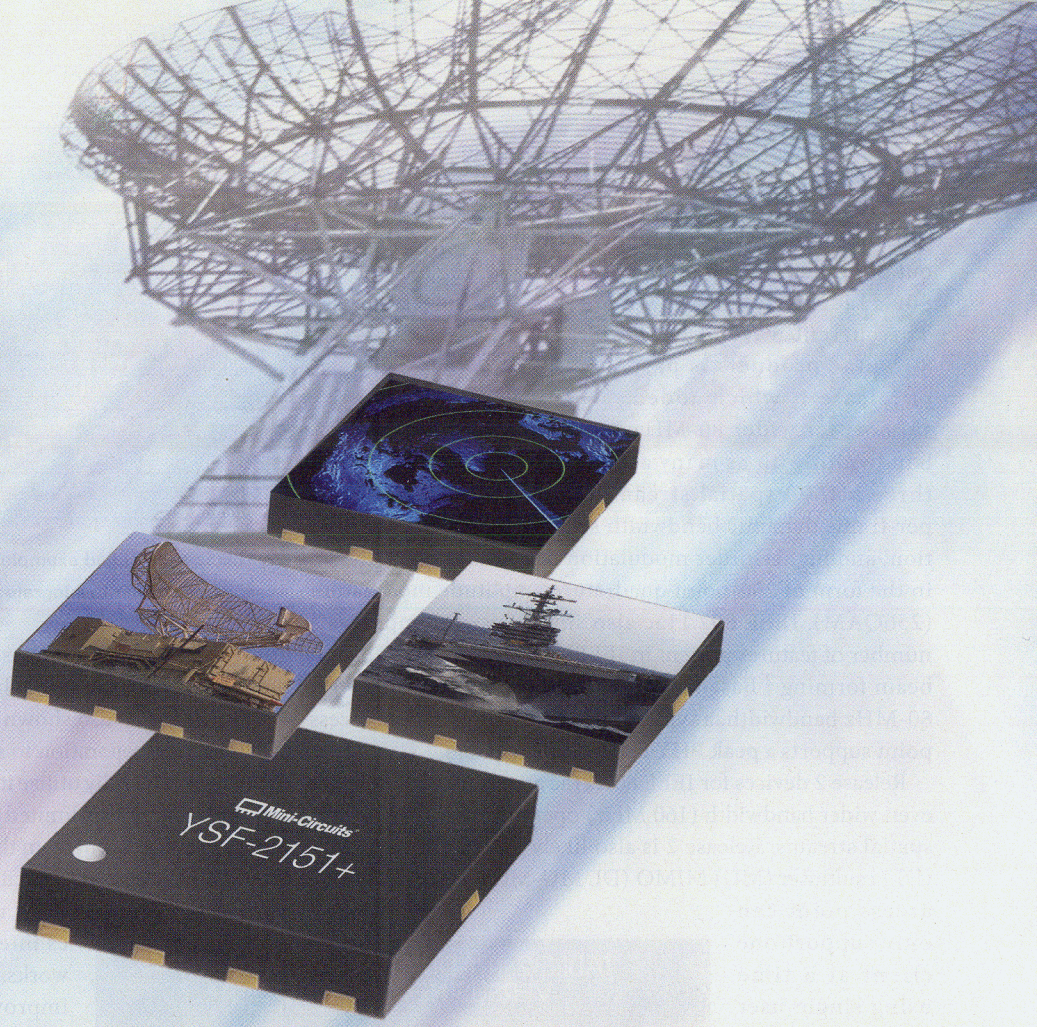
Wireless-local-area-networks (WLANs) based on WiFi technology have become a standard part of life for many, whether integrated within a home television or a radio-controlled drone helicopter. The latest commercially available version of WiFi, based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11ac standard, provides significant connectivity improvements. In addition, it is driving upgrades in consumer and enterprise markets from earlier versions, such as IEEE 802.11n. As the use of WLANs has grown, so have feature requests, helping to drive the evolution of WiFi more rapidly than ever.

The "WiFi" brand name popularized by the WiFi Alliance (www.WiFi.org) refers to products based on the IEEE 802.11 family of WLAN standards.[1] The IEEE 802.11 standard was first approved in 1997. Subsequent amendments added innovations such as orthogonal frequency division multiplexing (OFDM; from IEEE 802.11a) and multiple-input, multiple-output (MIMO) antenna systems (from IEEE 802.11n) to keep up with market requirements.

As *Table 1* shows, the theoretical peak physical layer (PHY) data rate supported by the standard has increased by more than 100× over the past decade: from 54 Mb/s in IEEE 802.11g to 6.9 Gb/s in IEEE 802.11ac. Although these PHY rates do not directly translate to data throughput due to channel access and protocol overheads, improvements in the IEEE 802.11 medium access control (MAC) layer (such as packet aggregation and block acknowledgments) enable present-day IEEE 802.11 devices to achieve 70% to 80% efficiency.[2] Improvements in data rate are not the only trend in WiFi evolution. What follows is a review of five important trends expected to shape the WiFi ecosystem over the next decade.



1. A MU-MIMO can better utilize the MIMO capabilities of a WiFi network.



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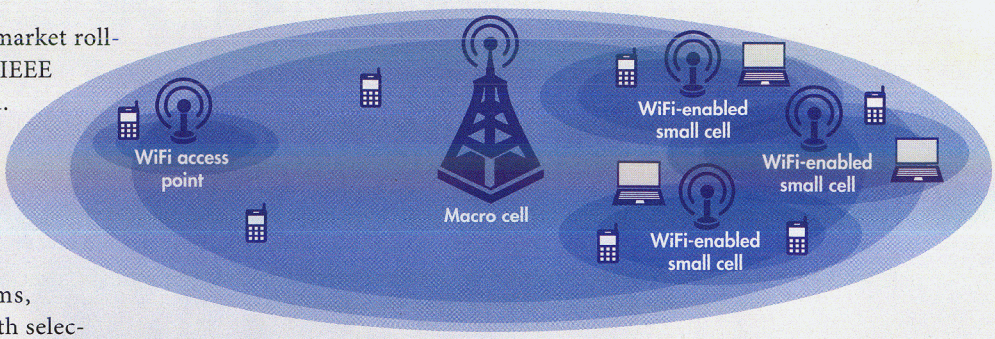
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MARKET ROLLOUT

The first trend involves the market rollout of products based on the IEEE 802.11ac wireless standard. The current wave of IEEE 802.11ac products is part of release 1, which added support for wider 80-MHz bandwidth with as many as three MIMO spatial streams, per-frame dynamic bandwidth selection, and higher-order modulation operation, in the form of 256-point quadrature amplitude modulation (256QAM). IEEE 802.11ac also simplifies and improves a number of features present in IEEE 802.11n, such as transmit beam forming.[2] Based on a 3×3 MIMO configuration with 80-MHz bandwidth, a typical release 1 IEEE 802.11ac access point supports a peak PHY data rate of 1.3 Gb/s.



2. This is a simplified example of a next-generation heterogeneous cellular network with integrated WiFi.

Release 2 devices for IEEE 802.11ac are expected to support even wider bandwidth (160 MHz) operation and four MIMO spatial streams. Release 2 is also likely to support downlink (DL) multiuser (MU) MIMO (DL MU-MIMO). Today's WiFi access point can only support one client at a time using single-user MIMO (SU-MIMO) operation *(Fig. 1)*. Since devices like laptops and smartphones usually support only one or two antennas and most IEEE 802.11ac access points support three or four antennas, this leads to a "waste" of MIMO resources and lower throughput for many WLAN systems.

MU-MIMO, also shown in *Fig. 1*, allows the access point to use spatial separation to send data to multiple clients at the same time and fully utilize its MIMO capabilities. MU-MIMO in IEEE 802.11ac is limited to the "downlink" direction—i.e., for data packets sent from the access point. It has the potential to increase network capacity since it minimizes packet collisions, reduces network usage, and reduces interference with neighboring networks. Note, however, that performance improvements due to MU-MIMO can vary drastically depending upon the spatial distribution of devices and data traffic patterns.

TABLE 2: TRADITIONAL IEEE 802.11 VERSUS HEW SG GOALS

Traditional IEEE 802.11	HEW SG
Low-density deployments (e.g., single-family home)	High-density deployments (e.g., enterprise/carrier deployed WiFi)
Focus on peak data rate of a point-to-point link	Focus on average data rate per user and per unit area
Limited inter-access point interference management	Manage interference to improve spectral reuse and robustness
Focus on indoor performance	Considers indoor and outdoor performance

TABLE 1: WLAN PHYSICAL LAYER EVOLUTION

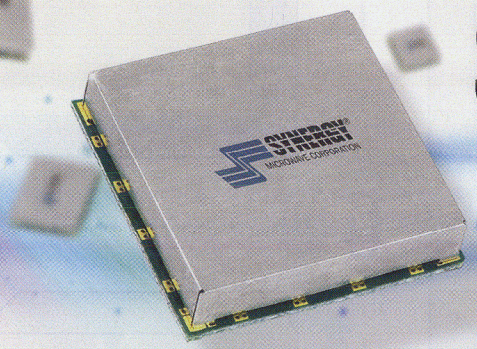
Year	Standard	Peak PHY rate (Mb/s) including optional modes	Typical access point	Key technology
1997	802.11	2	2	Spread spectrum
1999	802.11b	11	11	CCK, spread spectrum
1999	802.11a	54	54	OFDM
2003	802.11g	54	54	OFDM
2009	802.11n	600	300-450	MIMO OFDM, wide bandwidth (40 MHz)
2013	802.11ac	6933	1300-3466	DL MU-MIMO, wide bandwidth (80 and 160 MHz)

HIGH-EFFICIENCY WLAN

The second trend in WiFi is the development of high-efficiency WLANs. WiFi has become so ubiquitous that it is being deployed in dense, high-interference environments, such as airports and office buildings. Use in such environments usually results in lower-than-expected data rates and sluggish performance. For example, WiFi users may experience a WiFi network crash at a tradeshow or other event where the presence of a large number of WiFi devices leads to high interference.

This is because, traditionally, IEEE 802.11 standards have focused on point-to-point link data rate improvements in an indoor network consisting of a single access point and a few clients working under light external interference. This objective needs to be amended to consider total system throughput and

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HFSO776R82-5	776.82	0.5 - 12	+5 @ 35 mA	-146
HFSO800-5	800	0.5 - 12	+5 @ 30 mA	-146
HFSO914R8-5	914.8	0.5 - 12	+5 @ 35 mA	-139
HFSO1000-5	1000	0.5 - 12	+5 @ 35 mA	-141
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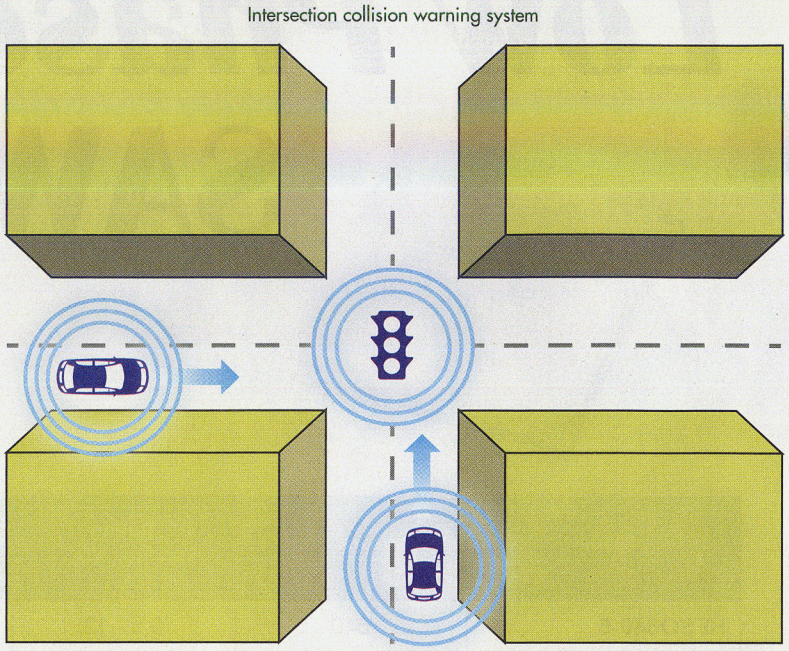
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fairness, given the market reality of denser indoor and outdoor deployments.

To address this, the IEEE formed a new IEEE 802.11 study group (SG) called High-Efficiency WLAN (HEW) in July 2013.[3] Its efforts are expected to lead to the next major evolution of the IEEE 802.11 standard after IEEE 802.11ac. *Table 2* compares the key differences in objectives between the HEW SG and past IEEE 802.11 efforts. The HEW SG will consider both PHY innovations [such as orthogonal frequency division multiple access (OFDMA) modulation] and uplink MU-MIMO and MAC innovations [such as interference management and dynamic sensitivity control]. The initial target of the HEW SG is to improve average throughput per station by at least 4× in dense deployments.



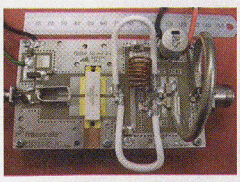
3. This example shows how IEEE 802.11p-enabled automobiles and traffic infrastructure (e.g., a traffic light) cooperate to avoid any potential collisions in the intersection.

A HEW USE CASE

The cellular ecosystem is preparing for increases of as much as 1000× over present demand in cellular data traffic in future Long-Term-Evolution (LTE) and Fifth-Generation (5G) cellular networks.[4] Given this expected volume, offloading some user traffic to a WiFi network represents an attractive solution to meet this data demand. As a result, cellular carriers around the world are deploying or partnering with WiFi networks.

Figure 2 shows a simplified example of a next-generation heterogeneous cellular network with integrated WiFi. In addition to the traditional wide-area macrocell tower, the network includes a dense network of indoor and outdoor small cells with varying range servicing areas of high handset density ("hotspots") such as downtown neighborhoods. Most of the small cells will have integrated cellular and WiFi access-point capabilities, but some may be WiFi- or cellular-only cells. The network pictured shows a number of cellphone icons to represent the ubiquitous portable wireless devices that share the transmit/receive functions with the WiFi equipment.

The network will cooperatively make decisions (e.g., when to offload a user from cellular to WiFi) to meet data traffic demand. In hotspots, it is beneficial to have a very dense deployment. However, carriers have found that efficient scaling of a network based on current WiFi

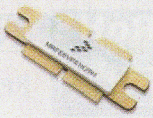


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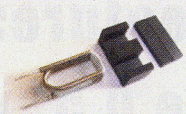
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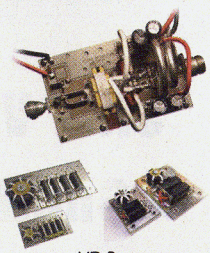




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technology is challenging in dense scenarios and, hence, the interest in HEW SG.

There are other pieces to the "carrier-grade WiFi" puzzle, such as RF coexistence testing, integration with cellular network infrastructure, and optimizing handoffs between WiFi and cellular networks. The WiFi Alliance is working on a first version of carrier-grade WiFi certification based on existing WiFi technologies and some incremental changes. But, if HEW SG is successful, it has the potential to revolutionize the performance of carrier-deployed WiFi and beyond.

INTERNET OF THINGS

The third trend influencing the future of WiFi is the exponential growth expected in the Internet of Things (IoT) and machine-to-machine (M2M) communications. Wireless connectivity is seen as an important enhancement for the sensors and meters used in markets such as smart grid, healthcare, fitness, consumer wearable devices, and industrial monitoring.

IEEE 802.11ah defines a lower-power version of WLAN to better address these use cases. To reduce power requirements, IEEE 802.11ah adds support for lower bandwidths (1 and 2 MHz are mandatory modes) and lower data rates (typically less than 2 Mb/s). It also uses unlicensed spectrum in the 900-MHz range. MAC layer enhancements in IEEE 802.11ah improve power-save modes and network scalability. As a result, access points can support a huge number of very-low-rate sensors efficiently.

An example use case is in smart grids, where IEEE 802.11ah access points attached to electric utility poles connect wirelessly to sensors/meters in nearby homes to collect information on energy usage. The instantaneous information provided can be used for customer billing purposes and to improve power grid performance. For the most part, for such applications, wide channel bandwidths and high data rates are not required, since this is only limited data being passed from sensors to a central computer.

INTELLIGENT TRANSPORT SYSTEMS

The fourth trend impacting WiFi is the use of intelligent transport systems and the growing application of IEEE 802.11p. The IEEE 802.11p amendment supports vehicle-to-vehicle and vehicle-to-infrastructure communications for intelligent transport system applications.

Regulators in the European Union (EU) and in the United States have designated spectrum near 5.9 GHz for this application.[5] In the US, specifically, this spectrum is typically referred to as dedicated short-range communications (DSRC) spectrum.

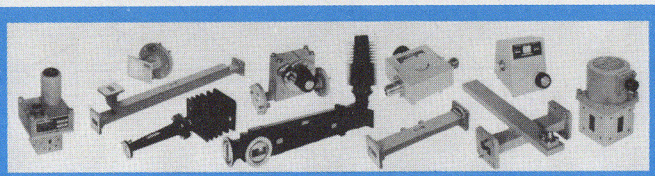
Figure 3 shows an example use case, where IEEE 802.11p-enabled automobiles and traffic infrastructure (e.g., a traffic light) cooperate to avoid any potential automobile collisions in the intersection. Other vehicular safety use cases include such functions as forward collision warning and blind spot warning.

A model deployment of the collision-avoidance system was launched in Ann Arbor, Mich., by the US Department of Transportation in the fall of 2012 using a pool of 3000 cars.[6] Based on the positive results of this trial, the Department of Transportation announced in February 2014 that it is working on regulations to require this technology in light vehicles such as personal automobiles.

(continued on p.72)

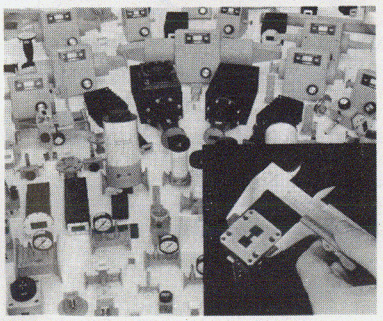
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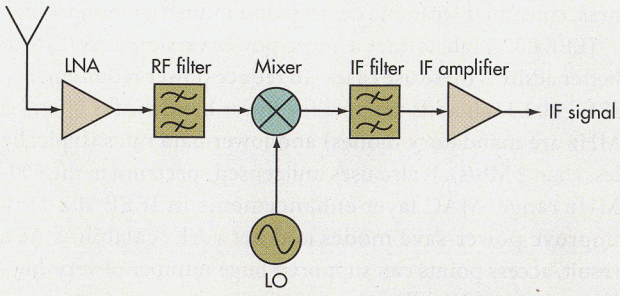
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Low-Cost Front End Receives 9 GHz

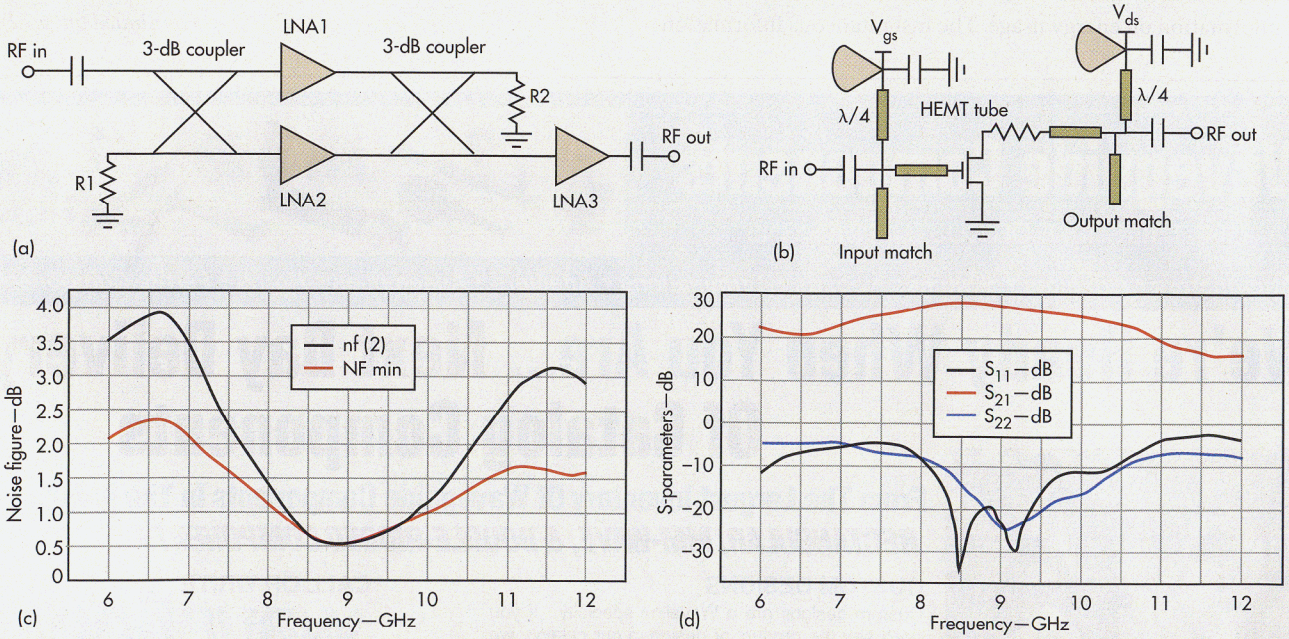
This wideband, low-cost superheterodyne receiver front end employs GaAs HEMTs with a commercial mixer, achieving outstanding performance within a 200-MHz bandwidth centered at X-band.

Increasing use of wireless systems and their services is continuing to drive data rates and consume available bandwidths. In recognition of this, the Radiocommunications Sector of the International Telecommunication Union (ITU-R; www.itu.int) has established wireless data rates to 100 Mb/s for high-mobility applications and 1 Gb/s for low-mobility applications[1] through its IMT-Advanced standards. The ITU recognizes the need to support wireless data rates to 10 Gb/s and beyond.

These higher data rates will require greater spectrum resources and a push to higher frequencies, such as the use of the 3.5-GHz band for the Time-Division, Long-Term-Evolution (TD-LTE) system detailed in ref. 2. Therefore, lowering



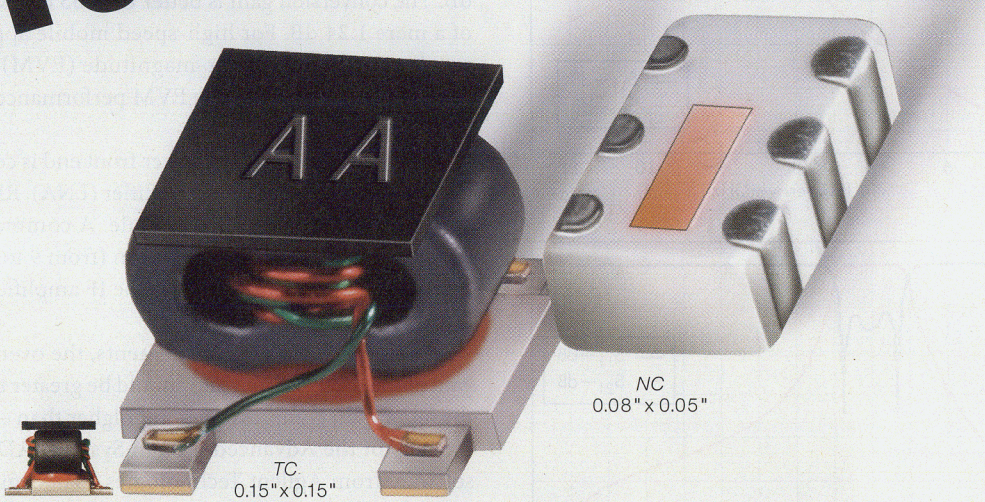
1. This block diagram shows the basic elements of the 9-GHz RF receiver front end.



2. The receiver front end includes (a) a two-stage LNA and how it compared to (b) a single amplifier, with (c) simulated noise figure performance for the two-stage LNA, and (d) simulated S-parameters for the two-stage LNA.

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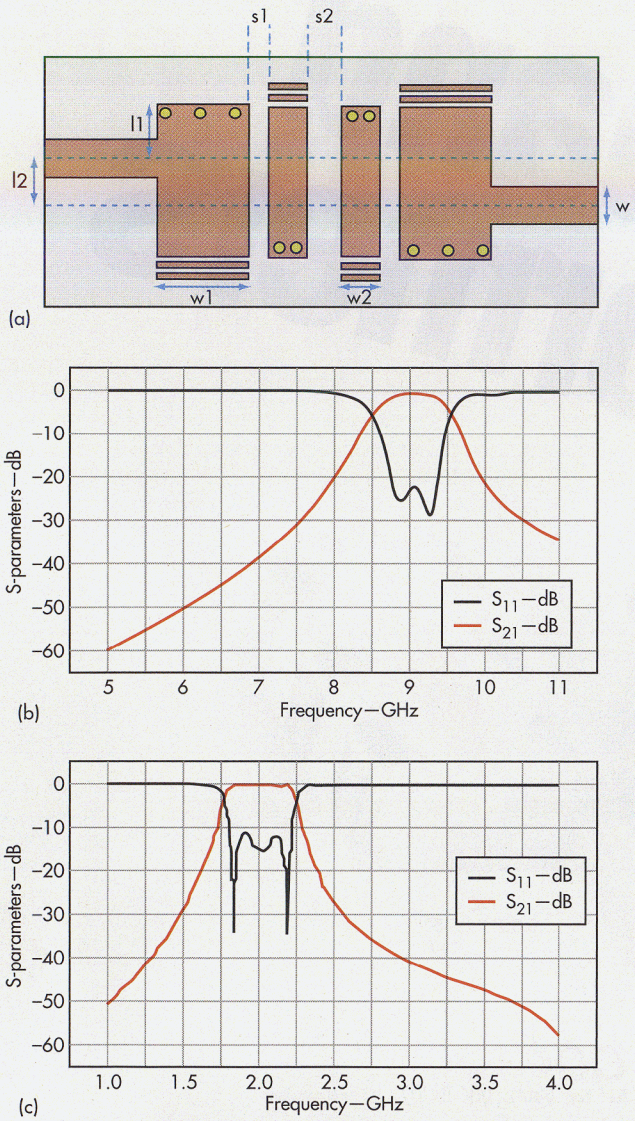
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3. The receiver front end (a) includes RF (b) and IF filter (c) circuitry to reject unwanted signals.

TABLE 1: LINK BUDGET FOR THE RECEIVER FRONT END

Component	Noise figure (dB)	Gain (dB)	IIP3 (dBm)
LNA	1	22	−8
RF filter	3	-3	>80
Mixer	9	-9	21
IF filter	3	-3	>80
IF amplifier	2.7	24	12
Total	2.2	32.6	>−9

the complexity and cost of a wireless transceiver's front end is vital in implementing mobile communication systems for these higher-frequency bands. As an example, ref. 3 details a receiver in the 6.1-GHz band with 100-MHz bandwidth designed to support 1-Gb/s wireless service. For systems operating beyond IMT bands, even wider channel bandwidths will be required.[4,5]

To support higher-frequency wireless applications, a wideband superheterodyne receiver was designed for X-band use at 9 GHz. The front end, which employs a commercial mixer and GaAs high-electron-mobility-transistor (HEMT) amplifiers, can be fabricated with standard printed-circuit-board (PCB) techniques and low-cost PCB laminates. It translates RF input signals to a 2-GHz intermediate-frequency (IF) band and provides a 200-MHz bandwidth at 9 GHz, with better than 3.5-dB noise figure and input return loss of better than 19 dB. The conversion gain is better than 35 dB, with gain ripple of a mere 1.24 dB. For high-speed mobile applications that require good error-vector-magnitude (EVM) performance, the front end also meets the EVM performance requirements of those systems.

As shown in *Fig. 1*, the receiver front end is composed of six parts, including a low-noise amplifier (LNA), RF and IF filters, and a local-oscillator (LO) module. A commercial mixer is used for frequency downconversion (from 9 to 2 GHz), while a two-stage gain block is used as the IF amplifier to guarantee link gain.

According to system requirements, the overall conversion gain of the receiver front end should be greater than 30 dB and the input 1-dB compression point higher than −30 dBm. With the help of the Advanced Design System (ADS) simulation software from Agilent Technologies (www.agilent.com), the different components were combined and simulated, and the link budget of the receiver front end was simulated and optimized. *Table 1* shows the final gain distribution of the RF and IF modules, as well as the simulated final noise figure, gain, and intercept points.

Compared to GaAs metal-epitaxial-semiconductor field-effect-transistor (MESFET) semiconductor technology, GaAs HEMT technology has advantages in noise, gain, and linearity.[6] In this work, a super-low-noise HEMT tube is used for the design of a low-noise amplifier (LNA). *Figure 2(a)* shows the structure of the two-stage LNA, with the two-stage (rather than single-stage) configuration chosen to provide sufficient gain. To improve input VSWR, a balanced structure is used in the first stage, with a 3-dB directional coupler employed. Since the noise figure of the two-stage LNA depends mainly on the first stage, the first-stage amplifier (LNA1 and LNA2) employs minimum noise figure matching, while the second stage (LNA3) employs maximum gain matching.

Figure 2(b) shows the circuit topology of a single amplifier (LNA1, LNA2, and LNA3). Since the HEMT tube is condi-

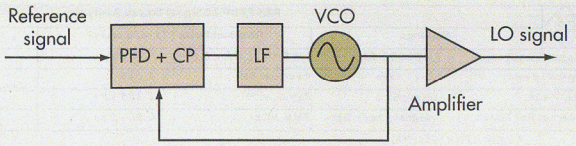
tionally stable over the frequency band of interest, a small resistance is added behind it to improve stability. A bandstop filter with quarter-wavelength microstrip line and open-circuit sector stub is designed in a bias network to choke off RF transmission over its stopband, all the while maintaining optimum transmission characteristics for direct current.[7,8]

In simulations of the two-stage LNA using ADS simulation software, the LNA design yielded a simulated noise figure of less than 0.7 dB, with $|S_{21}|$ of greater than 27 dB, and $|S_{11}|$ and $|S_{22}|$ of less than −20 dB from 8.8 to 9.2 GHz.

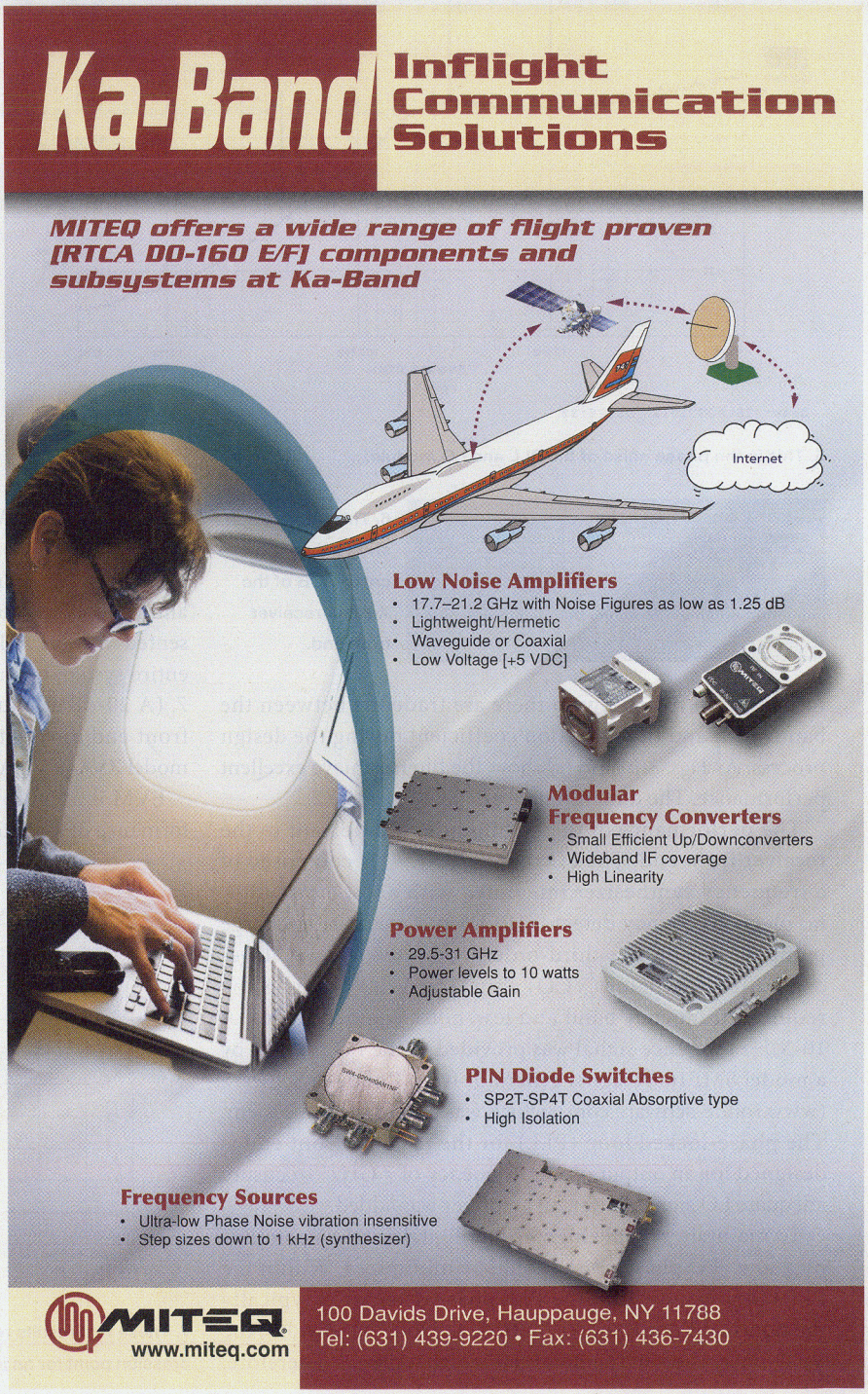
Channel filtering for the receiver front end is performed in the IF blocks by means of passive filters with high selectivity.[9] To prevent possible image-signal interference of desired signals, and to keep unwanted signals from jamming the receiver front end, an RF image-rejection filter is needed in the front end. A microstrip interdigital filter was adopted in this design due to advantages of simple structure, easy implementation, compact size, and low cost. *Figure 3(a)* shows the layout of the designed microstrip interdigital bandpass filter. Simulated responses for the filter design were obtained by means of ADS Momentum software simulation and are plotted in *Figs. 3(b)* and *(c)*.

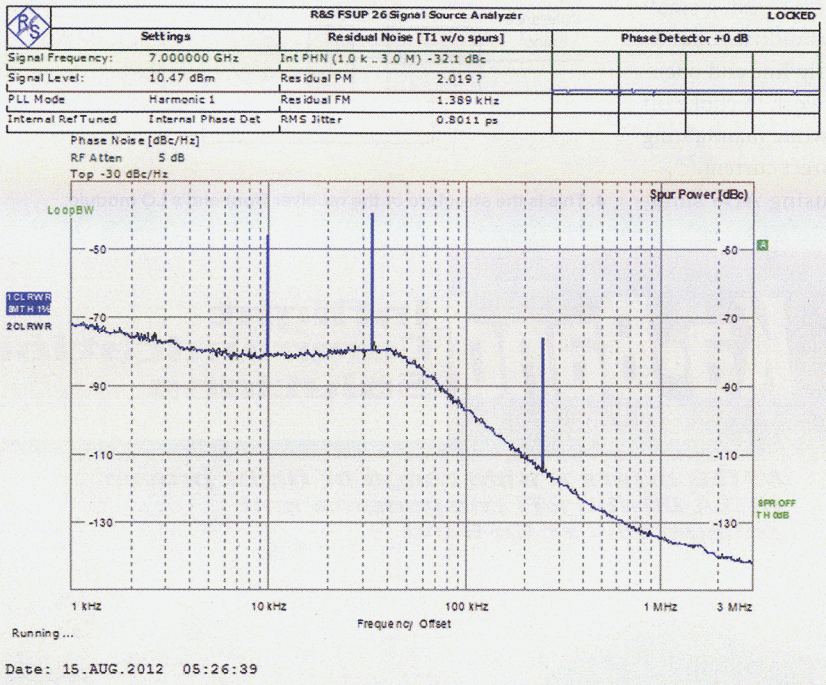
As shown in *Fig. 3(a)*, the bandpass filter consists of an array of quasi-TEM-mode transmission-line resonators, each of which has an electrical length of 90 deg. at the midband frequency and is short-circuited at one end while open-circuited at the other end with alternative orientation. Tapped lines with a characteristic admittance equal to the source/load characteristic admittance are used for the filter's input and output ports.[8] The position of the input/output tapped line affects the filter's matching.

The center frequency depends on lengths l1 and l2. Coupling is achieved by the fields fringing between adjacent resonators separated by spacings s1 and s2. Coupling grows stronger with narrower spacings, and the bandwidth increases. Spacings s1 and s2 have great

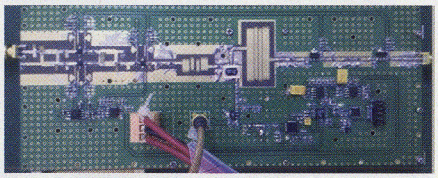


4. This is the structure of the receiver front end's LO module.





5. This is the phase noise of the PLL and LO module.



6. This photograph shows the fabricated PCB of the X-band receiver front end.

influence on matching, so there are tradeoffs between the bandwidth and the reflection coefficient during the design process. As *Figs. 3(b)* and *(c)* show, the filters achieve excellent performance. The dimensions are detailed in *Table 2*.

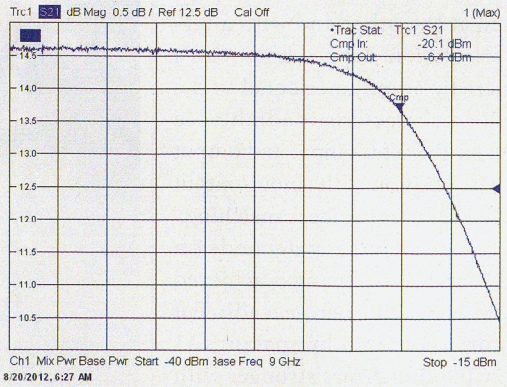
The performance of the LO module is important to the receiver front end. The LO module *(Fig. 4)* is composed of a frequency synthesizer integrated with a low-noise digital phase frequency detector (PFD) and a precision charge pump (CP), a passive third-order loop filter, and a voltage-controlled-oscillator (VCO) chip. The VCO provides the required frequency band and low-noise characteristics. A 10-MHz reference signal was provided to the LO module by a model SMF100A signal generator from Rohde & Schwarz (www.rohde-schwarz.com), which was part of the test system. The phase-locked loop (PLL) for the receiver front end is designed for an output center frequency of 7 GHz. To ensure adequate LO signal power, an amplifier was added.

To maintain reliable high-speed digital wireless communications, LO phase noise should be minimized. Within the PLL's loop bandwidth, the PLL phase detector is typically the dominant noise source; outside the loop bandwidth, the VCO noise is often the dominate noise source.[10] Therefore, the loop bandwidth is optimized to improve the phase-noise performance. *Figure 5* shows the measured phase-noise performance of the PLL used in the receiver front end. The phase noise is better than –70 dBc/Hz offset 1 kHz from the carrier, better than –80 dBc/Hz offset 10 kHz from the carrier, and better than –90 dBc/Hz offset 100 kHz from the carrier, assuming a test carrier frequency of 7 GHz.

TEST RESULTS

The RF receiver front end was fabricated using a standard PCB process *(Fig. 6)* and was evaluated with the aid of commercial test equipment. The measurement system included a model SMF100A signal generator, a model ZVA40 vector network analyzer (VNA), a model FSUP signal source analyzer, and a model FSQ signal analyzer, all from Rohde & Schwarz, and a model E8267D signal generator with option H44 from Agilent Technologies. Measurements were made of a variety of performance parameters, including gain, gain flatness, input VSWR, noise figure, image rejection, and input 1-dB compression point, with summaries presented in *Table 3*. The input 1-dB compression point for the entire system was measured at –20.1 dBm, as shown in *Fig. 7*. (A 20-dB attenuator was added at the IF port of the RF front end during the test to protect the input port of the model ZVA40 VNA.)

EVM is a figure of merit often used to quantify the performance of a digital radio transmitter or receiver, especially



7. These test results reveal the receiver front end's input 1-dB compression point for an input of about +20 dBm.

when it will be used for high-speed mobile wireless applications. Noise, distortion, spurious signals, and phase noise all degrade EVM; therefore, EVM provides a comprehensive measure of the quality of the radio receiver or transmitter in digital communications applications. *Figure 8* shows the EVM performance of the RF receiver front end with 16-state quadrature-amplitude-modulation (16QAM) signals. When the input power of RF signal is −30 dBm and the bandwidth is 20 MHz, the EVM levels of the RF receiver front end with 16QAM and quadrature-phase-shift-keying (QPSK) signals are 3.3% and 3.1%, respectively. When the signal source is connected directly to the test signal analyzer, the EVM is about 2%, indicating excellent RF front-

8. The EVM performance of the receiver front end was measured with a 16QAM signal.

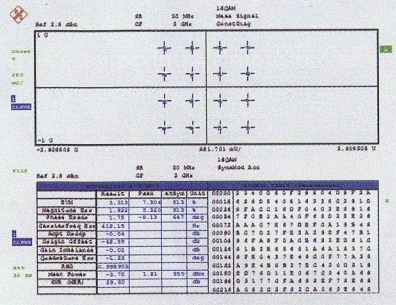


TABLE 3: MEASURED PERFORMANCE OF THE RECEIVER FRONT END

Parameter	Measured results
Operating frequency band	8.9 to 9.1 GHz
Bandwidth	200 MHz
Noise figure	<3.5 dB
Gain	35 dB
Gain fluctuation	<1.3 dB
Image rejection	>38 dB
$\|S_{11}\|$	<−19 dB
$P_{in\text{-}1Db}$	−20.1 dBm
EVM	<3.4%

TABLE 2: RF AND IF FILTER DIMENSIONS (mm) ON SUBSTRATE WITH ε_r = 2.55 AND h = 0.5 mm

Band	w	r	w_1	w_2	l_1	l_2	s_1	s_2
RF	1.38	0.4	3.3	1.4	1.96	1.68	0.73	1.29
IF	1.38	0.4	3.4	1.5	9.68	5.68	0.30	0.49

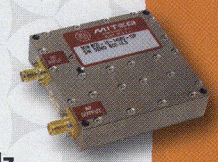
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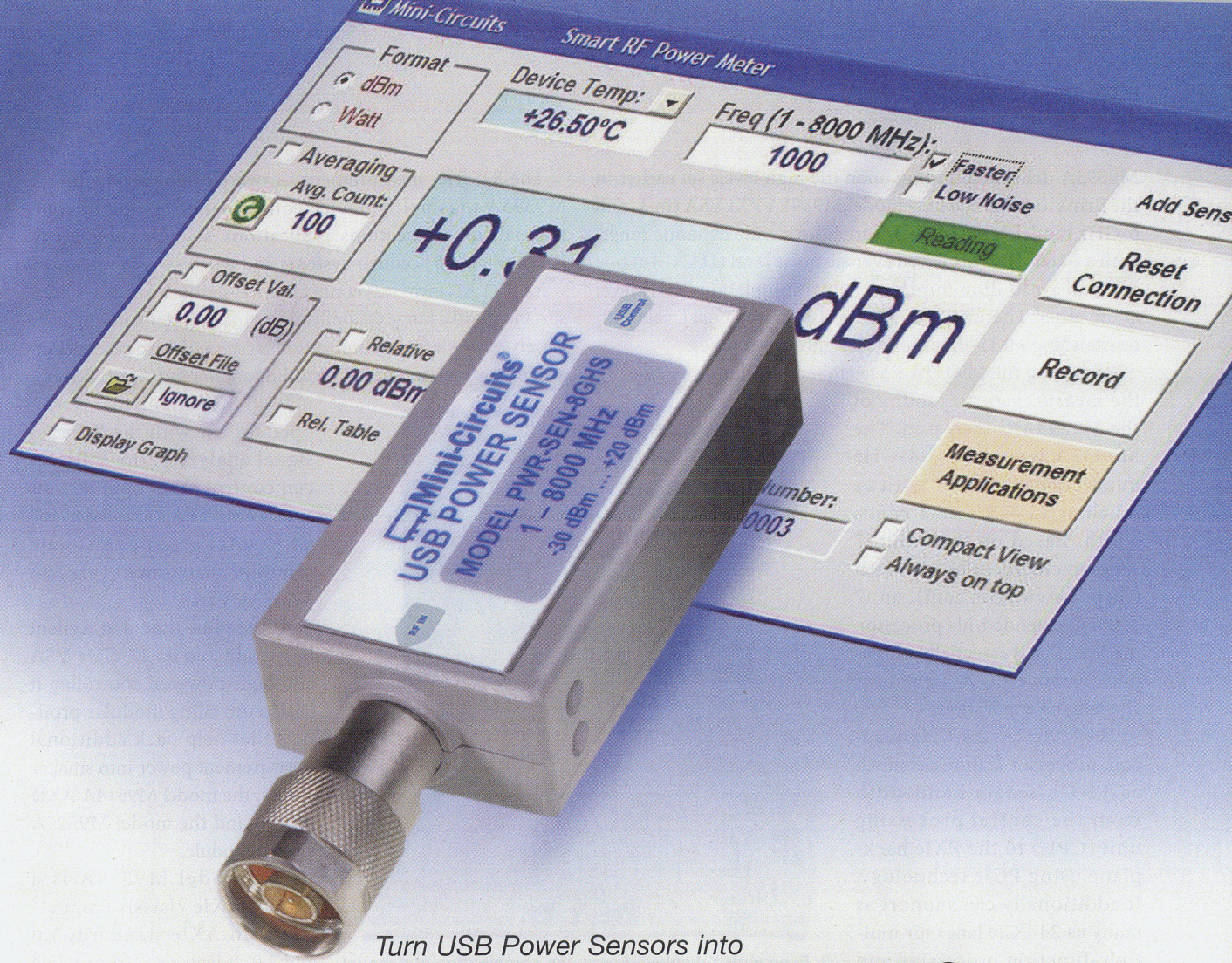
Vida Ilderem - *Vice President, Intel Labs; Director, Integrated Computing Research, INTEL CORPORATION*

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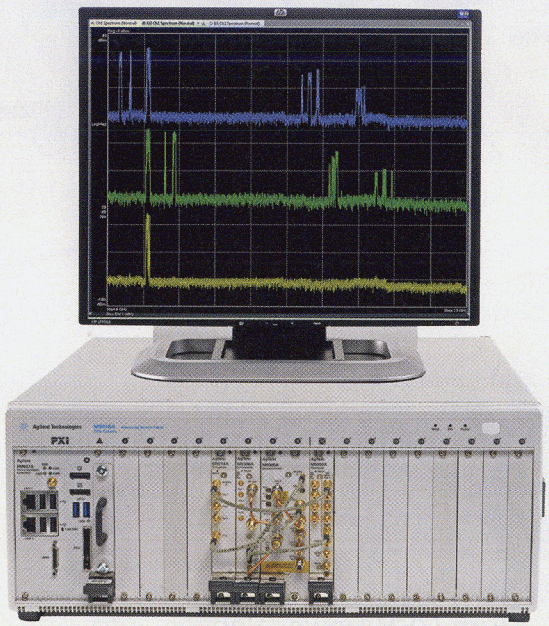
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M9393A delivers. Building upon the high levels set earlier in the firm's lower-frequency model M9391A PXI VSA (in 3- and 6-GHz models), the M9393A provides a wide dynamic range, with a −160-dBm displayed average noise level (DANL) at one end and a +30-dBm third-order-intermodulation (TOI) level at the other. These M9393A VSAs also show signal levels with outstanding ±0.15-dB absolute amplitude accuracy.

By adding the M9037A PXIe embedded controller *(Fig. 3)*, the measurement capability of the M9393A is increased. The M9037A features a 2.4-GHz quad-core processor with as much as 12-GB/s data bandwidth. Based on the latest i7 series microprocessor from Intel Corp. (www.intel.com), an i7 4700EQ extended-life processor, the M9037A is essentially a high-performance PC designed for challenging applications.

The M9037A's 2.4-GHz quad-core processor features as much as 12-Gb/s data bandwidth from the central processing unit (CPU) to the PXIe backplane using PCIe technology. It additionally can support as many as 24 PCIe lanes for multiple-function processing and fast computations on complex measurements, such as microwave power and error-vector-magnitude (EVM) measurements.



3. Even with a display screen, the combination of a model M9393A VSA and model M9037A embedded controller still leaves room for other measurement functions in a PXIe chassis.

The M9037A PXIe embedded controller even includes an X8 PCIe front-panel connector to link to a second PXIe chassis or to redundant-array-of-independent-disks (RAID) data storage. It is bolstered by preloaded libraries and drivers, and it features the convenience of a front-panel removable 240-Gb solid-state memory drive.

In addition to its modular hardware capabilities in vector signal generators and arbitrary waveform generators, Agilent has developed extensive measurement software that also supports the PXIe M9393A modular VSA. Software tools include the 89600 VSA software and the X-Series measurement applications. The 89600 VSA software was recently enhanced with stepped spectrum measurement capabilities.

Given the frequency switching speed of the M9393A and the control of the 89600 VSA software, the combination can perform stepped spectrum measurements across a 27-GHz bandwidth in less than 1 s with a 10-kHz resolution bandwidth. Such measurement capability is invaluable when checking for harmonic and spurious signals across wide bandwidths.

The X-Series measurement software can be used with the M9393A to simplify device conformance testing of commercial communications applications, such as Long-Term-Evolution (LTE) cellular systems and wireless-local-area-network (WLAN) wireless connectivity systems. It supports measurements on a range of applications, including Bluetooth and a variety of wireless communications systems. It also eases general-purpose measurements, including analog and digital demodulation measurements. Developed for use with the X-Series signal analyzers, the software can control other applications such as MATLAB and the 89600 VSA software on the same modular instrument (e.g., an M9393A VSA).

At the same time that Agilent is introducing its 27-GHz VSA and high-powered controller, it is also unveiling modular products that help pack additional measurement power into smaller spaces: the model M9514A AXIe chassis and the model M9521A system module.

The model M9514A is a 14-slot AXIe chassis compatible with AXIe standards 1.0 and 2.0. It features a front-panel Gen 2×8 PCIe interface for connecting multiple AXIe and PXIe chassis, PCIe and gigabit LAN for connections to a host computer, and 62 differential local bus lines for module-to-module communications. To make such high measurement density possible, the M9514A chassis is designed with an innovative cooling configuration to achieve 200 W cooling per slot.

With their high-performance AXIe communications bus, the chassis and module support many measurements of interest to military and aerospace customers. These include phase-coherent measurements across many test modules and modulation-quality measurements in satellite-communications (satcom) systems. Equipped with the appropriate function modules, the chassis and system module can perform multiple-channel antenna testing and high-speed digital testing with tight timing synchronization possible between modules. The M9393A is available for order but will ship in July. P&A: $42,000 and up (M9393A VSA) and $6950 and up (M9037A controller). MW

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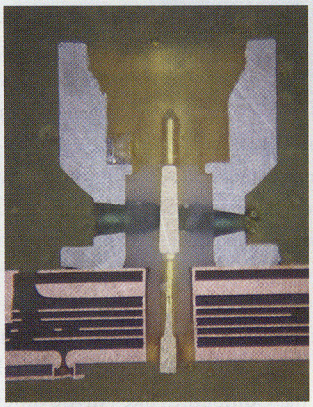
JEAN-JACQUES DELISLE | Technical Engineering Editor

Millimeter-Wave Technology Prepares For A Wealth Of Applications

Fiber-optic-like data rates, micro-antennas, and high-resolution imagers are just the tip of the iceberg when it comes to millimeter-wave technology's capabilities.

MILLIMETER-WAVE TECHNOLOGIES WILL soon touch virtually every industry. Until recently, the semiconductor and machining capabilities of manufacturers were too inaccurate or cost prohibitive to enable millimeter-wave device production for all but specialized applications. Now, advances in semiconductor technology, testing techniques, and micromachining are beginning to bring millimeter-wave solutions to a wide range of applications.

The growth of the global millimeter-wave technology market in terms of revenue is expected to reach $1.1 billion in 2018 at a CAGR of 59.10%. Millimeter-wave product volumes are estimated to grow from roughly 11,800 units to more than 360,000 units in 2018. Alongside this growth, the demand for high-data-rate technologies for wireless backhaul is driving innovation in the unlicensed 57-to-64-GHz frequency band.

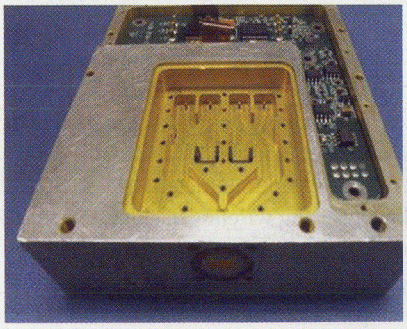


1. A frequency-modulated-continuous-wave (FMCW) millimeter-wave imager can be used safely to produce high-resolution security scans.

For decades, millimeter-wave technology has been implemented in many military, aerospace, meteorology, and satellite applications. Mono-pulsed radar systems and weather radiometers were very common. Another example of applied millimeter-wave technology is the imaging of objects in space with large radar installations that pick up millimeter-wave radiation. Discrete satellite-to-satellite communications also is enabled by highly directional millimeter-wave signals. More recently, homeland security has been using millimeter-wave imagers for security screeners *(Fig. 1)*. Because millimeter-wave energy is non-ionizing and depletes rapidly in the environment, the technology can be safely used to image metallic and non-metallic objects on people.

The rapid atmospheric attenuation of millimeter-wave signals also can benefit high-speed wireless-technology links by limiting interference between transceivers. The dimensions of millimeter waves lead to very directional and high-gain antennas. Such antennas, in turn, translate into lower levels of interference and higher data rates *(Fig. 2)*. These millimeter-wave properties have nurtured the development of a variety of short- to mid-range high-speed data-link technologies *(Fig. 3)*. Development is being focused on applications for these high-speed data links, such as pico-cell wireless, wireless backhaul, chip-to-chip communication, and higher-performing RF electronics.

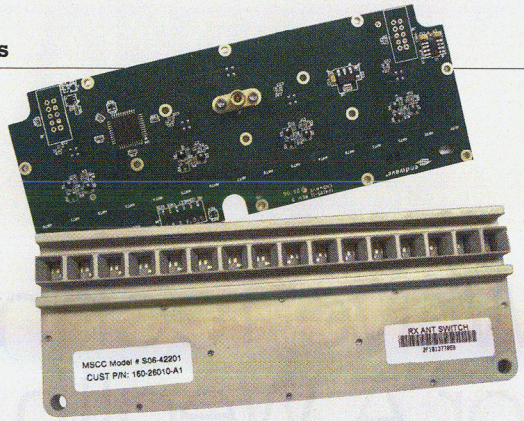
The increased interest in these data links also has been driven by the limited licensing issues in the unlicensed 60-GHz band as well as the lightly licensed frequencies from 71 to 76 GHz and 81 to 86 GHz. These frequency bands require a very minimal cost per license or no license at all, depending upon where the links are in the world. There are, however, constraints in transmit power in accordance with the Maximum Permissible Exposure (MPE) limits. Technical complexities also arise when



2. As a product of atmospheric absorption and millimeter-wave dimensions, antennas for millimeter-wave transmission can benefit from extraordinarily narrow beam widths.

maintaining stable output power at millimeter-wave frequencies.

Because these technologies have a wealth of bandwidth options in which to operate their links, fully duplex data rates beyond the common 1.25 Gbps are possible. Less spectral clutter also enables the use of modulation schemes, such as direct digital modulation, which lead to lower communication-electronics costs. This is detailed in the Shannon-Hartley theorem in the equation:



3. The very small dimensions of millimeter-wave devices allow for direct orthogonal mounting on PCB substrates. Copper patterns are used to create controlled impedance paths across the laminate and through the board.

$$C = B \log (1 + S/N)$$

where C is the channel capacity in bits per seconds, B is the bandwidth in hertz, S is the average received signal power over the bandwidth in watts, and N is the average noise figure over the bandwidth in watts.

It is evident in the equation that even with lower signal power, the lack of interference noise and the ability to use a very wide bandwidth can offer a very-high-capacity channel link. The atmospheric absorption does limit these devices to a range of a few hundred to a few thousand meters when used in a directional manner. The very narrow transmission beam also requires that the alignment between the two transceivers is accurate.



4. Millimeter-wave wireless links are a potential solution to enable fiber-optic-like speeds in highly congested areas or in environments where routing fiber might not be feasible.

For this reason, companies like HXI provide gun-sight mounts on their HDTV-link systems. These links have an aggregate throughput of 2.97 Gbps with a two-channel unit and an operating range from 20 to 300 m. In the telecommunications arena, more carriers are employing Long-Term-Evolution (LTE) networks to meet the data demand for mobile broadband.

Small-cell solutions also are increasingly being adopted to service the higher-demand areas that are not being fully served by larger macrocells. Offering these services in congested areas, either in-building or externally, is often prohibitively expensive to implement with fiber-optic cabling. And, it is impossible to service the growing capacity demands with slower-speed passive cabling. Using fiber-optic-speed millimeter-wave solutions is a proposed method for offering wireless backhaul in these difficult-to-service areas with minimal cost compared to other solutions. The available bandwidth also may eventually allow data rates as high as 40 Gbps.

Another advantage of millimeter-wave devices is the relative size of the antennas and the device components. These compact components can be very light and portable, which opens doors to more environments in which millimeter-wave devices could be used. On the other hand, the wavelength dimensions of these signals require very precise tolerances on small components *(Fig. 4)*.

The skin effect causes these higher-frequency waves to travel at the surface of the conductors, making surface finish and plating serious concerns. Small imprecisions in machining also lead to very low yields and higher costs. A solution to these problems has been to develop semiconductor-based millimeter-wave systems and other micro-fabrication techniques.

Another growing trend has been to implement on-chip antennas with self-testing electronics to cut down on expensive millimeter-wave test. Companies like IBM and United Monolithic Semiconductors have implemented processes with tool support for enabling millimeter-wave design as well as digital integration. Testing systems like digital-signal processing, internal noise sources, and loop-back sensing methods can all enable a self-testing device. IBM's 9HP process uses silicon-germanium (SiGe) BiCMOS for this integration. Other semiconductors used for millimeter-wave electronics are implemented in gallium arsenide (GaAs), indium phosphide (InP), and gallium nitride (GaN).

When working with semiconductor components, difficulties often arise when interfacing to the external electronics or antenna. Companies like Nuvotronics have developed highly refined micro-fabrication methods to create complete millimeter-wave structures in a monolithic process. Nuvotronics claims that its PolyStrata manufacturing technology can be used to make 3D transmission lines with advanced routing while enabling other features with 3D stacking. In addition to being able to create an effective millimeter-wave interface, millimeter-wave surface-mount-technology (SMT) components and other monolithic microwave integrated circuits (MMICs) can be included in the 3D design.

With these advanced fabrication techniques, millimeter-wave devices could soon be found in many commercial and industry environments. With the potential for integrated, ultra-high-speed data connections and low transmission power, this technology also could enable the Internet of Things and Big Data revolutions. mw

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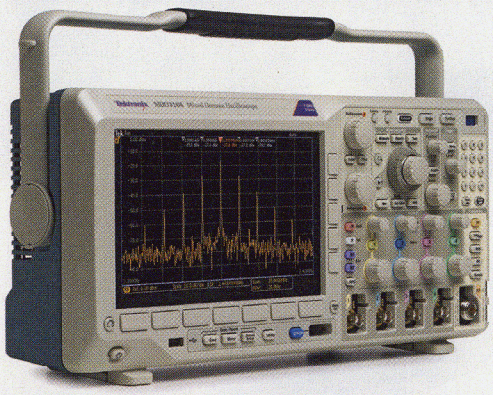
Test Instruments Pack Six Essential Tools

Each of these portable powerhouses boasts a 1-GHz oscilloscope, 3-GHz spectrum analyzer, logic analyzer, protocol analyzer, arbitrary function generator, and digital voltmeter.

SEARCHING FOR A particular test instrument is the time-consuming bane of many an RF/microwave engineer. But with the MDO3000 series of mixed-domain oscilloscopes (MDOs) from Tektronix (www.tek.com), finding many critical test tools will now come down to finding one compact unit.

Each MDO3000 is potentially six instruments in one, with an oscilloscope, spectrum analyzer, logic analyzer, protocol analyzer, arbitrary function generator (AFG), and digital voltmeter (DVM) contained within a single housing. These instruments can cover a lot of ground, since the oscilloscopes are available with two or four analog input channels and bandwidths ranging from 100 MHz to 1 GHz. The spectrum analyzer can reach as high as 3 GHz.

Tektronix's portable test laboratories *(see photo)* are based on the company's MSO/DPO3000 Mixed Signal Oscilloscope series, starting with a versatile and powerful MSO and new FastAcq functionality. Although they are "packaged" as standard instruments, they feature a host of options that allow specifiers to essentially customize each instrument to a particular set of needs.



The MDO3104 is one of the multiple-function portable instruments that packs as many as six measurement functions to 3 GHz in a compact housing.

The oscilloscopes provide two or four analog input channels and 16 (optional) digital input channels. Standard oscilloscope bandwidths include models for 100, 200, 350, 500, and 1000 MHz, and the spectrum analyzer frequency range of any model can be extended to 3 GHz as an option.

Also, the oscilloscopes offer more than 125 trigger combinations to help capture the most complex signal anomalies. They include automated serial and parallel bus analysis as well. The optional logic analyzers provide 16 digital channels with a main sample rate of 500 MSamples/s (2-ns timing resolution) and 10-Mpoint record length for capturing details on high-speed signals. When even higher-resolution timing measurements are required, the MDO3000 employs a parallel high-speed sampling technology (called MagniVu) that samples each digital channel at 8.25 GSamples/s (121.2-ps timing resolution) into a shorter record that is centered on the trigger event.

With the integrated protocol analyzer, details shown on the oscilloscope screen can be used to decode a bus under analysis. This analyzer makes it possible to trigger on specific packet data and view decoded data with physical layer or event details. The addition of one or more of the nine optional serial analysis software packages mentioned previously enables the measurement power of the protocol analyzer.

Adding to the integrated instrument list, an integrated AFG capable of output rates to 250 MSamples/s is available as an option. It includes 128-kpoint waveform memory to enable a user to capture and replicate a signal from the oscilloscope. With its capabilities, it can recreate or generate sine waves to 50 MHz and pulsed signals to 25 MHz. A built-in waveform editor and integrated software provide 13 predefined functions.

When considering the relatively low prices for the MDO3000 Series instruments (starting at $3350 USD), packing multiple test functions into one compact box can save a great deal on the total cost of multiple instruments. mw

TEKTRONIX INC., 14150 SW Karl Braun Dr., P.O. Box 500, Beaverton, OR 97077; (800) 833-9200, *www.tektronix.com*

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Multifunction Test Sets Target Wireless Devices

These flexible measurement instruments are well suited for testing 4G wireless devices and systems, both established and emerging.

WIRELESS COMMUNICATIONS DEVICES continue to evolve, with designers attempting to keep pace with customers' demands for increasing data uplink and downlink rates over limited swaths of available bandwidth. For testing newer wireless devices, such as Fourth-Generation (4G) and Long-Term-Evolution-Advanced (LTE-A) cellular communications systems, Agilent Technologies (www.agilent.com) has launched two families of highly integrated, flexible test sets: the UXM and EXM series.

The UXM wireless test set includes the model E7515A *(Fig. 1)*, with a large, 15-in. touchscreen to simplify data entry and programming control. The UXM test set may be configured for two independent 100-MHz-wide RF transceivers and can use a wide range of test libraries by means of backwards-compatible SCPI. They can perform signaling and non-signaling tests, effectively recreating operating environments with multiple cells, with carrier aggregation, multiple-input, and multiple-output (MIMO) system configurations to 4×2.

The UXM test set is designed to test complex handover scenarios with VoLTE support, making it possible to verify bidirectional category-6 performance levels at downlink rates to 300 Mb/s and uplink rates to 50 Mb/s. They can also simulate real-world conditions by introducing noise and impairments such as signal fading.

The UXM test set has built-in servers to support a wide range of test functions and capabilities. The testers include multiple expansion slots and upgradable processors to evolve as wireless communications devices continue to change and grow. To speed creation of automated test routines, the UXM wireless test set works with the firm's Wireless Test Manager (WTM) software to quickly adapt to changing wireless conditions.

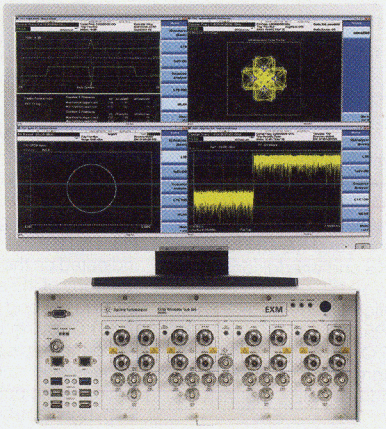
The EXM wireless test set includes variants of the model E6640A modular unit, suitable for production and manufacturing testing *(Fig. 2)*. The scalable system is suitable for testing 2G, 3G, LTE, LTE-A, Bluetooth, and wireless-local-area-network (WLAN) products and devices. With up to four transceiver channels, each EXM tester can perform parallel testing of wireless devices to speed production testing.

The EXM wireless test set delivers absolute level accuracy of ±0.5 dB from 0.38 to 3.80 GHz, with a wide transmit output-power range extending from −120 to +5 dBm for frequencies from 380 MHz to 6 GHz. The EXM receivers achieve typical error-vector-magnitude (EVM) performance of −42 dB for 160 MHz IEEE 802.11ac testing. These scalable modular test sets can directly connect as many as 16 devices under test (DUTs) for fast-sequenced, non-signaling testing and as many as 32 DUTs with customizable MPA technology. Both the UXM and EXM test sets provide the flexibility to evolve as test requirements change, whether in the research laboratory or on the production floor. mw

AGILENT TECHNOLOGIES, 5301 Stevens Creek Blvd., Santa Clara, CA 95051; (408) 345-8886, *www.agilent.com*



1. The model E7515A is a member of the UXM wireless test set series, which features a 15-in. touchscreen display for ease of control and programming.



2. The model E6640A test set is one of the EXM wireless test sets that provide bandwidths of 40, 80, or 160 MHz for testing devices and products through 6 GHz.

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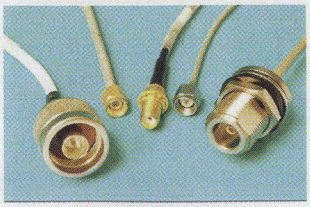
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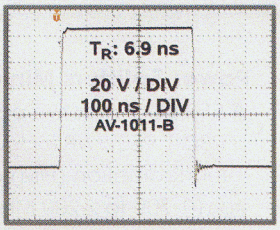
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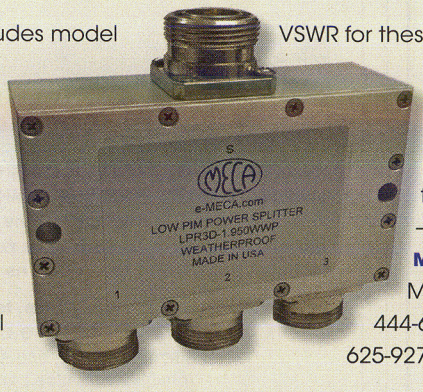
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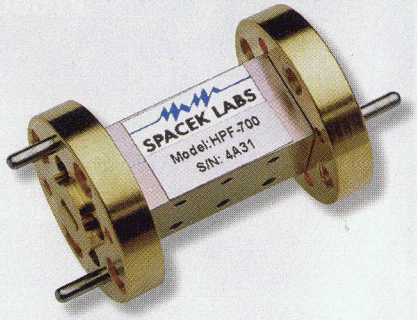
MODEL 4804-10AZ is a compact variable attenuator designed for use from 2 to 4 GHz. It features a 10-dB attenuation range with 0.1-dB or better resettability from –55 to 85°C. The variable attenuator exhibits maximum VSWR of 1.80:1 with 0.5-dB maximum insertion loss. It is housed in an aluminum package with SMA female stainless-steel connectors. The variable attenuator is rated for 5-W average power-handling capability and 3-kW peak power-handling capability. Additional variable attenuators in the series are available for bands from 1 to 18 GHz with as much as 40-dB attenuation.



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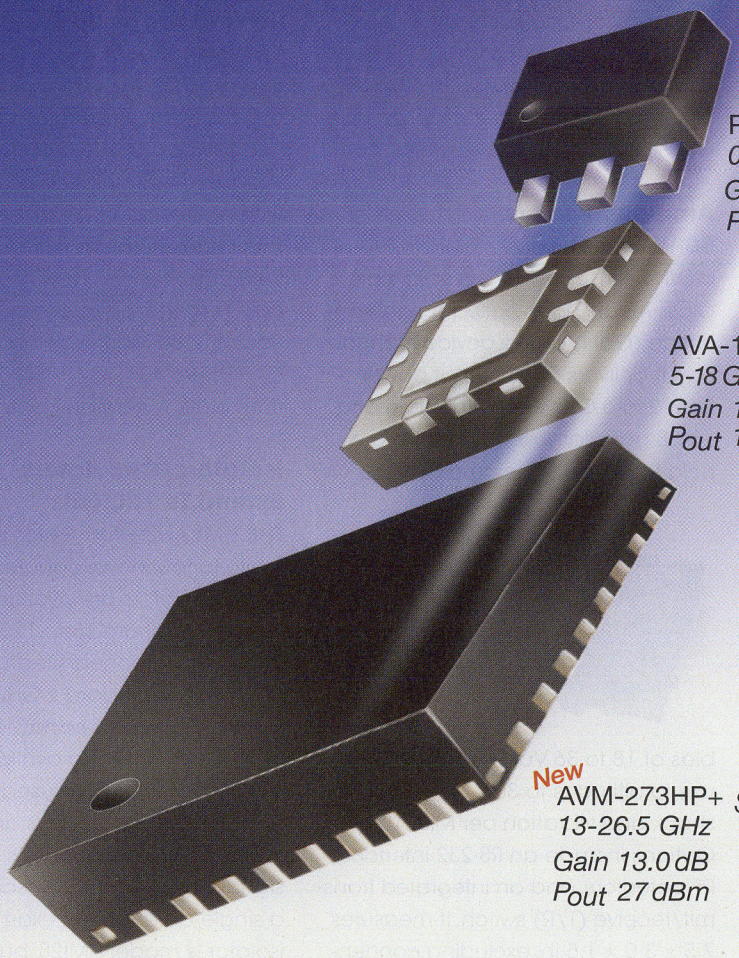
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THE MODEL SKY8021 SkyOne hybrid front-end module (FEM) serves numerous cellular communications bands and operating modes with transmit and receive functions for use in multiband wireless handsets. It includes features for 2.5G. 3G, and 4G cellular applications and consists of several different power-amplifier (PA) blocks, including for Global System for Mobile (GSM) Communications, Digital Cellular Service (DCS), wideband-code-division-multiple-access (WCDMA), and Long Term Evolution (LTE) systems, a logic-control block for multiple power-control levels, and band-enable functions for both cellular and UMTS use. In addition, the SKY8021 includes a receiver section with switching, duplexers, and integrated filters. The FEM is fabricated with InGaP/GaAs die and passive components mounted on a multilayer circuit laminate and housed in a compact 8 × 9 × 0.9 mm, 60-pad package.

SKYWORKS SOLUTIONS INC., 20 Sylvan Rd., Woburn, MA 01801; (781) 376-3000, FAX: (781) 376-3100, e-mail: sales@skyworksinc.com, *www.skyworksinc.com*

Amplifier Powers 50 W To 6 GHz

MODEL BME2969-50 is a solid-state, Class AB amplifier based on gallium-nitride (GaN) active-device technology. It delivers 50-W output power from 2 to 6 GHz with 54-dB gain and ±3-dB gain flatness. Harmonics are held to –13 dBc. The amplifier runs on



bias of 18 to 36 Vdc. It is screened for use to altitudes to 30,000 feet and for shock and vibration per MIL-STD-810F. Options include an RS-232 interface, RF detectors, and an integrated transmit/receive (T/R) switch. It measures 7.5 × 3.0 × 1.5 in. excluding connectors and weighs 3 lb.

COMTECH PST, 105 Baylis Rd., Melville, NY 11747; (631) 777-8900, FAX: (631) 777-8877, *www.comtechpst.com*

Coaxial Switches Trim PIM To 18 GHz

A LINE of coaxial switches from Radiall features low levels of passive intermodulation (PIM) for use in different systems and test applications. These switches, which are available with Type-N connectors for use to 12.4 GHz and SMA connectors for use to 18 GHz, can be specified in a variety of configurations, including in single-pole, double-throw (SPDT), double-pole, double-throw (DPDT), single-pole, four-throw (SP4T), and single-pole, six-throw (SP6T) versions. The switches feature long life cycles, with 2 million actuations guaranteed. Type-N models achieve 60-dB isolation at 12.4 GHz, with maximum VSWR of 1.50:1 and maximum insertion loss of 0.5 dB at 12.4 GHz. SMA models provide 60-dB isolation at 18.0 GHz, with maximum VSWR of 1.50:1 and maximum insertion loss of 0.5 dB at 18.0 GHz.

RFMW LTD. (stocking distributor for Radiall), 188 Martinvale Lane, San Jose, CA 95119; (408) 414-1450, e-mail: info@rfmw.com, *www.rfmw.com*

Isolators/Circulators Extend To 120 GHz

THE HMI AND HMC Series broadband ferrite-junction waveguide isolators and circulators are available for frequencies from 18 to 120 GHz. These low-loss components feature 20-dB isolation in standard 2-GHz configurations, with wider bandwidths and higher isolation also available. The isolators are typically used to buffer the outputs of amplifiers and oscillators while the circulators serve as signal duplexers on transceivers with a single antenna. An example of an isolator is model HMI28, built with WR-28 waveguide. With a frequency range of 26.5 to 40.0 GHz, it handles 1 W power with 0.4-dB insertion loss and 20-dB isolation. An example of a circulator, at slightly higher frequency, Model HMC19 employs WR-19 waveguide for frequency coverage from 40 to 60 GHz. Over that range, it boasts 20-dB isolation with only 0.5-dB insertion loss and power-handling capability of 1 W.

HXI MILLIMETER WAVE PRODUCTS, 12 Lancaster County Rd., Harvard, MA 01451; (978) 772-7774, FAX: (978) 772-7775, e-mail: MMWcomponents@hxi.com, *www.hxi.com*

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- SMA or Type N conn.
- 50 W average models



4425 Types

Freq. Range (GHz)	Average Power (W)	Model No. N Conn.	Model No. SMA Conn.
DC-18.0	1	N9412 *	9412 *
DC- 5.0	1	N4402 *	4401 *
DC- 4.0	5	N4405 *	4405 *
DC- 4.0	10	N4410 *	4410 *
DC- 4.0	25	N4425 *	4425 *
DC- 4.0	50	N4450 *	4450 *

*Value of attenuation



9412 & 4401 Types (1.14")



N9412 Types (2.42")

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DC-18.0	1		9512
DC-12.4	2	N9512	
DC-12.4	5	N9505	9505
DC-12.4	10	N9510	9510
DC- 8.0	25	N9525	9525
DC- 8.0	50	N9550	



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3.30- 4.90	1000	229-925	3000	229-920
3.95- 5.85	750	187-925	2000	187-920
4.90- 7.05	625	159-925	1500	159-920
5.85- 8.20	500	137-925	1000	137-920
7.05-10.0	425	112-925	600	112-920
7.00-11.0	325	102-925	500	102-920
8.20-12.4	225	90-925	500	90-920
12.4 -18.0	200	62-925	250	62-920

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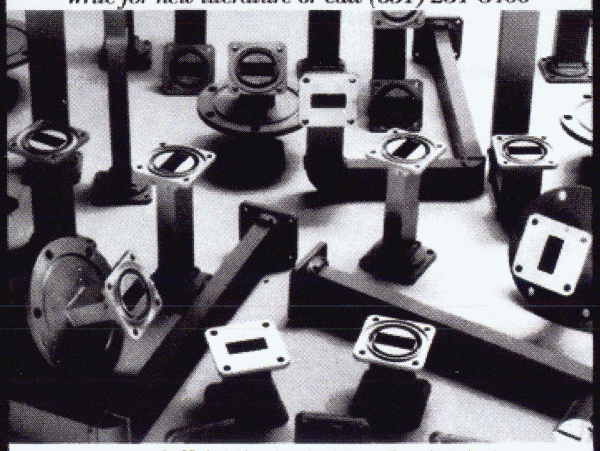
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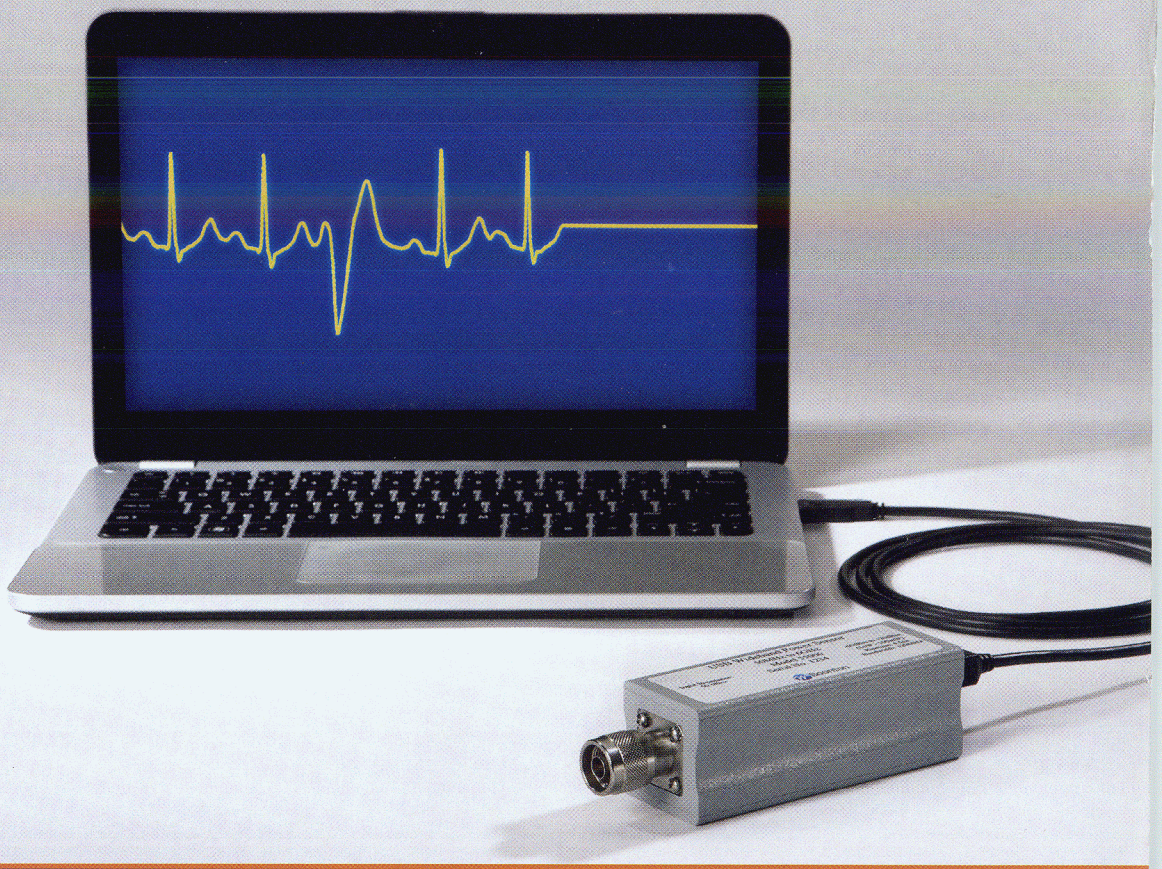
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