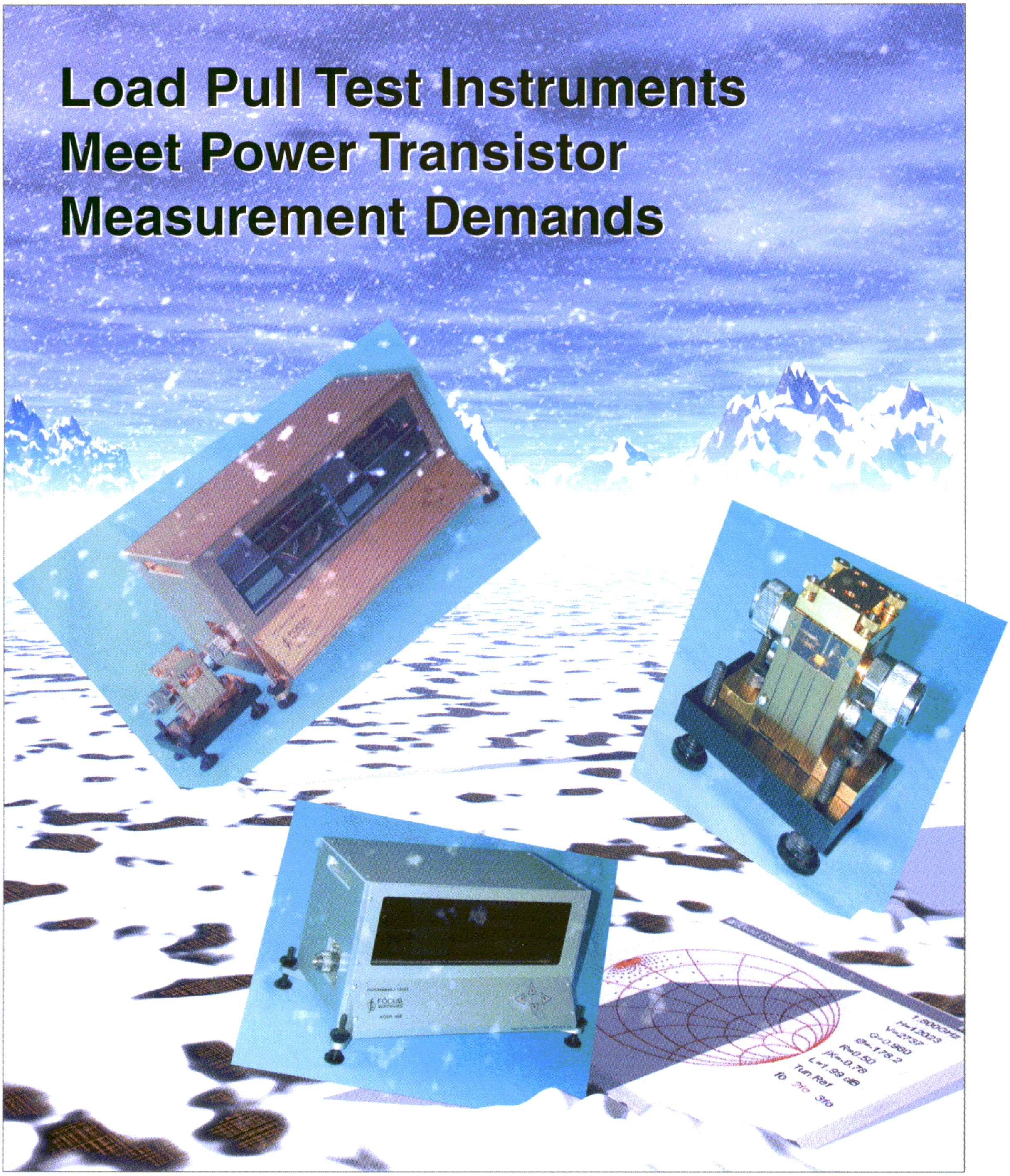
December 1999

Applied MICROWAVE & WIRELESS



System Performance

A Review of Time and Frequency Standards

Circuit Design

Design and Performance 3.4 to 4.6 GHz Active Equalizer

Design Ideas

Notes on Low Cost Design Techniques

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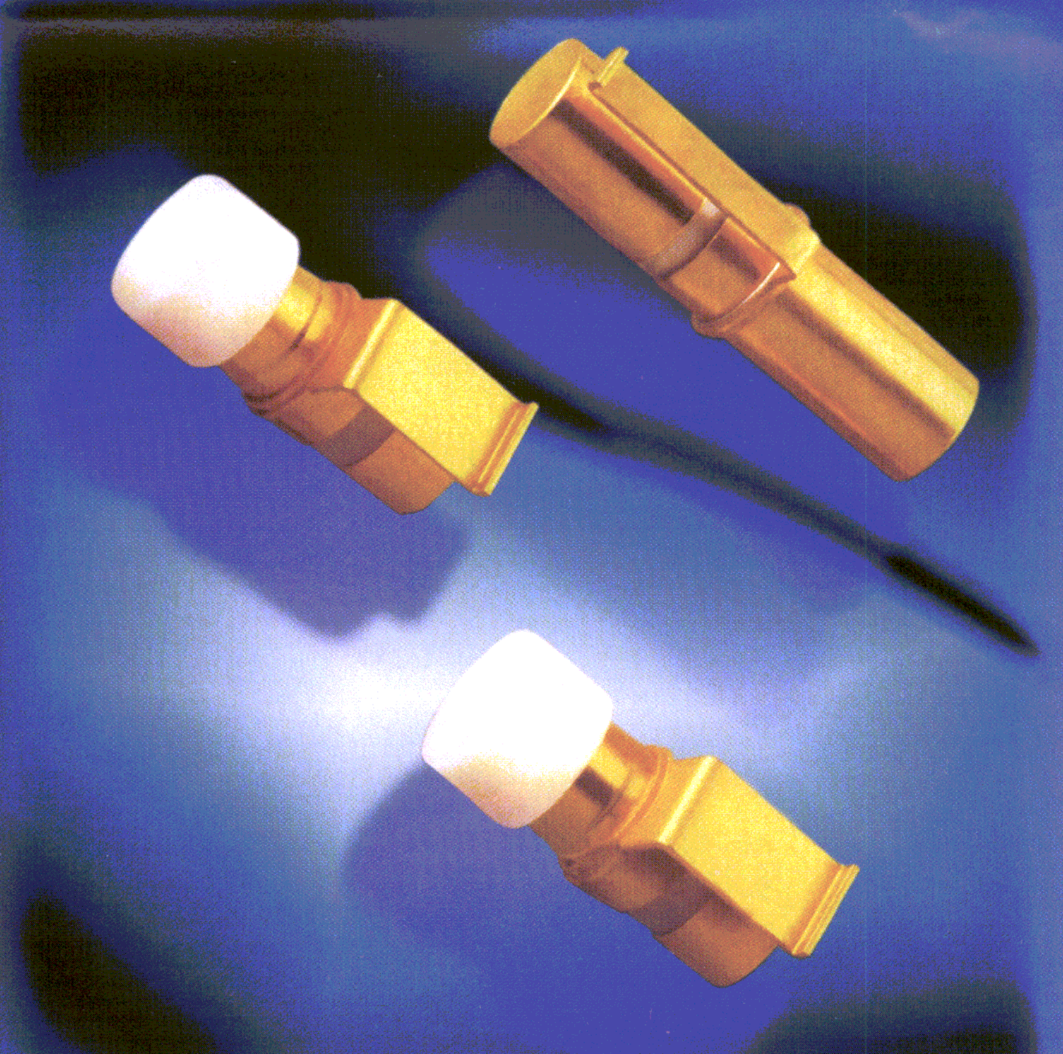

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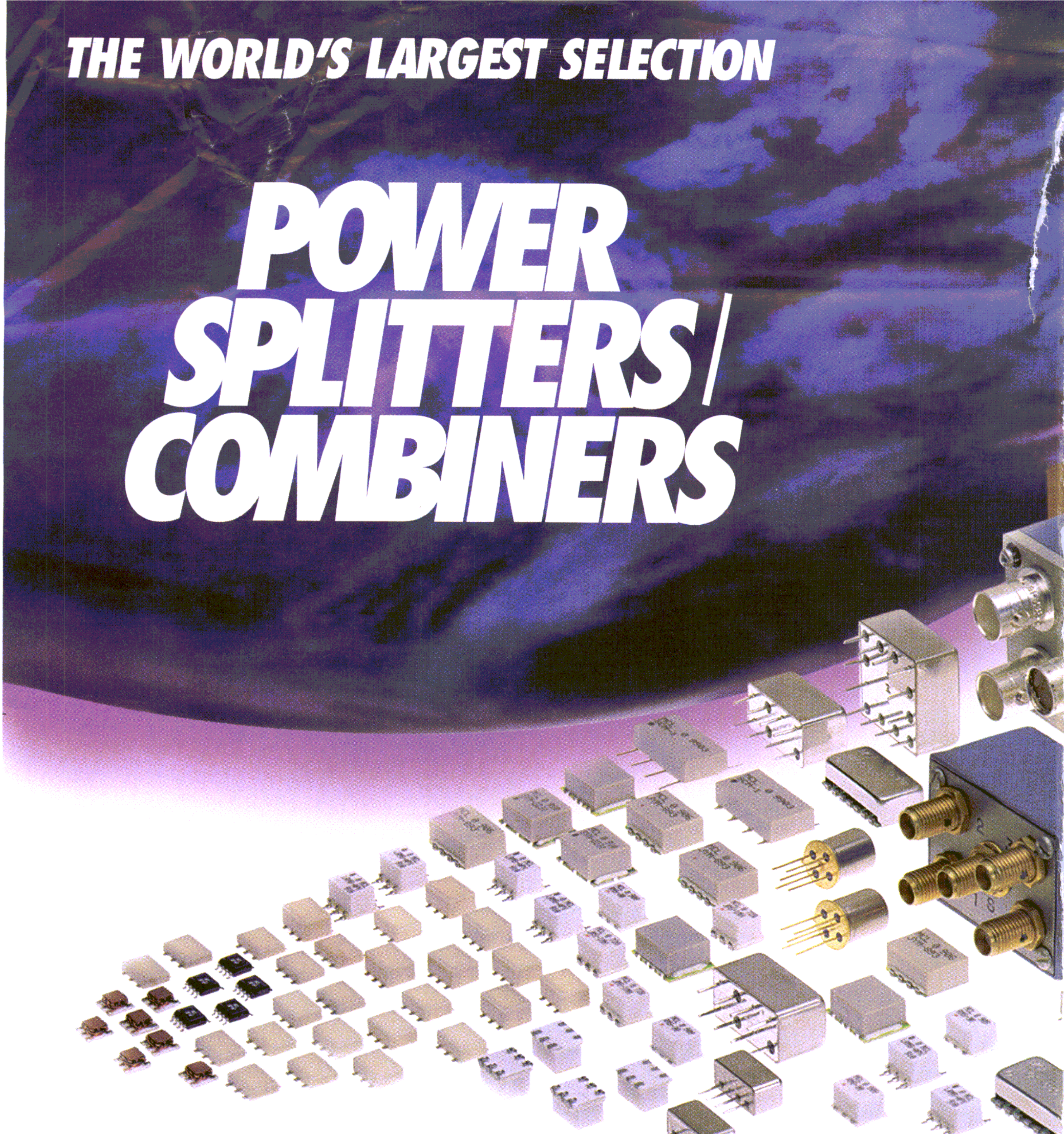

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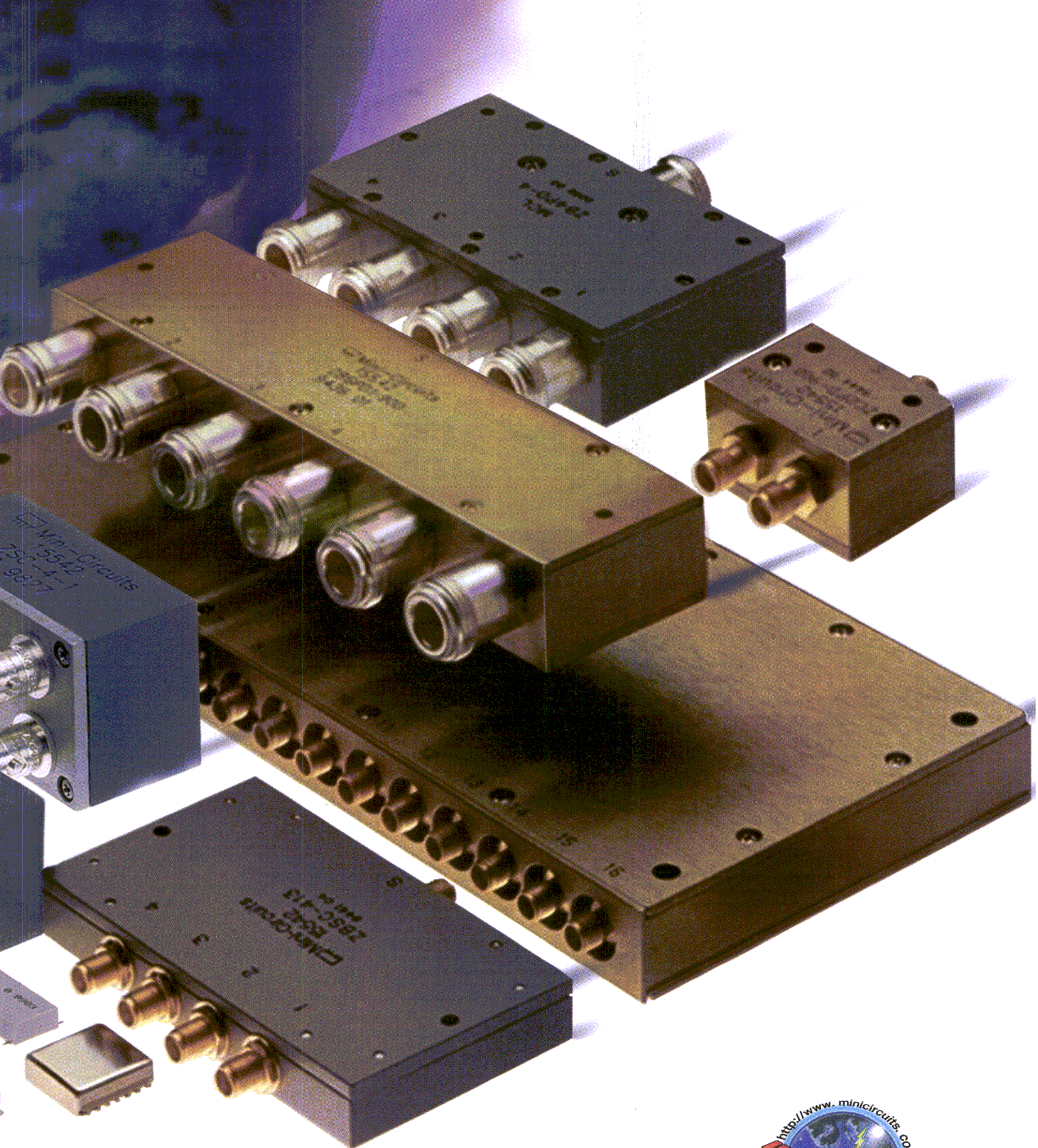

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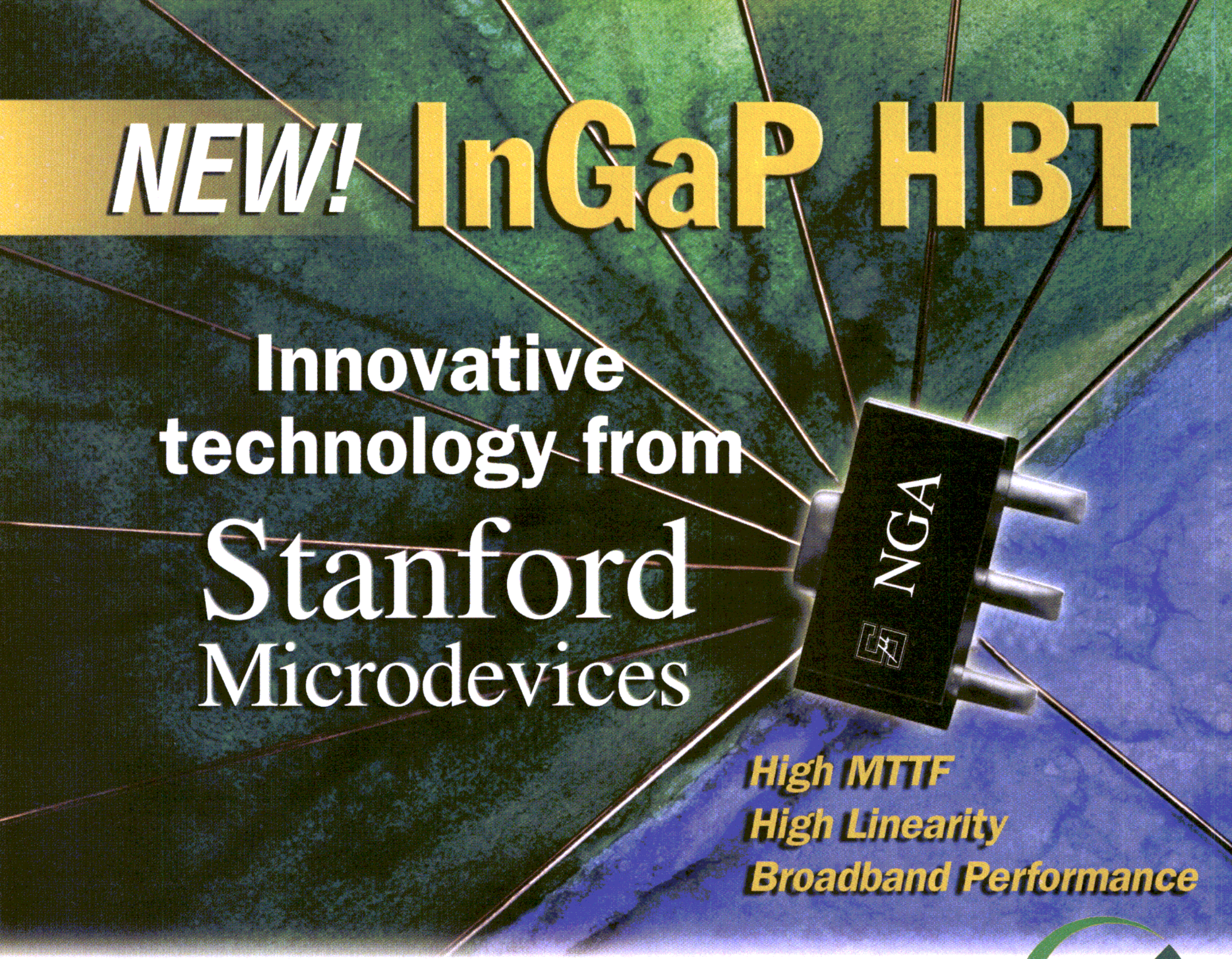

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NGA-489 DC-8 GHz

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- Cascadable 50Ω: 1.5:1 VSWR
- Low positive voltage supply
- Low thermal resistance package
- High linearity

SPECIFICATION MATRIX

	NGA-489	NGA-589
Frequency (GHz)	DC-8.0	DC -6.0
Gain (dB)	14.5	19.0
TOIP (dBm)	38.5	38.0
N.F. (dB)	4.5	4.5
P1dB (dBm)	17.5	19.0
Supply Voltage	4.2	5.0
Supply Current	80	80

All data measured at 900MHz and is typical.
MTTF @ 150C T_j = 2 million hrs. (R_{TH} = 110 C/W typ.)

NGA-589 DC-6 GHz

High gain and high output make this heterojunction bipolar transistor MMIC amplifier ideal for use in all wireless applications. InGaP HBT technology improves the reliability and performance and minimizes leakage current between junctions. Other features include:

- Cascadable 50Ω: 1.5:1 VSWR
- Low thermal resistance package
- High linearity
- High gain
- High P1dB

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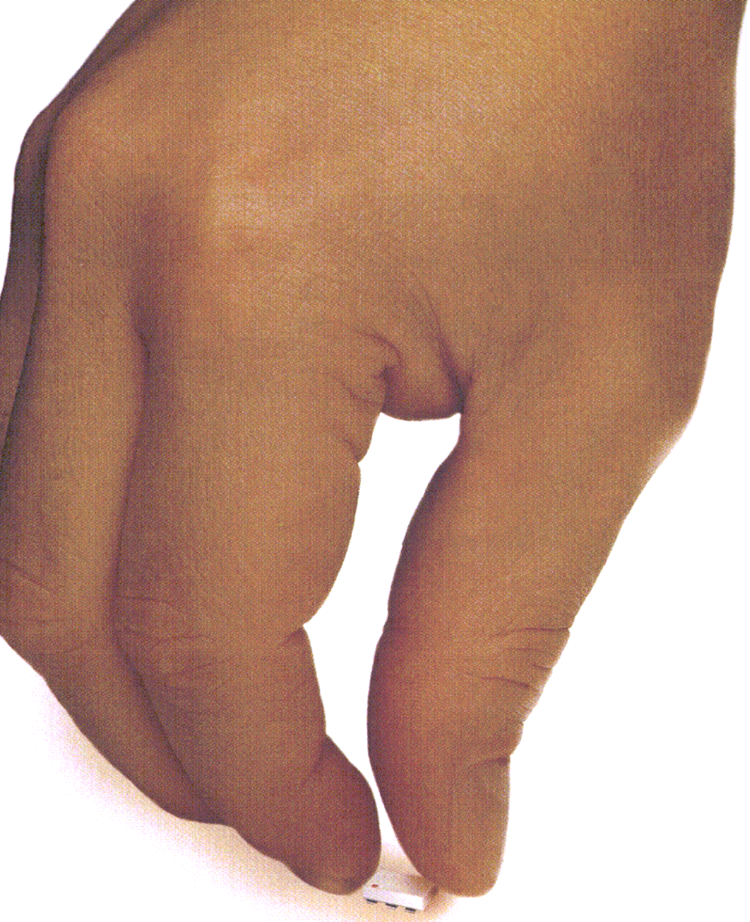

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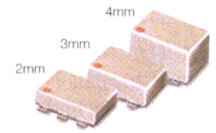

ACTUAL SIZE

ADE Mixers...Innovations Without Traditional Limitations!

ADE* TYPICAL SPECIFICATIONS:

Model	Height (mm)	Freq. (MHz)	LO (dBm)	Conv. Loss Midband (dB)	L-R Isol. Bandwide (dB)	IP3 (dBm) @ Midband	Price ($ea.) Qty. 10-49
ADE-1L	3	2-500	+3	5.2	55**	16	3.95
ADE-3L	4	0.2-400	+3	5.3	47**	10	4.25
ADE-1	4	0.5-500	+7	5.0	55**	15	1.99
ADE-1ASK	3	2-600	+7	5.3	50**	16	3.95
ADE-2ASK	3	1-1000	+7	5.4	45**	12	4.25
ADE-12	2	50-1000	+7	7.0	35	17	2.95
ADE-4	3	200-1000	+7	6.8	53**	15	4.25
ADE-14	2	800-1000	+7	7.4	32	17	3.25
ADE-901	3	800-1000	+7	5.9	32	13	2.95
ADE-5	3	5-1500	+7	6.6	40**	15	3.45
ADE-13	2	50-1600	+7	8.1	40**	11	3.10
ADE-20	3	1500-2000	+7	5.4	31	14	4.95
ADE-18	3	1700-2500	+7	4.9	27	10	3.45
ADE-3GL	2	2100-2600	+7	6.0	34	17	4.95
ADE-3G	3	2300-2700	+7	5.6	36	13	3.45
ADE-30	3	200-3000	+7	4.5	35	14	6.95
ADE-32	3	2500-3200	+7	5.4	29	15	6.95
ADE-35	3	1600-3500	+7	6.3	25	11	4.95
ADE-18W	3	1750-3500	+7	5.4	33	11	3.95
ADE-30W	3	300-4000	+7	6.8	35	12	8.95
ADE-1LH	4	0.5-500	+10	5.0	55**	15	2.99
ADE-1LHW	3	2-750	+10	5.3	52**	15	4.95
ADE-1MH	3	2-500	+13	5.2	50**	17	5.95
ADE-1MHW	4	0.5-600	+13	5.2	53**	17	6.45
ADE-12MH	3	10-1200	+13	6.3	45**	22	6.45
ADE-25MH	3	5-2500	+13	6.9	34**	18	6.95
ADE-35MH	3	5-3500	+13	6.9	33**	18	9.95
ADE-42MH	3	5-4200	+13	7.5	29**	17	14.95
ADE-1H	4	0.5-500	+17	5.3	52**	23	4.95
ADE-10H	3	400-1000	+17	7.0	39	30	7.95
ADE-12H	3	500-1200	+17	6.7	34	28	8.95
ADE-20H	3	1500-2000	+17	5.2	29	24	8.95

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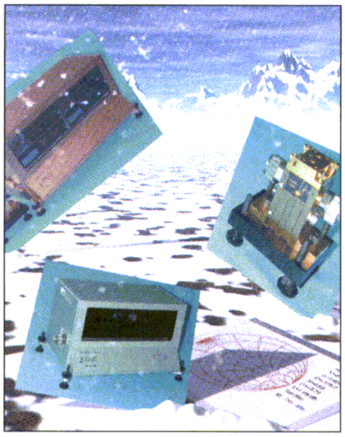

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December 1999
Vol. 11 No. 12

Applied MICROWAVE & WIRELESS

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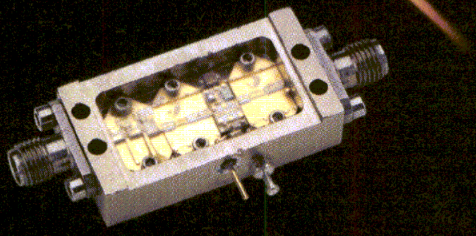
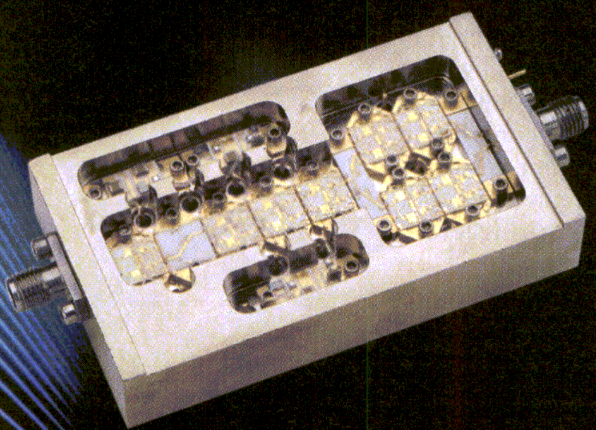
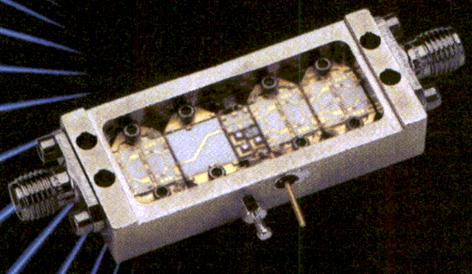
AMPLIFIERS

for every application







ULTRA BROAD BAND

Model	Freq. Range GHz	Gain dB min	N/F dB max	Gain Flat +/-dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA018-203	0.5-18.0	20	5.0	2.5	7	17	2.0:1	250
JCA018-204	0.5-18.0	25	4.0	2.5	10	20	2.0:1	300
JCA218-506	2.0-18.0	35	5.0	2.5	15	25	2.0:1	400
JCA218-507	2.0-18.0	35	5.0	2.5	18	28	2.0:1	450
JCA218-407	2.0-18.0	30	5.0	2.5	21	31	2.0:1	500

MULTI OCTAVE AMPLIFIERS

Model	Freq. Range GHz	Gain dB min	N/F dB max	Gain Flat +/-dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA04-403	0.5-4.0	27	5.0	1.5	17	27	2.0:1	550
JCA08-417	0.5-8.0	32	4.5	1.5	17	27	2.0:1	550
JCA28-305	2.0-8.0	22	5.0	1.0	20	30	2.0:1	550
JCA212-603	2.0-12.0	32	5.0	3.0	14	24	2.0:1	550
JCA618-406	6.0-18.0	20	6.0	2.0	25	35	2.0:1	600
JCA618-507	6.0-18.0	25	6.0	2.0	27	37	2.0:1	800

MEDIUM POWER AMPLIFIERS

Model	Freq. Range GHz	Gain dB min	N/F dB max	Gain Flat +/-dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA12-P01	1.35-1.85	35	4.0	1.0	33	41	2.0:1	1000
JCA34-P02	3.1-3.5	40	4.5	1.0	37	45	2.0:1	2200
JCA56-P01	5.9-6.4	30	5.0	1.0	34	42	2.0:1	1200
JCA812-P03	8.0-12.0	40	5.0	1.5	33	40	2.0:1	1700
JCA1218-P02	12.0-18.0	22	4.0	2.0	25	35	2.0:1	700

LOW NOISE OCTAVE BAND LNA'S

Model	Freq. Range GHz	Gain dB min	N/F dB max	Gain Flat +/-dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA12-3001	1.0-2.0	40	0.8	1.0	10	20	2.0:1	200
JCA24-3001	2.0-4.0	32	1.2	1.0	10	20	2.0:1	200
JCA48-3001	4.0-8.0	40	1.3	1.0	10	20	2.0:1	200
JCA812-3001	8.0-12.0	32	1.8	1.0	10	20	2.0:1	200
JCA1218-800	12.0-18.0	45	2.0	1.0	10	20	2.0:1	250

NARROW BAND LNA'S

Model	Freq. Range GHz	Gain dB min	N/F dB max	Gain Flat +/-dB	1 dB Comp. pt. dBm min	3rd Order ICP typ	VSWR In/Out max	DC Current mA
JCA12-1000	1.2-1.6	25	0.75	0.5	10	20	2.0:1	80
JCA23-302	2.2-2.3	30	0.8	0.5	10	20	2.0:1	80
JCA34-301	3.7-4.2	30	1.0	0.5	10	20	2.0:1	90
JCA56-401	5.4-5.9	40	1.0	0.5	10	20	2.0:1	120
JCA78-300	7.25-7.75	27	1.2	0.5	13	23	2.0:1	120
JCA910-3000	9.0-9.5	25	1.2	0.5	13	23	1.5:1	150
JCA910-3001	9.5-10.0	25	1.2	0.5	13	23	1.5:1	150
JCA1112-3000	11.7-12.2	27	1.1	0.5	13	23	1.5:1	150
JCA1213-3001	12.2-12.7	25	1.1	0.5	10	20	2.0:1	200
JCA1415-3001	14.4-15.4	35	1.4	1.0	14	24	2.0:1	200
JCA1819-3001	18.1-18.6	25	1.8	0.5	10	20	2.0:1	200
JCA2021-3001	20.2-21.2	25	2.0	0.5	10	20	2.0:1	200

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A Few Thoughts About 1999

By Gary A. Breed
Publisher

Since it's December, I feel an obligation to stick with tradition and reflect on the past year. 1999 has had plenty of activity in both the wireless marketplace and RF/microwave technical developments.

Those of you with business interests remember the difficulties of 1998 that finally stabilized and partially recovered in 1999. The "Asian Flu" is nearly over in most major Far East countries, although worries remain. Some U.S. companies with major customers in Japan, Korea, Indonesia, Thailand, etc., have not yet returned to previous manufacturing levels, but things are getting better.

The wireless data market (both dedicated link and WLAN) accelerated during 1999, driven by the finalization of 802.11 standards and the Bluetooth initiatives. These provide the means to put wireless connectivity into nearly any device. The industry is expecting an announcement from Apple Computer that would put an exclamation point at the end of this year's WLAN story.

mm-wave point-to-point and point-to-multipoint systems (mainly LMDS) are another developing story. Auctions for LMDS licenses were barely complete at the beginning of the year; now ambitious license holders and industry experts are working furiously to hammer out technical standards to enable the initial system trials, then ensure that equipment suppliers have a large enough market to achieve the economies of mass production.

In the technology arena, an accelerating demand for linear power has been met with significant improvements in both LDMOS and GaAs devices, together with refinements in linearity-correction techniques. The quest for linearity is an interesting example of combined analog and digital techniques. Engineers are developing new ways to reduce unwanted distortion products while keeping some of the greater efficiency of nonlinear circuits.

Digital signal processing (DSP) is increasing its impact on RF technology. In addition to its use in the linearization schemes just noted, DSP is being harnessed to create adaptive or reconfigurable baseband and IF circuits. In the future, one set of hardware may provide TDMA, CDMA, W-CDMA or new formats using the specific coding and modulation for each of dozens of different applications. These products could also be reprogrammed for new systems as they are deployed. The RF/microwave front end ahead of the DSP and the upconverter/amplifier chain following will have new demands for flexibility and dynamic range.

1999 has been fascinating. I can't wait to see what happens in 2000! ■

Calendar

CONFERENCES

DECEMBER

December 5-8, 1999
IEEE International Electron Devices Meeting (IEDM)
Washington, DC
Information: Phyllis Mahoney
Tel: 301-527-0900; Fax: 301-527-0994
E-mail: pwmahoney@aol.com

December 7-9, 1999
Bluetooth Developers Conference
Los Angeles, CA
Information: Bluetooth Developers Conference
Tel: 1-800-722-9798 or 978-349-7898
Fax: 972-349-7715
Internet: http://www.bluetooth.com/developers99

FEBRUARY 2000

February 15-17, 2000
IZS 2000 — 2000 International Zurich Seminar on Broadband Communications
Zurich, Switzerland
Information: Professor R. Vahldieck
Tel: +411 632 27 42; Fax: +411 632 11 98
E-mail: vahldieck@ifh.ee.ethz.ch

MARCH 2000

March 20-25, 2000
Hannover Fair 2000
Hannover, Germany
Information: Hannover Fairs USA Inc.
Tel: 609-987-1202; Fax: 609-987-0092
E-mail: info@hfusa.com
Internet: http://www.hfusa.com

March 28-30, 2000
RTS 2000
Paris, France
Information: BRIP
Tel: + 33 01 53 17 11 44
E-mail: crey@birp.fr
Internet: http://www.birp.com/rts

APRIL 2000

April 10-11, 2000
2000 IEEE Emerging Technologies Symposium on Broadband Wireless Internet Access
Dallas, TX
Information: Dr. Jon Velhl
Tel: 972-952-4190
Internet: http://www.ieeedallas-els.org

MAY 2000

May 20-26, 2000
IEEE International Conference on Phased Array Systems and Technology
Dana Point, CA
Information: Dr. Michael Thorburn
Tel: 310-336-2197; Fax: 310-336-6225
E-mail: m.a.thorburn@IEEE.org
Internet: http://www.ieee.org

JUNE 2000

June 7-9, 2000
2000 IEEE/EIA International Frequency Control Symposium and Exhibition
Kansas City, MO
Information: IEEE Ultrasonics, Ferroelectrics and Frequency Control Society
Internet: http://www.ieee.org/uffc/fc

June 11-13, 2000
2000 IEEE Radio Frequency Integrated Circuits Symposium
Boston, MA
Information: Jyoti Mondal
Tel: 847-259-9600, ext. 4130
E-mail: mondajy@mail.northgrum.com
Internet: http://www.ims2000.org/rfic.htm

June 11-16, 2000
MTT-S International Microwave Symposium
Boston, MA
Information: LRW Associates
Tel: 704-841-1915
Fax: 704-845-3078
E-mail: lrwassoc@sprintmail.com
Internet: http://www.ims2000.org

June 15-16, 2000
Automatic RF Techniques Group 55th Conference
Boston, MA
Information: D. Michael Fennelly
Tel: 978-258-4101; Fax: 978-258-4102
E-mail: m.fennelly@ieee.org
Internet: http://www.arftg.org

June 18-20, 2000
IMAPS Europe Prague 2000 — European Microelectronics, Packaging and Interconnection Symposium
Prague, Czech Republic
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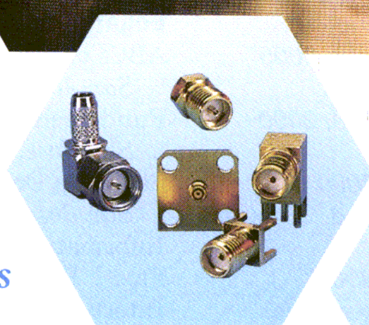
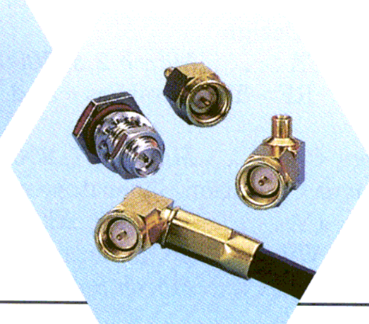
Internet: http://K313.feld.cvut.cz/micro





Calendar

SHORT COURSES

University of California at Los Angeles Extension

Automatic Test Equipment (ATE) Selection, Design, and Programming
Los Angeles, CA . . . . .December 6-7, 1999
Design Testability and Built-In Self Test
Los Angeles, CA . . . . .December 8-10, 1999
Digital Signal Processing: Theory, Algorithms, and Implementation
Los Angeles, CA . . . . .January 10-14, 2000
Introduction to Software Radio and Wireless Networks
Los Angeles, CA . . . . .January 24-26, 2000
Digital Avionics Systems
Los Angeles, CA . . . . .Feb. 28-March 3, 2000
Kalman Filtering
Los Angeles, CA . . . . .March 13-16, 2000
Information: UCLA Extension, Short Course Program Office, Tel: 310-825-3344; Fax: 310-206-2815.

Besser Associates

DSP Made Simple for Engineers
Mountain View, CA . . . . . .December 6-8, 1999
Applied RF Techniques I
Orlando, FL . . . . .December 6-10, 1999
Phoenix, AZ . . . . .March 27-31, 2000
Applied RF Techniques II: Nonlinear RF and Wireless Circuit Design
Orlando, FL . . . . .December 6-10, 1999
Phoenix, AZ . . . . .March 26-31, 2000
Behavorial Modeling and Nonlinear Device Model Extraction
Orlando, FL . . . . .December 7-10, 1999
Digital RF Communication Systems
Mountain View, CA . . . . . .January 24-28, 2000
RF Component Modeling
Mountain View, CA . . . . . .Jan. 31-Feb. 4, 2000
Wireless Measurements: Theory and Practice
Mountain View, CA . . . . . .February 14-18, 2000
Signal Integrity of High-Speed Digital Design
Mountain View, CA . . . . . .February 28-29, 2000
Multitone Amplifier Design
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Authors should submit a camera-ready manuscript of a four-page paper, along with a cover letter containing the topic area, complete contact information, and any audio-visual requirements for presentation. Send to:

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Los Angeles, CA 90009-2957
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Fax: (310) 336-6225
E-mail: m.a.thorburn@ieee.org
Internet: http://www.ieeeaps.org/ISPAST00

Deadlines: December 5, 1999 (electronic)
December 15, 1999 (regular mail)

2000 Virginia Tech Symposium on Wireless Personal Communications

June 14-16, 2000 — Blacksburg, VA

Topics: Novel wireless products, applications of DSP techniques to wireless communications, propagation measurement and prediction, diversity and multiple access techniques, simulation and performance analysis of wireless systems, network issues, supporting technologies for wireless systems and business opportunities in wireless telecommunications.

Authors should submit a 200- to 500-word abstract to:

Dr. William H. Tranter
MPRG — Bradley Department of Electrical and Computer Engineering
Virginia Tech
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Blacksburg, VA 24061
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Topics: Fundamental properties of materials, theory and design of resonators and filters, BAW and SAW oscillators, synthesizers, noise phenomena and aging, atomic frequency standards, frequency and time coordination,transducers, manufacturing technology, cold atom frequency standards, high stability time and frequency transfer, sensors and clock jitter.

Authors should send in a one-page, camera-ready summary of the article, including complete contact information. Detailed instructions are available online at the URL given below. E-mail submission is preferred, in Word, WordPerfect or ASCII format. Send to:

John Prestage
E-mail: prestage@horology.jpl.nasa.gov
Internet: http://www.ieee.org/uffc/fc

Deadline: December 17, 1999

Automatic RF Techniques Group 55th Conference

June 15-16, 2000 — Boston, MA

Topics: Calibration of large-signal measurement systems, measurement and simulation of large-signal behavior, definition of large-signal network parameters and creation of large-signal models.

Authors should submit a one-page abstract and a 500- to 1,000-word summary, including illustrations. Submissions should be made through ARFTG web site (URL below). Submit to:

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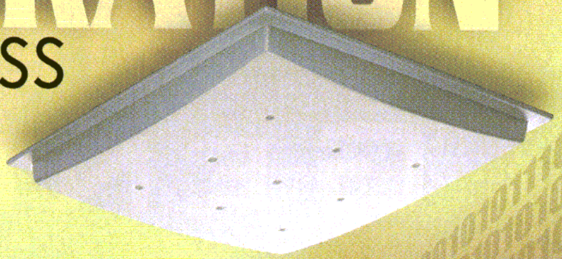


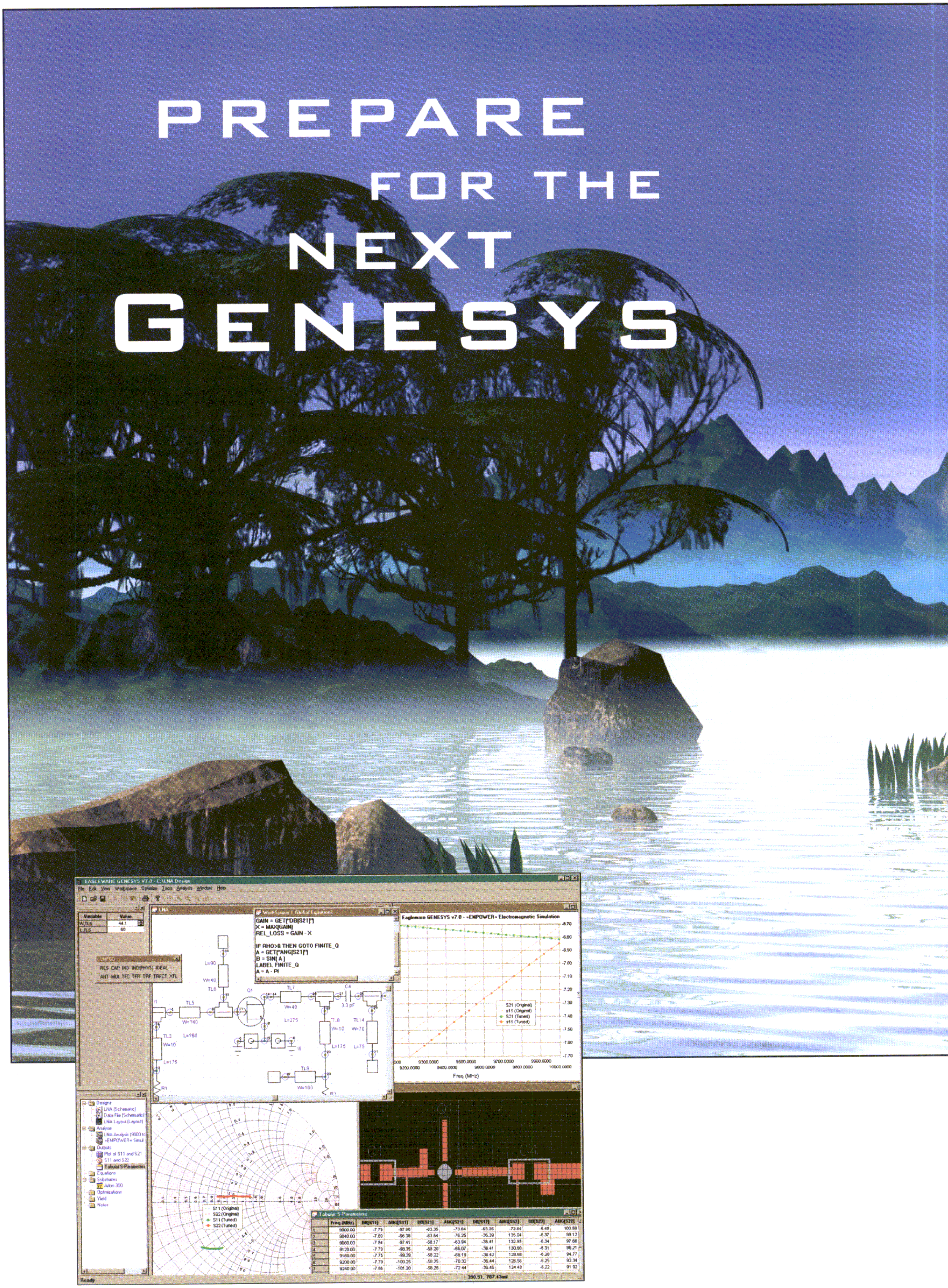
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BRIEFS

• State of the Art Inc. has upgraded its web site, at www.resistor.com, to include downloads of technical data sheets and other product information, as well as an overview of manufacturing facilities and capabilities.

• Jensen Tools has launched an e-mail newsletter, TooLink™, offering company and product information monthly. Subscriptions are available through the company's web site, www.jensentools.com.

• RLC Electronics Inc. has opened a new web site and e-catalog at www.rlcelectronics.com.

• AMIRIX Systems Inc., formerly Applied Microelectronics, has moved into a new 30,000-square-foot headquarters facility in Halifax, Nova Scotia, Canada.

• Anritsu Company has opened two new facilities on its Morgan Hill, CA, campus to house manufacturing, research and training.

• RF Micro Devices Inc. has opened a new engineering design center in Billerica, MA. The center will including offices, labs and CAD equipment.

Wireless power device market to rise by billions, report says

The market for wireless power products, including gallium arsenide (GaAs) integrated circuits and transistors as well as silicon power modules and transistors, will rise from $1.7 billion in 1999 to $5 billion in 2004, according to a new study from Allied Business Intelligence.

"Early growth will be driven by the use of GaAc IC power amplifiers in the fast-paced cellular/PCS handset market," said ABI Senior Analyst Andy Fuertes, author of the report. "Wireless broadband strategies such as local multipoint distribution systems (LMDS) and third-generation (3G) cellular systems will spur significant growth in the latter part of the study period."

Today, GaAs ICs represent 53 percent of the total market for RF power products. This segment is experiencing the highest annual growth of any of the devices considered for the report, with annual growth expected to be about 32 percent over the next five years.

However, the report says, product attributes are changing in this sector. Once the leading product in the market, MESFET ICs are expected to fall from roughly 40 percent of the market in 1999 to just over 10 percent in 2004.

Power Products Forecast
World Serviceable Available Market, 1999-2004

Year	Value
1998	$1,729,000
1999	$2,172,000
2000	$2,701,000
2001	$3,314,000
2002	$4,094,000
2003	$5,017,000

The leading process in the GaAs IC power amplifier market in 1999 is HBT, with nearly a 50 percent share. LDMOS is also on the upswing, with 29 percent of the market in 1999 and a share of 50 percent expected by 2004.

ABI is an Oyster, NY-based technology research think tank that publishes strategic research on the broadband, wireless, electronics, automation, energy and transportation industries.

FCC releases policy statement covering guidelines for management of new spectrum

The Federal Communications Commission has outlined a new set of principles for spectrum management activities. The policies will serve as guidelines for the reallocation of approximately 200 MHz of spectrum for a broad range of new radio communications services.

The additional spectrum has been made available through transfer of frequencies from government uses and from reallocation of frequencies used by existing non-government radio services.

Provisions included:

• Expand the General Wireless Communications Service (GWCS) spectrum to 50 MHz, from the current 25 MHz, and relocate it to the 4940-4990 MHz band. This provision comes at the request of the National Telecommunications and Information Agency.

• Allocate 90 MHz for Advanced Mobile and Fixed Communications Service (AMFCS) at 1710-1755 MHz, 2110-2150 MHz and 2160-2165 MHz. This will be a flexible use service for mobile and fixed wireless service, possibly for the introduction of future third generation systems.

• Establish a new Land Mobile Communications Service (LMCS) in 10 megahertz of spectrum at 1390-1395 MHz, 1427-1429 MHz and 1432-1435 MHz.

• Reallocate the 48 MHz at 698-766 MHz (TV channels 52-59) for Fixed, Mobile and new Broadcast services for commercial uses.

• Allocate 10 MHz of additional spectrum for Fixed and Mobile service in two bands at 1670-1675 MHz, and 2385-2390 MHz, and adopt appropriate service rules to permit licensees broad flexibility in the types of service to be offered and the technologies to be used.

The Commission has also created a Spectrum Policy Executive Committee that will address broad policy issues affecting spectrum management; implement the initiatives consistent with the principles covered in the policy statement; and coordinate interbureau issues.

Companies, organizations and institutions may submit information for our News section to: Shannon O'Connor, Managing Editor, Applied Microwave & Wireless, 4772 Stone Drive, Tucker, GA, 30084; Fax: (770) 939-0157; E-mail: amw@amwireless.com.

BUSINESS AND FINANCE

Fox Paine to acquire WJ in recapitalization merger

Watkins-Johnson Company has entered into a definitive merger agreement with FP-WJ Acquisition Corp., a new company formed by investment funds managed by Fox Paine & Company, LLC. Under the agreement, WJ would be acquired in a recapitalization merger transaction, with outstanding shares of WJ to be converted into the right to receive $41.125 per share in cash.

The agreement follows the pending sale of WJ's Telecommunications Group to a subsidiary of Marconi North America, and the July sale of WJ's Semiconductor Equipment Group to Silicon Valley Group, Inc.

After the recapitalization, WJ's primary operations will consist of its Wireless Products Group (WPG), a global supplier of radio-frequency components and subsystems for wireless and wire line communications equipment. WJ is based in Palo Alto, CA.

Nokia to provide GPRS for Philippine network

Nokia and SMART Communications, Inc., have signed a contract valued at $150 million for the supply of Nokia's General Packet Radio Service (GPRS) core network solution and expansion of SMART's dual band GSM network in the Philippines.

SMART, a joint venture between several local investors, provides national cellular mobile telephone services and related operations in the Philippines. Nokia, based in Helsinki, Finland, supplies mobile phones and mobile, fixed and IP networks.

L-3 division to upgrade satellite facility in Kenya

L-3 Communications' Global Network Solutions (GNS) business unit has been awarded a contract to provide the Kenya Posts and Telecommunications Corporation with an end-to-end upgrade and modernization of the satellite communication system at its Longonot Earth Station in Nairobi. The contract is valued at $2.4 million.

Headquartered in New York, NY, L-3 Communications supplies secure communication systems and products, avionics and ocean systems, microwave components and telemetry, instrumentation, space and wireless products. Its GNS unit provides consulting, network design, installation, project management and operation services.

BUSINESS AND FINANCE

Hughes adds 11th satellite to U.S. Navy contract

Hughes Space and Communications Company (HSC) has signed an agreement with the U.S. Navy to build the 11th in a series of UHF Follow-On (UFO) satellites, which provide global communications services for the armed forces. The agreement extends an existing $1.9 billion contract.

HSC, based in El Segundo, CA, is a unit of Hughes Electronics Corp., a provider of digital television entertainment, and satellite and wireless systems and services.

Analog Devices awarded contracts for ADC modules

Analog Devices Inc., based in Norwood, MA, has received two contracts from Raytheon Company to provide data conversion modules for upgrading two missile systems. Terms were not disclosed.

Under the contracts, Analog Devices will develop high-speed analog-to-digital converter (ADC) modules to support upgrades to both the both the Patriot and Advanced Medium-Range Air-to-Air Missile (AMRAAM).

Andrew acquires Chesapeake Microwave

Andrew Corporation has announced the acquisition of Chesapeake Microwave Technologies Inc., a provider of RF and microwave amplifiers and assemblies based in Glen Rock, PA. Terms were not disclosed.

Andrew, based in Orland Park, IL, supplies communications systems equipment and services.

Frequency Electronics announces $1 million order

Frequency Electronics Inc. has received an order valued at $1 million from the government of India for its generic DC/DC Electronic Power Converters. The converters will be used in satellite programs.

Frequency Electronics, Inc., based in Mitchel Field, NY, manufactures high technology precision time and frequency products for the wireless market.

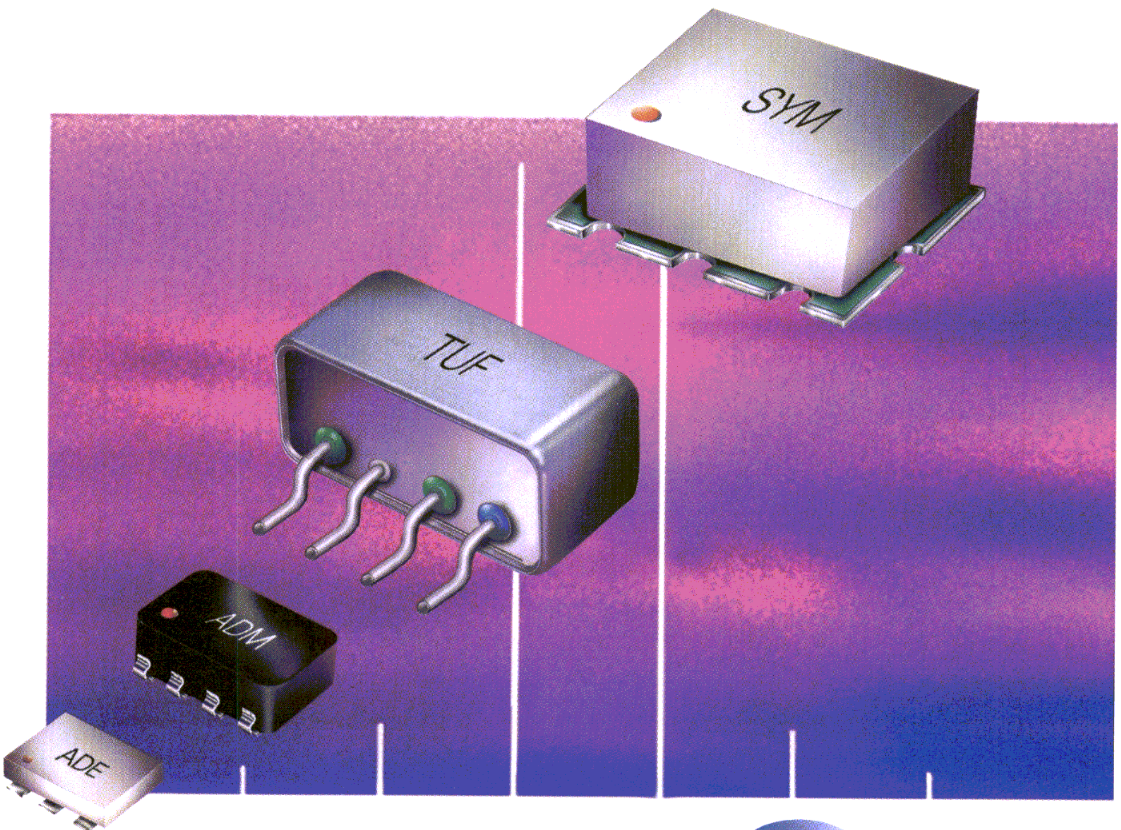
RF Micro Devices forms broadband product line

RF Micro Devices Inc. has created a fifth product line, Broadband Products, to focus on developing semiconductors for broadband cable communications.

RF Micro Devices, based in Greensboro, NC, manufactures proprietary RFICs for wireless communications.

HIGH IP3 MIXERS

suppress noisy intermods



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SYM-18H	5 -1800	30	45	40	5.75	17.95
SYM-15VH	10 -1500	31	40	35	6.5	29.95
SYM-10DH	800 -1000	31	45	29	7.6	18.95
SYM-22H	1500 -2200	30	33	38	5.6	19.95
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Circle 16

Design and Performance of a 3.4 to 4.6 GHz Active Equalizer with Controlled Gain-Slope

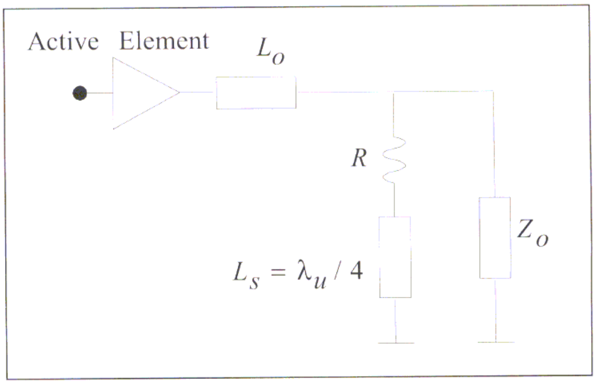
This circuit is designed to provide adjustable compensation for cable losses

By V. Vassilev, I. Angelov and V. Belitsky
Chalmers University of Technology

This article presents the design and performance of a low-noise tuneable active equalizer (AEQ) intended to compensate for frequency dependent losses in the coaxial cable. The equalizer achieves 11 dB gain with a typical noise figure of 2.2 dB and has a slope of 3.5 dB within the 3.4 to 4.6 GHz band. Two PIN diodes serving as voltage-controlled resistors provide the ability to tune the AEQ gain-slope and hence obtain accurate flatness inside the passband. The slope can be varied by ±0.7 dB without disturbing slope linearity.

Using coaxial cable as a transmission medium introduces the problem of compensating the slope inside the desired frequency band due to the cable's frequency dependent attenuation. The cable slope is linear and depends on the physical characteristics of the cable and its length. This slope can be compensated by connecting the cable's output to the equalizer having a slope opposite to that of the cable. Additional signal slope can also appear as a result of inconstant power gain of amplifiers matched for minimum noise figure. A technique used to compensate for the MESFET's gain-slope and thus to achieve a flat amplification has been presented in [1] and [2]. A passive microwave fixed-slope equalizer is reported in [3], where a direct-coupled bandpass filter topology has been used.

The equalizer desribed here was designed to compensate for 3.5 dB slope within the 3.4 to 4.6 GHz IF band used in radio astronomical spectral line observations. The front-end receiver placed next to the focal plane of the antenna is connected via coaxial cable to the correlator-spectrometer located in the control room. The AEQ gain slope control gives the opportunity to tune the equalizer's frequency response slope and thus to adjust the flatness inside the IF band. This article suggests a possible structure for an AEQ with linear and adjustable gain-slope.



▲ **Figure 1. To create a slope over frequency, an active element resonates with the output reactance at frequency above the pass band. The shunt branch contains short-circuited stub tuned to the same frequency.**

Equalizer design

It is possible to create a linear slope over the gain of an active element (HP MGA-86576) by coupling the output of the active element to a resonant circuit tuned above the highest frequency in the pass band f_u. Using this method, lossless impedance matching is provided for f_u and increasing attenuation is introduced as the frequency decreases. A suitable structure contains a long short-circuited shunt stub ($\lambda_u/4$) with a connecting line (Figure 1).

The high impedance series transmission line L_0 resonates with the active element output

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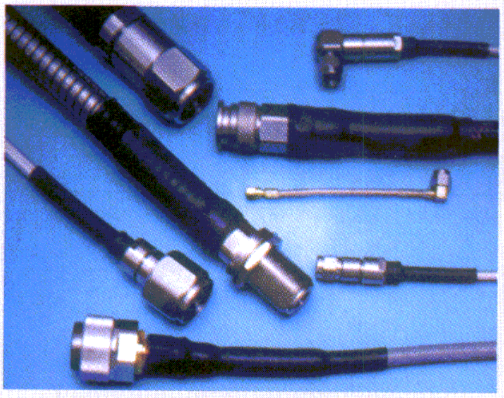
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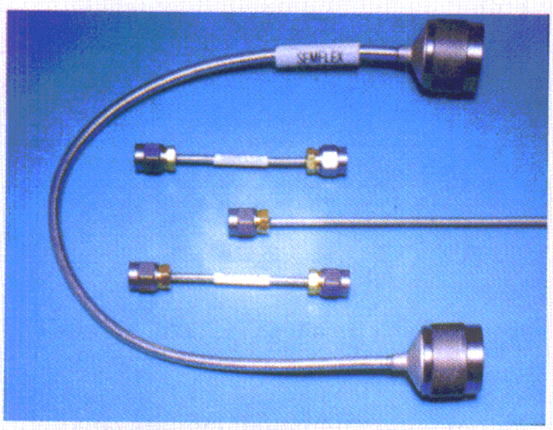
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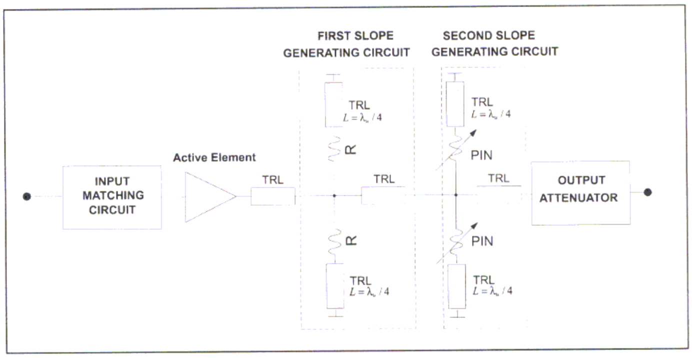
Circle 21

reactance at the frequency (f_u) above the bandpass. L_s is a short-circuited shunt stub that is resonant at the same frequency. At f_u, no power is dissipated in the resistor (R) due to the high impedance in the shunt branch. Thus, maximum power is transferred to the load Z_0. Below f_u, the L_0 impedance decreases and the shunt branch introduces frequency-dependent losses.

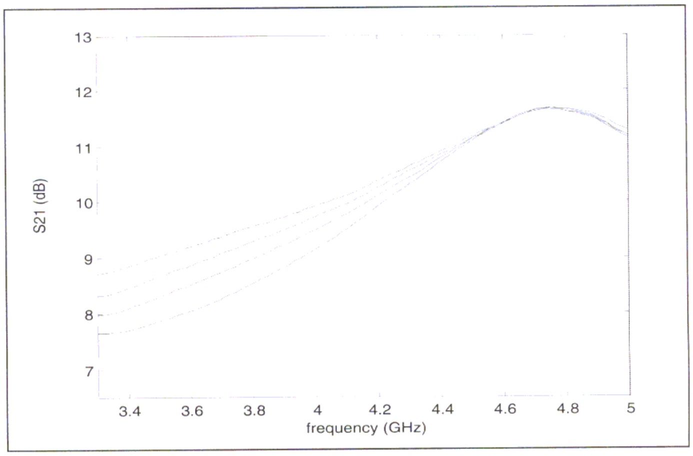
Since the gain-slope is provided as a result of reactive mismatch, it leads to increased standing waves at the output circuitry of the equalizer. Introducing resistance in series with L_s, as shown in Figure 1, creates resistive losses for the frequencies at the low- and mid-band and thus improves the VSWR. Moreover, changing the resistance value allows control of the filter Q-factor, thus adjusting the slope. The block-diagram of the AEQ is shown in Figure 2.

In order to provide slope adjustment, the overall slope-generation circuitry is divided between two symmetrical and identical branches (Figure 2). The first branch gives the initial and fixed slope of 3.5 dB over 3.4 to 4.6 GHz, while the second slope-generating branch allows fine slope adjustment. For this purpose, we use PIN diodes (HP HSMP 4810) as a voltage-controlled resistance. This diode features a total parasitic inductance of 0.75 nH, which is low compared to the parasitic inductance typical for a SOT-23 package and is designed for use at frequencies higher than the upper limit for conventional SOT-23 PIN diodes. The diode's parasitic lead inductance, along with the parasitic capacitance of 0.3 pF confines the values of obtainable PIN diode intrinsic resistance within the range of 22 ohms and 115 ohms at frequency of 4.6 GHz. As a result of these limitations, the AEQ can provide linear slope from 2.8 dB up to 4.2 dB within the band of 3.3 to 4.6 GHz (Figure 3).

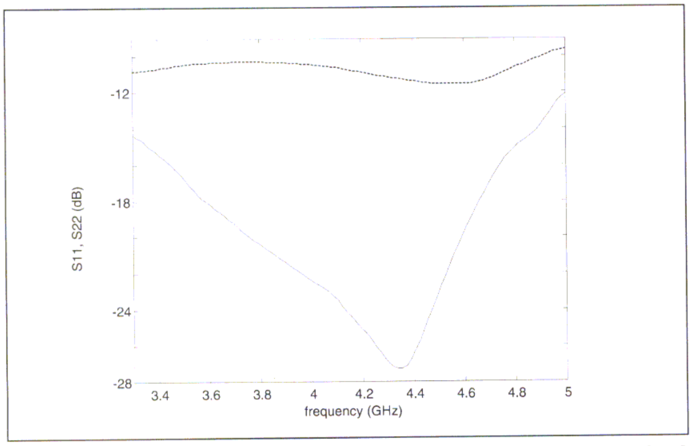
A matching circuit at the AEQ input is minimally tuned at the center of the bandpass (Figure 4). As described above, the gain-slope generation via reactive mismatch causes poor VSWR at the output circuits for the mid and low frequencies in the band. It is difficult to achieve output matching better than $s_{22} \leq 3$ dB at the lower band edge. In order to improve s_{22}, we use an attenuator-type matching circuit at the output of the experimental prototype. That allows s_{22} to be better than −10 dB over the working band. Simulations and optimizations were carried out independently with two CAD software [4, 5].



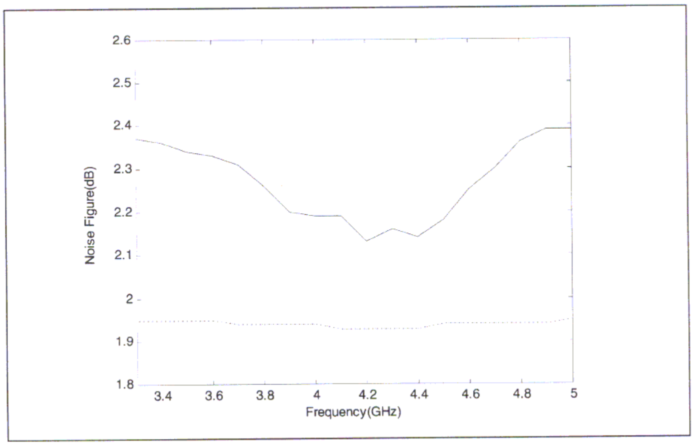
▲ **Figure 2. The AEQ block diagram.**



▲ **Figure 3. Measured gain of the AEQ for four values of the PIN diode resistance.**



▲ **Figure 4. Measured input (solid line) and output (dashed line) reflection coefficient.**



▲ **Figure 5. Measured noise figure of the equalizer (solid line) and MMIC NF when matched for maximum gain (dashed line).**

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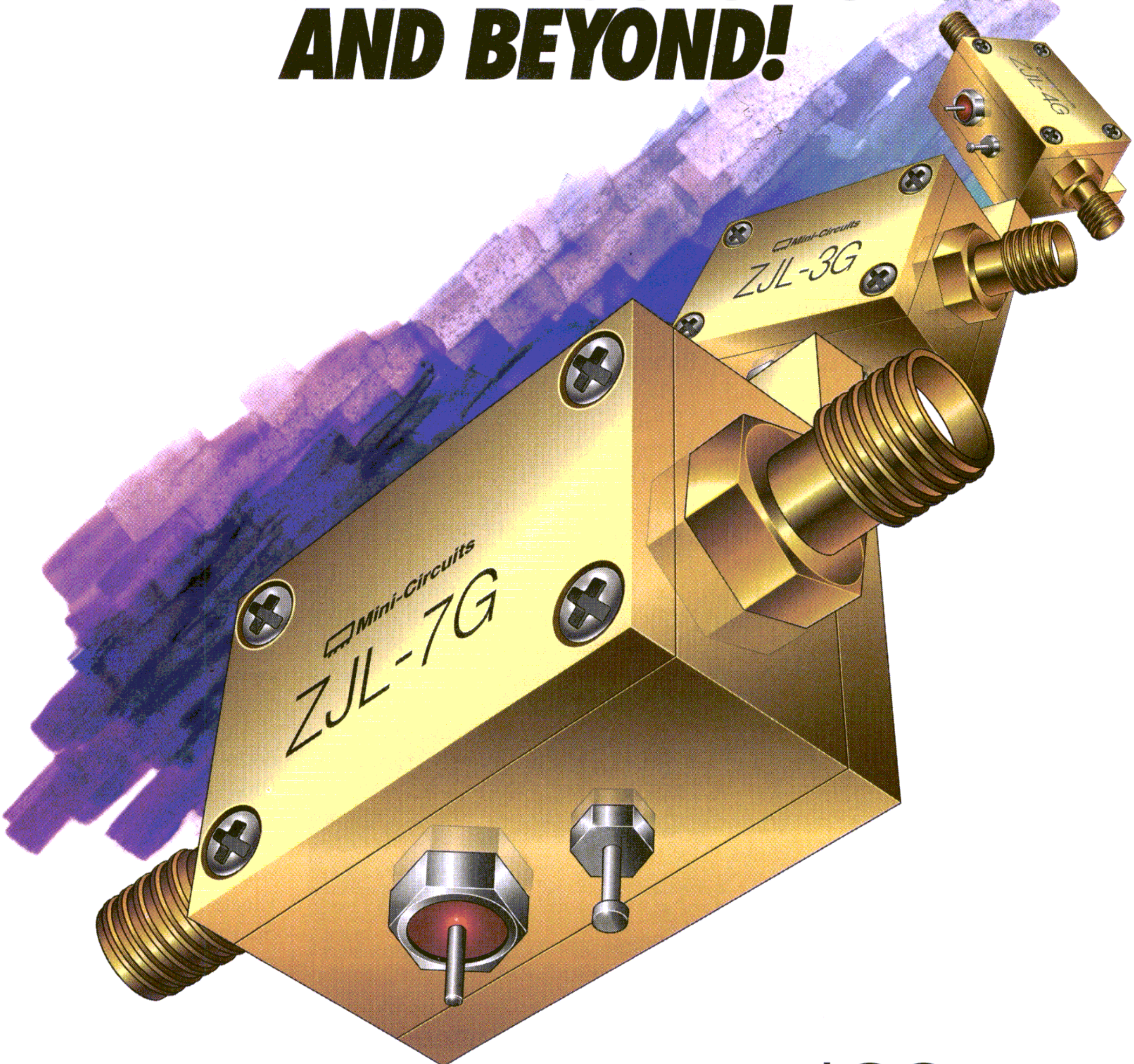

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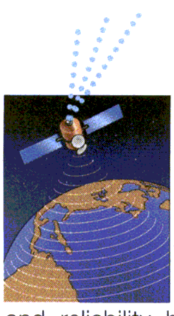

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Model	Freq (MHz)	Gain (typ) Midband (dB)	Gain (typ) Flat (±dB)	Max. P_{out} 1 (dBm)	Dynamic Range (Typ @2GHz 2) NF(dB)	Dynamic Range (Typ @2GHz 2) IP3(dBm)	I(mA) 3	Price $ea. (1-9)
ZJL-5G	20-5000	9.0	±0.55	15.0	8.5	32.0	80	129.95
ZJL-7G	20-7000	10.0	±1.0	8.0	5.0	24.0	50	99.95
ZJL-4G	20-4000	12.4	±0.25	13.5	5.5	30.5	75	129.95
ZJL-6G	20-6000	13.0	±1.6	9.0	4.5	24.0	50	114.95
ZJL-4HG	20-4000	17.0	±1.5	15.0	4.5	30.5	75	129.95
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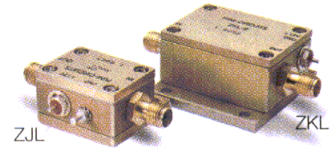
ZKL-2R5	10-2500	30.0	±1.5	15.0	5.0	31.0	120	149.95
ZKL-2	10-2000	33.5	±1.0	15.0	4.0	31.0	120	149.95
ZKL-1R5	10-1500	40.0	±1.2	15.0	3.0	31.0	115	149.95

NOTES:
1. Typical at 1dB compression.
2. ZKL dynamic range specified at 1GHz.
3. All units at 12V DC.



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Measured performance

The measured gain of the equalizer versus frequency is plotted in Figure 3 for four values of the PIN diode resistance, which determines the region where the slope remains linear within the passband of 3.4 to 4.6 GHz.

The measured input and output return loss performance of the AEQ is plotted in Figure 4. The minimum is reached at the center of the band, whereas the minimum in s_{22} is positioned above the highest pass-band frequency 4.6 GHz.

The noise figure (NF) of the AEQ is plotted in Figure 5 together with the NF specified from the manufacturer for the gain block. Though the input matching circuit is optimized for maximum gain, the minimum in the noise performance is located at the middle of the pass-band.

Conclusion

A low-noise adjustable active equalizer has been designed and tested. The equalizer's measured gain is 11 dB with a typical noise figure of 2.2 dB. The device has a linear adjustable slope from 2.8 dB up to 4.2 dB within the 3.4 to 4.6 GHz band. The attenuator type matching circuit is used at the output of the equalizer to provide output reflection below –10 dB. The predictions from the simulations agree with the prototype measurement results. ■

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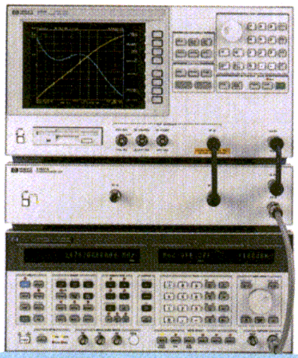

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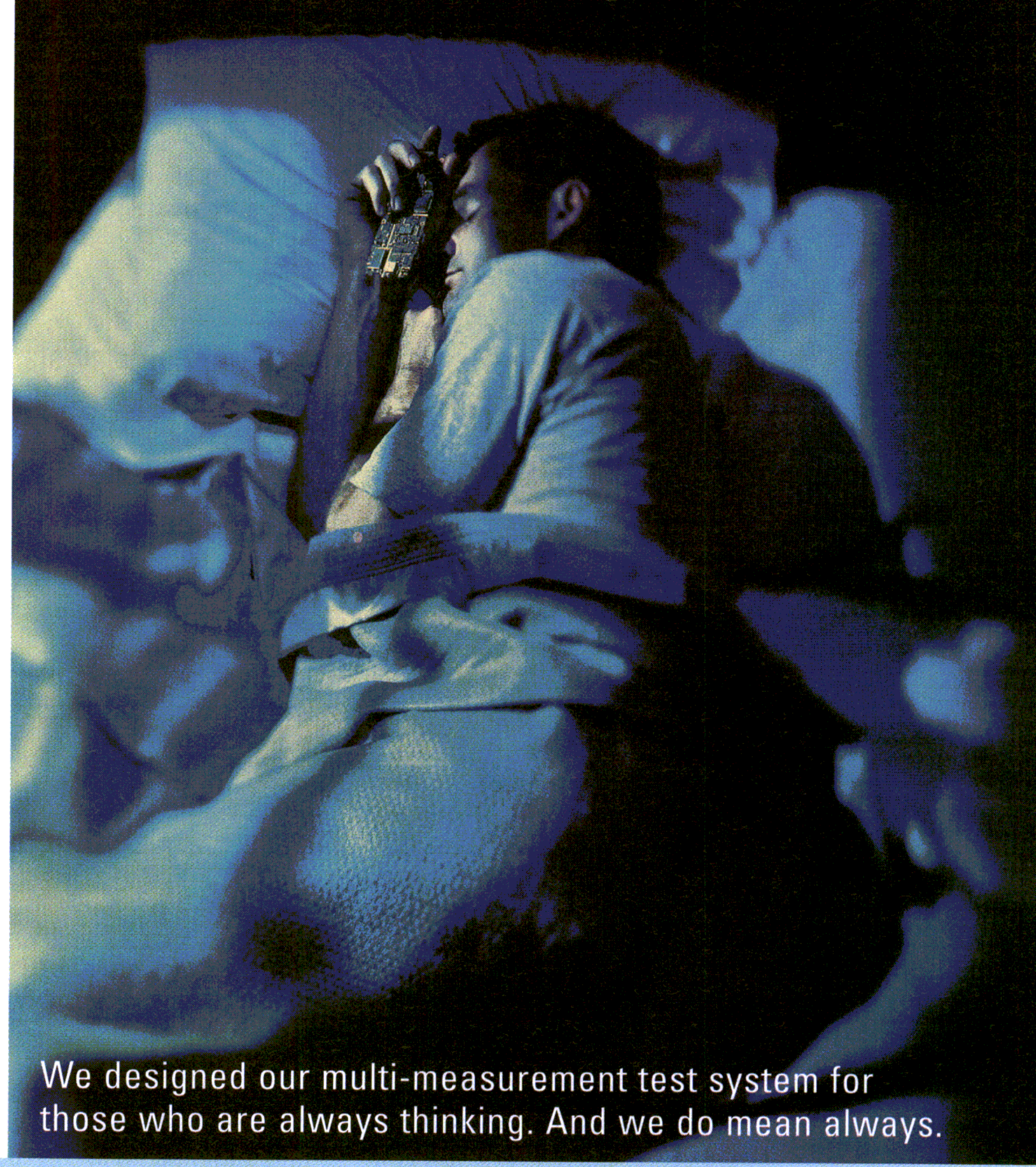

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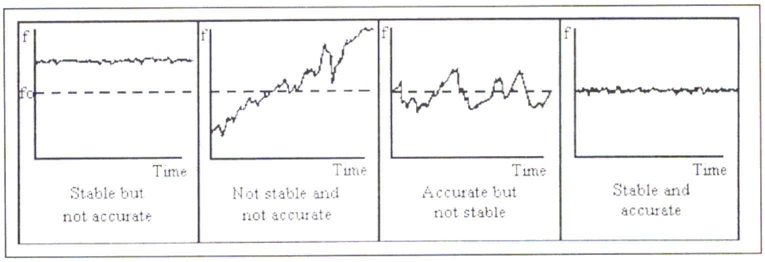
Time and Frequency Standards

Here is a thorough review of the types of frequency standards, comparing their accuracy, stability and cost

By Richard Percival
Quartzlock Limited

As we move towards a world increasingly dominated by technology, the need for accurate and reliable frequency and time standards has risen. The market consists of a variety of devices varying in accuracy, stability and price. This article will briefly review some of the medium performance frequency standards and discuss in depth the atomic frequency standards and their indirect derivatives — GPS, Rubidium Gas Cell, Cesium Beam and Hydrogen Masers. The article will then outline the principle behind the Primary Reference Clock currently under development, with an examination of what the future holds for high performance frequency and time standards.

The first question: what is a clock? In basic terms a clock may be thought of as a resonator or frequency source with a counter to keep track of the number of oscillations [Allan 2]. On the atomic scale the oscillator would be the Cs^{133} or Rb^{87} atom and the counter would be a fast electronic one. The oscillator is generally referred to as the clock's frequency standard, the oscillations of which are determined by the laws of physics. An example of a simple oscillator would be the quartz crystal found in wrist watches. Quartz crystal oscillators are very stable over short averaging times, but their frequencies can drift quite rapidly. Drift is due to both internal changes (aging) and external environmental changes [NIST 1]. This is why your watch needs periodic calibration against a more accurate clock. Based on the price, however, the accuracy of the quartz crystal is remarkably good.



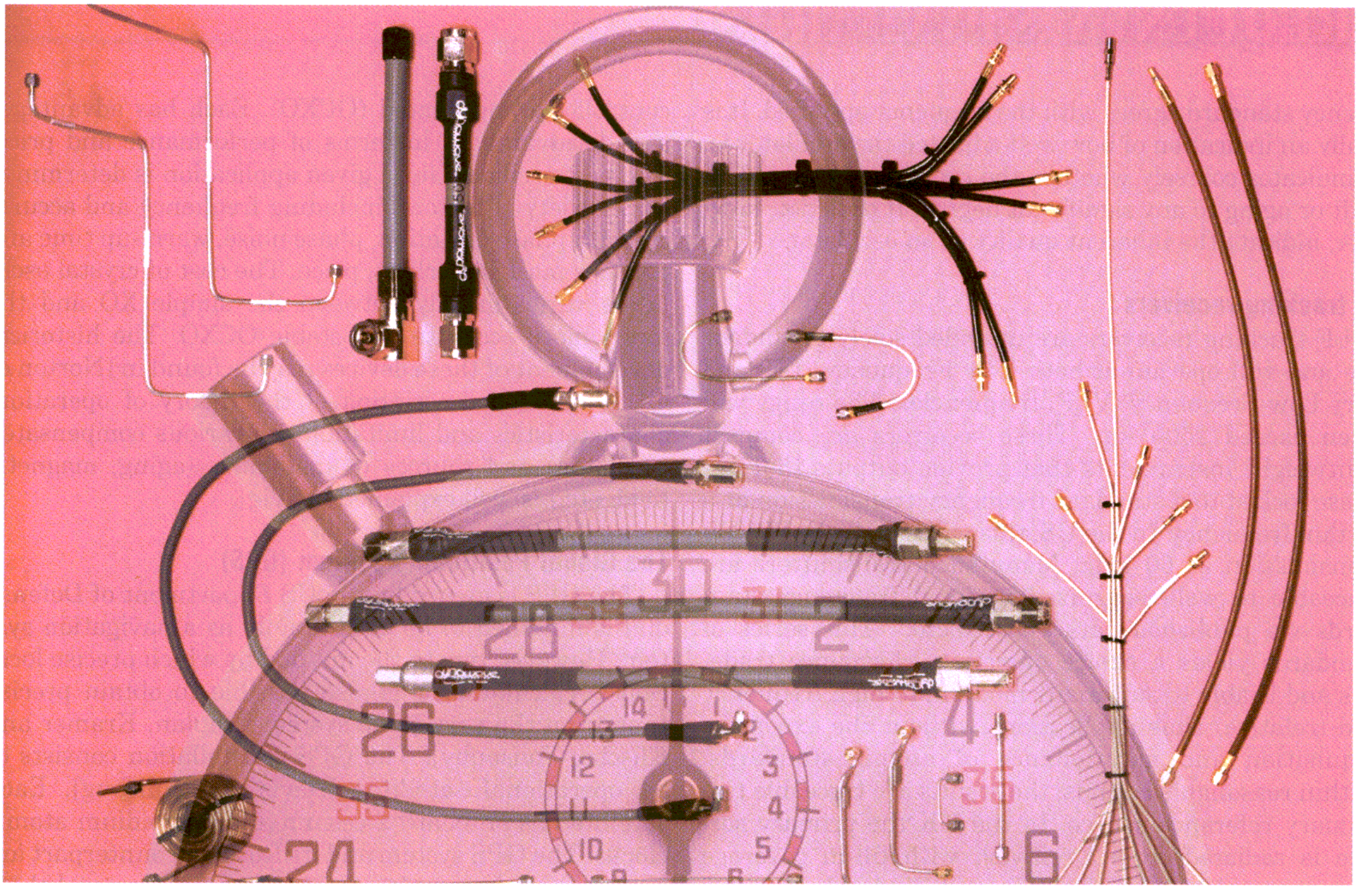
▲ **Figure 1. Comparisons of the basic performance definitions for frequency sources: stability and accuracy.**

When a higher degree of accuracy is required for scientific purposes, atomic clocks easily outperform any physical oscillator. The frequency standard is obtained by the oscillation of an electromagnetic signal associated with a quantum transition between two energy levels in an atom. The advantage of using atomic resonant transitions as the reference frequency is that they are determined by fundamental constants, which result from the basic interactions between elementary particles.

To understand how time and frequency standards are compared against one another, it is necessary to define some technical terms which will be used throughout this article.

The most important term used within the time and frequency community is *stability*. It is defined as "the statistical estimate of the frequency fluctuations of a signal over a given period of time." [Lombardi 1]. While this does not indicate the accuracy of a signal, it does indicate whether it changes. It is the stability which indicates the quality of the oscillator.

The other term very often quoted is the *accuracy* or the *fractional frequency offset*. This indicates to the user how accurately the supplied fre-



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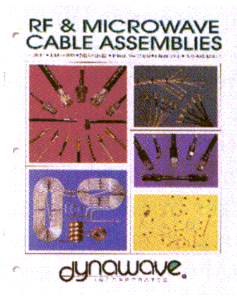

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Circle 12

quency standard agrees with the frequency specified. It is really an indication of how well-adjusted the oscillator is. It indicates coarsely whether the oscillator is subject to drift or aging to any significant degree. It does not, however, indicate the inherent quality of an oscillator.

LF tracking receivers

LF tracking receivers are intended solely for indoor use and will operate at both Low Frequency (LF) and Very Low Frequency (VLF) frequencies. The range will often exceed 2500 km. These receivers are compact lightweight instruments that provide outputs that are phase locked to a standard frequency transmission at a certain frequency. In the US, this will usually be WWVB transmission at 60 kHz. Many such transmitters are traceable to well-recognized national frequency standards via published data "post facto." This series of standards yields a choice of price/performance tradeoffs and is able to suit many medium to high frequency and (relative) time applications without the expensive acquisition and maintenance of atomic standards. Within reasonable bounds, the results are traceable to a primary reference source. In the UK the primary service is radiated from Droitwich with fill-in coverage from transmitters at Aberdeen and Westerglen on 198 kHz [Quartzlock 1]. The France Inter transmission on 162 kHz provides a corrected cesium reference.

Crystal oscillators

Crystal oscillators are among the most important electronic components in use today and are second only to the atomic sources mentioned below as the most stable frequency devices. Most complex electronic systems rely on a crystal oscillator to provide a stable reference so that other frequencies of the system can be compared to or generated from this reference. More than 1 billion quartz crystal oscillators are produced annually for a variety of applications [Vig].

The link with today's high-precision oscillators may be traced directly back to the work carried out at Bell Labs in the early 1950s by Warner. Following the development of the transistor by Shockley et al, the first frequency standard based on all-transistor technology was built at Sulzer in 1958 [Norton et al].

The quartz crystal resonator, which is the backbone of the crystal oscillator, uses the piezoelectric effect (by application of an electrical signal, the quartz resonates, and vice versa). As long as this signal is maintained, the crystal will continue to oscillate at a frequency unique to the shape, size and cut of the crystal. During the last 50 years, huge improvements in performance have been made in the design and manufacture of the resonator.

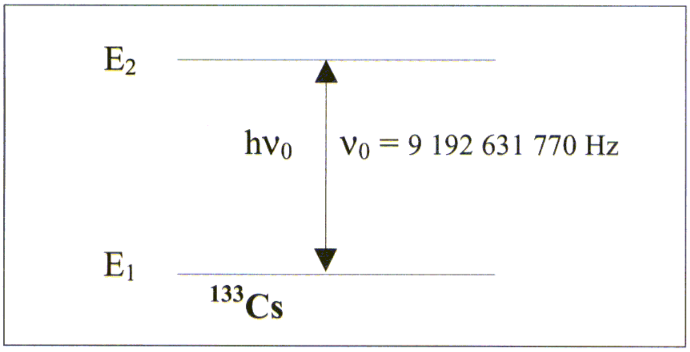
The range of different oscillator types includes simple uncompensated oscillators (XO), temperature compensated (TCXO), microcomputer compensated (MCXO), voltage compensated (VCXO) and oven or double-oven controlled compensated (OCXO). Each has advantages and disadvantages in terms of performance and price. The best oscillator for a given application is determined by a variety of factors, including frequency and accuracy, drift, phase deviation, phase noise, warm-up time and perhaps most important, price. The cost of crystal oscillators varies greatly between the simple XO and the much more accurate and stable OCXO. The historical development of these devices may be found in [Norton et al]. A detailed description of the theory of operation, characteristics and limitations of various compensated oscillators and sources of instability (aging, magnetic field, etc.) is well explained in [Vig].

The Global Positioning System (GPS)

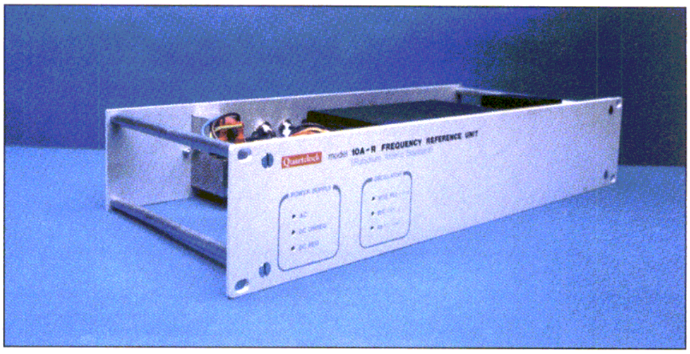
The GPS is owned by the US Department of Defense and is intended to be used mainly as a navigation system. However, due to the method by which precise location is calculated, it is also possible to obtain precise time from the very same system [Kaplan, Kramer and Klische, Ponsonby]. The GPS constellation consists of 24 operational satellites [Davis and Furlong]. Each satellite has on board 2 cesium and 2 rubidium atomic clocks. The GPS system and its Russian counterpart are both extremely complex, using Einstein's general theory of relativity for the first time in a practical application, thus an explanation is beyond the scope of this article. However, its use for time and frequency dissemination can be described. The GPS carrier signal is operated on two frequencies: L1 is at 1575.42 MHz (10.23 MHz × 154) and L2 is at 1227.60 MHz (10.23 MHz × 120). L1 is the only code available to civilians, since it has both the P-code (Precise Code) modulation and the C/A code (Clear/Acquisition) modulation. L2, however, only has the P-Code modulation. The P-code is only available to users trusted by the US DoD. Unfortunately, full accuracy of GPS is denied to the Time Metrology community (and all other "non-authorized" users) by the introduction of pseudo-random noise into the carrier signal [Thomas 1]. As David Allan [Allan 2] said, "If it were turned off, the venetian blinds would go up, and we would be able to see the GPS satellite clocks very clearly."

At present, a user interested in acquisition of precise

▲ **Figure 2. A receiver can recover accurate frequency information transmitted by GPS satellites.**



▲ **Figure 3. Energy levels for cesium, hydrogen and rubidium resonances.**



▲ **Figure 4. A commercial rubidium standard.**

time or frequency must accept degradation of stability. A GPS disciplined oscillator (GPS-DO) is an attempt to overcome this short to medium term noise through the slaving of a quartz oscillator or rubidium oscillator to the GPS carrier signal. By combining this stable oscillator with a good disciplining algorithm, the effects of the errors be greatly reduced. It has been shown [Davis and Furlong] that in the short term (<50 s) the stability of a GPS-DO is almost completely determined by the quality of the local slave oscillator and in the long term (>1 day) by the GPS signal itself (generally $<1\times10^{-13}$ at 1 day averaging time).

The use of GPS-DO's as stable and accurate frequency and time standards has significant advantages over free-running oscillators (such as rubidium or cesium), despite the obvious disadvantages mentioned above. The GPS system is referenced to the United States Naval Observatory (USNO), thus, a GPS-DO will not require periodic calibration. The devices are light and easily transportable, enabling them to be used anywhere in the world, which is unimaginable for a high quality cesium beam or hydrogen haser. A simple quartz-based GPS-DO can be bought for under $5,000.

Atomic frequency standards: 1. Rubidium

The first realized rubidium frequency standard arose out of the work of Carpenter [Carpenter et al] and Arditi [Arditi]. The first commercial devices came onto the market primarily due to the work of Packard and Schwartz. Unlike much of the research done on frequency standards at that time, the rubidium maser was high on the research agenda. It was understood that such a device would have extremely good short-term stability relative to size and price. In 1964, Davidovits brought such research to fruition, with the first operational rubidium frequency standard [Vanier and Audoin]. Zepler et al at Plessey, UK did much work on making the rubidium into a small compact unit [Zepler et al, Bennett et al].

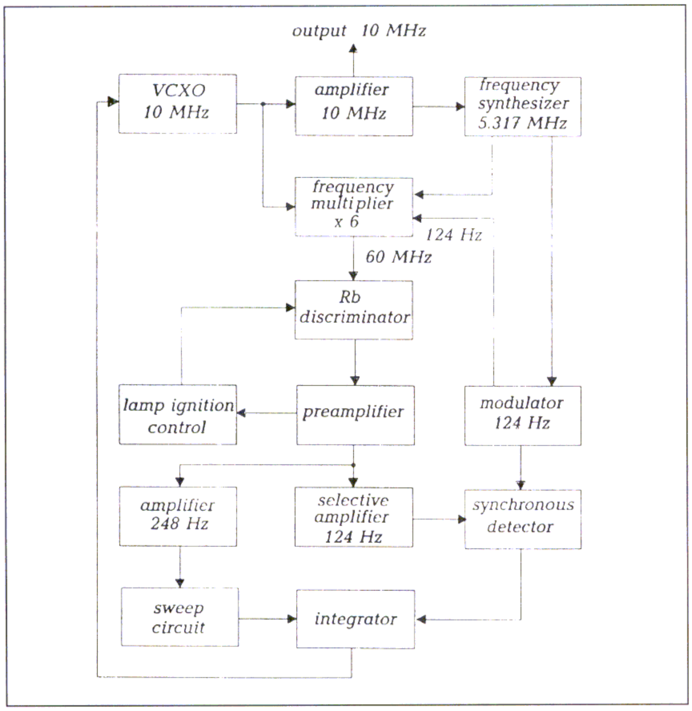
The Rubidium Frequency Standard, like its more expensive cousin, the Hydrogen Maser, may be operated either as a passive or as an active device. The passive rubidium frequency standard has proved the most useful, as it may be reduced to the smallest size while retaining excellent frequency stability. The applications for such a device abound in the communication, space and navigation fields.

The rubidium standard may be thought of as consisting of a cell containing the rubidium in its vapor state, placed into a microwave cavity resonant at the hyperfine frequency of the ground state. Optical pumping ensures state selection. The cell contains a buffer gas primarily to inhibit wall relaxation and Doppler broadening. The rubidium frequency standard essentially consists of a voltage-controlled crystal oscillator, which is locked to a highly stable atomic transition in the ground state of the Rb^{87} atom. [Zepler et al, Bennett et al].

Rubidium accuracy is comparable with that of the standard cesium with an operating life approximately five times that of cesium. Furthermore, the cost of a replacement physics package ranges from free to about $50. Moreover, the stability of the rubidium frequency standard over short time-scales (hundreds of seconds) is better than cesium (cesium standards are more stable over longer time periods, from hours to years). The phase noise of a good quality compact rubidium standard is –145 dBc/Hz at 10 kHz from the carrier, identical to the popular HP5071 cesium beam atomic clock [Vanier and Audoin].

There are, however, a few drawbacks to the use of rubidium as a frequency standard. In the past, these included the limited life of the rubidium lamp (since improved to >10 years), although the cesium beam is affected to a greater degree than this, while the H-maser operates differently and is not affected. The thermal stability of rubidium is inferior to that of either cesium or H-masers, and previously required access to a primary reference signal or synchronization source (GPS or Glonass) to maintain long-term cesium-level accuracy [Vanier and Audoin].

The cost of a rubidium frequency standard instrument (around $5000) is significantly cheaper than a cesium standard. Due to its small size, low weight and environmental tolerance, the rubidium frequency stan-



▲ **Figure 5. Block diagram of a rubidium standard using a VCXO locked to the rubidium atomic transitions.**

dard is ideal for mobile applications. Rubidium atomic clocks are beginning to be implemented into the new generation of GPS satellites. Rubidium is also extremely quick to reach operational performance, reaching five parts in 10^{10} within five minutes of turn-on.

GPS disciplined oscillator, (GPS-DO), slaving a rubidium oscillator to a GPC carrier signal, is challenging the dominance once held by cesium within timing centers. A major advantage, if the disciplining algorithm is correctly implemented, is that superior rubidium short-term stability may be obtained, while the characteristic frequency aging is removed. This gives the GPS-DO cesium-derived accuracy at 1/5 the price. It is also able to give Coordinated Universal Time. The future for such devices, if they are accepted as traceable to the national time scale [Davis and Furlong], is very promising.

2. Cesium beam

The heart of a cesium beam clock is the cesium beam resonator. The operation is based on the population difference between the two hyperfine levels of the ground state of the Cs^{133} atom on which the definition of the second is based. It works by passing a beam of state-selected cesium atoms through an excited microwave cavity. On exciting the cavity further, state selection is used to select atoms that have made a microwave transition, and eventually obtain a signal that is maximum when the microwave excitation frequency equals the resonance frequency of the atoms. Some form of frequency or phase modulation of the microwave excitation is used to allow precise determination of the line center.

The major advantage of the cesium beam is its very high accuracy and reproductability. However, the short-term stability of commercial cesium beam standards is rather poor in comparison to hydrogen masers. There exist two types of cesium beam devices — standard and high performance. They differ significantly in accuracy, stability and hence price.

The initial work into developing a Cesium Beam Frequency Standard was carried out by NIST (then NBS) with the first unit built in 1955 [Essen and Parry]. After 1958, the first commercial units became available. This led to the present definition of the SI second which is "the the duration of 9,191,631,770 periods of radiation corresponding to the transition between the hyperfine levels of the ground state of the cesium atom" [BIPM].

Laboratory cesium beam frequency standards are actually built for the purpose of realizing the SI definition of the second with as much accuracy as possible. They are true primary frequency standards because their accuracy is "the normalized uncertainty of the measured or estimated frequency difference between the realized value of the hyperfine transition frequency and the unperturbed transition frequency" [ITU p18]. Neither rubidium nor hydrogen masers are capable of this, regardless of their superior performance in other areas. At present, the best accuracy of a primary Cesium is about 1 to 2×10^{-14} [Bauch]. It is also important to realize that there is a great difference between high performance $1 million primary cesium standards and those available commercially.

Cesium beam frequency standards are important where high accuracy, reproducibility and negligible drift are required. High end commercial units are capable of the following performance: accuracy $\sim1\times10^{-12}$, drift $<1\times10^{-15}$/day, flicker floor stability level $<1\times10^{-14}$, short-term stability $<8\times10^{-12} \times t^{-1/2}$, and temperature coefficient $<1\times10^{-15}$/ °C, summarized in Figure 6.

Several frequency offsets afflict current cesium beam standards. These are the existence of additional levels very close to the levels of interest, which lead to frequency offsets; residual first and second order Doppler effects due to atomic motion; very small distortion of the atomic wave function; state selection difficulties; coupling of the interrogation magnetic field; and sensitivity of the measured resonance frequency to the quality of the frequency modulated signal used to make the transition. However, primary cesium standards use a complex method of evaluating such shifts and compensating for them [Guinot and Azoubib].

In addition, cesium is much more expensive than rubidium, with a far greater weight (>25 kg). Cesium reliability also depends upon the life-time of the beam tube, which has proven to be poor. Improvements in the beam tube performance have led to reduced tube life. This is a big issue for cesium users, with a new tube

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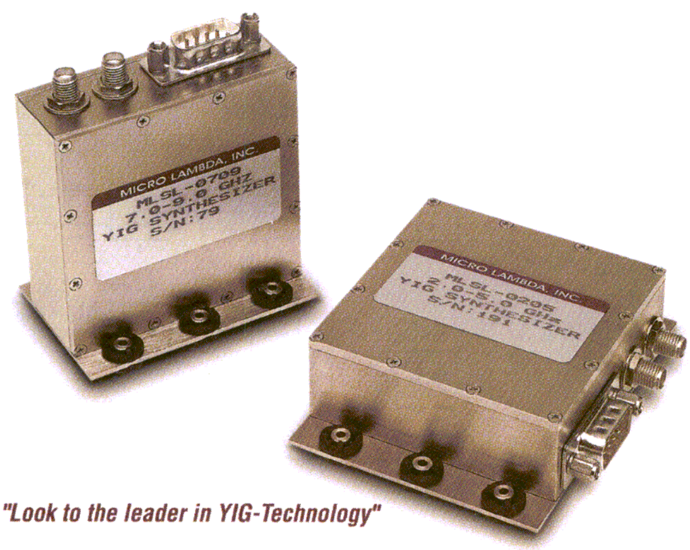

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Despite these drawbacks, cesium plays a major role in the frequency and time community, with over 80 percent of clocks used in the estimation of TAI/UTC. This is mainly due to their lower long-term drift than hydrogen masers. However, their usage is limited for applications like Very Long Baseline Interferometry (VLBI), where short-term stability requirements are most important.

Unit	Standard	High Performance	Digital Controlled	Primary Laboratory
Accuracy	7E-12	7E-12	1E-12	1E-14
$\sigma_y(\tau$=100s)	3E-12	<1E-12	<1E-12	<1E-13
Flicker Floor (σ_y^{min})	1E-13	3E-14	5E-15	3E-15
$\sigma_y(\tau$=1 month)	1E-13	3E-14	5E-15	N/A
Temperature (per K)	1E-13	1E-13	<1E-15	1E-15
Magnetic Field (per 10^{-4} t)	1E-12	1E-13	<1E-14	N/A

▲ **Figure 6. Performance summary for cesium atomic clocks.**

Recent developments in cesium beam technology have led to standards that operate by optical pumping. This leads to better state selection and atom detection. The most high profile frequency standard developed using this technology is the new primary cesium frequency standard, NIST 7, in operation at NIST. Several of the deleterious frequency shifts affecting current cesium standards are reduced, consequently, performance is very much improved. Such improvements are critical if cesium beam standards are to compete with rubidium-based GPS receivers.

3. Hydrogen masers

The first hydrogen maser was the brainchild Ramsey who, at Harvard University in 1960, succeeded in making the first operational model [Goldenburg et al, Ramsey]. He completed the design after the discovery of the maser effect in 1955 by Townes, Basov and Prokhorov [ITU p. 11]. Kleppner realized that the hydrogen maser was able to deliver an extremely stable frequency reference signal. This led to the consideration of using it as a primary frequency standard. The frequency of the hyperfine transition of the hydrogen atom has been measured with accuracy of the order of 1×10^{-12}.

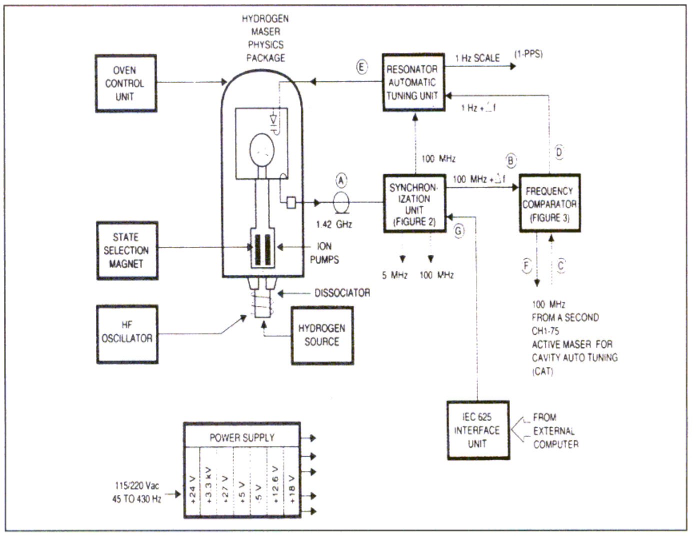
A major difference among hydrogen masers, cesium beam, and rubidium cell frequency standards is that there is no direct access to the population difference change in hydrogen masers. This is because there is, at present, no efficient means of detecting hydrogen atoms. The basic principle of operation is that the strong coupling between the atomic medium and the microwave field in the resonant cavity makes it very easy to see the necessary hyperfine transition via amplification of the microwave field by stimulating the emission of radiation. If the amplification is large enough, the oscillation may be sustained. The hydrogen maser may be operated actively, as an oscillator or passively, as an amplifier.

The principle of operation for the active hydrogen maser is based upon a 5 MHz quartz crystal oscillator, phase locked to the hyperfine transition of the hydrogen atom. The atomic hydrogen signal generated within the physics package is then picked up by an antenna in the cavity and coupled to the synchronization unit, which synchronizes the 5 MHz crystal oscillator signal phase to the hydrogen signal phase producing the 5 MHz and 100 MHz spectrally pure sine-wave signal output (Figure 7).

The Active Hydrogen Maser (AHM) provides the best known frequency stability for a commercially-available standard. It excels in the domain of 1 second to 1 day. At a 1-hour averaging time, it exceeds the stability of the best known cesium oscillators by a factor of up to 100, with an Allan deviation of $\sim2\times10^{-15}$. The AHM owes its high stability to the following factors [Vanier & Audoin]:

1. The resonant line is narrow due to the long storage time spent in the storage volume (1 s).
2. If the amplifying elements are isolated atoms the noise level of the maser is very low.
3. The storage of atoms at low pressure leading to free and unperturbed movement during radiation.
4. The exposure of atoms to a standing wave leads to removal of the first order Doppler shift. Also the average velocity for stored atoms is very low.

At present, the PHM's stability outperforms the best available cesium by a factor of 10. One of the big advantages of the PHM is that it is not constrained by the 3- to 7-year life cycle of the cesium tube. Figure 8 shows a commercial PHM unit.



▲ **Figure 7. Hydrogen maser block diagram.**

Long term frequency stability of H-masers depends on whether the Cavity Pulling effect is eliminated by the cavity auto-tuning system (CAT) [Koshelyaevsky and Pushkin]. In CAT systems, long term frequency stability similar to laboratory primary cesium beam frequency standards has been observed over several years. The accuracy of the H-masers is on par with the best commercially available cesium. Reproducability is the degree to which the frequency standard reproduces its normal output frequency without the need for calibration against another frequency standards. The H-maser has a reproducability of 10^{-14}, an order of magnitude better than cesium.

There are many present and future applications for hydrogen masers, such as:

1. In radio astronomy for very long baseline interferometry (VLBI) timing for data recording.
2. Laboratory standard/in-house reference. Two active hydrogen masers coupled together by auto cavity tuning form the UK time scale.
3. The ultimate Stratum 1 primary reference clock standard for telephone networks.
4. Satellite ground station clock/frequency standard.
5. Test equipment reference for measuring the quality of GPS disciplined oscillators.
6. Deep space missions clocks.
7. Scientific research, e.g. testing Einstein's theory of special relativity [Wolf and Petit].

Relatively little research has been carried out in the West concerning the development of the H-maser. In contrast, work in the former Soviet Union was far more advanced, with many hundreds of devices having been manufactured and sold [Demidov and Uljanov]. Until now, the market has been rather limited for H-masers, but with the increased emphasis on high frequency stability (e.g. VLBI) rather than high accuracy, the demand is growing rapidly. One example of how this technology is being applied in the west is through a teaming relationship between Quartzlock (UK) Ltd. and KVARZ Institute of Electronic Measurements in Russia. These units have been built in substantial quantities for the last 30 years and form the major time-scales in Germany, Brazil, Spain, Japan, Russia, China, Belgium, Taiwan, S. Korea and the UK. The instruments are produced in Russia and are shipped to Quartzlock, where they are prepared for delivery. It is also possible for these instruments to be tested by NIST in the USA [Allan and Weiss, Weiss and Walls], PTB in Germany, BIPM in France [Azoubib and Thomas] or at NPL in the UK.

H-Masers will continue to be useful for applications where very high stability is required for intervals between 1 second and 105 seconds. However, the medium term frequency stability is limited by the cavity thermal noise and goes as $t^{-1/2}$ [Demidov 1]. Similarly, the

▲ **Figure 8. A commercial Passive Hydrogen Maser.**

short term frequency stability depends on the cavity thermal noise and on the electronic noise in the first stage of amplification. A reduction in the operating temperature of both the cavity and system electronics should lead to an improvement in the frequency stability. The development of a cryogenic H-maser has stimulated a lot of research interest. Early results show that it can become a field operable atomic frequency standard with fractional frequency stability in the 10^{-18} range [Vessot].

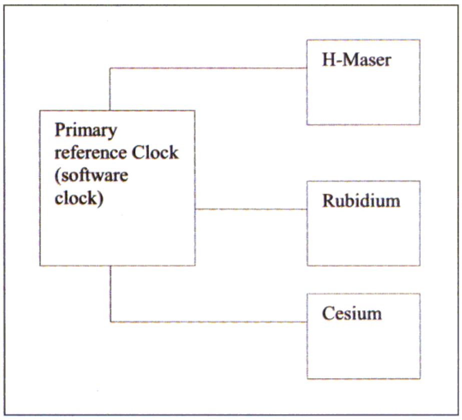
Primary reference clocks (software clocks)

The objective of a primary reference clock is to combine a number of diverse frequency standards into a single output to achieve improved performance and higher reliability. The output should not show any sudden phase glitches if the output of one or more of the sources should fail. In addition, it is desirable that the random behavior of the output phase of a source be detectable in comparison with the phase of other sources. A simplified bock diagram is shown in Figure 9.

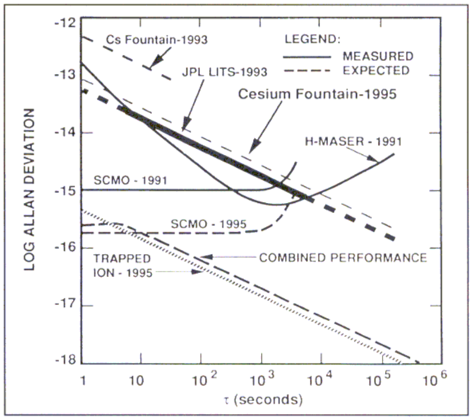
The sources may be divided into two classes. The first is the free running oscillator type of source, which may show a frequency offset from an internationally defined time scale. The hydrogen maser and the rubidium oscillator are in this class. They may have excellent stability, but can still have an unknown frequency offset.

The second class is the type which supplies a replica of a time scale elsewhere. The GPS standard and the LF tracking receiver are of this type. They provide a link to an ensemble of standards, which are monitored and referred to other internationally maintained time scales. The quality of the link controls the short and medium term stability of the standard. In the long term, the stability of this type will approach that of the host.

The local first class standards are likely to have better short and medium term stability than second class standards. For example, the hydrogen maser will be superior to either the GPS standard or the LF tracking receiver for averaging times up to weeks. The final outputs of the PRC should have short-term quality of the hydrogen maser, but long-term quality of the GPS.



▲ **Figure 9. Three device software clock.**



▲ **Figure 10. Peformance of newly-developed standards.**

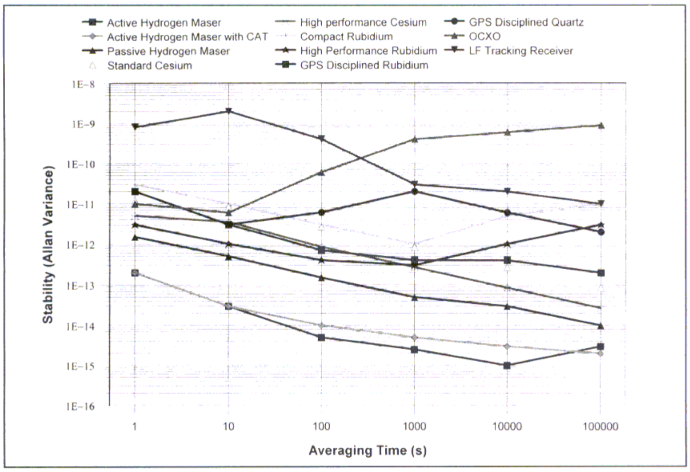
next best source (e.g., rubidium oscillator) could then be designated the master and used for phase alignment, although it may be difficult to achieve a smooth changeover.

A better solution might be to derive a notional time scale based on phase measurement of all the sources and phase align them to the notional time scale. This way, the need for a master is eliminated. Careful consideration of the weighting of each source contribution to the notional time scale would be required, with each contribution at a different averaging time. To clarify, a source of the second class would have more weighting for the phase averaged over a long period of time as it is referenced to an international time scale.

The redundancy requirement poses several problems. The outputs of the various standards can only be combined if they are all in phase. If we consider a simple system where one source is considered to be the master, then the other sources may be phase aligned to the master. If one source should fail, the amplitude of the output will only drop by the ratio of the number of sources. This simple system would work quite well if all the sources were of the same class and the same degree of frequency (phase) stability.

If we are combining sources of different performance levels, the output should be that of the best standard, in this case the hydrogen maser. However, if that unit should fail, the output may fall to an unacceptably low level. Thus the performance requirement conflicts with the redundancy requirement.

One could improve the short-term stability of the lesser sources by phase comparison with the hydrogen maser. One could then use a higher percentage of the improved (phase adjusted) standard in the final output. If the hydrogen maser did fail, the reference source for the phase adjustment would vanish, and the basic noise characteristics of the lesser sources would reappear. The



▲ **Figure 12. Comparison of high performance standards.**

The future

A great deal of research is underway to improve present frequency standards. Many devices already exist in laboratories that outperform anything commercially available. They include such exotic sounding devices as trapped ion standards [Tjoelker et al, Fisk], cesium fountains [Weyers et al], oscillators stabilized with cooled sapphire resonators, optical frequency standards [Hamouda et al] and flywheel oscillators. Such high performance devices are almost certain to replace the existing primary standards in laboratories around the world but will have a somewhat restricted niche market. The real challenge lies in the ability to improve crystal oscillators and low-cost atomic standards such as rubidium. This is crucial for 21st Century communication systems, computer networks, navigation and transportation systems including avionics, electric power systems [Martin], space exploration [Emma, Hartl], astronomy and astrometry, geodesy, geology, earthquake monitoring and many others. Performance of these new systems is noted in Figure 10. Figure 12 reviews the relative performance of the various time and frequency standards. ■

References

It was impractical to print the extensive list of references accompanying this article. They have been included with the archived version of this article, which is available via the Internet at www.amwireless.com.

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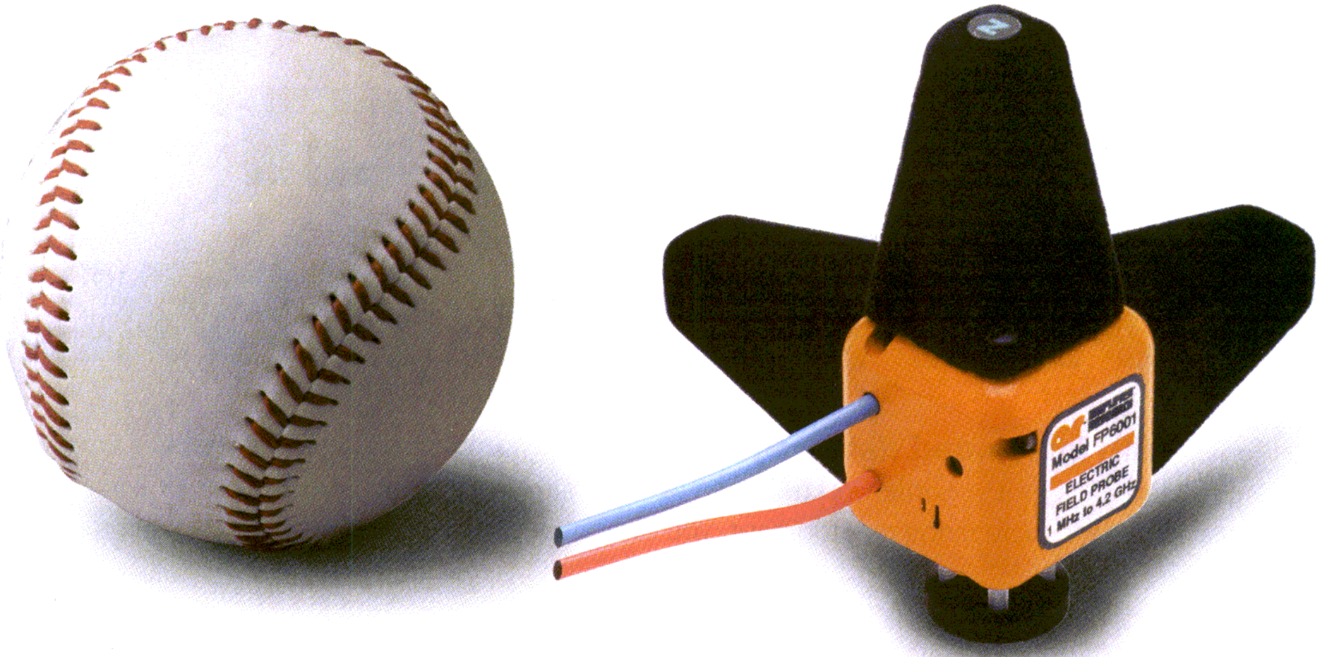

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Circle 40

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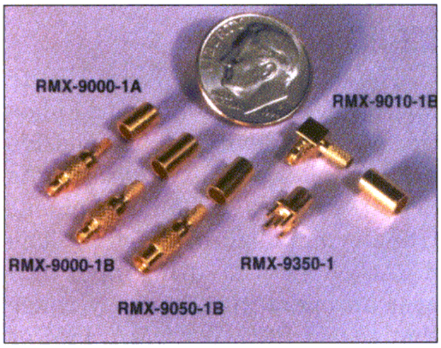
Circle 35

Product Focus: Connectors and Cable Assemblies

MMCX Connectors

Several new MMCX connectors are available from RF Connectors, including the RFX-9010-1A, a right-angle plug for RG-178/U cable.



Miniature MMCX connectors are approximately 45 percent smaller than SMB connectors, making them useful where space requirements are quite small. Straight and right-angle styles are available in PCB types, plus crimp plug and jack configurations for RG-174/u, RG-316/U and RG-188/U cables. These snap-in connectors are made of machined brass with gold plated bodies, gold plated contacts and PTFE insulation.

RF Connectors
Circle #163

Assemblies feature low passive IMD

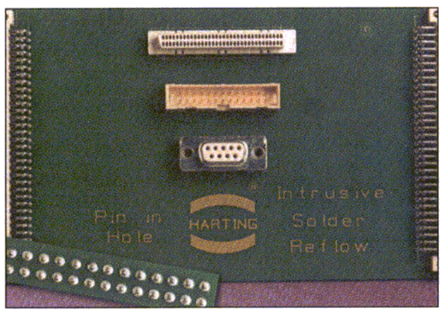
Semflex announces the RTI series of application specific cable

assemblies (ASCA™). The new series is designed for applications in the communications market that require low passive intermodulation distortion. Third order passive IMD levels have been measured to better than –110 dBm (–153 dBc) with two +43 dBm tones at 1800 and 1850 MHz. The cable assemblies feature brass connectors with Semflex' own TechnaPlate™ plating and are constructed with flexible low loss double shielded cable with a FEP jacket. Standard connectors and lengths of 6, 12, 18, 24 and 30 inches in 0.110, 0.150 and 0.180 inch diameters are available from stocking distributors.

Semflex Inc.
Circle #164

High temperature connectors

Harting offers an expanded selection of high temperature connectors that can soldered simulta-

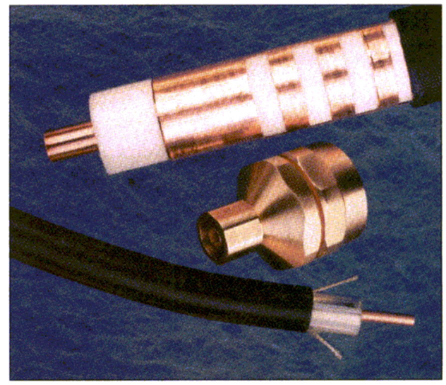


neously with surface mount components using the Pin-in-Hole Intrusive Reflow process. Connector types include VEM 64, DIN 41 612, SCSI connectors, shrouded headers and D-sub types.

Harting, Inc.
Circle #165

Enhanced performance radiating cables

Times Microwave Systems announces the Nu-RAD series of radiating cables for optimum performance in subway, transit, tunneling and in-building applications. These cables (patent applied for) offer a combination of surface wave at lower frequencies and a radiating mode at higher frequencies, allowing multiple services to be provided on a single cable. Nu-RAD cables are available in 1/2, 5/8, 7/8 and 1-1/4 inch sizes. They are offered in non-flame retardant polyethylene

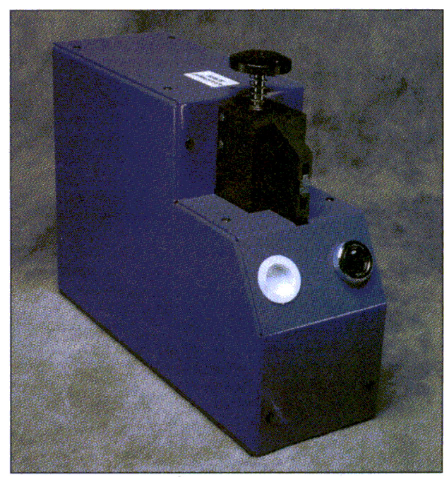


as well as flame retardant non-halogen jacketed designs. Type N and 7/16 DIN connectors are offered.

Times Microwave Systems
Circle #166

Pneumatic crimp machine installs connectors

Connex Corporation now offers the #47-10190 pneumatic crimp machine. This compact (under 20 lbs.) unit is hand activated, with optional foot pedal operation. It



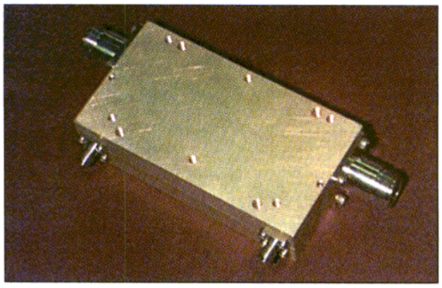
comes with dual-position feet for vertical or horizontal loading. The loading mechanism is spring-loaded to keep hands clear of the work area. The die holder is compatible with industry-standard die sets. An adjustable crimp height allows for custom crimp applications.

Connex Corporation
Circle #167

SIGNAL PROCESSING

High power coupler

Sage Laboratories now offers a 50 dB high power coupler for use in base station power and VSWR monitoring. Over the range of 825 to

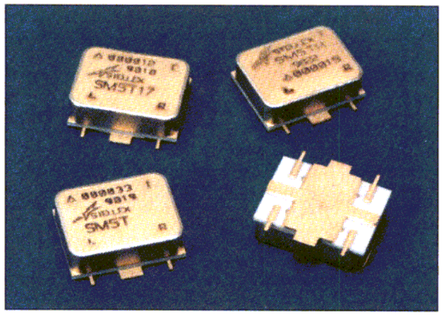


895 MHz, the model FC6486-1 coupler offers isolation of 15 dB minimum, insertion loss of 0.5 dB maximum, a return loss of 26 dB on the primary line and 20 dB on the secondary line, with a phase deviation of no more than ±3 degrees. Power handling is rated at 360 watts average and 16 kW peak. The coupler is packaged in a 4 × 2.1 × 1 inch enclosure with type N connectors on the main line and SMA connectors on the coupled line. Variations in the basic configuration and connectors are also offered.

Sage Laboratories
Circle #168

Load insensitive mixers

Stellex Microwave Systems' Models SM5T/SM5T17/SM5TH are wideband load insensitive mixers,



offered in hermetic surface mount packages for high reliability applications. The mixers cover 50 to 500 MHz LO and RF, 50 to 3000 MHz IF and are available in versions requiring +10, +17 and +23 dBm LO drive levels. Typical performance specifications include 7.2 dB conversion loss and 35 dB isolation.

Stellex Microwave Systems
Circle #169

MMIC mixer

The HMC272MS8 from Hittite Microwave Corp. is an 8-lead plastic MSOP device. The passive MMIC balanced mixer uses GaAs Schottky diodes and a novel planar transformer balun on-chip. The mixer offers +21 dBm input IP3 over an operating frequency range that covers PCS, W-CDMA, ISM or MMDS applications. Pricing of the HMC272MS8 is $0.69 each in 100,000 unit quantities.

Hittite Microwave Corporation
Circle #170

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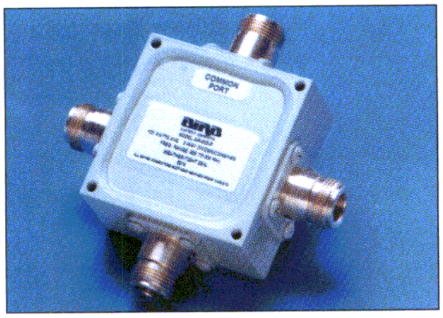
Products

Weather-tight 3-way divider/combiner

Bird Component Products offers the Model 100-AD-FFN-03 with rugged weatherproof construction. This 3-way power divider/combiner has a power rating of 100 watts CW over the frequency range of 806-

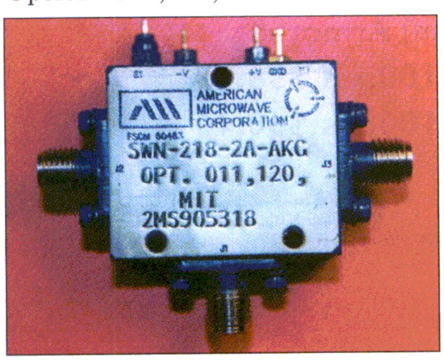


906 MHz. Other specifications include insertion loss of less than 6.5 dB maximum and a VSWR for all ports of 1.25:1 maximum. Type N female connectors are shown, but other connector options are available. This Wilkinson coupler type is available in 2-way to 8-way designs in the frequency range of 500 MHz to 3 GHz.

Bird Component Products
Circle #171

100 dB isolation SP2T switch

AMC Model SWN-218-2A-AKG Option 011,120,MIT is a SP2T

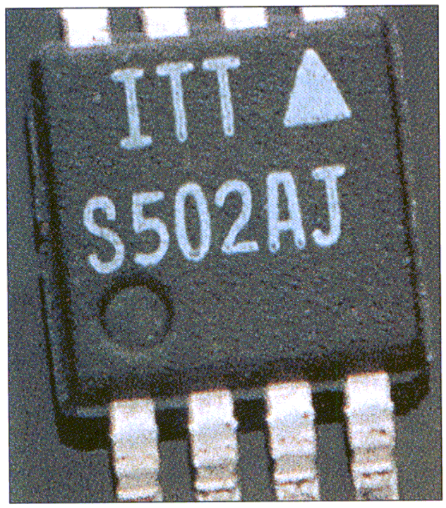


switch capable of 100 dB isolation from 0.1 GHz to 20 GHz. Insertion loss is less than 4 dB, with a VSWR of 2.0:1. The required supply voltages are +5 VDC at 75 mA and –12 VDC at 55 mA, with other voltages available. The switch has a specified turn-on time of less than 65 ns and a turn-off time of less than 40 ns. The package is 1.2 × 1.0 × 0.5 inches, plus connectors, and unit weights 1.2 ounces, typical.

American Microwave Corporation
Circle #172

GaAs T/R switches

GaAsTEK adds three new switches to its line of T/R switching products. The switches are designed to cover DC-3.5 GHz with 3 and 5 volt positive control volt-

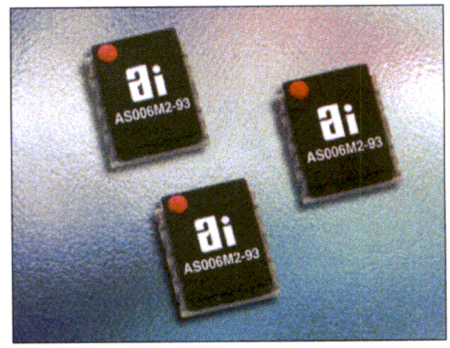


age. Applications include wireless handsets, LANs, data base stations and other wireless products. The ITTS502AJ is a SPDT medium power model with 0.5 dB insertion loss at 1 GHz. P_{1dB} is 33 dBm. The ITTS505AJ is a SPDT switch for operation from 4.5 to 5.0 GHz with 1.7 dB insertion loss. The ITT506AJ is a SPDT switch for the 5.0 to 6.0 GHz range, for emerging NII applications and 5.8 GHz ISM products. All three switches are provided in a MSOP-8 package.

GaAsTEK
Circle #173

Chip on board control product family

Alpha Industries announces a new family of low cost chip on board control IC products. The new platform of control products includes the pictured ASOO6M2-93 SPDT switch. The small packages offer freedom in layout and circuit density, with reduced parasitics that enable operation up to 6 GHz. Target applications include low fre-



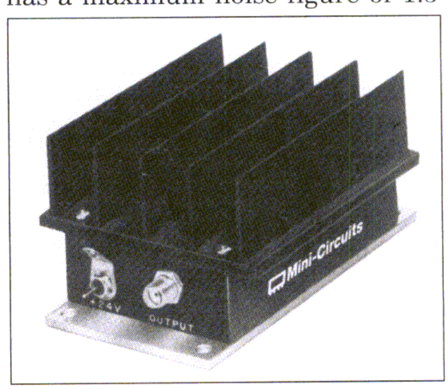
quency, broadband test equipment, wireless data radios in the 5 to 6 GHz range, electronic toll collection and wireless local loop systems. Pricing of products in the family is as low as $5.75 in 1,000 piece quantities.

Alpha Industries
Circle #174

AMPLIFIERS

Medium power amplifier for 1700 to 2400 MHz

Mini-Circuits has introduced a broad band 1700 to 2400 MHz ultra low noise coaxial amplifier. At room temperature, the ZHL-1724MLN has a maximum noise figure of 1.5



dB and +22 output power at 1 dB compression. Typical gain is 30 dB with ±0.6 dB flatness. IP3 is specified as 32 dBm typical. The amplifier is equipped with a heat sink and SMA female connectors. The ZHL-1724MLN is available off-the-shelf and is priced at $295 each in quantities of 1 to 9.

Mini-Circuits
Circle #175

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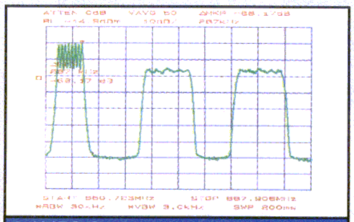

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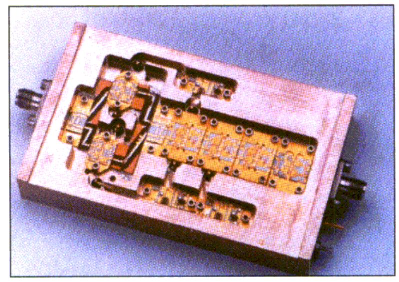
Circle 17

Products

2 watt amplifier for Ku-band

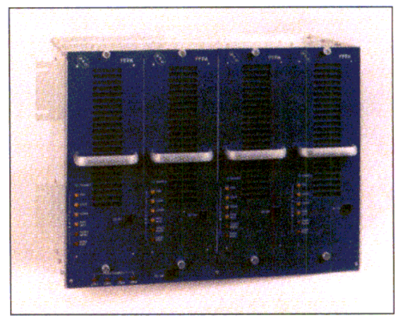
JCA Technology offers the Model JCA1214-900 power amplifier, providing +33 dBm P_{1dB} in the 12.0 to 14.0 GHz band. The amplifier has a minimum gain of 30 dB with maximum variation of ±1.0 dB. Typical noise figure is 5.0 dB and the input/output VSWR specifications are 2.0:1 maximum. The unit offers a drop-in style package, but can be customized for specific requirements.



JCA Technology
Circle #176

Cellular 400 watt feed forward amplifier

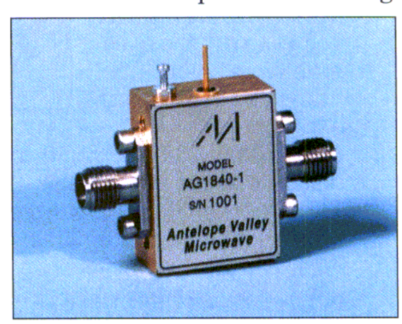
MPD Technologies announces the availability of the Cellular 400W FFPA System utilizing feed forward technology for simultaneously transmitting multiple AMPS, CDMA, TDMA and 3G modulation formats with IMD greater than –65 dBc. Each of the system's four FFPAs are capable of delivering 120 watts, achieving up to 400 watts from four FFPAs.



MPD Technologies, Inc.
Circle #177

mm-wave units cover 18 to 42 GHz

Antelope Valley Microwave now offers a line of low cost connectorized millimeter-wave amplifiers covering the frequency range of 18 to 42 GHz. The Low Noise Amplifier line features noise figures from 3.0 dB at 20 to 24 GHz (Model AL2024-30) and 4.0 dB from 18 to 26.5 GHz (Model 1826-40). The General Purpose Amplifier line features Model AG1840-1, a wideband unit with 9 dB of gain from 18 to 40 GHz, and other models with up to +17 dBm output power. These mm-wave amplifiers have typical input and output VSWR or 2.5:1 with SMQ or 2.92 mm connectors. Standard units are priced from $495 in small quantities.



Antelope Valley Microwave
Circle #178

NEW PRODUCTS

NO.65

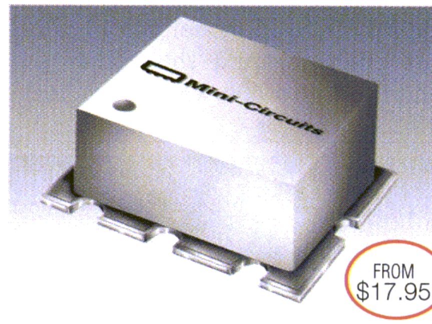
RF/IF MICROWAVE COMPONENTS

LEVEL 7 (LO) VHF/UHF MIXERS HAVE VERY HIGH CPK

Mini-Circuits patent pending 0.5 to 500MHz ADE-1 frequency mixers deliver 6 sigma performance reliability with failure rate less than 3 units per million. Typically at midband, the unit exhibits low 5.0dB conversion loss, excellent 55dB L-R isolation, and excellent 15dBm IP3 to reduce intermodulation. Low profile package stands only .155" (max.), and a 5 year Ultra-Rel® reliability guarantee is included. Available from stock.

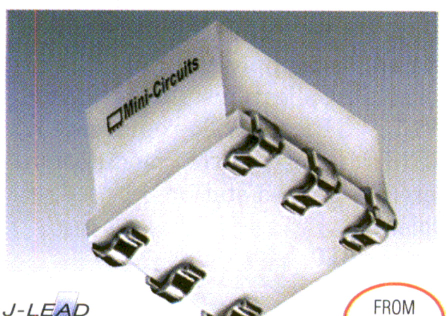
12V VCO HAS 1550 TO 1720MHz LINEAR TUNING

Mini-Circuits has introduced the ROS-1720, a compact 0.5"x0.5"x0.18" voltage controlled oscillator. Typically, this 1550 to 1720MHz VCO displays low -101dBc/Hz SSB phase noise at 10kHz offset, 28 to 34MHz/V tuning sensitivity, and -17dBc harmonic suppression. Tuning voltage is 0.5 to 12V (min. to max.), and power output is 7dBm typical. Applications include PCS.



LOW COST MIXER REDUCES INTERMODULATION 5 TO 1800MHz

This level 17 (LO) SYM-18H surface mount frequency mixer from Mini-Circuits targets PCS and cellular applications within 5MHz to 1800MHz. Typically at center band, the component exhibits high 30dBm IP3, low 5.75dB conversion loss, and very high 45dB L-R, 50dB L-I isolation. Ruggedly constructed in a low cost plastic package with solder plated terminations, this high performance solution includes a 5 year Ultra-Rel® guarantee.



20dB DIRECTIONAL COUPLER PERFORMS TO 1500MHz

Mini-Circuits 50 ohm JDC-20-5 is a broad band 50 to 1500MHz directional coupler offering a 20.5dB±0.5dB nominal coupling value with ±0.75dB maximum flatness. Insertion loss is low at 0.5dB (typ) and directivity is 22dB typical at midband. This compact 0.28"x0.31"x0.23" all-ceramic surface mount device is equipped with solder plated J leads for superior mechanical integrity over temperature. Applications include cellular signal sampling.

3MHz TO 800MHz TRANSFORMERS FEATURE GOOD RETURN LOSS

Mini-Circuits broad band TCM4-1W surface mount RF transformers operate in the 3 to 800MHz band with 4:1 impedance ratio. Referenced to midband loss (0.8dB typ), insertion loss is 1dB from 10MHz to 100MHz, 2dB in the 5 to 400MHz range, and 3dB band wide. Input return loss is 20dB (typ) at midband and maximum RF power is 250mW. Uses include CATV, VHF/UHF receivers, balanced amplifiers, and impedance matching. Shipped from stock.

BROAD BAND CHOKE BIASES AMPLIFIER CIRCUITS TO 8GHz

Mini-Circuits low cost ADCH-80 is a very broad band 50MHz to 8000MHz RF choke housed in an ultra-low profile 0.108" patent pending package. Typically, the unit displays low 0.3dB insertion loss, 1.1:1 VSWR, and 1.8μH inductance at 50mA when operated at -20°C to +85°C (max.). Parasitic capacitance is low at 0.1pF typical. This patent pending circuit outperforms previous generation units by providing high RF impedance over a very broad frequency range.

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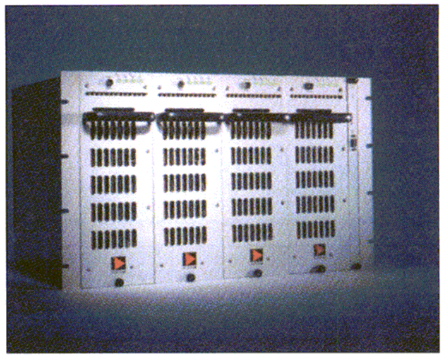
F 313 Rev. Org.

Multicarrier power amplifier series

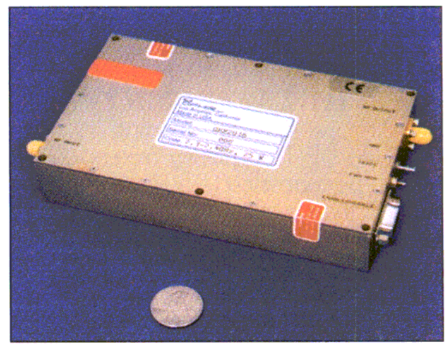


Spectrian announces its MCPS 3000 Series of multicarrier power amplifiers. The new series offers the flexibility and upgrade capability of the company's product family. The MCPS 3135 model has 11 percent efficiency and the ability to generate up to 500 watts of digital or analog power by combining four 135 watt units in a 23 × 14 × 18 inch shelf. The combining architecture provides a "soft fail" mode to avoid outages, along with "hot swapping" replacement of amplifier modules.

Spectrian
Circle #179

WCS/WLL band amplifier

Model GRF2016 from Ophir RF provides 40 watts linear power or 7.5 watts W-CDMA in the 2.3 to 2.4 GHz band. The unit uses advanced GaAs FET devices and unique



microstrip techniques to achieve high dynamic range, low distortion and a low noise figure. For reliability, the unit includes a voltage regulated bias supply and EMI/RFI filtering. Applications include WCS, WLL, GPS, TWT replacement, RFI/EMI test, laser modulation, satellite ground stations.

Ophir RF
Circle #180

DSP-based multicarrier cellular amplifier

WiseBand Communications has introduced the WISE-800, a fully DSP-based ultralinear power amplifier. The unit provides 80 watts over 869 to 894 MHz and supports up to four modules for 300 watts total power. Efficiency is higher than 10 percent. The WISE-800 uses DSP to continuously correct RF distortion to meet required emission limits without tuning and with low maintenance.

WiseBand Communications Ltd.
Circle #181

SEMICONDUCTORS

RF telemetry receiver ICs

Micrel Semiconductor has added two complete data receivers to its QwikRadio™ IC line. The MICRF004 and MICRF044. The MICRF004 includes all available features of the chip in a SOIC-16

package, providing a complete 140 to 200 MHz range receiver for OOK signals used in remote meter reading in the VHF band. The receiver can be used in a fixed mode when stable, accurate transmitters are used, or in a sweep mode to capture signals from simpler LC oscillators used in some transmitters. The MICRF044 is a reduced feature set version in a smaller SOIC08 package. The ICs draw 2.4 mA from a 5 VDC supply when operating, which is reduced to 240 μA in polled operation (10:1 duty cycle). The price of the 16-pin MICRF044 is $5.17 each in quantities of 1,000.

Micrel, Inc.
Circle #182

2.4 GHz transceiver IC

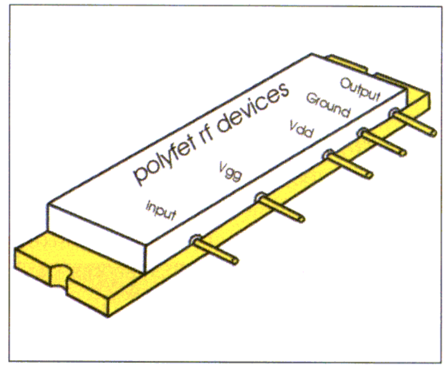
RF Micro Devices' RF2938 is a highly integrated RF/IF transceiver for 2.4 GHz ISM wireless data applications. The receive circuitry includes AGC, quadrature mixers and user-programmable I and Q filters. Typically, the RF2938 would be used with an RF2444 LNA/mixer to implement a spread spectrum transceiver. The transmitter also includes programmable filters and transmit VGA. It also has a second on-chip 2.4 GHz up-converter and an internal RF amplifier providing +6 dBm output.

RF Micro Device
Circle #183

RF power modules

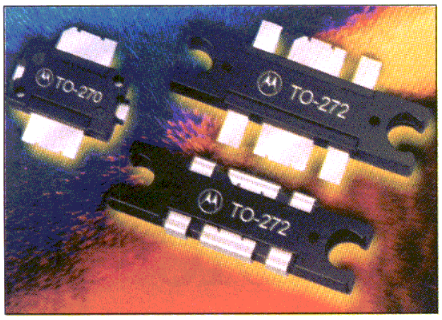
Polyfet has introduced power modules for new or replacement applications. These 50 ohm gain blocks are available in frequencies that cover the 30 to 1,000 MHz range, with 2 to 30 watts output. Nominal gain is 25 dB and operating voltages are from 7.5 to 50 VDC.

Polyfet RF Devices
Circle #184



RF plastic packages receive JEDEC approval

Motorola has received JEDEC registration on two RF power plastic packages, TO-270 and TO-272. These packages are used for high power LDMOS discrete transistors

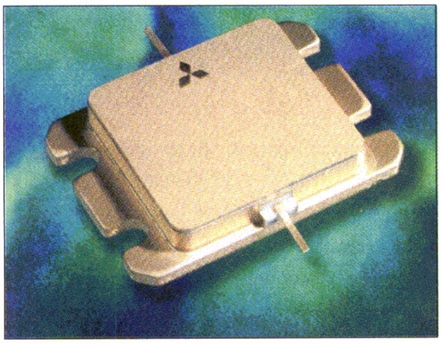


capable of handling up to 65 watts. TO-270 is a two-lead surface mount RF package and the TO-272 is a six-lead screw mount package. Both are completely gold-free and use IC-like coplanar design with solderable leads and a copper heat sink. The packages will be used for new Motorola LDMOS transistors released in 2000.

Motorola
Circle #185

High power 3.4 to 3.6 GHz GaAs FETs

The Electronic Device Group of Mitsubishi has announced sampling of a family of GaAs FETs for C-band wireless local loop (WLL)



power amplifiers operating in the 3.4 to 3.6 GHz band. The FETs have internal 50 ohm matching, high linearity and low third order IMD. The devices operate in class A and are provided in hermetically sealed ceramic packages. Available P_{1dB} outputs range from 4 watts to watts, with typical IMD_3 specifications of –45 dBc.

Mitsubishi Electric Corporation
Circle #186

Bluetooth wireless link IC

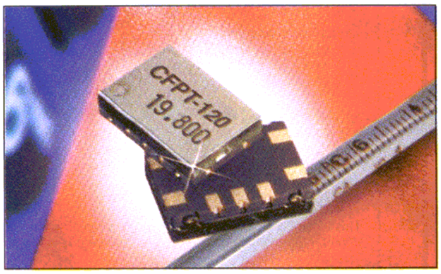
Silicon Wave has developed a "system-on-a-chip" IC for operation using the Bluetooth technical standard for short range wireless data links. The device includes all radio, modem and synthesizer functions on a single piece of silicon, allowing low cost manufacturing of wireless-connected PDAs, computer peripherals, home and office networks, remote controls and digital consumer products.

Silicon Wave
Circle #187

FREQUENCY CONTROL

TCXO for mobile communications equipment

A series of compact surface mount TCXOs has been introduced by C-MAC. The CFPT-120 is available in a frequency range between

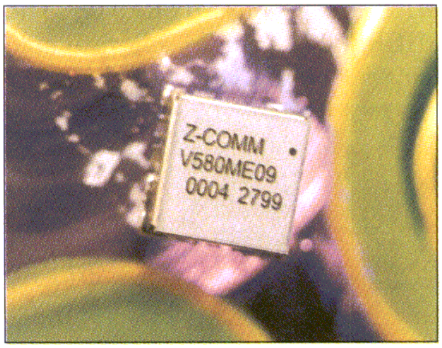


12.6 and 19.8 MHz, including standard mobile telecom frequencies of 13.0 and 19.44 MHz. Voltage control trimming of the frequency allows 8.0 ppm adjustment. Frequency stability may be as low as ±2 ppm over –10° to +60° C. The standard stability specification is ±2.5 ppm over –20° to +75° C. Aging is typically ±1 ppm over the first year. The CFPT-120 draws 2 mA from a 3 volt supply. It is priced at $3 to $4.80 each for common frequencies and standard specifications (5,000 quantity).

C-MAC Frequency Products
Circle #188

VCO covers SMR band

The V580ME09 from Z-Communications is a surface mount VCO covering a frequency range of 805-825 MHz, operating from a +5 VDC supply. The typical

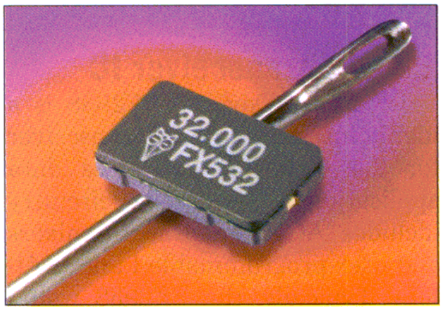


phase specification is –110 dBc/Hz at 10 kHz offset, with tuning sensitivity of 43 MHz/V over the 0.5 to 4.5 VDC tuning range. Power output into a 50 ohm load is +5.5 ±2 dBm. Second harmonic levels are typically –12 dBc. In 1,000 piece quantities, the VCO is priced at approximately $15 each.

Z-Communications, Inc.
Circle #189

Ultra miniature crystal

Fox Electronics offers a low cost ultra miniature crystal suitable for many portable applications. The FX532A measures 5.0 × 3.2 × 1.0 mm, and is offered in a fundamental frequency range of 14 to 40

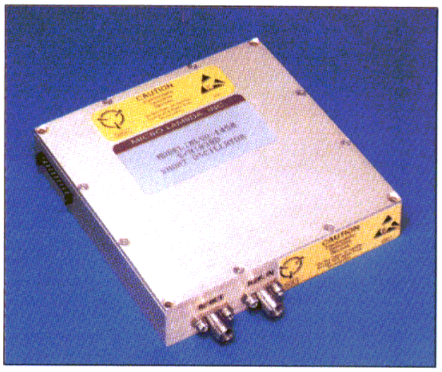


MHz. The crystal has a standard frequency tolerance of ±100 ppm, stability of ±100 ppm and an operating temperature range of –10° to +60° C, with other tolerances and stability options also available. Pricing starts at $0.99 in modest quantities.

Fox Electronics
Circle #190

Digital controlled phase locked sources

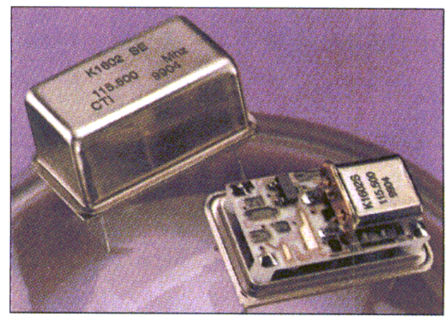
The MLSO Series oscillators from Micro Lambda are tunable low noise sources using a 12-bit digital interface for precise tuning. Tuning steps of 50 MHz to 200 MHz are provided, which are related to and are an exact multiple of the reference frequency used. The sources provide octave and multi-octave tuning up to 8 GHz, or 2 to 3 GHz tuning ranges up to 20 GHz. All models provide power output levels of +12 to +20 dBm. Guaranteed noise specifications for units covering 2 to 7 GHz are –120 dBc/Hz at 100 kHz offset, –135 dBc/Hz at 1 MHz offset. Noise within the loop bandwidth is dependent on the reference noise and frequency division ratio.



Micro Lambda
Circle #191

High frequency, low noise TCVCXOs

Champion Technologies has expanded its line of oscillator products with the K1600SE family of TCVCXOs, packaged in an indus-



try-standard 14/4 DIL metal package. The K1600SE is offered in discrete frequencies from 30 MHz to 120 MHz. The operating temperature range is –40° to +85° C with temperature stability of ±2.0 ppm. The units provide voltage control for trimming the output frequency. pricing starts at $45 each in 1,000-unit quantities.

Champion Technologies
Circle #192

Low profile OCXO series

Micro Crystal offers a small, light OCXO operating from a 5 VDC supply. The oscillator provides stability of $\pm 5\times 10^{-8}$ with aging of less the 1×10^{-9}/day. The unit also features high shock and vibration resistance. The 10 MHz OCXO model is priced at $20 in 1,000-piece quantities.

Micro Crystal
Circle #193

LITERATURE

Static control products

Richmond Technology has introduced a new full line catalog. This 76-page Static Control Product Guide contains a complete detailed listing of Richmond's static control packaging, wrist straps, grounding

mats, monitors, and meters, and cleanroom flexible packaging in full color with pictures, useful technical data, specifications, features and benefits. It also includes a glossary of frequently used terms and symbols, an ESD tutorial that explains ESD cause, effect and prevention, and information and charts to assist in understanding and choosing the right ESD products.

Richmond Technology
Circle #194

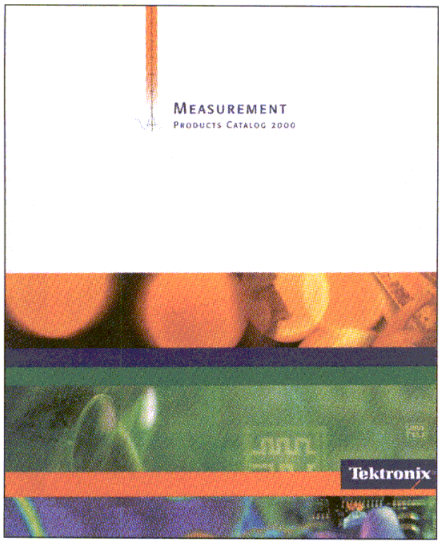
White paper outlines circuit protection rules

Raychem Circuit Protection has issued a white paper to help manufacturers of information technology equipment (ITE) that connects to the Public Switched Telephone Network to clearly understand the protection requirements of the new UL 1950 3rd Edition safety standard. All new ITE products submitted for UL Listing beginning April 1, 2000, such as computers, fax machines, telephones and modems, must be approved to UL 1950 3rd Edition. The white paper explains the new safety specification, its background and the paths available for compliance, including the use of Raychem's circuit protection solutions such as the surface mount TS600 and radial-leaded TR600 product families.

Raychem Circuit Protection
Circle #195

Measurement products

Tektronix, Inc. recently announced the availability of its new 2000 Measurement Products Catalog. Available in print and on CD-ROM, the catalog features a broad offering of test equipment. With a comprehensive family of more than 1,400 test and measurement products, Tektronix is providing solutions for next-generation global communications networks and Internet technologies. Solutions range from low-cost instrumentation and handheld products to conventional measurement products and advanced mixed-signal test solutions. The 600-page, soft cover catalog includes a full cover new product section that highlights new prod-

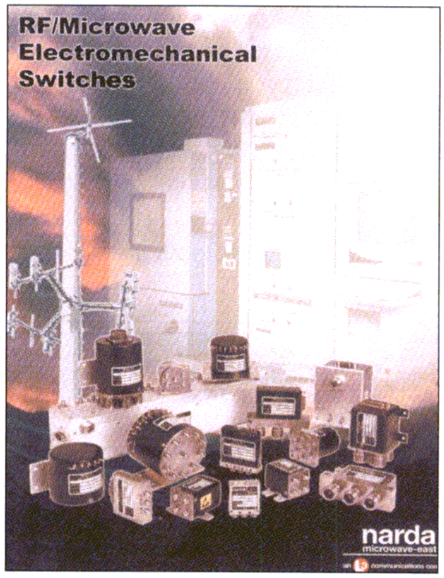


ucts and measurement solutions for Rambus systems, RF design, and mobile and core telecommunications networks. Indexes list products by name and function, as well as by categories.

Tektronix Inc.
Circle #196

RF and microwave switch catalog

Link Microwave Ltd. has released a new 124-page catalog featuring the comprehensive lineup of RF and microwave electromechanical switches manufactured by Narda. In addition to the company's standard switches covering the frequency range DC to 26.5 GHz, the catalog includes details of how to order custom switches for application requirements that are not satisfied by off-the-shelf products. For each product type, the catalog presents a summary of key technical specifications, together with a photograph and dimensioned line diagrams. Major new products are highlighted at the beginning of the catalog, and there is also an informative section outlining Narda's

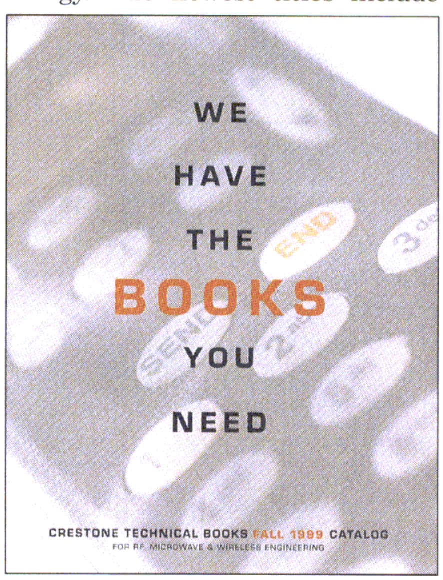


design, manufacturing and service capabilities.

Link Microwave Ltd.
Circle #197

Specialized RF, microwave and wireless books

Crestone Technical Books' new catalog features nearly 250 books, video courses and software products specifically selected to meet the reference needs of engineers working in RF and microwave technology. The newest titles include



books on power amplifiers, oscillators, microwave design techniques, W-CDMA, WLAN and other key topics. Also featured is the "Wireless Made Simple" CD-ROM course and ELEKTA Professional CD-ROM based analog/RF electronics tutorial, reference and design tools package. Quantity discounts are offered and books can be purchased and shipped worldwide.

Crestone Technical Books
Circle #198

Phase stable coaxial cable assemblies brochure

Insulated Wire Inc., has released a new product brochure, featuring the company's new phase stable coaxial cable assemblies. The new line of cables and assemblies has improved the performance of characteristics for all types of microwave applications. The line yields smaller diameters, lighter

weights, lower insertion loss, and enhanced electrical stability versus temperature and flexure. The brochure includes detailed description of the products' performance capabilities, including graphs and tables that overview cable specifications, cable assembly specifications, attenuation curves and power handling curves.

Insulated Wire Inc.
Circle #199

Submit New Product announcements to *Applied Microwave & Wireless* at the address on page 8.

Notes on Low Cost Design Techniques

By Gary A. Breed
Publisher

I have always paid attention to the ways engineers go about their jobs. I ask questions and listen to their answers. Here are some of the things RF and microwave engineers say are important when designing for a low finished product cost.

Low parts count

A design that is carefully thought out with regard to the minimum necessary package of components is on the right track. Direct benefits are lower inventory and a little less overhead in Purchasing and Receiving. Assembly time may be reduced, but the savings may be small if there are specialized or non-standard components, or if the mechanical assembly is complex. The trade offs seem to be in two main areas: sacrificing performance for simplicity and substituting adjustable parts (and assembly line tweaking) to avoid a more complex no-tune design.

Standard components

This is one of the most-often mentioned factors. Using parts common to all types of electronics, using the same value parts whenever possible, and using ICs in the easiest packages for automated assembly all are recommended for a low cost design. The decision to deviate from this practice must be justified to achieve required performance or by some other quality factor.

Avoid leading edge technology

For lowest cost, stay with the "tried and true." It can be hard to resist using the latest multi-function IC from XYZ company. But before you design it into a product, be 100 percent sure that it is in full production and that its manufacture is certain for the life of your product (and beyond if service is an issue). Too many re-designs have resulted from a production problem or early discontinuation of a key component. Mature component technology that is widely used by other companies is always safe. Sometimes, however, the design simplification or performance advantages will justify taking a modest risk.

Understand manufacturing and test

Design-for-manufacturing is not an academic concept. Talk to the production people, see what kind of equipment and personnel are doing the final tests. Maybe even take your turn on the assembly line for an hour or two.

In a large company, the value of this information is often overlooked when an engineer is designing a new widget; it is too easy for departments to remain isolated. The next time a small entrepreneurial company beats your behemoth employer to the market with a terrific product, remember that the engineer who managed its design may have been responsible for its manufacturing, testing and quality control. This kind of start-to-finish responsibility often results in a superior product.

Make sure the specs are right

When a product is conceived by the Marketing Department or whatever management team has that role in your company, it usually includes both realistic and innovative attributes. The innovation required to achieve a successful design should follow a clear path from concept to design. It should be "Here's how we are going to do this," not, "Here's how I think this will work." A well-defined set of product specifications will enable the engineering team to execute a good design. Specs must include performance goals, cost goals, size and weight goals, external appearance goals and all the other things that will make the product sell.

Know when to stop designing and start building!

These notes have discussed cost issues from the bottom up — the #1 comment from engineers on the subject is to conserve *time*. Of course, time to market is essential in today's highly competitive wireless business, but I heard this comment years ago from engineers with much less stressful time constraints.

Time has an effect on design quality. At the beginning of a project, the excitement of a new design, the rapid progress on major design criteria and the distance from deadlines combine to create a fast "rise time" in the design cycle. Once the first prototype is built, interest diminishes, then peaks again as revisions bring the results closer to the goal.

After two or three revision cycles, interest and, inevitably, quality of work will decline. Continued work will probably not result in a better product. At this point, the product should declared either "finished" or "dead." Note that the "dead" state is not all bad. Sometimes a legitimate dead end is reached due to unobtainable specs or unrealistic product definition. A restart from the beginning may result in a product that exceeds the original expectations. ■

The LogProbe Logarithmic Detector

Here is a design case history describing a versatile measurement accessory with many RF applications

By Carl Lodstrom
Pressebo Electronics

During the last few years, some attractive RF detector ICs have become available. An IC in itself, of course, cannot be used directly for the many daily test and measurement challenges on the lab bench. Thus, an instrument to meet these challenges needed to be designed. This article introduces the LogProbe® a versatile logarithmic detector with a wide frequency and dynamic range.

In contemplating the design of such an instrument, no such device was known to exist, so "prior art" was not of much use. Several points had to be addressed if the instrument was to become an acceptable general purpose tool, including power supply, enclosure, system considerations, output signal conditioning, manufacturing cost and ease, and internet friendliness.

Design requirements for each feature

Power supply — The detector IC runs on 5 volts. It would be useful if the instrument could run on all kinds of voltages. A series regulator that can handle >30 volts would suffice.

Enclosure and system — The detector was visualized to be used with all kinds of "probe tips." The problem, then, is to identify a connector format that will accommodate those probes but that is inexpensive and available worldwide. The chosen connector should not require an enclosure any larger than necessary. These requirements are set by several applications foreseen from the outset.

With a differential input on the IC, one obvious use is to connect a floating pick-up coil for detecting magnetic (RF) fields. In general, this excludes coaxial connectors. Another use is to ground one input and connect a small wire to the other input to detect electric fields. The convenience of just plugging in a wire or pin speaks for a female connector.

Other applications will connect a signal via a coaxial connector, with or without a 50 or 75 ohm internal termination. Thus, an adapter must be designed. Another suggestion may be the implication of a tuned input circuit for sensitizing the detector for one frequency range.

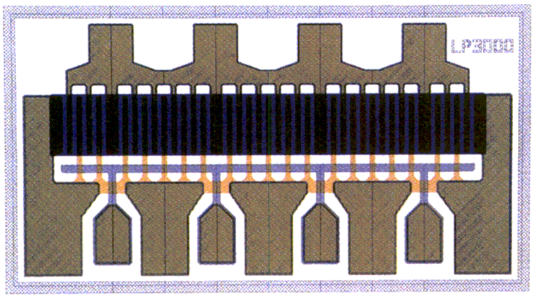
The same housing as an adapter might be used for a 20 dB preamplifier for small-signal work, or a directional coupler for measuring return loss from filters and antennas using a sweep or signal generator.

Non-RF uses may also be considered. An accelerometer will need a charge amplifier, and a fiber optic detector needs a photo detector and a transconductance amplifier. With the large dynamic range, a logarithmic detector is an excellent bridge detector; could we possibly make an entire "plug-in" RF bridge? More applications are likely to be found and developed in response to the user's own applications.

Obviously, the right connector body type needed to be chosen from the start. It had to be flexible, small and rugged, as well as shielded, since the detector is very sensitive.

Output signals — Output signals from detector ICs do not have a good scale factor or much drive capability. Thus, an output amplifier is needed. Since a dual op amp takes as much room as a single one, at least in an 8-pin package, one could let the second one perform DC offset of the output to almost 0 volts for no input signal. With a possibility of >30 volts applied, the op amp will have to be able to handle this or run off of only 5 volts. As we will see later, an output voltage of 10 volts may be desirable, so

pHEMTs in Production...
from low noise to power!



Product Features*:

Noise Figure:	1.0 dB @ 18 GHz
Gain:	10 dB @ 18 GHz
P_{1dB}:	33 dBm @ 18 GHz
IP3:	48 dBm @ 18 GHz

*with optimum biasing

Filtronic Solid State offers a variety of Single and Double Hetero structured pHEMTs with a 0.25-micron gate length for low noise amplifiers, drivers, and gain and output stages up to 2 watts from DC to millimeter wave for Pt-to-Pt Radio Links, Local Area Networks, Military Programs and Space Applications.

Complete specifications are available on our web page. These devices are also available in a variety of low-cost packages.

Model Number[1]	P_{1dB}	Gain	Power-Added Efficiency
LPD200	21 dBm	12 dB	60%
LP6836	25 dBm	9.5 dB	55%
LP750	28 dBm	10 dB	55%
LP1500	31.5 dBm	8 dB	50%
LP3000	33.5 dBm	7 dB	45%

LPS200 available in single hetero stucture with noise figure 0.7 dB.

[1] All specs recorded at 18Ghz

Wireless **Military** **Satellite**

Visit our website, http://www.FiltronicSolidState.com

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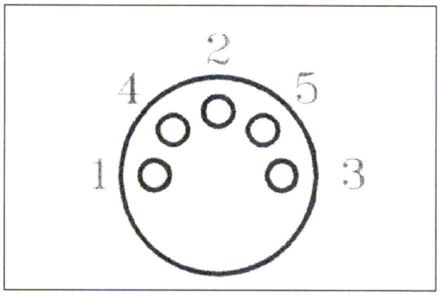
Circle 48

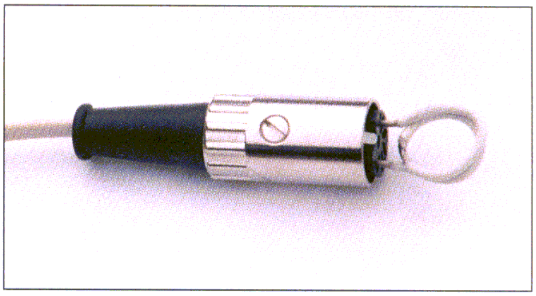
the >30 volt option is really the only choice.

Cost and manufacturing — If the entire device could be built on a printed circuit board that fits into a strong connector body, many of the goals would be reached.

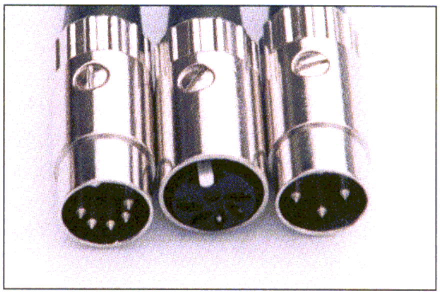
Internet support — Recently, a product does not seem to be considered a product unless it has a web site. A name suitable for the product and a web site both were both of prime importance. Thus, the the name LogProbe was chosen; fortunately, the trade name and the site name both were available.



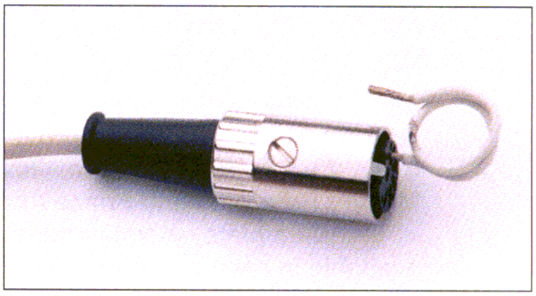
▲ **Figure 1. LogProbe front view showing connector pins.**



▲ **Figure 3. A simple pickup for magnetic fields.**



▲ **Figure 2. Both a 3-pin and a 5-pin plug fit into LogProbe.**



▲ **Figure 4. The same device as a pickup for electric fields.**

The final design choices

For the enclosure, a DIN audio connector housing by Preh-Werke, Bad Neustadt, Germany, was chosen. It is a one-piece cast metal device, strong enough to survive rough handling, and the DIN format is a common standard throughout the world. It is economical and compatible with many mating plugs. Connector and enclosure problems were both solved with one product.

The inherent symmetry of the connector is appealing, using the center pin for ground and the outermost two for the differential input signal. This leaves two pins in between, which is fine since any active plug-in will need power. I elected to put out the input supply V+ direct through to pin 4. Pin 5 can be used for the output signal from the detector output amplifier. This is not initally connected, since it causes the output to be noisy if the input is open. The customer can easily add this internal wire if he wishes, making the entire device independent of the cable at the other end. It can be a temporary plug in itself for some other instrument! (See: Output on pin 5)

Another advantage of the DIN audio connector format is that the 3-pin 180 degree version fits in a 5-pin 180 degree receptacle, leaving the "in-between" positions open. A passive device can use a 3-pin plug and an active device the 5-pin plug.

The output should have some sensible scale factor. I decided upon 10 dB/V. For the full dynamic range of 92 dB (9.2 V out plus a little "at the bottom" for no input condition), this requires at least a 10 volt supply. A 9 volt battery will do quite well, except for the uppermost 5-10 dB of range. As a matter of fact, 5 volts are already usable for the first ~30 dB. Each customer can provide whatever supply they like. Each LogProbe is delivered with a 9 volt battery, which should do until the customer identifies his needs and chooses a wall plug transformer, a couple of 6 volt Lithium batteries or other power supply.

The current consumption is 20 mA; the output amplifier has a ±40 mA drive capability; and there is a 50 ohm resistor in series with the output line, eliminating capacitive load problems. If operated with very high input voltages and large output currents, the internal 5 volt regulator may shut down thermally, but it will restart after it has cooled down.

A prototype BNC adapter was built with an internal 50 ohm termination, and the sensitivity was measured over frequency as far as the available source allowed. In the plot in Figure 5, the output voltage is entered for several frequencies and for each 5 dBm from 10 MHz to 1.3 GHz. In Figure 6, the same set of data is presented, but with the power as a parameter.

We can see in the first diagram how linear the response is and in the second how it is almost flat to 600 MHz (a 3 dB rolloff), and thereafter dropping by about 6 dB/100 MHz. The temporary BNC adapter may be the cause of much of this. An improved design has not yet been tested.

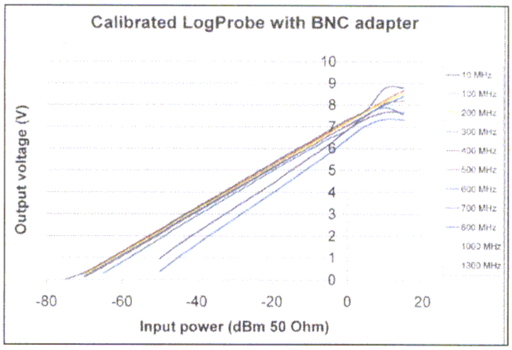
We can also see how the output signal for very small input levels actually reaches 0 volts. I have since adopted the practice of adjusting the output to 5 volts for –30 dBm at 100 MHz. This leaves the output level at a few hundred mV with no signal. This way, very small levels can be detected, even if they are not yet driving the detec-

tor into the "linear dB" region. A range of 20 to 30 μV can be detected, and the "linear dB range" covers from about 55 μV to 2.2 V, a dynamic range of 92 dB.

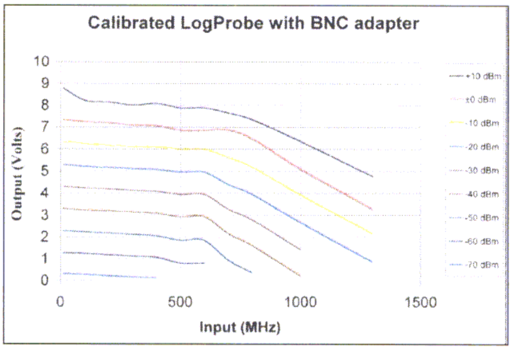
Applications

As a scalar network analyzer — I put together a 100 to 180 MHz VCO (Mini-Circuits JTOS-200), tuned by the oscilloscope sweep output, and a directional coupler (Mini-Circuits ADC-10-4) to measure the reflected signals from objects. LogProbe can be plugged in via three short 1.2 mm diameter wires sticking up from the circuit board. Figure 7 shows the setup.

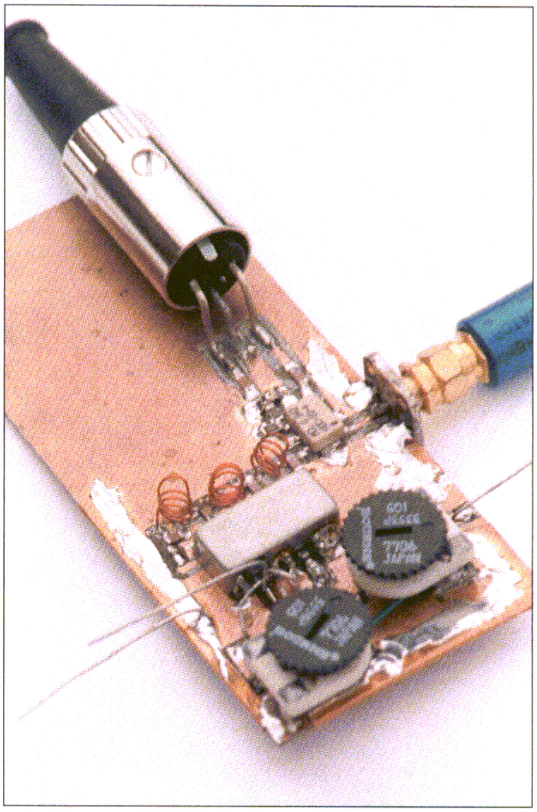
The VCO output signal has a strong harmonic content. For accurate measurements, especially of return loss ($|s_{11}|$), they must be removed with a low pass filter.



▲ **Figure 5. Response with frequency as a parameter.**



▲ **Figure 6. Response with power as a parameter.**

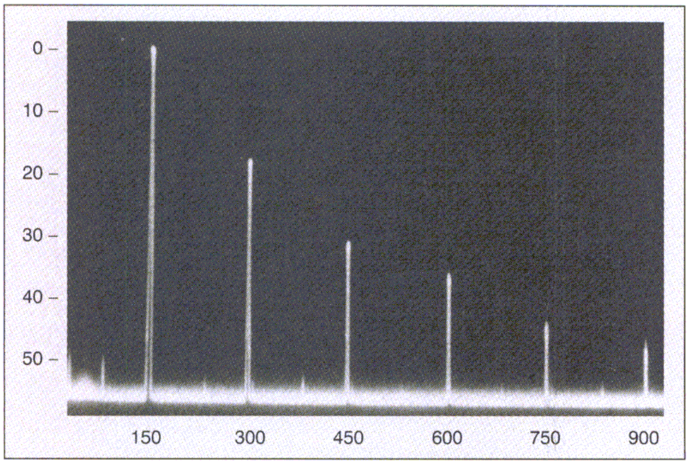


▲ **Figure 7. The VCO, low pass filter and directional coupler with LogProbe plugged in.**

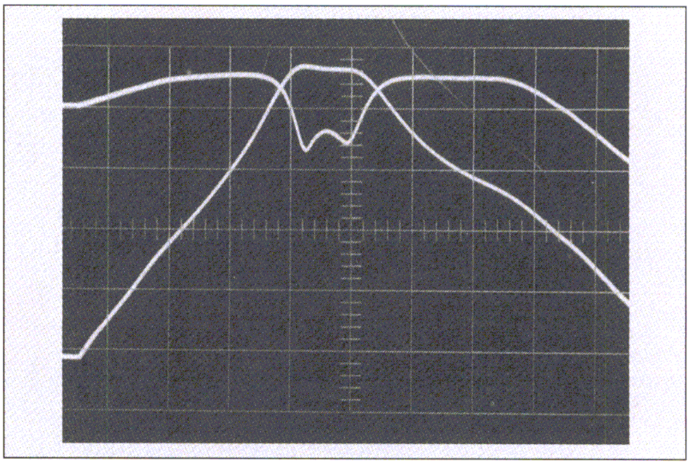
When the JTOS-200 is set to 150 MHz, the second harmonic is only 20 dB lower (Figure 8). If a load is well-tuned for 150 MHz, with a return loss (RL) of about 30 dB, the RL for the 300 MHz tone may be near zero. This limits the RL measurement at 150 MHz to –20 dB. A 5th order LP filter for 200 MHz was built to follow the VCO, and the result was more pleasing.

A bandpass filter for 137 MHz was the test circuit. The output was terminated and the RL $|s_{11}|$ was measured. Its output was then connected to the LogProbe via the BNC adapter and the $|s_{21}|$ plot was double-exposed onto the same scope camera film.

On both traces, the vertical scale is 10 dB/cm. The bandpass filter has, at best, only a ~10 dB RL and can clearly use some tweaking. On the left edge we can see the $|S_{21}|$ flatten out at –47 dBc. This is most likely the level of the second tone going through the lowpass filter, reflecting from the test bandpass filter as it should. (The sweep start is ~100 MHz, the second tone is ~200 MHz, barely reduced by the lowpass filter.) The RL from the pass region of a filter is a very sensitive indi-



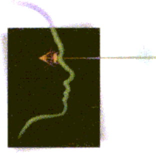
▲ **Figure 8. JTOS-200 output set to 150 MHz.**



▲ **Figure 9. Plot of the output of a BP filter.**

IC

Ultra-High Efficiency In A Low-Cost Step Down Converter



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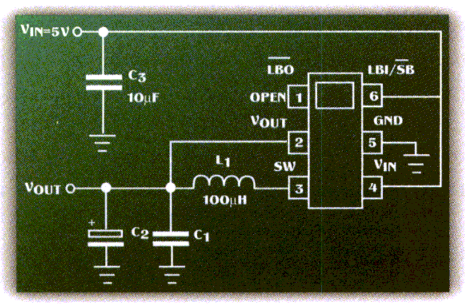

Simple design accounts for small package, low cost

The TK654 is ideal for systems that operate on single Li-ion, multiple alkaline, or recharge (NiCd or NiMH) cells where longer battery life is key. This includes wireless phones, pagers, radio controlled systems, toys – anyplace you need high performance step down conversion.

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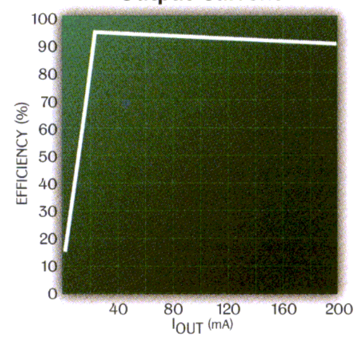
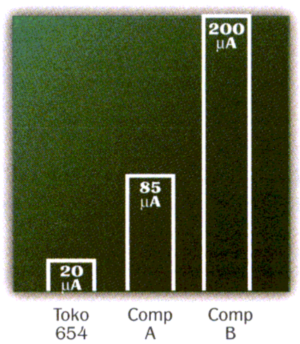
TK65433 Efficiency vs. Output Current



High efficiency across a range of output current to 200 mA



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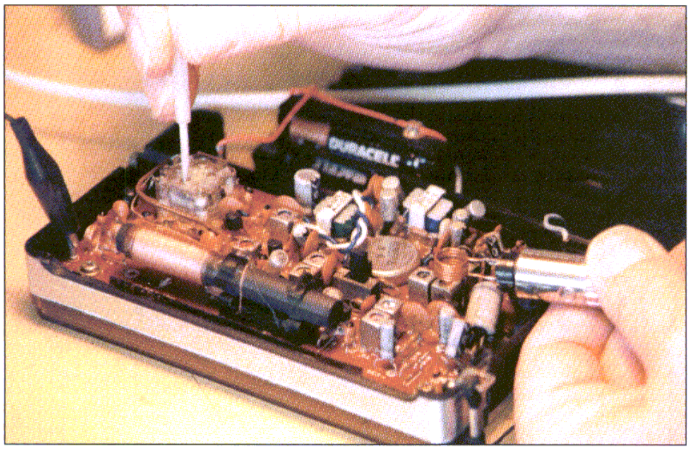
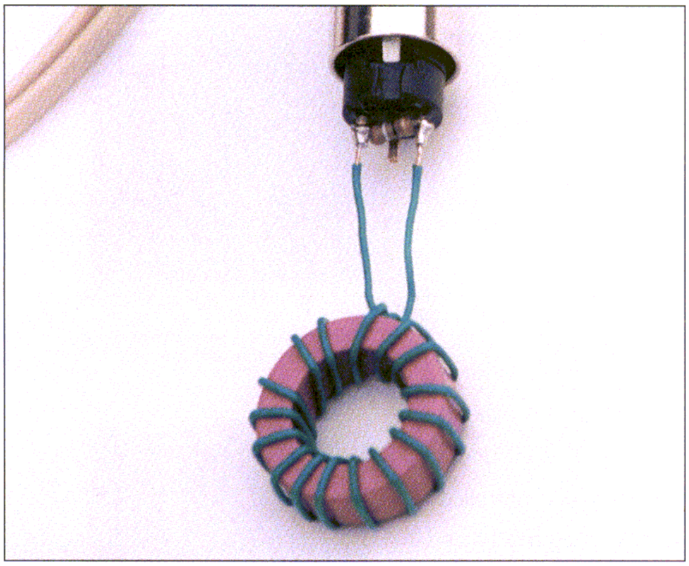
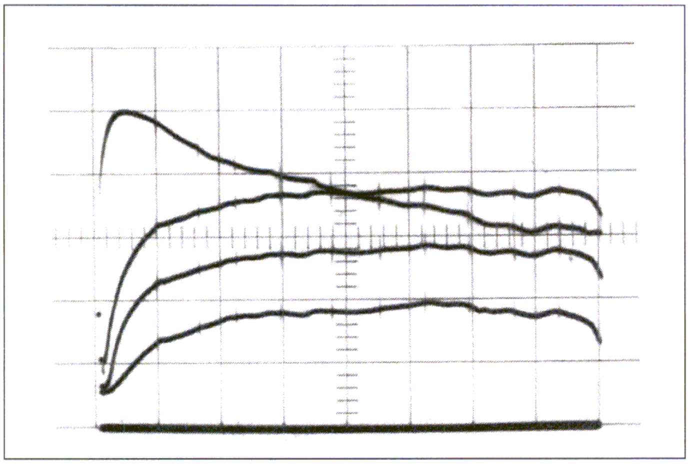
Circle 33



▲ **Figure 10. When coupling to some IF transformers, one can pick up enough signal with a coil outside the ferrite core trimmer hole.**



▲ **Figure 11. LogProbe fitted with a larger toroidal coil (useful for antenna element current measurements).**



▲ **Figure 12. The oscillogram results from a current transformer used directly on a 50 ohm adapter.**

cator of how well the filter is tuned.

Tuning up RF and IF circuits — With LogProbe's sensitivity, it is easy to pick up a signal with a small piece of wire in one input. Holding the wire near the collector of an IF or RF transistor (or the plate pin of a tube, for the more nostalgic among you) while applying a swept source to the receiver input is a useful method that speeds up the work and presents almost no load of the circuits to be tuned. The large dynamic range makes this method possible with one instrument, detecting the weak signals near the receiver input to the near volt levels at the end of an IF strip.

On some IF transformers, one can even pick up enough signal with a coil outside the ferrite core trimmer hole, as shown in Figure 10. Current monitoring with LogProbe connected to a toroidal coil will suffice. LogProbe also works with a larger toroidal coil, e.g. for antenna element current measurements (Figure 11).

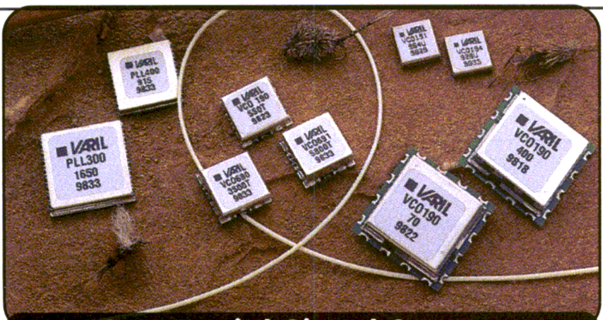
Remember that a current transformer must always be terminated with a low resistance. It can thus be used directly on a 50 ohm adapter. If the toroid has 7 turns and the measured currents pass through once, the 1:7 turn ratio reduces the 50 ohm adapter load by 1/49 in series with the current carrying line, or about 1 ohm.

The oscillogram in Figure 12 (4 exposures) shows an application of just this (but using a very small toroidal coil). The three horizontal traces are the base currents into a transistor, swept from 0 to 500 MHz with a 10 dB level difference between each trace. The source level is then returned to the middle trace and the current probe is moved to the collector (RF grounded), and a graph shows the results. We can see that the current gain at the peak, ~50 MHz, is close to 30 dB higher than the middle base current trace, and at ~250 MHz, the collector current is about 9 dB stronger. So, the current gain at 250 MHz for this transistor is ~9 dB. Vary the bias conditions and see the gain vary in real time on the screen.

In another practical use, a friend needed his satellite dish adjusted. A directional coupler and LogProbe did the job quickly. Even though LogProbe does not have much sensitivity left at the high end of the downconverted band, there is enough at the lower end (950 MHz) so that the dish can be aligned.

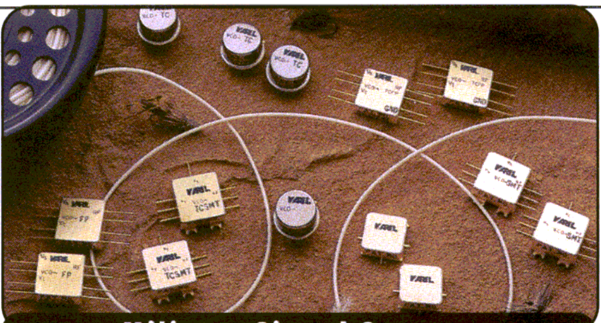
Output on pin 5 — Imagine that you have built some kind of signal or sweep generator and you want to maintain a level output amplitude. Connect the LogProbe output to pin 5 internally and provide a 5-pin plug on the generator. You can now incorporate LogProbe and supply power through pin 4, signal(s) on pin(s) 1 and 3, ground on pin 2, and you can get a control signal for a PIN diode attenuator on pin 5. When using LogProbe for other uses, unplug it and use it. The only drawback is that the output signal gets a bit noisy for pin 3 open and there are no signal conditions. If you use one input only, use pin 1 and ground pin 3.

If the LogProbe is permanently hooked up to a meter



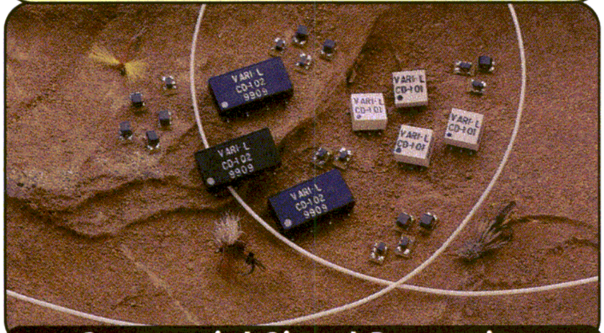
Commercial Signal Sources

- High Performance Voltage Controlled Oscillator Modules
- High Performance PLL Synthesizer Modules



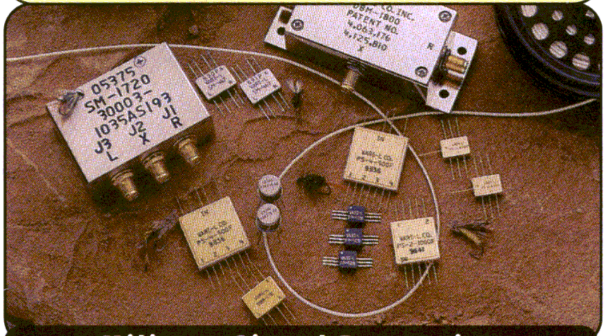
Military Signal Sources

- Ruggedized High Performance Hybrid
- Voltage Controlled Oscillators



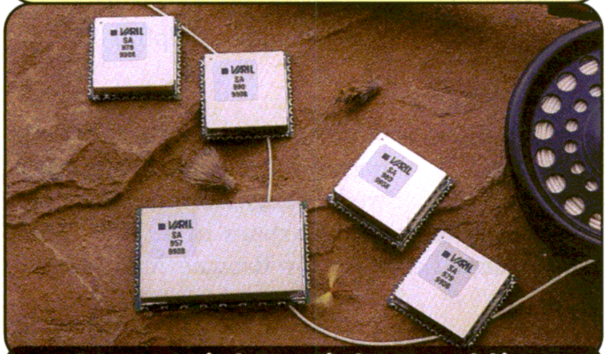
Commercial Signal Processing

- High Performance Wideband RF Transformers
- High Performance Power Dividers and Couplers
- High Performance Double Balanced Mixers
- High Performance RF Chokes
- High Performance Bias Tees



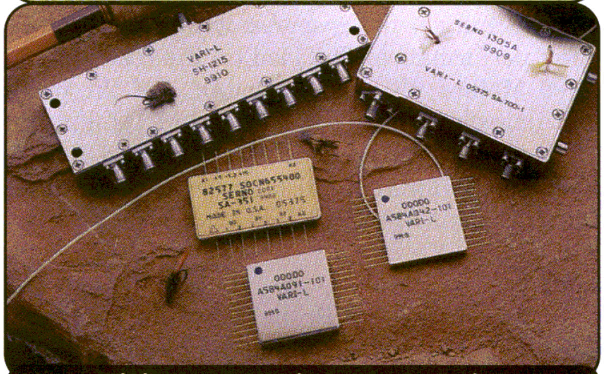
Military Signal Processing

- Ruggedized Double Balanced Mixers
- Ruggedized Wideband RF Transformers
- Ruggedized Power Dividers and Couplers
- Ruggedized I/Q Modulators and Demodulators



Commercial Special Assemblies

- Special Frequency Conversion Modules
- Special Frequency Generation Modules



Military Special Assemblies

- Ruggedized Special Frequency Generation Assemblies
- Ruggedized Special Frequency Conversion Assemblies
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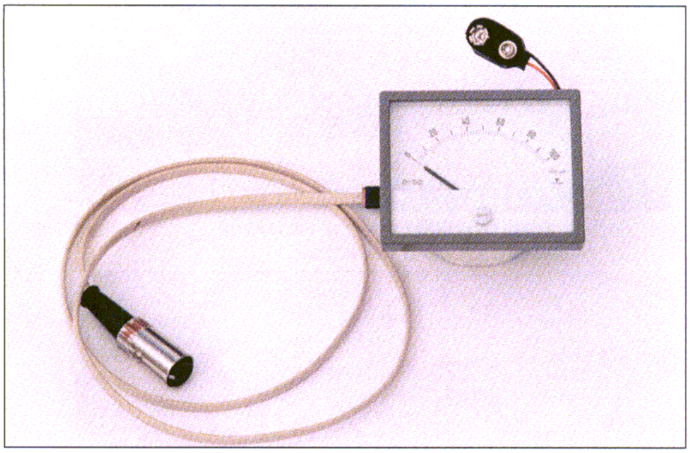


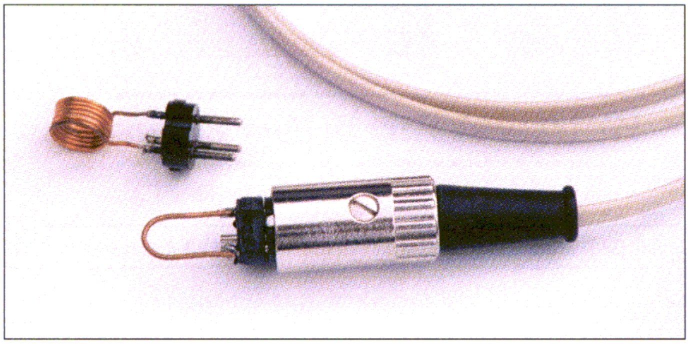
▲ **Figure 13. LogProbe is permanently hooked up to a meter, and if one needs to look at the response with an oscilloscope, the probe is clipped to the back of the meter.**

(FS = 10 volts) and we to look at the response with an oscilloscope, simply clip the probe to the back of the meter. With a BNC adapter (preferably without the 50 ohm termination), one can even use a regular 10:1 oscilloscope probe and get flat response within the limits of the probe's performance. The load on the tested circuit is then ~9 Mohms plus the capacitance of the probe. The input impedance of the LogProbe is 1.1 kohms differential, in parallel with ~3 pF. An inserted DIN plug adds about 2 pF. Plugged in, the 6-turn coil (350 nH) resonates at approximately 250 MHz.

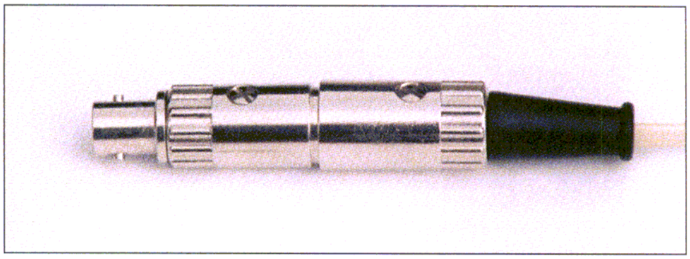
Limitations

The inputs of the LogProbe have no protection against overvoltages. Protection circuits would compromise both sensitivity and frequency response. If needed, one can easily make a protection for both inputs with four diodes and a 5 volt Zener diode fed via a resistor from the V+ at pin 4. Do not expose the inputs to voltages outside $0<V_{IN}<5$.

The usefulness of this device does not extend down to DC. For frequencies below a few MHz, the output "ripples" at twice the input frequency. Both positive and negative input signals will give a positive output signal.



▲ **Figure 15. Plugged in, the 6-turn pickup coil resonates at ~250 MHz.**



▲ **Figure 14. A regular 10:1 oscilloscope probe can be used with a BNC adapter.**

Conclusions

The LogProbe is not just a detector, it is an instrument in itself and the heart of a whole measurement system that will continue to grow as more attachments are developed. As it allows for unusual and efficient methods in measurements and trouble shooting, it is a rule maker and a rule breaker. ■

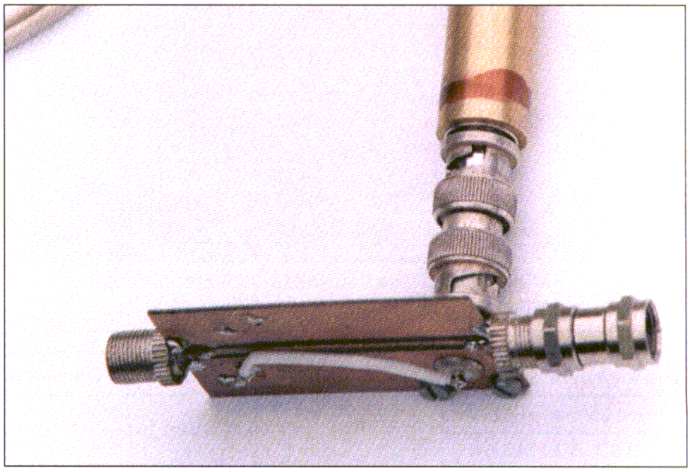
References

When reading this article, it may be useful reading to study the data sheets of some ICs performing these functions. Data sheets for the Analog Devices AD8307, AD8309 and AD8313 will be quite helpful.

Author information

Carl Lodstrom is a consulting engineer and proprietor of Pressebo Electronics, Ventura, CA. He graduated in 1975 from TGG, a Swedish engineering school. He came to California and Santa Barbara in 1982 to work as a Senior Design Engineer for Browne Medical and Dow Key Microwave. Since 1987, he has mainly been a self employed consultant. He can be reached by e-mail at pressebo@jetlink.net.

Pressebo Electronics' web address may be accessed at www.pressebo.com, and the LogProbe information is at www.logprobe.com. LogProbe is a registered trademark of Pressebo Electronics.



▲ **Figure 16. LogProbe with a directional coupler.**

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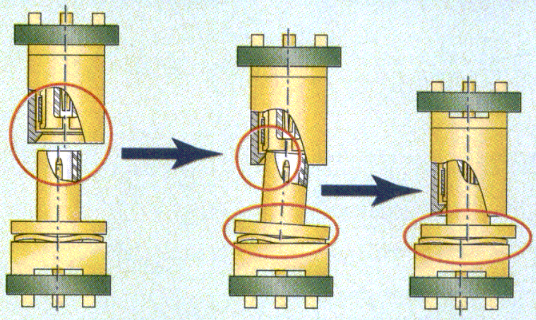
When misaligned connector pairs come into contact, the front end of the self-aligning connector tilts as it is guided by the closed-entry hood of the mating connector.



When fully mated, the front end of the self-aligning connector is shifted radially into alignment with the mating connector.

The spring washer prevents ground interrupts, and compensates for axial misalignment.

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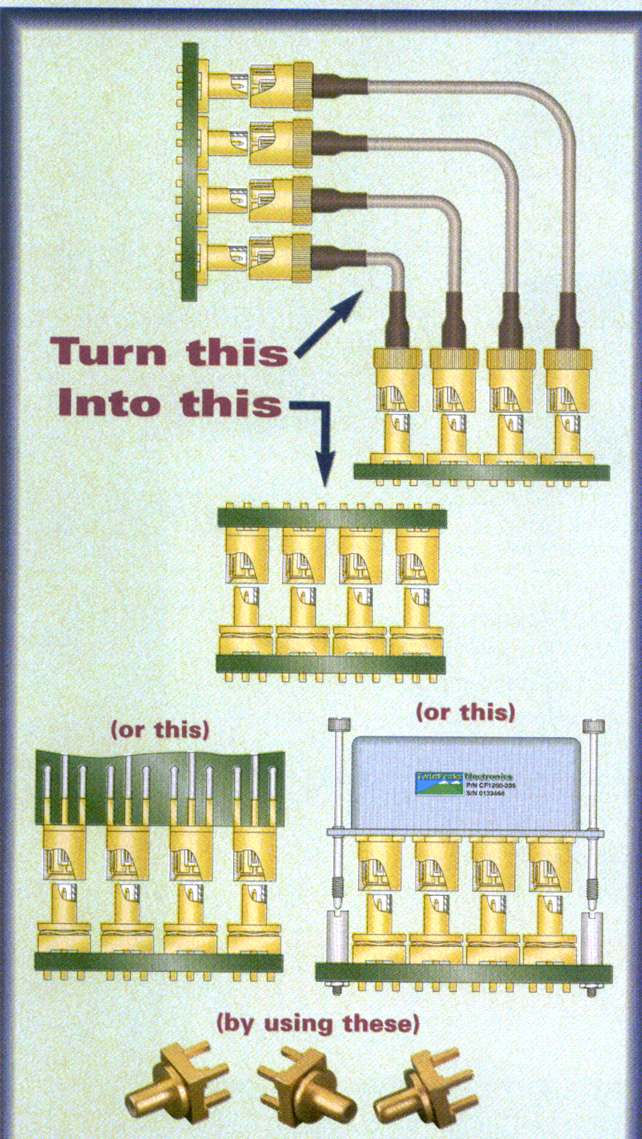

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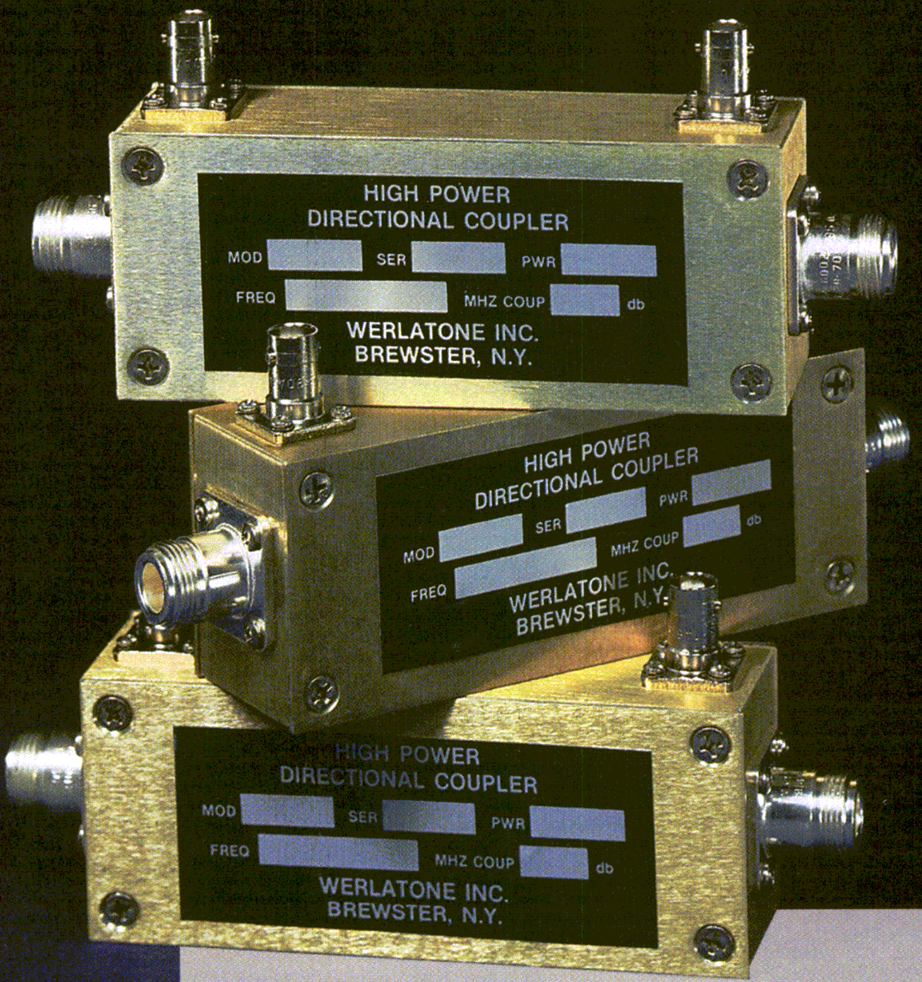

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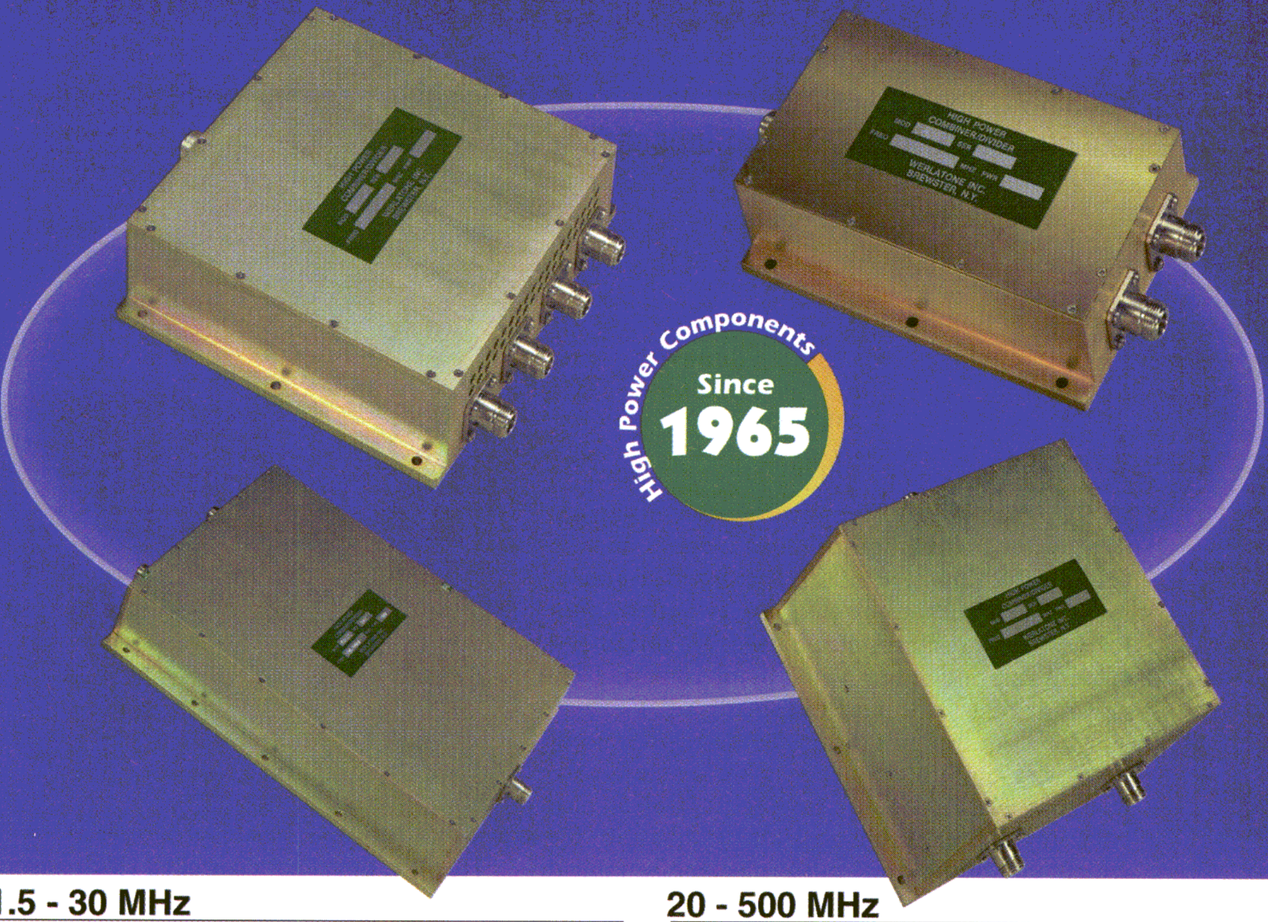

1.5 - 30 MHz

Type	Power Level(s)	Insertion Loss
2-Way	3000 W	0.1 dB
2-Way	6000 W	0.25 dB
4-Way	1000 W	0.2 dB
4-Way	7000 W	0.3 dB

20 - 100 MHz

Type	Power Level(s)	Insertion Loss
2-Way	200, 500, and 1500 W	0.3 dB
4-Way	400 W	0.4 dB
4-Way	3000 and 7000 W	0.3 dB

20 - 500 MHz

Type	Power Level(s)	Insertion Loss
2-Way	100 and 500 W	0.4 dB
2-Way	1500 W	0.5 dB
4-Way	100, 500 and 750 W	0.7 dB

100 - 1000 MHz

Type	Power Level(s)	Insertion Loss
2-Way	300 W	0.5 dB
4-Way	100 W	0.6 dB
4-Way	250 and 400 W	0.8 dB

Note: All units are isolated and withstand at least one input failure at rated power.

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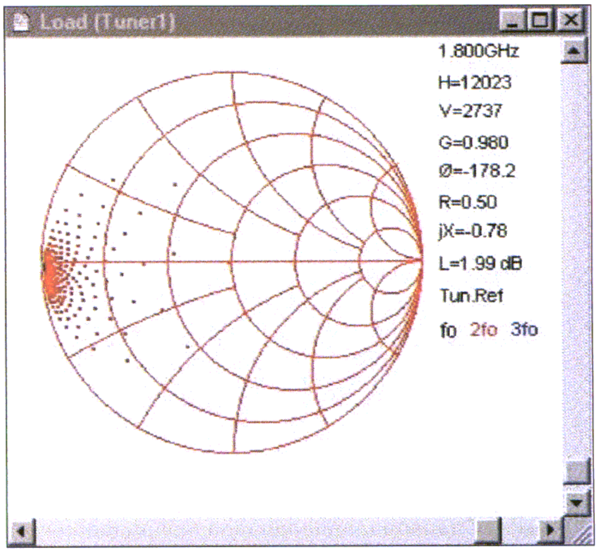
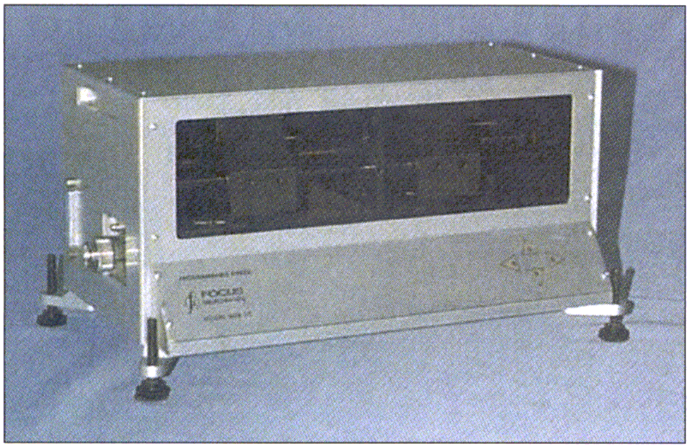
▲ **Figure 1. Computer controlled electromechanical slide screw tuner.**

The present situation

The best electromechanical tuners may accurately generate maximum VSWR >>15:1, which corresponds to the real part of the internal impedance of the transistors, about 3.3 ohms or a reflection coefficient of Γ = 0.875). Beyond this reflection coefficient level, the calibration and repeatability of the tuners may cause accuracy and measurement repeatability problems. Some lossy test fixtures will further reduce the available reflection factor at the DUT reference plane to unacceptable values (VSWR >>10:1 or R_{min} >>5 ohms). For testing very low impedance power transistors there are actually only two solutions possible: One is to use λ/4 microstrip transformers on the test fixture at the test frequency [1], and the other is to use "active" systems, such as "active modules" [2] combined with passive tuners or entirely "active" load pull systems [3]. Active systems



▲ **Figure 2. Once the transformers are made, tuning outside the prematched area of the Smith Chart is impossible.**



▲ **Figure 3. High VSWR prematching tuner.**

reveal that they are inadequate for packaged high power transistor testing, because of power limitations and notorious parasitic oscillation problems. The only remaining solution is the $\lambda/4$ transformer solution, which is affordable and easy to design and build, but has the shortcomings of being cumbersome, frequency selective and may have to be redesigned for each particular DUT. By there nature, the transformers pre-tune only into a specific area of the Smith Chart, which is normally, but not always, the area around a short circuit (ϕ = 180°). The problem is that, once the transformers are made, tuning "outside" the prematched area of the Smith Chart is impossible (Figure 2).

A new solution

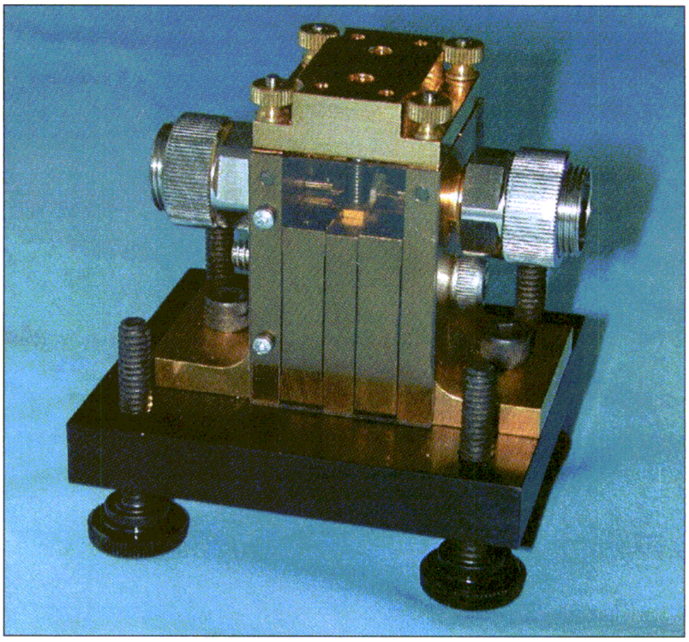
Focus Microwaves has developed a completely new solution to this problem using traditional techniques, i.e. both minimizing the test fixture losses and increasing the maximum reflection coefficient of the tuners. This solution consists of simultaneously employing very high VSWR Prematching Tuners (PMT, Figure 3) with maximum VSWR >>150:1 and Minimum Loss Test Fixtures (MLTF, Figure 4) with insertion loss of 0.02 dB at 2 GHz (Figure 5). The consequent combination of these two new components allows the synthesis of very low impedances (or high VSWR) at the DUT reference plane with excellent tuning accuracy, high power handling capability and low overall loss, without the requirement of $\lambda/4$ transformers, which until now have been the only practical way to approach this kind of load pull testing.

Using this technique, resistances of less than 0.4 ohms can be synthesized at the DUT reference plane at cellular and PCS frequencies (equivalent VSWR >100:1).

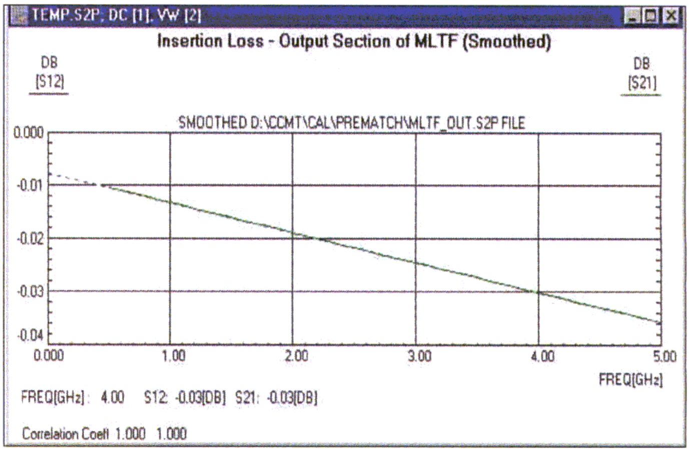
Advantages

The proposed solution, combining high VSWR prematching tuners and ultra low loss test fixtures, has many natural advantages.

First, the total system can be calibrated easily, quickly and accurately. This is due to the fact that the total reflection of the tuners is generated by cascading two medium-sized reflections of VSWR >>12:1, resulting in a total VSWR >>150:1 at tuner reference plane.



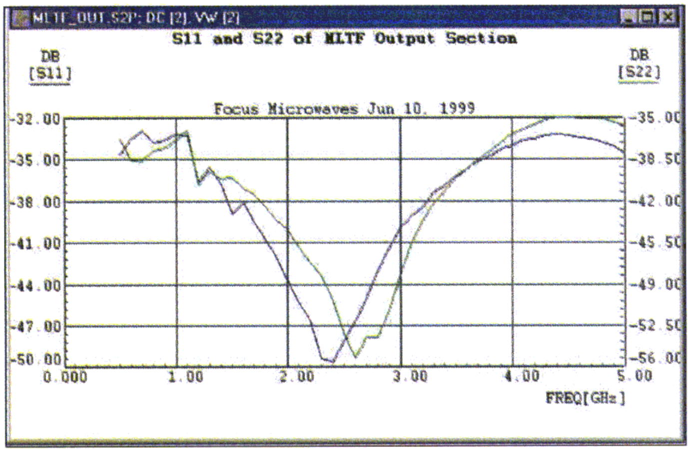
▲ **Figure 4. Minimum loss test fixtures.**



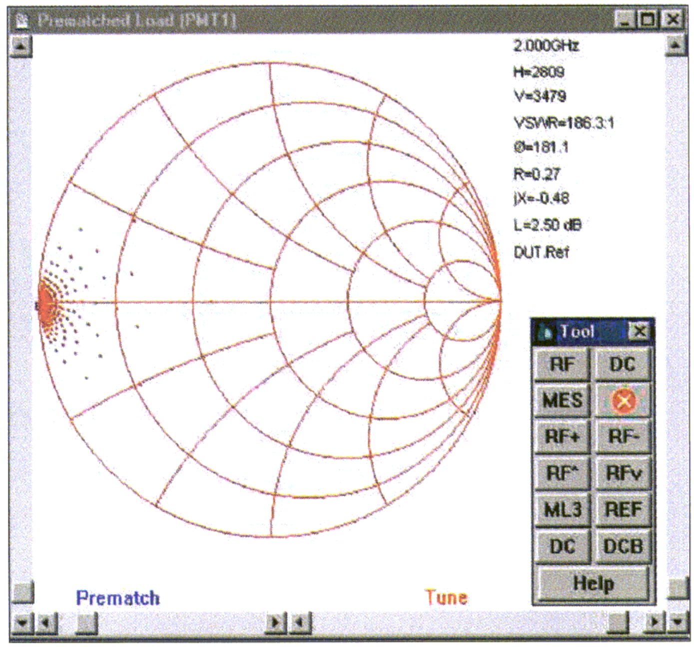
▲ **Figure 5. The results of employing a very high prematching tuner and minimum loss test fixture with insertion loss of 0.02 dB at 2 GHz.**

Second, the system can handle significantly more power at the same level of VSWR, because the probes in the slide screw tuners stay further away from the center conductor, since each individual probe needs to generate a lower individual VSWR.

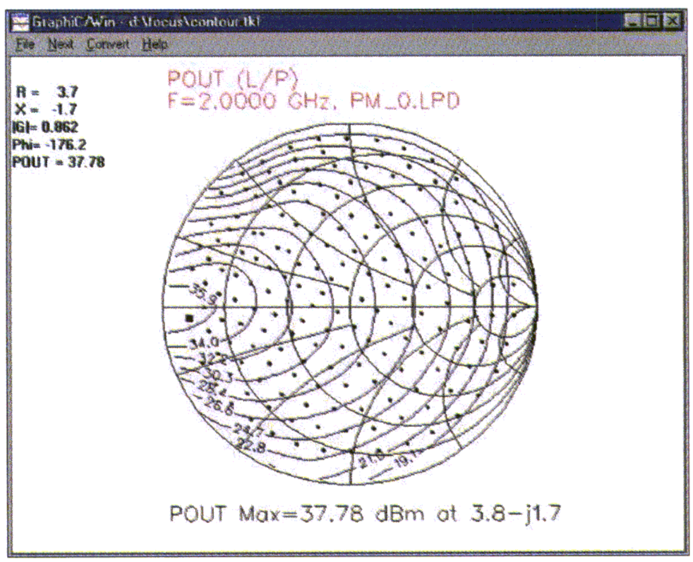
Third, the tuning area can be pointed to any angle of the Smith Chart (not only around 180°, as is the case with $\lambda/4$ transformers). Finally, the transforming ratio and, consequently, the surface of the tuning area and Γ_{max} can be freely adjusted.



▲ **Figure 6. Insertion loss and reflection coefficient of the output half of a Minimum Loss Test Fixture (MLTF).**



▲ **Figure 7. Maximum tuning range of the Focus prematching tuner (PMT).**



▲ **Figure 8. Load pull using a normal tuner and microstrip with 50 ohm microstrip lines. Z_0=50 ohms.**

Low loss test fixture, MLTF

Extremely low loss test fixtures must use air as a dielectric. The only commercially available transistor test fixture using air as a dielectric is the TTF [4]; but this fixture is coaxial and supports only small signal transistors with packages from 0.05 to 0.1 inches in width (1.3 to 2.5 mm).This fixture can only be used for low noise transistor measurements.

Focus' MLTF is made differently. It also uses air as a dielectric but is not a coaxial structure. Rather, it adapts to the nature of power transistor packages to be tested, which basically use a microstrip configuration, since their final destination in circuits is a microstrip matching network. In other words, MLTF uses a non-symmetrical transmission structure in which the metallic cover is at a different distance than the ground plane. Proprietary designed clamps (patent pending) attach the transistor leads firmly to the central conductors of the coaxial connectors of the fixture in order to minimize losses and, more important, DC residual resistances, which would dissipate power and heat and possibly thermally destroy the RF connectors.

The test fixture uses two connector launchers, a common base on which one launcher is sliding and one is fixed, a fixture cover, and calibration and measurement inserts. The cover and inserts are made individually for each transistor package, and handle packages from 0.1 to more than 1 inch (2.5 to 25 mm) wide. The calibration inserts include THROUGH and DELAY TRL standards, because the most accurate way to characterize this fixture is the TRL (Through-Reflect-Line) technique, supported by the Focus calibration software. The measurement inserts can have the option of being fitted for cooling water flow for extremely high power applications between 50 and 250 watts RF. MLTF uses either 7 mm precision (GPC-7) or type N connectors. Both connector systems have inner conductors with the same diameter (3 mm) and are therefore fully compatible with the present layout of MLTF. MLTF for 7/16 connector types (7 mm inner conductor diameter) are in development, allowing RF power testing beyond 100 watts.

Insertion and return loss of MLTF is excellent. After calibration, using TRL, the s_{21} and s_{11} of each half of the test fixture are plotted separately (Figures 5 and 6). MLTF has been tested up to 6 GHz and higher frequency units are in work.

Mounting transistors into MLTF is easy: Remove the cover using four knurled screws, unclamp the transistor package, insert a new one, fasten the package leads and

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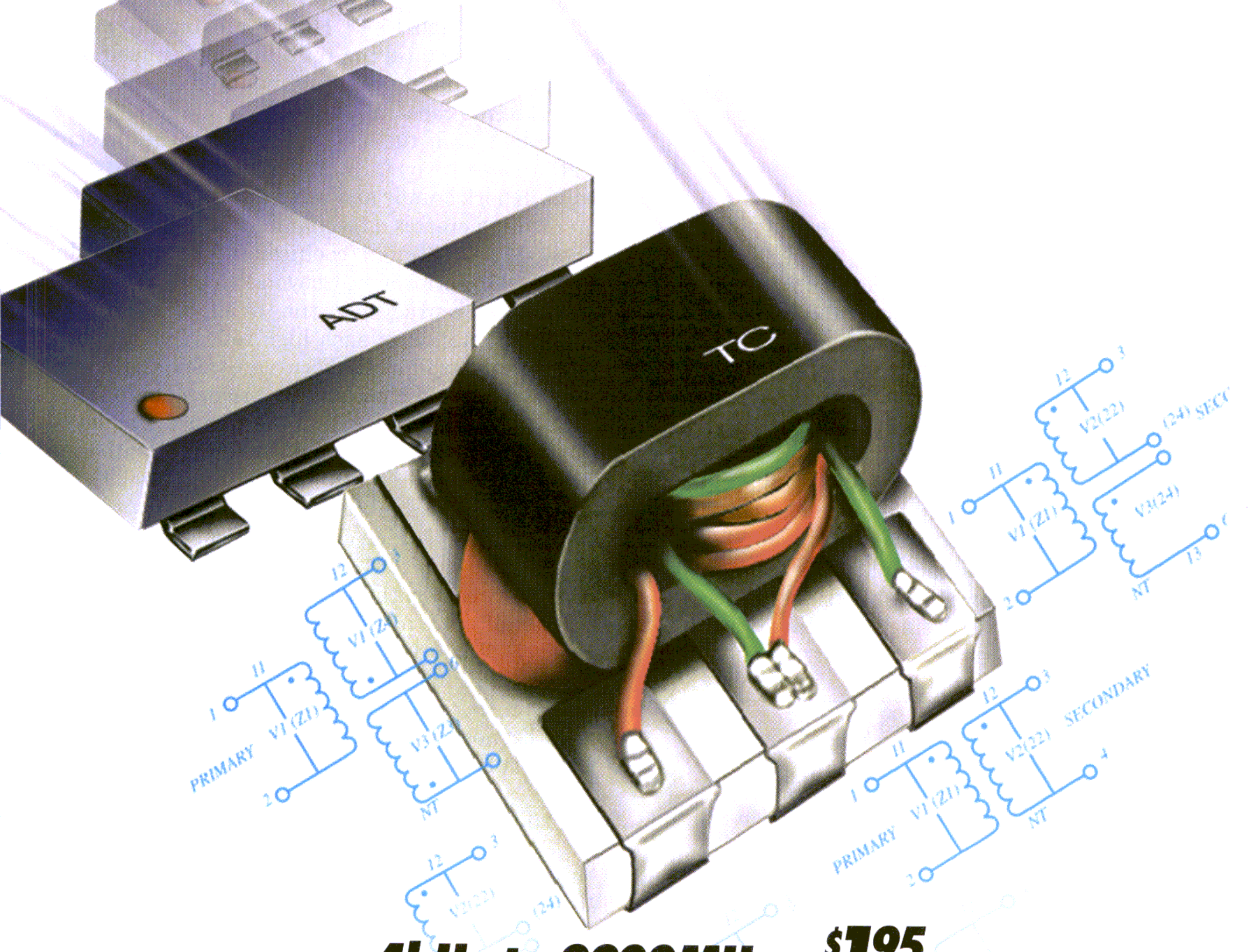

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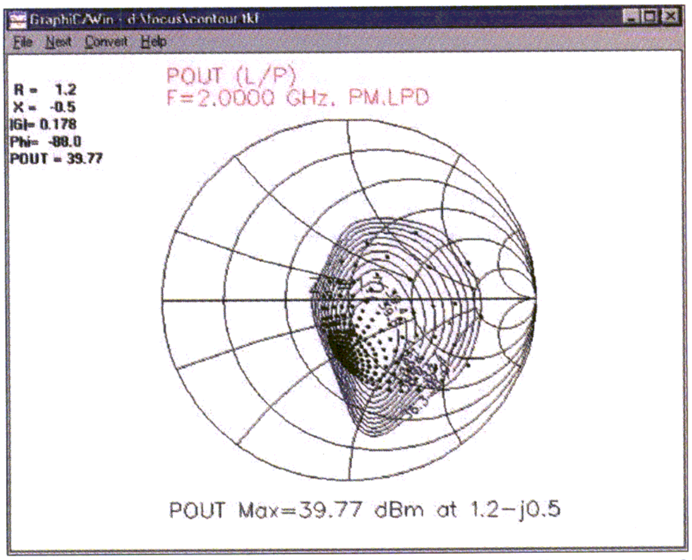

▲ **Figure 9. Normalized (Z_0=1.3 ohms) load pull contours of the same transistor as Figure 8, using a PMT-MLTF setup.**

replace the cover. The body of the package is pressed firmly to the ground of the measurement insert by two adjustable screws in the cover for good RF return and heat dissipation.

High VSWR prematching tuner, PMT

Normal slide screw tuners, as available on the market today, use one or two microwave probes (slugs) to generate high reflection (Figure 1). Using two rather than one probe normally serves the purpose of increasing instantaneous operation bandwidth. The probes are independent in the vertical direction but move together horizontally. A single probe can instantaneously cover up to a 3 octave frequency range (f_{max}/f_{min} = 8), whereas the combination of two probes covers four to five octaves. Examples for such tuners are available from Focus Microwaves and operate in the frequency range of 0.2 to 6 GHz or 2 to 40 GHz [5, 6]. However, using two parallel probes does not raise the reflection factor itself dramatically, even if both probes are mounted close together to increase the capacitive effect.

R (ohms)	jX	|Γ|	Φ	ΔΓ (dB)
		Area 1: tuning around 1 ohm		
0.986	0.0918	0.961	179.8	–47.26
0.996	0.2147	0.961	179.5	–49.35
0.949	–0.0245	0.963	180.1	–53.10
0.977	0.3455	0.962	179.2	–45.05
0.845	0.2406	0.967	179.5	–50.32
0.798	–0.0107	0.969	180.0	–47.06
1.093	–0.1666	0.957	180.4	–47.32
1.359	0.4402	0.947	179.0	–55.03
		Area 2: Tuning around 0.4 ohm		
0.414	–0.1211	0.984	180.3	–47.43
0.409	–0.0106	0.984	180.0	–54.03
0.408	0.0954	0.984	179.8	–51.13
0.406	0.2044	0.984	179.5	–55.49
0.407	0.3217	0.984	179.3	–45.48
0.418	0.4574	0.983	179.0	–51.18
0.428	0.6284	0.983	178.6	–45.02
0.453	0.8637	0.982	178.0	–51.74

▲ **Table 1. Tuning accuracy of PMT at very low impedances.**

The prematching tuners developed for the present application use two fully independent microwave probes, both horizontally and vertically (Figure 3). Their synchronization creates a resonant effect that generates extremely high reflection coefficients (Γ), practically equal to 0.995. Performance beyond this is limited in measurement accuracy by the available Network Analyzers. Calibration of such high reflections is, obviously, a difficult operation. Focus provides a specially designed algorithm for calibrating prematching tuners in very short time (about 10 minutes per frequency point) enabling the measurement software to synthesize any impedance on the Smith Chart with Γ ≤0.99 (or VSWR ≤200:1) combining the reflections of both microwave probes. Tuning accuracy of such a tuner has been verified at very low impedances and we measure deviations between synthesized and measured reflection coefficients of –40 to –55 dB around 0.4 ohm (V >>0.985) [7]. Table 1 shows the impedance and reflection factor of a PMT as tuned by the software and as measured on the calibrated network analyzer. The difference Δ between measured and synthesized reflection factor is calculated using the formula:

$$\Delta\Gamma = 20 \log |s_{11meas} - s_{11calc}| \quad (1)$$

The first set of data, "Area 1: Tuning around 1 ohm," in Table I means that the tuning section of PMT (probe 2) moves around vertical zero (initialized), while the prematching section (probe 1) stays put to high VSWR. The second set of data, "Area 2: Tuning around 0.4 ohm," is the final tuning area, when probe 2 (tuning probe) is close to the central conductor. This is the real operation area of PMT. The tuning accuracy shown varies between –40 and –55 dB which is excellent for this type of operation.

Experimental results

We measured high power transistors using a traditional setup and compared the same transistor measured with the new technique. The effect is especially significant when the traditional setup cannot reach the low impedance required by the transistor (Figure 8). In this case the optimum reflection factor is at the edge of www.ericsson.com/rfpower

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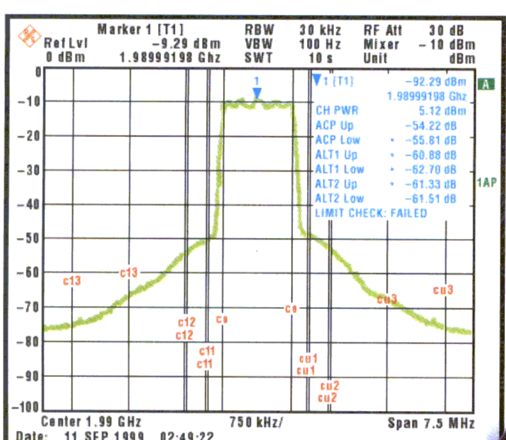

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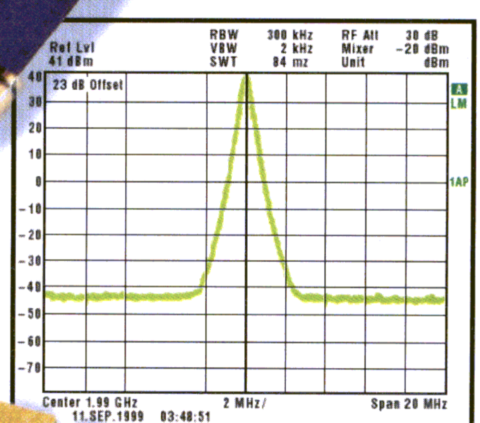

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the calibration region of the tuners and test fixture (R_{min} >>3.8 ohms). As we can see the contours are not closing around the optimum point and, by comparison with the contours of Figure 9, we understand that the transistor has not yet been effectively power matched. When we employ a MLTF-PMT combination, however, we can envelop the optimum Γ with calibrated points. The contours are closed around the optimum point and the measurement accuracy is increased. We also obtain a much higher value for maximum power, nearly 2 dB more (Figure 9).

Conclusion

New equipment presented by Focus Microwaves allows fast, accurate and easy load pull testing of high power packaged transistors at very low impedance levels. This equipment includes extremely low loss test fixtures (MLTF), compatible with most power transistor packages, and high VSWR programmable prematching tuners, PMT. Impedances as low as 0.35 ohm at DUT reference plane are possible at cellular and PCS frequencies.

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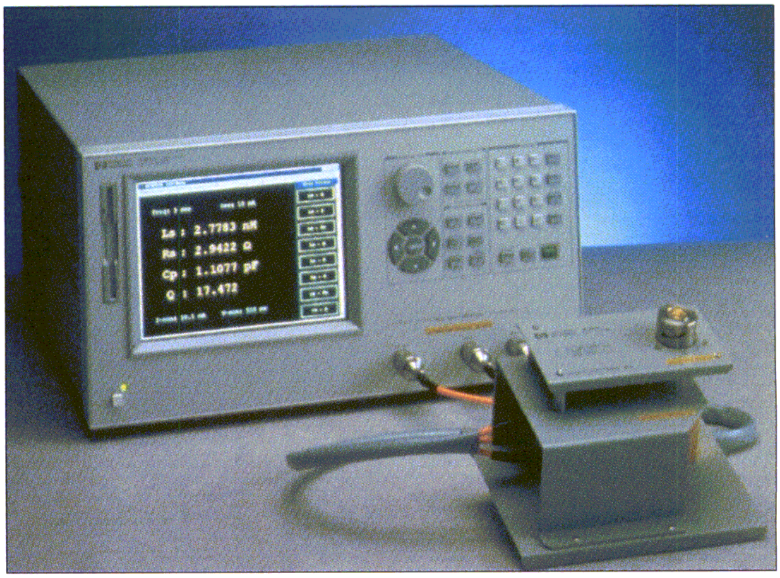

▲ **The Agilent 4287A LCR meter and 16196x test fixture platform offer improved measurement speed and accuracy over previous passive component production test instruments.**

The LCR meter provides fast throughput and stable measurements at low test signal levels. It employs a direct current and voltage technique for accurate impedance measurements over a wider range than is obtained with reflection measurement techniques. The noise floor is ten times lower than previous meters, and throughput is improved with measurement speed as fast as 9 msec/point using high-speed GP-IB. There is also a comparator function for bin sorting which includes multiple frequency, channel and parameter capabilities.

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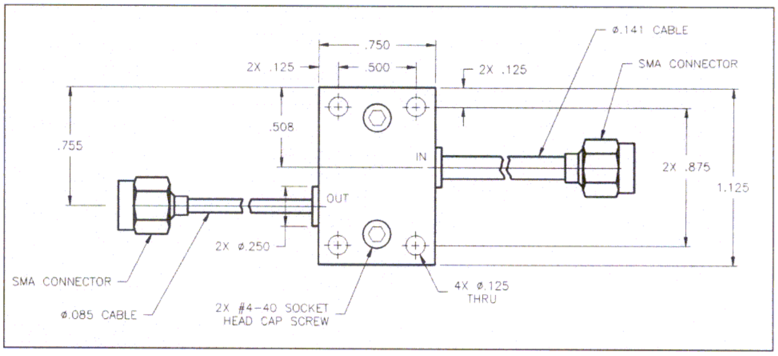

▲ **Outline drawing of the Florida RF Labs Sampling Remote Termination, with lower VSWR than large-value attenuators.**

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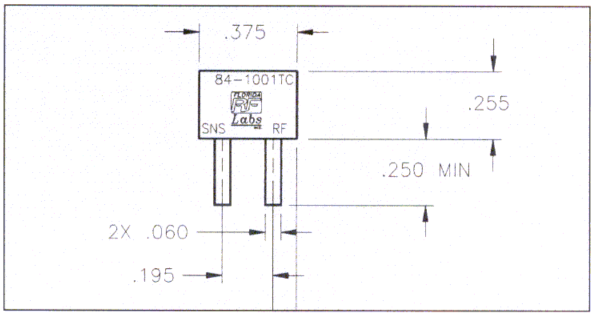

▲ **The 84-1001TC provide 60 watts power termination with integral temperature sensing.**

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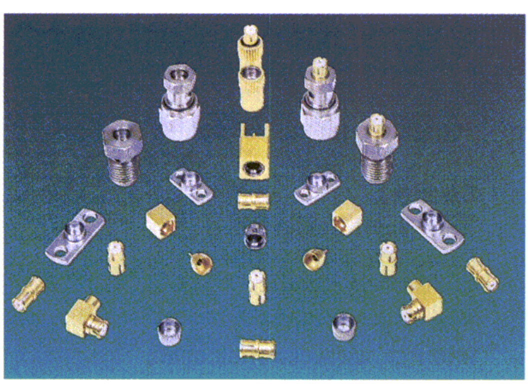

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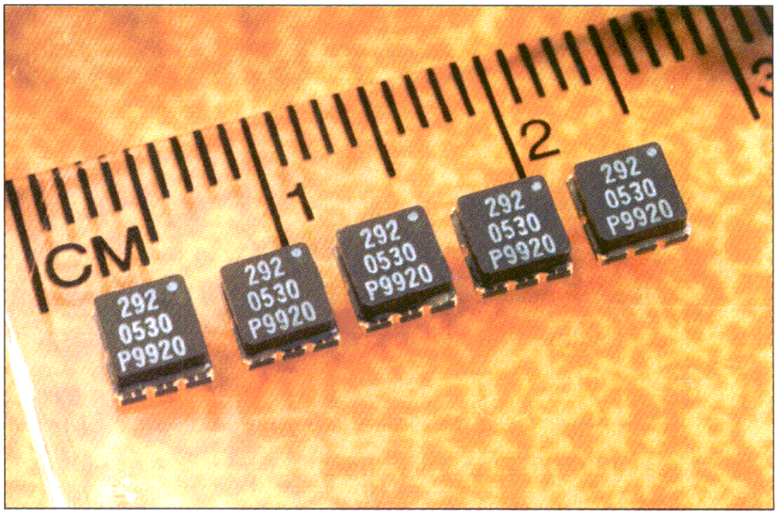

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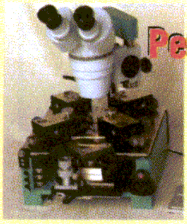

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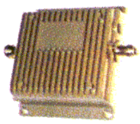

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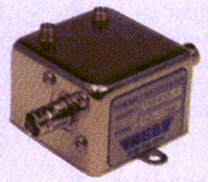

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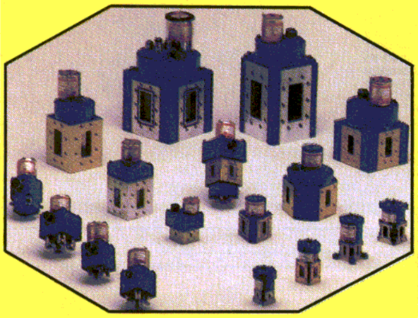

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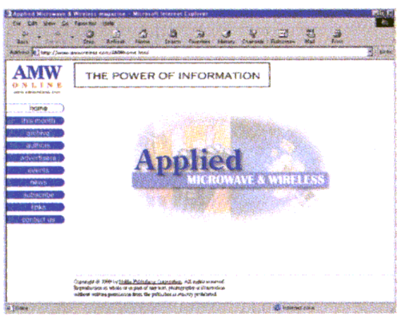

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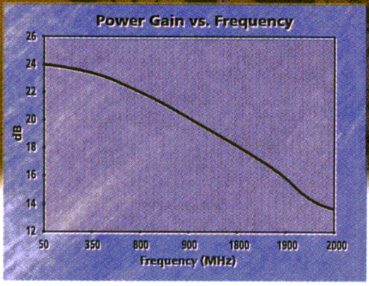

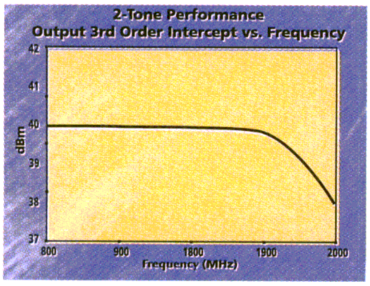

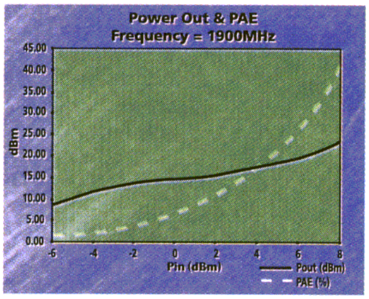

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Some of the Changes from 1989 to 1999

Applied Microwave & Wireless was founded in 1989, starting a tradition of publishing useful, substantive technical material. With more than ten years of success behind us, it is both interesting and enlightening to look at some of the changes that have occurred in our industry during that time.

Products

In 1989, the "world's smallest surface mount mixer" had dimensions of 0.25 × 0.30 × 0.2 inch. Today, each of those dimensions has been cut in half for the same performance specifications; a factor of eight reduction in volume! In semiconductors, the SO-8 (and other pin counts) was the most common small package for integrated circuits, with lead spacing half that of the venerable dual inline package (DIP). Then we got the SSOP with another size reduction, TSSOP (thin SSOP), and now we have minimum-size packages with solder bumps instead of leads. Transistors have gone from a similar SO package to fly specks so small you need a microscope to look at them and precision assembly equipment to build the circuits.

Remarkably, the outward appearance of most coupler, combiner and divider circuits hasn't changed as dramatically as other products. At least, this is true for high performance parts. The technology inside has changed, however, taking advantage of new substrate materials, some design innovations, and most important, the widespread availability of electromagnetic analysis software. For less critical applications, the trend toward smaller size has matched that of other components. Miniature ceramic and p.c.-board based multilayer technology was rarely seen in 1989; now, it is common.

Common components like resistors, capacitors and inductors have followed the same miniaturization path, reaching sizes that may not have been envisioned in 1989. The demands for smaller, lighter, cheaper and lower power consumption just weren't as strong then.

Instrumentation

In 1989, most test systems were still a stack of single-function boxes, probably operated by an external computer using an GP-IB/IEEE-488 interface bus. Soon, multiple functions began appearing in one instrument, first for field service, then for the assembly line and finally reaching performance levels appropriate for the lab bench. The growth in commercial applications and resulting need for lower cost and greater functionality was the early force behind these changes.

Digital communications changed test instrument philosophies again. Bit-error-rate became more common than dynamic range as a receiver performance parameter, then we started describing power amplifiers in terms of dynamic range and distortion performance instead of just power output. Noise became a valuable test signal in addition to single or multiple sine waves.

Microwaves and mm-waves

In 1989, anything above 2 GHz was reserved for specialized communications — point-to-point or satellite communications, or the occasional MMDS/ITFS television distribution system. In 1999, there are millions of consumer products in this frequency range, from PCS phones operating just below 2 GHz to consumer wireless devices at 2.4 GHz (soon 5.8 GHz). The laws of physics didn't change, but our ability to deal with them certainly has. By making circuits smaller and by integrating functions instead of connecting them together with transmission lines, many of the old "microwave" engineering difficulties have been overcome.

mm-waves had few uses in 1989. Some point-to-point microwave systems and radars were in use, but little else. Now the industry is contemplating the build-out of a massive communications infrastructure at 28-32 GHz (Local Multipoint Distribution Service, or LMDS). Many campus point-to-multipoint systems are in place as well. The drive for more bandwidth has pushed development into a frequency range that was once thought impossible. Remember, before 1970 there were no allocated uses above 10 GHz, then the ceiling was raised to 30 GHz, now there are real applications at 77 GHz and developing uses beyond 100 GHz.

Software tools

The ubiquitous PC, with its impressive power and dropping prices has had arguably the single biggest impact on the engineering community over the past 10 years. In 1989, we had good linear circuit analysis and early nonlinear and electromagnetic analysis tools. They were expensive and often shared among many engineers. Now we have highly refined linear, nonlinear, EM, and communication system synthesis and analysis software that could conceivably be available to every engineer. The accuracy and computation speed available today was only a dream for engineers in 1989. This performance is welcome, with present demands for higher productivity and faster development.

The past ten years have brought many changes and a few things that have not (e.g., not enough really good new engineers). What will the next ten years bring? ■