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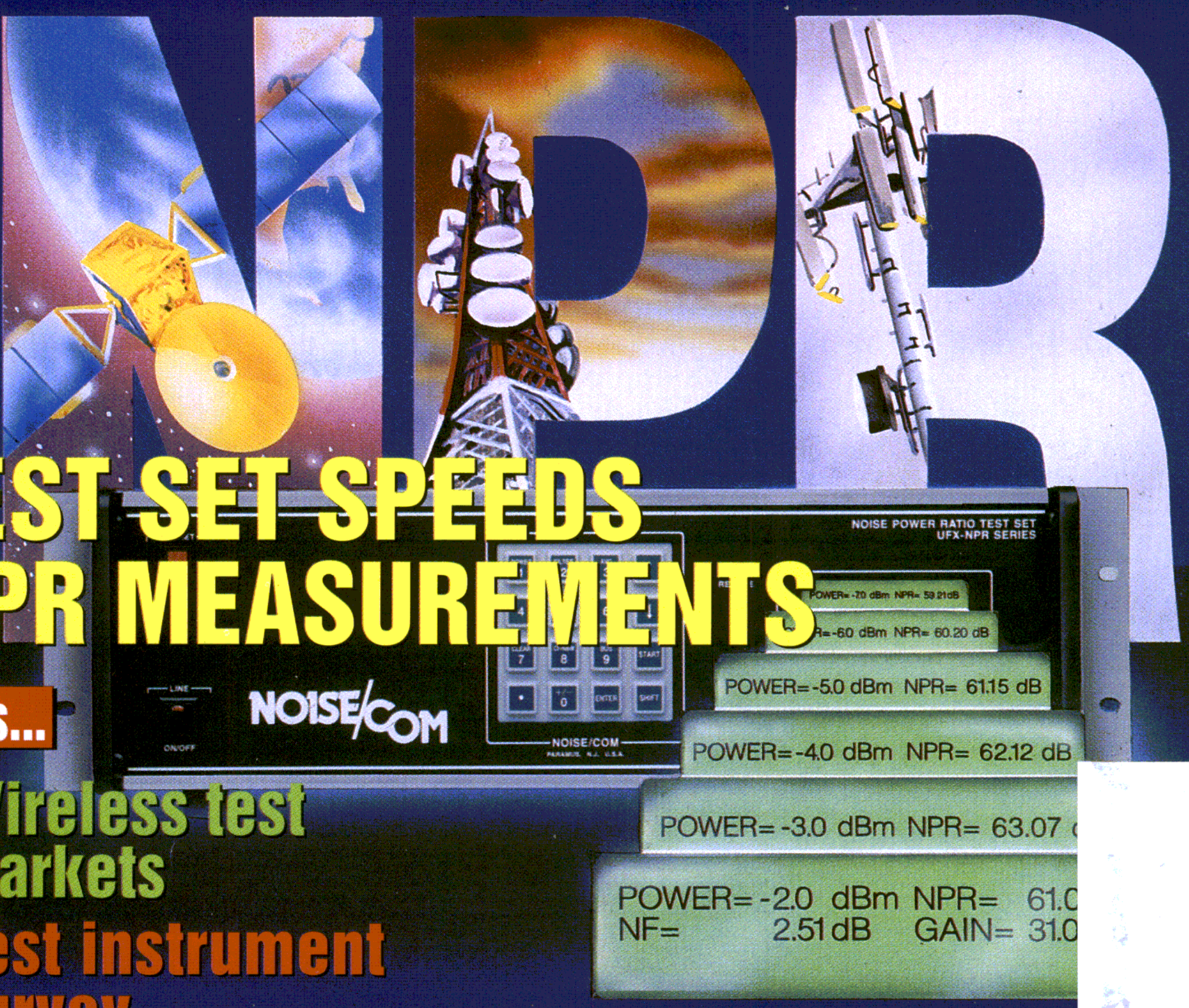
Microwaves & RF

A PENTON PUBLICATION ▪ JANUARY 1994



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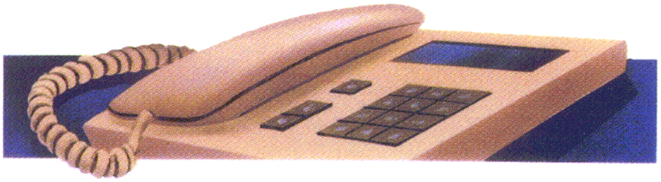
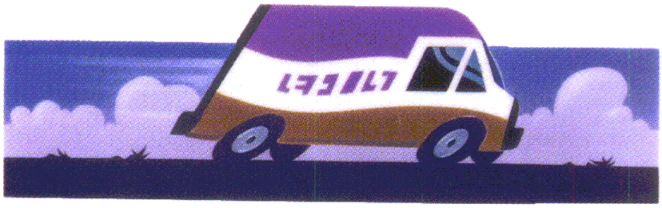
- **Questions** – they're handled in a jiffy, with just a phone call; no waiting for P.O. changes
- **Your order is shipped** – within 48 hours your standard device order is on its way



TI's standard GaAs MMICs and FETs are on the shelf, in easy-to-handle, easy-to-ship *GaAs-Packs*. They come in waffle-packs, available in increments of five devices, and ready to ship. All *GaAs-Pack* devices meet TI's strict standards for quality,



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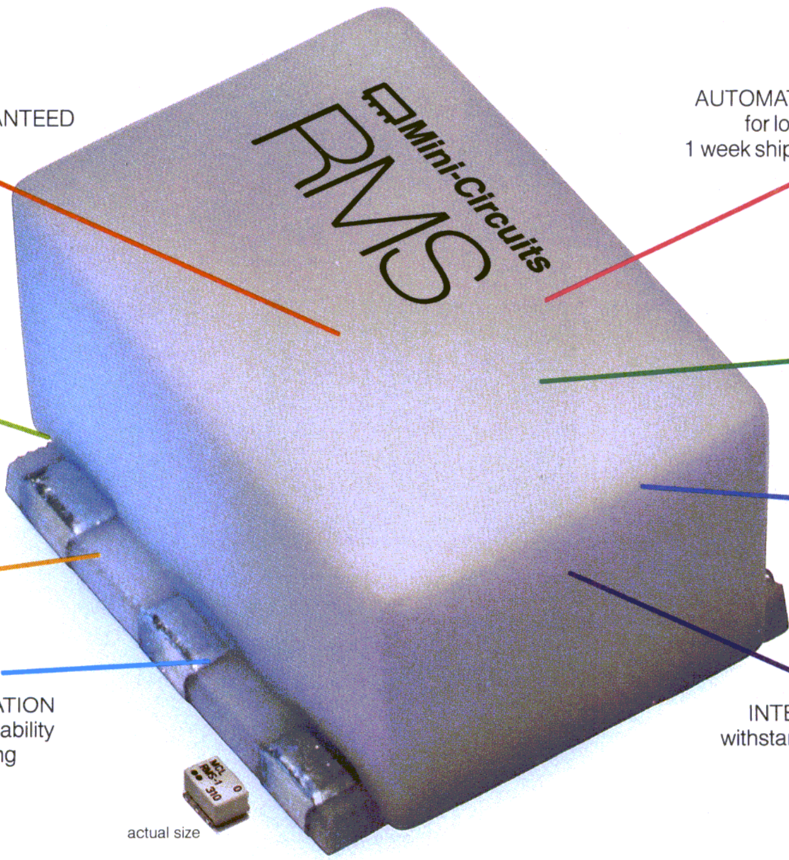

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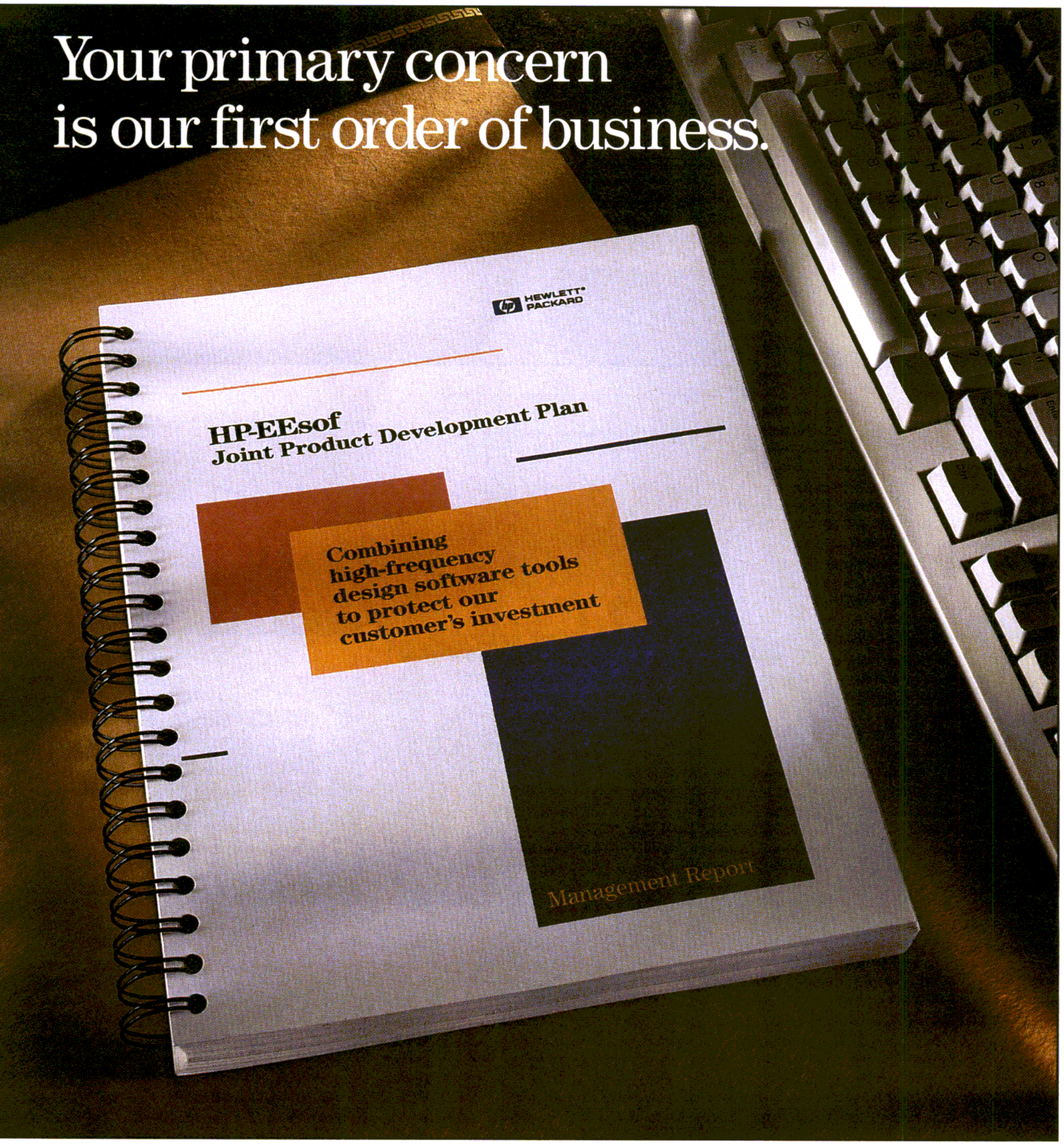

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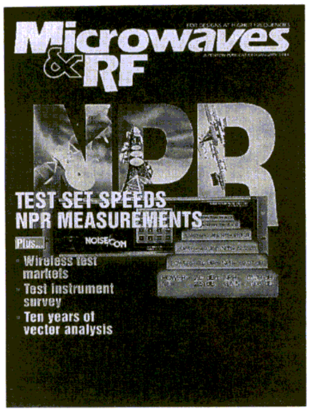
Microwaves & RF

Cover feature



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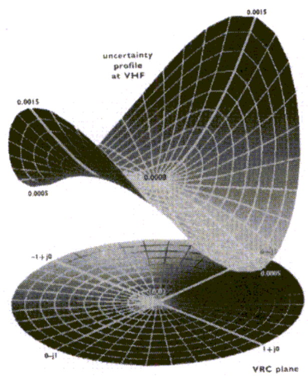
News

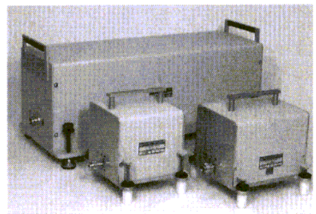
Wireless T&M

Design features



Impedance measurements

Product technology



Electromechanical tuners

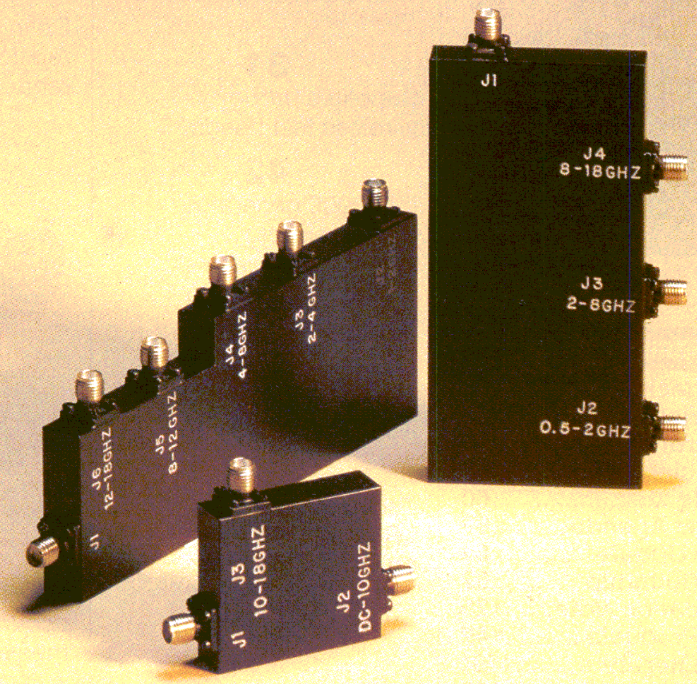
0.400" thin
LOW PROFILE

0.5 GHz to 40.0 GHz

- Diplexers
- Triplexers
- Quadruplexers
- Quintaplexers

Standard Crossover Frequencies:

1 GHz
2 GHz
4 GHz
6 GHz
8 GHz
10 GHz
12 GHz
14 GHz
18 GHz
20 GHz
26 GHz



The Microphase "Low Profile" contiguous-channel Diplexer and Multiplexer Series is available over the 0.5 to 40.0 GHz range and offers a number of features:

SIZE / PERFORMANCE
Compact and light weight, all models are 0.400″ thin, yet the recognized exceptionally high Microphase product performance has not been compromised.

DESIGN FLEXIBILITY
The Low Profile series has the design flexibility of eleven specific crossover frequency choices (from 1.0 to 26.0 GHz) that define the most popular allocated EW-bands from 0.5 to 40.0 GHz. Engineers and systems planners may select and specify almost any combination of multiplexed bands to easily satisfy their requirements in a standard Microphase catalog model.

TEMPERATURE STABILITY
All multiplexers are temperature stabilized from −54°C to +95°C. Over this temperature range, the crossover frequency shift is less than ±0.5%.

MICROPHASE

SPECIFICATIONS

Frequency Range:	0.5 to 40.0 GHz
Crossover Frequencies:	1-2-4-6-8-10-12-14-18-20 and 26 GHz
Crossover Regions:	±4% f_{co} max.
Crossover Insertion Loss:	4.5 dB max.
Passband Insertion Loss:	1.0 dB max. (DC-18 GHz) 1.5 dB max. (18-40 GHz)
Common Port VSWR:	2.0:1 max. (DC-18 GHz)* 2.5:1 max. (18-40 GHz)
Selectivity:	60 dB min., ±15% f_{co} and band ends when specified
Operating Temperature:	−54°C to +95°C

*Diplexers only. For other multiplexers, VSWR−2.2:1 max.

The Low Profile diplexers, triplexers, quadruplexers and quintaplexers may be custom specified, based on eleven standardized crossover frequencies. Adjacent bands defined by these standard crossovers may be combined for any desired bandwidth multiplexing. Band-edge rejection options are also available.

Notes: a. Most multiplexing combinations are available. Some exceptions may apply, for example, when the channel bandwidths are extremely wide (greater than 18:1).

b. Whenever a high pass performance is not specified at the low band edge, the channel pass band extends to DC.

c. In units where the channel operates to 40.0 GHz, no band end rejection is available.

d. Rejection beyond 40 GHz is not provided.

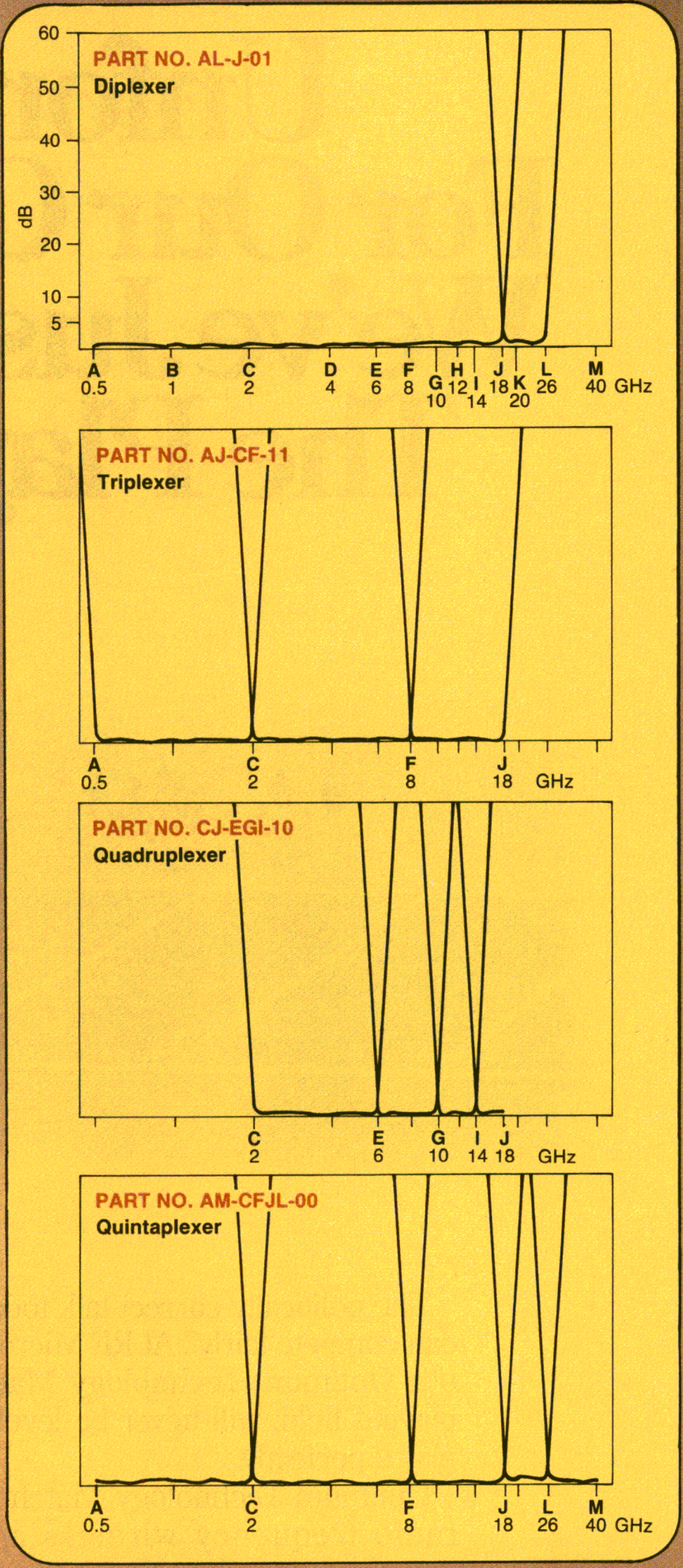
e. All connectors are SMA female except in models that have 18-40 GHz channels in which case the common input and the high frequency channels are supplied with Type-K female connectors

PART NO. DESIGNATION

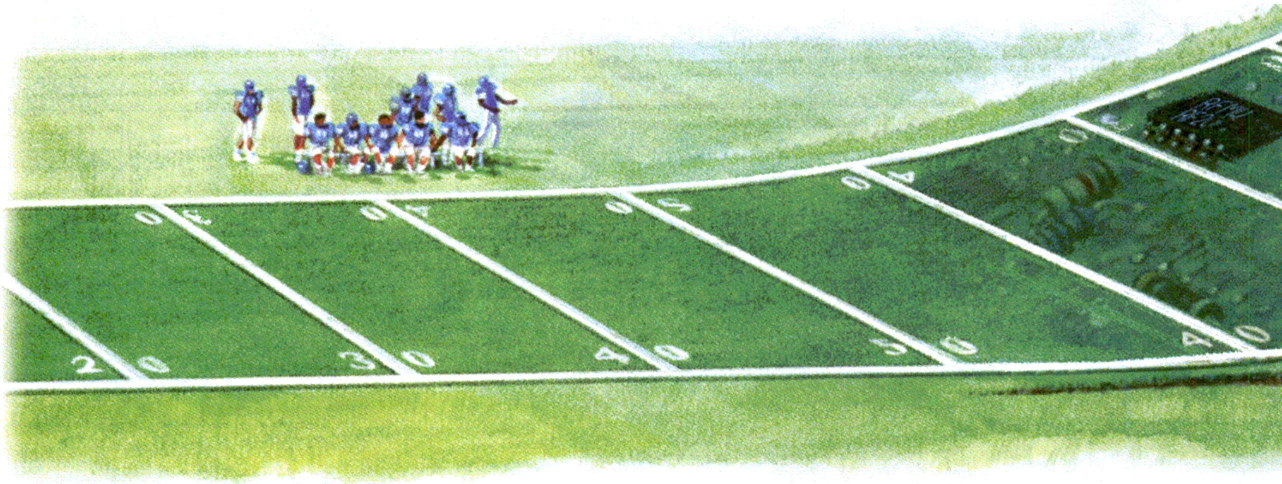
An alpha-numeric part number identifies the performance characteristics. Thirteen frequencies have been assigned letters A-M, covering 0.5-40.0 GHz (see examples).

- First two letters give the total operating band (low/high)
- Second group of letters are crossover frequencies (in low-to-high order) offset by a dash
- A two number suffix indicates if rejection is required at the end channels: No end channel rejection required, −00; Rejection at low end only, −10; Rejection at high end only, −01; Rejection at both ends, −11

REPRESENTATIVE EXAMPLES



Unfortunately For Our Competition, We've Just Unleveled The Playing Field.



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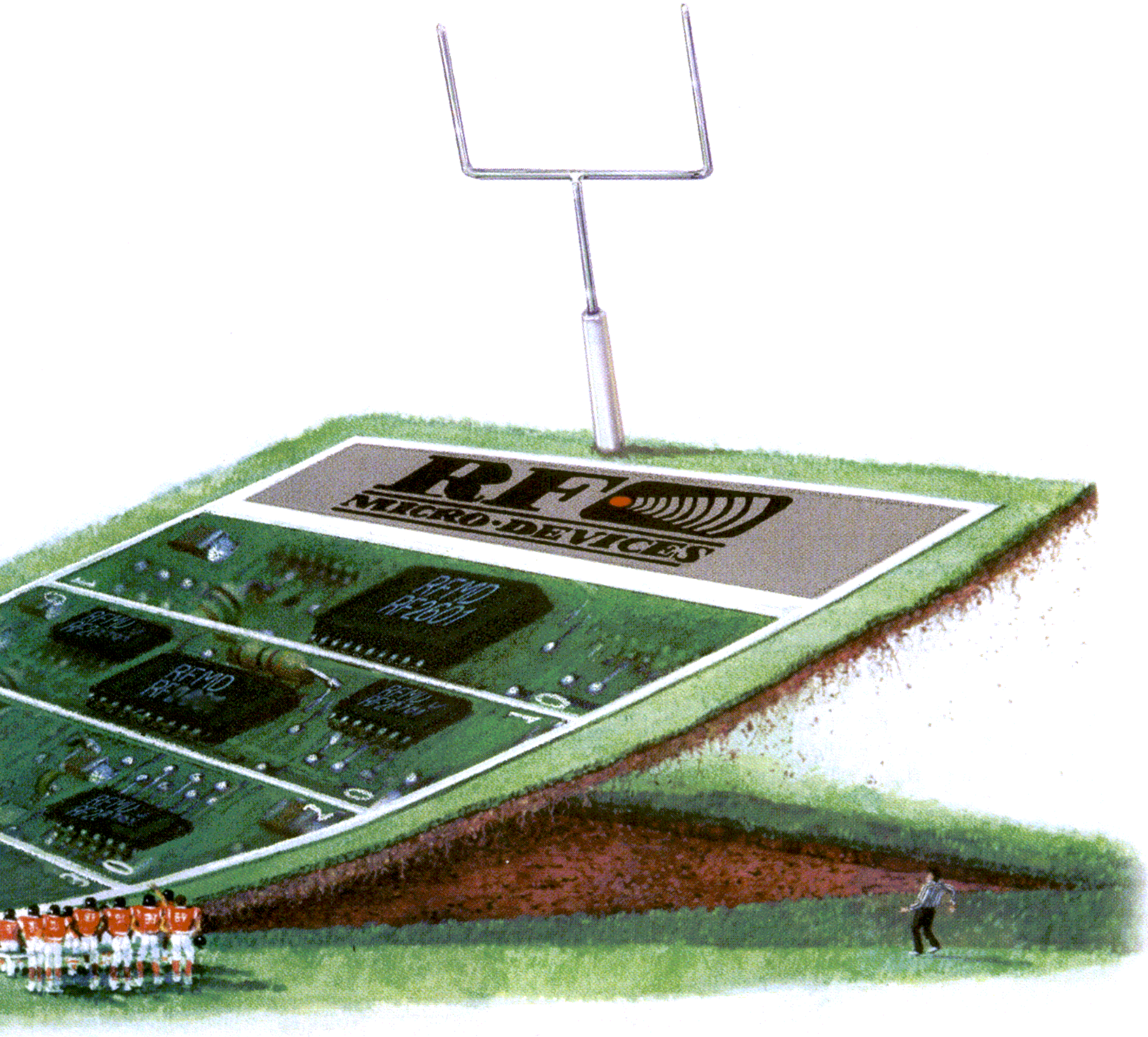

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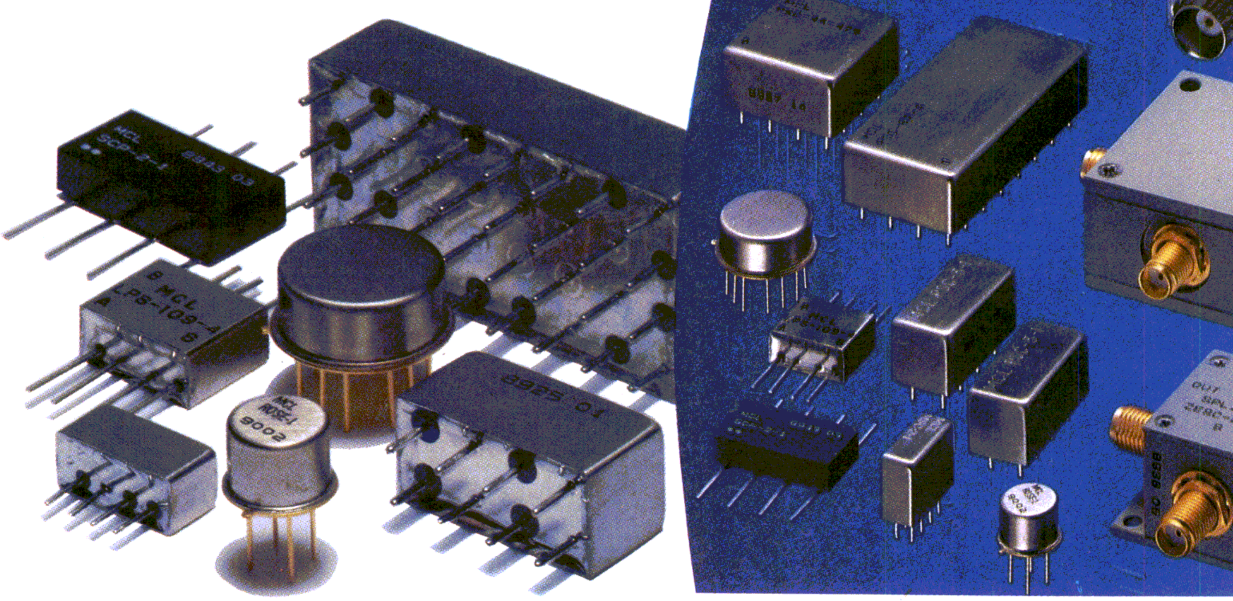

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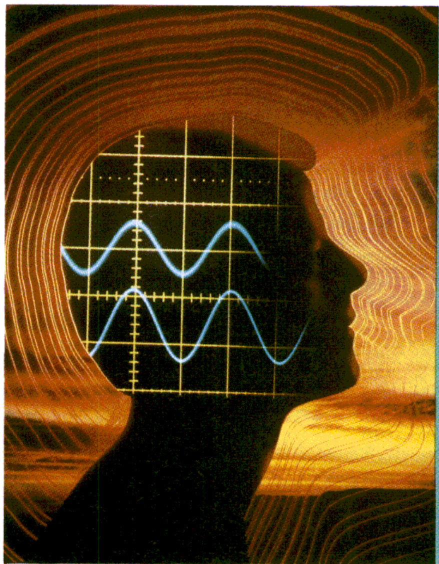

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L-Band Low Noise, High Speed Synthesizer

The unit pictured here was custom-built for an airborne radar application. It includes two independent channels which can be switched in as little as 500 nanoseconds.

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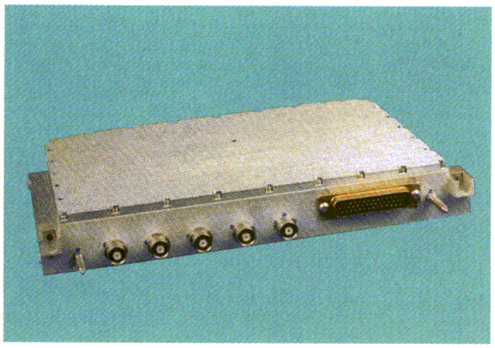
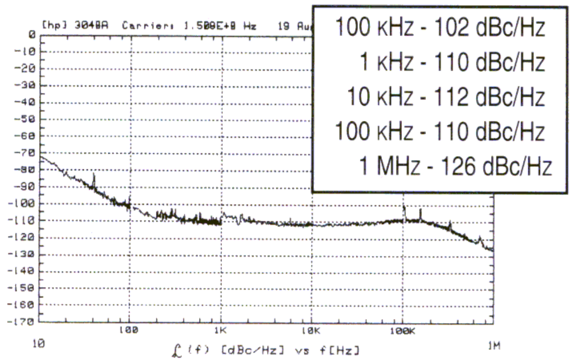
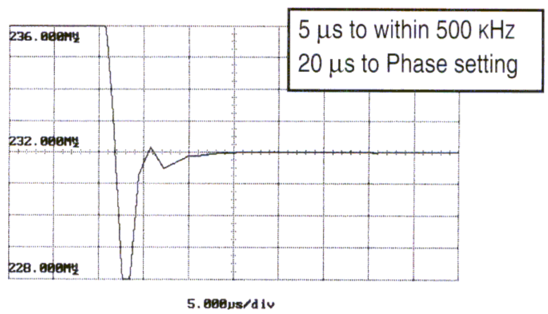




SPECIFICATIONS

Frequency Range:	1500-1800 MHz
Frequency Step Size:	2 MHz
Switching Speed:	25 µsec
Between channels:	500 nanoseconds
Output Power:	+12 dBm
Spurious:	-60 dBc
Harmonics:	-30 dBc
Reference:	L Band
Size:	6" x 9" x 1.2"



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Device termination

To the editor:

In the article "Quickly convert S-parameters to add applications" (November 1992, p. 91), the author shows how to convert transistor S-parameters, measured in one two-port configuration, to the other two configurations that can exist. However, the article ignores the fact that the conversion relies on the transistor being a three-terminal device. Kirchoff's current law applies to terminals, not ports. A packaged device will have significant capacitance to ground and is actually a four-terminal device including ground.

The conversions should be good enough for chip S-parameters at frequencies where the very-small capacitance to ground can be ignored.

The moral is: if you are using two-port transistor S-parameters in Touchstone, Compact, or HP-MDS [CAE software packages], do a good job of de-embedding the transistor from its package.

Brian S. Farley
Principle Research Engineer
BNR Europe
Harlow, England

Giving credit

To the editor:

I noted with interest the article "Technique measures gain for different antenna polarizations" (July 1993, p. 94). This field was my specialty 40 years ago. My interest was further heightened by realizing that the three drawings you published as Fig. 1 were originally drawn by me in 1958 using a T-square, a triangle, and the top of my wife's sewing cabinet as a drawing board. These drawings appeared in the original edition of the *Antenna Engineering Handbook*, published by McGraw-Hill.

It seems to me that it would have been appropriate for your publication to cite the *Antenna Engineering Handbook* as a reference, especially since the copyright for the illustrations is owned by McGraw-Hill.

Warren Offutt
W&B Observatory
Cloudcroft, NM

Cell coverage

To the editor:

Thank you very much for your coverage of the WTEM cell in your R&D ROUNDUP section ("Wire array forms a novel EMI test device," July 1993, p. 58). However, I observed some important inaccuracies about the performance of the cell.

It is reported that "The device's cutoff frequency was found to be 154.3 ±1 MHz, while the input VSWR was less than 1.80:1 at frequencies up to 3 GHz." The reference quoted is from the paper "Comparison of analysis of the WTEM cell with standard TEM cells for generating FM fields," *IEEE Transactions on Electromagnetic Compatibility*, Vol. 35, No. 2, May 1993, p. 255. The reported cutoff frequency (154.3 ±1 MHz) is referred to a cell without the anechoic material inside, but for the complete WTEM cell, the frequency band extends well above 1 GHz.

Lorenzo Carbonini
ALENIA Sistemi Difesa
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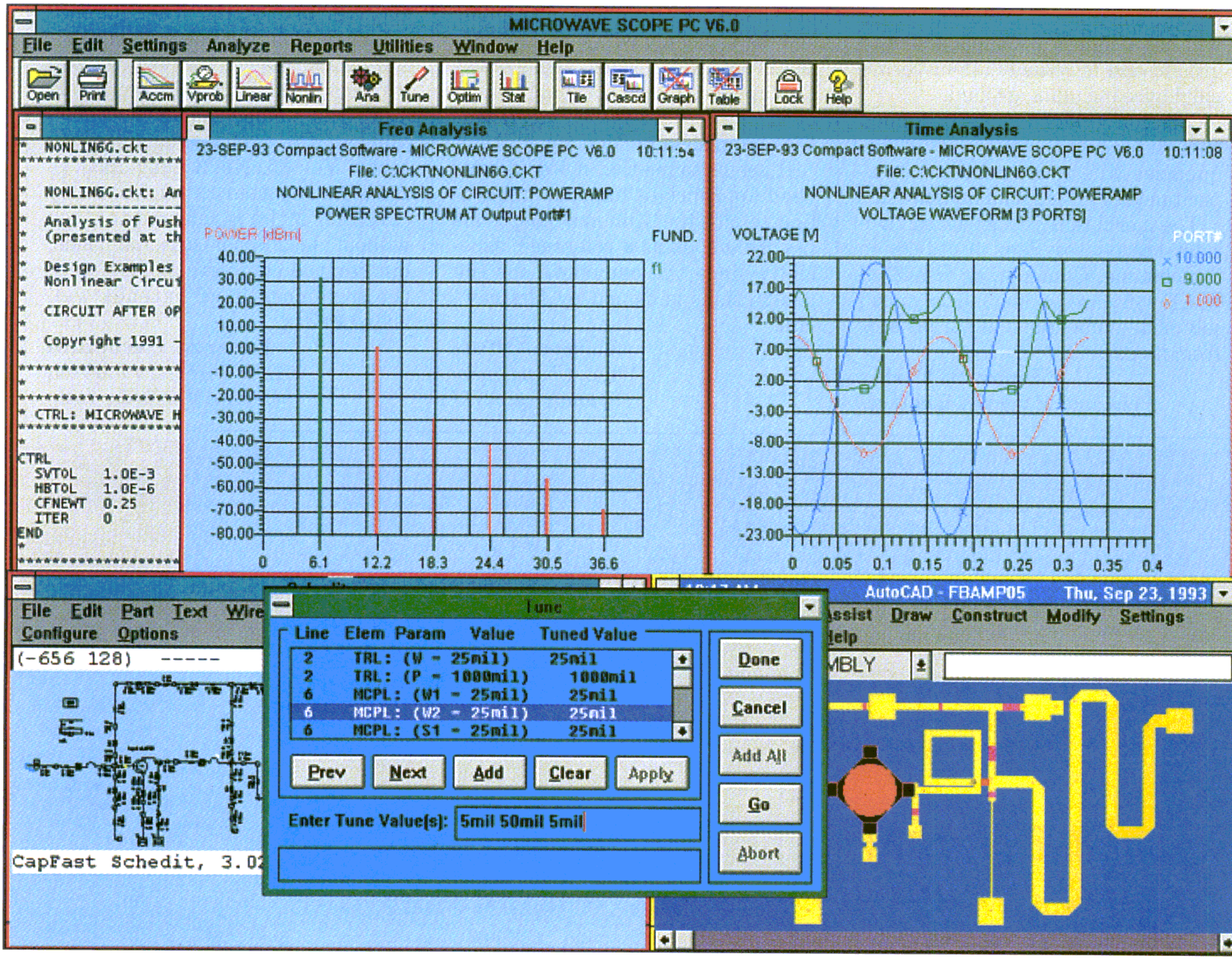

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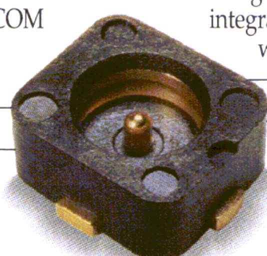

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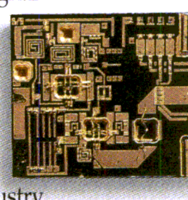

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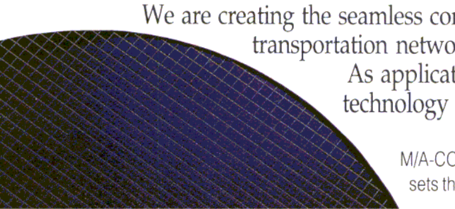

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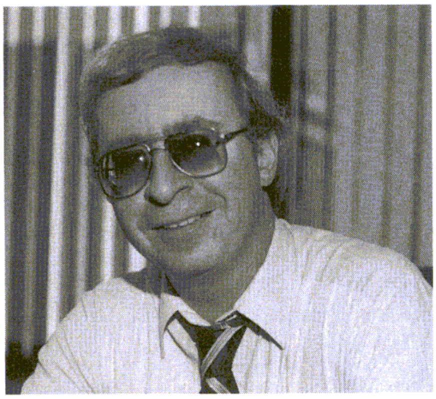
M/A-COM

TESTING THE WATERS IN A WIRELESS WORLD



Test-equipment manufacturers have always held a rather unenviable position in this field: damned if they do and damned if they don't. Device manufacturers will always complain that the test gear is limited when evaluating their latest developments. But makers of measurement equipment can only provide performance as good as the best devices available when designing an instrument, not necessarily the best devices available when the instrument is finally introduced.

The frantic pace of emerging wireless markets and technologies has not made the test manufacturer's task any easier. Instead of the five-year design and development cycle equipment manufacturers once enjoyed when supplying instruments for a largely defense-oriented customer base, these same manufacturers must now cater to the needs of commercial customers with applications that seem to change on an almost monthly basis. In many cases, the equipment supplier must anticipate the needs of a customer who is not really sure what he wants because of the chameleon-like nature of many wireless markets.

Ironically, certain instruments that appeared in need of an application a few years ago are being revisited by wireless engineers as possible measurement solutions. At the time of their introduction several years ago, the modulation-domain analyzers from Hewlett-Packard Co. (Palo Alto, CA), for example, mystified customers by providing unfamiliar measurements: frequency and phase as functions of time. Like a cross between an oscilloscope and a frequency counter, customers were slow to find needs for these instruments—until such things as wireless transmitter turn-on parameters needed to be characterized.

In some cases, it is the smaller test-equipment houses that achieve the design and production agility required to stay even with, if not ahead of, the needs of emerging wireless applications. Two examples are RDL, Inc. (Conshohocken, PA) and NOISE/COM, Inc. (Paramus, NJ). The former, with a background of mostly military sales, discovered that phase sensitivities related to multitone intermodulation-distortion (IMD) measurements. Their solution is a series of multitone signal generators in which the phase of each tone can be controlled and aligned for more representative IMD tests. The latter, which for years has supplied noise sources and instruments for noise-figure device and component testing, has learned what the military has known for years: that white noise is a near-ideal test signal for most communications applications.

Most test-equipment suppliers find themselves taking gambles when trying to guess which particular wireless standards will be adopted for a given application, such as personal communications services (PCS). It is not simply a matter of providing more than enough performance, since modern commercial customers demand reasonable prices and operating simplicity. The world has changed, but test-equipment suppliers are still in that unenviable position.••

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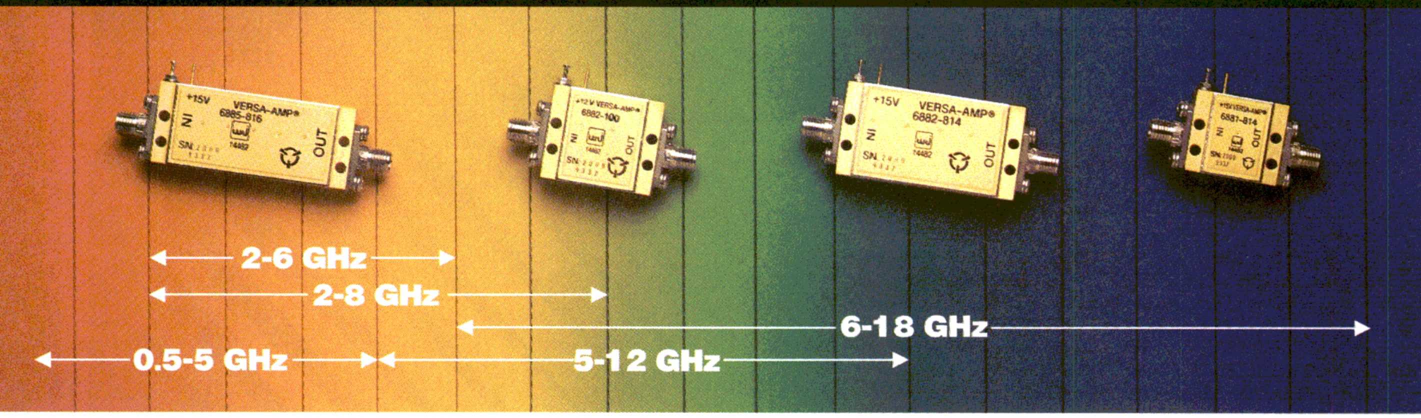
A Hot New Band Member.



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Model Number	Gain (dB, min)	Flatness (dB, max)	NF (dB, max)	P_{out} @ -1 dB (dBm, min)	Reverse Isolation (dB)	DC Current +15 VDC (mA, max)
0.5-5.0 GHz						
6881-812	17	1.0	4.5	18	40	150
6881-813	25	1.0	4.5	18	55	220
6881-814	35	1.0	4.5	18	65	300
2.0-6.0 GHz						
6882-100	26	1.0	2.5	12	40	120
2.0-8.0 GHz						
6882-812	22	0.8	4.0	20	40	185
6882-813	33	1.0	4.0	20	55	265
6882-814	44	1.0	4.0	20	65	325
6882-824	40	1.0	4.0	24	65	475
5.0-12.0 GHz						
6884-812	16	0.8	4.8	18	35	150
6884-813	25	0.8	4.8	18	50	220
6884-814	34	0.8	4.8	18	65	290
6884-824	30	1.0	4.8	23	65	450
6.0-18.0 GHz						
6885-813	18	1.0	6.0	15	45	210
6885-814	25	1.5	6.0	15	65	250
6885-815	30	1.5	6.0	15	65	310
6885-816	38	1.8	6.0	15	70	360

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CIRCLE NO. 261

Hughes launches DBS satellite

LOS ANGELES, CA—Hughes Aircraft Co. last month launched a direct-broadcast satellite (DBS) capable of feeding up to 150 television channels into homes across North America. Service is scheduled to begin in 1994.

At virtually the same time, Thomson Consumer Electronics began production of the RCA-brand digital receiving system to be used by Hughes's DirecTV subsidiary for DBS. The Thomson system, which carries a suggested retail price of $699, consists of an 18-in. (45.72-cm) satellite dish, a compact receiver/decoder, and a hand-held remote control. DirecTV and United States Satellite Broadcasting (Minneapolis, MN) will provide the programming for the new DBS system.

The Thomson/RCA system will enable consumers to access up to 150 channels of TV programming from Hughes' direct-broadcast satellite.

Thomson expects to begin delivering its system to retailers in April and will gradually build up to a capacity of 100,000 units per month. Thomson will retain exclusive marketing rights to the system through the first 18 months of availability or until one million units are sold.

Thomson officials believe the market for their system is huge, noting that cable television is unavailable for 10 to 15 million US homes while another 20 to 30 million homes in cable areas remain unconnected.

OKI enters comm IC market

SUNNYVALE, CA—OKI Semiconductor says it plans to introduce a new family of integrated circuits (ICs) for cellular, fiber-optic, and infrared (IR) communications applications. The new products, which include GaAs digital devices, will be introduced to the North American market over the next nine months.

"The over-800-MHz wireless communications market in the US is about to explode," says Cliff Vaughn, OKI marketing manager. "No one is better positioned to offer GaAs devices with 3-V, high-efficiency output drive capability than OKI's Electronic Component Group."

Initially, the new products will fall into three categories: GaAs RF communications devices such as low-noise microwave amplifiers; high-speed digital and high-speed logic devices for wireless communications applications such as cellular phones; and laser, fiber-optic, and IR communications products, including laser diodes and optical transmitter/receiver modules.

Vaughn says the first product in the series will be a GaAs FET MMIC, broadband feedback, AGC amplifier.

TRW to make cordless chips

REDONDO BEACH, CA—In its first move into the all-digital cordless-telephone market, the TRW Space & Electronics Group has agreed to fabricate GaAs integrated circuits (ICs) for RF Micro-Devices (Greensboro, NC).

Under terms of the three-year agreement, TRW will fabricate a majority of the GaAs heterojunction-bipolar-transistor (HBT) chips developed by RF Micro-Devices for wireless communications products. RF Micro-Devices is already supplying devices based on TRW technology to AT&T for its new all-digital cordless phones.

The HBT chip that TRW is currently fabricating is a linear power amplifier designed by RF Micro-Devices.

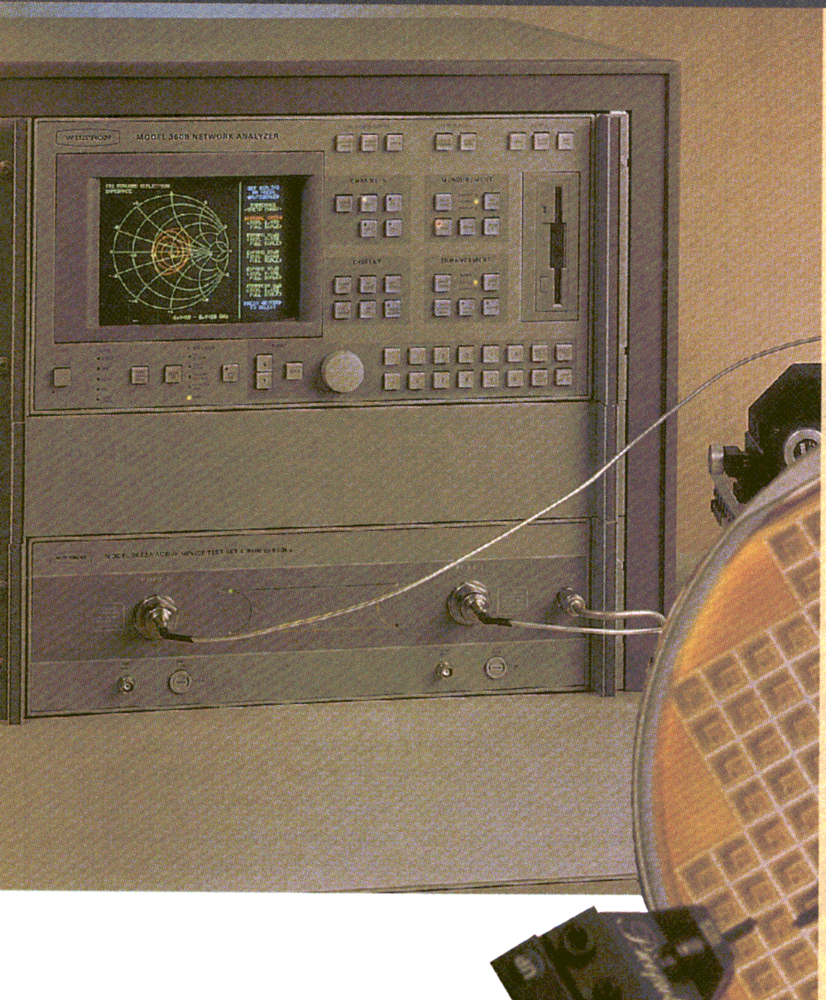
NATA projects growth

WASHINGTON, DC—Mobile-communications revenue will grow 20 percent per year through the 1990s while personal-communications-services (PCS) equipment sales are expected to explode from $14 million in 1993 to almost $600 million by 1997, according to the 1993/1994 edition of the Market Review and Forecast published by the North American Telecommunications Association (NATA).

Looking at the international market, the NATA believes aggregate cellular subscriber growth in the Asia-Pacific region increased to approximately $5 million in 1993 from $1 million in 1990, and should reach $17 million in 1997.

The NATA also expects the total annual US telecommunications-equipment market to almost double by 1997, jumping from $59.5 billion in 1993 to $103.8 billion in 1997.

MMIC On-Wafer Vector Analysis Unmatched Performance, Coax or Waveguide



There's more to the Wiltron 360B performance advantage than just the widest dynamic range and widest frequency range in the industry.

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- ***Time Gated Sampling & Pulsed Signal Testing***
- ***Thermally Stable Calibration***
- ***67 GHz In Coax***
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Low-Loss Wafer Probing

In some vector analysis systems, excessive test port attenuation reduces stability, directivity, and dynamic range. Wiltron's low loss connection systems won't lose your test signal in the noise.

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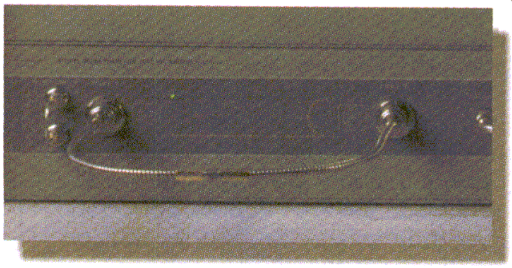

3636 Pulse/CW Test Set
Analyze high power MMICs on-wafer without heat sinks using Wiltron's high dynamic range pulse sampling technique.

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WILTRON

Wireless advances semicon sales

LOS ALTOS, CA—The total number of digital wireless terminals in worldwide operation will increase from 16.2 million at the end of 1993 to 185 million at the end of 1997, according to Kenneth W. Taylor & Associates' Digital Wireless Communications Strategic Industry Information Service.

"Many portable/mobile terminal manufacturers and their semiconductor suppliers are missing several of the medium- and high-volume wireless-market segments which will actually drive future cost trends and competitiveness," says Taylor, president of the research and strategic-planning organization. "Many firms who have established a singular business migration path from digital cellular and cordless telephones to wireless local-area networks (WLANs) and wide-area networks (WANs) are going to be in trouble."

Taylor's 420-page report, *Worldwide Outlook for Digital Wireless Communications—Applications, Technologies, and Markets*, indicates co-existence and interdependence between silicon and GaAs semiconductor technologies. Interestingly, the report indicates that digital wireless terminal manufacturers who use GaAs are likely to be more profitable in the long run. "This is attributable to the greater performance and logistical advantages provided by GaAs-enriched equipment," says Taylor.

Apple Newton attracts DOD

CUPERTINO, CA—Apple Computer, Inc. has received a $1-million contract from the US Department of Defense (DOD) to explore and validate the application of Apple's hand-held Newton MessagePad personal digital assistant (PDA) for medical use by the military.

In collaboration with KPMG/Peat Marwick (New York, NY), a management consulting firm, Apple will lead the ProMED project until August 1994, investigating how the DOD can improve health-care services, streamline processes, and lower the cost of health care by incorporating Newton technology into the DOD's health-care practices.

Since its introduction in August 1993, more than 50,000 Newton MessagePad units have been sold in North America and the United Kingdom.

Analog Devices, IBM join forces

NORWOOD, MA—Analog Devices and IBM have announced plans to work together to develop and market RF and mixed-signal integrated circuits (ICs) for wireless communications applications. The devices will be based on IBM's chemical-vapor-deposition silicon-germanium (SiGe) manufacturing process.

Initially, the devices will be produced at the IBM Microelectronics Advanced Semiconductor Technology Center (Hopewell Junction, NY). The process enables silicon transistor speeds of over 60 GHz. It can be integrated with digital CMOS into BiCMOS. Using IBM's 8-in. (20.32-cm) wafer-production facility is expected to provide cost advantages over RF-industry-standard 4-in. (10.16-cm) wafers.

Analog Devices and IBM began discussing the potential of the SiGe process for mixed-signal and RF applications in April 1992. Their initial efforts resulted in the fabrication of a 1-GHz, 12-b digital-to-analog converter (DAC).

Analog Devices plans to introduce, within the next nine months, a family of RF and mixed-signal circuits for wireless communications based on the SiGe process. The process will also be used to produce high-speed circuits, such as the 1-GHz DAC that enables broadband video over fiber optics or coaxial cable, for multimedia telecommunications and data-communications markets.

Cadence, Siemens reach accord

SAN JOSE, CA—In an agreement that Cadence Design Systems, Inc. values at more than $15 million over five years, the design-automation software and services company has signed Siemens Semiconductor Group (Munich, Germany) to a contract under which Cadence will provide Siemens with consulting services and assistance in migrating Siemens' existing databases and tools to the Cadence design environment.

The agreement covers digital logic design, analog/mixed-signal circuit design, simulation, integrated-circuit (IC) physical design, verification, and local engineering support and services. It also covers Cadence's Comdisco Signal Processing WorkSystem tools for digital-signal-processing (DSP) design. Siemens is also collaborating with Cadence in the development of advanced verification solutions.

Cadence has also agreed to sell its Automated Systems Division (Brookfield, WI) to a corporation owned by members of ASI management. ASI, which manufactures design services for complex printed-circuit boards (PCBs), had annual sales of about $12 million.

"When we acquired ASI in 1990, we were primarily interested in the Prance line of advanced PCB physical design software," says Joseph B. Costello, president of Cadence. "With Cadence having successfully integrated the Prance-XL autorouting technology and its Allegro Correct-by-Design system, ASI is now focused exclusively on designing and fabricating complex PCBs."

As primarily a hardware manufacturer, Costello says that ASI is no longer a good strategic fit with Cadence's overall business.

Cellular health research

WASHINGTON, DC—The Scientific Advisory Group (SAG) on Cellular Telephone Research has commissioned a series of initial studies on possible health effects from portable cellular telephones and is requesting proposals for additional studies in specific areas.

Initial dosimetry, epidemiology, and laboratory studies will investigate possible effects in humans of exposure to RF energy from portable cellular phones, according to George L. Carlo, an epidemiologist and chairman of the SAG.

The SAG is requesting proposals for research in the following areas:

- *in vivo* studies examining possible genetic effects of typical exposures from cellular telephones in the frequency bands and power levels approved by the Federal Communications Commission (FCC) for these types of communications systems (800 to 900 MHz and 1850 to 2200 MHz). Both continuous waves (CW) and pulsed waves will be studied.
- Concept papers critically evaluating the relevance of experimental promotion studies to human-health risk assessment of RF.

According to Carlo, the primary goal of the SAG is "to develop a research agenda outlining a course of study which will definitely address the question of possible health effects from cellular telephones."

Loral buys IBM Federal Systems

NEW YORK, NY—Loral Corp. has signed a definitive agreement with IBM Corp. to purchase IBM's Federal Systems Division for $1.575 billion in cash.

Following the acquisition, which is expected to be completed during the first quarter of 1994, Loral will have a combined annual revenue of approximately $6 billion, with a backlog of $7 billion.

The IBM Federal Systems Division has broad experience in avionics; communications, command, and control (C^3); and space applications; as well as a systems integrator for commercial and government applications.

About 60 percent of the Federal Systems' business is defense-related, while 40 percent goes toward systems-integration applications for such agencies as the Federal Aviation Administration (FAA) and the US Postal Service. The IBM division also has a substantial international business.

FCC grants three PCS awards

WASHINGTON, DC—The Federal Communications Commission (FCC) says it will grant three companies essentially free access to spectrum for personal communications services (PCS) under its "Pioneer's Preference" rules, which the FCC established to help companies that developed innovative technologies for PCS.

American Personal Communications (Baltimore, MD), Omnipoint Communications (Colorado Springs, CO), and Cox Enterprises Inc. (Atlanta, GA) were selected among 50 companies which applied for Pioneer's Preference status. The other companies will have to compete for spectrum in an auction beginning in May or June. Several of the companies not attaining PCS innovator status by the FCC are expected to challenge the commission's decisions, either through appeals or lawsuits.

Each of the three companies, which had already received tentative preference status from the FCC, will be awarded 30 MHz of spectrum in three of the biggest markets in the auction: New York; Washington, DC; and Los Angeles. The FCC announced in September that it would award two 30-MHz blocks of spectrum in each of 49 regions, as well as awarding blocks of spectrum in 487 smaller regions.

American Airlines tests GPS

DALLAS, TX—American Airlines, ARINC (Annapolis, MD), which provides voice- and data-communications services for the air-transport industry, and the Federal Aviation Administration (FAA) have installed a global positioning system (GPS) at Dallas/Fort Worth International Airport to establish GPS-certification requirements for commercial aircraft.

Specifically, the facility will be used to develop baselines for the operational capabilities of different aircraft and avionics equipment. Aircraft to be tested include American Airlines' Boeing 757 and American's McDonnell Douglas Super 80 aircraft. Vendors providing GPS equipment include Litton Aero Products, Trimble Navigation, and Interstate Electronics Corp.

CableLabs turns to more RF

BOULDER, CO—Cable Television Laboratories, Inc. (CableLabs), the research and development (R&D) consortium of cable-television system operators, has decided to shift more of its $12.4-million budget in 1994 to wireless data and video projects.

"We will concentrate in 1994 on hiring new personnel in key competency areas in order to gain and retain their knowledge for the benefit of our members," says Richard R. Green, CableLabs president.

Vacancies expected to be filled in the near-term include project managers for new multimedia projects and RF and digital-signal-processing (DSP) programs.

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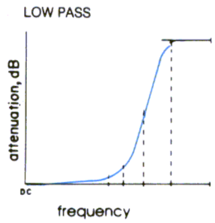
low pass, Plug-in, dc to 1200MHz



Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
★LP-5	DC-5	8-10	10-200
★LP-10.7	DC-11	19-24	24-200
★LP-21.4	DC-22	32-41	41-200
★LP-30	DC-32	47-61	61-200
★LP-50	DC-48	70-90	90-200
★LP-70	DC-60	90-117	117-300
★P-90	DC-81	121-137	167-400
★LP-100	DC-98	146-189	189-400
★LP-150	DC-140	210-300	300-600
★LP-200	DC-190	290-390	390-800
★LP-250	DC-225	320-400	400-1200
★LP-300	DC-270	410-550	550-1200
★LP-450	DC-400	580-750	750-1800
★LP-550	DC-520	750-920	920-2000
★LP-600	DC-680	840-1120	1120-2000
★LP-750	DC-700	1000-1300	1300-2000
★LP-800	DC-720	1080-1400	1400-2000
★LP-850	DC-760	1100-1400	1400-2000
★LP-1000	DC-900	1340-1750	1750-2000
★LP-1200	DC-1000	1620-2100	2100-2500

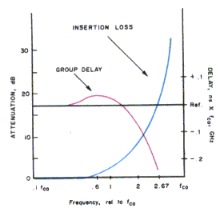
Price, (1-9 qty), all models: plug-in $14.95, BNC $32.95, SMA $34.95, Type N $35.95

Surface-mount, dc to 570MHz

Model No.	Passband MHz loss < 1dB	Stopband, MHz loss > 20dB	Stopband, MHz loss > 40dB
SCLF-21.4	DC-22	32-41	41-200
SCLF-30	DC-30	47-61	61-200
SCLF-45	DC-45	70-90	90-200
SCLF-135	DC-135	210-300	300-600
SCLF-190	DC-190	290-390	390-800
SCLF-380	DC-380	580-750	750-1800
SCLF-420	DC-420	750-920	920-2000

Price, (1-9 qty), all models: $11.45

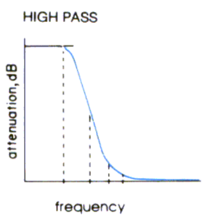
Flat Time Delay, dc to 1870MHz



Model No.	Passband MHz loss < 1.2dB	Stopband MHz loss > 10dB	Stopband MHz loss > 20dB	VSWR Freq. Range, DC thru 0.2fco X	VSWR Freq. Range, DC thru 0.6fco X	Group Delay Variations, ns Freq. Range, DC thru fco X	2fco X	2.67fco X
★BLP-39	DC-23	78-117	117	1.3:1	2.3:1	0.7	4.0	5.0
★BLP-117	DC-65	234-312	312	1.3:1	2.4:1	0.35	1.4	1.9
★BLP-156	DC-94	312-416	416	0.3:1	1.1:1	0.3	1.1	1.5
★BLP-200	DC-120	400-534	534	1.6:1	1.9:1	0.4	1.3	1.6
★BLP-300	DC-180	600-801	801	1.25:1	2.2:1	0.2	0.6	0.8
★BLP-467	DC-280	934-1246	1246	1.25:1	2.2:1	0.15	0.4	0.55
▲BLP-933	DC-560	1866-2490	2490	1.3:1	2.2:1	0.09	0.2	0.28
▲BLP-1870	DC-850	3740-6000	5000	1.45:1	2.9:1	0.05	0.1	0.15

Price, (1-9 qty), all models: plug-in $19.95, BNC $36.95, SMA $38.95, Type N $39.95
NOTE: ▲: -933 and -1870 only with connectors, at additional $2 above other connector models.

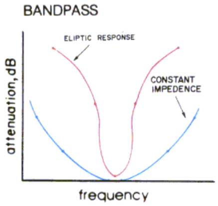
high pass, Plug-in, 27.5 to 2200MHz



Model No.	Stopband MHz loss < 40dB	Stopband MHz loss < 20dB	Passband, MHz loss < 1dB	VSWR Pass-band Typ.
★HP-25	DC-13	13-19	27.5-200	1.8:1
★HP-50	DC-20	20-26	41-200	1.5:1
★HP-100	DC-40	40-55	90-400	1.8:1
★HP-150	DC-70	70-95	133-600	1.8:1
★HP-175	DC-70	70-105	160-800	1.5:1
★HP-200	DC-90	90-116	185-800	1.6:1
★HP-250	DC-100	100-150	225-1200	1.3:1
★HP-300	DC-145	145-170	290-1200	1.7:1
★HP-400	DC-210	210-290	395-1600	1.7:1
★HP-500	DC-280	280-365	500-1600	1.8:1
★HP-600	DC-350	350-440	600-1600	2.0:1
★HP-700	DC-400	400-520	700-1800	1.6:1
★HP-800	DC-445	445-570	780-2000	2.1:1
★HP-900	DC-520	520-660	910-2100	1.8:1
★HP-1000	DC-550	550-720	1000-2200	1.9:1

Price, (1-9 qty), all models: plug-in $14.95, BNC $36.95, SMA $38.95, Type N $39.95

bandpass, Elliptic Response, 10.7 to 70MHz



Model No.	Center Freq. (MHz)	Passband I.L. 1.5 dB Max. (MHz)	3 dB Bandwidth Typ. (MHz)	Stopbands I.L. > 20dB at MHz	Stopbands I.L. > 35dB at MHz
★BP-10.7	10.7	9.6-11.5	8.9-12.7	7.5 & 15	0.6 & 50-1000
★BP-21.4	21.4	19.2-23.6	17.9-25.3	15.5 & 29	3.0 & 80-1000
★BP-30	30.0	27.0-33.0	25-35	22 & 40	3.2 & 99-1000
★BP-60	60.0	55.0-67.0	49.5-70.5	44 & 79	4.6 & 190-1000
★BP-70	70.0	63.0-77.0	68.0-82.0	51 & 94	6.0 & 193-1000

Price, (1-9 qty), all models: plug-in $18.95, BNC $40.95, SMA $42.95, Type N $43.95

Constant Impedance, 21.4 to 70MHz

Model No.	Center Freq. MHz	Passband MHz loss < 1dB	Stopband loss > 20dB at MHz	VSWR 1.3:1 Total Band MHz
★IF-21.4	21.4	18-25	1.3 & 150	DC-220
★IF-30	30	25-35	1.9 & 210	DC-330
★IF-40	42	35-49	2.6 & 300	DC-400
★IF-50	50	41-58	3.1 & 350	DC-440
★IF-60	60	50-70	3.8 & 400	DC-500
★IF-70	70	58-82	4.4 & 490	DC-550

Price, (1-9 qty), all models: plug-in $14.95, BNC $36.95, SMA $38.95, Type N $39.95

NOTE: ★**Add Prefix P, B, N, or S for Pin, BNC, N, or SMA connector requirement.**

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SUPPLIERS PROBE WIRELESS TEST NEEDS

Wireless communications requirements are testing the ability of instrument manufacturers to meet market demands.

RON SCHNEIDERMAN
SENIOR EDITOR/NEWS

WIRELESS COMMUNICATIONS MARkets are hot, and instrument manufacturers are warming to the challenge with new and improved products.

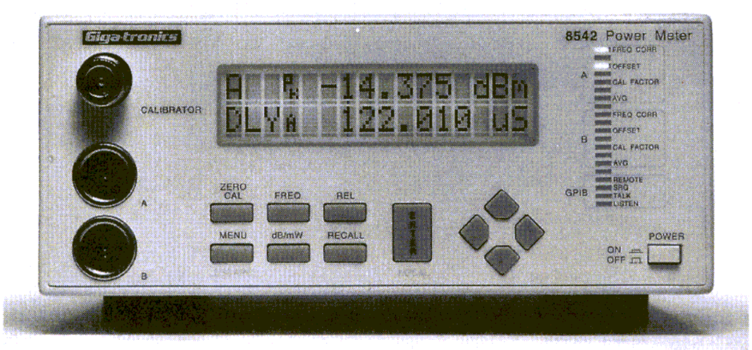
"Wireless is a very good opportunity for the future, not only for RF, which has been a real player in cellular for years, but in microwave," says Duane Hartley, general manager of Hewlett-Packard's Microwave Instruments Division (Santa Rosa, CA). Indeed, HP, which has seven divisions devoted to wireless communications markets and publishes a brochure with more than 30 wireless test and measurement (T&M) products, is already looking beyond today's markets to new T&M opportunities, such as wireless cable for "last-mile" applications, mobile satellite communications, emerging multi-media applications, and digital cellular.

Already a force in Europe's Global System for Mobile Communications (GSM) digital cellular system (HP was the first company to deliver T&M equipment for GSM) HP, Advantest Corp. (Tokyo, Japan), and SAFCO Corp. (Tokyo, Japan) have signed licensing agreements with QUALCOMM, Inc. (San Diego, CA) to manufacture and sell test equipment worldwide based on QUALCOMM's digital code-division-multiple-access (CDMA) technology.

"We are seeing significant steps toward the commercialization of CDMA in the personal-communications-services (PCS), cellular, and wireless local-loop markets," says Marv Blecker, vice president and assistant general manager of QUALCOMM's wireless telecommunications business group. "Meeting the equipment demands in these markets will require CDMA test equipment." According to Blecker, Advantest, HP, and SAFCO will provide a "full complement" of test equipment, from the manufacturing floor to coverage in the field.

Rodger C. Tracy, marketing manager at the HP RF Communications Division, says HP has been working on the development of the CDMA test equipment for some time. "Our plans are to have appropriate test equipment available to carriers and manufacturers to facilitate early roll-out of CDMA networks."

HP also expects to get help from its in-house GaAs capability in Santa Rosa. Hartley says the facility will



Giga-tronics has doubled the speed of its 8540 series universal power meters.

play a significant role in the next few years in HP's efforts to develop new products for wireless applications.

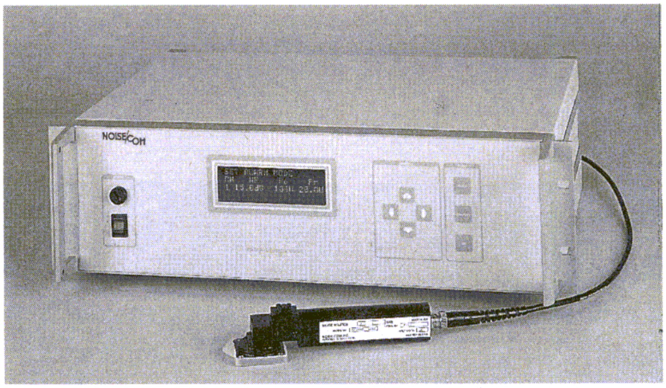
Tektronix is taking a different approach to the market. With so much at stake, Tom Brinkoetter, marketing manager for the Tektronix Frequency Domain Instruments Division (Beaverton, OR), believes most companies will use standard instruments to fulfill their wireless requirements, at least for awhile. "There will be a few applications for which people will build custom testers, and that capability will then be wrapped into standard products."

However, Rohde & Schwarz GmbH & Co. KG (Munich, Germany), which entered into a marketing alliance with Tektronix in August 1993 (more than doubling Tektronix's addressable market in the growing telecommunications sector), is already responding to the market with several products designed specifically for the GSM standard. But Rohde & Schwarz, says Brinkoetter, is in a different position than Tektronix. "They helped define the GSM standard. They know the modulations and the market, and they feel comfortable making that investment."

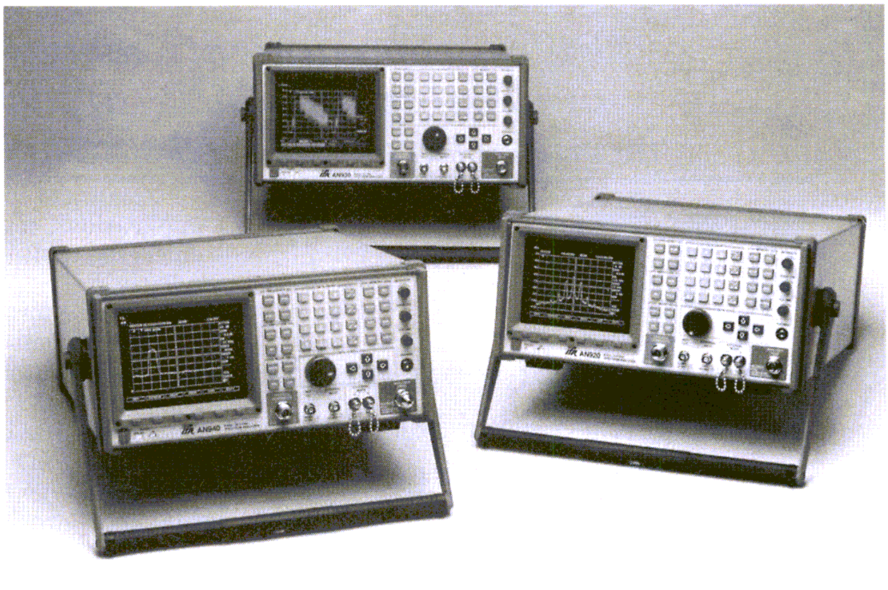
Rohde & Schwarz also claims to be the first European company to implement fully-automatic trimming and test equipment in the production of CT-2 (second-generation cordless telephones) and Digital European Cordless Telecommunications (DECT)-standard phones.

The Tektronix marketing manager says, "The hottest thing going for us now is the Rohde & Schwarz SMHU58 arbitrary waveform generator; it goes to 3 GHz. We're seeing some action in the ISM (industrial, scientific, medical) band for this unit at 2.4 GHz."

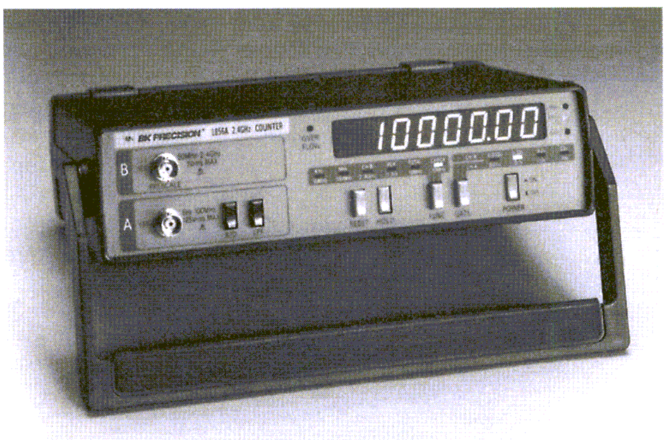
As more wireless-specific T&M equipment is developed, Brinkoetter believes the big trick will be to lower the cost and shrink the size of the product to gain market share. "That's the challenge. We're not reinventing measurement instruments as much as we're defining products that are appropriate for the size and range of a specific market."



NOISE/COM's cell-site monitoring system is available in several frequency bands.



IFR Systems' spectrum analyzer series provides frequency coverage to 26.5 GHz.



BK Precision's model 1856A microwave multi-function counter extends to 2.4 GHz for use in personal-communications-services (PCS) applications.

Tektronix also helped its position in the market when it joined forces earlier this year with Advantest Corp. The agreement allows Tektronix to distribute and service Advantest's telecommunications and industrial T&M products, as well as its general-purpose benchtop instruments, in the US, Canada, and Mexico. Advantest has a modulation adapter for its R3265 spectrum analyzer, which measures phase and can

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where QTY B = cumulative annual quantity purchased in preceding years as of January 1, 1990.

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A good credit standing with Mini-Circuits is a criteria to remain a participant of the program.

purchase location eligibility

Purchases from Mini-Circuits or a Mini-Circuits distribution center qualify for the program. Purchases from an authorized participating distributor qualify for the program when documentation of purchase is supplied to Mini-Circuits.

product eligibility

All catalog models and most special models are included in the program.

product ineligibility

Purchases made for the following do not qualify for the program: special testing, lot testing, serializing, source inspections, and qualification testing. Furthermore, purchases during special promotions or for multi-year or special contracts do not qualify. Highly specialized custom designed models may not be included in the program. Please consult with the Partner Program manager.

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Quantities credited to the program include only the net quantity of each model shipped to the customer in a specific calendar year. Different models may not be combined.

minimum purchase quantities

The base year quantity equals the total cumulative consecutive annual quantity purchased in preceding years as of January 1, 1990. However, if the quantity purchased for a model in a year is less than 2% of the quantity purchased in the previous year, then the cumulative total for the previous years shall revert to zero, i.e., base year quantity equals zero.

partner program changes

Mini-Circuits reserves the right to make changes to the program without prior notice.

partner program validity

The partner program is void where prohibited by law.

[1]Subject to the provisions of the terms and conditions given herein.
[2]All catalogs and most special products are eligible.

WIRELESS TESTING

Fluke's Wireless Logger can transmit data up to 800 ft. (244 m) to a personal computer for analysis.

do the phase-modulation measurements for US digital cellular phones, Japan's Personal Handy Phone (PHP), and Japan Digital Cellular (JDC) phones. "The product has not actually been announced, but we have sold several in the US," says Brinkoetter.

Tektronix's most-recently published *Comm Test Topics* newsletter lists 46 "wireless products" that are available from Tektronix, Advantest, and Rohde & Schwarz.

IMPROVED PRODUCTIVITY

Giga-tronics, Inc. (Pleasant Hill, CA) introduced its 8540 series universal power meter about 18 months ago, but David White, vice president of marketing and sales, says he did not realize just how big an opportunity the wireless market could be for the 8540 until six months ago. "At that time, power meters were making 2500 to 3000 readings per second. Based on input from cellular-phone manufacturers, we upped the speed of the 8540 to 4200 readings per second. We actually changed the product to address this particular market.

"[Mobile-phone] manufacturers get measured on two things: the number of units they can turn out per hour and the number of phones they produce per square foot." White says the faster 8540 can save 15 to 20 seconds in a 30-second test.

White will not comment on Giga-tronics' future plans for the wireless market. "This is a very competitive market. We just don't want to indicate where we're headed."

Malcolm Levy, Racal Instruments' (Irvine, CA) vice president of sales and marketing, has the same attitude. "This is a big market. Everyone wants to have as much lead as possible on the competition."

Racal, through its parent Racal Instruments Limited (Slough, Berkshire, England), is a major supplier of GSM test equipment. "Our position is that we are probably the number-one supplier of digital test systems to GSM," says Levy.

Racal introduced its first GSM test set in March 1990 and followed it a year later with two other GSM products designed for engineering, production, and base-station testing. Early in 1993, Racal Instruments launched the 6102, a GSM mobile tester. Since then, the company has introduced two base-station models for DCS-1800, the GSM-based 1.8-GHz digital communications system which is currently in use in the United Kingdom and Germany. Racal Instruments is also involved in the DECT and mobile satellite systems. "We expect to make some new product announcements in four to five months," says Levy.

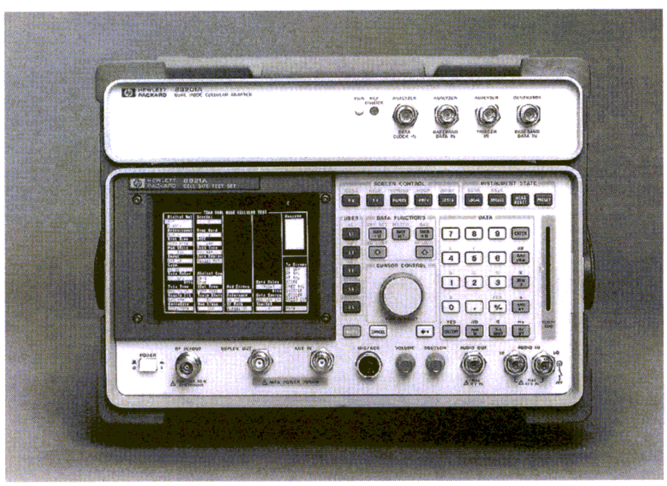
SUCCESSFUL SALES

Some T&M manufacturers are having some success selling their current product line to wireless components and systems developers.

"We have been talking to our mainstream customers about wireless applications for about two years, and in the past two months there has been an exponential acceleration in the interest level," says Steve Devino, a product manager at Teradyne, Inc. (Boston, MA).

Most of the interest at the moment is in GSM. "It's becoming a reality," notes Devino. "That seems to be the immediate market for T&M. PCS will probably be next—that's where most people think the real volume is."

When it is not looking at the market, Devino says Teradyne is considering the technical issues, such as what the baseband and modulation format will look like. "Once you get past the front end, it doesn't matter if it's DECT, CDMA, or whatever. The baseband is what changes and



Hewlett-Packard's portable analog and digital cell-site test sets are designed to guide the user through recommended procedures.

that's all being accomplished with a generic DSP (digital-signal-processing) device. You rewrite the program to accommodate the standard."

Devino says Teradyne has begun delivering a new tester—designated the 8530RF—which has not been formally announced. "It's a variant of technology that we are currently delivering."

Art Pini, a product manager at LeCroy Corp. (Chestnut Ridge, NY), says his company's wideband oscillators with bandwidths to 4 GHz work well in many wireless applications, but the products were not developed with wireless in mind.

"Most people don't think of us when they look at high-frequency testing," says Mark Hoersten, marketing manager of Keithley Instruments, Inc.'s Instrument Division (Cleveland, OH); however, Hoersten says that Keithley counts mobile-phone manufacturers among its customers, mainly for the company's frequency counters and its model 7001 and 7002 switching products that are used to route test signals up to 500 MHz.

ENHANCED PRODUCTS

Others are moving into the wireless market by enhancing existing products.

NOISE/COM, Inc. (Paramus, NJ), for example, recently introduced a series of earth-station and cell-site monitoring systems. They are capable of monitoring the output power, antenna VSWR, and noise figure of up to four cellular, satellite, or radar channels. The instruments are available at 30-, 60-, and 70-MHz intermediate frequencies (IFs) as well as in frequency bands up to 18 GHz, 824 to 928 MHz, 1710 to 1930 MHz, and 2400 to 2500 MHz.

BK Precision (Chicago, IL) has nearly doubled the bandwidth of its model 1856A microwave multifunction counter (5.0 Hz to 2.4 GHz), which puts it into the PCS applications realm. The unit's sensitivity at 2.4 GHz is 50 mV. Optional accessories include an accessory antenna for checking transmitter frequency and a 10:1 probe. It also continues to be priced at $499.

IFR Systems, Inc. (Wichita, KS) has introduced a spectrum analyzer with frequency coverage to 26.5 GHz. The three models in the AN900 series were developed specifically for remote or field service use; they can be powered from 12-to-30-VDC sources or from an optional rechargeable battery pack. Standard RS-232 and GPIB interfaces allow remote-control operation or direct hard-copy output to a plotter. The units also feature an optional, built-in, 2.9-GHz tracking generator, quasi-peak detector, and 0.02-PPM time base.

Fluke Corp. (Everett, WA) has actually introduced a wireless prod-

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These bipolars operate below 3V and at low current to reduce battery size and increase battery life for your wireless applications.

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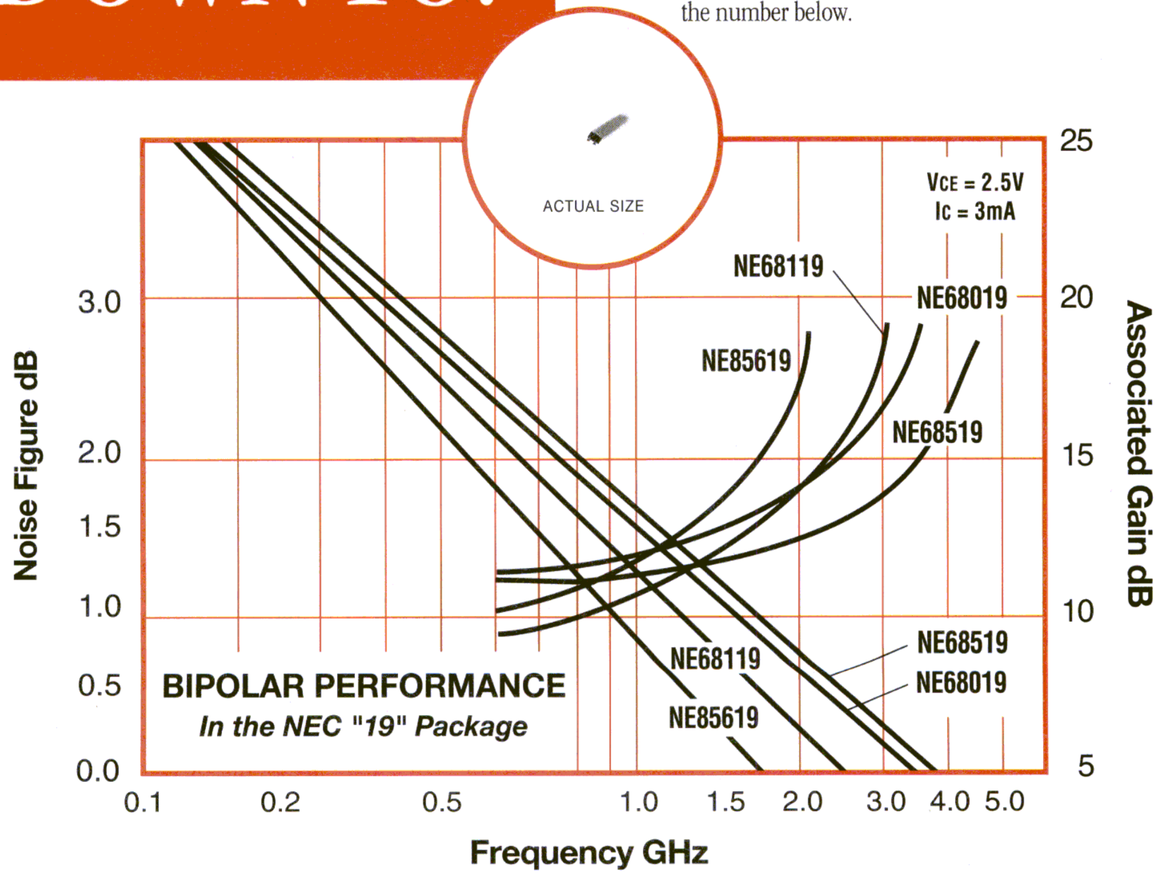

NEC Bipolars are available in these packages (shown approx. 2X size)

NEC "19" Pkg	NEC "18" Pkg	NEC "30" Pkg	NEC "33" Pkg	NEC "39" Pkg
Ultra Super Mini Mold	4 Pin Super Mini Mold	SOT-323 Style	SOT-23 Style	SOT-143 Style

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uct—a data logger for quick and easy data collection and transmission to a personal computer (PC) from remote locations. Developed to monitor a variety of parameters in testing, process-improvement, or other verification-based applications, the Fluke 2625A/WL portable 21-channel spread-spectrum-based unit can transmit data up to 800 ft. (244 m) to a PC for analysis. Each of the channels is user-programmable for any of several inputs: thermocouples, AC/DC voltage or current, resistance, and frequency.

Marconi Instruments (Allendale, NJ), which about two years ago offered a family of radio test sets with AMPS, N-AMPS, and D-AMPS adapters, now has a digital- and vector-modulation option for D-AMPS, JDC, and TETRA (a proposed European time-division-multiple-access, or TDMA-based, standard) modes for its 2030 series 10-kHz-to-5.4-GHz signal generators. So far, however, the company has no instruments dedicated specifically to wireless applications.

From at least one chip manufacturer's point of view, T&M suppliers are not meeting manufacturing needs.

"The rack-mounted stuff is sort of build-as-we-need," says Bob Lussier, the wireless local-area-network (WLAN) engineering manager for GEC Plessey Semiconductor (Scotts Valley, CA). "My perception is that for most applications, it may be cheaper to do it yourself than to buy a multi-million-dollar shielded-room-type tester that would work for many applications."

However, Brent Wilkens, GEC Plessey's WLAN manager, says the industry is in a chicken and egg situation. "We have to provide them with the fastest technology we can so they can build their testers. We have to test those products before they develop a tester. So, we have to be at the cutting edge before they're at the cutting edge."

There are other concerns, such as standards. "We think that's a real challenge," says HP's Duane Hartley. "The standards are being defined at the same time the products are being developed."

And that creates time-to-market problems, which Teradyne's Steve Devino calls "the life and death in this market." Bottom line, Devino says, "There are too many competitors for the size of the market."••

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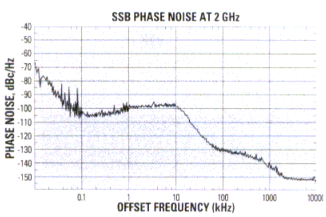
No microwave signal generator gives you better signal quality from 10 MHz to 20 GHz than the GT 9000.

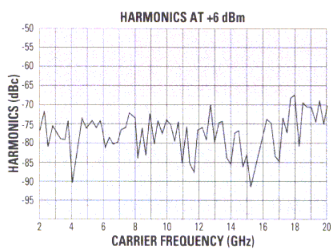
Want proof? Compare the phase noise, harmonics, output power and the other critical specifications of the GT 9000 with those from any of our competitor's microwave signal generators — including ones that cost over $40,000.



Low phase noise assures you of more accurate narrow-band measurements.

And after you see how much better our specs are, compare prices. Not only does the GT 9000 give you far better performance than their highest priced boxes, but it does so for thousands of dollars less than their lowest priced box — well under $30,000.

The key to the performance of the GT 9000 is a new single RF module design. This unique design gives you several significant advantages.



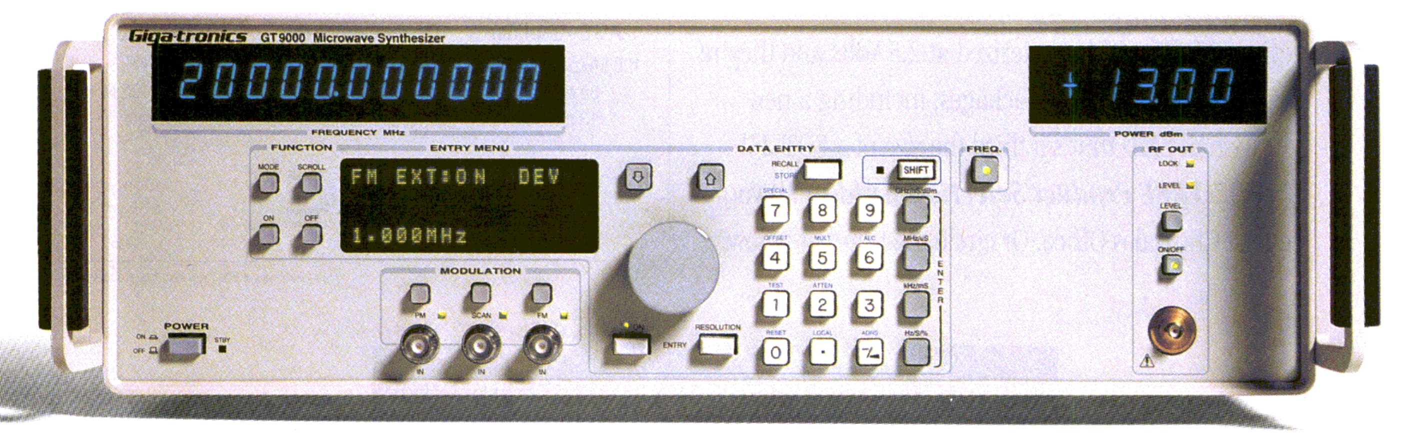
Harmonics are less than -65 dBc at +6 dBm and -55 dBc at +13 dBm for more accurate measurements over a wide bandwidth.

For example.

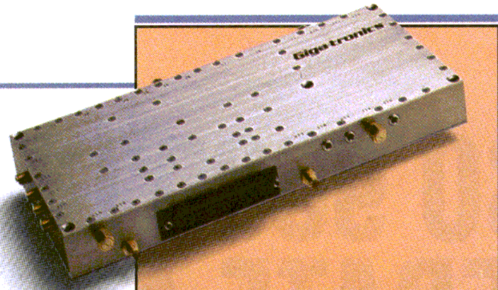
Phase noise at 2 GHz is -120 dBc/Hz at 100 kHz offset, making the GT 9000 ideal for measuring critical narrow-band characteristics such as adjacent channel sensitivity.

Output power is +13 dBm or greater from 10 MHz to 20 GHz. That's enough to overcome most system losses without adding the signal degradation and extra cost of external power amplifiers.

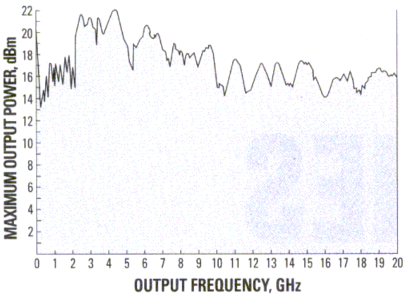
With harmonics less than -65 dBc at +6 dBm and -55 dBc at



The GT 9000 gives you outstanding performance and proven reliability at the lowest price available for a broad-band synthesizer.



The unique single RF module design is more reliable and less costly than multiple module designs.



Output power greater than +13 dBm lets you overcome most system losses without having to add external amplifiers.

With A Single RF Module, Less Is Significantly More

Most broad-band synthesizers use several RF modules for signal generation. The innovative single RF module design of the GT 9000 uses fewer parts and interconnections. This unique design yields higher performance, greater reliability and better serviceability, as well as less expensive manufacturing and testing. So you get significantly more for a lot less money.

+13 dBm, you can accurately test over a wide bandwidth with confidence that the measurements you make are a result of the system under test, and not your synthesizer.

And since more and more test applications require signals below 1 GHz, the GT 9000 starts with standard coverage from 500 MHz to 20 GHz. And if you need even lower frequencies, we've got a model that covers 10 MHz to 20 GHz.

In addition to standard internal pulse modulation, you can add internally generated AM and FM, eliminating the need for costly external generators. And for really complex patterns, we offer fast scan modulation with 60 dB depth.

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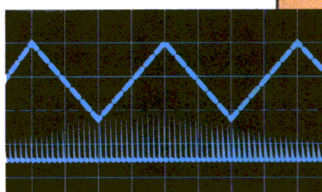

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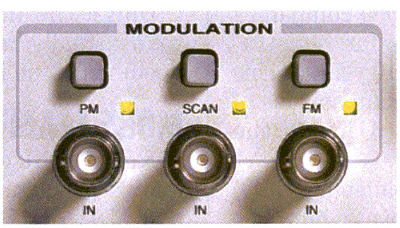

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ISO 9000 GENERATES DEBATE AMONG INDUSTRY COMPANIES

Opinions on ISO 9000 certification standards are mixed, but almost everyone is getting on board.

RON SCHNEIDERMAN
SENIOR EDITOR/NEWS

WHETHER they want to or not, a growing number of industry companies are getting on the ISO 9000 bandwagon, and for good reason: Not only are European customers requiring their US suppliers to become ISO 9000 certified, but so are many of their US customers. At the same time, the US Department of Defense has indicated that it may require its suppliers to meet the ISO standard.

Many companies, however, particularly the smaller ones, are not happy about the ISO 9000 program. They view it as more of a financial burden and a distraction than as an opportunity to improve quality.

"It is a burden," says David T. Kenney, director of quality at ADC Kentrox (Portland, OR), which has already been certified under ISO 9001. [ISO 9001 is the most stringent and comprehensive of the ISO requirements, covering design, production, test and inspection, repair, customer service, field service, and quality management systems.] "If I was running a small company, I wouldn't rush into it. This is not something you have to do in the next six months. It's like everything else; you have to consider what your customers are asking of you and what's your competitive situation."

Nevertheless, George Winn, president and chief operating officer of Fluke Corp. (formerly John Fluke Mfg. Co.), which received ISO 9001 certification for all of its North American service and manufacturing facilities in July 1993, says, "It is becoming increasingly difficult for companies to sell products internationally without having ISO 9001 registration."

European companies got a running start in meeting the objectives of the standard. Today, more than 20,000 companies in the United Kingdom alone are registered. In the US, the number only recently topped 1000. According to Bill Allred, Fluke's corporate ISO coordinator, more than 200,000 companies are expected to apply for registration in the next five to 10 years. "This estimate is based on comparisons of the economies of the UK and the US," says Allred.

K&L Microwave (Salisbury, MD) is well along in the process, but does not expect to become ISO 9001 certified until the third quarter of 1994. Meanwhile, Jack McNally, K&L's ISO 9000 management representative, says the company is working with the Maryland Department of Economic and Employment Development to organize an ISO 9000 consortium to help companies in the state achieve ISO 9000 certification. The state has already agreed to pay half of all ISO 9000 training costs of Maryland-based companies. Delaware and Pennsylvania have similar programs.

McNally says K&L expects ISO 9000 certification to cost about $20,000, plus $10,000 for each additional semi-annual audit. Still, he says he is positive about the program. "Now, we can have people on the [manufacturing] floor write down how they do their jobs instead of having me, as the quality manager, look at the MIL-I and MIL-Q, which we have been using for 25 years. We now have a document that gives us some flexibility."

Kenney agrees. "There is enough leeway in this program to tailor it to your needs. For example, I think we're overdocumented. As we go through the improvement cycles, we'll actually reduce the amount of documentation that we have."

MORE TEAMWORK

Key facilities of Scientific-Atlanta's Electronic Systems Division and Network Systems, Instrumentation, and Broadband Communications Groups (Atlanta, GA) have also won certification to ISO 9001. "One of the biggest benefits of this process," says Vino Mody, the Broadband group's vice president of qual-

ISO 9000

ity assurance, "has been the teamwork required to successfully carry out our quality commitment."

Burr-Brown Corp. (Tucson, AZ), whose products range from linear integrated circuits to data-collection systems, has received certification in the US and Europe simultaneously from AT&T Quality Registrar. "For Burr-Brown, it means fewer and simpler customer audits, source inspections, print reviews, and questionnaire activities," says Michael E. Paugh, vice president of quality. "For our customers, ISO 9001 certification means lower costs associated with the same activities."

Silicon Systems (Tustin, CA) has also been awarded ISO 9002 certification at its Singapore Technical Center, site of virtually all of the company's application-specific, mixed-signal, integrated-circuit assembly and test operations. ISO 9002 is a production and installation subset of ISO 9000.

A survey published in August by the Institute for Interconnecting and Packaging Electronic Circuits (IPC) shows broad acceptance of ISO 9000 certification throughout the electronic-interconnection supply chain. IPC surveyed printed-wiring-board manufacturers, electronic manufacturing service providers and their suppliers, and OEMs who are members of IPC. Among the survey respondents, more than 18 percent of the companies had already received ISO 9000 certification and an additional 64 percent of the companies were preparing for or seeking certification.

ISO 9002 is the standard of choice for most IPC members responding to this survey; however, 73 percent of the OEMs reported seeking or receiving certification to ISO 9001. Those companies that have already received ISO 9000 certification reported on average that they invested nearly $100,000 to prepare and achieve ISO 9000 certification.

According to Thom Dammrich, executive director of the IPC, the top three reasons for seeking ISO 9000 certification were: becoming more competitive, improving quality, and meeting customer demands.

To assist its members in attaining ISO 9000 status, the IPC has published the *General Requirements for Implementation of ISO 9000 Quality Systems, IPC-QS-95*, which explains the product-conformance specifications for suppliers and manufacturers of electronic components, base materials, printed boards, and related products.

The Electronic Industries Association (Washington, DC) has taken a similar, if not more aggressive, approach, creating the Electronic Industries Quality Registry (EQR). The EQR received its accreditation from the Dutch Council for Certification as an ISO 9000 registrar in July 1993. Since it was announced, the EQR has formed an alliance with the AT&T Quality Registrar to offer US and European registration from a single assessment.

Eli Lesser, the EQR's executive director, sees the process as a way to "level the playing field." He says the industry is "being forced to become ISO 9000 certified by marketplace demand."

So far, 33 US electronics companies have become ISO 9000-registered through the EQR. The EQR is also working with several Asian companies. "Most companies don't understand what is required of them," notes Lesser. "They are more comfortable working with us. European companies prefer to work with European registrants."

But Lesser admits that small companies do not like the ISO 9000 effort. "They're complaining. They see it as an added burden and expense, particularly the on-going surveillance requirement."

Despite the complaints, Lesser

JAPAN IS QUICK TO ADOPT ISO 9000

Long praised for their attention to quality, Japanese companies are moving aggressively to become ISO 9000 certified.

Translated verbatim in October 1991, the ISO 9000 quality-related standards have been widely adopted by Japanese industry. While the initial impetus to ISO 9000 certification has been the fact that many European Community (EC) customers require it as a condition for qualifying as a supplier, Tokyo-based John Stern, vice president for Asian Operations of the American Electronics Association, says the ISO 9000 series has also been embraced as a model for intracompany use and domestic transactions in Japan. Several offshore Japanese facilities have also been certified. "In fact, hardly a week goes by without a Japanese electronics company taking out an advertisement in the Japanese press crowing about ISO 9000 certification of its factories," notes Stern.

ISO 9000 is a big business: the Keidanren, Japan's largest chamber of commerce, has established an organization to help companies cope with certifications. JMI, one of the testing organizations, certified only three facilities in 1990; as of September 1, 1993, JMI has issued 247 ISO 9000 certifications. (Some Japanese electronics companies use foreign registrars for ISO 9000 certification, mainly Lloyd's Register Quality Assurance and the British Standards Institution.)

NEC, which has already certified 83 of its facilities (the NEC Microwave Division was ISO 9002-certified in May 1992), in July 1993 formed a new company, NEC Factory Engineering Inc., that hopes to do $25 million of business in its first year as an ISO 9000 consultant.

Says Stern: "ISO 9000 will remain a factor in competing with Japanese companies in Japan and the EC for at least the next five years." ••

ISO 9000

says he expects the pace of ISO 9000 certification to increase significantly. "There will be a lot more ISO 9000 certifications in 1994."

Some companies manage to save money. Maxim Integrated Products (Sunnyvale, CA) recently received ISO 9001 certification. Ken Huening, vice president of Maxim, says his company spent only $25,000—far less, he claims, than most companies to attain ISO 9001 status—because many systems were already in place. "The importance of ISO 9001 certification is measured by economic and strategic benefits. One major benefit is reduced supplier auditing. The certification demonstrates to the customer that Maxim has a sound and reliable quality-assurance system in place." Another benefit, he says, is Maxim's inclusion in a directory of ISO-compliant companies, providing greater visibility and accessibility.

US GOVERNMENT'S ROLE

The US government's role in ISO 9000 has been peripheral, but some help is available. The National Institute of Standards and Technology (NIST) maintains a list of more than 50 organizations which offer ISO 9000 registration, but the NIST has made no attempt to evaluate any of these programs.

However, the NIST operates seven regional Manufacturing Technology Centers which serve as resource facilities to help manufacturers improve their competitive position by improving their manufacturing facilities. Several of these centers have sponsored workshops on ISO 9000.

The Department of Commerce's International Trade Administration's Single Internal Market Information Service (SIMIS) offers an information package on ISO 9000 featuring a booklet, *Questions and Answers on Quality, the ISO 9000 Standard Series, Quality System Registration, and Related Issues.* SIMIS estimates that more than 10,000 companies have already requested the ISO 9000 information kit. [To obtain the package, call SIMIS at (202) 482-5279.]

Also, the Commerce Department's Economic Development Administration funds a Trade Adjustment Assistance Program to help ailing companies. The program funds 12 regional centers which provide financial assistance to companies, including assisting them with costs associated with ISO 9000 registration.

[Information on accreditation bodies operating in the field of quality-system registration in the US (as well as on the registrars that they have accredited) can be obtained from The Registrar Accreditation Board (RAB), c/o American Society for Quality Control (ASQC), 611 East Wisconsin Ave., Milwaukee, WI 53202; (414) 272-8575, and from


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According to ISO procedures, all ISO standards, including those in the ISO 9000 series, must be reviewed, revised, or reaffirmed at least once every five years. ISO has already begun to revise and supplement the ISO 9000 series. The first revisions are expected to be published in 1994.

In most cases, the changes will be structural. For example, the numbering system will be changed to make room for the revisions. Also, the term "purchaser" which now appears in ISO 9000 documentation will be changed to "customer." In addition, customer satisfaction will be introduced for the first time into the standard. Design validation, which did not appear in the original 1987 ISO 9000 standard, will be clarified in the revisions. [Copies of the ISO draft/final standards and European standards can be purchased from the American National Standards Institute; (212) 642-4900.]

According to ISO procedures, all ISO standards must be reviewed, revised, or reaffirmed at least once every five years.

With more than 50 registrants to choose from, David Kenney of ADC Kentrox says it may make sense for companies to shop around for a qualified registrar, and not only just to get the best price. According to Kenney, an informal network of quality professionals has begun to rate the ISO 9000 registrants. "What we have found," he says, "is that some are easier than others." ••

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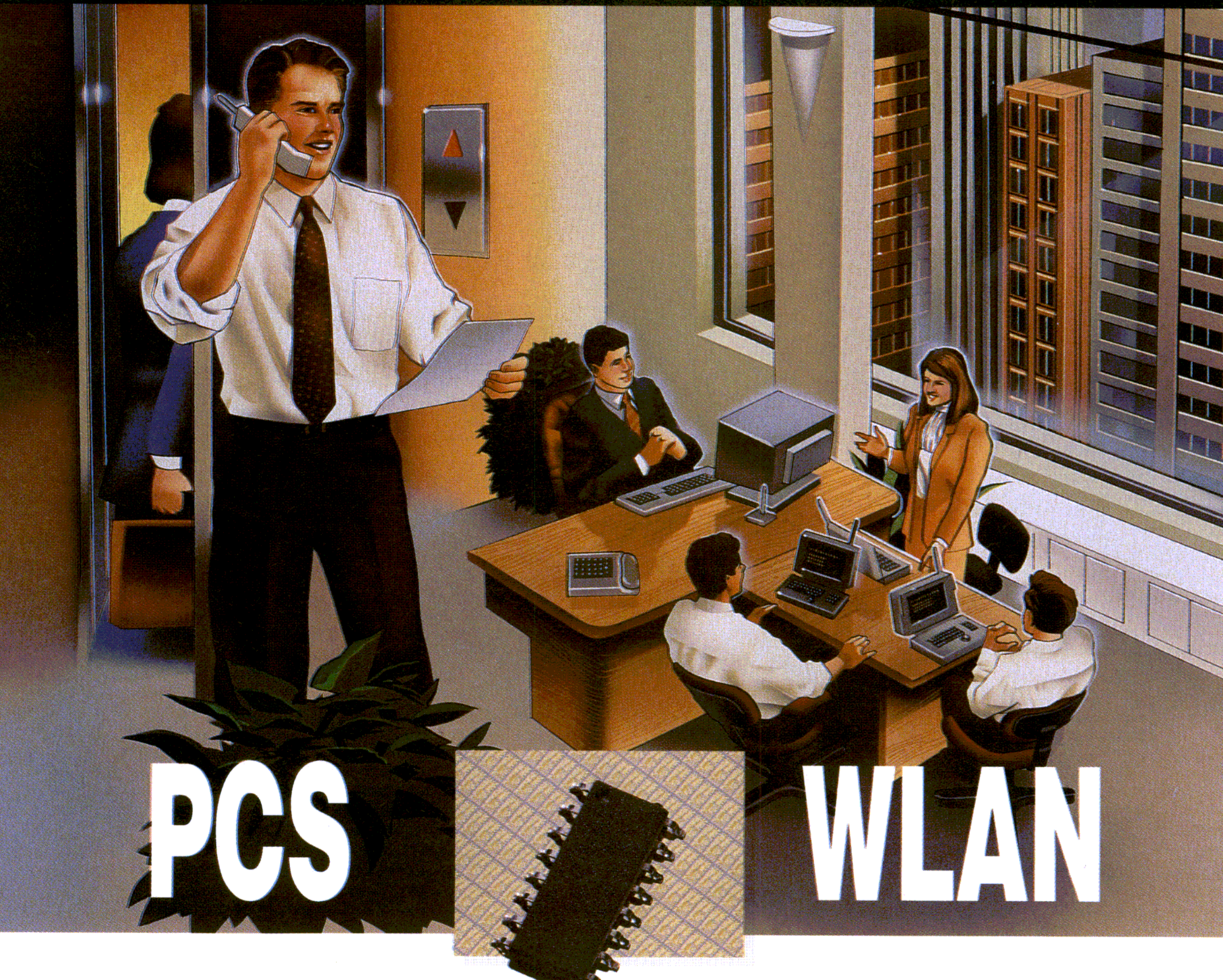

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1.7-2.0 GHz										
CAS1401	22.5	23.5	25	21	2.0:1	16	20	0.8	1.0	100
CAS1402*	22.5	23.5	25	21	2.0:1	16	20	0.8	1.0	100
CMM1301**	23.5	24.5	30	22	2.0:1	16	20	—	—	—
2.3-2.5 GHz										
CAS2401	22	23	20	18	2.0:1	16	20	0.8	1.0	100
CAS2402*	22	23	20	18	2.0:1	16	20	0.8	1.0	100
CMM2301**	23	24	25	19	2.0:1	16	20	—	—	—

*0.5 mA current required for switching. **Amplifier without switch.

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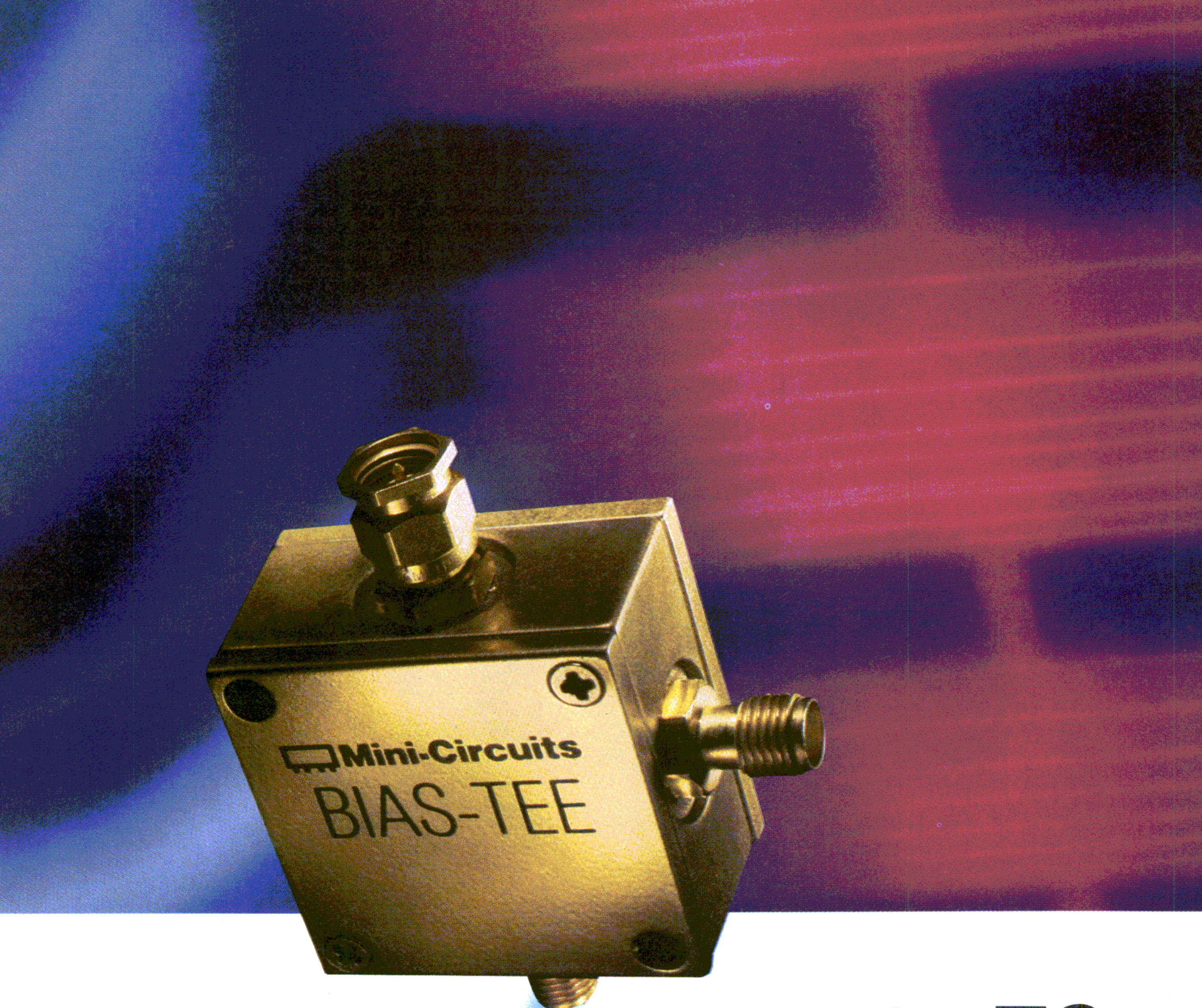

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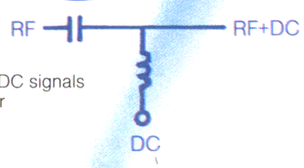

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ZFBT-4R2GW	0.1-4200	0.15	0.6	0.6	25	40	50	1.3:1	79.95
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CROSSTALK

Charles Schaub *is president of K&L Microwave (Salisbury, MD), a leading manufacturer of filters, switches, and integrated subassemblies for commercial and military applications. This interview was conducted during a plant tour.*

MRF: *K&L is often thought of as the country's largest filter house. But when one walks around the company, it is apparently much more. How is the company structured?*

Schaub: K&L, which employs about 500 people, actually consists of many companies within a company. Groups or divisions are devoted to different types of high-performance filters, switches, integrated assemblies, commercial products, space applications, and the high-volume filters manufactured in the KeL-COM Division. As we've seen, these groups may be further divided into manufacturing cells, with each cell accounting for its own assembly, quality control, and production testing. Everyone in the cell is being trained to do all of the tasks involved, from working with designers to final performance testing. In many cases, we have even moved inventory away from a central location and more into the control of each manufacturing cell. Each cell can then monitor the parts that it requires and order more parts as the flow of production dictates.

MRF: *Who has been one of your most difficult customers over the years?*

Schaub: Hewlett-Packard is certainly one of our most demanding customers, so much so that seven of our employees have visited their plants in California and Scotland to see how we could improve our relationship with them. Hewlett-Packard has a rating system for its vendors that encompasses what it takes to be a world-class supplier. By focusing on systems and processes such as customer service, technical support, delivery time, business practices, environmental practices, and cost, our rating has vastly improved. By satisfying one of our most demanding customers, K&L has been able to better serve all of our customers.

MRF: *What is your relationship with Dover Technologies?*

Schaub: Dover is a $2.5-billion company with more than 50 operating companies divided into five business segments. We are part of Dover Technologies, which is one of the five units. Dover Technologies is a $500-million subsidiary serving the electronics industry. The company has 23 people at corporate headquarters and only four at the Dover Technologies office. The relationship with Dover is one of trust, open communication, and individual autonomy. The basic focus within Dover is on growing the various business units, concentrating on niche markets, and achieving market leadership.

MRF: *Even though not everyone agrees with obtaining ISO 9000 certification, you appear to have taken the guidelines seriously at K&L.*

Schaub: We take it so seriously that we have appointed Jack McNally as the director in charge of leading the company to certification of ISO 9001. He and our steering committee are working to ensure that all of our processes are documented to the ISO 9000 guidelines. He has trained a staff of auditors to verify that we operate in compliance with our procedures. One of the benefits of ISO 9000 is that it forces a

CROSSTALK

company to take a hard look at its processes. The resulting changes provide a system necessary to compete in the global markets.

Adopting ISO 9000 is just a part of the way that people here take pride in what they do and in the level of quality that they try to achieve. No one here works in a vacuum. Everyone tries to learn how their efforts can contribute to the final product. The people within our cells, for example, will often visit our plating facility and printed-circuit-board facility to discuss and work out processes to improve the methods and procedures necessary for new products. Processes are monitored throughout at different test stations and within the cells so that we can expose any problems early in the manufacturing cycle before value is added to the product.

We have implemented statistical process control (SPC) throughout K&L and are getting everyone involved. Anyone within a cell can stop the production process at any time for any reason that interferes with quality. We keep complete records of any problems in our process so we can eliminate them. When we get people together from our different cells and have everyone talking about solutions that turn out to be mutually beneficial, there is a sense of a team trying to solve problems together, rather than adversarial working relationships that are common within large companies.

MRF: *The company appears to be fairly diversified in terms of capabilities. Is there much need for outside services?*

Schaub: We've actually tried to make K&L as self-contained as possible, with our own environmental test facilities, plating facilities, microwave test laboratories, and computer-controlled (CNC) machinery throughout the company. This level of integration exists solely to create cycle-time reduction to allow us to provide timely solutions for our customers. In the environmental facility, for example, we have two vibration tables, a shock test station, thermal-shock stations, thermal-cycling equipment, a humidity chamber complete with a dedicated HP 8510B vector network analyzer from Hewlett-Packard Co., hermeticity/leak testers, a salt-spray test station—in short, all the equipment needed for full MIL-STD-883 testing. We can even perform vibration testing over the full military temperature range. We have our own laser-welding equipment for sealing hermetic packages. Our testing capability is such that we occasionally sell our services to local firms.

MRF: *K&L appears to be structured much differently than it appeared several years ago. What changes have you implemented since becoming president of the company?*

Schaub: The basic structure of the company can be attributed to our founder, Richard Bernstein. However, with the many changes our industry continues to undergo, we are constantly evolving and growing. For one thing, you will notice that a great many more computers are being used now than just a few years ago. We are currently in the midst of a project to link our computer design stations, by means of a company-wide network, directly to our CNC machines. We are using three-dimensional design software that selects the machine tools and creates the programs needed for the CNC machines. Once the network is hooked up, we will be able to take a design directly from software to hardware with none of the usual setup time needed to program the CNC equipment.

Another thing we have done is to utilize our wealth of CNC machinery better than in the past. Rather than have a totally-dedicated machining equipment area, we have moved a lot of that equipment within cells or production areas so that there is better access to the equipment by the people that use it every day. In doing this, we have eliminated some of the bureaucracy within K&L that contributed manufacturing inefficiency. Other investments within the company include more than 80 state-of-the-art network analyzers, advanced software tools for design, and new information system technology. This investment helps maintain the leadership position we enjoy in the markets we serve.

The most significant change is the training and education of our associates to meet the accelerated pace in today's market. We have instituted internal training and used university programs to achieve this goal. Our training and educational efforts account for about 5 percent of the work week.

MRF: *When we first discussed the concept for KeL-COM (see* Microwaves & RF, *February 1993, p. 138), you were starting with four KeL-COM employees that were hand-picked from the ranks of K&L personnel. How is KeL-COM currently faring?*

Schaub: KeL-COM's sales have really expanded all year. We will have 10 employees with additional staffing required for next year. In fact, we are looking for more than 100-percent growth for 1994, a fantastic pace. Of course, that growth has to slow down sometime. But we think that 100-percent growth rate for 1994 could be conservative. The interesting thing is that through KeL-COM, which has a truly commercial reputation, we have been able to add customers that we haven't served before. In fact 90 percent of the customer list for KeL-COM is different from that of K&L.

MRF: *What types of new products can be expected from K&L?*

Schaub: We are about to release a family of surface-mount dielectric resonator filters. The filters, which achieve high quality-factor (Q) values over standard communication bands, measure only about 0.5 × 0.5 in. (1.27 × 1.27 cm) with RF leads. A complete line of switch matrix products (from audio through microwave) is planned for 1994. Other products such as cellular subsystems are under development, with prototypes being evaluated by several customers. The explosive growth in wireless communications is creating a great growth opportunity for our industry, and we will be a major player with many new products.●●

TriQuint IPO raises $22 million

TriQuint Semiconductor, Inc. (Beaverton, OR) raised $22 million in its initial public offering (IPO) of two million shares of common stock in December.

The stock, which opened at $11, traded as high as $13 in late December on the NASDAQ national stock exchange. TriQuint is traded under the symbol "TQNT."

Steven J. Sharp, TriQuint's president and chief executive officer, says the company expects to use the proceeds from the sale of common stock to retire some debt and, along with cash anticipated from operations, to help satisfy the company's projected working capital and capital expenditure requirements through at least the end of 1994. "We'll also pay off about $2 million on a bank line guaranteed by Tektronix."

According to Sharp, about one-fourth of the proceeds from the stock sale went to Tektronix as the only selling stockholder. However, with the stock sale and the purchase of part of Tektronix's holdings just prior to the IPO, Kleiner, Perkins, Caulfield & Byers IV (the Palo Alto, CA-based venture capital firm) emerges as the largest stockholder in TriQuint.

The second largest stockholder in TriQuint is now AT&T. In August 1993, TriQuint and AT&T Microelectronics entered into an agreement involving the development, production, and marketing of GaAs integrated circuits (ICs). Specific financial terms of the arrangement were not discussed; however, the companies expect to jointly develop a process based on AT&T's GaAs technology for wireless and next-generation fiber-optic communications applications. AT&T will continue to design and market GaAs ICs for both internal and OEM customers. AT&T also gains a seat on TriQuint's board of directors.

TriQuint's revenues have grown steadily over the past several years, but the company has only recently begun to report profits. TriQuint had net losses of $5,869,000 in 1989, $5,846,000 in 1990, and $4,928,000 in 1991. TriQuint's total revenues for the nine months ended September 30 were $23,770,000 with a net income for the period of $512,000. According to the company's prospectus, sales outside of North America accounted for about 11.5 percent of TriQuint's total revenues for those nine months. Although they represented a decreasing portion of the company's business, defense-application products represented about 12 percent of TriQuint's revenues in the first nine months of 1993.

The prospectus also notes that TriQuint's largest customer, Northern Telecom, accounted for about 16 percent of the company's total revenue in 1992 and 27 percent in the first nine months of 1993.●●

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Pictured from left to right: Karen Okumura-*Customer Service Rep.*, Sumi Nakagami-*Lead PCB Assembler*, Pete Pragastis-*Sr. Microwave Engineer*, Rick Bush-*Dir. of Sales*, Chuck Russell-*Lead Final Assembler*

Contracts

Hughes Network Systems—An estimated $400 million from BellSouth Cellular Corp. for cellular-networking equipment. Under terms of the multi-year agreement, Hughes will deploy its GMH 2000 network in more than 50 markets in the southeastern US.

Texas Instruments—$42.2 million to TI's Defense Systems & Electronics Group from the US Naval Air Systems Command for additional High-Speed Anti-Radar Missile (HARM) hardware.

Beech Aircraft Corp.—$17.9 million to the Raytheon Co. subsidiary from the US Navy for 92 AQM-37C target missiles. Also, $3.6 million to Raytheon from the US Naval Systems Weapon Center to develop a module foundry service, as well as $500,000 from the US Naval Avionics Weapons Center to develop a high-density gold connector for use on the next-generation of standard electronic modules.

California Microwave, Inc.—$16.4 million from Singapore Telecom to design, build, and install two Intelsat Standard-A earth stations.

Nokia Telecommunications—$50 million from the Czech Republic's Eurotel Prague and Slovakia's Eurotel Bratislava to expand their cellular networks. Also, $25 million from Pannon Global System for Mobile Communications (Pannon GSM), a Hungarian digital cellular-network operator, to supply a GSM network in East Central Europe. Pannon GSM is a consortium of three Hungarian companies, four Nordic telecommunications operators, and the Dutch Post Telephone and Telegraph (PTT) system. Also, $20 million from Centertel, the Polish network operator, for extension of its cellular-phone network.

Electronic Space Systems Corp.—$10 million from the Federal Aviation Administration (FAA) to manufacture and install radomes to protect primary and secondary surveillance systems at FAA facilities nationwide.

Aydin Corp.—$5.5 million from a US defense contractor for airborne transmitters, receivers, and power amplifiers for missile applications.

TRW Space & Electronics Group—$3.8 million from the US Air Force Space and Missile Systems Center to develop system architecture and design concepts for future military satellites.

Alcatel Network Systems—$2.4 million from Smart Information Technologies, Inc., a cellular-telephone service provider in the Philippines, to build a cellular telecommunications network.

MPR Teltech Ltd.—$2 million from New Delhi-based Himachal Futuristic Communications Ltd. to develop prototype 7-GHz digital radio systems for use in rural villages in India.

Fresh Starts

Scientific-Atlanta, Inc.—Has formed a joint venture with ANTEC Corp. to provide a range of broadband network communications products and services to cable-television and telephone companies in Latin American markets.

Proxim, Inc.—Has filed a registration statement with the Securities and Exchange Commission (SEC) relating to the proposed initial public offering of 2 million shares of common stock. The initial public offering is expected to be between $9 and $11 per share. The offering will be managed by Volpe, Welty & Co. and Unterberg Harris.

Varian Associates, Inc.—Has announced that its subsidiary, Varian Canada, Inc., has acquired the assets of Quality Hermetics Co. (1990) Inc. (Toronto, Ontario, Canada), a privately-held company which designs and manufactures glass-to-metal hermetic seals. Terms were not disclosed.

Plexsys International Corp.—Has been selected as a major equipment supplier to the CTI consortium, which Argentina's National Telecommunications Board has named to provide cellular networks for the northern and southern regions of Argentina.

LeBLANC Communications, Inc.—Has relocated its Portland, OR office to Vancouver, WA. Its new address is 600 S.E. Maritime Dr., Suite 190, Vancouver, WA; (206) 694-1204.

California Microwave, Inc.—Has filed a registration statement with the Securities and Exchange Commission (SEC) in connection with an offering by the company of $50 million principal amount of 10-year convertible subordinated notes. Bear, Stearns & Co. and Oppenheimer & Co. will be the underwriters of the offering.

Thomson Tubes Electroniques—As part of an agreement between Thomson-CSF and ABB (Asea Brown Boiveri), Thomson has taken control of ABB's electron-tube production center at Lensburg, Switzerland. Thomson has also taken control of Siemens' coaxial tubes for radars and television transmitters and traveling-wave tubes (TWTs) manufactured at Siemens' facility in Munich, Germany. Production of the Siemens products will be transferred to Thomson facilities during 1994 and 1995.

Spectrum Information Technologies, Inc.—Has signed a letter of intent to acquire C.P.U. (Rochester, NY), a software company. C.P.U. has annual revenues of about $18 million. Terms were not disclosed.

Norsal Industries Inc.—Has moved to a new 4000-sq.-ft. facility at 95G Hoffman Lane, Central Islip, NY 11722; (516) 234-1589.

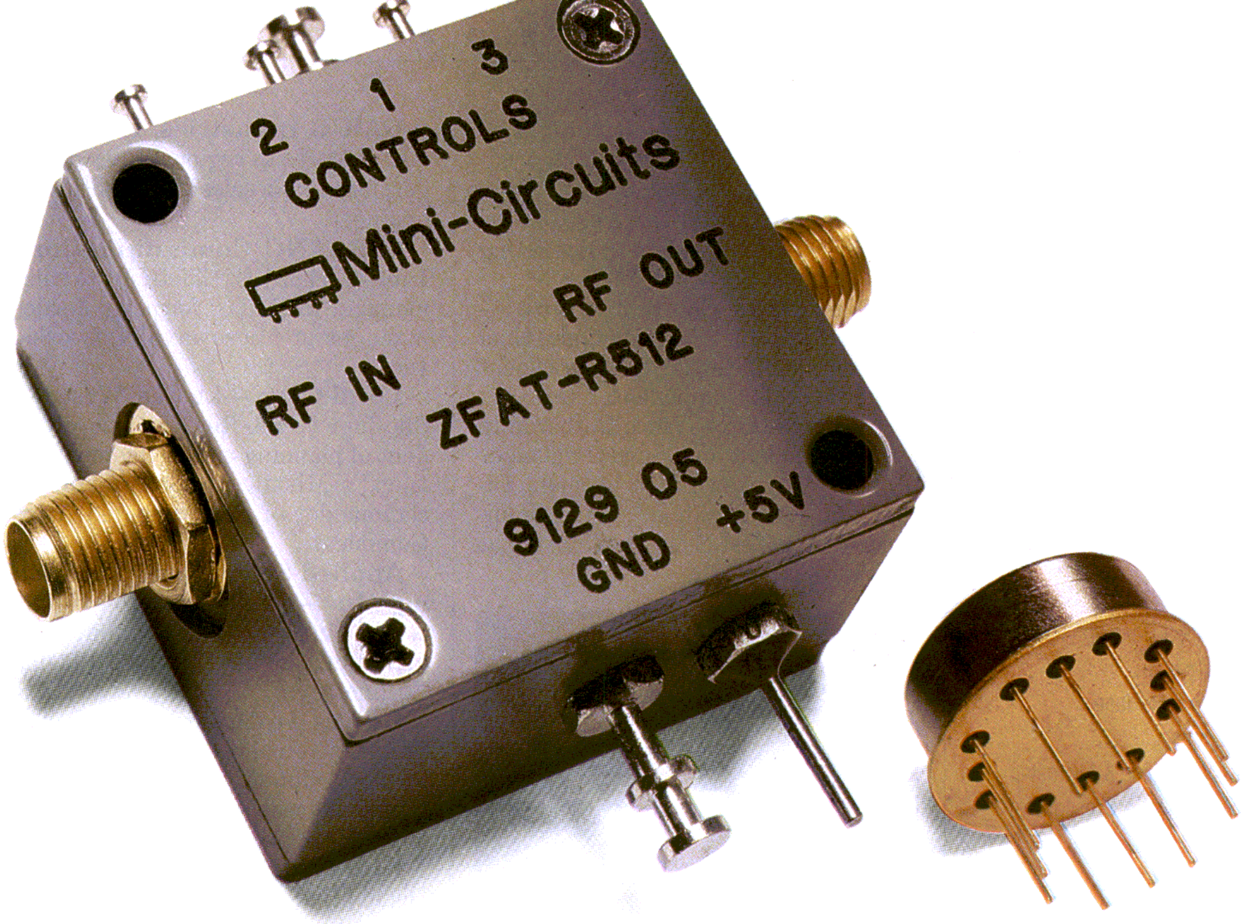
Superconductor Technologies Inc.—Has announced that it will double its high-temperature-superconductor (HTS) manufacturing capability through the purchase of a new deposition system.

Illinois Superconductor Corp.—Has announced the public offering of 1.35 million shares of its common stock at a price of $11.25 per share. The initial offering is being managed by Gruntal & Co.

Spectrum Thin Films—Has been established to manufacture thin-film resistor, conductor, and multilayer products for the hybrid microelectronic and optoelectronic industries. The new company is located at One Wall St., Hudson, NH 03051; (603) 598-9094.

ISHM (The Microelectronics Society)—Has moved to 1850 Centennial Park Dr., Suite 105, Reston, VA 22091; (703) 758-1060.

IVHS America—Has moved to 400 Virginia Ave. S.W., Suite 800, Washington, DC 20024; (202) 484-IVHS.



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1.0	**0.2**	**2.0**	**0.2**	**6.0**	**0.3**	**8.0**	**0.3**	**10.0**	**0.3**
1.5	0.32	3.0	0.4	9.0	0.6	12.0	0.6	15.0	0.6
2.0	**0.2**	**4.0**	**0.3**	**10.0**	**0.3**	**16.0**	**0.5**	**20.0**	**0.4**
2.5	0.32	5.0	0.5	13.0	0.6	20.0	0.8	25.0	0.7
3.0	0.4	6.0	0.5	16.0	0.6	24.0	0.8	30.0	0.7
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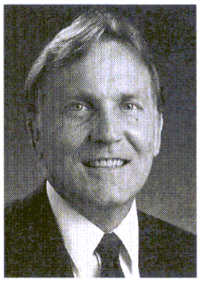
Raytheon Co.—Raymond S. Pengelly to MMIC design and product development manager at Raytheon's Advanced Devices Center; formerly vice president of marketing at Compact Software, Inc.

Novellus Systems, Inc.—Richard S. Hill to president and chief executive officer; formerly president of Tektronix Components Corp.

Wiltron Co.—Vince Lutheran to vice president and general manager of the Microwave Measurement Division; formerly head of the Semiconductor Test Systems Division at Tektronix.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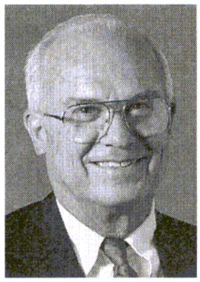
CARTER

Burr-Brown Corp.—John L. Carter to executive vice president; formerly a management consultant to the company.

Harris Farinon—Denis Cote to vice president for worldwide marketing and sales; formerly vice president for marketing and North American sales.

MCI Communications Corp.—Laurence E. Harris to general manager of wireless communications services; formerly president and CEO of International Telecom Systems Inc., an importer and distributor of Ericsson pagers.

Superconductor Technologies, Inc.—Donald Sharpe to director of contract marketing; formerly general manager of Honeywell's Santa Barbara Microwave Center.

Microwave Development Laboratories, Inc.—William F. Berry to president; formerly vice president of administration. Also, Edward J. Scollins to manager of sales and marketing; formerly vice president of Dimond Antenna and Microwave Corp.

Florida RF Labs, Inc.—Douglas C. Sampson to chief executive officer; formerly treasurer. Also, Gerald G. Fenex to president; formerly marketing manager.

DAICO Industries, Inc.—Bryan Takamiya to regional sales manager; formerly a sales and applications engineer.

LeBLANC Communications Inc.—Richard E. Elliott, Jr. to sales manager in Dallas; formerly a sales manager at Microwave Networks, Inc.

Loral Corp.—Lt. Gen. Wilson A. Shoffner (USA-Ret.) to vice president of planning and development of Loral's Missiles Group; formerly commander of the Combined Arms Command.

Applied Science and Technology, Inc.—Paul Blackboro to director of business development; formerly president of Oxford Plasma Technology.

Lucas Industries—George Simpson to chief executive officer; formerly deputy chief executive of British Aerospace Plc and chairman of the Rover Group.

Electronic Devices, Inc.—Donald Bedell to national sales manager; formerly director of marketing of the Power Semiconductor Division of General Instrument Corp.

Watkins-Johnson Co.—Lawrence W. Wong to vice president and manager for defense technology applications; formerly an engineering manager in the company's San Jose, CA facilities.


WONG


HERNANDEZ

Microwave Networks Inc.—Otoniel Hernandez to director of sales for Mexico; formerly regional manager of Mexico.

Cellular Telecommunications Industry Association—Edward A. Hall to director of network operations; formerly a senior analyst at PRC, Inc.

Federal Communications Commission—Reed E. Hundt to chairman of the FCC; formerly a partner in the law firm of Latham & Wilkins.

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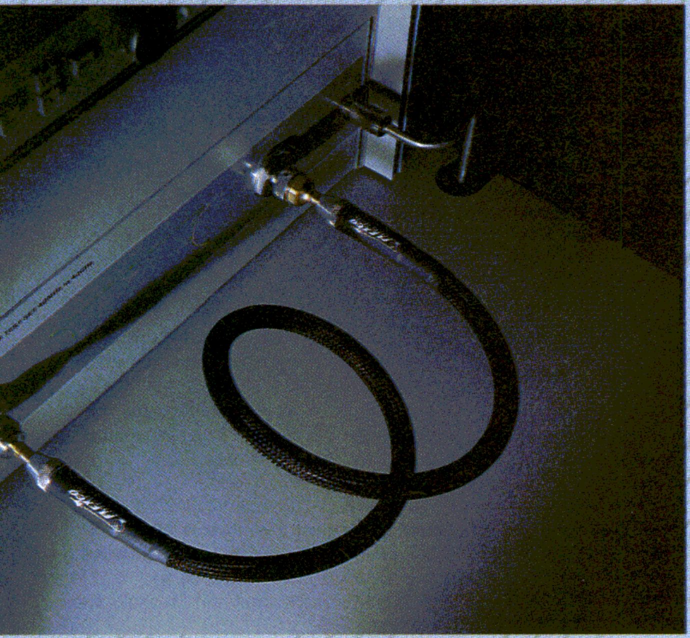

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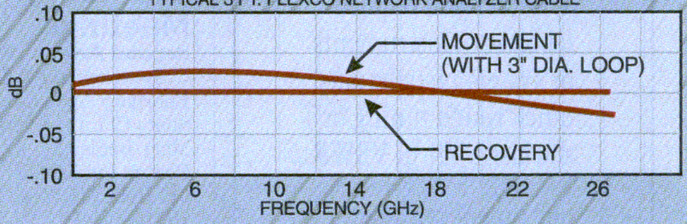
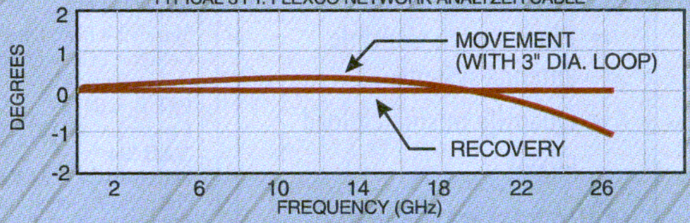


Change in amplitude measures less than .05 dB when flexed and returns virtually to zero when uncoiled.

PHASE MOVEMENT AND RECOVERY VS. FREQ.

TYPICAL 3 FT. FLEXCO NETWORK ANALYZER CABLE



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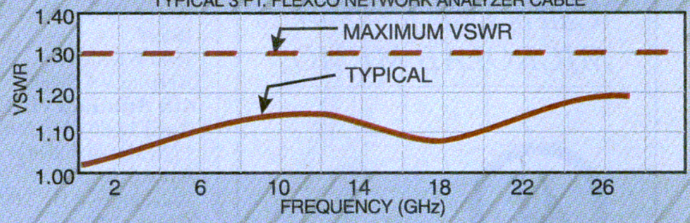

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February 22 (San Jose, CA)
IEEE MTT-S/Optical Society of America
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Washington, DC 20036; (202) 416-6100

Antenna Parameter Measurement by Near-Field Techniques
March 21-25 (Boulder, CO)
National Institute of Standards and Technology (NIST)
Electromagnetics Fields Division
Carl Stubenrauch
NIST
325 Broadway
Boulder, CO 80303; (303) 497-3927

Meetings

Second Annual WIRELESS Symposium & Exhibition
February 15-18 (Santa Clara, CA)
Santa Clara Convention Center
Mary Begley
Penton Publishing
611 Route 46 West
Hasbrouck Hts., NJ 07604
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IEEE International Solid-State Circuits Conference
February 16-18 (San Francisco, CA)
John H. Wuorinen
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P.O. Box 304
Castine, ME 04421; (207) 326-8811

Wireless '94
March 2-4 (San Diego, CA)
Cellular Telecommunications Industry Association
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Frederick, MD 21705; (301) 694-5596

NAB '94
March 20-24 (Las Vegas, NV)
National Association of Broadcasters
1771 N St., N.W.
Washington, DC 20036; (202) 429-5353

RF Expo West
March 22-24 (San Jose, CA)
6300 S. Syracuse Way, Suite 650
Englewood, CO 80111; (303) 220-0600

Third International Conference on Multichip Modules
March 29-31 (Denver, CO)
ISHM
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Reston, VA 22090

4th Annual IVHS America
April 17-20 (Atlanta, GA)
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Suite 510
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Electro/Electronics USA '94
April 26-29 (Sao Paulo, Brazil)
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US Department of Commerce
Technology & Aerospace Industries
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Custom Integrated Circuits Conference
May 1-4 (San Diego, CA)
CICC
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1994 US Conference on Gallium-Arsenide Manufacturing Technology
May 2-5 (Las Vegas, NV)
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IEEE MTT-S International Microwave Symposium
May 23-27 (San Diego, CA)
MTT-S Symposium 1994
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Time & Frequency Systems Research Group
Jet Propulsion Laboratory
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AFCEA International Convention and Exposition
June 7-9 (Washington, DC)
AFCEA
4400 Fair Lakes Court
Fairfax, VA 22033; (703) 631-6200

IEEE AP-S International Symposium and URSI Radio Science Meeting
June 19-24 (Seattle, WA)
Jan Kvamme, Conference Manager
University of Washington Engineering Professional Programs
3201 Fremont Ave. North
Seattle, WA 98103; (206) 543-5539

Conference on Precision Electromagnetic Measurements
June 27-July 1 (Boulder, CO)
IEEE Instrumentation and Measurement Society
Gwen E. Bennett, Conference Secretary
National Institute of Standards and Technology (NIST)
325 Broadway
Boulder, CO 80303; (303) 497-3295

Vehicle Navigation & Information Systems International Conference
August 31-September 2 (Tokyo, Japan)
IEEE Vehicular Technology Society
VNIS '94 Secretariat
REN Associates, Inc.
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Minato-ku, Tokyo 105, Japan
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Call for Papers

Automatic RF Techniques Group (ARFTG) Conference
May 27 (San Diego, CA)
IEEE MTT-S
S.D. Phleger
TRW Space and Electronics Group
Measurement Engineering
Mail Stop S/2767, One Space Park
Redondo Beach, CA 90278; (310) 812-4667
Deadline for abstracts: February 18

Government Microcircuit Applications Conference (GOMAC)
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Sven A. Roosild, Technical Program Chair
ARPA
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Arlington, VA 22203; (703) 696-2235
Deadline for abstracts: March 15

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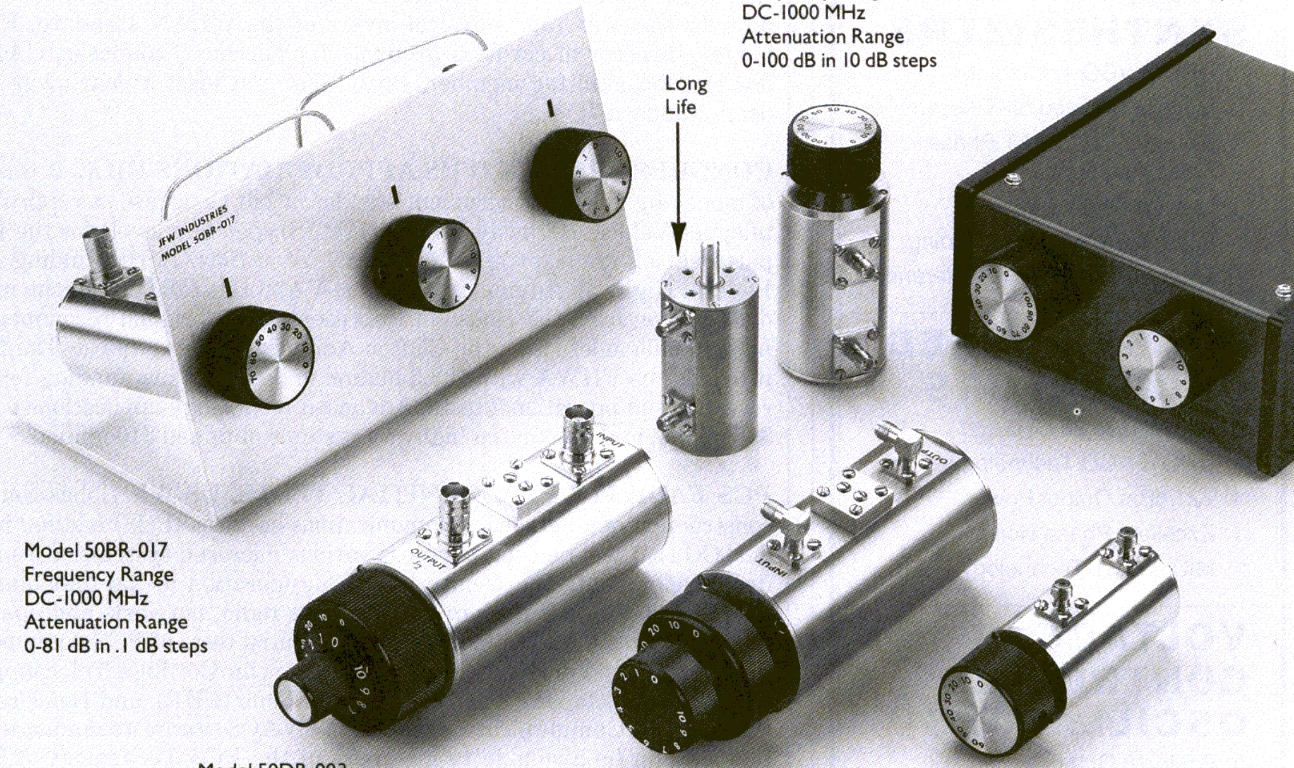

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NEWS UPDATE

TRACKING STORIES PREVIOUSLY REPORTED IN MICROWAVES & RF

GETTING CLOSER TO A WIRELESS LAN STANDARD. After more than two years of meetings, the IEEE 802.11 group working to develop a standard for wireless local-area networks (WLANs) has made some progress, announcing its support of a unified medium-access control (MAC) "foundation" for WLANs. The foundation protocol represents a basic framework upon which enhancements and refinements will be added in future 802.11 meetings. To accommodate this protocol, all current vendors will be required to modify their existing products to ensure compliance. The new standard will support more than 1000 nodes operating within several hundred meters of each other at transmit speeds up to 20 Mb/s (current wireless products support up to 2 Mb/s.) But there is more work to be done on both the MAC and physical layers of the WLAN standard. Phil Belanger, director of cordless products for Xircom (Calabasas, CA) and a 802.11 subcommittee member, says, "We're at least a year away from a draft standard."

CONGRESS PASSES IVHS APPROPRIATIONS BILL. It is not a lot of money by federal government standards, but Congress has approved Intelligent Vehicle Highway Systems (IVHS) spending levels for the US Department of Transportation for Fiscal Year 1994. IVHS funding for the Federal Highway Administration (FHWA) totals $203 million, an increase of $4 million from the House of Representatives' original recommendation but $10 million less than the Clinton Administration's request. The funding provides the FHWA with $33.5 million in discretionary funding for IVHS research and operational tests. Advanced technology applications received $15 million and automated highway systems obtained $10 million.

PCS FACILITY PLANS INITIAL TESTS. US WEST has completed construction of a personal-communications-services (PCS) testbed in Boulder, CO that will be used to assess various microcell systems currently under development. The facility will be in operation in the first quarter of 1994. The testbed is designed to evaluate radio, network, and operations equipment in a variety of environments. Initial tests of PCS equipment are being conducted on Ericsson Digital European Cordless Telecommunications (DECT), Japan's Personal Handy Phone (PHP), and Bellcore Wireless Access Communication Services (WACS) radio technologies. The testbed will be available to members of the PCS Technology Advocacy Group (PTAG) as a common testing facility. The PTAG has been established to help advance technical standards and open interfaces for PCS systems. The group includes Bell Atlantic Corp., BellSouth Corp., Pacific Bell, Stentor, Time Warner, and US WEST. The PTAG plans to work with manufacturers and established standards-setting bodies to speed the development process. The Federal Communications Commission (FCC) has issued an experimental license for the Boulder facility at 1850 to 1990 MHz.

DEFENSE AEROSPACE SALES SLIP—AGAIN. In 1987, when actual outlays for aerospace programs began to decrease, defense product sales (both foreign and domestic) accounted for 62 percent of total aerospace industry sales. According to a 1993 mid-year review of the US aerospace industry by the Aerospace Industries Association (AIA), that figure is now at 45 percent. Through the first half of 1993, aircraft sales to the US military were 8 percent lower than they were during the same period a year earlier. Missile procurement experienced a similar decline. Defense exports were also lower, by 17 percent.

—RON SCHNEIDERMAN

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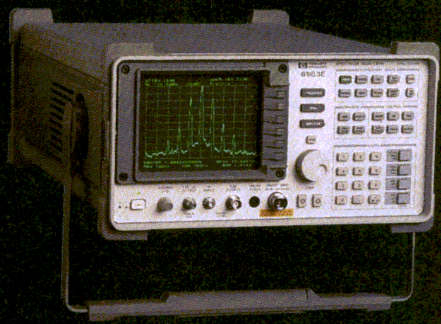

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CIRCLE NO. 245

Multilayered CPW structures minimize leakage

Conductor-backed coplanar waveguide (CPW) provide good mechanical strength and heat-sinking ability, but suffer from leakage in the transverse direction. This leakage can result in unexpected coupling with neighboring lines or devices. Y. Liu and T. Itoh at the University of California at Los Angeles propose two multilayered structures that can control the leakage: one has an additional top layer whose dielectric constant is higher than that of the substrate; the other has a similar additional layer placed between the metal and substrate. The added layer produces an effective CPW-mode dielectric constant that is greater than that of the dominant parallel-plate mode. See "Leakage Phenomena in Multilayered Conductor-Backed Coplanar Waveguide," *IEEE Microwave and Guided Wave Letters*, Vol. 3, No. 11, November 1993, p. 426.

High-aspect-ratio lines form off-chip interconnects

As an electronic system's operating frequency increases, the skin effect becomes more pronounced, resulting in attenuation and dispersion that distort the propagated signal waveform. A potential method of reducing distortion is to employ high-aspect-ratio lines, which achieve low distortion at higher planar densities. H.C. Blennemann at IBM Networking Systems (Research Triangle Park, NC) and R.F.W. Pease at Stanford University (Stanford, CA) overview the fabrication and performance of high-aspect-ratio, off-chip interconnects. Several lines were fabricated and tested, with a typical line of 13.5-μm height and 4.5-μm width (i.e., 3:1 aspect ratio) exhibiting an attenuation of 0.6 dB/cm at 1 GHz. See "High-Aspect-Ratio Lines as Low-Distortion, High-Frequency Off-Chip Interconnects," *IEEE Transactions on Components, Hybrids, and Manufacturing Technology*, Vol. 16, No. 7, November 1993, p. 692.

InP-based HEMT amp delivers high power at Q-band

Indium-phosphide (InP)-based high-electron-mobility transistors (HEMTs) promise several performance advantages, including low noise figure, high gain, and high power-added efficiency. W. Lam, A. Kurdoghlian, and A. Igawa at Hughes Microelectronic Circuits Division (Torrance, CA) and M. Matloubian *et al.* at Hughes Research Laboratory (Malibu, CA) describe a MMIC amplifier that uses 0.15-μm InP-based HEMTs to provide +24-dBm output power and 33-percent power-added efficiency at 44 GHz. The amplifier features small-signal gain of 8.6 ±0.2 dB with a 1-dB input compression point of +14 dBm. The MMIC chip measures 1.9 × 2.0 mm. See "High-Efficiency InP-Based HEMT MMIC Power Amplifier for Q-Band Applications," *IEEE Microwave and Guided Wave Letters*, Vol. 3, No. 11, November 1993, p. 420.

Josephson tunnel junction provides microwave attenuation

The use of semiconductor-insulator-semiconductor (SIS) mixer receivers at microwave frequencies has received considerable attention. In order to optimize the performance of SIS mixers, the applied local-oscillator (LO) power must be adjusted with an accuracy of about 1 dB. V.P. Koshelets *et al.* at the Institute of Radio Engineering and Electronics (Moscow, Russia) and G.M. Fischer and J. Mygind at the Technical University of Denmark (Lyngby, Denmark) describe a circuit, termed the superconducting attenuator, that provides on-chip tuning of high-frequency signal amplitudes using the change in microwave impedance of a small Josephson tunnel junction. Measurements performed at 70 GHz indicate a dynamic range of 15 dB for a single stage. See "Josephson Tunnel Junction Microwave Attenuator," *Applied Physics Letters*, Vol. 63, No. 23, December 6, 1993, p. 3218.

Quasi-optical switch serves radiometry applications

Radiometric imaging systems operating in the 94-GHz range have shown promise in a variety of remote-sensing applications. These systems employ Dicke switches to compensate for receiver gain drift, which can appear as noise in the images. K.D. Stephan, F.H. Spooner, and P.F. Goldsmith at Millitech Corp. (S. Deerfield, MA) present a quasi-optical Dicke switch that provides 1-dB reflection loss and 20-dB isolation in hybrid form, with a monolithic version delivering comparable results in a smaller architecture. The core of the switch design is an array of PIN diodes embedded in a conducting metal grid. The hybrid switch employs a circular pattern of 464 diodes, while the monolithic version uses a square array of 625 diodes. See "Quasi-Optical Millimeter-Wave Hybrid and Monolithic PIN-Diode Switches," *IEEE Transactions on Microwave Theory and Techniques*, Vol. 41, No. 10, October 1993, p. 1791.

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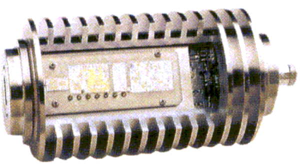

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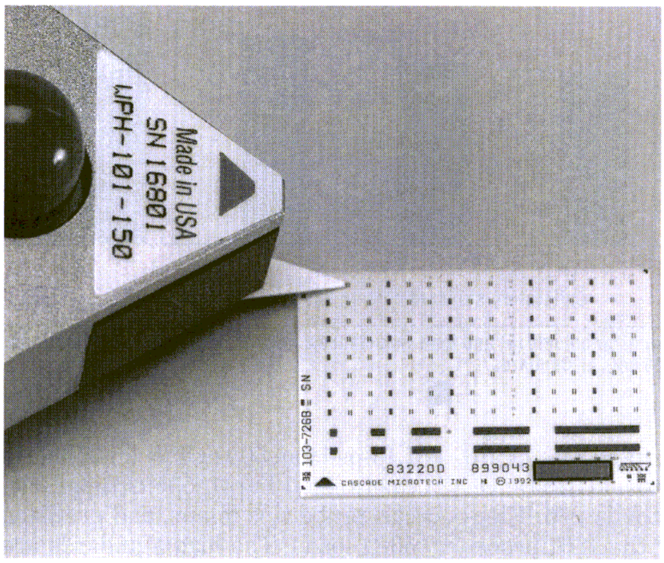
TECHNIQUE VERIFIES LRRM CALIBRATIONS ON GaAs SUBSTRATES

A multi-line GaAs TRL calibration is used as a benchmark for verification of automated LRRM wafer-probe calibrations.



1. An alumina-based CPW impedance standard substrate verifies on-wafer LRRM calibrations from 1 to 40 GHz.

ENGINEERS in the on-wafer microwave measurement field have long sought a method to quantify S-parameter calibration inaccuracies. A powerful verification technique developed by the National Institute of Standards and Technology (NIST; Boulder, CO) determines error bounds for a working calibration through comparison with the NIST multi-line GaAs through-reflect-line (TRL) calibration.

Traceability of on-wafer calibration standards has been an issue among microwave test engineers for some time. The great diversity of calibration standards and methods used throughout the high-frequency industry has made traceability of these standards to some physical reference impractical. The novel calibration procedure and software package developed by the NIST enables calibration verifications to be performed, thus making it possible to demonstrate the traceability of a calibration rather than the traceability of the individual calibration standards.

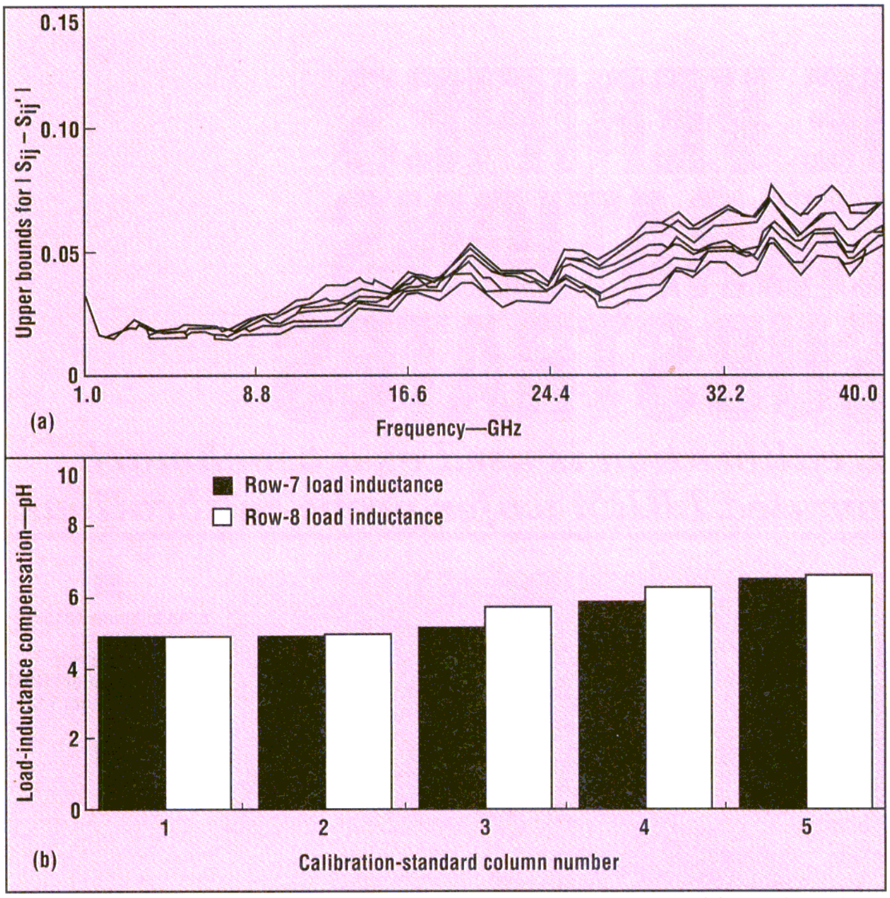
The verification technique is applied to automated line-reflect-reflect-match (LRRM) calibrations with load-inductance compensation performed on commercially-available alumina coplanar-waveguide (CPW) standards over a frequency range of 1 to 40 GHz. Two experiments are performed. In the first analysis, 10 automated calibrations are made using 10 different sets of standards on the same impedance standard substrate (ISS). In the second test, 10 automated calibrations are made using a single set of standards. Each of the calibrations from the two experiments is then compared with a manual NIST, multi-line GaAs CPW reference calibration. The worst-case error bounds for each automated calibration are calculated using the NIST verification software.

PROBING SYSTEM

The probing-system configuration employed for this investigation makes use of commercially-available equipment. In both experiments, the automated calibrations are performed on a semi-automatic wafer-probe station from Cascade Microtech, Inc. (Beaverton, OR) capable of ± 3-μm placement repeatability. All calibrations contain 51 data points obtained with an HP 8510C vector network analyzer (VNA)

JOHN E. PENCE, Product Marketing Manager, Cascade Microtech, Inc., 14255 S.W. Brigadoon Ct., Beaverton, OR 97005; (503) 626-9222, FAX: (503) 626-9255.

LRRM VERIFICATION



2. Worst-case S-parameter error bounds (a) and load-inductance compensation (b) were determined for 10 calibrations using 10 sets of standards.

from Hewlett-Packard Co. (Palo Alto, CA) over a 1-to-40-GHz range. The averaging factor is 256. Electronic alignment of the ISS, probe-station control, VNA control, and automatic load-inductance compensation is performed by the probe station's automatic VNA calibration software.

For each calibration, raw data is read from the VNA. The calibration software then calculates the inductance-compensated error coefficients and stores them back into the network analyzer. The two wafer probes employed have a standard ceramic-tip, ground-signal-ground (GSG) configuration with 100-µm pitch. Flexible 2.4-mm RF cables are used to connect the wafer probes to the VNA.

The automated calibrations employ commercially-available, alumina-based CPW standards from Cascade Microtech, Inc., including 1.15-ps-long, 50-Ω CPW lines, shorts (metallized bars), opens (open-circuit probe tips in air), and precision 50-Ω loads. The load standards are trimmed at DC to be 50 Ω ±0.3 percent. Alignment marks on the ISS (Fig. 1) set the contact force, separation, and initial position of the wafer probes.

NIST STANDARDS

The NIST benchmark-calibration standards consist of a 550-µm CPW through line, an offset short, and four CPW lines with additional lengths of 2.135, 3.200, 6.565, and 19.695 mm, respectively. These standards are fabricated on 500-µm-thick GaAs.[1] The NIST software is run on an HP 9000 series 300 computer under HP Basic 5.1. The specific programs used in the experiments are DEEMBED revision 4.04 and VERIFY revision 1.03.[2]

The first step in the verification procedure is to make an on-wafer calibration. With this correction applied to the VNA, an NIST benchmark calibration is performed using the DEEMBED software. Each of the five NIST standards is measured and the data is stored on disk. The program de-embeds this data, calculating the effective dielectric constant and the "error boxes" for ports 1 and 2.

In effect, a two-tier calibration is performed, with the error coefficients representing the differences between the working calibration and benchmark calibration. The VERIFY program then calculates and plots the worst-case deviation after the reference plane of the benchmark calibration is adjusted to be as close as possible to the reference plane of the working calibration.

VERIFICATION RESULTS

For each of the 20 working calibrations in the two verification experiments, the load-inductance-compensation value is recorded and the VNA error coefficients are stored on disk. The time required to complete both sets of calibrations and to store the test data is approximately 50 min.

Following the verification technique, a benchmark GaAs TRL calibration is performed using the DEEMBED program. Each of the six NIST standards is contacted with the wafer probes only once. Every standard is measured using each of the 20 stored calibration sets, with the test data stored on disk. This procedure minimizes the number of required probe contacts, thus reducing uncertainty in probe-placement repeatability.

After all of the standards are measured, there are six data files for each working calibration, for a total of 120 files. This portion of the verification procedure is particularly slow, with a total time of about 2 hours and 45 min. required to complete the process. Thus, the total time needed to collect all of the verification data is 3 hours and 35 min.

The NIST DEEMBED program then uses the six data files for each working calibration to calculate new

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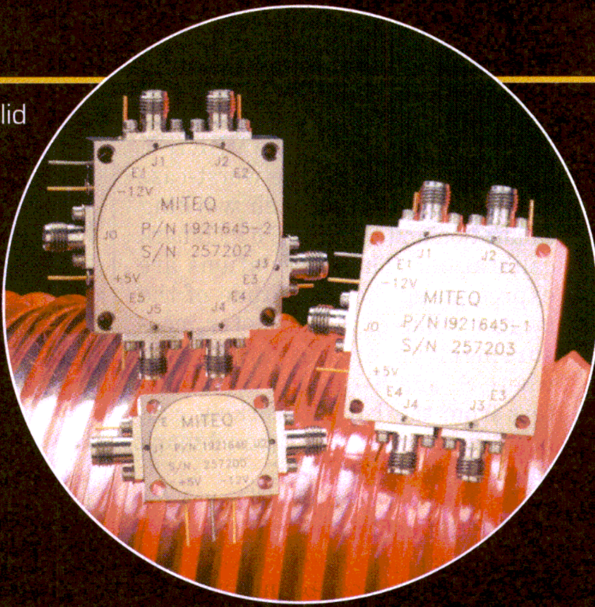

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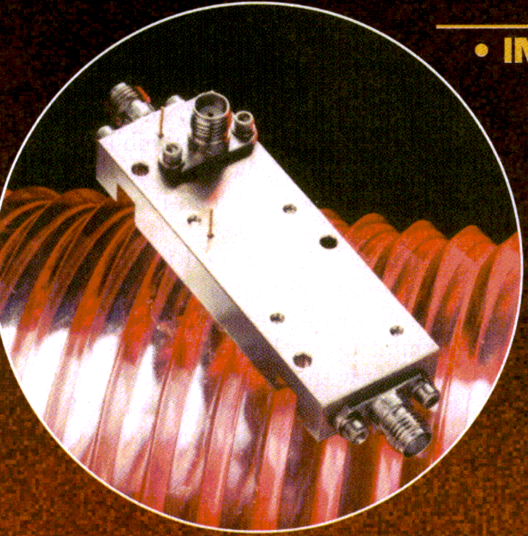

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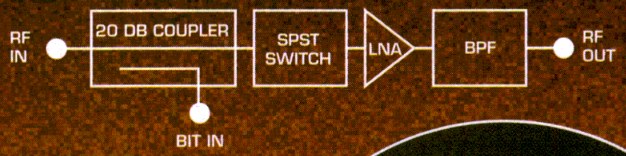

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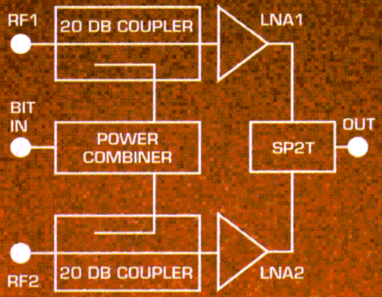

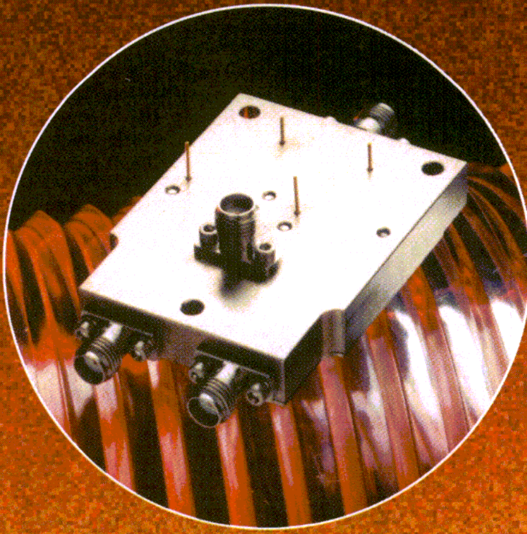

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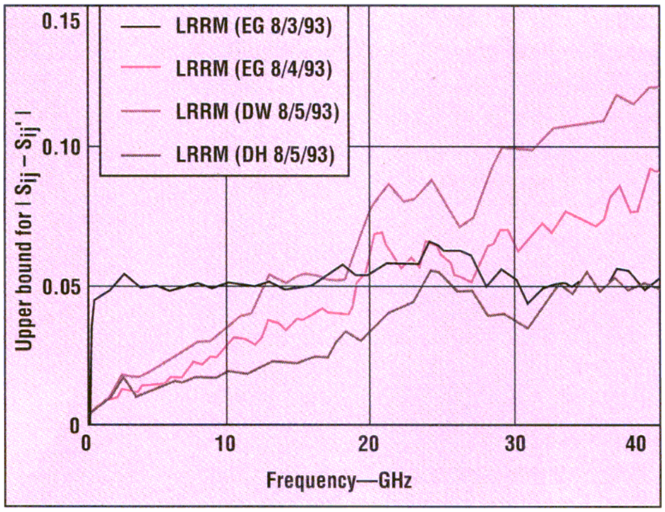
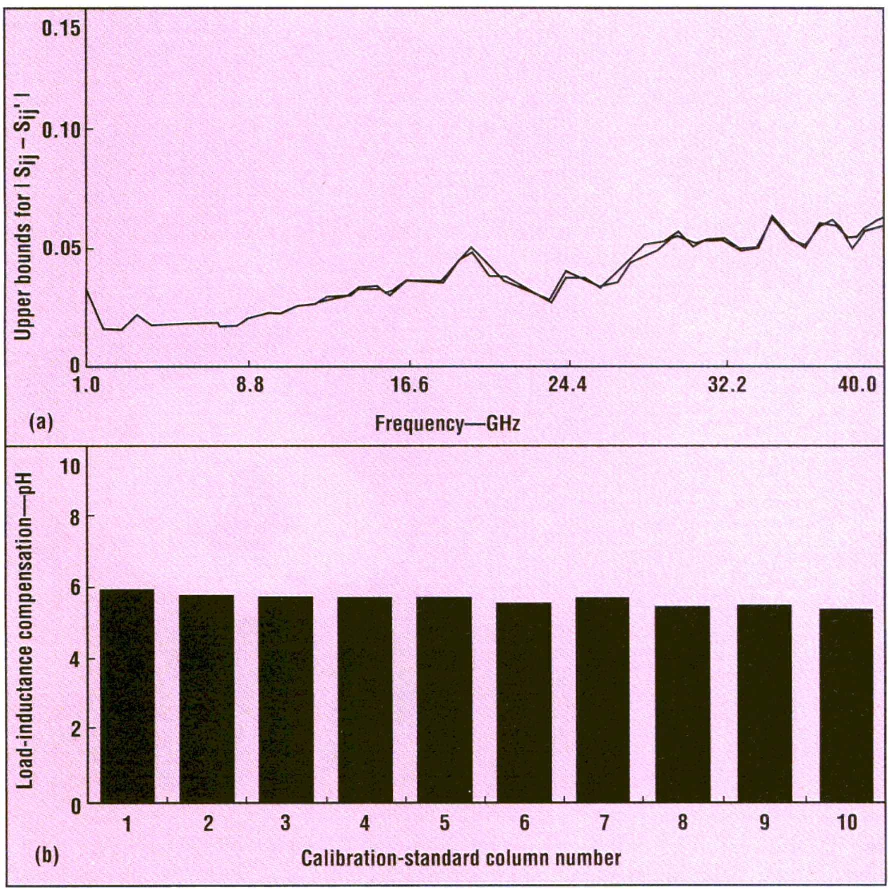
error coefficients. Three output files are stored on disk: the error box for port 1, the error box for port 2, and the effective dielectric constant. These files are used by the VERIFY program to calculate the worst-case deviations between each working calibration and the NIST benchmark calibration.[3] These deviations are expressed as the magnitude of the largest value of S-parameter measurement uncertainty $|S_{ij} - S_{ij}'|$, where S_{ij} and S_{ij}' are the S-parameters from the LRRM working calibration and the NIST benchmark calibration, respectively.

Verification results (Fig. 2a) for the LRRM calibration with load-inductance compensation indicate that the calculated upper bounds increase linearly with frequency. The average worst-case deviation is 0.067, which occurs at 34.5 GHz. The worst-case deviation for any single calibration is 0.079 at 37.7 GHz. The worst-case total variation is observed to be less than 0.032, also occurring at 37.7 GHz.



4. Upper-bound terms obtained with a manual LRRM verification technique tend to increase linearly with frequency.

The load-inductance compensation calculated for each working calibration (Fig. 2b) exhibits an average value of 5.63 pH with a variation of ±15 percent. It is interesting to note that the inductance-compensation values increase from column 1 to column 5 in rows 7 and 8. This can be attributed to the ±3-mm mechanical placement uncertainty. In addition, the calibrations which exhibited the greatest deviations in Fig. 2a had the largest associated load-inductance-compensation values.



3. These plots illustrate the worst-case error bounds (a) and load-inductance compensation (b) for 10 calibrations made with a single set of standards.

The calculated load-inductance-compensation values from the second verification experiment (Fig. 3a) exhibit upper bounds that increase linearly with frequency. The average worst-case deviation is 0.063 at 34.5 GHz, while the worst-case total variation is an impressive 0.005 at 28.3 GHz. The worst-case deviation for any single calibration is 0.064 at 34.5 GHz.

Once again, the load-inductance compensation value was calculated for each working calibration (Fig. 3b). The average value obtained was 5.66 pH with a variation of only ±5 percent.

EVALUATION OF RESULTS

When evaluating the results of the automated LRRM calibration verifications, it is helpful to compare this data with verification results obtained from manual LRRM verification experiments. Figure 4 presents results from manual LRRM verifications performed by Williams at the NIST.[4] Again, the calculated upper bounds increase linearly with frequency. The worst-case deviation for these measurements ranged from

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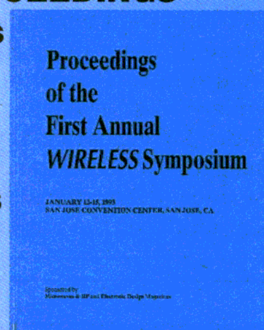

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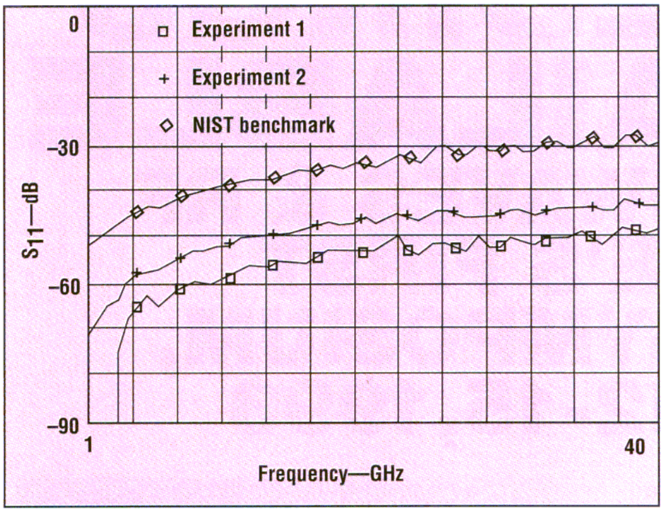

5. The upward slope of these calibration stability plots indicate that the measurement system produces greater drift with increasing frequency.

0.060 to 0.125. Although the accuracy of three of the four calibrations is comparable to that obtained with automated calibrations, the large variation suggests that repeatability is much more difficult to achieve with the manual calibrations. In fact, the repeatability of the automated calibrations appears to be an order of magnitude better than that obtained with the manual calibrations.

Instrument drift is the biggest concern in both manual and automated LRRM verification experiments. The automated verifications required nearly 4 hours to complete, and the temperature and relative humidity in the room where the measurements were performed was uncontrolled. In order to assess the possible impact of instrument drift on the results, a calibration stability test was performed at the end of each experiment and at the completion of the verification procedure. This test determines the change in $|S_{11} - S_{11}'|$ for an open-circuit probe tip, where S_{11}' is measured periodically after the initial S_{11} data has been recorded.

The results of the calibration stability test (Fig. 5) indicate that the system will generally produce more drift at higher frequencies. This explains why the curves in Fig. 5 all tend to slope upward. A new calibration is usually performed when the worst-case $|S_{11} - S_{11}'|$ reaches −40 dB. This corresponds to a 1-percent error in the S_{11} measurement of the open-circuit probe tip.

At the completion of experiments

LRRM VERIFICATION

1 and 2, the system had a worst-case stability of better than –40 dB. However, due to the extended period of time required to perform the verification procedure, the worst-case system stability at the completion of verification was only –27 dB. This corresponds to a measurement accuracy of about 4.5 percent. Based on this data, it is quite likely that system drift had a significant effect on the verification results. Reducing the time required to perform the verification would probably improve the results.

The results presented in Fig. 3a indicate that the contact repeatability of the automated calibrations is very good, so its impact on verification results is very subtle. If the ISS is not properly aligned, probe placement errors will occur. These errors, in conjunction with the subtle contact-repeatability errors, may help explain the apparent increase in load inductance across the ISS in Fig. 2b. It has been observed[5] that the load inductance varies by about 0.14 pH per micron change in probe placement. It is likely that slight ISS alignment errors contributed to the accuracy variation observed in Fig. 2a. However, the data is still highly reproducible and is probably representative of what a typical user would observe. ●●

The effect of system drift on verification results may be decreased by reducing the time needed to perform the verifications.

Note

A version of this paper was presented at the 42nd ARFTG Conference, which was held on December 2-3, 1993 in San Jose, CA.

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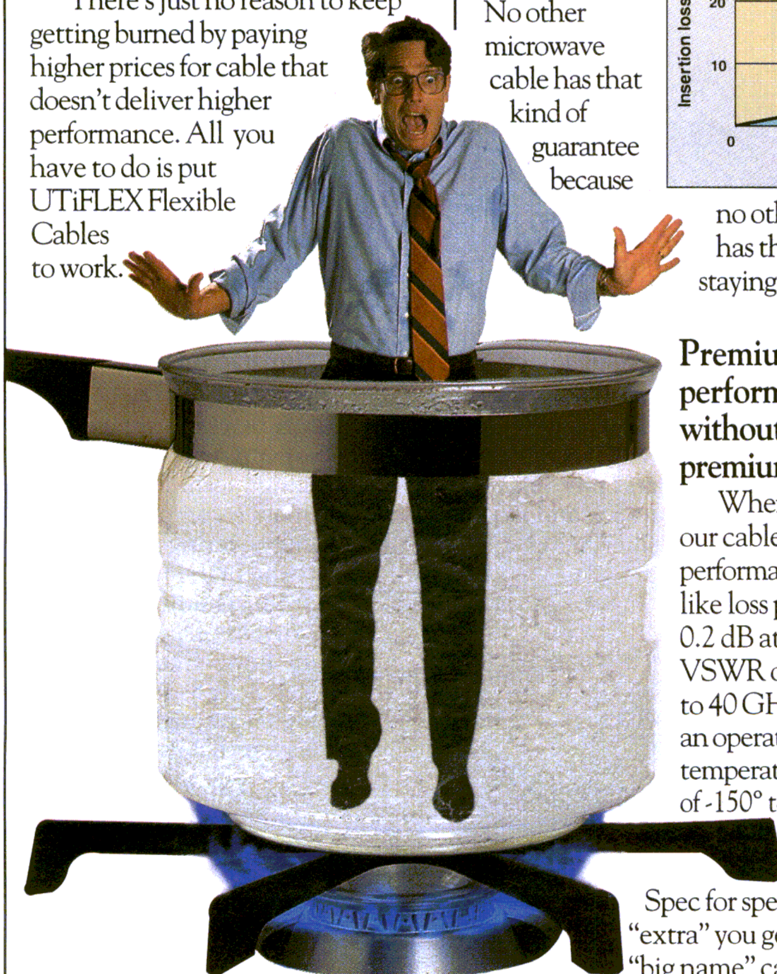

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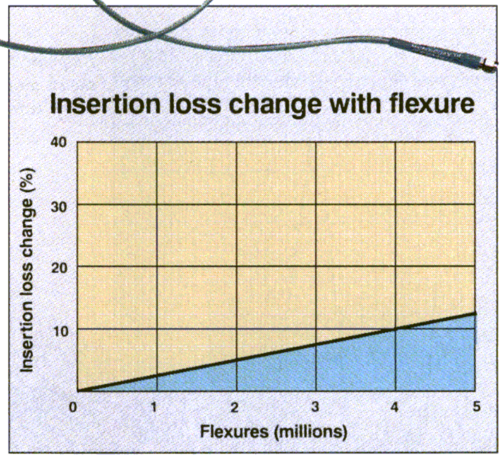

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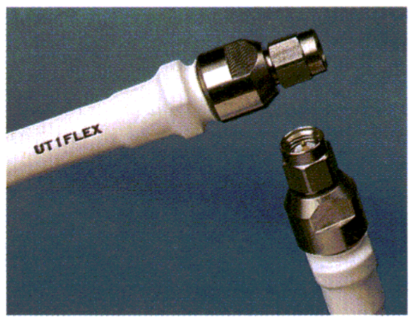

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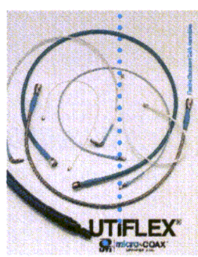

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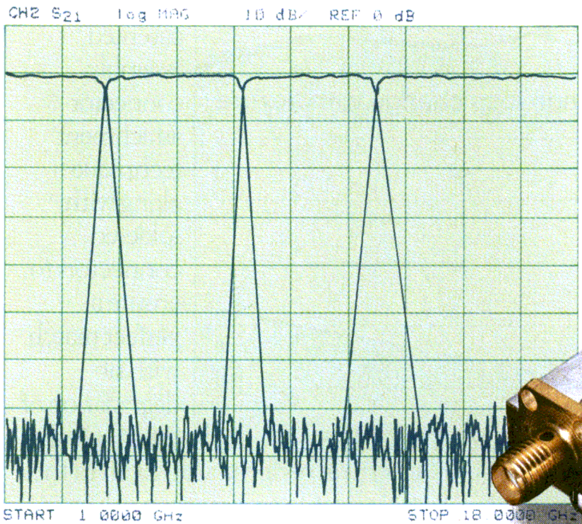

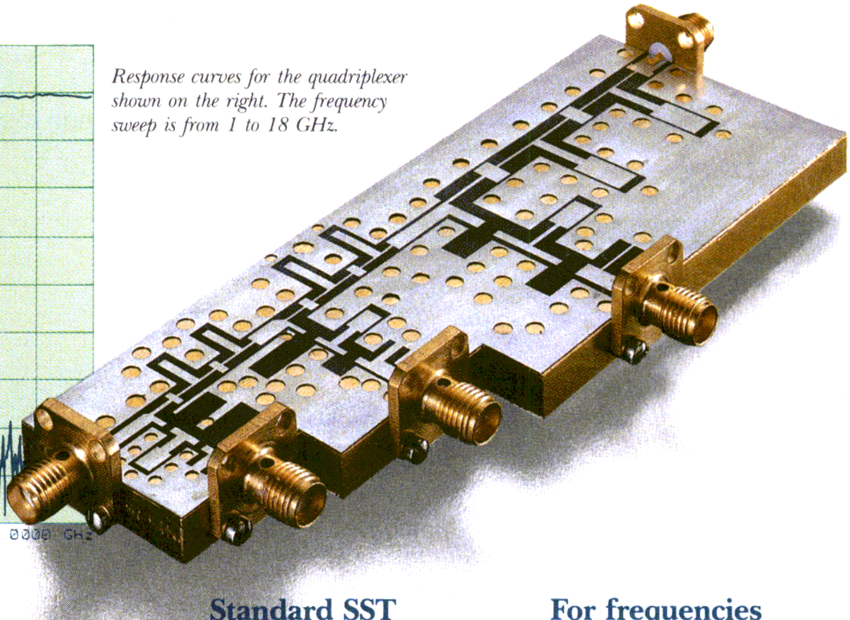

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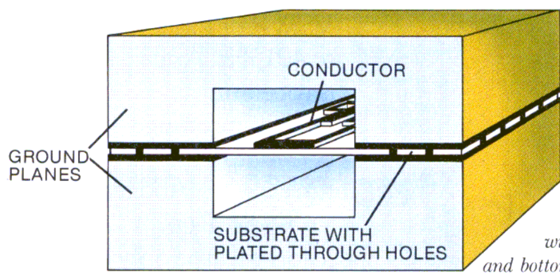

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APPLICATIONS DRIVE THE EVOLUTION OF NETWORK ANALYZERS

These sensitive receivers continue to add microwave measurement power and versatility

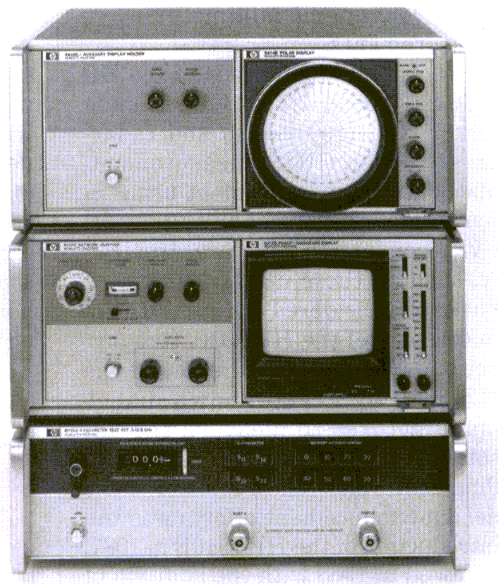
OVER the past decade, microwave circuit designers and test engineers have benefited from major improvements in network-analyzer performance. With the help of instruments such as the HP 8510A network analyzer from Hewlett-Packard Co. (Palo Alto, CA), measurements that were once time-consuming and difficult to perform are now commonplace and are no longer the exclusive dominion of the in-house microwave test "guru."

For example, the state of the art in the early 1980s was the HP 8409 vector automatic network analyzer (VANA), which was based on the HP 8410C network analyzer (Fig. 1). The HP 8409 employed an HP 9845 computer and provided vector-error-corrected measurements, covering bandwidths of 110 kHz to 18 GHz in a single sweep. Although the 8409 was a basic piece of equipment in every microwave lab, it took many minutes, even hours, to perform a single fully-corrected measurement.

PHILIP LORCH, Hewlett-Packard Co., Santa Rosa Systems Division, 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403-1790; (707) 577-1400.

The early 1980s saw a period of incredible growth in the microwave component industry. Fueled by rapid expansion in the military and aerospace industries, there was a worldwide demand for new technology in defense electronics, especially in the US. This activity begged for a faster and more-usable approach to performing stimulus/response and phase measurements on the microwave components and subsystems that are crucial to any communications system, radar, jammer, or other high-frequency military or commercial applications.

In January 1984, Hewlett-Packard Co. announced the world's first microprocessor-based network analyzer, the HP 8510A (see "Ten Years with the HP 8510A"). This instrument allowed the microwave component or subsystem designer to make fast and convenient magnitude or phase-response measurements in near-real-time across previously unheard-of frequency ranges. For the first time, the S-parameter-based technique for network design, analysis, and measurement became practical for everyday use.[1]



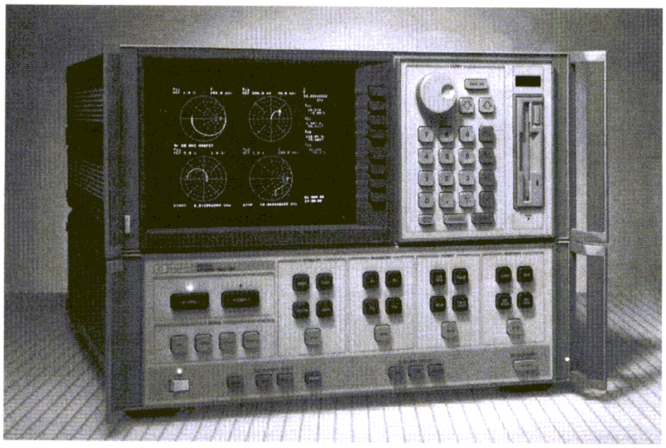
1. The predecessor to the HP 8510, the HP 8410 network analyzer formed the basis of the HP 8409 ANA. More than 10,000 8410s and 8409s were sold worldwide, with many of these instruments still in use today.

For many designers, however, just having a high-speed measurement engine for network measurements was not enough. Designers wanted the ability to measure devices without coaxial connectors, whether in-fixture or on-wafer. Engineers wanted to measure at frequencies above 26.5 GHz or under pulsed-RF conditions. Once the design of a particular device, component, or subsystem went into production, many test departments wanted the same type of measurement performance that the R&D personnel had access to, so the need for remote computer control and higher measurement speed became more important.

As the demands of analyzer users evolved, the need to expand the instrument's capabilities became evident. Within a year of the original HP 8510A introduction, work began on a second-generation version aimed at meeting some of the aforementioned requirements. New calibration techniques were implemented based on work originally proposed by Engen and Hoer[2] (through-reflect-line calibration). The ability to measure non-insertable devices, such as coax-to-waveguide adapters or coaxial devices with same-sex connectors on both ports, was added. A more user-friendly system extension was developed to allow convenient millimeter-wave measurements.

Specialized applications of the HP 8510 have been developed, including mixer testing, antenna and radar-cross-section (RCS) measurement, and material measurement using S-parameter-to-permeability/permittivity conversion software. Ironically, some of these utilizations where not even considered during the original design of the HP 8510. One favorite application was the use of the HP 8510 by a well-known diaper manufacturer to measure the absorptive properties of different wadding materials. The result of these design-enhancement efforts was the introduction of the HP 8510B in 1987, followed in 1988 with the addition of a fundamentally-mixed S-parameter test set and optional wideband in-phase/quadrature (I/Q) detectors, which allowed fully-synchronized network measurements under pulsed-RF conditions.

Hewlett-Packard was not alone in the automatic-network-analyzer (ANA) market for long. In the summer of 1987, Wiltron Co. (Morgan Hill, CA) introduced the 360 network analyzer. The 360 contributed enhanced usability features, such as guided calibration, a four-channel color display, broadband frequency coverage to 40 GHz, and a tuned-receiver architecture that allowed the use of a low-cost, swept-RF source while maintaining synthesized frequency accuracy.



2. The HP 8510C is the third-generation version of the HP 8510 VANA. The latest version covers a wider range of test applications than its predecessor, which celebrates its 10th anniversary this month.

EIP Microwave (Milpitas, CA) introduced their Measurement and Computation Tools™ modular workstation shortly thereafter. Initially using an ANA feature set, the EIP solution included an innovative modular approach that distributed the instrument into its main components: an external personal computer which served as the system controller, an intermediate-frequency (IF) processing section, a stimulus source, and external removable "test heads" which housed the test ports and RF downconverters.

More recently, Scientific-Atlanta (Atlanta, GA) added network-analysis capability to their model 1795 microwave receiver, which was originally aimed at antenna and RCS measurement applications.

ECONOMY FAMILY

Another major contribution to network-analysis instrumentation was the development of the HP 8700 family of network analyzers. Even before the HP 8510A was introduced, engineers at HP's Network Measurements Division (Santa Rosa, CA) were hard at work leveraging some of the key technologies developed for the HP 8510 (see "Core Technologies Improve Net-

TEN YEARS WITH THE HP 8510A

The microwave component world was revolutionized in January 1984 with the introduction the HP 8510A network analyzer (see figure). This analysis tool provided near-real-time S-parameter measurements with high accuracy and broadband frequency coverage. With the use of microprocessors, the HP 8510A became much more versatile than its predecessors, giving the user access to powerful capabilities such as accuracy enhancement (12-term vector error correction) and time-domain measurement by performing high-speed inverse Fourier transforms on frequency-domain measurement data. The HP 8510A became a workhorse of the microwave component industry and the standard in network analysis. Many newer versions have been introduced (the most recent in December 1993), adding more features and enhanced RF performance.••

The HP 8510 network analyzer revolutionized the way in which microwave component designers tested their devices.

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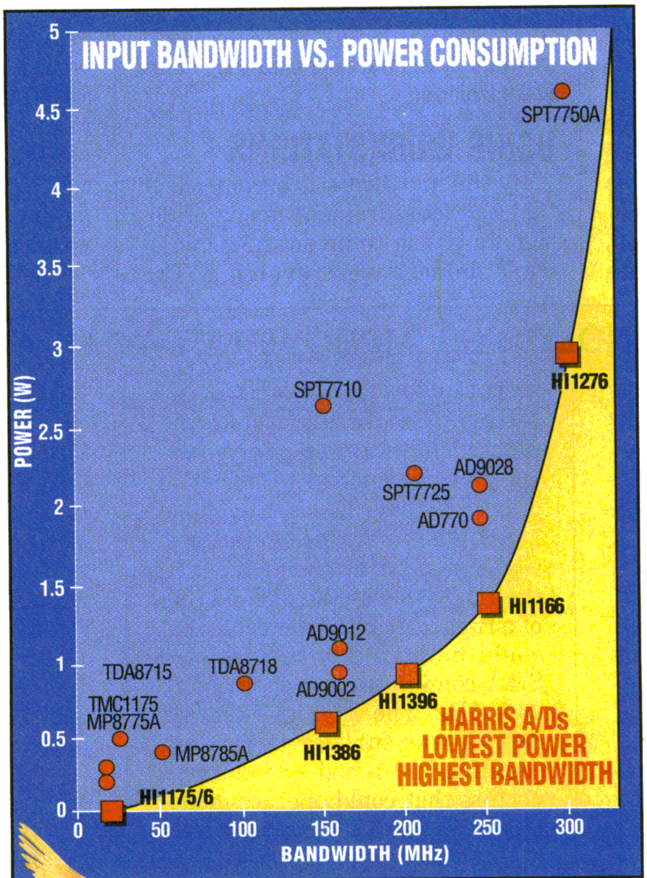

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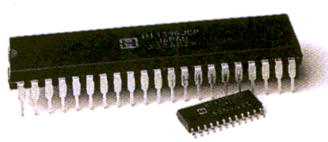

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work Analysis"). The sampler architecture and much of the analyzer's operating-system firmware and error-correction algorithms were ported to the HP 8753A, the first self-contained RF ANA [300 kHz to 3 GHz (and later to 6 GHz)], and its microwave counterpart, the HP 8720A. These alternatives to the more-flexible, higher-performance HP 8510 added to the array of ANAs available to the designer or production test technician.

The advent of modern analyzers helped spawn many small, highly-specialized companies that provided complementary hardware and software to augment the standard network analyzer's capability. All of these companies continue to advance the state of the art in their respective areas of expertise. Some notable examples are:

- Cascade Microtech (Beaverton, OR): coplanar probe tips and analytical wafer-probing stations.
- Intercontinental Microwave (Santa Clara, CA): high-repeatability broadband test fixtures for packaged devices and chips.
- ATN Microwave (Billerica, MA): device-characterization systems for noise-parameter or large-signal measurement applications.
- Flam and Russell (Horsham, PA): far-field antenna and RCS measurement systems and software.
- March Microwave (Eindhoven, The Netherlands): compact far-field antenna ranges and RCS software.
- Nearfield Systems (Carson, CA): near-field antenna measurement systems and anechoic-chamber characterization.

USING WORKSTATIONS

By the mid-1980s, it became clear that the measurement needs of designers trying to invent new microwave devices were evolving. The advent of high-performance workstation computers at affordable prices allowed the microwave circuit designer to take advantage of circuit-simulation software. Computer-aided-engineering (CAE) products gave the designer a powerful tool for performing the first few design iterations before the costly first pass through a wafer process or microcircuit thin-film process. Design cycle times were substantially reduced. This lessened the need for high-performance network analyzers in every microwave design lab. Hewlett-Packard soon entered the microwave design software market with its own CAE product, the HP 85150A Microwave Design System, in 1987. With built-in links to network analyzers, the software could collect actual measurement data for model and device optimization and verification.

The HP 8510 and its family of re-

CORE TECHNOLOGIES IMPROVE NETWORK ANALYSIS

Crucial to the development of the HP 8510 were several key improvements in fundamental microwave and data-processing technology. Those of major importance include:

Broadband samplers: The HP 8510 uses a proprietary, patented step-recovery-diode-based comb generation architecture for microwave signal downconversion. The use of samplers allowed the original HP 8515A S-parameter test sets employed with the HP 8510 to cover frequencies up to 26.5 GHz. Since then, sampler-based (and now fundamentally-mixed) test sets operating to 50 GHz have been introduced.

RF bridge at 26.5 GHz: The S-parameter test sets used with the HP 8510 employed a first-of-its-kind resistive broadband RF bridge. The use of the bridge for signal separation provided the test sets with excellent impedance match (raw test-port return loss and directivity were each better than 20 dB), outstanding stability, and flat frequency response down to 45 MHz. A 45-MHz-to-50-GHz directional coupler with similar performance was later developed with the aid of CAE software tools.

Precision coaxial connectors: Coinciding with development of the HP 8510 was the engineering of a rugged coaxial connector that could be mated with standard SMA connectors and operated to 26.5 GHz. The 3.5-mm-diameter design was further improved, resulting in 2.4- and 1.85-mm connectors that could operate mode-free to 50 and 65 GHz, respectively. Metrology-grade versions of the 3.5- and 2.4-mm connectors featured slotless female center contacts for highly-predictable and repeatable geometries that resulted in extremely-high accuracy. Recently-developed connector designs with a 1.0-mm line diameter allow coaxial operation to 110 GHz.

Microwave synthesized source: A companion stimulus source for the HP 8510, the HP 8340A synthesized sweeper was actually introduced 18 months before the network analyzer. This synthesized source featured excellent output power, 1-Hz frequency resolution, and 26.5-GHz frequency coverage. In addition, it could perform analog "ramp" sweeps, allowing the HP 8510 to display swept device response with full 12-term error correction up to 1000 times faster than the HP 8409. The 8340A was later replaced with the HP 8360 series of synthesized sweepers, which offer coverage to 110 GHz.

Time-domain transformation: The HP 8510A included an optional capability to view swept frequency-domain data in the time domain. A proprietary implementation of the Chirp-Z inverse Fourier transform allowed the user to view the impulse response of the device under test. When applied to frequency-domain data, the user-specified "gating" and "windowing" functions allowed the viewing of device response free from discontinuities caused by connector or fixture transitions.••

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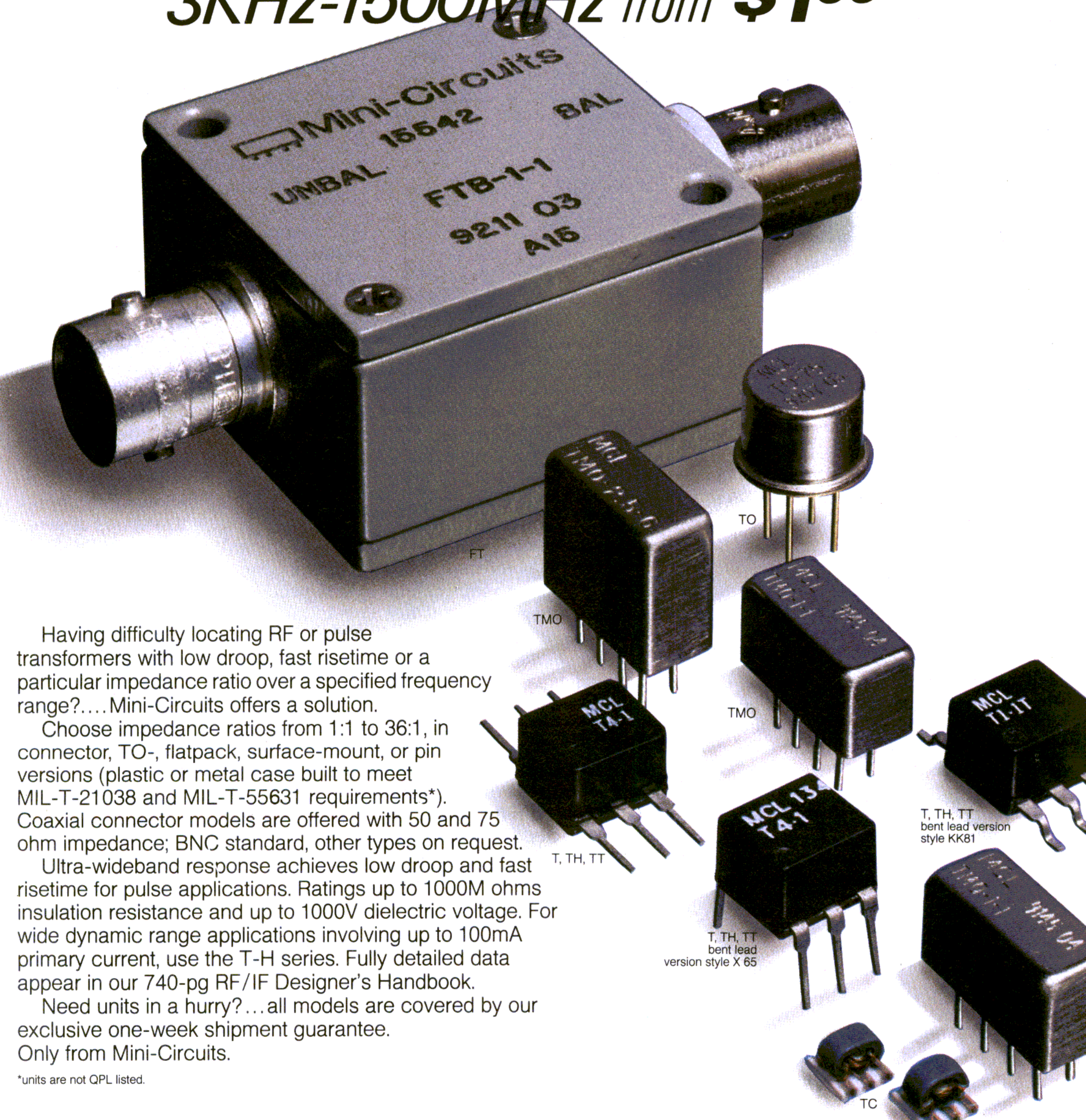

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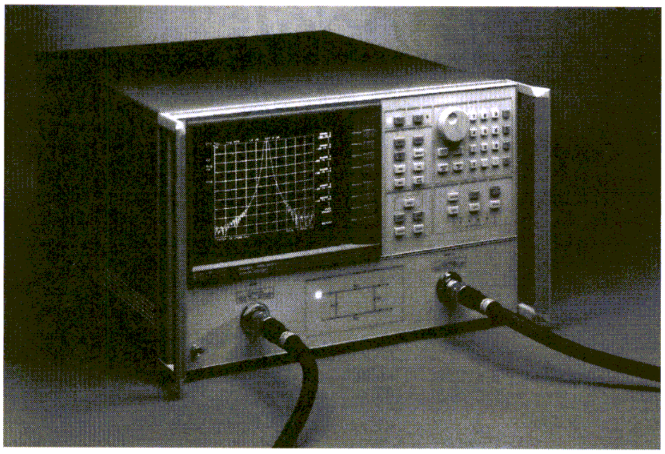

3. The HP 8700 family of ANAs leveraged technologies developed for the HP 8510. This line of analyzers has recently been extended to 40 GHz with the introduction of the HP 8722C.

lated products (test sets, microwave sources, and accessories) have evolved tremendously since the original introduction 10 years ago. Currently available in its third-generation version as the HP 8510C, the instrument is the basis for many types of component test systems. Systems based on the HP 8510C (Fig. 2) and its high-speed companion, the HP 8530A microwave receiver, are employed throughout the microwave component industry in an increasing variety of applications. Enhancements to the HP 8720 (Fig. 3) and 8753 families have also evolved to cover a wider range of frequencies and to serve more diverse applications, including mixer testing and material characterization. The Wiltron 360 is now available in a "B" model, with coaxial broadband coverage to 62.5 GHz.

THE NEXT 10 YEARS

The microwave world has greatly changed in the past 10 years. Military expansion has slowed and the corresponding expenditures for defense electronics have been significantly reduced. However, that is not to say that the market for defense and aerospace applications of high-frequency technology is dead. There will continue to be a stream of modernization programs, as well as more focus on C^3I applications, that will demand the best available microwave components and subsystems. The coming information age will bring explosive growth in commercial and consumer communications, with abundant opportunities for any company that possesses a core competency in high-frequency circuit and system design. Many of the fundamental technologies and platform concepts currently used in military applications will be leveraged into commercial applications.

On the R&D side, the next 10 years will see further expansion of the use of microwave CAE tools, augmented by customized network-analyzer-based parameter-extraction systems for model development and verification. Eventually, the same CAE software may include extensions that can generate the test vectors used to drive network analyzers once the parts being designed reach production.

The demand for general-purpose benchtop analyzers will be combined with the need for custom-tailored systems that bridge the gap between circuit-simulation software and actual parametric measurements on prototype devices. Designers will want to perform system simulation using the complex modulation formats being proposed for new communications standards. These customer needs will result in the basic RF stimulus sources being augmented by or replaced with more-flexible sources capable of complex or pulsed-RF modulation to perform functional testing of the new devices. High-current, precision, pulsed-DC supplies will be required for high-power device testing.

With RF and microwave devices becoming more integrated and increasingly complex, network analyzers will be used more extensively in manufacturing applications such as RF integrated-circuit (IC) and transmit/receive (T/R) module testing. As the market for microwave devices used in commercial, low-cost wireless communications grows, IC manufacturers currently focused on DC or low-frequency functional testing will have an additional need for RF testing.

The increased need for RF testing in manufacturing will drive the demand for higher throughput with "just enough" instrumentation performance. Modularity, scalability, and upgradability of instruments will become important factors on the production floor. As a result, future high-performance network analyzers used in these applications will be more modular and might incorporate digital IF processing, as well as RF stimulus modulation.

Of course, increased measurement speed will be critical. Novel IF architectures will permit the use of a single receiver for multiple applications. Newer generations of analog-to-digital converters (ADCs), combined with improved digital-signal-processing (DSP) technology, will allow much faster data acquisition and processing. Customers will also demand that test systems be optimized for their specific needs and integrated seamlessly with their existing or newly-implemented data-management and information networks.●●

Acknowledgments

The author wishes to thank John Barr, Julius Botka, Rolf Dalichow, Bruce Donecker, Jim Fitzpatrick, Mike Pervere, Doug Rytting, Dave Sharrit, Hugo Viñan, and many others, some of whom contributed to this article and all of whom helped shape the world of microwave network analysis.

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2. G. Engen and C. Hoer, " 'Thru-Reflect-Line': An Improved Technique for Calibrating the Dual Six-Port Automatic Network Analyzer," *IEEE MTT-S Symposium Digest*, 1979.

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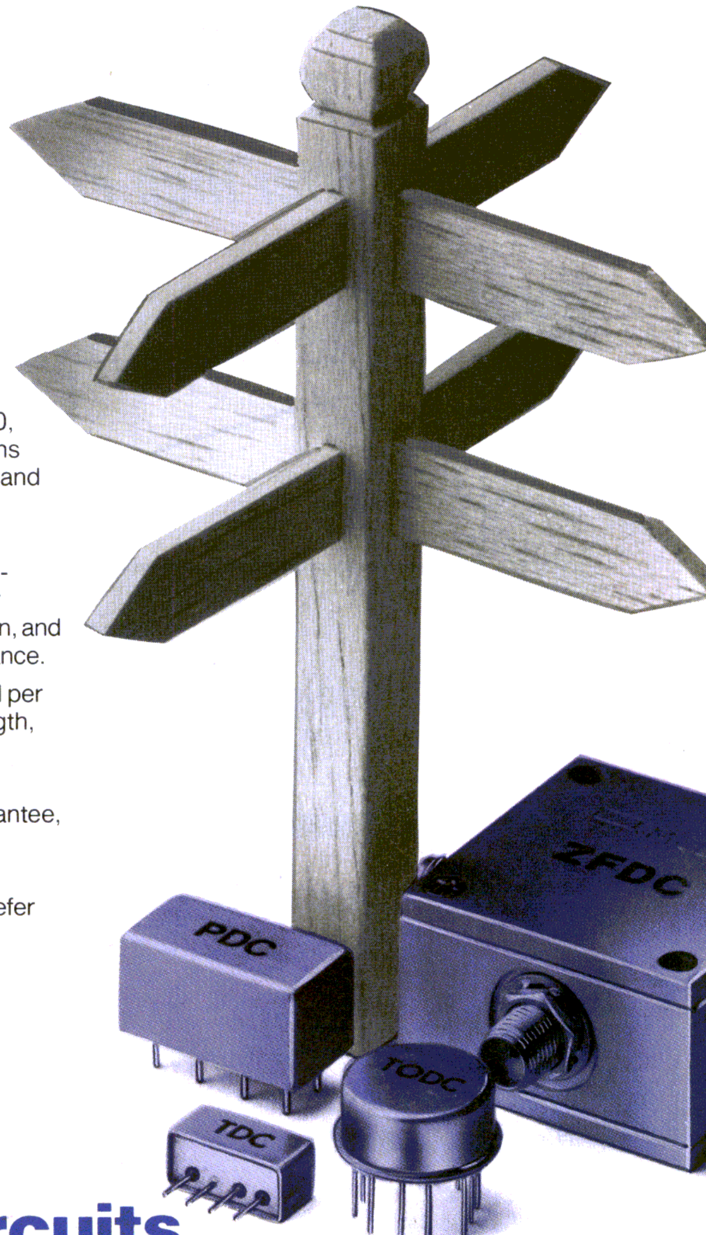

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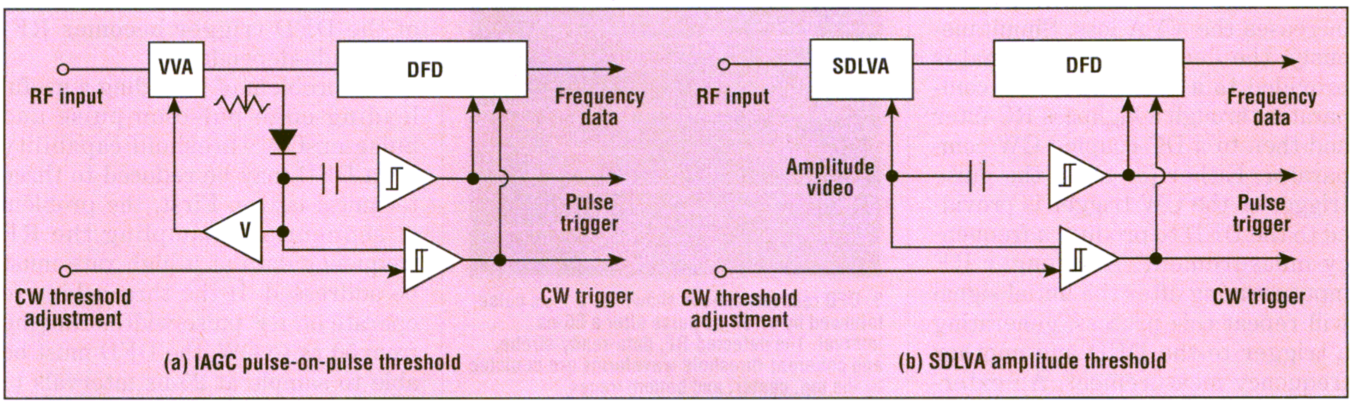
DIGITAL frequency discriminators (DFDs) are employed in a variety of electronic-warfare (EW) systems to provide accurate digital frequency data on received pulsed and continuous-wave (CW) RF signals. By employing the proper leading-edge triggering scheme, a DFD can detect and process pulse-on-pulse and pulse-on-CW signal events at high data rates.

WILLIAM B. SULLIVAN, President, Wide Band Systems, Inc., 1 Munsonhurst Rd., P.O. Box 408, Franklin, NJ 07416; (201) 827-5656, FAX: (201) 827-7300.

Characteristics of the modern DFD include instantaneous frequency coverage that can span multiple octaves in the microwave band and instantaneous dynamic ranges in excess of 60 dB. Various designs have been developed to provide accurate frequency data on RF pulse widths as short as 10 ns, with typical designs providing 50-ns-to-CW coverage. The modern DFD is a fast digital encoder capable of processing and outputting measured data at a rate that can exceed four million RF pulses per second.

The DFD, by its nature, is a serial data processor, providing measured frequency data on the strongest signal observed within the RF bandwidth. CW and long RF pulse widths, therefore, can "capture" the DFD, often preventing the observation and measurement of other RF signals that may be simultaneously present. In the event that a simultaneous signal is of a higher RF power than the initial RF input, the "capture" problem can be reduced if the DFD has the ability to detect the presence of a measurable simultaneous RF input, then performing the frequency measurement of the simultaneous signal subsequent to measurement of the initial RF input.

The utility of a DFD capable of detecting and processing pulse-on-pulse and pulse-on-CW signal events may be offset by the inability of the host-system processor to accommodate the higher data rates that can result. The impact of the higher digital data rates can be minimized by providing a leading-edge trigger capability where, for example, if a short-duration, high-power RF pulse is received during a longer-duration, low-power RF pulse, the DFD will respond sequentially to the two pulses. That is, the DFD will respond to the frequency data on the



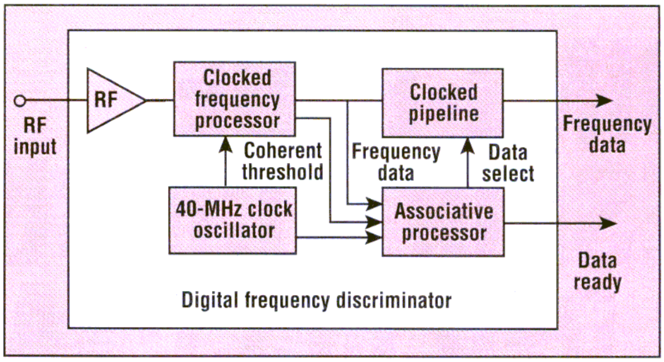
1. Two methods for providing leading-edge threshold capability involve instantaneous AGC (a) and SDLVA circuitry (b).

initial signal, then to the frequency data on the short-duration signal while suppressing a subsequent report which would repeat the initial frequency data.

In a multipath environment, an RF signal is received first over the direct path from the emitter, then subsequently over one or more indirect paths caused by reflections from objects or surfaces located off the direct path. The multipath reflected signal is always at the same frequency as the direct-path signal (except for Doppler effects, which can usually be ignored) but presents an RF amplitude that may be different. The leading-edge trigger capability tends to suppress the effect of RF multipath, as equal-frequency signals received subsequent to the direct path are ignored. Further, if RF amplitude measurements are triggered by the DFD for the purpose of amplitude-comparison direction finding, the leading-edge trigger circuit will suppress angular measurement errors for all scenarios except a small geometric area known as the error-susceptibility region.

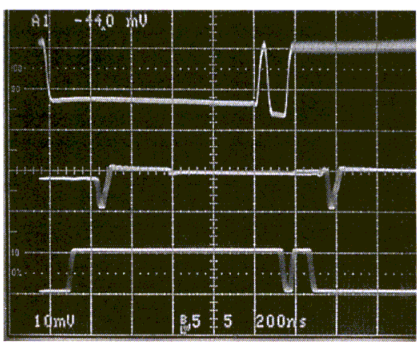
A number of approaches have been used to meet these objectives. For instance, one technique employs a voltage-variable attenuator (VVA) as part of a fast, low-gain, instantaneous automatic-gain-control (IAGC) loop. This loop is designed to provide an output-RF-level variation of approximately 15 dB for a 70-dB variation in input RF level.

In operation, a long-duration RF input is read by the detector. The detected video output is then provided to a fast video amplifier, which increases the VVA loss. Simultaneously, the detected video signal is provided to a pulse threshold comparator through a highpass RC filter and then to a DC-coupled CW comparator. Either (or both) the pulse trigger or the CW trigger is provided to the DFD to produce a frequency measurement. A stronger RF input arriving after the initial signal will repeat this process, generating a trigger to the DFD and another frequency measurement. An external voltage is required for the CW threshold reference to allow the processing of slow-rise-time RF signals.



2. This DFD architecture features an associative processor block, which can determine whether the present frequency sample is due to a new or previously-detected signal.

While the IAGC threshold circuit (Fig. 1a) was largely effective in providing the appropriate trigger responses for the DFD, there were some drawbacks. First, the threshold circuit's recovery time from strong signals was poor, requiring almost a microsecond to return to full sensitivity. Second, the process of thresholding frequency data based on amplitude measurements has an inherent flaw in that it is assumed that merely because there is a measurable amplitude difference, there will also be measurable frequency data. This problem is particularly acute when there is substantial RF gain between the VVA and DFD, as the small-signal gain variation of an RF amplifier will add to the amplitude margin required to provide a useful trigger. Since the setting of the CW threshold is based on the noise-level input to the DFD, a band-switched RF front end requires a programmable voltage input to accommodate the RF-noise-level variation as the RF input band is switched.



3. DFD recovery time is shown for a 1-μs pulse followed by a 100-ns pulse after a 50-ns interval. The detected-RF, data-ready-strobe, and coherent-threshold waveforms are depicted by the top, center, and bottom traces, respectively.

The sequential-detector-logarithmic-video-amplifier (SDLVA) threshold circuit (Fig. 1b) can also provide a leading-edge threshold capability for the DFD. In this approach, the SDLVA produces a voltage output which is proportional to the logarithm of the RF input-power level.

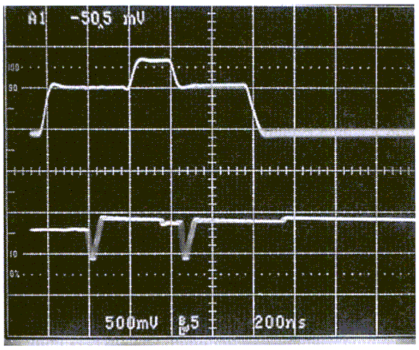
This method has the advantage of providing RF amplitude data along with frequency data, with the circuit recovering faster than the IAGC threshold. Unfortunately, it suffers from the basic problems of employing RF amplitude data to trigger an RF frequency measurement, as well as having a variable CW threshold. In addition, the basic process of resolving a pulse-on-pulse threshold level with this logarithmic technique is mathematically different from the square-law detection and threshold process of Fig. 1a. Also, the SDLVA has an inherent variation of the log-video-output timing related to the RF input power level. This can cause problems in the measurement of short RF pulses because the timing of the DFD trigger becomes RF-amplitude-dependent.

The problem of providing a useful leading-edge pulse-on-pulse and pulse-on-CW threshold capability for a DFD may be reduced to three technical issues. First, the problem of sequentially sampling the RF frequency data at a high rate must be addressed. If the threshold is to operate on RF pulse widths ranging from 50 ns to CW, the DFD must be able to sample at 25-ns intervals to assure (given the video settling-time requirements and effective RF-

DFD TRIGGERING

pulse-width loss due to delay lines) that at least one valid frequency measurement is obtained for each RF input signal. This requires the DFD to clock data at a 40-MHz rate.

Second, the validity of each measured frequency sample must be determined on a sample-by-sample basis. This validity question takes two forms: first, the signal-to-noise ratio (SNR) must be estimated for each frequency measurement sample; second, given that a sufficient SNR exists, the measurement validity must be determined. The first task can be accomplished by the coherent threshold circuit developed by Wide Band Systems, Inc. (Franklin, NJ). This circuit provides a sample-by-sample estimate of the SNR observed by the frequency-measurement process. Since the coherent threshold output is only a function of the SNR, the DFD can determine the threshold (in terms of the RF SNR) independently of the external



4. DFD response to a typical pulse-on-pulse situation is shown. The video-amplitude and data-ready traces are shown at the top and bottom, respectively.

noise-power level. The second task is accomplished on a sample-by-sample basis by the SSD function.

The third major technical challenge involves a frequency sample obtained in 25 ns, with the sample having a sufficient SNR to provide useful frequency data and being free from errors due to, for example, a simultaneous signal at approximately the same RF input level. Given these conditions, it must be determined whether the sample is due to a new signal. The problem becomes complex since the frequency being sampled may correspond to a previous RF input while there may have been other frequencies present in the intervening period, such as would occur if a short-duration, high-power RF input is present during a long-duration, low-power RF input. The DFD must recognize that the frequency measurement which follows the short-duration signal is similar to (but not necessarily identical to) the measurement that occurred prior to the short-duration signal. The technical objective is achieved by the associative processor, which is a digital circuit that can quickly recognize that the present frequency digital sample is similar to a previous (but not necessarily time-contiguous) frequency sample.

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DFD TRIGGERING

Figure 2 is a block diagram of the DFD. The RF input is amplified to produce hard limiting over the full dynamic range. A 40-MHz clocked processor generates a digital frequency sample every 25 ns. Each sample includes a coherent threshold tag, with the stream of frequency samples clocked through a pipeline circuit. The associative processor is active whenever the coherent threshold indicates that an above-threshold signal is present. When the associative processor determines that a new RF input is present, the appropriate sample is selected in the clocked pipeline for output and a data-ready strobe is issued. The circuit ignores data resulting from simultaneous signal errors.

A working DFD with these characteristics has been produced. The DFD operates from 7.5 to 18 GHz with 3-MHz resolution over an RF dynamic range of –60 to +10 dBm using an internal RF limiting amplifier. Figure 3 demonstrates the DFD recovery time, showing a 0-dBm, 1-μs RF pulse followed by a –60-dBm, 100-ns RF pulse with a 50-ns interval in between the pulses. The interval was provided for illustration purposes, as the DFD only requires that the second signal exist for more than 50 ns beyond the strong signal.

Figure 4 presents the DFD response to the classic pulse-on-pulse situation, providing one data-ready output for each RF input event. The short-duration RF pulse was 6 dB stronger than the long-duration RF pulse. The DFD output data-ready port was connected to the DFD-input data acknowledge, causing a very short data-ready strobe width.

This DFD uses a digital technique to provide leading-edge pulse-on-pulse and pulse-on-CW threshold triggering. This eliminates the need for VVAs, SDLVAs, and external CW threshold voltage references, as the DFD threshold is instantaneously self-adaptive to the current RF SNR. The circuits employed are entirely digital, using "F"-series TTL logic. The DFD was tested over a temperature range of –54 to +85°C. The 7.5-to-18-GHz DFD uses a standard 7 × 12 × 12 in. (17.8 × 30.5 × 30.5 cm) package, while the 2-to-6-GHz version employs a 7.3 × 6.2 × 0.6 in. (18.5 × 15.7 × 1.5 cm) miniature package. Other bands and physical configurations are available.●●

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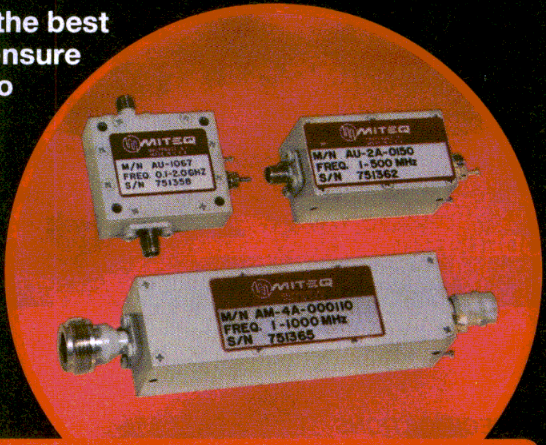

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AU-1310	.01 – 500	30	0.50	1.3	1.4	1.5	2:1	8	15	50
AM-1300	.01 – 1000	25	0.75	1.4	1.6	1.8	2:1	6	15	50
AU-1378*	1 – 300	17	0.50	1.9	1.9	1.9	2:1	–2	6	10
AU-1379*	1 – 500	13	0.50	2.2	2.3	2.4	2:1	–2	6	10
AU-2A-0150	1 – 500	30	0.50	1.3	1.4	1.5	2:1	8	15	50
AU-3A-0150	1 – 500	45	0.50	1.3	1.4	1.5	2:1	10	15	75
AM-2A-000110	1 – 1000	25	0.75	1.4	1.6	1.8	2:1	8	15	50
AM-3A-000110	1 – 1000	37	0.75	1.4	1.6	1.8	2:1	9	15	75
AU-1021	5 – 300	24	0.50	2.2	2.4	2.6	2:1	20	15	175
AU-1158	20 – 200	30	0.50	2.7	2.7	2.7	2:1	17	15	125
AMMIC-1318	100 – 2000	6	1.00	4.5	4.0	4.0	2:1	12	15	35
AMMIC-1348	100 – 2000	14	1.00	5.0	5.0	5.0	2:1	14	15	150
AM-2A-0510	500 – 1000	24	0.50	1.4	1.5	1.6	2:1	0	15	50
AM-3A-0510	500 – 1000	38	0.50	1.4	1.5	1.6	2:1	10	15	75
AM-3A-1020	1000 – 2000	30	0.50	1.8	2.1	2.4	2:1	10	15	75

*Designed for low current battery operation

POWER AMPLIFIERS

Model Number	Frequency (MHz)	Gain (Min.) (dB)	Gain Var. (Max.) (±dB)	Noise Figure Low	Mid	High	VSWR (Max.)	Output 1 dB Gain Comp. (Min., dBm)	DC Power (+V)	(@ mA)
AUP-1374	10 – 500	30	1.50	4.5	5.0	5.5	2:1	29	21	550
AUP-1383	20 – 300	35	1.50	2.4	2.5	2.6	2:1	29	21	650
AUP-1382	20 – 300	40	1.50	2.4	2.5	2.6	2:1	29	21	630
AMP-1380	10 – 1000	20	1.50	6.0	6.5	7.0	2:1	29	21	590
AMP-1381	20 – 1000	30	1.50	4.2	3.6	3.8	2:1	29	21	670
AMP-1389	10 – 1000	12	1.00	10.0	10.0	10.0	2:1	29	21	500

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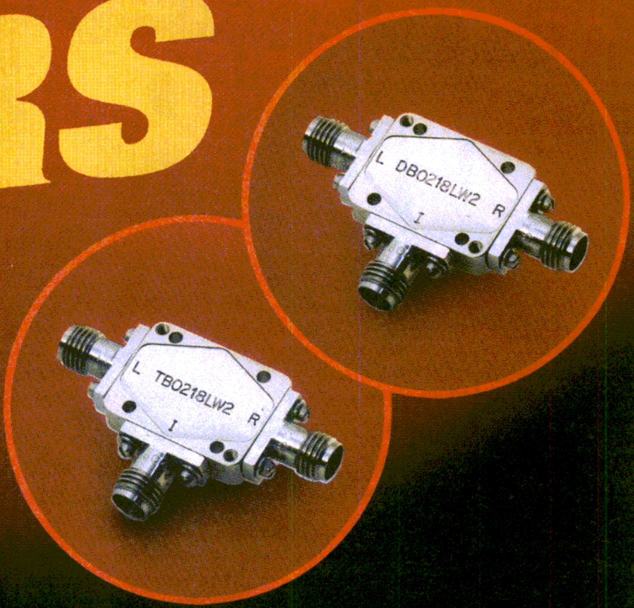

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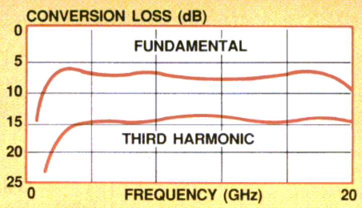
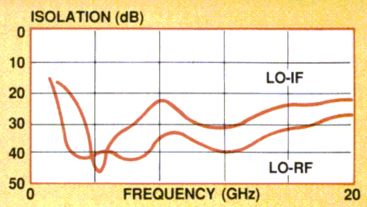
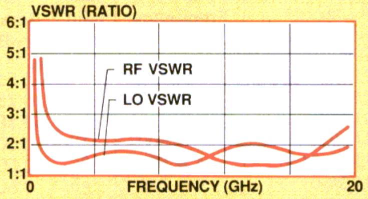
MODEL DB0218LW2 DOUBLE BALANCED MIXER

SPECIFICATIONS

RF frequency .... 2 to 18 GHz
LO frequency .... 2 to 18 GHz
IF frequency .... DC to 700 MHz
LO power range ...... +7 to +13 dBm
Conversion loss ...... 6.5 dB typ.
8.5 dB max.
LO-RF isolation .... 30 dB typ.
22 dB min.
RF-IF isolation .... 20 dB typ.
Input IP³ .... +12 dBm*







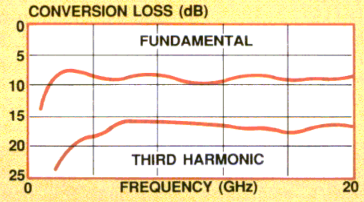
SINGLE TONE SPURIOUS (dBc)*

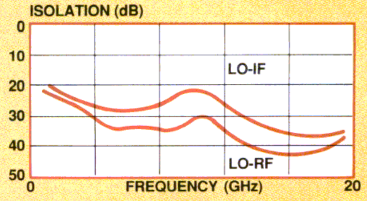
RF HARMONIC (-10 dBm INPUT) \ LO HARMONIC (+10 INPUT)	1	2	3	4	5
5	>85	>85	>85	>85	>85
4	75	75	80	85	80
3	45	60	55	65	55
2	43	49	50	50	60
1	REF	30	11	33	20

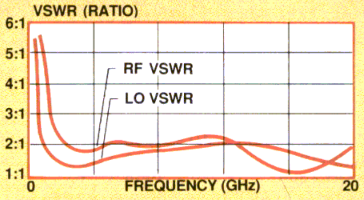
MODEL TB0218LW2 TRIPLE BALANCED MIXER

SPECIFICATIONS

RF frequency .... 2 to 18 GHz
LO frequency .... 2 to 18 GHz
IF frequency .... 0.5 to 8 GHz
LO power range .... +10 to +13 dBm
Conversion loss .... 7.0 dB typ.
9.0 dB max.
LO-RF isolation .... 30 dB typ.
22 dB min.
RF-IF isolation ...... 20 dB typ.
Input IP³ .... +15 dBm*







SINGLE TONE SPURIOUS (dBc)*

RF HARMONIC (-10 dBm INPUT) \ LO HARMONIC (+10 INPUT)	1	2	3	4	5
5	>85	>85	>85	>85	>85
4	80	>85	80	>85	>85
3	58	63	59	70	63
2	46	52	46	56	47
1	REF	26	12	33	22

* Higher third order intercept point and improved single tone spurious performance are available through the use of high level Schottky diodes. Contact MITEQ for additional options.

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Phase Noise and BER, Part 2

DEFINING THE RELATIONSHIPS FOR RANDOM PHASE ERRORS

Random phase errors can be categorized by different distributions and probability density functions (PDFs).

PHASE noise and its relationship to communications bit-error-rate (BER) performance was introduced in last month's article. The second installment of this series on the mathematics of phase noise will examine random phase errors.

In Part 1, relationships were shown for the degradation of quadrature-phase-shift-keying (QPSK) performance versus the simplified case of static phase errors. In practice, if a carrier-recovery circuit creates a static phase shift (θ_s) on the local oscillator (LO) with respect to the carrier, it may be equalized so that this phase shift is some multiple of 360 deg. (in effect the same as a 0-deg. phase shift).

Since carrier recovery invariably requires some form of filtering, static phase errors must be addressed. Random fluctuations of phase due to the different noise contributions in the system also need to be characterized, and these errors cannot be equalized. Because these errors occur as a random process, they can be described as a probability density function (PDF) expressed by $p(\theta_e)$.

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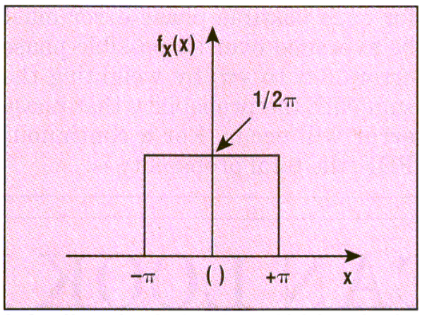


3. A uniform density function, which is a simple probability density function (PDF), implies that the phase may take on any value of phase at any instant.

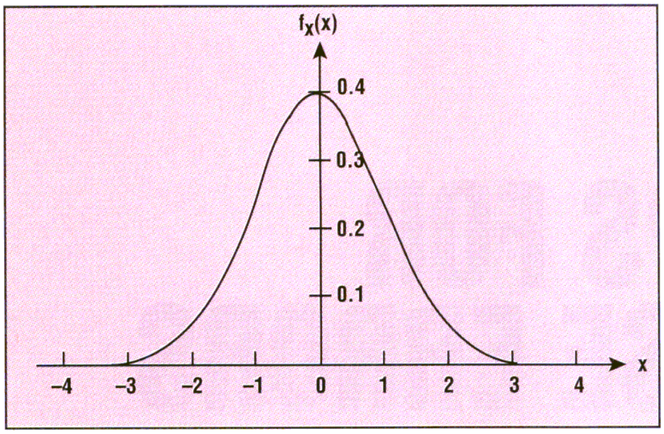
As a simple PDF example, consider a source with uniform phase density. The uniform density implies that the phase at some instant may take on any value on the interval −π, +π with equal probability (Fig. 3). The area under a PDF curve from −∞ to +∞ must always be equal to unity, indicating that the sum of the probabilities for all the possible events is unity (the phase must have some value).

As another example, consider a Gaussian PDF. It is the single most-important density for communications engineering (Fig. 4) and is expressed as:

$$p(x) = 1/\sigma(2\pi)^{0.5} \times exp[(x-m)^2/2\sigma^2] \qquad (A)$$

In this example, which is centered around zero (which is the mean value, m), a phase error closer to zero is more likely to occur than a phase value far from zero. The likelihood of a particular phase can be determined by properly using the error-function integral described by Eq. 3. The variance, σ^2, of the PDF is a measure of the spread of the density around its mean, and can be evaluated by the width of the bell-shaped curve. A tall, thin bell shape has a small variance, while a bell shape with a large width at the expense of height indicates more potential for the phase error to take on a large value. Another measure of width is the standard deviation, which is the square root of the variance. The variance itself is significant because it represents the noise power when the mean is zero.

The mean and variance together carry extra significance for the Gaussian PDF because these two parameters completely characterize the probability density. Thus, if a density is known or assumed to be Gaussian, the PDF can be written when the mean and the variance are known, and the PDF will be the complete statistical description of the random variable. A further crucial property of the Gaussian PDF is that if a Gaussian random variable undergoes a linear transformation (is pro-



4. The probability density function for a Gaussian density assumes the classic bell-shaped curve.

cessed through a component described by a linear function), the output of the transformation will also be Gaussian in nature. Finally, another useful property of Gaussian random variables is that uncorrelated random variables are also independent.

For the average bit-error probability for a generalized distribution of phase error, the bit-error probability for a given θ_e is multiplied by the likelihood of that θ_e occurring, then summed with all the other possibilities. The bit-error probability for each possible phase error must be averaged over all possible phase errors ($-\pi$ to $+\pi$) by weighting the sum with the probability that phase error will occur. For a continuous PDF, the total probability is:

$$P_e = \int_{-\pi}^{\pi} P(E/\theta_e)p(\theta_e)d\theta_e \qquad (6)$$

Based on Eqs. 4 and 5 for $P(E/\theta_e)$ for the PSK systems mentioned, the problem evolves into one of determining $p(\theta_e)$, the PDF of the phase-error random variable. More precisely, the first term in the integral, $P(E/\theta_e)$, has an exact form for binary PSK (BPSK) of:

$$P_e(\theta_e) = Q[(2E_b/N_o)^{0.5}] \times 1/T \int_0^T cos[\theta_e(t)]dt \qquad (7)$$

which reduces to Eq. 4 when θ_e is constant. Also, if the bit rate 1/T is much greater than the carrier-loop noise bandwidth (which is often the situation since carrier-loop bandwidths on the order of 100 Hz are common), the $\theta_e(t)$ variation is very slow within a bit interval (0, T) and can be considered constant during the bit interval. This allows Eq. 7 to be approximated by:

$$P_e(\theta_e) = Q[(2E_b/N_o)^{0.5} \times \cos(\theta_e)] \qquad (8)$$

The results can easily be extended to validate the QPSK version of Eq. 8. Slowly-varying phase will generally be assumed throughout this analysis since rapid phase variations complicate the process. The approach will be described below for a BPSK system.

If the phase error varies rapidly with respect to a bit interval, such as for a very low data rate, the BPSK case described by the integral in Eq. 7 reduces approximately to the time average of the cosine of the phase error, or $E\{\cos[\theta_e(t)]\}$, where E{ } represents the expectation operator whose output is the mean value. The expectation can be evaluated by noting that the mean of a random-variable function is determined by substituting the function itself into the calculation of the integral for the mean in place of the random variable. Since the phase-error process is assumed to be ergodic, this time average will present a statistical average phase error.

It no longer makes sense to evaluate the BER as in Eq. 6 since we can no longer associate a single value of phase error during detection of a bit. Instead, a single bit detected sees an average phase error $E[\cos(\theta_e)]$, so that the analogous expression for Eq. 8 is:

$$P_e(\theta_e) = Q\{[2E_b/N_o]^{0.5} \times E[\cos(\theta_e)]\} \qquad (9)$$

In this case, a Gaussian phase-error process is assumed. Although a full explanation of this assumption will be presented later in this series, the assumption is used because it has proven to be a reliable model for performance predictions. The expected value is defined as:

$$E[\theta_e] = \int_{-\pi}^{\pi} \theta_e p(\theta_e) d\theta_e \qquad (B)$$

For a function of a random variable, this is:

$$E[g(\theta_e)] = \int_{-\pi}^{\pi} g(\theta_e) \times p(\theta_e) d\theta_e \qquad (10)$$

It is not necessary to know the complete statistics of $\cos(\theta_e)$ to find its mean. By assuming that the mean of the random variable θ_e is zero (the Gaussian error fluctuates nominally around zero), the integral can be evaluated as:

$$E[\cos(\theta_e)] = 1/\sigma(2\pi)^{0.5} \int_{-\pi}^{\pi} \cos(\theta_e) \times \exp(-\theta_e^2/2\sigma^2) d\theta_e =$$

$$1/\sigma(2\pi)^{0.5}\int_{-\pi}^{\pi}exp\ (j\theta_e)\ \times$$
$$exp(-\theta_e^2/2\sigma^2)d\theta_e\ +$$
$$1/\sigma(2\pi)^{0.5}\int_{-\pi}^{\pi}exp\ (j\theta_e)\ \times$$
$$exp(-\theta_e^2/2\sigma^2)d\theta_e =$$
$$0.5\,exp(-\sigma^2/2)\ +\ 0.5\ \times$$
$$exp(-\sigma^2/2) = exp(-\sigma^2/2) \qquad (C)$$

For the BPSK case, Eq. 9 then becomes:

$$P_e = Q[(2E_b/N_o)^{0.5}\ \times$$
$$exp(-\sigma^2/2)] \qquad (11)$$

and σ^2 is needed. The approach for obtaining this will be described later in the analysis. The problem becomes more complex for QPSK due to the crosstalk mechanism as the phase error progresses. The remainder of the analysis will concentrate on the practical situation of slowly-varying phase error, considered to be equal to the loop bandwidth < 1/10(data rate).

In addition to the assumption of a slowly-varying phase error in this phase-error analysis, other important assumptions are presented:

1. The analysis assumes perfect frequency synchronization, with no dynamic tracking errors (such as Doppler errors) and no spurious frequencies which contribute to the total phase error (although they are treated the same way, as independent sources).

2. Steady-state phase error in the receiver is considered negligible (zero mean). Modern phase-locked-loop (PLL) design using a common second-order PLL with an operational-amplifier (opamp) integrator as the loop filter reduces the phase error at the output of the phase detector to near zero when the frequency is offset but in the phase-lock range. Additional filtering in the loop or detection chain must be carefully arranged to avoid static phase offsets between modulated data and the demodulated LO. Phase-detection techniques that avoid the "dead zone" effect, maintaining a linear transfer response near zero phase difference, reduce the associated static phase errors. Linearized dynamics are assumed in the analysis, allowing the use of the Gaussian-to-Gaussian linear transform property.

3. Bit timing is assumed to be ideal. This is equivalent to perfect clock-recovery phase generation so that detection instants are exactly at the peak of the matched filter outputs. This assumption is made with the following notes:

- More relative clock phase offset can be allowed for the same amount of performance penalty that can be allowed for the carrier. This makes the clock-recovery circuitry generally less critical than the carrier-recovery circuits.
- Clock-recovery circuits that are not dependent upon carrier phase are possible and practical, such as an intermediate-frequency (IF) envelope detection (a band-limited PSK modulation). Therefore, it is entirely practical to analyze carrier-contributed phase noise itself as an independent contributor to BER degradation.
- In spite of its general subordinate nature to carrier-recovery loops, the clock-recovery circuitry should not be considered an insignificant part of the receiver design. In fact, very careful selection of clock filtering must occur to realize good performance against noise, both external and internal system noise. The clock filtering selection is more critical to the performance of the clock-recovery circuitry than the carrier-recovery bandpass filtering is in the performance of the carrier-recovery loop.

The mean and variance carry extra significance for the Gaussian PDF because they completely characterize the probability density.

4. Intersymbol interference (IFI), from the dispersive effects of the transmission media and filtering components, should be neglected to make the analysis tractable with little effect on the end results.

5. Filter distortion effects, such as incidental AM and passband flatness, are neglected.

6. Phase ambiguities are assumed to be resolved. Minimum-PSK systems require some sort of phase-ambiguity resolution to set absolute phase at the receiver. Whenever carrier recovery from a modulated signal is mentioned, the phase ambiguities will be considered resolved. There is no such concern for an auxiliary carrier transmission. The BER analysis assumes steady-state loop operation.

7. Carrier phase modulation also is neglected. The analysis assumes a carrier-recovery loop with reference to an unmodulated carrier sinusoid, which contains both AWGN and 1/f Gaussian frequency instability. The analysis of square- and fourth-order-law carrier recovery, as well as Costas recovery loops, will not be treated. These types of loops deal directly with suppressed carrier modulation, such as BPSK and QPSK. This is equivalent to assuming a tone of specific noise properties is available for synchronization purposes only. The effect of the modulation is to lower the effective loop signal to noise ratio by lowering the carrier power and adding another noise term. However, it is possible to analyze the effect of lower loop signal to noise ratio on the phase-error PDF in some cases, such as the AWGN phase error and Tikhonov PDF.

Armed with Eqs. 4 and 5, it is now possible to search for the missing ingredient in Eq. 6: the PDF for the phase error, $p(\theta_e)$. This will be attacked from the noise characteristics

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SPECIFICATIONS

Pin Model	TO 0812LN	TO 1217LN	TO 1724LN			
Connector Version	ZEL 0812LN	ZEL 1217LN	ZEL 1724LN	ZHL 0812HLN	ZHL 1217HLN	ZHL 1724HLN
Freq. (GHz)	0.8-1.2	1.2-1.7	1.7-2.4	0.8-1.2	1.2-1.7	1.7-2.4
NF, db, max*	1.6 1.5	1.6 1.5	1.6 1.5	1.5	1.5	1.5
Gain dB, min.	20	20	20	30	30	30
Output Pwr., dBm 1dB Comp.	+8	+10	+10	+26	+26	+26
Intercept Pt. 3rd order, dBm typ.	18	25	22	36	36	36
Price $ (Qty. 1-9)	TO $199.00		ZEL $274.00		ZHL $349.95	

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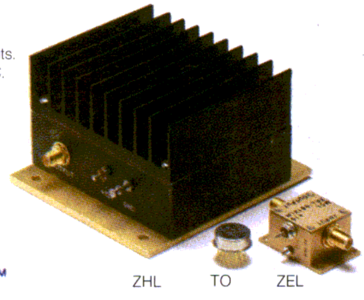

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PHASE NOISE/BER

of free-running oscillators, phase-locked oscillators, transmit/receive subsystems, and complete coherent transponders. Gaussian behavior will remain a key for each system description. Postulation of this model is based on the central-limit theorem, the repeated natural occurrence of the Gaussian density in many applications, and the straightforward analysis that results from the many convenient properties of Gaussian statistics. The central-limit theorem qualitatively states that the sum of random variables with arbitrary PDFs produces an overall PDF that more closely approaches a Gaussian nature as the number of individual contributors increases. Therefore, given the many independent physical processes that produce the composite oscillator phase noise and, additionally, the number of individual hardware contributors in a system that contribute to phase noise, the Gaussian assumption appears to have merit. It is further validated by the comparison of predicted performance using the Gaussian model versus actual performance.

The linearity property is also useful when discussing PLL subsystems. In PLLs, although their behavior is inherently nonlinear, the use of linearized analysis holds up well for good loop signal-to-noise ratios (on the order of 10 dB or better) where most PLLs need to operate. Cycle slippage (random unlocking), which must realistically be kept at a low rate of occurrence, is a function of loop signal-to-noise ratio.

The Gaussian PDF is completely determined by its first two moments. This can be further simplified by assuming a zero-mean phase-error process, as would be the case for a PLL using an ideal integrator in the carrier-recovery loop. Since opamp-based loop filters are the norm, this is a valid simplifying assumption. Other than the minute phase error due to frequency offset, there should be no particular bias expected for the phase error created by various noise processes. For the zero-mean case, the variance simply defines the power, which for this case is the phase-error power. By determining the power, the PDF can be completely expressed and used in Eq. 6.

Next month, this series on phase noise and BER will continue with a review of the noise mechanisms in solid-state oscillators.●●

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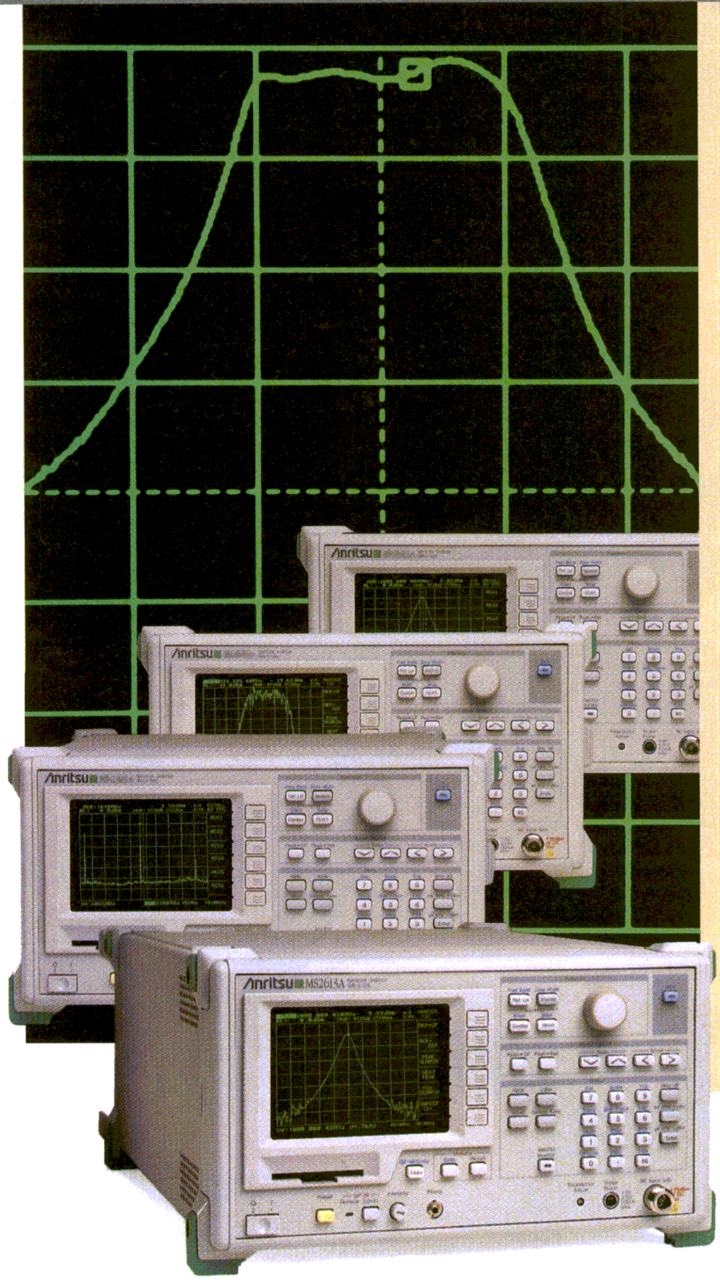

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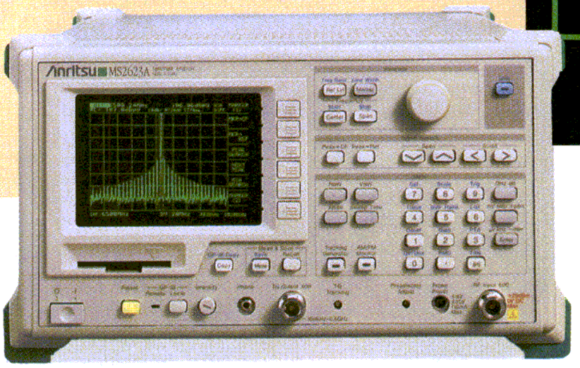

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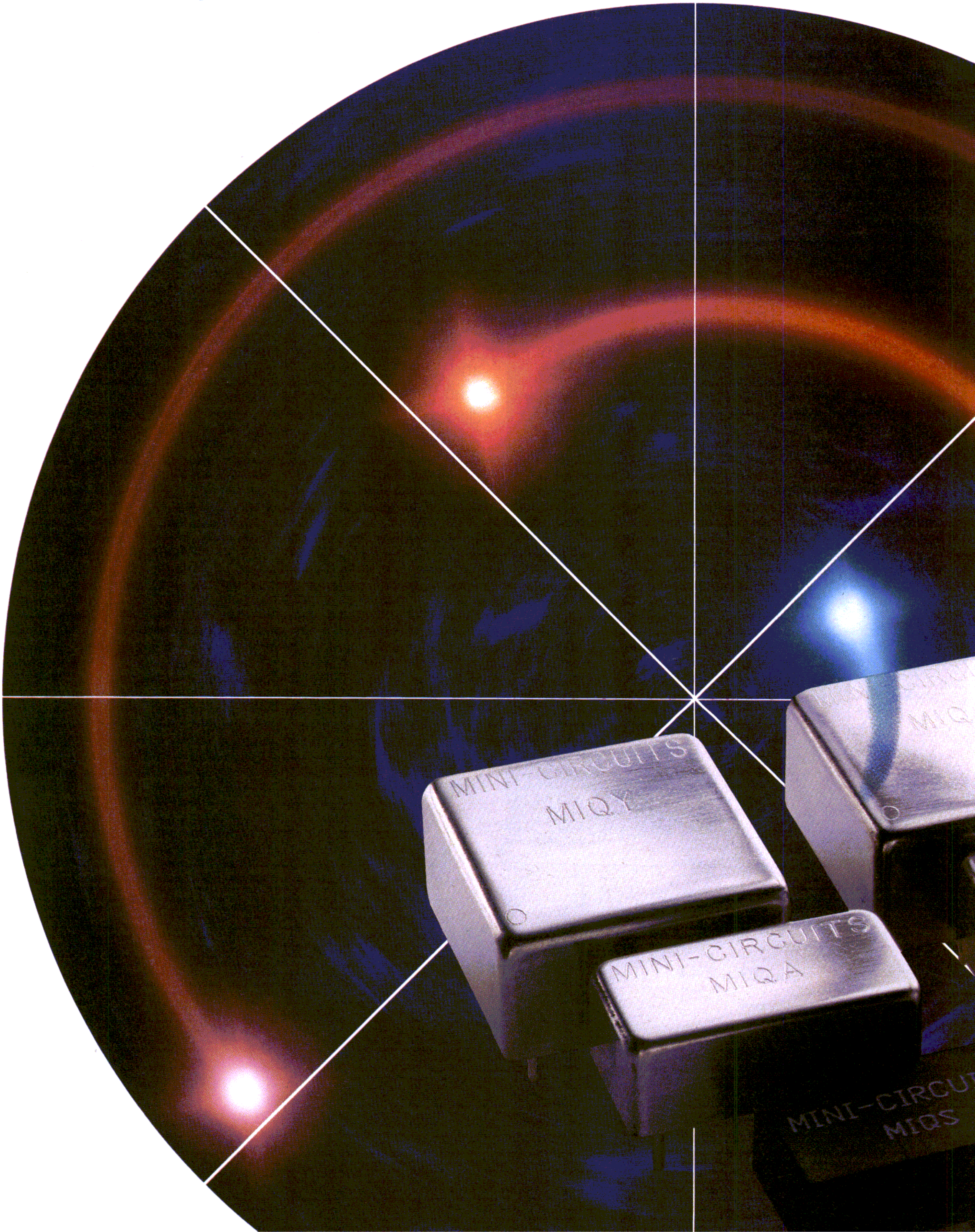

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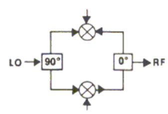

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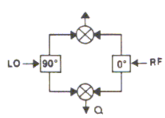
MODEL NO.	FREQ. (MHz) f_L	f_U	CONV. LOSS (dB) x	σ	CARRIER REJ. (dBc) Typ.	SIDEBAND REJ. (dBc) Typ.	HARM. SUPPRESS (dBc) Typ. 3xI/Q	5xI/Q	PRICE $ QTY (1-9)
MIQA-10M	9	11	5.8	0.20	41	40	58	68	49.95
MIQA-21M	20	23	6.2	0.14	50	40	48	65	39.95
MIQA-70M	66	73	6.2	0.10	38	38	48	58	39.95
MIQA-70ML	66	73	5.7	0.10	38	38	48	58	49.95
MIQA-91M	86	95	5.5	0.10	38	38	48	58	49.95
MIQA-100M	95	105	5.5	0.10	38	38	48	58	49.95
MIQA-108M	103	113	5.5	0.10	38	38	48	58	49.95
MIQA-195M	185	205	5.6	0.10	38	38	48	58	49.95
MIQC-88M	52	88	5.7	0.10	41	34	52	66	49.95
MIQC-176M	104	176	5.5	0.10	38	36	47	70	54.95
MIQC-895M	868	895	8.0	0.10	40	40	52	58	99.95
MIQC-1785M	1710	1785	9.0	0.30	35	35	40	65	99.95
MIQC-1880M	1805	1880	9.0	0.30	35	35	40	65	99.95
☐ MIQY-70M	67	73	5.8	0.20	40	36	47	60	19.95
☐ MIQY-140M	137	143	5.8	0.20	34	36	45	60	19.95



I/Q DEMODULATORS

MODEL NO	FREQ. (MHz) f_L	f_U	CONV. LOSS (dB) x	σ	AMP. UNBAL. (dB) Typ.	PHASE UNBAL. (Deg.) Typ.	HARM. SUPPRESS (dBc) Typ. 3xI/Q	5xI/Q	PRICE $ QTY (1-9)
MIQA-10D	9	11	6.0	0.10	0.15	1.0	50	65	49.95
MIQA-21D	20	23	6.1	0.15	0.15	0.7	64	67	49.95
MIQC-895D	868	895	8.0	0.20	0.15	1.5	40	55	99.95
☐ MIQY-1.25D	1.15	1.35	5.0	0.10	0.15	1.0	59	67	29.95
☐ MIQY-70D	67	73	5.5	0.25	0.10	0.5	52	66	19.95
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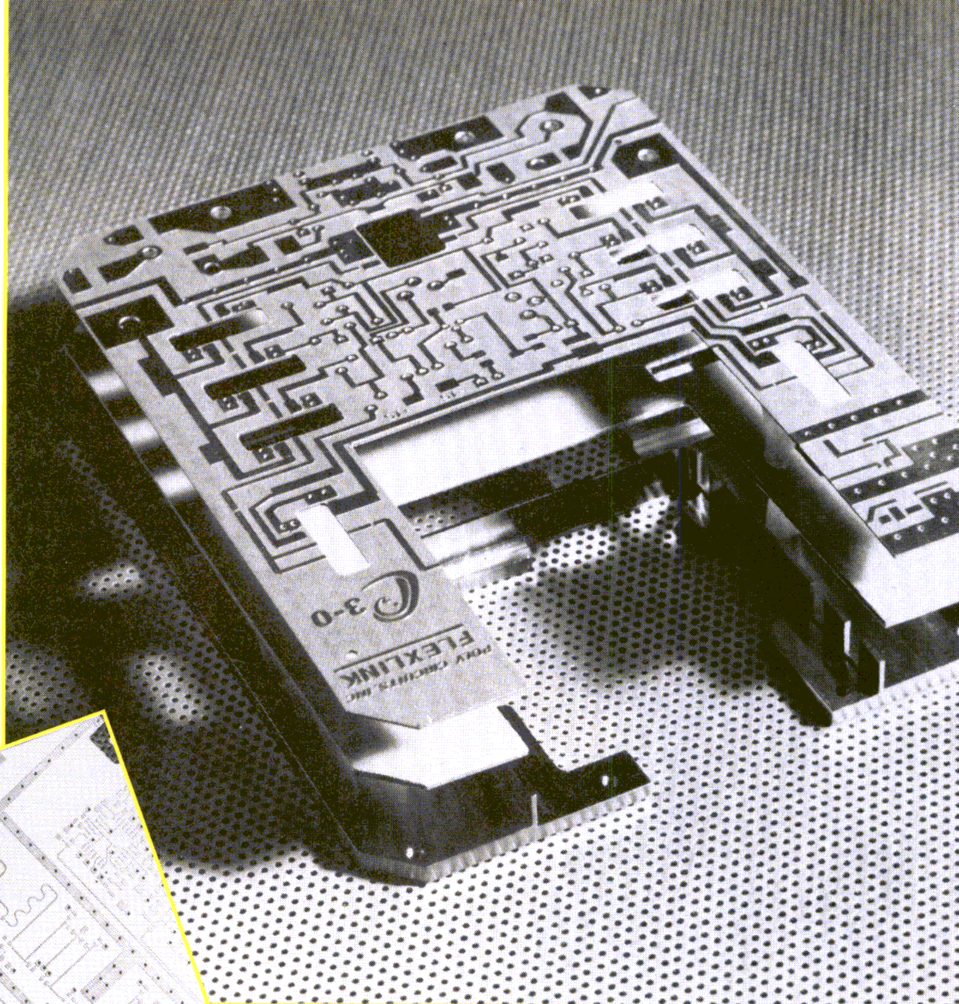

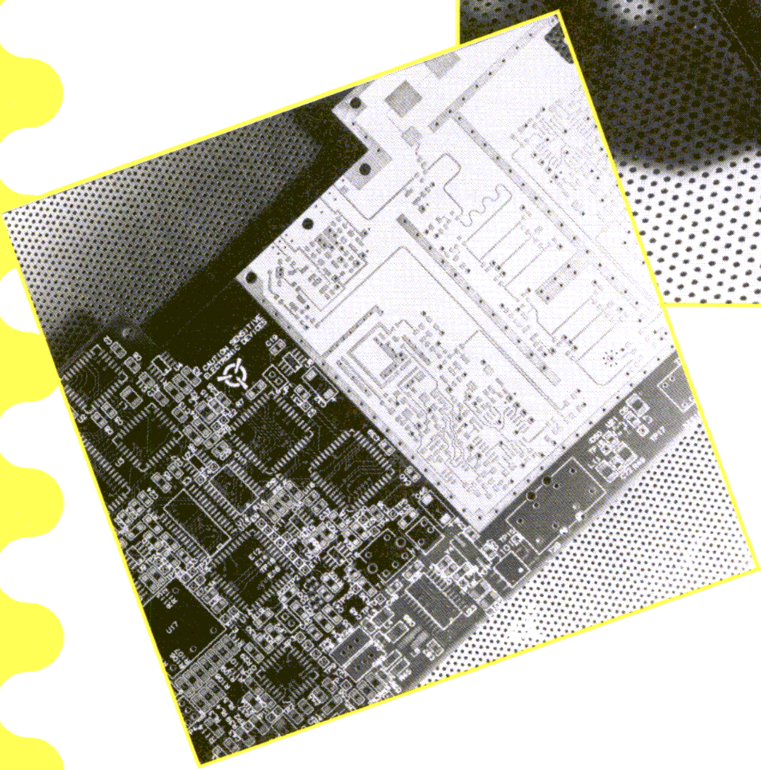

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NEW TECHNIQUE CHECKS ACCURACY OF IMPEDANCE MEASUREMENTS

This method evaluates measurement uncertainties for vector network-analyzer and calibration standards.

VECTOR network analyzers can provide high measurement resolution with amazing accuracy, but that accuracy should never be taken for granted. By properly tracking measurement uncertainties, it is possible to safeguard that accuracy with a wide range of calibration standards.

For years, the United Kingdom's National Physical Laboratory (NPL) has been developing automatic network analyzers (ANAs) and reflectometers based on the six-port technique.[1] A difficulty in the performance of these instruments has been the need to assess the accuracy of each instrument following design and development stages. However, a new evaluation method, which can be applied to all instruments of this type, solves this problem.

The technique assesses the accuracy of the United Kingdom's primary coaxial standards at RF and microwave frequencies. It has also been applied to commercial vector network analyzers such as the HP 8510 an HP 8753 analyzers from Hewlett-Packard Co. (Palo Alto, CA).[2,3] In principle, the technique can be applied to any ANA since minimal assumptions are made about the instrument itself.

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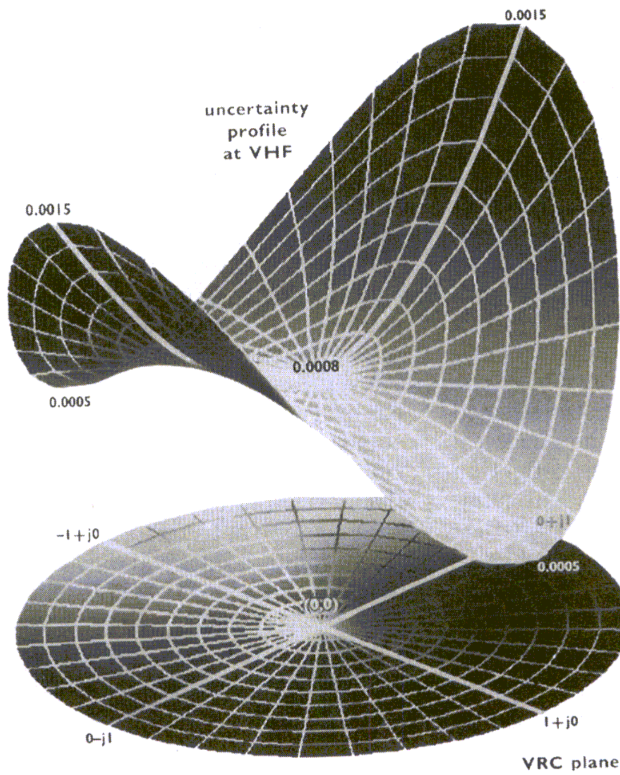
National Physical Laboratory, Microwave Standards Branch C, Division of Electrical Science, St. Andrews Rd., Malverne, Worcestershire, England WR14 3PS; (0684) 89-4645, FAX: (0684) 89-5547.



1. This complex-plane plot represents the uncertainty profile for reflection-coefficient measurements at VHF.

As described in this article, the technique will concentrate on vector network analyzers used for one-port (reflection) measurements. (A more-detailed exposition of the technique is available elsewhere.[4])

Numerous processes affect the accuracy of an ANA. These processes are known as contributions to the measurement uncertainty, which represents the doubt about the accuracy of the measurement. In accordance with international recommendations,[5] contributions evaluated statistically are termed type A contributions, while those evaluated by other means are termed type B contributions. For this evaluation method, measurement and calibration repeatability (including connector repeatability), instrument stability, and noise are treated as type A contributions. Incomplete knowledge of the calibration items' properties and detector nonlinearities are treated as type B contributions.

The evaluation technique uses the facility available on most modern network analyzers to send uncorrected vector readings to an external storage medium. Such data is collected for both calibration artifacts and devices under test (DUTs). The data are then processed using in-house calibration and measurement algorithms. This allows uncertainty contributions to be evaluated off-line in a controlled manner.

Type A contributions are evaluated by performing a series of n calibrations (cal) and measurements (meas) sequentially, i.e., cal 1, meas 1, cal 2, meas 2,...cal n, meas n.

The term calibration denotes the process in which an ANA's vector readings are collected for the items (such as impedance standards) which will be used to calculate the instrument's calibration constants at each frequency. The term measurement denotes the process in which the ANA's vector readings are collected for a DUT for which the electrical characteristics (such as reflection coefficient) are required. The number n is chosen to enable statistical techniques to be applied meaningfully, and is usually between 6 and 10.

Results are produced for the DUT in two stages: (1) the vector readings for the calibration items are used to determine the calibration constants at each frequency, and (2) the vector readings for the DUT are corrected using the calibration constants. For n sets of calibration and measurement data, these readings are combined in the two-stage results process to produce n × n permutations. Care must be taken in the subsequent statistical manipulations to allow for the interdependence of these permutations. The interdependence is apparent if one considers an error in one of the calibrations; if the results were truly independent, this error would affect just one result, whereas in the new method, all n results using the calibration containing an error will be affected. The interdependence affects the choice of the number of degrees of freedom in the statistical evaluation (for example, variance calculations and the choice of Student's t-statistic used to obtain confidence intervals).

Gross errors (statistical anomalies caused by experimental blunders) can occur during both calibration and measurement processes. For example, a gross calibration error can occur by a poor connection of an air-line standard, since these items are notoriously difficult to connect properly. Such errors in calibration and measurement are detected prior to calculation using a data-validation process which examines the dispersion of all vectors collected for an item, rejecting vectors which fall outside of a predetermined range. The rejected vectors play no part in the calculation of results.

Different calibration items of the same class (such as open circuits or short circuits) are used, when available, in the multiple calibrations to allow for item-to-item differences such as surface finish and asymmetry. For the same reasons, the orientation of air-line standards is also varied for each of the calibrations.

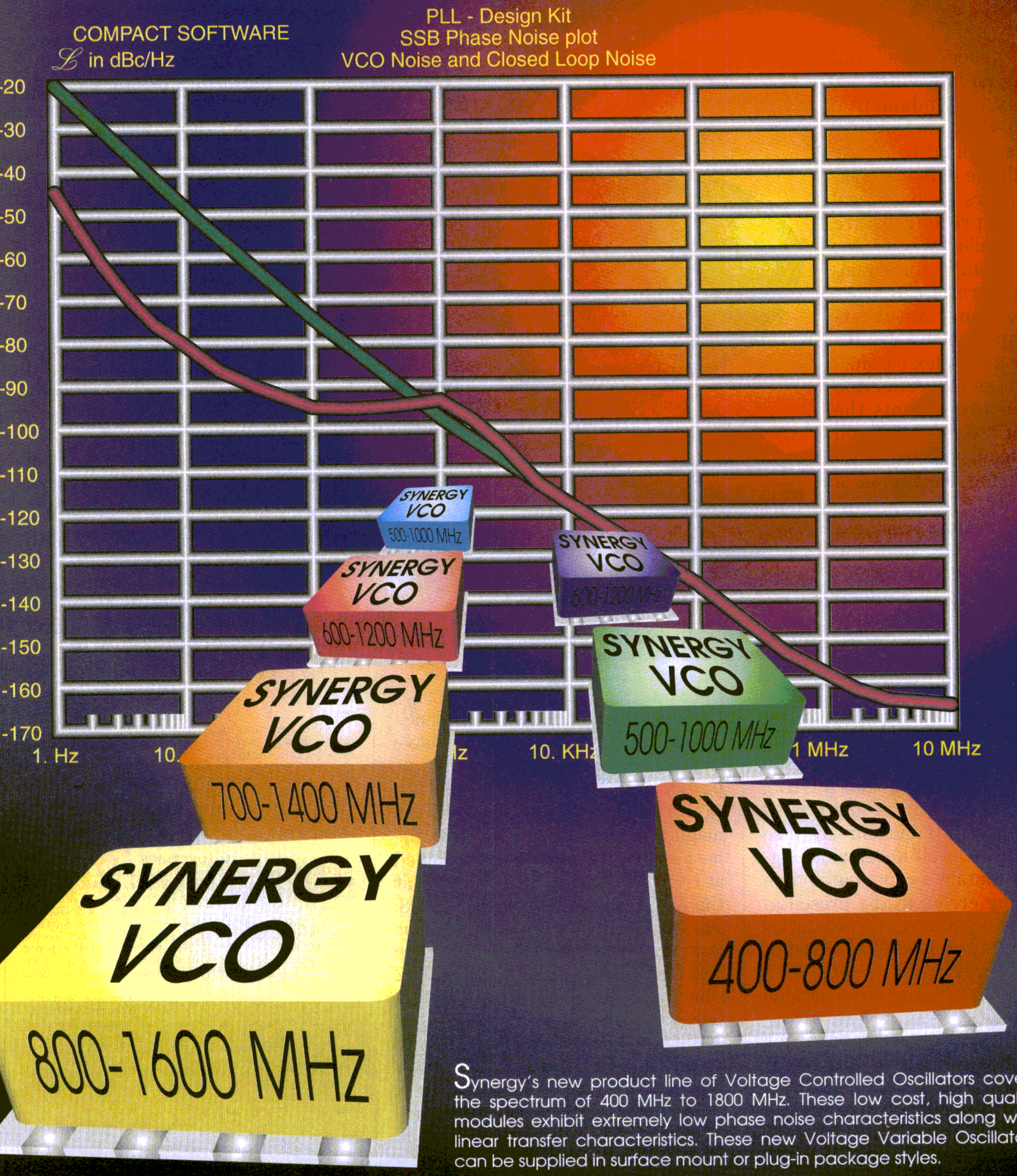
An error in the characterization of the measurement system contributes to the final uncertainty of a measurement. Parameters used in modeling calibration items (such as the dimensions and conductivity of conductors, permittivity of dielectric and source frequency) have associated contributions to the overall uncertainty, and these are treated as type B contributions.

Each such parameter is modeled, either theoretically or from experimental data, to give an expected value and estimated error. Two results are then calculated; the first using the expected value of the parameter and the second using an upper limit derived from the parameter model. The difference between these results is treated as the uncertainty contribution due to this parameter. The contributions are calculated again for each DUT.

The overall uncertainty is obtained by combining type A and type B contributions using accepted sta-

Frequency (GHz)	Magnitude		Phase (deg.)		Uncertainties	
	Mean	Uncertainty	Mean	Uncertainty	Type A	Type B
Reflection coefficients for a 50-Ω resistor						
0.1	0.00053	0.00073	+114	180	0.00011	0.00072
0.2	0.00073	0.00073	+78	180	0.00006	0.00072
0.3	0.00088	0.00073	+76	55	0.00011	0.00071
1.0	0.00150	0.00078	+26	32	0.00030	0.00071
2.0	0.00208	0.00093	–5	27	0.00049	0.00078
3.0	0.00340	0.00150	–68	26	0.00083	0.00118
Reflection coefficients for a 1-pF capacitor						
0.1	1.00001	0.00013	–3.604	0.007	0.00007	0.00010
0.2	1.00005	0.00022	–7.210	0.012	0.00008	0.00020
0.3	1.00003	0.00033	–10.807	0.018	0.00013	0.00029
1.0	1.00000	0.00110	–36.045	0.058	0.00040	0.00093
2.0	1.00000	0.00170	–72.385	0.094	0.00049	0.00161
3.0	0.99970	0.00250	–109.230	0.150	0.00124	0.00200

VCO VCO VCO VCO VCO



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VCO VCO VCO VCO VCO VCO

tistical procedures[6] and obtaining an interval about the mean. A fundamental problem with uncertainty concepts applied to ANAs is that all the data are complex numbers. Conventional statistical procedures are adapted to allow for complex data, resulting in uncertainties which form circles in the complex plane. An uncertainty expressed as a single value for a complex parameter (such as the reflection coefficient) represents the radius of a circle centered on the mean, with the circle representing the region of uncertainty.

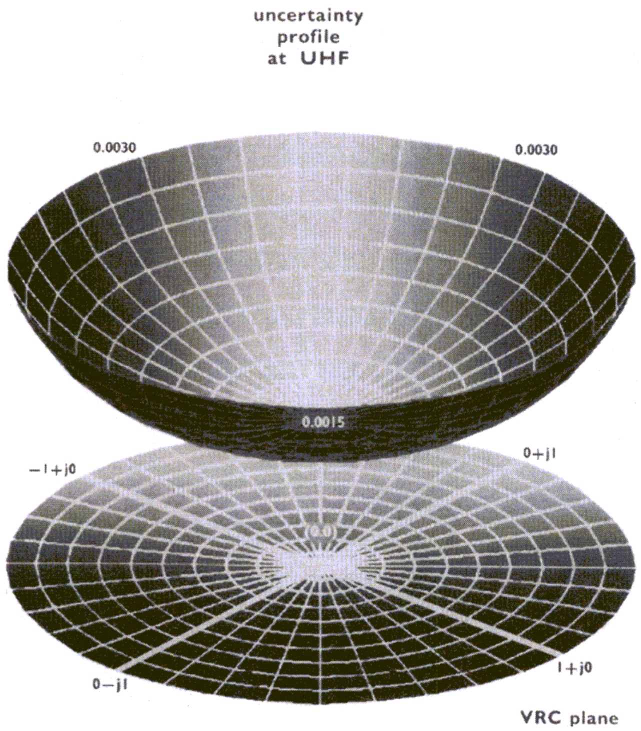
Typical results were obtained using the evaluation technique applied to an HP 8753B ANA for a nominal 50-Ω resistor and a 1-pF capacitor (see table). Both items were fitted with precision coaxial connectors. The measured voltage reflection coefficients, with respect to 50 Ω, are given at VHF (100, 200, and 300 MHz) and UHF (1, 2, and 3 GHz). The sizes of the type A and type B uncertainty contributions are also shown. The overall uncertainty figures also contain a contribution due to rounding errors in the presentation of the results. All uncertainties are quoted at a confidence level of 95 percent or higher.

Several interesting observations can be made about the size of the overall estimated uncertainties for the reflection-coefficient magnitude results. The results are a function of frequency and nominal value of the DUT, they are smaller for both items at VHF compared to UHF, and they are lower for the capacitor than for the resistor at VHF, although this is reversed at UHF. This can be explained by examining the uncertainties in the reflection-coefficient magnitude produced by DUTs over the entire complex plane at both frequency bands. This gives rise to a surface (for each band) in three dimensions representing the size of the expected uncertainties as a function of position in the complex plane.

The height of the surface above the complex plane at any point is proportional to the measurement uncertainty in the reflection-coefficient magnitude. Figure 1 shows that the best resolution (0.0005) is achieved at 1 + j and –1 + j. The uncertainty at the VHF origin is typically 0.0008. The surface in Figure 1 transforms gradually into the surface of Figure 2 as frequency is increased. Figure 2 shows that, at UHF, the best resolution (0.0015) is achieved at the origin, while the worst resolution (0.0030) occurs around the circumference of the unit circle.

The shape of the uncertainty profiles are dependent upon the method used to calibrate the ANA. These profiles were produced using short-circuit and open-circuit standards as calibration items.

It is also interesting to note that measurement uncertainties in the reflection-coefficient phase results are ±180 deg. at two VHF points for the 50-Ω resistor. This indicates that the region of uncertainty in the complex plane encompasses the origin, implying that phase information can not be discerned, which is consistent with a near-ideally-matched termination.



2. This complex-plane plot represents the uncertainty profile for reflection-coefficient measurements at UHF.

A further observation is that the majority of the reflection-coefficient magnitude measurements for the 1-pF capacitor are greater than 1, implying gain. This obvious error in the measurement is allowed for, however, since the uncertainty accompanying the measured value produces a range of suitable values (including values of less than 1).

The expected performance of the new technique as applied to an HP 8753A ANA reveals equivalent return loss of 66 dB at VHF and 56 dB at UHF. Expected return-loss performance for a nominally-matched 50-Ω load is 62 dB at VHF and 56 dB at UHF. ●●

Note

Nick Ridler works under contract to the National Physical Laboratory (NPL) and is an employee of Assessment Services Ltd., United Kingdom.

Acknowledgments

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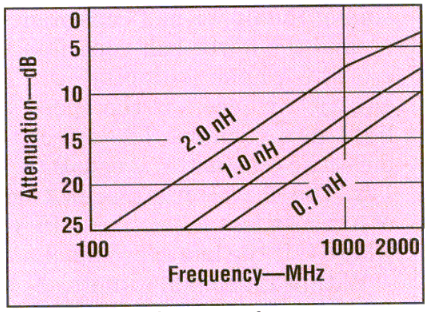
SPDT SWITCH SERVES PCN APPLICATIONS

Minimal loss, high isolation, and low cost were driving forces in the design of this battery-powered transmit/receive switch.

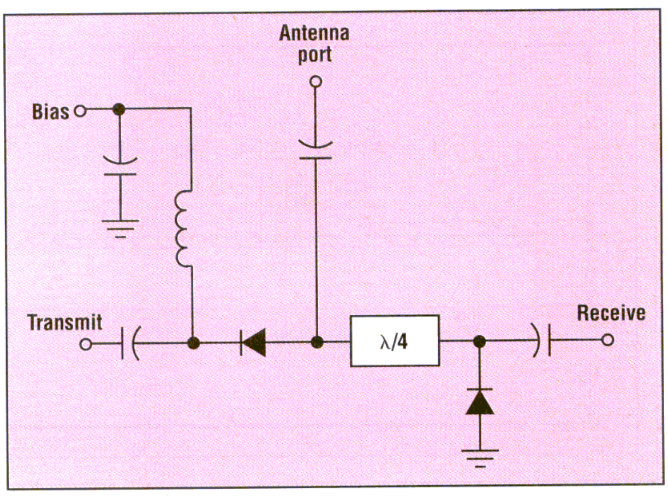
THE personal-communications-network (PCN) market promises to be huge. Hand-held terminals providing voice and data transmission in cells smaller than those used for cellular telephones are either in the design phase or undergoing trials in Europe, Japan, and the US. Various frequency bands are being used, but most of the activity will be from 1.7 to 2.0 GHz. In anticipation of those systems, a single-pole, double-throw (SPDT) transmit/receiver (T/R) antenna switch has been developed for use at 1750 MHz. Basic design concepts for the switch can be applied to other frequencies as well.

Since the switch is for battery operation, it must have low or zero current consumption in standby and receive modes, while having moderate current consumption in transmit mode. It should have high isolation in the receive arm to protect the receiver front end from damage when the transmitter is operating, and sufficient isolation in the transmit arm to isolate the receiver from variations in the transmitter's output impedance. The switch should also be small in size, inexpensive, and able to support surface-mount assembly.

Such a switch is not necessarily symmetrical. For example, 10 dB of isolation in the transmit arm is sufficient to prevent any variation in the output impedance of the transmitter (when in standby mode) from affecting the performance of the receiver. However, to protect the receiver (input power of less than +10 dBm) from being damaged by a 1-W transmitter, more than 20 dB of isolation will be required in the receiver arm. Putting numbers to these design requirements results in the following specifications: insertion loss of less than 1 dB for both the transmit and receiver arms, isolation of more than 10 dB for the transmit arm and more than 25 dB for the receive arm, return loss of greater than 15 dB for both arms, and minimum bias cur-



2. These attenuation-versus-frequency characteristics compare three different inductors shunting a 50-Ω line.



1. This transmit-receive switch is designed for low-current operation from a battery power supply.

RAYMOND W. WAUGH, Applications Engineer, Hewlett-Packard Co., Communications Components Div., 350 West Trimble Rd., San Jose, CA 95131, and **RAYMOND M. WAUGH,** Senior Engineer, ANADIGICS, Inc., 35 Technology Dr., Warren, NJ 07059.

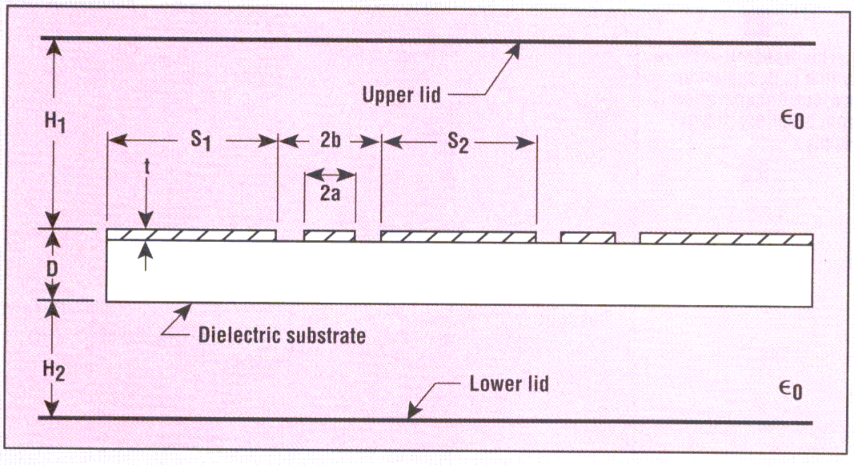
UNDERSTANDING COPLANAR WAVEGUIDE

Coplanar waveguide (CPW) has all conducting elements on the same side of a suspended substrate. The CPW transmission line consists of a center strip conductor with semi-infinite ground planes running in parallel on both sides, separated from the center conductor by a width of exposed dielectric material (see figure). The characteristic impedance and effective dielectric constant are analyzed by modeling the slots between the conductor as magnetic walls. Assuming a metallization thickness of zero, the line capacitance per unit length can be computed as the sum of the upper-half capacitance, ϵ_o, and the lower-half capacitance, ϵ_r. The phase velocity, v_p, is $c/(\epsilon_{eff})^{0.5}$, where c is the speed of light in a vacuum. The effective dielectric constant, ϵ_{eff}, equals $(\epsilon_r + 1)/2$. The characteristic impedance of a transmission line, Z_0, is $1/Cv_p$, where C is the line capacitance.

Within reasonable limits, Z_0 is unaffected by substrate thickness and is solely dependent upon the ratio 2a/2b. Parameter ϵ_{eff} is relatively independent of Z_0, unlike microstrip. The first assumption is true provided that substrate thickness D is greater than line spacing 2b. With ground plane S_1 greater than line width 3b, it can be considered semi-infinite and neglected. Reducing the width of the ground planes leads to increases in Z_0. Upper and lower metal covers can be neglected provided that their distances from the substrate are $H_1 > 4b$ and $H_2 > 3b$. If not, the covers will lower Z_0. Coupling between lines is dependent upon the width of the ground plane between them. A spacing of $S_2 > 5b$ avoids coupling between parallel conductors.

CPW offers several advantages over microstrip, including low radiation loss and shunt connections that are easy to make as series connections. CPW does have higher ohmic losses than microstrip due to the concentration of currents near the metal edges, although this has negligible effects at RF.

When laying out CPW designs, all ground planes should be kept at the same potential, which can be done through the use of proper spacing and conductive bridges. Anytime there is an intersection of conductors, or open or short-circuit stubs, the conductive bridges can ensure that the ground planes on either side of the center conductor remain at the same potential. The same is true for bends in transmission lines. The best approach is to break the line at the bend and allow metallization on the substrate to connect the ground planes while joining the conductors with a conductive bridge. For CPW on plastic laminate boards such as FR-4, conductive bridges are easily formed with plated through holes to make connections to a small etched line on the underside of the board. ••



rent for the transmit arm and zero bias current for the receive arm.

This set of specifications formed the design goal for a recently-developed SPDT T/R switch (Fig. 1). When zero (or a small positive) voltage is applied to the bias port, both PIN diodes are in the high-resistance (reverse-bias) state. This isolates the transmitter from the antenna and connects the receiver to it.

The application of a negative voltage to the bias port causes current to flow through both diodes. This puts the diodes into their low-resistance (forward-bias) state, connecting the transmitter to the antenna and isolating the receiver. Such a design approach, using a quarter-wavelength section to transform the short circuit formed by the shunt diode to an open circuit at the common junction, will operate only over a limited bandwidth. However, good performance will be obtained over a 20-to-30-percent bandwidth, which is more than sufficient for most applications. Having the diodes in series in the bias circuit conserves current when compared to operating them in parallel.

PERFECTING PLASTIC

PIN-diode switches, operating in the frequency ranges of HF through millimeter waves, have been produced for years. However, in an application such as this one, cost considerations require that plastic-packaged SOT-23 surface-mount diodes be used in some type of planar transmission line. Unfortunately, SOT-23 package leads and bond wire add approximately 2.0-nH parasitic inductance to the diode. Even an ideal diode ($R = 0\ \Omega$) with this much inductance will produce less than 5 dB of isolation when shunt-mounted in a 50-Ω system (Fig. 2).

The HSMP-4890 PIN diode overcomes excessive SOT-23 parasitic inductance by using two leads for the anode contact (Fig. 3). This diode is a special low-inductance variation of the standard HSMP-3890 series. Measured inductance is approximately 1.0 nH (half the usual value) with an improvement in isolation compared to a conventional diode. However, isolation in the PCN band

is still less than 10 dB, and other methods must be sought to bring the receiver-arm isolation up to the required design value.

Two circuit-design "tricks" can be used to extract sufficient isolation from the shunt HSMP-4890 diode. The first is to substitute coplanar-waveguide (CPW) transmission line for the familiar microstrip.[1-6] This planar transmission medium (see "Understanding coplanar waveguide") offers the advantage of having the ground plane on the same (top) surface of the board as the conductor. When the HSMP-4890 is mounted such that it straddles the CPW (Fig. 4), the availability of ground potential within 0.006 in. (0.15 mm) of both sides of the center conductor reduces the parasitic inductance of the HSMP-4890 to about 0.7 nH. An ideal shunt diode with this value of inductance produces more than 10 dB of isolation in the PCN band. Thus, CPW was chosen over microstrip for the design of this switch.

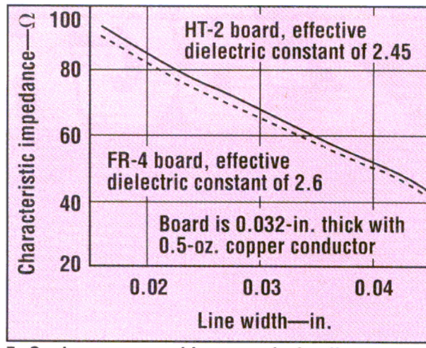
In order to ensure that an SOT-23 package can straddle CPW, the sum of the line width plus both gap widths must be less than 0.055 in. (1.39 mm). A design curve[7] for CPW on HT-2 PCB material (see "Printed-circuit-board material") reveals why this material was selected for the SPDT switch over FR-4 (Fig. 5).

The second circuit approach which can be used to realize sufficient isolation in the switch's receiver arm is to use two shunt diodes separated by a 90-deg. electrical length. If a single shunt diode produces 11-dB isolation at 1.75 GHz, then two in cascade with 90 deg. between them will exhibit (2 × 11) + 6 = 28 dB. At frequencies below the PCN band, a lumped-element, phase-delay circuit (Fig. 6) offers low losses and compact size. However, as frequencies approach 2 GHz, the losses in inductors (and, to a lesser extent, capacitors) become excessive, making quarter-wavelength transmission lines more attractive.

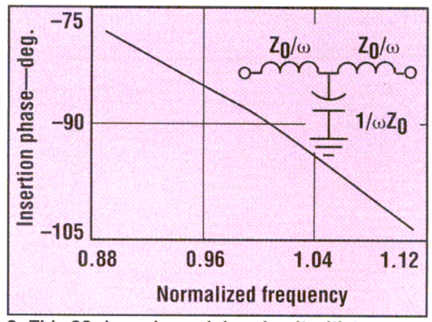
PRODUCING A PROTOTYPE

Using this combination of diode and circuit design elements, a prototype SPDT T/R switch was designed, laid out, and fabricated (Fig. 7). At frequencies above 1 GHz, care must be taken to avoid unnecessary losses in any circuit. Before building the prototype, the initial design was modelled and analyzed using the linear simulator MMICAD from Optotek (Kanata, Ontario, Canada). In particular, it was found that the distance from series diode D1 to the switch common junction had a significant effect upon the reverse-bias insertion loss in the receive arm. This distance was, therefore, kept to an absolute minimum. An air-core solenoid was selected for L1, in that it provided 50-nH inductance with high quality factor (Q) and low cost.

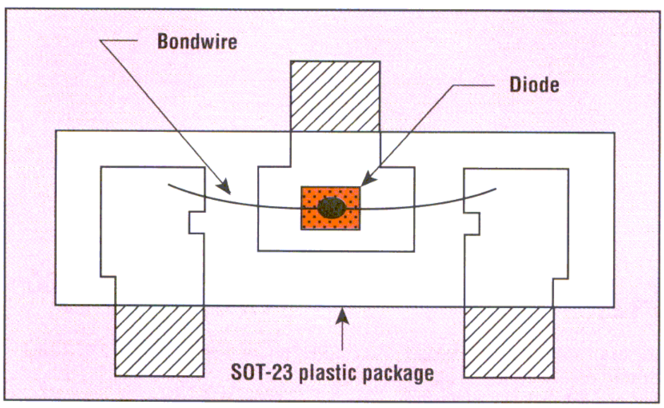
Since this is a surface-mount design, chip capacitors were selected for bypassing and bias blocking. However, it was found that many chip capacitors which show good performance at VHF frequencies can exhibit losses of 0.2 to 0.3 dB each when they are used for bypass and blocking devices in the PCN band. Several different types were characterized before the final components were chosen. In order to save board space, the quarter-wavelength 50-Ω line between D2 and D3 was folded



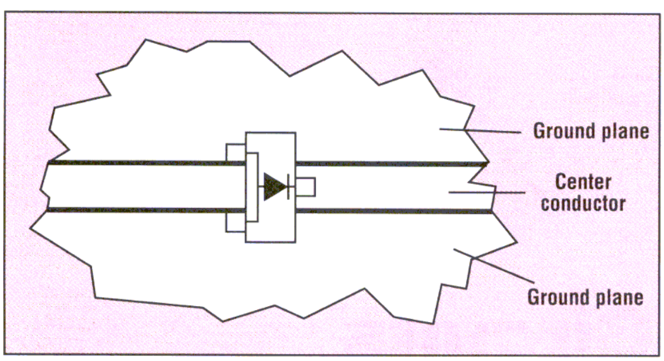
5. Coplanar-waveguide transmission lines yield the following impedance values on two different PCB materials.



6. This 90-deg. phase-delay circuit with two cascaded diodes provides low losses and compact size below 2 GHz.

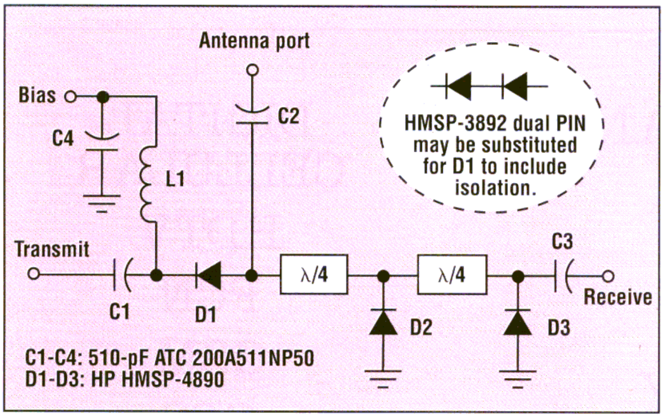


3. The HSMP-4890 diode achieves low inductance with two leads for the anode contact.



4. The HSMP-4890 diode is mounted in this manner when shunting a coplanar-waveguide transmission line.

CIRCLE NO. 302



7. A prototype SPDT T/R switch incorporates SOT-23 PIN diodes and 510-pF capacitors with coplanar-waveguide transmission lines.

upon itself. The switch's final width and length are 1.6 and 1.8 in. (4.06 and 4.57 cm), respectively.

CPW brings with it a number of layout requirements which are unique. It is essential that the grounds on both sides of the conductor are maintained at the same potential. The two anode leads of D2 and D3 serve the purpose of providing a bridge between ground planes in the switch's only long transmission line (Fig. 8). The common junction deserved some special attention because it is a tee junction. Three via holes were used to connect the three ground surfaces to a triangular interconnecting patch on the otherwise blank underside of the board.

Alternatively, the ground plane could have been interconnected on the top surface and the conductors interconnected on the underside. This need to maintain symmetry in a CPW circuit is illustrated by the use of a pair of capacitors to realize the bypass C4. If only one is used, touching the bias conductor at the input will induce ripples in the passband response of the switch.

Finally, any circuit realized in CPW must, at some point, connect with conventional microstrip. A straightforward transition between the two lines employs twin via holes to connect the two overlapping ground planes.

The prototype switch was fabricated and fitted with 142-0701-801 SMA connectors from E.F. Johnson (Waseca, MN). These end-launch connectors have ground fingers in the same plane as the connector center conductor, making them ideal for use with CPW.

INCREASING ISOLATION

Before final measurements were made, an HSMP-3892 PIN-diode pair (two diodes connected in series in a single SOT-23 package) was substituted for series diode D1. This was done to increase the transmitter-arm isolation by halving the effective reverse-bias capacitance of D1. The layout of the circuit board allows physical interchangeability between the HSMP-3892 and the HSMP-4890 products.

Swept-frequency measurements were performed on the prototype switch, showing return loss at 1750 MHz of greater than 15 dB at all ports for both bias conditions (+5 VDC and 20 mA). Receiver-arm isolation is 28 dB at the design frequen-

PRINTED-CIRCUIT-BOARD MATERIAL

Several printed-circuit-board (PCB) materials commonly used for circuits such as the SPDT T/R switch include FR-4 and fiberglass reinforced PTFE (Teflon). The former provides good mechanical stability and durability at low cost, but suffers high losses and a dielectric constant which is poorly controlled and strongly frequency-dependent. The latter exhibits very good RF properties, but is expensive, suffers from poor mechanical stability, and cannot survive certain surface-mount-technology (SMT) processing steps.

The proprietary HT-2 board material from Hewlett-Packard Co.'s Printed Circuit Operation [Cupertino, CA; (408) 447-6114] provides durability and high temperature performance which are actually superior to FR-4, with a controlled dielectric constant (dielectric constant of 4.3) and a loss tangent which is one third less than that of FR-4. These properties make the proprietary material ideal for microstrip circuits operating at frequencies to 6 GHz and beyond.

To compare the performance of this material with FR-4 in CPW, two experimental 50-Ω lines, with 3.6-in. (9.14-cm) length, were fabricated and tested. Cross-section dimensions were identical in both cases, with board thickness of 0.032 in. (0.81 mm), line width of 0.043 in. (1.09 mm), and gap width of 0.006 in. (0.15 mm). Insertion loss and return loss were measured from 10 MHz to 8 GHz using model 142-0701-801 SMA connectors from E.F. Johnson.

When the losses due to connector mismatch were subtracted, the resulting curve of resistive loss versus frequency was linear in both cases. Using an effective dielectric-constant value of 2.70 for the FR-4 material and 2.57 for the HT-2, the loss versus frequency curve was found to correspond to constant values of loss per wavelength (λ). For the HT-2 line, that constant was 0.5 dB/λ, much less than the 0.8 dB/λ of the FR-4 line. It is interesting to note that similar measurements on microstrip lines with heights of 0.032 in. (0.81 mm) have resulted in identical values of loss/wavelength, even though the higher value of effective dielectric constant on microstrip results in wavelengths which are shorter than those in CPW.●●

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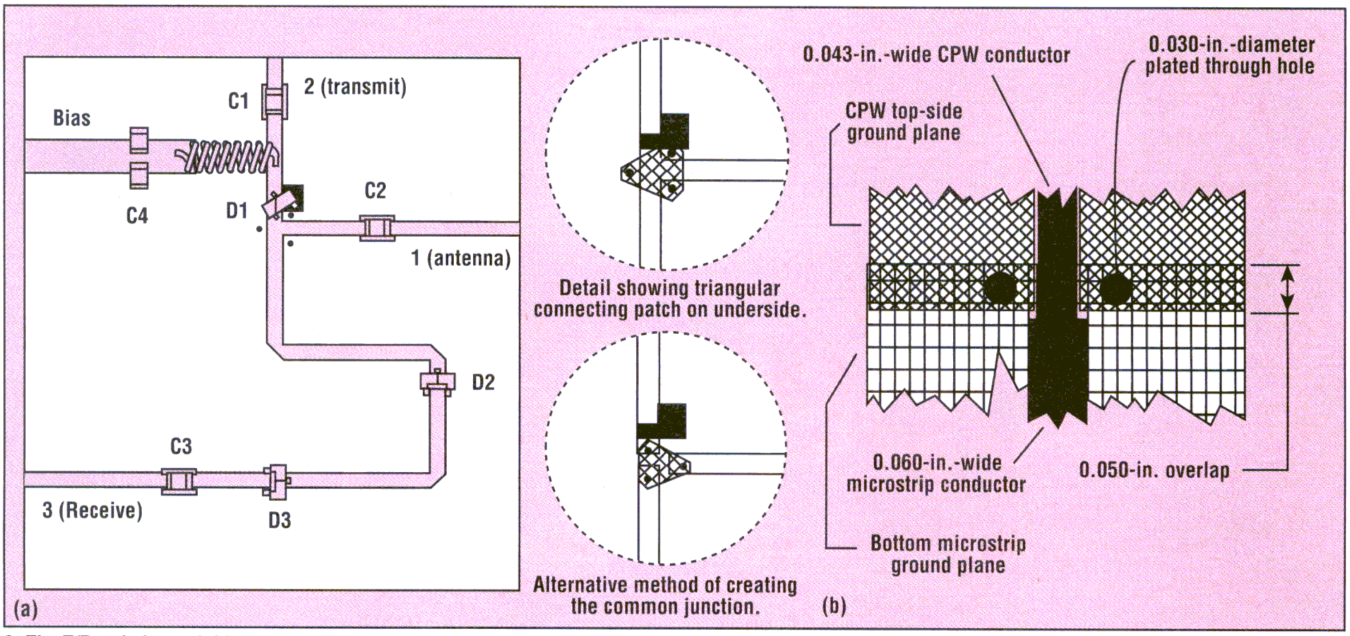
CIRCLE NO. 249

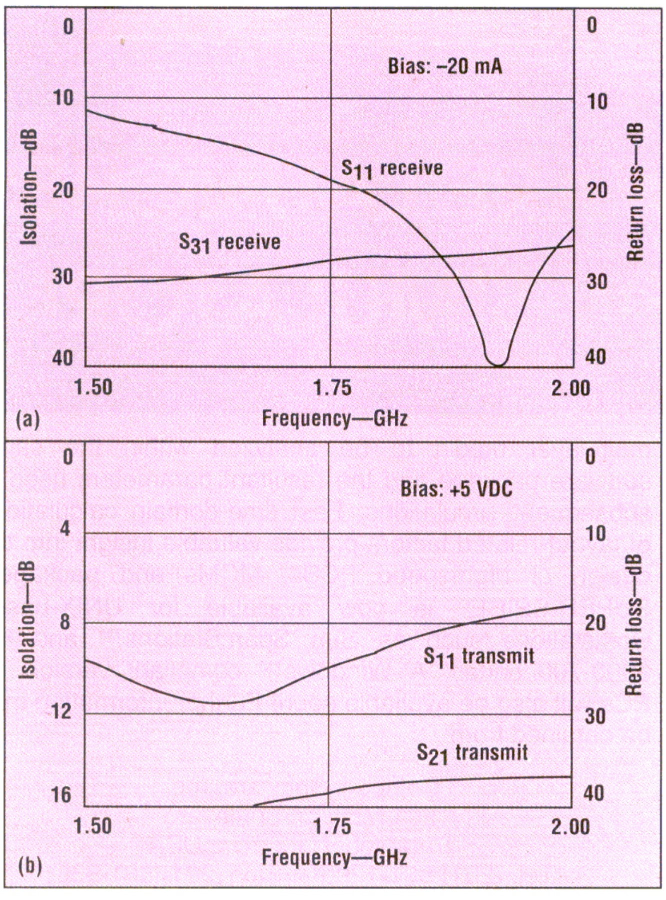
T/R SWITCH



8. The T/R switch was laid out on proprietary HT-2 PCB material (a) with microstrip-to-CPW transitions made via plated through holes (b).

cy, while the transmit-arm isolation is 15 dB (Fig. 9). Insertion loss for the same two arms is 0.8 and 0.7 dB, respectively.

The measured value of transmitter-arm isolation was well above the 10 dB originally specified. Use of the HSMP-4890 (or standard product HSMP-3890) for the HSMP-3892 dual diode in the D1 position would result in a reduction in isolation to approximately 12 dB, which would be satisfactory for many applications. This might be considered by those manufacturers who wish to minimize the number of different diode part numbers kept in stock.●●



9. Swept-frequency measurements reveal the return loss (S_{11}) and isolation of the T/R switch receive (a) and transmit (b) arms.

Note

Work by Raymond M. Waugh was performed while at Electrodyne Systems Corp. (S. Hackensack, NJ). Yes, the authors are related, as father and son.

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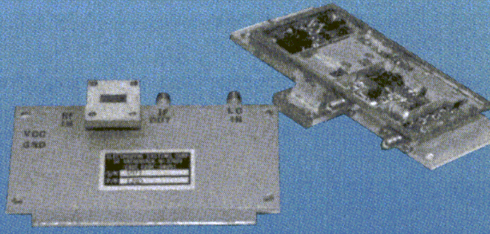

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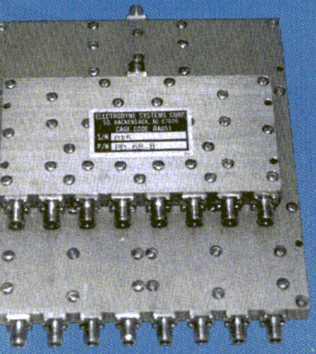

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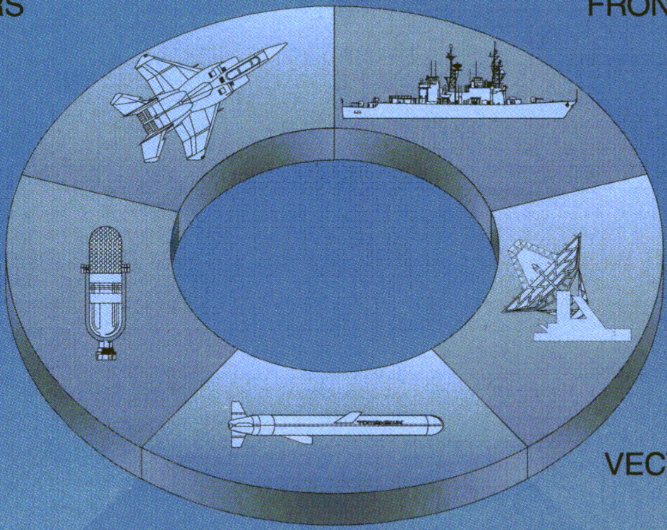

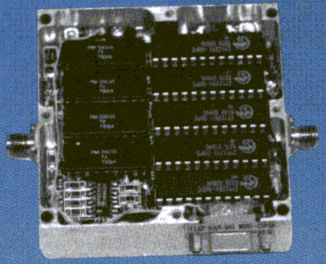

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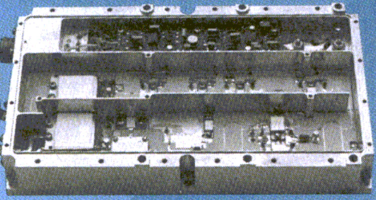
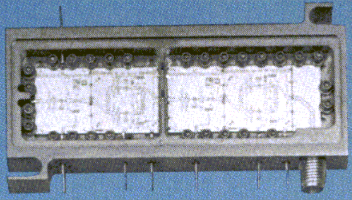


HIGH POWER AMPLIFIERS



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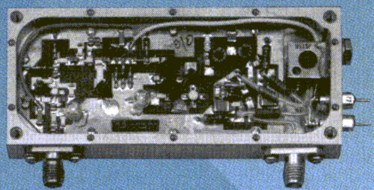

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ANALYZE THIRD-ORDER IMD IN POWER AMPLIFIERS

A simplified mathematical analysis method is applied to an unequal-tone power amplifier.

INTRODUCTION of the 1992 Cable Act has generated considerable interest in defining the performance of solid-state power amplifiers (SSPAs) operating with unequal tones. By extending a simplified mathematical analysis technique for nonlinear amplifiers, third-order intermodulation distortion (IMD) can be determined for an unequal-tone amplifier operating at 2.5 GHz with 50-W output power.

Video transmission normally requires the use of two signals (video and audio) which have unequal levels and are closely spaced together. When two such signals are fed into a power amplifier, the resultant in-band third-order IMD can create problems in terms of meeting the Federal Communications Commission's (FCC) mask for television transmitters.

This is similar to the problem that appears in digital, line-of-sight, radio-transmitter power amplifiers, where the sidebands due to third-order IMD must be controlled. Predistortion and linearization are possible ways to reduce the effect of the sidebands.

A simplified mathematical analysis of a nonlinear amplifier indicates that the third-order in-band product variation with the fundamental is 3:1.[1] This analysis can be extended to show that two unequal tones (A and B) operating at frequencies w_1 and w_2, respectively, vary as follows:

$$2w_1 - w_2 \text{ varies 1:1 with B and 2:1 with A} \quad (1a)$$

$$2w_2 - w_1 \text{ varies 2:1 with B and 1:1 with A} \quad (1b)$$

The analysis begins by considering a nonlinear two-port network that can be approximated by only the first three terms:

$$e_o = k_1e_1 + k_2e_1^2 + k_3e_1^3 \quad (2)$$

where:

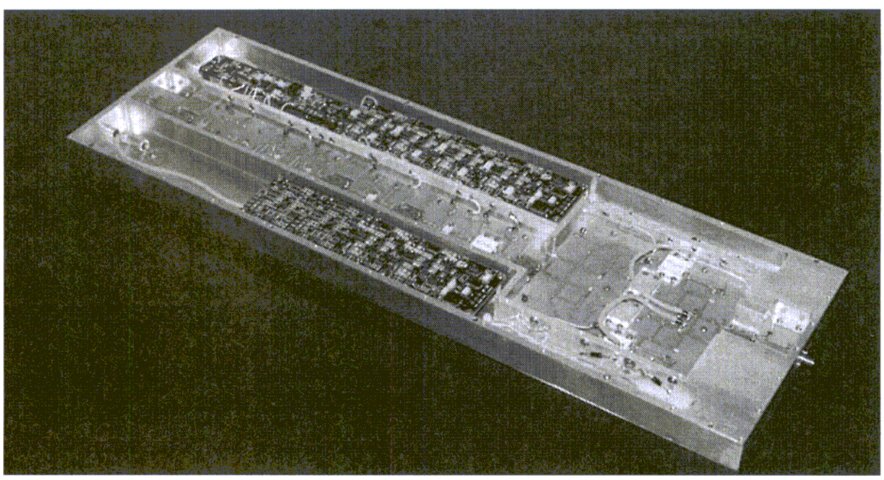
e_o = the output voltage,
e_1 = the input voltage, and
k_1, k_2, and k_3 = constants defining the nonlinear two-port network.

e_1 is given by:

$$e_1 = A \cos w_1t + B \cos w_2t = B[(A/B)c_1 + c_2] \quad (3)$$

Consequently:

$$e_o = k_1B[(A/B)c_1 + c_2] + k_2B^2[(A/B)c_1^2 + c_2^2 + 2(A/B)c_1c_2] + k_3B^3[(A/B)^3c_1^3 + c_2^3 + 3(A/B)c_1c_2^2 + 3(A/B)^2c_1^2c_2] \quad (4)$$



This solid-state power amplifier provides 50-W output power from 2.5 to 2.7 GHz.

RAFFI ANTEPYAN, President, Wavesat, Inc., 5607 Ch. St. Francois, Montreal, Quebec, Canada H4S 1W6; (514) 956-0817, FAX: (514) 956-0670.

IMD ANALYSIS

The portion of e_o containing the first- and third-order terms can then be written as:

$$e_o = [k_1A + (3/4)k_3A^3 + (3/2)k_3AB^2]\cos w_1t + [k_1B + (3/4)k_3B^3 + (3/2)k_3A^2B]\cos w_2t + (3/4)k_3A^2B[\cos \times (2w_1 - w_2) + \cos(2w_1 + w_2)] + (3/4)k_3AB^2 \times [\cos(2w_2 - w_1) + \cos(2w_2 + w_1)] \quad (5)$$

Therefore, the output for the fundamental and third-order in-band $(2w_1 - w_2)$ and $(2w_2 - w_1)$ products varies as shown in Eq. 1.

ANALYSIS EXAMPLE

The analysis can be further illustrated using an amplifier example. The SSPA operates at its 1-dB compression point (P_{1dB}) with two equal-tone third-order intermodulation points of about 20 dB (following Ha's analysis).

The result of this simplified analysis was compared to measurements taken on a 50-W, 2.5-GHz SSPA from Wavesat (see figure). The amplifier front end consists of four 16-W devices in parallel using a low-loss, four-way divider/combiner. It is driven by a five-stage, 12.5-W amplifier. For the high-power devices, both the model NES2527-20B-4 field-effect transistor (FET) from NEC (Santa Clara, CA) and the FLM2527L-20 FET from Fujitsu (San Jose, CA) were tested, with the two devices producing comparable results.

The GaAs power FETs' measured IMD is slightly different from the distortion predicted by the preceding analysis. This performance depends largely on the manufacturing method employed and can have a variation greater than 3:1 for a given power range.[2] This feature is particularly useful when the amplifier is "backed off" from its P_{1dB} at a level where the IMD displays such behavior.

Care should be taken in the amplifier design to avoid having the driver-stage distortion dominate the overall IMD when the amplifier is backed off. Harmonic-balance simulators are useful for analyzing the performance of a cascaded amplifier. However, since power-FET nonlinear models are not readily available, an accurate model must be created that fits the measured IMD data.●●

References

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For further reading

R. Schneiderman, "Vendor Picture Brightens in Wireless Cable Television," *Microwaves & RF*, September 1993, p. 42.

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HIGH-POWER – SOLID STATE TWT REPLACEMENTS

FREQUENCY (GHz)	P_{SAT} (dBm)	P_{1dB} (dBm)	I_D@+15V (A)	MODEL
5.9 – 6.4	51	50	50	CHN – 81110
14 – 14.5	50	49	50	CJQ – 81110
8 – 12	42	41	25	CHJ – 52310
16 – 18	45	44	35	CJJ – 32616

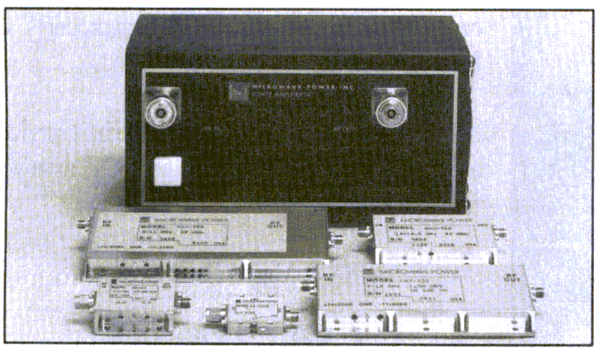
However, thanks to our proprietary monolithic ceramic technology, we can also provide the highest power outputs in the less common, or much broader bands, where internally matched are not available. Indeed, our solid gold vias, placed directly under the GaAs FETs, allow for optimal electrical matching and the best possible heat sinking. In the following table we have listed examples of both type. In addition, we have included a couple of examples taken from our family of low noise, medium power amplifiers, which are especially designed for low-distortion application in telecommunications, and are available in either narrow or medium bands. Since in many cases the same performance is available in a number of different frequency bands, we have listed, next to a given model, various other bands where a similar (or in some cases identical) performance can be obtained.

BROADBAND – *FOR INSTRUMENTATION AND ECM*

FREQUENCY (GHz)	P_{SAT} (dBm)	P_{1dB} (dBm)	I_D@+15V (A)	MODEL
6 – 9	35	34	2.5	LHI – 527
6 – 16	34	32.5	5.5	LHJ – 292
6 – 18	31.5	30.5	2.5	LHJ – 121
6 – 20	30	28.5	2.5	LHJ – 114
7 – 11	39	37.5	12.0	LHJ – 591
8 – 12	36	35	5.0	LHJ – 553

NARROW BAND – *FOR RADAR AND TELECOMMUNICATION*

FREQUENCY (GHz)	P_{SAT} (dBm)	P_{1dB} (dBm)	I_D@+15V (A)	MODEL	OTHER BANDS WITH SAME PERFORMANCE (GHz)
7.7 – 8.5	41	40	8.0	LIN – 811	5.3 – 5.9, 5.9 – 6.4, 6.4 – 7.2, 7.1 – 7.7
10 – 12	38.5	37.5	7.5	LJJ – 571	5 – 7, 6 – 8, 8 – 10
14.0 – 14.5	40	39	8.0	LJQ – 811	8.5 – 9.6, 9.0 – 10.5, 10.7 – 11.7, 12.7 – 13.2
16 – 18	37	36	8.0	LJJ – 393	13 – 15, 14 – 16
18.1 – 18.6	35	34	4.5	LJJ – 362	17.3 – 17.7



LOW NOISE / MEDIUM POWER – *FOR TELECOMMUNICATION*

FREQUENCY (GHz)	NF (dB)	P_{1dB} (dBm)	I_D@+15V (A)	MODEL	OTHER BANDS WITH SAME PERFORMANCE (GHz)
7.8 – 8.4	2.5	23	0.2	NHQ – 621	5.0 – 5.5, 5.4 – 6.0, 5.9 – 6.4, 7.2 – 7.8
14.0 – 14.5	3.0	23	0.2	NJQ – 627	8.5 – 9.6, 9.5 – 10.5, 10.9 – 12.2, 12.7 – 13.2
19.2 – 20.2	3.5	22	0.2	NJS – 613	18.3 – 19.4

Most of these amplifiers can be ordered in three different versions: 1. In a small case, as an amplifying module to be incorporated in systems where regulated and correct voltages are available. 2. In a larger case, including a power conditioner which regulates the required voltages and provides for their correct sequencing. This is the most popular version. Generally, it requires a positive and a negative voltage, although a single supply option is available for most models. 3. In a table-top version, including power supply, ready to be plugged in the wall (the so-called Amplifier Set or AS-version). Whichever version you choose, you will get fast delivery and competitive price! We have recently moved to a new and larger facility, but our phone and fax numbers have remained unchanged:

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Photo courtesy of Boeing Helicopters

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DIGITAL MEDICAL MICROWAVE INDUSTRIAL

Employing RF filters

Improved manufacturing processes permit the production of compact distributed-constant filters operating in the UHF and VHF bands, where they provide lower insertion loss and higher reliability than their lumped-constant counterparts. The November 1993 issue of Microlab Memo, titled "High-Power Rod-and-Bead Filters," describes a line of distributed-constant "rod-and-bead" filters designed with the company's proprietary computer-aided-design (CAD) program.

For instance, the rod-and-bead filters feature symmetrical shapes and minimal cross sections at RF frequencies, thus preventing launching and propagation of higher-order waveguide modes. This results in a more controlled and predictable stopband loss than that obtained with lumped-constant filters.

By designing rod-and-bead filters to pass only the band of interest rather than all frequencies from DC to a specified cutoff frequency, they require fewer sections and employ smaller inductors.

In addition, the novel filters employ a larger outer rod diameter and smaller inner diameter, resulting in an increased inductance per unit length. Further length reduction is obtained from their relatively long beads and short rods.

A copy of the note is available from: **Microlab/FXR, 10 Microlab Rd., Livingston, NJ 07039-1682; (201) 992-7700, FAX: (201) 992-0513.**

CIRCLE NO. 194

Using oscilloscopes

Oscilloscopes are among the most useful instruments for time-domain analysis of electrical signals. The features and applications of these analysis tools are outlined in a bulletin titled "The XYZs of Oscilloscopes."

Oscilloscopes can be classified into two types: analog and digital. Analog scopes apply the voltage being measured to an electron beam moving across the screen. The voltage deflects the beam up and down proportionally, thus tracing the waveform on the screen. Digital scopes sample the waveform under test and use an analog-to-digital converter (ADC) to transform the measured voltage into digital data, which is used to reconstruct the waveform on the screen.

Digital oscilloscopes use either of two methods to measure test waveforms. In real-time sampling, the scope measures a few sample points in a single pass and then uses interpolation to obtain an estimate of the waveform. In equivalent-time sampling, waveform information is obtained in several sampling repetitions, so a picture of the waveform is built over a period of time.

The choice of an oscilloscope probe can also influence measurement accuracy. Passive probes usually provide some degree of attenuation and are used to minimize circuit loading. Active probes provide amplification or some other type of processing of the test signal before it reaches the oscilloscope. Current probes are used to directly observe current waveforms (rather than voltages).

While the wide variety of oscilloscope types offer a broad range of user controls, the handbook outlines some of the more popular scope controls. For instance, display controls are used to adjust the trace brightness, focus, and alignment with the screen's horizontal axis. Vertical controls are employed to tune the trace's vertical position and scale factor. In addition, some scopes include controls that set the input coupling, limit the measurement bandwidth, and add or subtract waveforms. Horizontal controls are used to adjust the waveform's position, time base, or magnification. Trigger controls are employed to stabilize repeating traces or to capture one-shot waveforms.

Since oscilloscopes' vertical and horizontal scales represent voltage and time, respectively, these parameters form the basis of all scope measurements. For instance, by gauging the amount of time a pulse takes to move from a low voltage to a high voltage, the pulse's rise time can be obtained. If the scope's horizontal-control section has an XY mode, an input signal (rather than the time base) can be displayed on the horizontal axis. The shape of the resultant trace (which is known as a Lissajous pattern) can then be used to determine the phase difference between the input and test signals.

For a copy of the handbook, contact: **Tektronix, Inc., P.O. Box 500, Beaverton, OR 97077-0001; (800) 426-2200.**

CIRCLE NO. 195

Deciphering noise

Noise in electronic circuits can be divided into three categories: transmitted noise, which is received with the desired signal; intrinsic noise, which originates within devices forming the circuit (i.e., shot noise); and interference noise, which is picked up from outside the circuit. The causes of interference noise are overviewed in application note AN-346, titled "Understanding Interference-Type Noise," which is included in Analog Devices' Applications Reference Manual

Interference noise is produced by a wide range of sources. For instance, noise can be generated from an impedance that is common to several circuits. The origin of this noise can often be determined from its repetition rate, since the noise and its source are synchronized. Another source of interference noise is capacitive coupling. This is often produced when signals with fast rise/fall times or high-frequency content are in close proximity to high-impedance circuits.

Strong magnetic fields, such as those found near machinery or power transformers, produce coupling that results in interference noise. In addition, interference noise can be produced from high-voltage transients in inductive circuits, such as relays or solenoids.

A copy of the note can be obtained by contacting: **Analog Devices, One Technology Way, P.O. Box 9106, Norwood, MA 02062-9106; (617) 329-4700, FAX: (617) 326-8703.**

CIRCLE NO. 196

COVER FEATURE

TEST SET SPEEDS NPR MEASUREMENTS

This self-contained instrument characterizes a wide range of communications amplifiers under multiple-signal conditions.

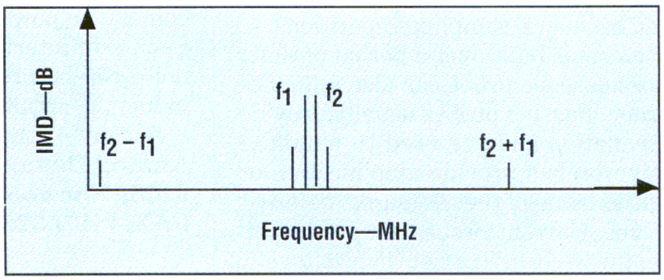
AMPLIFIER linearity is a key parameter in wireless communications systems. The low-noise amplifier (LNA) in a hand-held receiver and the power amplifier in base stations are both loaded simultaneously with a multitude of carriers. These many carrier signals generate intermodulation distortion (IMD) in the amplifiers and cause spectral regrowth. Fortunately, the UFX-NPR test set from NOISE/COM, Inc. (Paramus, NJ) helps characterize these amplifiers under such conditions with automatic noise-power-ratio (NPR) measurements.

IMD manifests itself in two primary ways. In a receiver LNA, adjacent-channel signals cause in-band distortion products. In a transmitter power amplifier, distortion of the primary signal will spread the signal power and cause interference in adjacent channels—a phenomenon known as spectral regrowth. Both cases are closely related and are functions of amplifier loading. NPR tests reproduce these effects and accurately determine an amplifier's performance under different loading conditions. In the UFX-NPR test set (Fig. 1), the device under test (DUT) is loaded with white noise to emulate a situation with many simultaneous signals.

When two uncorrelated tones of equal power levels are simultaneously present at the input of a DUT, they may at times add in-phase and create peak voltages that are 2 ($2^{0.5}$)

BENT HESSEN-SCHMIDT, Marketing Manager, NOISE/COM, Inc., E. 49 Midland Ave., Paramus, NJ 07652; (201) 261-8797.

1. The UFX-NPR test set incorporates a white-noise generator to emulate multi-signal conditions.



2. Test tones f_1 and f_2 generate intermodulation products in ranges that are above and below the original signals.

NPR TEST SET

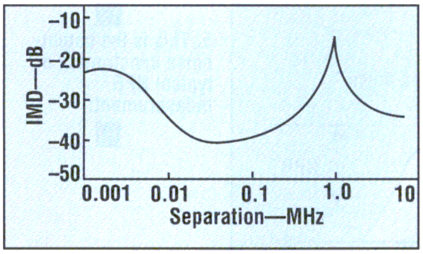
times the average power of each of the individual signals. The ratio of the peak power to the RMS power of the combined signal is called the crest factor. For the above example with two tones, this is $20\log[2(2^{0.5})/(2^{0.5})] = 6$ dB. When, as in many mobile-telephone systems, n uncorrelated signals of equal level are simultaneously present, the crest factor is $20\log[n(2^{0.5})/(n^{0.5})]$ dB, or $10\log(2n)$ dB.

According to the central-limit theorem, the resulting voltage approaches a Gaussian distribution function when many uncorrelated signals are added, provided that none of the signals dominate the sum. A DUT will perform differently when loaded with many signals, as opposed to just two signals.

True white noise, which is employed in the UFX-NPR test set, covers a frequency range of interest continuously, unlike discrete signals. This is important because the spectral regrowth and the amplitude of the intermodulation products are strongly dependent upon the frequency spacing of the test signals and the DC properties of the DUT.[1]

In the case of two tones, f_1 and f_2, applied to a DUT, third-order intermodulation products will be generated at $2f_2 - f_1$ and $2f_1 - f_2$. However there will also be second-order intermodulation products at $f_2 + f_1$ and $f_2 - f_1$ (Fig. 2).

The $f_2 - f_1$ second-order intermodulation product falls close to DC. The DC bias for the DUT is often applied through a circuit having a lowpass filter response. The $f_2 - f_1$ product may therefore be rejected by this lowpass filter response or by any



3. The level of IMD can be plotted as a function of the separation between the two test tones.

resonances in the bias circuitry. The energy which would normally have been present in the $f_2 - f_1$ product must be transferred and added to the amplitudes of the other intermodulation products. These will be strongly dependent upon the spacing of the input signals, f_1 and f_2 (Fig. 3). In the UFX-NPR, the white-noise test signal automatically fills out all spacings between f_1 and f_2, thus all combinations of carrier frequencies are taken into account and a true worst-case measurement is made.

Third-order IMD products always fall above and below the frequencies of the test tones, which is why spectral regrowth causes interference in the adjacent channels. The NPR test measures the amount of IMD power between the two frequency ranges of white Gaussian noise.

If the upper-side spectral regrowth of the two frequency ranges are considered to be identical and the two lower sides are also identical, then the NPR is the measurement of the total spectral regrowth from one of the ranges. The measurement of NPR versus input noise power, or loading, can, in addition to determining the compliance with spectral-regrowth specifications, be used to define the optimum operating point for maximum signal-to-noise ratio.

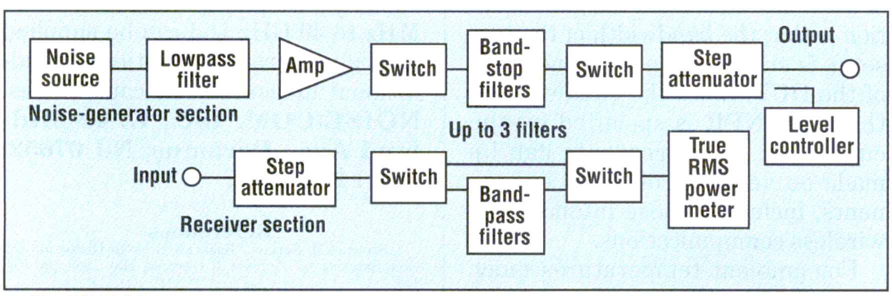
Within the UFX-NPR test set, an internal generator applies an accurate level of white Gaussian noise power with known bandwidth to the DUT (Fig. 4). A bandstop (notch) filter is then inserted to create a "quiet" channel. The noise power measured in the "quiet" channel at the output of the DUT is due to thermal noise and IMD introduced by the DUT (Fig. 5). The generator automatically corrects the loading power level for the insertion loss of the notch filter. The level control maintains the applied noise power within ±0.1 dB of the initial setting at constant ambient temperature when switching filters.

The receiver section of the NPR test station measures the output power of the DUT within the notch bandwidth. The NPR is the ratio between the noise power measured without the notch filter inserted before the DUT to that measured with a notch filter.[2] The NPR value is calculated and displayed in decibels on the front panel. The result is automatically separated into intrinsic and distortion components.

NPR DEGRADATION

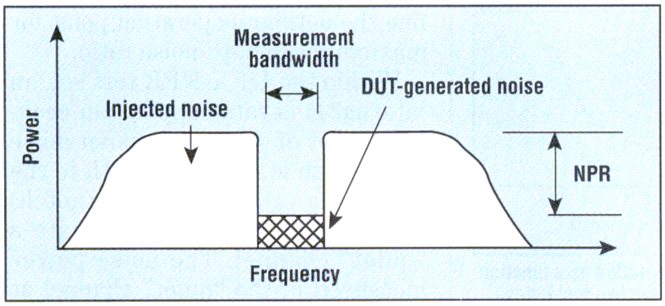
NPR is degraded primarily by two factors. One is the distortion products which are produced under high loading conditions. The second is the noise floor of the amplifier which will become dominate under very-low loading conditions. By making numerous measurements at different loading levels, a curve will be generated.

The NPR is poor at low loading levels because the amplifier is being operated near its own noise floor. This noise is also known as the intrinsic noise. The NPR will improve approximately 1 dB for every 1 dB the loading level is increased above the intrinsic noise. The NPR is also poor at very-high loading levels, but the slope on this side of the curve is steeper since the distortion products dominate. If these are third-order distortions, then the intermodulation products increase 2 dB for every



4. The UFX-NPR series test set consists of signal-generation and signal-analysis sections at customer-specified frequencies.

NPR TEST SET



5. This is the output-noise spectrum of a typical NPR measurement.

1 dB increase of the loading level.

The UFX-NPR test set automatically sweeps the loading between user-entered start and stop levels, with up to 25 steps of noise output power for data generation of NPR curves. The data is stored in non-volatile memory and the largest measured NPR value and associated noise-power loading level are automatically displayed. The results can be viewed on the front panel or transferred via GPIB.

Simultaneous automatic measurements of noise figure and gain are available as an option. This option includes internal noise and gain calibration, plus corrections for second-stage effects, etc. Noise figure and gain are displayed simultaneously with the result of the NPR measurement, providing comprehensive data for amplifier evaluation all from one test station.

The noise-figure and gain measurements are made by using a noise source and several simple power-ratio measurements. Noise figure (NF) is defined (in dB) as:

$$NF = 10log[(T_e + 290)/290] \quad (1)$$

where T_e is the noise temperature of the DUT.

Using the Y-factor method, NF (in dB) is then equal to:

$$NF = ENR - 10log(Y - 1) \quad (2)$$

where Y is the ratio of the output power of the DUT with the noise source in an "ON" state to the output power of the DUT with the noise source in an "OFF" state:

$$Y = P_{ON1}/P_{OFF1} = k(T_h + T_e BG_m G_a /k(T_c + T_e BG_m G_a \quad (3)$$

where:

k = Boltzmann's constant (1.38×10^{-23}) (J/K),

T_h = the output power of the noise source when it is turned on {290[1 + 10(ENR/10)]} (K),

T_c = the ambient room temperature when the noise source is turned off (K),

B = the noise bandwidth of the measurement system,

G_m = the available gain of the test setup (not in dB), and

G_a = the available gain of the DUT (not in dB).

Two additional measurements are performed in order to calculate the gain. The noise source is connected directly to the test setup, while the power levels P_{ON2} and P_{OFF2}, respectively, are measured with the noise source turned on and then off. These measurements, which are performed as part of the test-setup calibration, eliminate the bandwidth, gain, and noise figure of the test setup from the gain equation:

$$G_a = (P_{ON1} - P_{OFF1})/(P_{ON2} - P_{OFF2}) \quad (4)$$

where:

$P_{ON2} = k(T_h + T_m)BG_m$,

$P_{OFF2} = k(T_C + T_m)BG_m$, and

T_m = the noise temperature of the test setup.

The condition for the elimination of the bandwidth from the gain equation is that the bandwidth of the test setup is smaller than the bandwidth of the DUT. Since the bandwidth of the UFX-NPR is specified by the customer, measurements can be made on very-narrow-band components, including those intended for wireless communications.

For ambient temperatures much different than 290 K (17°C), a correction factor (10logA) should be added to the right side of the Y-factor noise-figure equation, with A defined as:

$$A = 1 - [(T_c/290) - 1] \times [Y/10(ENR/10)] \quad (5)$$

The correction is most significant when measuring low noise figures and can, in most cases, be disregarded in order to simplify the measurement. Corrections for second-stage effects (the test-setup noise figure) are made by use of the following equation:

$$F_{actual} = F_{measured} - [(F_m - 1)/G_a] \quad (6)$$

where:

F_{actual} = the actual noise factor of the DUT (not in dB), $F_{measured}$ = the measured noise factor (not in dB), and

F_m = the noise factor of the test setup (not in dB).

Impedance mismatch between the DUT, the noise source, and the test setup may lead to measurement uncertainty. Thus, the impedances should be kept as close to 50 Ω as possible by using a well-matched noise source with minimum variation of the output impedance as it is turned from on to off. Noise sources with built-in isolators are ideal for less-than-octave frequency ranges, while noise sources with built-in attenuators are best for wider-than-octave band applications.

Instruments in the UFX-NPR series simplify IMD and, optionally, noise-figure and gain measurements in mobile analog/digital telephone, satellite, and other wireless communication systems operating in multi-signal environments. The programmable instruments are available in specified frequency ranges from 10 MHz to 40 GHz and can be supplied with a wide range of options for additional measurement capabilities. **NOISE/COM, Inc., E. 49 Midland Ave., Paramus, NJ 07652; (201) 261-8797.**

References

1. Stewart M. Perlow, "Basic Facts about Distortion and Gain Saturation," *Applied Microwave*, May 1989, pp. 107-117.

2. M.J. Tant, "Multichannel Communication Systems and White Noise Testing," *The White Noise Book*, Marconi Instruments, Allendale, NJ, 1990.

CIRCLE NO. 51

SOLID-STATE MICROWAVE POWER OSCILLATOR DESIGN

Eric L. Holzman and Ralston S. Robertson

Microwave power oscillators are employed as sources in a wide variety of communications, radar, and electronic-warfare applications. The characteristics of these key components are outlined in *Solid-State Microwave Power Oscillator Design*.

Appropriately, the book begins with a review of electromagnetic theory. Maxwell's equations are outlined and applied to the analysis of transverse-electromagnetic (TEM) and quasi-TEM transmission lines and rectangular waveguide. Propagation analysis using the Smith chart and network analysis using Y-, Z-, and S-parameters are discussed.

An overview of oscillation theory follows the electromagnetic review. As the authors note, an oscillator contains two basic parts: the active device and the passive circuit. After the onset of oscillation, the RF power level increases from zero until it reaches a steady-state value. Resonance is achieved using inductive and capacitive energy-storing elements. Typical microwave resonators include dielectric, waveguide, and yttrium-iron-garnet (YIG)-sphere types.

Oscillation conditions are derived using both impedances and reflection coefficients. Multiple-port oscillation is discussed, along with amplitude modulation (AM), phase noise, and pulling figure.

The next chapter provides more detailed coverage of active devices. Semiconductor theory is reviewed and applied to two- and three-terminal devices (including bipolar-junction and field-effect transistors).

Oscillator design is the focus of the following four chapters. For instance, single-device oscillators (SDOs) are either fixed to a single operating frequency or mechanically tuned to a frequency range. These devices are generally categorized by the circuit medium from which they are fabricated: planar SDOs employ two-dimensional microstrip circuits while cavity SDOs use three-dimensional waveguide cavities.

External stimuli are sometimes used to control oscillator operation. For instance, a DC voltage may be used to control the oscillating frequency. Alternatively, an RF signal can be applied to the input of a free-running oscillator to cause the oscillation frequency to shift or lock to the applied signal's frequency. This is known as injection locking.

The book's final chapter presents an overview of power combiners, the designs of which are based on SDO and injection-locking concepts.

With its detailed explanations and emphasis on fundamental concepts, *Solid-State Microwave Power Oscillator Design* is useful as an introductory textbook for both engineers and students. (1992, 462 pp., hardcover, ISBN: 0-89006-487-3, $88.00). **Artech House, Inc., 685 Canton St., Norwood, MA 02062; (617) 769-9750.**

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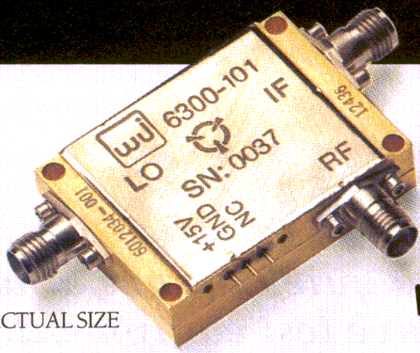

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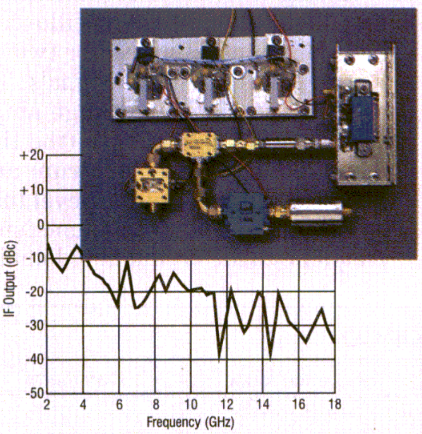
Units can be selected for downconverting using LO frequencies from 180 MHz to 1.6 GHz.



IF Output the Old Fashioned Way

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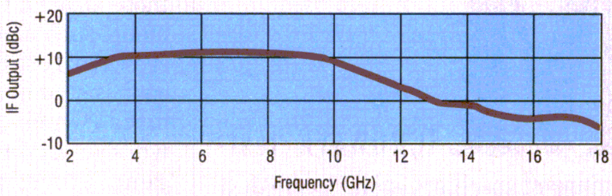

Typical IF Output of the WJ-6300-350 Sampling Downconverter

Ask for applications data.

For more information, including a new data sheet and application note, please contact Watkins-Johnson Company, 3333 Hillview Ave., Palo Alto, CA 94304. Phone (415) 493-4141. Fax (415) 813-2402.

WJ-6300 Series Specifications

Model Number	LO Frequency (MHz)	Conversion Loss Max (dB)	L-R Leakage Max (dBm)	IF Frequency (MHz)
6300-310	200 ± 20	25	-40	10-70
6300-311	200 ± 20	22	-75	10-70
6300-320	500 ± 50	20	-35	10-175
6300-321	500 ± 50	17	-70	10-175
6300-330	750 ± 50	20	-30	10-260
6300-331	750 ± 50	17	-65	10-260
6300-340	1000 ± 100	15	-25	10-300
6300-341	1000 ± 100	15	-60	10-300
6300-350	1250 ± 100	13	-20	10-440
6300-351	1250 ± 100	13	-60	10-440
6300-360	1500 ± 100	13	-15	10-500
6300-361	1500 ± 100	13	-50	10-500
6300-370	1000 - 1500	22	-15	10-500
6300-371	1000 - 1500	22	-50	10-500

All units operate across the 2 to 18 GHz frequency range; R-Port and L-Port VSWR: 2.8:1 (max); Spurious Suppression: 15 dBc (min); Second Harmonic: 10 dBc (min)

EXCELLENCE IN ELECTRONICS

WATKINS-JOHNSON

GEAR GENERATES AND ANALYZES MICROWAVE SIGNALS

This "short-form catalog" provides a quick glance at who makes what in the world of microwave test equipment.

ALAN CONRAD
SPECIAL PROJECTS EDITOR
JACK BROWNE
ASSOCIATE PUBLISHER/EDITOR

MICROWAVE test-equipment specifiers enjoy the greatest selection of equipment this field has ever seen. With coaxial signal sources and analyzers pushing well beyond 40 GHz, test stations can be assembled for extremely-broadband measurements in the frequency and time domains.

Test equipment designed for microwave applications can generally be divided into instruments that produce stimuli and those that analyze those stimuli. Of course, some equipment, such as the 6200 series of Microwave Test Sets (MTS) from Marconi Instruments, does both. These units (which integrate scaler network analyzers, synthesized signal generators, power meters, frequency counters, and programmable current/voltage sources) range in frequency from 10 MHz to 46 GHz. The latest addition to the line, the 70-MHz-to-20-GHz model 6145, adds pulse-modulation capability to the integral frequency synthesizer for radar measurements.

The 6200 MTS units actually borrow, in concept, from RF communications service monitors, such as those available from Motorola, Inc., IFR, and Hewlett-Packard Co. Such monitors integrate 1-GHz signal generators, power meters, modulation analyzers, and various other instruments into a portable unit designed for remote transmitter/receiver testing.

Among the workhorse microwave test instruments, the oscilloscope and spectrum analyzer offer two different views of similar signals. The oscilloscope displays voltage amplitude as a function of time (the time domain), while the spectrum analyzer shows signal power level (usually logarithmically) as a function of frequency (the frequency domain).

Microwave test equipment at a glance

Manufacturer	Instruments	Frequency range	Comments
Advantest Corp. (available from Tektronix, Inc.). **CIRCLE NO. 360**	spectrum analyzers network analyzers	100 Hz to 26.5 GHz 100 kHz to 3.5 GHz	
Alessi, Inc., 35 Parker, Irvine, CA 92718; (714) 830-0660. **CIRCLE NO. 361**	wafer-probe stations	—	
Amplifier Research, 160 School House Rd., Souderton, PA 18964-9990; (215) 723-8181, FAX: (215) 723-5688. **CIRCLE NO. 362**	EMI antennas EMI amplifiers EMI/RFI analyzers	10 kHz to 40 GHz 10 kHz to 1.5 GHz 10 kHz to 40 GHz	GPIB
Anritsu-Wiltron Sales Co., 685 Jarvis Dr., Morgan Hill, CA 95037-2809; (408) 776-8300, FAX: (408) 776-1744. **CIRCLE NO. 363**	scalar network analyzers vector network analyzers swept-signal generators frequency synthesizers	10 MHz to 40 GHz 10 MHz to 62 GHz 10 MHz to 40 GHz 10 MHz to 60 GHz	coax
April Instruments Co., P.O. Box 62046, Sunnyvale, CA 94088-2046; (415) 964-8379, FAX: (415) 965-3711. **CIRCLE NO. 364**	signal generators	10 MHz to 60 GHz	

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Using ultra-linear Class A design, these state-of-the-art amplifiers provide up to 40 dB, flat (±1.0dB), are unconditionally stable, include overvoltage protection, and can be connected to any load impedance without amplifier damage or oscilation.

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SPECIFICATIONS	ZHL-42	ZHL-4240	ZHL-42-W	ZHL-4240W
Frequency, GHz	.07 to 4.2	0.7 to 4.2	0.01 to 4.2	0.01 to 4.2
Gain, dB min.	30	40	30	40
Gain Flatness, dB	±1.0	±1.5	±1.5	±1.5
Power Out @ 1 dB CP, dBm min	+29	+29	+29*	+29*
VSWR in/Out, max.	2.5:1	2.5:1	2.5:1	2.5:1
Noise Figure, dB typ	10.0	4.0	8.0**	8.0**
Power Supply, V/ma	+15/690	+15/700	+15/750	+15/850
Third Order Intercept, dBm min.	38	38	38	38
Second Order Intercept, dBm min.	48	48	48	48
Size, in.	7 x 3¼ x 2⅛ h.	7 x 3¼ x 2⅛ h.	7 x 3¼ x 2⅛ h.	7 x 3¼ x 2⅛ h.
Price	**$895.00**	**$1395.00**	**$1095.00**	**$1495.00**

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CIRCLE NO. 322

C 97 REV.E

TEST EQUIPMENT

Tektronix, Inc., a pioneering company in the development of the oscilloscope, offers a wide range of portable spectrum analyzers with coaxial coverage to 33 GHz. (The operating range of most spectrum analyzers can be extended through millimeter-wave frequencies by downconverting test signals with external waveguide mixers.)

The spectrum analyzers from Tektronix and many other suppliers, such as Advantest America, Anritsu Wiltron Sales Co., IFR, Hewlett-Packard, and Rohde & Schwarz, of-

Microwave test equipment at a glance

Manufacturer	Instruments	Frequency range	Comments
ATN Microwave, Inc., 11 Executive Park Dr., Billerica, MA 01862; (508) 667-4200, FAX: (508) 667-8548. **CIRCLE NO. 365**	device test systems	0.3 to 40 GHz	
	load-pull test sets	0.3 to 40 GHz	diode based
BK Precision, Div. of Maxtec Int. Co., 6470 W. Cortland St., Chicago, IL 60635; (312) 889-1448, FAX: (312) 804-9425. **CIRCLE NO. 366**	microwave counters	5 Hz to 2.4 GHz	
Boonton Electronics Corp., 791 Route 10, Randolph, NJ 07869; (201) 584-1077, FAX: (201) 584-3037. **CIRCLE NO. 367**	power meters	30 MHz to 40 GHz	
	modulation analyzers	100 kHz to 2.5 GHz	
Cascade Microtech, Inc., 14255 S.W. Brigadoon Ct., Beaverton, OR 97005; (503) 626-9231, FAX: (503) 626-6023. **CIRCLE NO. 368**	on-wafer test probes	DC to 110 GHz	
	noise-figure test sets	DC to 26.5 GHz	
Colby Instruments, Inc., 1810 14th St., Santa Monica, CA 90404; (310) 450-0261, FAX: (310) 452-0027. **CIRCLE NO. 369**	signal generators	100 kHz to 1 GHz	
	pulse generators	100 kHz to 8 GHz	
	programmable delay lines	DC to 18 GHz	
Comstron, Div. of Aeroflex Laboratories, Inc., 35 South Service Rd., Plainview, NY 11803; (516) 694-6700, FAX: (516) 694-6771. **CIRCLE NO. 370**	frequency synthesizers	10 MHz to 18.4 GHz	
	phase-noise test sets	5 MHz to 18 GHz	PC based
EIP Microwave, Inc., 1589 Centre Pointe Dr., Milpitas, CA 95035; (800) 232 3471, FAX: (408) 945-0977. **CIRCLE NO. 371**	frequency synthesizers	0.01 to 20 GHz	
	CW/pulse counters	CW to 170 GHz	VXI
	frequency synthesizers	0.01 to 20 GHz	VXI
Electronics Development Corp., 9055F Guilford Rd., Columbia, MD 21046; (410) 312-6650, FAX: (410) 312-6653. **CIRCLE NO. 372**	range simulator	0.8 to 8 GHz	
Focus Microwaves, Inc., 227 Lakeshore Rd., Pointe Claire, Quebec, Canada H9S 4L2; (514) 630-6067, FAX: (514) 630-7466. **CIRCLE NO. 373**	load-pull test sets	0.4 to 100 GHz	
	load-pull tuners	0.4 to 100 GHz	
General Microwave Corp., 5500 New Horizons Blvd., Amityville, NY 11701; (516) 226-8900, FAX: (516) 226-8966. **CIRCLE NO. 374**	radiation-hazard meters	200 kHz to 40 GHz	
	peak power meters	0.75 to 40 GHz	
Giga-tronics, Inc., 2495 Estrand Way, Pleasant Hill, CA 94523-6015; (510) 680-8160. **CIRCLE NO. 375**	peak power meters	10 MHz to 40 GHz	
	signal sweepers	10 MHz to 40 GHz	
	frequency synthesizers	100 kHz to 40 GHz	
	scalar network analyzers	10 MHz to 40 GHz	
Hewlett-Packard Co., Direct Marketing Organization, P.O. Box 58059, Mail Stop 51L-SJ, Santa Clara, CA 95051-8059. **CIRCLE NO. 376**	synthesized generators	0.1 to 6 GHz	
	swept-signal sources	0.01 to 110 GHz	
	millimeter-wave sources	26.5 to 110 GHz	
	digitizing oscilloscopes	DC to 50 GHz	
	vector network analyzers	300 kHz to 110 GHz	
	scalar network analyzers	10 Hz to 110 GHz	
	frequency/time-interval analyzers	DC to 18 GHz	
	frequency counters	DC to 46 GHz	
	power meters	10 MHz to 50 GHz	
	spectrum analyzers	10 Hz to 26.5 GHz	coax
	comm test sets	DC to 2.5 GHz	
	transition analyzers	10 kHz to 40 GHz	
	phase-noise test sets	5 MHz to 18 GHz	

TEST EQUIPMENT

ten integrate some of the traditional microwave stand-alone instruments, such as power meters and frequency counters. In doing so, the need for those separate instruments has declined somewhat in recent years.

Long a leader in microwave test equipment, Hewlett-Packard popularized the use of vector network analysis with the introduction of the HP 8510A analyzer in 1984 (see p. 79). While that analyzer operates with a separate signal source, the company's later HP 8720 series of analyzers includes both a frequency synthesizer and analyzer in a compact configuration. In addition to the HP 8510, the 360 series of vector network analyzers from Anritsu Wiltron Sales Co. offer coaxial measurements past 60 GHz with the company's 1.85-mm V connector.

Hewlett-Packard and Marconi offer two of the more comprehensive

Microwave test equipment at a glance

Manufacturer	Instruments	Frequency range	Comments
IFR Systems, Inc., 10200 W. York St., Wichita, KS 67215-8935; (316) 522-4981, FAX: (316) 524-2623. **CIRCLE NO. 377**	spectrum analyzers service monitors	9 kHz to 26.5 GHz 100 kHz to 1 GHz	
Instruments For Industry, Inc., 731 Union Pkwy., Ronkonkoma, NY 11779; (516) 467-8400, FAX: (516) 467-8558. **CIRCLE NO. 378**	TEM-mode test chambers	DC to 1 GHz	
Inter-Continental Microwave, 1515 Wyatt Dr., Santa Clara, CA 95054; (408) 727-1596, FAX: (408) 727-0105. **CIRCLE NO. 379**	test fixtures	DC to 40 GHz	
LeCroy Corp., 700 Chestnut Ridge Rd., Chestnut Ridge, NY 10977-6499; (914) 425-2000, FAX: (914) 425-8967. **CIRCLE NO. 380**	digitizing oscilloscopes	DC to 4 GHz	
LNR Communications Inc., 180 Marcus Blvd., Hauppauge, NY 11788; (516) 273-7111, FAX: (516) 273 7199. **CIRCLE NO. 381**	spread-spectrun generators spread-spectrum analyzers	0.8 to 2.5 GHz 0.8 to 2.5 GHz	
Loral Microwave-Narda, 435 Moreland Ave., Hauppauge, NY 11788; (516) 231-1700, FAX: (516) 231-1711. **CIRCLE NO. 382**	radiation-hazard monitors cell-site monitors	300 kHz to 40 GHz 800 to 1000 MHz	
Marconi Instruments Co., 3 Pearl Court, Allendale, NJ 07401; (201) 934-9050, FAX: (201) 934-9229. **CIRCLE NO. 383**	signal generators power meters frequency counters microwave test sets	10 MHz to 40 GHz 10 MHz to 40 GHz 10 MHz to 40 GHz 10 MHz to 46 GHz	
Maury Microwave Corp., 2900 Inland Empire Blvd., Ontario, CA 91764; (909) 987-4715, FAX: (909) 987-1112. **CIRCLE NO. 384**	impedance tuners load-pull test sets noise-gain analyzers	0.2 to 26.5 GHz 0.2 to 26.5 GHz 10 MHz to 2 GHz	
Micronetics, Microwave Div., 26 Hampshire Dr., Hudson, NH 03051; (603) 883-2900, FAX: (603) 882-8987. **CIRCLE NO. 385**	noise generators	customer-specified	
Micro-Now Instrument Co., Inc., 8260 N. Elmwood St., P.O. Box 1488, Skokie, IL 60076; (708) 677-4700, FAX: (708) 677-0394. **CIRCLE NO. 386**	millimeter-wave sources	2 to 170 GHz	
NOISE/COM, Inc., E. 49 Midland Ave., Paramus, NJ 07652; (201) 261-8797, FAX: (201) 261-8339. **CIRCLE NO. 387**	precision C/N generators BER testers calibrated noise sources noise-figure test sets noise generators	DC to 2.5 GHz DC to 2.5 GHz 10 kHz to 60 GHz 10 kHz to 18 GHz 10 MHz to 40 GHz	VXI
Nearfield Systems, Inc., 1330 E. 223rd St. No. 524, Carson, CA 90745; (310) 518-4277, FAX: (310) 518-4279. **CIRCLE NO. 388**	near-field antenna test ranges	2 to 40 GHz	
Programmed Test Sources, Inc., 9 Beaver Brook Rd., P.O. Box 517, Littleton, MA, 01460; (508) 486-3008, FAX: (508) 486-4495. **CIRCLE NO. 389**	frequency synthesizers	100 kHz to 1 GHz	direct
Racal Instruments, Inc., 4 Goodyear St., P.O. Box C-19541, Irvine, CA 92713; (800) 722-3262, FAX: (714) 859-2505. **CIRCLE NO. 390**	frequency counters switch matrices	0.1 to 1000 MHz	

TEST EQUIPMENT

lines of microwave test equipment, both representing products in all the traditional function areas: signal generators, frequency counters, power meters, spectrum analyzers, and scalar network analyzers. In recent years, Hewlett-Packard has also developed new microwave measurements, such as the modulation-domain analyzer, which is, in a sense, a frequency-based offshoot of an oscilloscope.

Instruments for producing microwave stimuli generally fall into two categories: signal generators or sweepers (which are not phase-locked) and frequency synthesizers (which are phase-locked).●●

Microwave test equipment at a glance

Manufacturer	Instruments	Frequency range	Comments
RDL, Inc., 7th Ave. and Freedley St., Conshohocken, PA 19428; (215) 825-3750. **CIRCLE NO. 391**	signal generators	0.8 to 2.5 GHz	multitone
Rohde & Schwarz (available from Tektronix, Inc.). **CIRCLE NO. 392**	radio testers signal generators EMI receivers	100 kHz to 1 GHz 100 kHz to 26.5 GHz 5 Hz to 26.5 GHz	
Scientific-Atlanta, Inc., 3845 Pleasantdale Rd., Atlanta, GA 30340-4266; (800) 848-7921, FAX: (404) 903-2020. **CIRCLE NO. 393**	antenna test instruments wafer test systems programmable receivers programmable sources	0.025 to 140 GHz 0.025 to 140 GHz 0.1 to 40 GHz 0.1 to 60 GHz	
Sonoma Instrument Co., P.O. Box 9011, Santa Rosa, CA 95405; (707) 542-8569. **CIRCLE NO. 394**	low-noise amplifiers	10 kHz to 2.5 GHz	
Tektronix, Inc., P.O. Box 500, Beaverton, OR 97077; (503) 627-7999. **CIRCLE NO. 395**	comm signal analyzers spectrum analyzers transient-event analyzers digital oscilloscopes analog oscilloscopes	DC to 50 GHz 100 Hz to 33 GHz DC to 4.5 GHz DC to 50 GHz DC to 400 MHz	coax
Wayne-Kerr, 11 Sixth Rd., Woburn, MA 01801-1744; (617) 938-8390, FAX: (617) 933-9523. **CIRCLE NO. 396**	signal generators spectrum analyzers	100 kHz to 2.4 GHz 10 kHz to 1 GHz	
Weinschel Associates, 42 Cesna Court, Gaithersburg, MD 20879; (301) 948-8342, FAX: (301) 869-9783. **CIRCLE NO. 397**	slotted lines impedance standards	2 to 18 GHz DC to 40 GHz	
XL Microwave Co., 5811 Racine St., Oakland CA, 94609-1519; (510) 428-9488, FAX: (510) 428-9469. **CIRCLE NO. 398**	frequency counters	10 MHz to 40 GHz	

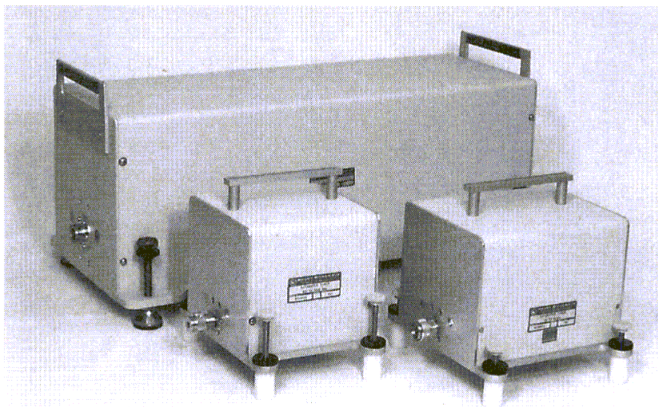
AUTOMATED TUNER SYSTEM AIDS IMD TESTING

Based on electromechanical impedance tuners, this system automatically measures a wide range of output parameters.

IMPEDANCE tuners such as the MT980 series mechanical tuners from Maury Microwave (Ontario, CA) can now be combined with power-characterization software and newly-written test software for automated two-tone, third-order intermodulation-distortion (IMD) testing. The new program, which is written in Microsoft C for use on a personal computer, quickly delivers a variety of additional measured parameters, such as output power, available gain, and power-added efficiency. The automated system can also be used to measure device response to swept- and fixed-power inputs at user-selected source and load impedances.

Such electromechanical slide-screw tuners (Fig. 1) have been used in the past for characterizing the noise and nonlinear parameters of active devices,[1,2] but the units are just as suitable for third-order IMD measurements. The tuners are based on a coaxial slide-screw design which utilizes a slab line as the primary transmission structure. The slab line is inherently broadband and the use of two permanently-mounted tuning probes provides for a typical matching capability often exceeding 20:1 (equivalent VSWR) over very broad frequency ranges of generally a decade or more.

WILLIAM E. PASTORI, Marketing Applications Manager, and **GARY R. SIMPSON,** Engineering Section Manager, Maury Microwave Corp., 2900 Inland Empire Blvd., Ontario, CA 91764; (909) 987-4716, FAX: (909) 987-1112.



1. Slide-screw electromechanical tuners in the MT980 series cover bands from 0.2 to 26.5 GHz.

Tuners are available from 0.2 to 26.5 GHz.[3] The tuner is a non-contacting design; that is, even though it is capable of generating very high mismatches, the probe does not contact the center conductor or the side walls. This improves performance, extends operating life, and allows for high-speed tuning.

Load- and source-pull measurements require moving the appropriate tuner to a variety of positions to establish known terminating conditions. In IMD and power characterization, development of parameter contours requires that source and load tuner(s) be moved to many different, pre-characterized positions. Measured results, therefore, are highly dependent upon the repeatability of these tuners.

The repeatability of these tuners, such as the 0.4-to-4.0-GHz model MT981B unit, is specified at –50 dB, although the actual measured repeatability of the tuner is better than –60 dB. Repeatability is defined as the worst-case vector difference between the measured value at a given tuner position and a reference value stored in memory.

Two-tone IMD generally refers to the spurious mixing products generated by the nonlinearity of an active device when simultaneously stimu-

lated by two signals. Third-order intermodulation (which results from mixing the fundamental frequency of one signal with the second harmonic of another signal) is particularly troublesome because the difference signal is often in close proximity to the frequency of the fundamental signal, which can cause adjacent-channel interference in a communication system.

The automated tuner system (ATS) and new IMD software simplify the process of measuring IMD (Fig. 2). Because the new IMD software is appended to an existing power-characterization program, the IMD results are available along with any of the standard power parameters, including available input power, measured input current and voltage, delivered input power, carrier power, measured output current and voltage, delivered output power, intermodulation power, transducer gain, carrier-to-intermodulation ratio, third-order intercept point, and power gain. The system even includes the means by which the user can actually define an output function, such as power-added efficiency.

SYSTEM CALIBRATION

Prior to system calibration and measurement, the S-parameters of all elements are characterized over the measurement frequency range and stored. The software incorporates several vector-network-analyzer drivers, a general-purpose S-parameter measurement program, and a module for both automatic and manual characterization of the tuners to facilitate generation of these files. If the measurement results are to be de-embedded (i.e., referenced to the device-under-test (DUT) interfaces), the test fixture containing the DUT can be defined in the form of models of the input and output halves (such as with a model MT950 test fixture) or S-parameter files. This latter feature accommodates on-wafer measurements since the files can be made up of the S-parameters of the input and output probes.

Optional output filters and attenuators can be used to prevent harmonics from affecting the power-meter measurements and to avoid overdriving the output-power sensor. The transmission characteristics of these elements must be accounted for by inclusion in the tuner characterization or adjustment of the output-power-sensor efficiency file.

The system is calibrated by inserting a pre-characterized in-circuit throughline in the fixture and measuring the output power over a range of input powers with the tuners in the matched position. This data is then used to calibrate the output coupler/spectrum analyzer and determine the available power. Moving the source tuner to a variety of positions then permits calibration of the input coupler. During measurements, this information is used to determine the reflected and, therefore, the delivered power. Once calibration is complete, the system may be used for load- and source-pull measurements or swept- and single-power measurements at user-selected source/load impedances.

At the completion of the calibration process, the user can select a measurement frequency and a specific DUT.

TUNER SYSTEM

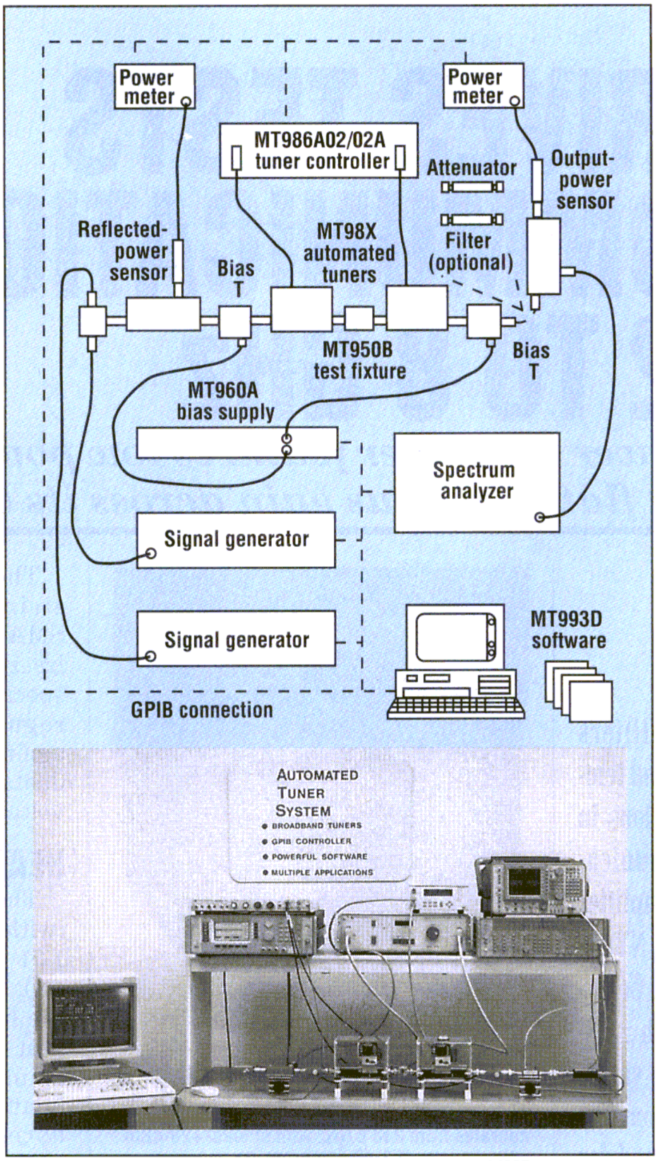
A 386/486 computer display screen shows the types of measurements available and the measurement parameters, which can be selected by a mouse. The distribution of available impedances is shown at both the source and load DUT interfaces. Cursors show the user-selectable, current-terminating impedances used for a swept or single-point measurement, as well as the DUT S_{11} and S_{22} conjugates, which are convienent when searching for impedances for a given optimum parameter value. If the stability factor (k) of the DUT is less than unity, the regions of potential device instability are shown on both source- and load-impedance plots. When the mouse pointer is within the boundary of one of the Smith charts, its position is continuously displayed directly below the chart.

The IMD-measurement software display permits a good deal of user interaction. In addition to setting up the conditions for a pull measurement, the operator can determine device performance at specific terminating conditions (e.g., determination of the compromise in device performance when the optimum terminating conditions for two parameters are not coincident and it is necessary to terminate the device at some intermediate position) and verify the results of a pull measurement.

A load- or source-pull measurement is made by varying the appropriate impedance (load or source) and measuring the effect on the desired parameter. Through the use of a random contouring algorithm, these data can be used to develop contours of constant carrier power, power-added efficiency, and intermodulation power.

The measurement frequency, available input power, and source termination are set by the user from the opening measurement display. The readouts on the left of the screen also show the parameter optimum, the reflection coefficient for the optimum, and the contour scaling. The number of contours and the step size are all controllable by the user. The program also permits adjustment of the contour resolution. Of course, finer resolution results in smoother contours, but takes longer to calculate than coarser resolution.

The software also has a swept-power mode which provides for measurements over a range of input powers. The input and output terminating conditions can be set from the opening measurement display or simply left at the optimum positions established by the pull measurements.



2. The slide-screw tuners form the heart of an automated IMD test system.

The software instrument library contains a wide variety of all instruments required for power and IMD measurements; however, occasionally the user may wish to use an instrument (a special bias supply, signal source, spectrum analyzer, etc.) not represented in the supported list. All instrument control is by means of drivers incorporated in small, stand-alone modules. The Microsoft C source code for these modules is available and can be edited by the user. Drivers for instruments not supported in the standard software can be easily developed by using an existing driver as a template. The new drivers can then be activated in the configuration file that establishes the measurement setup in the software.

The software also incorporates the means by which the user can write a function (using any of the measured or calculated values in the program) and define a scalar output. The user-defined function can be used to develop a specific output required for a unique application. A typical user-defined function would be simple efficiency which may be required for historical comparison purposes, but has been largely displaced by power-added efficiency. **Maury Microwave Corp., 2900 Inland Empire Blvd., Ontario, CA 91764; (909) 987-4716, FAX: (909) 987-1112.**

References

1. R.D. Pollard *et al.*, "Programmable Tuner System Characterizes Gain and Noise," *Microwaves & RF*, Vol. 26, No. 5, May 1987.
2. W.E. Pastori and G.R Simpson, "ATS for Power and Noise Characterization Using PC-AT Based Software," *Microwave Journal*, Vol. 36, No. 5, January 1993.
3. W.E. Pastori, "Programmable Tuner Commands Impedances from 4 to 26.5 GHz," *Microwaves & RF*, Vol. 28, No. 6, June 1989.

CIRCLE NO. 52

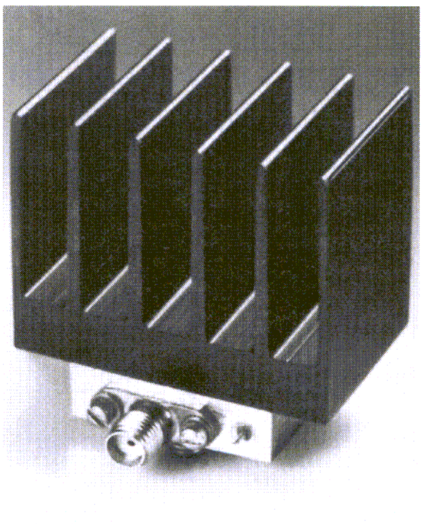
AMP DRIVES TESTS AND COMMUNICATIONS FROM 2 TO 8 GHz

This medium-power amplifier features low power consumption while delivering flat, generous gain across its bandwidth.

BROADBAND amplifiers with flat gain across frequency and temperature find a host of applications in both measurement and communications systems. The ZRON-8G amplifier from Mini-Circuits (Brooklyn, NY) is sure to fill many of these needs, boasting a bandwidth of 2 to 8 GHz with ±0.8-dB gain flatness. The gain also varies only ±0.9 dB at temperatures from 0 to +60°C. The amplifier is designed for typical output power of +22.5 dBm at 1-dB gain compression.

The ZRON-8G amplifier (see figure) is a versatile +15-VDC component with extremely linear characteristics, usable over broad or narrow bands for optical links, measurements, line-of-sight communications systems, and satellite communications. It is rated for minimum gain of 20 dB and typical gain of 22 dB. Minimum output power is rated at +20 dBm for 1-dB compression (although the measured compression at this output level is less than 0.5 dB).

The typical noise figure is 6 dB, dropping to less than 5.5 dB over the upper-half of the frequency range. The typical third-order intercept point is +30 dBm. Input and output VSWRs are 2.00:1. When connected to a load, the amplifier can withstand maximum input levels of +10 dBm without damage; without a load connected, the maximum input level is +1 dBm without damage. Measured directivity, which is the difference between amplifier isolation and gain, is typically 35 dB and at least 32 dB across the full bandwidth. The amplifier draws 310-mA maximum current and can operate from power supplies as high as +18 VDC without damage.



The medium-power ZRON-8G amplifier operates from 2 to 8 GHz with at least +20-dBm output power at 1-dB compression.

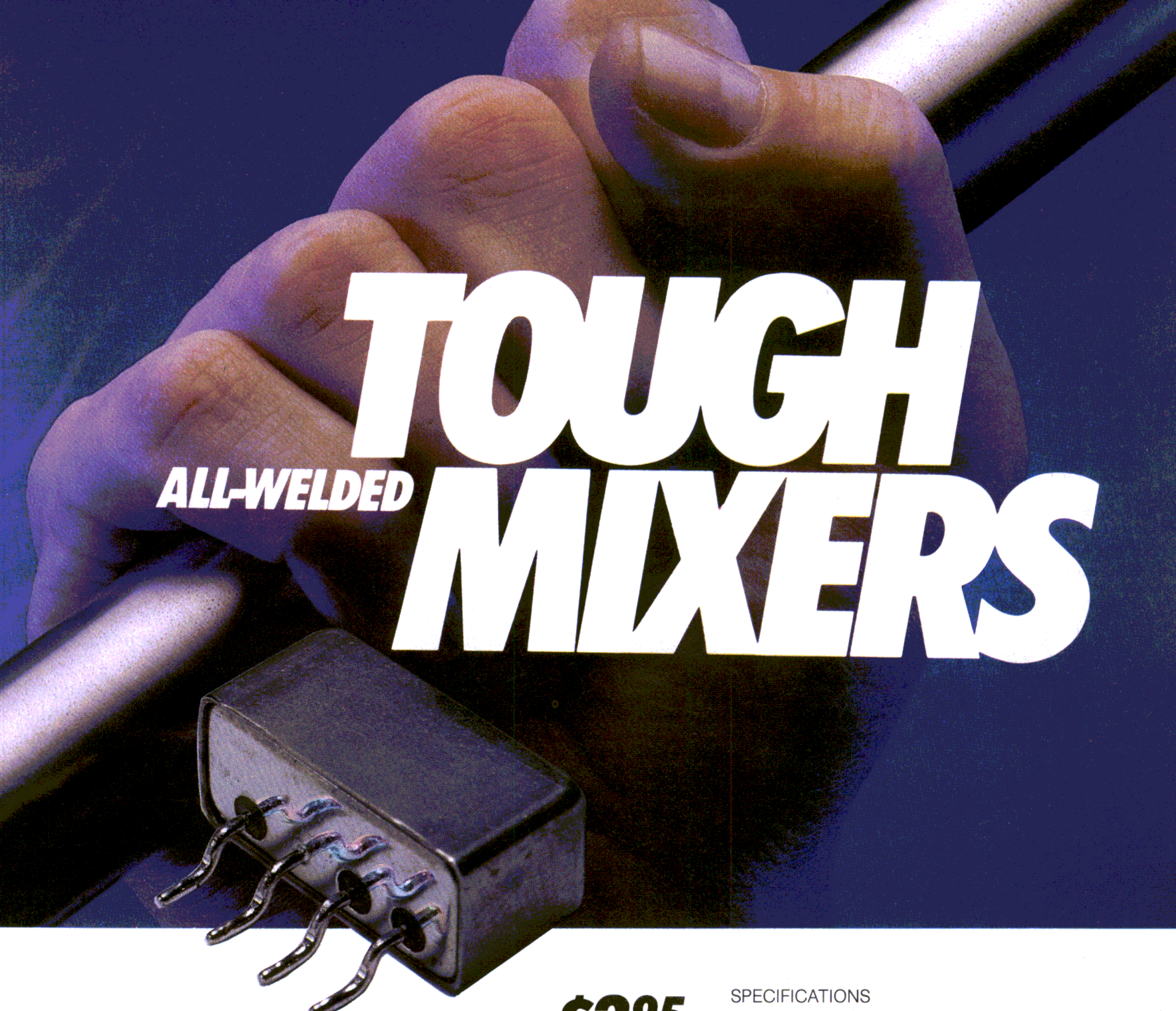
The ZRON-8G is supplied with stainless-steel, field-replaceable SMA connectors and is encased in a laser-welded, hermetic package. A specially-designed internal voltage regulator protects the amplifier against transients caused by accidental shorting of the power-supply voltage.

HEAT-SINK OPTION

The basic ZRON-8G amplifier (without heat sink) measures 1.05 × 1.01 × 0.30 in. (2.67 × 2.57 × 0.76 cm). An integral heat sink increases the height to 1.6 in. (4.06 cm). The heat sink can also be omitted and the amplifier can be mounted on any heat-dissipating surface. During normal operating conditions, the typical rise in temperature is 27°C above the ambient temperature, although the amplifier can withstand operating case temperatures as high as +95°C.

The amplifier is 100-percent screened with 24-hour burn-in performed at a case temperature of +100°C and applied voltage of +15 VDC. Gross leak testing is conducted according to the requirements of MIL-STD-202 Method 112, Condition D, while 10 cycles of thermal shock are conducted at extremes of –55 and +125°C. P&A: $495; stock. **Mini-Circuits, P.O. Box 350166, Brooklyn, NY 11235-4500; (800) 654-7949, (718) 934-4500, FAX: (718) 332-4661.**

CIRCLE NO. 53



SURFACE-MOUNT or PLUG-IN

FROM **$3.95** (10 qty)

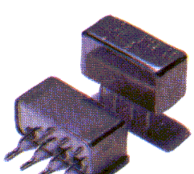
Expose Mini-Circuits' TUF-mixers to 250°C for five minutes, or to the extreme shock and vibration stresses of MIL-M-28837, or to 200 cycles of thermal shock from -55° to +100°C…they'll survive without any change in specs. They are mighty tough mixers!

Available with LO drive levels from +7 to +17dBm, performance features include very low conversion loss flat over the entire band, high isolation (L-R, L-I), and well-matched VSWR at all ports.

All-welded internal and external construction is used to assemble and package the TUF-unit in its tiny 0.5 by 0.2 by 0.25 in. metal case, for plug-in or surface-mount* assembly.

TUF-Ultra-Rel™ mixers are guaranteed for five years and boast unprecedented "skinny" sigma (δ) unit-to-unit repeatability as shown in the Table.

Tough, tiny, and with tight repeatability…Mini-Circuits' Ultra-Rel™ TUF-mixers with a five-year guarantee, priced from $3.95…available only from Mini-Circuits.



actual size

ULTRA-REL™ MIXERS

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with extra long life due to unique HP monolithic diode construction, 300°C high temp. storage, 1000 cycles thermal shock, vibration, acceleration, and mechanical shock exceeding MIL requirements.

SPECIFICATIONS

Model	LO Power (dBm)	Freq. LO/RF (MHz)	■ Conv. Loss (dB) $\overline{X}$	■ Conv. Loss (dB) δ	Isol. L-R (dB)	Price,$ Ea. 10 qty
TUF-3	7	0.15-400	4.98	0.34	46	5.95
TUF-3LH	10		4.8	0.37	51	7.95
TUF-3MH	13		5.0	0.33	46	8.95
TUF-3H	17		5.0	0.33	50	10.95
TUF-1	7	2-600	5.82	0.19	42	3.95
TUF-1LH	10		6.0	0.17	50	5.95
TUF-1MH	13		6.3	0.12	50	6.95
TUF-1H	17		5.9	0.18	50	8.95
TUF-2	7	50-1000	5.73	0.30	47	4.95
TUF-2LH	10		5.2	0.3	44	6.95
TUF-2MH	13		6.0	0.25	47	7.95
TUF-2H	17		6.2	0.22	47	9..95
TUF-5	7	20-1500	6.58	0.40	42	8.95
TUF-5LH	10		6.9	0.27	42	10.95
TUF-5MH	13		7.0	0.25	41	11.95
TUF-5H	17		7.5	0.17	50	13.95
TUF-860	7	860-1050	6.2	0.37	35	8.95
TUF-860LH	10		6.3	0.27	35	10.95
TUF-860MH	13		6.8	0.32	35	11.95
TUF-860H	17		6.8	0.31	38	13.95
TUF-11A	7	1400-1900	6.83	0.30	33	14.95
TUF-11ALH	10		7.0	0.20	36	16.95
TUF-11AMH	13		7.4	0.20	33	17.95
TUF-11AH	17		7.3	0.28	35	19.95

*To specify surface-mount models, add SM after P/N shown.

■ $\overline{X}$ = Average conversion loss at upper end of midband ($f_U/2$)

δ = Sigma or standard deviation

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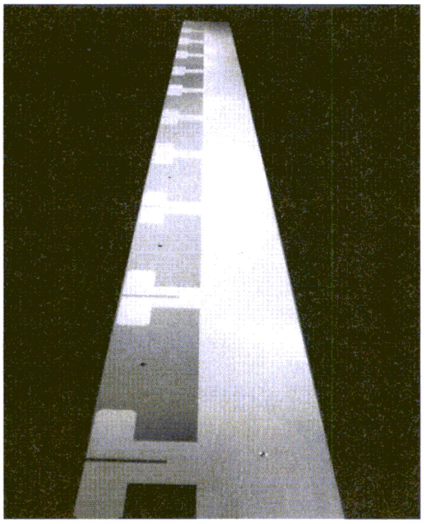
LOW-COST SUBSTRATES CHALLENGE PTFE PERFORMANCE LEVELS

These materials blend PTFE electrical properties with the cost and mechanical characteristics of FR-4 substrates.

MICROWAVE substrate materials have served traditional military markets with high performance, albeit at high prices. The TLC-32 substrate material from Taconic Plastics Ltd. (Petersburg, NY), however, offers good performance at relatively low cost, making it suitable for a wide range of emerging commercial applications.

The TLC-32 material (see figure), with a typical dielectric constant of 3.2, provides performance comparable to PTFE substrates but at 25 to 40 percent less cost per square foot. The TLC-32 material is fabricated with technology borrowed from FR-4 substrate manufacturing, using different plies of a commercial style of glass cloth as the base material rather than the more expensive fiberglass cloth incorporated in PTFE substrates.

JACK DANIELS, Technical Service Engineering Manager, Taconic Plastics Ltd., Microwave Dielectrics Div., Coonbrook Rd., P.O. Box 69, Petersburg, NY 12138; (518) 658-3202, FAX: (518) 658-3204.



TLC-32 substrates combine the electrical properties of PTFE materials with the cost and mechanical advantages of FR-4 substrates.

These cloths are also more rugged on a per ply basis than the cloths used in standard PTFE material manufacture. In addition, they are readily available due to use in FR-4 production. This low-cost cloth is coated with PTFE resin and then laminated with various thicknesses of copper foil.

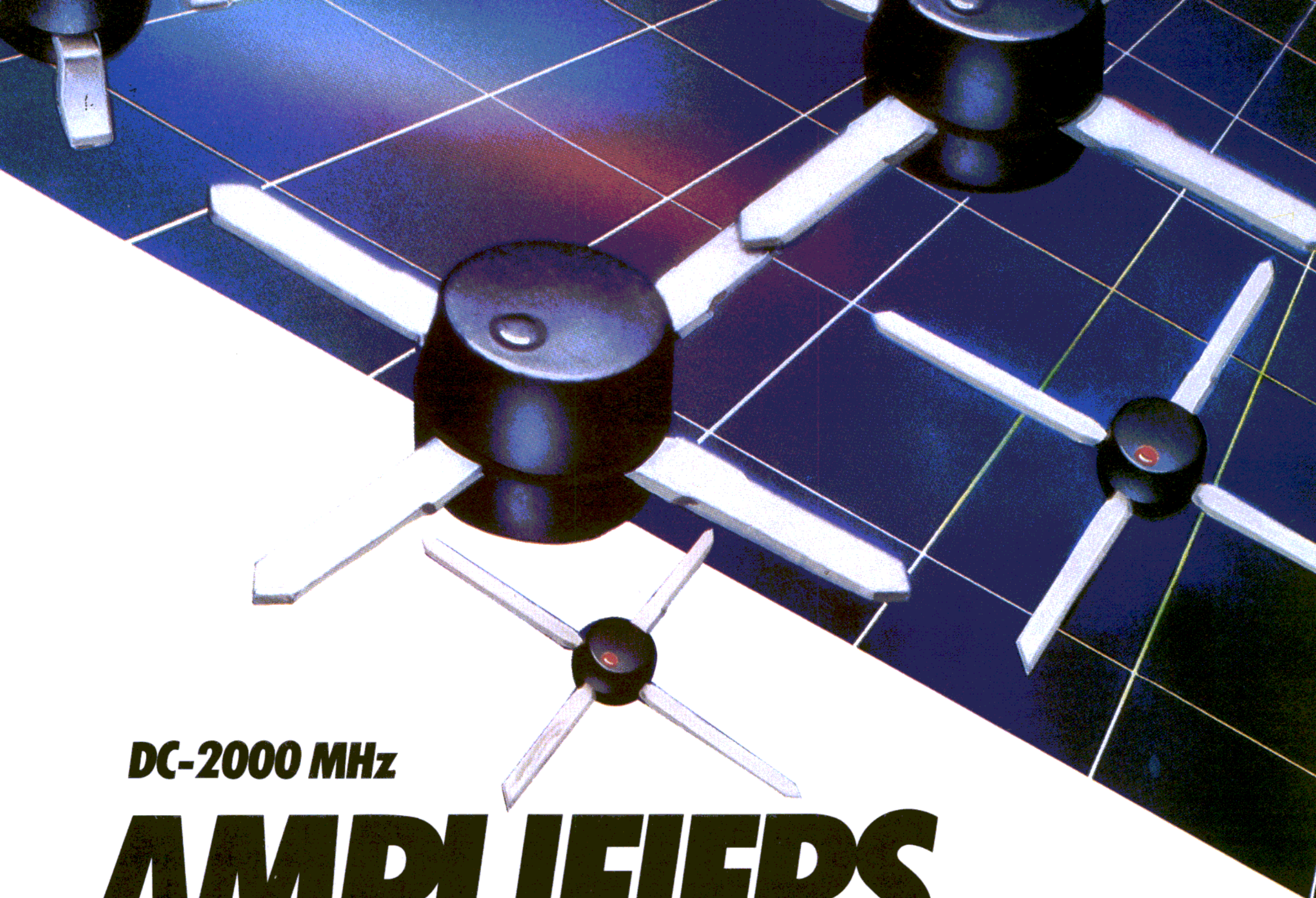
With its structural strength and low coefficients of thermal expansion (see table), the TLC-32 materials have a reduced need for thick metal heat sinks and board-edge stiffening compared to traditional microwave substrates.

The material has been used in a wide range of designs to 15 GHz, including personal-communications-network (PCN) antennas, vehicle tags for automatic toll-collection booths, C- and Ku-band low-noise block downconverters (LNBs), and power dividers. The most common application is power amplifiers for digital cellular and paging-system base stations. In fact, TLC-32 with FR-4 in a multilayer hybrid construction allows RF and digital circuits to be fabricated on the same printed-circuit board. The material is available in thicknesses of 14 mils and greater. **Taconic Plastics Ltd., Microwave Dielectrics Div., Coonbrook Rd., P.O. Box 69, Petersburg, NY 12138; (518) 658-3202, FAX: (518) 658-3204.**

CIRCLE NO. 54

The TLC-32 at a glance

Dielectric constant (at 1 MHz)	3.2
Dissipation factor (at 1 MHz)	0.003
Volume resistivity	10^7 MΩ/cm
Surface resistivity	10^7 MΩ
Peel strength	12 lb./in.
Moisture absorption	<0.02 percent



DC-2000 MHz

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It's just as easy to create an amplifier that meets other specific needs, whether it be low noise, high gain, or medium power. Select from Mini-Circuits' wide assortment of models (see Chart), sketch a simple interconnect layout, and the design is done. Each model is characterized with S parameter data included in our 740-page RF/IF Designers' Handbook.

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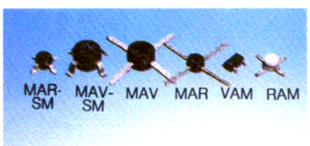


Models above shown actual size

from **99¢** Unit price $ (25 qty)

PLASTIC SURFACE-MOUNT			++VAM-3 1.45		+VAM-6 1.29	++VAM-7 1.75		
add suffix SM to model no. (ex. MAR-ISM)	MAR-1 1.04	MAR-2 1.40	MAR-3 1.50	MAR-4 1.60	MAR-6 1.34	MAR-7 1.80	MAR-8 1.75	
	MAV-1 1.15	+MAV-2 1.45	+MAV-3 1.55	MAV-4 1.65				MAV-11 2.15
CERAMIC SURFACE-MOUNT	RAM-1 4.95	RAM-2 4.95	RAM-3 4.95	RAM-4 4.95	RAM-6 4.95	RAM-7 4.95	RAM-8 4.95	
PLASTIC FLAT-PACK	MAV-1 1.10	+MAV-2 1.40	+MAV-3 1.50	+MAV-4 1.60				MAV-11 2.10
	MAR-1 0.99	MAR-2 1.35	MAR-3 1.45	MAR-4 1.55	MAR-6 1.29	MAR-7 1.75	MAR-8 1.70	
Freq.MHz,DC to	1000	2000	2000	1000	2000	2000	1000	1000
Gain, dB at 100MHz	18.5	12.5	12.5	8.3	20	13.5	32.5	12.7
Output Pwr. +dBm	1.5	4.5	10.0	12.5	2.0	5.5	12.5	17.5
NF, dB	5.5	6.5	6.0	6.5	3.0	5.0	3.3	3.6

Notes: + Frequency range DC-1500MHz ++ Gain 1/2 dB less than shown

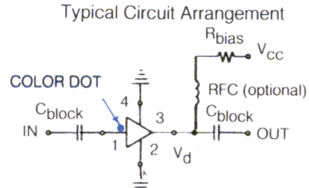
designer's amplifier kits
DAK-2: 5 of each MAR-model (35 pcs), only $59.95
DAK-2SM: 5 of each MAR-SM model (35 pcs) only $61.95
DAK-3: 3 of each MAR, MAR-SM, MAV-11, MAV-11SM (48 pcs) $74.95

designer's chip capacitor kit
KCAP-1: 50 of 17 values, 10pf to 0.1µf (850 pc), $99.95

chip coupling capacitors at .12¢ each (50 min.)

Size (mils)	Value
80 x 50	10, 22, 47, 68, 100, 220, 470, 680 pf
80 x 50	1000, 2200, 4700, 6800, 10,000 pf
120 x 60	.022, .047, .068, .1µf

Typical Circuit Arrangement



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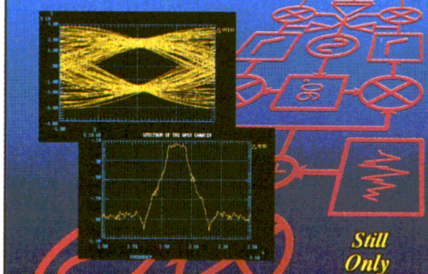

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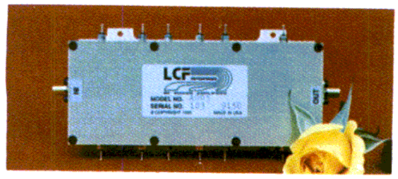

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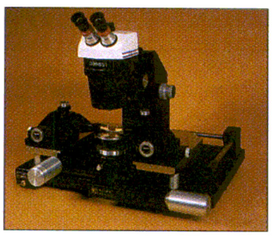

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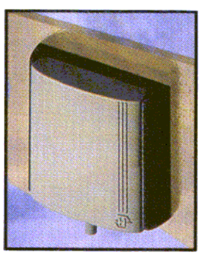

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OCXOs feature –120-dBc/Hz phase noise

The 840 series of oven-controlled crystal oscillators (OCXOs) exhibit –120-dBc/Hz phase noise offset 10 Hz from a 10-MHz carrier. Generating sine-wave output signals in standard units, the oscillators consume 1.5-W power from a +15-VDC supply. Aging is less than 0.1 PPM/yr. Mechanical frequency adjustment is ±1 PPM minimum. The sources measure 2 × 2 × 1 in. (5.08 × 5.08 × 2.54 cm). **Oak Frequency Control Group, 100 Watts St., P.O. Box B, Mount Holly Springs, PA 17065; (717) 486-3411, FAX: (717) 486-5920.**

CIRCLE NO. 111

CATV lasers operate at 1310 nm

The 3620 series of community-access-television (CATV) lasers and board assemblies offers up to 16-mW output power and is available in 600- and 860-MHz versions. The series, which operates at 1310 nm, includes a high-performance distributed-feedback (DFB) laser and an RF predistorter board. **Ortel Corp., 2015 Chestnut St., Alhambra, CA 91803; (818) 281-3636.**

CIRCLE NO. 112

Diplexer crosses at 1.0 GHz

The DP1G-21SS diplexer covers a passband range of 0.5 to 2.0 GHz with maximum VSWR of 2.00:1. Crossover frequency is 1.0 ±0.01 GHz. Maximum insertion loss at the crossover is 5.5 dB, while passband insertion loss at the crossover is 1.5 dB. Minimum attenuation is 60 dB. **FSY Microwave, Inc., 1055 First St., Rockville, MD 20850; (301) 294-8950, FAX: (301) 294-3007.**

CIRCLE NO. 113

Circuit offers 50-MHz clock rate

The model AD7008 monolithic direct-digital-synthesis (DDS) circuit combines a numerically-controlled oscillator (NCO) and a 10-b digital-to-analog converter into a single 44-pin PLCC housing. Clock rates up to 50 MHz are supported. A power-down pin provides 100-mW power from a +5-V supply. Spurious-free dynamic range is –70 dB, signal-to-noise ratio is 50 dB, and total harmonic distortion is –55 dB. Typical integral and differential nonlinearity is ±1 least significant bit. **Analog Devices, Inc., 181 Ballardvale St., Wilmington, MA 01887; (617) 937-1428, FAX: (617) 821-4273.**

CIRCLE NO. 114

Cellular coupler handles 600-W CW

Model CEL30243 is a 50-dB directional coupler designed for cellular-transmitter power-monitoring applications. Minimum directivity is 25 dB, with typical values exceeding 30 dB. Input VSWR is 1.10:1, while insertion loss is 0.25 dB. The coupler is rated at 600-W CW input power. **Loral Microwave-Narda, 435 Moreland Rd., Hauppauge, NY 11788; (516) 231-1700, FAX: (516) 231-1711.**

CIRCLE NO. 115

Filters tune 174 and 512 MHz

A bandpass cavity filter is available in two models. The VHF model covers the frequency range of 132 to 174 MHz while the UHF model operates from 406 to 512 MHz. Frequency stability is typically 0.6 PPM/°C for the VHF model and 0.4 PPM/°C for the UHF model across a –40 to +70°C temperature range. Both models have adjustable loops from 0.5 to 3.0 dB. **RELM Communications, 7707 Records St., Indianapolis, IN 46226; (317) 545-4281, FAX: (317) 545-2170.**

CIRCLE NO. 116

Power sources are ruggedized

The PA and PB series of power sources are available in single- and three-phase models. Nominal VDC output ranges from 24 to 270 V. The models feature 0.99 power-factor correction and a temperature coefficient of 0.01 percent/°C from –55 to +85°C. Mean time before failure (MTBF) is 350,000 hours. **Arnold Magnetics Corp., 4000 Via Pescador, Camarillo, CA 93012; (805) 484-4221, FAX: (805) 484-4113.**

CIRCLE NO. 117

Equalizers have ±0.5-dB linearity

Field-adjustable and fixed gain equalizers in the SME series feature ±0.5-dB linearity from 2 to 18 GHz. Maximum attenuation ranges from 5 to 6 dB, while maximum insertion loss ranges from 0.6 to 1.0 dB. The adjustable units are typically rated at 5-W CW and the fixed units are rated at 0.25-W CW. The series operates from –55 to +95°C. **Sierra Microwave Technology, One Sierra Way, Georgetown, TX 78626; (512) 869-5007, FAX: (512) 869-2730.**

CIRCLE NO. 118

TCXO generates 16 to 75 MHz

Model XO3022C is a temperature-controlled crystal oscillator (TCXO) operating across a 16-to-75-MHz frequency range. Temperature stability is ±0.5 PPM from –25 to +75°C. The TCXO offers 3-mA current from a 5-V supply. The oscillator measures 0.20 × 1.00 × 1.25 in. (0.51 × 2.54 × 3.18 cm). **Piezo Technology, Inc., P.O. Box 547859, Orlando, FL 32854-7859; (407) 298-2000.**

CIRCLE NO. 119

Power systems deliver 550 W

The PS-3 series of power systems is specifically designed for continuous operation in gas-plasma process applications. The series comes in 100-, 300-, and 550-W models. Output frequency is 13.56 or 40.68 MHz, while output impedance is 50 Ω. All even and odd harmonics are at least 60 dB below the fundamental frequency. Input power is 115 or 230 VAC. **Manitou Systems, Inc., 12 Lower South St., Danbury, CT 06810; (203) 792-8797, FAX: (203) 792-7097.**

CIRCLE NO. 120

GaAs MESFET suits L-band

Suitable for L-band applications, the NE345L-10B power GaAs MESFET features typical output power of 10 W (40 dB). Power-added efficiency is 40 percent at 1.6 GHz and 37 percent at 2.3 GHz. Linear gain is 12 dB at 1.6 GHz and 9 dB at 2.3 GHz. Third-order intermodulation distortion is –45 dBc. Total power dissipation is 50 W. **California Eastern Laboratories, Inc., 4590 Patrick Henry Dr., Santa Clara, CA 95056-0964; (408) 988-3500, FAX: (408) 988-0279.**

CIRCLE NO. 121

VCXO ranges from 60 to 150 MHz

Surface-mount voltage-controlled crystal oscillator (VCXO) model VXS-1815C operates from 60 to 150 MHz. The VCXO is able to handle a standard load of 50 Ω ±10 percent. The aging rate is ±1 PPM/year, while harmonics are –20 dBc. The oscillator has a supply current of 5 mA and supply voltage of +5 VDC. **TEW North America, 5903-B Peachtree Industrial Blvd., Norcross, GA 30092; (800) 762-0420, FAX: (404) 441-3076.**

CIRCLE NO. 122

Filter ICs dissipate 95 mW

The 32F810X series of digitally-programmable filter integrated circuits (ICs) boasts a typical power dissipation of 95 mW and less than 1 mW in idle mode at 5-V operation. The filter ICs offer 0.5-deg. linear phase and programmable boost/equalization of 0 to 13 dB. The ICs are available in four frequency ranges: 9 to 27 MHz, 6 to 18 MHz, 4 to 12 MHz, and 3 to 9 MHz. Frequencies are accurate to within ±10 percent. **Silicon Systems, 14351 Myford Rd., Tustin, CA 92680; (800) 624-6999.**

CIRCLE NO. 123

Amplifier spans cellular band

A multichannel, cellular microcell amplifier, model LWA 880-30/14288, is designed for low intermodulation, multicarrier operation from 869 to 894 MHz. Linear output power is 44 dBm at 1-dB gain compression, while the third-order intercept point is 54 dBm. The amplifier has a built-in digital attenuator that provides 30-dB control in 1-dB steps. **Microwave Power Devices, Inc., 49 Wireless Blvd., Hauppauge, NY 11788; (516) 231-1400, FAX: (516) 231-8081.**

CIRCLE NO. 124

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MESFET features 20-W output power

Model NES1818-20B is an L-band GaAs MESFET with a typical output power of 20 W (43 dB). Power-added efficiency is 44 percent and linear gain is 14 dB. Third-order intermodulation distortion is –45 dBc. Total power dissipation is 100 W. **California Eastern Laboratories, Inc., 4590 Patrick Henry Dr., Santa Clara, CA 95056-0964; (408) 988-3500, FAX: (408) 988-0279.**

CIRCLE NO. 125

Cellular diplexer hits 824 to 849 MHz

Featuring maximum VSWR of 1.40:1, a dielectric-resonator diplexer channels frequency bands from 824 to 849 MHz and from 869 to 894 MHz to one common port. Maximum insertion loss is 3 dB across the entire band and 2 dB at the midbands. The receiver portion is followed by a low-noise amplifier (LNA) which can be incorporated into the cellular unit. Dimensions are 3.50 × 1.33 × 0.80 in. (8.89 × 3.38 × 2.03 cm). **K&L Microwave, Inc., 408 Coles Circle, Salisbury, MD 21801; (410) 749-2424, FAX: (410) 749-5725.**

CIRCLE NO. 126

Isolators/circulators handle 50-W power

A family of drop-in isolators and circulators handles 50-W peak power from 8.6 to 18 GHz. Minimum isolation is either 17 or 20 dB. Maximum insertion loss ranges from 0.4 to 0.7 dB and maximum VSWR is 1.50:1. The models operate from –54 to +95°C and are available in circular or rectangular packages. **Sierra Microwave Technology, One Sierra Way, Georgetown, TX 78626; (512) 869-5007, FAX: (512) 869-2730.**

CIRCLE NO. 127

Broadband amps output +10 dBm

Broadband amplifier models MSH-7475201-PS and MSH-3494201-PS operate from 6 to 18 GHz and 0.1 to 3.0 GHz, respectively. The amplifiers have a typical output power of +10 dBm and gain of 26 dB. Input/output VSWR is 2.00:1 maximum, while noise figure is 5.0 dB. The amplifiers measure 5.4 × 3.0 × 1.9 in. (13.72 × 7.62 × 4.83 cm). **Microwave Solutions, Inc., 3200 Highland Ave., Suite 3A, National City, CA 91950; (800) 967-4267, FAX: (619) 474-7003.**

CIRCLE NO. 128

LNA provides +60-dBm intercept

Model RF-2286A is a low-noise amplifier (LNA) which provides an output second-harmonic intercept point of +60 dBm. The frequency range is 0.5 to 1.5 GHz. Small-signal gain is 16 dB with ±0.5-dB gain flatness. The noise figure at +25°C is 3.5 dB, while output power at 1-dB compression is +14 dBm. The LNA requires 250-mA current. **Locus, Inc., P.O. Box 740, State College, PA 16804; (814) 466-6275, FAX: (814) 466-3341.**

CIRCLE NO. 129

Resonators/inductors cover 0.3 to 6.0 GHz

A line of coaxial resonators/inductors offers a typical quality factor (Q) of 1000 from 0.3 to 6.0 GHz. The quarter- or half-wavelength components feature a dielectric constant of 38.6 or 90.5. The components range in size from 2 × 2 mm to 12 × 12 mm. **Trans-Tech, Inc., 5520 Adamstown Rd., Adamstown, MD 21710; (301) 695-9400, FAX: (301) 695-7065.**

CIRCLE NO. 130

Antenna covers 820 to 900 MHz

Covering the 820-to-900-MHz frequency range, the FP-5016 directional antenna delivers 5 dB of gain. The unit offers vertical polarization and 1.50:1 VSWR. Input power is rated at 100 W and impedance is 50 Ω. **Radiation Systems, Inc., Mark Antennas Div., P.O. Box 1548, Des Plaines, IL 60017; (708) 298-9420.**

CIRCLE NO. 131

Transistors feature 1.0-dB noise figure

The BFG500, BFR500, and BFS-500 series of RF bipolar transistors operate from 0.9 to 2.0 GHz. Noise figure ranges from 1.0 to 1.2 dB, while gain ranges from 16 to 19 dB. The series offer optimized performance at collector currents as low as 0.5 mA. **Philips Components, Discrete Products Div., 2001 W. Blue Heron Blvd., Riviera Beach, FL 33404; (800) 447-3762, (407) 881-3200, FAX: (407) 881-3300.**

CIRCLE NO. 132

Chip capacitors work to 5000 VDC

A line of surface-mount ceramic chip capacitors offers voltage ratings from 500 to 5000 VDC. The capacitors come in six standard EIA chip sizes: 1206, 1210, 1808, 1812, 1825, and 2225. They are available with solder-plated, nickel-barrier terminations and can be packaged in 8- or 12-mm embossed tape. **Johanson Dielectrics, Inc., 15191 Bledsoe St., Sylmar, CA 91342; (818) 364-9800, FAX: (818) 364-6100.**

CIRCLE NO. 133

Power amplifier handles 2 GHz

The PM2102 is a low-voltage GaAs MMIC power amplifier developed for digital wireless applications in the 2-GHz frequency range. RF output power is +27.5 dBm and DC-to-RF efficiency is 50 percent. The PM2102 is able to operate off a 3-V battery. **Pacific Monolithics, Inc., 245 Santa Ana Court, Sunnyvale, CA 94086; (408) 732-8000, FAX: (408) 732-3413.**

CIRCLE NO. 134

Test set spans 45 MHz to 50 GHz

Designed for use with the HP 8510C vector network analyzer, the HP 8517B test set spans the frequency range of 45 MHz to 50 GHz. When Option 007 is added to the test set, available power is –14 dBm and system dynamic range is 75 dB at 50 GHz. Other features include an internal broadband-input amplifier and a tapered attenuator. **Hewlett-Packard Co., Direct Marketing Organization, P.O. Box 58059, Mail Stop 51L-SJ, Santa Clara, CA 95051-8059.**

CIRCLE NO. 135

Switches cover DC to 2.2 GHz

A series of electromechanical switches operates from DC to 2.2 GHz. Insertion loss is 0.2 dB maximum, while isolation is 80 dB minimum. Switching time is 15 ms maximum. The switches handle 150 W at 1 GHz with SMA connectors and 400 W at 1 GHz with type N connectors. **Loral Microwave-Narda, 435 Moreland Rd., Hauppauge, NY 11788; (516) 231-1700, FAX: (516) 231-1711.**

CIRCLE NO. 136

SONET filter passes 2.488 GHz

A 2.488-GHz timing-recovery filter designed for SONET applications provides a 6-dB bandwidth of 6.3 MHz. Insertion loss is 20 dB and first-sidelobe attenuation is 30 dB. The filter is available in a TO-39 or surface-mount package. **Sawtek, Inc., P.O. Box 609501, Orlando, FL 32860-9501; (407) 886-8860, FAX: (407) 886-7061.**

CIRCLE NO. 137

Power divider/combiner goes four ways

Four-way power divider/combiner model CEL30373 can combine power signals of up to 25 W per channel or take a 100-W CW input and divide it into four equal levels. Maximum insertion loss is 0.55 dB and isolation between channels is 20 dB. **Loral Microwave-Narda, 435 Moreland Rd., Hauppauge, NY 11788; (516) 231-1700, FAX: (516) 231-1711.**

CIRCLE NO. 138

Coaxial protectors shield DC to 2 GHz

The PTC series of coaxial protectors provides shielding from lightning or electromagnetic pulses (EMP) from DC to 2 GHz. Available in a variety of connector types (including BNC, SMB, TNC, and SMA), the protectors can handle 5, 10, or 20 kA of input current. Insertion loss is 0.20 dB and VSWR is 1.25:1 at 2 GHz. **NexTek, Inc., 439 Littleton Rd., Westford, MA 01886; (508) 486-0582, FAX: (508) 486-0583.**

CIRCLE NO. 139

Oscillators span 600 MHz to 3 GHz

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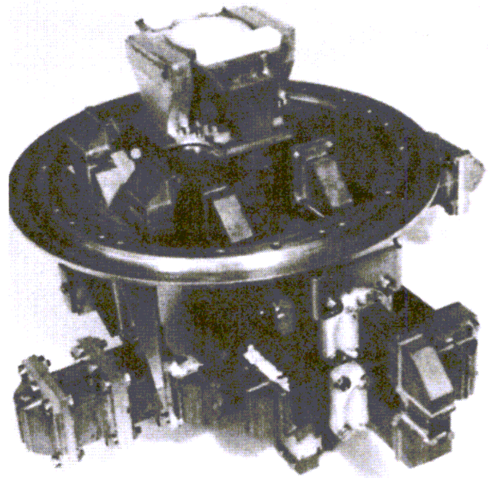

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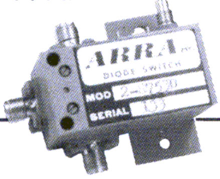

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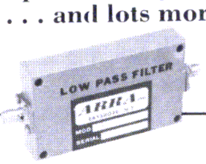

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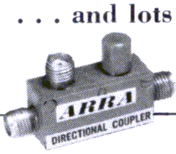

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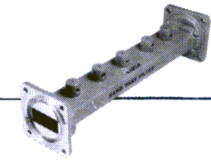

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