RFdesign™

engineering principles and practices

August 1993

Cover Story

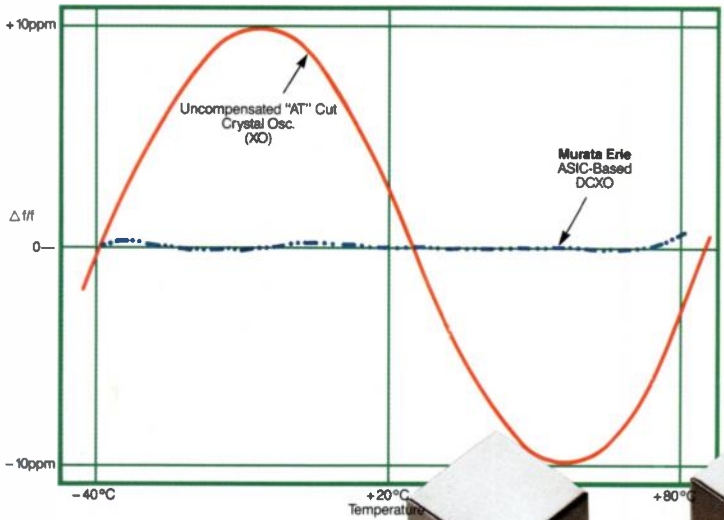
Chipset Targets 900MHz RF Applications

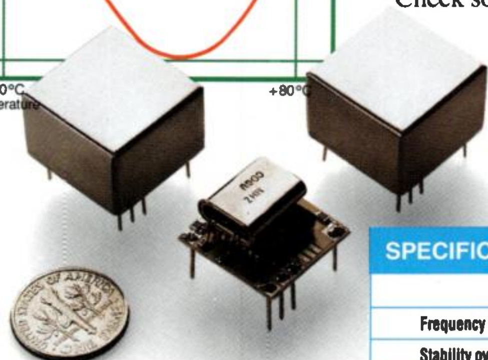
Featured Technology

Wireless System Design

No compromise necessary.

Murata Erie's new ASIC-based DCXO





Excellent frequency stability has been a fact of life with crystal oscillators for years. So has small size (a relative term), low cost and flexibility. **But**, did you ever try to get everything that you needed in a single oscillator/package? No way. One, maybe two desirable characteristics but certainly not all. You had to compromise.

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SPECIFICATIONS

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Short Term Stability	1×10E−9 @ T=1 sec.
Package Size	0.79" × 0.79" × 0.45", PC PINS

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INFO/CARD 2

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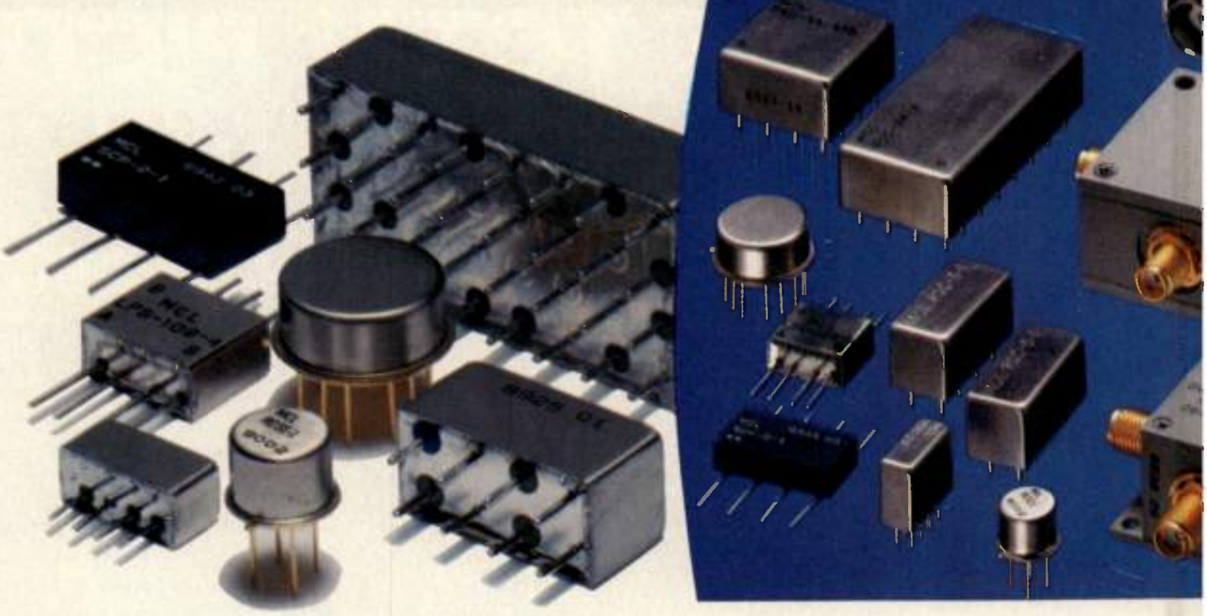

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SP2T	5-4000	1.0	79	0.035	TTL	SMA	CDSO882
SP4T	20-2000	0.9	72	3.000	TTL	SMA	CDSO624
SP2T	10-2000	0.60	82	1.000	TTL	14 Pin DIP	DSO052
SPST	10-2000	1.8	67	0.035	TTL	14 Pin SMP	DSO790
SP2T	DC-2000	0.7	50	0.200	TTL	TO-5	DSO813-T
SP4T	DC-2000	1.7	70	0.075	TTL	14 Pin DIP	DSO874

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6	10-1000	1-63	4.2	0.050	TTL	24 Pin DIP	DAO886
7	DC-1000	0.5-63.5	7.1	0.100	TTL	38 Pin DIP	DAO897
7	10-1000	0.5-63.5	6.4	0.035	TTL	SMA	CDAO867

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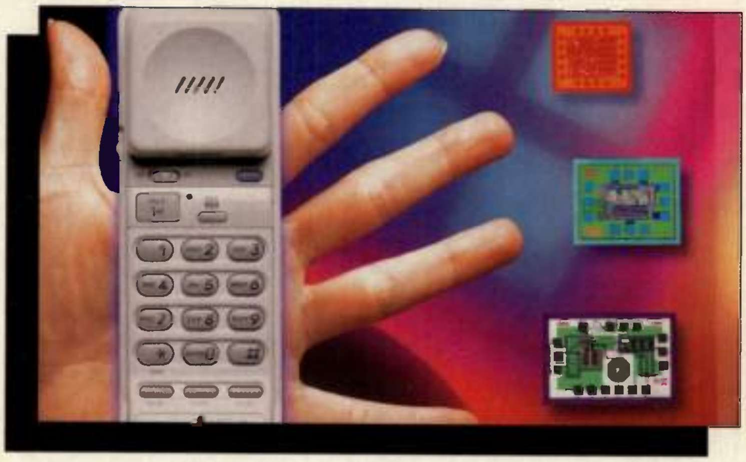
INFO/CARD 4

RF design

contents

August 1993

featured technology



cover story

tutorial

design awards

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RF editorial

Will New RF Markets Create or Cost Jobs?

By Gary A. Breed
Editor

Many potential new RF markets involve consumer products and widely- used commercial products. Since these types of electronic products are typically manufactured offshore, isn't this really just an opportunity for the Pacific Rim and other regions to take more dollars from U.S. consumers?

How about another question: If services like shop-at-home, pay-per-view and banking-by-phone become as popular as some would predict, wouldn't they eliminate jobs in retail stores, entertainment establishments and banks?

There are a lot of RF applications being developed that could radically change the way people go about their personal and business lives. We would all like our own parts of the RF business to be successful, but are there effects on the rest of the country that we should be concerned about? Here are some ideas to consider:

First, regarding offshore manufacturing of consumer products — If there are no changes in our business practices, new consumer products will be manufactured outside the U.S. and have little benefit for our industries. We can avoid catastrophe by taking the initiative. Part of the excitement surrounding these new products is that they represent new markets big enough to justify investment in advanced manufacturing. Motorola and Philips have had notable success in large-scale U.S. electronics manufacturing, as have Honda and Nissan in the automotive industry. It is my feeling that there is no inherent disadvantage to manufacturing in the U.S. — but we're sadly out of practice and we need some new equipment. New RF products may be the excuse we need to catch up again.

On the subject of services that cut jobs out of the traditional buying and selling scheme, I have other thoughts entirely. I don't believe that such stay-at-home services will become universal (at least, not for a long time). Some of these services will find enough users to support them, while others will never reach critical mass. Humans are social animals and the marketplace is a natural gathering place, whether it is a bazaar in Marrakesh or the local shopping mall. Although there are video stores on every corner, films are bringing in record revenues. Despite video games in every home, amusement parks are full and sporting events are sold out. No, I don't think there is a job threat.

These two questions illustrate the two sides of the market. First, paying customers decide whether an application is a success. They will decide on the value of 500 cable channels or the ability to order new shoes from the beach using a wireless personal digital assistant. On the other hand, where successful products are manufactured is not important to the customer. He or she only wants the right combination of price, performance and quality. If U.S. industry wants a larger number of these products to be made here, now is the time to quit talking and start acting.

RF design

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What does that get you? An extensive line of RF connectors and cable assemblies including standard SMA, SMB, SMC, SSMB, SSMC, K, TNC, N, Slide-on, QPL and Between-Series adapters as well as custom designs built to meet the most exacting standards. All delivered on time. Every time.

Take, for example, our MCX connectors. Lighter and more compact than SMBs, they're an ideal choice for small, portable 50 ohm applications ranging to 3 GHz. And for a low-cost, easy assembly cable junction to printed circuits, take a look at our two-piece coaxial terminators. They come in a variety of styles for popular RG series and similar cable types and allow pre-assembly to simplify wave soldering.

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INFO/CARD 8

GIGA-TRONICS 8540 UNIVERSAL POWER METER

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Incredible is credible when describing the 8540 Series of Universal Power Meters.

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For the very first time, you can make CW *and* peak power measurements quickly and accurately with a single meter—a Universal Power Meter.

And all for about the same price you'd pay for the competitor's CW *only* power meter.

The two-line display also lets you set the desired resolution and select either Lin or Log readout for each line.

POWER MEASUREMENTS INSTANTLY

Imagine seeing display updates instantly: measurement speeds over the GPIB exceeding 200 readings per second and an exclusive Burst Mode capturing more than 2,000 readings in the same tick of a clock.

And because the 8540 Series uses diode sensors, you can measure all the way from −70 to +20 dBm with the same sensor, and without range changing delays.

If you're worried about having to write new code for your computer controlled testing, don't be: The 8540 Series uses the same GPIB command set as HP's 436A, 437B and 438A.

Think about what all this will do for your ATE productivity as well as for your company's bottom line.

FAST, EASY PEAK POWER MEASUREMENT

Now, an easy-to-use CW power meter can also measure pulsed RF signals with the simple addition of a peak power sensor.

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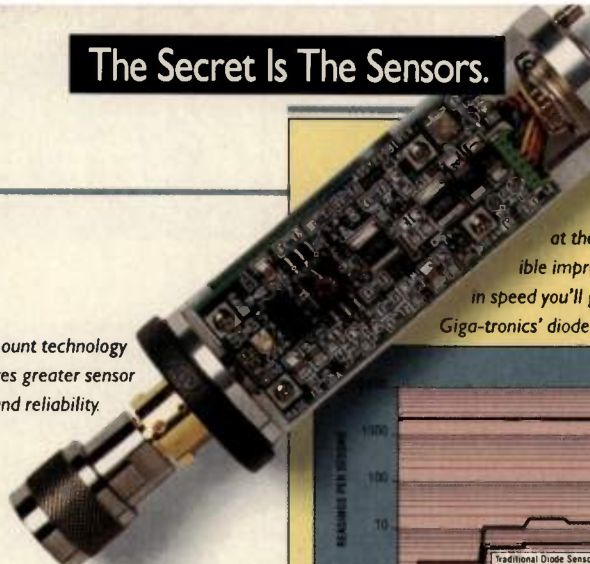
View the pulsed signal's amplitude profile on a scope and see the exact power measurement point on the pulse. Measure the overshoot. Measure the droop.

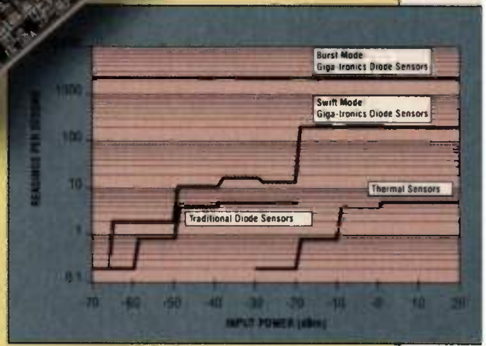
The 8540 Series features intelligent design and sophisticated software. The result is a simplified front panel and extensive built-in capabilities that prevent many common operational mistakes that typically lead to inaccurate measurements.

The Secret Is The Sensors.



Surface Mount technology assures greater sensor accuracy and reliability.

Just look at the incred-ible improvement in speed you'll get with Giga-tronics' diode sensors.



The Giga-tronics 8540 Series delivers incredible performance by taking full advantage of the speed and dynamic range of diode sensors.

What's more, Giga-tronics has solved the challenge that previously limited diode sensors to the "square law" region—below −20 dBm—by utilizing a built-in power sweep calibration system. So you get speed and a full 90 dB dynamic range without sacrificing accuracy.

You'll be confident of your peak power readings, and still have all the benefits of an incredibly fast CW power meter.

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If a single-channel meter is what you need, the Model 8541 is the meter for you. But if you need two-channel capability, the Model 8542 lets you see readings from both channels *simultaneously.*

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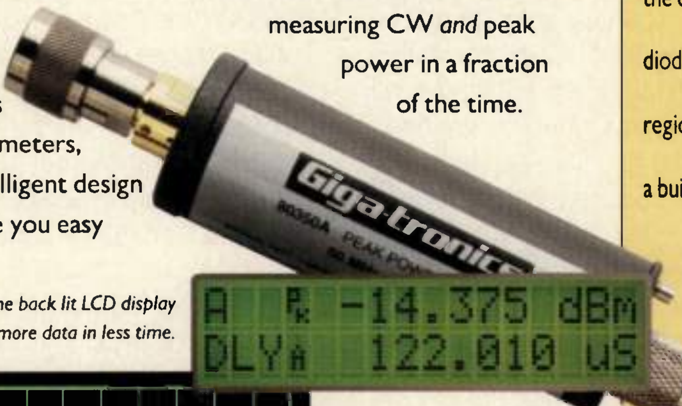
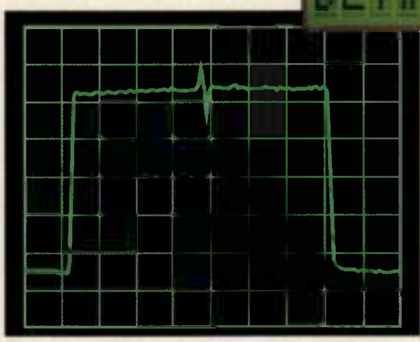
The 8540 Series has only half as many controls as other power meters, but don't let that fool you. Intelligent design and sophisticated software give you easy access to extensive built-in capabilities.

For example, you use the same key to zero and calibrate the power sensors. The meter automatically determines the function you want by detecting whether a sensor is connected to the calibrator.

Imagine all this power and performance. But why just imagine? Get the truly incredible Giga-tronics 8540 Series Universal Power Meter, and start measuring CW *and* peak power in a fraction of the time.



A two-line back lit LCD display provides you more data in less time.



The peak sensor adds a marker on a monitor output for setting an exact measurement point on pulsed signals.

Call us toll-free at **1 800 726 GIGA.** Outside the U.S. call your local Giga-tronics representative, or call 001 408 734 5780. We'll send you more information or arrange for an incredible hands-on demonstration.

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INFO/CARD 9

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RF letters

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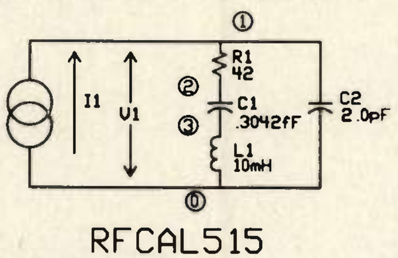
More Simple RF Calculations

Editor:

I read with interest the article by Andrzej Przedpelski on "A Comparison of Simple Software Methods for RF Calculations", (*RF Design*, May 1993). I have for many years searched for less expensive and better software for both my private consulting practice and my engineering students. I have used Lotus™ and taught/consulted on Mathcad™. The one I have found most useful is PSPICE™. Its cost is dependent on what version/features are used. The student version was less than $100 in 1992. It has a wide variety of features including noise, transient and Monte Carlo analysis. I have enclosed the solution to the example given in the article, obtained with the student version of PSPICE.

To produce this solution, I first wrote a .cir file showing the defining nodes and links with the proper values. The file RFCAL515 is defined in Figure 1. From there on it was simply a matter of doing the analysis per the program's procedures. Figure 2 shows the resulting impedance magnitude plot. [*Plots showing series and parallel resonance were also produced, but are not reproduced here. Ed.*] The weakness in this student version is that the graphics are rather primitive, however, a cursor feature allows fine analysis.

G. Burton Harrold, P.E.
Manlius, NY




```
RFCAL515     G. B. Harrold     May 15,1993
RDC 1 0 9000000
R1 1 2 42
C1 2 3 0.0003042pF
C2 1 0 2pF
L1 3 0 10mH
V1 1 0 AC 1
.AC lin 100 91.248meg 91.26meg ; *ipsp*
.PLOT AC I(V1)
.probe     ; *ipsp*
.options numdgt = 8  ; *ipsp*
.END
```

Figure 1.

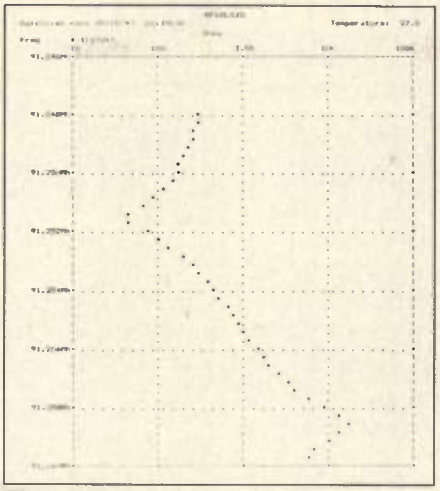


Figure 2.

Early Single Sideband

Editor:

I enjoyed your article entitled "A Historic Look at RF Modulation Methods" in the February, 1993 issue of *RF Design*. At the risk of being called a "nit-picker", I'd like to offer a slight correction. You implied that single-sideband modulation was developed after WW II, when in fact it was already in commercial use by AT&T for trans-Atlantic radiotelephone service in the 1930's.

My first exposure to SSB was in 1943, when I studied it at various AT&T facilities as part of my Signal Corps training. Later on, I was NCO-in-Charge of a major Army transmitting station in Australia where, among other equipment, we used a Western Electric D-156000 SSB transmitter on our circuit to San Francisco. (The SSB receiver was at a different facility several miles away.)

A unique feature of the W.E. system was the use of both sidebands. The upper SB carried six two-tone RTTY channels, and the lower SB was used for a voice "order wire". (It was necessary to change frequency several times a day, and this was coordinated over the order wire.) The LSB was also used for a special super-secret scrambled voice circuit popularly referred to as the "Green Hornet", because it sounded like a swarm of angry insects. Supposedly, General MacArthur used it to talk directly with the Pentagon.

An IRE paper explaining the AT&T system was published in the *Proceedings of the IRE*, Volume 26, pp. 1431-1454, Dec., 1938.

Elmer P. Orvis, KD5KE
Sherwood, AR

RF calendar

August

18-21 **IEEE 1993 International Geoscience and Remote Sensing Symposium (IGARSS '93)**
Tokyo, Japan
Information: Mr. Natsuhiko Motomura, Remote Sensing Technology Center of Japan, 7-15-17 Roppongi, Minato-ku, Tokyo 106, Japan. Tel: +81-3-3403-1761. Fax: +81-3-3403-1766.

18-21 **International Symposium of Radio Propagation (ISRP '93)**
Beijing, P.R. China
Information: Prof. Zong Sha, China Research Institute of Radiowave Propagation, P.O. Box 138/93, Xinxiang, Henan 453003, China.

24-26 **Advanced Microelectronic Qualification/Reliability Workshop**
Denver, CO
Information: Dorthy Kelly, GTS, Inc., 3100 Route 138, Wall, NJ 07719. Tel: (908) 544-3231. Fax: (908) 389-3992.

25-2 **XXIV General Assembly of the International Union of Radio Science (URSI)**
Koyoto, Japan
Information: Prof I. Kimura, c/o Osaka Office, Business Center for Academic Societies of Japan, 10th Tabuchi Bldg, 6-3 Matsugaecho, Kita-ku, Osaka 530, Japan. Tel: (81) 6-356-6041. Fax: (81) 6-356-6190.

30-3 **European Conference on Circuit Theory and Design**
Davos, Switzerland
Information: Prof. J. Neirynck or Mrs. Renate Agotai. Tel: (41) 1-256-51-93. Fax: (41) 1-262-08-23.

September

6-9 **23rd European Microwave Conference and Exhibition**
Madrid, Spain
Information: Microwave Exhibitions and Publishers, 90 Calverley Road, Tunbridge Wells, Kent TN1 1BR, England.

6-9 **Third International Symposium on Antennas and EM Theory (ISAE '93)**
Nanjing, P.R. China
Information: Prof. Wen Xun Zhang, Chairman of TPC, ISAE '93, Southeast University, Nanjing 210018, P.R. China. Fax: (86) 25-713-019.

6-10 **IREECON 1993**
Melbourne, Australia
Information: TWI, International Exhibition Logistics, 3190 Clearview Way, San Mateo, CA 94402. Tel: (415) 573-6900. Fax: (415) 573-1727.

8-11 **NAB Radio Show**
Dallas, TX
Information: Andy Peluso, NAB Radio Show Registration '93, 1771 N Street, NW, Washington, DC 20036-2891. Tel: (202) 429-5350. Fax: (202) 429-5406.

12-16 **International Electronics Packaging Conference**
San Diego, CA
Information: I.E.P.S., 114 N. Hale Street, Wheaton, IL, 60187. Tel: (708) 260-1044. Fax: (708) 260-0867.

RF courses

Radar Design Workshop
August 17-19, 1993, Atlanta, GA
Information: Georgia Institute of Technology, Continuing Education. Tel: (404) 894-2547.

RF and High Speed Digital Circuit Components: Measurements, Models and Data Extraction
August 16-20, 1993, Los Angeles, CA
Information: UCLA Short Course Program Office. Tel: (310) 825- 1047. Fax: (310) 206-2815.

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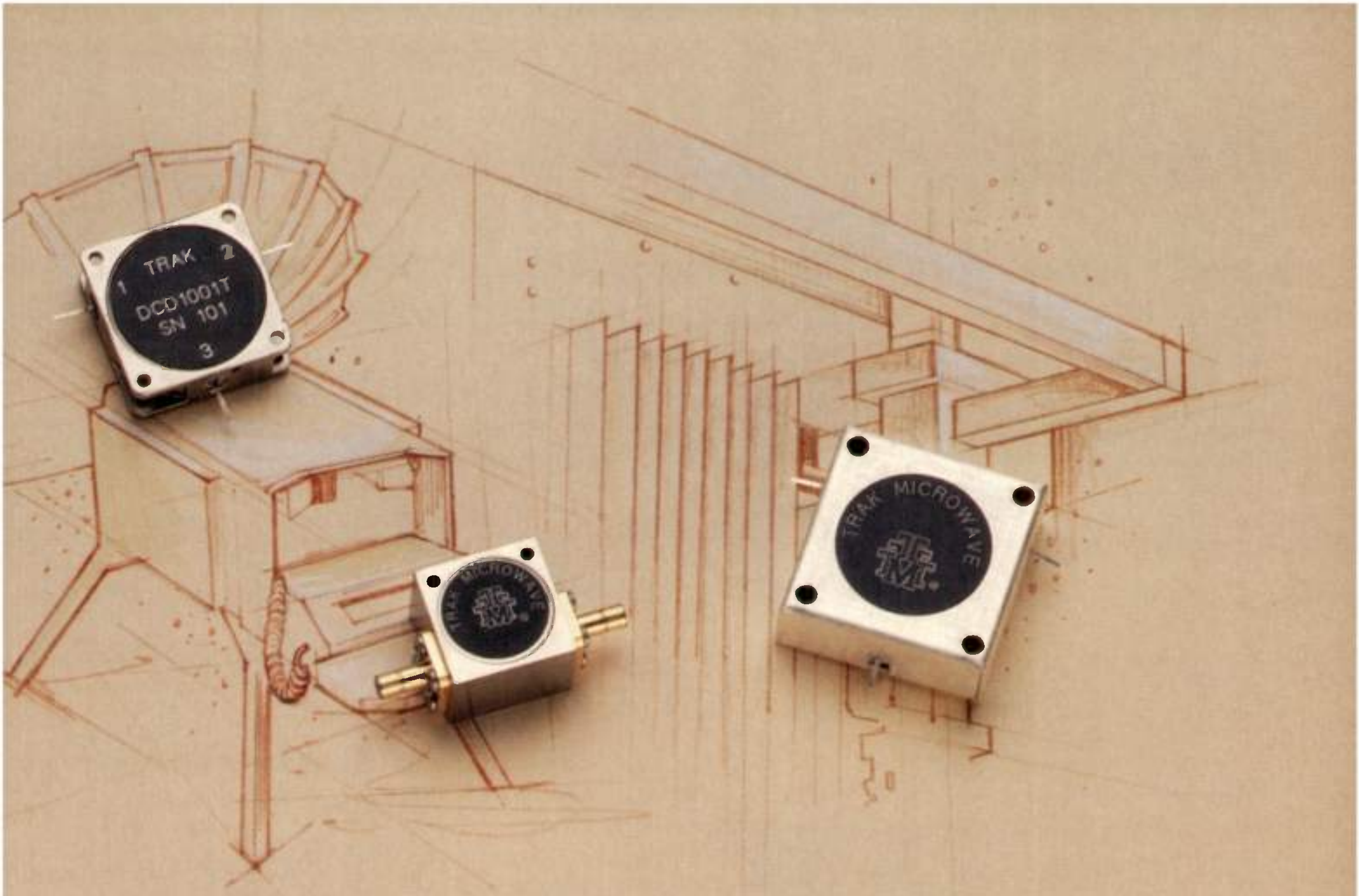

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Virginia Tech Symposium Spotlights Young Professors

The Third Virginia Tech Symposium on Wireless Personal Communications was held on the Virginia Tech Blacksburg campus June 9-11. The symposium is held to exchange both theoretical and experimental research results in wireless communications. The conference has become a major forum for presentation of work done by young professors and their graduate researchers at many different universities. Most presentations addressed the errors that arise from RF transmission in an environment subject to fading, multipath and interfering signals. These papers describe error-correction methods, transmission path simulation, beam-steering, adaptive coding and other specific methods for improvement of signal integrity. Papers of particular interest to RF designers include a description of the modulation method and system architecture used by MTEL for its newly-approved 24 kbit/s paging system with talk-back/acknowledgement capability. Also, a research group from UCLA described progress on an ARPA-funded 915 MHz handheld communicator, which utilizes custom 3-volt CMOS integrated circuits for all transceiver functions, including the RF front-end. Proceedings have been published, and all papers will be included in an upcoming book. To obtain these publications contact the Mobile and Portable Radio Research Group at Virginia Tech, tel. (703) 231-5643.

MTEL Receives Paging System Approval

The Federal Communications Commission has granted a pioneer's preference license to Mobile Telecommunications Technologies Corp. (MTEL) for their Nationwide Wireless Network paging system. The MTEL system will operate on 50 kHz channels in the 900 MHz band. A unique multicarrier modulation scheme allows a high data rate in a multipath environment. For each channel, eight sub-transmitters are spaced at 5 kHz intervals, each transmitting a 4-FSK data signal. Four-of-eight on-off keying of the transmitters results in a total data transmission rate of 24 kbit/s. This high data rate allows much more information to be transmitted than conventional paging, allowing longer messages or images to be transmitted. The system also includes a talk-back feature which allows each user to send an acknowledgement or reply message.

325 Attend Frequency Control Symposium

The 1993 IEEE International Frequency Control Symposium, held June 2-4, drew 325 attendees to Salt Lake City. A description of the new U.S. Primary Frequency Standard, NIST-7 was presented, as was a fast, new way of making phase noise measurements. Among the other topics discussed at the symposium were time and frequency coordination using GPS, and the application of piezoelectric transducers for pressure and viscosity sensing. The 1994 Frequency Control Symposium will be held June 1-4, 1994, in Boston, MA.

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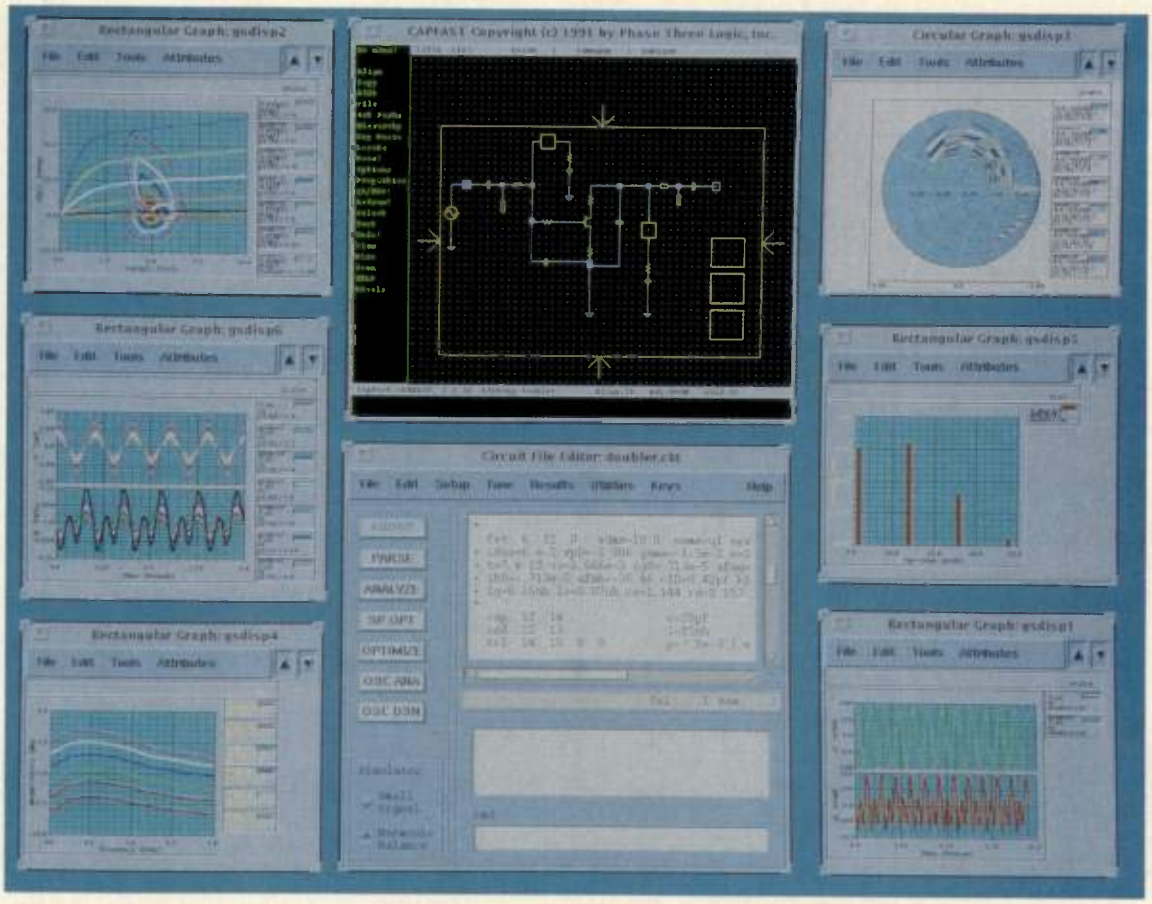

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SME Education Foundation 1993 Grants Awarded — The Manufacturing Engineering Education Foundation of the Society of Manufacturing Engineers recently announced its 1993 grant winners. MEEF awarded $11.3 million in grants, equipment and software to 102 universities and technical institutions across the country. Total gift distribution in 1993 included $10.8 million to support in kind equipment including CAD/CAM software, milling machines, lathes and robots. Cash grants totaled $490,810 in five funding areas: capital equipment, student development, faculty development, curriculum development and research initiation. Applications for 1994 funding will be available in October from the SME Foundation by calling Dora Murray, grants coordinator, (313) 271-1500 ext. 512.

Comlinear and TriQuint Form Alliance — Comlinear Corporation and TriQuint Semiconductor recently announced the formation of an alliance to commercialize Acoustic Charge Transport (ACT) technology. ACT, fabricated in GaAs, is a high-speed analog signal processing technology that brings massive computational power to challenging electronic opportunities such as data storage, digital audio broadcast, and other potential applications including speech processing, wireless communications, video processing and collision avoidance. Both companies will be jointly seeking strategic partners in specific application areas in order to develop multichip modules of GaAs and silicon that work together as complete solutions.

Oak Industries and the Sural Group Announce Crystal Venture — Oak Industries Inc. and the SURAL Group have announced the formation of a strategic alliance between Oak's McCoy and Croven crystal operations and SURAL's Alfa Quartz affiliate. The initial focus of the venture will be to market and sell high quality quartz crystal blanks and other related products manufactured by Alfa Quartz and used in the production of frequency control devices such as crystals, filters and oscillators. The venture will market and sell its products worldwide under the name of McCoy International.

Development of a New Transfer Standard — A long-standing problem for measuring microwaves has been providing a meaningful traceability between NIST's primary (six-port) microwave measurement system and automated vector network analyzers used extensively in government and private industry. Existing methods require numerous connections to the six port system; these connections are time consuming and a major source of measurement error. A new NIST cooperative research and development agreement with ATN Microwave calls for the partners to use programmable multistate tuners as a transfer standard. This requires only one connection and should reduce significantly the amount of operator effort needed. NIST will initially evaluate the stability of ATN's tuner and then work with the company to develop state-of- the-art statistical methods for uncertainty analysis. For more information, contact Bob Judish of NIST at (303) 497-3380 or Mike Fennelly of ATN Microwave at (508) 667-4200.

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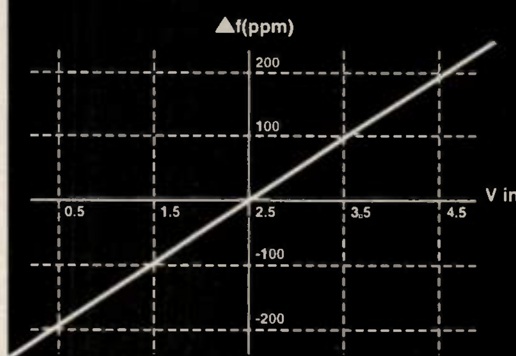

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New Company Formed — Watchband RF Contact Springs is a new company formed to manufacture helically wound springs with wide flat surfaces for use in high power RF contact applications as well as EMI/RFI shielding. Their address is Watchband RF Contact Springs, 1485 Roosevelt Trail, Raymond, ME 04071. Tel: (207) 655-3259.

Portable Two-Way Radio Celebrates 50 Years — The FM two-way portable radio was developed fifty years ago at the request of the U.S. Army Signal Corps. Motorola developed the SCR-300 "walkie-talkie" backpack radio using a design that incorporated FM circuits. The radio was developed in the midst of World War II and reached the battlefields in 1943. The first FM two-way portable radios had a range of 10 to 40 miles, weighed 35 pounds, and could operate over multiple frequencies.

Motorola's SCR-300 "walkie-talkie" backpack radio was among the most significant communications advances of World War II. Designed for the U.S. Army Signal Corps in 1943, it was the world's first FM two-way portable radio.

Bell Atlantic Mobile to Provide Cellular Digital Packet Data — Based on sophisticated Cellular Digital Packet Data (CDPD) technology, being developed by a consortium of the largest cellular carriers, Bell Atlantic Mobile plans to deploy the service in its six regions nationwide by the end of 1994. Bell Atlantic Mobile has selected AT&T Network Systems to help bring its wireless digital data service to Washington, DC customers in November 1993. CDPD technology finds unused space in a network of voice messages and fills it with the "1s" and "0s" of digital code. The new service will allow people on the move to transmit high-speed bursts of information — inserted before and after voice conversations — on a single, wireless channel, using a laptop or pen-based computer or personal digital assistant.

Broadcasters Initiate Electromagnetics Study — The National Association of Broadcasters is seeking bids to develop new techniques that will help radio and TV stations comply with proposed safety guidelines relating to electromagnetic fields caused by broadcast tower emissions. The new techniques are needed to help broadcasters meet new RF exposure guidelines proposed by the FCC. The FCC guidelines were proposed as part of ET Docket 93062. The Commission is proposing to adopt a voluntary industry standard called ANSI C95.1-1992. NAB plans to submit the results of the study as part of its own comments to the FCC due later this year.

SOITEC Establishes U.S. Headquarters — Silicon-on-Insulator Technologies (SOITEC), recently announced the formation of SOITEC/USA. A commercial spinoff of LETI (the French technology and instrumentation laboratory), SOITEC is a producer of very high quality silicon-on-insulator substrates for use in making advanced semiconductor devices. SOITEC/USA is located at 2 Centennial Drive, Peabody, MA 01960. Tel: (508) 531-2222.

Frequency Electronics Sell Product Lines — Frequency Electronics, Inc. has entered into an agreement to sell their components, detector log video amplifiers and digital frequency discriminator product lines to the Signal Technology Corporation. The divestiture of these product lines leaves the company with a broad capability in all areas of microwave assemblies for spacecraft and ground station converters in addition to a dominant position of Frequency Electronics in the time and frequency control markets. Financial terms of the contract were not released.

ADC Kentrox Acquires Waseca Technology — ADC Kentrox has announced the acquisition of Waseca Technology Inc., an RF development company. Details of the contract were not disclosed, however company sources indicate that the two companies have been working closely over the past year on their recently introduced CityCell™ Digital Microcell System.

Monitor Receives NASA Contract for TCXOs — Monitor Products recently announced that they were chosen by NASA to supply hybrid oscillators and discrete tight tolerance TCXOs for the Fast Auroral Snapshot Explorer (FAST) Satellite. The oscillators are key elements in controlling the heart of the FAST control and data handling system, Small Explorer Data System. The FAST satellite, which weighs approximately 400 pounds is scheduled to be launched into Earth orbit in August 1994 by an Enhanced Pegasus expendable launch vehicle.

Harris Wins Saudi Radio Contract — Harris RF Communications has been awarded a $52 million contract by the U.S. Army Communications Electronic Command (CECOM), to provide HF radio systems to the Saudi Arabian National Guard. The contract calls for Harris to supply RF-5000 FALCON-Series HF digital tactical radio systems. They will be installed in vehicles and base station sites. Harris will provide Arabic-language data terminals, turnkey logistical support and technical assistance.

Stanford Telecom to Supply Viterbi Decoders — Stanford Telecommunications, Inc. has announced that its ASIC & Custom Products Division has entered into an agreement with Scientific-Atlanta, Inc. to develop and supply a specialized ASIC device for use in delivering Scientific-Atlanta's MPEG-based digital video compression over satellite for the cable TV and other markets. Financial terms of the agreement were not disclosed.

New Services Overhead

By Andy Kellett
Technical Editor

Makers of RF equipment for satellite systems have their choice of markets to which they can sell. Large geosynchronous satellites are still being built to satisfy the needs of regions which are striving to connect to the rest of the worldwide telecommunications network. Low Earth Orbit (LEO) systems such as Motorola's Iridium will connect individual users' voice and data traffic to the telecommunications net from anywhere in the world. Direct Broadcast Satellite (DBS) is already an established provider of television programming in Europe, Asia and South America, and is about to be launched in the U.S. In addition to these communications systems, NAVSTAR Global Positioning Service (GPS) is emerging as a widely used utility. Military systems, (of which GPS is one) are also an important part of today's satellite electronics market.

Satellite Services

Geosynchronous satellites, and their associated ground station equipment, continue to be a large part of the satellite communications market. According to David Hartshorn, editor of *Satellite Communications* magazine, there is pent up demand for connection to the rest of the worldwide communications network in places like Eastern Europe, Asia, Latin America, and the Middle East. "These countries know that domestic and international connectivity drive hard currency earnings, so they are trying to accelerate their entry to the global marketplace by getting satellites up as fast as they can or by accessing existing orbital capacity." Keith Morrison, Regional Sales Manager for Trak Microwave noted that not only do they sell oscillators, isolators, circulators and multipliers into new Asian and Eastern European satellites, they are also selling parts for next generation satellites in established systems like Intelsat and Inmarsat.

Another service which primarily employs geosynchronous satellites is DBS. Virtually unknown to consumers in the U.S., DBS is established in Europe, Asia and South America, and is probably the biggest market for manufacturers of satellite communications equipment. DBS transmits television programming to earth stations in the Ku band. The higher frequency allows DBS receivers to use antennas a only few feet across. "We sell a large number of components into DBS terminals," notes Gary LaBelle, Product Marketing Manager for Wireless Components at Hewlett-Packard Co. According to Satellite Communication's Hartshorn, the first high-power, U.S. consumer version of this service will debut next year.

In addition to DBS, other satellite systems are trying to find a market in the United Sates. The U.S. is well covered by wired and cellular telecommunications, but where these systems leave gaps, satellite services are vying to fill in. For this type of service, many companies are planning to employ LEO satellites. These satellites are smaller and less expensive than geosynchronous types. Mostly deployed in "constellations" of a dozen or more spacecraft, LEO satellites are placed in polar orbit so that several satellites are constantly visible to receivers on earth. The 66 LEO satellites belonging to Motorola's Iridium constellation are planned to provide voice and data communication anywhere on earth. Scientific Atlanta, as part of the group producing Iridium, will supply gateway terminals along with telemetry, tracking and control terminals. "Iridium is truly a revolutionary concept in the satellite communications area," says Theodore R. Wieber Jr., President of the Electronic Systems Division of Scientific Atlanta. "It brings what is traditionally NASA and DoD types of technology, namely orbiting rather than geosynchronous technology, to a commercial communications application."

Now that smaller, rapidly developing conflicts are the main concern of the U.S. military, real-time intelligence is more important than ever to U.S. tactical forces. "The military is still a major player in the satellite business," says Roger Lesser, Editor of *Defense Electronics* magazine. According to Lesser, the retirement of older reconnaissance aircraft like the SR-71 Blackbird has put more of the intelligence gathering burden on satellite systems. In addition to reconnaissance, the military also has a need for communication satellites. Modern weaponry produces torrents of data. In some instances, satellites are used to relay this data from the battlefield to the command center. Many of these military satellites are now being designed to provide civilian services also; these programs are said to have "dual-use".

The prototypical example of a dual-use system is NAVSTAR GPS. From its inception in the mid 1970's, GPS was intended to be a military system which afforded some use by civilians. Today, GPS is viewed as a utility. Using differential GPS it is even possible to attain military accuracies (less than 1 meter) with the civilian, C/A coded signal. Users can calculate their own differential GPS fix, or they can use Pinpoint, a Magnavox project which transmits GPS corrections over local FM radio broadcast subcarriers. In addition to its use as a navigational and surveying tool, GPS is finding use as a time base.

Satellite Technology

Satellite systems are touched by most of the same technological advances that are affecting the rest of the RF industry. Digital transmission and digital signal processing are the norm across the satellite industry. Among the most important processing for satellite users is video compression using the MPEG and JPEG standards. Video compression under these standards provides three times or more the traffic capability of uncompressed video. Higher integration is bringing the cost of complex systems down. GEC Plessey is one of a few companies producing chipsets for GPS receivers. Their four chip set includes a SAW filter, downconverter, autocorrelator and processor. According to Dan Sowin, Plessey's Marketing Manager for Navigation Systems, "Now it is a matter of reducing GPS receiver size, power consumption and cost. I think through high integration technologies like these we have the answer to those issues."

Once the province of governmental and semi-governmental agencies, satellite systems are entering a new era in which market forces can demand new systems and technology can supply them at an affordable price. ***RF***

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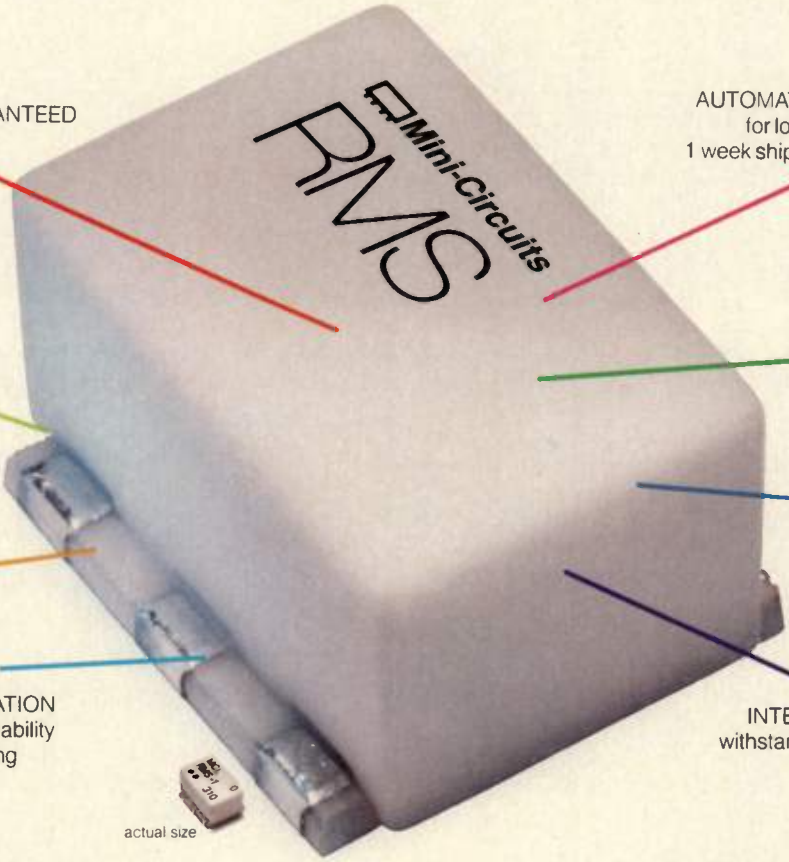

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INFO/CARD 27

Improved Design Equations for Part 15/ISM Microstrip Bandpass Filters

By Theodore S. Rappaport and Alan S. Fox
Virginia Polytechnic Institute and State University

It is well known that microstrip transmission line coupling can provide reliable and inexpensive filtering at microwave frequencies (1,2,3). As fiber optic communications and personal wireless communications systems evolve, microstrip filters designed on a wide variety of dielectric materials and board thicknesses will be required in microwave sub-carrier transmission equipment (4) and pocket-sized two-way radio equipment (5).

In this work, the basic equations and techniques for designing microstrip filters were extracted from the published literature (1-3, 6-15) and implemented in a design procedure. Approximately 100 filters within the 900 MHz to 5800 MHz range were designed and constructed from published equations using different substrate thicknesses and ε_r values. We found that the measured responses of these filters consistently showed errors in center frequency when a variety of substrate thicknesses or ε_r values were used. These errors have led us to attempt to relate theoretical design techniques to experimental results. The large data base of measured filter responses was analyzed using regression techniques to find qualitative relationships between center frequency error and numerous design parameters. The data indicate that a correction factor for the length of microstrip resonators is needed, and that this length correction is a function of both center frequency and substrate thickness. From this work, we propose that the well accepted microstrip bandpass filter design equations given previously in References such as (2,3,10,11 and 14) include a modified length correction factor to facilitate more accurate microstrip filter design for a wide variety of microstrip filters. While this experimental study has concentrated on a relatively small class of filters (i.e. Butterworth filters having fewer than six poles, designed on inexpensive substrates for use in the low microwave region), it offers insight into the design and error analysis of microstrip filters in general, and may have applications to future edge correction techniques.

Microstrip Bandpass Filter Design

The filter design method for microstrip filters studied in this paper uses a lumped-element, lowpass prototype technique to derive the necessary bandpass transmission characteristics for a Butterworth (maximally flat) filter. A mathematical mapping is made between the transmission characteristics of the desired bandpass response and those of the lowpass prototype (3). The lowpass prototype parameters are lumped element values (capacitances and inductances). These capacitances and inductances are paired and act as resonators. The prototype parameters are then converted to inverter parameters, which are then converted to mode impedances. The mode impedances are used to determine the dimensions of the filter resonator pairs. We used published techniques from (2,3 and 10) to explicitly compute the mode impedances for a wide variety of filters using different ε_r values, thicknesses, and frequencies in the low microwave region. Then, an iterative method described in (16) was used to find appropriate design dimensions. Length and width corrections were then determined for the resonator segments by measuring the tuning needed to eventually provide the desired center frequency response.

Length Correction Factors

The length of the resonator pair segments, L_r, are theoretically one quarter wavelength long at the center frequency of the filter. The wavelength used in this calculation is that found by using the frequency dependent effective dielectric constant. That is,

$$L_r = \frac{\lambda_g}{4} = \frac{c}{4\ f\ \sqrt{\varepsilon_{eff}(f)}} \qquad (1)$$

In practice, the actual length of each resonator is not exactly a quarter-wavelength, due to electrical lengthening of the resonator by fringe capacitance. Authors have proposed length correction factors to predict the necessary length subtraction at the end of each resonator segment in microstrip filter designs. The adjustment of the resonator length affects the resonant frequency of the resonator, and therefore, the center frequency of the filter.

A correction factor cited in (3) and (12) accounts for fringing capacitance at the ends of each resonator. This correction factor, d, is only a function of the substrate thickness, and is given by,

$$d = -0.165h \qquad (2)$$

That is, for a specific center frequency, equation 2 suggests microstrip filters should use resonator segments with $L_r = \lambda_g/4 + d = \lambda_g/4 - 0.165h$. However, as described in (12), equation 2 was experimentally justified by the measured response of just one stripline filter (10). Stripline is similar to microstrip, except the substrate and ground plane sandwich the resonators. Experimental results published in (13) give a correction factor for microstrip filters as

$$d = -0.33h \qquad (3)$$

which is exactly twice the value of equation 2. It is not clear from (13) how many filter responses, substrate thicknesses or center frequencies were used to determine the experimentally based correction factor in equation 3.

Unfortunately, in previous work deal-

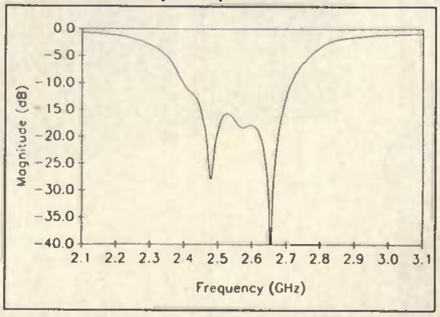

Figure 1. S_{11} (return loss) of filter 2440200A. Measured center frequency is about 4 percent higher than the desired 2440 MHz center frequency.

Y	X	A_0	A_1	r
$\%\Delta F$	T	–0.155	16.6	0.60
$\%\Delta F$	F	$-1.75E^{-3}$	10.8	0.59
$\%\Delta F$	BP	0.125	3.88	0.15
$\%\Delta F$	P	0.104	4.68	0.02
914 $\%\Delta L_r$	T	–0.076	14.1	0.72
2400 $\%\Delta L_r$	T	–0.162	21.0	0.80
2440 $\%\Delta L_r$	T	–0.118	13.9	0.89
4000 $\%\Delta L_r$	T	–0.161	15.8	0.87
5790 $\%\Delta L_r$	T	–0.268	19.8	0.88
$\%\Delta L_r$	T	–0.164	16.6	0.62
$\%\Delta L_r$	F	$-1.86E^{-3}$	10.5	0.61
$\%\Delta L_r$	BP	0.139	3.17	0.17
$\%\Delta L_r$	P	$-7.14E^{-3}$	4.32	0.001
$\%\Delta L_r$*	F	$-1.80E^{-3}$	10.1	0.60
$\%\Delta L_r$*	T	–0.155	15.8	0.59

Notes:
* denotes plot without data points corresponding to CEM-1 substrate
F = Center Frequency (MHz)
L_r = Resonator Length (mils)
B = 3 dB Bandwidth (MHz)
T = Substrate Thickness (mils)
BP = Percentage Bandwidth (B/F)
P = Number of Poles
L_i = Insertion Loss (dB)

Table 1. Linear regression equation ($y = A_0X + A_1$) coefficients and correlation coefficients (r) for the data base of 60 filters.

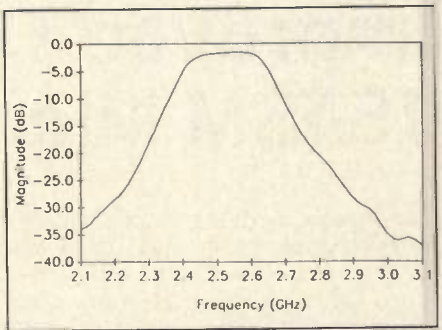

Figure 2. S_{21} (gain) of filter 2440200A. Despite error in center frequency, the passband is very flat.

ing with length correction factors, little information is available concerning the exact design methodology used to determine the uncorrected resonator lengths, and therefore it is unknown what values of $\varepsilon_{eff}(f)$ were used in length calculations. Therefore, one of the goals in this work was to carefully evaluate the major parameters for a class of filters using an extensive data base of measured responses.

Filter Name	f_c (MHz)	Measured Response BW (MHz)	A (dB)	f_{stop} (MHz)	L (dB)	S_{11} 10dB Bandwidth (MHz)
91450C-42	915	45	20	842/1004	2.6	30
914100D-42	920	112	20	752/—	4.3	79
914200A-42	930	184	15	748/—	0.7	134
244050B-42	2416	82	15	2218/2706	2.6	24
2440100D-42	2460	98	25	2270/2646	12.9	98
400050A-42	3950	160	10	3715/4269	6.2	24
4000400B-42	3988	523	15	3579/4433	2.4	—
5790100C-42	5921	251	10	5669/—	4.6	88
5790200A-42	5653	223	10	5293/5902	8.5	—
57901K2B-42	6036	1332	10	4997/6921	2.8	745
91450C-42P	903	54	20	820/1006	4.3	37
914100D-42P	918	114	20	747/—	4.3	85
914200A-42P	930	174	15	752/—	0.7	125
244050B-42P	2450	102	15	2231/2714	2.4	34
2440100D-42P	2456	101	25	2267/2626	13.7	84
400050A-42P	3921	146	10	3695/4354	6.7	—
4000400B-42P	3993	457	15	3614/4450	1.9	97
5790100C-42P	5962	346	10	5641/—	5.2	191
5790200A-42P	5603	275	10	—/5867	8.4	271
57901K2B-42P	6060	1323	10	4988/6953	2.0	1277

Table 2. Measured responses of two batches of bandpass filters designed with new resonator length correction factor given by equations 5 and 6.

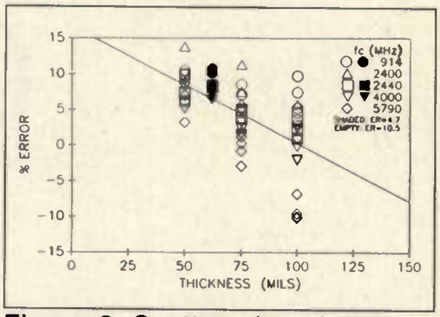

Figure 3. Scatter plot of percent resonator length error versus substrate thickness for 60 filters.

CAD of Microstrip Bandpass Filters

To design a microstrip bandpass filter for a specific operating characteristic, it is necessary to determine the widths, spacings, and lengths of all filter resonator pairs and input/output feed lines. These dimensions depend on several substrate characteristics as well as the desired filter response.

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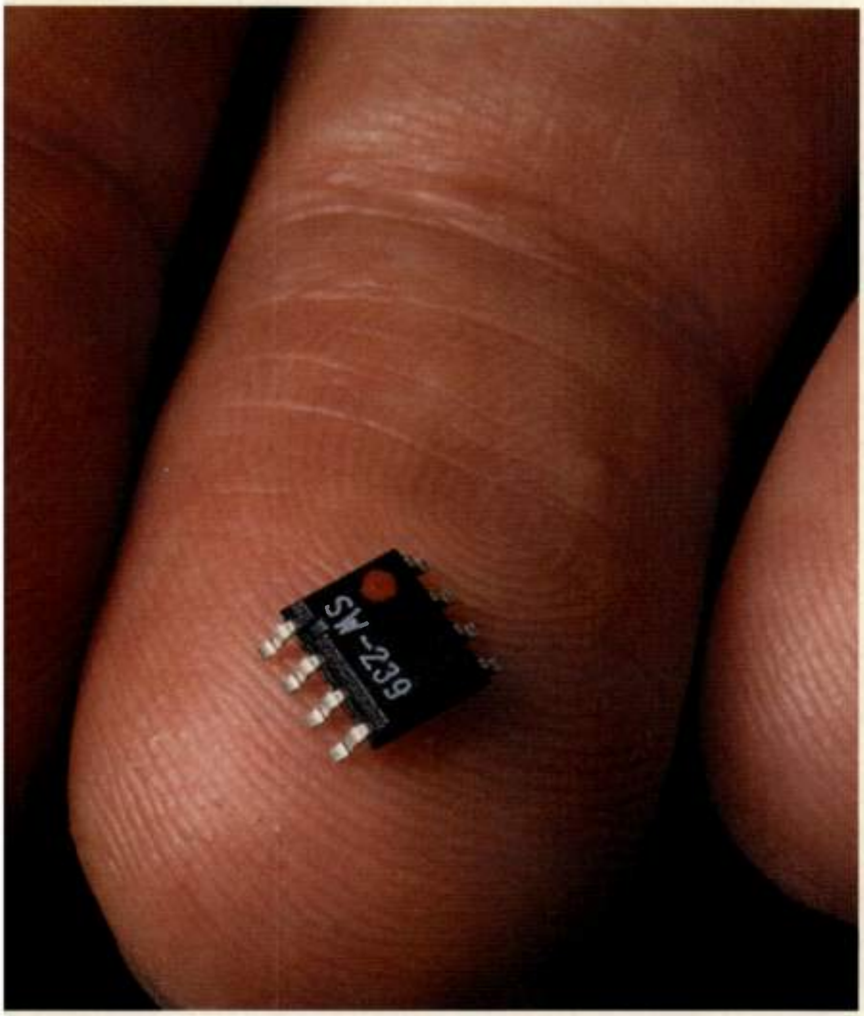

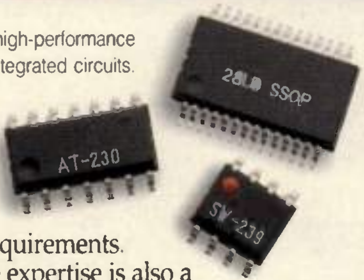

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bandpass filter design are:

Center Frequency (f_c in MHz)
3 dB pass band bandwidth (BW in MHz)
Stop Band Attenuation (a in nepers, or A in dB)
Stop Band Frequency (f_{stop} in MHz)
Characteristic Impedance (Z_0 in ohms)
Relative Epsilon (ε_r) of the substrate
Substrate Thickness (h in mils)
Conductor Thickness (t in mils)

The desired transmission response is derived from a lowpass prototype response. After the desired bandpass response is determined, a conversion is made to a lowpass prototype response. The design procedure is well documented in the literature (i.e. (2)), and computer program implementations for the design procedures used in this work are given in (16).

The odd and even mode impedance values, Z_{0o} and Z_{0e}, for a pair of microstrip coupled lines can equivalently be modeled as the odd and even mode impedances for a single microstrip line (2,17). These impedances are then used to obtain design ratios w/h and s/h. Finally, width and length correction factors are applied to the design ratios, which are then multiplied by the substrate height to yield physical dimensions for filter construction.

Experimental Evaluation of Design Equations

Our original hypothesis was that the published design techniques outlined in the previous section were robust with respect to dielectric substrate thickness, substrate dielectric constant, and filter center frequency within the low microwave frequency regime. This hypothesis was based on the fact that we did not find published results which considered such parameters explicitly in the design equations. To test the robustness of bandpass filter design techniques to substrate thickness, dielectric constant, center frequency, and passband bandwidth, we fabricated over 100 microstrip filters with center frequencies between 900 MHz and 5800 MHz. The filters we tested used between 1 and 5 poles, and were fabricated using rubilith mask and a photoetching procedure which produced reliable line widths and spacings to within a mil. To ensure accurate fabrication using etching techniques and reproducibility with hand taping techniques, microstrip line widths and spacings exceeded 10 mils for all filters. We found that by using careful hand taping procedures, it was possible to consistently recreate filters within several mils of photoetched counterparts.

The three types of substrate used for filter fabrication in this work are listed below.

1) CEM-1 is a substrate supplied by Norplex/Oak, Inc. and uses a core of cotton linter paper and surface plies of woven glass fabric. CEM-1 has typical ε_r of 4.7, and is commonly used for inexpensive printed circuit board applications. Recently, it has been used for inexpensive no-tune microstrip filter design (18,19). Substrate height of 62 mils was used.

2) Rogers Duroid 6010 PTFE is a PTFE-based substrate with ε_r values near 10. Heights of 50, 75 and 100 mils were used for substrates with nominal ε_r = 10.5.

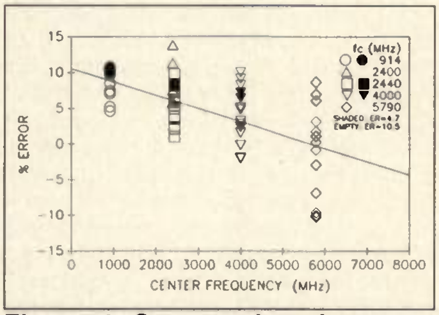

Figure 4. Scatter plot of percent resonator length error versus nominal center frequency for 60 filters.

3) Rogers Duroid 6010 PTFE with nominal ε_r of 10.8 and h = 100 mils was used to study the responses of several of the first fifteen bandpass filters developed in this work.

Using the design procedure outlined in Section 2, fifteen filters were first designed and fabricated with a variety of length correction factors. Experiments revealed that a length correction factor which is independent of frequency resulted in filter resonances which differ from desired values by as much as 10 percent over the 900 MHz to 5800 MHz range, depending on the substrate material or thickness used. Insertion loss values, passband widths, and passband shapes of the fabricated filters, however, were very close to values predicted by published design equations (16). Experimentally observing the length correction factor's frequency dependence led us to conduct controlled experiments using a variety of frequencies and substrates in the low microwave frequency region.

Sixty filters, with desired center frequencies of 914, 2400, 2440, 4000 and 5790 MHz and with desired 3 dB pass band bandwidths of 50, 100, 200, 400, 800 and 1200 MHz were developed on all three substrates and thicknesses listed above. The correction factor given in (3) was used to determine resonator lengths for all filters.

The insertion losses and return losses for all fabricated filters were reasonably close to desired specifications (insertion losses were within a couple dB of theory for most filters, and return losses were well below 10 dB throughout a large portion of the pass band for all filters). As an example, Figures 1 and 2 show the return loss (S_{11}) and transmissivity (S_{21}) of filter 2440200A, a filter with a desired center frequency of 2440 MHz and 200 MHz 3 dB passband bandwidth, built on Rogers Duroid 100 mil substrate with ε_r = 10.5. Figures 1 and 2 were measured using an HP 8510, and describe the characteristics of a filter using resonator lengths derived from the correction factor given by equation 3. The figures, which are typical of measured data, show that the measured frequency is several percent higher than desired. As shown subsequently, our work shows that equation 3 yields center frequencies which are consistently higher than desired, except for filters designed at frequencies above 4 GHz on the 100 mil substrate. That is, equation 3 overestimates the length subtraction needed to provide resonance at the appropriate frequency for a majority of the filters we constructed, and under-estimates the length subtraction for other filters. The next section shows that the appropriate

correction is a function of both substrate thickness and desired center frequency. Other measured parameters, such as stopband attenuation and passband bandwidth, agree closely with design specifications.

The need for a length correction factor which holds for a broad family of filters became evident from the actual responses of a large number of filters developed using methods described in the literature. Our filter data base involved a large number of filter responses made with a wide variety of resonator lengths and substrates which have permittivities differing by over a factor of two. From the wide range of measured center frequencies for the filters, we found that the actual center frequencies of the filters ranged between –5 percent and 5 percent of the desired design frequency (16). Thus, we strived to develop an accurate length correction factor which could be represented as a percentage of the uncorrected resonator segment length (i.e. $\lambda_g/4$) for the wide range of frequencies, permittivities, and substrate thicknesses used in our work.

A set of sixty filters was built using resonator lengths of $L_r = \lambda_g/4$ with no resonator length correction factor. From the resulting measured filter responses, scatter plots were made using percentage center frequency error or percentage resonator length error as the dependent variable, and the following filter parameters were each considered as the independent variable: center frequency, 3 dB bandwidth, percentage bandwidth, number of poles, dielectric constant, and substrate thickness. From these scatter plots, it was possible to see which filter design parameters were most acutely affected (i.e. were highly correlated with) center frequency error. Linear regression analysis (20) was used to statistically analyze and quantize the results of the new set of filter responses in order to determine how the length correction factor is affected by various design parameters. Some design parameters, such as the specified stop band attenuation and stop band frequency, were implicitly accounted for by the number of poles. The conductor thickness had a negligible effect on design dimensions, and was therefore not considered. Loss tangent and conductor conductivity were used only in the calculation of theoretical insertion loss, and were not considered as causes for center frequency error. Details of the various analyses are given in (16). For brevity, only the important results are given here.

Enhanced Resonator Length Correction Factor

Linear regression analysis for one independent variable was used to find correlations between the dependent variable and the above mentioned filter design parameters. The correlation coefficient, r, is an estimate of how well the given data is approximated by the regression curve, and is defined in (20). For each scatter plot, two graphs were made: one with data points corresponding to the center frequencies and dielectric constants, and one with data points corresponding to the filter bandwidths.

These plots allowed us to quickly determine if the independent variable had a significant effect on the center frequency accuracy. We used percentage differences, rather than absolute differences, so the operating wavelength or frequency did not bias the error statistics. Examples of such plots are given in Figures 3 and 4. The linear regression equation coefficients and the correlation coefficient for Figures 3 and 4 are given in Table 1. The far right column of Table 1 represents the correlation coefficient between the filter parameters in columns X and Y. A_0 and A_1 denote coefficients for the best-fit line through the scatter plots, and Y is the dependent variable which depends on the independent design parameter X under test.

Previous work has produced length correction factors which are dependent solely on substrate thickness. Our data confirms that the length correction indeed depends on substrate thickness. Table 1 shows there is a high correlation ($0.72 \le r \le 0.89$) between $\%\Delta L_r$, which we call the percent error in resonator segment length defined as the percent difference between the uncorrected resonator length and the actual corrected resonator length needed to provide the desired center frequency response) and T (the substrate thickness). The correlation coefficient decreases slightly to 0.62 when all filter responses are lumped together without regard for center frequency. The scatter plot in Figure 3 shows the relationship of substrate thickness to resonator length error. It can be seen that for smaller values of T, the uncorrected length is consistently too large, and that this error is largest at the lower frequencies. For filters built on T = 100 mil substrates, however, the error has zero mean, and for the highest frequency tested (5790 MHz), it appears that resonator length must be increased over the uncorrected length.

Our data also show that there is a high correlation between $\%\Delta L_r$ and the operating frequency F, as indicated by Figure 4 and the correlation coefficient value of 0.61 in Table 1. Figure 4 shows that over a wide range of passband bandwidths (i.e. number of poles), there is a higher spread of resonator length error at higher frequencies. Figure 4 also shows how the average resonator length error is a strong function of the center frequency. Thus, we conclude that both thickness and the center frequency should be included in a resonator length correction factor. In (16), we show that $\%\Delta L_r$ is also weakly affected by passband bandwidth, as well. This can be seen from Table 1, where the percentage bandwidth of the filters show a correlation of 0.17 with the resonator length correction factor needed for proper center frequency operation.

Having determined that correction factors are highly correlated (r>0.5) with both substrate height (T) and frequency (F), we use dual variable linear regression to determine the best linear fit for the data base. The dependent variable was $\%\Delta L_r$, and the independent variables were substrate height and desired center frequency. From (16), the best (minimum mean square error) resonator design length was found to be

$$L_r = (\lambda_g/4)[1 - \%\Delta L_r/100] = \frac{c}{4 f\sqrt{\varepsilon_{eff}(f)}}[1 - \%\Delta L_r/100] \quad (5)$$

where the correction factor $\%\Delta L_r$ is given by

$$\%\Delta L_r = (-1.8352\times10^{-3})f_c + (-1.6146\times10^{-1})h + 22.627. \quad (6)$$

and f_c is the desired center frequency in MHz and h is the substrate thickness in mils. The dual-variable normalized correlation coefficient for equation 6, which was found using the entire data base of filter responses, is r = 0.75, which is 25 percent higher than the correlation coefficient calculated for the single variable linear regression performed on either the center frequency or substrate thickness alone. This high value of correlation confirms that the correction factor is a function of both center frequency and substrate thickness. The standard error of estimate is on the order of 2 percent for the dual variable regression result in equation 6, compared with approximately 9 percent for each of the single vari-

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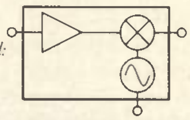

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able cases. The frequency dependence of equation 6 indicates it is necessary to decrease the designed resonator length as both frequency and substrate thickness decrease. We note that equation 6 should not be considered valid for designs which use filter parameters much different than those considered in this study, but it may turn out that similar behavior occurs in a broader class of filters than those considered here.

To test the correction factor in equations 5 and 6, we redesigned 10 filters from the original group of 60 using the design techniques used earlier, except equations 5 and 6 were was used instead of equation 3 to determine corrected resonator segment lengths. The 10 filters, which were carefully hand taped, represented a random sampling of the data base that incorporated all frequencies, pass band widths, and substrates used in this study. The result was a set of filters which exhibited significantly less error between desired and actual operating frequency as compared to the same filters built using standard correction factors, although the filters at 5790 MHz experienced center frequency errors on the order of ±3 percent, even with the new correction factor.

Table 2 lists the measured responses of two separate batches of the 10 filters, which were designed using equations 5 and 6 in a computer program called USTRIP4.2 (16). The last 10 filters listed in Table 2 were hand taped by a new graduate student in order to verify the repeatability of manual fabrication techniques. it can be seen from Table 2 that by using equations 5 and 6, the average center frequency error is well below 0.5 percent for filters operating at and below 4 GHz, as compared to about 5 percent frequency error for the original filter data base.

Conclusion

A microstrip bandpass filter design procedure has been developed from equations available in the literature. We found that filters using previously published length correction factors consistently exhibited discrepancies between measured and desired center frequency over the 900 MHz to 5800 MHz band when a variety of substrates were used. This work developed an enhanced length correction factor based on the measured responses of many edge-coupled Butterworth microstrip filters. From the data base of filter responses, we performed linear regression to find a new length correction factor, equations 5 and 6, that is a function of both substrate height and desired center frequency. This correction factor improves the center frequency performance of microstrip filters in the low microwave region. Specifically, the new correction factor reduces average center frequency error from 5 percent to less than 0.5 percent for several frequencies and substrate types. A PC-based design program that uses the enhanced correction factor for Butterworth microstrip filter design has been developed (16) and is available from the authors. ***RF***

Acknowledgements

The authors thank Rogers Corporation for providing numerous samples of Rogers Duroid 6010 PTFE substrate, and Professors W.A. Davis and A. Elshabini-Riad for their assistance with the fabrication and measurement of filters developed in this work. This work was supported by the MPRG industrial affiliates program, Virginia's Center for Innovative Technology, and by a grant from AICOMM, Inc., Raleigh, N.C.

References

1. I.J. Bahl and D.K. Trivedi, "A Designer's Guide to Microstrip Line", *Microwaves,* May 1977.
2. K.C. Gupta, R. Garg, and R. Chadha, *Computer Aided Design of Microwave Circuits,* Artech House, Inc., Dedham, Mass., c. 1981, pp. 82-84.
3. G.L. Matthaei, L. Young, E.M.T. Jones, *Design of Microwave Filters, Impedance Matching Networks, and Coupling Structures,* Artech House, Inc., Dedham, Mass., c. 1980.
4. D.A. Fishman, "A Narrow Bandpass Microstrip Filter for High- Speed Fiber Optic Systems," *IEEE Trans. Communications,* Vol. 38, no. 8, August 1990, pp. 1122-1124.
5. T.S. Rappaport, "Indoor Radio Communications for Factories of the Future," *IEEE Communications Magazine,* Vol. 27, No. 5, May 1989, pp. 15-24.
6. T.A. Milligan, "Dimensions of Microstrip Coupled Lines and Interdigital Structures," *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-23, No. 5, May 1977, pp. 405-410.
7. E.C. Niehenke, *Microstrip Circuits,* c. 1982, pp. 8, 22-38.
8. A. Tam, "Principles of Microstrip Design", *RF Design,* June 1988, pp. 29-34.
9. J.H. Hinton, "On Design of Coupled Microstrip Lines", Letters, *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT- 28, No. 3, March 1980, p. 272.
10. S. Akhtarzad, T.R. Rowbotham, and P.B. Johns, "The Design of Coupled Microstrip Lines", *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-23, No. 6, June 1975, pp. 486-492.
11. A. Schwarzmann, "Microstrip Plus Equations Adds Up to Fast Designs", *Electronics,* October 2, 1967, pp. 109-112.
12. S.B. Cohn, "Parallel-Coupled Transmission-Line-Resonator Filters", *IRE Transactions on Microwave Theory and Techniques,* Vol. MTT-6, No. 4, April 1958, pp. 223-232.
13. D. Kelley, A.G. Kramer, and F.G. Willwerth, "Microstrip Filters and Couplers", *IEEE Transactions on Microwave Theory and Techniques,* August 1968, pp. 560-562.
14. T.C. Edwards, *Foundations of Microstrip Circuit Design,* John Wiley & Sons, New York, c. 1981.
15. R.H. Jansen, "High-speed Computations of Single and Coupled Microstrip Parameters Including Dispersion, High Order Modes, Loss and Finite Strip Thickness", *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-26, No. 2, February 1978, pp. 75- 82.
16. A.S. Fox, "An Enhanced Design Procedure for Microstrip Band Pass Filters", Masters Thesis in Electrical Engineering, VPI & SU, Blacksburg, VA, August 1990.
17. E.G. Cristal and S. Frankel, "Hairpin-Line and Hybrid Hairpin-Line/Half-Wave Parallel-Coupled-Line Filters", *IEEE Transactions on Microwave Theory and Techniques,* Vol. MTT-20, No. 11, November 1972, pp. 719-728.
18. J.H. Davey, "Microstrip Bandpass Filters", *Proceedings of Microwave Update '87,* American Radio Relay League, c. 1987, pp. 42-53.
19. R.L. Campbell, "A Clean Low-Cost Microwave Local Oscillator", *QST,* The American Radio Relay League, July 1989, p. 15.
20. W.J. Dixon and F.J. Massey, Jr., *Introduction to Statistical Analysis,* Fourth Edition, McGraw-Hill Book Co., New York, c. 1983.

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Limits of Range Calculations

By Bernard Kasmir
Alarm Device Manufacturing Co.

In evaluating the performance of a radio system, it is desirable to calculate theoretical performance, and then to measure performance to verify the theoretical values. Operating range, or distance of reliable communications is an important parameter. For Part 15 communications systems, usually operating in indoor conditions, we would find that the measured operating range is significantly poorer than the theoretical values.

The theoretical range is calculated by the path loss equation:

$$PPL = 20\log(F) + 20\log(S) - G1 - G2 - 27.6 \quad (1)$$

Where, F = frequency in MHz, S = distance in meters, and G1,G2 = antenna gains of the transmitter and receiver (in dB).

Knowing the allowable path loss, the range "S" is calculated. This is calculated on the basis of path attenuation following a 20 dB/decade slope. This assumption is true with sufficient antenna height. However, at short distances above ground, studies (1) have found that the attenuation slope may be considerably greater.

In this study, a line-of-sight equation consists of a piecewise linear model where the slope starts off at 20 dB/decade until it hits a break point. Hereafter the slope becomes 40 dB/decade. The equations for this model are:

$$L_u = L_b \begin{array}{l} + 20\log(d/R_b),\ d \le R_b \\ + 40\log(d/R_b),\ d > R_b \end{array} \quad (2)$$

$$L_l = L_b \begin{array}{l} + 25\log(d/R_b),\ d \le R_b \\ + 20 + 40\log(d/R_b),\ d > R_b \end{array}$$

$$R_b = 4h_bh_m/\lambda$$

$$L_b = \text{abs}(20\log((\lambda^2)/8\pi h_bh_m))$$

Where:
h_b=height of transmitting antenna
h_m=height of receiving antenna
d=distance in meters
λ=wavelength in meters
R_b=breakpoint in the bound
L_u=upper bound
L_l=lower bound

In addition, a discontinuity or blockage of the signal path not only produces a step in signal level, but the attenuation slope beyond this point becomes steeper.

Figure 1 shows expected path attenuations both for equation 1 and equation 2. Equation 1's path attenuation starts and remains at 20dB/decade. Equation 2's path attenuation is 20 dB/decade until a break point (in this example, 100 feet). The slope then becomes 40 dB/decade until the signal encounters a blockage (in this example, 10 dB). Thereafter, the attenuation continues at a slope of 60 dB/decade. Discontinuities can occur at any distance. One or more discontinuities occur in an indoor installation.

The break point, R_b, is dependent upon frequency and height of transmitter and receiver antennas. For convenience, only the upper bound of equation 2 is shown on the curve. From this equation, note that the lower bound starts with 20 dB more attenuation and follows a 25 dB/decade curve until the break point.

Table 1 shows some typical attenuations caused by various structural members. The actual signal attenuation is usually considerably more than the theoretical 20 dB/decade. By using the chart of Figure 1 as a template, a system's performance can be evaluated and compared to the theoretical values.

A numerical example would be useful:

The following parameters are given:

Transmitter power	= 100 mW
Transmitter antenna gain	= 1*
Receiver sensitivity	= –110 dBm
Receiver antenna gain	= 1*
Frequency	= 915 MHz

*-isotropic for this example.

The transmitter field intensity is

$$E = \frac{\sqrt{30PG}}{S} \quad (3)$$

Where P = transmitter power
G = antenna gain (1 for this example)
S = distance measured (usually 3 meters)

Using these numbers, the field intensity at 3 meters is: sqrt(30 × 0.1 × 1) × $1\times10^6/3$ = 577,305 uV/m.

For the receiver, –110 dBm sensitivity is 0.69 uV into 50 ohms. The antenna factor is:

$$AF\ (\text{numerically}) = 9.75/\lambda\sqrt{G}) \quad (4)$$

Where G is antenna gain and λ = 300/frequency in MHz. For this example, the antenna factor = 29.7. Therefore, the receiver sensitivity = 50 ohms sensitivity × antenna factor = 20.49 uV/m.

Using linear interpolation, the field intensity at any distance from a field source can be calculated by multiplying the field intensity at a defined point by the ratio: (source to defined-point distance/source to desired-point distance).

If we have a field intensity of 577,305 uV/meter at 3 meters, and the receiver sensitivity is about 20.5 uV/m, then the range would be: 577,305 × 3 / 20.5 = 84,431 meters, or 277,000 feet, or 52.4 miles. In this example, the maximum attenuation from an anchor point of 10 feet, (about 3 meters), would be 20 log(577,305/20.5)=89 dB. The following graphs have normalized path attenuation over a range of 85 dB. By scaling the Y axis to the path loss value of 88.5 dB (85 for convenience), we can look at the measured value at any distance and

Structure	Attenuation
a) Through window in brick wall	2 dB
b) Through metal frame in glass wall	0 dB
c) Through metal frame, glass wall into bldg	6 dB
d) Through office wall	6 dB
e) Through metal door in office wall	6 dB
f) Through cinderblock wall	4 dB
g) Through metal door in brick wall	12.4 dB
h) Through brick wall next to metal door	3 dB

Table 1. Attenuations caused by typical structures.

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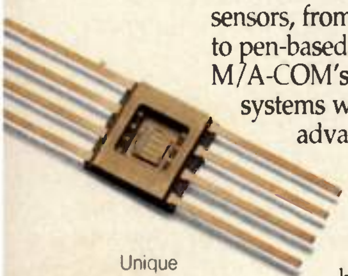

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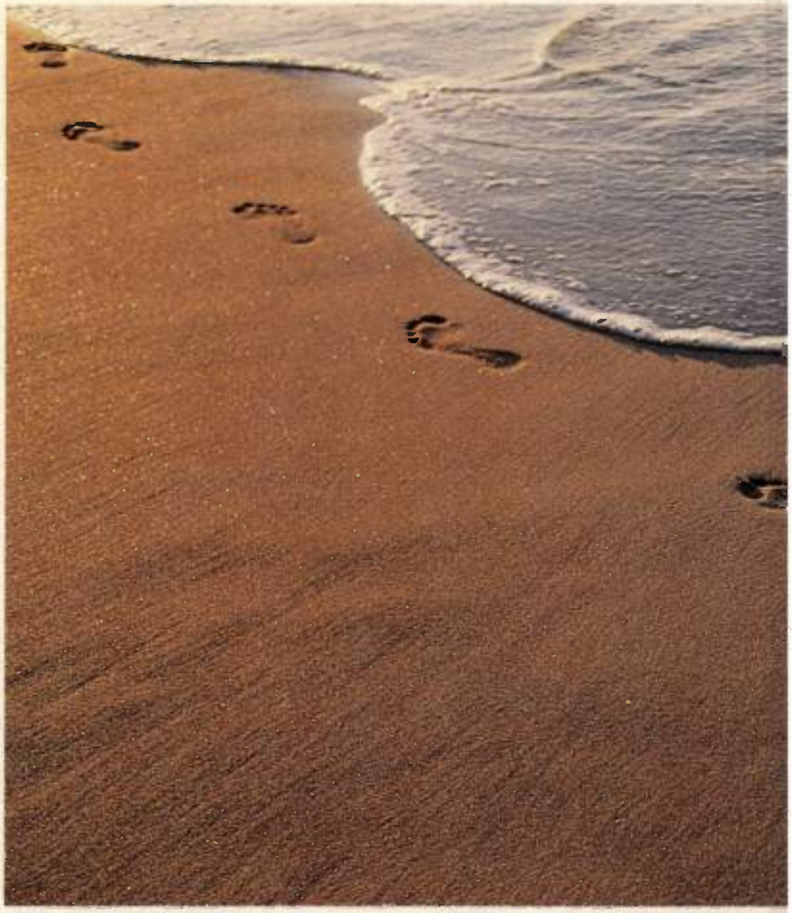

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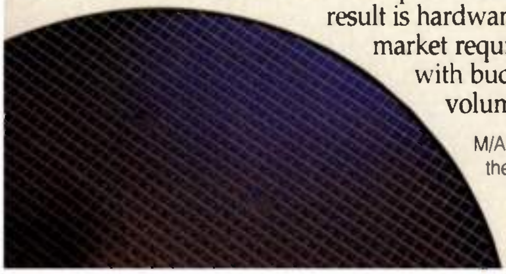


M/A-COM's GaAs technology sets the industry standard.

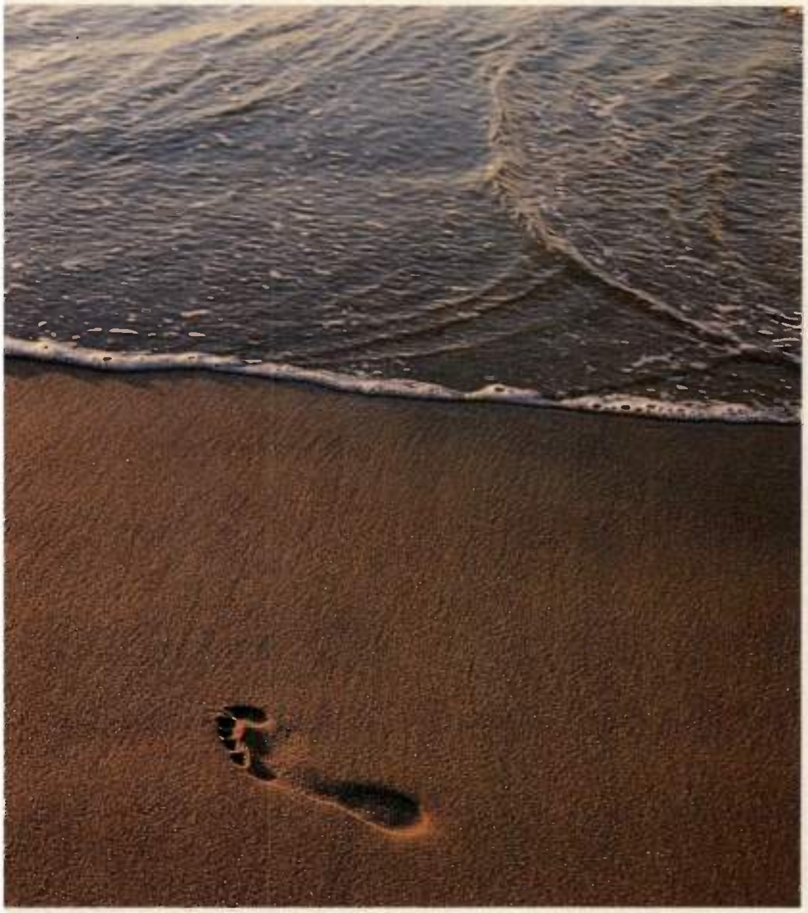
We speak digital.

Today, we are integrating the worlds of digital and microwave technology and creating the seamless communications and transportation networks of tomorrow.

Microwave coaxial surface mount connector.

As applications for wireless technology increase, the interface between microwave and digital technology becomes increasingly important. Our digital signal processing capabilities transparently link

out in front, 'll get there first.

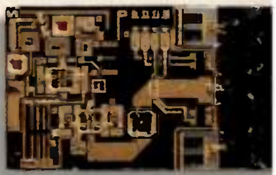


microwave technology to the digital world. And make possible the highly integrated, multifunction solutions which will become the standards of the wireless industry.

We're thinking smaller.

Lower power consumption, reduced size, lessened noise, and increased efficiency are all critical attributes of today's portable, high-performance products. Because we have expertise in areas such as high-speed digital signal processing, voice and data compression, miniaturization, and end-to-end systems modeling and simulation, we can provide the portable marketplace with the products and solutions they require. At competitive prices.

At M/A-COM, the changing demands of the marketplace don't come as a surprise because our R&D initiatives are structured to encompass both near term and longer range product development. In this way, we can anticipate change and ensure reliable, predictable transitions from initial product concept to timely delivery.



Switch, Limiter and LNA integrated into a common medium.

Choose your partner.

The most important technological choices and decisions are made in the earliest stages of the product development process, and demand an understanding and awareness of each system and its unique technological needs. This is when M/A-COM's strengths and experience are of greatest benefit to customers. Our expertise, our ability to adapt to the changing needs of both commercial and government industries, and our commitment to our customers make us your best choice as a technology partner. A partner you can count on to help you get to your destination first.

But whether you are currently looking for solutions designed in at board level or off-the-shelf components, you will benefit from calling us at 1-800-366-2266. In Europe: +44 (0344) 869 595. In Asia: +81 (03) 3226-1671.

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INFO/CARD 35

compare that with the theoretical 20 dB/decade attenuation slope.

If the desired range of this system were 500 feet, from Figure 1, the signal margin at 20 dB/decade would be about 49 dB. This means that the signal level is 49 dB higher than the minimum signal level for detection. At 40 dB/decade, the signal margin would be 38 dB, and at 60 dB/decade, the signal margin would be 23 dB.

This signal margin can be related to systems reliability. According to the Rayleigh probability distribution model, reliability in terms of signal margin can be expressed as follows:

Margin	Reliability
0	50%
20	90%
30	99.9%
40	99.99%

Figure 2 shows the actual path attenuation measured between two buildings. Measurements were made at different locations, not necessarily in a straight line. As a result, the curve has some perturbations. Basically, the curve initially follows 40 dB/decade, then becomes 20 dB/decade. After encountering blockages in the signal path, the curve finally follows a 60 dB/decade slope. At 500 feet, signal margin is 10 dB.

Figure 3 shows path attenuation at another industrial site. This time, measurements were essentially made in a straight line. Measurements were made from the inside of one building, down the street

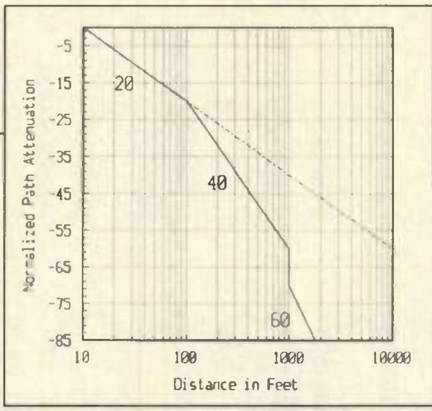

Figure 1. Plot of attenuation vs. distance for equations 1 and 2, with arbitrary breakpoints inserted in equation 2.

and into the inside of a second building. Again, the attenuation initially follows about 40 dB/decade. Upon entering the second building (at a distance roughly of 400 feet), the attenuation curve exceeds the 60 dB/decade slope. At 500 feet, the signal margin is about 22 dB.

In practice, it is difficult to predict break points and attenuation slopes. Each site must be surveyed to determine if there is sufficient signal margin at the desired distance.

One could measure range simply by separating the transmitter and receiver until the receiver no longer decodes (or some defined bit error rate is reached). This may be useful in comparing two different systems. If the two systems have identical measurment conditions and performance criteria, then the system with the greatest measured distance may be considered the better system.

However, to simply walk out the system until there is no more communication yields little useful information on the system's performance at any intermediate position. A "go/no-go" test for maximum distance tells nothing of performance in the range of operation. As noted earlier, the only significant measurement is the signal margin at some defined distance.

The moral of this story is that we cannot use "best case," theoretical values to predict actual operation in a hostile environment. The bottom line is that a survey of the proposed site is required to determine if the actual signal margin at the maximum distance is acceptable. The calculated theoretical range (which may be in miles) is not a good predictor of performance within the anticipated range of operation.

Not only does the attenuation curve deviate from the theoretical 20 dB/decade, but each obstacle produces an attenuation step plus a steeper attenuation curve. ***RF***

References

1. Vinko Erceg, Saeed Ghassemzadeh, Maxwell Taylog, Dong Li, and Donald L. Schilling, "Urban/Suburban Out-of-Sight Propagation Modeling", *IEEE Communications Magazine*, June 1992.

About the Author

Bernard Kasmir is Senior RF Design Engineer at Alarm Devices Manufacturing Company (ADEMCO). He holds BSEE and MSEE degrees and a P.E. license. He can be reached at 160 Eileen Way, Syosset, NY 11791.

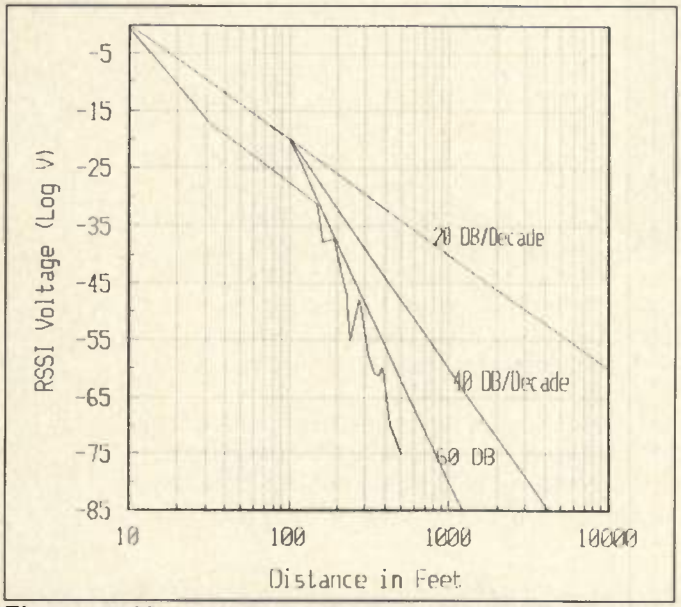

Figure 2. Measured received signal strength along path between transmitter inside one building to receiver in another building.

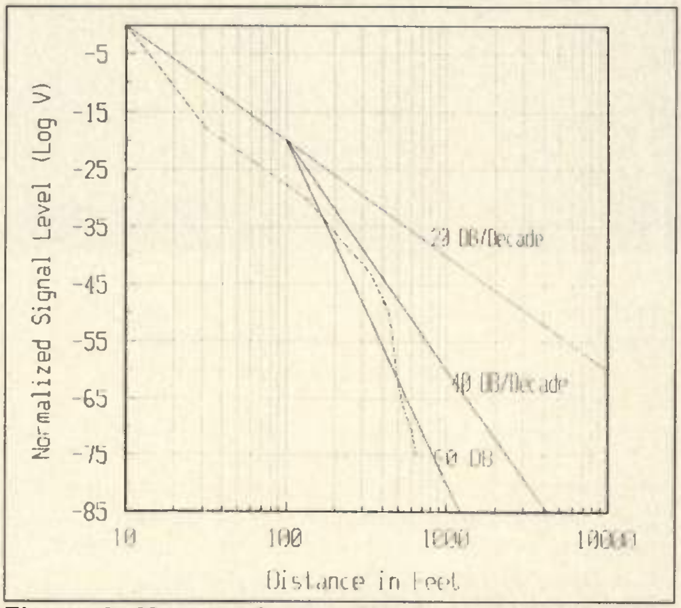

Figure 3. Measured normalized signal level along straight-line path between transmitter in one building and receiver in another building.

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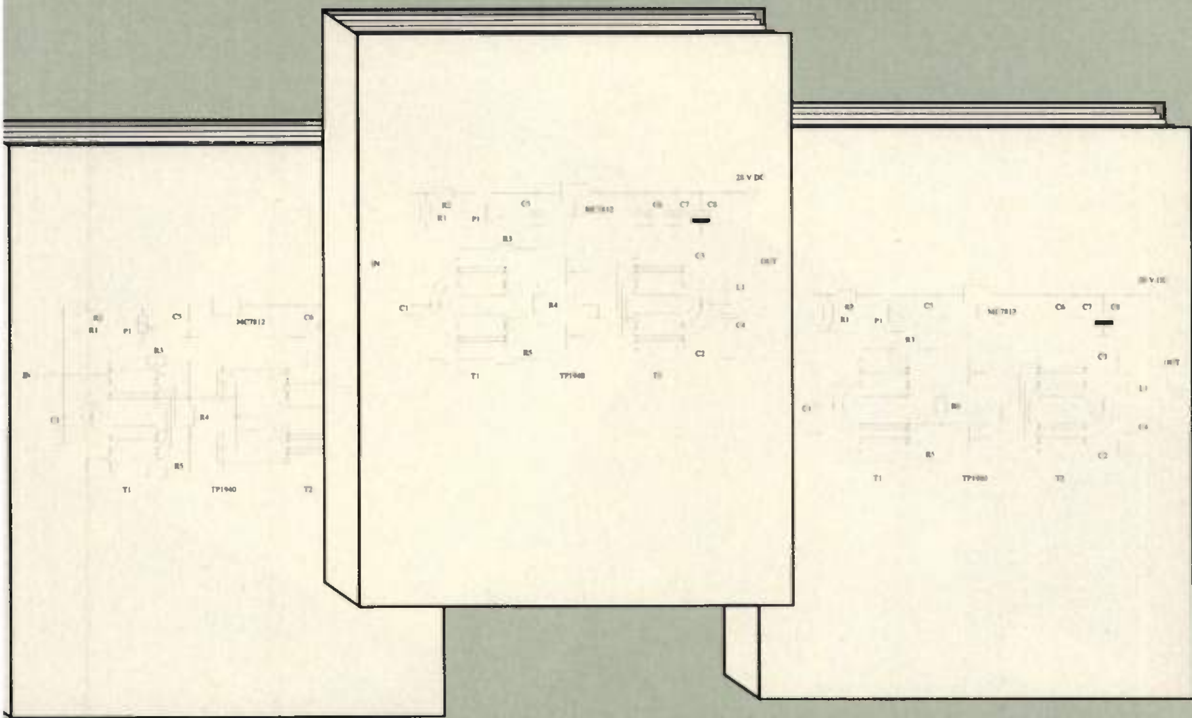

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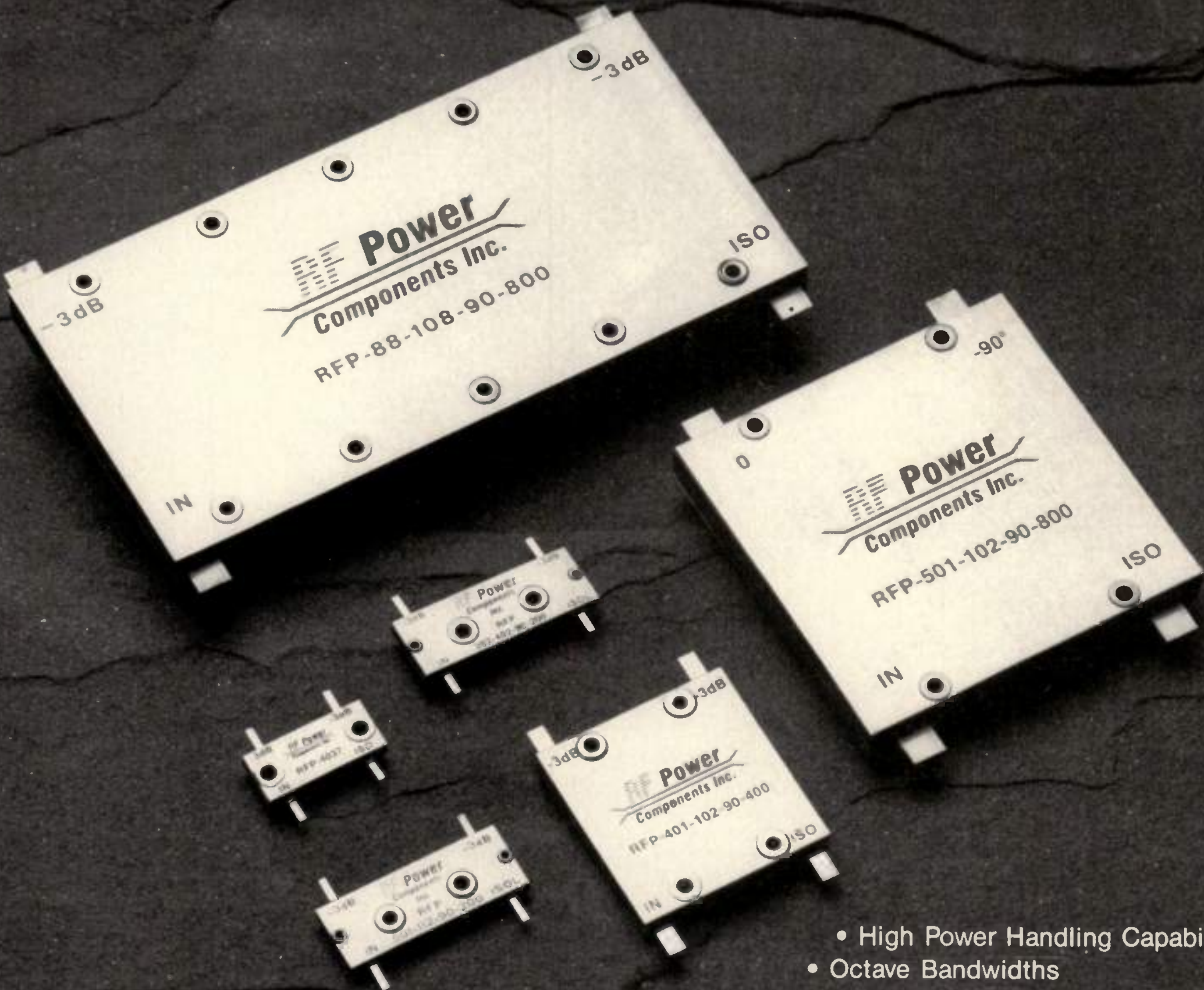

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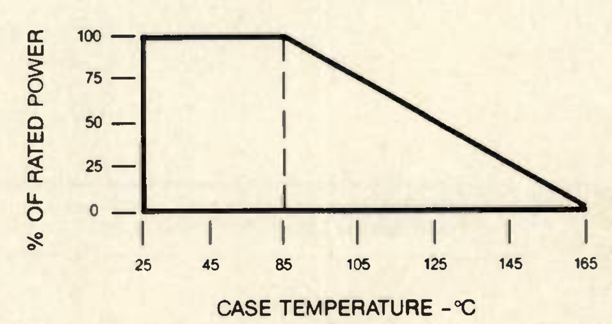
ELECTRICAL SPECIFICATIONS

RF Power Components Inc.

MODEL	FREQUENCY RANGE (MHz)	AMPLITUDE BALANCE (dB) Max.	PHASE BALANCE DEG. Max.	POWER WATTS (CW)	ISOLATION (dB) Min.	MAXIMUM VSWR	INSERTION LOSS (dB) Max.	DROP-IN STYLE	CONNECTOR-STYLE
RFP-88-108-90-200		±0.3	±1.5	200	23.0	1.15:1	0.3	205A	305
RFP-88-108-90-400	88–108	±0.3	±1.5	400	23.0	1.15:1	0.3	205B	305
RFP-88-108-90-800		±0.3	±1.5	800	23.0	1.15:1	0.2	205C	305
RFP-101-501-90-200	100–500	±0.6	±1.5	200	20.0	1.15:1	0.5	205D	305
RFP-101-501-90-400		±0.6	±1.5	400	20.0	1.15:1	0.5	205C	305
RFP-251-102-90-200	250–1000	±0.5	±1.5	200	20.0	1.15:1	0.5	205D	305
RFP-251-102-90-400		±0.6	±1.5	400	20.0	1.15:1	0.5	205C	305
RFP-201-401-90-200		±0.5	±1.5	200	23.0	1.15:1	0.3	202	302
RFP-201-401-90-400	200–400	±0.5	±1.5	400	23.0	1.15:1	0.3	203	303
RFP-201-401-90-800		±0.5	±1.5	800	23.0	1.15:1	0.4	204	304
RFP-401-102-90-200		±0.5	±1.5	200	25.0	1.20:1	0.3	201	301
RFP-401-102-90-400	400–1000	±0.5	±1.5	400	20.0	1.20:1	0.3	203	303
RFP-401-102-90-800		±0.5	±1.5	800	20.0	1.25:1	0.3	204	304
RFP-501-102-90-200		±0.5	±1.5	200	25.0	1.20:1	0.3	201	301
RFP-501-102-90-400	500–1000	±0.5	±1.5	400	20.0	1.25:1	0.3	203	303
RFP-501-102-90-800		±0.5	±1.5	800	20.0	1.25:1	0.3	204	304
RFP-102-202-90-200	1000–2000	±0.5	±1.5	200	20.0	1.20:1	0.3	201	301
RFP-102-202-90-400		±0.5	±1.5	400	20.0	1.20:1	0.3	203	303
RFP-202-402-90-200	2000–4000	±0.5	±1.5	200	18.0	1.25:1	0.3	201	301

NOTES

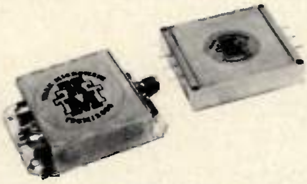
1. Above data applies with tests performed in properly designed microstrip test fixtures and terminated into 50 ohms.
2. Precautions should be taken for high power applications at the lead interface to avoid voltage breakdown and arching; conformal coating is recommended.
3. Couplers must lay flat on the mounting surface for good ground plane contact and thermal path. Mechanical relief for eyelet projection is necessary.
4. For power derating, refer to the chart at right.
5. All dimensions are in inches.
6. Mechanical tolerance: ±.02″, unless otherwise specified.
7. Lead material: Gold-plated copper per MIL-G-45204, minimum length .15″.
8. Package material: Aluminum alloy 6061-T651.
   Drop-in units are treated with clear irridite per MIL-C-5541A Type 1, Class 1.
   Connectorized units are painted as per MIL-E-15090, Class 2.
9. Standard connectors as per outline; other connectors, frequencies and configurations are available upon request. Please contact the factory for technical support when selecting a coupler for a specific application.



TRAK® MICROWAVE

Crystal Controlled Oscillators

60 MHz–18 GHz Miniature Crystal Controlled Oscillators and Oscillator/Multipliers



ELECTRICAL SPECIFICATIONS (general)
Frequency set accuracy at room temperature: ±0.001%
Frequency stability: ±0.003%
Aging rate: ±0.0005% per year
Power variation with temperature: ±2 dB

Power supply: +15 VDC (other voltages optional)
Load VSWR: 1.5:1 maximum
Temperature Range: -55 to +85°C. (to +125°C with degradation)
Contact factory for other frequencies and/or power levels. (A 1 watt output series is available.)

10 MILLIWATTS MINIMUM OUTPUT

FREQUENCY RANGE	CURRENT mA, nom. at +15 VOLTS	P.C. BOARD MOUNT MODEL NUMBER	MICROSTRIP MODEL NUMBER	BASE PLATE MOUNT MODEL NUMBER	HARMONICS OF CRYSTAL OSCILLATOR UP TO 2nd HARMONIC OF OUTPUT FREQUENCY
60 - 120 MHz	25	5040 - 1056	5140 - 1057	5040 - 1057	> 30 dBc
121 - 240 MHz	35	5041 - 1056	5141 - 1057	5041 - 1057	> 30 dBc
241 - 360 MHz	35	5042 - 1056	5142 - 1057	5042 - 1057	> 30 dBc
361 - 720 MHz	50	5043 - 1056	5143 - 1057	5043 - 1057	> 30 dBc
721 - 1200 MHz	50	5044 - 1056	5144 - 1057	5044 - 1057	> 30 dBc
1.2 - 1.7 GHz	60	-	-	5044 - 1110	> 40 dBc
1.7 - 2.0 GHz	65	-	-	5044 - 1111	> 40 dBc
2.0 - 2.3 GHz	65	-	-	5044 - 1310	> 40 dBc
2.3 - 2.5 GHz	75	-	-	5044 - 1313	> 40 dBc
2.5 - 4.0 GHz	100	-	-	5044 - 1311	> 40 dBc
4.0 - 6.0 GHz	110	-	-	5044 - 1611	> 40 dBc
6.0 - 8.0 GHz	110	-	-	5044 - 1615	> 40 dBc
8.0 - 10.0 GHz	120	-	-	5045 - 1911	> 40 dBc
10.0 - 12.0 GHz	140	-	-	5045 - 1913	> 40 dBc
12.0 - 18.0 GHz	150	-	-	5045 - 1240	> 40 dBc

100 MILLIWATTS MINIMUM OUTPUT

FREQUENCY RANGE	CURRENT mA, nom. at +15 VOLTS	P.C. BOARD MOUNT MODEL NUMBER	MICROSTRIP MODEL NUMBER	BASE PLATE MOUNT MODEL NUMBER	HARMONICS OF CRYSTAL OSCILLATOR UP TO 2nd HARMONIC OF OUTPUT FREQUENCY
60 - 120 MHz	40	5040 - 1086	5140 - 1087	5040 - 1087	> 20 dBc
121 - 240 MHz	50	5041 - 1086	5141 - 1087	5041 - 1087	> 20 dBc
241 - 360 MHz	50	5042 - 1086	5142 - 1087	5042 - 1087	> 20 dBc
361 - 720 MHz	70	5043 - 1086	5143 - 1087	5043 - 1087	> 20 dBc
721 - 1200 MHz	70	5044 - 1086	-	5044 - 1087	> 20 dBc
1.2 - 1.7 GHz	80	-	-	5044 - 1120	> 40 dBc
1.7 - 2.0 GHz	90	-	-	5044 - 1121	> 40 dBc
2.0 - 2.3 GHz	90	-	-	5044 - 1320	> 40 dBc
2.3 - 2.5 GHz	100	-	-	5044 - 1321	> 40 dBc

AVAILABLE OPTIONS:
- Gating
- Heater Control
- Frequency Trim
- One watt versions are available

NOTE: Size may vary with options. Contact Factory.

SC Cut Crystal Controlled Oscillators

These oscillators are similar to those above but offer the advantage of higher stability over temperature (2 ppm from -54 to +85°C) and lower phase noise under vibration. See our complete catalog or contact our representative or the factory for complete specifications.

Frequency Range (MHz)	Power Output +10 dBm MIN. MODEL NO.	Power Out +20 dBm MIN. MODEL NO.
60– 120	5091–1000	5092–1000
121– 240	5091–1001	5092–1001
241– 360	5091–1003	5092–1003
361– 720	5091–1004	5092–1004
721–1200	5091–1005	5092–1005

Above 1200 MHz contact factory

Current	180 mA typical at +25°C 230 mA typical at -54°C	250 mA typical at +25°C 300 mA typical at -54°C

How to order: *Specify model number and exact frequency*

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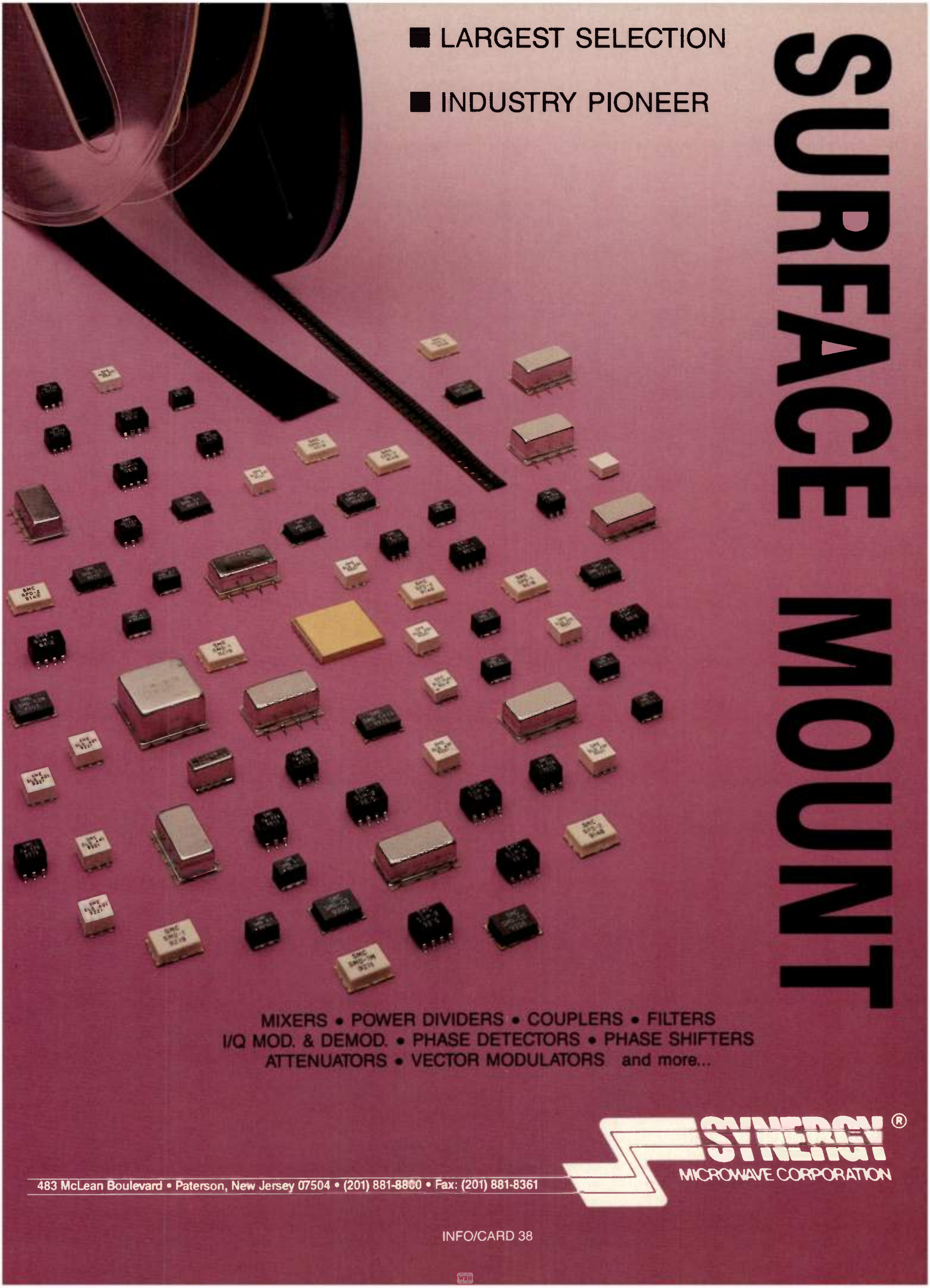
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Miniature Coaxial Line Elements

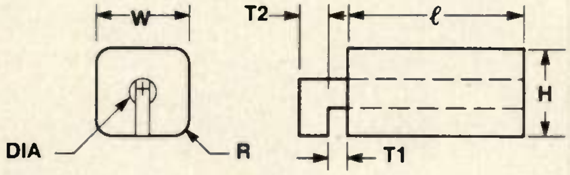
for Wireless Designs

Preliminary

Trans-Tech

Features	Benefits
Miniature Size	Extremely Compact Design
High Dielectric Constant	Circuit Miniaturization
Rugged Construction	Eliminate Microphonics
SMT Configuration	Automation Compatible
Tight τ_f Tolerance	Repeatability of Design
Long Term Stability	Negligible Aging Effects
Low Loss Silver Plating	High Q, Excellent Solderability
Shielded Transmission Line	Minimizes Environmental Effects

Trans–Tech introduces extremely small coaxial transmission line elements for use where circuit miniaturization is of utmost importance, such as in cellular telephone, PCS, and other wireless products.



Dimensions and Configurations

Profile	Size	Height	Width	Diameter	Radius	T1	T2
Miniature Profile (MP)	3 mm	.120 ± .003	.120 ± .003	.033 ± .002	.015 typical	.020	.040
Sub–Miniature Profile (SM)	2 mm	.081 ± .003	.081 ± .003	.033 ± .002	.015 typical	.020	.040

Note: Dimensions are in inches. Tab thickness is 0.020" for both profiles.

Material Characteristics

The listed Q values are guaranteed for the lowest recommended and highest recommended frequency of each profile and material. The Q increases approximately as the square–root of increasing frequency.

Material	Dielectric Constant	Profile	Electrical Q Factor	
			@ Low Freq.	@ High Freq.
8800	38.6 ± 2	MP SM	320 200	560 360
9000	90.5 ± 2	MP SM	160 105	380 240

Selection Specificaitons

At any frequency, the approximate length can be determined by using the nominal length formula (ℓ) in the following table. While the component is manufactured and guaranteed to the selected resonant frequency, the formula is given to estimate the length.

Type	Material	Nominal Length Formula (in. ± .010")	Recommended Range f_0 (MHz)
Q (λ4) Quarter Wavelength	8800	ℓ = 475/f_0 (MHz)	1650 to 2500
H (λ2) Half Wavelength	8800	ℓ = 951/f_0 (MHz)	3300 to 5000
Q (λ4) Quarter Wavelength	9000	ℓ = 309/f_0 (MHz)	620 to 1650
H (λ2) Half Wavelength	9000	ℓ = 619/f_0 (MHz)	1240 t0 3300

Packaging and Delivery Consult factory for details.

For additional technical information on the use, measurement technique, and design equations related to Trans–Tech's Coaxial Line Elements, see Coaxial Transmission Line Elements, Trans–Tech publication #50030170.

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Werlatone's extensive line of broadband high power combiner/dividers span the range of 1.0 to 2000 MHz. Both two and four way, as well as n-way power combiners, cover the power range to 20 Kilowatts. Two way combiners are available in 0, 180 and 90 degree models. High power models feature external 50 ohm isolation terminations and **WERLATONE WIDEBAND TECHNOLOGY** which assures low loss, high performance, and reliability you can count on.

MODEL	FREQUENCY RANGE MHz	INSERTION LOSS db	ISOLATION db	POWER WATTS	POWER SPLIT
D1572	1.0-1000	1.0	20	40	4-way
D1635	2.0-220	0.4	20	200	2-way
D2500	10-500	0.7	20	400	2-way
D2599	400-1000	0.5	20	400	16-way
D2076	1.5-30	0.1	22	3000	2-way
D1996	20-100	0.3	20	1500	4-way

Over 600 additional models to choose from.

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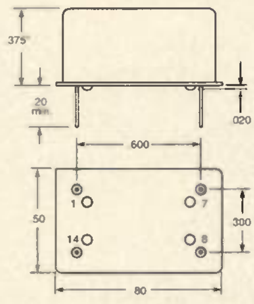
14/4 Pin TCXO



PINS ARE .018 DIAMETER

B8 Package

Output Options:

TC	= LS TTL	=	1.0 to	90 MHz
AC	= CMOS AC	=	1.0 to	90 MHz
HC	= HCMOS	=	10 to	50 MHz

Stability Options:

A16	=	±1.0 PPM	0° to +50°C	1 to 24 MHz
AB6	=	±2.5 PPM	0° to +50°C	1 to 70 MHz
A56	=	±5.0 PPM	0° to +50°C	1 to 90 MHz
D15	=	±10.0 PPM	-40° to +85°C	1 to 70 MHz

Screening Options:

C = Standard Commercial
S = Class "B" per MIL-O-55310

Typical P/N: HC B8 GO A16 C 24.000 MHz
GO is predetermined

Pinouts:

Pin 1	=	Tune 0 to +5V
Pin 7	=	Ground
Pin 8	=	Output
Pin 14	=	+5.0 VDC

General Specifications:

Supply Voltage:	+5.0 VDC ±5%
Voltage Stability:	<1.0 PPM for ±5%
Trim Range:	>15 PPM
Tuning Voltage:	0 to +5.0 VDC
Seal:	<1 x 10⁻⁸ cc/second

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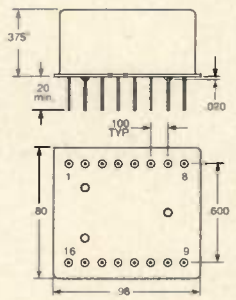
16 Pin Doublewide DIP TCXO



PINS ARE .018 DIAMETER

F4 Package

Output Options:

TC	= LS TTL	=	1.0 to 70 MHz
AC	= CMOS AC	=	1.0 to 70 MHz
HC	= HCMOS	=	1.0 to 50 MHz

Stability Options:

B57	=	±0.5 PPM	0° to +70°C	1 to 24 MHz
B16	=	±1.0 PPM	0° to +70°C	1 to 50 MHz
D16	=	±1.0 PPM	-40° to +85°C	1 to 24 MHz
DB6	=	±2.5 PPM	-40° to +85°C	1 to 50 MHz

Screening Options:

C = Standard Commercial
S = Class "B" per MIL-O-55310

Typical P/N: TC F4 GO D16 S 6.4000 MHz
GO is predetermined

Pinouts

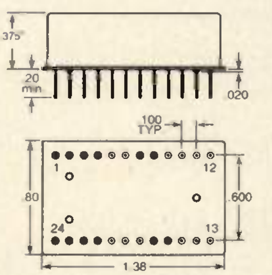
Pin 6	=	Tune 0 to +5V
Pin 8	=	Ground
Pin 9	=	Output
Pin 16	=	+5.0 VDC

General Specifications:

Supply Voltage:	+5.0 VDC ±5%
Voltage Stability:	<1.0 PPM for ±5%
Trim Range:	>10 PPM
Tuning Voltage:	0 to +5.0 VDC
Aging:	< 2 PPM per year <10 PPM per 10 yrs
Seal:	<1 x 10⁻⁸ cc/second

---

24 Pin Doublewide DIP TCXO



PINS ARE .018 DIAMETER
12 thru

G2 Package

Output Options:

TC	= LS TTL	=	1.0 to	90 MHz
AC	= CMOS AC	=	1.0 to	90 MHz
HC	= HCMOS	=	1.0 to	50 MHz

Stability Options

B57	=	±0.5 PPM	0° to +70°C	1 to 24 MHz
B16	=	±1.0 PPM	0° to +70°C	1 to 50 MHz
BB6	=	±2.5 PPM	0° to +70°C	1 to 90 MHz
D16	=	±1.0 PPM	-40° to +85°C	1 to 26 MHz
EB6	=	±2.5 PPM	-55° to +85°C	1 to 26 MHz

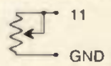
Screening Options:

C = Standard Commercial
S = Class "B" per MIL-O-55310

Typical P/N: TC G2 GO A16 C 90.000 MHz
GO is predetermined

Pinouts

Pin 1	=	Gnd, Case
Pin 3	=	Output
Pin 11	=	Resistor Tune
Pin 12 to 17	=	Gnd, Case
Pin 23	=	Gnd, Case
Pin 24	=	+5.0 VDC



General Specifications:

Supply Voltage:	+5.0 VDC ±5%
Voltage Stability:	<0.25 PPM for ±5%
Trim Range:	>5 PPM
Tuning Voltage:	0 to +5.0 VDC
Tuning Resistor:	20KΩ Pot.11 to Gnd
Aging:	<1 PPM per year <5 PPM per 10 yrs
Seal:	<1 x 10⁻⁸ cc/second

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INFO/CARD 43

HIGH DYNAMIC RANGE

MIXERS / CONVERTERS / AMPLIFIERS / MULTICOUPLERS

Modern receiving equipment is subjected to dense and high level RF environments. State of the art solutions are required to handle multiple strong signals without masking desired weak signals. LOCUS has developed a series of high dynamic range components for such applications in the HF/VHF frequency ranges.

HDR MIXERS AND CONVERTERS

LOCUS high dynamic range mixers typically provide an intercept point of +45 dBm which translates to 90 dB down products of 0 dBm signals. For frequency ranges of an octave or greater, second-order intermodulation products are of concern. The LOCUS mixers provide comparable level rejection of second-order products. Single tone (one input signal) mixer spurs are also consistent at typically 90 dB down.

MODEL	TYPE	IN (MHz)	LO (MHz)	OUT (MHz)
RFC-251A	Image Reject Downconv	8-20	17-19	0.5-10
RFC-400A	Downconv/I&Q Out	160±24	160	dc-12
RFC-400B	Downconv/I&Q Out	70±12	70	dc-6
RFC-500A	Downconv/BB Out	160±6	153	1-13
RFC-550A	Image Reject Downconv	70±5	76	1-11
RFC-600A	Tunable HF Upconv	2-32	52-82	50
RFC-600B	Tunable HF Upconv	2-32	72-102	70
RFC-650A	Image Reject (SSB) Upconv	1-11	76	65-75

FEED FORWARD AMPLIFIERS

LOCUS RF-2800 Series Feed Forward Amplifiers provide a 3rd order output intercept of +65 dBm typical, +60 dBm minimum over the 1 to 88 MHz range with reduced performance to 200 MHz. This is accomplished with gains as low as 7 dB, giving input intercepts as high as +58 dBm typical, +53 dBm minimum.

MODEL/GAIN	FREQ. RANGE (MHz)	TYPICAL OUTPUT INTERCEPT POINT 3rd ORDER (dBm)	2nd ORDER (dBm)
RF-2801A/16	1-88	+65	+120
RF-2801B/11	2-30	+65	+120
RF-2802C/16	1-30	+65	+120
RF-2810B/16	2-30	+68	+120

MULTICOUPLERS

The RF-2800 Series Feedforward Amplifiers are incorporated in various multicoupler configurations that contain unique, high level power dividers. LOCUS developed the high dynamic range power dividers to overcome the limitations of typical catalog item power dividers when used with the Feedforward Amplifiers.

Complete converter subsystems are available to provide >90 dB of image rejection, and high dynamic range baseband amplification. Anti-aliasing lowpass filtering and group delay equalization for various output bandwidths are also available. Passband amplitude ripple/variations are 1 dB maximum for these configurations. Units can also be supplied with digital output.

Kaman Sciences Corporation
Locus Division
P.O. Box 740 • State College, PA 16804-0740 USA
(814)466-6275 • FAX:(814)466-3341

KAMAN

INFO/CARD 44

RFIC Chip Set Targets 900 MHz Transceivers

By Jeff Ortiz, Sheryl Zavion and Paul Holmes
Motorola, Inc., Semiconductor Products Sector

The era of tetherless communications, where a person may initiate or receive a communication unfettered by wires, is just beginning. By the end of 1992, there were 21 million cellular subscribers, more than 20 million pagers in operation and 60-plus million cordless phones worldwide. In the United States alone there are over eleven million cellular subscribers and eleven million pagers in operation. In addition, approximately ten million cordless telephones are purchased annually.

The Personal Communicator, as described by A.D. Little's 1990 study on Personal Communication Services, is rapidly becoming a reality. This system will allow a person to place or receive a call at home, the office, a shopping center, restaurant, or in the next city or state with a handset cost of under $100. This and subsequent market studies have found that almost 50 million U.S. households would subscribe to such a system. Similar opportunities for tetherless communications exist worldwide, where the next generation cordless systems such as cordless telephony (CT1), Telepoint (CT2, CT2-Plus), PCN, Japan Personal Handy Phone (JPHP) and wireless PBX (DECT, CT2) are being implemented. In the U.S., similar services could be offered in the ISM bands under Part 15 operation using spread spectrum or very low power transmission. It is expected that by 1994 the direction of PCS in the United States will be clearly defined by the FCC.

The system designer has a daunting task in meeting his customers' (the end users') expectations for the performance of these new generation wireless systems. The criteria are small size and weight of the handset, long talk time, landline quality voice reception, and low cost. At the system design level, this means high integration levels, minimal number of batteries, low current drain,

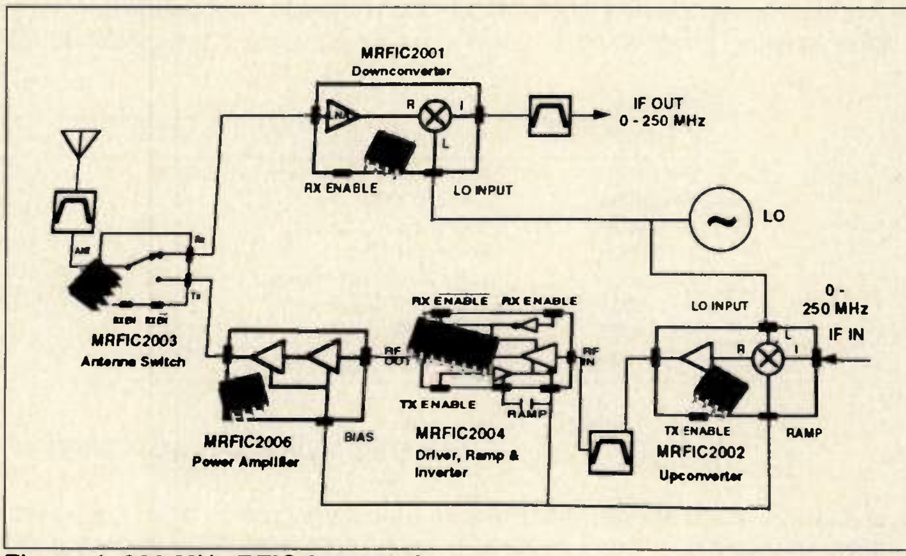


Figure 1. 900 MHz RFIC front end.

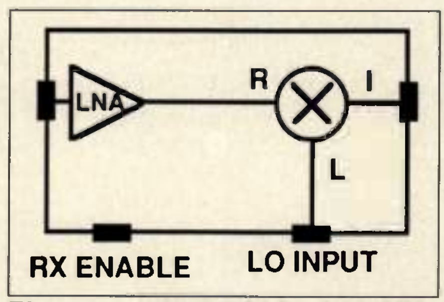


Figure 2. MRFIC2001 900 MHz downconverter.

Chip Set Requirements		
Customer Expectations		Solutions
End User	Systems Designer	
Small size & weight	High Level of Integration Chip Compatibility Low Voltage	RFICs Partitioned for ease of integration, 3V or less designs
Long talk time	High device efficiency Long battery life	High efficiency functions Standby mode
Landline quality	Functions which meet requirements	Functions which meet system requirements Performance over temperature
Low Cost	Inexpensive but easy to use. Flexibility across platforms	Lowest cost circuit technology. Meet several platform requirements. On-chip system functions. Plastic surface mount packages

Table 1. Generic RFIC front end requirements.

Parameter	MIN	TYP	MAX	UNITS
Supply Voltage	2.7	3.0	5.0	V
RF Frequency	500		1000	MHz
IF Output Frequency	0 (DC)		250	MHz
@3V, 900 MHz, 25 °C:				
Supply Current				
On-Mode		4.7	5.5	mA
Off-Mode (Enable < 1.0 V)		0.1	2.0	μA
Conversion Gain	20	23	26	dB
SSB Noise Figure		5.5		dB
Third Order Intercept (Input)	–26	–22.5		dBm
P_{out}, 1 dB Compression		–10		dBm
LO Drive Level		–10		dBm

Table 2. MRFIC2001 performance parameters.

Parameter	MIN	TYP	MAX	UNITS
Supply Voltage	2.7	3.0	5.0	V
RF Frequency	500		1000	MHz
IF Input Frequency	0 (DC)		250	MHz
@3V, 900 MHz, 25 °C:				
Supply Current				
On-Mode (Enable > 2.0 V)		5.5	7.0	mA
Off-Mode (Enable < 1.0 V)		0.1	2.0	µA
Conversion Gain (IF Matched)	8	10	12	dB
SSB Noise Figure		10		dB
P_{out}, 1 dB Compression		−18		dBm
P_{out}, Saturated	−16	−14		dBm
LO Drive Level		−10		dBm

Table 3. MRFIC2002 performance parameters.

Parameter	MIN	TYP	MAX	UNITS
Supply Voltage	2.8	3.0	6.0	V
RF Frequency	100		1000	MHz
@3V, 900 MHz, 25 °C:				
Supply Current			100	µA
Antenna - Rx Loss		0.5	0.8	dB
Antenna - Tx Loss		0.8	1.0	dB
Isolation - Rx	17	20		dB
Isolation - TX	19	23		dB
P_{out}, 1 dB Compression		21		dBm

Table 4. MRFIC2003 performance parameters.

Parameter	MIN	TYP	MAX	UNITS
Supply Voltage	2.7	3.0	4.0	V
RF Frequency	800		1000	MHz
@3V, 900 MHz, 25 °C:				
Supply Current,				
TX EN High, RX EN Low		11	13	mA
Supply Current,				
TX EN Low, RX EN High		0.7	1.5	mA
Standby Current		700		µA
Gain Control Range		34		dB
Gain (Small Signal)	19	21.5	24	dB
Third Order Intercept (Output)		7.5		dBm
P_{out}, 1 dB Compression	−4.0	−1.0		dBm

Table 5. MRFIC2004 performance parameters.

Parameter	MIN	TYP	MAX	UNITS
Supply Voltage	2.7	3.0	4.0	V
RF Frequency	500		1000	MHz
@3V, 900 MHz, 25 °C:				
Supply Current - Total		46	50	mA
Gain (Small Signal)	19	23	26	dB
P_{out}, 1 dB Compression	+12	+15.5		dBm
Third Order Intercept		+25		dBm

Table 6. MRFIC2006 performance parameters.

long battery life, functional performance meeting or exceeding the requirements of the new wireless systems' specifications and, finally, inexpensive but easy-to-use chip sets. The chip sets should also be flexible enough to use in several platforms. Table 1 translates what customer expectations and system design requirements mean at the RF device level.

The first systems to be introduced are in the 800 MHz to 1000 MHz frequency spectrum — generically referred to as 900 MHz. At the same time, new digital cellular systems are being implemented in Europe (GSM), Asia (GSM and TDMA/FDD), Japan (JDC) and North America (TDMA/ FDD, CDMA) in the same frequency band.

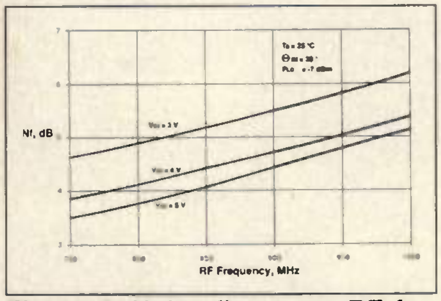


Figure 3. Noise figure vs. RF frequency — MRFIC2001 downconverter.

A System Solution

Previously, a 900 MHz transceiver front end was dominated by discrete transistors, passive elements and a few general purpose MMICs tied together with minimal integration. As a result, the system's designer had to perform significant RF matching analysis among disparate components. It is difficult to optimize system performance versus board layout and size. The discrete component solution also increases the number of devices and solder joints, creating the potential for reduced reliability.

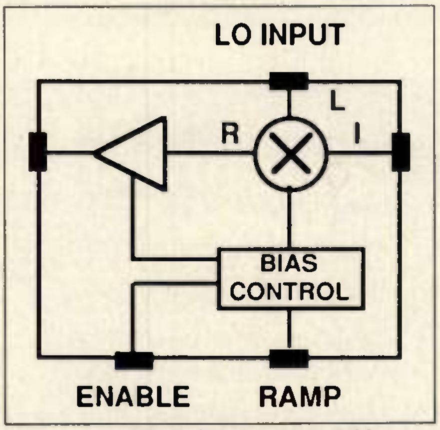


Figure 4. MRFIC2002 900 MHz upconverter.

The MRFIC200X chip set provides the RF system designer with a complete CT2 front end requiring minimal filtering and off-chip interface circuitry. In designing the chip set, a systems approach was taken in partitioning the receive and transmit functions to provide for ease of insertion and device compatibility. Additional user features such as adjustable bias current, receive and transmit enable and a selectable transmit ramp function are provided through on-chip system functions. The chip set, consisting of an antenna switch, down-

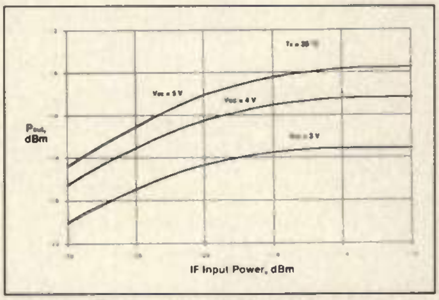


Figure 5. P_{out} vs. IF input power — MRFIC2002 upconverter.

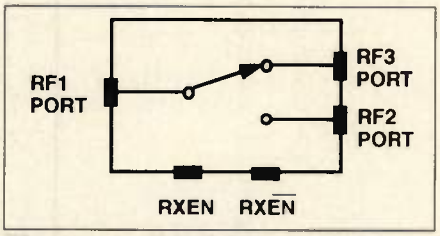


Figure 6. MRFIC2003 antenna switch.

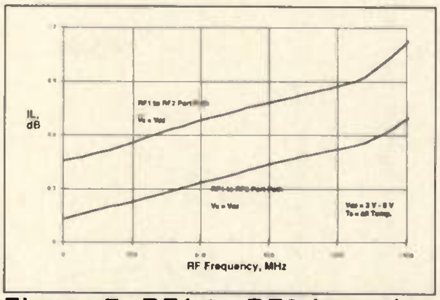


Figure 7. RF1 to RF3 insertion loss vs. frequency — MRFIC2003 antenna switch.

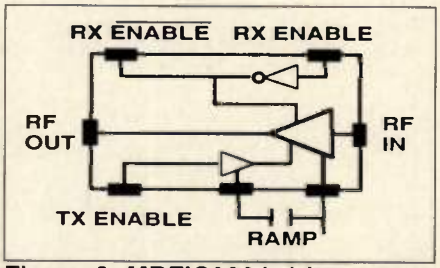


Figure 8. MRFIC2004 driver, ramp and inverter.

converter, upconverter, driver/ramp/inverter and power amplifier, is shown in Figure 1. While designed as a complete chip set for the CT2 application, partitioning of the functions makes these devices usable in CT1, GSM and ISM system designs as well.

Each device is designed for 3 volt operation and supports the system desire for smaller and lighter handsets. All the devices except the driver/ramp/inverter and the power amplifier are usable up to 5 volts, allowing for design flexibility in many 900 MHz systems. Since longer battery life is necessary to provide more talk time for the user, the power down standby mode keeps the "not-in-use" current drain to microamps. Design utilization has also been simplified by having single-ended inputs and outputs on the devices, which require no off-chip baluns. Application flexibility is provided by external LO and IF matching.

Since the systems for which this chip set is intended are under significant pressure to provide excellent performance while keeping costs to a minimum, all devices except the antenna switch are fabricated in a high volume, high performance silicon process known as MOSAIC™ 3. The antenna switch is built in Motorola's fully qualified Gallium Arsenide wafer fab which has been built and is operated to silicon production standards. Each device is packaged in plastic SOIC packages (8 or 16 pin) at one of Motorola's high volume manufacturing sites.

900 MHz Downconverter

The MRFIC2001, shown in Figure 2, is a double-balanced mixer design with single-ended inputs, requiring no filter-

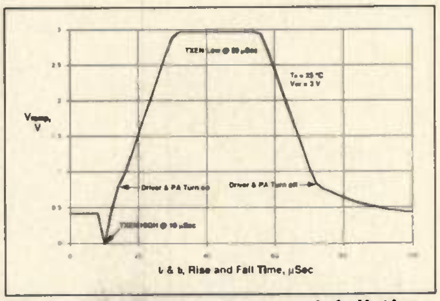


Figure 9. Ramp rise and fall time — MRFIC2004 driver, ramp and inverter.

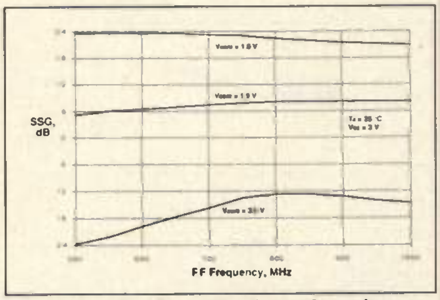


Figure 10. Small signal gain vs. RF frequency — MRFIC2004 driver, ramp and inverter.

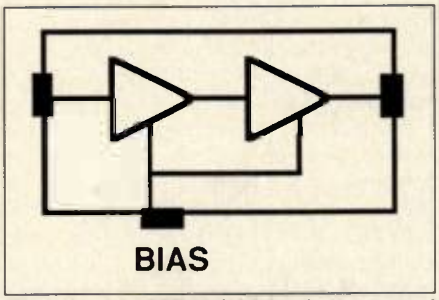


Figure 11. MRFIC2006 integrated power amplifier.

ing between the LNA and the mixer. The internal matching of the RF port reduces board space and minimizes design considerations.

To keep current drain to a minimum the device has a logic controlled power down with an off-mode current drain of less than 2 microamps. A tradeoff has also been made between operating current and linearity (third order intercept point) to further reduce current drain.

The downconverter design allows for a very broad RF frequency range of 500 MHz to 1000 MHz and a wide IF (DC to 250 MHz) which makes the device useful in many of the developing 900 MHz systems. Noise figure results over frequency are shown in Figure 3.

900 MHz Upconverter

Like the down converter, the MRFIC2002 (Figure 4), employs a double balanced mixer with single-ended inputs. The on-chip matching of the RF port reduces board space and minimizes the design interface issues.

This device also minimizes current drain by a TTL/CMOS logic controlled power down through the "Enabled" pin. In the off-mode, current drain is less than 2 microamps. The mixer circuit provides conversion gain of 10 dB. When the IF port is properly matched to the system IF, the mixer's high gain eliminates the need for an input buffer amp between the modulator and the mixer. Figure 5 charts power output as a function of the IF input power.

To save current further in various TDD/TDMA systems, a second method of enabling/disabling the MRFIC2002 is provided. In this method the device is triggered from a ramp provided by the MRFIC2004, which will be discussed later. This method is more desirable as it allows the MRFIC2002 to remain off during guard band times as well as during idle mode. As with the downconverter, the upconverter handles a very broad RF frequency range of 500 MHz to 1000 MHz and a wide IF (DC to 250 MHz).

900 MHz Antenna Switch

The MRFIC2003, shown in Figure 6, is a UHF Gallium Arsenide antenna switch capable of operating between 100 and 1000 MHz. The circuit utilizes MAFET™ (Motorola Advanced FET) devices which provide the system designer with high isolation and low loss. The need for a negative supply is alleviated by an on-board capacitor.

The excellent capability of GaAs to provide good isolation between the receive and the transmit functions as well as to limit signal loss is shown in Table 4. Typical isolation is 20 dB for the receive path and 23 dB for the transmit. Receive path loss is 0.5 dB typical and the transmit path loss is 0.8 dB typical, both at 900 MHz. Receive path and transmit path loss budgets over frequency are shown in Figure 7.

Switching is handled with TTL/CMOS inputs: "Receive Path Enable" and "Receive Path Not Enable", requiring no off-chip interface. Since the switch is designed for applications in low power systems, the power handling was targeted at 50 mW (17 dBm) or less to minimize chip size and therefore cost.

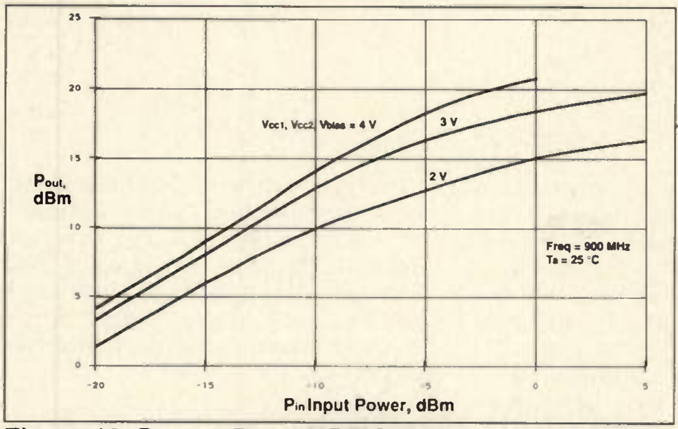


Figure 12. P_{out} vs. P_{In} — MRFIC2006 power amplifier.

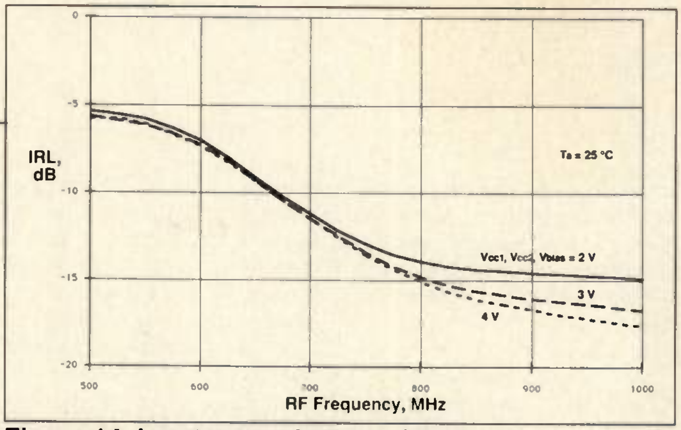


Figure 14. Input return loss vs. frequency.

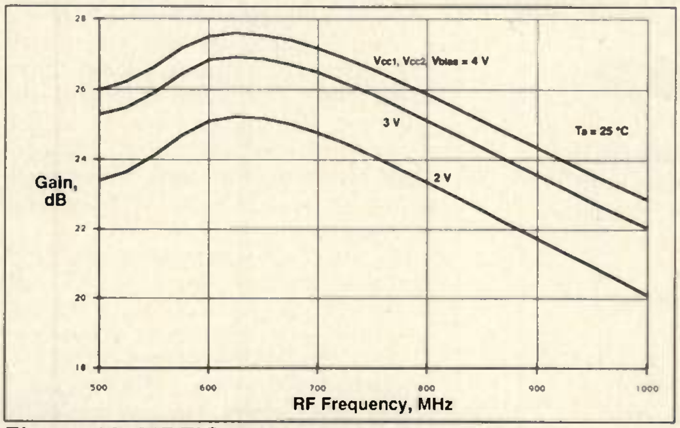


Figure 13. MRFIC2006 gain vs. frequency.

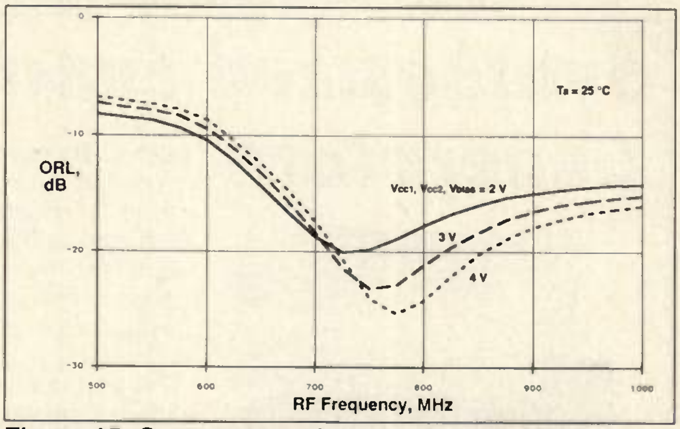


Figure 15. Output return loss vs. frequency.

900 MHz Driver, Ramp & Inverter

The new Time Division Duplex (TDD) wireless systems now being introduced require envelope shaping of the transmit burst to reduce spectral splatter. The MRFIC2004, shown in Figure 8, has a ramp function controlled by a user-selected capacitor connected between the two leads as shown. Figure 9 shows an example of the ramp voltage profile for the CT2 application. The driver, ramp and inverter can also perform the ramping fúnction in GSM systems.

The device contains an on-chip inverter function to control the antenna switch and upconverter, eliminating the need for the system designer to worry about these interface issues. The 34 dB of gain control provides a method to trim the PA output power and realize the CT2 low power mode. Gain over frequency as a function of gain control voltage is charted in Figure 10. To extend battery life, the standby current in the power down mode is 700 uA. The MRFIC2004 is usable from 800 MHz to 1 GHz.

900 MHz Integrated Power Amplifier

The MRFIC2006 in Figure 11 is a low cost, low power integrated 2-stage PA with 50 ohm input and output. Intended for low power systems such as CT2, CT2-Plus, CT1 and the U.S. ISM spread spectrum applications, the PA has a typical power output at 1 dB compression of 35.5 mW (15.5 dBm).

The bias pin feature allows the system designer to operate the amplifier in either class A or class AB by externally adjusting the bias current. Another advantage of this bias control is that it gives the system designer an easy method to set the output power. Table 6 lists the key performance parameters of the device.

For those systems where transmit waveform shaping is required, the MRFIC2006 can be ramped by applying the ramp voltage from the MRFIC2004 to the bias pin. Key performance parameter plots of interest to the system designer are shown in Figures 12, 13, 14 and 15.

Future System Solutions

900 MHz wireless communications systems are the first of the personal communication systems to be offered to the business and consumer markets. Before long, systems in the 1.8 GHz to 2.0 GHz spectrum (DECT, JPHP, USPCS) will be available for in-building and pedestrian use. While these systems will accommodate moderate data transmission rates, there is growing interest in the 2.4 GHz to 2.6 GHz spectrum for high speed wireless local data transmission. These higher frequency applications will have the same user expectations as the 900 MHz systems —

small form factors, long talk time, high quality connections, and low cost. These expectations result in the same system requirements at 2 GHz as at 900 MHz — high efficiency functions, low cost, quick design turnaround, high functionality, low voltage.

Motorola Semiconductors is prepared to support these requirements with a higher frequency bipolar process (MOSAIC 5), the GaAs MAFET process and an advanced BiCMOS process. Both MOSAIC 5 and the BiCMOS processes offer increased F_t and more gain with fewer parasitics. Device sizes will be one-quarter smaller resulting in a die shrink of 50 percent. This all results in the desired performance attributes of the systems designers — higher frequency, more gain and lower noise.

The advent of Type II PCMCIA cards containing complete 2 GHz radios will require more sophisticated low cost packaging. Motorola is developing plastic surface mount packaging with much finer lead pitch, a lower height profile and much higher frequency characteristics than today's standard.

System Summary

The MRFIC200X chip set from Motorola is a complete 900 MHz front-end solution. The chip set was designed according to market demands for short design cycles, small size and weight, long talk time, high quality voice reception and low cost. This chip set will allow designers to design for today's communication systems as well as the systems of tomorrow.

For more information about this product, circle info/card #75. **RF**

About the Authors

Jeffrey P. Ortiz joined the RFIC organization of the Communications Semiconductor Products Division (CSPD) of Motorola's Semiconductor Products Sector (SPS) in 1990, where he is responsible for the design and development of Si RFICs for the portable personal communications systems. Sheryl S. Zavion joined the RFIC organization in Motorola CSPD upon its formation in 1990, developing 900 MHz GaAs and Si MMICs for commercial personal communications systems. Paul Holmes joined CSPD in 1993 as the marketing strategy manager for the RFIC organization and the wireless microcell market segment. They may be reached at Motorola Inc., Communication Semiconductor Products Division, Phoenix Technology Center, 7755 South Research Drive, Suite 110, Tempe, AZ 85284. Tel: (602) 897-4480.

RF products

Ultra-Small 2.4 GHz Power Amplifier

Teledyne Microwave has introduced the TAE-1010A, a new GaAs MMIC amplifier that covers the "license-free" 2.4 GHz band. A class AB amplifier, this product offers designers of wireless communication systems a versatile solution for applications such as LANs, point-of-sale and data collection terminals, PBXs and mobile computing. The ultra-small surface mountable gullwing package lends itself well to low-cost, high-volume manufacturing processes. The TAE-1010A provides +27 dBm of output power with 30 dB gain. Third order intermodulation distortion is typically 39 dBm. The typical current consumption is 420 mA at +5 VDC (V_{DD}) and less than 25 mA at –5 VDC (V_{GG}). In addition, this miniature amplifier offers a unique benefit of bias flexibility: 3.3 VDC with 150 mW output and 30 dB gain, and 7.0 VDC with 1 W output and 27 dB gain. The TAE-1010A is available from stock. The amplifier is $150 for low quantities, with volume pricing available.
Teledyne Microwave
INFO/CARD #250

Broadband Directional Couplers

Two new dual directional couplers introduced by Amplifier Research further simplify swept-frequency testing to match the broadband capabilities of Amplifier Research RF power amplifiers.

The couplers are matched to the bandwidths and power capabilities of AR amplifiers and antennas, reducing band switching to a minimum. Model DC3010 carries 50 watts continuous power and 1000 watts peak pulse through the five-decade bandwidth of 10 kHz to 1 GHz. Model DC6100 has 500 watt continuous power capability and 1000 watt peak power capability through a bandwidth of 100 MHz to 1 GHz. Both couplers have typical directivity of 25 dB. The coupling factor of Model DC3010 is 40 ±0.6 dB, while that for Model 6100 is 53 ±1 dB. The Model 3010 costs $1600; Model DC6100 costs $850. Delivery is from stock.
Amplifier Research
INFO/CARD #249

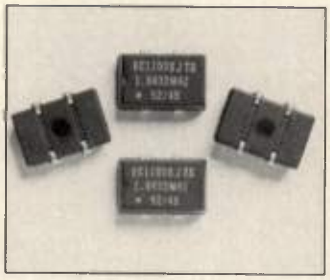
150W Transistor

Specifically designed for use in base station power amplifiers in digital and dual-mode cellular telephone systems, a new class AB linear power transistor from SGS-Thomson Microelectronics provides 150 W PEP output and is characterized over an operating frequency range of 800 to 960 MHz. Designated SD4590, the new device is a common emitter silicon NPN planar transisitor that features internal input/output matching, high saturated power capability for excellent linearity, and long term reliability. The SD4590 has 3 dB overdrive capability and 5:1 VSWR load mismatch capability at rated conditions. In addition, refractory gold metallization and diffused emitter ballast resistors ensure

low thermal resistance and reliability under class AB operation. Minimum power gain is 8.0 dB at 900 MHz, and maximum intermodulation distortion is –28 dBc at 150 W PEP.
SGS-Thomson Microelectronics
INFO/CARD #248

Surface-Mount Oscillators

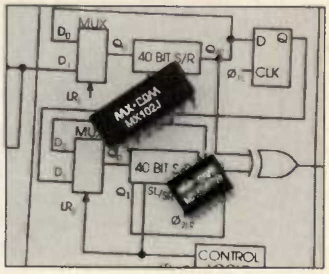
The EC1100SJ series of J-lead, plastic, surface-mount crystal oscillators are available in both TTL- and HCMOS/TTL-compatible designs. Key features of the EC1100SJ series include fit, form and function equal to the de facto industry standard for maximum design and sourcing flexibility; delivery lead-time as short as eight to 12 weeks (up to 50 MHz); "AT" cut crystal, hermetically



sealed in a metal can and encapsulated in a molded plastic package; four "J" leads for excellent stress relief when mounted on printed circuit boards and compatibility with common industry solder pad geometries; optional tri-state outputs. General specifications for the series include frequency range of 1.5 - 70.0 MHz, operating temperature range of –10 to +70 degrees C, operating voltage of +5.0 ±10 percent, with absolute maximum and minimum input voltages of +7.0 V and –0.3V, and load drive capability of up to 10 TTL or 50 pF.
Ecliptek Corp.
INFO/CARD #247

Autocorrelator

MX.COM's MX102 low power CMOS Autocorrelator extracts periodic signals from random noise. It eliminates non-periodic components and improves signal sensitivity. It features a low signal level input of 20 mVrms and a wide signal frequency range — from 2 to 12 kHz. The MX102's operating range of 2.5 to 5.5 volts allows it to be used in a variety of designs, including 2-cell applications such as sport radios. Other applications include medical instruments, sonar detection, remote signaling, paging and mobile radio. The MX102 cascades two autocorrelators, each one improving the signal to noise



ratio. The signal between these two autocorrelators is centered at twice the incoming frequency, and the output signal is centered at four times the incoming signal. The output signal delay is fixed by the frequency of the on-chip clock and the length of the internal register. The MX102 is available in 16-pin SOIC and CDIP packages. Pricing for the MX102 is $9.37 for quantities in the thousands.
MX.COM, Inc.
INFO/CARD #246

Product Spotlight: Software

Radio Management

Thomson-CSF has developed PC-based software and systems for administrative data management and allocation of frequencies as well as technical monitoring of transmissions in HF, VHF, UHF, and SHF radio communications systems. The software simulates interference patterns between transmitters in specific locations, and locates optimal positions for transmitters. Information on operators, licenses, allocated frequencies and equipment can also be adminstered by the system. A family of equipment to accompany the software is also offered.
Thomson-CSF Inc.
INFO/CARD #245

Distributed Filters

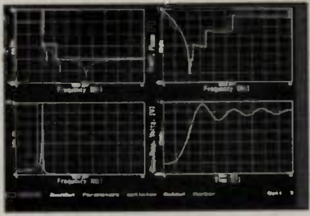
A complete set of distributed structures can be designed with =M/FILTER= by Eagleware. Filters in microstrip, stripline, coax and slabline (machined) can be synthesized and simulated. Automatic end, bend, tee and cross absorbtion is performed by =M/FILTER='s algorithms, as is correction for dispersion and differential phase velocity. Designs can be sent to plotters and laser printers, or to HPG or DXF files for board fabrication.
Eagleware Corporation
INFO/CARD #244

Transistor Modeling

EEsof is now offering a Transistor Modeling Service (TMS) for customers who need accurate linear and nonlinear models. TMS provides models for medium- and high-power silicon and GaAs transistors. These models are immediately usable with EEsof's Libra, J-Omega and Touchstone circuit simulators.
EEsof, Inc.
INFO/CARD #243

Active Filters

FilterMaster Active is a PC-based CAE tool for designing and analyzing active RC filters. It allows synthesis, "tweaking" and graphical display of filter response. An interface to Intusoft's SPICE simulation system allows more complex analyses, such as Monte Carlo Analysis. Cascaded filter sections are



modeled such that individual sections operate at optimal gains. The resulting filter has optimal signal/noise ratio and avoids any possible over modulation.
Intusoft
INFO/CARD #242

Op Amp SPICE Models

Comlinear's PSPICE-compatible models have been upgraded to include 16 high-speed, DC-coupled op amps with –3 dB bandwidths from 45 MHZ to 350 MHz. The ultra-low noise, wideband CLC425 is among the devices modeled. Actual transistor models in the signal path provide superior high-fequency simulation. The SPICE model disk is free of charge.
Comlinear Corp.
INFO/CARD #241

Electromagnetic Simulation

The IE3D Electromagnetic Simulation and Optimization Package consists of an integral equation, method of moments based electromagnetic simulator, an electromagnetic and circuit combined simulator, and two post processing applications for circuit parameter display and for current distribution display and animation. The software currently runs on PC compatibles running Windows 3.1, and will soon be available on all Windows NT machines and Sun SPARCstations. The introductory price is $17,000, with

TECHNICAL BOOKS

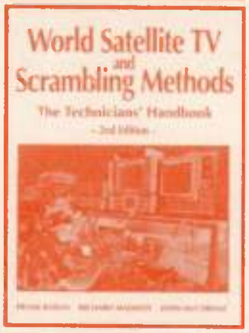
66. Telecommunications Transistors Systems

Robert G. Winch

This comprehensive book presents the operating principles, standards and system architectures for major telecommunications systems.Included are wireline, microwave digital links, fiber optic and mobile radio systems. Additional topics include propagation, signal processing and future transmission systems like broadband ISDN. A great reference for engineers and senior technicians, as well as technically-experienced non-engineers.

ISBN 0-07-070964-5 McGraw Hill 541pg. **$70**

67. World Satellite TV & Scrambling Methods



Dr. Frank Baylin, Richard Maddox, John McCormac

This book provides information for technicians and satellite professionals. The design, operation and repair of satellite antennas, feeds, LNBs and receivers/modulators are covered in detail.

ISBN 0-917893-15-8 Baylin Publications 356pg. **$40**

68. Ku-Band Satellite TV

Dr. Frank Baylin, Brent Gale, John McCormac

This book includes a presentation and an explanation for all aspects of Ku-band satellite television. A list of manufacturers around the globe is also included.

ISBN 0-917893-14-X Baylin Publications 426pg. **$30**

69. 1993 World Satellite Yearly

Dr. Frank Baylin

This book provides the information needed to determine the satellite programming available and the necessary equipment for receiving satellite.

ISBN 0-917893-18-2 Baylin Publications 450pg. **$50**

70. Radio Frequency Transistors

Norm Dye, Helge Granberg

The design of solid state power and small-signal amplifiers for HJF through UHF is covered thoroughly in this excellent practical book. The authors start with a basic understanding of transistor specifications and continue with explanations of biasing,matching, combining, CAD and other design principles, clearly illustrated with diagrams and photographs.

ISBN 0-750-69059-3 Butterworth,Heinman 235pg. **$40**

71. Electrostatic Discharge and Electronic Equipment

Warren Boxleitner

Subtitled "A Practical Guide to Designing to Prevent ESD Problems," this is an excellent guide to ESD prevention and troubleshooting from the circuit and interconnection level to the finished product. This book is a "must have" for electronic equipment designers.

ISBN 0-87942-244-0 IEEE Press 118pg. **$29**

TECHNICAL BOOKS

72. Spread Spectrum Systems

Robert C. Dixon

The classic textbook on spread spectrum theory and its application to communications. This book is essential for every engineer's library, covering direct sequence and frequency hopping, plus spread code generation and detection.

ISBN 0-471-88309-3 John Wiley and Sons 422pg. **$79**

73. Introduction to Electromagnetic Compatibility

Clayton R. Paul

This is the primary textbook in the world of EMC. All of the key concepts are covered in a balanced blend of theory and applications, intended to be both a teaching text for advanced undergraduate and graduate engineering courses as well as an indispensable reference for working EMC professionals.

ISBN 0-471-54927-4 John Wiley and Sons 765pg. **$74**

74. ESD from A-Z

John M. Koyler, Donald E. Watson

Here is a guide to proven, cost-effective methods for implementation of an ESD control program. Both conceptual ESD principles and practical control methods are presented for material handling, packaging and workstations, as well as guidelines for a complete ESD control program.

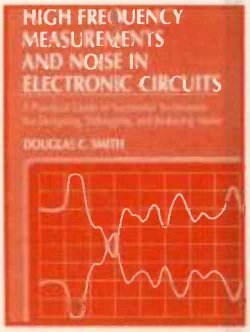
ISBN 0-442-00347-1 Van Nostrand Reinhold 290pg. **$46**

75. Controlling Radiated Emissions By Design

Michel Mardiguian

Every designer engineer should have this book, a thorough yet practical guide to EMC control through design. Radiation sources and mechanisms are described in detail, with guidelines for dealing with them at the component, board, interconnection and enclosure levels.

ISBN 0-442-00949-6 Van Nostrand Reinhold 250pg. **$59**



76. High Frequency Measurements and Noise in Electronic Circuits

Douglas C. Smith

A complete guide to methods and tools for EMC troubleshooting, whether the problem is radiation, ground loops, noise or other type of EMI. The book covers instruments,active and passive probes, noncontact measurements and procedures to obtain the best results.

ISBN 0-442-00636-5 Van Nostrand Reinhold 231pg. **$49**

free upgrade to other platforms when available.
Zeland Software, Inc.
INFO/CARD #240

S-Parameter Plotting

Motorola has developed the Quick S-Parameter Plotting

Program (QSPLOT) that lets the user view S11 and S22 on a Smith® Chart plot, and S12 and S21 on a scaled polar plot. In addition, the user can view input and output stability circles, f_T vs. log frequency and GMAX (in dB) vs. log frequency. A DOS machine with 1.2M floppy drive, mathcoprocessor and VGA display is required to run the program. The program is available fre of charge. Call Motorola Literature Distribution at: 1-800-441-2447.
Motorola Semiconductor
INFO/CARD #239

CAD for Windows

Optotek has unveiled MMICAD for Windows Version 1.0. The Windows 3.1 version takes advantage of the memory and multitasking capabilities of the Windows operating system. MMICAD for Windows can analyze circuits of unlimited complexity with up to 20 ports, and 8192 frequency or parameter points. An extensive library of manufacturer's S-parameter data files are included at no additional charge.
Optotek Ltd.
INFO/CARD #238

Mixed Signal Design

Analog Workbench/Mixed Signal from Cadence provides board and system designers with an integrated, top-down, mixed-level design and simulation environment. The OpenSim Backplane, integrated into the Analog Workbench/Mixed Signal system, allows other Cadence simulators to operate on the same circuit. Analog Workbench/Mixed Signal, featuring the OpenSim Backplane, is priced at $80,000 (U.S. list).
Cadence Design Systems, Inc.
INFO/CARD #237

SEMICONDUCTORS

Power Amp MMICs

Mitsubishi Electronics America now offers ultra-small GaAs MMIC power amplifiers which operate in the 1.85 to 1.95 GHz

band. The Mitsubishi MGF7122 measures 0.232 × 0.488 × 0.068 inches and can operate at 3.4 or 5.0 V with power outputs of 22.0 dBm and 24.0 dBm, respectively. Offered in hermetically-sealed, 8-pin ceramic packages, the MGF7122 cost $40 each in quantities of 10.
Mitsubishi Electronics America,
Electronic Device Group
INFO/CARD #235

Plastic PHEMPTs

Stanford Microdevices has released the first in a planned family of low-cost, plastic, surface mount, Pseudomorphic High Electron Mobility Transistors (PHEMTs). The SPF-284's typical noise figure is 0.7 dB at 2 GHz while supplying 16 dB of gain and consuming only 20 mW power. The SPF-484 achieves a typical noise figure of 0.8 dB at 4 GHz. Pricing for the SPF series starts at $0.99 in quantities of 10k.
Stanford Microdevices
INFO/CARD #236

RF products

3V MMIC Amps

California Eastern Laboratories announces the availability of four new NEC 3 V silicon MMIC amplifiers. The UPC2745 and UPC2746 wideband models offer bandwidths to 2.7 GHz. The 900 MHz UPC2747 and UPC2748 low noise models require as little as 5 mA operating current and feature up to 19 dB gain and noise figures as low as 2.8 dB. The devices are available in 6-pin mini-mold packages on tape and reel.
California Eastern Laboratories
INFO/CARD #234

Power MOSFET

The F9012 from Polyfet RF Devices is a silicon vertical DMOS designed for the 850 to 950 MHz range. The device has output power of 10 W at 24 V and has excellent high order products. The POLYFET™ process uses gold metal for extended lifetime. The transistor comes in an AP style package.
Polyfet RF Devices
INFO/CARD #233

MIC Amps

The MwT-0206-9P2 and MwT-0206-11P2 are 2-6 GHz power amplifier stages. The -9P2 has +26 dBm output power and 11 dB gain at 1 dB compression, while the -11P2 has +30 dBm output power and 6 dB gain at 1 dB compression. The MwT-0208-101DG/TC is a 2 to 8 GHz, self-temperature compensating, MMIC gain stage.
MicroWave Technology
INFO/CARD #232

UHF Transistors

Two dual-gate MOSFETs designed for the AGC stages of VHF and UHF tuners have been released by Philips. The BF908 operates from a 12V supply, has high transfer admittance, low input capacitance and superior cross-modulation performance. The BF904 offers similar performance but is designed for tuners operating from a 5V supply.
Philips Semiconductors
INFO/CARD #231

DBS Tuner IC

Anadigics announces the availability of a 950-1450 MHz direct broadcast satellite (DBS) tuner IC for digital applications. Designated the ADC20014 Tuner IC, the device offers a low phase noise oscillator, 10 dB noise figure, 5 dB conversion gain, operation from a +5V supply and 16-pin SOIC packaging.
Anadigics
INFO/CARD #230

TEST EQUIPMENT

Reflection Analyzer

Marconi's 6210 Reflection Analyzer, an add-on for the 6200 microwave test set family, provides precision reflection analysis for RF and microwave systems and components. The unit makes measurements across the frequency range of 250 MHz to 26.5 GHz. Price for the 6210 upgrade is $13,775.
Marconi Instruments
INFO/CARD #229

DDS Signal Source

Novatech Instruments is now offering the Model 2910A, a benchtop instrument using direct digital synthesis (DDS) to generate a sinewave signal that is programmable up to 48 MHz. Output frequency and amplitude are set with a front panel knob or via EIA232 computer interface. The 2910A price is $1499 each, and delivery is from stock.
Novatech Instruments, Inc.
INFO/CARD #228

Dual Channel Synthesizer

PTS introduces the PTS D620, a broadband dual-channel frequency synthesizer. The D620 contains two fully independent high-performance frequency synthesizers, each covering 1 to 620 MHz, within the space traditionaly occupied by a single synthesizer. Maximum frequency switching time is 20 us. The U.S. list price

is $12,725, including an OCXO frequency standard.
Programmed Test Sources, Inc.
INFO/CARD #227

Signal Generators

Panasonic Factory Automation has introduced a line of signal generators which includes the VP-8120A (standard), VP-8121A (with FM stereo modulator) and the VP-8122A (with AM/FM stereo modulator). The series features high output (+19 dBm) over a 10 kHz to 280 MHz band.
Panasonic Factory Automation
INFO/CARD #226

Waveform Synthesizer

Analogic annouces the DBS8750, a 16-bit, 400 kHz, dual-channel isolated VXI arbitrary waveform synthesizer. The single-slot, C-size VXI instrument generates very accurate standard and arbitrary waveforms with 96 dB spurious free dynamic range across its bandwidth. The Analogic DBS8750 VXI arbitrary waveform synthesizer is priced at $3990.
Analogic Corp.
INFO/CARD #225

Radar Simulator

ECI Systems and Engineering announces production of the ECI portable radar simulator (PRS). The microprocessor controlled simulator uses a solid-state transmitter design, is in a non- ventilated case, has nonvolatile memory and meets MIL-STD-461 for EMI/RFI and MIL-STD-810 for temperature and transportation vibration ruggedness.
ECI Systems and Engineering
INFO/CARD #224

Field Strength Meter

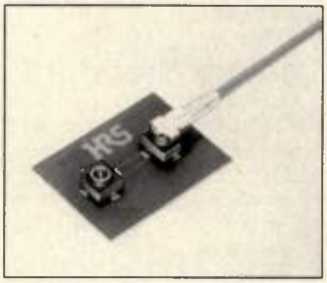
The Digi-Field field strength meter's frequency response covers DC to 12 GHZ, and signal strength is displayed on a 3.5 digit LCD with overranging indicator. Model "A" detects an injected 100 MHz signal over the power range of 150 nW to 3.5 mW, model "B" from 2nW to 60 uW. Gain is dependent on antenna length. The unit is powered with a 9V battery. Price is $119.95 with $4.50 S&H.

IC Engineering
INFO/CARD #223

CABLES & CONNECTORS

SMT Coaxial Connector

Hirose Electric has introduced its H.FL series SMT low-profile super-miniature coax connector, boasting a mated height of only 3mm. The H.FL series offers 360 degree mating orientation and



operates with less than 1.3 VSWR from DC to 3 GHz. The connector is crimped to the cable and a tool is provided for un-mating the plug and receptacle. Plug cable assemblies with connectors on both ends of a 66mm cable are $6.95 each, recepticles are $1.35 each, both in quantities of 100.
Hirose Electric
INFO/CARD #222

High Power Connector

A blind mate connector capable of handling up to 950 W at 16 GHz with axial float of ±.060 inch and radial float of ±.020 inch has been developed by C.E. Precision Industries. Low loss and low

VSWR are inherent in the connector's design. Versions are available to handle 300 W at 26 GHz.
C.E. Precision Assemblies
INFO/CARD #221

Rotary Joint

Sage Laboratories has developed a high performance rotary joint, model 351SP. The joint has K-type connectors, 0.5 inch diameter, and length less than 1.1 inches. The rotary joint provides performance to 26.5 GHz, weighs 0.5 ounces, and handles rotational speeds to 250 rpm.
Sage Laboratories, Inc.
INFO/CARD #220

Mini-UHF Plug

RF Industries announces the availability of its RFU-600-6 Mini-UHF crimp plug for RG58/U cable. It has a gold plated brass crimp pin and delrin dielectric. The cable crimps to both the pin as well as the shield crimping ferrule stud. A standard crimping tool can be used for installation. Dealer price is $1.70 each in quantities less than 25.
RF Industries Ltd.
INFO/CARD #219

SIGNAL SOURCES

Phase Locked Oscillator

The CS-312 is one of a series of phase-locked oscillators with frequencies ranging from low MHZ to low GHz. Typical phase noise for a 1100 MHz unit is –85 dBc at 100 Hz, –90 dBc at 1 kHz and –95 dBc at 10 kHz offset. Some members of the series have selectable frequencies via TTL inputs.
Communication Solutions, Inc.
INFO/CARD #218

OCXO

Frequency stability of $\pm 5\times10^{-9}$ at temperatures of –55 to +80 degrees C is offered by an oven controlled crystal oscillator from Bliley Electric. Designated Bliley Type N96B, the oscillator also features an aging characteristic of 1×10^{-9}/day. Mechanical adjustment is sufficient for a 5 to 10 year aging cycle. In 100 piece quantities, the Bliley N96B crystal oscillator is priced at $789.
Bliley Electric Co.
INFO/CARD #217

BiCMOS Oscillator

Designed for use with Intel's Pentium microprocessor, Connor-Winfield's BiCMOS oscillator, MPB53R, is available at 60.000 and 66.666 MHz. Stabilities are from ±25 ppm to ±100 ppm. Typical symmetry is ±1 percent, with rise/fall times of 3 ns max. The part is available in a tri-state version. Prototype quantities of the 60 MHz version are available at $22.50.
Connor-Winfield Corp.
INFO/CARD #216

Low Power Consumption

Operating from 5 VDC, Techtrol Cyclonetics' XO835 draws less than 12 mA of current. The unit is housed in a 1.50 × 1.50 × 0.50 inch case. Model XO835 is available from 40 to 120 MHz, with ultra low noise of –170 dBc/Hz at 100 kHz, ±.001 percent stability and +10 dBm output power.
Techtrol Cyclonetics, Inc.
INFO/CARD #215

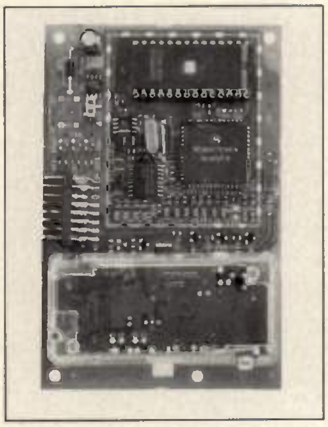
SAW-Stabilized Clocks

RF Monolithics has introduced a new line of integrated SAW-stabilized digital clocks with frequencies from 200 to 700 MHz. Called the HC series, the clocks feature differential ECLinPS outputs, clock jitter typically under 1 ps rms and clock symmetry better than ±5 percent. The HC series is packaged in 14-pin metal DIP packaging and is priced at $75 each in small quantities.
RF Monolithics, Inc.
INFO/CARD #214

SUBSYSTEMS

Pager Receiver

A board-level OEM paging data receiver from Motorola receives and decodes data broadcast over existing paging networks. The RNet™ Paging Data Receiver operates at 138-174 MHz, 435-480 MHz and 900 MHz. The receiver can send data at 1200, 2400 or 9600 baud via a serial



RS232 or TTL interface.
Motorola Wireless Data LAN Div.
INFO/CARD #213

Switch Filter Assembly

Dynatech has developed a high power HF/VHF switch filter assembly, integrating a filter and solid state PIN diode switch into a single package. Passband attenuation is typically less than 0.3 dB, and power handling capability is 2 kW. VSWR is held to less than 1.3:1.
Dynatech Microwave Technology
INFO/CARD #212

Cesium Standard

A small, lightweight cesium standard from Frequency and Time Systems offers calibrated accuracy of $\pm 3\times10^{-12}$ over the environment and life of the product. The FTS 4040A/RS offers remote control and monitoring via an RS232 interface. The FTS 4040A/RS weighs only 45 lbs. and measures 17.31 × 17.4 × 5.22 inches.
Frequency and Time Systems, Inc.
INFO/CARD #211

GPS Timing Receiver

The GPS Clock™, Model 100 Series, is a small, lightweight, L1 C/A Code, digital GPS timing receiver. The GPS Clock offers standard 10 MHz output with accuracy of 5×10^{-12} and a 1 pulse per second output with less than 1 ns jitter. The unit is self contained, but output for computers or printers is via an RS-232 port. The Model 100 is listed at $2495.
Stellar GPS Corp.
INFO/CARD #210

Direction Finding Antennas

A series of radio direction finder antennas offer extended frequency coverage to 2 GHz. Various models are designed for mobile, transportable or fixed-site applications. These DF antennas are characterized by their small size and high sensitivity. They may be utilized in single channel (goniometric) or multichannel (interferometric) systems.
Tech Comm, Inc.
INFO/CARD #209

Digital Cellular Antenna

The Antenna Specialists have announced a version of its ON-GLASS® cellular vehicular antenna designed for use with GSM and TACS systems. Model APG855.3 has less than 1.9:1 VSWR over the frequency range 870 to 960 MHz. Both TNC and mini-UHF connectors are available.
The Antenna Specialists
INFO/CARD #208

SIGNAL PROCESSING COMPONENTS

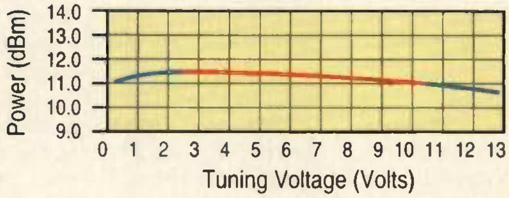
SSB Modulator

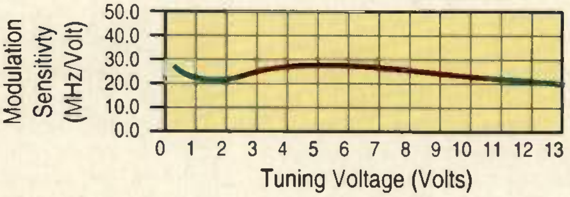
Model SSM 352 from TRM, features low conversion loss and high sideband suppression for single sideband modulation of an RF signal at a frequency of 352 ±15 MHz. I and Q baseband modulation inputs are DC coupled, providing a frequency range of DC to 10 MHz. The SSM 352 is available with SMA connectors or in various flatpack configurations.
TRM, Inc.
INFO/CARD #207

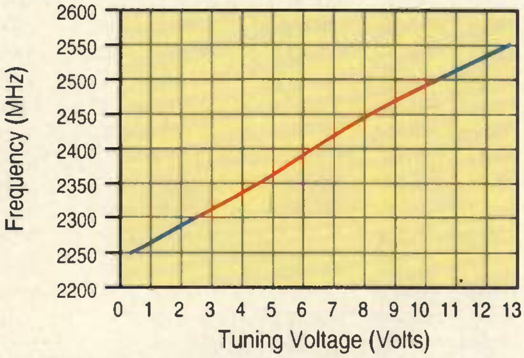
VSB Filters

A complete line of vestigial sideband (VSB) filters from Sawtek incorporate NTSC group delay pre-distortion. The VSB filters also provide excellent amplitude, phase and delay linearity, and superior stopband rejection. The filters are packaged in hermetically-sealed metal DIP packages.
Sawtek, Inc.
INFO/CARD #206

Voltage Controlled Oscillators







MA87CA02300250 (TO-8 and surface mount packaging available)

Parameter	Min	Max	Units	Conditions
Frequency Range	2300	2500	MHz	
Output Power	+10	+13	dBm	50 Ω load, 15 V supply
Tuning Voltage	+2	+12	Volts	
Linearity		±.25	%	Deviation from best fit straight line
Harmonics		- 25	dBc	
Phase Noise		-110	dBc/Hz	100 kHz offset
Frequency Drift		±150	kHz/°C	-30 to +70 °C
Frequency Pushing		3	MHz/Volt	+15 ± .5 V
Frequency Pulling		30	MHz	12 dB return loss, all phases
Supply Voltage	+14.5	+15.5	Volts	
Supply Current		50	mA	
Temperature Range	-30	+70	°C	

M/A-COM Voltage Controlled Oscillators are suitable for commercial and industrial applications in synthesizers, local oscillators, and wherever a frequency is needed for signal generation or conversion. Oscillators are available in many frequency bands between 1 and 10 GHz, with bandwidths from 5 to 30 percent. Individual test data and serialization also are available, and custom orders are welcome. For more information, please call (617) 272-3100 ext. 1756 FAX (617) 221-3108.

M/A-COM, Inc.
Burlington Semiconductor Operations
43 South Avenue
Burlington, MA 01803

M/A-COM

INFO/CARD 58

Classes of Power Amplification

By Gary A. Breed
Editor

The subject of power amplifier operating class is not particularly complex in concept, but the beginning reader should be warned that completing an amplifier design for a particular class may not be so simple. This tutorial covers the basics: the definitions of six operating classes that are the most commonly used. A few notes are included on implementation, but much additional reading and study should be undertaken to get a better understanding of the complexity of power amplifier design.

The most-often used classes of operation for power amplifiers are A, AB, B, C, D and E. Although other classes have been defined and used in some applications, they are far less common than these.

Class A

By definition, class A means that the amplifying device (bipolar transistor, MOSFET, vacuum tube or other device) is conducting at all times. This is usually defined as conduction for all 360 degrees of the sine wave input. This class offers the highest linearity as long as the active device operates in the linear portion of its transfer function, does not saturate during any part of the cycle, and stays within its power dissipation limits.

The design requirements that must be met include proper bias (base, gate or grid) to keep the device turned on during the entire input voltage swing; some type of current limiting (usually a collector, source or cathode resistor) to keep the device from dissipating excessive power; and selection of operating voltage to maintain performance according to device specifications. Temperature compensation will be required when the amplifying device is operated at a significant percentage of its power handling capacity.

Class B

Class B is defined as conduction over 180 degrees of the input sine wave. The typical application of class B is in push-pull amplifiers, where two devices share the total amplification load, each contributing power during one-half of the waveform. This class allows convenient combining of two devices for higher power output, while maintaining generally linear operation during each half of the cycle.

The limitation of class B is that it is not sufficiently linear. Amplifying devices do not have linear transfer functions over 180 degrees. There is a transition region near the turn-on point that is non-linear before the input/output slope becomes linear. The effect of this region is "crossover distortion," a bump or step in the waveform at the zero crossing (where one device stops delivering power and the other one takes over). For this reason, true class B amplifiers are rarely used.

Class AB

To overcome the crossover distortion problem of class B, the devices are usually slightly forward-biased to reach the edge of the linear region of the transfer function. This small bias, which typically causes a quiescent current of two to ten percent of the total current, moves the operating point away from class B, closer to class A — hence the name class AB.

Class AB is also occasionally used in single-ended amplifiers. Because the device does not draw full current all the time, class AB results in greater efficiency than class A. For amplifiers which must be reasonably linear, but can tolerate some degree of non-linearity, class AB may be an option for the designer.

The critical design task is identifying what tradeoff to make between quiescent current (and efficiency) and linearity. This is usually dictated by the requirements of the modulation applied, and the regulations that must be met regarding the level of distortion products that are generated by the amplifier's non-linearity.

Class C

Class is defined as conduction over something less than 180 degrees. The most common use of class C is in self-biased amplifier circuits. For example, an applied sine wave does not turn on a bipolar transistor until its voltage reaches the forward voltage of the base-emitter junction. Also, if the emitter is above ground due to the presence of a resistor, the input must also overcome the voltage drop caused by current through this resistor. As a result, the transistor is turned on for less than the 180 degrees that the input waveform is positive.

Since class C amplifiers behave something like an impulse function, they are very non-linear; the output waveform bears little resemblance to the input. However, the device is turned on for less time, while delivering the same peak power, so its efficiency is higher than class A, B or AB. For modulation types that do not need linearity (FM, PM, CW), or for modulation types that are applied at the power amplifier (AM, pulse), class C is often the operation chosen. The simplicity of self-bias or uncompensated bias circuits, along with the good efficiency, make class C the first choice for many designs.

Class D

This is the first of two switching-mode classes to be discussed. The advantage of an ideal switching amplifier is simple to explain. Consider a switching device connected to a resistive load — when the device is off, it draws no current; when it is fully on, its resistance is very

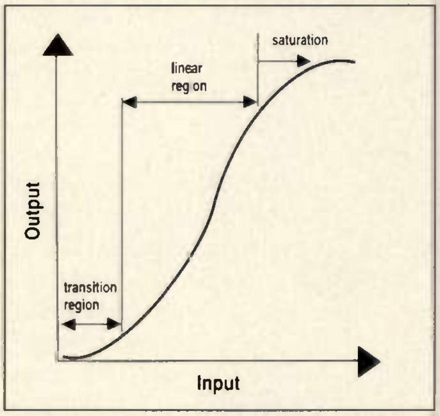


Figure 1. Typical input/output transfer function for power amplifier devices.

low compared to the load, and it dissipates little power. If the device can switch between these two states instantaneously, it will allow a great deal of power to be transferred to the load, without absorbing (and dissipating) much power itself. A perfect switching amplifier would be 100 percent efficient.

Of course, this is an ideal situation that can only be approached in real life. At low frequencies, the approach is very close; the switching time (rise and fall times) is very small compared to the total on or off time. However, as the operating frequency increases, limitations of the device (junction storage time, inter-electrode capacitance) and reactance of the circuit elements prohibit near-perfect switching. Fortunately, an improvement in efficiency can be obtained without ideal performance.

Class D has two forms, current-switching and voltage-switching. For RF amplification, the current switching type is probably most common. It requires a square wave input, and rapid charging and discharging of the gate capacitance of the MOSFET that is usually the amplifying device. Voltage switching can also be used in some applications, with the advantage that a sine wave can be used as the driving signal instead of a square wave, as long as the sine wave has sufficient amplitude for complete turn on and cutoff of the device.

Class D is inherently wideband (given the rise and fall time limitations), and can yield high efficiency amplifiers of over a decade in frequency range. The complexity of square wave or high level sine wave input can deter engineers from its use when economy is a consideration, but it is an excellent choice when overall efficiency is a major concern. For example, nearly all AM broadcast transmitters employ switching amplifiers because their efficiency saves a considerable amount of money in a reduced power bill.

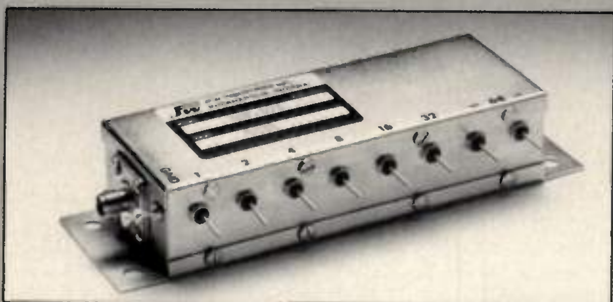
Class E

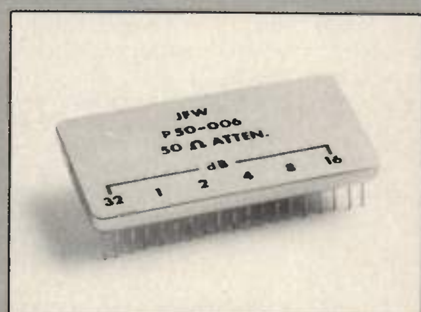
Class E is a particular class of switching amplifier that can improve efficiency over an equivalent class D amplifier. Class E uses an output tuned circuit to partially compensate for the amplifiers' output capacitance, and as a "flywheel" to keep switching voltages and currents in proper phase. In some cases, the improved efficiency can be significant, but this class is inherently narrow-band, requiring switched circuits for wide frequency coverage.

Choices of any of these amplifier classes are dictated by system requirements. Power consumption, modulation type, power level, occupied bandwidth constraints and cost of manufacturing are all major factors to consider. Also, power amplifier designers are nearly always faced with contradictory requirements; evaluating the tradeoffs is the engineer's primary design task. *RF*

References

1. N. Dye and H. Granberg, *Radio Frequency Transistors*, Butterworth-Heinemann, 1993, Ch. 4.
2. D. Fink and D. Christiansen, *Electronics Engineers' Handbook*, 3rd Edition, McGraw-Hill 1989, Section 13.
3. *Power Amplifier Handbook*, Cardiff Publishing Co. 1991 (collected articles from RF Design).





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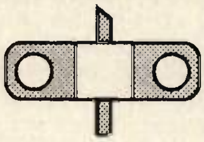
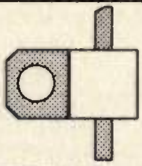
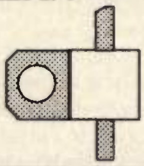
MPS-202201-71	+34	+22	9	5.0/90	
MPS-202409-85	+37	+24	11	10.0/135	
MPS-202708-85	+40	+27	11	12.5/170	

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Program Performs Symbolic Circuit Analysis

By Henry Yiu
YY Software

The purpose of the program XFUNC is to compute the frequency domain transfer function of a circuit in symbolic format, given a circuit description netlist using linear models. In addition to this basic feature, the program provides various extras, which will be discussed in the following sections.

Electronic engineers, research scientists, and mathematicians will find XFUNC most useful. Most circuit analysis software on the market today, such as SPICE, only give a numerical frequency response solution to a given circuit. But it is sometimes necessary to find the frequency response with respect to various circuit parameters, and to choose component values to optimize the performance. The most direct and proven way to achieve these goals is to generate the mathematical transfer function description of the circuit. XFUNC saves the engineer's time and tedious efforts by generating the symbolic mathematical transfer function.

Another important feature of XFUNC, when compared to most other circuit analysis software, is its ability to use the state-space averaging technique to analyze a switching circuit. Although SPICE based programs can calculate transient response, they do not provide a frequency response solution to a switching circuit. It should be noted that because XFUNC is symbol based, it is not designed to handle large circuits. For most analog circuit analysis, it is best to break up a large circuit into small blocks and to analyze each block.

In addition to circuit analysis, XFUNC can be used as a simple tool for symbolic algebra. Besides addition, multiplication, etc., it can be used as a symbolic matrix simplifier and solver. It also generates plots of the results.

Requirements

XFUNC requires an IBM compatible with 286 processor or better, at least 512k bytes of free memory, 1 Meg or more of hard drive space, EGA color monitor or better and DOS 2.0 or better. A mouse and math coprocessor are recommended but not required.

Using XFUNC

Most of XFUNC's routines can be run from either the DOS command line, or from the integrated environment that XFUNC provides. Several file, data, analysis and plotting options are available. Transforms between the frequency, S- and Z-domains are possible. Under the Plot option, gain-phase, Bode, pole-zero, Nyquist, impulse response and step response plots are available.

The circuit to be analyzed is described in an ASCII file with a .CIR extension. Each line of the circuit file contains either a circuit component description, the type of analysis to be made, the user option to control the analysis, or just a comment. These lines can be written in any order, as long as the list is ended with an ".END". The circuit files use the same node numbering scheme employed by SPICE. Figure 1 shows a ladder network netlist being edited by

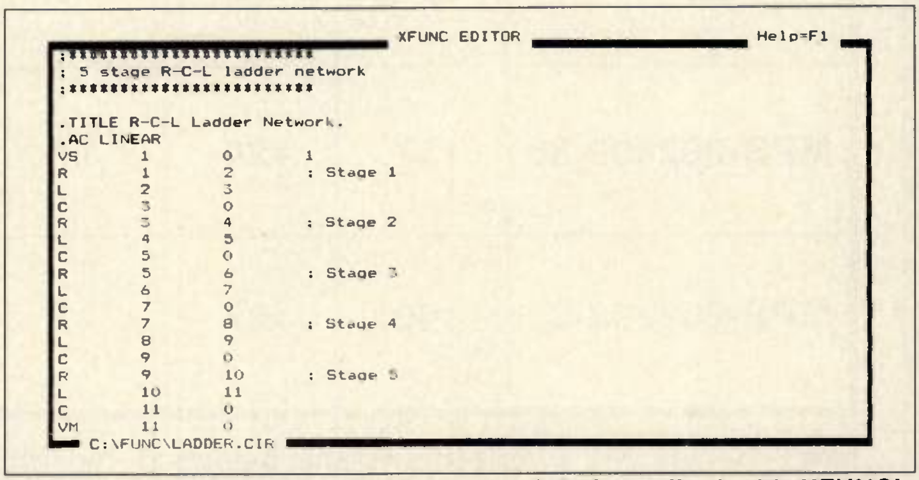

Figure 1. Circuit file for a ladder network being edited with XFUNC's built-in editor.

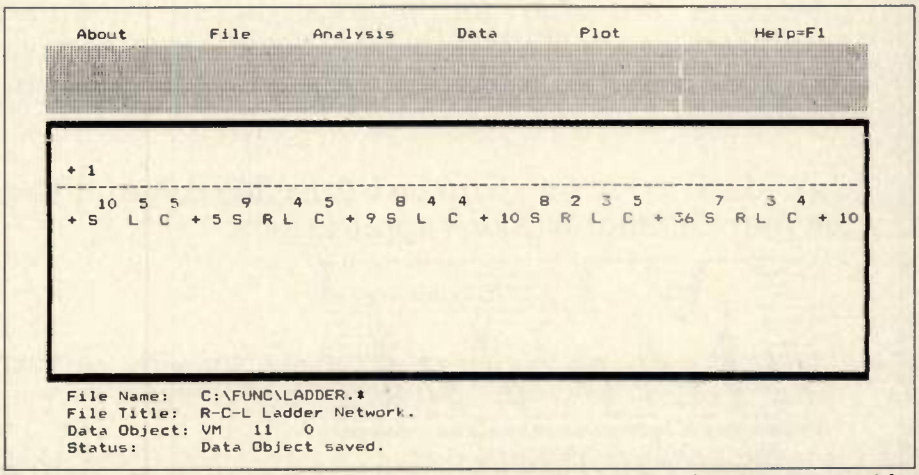

Figure 2. First five terms of the denominator of the ladder network's transfer function.

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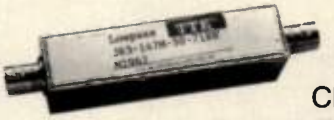

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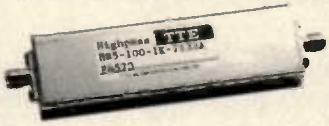

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DL-10.7	11MHz	14MHz	24MHz	DK-21.4-5P	21.4MHz	5%F_o
DL-21.4	22MHz	24.5MHz	41MHz	DK-30-5P	30.0MHz	5%F_o
DL-30	32MHz	35MHz	61MHz	DK-40-5P	40.0MHz	5%F_o
DL-50	48MHz	55MHz	90MHz	DK-50-5P	50.0MHz	5%F_o
DL-70	60MHz	67MHz	117MHz	DK-60-5P	60.0MHz	5%F_o
DL-90	81MHz	90MHz	157MHz	DK-70-5P	70.0MHz	5%F_o
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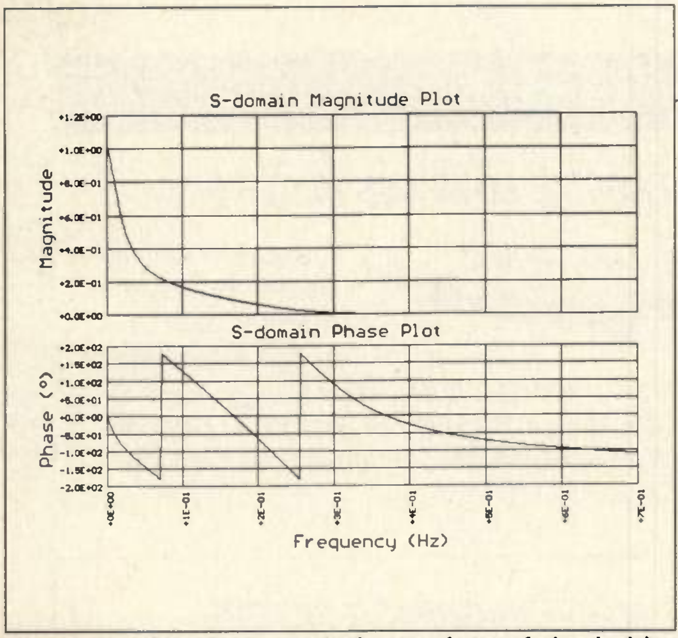

Figure 3. Magnitude and phase plots of the ladder network transfer function.

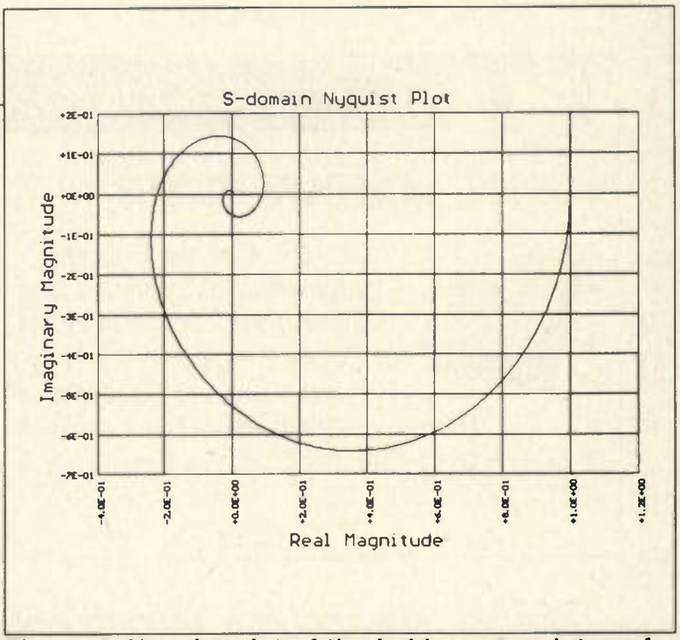

Figure 4. Nyquist plot of the ladder network transfer function.

XFUNC's editor.

The program "analysis.exe" calculates the transfer function of the circuit contained in a .CIR file. Selecting "Analysis - Go" from the integrated environment's menu executes this program, or it can be run from the DOS command line. It produces two files, an output file (with a .OUT extension) and a data file (with a .DAT extension). Figure 2 shows the first five terms in a ladder network's S-domain transfer function, (contained in an .OUT file). The rest of the transfer function's terms are outside the editor's window.

The program "operate.exe" performs operations on the .DAT files and plots graphs. Once a circuit file has been analyzed with "analysis.exe" the resulting data file can be modified. All arithmetical operations can be performed on the data file as well as substitutions, frequency to time domain transformations and S- to Z-domain transformations. The modified data is stored in a .MOD file.

Plotting is also accomplished by "operate.exe". The plots are derived from rational functions in S or Z. If any other variables are present, they must be re-

About the Author

Henry Yiu is presently working as an Electronics Design Engineer at Beckman Instruments, in Brea, California. He received a BSEE degree from the University of Texas at Austin in 1985 and a MSEE degree from the California Institute of Technology in 1986. He has experience in low noise signal conditioners, low power circuits, high speed amplifiers, analog and digital ASIC design, switching power converters, high voltage power supplies, digital signal processing and microprocessor based instruments, and software development and maintenance.

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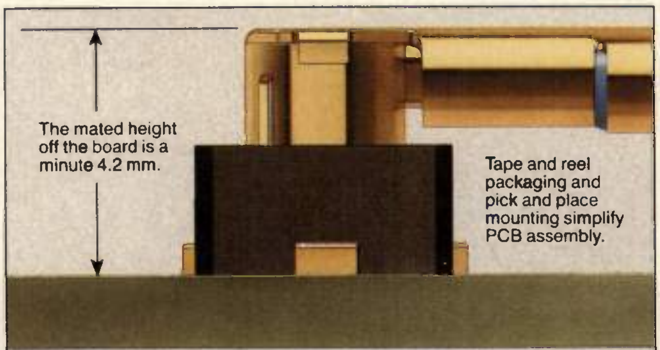

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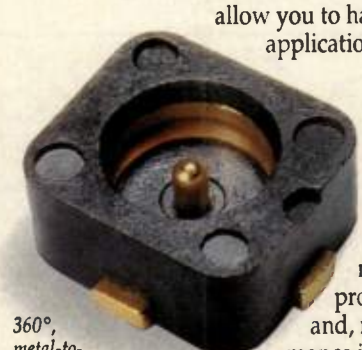
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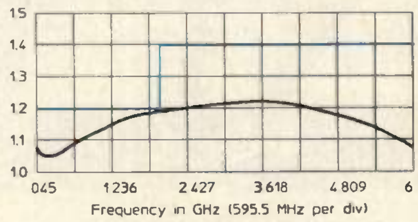

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placed with numerical values via the Data-Modify option. Gain-phase, Bode, pole-zero, Nyquist, impulse response and step response plots are all available. Figure 3 is a magnitude/phase plot of a ladder network, and Figure 4 is a Nyquist plot of the same network. For both plots, the values of R, L and C were set to 1 using XFUNC's Data-Modify option.

To summarize XFUNC's features:

- User friendly pop-up screen and pull-down menu interface.
- Calculate AC or DC symbolic transfer function.
- Calculate transfer function in S-domain for Linear Circuits or Z-domain for Switching Circuits.
- Accept resistors, capacitors, inductors, dependent sources, ideal opamps, and ideal switches.
- Component values can be real numbers, symbols, or user defined symbolic expressions.
- Analysis results can be interactively modified.
- Frequency domain results can be transformed to time domain via
- Inverse Laplace or Z Transform.
- Transformation between S-domain and Z-domain results can be done via Forward or Backward Derivatives (Euler Transform), Bilinear, or Impulse Invariant Transforms.
- Provide Bode, Gain-Phase, Nyquist, Pole-zero, Impulse, and Step response plots. Plot ranges can be set manually or automatically.
- Dynamic array memory allocation avoids overflows while minimizing memory requirements.
- Supplied with its own ASCII editor.
- Supplied with FASTDUMP utility to plot graphs to Epson, IBM Pro, HP Laserjet, or disk files. ***RF***

This program is available on disk from the RF Design Software Service - see page 96 for ordering information.

25 Mbps Differential Receiver with 1000 Volts of Isolation

By Pavlo Bobrek
Loral Data Systems

This circuit is useful when high speed digital data must be transmitted over long cables in a harsh environment, e.g. where there are lightning induced transients. It was developed in support of the Boeing 777 test program which required data and clock signals to be transmitted at various rates over differential cables at distances up to 300 ft. Specifications required the receiver to operate at 24 Megabits/sec and withstand common mode surges of 600 volts as specified in standard RTCA/DO-160C section 22, category K. The high data rate eliminated the possible use of opto-isolators because their high delay variance causes unpredictable skew between clock and data. The receiver requirements are met with a simple MMIC oscillator driving two pairs of mixers creating a synchronous modulator/demodulator for both the data and clock signals.

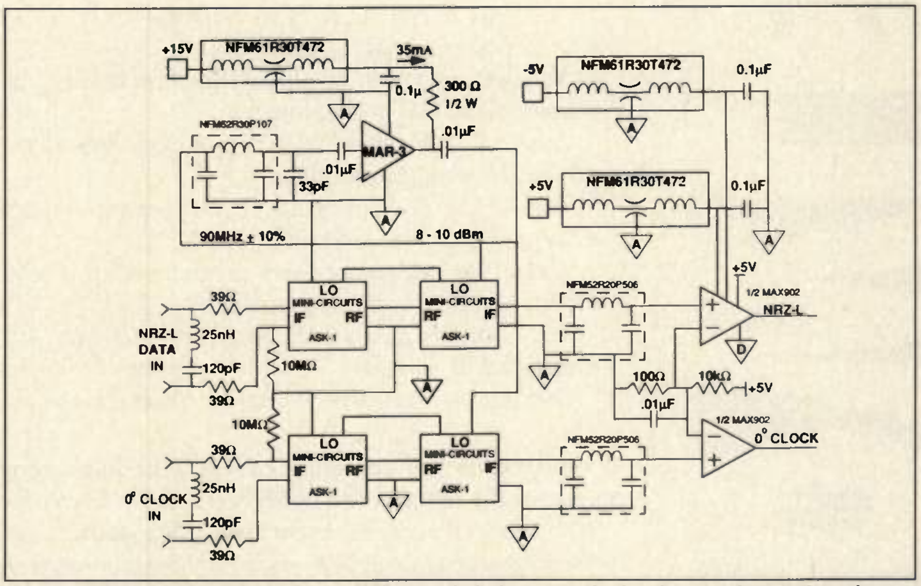

Figure 1. Isolated 25 Mbps differential data and clock receiver circuit.

Figure 1 is a schematic of the dual-channel differential receiver. A low cost MMIC amplifier is used to construct a 90 MHz oscillator with over +8 dBm of output power to drive all four mixers. An ultra-miniature EMI suppression filter is used as the resonator element (the exact frequency of oscillation is not critical). Each differential receiver channel consists of a pair of mixers connected back to back to create a synchronous modulator/demodulator. The filtered output of the second mixer is fed into a digital comparator to reconstruct the digital signal.

The oscillator design was inspired by a November 1987 *RF Design* article on the use of MMICs in oscillator circuits (1). The EMI bead filter provided the simplest choice of resonating element since the oscillator frequency was not critical. It is possible to greatly increase the data rates at which the design will operate by increasing the oscillator frequency (using either a discrete LC lad-

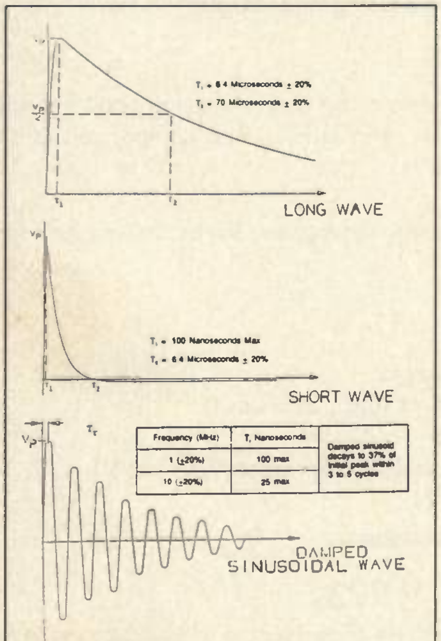

Figure 2. Voltage wave forms.

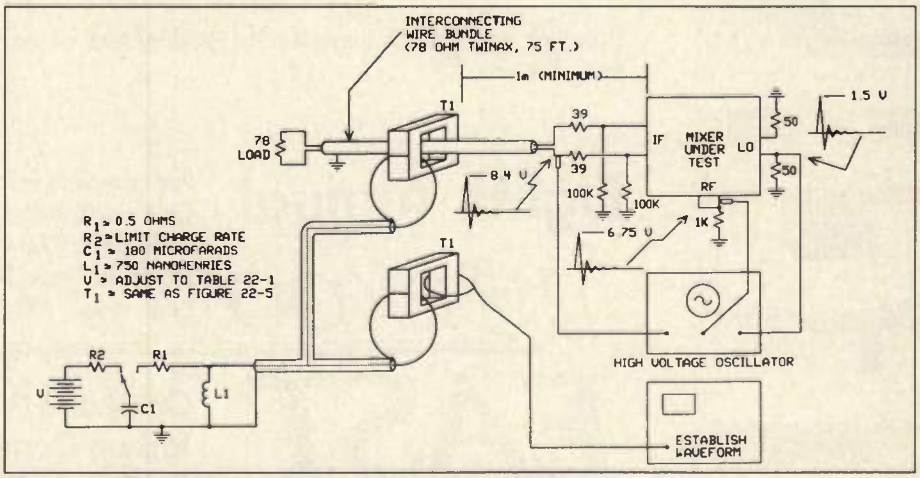

Figure 3. Typical test setup: short wave test.

der or equivalent distributed element circuit) and by selecting a higher frequency mixer. However, at higher oscillator frequencies, the signal delay through each mixer may not be an insignificant fraction of the carrier wavelength. This results in an apparent phase shift between the synchronous LO of the second mixer with respect to the carrier signal present at the mixers' RF ports. This problem could be corrected somewhat by connecting the MMIC amplifier's output to supply the first (modulator) mixer in each chain rather than the second (demodulator). This modification would make the MMIC more vulnerable to common mode feed-through and so reduces isolation. An alternative would be to fix the phase shift by controlling path delay or using a phase shift circuit. Neither of these modifications is necessay to operate at 25 Megabits/sec.

The mixers were chosen for their small size, however, virtually any double balanced mixer will work. Since the received signal is fed into the IF port of the first mixer, the differential DC content of the signal is preserved at the IF output port of the second mixer. This circuit is designed to receive signals over a 78 ohm twinax cable which is source terminated. The series 39 ohm resistors were put in for current limiting and to limit reflection of any large transients. The LO to IF feedthrough was measured to be 20 millivolts peak to peak at 90 MHz. The LC notch filter at the input of the first mixer reduced the LO feedthrough to under 2 millivolts. The 25 nH inductor has an air core and is made of 4 turns of #20 magnet wire on a 0.1 inch form.

The comparator has a 50 millivolt positive bias to provide noise immunity, enabling the receiver to work with unipolar signals. The EMI filter between the filter and the comparator, together with the comparator's response, adequately suppresses the carrier's first harmonic.

The combined circuit is able to operate with a received signal amplitude as low as 250 millivolts peak to peak. The maximum differential signal is dependent on the current levels that the mixer's IF diodes will tolerate (about 40 mA). The entire circuit occupies about 1.5 square inches of a single side of a printed circuit board.

Performance Results

This circuit was primarily designed to meet the requirements specified in standard RTCA/DO-160C section 22, category K. That document specifies the test which must be performed to ascertain a high level of isolation. There are four test waveforms which are used. These are shown in Figure 2 (one sketch is used to illustrate two different sinusoids in that figure). RTCA/DO-160C also specifies the construction details of the test setup required to conduct the test on a given system. We connected a single mixer as shown in Figures 3 through 6 as the unit under test. The voltages

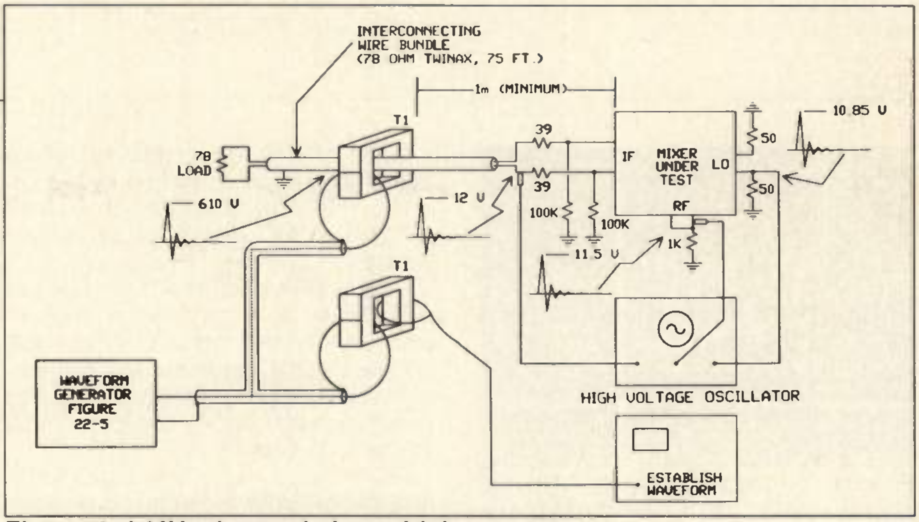

Figure 4. 1 MHz damped sinusoidal wave test.

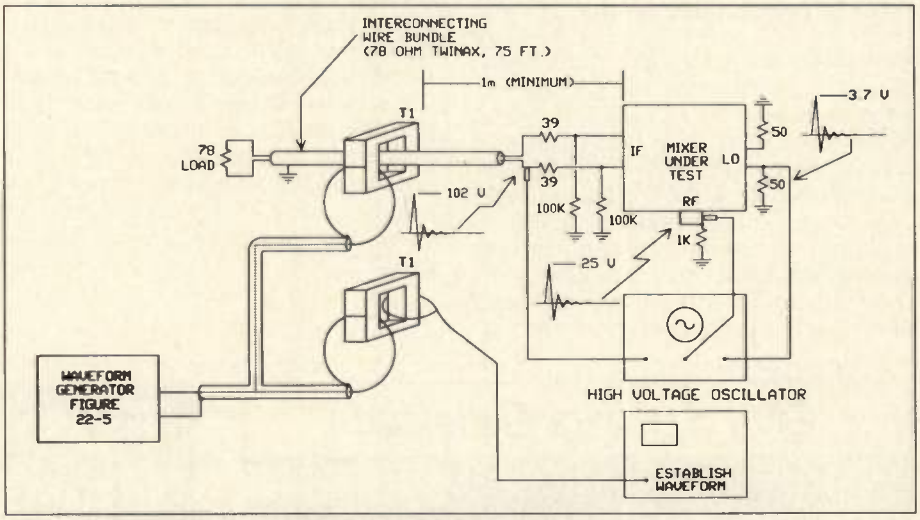

Figure 5. 10 MHz damped sinusoidal wave test.

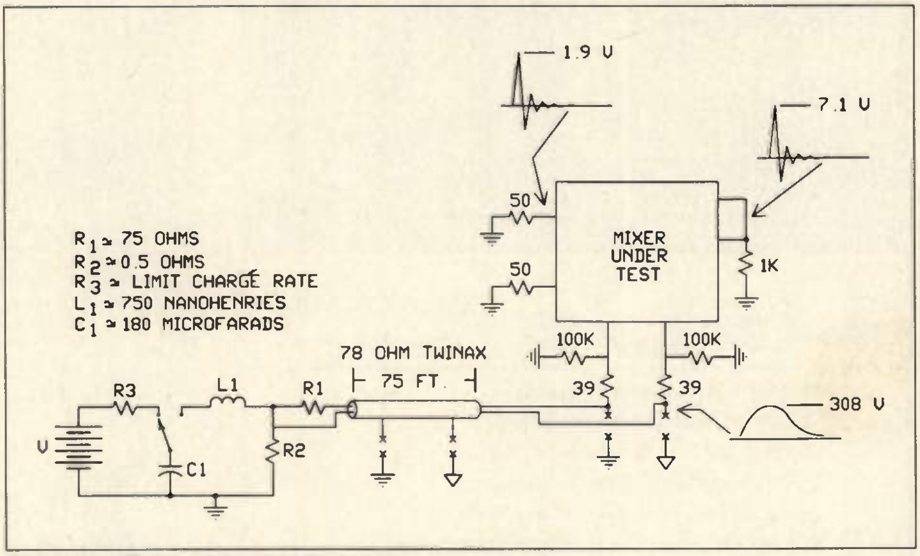

Figure 6. Typical test setup: long wave test.

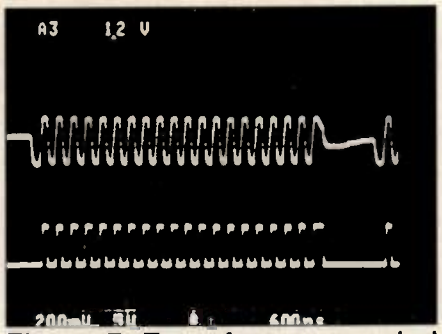

Figure 7. Transformer-coupled clock signal (20 cycle burst) received as 1.2 Volts p-p. Bottom trace is comparator output.

were monitored at the input to the mixer as well as at the other two ports which were terminated as shown. The waveforms which were observed with an oscillaoscope are sketched in the figures next to each port. As the figures indicate, a single mixer provides sufficient isolation to prevent damage to the downstream electronics. Therefore, our two mixer circuit is more than sufficient to ensure that a subsystem requiring isolated differential reception of remote digital signals in an airborne environment will repeatably withstand RTCA/DO-160C section 22, category K testing.

Next, a DC static breakdown test was conducted. With the two terminals of each port shorted together, a high voltage variable DC generator was connected between each pair of ports. It was determined that the DC breakdown voltage was in excess of 1000 VDC!

Finally, we demonstrated the capability of the circuit as a differential receiver. The top trace of the oscilloscope photograph (Figure 7) shows 20 cycles of a 5 MHz clock. This signal was passed through an isolation transformer at the transmitter. The output of the comparator is shown in the bottom trace. Note that the small bias added to the comparator (50 mV) enables our differential receiver to handle the absence of a signal at the input. With a 90 MHz LO, our circuit has proven to be reliable even above 25 MHz. *RF*

References

1. Wes Hayward, "VHF Oscillators Using Microwave Integrated Circuits", *RF Design*, November 1987.

About the Author

Pavlo Bobrek is a Principal Engineer with Loral Data Systems. He holds a BSEE from MIT and an MSEE from the University of South Florida where he is currently a Ph.D. candidate. His research interests include reduced state sequence estimation and design of multidimensional trellis coded modulation. As the project engineer in charge of hardware development, he led a design team which recently successfully completed the development of the Central Multiplexer, an airborne bus concentrator to be used in the testing of the new Boeing 777. He is currently involved in the design and planning of ATM networks. He may be reached at Loral Data Systems, PO Box 3041, MS 47, Sarasota, FL 34230. Tel: (813) 371-0811. ext. 6719.

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RF product report

The Oscillator Business is Humming

By Gary A. Breed
Editor

Representing over 150 companies, the oscillator business is a major portion of the RF, computer and general electronics industries. Continued growth in the computer industry is generating new business for one part of this group, advances in display and imaging systems are driving other type of products, while new RF applications are providing opportunities of another sort.

This does not suggest that everything is rosy for all oscillator companies. The wide range of applications requiring timing or frequency control has attracted a large number of companies. Competition is extremely strong, and success requires a new ability to adapt to new markets and new price and performance expectations.

According to Ron Stephens, President of Oscillatek and Chairman of the Piezoelectric Devices Group of the Electronics Industries Association, business is improving for U.S. oscillator companies. This is partly due to consolidation within the industry, but also due to improved markets for products with better precision. "A lot of the growth is in telecommunications: telephone switching equipment, especially fiber-optic-based systems. A lot of these systems are in Europe, and together with GSM digital cellular equipment, this makes Europe a good export market right now."

Oscillator Applications

Many oscillator application areas are experiencing market growth and/or changing requirements.

High-resolution display and imaging — Large-screen, high resolution display systems require scan rates and video writing rates into the 100s of MHz. SAW resonator oscillators, multiplied crystal oscillators and phase-locked sources are used to obtain these clock signals, typically up to 400 MHz. Most applications require limited tunability for phase locking.

Digital clock oscillators — The inclusion of digital circuitry in products of all kinds continues to grow, although these applications are dominated by Far East manufacturers. Toys, appliances, industrial machinery and automotive controls are growing users of oscillators, in addition to ongoing sales of computers, monitors, modems and related equipment. For example, the typical PC may use seven or more oscillators; implemented as either packaged oscillator products, or using crystals in conjunction with on-chip oscillator circuitry.

VCXOs like this unit for VHF PLLs are a growing part of oscillator market (photo courtesy TEW North America)

High-performance oscillators — Demand is growing for oscillators with improved performance in stability, accuracy and over temperature. Instrumentation products need this performance to measure increasingly complex and precise products and systems. Precise calibration of existing test equipment is a growing need, as well. A major force in this market is digital communications via wire, fiber optics and satellite. High reliability digital communications networks demand accurate timing to keep transmission errors to an absolute minimum.

Low cost TCXOs — Better performance with low cost promises to be a growing opportunity. Digital cellular requires precision to maintain error-free communications, Global Positioning System (GPS) receivers must have short-term accuracy sufficient to correlate data from several satellites, and new consumer spread spectrum products need a sufficient level of performance to assure that the receiver and transmitter can "find" each other in the RF stew of many signals using the same frequency band.

Super low cost oscillators — An absolute minimum product cost is the goal of all consumer products. Traditionally, this has been the realm of ceramic resonators, mass-produced crystals, and more recently, SAW resonators. A number of short-range control devices are keeping this market hopping. Car keys with automatic lock and alarm controls are becoming commonplace. Cordless telephones are still a large market, sharing their low-cost technology with simple walkie-talkies, baby monitors, pet monitors and many toys

Voltage-controlled oscillators — The number of products with synthesized frequency control is an area with growth potential. Cellular phones, PCN/PCS units, and test instruments are a few specific applications that are opportunities for makers of packaged VCOs. In addition, some wireless local area network (WLAN) equipment, satellite systems and CATV tuners require these products

Military products — Without question, the military market has slowed considerably. Remaining oscillator markets include continuing satellite, terrestrial and data communications programs. Stephens notes that there has been a modest increase in business with foreign defense manufacturers, mainly in the Third World, as countries develop their production capabilities.

Summary

Cautious optimism is the attitude of most oscillator companies. Like every other major part of the RF business, a few companies are doing extremely well and a few are struggling. Most are still adjusting to new demands in pricing, size, power consumption and delivery schedules. Specific companies may see difficult times in the near future, but the industry as a whole can only grow along with the growth that is occurring in all electronics. **RF**

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July Program: RFD-0793 — Contest Grand Prize Winner!
"Synthesizer Design With Detailed Noise Analysis" by Terry Hock. This program was written to simplify the design of PLLs using commercial synthesizer ICs. It includes loop analysis, including effects of the reference, phase detector, loop filter and VCO. Noise analysis includes application of Leeson's equation for VCO noise performance, and uses data for specific op amps in the loop filter. (Requires VGA)

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Mixed Signal ICs
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MX.COM, Inc.
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Components and Instruments
The newest Loral Microwave-Narda catalog covers 15 product categories in 360 pages. Mixers, sources, isolators, switchers, attenuators and radiation safety products are among the products offered.
Loral Microwave-Narda
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Filters and Subassemblies
Filters in several different forms and for several different applications are listed in K&L Microwave's 140-page catalog. Duplexers, switching systems, channelizers and multiplexers are also offered, along with information on how to specify filters.
K&L Microwave Incorporated
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Switching Systems
A brochure from Signal Switch Company describes their lines of switches, matrices and systems for switching DC to 1.2 GHz signals. Typical switching times, including bounce, are less than 1 ms.
Signal Switch Company
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Product Selection Guide
The Semiconductor Division of Raytheon has published a product selection guide targeted for video processing, multimedia, test & measurement, avionics and high-speed communications. The 60-page book highlights application specific standard products, standard products and ASIC arrays and standard cells.
Raytheon, Semiconductor Division
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Feed-Forward Amplifiers
AML has released a brochure that includes full specifications for seventeen power efficient, feed-forward, linear power amplifiers. Peak envelope powers range from 7 to 120 watts with gains to 70 dB. Both rack mount and compact units are described.
AML, Inc.
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Test Instruments
"Test and Design Instrumentation" is the new 1993 catalog from Global Specialties®. The catalog contains American-made frequency counters, pulse generators, power supplies and solderless breadboards.
Global Specialties
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Coaxial Connectors
BNC, TNC, N, UHF, and many other connector types are extensively covered in RF Industries' 36-page catalog. The catalog includes over 750 coax products, including cable assemblies, connector kits, and Unidapt® and Celludapt® universal adapter products.
RF Industries, Ltd.
INFO/CARD #193

Isolators and Circulators
A 16-page catalog from Ute Microwave contains information on a broad line of ferrite components spanning 200 MHz through 20 GHz. High power units for PCS and medical-scientific applications are listed. A tutorial and useful application charts are provided.
Ute Microwave, Inc.
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Custom Coaxial Connectors
A brochure describing Aviel Electronics' ability to provide custom coaxial connectors is available. Aviel can provide all popular series as well as hermetically sealed, blind-mate, and floating designs in short runs and with quick delivery.
Aviel Electronics
INFO/CARD #191

Mixed Signal IC Newsletter
The Spring edition of Silicon Systems "SSignals" newsletter describes the architectures of two custom IF modem ICs, one for CDMA, the other for TDMA. The 1993 Silicon Systems data books are also presented, along with a 20-108 MHz programmable frequency reference.
Silicon Systems
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Product Information Brochures
VARI-L offers a brochure briefly describing each member of their VCO, sythesizer, mixer, and other product lines. Additional information on any product can be obtained by filling out the card included with the brochure. A brochure describing VARI-L's PLL-200 series of low-cost phase locked synthesizers is also available.
VARI-L Company, Inc.
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Microwave Prodoucts Catalog
A 22-page products catalog is available from Tampa Microwave Lab. The catalog contains information on Tampa Microwave's lines of CRO and DRO oscillators. Also included are microwave products including upconverters and downconverters. Detailed electrical and mechanical details are included.
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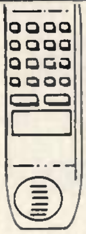

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RF Design Manager: To establish and direct an RF product center. Will lead a small team in a design effort to develop functional modular products for the wireless communications market. Will come up with new product concepts and specifications for modules (basic idea is to replace portions of RF circuit with smaller, cheaper functional modules). Target end markets are cordless phone, cellular, RF Data Units and RF LAN. BSEE, MSEE preferred. Minimum 10 years experience with indepth knowledge complete RF circuit design. 2GHz-Audio. Experience with spread spectrum technology. Familiar with current SST components. Experience with low cost high volume design for consumer applications. Proven products development experience. Good technical writing skills.

VSAT Sr. Staff Engineer: Familiarity with equipmentand systems utilized by broadcast organizations for the distribution of analog and digital audio programming via satellite. Experience with communications systems design, data communications receiver design and satellite link budget calculations. BSEE.

SATCOM Systems Engineers: Opportunities for satellite communications systems engineers. Responsibilities include satellite calculations, block diagram designs, equipment definitions, and specification for proposals and porgrams. Requirements include a BSEE, MSEE preferred, and a minimum of 5 years of applicable experience. This must include the design, propose and implementation of medium-to-large aperture (4.5 to 21 meters) earth stations for commercial satellite computer spreadsheets is a must.

RF Design Engineer: Responsible for design of analog and RF systems and circuits for consumer and commercial digital wireless products. Five to ten years experience in RF systems analysis and design. Experience with low-cost design techniques for frequency synthesizers, power amplifiers, up/down converters and baseband circuits for digital communications systems. Must be able to derive RF systems and module requirements to meet overall performance and cost goals. Familiarity with time division duplex or CDMA a plus.

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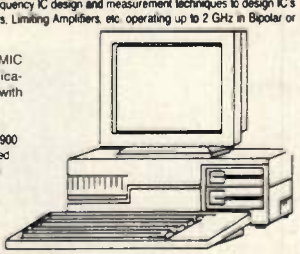

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