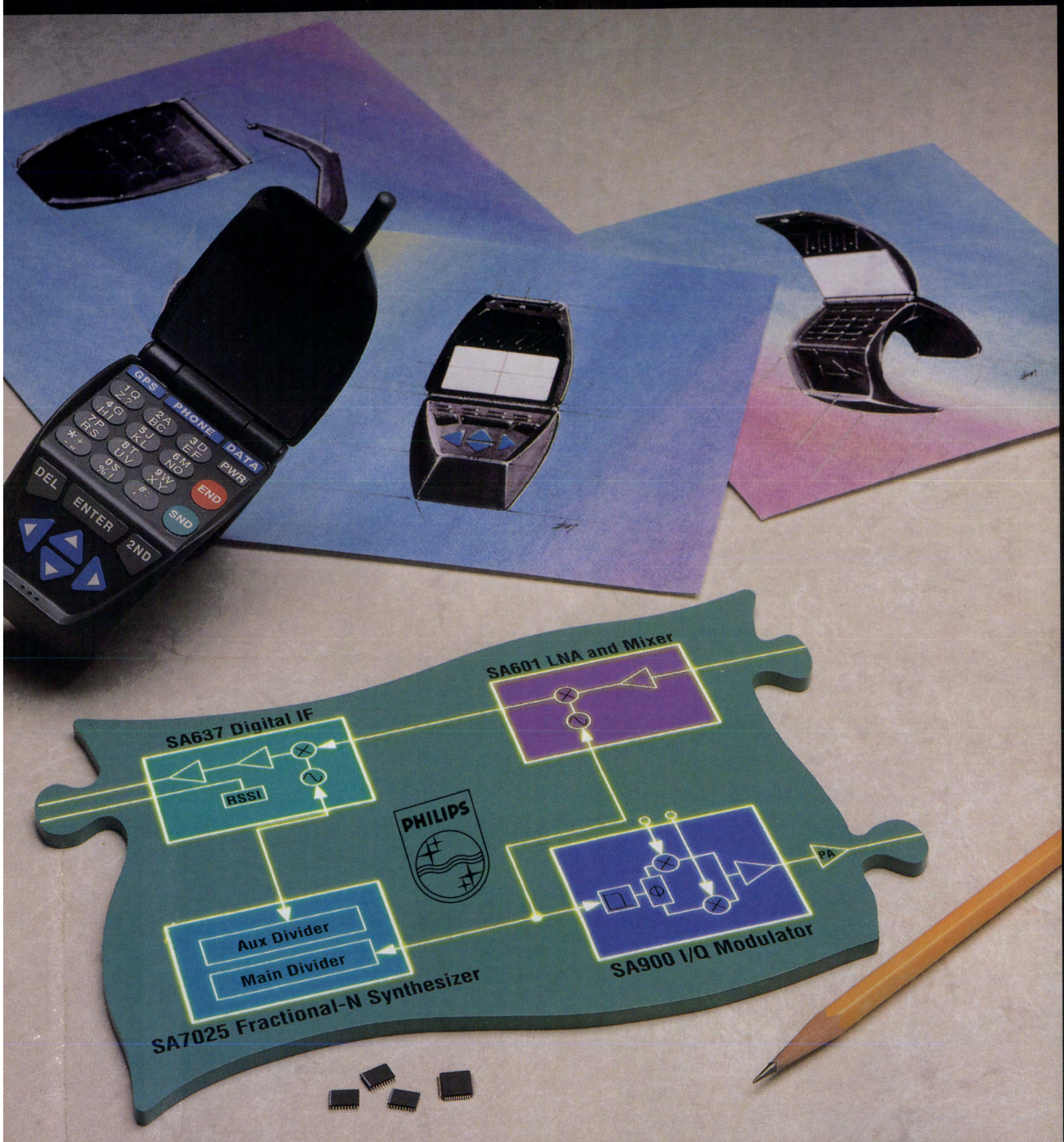
RF design™

engineering principles and practices

March 1994



Official Show Issue:
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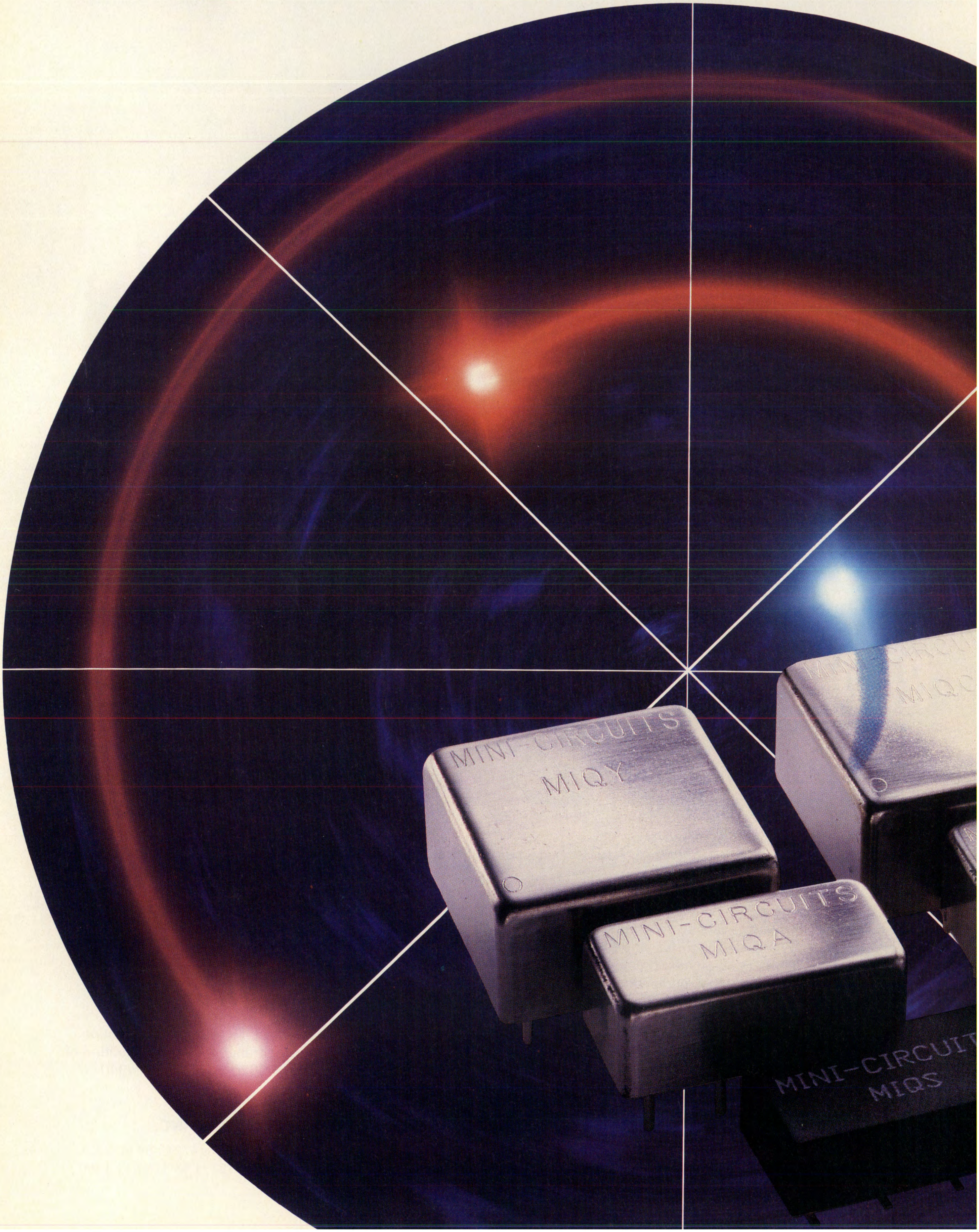
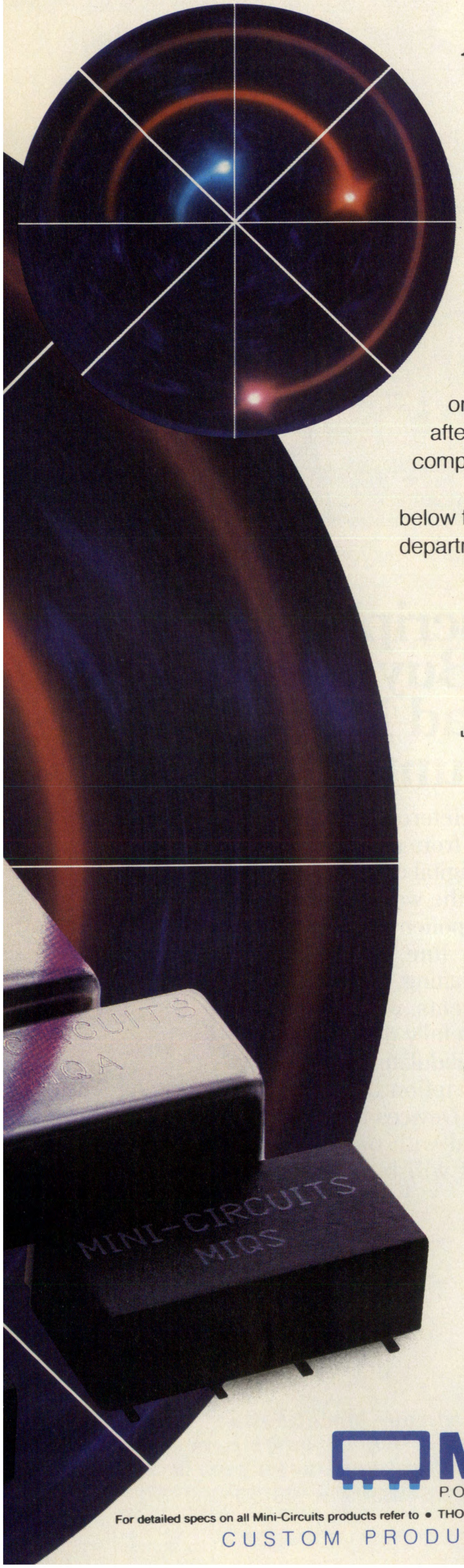
Cover Story
New Chip Set Targets IS-54

I&Q MODULATORS



DEMODULATORS



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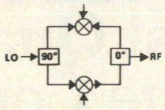
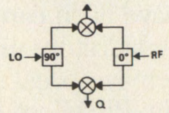


I/Q MODULATORS

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



I/Q DEMODULATORS

MODEL NO	FREQ. (MHz) f_L	f_U	CONV. LOSS (dB) x	σ	AMP. UNBAL. (dB) Typ.	PHASE UNBAL. (Deg.) Typ.	HARM. SUPPRESS (dBc) Typ. 3xI/Q	5xI/Q	PRICE $ QTY (1-9)
MIQA-10D	9	11	6.0	0.10	0.15	1.0	50	65	49.95
MIQA-21D	20	23	6.1	0.15	0.15	0.7	64	67	49.95
MIQC-895D	868	895	8.0	0.20	0.15	1.5	40	55	99.95
☐ MIQY-1.25D	1.15	1.35	5.0	0.10	0.15	1.0	59	67	29.95
☐ MIQY-70D	67	73	5.5	0.25	0.10	0.5	52	66	19.95
☐ MIQY-140D	137	143	5.5	0.25	0.10	0.5	47	70	19.95

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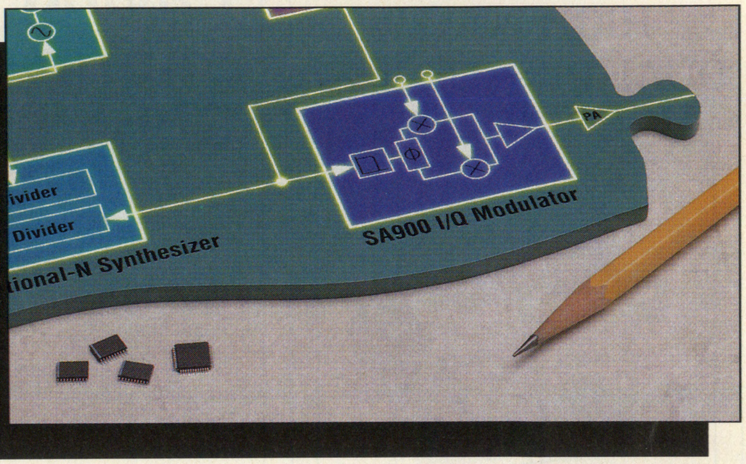

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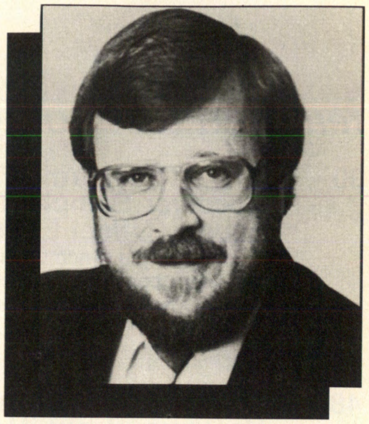
RF editorial

RF Engineers: Paving the Information Superhighway



By Gary A. Breed
Editor

I'd like to clear up a common misconception about who is building the "information superhighway" or "national information infrastructure."

Although this universal communications network will carry information in digital form, it is *not* being built just by digital engineers. After all, a normal superhighway carries cars and trucks, but it isn't built by automotive engineers! No, the information superhighway is being built by *communications* engineers representing RF, microwave, optical, and digital specialties.

Some people interpreted my December editorial as saying that RF technology would benefit as a spin-off from the efforts being made in telecommunications. That's the wrong interpretation, because *RF is an integral part of the process!* Here's how *RF Design* readers are taking part:

RF links — This is the "wireless" technology everyone is talking about. Cellular telephones, new Personal Communications System applications, wireless links for personal computers, RFID "radio bar codes," no-stopping toll collection, data links for inventory reporting, wireless office networks, remote meter reading, and a zillion other applications.

Coaxial cable technology — Your cable company simply takes ordinary RF signals and transmits them through a cable instead of over the airwaves. An intermediate step in the building of a new infrastructure will be extended use of cable technology — which is completely RF!

Fiber optics — Lots of RF technology is found here, too. Light beams carry the information through these glass fibers, but the circuits that drive the laser diodes at one end, and recover the information at the other end are very much like radio transmitters and receivers.

Microwave and satellite links — This is RF communications at the higher frequencies, but still RF. The lower frequencies emphasized in *RF Design* are a major part of these systems, too, in the modulation, demodulation, frequency conversion, amplification and signal processing functions.

High speed computing — Making the new infrastructure work will require plenty of computing power. There are some terrific digital engineers designing computer circuits for high speed digital signal processing, error detection and correction, and encryption/decryption. But they also need a solid footing in RF theory and techniques! Remember that a 66 MHz PC operates with timing signals that would fall in television channel 3 if they were radiated like RF signals!

I think I've made my point — RF is one of the key areas of engineering that will make the new information superhighway possible! Now that Congress, the President, and private industry are working together (at least in this one area!), work is accelerating in the rewiring of our nation.

I'd love to hear what some of you are doing to make it happen!

RF design

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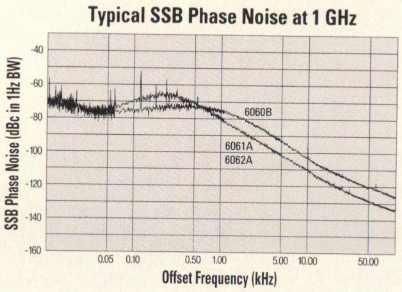
Whether you're responsible for testing general purpose RF components or sophisticated communications systems, one of the Giga-tronics 6060 Series Synthesized RF Signal Generators will meet your needs, as well as your budget.

The Giga-tronics 6060B Signal Generator is ideal for general purpose RF testing. Frequency range is 10 kHz to 1.05 GHz. Phase noise at 1 GHz is -110 dBc/Hz at 20 kHz offset. And accuracy is ±1.0 dB from -127 to +13 dBm, above 400 kHz. Better still, the 6060B is priced hundreds to thousands of dollars less than signal generators with comparable specifications.

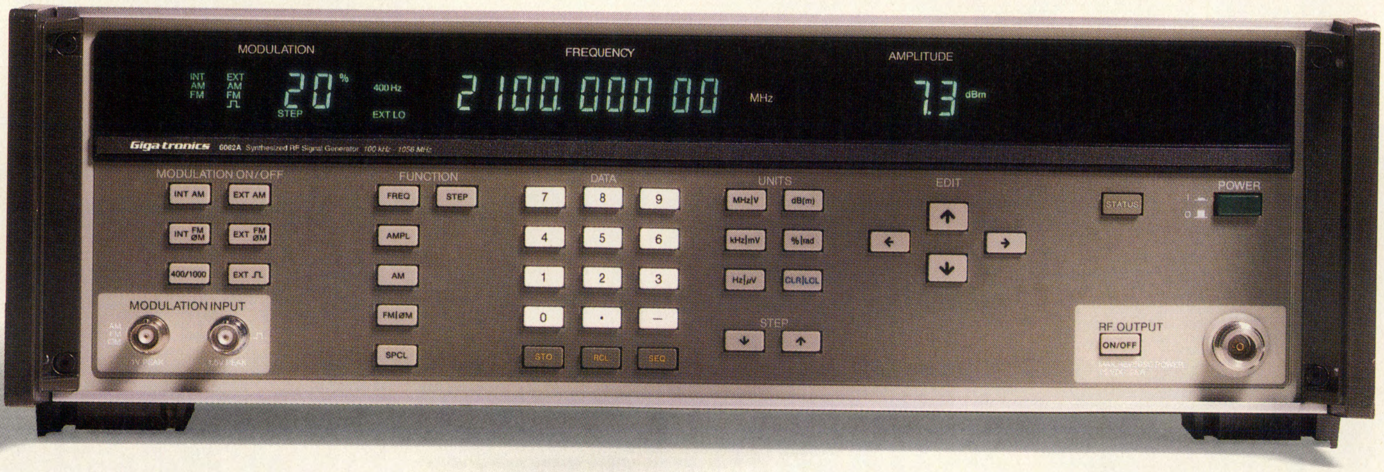


Low phase noise assures accurate narrow-band test measurements.

For just a little more money the Giga-tronics 6061A Signal Generator provides even higher-quality signal output, making it the right choice for many communications test applications. Frequency range and accuracy are identical to the 6060B, while phase noise at 1 GHz is -117 dBc/Hz at 20 kHz offset. Plus, the 6061A gives you lower out-of-band spurious noise and lower residual FM.

For greater capability, both the 6060B and 6061A come with built-in AM and FM generators.

The Giga-tronics 6062A generates complex signals, from 100 kHz to 2.1 GHz, for testing such applications as long-range radar and sophisticated communications systems. In addition to AM and FM, the 6062A includes fast-rise



The Giga-tronics 6060 Series RF Synthesized Signal Generators give you accurate test measurements at an affordable price.

pulse modulation (<15 ns). So you can test pulsed communication and navigation circuits, such as radar and avionics transponders, without having to pay extra for an external generator. You also get built-in phase modulation for critical receiver testing.

And all 6060 Series instruments have a standard IEEE-488 interface for ATE applications.

Originally introduced by the John Fluke Manufacturing Company, thousands of these instruments are in service, attesting to product reliability. For added confidence, self-diagnostics are performed automatically every time you turn on the power.

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But at Giga-tronics, customer service starts even before you become a customer. Whether you're looking to buy one unit or one hundred, you'll get the same assistance, including a demonstration at your facility.

So, if you need a reliable signal generator that lets you make accurate test measurements at an affordable price, call us toll free at **800 726 GIGA** (4442).

We'll send you more information. And, if you like, we'll arrange a demonstration of the 6060 Series instrument that best meets your needs, as well as your budget.

Meeting Your Needs, As Well As Your Budget.

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The Giga-tronics 6060B RF Synthesized Signal Generator is ideal for general purpose RF testing from 10 kHz to 1.05 GHz.

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The Giga-tronics 6062A RF Synthesized Signal Generator has built-in AM, FM, pulse and phase modulation generators for generating complex signals from 100 kHz to 2.1 GHz.

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GIGA-TRONICS 6080A & 6082A SYNTHESIZED RF SIGNAL GENERATORS

Giga-tronics Presents The Alternative To $30,000 And $40,000 RF Synthesizers.

Hewlett-Packard makes a couple of very good RF synthesizers. And if you can afford the luxury of paying $30,000 or $40,000 for the name, by all means, call HP right now. They'll be happy to take your order, and your money.

However, if you're looking for an RF synthesizer with outstanding performance and proven reliability for about half the price, you'd better call Giga-tronics.

Here's why:

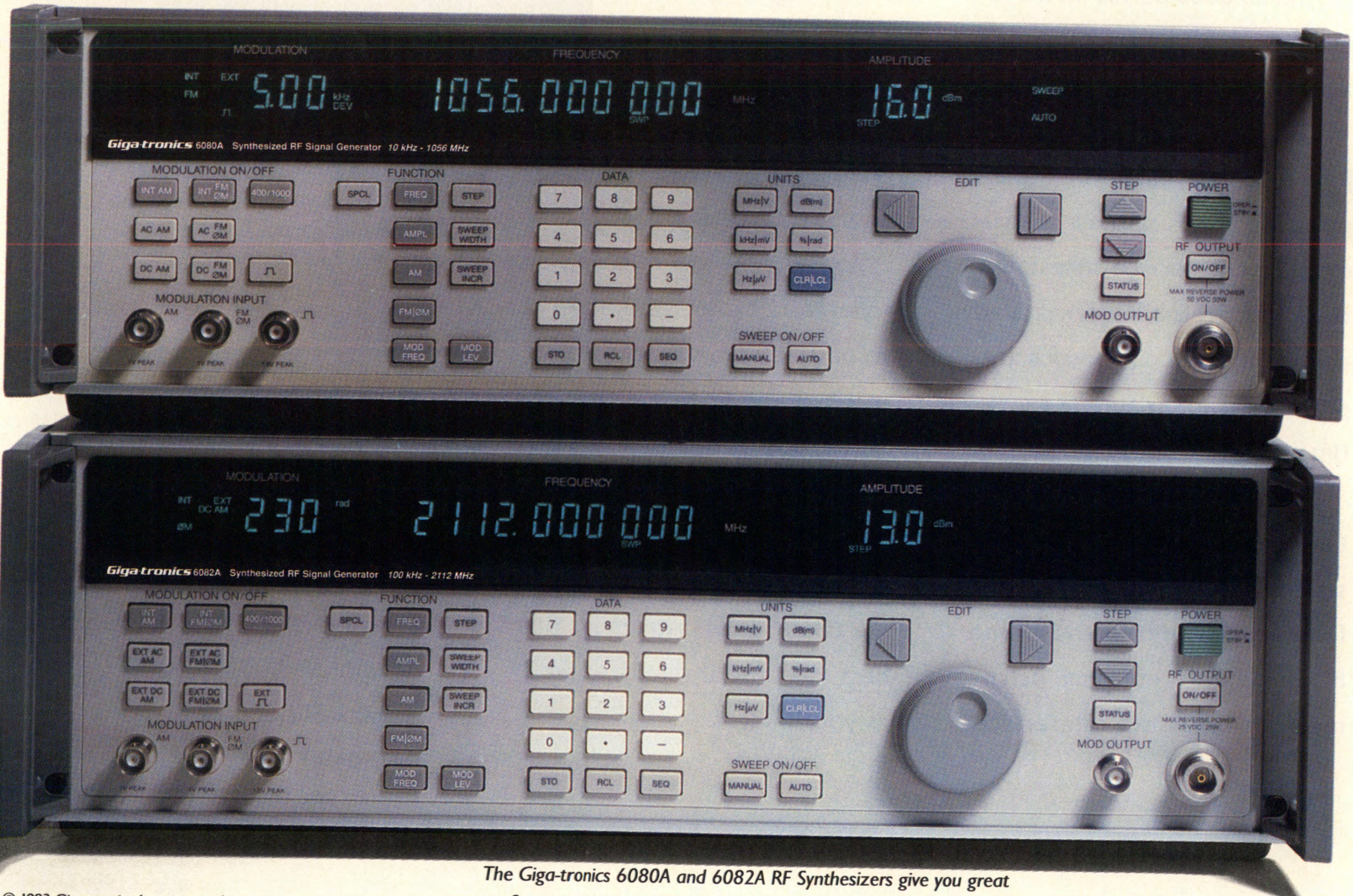
Performance.
Check the charts. In virtually every category, the Giga-tronics 6080A and 6082A RF Synthesizers meet or exceed the specs of the HP machines. And they use the same GPIB command set, for direct replacement without expensive new software.

Experience.
Granted, Hewlett-Packard has been around a long time. But, Giga-tronics is no Johnny-come-lately.

Giga-tronics has a 13-year history of building test and measurement gear for the most demanding requirements. We've shipped thousands of instruments for use in the testing of radar, EW and communications systems.

Reliability.
Making reliable RF synthesizers is usually no fluke.

However, in this case, it is.



The Giga-tronics 6080A and 6082A RF Synthesizers give you great performance and proven reliability for a lot less money.

Specifications	Hewlett-Packard HP 8642A	Giga-tronics 6080A	Hewlett-Packard HP 8642B	Giga-tronics 6082A
Frequency Range Switching speed	.1 to 1057 MHz <85 ms	.01 to 1056 MHz <100 ms	.1 to 2115 MHz <85 ms	.1 to 2112 MHz <100 ms
Spectral Purity* Spurious Subharmonics	<-100 dBc None	<-100 dBc None	<-94 dBc <-45 dBc	<-94 dBc <-45 dBc
Phase Noise* @ 20 kHz offset	<-134 dBc/Hz	<-131 dBc/Hz	<-125 dBc/Hz	<-125 dBc/Hz
Residual FM* (.3 to 3 kHz BW)	<2 Hz	<1.5 Hz	<5 Hz	<3 Hz
Output Range* Accuracy Reverse Power Protection	+16 to -140 dBm ±1 dB >-127 dBm 50 Watts/50 Vdc	+17 to -140 dBm ±1 dB >-127 dBm 50 Watts/50 Vdc	+16 to -140 dBm ±1 dB >-127 dBm 25 Watts/25 Vdc	+13 to -140 dBm ±1 dB >-127 dBm 25 Watts/25 Vdc
Amplitude Modulation Depth Distortion @ 30%	0–99.9% <2%	0–99.9% <1.5%	0–99.9% <2%	0–99.9% <1.5%
Frequency Modulation Max. Deviation* Distortion	3 MHz <2%	4 MHz <1% @ 50% Dev.	3 MHz <2%	8 MHz <1% @ 50% Dev.
Phase Modulation Max. Deviation*	100 Rad.	40/400 Rad.	200 Rad.	80/800 Rad.
Pulse Modulation On/off Rise/fall time Minimum Pulse Width	>40 dB <400 ns <2 µs	>40/60 dB <15 ns (Typ 7.5 ns) <30 ns	>40/80 dB <400 ns <2 µs	>80 dB <15 ns (Typ 7.5 ns) <30 ns
Internal Modulation Source Level Range Waveforms Programmable	20 Hz to 100 kHz 0 to 3 Vpk Sine Yes	0.1 Hz to 200 kHz 0 to 4 Vpk Sine/Sq/Tri/Pulse Yes	20 Hz to 100 kHz 0 to 3 Vpk Sine Yes	0.1 Hz to 200 kHz 0 to 4 Vpk Sine/Sq/Tri/Pulse Yes
Memory Locations (NVM)	51 Full Function	50 Full Function	51 Full Function	50 Full Function
U.S. List Price	$30,340	$16,950	$41,680	$22,950

The question is not why Giga-tronics is so much less, but rather, why Hewlett-Packard wants so much more.

*Specifications for both the 6080A and the HP 8642A are at 1GHz. Specifications for both the 6082A and the HP 8642B are at 2GHz. Prices and specifications for the HP 8642A and HP 8642B are from the Hewlett-Packard 1993 catalog. Prices for the Giga-tronics 6080A and 6082A are U.S. list prices.

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But at Giga-tronics, customer service starts even before you become a customer.

Whether you're looking to buy one unit or one hundred, you'll get the same assistance, including a demonstration at your facility.

Price.
Considering all this, the real question is not why Giga-tronics is so much less, but rather, why Hewlett-Packard wants so much more?

So, if you're interested in paying a lot less for great performance and proven reliability, backed by a worldwide network of service and support, call us toll free at **800 726 GIGA** (4442). We'll send you more information and arrange for a demonstration.

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INFO/CARD 11

Letters should be addressed to: Editor, RF Design, *6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Letters may be edited for length and clarity.*

Receiver Analysis Correction

Editor:

In the article, "A Program for Design and Analysis of Receivers" by John Donohue (October 1993 *RF Design*), there is a minor error. Using data from Figure 4, Receiver Design Example, the correct cascaded second order intercept point is 13.38 dBm rather than 19.07 dBm as shown in Table 1.

All the equations are correct; the error is shown in Table 1, where the second order intercept point of 30 dBm was used for the 7th stage and 20 dBm for the 10th stage. Figure 4 shows that this data should have been 28 and 14 dBm, respectively.

The article was well written and very useful.

Larry W. Miller
Trak Microwave Corp.

Another Look at Single Tone Intermodulation Testing

Editor:

I enjoy the articles in *RF Design* and often use them as supplementary information for my students in the RF circuits course here at the University of Illinois.

I am writing to point out a potentially misleading section of the otherwise very useful article by Steve Winder in the December 1993 issue. In particular, the derivation that attempts to relate P_{1dB} to IP3 (equations 13-19) is technically incorrect. A misleading intermediate result is given in equation (18) which seems to indicate the some fixed relationship exists between the first- and third-order coefficients (a and c) in the amplifier input/output characteristic. This incorrect result is apparently the result of explicitly assuming a peak voltage of 1 volt (eq. 13) and a mistake in writing eq. (17b).

Surprisingly (to me, at least!) is the fact that the final result is correct, and can be derived without ever invoking a particular relationship between a and c, other than that they must have opposite signs. This can be done by replacing the second part of eq. (13) with:

$$V_{in} = V_i \cos xt$$

where V_i represents the peak input voltage. The change here is to allow for arbitrary input voltage amplitude rather than 1.0 volt. Equation (17) would then read:

$$V_{out}' = 0.89125\, a\, V_i \qquad (17a)$$
$$= a\, V_o + 0.75\, c\, V_i^3 \qquad (17b)$$

where the symbol V_{out}' represents the peak value of the time-varying output voltage at the fundamental frequency. Clearly, the input voltage cannot be eliminated from this equation (as the author has done by writing (18)), and can be used only to solve for the input voltage level at which 1 dB compression occurs. The existence of compression is evidence that $ac < 0$, i.e. that a and c have opposite signs. With this assumption, the input power required for 1 dB compression (computed assuming 1 ohm basis for input impedance) is:

$$P_{1dB} = 0.0725 \frac{|a|}{|c|}$$

This shows that the 1 dB compression level depends only on the ratio of the third order coefficients. It can be shown that IP3 depends on the same ratio, which is why P_{1dB} and IP3 can be related simply by a scaling factor (10.66 dB), as Steve pointed out.

Since the final result given is correct, this whole issue is probably only of academic interest — which is why I was interested!

Steve Franke, Professor
University of Illinois

ISO 9000 Discussion

Editor:

I write a column in *Electronic Design* magazine. People have asked me, "Why don't you write, 'What's All This ISO 9000 Stuff, Anyhow?' " I tell them: (a) I don't know what to say — I'm not an expert, and (b) whatever I say wouldn't make any difference. However, I wish the hell I had written what George Lohrer wrote.

I will write about quality.

Robert A. Pease, Engineer
National Semiconductor

Editor:

This is the first time I have responded to anyone's material because I do not have the time or the resources to do so. In this case, however, I feel deeply compelled to make a rebuttal to the comments made by Mr. Lohrer (October 1993 Letters column).

Based on his correspondence, Mr. Lohrer appears to be a self-proclaimed anti-ISO vigilante. He states that there is nothing new in ISO and that as a manager of a company, one would have seen that the measures required by ISO 9000 are already implemented. If the ISO requirements represent good business practice, as he is suggesting (and they do), then what is his problem?

His dislike for ISO 9000 is apparently based on the failures of previous quality strategies, where he has a valid point. Previous popular quality systems typically advocated the "thou shalt" or "thou shalt not" approach. they were restrictive and forced the user to conform to pre-conceived definitions and requirements for quality assurance, regardless of the specific application. ISO 9000 is different. This standard provides for an "umbrella" of criteria which represent proven quality practices. In its most simple form, ISO 9000 asks you to document what you do, and do what you document. Of course, what you do should result in the production of a quality product.

I predict that Mr. Lohrer will eventually recognize the benefits the ISO 900 provides and choose to switch rather than fight. While ISO is not the perfect solution, it does cover, in a much better way, the issues required to produce quality products. If it did not, why would at least fifty countries choose to adopt and promote the standard? ISO is an effective method to dramatically make a difference in quality. As more and more companies use it, the result will be not only higher quality products, but products produced with improved efficiency, as well.

Ron Rapczynski
Surface Mount Product Development

Editor:

I read George Lohrer's letter and the responses with more than passing interest. My organization buys PTS synthesizers in quantity and I can tell you that if every company were run the way PTS is run, there would be no need for ISO 9000.

Robert G. Huenemann
LaHonda, CA

RF calendar

March

14-17 **The Second International Symposium on Digital Audio Broadcasting**
Toronto, Canada
Information: DAB Symposium '94, 126 York Street, Suite 401, Ottawa, Ontario, Canada, K1N 5T5.
Tel: (613) 594–8226. Fax: (613) 565–2173.

20-24 **National Association of Broadcasters '94**
Las Vegas, NV
Information: NAB '94 Convention, 1771 N Street, NW, Washington, DC 20036–2891.Fax: (202) 775–2146
Tel: (800) 342–2460, (202) 775–4972. .

21-29 **World Telecommunication Development Conference**
Buenos Aires, Argentina
Information: Ms. F. Lambert, Chief, Press and Public Information, Offiice of the Secretary-General, International Telecommunication Union. Tel:41–22–730–5969.
Fax: 41–22–730–5939

22-24 **RF Expo West**
San Jose, CA
Information: RF Expo West, Registration Coordinator, 6151 Powers Ferry Rd. NW, Atlanta, GA 30339.
Tel: (800) 828–0420. Fax: (404) 618–0441.

29-30 **IEEE SCV EMC '94**
Santa Clara, CA
Information: David Hanttula, Chairman Santa Clara Valley EMC '94, P.O. Box 2102, Cupertino, CA 95015-2102.
Tel: (415) 390-1071.

23-30 **National Radar Conference**
Atlanta, GA
Information: Robert Trebits, Georgia Tech Research Institute, 7220 Richardson Rd., Smyrna, GA 30080.
Tel: (404) 528–7769. Fax: (404) 528–7883.

April

5-7 **Second International Conference on Ultra-Wideband, Short-Pulse Electromagnetics**
New York, NY
Information: Lawrence Carin, Weber Research Institute, Polytechnic University, Six MetroTech Center, Brooklyn, NY 11201. Tel: (718) 260-3876.
Fax: (718) 260-3906.

11-15 **Position Location and Navigation Symposium**
Las Vegas, NV
Information: Michael Hadfield, 12449 84th Way N., Largo, FL 34643. Tel: (813) 531–5715.

12-15 **EMC/ESD International**
Anaheim, CA
Information: EMC/ESD International, Registration Coordinator, 6151 Powers Ferry Rd. NW, Atlanta, GA 30339. Tel: (800) 828–0420.
Fax: (404) 618–0441.

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The SA7025 Fractional-N Synthesizer locks both first and second LOs and meets the fast IS-54 switching requirements.

The SA900 I/Q Transmit Modulator completes the chip set with transmit paths for both digital and analog signals.

These ICs are designed to work together, so fewer external components are required. The entire receiver runs at 3V and each IC has a power down mode to extend battery life. Plus our small SSOP-20 and TQFP-48 packages help make your products smaller and lighter.

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Philips Semiconductors

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RF courses

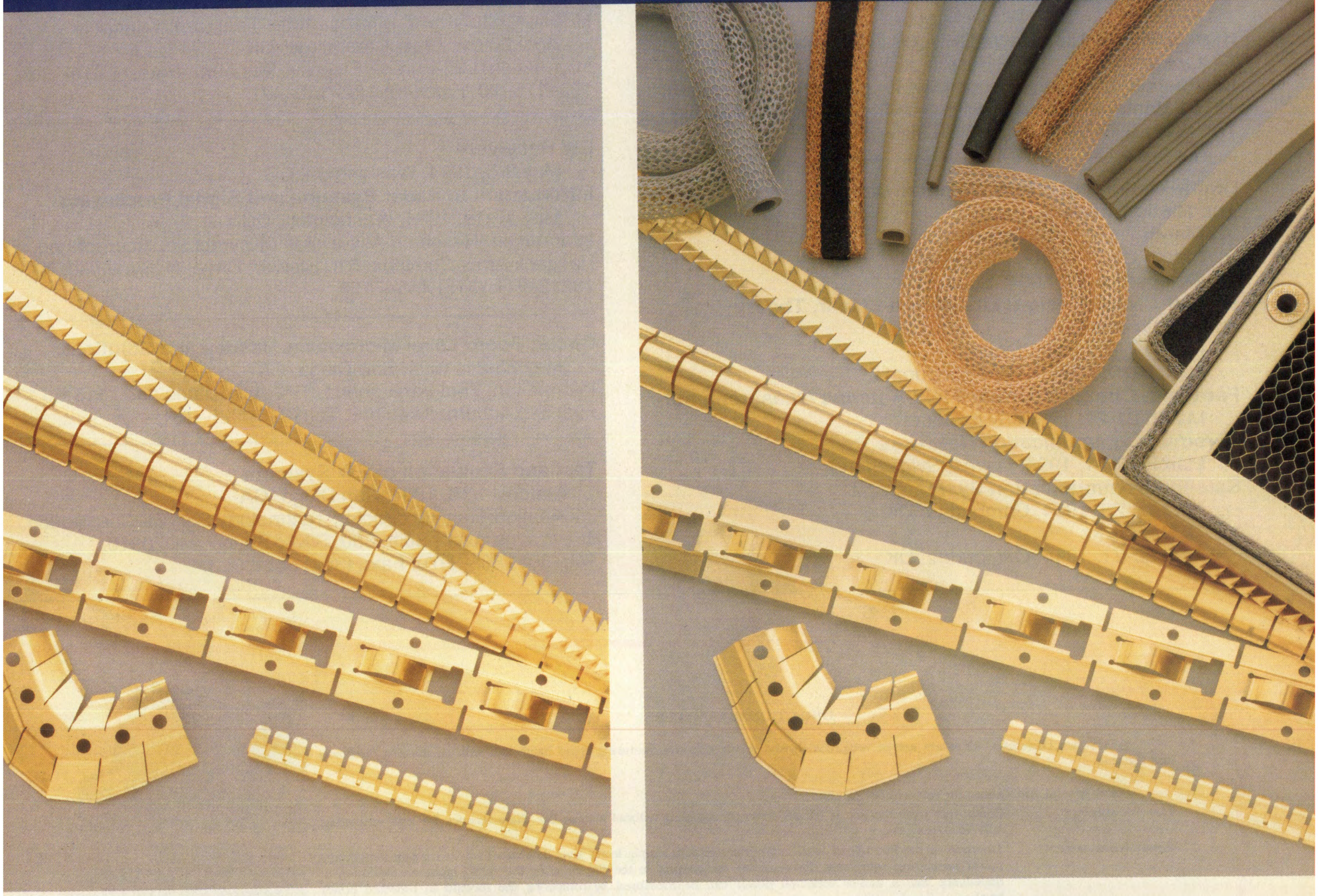
Radar Cross Section Reduction
March 22-25, 1994, Atlanta, GA
Phased-Array Radar System Design
April 19-22, 1994, Atlanta, GA
Information: Georgia Institute of Technology, Continuing Education. Tel: (404) 894–2547.

Hybrid Microcircuit and Multichip Module Packaging Technologies
April 11-13, 1994, Los Angeles, CA
Advanced Communication Systems Using Digital Signal Processing
April 11-15, 1994, Los Angeles, CA
Microwave/Millimeter-Wave Monolithic Integrated Circuits
May 17-20, 1994, Los Angeles, CA
Information: UCLA Extension, Engineering Short Courses, 10995 LeConte Ave., Ste. 542, Los Angeles, CA 90024. Tel: (310) 825–1047. Fax: (310) 206–2815.

Mobile Cellular Telecommunication Systems
March 30-April 1, 1994, Washington, DC
Modern Radar Technology: Monopulse Tracking Techniques and High-Performance Developments
April 11-15, 1994, Washington, DC
Hazardous Radio-Frequency Electromagnetic Radiation: Evaluation, Control, Effects, and Standards
April 13-15, 1994, Washington, DC
October 5-7, 1994, Washington, DC
Microwave High-Power Tubes and Transmitters
April 18-22, 1994, Washington, DC
Microwave System Engineering
April 18-22, 1994, Dallas, TX
Mobile Communication Engineering
May 4-6, 1994, San Diego, CA
Digital Transmission Systems
May 9-12, 1994, Washington, DC
Low Earth Orbit Satellite Systems (LEO's)
May 16-18, 1994, Washington, DC
Radio Frequency Spectrum Management
June 6-10, 1994, Washington, DC
Global Positioning System: Principles and Practice
June 7-10, 1994, Orlando, FL
Information: The George Washington University, Continuing Engineering Education, Academic Center, Room T-308, 801 22nd Street, N.W., Washington, DC 20052. Tel: (202) 994–6106 or (800) 424–9773. Fax: (202) 872–0645.

EW Data Bases Technical Short Course
April 26, 1994, Chesapeake Bay area
Information: The Association of Old Crows, The AOC Building, 1000 North Payne Street, Alexandria, VA 22314–1696. Tel: (703) 549–1600.

BeCu. After.



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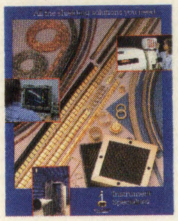

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Avionics & Weapons Systems Flight Test
August 22-26, 1994, San Diego, CA
Navstar/GPS: Design Applications
August 1-3, 1994, Washington, DC
High Speed & Microwave Devices & Applications
October 24-27, 1994, Boston, MA
Information: University Consortium for Continuing Education, 16161 Ventura Boulevard, M/S C-752, Encino, CA 91436. Tel: (818) 995–6335. Fax: (818) 995–2932.

Digital Cellular and PCS Communications - The Radio Interface
March 7-11, 1994. Sweden
March 21-24, 1994, Switzerland
October 10-14, 1994, Spain
RF/MW Circuit Design: Linear/Non-Linear, Theory and Applications
March 7-11, 1994, Sweden
June 6-10, 1994, United Kingdom
Far-Field, Compact & Near-Field Antenna Measurements
March 21-24, 1994, Switzerland
Personal Communication Networks
March 28-31, 1994, Davos, Switzerland
Satellite Communication Systems
April 18-22, 1994, Cambridge, UK
VSAT Networks
April 20-21, 1994, Cambridge, UK

Active and Passive RF Components: Measurements, Models, and Data Extraction
June 8-14, 1994, United Kingdom
Mobile Cellular and Microcellular Telecommunications
April 20-22, 1994, Cambridge, UK
Information: CEI-Europe/Elsevier, Mrs. Tina Persson. Tel: (46) 122–175–70. Fax: (46) 122–143–47.

EW Receivers
May 3-5, 1994, Washington, DC
Introduction to Radar Systems and Signal Processing
May 17-19, 1994, Washington, DC
Information: Research Associates of Syracuse, Incorporated, Hancock Army Complex, 510 Stewart Drive, N. Syracuse, NY 13212. Tel: (315) 455–7157.

Circuit Board Level Microwaves: Issues and Solutions
May 23-24, 1994, San Diego, CA
Information: Tom Laverghetta, TPL Associates, Inc., 516 E. First St., Auburn, IN 46706. Tel: (219) 925–1819.

Test and Evaluation of EW Systems
March 14-16, 1994, San Diego, CA
Information:Training director, Technology Service Corporation, 962 Wayne Ave. , Suite 800, Silver Spring, MD20910. Tel: (301) 565-2970. Fax:: (301) 565-0673.

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Polyfet RF Devices Relocates – Producers of power MOSFET RF transistors Polyfet RF Devices will be relocating from its Newbury Park location to Camarillo, California. A new and larger facility was needed due to increases in their wireless business. The new address will be 1110 Avenida Acaso, Camarillo, California 93012 about 55 miles NW of Los Angeles.

Battellle Forecasts 1994 R&D – This translates into $164.5 billion which is $3.8 billion over the $160.7 billion the National Science Foundation estimates actually was spent for R&D in 1993 or a 2.3 percent increase. Two percent of the increase will be absorbed by inflation so Battelle forecasts a negligible increase in real total R&D expenditures. This is considerably less than the 10-year average real increase of 2.5 percent since 1983. The cause for the R&D decrease is the slowdown in industrial support and the federal government shifting priorities. Battelle President and Chief Executive Officer Douglas E. Olesen said that there's so much technology diversity that industry needs to focus on a few core competencies because no one can be world-class in everything. He states that industry must create strategic alliances with technology organizations that can provide a critical and constant flow of information about emerging technology.

Tektronix and Maxim Alliance – On January 3, 1994, Tektronix, Inc. and Maxim Integrated Products, Inc. announced signing a letter of intent for Maxim to acquire Tektronix' Integrated Circuits Operation (ICO). Also, the two companies have reached an understanding to form a joint venture for the operation of Tektronix' Hybrid Circuits Operation (HCO). The ICO transaction involves the purchase of assets and facilities for an undisclosed amount of cash. The contract includes a long term agreement for Maxim to supply components to Tektronix and to continue to supply integrated circuit products to existing Tektronix customers. Also, Tektronix ICO and HCO employees will be offered employment with the new operations, to be based in their current Beaverton, Oregon location.

$1.4 Million Modems Contract – Electronic Systems Technology Inc.has signed a subcontract with UNISYS Corporation to provide ESTeem wireless modems for the U.S. Air Force. They will provide a mobile remote terminal to a base's main frame computer, both on the flight-line and in the maintenance hangers. This will allow the Air Force paperless real-time input of logistics and maintenance data. The subcontract is an indefinite delivery and quantity, with a firm fixed-price contract to September 30, 1997.

Penstock Relocates New England Field Office – The new address is: Penstock New England, 60 Mall Road, Suite 310, Burlington, MA 01803. Tel: (617) 229-9100. Fax: (617) 229-2429. Penstock carries Spread Spectrum, wireless LAN's and modems, DSP, V-SAT and distributes name manufacturers products such as amplifiers, MMICs, filter, splitters, mixers, connectors, cables and multifunction assemblies.

Murata's Name Is Changed – The international manufacturer of electronic components for the automotive, telecommunications and computer industries has changed their name from Murata Erie North America to Murata Electronics North America as of January 1, 1994. It represents a closer image with their parent company, Murata Manufacturing Co, Ltd., Kyoto, Japan, celebrating its 50th anniversary as a manufacturer of electronic components.

Webb Laboratories Update – Webb Laboratories relocated in May of 1993 to 13731 W. Capitol Drive, Suite 260, Brookfield, WI 53005. Tel: (414) 367-6823, Main/original number. Fax: (414) 367-6824, Original Fax. New Tel: (414) 367-6825, New line-preferred for listings and directories.

Sage Laboratories' Subsidiary – A wholly owned subsidiary, Sage Laboratories Active Microwave, Inc. (SLAM), in New Hampshire was formed on January 4, 1994. Two million dollars will be invested in SLAM which designs and manufactures solid state microwave components and assemblies for both defense and commercial applications, with particular expertise in microwave mixers, switches, amplifiers, detectors, and multi-function assemblies. The new company's facility is expected to be ready for occupancy in March 1994 and to be fully operational by the summer of 1994.

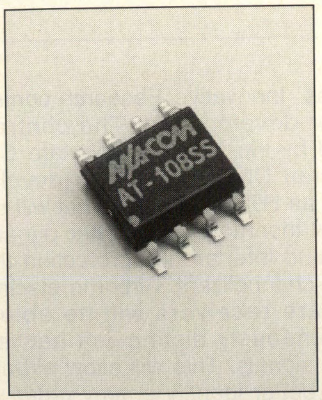
HP Semiconductor Test Operations – This operation will focus on mixed signal integrated circuit (IC) testing under the name of California Semiconductor Test Operation (CSTO). Also included will be production testing and software for circuit characterization. CSTO is from HP's former AOT operation which is involved with linear and power IC testing and also from HP's semiconductor characterization and modeling products, IC-MS and IC-CAP. CSTO will continue to develop the HP 947X family of linear and power IC configurable test products, including the HP 9472 mixed-signal system.

Papa New Guinea Upgrades Satellite System – The $3.3 million contract has Scientific-Atlanta providing the Post and Telecommunication Corporation (PTC) upgrades for the country's domestic satellite operations system so it can transfer from PALAPA to INTELSAT. The system will be upgraded from a microwave restoration network to one providing distribution of voice, data and facsimile services to PNG's major urban areas. Included will be an 18-meter INTELSAT Standard "A" Satellite earth station which will serve as the network's master site. The company will also supply data converters and high-speed modems to remote sites and retrofit the antennas.

ARRL Call For Papers – The 1994 ARRL National Digital Communications Conference on August 19-21 in Bloomington, MN, is calling for papers on digital communications. Presentation at the conference is not required for publication. Papers are due by June 20 and should be submitted to Maty Weinberg, ARRL, 225 Main St., Newington CT 06111 or via Internet at lweinber@arrl.org.

Wireless Computing Solutions Award – CliniCom Inc. and the Children's Hospital of Orange County (CHOC) were awarded with the first Best Local Area Mobile Wireless Computing solutions Award on December 7, at the Wireless Data Comm '93 Conference in Washington, DC. The award recognized CliniCom for developing the Wireless Interactive Network which CHOC implemented thereby allowing clinicians more time with their patients at the point of care instead of at remote computer stations.

Amateur Radio Offers Scholarships – The Foundation for Amateur Radio, Inc.This non-profit organization plans to administer 49 scholarships for licensed radio amateurs who are pursuing a full-time course of studies beyond high school and are enrolled in or have been accepted for enrollment at an accredited



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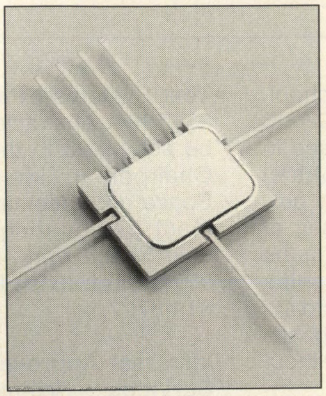

Dual Use - GaAs MMIC Power Amplifier

2 - 6 GHz GaAs MMIC power amplifiers. This amplifier has output power, (saturated), of +29 dBm with 25% power added efficiency and a gain of 18 dB. This dual use amplifier is designed for defense EW, radar, communications and commercial communications.

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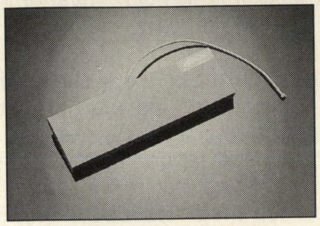

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This hemispherical/omnidirectional antenna has a gain of +4 dBic @ zenith. The diversity patch antenna switches between two individual antennas to achieve optimum gain. Typical application is connecting laptop computers into a local area network. Polarization: RHCP.

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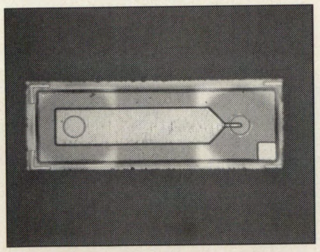

SurMOUNT Chip Monolithic Low Barrier Schottky Diodes

This new beam lead diode has the same electrical characteristics as standard beam leads, but eliminates the problem of brittle beams and the need to wire bond to chips. The beams have been replaced with bonding pads, making them easy to handle, and can be connected using normal die attach techniques.

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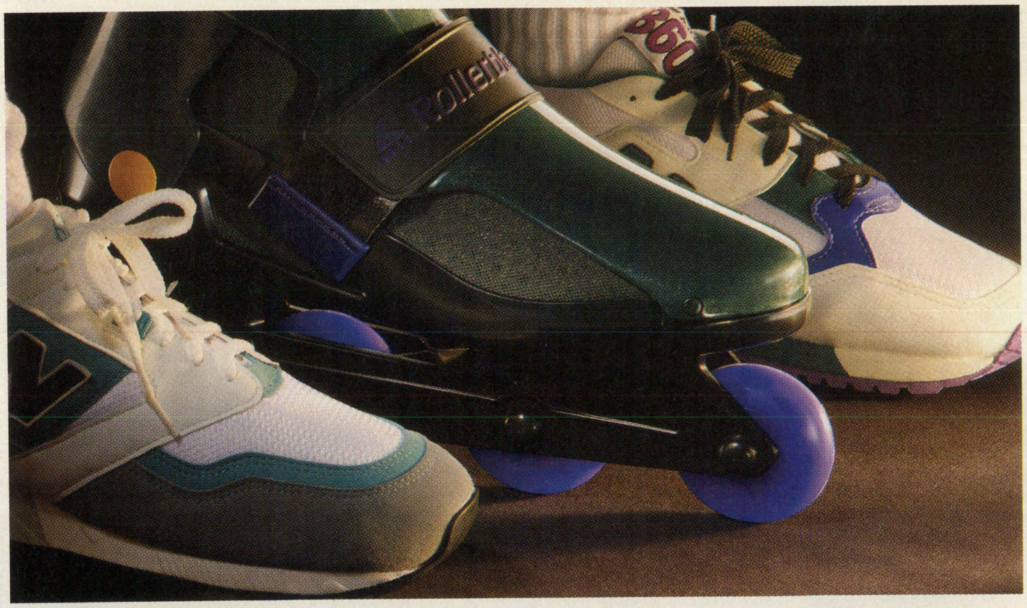
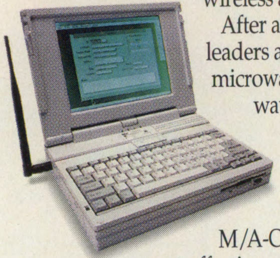


In today's intensely competitive wireless environment, the race goes to the swift (and the smart). That's why so many smart companies are turning to M/A-COM to help make their wireless applications a reality.



After all, we've been leaders and innovators in RF, microwave and millimeter wave technology for more than 40 years.

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You'll find our products are already hard at work around the world in both LANs and WANs. Connecting everything from pen-based computers to bar code scanners to personal communicators. And while today we're helping you with data and voice transmission, we're also ready to take you into the realm of integrated data, voice and video applications.

So if you're looking for more than a supplier, if you're looking for a strategic partner that will help you with product development, innovative solutions and high-volume low-cost manufacturing, look to M/A-COM. We'll give you such a competitive advantage, it'll almost be unfair.

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university, college or technical school. The awards range from $50 to $2000 with preference given in some cases to residents of specified geographical areas or are pursuing certain study programs. The Foundation , composed of 50 Washington, D.C. local area clubs fully funds five of these scholarships with the income from grants and its annual Hamfest. The remaining are administered by the Foundation without cost to the various donors.

ARFTG's 43rd Conference Issues Call For Papers – The conference will be held on May 27, 1994, in San Diego, CA, in conjunction with the International Microwave Symposium. ARFTG is an independent professional society that is affiliated with the IEEE Microwave Theory and Techniques Society (MTT-S). Papers are invited that focus on improved techniques for calibration and verification of automated equipment, MMIC design and probing, CAD, circuit modeling, and topics on the conferences' theme, "Improving Performance and Quality of Automated Microwave Test Systems". Papers are due March 25, 1994. Abstracts and summaries can be submitted to the Technical program Chairperson: Mr. S.D. Phleger, TRW Space and Electronics Group, Measurement Engineering, Mail Stop S/2767, One Space Park, Redondo Beach, CA 90278. Tel: (310) 812-4667. Fax: (310) 814-8797.

Inmarsat Approval for Voice and Fax Services – Scientific-Atlanta, Inc. has had its briefcase-sized earth station approved to offer voice and fax services. The TerraStar-M™ is now the only such station that can provide both capabilities using the Inmarsat-M satellite network. In addition to monitoring rural voting in last December's Chilean presidential elections, the equipment was also used to report results from their territory in Antarctica.

Small Business Innovative Research Contract – Superconductor Technologies Inc. , a supplier of high-temperature superconductor (HTS) products and services, has received a $500,000 Small Business Innovative Research contract for filter development. The contract, directed by the Naval Air Warfare Center Aircraft Division, calls for development of an HTS multiplexer that will provide low insertion loss, better dynamic range, and interference protection than existing channelizers. Airborne electronic warfare receivers will be able to instantaneously distinguish between multiple signals. This will allow airborne units to better identify enemy radar signals in dense interference environments such as the Persian Gulf.

Montreal's Tunnels Gets Cellular – Andrew Corporation installed a Distributed Communications System in the eight tunnels that range in size from single lane entrance/exit ramp tunnels to five-lane wide major thoroughfares. The two main arteries that are equipped with cellular service are nearly two miles long and range from three to five lanes in width. The cable brings cellular service to the tunnels from cellular cell site. Involved were 7,500 meters of 1-5/8" fire retardant RADIAX® foam dielectric cable, 17 cellular tunnel bidirectional amplifiers, HELIAX® cable and other system integration components.

IVHS For Nine California Bridges – MFS Network Technologies, Inc., has been awarded a $30 million contract to engineer and build an electronic toll collection system for nine Caltran bridges located throughout California. This is an important component of the state's plan to use advanced technologies to create an Intelligent Vehicle Highway System (IVHS).

Aydin Vector Gets British Contract – The Newtown, PA, maufacturer has been awarded $4.6 million to supply the British Aerospace Defence its Telemetry Interface Unit, ISM-800, and Flight Termination Receiver, VFTR-321, for the ASRAAM Program. The contract covers the development and production phases of the air-to-air missile.

Rohde & Schwarz and Grundig Electronics Cooperate – The two companies agreed to work together in the field of system solutions for automated in-line production testing. They both intend to implement both turnkey production lines with integrated test equipment and individual parts. Grundig electronics produces and markets mechanical and electrical production technology products as well as integrated production systems. Rohde & Schwarz markets communications and measuring instruments and systems with emphasis on mobile radio, sound and TV broadcasting, EMC measurements, lab test equipment, environmental measurements, radiomonitoring/radiolocation and radio transmission systems.

IRIDIUM™ SM Gets Earth Terminals – Scientific-Atlanta, Inc. has been named the exclusive supplier of satellite earth terminals for the IRIDIUM™ global communications system. The company's Electronic Systems Division, a unit of the Instrumentation Group, received a $15 million contract from Motorola's Satellite Communications Strategic Business Unit to provide ten system control terminals for the system's telemetry tracking and command centers. In addition, the contract contains options valued at an additional $20 million. IRIDIUM™ will provide a world wide digital, satellite-based personal communications system to transmit and receive digitized voice, data and facsimile signals via hand-held mobile units.

IEEE-1076 Standard and VHDL – Sharp Electronics Corp. and Cadence Design Systems, Inc. revealed that Sharp will transition its worldwide development efforts to a top-down design methodology based on Cadence's VHDL design environment in an agreement that represents the single largest commitment by an electronics manufacturer to the IEEE-1076 standard hardware description language. The three-year deal is valued at $30 million and includes the purchase of Cadence's Leapfrog™ VHDL simulator and Team Design Manger™ design data management system as well as the adoption of Cadence's VHDL ASIC design methodology. Sharp developers estimate that their transition to VHDL-based top-down design can reduce design cycles by a factor of ten.

High Volumes, Accurate Designs Obtained with Advanced Test

By Andy Kellett
Technical Editor

The number and types of RF devices being built have changed over the years, and so have the test methods and equipment necessary to bring those devices to market. Complex RF devices built in high volumes have made automatic test equipment necessary for manufacturers. At the same time, manufacturers trying to squeeze every last milliwatt out of battery-powered RF devices have increased the demand for precise device characterization.

Automatic Test Equipment & VXI

The price of test is a driving factor for the cost of MMICs says Mike Caldwell, Marketing Manager for MMIC test products at Scientific Atlanta (SA). And for MMICs, 100% testing is almost mandatory, "The companies that just test a part here and a part there won't be around very long," says Caldwell.

According to him, automatic test equipment users are particularly interested in single connect multi-measurement (SCMM), high speed, and flexibility. "When specifications and parts change, you shouldn't have to go get a test engineer," says Caldwell.

VXIbus instruments have not taken over large portions of the RF test market says Racal Instruments Product Marketing Specialist, Arlene Meadows, "but it is beginning to make inroads." The VXI specifications are meant to provide modular, compact test equipment, making VXI instruments useful in applications where instruments must be brought to the device to be tested; on flightlines for example.

VXI's compact form factor may also be part of the reason RF instruments have been slower than other instruments to make it to the VXI format. RF instruments tend to be larger because of shielding requirements says Meadows. However, RF instruments are beginning to appear more and more in VXI form. According to Meadows there exist VXI RF sources, frequency counters, downconverters and attenuators. "I expect to see a good spectrum analyzer within a year."

Load Pull Measurements

Power amplifier design for wireless applications must be both cost and power efficient. "You can't afford to oversize the device; you have to find the best solution," says Christos Tsironis, President of Focus Microwaves. In the case of designing RF power amplifiers, the way to quickly achieve an optimum design is to know the transistor's large signal parameters. However, Tsironis says, "Practically no manufacturer provides large-signal parameters." That's where load-pull analysis comes in. Focus Microwaves, Maury Microwave and ATN Microwave are among the companies that produce load-pull test set-ups.

"You can really call these variable impedance measurements," says Michael Fennelly, Sales and Marketing Manager for ATN Microwave. "most measurable power dependent properties are functions of termination impedances," says Fennelly.

Removing the effects introduced by the test set-up (de-embedding) is an important part of these measurements. While some systems must be slowly "pre-calibrated" to obtain de-embedding information, ATN's systems can be quickly calibrated "in situ", says Fennelly, because they are continuously connected to a vector network analyzer. This eliminates the need to assemble and disassemble connections for every test.

Vector Network Analyzers

Vector network analyzer (VNA) manufacturers continue to extend the capabilities of their instruments.

The 6210 reflection analyzer option for Marconi Instruments' 6200 microwave test set gives users a limited vector analysis capability along with its time domain capabilities. With this option, a user can measure both magnitude and phase of S11 and S22, and magnitude of S12 and S21. According to Rick Warrick, National Microwave Product Manager for Marconi, for applications that don't need full vector analysis for all 2-port S parameters, this option provides a good solution at a good price. In addition, the 6210 allows signals to be fenced, which Warrick describes as the inverse of gating. What this means is an offending reflection can be selectively "ignored" by the instrument, allow simulation of system performance without that reflection.

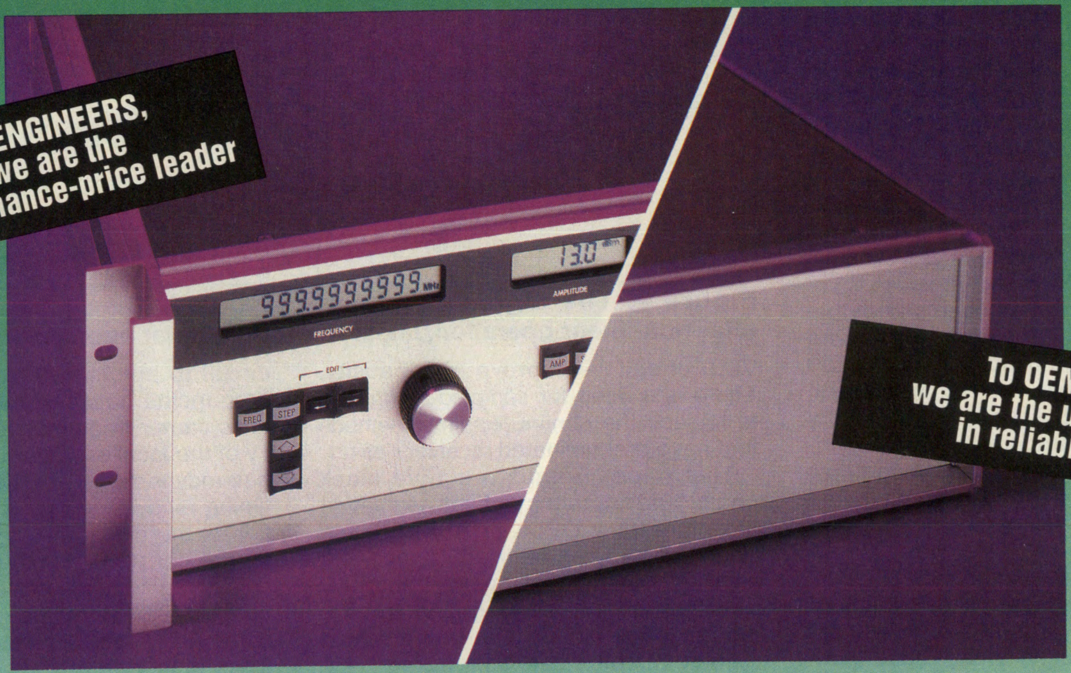
Wiltron continues to expand the capabilities of its 360B line of vector network analyzers, extending the upper end of the instrument's frequency range to 50 GHz and adding packages that measure material properties and connector specifications. Wiltron Director of Corporate Technology, Dr. Martin Grace says he expects to see a lot more automation of measurements, requiring less skill on the part of the operator. "I suspect we will lose some accuracy in that process."

A new transfer standard for VNAs takes a step in that direction, but without a reduction of accuracy. Developed by Hewlett-Packard, in cooperation with ATN Microwave, the ECal transfer standard can calibrate a VNA for all four 2-port s-parameters in less than three minutes. "In the past, if users cleaned up the connectors and did everything just so, a full 2-port calibration could take 20 to 25 minutes," says Kevin Coffey, Product Marketing Manager at HP's Santa Rosa Systems Division. The ECal requires only two connection which are only made once, cutting down on time, opportunity for error, and wear and tear on connectors.

ECal incorporates a series of electronically switched impedances contained in a box called the "module" and a control box which can be connected to most HP vector network analyzers. Each "module" is characterized on a NIST-traceable VNA, "the golden HP 8510", says ECal Product Manager. The de-embedding information obtained this way is stored in ROM in the module.

It has become a recurring theme in this column that the increasing demand for portable RF products has prompted manufacturers to produce large volumes of complex, low-power devices more cheaply than ever. The test equipment presented in this article is all geared to do just that. *RF*

Split Personality



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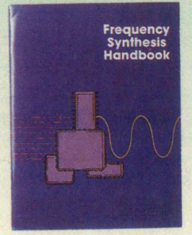

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INFO/CARD 24

An Algorithm For Combined Receiver Sample Timing And Frequency Offset Estimation

By K. Anvari
Teknekron Communications Systems

A combined automatic frequency control (AFC) and clock timing recovery algorithm is discussed. The algorithm extracts the frequency offset of the carrier and timing offset of the clock from a discrete component of the clock which is produced by a non-linear function. The non-linear function requires four samples per symbol for its operation. This technique depends on received symbols and performs best if the received symbols are random. It has been shown that using this technique very fast timing acquisition in the order of 100 to 200 symbols is possible. It is also possible to calculate the clock frequency drift by using a higher number of received symbols. The simulation results also show that frequency offset can be estimated with resolution of few tenths of Hz.

The development of the IS-54, dual mode cellular system has invoked much research in the area of digital signal processing techniques. These techniques have a fundamental role in furthering VLSI integration of transceivers. Any integration in the form of a generic chip set would reduce the development time for a family of products based on a common core architecture. It also results in low cost, easy reproducibility and high reliability.

Sampled implementation of the receivers for digital data signals are growing more popular as components – notably digital signal processors and VLSI circuits – improve in capability. There is a need for sampled algorithms to replace the continuous-time methods that have predominated receiver design.

This paper details a simple clock phase and frequency offset estimation algorithm for a QPSK or ASK receiver. The algorithm can be used for receivers with two samples per symbol and performs combined sampling time and frequency error calculation. It is a robust algorithm which can work in the presence of various channel impairments and a fast fading environment [1],[2]. Naturally, adjustment speed is critical, and it is an important feature of the present technique that the adjustment of sampling time and the correction of the frequency offset are substantially accomplished in the shortest possible time and with minimum estimation error.

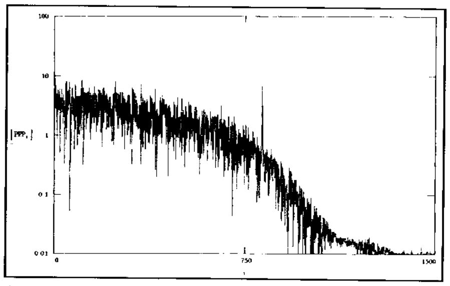

Figure 2. The signal spectrum after non-linear operation, linear IF

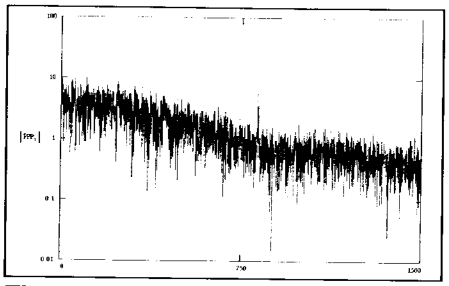

Figure 3. The signal spectrum after non-linear operation, limiting IF

Synchronization Techniques

Digital radio receivers often utilize a circuit to automatically correct for discrepancies between the received signal's carrier frequency and the frequency of the local oscillator used in a superheterodyne receiver. They also utilize a timing recovery circuit for correct detection of the digital data that the received signal conveys. Timing recovery and carrier recovery are two of the most critical receiver functions in synchronous communication systems. The receiver clock must be continuously adjusted in its frequency and phase to optimize the sampling instants of the received data signal. To avoid performance degradation caused by carrier phase and frequency error, the incoming signal carrier has to be tracked. The choice of sampling time is critical for minimizing the error probability due to inter-symbol interference and noise, particularly when the signal has been subjected to sharp roll off filtering. The timing and frequency information is usually derived from

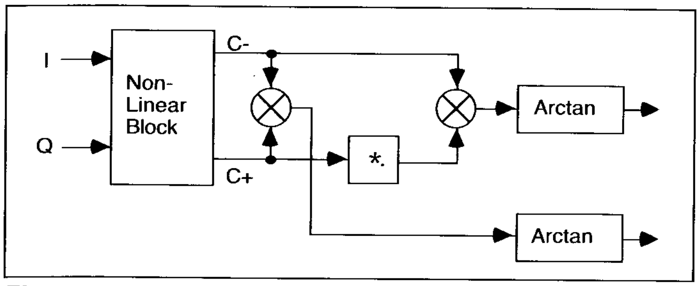

Figure 1. Joint AFC and Symbol Timing Recovery Algorithm

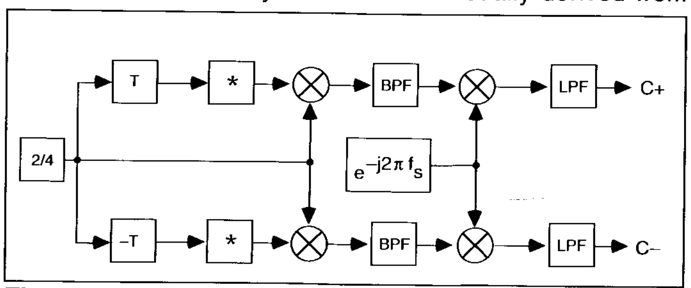

Figure 4. Non-linear operator

the data signal using some meaningful optimization criterion which determines the steady-state location of the timing instants and incoming carrier frequency.

In mobile communication environments, where the modulated carrier is subject to fast multi-path fading, conventional continuous time synchronization techniques can not perform satisfactorily and sampled-data synchronization techniques are the most practical approach. In time domain multiple access systems where each user is assigned one time slot the receiver has to perform its timing and frequency synchronization task on a slot by slot basis. Frequency synchronization is usually achieved by automatic frequency control circuits which have some inherent frequency error. Therefore, the timing recovery circuit or algorithm has to accommodate some limited amount of frequency error without significant performance degradation.

The technique described in next section is a discrete-time technique using a non-linear operation. It is applicable to radio telephones as well as computer and other data communication receivers. However the technique will find particular utility in cellular radio-telephones.

Algorithm Description

Performing non-linear operations on a signal may produce periodic components whose magnitude, phase and amplitude provide useful information about the signal. This algorithm applies this concept to the received signal to perform both AFC and clock phase recovery.

The non-linear operations which have been reported in the literature are squaring, full wave rectification, and multiplication of the received signal by a delayed version of the same signal. These functions can be performed at any location in the receiver before digital demodulation. The non-linear operations produce periodic components at the multiple of the symbol rate which can be used to recover the symbol clock. In this algorithm the non-linear operation is performed at baseband by multiplying the complex representation of the received in-phase (I) and the quadrature phase (Q) signal by a delayed and conjugated version of the same signal.

The objective of this algorithm as shown in Figure 1 is to perform this non-linear operation on the received signal and estimate the phases of the periodic component at the symbol rate. These phases are used to estimate the frequency offset and the symbol clock phase offset, and then used to correct these with appropriate feedback loops.

The non-linear operations used in this algorithm are:

a) $r(t)\cdot r^*(t-T)$, and
b) $r(t)\cdot r^*(t+T)$,

where * indicates complex conjugation and T is the symbol period. Figure 2 and Figure 3 show the Fourier transform of the non-linear operation for a channel with linear amplification and a channel with a limiter amplifier. The vertical axis of these two curves is the power spectrum and the horizontal axis i can be used to calculate the frequency using

$$f = \frac{5\cdot i\cdot f_s}{4048} \tag{1}$$

where
f_s=sampling frequency.

The resulting baseband complex signal contains periodic components at the clock frequency and the negative of the clock frequency. The phase of these components are related to the sampler phase error and to the local oscillator frequency error. The phase of the first discrete spectral component that appears at the positive clock frequency is used to derive the information for sampling phase and frequency offsets.

Both the demodulator frequency error and the sampler phase error can be estimated by an examination of these two phases. The complex signal at the output of the demodulator is divided into two paths. One path is used for frequency error and clock phase estimation and the other path follows the received channel path for other receiver functions.

The non-linear operator is shown in Figure 4 as dual cyclic correlators, with one correlator being temporally advanced, and the other being temporally delayed. The illustrated non-linear operator thus consists of a two to four interpolator, one-symbol-period delays, conjugators, multipliers, lowpass filters and averagers. The non-linear operator provides two signals, C_+ and C_-. C_+ is a composite signal having phase components of interest at the positive symbol frequency, F_s. A first phase component of C_+ varies with respect to the relative carrier frequency error, f_e; a second phase component is related principally to the symbol timing error, τ. A third, constant component equal to π radians is also present in C_+.

The first composite signal, C_+, thus takes the form of

$$C_+ = K_1 e^{j2\pi\left(f_e\cdot T \pm \frac{\tau}{T} + \frac{1}{2}\right)} \tag{2}$$

where K_1 is a constant, and f_e, T and τ are defined as previously.

The second composite signal C_-, also has phase components of interest; these also appear at the positive of the symbol frequency, F_s. C_- is given by

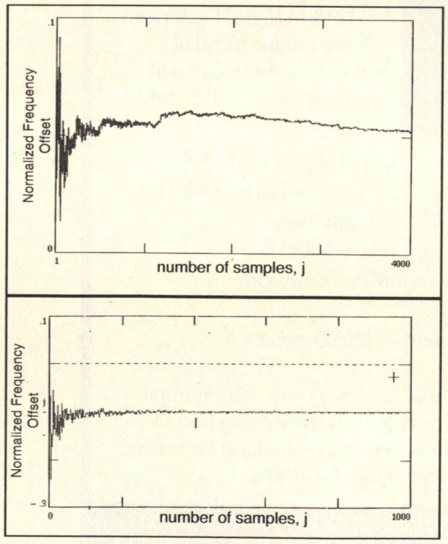

Figure 5. The estimated response for noise-free and fading-free condition.

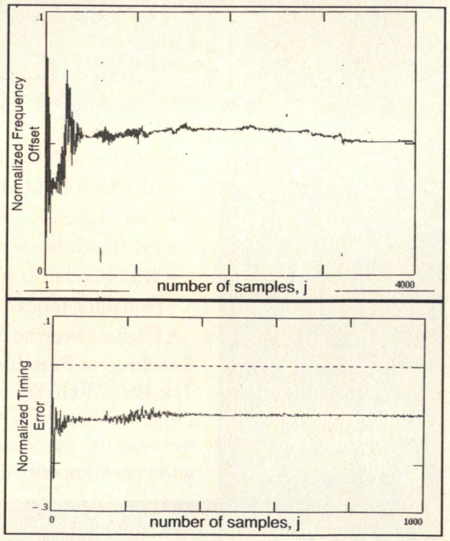

Figure 6. The estimated response for noise-free condition and 80 Hz fade rate

$$C_{\pm} = K_2 e^{j2\pi\left(\pm f_e \cdot T \pm \frac{\tau}{T} + \frac{1}{2}\right)} \quad (3)$$

where K_2 is another constant; C_- thus also has two phase components which are related to f_e and τ.

In other words, C_+ is a signal having a first phase component related to the ratio of the demodulator frequency error to the symbol clock rate, and a second phase component related to the ratio of the timing error to the clock interval. Likewise, C_- also has two phase components of interest, with the first component being related to the ratio of the negative of the demodulator frequency error to the clock rate, and the second component being the ratio of the timing error to the clock interval.

One way to estimate the phase of the signal components is to complex demodulate the component of interest to DC, average and estimate the phase by an arctangent operation.

In order to have the phase components of interest in the C_+ and C_- signals appear directly at or near DC, the output of the multipliers are bandpass filtered and then down converted to DC.

The averagers assist in obtaining timing and frequency error estimates having accurate means and low variances; averaging is preferably performed over several tens or hundreds of symbol periods.

The remainder of the blocks shown in Figure 1 are concerned with extracting f_e and τ from the composite signals C_+ and C_-.

The timing error detector extracts the timing error, τ, from C_+ and C_- by multiplying them together and performing an arctangent operation. It should be noted that the arctangent function takes a complex argument and returns a non-ambiguous angle in radians from $-\pi$ to π.

To understand why τ can be extracted in this way, consider that the expressions for C_+ and C_- can be written as

$$C_+ = K_1 e^{j(\theta_1 \pm \theta_2)} \quad (4)$$

and

$$C_{\pm} = K_1 e^{j(\pm\theta_1 \pm \theta_2)} \quad (5)$$

where

$$\theta_1 = 2\pi \cdot f_e \cdot T \quad (6)$$

and

$$\theta_2 = 2\pi \cdot \frac{\tau}{T} + \pi \quad (7)$$

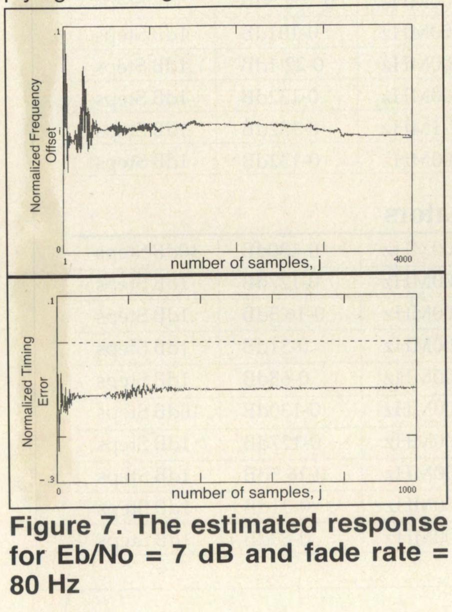

Figure 7. The estimated response for Eb/No = 7 dB and fade rate = 80 Hz

so that

$$C_+ \cdot C_\pm = e^{\pm j(2\cdot\theta_2)} \qquad (8)$$

Thus, the arctangent operation extracts a signal equal to twice θ_2; since

$$\pm 2\theta_2 = 4\pi \frac{\tau}{T} \qquad (9)$$

which is proportional to τ.

Similarly, the frequency error extractor extracts the frequency error, f_e, from C_+ and C_- by using a multiplier to multiply C_- by the conjugate of C_+. An arctangent operation results in the detection of f_e to within a scale factor. This can be better understood by considering that

$$C_+ \cdot C^*_\pm = e^{j(2\cdot\theta_1)} \qquad (10)$$

and

$$2\theta_1 = 4\pi \cdot f_e \cdot T \qquad (11)$$

The operations may be performed on the sampled data as long as the sampling rate is above the Nyquist rate. Sampling twice per symbol is usually adequate to meet or exceed this condition.

Simulation Results

To investigate the performance of the algorithm it was simulated in software. This was done for three channel conditions: no noise and no fading, noise and fading, and with delay spread. Our discussion will touch three major points, the first of which is related to the algorithm and its time constant. The step response of the algorithm has been tested by simultaneously applying a frequency offset equivalent to 5% of the symbol frequency and a negative timing error equal to 10% of the symbol period. Figures 5 through 7 illustrate the results for the first two conditions mentioned earlier. For the simulation, the sampling rate was two samples per symbol and a Rayleigh fading channel with 80 Hz fade rate has been used.

In the noise-free and fading-free conditions of Figure 5, the timing offset can be estimated within a time period much less than 500 symbols. The frequency offset needs longer averaging time to provide a good estimation. The averaging time depends on the required resolution. For a noise-free Rayleigh faded

channel (fade rate = 80 Hz) the algorithm's response is shown in Figure 6. It can be seen that the timing offset estimation is similar to the previous condition while the frequency error estimation unexpectedly is more accurate. This is also the case for a channel with 80 Hz fade rate and Eb/N0 = 7 dB (Eb = bit energy, N0 = noise density) as shown in Figure 7. A possible explanation for the improvement in frequency offset estimation in the last two conditions is that the addition of noise or fading makes the signal statistically more random.

Channel impairments are not expected to deteriorate the accuracy of the estimation of both frequency and timing offset. However, channel dispersion due to echo or delay spread can degrade the performance of the algorithm. Figure 8 illustrates the performance of the estimator for a channel with the following characteristics:

1. Eb/N0 = 17 dB, fade rate = 80 Hz
2. Two ray model with two independent channels for each ray
3. Equal amplitude for both rays and delay = T/4

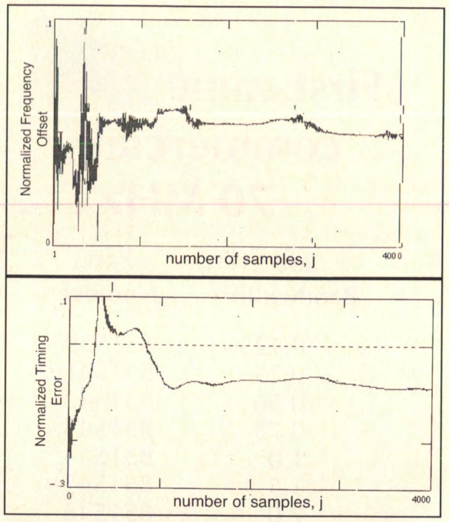

Figure 8. The estimated response in the presence of delay dispersion

4. Frequency offset = 5% of F_s and timing offset = 25% of T

It can be seen that the frequency offset can be estimated with good accuracy, but timing offset estimation is dis-

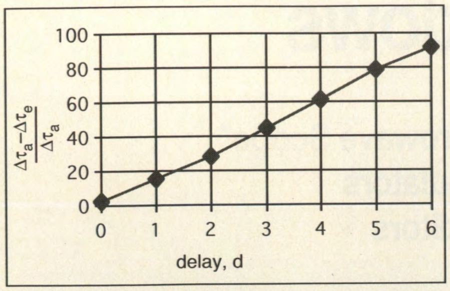

Figure 9. Estimation error for equal gain condition

tanced from the timing error of the signal. This distance was calculated for various delay when the main and delay signals are of equal amplitude and when the delay signal amplitude is 5 dB lower. The results are shown in Figure 9 and Figure 10, and indicate that the diversion from the actual offset decreases as the amplitude differential between main and delay signals increases. In these two figures, Δt_a is the actual timing offset, Δt_e is the estimated timing offset and delay $=d \cdot T/20$.

Conclusion

A new method of symbol synchronization and frequency offset correction, using two samples per symbol, has been presented [3]. The effects of various system parameters (such as signal filtering, signal-to-noise ratio, multi-path Rayleigh fading, and delay dispersion) has been considered.

The results indicates that the clock phase and the frequency offset can be estimated using considerably small number of samples or symbols. This feature makes the algorithm very attractive for utilization in burst receivers. ***RF***

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2. K. Anvari, M. Kaube, "Performance of a Direct Conversion Receiver With $\pi/4$-DQPSK Modulated Signal", IEEE VTC 91, May 1991.
3. Patent pending

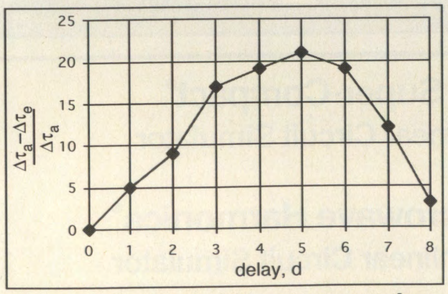

Figure 10. Estimation error when main to echo signal amplitude ratio is +5 dB

About the Author

Dr. Anvari's PhD is in electrical engineering from Bradford University in the UK. He worked three years for GEC/Plessey as a digital microwave system engineer, and four years as program manager for North American Digital Cellular development at Novatel Communication Ltd. in Calgary, Canada. Presently he is the Japanese Digital Cellular development program director with Teknekron Communications Systems at Berkeley, California. He can be reached at (510) 649-3579.

Design and Performance of a Low Voltage, Low Noise 900 MHz Amplifier

By Nagaraj V. Dixit
Motorola SPS, Asia Pacific Division

This technical article describes the design and performance of a 900 MHz low noise amplifier (LNA) covering the 840 to 960 MHz frequency band. The amplifier operates with a low supply voltage (4.0 V) and requires a supply current of <3.4 mA. Performance is highlighted by a very low noise figure of 1.7 dB and a gain of 11 dB with unconditional stability across all frequencies. Applications of this amplifier include CT1 and CT2 cordless telephones, remote control receivers, GSM, video and audio short range links, low cost cellular radios and ISM spread spectrum receivers.

The transistor selected for the LNA is the Motorola MRF9411L which is supplied in a SOT-143 surface mount package ideal for automated manufacturing using micro-strip printed circuit board (PCB) construction. Its performance characteristics indicate a unilateral gain of approximately 17 dB with a optimum noise figure of 1.3 dB over the desired range of frequencies. Gain and noise figure contours for the MRF9411L are shown in Figure 1.

The theoretical design was done using the measured S-parameters shown in Table 1 and with noise parameters measured at 880 MHz. The source reflection coefficient was chosen to achieve optimum noise figure of 1.3 dB. EESof's analysis and optimization software program Libra™ was used for stability analysis and matching circuit optimization. After careful observation of the data shown in Figure 1 and Table 1, note the following points:

- The device and conventional matching networks are potentially unstable. Some form of stability is required.
- There are regions of instability in both the input and output impedance planes.
- As would be expected, gain and noise figure contours do not coincide.

A redesign of the circuit was required in order to stabilize the circuit at all frequencies–below the desired band, in the band and above the band. And, of course, the desire is to achieve stability while retaining minimum noise figure performance and acceptable gain.

At least three methods of stabilizing the circuit are available to the design engineer:

- Input shunt resistive loading
- Output shunt resistive loading
- Voltage shunt feedback

Methods 1 and 3 degrade the minimum noise figure performance and, therefore, were not acceptable. Output shunt resistive loading was implemented since it did not affect the noise figure, and because S12 is so small the previously determined input impedance

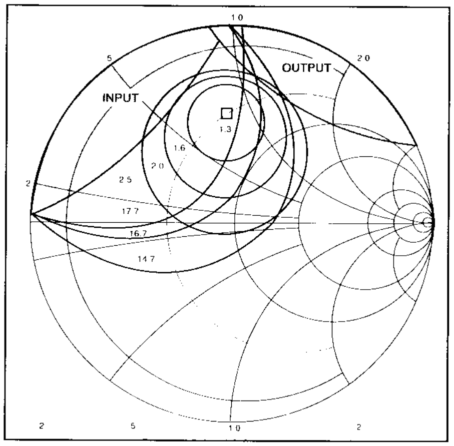

Figure 1. Gain and NF contours for MRF9411L.

matching is also unaffected (the amplifier can be assumed to be unilateral). Simulated S-parameters and "k" factors over a wide range of frequencies with output resistive loading are shown in Table 2.

The input matching circuit chosen uses low pass topology and is designed to transform the generator impedance (nominal 50 ohms) to Γ_{opt} of the MRF9411L in order to obtain best noise performance. This configuration will not affect the low frequency stability of the amplifier since at low frequencies, a low pass network tends to be "transparent" and does not transform impedances any

Freq. MHz	S11 (mag, phase)	S21 (mag, phase)	S12 (mag, phase)	S22 (mag, phase)	GU_{max} dB	K
840	0.57, –111	5.13, 109	0.08, 42	0.63, –42	18.1	0.49
860	0.57, –112	5.05, 108	0.085, 41.6	0.62, –42	17.9	0.50
880	0.56, –114	4.97, 107	0.085, 41.3	0.62, –43	17.7	0.52
900	0.56, –115	4.89, 106	0.086, 41.4	0.61, –43	17.5	0.52
920	0.55, –117	4.80, 105	0.086, 40.8	0.61, –43	17.2	0.54
940	0.55, –118	4.74, 104	0.087, 40.3	0.60, –44	17.0	0.55
960	0.54, –120	4.68, 104	0.088, 40.4	0.60, –44	16.8	0.56
S-parameters measured at V_{ce} = 3V, I_c = 3mA						

Table 1.

Freq. MHz	S11 (mag, phase)	S12 (mag, phase)	S21 (mag, phase)	S22 (mag, phase)	K dB
100	0.57, –60.804	5.27E–4, 71.249	4.45, 154.249	0.106, –53.701	142.8
840	0.58, –99.393	0.0504, 48.695	3.08, 115.095	0.180, –122.145	2.040
860	0.58, 100.758	0.0511, 48.086	3.04, 114.186	0.181, –122.917	2.048
880	0.57, 102.325	0.0512, 47.782	2.99, 113.282	0.183, –123.462	2.091
900	0.57, 103.663	0.0519, 47.88	2.95, 112.48	0.184, –124.11	2.107
920	0.56, 105.229	0.052, 47.247	2.91, 111.647	0.185, –124.665	2.157
940	0.56, 106.517	0.0527, 46.740	2.87, 110.940	0.186, –125.201	2.179
960	0.56, 107.942	0.0534, 46.822	2.84, 110.022	0.187, –125.845	2.185
1000	0.55, 110.370	0.056, 46.810	2.78, 108.010	0.191, –127.099	2.145

Table 2.

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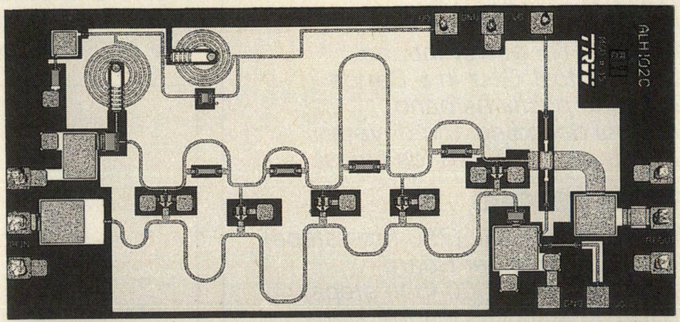

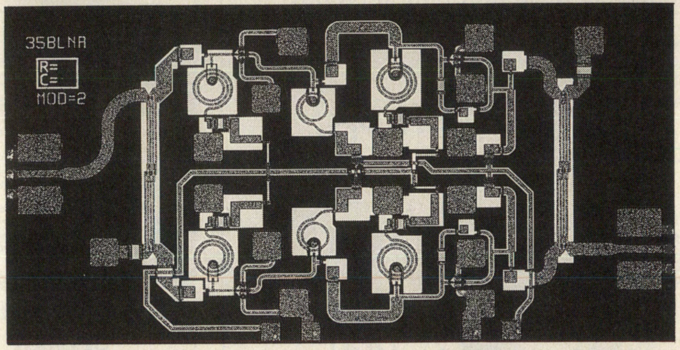

Model AL-H103C

MMIC Device Type	Specifications	Features
Low Noise Amplifiers	2 - 20 GHz, 3.5 dB NF, 10 dB Gain 20 - 40 GHz, 4 dB NF, 10 dB Gain	HEMT Amplifiers. High-Rel qualified.
Successive Detection Log Amplifiers (SDLA). 5-stage HBT	.12 - 1.35 GHz, -65 - +5 dBm Extended Dynamic Range	Chips, flat packs, or connectorized. Short pulse capability.
Darlington Amplifiers 2-stage HBT	DC - 3 GHz, < 5 dB NF, 22 dB Gain DC - 6.5 GHz, < 6 dB NF, 16 dB Gain DC - 10 GHz, < 7 dB NF, 12 dB Gain	Chips or packages. Cascadable. Flat gain. High efficiency.
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significant amount.

For the output, the load reflection coefficient is matched to a 50-ohm load. Optimization of both input and output matching networks was accomplished by means of trial-and-error iterations using the power of Libra. A final RF schematic for the LNA is shown in Figure 2. R1 is the output shunt resistor and C2 acts as a DC block.

A PNP active bias network shown in Figure 3 is used to establish the bias point at 3 V and 3 mA and to ensure that it remains constant over temperature. Bias current for the transistor is set by R4. Operation of the bias network is as follows: If the collector current through Q2 tends to increase, the current through R4 increases and the emitter-to-base voltage of Q1 decreases. This decrease in emitter-base voltage in turn decreases the base and collector current of Q2, effectively achieving the desired bias stability.

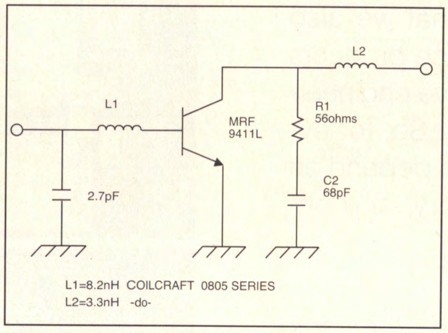

Figure 2. LNA schematic.

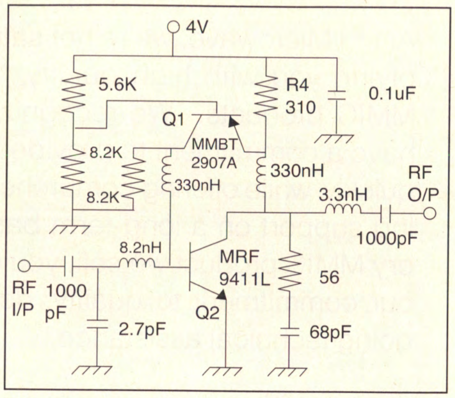

Figure 3. LNA schematic including DC bias.

Implementation and Performance

Epoxy glass was chosen as the PCB substrate material with a thickness of 0.8 mm and a relative dielectric constant of approximately 4. Because cost is a major consideration in the design, size of the PCB is at a premium which dictated the use of a lumped component approach to the circuit realization. The passive components used are surface mount with inductors from Coilcraft 0805 series having a moderate Q of >50. The circuit layout is shown in Figure 4 while Figure 5 is a photograph of the finished amplifier.

After building the amplifier, measured performance of the LNA was found to be very near the predicted performance obtained from circuit simulation. Differences between measured and predicted performance were primarily due to circuit losses, which for the sake of simplicity, were assumed to be zero throughout the simulation.

Results are shown in Table 3. Note that an average noise figure of 1.7 dB is achieved across the desired frequency band, with a moderate gain of around 11 dB and relatively good input and output return losses. The out-of-band noise figure was measured at 800 MHz (1.75 dB) and 1000 MHz (1.95 dB). Other measured parameters were 3rd order intercept point (IP3) of –9

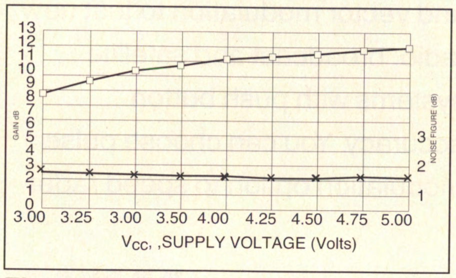

Figure 6. Gain and NF vs supply voltage.

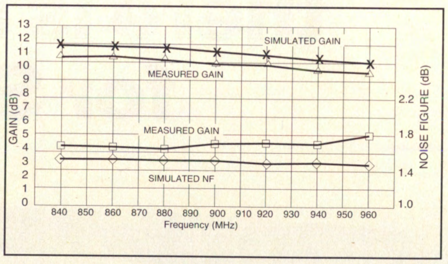

Figure 7. Simulated and measured – gain/NF vs frequency.

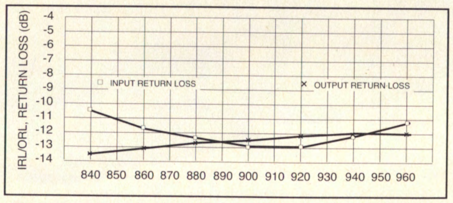

Figure 8. Measured input/output return loss vs frequency.

Freq. MHz	N.F. dB	Gain dB	Input Return Loss dB	Output Return Loss dB
840	1.67	11.43	10.5	13.4
860	1.66	11.35	11.7	13.1
880	1.63	11.27	12.4	12.8
900	1.69	11.05	12.9	12.6
920	1.71	10.95	13.0	12.3
940	1.72	10.74	12.3	12.1
960	1.81	10.70	11.5	12.0

Table 3.

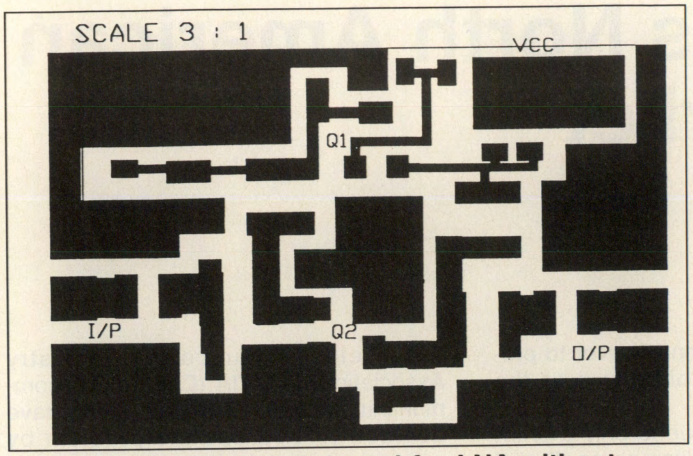

Figure 4. Printed circuit board for LNA without component locations.

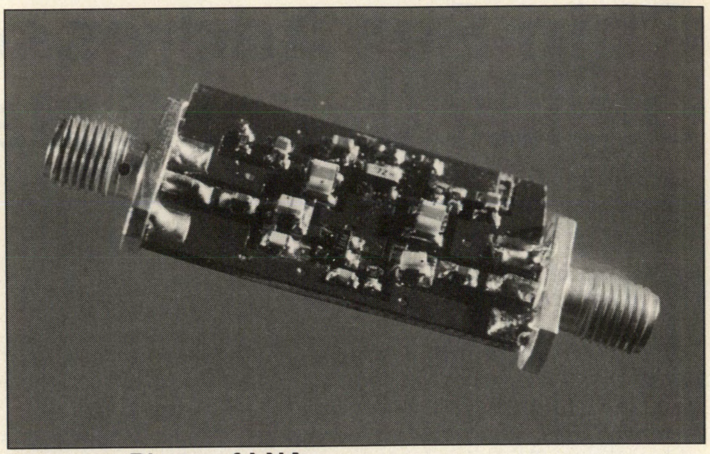

Figure 5. Photo of LNA.

dBm and 1 dB gain compression point of –12 dBm. Figure 6 shows gain and noise figure variations with supply voltage at a frequency of 900 MHz. Figure 7 shows the comparison between simulated and measured gain and noise figure, while Figure 8 gives the variation of input and output return loss with frequency. *RF*

About the Author

Nagaraj V. Dixit is an applications engineer for Motorola's Semiconductor Products Sector. Mr. dixit joined Motorola in 1992 and is currently located in their Silicon Harbour Centre in Hong Kong where he performs RF applications assistance for customers throughout Asia-Pacific. He may reached by telephone in Hong Kong at 852-666-6108

Chip Set Addresses North American Digital Cellular Market

By Michael M. Sera
Philips Semiconductors

Being compatible with divergent standards is not the only challenge cellular handset manufacturers must meet — flexibility, size, and price are also considerations. To help designers meet these challenges, a new chip set targeting dual-mode (IS-54) cellular telephone applications has been introduced.

Cellular phone use has dramatically changed over the past decade, from an eccentric communication device that only the privileged few could afford, to one that is now being given to family members as a security device. The cellular phone has reached the mass market, a dream come true for all cellular manufacturers and service providers. Now the problem becomes maintaining the same level of service. Users will quickly become frustrated if, from downtown San Francisco, they receive a fast busy signal. This condition is unacceptable if the cellular phone is ever to provide the same level of service as the wired system.

Note: Since this issue is only a problem in major metropolitan areas, Digital Cellular is not necessarily required everywhere today.

There are many ways to tackle this problem. Service providers could increase the cost of service during peak times to discourage use. The disadvantage is that cellular would lose the mass market appeal and make other services such as Personal Communications Systems (PCS) or Personal Communication Networks (PCN), Private Mobile Radio (PMR) and Long Range Cordless more attractive. Another alternative would be to increase the number of channels currently allocated. The disadvantage here is that other services already exist in adjacent frequencies. Instead, the cellular companies as a group, through the TIA (Telecommunications Industry Association) or CTIA (Cellular Telecommunications Industry Association), have decided to address the problem by using the existing channels more efficiently.

The current North American analog Advanced Mobile Phone Service (AMPS), specifies the use of Frequency Division Multiple Access (FDMA) with 832 channels separated by 30kHz. The cellular manufacturers have come up with several schemes to share a single channel with multiple users. The first being Narrow band AMPS (NAMPS), which takes an existing 30kHz channel and divides it into three 10kHz channels. The increase is from one user to three users per channel. However, to date, the NAMPS scheme has not been widely accepted by the cellular community.

TDMA (Time Division Multiple Access), standardized as IS-54, uses

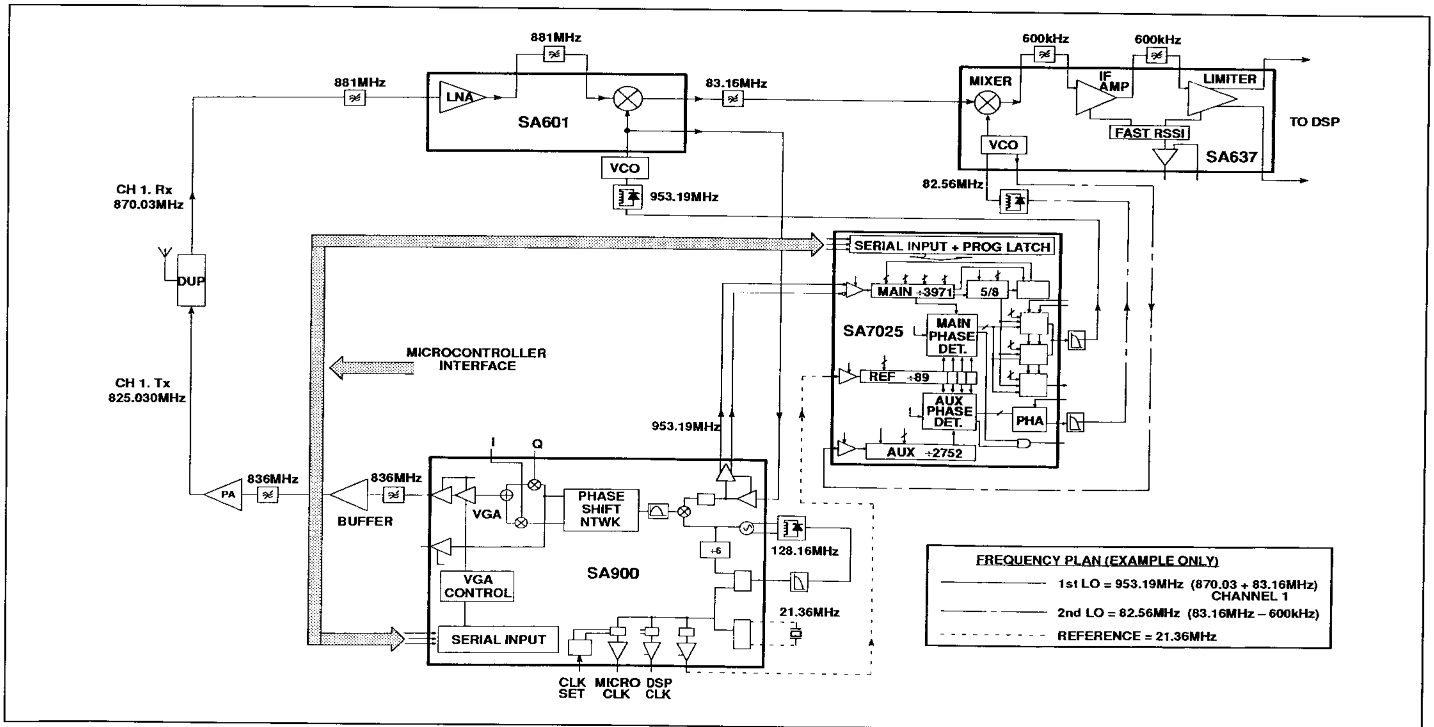

Figure. 1 Block diagram of TDMA IS-54 chip set.

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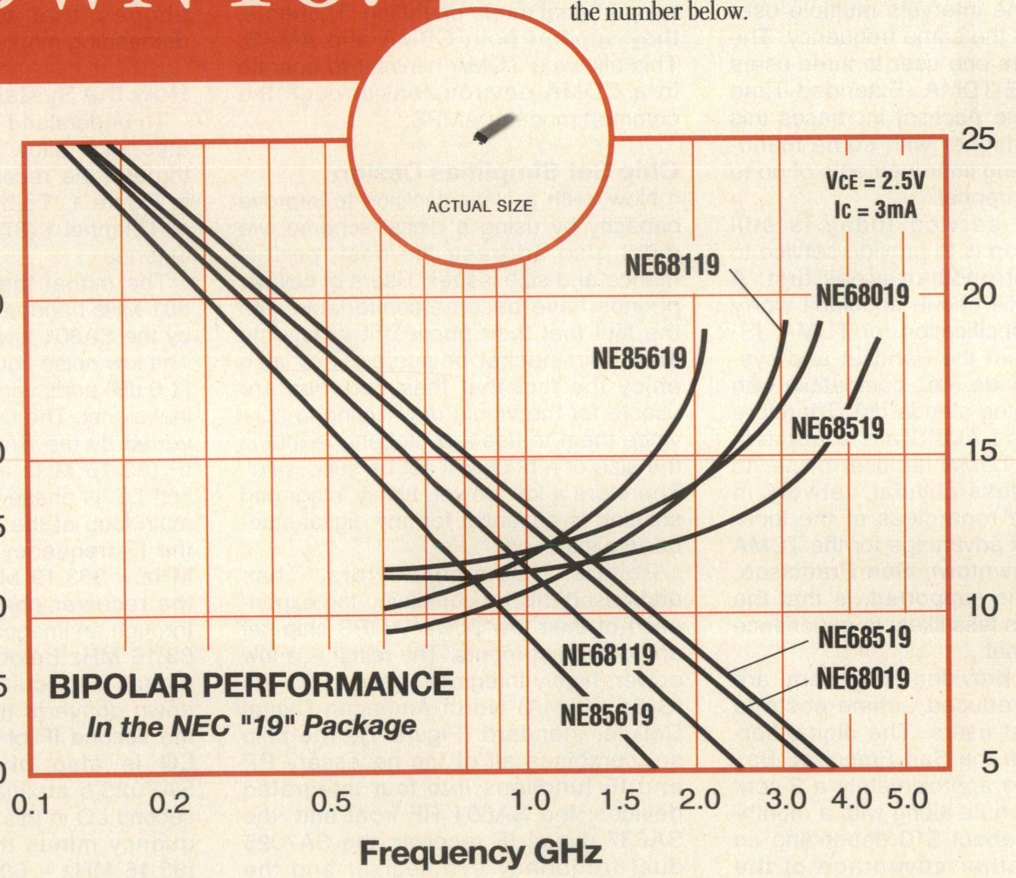

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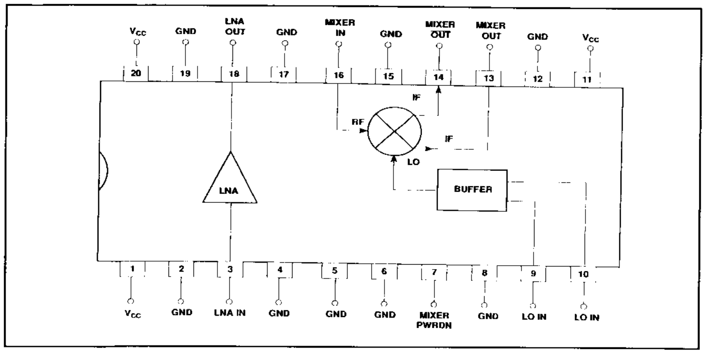

Figure 2. Block diagram of SA601.

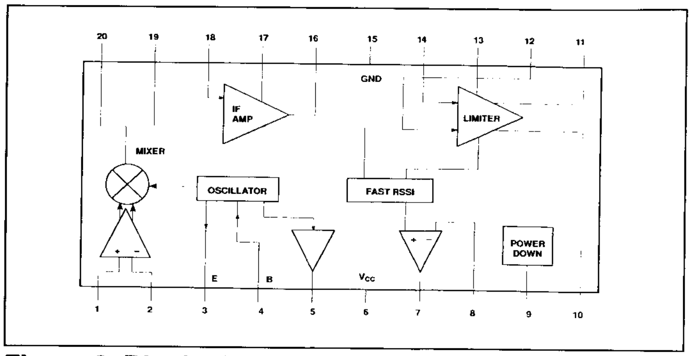

Figure 3. Block diagram of SA637.

the same 30kHz channel spacing but multiplexes users over time. Therefore at different time intervals multiple user are present on the same frequency. The increase is from one user to three users per channel. E-TDMA (Extended Time Division Multiple Access) increases this number even higher with some manufactures reporting improvements of up to ten users per channel.

The TDMA service today is still sparse. The plan is to provide service to the major metropolitan areas first. A user of a TDMA phone shouldn't worry though, the specification for TDMA, IS-54, requires that the handset and system be dual mode (i.e.; compatible with digital and analog standards). Therefore both TDMA and AMPS are supported. This allows a TDMA handset owner to have a seamless cellular network in North America regardless of the location. The major advantage for the TDMA handset in downtown San Francisco, where TDMA is supported, is that the TDMA phone is less likely to experience a fast busy signal.

The service providers in general are also offering reduced airtime costs to TDMA handset users. The digital service provider in the San Francisco Bay Area is offering approximately a 3-cent discount per minute along with a monthly discount of about $10 depending on the plan. Another advantage of the TDMA standard is that the modulation is digital and a conventional scanner will not be able to eavesdrop on calls. If the analysts are correct, TDMA will grow to over 1 million users in 3 years. This will help drive the economy of scale for this new and upcoming standard.

The North American cellular market has another digital standard called CDMA (Code Division Multiple Access) adopted by the TIA as IS-95. This scheme uses a combination of spread spectrum technology plus a coding scheme that San Diego based Qualcomm Inc. has licensed. CDMA also requires that the handsets and system support dual mode operation. Therefore, they support both CDMA and AMPS. This allows a TDMA handset to operate in a CDMA environment through the common mode of AMPS.

Chip Set Simplifies Design

Now, with a clear decision to improve capacity by using a digital scheme, we must also address the cost, performance and size issues. Users of cellular phones have become comfortable with the fact that their phones fit nicely into their shirt pocket or purse. They also enjoy the fact that their batteries are usable for the whole day. Trying to convince them to use a digital phone that is the size of a brick will not be successful. Therefore a low power, highly integrated solution is essential for any digital standard to succeed.

Philips Semiconductors has addressed this by combining the experience of their low power AMPS chip set and customer inputs. The result is a low power, highly integrated chip set for the IS-54 (TDMA) North American Digital Cellular standard (Figure 1). The chip set combines all of the necessary RF and IF functions into four integrated devices: the SA601 RF front end, the SA637 digital IF receiver, the SA7025 dual frequency synthesizer and the SA900 I/Q transmit modulator.

These devices were designed as a system and therefore have interface levels which are matched, this eliminates the need for additional buffers and interface devices. There is also a common high speed serial interface bus, making addressing the devices simpler. Additionally the frequency plan was designed to eliminate the need for an additional synthesizer and VCO loop. All of these features dramatically reduce the cost and size while improving the performance of the overall system. These features ensure that a TDMA handset manufacturer can produce phones that will succeed in this demanding market.

How the System Works

To understand how this chip set operates let's follow a signal at Channel 1 through the receive and transmit paths in Figure 1. To begin, a received signal on Channel 1 (870.03MHz) enters at the antenna.

The signal then moves through the 881 MHz bandpass filter, to be amplified by the SA601 low noise amplifier (LNA). The low noise figure of the SA601's LNA (1.6 dB) adds very little noise to the original signal. The signal is then down converted by the SA601's mixer to the first IF (83.16 MHz for this example). The first LO is phase locked by the SA7025 main loop at the receive frequency plus the IF frequency (870.03MHz + 83.16 MHz = 953.19 MHz). Continuing down the receiver chain, the signal passes through an image reject filter centered at 83.16 MHz before entering the SA637 digital IF circuit. The SA637's mixer down converts the incoming signal to the second IF of 600 kHz. The second LO is also phase locked by the SA7025's auxiliary synthesizer. The second LO in this case is the 1st IF Frequency minus the 2nd IF frequency (83.16 MHz – 600 kHz = 82.56 MHz). The signal is then amplified and passes to the DSP/baseband processor for demodulation and decoding.

Looking at the transmit side, a carrier is first generated for Channel 1 (825.03 MHz). This is accomplished by using the same receiver first LO signal from the SA7025 at 953.19 MHz and the SA900's on-chip mixer and synthesizer loop. The SA900's synthesizer loop is fixed at the receiver's second LO frequency plus the TX/RF offset of 45 MHz (83.16 MHz + 45 MHz = 128.16 MHz). When the synthesizer loop and the first LO signals are

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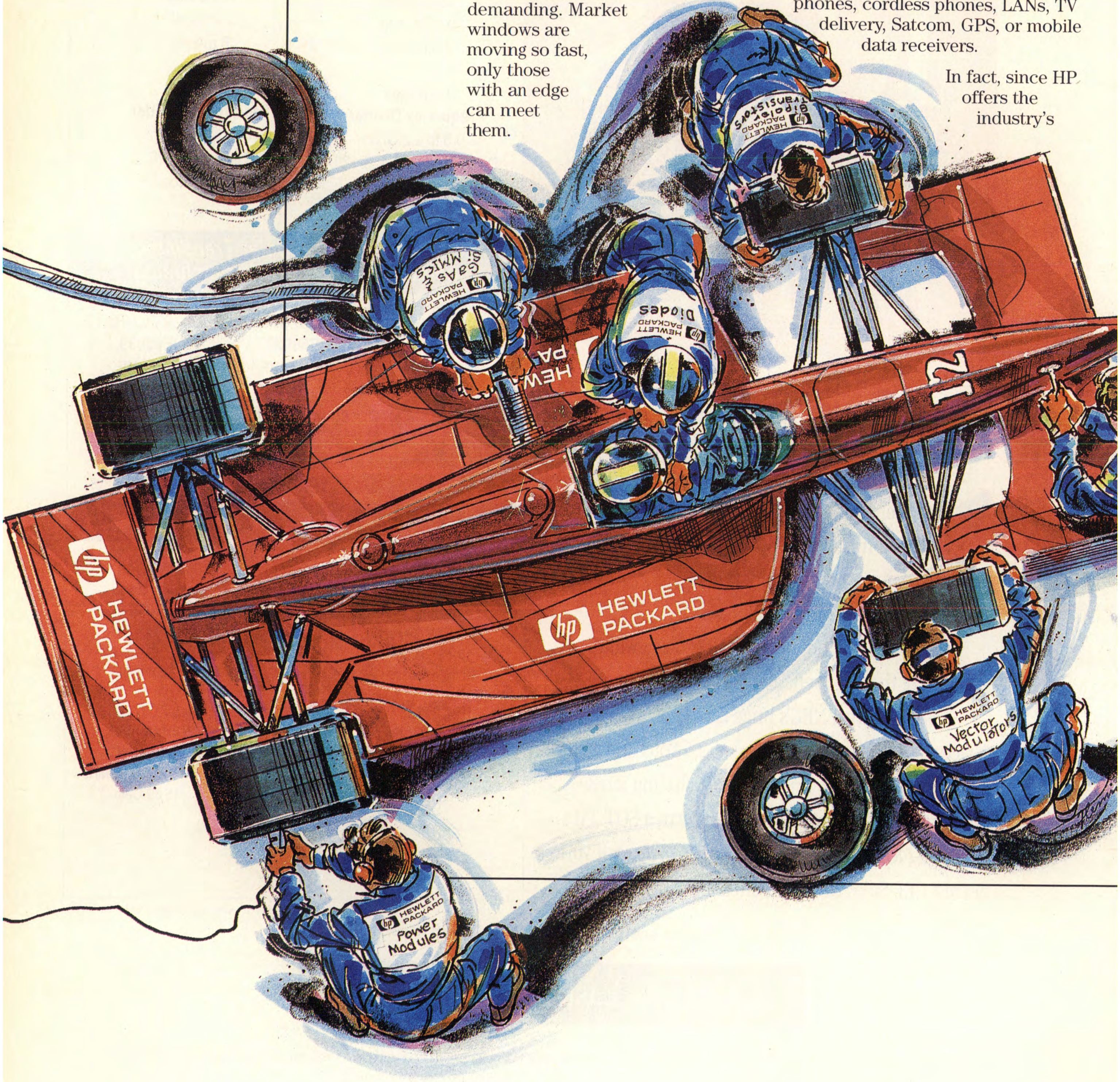

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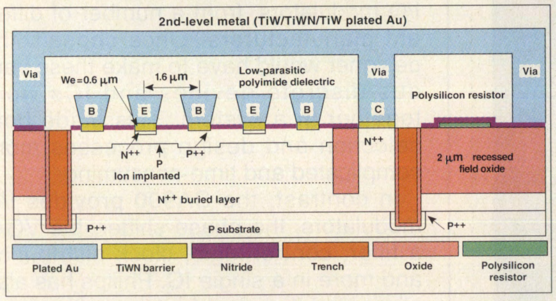

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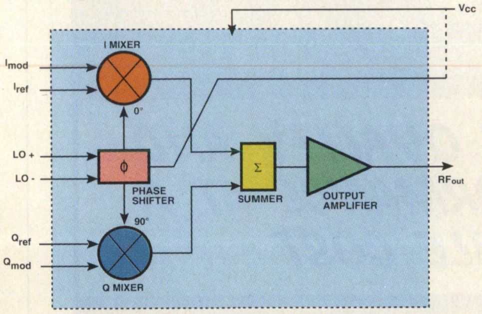

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mixed together on the SA900 the sum (1081.35 MHz) and difference (825.03 MHz) are generated. A low pass filtering function in the SA900 will pass the desired 825.03 MHz signal while rejecting the undesired sum frequency. The carrier is then phase shifted by 90° to create the quadrature for I and Q mixers. The I and Q differential data inputs are provided from the DSP. The I and Q inputs can be used to generate a variety of digital and analog modulation schemes. IS-54 requires $\pi/4$ DQPSK (digital) and FM (analog) modulation. Before leaving the SA900, the modulated signal is finally passed through a variable gain amplifier (VGA) which provides precise control of the output power level. Once off-chip the modulated signal is filtered and amplified to the desired power level before being transmitted out the antenna.

Integration and Connectivity

Although, certainly, this is not the only IS-54 solution, the Philips four-chip configuration described here is the most integrated and easy to use chip set available today. The SA900 is a good example of this; it incorporates many components that would otherwise be realized with a large number of discrete devices or single-function ICs.

Previously, a designer had to select these individual components, such as I/Q modulators, from a number of different manufacturers. Once chosen, the designer would have to make these various discrete devices and ICs work together in a system. This made both selection and design processes more complicated and time-consuming.

In contrast, the SA900 provides I/Q modulators, the phase shifter, the VGA, a filter, control logic, clock distribution and more in a single IC. Philips has also eliminated the need for two synthesizers by closely coupling the SA7025 and the SA900 so it is possible to use the main synthesizer to simultaneously generate receive and transmit signals. The integration and connectivity of the chip set promote significant cost reduction. If the functions contained in the SA900 were realized discretely, they would cost approximately $30.00. The SA900, however, sells for about half the price. In addition this integrated solution reduces the time to a final product by simplyfing the design effort. The result is a smaller, cost effective, low power phone that is ultimately more attractive to users.

The Future of NADC

Moving to a digital standard not only provides for increase in capacity, but offers the advantages of service integration. With the use of a digital modulation, other services such as data and FAX can also be handled more easily over this system.

The SA601

The SA601 (Figure 2), which translates the received RF signal to a first IF, is a RF LNA and mixer designed as a front end for high-performance low-power communication systems from 800 to 1200 MHz. The low-noise preamplifier has a 1.6 dB noise figure at 900 MHz with 11.5 dB gain and an IIP3 intercept of –3 dBm. Gain is stabilized by on-chip compensation to vary less than 0.2 dB over a –40 to +85°C range. The wide

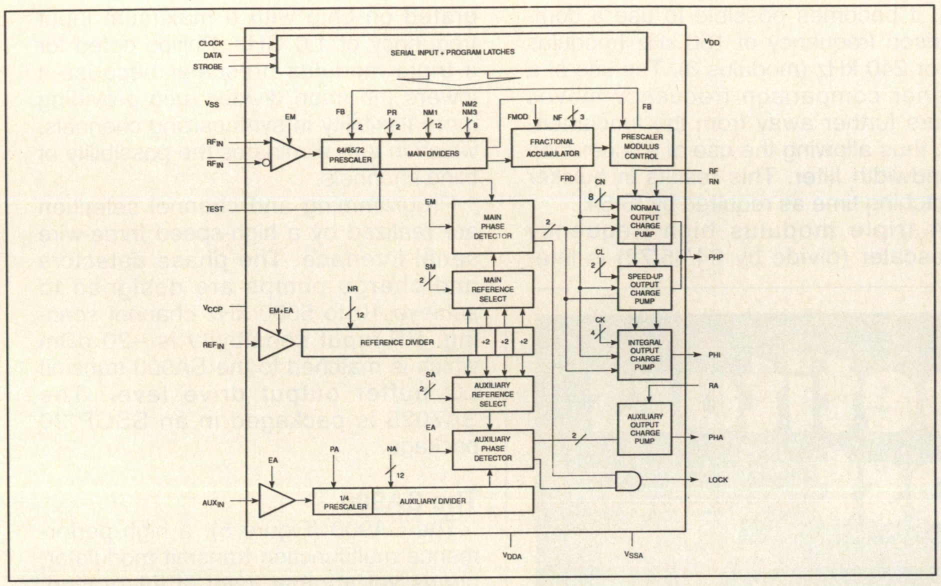

Figure 4. Block diagram of SA7025.

dynamic range mixer has 7 dB of power gain, a 10 dB noise figure, and an IIP3 of 0 dBm at 900 MHz.

The SA601's nominal current consumption from a single 3 V supply is 7.4 mA. Additionally, the mixer can be powered down to further reduce the current supply to 4.4 mA. This part addresses three main design concerns: low power requirements to extend talk time, size (it comes in an SSOP-20 configuration, the smallest 20-pin commercially available package), and performance.

The SA637

The SA637 (Figure 3) is a low-voltage high performance monolithic digital IF receiver with a high-speed received signal strength indicator (RSSI). It is composed of a mixer, oscillator with buffered output, two limiting intermediate frequency amplifiers, fast logarithmic RSSI, voltage regulator, RSSI output op amp and power down pin. It, too, comes in an SSOP-20.

This device is designed for portable digital communication applications and will function down to 2.7 V. The limiter amplifier has differential outputs with 2 MHz small signal bandwidth. The RSSI output op amp feedback pin is accessible, enabling the designer to level adjust the output or add filtering. This one chip provides everything needed to get to the limited second IF.

The SA7025

The next block in the transceiver is the SA7025 (Figure 4) low power, dual frequency fractional-N synthesizer. This IC

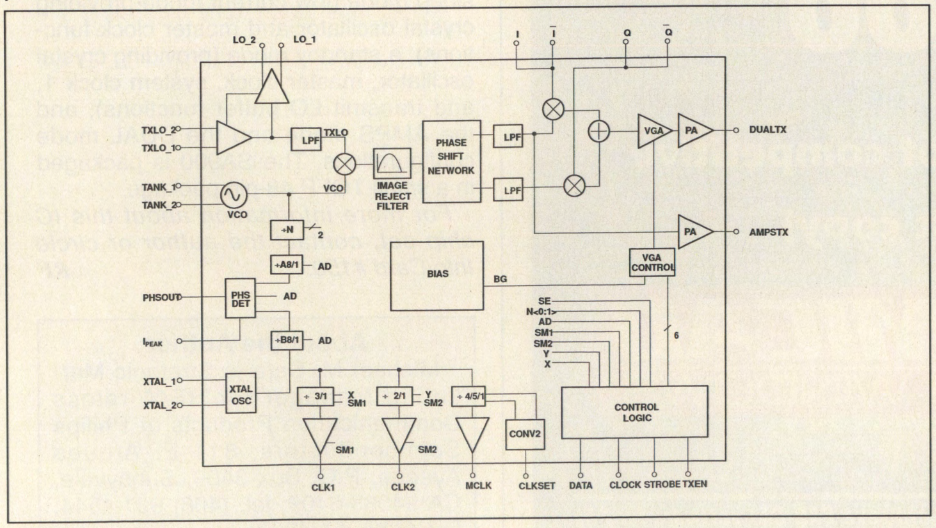

Figure 5. Block diagram of SA900.

is fabricated using the Phillips QUBiC BiCMOS technology and represents another first for Philips. The SA7025 features fractional-N with selectable modulo five or eight implemented in the main synthesizer. This allows the phase detector comparison frequency to be five or eight times the channel spacing. So if the channel spacing is 30 kHz which is what is used for AMPS and IS-54, it becomes possible to use a comparison frequency of 150 kHz (modulus 5) or 240 kHz (modulus 8). The use of a higher comparison frequency moves spurs further away from the fundamental, thus allowing the use of a wider loop bandwidth filter. This results in quicker switching time as required by IS-54.

A triple modulus high frequency prescaler (divide by 64/65/72) is integrated on chip with a maximum input frequency of 1.0 GHz. Philips opted for a triple modulus prescaler because it lowers the main divider ratio providing more flexibility in synthesizing channels, which in turn eliminates the possibility of blind channels.

Programming and channel selection are realized by a high-speed three-wire serial interface. The phase detectors and charge pumps are designed to achieve 10 to 5000 kHz channel spacing. RF input sensitivity is –20 dBm which is matched to the SA900 transmit LO buffer output drive level. The SA7025 is packaged in an SSOP-20 package.

The SA900

The SA900 (Figure 5), a high performance multifunction transmit modulator, brings yet another level of integration. Fabricated in QUBiC BiCMOS technology, it features both analog (AMPS) mode and complex I/Q dual mode (IS-54) functions, a PLL synthesizer with VCO, a crystal oscillator, buffer, programmable prescalers, and Gilbert cell multiplier phase detector with programmable charge pump output. The DUALTX output can be used in DUAL mode cellular phone applications with the AMPS and NADC modulation being applied to the I/Q baseband inputs. The DUALTX output also provides 6-bit power control with 40 dB of gain range in 0.63 dB steps. In addition, the crystal oscillator buffer feeds three programmable prescaler outputs to support system clock reference needs. Programming of the devices function is realized by a high-speed, three-wire serial interface. The SA900 can be programmed into a sleep mode (low current mode providing crystal oscillator and master clock functions), a standby mode (providing crystal oscillator, master clock, system clock 1, and transmit LO buffer functions), and the AMPS mode and the DUAL mode configurations. The SA900 is packaged in a small TQFP 48-pin package.

For more information about this IC chip set, contact the author or circle Info/Card #150. **RF**

About the Author
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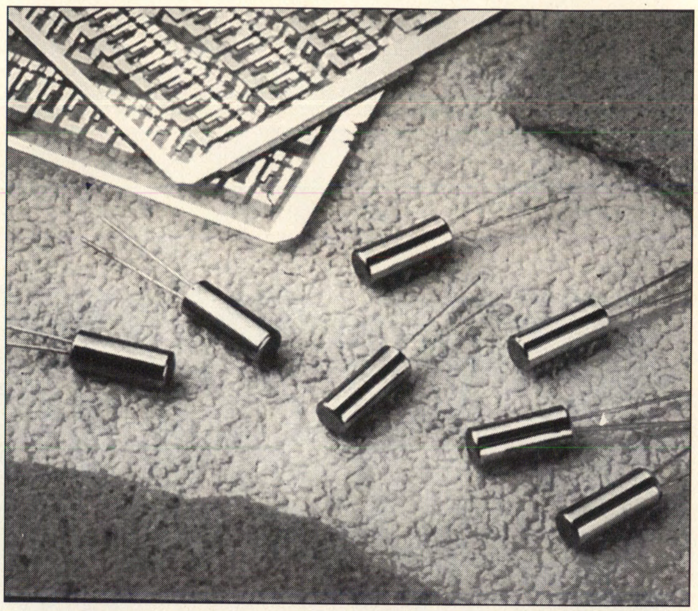
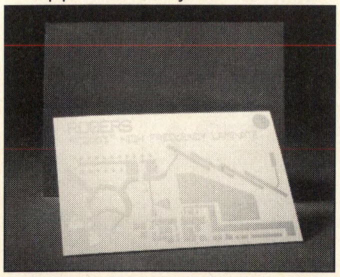
SaRonix, Inc.
INFO/CARD #232



Low-Price, PCB Material

Rogers Corporation introduces a major new product, RO3003™ high frequency circuit materials for commercial printed circuit boards. The RO3003 materials are the first of a new line of economical, high frequency circuit material products which offer a range of electrical properties, all improving performance at high frequencies over FR-4 type circuit boards. The material is introduced at approximately 25-30% less

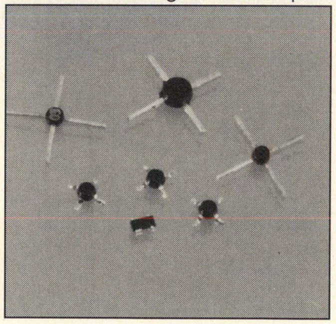


than the price of competitive PTFE fiberglass materials. The performance characteristics of Rogers RO3003 material include uniform dielectric constant, low loss, stable electrical performance over temperature, very good dimensional stability, and excellent plated through-hole reliability. RO3003 high frequency material is offered initially in the standard panel size of 18 x 24 inches, in thicknesses of 0.010", 0.020", and 0.030", and with 1/2 and 1 oz. electro-deposited copper.

Rogers Corp.
INFO/CARD #231

MMIC Amplifiers

Amplifonix has announced a new series of MMIC amplifiers with 3 dB rolloff points up to 2.2 GHz. Members of the AX0X86 series are matched 50 ohm gain blocks consisting of DC coupled

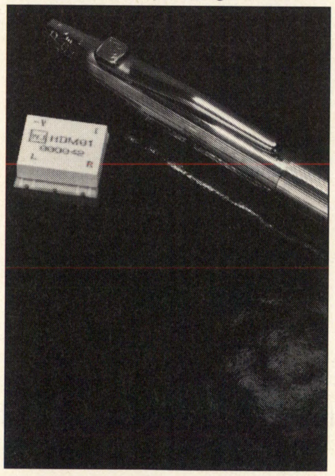


Darlington amplifiers. A few representative members of this series have the following specifications: The AX0186 typically has 17.5 dB gain and 3rd order two-tone intercept point of +15 dBm, both at 0.5 GHz. The amplifier's power consumption is typically 17 mA at +5 VDC. The AX0886 operates to 3 GHz, has 18.5 dB gain and 3rd order two-tone intercept point of +27 dBm, both at 1.0 GHz. The A0886 also has a typical noise figure of 3.3 dB at 1.0 GHz. Power consumption for this amplifier is 36 mA at 7.8 VDC. Amplifonix package styles, -11, -85, and -86 are available on tape and reel. Environmental screening is also available.

Amplifonix, Inc.
INFO/CARD #230

FET Mixer

Watkins-Johnson Company has introduced a high-dynamic-range FET mixer with applications at the cell-site level of cellular communications networks. The new model HDM1 features +40 dBm (typ.) third-order intercept point with a nominal +21 dBm LO drive, yielding an LO uti-

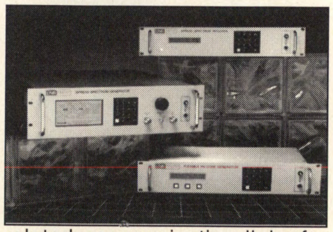


lization of 17 to 22 dB. The HDM1's typical conversion loss is 8.0 dB. The mixer is designed for LO and RF frequencies from 800 to 1000 MHz and IF frequencies from 10 to 200 MHz. Typical LO to RF isolation is 35 dB, and typical LO to IF isolation is 40 dB. The mixer is supplied in a low-cost, surface-mount package and is available on tape and reel for high-volume manufacturing.

Watkins-Johnson Co.
INFO/CARD #229

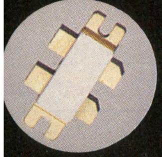
Spread Spectrum Test Equipment

LNR Communications has developed a series of flexible, spread spectrum transmit/receive test equipment. They can be configured in a variety of field deployed or simulated end-to-end wireless, cellular telephone and



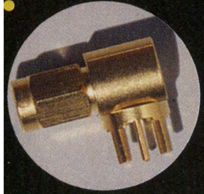
related communication links for wireless LAN and ISDN service diagnostics, CDMA equipment testing/evaluation, communications link testing, and propagation testing. The MCS-T spread spectrum generator operates in various frequency bands from 800 to 2500 MHz, with maximum BW of 100 MHz and power output from 0 dBm to –60 dBm. The unit has built-in PN code generation and can operate in direct sequence or frequency hopping modes. The MCS-R spread spectrum receiver consists of a synthesized downconverter, IF despreader/demodulator and µP-based control. The PNCG (pseudorandom noise code generator) has programmable tap weights, code rates , code lengths and offset. Both linear and Gold codes can be selected.

LNR Communications Inc.
INFO/CARD #228



Richardson Electronics is Your Global Partner in RF Technology

Offering solutions to customer problems for more than 40 years, Richardson Electronics, Ltd. has grown into one of the world's premier suppliers of RF devices.



This Month's Feature . . .

MWT
MICROWAVE TECHNOLOGY

Ultra-linear, Class A, Self Baised Power FET, 1 to 50 MHz

Slam-0111
- 25 watt Ultra Linear Operation
- Push-Pull device
- +55 dBm (third order intercept)
- 15 dB Power Gain
- 28 volt, Single Supply Operation

Slam-0122
- 50 watt Ultra Linear Operation
- Push-Pull device
- +58 dBm (Third order intercept)
- 14 dB Power Gain
- 40 volt, Single Supply Operation

Slam-0133
- 10 watt Ultra Linear Operation
- +52 dBm (Third order intercept)
- 50 ohm in, 50 ohm out, no Z-match required.
- 13.5 dB Power Gain
- 32 volt, Single Supply Operation

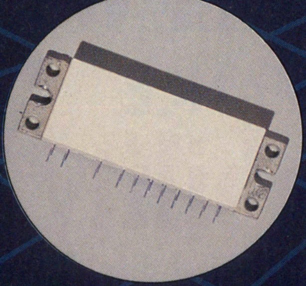
Slam Operation can be extended into VHF with External Impedance Matching

High Linearity Self-Baised GaAs FET Power Amplifier Modules For Digital Wireless Applications 100-2000 MHz

Model	IPS (dBm)	P-IdB (dBm)	Gain (dB)	Bias Vlmp
MPS-202201-71	+34	+22	9.5	5.0/100
MPS-202409-85	+36	+24	11	10.0/160
MPS-202708-85	+39	+27	10.5	12.0/300

*Packages shown are not to scale.

- Technical Expertise
- Experience
- Inventory
- Market Knowledge
- Supplier Literature



Richardson Electronics, Ltd. has combined its' worldwide marketing organization with MWT's quality group of products. Richardson has available MWT's line of Power FETs and GaAs FET Amplifiers. Call Richardson Electronics for state-of-the-art MWT devices.

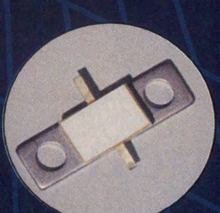
Our industry-leading RF suppliers . . .

MOTOROLA
SGS-THOMSON
Amphenol®
M/A-COM
EF JOHNSON
PHILIPS
RF PRODUCTS
AMERICAN MICROWAVE TECHNOLOGY
PINEAPPLE TECHNOLOGY
GORE

U.S.	(800) RF POWER
CANADA	(800) 348-5580
U.K.	(0522) 542631
FRANCE	(1) 34-26-4000
ITALY	(055) 420-10-30
SPAIN	(1) 528-37-00
GERMANY	(089) 80-02-13-1
JAPAN	(3) 3874-9933
SINGAPORE	(65) 298-4974

Committed to the RF Market—

Richardson Electronics, Ltd.
40W267 Keslinger Road
LaFox, Illinois 60147
(708) 208-2200
INFO/CARD 51



Latin America and other international inquiries, contact Corporate Headquarters at (708) 208-2200

Please see us at RFEW, Booths #829, 831.

Product Spotlight: Couplers, Attenuators, Terminations

High-Power Coupler

Western Microwave has developed a high power, dual directional coupler, model C-9301, that operates over the frequency range of 125 to 1500 MHz. Directivity is greater than 20 dB, nominal coupling is 50 dB, and coupling flatness is typically ±1.0 dB, and the unit handles 2000 W CW.

Western Microwave
INFO/CARD #227

Bench Test Components

A new line of high power components is available for use in laboratory and production test setups. Each power attenuator or power termination is designed with its own cooling fan.

Chronix International, Inc.
INFO/CARD #226

Programmable Attenuators

A series of miniature programmable attenuators, with a frequency range of DC-3 GHz, is now offered by Alan Industries. Four models in this SDA series are available in attenuation ranges of 0-15 dB, 0-31 dB, 0-63 dB and 0-70 dB. Height and width for all models is 1 x 1 inches and the length varies from 3.175 to 4.00", depending on attenuation. Average power handling is 1 W. Prices range from $550 to $850.

Alan Industries, Inc.
INFO/CARD #225

Dual Directional Couplers

Amplifier Research's full line of directional couplers, (covering 10 kHz to 1 GHz), has been joined by two new dual directional couplers. Model DC6180 carries up to 600 W continuous power (1000 W peak pulse) through a frequency range of 80 to 1000 MHz. Model DC6280 carries 1500 W continuous power over the same bandwidth. Both couplers have typical directivity of 25 dB and maximum insertion loss of 0.15 dB. The DC6180 sells for $900, the DC6280 for $1100.

Amplifier Research
INFO/CARD #224

Wireless Components

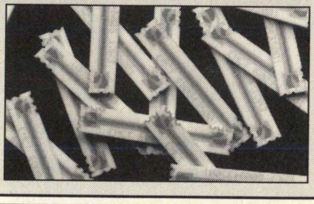
Lucas Weinschel now offers a complete line of programmable, fixed, and variable attenuators and terminations designed specifically for wireless communication and cellular applications. These new designs are optimized for performance over the DC to 3 GHz range, and are available in Type N and SMA connectors.

Lucas Weinschel
INFO/CARD #223

SMT Couplers

EMC Technology's thick-film hybrid 3 dB couplers are aimed at commercial applications. Operation is optimized for the cellular and GPS bands, with a maximum VSWR of 1.3:1 and minimum isolation of 20 dB. The coupler will handle in excess of 100 W CW. Options include integral terminations and other frequencies of operation.

EMC Technology, Inc.
INFO/CARD #222



TEST EQUIPMENT

Baseband Network Analyzer

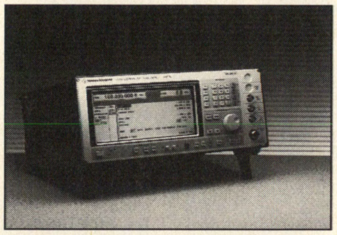
Model 102A analog network analyzer from AP Instruments has two channels for ratioed frequency response measurements. The analyzer displays magnitude, phase and group delay data with 110 dB dynamic range. It covers 0.01 Hz to 15 MHz with linear or logarithmic frequency sweeps. The model 102 A includes a source/receiver unit, a DSP board, cables, probes and software. The system price is $5500.
AP Instruments
INFO/CARD #221

VXI Noise Modules

Noise Com has introduced a new series of VXIbus test equipment in double slot C size modules. The VXI-7000 Series generates additive white Gaussian noise. The VXI-7000 Series has a message-based interface and covers frequency bands between 10 Hz and 40 GHz. Noise power can be controlled in 1 dB steps (0.1 dB optionally).
Noise Com
INFO/CARD #220

Signal Generator

The SMT Signal Generator from Rohde & Schwarz covers RF frequencies up to 3 GHz. AM, FM, ΦM and pulse modulation can be used with various internal



and external modulation sources. An additional LF generator can be fitted which, besides sinewave, squarewave and triangular signals, also supplies a noise signal. In addition to the modulation signals produced by the LF generator, the optional multifunction generator produces stereo multiplex and VOR/ILS modulation signals.
Rohde & Schwarz GmbH
INFO/CARD #219

SIGNAL SOURCES

Surface Mount Oscillators

Valpey-Fisher has developed a miniature surface mount package. The complete package is 0.55" long, 0.35" wide and 0.185" high. It is hermetically seam welded with a nickel plated kovar lid and has "J" lead terminations that match the common 0.200" and 0.300" footprint of common plastic oscillators. The hybrid oscillators that use this package are available over the frequency range of 2 to 300 MHz and with TTL, HCMOS, ACMOS and ECL Logic outputs. The price ranges from $10 to $33.
Valpey-Fisher Corp.
INFO/CARD #218

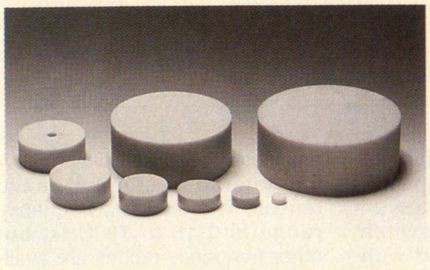
OCXO

Micro Crystal announces production of an oven operated crystal oscillator in a 14-pin dual-in-line package. The oscillator is 0.300" tall and weighs 5 grams. The OCXO series is available in versions operating from 0.01 and 24 MHz. Warm-up time is 20 seconds, and frequency stability is ±0.2 ppm over the standard temperature range of –20 to +70° C. The OCXO in a 10 MHz, standard temperature range version sells for $185.00 in quantities of 25. Lead time is four to eight weeks for standard frequencies.
Micro Crystal
A Div. of SMH
INFO/CARD #217

DISCRETE COMPONENTS

Molded Inductors

A series of molded polypropylene inductors from J.W. Miller are intended for equipment oper-



Dielectric Resonators-400 MHz to 32 GHz

A variety of materials and characteristics allow Trans-Tech to satisfy a particular design need. Extremely

Standard materials	Nominal Dielectric Constant	Temperature Coefficient Range	Minimum Q	Recommended Frequencies (GHz)
8500	36.0	–3 to +6 ppm/°C	10.000 @ 4.5 GHz	1.4 to 13.5
8600	80.0	–6 to +9 ppm/°C	3.000 @ 3.0 GHz	0.7 to 3.5
8700	29.1	–4 to +4 ppm/°C	10.000 @ 10.0 GHz	5.6 to 32.1
8800	37.5	0 to +4 ppm/°C	6.000 @ 4.5 GHz	0.8 to 5.2
8300	36.0	0 ppm/°C	27.000 @ 850 GHz	0.8 to 1.0

High Q D8300 material has been developed especially for narrowband Cellular Base Station filtering. In DRO's for digital DBS lower phase noise can be achieved by using High Q dielectric resonators. Materials are available with high E' for smaller size and in a wide range of temperature coefficients to compensate for temperature drift.

INFO/CARD 98

Miniature Coaxial Line Elements

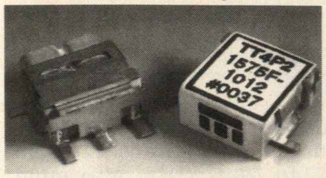
The miniature profile (MP) and subminiature profile (SM) series ceramic coaxial elements are appropriate where circuit miniaturization is of utmost importance, such as in cellular telephones, PCS and other wireless products. They cover a frequency range of use from 650 Mhz to 5.0 GHz.

As a miniature shielded resonator, these devices feature rugged construction to eliminate microphonics and offer excellent temperature coefficient of resonant frequency. Two materials are available to provide the designer with high unloaded Q and small size.

The resonator is metallized with low loss silver plating and may be ordered in quarter or half wavelength with or without tabs for attaching the center conductor to the external circuit.

INFO/CARD 99

4mm SMT Ceramic Bandpass Filters



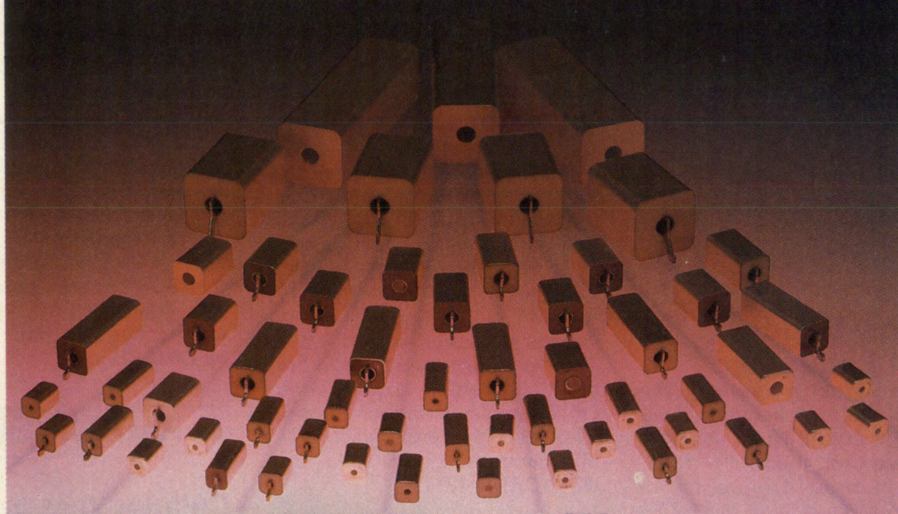
A line of high quality factor (Q) ceramic filters is available for cellular, ISM, Spread Spectrum, and GPS applications. The filters are 2 and 3 pole, flat surface mount design with a maximum case height of 4.5mm. They offer low insertion loss and good frequency stability.

Center Frequency	Bandwidth f_0+/-MHz	Insertion Loss (dB) in BW	Ripple (dB Max.) in BW	V.S.W.R. in BW Max.	Attenuation (@ f_0+/-MHz) Min.
881.5	13.0	3.0	1.0	2:1	12(f_0+/- 32.5)
915.0	13.0	3.0	1.0	2:1	12(f_0+/- 32.5)
1227.0	5.0	1.2	0.5	2:1	20(f_0 - 140.0) 17(f_0 + 140.0)
1575.0	5.0	1.2	0.5	2:1	20(f_0 - 140.0) 17(f_0 + 140.0)

INFO/CARD 55

"ASK ABOUT OUR NEW CERAMIC BANDPASS FILTERS"

Need a Rugged Tank Circuit?



300 MHz – 4.8 GHz

Solid, durable construction makes Trans-Tech's Ceramic Coaxial Transmission Line Elements a rugged alternative to classical parallel LC circuits. Performance benefits include: higher circuit Q, greater temperature stability and circuit miniaturization, together with reduced microphonics, fewer environmental effects on frequency and excellent solderability. Typical applications involve wireless communications, nationwide pagers, and Global Positioning Satellite (GPS) applications. Call for more information...today!

Please see us at RFEW, Booth #429.

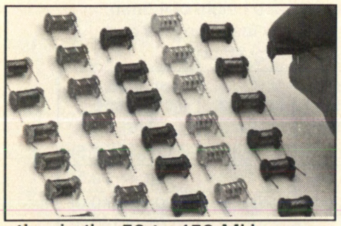
Alpha

Trans-Tech

Trans-Tech, Inc., a subsidiary of Alpha Industries, Inc.
5520 Adamstown Rd. ▪ Adamstown, MD 21710
Tel. (301) 695-9400 ▪ FAX: (301) 695-7065

Trans-Tech...The Ceramic Solution

INFO/CARD 100



ating in the 50 to 450 MHz range. Series 75F inductors are available from 0.0264 uH through 0.660 uH. Production quantities can be delivered from stock. Application assistance and custom wound inductors can be furnished on request.
J.W. Miller
INFO/CARD #216

Surface Mount Capacitors

Cornell Dubilier announces Type MC surface mount capacitors for instruments and RF. The capacitors have self resonant frequencies typically above 1 GHz for popular RF capacitance values, and have a Q above 2000. Case sizes 0805, 1210, 1812 and 2220 are available. Capacitance is available in tight tolerance, exact values from 0.5 pF to 2000 pF. Pricing is from \$0.31 in 1000 piece qty.
Cornell Dubilier
INFO/CARD #215

SIGNAL PROCESSING COMPONENTS

Narrow Band X-tall Filters

Filtronetics announces the availability of high frequency, narrow band crystal filters. A representative unit, model FN-1801, has a center frequency of 148.275 MHz, a 3 dB BW of 50 kHz, and a 60 dB BW of 300 kHz. The size is 1.5" x 0.5" x 0.4" in flatpack style and 1" x 0.5" x 0.43" in PC mount style. The filters are available up to 200 MHz.
Filtronetics, Inc.
INFO/CARD #214

Power Dividers

Inmet Corp's Series 6005 power dividers feature 2.92 mm stainless steel connectors, offering non-destructive compatibility with SMA, K and 3.5 mm series. Rated at 1 W input power, all models have exceptional amplitude and phase tracking characteristics: ±0.6 dB and ±4° from DC to 26.5 GHz. Maximum VSWR is 1.50:1 over the full DC to 26.5 GHz. The T-shaped units weigh 60 grams.
Inmet Corporation
INFO/CARD #213

Quadrature Hybrids

The SQ-series of unleaded hybrids cover 10% bandwidths centered from 10.7 MHz to 1880 MHz. Maximum insertion loss is 0.4 dB, and amplitude unbalance is 0.5 dB (typ.). Phase unbalance is 3° over the full band and 2° maximum at each center frequency. The SLQ-series of leaded quads are available in various 10% and octave BW from 10.7 to 1880 MHz, offering 0.7 dB typical insertion loss. Typical amplitude and phase imbalances are 0.6 dB and 3°, respectively. For both series, isolation between quadrature outputs is 15 dB and pricing begins at \$17.95 in quantities of 1 to 9.
Synergy Microwave Corp.
INFO/CARD #212

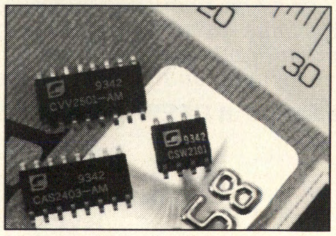
SEMI-CONDUCTORS

Varactor Diodes

MSI Electronics' DO-220B series incorporates eight types of exponential varactor with capacitances from 6.8 to 100 pF at a nominal 2.5 V bias. Tuning linearity is better than 5% for the DO-220B series and better than 1% for the DO-220C series. Tuning voltage does not exceed 4.5 V. The diodes are packaged in hermetically sealed, axial leaded, D0-7 glass packages. Price is \$1.68 each in 10k qty.
MSI Electronics, Inc.
INFO/CARD #211

LAN Transceiver Chip Set

Celeritek's CCS2900 is a three-chip set designed for wireless LANs operating in the 2.4 GHz ISM band. The set consists



of an integrated converter (CCV2501), a power amplifier-T/R switch (CAS2403), and an antenna diversity switch (CSW2101). When used with external filters and a voltage-controlled resonator, this chip set forms a high performance RF transceiver that is power efficient, fully compatible with the dimensional requirements of the PCMCIA standard, and compliant with the specifications of the IEEE 802.11 committee for WLANs.
Celeritek
INFO/CARD #210

Wideband Buffers

Comlinear introduces two new low-cost buffers, the CLC109 and CLC111. These buffers can operate from a single 3 V power supply and use a patented closed-loop design. The CLC109 features a wide BW of 270 MHz, and ±0.1 dB gain flatness to 30 MHz. The CLC111 provides a very wide bandwidth of 800 MHz, using only 10.5 mA with a ±5 V supply. The CLC111's 2nd and 3rd harmonics are at –62 dBc at 20 MHz. 1000 piece pricing for the CLC109 is \$1.49, and \$2.75 for the CLC111.
Comlinear Corp.
INFO/CARD #209

Varactors

The SMV 1204 series of hyperabrupt varactors are designed to be used in portable applications. The series features linear octave tuning from 0 to 6 V, very low series resistance, surface mountable SOT-23 packages and availability from stock.
Alpha Industries, Inc.
INFO/CARD #208

AMPLIFIERS

Cellular Test Amp

Model AR88168-10 from Power Systems Technology is a wide band class A amplifier covering 800 to 1600 MHz. Power output at 1 dB compression is 10 W, with 40 dB gain. The amplifier has a built-in power supply and is housed in a 5.25 x 19 x 22 inch, rack- or bench-mountable cabinet.
Power Systems Technology, Inc.
INFO/CARD #207

Equalization Amp

The CS-801 is a ruggedized amplifier with an internal equalizer to flatten frequency versus amplitude response, thus improving overall system dynamic ranges. The standard frequency range is 0.15 to 18 GHz, but other frequency ranges are available.
Communication Solutions, Inc.
INFO/CARD #206

CATV Amplifiers

Motorola has introduced three new devices for CATV applications. Designed for trunk and line extender amplifiers, the MHW5185B and MHW6185B power doublers have improved composite triple beat and third order distortion characteristics compared to the Motorola MHW5185 and MHW6185 devices. The MHW6185-6 power doubler has a frequency range of 40 to 600 MHz. Low volume pricing is \$45.00 for the MHW5185B, \$50.00 for the MHW6185B, and \$54.00 for the MHW6185-6.
Motorola Semiconductor
INFO/CARD #205

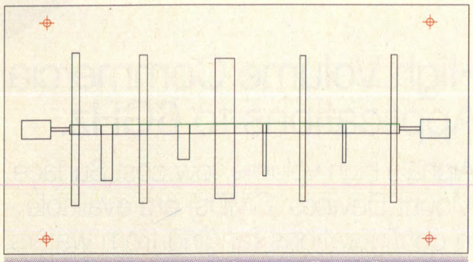
RF Power Modules

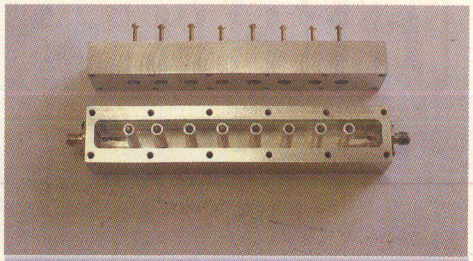
Hitachi has introduced four MOSFET-based RF power modules that simplify and shrink many cellular phone designs. The PF0045 and PF0045A provide 1.2 W of class C power at 58% efficiency, using 6 and 4.5 V supplies, respectively. The PF0210 and PF0231 are meant for digital cellular applications, operating in either class A or class B modes. The PF0210 produces 6.0 W with a 12 V supply, while the PF0231 produces 1.2 W from a 6 V supply. In quantities of 10,000, the PF0045 costs \$11.85; the PF0045A, \$12.65; the PF0210, \$12.30; and the PF0231, \$15.65.
Hitachi America Semiconductor & IC Div.
INFO/CARD #204

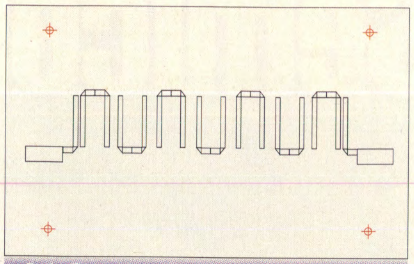
High Power Module

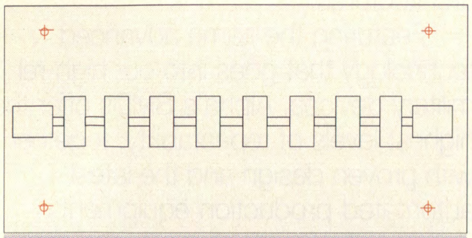
The FPS3N from Directed Energy Inc., (DEI), is a high power, high frequency switch for class D and class E RF operation. The FPS3N is used with a DEI MOSFET to produce high power RF up to 50 MHz at one-quarter the cost of conventional technology. A 16-page application note on the design of a 1 kW, 13.56 MHz RF generator using the FPS3N is available from DEI.
Directed Energy, Inc.
INFO/CARD #203

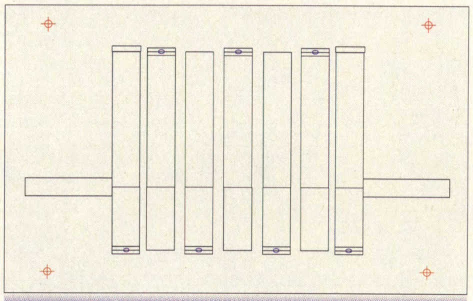
WHAT DO THESE FILTERS HAVE IN COMMON?

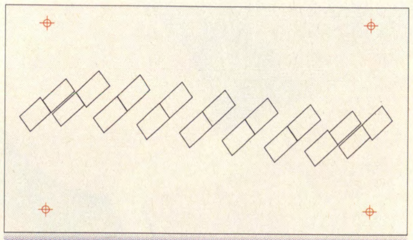

5.6 GHz Elliptic Bandpass on Teflon Board

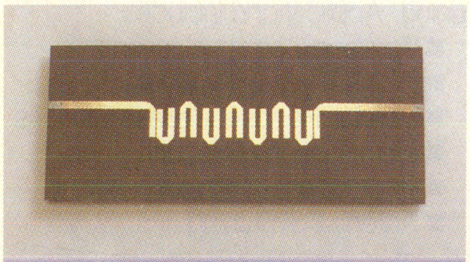

1.27 GHz Machined Combline Bandpass

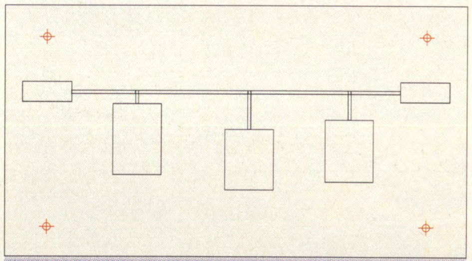

2.2 GHz Hairpin Bandpass on Teflon

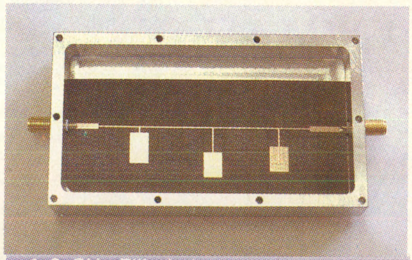

6.4 GHz High-Order Stepped-Z Lowpass


10 GHz Wideband Interdigital BP


5.6 GHz Edge-Coupled BP on Teflon


5.6 GHz Hairpin Bandpass on Teflon


1.2 GHz Elliptic Lowpass on G-10/FR-4


1.2 GHz Elliptic Lowpass (Mounted)

THEY WERE DESIGNED WITH THE NEW =M/FILTER=

COMPLETE SET OF DISTRIBUTED STRUCTURES

- Lowpass, bandpass, highpass & bandstop
- Microstrip, stripline, coax & slabline (machined)
- Edge coupled, end coupled, direct coupled
- Hairpin, combline, interdigital, elliptic, stepped-Z

START TO ART

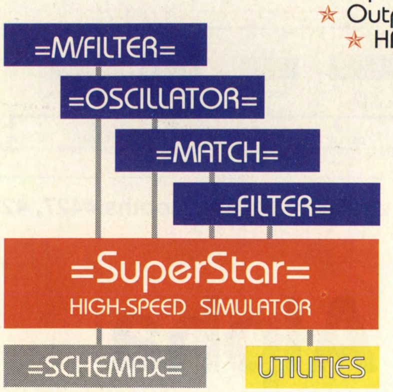
- Complete design including synthesis & simulation
- Output layout to plotters & laser printers
- HPG and DXF files ready for board suppliers

STATE-OF-THE-ART ALGORITHMS

- Automatic end, bend, tee and cross absorption
- Corrects dispersion & differential phase velocity
- Accurate design bandwidth
- N-coupled line models

start to art

Design began at 11AM on four microstrip filters and HPG files were ready for board suppliers by 1 PM. Using T-Tech's Quick Circuit milling platform, boards were ready for test by 5PM. =M/FILTER= files were tested by several board suppliers to insure compatibility.



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INFO/CARD 57

Please see us at RFEW, Booth #522.

RF expo WEST

March 22-24, 1994

San Jose Convention Center

San Jose, California

Don't Miss the 10th Annual RF Expo West!

Special Pre-Show Program!

- Show Events Schedule
- Exhibitor List and Exhibit Booth Map
- "Show-in-Print" Exhibitor Highlights

Schedule of Events

Monday, March 21, 1994

7:00 a.m.-6:00 p.m.
Registration Open

8:00 a.m.-5:00 p.m.
Special Courses

Tuesday, March 22, 1994

7:00 a.m.-6:00 p.m.
Registration Open

10:00a.m.-6:00 p.m.
Exhibit Hall Open

8:00 a.m.-5:00 p.m.
Special Course

8:30 -11:30 a.m. Morning Sessions

Session A-l: **RF Data Communications I**

- FQPSK, A Modulation that Outperforms Pi/4 DQPSK in Both Radiation Effects and Battery Power Dissipation While Maintaining Equal Capacity
- Theory and Development of a Digital Amplitude Modulator
- A I-Q Demodulator IC for Compressed Video Applications

Session A-2: **Power Amplifiers I**

- Low Cost Antenna Interface RFIC for Wireless Applications
- HF and VHF Linear Power Amplifiers Using SSTS and SLAMs
- Comparative Study of Four Broadband Microwave Amplifier Concepts

Session A-3: **Filter Design**

- Dielectric Filter Design
- Microstrip Techniques and Filter Design

11:30 a.m.-1:30 p.m.
Deli Luncheon served in Exhibit Hall

1:30-4:30 p.m. Afternoon Sessions

Session B-l: **Oscillators**

- SAW Resonator Oscillator Design Utilizing Linear RF Simulation
- Injection Lock
- Oscillator Design for Lowest Phase Noise

Ssesion B-2 **Product Design and Manufacturing**

- Improving Product Design/Development by Identifying Key Customer Values and Product Features
- High Frequency High Bandwidth IF Crystal Filter Designed for Manufacturing

Session B-3: **RF Materials**

- A High Power RF Package Using Aluminum Nitride Ceramic
- Microwave Based Measurements of Layered Homogeneous Dielectric Medium
- Conducting Solutions/Liquids as a New Transmission Medium for Microwaves

5:00-6:00 p.m.
Cocktail Reception

Schedule of Events

Wednesday, March 23, 1994

7:00 a.m.-6:00 p.m. — Registration Open

10:00 a.m.-6:00 p.m. — Exhibit Hall Open

8:00 a.m.-5:00 p.m. — Special Course

8:30 -11:30 a.m. — Morning Sessions

Session C-1: **Data Communications II**
- IF Amplifiers and Quadrature Demodulators for Digital Communication Receivers
- An FSK Modulation Data Receiver for 900 MHZ Using a Low Cost Silicon Monolithic IC Chip Set
- A Low Power Spread Spectrum CMOS RFIC Operates at a Center Frequency of 2.45 GHz for Use in Radio Identification Applications

Session C-2: **RF Power II**
- Linearisation Techniques for RF Amplifiers
- Some Improvements on the Feedforward Technique
- Amplitude Modulation in Class E Power Amplifiers

Session C-3: **RF Components**
- RF Circuit Components: Measurements, De-embedding and Equivalent Circuits
- Numerical Simulation of Silicon Hyperabrupt Diodes for VCO and Filter Applications

1:30-4:30 p.m. — Afternoon Sessions

Session D-1: **Wireless Communications**
- The Design of UHF and VHF Loop Antennas
- Techniques for Open Loop Modulation of a Wideband VCO for DECT
- A Covert Video Communications System

Session D-2: **Synthesizers**
- Frequency Synthesizer Technology in the Nineties
- A Synthesizer Design Program With Detailed Noise Analysis
- NCO - The Next Generation Oscillators

Session D-3: **Communications Systems**
- LINK 16: Tactical Advantage in the 21st Century
- A Simple Technique for Assessing HF Automatic Link Establishment Radio Interoperability
- The Art of CW Rejection in ESM Receivers

5:00-6:00 p.m. — Cocktail Reception

6:00-7:30 p.m. — Ham Radio Reception, San Jose Hilton and Towers

Thursday, March 24, 1994

8:00 a.m.-1:00 p.m. — Registration Open

9:00 a.m.-1:00 p.m. — Exhibit Hall Open

8:00 a.m.-4:00 p.m. — Special Course

8:30-11:30 a.m. — Morning Sessions

Sesson E-1: **Data Communications III**
- Multi-Mode Radio Transceiver Design
- Design an Infrared Data Link Using an Integrated FSK Transceiver
- Data Communications by Means of Reflective Transmission

Session E-2: **Circuit Design Methods**
- Ground Current Control in RF and High Speed Digital Circuits
- Design Microstrip Components With a Dielectric Cover Without Buying Additional Software
- Crosstalk Between Coupled Transmission Lines, and Circuit Theory Approach Versus Field Theory Approach in Shielding Evaluation

Session E-3: **Integrated Circuit Solutions**
- Design of an Integrated Chipset for Digital Cellular Communications
- RF/IF Processes and Circuits for Wireless Communications
- Digital Receivers and DDS for Base Stations

RF expo WEST

March 22-24, 1994
San Jose Convention Center
San Jose, California

Show-in-Print

STETCO, Inc.
STETCO, Inc. manufactures a high quality line of surface mount coils designed for use in a wide variety of environmental applications. The wire which comprises the coil is welded to the terminals and will not unravel during manufacturing soldering processes. The terminations are available in gold, nickel and 90/10 tin/lead to insure extended shelf life before the soldering process. These coils are available in the standard 1008 package and a low profile 1008 package. A new 0805 series is also available with an inductance range of 2.2 nH to 680 nH. All coils can be tested at the customer's application frequency and are available in bulk, waffle and 8 mm tape and reel packaging.

JFW Industries
JFW is celebrating 15 years as a leader in the design and manufacture of RF components and custom sub-assemblies. New products include custom thick film resistors, attenuators, terminations, high power variable attenuators, phase constant programmable attenuators, weather-proofed power dividers, single pole/multithrow switches and custom RF switching matrices.

Pole Zero Corp.
Digitally tuned filters, once born from the need to provide selectivity to frequency agile and scanning radios have found their way into general applications. Consider: Pole Zero's Mini and Maxi Poles, Power Poles and Preselectors. Benefits include: low power consumption, high selectivity, low insertion loss, The ability to tune a very narrow pass band continuously over a frequency range(from 1.5 MHz to 1 GHz) in microseconds, makes these miniaturize modularly designed RF Filters and Preselectors ideal for a wide variety of uses. The affordable solution.

E.F. Johnson
E.F. Johnson Components manufactures a full range of subminiature RF connectors with SMA, SMB and SMC interfaces. All E.F. Johnson connectors are designed to meet the electrical and mechanical specs of MIL-C-39012. In addition, E.F. Johnson manufactures a complete line of electronic components and hardware items. Whether for standard catalog items, modified existing parts or fully custom items, E.F. Johnson offers you the advantage and flexibility you require. Outstanding quality at the right price.

Wayne Kerr/Farnell
Wayne Kerr/Farnell has released the EASY 1 Emissions Assessment System for precompliance EMC testing. The EASY 1 is PC based and consists of a Wayne Kerr SSA1000A 9 kHz-1 GHz Spectrum Analyzer, Windows 3.1 compatible software, a GPIB card for the PC, a near field probe kit, a Line Impedance Stabilization Network (LISN) 6/16 AMP and a specially designed broadband antenna, plus cables and detailed documentation. The EASY 1 is ideal for companies who want to test for conducted and radiated emission of their products during the development and production stages to ensure EMC compliance.

Tecdia, Inc.
Tecdia capacitors will satisfy a wide variety of your microwave capacitor needs. These chip caps are designed and manufactured specifically for both thin and thick film hybrid integrated circuits. The safety margin around the electrode structure (A & B Types) helps to prevent shorts after epoxy attachment and makes them ideal for high component density applications. Tecdia C-Type chip caps are made with platinum metallization to ease soldering with materials such as Sn60, Sn62, etc.

Sciteq Electronics, Inc.
Sciteq's mission is to develop, produce, and market advanced-technology frequency synthesizers and other RF subsystems. Quality ranges from military (easiest) to commercial (tough because failures are unacceptable). Specialties include broadband DDSs, digital chip generators, the Arithmetically Locked Loop (a fractional-n derivative), and combination architectures. Standard products are tailored for PCS/wireless, communication, imaging radars, VSAT, satcom earth stations, and research projects. Sciteq offers enabling solutions to aggressive system development.

Giga-tronics Inc.
Giga-tronics Incorporated will demonstrate RF signal generators and power meters in booth 146/148. The Giga-tronics 6060 Series Synthesized RF Signal Generators provide accurate and reliable operation from 10 kHz to 2 GHz, at prices that fit almost ant budget. The Giga-tronics 6080A and 6082A Synthesized Signal Generators provide the highest performance available from 10 kHz to 2 GHz. The Giga-tronics 8540 Series Universal Power Meters provide fast and accurate CW and peak power measurements from single meter.

Bal Seal Engineering Co.
Bal Seal Engineering Company Inc. manufactures canted-coil springs for EMI shielding from very small diameters to long lengths. Each coil deflects independently, maintaining a nearly constant force. Metal segments cannot break off and damage internal circuits. Bal Seal supplies springs in beryllium-copper and other materials. Nickel, tin, silver and gold platings improve compatibility or conductivity. Specify light, medium, and heavy force in standard coil height, from 0.015 to 0.450 inch.

Hewlett-Packard Co.
Hewlett-Packard will be showing RF components and communication test instrumentation, plus electronic design automation(EDA) software tools for high-frequency analog circuit and system design. RF frequency computer aided engineering(CAE) systems will also be demonstrated. See H-P in booth 710.

California Eastern Laboratories
New from California Eastern Laboratories is the NEC Wireless Sampler. Designed to help speed up wireless circuit design, this kit puts over 100 NEC parts right at the design engineer's fingertips. Data sheets, application notes, and S-parameters on diskette are included. CEL will also be introducing NEC's new UPA800T. Developed for pager and other wireless applications to 2.5 GHz, this unique NPN transistor combines a pair of 10 GHz f_T NE680 die in an ultraminiature (1.25 mm x 2 mm) surface mount package. Booth 818.

CAD Design Services
CAD Design Services is a service bureau and software developer, expert in R/F , microwave, power supply, flex and digital PC board design as well as E/M packaging developed on AutoCAD databases. As an AutoCAD third-party developer we publish programs that, when used with AutoCAD, provide reliable production system — from AuotCAD drawing to Gerber Film plot. This powerful, easy to use software generates parts lists and net lists in varied formats. It can optionally work in the sane AutoCAD drawing as the PCB database for automatic forward and back annotation. Information changed in the parts list, schematic or PCB is automatically updated in the other two. Simple dialog box controls, with rapid library access, makes learning this software intuitive. For use with AutoCAD Release 12 or above.

Herotek
Herotek features RF and microwave components and subsystems from 0.01 to 40 GHz. The products offered include: detectors, limiter/amplifier/filter detectors, comb generators, multipliers, GaAs FET amplifiers (low noise and power), limiters, switches, harmonic mixers, down-converters, integrated subsystems, power amplifiers, threshold detectors and frequency doublers — for commercial cellular radios, PCS, LAN, DCN, etc.

LAP-TECH
LAP-TECH manufactures high precision custom quartz crystals and hermetically sealed TTL or CMOS clock oscillators. The glass and cold weld sealed crystals are particularly suitable for military and high reliability industrial applications. The range of resistance weld enclosures includes conventional leaded types as well as surface mount and special subminiature styles. The in-house quality meets NATO AQAP-4 / MIL-Q-9858 standards. ISO 9002 certification is pending.

Motorola
Motorola is known and respected worldwide as a leading semiconductor supplier to manufacturers of communications products, including switching, transmission, wireless and customer premise equipment. With its passion for quality and service, depth of immersion in key enabling technologies, and the broadest portfolio of products in the semiconductor industry, Motorola is dedicated and equipped to anticipate and meet your communication needs.

Eagleware
Eagleware is announcing the new SYSTEM 32 family of integrated HF synthesis and simulation software for IBM PCs. This family supports DOS and 32-bit Microsoft Windows and Windows NT operating systems with totally interchangeable files. The 32-bit versions are faster than 16-bit Windows product, break memory barriers, support multitasking and support multiple instance. Engineering departments may operate in a mix of these operating environments and still share user circuit and data files. All Eagleware synthesis and simulation programs are available as SYSTEM 32 products.

International Crystal Manufacturing Company
International Crystal Manufacturing Company (ICM) has been serving the communication industry for 43 years. ICM specializes in custom crystals from as low as 70 kHz to as high as 200 MHz. ICM will custom engineer to your specifications. ICM can also supply special motional parameters as well as many different metals and holders. Rigid standards and lifetime warranty insure quality and satisfaction. ICM also manufactures a wide range of custom oscillators, and markets products for the communications industry, including pagers, chargers, portable and mobile radios. All items come with a manufacturers warranty and ICM operates a full service repair department.

EMC Technology
EMC Technology, Inc. is a leading provider of Microwave components including: terminations, attenuators, programmable attenuators, temperature compensating attenuators, and hybrid couplers.

Sawtek Inc.
At RF Expo West, Sawtek will display SAW products that operate at frequencies from 10 MHz to 3 GHz. These include bandpass filters, delay lines, low-loss filters, oscillators, pulse expanders and compressors, resonator products and SAW-based subsystems. These products are designed for both low-volume and high-volume programs in communications, cellular telephony, modems, wireless data transmission, radar, electronic warfare, cable television, security systems, and other signal processing applications. In addition to the product display, Sawtek will distribute its 1994 Product Catalog which features the newest in SAW product technology. The new catalog, designed as a practical guide to SAW devices and their applications, will be available to all those who stop by Booth 930.

T-TECH
Quick Circuit is a milling, drilling and contour routing system for making prototype single or double-sided circuit boards. The system removes copper by milling instead of chemical etching. Quick Circuit can take files (HPGL, Gerber & Excellon/NC drill) from any CAD package. The system allows for a minimum engraving width of .005". Quick Circuit features an adjustable feed rate for working with a variety of materials.

TRAK Microwave
TRAK will be introducing its newest product line of signal processing components. These include mixers, couplers, quadrature hybrids, power splitters, PIN diode switches, phase shifters, and I/Q networks such as modulators, demodulators, phase comparators, image reject mixers, and discriminators. Another new product on display will be the Model 8860 Primary Reference Clock which provides cesium accuracy at much lower cost. Other featured products will include phase locked and crystal controlled oscillators, frequency multipliers, synthesizers, circulators, and isolators.

RF Micro Devices
RF Micro Devices is emerging as a leading supplier of low cost integrated circuits for wireless applications extending to 2.5 GHz. Our components include LNA/mixers, IF amplifiers, linear power amplifiers, quadrature modulators/demodulators and attenuators. Our use of gallium arsenide, Heterojunction Bipolar Transistor and silicon technologies enables us to provide the customer with OPTIMUM TECHNOLOGY MATCHING™.

Raltron Electronics
Raltron Electronics Corp.(Miami FL) is a broad line supplier of quartz crystal oscillators for a wide spectrum of radio frequency applications. Product lines include VCXOs, TCXOs and OCXOs for high end communications products; fully integrated crystal oscillators for cellular phones and pagers; hard disk drives, desktop, notebook and palmtop computers and peripherals and industrial control applications, and low cost crystal units in both surface mount and through-hole technology. New products include the industry's thinnest crystals and oscillators for emerging portable products and also special new High Frequency VCXOs for the new Sonet and Sonet-like synchronous data networks in the USA and Europe.

IFR Systems
IFR Systems, Inc. manufactures portable RF and microwave spectrum analyzers and communications service monitors for cellular telephone, UHF/VHF communications, and wireless telecommunications. Four models of spectrum analyzers provide frequency coverage to 1 Ghz provide a full range of communications testing features including popular cellular, paging, and trunking protocols.

Show-in-Print

M/A-COM
During RF Expo West, M/A-COM will promote our new line of MMIC transceiver chip sets, mixers, low noise amplifiers, switches and power amplifiers that are manufactured using GaAs and silicon, MMIC, HMIC™ and GMIC™ technologies. M/A - COM will also feature wireless antennas, RF connectors, fiber optic cable/connector assemblies and discrete semiconductors. These low cost, small and energy efficient products are designed for wireless data, voice cellular, PCS and PHP applications for infrastructure and subscriber terminal products. M/A-COM, Inc. is a leading supplier to the wireless telecommunications, surveillance and defense related industries of radio frequency, microwave and millimeter wave semiconductors and components. The Company's largest market is the global commercial market, which includes wireless communication and automotive sensor applications. Currently, one third of the Company's business is for U.S. Department of Defense applications.

Alpha Industries
No other exhibitor at the RF Expo can offer you as wide a variety of low-cost, high performance components for your wireless needs as Alpha. Our new products include GaAs MMIC control products with integral drivers, coaxial line filters and discrete components (like hyperabrupt varactors, mixer diodes and FETs) in ultra-small surface-mount packages. Be sure to ask about these new products designed specifically for your low-cost commercial applications.

Philips Semiconductors
Philips Semiconductors announces the introduction of their North American Digital Cellular Chip Set IS-54 (AMPS/TDMA). The chip set consists of four low power, highly integrated devices: the SA601 RF Front-end, the SA637 digital IF receiver, the SA7025 dual frequency synthesizer and the SA900 I/Q transmit modulator. Philips Semiconductors is a world leader in the RF integrated circuit design, development and manufacturing. Philips produces low power IC solutions for most worldwide cellular and cordless telecom standards as well as for paging and other wireless applications. Highlighting our commitment to the digital cellular market, we will be exhibiting our North American Digital Cellular Chip Set IS-54 (AMPS/TDMA) at RF Expo West '94. Booth 523, 525

Kalmus Engineering
Kalmus Engineering, Inc. is a leader in the design and manufacture of broadband RF power amplifiers both domestically and internationally. Applications include, but are not limited to, general laboratory use, communications, EMC testing, EMI/RFI, NMR/MRI and Spectroscopy. Our broad product range consists of both 100% solid-state amplifiers and distributed tube amplifiers with power ranges from 1.5 W to 3 kW CW and 12 kW pulse, frequency ranges from 25 Hz to 1000 MHz. Call or fax us for a quotation.

Bird Electronic Corp.
The 4000 Series from Bird Electronic Corp., is a modular RF power measurement system designed for metrology, research and process control applications. The system consists of the Model 4421 digital power meter and display, and a RF power sensor. A calibration card, an IEEE-488 or RS-232 interface are options. The direct-reading Model 4421 power meter measures forward and reflected RF power with $\pm$ 3 percent of reading accuracy. Typical readings are made with less than 0.1 percent repeatability error. Power can be measured from 300 mW to 10 kW, at frequencies from 100 kHz to 1.0 GHz.

Merrimac Industries
Merrimac will be showing latest in power dividers, quadrature hybrids, hybrid junctions, phase shifters, attenuators, directional couplers extending to 65 GHz, and a wide variety of mixers and I/Q Products which now extend up to 18 GHz. Of special note are the new Casefree devices which are miniaturized lumped element components designed for inclusion with MMIC circuits. Design engineers will be present to discuss how to optimize circuit performance.

Instrument Specialties
Instrument Specialties is the leader in the EMC technology and provides complete consulting, design and testing services to the electronics industry. The full product line includes beryllium copper spring fingers, knitted wire mesh, and conductive elastomer, shielded vent and filter panels, as well as ESD grounding and shielding contacts. Headquartered in Delaware Water Gap, PA, the company also operates manufacturing and distribution facilities in Placentia, CA, and Barchon, Belgium. All sites are registered to the ISO 9000 series of standards.

Hewlett-Packard Components/ Avantek
Avantek is featuring high performance oscillators, power modules and PlanarPak™ components for military and industrial applications. Hewlett-Packard is featuring RF integrated circuits including amplifiers, active mixers, digital modulators, oscillators, prescalers/frequency dividers and semiconductor RF switches, as well as diodes and transistors.

Compact Software
Compact Software, Inc. provides integrated CAE/CAD solutions for RF, microwave and lightwave design. Compact's product offering includes schematic capture, linear, nonlinear and electro-optical frequency domain simulation, physical layout with back-annotation, system simulation, time domain simulation and full-wave EM simulation tools. Compact products are available for PC/DOS, PC/Windows, Sun SPARCstation, DECstation, and HP 9000/700 systems. The company offers its products as both integrated design suites and individual point-solution analysis tools.

Voltronics Corp.
Voltronics Corporation manufactures a complete line of variable capacitors. Multi-turn precision air, glass, quartz, sapphire and Teflon™ dielectric styles are available with ranges to 250 pF and voltage ratings to 15,000 volts. Most capacitors are 40 P.S.I. sealed and have non-rotating pistons for linear adjusting. The newest additions to the Voltronics capacitor line are 8 styles of single turn surface mount and p.c. mount ceramic trimmers. A full line of DRO and microwave tuners are also available.

Salisbury Engineering
Salisbury Engineering designs, develops, and manufactures a complete line of RF and microwave filters and subassemblies covering the frequency range of 1 MHz to 20 GHz. Models include highpass, lowpass, band reject, bandpass, switch banks, GPS preamps and ceramic filters. All filters are manufactured using the latest techniques in computer aided design, drafting, machining and testing with units checked for conformity to specifications at each stage of the manufacturing process. Salisbury Engineering is always ready to assist you, our most important asset, our customer.

Cougar Components
On display will be RF and microwave cascadable amplifiers and amp assemblies for commercial, military and space level applications. Also see low noise, high dynamic range, low voltage, AGC limiting amps, limiters and attenuators, 0.1 to 6000 MHz, with up to 1 Watt output in TO-8, TO-8B, flatpack, surface mount and SMA connectorized packages.

Sprague-Goodman Electronics
Sprague-Goodman Electronics, Inc. offers the world's broadest line of trimmer capacitors, metallized glass and surface mount inductors, and microwave tuning elements. Samples of our products are exhibited at booth 718 - see our newest model surface mount trimmer (only 3.8 x 3.2 x 1.5 mm). Sprague-Goodman is the North American distributor of Radiocer® high power RF ceramic capacitors (for AM broadcasting and induction heating). Plate and tubular models are shown.

Trans-Tech
Trans-Tech is a manufacturer of advanced technical ceramics for RF and microwave applications. Their expertise in ceramics, coupled with engineering and R&D skills enable them to provide highest quality solutions for the best value. Products include bandpass filters, coaxial resonators/inductors, dielectric resonators, ferrite circulator and isolator elements, ceramic substrates, technical ceramic powders, and ferrite, garnet, and dielectric materials. New products include miniature coaxial resonators (2 mm), and 2 mm & 4 mm bandpass filters for applications where small size is of utmost importance.

Vectron Laboratories
Vectron Laboratories, Inc. — Booth 510 — will be featuring a complete line of crystal oscillators available from .01 Hz to beyond 2 GHz. Products on display will include the following: Moderate Stability Clock Oscillators available with sine or logic output in a broad range of configuration; Temperature Compensated Crystal Oscillators (TCXOs) to better than ±1 x 10^{-7}; subminiature Oven Controlled Crystal Oscillators (OCXOs) available with stabilities to 1 x 10^{-10}; Voltage Controlled Crystal Oscillators (VCXOs) for phase locking applications and linear VCXOs with ±2500 ppm deviation; SONET/SDH clock recovery and data regeneration products which meet CCITT Type A and B jitter standards.

ENI
ENI manufactures broadband RF amplifiers for EMC testing, ultrasonics, broadcast communications, Magnetic Resonance Imaging, and general laboratory use. With power outputs ranging from 3 watts to 5 Kilowatts, and frequency coverage from 9 kHz to 1 GHz, ENI amplifiers feature rugged solid state design, unconditional RF stability and infinite maximum load VSWR. ENI maintains sales and service offices in New York, California, Texas, Germany, the United Kingdom, and Japan.

RF Monolithics
RFM supplies advanced SAW products for low power wireless communications, telecommunications and computer applications. RFM products are used to achieve high performance, and to reduce size, complexity and power consumption. RFM manufactures a wide range of SAW components including filters, resonators and delay lines. RFM also manufactures radio transmitter and receiver hybrids, UHF frequency sources, and high-frequency digital clocks.

CTIA
Cellular Base Site optimization in under five hours and Scan Calibration in under 15 minutes is now possible with the new R-2600 CCBS testing system. Using software driven CBS AutocalTM fully prompted procedures speeds the test process, and all results can be saved to disk for convenient handling. Add to that a new optional LPA test capability and you have efficient, repeatable, reliable control over the cellular infrastructure.

Richardson Electronics
To see what's new from Motorola, SGS-Thomson, M/A-COM, Philips, RF Products, Inc. and other leading RF and microwave component manufactures, visit Richardson Electronics in booth 829 at RF Expo West. In addition to an extensive inventory, Richardson offers matching, selecting and testing value-added services for transistors, SCRs and MOSFETs as well as RF testing. Richardson has added top RF and DC application engineers to provide customers with unparalleled design-in support and technical assistance. For purchasing convenience, Richardson offers EDI capabilities and JIT stocking programs. Visit Richardson at RF Expo West or call 1-800-RF POWER.

Trilithic Inc.
Trilithic Inc. of Indianapolis, Indiana placed #10 on the Inc. 500 list which ranks the top 500 fastest-growing, privately-held companies in the united states. The company's spectacular growth (over 7,000 percent) can be partially attributed to the acquistion of Texscan Instruments Division's assets in March of 1989, the introduction of miniature LC filters, expansion into switching and control subsystems, and the asset acquisition of Cir-Q-Tel Microwave of Beltsville, Maryland in April of 1992. Trilithic has opened Trilithic Ltd. near London to serve expanding UK market. See them in booths 430-432 at the RF Expo West.

Emhiser Micro-Tech
Emhiser manufactures low cost and hermetic VCOs covering 10 MHz to 4 GHz in selected frequency bands, with up to a full octave of tuning range.

American Technical Ceramics
ATC manufactures high quality RF/microwave capacitors including high Q, low ESR porcelain MLCs, high performance ceramic MLCs, space qualified SLCs, low cost commercial line SLCs and low cost standard size MLCs. ATC also offers special assemblies, dielectric substrates, non-magnetic capacitors, custom SLCs, and Thin Film Technology. This product line is described in the new ATC Surface Mount and Leaded Capacitor brochure.

Compex Corp.
Compex manufactures single layer parallel plate chip capacitors in a wide variety of configurations values and sizes. These include gap caps, marjin caps, row caps, binary caps and custom arrays. Values from 0.06 pF and case sizes from 10 x 10 mils.

Reeves-Hoffman
You may know that Reeves-Hoffman is a manufacturer of crystal (1 kHz to 250 MHz), oscillators and hermetic seal packages. Reeves-Hoffman continues to expand its capabilities in a rapidly changing market. Do you know that we manufacture high frequency fundamental crystals up to 120 MHz? Are you familiar with Reeves-Hoffman's Model 322 DIP VCXO? Do you know that Reeves-Hoffman manufactures custom packages as well as crystal bases and glass-to-metal seal hybrid packages? Stop by the Reeves-Hoffman booth to learn more about our products and capabilities. See you at the show.

RF Expo West Exhibitor Locator

AEL Industries, Inc.	640
Alan Industries, Inc.	713
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Allis Associates	935-940
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American Technical Ceramics	**128, 130**
AMP Incorporated	320, 322
Amphenol RF/Microwave Opns.	836
Amplifier Research	**610, 612**
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AT&T Microelectronics	122, 124
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Coilcraft, Inc.	137
Compac Development Corp.	**821**
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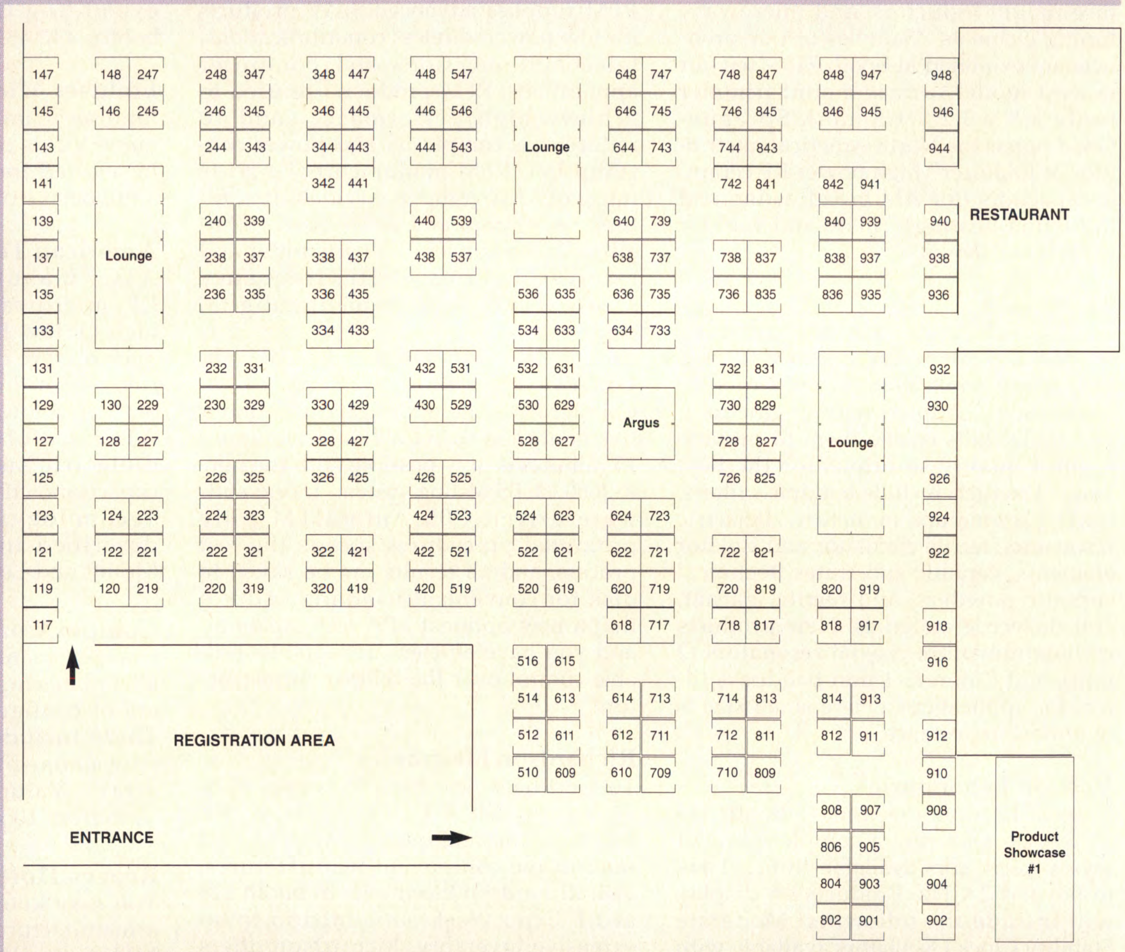

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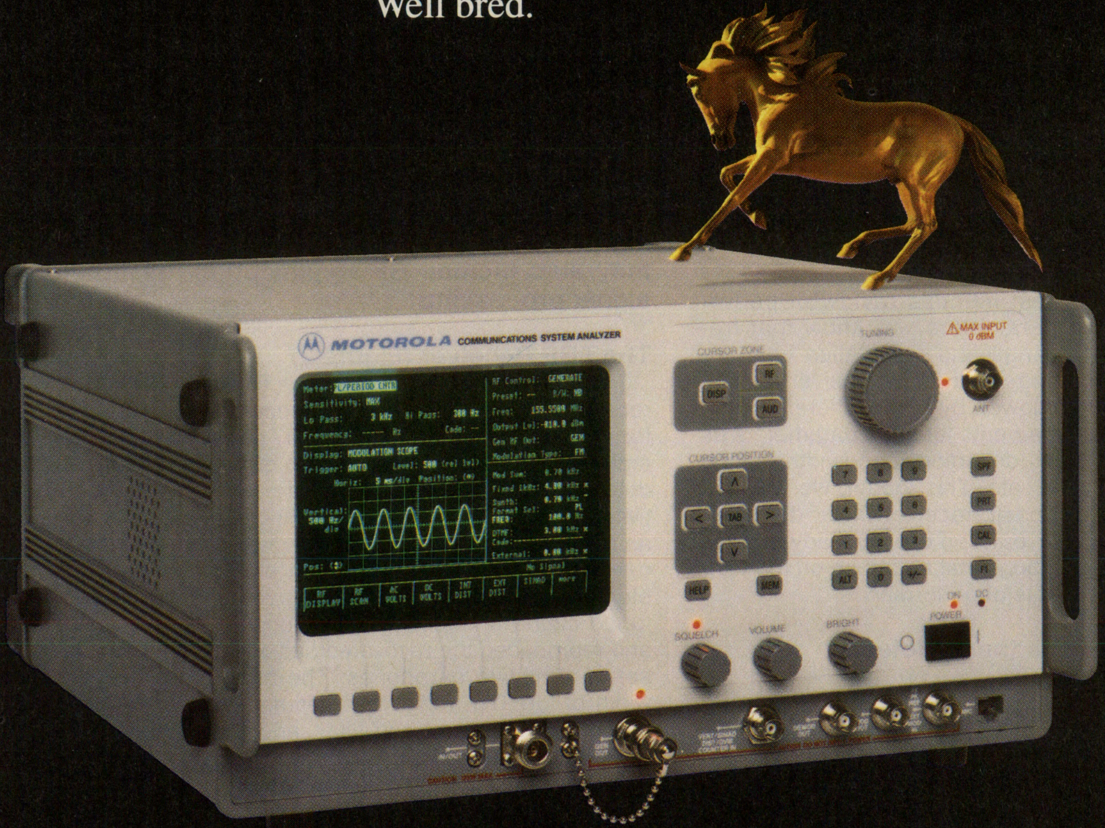

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Receiver Basics — Part 2: Fundamental Receiver Architectures

By Gary A. Breed
Editor

Our basic tutorial on receiver design continues with a review of the commonly-used architectures. The particular arrangement of amplifiers, filters, mixers, oscillators and detectors into a working system has a profound effect on the performance, complexity, and cost of a receiver. Every possible block diagram cannot be presented here, but a few of the most common configurations are included.

From last month's review of performance parameters, we know that frequency range and modulation type are the starting point for a receiver specification, followed by many different possible requirements for such parameters as sensitivity, distortion, bandwidth, tuning resolution, etc. This month, we will look at some basic receiver block diagrams and point out some of the advantages and limitations that each has on the various aspects of performance.

The Broadband Detector (Figure 1)

An untuned detector isn't often considered a receiver, but that is exactly its function. Modulation is usually CW, and the recovered information is a DC level proportional to amplitude. A simple detector is nearly always used in a closed system, for monitoring a known signal source or as an indicator in a test system (e.g. forward and reflected power measurement). In an amplitude modulated (AM) broadcast transmitter, a detector may be a high-level audio demodulator for monitoring purposes. With such a strong input and no outside signals to select from, there is no need for any supporting receiver circuitry.

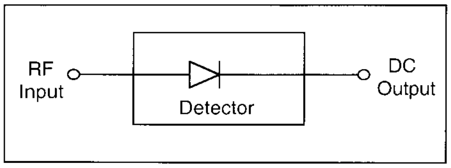

Figure 1. The broadband detector — the simplest receiver.

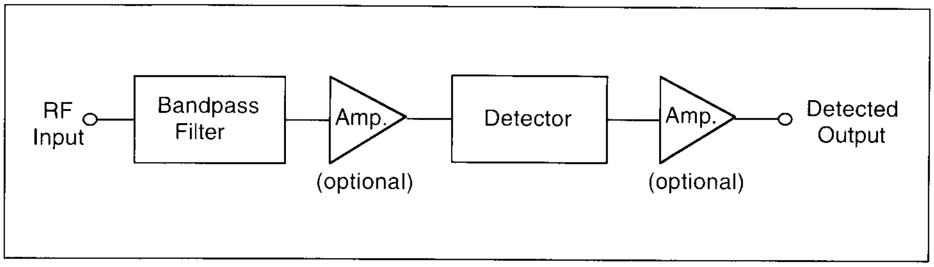

Figure 2. The TRF receiver includes a filter before signal detection, and may also include RF amplification, baseband amplification and other signal processing.

The TRF Receiver (Figure 2)

The tuned radio frequency (TRF) receiver is the simplest practical receiver for picking up signals "off the air." This architecture places a filter ahead of the detector to provide a measure of selectivity. The TRF receiver may also include an amplifier to boost signal levels prior to detection. This is the basic form of the old crystal set radios, which placed a tuned circuit ahead of a diode junction and reproduced the recovered audio in a set of sensitive earphones. The bandwidth of the TRF receiver is determined entirely by the front-end filter, and the modulation type is exclusively AM.

Despite its simplicity and apparent limited usefulness, the TRF receiver is quite common: remote control devices of all types typically use this architecture. Its implementation is usually on a single frequency, with on-off keyed (OOK) digital transmission most commonly used (although there may still be some tone-modulated AM units still in service). More sophisticated detection is often employed, as well, including super-regenerative detectors and enhanced active envelope detectors.

Maximum performance from a TRF receiver requires a very good front-end filter. In current low power/short range devices, a high-Q SAW filter is typically used, resulting in a receiver with several kHz selectivity and sensitivity down to −100 dBm or better.

The Direct-Conversion Receiver (Figure 3)

Terminology for this type of receiver varies; it has been called homodyne, synchrodyne, and zero-IF, as well as direct-conversion (D-C). The D-C receiver is mixer that converts the RF frequency to baseband. The output of the mixer contains the sum and difference of the local oscillator (LO) and the desired signal. In the D-C receiver, the LO is very

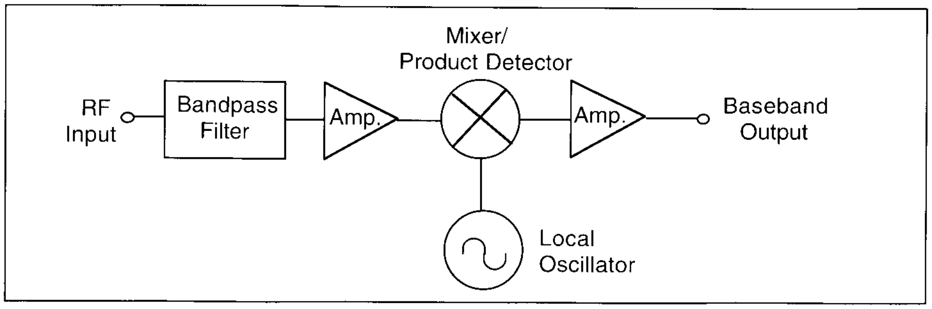

Figure 3. The Direct-Conversion or Zero-IF receiver performs frequency translation from RF to baseband.

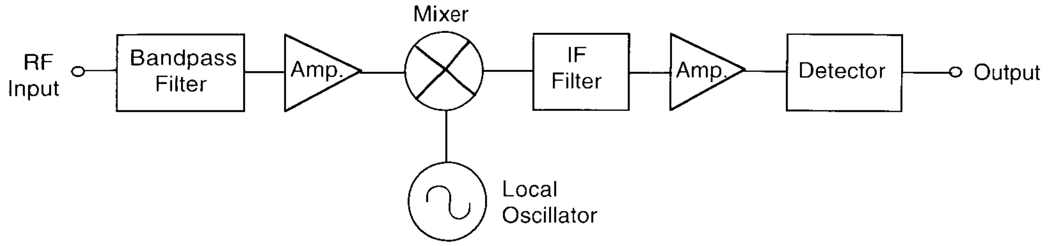

Figure 4. The single-conversion superhetrodyne receiver can be described as a frequency conversion stage preceding a TRF or direct-conversion receiver. Other detector options include FM, I and Q, or logarithmic.

close to the desired signal. For example, if the signal is at 2.000 MHz and the LO is at 2.001 MHz, then the mixer output will be 1000 Hz and 4.001 MHz. If the LO is exactly the same as the center frequency of the desired signal, then the center (or carrier) frequency will appear at zero Hz (hence, the zero-IF name), and the sidebands will be recovered with the same relationship they had to the carrier, translated to baseband. If this circuit is part of a larger receiver system, it is called a product detector.

For example, in a single-sideband signal, the LO of the D-C receiver can be tuned to the suppressed carrier frequency, and the modulation will be translated directly to audio frequencies. With the LO tuned to the carrier of an AM signal, the carrier will appear at zero Hz and the sideband modulation recovered as audio. A special case of the D-C receiver actually uses the carrier of an AM signal as the LO, after hard limiting to remove the modulation. This guarantees that the audio (or video in the case of television signals, which are also AM) is exactly reproduced. This type of circuit is called a synchronous demodulator.

The Superhetrodyne Receiver (Figures 4 and 5)

In its various forms, the superhetrodyne is the most common receiver architecture. The key feature of the superhet architecture is one or more frequency conversions between the RF input and the detector. The frequency conversion accomplishes two major objectives — translating the RF to a lower frequency where a narrow bandpass filter is easy to implement, and using the frequency offset to reject potential interfering signals.

The original purpose of the superhet was to improve selectivity. A good TRF receiver could be built at the very low frequencies used in early radio, such as 50 kHz. At these frequencies, stable narrow bandwidth LC filters are practical, making it possible to obtain good receiver performance.

However, when frequencies above 1 MHz came into common use, TRF techniques were insufficient for good performance. Implementing a frequency conversion from MHz to 50 kHz allowed the selectivity of the lower frequency to be used with the higher operating frequency. A simple superhet is a mixer/local oscillator followed by a TRF receiver. In the superhet scheme, that TRF section is now called the intermediate frequency (IF), since it is an intermediate stage between the mixer and detector.

This simple arrangement, and any other that uses one mixer ahead of an IF, is the single-conversion superhetrodyne receiver. The superhet IF can include selective elements (filters) of various types, amplification as desired, and any type of detector — a diode (envelope detector), product detector, discriminator, logarithmic, or anything else. The relationship between the LO, RF and IF can be any combination; there is no need for the IF to be a lower frequency than the RF, or for the LO to higher or lower than the RF or IF.

As receiver designers learned how the superhet worked, double and triple frequency conversion stages became common. Reasons for their use include converting even higher frequencies down to a very low frequency IF to take advantage of the easily obtained selectivity. However, converting directly from, say, 100 MHz to 100 kHz cannot easily be done, since the mixer image is only 200 kHz away from the desired frequency. Instead, converting 100 MHz to 10 MHz, then converting 10 MHz down to 100 kHz allows practical filters to be used for rejecting the unwanted mixer products.

Another useful feature of the superhet, especially multiple conversion types, is control of the gain throughout the receiver system. Too much gain at a single frequency invites instability and potential oscillation. By dividing the total system gain among sections of the receiver that operate at different frequencies, stability problems are minimized. With control over gain, the absolute levels can be optimized to

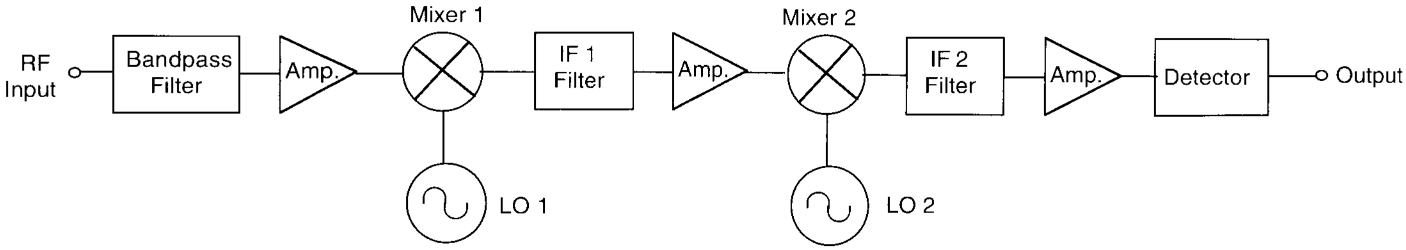

Figure 5. The double-conversion superhetrodyne architecture adds another frequency conversion stage, usually to aid in rejection of image signals. Triple and quadruple conversion schemes may also be used.

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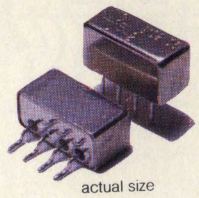

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Model	LO Power (dBm)	Freq. LO/RF (MHz)	■ Conv. Loss (dB) $\bar{X}$	δ	Isol. L-R (dB)	Price,$ Ea. 10 qty
TUF-3	7	0.15-400	4.98	0.34	46	5.95
TUF-3LH	10		4.8	0.37	51	7.95
TUF-3MH	13		5.0	0.33	46	8.95
TUF-3H	17		5.0	0.33	50	10.95
TUF-1	7	2-600	5.82	0.19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

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

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

δ = Sigma or standard deviation

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avoid overloading of crystal filters, or to provide sufficient levels for optimum operation of detectors.

I and Q Receiver/Detector (Figure 5)

The final basic receiver type we'll look at is the I and Q, or quadrature receiver, which can be used alone or as a detector following one or more frequency conversion and amplification stages. This architecture is based on a powerful concept — all signal types and modulations can be completely defined in terms of their orthogonal components; in-phase (I) and quadrature (Q). With the proper signal processing following the I and Q detectors, such a receiver can be used to recover information from any type of signal, using simple or complex modulation. The basic I and Q detector is noted within Figure 5.

For "routine" analog modulation (AM, FM, SSB), I and Q detection is usually more complicated than is economically feasible. However, it is ideal for the complex modulation typically used in radar and digital communications, for systems which require highly flexible demodulation capabilities, and for systems which use digital signal processing for IF and demodulation functions.

To obtain the I and Q outputs, the detector consists of two mixers (or product detectors), driven by the same local oscillator, but at a relative phase of 90 degrees. Because phase shift is maintained in the mixing process, the outputs appear at baseband with the same relative phase of 90 degrees (or at an IF if the system calls for it). This signal is then presented to signal processing circuitry for filtering, gain control and demodulation.

A simple case that many engineers are familiar with is the phasing method of SSB demodulation (Figure 5), which is also the same principle as the image-

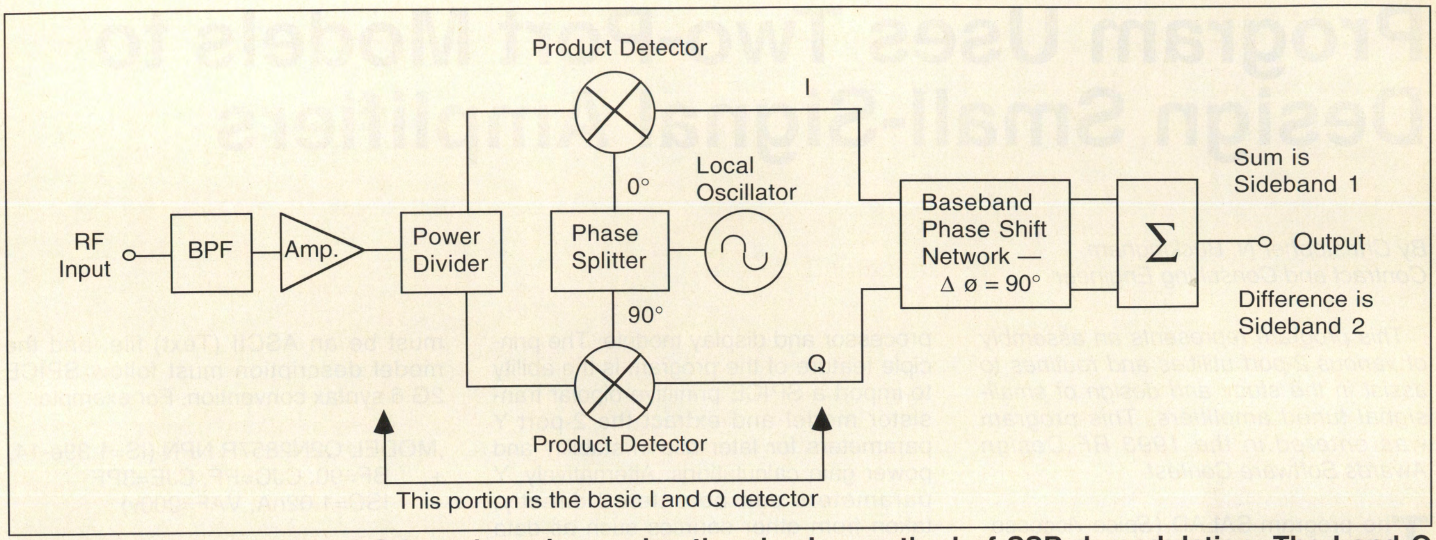

Figure 5. A complete I and Q based receiver, using the phasing method of SSB demodulation. The I and Q detector portion of the circuit is noted.

reject mixer. If the I and Q outputs from the product detectors are further shifted in phase by a relative difference of 90 degrees, the sum of the two signals will contain only one sideband and the difference will contain only the opposite sideband. At IF, the sum will contain only one mixer product (e.g. F1 + F2) and the difference will contain only the other (e.g. F1 – F2). The double-quadrature action results in the desired sideband appearing at each output in-phase, and the unwanted sideband appearing at a phase of 180. If the amplitude is equal in both signal paths, and if the phase is accurately maintained at 90 degrees for each phase shift, there will be perfect summation of one and cancellation of the other. In practice, narrowband rejection of the unwanted sideband can easily be more than 40 dB.

Various types of digital modulation employ both amplitude and phase information to carry information. The I and Q configuration is the best method for obtaining and IF or baseband signal pair from which the necessary relationships can be extracted.

Summary

Receiver architectures must be selected to obtain the appropriate combination of performance and economic features. This tutorial has reviewed the most commonly used block diagrams, with the intention of helping less-experienced engineers begin their education on receivers. To investigate these and other architectures in greater detail, the following Bibliography includes selected reference material. *RF*

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Program Uses Two-Port Models to Design Small-Signal Amplifiers

By Christopher N. Buckingham
Contract and Consulting Engineer

This program represents an assembly of various 2-port utilities and routines to assist in the study and design of small-signal tuned amplifiers. This program was entered in the 1993 RF Design Awards Software Contest.

The program SALAD (*S*pice *A*ccessory for *L*inear *A*mplifier *D*esign) is an application intended to aid in the implementation and verification of 2-port small-signal tuned narrow-band amplifier design routines, utilizing the U.C. Berkeley 2G.6 simulation program (if so chosen) as an independent external test and verification platform.

This serves two purposes — to learn 2-port amplifier design, and to exercise or practice a design run in an abstract environment. If the design is successful within SPICE, then most likely the design will work in practice! In fact, if a bonafide SPICE BJT or FET model is used, then the design abstract is complete and the real world laboratory prototype can be constructed.

How The Program Works

SALAD is an integrated program with a data input editor, linked to a data processor and display module. The principle feature of the program is the ability to import a SPICE primitive bipolar transistor model and extract the 2-port Y parameters for later use in stability and power gain calculations. Alternatively, Y parameters can be entered directly, taken from other sources such as data sheets, or measurements.

Once a set of 2-port Y parameters is entered then the following calculations can be made:

- Linvill "C" stability factor
- Transducer power gain "GT"
- Optimum source and load terminations

The user provides 2-port h, y, or S parameters at some frequency (in MHz). This can be done in two ways: 1) The data is taken from direct device measurements, or taken from the manufacturers data sheets, and is entered manually via the computer keyboard; or 2) Provide a SPICE bipolar or JFET model of either polarity. This is done by giving the program the model name e.g. (Q2N2222A or MPF102 etc.), and the file name where the model can be found, e.g. A:.lib, c:.lib , etc. The file must be an ASCII (Text) file, and the model description must follow SPICE 2G.6 syntax convention. For example:

```
.MODEL Q2N2857R NPN (IS=1.39e-14,
+    BF=90, CJC=PF, CJE=3PF
+    ISC=1.02nA, VAF=200v)
```

Alternatively the model can be entered manually via the keyboard. Look at file MODEL.LIB with a text editor; this file has a small collection of typical bipolar devices. If the SPICE option is selected, then after properly loading a SPICE model, select a DC bias level (collector, or drain current and voltage). The program then proceeds to calculate all junction currents and voltages, and returns the small-signal hybrid-pi parameters. The program asks for the operating frequency in MHz, and the program calculates the associated 2-port Y parameters.

2-Port Small Signal Parameters

The actual design calculations can start once we have a set of 2- port parameters. All starting data must be either common-emitter or common-source measurements. These may be short cir-

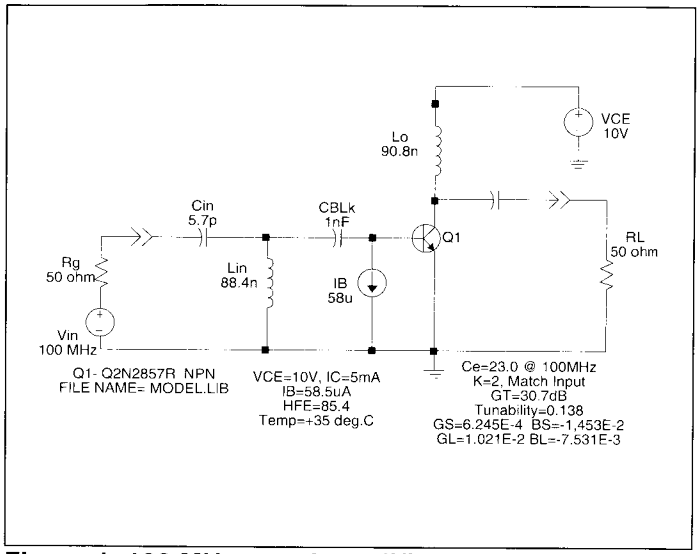

Figure 1. 100 MHz tuned amplifier circuit.

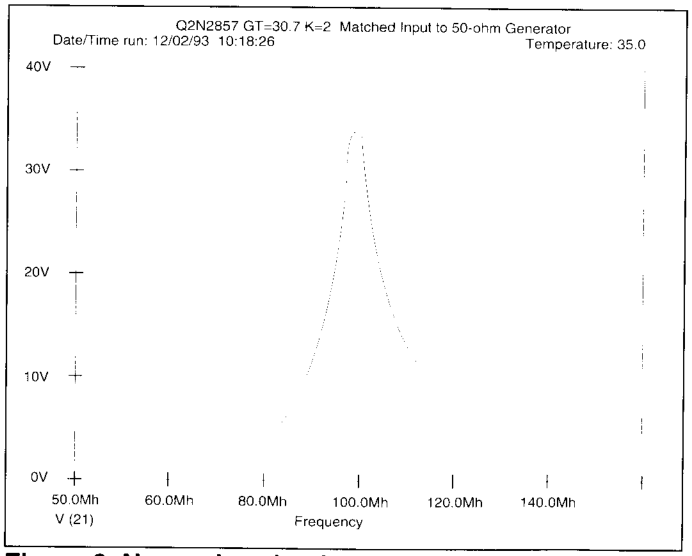

Figure 2. Narrowband gain plot of the amplifier.

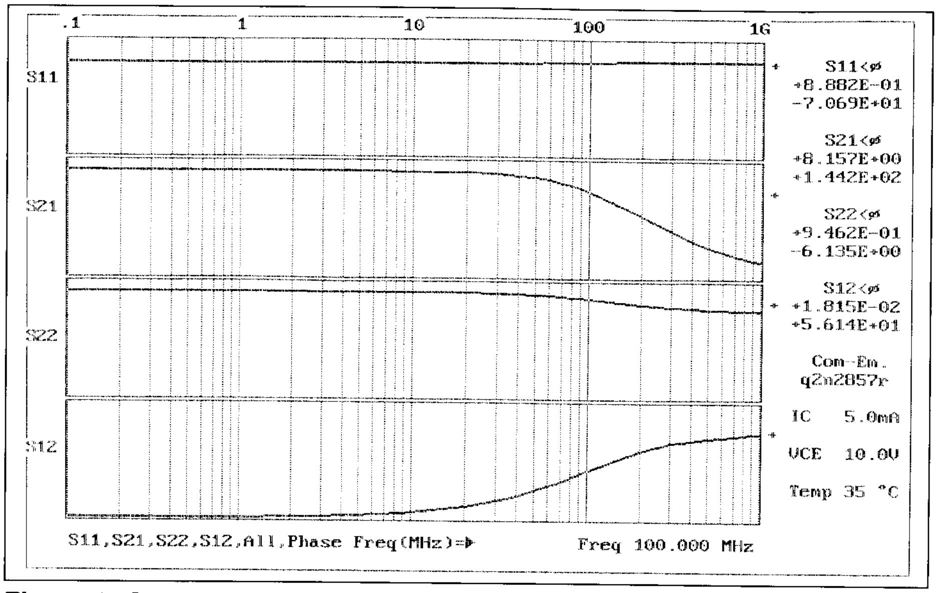

Figure 3. S-Parameter phase plots for the 100 MHz amplifier.

cuit (y-parameters), hybrid open and short circuit (h-parameters), or alternatively, scattering (s-parameters).

Note: S-parameters are assumed to be 50 ohm line measurements. Any other referenced characteristic impedance measurements must be converted to 50 ohm data before entry.

When entering data manually via the keyboard, number format is freeform as shown in examples below. Deviations or errors from the legal format will either corrupt the intended number or produce a zero. Be extra cautious when editing or entering your data! For example:

Good	Bad
–0.001	a.123 -> 0
–1.0m	*0.23e-6 -> 0
+1.3e-3	–0.02.5 - > –0.02

Suffixes are allowed: M, U, N, P, MEG, G etc. Frequency is scaled to Megahertz, so enter your number in MHz. Two-port data is entered in absolute value (not scaled).

Stability and Gain

With a set of 2-port parameters specified, the program proceeds to calculate the Linvill open circuit "C" stability factor. The stability factor is calculated for common emitter (Ce), common base (Cb), common collector (Cc), and Cascode (Ca) configurations This shows the relative stability for the same device used in different small-signal configurations (with the DC bias network fixed).

The user can then select the configuration of choice and proceed to calculate power gain. If the device is unconditionally stable (0=<C<1), the simultaneously matched input and output maximum transducer gain GT is calculated. If the device is potentially unstable (C=>1), then the Stern "k" power gain is calculated. The user is prompted for a stability factor "k" between 2 and 10, and the maximum transducer gain GT is calculated along with input/output terminations.

Limitations and Future Plans

There are some incomplete or limited portions of the program at this time. Readers can contact the author for additional information:

The FET model parameter worksheet menu is not complete, therefore a simplified manual entry via the keyboard is the only input for the FET model. Also at this time, there is no file or data save mode, that is, model parameters and data can only be saved with a screen dump (use GRAPHICS.COM to print graphs). Once the program is terminated all data is lost, so write down your numbers!

H and S parameter menus are not ready, this means that all 2-port calculations are done in the y-parameter menu. Data can be entered in "h" or "S", and linked to "y" for power gain calculations. This data link also provides conversion between h, y, and S data sets.

The following options are still being developed, but are planned for future versions of SALAD:

Augment Data — This feature represents the complex matrix math to combine two or more sets of 2-port parameters, such as cascading, paralleling, and the like. This is a powerful feature and allows optimizing the active device in a network (feedback, for stability, broadbanding etc.).

Conversion — This feature will allow

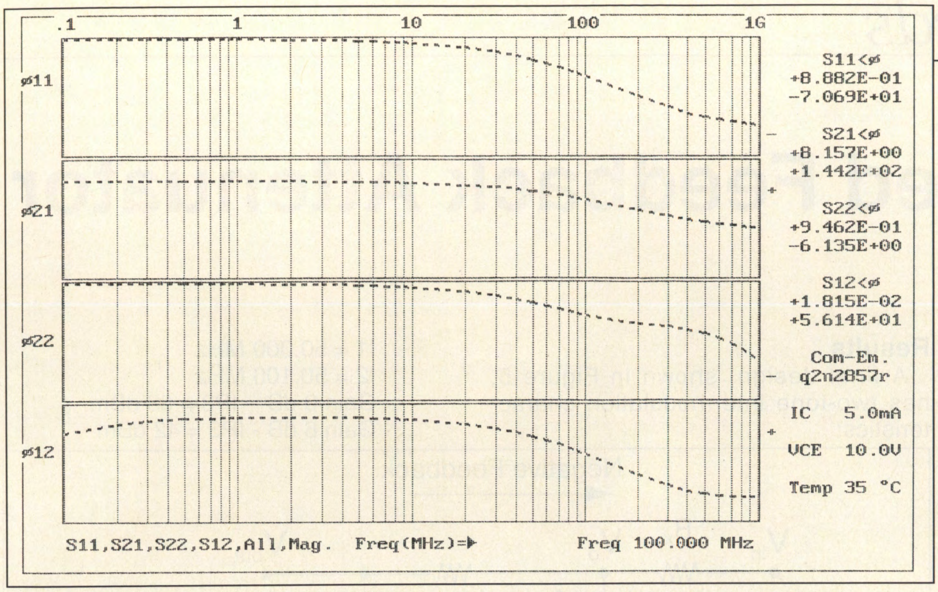

Figure 4. S-Parameter magnitude plots for the 100 MHz amplifier.

conversion from rectangular to polar representations, and conversion between 2-port formats (y and S to ABCD and the like). Conversion and Augment are interlinked.

Additionally, input and output matching design is not provided, except for a simplified L-Matching routine to test the gain calculations with SPICE.

Other features to be added include frequency response display of input/output reflections, forward and reverse transmissions of final 2-port calculations, and a SPICE netlist ready to run from SPICE.

Computer Requirements

SALADwill run on 80286/386/486 class computers with a minimum 256K RAM under DOS version 2.xx or higher. The program will only run with VGA, (EGA, CGA, and Hercules not supported). The numeric coprocessor will be used if available. Please direct any comments or questions to author at the address below.

The SALAD program is available on disk from RF Design. *See page 134 for ordering information.* *RF*

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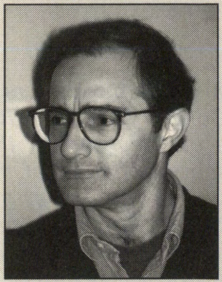
About the Author



Christopher Buckingham attended Northeastern University in Boston, MA, and graduated with a BSEE in 1978. He has worked for Teledyne as a test engineer in discrete semiconductors, and worked for ten years at the Raytheon Company as a product engineer, specializing in small-signal hybrid thick-film RF modules. He is presently engaged in contract and consulting assignments as an electronics development and test engineer. He can be reached at: 158 Summer St., #406, Somerville, MA 02143, tel. (617) 776-6553.

A Transformed Feedback Attenuator

By Carl Zatl

One weak spot in modern receivers is Automatic Gain Control (AGC). Automatic regulation of the gain of the receiver is necessary because of the wide variations in signal strength encountered at the antenna terminal. AGC voltage is used to vary the bias on the amplifier stages, increasing or decreasing the gain. As signal strength increases, less gain is needed, and the AGC voltage changes the operating characteristics of the device to a less linear mode . The result is a strong signal is applied to an increasingly non-linear device. That is exactly the opposite of what we need for good intermodulation performance. This old problem has existed as long as the AGC has. My goal was to mend or end that unfavorable condition.

Variable attenuators often use PIN diodes or field effect transistors as variable resistances. If these devices are driven to higher attenuation, the non-linearity of the device can produce distortion. When two or more signals are present, the result can be some level of intermodulation or cross modulation. This problem can be significantly improved if the attenuating element is placed into negative feedback of an amplifier where amplitude is smaller.

In Figure 1, between the Vout and Vin on the resistor R_x can be found the point where the attenuating course is acceptable (Figure 2).

Further improvement is reached when the resistor R is replaced by an impedance transformer with resistance R_t (Figure 3). The main reason for this is to reduce voltage on the resistance R_t by T1/T2. The resistance Rt can be voltage controlled field effect transistors, current controlled PIN diodes, etc., in balanced configurations.

In Figure 4, nonlinearity of one diode is reduced by the same but opposite nonlinearity of the other diode. A resistor is placed in parallel to maintain some reasonable impedance for the transformer while the diodes are off. The ratios of T_1/T_2 and R_{x1}/R_{x2} are main factors to specify feature of the attenuator.

Results

A final design, shown in Figure 5, has two-tone intermodulation characteristics:

f1 = 50.000 MHz
f2 = 50.100 MHz
Gain 0 dB - IP3 = 38 dBm
Gain 6 dB - IP3 = 42 dBm

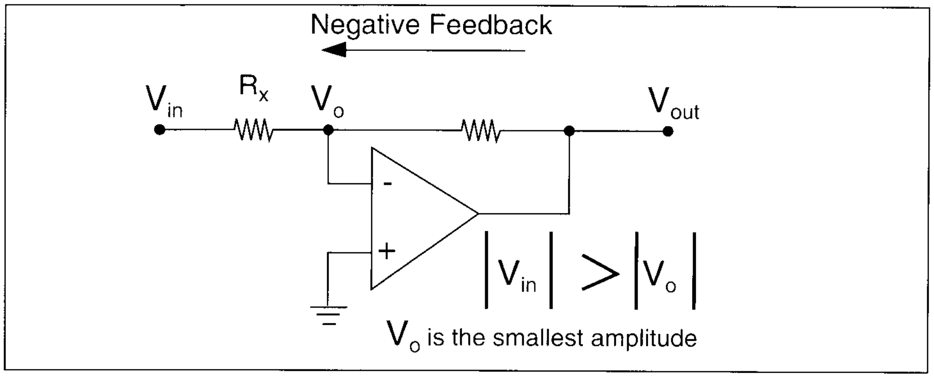


Figure 1. Amplifier with negative feedback.

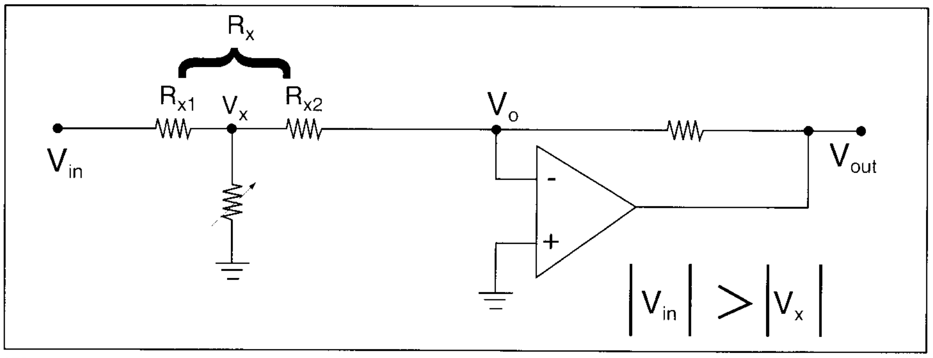


Figure 2. Attenuator placed at a point between V_{in} and V_{out}

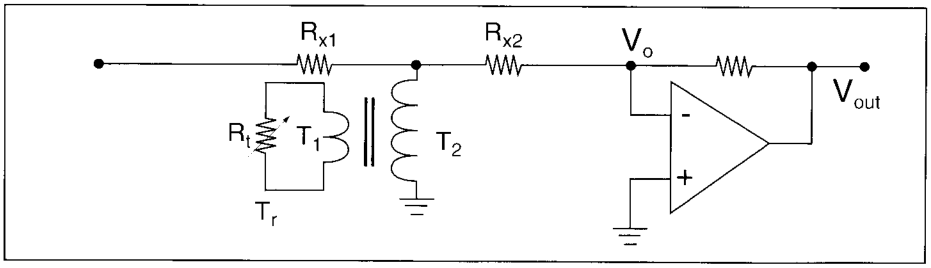


Figure 3. Transformer T_r reduces the voltage across R_t

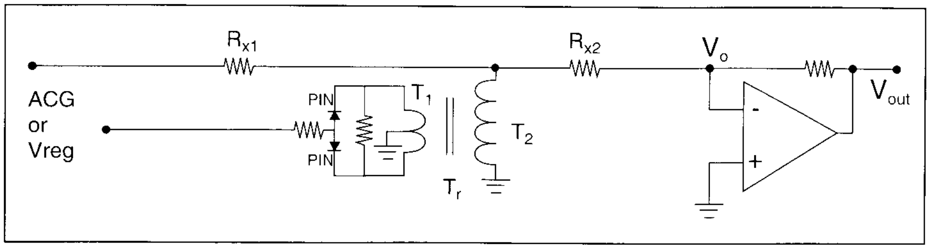


Figure 4. Balanced PIN diodes provide linear attenuation

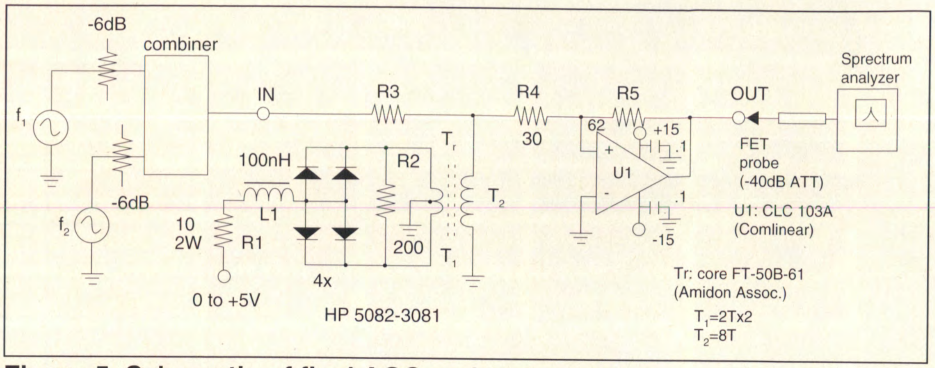


Figure 5. Schematic of final AGC and test set-up

Gain 12 dB - IP3 = 45 dBm
Input impedance = 50 ±10 ohms

These characteristics are very favorable and opposite from any other AGC amplifier or attenuator available; as gain is decreased, the circuit's capability to handle strong signals grows. *RF*

About the Author

Carl Zatl received diplomas in electronics and radio communications in 1970 and 1972 in the former Czechoslovakia. Radios have been his hobby since 1958 when he built his first shortwave receiver with tubes. He owns several patents. Mr. Zatl has been in the U.S. since 1981, and he is working as a contractor to design and develop equipment for radio communications from DC to microwaves. He can be reached by mail at 585 Hacienda Ave., #102, Campbell, CA 95008.

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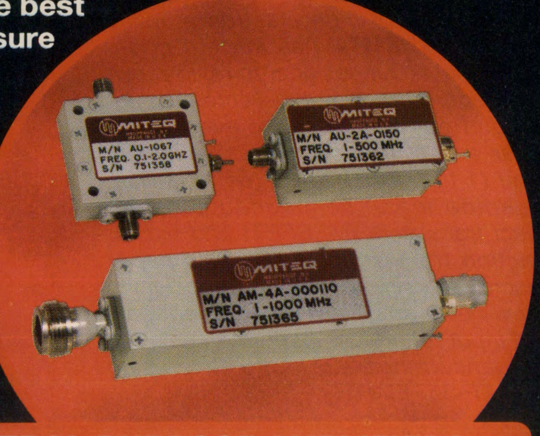

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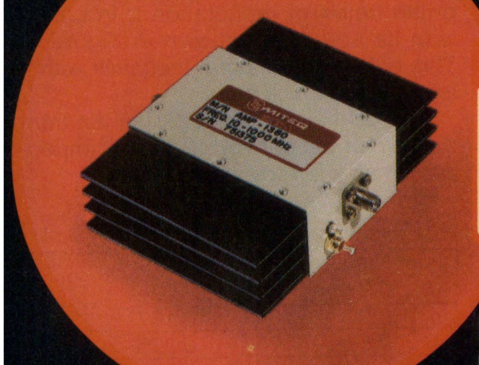
AU-1310	.01 – 500	30	0.50	1.3	1.4	1.5	2:1	8	15	50
AM-1300	.01 – 1000	25	0.75	1.4	1.6	1.8	2:1	6	15	50
AU-1378*	1 – 300	17	0.50	1.9	1.9	1.9	2:1	–2	6	10
AU-1379*	1 – 500	13	0.50	2.2	2.3	2.4	2:1	–2	6	10
AU-2A-0150	1 – 500	30	0.50	1.3	1.4	1.5	2:1	8	15	50
AU-3A-0150	1 – 500	45	0.50	1.3	1.4	1.5	2:1	10	15	75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

*Designed for low current battery operation



POWER AMPLIFIERS

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

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Design of a Low-Noise Amplifier Using HEMTs

By S. Satyanarayana
Vikram Sarabhai Space Centre

Availability of high electron mobility transistors (HEMTs) has made it possible for the circuit designer to realize low-noise amplifiers with excellent noise-figure and gain performance even in the lower end of the microwave frequency band (1 to 5 GHz) compared to gallium arsenide metal semiconductor field effect transistors (MESFET) and bipolar junction transistors (BJT). This paper describes a simple method of designing a low-noise amplifier with excellent gain and input return-loss performance in the frequency range 2.5 to 3.0 GHz using the ATF-35 HEMT.

Any low-noise transistor provides its minimum noise-figure, NF_{min}, when an optimum source reflection coefficient ($\Gamma_{s(opt)}$), is present at its input port. An arbitrary source reflection coefficient, Γ_s, yields a noise-figure NF is given by

$$NF = NF_{min} + \frac{4r_n \left|\Gamma_s - \Gamma_{s(opt)}\right|}{\left|1+\Gamma_{s(opt)}\right|^2 \left[1-\left|\Gamma_s\right|^2\right]} \qquad (1)$$

where $r_n = R_N/50$, R_N is the equivalent noise resistance.

Noise-figure can be also expressed as

$$NF = NF_{min} + \frac{R_N}{G_s}\left[\left(G_s - G_{opt}\right)^2 + \left(B_s - B_{s(opt)}\right)^2\right] \qquad (2)$$

$$= NF_{min} + \Delta F$$

Where

$$\Delta F = \frac{R_N}{G_s}\left[\left(G_s - G_{opt}\right)^2 + \left(B_s - B_{s(opt)}\right)^2\right] \qquad (3)$$

The term ΔF gives the measure of noise mismatch to an arbitrary source reflection coefficient (Γ_s) from an optimum source reflection coefficient ($\Gamma_{s(opt)}$)

$$\Gamma_{s(opt)} = \frac{\left(Y_0 - Y_{s(opt)}\right)}{\left(Y_0 + Y_{s(opt)}\right)} \qquad (4)$$

$$\Gamma_s = \frac{\left(Y_0 - Y_s\right)}{\left(Y_0 + Y_s\right)} \qquad (5)$$

where

$Y_{s(opt)}$ = Optimum source admittance $= G_{s(opt)} + JB_{s(opt)}$
Y_s = Source admittance$=G_s+JB_s$
Y_0 = Characteristic admittance

The ATF-35, a pseudomorphic HEMT, is used in this low-noise amplifier design covering 2 to 3 GHz. The typical noise-parameters of this device as provided by the manufacturer are given in Table 1.

Stability Factor

For a transistor to be unconditionally stable, S11 and S22 must be less than unity and the transistor's inherent stability factor K must be positive and greater than unity. K is computed using equation 4.

$$K = \frac{1+\left|\Delta\right|^2 - \left|S11\right|^2 - \left|S22\right|^2}{2\left|S12 \cdot S21\right|} \qquad (6)$$

Where $\Delta = S11S22 - S12S21$. The S-parameters of the ATF-35 at $V_{DS} = 1.5V$ and $I_{DS} = 10$ mA are given in Table 2.

The stability factor K for the ATF-35 is computed using equation 6 and is given in Table 3.

As is evident from Table 3, the stability factor of the device is less than unity.

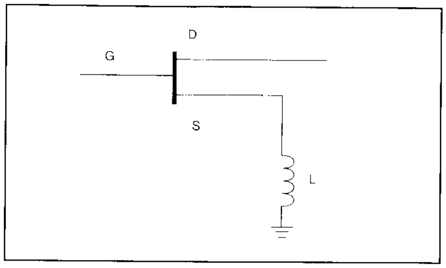

Figure 1. The inductor between the source lead and ground insures stabilitity.

Hence it is potentially unstable and can go into oscillations for certain combinations of source and load admittances. In 2-3 GHz range, the stability factor is very low. Because of the small value of $Y_{s(opt)}$ and the low value of NF_{min} for HEMTs, ΔF increases rapidly if Y_s differs from $Y_{s(opt)}$. For a good design, ΔF should be minimized. Even though HEMTs are sensitive to noise mismatch and are highly unstable, with suitable design techniques very low noise-figure of 0.25 dB can be achieved because of their inherent low NF_{min} and high gain in the frequency band of 1.0 to 4.0 GHz.

Feedback Technique

HEMTs can be made unconditionally stable in the frequency band of interest (below 4 GHz) by connecting an appropriate value of inductance L in series with its source as shown in Figure 1. This offsets the internal feedback with a lossless feedback path.

The scattering matrix [S1] of the transistor can be converted to the impedance matrix [Z1] by the relation

$$[Z1] = Z_0[I2+s1][I2-S1]^{-1} \qquad (7)$$

Freq. GHz	NF_{min} dB	RN/50	$G_{s(opt)}$ (mag, deg)	$Y_{s(opt)}$ millimohs
2.0	0.13	0.23	0.82,23	2.060–j4.03
2.5	0.16	0.22	0.80, 28	2.359–j4.92
3.0	0.20	0.21	0.78, 33	2.685–j5.83
4.0	0.25	0.19	0.74, 43	3.44 –j7.68
5.0	0.31	0.16	0.68, 51	4.64 –j9.12
6.0	0.38	0.13	0.62, 69	6.73 –j12.67

Table 1.

Freq. GHz	S11 mag, deg	S12 mag, deg	S21 mag, deg	S22 mag, deg
2.0	0.980, –31	0.035, 67	4.10, 149	0.49, –24.0
2.5	0.965, –37	0.043, 63	4.07, 143	0.48, –28.5
3.0	0.950, –43	0.051, 59	4.04, 137	0.47, –33.0
4.0	0.920, –60	0.067, 48	4.01, 122	0.45, –45.0
5.0	0.880, –76	0.080, 36	3.91, 106	0.41, –58.0
6.0	0.830, –92	0.092, 26	3.76, 91	0.38, –70.0

Table 2.

Freq. (MHz)	K
2.0	0.167
2.5	0.226
3.0	0.271
4.0	0.325
5.0	0.479
6.0	0.508

Table 3.

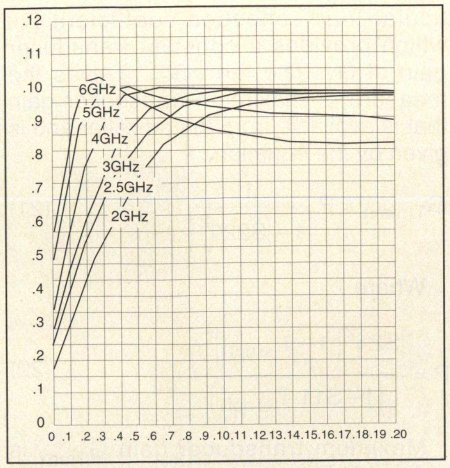

Figure 2. Variation of stability factor (K) versus inductance.

where Z_0 is the characteristic impedance.

The impedance matrix [Z2] of the two-port network with L as a shunt inductance is given by

$$[Z2] = j\omega L \begin{bmatrix} 1 & 1 \\ 1 & 1 \end{bmatrix} \tag{8}$$

The scattering matrix [S] of the interconnected network is obtained from impedance matrix, Z = Z1+ Z2, by using the following equation :

$$[S] = \left[Z + Z_0 \cdot I2\right]^{-1}\left[Z - Z_0 \cdot I2\right] \tag{9}$$

With the above [S] matrix, the stability factor of the interconnected network can be calculated using equation 4. Figure 2 shows how stability factor varies with the value of inductance for the ATF-25 HEMT. From Figure 2 it can be seen that the stability factor increases with an increase in inductance up to a certain value of inductance, then it starts decreasing with inductance. It can be also seen that dk/dL increases with frequency. Also, the four noise-parameters: NF_{min}, RN, $G_{s(opt)}$ and $B_{s(opt)}$ get modified because of series feedback. The following table shows how modified noise parameters vary with inductance. With increasing inductance, the modified noise-parameters ($\widehat{NF}_{min}$), ($\widehat{\Gamma}_{s(opt)}$) and ($\widehat{RN}$) decrease. Even though NF_{min} decreases, modified noise-measure (NM_{min}) is almost constant. The noise-measure $\widehat{NM}_{min}$ is defined as

$$NM_{min} = \left[\frac{NF_{min} - 1}{1 - \dfrac{1}{G_a}}\right] \tag{10}$$

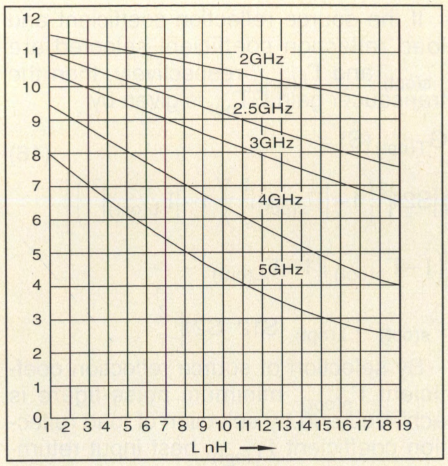

Figure 3. Noise resistance versus feedback inductance.

where G_a is available gain which is equal to G_{opt} (defined later) in this design approach.

Table 4 illustrates the variation of noise parameters with inductance. Fig. 3 shows how noise-resistance R_N decreases with the value of feed back inductance for the ATF-25 HEMT.

Table 5 shows how modified S-parameters vary with inductance. From the table it can be seen that S11 decreases as the value of inductance is increased to a certain limit and then increases whereas S22 increases with an increase in the value of inductance. But S21 decreases with increasing inductance value. Fig. 4 shows how S11 and S22 vary with inductance.

Load Reflection Coefficient

A general technique to achieve best put-return loss (≥15 dB) for a low-noise amplifier is to match the input port with an isolator or some balancing device (typically a hybrid coupler). Since the NF_{min} of HEMTs are very low, even the very low-insertion loss of an isolator deteriorates noise-figure of the amplifier.

A better technique is to choose the load reflection coefficient of the first stage of the amplifier such that input

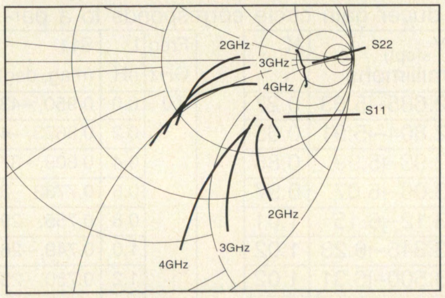

Figure 4. Variation of S11 and S22 with inductance.

reflection coefficient (S11') is the complex conjugate of the optimum source reflection coefficient $\Gamma_{s(opt)}$. Compute input reflection coefficient, S11' from the following equation:

$$S11' = S11 + \frac{S12 \cdot S21 \cdot \Gamma_L}{1 - S22 \cdot \Gamma_L} \tag{11}$$

Now choose Γ_L such that S11' = $\Gamma^*_{s(opt)}$. Therefore,

$$\Gamma^*_{s(opt)} = S11 + \frac{S12 \cdot S21 \cdot \Gamma_{L(opt)}}{1 - S22 \cdot \Gamma_{L(opt)}} \tag{12}$$

and one can derive the optimum load reflection coefficient $\Gamma_{L(opt)}$ from equation 6, which is given by

$$\Gamma_{L(opt)} = \frac{S11 - \Gamma^*_{s(opt)}}{\Delta - S22 \cdot \Gamma^*_{s(opt)}} \tag{13}$$

Transducer Gain (G_T):

Transducer gain is a function of source reflection coefficient Γ_s and load reflection coefficient Γ_L.

$$G_T(S, \Gamma_s, \Gamma_L) = \left[|S21|^2\left(1 - \left|\Gamma_{s(opt)}\right|^2\right)\left(1 - \left|\Gamma_L\right|^2\right)\right] \cdot \left|(1 - \Gamma_s \cdot S11)(1 - \Gamma_L \cdot S22) - \Gamma_s \cdot \Gamma_L \cdot S12 \cdot S21\right|^{-2} \tag{14}$$

To achieve the minimum noise-figure, the first stage source reflection coefficient Γ_s must be equal to optimum source reflection coefficient $\Gamma_{s(opt)}$. Once the source reflection coefficient is chosen, transducer gain G_T is a function of load reflection coefficient Γ_L only and can be expressed as

$$G_T(S, \Gamma_L) = \left[|S21|^2\left(1 - \left|\Gamma_{s(opt)}\right|^2\right)\left(1 - \left|\Gamma_L\right|^2\right)\right] \cdot \left|(1 - \Gamma_{s(opt)} \cdot S11)(1 - \Gamma_L \cdot S22) - \Gamma_{s(opt)} \cdot \Gamma_L \cdot S12 \cdot S21\right|^{-2} \tag{15}$$

If the source reflection coefficient and load reflection coefficient selected are $\Gamma_{s(opt)}$ and $\Gamma_{L(opt)}$, respectively, then the transducer gain GT_{opt} is given by

$$G_{T(opt)}(S) = \left[|S21|^2\left(1 - \left|\Gamma_{s(opt)}\right|^2\right)\left(1 - \left|\Gamma_{L(opt)}\right|^2\right)\right] \cdot \left|(1 - \Gamma_{s(opt)})(1 - \Gamma_{L(opt)}) - \Gamma_{s(opt)} \cdot \Gamma_{L(opt)} \cdot S12 \cdot S21\right|^{-2} \tag{16}$$

By selection of source reflection coefficient $\Gamma_{s(opt)}$, minimum noise-figure is achieved and by selection of load reflection coefficient $\Gamma_{L(opt)}$, best input return-loss is achieved. Table 6 shows how $G_{T(opt)}$ and output return-loss vary with feedback inductance. From the table it can be seen that $G_{T(opt)}$ increases as the value of inductance is increased to a certain limit and then decreases whereas output return-loss improves with increase of inductance value.

Transducer Gain Circles

Equation 7 defines a family of circles called constant transducer gain (G_T) circles whose centers and radii on the load plane are given by:

$$\text{Radius} = \frac{\sqrt{1 - g_i}\left[1 - |S22'|^2\right]}{1 - |S22'|^2(1 - g_i)} \tag{17}$$

$$\text{Center} = \frac{g_i|S22'|}{1 - |S22'|^2(1 - g_i)}, \tag{18a}$$

$$\angle \tan^{-1}\left(\frac{B_i}{A_i}\right) \tag{18b}$$

Where

$$S22' = \frac{S22 - \Delta\Gamma_s}{1 - S11 \cdot \Gamma_s} = A_i + jB_i \tag{19}$$

and

$$g_i = \frac{G_T}{G_{T(max)}} \tag{20}$$

Each point on the locus of the transducer gain circle corresponds to a particular load reflection coefficient Γ_L, which provides a constant transducer gain of G_T. The term G_{Tmax} gives the measure of maximum transducer gain that is available from the amplifier and is given by the equation

$$G_{T(max)} = P \frac{1}{\left[1 - |S22'|^2\right]} \tag{21}$$

Where

$$P = \frac{|S21|^2\left(1 - \left|\Gamma_{s(opt)}\right|^2\right)}{\left(1 - S11 \cdot \Gamma_{s(opt)}\right)} \tag{22}$$

Maximum transducer gain G_{Tmax} is obtained when the load reflection coefficient is equal to $\Gamma_{L(max)}$ and it is given by

$$\Gamma_{L(max)} = \left[\frac{S22 - \Delta\Gamma_s}{1 - S11 \cdot \Gamma_s}\right] \tag{23}$$

For a given transistor, if $\Gamma_{s(opt)}$ and $\Gamma_{L(max)}$ are chosen as source reflection coefficient and load reflection coefficient respectively, maximum transducer gain, good output return-loss, lowest noise-figure can be achieved but the input return-loss would be poor. (it depends upon value of feedback inductance). Table 7 shows how G_{Tmax}, input return-loss and $\Gamma_{L(max)}$ vary with feedback inductance .

From Table 7 it is evident that G_{Tmax} can be traded off for better input return-loss by using higher value of inductance.

Fig. 7 shows variation of GT_{max} and GT_{opt} as a function of feedback inductance .

From Fig 7 and Tables 6 and 7 the following inferences can be drawn

1. Up to 3 GHz for low values of inductance GT_{max} is undefined as the input return-loss is negative, i.e. the input impedance is negative and for a particular value of source impedance it becomes unstable.
2. GT_{max} decreases rapidly with increase in inductance up to a certain value of inductance.

Freq GHz	L nH	NF_{min} dB	$G_{s(opt)}$ mag, deg	R_n ohms	$Y_{s(opt)}$ millimohs	K
3.0	0.0	0.200	0.78, 33.00	10.5	2.685–j5.83	0.27
	0.2	0.199	0.772, 33.48	10.0	2.804–j5.91	0.65
	0.4	0.198	0.764, 33.96	9.54	2.93–j5.99	0.85
	0.6	0.197	0.7547, 34.45	9.08	3.06–j6.07	0.97
	0.8	0.196	0.7455, 34.95	8.65	3.12–j6.15	1.01
	1.0	0.195	0.736, 35.44	8.23	3.345–j6.23	1.02
	1.2	0.194	0.726, 35.95	7.83	3.500–j6.31	1.02

Table 4.

Freq GHz	L nH	S11 (mag, deg)	S12 (mag, deg)	S21 (mag, deg)	S22 (mag, deg)
3.0	0.0	0.950, –43.00	0.0510, 59.00	4.04, 137.00	0.4700, –33
	0.2	0.8673, –40.74	0.0484, 75.31	3.755, 129.41	0.4623, –25.41
	0.4	0.809, –37.35	0.0523, 88.46	3.461, 122.99	0.4894, –12.5
	0.6	0.7733, –33.49	0.0590, 96.38	3.18, 117.62	0.5315, –6.71
	0.8	0.755, –29.72	0.0661, 100.6	2.922, 113.16	0.5766, –3.31
	1.0	0.749, –26.33	0.0728, 102.75	2.69, 109.43	0.6189, –1.41
	1.2	0.750, –23.43	0.0787, 103.74	2.489, 106.3	0.6566, –0.4
	1.4	0.756, –21.02	0.0838, 104.1	2.3097, 103.6	0.7044, 0.2

Table 5.

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X	.050 (1.27) ±.010 (0.25)	

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	T.C. (-55 °C to +125°C)	Max. D.F. @ 1 MHz (%)	Max. D.F. @ 1 KHz (%)
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EA	N4700 ±1500 PPM/°C	.25	N/A
BX	±15%	4	2
XR	±15%	3	3
ZV	+22 -82% (+10°C to +85°C)	4	4

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BG DIELECTRIC (NPO)			EA DIELECTRIC (N4700)			BX DIELECTRIC			XR DIELECTRIC (X7R)			ZV DIELECTRIC (Z5V)		
Cap. (pF)	Size	Tol.	Cap. (pF)	Size	Tol.	Cap. (pF)	Size	Tol.	Cap. (pF)	Size	Tol.	Cap. (pF)	Size	Tol.
1.0			6.8		B, C, D	27			47			120		
1.2	T		8.2	T		33	T		56	T		180	T	
1.5			10			39			68			220		
1.8			12			47			100			330	U	
2.0			15			56		J, K, M	120	U	J, K, M	390		J, K, M
2.4	U		18	U	J, K, M	68	U		150			470		
2.7		B, C, D	22			82			180			560	X	
3.0			27			120	X		220	X		680		
3.3			33			150			270			820		
3.9			39	X										
4.7	X		47											
5.1														
6.2														
6.8														

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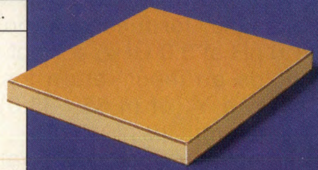

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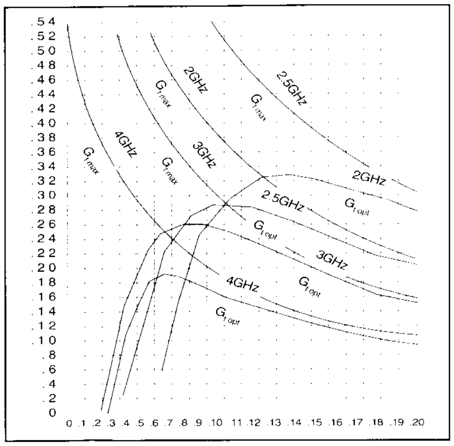

Figure 7. Variation of $G_{T(opt)}$ and $G_{T(max)}$ with frequency.

3. GT_{opt} increases with increase in inductance up to certain value of inductance and then decreases.
4. The difference of GT_{max} and GT_{opt} decreases with increase in inductance value.
5. The input return-loss is less sensitive to load admittance variations with increase in inductance value. For example, for feedback inductance of 1.0 nH at 3.0 GHz, a Y_L of (7.8, –j2.3) yields an input return loss ≥15 dB, while a Y_L of (4.65, –j5.0) yields an input return loss = 13 dB.
6. For higher inductance values $\Gamma_{L(opt)}$ and $\Gamma_{L(max)}$ increase and hence realizing a broadband matching network will be difficult. For example, for feedback inductance of 2.0 nH at 3.0 GHz: At $\Gamma_{L(opt)}$ = (0.7415∠9.39), Y_L = (3.0,–j1.6), input return loss ≥ 15, G_T = 14.8. At $\Gamma_{L(max)}$=(0.763∠16.92), Y_L = (2.75,–j2.9), input return loss = 15, G_T = 15.6.

For realizing a 3 GHz amplifier using the ATF-35, the optimum feedback inductance value is about 1.0 nH.

Realizing Feedback Inductance:

Generally, for microwave transistors the manufacturer provides two source leads. A shorted transmission line, whose length is less than λ/8 and having high characteristic impedance is equivalent to a lumped inductance. Realization of inductance by four shorted transmission lines of 125 ohms impedance makes it less sensitive to fabrication errors. For example at 3.0 GHz, let 1.0 nH be selected as the series feedback inductance, and let ε_r for the substrate be 2.22. Then the length of the transmission line can be computed using standard relation as shown below.

$$Z = 4j\omega L = 75.0 = jZ_0 \tan\beta L = j125\tan\frac{2\pi L}{\lambda} = j125\tan\theta \quad (24a)$$

$$\tan\theta = \frac{125}{75}, \theta = 31^\circ \quad (24b)$$

$$\frac{2\pi L}{\lambda_g} = 31^\circ, L = \frac{31\cdot\lambda_g}{360} = 7.6\text{mm} \quad (24c)$$

Design Example:

Let us consider design of 2.5 to 3.0 GHz low-noise amplifier using ATF-35

Selection of feedback inductance - From Fig. 2, for inductance value of 1.0 nH, the stability factor is more than one for the band of 2.5 to 3.0 GHz. From Fig. 7 for 1.0 nH, the value of GT_{max} is not in the steep fall region, indicating less variation with the value of the inductor. However the GT_{opt} is less than peak value. So based on these factors 1.0 nH feedback inductor has been selected.

Several programs were developed for converting manufacture's S parameters to the various quantities used in amplifier design, resulting in the following data:

At 2.5 GHz:
$\Gamma_{L(opt)}$ = 0.772∠29.38
$Y_{s(opt)}$ = 2.75 – j5.15 (m mhos)
$\Gamma_{L(max)}$ = 2.84∠9.19
$Y_{L(opt)}$ = 11.2 – j1.1 (m mhos)
RL (out) = 7.22 dB
RL(in) >15 dB

At 3.0 GHz:
$\Gamma_{L(opt)}$ = 0.736∠35.45
$Y_{s(opt)}$ = 3.345 – j6.23 (m mhos)
$\Gamma_{L(max)}$ = .4456∠15.50
$Y_{L(opt)}$ = 7.80 – j2.32 (m mhos)
RL (out) = 9.69 dB
RL(in) >15 dB

Design of Single Stage Amplifier :

If the input and output matching networks are designed to realize $Y_{s(opt)}$ and Y_{opt}, the following are the various parameters for the single stage amplifier

At 2.5 GHz:
gain = 14.5 dB, NF = 0.16 dB

At 3.0 GHz:
gain = 13.7 dB, NF = 0.20 dB

Then to achieve good output return-loss an isolator can be used in the output port. Thus, best input return-loss, best output return-loss, best noise-figure can be achieved but constant gain can not be achieved over the required band-

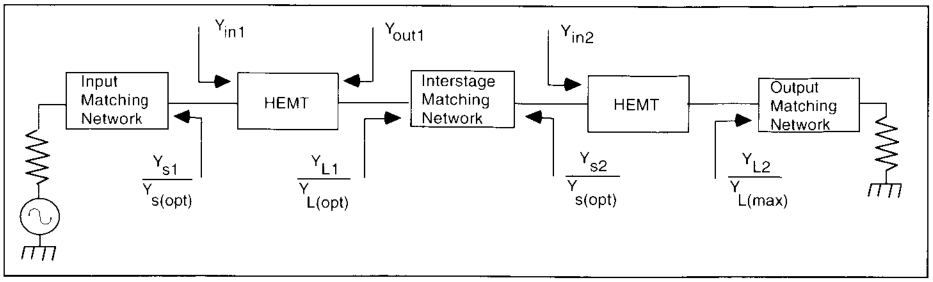

Figure 10. Admittances for two-stage amplifier.

Freq GHz	L nH	$\Gamma_{L(opt)}$ (mag, deg)	$R_{L(out)}$	$G_{t(opt)}$	$Y_{L(opt)}$ millimohs
3.0	0.0	1.3986, –64.94	–1.02	–24.68	–4.62+j12.2
	0.2	0.9554, –89.92	0.14	2.01	0.91+j20.0
	0.4	0.3955, –103.6	2.51	20.05	17.4+j15.86
	0.6	0.1147, –31.34	5.21	25.54	16.32+j1.98
	0.8	0.2975, 13.82	7.68	25.32	10.94–j1.7
	1.0	0.4456, 15.50	9.69	23.42	7.79–j2.32
	1.2	0.5463, 14.23	11.16	21.27	5.95–j2.28
	2.0	0.7415, 9.39	12.88	14.79	2.99–j1.60

Table 6.

Freq GHz	L nH	$\Gamma_{L(opt)}$ (mag, deg)	$R_{L(in)}$	$G_{t(max)}$	$Y_{L(max)}$ millimohs
3.0	0.0	0.4812, 101.68	–2.4	93.82	14.83–j18.19
	0.2	0.4661, 85.84	0.1	73.69	10.34–j12.02
	0.4	0.5128, 54.33	5.73	45.71	7.92–j8.96
	0.6	0.5606, 42.81	8.58	36.57	6.42–j7.14
	0.8	0.6045, 35.19	10.89	30.53	5.39–j5.92
	1.0	0.6423, 29.85	12.68	26.23	4.65–j5.06
	1.2	0.6745, 25.90	13.92	23.03	4.08–j4.42
	2.0	0.763, 16.92	14.98	15.59	2.75–j2.90

Table 7.

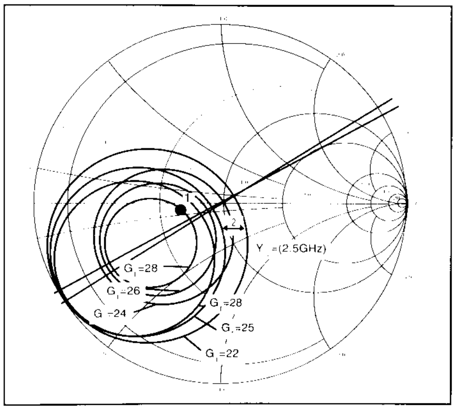

Figure 11. Transducer gain circles

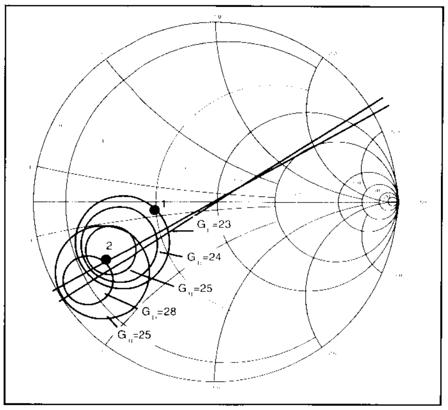

Figure 12. Power gain circles

width in a single stage amplifier.

Design of Two Stage LNA:

Only occasionally does a single-stage amplifier provide all the gain a system requires, hence, multi-stage amplifiers are commonly used. The total gain of a two stage amplifier is given by

$$G = G_{T1} \cdot G_{P2} \qquad (25)$$

Where
G_{T1} = Transducer gain of 1st stage
G_{P2} = Power gain of 2nd stage

Using the same programs mentioned earlier, the following data was derived:

At 2.5 GHz:
$\Gamma_{L(max)} = 0.6125\angle 31.64$
$Y_{L(max)} = (5.17\text{–}j5.32)$ m mhos
$\Gamma_{T(max)} = 34.79$ (15.4 dB)
$G_{opt} = 28.2$ (14.50 dB)
$G_{P(max)} = 47.53$ (16.77 dB)
$\Gamma_{smp} = 0.981\angle 36.70$
$Y_{smp} = (0.20\text{–}j6.6)$ m mhos
$\Gamma_{Lmp} = 0.959\angle 34.67$
$Y_{Lmp} = (0.50\text{–}j6.2)$ m mhos
Maximum gain = 28.2·47.53
= 1340.35 (31.27 dB)

At 3.0 GHz:
$\Gamma_{L(max)} = 0.6424\angle 29.84$
$Y_{L(max)} = (4.65\text{–}j5.06)$ m mhos
$\Gamma_{T(max)} = 26.23$ (14.2 dB)
$G_{opt} = 23.42$ (13.7 dB)
$G_{P(max)} = 30.07$ (14.78 dB)
$\Gamma_{smp} = 0.9065\angle 40.99$
$Y_{smp} = (1.10\text{–}j7.5)$ m mhos
$\Gamma_{Lmp} = 0.8419\angle 34.01$
$Y_{Lmp} = (1.9\text{–}j6.1)$ m mhos
Maximum gain = 23.42·30.07
= 704.34 (28.48 dB)

The following design objectives were laid out for each of the matching networks:

1. The input matching network should transform 50 ohms to $Y_{s(opt)}$ to achieve minimum noise-figure.
2. The interstage matching network is designed to transform the 2nd stage input admittance to $Y_{L(opt)}$ to achieve best input return-loss, and, transform the 1st stage output admittance to $Y_{s(opt)}$ to achieve minimum noise contribution from the 2nd stage.
3. The output matching network is designed to achieve uniform gain over the 2.5 to 3.0 GHz band and to achieve best output return loss.

Gain at 3.0 GHz limits the highest gain attainable across the 2.5 to 3.0 GHz band, so to make gain uniform across that band, the gain at 3.0 GHz must be optimized. To do this, Y_{s2} is chosen equal to $Y_{s(opt)}$, therefore, Y_{s2} = (3.4-J6.2) m mhos. Using standard equation Y_{out} is computed. Y_{out2} = (4.65 +j5.06) m mhos Choose Y_{L2} (load admittance) = Y_{out2} = (4.65-J 5.06)m mhos From Fig 11 power gain G_{P2} for a load admittance of (4.65-J5.06)m mhos is 28.0 (14.5 dB). This value of load admittance provides best output return-loss also. Then the input admittance Y_{IN2} is equal to (2.3–j7.0) m mhos. Even though for a load admittance of (1.9 – j6.1) m mhos, power gain G_{P2} of 30.0 (14.8dB) is achieved but the corresponding input admittance (Y_{IN2}) is (1.1 + j7.4)m mhos and with this low input admittance (Y_{in2}) inter-stage matching network design becomes difficult.

The maximum power gain at 2.5 GHz is 47.53. But to achieve uniform gain in the frequency band of 2.5 to 3.0 GHz, choose load admittance, Y_{L2} such that more conductive mismatch is provided on power gain circle. This will assure less sensitivity to variation in loads. Thus Y_{L2} is chosen on power gain circle of 25.0 (14 dB) as shown in Figure 12. If Y_{L1} differs from $Y_{L(opt)}$, one can obtain actual value of transducer gain circles shown in Figures 11 and 12.

Conclusion

This paper describes design of a low noise RF amplifier in 2.5 - 3.0 GHz band using a HEMT. An illustrative example using the ATF-35 is also included. The design is completed using simple analytical techniques and the best solution for a two stage amplifier is achieved. Even though computer optimization is a powerful design tool, it does not provide best solution and is time consuming and costly when a number of variables over a large range are to be optimized. Hence, for a cost effective optimum design, use analytical techniques as described in the paper and then apply optimization techniques.

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S. Satyanarayana received his engineering degree from the Govt. College of Engineering, Kakinada, Andhra Pradesh, India, in 1971, and in the same year joined the Vikram Sarabhai Space Centre. He is responsible for the development of on-board S-band coherent transponders, and is currently working on numerically controlled oscillators and phase locked loop circuits. He can be reached at the Vikram Sarabhai Space Centre, Trivandrum, 695 022, India.

RF Receiver For A Bistatic Radar

By Ramir De Porrata-Dòria i Yagüe,
Antoni Elias Fusté and
Javier Fernández de Muniain
Universitat Politècnica de Catalunya

It is well known that implementing a radar system design is a very costly task. When the radar is bistatic, the cost is even higher. Bistatic radar is defined as a radar that uses antennas at different locations for transmission and reception [1]. The separation between the transmitter and receiver subsystems requires the development of unique synchronization techniques and processing complexity. This article presents the design of a RF receiver for a low-cost bistatic radar, using as a transmitter one of the Barcelona airport's two monostatic radars. This inexpensive RF receiver is tunable between 2.55 GHz and 3 GHz, has high gain (45 dB), low noise figure (1.3 dB), high selectivity (ΔB-3 dB = 5 MHz) and remarkable immunity against temperature changes.

In this case, the transmitter subsystem is located at Barcelona's airport and the receiver subsystem is located at the Department of Signal Theory and Communications of the Universitat Politecnica de Catalunya, giving a baseline of 10.9 km. The cost of the system is reduced because of the hitchhiking techniques used to synchronize the transmitter and receiver on a monostatic airport radar already in use.

In order to synchronize both subsystems the receiver has been divided in two parts–one for receiving and processing the echoes backscattered by targets and another for synchronization purposes (hitchhiking). The first one, which we will refer to as the receiver module, uses an omnidirectional antenna (monopole), whereas the second one, which we will refer to as the synchronization module, uses a directional Yagi antenna aiming at the transmitter subsystem. The geometry for the radar is shown in Figure 1.

The two monostatic radars of Barcelona's airport operate with two frequency diversity bands each, which requires that the RF receiver be tunable over a wide range. In addition, gain, noise figure and strength are very restrictive as the RF receiver will deal with very small signals and will be exposed to wind and weather.

Structure Used

The schematic diagram of the RF receiver is shown in Figure 2. The subdivision between the receiver and synchronization modules, which are functionally identical, is easy to recognize. As shown in Figure 2, each part consists of a low noise amplifier, followed by a RF filter, a mixer, an intermediate frequency (IF) filter and an IF amplifier. Since the requirements for both modules are basically the same and in order to minimize the cost, the two receivers were built using the same design.

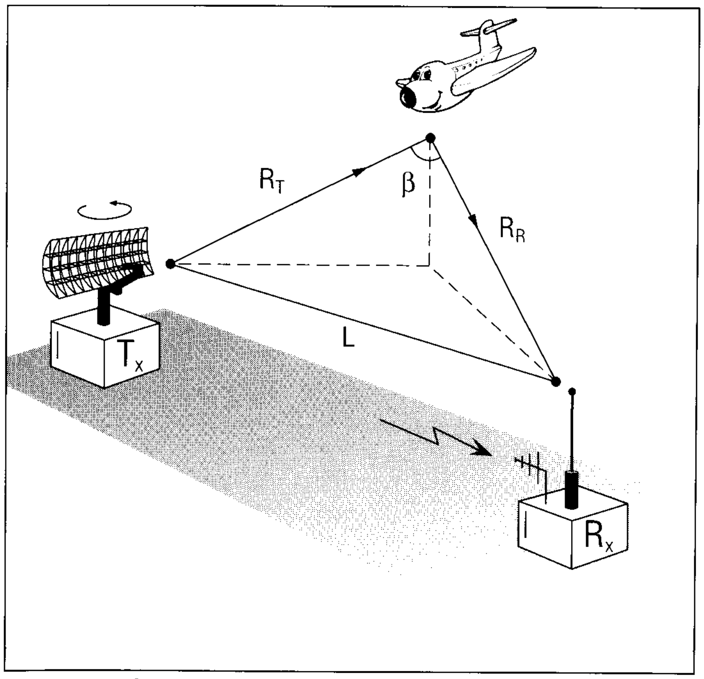


Figure 1. Geometry for the bistatic radar.

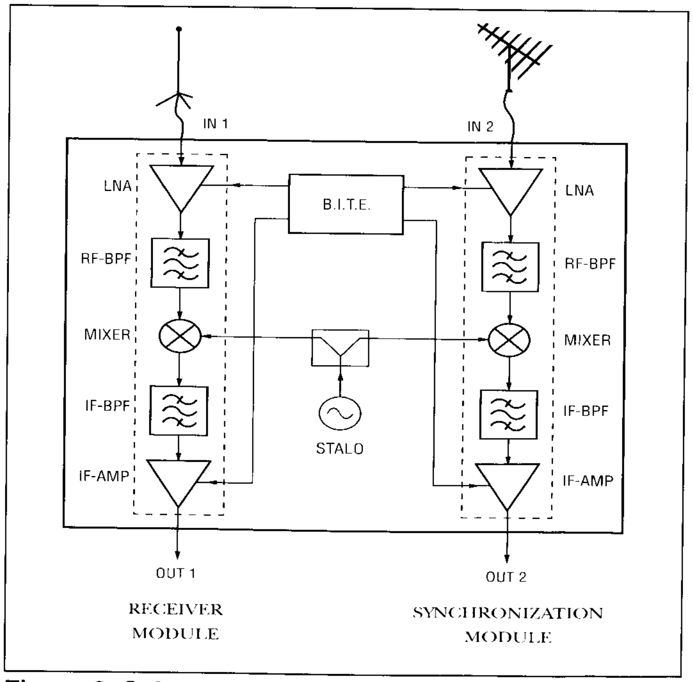
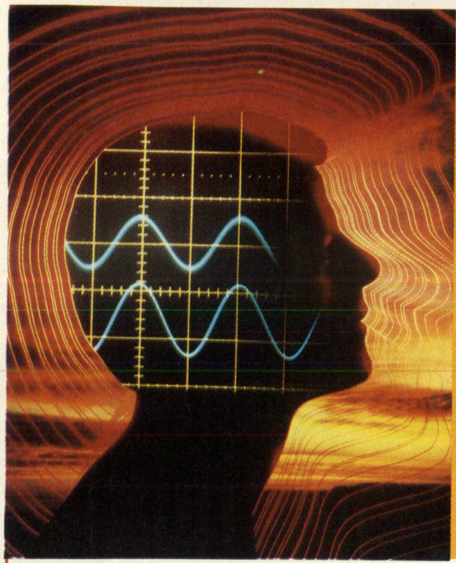


Figure 2. Schematic diagram of the RF receiver.



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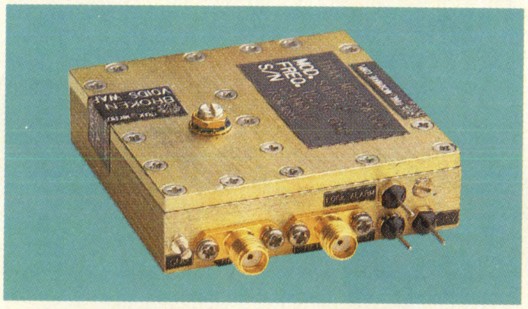

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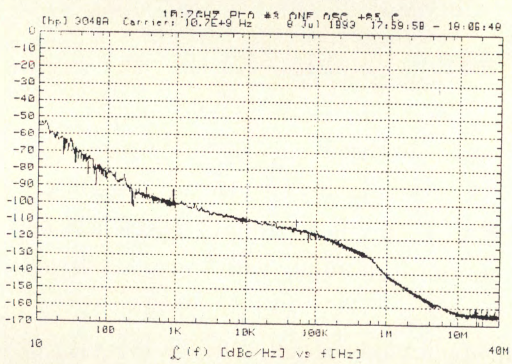
100 KHz	-118 dBc/Hz
1 MHz	-142 dBc/Hz
10 MHz	-163 dBc/Hz



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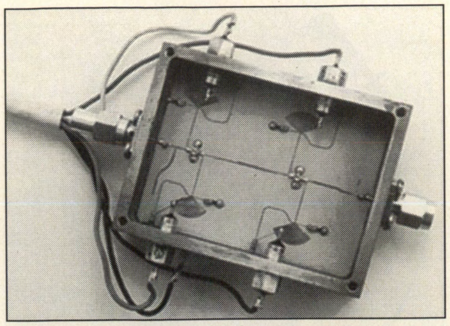

Figure 3. Low noise amplifier.

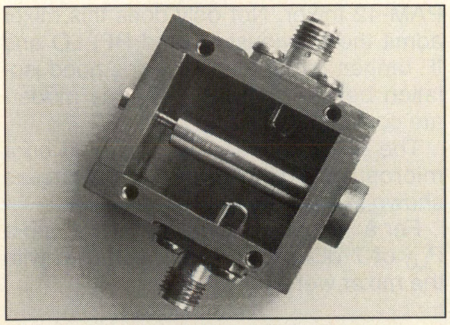

Figure 4. Bandpass RF filter.

Design Process

Low Noise Amplifier (LNA) — The low noise RF amplifier is one of the most important devices of the RF receiver since it determines the noise figure of the whole subsystem and thus the reduction of the signal to noise ratio.

The configuration used is that of a single-ended, two-stage amplifier with reactive matching networks. The technology is microstrip over Epsilam-10 substrate, and the central design frequency is 2.75 GHz. The chosen transistors were the Fujitsu FSX02FA for the first stage and the Fujitsu FSC10FA for the second.

The design process was developed with the Hewlett Packard software package M.D.S. (Microwave Design System). In this process, the input matching network was optimized in order to achieve minimum noise figure, whereas the interstage and output matching networks were designed to maximize the gain of the amplifier. The DC-blocking needed in the interstage network was obtained using a parallel coupled-lines configuration. The appearance of the amplifier is shown in Figure 3.

The results (gain, noise figure, bandwidth and 1 dB compression point) obtained at 2.75 GHz were the following:

$$G = 25 \text{ dB}$$
$$F = 1.3 \text{ dB}$$
$$\Delta B_{-3dB} = 700 \text{ MHz}$$
$$P_{1dB} = -8 \text{ dBm}$$

RF filter (RF-BPF) — As it has been mentioned, there are two monostatic radars operating simultaneously at Barcelona's airport. Therefore, one receiver has to reject the unwanted radar signal while permitting the transmission of the desired one. This, together with the need to reject the image band of the conversion to intermediate frequency, make it necessary to filter the input signal. Since both transmitters are very close in frequency (35 MHz at 2.75 GHz in the worst case) and both operate in two diversity frequency bands, the filter must be highly selective, easily tunable between 2.7 and 2.9 GHz, and have low insertion loss, which requires a high quality factor, widely-tunable bandpass filter.

To achieve these requirements, the structure chosen was that of a coaxial resonator in a re-entrant cavity with inductive loop couplings, using air as a dielectric and brass as a conductive material. This type of filter, [2, 3], consists of a conductive cavity with a quarter-wavelength center post inside. Energy flows into the cavity through an inductive loop and is extracted through another inductive loop placed at the opposite side. The resonant frequency is determined by the length of the resonator post, while the QL (loaded Q) of the filter is determined by the dimensions and location of the couplings.

The tuning circuit consists of a Tekelek 6924-0 tuning screw placed at the top of the center post. Because the screw is connected to ground, it has the effect of providing capacity loading for the resonant post, resulting in a change in the resonant frequency of the filter. When the screw is rotated inward, the capacitive loading is increased and the resonant frequency is lowered.

The transverse dimensions of the cavity and center post, which determine the characteristic impedance of the resonator, were calculated analytically. To obtain the optimum longitudinal dimensions of the filter, an equivalent circuit was first proposed, then its performance was computed and afterwards its dimensions were optimized in the Hewlett Packard M.D.S. program. Finally, the dimensions of the couplings were adjusted experimentally. The filter, with its definitive dimensions, provided the following results

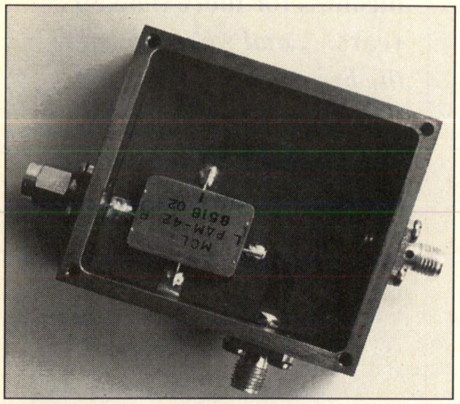

Figure 5. Photograph of the mixer.

(also see Figure 4):

Tunable range (f_0):	2.55 - 2.99 GHz
Tuning resolution:	1 MHz
Quality factors:	$Q_L = 275$
	$Q_u = 1030$
	$Q_e = 375$
Bandwidth:	10 MHz
Insertion loss (IL):	2.7 dB
Return loss:	11.8 dB
Temperature stability:	$\Delta f_0 < 2$ MHz
	$\Delta IL < 1$ dB

($-10°C < T < 60°C$)

Mixer (down-conversion to IF) — The bistatic radar receiver is superheterodyne with a double conversion to intermediate frequency. The first conversion takes place at the RF receiver and, consequently, two mixer circuits are required (one for the receiver module and another for the synchronization module).

To obtain a fixed intermediate frequency of 332 MHz for a variable RF frequency (2.7 - 2.9 GHz), the local oscillator (STALO) must be tunable between 2.368 GHz and 2.568 GHz, which requires a mixer operative in these ranges. Considering this, the model chosen was the Mini-Circuits PAM-42 mixer. Not only does this mixer admit the previously stated RF, LO and IF ranges, but it also provides good isolation between ports as well as moderate conversion losses.

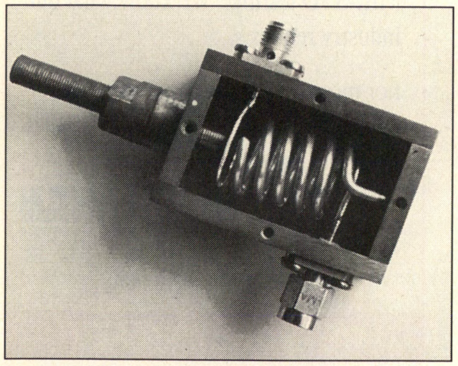

Figure 6. Bandpass IF filter.

The mixer was surface-mounted on a microstrip CUCLAD-250 substrate as shown in Figure 5.

For a RF frequency of 2.75 GHz and a P_{LO} of 7 dBm, the results obtained with the mixer were:

f_{RF} = 2.75 GHZ	P_{1dB} = 1 dBm
f_{LO} = 2.418 GHZ	$I_{LO\text{-}IF}$ = 18 dB
f_{FI} = 332 MHz	$I_{RF\text{-}IF}$ = 12.5 dB
L_c = 9 dB	$I_{LO\text{-}RF}$ = 24 dB

IF filter (IF-BPF) — Signficant RF and LO components are present at the mixer's IF output—the result of limited isolation between the mixer ports. The goal of the IF filter is to attenuate those components as well as the second and third order intermodulation products generated by the mixer and to increase the selectivity of the receiver in order to reject the unwanted radar signal.

The central frequency of the filter will therefore be the IF frequency (332 MHz). In this band (VHF - low UHF), filters with high quality factors cannot be realized by conventional techniques. Lumped components like inductors and capacitors perform poorly at these frequencies, whereas coaxial resonators cannot be used because of their large size. Nevertheless, helical resonators provide a solution to all these problems filling an important void in the frequency spectrum.

Helical resonators are very similar to coaxial resonators except that a helical conductor is substituted for the central post. The helical conductor operates as a quarter-wavelength resonant line. The operating principle and performance are identical to those of coaxial filters although the resonant frequency is much lower.

In the design process, the dimensions of the resonator and the cavity were calculated analytically following the process in Reference 3.

Coupling into the resonator was achieved with an inductive loop positioned where the magnetic field is maximum, that is, slightly below the helix in a plane perpendicular to the helix axis. Output coupling was achieved with a capacitive probe placed on top of the helix, where the electric field is maximum. This configuration avoids direct coupling effects which would have resulted in a stopband rather than a passband frequency response. The adjustment of the couplings was done experimentally.

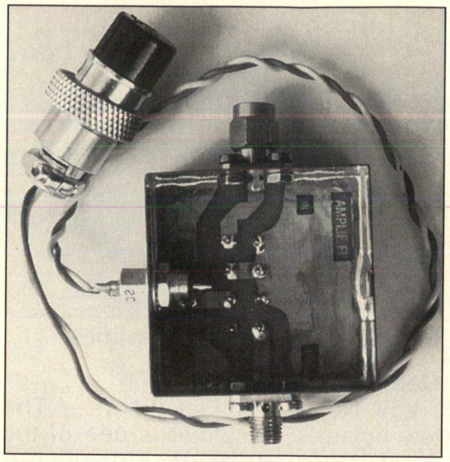

Figure 7. IF amplifier.

The tuning circuit, like the RF filter, consists of a tuning screw placed at the top of the helix and follows the same previously stated principle.

In the construction of the cavity, brass was used as a conductive material and copper was employed for the helix and for the couplings. A photograph of the filter is shown in figure 6.

The measured parameters of the filter are the following:

Central frequency (f_0):	332 MHz
Quality factors:	$Q_L = 59$
	$Q_u = 600$
	$Q_e = 65$
Bandwidth:	5.6 MHz
Insertion loss (IL):	0.9 dB
Return loss:	23 dB
Temperature stability:	$\Delta f_0 < 200$ kHz
	$\Delta IL < 1$ dB

($-10°C < T < 60°C$)

IF Amplifier (IF-AMP) — The distance between the external (first IF conversion) and internal (second IF conversion) units of the radar receiver is 25 meters. Compensating the attenuation of this cable and avoiding the reduction of the signal-to-noise ratio are the main goals of the IF amplifier.

The choice of the amplifier was based on gain and compression point considerations. The model selected was the Mini-Circuits MAN-1LN and was mounted on a fiberglass-substrate using microstrip technology. The amplifier is shown in Figure 7.

The measured characteristics of the amplifier for a DC polarization of 12 V were:

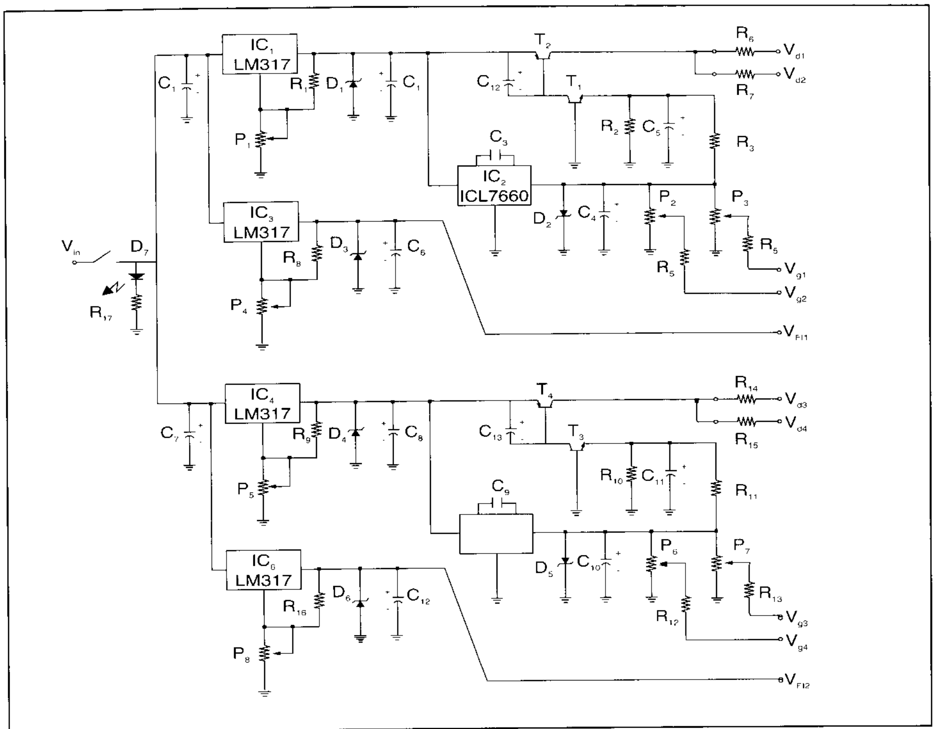

Figure 8. Circuit diagram of the Built In Test Equipment.

G = 30.9 dB
RL = 21.3 dB
P_{1dB} = -19 dBm
F = 2.6 dB

Built-In Test Equipment (B.I.T.E.) — A circuit capable of supplying regulated voltages and currents was needed to bias the active devices of the RF receiver. The B.I.T.E. was designed in order to

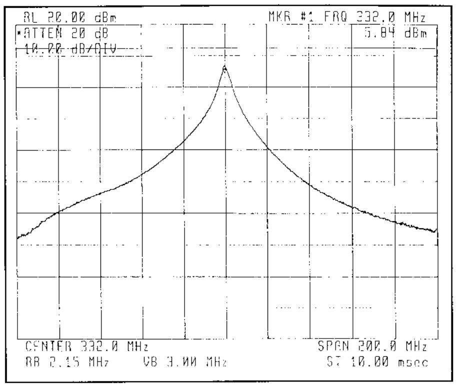

Figure 9. Frequency response of the RF receiver.

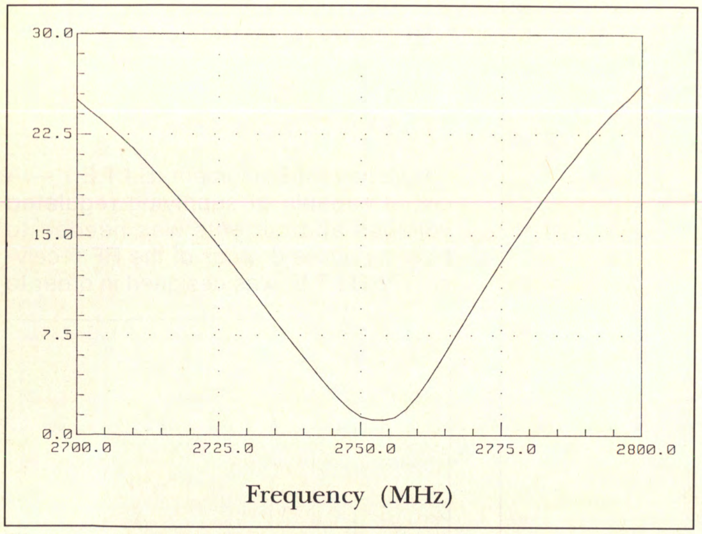

Figure 10. Noise figure of the RF receiver.

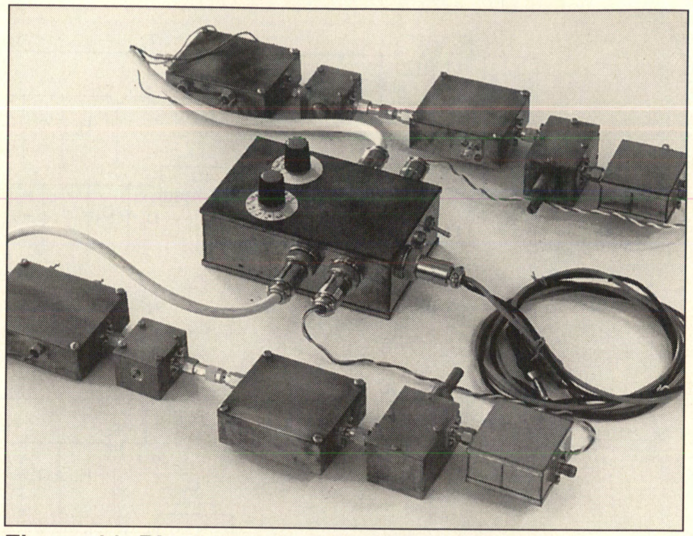

Figure 11. Photograph of the RF receiver.

precisely adjust these voltages and currents and, at the same time, to provide an easy and reliable way to monitor them.

As it can be seen in Figure 8, the circuit diagram only contains lumped elements. In the design process, special care was taken in the turn-on and turn-off transient responses to extend the life of the low-noise amplifier MESFETs. In this sense, during the circuit turn-on, MESFET gates are biased before the drains, whereas in the turn-off, drains are unbiased before the gates.

Monitoring the ten voltages and four currents supplied by the B.I.T.E. is done by externally connecting two volt meters and selecting the desired voltage or cur-

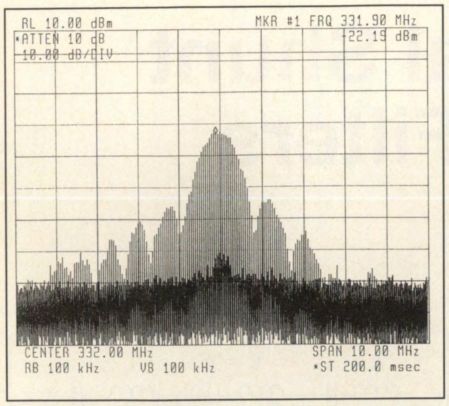

Figure 12. Signal obtained with the synchronization module in a real environment.

rent with two multi-position switches.

The values of the components used are the following:

$R_1 = R_9 = 200\ \Omega$
$R_2 = R_{10} = 2.4\ k\Omega$
$R_3 = R_{11} = 3.9\ k\Omega$
$R_4 = R_5 = R_{12} = R_{13} = 5.1\ k\Omega$
$R_6 = R_7 = R_{14} = R_{15} = 10\Omega$
$R_8 = R_{16} = 220\ \Omega$
$R_{17} = 1.2\ k\Omega$
$C_1 = C_7 = 0.1\ \mu F$
$C_2 = C_6 = C_8 = C_{12} = 1\mu F$
$C_3 = C_9 = 10\ \mu F$
$C_4 = C_5 = C_{10} = C_{11} = 47\ \mu F$
$C_{12} = C_{13} = 1\ nF$
$P_1 = P_5 = 500\ \Omega$
$P_2 = P_3 = P_6 = P_7 = 5\ k\Omega$
$P_4 = P_8 = 2\ k\Omega$
$D_1 = D_2 = D_4 = D_5 = 4.7\ V$
$D_3 = D_6 = 13\ V$
$T_1 = T_3 = SC147$
$T_2 = T_4 = SC257$

Characterization Of The RF Receiver

The results obtained with the RF receiver for a P_{LO} of 8 dBm were the following:

	Receiver module	Sync. module
f_0 (MHz)	332	332
G (dB)	45.6	45.1
ΔB_{-3dB} (MHz)	3.8	5.0
F (dB)	1.3	1.4
P_{1dB} (dBm)	–35	–33
$P_{LO\ out}$ (dBm)	–21.6	–8.3

The system performs extremely well. Moreover, the variation in gain in a temperature range between 0°C and 55°C is less than 1 dB in both modules. The frequency response of the receiver module, the noise figure distribution as a function of the RF frequency and the appearance of the RF receiver are shown in Figures 9, 10 and 11, respectively. Finally, Figure 12 shows the signal obtained with the synchronization module in a real environment, that is, with the Yagi antenna aiming at the transmitter. This last figure shows clearly the typical spectrum of a pulsed radar signal.

Conclusions

In this article we have presented an original idea for implementing a low cost bistatic radar system as well as the design and construction of a high-performance low cost RF receiver for that type radar.

To minimize the radar cost, a monostatic pulsed radar already in operation is used as a transmitter. The transmitter used is one of the two radars located at Barcelona's airport, operating at 2.75 GHz. The added bistatic system uses a hitchhiking technique that synchronizes the transmitter and receiver subsystems.

The RF receiver has been designed in order to maximize its performance and, at the same time, to reduce its cost and complexity as much as possible. The results are a high gain, low noise figure and high selectivity as well as great strength, reliability and low sensitivity to temperature. ***RF***

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3. A. Zverev, Handbook of Filter Synthesis, Wiley & Sons, 1967, p. 27-28, 499-520.

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Computer Design of Equal Shunt Value Tubular Bandpass Filters

By Albert J. Klappenberger
Consultant

The tubular bandpass filter, (sometimes called the coaxial bandpass filter), has enjoyed wide acceptance throughout the electronics industry due to its fine ultimate rejection, low insertion loss and wide frequency range characteristics. It is however, a difficult filter to design. Tubular filters having equal value shunt capacitors (or "slugs" as they are generally referred to) have traditionally been designed by empirical means. Correct computer designs have been an elusive matter. The method that will be presented here has been implemented in a filter design program called PCFILT, and it goes a long way toward an acceptable compromise solution.

A coaxial bandpass filter is built using metal disks, referred to as "slugs", for the shunt capacitors, with thin PTFE "coupling" washers between them. These "slugs" and coupling washers have holes in the center through which a PTFE rod is passed and then screwed into both "end-slugs" to hold the entire assembly together. The inductors are wound on PTFE tubes referred to as "forms" that slip over the PTFE rod, holding the slugs on each side of the inductor a precise distance apart. The entire assembly is surrounded by PTFE tape to insulate it from ground and then pushed down a metal tube to form the shunt capacitors at each slug.

The design procedure presented here begins with a lumped element "mesh" filter. Each capacitor associated with the inner "sections" of the filter are replaced with two capacitors of twice the value placed on either side of the section inductor. This generates a "Tee" configuration at each shunt coupling that is then converted to a "Pi" or "delta" configuration as illustrated in Figure 1.

The initial mesh filter can be synthesized by a number of methods including the insertion of "j" inverters between each pole of a direct scaled filter [1] or by exact synthesis techniques. In either case, the values of the shunt capacitors are often equal in pairs around each series coupling capacitor (except at the ends) but are never all equal to each other.

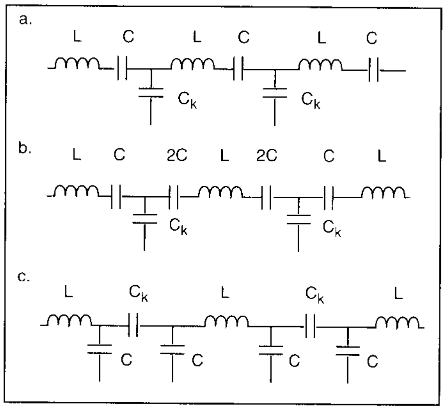


Figure 1. Transformation of a filter to the tubular form.

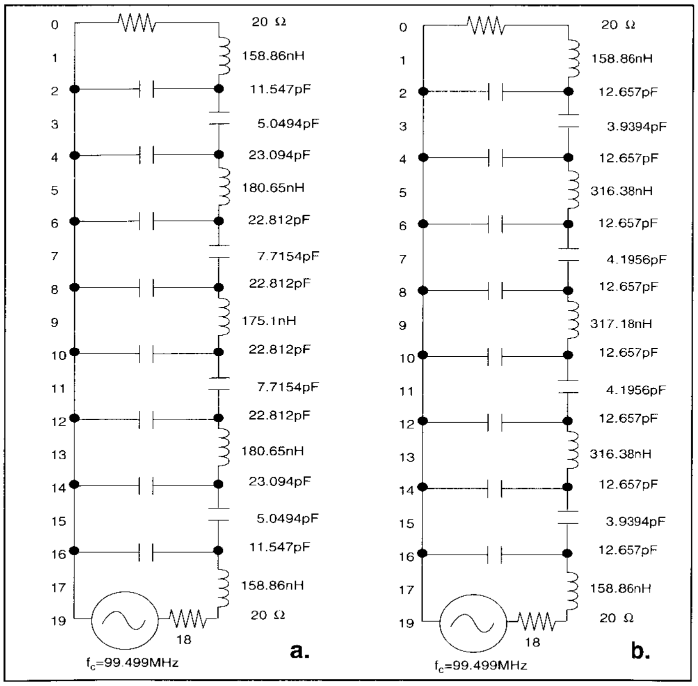


Figure 2a. Initial sytnthesis of bandpass filter.
Figure 2b. Filter after equal-value transformation.

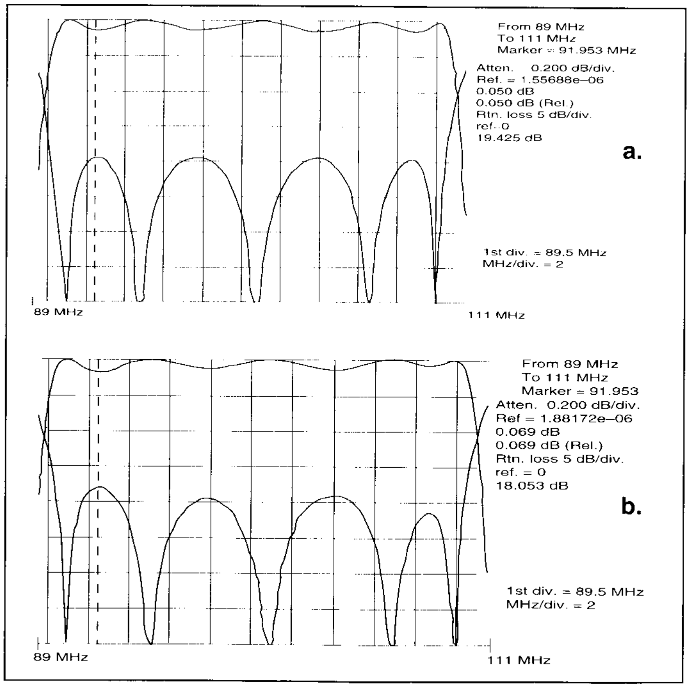
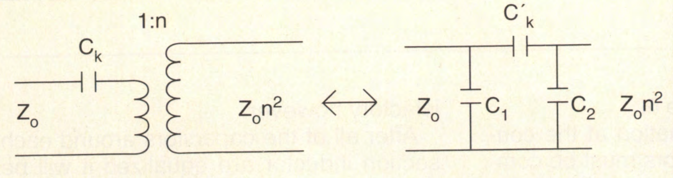
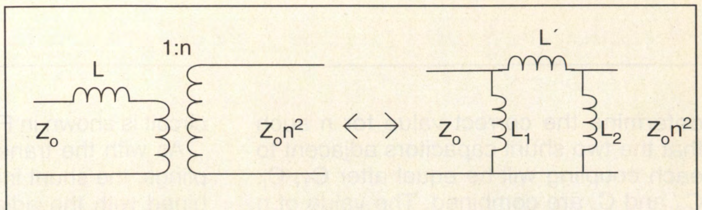


Figure 3a. Calculated response of original filter.
Figure 3b. Calculated response of transformed filter.



$$C_1 = \frac{(n-1)C_k}{n} \qquad C_k' = nC_k \qquad C_2 = \frac{(1-n)C_k}{n^2}$$

Figure 4. Norton's first transformation applied to a capacitor.



$$L_1 = \frac{nL}{n-1} \qquad L' = nL \qquad L_2 = \frac{n^2L}{1-n}$$

Figure 6. Norton's first transformation applied to an inductor

The initial mesh design to be used for the example is shown in Figure 2a and was exactly synthesized, having perfectly equal passband ripple. This allows the degradation caused by the equal value transformation to be shown. It was designed to the following specifications:

passband ripple = 0.05 dB.
arithmetic F_0 = 100 MHz.
Bandwidth = 20 MHz.
design Z_0 = 20 Ohms
Zeros at zero (DC) = 1
Zeros at Infinity = 9

The equal value forcing procedure was performed on this design, resulting in the filter shown in Figure 2b. The value of 12.657 pF of all shunt capacitors is a result of the iteration and is not predictable but may be changed to any value desired by scaling the impedance level after the iteration. Analysis of the two designs clearly demonstrate the validity of the procedure (Figures 3a and 3b).

Calculating Equal Value Elements

At the heart of the procedure is Norton's first transform which states that a perfect transformer inserted after a series connected capacitor or inductor will have an equivalent circuit consisting of three components in a "Pi" configuration where the component on the high impedance side of the transformation has a negative value [2]. With capacitors, the equivalent circuits are shown in Figure 4.

The new parts generated by the transform (C_1 and C_2 in Figure 4) must be combined with the adjacent shunt parts (see Figure 5). Also, all of the existing parts from the transformer on to the termination must be scaled by the impedance ratio (n^2). The shunt capacitor on the transformed side (C_r) must be scaled before it is combined with C_2.

The first step in the procedure is to

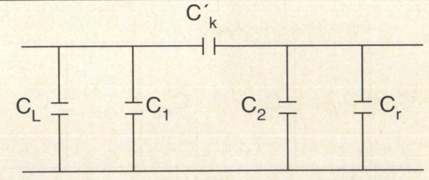


Figure 5. "New" capacitors C1 and C2 and adjacent capacitors

determine the correct value for n such that the two shunt capacitors adjacent to each coupling will be equal after C_1, C_l, C_2 and C_r are combined. The value of n for each "Pi" coupling transform can be determined by:

$$n^2 = \frac{C_r + C_k}{C_l + C_k} \qquad (1)$$

This transformation is theoretically correct and will not degrade the filter's passband in any way.

This will leave the network with all of the shunt couplings equal in pairs. The next problem is to make the shunt capacitors adjacent to each section inductor equal. Here too the Norton transform is employed. With inductors, the equivalent

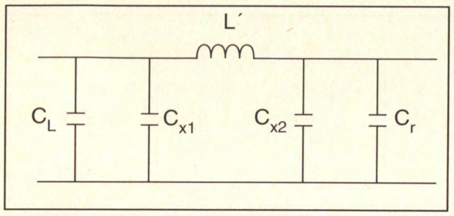


Figure 7. "New" negative capacitors and adjacent capacitors.

circuit is shown in Figure 6.

As with the transformation at the couplings, the shunt inductors must be combined with the adjacent capacitors (see Figure 7) after the network has been impedance scaled. In this case both inductors must be "inverted" to become "negative capacitors" in order to be combined. This is done by substituting a capacitor of equal reactance and the negative of its value in place of L_1 and L_2.

L_1 and L_2 are substituted with capacitors of:

$$C_x = \frac{-1}{(2\pi F_0)^2 L_x} \qquad (2)$$

In order to make the two shunt capacitors adjacent to each section inductor equal, n may be calculated from:

$$n^2 = \frac{1 - C_r W_l}{1 - C_l W_l} \qquad (3)$$

where: $W_l = L\,(2\,\pi\,F_0)$

This step is a slight fudge because converting L_1 and L_2 to negative capacitors is not ideal. It has proven to be satisfactory however.

After all of the capacitors around each section inductor are equalized it will be necessary to go back and equalize the coupling pairs again. The final design is arrived at by using a computer loop that continuously repeats both operations until all the shunt capacitors are equal within some specified tolerance. This loop is quite fast and requires only a fraction of a second to converge even on a slower than average desk top computer. After the shunt capacitors are equalized, the filter will be symmetrical about its center. Any filter that was symmetrical before the procedure will still have the termination impedance it began with, however, the termination Z_0 of a non-symmetrical filter will change as the capacitors are equalized.

Impedance Matching

The example given earlier was done at an impedance level of 20 ohms. Normally, tubular filters are intended to operate in 50 or 75 ohm systems requiring an impedance transformation at each end. This transformation is usually accom-

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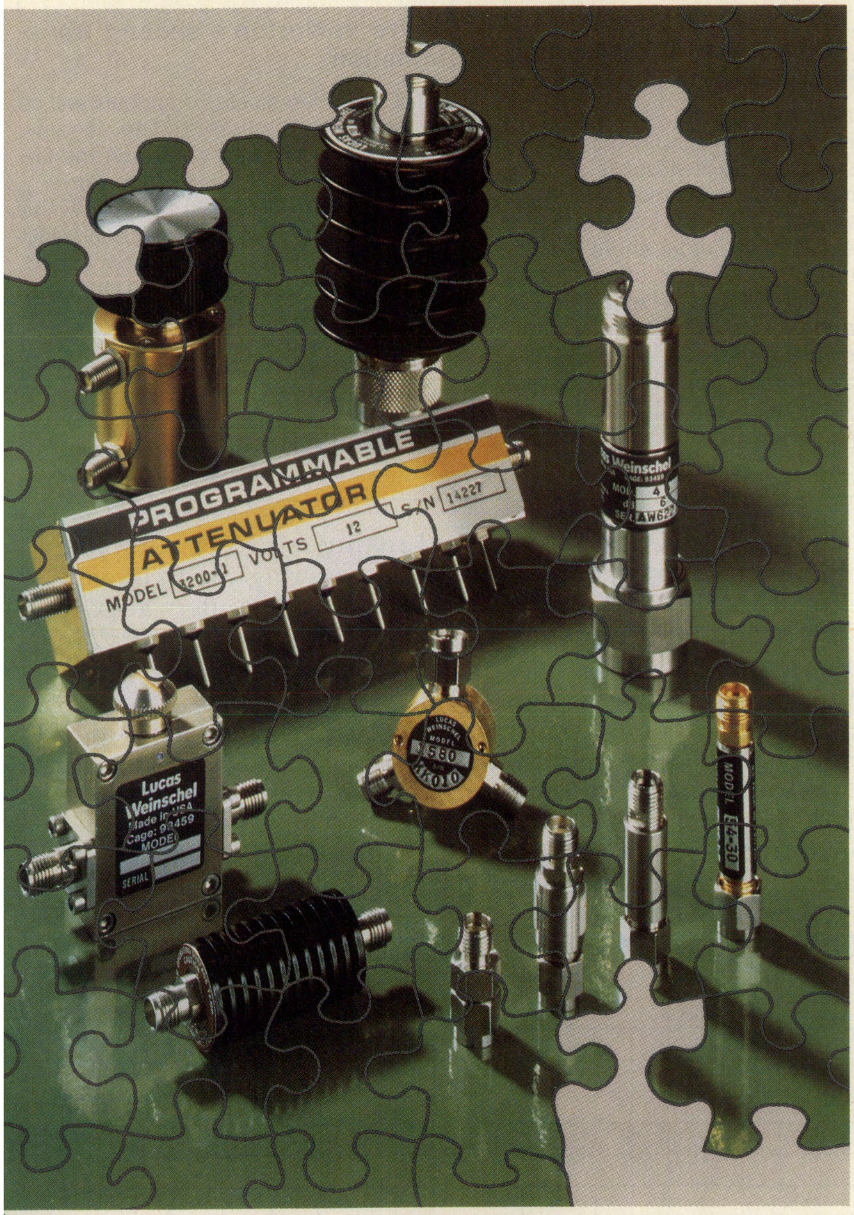

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plished by a simple shunt capacitor at each end of the filter with the added capacitive effects being absorbed by increasing the first section capacitor. This matching is usually done before the initial mesh filter is converted to tubular form as shown in figure 1. The equations for this matching scheme are given below (also see Figure 8):

$$X_{cs} = \sqrt{RZ - R^2} \tag{4}$$

$$C_s = \frac{1}{2\pi F_0 X_{cs}} \tag{5}$$

$$X_{cp} = \frac{RZ}{X_{cs}} \tag{6}$$

$$C_p = \frac{1}{2\pi F_0 X_{cp}} \tag{7}$$

where:
R = Initial design Z_0
Z = System Z_0
F_0 = Geometric center frequency

This matching scheme is narrowband in nature and will do far more to degrade the passband of the filter than the scheme described earlier to equalize the shunt capacitor values, especially to wider bandwidth designs. The degradation is a necessary evil but is usually acceptable. At narrow bandwidths however, the value of C_p can become many times the size of the other shunt capacitors in the filter. The solution to this problem is the "Pi section end slug". In this situation Norton's second transformation will be employed.

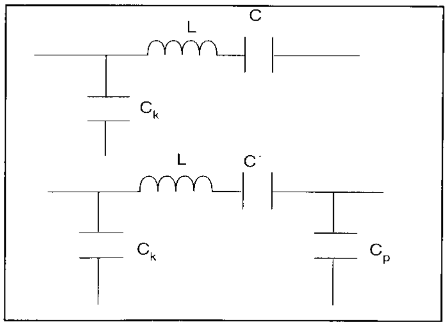
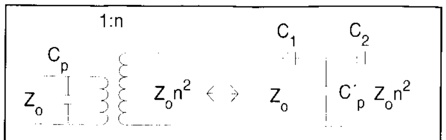


Figure 8. End section (top) and matched end section (bottom)

Norton's second transformation, like the first, equates a single component followed by a perfect transformer (Figure 9).



$$C_1 = C_p \frac{n}{n-1} \qquad C_2 = \frac{n^2}{1-n} C_p$$

$$C_p' = nC_p$$

Figure 9. Norton's second transformation

In this case, the single component will be the parallel capacitor C_p. The negative component generated will be on the low impedance side of the transformation.

Figures 10a through 10d show the stages of converting a narrow bandwidth mesh filter designed at a 4 Ohm impedance level to operate into a 50 Ohm system. First, the standard shunt capacitor method is used to bring the impedance to an intermediate impedance of about twice the design impedance (Figure 10a). The intermediate impedance you choose will determine the size ratio of

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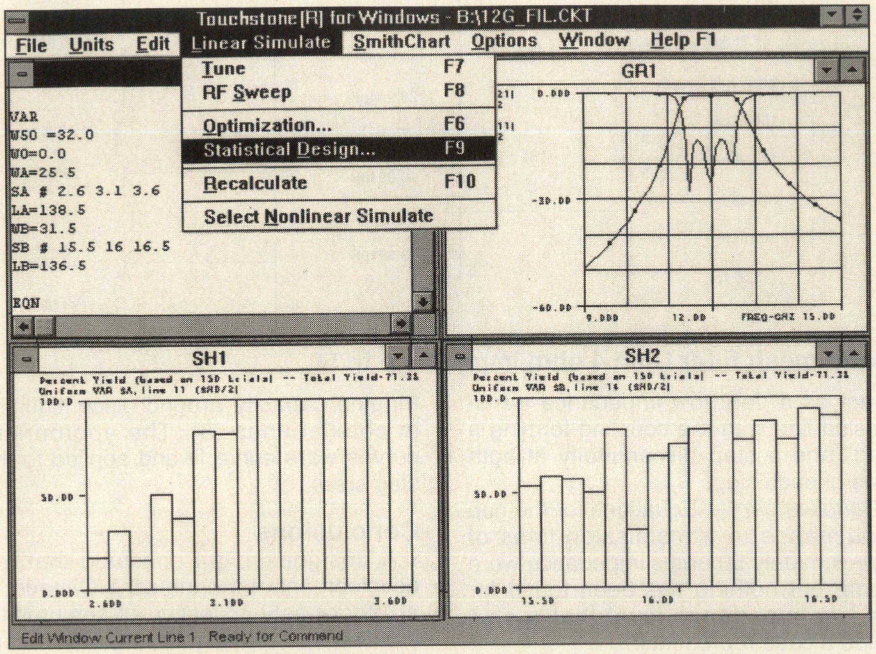

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4. If the entry is a design method, it must include an example of a circuit designed using the method described.
5. If the entry is a test method, it must include actual results of the measurement described.
6. If the entry is a computer program, it must operate on either an MS-DOS or Apple Macintosh system. It must be provided in a form that can be operated directly, without additional software (e.g., compiled). Programs must be submitted on disk, with supporting documentation provided in printed form.
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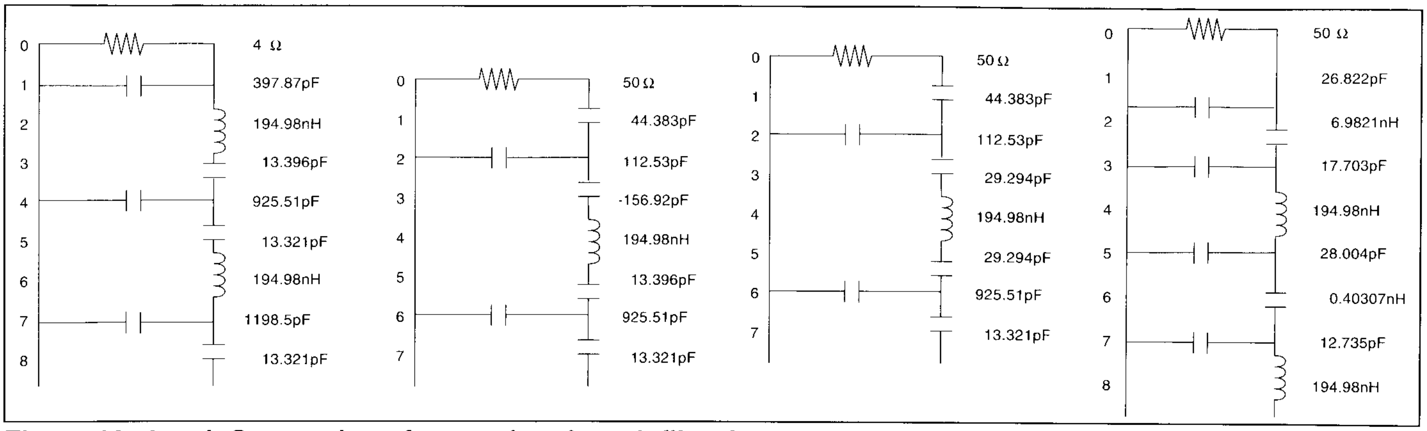

Figure 10a,b,c,d. Conversion of narrowband mesh filter from 4 ohm impedance to 50.

the two end slugs in the final design. Nortons second transformation is performed at C_p with n chosen to equal $\sqrt{(50/4)}$ (Figure 10b). The negative capacitor generated is combined with the last section capacitor and its value is split into two creating two "Tee" networks (Figure 10c) which are each converted to "Pi" networks completing the matching (Figure 10d).

It should be pointed out here that if all the shunt capacitors are to be equalized, application of the equal shunt value procedure must be done *after* the impedance matching. If it is desired to force all the shunt capacitors to be equal to some standard value, another iteration will be required as the value will no longer be linear with respect to design impedance changes because of the matching. A Newton's method iteration was employed which generally yields the desired value within a few seconds, depending on the bandwidth and the filter order. Making corrections by inverse proportion to the impedance works when the change is small, but is much slower when large Z_0 changes are required.

Mechanical Dimensions

The last design step, (at least in the first iteration), is to translate the calculated capacitances and inductances to mechanical dimensions. A number of empirical methods are used to arive at these numbers.

The section inductors — It is well known that the usual formula for the inductance for a single layer coil yields a value that is too high when the winding is placed inside a metal tube. The tube (case) acts as a long shorted turn reducing the inductance. To compensate, a set of curves relating coil and shield dimensions to inductance was curve fit [3].

Slug and coupling capacitance —The Slug - coupling - slug "pi" sections seem to act as a very low impedance transmission line with the coupling forming a "gap" and a step discontinuity at both ends of each slug.

Coupling gap — Equations for the gap capacitance in transmission lines of approximately 50 ohms impedance were found, but nothing has been found for the low impedance level that a slug inside a case represents.

The basic equation for a 50 Ohm line was [4]:

$$C = 0.706\varepsilon_r \frac{b^2}{s} + 0.442b\ln\left(\frac{2a-2b}{s}\right) \quad (8)$$

where a = case inner radius
b = slug inner radius
$\varepsilon_r = 2.1$ (PTFE)
s = gap distance

The left term of the equation is simply the standard formula for the capacitance between two metal plates. The second term however tends to begin correction at the point the gap becomes wider that twice the thickness of the teflon tape that insulates the slugs from the case. Below this distance, the left term dominates. It is hoped that the 0.442 constant could be adjusted as a fudge factor to attempt to correct for the much lower impedance in this situation. A number of reliable coaxial filter designs were reverse-engineered using this procedure to dermine the "fudge factor" for the coupling correction. A factor of approximately 0.7 was determined after averaging the results. This changes the 0.442 factor in the second term of the coupling equation to approximately 0.309. It was also found to be adventageous to allow for a correction factor to be applied to the PTFE wrap. Reducing the theoretical value of 2.1 effectively compensates for the fit of the case and any gap that might occur in the wrap.

Slug fringe capacitance — Quite a bit of data has been published about fringing capacity around discontinuities in coaxial lines [5]. The appropriate curves were curve fit and applied to the slug sizes.

Conclusions

A designer might conclude that the development of the tubular L/C model is a rather nasty collection of compromises. The same designer might also conclude that the process of converting the L/C parts into mechanical dimensions for the actual coaxial realization could be considered akin to black magic. At this point, I would tend to agree! The methods described are only a starting point. However, the PCFILT implementation of this procedure has proven quite accurate after a six-month evaluation at a major filter manufacturer. ***RF***

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5. P. I. Somlo, "The Computation of Coaxial Line Step Capacitances", *IEEE Transactions on Microwave Theory and Techniques*, Vol. MTT-15, No. 1, January 1967

About the Author

Albert Klappenberger is currently working as a consultant to a major filter manufacturer. He, and the late Fredrick J. Radler, developed PCFILT, a filter design program which designs several classes of filter, including the tubular bandpass filters discussed in this article. Mr. Klappenberger can be reached at 7525 Titleist Dr., Salisbury, Maryland 21801, or by phone at (410) 546-5573.

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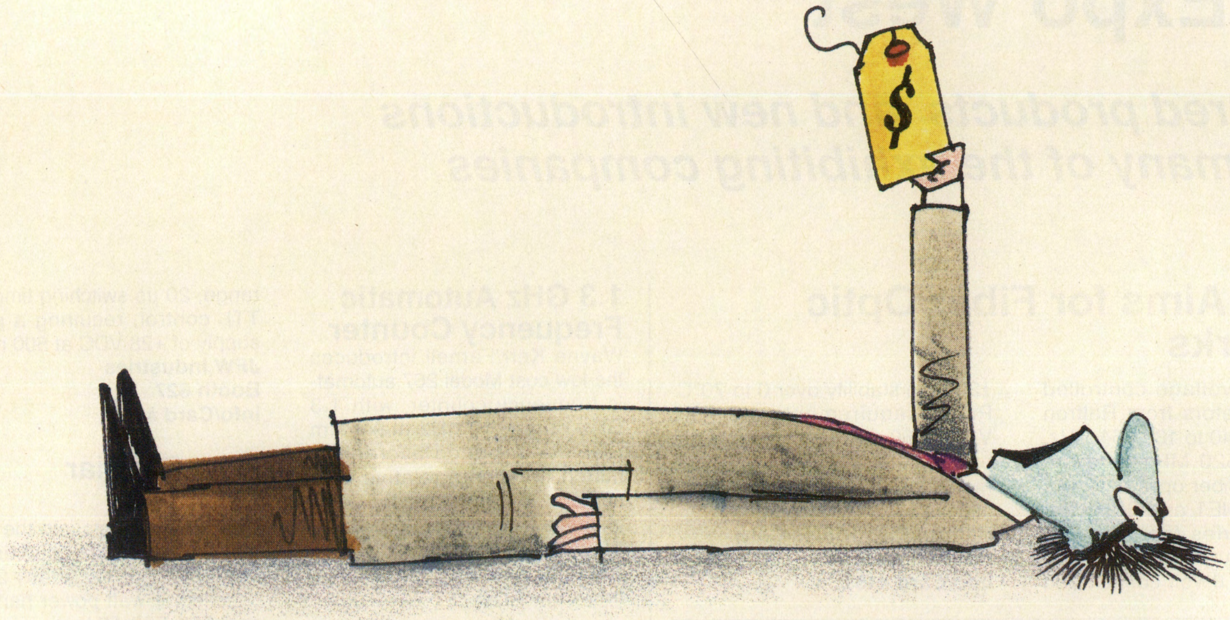

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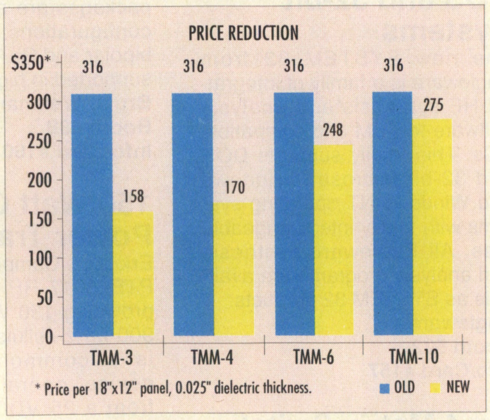

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Raltron Electronics Corp.
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Vector Signal Analyzer Monitors Digital Communications

Hewlett-Packard announces the HP 89441A DC-2.65 GHz vector signal analyzer, providing designers of digital communications equipment with measurement power to characterize system performance, evaluate quality of modulated signals and identify areas of performance degradation. Among the modulation types supported are FSK, QPSK, DQPSK, MSK and QAM. The HP 89441A is priced at $57,000.
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JFW Industries announces a new 4 × 4 matrix switch, the Model 50MS-028. The switch is a non-blocking solid state matrix with 20-980 MHz frequency range, 20 µs switching time, and TTL control, requiring a power supply of +28 VDC at 500 mA, .
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Two new couplers join the Sage 500 to 1800 MHz coupler line. Model FC5621X offers 20 dB coupling, 1 watt power handling, and 824-849 MHz coverage at low cost. Model 5268X offers higher power of 2000 watts with 31 dB coupling and 7/16 series connectors. This model is available for the popular bands between 600 and 1800 MHz.
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Wide Range Trimmer Capacitors

Sprague-Goodman Electronics adds two new polyimide dielectric capacitors to its FILMTRIM® series. Both capacitors offer 25 to 600 pF range; the GZN60100 adjusts from the top, and the GZP60100 adjusts from the side. Both are through-hole mounted, operate from –40 to +85°C, and have a temperature coefficient of ±350 ppm/°C. In 1000s, the price is $7.50 each.
Sprague-Goodman Electronics
Booth 718
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New Course Offered

Besser Associates introduces two new technical training courses: Cellular Communications System Design and Statistical Design/Yield Optimization. Also announced is Version 2 of the company's EEZ Match program, and the new EZ Chart program.
Besser Associates
Booth 736
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High Power, Wide Bandwidth Amplifier

Model 1000W1000M7 is a self-contained, air-cooled solid state amplifier from Amplifier Research. Output power is 1000 watts minimum, with 60 dB gain and ±0.8 dB gain flatness over the 100-1000 MHz band. The unit operates at 50 ohm impedance with VSWR under 2.0:1.
Amplifier Research
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915/2450 MHz Transceiver

Teledyne's TFE-1050 MMIC transceiver translates current 915 MHz applications up to the 2450 MHz band. Upconvert path gain is 35 dB with +24 dBm output at 1 dB compression. The downconversion path includes an LNA with switchable gain states and consumes less than 250 mW of DC power. The chip includes T/R switching at 2450 MHz.
Teledyne Electronic Technologies
Booth 117, 119
Info/Card #167

Fine-Resolution Synthesizer

The VDS-6012 from Sciteq uses their patented Arithmetically Locked Loop to obtain fine resolution with phase noise performance that usually requires multiple loops. The unit can cover segments of UHF or L-Band for applications such as Inmarsat, L-Band SCADA, cellular systems and others
Sciteq Electronics
Booth 827
Info/Card #168

Cellular Antenna Tester

Bird Electronics introduces the AT-800 Cellular Antenna Tester, measuring antenna performance in the 806 to 960 MHz frequency range.
Bird Electronic Corp.
Booth 426
Info/Card #169

Phase-Locked Oscillators

Using VCO and synthesizer-based techniques, EM Research Engineering introduces miniaturized oscillators for 10-2500 MHz. Also offered is a line of power amplifiers operating up to 2500 MHz with power output to 1 kW.
EM Research Engineering
Booth 939
Info/Card #170

Ceramic Capacitor Product Line

The new 114 Series of miilimeter-wavelength single-layer ceramic capacitors is announced by American Technical Ceramics. Designed for low cost, high volume applications, the capacitors are available in values from 1 to 820 pF, and are offered in three case sizes — T (.025 in.^{2}), U (.035 in.^{2}) and X (.050 in.^{2}) — and in five dielectrics.
American Technical Ceramics
Booth 128, 130
Info/Card #171

Low-Profile 2.33 mm Ceramic Bandpass Filters

Trans-Tech introduces a smaller, lower profile ceramic bandpass filter with maximum case height of 2.33 mm (.092 in.) The preliminary design is for a center frequency of 2450 MHz, three-pole surface mount design with 50 MHz bandwidth. Insertion loss is under 2 dB and VSWR is 2.0:1 maximum. Other frequencies and bandwidths can be manufactured.
Trans-Tech
Booth 429
Info/Card #172

Multiport Power Dividers for Cellular

Tele-Tech introduces the DC-xx family of multiport power dividers for cellular applications. They are available from 2-way through 32-way, covering 750 to 1200 MHz, and feature low loss performance and 10-watt power handling capability.
Tele-Tech Corp.
Booth 726
Info/Card #173

Low Cost SMA Connectors

E.F. Johnson Company introduces a line of low cost extended dielectric SMA flange mount connectors. These connectors have been designed with special mechanical captivation in brass bodies to obtain performance up to 18 GHz at a low price.
E.F. Johnson Company
Booth 244, 246
Info/Card #174

Capacitively Filtered D Connectors

Stetco introduces a new line of capacitively filtered D-subminiature connectors. These devices allow individual filtering of each pin with capacitance values from 2 to 2000 pF, providing attenuation of up to 50 dB. Straight or angle-pin connectors with 9 to 50 pins are available.
Stetco, Inc.
Booth 631
Info/Card #175

Wireless Data Transceiver

GRE America offers the GINA wireless data transceiver that uses spread spectrum technology for data rates up to 128 kbps with no FCC licensing required. The transceiver can be integrated into many different data communications applications.
GRE America
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SMT Jumpers

Copper clad jumpers, or "zero-ohm resistors," are announced by Cirqon Technologies. Provided in standard chip component sizes, the jumpers offer excellent electrical and thermal properties through their copper and ceramic construction. Single or multiple trace configurations are available.
Cirqon Technologies Corp.
Booth 615
Info/Card #177

Three New Downconverters

California Eastern Laboratories announces the new NEC UPC2753GR, UPC2757T and UPC2758T downconverter ICs. The UPC2753GR accepts RF input of DC-400 MHz, with , including 79 dB of small-signal gain, AGC IF amplifer and limiting IF output up to 20 MHz. The UPC2757T converts 0.1-2.0 GHz RF to an IF with 13 dB gain and 0.8 dBm third order intercept and 5.6 mA current draw at 3 volts. The UPC 2758T provides 17 dB gain with 11 mA current requirements.
California Eastern Laboratories
Booth 818, 820
Info/Card #178

SAW IF Filters for DECT

RF Monolithics offers the SF1051 for DECT and wireless local area network applications. This filter features a center frequency of 110.592 MHz, maximum insertion loss of 10 dB, and 3 dB bandwidth of 1.152 MHz and in-band group delay variation of less than 200 ns p-p. SF1052 is designed for GSM, and operates at 71.0 MHz with 8 dB insertion loss, 300 kHz bandwidth and 300 ns p-p group delay deviation.
RF Monolithics
Booth 529, 531
Info/Card #179

FM Broadcast Reject Filter

Model NX88-108 is an FM broadcast band suppression filter that passes DC to 80 MHz and 118 to 400 MHz, while suppressing the 88-108 MHz band. Insertion loss is 0.5 dB maximum and power handling capability is 25 watts, with VSWR under 1.4:1. Small quantity pricing is $175 each.
Trilithic, Inc.
Booth 430, 432
Info/Card #180

Ovenized Oscillator

Isotemp Research announces the OCXO118-2, an ovenized oscillator with user-interchangeable crystals. Frequency coverage is 2 to 10 MHz, with fixed or adjustable oven temperature. Holds HC-27/U or HC-36/U crystals. Crystal specifications are provided.
Isotemp Research
Booth 648
Info/Card #181

High Frequency Crystal Filters

Filtronetics offers high frequency, narrow band crystal filters for applications up to 200 MHz. An example is the FN-1801, operating 148.275 MHz with a 3 dB bandwidth of 50 kHz and 60 dB bandwidth of 300 kHz. The size of this unit is 1 × 0.5 × 0.43 inches, in a p.c. mount package.
Filtronetics
Booth 240
Info/Card #182

Time Interval Analyzers

Guide Technology will demonstrate time interval analyzers with 100 ps single-shot resolution and 2 million measurements per second. Also available are PC-based frequency counters.
Guide Technology
Booth 512
Info/Card #183

Super-Spice Program

Compact Software announces the introduction of Super-Spice 1.0, an enhanced version of Spice targeted for high frequency RF and microwave applications. Super-Spice 1.0 currently runs on Sun SPARC and HP 700 series workstations, and operates under Compact's EASi user interface.
Compact Software
Booth 319, 321
Info/Card #184

Transistor Develops 60 Watts at 1.7 GHz

The LFE15600X from Philips Semiconductors is a class AB silicon NPN transistor for operation in the 1.5-1.7 GHz band. Low distortion and easy paralleling for high power make the devices useful for PCS, mobile satellite and digital audio broadcast applications. A similar device for 1.7-2.0 GHz is under development.
Philips Semiconductors
Booth 519, 521
Info/Card #185

RF expo products *continued*

Helical Filters for 2.4 GHz Products

Toko America announces the line of GHz helical filters, the 4CHW series. These filters cover 1.3 to 2.5 GHz with bandwidths from 50 to 100 MHz. Footprint size is 0.37 × 0.23 inches, with 0.16 inch height, suitable for PCMCIA type III cards. Part number 669BB-1011 has been designed specifically for 50-ohm 2.45 GHz ISM band applications. Pricing for the 4HCW line begins at $8.00 for 100 piece quantities.
Toko America
Booth 336, 338
Info/Card #186

Miniature I & Q Mixer

Merrimac Industries announces the IQG-20G series of I & Q demodulator/mixers, for applications covering 10 to 1000 MHz. Center band accuracies are 0.1 dB amplitude and and 1° phase up to 500 MHz. The devices are provided in a 0.6 inch square SMT hermetic welded package. Common center frequencies are available off-the-shelf.
Merrimac Industries
Booth 941
Info/Card #187

Chip DBM for Cellular

CDB-2109 from ST Olektron is a passivated printed structure double balanced mixer for the 860-970 MHz band. 8 dB conversion loss, 0 dBm compression point, 20 dB LO-RF isolation and 14 dB RF-IF isolation are key features. Chip size is 0.177 × 0.197 × 0.060 inches, and pricing is $4.95 each for 25-1000 quantities, from stock.
ST Olektron
Booth 433, 435, 437
Info/Card #188

Signal Generators

The HP 8648 series of signal generators from Hewlett-Packard are designed to be easy and efficient to use. Measurement sequences can be preloaded for one-button testing in a manufacturing environment. Target applications include service and production line testing of cordless phones, pagers and low cost two-way radios.
Hewlett-Packard Co.
Booth 710
Info/Card #189

Noise-Based Testing

Noise/Com offers noise sources, programmable noise generators, bit-error-rate testers, NPR testers and multipath fadin emulators, for calibration, BITE and operational testing.
Noise/Com
Booth 940
Info/Card #190

RF Transmission Components

Delta Microwave introduces a line of filter and couplers for HF through microwave applications.
Delta Microwave
Booth 937
Info/Card #191

Broadband Amplifers

Q-bit Corporation offers broadband RF amplifiers featuring patented power feedback technology, flat gain, low noise figure, low VSWR and high intercept points.
Q-bit Corporation
Booth 936
Info/Card #192

Ferrite Devices

RF and microwave ferrite devices in coaxial and waveguide transmission lines are offered by Channel Microwave. The frequency range covered includes 100 MHz to 50 GHz.
Channel Microwave
Booth 935
Info/Card #193

MMICs and Modules

Hittite Microwave announces RF/microwave MMIC chips and modules for wireless applications. Products include switches, voltage variable amplifiers and power amplifiers.
Hittite Microwave
Booth 938
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Gold Plating Capabilities

INTA offers low cost gold plating, in a method redesigned to use a palladium underplate and gold topcoating, for lower porosity, better solderability and materials savings of up to 40 percent.
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Increasing Linearity in Amplifiers with IF Predistortion

By Nick Ierfino
Harris Farinon

Since the advent of digital radio, much effort has been placed in high power efficiency to save both cost and power. As the proliferation in communications flourishes especially in digital cellular radio, an interest in techniques to remove non-linearity in power amplifiers is being commonly investigated. This paper outlines IF predistortion including actual results using SSPA (solid-state-power-amplifiers). A block diagram of a generic model is included with some measured results in a complete digital radio system.

Given that FET amplifiers are generally used in microwave systems and that nonlinearity above the 3rd order intermodulation product is negligible at reasonable output powers, the derivation of higher order products is omitted.

Using the Taylor series with only odd order terms:

$$Z = a_1X + a_3X^3 \tag{1}$$

$$Y = b_1Z + b_3Z \tag{2}$$

where

$$Z^3 = (a_1X + a_3X^3)^3$$

By combining (1) and (2):

$$Y = b_1a_1X + (b_1a_3 + a_1^3b_3)X^3 + 3a_1^2a_3b_3X^5 + \text{higher order terms.} \tag{3}$$

In an experiment, predominantly 3rd order intermodulation products were produced when a two-tone signal (68 and 72 MHz) was upconverted and fed into an 8 GHz, 1 W power amplifier. Therefore from equation 3 it is evident that to fully suppress the 3rd order-generated products, the following equation must be met:

$$b_1a_3 + a_1^3b_3 = 0 \tag{4}$$

or

$$-\frac{a_1^3}{a_3} = \frac{b_1}{b_3}$$

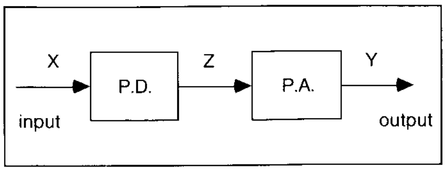

Figure 1. Block diagram showing the pre-distorter (P.D.) before the power amplifier (P.A.).

Vector Representation

In order to explain in more detail, a vector representation of equations 1 and 2 is shown in Figure 2. The input vector is X, which, after passing through the predistorter, generates a_1X and a_3X^3. The vector a_3X^3 is controlled by a 4-quadrant phase shifter and may be rotated to any desired phase ϕ. After a linear upconversion the power amplifier amplifies vectors a_1X and a_3X^3. At a fairly high output power the generated vectors are a_1b_1X (fundamental signal), $a_1^3b_3X^3$ (3rd order non-linear effect) and $a_3b_1X^3$ (function of the predistortion effect). For simplicity, the vector $a_3b_1X^3$ is shown as an amplification without any absolute delay. To fully suppress vector $a_1^3b_3X^3$ we simply shift $a_3b_1X^3$ by ϕ and make sure the amplitudes meet equation 4. The entire system nonlinearity reduction may be calculated as follows:

$$\text{3rd order reduction } (U) = \frac{\text{3rd order in the entire system}}{\text{3rd order P.A. distortion}} \tag{5a}$$

$$U = -20\log\left|\frac{a_3b_1 + a_1^3b_3}{a_1^3b_3}\right| = -20\log\left|\frac{a_3b_1}{a_1^3b_3} + 1\right| \tag{5b}$$

As an example, using equation 5, if the goal was to suppress the 3rd order intermodulation products by at least 20 dB, the necessary rotation is calculated at no more than 6° from its expected 180° phase shift. Also, this calculation assumes that the AM-AM is completely compensated. Experimentally, the IMD suppression was measured at different power amplifier back-offs as shown in Figure 3. The experiment was conducted using a two-tone signal at the input of the predistorter and monitoring the output of an 8 GHz power amplifier with a gain compression-point of 34 dBm. Results were obtained by manually adjusting the amplitude and phase of the generated distortion until the 3rd order products at the output of the power amplifier were suppressed to their minimum. Figure 3's ordinate values are:

$$\text{IMD(db)} = 20\log\left|\frac{K}{\text{IMD}}\right| \tag{6}$$

Where K is the power of the two-tone

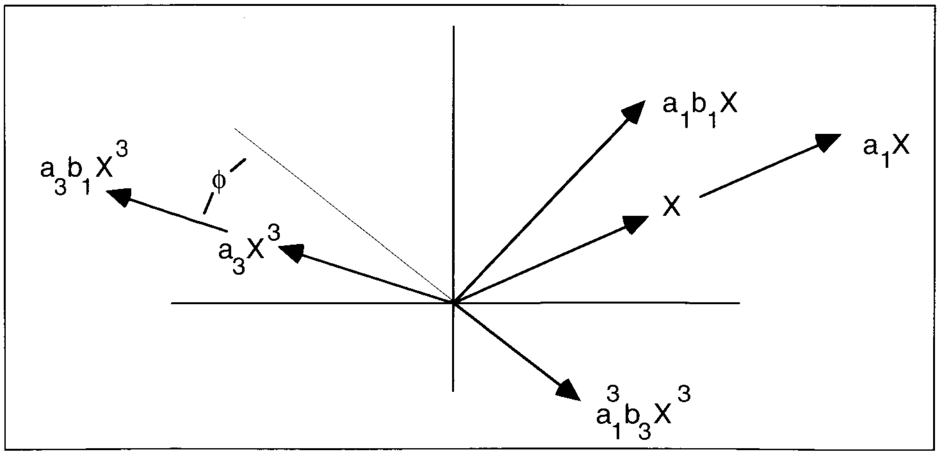

Figure 2. Vector representation of input signal, pre-distortion signal, and signals after amplification.

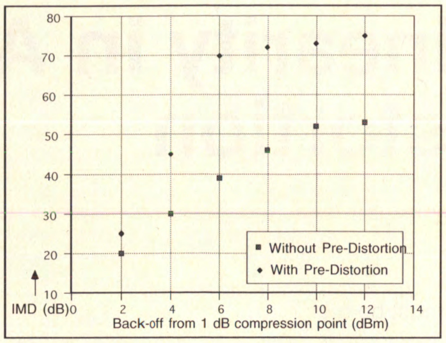

Figure 3. IMD vs. input power pull-back from 1 dB compression point with pre-distortion and without.

signal and IMD is the power of the third-order intermod product. The abscissa is the power measurement of a two-tone signal in dBm back-off from the 1 dB gain compression point.

Implementation

Referring to Figure 4, the input is split into two paths (path 1, path 2). Path 1 is further split in order to obtain the nonlinear components, this 3rd order-intermodulation-product generator is implemented by using schottky diodes. Its adjacent path contains an amplified delay so that the fundamental is totally removed at its summing port.

Experimental results show greater than 20 dB fundamental reduction from the 3rd order intermod products is possible. The variable gain after the summing junction controls the AM-AM power relationship of the power amplifier. Path 2 is the main path with a total gain of unity. The 4-quadrant phase-shifter produces the necessary phase correction in order to obtain the needed AM-PM correction. The delay adjustment in this path compensates for the total signal delay in path 1. The AGC stage is necessary to maintain the output power constant as the intermods are increased. With the two-tone test the fundamental and the intermods were successfully controlled using the attenuator circuitry, actual results gave a variation of 40 to 65 dBc.

The predistorter circuit was inserted at the output of a 64 QAM modem, with a constant residual BER of 10^{-6} the E_b/N_o ratio was measured at different power amplifier output powers. With the predistorter in the system, a gain of 2 dB output power was attained (E_b/N_o constant). Also, perhaps the most advantageous reason to use this type of linearization is its effect in reducing the out-of-band spectral emissions. Findings show as much as 10 dB reduction is possible with both 16 or 64QAM modulation in a 10 MHz bandwidth.

Conclusion

This introduction to IF predistortion explains both the theory and practical implementation of increasing linearity in microwave amplifiers. The actual block diagram may also be implemented at different frequencies, and with clever design techniques this linearization method may prove to be a very inexpensive way to enhance power amplifier performance. ***RF***

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About the Author

Nick Ierfino holds a college D.E.C in electrotechnology and a BSEE in communications. He spent five years with Northern Telecom, involved mainly with high capacity modems. He currently works for Harris Farinon Corp. He can be reached at 3 Hotel de Ville, Dollard-des-Ormmeaux, Quebec, Canada H9B 3G4.

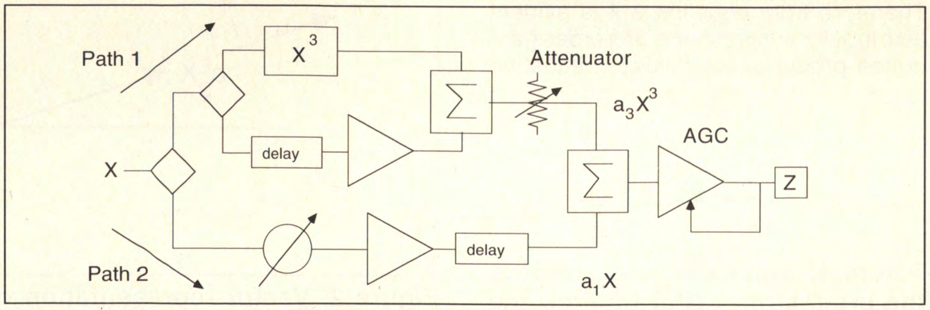

Figure 4. Block diagram of the pre-distorter.

Coaxial Cable Industry Copes With Changes

Ann Marie Trudeau
Assistant Editor

The coax cable industry has stabilized most of its manufacturing processes over the years. The focus for the industry today is how best to meet the needs of the market which is cost driven and looking for smaller cables to carry the same or higher power. Now that the military has downsized, some manufacturers have had to refocus their efforts. Various companies have chosen to jump into the commercial market and others have decided that the military is still the market they can serve. Others have a very, very narrow niche in the coax market or are combining two focuses.

Times Microwave Systems is looking at the commercial market and dealing with the changes within the military. Bob Perelman, Manager of Commercial Sales and Marketing, said that the military has changed the specs for coax. He said that low smoke, non-toxic, non-halogenated jacketing is required to conform to MIL C-17/180-200 cable requirements. Cables made under previous shipboard requirements used chlorine- and bromine-containing materials to make them fire retardant. The down side was that when the cables were involved in a fire they formed toxic and corrosive fumes. Upgraded standards are now required for all new military programs. Times Microwave is also looking at flexible replacements for semi-rigid and corrugated cables.

Coax Product Manager Grant Walter of W.L. Gore & Associate, Inc., said what Gore is doing is getting into the retrofit business supplying cables where the requirements are higher than they normally have been, for instance, missiles and custom coax applications. "What I'm seeing in the RF business," he said, "is a decline in general spending but no reluctance to spend on R&D, high performance or advanced systems."

Military Transition

Micro Coax Components, Inc. Product Manager Ron Souders said that their company represents a successful transition from the military to the commercial market while still servicing the military. "It's not as much as it used to be, but it's still huge," Souders said. The company is now working on a radar system for the military.

He said that Micro Coax is focusing on the cellular market and because of that their former biggest seller, UT 1.41" coax is now outsold by the UT 0.47". "Some companies are suffering because they haven't made the transition," Souder said.

Defense Still a Focus

Then there are the companies, like Kaman Instrumentation Corp., that have focused heavily on the military. Terry Dillahunty, Sales and Marketing Manager of the microwave products group, said that cutting the military budget to $200 billion still leaves a huge market for those manufacturers who years ago, committed themselves to the military market. The awarding of contracts is no longer going to the lowest bidder. "Prime military contracts are going to those who have an outstanding product, meet delivery dates and have good engineering services," Dillahunty said. Kaman presently fills contracts for the major flying programs–fighter aircraft, missiles and satellites–by producing a 100% shielded coax with an oxygen free high conductivity center conductor, silicon dioxide (SiO_2) insulating material, and laser welded connectors. Dillahunty said that companies that primarily handled the military could be making a mistake by struggling to make a place in the commercial market. The only commercial market that Kaman is looking at has similar requirements as the military and that is the satellite industry.

Telecommunications

Huber + Suhner, Inc. Applications Engineer Doug Finan said that they are focusing on telecommunications and avionics. One of their newer processes is running typical coax braid through a molten tin bath to create a 100% shield.

Andrew Corp. found a niche in the Personal Communications Network (PCN) by providing a coax cable that is between two available sizes. Vince Caputo, Product Manager of Marketing, explained that the previously used coax didn't exactly match the application. One size was too small for the power needed and the larger size was overkill, so Andrew came up with 3/8 inch coax.

In addition to applications used in tunnels and enclosed places Andrew sees increased activity in the radiating cable market. New applications would give offices more flexibility because the computers wouldn't have to be hard-linked. Cellular users would find that they could use their phones above the tenth story in a building.

Storm Products Co. also has made a small niche in the space flight market by customizing for customers. Brian Holland, General Manager, told of a space flight application which required a cable whose jacket was both resistant to UV and other radiation and non-glaring because it was going to be in line with a camera. He feels that there is opportunity for growth in the coax industry for the next ten years, part of which fiber optics will influence because it is microwave driven.

Growth is seen even in tools. Joe Brown, President of Coastel Cable Tools has focused on the needs of the semi-rigid coax cable industry and come up with portable and production semi-rigid stripping tools with interchangeable cutting heads. He also sees dramatic growth for coax that comes from observing the expensive labor that occurs with fiber optics.

Summary

Current military needs and the expansion of the communications markets has caused fierce competition. But, it looks like coax manufacturers are focusing on the various processes to give customer satisfaction at a lower cost and still stay in business. *RF*

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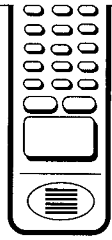

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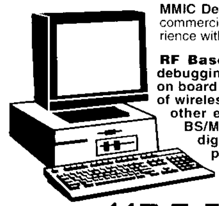

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