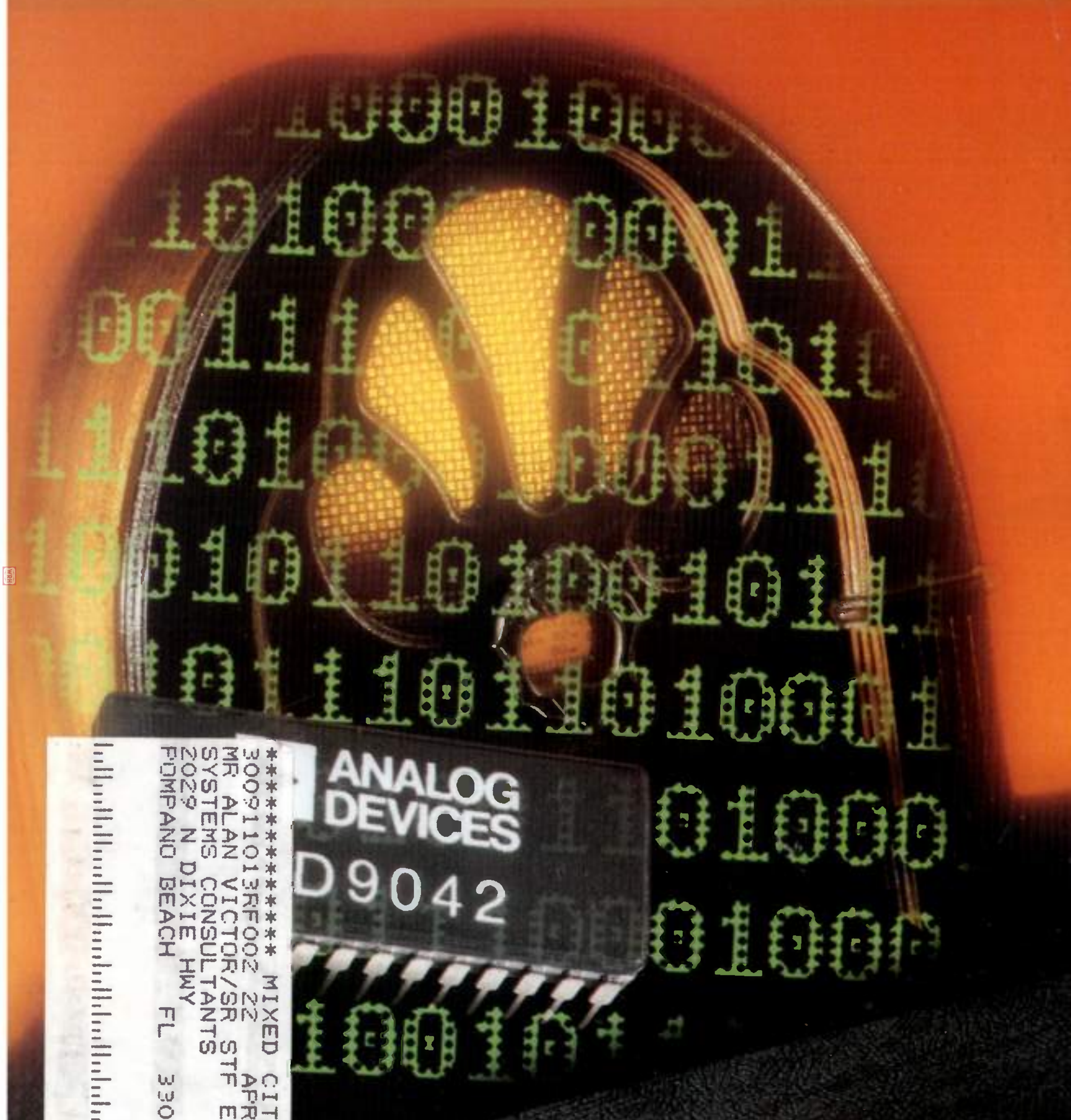
WIRELESS LEADERSHIP 16 YRS

RF design™

engineering principles and practices

May 1995



Cover Story
New A/D Converter Benefits Digital IFs

Featured Technology —
Circuits for RF Power

In the race to market, we offer you a few shortcuts.

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Inductance: 4.7 nH - 10 µH
42 values (10 of each) **Kit C100 $125**

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"Spring" Surface Mount Air Core Inductors
Inductance: 2.5 nH - 43 nH
10 values (12 of each) **Kit C102 $60**

RF Inductor Kits

"Unicoil" 7/10 mm Tuneable Inductors
Inductance: .0435 µH - 1.5 µH
49 shielded, 49 unshielded (2 of each)
Kit M102 $60

"Unicoil" 5 mm Tuneable Inductors
Inductance: 9 nH - 281 nH
19 Shielded, 19 unshielded (2 of each)
Kit M105 $60

"Slot Ten" 10 mm Tuneable Inductors
Inductance: 0.7 µH - 1143 µH
18 shielded, 18 unshielded (3 of each)
Kit M100 $60

"Slot Seven" 7 mm Tuneable Inductors
Inductance: 0.094 µH - 275 µH
39 values (3 of each) **Kit M106 $60**

Axial Lead Chokes
Inductance: 0.1 µH - 1000 µH
25 values (5 of each) **Kit F102 $50**

Horizontal Mount Inductors
Tuneable and fixed
Inductance: 31.5 nH - 720 nH
33 values (3 of each) **Kit M104 $60**

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Common Mode Data Line EMI Filters
Attenuation: 15 dBm, 1.5 - 300 MHz
DC current capacity: 100 mA
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Common Mode Line Chokes
Current: .25 - 9 Amps rms
Inductance: 508 µH - 10.5 mH
8 styles (2 of each) **Kit P202 $100**

Power Magnetics Kits

Current Sensors
Sensing range: 0.5 - 35 Amps
Freq. resp.: 1 - 100 kHz, 50 - 400 Hz
Transformer and sensor-only versions
8 styles (15 total pieces) **Kit P203 $50**

Base/Gate Driver Transformers
Inductance: 1.5 mH Min. Freq: 10 - 250 kHz
2 single, 2 double section (2 of each)
Kit P204 $50

Mag Amp Toroids
Current: 1.5 Amps
Volt-time product: 42 - 372 V - µsec
6 styles (2 of each) **Kit P206 $100**

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Current: 3, 5, 10 Amps Inductance: 5 - 300 µH
18 styles (48 total pieces) **Kit P205 $75**

Axial Lead Power Chokes
Current: .04 - 4.3 AC Amps
Inductance: 3.9 µH - 82 µH
30 values (2 of each) **Kit P209 $150**

Other Magnetics Kits

Low Pass LC Filters
Poles: 3, 5 and 7 Cutoff frequency: 17 MHz
Impedance: 50 Ohms
3 filters (4 each) **Kit D102 $60**

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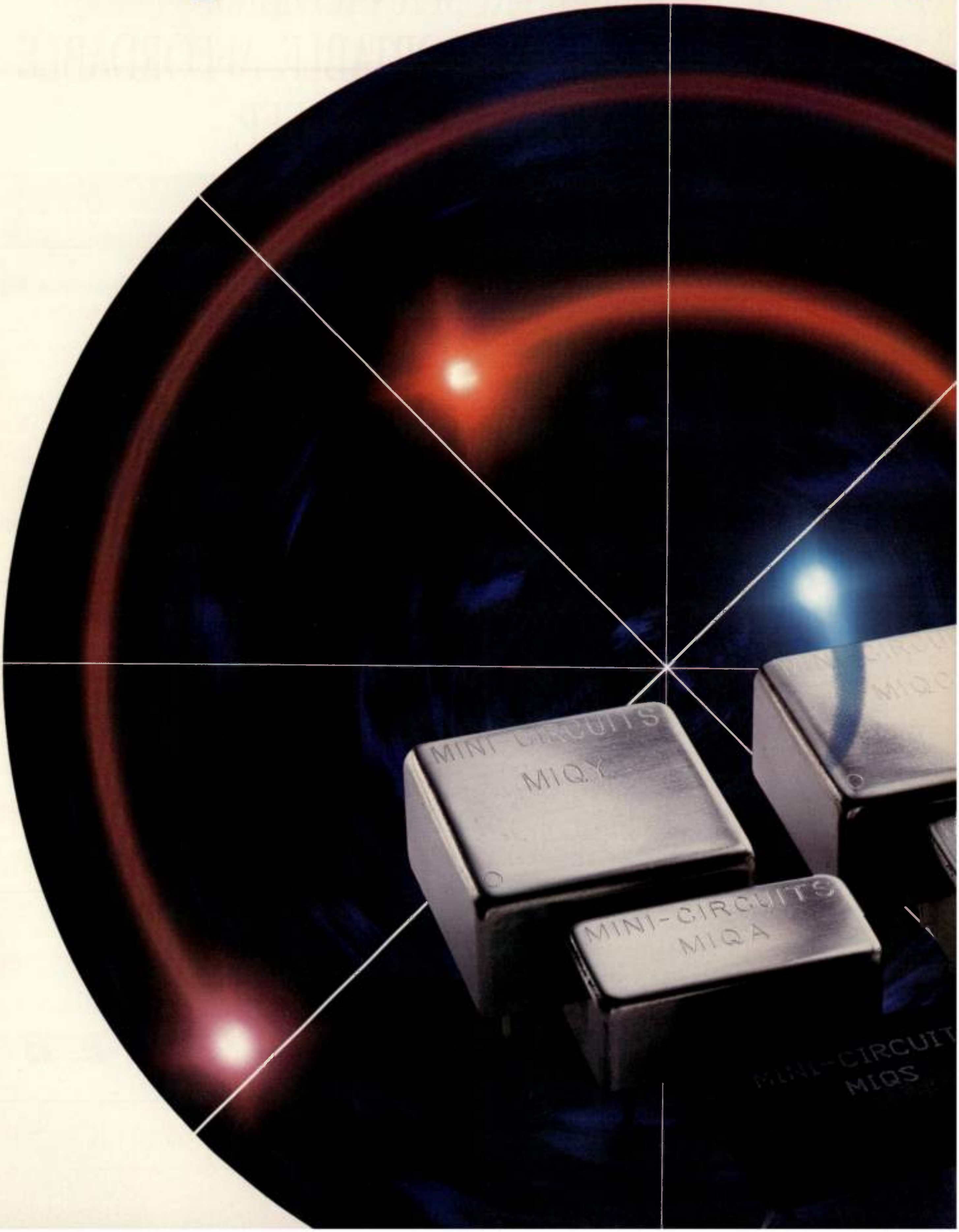
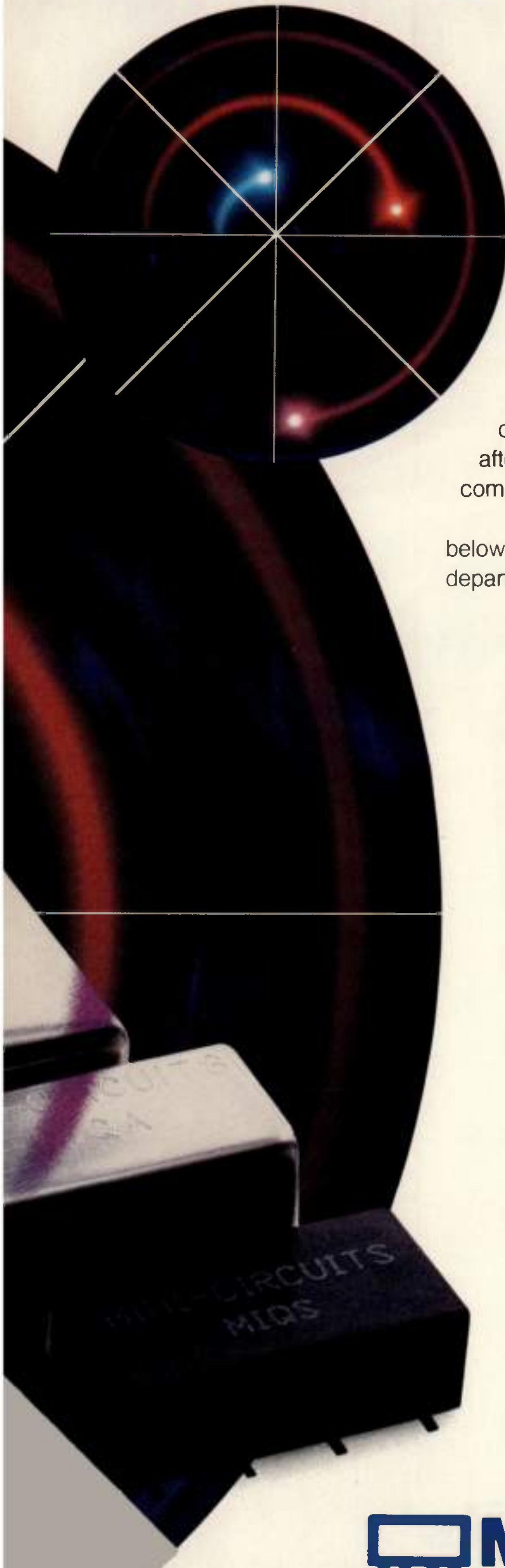
I&Q MODULATORS



DEMODULATORS



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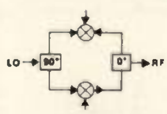
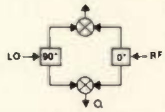
So, call your Mini-Circuits distribution center at a number listed below for guaranteed one week shipment or, turn to our applications department with your special specs for custom units at catalogue prices.

We're redefining what VALUE is all about!



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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MIQA case .4 x .8 x .4 in.
MIQY case .8 x .8 x .4 in.
MIQC case .8 x .8 x .4 in.
MIQS case .8 x .4 x .2 in.

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K-POS2 $79.95(contains 1ea. all models except POS-75,-150,-300).

Model No.	Freq. Range (MHz) Min.	Phase Noise (dBc/Hz) SSB @10kHz Typ.	Harmonics (dBc) Typ.	Power 12V DC Current mA	Price (Qty.5-49) $ ea.
POS-50	25-50	-110	-19	17	11.95
POS-75	37.5-75	-110	-27	17	11.95
POS-100	50-100	-107	-23	18	11.95
POS-150	75-150	-103	-23	18	11.95
POS-200	100-200	-102	-24	18	11.95
POS-300	150-280	-100	-30	18	13.95
POS-400	200-380	-98	-28	18	13.95
POS-535	300-525	-93	-26	18	13.95
POS-765	485-765	-85	-21	22	14.95
POS-1025	685-1025	-84	-23	22	16.95

Notes: Tuning voltage 1 to 16V required to cover freq. range.
Operating temperature range: - 55°C to +85°C.

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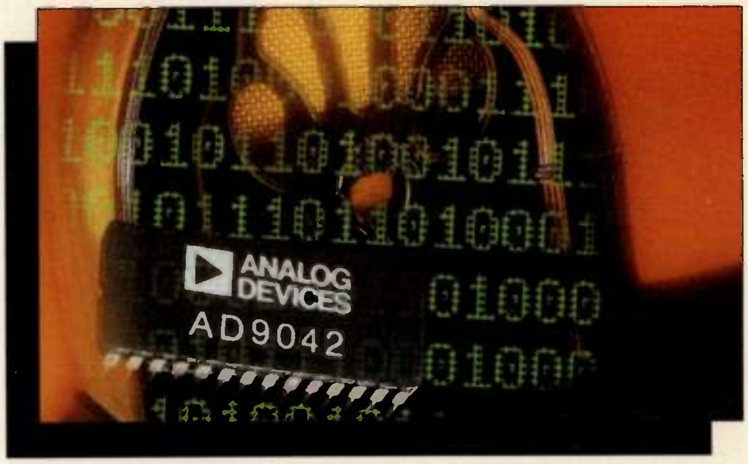
May 1995



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RF editorial

Retraining Eases the Impact of Defense Cuts

By Gary A. Breed
Editor

As I write this, local industry giant Martin Marietta has just run full-page ads announcing stockholder approval of its merger with Lockheed.

According to newspaper reports, the successful merger will result in millions of dollars in bonuses to the executives of both companies. However, the grand announcement of the merger's "success" is really an acknowledgement that defense business remains on a steep decline: The reports also note a planned 10-15 percent reduction in the workforce of the combined company. That translates into 15,000-25,000 people laid off or involuntarily retired.

The Lockheed-Martin deal was followed by the announcement of the intended takeover of E-Systems by Raytheon, adding another chapter to the story of a shrinking defense industry. Every major contractor has only a fraction of the defense business it once had. While some have made big investments in commercial development, so far the results are mixed.

For several years, displaced engineers with RF and microwave experience have been cast adrift from these companies as defense programs for communications, weapons and countermeasures have been eliminated or slowed. These engineers' success at maintaining meaningful careers has also had mixed results.

How should these engineers prepare for jobs in commercial markets — markets with a different style of business and a vastly different set of design requirements?

Or, how do the companies hiring ex-defense engineers bring their new employees up to speed on the latest technologies like digital cellular, two-way paging, wireless LAN, or keyless entry systems?

The answer is *retraining* through continuing education courses. Formal classwork has proven to be effective in developing new expertise. In contrast to informal on-the-job or self-training, classroom instruction is planned, structured and taught by experienced instructors, the best approach for most engineering subjects.

In a well-organized one-day to one-week course, a lot of material can be covered without taking an entire semester. The engineers taking the course may not commit everything to memory, but they will have a clear idea of the major issues, and will have their class notes and textbooks for reference when the class is over.

This month's Product Forum (page 116) discusses the "product" of continuing education courses. Companies and institutions that provide RF-related short courses offer their observations on the growth of their business and the nature of their students. This discussion should prove enlightening to engineers contemplating coursework, and engineering managers who may use them to enhance the capabilities of the staff they direct.

Of course, all engineers can benefit from formal classroom training, not just those who need major retraining. Staying sharp within your area of expertise is every bit as important in the long run as getting the initial education. As many successful people have noted, learning is life-long process!

RF design

Established 1978

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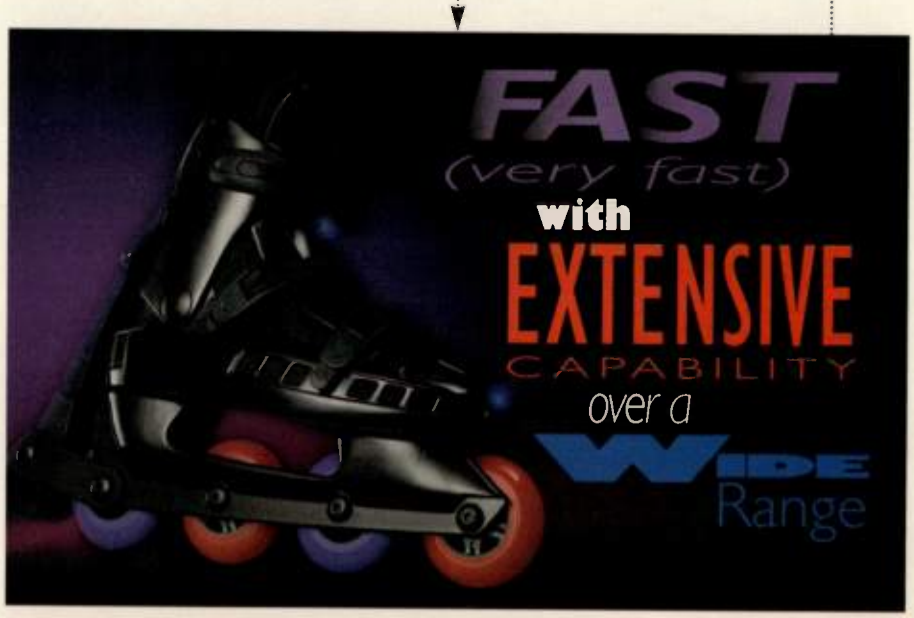

Hewlett-Packard specifications are from the HP 437B and HP 438A technical data sheets dated April 1988 and July 1984, respectively.

RF letters

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

Explanation Errors

Editor:

I was disappointed in most of the "Laymen's Guide to RF" letters [March 1995]. They really don't do the job. But then, I don't know that I could do any better. You really can't do justice to RF in a simple analogy. However, I would like to point out two letters which are erroneous. On Frequency Conversion, Robert Tso claims that a spinning wheel appears to stand still because of a "sampling process performed by the brain". I don't know of anyone actually observing this effect on direct viewing of the wheel, and I have not heard of the sampling process in the brain. The effect is observed when watching a motion picture of wagon wheels, because it is the camera which performs the sampling at 16 or 24 frames per second.

On ERP, Bill Ungar states that "ERP is the same" when you put a reflector behind a light bulb. The fact is that ERP (effective radiated power) is greatly increased with the reflector. The total power remains constant with a perfect reflector, but the apparent power is greater in the direction of the beam.

Kenneth Lundgren
Bloomingdale, IL

Another Albright Protege

Editor:

David Hertling's reference to Professor Albright of the University of Illinois in Andy Kellett's article ["Industry Insight - RF Engineering Education", Feb. 95] as, "...the one good person ... who got me and a number of other people started [in RF engineering]," brought back found memories. I too, am one of those "other people" that Professor Hertling refers to.

In addition, I hope that the statement, "funding has gone down the tubes" regarding university research funding in RF technology was purely accidental.

Keep up the good work! I truly enjoy reading *RF Design* every month.

Charles E. Glenn
LORAL Federal Systems – Owego

Units Error

Editor:

I think that there might be an a little typo in Frank L. Egenstafer's excellent article, "Path Loss and Antenna Gain Elementary Calculations" [Feb. 95]. On page 54, just above equation 9, the text should read "...P_d, in W/m^2...", not, "W/m".

Jeffrey A. Harvey
Enfield, N.S., Canada

Errata

The name of Dr. Thomas Charlton, Group Vice President for Communications Products at Andrew Corporation was misspelled in the April "Industry Insight".

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RF calendar

May

16-18 **DXPX '95 Exhibition and Symposium**
San Jose, CA
Information: Reed Exhibition Companies, 383 Main Avenue, Norwalk, CT 06851. Tel: (203) 840–5398. Fax: (203) 840–9398.

19 **Fifth-Annual IEEE Regional Symposium on EMC**
Boulder, CO
Information: Bob German, Henry Ott Consultants, 1410 Moss Rock Place, Boulder, CO 80304. Tel: (303) 444–2472.

21-24 **45th Electronic Components and Technology Conference**
Las Vegas, NV
Information: Jim Bruorton, Publicity Chairman, 1995 Electronic Components and Technology Conference, c/o KEMET Electronics Corporation, P.O. Box 5928, Greenville, SC 29606. Tel: (803) 963–6621. Fax: (803) 963–6521.

31-2 **1995 IEEE International Frequency Control Symposium**
San Francisco, CA
Information: Barbara McGivney, Synergistics Management, Inc., 3100 Route 138, Wall Township, NJ 07719. Tel: (908) 280–2024. Fax: (908) 681–9314.

31-2 **1995 Virginia Tech Symposium on Wireless Personal Communications**
Blacksburg, VA
Information, Jenny Frank, Administrator, Mobile and Portable Radio Research Group. Tel: (703) 231–2958.

June

1-2 **CEM 95: The 3rd Portuguese Seminar on Electromagnetic Compatibility**
Lisbon, Portugal
Information: Silicon Electronica E Telematica, Edificio Pascoal de Melo, Rua Pascoal de Melo, N. 3, 1100 Lisboa, Portugal. Tel: 8151234. Fax: 8130796.

13-15 **Nepcon East**
Boston, MA
Information: Reed Exhibition Companies, 383 Main Avenue, Norwalk, CT 06851. Tel: (203) 840–5398. Fax: (203) 840–9398.

21-23 **Electro/International 1995**
Boston, MA
Information: Miller Freeman, Kathryn Piersall, 13/6D Noel Road, Suite 500, Dallas, TX 75240. Tel: (214) 419–7969. Fax: (214) 419–7915.

July

9-12 **30th Annual Microwave Power Symposium**
Denver, CO
Information: IMPI, 10210 Leatherleaf Court, Manassas, VA 22111. Tel: (703) 251–1415.

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And all of this at a *very* affordable number.

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INFO/CARD 14

ITT GTC

RF courses

Electrical Grounding of Communications Systems
June 21-23, 1995, Madison, WI
Technical Cellular
July 31-August 3, 1995, Madison, WI
Radio System Design for Telecommunications
August 21-24, 1995, Madison, WI
Information: Department of Engineering Professional Development, University of Wisconsin-Madison, 432 North Lake Street, Madison, WI 53706. Tel: (800) 462–0876. Fax: (608) 263–3160.

Fuzzy Logic, Chaos, and Neural Networks: Principles and Applications
May 22-24, 1995, 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.

Microwave Antenna Measurements: Far-Field, Near-Field, Compact Ranges and Anechoic Chambers
June 13-16, 1995, Northridge, CA
Information: Shirley Lang, Center for Research & Services, School of Engineering & Computer Science, California State University-Northridge, 18111 Nordhoff Street, Northridge, CA 91330–8295. Tel: (818) 885–2146. Fax: (818) 885–2140.

Simulation of Communication Networks
May 22-24, 1995, Washington, DC
ATM-Based Enterprise Networking and Internetworking
June 5-7, 1995, Washington, DC
Radio Frequency Spectrum Management
June 5-9, 1995, Washington, DC
Analyzing Communications System Performance
June 12-15, 1995, San Diego, CA
Modern Receiver Design
June 12-16, 1995, San Diego, CA
Wireless Infrastructure Network Engineering for Cellular, PCS, LEO, and WPBX
June 12-16, 1995, San Diego, CA
Digital Cellular Radio
July 11-14, 1995, Washington, DC
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.

Grounding and Shielding Electronic Systems
July 25-26, 1995, Bloomington, MN
Circuit Board Layout to Reduce Noise Emission and Susceptibility
July 27, 1995, Bloomington, MN
Information: Continuing Education, 119 Mechanical Engineering Annex, University of Missouri - Rolla, Rolla, MO 65401–4992. Tel: (314) 341–4132. Fax: (314) 341–4992.

Thin Films of Semiconductor Deposition Processes
May 22-24, 1995, Monterey, CA
Microwaves and RF Measurements & Applications
July 10-13, 1995, Monterey, CA
Information: University Consortium for Continuing Education, 16161 Ventura Boulevard, M/S C-752, Encino, CA 91436. Tel: (818) 995–6335. Fax: (818) 995–2932.

Real-Time Digital Signal Processing
May 16-18, 1995, Kansas City, KS
Design of High-Performance Wireless Communication Systems
May 16-18, 1995, Kansas City, KS
Information: The University of Kansas, Division of Continuing Education, Attn: Lorene Damewood, Continuing Education Building, Lawrence, KS 66045–2607. Tel: (913) 864–3284. Fax: (913) 864–5074.

Electromagnetic Compatibility Engineering: EMC Design and EMI Mitigation
May 22-23, 1995, East Brunswick, NJ
International EMC Standards, Requirements, Measurements, and the European Union Approach
May 24-26, 1995, East Brunswick, NJ
Information: Registrat, The Center for Professional Advancement, P.O. Box 1052, East Brunswick, NJ 08816. Tel: (908) 613–4500. Fax: (908) 238–9113.

High-Frequency Analog Circuit Design for Communication Systems
June 12-15, 1995, United Kingdom
Information: CEI-Europe/Elsevier, Mrs. Tina Persson. Tel: (46) 122–175–70. Fax: (46) 122–143–47.

RF/MW Measurement Techniques I
June 12-16, 1995, Cambridge, UK
Applied RF Techniques I
June 12-16, 1995, Cambridge, UK
Digital Cellular and PCS Communications – The Radio Interface
June 13-16, 1995, Singapore
RF Component Modeling
June 19-22, 1995, Cambridge, UK
Applied RF Techniques II
June 19-23, 1995, Cambridge, UK
Applied RF Techniques
June 26-30, 1995, Morristown, NJ
Wireless RF System Design
June 26-30, 1995, Morristown, NJ
Information: Besser Associates, 4600 El Camino Real, Suite 210, Los Altos, CA 94022. Tel: (415) 949–3300. Fax: (415) 949–4400.

EMC Workshop – Immunity Measurements
July 4-5, 1995, Surrey, England
EMC Diagnostics Workshop – Emission Measurements
July 6-7, 1995, Surrey, England
Information: Miss Nikki Hamann, Conference Group, Technical Services Division, ERA Technology Ltd., Cleeve Road, Leatherhead, Surrey, KT22 7SA England. Tel: 44 (0)372–374151 ext. 2595. Fax: 44 (0)372–377927.

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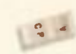

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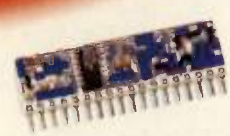

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Business Briefs

Anadigics Celebrates 10th Anniversary — Anadigics, supplier of gallium arsenide (GaAs) integrated circuits, recently marked its 10th anniversary. Since its inception in 1985, Anadigics has grown to more than 270 employees, expanded it manufacturing and office facilities to 75,000 square feet, and today generates annual sales in excess of $34 million.

Comtech Merges Operating Units — Comtech Telecommunications Corp. has merged its operating units: Comtech Microwave Corp., Power Systems Technology, Inc., and Scientific Power Systems, Inc. The companies will operate as Comtech Microwave Products Corp.

Monsanto Enters Wireless Arena — Monsanto and Lawrence Behr Associates, Inc. (LBA) have teamed up to target effective reduction of unwanted electromagnetic interference within cellular site facilities. Monsanto is working with LBA to implement a "system" approach to shielding cellular shelters.

Telesat Switches to Digital — Telesat Canada, which provides uplink services and transponder capacity to Canada's broadcast industry, is switching from analog services to the Scientific-Atlanta, Inc. digital video compression system. This will increase the channel capacity available to Telesat customers.

SaRonix Acquires Philips Manufacturing Plant — SaRonix has acquired the Philips Electronics N.V. crystal and oscillator manufacturing division based in Doetinchem, The Netherlands. Separately, SaRonix has entered into a resale agreement with Philips to supply the Philips worldwide Passive Components Sales Organization with advanced crystal and oscillator products to be marketed under the Philips brand name.

Datum Acquires Efratom — Datum Inc. has acquired the Efratom Division of Ball Corp's Aerospace and Communications Group. The addition of Efratom will more than double Datum's revenues while enhancing its worldwide market position in selected telecommunications products.

Richardson Joins Micro Crystal in 2-Year Agreement — Richardson Electronics will be the exclusive distributor for Micro Crystal in the crystal and oscillator market.

IBM Using Vari-L Components — IBM has selected Vari-L's voltage controlled oscillator (VCO) to control the signal processing function of IBM's wireless local area network product. The RF wireless PCMCIA spread spectrum, frequency-hopping LAN incorporates Vari-L's VCO product.

Glenayre and MobileComm Announce Partnership — Glenayre Technologies, Inc. and MobileComm have formed a technology partnership to build a test system of two-way wireless messaging services. MobileComm will begin beta testing the new services in mid-1995 with Glenayre equipment.

Conductus Demonstrates Thin-Film Filter — Conductus Inc. has demonstrated the world's first nineteen-pole planar bandpass filter on a single superconducting wafer. This filter rejects unwanted signals at a rate six times steeper than a conventional 8-pole filter found in cellular base stations. Conductus believes such improvements will help the wireless communications industry achieve higher quality communications, increased capacity in base stations and reduced component size.

NYNEX Offers Cellular Service in Lincoln Tunnel — NYNEX Mobile Communications Co. recently completed installation and activated service in the Lincoln Tunnel with the ADC Telecommunications Wireless Systems Division CityCell™ Digital Fiberoptic Microcell system. The system will provide NYNEX customers with cellular service throughout the three tubes that comprise the nation's busiest mile-long tunnel.

Contracts

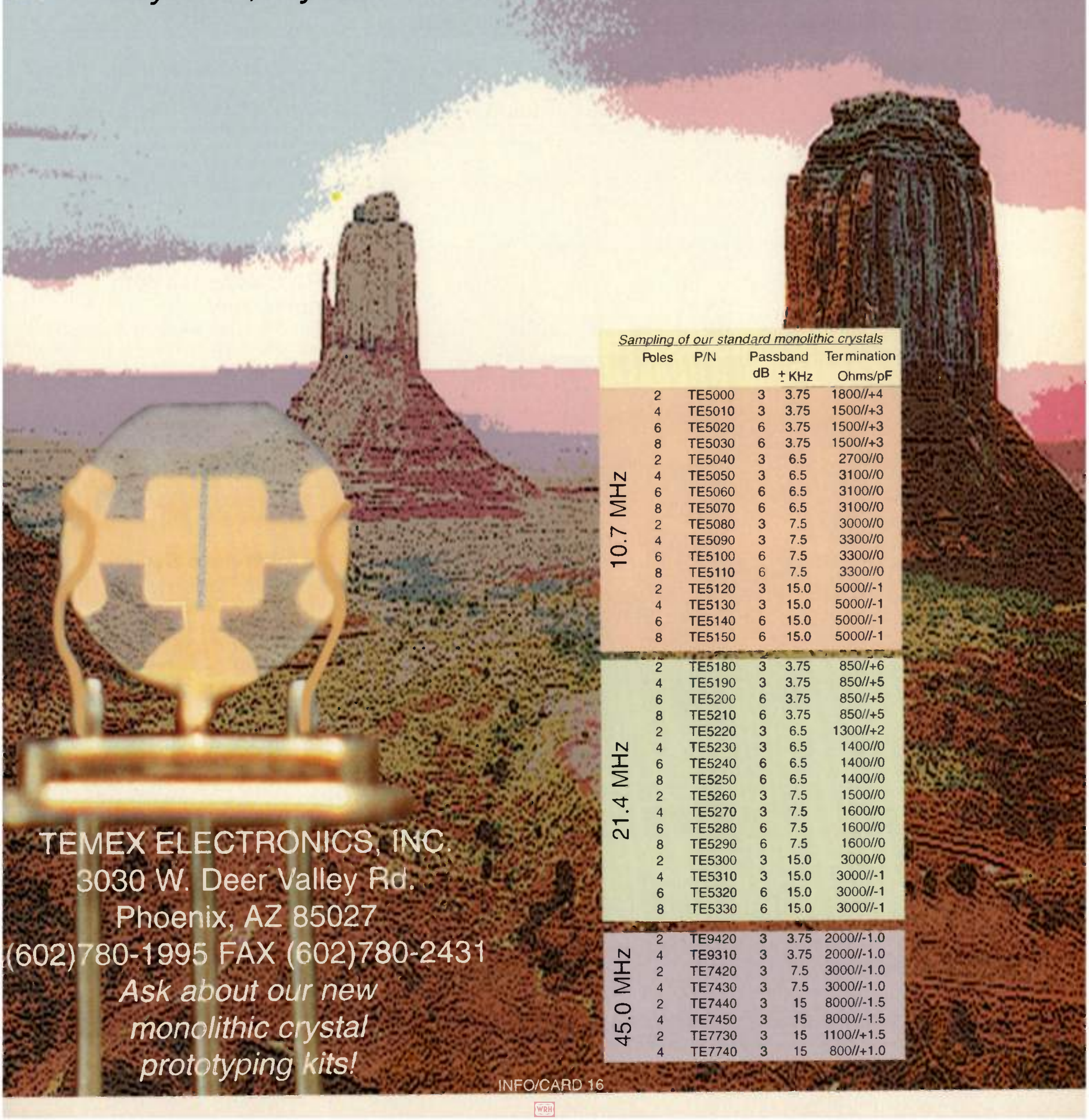
Litton Awarded Contract from Westinghouse — Litton's Electron Devices Division has been awarded a contract valued at over $4 million from Westinghouse Electric Corporation for more than 500 traveling wave tubes. The order is for the mid-life upgrade of radars on F-16 aircraft from NATO countries and Taiwan.

Oki Electric Awards Contracts to Berkeley Varitronics — Oki Electric of Tokyo has awarded two contracts to Berkeley Varitronics Systems for the design and manufacture of both base station and personal station transceivers for the 1.85-1.97 GHz PCS band according to Oki's WCDMA specifications. The first contract, covering radio frequency design, has already been completed. The second contract, encompassing the digital LSI section of the system for both the base and personal station prototypes, is near completion in an accelerated program expected to be completed in a nine-month turnaround time.

KVH Signs with Mitsubishi Electric — KVH Industries signed a contract with Mitsubishi Electric Corporation to manufacture satellite tracking antennas for use in Mitsubishi's new marine telecommunications product. The product is designed for use on the American Mobile Satellite Corporation Mobile Satellite System. The new Mitsubishi product will provide direct-dial telecommunications capability with voice and data as standard features and facsimile as an optional feature.

UK-MOD Selects Aydin to Supply Instrumentation — Aydin International U.K. has been awarded a contract from the United Kingdom Ministry of Defense (UK-MOD) for the supply of service practice instrumentation (SPI) used in SKYFLASH air-to-air missiles. The contract, with additional options valued around $13.5 million, calls for the design, qualification and delivery of SPI kits with supporting test sets and integrated logic support items.

NASA Selects Ball — NASA Langley Research Center has awarded Ball Corporation's Aerospace and Communications Group a $20 million contract to build three Stratospheric Aerosol and Gas Experiment III instruments for the Earth Observations Station.



AMP and M/A-COM Announce Merger Agreement

The directors of AMP Incorporated and M/A-COM, Inc. have approved a definitive merger agreement. This merger will enhance AMP's strategic presence in the high-growth market for advanced wireless components. The merger is expected to close in June.

M/A-COM will be set up as a wholly-owned AMP subsidiary, serving as the cornerstone of a new AMP business group dedicated to the wireless industry. This independent structure will support the growth of the company's combined presence in the wireless market, while providing flexibility over time to selectively integrate or realign particular business elements of M/A-COM or AMP to fully capitalize on the synergistic opportunities presented by this merger.

1995 Commemorates 100 Years of Radiocommunications

The International Telecommunication Union (ITU) has chosen 1995 to celebrate the centenary of radiocommunications. A calendar of events has been prepared to celebrate the 100 years of radiocommunications throughout 1995. It includes a special program to take place on May 17, World Telecommunication Day. This will include two lectures and a discussion panel to preview wireless communications in the 21st century. The ITU and the Radiocommunication Sector hope to remind everyone of the importance of radiocommunication in our daily life.

ERA Celebrates 60th Anniversary

The Electronics Representatives Association (ERA), the organization of manufacturers' representatives serving all segments of the international electronics industry, is celebrating its 60th anniversary during 1995. A major event marking the six-decade birthday is the association's 33rd Biennial Management and Marketing Conference, to be held at the PGA National Resort in West Palm Beach, FL.

ARIA Wireless System Available Nationwide

Comtek Research, Inc. announced that ARIA Wireless Systems rolled out PDDN service in the 32 markets for which it held FCC licenses. With Win-Comm, Inc. using PDDN technology in approximately 170 other markets, PDDN will now be available in over 200 markets. PDDN provides a reliable wireless connection that links automated teller machines, point-of-sale systems, and other electronic fund transfer applications to a "processing host" or electronic clearinghouse anywhere in the United states with one connection and one low monthly fee.

DAR Testing Program Reaches Mid-Point

The EIA/CEG Digital Audio Radio (DAR) Subcommittee's testing program has reached its mid-point in tests of nine DAR proponent systems vying to become the U.S. standard. CD quality sound and immunity to interference are the claims of proponents hoping to give birth to a new high-quality broadcast audio service. The EIA DAR Test Lab is completing all the digital tests including: overall quality; signal failure; and performance with impairments like noise, interference and multipath reflections. Test results should be reported soon and will consist of quality assessments, laboratory test results, impairment subjective assessments, AM/FM compatibility assessments and, soon thereafter, field test results.

Compact Sponsors User's Group Dinner at MTT

Compact Software will sponsor a user's group dinner at this year's MTT Symposium in Orlando. Compact utilizes the annual event as a forum for getting together with its customers, providing information about upcoming software releases and soliciting feedback from its user base. This year's meeting will be held on Tuesday, May 16.

Business Briefs *continued*

Proxima Signs Agreement with Anixter — Proxima, Inc. has signed a distribution agreement with Anixter Inc. Under the terms of the agreement, Anixter will resell Proxima's entire line of 2.4 GHz frequency hopping spread spectrum wireless networking products.

SGS-Thomson Delivers Millionth Decoder Chip — SGS-Thomson Microelectronics announced that its total shipments of MPEG decoder integrated circuits have passed the million mark. The million MPEG decoder ICs include dedicated compression circuits aimed at applications like consumer video CD products, multimedia PC and digital TV.

ATG Donates to Academic Research — A/S Site Products Division of Allen Telecom Group (ATG) donated $15,000 to the University of Maryland's College of Engineering. The donation is designated for the Antenna Specialists Fund, where it will be used to support research and study of advanced radio frequency filtering technologies.

Polyflon Moves — Polyflon has relocated its offices and manufacturing operations. Their new address is Polyflon Company, One Willard Road, Norwalk, CT 06851. Tel: (203) 840–7555. Fax: (203) 840–7565.

American KSS Moves Corporate Office — American KSS has moved its corporate office to 3295 Scott Blvd., Suite #100, Santa Clara, CA 95054. Tel: (408) 986–9577. Fax: (408) 986–1717.

Cost Pressures Squeeze More Functions onto RF Chips

By Andy Kellett
Technical Editor

Open up an RF assembly from fifteen or twenty years ago (say, a surplus military radio, or a mobile radio used by a utility company) and you will see a jumble of transistors, coils, capacitors, and some connecting hardware. Open up an RF assembly being produced today (say, a neon blue pager sold in a plastic blister-pack, or the wireless modem you bought to go with your notebook computer) and you will see a much tidier piece of PCB real estate.

True, today's RF devices still use capacitors, coils, resistors and all the other parts that used to fill RF assemblies, but now they are most likely there to "glue" together the inputs and outputs of the highly integrated RF ICs that make such devices affordable – and affordability is the driving force behind the increased integration of RF circuits.

More Integration, More Specificity

"The degree of integration will be driven by the market, as opposed to being driven by technology capability," says Paul Litzenberg, Engineering Manager for Power Products at TriQuint Semiconductor.

The market is demanding radios which replace the cable in previously cabled applications, says Phillip Snow, TriQuint's Vice President and General Manager for the Wireless Communications Division. "There are several ways to do that, and it's up to us to understand the preferred way in each of the market segments in which we compete," says Snow.

The trend in recent years has been for a market to present itself, for instance GSM, and for the IC manufacturers to follow with highly integrated circuits tailored specifically for that market. However, manufacturers still make "building-block-level" ICs for new, developing markets and for low volume designs for which high integration is not cost effective.

How Much Integration?

Construction for an RF application is most cost effective somewhere between discrete construction and total integration. At first, integration reduces circuit size, reduces the overall cost of a radio, and even eases some technical requirements. Senior Member of the Technical Staff at Maxim Integrated Products, Hans Dropmann points out an example. "If you don't have to go off chip with say, 1.8 GHz signals, you can run these signals at much lower power levels."

However, there is a limit to the degree of integration in a radio that makes sense. After a certain point, size reduction ceases to be an advantage. Also, the cost of the IC goes up as integration passes a certain point because manufacturing yields go down.

In addition, certain elements of radio circuits cannot be created on a semiconductor die. These portions of the radio circuit must be connected to the devices on-chip, while they remain off-chip. "...you end up with a system design that looks like a rat's nest of components piled up around this highly integrated IC," says Dropmann, "so this is one reason you don't want to push for too high an integration level."

Packaging strongly affects the extent of integration in RF circuits. Packages with more legs can have more parasitics, and the cost of a complex package can approach the cost of the die it contains. "You might be better off using a high volume package like a 16-pin narrow SO and use two of them instead," says Dropmann.

Semiconductor Technologies

Another reason integrating a radio completely from RF to baseband may not make sense is the efficaciousness of different technologies at different frequencies. This is particularly true for radios with RF front ends in the GHz range. At these frequencies, RF front ends are generally most easily implemented in GaAs, while silicon is generally the best technology for circuits in the lower frequency ranges.

Of course manufacturers are working to improve both silicon and GaAs processes to extend the frequency ranges in which those processes are effective. "GaAs processes are getting simpler to meet the wireless market demands, as they come down from military applications," says TriQuint Application Engineer Rob Christ, "on the other hand, Si bipolar processes are getting more complicated to reach up into those regions."

All is not Analog

Most of the transistors in modern RF products such as cellular phones, wireless modems and pagers are devoted to digital functions. Highly integrated RFICs typically contain at least some digital circuitry – if not for baseband processing, then for the dividers or registers in a synthesizer, or for simple control functions. "All these RFICs are generally controlled off a digital bus, so you have to be able to interface with that," says TriQuint's Snow.

Designing with RFICs

While highly integrated RF ICs provide a lot of the circuitry needed to implement wireless devices, a good dose of RF engineering is still necessary to make them work. Reynolds Jenkins, Product Marketing Manager for Wireless at AT&T points to his company's W2020 chip as an example. The W2020 incorporates mixers, amplifiers, a modulator and demodulator, a UHF synthesizer, two fixed oscillators and control circuits.

"People see it as one big block that they can put down on a circuit board and be able to run with it, but that's really not the case," says Jenkins, "There's still a lot of RF art necessary to get this working on a printed circuit board with a small form factor." *RF*

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MPN2-00100200-27P	.1–2*	23	1.5	2.5	2.0:1/2.5:1	27	$ 750
MPN2-00500100-30P	.5–1*	23	1.5	1.5	2.0:1/2.0:1	30	$ 850
MPN2-01000200-30P	1–2*	23	1.5	1.5	2.0:1/2.0:1	30	$ 850
MPN2-02000400-27P	2–4	21	1.5	2.0	2.0:1/2.0:1	27	$ 850
MPN3-02001800-20P	2–18	15	2.5	5.0	2.5:1/2.0:1	20	$ 900
MPN4-02001800-23P	2–18	23	2.5	5.5	2.5:1/2.0:1	23	$ 950

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High-Efficiency Power Amplifiers for 13.56 ISM and HF Communications

*By Ken Dierberger, Advanced Power Technology, Inc.,
Frederick H. Raab, Green Mountain Radio Research Co.,
Bobby McDonald, Uni-West Engineering, and
Lee Max, Independent Consultant*

This article describes the design of a 400 watt class C amplifier and a 250 watt class D amplifier using recently-introduced power MOSFET devices from Advanced Power Technology (APT). Both amplifiers provide high gain and high efficiency for 13.56 MHz industrial, scientific and medical (ISM) applications, and may also be used for HF communications. This article summarizes information presented at RF Expo East 1994 [1] and RF Expo West 1995 [2].

The boom in RF equipment operating in the UHF region has overshadowed the growth in lower frequency ISM systems. As a result, ISM applications have had to use high-cost RF power devices that are optimized for higher frequencies, or use devices that are intended mainly for switching power supply applications at lower frequencies. These latter devices, although low cost, are packaged in a standard common-drain configuration, requiring insulated mounting with added shunt capacitance, and which have significant inductance in the source connection, which combine to limit RF performance.

The APT devices used in the amplifiers described here are provided in a common-source configuration, eliminating the need for an insulator between case and heat sink. The additional internal BeO insulator required to achieve this configuration adds some thermal resistance, but less than would be added by the usual mounting insulator. The isolated die also permits the interchange of gate and drain leads, making "left hand" and "right hand" devices possible.

Design of a 400 Watt, 13.56 MHz Class C Amplifier

The first amplifier described is a 400 watt, 13.56 MHz design operating in class C with a 100 VDC power supply. Efficiency of this amplifier is 75 percent. The power amplifier is built around a "symmetric pair" of ARF442/ARF443 300V RF power MOSFETs provided in TO-247 plastic packages. The devices are identical, except that they are packaged in "mirror image" pairs to facilitate a symmetrical layout that helps maintain the electrical symmetry required for push-pull operation.

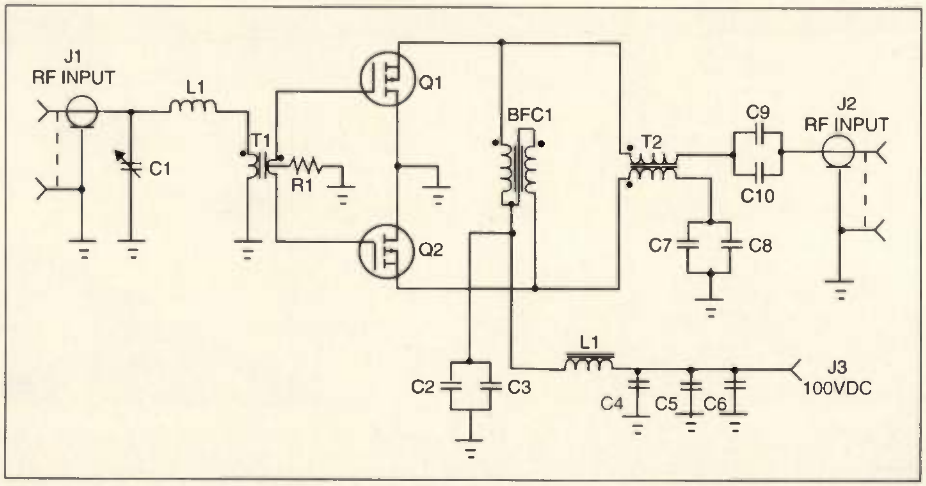

Figure 1. Circuit diagram of the 400 watt class C amplifier.

Figure 1 shows the circuit diagram of the amplifier, with its parts list given in Table 1. The amplifier is a classical push-pull configuration of a straight forward nature, using a simple L-C network for impedance matching and transformer-coupling to achieve the required complentary gate drive signals. A wideband transmission line transformer output circuit is used, with a conventional bifilar-wound RF choke for DC power supply isolation.

Part number	Description
C1	75-480 pF mica compression trimmer
C2, C3, C4, C5, C6, C7, C8	0.01 μF 200V CK06
C9	0.1 μF 100V CK06
C10	10 μF 100V electrolytic
R1	10k 5% 1/4 watt carbon
Q1, Q2	ARF442, ARF443
L1	0.5 μH: 7T, #18 AWG, I.D. = 0.438 in.
BFC1	Balanced DC feed choke, 7T, #22 stranded PTFE insulated twisted pair on Indiana General #F624-19-Q1 toroid, $\mu_i = 125$
RFC1	2T, #18 stranded PTFE on a Fair-Rite #2677006301 bead, $\mu_i = 2000$
T1	4:1 (Z) conventional transformer; 2:1T, #22 stranded PTFE on a Fair-Rite #2843000202 balun core, $\mu_i = 850$
T2	1:1 (Z) transmission line transformer; 4 turns (approx 22 in.) of mini 50 ohm PTFE coax, O.D. = 0.095, on a two-hole core made from two Fair-Rite #2643102002 cores, $\mu_i = 850$
PCB	0.062 in. G10 epoxy glass

Table 1. Parts list for the amplifier of Figure 1.

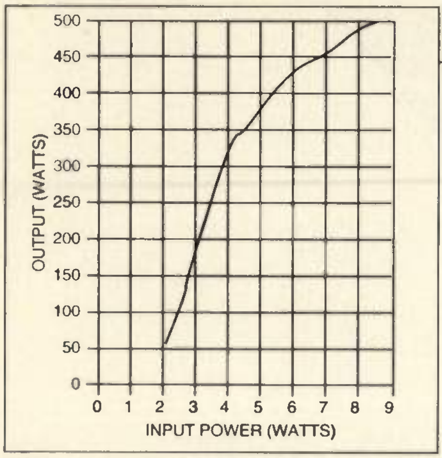

Figure 2. Output power versus input power.

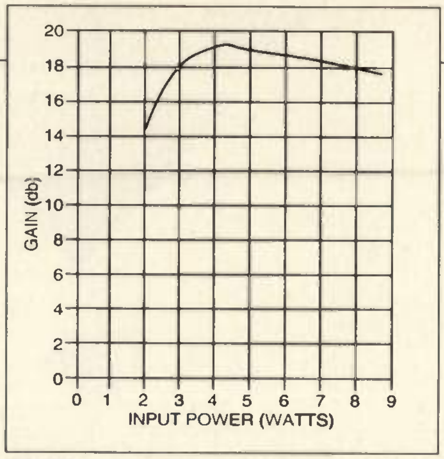

Figure 3. Gain versus input power.

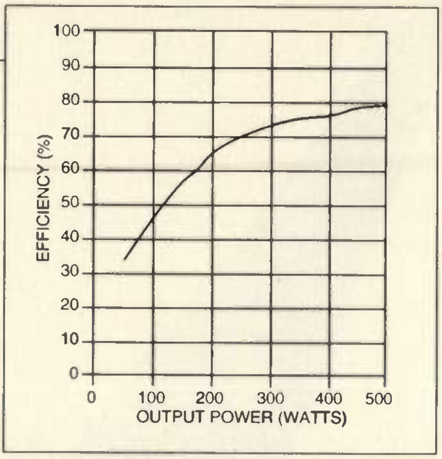

Figure 4. Efficiency versus output power.

Short, low inductance interconnections are easily made using the ARF442/ARF443 devices, because they can be mounted symmetrically. In particular, the gate circuit should minimize inductance to avoid instability and losses when that inductance is combined with the high capacitance of the gates. Similarly, the frequency response of the output circuitry is improved with minimum stray inductance due to interconnections.

The amplifier is operated from a 100 VDC power supply, and is constructed on a heat sink sized for proper dissipation at the expected power levels.

Input Network

The input network provides a 50 ohm impedance to the driving source. Transformer T1 provides impedance transformation for the MOSFET gate impedance, as well as balanced drive to push-pull operation. The input pi network comprises capacitor C1, inductor L1 and the input capacitance of the power MOSFETs, transformed by T1. The network is tuned for minimum return loss at the operating frequency by adjusting C1.

Transformer T1 provides a 4:1 impedance transformation of the MOSFET input impedance. It is constructed using a Fair-Rite two-hole balun core with 2 turns on the primary and 1 turn on the secondary. The secondary center tap is connected to ground through a 10 kohm resistor, which provides a DC path to ground for the gates, improving the stability and ruggedness of the amplifier. Without this resistor, the gate voltages may become unbalanced due to slight differences in the input of the MOSFETs or a small imbalance in the transformer voltage.

Output Circuit

The 100 VDC power input is delivered through a balanced feed choke. The choke is designed to create a zero DC magnetic bias in the core when both transistors draw the same average current. With the devices operating 180 degrees out of phase, the construction of the windings presents a high impedance at 13.56 MHz to the drain of each MOSFET. The choke is constructed by winding seven turns of #22 AWG PTFE twisted pair around a 0.5 inch diameter, μ_i = 125 toroidal core (Indiana General F624-19-Q1).

The output of the power devices is coupled to the load through a wideband 1:1 transmission line transformer. No output tuning or filtering was used in the test amplifier, which has the third harmonic 16 dB down and the second harmonic 45 dB below the 400 watt output power level.

The transformer is four turns of mini PTFE 50 ohm coaxial cable, wound on a special core. The core is made from two Fair-Rite #2643102002 μ_i = 850 cores (large beads) glued side-by-side to make a large two-hole balun core. The inductance provided by four turns through the ferrite cores is sufficient to isolate the input and output of the coaxial cable, creating an effective balun transformer.

Performance Measurements

Figures 2 through 6 show the performance data for this amplifier. Figure 2 is a plot of P_{out} versus P_{in} and Figure 3 is shows gain versus P_{in}. The curves show the classical class C characteristics, with low gain at low power output, improving as the output power increases. The gain plateaus at 19 dB when the amplifier output is 400 W, with a rolloff to 17.5 dB at 500 W.

Efficiency versus P_{out} is shown in Figure 4. As would be expected in class C, the efficiency is below 50 percent at lower power outputs, rising to an outstanding 75.5 percent at 400 W, continuing upward to 79.4 percent at 500 W output. Other plots of interest are Figure 5, DC supply current versus P_{out}, and Figure 6, total power dissipation versus P_{out}.

400 W Amplifier Summary

High power amplifiers for 13.56 MHz can be made economically using low cost MOSFETs in standard plastic

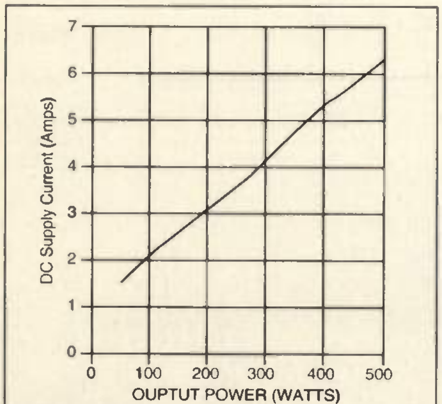

Figure 5. DC supply current versus output power.

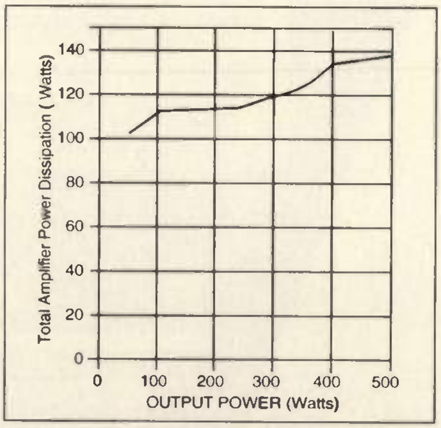

Figure 6. Total amplifier power dissipation versus output power.

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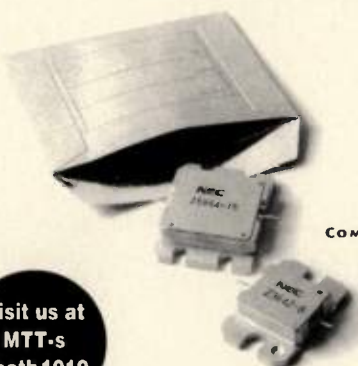

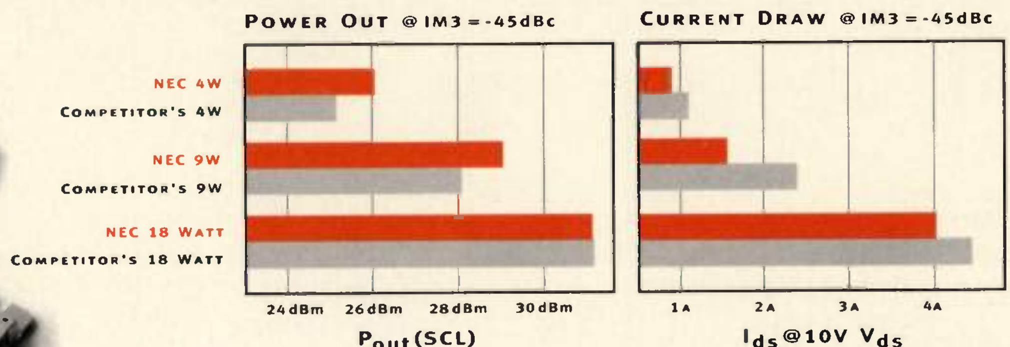

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packages. The combination of high voltage, high gain and 75 percent efficiency make this an attrative alternative to vacuum tube technology for ISM band RF power supplies. The physical layout of the amplifier is shown in Figure 7.

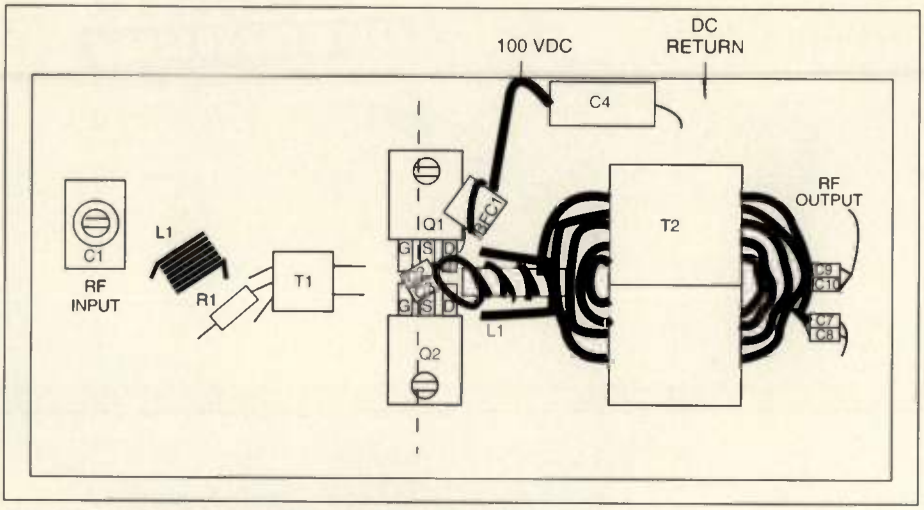

Figure 7. 400 watt class C power amplifier layout.

A High-Efficiency Class D Amplifier Using Power MOSFETs

The second amplifier described in this article is a class D design using transformerless input circuitry and simple output circuitry. The PA operates from 50 VDC, while the driver is powered from 12 VDC. A power input of just 10 mW provides an output of 250 W or more over 1.8 to 13.56 MHz.

The basic design concept ensures an amplifier that is inexpensive and easy to manufacture. However, in the prototype described, no effort has been made to minimize the parts count in the interest of robust design.

In class D, devices are operated in push-pull, driven to act as switches, generating a square-wave voltage. The fundamental-frequency component of that square wave is passed to the load through a filter. Power output is controlled by varying the supply voltage.

The power output of a class D power amplifier [3] [4] is :

$$P_o = \frac{V_{eff}^2}{2R} \qquad (1)$$

C1, C2	33 μF, 50V
C3	20 μF, 250V
C4–C27	0.1 μF, 50WV chip
C28	(See table below)
D1, D2, D3	5.1V, 0.25W Zener, 1N751A
J1, J2	BNC female connector
J3-J8	European-style binding post
L1	3.5 μH (7t. #24 on Ferroxcube 768XT188, 4C4 toroid)
L2	(See table below)
Q1, Q3	p-channel MOSFET, 2N7016
Q2, Q4	n-channel MOSFET, 2N7012
Q5	APT ARF440
Q6	APT ARF441
R1, R2	330 Ω RC07
R3	220 Ω RC07
R4	10 kΩ RC07
R5	51 Ω RC07
R6, R8, R10, R12, R14, R16, R18, R20	1 kΩ trimmer potentiometer
R7, R9, R11, R13, R15, R17, R19, R21	4.7 kΩ RC07
T1	2t. center-tapped primary, 3t. secondary #22 insulated wire, wound on Ceramic Magnetics 3000-4-CMD5005 ferrite
U1, U2	Schmitt trigger/limiter, Elantec EL7144C

Frequency-Dependent Components

1.8 MHz —	L2: 22 μH, 52t. #24 on Micrometals T200-6 core; C28: 354 pF, 2.5 kV padder
3.5 MHz —	L2: 11.4 μH, 32t. #24 on T200-6 C28: 180 pF, 2.5 kV padder
7 MHz —	L2: 5.7 μH, 20t. #24 on T200-6 C28: 90 pF, 2.5 kV padder
10 MHz —	L2: 2.93 μH, 14t. #20 on T200-6 C28: 86 pF, 2.5 kV padder
12 MHz —	L2: 2.93 μH, 14t. #20 on T200-6 C28: 60 pF, 2.5 kV padder
13.56 MHz —	L2: 2.93 μH, 14t. #20 on T200-6 C28: 47 pF, 2.5 kV padder.

Table 2. Parts list for the class D amplifier.

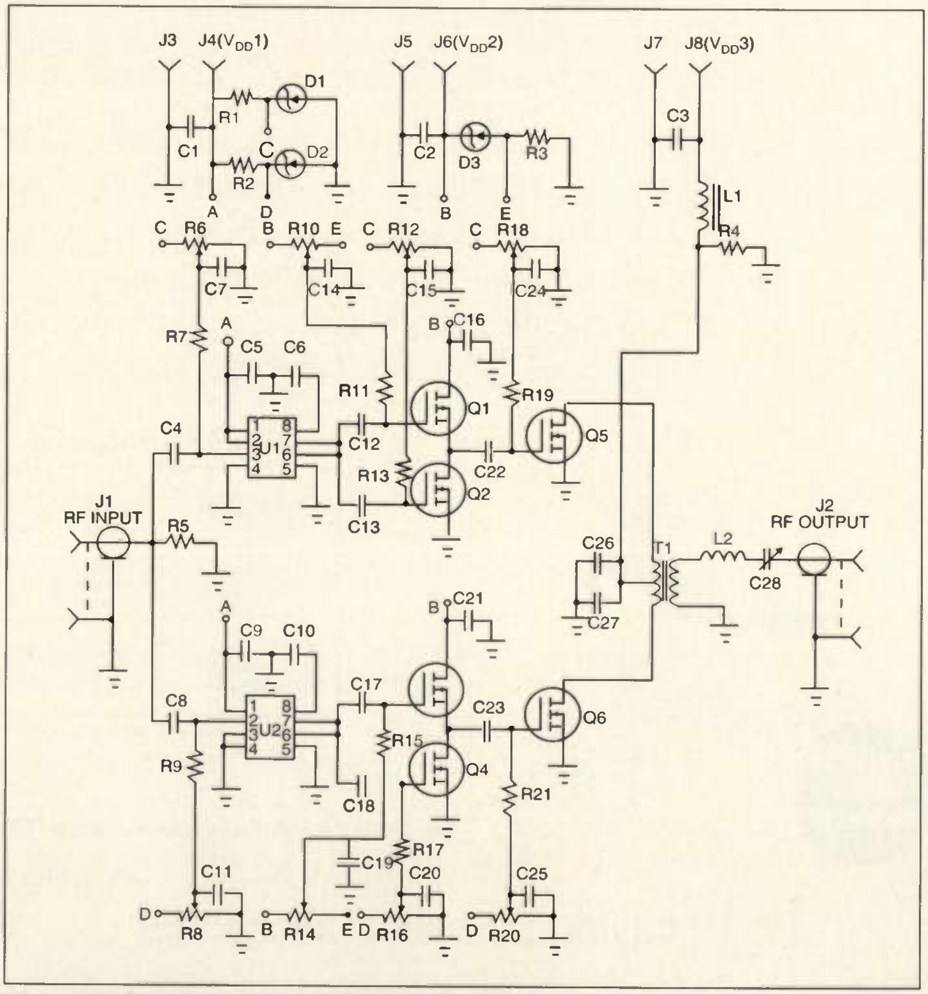

Figure 8. Circuit diagram of the class D amplifier and driver.

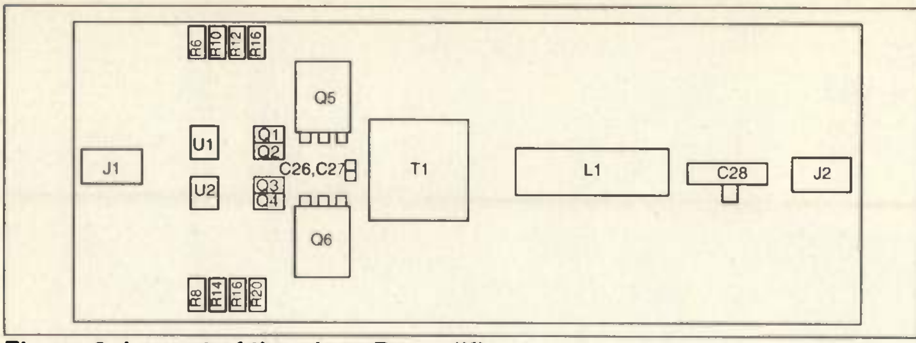

Figure 9. Layout of the class D amplifier.

where the effective supply voltage is:

$$V_{eff} = V_{DD} \frac{R}{R + R_{ON}} \tag{2}$$

Above, R is the drain-load line (seen by one drain with the other open) and R_{ON} is the on-state drain-source resistance. For the ARF440/ARF441 used in this amplifier, $R_{ON} \approx 0.8$ ohms. A 250 W output with a 50 V supply voltage thus requires $R \le 6.4$ ohms. Using a simple transformer with a 3:1 turns ratio (9:1 impedance ratio), a 50 ohm load is transformed to 5.56 ohms.

Considering only V_{eff}/V_{DD} (the effect of R_{on}), the efficiency of an otherwise ideal class D amplifier would be 87.4 percent. Adding the effects of switching and drain capacitance [4] yields 76.2 percent efficiency at 13.56 MHz. Typical losses in the transformer and output filter result in an expected efficiency of about 70 percent.

Expected peak drain current in this amplifier is 10 A, which corresponds to I_{DC} = 6.3 A. Data sheets for the ARF440/ARF441 show that a gate-source voltage of 9 to 10 V should be sufficient to maintain minimum R_{ON} at 10 A drain current. Setting the gate threshold to about 3.5 V means that 6.5 volts of RF is required.

Effective capacitance of the gate during the switching process is close to 2600 pF [5]. If transition occurs in one-tenth of the RF period, or 73.7 ns at 13.56 MHz, an average of 5 A of gate current is required. Hence, a low driving resistance and low inductance are clearly required.

Class D Amplifier Circuit

Figure 8 shows the circuit of the amplifier and driver. The parts list is included in Table 2. In small quantities, the total parts cost is about $190.

The predriver uses a pair of low-cost integrated circuits, rather than the conventional RF transformer, to provide the out-of-phase driving signals. It also provides hard-limiting of the input signal, creating the desired square wave waveform. U1 and U2 are Elantec EL7144C gate driver ICs, with both inverting and non-inverting inputs, simplfying phase inversion.

RF is AC-coupled to U1 and U2, with DC bias adjustment through R6 and R8 to control the duty cycle. Below 4 MHz, these can be symmetrical, but above 10 MHz, the difference between the MOSFET turn-on and turn-off times require pre-distortion of the drive signal to assure 50 percent duty cycle of the final stage devices. Best switching speed is achieved when V_{DD1} = 12 V.

Although the EL7144C devices provide sufficient drive at low frequencies, operation at higher frequencies requires a lower impedance, higher current circuit. Complimentary pairs of smaller MOSFETs (2N7016/2N7012 or IRFD110/IRFD9120), also operating at 12 V, are used to drive the gates of the ARF440/ARF441.

The Final Amplifier

Quiescent currents should be set to about 0.1 A for each device, requiring bias of 3.5 to 3.8 V. The drivers and the final amplifier MOSFETs are AC-coupled and provided with adjustable bias for flexibility in the prototype stage. Direct coupling can be used to simplify the final design, with proper consideration for cutoff in the absence of a driving signal.

The output transformer is constructed by winding #22 insulated wire through one block of CMD5005 ferrite. DC is fed at the center tap of the primary winding. Bypass capacitors and L1 maintain RF ground and keep RF out of the power supply line.

The prototype uses simple series-tuned circuits (Table 2) with Q = 5 at the frequency of operation. Tuning is accomplished by adjusting padder C28 for maximum output power. Other filters may be used as long as they have an inductor on the transformer side to keep current from flowing at harmonic frequencies.

Construction

Layout of the principal components is shown in Figure 9. MOSFETs Q5 and Q6 are separated by about 0.8 inches to line up with leads from T1. Drivers and predrivers are installed roughly in line for minimum lead lengths.

The predriver input is high impedance and not especially critical. Short, low-inductance leads connect predrivers to drivers, and similarly, connect the drivers to the final amplifiers. Bypass chip capacitors are placed as close as possible to the ICs and MOSFETs.

The tuned output is used for transmitters and resonant loads. The series-tuned output reduces the levels of the harmonics so that they contribute negligibly to the output power.

Performance

Figures 10 and 11 show the performance of this class D amplifier. Figure 10 plots the efficiency (top) and power output (bottom) versus frequency. The predicted performance curve is included on the graphs, as well, which is based on resistance, switching time and drain capacitance, but not any of the other system losses. At lower frequencies, the amplifier approaches predicted efficiency. At higher frequencies, V_{DD} is reduced slightly to maintain safe drain current, which reduces power output. The most probable reason for lower efficiency is imperfect timing of the drive and the turn-on characteristics of the MOSFETs. The data points are listed in the table.

Figure 11 shows efficiency and out-

f, MHz	V_{DD}, V	I_{DC}, A	P_i, W	P_o, W	η
1.8	50.0	6.55	327.5	273.0	0.833
3.5	50.0	6.83	341.5	274.0	0.802
7.0	48.6	6.85	333.0	250.0	0.751
10.0	45.0	6.74	303.5	206.3	0.679
12.0	40.0	6.72	268.6	184.8	0.688
13.56	45.0	6.72	302.6	184.7	0.610

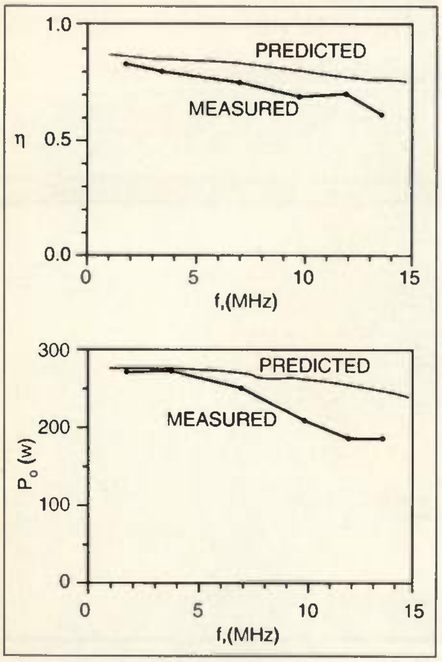

Figure 10. Efficiency and output power versus frequency.

V_{DD}, V	1.8 MHz		7.0 MHz		13.56 MHz	
	v_{om}, V	η	v_{om}, V	η	v_{om}, V	η
10	34.4	0.823	34.6	0.705	36.7	0.573
20	68.6	0.845	69.6	0.751	69.2	0.613
30	102.4	0.853	102.3	0.745	101.1	0.645
40	135.0	0.847	133.4	0.755	125.4	0.626
45	149.7	0.837	148.0	0.753	135.9	0.610
47.8	158.1	0.833	–	–	–	–
48.6	–	–	158.1	0.751	–	–
50	165.2	0.833	–	–	–	–

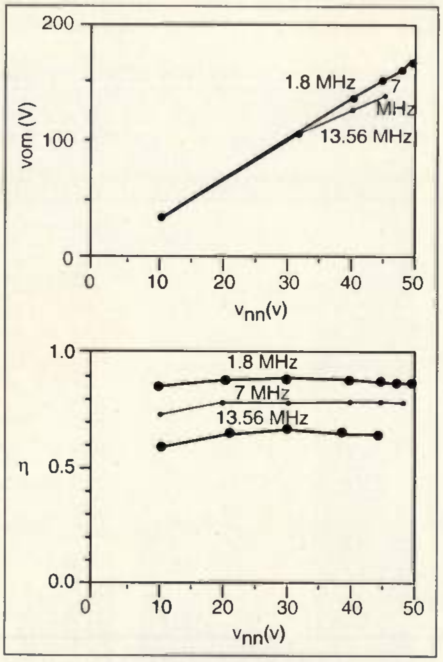

Figure 11. Efficiency and output versus supply voltage.

put versus supply voltage at three frequencies. unlike class A or class B, this amplifier has consistent efficiency at all power levels, with a modest peak at mid-level supply voltages. Linearity for control and modulation is generally excellent. The data collected for this figure is included in the table.

Untuned output can be used to deliver the maximum power to a resistive load. Efficiency and output versus frequency for an untuned load will be higher than for a tuned load. With a square wave output, this mode of operation can deliver 27 percent more RF power than tuned class D. Efficiency reaches a maximum of 85 percent at 300 watts output, with a higher value achieved at 100 watts.

Driver power consumption should be noted, since it is part of the system power requirement. DC power consumption ranges from 2.16 W at 1.8 MHz to 15.0 W at 13.56 MHz.

Suggested Improvements

Additional efforts that would improve the performance of the prorotype class D amplifier include:

- Add monostable (timer) circuits to the predriver for control of both phase and pulse width of the driving signals.
- Identify better complementary pairs for the driver.
- Use a better circuit board layout with low inductance traces and greater use of surface-mount components.

The switching times of the ARF440/ARF441 suggest that full-power operation in class B is possible to frequencies as high as 30 MHz. TO achieve this, the following steps are recommended:

- Develop a new output transformer with good broadband performance (transmission line transformer).
- Implement a conventional drive circuit using a transmission line transformer and gate swamping.
- Test the PA in both class B and D operations (as in [4]).

Summary

Two amplifier designs based on new APT power MOSFETs have been presented, demonstrating the simplicity of class C and the efficiency and control afforded by class D. The use of devices that are both lower in cost than VHF-capable RF power MOSFETs, and provided in standard plastic packages results in designs that can be manufactured at costs that are comparable to vacuum tube techniques. For more information, contact Ken Dierberger at the address listed below. *RF*

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1. K. Dierberger, B. McDonald, L.B. Max, "A High-Efficiency 400 Watt 13.56 MHz RF Power Amplifier," *Conference Proceedings*, RF Expo West 1995.
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5. K. Dierberger, "Gate Drive Design for Large Die MOSFETs," Application Note APT9302, Advanced Power Technology (Also *Proc. PCIM '93 Europe)*.

About the Authors

Ken Dierberger is Applications Engineering Manager at Advanced Power Technology Inc., 405 SW Columbia St., Bend, OR 97702. He can be reached at (503) 382-8028; fax: (503) 388-0364. The 400 watt class C amplifier was developed by Bobby McDonald of Uni-West Engineering, P.O. Box 919, Bethel Island, CA 94511. The class D amplifier circuit was developed by Frederick H. Raab, President of Green Mountain Radio Research Co., 50 Vermont Ave., Fort Ethan Allan, Colchester, V T 05466. Assiting in the development and publication of both designs was Lee Max, RF and Microwave Consultant, 6284 Squiredale Drive, San Jose, CA 95129.

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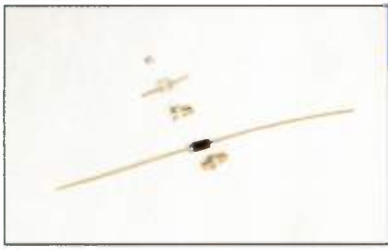

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NC 401	100 MHz – 18 GHz
NC 406	18 GHz – 110 GHz

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NC 506/15	0.2 MHz – 5 GHz	31 dB
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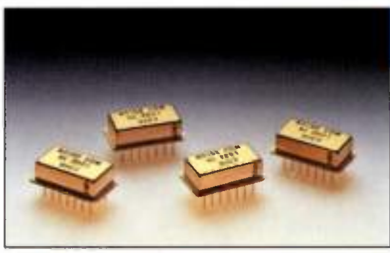
NC 513/15	0.2 MHz – 2 GHz	51 dB



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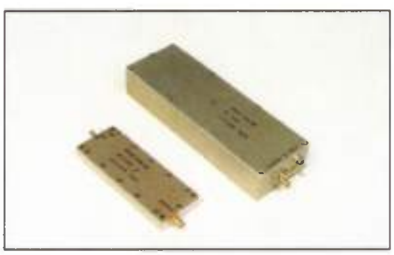
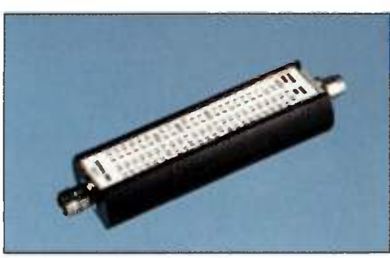
TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT
NC 2101	100 Hz – 20 kHz	0.15 Vrms
NC 2105	500 Hz – 10 MHz	0.15 Vrms
NC 2201	1 MHz – 100 MHz	+5 dBm
NC 2601	1 MHz – 2 GHz	-5 dBm



The NC 1000 series amplified noise modules produce white Gaussian noise from -14 dBm to +13 dBm at frequencies up to 6 GHz. They are designed for coaxial test systems, and are available with several bias voltages and connector options.

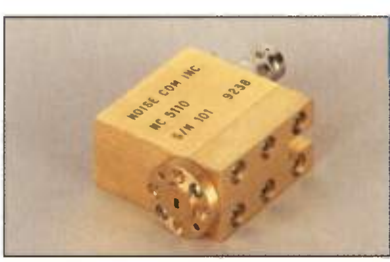
TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT
NC 1101A	10 Hz – 20 kHz	+13 dBm
NC 1107A	100 Hz– 100 MHz	+13 dBm
NC 1112B	20 MHz – 2 GHz	0 dBm
NC 1126A	2 GHz – 6 GHz	-14 dBm



Broadband Precision, Calibrated Coaxial

Noise Com's NC 346 series is designed for precision noise figure measurement applications. These products are available with coaxial or waveguide outputs. For OEM applications, the NC 3200 series provides high performance in a small ruggedized package.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	OUTPUT ENR
NC 346A	0.01 GHz – 18 GHz	6 dB
NC 346B	0.01 GHz – 18 GHz	15 dB
NC 346D	0.01 GHz – 18 GHz	25 dB
NC 346Ka	0.1 GHz – 40 GHz	15 dB



Broadband Calibrated Millimeter-wave

The NC 5000 series noise sources feature outstanding stability and convenience in waveguide bands up to 110 GHz.

TYPICAL STANDARD MODELS		
MODEL	FREQUENCY RANGE	WAVEGUIDE
NC 5142	18 GHz – 26.5 GHz	WR-42
NC 5128	26 GHz – 40 GHz	WR-28
NC 5115	50 GHz – 75 GHz	WR-15
NC 5110	75 GHz – 110 GHz	WR-10

Coaxial with Built-in Isolators

The NC 3400 series are precision calibrated noise sources for extreme accuracy and flatness enhanced by their low VSWR 1.25:1.

TYPICAL STANDARD MODELS

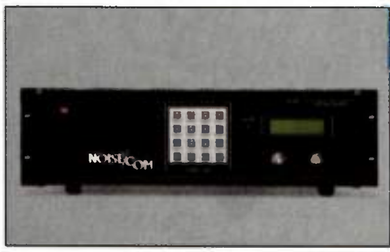
MODEL	FREQUENCY RANGE	OUTPUT ENR
NC 3404	2 – 4 GHz	30–36
NC 3405	4 – 8 GHz	30–35
NC 3406	8 – 12 GHz	28–33
NC 3407	12 – 18 GHz	26–32

BER Testing Equipment

The UFX-BER accurately sets and displays Eb/No, C/N, C/No, or C/I between a user supplied signal and internally generated white Gaussian noise. The UFX-BER can be used for back to back or IF loop-back testing with extreme precision over a broad range of input or output power. Eb/No values can be entered directly from the front panel or by IEEE-488 bus.

TYPICAL STANDARD MODELS

MODEL	FREQUENCY RANGE	APPLICATION
UFX-BER-70	50 MHz – 90 MHz	General
UFX-BER-IBS/IDR	50 – 90; 100 – 180 MHz	IBS/IDR
UFX-BER-836	824 MHz – 849 MHz	CDMA
UFX-BER-1850	1800 MHz – 1900 MHz	DCS–1800



Amplifier Test Station

The UFX-NPR series instruments perform automatic distortion measurements in mobile telephone (CDMA and FDM) base stations, satellite communications systems, CATV, and other equipment operating in multi-signal environments. Some models are available with tunable measurement frequency or with multiple measurement frequencies.

TYPICAL STANDARD MODELS

MODEL	FREQUENCY RANGE
UFX-NPR-70	50 MHz – 90 MHz
UFX-NPR-CATV	50 MHz – 1.0 GHz
UFX-NPR-1700	1.6 GHz – 1.9 GHz
UFX-NPR-2400	2.2 GHz – 2.6 GHz
UFX-NPR-11900	10.95 GHz – 12.8 GHz

Broadband Noise Generators

The NC 6000 and NC 8000 series noise generating instruments are designed for applications on the test bench or incorporated with other equipment to provide a wide variety of functions. Each instrument contains a precision noise source, amplification, and step attenuators to provide repeatable symmetrical white Gaussian noise with variable output power.

TYPICAL STANDARD MODELS

MODEL	FREQUENCY RANGE	OUTPUT POWER
NC 6107	100 Hz – 100 MHz	+13 dBm
NC 6110	100 Hz – 1500 MHz	+10 dBm
NC 6124	2 GHz – 4 GHz	-10 dBm
NC 8107	250 kHz – 100 MHz	+30 dBm

The new UFX-7000 series noise generating instruments are extremely easy to use, combining dedicated keys for control of operations and programming, with a large 4 x 20 character LCD display. Control of output power, filter settings, and attenuator step size for both the noise and the signal (for units with internal combiners) is performed from the front panel or remotely using the IEEE-488 interface.

TYPICAL STANDARD MODELS

MODEL	FREQUENCY RANGE	OUTPUT POWER
UFX-7107	10 Hz – 100 MHz	+13 dBm
UFX-7108	100 Hz – 500 MHz	+10 dBm
UFX-7110	100 Hz – 1500 MHz	+10 dBm
UFX-7218	2 GHz – 18 GHz	-20 dBm
UFX-7909	1 MHz – 300 MHz	+30 dBm

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Broadband Transmission Line Transformer Family Matches a Wide Range of Impedances – Part 2

By Donald A. McClure

This article is the second of a two-part series introducing a family of transmission-line transformers. This family achieves impedance matching flexibility that has not been possible with earlier designs. This second article provides further information on the class of transmission-line transformers dubbed RAVOR devices (for RAtional VOltage Ratio) by the author. The first article was published in the February 1994 issue of RF Design. *To avoid confusion between the two papers, figures and references in this present work are numbered in sequence beyond those in the previous work.*

In the first article [4], the theoretical basis for and the general principles of the RAVOR class of broadband transmission-line transformers were presented. These devices comprise various numbers of equal length transmission lines of equal characteristic impedance connected in various combinations of series and parallel and have voltage transformation ratios of rational form, m/n, where m and n are integers. The basis of operation is viewed in the light of current-voltage duality arising from the series-to-parallel and the reverse interchange of connections between the ends.

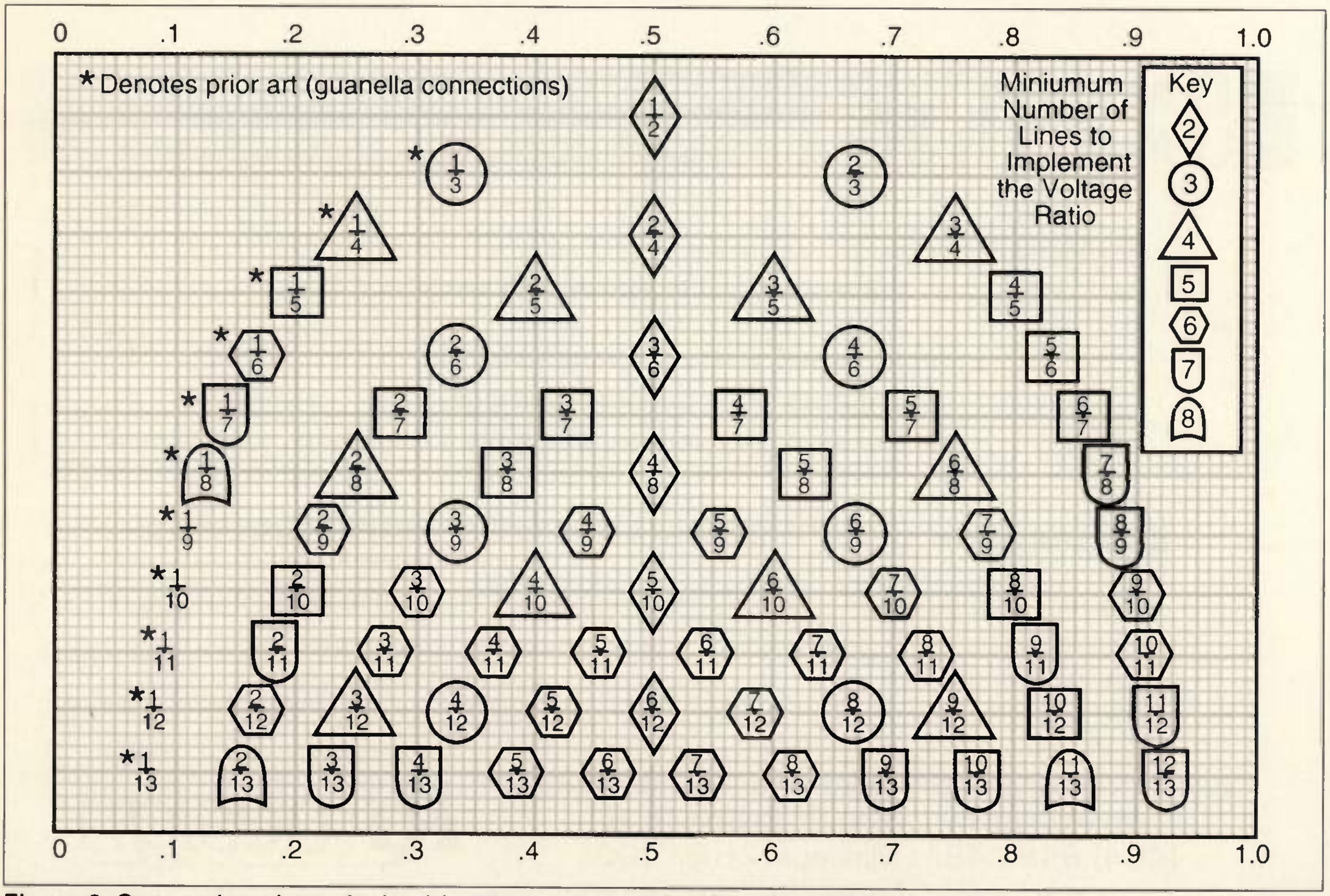

Figure 6. Conversion chart, decimal fractions to rational ratios, denominators 2 through 13.

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F 71 Rev F

A system of notation was introduced to describe the end connections without having to sketch the cables and wiring. The notation scheme is re-introduced here for the convenience of the reader:

2S
>S
2P

The above symbology means that two lines are connected in series to form a group; two other lines are connected in parallel to form a group; then the two groups are connected in series. The opposite end of the transformer is connected in the complementary manner and is denoted by:

2P
>P
2S

The transformer end-connections are completely defined by either the input or output end notations above and describe the 2/5 voltage-ratio transformer shown in Figure 9, except that DC isolating capacitors have been added in the figure.

Table 1 of the first article [4] lists 27 ratios and the connection notation for each, along with the number of lines required to implement each ratio. Two design examples were provided to approximate a 1 to 2 impedance transformation.

The transformer input and output impedances are written in terms of the lines' characteristic impedance, Z_0, and the voltage transformation ratio, K, as follows:

At the low impedance end,

$$Z_1 = K \cdot Z_0, \qquad 0 < K < 1 \tag{1}$$

and at the opposite end,

$$Z_2 = \frac{1}{K} \cdot Z_0 \tag{2}$$

The Z_0 of the constituent transmission lines is the geometric mean of the end impedances:

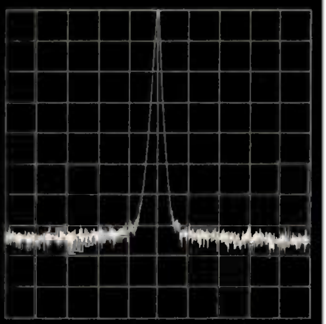
$$Z_0^2 = \frac{Z_1}{K} \cdot KZ_2 = Z_1 Z_2 \tag{3}$$

$$Z_0 = \sqrt{Z_1 Z_2} \tag{4}$$

The Ratio Chart

It is a useful fact of number theory that all rational numbers between one and infinity can be positioned on a linear scale in the space between zero and one simply by taking the reciprocal of each. Thus, it is convenient to have a chart showing the gamut of practical fractional voltage ratios, K, positioned according to their decimal values. The chart is presented in Figure 6. Any ratio larger than one may be entered on the chart merely by taking the reciprocal, which is the same as turning the transformer end-for-end. The dot on the underside of each fraction-bar locates the decimal equivalent value of the fraction on the abscissa of the chart.

The ratio chart is a design aid which allows the reader to visuallize easily the m/n voltage ratios that lie close in value to the desired decimal fraction. This decimal fraction is found by taking the square root of the desired impdance ratio. The symbols enclosing the ratios indicate the minimum number of trans-



Ultra-low phase noise floor says it all.

Voltage Ratio (K)	Connections	Min. # Lines
2/3	(2S, 1) > P	3
1/10	10P*	10
3/10	((2P, 3S) > P, 1) > P	6
7/10	((2S, 3P) > S, 1) > P	6
9/10	((2S, 2P) > P, 2P) > S	6
1/11	11P*	11
2/11	(5P, 2S) > P	7
3/11	((2P, 1) > S, 3P) > P	6
4/11	((3P, 1) > S, 2P) > P	6
5/11	((2P, 3P) > S, 1) > P	6
6/11	((2S, 3S) > P, 1) > P	6
7/11	(((3S, 1) > P, 1) > S, 1) > P	6
8/11	(((2S, 1) > P, 2S) > S, 1) > P	6
9/11	(((3S, 2P) > S, 1) > S, 1) > P	7
10/11	(((2S, 1) > P, 1) > S, 2S) > P	6
1/12	12P*	12
5/12	((2P, 2S) > S, 2P) > P	6
7/12	(((2P, 2S) > P, 1) > S, 1) > P	6
11/12	((2S, 1) > P, 4P) > S	7
1/13	13P*	13
2/13	(2S, 6P) > P	8
3/13	(4P, 3S) > P	7
4/13	(4S, 3P) > P	7
5/13	(((2S, 1) > P, 1) > S, 2P) > P	6
6/13	(((2P, 1) > S, 1) > P, 2S) > P	6
7/13	(((2S, 1) > P, 2P) > S, 1) > P	6
8/13	((((2P, 1) > S, 1) > P, 1) > S, 1) > P	6
9/13	((2S, 4P) > S, 1) > P	7
10/13	((3S, 3P) > S, 1) > P	7
11/13	((5S, 2P) > S, 1) > P	8
12/13	((3P, 1) > S, 3S) > P	7

Table 1 (Part 2). Continuation of the voltage ratio and connection data for the RAVOR transformers, covering denominators 9 through 13. (Plus corrected entry for 2/3). (*) indicates a Guanella connection.

mission lines to implement each ratio. The key in Figure 6 matches each of these symbols to the minimum number of lines. Ratios in which the numerator and denominator contain some common factor, such as 2/6, or 6/10, are shown as being attained by the minimum number of lines to implement the equivalent, irreducible fraction.

The ratios that are not symbol-enclosed (at the left of the chart) result from Guanella (IVOR) [4] connections having denominators 9 through 13. The number of lines required is simply the same as the value of the denominator.

The design procedure outlined in the first article [4], page 66, "Configuration Selection", should be modified to include the use of the Ratio Chart of Figure 6 to ease the transition from the decimal value to the rational form. After choosing a rational ratio from the chart that is a suitable approximation to the desired decimal value, refer to Table 1 and/or Table 1 (Part 2) to determine a set of end-connections to achieve the selected ratio.

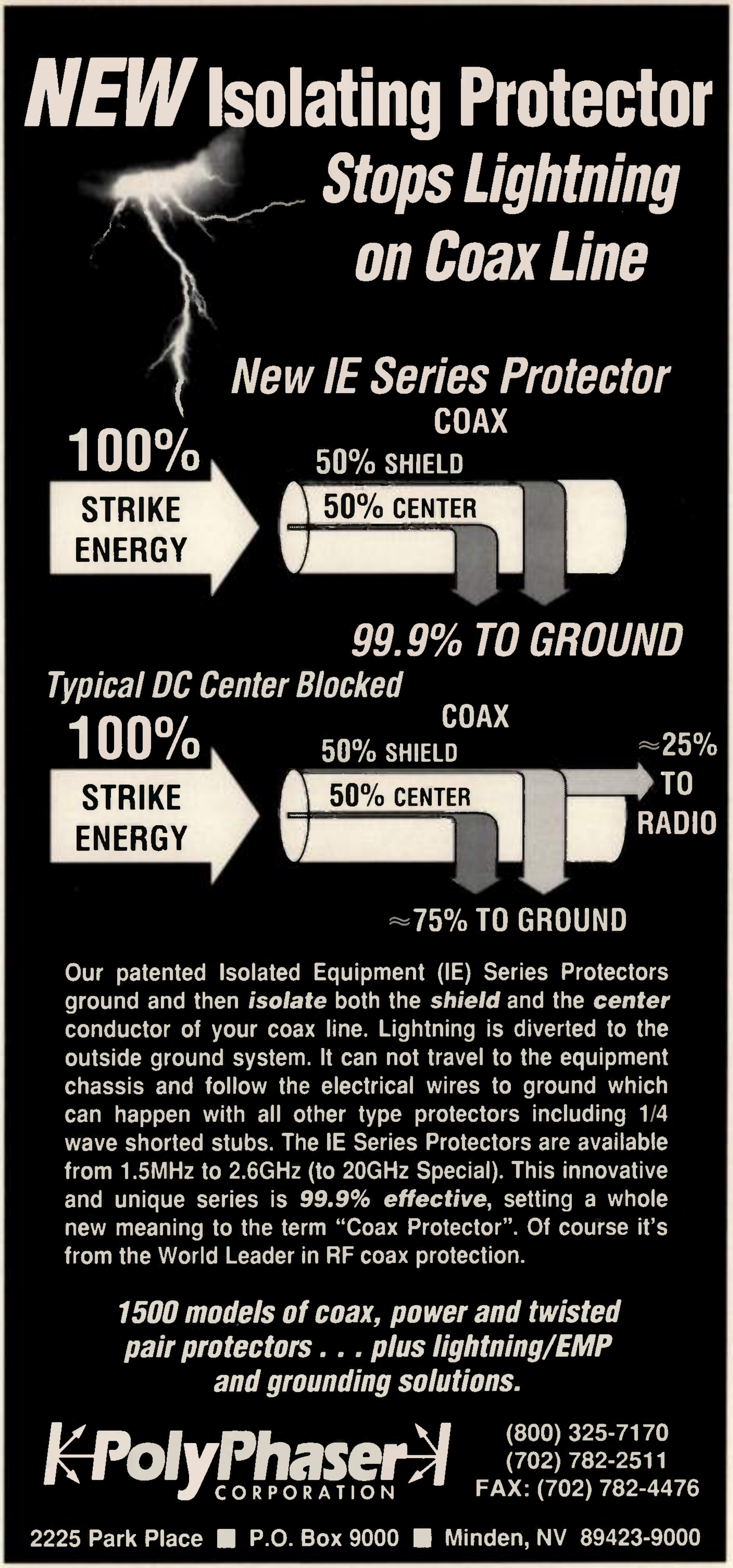
A continuation of Table 1 from the first article is presented here, and it provides connection data for 30 more voltage ratios. These additional ratios offer finer-grained steps of transformation than were presented previously. The complete Table 1 now contains 57 ratios in irreducible form and covers fractions having denominators 2 through 13 as does the chart of Figure 6. Figure 6 shows 78 ratios, but 21 of them are reducible to the simpler forms presented in the complete Table 1. Also note the corrected connection notation for the voltage ratio 2/3.

Synthesis Techniques

Most of the connections for the ratios enclosed by line-quantity symbols in Figure 6 were first determined by making tables of all possible combinations of a given number of lines and then calculating the resulting voltage ratios. Some mistakes in the calculations were discovered, but were corrected by using a synthesis procedure. This procedure is demonstrated below for the example ratio, 8/11.

Inverting and expanding in the continued fraction form,

$$\frac{11}{8} = 1 + \frac{1}{\frac{8}{3}} = 1 + \frac{1}{2 + \frac{1}{\frac{3}{2}}} \qquad (5)$$



and continuing to divide until all the numerators are unity results in a complete expansion,

$$\frac{11}{8} = 1 + \cfrac{1}{2 + \cfrac{1}{1 + \cfrac{1}{2}}} \tag{6}$$

The physical significance of the continued fraction can be more easily understood by multiplying both sides of the equation by Z_0 so that the expressions are for a port impedance of the transformer. In this case that port is the high impedance end because the fractional ratio, 8/11, has been inverted to be greater than one. Bear in mind that $Y_0 = 1/Z_0$:

$$Z_2 = \frac{1}{K} Z_0 = \frac{11}{8} Z_0 \tag{7}$$

$$Z_2 = \frac{11}{8} Z_0 = Z_0 + \cfrac{1}{2Y_0 + \cfrac{1}{Z_0 + \cfrac{1}{2Y_0}}}$$

Thus, the continued fraction expansion (c.f.e.) here is an impedance expression written in terms of Z_0 and its reciprocal, Y_0, and the integer coefficients on each. The author has algebraically manipulated the positions of Z_0 and Y_0 to achieve unity in all numerators so that a complete expansion is obtained.

To visualize the resultant transformer end-connections, it should be borne in mind that $2Y_0$, or $Z_0/2$ both mean two transmission lines in parallel and that

$$Z_0 + \frac{1}{2Y_0} \tag{8}$$

and

$$Z_0 + \frac{Z_0}{2} \tag{9}$$

both mean one line in series with two lines that are in parallel. The plus sign in a Z expression indicates a series connection.

Conversely,

$$Y_0 + \frac{1}{2Z_0} \tag{10}$$

and

$$Y_0 + \frac{Y_0}{2} \tag{11}$$

both mean one line in parallel with two that are in series. The plus sign in a Y expression indicates a parallel connection. From the above c.f.e. and the indicated interpretations of the Z_0 and Y_0 expressions, a transformer end-structure can be inferred by inspection and is shown in Figure 7a. The lower case letters in the following discussion refer to the cable identifiers, a through f, in Figure 7a.

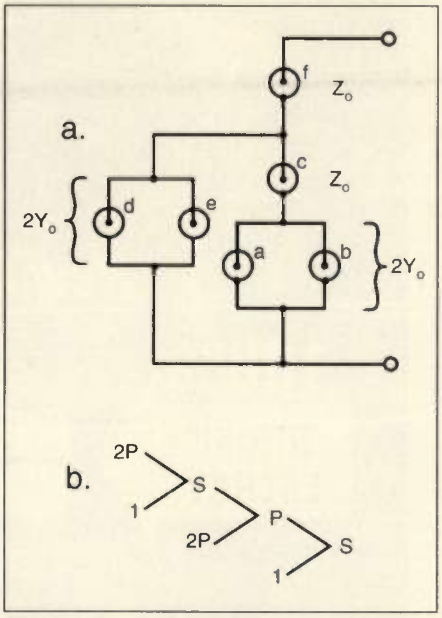


Figure 7. a) End structure derived from continued fraction expansion of $Z_0 \cdot 11/8$. b) Short-hand notation for connections in 7a.

Starting at the lower right of the expansion of equation 7 and looking at the lower two tiers,

$$Y_0 + \frac{1}{2Z_0} \tag{12}$$

means two transmission lines, (a and b), are connected in parallel with each other and the combination is in series with another line, (c). Proceeding up to the next tier of the expansion, $2Y_0$ + means that two lines in parallel, (d and e), are connected in parallel with all that went before. At the uppermost tier, Z_0 + means that one line, (f), is in series with all that went before.

Thus, using the foregoing thought process, the structure of Figure 7a is assembled, starting at the lower part of the figure and ending at the top.

Figure 7b shows the short-hand notation for the end-connections of Figure 7a. These connections are for the high impedance end of the transformer as mentioned above. To describe the structure at the low-impedance end, simply exchange the S's and P's in the notation of Figure 7b to yield the notation of Figure 8b which is the same as the connection symbol shown for a K of 8/11 in Table 1, (Part 2).

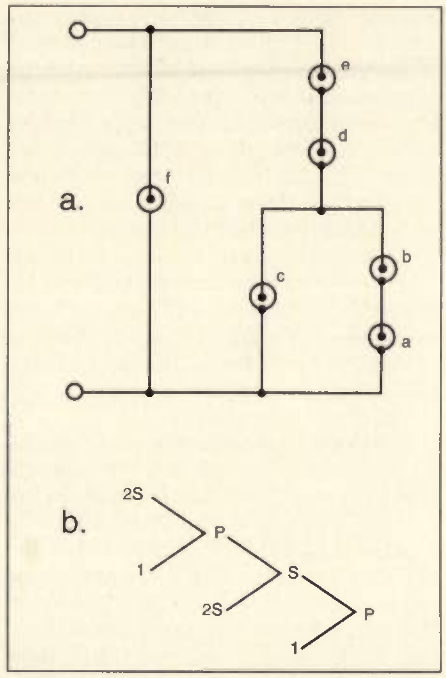


Figure 8. a) End-structure at opposite end of transformer from that shown in Figure 7a. b) Short-hand connection notation.

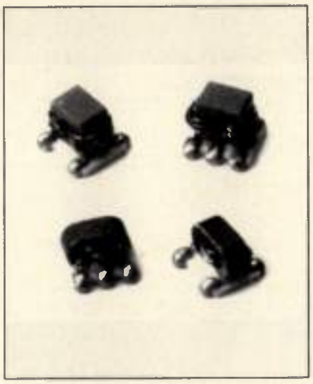
The ends of corresponding transmission lines in Figures 7a and 8a have been labeled with letters, a through f, in each figure so that, in comparing the two figures, the exchange of connections between the two ends of the transformer is readily discernible.

As a check that the synthesis of the end-connections has been done properly, an analysis of the configuration of Figure 7 is easily performed by setting the Z_0 of each transmission line to one ohm and then calculating the resultant output impedance. This impedance is numerically equal to the voltage ratio l/K as follows:

$$\frac{\left(\frac{1}{2}+1\right)\cdot\frac{1}{2}}{\frac{1}{2}+1+\frac{1}{2}} + 1 = \frac{\frac{3}{4}}{2} + 1 = \frac{3}{8} + \frac{8}{8} = \frac{11}{8} \tag{13}$$

Synthesis using Partial Fraction Expansions

A connection should result for any rational voltage ratio by using the c.f.e synthesis method, but the connection may not be the simplest (i.e., may not



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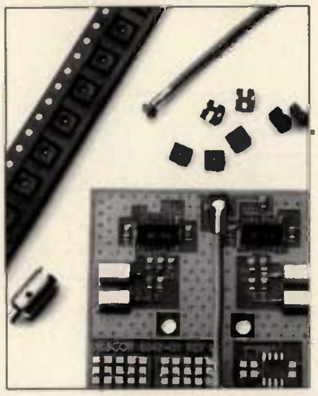

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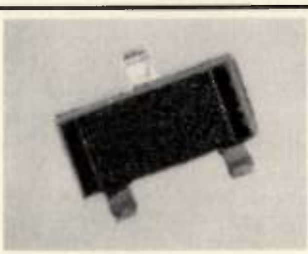

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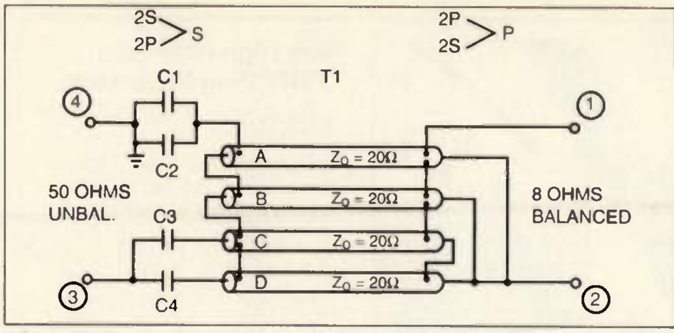

Figure 9. Schematic diagram of T1, 50 to 8 Ohm transformer, 5 to 2 voltage ratio.

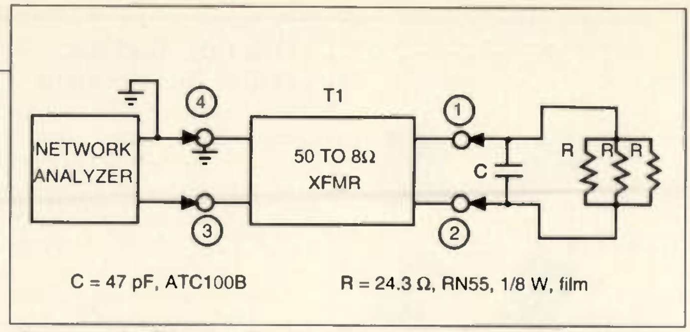

Figure 11. Block diagram of test set-up for measuring performance of T1.

have the smallest number of lines possible) to implement the ratio of interest. Some ratios possess partial fraction components that can allow simpler implementations. A case in point is the economy of lines afforded by partial fraction expansion (p.f.e.) of the ratio, 6/7:

Expanding the inverted ratio in continued form,

$$\frac{7}{6} = 1 + \frac{1}{6}$$

the end connections are

$$\begin{array}{l} 6P \\ \quad > S \\ 1 \end{array}$$

requiring 7 transmission lines. But in partial fraction form,

$$\frac{7}{6} = \frac{3}{6} + \frac{4}{6} = \frac{1}{2} + \frac{2}{3}$$

for which the end connections are,

$$\begin{array}{l} 2S \\ \quad > P \\ 1 \quad\quad > S \\ \quad 2P \end{array}$$

The inverse connections at the opposite end are,

$$\begin{array}{l} 2P \\ \quad > S \\ 1 \quad\quad > P \\ \quad 2S \end{array}$$

which are the connections seen in Table 1 for the ratio 6/7, requiring only five transmission lines instead of the 7 lines needed for the c.f.e case shown above.

Although many of the ratios can be expanded into partial fractions, it is only in a certain few cases, mostly involving ratios toward the right-hand side of the chart of Figure 6, that this kind of expansion yields a simpler structure than the continued fraction case.

Physical Example of a RAVOR Transformer

In the design of a 300 Watt, 2 to 30 MHz, push-pull, solid state power amplifier module, the need arose for a device that would transform the 50 Ohm, unbalanced, external load to an 8 Ohm, balanced, collector-to-collector load. Isolation of the external circuits from the D.C. potential at the collectors was also required.

The configuration shown schematically in Figure 9 was chosen and is labeled T1 here for convenience of reference. This transformer provides a 5/2 voltage ratio and comprises four, 20 Ohm Z_0 coaxial cables, each wound in ten turns on a 1 inch O.D., ferrite toroidal core having an initial permeability of about 125. A separate, push-pull coupling transformer/feed choke (not shown) powered the transistors. The D.C. isolating capacitors, C1 through C4, are placed at the high impedance (50 Ohm) end of T1 where the currents are smaller, thus fewer capacitors are required. Because there is no D.C. return-path through the windings, it doesn't matter that each of the conductors carries about 45 Volts D.C with respect to ground. This transformer is schematically the same as that shown in Figure 2 of the preceding article [4], except that in Figure 2 no D.C. isolation was shown and in T1 all the center-conductor and shield connections have been interchanged relative to those shown in Figure 2. The wiring interchange is of no electrical consequence and was done for convenience of layout. The physical implementation of T1 is shown in the photograph of Figure 10. The substrate of the device is a 2.5 by 3.3 inch glass-epoxy printed circuit board having lands and traces designed to accommodate the cable interconnections and connections to external circuits. In the photograph, the external connection places have been labeled as 1 and 2 at the balanced end, and 3 and 4 at the opposite port. These numbers correspond to terminals of the same numbers on the schematic diagram of Figure 9. The trace labeled 4 is grounded in several places by plated-through holes.

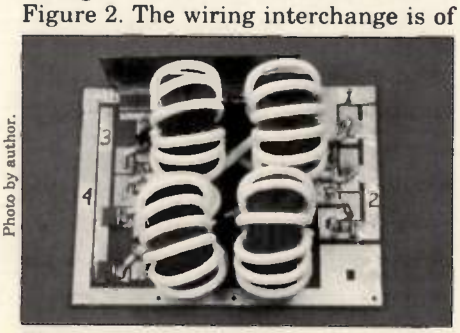
Photo by author.

Figure 10. Photograph of physical implementation of T1.

The copper sheet mounted vertically at the rear edge of T1 is a Faraday shield installed to protect a nearby circuit from electric fields. It should be noted that the T1 construction shown here was for an engineering "brassboard" assembly and was not intended to survive rigorous environmental tests, such as shock and vibration.

A test set-up to measure the characteristics of T1 was made as shown in the block diagram of Figure 11. Because the intended use of T1 was over the 2 to 30 MHz range, the transformer and test-load combination was optimized for minimal VSWR in a 50 ohm circuit at just above 30 MHz. The optimization was made by the choice of value of the shunt capacitance trimmer, C, installed across terminals 1 and 2 at the load end. C is a porcelain chip capacitor, 47 pF, type ATC-100B, and compensates for some stray inductances in the test-load and in the cable terminations.

In Figure 12, curves of R and X versus frequency, taken at the high-impedance (50 Ohm) port of T1, are presented. The curves show tolerable variations from the ideal values over the 2 to 30 MHz range. The curve in Figure 13 is for VSWR at the same port and shows that the largest VSWR encountered over the frequency range

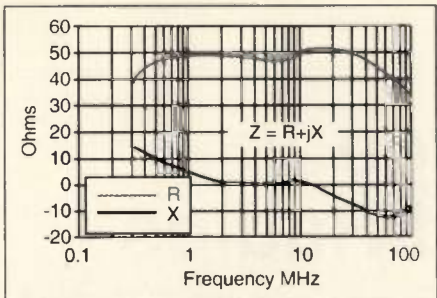

Figure 12. Impedance components, R and X, versus frequency for transformer T1.

of interest was about 1.06. That's good enough for most purposes.

Summary and Conclusions

In this second article on the subject of the RAVOR transmission-line transformers, we have presented further information for which there was insufficient space in the first article[4].

The ratio chart (Figure 6) introduced here is an important design tool that overcomes the difficulty in the selection of a rational voltage ratio to approximate the desired decimal fraction. The ratio chart enables the designer to visualize the options which are difficult to see otherwise.

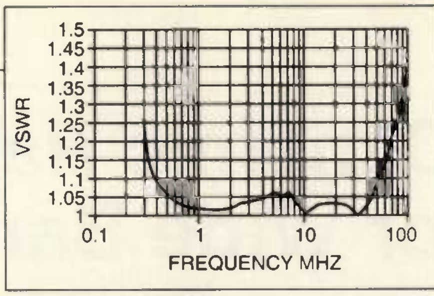

Figure 13. VSWR versus frequency for transformer T1.

The Part 2 augmentation to Table 1 provides 30 more ratios so that finer-grained transformation steps are available. The now complete Table 1 provides connection data for all ratios having denominator 2 through 13, as appear on the chart of Figure 6.

The section on ratio synthesis offers some insight into the kinds of mathematics that apply to the RAVOR devices, thus enabling the reader to check out the connections for himself.

A physical example illustrates the construction of a transformer, T1, which provides balanced-to-unbalanced conversion and a voltage transformation of 2/5. Plots of measured performance data pertaining to T1 show that the RAVOR devices truly work.

Acknowledgments

Many thanks to John Caton of Buckingham, PA, for contributing measured data on T1. *RF*

References

Note: The first three references were listed at the end of the first article which is here listed as reference 4.

4. McClure, Donald A., "Broadband Transmission Line Transformer Family Matches a Wide Range of Impedances", *RF Design*, February, 1994, pp. 62-66.

About the Author

Don McClure is an E.E. graduate of Kansas State University, Class of '58. He is retired after a long career with the RCA Corporation and resides at 12 W. Azalea Ln., Mt. Laurel, NJ 08054.

Using Wide Dynamic Range Converters for Wide Band Radios

By Brad Brannon
Analog Devices

Current radio architectures have been around since WW2 times with few changes outside the fantastic integration of components that has been accomplished over the last three decades. If Armstrong were alive today he would still understand the concepts behind modern communications receivers and marvel at the level of integration. The primary architecture, the superheterodyne receiver, has stood the test of time.

One of the main benefits of the superheterodyne receiver is its ability to offer consistent performance across relatively large bandwidths. Even though a single channel may occupy just several hundred kHz, a receiver for FM broadcast will cover 20 MHz; an AMPS cellular receiver 25 MHz. Variations in sensitivity or fidelity across these bands could make some frequencies unusable or worse, unreceivable. In the case of broadcast radio, this could pose an unfair advantage to stations at one end of the band or the other.

As shown in Figure 1, the typical superheterodyne radio consists of an antenna, preamp, mixer, local oscillators, filters and demodulator. The process starts in the antenna where the electromagnetic signal is gathered with a resonant antenna. In most cases, the antenna provides some selectivity and directivity, both of which help to reject out-of-band signals. Additional selectivity is achieved with pre-selection filters that follow the antenna. A preamp in the antenna line may compensate for line loss of the signal as well as improve signal sensitivity. The output of the preamplifier stage is combined with the local oscillator in the mixer to convert the RF signal to an IF frequency. In many receivers, two down conversion stages are used. This common technique is called double conversion. The same IF frequency is used across the entire reception band, where demodulation takes place. Since all received frequencies are converted to the same IF frequency, demodulation is performed consistently at all frequencies. This ensures consistent performance across large bands of frequencies. This type of architecture is referred to as *narrow band* in the context of this report. In this case, narrow band refers not to signal bandwidth but to receiver properties. The typical communications receiver may actually process only 10-30 kHz at any one time (in commercial FM broadcast, only two hundred kHz).

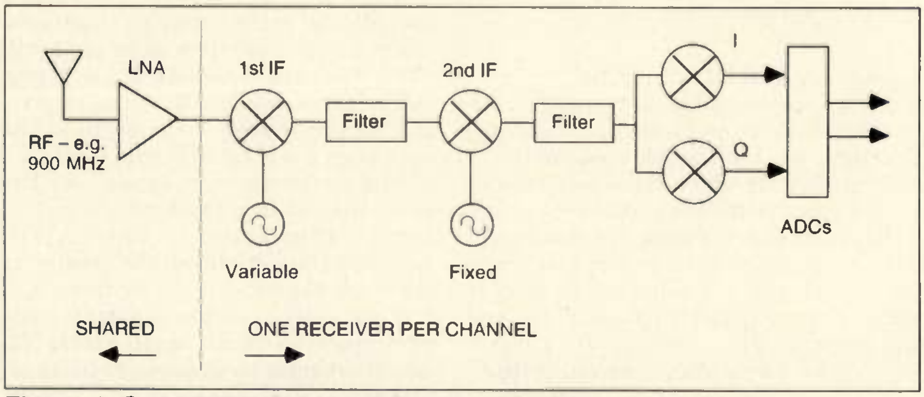

Figure 1. Superhetrodyne architecture (double conversion).

The components used within a receiver will vary depending on the performance specifications (sensitivity, selectivity, modulation bandwidth etc.). For example, the IF filters within a narrow band receiver must be selected to allow only the bandwidth of the single desired signal into the demodulator. If the bandwidth is too wide, other signals may interfere with the demodulation of the signal desired. If too narrow, the filter might ring or signal modulation sidebands might be attenuated, causing improper demodulation. The same is true of the amplifiers, mixers and demodulators. With the narrow bands, these components tend to be inexpensive and small. Frequently, performance is not all that critical in a narrow band receiver [1].

The complement of this narrow band receiver is a *wide band* receiver. A wide band receiver allows many MHz of signals to pass to the demodulation stage. The typical block diagram of the wide band receiver is similar to it's narrow

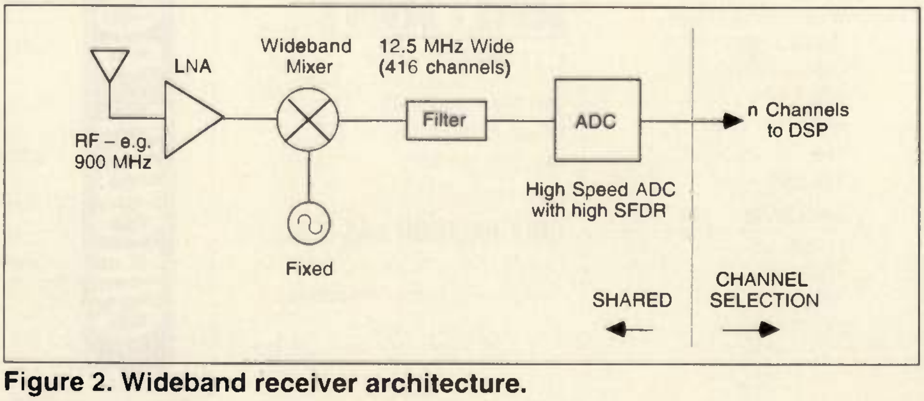

Figure 2. Wideband receiver architecture.

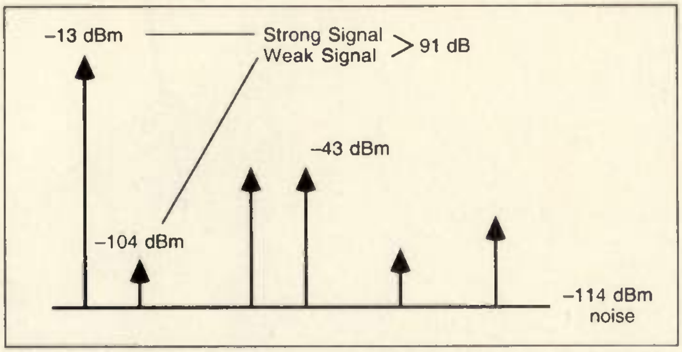

Figure 3. GSM requires reception of weak signals in the presence of nearby strong signals.

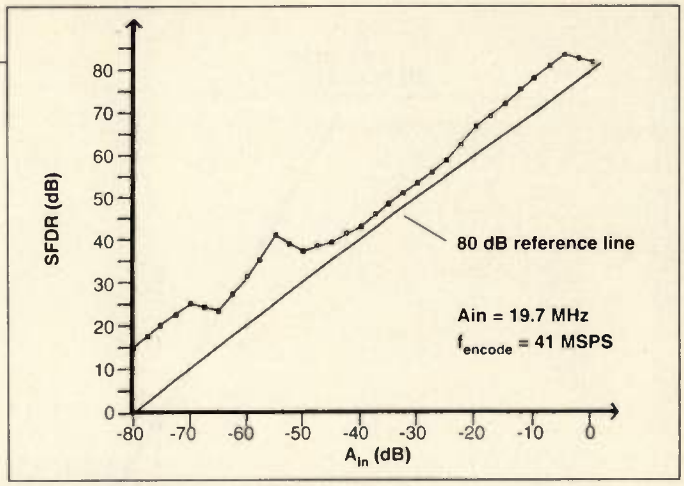

Figure 4. AD9042 SFDR versus input amplitude.

band counterpart. The difference of course is the bandwidth of the components used and that a variable local oscillator is not required (i.e. a fixed frequency). A typical wide band receiver may process 5 to 25 MHz worth of signals simultaneously. This approach is frequently called block conversion. Figure 2 shows a wideband solution to the multi-channel radio. The only difference between a standard narrow band receiver and this wideband approach is that more than one signal is processed at a time. This is especially useful in multiple channel receivers such as cellular base stations or frequency scanners because multiple front ends are replaced with a single down conversion unit. In the case of the cellular base station, one wideband receiver can easily replace the 48 independent receivers required in the narrow band approach saving thousands of dollars in components and racks of equipment. A complete wide band transceiver can be assembled in a one cubic foot chassis.

The final frequency selection process is performed digitally using channelizers to select and filter the desired signal. Once selected, the digital data representing this signal is passed to a digital signal processor. Once inside the DSP chip, demodulation and signal conditioning can proceed. Since the DSP is programmable, the demodulation can be AM, FM, SSB, QAM, QPSK or almost any other conceivable scheme. Since this can be changed at will or as a field upgrade, it is frequently referred to as a software radio. Since filtering can also be performed in DSP, many unique filters can be realized that in an analog world would prove impossible to realize. Since these filters can have linear phase by design, ringing is minimal even for filters such as a 25 Hz brick wall band pass filters!

Considerations For Selection of A/D Converters in Radio Designs

Analog-to-digital converter specifications for wideband receivers come from the radio standards for which they are digitizing. To combat the near-far phenomena, a cellular base station receiver must have an excellent dynamic range. For example, when receiving GSM (European Digital Cellular), the specification requires the converter to be able to accurately digitize signals between –13 dBm and –104 dBm in the presence of many other signals, as shown in Figure 3. This is a dynamic range of 91 dB! This implies that the Spurious Free Dynamic Range (SFDR) of the converter and analog front end must be in the neighborhood of 95-100 dBFS. Therefore, SFDR is a very important specification when a unit is near the tower because it is an indication of how the signal interferes with adjacent channels. From Figure 4, we see that strong signals usually produce the largest spurs due to front end harmonics. These spurs could mask weaker signals from the cell fringes. Here SFDR is important because it provides a measurement of performance as the signal approaches the noise floor of the receiver, providing an indication of overall receiver SNR or bit error rate in the case of a digital receiver where BER has an inverse relationship to remaining SINAD at low signal levels. While GSM is one of the more difficult standards to realize using a broad band technique, it serves as an excellent example of the importance of certain converter specifications. Other standards, such as AMPS, are less demanding on receiver designs and are readily implemented using broad band techniques.

When the input to a converter is a single signal, full scale SINAD and SNR are usually the specifications of choice. However, when digitizing broad bands of spectrum, full scale single tone evaluations no longer provide the complete picture. In wide band radios a myriad of signals are present, therefore multiple tone testing and SFDR power sweeps are better indicators of converter performance than a single tone test.

For instance, many converters perform differently when digitizing a full-scale signal versus a signal 10, 20, 30 or more dB below full scale as is the case with broad band radios, as shown in the AD9042 SFDR plots of Figure 4. As shown, it is clear that the SFDR actually improves as the signal level is reduced from full scale to almost –10 dBFS. In some cases, the improvement is greater than the loss of signal range and actually provides more dynamic range despite the reduction in signal amplitude. The full scale degradation usually comes from integral non-linearities associated with the static transfer function near full scale as well as slew rate limitations of the track and hold. As the signal level is reduced from full scale, the SFDR improves because the converter is more linear over the remaining range of the device. Even when multiple signals are present and the converter produces codes near full scale, the randomizing effects of the sum of all non-correlated received signals has the same effect as dithering. Therefore, in some cases single tone full scale testing may be considered a worst case condition even above multi-tone testing.

Dithering is a technique used to lower non-linearities into the effective noise floor by forcing the converter to use different parts of its range each time it samples a given analog value. This technique can be implemented in a number of methods which encom-

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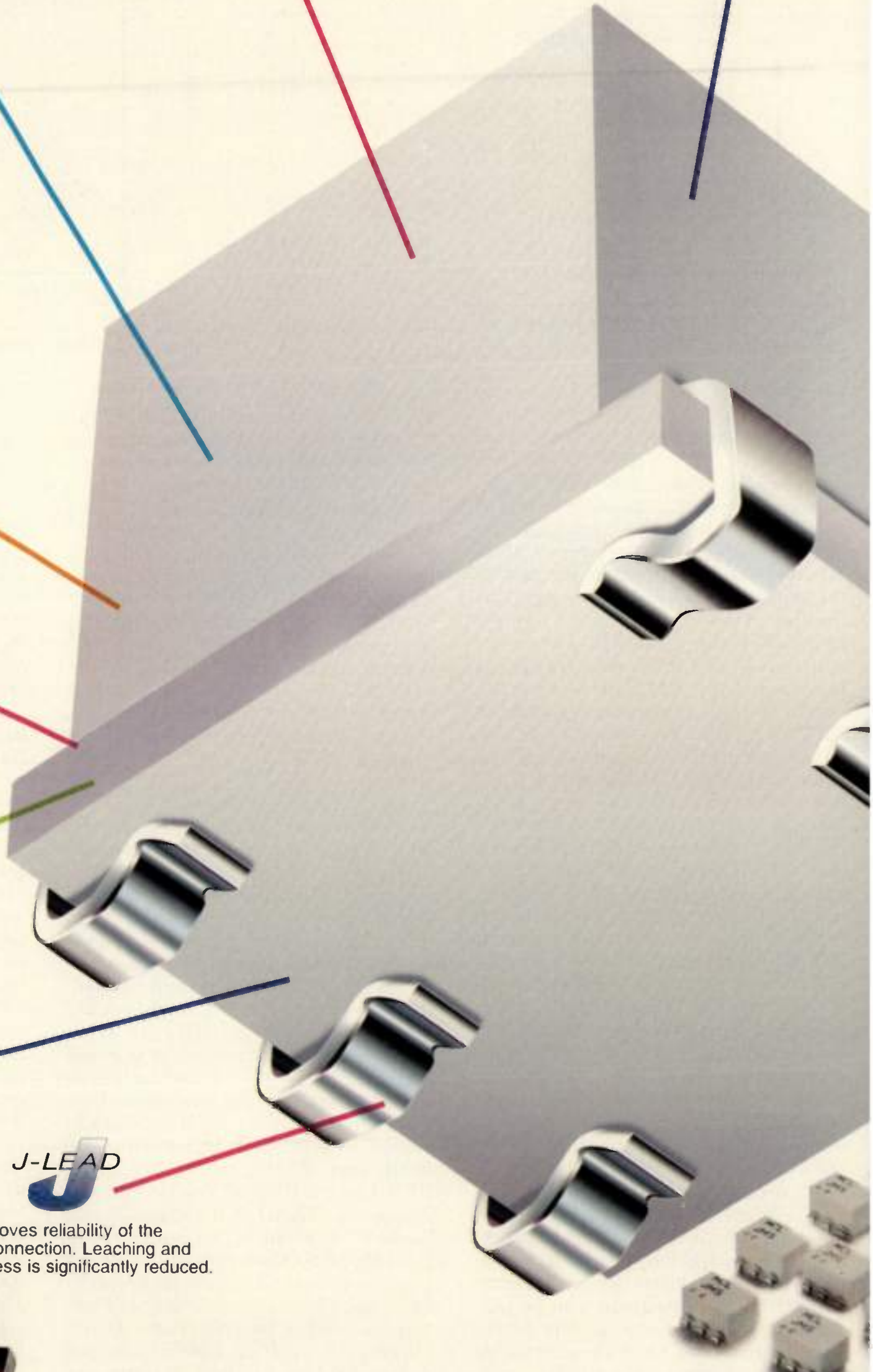

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SPECIFICATIONS

Model	LO (dBm)	Freq. (MHz) LO/RF	Freq. (MHz) IF	Midband (dB, Typ.) Conv. Loss	Isol. L-R	Isol. L-I	$ea. (qty. 1-9)
JMS-1	+7	2-500	DC-500	5.75	45	45	4.95
JMS-1LH	+10	2-500	DC-500	5.75	55	45	8.45
JMS-1MH	+13	2-500	DC-500	5.75	60	45	9.45
JMS-1H	+17	2-500	DC-500	5.90	50	50	11.45
JMS-2L	+3	800-1000	DC-200	7.0	24	20	7.45
JMS-2	+7	20-1000	DC-1000	7.0	50	47	7.45
JMS-2LH	+10	20-1000	DC-1000	6.5	48	35	9.45
JMS-2MH	+13	20-1000	DC-1000	7.0	50	47	10.45
JMS-2H	+17	20-1000	DC-1000	7.0	50	47	12.45
JMS-2W	+7	5-1200	DC-500	6.8	60	48	7.95
JMS-11X	+7	5-1900	5-1000	6.7	35	37	4.25*

Note: *10-49 qty.

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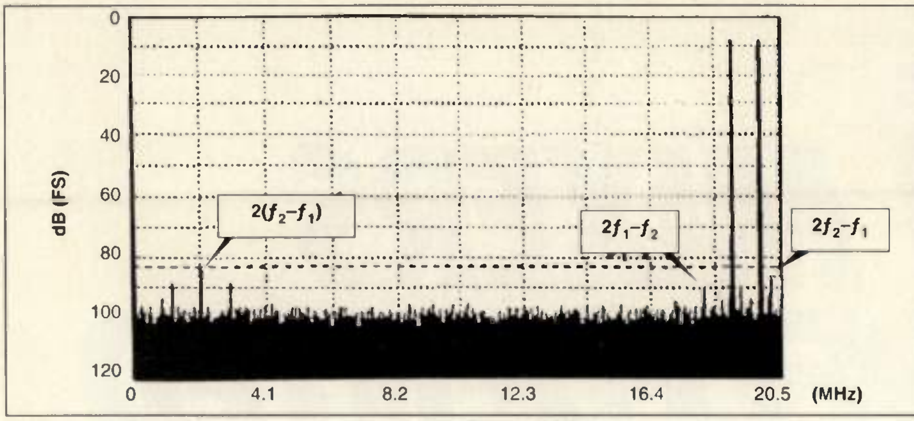


Figure 5. Spurious signals resulting from IMD.

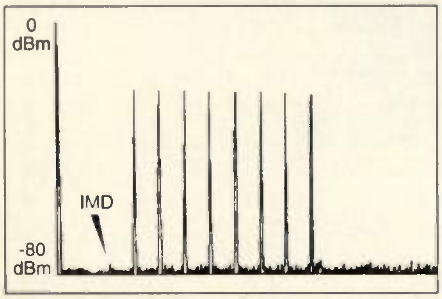


Figure 6. IMD outside group of test signals.

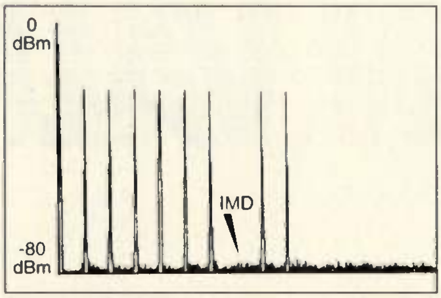


Figure 7. IMD in place of missing test signal.

pass both analog and digital circuits. To accomplish this, a pseudo random number is digitally generated and applied to a DAC. This signal is summed with the analog input to be processed. The converter operates as usual except after the conversion is complete, the pseudo random number applied through the DAC is then subtracted from the digital output. The effect of this technique is to randomize the non-linearities of the converter and reduce the spectral content generated by repetitively exercising the same non-linearity. Although in a wideband receiver, background noise and other non-correlated signals offer some of the same benefits as externally generated dither, additional dither is frequently added to further improve dynamic performance.

The most common form of multi-tone testing is that of two-tones. From these two tones, Third Order Intermodulation Distortion or IMD may be measured. IMD is important in situations where there are two larger signals in the presence of many smaller signals. The two larger signals will generate spurs caused by non-linearities at $2f_2-f_1$ and $2f_1-f_2$. These spurs, if significant, can override smaller desired signals located at these same frequencies in the same way that harmonics can mask small signals, and since these products always fall in band, they cannot be filtered. Therefore IMD performance is important not for how it effects the two larger signals, but how it effects smaller adjacent signals or channels. Although the upper IMD product in Figure 5 has been aliased back in-band, it can clearly be seen. Although IMD is an important specification, Figure 5 also shows that other spurs can often present problems in receiver designs. In this case, the spur appears at $2(f_2-f_1)$indicating that measurements such as two tone SFDR are just as important as two tone IMD.

Multi-tone testing is not limited to two tones. Many transceiver manufacturers are now using 4, 8, 16, 24 or even 48 tones to test their products. When stimulated by this many tones, performance is measured by looking at the regions just outside of the tones or in between the tones where a void has been placed. In examining Figure 6, non-linearities cause the eight signals to generate tones evenly spaced outside of the pattern of eight. In other cases, where one tone is missing, non-linearities cause images to fill in the gap between the tones as shown in Figure 7. When dealing with many tones, care should be taken to ensure that phase alignment is carefully selected such that signals are appropriately handled when they add constructively to occupy the entire converter range and when they occupy only a small cluster of codes near mid-scale as in Figures 8 and 9. If the number of tones is increased and the spacing decreased, multi-tone testing begins to approximate Noise Power Ratio or NPR testing, a well known FDM communications test to determine cross channel interference.

One final dynamic specification that is vital to good radio performance is jitter. Jitter is the sample to sample variation in the periodic nature of the encode clock path. Although low jitter is important for excellent base band performance, its effect is magnified when sampling higher frequency signals (higher slew rate) as is found in undersampling configurations such as IF sampling. The overall effect of a poor jitter specification is a reduction in SNR as input frequencies increase. This is demonstrated in the equation:

$$\mathrm{SNR} = 20\log_{10}\left[\frac{1}{2\pi f t_a}\right]$$

From this equation, as frequency f increases, SNR is reduced for a given jitter t_a. This equation shows that for ideal 12 bit performance with a 70 MHz analog signal, $t_a \leq 0.5$ ps.

ADC Static Specifications

Specifications such as DNL and INL are degraded largely by mismatches within a multi-stage converter, which is architecture dependent. To gain a better understanding, see Figure 10.

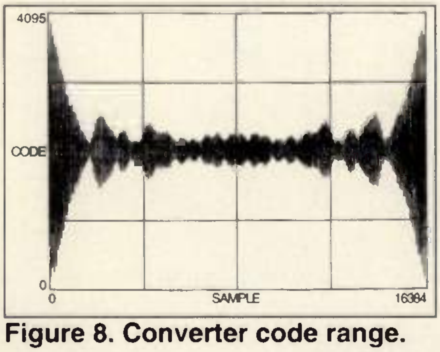


Figure 8. Converter code range.

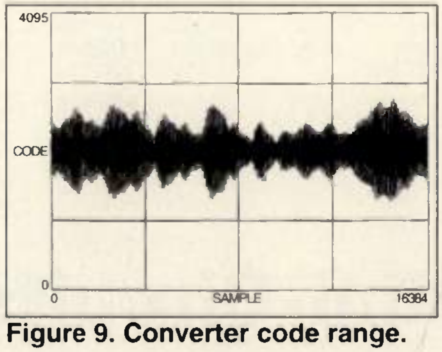


Figure 9. Converter code range.

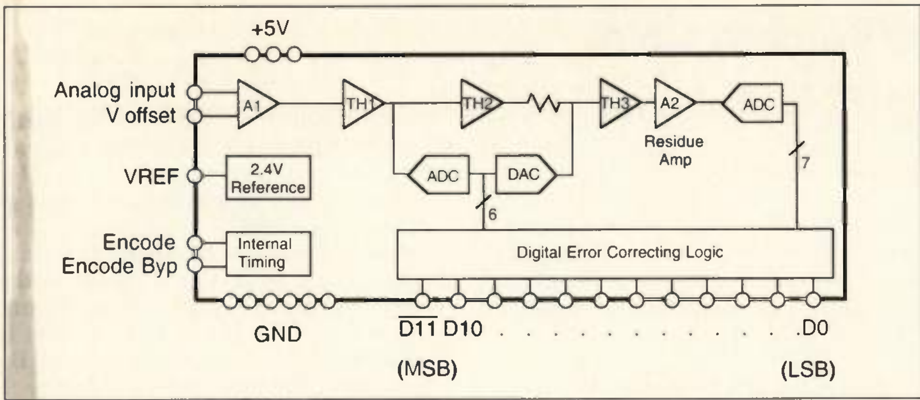


Figure 10. AD9042 block diagram.

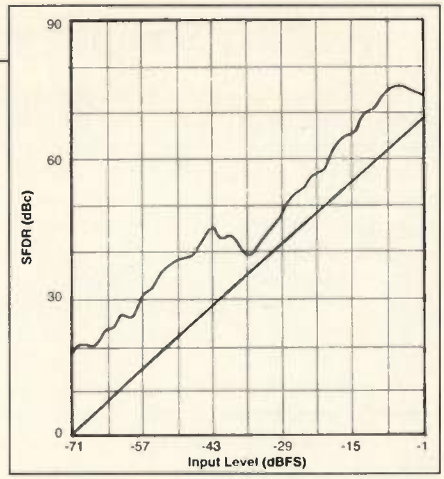


Figure 11. Example of a bad SFDR plot.

This is a block diagram of the AD9042. The first encoder in the AD9042 is a 6 bit ADC. The output is fed to a 14 bit accurate DAC that is subtracted from the analog input leaving a residue or error signal. This residue is amplified and digitized with a 7 bit ADC. To the extent that the residue amplifier can match the DAC output and 7 bit ADC input, the digital error correcting logic can produce an accurate 12 bit ADC. These mismatches determine the worst DNL errors. Typically products such as the AD9026/27 and AD9042 have matching of better than 1/4 of an lsb, yet these matching errors dominate the DNL specifications.

DNL becomes important with low signal levels when the signal may straddle one of the "subrange zones." This can be seen in Figure 11 by the reduction in SFDR between –25 and –40 dBFS. Although the rms error of the mismatch remains constant, as the signal level is reduced, the SINAD becomes worse because this error becomes a more significant portion of the noise term until the signal becomes so small that it no longer crosses any more of these mismatches. Since these zones occur at one or more repetitive locations within the transfer function of the converter, they also will contribute to the harmonically related spurs causing a degradation in SFDR. As before, multiple signals tend to dither this error source into the noise floor of the converter significantly reducing its impact on the receiver.

One very interesting and important characteristic of analog to digital converters when receiving multiple channels in a broad band architecture is that the signal levels must be placed [illegible] from full scale of the converter. For instance with one signal on the ADC input, the full scale range of the converter may be used. However, when two signals are present, each signal must be 6 dB below full scale or half amplitude (assuming equal signal power) to prevent clipping of the converter as these signals sum together at their peaks as in Figure 8. For each doubling of the number of signals, the level must be reduced by six dB. Therefore with 4 channels, signal level will be –12 dBFS and 8 channels will be –18 dBFS. Thus, a multi-channel radio must have additional dynamic range to account for the SNR lost through reduction in usable signal levels. In addition, radio designers keep from 3 to 15 dB in reserve as headroom at the top of the ADC range to prevent clipping that comes from the peak to rms ratios that are inevitable and to prevent ADC saturation should an additional signal come in band as new callers enter the cell zone.

ADC Sample Rate Requirements, Drive and Filtering

Many wide band radios mix down the RF spectrum to baseband signals using wide dynamic range, ultra high intercept point mixers such as the

Over Sampling and Process Gain

So far, every scenario has provided only a loss of dynamic range. However, there are important situations where SNR is improved by various numerical operations, called process gains as alluded to earlier in this discussion. In any digitization process, the faster that the signal is sampled, the lower the noise floor. This is not to say that the SNR improves. It does not. The total integrated noise remains constant but is spread out over more frequencies. This noise floor follows the equation:

$$\text{Noise Floor} = 6.02\times B+18+10\log(FS/2)$$

This equation represents the level of the quantization noise within the converter and shows the relationship between noise and the sample rate FS. Therefore each time the sample rate is doubled, the effective noise floor improves by 3 dB!

Although some gains may be made by increasing the sample rate, they are relatively small. However, large processing gains are achieved in the digital filtering process. Up until now, all the work has been in the broad band sense. When it is time to channelize and filter the signals with digital signal processing chips, large gains in SNR may be realized. For instance, if a 30 kHz AMPS signal is being digitized with an AD9042 sampling at 40.96 MSPS only a small portion of the broad band noise is passed through the digital filter pass band. The percentage of the noise in the pass band is 0.03 MHz/20.48 MHz. Expressed in log form, the processing gain 28.3 dB!

With this in mind, the effective SNR for a given signal is then:

$$SNR=6.02\times B+1.8+10\log(FS/(2BW))-HR$$

This equation may be written a little differently if the actual SNR specifications is known. In that case, the actual SNR may be used. If the converter has an SNR specification of 67 dB, the equation may be written as:

$$SNR = 67+10\log(FS/(2BW))-HR$$

With 8 signals, each signal will be 18 dB below full scale. Along with 12 dB of headroom, each signal the overall signal levels will be 30 dB below full scale. The effective SNR would be 65.3 dB although the actual SNR is only about 37 dB.

AD831. In radios such as these, the converter requires a sample rate that is at least twice the highest frequency. (the Nyquist rate). If the signal range is from DC to 10 MHz then the ADC must sample at a minimum of 20 MSPS at least a 20 percent excess sample rate usually recommended for margin. This raises the required encode rate to about 25 MSPS.

Other considerations involve the type of signal being received. If the signal is digitally modulated data, for instance, the ADC should sample at an integer multiple of the data rate. For example, if the receiver were decoding GSM packets, the sample rate would be a multiple of the data rate of 270.833 kHz. The typical GSM receivers use a multiple of 48 samples per bit giving a base sample rate of 13 MHz, with 26 MHz and 39 MHz also usable. Analog modulations such as AM and FM use sample rates that are multiples of the channel bandwidth. For instance AMPS is a 30 kHz standard. Typically, the sample rate is 1024 times higher than the bandwidth. This gives a sample rate of 30.72 MHz. By using this technique, one of three things will be accomplished. First, for digital standards, an integer number of samples will be taken for each packet of data. Second, filter choices will be simpler since frequencies will fall in FFT or filter bin centers. Third, this over-sampling provides a processing gain that improves the effective signal-to-noise ratio. These items allow for easier processing and keeping track of channel locations.

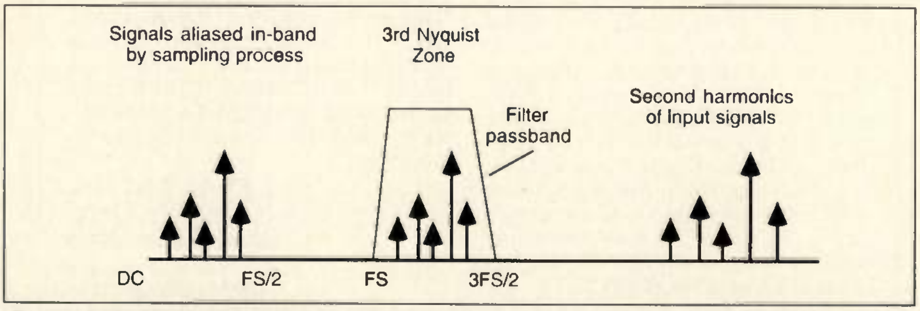


Figure 12. Undersampling selects signals in a Nyquist zone other than baseband for easier filtering.

An alternative to baseband sampling is to sample an IF signal that is in the second or third Nyquist zone (Figure 12). DC to FS/2 (FS = sample rate) is considered the first Nyquist zone. By this logic, the second Nyquist zone is from FS/2 to FS and the third is from FS to 3FS/2. In our 25 MSPS example above, the second Nyquist zone would extend from 12.5 MHz to 25 MHz and the third from 25 MHz to 37.5 MHz. What advantages does this have? It can greatly relax the harmonic requirements of the driving amplifier because filtering is much easier when shifted above the first Nyquist zone. If in our baseband example above, we required 70 dB harmonic performance with a 1 MHz signal, the drive amplifier must have harmonic performance of 70 dB because the anti-alias filter does not filter out signals below 10 MHz. If on the other hand, we designed our system such that the 1 MHz baseband signal was instead at 26 MHz (in the third Nyquist zone) the second harmonic would be at 52 MHz, well outside the anti-alias pass band filter of our digitizer which is from 25 to 37.5 MHz (Figure 5). It is important to note that converter accuracy may not be sacrificed because all converter harmonics always fall in-band due to signal folding that occurs within a sampled system. Thus amplifier requirements are greatly simplified by trading off amplifier performance for filter specifications. Although harmonic performance is relaxed by this technique, intermodulation performance can not be sacrificed since intermods must be assumed to always fall in-band for both amplifiers and converters.

Next Generation

As converter technology improves, several important items become apparent. Already, improved dynamic range has opened the door to broadband, multi-channel receivers as found in cellular base stations. This has allowed costs to fall and sizes to be reduced as mini-cells become common and economic to place where full size base stations could never be afforded. Not only have these mini-cells been cost effective in locations not previously attainable, but they are allowing cost savings and reduction of individual cell sites size. However, as stated early on, wideband is not always the most viable solution, as in the case of GSM. In fact, since each RF channel of GSM can carry up to 16 voice channels, the economy is to use a narrow band.

In narrow band receivers, cost savings can be gained by eliminating an IF stage. In this application, the ADC can be used as an IF sampler to perform the last mix-down. The advantages of this technique are several. For example, using the ADC in this undersampling mode eliminates the need for the final mixer. Filtering requirements are also eased because once digitized, filtering can be performed in DSP or an ASIC using FIR filter techniques. Unique converter design combined with proprietary wafer processing is producing converters with greatly improved input slew rate characteristics. This combined with low jitter in the sampling process is allowing converters like the AD9042 to sample IF signals. Next generation products will perhaps be capable of sampling IF frequencies up to several hundred megahertz.

Software Radio

Whether the future holds wideband or narrow band radio solutions, DSPs play an important role in future generations of radios. No longer are the demodulation solutions limited to hardware, the future is in the use of DSP to demodulate carrier information. Once high performance ADCs are available and the RF signal has been digitized, demodulation is simply a function of software. Future radios may well consist of an RF strip, high performance ADC followed by a DSP chip. Receiver mode selection may well be as simple as selecting a different subroutine from the available software choices. Field upgrades to future generations of radios may well come in the form of updated ROMs or perhaps even from an over the air interface!

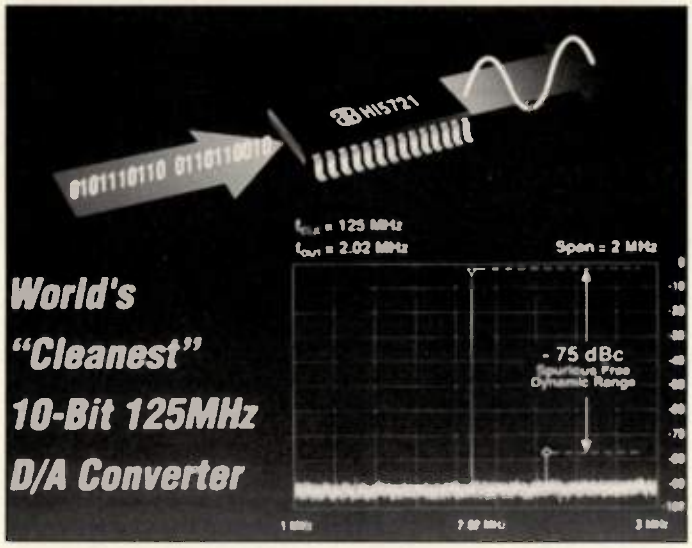
For more information on the AD9042, circle Info/Card #251. Telephone inquiries can be made to Analog Devices' Customer Applications Support at: (617) 937-1428. *RF*

About the Author

Brad Brannon is Senior Applications Engineer at Analog Devices' Wireless Infrastructure Group in Greensboro, North Carolina.

10-bit, 125 MHz DAC

Harris' HI5721 is a 10-bit, 125 MHz digital-to-analog converter (DAC) for direct digital synthesis (DDS) in communications systems. The HI5721's 125 MHz conversion rate moves spurs and harmonics away from the fundamental frequency, allowing the use of a simpler, less expensive, lowpass filter after the DAC. The TTL/CMOS-input DAC consumes only 775 mW (max). The device also features 3.5 pV-s peak and 1.5 pV-s doublet glitch energy ratings. At 125 MHz, the HI5721's typical spur-free-dynamic-range (SFDR) to it's Nyquist frequency (62.5 MHz) is –59 dBc for a 2.02 MHz fundamental frequency, and –53 dBc for a 25 MHz fundamental frequency. Within a 2 MHz window, typical SFDR for a 2.02 MHz fundamental is –75 dBc and for a 25 MHz fundemental, it is –70 dBc. At 125 MHz, the DAC features 54 dB typical SNR to Nyquist for a 2.02 MHz output frequency and 51.5 dB for a 25 MHz fundamental. The HI5721 has 0.5 ns hold time. The HI5721 is available from stock in 28-lead PDIPs and SOIC packages. Either version costs $38.00 in 100-piece quantities.
Harris Semiconductor
INFO/CARD #245



RF Voltmeter

The Model 9200B RF voltmeter has been enhanced by Boonton Electronics with increased stored program memory and seperate non-volatile memory. Because of special low noise circuitry, the Model 9200B provides 200 µV sensitivity over the 10 kHz to 1.2 GHz or 10 Hz to 100 MHz frequency ranges, when used with Boonton RF voltage probes. Data from up to eight probes, including sensitivity and range linearization requirements, can be stored in the Model 9200B's non-volatile memory. True RMS response is

provided for input below 30 mV. The meter also has a zero correction function that stores zero offsets of each range and automatically corrects all subsequent readings. Model 9200B has two measurement channels and can display measurements from both probes or their instanaeous difference. The meter is priced at $3,550.
Boonton Electronics Corp.
INFO/CARD #244

Broadband Amplifiers

Amplifier Research has announced the development of a line of broadband microwave amplifiers for susceptibility and general laboratory testing in the L, S, C, X and IJ bands. Three new solid-state amplifiers pro-

vide 1, 5, and 10 W minimum output from 1.0 to 4.2 GHz. Four new high-power TWT amplifiers, also rated according to minimum power, provide 200 W output from 1-2 GHz, 2-4 GHz, 4-8 GHz, and 8-18 GHz, respectively. In response to customer requirements, these amplifiers are rated in terms of minimum output power at the output connector over the full operating bandwidth. This type of specification reduces performance uncertainties. The new amplifiers automatically reduce output power during severe load mismatches, and resume full-power operation when the mismatch ceases. Standard features include gain control, RF input overdrive protection, over-temperature protection, and instantaneous bandwidth without bandswitching.
Amplifier Research
INFO/CARD #243

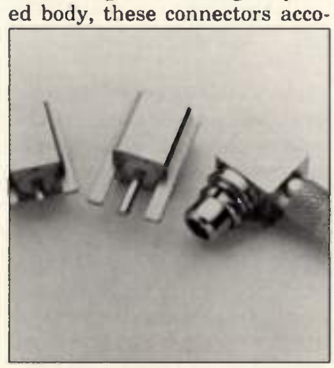
10 MHz Ovenized Oscillator

The SC10 high stability oscillator uses an SC cut crystal to provide very low phase noise (–130 dBc/Hz at 10 Hz), a 1s Allen varience of 2×10^{-12} and an aging rate of only 2×10^{-10}/day. An electronic double oven minimizes temperature gradients, providing a stability of 5×10^{-10}. Oscillators are available with a grade dependent set of options including phase noise, aging, Allen varience, temperature stability and EFC. Output level is +13 ±0.5 dB into 50 Ω (≈ 1 V_{rms}). The SC10 measures 4.00 × 2.00 × 2.00 inches. Versions are available with supply

voltages of 15 and 24 VDC. Power consumption is 8 W for warm-up and 3 W for normal operation at 25 °C. The oscillator weighs 11 oz and is available with pin, SMA, SMB, or SMC connectors. Base price is $250 in 100 piece quantities.
Stanford Research Systems
INFO/CARD #242

Miniature RF Connectors

Amphenol RF/Microwave Operations has developed the MicroMate™ line of connectors to satisfy the need for a high density, light weight RF interconnection system for the wireless communication and data market, including PCMCIA. These 50 ohm connectors have a frequency range of DC to 6 GHz as well as a temperature range of –65 °C to +165 °C. The small profile MicroMate connectors save printed circuit board space and feature positive snap mating, providing excellent retension and 500 mating cycles. Consisting of a brass/gold plated body, these connectors acco-



modate RG-178 and RG-316 cables. The connectors have a voltage rating of 170 V_{rms} and dielectric withstanding voltage of 500 V_{rms}. Maximum VSWR is 1.15 for straight connectors and 1.25 for right angle connectors from 0 to 6 GHz.
Amphenol Corp.
INFO/CARD #241

SIGNAL SOURCES

OCXO

Oak Frequency Control Group's 4597 OCXO features a TCXO-sized footprint of just 30.3 × 30.3 mm and a seated height of 10.2 mm. Available in frequencies from 12 to 30 MHz, the 4597 meets a temperature stability spec of $\pm 3\times10^{-8}$ over 0 to 70 °C and features aging of ±0.5 ppm per year. The OCXO operates from +5 V and is priced at $120 each in quantities of 1000.
Oak Frequency Control Group
INFO/CARD #240

DDS Assembly

A direct digital synthesizer (DDS) board-level assembly incorporating a complete BPSK/QPSK transmitter on a single ASIC device has been introduced by Stanford Telecommunications. The STEL-1203A uses the STEL-1103 modulator chip to drive a high speed, 10-bit DAC and low-pass filter. A programable attenuator is included to allow output level to be varied. The system is guaranteed to operate up to a maximum clock frequency of 100 MHz.
Stanford Telecom
ASIC & Custom Products Div.
INFO/CARD #239

Ultra Stable OCXO

MTI - Milliren Technologies introduces their next generation of ultra high stability/high reliability oven-controlled crystal oscillators. The 260-0536 (10 MHz) model utilizes an SC-cut resonator to offer thermal stability of $\pm 1.0\times10^{-9}$ from –30 to +70 °C. Phase noise at 10 Hz offset is –125 dBc/Hz. The device measures 2.0 × 2.0 × 1.5 inches. Cost for 1 - 99 pieces is $480.00 each.
Milliren Technologies, Inc.
INFO/CARD #238

Clock Oscillators

Micro Networks announces the release of three new precision clock oscillator product families. The M100 series is a family of master clock oscillators whose ECL/PECL clock output can be specified for operation in the 300 to 650 MHz frequency range. The M200 and M210 series is a family of frequency multipliers specified for operation over 300 to 650 MHz. The M300 is a family of VCXOs whose output frequency is centered at 622.0800 MHz.
Micro Networks
INFO/CARD #237

SONET VCXOs

Conner-Winfield has developed a true surface mount VCXO for SONET applications. The VCXO has a 0.450 × 0.550 inch footprint and a 0.150 inch seated height. Available in frequencies of 155.52 MHz, 311.04 MHz, and 622.084 MHz, the VCXO's frequency tolerance is specified at ±20 ppm. Minimum deviation is ±75 ppm. Prototypes at 622.084 MHz are priced at $112.55 each for 5 to 9 units.
Connor-Winfield Corp.
INFO/CARD #236

SURGE PROTECTORS

Suppressors for 3V

ProTek Devices has announced what it believes to be the industry's first 3-volt silicon avalanche transient voltage suppressors. The series is designed for 3.0/3.3 volt applications. These 500 W devices can protect one unidirectional line (SOT-23 version), or four unidirectional lines (SO-8 version). Single quantity pricing at the 10,000 piece level starts at $0.20 for the SOT-23 devices and $1.25 for the SO-8s.
Protek Devices
INFO/CARD #235

Coaxial Transient Suppressors

The PTC series of coaxial transient suppressors is now available in N, BNC, SMA, TNC, UHF and other standard

connector styles. The PTC series offers low VSWR, frequency range to 2.5 GHz, RF power rating to 4 kW, and 20 kA transient current capacity.
NexTek, Inc.
INFO/CARD #234

CABLES & CONNECTORS

7/16 DIN Connectors

A line of 7/16 panel mount male and female connectors from Tru-Connector incorporate the standard Type N 1" mounting flange. Tru-7666 series 7/16 panel mount receptacles conform to DIN 47223, IEC 169-4 and CECC 22 190 specifications. The series is priced from $37.00 each, depending on quantity.
Tru-Connector Corp.
INFO/CARD #233

Mobile Antenna Cable

Times Microwave Systems announces the availability of low loss LMR-200-MA and LMR-240-MA mobile antenna cables. At 900 MHz, LMR-240-MA has loss of only 7.6 dB/100 feet, compared to 16.5 db/100 feet for RG-58. The new MA versions of the LMR cable have non-bonded aluminum tape outer conductors and polyethylene jackets. LMR-240-MA is $0.43/ft and LMR-200-MA is $0.35/ft.
Times Microwave Systems
INFO/CARD #232

SUBSYSTEMS

Card-Level Telemetry

Microdyne Corp. has unveiled a series of card-level telemetry receivers and diversity combiners. Telemetry receivers, predetection and post-detection combiners are available in VXI, VME and PC-AT ISA bus configurations. The receivers operate in the L- and S-bands.
Microdyne Corp. Telemetry Div.
INFO/CARD #231

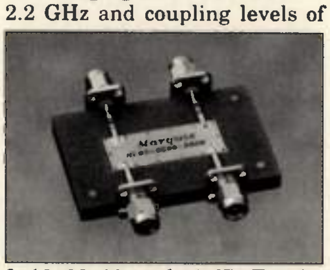
Wireless Data Link

Proxim has introduced the RangeLINK™ family of high speed data links. The line includes a number of speed and range options ranging from $2,975. RangeLINK remotely bridges Ethernet LANs in buildings separated by up to three miles using frequency hopping spread spectrum RF technology. Net throughputs range from 500 kbps to 1,200 kbps, and transmission occurs in the 2.4 GHz band.
Proxim, Inc.
INFO/CARD #230

SIGNAL PROCESSING COMPONENTS

Hybrid Couplers

The Marquis family of 90° hybrid couplers offer significant advantages for balanced circuits requiring phase quadrature (90°) signal coupling. Designed for superior performance, this competitively priced family of couplers is available at frequencies ranging from 400 MHz to 2.2 GHz and coupling levels of



3, 10, 20, 30, and 40 dB. For the standard line of hybrid couplers offered, electrical performance of ±1.0° phase and ±0.25 dB amplitude balance is nominal with a maximum of 0.25 dB of insertion loss.
M-Wave
INFO/CARD #229

Chip Dielectric Filters

The TDF family of chip dielectric filters from Toko America are now available with a low 2.5 mm maximum height. The TDF2A-2450T-10 is centered at 2.45 GHz with a passband of 100 MHz and offers typical insertion loss of 1.16 dB. The TDF3A-1575B-10 is centered at 1575.4 MHz with a minimum bandwidth of 10 MHz and offers typical insertion loss of just over 2 dB. Pricing in quantities of 100 starts at $8.00 to $11.00.
Toko America, Inc.
INFO/CARD #228

Wide Range SMT Mixer

The RMS-42MH from Mini-Circuits covers a wide 800 to 4200 MHz frequency range. The device is housed in a miniature unleaded surface mount package, which features solder-plated terminations with a nickel barrier. Typical mid-band conversion loss is 5.3 dB. LO to RF isolation is 35 dB from 800 to 2100 MHz and 28 dB from 2100 to 4200 MHz. LO to IF isolation is 18 dB and 15 dB in the same ranges.
Mini-Circuits
INFO/CARD #227

Couplers for Wireless

Electrodyne has developed lines of both high- and low-power broadband couplers for wireless applications. QC-214D works over the 0.8 to 4 GHz range, has 30 dB coupling and operating power of 500 W. Directivity is > 30 dB. Coupler QC-052 operates from 0.5 to 2 GHz with available coupling values of 6, 10, and 20 dB. Average operating power is 50 W. QC-118ABN operates over 0.8 to 18.5 GHz with a nominal coupling value of 16 dB. Minimum directivity is 15 dB.
Electrodyne Systems Corp.
INFO/CARD #226

1P2T Relay

A coaxial 1P2T function relay, model RDS-2S1AB-D, requires 25 percent less actuating current than conventional designs and operates from a 28 VDC supply. The device operates from DC to 18 GHz, has nominal 50 Ω impedance, less than 1.2:1 VSWR, less than 0.2 dB insertion loss and more than 80 dB isolation from DC to 4 GHz. Price is less than $100.00 in quantity.
RelComm Technologies, Inc.
INFO/CARD #225

TEST EQUIPMENT

LCR Meter

Hewlett-Packard has announced an RF LCF meter with a frequency range of 1 GHz. The HP 4286A uses a new measurement technique called RF-IV to measure RF components accurately. The meter operates from 1 to 1,000 MHz, with 10 kHz resolution and can measure impedances from 200 mΩ to 3 kΩ. Measurement speed is 15 ms, and measurement results are seen on a monochrome CRT. U.S. price for the HP 4286A RF LCR meter is $27,600.
Hewlett-Packard Co.
INFO/CARD #224

TRL Calibration Kit

Focus Microwaves has introduced a new member of the line of coaxial TRL calibration kits for HP-8510/8720 and Wiltron 360/37000 network analyzers. Model GPC-3.5-TRL-CV uses precision 3.5 mm connectors for calibrations between 200 MHz and 30 GHz. The calibration kit contains two shorts, two 50Ω loads, one delay line with Connector Extender® and three male/female adapters.
Focus Microwaves Inc.
INFO/CARD #223

H-Field Probe

ScanEM®-H, model CTM022, is a hand-held, self-contained magnetic field EMI probe. Magnetic fields from 100 kHz to 100

MHz can be measured. Sensitivity is adjustable, and field intensity is indicated by both a series of LEDs and the pitch of the device's audio tone. The ScanEM-H weighs approximately 2 ounces and is powered by two AAA batteries. A companion E-field probe is also available. The ScanEM-H is priced at $144.95.
Credence Technologies, Inc.
INFO/CARD #222

Richardson Electronics, Ltd.
A Powerful Source of RF and Microwave Energy Is Sending A Charge Through the Distribution Industry

Richardson Electronics, an electronic components distributor since 1947, continues to draw the attention of design engineers worldwide thanks to its impressive portfolio of RF, microwave and power semiconductors and related components. In the USA, Richardson has distribution agreements with major manufacturers of power semiconductors, including Motorola, SGS-Thomson, Philips, Powerex and M/A-COM.

Richardson's annual sales for its most recent fiscal year ended May 28, 1994, reached $200 million. The company sells primarily through a direct sales force located in 42 worldwide offices. The Richardson concept emphasizes value-added distribution to a worldwide customer base of 70,000.

"The customers served by Richardson's Solid State and Components group evolved over years of concentrating on the niche markets and products and winning the customer's trust," said Greg Peloquin, Business Unit Manager for Richardson's RF division. "By focusing resources and marketing these highly technical niche products, Richardson truly is an extension of our suppliers' salesforces."

Worldwide Focus

Because of its specialization on niche markets and products, Richardson has become the world's largest RF transistor distributor. The Company is Motorola's largest North American RF distributor and is the largest worldwide distributor for many other component manufacturers, including SGS-THOMSON, Comet, RF Products and RF Power Components. It is also the largest distributor for M/A-COM's PHO Division.

In a move to increase its presence in Europe, Richardson recently announced the addition of five new lines now available to its European customers. The Company has added Watkins-Johnson and RF Prime to its distribution coverage and expanded its distribution agreements with W.L. Gore, Amphenol and Ericsson to include Europe.

Richardson's European operations is continuing to add RF and microwave sales specialists and expanding sales offices to provide better coverage and increased technical support. Currently, Richardson has offices in Lincoln, England; Paris, Munich, Rome, Florence, Milan, Madrid, Barcelona. The Company will be expanding operations into London, Amsterdam, Hamburg and adding an office in Scandinavia.

While the Company's presence has been felt in North America, the addition of these lines in Europe provide further proof of Richardson's dedication to be THE choice for each type of RF, microwave and power semiconductor and related component it carries.

"Richardson Electronics has made a commitment to the RF marketplace on a global basis," said Peter Saxby, Product Marketing Manager for Richardson's Solid State and Components Strategic Business Unit and former technical sales person for M/A-COM and BFI. "Due to a number of customer-focused programs, we have built ourselves into one of the largest RF distribution specialists in the world."

Growth

Richardson's growing success can be attributed to a few key areas.

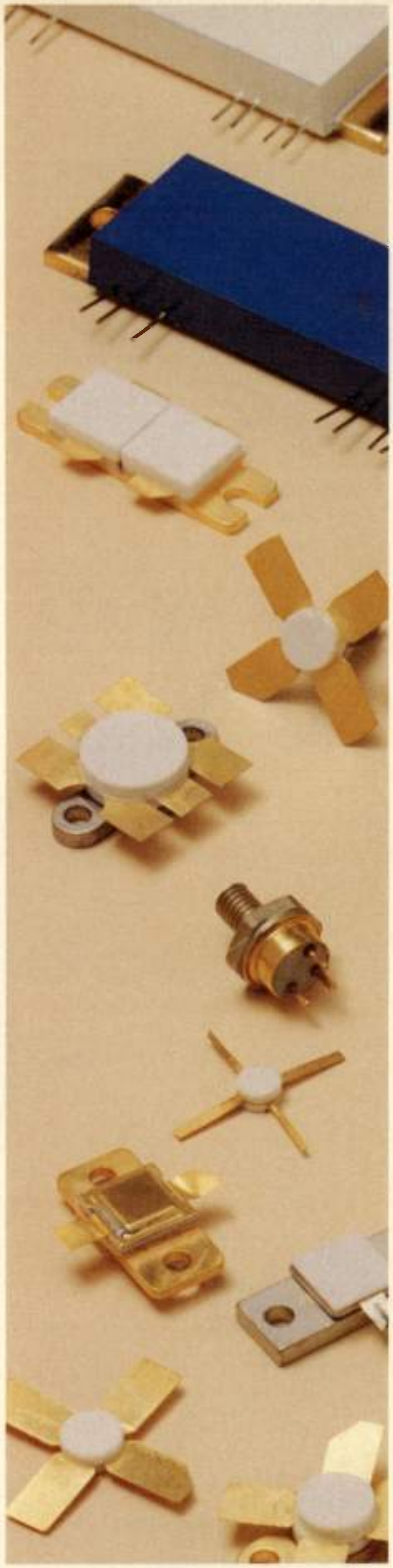
Inventory

Currently an $10 million RF semiconductor inventory housed in 14 worldwide stocking locations. In most cases, Richardson can ship the RF, microwave or power semiconductors its customers need the same day they call. This extensive inventory also enables the Company to handle a customer's midstream production increases.

Technical Sales Support

The Company has brought together sales and marketing people from leading manufacturers in the RF and microwave industry. Richardson is capable of assisting OEMs with new designs as easily as suggesting the proper replacement to service dealers and end users. Value-added services: Stocking programs, electronic data interchange, special testing, selecting and matching, bar coding. Richardson routinely provides the extra services its customers demand.

"There are many "broad-line" distributors; however, the markets addressed by Richardson are unique and (they) require specialized service," said Joel Levine, Vice President and Strategic Business Unit Manager for Richardson's Solid State and Components group. "Concentrating on our specific niche, Richardson Electronics has reached an unparalleled position in the electron tube and power semiconductor industry."



Richardson Electronics, Ltd.

INFO/CARD 43

Your Strongest Link to High Quality RF & Microwave Components
U.S. & Canada 1-800-348-5580

Digital Transmitter Tester

Anritsu Wiltron has enhanced its MS8604A with optional software that allows measurement of GMSK, GFSK, GSM, PCS1900, CT2, and DECT transmitters. The MS8604A combines a 100 Hz to 8.5 GHz spectrum analyzer and 400 kHz to 2.1 GHz digital modulation analyzer with digital signal processing and a unique Anritsu algorithm for fast accurate instrument.The MS8604A has a suggested U.S. price of $48,950, optional software begins at $5,100.
Anritsu Wiltron
INFO/CARD #221

Poratable Spectrum Analyzers

Tektronix has introduced the Advantest R3272 portable spectrum analyzer covering 9 kHz to 26.5 GHz. The R3272 utilizes direct digital synthesis and has 100 dB display dynamic range and 300 Hz to 5 MHz resolution. The analyzer uses a 256-color TFT LCD display and has two PCMCIA interfaces. The R3272 weighs 34 pounds and measures 7 × 17 × 16.5 inches. U.S. price is $28,990.

Tektronix
INFO/CARD #220

Mobile Signal Analysis

The STI-9000 is a compact, mobile signal analysis system consisting of a personal computer with internal GPS receiver, remote touch panel display, power inverter, application specific receiver and customized software. The STI-9000 is used to quickly measure and display signal quality over an area of expected coverage. Geographic contour plots from measured signal behavior are produced, along with statistics and data for selected areas. Base price for the STI-9000 is around $25,000.
Survey Technologies Inc.
INFO/CARD #219

Field Strength Meter

The R-505 field strength meter from Z Technology covers 3.0 to 1000 MHz and has a measurement range of 0 to +110 dBµV (−10 dBµV with option). Measurement accuracy is ±2 dB. The R-505 has an RS-232 interface for remote control and data collection, but also has internal data logging. Battery operation and internal RF filters and preamplifier also make portable operation simple. The standard R-505 is priced at $6,750.
Z Technology, Inc.
INFO/CARD #218

AMPLIFIERS

Pulsed Radar Amplifiers

A new line of pulsed amplifiers can operate in the frequency range of 150 to 200 MHz, with 200 W output power. The modules measure 4.84 × 2 × 1 inches, with 35 dB of gain. The amplifiers can be biased class AB for full power or class A with reduced power. Rise time in class A operation is typically 5 ns. High speed blanking is available as an option.
LCF Enterprises
INFO/CARD #217

Super-Low Noise Amp

Microwave Solutions has introduced a

low noise amplifier which has a noise temperature of 35 kelvins and operates in the 2.2 to 2.3 GHz frequency range. Model MSD-3800205 has +10.0 dBm at 1 dB compression and minimum gain of 50.0 dB. Input and output impedances are 50Ω and VSWRs are 1.3:1 and 1.5:1 for the input and output, respectively. The amplifier operates from +15 V and 150 mA.
Microwave Solutions, Inc.
INFO/CARD #216

Multi-Octave, High Intercept

Model BP60070046, from AML Communications, has an IP3 of +43 dBm and IP2 of 66 dBm. Gain is 22 dB, noise figure is 4.8 dB, and the 1 dB compression point power is +30 dBm. This multi-octave amplifier operates from 20 to 2000 MHz and measures 1.5 × 1.1 × 0.4 inches.
AML Communications
INFO/CARD #215

Variable Gain Amplifier

Miteq introduces a series of ultra wideband, low-noise amplifiers with variable gain options. Designated model AVG6-00102100-8, the amplifier covers the 100 MHz to 21 GHz range with 24 dB gain that can be continuously adjusted over a 15 dB range, The amplifier's input/output ports are matched to 10 dB min return loss. Optional gains, bandwidths, and noise figures are available.
Miteq
INFO/CARD #214

Feed Forward Amplifier

Microwave Power Devices now offers a solid-state linear amplifier using feedforward

techniques to achieve ultra linearity for up to 24 simultaneous channel operation. The amplifier operates over the 869 to 894 MHz band at 25 W total average output power (370 W PEP). IMD is 60 dBc. Gain is 45 dB and has load stability to infinite VSWR.
Microwave Power Devices, Inc.
INFO/CARD #213

SEMICONDUCTORS

Power Amp MMICs

Five power amplifier ICs from Anadigics provide high efficiency and high power output for a number of wireless applications. The AWT0901X provides 28 dBm and 22 dB gain for DAMPS cellular telephone applications. The AWT0902X typically provides 30 dBm at 23 dB gain for AMPS applications. The AWT0903X provides 30 dBm power output and 23 dB gain for ETACS applications. The AWT0904X is designed for GSM application and has 34.5 dBm power output and 23 dB gain. ISM applications from 902 to 928 MHz are supported with the AWT0905X, with power output of 30 dBm and gain of 23 dB. All these devices are two-stage amplifiers in surface mount packages.

Anadigics, Inc.
INFO/CARD #212

12-bit SO-8 DACs

The LTC1451, 1452, and 1453 are complete monolithic micropower 12 bit DACs that offer true rail-to-rail performance in an SO-8 package. The LTC 1451 (5 V version) and LTC1453 (3 V version) have on-board references and output buffers and dissipate 2 mW and 0.75 mW, respectively. The LTC1452 is a multiplying version and dissipates 1.1 mW. Typical settling time at the output is 14 μs. Pricing in quantities greater than 1,000 is $4.65.
Linear Technology Corp.
INFO/CARD #211

GaAs MMIC Amplifiers

The AH-B102D-1 series of cascadable HBT GaAs MMIC amplifiers is available in chip form or in ceramic packaging. The series features typical gain of 12 dB, RF frequency range of DC to 10 GHz, < 7 dB noise figure, P1dB > 13 dBm, and typical VSWR for input and output of 2.0:1 for frequencies < 7 GHz. The series is part of a family of HBT Darlington amplifiers designed for use as a general purpose 50 Ω gain block.
FEI Communications, Inc.
INFO/CARD #210

SOT-Package Amplifiers

Hewlett-Packard has introduced a series of six, 3- and 5-volt silicon and GaAs RFIC amplifiers in SOT-363 and SOT-143 packages. The INA-30311 is a 3 V, 13 dB gain amplifier useable to 1 GHz. The INA-50311 is a 5 V, 19 dB gain amplifier useable to 1 GHz. The INA-51063 is a 5 V amplifier with 20.5 dB gain, useable to 2.4 GHz. The INA-52063 is a 5 V amplifier with 20 dB gain and is useable to 1.5 GHz. MGA-86563 is a 5 V, low noise amplifier for 500 MHz to 6 GHz. MGA-87563 is a 3 V, low noise amplifier operating from 500 MHz to 4 GHz. Pricing for these parts, in 10k to 25k quantities, ranges from $0.75 each to $2.37 each.
Hewlett-Packard Co.
INFO/CARD #209

DDS Evaluation Board

The AD7008/PCB is an evaluation board for direct digital synthesis (DDS) implementations. The board is based on the AD7008, which integrates a numerically controlled oscillator with a 32-bit phase accumulator, sine and cosine lookup tables, control circuitry and a high performance 10-bit DAC. The evaluation board can be used to completely control amplitude, phase and frequency for signals with bandwidths of up to 25 MHz. The AD7008/PCB is priced at $200.
Analog Devices, Inc.
INFO/CARD #208

Prescaler/Synthesizer

Motorola has introduced a 2.5 GHz serial input PLL frequency synthesizer with pulse swallow functionality and an integrated dual modulus prescaler. The device operates within a power supply range of 2.7 to 5.5 V. The dual modulus prescaler provides divide ratios of either 32/33 or 64/65. The device is available in both TSSOP and SOIC packages. Pricing for the SOIC version of the MC12210 is $7.28 in 1000 piece quantities.
Motorola Semiconductor
INFO/CARD #207

DISCRETE COMPONENTS

Multilayer Capacitors

The MPR series of micro-porcelain multilayer capacitors from the North American Capacitor Company is designed for high-performance, surface mount applications. The series operates at frequencies up to 30 GHz. Capacitances range from 0.2 pF to 0.1 µF. typical Q factors are 10,000 (min.) at 1 MHz, and temperature ranges as wide as –55 to +200 °C can be specified.
North American Capacitor Co.
INFO/CARD #206

RF Variable Cap

The "P" series of variable capacitors from Polyflon features a virgin PTFE dielectric. These components are non-magnetic, which makes them well suited for use in applications involving magnetic resonance imaging coils. The capacitors are compact, yet have a 2 to 18 pF tuning range. Peak test voltage is 2 kV, and peak working voltage is 1 kV. Pricing is $52.00 each in 100 piece quantities.

Polyflon Co.
INFO/CARD #205

Implantable Grade Crystals

CC4 series crystals from Micro Crystal are packaged in a ceramic package with a thickness of only 1.2 mm. The ceramic package is of implantable grade. Standard frequency range is 32 kHz to 1.0 MHz, with standard tolerance of ±130 ppm. The crystals have shock resistance of 5000 g / 0.3 ms (1/2 sine). The standard temperature range is –40 to +85 °C.
Micro Crystal
INFO/CARD #204

Program Synthesizes Antenna Matching Networks for Maximum Bandwidth

By Robert J. Dehoney
RJD Consultants

A method is presented for designing matching networks for dipole and monopole antennas. With these networks, the 2:1 VSWR bandwidth can exceed 40 percent. The method can be extended to other antenna types.

One of the more vexing problems the RF engineer faces is trading off antenna complexity and bandwidth. Simple dipoles and monopoles have bandwidths ranging from a few percent at VSWRs below 1.2:1 to perhaps 15 percent at VSWRs below 2:1. Increasing the bandwidth without adding extra elements or increasing the element diameter has proven to be a challenging task. In addition, matching methods are traditionally cut-and-try involving the use of the Smith Chart or computer equivalents.

If the antenna can be represented as a circuit, then the powerful methods developed in network theory can be utilized to synthesize matching networks. Attempts to develop equivalent circuits have a long history, the latest efforts being reported in a recently published article which describes an improved equivalent circuit for dipole antennas [1]. In this circuit, the element values are functions only of the antenna length and diameter. The circuit is accurate for length to diameter ratios, L/D, as low as 50, provided the dipole length to wavelength ratio is 0.6 or less. Our matching scheme has been developed for use with this equivalent circuit.

Matching Scheme

The antenna equivalent circuit is shown in Figure 1a. For a dipole far from ground, the element values are:

$$R_A = 412.88 L_S^2 + 7407.54 S^{-0.02389} - 7274.08\ \Omega$$

$$C_A = 2(H)(0.89075)/(L_S^{0.8006} - 0.861) - 0.02541\ \text{pF}$$

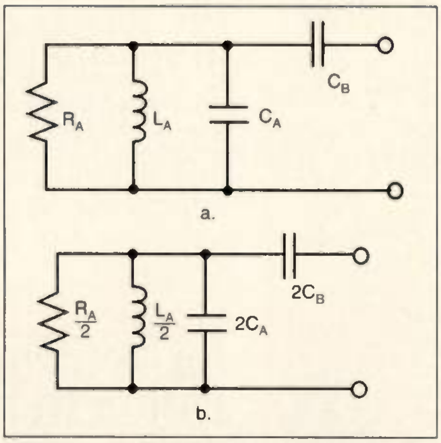


Figure 1. Equivalent circuit for dipole antenna, a. far from ground, and b. above a perfect ground.

$$L_A = 2(H)(148.13)(L_S^{1.012}) - 61.88\ \text{nH}$$

$$C_B = 12.0674H/(L_S - 0.7245)\ \text{pF}$$

where $L_S = \log(S)$; $S = 4H/D$; H and D are the dipole half length and diameter in meters.

For a monopole over perfect ground, H is the length of the monopole, and the circuit is shown in Figure 1b. This circuit looks very much like a fragment of an LC bandpass filter. Simply completing the filter does not accomplish anything useful since ω_0, as defined by C_A and L_A, represents the antenna parallel resonance peak and is well above the useful range of the equivalent circuit. In addition, R_A is generally 500 to 5000 ohms, requiring extensive transformation to get to normal impedance levels.

One solution is to take advantage of a circuit trick known for at least 60 years. It is easily shown that a pi network of capacitors is exactly equivalent to an L capacitor network driving an ideal transformer. Figure 2 shows this equivalence.

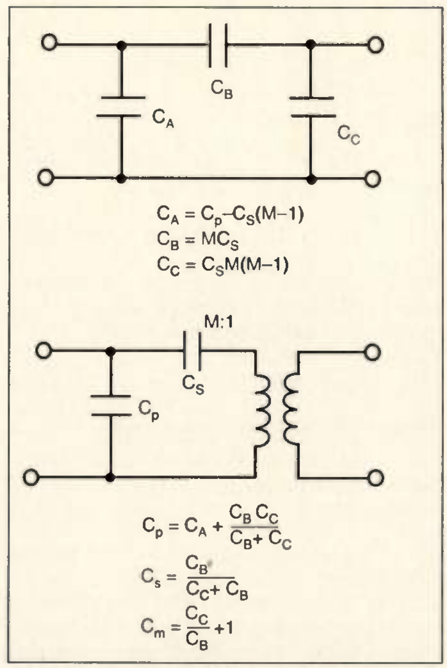


Figure 2. Equivalent capacitor pi network and capacitor L network driving a transformer.

Note that in the equivalence, C_P is larger than C_A, and M is greater than 1; both facts benefit us. What this tells us is that by adding a capacitor, C_C, to the antenna terminals, we can lower both ω_0 and Z_0. The design procedure is illustrated in Figure 3.

In Figure 3a, we form a pi network of capacitors by adding C_C across the antenna circuit terminals. We draw the circuit in equivalent form in figure 3b. In 3c, we pretend that we can add components between C_S and the ideal transformer and finish off the band pass filter started by R_A, L_A, and C_P. We add C_2' such that the series combination of C_S and C_2' resonates with

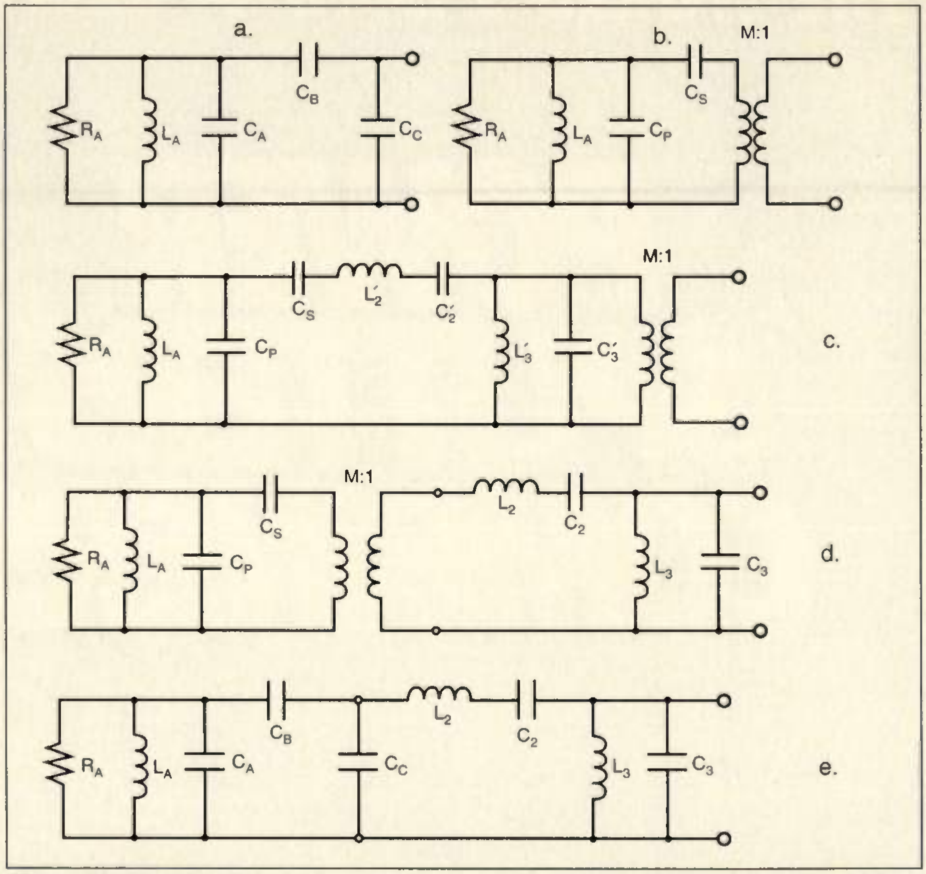


Figure 3. Synthesis of matching network starting with antenna equivalent circuit and applying equivalence shown in Figure 2 to match antenna to a bandpass filter.

L_2'. A three pole network is shown; any order can be used. In 3d, we move the added elements across the transformer to the real side of the network, dividing inductor and resistor values by M^2; multiplying capacitor values by M^2. Figure 3e shows the final circuit with the original pi representation restored.

To carry out the synthesis procedure, we need to know the antenna length and diameter in order to calculate R_A, L_A, and C_A. We need to know the network order and the passband VSWR's in order to calculate the lowpass Chebychev prototype element values, and we need the highest passband frequency to make the lowpass/bandpass conversion. (We can't use F_0 since the upper frequency might then exceed the allowable 0.6 wavelength limit.)

The significant equations are these:

$$F_l = F_h / [g(1) \cdot F_h \cdot 2\pi \cdot L_A / R_A + 1],$$

where F_l is the lower passband frequency, F_h is the higher passband frequency, and g(1) is the value of the first lowpass prototype element. L_A and R_A are antenna circuit elements.

$$BW = F_h - F_l$$

$$BWR = 2\pi BW$$

$$\omega_0 = 2\pi\sqrt{F_h F_l}$$

$$C_P = \frac{g(1)}{BWR(R_A)}$$

$$M = \frac{C_B}{(C_A + C_B - C_P)}$$

$$C_S = \frac{C_B}{M}$$

$$C_C = C_S M(M-1)$$

$$Z_0 = \frac{R_A}{M^2 SWR_{min}}, \text{ for N odd}$$

$$Z_0 = \frac{R_A}{M^2 SWR_{max}}, \text{ for N even}$$

$$L_2 = \frac{g(2)R_A}{BWR \cdot M^2}$$

$$C_L = \left(L_2 \omega_0^{\,2}\right)^{-1}$$

$$C_L' = \frac{C_L}{M^2}$$

$$C_2 = \frac{C_S C_L'}{M^2\left(C_S - C_L'\right)}$$

```
Is antenna a dipole or a monopole (D/M)? m
Enter highest operating frequency, Fh in MHz 174
Lmax= .5172414 meters     Enter antenna length, meters 0.517
Enter diameter, cm, or, to select diameter, enter <CR> 2
Enter network order (must be greater than 1) 3

|------|------|------CB-----|----C2-----L2 * * ** * * * C4 * L4 *
|      |      |             |             *    *
RA     LA     CA            CC            C3   L3          INPUT
|      |      |             |             *    *
|------|------|-------------|---------- ------* * ** * * * * * * * *

|-----antenna------|-----------matching network------------|


        MONOPOLE and MATCHING NETWORK

Enter MAX and MIN passband VSWR  1.5,1.4
```

Figure 4. Data for EQUIV analysis of a VHF whip.

```
     Lmax= .5172414 meters      (L/D)min= 25
L= .517 METERS  D= 2 CM     L/D= 25.85
FL= 127.0806 MHz   FH= 174 MHz
N= 3   SWRMAX= 1.5    SWRMIN= 1.4

     *****ANTENNA ELEMENTS*****
    RA= 516.0105 OHMS   LA= 1.235886E-07
    CA= 2.015005E-12    CB= 9.672475E-12

     *****NETWORK ELEMENTS*****
          CC= 2.901204E-11
   C 2 = 1.861993E-11  L 2 = 9.113513E-08
   C 3 = 9.699232E-11  L 3 = 1.181069E-08
          Z0= 23.0426

If values are OK, save with <PRT SC>
For new length, diameter, or network order, enter <L,D, or N>
For new SWR's, enter <S>
To see input VSWR vs freq, enter <V>
To see Zin of antenna equivalent circuit only, enter <A>
To restart program, enter <R>.  To end program, enter <Q>
```

Figure 5. Results for data input in Figure 4.

```
     Lmax= .5172414 meters      (L/D)min= 25
L= .505 METERS  D= 2 CM     L/D= 25.25
FL= 143.0191 MHz   FH= 174 MHz
N= 3   SWRMAX= 1.2    SWRMIN= 1.02

     *****ANTENNA ELEMENTS*****
    RA= 509.4099 OHMS   LA= 1.199414E-07
    CA= 1.984469E-12    CB= 9.52326E-12

     *****NETWORK ELEMENTS*****
          CC= 2.049513E-11
   C 2 = 4.07516E-12   L 2 = 2.83686E-07
   C 3 = 8.105418E-11  L 3 = 1.255805E-08
          Z0= 50.26478

If values are OK, save with <PRT SC>
For new length, diameter, or network order, enter <L,D, or N>
For new SWR's, enter <S>
To see input VSWR vs freq, enter <V>
To see Zin of antenna equivalent circuit only, enter <A>
To restart program, enter <R>.  To end program, enter <Q>
```

Figure 6. Effect of slightly changing VSWRs and reducing L.

```
     Lmax= .5113636 meters      (L/D)min= 25
L= .508001 METERS  D= 1.905 CM     L/D= 26.66672
FL= 142.3824 MHz   FH= 176 MHz
N= 3   SWRMAX= 1.21    SWRMIN= 1.15

     *****ANTENNA ELEMENTS*****
    RA= 524.8215 OHMS   LA= 1.224749E-07
    CA= 1.958723E-12    CB= 9.40562E-12

     *****NETWORK ELEMENTS*****
          CC= 1.902995E-11
   C 2 = 4.745565E-12  L 2 = 2.485498E-07
   C 3 = 5.493153E-11  L 3 = 1.840138E-08
          Z0= 49.93037

If values are OK, save with <PRT SC>
For new length, diameter, or network order, enter <L,D, or N>
For new SWR's, enter <S>
To see input VSWR vs freq, enter <V>
To see Zin of antenna equivalent circuit only, enter <A>
To restart program, enter <R>.  To end program, enter <Q>
```

Figure 7. Results of changes done to increase the self resonant frequency of L_2.

$$C_3 = \frac{g(3)}{BWR \cdot R_A M^2}$$

$$L_3 = (C_3 \omega_0^2)$$

and so on.

The lowpass prototype element values are obtained in the usual way [2]. The in-band VSWR limits are converted to max and min ripple which, together with the number of poles, determine g(in) and the g(n)'s. Note that we specify a minimum as well as a maximum value of VSWR. Allowing the minimum VSWR to assume values other than 1.0:1 has two benefits. First, a value can be found that will maximize the bandwidth; second, VSWR min affects the value of Z_0, allowing that parameter to be adjusted.

The procedure described above has been automated in a GWBASIC program, EQUIV.BAS/EXE. The following example illustrates its use.

VHF Whip Example

Suppose we want to design a vertical whip for use over the high VHF mobile band, 150 to 174 MHz. We want the VSWR to be as low as possible for maximum transmitter efficiency.

After the entry screen, the program asks if we want a dipole or monopole. We enter <M>, for monopole. We are then asked to enter the highest operating frequency in MHz. We enter <174>. After this entry, the program prints the maximum permissible length of our monopole, 0.51724 meters, then asks us to enter a length. We enter <.515>. The program asks for a diameter in cm; we enter <2>. (If we had simply entered <CR>, the program would have asked for some other parameters and then would have printed out F_l, Z_0, and D for various L/D ratios from 25 to 5000. We could then have chosen a suitable L/D.) The program asks for the network order; we enter <3>, representing a reasonable complexity. The program then displays a schematic of the circuit and asks for the maximum and minimum pass band VSWR's. We enter <1.5> and <1.4>, for starting values. The program displays our entries, shows the lower frequency of the pass band, shows the values of the antenna equivalent circuit, then shows the values of the matching circuit elements and Z_0. We can now change parameters and recalculate all the values, calculate the input VSWR vs frequency, or calculate the impedance and VSWR at the antenna terminals.

Figures 4 through 8 show typical screens. Figure 4 shows the data entry for the above example. Note that the schematic is different than Figure 1b. The program takes into account the dipole/monopole differences, and gives the proper values.

Figure 5 shows the results screen. Notice that the bandwidth is excessive and the input Z_0 is low. Improving the VSWR narrows the bandwidth and increases Z_0, both effects desirable in this case.

Figure 6 shows the effects of changing the VSWR's, then slightly reducing L to obtain the desired bandwidth

Enter the lower frequency in MHz 138
Enter the upper frequency in MHz 182
Enter the step size in MHz 4

Frequency	VSWR	Rin	Xin
138	1.881979	82.23817	-25.56236
142	1.236979	49.05819	-10.50936
146	1.167448	42.98123	1.803292
150	1.209964	46.18889	8.368316
154	1.182057	53.16257	7.998903
158	1.1502	57.39625	.6863057
162	1.174317	54.29416	-7.148796
166	1.208303	47.71851	-8.981485
170	1.190299	43.37855	-4.792608
174	1.151801	44.32054	3.57811
178	1.358167	54.54303	15.36078
182	1.969285	87.5354	25.9044

Do you want to review antenna/network values? (Y/N)

Figure 8. EQUIV analysis of network from 138 MHz to 182 MHz.

ANTENNA3

Frequency	VSWR		Transducer Gain		VSWR	
138.00M	1.88	–27.47	–0.43	102.59	1.88	52.66
14.200M	1.24	–89.07	–0.05	76.65	1.24	62.38
146.00M	1.17	164.48	–0.03	54.93	1.17	125.37
150.00M	1.25	109.52	–0.04	35.90	1.21	142.28
154.00M	1.18	64.00	–0.03	18.23	1.18	152.47
158.00M	1.15	4.93	–0.02	1.26	1.15	177.58
162.00M	1.17	–55.09	–0.03	–15.28	1.17	–155.47
166.00M	1.21	–99.01	–0.04	–31.57	1.21	–144.14
170.00M	1.19	–141.17	–0.03	–48.01	1.19	–134.85
174.00M	1.15	145.62	–0.02	–65.24	1.15	–96.10
178.00M	1.36	65.17	–0.10	–84.06	1.36	–53.29
182.00M	1.97	23.94	–0.49	–104.80	1.97	–53.54
186.00M	3.27	–6.61	–1.44	–126.44	3.27	–66.27

Figure 10. ACANAL analysis of circuit of Figure 9.

ANTENNA3

RS=50.00 1
RL=524.82 4

1	CAP	C3	1	0	54.9328p
2	IND	L3	1	0	18.4010n
3	CAP	C2	1	2	4.7457p
4	IND	L2	2	3	248.5448n
5	CAP	CC	3	0	19.0302p
6	CAP	CB	3	4	9.4056p
7	CAP	CA	4	0	1.9587p
8	IND	LA	4	0	122.4746n

1 LIN 138.0000M 182.0000M 4.0000M

Figure 9. Circuit file used for analysis using ACANAL.

with a 50 ohm Z_0. A critical element is L_2. Its self resonant frequency must be as high as possible. Figure 7 shows the values modified to obtain a smaller L_2. This illustrates the kinds of trade-offs that can be accomplished in a few minutes at the keyboard.

To check the performance of the network, we take advantage of the built-in ladder analysis routine and ask for a calculation from 138 to 182 MHz in 4 MHz steps. Figure 8 shows the results, which match the desired performance.

There are, however, some limitations to the scheme described above. First, Z_0 drops very quickly as the antenna length, L, is decreased and the matching element values become impractical or even negative. Second, even with L at a reasonable length, attention must be paid to the matching element parasitics. Use a circuit analysis program such as Gary Appel's ACANAL (RFD 11-89) and include coil and capacitor Q's, and coil self resonant frequencies.

Figure 9 shows the ACANAL file for the above example, using ideal elements. Figure 10 shows the analysis, which closely matches Figure 8. Figure 11 shows the modified circuit file including losses and parasitics. Notice that the value of L_2 had to be reduced from 248.5 to 200 nH to compensate for stray capacity C_S. Figure 12 shows the final performance. Notice that even with lossy elements, the in-band insertion loss is less than 1 dB.

Final Comments

The ultimate limitation is, of course, the accuracy of the antenna equivalent circuit. Most dipole antennas are not far from ground, nor are monopoles over an infinite, perfectly conducting ground plane. However, these are often second order effects and moderate tweaking will result in acceptable performance.

This matching scheme is useful for any device whose behavior can be simulated by a capacitively coupled RLC network. It should be possible to develop a dual network applicable to loop antennas.

EQUIV is available through Argus Direct Marketing. To order, see the ad on page 118. *RF*

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1. "Equivalent Circuit of a Dipole Antenna Using Frequency Independent Lumped Elements," Quang, Tieng, and Gunn. *IEEE Trans Antennas and Propagation*, January 1993
2. "On the Design of Filters by Synthesis," Saal and Ulbrich. *IRE Transactions on Circuit Theory*, December 1958.
3. *Transmission Line Transformers*, Jerry Sevick, American Radio Relay League.
4. "Broadband Transmission Line Transformer Family Matches a Wide Range of Impedances," Donald A. McClure, *RF Design*, February 1994.

About the Author

Robert Dehoney received his BSEE from MIT in 1950. After graduation he worked for Allen B. DuMont Labs designing RF equipment for UHF TV. He retired from Fairchild Weston in 1987 as a Technical Director in ECM. He is now a private consultant. He can be reached at 4602 Palm Blvd., Isle of Palms, SC 29451, or by phone at (803) 886-5785.

ANTENNA4

RS=50.00 1
RL=524.824

1	CAP	C3	1	0	54.0000p	1000.0
2	IND	L3	1	0	18.4000n	100.0
3	CAP	C2	1	2	4.7500p	1000.0
4	IND	L2	2	3	200.0000n	100
5	CAP	CS	2	3	1.0000p	
6	CAP	CS	3	0	19.0000p	1000.0
7	CAP	CB	3	4	9.4056p	
8	CAP	CA	4	0	1.9587p	
9	IND	LA	4	0	122.4746n	

1 LIN 138.0000M 182.0000M 4.0000M

Figure 11. Revised circuit file for ACANAL.

ANTENNA3

Frequency	VSWR		Transducer Gain		VSWR	
138.00M	2.30	–2.67	–1.54	111.67	2.72	55.82
142.00M	1.39	–37.47	–0.69	84.21	1.58	39.56
146.00M	1.03	–100.86	–0.46	60.10	1.15	43.97
150.00M	1.12	89.50	–0.43	38.97	1.07	29.55
154.00M	1.17	50.27	–0.43	19.56	1.11	57.72
158.00M	1.18	9.89	–0.43	0.99	1.11	168.69
162.00M	1.16	–27.22	–0.44	–17.33	1.08	177.97
166.00M	1.10	–48.76	–0.46	–35.92	1.01	–34.61
170.00M	1.08	24.05	–0.53	–55.44	1.16	–19.11
174.00M	1.38	31.00	–0.76	–76.66	1.55	–28.43
178.00M	2.06	9.090	–1.42	–99.67	2.38	–44.30
182.00M	3.45	–15.49	–2.74	–122.95	4.14	–62.63
186.00M	6.04	–38.02	–4.72	–143.93	7.70	79.97

Figure 12. Final performance analysis using ACANAL.

The IEEE 802.11 Standard Enables WLAN Market Growth

By Gary A. Breed
Editor

This short report emphasizes the affect the the nearly-completed IEEE 802.11 wireless LAN (WLAN) standard will have on the marketplace. Interested engineers should obtain a copy of the draft standard to study its specific requirements, then stay abreast of any late changes that may be made before its final approval.

In the opinion of most analysts, the market for WLAN products has been impeded by the lack of uniform operating standards that would allow interoperability of equipment from different manufacturers. The purpose of the IEEE 802.11 standard is the creation of a uniform system under which many different products can be produced; with the ability to work with one another. An "XYZ Company" WLAN adapter for a notebook computer would be able to connect to a wireless office system from any other company, as long as both used the same transmission scheme defined in the 802.11 standard.

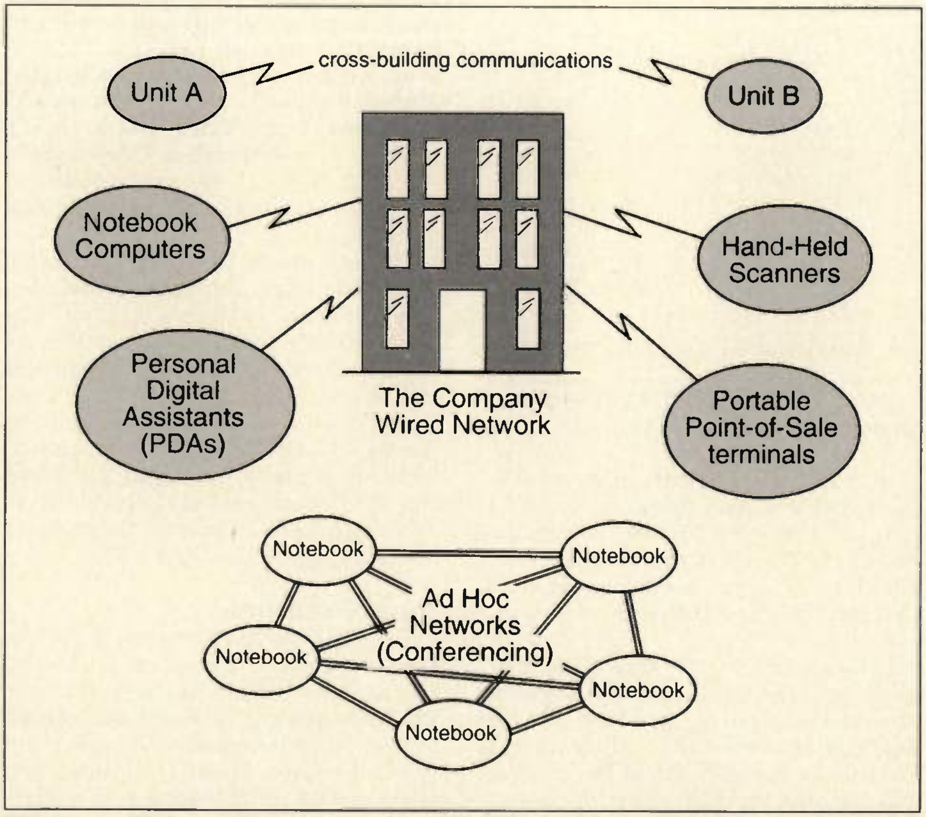

Figure 1. Major applications for WLANs include portable access to a wired network and flexible networking of portable devices.

Proprietary Systems

At present, and into the foreseeable future, WLAN systems are available that are not compatible with 802.11, or any other proposed or *de facto* standard. Even with a universal standard, companies will continue to use their own choice of technologies. The reasons are generally legitimate: the support of different data rates and operating frequencies, the inherent security of a unique transmission system, and seamless compatibility with the digital portion of the system.

The principle drawback of product-specific operating systems is, of course, interoperability. Standardized WLAN systems offer the opportunity for more flexible and open usage.

WLAN Applications

Figure 1 illustrates the major uses of WLANs. They all follow from the increased used of portable computing and communications equipment. WLAN is seen as the technology that will enable the most convenient link between existing wired networks and portable users at the office or campus level. Some of the most capable systems may also add campus-wide data communications, reducing the need for wiring among several buildings.

Another potentially large application is factory automation. In fact, this may the first application envisioned for a wireless network, as evidenced by work started by IBM in the 1970s, and early indoor propagation research oriented toward factories rather than offices. The possibilities of completely untethered monitoring and control of factory operations, inventory control, materials flow, and process control are attractive concepts for designers of efficient, highly-automated manufacturing systems.

In summary, the applications of WLAN systems range from simple communications between two computers, or between a computer and a wired network, all the way up to a complete wireless network with many users and many possible data paths.

INFO/CARD 53

Addressing WLAN with 802.11

The IEEE 802.11 standard covers three different, and mutually exclusive, modes of transmission: Direct Sequence Spread Spectrum (DSSS), Frequency Hopping Spread Spectrum (FHSS) and Diffused Infrared (DFIR). These three modes are the most effective transmission methods for relatively high data rates and resistance to interference, especially from other units in proximity operating on the same network.

802.11 focuses on the physical and media access protocol layers in both unit-to-unit and unit-to-network topologies. The initial standard covers the 2400-2483.5 MHz band allocated for Industrial Scientific and Medical (ISM) applications. Unlicensed operation is permitted on this band. This band was selected for availability in the U.S. and other major international markets, and for its lower hardware costs compared to higher microwave frequencies.

DSSS is supported using BPSK modulation and a 1 Mb/s data rate, or QPSK modulation and 2 Mb/s data rate. Five overlapping 26 MHz bands within the ISM allocation are centered at 2412, 2427, 2442, 2457 and 2470 MHz. Multiple center frequencies can help combat interference or even severe selective fading.

FHSS under 802.11 uses GFSK modulation and two hopping patterns with data rates of 1 Mb/s and 2 Mb/s. The ISM band is divided into 79 i MHz bands, and three patterns of 22 hops. The minimum hop rate is 2.5 hops per second for slow hopping with one data packet per hop. Successive packets are sent on different frequencies, creating time and frequency diversity for retransmission of a bad packet.

DFIR uses OOK at a data rate of 1 Mb/s. Infrared systems are non-directional, line-of-sight systems, with some potential for a reflected-transmission mode, as well. Typical range is 10-50 foot, usually limited to a single-room. Most observers suggest that the best applications for DFIR are wireless peripherals and other short-range links that may attractive for operating a notebook computer at a normal workplace, without the need for connecting cables.

Range of WLAN products operated according to 802.11 is estimated to be typically 300-400 feet. Of course, this range can vary widely in different environments — it can be much greater in open, unobstructed areas, or much less inside buildings with large amounts of metal in the structure and furnishings. The 300-400 foot range will allow WLAN coverage within most single office buildings, and certainly within a single office suite.

The 2400 MHz band is available for use in the U.S., the U.K., the European Continent (E.U. countries), and Japan. (The U.K. and the E.U. are mentioned separately because they do not yet have the same allocation — this will eventually take place.) These areas easily represent the vast majority of potential markets for WLAN products.

Other frequency ranges, particularly the 5725-5850 MHz ISM band, are potential subjects of future expansion of IEEE 802.11 or a new standard. There is some concern that the 2 Mb/s maximum data rate under 802.11 is insufficient for many WLAN applications. 10 to 20 Mb/s is often cited as a realistic target for the next generation of WLANs. With higher data rates, these systems could support wireless access with nearly the same operating conditions as most wired networks (e.g. Ethernet).

Status of the Standard

IEEE 802.11 is currently at the final draft stage, and is in the committee voting process at the time of publication. Later this year, it is expected to be approved.

Products compliant with the draft standard are expected to be advertised for sale in the third quarter of 1995. Prices for an add-on card or standalone adapter are expected to initially be in the $500 range, with prices dropping according to consumer response to the technology. Prices in the $250 range are anticipated by late 1996.

For more information on IEEE 802.11, or other IEEE standards, the address and telephone number are:

IEEE Service Center
The Institute of Electrical and Electronic Engineers
445 Hoes Lane
P.O. Box 1331
Piscataway, NJ 08854-1331
(908) 981-0060

Measurement Sweep Times During Conducted Emissions Testing

K.P. Slattery
FFD Ricardo, USA

Some questions have been raised as to how long the spectrum analyzer should be set to sweep during conducted emissions testing for automotive type electronics. Conducted emissions is a bench level test meant to indicate where a module may have problems in terms of radiated in-vehicle emissions. The test measures all I/O pins unterminated, with only necessary power and ground applied. Good correlation with in-vehicle emissions has been noted using this measurement method

Using an automotive transmission controller as a reasonable test module, we made a series of measurements in the 2-200 MHz band. We chose to measure the maximum level over the limit, and the noise density number, at the following sweep speeds (RBW=10kHz=VBW): 5, 10, 30, 50, 100, 300 seconds. One sweep was made for each measurement. In addition, we also made a similar series of sweeps measuring the variations in the ambient level, and also a series of measurements using a signal generator.

Our results indicate that there is no statistically significant difference between a 5 second sweep and a sweep equal to 300 seconds. However, while there isn't a significant overall difference, there is quite a bit of difference from measure to measure. The spread of means for the controller was 17.4 dB at 5 sec to 18.7 dB at 300 sec, or 1.3 dB. The standard deviations were fairly consistent across the sweep speeds, and we should expect this for a signal that is semi-coherent. For the ambient run, we found a spread of means of 2.1 dB at 5 seconds to 5.1 dB at 300 seconds. The standard deviations showed a downward tendency in value as the sweep speed increased, and for a random signal this tendency should be expected. An interesting effect for the ambient data is noted at the end.

Finally, we also characterized the output of a signal generator, set to 150 MHz with an output level sufficient to give us a constant level over the limit. The signal generator ranged from 9.5 dB at 5 seconds to 9.88 dB at 300 seconds, with a correspondingly low standard deviation.

In addition to the max level over the

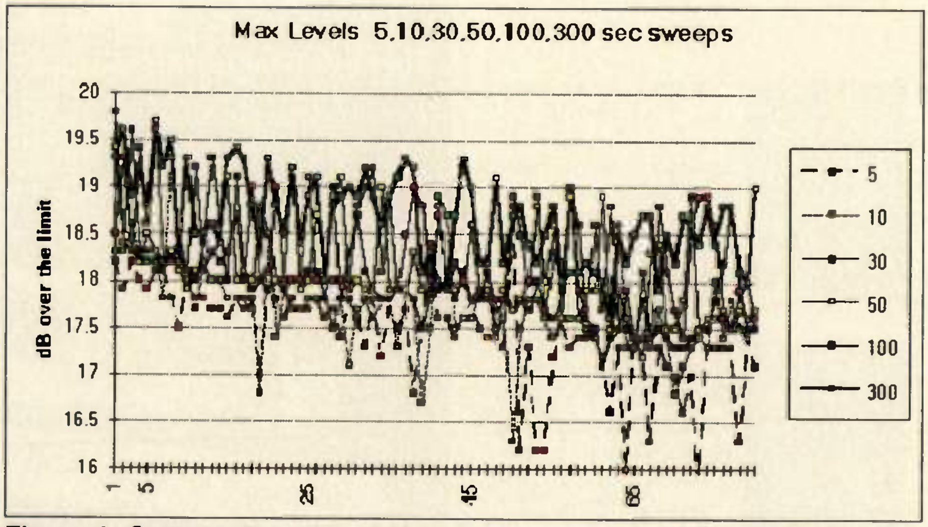

Figure 1. Comparative plot of six measurement sets of maximum emission level over the limit.

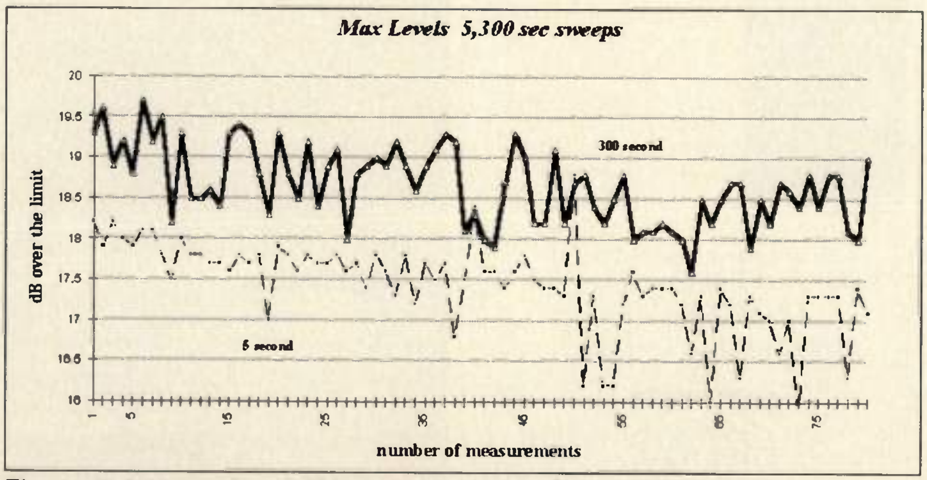

Figure 2. 5 second and 300 second sweep data.

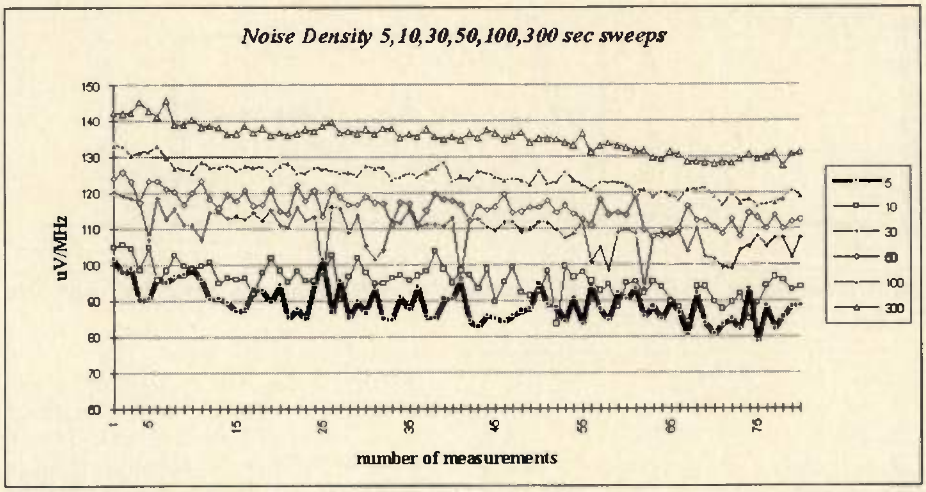

Figure 3. Comparative plot for noise density for all measured sweep speeds.

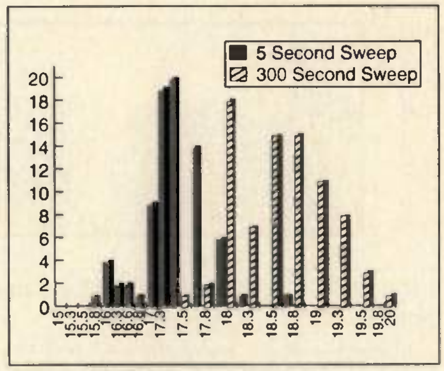

Figure 4. Distribution of max measured values for the 5 and 300 second sweep.

limit, we measured the noise density. We derive the noise density (ND) as

$$ND = \frac{1}{f_{max} - f_{min}} \sum_{n=1}^{T_{pks}} peaks \qquad (1)$$

$$peaks \geq limit \;\; level$$

where the limit level is determined by the frequency at which the measurement is being made, in this case = –80 dBV. T_{pks} is the number of points actually measured.

Figure 1 shows a comparative plot of the 6 measurement sets for the maximum emission level over the limit for the controller. One can see that the data are pretty well clustered between 17.5 and 19 dB, with occasional deviations down toward 16 dB.

Figure 2 shows only the 5 second and the 300 second data, showing more clearly the spread in measured levels. Figure 3 shows the comparative plot for noise density for all measured sweep speeds.

While Figure 3 would seem to indicate that there should be a significant difference between 5 and 300 second sweeps, when the F Test is run, there is none. However, one can observe that the 5 second data is much noisier than the 300 second data which was not evident in comparing the max level data. We take this to mean that the noise density number is better behaved and gives a more stable representation as the sweep speed increases since it is integrating over the entire measured frequency range while the max level over the limit is a measure at a single specific frequency.

Table 1 shows the F-Test between 10 seconds and 300 seconds.

Table 1.
F-Test: Two-Sample for Variances

	Variable 1	Variable 2
Mean	95.57875	135.25
Variance	21.56625	17.08861
Observations	80	80
df	79	79
F	1.262	
P(F<=f) one-tail	0.151553	
F Critical one-tail	1.4512	

Comparing 5 with 300 second.

Figure 4 shows the distribution of max measured values for the 5 second and 300 second sweep for the controller.

In looking at the data, a certain trend is unmistakable; there is a definite downward nature to the measurements as time goes on. Taking the data, and fitting it to a linear function, we can definitely see that the measurement level decreases as the module on-time increases. This is shown in

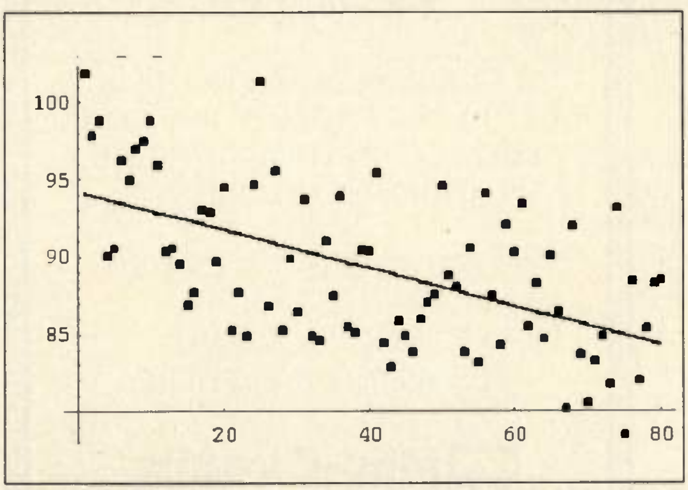

Figure 5. Distributed values of spectral density for 5 second sweep.

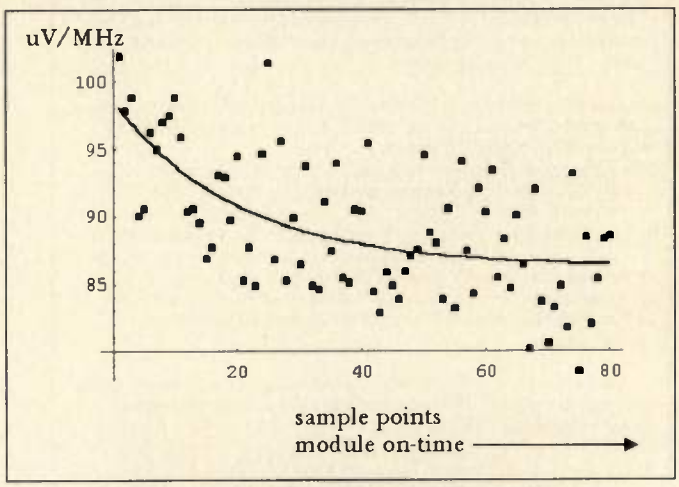

Figure 6. Exponential fit to data in Figure 5.

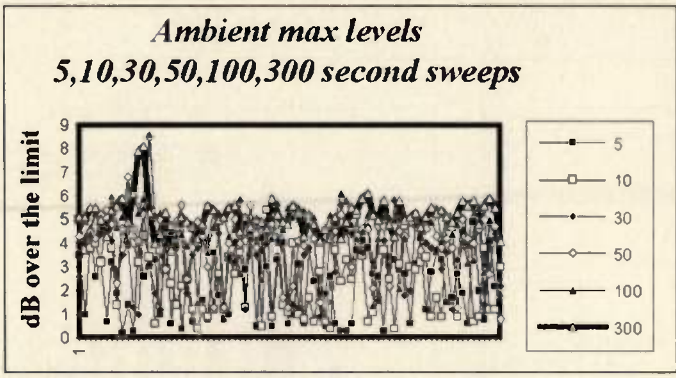

Figure 7. Comparative plot of maximum measured levels.

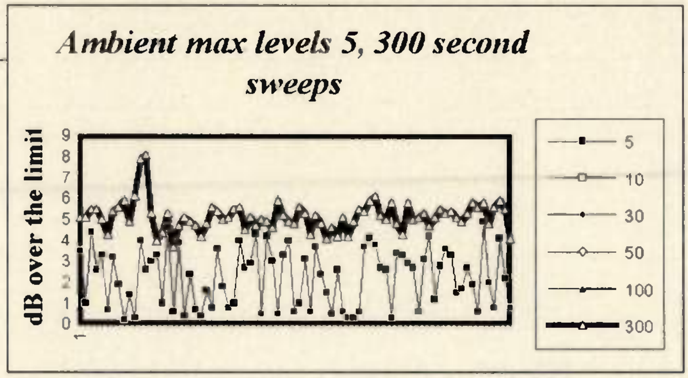

Figure 8. Comparison between 5 and 300 second data.

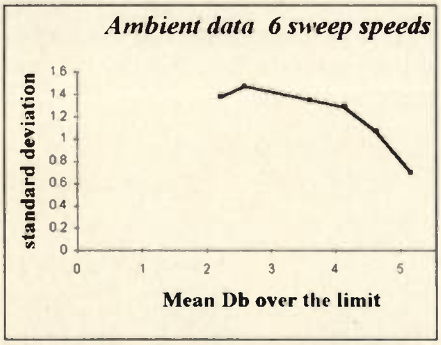

Figure 9. Averaged max level means and standard deviations.

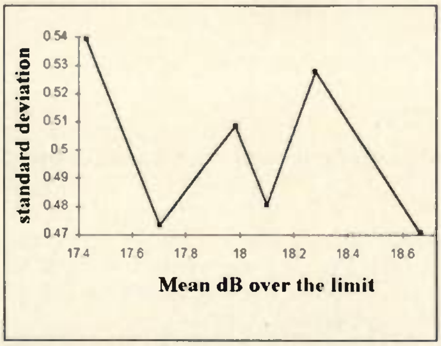

Figure 10. Controller mean and standard data.

Figure 5.

Figure 5 shows the distributed values of the spectral density for the 5 second sweep. The straight line fit shows a definite decreasing trend in the measured values as the module on-time increases.

Figure 6 shows an exponential fit to the data. The fitting equation is

$$y = 86.23 + \frac{12.42}{e^{0.05x}} \tag{2}$$

Equation 2 was determined using Mathematica, a symbolic mathematics

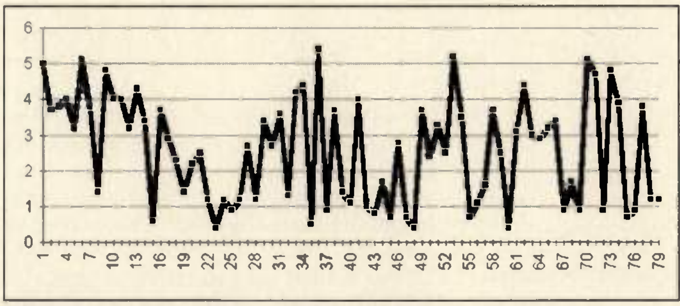

Figure 11. 10 second ambient data.

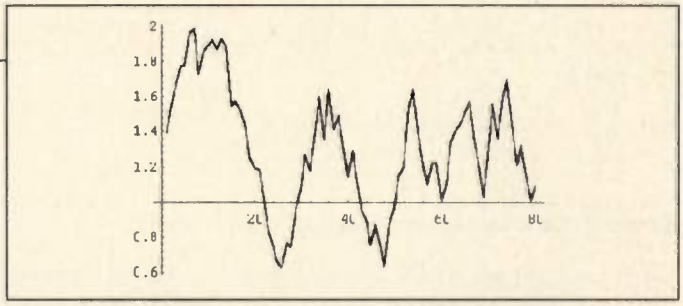
Figure 12. Inverse Fourier transform results.

program developed by Wolfram Research.

An exponential fit would appear to better describe the data. Our problem here is to decide whether the measured value is decreasing in value as a function of time because the module itself has been powered for a length of time and is therefore approaching heat equilibrium, or whether it is the measurement system itself that is equalizing. This can be better ascertained when we run the same series of measurements characterizing the ambient of the semi-anechoic chamber. If we assume that it is the module itself then, by referring to the data in Figure 6, we can see that the readings stabilize by approximately the 60th measurement. This corresponds to an on-time of 10 hours (each measurement cycle ≅ 10 minutes).

The ambient data is interesting in and of itself. Figure 7 is a comparative plot of the maximum measured levels. To obtain these values, we shifted the failure limit down to –130 dBm.

As can be seen, there is no downward tendency in value as there was with the controller. The peaks in the data early on, approximately 3 hours into the scan, are in the 50, 100, and 300 second sweep data. Apparently something was happening at that time that the shorter sweeps could not resolve adequately. The overall data reflects a random process. Figure 8 shows a comparison between the 5 second and the 300 second data. Again, it can be seen that the 5 second data is much noisier than is the 300 second.

Table 2 shows the calculated correlation coefficients. You can see that the sweep speed sets are relatively uncorrelated.

Figure 9 shows the averaged max level means and standard deviations for the ambient run at the 6 sweep speeds.

Figure 10 shows a similar scatter plot for the controller. In comparing the two plots we see that the controller appears to have no dependence between the standard deviation and

Correlation Coefficient	5 sec.	10 sec.	30 sec.	50 sec.	100 sec.	300 sec.
5 sec.	1					
10 sec.	–0.12291	1				
30 sec.	0.208644	–0.0041	1			
50 sec.	0.002877	0.260716	0.267398	1		
100 sec.	0.007606	0.09288	–0.01523	0.267468	1	
300 sec.	0.199686	0.185523	0.026368	0.05976	0.121013	1

Table 2. Calculated correlation coefficients.

the sweep speed, while the ambient data clearly shows a dependence.

Selecting the 10 second data to examine, in Figure 11 we can discern some possible time dependence in the data.

We can investigate this possibility by convolving this data. This is done by multiplying the Fourier transform of the ambient data by the Fourier transform of a smoothing kernel. We then take the inverse Fourier transform of that result, shown in Figure 12.

In Figure 12 we can see an oscillation over time with a cycle approximately equal to 7 hours.

When we sort the 10 second data we get Figure 13 and we can clearly see two groupings of the data.

For comparison, in Figure 14 we also show the convolution of the controller 10 second data. And, while we can see the downward drift in level, there would appear to be no oscillation similar to the ambient data. Also, referring back to the histogram for the controller we see no similar structure.

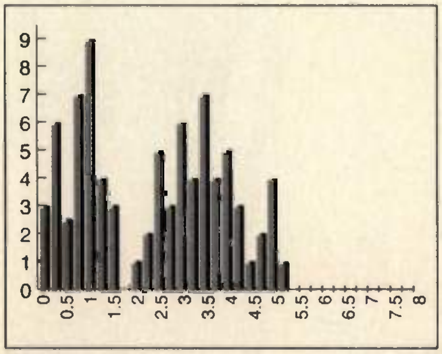

Figure 13. Controller 10 second ambient data.

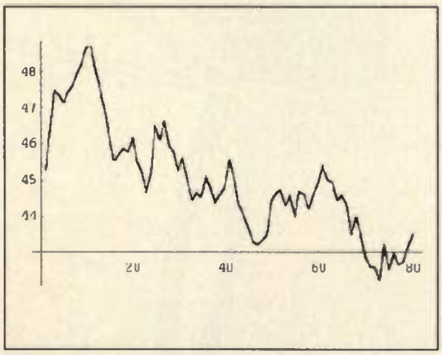

Figure 14. Convolution of the controller 10 second data.

Interestingly, when we sort the six sets of sweep data and plot them in the form of histograms, we find an interesting effect. (See Figures 15-20.)

The data sets appear to move from a uniform distribution, as seen in the 5 second data, to a normal distribution by the 300 second data set. The longer we look at random events, the more Gaussian they are, and when we observe these events for shorter periods of time they appear uniformly distributed.

The signal generator data is shown in Figure 21. Obviously the signal generator is quite stable with respect to time and with respect to sweep speed.

Figure 22 shows the distribution for the 5 second sweep and Figure 23 shows the 300 second distribution.

Summary

We should be aware of the measurement variation inherent to any given signal source. In addition, long term

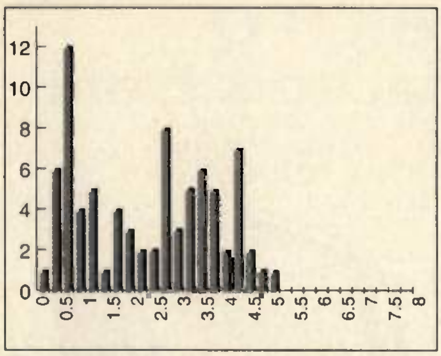

Figure 15. 5 second ambient data.

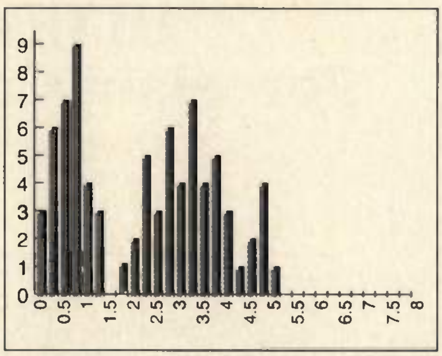

Figure 16. 10 second ambient data.

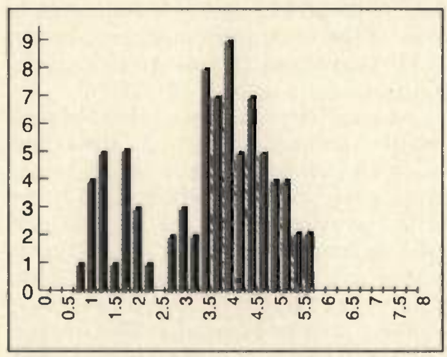

Figure 17. 30 second ambient data.

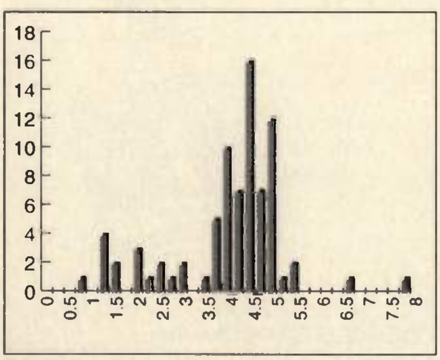

Figure 18. 50 second ambient data.

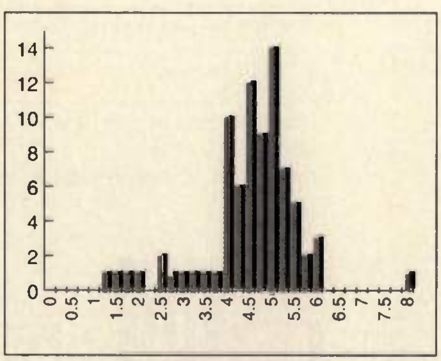

Figure 19. 100 second ambient data.

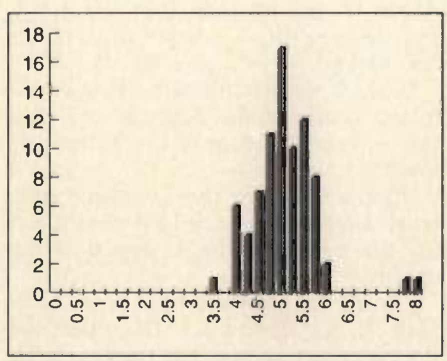

Figure 20. 300 second ambient data.

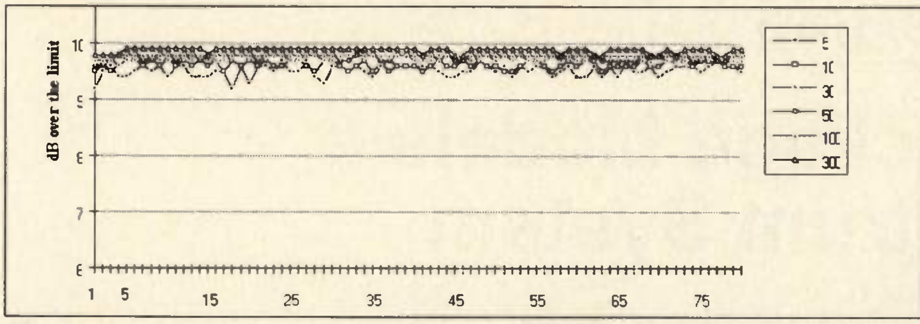

Figure 21. Signal generator data at 150 MHz for six measurement sweeps.

effects should be measured and understood, such as the downward tendency in the measured levels given here. This effect is probably due to the module requiring a period of time in order to reach equilibrium. We can see from the ambient data that the measuring system itself, consisting of the analyzer, amplifier and chamber does not exhibit any such tendency. However, we do note an oscillatory nature to the ambient measurements on the order of a seven hour cycle. Measurements from a coherent source, the signal generator, show data with very little measurement spread. Our measurements for modules, therefore, fall somewhere between random events, such as the ambient, and coherent, as in the case of the signal generator. *RF*

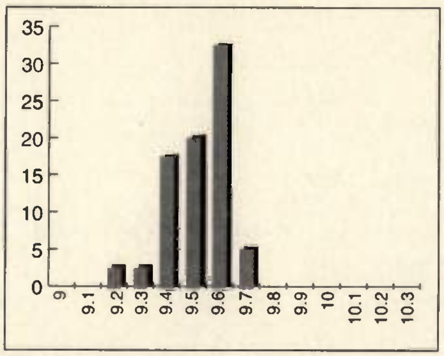

Figure 22. Distribution for 5 second sweep.

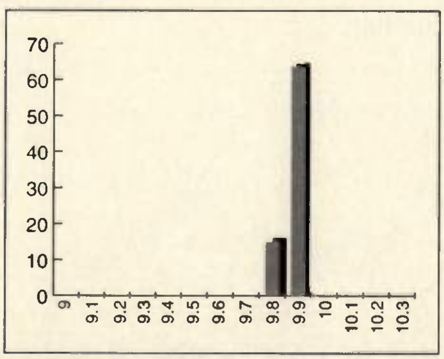

Figure 23. Distribution for 300 second sweep.

About the Author

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Simulator Package Models a Spread Spectrum System

Part 2: Transmitter and Receiver Simulation

By Stephen Kratzet
ELANIX, Inc.

Part 1 of this two part article discussed the modeling of three building blocks — a mixer, phase detector, and a biphase modulator using SystemView by ELANIX, Inc., a dynamic system simulator software package that runs on 386/486 and higher PCs operating with Microsoft Windows. In Part 2 the building blocks are used in the simulation of a transmitted reference spread spectrum system.

Direct Sequence SS PSK — Transmitted Reference

In this system the receiver design is greatly simplified by using a transmitted reference. [5, 6] The nature of this system is to send two modulated carriers as described below:

- Transmitted frequency 1: 28.5 MHz modulated with code only
- Transmitted frequency 2: 29.5 MHz modulated with code and data
- Code rate: 196.0 kHz
- Data rate: 50.0 kHz
- Highest filter frequency: 29.9 MHz

The Transmitter

The highest frequency component in the system is a bandpass filter at 29.0 MHz. Nyquist's sampling theorem [7, 8] would have us set the sample rate at a minimum of 2 × 29.9 Msps or 59.8 Msps. Out of a preference for powers-of-2 numbers the sample rate in this example is set to 81.92 Msps. Since the 50 kHz data rate is low relative to the 81.92 Msps sample rate, the number of samples is set to 32768 to view the data waveform. The transmitter simulation is divided into two blocks, and the receiver simulation into three blocks. The result of each block is saved as an external file, then the file is used as a source for the next block. Two reasons for this approach are (1) the pseudo noise (PN) sources will be repeatable sequences for "what if" comparisons, and (2) each block may be optimized with a minimum amount of execution time. However, if a user wants to organize this example as metasystems within metasystems

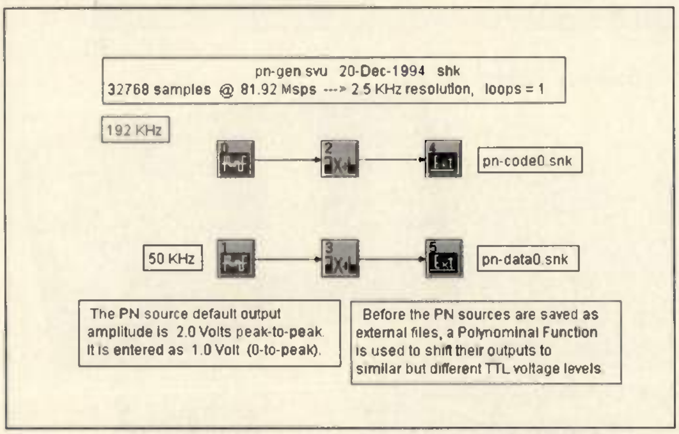

Figure 17. Transmitter code and data generation.

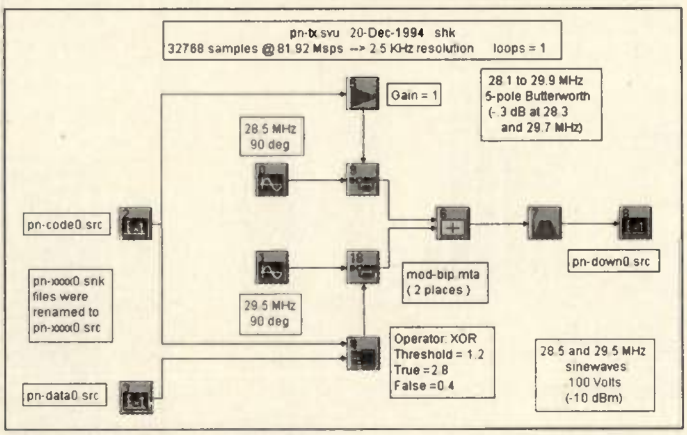

Figure 19. The transmitter.

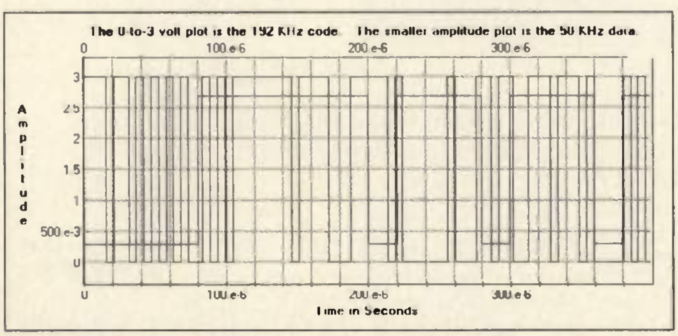

Figure 18. pn-code.snk and pn-data.snk.

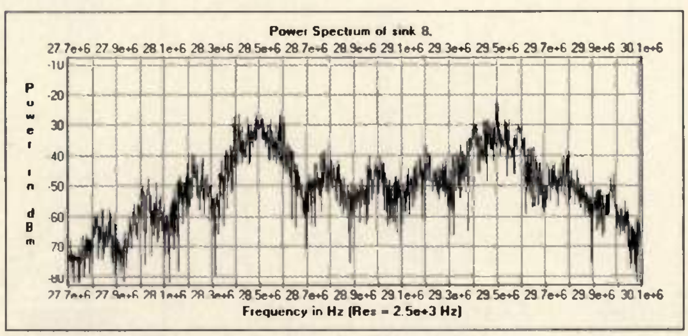

Figure 20. The transmitter's PN output.

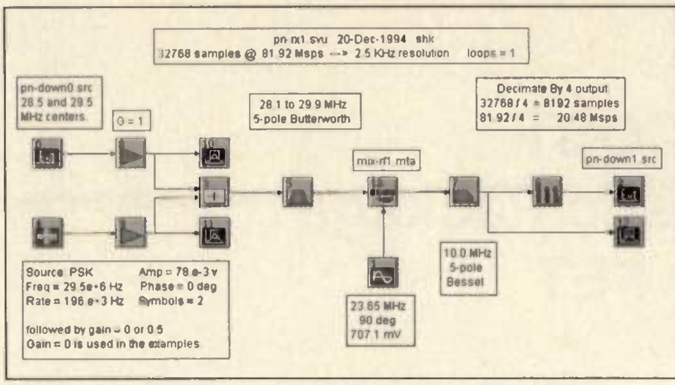

Figure 21. Receiver 1st down conversion stage.

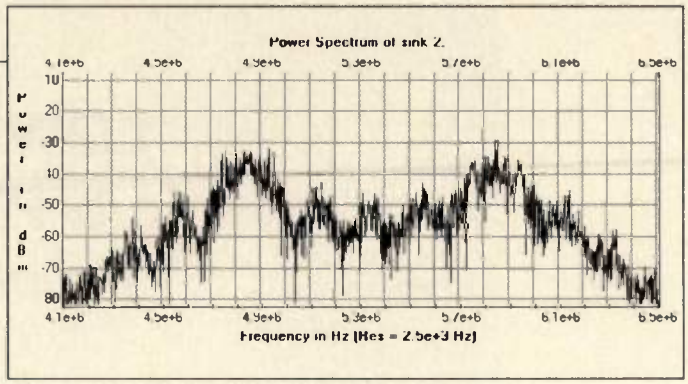

Figure 22. 1st down converter output.

without the use of external files, the whole system may be viewed as just a few tokens representing the blocks. With the View MetaSys button the internal layers of the building blocks are just a mouse click away. The first block is shown in Figure 17 generates the 2 test signals used in the simulation. The signal from each PN source is passed through a Polynomial Function to shift it to a TTL level. The two TTL signals have slightly different levels to allow easy recognition when viewed on the same vertical scale (Figure 18). In this block the external files have been given their default suffix (.snk). The files can be copied and given a new suffix (.src). This allows the first block to be re-executed without losing the original test signals.

In Figure 19 the two test signals are the external input sources. The external source, pn-code.src, modulates a 28.5 MHz carrier. Pn-code.src and another external source, pn-data.src, are exclusive-ORed and modulate a 29.5 MHz carrier. The unity gain token is used to route the connection for a more pleasing layout. The outputs of the two biphase modulators are summed together, bandpass filtered, and saved as a file.

Figure 20 shows the transmitter's PN output. Each of the two spectral peaks has a different structure. The plot was obtained by clicking the mouse on the following buttons in the SystemView View-Plots window: Calculator, Spectrum, Power Spectrum (dBm in 50 ohms), OK.

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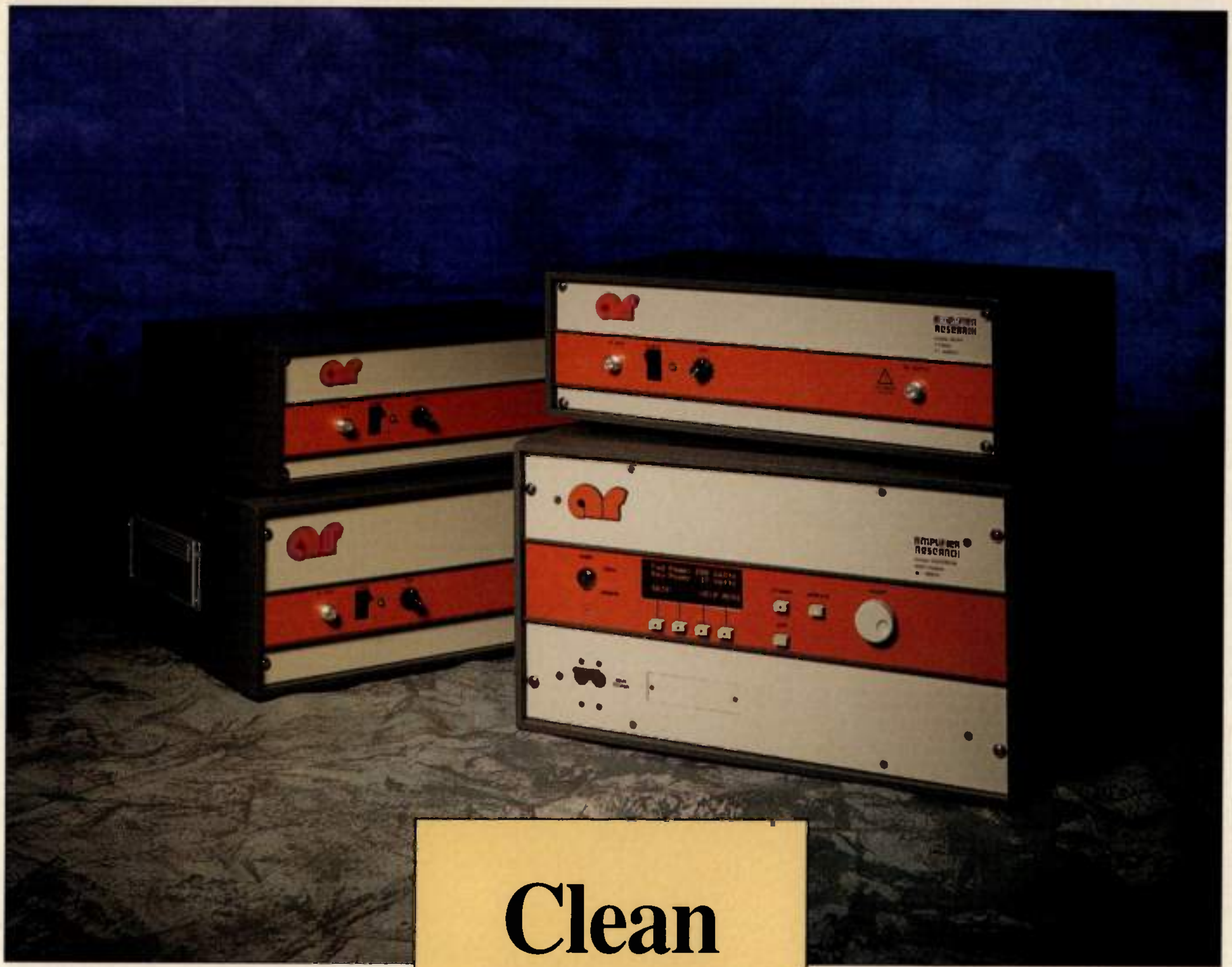
The Receiver — First Down Converter

The first of three receiver blocks is shown in Figure 21. The bandpass filtered input is down-converted to a lower frequency that is lowpass filtered. The output could be saved at this point. However, since the highest frequency of interest is now down to 7 MHz (as compared to the 29 MHz we started with), we can reduce simulation execution time if we reduce the system sample rate at this point in the system. The Decimate token is used to do this. In this case a decimation by 4 (looking at only every 4th signal point) will reduce the sample rate by 4 to 20.48 Msps. The number of samples also is divided by a factor of 4, reducing the amount of disk space required for the external sink (Figure 22). The next system that reads in this data must have its sample rate set to 20.48 Msps, and the number of samples set to 8192, in the System Time Specification. The input to the receiver has a provision to inject noise into the system. For the examples in this paper the noise is set to zero.

Second Down Converter

The second stage of the receiver, Figure 23, splits the two carriers into separate paths (Figure 24). One path feeds the RF input of a mixer, the other path drives the LO port of the same mixer. Normally, AGC is used in



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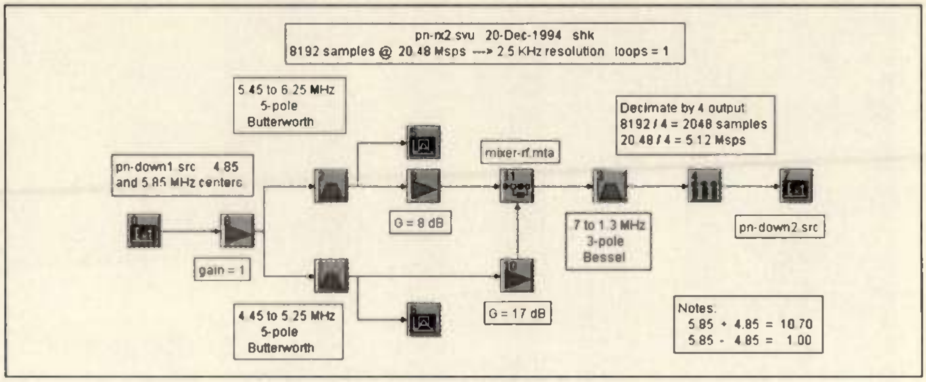

Figure 23. Receiver 2nd down conversion stage.

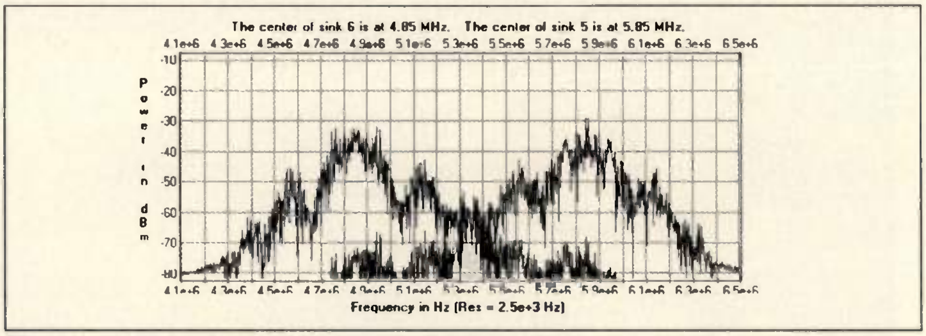

Figure 24. Input to 2nd down converter.

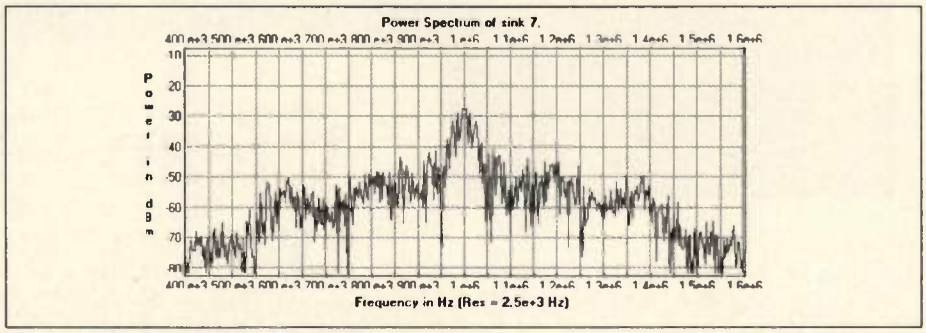

Figure 25. 2nd down converter output.

the receiver chain [9], but its complexity is not appropriate here. A gain token at the input allows testing of this block with various input levels.

Figure 25 shows the output of the second stage of the receiver. The frequency of interest has been down-converted to a center frequency of 1 MHz. The output has been decimated by 4 which gives us an output sample rate of 5.12 Msps.

Costas Loop Demodulator (Third Downconverter)

The last block in the receiver is a Costas Loop demodulator [10] (Figure 26). It is an extension of a phase locked loop (PLL). The Costas loop is implemented as a standard IQ down converter that has its filtered I and Q outputs passing through amplifier-limiters, then being applied to a 3rd mixer. The output of the 3rd mixer is filtered, amplified, and fed back to the VCO of the down converter. In this example lowpass filters (Fc = 500 kHz) are used before the amplifier-limiters to reduce the sum term output of the mixers. To give a clear view of the recovered data, lowpass filters (Fc = 60 kHz) are inserted before the I and Q sink tokens. Figure 27 shows the demodulated output. If each of the three mixer metasystems are replaced with the 4-quadrant multiplier token, the system becomes the DSP version of the down converter. The coefficients of any filter specified in SystemView can be saved as a file for inclusion in the software engineer's DSP code. A different frequency and gain plan would likely be required to be compatible with available DSP chips. (When multiplier tokens are used in place of the mixer metasystems the Costas loop simulation time is cut in half

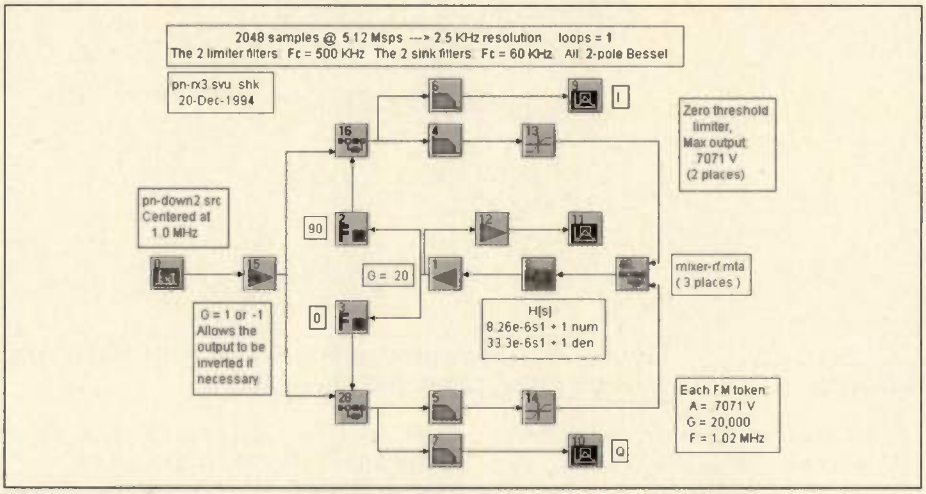

Figure 26. Costas Loop demodulator (3rd down conversion).

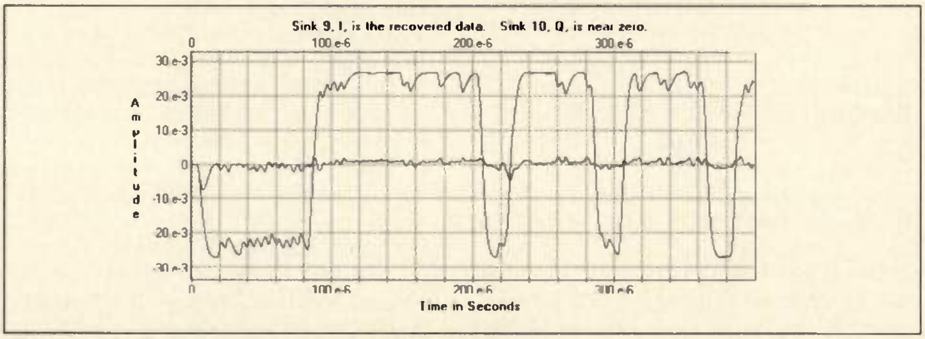

Figure 27. Costas Loop, I and Q outputs.

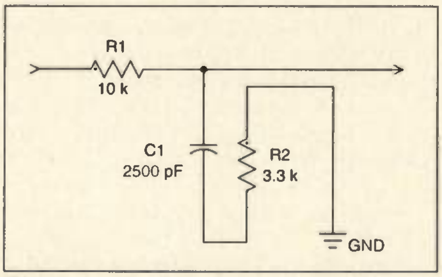

Figure 28. Single-pole lowpass RC filter.

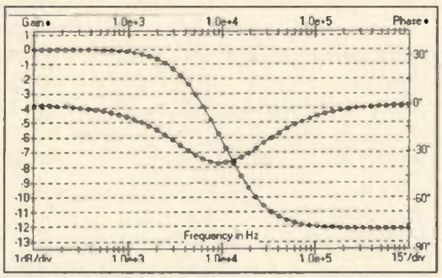

Figure 29. Bode plot of Costas Loop filter.

because the total token count of the system is reduced.) The Costas Loop is an example of a feedback circuit in SystemView. When the system sampling rate is high enough the execution order in a feedback circuit has only a small effect on the simulation. In this example the execution order is important, the paths from the FM tokens to the mixers should be executed last. SystemView allows a user-defined execution sequence to be set just by clicking each token in the desired order using the mouse. A note about phasing: In SystemView, when an FM token or Sinewave Generator token is set to 90 degrees phase, their outputs are maximum positive at zero system time. When set to zero degrees phase, their outputs are zero volts at zero system time, going positive at the first time tick.

$$H[s] = \frac{(T_2)s^1 + 1}{(T_2 + T_1)s^1 + 1} \quad \text{where } T_1 = R_1C_1 \text{ and } T_2 = R_2C_2$$

$$H[s] = \frac{(3.3k \cdot 2500pF)s^1 + 1}{[(3.3k \cdot 2500pF) + (10k \cdot 2500pF)]s^1 + 1} = \frac{8.25e-6s^1 + 1}{33.3e-6s^1 + 1}$$

Table 1. Laplace system design.

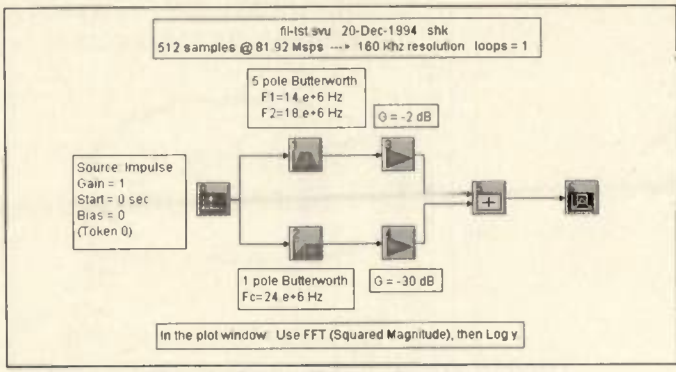

Figure 30. Simulating a filter with RF leakage.

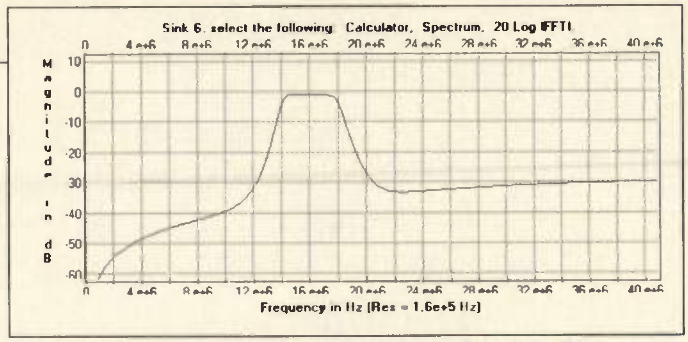

Figure 31. Frequency response of a RF filter with leakage (fixed stopband attenuation).

The filter for the Costas Loop phase detector is a classic single pole RC lowpass filter that contains a 2nd resistor in series with the capacitor to limit the high frequency cutoff (Figure 28). The Laplace system design is in Table 1.

The Bode plot in Figure 29 shows the lowpass filter –3 dB cutoff point at 5 kHz. At high frequencies the filter has a maximum loss (stopband) of –12.1 dB.

If an integrator type of lowpass filter is required, the 1 in the Laplace denominator can be changed to a zero.

All of the filters used in the TX/RX simulation are "perfect" – the skirts of the filters continue to attenuate regardless of the frequency. If a filter with a fixed attenuation stop-band is desired, a highpass filter can be paralleled with the main filter and their outputs summed together (Figures 30 and 31).

Productivity

The time to execute one transmitter block, and three receiver blocks, on a 486/66 MHz computer is summarized below. The simulation time measured for each block included viewing the sink plots in the time domain:

File Name	Min:Sec
PN-TX .SVU	5:00
PN-RX1 .SVU	4:45
PN-RX2. SVU	0:15
PN-RX3.SVU	0:40

Total time: 10 min. 40 sec.

Additionally, to view a FFT of a single plot time window, the following times are required: 32K FFT = 60 sec., 8K FFT = 15 sec., 2K FFT = 5 sec.

It is possible to speed up the simulation by a factor of about 4 if the following approach is taken: While maintaining the same code rate, data rate, and filter bandwidths, change the carrier frequencies, and the LO, to be closer together, then use the appropriate filters:

Item	Old freq. (MHz)	New freq. (MHz)
Carrier 1:	28.5	7.0
Carrier 2:	29.5	8.0
Bandpass filter:	28.1–29.9	6.6–8.4
LO:	23.65	5.0
Lowpass filter:	10.0	4.0
Bandpass filter:	5.55–6.25	3.6–4.4
Bandpass filter:	4.55–5.25	2.6–3.4

The lower frequencies will allow the use of lower sample rates, the highest being 20.48 Msps. Also, instead of decimating by 4, decimation by 2 can be used. As before, throughout the simulation, the frequency resolution is maintained at 2.5 kHz. When making these frequency substitutions kept in mind that shifting filters in frequency causes a change in the ratio of bandwidth to f_c. Additional time can be saved in the conceptual stage of a design if a multiplier token is substituted for the mixer metasystem.

Conclusion

The models of a mixer, phase detector, and phase modulator, have been combined with filters and digital logic to simulate a transmitter and receiver system. The simulation included the propagation of the mixer spurs throughout the system. Also, a brief look at SystemView showed how easy it is to design in today's wireless marketplace without needing to write any lines of code.

For more information on SystemView simulation software please contact: ELANIX, Inc. 5655 Lindero Canyon Road, Suite 721, Westlake Village CA 91362. Tel: (818) 597-1414 Fax: (818) 597-1427 *RF*

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Page numbers in ( ) refer to the third edition of Dixon. This list includes all references for Parts 1 and 2. Part 1 of this article appeared in the May 1995 issue of RF Design, page 44.

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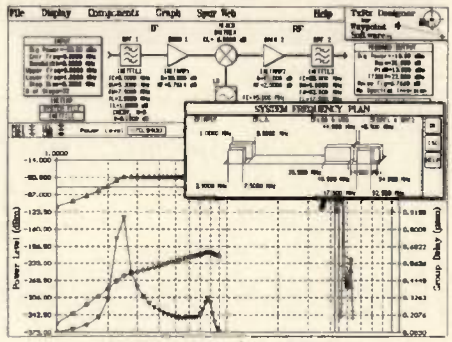

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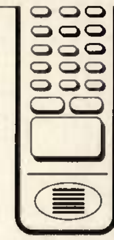

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Cellular Engineers: Design/Develop RF and analog circuits for high capacity cellular systems. Requires minimum of 2 years experience in any of the following: DSP, ASIC Design, CAE Development, Digital Modulation, Digital Mobile Communications, Channel Equalizers, Transmitter-Receiver-Synthesizer or Audio Design, Digital Signal Processing.

RF Engineer: Responsible for the design of 800 MHz and 1.9 GHz transmitters and receivers for cellular applications including AMPS, CDMA, and TDMA. Responsible for circuit system specification and analysis of portable products.

Systems Design Engineer: Requires B.S.E.E. (M.S.E.E. preferred) and 5+ years experience. Individual will be responsible for subsystem analysis of baseband through RF signal path for cellular basestation, Design will require an understanding of wireless standards (GSM, DECT, IS-54, PHS, etc.)

Design Engineer Communications ICs: Requires B.S.E.E. (M.S.E.E. preferred) and 5+ years experience. Individual will be responsible for leading the design and characterization of high frequency transceiver ICs for wireless communications applications. Design includes circuit integration of baseband, converter and RF/IF circuitry.

MMIC Engineer: Develop L/S band GAA's MMIC power amplifiers for commercial wireless communications. Requires: M.S. or BSEE, +2 years experience with GAA's MMIC design, simulation, packaging and test.

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Successful candidates will have three plus years hand-on experience in design RF/microwave circuits and/or subsystems. Must be familiar with microwave circuit simulation and layout CAD tools. Will work in Taiwan.

Microwave Hybrid Circuits Testing/Assembly Senior Engineer/Manager

Success candidates will have three plus years hand-on experience in design MIC circuits testing or have the knowledge of microwave hybrid circuit fabrication. Will work in Taiwan.

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Successful candidates will have five plus years experience in GaAs IC process. Will work in Taiwan.

Send Resume with salary history to:

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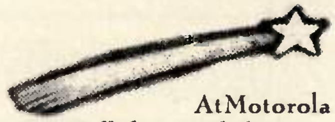
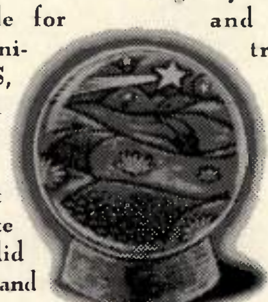


At Motorola Cellular, we believe in pushing beyond the practical paths of innovation to freely experiment with new and exciting technologies. If you are seeking an environment built on innovation, explore opportunities at one of our suburban Chicago locations.

RF ENGINEERS

Positions available for individuals with a minimum of 2 years PCS, GSM, CDMA/TDMA and all other areas of RF design, development and test experience. Candidate must also have solid experience in domestic and international protocols.



PRINTED CIRCUIT DESIGNERS

We have positions open at various levels for those who excel at directing and participating in very complex printed circuit board layouts for both new and redesigned products which conform to quality and manufacturability specifications. You will utilize C.A.D. workstations with application specific software as well as support terminals to access electronic data bases and various input/output peripheral equipment. The successful candidates will have a minimum of 5 years experience in printed circuit design with 3+ years C.A.D. experience using mentor boardstation software. Indepth knowledge with P.C.B. fabrication and assembly techniques essential.

ELECTRICAL ENGINEERS

You will design and develop circuits for digital cellular base stations. This includes developing RF and analog circuitry while utilizing high performance synthesizers, high dynamic range receivers and low/high power transmitters for our systems. A BSEE along with 4+ years related design experience is required. Post design experience in RF and analog circuitry, as well as a background in control systems essential. A MSEE preferred.

We offer an excellent salary, complete benefits, 401 (K), profit sharing and more. Forward your resume indicating position of interest to: Motorola Cellular, Department JWRF 1501 W. Shure Drive, Arlington Heights, IL 60004. Fax: 708-632-3873. Motorola is an equal opportunity/affirmative action employer. We welcome and encourage diversity in our workforce.

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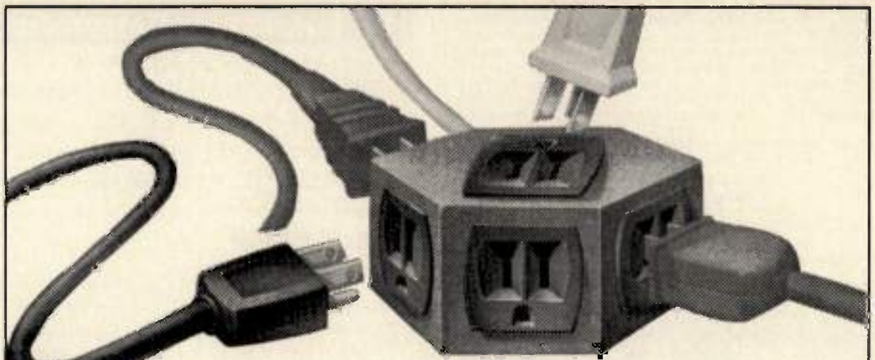

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BSEE or a minimum 5 years experience. We require expertise in design/development of Broadband (5-1000Mhz), Passive circuits and RF test fixtures; knowledge of Strip Line PC board techniques, surface mount components, ferrite materials, HP8753 Network Analyzer, and RF Computer Design Software; and some experience in "active" RF circuit design. Experience in designing telephone systems/devices and direct experience in CATV industry a plus.

For consideration, please send a resume with salary history to: **Philips Broadband Networks, Inc., 100 Fairgrounds Drive, Manlius, NY 13104.** No phone calls please. EOE.

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Discover The Next Generation of Cellular Technology. By connecting people, Finland-based NOKIA has become Europe's largest mobile phone manufacturer. In areas ranging from cellular phones and digital wireless systems to analog and digital infrastructure, we're defining the future of telecommunications and electronics technology. Steady growth worldwide has created the following opportunities:

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Selected individuals will develop RF analog circuitry including RF analog ICs for the next-generation CDMA phones using state-of-the-art tools for design and test; share ideas with a multitude of other RF Engineers in NOKIA worldwide working on systems like US TDMA, JDC, GSM and AMPS. Areas of opportunity include:

- **RF Team Leader** - 5+ years' in RF design with emphasis on low-cost radio design on implementation and system level; experience in production of high quality RF designs for high yield production. Code: BW/RFTL.
- **Systems Architecture** - 5+ years' experience defining self-contained RF system architectures and in low-cost receiver and transmitter design on discrete circuit level; knowledge of integrated circuit architectures, modulation theory and digital signal processing; ability to use CAD tools; analytical skills. Must have coordinated a project from initial system definition to first hardware implementation. Code: BW/RFS.
- **Circuit Development** - 5+ years' experience defining RF circuitry with demonstrated knowledge of amplification, oscillation, noise (phase and thermal), mixing, modulation, filtering, dynamic range, impedance matching and distortion; strong background designing, simulating and testing discrete RF circuitry. Code: BW/RFC.
- **IC Design (RF/Analog)** - 2+ years' experience with BiCMOS/Bipolar processes; design background in AMPS, mixers, VCOs, FM Demods, Op-AMPS and basic logic; understanding of specification generation, circuit design, layout, test board generation and testing. Code: BW/RFIC.
- **Analog ASIC Engineers** - 4+ years' experience in analog/digital A/D, D/A ASIC design, CMOS and BiCMOS. Code: BW/AA.
- **IC Test Engineer** - BS/MSEE and 3+ years' related experience; skills with remote programming of instrument; ability to write software and handle data post processing. Travel required. Code: BW/ICT.

TECHNICAL SUPPORT ENGINEER (After-sales)

Provide after-sales technical field support for hand-held CDMA products; interface with customers, Development Teams and European After-sales Support. Travel required. Code: BW/TSE.

FIELD TEST ENGINEERS

Requires experience in communications radio testing. Prefer TDMA and CDMA cellular experience plus BSEE or equivalent experience. Travel in U.S. and Europe required. Code: BW/FT.

In addition to these positions, we have opportunities in areas such as DSP, Software and Systems Development; Industry Standards; Cellular Field/Systems Test; Digital Hardware Development and Mechanical Design.

Please submit your resume, referencing position code, to: NOKIA Mobile Phones, Dept. 229, 9605 Scranton Rd., Ste. 500, San Diego, CA 92121; FAX: (619) 450-6090. EOE/ADA.

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Sr. Analog or RF Engineers

Solid knowledge of Analog/RF product design concepts such as Modulation, Amplification, Filtering, Mixing and Noise. A familiarity with FSK, BPSK, QPSK, QAM, & VSB demodulators and modulators, is desirable. Requires excellent analytical skills with the ability to design and simulate active and passive circuitry.

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At Motorola, our ideas push the limits of global communications. It's what we're good at. Our wireless communication interests span software and hardware, devices and systems. For you, this means an opportunity to share a vision unlike any in our industry. Currently, we are seeking a Senior RF Designer to be a resident expert in Radio design, and to lead a small group of RF designers.

Successful candidates will have a BSEE, MS a plus, and 10+ years' experience as a Senior Engineer involved in new product development. You must be experienced in UHF, 800, and 900Mhz transmitter and receiver design and be familiar with miniaturization and modern reflow process capabilities. Design experience must include very low current drain receivers, ZIF, dual conversion, Frac N, and PLL circuits.

Motorola offers a competitive salary, a comprehensive healthcare package and an excellent array of benefits. Please send your resume and cover letter to: Motorola Inc., Human Resources, RF595, 19807 Northcreek Parkway N., Bothell, WA 98011. No phone calls please. Equal Opportunity Employer.

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You may not see us, but you can bet we're out there. We're Hughes Space and Communications Company (HSC), and if you could see our accomplishments you would see a *proud legacy* of *technical achievement* and *growth* that has placed more than *100* communications satellites into orbit around Earth.

HSC currently has a variety of projects in both the *government* and *commercial* sectors, which affords individuals the opportunity to branch into exciting new technologies and broaden their skills. And, with a backlog of work resulting from major contract wins and the commercial popularity of our ***HS 601*** communications satellite, HSC is poised to offer outstanding growth potential and future success in any of the following areas:

ANTENNA DESIGN ENGINEERS (TA-1)

Responsible for electrical design and development of spacecraft antenna systems. All positions require a BS or MS in EE or Physics with coursework in electromagnetics, antennas and microwave theory.

MICROWAVE ENGINEERS (TA-2)

Responsibilities include designing and developing high reliability microwave devices such as multiplexers, filters, switches and ferrites. Entry level through senior scientist positions available. All positions require a BS or MS in EE or Physics with coursework in electromagnetics and microwave theory.

MECHANICAL ENGINEERS (TA-3)

Duties include mechanical design, stress analysis, integration and testing of spacecraft antenna, microwave and communications repeater assemblies. Requires a BSME or BSAE with 3-5 years' experience in the design of lightweight aerospace structures and components. Knowledge of CADDS 4X, CADDS 5 or other 3-D CAD software desirable.

POWER SUPPLY DESIGN (TK-1)

For travelling wave tube amplifiers. Requires 3-10 years of experience with high and low-voltage power supply design. Must also possess a MSEE/BSEE, strong analysis skills, design for manufacturing and assembly skills, a strong background in components and their failure mechanisms, and proven failure and reliability analysis skills.

MICROWAVE DESIGN ENGINEERS (TK-3)

Responsible for analysis of circuit performance, worst case, end of life, radiation and reliability. Requires MMIC and RF circuit design skills using Touchstone, Libra and Spice. BSEE required; MSEE preferred, with focus on RF microwave, antenna, electromagnetic and/or physics. Prefer at least 3 years' experience. Knowledge of cellular and/or GPS receivers a plus.

RECEIVER/SYNTHESIZER DESIGN (TK-5)

Your experience in PLL, DDS, Spread Spectrum, VSAT and Modem design will aid you in leading a team of engineers to develop the next generation of wireless telecommunication systems. Requires 5 years of experience and a BSEE.

ANALOG CIRCUIT DESIGN (TK-6)

Experience with Pspice analyzing OP amp circuits, signal processing and synthesizer circuits, stress analysis and failure mode effects analysis experience is highly desirable. Requires experience in Modem, VSAT, GPS and PCS design, 1 year of analog and mixed mode circuit design, and a BSEE.

SYSTEMS ENGINEERING (TK-7)

Responsibilities include providing analysis, signal processing, waveform acquisition, interface and environmental definitions, design requirement definition and specification flowdown, system integration and test of the next generation of wireless telecommunication systems. Requires 2 years of analog and digital experience and a BSEE or MSEE specializing in communications systems theory.

DIGITAL COMMUNICATIONS SUBSYSTEM ENGINEERS (TM-1)

Will develop unique, innovative DSP-based digital communication onboard processors using advanced technology. EHF communication system experience is desirable. Requires 6+ years of experience and an MSEE in Digital Communication Theory, with emphasis in digital signal processing.

SATELLITE COMMUNICATIONS SYSTEMS ENGINEERS (TM-2)

Responsible for performing system and payload architecture definition and design. Requires experience with preparing proposals and design reviews, and an understanding of MIL-STD-1582 and 1810 waveforms or commercial communications and networking standards. A BSEE or MSEE is also desired.

I.F. CIRCUIT AND ANALOG ASIC DESIGN ENGINEERS (TM-3)

Qualified candidates will have 3 or more years of experience in I.F. circuit and analog design (up to 1 GHz), using appropriate CAD tools. Experience with utilizing high-speed and performance analog to digital converter devices, digital communication equipment design and low-level signal design experience is a plus. A BSEE or MSEE is preferred.

DIGITAL CIRCUIT AND DIGITAL ASIC DESIGN ENGINEERS (TM-4)

Responsible for requirement definition, architectural and detailed design, simulation, worst-case analysis, design development and test. Digital circuit and digital ASIC design involves DSP arithmetic processor design. ASIC design using appropriate CAD tools. Digital communication equipment design and a BSEE are desired.

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Positions are responsible for developing the innovative concepts that will maintain our industry leadership into the next century. This involves evaluating customer needs and market opportunities, concept formulation, and top-level studies.

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- High speed RF analog/digital design
- High speed/high voltage switching
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- Competency in computer aided design in areas of analysis and circuit design layout and PC boards

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PROJECT MANAGERS – Responsible for project management of assigned digital cellular or land mobile communication products, including cross-functional interfaces with marketing, engineering and manufacturing. Will ensure timely tracking and integration of all resources for the development and production of new products. Successful candidates will have a BSEE with 5 or more years of directly related experience. *Job Code 94RTP-56*

SENIOR RF DESIGN ENGINEER – Responsible for the specification, design and development of transmitter/receiver RF hardware for digital/analog mobile cellular equipment. Successful candidates will have a BSEE and at least 5 years of directly applicable experience including RF systems, receiver or transmitter design. Broad knowledge of RF circuits and systems in mobile and cellular phones a plus. *Job Code 94RTP-24*

RF SYSTEMS DESIGN ENGINEER – Responsible for RF component design as well as hardware and software integration of advanced digital land mobile communications equipment. Successful candidates will have a BSEE and 3 or more years of directly related experience. Broad knowledge of RF circuits and systems in mobile and cellular phones a plus. *Job Code 94RTP-68*

SENIOR AUDIO/ACOUSTIC ENGINEER – Responsible for writing test plans, conducting electro-acoustic telephone and loudspeaker tests, automating tests and operating acoustic measurements laboratory. Must understand digital and analog audio filtering techniques and demonstrate a capacity to solve electro-mechanical acoustic problems. Should have a knowledge of IEEE, ELA and CCITT electro-acoustic telephone standards and electro-acoustic measurements. Successful candidate will have a BSEE with 5 or more years of related experience and an emphasis on RF systems. *Job Code 94RTP-57*

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Please send your resume to: **People Development, McCaw Cellular Communications, Inc., 10230 NE Points Drive, Kirkland, WA 98033, fax (206) 828-2395. No phone calls please.** Equal Opportunity Employer.

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Mobile Systems International (MSI) currently has engineering positions open for RF and Network engineers. MSI is a world class company with a reputation for providing high quality advanced consulting support to telecommunications, PCS/PCN, ESMR, Cellular, and Paging operators, as well as other wireless system operators worldwide. MSI offers a wide range of services covering CDMA, GSM, IS-54 TDMA, AMPS, MIRS, Paging, and other wireless technologies. Typical services provided to our customers include:

- Radio, Signaling, and Network System Planning and Design
- Technology and Vendor Selection
- New Technology Integration
- Strategic and Management Consultancy
- System Dimensioning
- System Design Audits
- System Performance Monitoring
- Technical Training

MSI offers the opportunity not only to be involved with all of the newest wireless technologies but to also work with a group of highly qualified and experienced engineers. At MSI our engineering team takes pride in holding themselves to the highest engineering standards. Applicants should possess a BSEE or MSEE degree with a minimum of 1 year experience in the wireless engineering industry, and must be innovative as well as highly detail and results oriented. Excellent presentation and technical writing skills are also required. Other useful skills include knowledge of DOS and UNIX operating systems, microwave engineering, networking of wireless communications systems including GSM, IS-41 and SS7, development of RF propagation models, traffic engineering, and knowledge of antenna and receiver design principles. Travel may be required.

We at MSI are committed to further expanding our RF and Network engineering consultancy by the addition of experienced, well qualified wireless engineers. Engineers are needed in our Chicago, Dallas, Atlanta and Washington DC offices as well as other customer locations throughout North and South America and Asia. If you are a highly motivated engineer who meets the above mentioned qualifications MSI is the career move you are seeking. Please send your resume in strictest confidence to the address below. MSI is an equal opportunity employer.

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In the fast-moving global telecommunicatons arena, ADC Telecommunications, Inc. is playing a highly visible and critical role in the electronics telecommunications marketplace.

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The successful candidate for this challenging position will have a BS degree in Electrical Engineering. MSEE preferred. Your work experience should include 5+ years developing production tests for high volume RF transmission products. You should also have 3 years experience developing tests on commercial ATE or IEEE controlled rack and stack test equipment and 3 years developing software in"C" programming language. Telecommunications industry experience is a plus.

To pursue this exciting opportunity, please submit your resume, with salary history for confidential consideration to:

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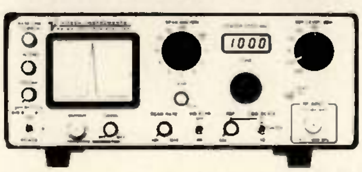

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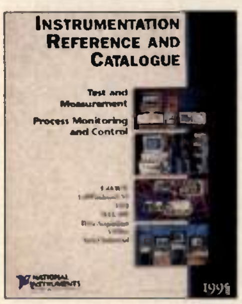

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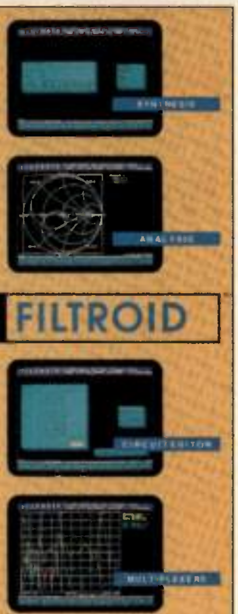

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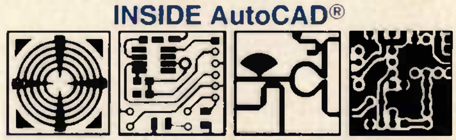

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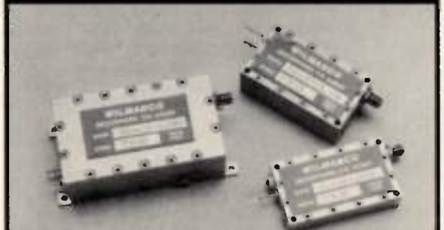

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RF Power

Silicon Valley Power Amplifiers, 529 Forman Dr. # B, Campbell, CA 95008..........(800) 986-9700

FILTERS

Crystal

Reeves-Hoffman, 400 W. North St., Carlisle, PA 17013.......................................(717) 243-5929

Saw

Phonon Corp., 7 Herman Dr., PO Box 549, Simsbury, CT 06070........................(203) 651-0211

SAW Components & Subsystems ....Fax (203) 651-8618

MIXERS

Merrimac Industries, Inc.,
41 Fairfield Pl., W. Caldwell, NJ 07006 ....(201) 575-1300 Fax (201) 575-0531

MODULATORS

FSK

Merrimac Industries, Inc.,
41 Fairfield Pl., W. Caldwell, NJ 07006 ....(201) 575-1300 Fax (201) 575-0531

I&Q

Merrimac Industries, Inc.,
41 Fairfield Pl., W. Caldwell, NJ 07006 ....(201) 575-1300 Fax (201) 575-0531

MODULAR COMPONENTS

OSCILLATORS

Crystal

Jan Crystals, P.O. Box 60017, Fort Myers, FL 33906-6017 .... (800) JAN-XTAL

Oak Frequency Control Group,
100 Watts St., PO Box 8, Mt. Holly Springs, PA 17065 .... (717) 486-3411

Wenzel Associates, Inc., 1005 La Posada Dr., Austin, TX 78752 .... (512) 450-1400

Wilmanco, 5350 Kazuko Ct., Moorpark, CA 93021 .... (805) 523-2390

Microwave

Electronic Surveillance Co., Inc., 33328 Howe Ln., Creswell, OR 97426 .... (503) 895-5071

SYSTEM SUBASSEMBLIES

AMPLIFIERS

Broadband

Trontech, Inc., 381 Industrial Way East, Eatontown, NJ 07724 .... (908) 542-1133 Fax (908) 542-1118

LNA

Trontech, Inc., 381 Industrial Way East, Eatontown, NJ 07724 .... (908) 542-1133 Fax (908) 542-1118

Linear Power, RF

RF Power

Trontech, Inc., 381 Industrial Way East, Eatontown, NJ 07724 .... (908) 542-1133 Fax (908) 542-1118

High Dynamic Range

Trontech, Inc., 381 Industrial Way East, Eatontown, NJ 07724 .... (908) 542-1133 Fax (908) 542-1118

PRINTED CIRCUIT BOARDS

SYNTHESIZERS

Sciteq Electronics, 4775 View Ridge Ave., San Diego, CA 92123 .... (619) 292-0500

RF TRANSMISSION COMPONENTS

ANTENNAS

Syndetix Inc., 2820 N. Telshor Blvd., Las Cruces, NM 88011 .... (505) 522-8762
Custom Antenna Design, High Power, Including Flight Certified .... Fax (505) 521-1619

ATTENUATORS

Coaxial

SV Microwave, 3301 Electronics Way, West Palm Beach, FL .. (407) 840-1800 Fax (407) 844-8551

CABLE ASSEMBLIES

Kaman Instrumentation, 1500 Garden of the Gods, Colorado Springs, CO 80907 .... (719) 599-1821

Storm Products, Advanced Tech Group, 116 Shore Drive, Hinsdale, IL 60521 .... (708) 323-9121

DIRECTIONAL COUPLERS

Merrimac Industries, Inc.,
41 Fairfield Pl., W. Caldwell, NJ 07006 .... (201) 575-1300 Fax (201) 575-0531

FILTER ASSEMBLIES

INDUCTORS AND CHOKES

Kintronic Labs, 144 Pleasant Grove Rd., Bluff City, TN 37618 .. (615) 878-3141 Fax (615) 878-4224

ISOLATORS/CIRCULATORS

MICROWAVE CONNECTORS

Southwest Microwave, Inc., 2922 S. Roosevelt St., Tempe, AZ 85282 .... (800) 587-5995

MULTICOUPLERS

Trontech, Inc., 381 Industrial Way East, Eatontown, NJ 07724 ..... (908) 542-1133 Fax (908) 542-1118

PHASE SHIFTERS

Merrimac Industries, Inc.,
41 Fairfield Pl., W. Caldwell, NJ 07006 .... (201) 575-1300 Fax (201) 575-0531

PRECISION

POWER DIVIDERS/COMBINERS

Merrimac Industries, Inc.,
41 Fairfield Pl., W. Caldwell, NJ 07006 .... (201) 575-1300 Fax (201) 575-0531

RF CONNECTORS

ITT Cannon RF Products, 585 E.Main ST., New Britain, CT 06051 .... (800) 532-3750

Molex, Inc., 2222 Wellington Ct., Lisle, IL 60532 .... 800-MOLEX78

Richardson Electronics, Ltd., 40W267 Keslinger Rd., LaFox, IL 60147 .... (800) 348-5580

SV Microwave, 3301 Electronics Way, West Palm Beach, FL .. (407) 840-1800 Fax (407) 844-8551

SURGE & TRANSIENT PROTECTORS

Polyphaser Corp., P.O. Box 9000, Minden, NV 89423 .... (800) 325-7170, (702) 782-2511

SWITCHES

Electromechanical

Dow-Key Microwave Corp., 1667 Walter St., Ventura, CA 93003 .... (805) 650-0260

MBF Microwave, Inc., Rt. 2, Box 252A, Hardy, AR 72542 .... (501) 856-2685

SYNTHESIZERS

Novatech Instruments,
1530 Eastlake Ave. E., #303, Seattle, WA 98102 .... (206) 322-1562 Fax (206) 328-6904

VACUUM CAPACITORS

COMET North America, 11 Belden Ave., Norwalk, CT 06850 .... (203) 852-1231

VACUUM TUBES

DIGITAL SIGNAL PROCESSING

SYSTEMS DEVELOPMENT REAL TIME

Adaptive Technology, Inc., 309 Curtis St Syracuse NY 13208 (800) 724-6968 Fax (315) 472-3279

MATERIALS AND HARDWARE

COMPONENTS/HYBRID PACKAGES

Reeves-Hoffman, 400 W. North St., Carlisle, PA 17013 .... (717) 243-5929

MATERIALS AND HARDWARE

CRYSTAL BLANKS
Reeves-Hoffman, 400 W. North St., Carlisle, PA 17013 .... (717) 243-5929

PC BOARDS
Laminates, Polyester Copper Clad
Glasteel Industrial Laminates, P.O. Box 910, Collierville, TN 38027 .... (901) 853-5070

SHIELDING MATERIALS
Ferrite Absorber Tiles
Fair-Rite Products Corp., P.O. Box J Wallkill, NY 12589 .... (800) 836-0427

TEST EQUIPMENT

Instrument Repair Labs, Inc., 2100 W. 6th Ave., Broomfield, CO 80020 .... (800) 345-6140

PRA, Inc., 8320 E. Gelding Dr., #103, Scottsdale, AZ 85260 .... (602) 991-4180
Test & Measurement Systems .... Fax (602) 991-4362
Racal Instruments, 4 Goodyear St., Irvine, CA 92718 .... (800) 722-3262

SPECTRUM ANALYZERS
DC TO LIGHT, P.O. Box 7140, Bozeman, MT 59771 (406) 586-5399 Fax (406) 586-6556

SERVICES

ANTENNA MEASUREMENT SYSTEMS
Jef Consultants, Inc., 8501 Beck Rd., Bldg 2227 Belleville, MI 48111-1254 .... (313) 482-5505

ANTENNA DESIGN & MEASUREMENT
Antenna Design Specialists, 1171 Melayn Dr., Lebanon, OH 45036 .... (513) 932-3385
Kintronic Labs, 144 Pleasant Grove Rd., Bluff City, TN 37618 .. (615) 878-3141 Fax (615) 878-4224

CONSULTANTS
Management Recruiters of Boulder .... Fax (303) 447-9536 Tel (303) 447-9900
Windy Bradfield CSAM, Bob Sund ....
Goldman Research, 12705 Monfort, Dallas, TX 75230 .... (214) 788-1122
RF Design & Modeling – Spice, EEsof, Wireless .... WNJU80A@PRODIGY.COM

EMC/EMI TESTING
Liberty BEL EMC SVCS., P.O. Box 5431, MS20, Compton, CA 90224 .... (310) 537-4235
Above MS20 represents RF Design
TUV Rheinland of North America, Inc.,
12 Commerce Road, Newtown, CT 06470 .... (203) 426-0888 Fax (203) 270-8883

EQUIPMENT CALIBRATION
Instrument Repair Labs, Inc., 2100 W. 6th Ave., Broomfield, CO 80020 .... (800) 345-6140

INSTRUMENT RENTAL/LEASING
Naptech, 12312 Hwy 175, Cobb, CA 95423 .... (800) 336-7723 Fax (707) 928-1963

OEM PRODUCTS
Locus, Inc., 1842 Hoffman St., Madison WI 53704 .... (608) 244-0500

TELEMETRY SYSTEMS & ENGINEERING
Telemetry Technologies, Inc., 3307 West St., Rosenberg, TX 77471 .... (713) 344-9000

SOFTWARE & SYSTEMS, CAD/CAE

SOFTWARE
Design Automation, Inc., 4 Tyler Rd., Lexington, MA 02173 .... (617) 862-8998 Fax (617) 862-3769
Waypoint Software, 1950 Bavaria Drive, #317, Colorado Springs, CO 80918 .... (719) 598-9592
Circuit Simulation
ingSoft Ltc. – the providers of the RF Designer® Solution .... (416) 730-9611
312 Dunview Ave., North York, ON M2N-4H9, Canada; bbs; Fax: 733-3884

SYSTEM SIMULATION
Tesoft, Inc., 205 Crossing Creek Ct., Roswell, GA 30076 .... (800) 631-1113
Makers of TESLA Com Simulator .... Fax (404) 664-5817 Intl (404) 751-9785

EMC TEST & DESIGN Products & Services Directory

The Products & Services Directory is a convenient guide to suppliers of products and services for the EMC/ESD industry. Products & Services Directory listings are sold on an annual basis.

For information on rates, closing dates and details on a special Introductory Offer, call **1-800-443-4969**. Ask for your yellow page representative.

ELECTRONIC COMPONENTS AND EQUIPMENT

EMI SUPPRESSION COMPONENTS
Cables and Connectors
Spectrum Control, Inc., 6000 West Ridge Rd., Erie, PA 16506 .... (814) 835-4000
EMI/RFI Filters
POTTER PRODUCTION CORPORATION, 3004 Hwy. 51 N., Wesson, MS 39191 .... (601) 643-2215
RFI Corp., 100 Pine Aire Dr., Bay Shore, NY 11706 .... (516) 231-6400
Santek, 9765 Marconi Dr., #205, San Diego, CA 92173 .... (619) 661-8119
Ferrite Beads, Rods, Forms
Fair-Rite Products Corp., P.O. Box J, Wallkil, NY 12589 .... (800) 836-0427
Steward, Inc., 1200 E. 36th Street, Chattonooga, TN 37401 .... (615) 867-4100 Fax (615) 867-4102
Ferrite Suppression Components
Steward, Inc., 1200 E. 36th Street, Chattonooga, TN 37401 .... (615) 867-4100 Fax (615) 867-4102
Filtered Connectors
Spectrum Control, Inc., 6000 West Ridge Rd., Erie, PA 16506 .... (814) 835-4000
Filters, Power Line
EMC Consulting PO Box 496, Merrickville, ONT., K0G1N0. .... (613) 269-4247
Qualtek Electronics Corp., 7675 Jenther Dr., Mentor, OH. 44060 .... (216) 951-3300
RtroN Corp., P.O. Box 743 Skokie, IL 60076 .... (708) 679-7180
Transformers/ Filters
Steward, Inc., 1200 E. 36th Street, Chattonooga, TN 37401 .... (615) 867-4100 Fax (615) 867-4102

ESD AND SURGE CONTROL COMPONENTS
Lightning Arrestors
Fischer Custom Communications, 2905 W. Lomita Blvd, Torrence, CA 90505 .... (310) 891-0635
Phoenix Contact Inc., PO Box 4100, Harrisburg, PA 17111-0100 .... (717) 944-1300
Polyphaser Corp., P.O. Box 9000, Minden, NV 89423 .... (800) 325-7170 (703) 782-2511

CABLE AND CONNECTORS
Connectors And Adapters
ADC Telecommunications, 4900 W. 78th St., Minneapolis, MN 55435 .... (800) 366-3891 X3000
Phoenix Contact Inc., PO Box 4100, Harrisburg, PA 1711-0100 .... (717) 944-1300
Optical Fibers And Connectors
ADC Telecommunications, 4900 W. 78th St., Minneapolis, MN 55435 .... (800) 366-3891 X3000

EMC TEST EQUIPMENT - EMISSIONS
Absorbers
Advanced Electromagnetics, Inc., P.O. Box 711719, Santee, CA. 92072- 1719 .... (619) 449-9492
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Rantec, 24003 Ventura Blvd., Calabasas, CA. 9130 .... (818) 591-8189
Anechoic Chambers
Advanced Electromagnetics, Inc., P.O. Box 711719, Santee, CA. 92072- 1719 .... (619) 449-9492
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Rantec, 24003 Ventura Blvd., Calabasas, CA. 9130 .... (818) 591-8189
Antennas
Antenna Research Associates, Inc., 11317 Fredrick Ave., Beltsville, MD 20705 .... (310) 937-8888
Antennas Above 30 MHz
A.H. Systems Inc., 9710 Cozy Croft Ave, Chatsworth, CA 91311 .. (818) 998-0223 Fax (818) 998-6892
EMCO, P.O. Box 1546, Austin, TX. 78767 .... (512) 835-4684
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Antennas Masts
Antenna Research Associates, Inc., 11317 Fredrick Ave., Beltsville, MD 20705 .... (310) 937-8888
EMCO, P.O. Box 1546, Austin, TX. 78767 .... (512) 835-4684
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Current Probes
Fischer Custom Communications, 2905 W. Lomita Blvd, Torrence, CA 90505 .... (310) 891-0635
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Ion Physics Corp., 11 Industrial Way, Atkinson NH 03811 .... (603) 893-6687
Ferrite Absorber Tiles
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
GTEM Cells
Antenna Research Associates, Inc., 11317 Fredrick Ave., Beltsville, MD 20705 .... (310) 937-8888
Line Impedance Stabilization Networks
EMCO, P.O. Box 1546, Austin, TX. 78767 .... (512) 835-4684
Fischer Custom Communications, 2905 W. Lomita Blvd, Torrence, CA 90505 .... (310) 891-0635
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Near Field Probes
Antenna Research Associates, Inc., 11317 Fredrick Ave., Beltsville, MD 20705 .... (310) 937-8888
EMCO, P.O. Box 1546, Austin, TX. 78767 .... (512) 835-4684
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Preamplifiers
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Preselectors
IBEX Group, Inc., 23 Markham Dr., Long Valley , NJ 07853 .... (800) 403-3930
Shielding Effectiveness Testers
Antenna Research Associates, Inc., 11317 Fredrick Ave., Beltsville, MD 20705 .... (310) 937-8888
Solar Preamplifiers
Picosecond Pulse Labs, PO Box 44, Boulder, CO 80306 .... (303) 443-1249

ELECTRONIC COMPONENTS AND EQUIPMENT

EMC TEST EQUIPMENT SUSCEPTIBILITY

Impulse Generators

EMCO, P.O. Box 1546, Austin, TX. 78767 ....(512) 835-4684

EMC TEST EQUIPMENT -SUSCEPTIBILITY

Power Amplifiers

Applied Systems Engineering, Inc., 8623 Hwy. 377 S., Fort Worth, TX 76126 ....(819) 249-4180

Varian Microwave Equip. Prods., 3200 Patrick Henry Dr, Santa Clara, CA 95054....(408) 496-6273

Sheilded Fiber Optic Links

Antenna Research Associates, Inc., 11317 Fredrick Ave., Beltsville, MD 20705....(310) 937-8888

Surge Generators

Velonex Corp., 560 Robert Avenue, Santa Clara, CA 95050 ....(408) 727-7370
Pulse, Surge, Transient, ESD, Hybrid Generators

ESD TEST EQUIPMENT

ESD Event Detectors

EMCO, P.O. Box 1546, Austin, TX. 78767 ....(512) 835-4684

Monroe Electronics, Inc., 100 Housel Avenue, Lyndonville, NY 14098 ....(800) 821-6001

TREK INC., 3932 Salt Works Rd., P.O. Box 728, Medina, NY. 14103 ....(800) FOR-TREK

Surface & Volume Resistivity Meters

Monroe Electronics, Inc., 100 Housel Avenue, Lyndonville, NY 14098 ....(800) 821-6001

TREK INC., 3932 Salt Works Rd., P.O. Box 728, Medina, NY. 14103 ....(800)FOR-TREK

EMC TEST EQUIPMENT - ADDITIONAL

Field Strength Meters

Antenna Research Associates, Inc., 11317 Fredrick Ave., Beltsville, MD 20705....(310) 937-8888

Combinova/Ergonomics, Inc., PO Box 964, Southhampton, PA 18966 ....(215) 357-5124

MATERIALS, HARDWARE AND PACKAGING

SHIELDING MATERIALS

Architectural Shielding

Specialty Technical Components, Inc., P.O. Box 2106, Southeastern, Pa 19399 ....(610) 647-9000

Broadband EMI

Steward, Inc., 1200 E. 36th Street, Chattonooga, TN 37401....(615) 867-4100 Fax (615) 867-4102

Conductive Adhesives

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 ....(617) 331-5900

Conductive Fiber/Fabric

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 ....(617) 331-5900

Electromagnetic Shielding

RFI Controls Co., 320 N. Santa Cruz Ave., Los Gatos, CA 95030-7243 ....(408) 399-7007

Ferrite Absorber Tiles

Fair-Rite Products Corp., P.O. Box J, Wallkil, NY 12589 ....(800) 836-0427

Gasketing Materials

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 ....(617) 331-5900

Laminates

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 ....(617) 331-5900

Magnetic Shielding

Ad-Vance Magnetics, Inc., 625 Monroe St., Rochester, IN 46975 ....(219) 223-3158

Open Area Test Site

RFI Controls Co., 320 N. Santa Cruz Ave., Los Gatos, CA 95030-7243 ....(408) 399-7007

Non-Compliance Investigation

RFI Controls Co., 320 N. Santa Cruz Ave., Los Gatos, CA 95030-7243 ....(408) 399-7007

Sheilding Foils and Tapes

Venture Tape Corp., 30 Commerce Rd., Rockland, MA 02370 ....(617) 331-5900

SHIELDING EMI/RFI SERVICES

Vacuum Platers, Inc., 115 S. Union Street, Mauston, WI 53948 ....(608) 847-5644

SHIELDED ENCLOSURES - EQUIPMENT

Component/Module Cases

Marmin-Hil Plastics, Inc., 101 Roselle St., Linden, NJ 07036....(908) 925-2940 (800) 886-2940

Tempest Enclosures

Technical Environment Control, Inc., 7950 Cessna Ave., Gaithersburg, MD 20879..(301) 948-5911

SHIELD ROOMS AND CHAMBERS

Shielded Rooms EMI/RFI/Magnetic

Rantec, 24003 Ventura Blvd., Calabasas, CA. 9130 ....(818) 591-8189

ESD PACKAGING

Antistatic Polyurethane/Polyethylene

Pad-Tastics, Inc., P.O. Box 50479, Cicero, IL 60650....(708) 780-8402 FAX (708) 780-1636

Antistatic/Shielding Bags

Texas Technologies, PO Box 200639, Austin, TX 78720 ....(512) 267-0100

Conductive Polyurethane

Pad-Tastics, Inc., P.O. Box 50479, Cicero, IL 60650....(708) 780-8402 FAX (708) 780-1636

Custom Packaging

Pad-Tastics, Inc., P.O. Box 50479, Cicero, IL 60650....(708) 780-8402 FAX (708) 780-1636

Sheet/Bulk Conductive Materials

Mitech Corp., 1780 Enterprise Parkway, Twinsbury, OH 44087 ....(216) 425-1634

ESD ENVIRONMENTAL CONTROL

Antistatic or Conductive Flooring

Freudenberg Building Systems, Inc./Nora Rubber Flooring
94 Glenn St., Lawrence, MA 01843 ....(508) 689-0530

Gloves & Finger Cots

Texas Technologies, PO Box 200639, Austin, TX 78720 ....(512) 267-0100

Ionizers

Texas Technologies, PO Box 200639, Austin, TX 78720 ....(512) 267-0100

Warner Technologies, 2211 E. Hennepin, Minneapolis, MN 55413 ....(800) 328-5482

Lab Coats, Smocks & Coveralls

Warner Technologies, 2211 E. Hennepin, Minneapolis, MN 55413, ...(800) 328-5482

TEST LABORATORIES AND CONSULTANTS

TEST LABORATORIES

Certelecom Laboratories, Inc., RR #5, Ottawa, Ontario, Canada K1G3N3 ....(613) 737-9680
Please see our ad in the Test Labs and Consultants Section

Spectrum Control, Inc., 6000 West Ridge Rd., Erie, PA 16506 ....(814) 835-4000

TUV Product Service, Inc., 1775 Old Hwy. 8, New Brighton, MN 55112 ....(800) 472-7999

EMI & Safety

Compliance Consulting Services, PO Box 612650, San Jose, CA 95161 ....(408) 463-0885

Open Area Test Sites

Compatible Electronics - 8 open field test sites In So. Calif ....(714) 579-0500

Phillps Consumer Electronics Co., One Philips Dr., Knoxville, TN 37914-1810 ....(615) 521-4720

Ultratech Eng. Labs, Inc.
33-481 Sladeview Cres., Mississauga, Ontario, Canada L5L 5R2 ....(905) 569-2550

TEST CAPABILITIES

Military EMC Standards

Northrop Grumman,
B-2 Division, 8900 E. Washington Blvd., T623/XE, Pico Rivera, CA 90660 ....(310) 942-3895

Shielding Effectiveness

Shielding Integrity Services, 1905 Hercules Dr., Colorado Springs, CO 80906 ....(719) 635-7719

Susceptibility/Immunity

Northrop Grumman,
B-2 Division, 8900 E. Washington Blvd., T623/XE, Pico Rivera, CA 90660.... (310) 942-3895

EMI/EMC TESTING

LambdaMetrics, P.O. Box 1029, Cedar Park, TX 78630-1029 ....(512) 219-8218
FCC listed lab, one EMC Engineer, 30 years RF design experience, Prompt Personal Service

Liberty BEL EMC SVCS., P.O. Box 5431, MS30, Compton, CA 90224 ....(310) 537-4235

Rockwell, 3370 Miraloma Ave., Anaheim, CA 92803-3105 ....(714) 762-6181

ADDITIONAL SERVICES

EMC Site Surveys

Philips Consumer Electronics Co., One Philips Dr., Knoxville, TN 37914-1810 ....(615) 521-4720

CONSULTANTS

Kimmel Gerke Assoc. Ltd., 1544 N. Pascal, St. Paul, MN 55108 ....(612) 330-3728
EMC Design/Troubleshooting-Medical, Industrial, ITE, Vehicles & More-50+ years exp.

Regulatory Consultants Network, P.O. Box 344, Liberty Hill, TX 78642 ....(800) 326-6336
EMC Design, EMC/EMI/EMS/ESD & Electrical Product Safety

EMI/EMC Consultants

EMC & I, 5700 Corsa Ave., #100 Westlake Village, CA 91362 .... (818) 889-2242

EMC Design

EMC Consulting, P.O. Box 496, Merrickville, ONT., K0G1N0 ....(613) 269-4247

ESD Protection

Texas Technologies, PO Box 200639, Austin, TX 78720 ....(512) 267-0100

Non-Compliance Investigation

Ultratech Eng. Labs, Inc.
33-481 Sladeview Cres., Mississauga, Ontario, Canada L5L 5R2 ....(905) 569-2550

EMI/EMC Compliance Consultants

EMC Consulting, P.O. Box 496, Merrickville, ONT., K0G1N0 ....(613) 269-4247

Continuing Education Serves a Changing RF Industry

This month's product forum looks at continuing engineering education courses.

UCLA Extension

UCLA Extension presents several short courses designed to serve the continuing education needs of the RF community. These include "Synthetic Aperture Radar," "High-Resolution Microwave Imaging", "Power Hybrids: Design and Processing," "Hybrid Microcircuit and Multichip Module Packaging Technologies," "Advanced Communications Systems Using Digital Signal Processing", "Wireless Voice and Data Communications," "Wavelet Transform Applications to Data, Signal, Image, and Video Processing," and "Active Circuit Design for Wireless Systems."

Our course participant population has shifted over the last several years from a primarily aerospace/defense audience to a more diverse audience that includes medical, communications, and automotive, as well as aerospace/defense customers. For many of these customers, "wireless" is the common theme, whether that applies to telephones, pagers, or modems. For other customers, the key word is "DSP", for images, data, or video. In general, course participants can no longer focus on performance as the only factor in their designs. They must now determine how best to achieve an appropriate balance among many factors including performance, cost, and manufacturability.

For more information contact William R. Goodin, Ph.D., Manager, Short Course Program, 10995 Le Conte Ave, Room 542, Los Angeles, CA 90024. Tel: (310) 825–5010, Fax: (310) 206–2815.

University Consortium for Continuing Education

UCCE specializes in the development of high technology courses on the cutting edge of innovation. Therefore, we work with industry and university research people who are working on innovative developments

For example, the last few years have brought a distinctive change in the complexion of high frequency systems and applications. The de-emphasis of military and military related systems development caused a brief lull in the HF instrumentation and measurement technology industry. More recently renewed interest and strong growth have come to the communications industry due to expansion of the wireless communications technology which boosted interest into new heights in the field of measurements.

More importantly, the expanding range of operating frequency and ever increasing speed of digital communications data processing and point-to-point data transfer reaches into the domain of RF and microwave regions, increasing the need of RF and HF measurement technology. This region of frequencies cannot use the customary lumped circuit theory but has to apply distributed line technology. Our *RF & Microwave Measurements & Applications* is based on this technology.

Z Domain Technologies, Inc.

DSP is the science and engineering of signal processing using digital hardware and software. DSP theory was

Courses Offered at RF Expo East 1995

Five one-day short courses are offered at RF Expo East 1995, August 20-23 in Baltimore, Md. All courses are geared to new engineers, or those desiring review or retraining. For more information, call (800) 828–0420.

Introduction to RF Circuit Design: Part I, Fundamental Concepts — This course presents the fundamentals of RF systems, components, transmission lines and impedance matching. Resonance, Q, and transmission line theory are key concepts discussed. Instructors: Dr. David Hertling and Dr. Robert Feeney of Georgia Tech. [August 20, 1995]

Introduction to RF Circuit Design: Part II, Active Circuit Design — Graphical methods for impedance matching are followed by active device models and concepts of power gain, stability and noise figure. Scattering parameters are introduced along with small-signal circuits. Large-signal circuits and various coupler designs conclude the class. Instructors: Dr. David Hertling and Dr. Robert Feeney of Georgia Tech. [August 21, 1995]

Introduction to Frequency Synthesis — The generation of radio frequency signals has evolved through many methods and technologies. This course covers the basics of direct synthesis, indirect synthesis (PLL and FLL) and direct digital synthesis (DDS). Examples show the use of frequency synthesis in radio communications systems. Instructor: Earl W. McCune, Jr. of RF Communications Consulting. [August 20, 1995]

Practical High-Frequency Filter Design — A detailed course covering LC, printed and machined filter design and specification. Element models, unloaded Q and various filter topologies are taught, with special emphasis on the design of practical, realizable filters. Instructor: Randall Rhea of Eagleware Corporation. [August 22, 1995]

Oscillator Design Principles — A unified approach to oscillator design is presented which describes how to create high-performance oscillators using any type of resonator and any type of active device. Design techniques are de-mystified, to eliminate the practice of copying and modifying existing circuits. Instructor: Randall Rhea of Eagleware Corporation. [August 23, 1995] conceived in the 60s, was refined in the 70s and became economically viable in the 80s. The emergence of low cost VLSI DSP chips in the early 80s expanded the market beyond the research laboratories.

Unfortunately the availability silicon and software will not guarantee a successful product development. DSP education lags behind. DSP courses and books tend to emphasize math and theory. It's very easy for an average engineer to get completely lost in a DSP textbook.

DSP is a combination of science and art. You have to go through the scientific part first before you get to the creative and fun stuff. Ten years ago you had to be a Ph.D. level scientist to tackle the math. Fortunately now with the user friendly DSP design tools, you can bypass the hard core math and get to the fun stuff quickly. This is the approach that we emphasize in our DSP Without Tears™ seminar. We minimize the math and maximize the practical applications. Needless to say mathematicians are usually offended by our approach! However, our course is geared towards an engineer who hasn't seen a calculus book in ten years and is not interested in proofs. We have even gone one step further and present the entire 3-day seminar by multimedia with lots of color, sounds, video and animations. That way we try to make a dry and dull subject more interesting.

For more information please contact Z Domain Technologies at 325 Pine Isle Court, Alpharetta, GA 30202. Tel: (404) 587–4812. Fax: (404) 518–8368.

Besser Associates

Besser Associates offers continuing education to RF and microwave professionals. We have carefully selected a group of highly qualified experts who are effective communicators. Our trainers do not focus on mathematical derivations or proofs; they simply pass on established circuit and system engineering procedures.

Besser Associates' students are designers who need retraining to work effectively. The sudden increase in development of consumer and commercial communication industries demands a new group of RF engineers. They require basic training and familiarization with efficient analog RF circuit and system design techniques.

As a recognized international leader, Besser Associates is dedicated to continuing education of RF and microwave professionals. Application of modern computer-aided engineering to RF and microwave circuit and system design is vital to manufacturing products with quality yield. Increasing emphasis on commercial application makes modernization critical. A well-planned continuing education program will enable your company to compete in an RF world.

CKC Laboratories

CKC Laboratories, Inc. provides seminars in the field of electromagnetic compatibility (EMC). These courses cover design (from PCBs to entire systems); CE mark design and compliance; HIRF (Aircraft) design and test; and medical device design and compliance. Our students come from a wide variety of job functions, including, PCB designers, system engineers, regulatory compliance managers, and others involved with EMC design, test, and certification. Due to the extending reach of European certification requirements, we are seeing a growing interest in courses that cover CE mark design, test, and certification.

Market expansion, especially among network products, has resulted in a growing demand for our basic EMC design seminars. CKC is also experiencing a higher demand for in-house seminars. Many companies are bringing our instructors to their facilities to educate a larger group of personnel for less money. It is apparent from this trend, that companies are wanting to extend the reach of EMC design and regulatory knowledge within their organizations. *RF*

For more information on continuing education courses circle the INFO/CARD numbers below:

Company	INFO/CARD
Besser Associates	185
CKC Laboratories	184
JASTECH	183
George Washington University	182
UCLA Extension	181
University Consortium for Continuing Education	180
Z Domain Technologies, Inc.	179

RF software

Circuit Simulation

NOVA-586 is an RF circuit simulator and optimizer. It is an improved version of the program originally distributed by the RF Design Software Service. NOVA-586 has added optimization, post assembly Monte Carlo analysis, Smith® charts and cable simulation. Analysis speed has been increased to more than 2000 frequencies per second for the typical RF circuit. The program runs under DOS, with virtually any processor from the 8088 to the Pentium, however, code is written to optimize Pentium performance. Price is $295.

Stanton Software
INFO/CARD #247

HP BASIC for Windows™

Hewlett-Packard has introduced HP BASIC for Microsoft Windows. HP BASIC is a computer language for measurement automation. Like the other HP BASIC programs, this version is compatible with all DOS and UNIX platforms. U.S. price for E2060A (HP BASIC for Windows) is $950. A $200 upgrade credit is available for owners of previous HP BASIC revisions.

Hewlett-Packard Co.
INFO/CARD #248

Spurious Analysis

Spurious Analysis 1.0 is a receiver spurious frequency frequency and PLL analysis program. The program analyzes the spurious frequencies generated during either dual or triple conversion receivers. The PLL section uses the first local oscillator values calculated from the analysis done in the receiver receiver spurious section and uses these to determine the value of the N and A counters used in a dual modulus PLL IC. The program is available in either DOS or Windows 3.1 version. Price for the Windows version is $79.95. Price for the DOS version is $69.95. Shipping and handling charges are $5.00.

Orion Software International
INFO/CARD #249

Analog Simulation

SUMO is an analog simulation package available in three versions. The shareware version of SUMO is a real-time, linear-only simulator; SUMO Professional adds a graphical schematic entry system and SUMO-Fusion, an integrated real-time non-linear simulator. SUMO Expert adds the ability to switch switch between other simulators (including MicroSim's PSpice®), FFT graphical analysis, sweeping, and SPICE extraction tools. Approximate prices range from around $50 for registration of the shareware version to around $300 for SUMO Expert.

Analogue System Engineering
INFO/CARD #250

Test Accessories Catalog
ITT Pomona's 1995 Electronic Test Accessories Catalog contains 172 pages of more than 3,800 products. A number of RF test equipment accessories are listed, including connector adapters and terminations and a new series of 30 to 450 MHz oscilloscope probes. The catalog is available free-of-charge.
ITT Pomona
INFO/CARD #202

ITU-T Recommendations on CD-ROM
The ITU is now able to supply ITU-T Recommendations on CD-ROM. The ITU-T Recommendations consist of several thousand pages using paper, but the entire collection is contained on a single CD-ROM. The texts can be consulted using the CD Answer HyperText software which is supplied with the product.
International Telecommunication Union
INFO/CARD #201

Test Equipment Guides
Wavetek has released two full color selection guides for communications test equipment. Their 16-page Wireless Communications Selection Guide features information on Wavetek's range of testing equipment for wireless applications. The 19-page Cable Television Selection Guide describes Wavetek's products designed to meet cable television's specific testing needs.
Wavetek Corporation
INFO/CARD #200

Quartz Catalog
Tele Quarz' six-page short form catalog describes the company's complete lines of quartz crystals, crystal oscillators, clock oscillators, crystal filters and other components.
Tele Quarz Group
INFO/CARD #199

Comm Products Guide
Celwave R.F. offers its Product Selection Guide. The 320-page, full-color catalog features all of Celwave's 1,000+ products, which include base station antennas, filters, transmitter combiners, Bi-directional amplifiers, distributed communications systems, duplexers, cavity devices, receiver multicouplers, mobile antennas and transmission lines.
Celwave R.F.
INFO/CARD #198

90° Hybrid Couplers
RF Power Components has released a six-page catalog which displays its full line of high power 90° hybrid couplers. The catalog features over 50 models of high power passive devices which offer power handling from 100 to 800 W and frequency ranges from 50 to 4000 MHz.
RF Power Components, Inc.
INFO/CARD #197

Data Aquisition News
Included in the Spring 1995 edition of National Instruments' Instrumentation Newsletter is an article describing the drivers written for several RF measurement instruments enabling these instruments to be controlled by LabVIEW and/or LabWindows instrumentation programs. Instruments from Anritsu Wiltron, Fluke, H-P, Rohde & Schwarz, and Wandel & Golterman are those for which the drivers were written.
National Instruments
INFO/CARD #196

RF Selector Guide
Motorola has released two additions to its technical literature of RF products and technology. The annual RF Selector Guide and Cross Reference for 1995 (SG46/D Rev 13) and a new RF Application Reports handbook (HB215/D) are now available. The debut of the RF Application Reports handbook offers 92 application notes, article reprints and engineering bulletins authored by Motorola employees.
Motorola
Semiconductor Products Sector
INFO/CARD #195

RF Power Amplifiers
A six-page, short form catalog from ENI, entitled "RF Power Amplifiers," is now available from ENI. The catalog contains primary specifications for 30 different broadband and pulse power amplifiers, with power outputs ranging from 3 to 8000 W and frequency coverage from 9 kHz to 1000 MHz.
ENI
INFO/CARD #194

Calibrated Microwave Tuner Notes
Focus Microwaves has released five new publications: Operation Manual - TWIN, Tuner Control and Measurement Software for Windows 3.1; Operation Manual - VEE-TUNE, Tuner operation Library under HP-VEE; Product Note 25 – Tuner Operation Library using HP-VEE; Product Note 26 – Tuner and GPIB operation using MATLAB; and Product Note 27 – TWIN, Tuner Control and Measurement Software for Windows.
Focus Microwaves Inc.
INFO/CARD #193

EMI Shielding
Tech-Etch has produced a 20-page catalog on EMI shielding products for doors, panels, covers, connectors, computers, electronic enclosures, and cabinets. The catalog includes information on Tech-etch's new Silvershield Knitted Mesh with elastomer core and economical Quiet Vents, which provide low noise and good attenuation for air vents requiring RFI/EMI shielding.
Tech-Etch, Inc.
INFO/CARD #192

Inductor Catalog
Gowanda's catalog details their complete line of surface mount products, toroidal chokes, power inductors, RF molded chokes, bobbin core chokes and custom designs. Included are specifications, selection guides, mechanical drawings and product photos.
Gowanda Electronics
INFO/CARD #191

Communications Products
The 1995 Silicon Systems Communications Products Data Book is available. The more than 700-page book adds six new products to the company's K-series family of modem support ICs, LAN, programmable filter products, PCM circuits, analog signaling and switching products. Also presented are the company's custom capabilities, its reliability and quality assurance program, packaging options, plus a listing of worldwide sales offices and distributors.
Silicon Systems
INFO/CARD #190

1995 Index of Standards
Global Engineering Documents has announced that the 1995 sedition of the Index and Directory of Industry Standards (IDIS) is available. The IDIS comprises seven volumes which provide customers with immediate access to over 425 standards-developing organizations and 34,000 new and revised industry standards.
Global Engineering Documents
INFO/CARD #189

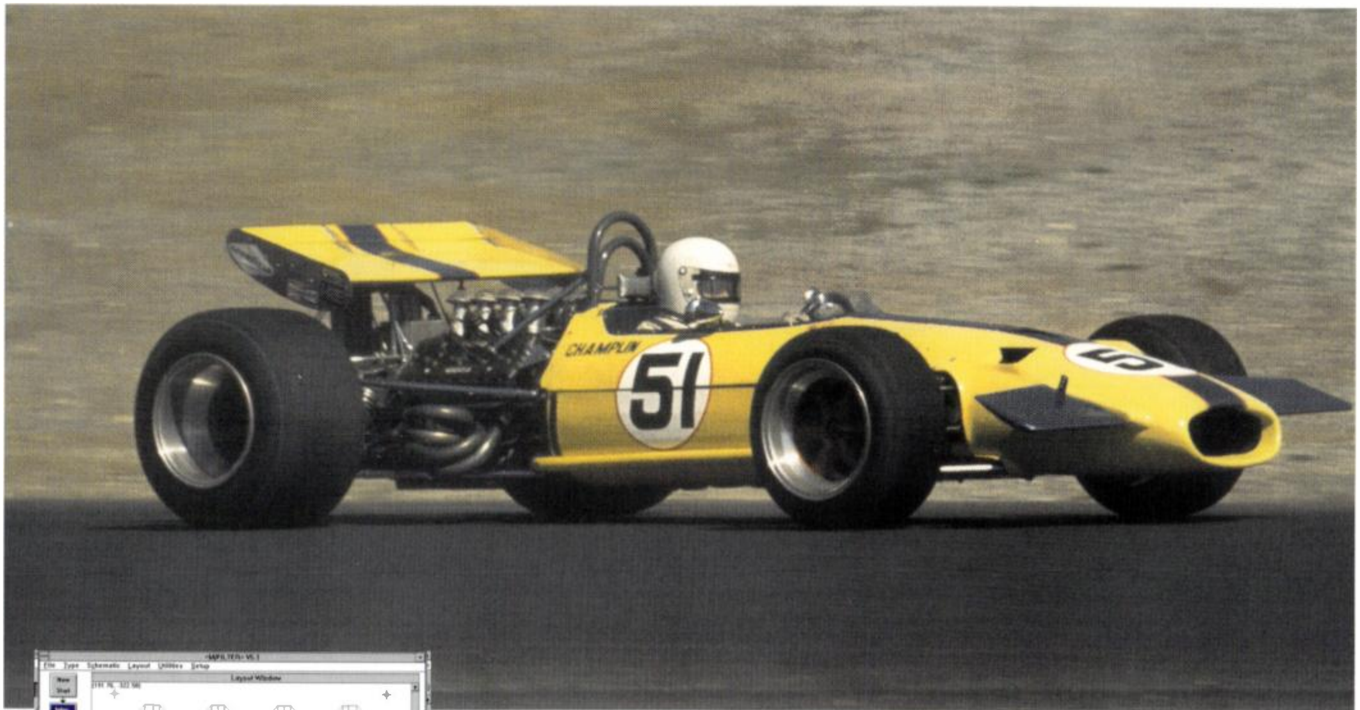
Ceramic Trimmer Data
The latest edition of Engineering Bulletin SG-305D from Sprague-Goodman Electronics provides updated product data for the complete line of ceramic dielectric trimmer capacitors. The SG-305D bulletin includes features, specifications, photographs, and outline drawings. Included are two new SURFTRIM® surface mount trimmers, which feature small size and multi-layer construction, and are available in carrier and reel packaging.
Sprague-Goodman Electronics, Inc.
INFO/CARD #188

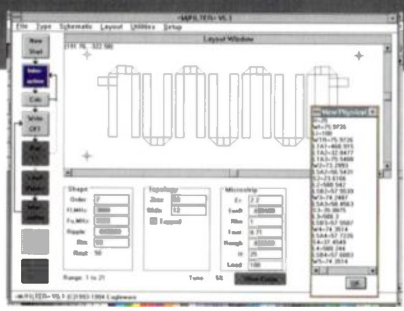
VXIbus Test & Measurement
Racal Instruments has introduced its new Test & Measurement Solutions catalog covering the complete product and service line, with detailed specifications on all VXIbus products. The catalog introduces eight new VXIbus products, including the Freedom Series™ custom ATE line, a new VXIbus chassis, four new switches, two new radio receivers and a line of digital cellular radio testing products.
Racal Instruments
INFO/CARD #187

RF guide to editorial coverage

RF advertising index

TURBO-CHARGE TOUCHSTONE





EXAMPLE GENESYS SCREEN

SUPER-CHARGE SPICE

with GENESYS, a suite of programs for synthesizing microwave filters amplifiers, oscillators, active filters, matching networks and L-C filters for your Touchstone, Spice and =SuperStar= simulator.

MICROWAVE FILTERS
End coupled
Edge coupled
Hairpin
Stepped-Z
Combline
Interdigital
Elliptic lowpass
Elliptic bandpass
Sub lowpass
Stub bandpass
Stub bandstop
Edge bandstop

OSCILLATORS
L-C series mode
L-C Colpitts
L-C Clapp
T-line and L-C VCO
VCO with xformer
Cavity bipolar and hybrid
Dielectric resonator
Terminal SAW bipolar
Port SAW hybrid
Port SAW MOSFET
Pierce and Colpitts crystal
Driscoll crystal
Butler overtone
Overtone with multiplier

MATCHING NETWORKS
L-C pi and L
L-C tee
T-line quarter wave
T-line single/double stub
General order bandpass
L-C pseudo lowpass
T-line pseudo lowpass
T-line stepped-Z
Custom with R' s and xformers

LUMPED FILTERS
Conventional all-pole
Conventional elliptic
Top-C coupled
Top-L coupled
Shunt-C coupled
Tubular
Blinchikoff flat delay
Zig-zag
Eagleware symmetric

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Multiple feedback
Low sensitivity
State variable (biquad)
VCVS
Dual amplifier

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INFO/CARD 69

FINALLY! 3 VOLT RF ICs FOR HANDHELD WIRELESS PRODUCTS

New 3 Volt NEC Silicon ICs

UPC2745 Ultra Broad Band Amplifier DC to 2.7 GHz 12 dB Gain -1 dBm PSAT 7.5 mA Icc	**UPC2747 Broad Band Low Noise Amplifier** 100 to 1800 MHz 12 dB Gain 3.3 dB NF, 5 mA Icc
UPC2746 High Gain Amplifier DC to 1500 MHz 19 dB Gain 0 dBm PSAT 7.5 mA Icc	**UPC2748 High Gain Low Noise Amplifier** 200 to 1500 MHz 19 dB Gain 2.8 dB NF 6 mA Icc
UPB1502 Frequency Divider 0.5 to 2.0 GHz Divide by 64/65, 128/129 6 mA Icc	**UPB587 Frequency Divider** 50 to 1000 MHz Divide by 2/4/8 5.5 mA Icc

...plus dozens of Bipolar Transistors characterized at 2.5 Volts, including:

f = 1500 MHz	*f = 2.5 GHz*	*f = 1000 MHz*
NE68519	**NE68030**	**NE68039**
1.3 dB NF	1.90 dB NF	1.0 dB NF
10.0 dB GA	7.2 dB GA	11.6 dB GA
@ only 3 mA Ic	*@ only 3 mA Ic*	*@ only 1 mA Ic*

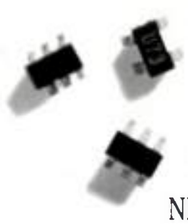
Surface Mount packages shown actual size

...and a variety of 5 Volt RF ICs including:

UPC2708 Wide Band Amplifier DC to 2.9 GHz 15 dB Gain 10 dBm PSAT	**UPC2710 Wide Band Amplifier** DC to 1000 MHz 33 dB Gain 3.5 dB NF	**UPC2713 Wide Band Amplifier** DC to 1200 MHz 29 dB Gain 3.2 dB NF
UPC2723 AGC Amplifier 100 to 1100 MHz 38 dB AGC 13 dB Gain	**UPC2721 Down Converter** RF = 0.4 to 3.0 GHz IF = 50 to 600 MHz 15 dB Conversion Gain	**UPC2726 Differential Amplifier** 400 to 1400 MHz 15 dB Gain

NEC

Typical Performance at 25°C. Frequency Range is 3 dB Bandwidth



NEC's NEW LOW CURRENT SILICON ICs not only reduce power consumption in your 3 Volt designs, they reduce the parts count, improve the reliability, and simplify the assembly.

NEC is committed to 3 Volt Silicon technology; these parts are just an introduction.

There are more on the way — soon!

If 5 Volt ICs are the solution, NEC has a wide selection of them as well, all available right now.

And don't forget NEC's huge family of discrete devices. Many are characterized at 2.5 Volts and they're available in a variety of packages, including a new ultra-small SMD that's a third the size of a SOT 23!

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INFO/CARD 70