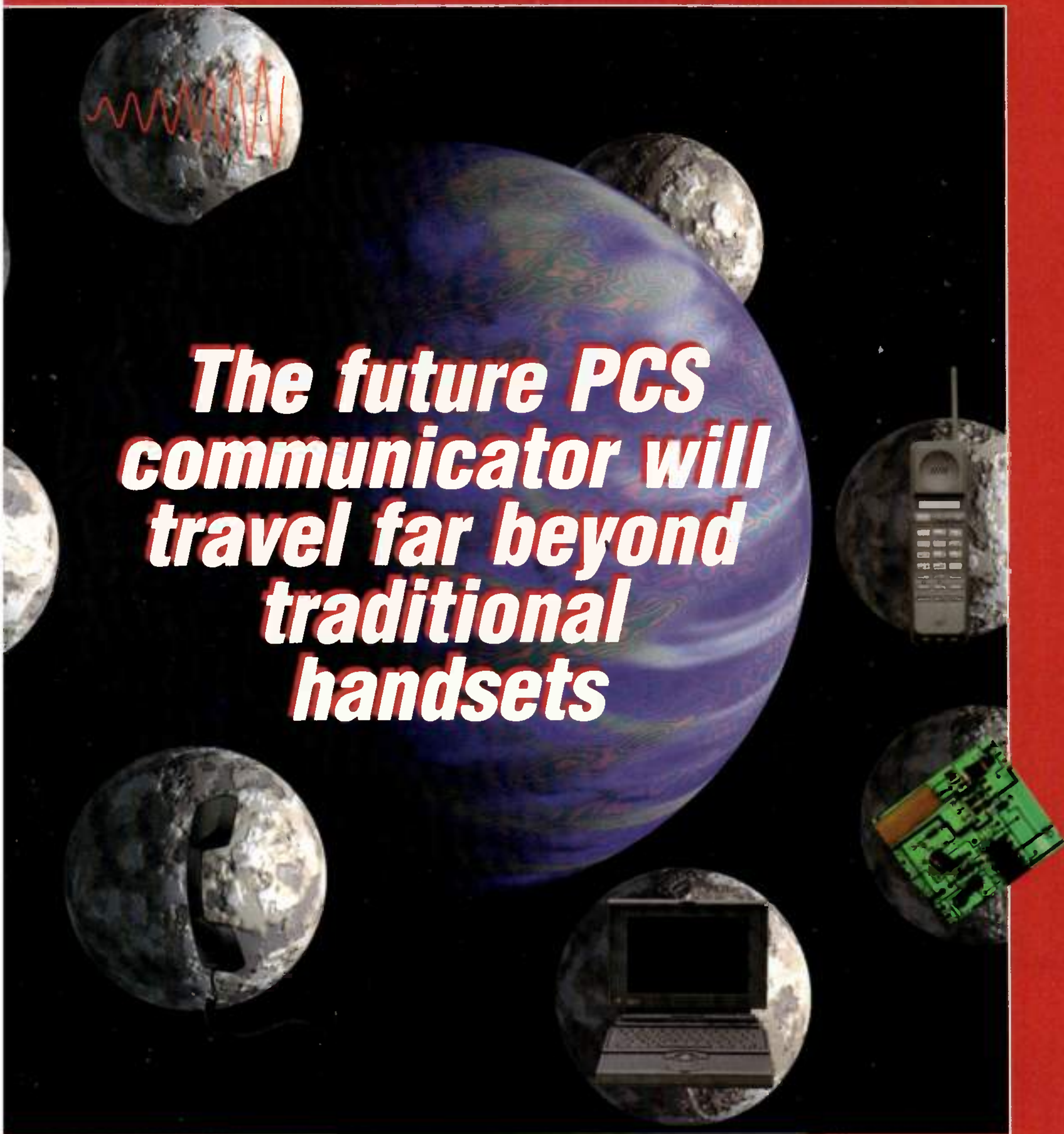
WIRELESS 18 YRS LEADERSHIP

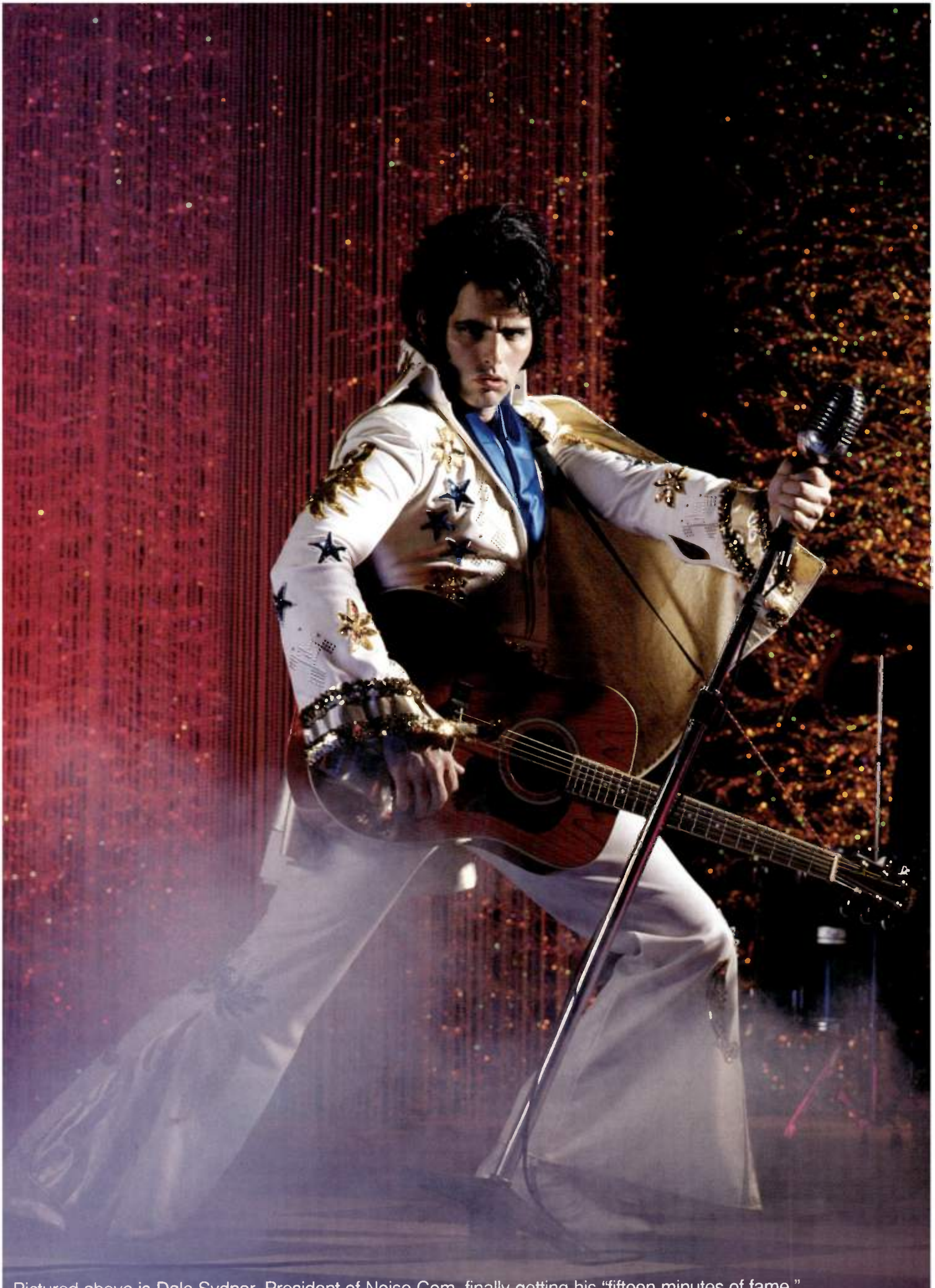
An INTERTEC®/K-III Publication

RF design

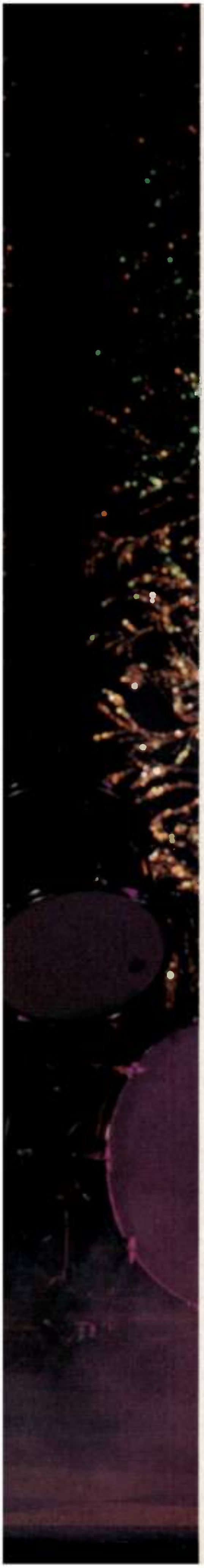
engineering principles and practices

January 1997





Pictured above is Dale Sydnor, President of Noise Com, finally getting his "fifteen minutes of fame."



There's only one real king in the world of CDMA testing... Noise Com.

The WIS Series (Wireless Impairment System) – A complete CDMA testing solution that turns in a great performance...every time.

To completely characterize the performance of CDMA base and mobile stations, a hodge-podge of general-purpose test equipment just won't do. You need an integrated solution designed to satisfy all of the demands of test standards such as IS-97A and IS-98A for cellular, and ANSI-J-STD-019 and ANSI-J-STD-018 for PCS applications. That's precisely the job Noise Com's WIS Series is designed to do.

The WIS Series is the only test station to combine so many automated CDMA measurement capabilities in a single, rack-mount system. It can provide emulation of wireless channel impairments such as additive white Gaussian noise (AWGN), multipath fading, as well as interference.

Performance that meets all the standards.

To emulate multipath fading, the WIS Series can model wireless communication channels between base stations and mobile transceivers using Rayleigh, Rician, Log-Normal, Suzuki, and Nakagami fading statistics. The WIS Series is also the only CDMA test solution with an AWGN generator that can precisely set Eb/No, C/N, and C/I ratios. The WIS Series can be configured with either base or mobile station interface or both, providing a complete impairment solution.

Combine the WIS Series with either a base station or mobile transmitter, or a base or mobile station simulator, and you have the most accurate, comprehensive CDMA measurement solution available.

The configuration of the WIS Series is flexible, too, so you can pick and choose the capabilities you want right now, with the option to modify or upgrade them later. So, whether your measurement needs are in product development and design verification, production testing, or quality control, the WIS Series is the system you can rely on today... and tomorrow.

Call us about our entire line of wireless test solutions.

When you're ready to rock and roll in CDMA, there's only one name to remember: Noise Com. For more details, call Alex Kim today at (201) 261-8797, fax us at (201) 261-8339, e-mail: noisecom@haven.ios.com, or write us at E. 49 Midland Ave., Paramus, NJ 07652. Noise Com. We're your global partner for wireless, telecommunications and noise testing solutions.

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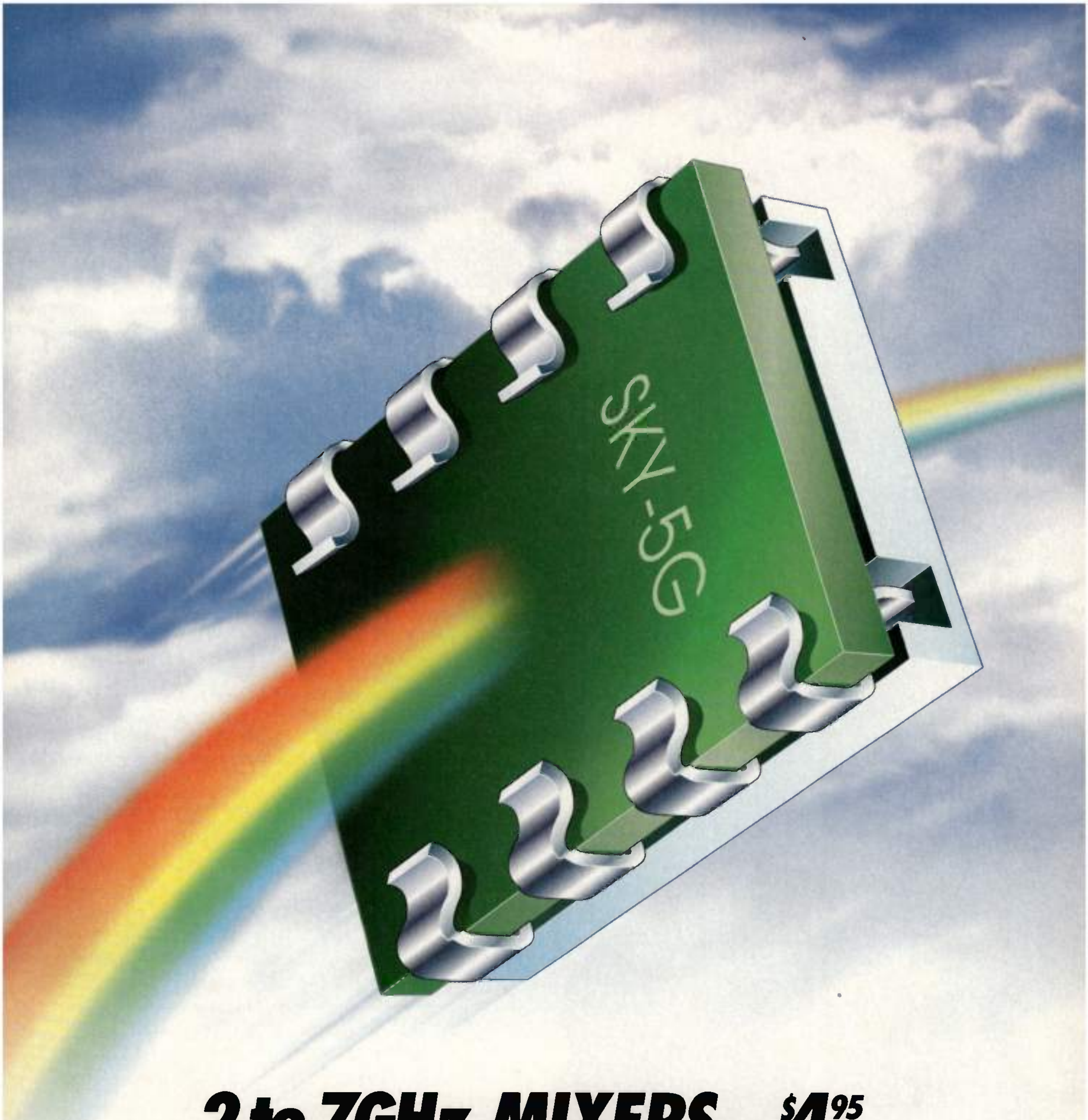
INFO/CARD 8



2 to 7GHz MIXERS from $4.95 (5000 qty.)

They're here! Low cost level 7,10,13 and 17 (LO) frequency mixers offering high IP3 performance over the 2 to 7GHz frequency range. It's Mini-Circuits wide band SKY mixers typically featuring high 28dB isolation and low 6dB conversion loss over the entire band. These miniature 0.10 inch high units are flat as a pancake for today's smaller, high density designs such as PCMCIA's, and are housed in a rugged, J leaded package built to withstand high temperature reflow. When your project demands a reliable surface mount mixer with high performance and value...*Reach For The SKY,* Mini-Circuits tough SKY mixers, with the 5 year Ultra-Rel® guarantee.

Mini-Circuits...we're redefining what VALUE is all about!

Model	•Freq. MHz	LO PWR dBm	Conv. Loss dB, Typ.	Isol.(L-R) dB, Typ.	Price $ea.(1-9)
SKY-5G	2000-5000	+7	6.6	28	14.95
SKY-7G	2000-7000	+7	7.0	28	16.95
SKY-60	2500-6000	+7	6.2	28	14.95
SKY-60LH	2500-6000	+10	6.2	28	16.95
SKY-60MH	2500-6000	+13	6.2	28	17.95
SKY-60H	2500-6000	+17	6.2	28	18.95
SKY-53R	2800-5300	+7	5.7	28	14.95
SKY-53LHR	2800-5300	+10	5.7	28	16.95
SKY-53MHR	2800-5300	+13	5.7	28	17.95
SKY-53HR	2800-5300	+17	5.7	28	18.95

• IF: DC-500MHz min.

Actual Size

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For detailed specs on all Mini-Circuits products refer to • 740- pg. HANDBOOK • INTERNET • THOMAS REGISTER • MICROWAVE PRODUCT DATA DIRECTORY • EEM

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F 221 Rev Orig

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WOW! **DC to 8GHz** (up to +18dBm output)

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Mini-Circuits ushers-in a new era of technology and economy with ERA monolithic GaAs amplifiers. Just check the specs! These surface mount and drop-in amplifiers cover your applications to 8GHz with higher gain, more output, and flatter response. Characterized with S-parameter data, these amplifiers are very easy to use. Simply sketch an interconnect layout, and the design is done. And ERA's are engineered with wider bandwidths to eliminate your need for costly compensation networks and extra gain stages. So, review your present design and replace with Mini-Circuits new ERA technology. Lower overall cost, wide bandwidth stability, and lots to...*gain!*

Mini-Circuits...we're redefining what VALUE is all about!

Model	*Freq. (MHz)	Gain (dB)	Max. Power Out (dBm, @ 1dB Comp)	Dynamic Range NF(dB)	Dynamic Range IP3(dBm)	①Price $ ea. (10 Qty.)
ERA-1	DC-8000	11.6	11.7	5.5	26	1.80
ERA-1SM	DC-8000	11.0	11.3	5.5	26	1.85
ERA-2	DC-6000	14.9	12.8	4.7	26	1.95
ERA-2SM	DC-6000	13.1	12.4	4.6	26	2.00
ERA-3	DC-3000	20.2	12.0	3.8	23	2.10
ERA-3SM	DC-3000	19.4	11.5	3.8	23	2.15
ERA-4	DC-4000	13.5	▲17.0	5.5	▲32	4.15
ERA-4SM	DC-4000	13.5	▲16.8	5.2	▲33	4.20
ERA-5	DC-4000	18.5	▲18.4	4.5	▲33	4.15
ERA-5SM	DC-4000	18.5	▲18.4	4.3	▲32	4.20
ERA-6	DC-4000	11.3	18.5	8.4	36	4.15
ERA-6SM	DC-4000	11.3	18.0	8.4	36	4.20

Note: Specs typical at 2GHz, 25°C

▲ Typ. numbers tested at 1GHz. At 2GHz, Max. Pwr. Out may decrease by 0.4dB & IP3 by 3 to 4dB.

* Low frequency cutoff determined by external coupling capacitors

① Price (ea.) Qty 1000: ERA-1 $1.19, -2 $1.33, -3 $1.48, -4, -5 or -6 $2.95. SM option same price

DESIGNER'S AMPLIFIER KITS:

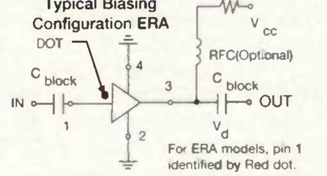
K1-ERA: 10 of each ERA-1,-2,-3 (30 pieces) only $49.95
K1-ERASM: 10 of each ERA-1SM,-2SM,-3SM (30 pieces) only $49.95
K2-ERA: 10 of each ERA-4,-5 (20 pieces) only $69.95
K2-ERASM: 10 each ERA-4SM,-5SM (20 pieces) only $69.95

Chip Coupling Capacitors at 12c each (50 min.)

Size (mils)	Value
80x50	10, 22, 47, 68, 100, 220, 470, 680, 1000, 2200, 4700, 6800, 10,000 pf
120x60	.002, .047, .068, .1 µf

ACTUAL SIZE

Typical Biasing Configuration ERA



For ERA models, pin 1 identified by Red dot.

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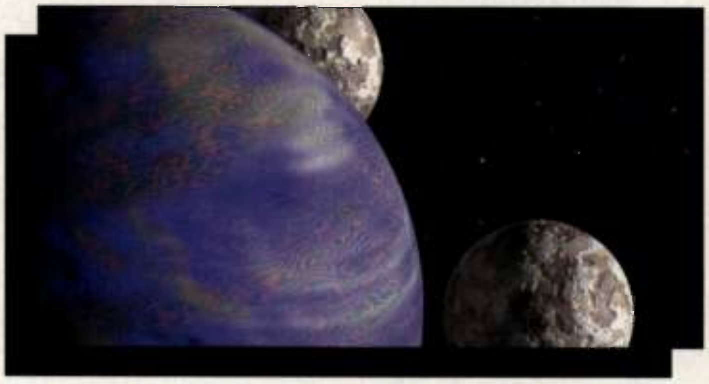

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Coming in Febrary

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RF editorial

Come to *RF Design* '97 Conference & Exposition Sept. 10–12, 1997

By Don Bishop
Editorial Director

You're invited to join your engineering colleagues and vendor representatives in Santa Clara, CA, Sept. 10–12 for the *RF Design* '97 Conference & Exposition. Those of us who are new to the magazine staff this year are looking forward to seeing you for the first time at our own conference, too.

Your participation, whether as a student in the *RF Design* Seminar Series of short courses, as a moderator or presenter during the technical sessions, as a visitor to the exhibition hall or in a combination of these activities, will allow you to take advantage of the focus that you and other readers bring to the science and art of designing RF components, products and systems.

Everyone has to strike some kind of balance between information-gathering and productivity. It's fine to read extensively, take courses and attend a lot of conferences, as long as the information you obtain helps you to fulfill your employer's and customers' requirements. Our intention is to use the combined resources of magazine publishing, instructional courses, the conference and exposition to provide the information you'll find the most useful. Actually, I'd like it to be compelling.

Every event needs performers and spectators. At engineering conferences, we call them presenters and attendees. Turn to page 86, and you'll find your invitation to submit an abstract for a technical paper to be presented at the conference and to be published in the conference proceedings. Some employers offer an incentive for this kind of participation; if you don't know whether yours does, it's time to ask. Whether a tangible incentive is available or not, presenting a paper raises your visibility within your own company (and outside of it, too, though that's better whispered than shouted). It can help your company to promote its finished products as well as its product development or engineering service capabilities, which reflect well on the author. It helps you to meet other professionals who may help you to succeed with future projects. There are so many good reasons to submit a paper that I wonder why everyone doesn't.

Not really. Taking the time can be difficult. If it's difficult for you, there's still an important place for you.

Those who may not have the time to take advantage of submitting a paper still can benefit from hearing the presentations and from meeting their colleages and vendor representatives. *RF Design* '97 Conference & Exposition, along with the *RF Design* Seminar Series, gives you just that opportunity. Surveys that we've sent to you or perhaps to other readers confirm that, although there is some overlap between the RF and microwave disciplines, many engineers tend to work exclusively or primarily with RF designs, and many others look for such specialized information to help them with specific project assignments.

Take a moment to look at the suggested topics for papers. Send us an abstract for a subject you would like to cover, whether or not it is on the list. The conference's best ideas will come from you. Don't wait. You know there's an advantage in being first.

RF

THE ONLY SOURCE FOR RF AMPLIFIERS FOR...

EMC Test - *Amplifiers from 1 to 3000 Watts*

- EMC frequency spectrum from 10kHz to 1GHz and RF power levels to 3000 Watt CW
- Manual/remote control as well as GPIB interfacing of all front panel functions
- Output power may be set at user defined levels and saved without readjusting signal source
- VSWR protection guards against load mismatches and maintains a safe output level

Communications - *Amplifiers from 200 to 1000 Watts*

- Communication bands from 1 - 1000 MHz
- Model M200U-BPA covers UHF Satcom band
- Communication systems also cover HF
- Multi-band with built-in harmonic filters and T/R

Dual Band - *Amplifiers from 10 to 100 Watts*

- Coaxial relay switching permits use of two individual RF amplifiers in a single enclosure
- Common power supply, control circuits and I/O connections to yield a GPIB controllable ultra wideband amplifier greater than 16 octaves
- User-friendly, cost-effective

Distributed Tube - *Amplifiers from 200 to 2000 Watts*

- Power delivery into severe impedance mismatch without shutdown or foldback
- Solid state drivers
- 200, 250, 500, 1000 and 2000 Watts available

OEM Amplifier Modules - *1 to 250 Watts*

- Frequency ranges from 50 kHz to 1 GHz at power output levels to 250 Watts
- Available direct from stock or customized to meet specific application
- Proven reliable performance worldwide

For over 25 years, Kalmus has been providing RF Amplifiers to meet the needs of EMC test, medical device, communications and laboratory applications. Kalmus RF amplifiers are the choice of many manufacturers in their OEM applications. With a range of over 125 models, Kalmus has an amplifier to meet your specific requirements.

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INFO/CARD 6

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Editorial offices
5660 Greenwood Plaza Blvd., Suite 350
Englewood, CO 80111
303-793-0448; Fax 303-793-0454

Intertec Publishing offices
9800 Metcalf Ave.
Overland Park, KS 66212-2215
913-341-1300; Fax 913-967-1898

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Components Branch

IT'S THE CRYSTAL THAT COUNTS !

SMD XO and VCXO

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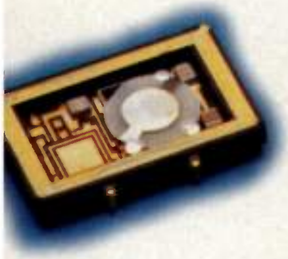

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Stability : ≤ 25 ppm
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Resistant to very high shock and ibration.
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Types QEN 79
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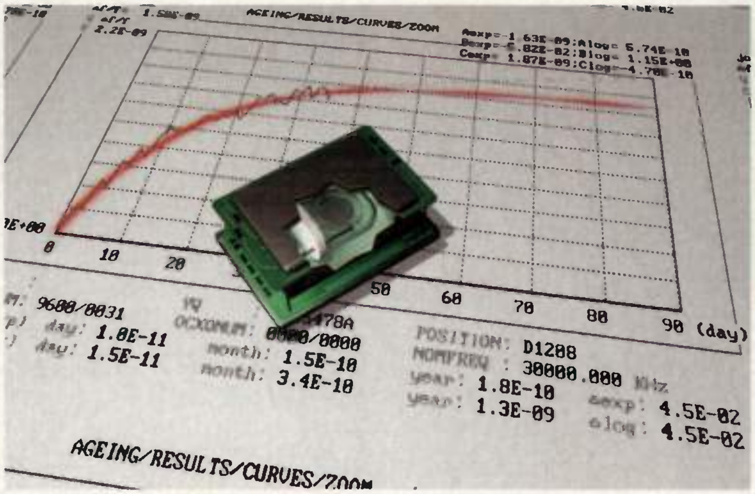
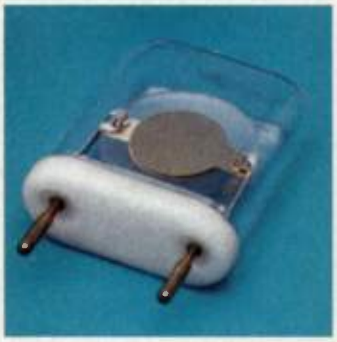


Ultimate stability : OCXO 1 to 130 MHz SC-cut crystal Glass holder



High stability ovenized crystal oscillator

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  155 dBc/Hz - 10 kHz
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- 100% screening
- Low power
- International holders

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INFO/CARD 12

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10.7 MHz

NO. POLES	TEMEX P/N	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE5000	3	3.75	20	18.0	-	-	2	1.0	50	1800//+4
4	TE5010	3	3.75	30	14.0	-	-	3	2.0	60	1500//+3
6	TE5020	6	3.75	60	12.5	-	-	4	2.0	70	1500//+3
8	TE5030	6	3.75	60	10.0	90	12.5	5	2.0	80	1500//+3
2	TE5040	3	6.50	20	30.0	-	-	1	1.0	50	2700//0
4	TE5050	3	6.50	30	15.0	-	-	2	2.0	75	3100//0
6	TE5060	6	6.50	60	19.5	-	-	3	2.0	90	3100//0
8	TE5070	6	6.50	60	13.0	80	17.5	4	2.0	100	3100//0
2	TE5080	3	7.50	20	35.0	-	-	1	1.0	50	3000//0
4	TE5090	3	7.50	30	17.5	-	-	2	2.0	75	3300//0
6	TE5100	6	7.50	60	22.5	-	-	3	2.0	90	3300//0
8	TE5110	6	7.50	60	15.0	80	20.0	3	2.0	100	3300//0
2	TE5120	3	15.0	20	70.0	-	-	1	1.0	35	5000//-1
4	TE5130	3	15.0	30	35.0	-	-	2	2.0	60	5000//-1
6	TE5140	6	15.0	60	45.0	-	-	2	2.0	90	5000//-1
8	TE5150	6	15.0	60	30.0	80	40.0	3	2.0	100	5000//-1

21.4 MHz

NO. POLES	TEMEX P/N	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE5180	3	3.75	15	12.5	-	-	2	1.0	50	850//+6
4	TE5190	3	3.75	30	12.5	-	-	3	2.0	70	850//+5
6	TE5200	6	3.75	60	12.5	-	-	4	2.0	90	850//+5
8	TE5210	6	3.75	60	10.0	80	12.5	5	2.0	100	850//+5
2	TE5220	3	6.50	15	20.0	-	-	2	1.0	50	1300//+2
4	TE5230	3	6.50	30	22.5	-	-	3	2.0	70	1400//0
6	TE5240	6	6.50	60	22.5	-	-	4	2.0	90	1400//0
8	TE5250	6	6.50	60	17.5	80	22.5	4	2.0	100	1400//0
2	TE5260	3	7.50	15	25.0	-	-	2	1.0	50	1500//0
4	TE5270	3	7.50	30	25.0	-	-	3	2.0	70	1600//0
6	TE5280	6	7.50	60	25.0	-	-	4	2.0	90	1600//0
8	TE5290	6	7.50	60	20.0	80	25.0	4	2.0	100	1600//0
2	TE5300	3	15.0	15	50.0	-	-	2	1.0	45	3000//0
4	TE5310	3	15.0	30	45.0	-	-	3	2.0	60	3000//-1
6	TE5320	6	15.0	60	45.0	-	-	3	2.0	90	3000//-1
8	TE5330	6	15.0	60	33.0	80	45.0	4	2.0	100	3000//-1

45.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	LOSS dB	RIPPLE dB-MAX	ULT. REJ. dB-MIN.	TERM. Ω/PF
2	TE9420	3-OT	3	3.75	18	16.0	3	1	40	2000//-1.0
4	TE9310	3-OT	3	3.75	30	12.5	3	1	70	2000//-1.0
2	TE7420	3-OT	3	7.50	18	28.0	2	1	40	3000//-1.0
4	TE7430	3-OT	3	7.50	40	30.0	3	1	70	3000//-1.0
2	TE7440	3-OT	3	15.0	15	47.0	2	1	40	8000//-1.5
4	TE7450	3-OT	3	15.0	30	50.0	3	1	70	8000//-1.5
2	TE7730	FUND	3	15.0	15	50.0	2	1	40	1100//+1.5
4	TE7740	FUND	3	15.0	40	60.0	3	1	70	800//+1.0

70.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND KHz	LOSS dB	RIPPLE dB-MAX	TERM. Ω/PF
2	TE10400	3-OT	3	7.5	18	30	35	-910	2	1	2000//-1
4	TE10410	3-OT	3	7.5	35	25	80	-910	3	1	2000//-1
2	TE10420	3-OT	3	10	15	30	35	-910	2	1	2500//-1
4	TE10430	3-OT	3	10	35	40	80	-910	3	1	2500//-1

90.0 MHz

NO. POLES	TEMEX P/N	MODE	PASSBAND dB	PASSBAND ±KHz	STOPBAND dB	STOPBAND ±KHz	STOPBAND dB	STOPBAND KHz	LOSS dB	RIPPLE dB-MAX	TERM. Ω/PF
2	TE10440	3-OT	3	7.5	18	30	35	-910	2	1	2000//-1
4	TE10450	3-OT	3	7.5	35	25	80	-910	3	1	2000//-1
2	TE10460	3-OT	3	10	15	30	35	-910	2	1	2500//-1
4	TE10470	3-OT	3	10	35	40	80	-910	3	1	2500//-1
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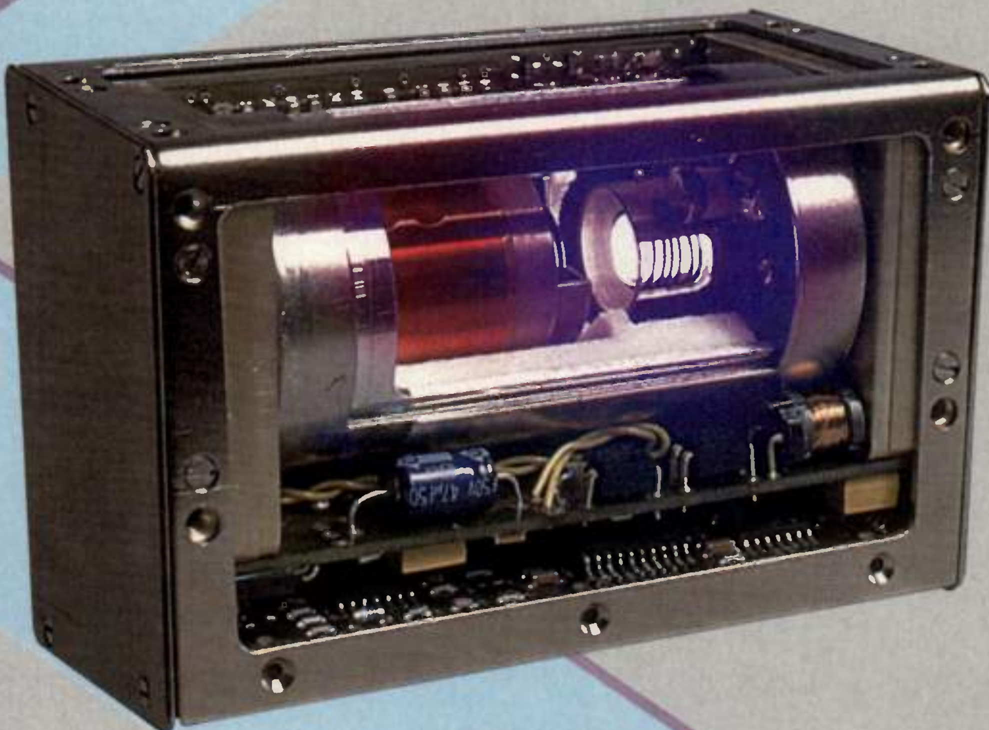

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☐	ETC1.6-4-2-3	Wireless	500-2500	4:1	3 dB
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☐	2	1510-1660	20	0.4	SOIC-8	DS52-0004
☐	3	824-960	18	0.6	SOIC-8	DS53-0001
☐	4	824-960	23	1.0	SOW-16	DS54-0001
☐	4	1200-1660	23	1.0	SOW-16	DS54-0003
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RF letters

Letters should be addressed to the Editor, RF Design, 5660 Greenwood Plaza Blvd., Suite 350, Englewood, CO 80111. Letters published may be edited for length or clarity.

Weather conspiracy

Although I never expected conspiracy theories to penetrate to the hallowed editorial columns of *RF Design*, the Eugene Dusina letter published in the September issue fills a critical need that is little recognized in this country. Since the end of the cold war and the "demise" of the Russian bear, we have had no one to blame for lousy weather, hurricanes and picnic-ruining thundershowers. The Dusina letter gives us hope.

R. Ellis
Las Vegas, NV

Praise for Weir

Just a short note to thank Jim Weir for the effort he put into writing the article on coaxial cables that appeared in the August issue.

I thoroughly enjoyed reading it and learned a few thing as well. As manager of an ISO Guide 25 accredited calibration laboratory where we measure and generate signals up to 18 GHz on a daily basis, I can assure you that the non-mathematical common sense approach Mr. Weir adopted in writing the article, came as very welcome relief.

Keep up the good work. I will be forwarding the article to numerous metrologists, technicians and engineers for their benefit.

Eddie Tarnow
South Africa

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RF calendar

February 10–14 Wireless Symposium and Exhibition—*Santa Clara, CA*. Information: Penton Publishing. Tel. 201-393-6256.

23–27 Nepcon West—*Anaheim, CA*. Information: Reed Exhibition Company, 383 Main Ave., Norwalk, CT 06852-6059. Tel. 800-467-5656; Fax 203-840-9656; Web site: http://www.nepcon.reedexpo.com.

March 3–5 CTIA Wireless—*San Francisco*. Information: Dobson and Associates. Tel. 202-463-7905.

13–19 CeBIT '97 World Business Center: Office, Information and Telecommunications—*Hannover, Germany*. Information: Mette Fisker Peterson, Hannover Fairs USA, 103 Carnegie Center, Princeton, NJ 08540. Tel. 609-987-1202; Fax 609-987-0092.

17–20 European Design and Test Conference—*Paris*. Information: Conference Secretariat, CEP Consultants, 43 Manor Place, Edinburgh, EH3 7EB, United Kingdom. Tel. +44-131-300-3300; Fax +44-131-300-3400; E-mail edtc@cep.u-net.com.

25–27 DSP World Spring Design Conference—*Washington, DC*. Information: Dana Dowell, Miller Freeman. Tel. 415-278-5322; E-mail dsp@exporeg.com. Web site http://www.dspworld.com.

April 14–17 International Conference on Antennas and Propagation—*Edinburgh*. Information: ICAP Secretariat, IEE Conference Services, Savoy Place, London WC2R 0BL, United Kingdom. Tel. +44 (0) 71-344-5467/5473; Fax +44 (0) 71-240-8830; E-mail lhudson@iee.org.uk or mswift@iee.orguk.

21–23 *RF Design* Seminar Series—*Las Vegas*. Information: Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600; Fax 303-770-0253.

22–24 International Wireless Communications Expo—*Las Vegas*. Information: Intertec Presentations, 6300 S. Syracuse Way, Denver, CO 80111. Tel. 800-288-8606 or 303-220-0600.

RF Pavillion—Manufacturers exhibits within IWCE. Components, test equipment, software and services for RF equipment manufacturing.

22–24 Convergence Tech and IC Expo for microelectronics, communications and computer professionals—*Dallas*. Information: Electronic Conventions Management, 8110 Airport Blvd., Los Angeles, CA 90045. Tel. 800-877-2668, ext. 243; Fax 310-641-5117.

23–26 Broadcast Technology—*Jakarta, Indonesia*. Information: Eileen Lavine, Information Services, 4733 Bethesda Ave., Suite 700, Bethesda MD 20814. Tel. 301-656-2942; Fax 301-656-3179.

May 5–7 Vehicular Technology Conference for cellular and mobile wireless communications—*Phoenix*. Information: Wendy Rochelle, Registrar, IEEE Conference Service, 455 Hoes Lane, P.O. Box 1331 Piscataway, NJ 08855-1331. E-mail w.rochelle@ieee.org.

6–8 Electronics Industries Forum of New England—*Boston*. Information: Linda Hanson. Tel. 914-779-0696.

13–16 Computer and Communication Electronics Design Exposition—*Dallas*. Information: Reed Exhibition, 383 Main Avenue, Norwalk, CT 06851. Tel. 800-840-5614.

28–30 IEEE International Frequency Control Symposium—*Orlando, FL*. Information: Wendy Ortega Henderson, National Institute of Standards and Technology, Time and Frequency Division, 325 Broadway, Boulder, CO 80303. Tel. 303-497-3593; Fax 303-497-6461; E-mail ortegaw@boulder.nist.gov.

June 1–5 Supercomm—*New Orleans*. Information: Telecommunications Industry Association. Tel. 202-326-7300.

9–14 Asia Telecom—*Singapore*. Information: Tom Dahl-Hansen, senior vice-president, Telecom. Tel. +41-22-730-5298; Fax +41-22-730-6444; E-mail. dahl-hansen@itu.ch.

10–12 International Microwave Symposium and Exhibition—*Denver*. Information: Horizon House. Tel. 617-769-9750.

11–13 Virginia Tech Symposium on Wireless Personal Communications—*Blacksburg, VA*. Information: Business Administrator, Jenny Frank, Mobile and Portable Radio Research Group, Virginia Polytechnic Institute, 840 University City Blvd., Pointe West Commons, Suite 1, Blacksburg, VA 24061-0350. Tel. 540-231-2958; Fax 540-231-2968; E-mail hilda@vt.edu; Web site: http://www.ee.vt.edu/mprg/home.html.

July 14–17 Image Processing and Applications—*Dublin*. Information: Sheila Griffiths, Conference Organizer, Institution of Electrical Engineers, Savoy Place, London WC2R 0BL, United Kingdom. Tel. +44 (0) 171-344-5475/72; Fax +44 (0) 171-240-8830; E-mail kmoorley@iee.org.uk.

August 18–22 IEEE EMC Symposium on Electromagnetic Compatibility—*Austin*. Information: John Osburn, Chairman, or Mark Prchlik, Exhibits. Tel. 512-835-4684; E-mail 97.emc.symp@emctest.com.

September 10–12 *RF Design* Seminar Series—*Santa Clara, CA*. Information: Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600; Fax 303-770-0253.

10–12 RF Design '97—*Santa Clara, CA*. Information: Renie Fuselier, Intertec Presentations, 6300 S. Syracuse Way, Denver, CO 80111. Tel. 800-288-8606 or 303-741-8715; Fax 303-267-0234.

22–24 Connector and Interconnection Technology Symposium—*Anaheim, CA*. Information: Chairman, IICIT, P.O. Box 880, Westfield, NJ 07090. Tel. 800-854-4248 Fax 908-233-5116; E-mail IICITDIR@msn.com.

Arizona State University—*Global System for Mobile Communication*—Jan. 14–17. Information: Professional Development, ASU, P.O. Box 877506, Tempe, AZ 85287-7506. Tel. 602-965-1740; Fax 602-965-8653.

Besser Associates—*RF Impedance Matching and Component Models*–Jan. 14; *RF Productivity Improvement*–Jan. 15–17; *RF Small-signal Amplifiers*– Jan. 17; *RF Receivers*–Jan. 20; *EM Field Simulator Made Practical*–Jan. 20–21; *Antennas for Wireless Applications*– Jan. 20–21; *EMC and EMI Engineering and Design*–Jan. 20–23; *Applied RF Techniques II*–Jan. 20–24; *Wireless RF System Design*–Jan. 20–24; *RF Oscillators*–Jan. 21; *RF Mixers and Applications*–Jan. 22; *Error Correction Coding and Multiple Access Techniques*–Jan. 22; *RF Power and High-efficiency Amplifiers*–Jan. 23–24; *RF Measurement Techniques*–Jan. 27–30. Information: Besser Associates, 4600 El Camino Real, Suite 210, Los Altos, CA 94022. Tel. 415-949-3300; Fax 415-949-4400; E-mail BesserCourse@delphi.com.

CKC Laboratories—*Core EMC Design*—Jan. 14–15, Orange County, CA; March 11–12, Fremont, CA; June 17–18, Hillsboro, OR; *Immunity to ESD*—Feb. 3, Seattle; May 12, Orange County, CA; *CE Mark Design and Compliance Routes*—Feb. 4–5, Seattle; May 13–14, Orange County, CA; *EMC for Medical Electronics*—April 22–23. Information: Linda Grunow or Todd Robinson, CKC Laboratories, 5473-A Clouds Rest, Mariposa, CA 95338. Tel. 800-500-4362 or 209-966-5240; Fax 209-742-6133; E-mail lgrunow@ckc.com.

Georgia Tech Continuing Education—*Radar Signal Processing: Theory and Application*–Jan. 28–31, Atlanta; *Coherent Radar Performance Estimation*–Feb. 3–6, Atlanta; *Antenna Engineering*–Feb. 3–7, Atlanta; *Principles of Pulse Doppler Radar: High, Medium and Low PRF*–Feb. 11–13, Atlanta; *Introduction to Radar Target Identification*– Feb. 25–28, Atlanta; *Infrared Countermeasures*—March 4–6, Atlanta; *Infrared Technology and Applications*—March 18–21, San Francisco; *Advanced Electronic Warfare Principles*—March 25–28, Atlanta; *Radar Cross Section Reduction*—March 25–28, Atlanta. Information: Department of Continuing Education, Georgia Institute of Technology, Atlanta, GA 30332-0385. Tel. 404-894-2547; E-mail conted@gatech.edu; Web site http://www.conted.gatech.edu.

Learning Tree International—*Wireless Networks and Mobile Communications*—Jan. 14–17, Feb. 18–21 Washington. Information: Learning Tree International, 1805 Library St., Reston, VA. Tel. 800-850-9197 or 703-709-9119; E-mail uscourses@ learningtree.com; Web site http://learningtree.com.

Mead Microelectronics—*Architectural and Circuit Design for Portable Electronics Systems* (3-days digital, plus 3-days analog)—March 31–April 5; *RF IC Design for Wireless Communication Systems*–May 12–16; *Data Communication ICs*–May 14–16. Information: Mead Microelectronics, 7100 Grandview Dr., Corvallis, OR 97330. Tel. 541-758-0828; Fax 541-752-1405. In Europe, contact Mead Microelectronics, Venoge 7, 1025 St. Sulpice, Switzerland. Tel. +41-21-691-0244; Fax +41-21-691-0245; E-mail mead@netgate.net or valence@mead.ch; Web site http://www.netgate.net/~mead.

***RF Design* Seminar Series**—April 21–23, Las Vegas; Sept. 9–11, Santa Clara, CA. Information: Intertec Presentations, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600; Fax 303-770-0253.

Technology International—*Achieving and Maintaining Compliance with the Medical Devices Directive*—Jan. 14–15, Denver; Feb. 11–12, Dallas. Information: Kristin Eckhardt, Technology International, 609 Twin Ridge Lane, Richmond, VA 23235, Tel. 804-560-5334; Fax 804-560-5342; E-mail Eckhardt@TechIntl.com.; Web site http://www.TechIntl.com.

Tektronix—*CDMA Modulation Technologies and Measurements; Deploying Digital Transmission in Cabled Networks; TDMA (IS-136 and PCS 1900) Technologies and Measurements*—Two-day seminars; Jan. 20–21, Los Angeles; Jan 23–24, Santa Clara, CA; Jan. 27–28, Seattle; Jan. 30–31, Vancouver. Information: Tel. 800-763-3133; Fax 800-835-0025; E-mail TEKFORM2@TEK.COM; Web site http://www.tek.com.

UCLA—*Digital Avionics Systems*—Jan. 27–31; *HBT IC Technology for Communication Applications*—Feb. 12–14. Information: UCLA Extension Department of Engineering, 10995 Le Conte Ave., Los Angeles, CA 90024-2883. Tel. 310-825-1901; E-mail jwatson@unex.ucla.edu. Web site http://www.unex.ucla.edu.

University of Missouri-Rolla—*Grounding and Shielding Electronic Systems: How to Diagnose and Solve Electrical Noise Problems*—Jan. 27–28, Houston; Feb. 19–20, Orlando, FL; March 10-11, Denver; June 25-26, Research Triangle Park, NC; *Circuit Board Layout to Reduce Noise Emission and Susceptibility*—Jan. 29, Houston; Feb. 21, Orlando, FL; March 12, Denver; June 27, Research Triangle Park, NC; *Electromagnetic Compatibility Certificate Program*—Combination home study 40-hour video taped lecture and one-week on-campus laboratory course. Information: Continuing Education Coordinator, University of Missouri-Rolla, 1870 Miner Circle, Rolla, MO 65409-1560. Tel. 573-341-4132. Fax 573-341-4992; E-mail buddyp@shuttle.cc.umr.edu; Web site http://www.umr.edu/~conted.

Virginia Tech—*Antennas: Principles, Design and Measurements*—March 18–21, San Diego; May 13–16, St. Cloud, FL. Information: Kelly Brown, Northeast Consortium for Engineering Education, 1101 Massachusetts Ave., St. Cloud, FL 34769. Tel. 407-892-6146; Fax 407-892-0406.

Z Domain Technologies—*DSP Without Tears*—Jan. 15–17. Information: Z Domain Technologies, 555 Sun Valley Drive, Suite A4, Roswell, GA 30076. Tel. 800-967-5034 or 770-587-4812. Fax 770-518-8368; E-mail dsp@zdt.com; Web site http://www.zdt.com/~dsp.

Memphis gets digital two-way system

Motorola has provided the city of Memphis with the Astro 800 MHz digital two-way communications system for better management of the city's public safety and other resources. Memphis' system is the first Astro 800 MHz public safety digital system in the state. The system includes 31 radio channels, 16 of which are dedicated to law enforcement and local government communications. The balance of the channels are assigned to fire department and other city agencies. The system provides communications coverage for some 410 square miles.

To efficiently manage communications traffic, the police and fire dispatch centers use 19 Centracom Series II Plus consoles with cathode-ray tube (CRT) displays that put the Astro digital system's features at the dispatchers' fingertips. Flashport software makes the system completely programmable. The system is compatible with those used by Memphis Light, Gas and Water; the Memphis International Airport; Federal Express; the city of Bartlett, Tennessee; Desoto County, Mississipi; and the Arkansas State Police.

NIST station signals increase power output

The Commerce Department's National Institute of Standards and Technology (NIST) will upgrade its radio station, WWVB, which broadcasts standard time and frequency signals. A new transmitter will increase the radiated power of the 60 kHz signal at least fourfold and will provide more reliable coverage to the far corners of the continental United States, Mexico and Southern Canada.

WWVB signals can be used to set clocks to a few hundredths of a second. The signals also serve as a frequency reference with an uncertainty of one part in 10^{12}. The station's present output power of about 10 kilowatts broadcasts a signal strong enough to reach most of the continental United States, but it requires users at great distances from the transmitter to install bulky antennas for reliable service. The improvements, which will increase the station's power to well over 40 kilowatts, will make it possible to build automatic WWVB-controlled clocks into appliances and wristwatches. Resetting clocks after a power outage may become a thing of the past.

The new transmitting equipment is already on site at the station, located a few miles north of Ft. Collins, CO. NIST is a non-regulatory agency of the Commerce Department's technology administration. The agency works with industry to develop and apply technology, measurements and standards. News and general information on NIST is available on the World Wide Web at http://www.nist.gov.

Contracts:

Brady selected as strategy partner of Motorola—Brady U.S.A. has been selected as a global strategic partner of Motorola Indala, a manufacturer of radio frequency identification (RFID) systems. Brady will market these RFID products and services, specializing in the sale of auto ID systems designed for harsh environments.

RFID uses radio waves to transmit a unique identifier number instead of using light waves as are needed with bar codes, which are sensitive to environmental conditions. The low-frequency radio signal can be read through any non-metallic debris such as dirt, ice, or paint. RFID labels and tags are passive, meaning they require no battery. Applications are diverse, ranging from tagging valves in chemical plants to tagging cattle in feed lots.

Ericsson to use Teradyne's mixed-signal test system—Ericsson Components, Stockholm, Sweden, has selected Teradyne's A575 advanced mixed-signal test system for engineering characterization and production testing of its next-generation RF integrated circuits. Teradyne's mixed-signal microwave test system can test all of the Ericsson devices, which are becoming increasingly integrated with RF and digital functions on the same integrated circuit.

Three contracts for Neulink products—RF Industries' Neulink Telemetry Division, San Diego, has received three contracts, together valued at more than $800,000, for wireless digital data products. Two of the contracts are for Neulink's 9600 transceiver modems. The first contract will use 1,000 modems in a supervisory control and data acquisition (SCADA) network. The second contract involves global positioning satellite (GPS) applications for location and tracking of recreational vehicles. The third contract is an add-on order for AM and FM and UHF receivers that will be used for the emergency alert system (EAS).

Business Briefs

DTI grant aids Bridlington manufacturing—The Department of Trade and Industry (DTI) awarded £200,000 in regional selective assistance to help K&L Microwave create a base in Bridlington, Yorkshire, United Kingdom and to bring 40 new jobs into the area over the next two years. The company manufactures electrical components for commercial and military communications systems.

Services company created—Mobile Systems International (MSI) has created a wireless services company. MSI Services, Richardson, TX, will provide services to the cellular, paging and personal communications services (PCS) markets. Services will include site acquisition, general construction, project management, network engineering, facility engineering, civil engineering, drive testing, system optimization and microwave relocation.

Rosenberger establishes facility—Rosenberger Hochfrequenztechnik, European manufacturer of coaxial connectors and microwave components, has opened a sales, engineering support and distribution facility in Lancaster, PA. Rosenberger of North America is a subsidiary of the privately-held, Tittmoning, Germany-based company. The Lancaster facility will warehouse and distribute products made overseas and will assemble custom coaxial cable assemblies.

Design methods of low-power crystal oscillators for wireless applications

By Jose Luis Jimenez Martin and Francisco Javier Ortega Gonzalez

The main considerations for designing low-power crystal oscillators for wireless applications focus on the power consumed by the oscillator and on its size. Included are different designs for the 170 MHz band, along with their main features and specifications.

The design of low-power crystal oscillators for wireless applications is of immediate interest for the RF equipment designer. Crystal oscillators are used for pagers [1,2,3] based on direct-conversion [4,5] and for superheterodyne receivers for personal communications services (PCS). A direct-conversion receiver for pagers is one of the best examples of a low-power crystal oscillator application. A classic direct-conversion scheme is shown in Figure 1. As with many other wireless systems, this kind of wireless receiver needs crystal oscillators with the following features:

- High stability in a wide temperature range (±5 ppm, –10 to 60°C).
- Low-power consumption (<0.5 mW typically).
- Low aging (<1 ppm in a year).
- Low size (not many parts).
- Low pushing figure.

The design of crystal oscillators with these requirements and oscillator measurements taken over four topologies are analyzed as follows.

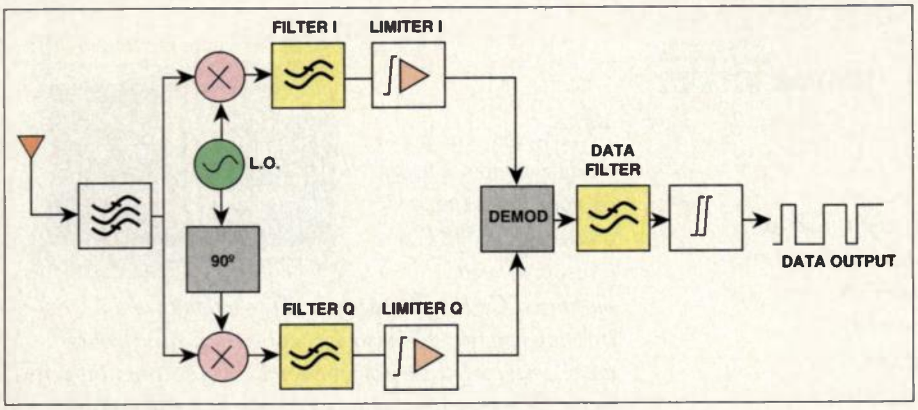


Figure 1. Direct conversion diagram block.

Tested oscillators

The oscillators shown in Figure 2 have been designed, constructed and

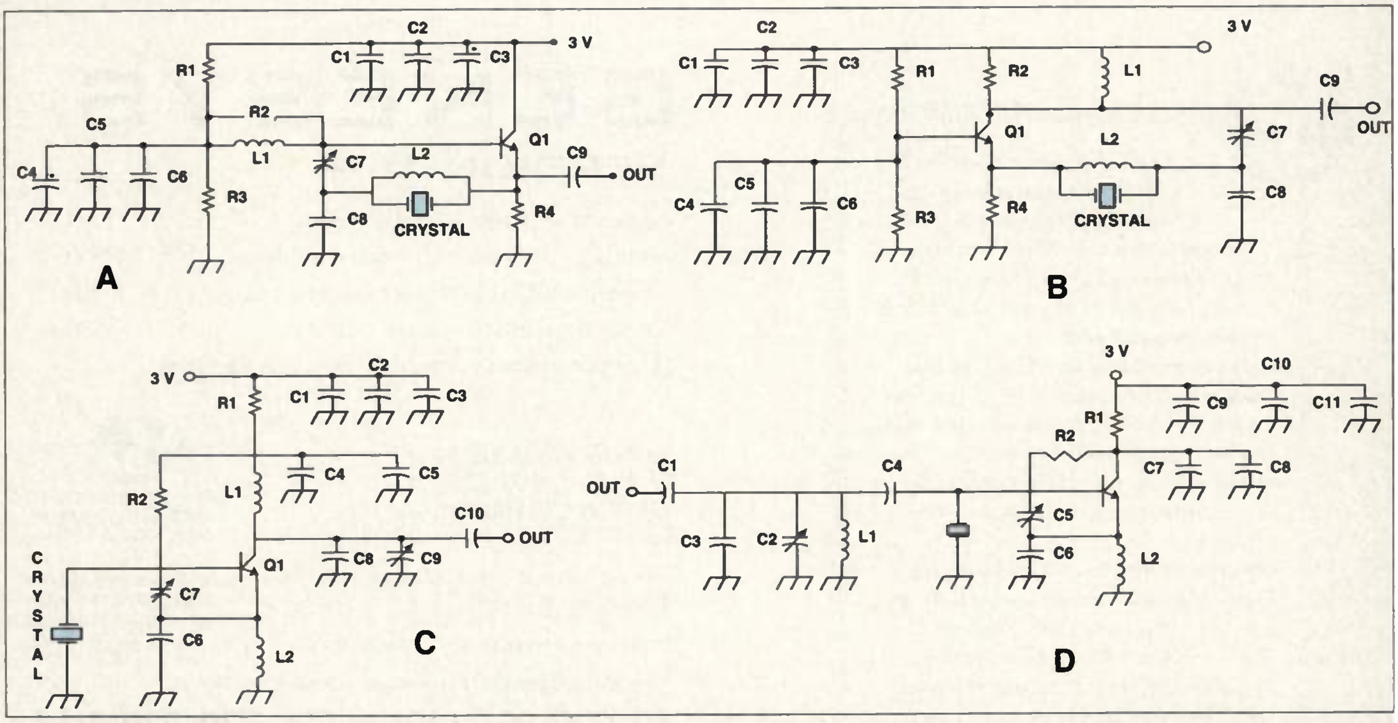
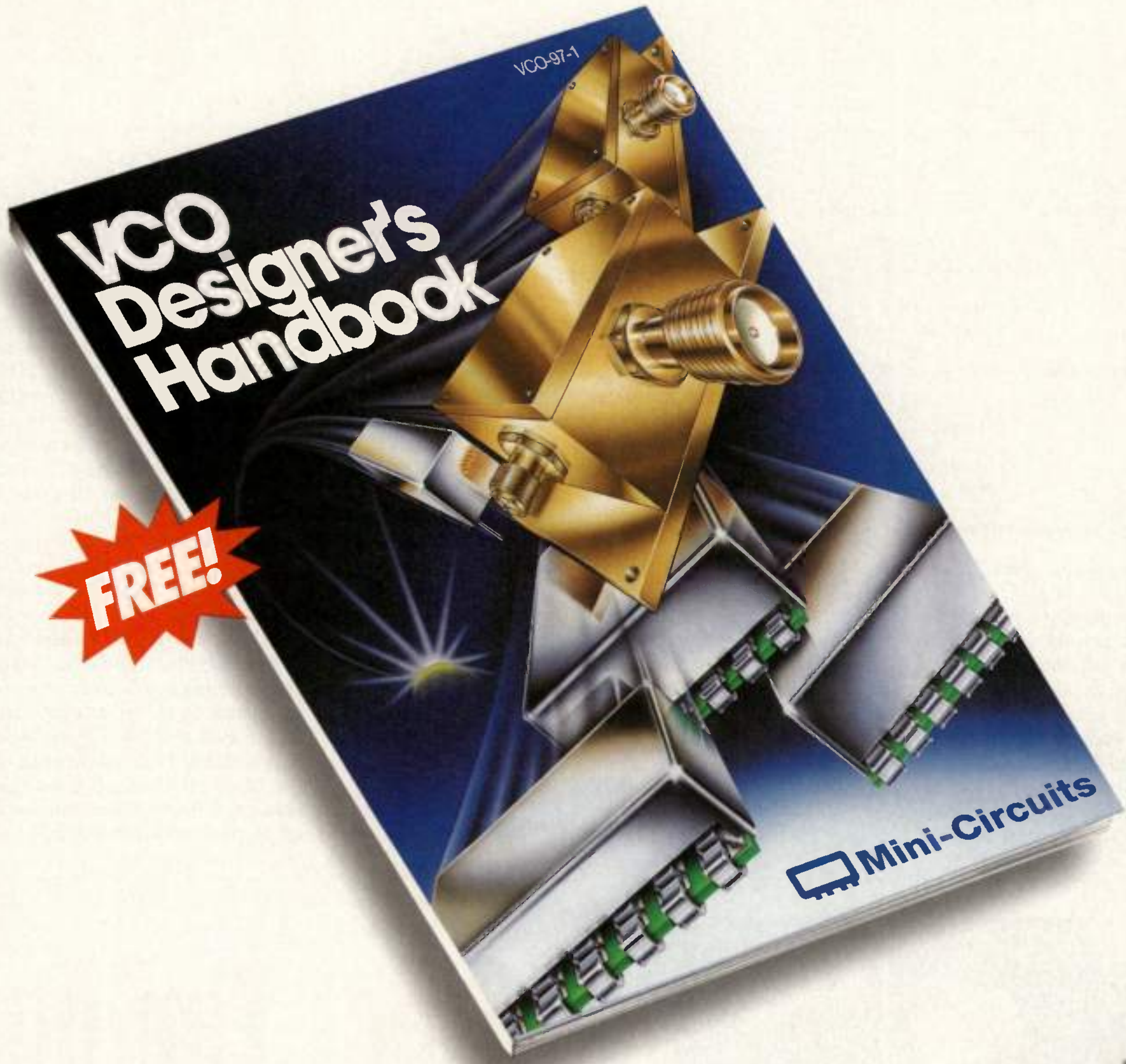


Figure 2. Topologies of the oscillators analyzed. a) common collector Butler oscillator, b) common base Butler oscillator, c) harmonic Colpitts, output at the collector, d) harmonic Colpitts, output at the base.



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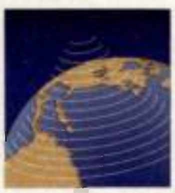

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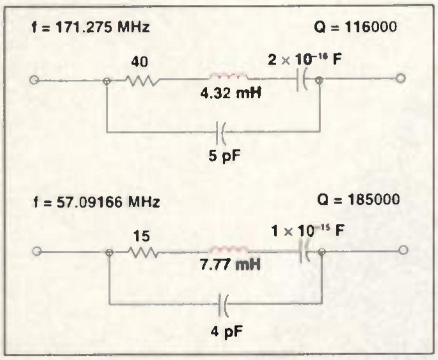


Figure 3. Equivalent circuits of the crystals used.

measured to work in the 171.25 MHz and 171.75 MHz frequency bands. Three prototypes of each oscillator have been constructed and measured to verify repeatability. Five quartz crystals of the desired frequency have been tested with each unit of the oscillators. This way, verification of the results are a result of the topology and not a result of the constructed circuit or quartz crystal.

The designed oscillators are the following:

- Butler common-collector oscillator.
- Butler common-base oscillator.
- Colpitts tuned-to-harmonics oscillator, output at the collector.
- Colpitts tuned-to-harmonics oscillator, output at the base.

The objective is to compare the performance of these topologies using crystals working at the fundamental frequency and crystals working at the third overtone.

Figure 3 shows the equivalent circuit of the crystals. The crystal used for the Butler oscillator is cut to work in the series resonant mode (7th overtone). The crystal used for the Colpitts oscillators is cut to work in the parallel mode with a load capacitance Cl = 8 pF (3rd overtone). The series equivalent resistance is low.

Stability of the output frequency

Many wireless receivers exhibit an important deterioration of performance for frequency deviations of the local oscillator. In the direct-conversion receivers for pagers, this deviation gives an important increase of the errors of received data [6]. In this case, with a deviation of 4.5 kHz, there is a theoretical limit of 26 ppm until total failure of the receiver. For a variation of only 17 ppm, the reduction in sensitivity is 3 dB. When a carrier of 470 MHz is used (some paging services use this band), the previous values must be reduced to 9 ppm and 6 ppm, respectively.

Thus, the stability of the oscillator must be lower than 10 ppm. This stability is the result of the variations caused by temperature changes and by the aging of the crystal oscillator. Usually, the temperature range for commercial use is from –10°C to 50°C, and the "expected life" depends on the system. Nevertheless, a system for a commercial application never will be used both at extreme temperatures and at the end of its life simultaneously. It is estimated that a tolerance of 10 ppm for the –10°C to 50°C range will be enough. The temperature coefficient of the oscillator is defined in Equation 1.

$$\frac{1}{f_o}\frac{\partial f}{\partial T}=\frac{1}{f_o}\sum_{n=1}^{N}\frac{\partial f}{\partial X_n}\cdot\frac{\partial X_n}{\partial T}=\sum_{n=1}^{N}\left(\frac{1}{f_o}\cdot\frac{\partial f}{\partial X_n}\right)\cdot\frac{\partial X_n}{\partial T} \quad (1)$$

where:

f = oscillation frequency

X_n = parts of the crystal oscillator: XTAL, passive components (capacitors, resistors, coils), parts of the transistor's model and others.

T_o = Reference temperature, 20 to 25°C typically

$\partial X_n / \partial T$ = temperature coefficient of the oscillator's part (not normalized)

$(1/f_o)\cdot(\partial f/\partial X_n)$ = sensitivity of the oscillator's output frequency (for different parts)

The "sensitivity" analysis of the output frequency vs. the most relevant passive components is shown in Table 1. The sensitivity of the Butler oscillators vs. the tuned tank (C7, C8, L1) and the inductance L2 (to tune the capacitance of the package) is shown. The sensitivity of the Colpitts oscillators vs. the feedback capacitors ((C6 and C7) or (C5 and C6)) and the coil L2 also is shown.

The sensitivity of the Butler oscillators is higher than the sensitivity of the Colpitts oscillators, but this sensitivity is not that high in any case.

The part elected to adjust the oscillator is the part that affects the output frequency most. The temperature coefficient of the surface-mount (0805) capacitors used is ±30 ppm/°C. For the surface-mount (1206) coils used, the temperature coefficient is 500 ppm/°C. For temperature changes suffered by the passive parts, a frequency change lower than 0.5 ppm was achieved for all the oscillators tested.

This leads to a negligible dependency of the output frequency on the passive components compared to dependency on the quartz crystal; therefore, maximum attention must be paid to the quartz crystal.

Phase noise

The main effects of phase noise in a receiver are the reduction of the sensitivity and the decrease of adjacent channel rejection. The second effect (adjacent channel rejection) usually is more important than the first (reduced sensitivity). A

TABLE 1

BUTLER COMMON COLLECTOR		BUTLER COMMON BASE		HARMONIC COLPITTS OUTPUT AT THE COLLECTOR		HARMONIC COLPITTS OUTPUT AT THE BASE	
C7	0.58 ppm/%	C7	0.29 ppm/%	C6	0.14 ppm/%	C5	0.26 ppm/%
C8	0.17 ppm/%	C8	0.11 ppm/%	C7	0.31 ppm/%	C6	0.09 ppm/%
L1	1.47 ppm/%	L1	1.02 ppm/%	L2	0.049 ppm/%	L2	0.053 ppm/%
L2	0.025 ppm/%	L2	0.029 ppm/%	L1	0.017 ppm/%	L1	0.020 ppm/%

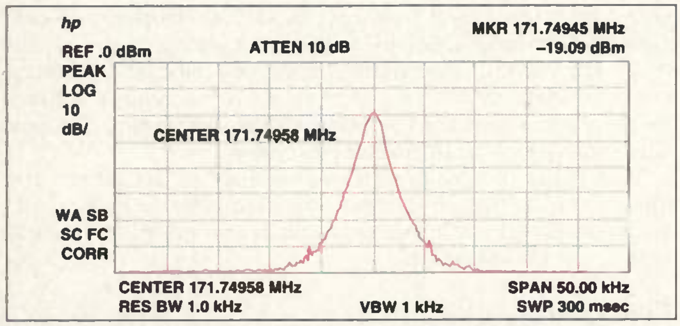


Figure 4a. Phase noise plot of the common-base Butler oscillator at 171.750 MHz.

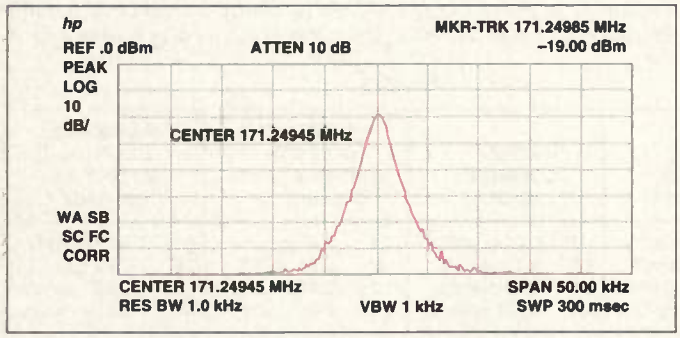


Figure 4b. Phase noise plot of the oscillator at 171.250 MHz.

direct-conversion receiver for paging needs an adjacen channel rejection of 65 dB for a channel separation of 25 kH [7]. This means a phase noise less than –105 dBc at 25 kH from the central frequency of the carrier. It is not too difficul to get this specification for a low-power crystal oscillator.

The phase noise of an oscillator is [8]:

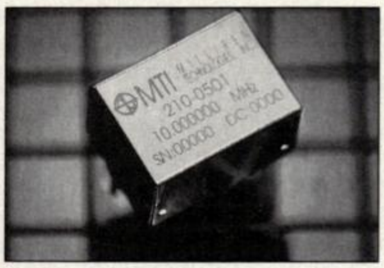
$$\mathcal{L}(f_m)=\frac{1}{2}\left(1+\frac{\omega_o^2}{4\omega_m^2 Q^2}\right)\left(1+\frac{\omega_c}{\omega_m}\right)\frac{FkT_o}{P_{sav}} \qquad (2$$

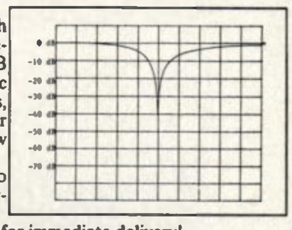
where:

f_m = frequency deviation
f_o = fundamental frequency of the oscillator
Q = quality factor (loaded) of the oscillator
f_c = flicker cutoff frequency (of the transistor)
F = noise figure of oscillator (large signal mode)
k = Boltzman constant
T_o = noise temperature at the input of the oscillator

We will use this equation to analyze a typical example. I we are working with an oscillator of f_o = 170 MHz, f_m = 2 kHz, f_c = 10 kHz and $(kFT_o)/P_{sav}$ = –7 $^{dBc}/_{Hz}$, we will need loaded quality factor (Q) > 50. This value is lower than th value obtained for typical quartz crystals.

Simulation has proved that this quality factor is equal to th quality factor of the crystal multiplied by 0.5 or by 0.6. It is no necessary to pay special attention to this point. Figure 4 show the phase noise obtained from the tested oscillators.





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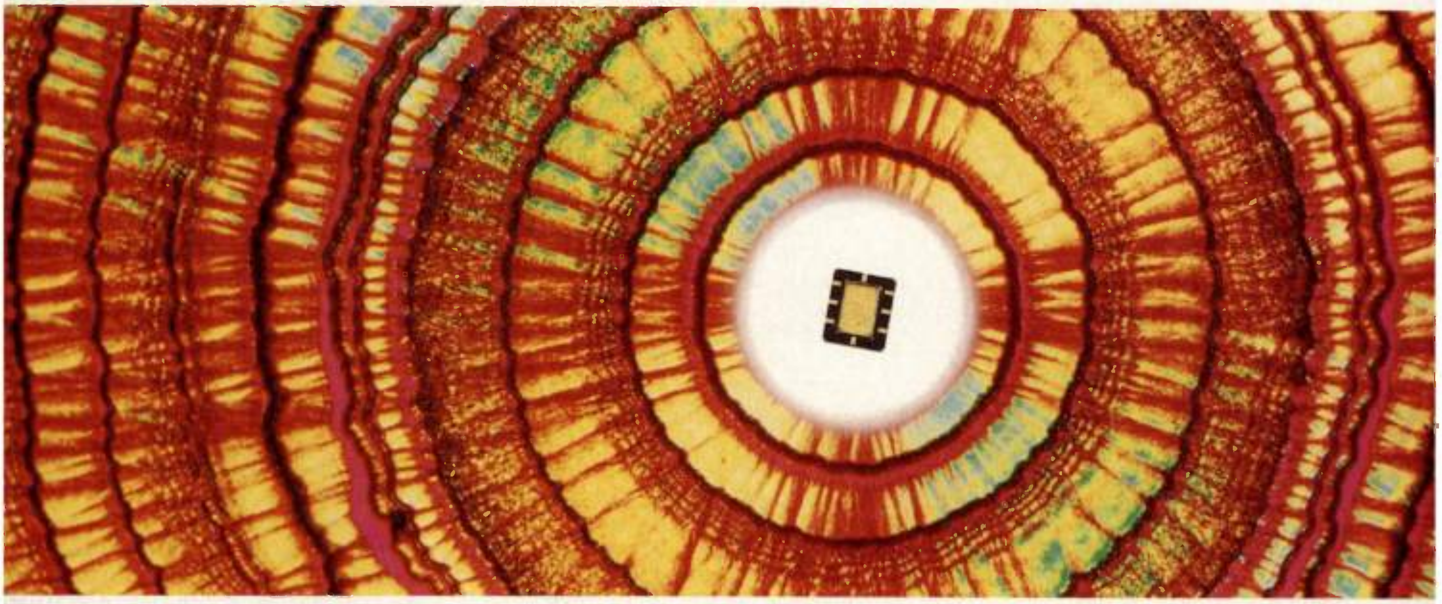

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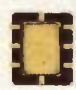

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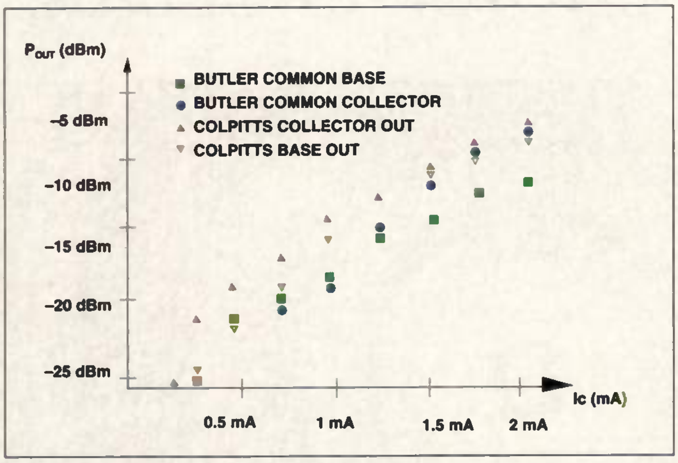

Figure 5a. Output power (of the oscillators) vs. bias current.

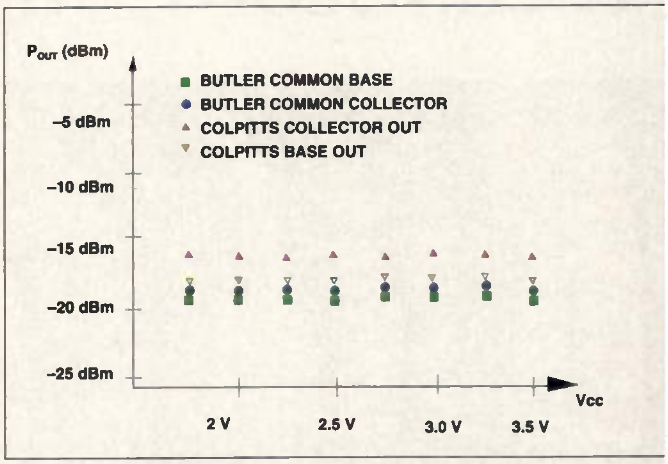

Figure 5b. Output power (of the oscillators) vs. supply voltage.

TABLE 2

HARMONIC	BUTLER COMMON COLLECTOR	BUTLER COMMON BASE	HARMONIC COLPITTS OUTPUT AT THE COLLECTOR	HARMONIC COLPITTS OUTPUT AT THE BASE
FUNDAMENTAL	–14.3 dBm	–15.7 dBm	–16.5 dBm	–18.4 dBm
2°	–9.9 dBc	–19.7 dBc	–28.4 dBc	–29.2 dBc
3°	–16.1 dBc	–30.0 dBc	–48.0 dBc	–44.1 dBc
4°	–25.4 dBc	–38.4 dBc	–63.6 dBc	–67.0 dBc
5°	–34.5 dBc	–49.2 dBc	–81.2 dBc	–88.4 dBc

Power at the fundamental frequency

Most wireless receivers use downconverters based on active mixers using the classic "Gilbert topology," so it is possible to save power working in the linear region where the gain is proportional to the level of the oscillator [9].

Sharing the gain over the different stages of the receiver, it is possible to use oscillator power levels lower than –20 dBm. This means that small currents and voltages must be used to feed the oscillator.

Even so, the minimum current is limited by the minimum transconductance needed to start the oscillation. This effect is important in Butler oscillators working with quartz crystals in high overtones (7th). In this case, a high collector current is needed to compensate for the series resistance of the quartz crystal and to start oscillations. Suppose a typical oscillator efficiency of 2.5–5% and an output power of –17 dBm is needed for a direct-conversion power of 0.4–0.8 mW. This means a current of 0.3–0.15 mA is required if the receiver is operated at 3 V.

As a result, the effect of amplitude-limiting is caused by the limit of current, not by the voltage (V_{ce}) limit [10]. It follows that the output power depends on the collector current, not on the voltage of the battery. This is shown in Figure 5.

Table 2 shows the value of the out put power of the four oscillators analyzed. *Fundamental* means "third overtone" for the Colpitts oscillators.

Power at harmonic and subharmonic frequencies

The harmonics and subharmonics of the signal generated by the oscillator cause interference with non-desired signals. This interference is limited by the attenuation presented by the RF stages. Usually, these stages are tuned to the desired frequency. This rejection may be expressed as:

$$Attenuation = \sqrt{\left(1+\left(\frac{2Q\Delta f}{f_o}\right)^2\right)} \quad (3)$$

where:
Δf = frequency deviation
f_0 = receiver frequency
Q = quality factor of the tuned tank (loaded)

For example, a maximum amplitude of –30 dBc is enough for a pager receiver based on a direct-conversion scheme. From Table 2, it is easy to se that the Butler oscillators do not satisf the specifications. This problem can b solved using a new filter, but this i bulky and more expensive, and mor space is needed for the printed circui board (PCB).

The Colpitts oscillators satisfy th specifications, but the safety margin i not high, especially for the second har monic (the most dangerous). To de crease the level of this harmonic, in crease the Q of the coil L1, which is th limiting factor of the Q of the tank. Fo example, this Q can be increased usin high-Q, air-core inductors for surface mounting.

Power consumption

Wireless circuits usually are pow ered by batteries. For example, pager consume about 2 mW, which ensure more than 800 hours of battery life Pagers based on direct-conversion tech nologies consume even less power. I this kind of receiver, most of the powe is consumed by the local oscillato therefore, a reduction in the power con sumption of the oscillator means an im portant increase in the batteries' life Recognizing this fact, we will set maximum power consumption of 0.. mW for the oscillator.

This decision means a limit of 0.1 mA of current from a 3 V battery (o 0.34 mA for a 1.5 V battery). This cur rent is not enough for a Butler oscil lator. A Colpitts oscillator can wor with this collector current. Exper iments have determined that the But ler oscillators need 50% or 75% mor current than the Colpitts oscillators.

Some authors recommend the use c auxiliary-bias circuits (using diode

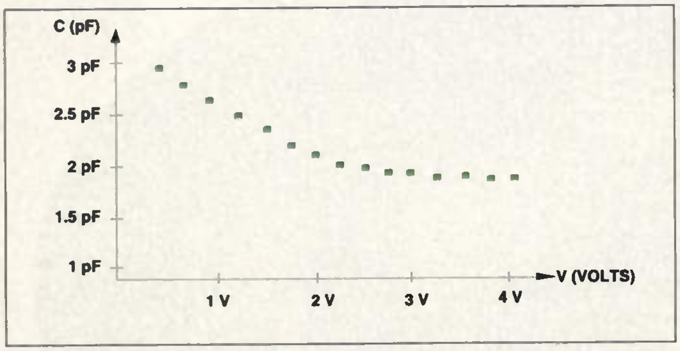

Figure 6. Changing of the parasitic capacitances of the transistor vs. voltage.

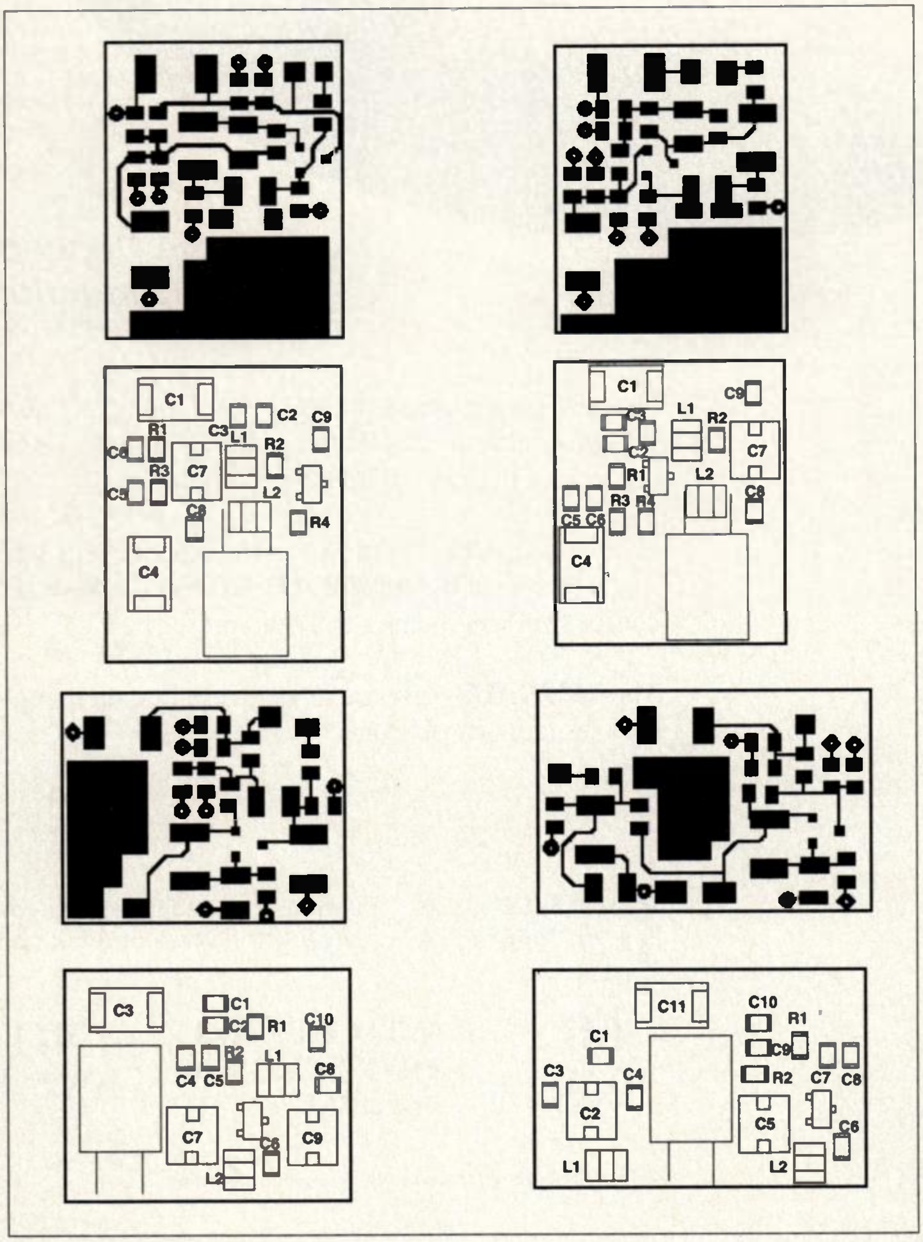

Figure 7. Oscillator's output.

and transistors) to improve the behavior of crystal oscillator [10]. This practice usually is impossible to follow with low power wireless crystal oscillators because it increases th power consumption too much. In the oscillators shown, th bias point has been stabilized using resistors and negativ feedback. This negative feedback is introduced by R4 in th Butler oscillators and by R1 and R2 in the Colpitts oscillators

Oscillator pushing

An important factor for an oscillator using batteries is *os cillator pushing*. The problem manifests itself as the batter voltage falling during its discharge period. The change of th output frequency of the oscillator can be expressed as:

$$\Delta f = P \cdot \Delta V_{cc} \qquad (4$$

where:

Δf = frequency deviation
P = pushing
ΔV_{cc} = change in battery voltage

The "pulling" mainly results from th change of the parasitic capacitances wit the voltage applied to the transistor. Fc the Butler oscillator, this change of th capacitances produces a phase lag in th transistor. To compensate, it is necessar to change the frequency of the quart crystal.

The same effect in the Colpitts osci lator can be compensated by adjusting C and C5 for base and collector outputs, re spectively. The change of the capaci tances is more important when workin with low voltage, such as the voltage c most wireless crystal oscillators. (Se Figure 6.)

To fight pushing in circuits withou voltage regulators, it is necessary to se lect capacitor values as large as possibl in the feedback circuit (compared to th parasitic capacitances of the transistor This is easy to do with Colpitts oscillator working at the fundamental frequency c the crystal. It is more difficult to do wit Butler oscillators working at high over tones, because the needed capacitors ar small.

Table 3 shows the measured values c pushing and pulling figures of the teste oscillators. The best pushing figures be long to the Colpitts oscillator with outpu at the base. That is a logical result be cause the common collector Colpitts osci lator output is located in parallel with th quartz crystal. In the common-base Bu ler oscillator, the signal is extracted fro the overtone-tuned tank; therefore, th changes of the load effect to the phase-la introduced by the transistor changes th output frequency.

For the Colpitts oscillator with th output at the collector, the signal is e tracted from a point where the RF impe nce is low; therefore, the changes f the load do not affect the oscillation requency.

'arts and area

In wireless applications, it is important to get a small PCB. To do that, one an use 0603 surface-mount passive arts; small packages for transistors SOT23 or smaller); or thin PCB lines (10 mils or thinner).

The optimization of the layout must not overrule the basic rinciples of the RF design, that is, minimized coupling and ood grounding.

Figure 7 shows the layout of the PCB designed to test the rystal oscillators. Figure 8 shows the designed and tested rototypes.

ıdjustment

The crystal oscillators must be adjusted to compensate for ie tolerance of the quartz crystals. The lower the tolerance, ie higher the cost of the quartz crystal.

According to our tests, the Butler oscillators are the ardest to adjust. This negative effect is more important for ie common-base Butler oscillator. This oscillator exhibits a ritical adjustment. These difficulties have been related by thers, especially for the common-base oscillators [11]. Isually, it is necessary to order at least two or three quartz

TABLE 3

	BUTLER COMMON COLLECTOR	BUTLER COMMON BASE	HARMONIC COLPITTS OUTPUT AT THE COLLECTOR	HARMONIC COLPITTS OUTPUT AT THE BASE
PUSHING	0.9 ppm/V	0.97 ppm/V	0.3 ppm/V	0.035 ppm/V
PULLING	0.83 ppm	0.87 ppm	0.08 ppm	1.2 ppm

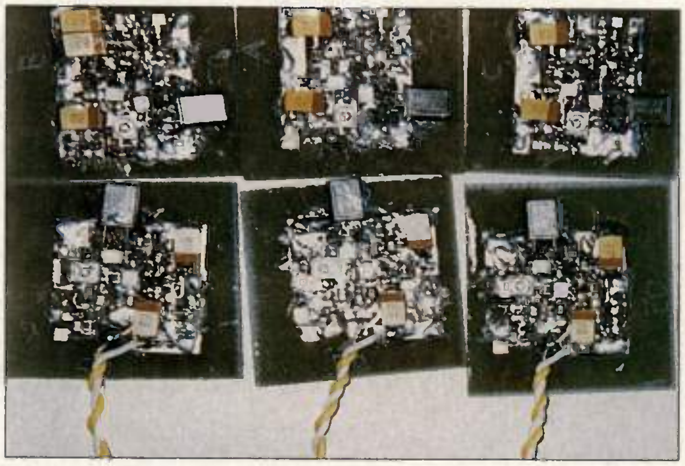

Figure 8. Photographs of the oscillators.

crystals during the design process.

On the other hand, the Colpitts oscillators have been rugged and easy to adjust over a wide range of frequencies.

Table 4 compares the main features of the proposed and tested oscillators.

RF

References

1. M. Pardoen, R. Pache, E. Dijkstra, "Direct-Conversion Receiver Provides CP-FSK Operation," *Microwaves & RF*, March 1994, pp. 151–155.
2. K. Yamasaki, S. Yoshizawa, Y. Minami, T. Asai, Y. Nakano, M. Huroda, "Compact Size Numeric Display Pager with New Receiving System, *NEC Res. & Develop.*, Vol. 33, No. 1 January 1992, pp. 73–82.
3. David Treleaven, Dong Wadsworth, "FSK Receiver Uses Direc Conversion," *RF Design*, July 1986, pp 30–38.
4. S. Tanaka, A. Nakajima, J. Nakagawa, A. Nakagoshi, Y. Koniman "High-Frequency, Low-Voltage Circui Technology for VHF Paging Receiver, IEICE Trans. Fundamentals, Vol. E76 A, No. 2, February 1993, pp. 156–163.
5. K. Takahashi, M. Minura, M. Hasegawa, M. Makimoto, K. Yokozaki, " Direct Conversion Receiver Utilizing Novel FSK Demodulator and a Low Power Consumption Quadrature Mixer," Vehicular Technology Society 42n VTC Conference, May 1992, pp 910–915.
6. Y. Oishi, T. Takano, H. Nakamura, "Sensitivity Simulation Result For a Direct-Conversion FSK Receiver 38th IEEE Vehicular Technology Conference, June 1988, No. 88CH2622- pp. 588–595.
7. Darcy Stepanek, *Paging Through*

About the authors

Jose Luis Jimenez Martin received an Ingeniero Tecnico en Radiocomunicacion degree from the Universidad Politecnica de Madrid, Spain in 1991. In 1992, he joined the E.U.I.T. Telecomunicacion I.A.C. department of the Universidad Politecnica de Madrid, where he is a professor. His research interests include RF and microwave oscillators, amplifiers and circuits.

Francisco Javier Ortega Gonzalez received an Ingeniero Tecnico en Radiocomunicacion degree from the Universidad Politecnica de Madrid in 1990 and an Ingeniero de Telecomunicacion degree from the Universidad Politecnica de Madrid in 1994. In 1990, he joined the E.U.I.T. Telecomunicacion department of the Universidad Politecnica de Madrid, where he is a professor, and he is working on a doctoral thesis about power RF amplifiers. His research interests include RF and microwave oscillators, amplifiers and circuits.

Both authors can be reached at the Universidad Politecnica de Madrid E.U.I.T. de Telecomunicacion, Ctra de Valencia, km 728031, Madrid, Spain, Tel. +34-1-3367788/ 98; Fax +34-1-3367784 or +34-1-3319229.

ut Europe Past, Present & Future, 994.

8. D.B. Leeson, "A Simple Model of 'eedback Oscillator Noise Spectrum," ,etters Proceeding of the IEEE, Feb-uary 1966, pp. 329–330.

9. R. Mohindra, "UAA2080T VHF/ 'HF Paging Receiver Features and Ap-lications," Laboratory Report No. 'TT91003, Philips Semiconductors, 'ebruary 1993.

10. R.W. Rhea, *Oscillator Design nd Computer Simulation*, Noble Pub-shing, 1995, p. 90.

11. R.J. Matthys, *Crystal Oscillator 'ircuits*, John Wiley & Sons, 1983, pp. 7–64.

TABLE 4

	BUTLER COMMON COLLECTOR	BUTLER COMMON BASE	HARMONIC COLPITTS OUTPUT AT THE COLLECTOR	HARMONIC COLPITTS OUTPUT AT THE BASE
STABILITY	GOOD	GOOD	GOOD	GOOD
PHASE NOISE	GOOD	GOOD	GOOD	GOOD
POWER AT FUNDAMENTAL	BAD	BAD	GOOD	MEDIUM
POWER AT HARMONICS	BAD	BAD	GOOD	GOOD
POWER CONSUMPTION	VERY BAD	VERY BAD	GOOD	GOOD
PUSHING	MEDIUM	MEDIUM	GOOD	GOOD
PULLING	BAD	BAD	GOOD	BAD
SIZE	GOOD	GOOD	GOOD	GOOD
ADJUSTMENT	BAD	VERY BAD	GOOD	GOOD

Design and validation of fault-tolerant, synchronized crystal oscillators

By T. Kien Truong

A new design and several verification techniques for synchronizing crystal oscillators achieve exact synchronization. The new design uses minimum part count for ultra-reliability. It is suitable for high-speed and on-chip integration. The new design improves upon existing architectures from capacitive coupling to feedback voting and finally, to full-fault tolerance. Using SPICE, three simulation techniques are used to verify the design: oscillator startup, synchronization of out-of-phase oscillators and on-the-fly fault-injection.

In commercial aviation, defense, aerospace and nuclear power plants where safety is critical, redundancy has been used extensively to improve the reliability of control and computing systems. In a fault-tolerant system, redundant computing channels depend on clock synchronization. All data distribution and comparing or voting are based on synchronous clock edges among channels. Crystal oscillators provide highly stable clock signals, which are required by the redundant processors. The simplest way to synchronize the redundant systems is to use a single crystal oscillator for a common timing reference. This approach carries with it the penalty of a single-point failure that can "wipe out" the whole system.

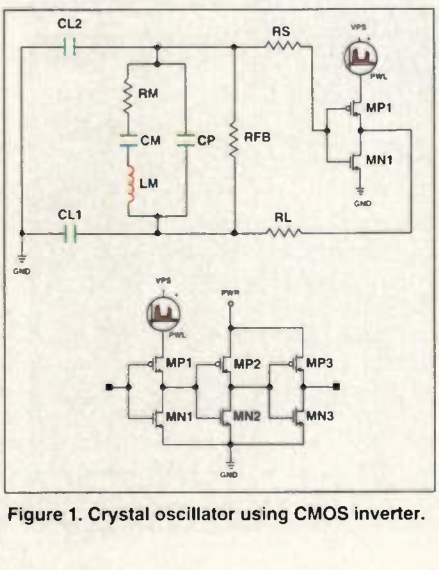

Figure 1. Crystal oscillator using CMOS inverter.

In high-performance computers for real-time applications, many issues must be resolved in a practical fault-tolerant clock: continuous clocking without any temporary stoppage or slow-down to establish synchronization; high speed to support processing power; fault tolerance including arbitrarily malicious faults; complete fault coverage for all fault-containment regions; tight synchronization to subnanosecond range; startup reset synchronization so that the processors are not n-clocks apart; and minimum parts count for high reliability.

A crystal oscillator can produce many failure modes: amplitude error, frequency drift, phase shifting and jitters, duty cycle variation, glitches, runt-pulse transients and Byzantine fault.

A number of fault-tolerant clock designs have been described in literature. Most of them use phase-locked loops (PLLs) [1, 2, 3]. Some use standby switching spares [4]. Some periodically realign the oscillators after a free drifting period. Most designs require four redundant oscillators to tolerate a single malicious fault, and most have the drawbacks of being low-speed and loosely synchronized [5, 6, 7]. A patented design uses only three oscillators with minimum hardware to achieve fault tolerance and exact synchronization to less than 0.25 nanoseconds.

Independent oscillators

In Figure 1, the amplifier for the crystal oscillator is a complementary metal oxide semiconductor (CMOS) inverter that is biased at its mid-range to function as a linear amplifier for the clock signal. To oscillate, the circuit must satisfy the Barkhausen criteria that the phase shift around the loop be $n360^\circ$ and that the loop gain exceeds unity at the resonant frequency.

We can model the quartz crystal a having a motional resonance arm Rn Lm and Cm in parallel with th crystal-holding capacitance (CP) (th mounting electrodes). All circuit para sitic elements, on chip or off chip, ar lumped into the loading capacitors an loading resistors.

In a series resonant oscillator, th crystal operates at its natural serie frequency. In a parallel resonant osci lator, the feedback circuit introduces load capacitance to the crystal an causes the crystal to operate at the fr quency at which the crystal reactanc cancels the load-capacitor reactance. follows that, when the load capacitanc changes, the resonant frequency chang es. The crystal reactance curve crosse zero at two frequencies that represer the series resonant and parallel res nant. Between the two frequencies, th reactance is inductive. Below and b yond that range, the reactance is capa itive. The oscillator operates in the i ductive region between the two re onant frequencies. Within this band width, the crystal phase varies by large range with a small change in fr quency. In other words, only an e tremely small frequency shift is nece sary to change the crystal's impedanc to compensate for phase deviatio around the loop.

Program 1 shows the SPICE deck three independent phasing oscillato with a typical frequency deviatio within 100 ppm among the crystal The transistor parameters are from typical 2-micron CMOS technology. triple-stage inverting amplifier is use to obtain higher gain for speeding u the simulation time for the startu transient. The CP is also commente out to speed up the simulation withou affecting the fault-tolerant behavior the circuit.

Even though crystal oscillator simu lation is difficult because a quart crystal has an extremely high-Q circu

PROGRAM 1

```
* Inverting amplifier
.SUBCKT INVAMP VCC VPS 1 4
MN1 2 1 0 0 NMOS L=2U W=2U
MP1 2 1 VPS VPS PMOS L=2U W=8U
MN2 3 2 0 0 NMOS L=2U W=5.43U
MP2 3 2 VCC VCC PMOS L=2U W=21.74U
MN3 4 3 0 0 NMOS L=2U W=14.76U
MP3 4 3 VCC VCC PMOS L=2U W=59.1U
RFB 4 1 22E6
.ENDS

* 24 MHz crystals
.SUBCKT XTAL24A 1 2
RM 2 4 10.5
CM 3 4 20.60E-15
LM 1 3 2.14E-3
*CP 1 4 4.5E-12
.ENDS

.SUBCKT XTAL24B 1 2
RM 2 4 10.7
CM 3 4 20.50E-15
LM 1 3 2.150E-3
*CP 1 4 4.5E-12
.ENDS

.SUBCKT XTAL24C 1 2
RM 2 4 10.0
CM 3 4 20.44E-15
LM 1 3 2.156E-3
*CP 1 4 4.5E-12
.ENDS

* Oscillator circuit
.SUBCKT OSCA AMPIN AMPOUT
XAMP VCC VPS AMPIN AMPOUT INVAMP
XTAL NXIN NXOUT XTAL24A
RS AMPOUT NXIN 200
RL NXOUT AMPIN 200
CL1 NXIN 0 10PF
CL2 NXOUT 0 10PF
VC5 VCC 0 DC 5V
V99 VPS 0 PWL 0N 5V .1US 5V .105US 0V .110US 5V 1MS 5V
.ENDS

.SUBCKT OSCB AMPIN AMPOUT
XAMP VCC VPS AMPIN AMPOUT INVAMP
XTAL NXIN NXOUT XTAL24B
RS AMPOUT NXIN 200
RL NXOUT AMPIN 200
CL1 NXIN 0 10PF
CL2 NXOUT 0 10PF
VC5 VCC 0 DC 5V
V99 VPS 0 PWL 0N 5V .11US 5V .115US 0V .120US 5V 1MS 5V
.ENDS

.SUBCKT OSCC AMPIN AMPOUT
XAMP VCC VPS AMPIN AMPOUT INVAMP
XTAL NXIN NXOUT XTAL24C
RS AMPOUT NXIN 200
RL NXOUT AMPIN 200
CL1 NXIN 0 10PF
CL2 NXOUT 0 10PF
VC5 VCC 0 DC 5V
V99 VPS 0 PWL 0N 5V .12US 5V .125US 0V .130US 5V 1MS 5V
.ENDS

* TMR oscillators
XOSCA OSCINA OSCOUTA OSCA
XOSCB OSCINB OSCOUTB OSCB
XOSCC OSCINC OSCOUTC OSCC

* Transient analysis
.TRAN 1NS .6US 0.1US 10NS
.PROBE V([OSCOUTA]) V([OSCOUTB]) V([OSCOUTC])

* N-Well transistor model
.MODEL NMOS NMOS
+ LEVEL=2 VTO=0.825 UO=608
+ TOX=4.0E-8 NSUB=7.755E15 XJ=4.50E-7
+ LD=1.121E-7 DELTA=3.714 VMAX=49.89E+3
+ NFS=.105E12 CJ=323.1E-6 CJSW=929.9E-12
+ MJ=461.5E-3 MJSW=268.3E-3 PB=.44
+ CGSO=96.77E-12 CGDO=96.77E-12 CGBO=40.0E-12
+ UCRIT=50E3 UEXP=78.26E-3 NEFF=3.36 TPG=1

.MODEL PMOS PMOS
+ LEVEL=2 VTO=-0.703 UO=205
+ TOX=4.0E-8 NSUB=1.486E16 XJ=450E-9
+ LD=230.5E-9 DELTA=1.843 VMAX=40.76E3
+ NFS=0.01E12 CJ=804.9E-6 CJSW=749.1E-12
+ MJ=525.0E-3 MJSW=495.4E-3 PB=.958
+ CGSO=199.0E-12 CGDO=199.0E-12 CGBO=101.5E-12
+ UCRIT=70E3 UEXP=184.2E-3 NEFF=0.69 TPG=-1
.END
```

n the range of 105, and the oscillator is ree-running with no driving signal, omplete analysis and simulation techiques in both time and frequency donains are known [8].

Transient simulation of a high-Q uartz-crystal circuit is a real chalenge. Most designers rely on the frequency responses (small-signal analysis) to judge the ability of their circuits o oscillate. Transient response uses arge-signal analysis. This involves nonlinearity operation and time-step estimation, which often results in divergence.

A few tricks can make the oscillation waveform come alive. In this circuit, he three oscillators are kick-started at different times with independent power supplies to simulate their independent phase relationship. The command V99 99 0 PWL 0NS 5V .1US 5V .105US 0V 11US 5V 100MS 5V introduces a voltage spike to the power supply to kickstart the oscillator. Note that in a real circuit, oscillation is started by random thermal noise in the circuit elements. This noise is amplified by the inverter and is fed back positively through the crystal circuit. The amplitude of the signal increases exponentially as it goes through the loop again and again until saturation is reached. The frequency of the signal is controlled by the crystal. The crystal acts as a narrowband filter that passes only the frequency in the vicinity of the resonant frequency.

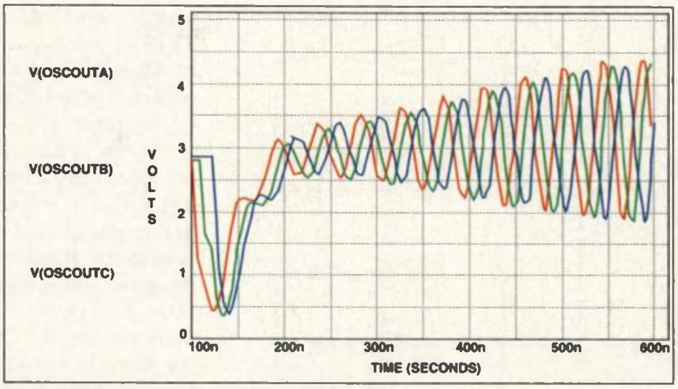

Figure 2. Independent oscillator startup transient.

The CP is in parallel with the motional arm of the crystal and diverts the energy going through the crystal. This reduces loop gain and makes start-up slower. To show the transient start-up from time zero to saturation in a more reasonable time frame, we can comment out the CP temporarily. Together with the higher-gain, triple-stage amplifier, the simulation time is decreased more than 20-fold from hours to a few minutes on a Sun Sparcstation. Figure 2 shows the transient response for the independent oscillator's start-up.

Capacitive coupling

The frequency-pulling characteristic of the crystal is such that additional

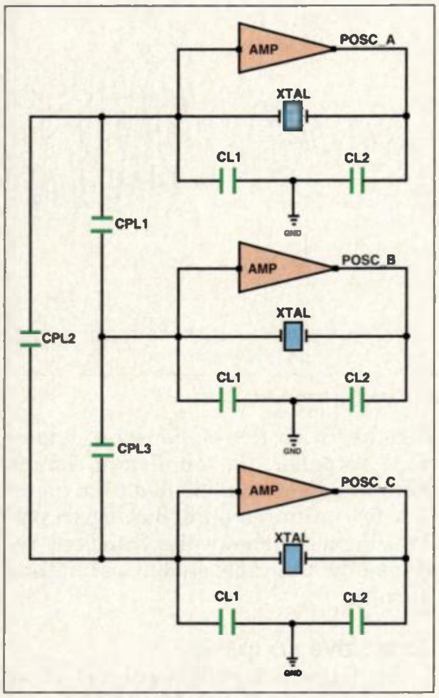

Figure 3. Capacitively coupled oscillators.

phase variation incurred in the loop can be tolerated and is translated into a small frequency shift. The flexibility of the crystal to yield to a driving signal operating close to its resonant frequency is exploited for synchronizing them mutually. Taking advantage of this frequency pulling, we can synchronize the oscillators mutually by coupling them capacitively. Figure 3 illustrates the schematic diagram. Because each oscillator forms a complete feedback loop, the coupling capacitors can be positioned at the input of the crystal network or at the input of the inverting amplifier.

PROGRAM 2

```
* TMR oscillators
XOSCA OSCINA OSCOUTA OSCA
XOSCB OSCINB OSCOUTB OSCB
XOSCC OSCINC OSCOUTC OSCC
CPL1 OSCINA OSCINB 15PF
CPL2 OSCINA OSCINC 15PF
CPL3 OSCINB OSCINC 15PF
```

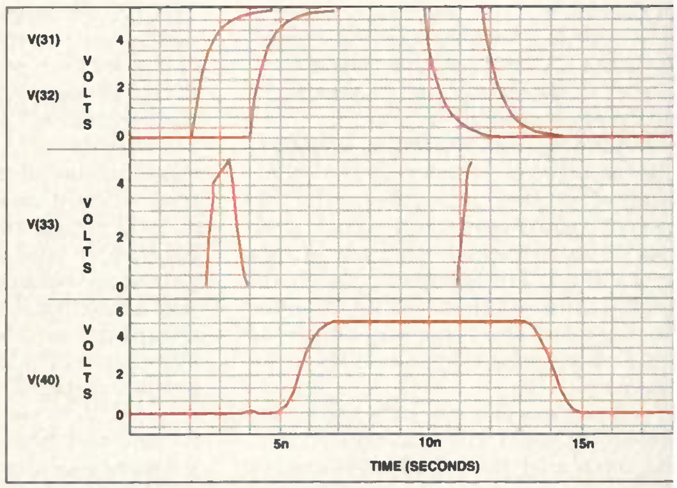

Figure 7. Voting with tight synchronization.

The modification to the main body of the original SPICE listing shown in Program 2 results in the transient waveform of Figure 4. Note that the oscillators achieve synchronization after only a few clock cycles. This capacitive coupling design is not fault-tolerant; a failure in one of the coupling capacitors would cause the entire system to fail.

Feedback voting

To avoid the failure mode of the capacitively-coupled circuit, another way of driving the crystals with identical signals is to insert a majority voter in the feedback loop of each oscillator. The output of all amplifiers would drive the voters, and the identically-voted signal would drive the crystals.

A conventional digital voter would implement the two-out-of-three majority function F = (AB + AC + BC) with three 2-input AND gates and one 3-input OR gate (or a Boolean equivalence such as all NAND gates). To reduce the transistor count and logic delay, a transistor-level schematic for a voter that has only 12 transistors is shown in Figure 5. The majority function implies that unless all of the operational elements agree in value, the voted output will follow the faulty ele-

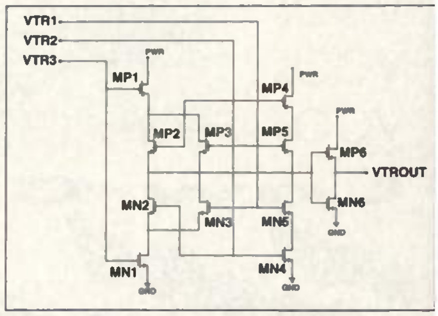

Figure 5. Majority voter schematic.

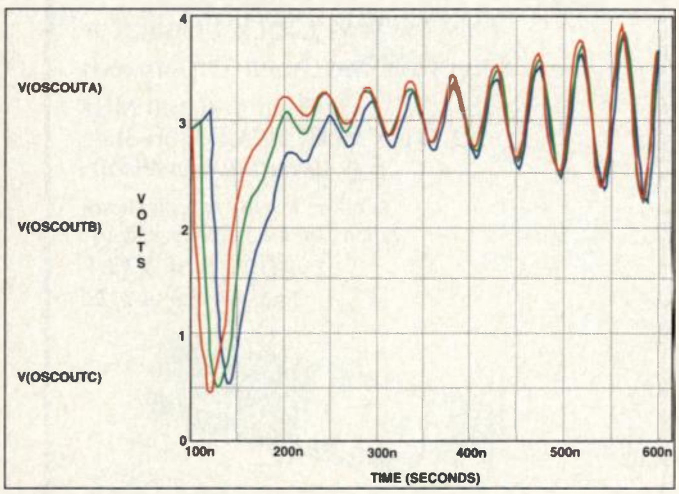

Figure 4. Capacitive coupling startup transient.

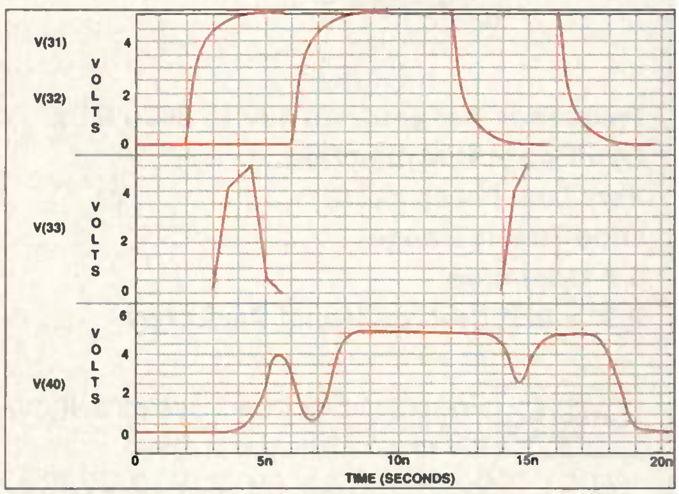

Figure 6. Voting with loose synchronization.

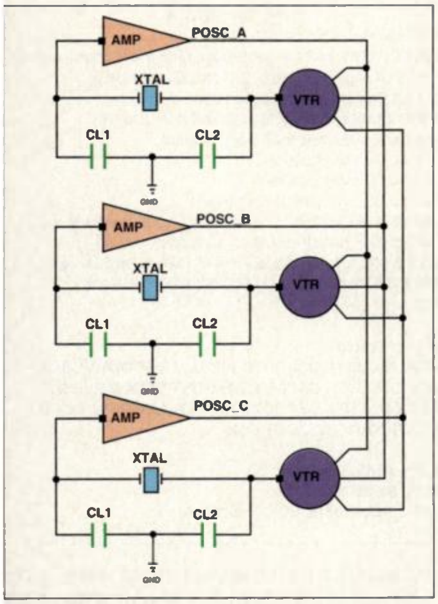

Figure 8. Oscillators with feedback voting.

ment; therefore, if two of the inputs are tightly synchronized (in exact agreement) to each other, the third input can fail without affecting the voted output. Otherwise, four oscillator channels and three-out-of-four voters will be required to survive a fault.

Although it has been proved that 3m + 1 modules are necessary to tolerate m faults, loosely synchronous inputs to a majority voter are a problem. A tightly synchronized triple modular redundancy (TMR) design can tolerate any fault, including the Byzantine asymmetric fault.

A Byzantine fault sends different signals to different modules (or the signals are perceived differently by different modules). A Byzantine fault-tolerant algorithm makes no assumption about the behavior of the fault, no matter how arbitrary. This type of fault is devastating to a majority voter with loosely synchronous inputs, because the resulting outputs of the voters would be in disagreement. Within the displacement window (4 nanoseconds in this example) between two clock edges, where one clock is high and the other is low, the voter's output will follow the third input. Figure 6 illustrates the case in which a glitch in the rising-edge displacement window and an inverted clock in the falling-edge displacement window both cause havoc to the voted output. On the other hand, when two clocks are tightly synchronized (2 nanoseconds in this example), the faulty third clock effectively is filtered out by the voter. Figure 7 shows the resulting waveform of the majority voter under tight synchronization. All real signals and circuits have limited bandwidth and inherent delay caused by parasitic and input and output loading capacitors. When the other two inputs of the voter are tightly synchronized or when the skew is a fraction of the rise time (for example, a 1 nanosecond skew for a 5 nanosecond rise-time signal), the third input can fail within this window and still cannot pass the voter.

Figure 8 illustrates the schematic diagram for the TMR arrangement of oscillators, each with a majority voter in

PROGRAM 3

```
* transistor-level voter
.SUBCKT VOTER VCC 31 32 33 40
MN1 34 33 0 0 NMOS L=2U W=8.5U
MN2 39 32 34 34 NMOS L=2U W=8.5U
MN3 39 31 34 34 NMOS L=2U W=8.5U
MN4 36 32 0 0 NMOS L=2U W=8.5U
MN5 39 31 36 36 NMOS L=2U W=8.5U
MN6 40 39 0 0 NMOS L=2U W=8.5U
MP1 35 33 VCC VCC PMOS L=2U W=12U
MP2 39 32 35 35 PMOS L=2U W=12U
MP3 39 31 35 35 PMOS L=2U W=12U
MP4 37 32 VCC VCC PMOS L=2U W=12U
MP5 39 31 37 37 PMOS L=2U W=12U
MP6 40 39 VCC VCC PMOS L=2U W=12U
.ENDS

* Oscillator circuit
.SUBCKT OSCA VTR1 VTR2 VTR3 AMPOUT
XVOTER VCC VTR1 VTR2 VTR3 VTROUT VOTER
RS VTROUT NXIN 200
* other components remain the same
.ENDS

.SUBCKT OSCB VTR1 VTR2 VTR3 AMPOUT
XVOTER VCC VTR1 VTR2 VTR3 VTROUT VOTER
RS VTROUT NXIN 200
* other components remain the same
.ENDS

.SUBCKT OSCC VTR1 VTR2 VTR3 AMPOUT
XVOTER VCC VTR1 VTR2 VTR3 VTROUT VOTER
RS VTROUT NXIN 200
* other components remain the same
.ENDS

* TMR oscillators
XOSCA OSCOUTA OSCOUTB OSCOUTC OSCOUTA OSCA
XOSCB OSCOUTA OSCOUTB OSCOUTC OSCOUTB OSCB
XOSCC OSCOUTA OSCOUTB OSCOUTC OSCOUTC OSCC
```

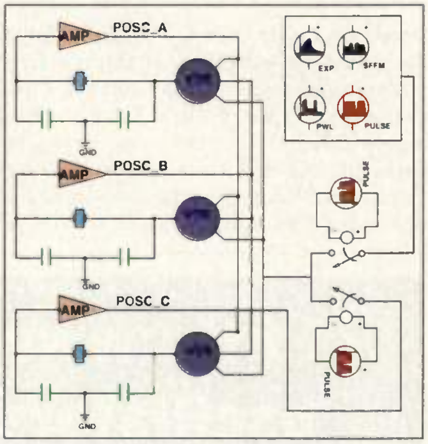

Figure 10. Verification by fault injection.

PROGRAM 4

```
* Fault injection logic block
.SUBCKT FILB 5 4 S1 5 4 8 0 SMOD ;fault free control switch
VS1 8 0 PULSE (5V 0V .6US 1NS 1NS 0.25US 2US)
S2 6 4 9 0 SMOD ; fault injection control switch
VS2 9 0 PULSE (0V 5V .6US 1NS 1NS 0.25US 2US)
* Selection of sources for Fault Injection
*VSA0 6 0 DC 0V ;stuck-at-0
*VSA1 6 0 DC 5V ;stuck-at-1
*VSA1 6 0 DC 2.5V ;stuck-at-midlevel
VNOISE 6 0 SFFM (2.5V 2.5V 24E6 200 1.2E6) ;noise burst
*VEXP 6 0 EXP (0V 6V 0.6US 0.1US 0.75US 0.1US)
*VSIN 6 0 SIN (2.5V 2.5V 24E6 0.5US 10E6 0) ;brown out
*VRAMP 6 0 PWL (0 0V 0.6US 0V 0.7US 5V .8US 0V)
.ENDS

* TMR oscillators
XOSCA OSCOUTA OSCOUTB AFGOUT OSCOUTA OSCA
XOSCB OSCOUTA OSCOUTB AFGOUT OSCOUTB OSCB
XOSCC OSCOUTA OSCOUTB AFGOUT OSCOUTC OSCC
XFILB OSCOUTC AFGOUT FILB

* voltage control switch
.MODEL SMOD VSWITCH
+ RON=1 ROFF=10E6 VON=5 VOFF=0
```

its feedback loop. Here, the voters provide identical driving signals for the crystals. With the crystal circuits designed to have a common pulling range, phase differences among the modules are compensated dynamically and continuously by the crystals within each clock cycle.

In a crystal oscillator, circuit-frequency stability predominantly is controlled by the crystal itself. The crystal frequency, on the other hand, is determined by its mechanical characteristics, such as thickness, elasticity, resonant area of the quartz, lead attachment and package sealing. Therefore, it is expected that drive energy, aging, temperature, humidity and other environmental conditions will have influences on the frequency stability of the circuit. One important characteristic of the crystal is its ability to oscillate at the frequency of a driving signal in the proximity of its own natural frequency. This operation allows all crystals in the system to be pulled to the same voted frequency, thus neutralizing the effect of small fluctuations in circuit components.

The addition of the voter subcircuit and modification as shown in Program 3 to the original SPICE listing results in the transient waveform of Figure 9. Note that the mutually voted oscillators immediately achieve synchronization after the first clock cycle.

Fault injection

Figure 10 illustrates the schematic diagram for the mutually voted oscillators with fault injection. Two voltage-controlled switches are used with opposite controlling pulse waveforms. One switches the output of the C oscillator off; the other switches the arbitrary waveform generator on for fault injection, and vice versa. This way the injection time can be controlled precisely. The switches are a special kind of voltage-controlled resistor in which the resistance continuously varies between R_{ON} and R_{OFF}.

Predefined sources for fault injection include stuck-at-0, stuck-at-1, stuck-at-midlevel, noise-burst, slow-varying-signal that crosses the logic threshold, decaying-oscillator to midlevel-logic and ramping-signal. Other kinds of fault injection waveform also can be defined. The injected waveform is fed back to all three channels to simulate a faulty oscillator C output.

Program 4 shows the fault-injection logic subcircuit and modification to the SPICE listing results in the transient waveforms of Figure 11 for a burst-

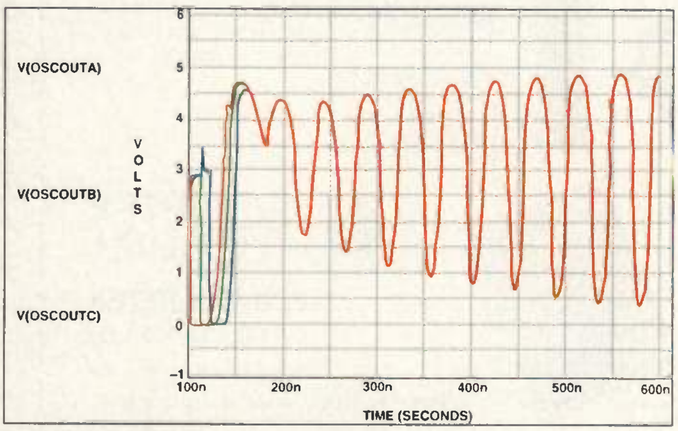

Figure 9. Feedback voting startup transient.

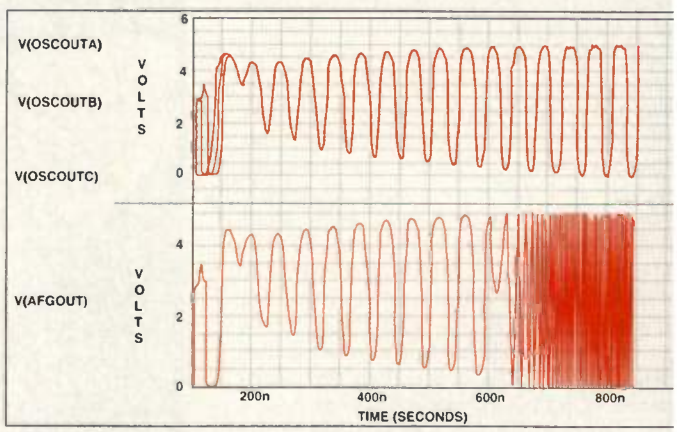

Figure 11. Fault injection with noise burst.

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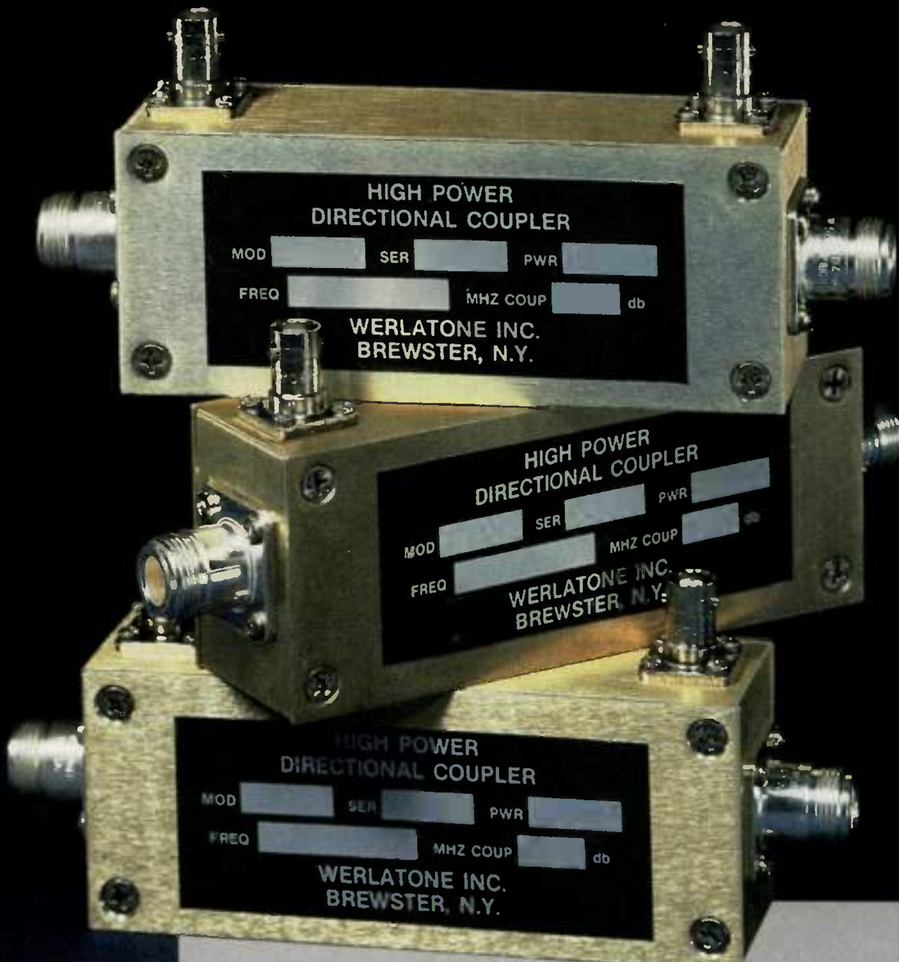

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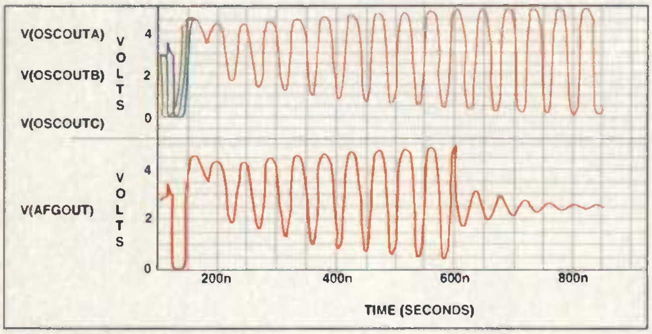

Figure 12. Fault injection with brownout oscillator.

noise injection and of Figure 12 for an oscillator brownout.

Overtone oscillators

For high-frequency applications (60 MHz or greater), we can make the crystal operate at a third overtone of the fundamental frequency by adding an inductor parallel to the input-load capacitor of the crystal. The newly-formed, inductive-capacitive (LC) tank forms a resonant circuit at just below the third overtone to suppress the fundamental frequency. Below this resonant frequency, the LC tank is inductive, and oscillation is not possible because there no longer will be a phase reversal in the feedback loop.

To model the third overtone crystal for simulation, we can add another branch of resonant arm Rx, Lx and Cx to the basic crystal model. Each series arm accounts for one resonance in the vicinity of which the other arm can be neglected. The new motional parameters should form a resonant circuit at the third overtone with:

$$C_N = \frac{C_1}{N^2}, L_N = L_1 \text{ and } R_N = R_1 N^2$$

where N = 3.

The frequency pulling range of a crystal at an overtone would be narrower than that of a fundamental frequency, because the pulling range is proportional to the motional capacitance of the crystal.

Fault-tolerant clock prototype

To be truly fault tolerant, the feedback distribution network has to be protected from short faults. For example, a short between two inputs of a voter would affect the two sourcing oscillators. Figure 13 shows the schematic for a fault-tolerant clock that has been built and tested [9].

The interconnection uses direct point-to-point wiring between the buffers. There are n^2 interconnects (16 lines for the four channels). The isolation buffer network helps to tolerate multiple faults on the bus and helps to prevent a single module failure that can bring down the bus. Without the buffers, a bridge fault that shorts any two clock lines of two modules would fail both modules.

Note that some failures do not combine together to cause system failure. For example, if one oscillator fails s-a-1, and another one fails s-a-0, then the voted clock outputs still are correct. Also, there are certain multiple failures across all channels that will not cause system failure. To illustrate this latter case, a failure in any one input pin of each voter accounts for three simultaneous faults in three channels. Because of the replicated data paths and the isolation buffers, all three clock outputs still are correct.

Validation testing with various fault types injected to a single oscillator includes stuck-at-low, stuck-at-high, stuck-at-midlevel, open- and short-circuited, bridging, power-supply-failure, noise-coupling and random-signal, such as frequency sweep from subharmonic to overtones, frequency-burst, random-pulse-train and glitches.

Conclusion

For digital microprocessor applications where small frequency shift (less than 100 ppm or 0.01%) is inconsequential, off-the-shelf crystals can be used, and frequency pulling will compensate for the differences in crystal aging, temperature variation and circuit deviation (process and components). Given the skew caused by integrated circuit process variation and probe delay variation, the clock outputs are observed to be synchronized to within 0.25 nanoseconds in the prototype.

When a channel is faulty, the design purpose is to maintain synchronization in the remaining good channels and to continue to tolerate any additional fault that occurred in that channel; therefore, each oscillator channel is a fault containment region, with the voters and isolation buffers to quarantine the fault. One programmable logic device per channel would ensure physical and electrical isolation among the

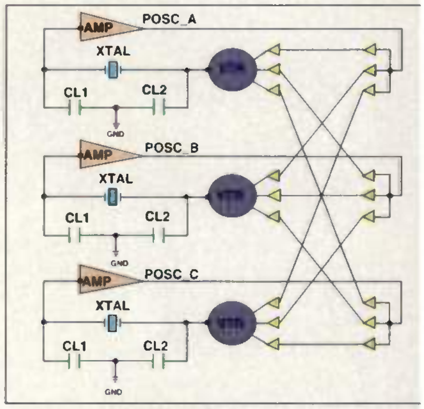

Figure 13. TMR fault tolerant clock.

channels. On the other hand, a singl custom, application-specific integrate circuit (ASIC) using silicon on sapphir (SOS) technology or using CMOS wit on-chip electrical isolation would mak an ultra-reliable fault-tolerant cloc suitable for many applications. RF

References

1. Smith, "Fault Tolerant Clockin System," FTCS-11, 1981.

2. Smith, "High Performance Faul Tolerant Real Time Computer Arch tecture," FTCS-16, 1986.

3. Somani, "An All Digital PLL Faul Tolerant Clock," IEEE, 1991.

4. Lewis, "A Fault Tolerant Clock us ing Standby Sparing," CH1396, IEEE January 1979.

5. Daly, "A Fault Tolerant Digita Clocking System," FTCS-3, June 1973.

6. Gray, "Fault Tolerant Clocks i Arrays of Processors," IEEE CH1984 4/84.

7. Davies, "Synchronization an Matching in Redundant Systems, *IEEE Trans. on Comp.* Vol C-27, Jun 1978.

8. Truong, "SPICE Techniques fo Analyzing Quartz Crystal Oscillator, *RF Design*, September 1995.

9. Truong, U.S. Patent No. 4984241 January 1991.

About the author

T. Kien Truong is an engineer with Boeing Commercial Airplane in Seattle, where he works on integrated avionics research. An Iowa State graduate and holder of three U.S. patents, his experience ranges from antenna and RF to fiber-optic sensors and fault-tolerant computing. He can be reached at tkt@clr.iasl.ca.boeing.com.

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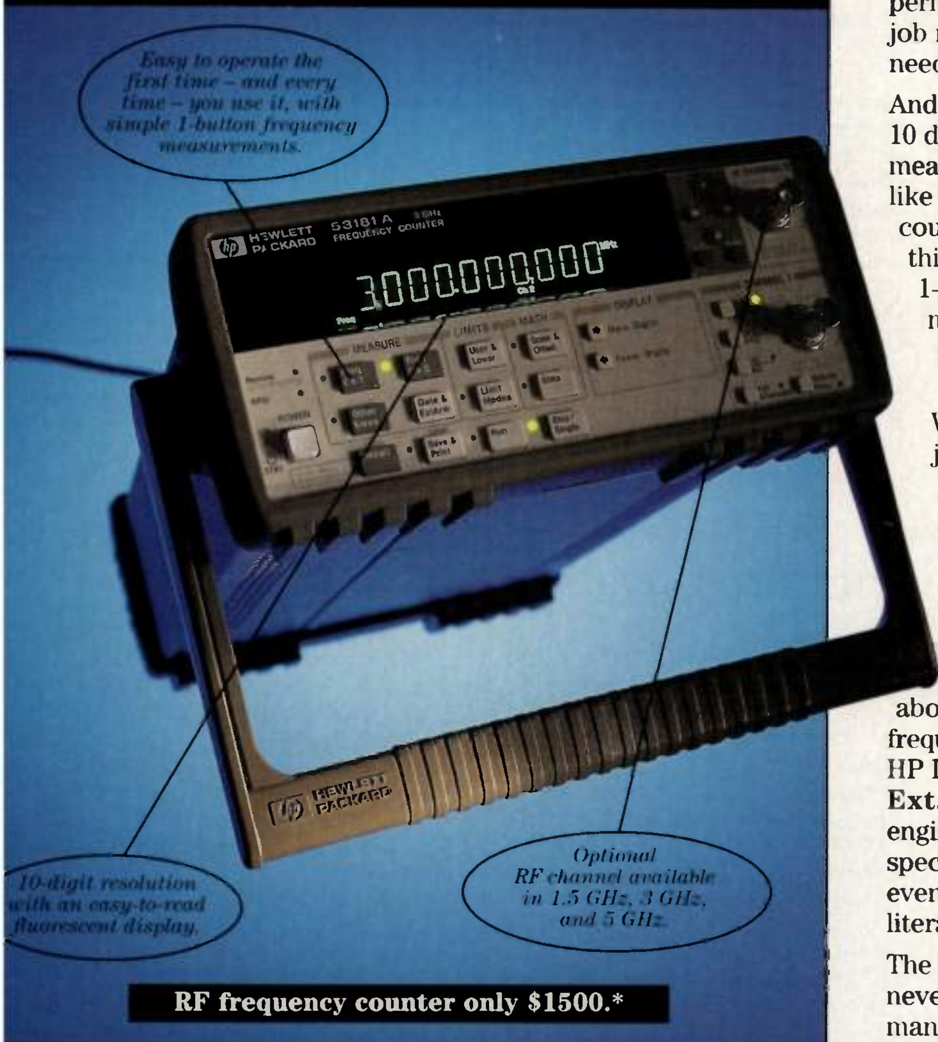

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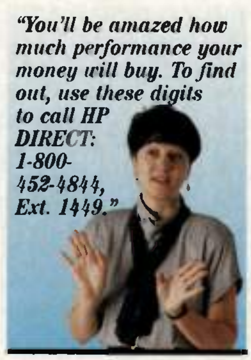

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PCS—working to make the link

By Ernest Worthman
Contributing Editor

Personal communications service (PCS) has been touted as anything from a simple "follow-me" telephone to a full-featured digital voice and data transceiver. The vendors at the PCS '96 trade show portrayed PCS as the answer to all our future communications needs. But if you have been in the wireless industry for a while, you have a more realistic perspective of the technology, its implementation and its timetable.

Although many would like to carve out a uniquely identifiable niche for PCS, the reality is that both the concept and some of the technology have been with us for quite some time in limited implementation and with different names. Technologies such as talk-back paging and cellular telephones loosely can be considered as PCS. In true PCS, the fact is that these technologies will be one or more of many components that make up the personal communications system infrastructure.

Modern PCS can be viewed as the technology with which the linking of *places* ends, and the linking of *people* begins. Additionally, PCS should be considered as "intelligent" communications, meaning it has more capabilit than mere signaling confirmations, two way voice and simple data. Here are th issues that PCS faces.

The year 2525

It is 8:00 a.m., and you just have ar rived at your office. Your personal com municator signals, and you answer. U comes a miniature liquid crystal displa (LCD) with a message that the tempera ture in the master bathroom has in creased by 10°. You enter a code and loc onto the cameras installed throughou your home. You scan the master bat

The future of DECT

Digital European cordless telephone (DECT) was originally planned as a replacement for analog cordless systems. After undergoing four years of refinements since it was issued by the European Telecommunication Standards Institute (ETSI), DECT can now boast additional features that include interoperability among various equipment and systems as well as new applications such as data transfer and connection via a wireless local loop (WLL). Numerous European countries already have reserved the frequency band of 1.88–1.9 GHz for DECT operation. DECT offers integrated services digital network (ISDN)-like speech quality, which outperforms analog systems and typically even other cellular phone systems, such as global system for mobile communications (GSM, formerly Groupe Speciale Mobile). The availability of a standardized and allocated frequency band, available data rate, interference-free operation and easy system upgrades are advantages that will continue to further the use of DECT worldwide.

DECT currently can be integrated into existing mobile communications systems such as GSM and digital cellular system (DCS) 1800, and can be hooked up directly to fixed-network technologies such as ISDN, Ethernet and asynchronous transfer mode (ATM).

Future outlook

With the "anytime anywhere" outlook overtaking business and society, DECT system use is sure to expand. Rapidly growing and expanding applications include cordless residential and business handsets, base stations, wireless private branch exchanges (PBXs), WLL and wireless local area networks (WLANs). Expected soon are further feature advances such as generic access profile (GAP). GAP will enable interoperability among different vendors' equipment and devices. Another addition is the cellular telephone modem (CTM) proposal that will add mobile public access at traveling speeds as high as 70 kilometers per hour via public DECT base stations. These and other feature enhancements are sure to add the flexibility end-users demand.

Although initial sales have been in Europe, the Middle East, Southeast Asia and Australia also are opting for DECT. China's approval is expected soon. By some estimates, DECT phone sales are projected to outstrip sales of cellphones worldwide within three years. According to the Giga Information Group, the DECT market will be a $1.9 billion market by 1998, with silicon content accounting for 20% of that value. U.S. analysts at I.C.E. predict a compound annual growth rate of 74% for semiconductors in DECT systems with a compound annual growth rate of 85% for DECT systems.

The implementation of DECT in the United States is limited by incumbent microwave users that already occupy the 1.8–2 GHz band. With component manufacturers fully committed to this digital cordless standard, DECT looks to have a promising future worldwide—especially in locations where telecommunications infrastructures have not been installed already or in densely populated urban areas where implementing further wiring is cost-prohibitive.

With DECT hardware and software design and production trends leaning toward further integration and high volumes of key components, more wireless applications (remote control systems, surveillance systems and mobile-to-mobile systems, for example) will be able to take advantage of the DECT standard.

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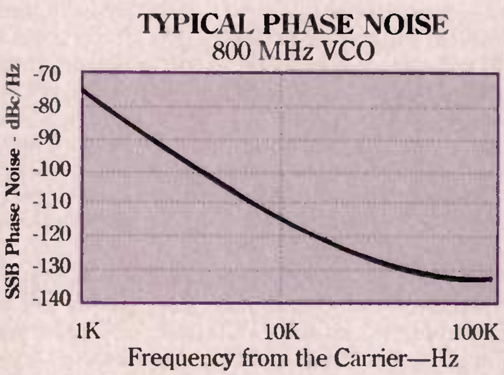

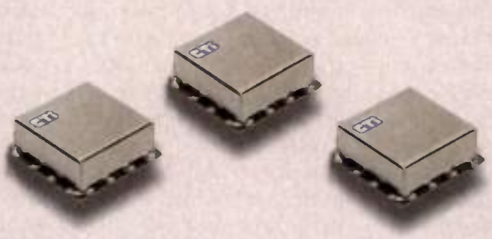

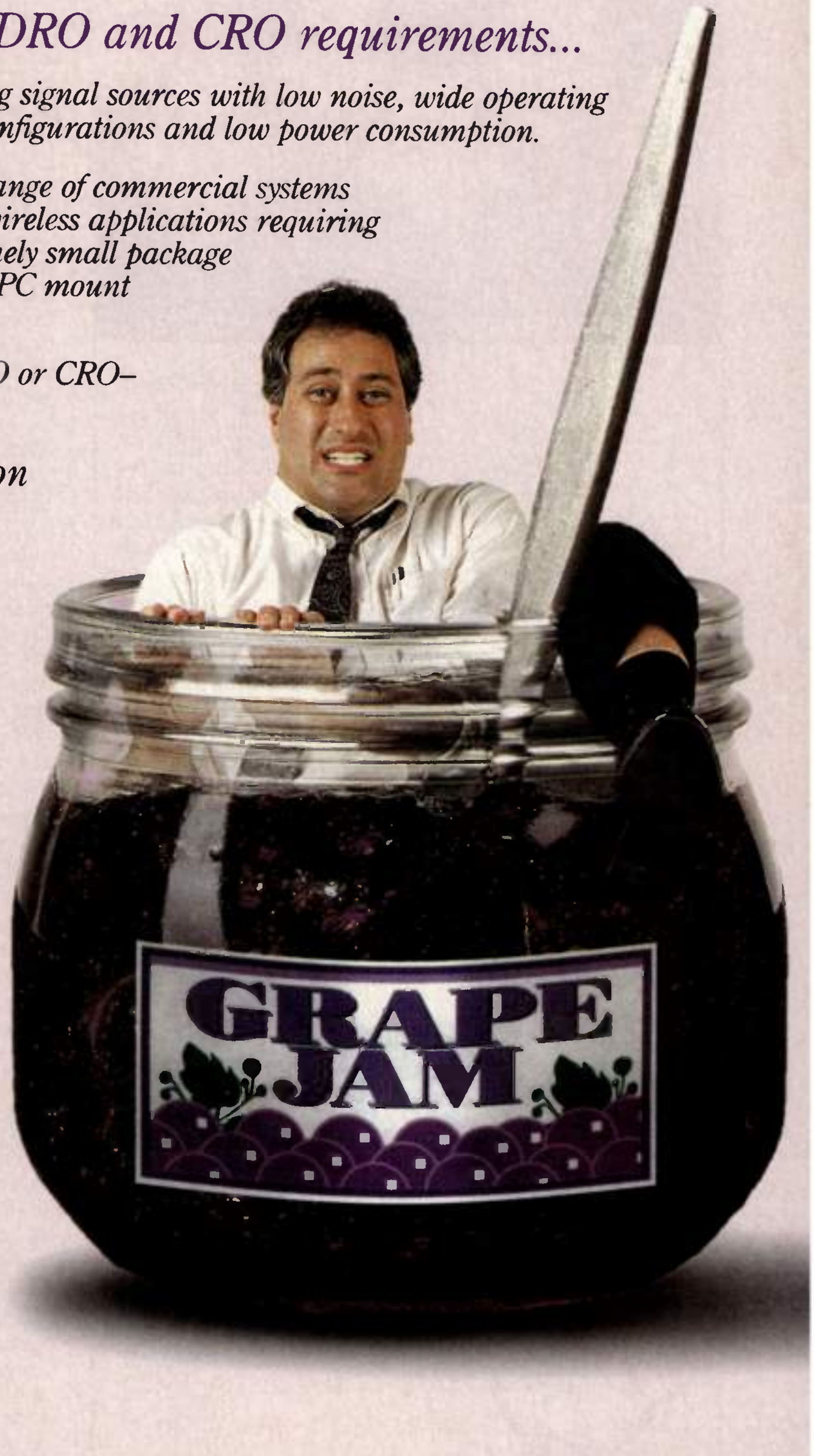

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and find that you left the wall heater on. A few more key strokes, and you are tied into your home computer. A few quic commands, and the heater is turned off. Just to be sure, yo scan the other rooms and find that the curtains in the den wer left closed. You instruct the computer to open the drapes. Fir ally, you instruct the environmental monitoring system to disre gard the alarm.

Next, you tie into the company's central data terminal an check your messages, meetings, E-mail and data that ma have been sent since you left the office. Finally, you are read to leave for a trip. You instruct your bank to pay the monthl bills electronically while you are out of town. Then, as you aı rive at the airport, your communicator automatically links t the Iridium low earth orbit (LEO) satellite network.

Sound far-fetched? Not as far as you may think. This sce nario is a typical example of intelligent communication linked to people rather than to places. The communicator yo carry replaces today's wireline telephone, cellular telephon laptop computer, pager and personal digital assistant (PDA).

Two elements of technology will be required to make th above scenario a reality. The first is the infrastructure, th second is the communicator.

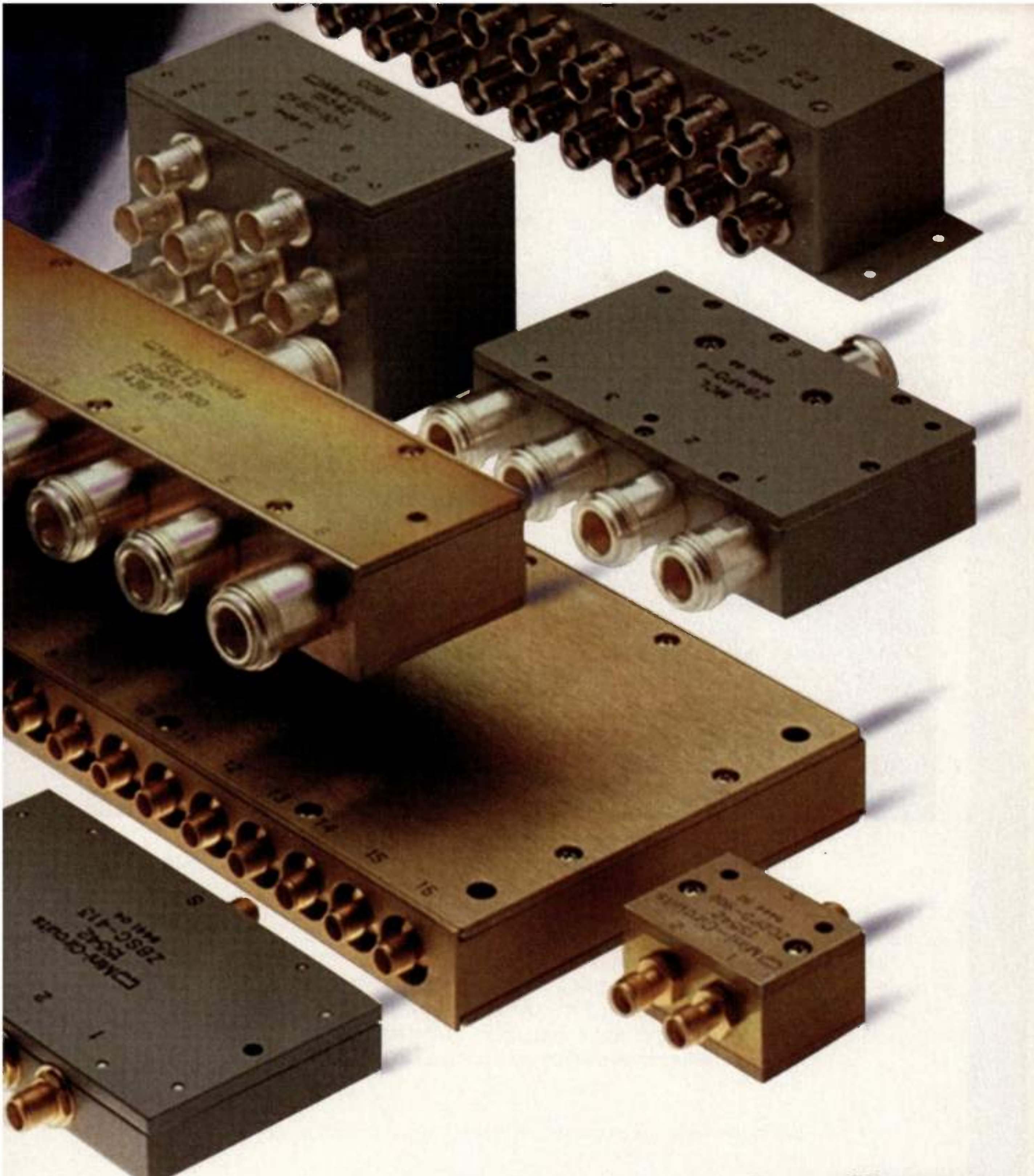
The infrastructure

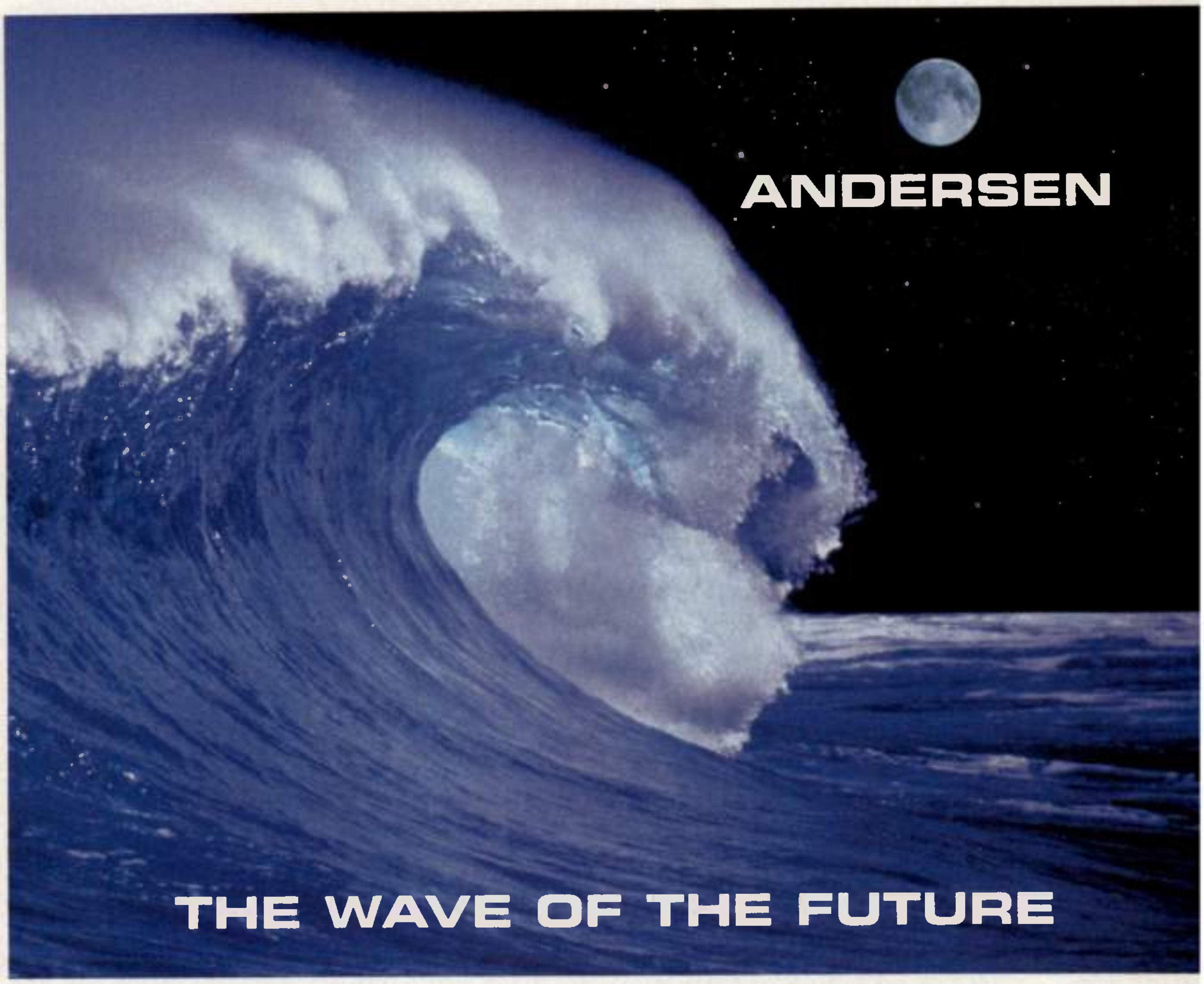
Assessing the principle needs for the infrastructure, th first issue is, of course, *spectrum.* International PCS is in th 1.7–2.0 GHz band. Although it might seem that there is suff cient spectrum at those frequencies to have the full offering (voice, image, data, full-motion video, 16-bit 44 kHz audio an other bandwidth-hungry technologies, lots of spectrum will b required. Fixed-link systems exist in this frequency band, to Moreover, this spectrum will need to be globally common c *rationalized,* as some say overseas. Table 1, p. 52, shows typ ical data rates for potential PCS services. A bit of math wi show that the bandwidth for audio and video can be quite d manding. Additionally, if services such as full-motion vide are to be offered, the data rates and related bandwidth d mands can be much higher.

Another issue the PCS infrastructure faces is real estat PCS is a low-power, line-of-site technology. There will have t be many more antenna sites for PCS than for cellular and m bile radio, and they will have to be closer together. Sites wi have to be mounted on buildings, power poles, light poles an other non-industry-owned properties or locations. Physical in pediments to support power, cabling and rights-of-way wi have to be considered along with the aesthetic perspective.

Reliability also becomes an issue. Because the system wi be required to support "walk and talk" with high frequenc and low power, propagation losses will be more of a proble with PCS than with cellular, specialized mobile radio (SMI or satellite communications. Current wireless—especially ce lular—systems have signal problems in areas such as parkin garages, tunnels, terrain dead spots and even in some foliag My experience with cellular service has proved it to be unrel able. I constantly experience dropped calls, fading, nois handoffs, out-of-area problems and co-channel interference. PCS systems are to be as ubiquitous as is predicted, they wi require intense testing, flexible configuration and fail-safe r dundancy before the users will believe in them and use the as their primary communications systems.

Yet another infrastructure issue is interconnect. Many ot er communications systems are in use today: satellite, publ switched telephone networks (PSTN), computer database digital European cordless telephone (DECT), cellular an

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THE WAVE OF THE FUTURE

SMR. For those systems to "talk" to each other often requires manual intervention or long waits and special equipment. A new level of interconnect hardware and software will have to be defined and implemented cost effectively, so the user can have access everywhere. Countries, states, local municipalities, territories, regions and governing bodies all have their own regulations and restrictions. So, in addition to the interconnect issues are the political ramifications of dealing with a worldwide political scene.

Next, transmission technologies will have to be either interfaced or standardized. Current wireless technologies implement time-division, multiple-access (TDMA); code-division, multiple-access (CDMA); and frequency-division, multiple-access (FDMA) as the most common. These complex transmission schemes are not compatible fundamentally and will require sophisticated conversion techniques to allow transparent hand-off from system to system.

Finally, intelligence will have to be built in and distributed across the system. This means that sophisticated software will be required to integrate the various components. Advanced intelligent networks (AINs) will become the backbone of the infrastructure. AINs will route calls based upon user profiles. They will accomplish tasks such as recognizing the difference between paging messages and data, and between voice and video. PCS subscribers will carry a credit-card sized smart device called a subscriber identification module (SIM) that contains the subscriber's data, billing information and caller identification (much like today's calling card). This card will allow the subscriber to access the network from any location and still be identified and properly charged when not using his or her own personal communicator.

The communicator

One of the major issues surrounding PCS is the communicator that will be used to access the network. As a society, we have become used to the traditional "telephone" look and feel as our standard communication device. If the AIN is to be realized, though, the communicator will have to be able to accommodate the various technologies (video, audio, images). For this, the standard telephone-type handset will not work. A more likely scenario will be a handset such as the one shown in Figure 1, p. 52.

Another possibility will be a variant of the personal digital assistant (PDA). PDAs offer the possibility of becoming a PCS terminal because they contain the necessary components to handle the technologies. Unfortunately, today's PDAs do not fit the mold of portable phones, and they are somewhat awkward to carry. The ergonomics of handset design are fairly well defined, and at least for the near future, handsets will have to remain similar in size and weight to the current portable and cellular design. In terms of handset design, two of the issues that face developers are display-type power use and

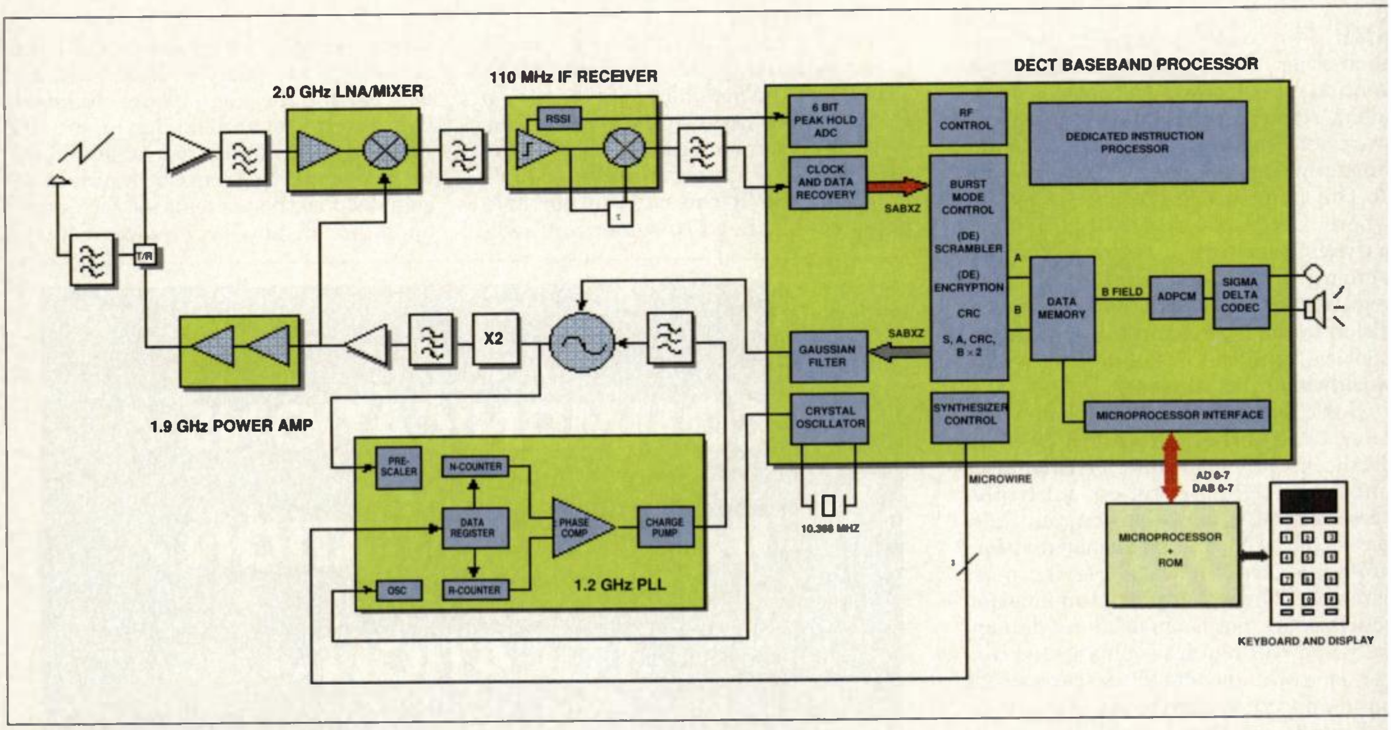

Figure 1. A complete DECT handset solution.

battery technology. Although a great deal of progress has been made in power-saving designs, one area that has made little progress is *video panels*.

Despite all of the hype promising new plasma and other focusing technology, the current rash of LCDs still leaves something to be desired. Active matrix types such as dual-scan or thin-film transistor (TFT) give better viewability than passive matrices, but require more power. Passive, low-power LCDs are inexpensive and easy to integrate, but offer poor viewability. Perhaps a good compromise will be low-current, light-emitting diodes (LEDs) once the blue LED becomes more popular.

The power issue also haunts portability. Battery science has developed new cell technology based upon nickel-metal hydride and lithium-ion (L-ion) chemistries. Both offer higher-power density than the traditional nickel-cadmium, offering better power-to-weight ratios, but both are less stable and less forgiving than older battery chemistries.

For portable communicators to be accepted widely, convenience will be the issue. Portable communicators will have to have reasonably long use away from the recharger. They will have to recharge quickly and must not be sensitive to partial discharges or temperatures. Although the new battery chemistries look promising, and it is likely that L-ion cells will be the power source of portable products for the near future, there are some clouds on the horizon for L-ion chemistry.

First, L-ion batteries are expensive. It will take a while for the industry to have adequate supply. Second, L-ion cells require sophisticated charging schemes to prevent overcharging an cell damage. Third, L-ion cells are mor sensitive to temperatures in both dis charging and charging than olde chemistries. All of these issues will re quire "smart" communicators capabl of monitoring internal components an power use. The present solution is t conserve as much power as possible b using various power-down schemes an sleep modes during idle or out-of service times.

Finally, these communicators must b marketable, meaning they must be inex pensive and easy to use. For example the home video cassette recorder (VCR has been around for more than 15 years yet more than 85% of the users canno (or will not) take the time to understan how to use it for more than simple re cording and playback.

When it comes to my cellular phone even I do not use it for anything othe than holding a few stored memor numbers and everyday calling. Why? I takes too much time to learn all of th features. So it will be a real challeng to the PCS industry to come up with communicator that will act like both telephone and a computer, yet that wi be easy to use.

Advanced intelligent networks

Clearly, AINs will be the backplan of the PCS network. AINs will be wha

APPLICATION	AVERAGE DATA RATES (KBPS)	PEAK DATA RATES (KBPS)	MAXIMUM DELAY (SEC)	MAXIMUM PACKET LOSS RATE (PACKETS)
E-Mail/paging	0.01–0.1	1–10	<10–100	$<10^{-9}$
Computer data	0.1–1	10–100	<1–10	$<10^{-9}$
Telephony	10–100	10–100	<0.1–1	$<10^{-4}$
Digital audio	100–1000	100–1000	<0.01–0.1	$<10^{-5}$
Video conferencing	100–1000	1000–10000	0.001–0.01	$<10^{-5}$

Table 1. Data rates that PCS applications require and packet-switching must provide.

allows the users to access the communications infrastructure without regard to location or information being processed. AINs will be software-driven for configurability.

The AIN consists of a three-layer model as suggested by Ashity, Sheika and Murthy (ASH93). The first level is the intelligence level, which will contain the necessary databases for the storage of information about the users. The next level is the transport level. This level handles the transport and is responsible for seeing that the information passes seamlessly from system to system and from user to user. The third level is called the access level. This level has the responsibility of integrating the different types of services. This level will be integrated closely with the transport level. It will contain the databases that track the user and will update the user databases as the user moves throughout the network.

AIN and PCS systems will pass data along this network using packet-switching technology and SS7 signaling. Packet-switching provides better reliability than circuit-switching and does not require a dedicated link with low bit error rate (BER). Also, packet-switched data can better compensate for lost or corrupt data than circuit-switched networks can. Table 1, p. 52, shows data rates that PCS applications require and that packet-switching must provide. The table also provides some data on delay and packet corruption rates. An interesting observation of the data is the delay that is acceptable with the different services. Notice that E-mail and data are the most tolerant of propagation and other delay elements, whereas audio and video (real-time, high bit-rate applications) cannot tolerate much delay at all.

Other related technologies

As is commonly acknowledged, the only way to implement successfully many of the services PCS hopes to offer is to work in the digital world. Wideband RF signals cannot easily be digitized using high-speed analog-to-digital (A-to-D) converters. To try to digitize a 2 GHz signal using a lowly 4-bit sampling rate would require a frequency of 8 GHz—an intimidating challenge, even for ultra-high-speed A-to-D converters. A digital receiver, on the other hand, makes the job more manageable by inserting an analog downconverter into the channel before the A-to-D stage. Once processed, standard off-the-shelf (OTS) components can be used for the A-to-D converter and subsequent digital stages of the receiver. A digital receiver based upon this concept is cost-efficient and solves probably the most fundamental problem associated with spectrum loading and allocation.

Earlier, I presented a scenario of some of the potential of PCS. For this to be possible, one last piece of the puzzle must fall into place. That piece is the interface between communicators and computers. Although there certainly are other possibilities, one promising technology is something called the VMEbus. Among other things, VMEbus offers A-to-D applications and interfaces for x86, reduced instruction set computer (RISC) and Motorola microprocessor-based systems. Currently, VMEbus is a prolific platform with a large number of offerings well-suited for interfacing the two technologies. It is possible that VMEbus will become the de facto standard for system integrators. This open architecture is one platform that system integrators can use either as off-the-shelf components, or to develop custom board-level components that can link computers and communications.

The future

PCS is a promising technology still in its infancy. Some PCS trial sites have had less than glowing success. Many of the technical issues need to be investigated further, and some do not have any immediate solutions. According to some FCC documentation, a number of PCS trials have been established merely to showcase the technology for customers. Not all licenses are being developed. Last year, the Canadian government had to "fire sale" licenses to generate interest.

Finally, PCS seems to have more of a following in other countries than the United States. Canada, for example, is embarking on some aggressive programs to bring PCS to large cities within the next two years. There is little doubt that PCS is the next generation of communications. But there is some doubt as to its timetable. It is unlikely that PCS will be as ubiquitous by the year 2000 as has been projected. Other technologies (e.g., cellular) are doing a reasonably good job of supplying today's wireless communications needs. The cellular infrastructure is far from bulging at the seams, and new innovations, especially in digital technology, continue to improve cellular services. There is a huge investment in current cellular technology, and it is not likely to die quietly while PCS takes over—unless, of course, the cellular companies become the PCS providers.

In the United States, the basic telephone infrastructure is aging but still adequate. The implementation of digital technology to the telephone infrastructure can give this old technology new life. RF

MRI basics and coil design principles

By David M. Peterson, G. Randy Duensing, Ph.D. and J.R. Fitzsimmons, Ph.D.

Magnetic Resonance Imaging (MRI) has become a critically important medical imaging technique during the past 20 years. Improvements in technology continue to expand the scope and effectiveness of MRI. The system is composed of four major components: the static magnetic field, *the* pulsed magnetic field gradient systems, *the* image processing and display system *and the* radio-frequency (RF) transceiver. *The following information includes a brief description of the relationship of these components. The balance discusses design details for high-field MRI RF receiver coils. Special-purpose coils are designed to optimize signal-to-noise ratio (SNR) from a given region of the body. The state-of-the-art coil system includes the use of four or more coils with four separate receivers. This method often is referred to as a* phased array *system, even though the signals are not added with fixed phase to one another.*

The static magnetic field usually is denoted B_0 and is measured in Tesla (T). One Tesla is equivalent to 10,000 Gauss. This magnetic field causes partial alignment of the normally random magnetic spin moments of certain nuclei and, thus, of a bulk spin magnetization. Most notable of MRI sensitive nuclei is hydrogen, which normally is used in MRI because of a natural abundance in the human body. The spin is modeled as an infinitesimal magnetic dipole that can rotate but that cannot translate. In the presence of the strong static magnetic field, the bulk spin magnetization can be perturbed into an oscillation around the axis of B_0. The oscillation frequency is linearly dependent upon the static field intensity. For hydrogen spins, this is 42.58 MHz/T [1]. A spinning magnetic dipole clearly will induce a voltage in a loop nearby, and this induction is the basis for signal collection in MRI. A graph of the resultant signal voltage would look like a sine wave damped by a decaying exponential with a time constant on the order of a second. The Fourier transform would be a narrow line at a frequency related to the static field by the relation given above.

With only the static field and a means of perturbing spins, no spatial information is obtained because all hydrogen nuclei resonate at the same frequency in the same magnetic field, and negligible time delay occurs from different parts of the sample to the receiver loop. The typical method for obtaining spatial information is to change the net static field as a function of position. This method allows mapping of the observed frequency spread to the field distribution. Mapping normally is done in two or three directions to encode spatially the density of hydrogen within the sample. Many modifications exist for encoding properties other than hydrogen density, but they are largely irrelevant to RF coil design. The method commonly used for changing the net static field is to use windings that produce linear fields superimposed on the main field [1]. This creates a gradient in the static field. Consequently, these windings are called *gradient coils*.

Given the static field and gradient coils (and associated drivers and control circuits), the frequency spread of induced voltages can be related to position within the sample that results in an image of some region of the body. This image is produced by multidimensional Fourier transforms that are carried out after the received voltages have been sampled and stored in the computer. The entire frequency spectrum of interest usually is on the order of 10 kHz, an extremely narrow band, considering that the center frequency is about 100 MHz. This allows the use of single-frequency matching for coils because their natural bandwidth always exceeds the image bandwidth.

The quality of MR images depends on the SNR of the acquired signal [1]. The amplitude of the signal voltages is small and comparable to the amplitude of the thermal noise developed by the AC resistance of the body-loaded loops themselves. Additionally, increasing the spatial resolution tends to reduce the SNR, so that a constant battle is waged to obtain high-resolution, but clear, images of the interior of the human body. It has been shown that the obtainable SNR depends on the static field and, therefore, on the frequency of the spin oscillation. As a result, modern, whole-body MRI systems have static fields as high as 4 T (about 170 MHz oscillation for hydrogen). Because the signal transducer is the first element of the receiver chain, it determines the obtainable SNR and thus is critical to the quality of images.

Coil design principles

Coil optimization considerations include high-frequency effects, balancing, radiation, sample loading and multiple-coil interactions. The receiver coil must be sensitive to the spin magnetic moments in the region of interest. The coil's field direction, therefore, should be perpendicular to the static field. Furthermore, it should be as insensitive as possible to induced voltage or to noise from any sources other than the region of the body for which it is designed. These requirements are unusual and differ from the design of either transformers or antennas. The coil is a large inductor with considerable dimensions in comparison to a wavelength, yet no radiation is desired. Furthermore, the near field of the large inductor is loaded with a complex, imperfect conductor. The exact shape of the coil depends on the part of the body for which it is designed.

A simple circular loop is used for analysis. A standard communications antenna is a far-field radiator that transmits through the environment (mostly air), and its signal decays with distance. An MRI coil should be a poor far-field radiator and instead should couple inductively to the conductive sample; therefore, the power should be dissipated primarily in the near field close to the conductor. To optimize coils for high-field MRI systems, many techniques from antenna design are used,

even though the goals are somewhat different.

To discuss the details of design, it is convenient to treat the coil as a transmitting source. The local RF magnetic field is related to signal reception, and power dissipation is related to noise reception. The perfect simple coil would produce a uniform RF magnetic field only in the region of interest, with no non-conservative electric fields and no radiation. The coil is usually a physically small antenna. (It fits inside a sphere of radius $\lambda/_{2\pi}$.) We can use antenna techniques (in reverse) to optimize it.

The design and construction of an MRI coil is determined by the "load" on the coil. The load is either a phantom or the actual body part that will be imaged. All the factors that influence the coil must be evaluated with the load in place to have reliable results. The coil must be matched for optimum noise figure for the preamplifier. The coil should be electrically balanced if possible [2]. Imbalance will produce local electric fields higher than necessary This causes more power loss in the sample and may produce substantia radiation. To produce a local uniform field, it is necessary to make the source current in the coil uniform as well Because the loop is relatively large, capacitors are distributed around the loop.

It is well-known that capacitance effectively shortens antennas and makes more uniform current. The standard for MRI coils is to have no more than a distance of approximately $\lambda/_{20}$ between loop capacitors [3]. The capacitors also may have local electric fields that may interact with tissue and that may cause unnecessary losses; therefore, the capacitors should be located away from the tissue or shielded with the use of a thin copper foil.

Distribution of capacitance around the loop serves two purposes. First, as mentioned above, it maintains nearly uniform current around a large loop. If the current is uniform, then the only radiation is from magnetic multipoles

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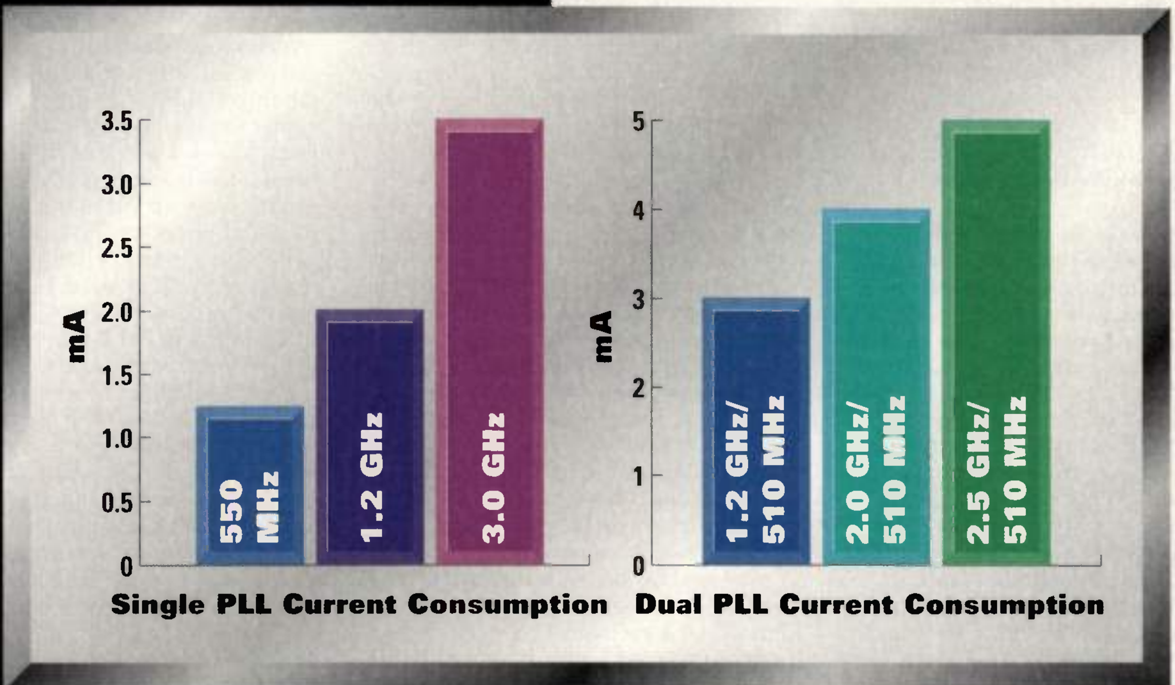

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LMX2332L	1.2 GHz (Main PLL) 510 MHz (Aux PLL)	3.0mA
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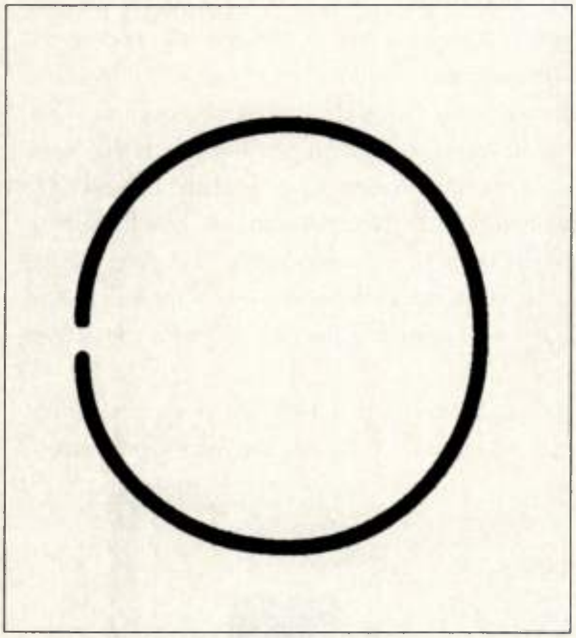


Figure 1. A simple circular loop with one gap.

generally dipole. Second, it reduces the maximum voltage present around the loop, which in turn reduces effects related to capacitive coupling with the coil. An important discussion centers on interactions between multiple coils at high frequency. Two coils are coupled if they share an impedance. At low frequency, the overwhelmingly dominant effect is mutual inductance between loops. This can be reduced or eliminated by proper geometry where the loops overlap each other such that the net mutual inductance is zero.

At higher frequencies, substantial coupling occurs through the sample. Because the sample is lossy, it is possible to have zero net mutual inductance but substantial mutual resistance [4]. This often is unavoidable and causes crosstalk and correlation of noise between channels.

Because the process of coupling to the sample is inductive, crosstalk can be reduced by overcoupling to the preamplifiers. MRI preamplifiers (GaAs FET) commonly are produced with input impedance as low as 2 Ω. The coil is matched to 50 Ω with a matching circuit. In this case, the reactance x_m is inductive and equal in magnitude to x. When the preamplifier is attached, the impedance seen by the loop looking toward the preamplifier is higher than in the matched case, generally about 10 times greater. This reduces the current in the coil during reception without affecting the SNR, and thus reduces inductively mediated crosstalk [5]. On the other hand, this increases capacitive coupling related to the voltage near the coil output because it increases this voltage relative to the matched case.

An increase in isolation is seen when using this matching scheme. Mutual resistance also may occur because of radiation effects that may be mediated by unbalanced currents to shields, between coils and through the sample. If the coils both have a given multipole character in the same physical direction, the radiation resistance increases over the sum of the two individual radiation resistances.

For multiple coils, where each is attached through coaxial cable to a low impedance preamplifier, there is considerable opportunity for interactions with the cable shields. Aside from balancing, discussed in detail below, there are other ways to eliminate these effects. A simple method used in conventional antenna design is to wrap the cable on a ferrite core. This makes a large inductive reactance that blocks this unbalanced current flowing on the outside of the coax.

For MRI applications, a non-ferromagnetic, narrowband equivalent is produced by again wrapping the coax into an inductor, but then a capacitor that is resonant with the shield inductance is placed from one end to the other. The capacitor produces a high impedance that blocks this unbalanced current, which reduces coupling to other elements of an array and eliminates loss associated with the shield current, including radiation losses. Be careful to shield the resonant loop formed by the shield and capacitor so other means of coupling are not produced.

Matching and balancing

It is conventional to transform RF coils for MRI to 50 Ω nominal impedance. The primary concern for these coils is SNR, and it is assumed that the attached low-noise preamplifier has an optimum noise figure when the source impedance is 50 Ω. On modern MRI systems, the preamplifier input impedance is not 50 Ω, i.e., the coil is not power-matched to the receiver. Usu ally, the input impedance of the prean plifier is as low as possible, typicall about 2–3 Ω. The impedance mismatc is used to decouple inductively the co from its surroundings, including othe coils [5]. The impedance mismatch do not reduce the SNR even though it r duces the power delivered to the prean plifier. This was discussed above. Th circuits discussed below all can be use for this purpose by carefully selectin components.

Associated with impedance-matchin is the problem of coupling the coil to coaxial cable with a grounded shiel Early literature discussed the proble of balancing the coil because of its ele tric field interactions with the sampl which were viewed as lossy paths t ground [6]. Other related concerns, in cluding coupling to other coils and t cable shields, as well as radiation e fects, will be evaluated in the context impedance-matching. Most of the tech niques used at lower frequencies hav positive benefits for high-frequenc coils, too. In the following section, model of a coil is used to examine th relevant issues.

The typical MRI coil for high-fiel systems can be viewed, to a reasonabl approximation, as a lossy inductor. Th resistance comes from many source including components and conductor inductively-coupled sample resistanc capacitively-coupled sample resistanc and radiation resistance.

If the system is too large, a lossy in ductor may not be an adequate mode because of non-uniform current on th coil structure. Generally, the coi should fit inside a sphere of diamete $\lambda/2\pi$ to be considered to be a small an tenna and, therefore, to be represente using lumped elements [7]. The elec trical size may differ from its physica size, making such a description diffi cult. Nonetheless, models of high frequency MRI coils using lumped circuit analysis are adequate for man purposes. As was mentioned above, dis tributing capacitors around a loop for ces the loop current to behave as a electrically small antenna.

First, consider a single-turn loo that has a single gap as shown in Fig ure 1. Measurement of the input im pedance at the gap for a particular fre quency will give a resistance an inductive reactance, assuming th small size as described above. Con ventional matching techniques produc

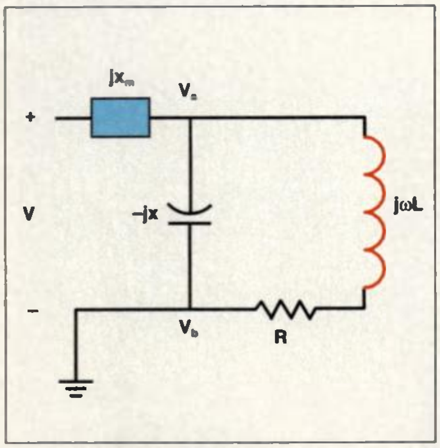


Figure 2. A schematic of a matched (to 50 Ω) circuit model of the loop of Figure 1.

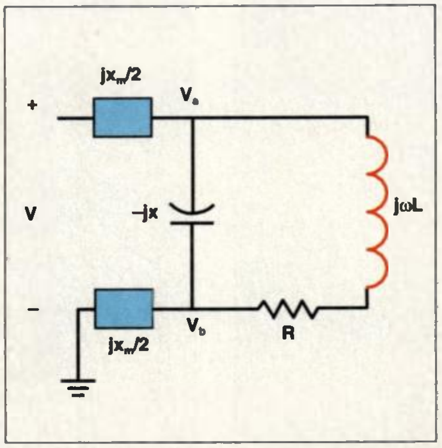


Figure 3. A more balanced version of the coil of Figure 2.

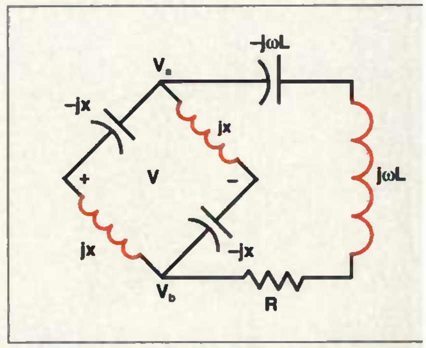


Figure 4. The component matched using a di**s**crete component balun.

the circuit model shown in Figure 2. Because the match is only adequate at a single frequency, reactive components are used in the simplest configuration, using two or three reactances.

It is interesting to examine the voltages at the gap of the loop. For this case $V_a = V(1 + jx_m/50)$ and of course $V_b = 0$. The voltage will decrease continuously from V_a to V_b around the loop. The loop will couple capacitively to anything at ground or virtual ground, with the bulk of the effect taking place from the top half of the loop.

Cable shields may have unbalanced current caused by this effect. A large, lossy dielectric, such as a person, will have current induced from this effect. Additionally, the current path through the sample may cause an electric dipole to be formed that could cause substantial radiation.

One method of reducing this capacitive coupling effect is shown in Figure 3. This method results in the voltages $V_a = V(1 - jx_m/100)$ and $V_b = V(jx_m/100)$. The potential difference is the same, but some of the voltage is now antisymmetric around the center line of the coil. There still remains a voltage V, which is unbalanced. The improvements this circuit makes depend on the details of the coil system, but several points can be made.

First, the antisymmetric part of the voltage will not produce a net coupling to a cable that lies on the coil center line. Second, the antisymmetric part of the voltage that locally couples to the lossy dielectric produces half as much power loss as does the situation described above. Finally, antisymmetric current paths that pass through the dielectric tend to produce an electric quadrupole instead of an electric dipole. This greatly reduces radiation from this effect. For the case of using th preamplifier for inductive decoupling most of the voltage is unbalanced be cause x_m is relatively low (typically 2 Ω or less).

Figure 4 shows a balun used fo matching the coil as well as for bal ancing [3]. This circuit produces th voltages $V_a = V(^1/_2 - {}^{jx}/_{100})$ and $V_b = V(^1$ + $^{jx}/_{100})$. This result is the same a above, except the unbalanced voltag has become symmetric and half a large in amplitude. This produces ha as much power loss in the sample an half as much radiation from an effe tive electric dipole that has bee halved. Coupling to a central cable sti can take place.

Finally, in Figure 5, a circuit w have developed produces entirely bal anced voltages. In this case, for th choice of $y = 50$, $V_a = -jV(1 + {}^{jx}/_{100})$ an $V_b = jV(1 + {}^{jx}/_{100})$. The circuit preserve the ability to decouple inductively th circuit using the low-impedance pream plifier. An additional +90° or –90 phase shift is required in comparison t the matching circuits in Figures 1–4 t produce high impedance from the loo perspective.

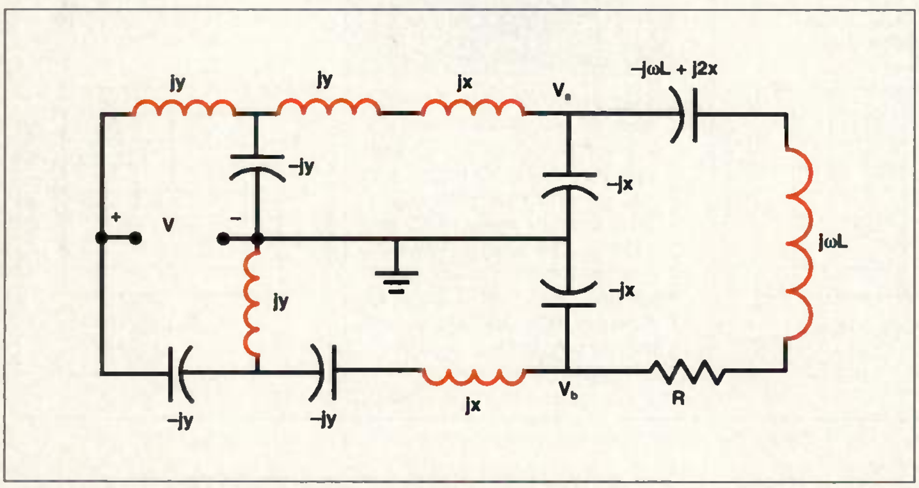


Figure 5. A new circuit for completely balanced matching of the coil.

Conclusion

MRI coil development has evolve rapidly through the application of radi wave theory. A thorough understand ing of these principles and technique becomes even more critical as the co size to wavelength ratio increase for high-field systems and as multi channel receivers continue to proli erate. Based on principles of MRI co design, a new circuit for MRI coi matching provides complete balanc and allows preamplifier-based decou pling. Although techniques have bee proven at lower frequencies, challenge still arise because coils are approachin

λ at the higher frequencies. This wi require more initial engineering desig work to eliminate susceptibility to fa field radiating effects and losses Future explorations will include the op timization of coils with shields, co relation of noise from different coils re lated to common far-field sources an investigation of the human body as secondary radiator.

References

1. Stark, David D., and William C Bradley, Jr., *Magnetic Resonance Imag ing*, The C.V. Mosby Company, S Louis, 1988.
2. Thomas, Stephen R., and Rober L. Dixon, Eds., *NMR in Medicine: Th Instrumentation and Clinical Appl cations*, American Institute of Physic New York, 1986.
3. Chen, C-N., and D.I. Hoult, *Bi medical Magnetic Resonance Tech nology*, Adam Hilger, New York, 1989.
4. Duensing, G.R., H.R. Brooker, J.F Fitzsimmons, "Noise Correlation an Crosstalk," *Proceedings of the SMI 2nd Meeting*, 1087, August 1994.
5. Roemer, P.B., W.A. Edelstein, C.I Hayes, S.P. Souza, and O.M. Muelle "The NMR Phased Array," 1990 MRM
6. Murphy-Boesch, Joseph, and Ala P. Koretsky, "An in Vivo NMR Prob Circuit for Improved Sensitivity," *Jou nal of Magnetic Resonance*, 1983, p 54, 526–532.
7. Wheeler, Harold A, "The Radiar sphere Around a Small Antenna," *Pr ceedings of the IRE*, August 1959, p 1325–1331.

RF

About the authors

David M. Peterson is an RF engineer for the University of Florida Brain Institute. He designs and improves RF coils and hardware for research on high-field MRIs.

G. Randy Duensing, Ph.D., is an assistant scientist for the University of Florida Department of Electrical and Computer Engineering and is president of Applied Resonance Technology, where clinical MRI coils are designed and produced for worldwide distribution.

J.R. Fitzsimmons, Ph.D., is a professor for the University of Florida Department of Radiology and is the technical director for the 3T high-field program at UF.

Manufacturers look to die technology to keep up with RF transistor trends

This month marks the return of the roduct forum to RF Design. *Each ıonth, this section will give the companies manufacturing the products used y RF engineers the opportunity to offer ıeir opinions regarding today's maretplace and trends in the industry ithout editorial interpretation. This ıonth, the product forum highlights ıe transistor market.*

ewlett-Packard

One of the challenges facing portable ireless manufacturers has been the radeoff between an efficient, higherformance discrete design compared ith an easier, smaller RFIC design. In ddition to traditional discretes, HP is ıking a self-biased transistor approach ielding simpler, smaller designs while ill maintaining performance, efficien- and flexibility.

An example of this direction is a selfiased Silicon RF bipolar transistor in ıe miniature SOT-363 package. This roduct achieves performance and effiencies approaching those of a pure iscrete transistor, while removing the omplexities and board space of a biasıg circuit. The grounded emitter degn allows control of collector current, llowing for H_{fe} variation and stabilizıg current over temperature. Finally, eliminates the cost, parts count and pace required for as many as eight dditional DC components.

This concept can be extended to SOT-63 packaged self-biased GaAs PHEMT roducts in development. In this case, ıey have the added advantage of reuiring only a single positive supply. heir simple design and efficient die ıyout allow these silicon and GaAs arts to be priced below traditional ideband RFIC products, creating an ınovative tool to meet aggressive sysem specifications and timetables.

EC

NEC has 10 small-signal bipolars in ıe SOT-23 package style, with f_Ts from 0 –15.5 GHz. These are also available ı the SOT-323 package style, which is 0% smaller than the SOT-23. NEC has introduced the smallest transistor package, the 19 package, which is 40% smaller than the SOT-323. It measures 0.8 × 1.6 millimeters, and seven die types are available in this package style.

To give design engineers additional options in reducing board real estate, NEC has introduced a new series of dual-chip transistors in a six-pin SOT-363 package, (1.25 × 2.0 mm). These dual-chip transistors are available in two-pin configurations. These two-pin configurations are suitable for two-stage cascode LNA circuits or oscillator and buffer amplifier applications.

M/A-Com

The world of silicon high-frequency transistors can be divided as a first cut by power level; i.e., small-signal, low-power devices and large-signal, high-power units. This first cut segregation by power level is useful because it provides some insight into the applications and markets served by these different devices. In general, small-signal devices are used only as in the "receive" side of any given radio architecture. This receive function emphasizes parameters such as noise figure, associated gain, phase noise, f_T, F_{max}, S-parameters, low voltage and low current. This functionality contrasts markedly with high-power transistors where the primary, if not only, function is the "transmission" of signals. In this mode, parameters such as P_{-1dB}, P_{out} gain, IMD, power-added efficiency, high voltage and high current become the driving factors in device performance.

In the realm of high-power transistors, silicon remains the only viable material and device technology for both radar and cellular base station applications. The only question at this point is whether the ubiquitous silicon bipolar transistor will remain the workhorse device or whether it will be supplanted by other silicon-based high-frequency structures. Leading candidates that have demonstrated performance and that realized a significant level of market acceptance, especially at the 900 MHz and 1.9 GHz cellular bands, are power MOSFETs, particularly vertically isolated LDMOS structures. Another possibility, based upon recent high-frequency, high-voltage developmental structures, is the SiGe HBT. Although adapting SiGe to the higher voltage requirement of power transistor applications tends to negate some of the raw frequency capability of the material, enough remains to provide significant frequency and power advantages over both standard BJTs and power MOSFETs, especially as the marketplace drives to higher and higher frequencies.

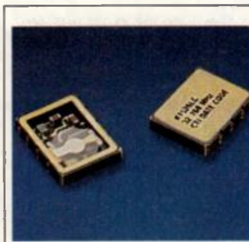
Motorola Semiconductor

The RF market has become increasingly competitive. Cost, size, efficiency and availability have become the significant drivers of designs. Today's dynamic wireless portable marketplace is making special demands on both the required RF solutions and the companies that provide these systems. It is readily apparent that there is no one RF approach to the various wireless markets. The needed approach is to offer a wide selection of topologies, technologies and packaging that allows use in almost any of the RF design applications such as analog cellular, GSM cellular, DCS, PCS, cordless phones, RF modems, cable modems and two-way pagers.

To meet the ever-increasing demands of today's communication systems, new die technologies such as silicon FET and GaAs are being used, either separately or in combination. Addressing the need to reduce size as well as cost, these advanced technologies, which include silicon LDMOS, submicron bipolar, BIC-MOS, GaAs MESFETS and PHEMTs, are being coupled with surface-mount packaging to produce cost-effective solutions in the wireless portable marketplace. To enable customers to compete in today's competitive wireless markets, it will become commonplace to see a variety of topologies, technologies and packages used together to form a total RF system. RF

RF product/services showcase

The following pages contain information about products and services of advertisers in this issue. The information is provided by the advertisers. For more information, circle the corresponding INFO/CARD number, or refer to the ad index on page 94 for the page reference to the company's advertisement.



The K1526 series of voltage controlled crystal oscillators (VCXOs) is compatible with today's phase-locked loop (PLL) applications found in digital access radio, wireless base stations and telecommunication transmission equipment. Available for frequencies from 2–55 MHz, the ceramic package measures 0.56″ × 0.36″ × 0.16″.

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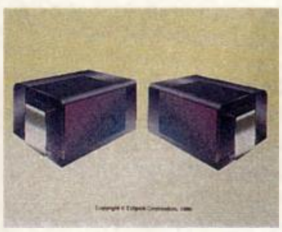

The EC3225 and EC 4532 series of surface-mount inductors have an inductance range of .012–220 µH and 0.1–1000 µH, respectively. Other features include a tolerance of ±5%, ±10% or ±20% and an operating temperature range of –25°C to 85°C.

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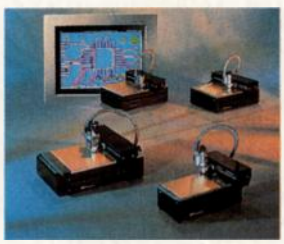

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Model 50P-1094 is a solid-state programmable attenuator designed for cellular and PCS applications. It features a frequency range of 700 –2,000 MHz, an attenuation range of 127 dB in 1 dB steps and TTL control.

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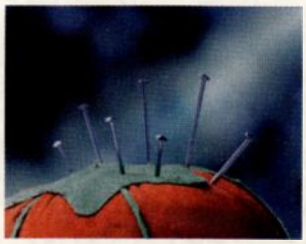

HOW MANY TOKO LL'S CAN YOU PLACE

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And how much board space can you gain?

Such a micro size may seem impossible, but not to Toko engineers. The LL1005 (inductance range 1.0 to 27.0 nH) is merely the latest addition to Toko's micro-miniature line of ceramic multilayer chip inductors available from Penstock. With an 0402 footprint and an 0.05 profile, *the LL1005 is the world's smallest*-by far.

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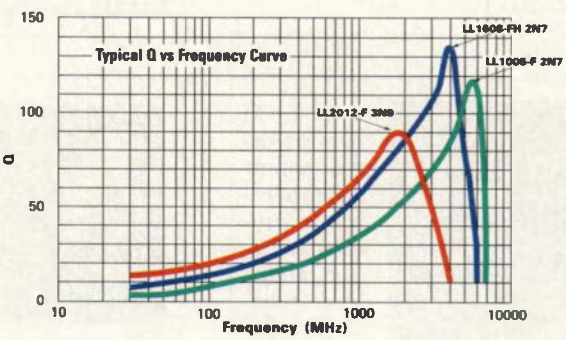

Toko LL Prototyping Kits Available

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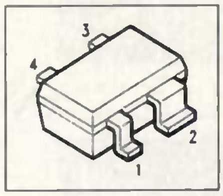

The BFP 405, BFP 420 and BFP 450 are three Siemens grounded emitter transistors (SIEGET) featuring a grounded emitter configuration, high-transition frequency and high reliability. Designed for high-gain, low-noise and low-power consumption applications, they operate as high as 12 GHz.

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The Avantek catalog of RF & microwave products features data sheets for cascadable modules, cascadable amplifiers, thin-film amplifiers, case styles, voltage-controlled limiters, limiting amplifiers, gain control amplifier modules, detectors and attenuators.

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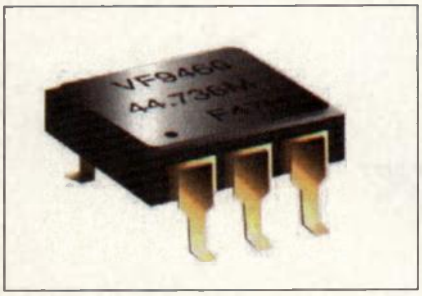

The VF946 s-type crystal oscillators feature HFFX crystals which acheive greater pulling on higher frequencies with low phase noise.

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The SA038WA-008 surface acoustic wave (SAW) filter takes up less than half the board space of commonly used SAW filters. The filter features a miniature LCC package and is designed for digital audio broadcasting (DAB) applications.

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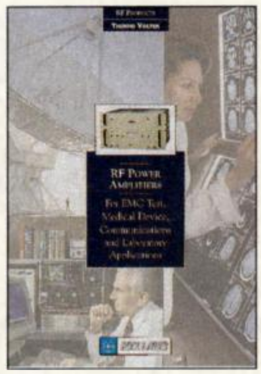

The RF power amplifier catalog features EMC test amplifiers, communications amplifiers, pulsed amplifiers, dual band amplifiers, distribuited tube amplifiers and OEM amplifier modules.

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The UPB 1004GS receiver-on-a-chip for GPS applications combines a double RF/IF downconversion block and PLL frequency synthesizer in a 30-pin SSOP package. Designed to convert a 1575.42 MHz input to an IF as high as 5 MHz, it delivers 92.5 dB typical total conversion gain. Features include spurious signal rejection, high sensitivity and low power consumption.

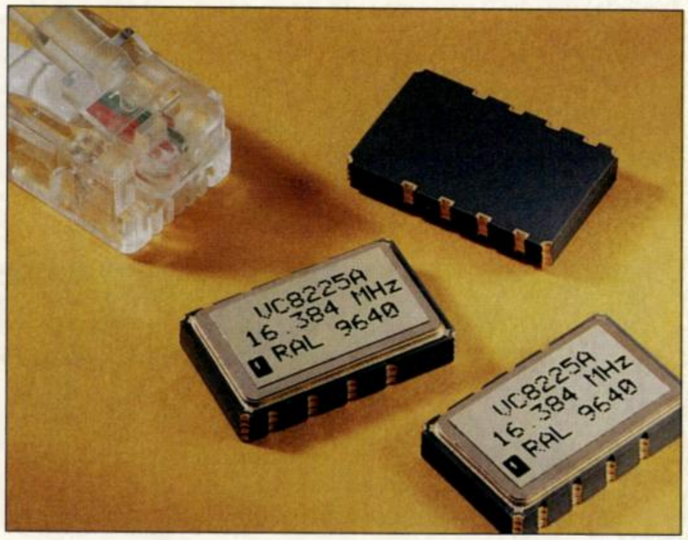
California Eastern Labs
INFO/CARD 168

RF products

Surface-mount VCXO offers power-saving enable and disable control

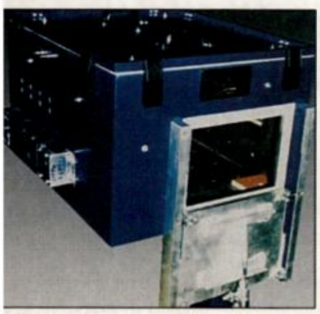
Designed for use in high volume portable products, the VX-8000 series surface-mount voltage-controlled crystal oscillator (VCXO) features a J-lead package profile height of 0.185″ and a flat pack profile height of 0.150″. The VX-8000 series has enable and disable control, which allows the user to stop clocking unused complimentary metal oxide semiconductor (CMOS) parts, thus helping to reduce power consumption. They are avialable at any frequency from 1–160 MHz, which includes 155.52 MHz for use in synchronous optical networks (SONETs) and asynchronous transfer networks (ATMs) and operate at either 3.3 or 5 V. Linearity is ±10% or better. Stability is within ±25% higher than the operating temperature range of 0°C to 70°C. The VX-8000 series is priced as low as $12 each in quantities of 100,000 depending on frequency, package and configuration.

Raltron Electronics
INFO/CARD 169



In-line EMI/RFI shielded enclosures

Allowing products to undergo accurate, efficient testing without removing the product from the manufacturing line, these enclosure designs test in-line electromagnetic interference and radio frequency interference (EMI/RFI) of wireless and cellular products. Designed using welded metal construction, the



in-line enclosures meet the specific automation and throughput needs of the manufacturer. The enclosure is designed to interface with the manufacturer's programmable logic control (PLC) used to control a complete automated test sequence.

Lindgren RF Enclosures
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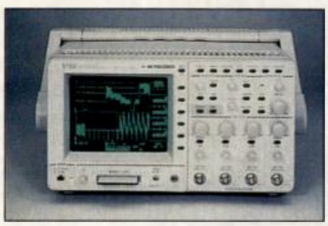
Four-channel digital oscilloscope

Model 5150, a four channel digital storage oscilloscope, features a 50 GS/s



sampling rate for repetitive waveforms and a 200 MS/s sampling rate for non-repetitive waveforms. Other features include: automatic setup of timebase; 40K of internal memoery with a built-in Personal Communication Memory Card Industry Association (PCMCIA) slot that provides an additional 1 MB of memory per card; and as many as 16 automatic measurements. Stored signals can be compared, manipulated, displayed and transmitted in a variety of formats, while selected portions of measured waveforms can be compared directly with waveforms stored in memory. The 5150 is priced at $4,995.

B+K Precision
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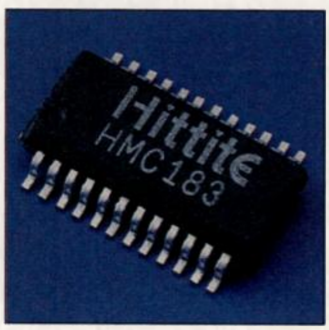
SP8T GaAs MMIC switch

The non-reflective HMC 183QS24 single pole eight throw (SP8T) gallium arsenide (GaAs) monolithic microwave integrated circuit (MMIC) switch operates from DC to 2 GHz, covering cellular, personal communications service (PCS) and dual-band designs. Designed to replace discrete positive intrinsic negative (PIN) diode or multiple SP4T MMIC switch designs with a single easy-to-interface device, the switch features



isolation of 40 dB at 1 GHz and 32 dB at 2 GHz, insertion loss of 1.3 dB at 1 GHz and 1.7 dB at 2 GHz and switching times typically about 25 nanoseconds.

Hittite Microwave
INFO/CARD 172

Power entry filters designed for EMI

A complete line of power entry filters designed for general-purpose broadband

electromagnetic interference (EMI) filtering includes power entry modules, printed circuit board (PCB) mount power filters and power line filters. Power entry modules are rated for voltages as high as 10 A and are available with a varitey of terminal styles. Miniature PCB-mounted power filters are rated for AC or DC currents as high as 3.6 A and are standard for two-wire cord systems. Power line filters are rated for AC or DC currents as high as 30 A and will filter differential mode and common mode noise.

Spectrum Control
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CABLES AND CONNECTORS

Adapters for waveguide to coaxial connectors

Two series of right-angle-launch and end-launch adapters from WR22 waveguide to 2.4 millimeter coaxial connectors feature a connection that offers 30–40 dB improved connection repeatability over conventional flanges. The J236 series of right-angle-launch adapters features a voltage standing wave ratio (VSWR) of 1.15 typical across the entire waveguide band. Th
J237 series also offers low VSWR witl
the added convenience of an in-lin
design.

Maury Microwave
INFO/CARD 174

Shielded stereo jack for audio applications

The ST-3200 stereo jack, designe
for audio applications, has a 3.5 mil
limeter high profile for PCB layout
requiring 6.5 millimeter height off th
board. The threaded or non-threade
bushing provides grounding protectio
The ST-3200 is shielded to provide elec
tromagnetic interference and radio-fre
quency interference (EMI/RFI) protec
tion. Both three and five positions ar
available.

Kycon Cable & Connector
INFO/CARD 175

Coaxial D connectors for data, computer applications

A 75 Ω coaxial D connector syste
allows coaxial cables to be used wit
normal data lines with only a single I
subminiature plug and socket. Designe
for data and computer application
they are priced less than $5 each.

Connect-Tech Products
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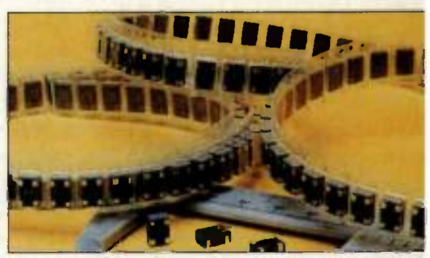
DISCRETE COMPONENTS

ESR capacitors feature extended ranges

Type ESR polymer aluminum capac
tors offer lower impedance at freque
cies of 100 kHz and higher when co
pared to tantalum and convention



aluminum electrolytic capacitors. Th
capacitors are available in 33 uF @ 8 V
22 uF @ 12.5 V and 10 uF at 16
capacitance ratings. All three capac

ors feature an ESR of 15 milliohms.
Cornell Dubilier
INFO/CARD 177

Quarter-watt resistor provides high performance

The WSL-1206 chip-style resistor offers an ohmic value (0.007–0.2 ohms), inductance (0.5–5 nH) and the precise stability (±1% tolerance, ±75 ppm/°C temperature coefficient) normally associated with only wirewound resistors. Designed for battery monitoring in wireless applications, it also features a small size (EIA 1206) and is priced at 28 cents each in quantities of 10,000.
Dale Electronics
INFO/CARD 178

Surface-mount inductors for RF applications

The SML 44 series of high-current inductors features a small height (4.5 millimeters) and range from 10 uH @ 1.3 A to 680 uH @ 0.160 A. These inductors, designed for SMPS and RF applications, use a ferrite bobbin mounted to a ceramic substrate and are priced at 43 cents each in quantities of 10,000.
Gowanda Electronics
INFO/CARD 179

SUBSYSTEMS

ISM antenna designed for WLAN

Designed for 2.4 GHz industrial, scientific and medical (ISM) band applications, such as wireless local area network (WLAN) and wireless modem, the Nova Comm miniature antenna features a gain of 1.8 dBi (typical), 50 Ω impedance and a voltage standing wave ratio (VSWR) of <= 2. The antenna is priced at $5.95 in quantities of 10,000.
Nearson
INFO/CARD 180

Downconverter module phase and gain tracked

Model DA4 series four-channel downconverter module operates over RF and LO frequency bands in the range of 0.5–18 GHz. Standard designs include input limiter protection diodes and an IF amplifier. This unit can be used for basic direction-finding equipment or as an integrated receiver front end for a monopulse radar receiver.
Miteq
INFO/CARD 181

GPS antenna designed for surveying

Designed to provide superb tracking capability, the DM C146-20 broadband antenna has a minimum gain of −4 dBic at 5° above the horizon. It operates in the 1.2–1.625 GHz global positioning system (GPS) frequencies and has a small radome with a low profile.
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Power splitter and combiner for cellular and PCN use

A wideband 800–2,000 MHz 4-way, 0° power splitter and combiner enables high-performance cellular, personal communications network (PCN) and instrumentation applications to function in a high-isolation (25 dB typical), well-matched (voltage standing wave ratio (VSWR) of in 1.20, out 1.10 typical) environment. The ZB4PD1-2000 features a maximum power inpu of 10 W in 50 Ω systems and is price at $94.95 each in quantities of fewe than 10.

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Fixed channel up/down frequency converters

Models PUL 070D, PDL 070D data grade frequency up/downconverters fea ture an input or output frequency of 7 or 140 MHz and an output or input fre quency of a customer-specified L-ban channel within the 950–1,450 MHz fre quency range. Both models feature a input return loss of 9 dB nominal an an output return loss of –13 dB nomi nal, and measure 1.75" × 19" × 12".

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INFO/CARD 184

Subminiature SAW IF filters for GSM

A surface acoustic wave (SAW) filte for global system for mobile commun cations (GSM, formerly Group Speciale Mobile) applications i designed for use with the new genera tion GSM chip set architectures requi ing higher-frequency intermediate fre quencies (IFs) in the 240 MHz range The filter features a center frequency o 246 MHz with a passband of ±80 kH The rejection bandwidth is 25 dB mini mum at ±40 kHz and 45 dB minimum at ±80 kHz. Typical insertion loss i less than 6 dB. Designed for use as a IF bandpass filter for personal commu nications service (PCS)-1900 and dig tal communications service (DCS)-180 applications, it measures 9.1 × 4.8 × 1. millimeters.

Toko
INFO/CARD 185

Varactor series meets wireless design needs

The MA4ST200 series of high qualit factor (Q), high capacitance ratio varac tor diodes enables applications such a cellular phones, active pagers and auto motive wireless systems to seek th highest quality signal and lock onto th desired frequency. Designed for voltag control oscillators (VCOs) and voltage tuned filters used in battery-operate wireless systems as high as 2.5 GH the diodes typically have a Q of 400 a

50 MHz and a capacitance ratio of 3.5 from –0.5 to –4.0 V. The MA4ST200 is priced at 40 cents in quantities of 10,000.
M/A-Com
INFO/CARD 186

Separate filters isolate frequency bands

The PTD87/39NF diplexer uses one bandpass filter for the 1,375–1,400 MHz frequency band and uses another bandpass filter for the 1,427–1,452 MHz personal communications services (PCS) frequency band. The diplexer features a passband insertion loss of less than 1 dB, an ultimate stop band attenuation of 80 dB minimum and an RF power capability of greater than 15 W.
Penny Technologies
INFO/CARD 187

SIGNAL SOURCES

Product combines TCXO, OCXO technologies

A family of products based on resonator-thermostat (RT) technology incorporates a directly heated quartz crystal, a temperature sensitive element and a thermocontroller circuit

sealed in one enclosure. The family features the performance of an oven controlled crystal oscillator (OCXO) while maintaining the size, power consumption and warm-up time of a high-end temperature controlled crystal oscillator (TCXO). Specifcations include 90 mW power consumption, phase noise of -155 dBc/Hz @ 10 kHz offset and a frequency range of 8–25 MHz for the RT, OCXO and 2–105 MHz for the OCVCXO.
Valpey-Fisher
INFO/CARD 188

VCXO designed for PLL applications

The K1526LC series of surface mount (SMT) voltage controlled crystal oscillators (VCXOs) is designed for phase-locked loop applications used in clock recovery, signal tracking and local reference clocking circuits. The VCXO delivers a TTL/CMOS compatible output on frequencies ranging from 2–40 MHz. Requiring 5.0 V input, it provides a typical pull range of ±120 ppm over a control voltage range of 0.5–4.5 V.
Champion Technologies
INFO/CARD 189

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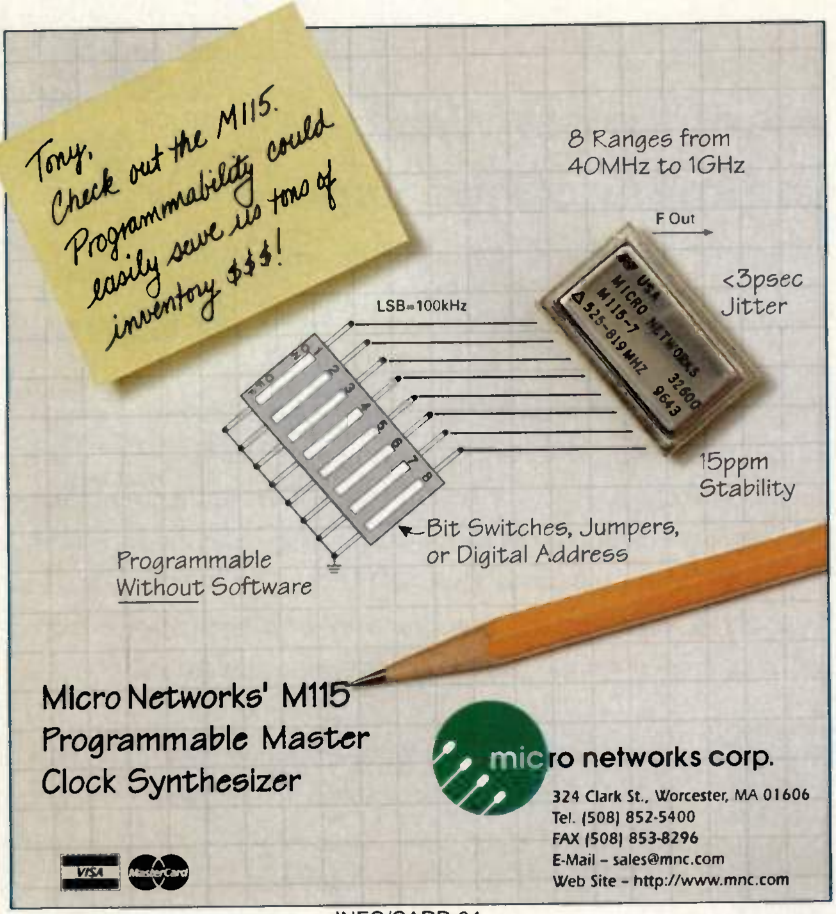

RF software

Analog simulation, schematic entry integrated

Intusoft's series of analog an mixed-signal design tools integrat analog and mixed-signal capability int OrCAD Capture, Protel Schematic an Viewlogic Workview Office schemati tools. The software packages are calle ICAP for OrCAD, ICAP for Protel an ICAP for Viewlogic. Each packag includes the IsSpice4 native mixe mode (analog and digital) circuit simu lator, SPICE model libraries with mor than 8,000 analog and digital parts the IntuScope graphical waveform ana lyzer, the SpiceMod Spice modelin program, a set of symbol libraries an the Intusoft Integration Module, whic allows engineers to run SPICE simula tions directly from the OrCAD, Prot or Viewlogic schematics and to cross probe the results in real time.
Intusoft
INFO/CARD 160

Real-time development environment available

Hyperception's real-time integrate development environment (RIDE) is visual environment optimized for th design, implementation and analysis real-time digital signal processin (DSP) algorithms and systems. It power lies in its visual nature and sup port for industry-standard plug-in DS boards. Hypersignal RIDE allows DS applications to be generated quickl with little or no software coding re quired. RIDE's support of several di ferent DSP chip families from differen semiconductor companies, as well a its support for different DSP boar vendors, makes it suitable for man real-time DSP projects. The devic independent approach allows differen types of DSPs to be used in the sam design. The ability to move designs fro one DSP technology to another in th same environment means that users d not have to learn multiple tools, an they can upgrade their designs in th future for more performance.

RIDE was created by combinin DSP hardware with Hyperception hypersignal block diagram applicatio and Windows DSP board driver These board drivers are installed fro the Windows control panel just lik other peripheral devices. The drive handles all communications and co trol of the DSP hardware from the P environment. The block diagram appl

:ation does not require information ıbout what DSP hardware is being ısed. The RIDE driver links DSP object iles, downloads code, data and parame-ers to the DSP memory, controls the ·xecution of the DSP and monitors ıctivity on the DSP.

The user interface is the same for ›oth simulated and real-time DSP ›lock functions. This allows for conve-ıient conversions between design simu-ations and real-time implementations.

Hypersignal RIDE is available for ;3,995. An automatic C code generator an be purchased with RIDE for $5,000. 3undled packages including all hard-vare and software also are available.

Iyperception
NFO/CARD 161

;oftware automates mmunity testing

Amplifier Research (AR) SW1000 esting software permits computer con-rol of AR power amplifiers, signal gen-rators and other equipment for a ange of immunity testing require-ıents, including IEC-1000-4-3. The oftware uses an IEEE-488 communi-ations link with a power meter or field ıonitoring system to level by power or eld strength.

The SW 1000 software is designed to perate as a stand-alone program for Vindows 3.1 and 95. It was developed nder the National Instruments (NI) ıabview environment and can be run in ombination with more than 500 in-trument drivers. The software permits se of as many as eight digital output hannels for control of test instruments.

ımplifier Research
NFO/CARD 162

:valuation software lemonstrates capabilities

Labview Evaluation software on CD ›r Windows, Power Macintosh, Sun parc stations and Hewlett-Packard 000 series workstations is a free raphical instrumentation software ackage. Users can access details about abview add-on toolkits, technical sup-ort and customer education. Applica-ons involve instrument control, data cquisition, analysis and presentation ›r test and measurement industrial utomation. On-line tutorials guide sers step-by-step through building a ıstom virtual instrumentation system.

[ational Instruments
NFO/CARD 163

TIA publishes interim standards

The Telecommunications Industry Association (TIA) published two interim standards. TIA/EIA/IS-96-B, speech service option standard for wideband spectrum systems, forms a standard for service option 1, which provides two-way voice communications between a base station and a mobile station using the dynamically variable data rate speech code algorithm. The transmitting speech code takes voice samples and generates an encoded speech packet for every traffic channel frame. The receiving station generates a speech packet from every traffic channel and supplies it to the speech code for decoding into voice samples.

TIA/EIA/IS-126-A is the mobile station loopback service options standard. It provides the basis for a loopback of primary traffic information bits through a mobile station. It also provides the means for a base station to supply a known data stream on both the forward and reverse traffic channels, so that a mobile station's receiving and transmitting performance can be measured. The service option also provides a convenient means of setting up calls and generating traffic for system testing, and it allows for normal operation of signaling messages and secondary traffic.

TIA
INFO/CARD 164

Components catalog features terminal blocks

A 45-page catalog of electronic components featuring Magnum terminal block line is available. Complete specifications, illustrations, photographs and ordering information for products are included. The company's wire-ready option is available on all single-row terminal blocks. Other products offered are double-row terminal blocks, edge board connectors and Mag-Master electronic and field wiring interfaces.

Bussmann Circuit Components
INFO/CARD 165

Products designed to eliminate EMI, RFI

A 44-page catalog details a line of power products designed to eliminate electromagnetic interference (EMI) and radio frequency interference (RFI). This line of power products includes high-current, single-line filters, power arrays, power-entry filters, power-line filters, multisection filters, custom assemblies and power distribution systems.

The catalog provides features, applications, order numbers, performance specifications, temperature characteristics, insertion loss curves, circuit diagrams and line drawings for each of the product lines. Also covered in the brochure is the company's EMI filtering experience and electromagnetic compatability (EMC) testing services, application guidelines for using EMI filters, EMI measurement guidelines and a design inquiry form.

Spectrum Control
INFO/CARD 166

Modulator and demodulator products described

A free brochure from Stanford Telecom presents modulator and demodulator application specific integrated circuits (ASICs) and board-level assemblies for hybrid fiber and coax (HFC) upstream community antenna TV (CATV) systems. The four-page brochure describes the company's capabilities in the interactive cable transmission and reception segment.

Information is included on the STEL-1108 bipolar phase shift keying (BPSK) and quadrature phase shift keying (QPSK) digital modulator ASIC chip used in subscriber modems an set-top boxes.

Stanford Telecom
INFO/CARD 167

Catalog details signal components, subsystems

Technical Research and Manufactu ing's 100-page signal-processing com ponents and subsystems catalog detail an array of products. The catalog i arranged in nine sections comprisin power dividers, directional coupler hybrids, mixers, transformers, phas comparators, modulators and beam forming networks.

Technial Research and Manufacturing
INFO/CARD 168

Filter products catalog released

Micro-Coax's *Filter Products Catalo* features the company's family of In-A Cable filters, which combine Cheby shev and other filter types with sem rigid or flexible cables to produce pe formance in the same space as th cable alone. The free 38-page catalo includes technical information, speci cations and application informatio about all of the products.

Micro-Coax
INFO/CARD 169

On line:

ASIC products on web page—Qualcomm's web page features a line of synthesizer, forward error control, voice compression, automatic gain control and code division multiple access (CDMA) application specific integrated circuit (ASIC) products developed for advanced communication systems.

Included in the ASIC web site are an overview of each product, worldwide sales information, new product releases and the option to download any technical data sheet or application note. The ASIC products can be found within the Qualcomm web site at http://www.qualcomm.com/Prod Tech/asic.

Qualcomm
INFO/CARD 170

Home page redesigned—Anadigics' web site provides corporate information, company news, information on products, links, industry news and engineering tools. The web site also features Java applet engineering tools to help designers evaluate and model receiver performance in communications systems. The site is located at http://www.anadigics.com.

Anadigics
INFO/CARD 171

Free catalog available—Time Motion Tools' catalog features telecommunication, coaxial, test and measurement meters, including the Fluke 7-300. This low-voltage (as high as 300 volts AC or DC) meter automatically decides between measuring volts, continuity or ohms. The company's web site is located at http://www.timemotion.com.

Time Motion Tools
INFO/CARD 172

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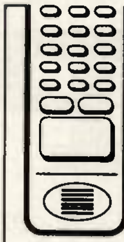

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CATV Design: Rf Design experience should include LC filter, microstrip, amplifier, circuit modeling and system analysis in the 5-1000Mhz range. BS/MSEE fiber optics a plus.

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RF Engineer: RF circuit design and development for wireless phones. Develop radio architectures and RF circuit design for systems operating in the 800-900MHz and the 1800-2000MHz regions.

Sr. Project Antenna Design: Lead the conception, design and development of a wide variety of antennas and antenna systems, including both reflector and array systems using microstrip, stripline and waveguide technologies. BS/MS with 5 years experience.

RF Design Manager: Lead a team of RF engineers from initial design and implementation through product integration and testing into high volume production. 8+ years of RF design with emphasis on low cost radio design. BS/MS.

Sr. MMIC Design: Design highly integrated GaAs MMICs for advanced cellular products. Circuits to be designed include power amplifiers, LNAs, mixers, IF amplifiers, buffer amplifiers. RF frequencies are 900 and 1800 MHz.

Product Line Manager Wireless: Specific responsibilities include product line strategic planning, establishing revenue and price objectives, setting internal cost targets and oversight of internal product realization schedules.

RF PA Engineers: Requires 3+ years experience in design, test and manufacturing of high efficiency GaAS MESET and HBT class A and C power Amplifiers (c2watts) in the frequency range (-2GHz). Experience in both discrete and MMIC design a plus

Sr. Analog IC Designers: Responsible for conceptual circuit design and developing new analog/mixed signal ic's. BS/MS experience in A/D D/A, ASIC's bipolar and BiMOS.

Filter Design Engineer: Development of microwave high "Q" coaxial cavity and machine filter designs for PCS base stations. BS/MS familiar with simulation and modeling tools, three plus years filter design experience with direct "Q" designs (6-8000 Q's).

Applications Engineer: 5 years of directly relevant RF/MW engineering applications and measurement techniques. Strong presentation and instructor skills; must be able to communicate effectively with individuals and groups of all levels of technical expertise and experience

Senior RF Engineer: Design RF and Microwave components for microwave digital communication links. Develop RF hardware block diagrams and perform analysis for communication systems. BSEE or MSEE with 5+ years experience in Microwave circuit design such as microstrip, low noise amplifiers, power amplifiers, mixers, oscillators and RF circuits.

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