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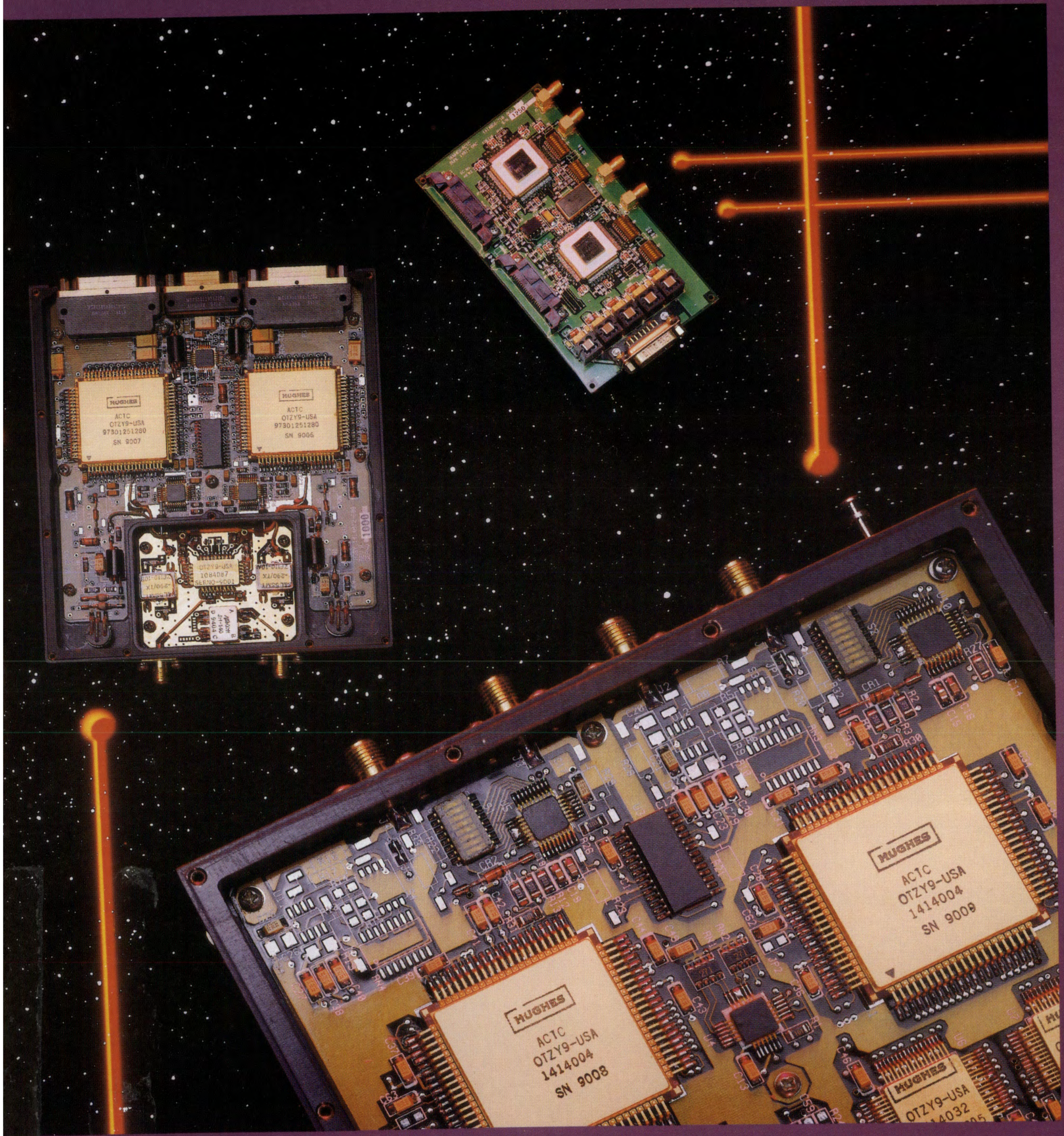
September 1994



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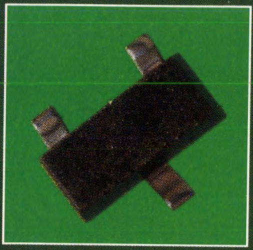

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- Excellent power handling
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- Hermetically sealed ceramic package
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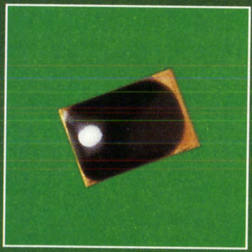

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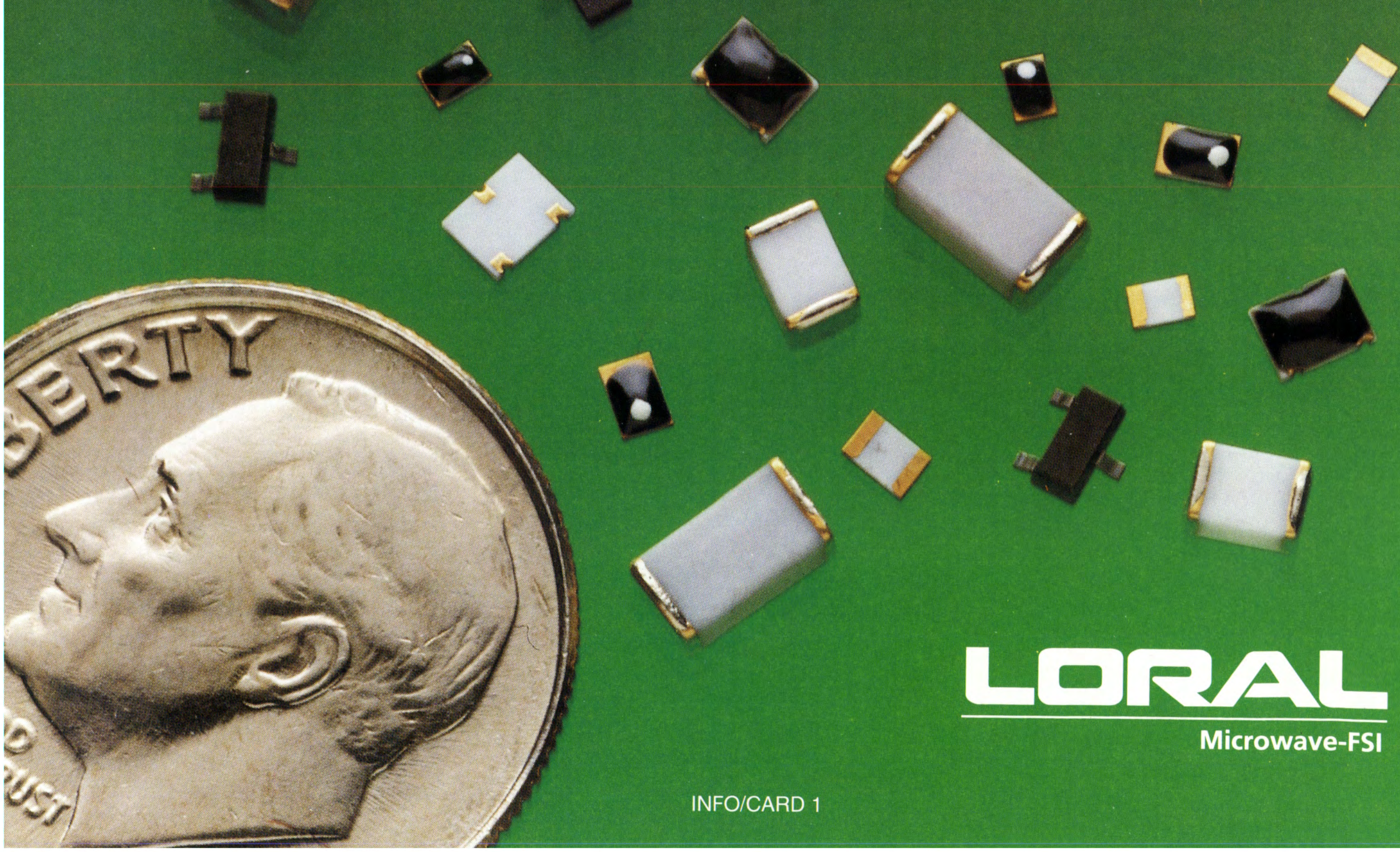
- Tough epoxy-on-alumina construction
- Ideal for microstrip or pick-and-place



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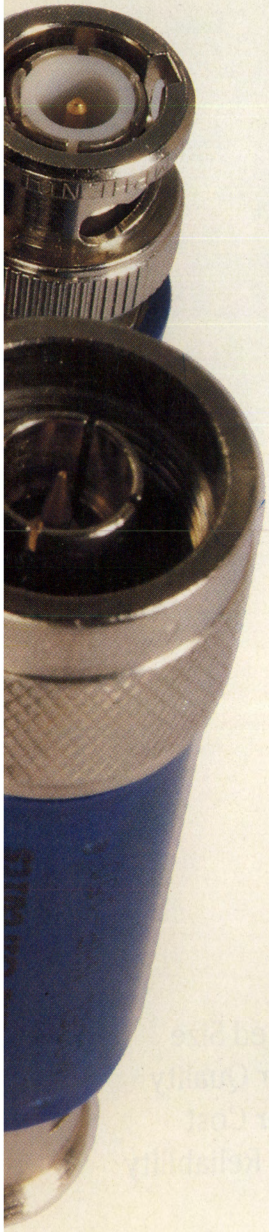
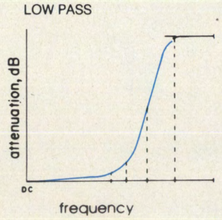


low pass, Plug-in, dc to 1200MHz



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

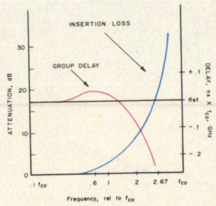
Price, (1-9 qty), all models: plug-in $14.95, BNC $32.95, SMA $34.95, Type N $35.95

Surface-mount, dc to 570MHz

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

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

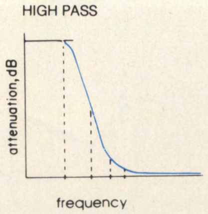
Flat Time Delay, dc to 1870MHz



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

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

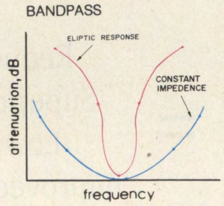
high pass, Plug-in, 27.5 to 2200MHz



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

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

bandpass, Elliptic Response, 10.7 to 70MHz



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

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

Constant Impedance, 21.4 to 70MHz

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

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

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

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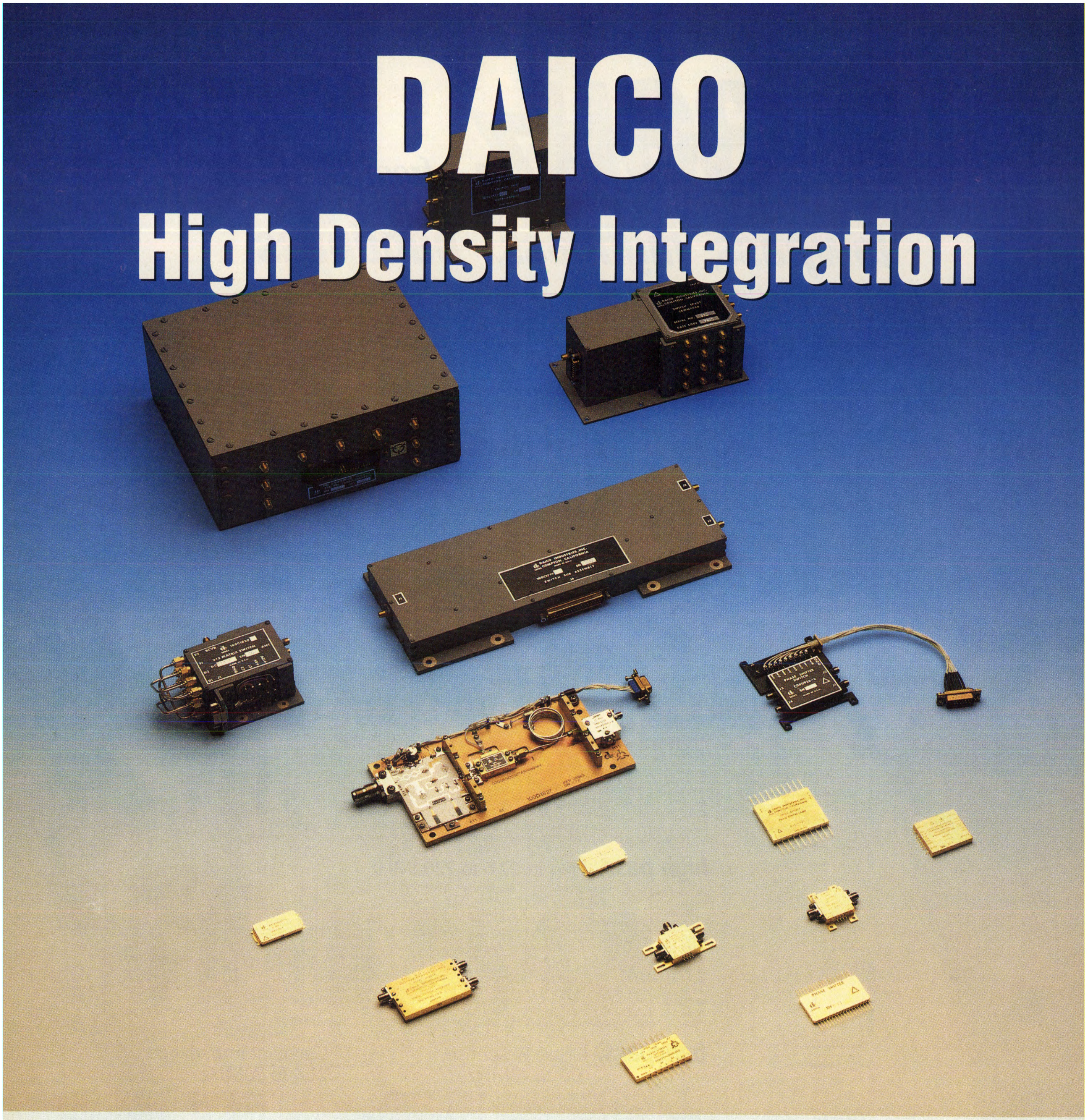

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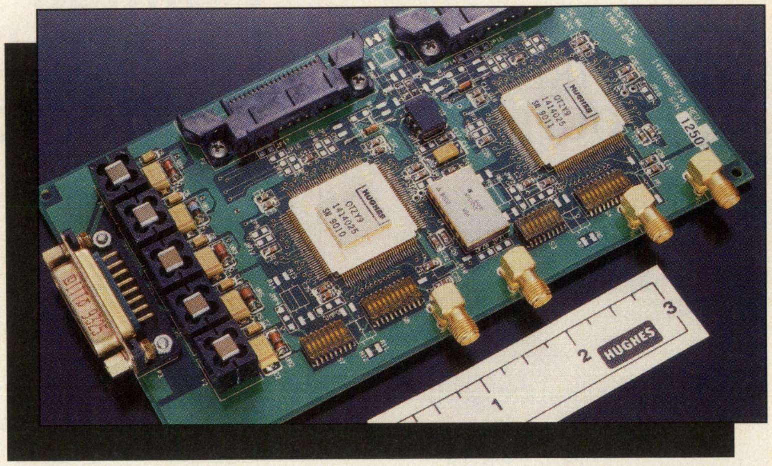

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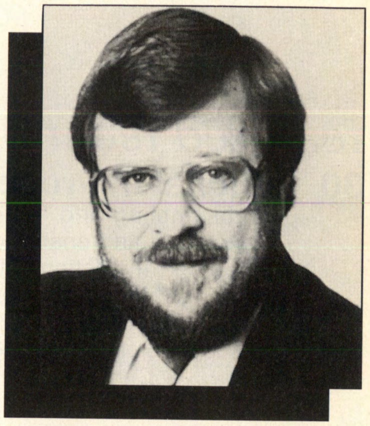
Enough Politics — Let's Talk Technology



By Gary A. Breed
Editor

For this month's column, I was tempted to write about the half-billion dollars that were bid for nationwide paging licenses in the new PCS band. The FCC's mid-stream changes in the fees for pioneer's preference PCS licensees crossed my mind, too. And, I thought briefly about a commentary on proposed changes to the patent law.

But I've gotten on my socio-techno-political soapbox often enough in the past few months! Let's talk technology. Specifically, let's talk DSP.

Digital signal processing is getting to be a big player in electronics of all sorts. DSP compresses, expands and enhances video so we can send more images to more places. DSP enhances our test instruments by adding a degree of precision that analog processing just can't accomplish. Computer modems use DSP to recover high-speed data from our narrow-band phone lines — quite a challenge. (I'm still not sure how they get 28.8 kbits/sec into a 4 kHz voice-grade bandwidth!)

As RF engineers, not all of us are familiar with the mathematics of the time domain. At best we had an introduction in a linear systems class, and maybe there was a chance to investigate some basic DSP filter designs. Fortunately, there is a growing group of RF engineers who have become expert in this realm, who are adding powerful new capabilities to the analog signal processing that RF engineers have so artistically applied for many years.

What does DSP offer? In all of its applications, the attraction is twofold: *mathematical precision* and *stability*. There are very few, if any, functions that cannot be performed using either analog or digital processing techniques. But, for example, analog filters are not practical when very high order responses are necessary. Plus, changing filter parameters means that a bunch of analog filters are needed to select from. DSP makes filtering a snap with its programmability.

DSP also very attractive for performing modulation and demodulation. All modulation techniques are readily defined in mathematical terms, an ideal match for DSP's computational engine. This is especially valuable with the complex modulation techniques being applied to high-speed digital communications.

But before we get totally enamored with DSP, we need to remember a few things that is can't do — at least, not yet. DSP is digital. It's quantized nature means that continuous functions are not handled as well as analog circuits will handle them. The sine wave is a good example of such a function. DSP needs anti-aliasing filters to reduce (but not eliminate) the signal distortion artifacts that are a necessary result of a finite number of bits of resolution.

The same limitation in resolution also limits dynamic range. High performance DSP may have 75 dB spurious-free dynamic range at IF, and 90 dB at baseband frequencies. However, 100-115 dB SFDR performance is readily obtained by analog circuitry, which is much closer to the range of signals found in real-world radio transmissions. If dynamic range is important, systems must use an optimum combination of analog and digital processing.

Still, let's get excited about DSP for RF applications! It's not an intrusion of digital technology into our familiar analog world — it's another powerful tool to get those analog RF signals transmitted and received with the greatest possible performance.

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713FC	15W CW	20-1000 MHz	42dB	$ 5,680
225LC	25W CW	.01-225 MHz	40dB	$ 3,295
*737LC	25W CW	.01-1000 MHz	45dB	$ 9,995
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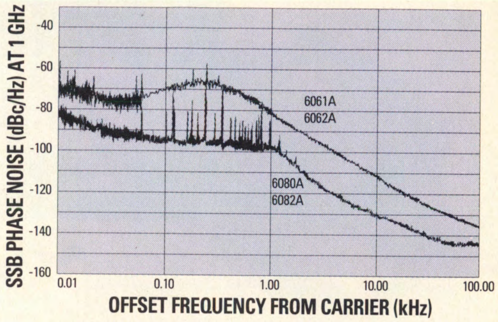
Performance.
Check the charts. Giga-tronics offers four instruments, each with its own unique combination of performance and capability.

The 6061A is ideal for accurate and affordable general purpose RF testing.

The 6062A adds the modulation capability you need to generate complex signals for communications and radar testing.

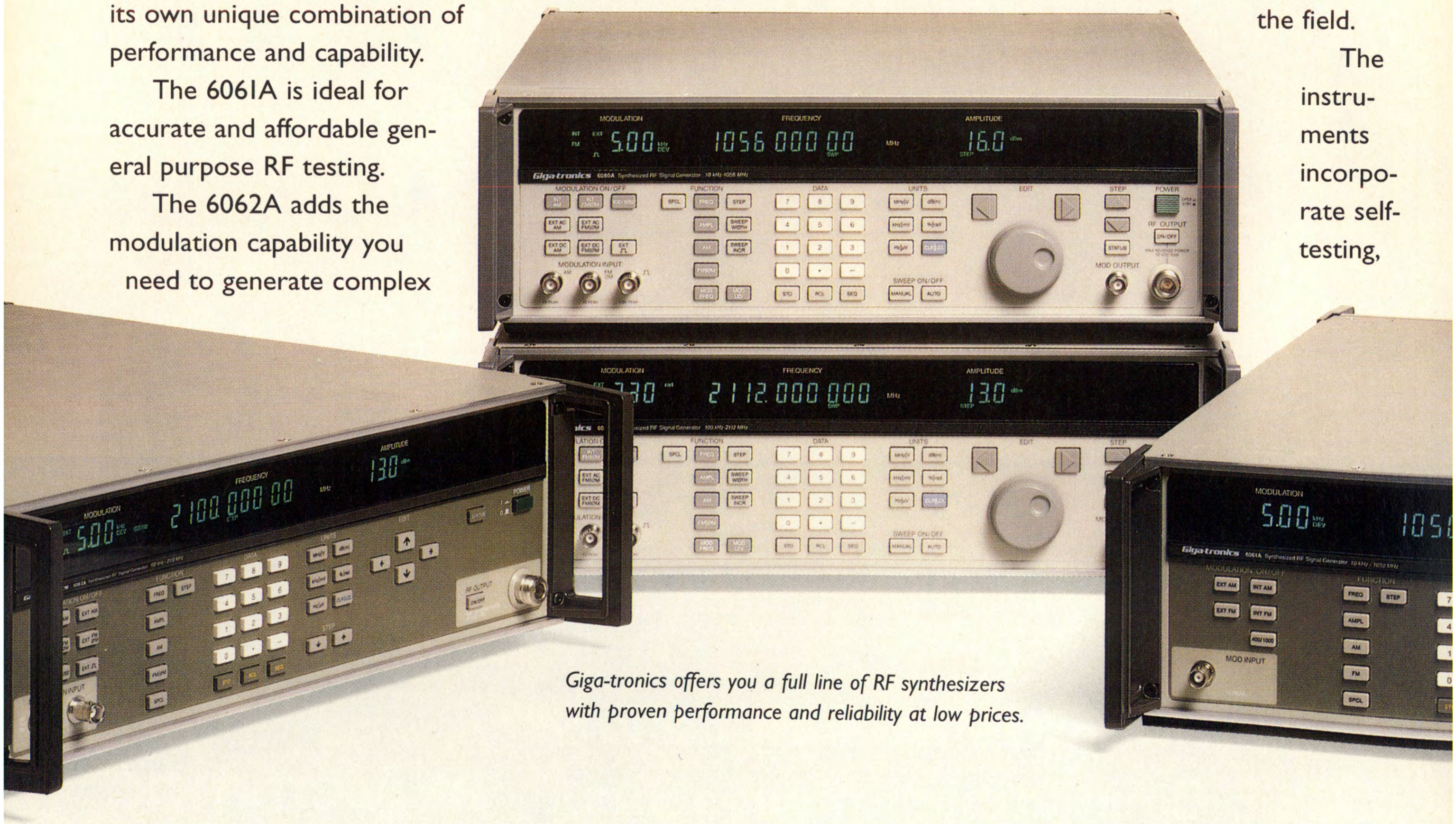
And the 6080A and 6082A give you the performance and capability to test sophisticated systems accurately and quickly.

It's easy to command the power and capability of each instrument from the front panel. And the low profile, standard rack size and IEEE-488 interface make each instrument ideal for ATE applications.



Reliability.
The John Fluke Manufacturing Company initially developed and introduced this line of synthesized RF signal generators. To date, thousands have performed flawlessly in the field.

The instruments incorporate self-testing,



Giga-tronics offers you a full line of RF synthesizers with proven performance and reliability at low prices.

Specifications	Giga-tronics 6061A	Giga-tronics 6062A	Giga-tronics 6080A	Giga-tronics 6082A
Frequency				
Range	.01 to 1050 MHz	.1 to 2100 MHz	.01 to 1056 MHz	.1 to 2112 MHz
Switching speed	<100 ms	<100 ms	<100 ms	<100 ms
Spectral Purity*				
Spurious	<-60 dBc	<-54 dBc	<-100 dBc	<-94 dBc
Subharmonics	None	<-45 dBc	None	<-45 dBc
Phase Noise*				
@ 20 kHz offset	<-117 dBc/Hz	<-110 dBc/Hz	<-131 dBc/Hz	<-125 dBc/Hz
Residual FM*	<12 Hz	<24 Hz	<1.5 Hz	<3 Hz
(Bandwidth)	(.5 to 3 kHz)	(.5 to 3 kHz)	(.3 to 3 kHz)	(.3 to 3 kHz)
Output				
Range*	+13 to -147 dBm	+13 to -147 dBm	+17 to -140 dBm	+13 to -140 dBm
Accuracy	±1 dB >127 dBm	±1.5 dB >-127 dBm	±1 dB >127 dBm	±1 dB >-127 dBm
Reverse Power Protection	50 Watts/50 Vdc	25 Watts/25 Vdc	50 Watts/50 Vdc	25 Watts/25 Vdc
Amplitude Modulation				
Depth	0–99.9%	0–99.9%	0–99.9%	0–99.9%
Distortion @ 30%	<3%	<3%	<1.5%	<1.5%
Frequency Modulation				
Max. Deviation*	100 kHz	400 kHz	4 MHz	8 MHz
Distortion	<1%	<1%	<1% @ 50% Dev.	<1% @ 50% Dev.
Phase Modulation	NA			
Max. Deviation*		40 Rad.	40/400 Rad.	80/800 Rad.
Pulse Modulation	NA			
On/off		>80 dB	>40/60 dB	>80 dB
Rise/fall time		<15 ns	<15 ns (Typ 7.5 ns)	<15 ns (Typ 7.5 ns)
Minimum Pulse Width		<2 µs	<30 ns	<30 ns
Internal Modulation Source	400, 1000 Hz	400, 1000 Hz	0.1 Hz to 200 kHz	0.1 Hz to 200 kHz
Level Range	NA	NA	0 to 4 Vpk	0 to 4 Vpk
Waveforms	Sine	Sine	Sine/Sq/Tri/Pulse	Sine/Sq/Tri/Pulse
Programmable	Yes	Yes	Yes	Yes
Memory Locations (NVM)	50 Full Function	50 Full Function	50 Full Function	50 Full Function

*Specifications for the 6061A and 6080A are at 1 GHz, and specifications for the 6062A and 6082A are at 2 GHz. Phase noise is typical for the 6061A and 6062A.

internal diagnostics and modular design for easy fault isolation.

Service.

If a problem occurs, our technical support staff can often help you find and fix it over the phone.

If you need to return an instrument for service, we can take care of it at our factory in California, or at one of our worldwide service centers.

Experience.

Granted, Giga-tronics may be a new name for RF synthesizers, but it's a trusted name to microwave test professionals.

Giga-tronics has a 14-year history of building test and measurement gear for the most demanding requirements. We've shipped thousands of instruments for use in testing communications, radar and EW systems.

Value.

What makes a Giga-tronics RF Signal Generator such an incredible value is its blend of proven performance and reliability at a low price.

Take a closer look at Giga-tronics. The new choice for RF synthesizers may be your best choice.

Call us toll free at **800 726 GIGA** (4442). We'll send you more information and arrange for a demonstration.

Giga-tronics

Giga-tronics Incorporated
4650 Norris Canyon Road
San Ramon, California 94583
Telephone: 800 726 4442 or
510 328 4650
Telefax: 510 328 4700

INFO/CARD 10

RF letters

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

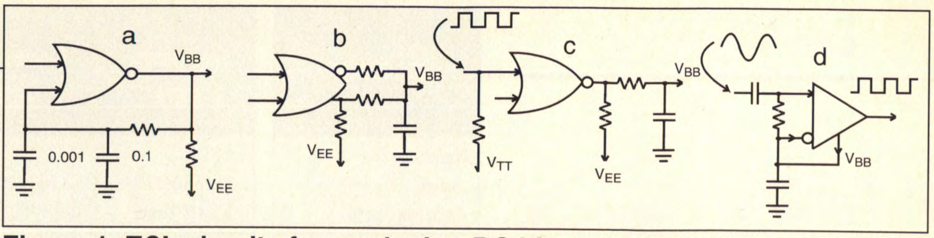


Figure 1. ECL circuits for producing DC bias and digital clock signals.

Another Note on ECL for RF

Editor:

I have the following comments on "A Note on ECL for RF" in RF letters in the June, 1994 issue of *RF Design* by David Freedman of Exetron. He was addressing the article on analog use of ECL by R.N. Mutagi in the April, 1994 issue.

Generation of V_{BB} in ECL circuitry is a problem. The V_{BB} output of the few devices which provide it generally cannot be heavily loaded. I have used the circuit of Figure 1a, similar to Mr. Freedman's, with the following reservations:

1. It may oscillate if the gain of the gate is unusually high and/or if the V_{BB} bypass capacitor has poor high frequency characteristics.

2. It produces a voltage approximately equal to the gate's internal V_{BB}, an unspecified parameter. With 2 kΩ resistance in the feedback path as shown by Mr. Freedman a 50 µA bias yields an additional 100 mV offset .

3. It may not "track" changes in the logic high and low levels caused by temperature and V_{EE} changes.

The circuits of Figures 1b and 1c produce a V_{BB} equal to the average of the logic high and low levels and by and large overcome the above objections. The input in Figure 1c is a logic square wave, or a delay-line oscillator could be used. These circuits correct some oversights, but they still should not be considered rigorously analyzed.

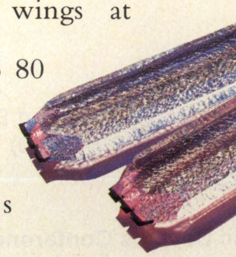
In addition, Mr. Freeman states that the circuit of Figure 1a (or similar to it) "has become a standard for developing a digital clock from a sine wave reference." This is problematical if the duty cycle of the digital signal is not 50% (it seldom is). It is preferable to use a device with differential inputs such as a line receiver, as in Figure 1d, or a comparator. Incorporation of hysteresis is recommended.

Pat Conway
Rancho Palos Verdes, CA

Dinged-Up Diagram

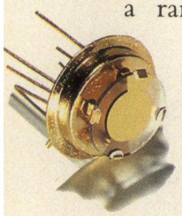
The schematic for Dominic Ciardullo's fast envelope detector, (July 1994, pg. 34, Figures 2a and 2b), contained several printing errors. Rather than print the diagram in this small space, we invite readers interested in studying or building the circuit to send a SASE to *RF Design*, 6300 S. Syracuse Way, Ste. 650, Englewood, CO 80111, to receive the full-size schematic. The schematic contains all component values and important notes. We apologize for any inconvenience the original schematic may have caused.

The Hummingbird is acclaimed as the epitome of stability. This it achieves by beating its wings at frequencies up to 80 beats per second.



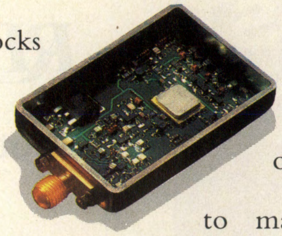
C-MAC's frequency control products are equally renowned for their perfect stability, even at frequencies up to 2.6 GHz.

This we achieve through growing flawless synthetic quartz and combining it with expertise in design and manufacture to produce a range of frequency control products with exacting stability and precision timing.



C-MAC oscillators are used worldwide in SONET / SDH systems and now in the latest ATM applications.

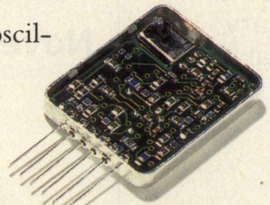
They are widely used in master and slave clocks in telecom networks and as precision references for frequency and time measurement instruments.



We have been providing frequency control products of the utmost reliability to many of the world's leading manufacturers of communications equipment for nearly 50 years.

PERFECT STABILITY

Our ASIC design expertise has enabled us to produce the world's smallest high stability, low power, temperature controlled oscillator (TCXO), which is highly successful in tactical radios and satellite navigation and positioning equipment for GPS.



Further development of our ASIC technology is in progress for a new generation of miniature oscillators.

We will continue to build strategic partnerships with our customers and suppliers, to pioneer new markets and set the pace in frequency control products.

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Edinburgh Way Harlow
Essex CM20 2DE England
Tel: +44 (0) 1279 626626
Fax: +44 (0) 1279 454825

C-MAC

INFO/CARD 12

RF calendar

September

27-29

Wescon 94
Anaheim, CA
Information: Wescon/94, 8110 Airport Blvd., Los Angeles, CA 90045. Tel: (800) 877–2668 or (310) 215–3976. Fax: (310) 641–5117.

27-29

16th Piezoelectric Devices Conference
Kansas City, MO
Information: Electronic Industries Association, 2001 Pennsylvania Avenue, N.W., Washington, DC 20006. Tel: (202) 457–4930. Fax: (202) 457–4985.

October

3-7

Antenna Measurement Techniques Association
Long Beach, CA
Information: 1994 AMTA Symposium, School of Engineering and Computer Science, Center for Research and Sciences, California State University, Northridge, 18111 Nordhoff St. - SECS, Northridge, CA 91330. Tel: (818) 885–2146. Fax: (818) 885–2140.

13-15

World Media Expo
Los Angeles, CA
Information: National Association of Broadcasters, Eric Udler. Tel: (202) 429–5336.

25-26

Radio Solutions, Exhibition and Conference for the Low Power Radio Industry
Birmingham, England
Information: Radio Solutions, Low Power Radio Association, The Old Vicarage, Haley Hill, Halifax, HX3 6DR, UK. Tel: 0422 380397. Fax: 0422 355604.

25-27

Microwaves '94
London, England
Information: Anna Tapster, Nexus Business Communications, Warwick House, Swanley, Kent BR8 8HY, United Kingdom. Tel: 44 322 660070. Fax: 44 322 614898.

November

2-5

Intelecom 94
Turin, Italy
Information: Kelly Muese, *Microwave Journal*, 685 Canton Street, Norwood, MA 02062. Fax: (617) 762-9230.

7-8

Second Adaptive Antenna Systems Symposium
Long Island, NY
Information: Tom Campell, P.O. Box 36, Greenlawn, NY 11740–0036. Tel: (516) 757–3008.

15-17

RF Expo East
Orlando, FL
Information: Argus Trade Shows, 6151 Powers Ferry Road, NW, Atlanta, GA 30339. Tel: (800) 828-0420. Fax: (404) 618-0441

Now you can rent or lease Noise Com test equipment from AT&T Capital Corp., Instrument and Data Services.

All of your test equipment needs can be answered immediately for short-term rental or long-term leasing from AT&T Capital. The UFX-BER Precision Carrier-to-Noise Generator and the MP2400 Multipath Fading Emulator are in stock for immediate delivery. Also available is our standard line of noise-generating products, the UFX-7000 series programmable instruments and the NC6000 series noise generators. Together, Noise Com and AT&T Capital can give you the outstanding service and support you have come to expect.

New products for wireless.

One example of the technology available is the MP2400 Multipath Fading Emulator. The instrument can test GSM, DCS, CDMA, TDMA, and most other wireless systems. It emulates up to two multipath faded RF channels, meeting the requirements of mobile telephone standards. Extremely easy to use, the MP2400 takes advantage of Microsoft Windows,™ an intuitively easy graphics interface. Plus, a built-in 486DX-33 computer with keyboard, mouse, and VGA display makes the MP2400 powerful and flexible enough to control an entire system!

We're better at BER.

BER testing can be very time consuming, so we designed an instrument to let you do it

Report Predicts $1.75 Billion Electronic Toll Collection Market

Short-range wireless toll collection systems are seeing increased use. These electronic toll collection (ETC) systems are poised for widespread application at toll roads, bridges and tunnels. According to Electronic Toll Collection: Technology Update and Market Analysis, a report by Waters Information Service, the aggregate market for ETC systems will be $1.75 billion by the year 2005. Estimates for the current market are $225 million, but within 10 years, more than 15 million vehicles are expected to be equipped with ETC transponders. The report contains forecasts for: (1) toll lane equipment, including automatic vehicle identification antennas, video enforcement and vehicle classification equipment; (2) ongoing maintenance costs; and (3) in-vehicle transponders and smart cards. More information can be obtained from Waters Information Service, (212) 925-6990.

ANSI Calls for U.S. to Focus on Global Standards

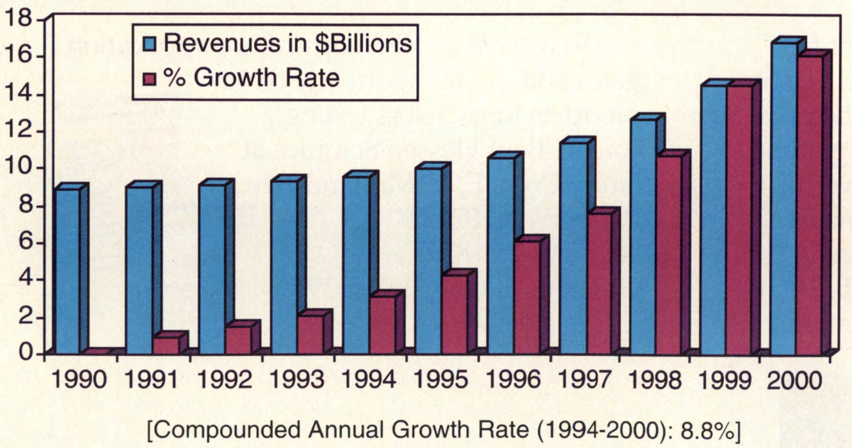
The American National Standards Institute (ANSI) has called for a greater emphasis on global standards by American business. The role of ANSI and its members is to promote, accelerate and coordinate timely development of voluntary consensus standards. ANSI is establishing an Information Infrastructure Standards Panel within the national voluntary standards system to support rapid development of a national and worldwide electronic superhighway. "Standards are all about global market access, strategic corporate advantage and a constructive cooperation between business and regulatory agencies throughout the world," according to ANSI president Sergio Mazza.

Call for Papers on Computational Electromagnetics

The Applied Computational Electromagnetics Society (ACES) announces the Call for Papers for the society's 11th annual conference to be held March 20-24, 1995 at the Naval Postgraduate School in Monterey, Calif. Papers may address general issues in applied computational electromagnetics, or may focus on specific applications, techniques, codes, or computational issues. Prospective authors should contact the Technical Program Chairman: Ray Luebbers, Department of Electrical Engineering, Pennsylvania State University, University Park, PA 16802; tel: (814) 865-2362; fax: (814) 865-7065; e-mail: lu4@psuvm.psu.edu. A 300-500 word summary is due by October 3, 1994.

Wireless Office System Growth Predicted

Market research firm Frost & Sullivan predicts that wireless office equipment will increase from virtually zero to 20 percent of the office telephone market by the year 2000 (see chart), helping fuel an overall growth of nine percent. Details are included in their report, "WORLD PBX, KEY, WIRELESS, PC-BASED AND SWITCH TELEPHONY MARKETS." The full report is available for $2295; For more information, contact Amy Arnell at (415) 961-9000. Frost & Sullivan is a subsidiary of Market Intelligence.



Total PBX, wireless, PC-based and switch telephony market: revenue forecasts (worldwide) 1990-2000. Source: Frost & Sullivan.

EIA Reports Jump in Medical Equipment Exports

U.S. electromedical equipment exports increased by nearly 20 percent during the first quarter of 1994, to $1.1 billion, according to the Electronic Industries Association (EIA). Leading the way were electro-surgical instruments and appliances, with a 36 percent increase. Apparatus based on X-ray uses were up 25 percent, and ultrasonic scanning equipment was up 20 percent. Japan was the largest U.S. export market during this period, with Canada, the Netherlands and France showing the largest percentage increases. Combined with a 6 percent fall in imports of this type of equipment, the positive U.S. trade balance was $540 million for the first quarter of 1993. For comparison, the trade balance for all of 1990 was $587 million, which has risen to $1.2 billion for 1993.

Student Engineers Revive 105-foot Radio Telescope

For two years, students at Georgia Tech have had a unique hands-on engineering opportunity. They have been working to restore to operation two large dishes at a former AT&T satellite tracking facility in Woodbury, Georgia. Originally built in the 1970s for defense-related satellite work, the facility was abandoned in the 1980s, and later acquired by the Georgia Tech Research Institute (GTRI), a non-profit research facility operating in conjunction with Georgia Tech. Using the help of about 50 students and donations of replacement equipment from AT&T, the facility has become operational once again, and was used to observe the impact of comet Shoemaker-Levy on Jupiter using the 5 cm wavelength microwave band.

Our chip caps fit in a pager so small, it comes clipped to a 4-inch belt.

These days, when design engineers think big, they're usually thinking *small*. So they need highly miniaturized components like Murata 0402 ceramic chip capacitors. Murata has led the world in setting standards for quality and miniaturization in chip capacitors. So it should be no surprise that the world's largest manufacturer of ceramic capacitors introduced the smallest size currently available, the 0402. Our array of capacitors includes monolithic ceramic capacitors, microwave capacitors, ceramic disc capacitors and variable capacitors. And whether your design includes high voltage or high frequency applications, or requires superior performance and stability under high temperatures, you should depend on the quality of Murata capacitors. Especially when you're designing a product to go on the wrist, instead of the waist. For more information, call **1-800-831-9172, ext.153.**

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INFO/CARD 16

RF Business Briefs

Penstock Adds Comlinear Line — Penstock has become a nationwide distributor for Comlinear's full line of analog signal processing components, including amplifiers, track and holds, A/D converters, multiplexers and buffers.

RF Power Components Makes a Move — RF Power Components, Inc. has moved to larger facilities at 125 Wilbur Place, Bohemia, NY 11716-2482. Their telephone number is (516) 563-5050 and the fax number is (516) 563-4747.

Cadence Establishes R&D Laboratory — Cadence Design Systems has established Cadence Berkeley Laboratories, an advanced research and development laboratory located in Berkeley, Calif. The lab will focus on applications that will rapidly advance computer aided design technologies. Cadence customers will be able to participate in selected research projects are Associate Scientists, and close cooperation has been established with the faculty of the University of California, Berkeley.

JCA Technology Relocates — Thin-film hybrid manufacturer JCA Technology has moved to a new facility featuring a class 100,000 clean room for its MIC line. The new address is 1090 Avenida Acaso, Camarillo, CA 90312; tel: (805) 445-9888; fax: (805) 987-6990.

Tektronix Spins off P.C. Board Facility — Merix Corporation was founded earlier this year following three decades as a manufacturing facility for Tektronix, Inc. Merix employs 700 at its 174,000 square foot facility in Forest Grove, Ore.

Varian Expands Japan Operations — Varian Japan Ltd. recently dedicated a new headquarters building in the Minato-ku district of Tokyo, housing representatives of the Health Care Systems, Instruments and Electron Devices businesses. 48 employees will be employed a the facility, 25 of them dedicated to service and support. Varian also operates an office in Osaka.

Unisys and Micron Team Up for RFID — Unisys Corporation and Micron Communications, Inc. have entered into a teaming agreement to develop markets for Radio Frequency Identification (RFID) products and related services. The agreement combines Unisys' experience in communications devices and system integration with Micron's semiconductor foundry and CMOS IC capability.

Teklogix Reports Growth — Teklogix Inc., a manufacturer of wireless data communication technology, reports a 62 percent increase in revenue and a 168 percent increase in operating profit for the first quarter of their fiscal year 1995. Sales through value-added resellers represented 48 percent of North American revenues.

RF Group Expands in the U.K. — The RF Group has purchased and moved into larger premises, a result of demands brought on by its entry into the GSM cellular market, particularly on the African continent in South Africa, Namibia and Zimbabwe. The RF Group is now located at Whitmore House, London Road, Ascot, Berkshire SL5 8DH. Their telephone is +44 (0344) 886909, fax: +44 (0344) 886936.

Bell Atlantic Introduces the "Information Sidewalk" — Not a superhighway, the "PCS Now" (sm) local service from Bell Atlantic has been launched in three Eastern U.S. test markets. The company hopes to establish a new class of wireless services that cater to value-conscious customers who need around-town mobile communications. The new service combines the convenience and economy of a home cordless phone with the enhanced mobility of cellular service. The test operations use existing cellular networks.

Magnum Microwave Acquires Avantek Products — Magnum Microwave has acquired product lines from Hewlett-Packard's Avantek subsidiary, and will produce connectorized microwave mixers, mixer preamplifiers, PIN diode switches and dielectrically stabilized oscillators formerly manufactured by Avantek.

Contract News

EST to Provide Wireless Lighting Control — Electronic Systems Technology Inc. (EST) announces that their ESTeem wireless modem was selected to provide wireless lighting control for more than forty Navy and Marine Corps airfields in the continental U.S. The Naval Air Systems Command has funded a program to standardize and replace obsolete airfield lighting control systems. Anticipated sales of EST hardware for the system is more than $130,000.

Scientific-Atlanta Installs Earth Station in Chile — A new 18-meter INTELSAT Standard A satellite earth station has been installed for BellSouth Chile. The Scientific-Atlanta system is located in the small town of Placilla, about 70 km from Santiago. The station will link BellSouth Chile's network with other carriers in North America, providing voice, data and fax services.

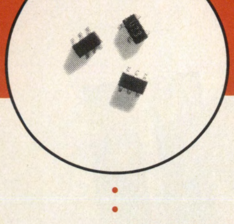
Washington State Patrol Expand mobile Data System — Dataradio announces that the award-winning pilot mobile computer project for the Washington State Patrol is being expanded with Dataradio's modem equipment. The Washington State Legislature has funded the project in a six-year implementation program.

SoftWright Announces Installations in Mexico — SoftWright LLC has successfully installed their Terrain Analysis Package (TAP™) engineering software in three prominent Mexican companies: Motorola Mexico, Comision Nacional del Agua, Comision Federal de Electricidad, Enlaces Radiofonicos and Codime. The software is used for digital mapping and RF coverage analysis.

EIP Receives VXIbus Order — EIP Microwave Inc. has received initial order releases from Grumman Aerospace Corp. for VXIbus broadband microwave synthesizers and pulse/CW microwave frequency counters for use in the new F-15 DST for the U.S. Air Force. EIP estimates the order volume to be more than $2 million over the next two years.

Rohde & Schwarz Gets Radio Modem Order — Bell South, a co-operator of the Dutch Mobitex radio data network, has made an initial order for 5000 mobitex radio modems from Rohde & Schwarz Netherlands B.V. The adaptive

New 3 Volt Downconverters: From RF to IF for 99¢



NEC miniature downconverters are the latest addition to CEL's growing family of 3 Volt RF ICs.

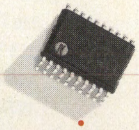
Need low distortion? Our new *UPC2758T* delivers +10 dBm output IP_3. Low current application? Choose the *UPC2757T*. It provides 13 dB of conversion gain from only 5.6 mA. Both feature a mixer, LO and IF buffer amplifier, and a *Power Down* function to prolong battery life.

Another low current device, the *UPC2756T*, helps simplify your designs by combining mixer, IF amplifier and oscillator — all on a single chip.

All three feature 3 dB RF bandwidth to 2.0 GHz, with 3 dB IF bandwidth of 10 to 300 MHz.

Housed in miniature packages no bigger than a SOT-143, these devices are available now on tape and reel and priced in quantity from only 99¢.

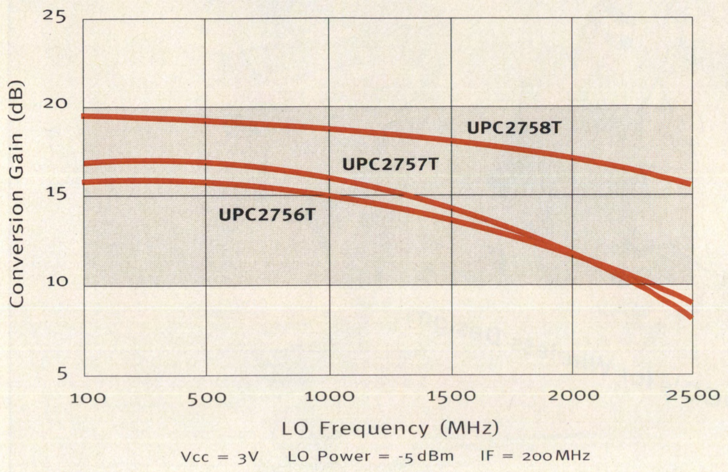
Best of all, they can be combined with CEL's other MMICs and discretes to provide complete GPS, PCN or 2.4 GHz wireless LAN solutions.



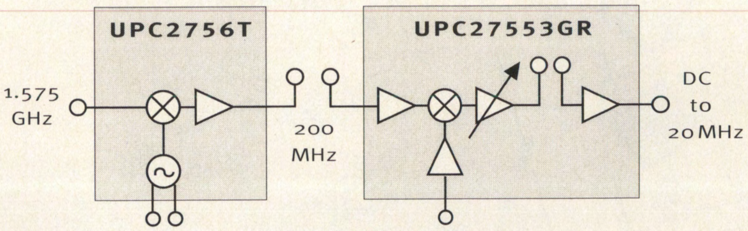
Need a higher level of integration? The 3 Volt *UPC2753GR* IF downconverter combines an RF input amplifier, Gilbert cell mixer, LO input buffer, IF amplifier with AGC, external filter port, and IF output limiting amplifier — all in a miniature 20 pin SSOP package. This device features DC to 400 MHz RF response, DC to 20 MHz IF response, and typical overall conversion gain of 79 dB.

For data sheets and a **Silicon MMIC Product Selection Guide**, call your nearest CEL Sales Office, or circle the number below.

CONVERSION GAIN



RECEIVER LINEUP



TYPICAL SPECIFICATIONS

PART	OPERATING VOLTAGE	Icc	CONVERSION GAIN	OUTPUT IP3
UPC2758T[1]	3V	11 mA	17 dB	+10 dBm
UPC2757T[1]	3V	5.6 mA	13 dB	+5 dBm
UPC2756T[2]	3V	5.9 mA	14 dB	+5 dBm

1. Measured at 2.0 GHz 2. Measured at 1.6 GHz

CEL California Eastern Laboratories

CEL Headquarters 4590 Patrick Henry Drive, Santa Clara, CA 95054-1817; (408) 988-3500 FAX (408) 988-0279 Santa Clara, (408) 988-7846 Los Angeles, CA (310) 645-0985 San Diego, CA (619) 450-4395 Bellevue, WA (206) 644-3307 Richardson, TX (214) 437-5487 Olathe, KS (913) 780-1380 Woodridge, IL (708) 241-3040 Cockeysville, MD (410) 667-1310 Peabody, MA (508) 535-2885 Hackensack, NJ (201) 487-1155 Palm Bay, FL (407) 727-8045 Snellville, GA (404) 978-4443

INFO/CARD 18

RF Business Briefs *continued*

Hybrids International Expands — A major expansion has been completed, adding 20,000 square feet to Hybrids International's manufacturing operations for custom hybrids and frequency control products. The original 8,600 square foot facility will be used for turnkey assembly services.

Motorola and Maxon in Pager Agreement — Motorola Paging Products Group has granted Maxon America a FLEX™ protocol manufacturing license for worldwide use. Maxon will manufacture a new line of pagers capable of receiving high volumes of data for numeric and alphanumeric messages.

Soft Ferrite Users' Conference Update — The Magnetic Materials Producers' Association will hold a conference on October 24-25, 1994 at the Westin Hotel – O'Hare in Rosemont, Illinois. The conference will feature sessions on the basics of soft ferrites, as well as applications in power electronics, EMI supression and specialty applications.

Texas Instruments TIRIS Program Catches the Bus — City officials in Leeds, England are evaluating a new system to speed up public transportation through congested areas. Using RFID technology, buses will trigger traffic signals, giving them priority over other vehicles.

Linear Technology Reports Record Sales — Linear Technology Corp., a maker of linear integrated circuits, reports that its recently-concluded fiscal year saw sales pass the $200 million mark, an increase of 33 percent over 1993 sales.

data modem ADAM is designed for use in the 405-460 MHz frequency range. The unit uses an RS-232C interface to the digital equipment (computer, bar code reader, or data terminal) with selectable data rates of 1200, 2400, 4800 and 9600 b/s.

Stanford Telecom Receives VSAT Contract — The ASIC and Custom Products Division of Stanford Telecom has received a contract from Mainstream Data for 6,000 VSAT receiver modules. The STEL-9236 modules provide a L-band to data stream receiver solution for Direct Broadcast Data applications providing background music and digital information to businesses.

American Superconductor Gets SBIR Grant — A $600,000 SBIR government research grant has been awarded to American Superconductor Corp. for methods of refining high temperature superconducting wire, for use in commercial electric power applications. The work will be done in partnership with Los Alamos National Laboratory. *RF*

Government and Industry Labs Advance RF Metrology

By Andy Kellett
Technical Editor

Metrology is the study of measurements. RF engineers depend on metrology to ensure that whatever quantities they measure with their instruments, they have a well defined correspondence to standards, that is, to ensure that their equipment is calibrated. This report looks at some of the work being done at the National Institute for Standards and Technology (NIST) and in metrology labs in industry.

On-Wafer Testing

Making accurate on-wafer measurements of semiconductor parameters is the goal of work by Drs. Dylan Williams and Roger B. Marks of NIST.

The two NIST researchers have developed methods for characterizing transmission lines and other devices in lossy dielectrics, and have created procedures for testing the accuracy of on-wafer microwave measurements.

The lossy transmission line models developed by Dr. Williams and Dr. Marks handle lossy and inhomogeneous dielectrics and yield frequency dependent transmission line parameters, which makes analysis in the frequency domain much easier. "Conventional theories don't include [lossy and inhomogeneous dielectrics] as properties unless they are very small order, in other words, they will include loss as a perturbation but not as a significant factor," says Dr. Marks.

"One of the reasons we are interested in these transmission line parameters is not only to characterize the transmission line itself, but also to do accurate S-parameter and impedance measurements," says Marks, "In order to accurately measure the impedance parameters you have to know the characteristic impedance of the transmission line."

Ultimately, the new technique will provide accurate models of various test fixtures and packages, allowing the effects of the fixtures or packages to be subtracted from device measurements. The work was funded by the NIST/Industrial MMIC Consortium, whose members include TRW, Cascade Microtech, Texas Instruments, Raytheon Corporation, ITT, and Newark Air Force Base.

Many of the recent advances in electronics metrology that have come from NIST labs are listed in a publication titled, *Electronics and Electrical Engineering Laboratory: 1993 Technical Accomplishments*. Also mentioned in the NIST publication are new calibration services offered by NIST, such as high accuracy power measurement, S-parameter measurements for devices with 2.92 mm connectors, improved power comparison measurements, and measurements of standard gain antennas.

What's Happening in Industry Labs?

While NIST's task is to be the ultimate source of calibration, many companies have their own metrology labs whose purpose is to be an in-house source of calibration.

Benny Smith, Metrology Manager for Hewlett-Packard's Microwave Instruments Division says his customers come from both inside HP and from HP customers. According to Smith, the three most important parameters for people who request work from his lab are power, attenuation, and frequency.

Smith says his lab handles many tasks, from answering customer's questions about the NIST-traceability of their equipment, to assisting in the development of new instruments, ensuring that instrument precision doesn't exceed capabilities of normal calibration labs.

Not every company has an explicit metrology department, however, calibration techniques are developed by company's design and manufacturing engineers. Hank Pfizenmayer, Principal Member of the Technical Staff and Product Manager for Linear Modules at Motorola Semiconductor says his group gets accurate de-embedding matrices for precise fixtures by simulating them on HP's High Frequency Structure Simulator.

"We think that if its done properly, its probably more accurate than trying to do an open-short-through type of calibration for fixture de-embedding," says Pfizenmayer.

Calibration of RF instruments is as important as ever, and NIST and industry labs are working together to make RF measurements more precise and accurate. *RF*

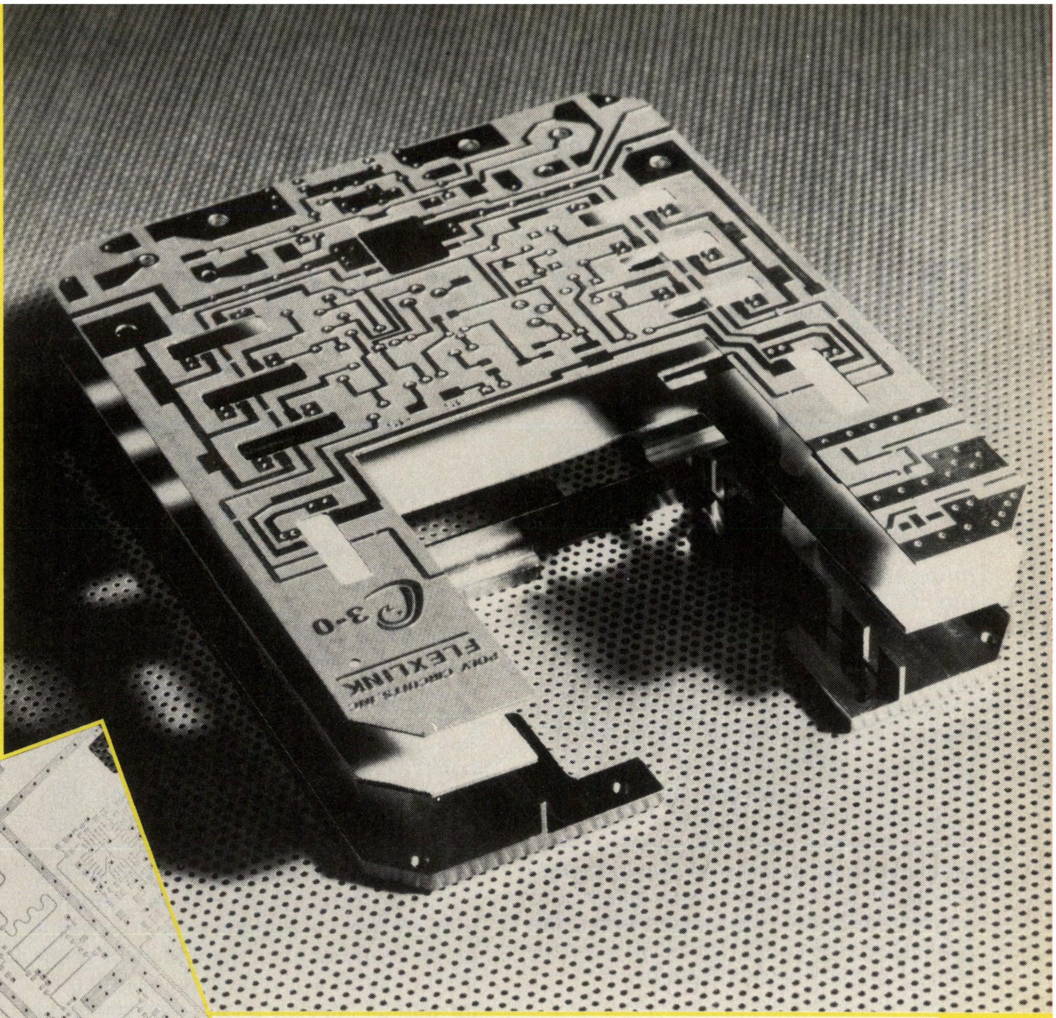
Make Your Know-How NIST-Traceable

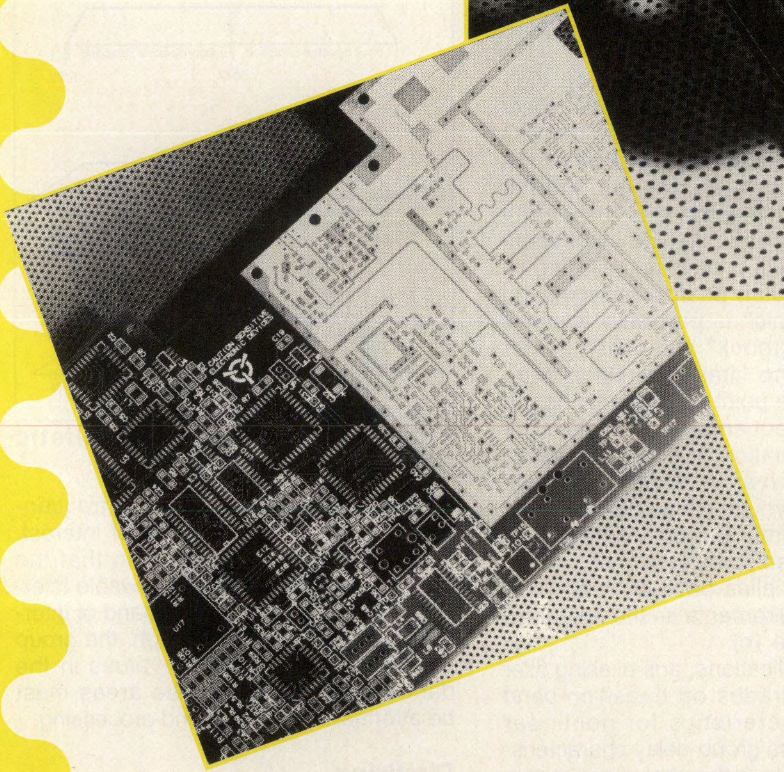
NIST publishes several items which describe their calibration services and research work.

The NIST *Calibration Services Users Guide* describes all of NIST's calibration capabilities and all its standard calibration services. Its appendix, a separate document, contains the fee schedule for the calibration services. It can be ordered by writing NIST at Rm A-104, Bldg. TRF, NIST, Gaithersburg, MD 20899-0001.

The *Electronics and Electrical Engineering Laboratory: 1993 Technical Accomplishments* (NISTIR 5355), describes some of the research advances made by NIST scientists in the fields of microwaves, EMC, semiconductors, superconductors and other fields. NISTIR 5355 is available for $17.50 prepaid from the National Technical Information Service, Springfield, VA 22161, or by phone at (800) 553-6847. Order by PB 94-136777.

Finally, a quarterly publication from NIST can keep you informed about NIST's activities. *Technology at a Glance* can be ordered from NIST by writing to: Public Affairs, A-903, NIST, Gaithersburg, MD 20899-0001.





Digital IF Processing

by Clay Olmstead and Mike Petrowski
Harris Semiconductor

With the expansion of wireless communications into new arenas, for example, CDPD, PCS, and wireless LANs, radio designers feel increasing pressure to keep overall system cost low while crafting high performance systems. Fortunately, advances in technology are making it possible to eliminate portions of the circuit that classical design techniques made necessary. Cutting stages reduces the cost and size of the radio and eliminates the time spent debugging the circuit and testing it in manufacturing. Because the receiver often consumes the bulk of the design effort, the greatest gains can be made in concentrating on this part of the circuit.

Analog errors that arise in traditional IF processing could be reduced by implementing as much of the receiver as possible with digital parts, but doing this creates its own problems. The A/D converter would have to be moved to one of the higher IF stages, which would result in a much higher sample rate. Because more of the input band would be digitized, the power of the input signal to the sample-and-hold (S&H) would be greatly increased, requiring a much larger dynamic range for the A/D converter.

Such a converter would be more expensive and consume more power than the one in the conventional design. In many cases the demands on the converter would be such that it would be impossible to build with current technology. Moreover, even if an acceptable A/D converter were available, the output sample rate would be too high for the microprocessor.

There is another alternative, however. Instead of sampling the signal at twice the IF frequency, the signal can be undersampled that is, sampled at a frequency that meets Nyquist's criterion with respect to its bandwidth, rather than its frequency. This creates a special set of considerations for the designer, but in many cases allows elimination of one or more IF stages, producing a circuit that is smaller, often consumes less power, and is less expensive than the traditional solution.

Anti-aliasing

Before turning to subsampling a review of anti-aliasing filter considerations is in order. (To simplify the arithmetic, assume that a real, as opposed to a complex, signal is digitized.)

Traditional baseband sampling digitizes a signal that theoretically has spectral content limited to the region from DC to the Nyquist frequency, or one-half the sampling rate. (In the figures, the flat topped, non-aliased areas are useful areas of the spectrum.) The input spectrum requires a low-pass anti-aliasing filter with an infinitely sharp transition band (Figure 1a), which is physically impossible. In a "textbook" anti-aliasing filter (Figure 1b), the filter's transition band begins at some point in frequency before the Nyquist frequency and reaches the required attenuation (which is related to the required dynamic range of the system) at the Nyquist frequency. In most practical systems, the anti-aliasing filter can be designed so that the filter's transition band can alias back on itself. This eases the requirements on the anti-aliasing filter (Figure 1c).

In many applications, anti-aliasing filter performance trades off transition-band roll-off characteristics for nonlinear phase, and thus group-delay characteristics. An example is the choice between a Butterworth or an elliptic active filter. A Butterworth filter has relatively flat group delay but also relatively slow roll-off characteristics. An elliptic filter, by contrast, has comparatively fast roll-off characteristics but more severe group delay characteristics.

The greatest amount of group delay in a filter typically occurs at the transition region between the passband to the transition band(s). (This phenomenon is a direct result of a filter's pole locations.) One common method of compromise is to design the anti-alias filter to have a passband wider than the final band of interest. Then the transition band reaches the required attenuation at frequencies that alias into the band of interest. The filter is also designed so that the group delay falls to within allowable tolerances at frequencies in the band of interest (Figure 1d,). In the graph, the group delay is above allowable values in the dark shaded areas. These areas must be attenuated by baseband processing.

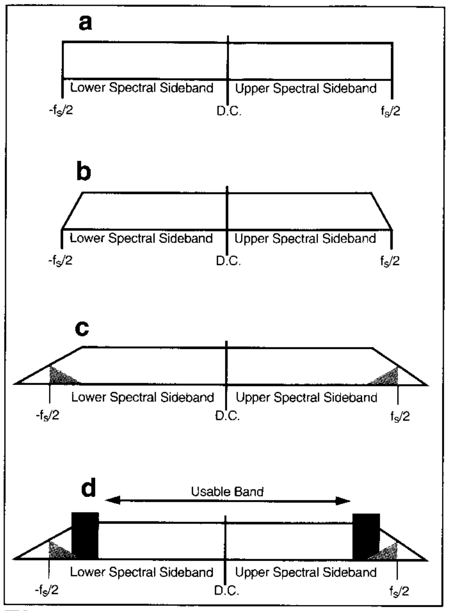


Figure 1. Increasingly realistic passband shapes.

Digitizing

Digitizing analog signals requires two components: a sample-and-hold or track-and-hold (T&H) and an A/D converter. (We use the term S&H generically to mean either sample-and-hold or track-and-hold. The primary difference is that a track-and-hold continuously tracks the input signal, while a sample-and-hold samples the value of the input signal during a finite period before the sample is taken.)

The S&H captures the signal at equally spaced sampling intervals and holds those values to within one-half of the A/D's least significant bit (LSB) of accuracy during the A/D's conversion time.

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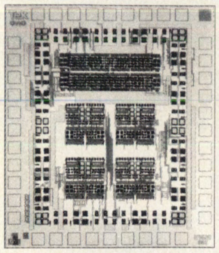

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NAME	NPN BV_{CEO} (V)	NPN f_T (GHz)	PNP BV_{CEO} (V)	PNP f_T (GHz)	JFET	DIGITAL DENSITY (GATES)	ISOLATION	METAL LAYERS	THIN FILM RESISTORS	SCHOTTKY DIODE
SHPi	8	9	9	0.1	YES	3K	OXIDE	2	YES	YES
C-Pi	9.5	9	10.5	5.5	YES	3K	OXIDE	2	YES	YES
GST-1	5.5	13	—	0.1	NO	20K	TRENCH	3	YES	YES
GST-2	4.5	27	—	0.1	NO	60K	TRENCH	3	YES	YES

- **C-Pi** is a recessed-oxide-isolated high-speed complementary bipolar process optimized for analog signal acquisition, amplification, and sourcing. Without the vertical PNP option, C-Pi is designated as **SHPi**.
- **GST-1** is a high-speed self-aligned double-polysilicon bipolar process ideally suited for highly integrated, mixed analog, and digital ICs. **GST-2** offers the highest speed and device density, with 27GHz f_Ts and up to 60K gates/IC.

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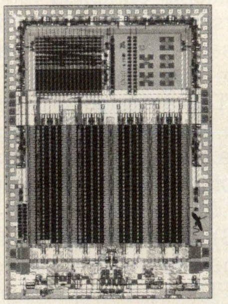

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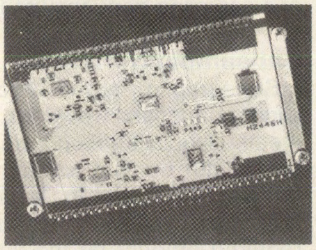

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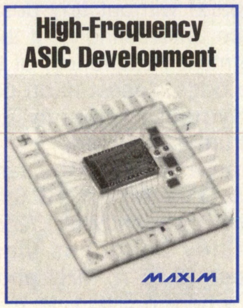

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The A/D converts the sample into a digital value. The S&H and A/D can be thought of as a single component, which we will refer to as the digitizer.

The accuracy of the combined S&H and A/D functions are characterized in signal-to-distortion ratio (SINAD) or effective number of bits (ENOB). The standard equation for ENOB is:

$$ENOB = \frac{SINAD(dB) - 1.76}{6.02} \qquad (1)$$

This is somewhat imprecise because SINAD is typically measured using pure sinusoidal inputs with synchronous sampling of the output, while the numerator of the equation assumes randomly distributed errors. However, this equation does provide a worst-case measure.

SINAD can be broken up into signal-to-noise ratio (SNR), and total harmonic distortion (THD). In most communication system applications the main concerns relative to the digitizer are SNR and derivatives of THD, which include single-tone, two-tone, or three-tone spurious free dynamic range (SFDR) and second- and third-harmonic levels.

In these specifications, SNR is the ratio of a full-scale input sinusoid to the sum of the noise components that are not, or can not, be easily identified as harmonics of the signal. (In an ideal digitizer, all noise is harmonically related to the input signal.) THD is the total power in the harmonics of a full-scale input sinusoid.

SFDR is an instantaneous measurement of power levels between a full-scale input and the largest resulting harmonic. Single-tone SFDR is measured with a full-scale single-tone input. Two-tone SFDR characterizes intermodulation characteristics and is measured with two tones at the input, each 6 dB below full scale. Three-tone SFDR is a less common method of characterizing intermodulation characteristics that uses three input tones.

SNR and THD are dominated by different parameters in different digitizer architectures. SNR is typically affected by aperture jitter and wideband noise in the S&H and differential nonlinearities (DNL) in the A/D. THD is typically affected by slew rate, clock skew and circuit nonlinearities in the S&H and by integral nonlinearities (INL) in the A/D. All of these parameters are a function of frequency. For example, the equation for maximum allowable aperture jitter for a given resolution is:

$$dt_{max} = \frac{1}{\pi f 2^{N+1}} \qquad (2)$$

where N is the desired ENOB and f is the highest frequency into the S&H [1].

Traditional sampling (analog to digital conversion) assumes that the waveform to be sampled is positioned between DC and the Nyquist frequency, so both S&H and A/D are designed to operate on signals in that frequency range. For example, if a baseband waveform has a passband of 5 MHz and is sampled at a rate of 12.5 megasamples per second (MSPS), both the S&H and A/D must be designed to provide the required SNR and SFDR for an input signal of up to 5 MHz in frequency. The A/D must be designed to provide these characteristics at a sampling frequency of 12.5 MSPS.

Subsampling

Subsampling is the process of sampling a bandpass waveform at a rate that meets Nyquist's criterion for the signal's bandwidth but not for its absolute frequency. If the bandpass signal is positioned so that it is attenuated by the required amount by the time it crosses integer multiples of the Nyquist frequency and folds back into the band of interest, then the band of interest will alias to baseband without any destructive interference. Interestingly, if the lower edge (in terms of frequency) of the passband is the edge closest to an odd multiple of the Nyquist frequency, the resulting spectrum is reversed.

As an example, if the sampling rate of the A/D is again 12.5 MSPS. The Nyquist frequency is $f_s/2$ or 6.25 MHz. Thus any bandpass signal must lie between [6.25 n] MHz and [6.25 (n+1)] MHz, where n = 0, 1, 2, ⋯ . If n is odd, the spectrum is reversed in the process. That is, frequencies in the lower portion of the bandpass signal are aliased into the upper portion of the baseband sampled result and frequencies in the upper portion of the bandpass signal are aliased into the lower portion of the baseband sampled result (Figure 2).

Destructive aliasing occurs when subsampling takes place with transition band folding (Figure 3). In the figures, the shading depicts areas of destructive aliasing and the unshaded regions depict the band of interest.

Because signals that originate at RF are bandpass in nature, both the upper and lower ends of the band of interest are affected by bandpass anti-alias filtering. As a result, the band of interest does not extend to DC but rather to the start of the lower transition band as in Figure 1d.

Subsampling shifts most of the performance burden of the digitizer to the

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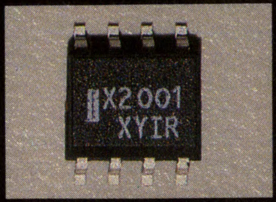

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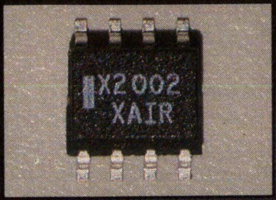

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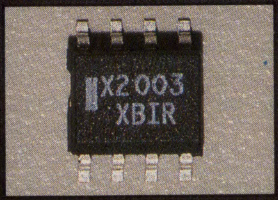

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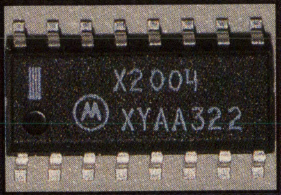

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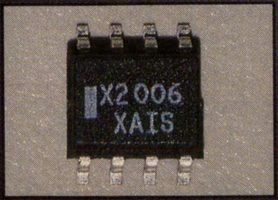

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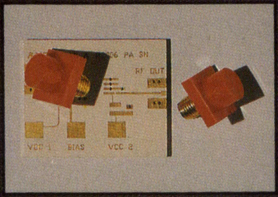

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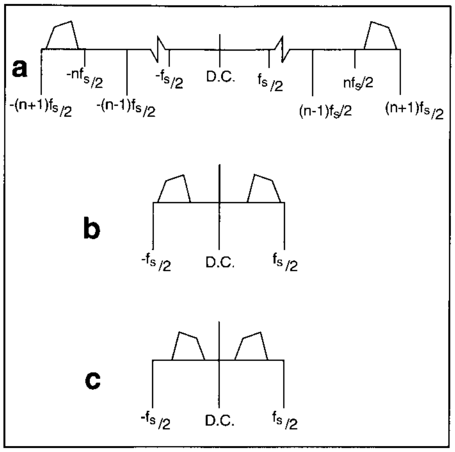

Figure 2. Original spectrum of bandlimited signal (a) and result of subsampling for n even (b) and n odd (c).

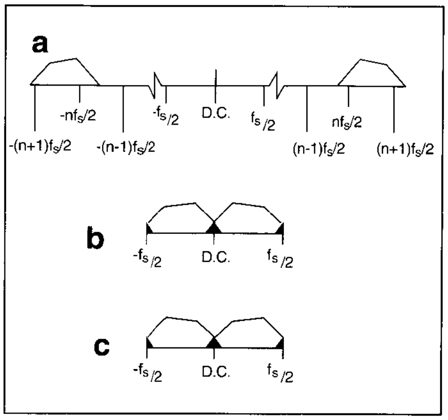

Figure 3. Original spectrum of bandlimited signal (a) and result of subsampling for n even (b) and n odd (c) with transition band folding.

S&H. This is because the A/D is operating at a rate consistent with the bandwidth of the band of interest while the S&H must operate with a bandwidth consistent with the IF location of the band of interest.

To illustrate this, extend the above example, still using a 12.5 MSPS A/D. Consider a 3.125 MHz-wide band of interest centered at a 71.875 MHz IF. The band of interest extends from 70.3125 to 73.4375 MHz. The band of interest is spectrally reversed in the subsampling process and extends from 1.5625 to 4.8125 MHz in the discrete baseband frequency domain. Therefore, the S&H must be designed to meet the SNR and SFDR specifications for signals of up to approximately 73.5 MHz in frequency while the A/D must meet them only for input frequencies up to approximately 5 MHz.

Another important consideration for subsampling is the relationship between the S&H clock and the A/D clock. The S&H must be designed for high-speed signal capture, a requirement that is incompatible with extended hold times. Thus, even though the time interval between samples is relatively long, the A/D must capture the sample immediately after the S&H samples the input signal. Otherwise sample droop before analog-to-digital conversion will cause signal distortion. If clock relationships can not be guaranteed, a secondary long-term hold circuit can be included in the S&H to prevent signal droop before the A/D captures the signal.

There are two major advantages to subsampling. First, it increases the allowable conversion time for the A/D Converter. Second, it performs a part of the downconversion task. As in the example above, the input passband signal is brought closer to baseband by the proper choice of sampling frequency. Because of this, the second IF stage can be eliminated in some cases (Figure 4). Note that the final IF stage is now a digital circuit, where a multiplier is used as a mixer, a numerically controlled oscillator (NCO) replaces the VCO, and digital filters are used instead of analog filters.

Practical subsampling

There are two keys to real-life implementation of subsampling: the S/H must have a wide input bandwidth, so that the S/H and A/D converter together maintain a high ENOB over a useful range of input frequencies, and there must be a way of processing the sampled signal.

Sampling A/D converters are available with 8-, 10-, and 12-bit resolution, conversion rates to 500 MSPS, and input bandwidths to 300 MHz. The graph (Figure 5) shows the effect of input frequency on ENOB for Harris' HI5702 10-bit, 40-MSPS A/D converter. Introduced in July of this year, this converter is a good indicator of the current state of the art.

Digital IF Processing

Once the IF signal has been digitized, additional digital signal processing often includes fine frequency tuning, real-to-complex signal conversion, channel selection filtering, matched filtering, and phase/frequency tracking of the carrier.

For example, to process narrowband input signals at low input sample rates (< 5 MSPS), an ultrahigh dynamic range down-converter may be constructed using two HSP43124 Serial I/O Filters (Figure 6). These ICs process serial data streams with word widths from 8 to 24 bits using a filter compute engine that utilizes 32 bit coefficients. The extended length coefficients provide floating-point filter performance that makes possible down-converter designs with well over 100 dB of dynamic range. The IC is called a serial I/O filter because it interfaces with the serial port of most common DSP processors. One advantage of this arrangement is that the serial I/O filter can off-load the downconversion function from the DSP µP when either

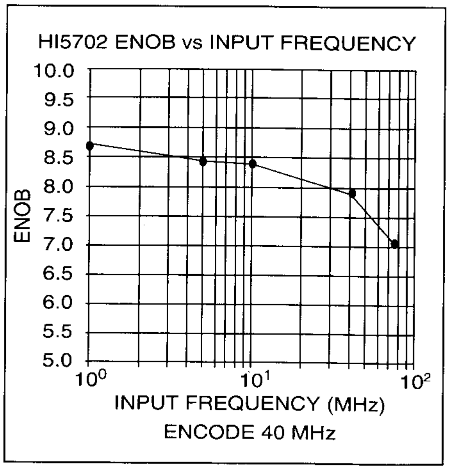

Figure 5. Effect of input frequency on ENOB of HI5702 ADC.

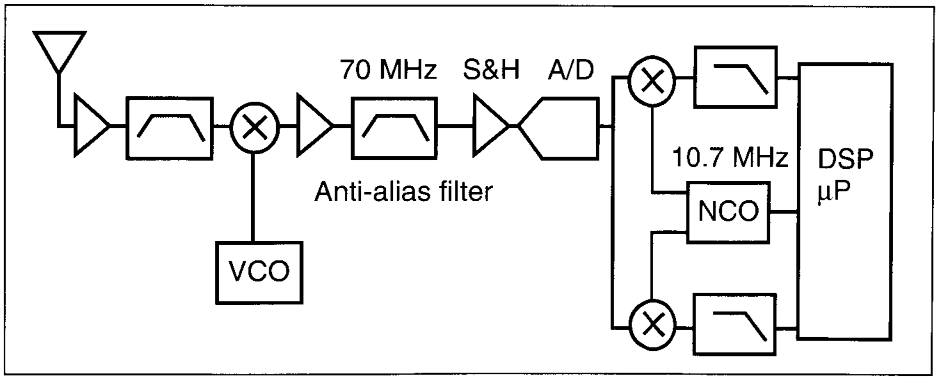

Figure 4. Receiver architecture using subsampling.

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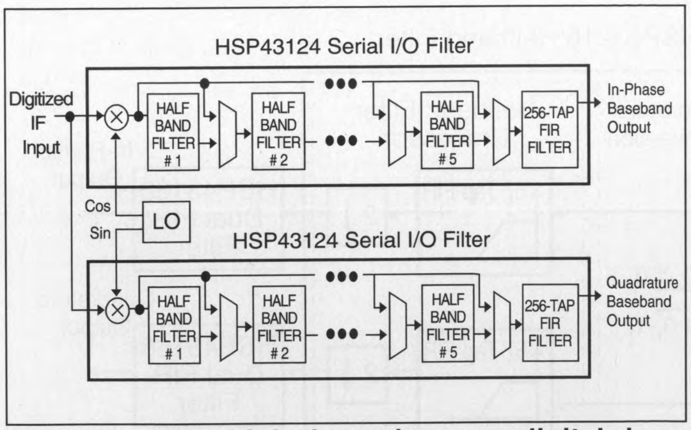

Figure 6. Ultra-high dynamic range digital down converter.

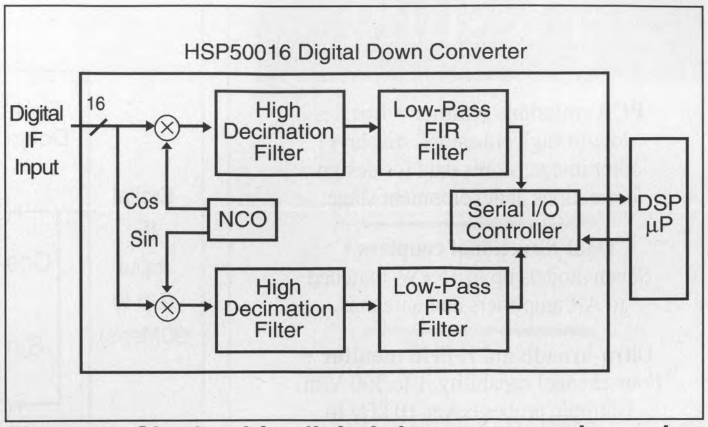

Figure 7. Single chip digital down conversion using HSP50016

performance or processing burden is an issue.

For tuning, the user mixes the incoming data with a mix factor that is either input via a 2-pin serial interface or selected from an on-chip look-up table. The table provides fixed down conversion by supplying mix factors derived from a sine wave sample at Fs/4.

Using these mix factors, the upper or low sideband of the input signal is translated to DC. The choice of upper or lower sideband depends on vector rotation. Following this frequency translation, the in-phase and quadrature components are filtered by a cascade of up to five decimate-by-two halfband filters and a programmable FIR of up to 256 taps. The IC supports decimation by factors from 1 to 256.

Alternatively, for applications that require the digital IF processor to extract narrow channels within a wideband input, the HSP50016 Digital Down-Converter (DDC) may be used (Figure 7). Using this chip, a real input sampled at up to 75 MSPS is mixed with the in-phase and quadrature components of a complex NCO. The tuning operation creates a complex signal in which the band of interest has been translated to DC. A two-stage filtering process is then used to extract the baseband signal. The first stage, a high-decimation filter, performs coarse filtering while providing decimation by a programmable factor from 16 to 32,768. The second stage is a fixed-coefficient FIR filter that has a narrow transition band to reject all but the desired signal. It also performs an additional decimation by four. Together, the high order decimation filter and the FIR can extract signal bandwidths from 320 Hz to 654 kHz from a wideband IF sampled at 75 MSPS. The quadrature baseband signal resulting from this process is then output in a serial format appropriate to the selected DSP microprocessor

The power of DSP algorithms is illustrated by the DDC's tuning and filtering performance. For example, the complex NCO maintains an SFDR > 102 dB while providing a tuning resolution < 0.02 Hz (at 75 MSPS input rates). In addition, the tuning frequency and phase can be updated in as little as 4 µs via the microprocessor interface. The two-stage filtering section provides an overall shape factor of 1.25-to-1 with less than 0.04 dB of passband ripple, over 104 dB of stopband attenuation, and constant group delay. In addition, the filtering section reduces the output sample rate to

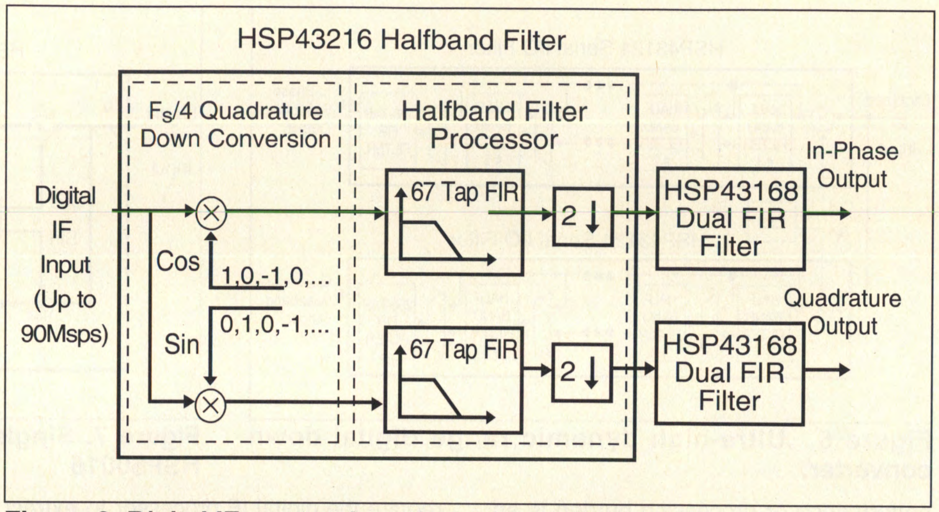

Figure 8. Digital IF processing of wideband signals.

match the frequency content of the baseband signal by providing decimation ranging from 64 to 131,072. This reduction in sample rate is what allows interfacing the wideband sampled IF to slower baseband DSP microprocessors.

In the two examples above, the bandwidth of the output signal is relatively low. In applications requiring wider band outputs, specialized processing architectures must be capable of performing down-conversion and filtering of a high data rate input (tens of MSPS) without significantly reducing the data rate of the output. One possible solution uses a chip called the HSP43216 Halfband Filter, followed by separate HSP43168 Dual FIR Filters (Figure 8).

In operation, the upper or lower sideband of a real input signal is translated in frequency to DC by mixing the input with a sinusoid at 1/4 the sample rate. The real and imaginary components of the resulting complex signal are then filtered by identical, decimate-by-2, 67-tap halfband filters. This process preserves the bandwidth of the input signal while changing the representation from that of a real signal to a complex signal at half the data rate. The task of spectrally shaping the output is performed by the dual FIR filters, which are used to realize between 16 to 256 taps, depending on decimation rate selected.

Conclusion

Traditionally, the use of DSP in various receivers has been limited to baseband processing by a DSP microprocessor. In general, this approach has done little to modify the design methodologies associated with the RF processing chain. ICs designed specifically for digital down-conversion allow higher IF sampling rates, which relaxes the requirements on RF filtering and mixer LOs. Shifting part of the tuning and filtering burden to IF DSP chips releases some of the DSP µP's processing bandwidth for other more value-added tasks.

With this approach, the use of undersampling techniques to capture band-limited signals after the first IF stage becomes more feasible. This architecture allows eliminating the second IF stage, reducing component and manufacturing costs. Further, the task of fine tuning and channel filtering is shifted into the DSP domain, which is better suited for those tasks. ***RF***

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Clay Olmstead and Mike Petrowski are engineers in Harris' DSP Applications department.

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Prior to his employment at Harris, Mike Petrowski worked as a Research Assistant at the Center for Communications, Speech, and Signal Processing at North Carolina State University where he investigated imaging system performance. He holds BSEE and MSEE degrees from North Carolina State University.

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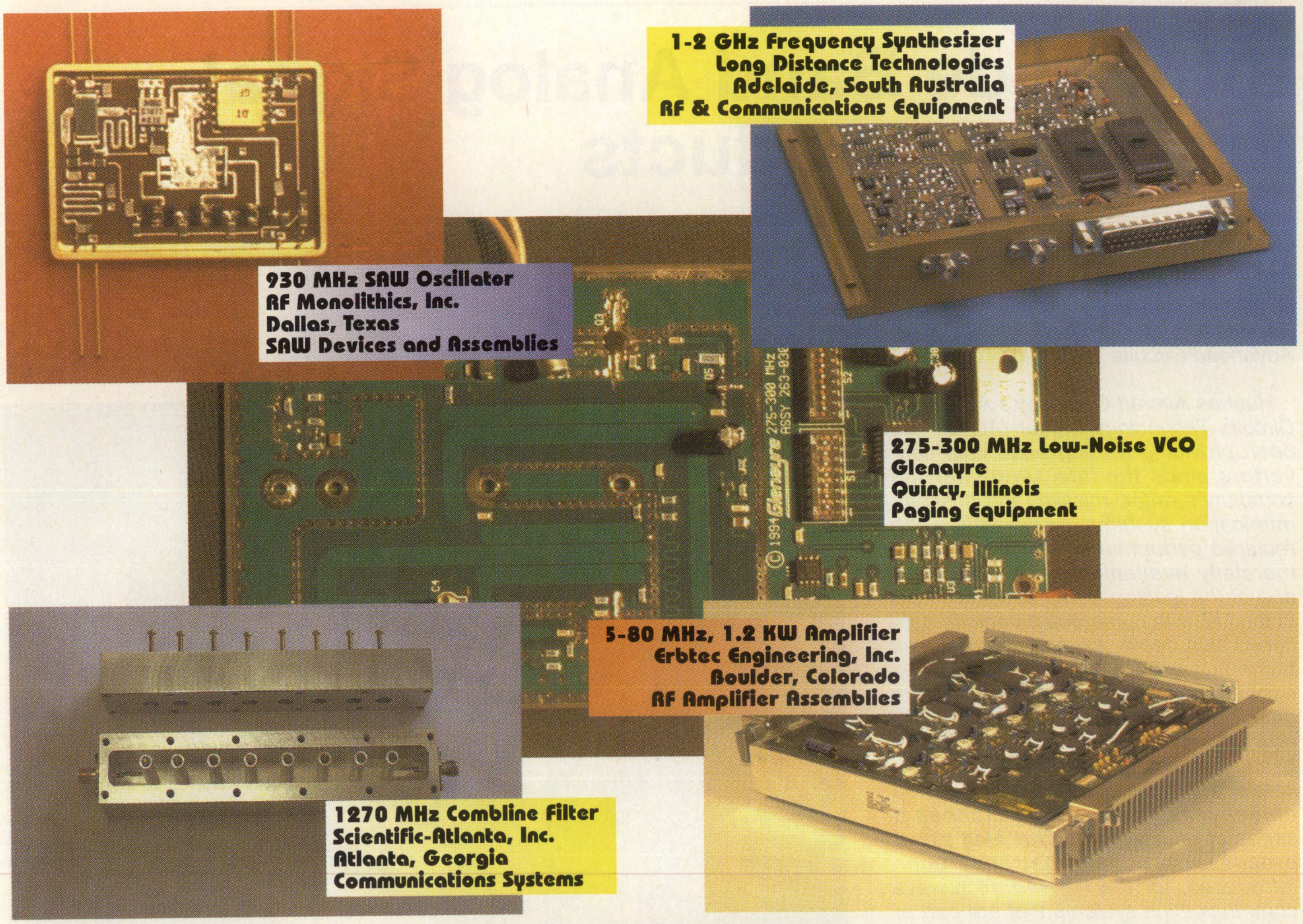

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INFO/CARD 31

Ultra Wide Band Analog Signal Processor Products

By William W. Cheng
Hughes Aircraft Company
Advanced Circuits Technology Center

Hughes Aircraft Company's Advanced Circuits Technology Center (ACTC) has been providing leading edge data converters since the late 1960's for the company's radar, missile, and telecommunication systems, particularly when required performance lies beyond commercially available devices. ACTC is one of the leading circuit design centers in the US with numerous patents in data conversion, receivers, and analog circuit techniques. Expanding on the unique expertise developed for Hughes' core defense electronics operations, ACTC is now offering cost-effective commercially-oriented solutions to the global marketplace in light of defense conversion objectives. This article describes a series of ultra wide band analog signal processor products that have been introduced, for the RF and microwave communication systems that are part of today's information superhighway.

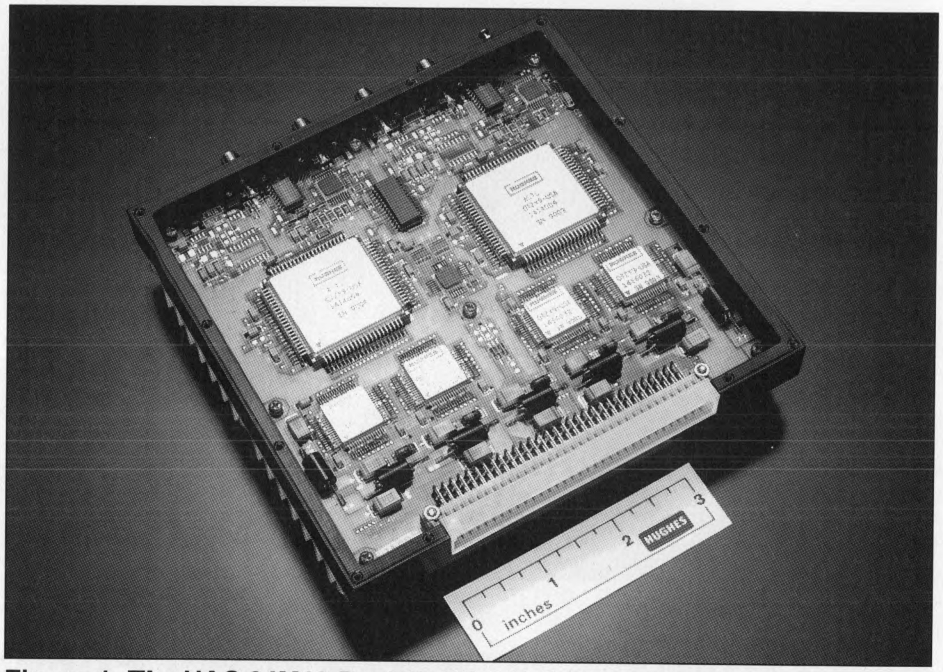


Figure 1. The HAC 94M12 Dual 12 Bit A/D Converter Module.

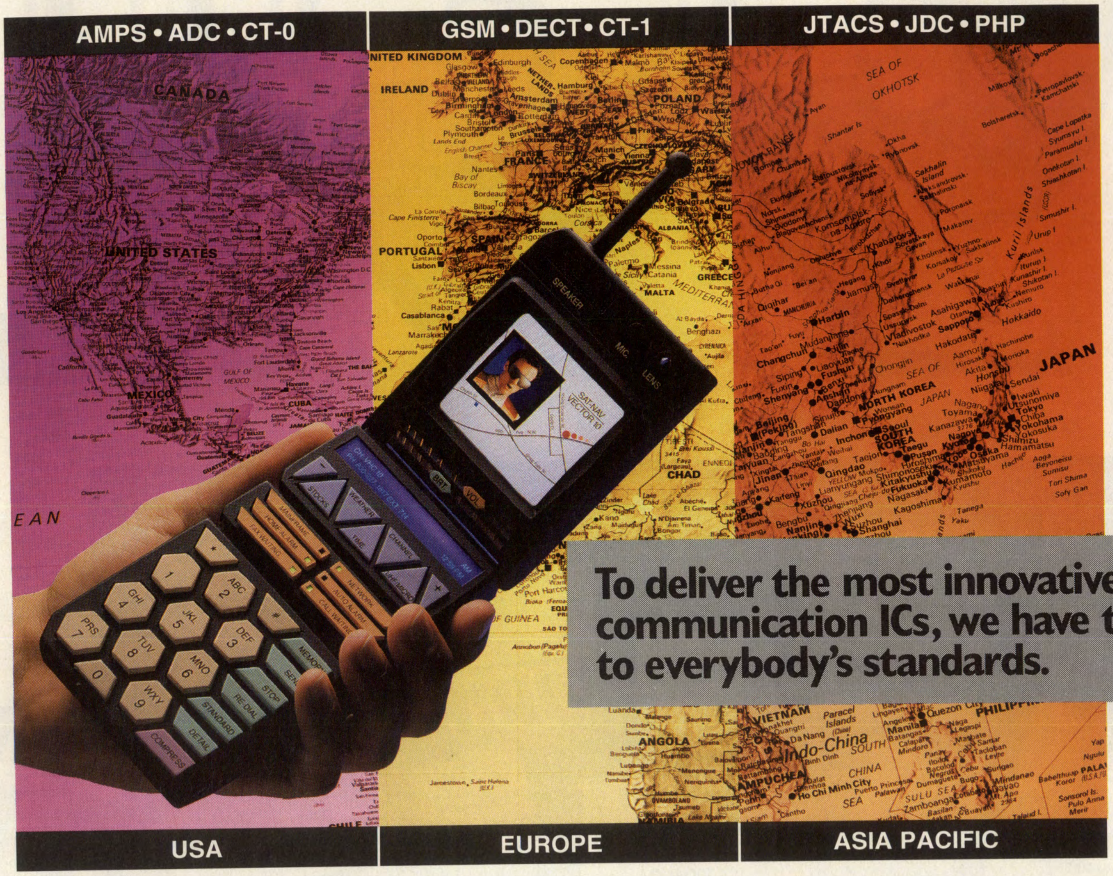
Hughes ACTC has developed data conversion building blocks for today's high speed, high performance communication signal processing systems that require high dynamic range and wide bandwidth analog to digital (A/D) and digital to analog (D/A) converters. A new family of signal processor products includes the HAC 94M12 Dual 12 Bit 50 MSPS Analog to Digital Converter Module with >80 dB SFDR at 10 MHz video, the HAC 94SC08 Programmable IF Frequency 8 Bit 400 MHz I/Q Synchronous Converter Module with 200 MHz RF bandwidth, and the HAC 94M14 Dual 14 bit 1 GHz Digital to Analog Converter with >75 dB spur-free performance at low video frequency. These building blocks are highly integrated and compact in size yet incorporate many supporting functions to simplify system interface. These products can be easily inserted into commercial or military systems and can significantly simplify and lower the cost of the overall system integration and implementation.

The Hughes high resolution A/D converter and I/Q A/D converter modules can be applied to radar and communication systems where the signal is digitized in the front end, before digital signal processing or compression. These converters are ideal for digital receivers that require wide signal bandwidth for multi-channel data processing. Applications include wireless communication systems, cellular base receivers, satellite transmission, test instrumentation, guidance and control systems. The Hughes high resolution D/A converter is ideal for frequency synthesizer and waveform generation applications. It offers the highest spur free dynamic range at the specified sample rate.

Dual 12 Bit 50 MSPS A/D Converter Module

The HAC 94M12 module, Figure 1, includes two identical channels of a Hughes developed analog to digital converter hybrid with supporting functions that can be clocked up to 50 MSPS. Some of the key features in the A/D module include offset adjust, clock buffering circuit, phase alignment between channels, output buffers for standard differential ECL levels, and power supply filtering. All digital outputs and power to the module are through a standard 96-pin Eurocard interface connector. Analog input signals and optional analog offset inputs are through SMA connectors.

The A/D offset can be adjusted by either analog or digital means. The A/D offset can be corrected through a pair of offset adjust SMA terminals with external analog voltages. Alternatively, a dual 12 bit serial digital to analog converter (DAC) in the module can be configured to accurately correct the offset. The DAC is easily connected to an external



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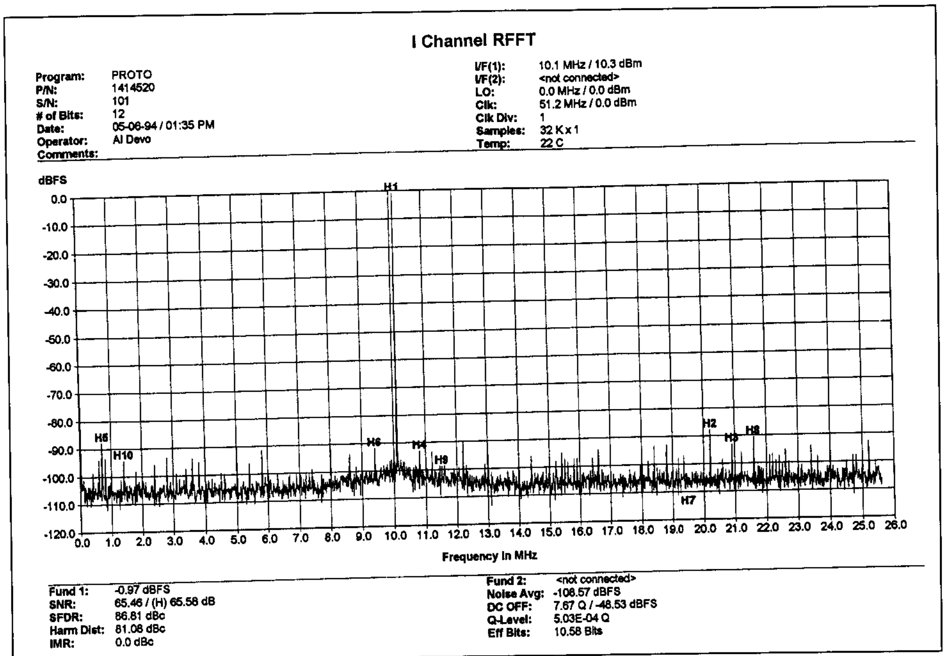

Figure 2. 12 bit A/D module at 1 MHz video, 51.2 MHz clock.

offset correction loop through the control lines in the interface connector. A corrected A/D can have the offset in fractions of an LSB.

In I/Q synchronous converter systems, phase match is an important consideration between the two A/D converter channels. When the analog input paths are not exactly equal, an error appears as a phase mismatch that could range from a few tenths of a degree to a few degrees. This error occurs when the analog signals are sampled at different points in the two A/D's at a specific instance of time. By sampling the analog signal in one channel at a slightly later time, the phase mismatch can be compensated accurately. A digital delay circuit is inserted in front of each A/D clock input to delay the clock signal for sampling the analog signal at a particular instant where the phase is optimally matched. Typically this method can correct phase error to better than half a degree over the operating frequency band. With this compensation, the output data for one channel will be shifted by the same amount as the input clock is delayed. Since this is typically small compared to the clock period, there is no impact on timing skew if the data for both channels are strobed in the middle of the valid data window.

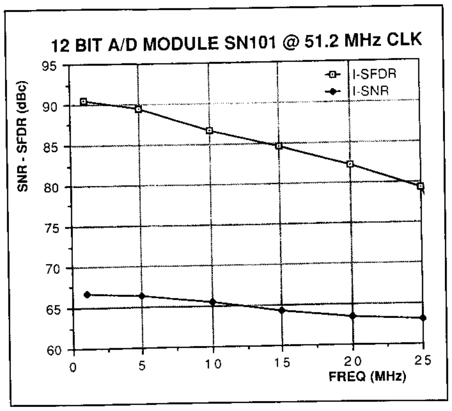

Figure 3. 12 bit A/D SNR and SFDR summary at 50 MHz clock.

The A/D data outputs are buffered by fully differential ECL output drivers configured to drive 100 ohm terminated loads. The output drivers buffer the A/D converters from any external system noise that may corrupt the performance of the A/D conversion. The output coding is in two's complement.

The A/D module is housed in a EMI shielded enclosure of the size 5.87 × 5.7 × 0.75 inches. A heat sink is mounted on the back of the housing to adequately dissipate the power in the unit. The A/D module uses ±7.5V and ±5V power supplies.

Dynamic Performance Summary

The A/D converter module is characterized by capturing its digital outputs into a buffer memory at speed and processing the FFT spectrum analysis in a desktop computer. Histogram and waveform reconstruction can be extracted from this analysis. The HAC 94M12 A/D Converter Module has been optimized

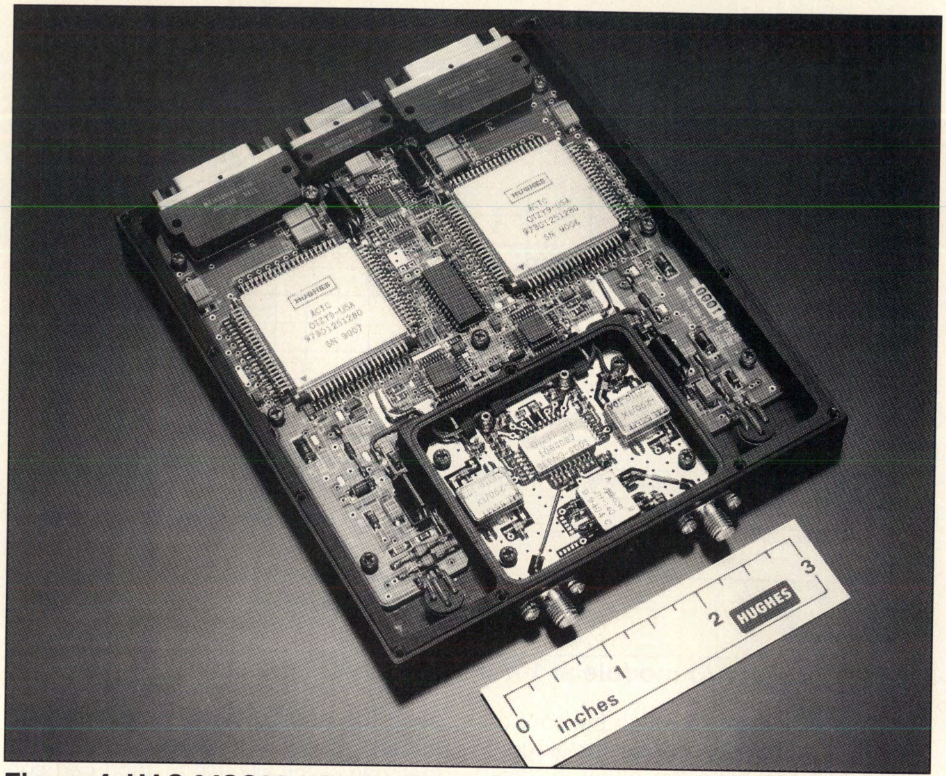

Figure 4. HAC 94SC08 8 Bit I/Q Synchronous Converter Module.

for Spur Free Dynamic Range (SFDR) of greater than 80 dB to 10 MHz video sampled at 51.2 MHz. Signal to Noise and Distortion Ratio (SNR) is greater than 65 dB to 10 MHz and better than 63 dB to Nyquist bandwidth. FFT data in Figure 2 shows 86 dB SFDR and 65 dB SNR for 10 MHz signal sampled at 51.2 MHz. The Integral Non-Linearity (INL) and Differential Non-Linearity (DNL) errors are better than 0.75 Q levels. The FFT summary illustrating SFDR and SNR sampling at 51.2 MHz is shown in Figure 3. This product offers the highest spur free performance at the specified sampling frequency than any device in the market today. The HAC 94M12 prototype has been independently evaluated by MIT-Lincoln Laboratory validating the performance results [1].

Programmable IF 8 Bit 400 MSPS I/Q Synchronous Converter Module

The 8 bit I/Q Synchronous Converter Module, HAC 94SC08, Figure 4, consists of a synchronous detector and separate I and Q channel 8 bit analog to digital converters with 1:2 demultiplexed data outputs. The IF frequency can be programmable from 350 MHz to 900 MHz with 200 MHz of RF bandwidth. The 8 bit A/D converters can be sampled at up to 400 MHz.

A dual wide band active mixer is the core of the synchronous detector unit. The LO into the I/Q mixer is split from a quadrature element for a particular frequency range. The mixer is fed into a low pass filter to eliminate high order products. The filtered RF outputs are amplified by low distortion video amplifiers before digitizing by the 8 bit A/D converters.

Supporting features in the module include offset adjust, sample clock buffering, phase match alignment, and differential ECL output interface. The LO and IF inputs are through SMA connectors to the synchronous detector unit that is shielded from the video data conversion section. Power is supplied through a 21 pin miniature connector while the I/Q multiplexed digital data are provided through two separate 51 pin miniature connectors. The synchronous converter is housed in a low profile EMI shielded enclosure of the size 5.5 × 4.75 × 0.5 inches.

The offset of the analog path through the A/D converter can be compensated by a 12 bit serial interface DAC in the module. In this mode, the offset DAC is programmed through the output connector from an external offset correction loop.

The phase match between the I/Q channels can be compensated using the

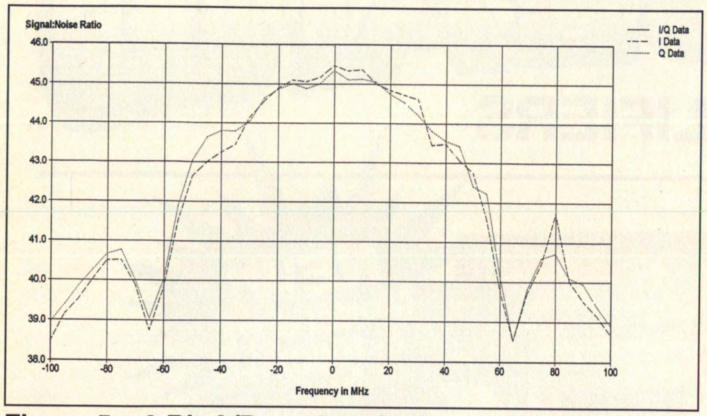

Figure 5a. 8 Bit A/D module SNR performance.

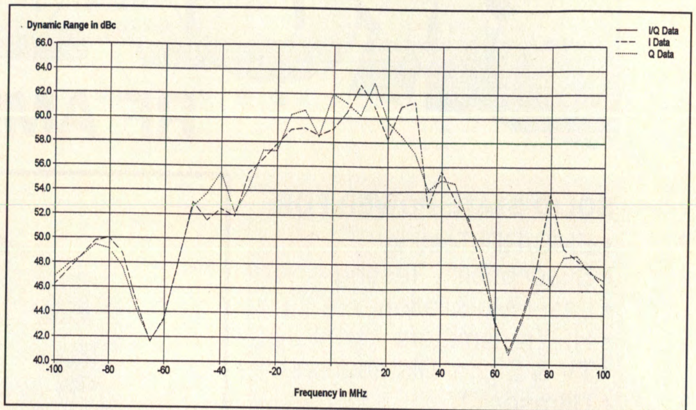

Figure 5b. 8 Bit A/D module SFDR performance.

delay sampling method described in the above 12 bit A/D converter. Typical phase match can be corrected to less than 1 degree for full RF bandwidth.

Each of the two 8 bit A/D converters are programmable to demultiplex into two paths, channels I-A, I-B and Q-A, Q-B, at half the speed to ease data interface. The output data can also be selected to convert in single I/Q channels at full sampling rate.

Dynamic Performance Summary

The HAC 94SC08 synchronous converter module has been extensively tested in the laboratory and also in systems in the field. The inputs require +7 dBm LO power and –12 dBm IF power. The power supplies require ±12V and ±5.2V through the miniature connector.

The dynamic performance of the unit is characterized by its FFT spectrum analysis when the IF frequency is swept in the Nyquist Band of the sampling rate from the LO. The unit is tested at 350 MHz sampling rate with the LO at 900 MHz. The IF is swept from 800 to 1000 MHz with a 200 MHz RF bandwidth. SNR for both I and Q channels is shown to have a peak SNR of 45 dB and an average of 44 dB across the half band in Figure 5a. SFDR has an average of 56 dB across half the band, Figure 5b. Other characteristics of interest are the

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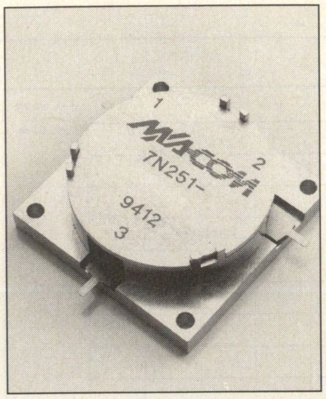

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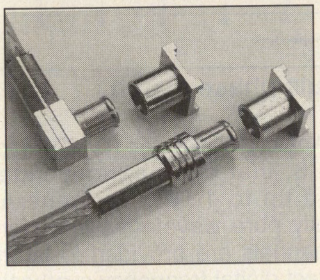

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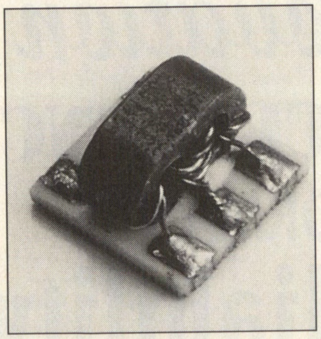

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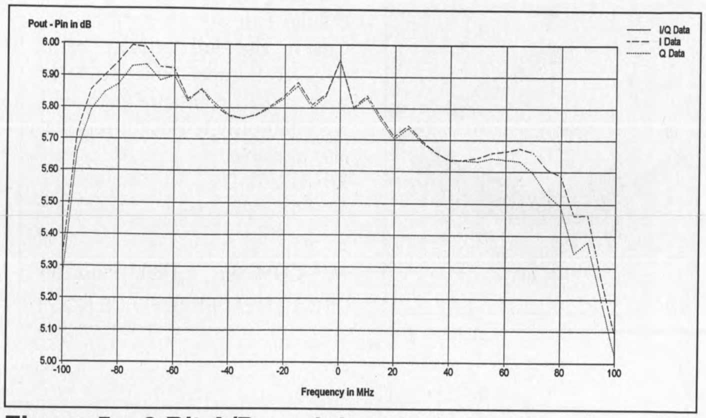

Figure 5c. 8 Bit A/D module gain flatness.

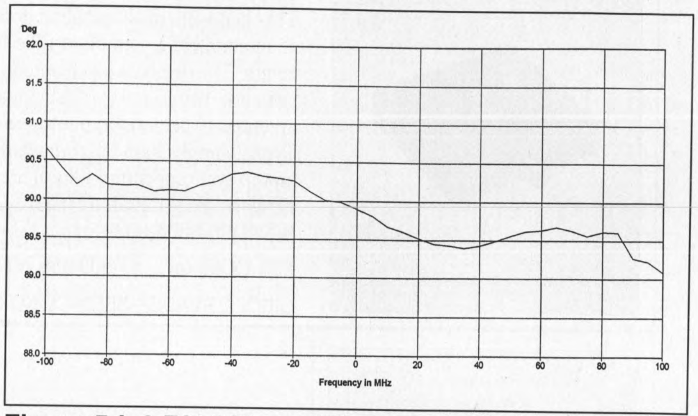

Figure 5d. 8 Bit A/D module phase match.

gain flatness, gain match and phase match between I and Q channels over the frequency band. The gain flatness is within 0.5 dB for 160 MHz band and is less than 1 dB for full 200 MHz bandwidth in Figure 5c. Typical amplitude match is within 0.2 dB over full band. The phase match between I and Q channels is better than 1 degree over the entire bandwidth in Figure 5d.

The HAC 94SC08 module uniquely combines the function of synchronous detection and 8 bit data conversion in a low profile compact unit. It offers the highest SNR and SFDR performance and the lowest gain and phase match errors between channels in its RF frequency band.

Dual 14 Bit 1 GHz Digital To Analog Converter Module

The HAC 94M14 is a dual 14 bit Digital to Analog Converter (DAC) Module, Figure 6, that can be independently clocked up to 1 GHz for generating spectrally pure waveforms and signals. Two channels are provided to interface with direct digital frequency synthesizers for generating orthogonal signals. The core circuit is a single chip silicon IC implementing a segmented unary architecture to minimize major transition glitches that are characteristic of binary

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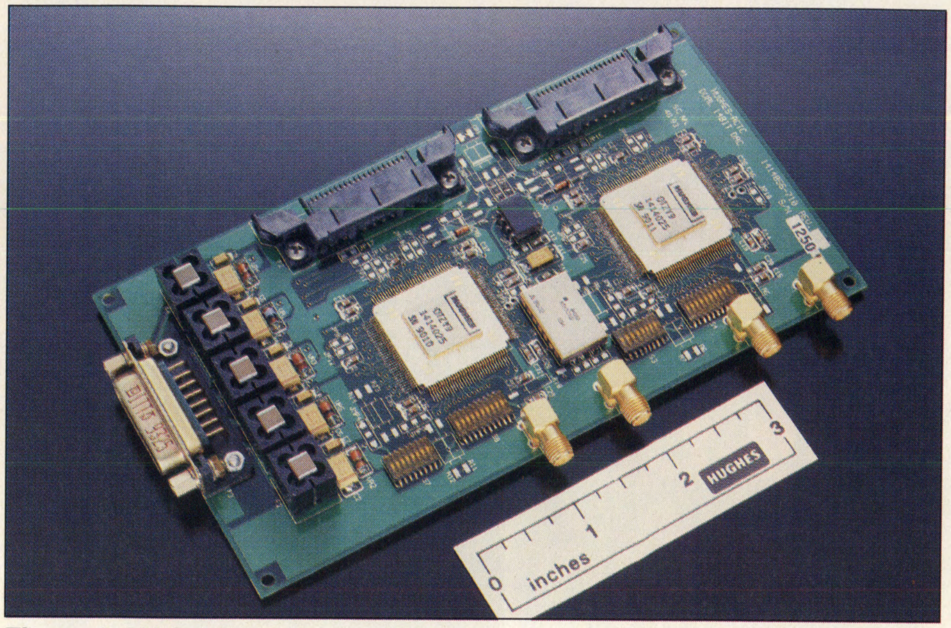


Figure 6. HAC 94M14 Dual 14 Bit DAC.

weighted DAC's. The output response is fast settling to ensure a clean signal synthesis at high frequencies.

The on chip reference amplifier loop regulating the output current enables an easy user interface. The differential output current is designed to drive at 40 mA full scale into doubly terminated 50 ohm resistive loads to 1V signal swing. The standard differential ECL inputs and clocks are terminated to the option of either 50 ohms to –2V or 100 ohms shunt between the differential inputs.

The DAC IC and termination resistors are housed in a multi-layer ceramic package with controlled impedance lines to ensure signal integrity at high frequency. Adequate heat sinking from the module is provided to prevent thermal changes from affecting dynamic performance. High frequency control impedance interconnect cables are used to interface the DAC module to system applications. SMA connectors are provided for the analog outputs. Power is brought into the module through a standard 15-pin D-connector. The DAC IC's in the module are powered by –5V and –12V supplies.

Dynamic Performance Summary

Spur Free Dynamic Range (SFDR) performance is the principal criteria in rating the quality of a high speed digital to analog converter. The SFDR is the magnitude difference between the fundamental tone being generated to the highest harmonic and spur in the Nyquist band. Most systems generally band-limit the signal before any signal mixing and post-processing. In particular, a common output frequency band of interest is the 1/8 to 3/8 ratio band of the clock frequency. The two specific 1/8 and 3/8 frequencies are the most stringent cases in measuring the SFDR because all out of band harmonics for these frequencies are all aliased back on top of each other in the base band. The 3/8 case is a worst case because the tone being synthesized is a high frequency to slew and settle. The other frequencies in the band have better SFDR than these two cases because the harmonics and spurs are being spread out in the base band. In particular, the 2/8 case has harmonics aliased on top of the fundamental and DC term, which shows the upper bound of the SFDR. SFDR can also vary significantly with different initial sinusoidal phase for a particular frequency because different DAC codes are sampled at different times for various phases. The SFDR over frequency has been thoroughly characterized for the HAC 94M14 DAC module.

A 1 GHz pattern generator is employed to synthesize the sinusoidal patterns to evaluate the dynamic performance of the DAC. The clock source is

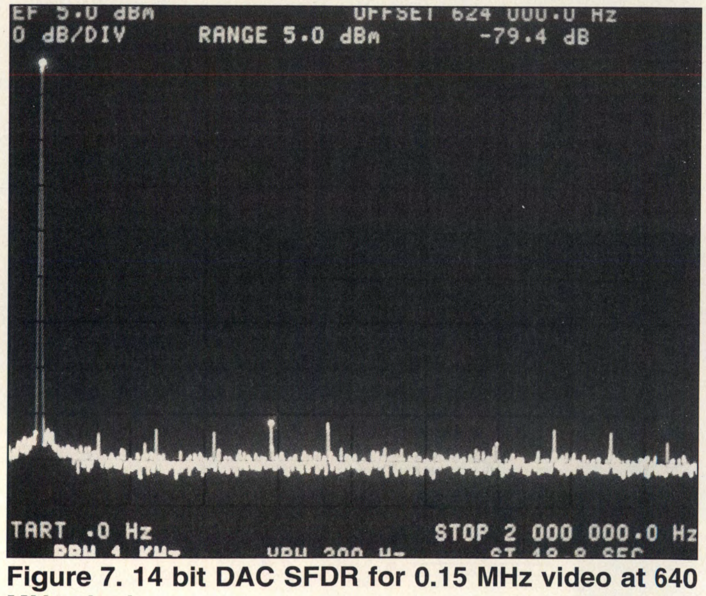


Figure 7. 14 bit DAC SFDR for 0.15 MHz video at 640 MHz clock.

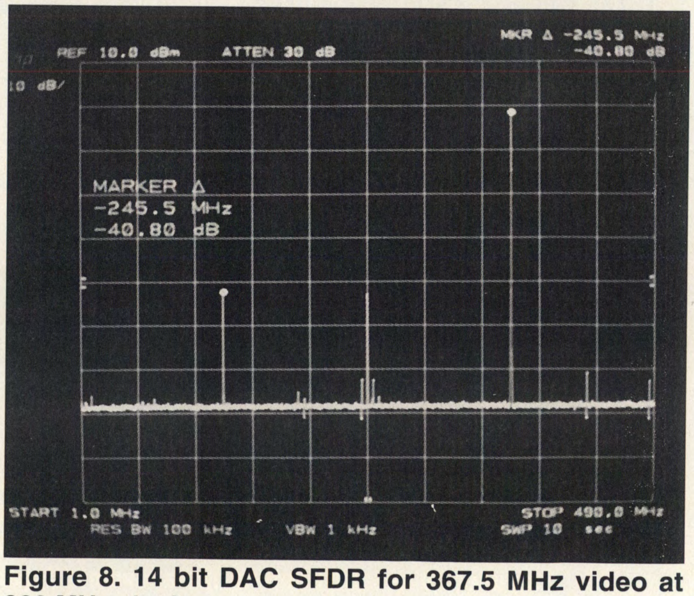


Figure 8. 14 bit DAC SFDR for 367.5 MHz video at 980 MHz clock.

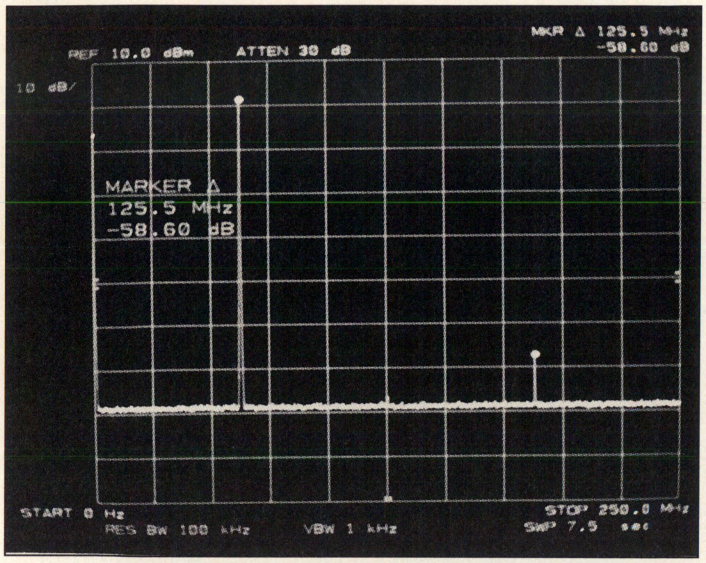


Figure 9. 14 bit DAC SFDR for 62.5 MHz video at 500 MHz clock.

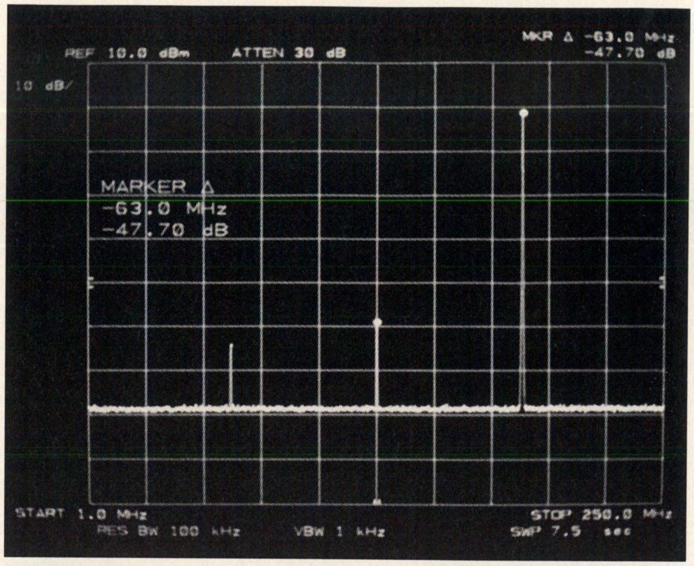


Figure 10. 14 bit DAC SFDR for 187.5 MHz video at 500 MHz clock.

a ultra-low phase noise frequency synthesizer squared up by a ultra-fast low jitter pulse amplifier to ensure a clean sample clock waveform. Any jitter in the clock is directly reflected in the degradation of SFDR performance.

The DAC output frequency is synthesized to step through the entire frequency band and the harmonics and spurs are observed in a spectrum analyzer from the unfiltered DAC output. Low frequency sine wave generation can be generated spectrally pure to 79 dB SFDR as shown in Figure 7. Typical SFDR for 1/8 and 3/8 tones at 500 MHz clock are 58 dB and 47 dB respectively; see Figures 9 and 10. The 3/8 tone is 40 dB at 980 MHz clock, Figure 8. When the sinusoidal phase is slipped at a particular frequency, the worse case SFDR can be observed using the max hold function on the spectrum analyzer. The typical SFDR for worse case phase performance at 480 MHz clock is summarized in Figure 11.

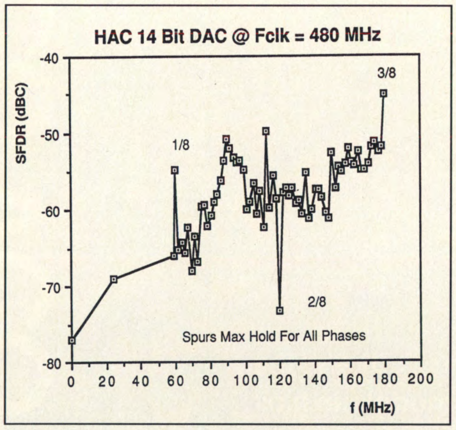


Figure 11. 14 bit DAC worse case phase SFDR at 480 MHz clock.

The HAC 94M14 module offers the highest sampling rate high resolution dual digital to analog converter in the market today characterized by outstanding dynamic performance.

Summary

Hughes data conversion technology has produced a product line of high performance I/Q A/D and D/A converter modules that can be applied to today's RF and microwave signal processing communication systems. The high resolution A/D and D/A converter modules are characterized by their exceptional high SFDR at high sampling rates. The 8 bit synchronous converter module offers a compact I/Q detector with high performance demultiplexed quantizers. These converter products have been installed and tested in systems requiring high quality and performance. All these units are available from the Advanced Circuits Technology Center of GM Hughes Electronics.

More information for the above products can be obtained from Hughes ACTC New Business Development Manager John Burns at (310) 517-6700 or by circling Info/Card #180.

Acknowledgement

The cover photo for this issue, and the module photos in this article, were done by Matt Weinberg of Hughes Aircraft Company's Santa Barbara Research Center. *RF*

Reference

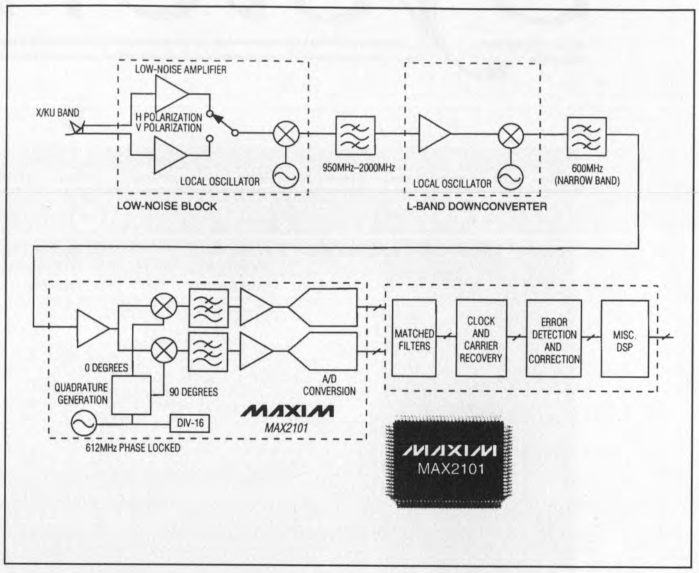
1. "Evaluation of the Hughes 12-bit 50 MHz ADC," MIT Lincoln Laboratory Project Report AST-36, to be published.

About the Author

Bill Cheng is a technical head responsible for analog IC design and data conversion product development. He has been with Hughes Aircraft Company for over 10 years. He received his BS, MS, & MBA from UCB, UCLA, & USC respectively. He can be reached at Hughes Aircraft Company, ACTC, Bldg. 232, P.O. Box 2999, Torrance, CA 90509-2999.

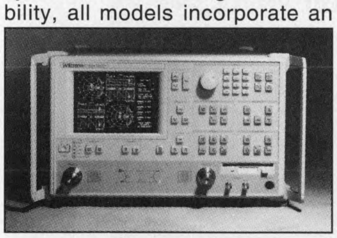
Quadrature Digitizer

Maxim Integrated Products introduces the MAX2101, a 6-bit quadrature digitizer that combines quadrature demodulation with analog-to-digital conversion on a single bipolar silicon die. The device accepts input signals from 400 MHz to 700 MHz and applies adjustable gain, providing at least 40 dB of dynamic range. The ADC provides greater than 5.3 effective bits at sampling rates of 60 Msps and F_{in} = 15 MHz. It also features fully integrated low-pass filters with externally variable bandwidth (10 MHz to 30 MHz), a programmable counter for variable sample rates, and a signal detection function. Each baseband is filtered by an on-chip, 5th-order Butterworth low-pass filter, or the user can use an external filter. Baseband sample rate is 60 Msps. Offset binary or twos-complement output data format can be selected. The MAX2101 also offers a signal-detection function, and automatic baseband offset cancellation. The device is designed for digital communications such as those used in DBS, TVRO, WLAN, and other applications. The MAX2101 is available in a 100-pin MQFP package in the commercial (0 to +70 °C) range. Prices start at $17.95 for quantities of 1000 and up.
Maxim Integrated Products
INFO/CARD #250



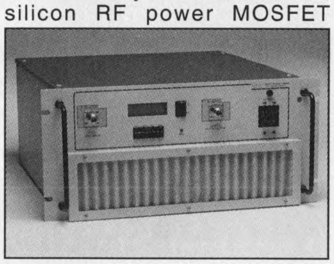
Vector Network Analyzers

Anritsu Wiltron announces the 37200A series of vector network analyzers. The 37200A series combines designs of Anritsu's 360B VNA with modern architectures that optimize productivity and measurement throughput. All models feature fast sweep speeds after 12-term calibration, wide dynamic range, and 1 Hz frequency resolution. For long-term reliability, all models incorporate an electronic transfer switch. The series covers the 22.5 MHz to 40 GHz range, and offers full IEEE-488.2 compatibility, fast GPIB data transfers, an internal 85 Mb hard drive and segmented limit lines for pass/fail testing. An internal 1.44 Mb MS-DOS floppy drive can be used for uploading and storage of setups. A large selection of calibration methods are available to the operator, and the series can also be used with Anritsu's new AUTOCAL system, which automatically makes full 12-term calibrations with a single connection. Prices for the series start at $41,000.
Anritsu Wiltron
INFO/CARD #249



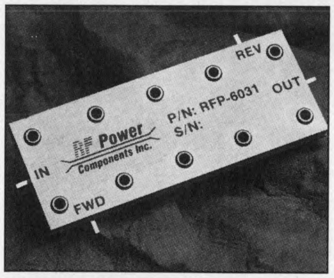
μP-Controlled Power Amplifier

Designed for wideband high-power application in the 200 to 500 MHz frequency range, GTC's GRF5006 is microprocessor controlled. This rack mounted amplifier utilizes fully isolated, class AB, silicon RF power MOSFET devices for high gain and wide dynamic range. Typical harmonics are –25 dBc at 1 dB compression, and spurious are > 60 dBc. The microprocessor controls the multi-function LCD display, ALC feedback, VSWR protection, calibration, and IEEE-488 remote control and remote monitoring. Output power is 500 W at 1 dB compression. Gain is 57 dB (min.) and the noise figure is 9 dB (max.). Protections and fault monitoring include thermal overload, load VSWR with graceful degradation, out of band drive, fan failure, over/under voltage, and over current. The amplifier is self contained with a power supply and cooling system. Each unit undergoes extensive burn-in prior to its final test and Q/A.
GTC
INFO/CARD #248



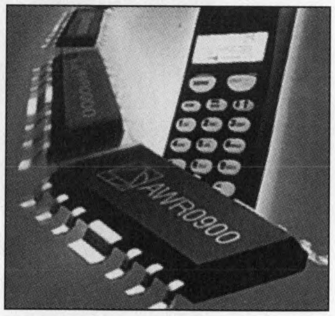
Drop-in Coupler

RF Power Components has introduced a dual directional cellular coupler with solder tabs for drop-in applications. The unique package design offers welded silver tabs for microstrip mounting in a moisture-sealed case. Model RFP-6031 operates from 800 to 1050 MHz, with up to 500 W CW power and covers the full cellular band. The broadband design of the RFP-6031 delivers precise coupled power levels that can be maintained over the cellular spectrum during channel hopping, reducing the need for additional signal leveling. In addition, the coupler has has a 50Ω internal termination. Maximum coupled-port VSWR is 1.25:1, nominal coupling is 20 ±1 dB, and directivity is typically 25 to 30 dB. Coupling flatness is ±0.25 dB. Model RFP-6031 is housed in a package measuring 3.00 x 1.50 x 0.25 inches. Connectorized units are also available. The device sells for under $95 in quantities of 100.
RF Power Components, Inc.
INFO/CARD #247



900 MHz Receiver MMIC

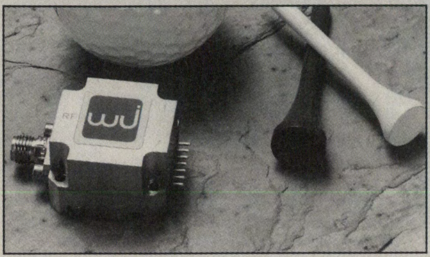
ANADIGICS' AWR0900 is a fully monolithic downconverter intended for cordless telephone and wireless LAN applications in the 900 MHz range. Features of the GaAs MMIC include an on-chip oscillator/image filter, 3 dB noise figure, 15 dB conversion gain, single +5V supply, and power-down capability. In addition, a small surface mount package and low current consumption make the AWR0900 ideal for both hand-held and battery operated applications. The device's input third order intercept point is –5 dBm and image rejection for a 110 MHz IF is 13 dB. Output IP3 varies from about –6.5 dBm to –1 dBm as supply voltage varies from 3.5 to 7 V. The LO's VCO covers a 20 MHz range with a tuning voltage of 0 to 4 V. Cost for the new receiver MMIC is $5 for quantities of 1000.
ANADIGICS
INFO/CARD #246



Product Spotlight: Oscillators

YIG Oscillators

Watkins-Johnson Co. has introduced two new models of YIG-tuned oscillators (YTOs) designed specifically for commercial and industrial applications. Both models cover the 3.7 to 8.0 GHz frequency range with +16 dBm output power, minimum. The WJ-6703-036F is housed in a hermetic case and uses capacitive feedthroughs, while the WJ-6755-206F is housed in a non-hermetic package using non-capacitive feedthroughs.



Watkins-Johnson Co.
INFO/CARD #245

Compact OCXO

Oak Frequency Control Group's 4899 oven controlled crystal oscillator (OCXO) is designed to provide superior performance in a compact, 1.5 inch square by 0.5 inch high package. The 4899 utilizes a precision SC-cut crystal to attain a temperature stability of $\pm 8 \times 10^{-9}$ from –20 to +70 °C and aging of only $\pm 5 \times 10^{-10}$ per day. The 4899 covers 7 to 20 MHz and offers Sine or HCMOS output.
Oak Frequency Control Group
INFO/CARD #244

Surface Mount VCXO

Champion Technologies introduces the K1526 series of voltage controlled crystal oscillators, available in compact ceramic packages for surface mount applications. The series operates at frequencies from 2.0 to 33.0 MHz, with frequency stability of ±50 ppm over an operating temperature of –40 to +85 °C. The K1526 series offers a deviation control range of 0.5 to 4.5 V, centered at 2.5 V, with a standard deviation sensitivity of ±50 ppm/V. The package measures 0.56 x 0.36 x 0.16 inches.
Champion Technologies, Inc.
INFO/CARD #243

3.5 to 4.0 GHz VCO

The V900ME01 from Z-Communications covers 3500 to 4000 MHz with a control voltage of 2 to 18 V. The device delivers 6 ±3 dBm into a 50 Ω load with a nominal 8V supply while drawing less than 35 mA. Phase noise at a 10 kHz offset from the carrier is specified at –90 dBc/Hz. Pushing is less than 7 MHz/V. The V900ME01 is packaged in Z-COMM's industry standard MINI surface mount package measuring 0.5 x 0.5 x 0.2 inches. Prototypes are available from stock for $55/VCO.
Z-Communications, Inc.
INFO/CARD #242

AMPLIFIERS

Broadband, 50 W Amp.

Amplifier Research has introduced a solid state RF power amplifier that delivers a minimum of 50 watts CW power across a frequency range of 1 to 1000 MHz. Model 50W1000A, weighing 45.0 lb and measuring 19.8 x 8.0 x 18.0 inches, joins nine other standard RF amplifiers in the ultra-broadband W-Series. Price is $19,000.
Amplifier Research
INFO/CARD #241

Miniature 225-400 MHz Amp.

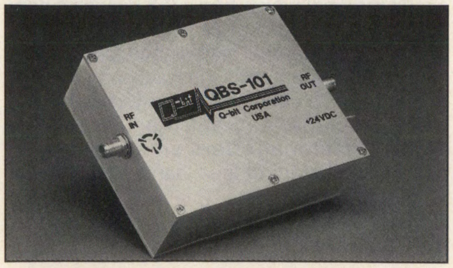
LCF Enterprises offers an amplifier that delivers 50 W CW power and operates from 225 MHz to 400 MHz in a module measuring 4.84 x 2.0 x 1.0 inches (excluding mounting feet and connectors). The amplifier delivers a minimum gain of 35 dB and operates from a 28 VDC supply with high efficiency. Another member of the same series delivers 100 W.
LCF Enterprises
INFO/CARD #240

1.85-1.98 GHz, 125 W Amp.

CMT has introduced an S-band, 125 watt PCS base-station amplifier. The CW amplifier uses GaAs FET technology and achieves gain of 55 dB, 1 dB compression output of 50.5 dBm and typical IP3 of +67 dBm. Designed for class A, class A/B operation, the unit operates from a 12 VDC power supply, drawing 30 A quiescent, and 47 A at maximum output. The amplifier is available in OEM or rack/chassis configurations.
Chesapeake Microwave Technologies, Inc.
INFO/CARD #239

Feedforward Amp.

The Q-bit model QBS-101 is a low gain, low noise, high intercept point feedforward amplifi-



er operating over the 2 to 70 MHz range. At 25 °C, the amplifier has 4.0 dB noise figure, 12.5 dB gain, +58 dBm OIP3, +93 dBm OIP2 and 44 dB reverse isolation. Packaged in a 3.0 x 3.5 x 1.23 inch housing, the amplifier operates from 24 VDC with 350 mA of current.
Q-bit Corp.
INFO/CARD #238

Pulse Amplifier

The ZPUL-21 50Ω pulse amplifier from Mini-Circuits has a bandwidth from 2.5 kHz to 700 MHz, with usable gain up to 1 GHz. Typical flatness characteristic is ±0.6 dB, and rise/fall times are 1.1 ns. The unit can typically handle pulses as wide as 15µs. The 24 V, 350 mA amplifier has a typical delay time of 1.5 ns and can be supplied in inverting configuration. Pricing for the ZPUL-21 is $249 each.
Mini-Circuits
INFO/CARD #237

TOOLS, MATERIALS & MANUFACTURING

Teflon Substrate

The Advanced Dielectric Division of Taconic Plastics now offers a new, low-cost, copper clad, PTFE/woven glass substrate called TLC. Dielectric constants of 2.70 ±0.05, 3.00 ±0.05 and 3.20 ±0.05 are available, as are electrodeposited, ultra low profile electrodeposited, and rolled/annealed copper claddings. TLC has high rigidity, very low moisture absorption, high peel strength and low loss tangent.
Taconic Plastics, Inc.
Adv. Dielectric Div.
INFO/CARD #236

Magnetic Shielding Kit

Magnetic Shield Corp. has introduced an improved model LK-120 magnetic shielding lab kit. Available for $129, the kit includes a selection of CO-NETIC and NETIC magnetic shielding alloys, a magnetic field evaluator probe, and complete design and technical literature.
Magnetic Shield Corp.
INFO/CARD #235

Al_2O_3-Matched Material

Rogers introduces an isotropic formulation of its TMM® temperature stable microwave circuit material which has a 9.8 dielectric constant matched to that of high-purity alumina (Al_2O_3). The material is designed for miniaturized, portable antenna applications, such as the antennas used in two-way pagers and PCMCIA cards, and patch antennas. The TMM10i material offers an anisotropy of dielectric constant of less than 3% across the x-, y- and z-axis.
Rogers Corp.
INFO/CARD #234

TEST EQUIPMENT

Multipath Channel Emulator

Noise Com introduces model MP2400 multipath fading emulator for CDMA, GSM and PHS applications at frequencies up to 2500 MHz. The MP2400 can contain up to 12 paths on one or two channels (2 x 6 paths).

Specifications, as well as customer generated two-dimensional map models can be run via a built-in 486 PC. A power meter AGC is also built-in to calculate output power from –10 to –100 dBm with ±1 dB accuracy.
Noise Com, Inc.
INFO/CARD #233

GSM Test Set

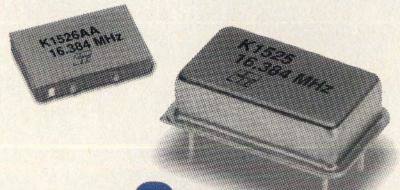
Model 6102 from Racal Instruments is a test set for GSM mobile units. The test set permits testing in the unsynchronized mode, which allows the generation of signals to simulate either the transmitter or receiver. This permits a level of fault diagnosis not previously available, and permits transmitters to be tested and adjusted without being in conversation. In addition, the test set has two independent, agile signal generators and can accommodate wide variations in input level from the handset. Prices begin at $35,000.
Racal Instruments
INFO/CARD #232

High-Frequency Test Contact

Johnstech International has announced the development of a test socket contact designed specifically for high performance testing of microwave IC devices. The 1/2-size Short Contacts™ are based on patented technology that combines outstanding electrical performance with superior contact reliability and integrity in automated and manual testing of microwave devices.
Johnstech International
INFO/CARD #231

CDMA Spectrum Analyzer

Hewlett-Packard has announced a CDMA spectrum analyzer that offers customized, one-button transmitter measurements and interactive troubleshooting capabilities. Tests include power timing and frequency-interference measurements. All tests meet EIA\TIA\IS-95, -97 and -98 CDMA standards. The CDMA portable spectrum analyzer combines the HP 85725A CDMA measurements personality and an HP 8590 E-series spectrum analyzer. A typical



CDMA spectrum analyzer configuration with frequency coverage to 2.9 GHz is $20,000.
Hewlett-Packard Co.
INFO/CARD #230

Crystal Stability Test

Model PC-100 from CCI/USA measures long term frequency stability and short term Allen variance in individually temperature-controlled cavities. Various crystal types and sizes, with Allen variances better than 1x10–12 seconds and drift rates of better than 5x1011 per day are accurately measured with this instrument. Model PC-100 holds up to 100 crystal devices from 4.0 MHz to 180 MHz.
Crystal Complete Interface USA, Inc.
INFO/CARD #229

Power Meter

Boonton introduces the model 4500 digital sampling power analyzer which allows precise analysis of digital communications products. When used with a peak power sensor, like the model 56518, peak power dynamic range exceeds 60 dB. This dynamic range is achieved without ranging, using a 12-bit A/D converter. Peak power range is –40 to +20 dB and average power range is –50 to +20 dBm. The 4500 has a statistics mode and can perform 14 measurements automatically in the pulse mode. A single channel version of the model 4500 sells for $15,000.
Boonton Electronics Corp.
INFO/CARD #228

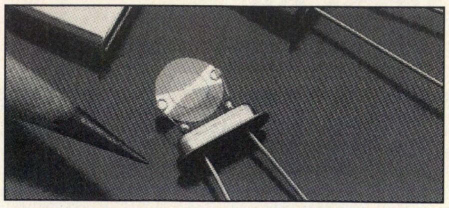
500 MHz Spectrum Analyzer

Hameg Instruments introduces the HM5005/HM5006 spectrum analyzer family. Both units offer a 0.5 to 500 MHz frequency analysis range, with continuously-variable center frequency tuning and selectable display scan width. Both also include a four-digit LED numeric display and on-screen marker. The HM5006 contains an integral tracking generator. The HM5005 and HM5006 are priced at $1048 and $1398, respectively.
Hameg Instruments
INFO/CARD #227

DISCRETE COMPONENTS

High Frequency Crystals

Reeves-Hoffman announces the availability of production quantities of its 155.52 MHz fundamental oscillator crystals for use in SONET telecommunication applications. The crystals are manufactured utilizing the inverted mesa technology. They are available in



HC-45 cold-weld packages.
Reeves-Hoffman
INFO/CARD #226

Short Glass Trim Caps

A new series of shorter glass dielectric trimmer capacitors have been added to Sprague-Goodman's PISTONCAP® line. The GDT series requires only 9.4 to 16 mm clearance above a circuit board mounting surface, depending on the model chosen. Models are available for surface or through-hole mounting. Six capacitance ranges are offered: 1.0 to 5.5 or 8.5 pF, and 1.5 to 10, 20, 30 and 40 pF.
Sprague-Goodman Electronics, Inc.
INFO/CARD #225

Multi-Turn, Sealed Trimmer

Voltronics is in production of a new 40 pF high voltage, sealed multi-turn trimmer capacitor. Dimensions are 1.0 inches long by 0.3 inches in diameter. Tuning is from 1.5 to 40 pF, with DC withstanding voltage of 2000 and DC working voltage of 1000. Q is over 1500 at 100 MHz. With a non-rotating piston, the trimmer's O-ring seal withstands 40 psi. It is available for printed circuit, panel and surface mount. Prices are $11.99 in quantities of 1000.
Voltronics Corp.
INFO/CARD #224

CABLES & CONNECTORS

Stable, Low-Loss Cables

MICRO-COAX has introduced a family of low-loss, semi-rigid coaxial cables that provide exceptionally low loss and high phase stability with temperature. The special PTFE dielectric used in the cables yields less attenuation, better phase stability with temperature, and more power handling capability. The cables are available with outside diameters of 0.047, 0.070, 0.0865, 0.120, and 0.141 inches.
MICRO-COAX
INFO/CARD #223

SQ Connectors

A line of quick connect-disconnect SQ connectors that replace 7/16-type connectors in high power applications is being introduced by Tru-Connector Corp. The SQ connector features a 7/16 center contact combined with a positive-locking quick-change design. The SQ connector can be supplied as a plug, jack, and mating receptacle in straight and right-angle configurations.
Tru-Connector Corp.
INFO/CARD #222

50Ω, Hermetic Feedthrough

Balo's 50 ohm, laser-weldable (MIL-C-39012), hermetic plug accepts standard threaded adapters. The family of feedthroughs include an RF plug which accepts standard 0.25" x 36 thread SMA jack-

to-jack adapters, an RF plug which accepts 3/16" x 36 thread SSMA jack-to-jack adapters, and an EMI-filtered plug.
Balo Precision Parts
INFO/CARD #221

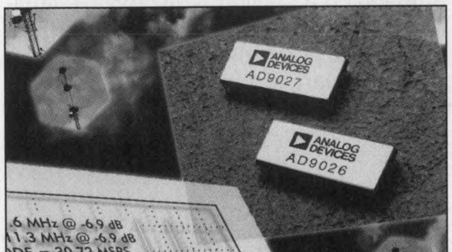
7/16 Coaxial Connectors

Delta's 7/16 series connectors conform to DIN 47223 and other applicable IEC, VG, and CECC standards. The connectors have high power handling capability, and VSWR as low as 1.07:1 at 2 GHz. Delta's 7/16 connectors are constructed of nickel-plated brass, with PTFE insulators. The line of connectors includes a variety of plugs and receptacles, with custom configurations available as well.
Delta Electronics
INFO/CARD #220

SEMICONDUCTORS

Low Distortion ADCs

Analog Devices' AD9026 and AD9027 analog-to-digital converters deliver true 12-bit accuracy and exceptional linearity at up to 31 Msps sampling rate. Both offer 72 dBc SFDR (at 13 MHz) and a full 200 MHz analog input bandwidth. They are well suited to down-convert band-limited signals with carrier frequencies in the 15 to 30 MHz range and can digitize an entire downcoverted cellular band. Both parts integrate all necessary circuit elements, including reference, track-and-hold amplifier, output logic and internal bypass capacitors. The AD9027 achieves somewhat better noise performance for sampling rates



above 26 Msps. Power consumption is 1.6 W with +5 V and –5.2 V supplies. The A9026 and AD9027 are packaged in 28-pin ceramic DIP. Their price is $238 in 1000s and are available from stock.
Analog Devices, Inc.
INFO/CARD #219

RF NPN Power Transistors

Motorola announced an increase in its RF portfolio today with the introduction of six new products capable of providing power in the range of 2 to 36 watts, depending on the device. The new lineup of class A RF NPN power transistors is designed to operate in the 800 to 960 MHz range. Intended for use in 24 V, UHF, large-signal, common emitter, linear amplifier applications, these devices feature high gain, are silicon nitride passivated and have guaranteed ruggedness specifications.
Motorola Semiconductor
INFO/CARD #218

Low Noise Op Amps

The CLC426 is a voltage-feedback op amp with 230 MHz gain-bandwidth product and very low noise (1.6 nV/√Hz and 2.0 pA/√Hz) and low distortion (–62/–68 dBc 2nd/3rd harmonics at 1 Vpp and 10 MHz). In addition the CLC426 operates from either a single supply (5 to 12 V) or dual supply (±5 V). The CLC428 provides 160 MHz unity-gain bandwidth with an ultra-low input voltage noise density (2.0 nV/√Hz), very low 2nd/3rd harmonic distortion (–60/–70 dBc) as well as high channel-channel isolation (–62 dB). Prices for the CLC426 start at $3.95, and the CLC428 start at $5.49, both in quantities of 1000.
Comlinear Corp.
INFO/CARD #217

Printed Circuit Board Considerations for Low Cost Design

By Gary A. Breed
Editor

Here is a short summary of the engineering issues surrounding current RF design practices using printed circuits. The materials, layout methods and assembly techniques all are subject to tradeoffs concerning cost and performance.

Printed circuits have been the standard method for electronic design and assembly for many years. In the RF realm, the electronic performance characteristics of p.c. board materials have been the principal selection criteria. However, in a changing marketplace, greater emphasis on cost has required RF engineers to evaluate materials that were previously considered low performance.

At the same time, p.c. board laminate manufacturers have been addressing the performance issues surrounding their "commodity" materials, as well as developing lower cost versions of their traditional RF/microwave materials. In particular, low dielectric constant materials are being developed that will sell for a much lower cost than the "classic" PTFE/glass laminates.

In addition to the materials, design and assembly methods are also being reevaluated for low cost RF design. High volume, low cost products must be assembled by automatic machinery, and the component selection and physical layout must accommodate this requirement. Often, however, optimum design for manufacturing is far less than optimum for RF performance.

Adapting Consumer Electronics Techniques

Consumer electronics, which generally involves entertainment products like radio, audio, television and games, is a good model for low cost, high volume production. These products almost exclusively use fiberglass-based laminates (the ubiquitous FR-4 or G-10). These are high dielectric constant materials (ε_r = 5 or greater). They are also much lossier than laminates that have been typically used in the higher RF and microwave range (ε_r = 2.4 or lower).

For many designers, the cost of materials and the cost of etching and assembly dictates that FR-4 type laminates will be used. What are the major tradeoffs, and how are performance factors to be dealt with?

If the entire design is to be included on the board, the designer may have to adapt the design to allow for practical impedances of any microstrip lines that are part of the circuit. Lines on 1/16 inch FR-4 are much narrower than on microwave laminate, for the same characteristic impedance. In a few cases, this will actually help, by making microstrip structures more compact. However, the increased dielectric and radiation losses will decrease the performance of those structures.

To combat performance losses, circuits can be made a small as possible to minimize the lengths of interconnecting lines. Localized shielding can be used where radiation is a problem. The total gain of the system, and its distribution in the circuit may be another way to compensate for the lower performance of inexpensive p.c. laminates.

Critical performance areas may require special attention. Many circuit elements are available as preassembled modules. VCOs, synthesizers, low-noise amplifiers, couplers and splitters, and filters are all available as board-mounted components. A last-resort possibility is embedding a section of microwave laminate within a larger glass board. This may solve performance problems when only one part of the circuit is the problem area — such as receiver front-end circuitry.

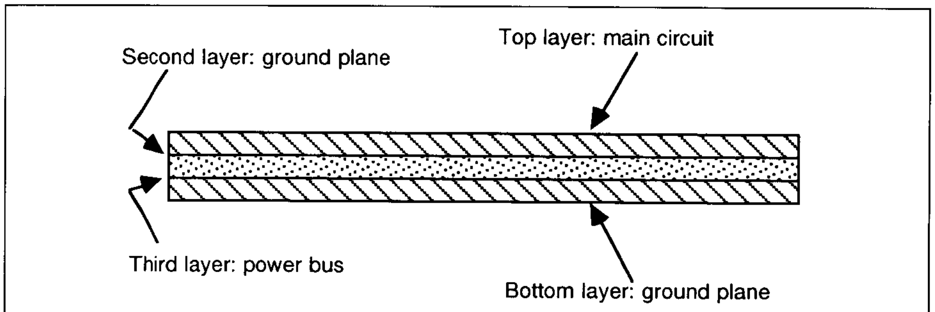


Figure 1. Basic concept of separating the power bus from the remainder of the circuit using a multilayer p.c. board.

Multilayer Boards

Increased use of multilayer p.c. boards is part of the new trend in design of RF products. Size reduction and performance requirements are the reasons for using multilayer boards.

A simple example, a four layer board (Figure 1) might be used. The top layer contains the main circuit paths for a normal SMT assembly. Below that is a ground plane, creating both shielding and a return path for transmission-line elements on the top layer.

Below this ground plane is a power distribution layer, which is used to carry power and bias voltages to various parts of the circuit. Again, there is a combination of shielding and transmission line effect that greatly helps isolate the power bus from the operating circuit, and reduces unwanted coupling that

SURFACE-MOUNT or PLUG-IN FROM $3.95 (10 qty)

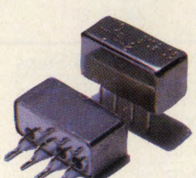
Expose Mini-Circuits' TUF-mixers to 250°C for five minutes, or to the extreme shock and vibration stresses of MIL-M-28837, or to 200 cycles of thermal shock from -55° to +100°C...they'll survive without any change in specs. They are mighty tough mixers!

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

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

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

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

5-YR. GUARANTEE

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

SPECIFICATIONS

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

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

δ = Sigma or standard deviation

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often occurs with unshielded power traces. Finally, another ground plane is the bottom layer, competely shielding the power distribution layer.

This simple example is for illustration only. Actual circuits may be three layers or more, depending on the circuit complexity, mainly the number of paths that must be kept isolated form one another. Densely packed SMT circuits often cannot accommodate the required interconnections without multiple layers for those signal and power paths.

Substrate Material	Dielectric Constant	Dissipation Factor	Coefficient of Thermal Expansion X-Y axis	Z-axis
FR-4	4.8	0.022	12-16 ppm/°	80 ppm/°
Polymide/glass	4.5	0.01	12-14	60
Alumina	9.6	0.0001	6.2	6.2
PTFE (woven glass filled)	2.4	0.0019	15	200
RT/Duroid 5880	2.2	—	2-3	28.3
RT/Duroid 6002	2.94	0.0012	16	24

Figure 2. Electrical properties and thermal expansion charactersitcs of some common substrate materials.

Physical Properties

While the electrical characteristics of p.c. board materials affect circuit performance, their physical properties affect manufacturability. One key factor is thermal performance. Components must match the substrate's coefficient of thermal expansion, or tolerate changes that occur over the operating temperature range. For example, chip resistors and capacitors are constructed of ceramic materials, which typically have very low thermal expansion coefficients. Yet, the p.c. board materials they are expected to be mounted on may have two or three times the rate of expansion. Figure 2 lists the thermal properties of some common substrate materials [1].

Thermal shock is another consideration for ceramic materials in high-volume manufacturing. Soldering, either wave or reflow, can cause undue stress on ceramic components unless it is performed properly. Repeated thermal stress and rapid changes in temperature (e.g. from soldering to washing) can cause damage that may not be detectable by ordinary visual inspection methods. It is best to establish industry-standard procedures for p.c. board manufacturing.

An additonal area of physical design is packaging. Mounting the p.c. board can not only impart stress on the components, but the board may actually be part of the supporting structure of the product, or at least have a stiffening or reinfocement role. This situation may be rare in high performance products, but cost demands may make it necessary to literally build a substrate into the equipment package.

If the board serves as a reinforcing structure, its flexure, tension and compresion forces must be evaluated. Board stiffeners are available, as are eyelets and other mounting hardware that can relieve some of the stress on the board.

Another option is to use the enclosure as the primary support for a flexible circuit board. Flexible circuitry for RF applications is not a well-developed technique. Flex circuits have generally been limited to interconnecting pathways.

Summary

Although RF designers are familiar with most types of circui board design and assembly techniques, increasing demand for low cost products makes it important to develop greater expertise. That expertise is not only for the design and layout of the circuit board, but also for selection of components and integration of the completed board into a finished unit. *RF*

References

1. R.L. Barron, W.J. Choe, "Manufacturing Considerations for the Design of RF Products," *RF Design*, October 1993.

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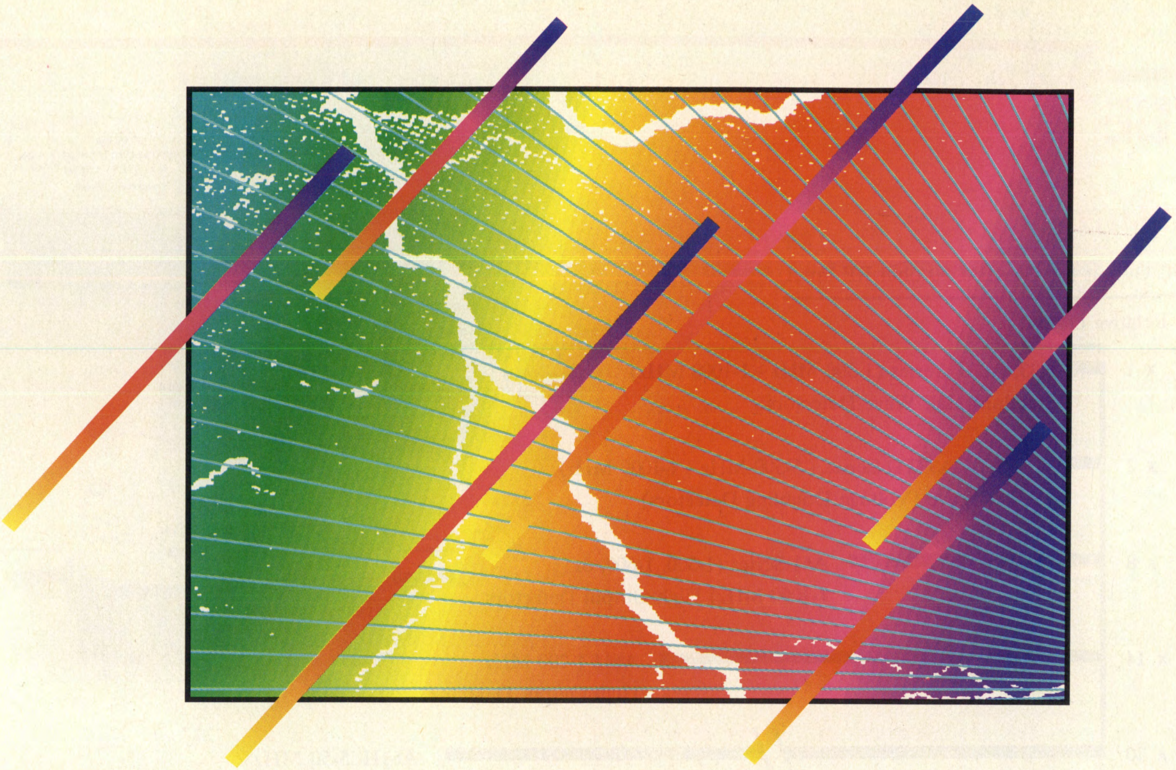

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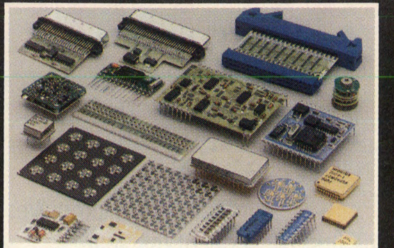

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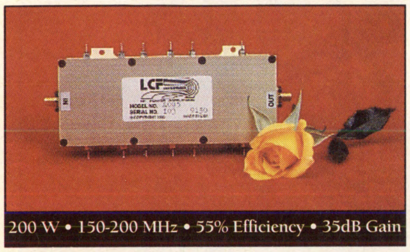

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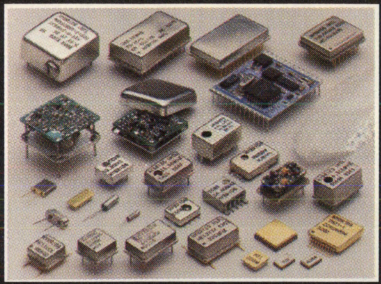

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0.50	851542
0.75	851543
1.0	851544
1.5	851545
2.0	851546
2.5	851547
3.0	851548
3.5	851549
4.0	851550
4.5	851551
5.0	851552
5.5	851553
6.0	851554
6.5	851555
7.0	851556
7.5	851505
8.0	851557
8.5	851558
9.0	851559
9.5	851560
10.0	851475
11.0	851841
12.0	851842
13.0	851843
14.0	851844
15.0	851845
16.0	851846
18.0	851847
20.0	851848
22.0	851849
24.0	851850
26.0	851851
28.0	851852
30.0	851853
32.0	851854
34.0	851855
36.0	851856
38.0	851857
40.0	851858

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0.50	851901
0.75	851902
1.0	851903
1.5	851904
2.0	851905
2.5	851906
3.0	851907
4.0	851909
5.0	851911
6.0	851913
7.0	851915
8.0	851917
9.0	851919
10.0	851921
12.0	851923
14.0	851925
16.0	851927
18.0	851929
20.0	851931
24.0	851933
28.0	851935
32.0	851937
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A Design Method For Unequally Terminated Elliptic Filters

By Michael G. Ellis
U.S. Army Corps of Engineers

Unevenly terminated passive elliptic filters can be obtained from normalized evenly terminated lowpass midshunt prototypes without the need for iterative techniques. This paper summarizes a method for obtaining these element values by modifying the expression for the input impedance.

The voltage transfer function, G(s), for any linear filter can be written as

$$G(s)G(-s) = \left[\frac{1}{1+\frac{F(s)F(-s)}{P(s)P(-s)}}\right] \quad (1)$$

$$= \frac{P(s)P(-s)}{P(s)P(-s)+F(s)F(-s)} = \frac{P(s)P(-s)}{E(s)E(-s)}$$

If the normalized filter has even terminations, as shown in Figure 1, then its input impedance is given by

$$Z_{in} = \frac{E(s)+F(s)}{E(s)-F(s)} \quad (2)$$

Both E(s) and F(s) contain even and odd powers of s since Z_{in}, as defined in Figure 1, includes the 1 ohm termination resistance.

If arbitrary source and load resistances are desired, then the new input impedance becomes

$$Z_{in} = \frac{R1E(s)+R1M(s)}{E(s)-M(s)} \quad (3)$$

where

$$M(s)M(-s) = E(s)E(-s) - \frac{4R1R2}{(R1+R2)^2}P(s)P(-s) \quad (4)$$

Since E(s), F(s), and P(s) can easily be found for the evenly terminated elliptical filter, equation (3) provides the input impedance for the unevenly terminated filter from which a new set of element values can be computed. The extraction process given in Table 1 will be used in the following example to find the element values of the unevenly terminated filter.

Example

The elliptic filter in Figure 2 is an evenly terminated normalized lowpass elliptic filter with 1 dB passband ripple, 50 dB stopband attenuation, and a cutoff frequency of 1 radian per second. The task is to modify it for a 2 ohm termination.

Step 1: Find E(s), F(s), and P(s) – E(s), F(s), and P(s) are normally given by the computer program in the initial design of the evenly terminated prototype[2]. There are other means of obtaining these polynomials such as the one given below.

1) From inspection:

$P(s) = K\,[s^2 + (1.630707)^2]\,[s^2+(1.273134)^2]$

where 1.630707 and 1.273134 are the resonant frequencies of the shunt L-C resonant circuits. The value of K can be determined once E(s) is known so that the DC gain of G(s) is unity.

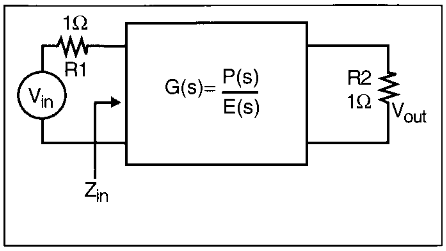

Figure 1. Network model for derivation of the input impedance, Z_{in}.

2) The input impedance, Z_{in}, for the evenly terminated filter can be determined from the element values. E(s) and F(s) can then be determined analytically using equation (2).

In this case:

$P(s) = 0.0356362\,[s^2+(1.273134)^2]\,[s^2+(1.630707)^2]$

and

$E(s) = s^6 + 1.179969s^5 + 2.234428s^4 + 1.781004s^3 + 1.345695s^2 + 0.602656s + 0.1519941$

Step 2: Determine M(s) – Since the source and load terminations are unequal, M(s) must be found using equation (4) with R1 = 1 and R2 = 2 such that

$$M(s)M(-s) = E(s)E(-s) - \frac{4\cdot 1\cdot 2}{(1+2)^2}P(s)P(-s) \quad (5)$$

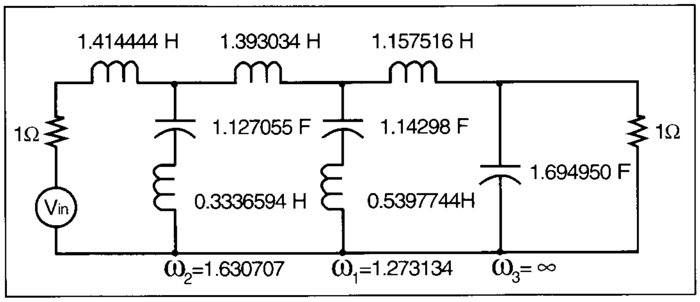

Figure 2. Evenly terminated normalized lowpass elliptic filter.

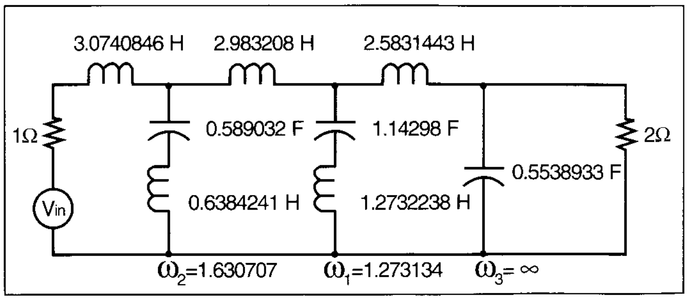

Figure 3. Final design for 6th order elliptic filter with 2Ω termination.

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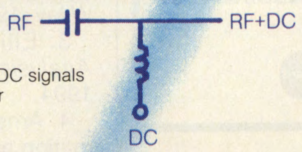

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ZFBT-4R2G	10-4200		0.15	0.6	0.6	32	40	50	1.3:1	$59.95
ZFBT-6G	10-6000		0.15	0.6	1.0	32	40	30	1.3:1	79.95
ZFBT-4R2GW	0.1-4200		0.15	0.6	0.6	25	40	50	1.3:1	79.95
ZFBT-6GW	0.1-6000		0.15	0.6	1.0	25	40	30	1.3:1	89.95

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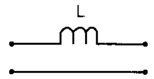
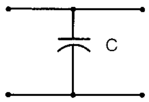
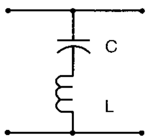
	pole	removal	remainder function
1		$L = \left. \frac{Z_{in}}{s} \right\|_{s=\infty}$	$Z'_{in} = Z_{in} - sL$
2		$C = \left. \frac{1/Z_{in}}{s} \right\|_{s=\infty}$	$\frac{1}{Z'_{in}} = \frac{1}{Z_{in}} - sC$
3		$L = \left. \frac{sZ_{in}}{s^2 + \omega_x^2} \right\|_{s^2=-\omega_x^2}$ $C = \frac{1}{L\omega_x^2}$	$\frac{1}{Z'_{in}} = \frac{1}{Z_{in}} - \frac{s/L}{s^2 + \omega_x^2}$

Table 1. Removal process for synthesis for elliptic filters [1].

A root-finding routine is used to find all the roots of the 12th-order polynomial that results from eq. 5. Taking those roots that are in the left-hand plane yields, (computation details can be found in [3]):

$M(s) = s^6 + 0.6276991s^5 + 1.735267s^4 + 0.8786084s^3 + 0.7858717s^2 + 0.273009s + 0.0506646$

Step 3: Find the new input impedance, Z_{in} – The input impedance, Z_{in}, given by

$$Z_{in} = \frac{R1E(s) + R1M(s)}{E(s) - M(s)} \quad (6)$$

becomes

$Z_{in} = (2s^6 + 1.80767s^4 + 2.65961s^3 + 2.13157s^2 + 0.8757s + 0.20266) / (0.552270s^5 + 0.4991s^4 + 0.90240s^3 + 0.55982s^2 + 0.3296s + 0.10133)$

Step 4: Extract the new element values – Using the extraction rules given in Table 1, the new filter is shown in Figure 3. Frequency and impedance scaling can now be applied, including bandpass transformations, to convert the lowpass prototype into a passband, stopband, or highpass filter.

Summary

Optimization routines that attempt to find the element values of an unevenly terminated filter from an evenly terminated prototype almost always converge to a sub-optimal solution and should be avoided. The method given here always preserves the exact shape of the frequency response regardless of the ratio of the source-to-load resistance. While classical methods were used to extract the element values for the new network, the permutation method of synthesis due to Amstutz [4] can be used in higher order filters without the accumulation of roundoff errors that eventually destroy the accuracy of classical synthesis methods. For elliptic filters where the polynomial P(s) is known from direct inspection of the trap elements, the polynomials E(s) and F(s) can be determined analytically if the first stopband frequency that meets the prescribed stopband loss is known. *RF*

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About the Author

Michael Ellis is received his BSEE and MSEE from Vanderbilt University, and his PhDEE from Mississippi State University. He works for the U.S. Army Corps of Engineers' Waterways Experiment Station in Vicksburg, Mississippi. He has worked in radar and microwaves at Georgia Tech Research Institute and Scientific Atlanta, and on modem design at Hayes Microcomputer. He can be reached at 412 Elmwood, Vicksburg, MS 39180.

Utility Programs Simplify RF Analysis in SPICE

David K. Lovelace
Motorola, Inc.

With increased use of SPICE for analysis of RF circuits, techniques are required to get common RF data into a usable format. This article describes two utility programs to be used with SPICE in the analysis of RF circuits. SSWEEP is used to command SPICE to change bias conditions for which an S-parameter analysis is conducted, then SSTRIP takes the SPICE formatted data and puts it into a Touchstone® type S-parameter data file.

The first of the programs to be described is SSWEEP, a SPICE utility written to aid the designer who requires that an AC analysis be conducted at several DC bias conditions on a circuit. SPICE does not allow an AC analysis to be conducted during a DC sweep. SSWEEP gives the SPICE user the ability to sweep up to two independent DC voltage or current sources and perform an AC analysis at these user defined DC operating conditions. SSWEEP could be used to generate S-parameters for a device at many different DC bias points on the I-V plane, and perform a noise analysis at several bias conditions. A description of how SSWEEP operates is given as follows:

1) The SPICE user writes a circuit file designed for AC analysis but that is desired to be evaluated at several DC bias conditions. A typical example is shown in file MOS_L.CIR (Appendix A). This example shows that through the use of SPICE, S Parameters can be generated for a device model at many DC operating conditions as set by the two independent sources VG and VD and swept by SSWEEP.

2) The SPICE file should contain a line with the following syntax:

*SWEEP PARAM1 START1 STOP1 STEP1 PARAM2 START2 STOP2 STEP2

```
* MOS _L.CIR
* LUMPED RD/CDS OUTPUT TO THE MOS MODEL
*
* THIS CIRCUIT FILE WILL GENERATE THE S-PARAMETERS FOR A CIRCUIT
* USING SPICE.
*
*REFERENCE:      "S-PARAMETER WTPUT FROM SPICE PROGRAM"
                 BY: RAVENDER GOYAL
*                MICROWAVE SYSTEM NEWS AND COMMUNICATIONS TECHNOLOGY
*                FEBRUARY 1988, PGS 63 -66.
*
*ASSUMPTIONS:    TERMINATIONS ARE IN 50 OHMS REAL IMPEDANCE
*                (COMPLEX IMPEDANCE TERMINATIONS CAN BE SIMULATED
*                THROUGH THE APPROPRIATE CIRCUIT ELEMENTS USED TO
*                REPLACE RS AND RL.)
*
* FILE NAME:     MOS_L.CIR
* DATE:          23 JUL 91
* BY:            DAVID LOVELACE
*                MOTOROLA, INC.
*                SEMICONDUCTOR CUSTOM TECHNOLOGIES CENTER
*
* INSERT THE CIRCUIT TO BE ANALYZED HERE AND USE AS A SUBCIRCUIT TO
* GENERATE THE S-PARAMETERS
*
*******************************************************************
*******************************************************************
* WE WANT TO GENERATE S-PARAMETERS FOR SEVERAL BIAS CONDITONS
* VARY VD 0 - 10V IN 0.5V INCREMENTS AND VG 3 - 5V IN 0.2V INCREMENTS
*
* THIS IS THE SSWEEP SYNTAX
* SWEEP VD 0 10 0.5 VG 3 5 0.2
*******************************************************************
*
*******************************************************************
*
* MOS MODEL
*
*******************************************************************
*
.SUBCKT TEST        1         2         PARAMS: CAX=(A1*C1)
L1 1 3 1MEG
VG 3 0 DC 4.0
RG 1 4 12.0
M1 10 4 0 0 NDMOS L=0.9U W=752U
M2 7 4 10 0 NDDMOS L=0.8U W=752U
CBLOCK 4 5 10.0
RX1 4 5 1MEG
D_CY 5 6 Y
RX2 5 6 0.03MEG
CX 6 7 (CAX)
RX3 6 7 1MEG
RNHV 7 8 0.1
DDS 99 8 CDS
REPI 99 0 20
RD2 8 2 10.0
L2 2 9 1MEG
VD 9 0 7.5
.ENDS TEST
*
*******************************************************************
*
* PARAMETERS SET FOR CAPACITANCES USED IN THE MODEL
*
*******************************************************************
*
* AREA FACTORS FOR CGD CAPACITANCES
```

(continued on next page)

Appendix A. A sample SPICE circuit file as used with SSWEEP.

```
.PARAM A1=3.5E-6
.PARAM A2=3.5E-6
* C1 CAN BE ADJUSTED +/- 30%
.PARAM C1=66E-9
* C2 CAN BE ADJUSTED +/- 200%
.PARAM C2=56E-9
* CX=A1*C1
* CY=A2*C2
* DISTR=DISTRIBUTION FACTOR FOR THE CDS DIODE
.PARAM DISTR=1
* SC=SCALING FACTOR FOR CDS, DEPENDENT ON THE P- DOPING
.PARAM SC=3
* CONSTANT FOR THE CDS CAPACITANCE
.PARAM CAPDS=4.3E-13
*
.MODEL NDDMOS NMOS LEVEL=3
+ VTO=0 PHI=0.6 TOX=400E-10 NSUB=1E14 UO=650 VMAX=2E5 THETA=0.2
.MODEL NDMOS NMOS LEVEL=3
+ VTO=2.8 PHI=0.7 TOX=400E-10 NSUB=1E15 UO=600 VMAX=2E5 THETA=0.2
.MODEL Y D VJ=0.6 M=0.5 CJO=(A2*C2)
.MODEL CDS D VJ=0.6 M=0.5 CJO=C(CAPDS*SC)/DISTR)
*********************************************************************
*
* CIRCUIT TO MEASURE S22 AND S12
*
*********************************************************************
*
RLR     1     0     50
E12     12    0     1      0      2
R12     12    0     1
* INSERT THE CIRCUIT TO BE ANALYZED HERE AS A SPICE SUBCIRCUIT
XCKTR   1     2     TEST
*
RSR     2     0     50
I2      2     0     AC     -20M
V22     20    22    AC     1
E22     20    0     20     0      2
R22     22    0     1
*
*********************************************************************
*
* CIRCUIT TO MEASURE S11 AND S21
*
*********************************************************************
*
RLF     4     0     50
E21     21    0     4      0      2
R21     21    0     1
* INSERT THE CIRCUIT TO BE ANALYZED HERE AS A SPICE SUBCIRCUIT
XCKTF   3     4     TEST
*
RSF     3     0     50
I1      3     0     AC     -20M
V33     10    11    AC     1
E33     10    0     3      0      2
R11     11    0     1
*
*
* SET THE FREQUENCIES TO BE ANALYZED HERE
.AC     LIN   50    500MEG  5G
*
* HERE IS THE OUTPUT FORMAT SO AS TO COINCIDE WITH THE "TOUCH-
STONE"
* FORMAT AND BE CONVERTED FOR USE WITH LINEAR CAD TOOLS
.OPTION WIDTH=132 NODE
*          |S11|   /_S11   |S21|   /_S21   |S12|   /_S12   |S22|   /_S22
.PRINT AC  VM(11)  VP(11)  VM(21)  VP(21)  VM(12)  VP(12)  VM(22)  VP(22)
*
*
.END
```

Appendix A (*continued*). Sample SPICE circuit for SSWEEP.

SSWEEP (c) 1991 David Lovelace

SPICE file name: x.cir Number of DC bias sweeps: 4

File Name	V1	11
x0.cir	5.00el+00	5.00e–06
x1.cir	5.00e+00	1.00e–05
x2.cir	1.00e+01	5.00e–06
x3.cir	1.00e+01	1.00e–05

Table 1. Bias conditions and resulting file names.

For example:

*SWEEP VCC 0 10 0.5 IB 10E-6 100E-6 10E-6

This will cause VCC to be stepped 20 times (0-10 volts in 0.5V increments) for ten values of IB (10-100 microamps in 10 microamp increments) for a total of 200 analyses!

Note that the line that sets the SSWEEP parameters starts with a "*". This will allow the user the option of running the circuit file in SPICE without having to use SSWEEP. The key word "SWEEP" is not case sensitive, "SWEEP" or "sweep" will work, but do not mix case by using syntax such as "Sweep", "SwEep", etc.

PARAM1 and PARAM2 are the names of the independent DC sources to sweep. They must match the names of the independent sources given in the circuit file. SSWEEP will only allow a DC source to be used in the SPICE circuit file as:

SOURCE_NAME NODEI NODE2 DC VALUE

Example: VCC 2 0 DC 10

SOURCE_NAME must be a valid SPICE source name and the same name as that given in PARAM1 and PARAM2. The type of source "DC" must be included on this line! The VALUE term can take on any value, this will be replaced in each iteration of SSWEEP. START1 and START2 are the DC starting conditions for conducting the AC analysis. STEP1 and STEP2 are the increments that the sources will be stepped until the values of STOP1 and STOP2 are achieved.

Note that all of the constants: start1, stop1, etc. must use numerical format instead of the typical spice syntax used to express numerical magnitude.

Example: Use 10E-6 instead of 10U, 1E-3 instead of IM, etc. as is typically done in SPICE.

3) Start the analysis from the command line:

ssweep file_name

Example: ssweep mos_l

Where "file name" is the SPICE circuit file name. This name should not include it's extension since SSWEEP will

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```
* SPAR.CIR
*
* THIS CIRCUIT FILE UILL GENERATE THE S-PARAMETERS FOR A CIRCUIT
* USING SPICE
*
* REFERENCE:    "S-PARAMETER OUTPUT FROM SPICE PROGRAM"
*               By: RAVENDER GOYAL
*               MICROWAVE SYSTEM NEWS AND
*               COMMUNICATIONS TECHNOLOGY
*               FEBRUARY1988, PGS 63-66.
*
* ASSUMPTIONS:  TERMINATIONS ARE IN 50 OHMS REAL IMPEDANCE
*               (COMPLEX IMPEDANCE TERMINATIONS CAN BE
*               SIMULATEDTHROUGH THE APPROPRIATE CIRCUIT
*               ELEMENTS USED TO REPLACE RS AND RL.)
*
* FILE NAME:    SPAR.CIR 23 JUL 91
* BY:           DAVID LOVELACE
*               MOTOROLA, INC.
*               SEMICONDUCTOR CUSTOM TECHNOLOGIES CENTER
*               2100 EAST ELLIOT ROAD
*               TEMPE, AZ 85284
*
* INSERT THE CIRCUIT TO BE ANALYZED HERE AND USE AS A SUBCIRCUIT
* TO GENERATE THE S-PARAMETERS
*
* A FILTER EXAMPLE FROM THE REFERENCED ARTICLE IS USED
* LARGE RESISTORS WERE USED TO ALLOW SPICE TO HAVE A DC PATH TO
* GROUND AT ALL NODES
* IF AN ACTIVE DEVICE IS USED, APPROPRIATE BIAS MUST BE APPLIED!
*
.SUBCKT TEST    1       11
C1      1       2       3.168P
L1      2       3       203N
*
R1      2       0       100MEG
R2      3       0       100MEG
*
C2      3       0       3.76P
C3      3       4       1.75P
C4      4       0       9.1P
L2      4       0       36.81N
C5      4       5       1.07P
C6      5       0       3.13p
L3      5       6       233.17N
C7      6       7       5.92P
*
R3      6       0       100MEG
R4      7       0       100MEG
*
C8      7       0       4.51P
C9      7       8       1.568P
C10     8       0       8.866P
L4      8       0       35.71N
C11     8       9       2.06P
C12     9       0       4.3P
L5      9       10      200.97N
C13     10      11      2.97P
*
R5      9       0       100MEG
R6      10      0       100MEG
*
.ENDS TEST
*
*
*
* CIRCUIT TO MEASURE S22 AND S12
*
*
V1 60   0       DC 1.0
L1 60 1 MEG
L2 70 2 1MEG
V2 70 0 DC 10
```

(continued on page 86)

Appendix B: SPAR.CIR — Example SPICE circuit file for SSTRIP.

assume an extension of .CIR. The *"file_name" cannot exceed five characters in length!*

Limiting the file name to five characters allows for up to 999 bias conditions to be evaluated since DOS allows a maximum of eight characters in a valid file name.

4) SSWEEP will start a SPICE analysis for each of the bias values given by the "*SWEEP ..." line of the circuit file.

5) A new SPICE circuit file and output file will be generated for each of these DC operation points.

Example: The circuit file MOS_L.CIR (see Appendix A) will generate the following files:

MOS_L0.CIR	MOS_L0.OUT
MOS_L1.CIR	MOS_LI.OUT
MOS_L3.CIR	MOS_L3.OUT

6) The file RESULTS.SWP will be generated giving a table of the DC operating points and the names of the files that resulted from SPICE.

Example: A sample of the RESULTS.SWP file:

The SPICE file included the following "*SWEEP ..." line:

*SWEEP V1 5 10 5 I1 SE-6 10E-6 5E-6

This caused an AC analysis to be performed at each of the bias conditions that are shown by the results file: RESULTS.SWP

SSTRIP Program Description

SSTRIP will strip out S-Parameter results from PSPICE and HSPICE two port network analysis and convert them to a "Touchstone" compatible two port S-parameter data file. SSTRIP converts data in the SPICE output files, .OUT for PSPICE and .LIS for HSPICE, into S-parameter data files with the same SPICE file name with the exception of a .S2P extension. Some important information concerning the successful use of SSTRIP is given as follows:

PSPICE — Although PSPICE was used in this example, most any SPICE program will function with SSTRIP including HSPICE, ISPICE, UCB SPICE, etc. A template circuit file that should be used with SSTRIP is given in Appendix B. This circuit file, SPAR.CIR was derived from previous work by other users of SPICE [1,2]. [3] describes how 2-port S-parameter data are derived from SPICE. Comments located within SPAR.CIR will describe any specific details concerning its use. SSTRIP assumes that the name of the PSPICE output file has a .OUT extension.

HSPICE — HSPICE users are less confined as are other SPICE users. HSPICE has a ".NET" command that will allow it to generate two port S-parameters. Users of SSTRIP need only do the following to their circuit file (this is based on the proper use of the .NET command; readers should refer to the HSPICE users manual):

1) Include the statements: CO=132 INGOLD = 2 in the .OPTION line. This

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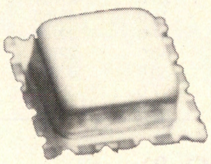

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- Linearized tuning improves PLL stability.
- Low phase noise.
- No dropouts or moding over temperature, 2:1 VSWR, any phase.
- Consistent output power over temperature (+15 dBm ± 2 dB).
- Applications include modems, synthesizers, GPS, DBS, VSAT.

Price is $69.00, single piece quantity. Contact Eliot Fenton, **Integrated Component Systems Inc., 5440 N.W. 55th Blvd, Ste 11-105, Coconut Creek, FL 33073. 1-800-396-5185.**

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```
*
RLR      1      0      50
E12      12     0      1       0       2
R12      12     0      1
* INSERT THE CIRCUIT TO BE ANALYZED HERE AS A SPICE SUBCIRCUIT
XCKTR    1      2      TEST
*

RSR      2      0      50
I2       2      0      AC      -20M
V22      20     22     AC      1
E22      20     0      2       0       2
R22      22     0      1
*
*
* CIRCUIT TO MEASURE S11 AND S21
*
*
L3       60     3      1MEG
L4       70     4      1MEG
*
RLF      4      0      50
E21      21     0      4       0       2
R21      21     0      1
* INSERT THE CIRCUIT TO BE ANALYZED HERE AS A SPICE SUBCIRCUIT
XCKTF    3      4      TEST
*
RSF      3      0      50
I1       3      0      AC      -20M
V33      10     11     AC      1
E3310    0      3      0       2
R11      11     0      1
*
*
* SET THE FREQUENCIES TO BE ANALYZED HERE
.AC      LIN    100    200MEG  300MEG
*
.MODEL TEST NPN
*
* HERE IS THE OUTPUT FORMAT SO AS TO COINCIDE WITH THE
* "TOUCHSTONE" AND "MMICAD" FORMAT AND BE CONVERTED FOR USE
*  WITH LINEAR CAD TOOLS
.OPTION WIDTH=132
*          IS11I   /_S11   IS21I   /_S21   IS21I   /_S21   IS22I   /_S22
.PRINT AC VM(11)  VP(11)  VM(21)  VP(21)  VM(12)  VP(12)  VM(22)  VP(22)
.PROBE
.END
```

Appendix B (continued).

```
* MOS MODEL EVALUATION - AC CHARACTERISTICS
*
* FILE NAME:          MOSFET.CIR
* DATE:       1 AUG 91
* BY:         DAVID LOVELACE
*             MOTOROLA, INC.
*             SEMICONDUCTOR CUSTOM TECHNOLOGIES CENTER
*             2100 EAST ELLIOT ROAD
*             TEMPE, AZ 85284
*
VI 1 0 DC 4.0 AC 1.0
V2 3 0 DC 5.0
M1 3 1 0 0 NDMOS L=2.5U U=752U
.MODEL NDMOS NMOS LEVEL=3
+ VTO=2.7 PHI=0.7 TOX=400E-10 NSU8=1E16 W=600 VMAX=2E5 THETA=0.2

* USE THIS STATEMENT IF WE ARE DOING JUST A SWEEP OF S-PARAMETERS
.AC LIN 101 100MEG 10G

* MEASURE S-PARAMETERS
.NET I(V2) V1 ROUT=50 RIN=50

* MAKE SURE THAT THE OPTION STATEMENT HAS THESE PARAMETERS SET
.OPTION CO=132 INGOLD=2

* PRINT OUT THE S-PARAMETER VALUES THAT WERE SIMULATED
*          IS11I    /_S11    IS21I    /_S21    IS12I    /_S12    IS22I    /_S22
.PRINT AC  S11(M)   S11(P)   S21(M)   S21(P)   S12(M)   S12(P)   S22(M)   S22(P)

.END
```

Appendix C: HSPICE example file.

is done to allow all four of the two port S-parameters to fit onto one output line and to format the output to a form readable by SSTRIP. For example:

.OPTION CO =132 INGOLD = 2

2) Include the .PRINT statement as follows:

PRINT AC SII(M) SII(P) S21(M) S21(P) S12(M) S12(P) S22(M) S22(P)

An example circuit file is shown in Appendix C. SSTRIP assumes that the name of the HSPICE output file has a .LIS extension.

SSTRIP Syntax:

sstrip -<h I p> spiceout

Where:
"-h" or "-p" is used to identify the type of SPICE output file
-h = > HSPICE
-p = > PSPICE or standard SPICE

"spiceout" identifies the SPICE output file name. Note that the extension is not used. SSTRIP will automatically determine the proper file name extension based on the use of the "-h" or "-p" parameter.

SSTRIP will use the "spiceout" file returned from a successful SPICE analysis to create the name of the resulting S-parameter file.

Example: sstrip-p mos I

This will cause the two port S-parameter data embedded within the PSPICE output file "mos_l.out" to be converted to the newly created S-parameter data file "mos_l.s2p."

SSTRIP was written for a DOS based machine using the Borland C++ compiler, but the code was intentionally written so that a migration across any C compiler could be possible. The author intends to port the code to a workstation environment as soon as possible.

Notes

HSPICE is a trademark of Meta Software, Inc.; PSPICE is a trademark of MicroSim Corp.; and Touchstone is a trademark of EESof, Inc.

The SSWEEP and SSTRIP programs are available on disk from Argus Inc., Direct Marketing Department. See the advertisement on page 97 for ordering information. **RF**

References

1. Ravender Goyal, "S-Parameter Output From Spice Program," *Microwave System News and Communications Technology*, February 1988.
2. Thomas B. Mills, "S-Parameters in Spice," *RF Design*, June 1989.
3. Fred Bonn, "Derivation of S-Parameter Circuit," Internal Memo, Motorola, Inc., November 1990.

About the Author

David Lovelace is a Design Engineer in the RF Development Group at Motorola Inc., Semiconductor Custom Technology Center, 2100 East Elliot Road, MD: EL609, Tempe, AZ 85284. David has previously published the QSPLOT S-parameter comparison and evaluation program.

Custom ICs and ASICs Provide Wireless Design Solutions

Custom and application-specific integrated circuits are seeing a rapidly growing level of interest from engineers who are designing new wireless products. Many variations of digital, analog and RF functions are required to meet design goals for a diverse collection of new radio-based communications products. In addition, the need to make those products small, with low power consumption, also leads many designers to investigate custom integrated components.

Basically, there are two general directions to follow: full custom and semi-custom. Full custom means that a specific integrated circuit is designed "from the ground up" to perform the desired functions. This is the same process used to develop standard catalog ICs, and has the greatest design flexibility, but by far the greatest engineering cost.

Semi-custom ICs can be divided into two further groups: configurable transistor arrays and standard-cells. Transistor arrays typically contain an assortment of single transistors, matched pairs and emitter-coupled pairs, perhaps representing a couple different speed/power levels, plus some resistors. The transistors are interconnected with additional metallization layers, which also include additional bias resistors. Standard cells are pre-designed amplifiers, mixers, gates, flip-flops, etc., with layouts that can be "glued" together to combine functions to meet the customer's needs.

The choice of whether to design with standard ICs or to pursue a custom IC is typically complex, relating to size of the production run, performance requirements of the product, time-to-market concerns, and short-term costs versus costs over the lifetime of the product.

Here are summaries of custom and semi-custom IC capabilities of just a few companies capable of handling RF applications:

Maxim Integrated Products

With their acquisition of Tektronix-developed high frequency IC processes, Maxim adds RF capabilities to their well-established lower-frequency analog expertise. Their QuickChip design automation approach is an array of transistors, capacitors and resistors that can be configured for a wide range of functions using Maxim's QuickTools design software package.

Full-custom high frequency ICs are also available for high-volume, performance-critical applications. Design tools are provided for this approach as well. Available semiconductor processes have NPN F_T ranging from 9 GHz to 27 GHz.

Raytheon

Raytheon has a wide range of IC services, drawing from the company's experience in high performance military applications. Their RPA90 and RPA160 precision grid/tile arrays are suited for high speed analog and digital systems requiring NPN transistors with 4 GHz F_T and PNPs with 1.5 GHz F_T.

The RSC4000 standard cell capability uses a complementary BiCMOS process with similar speeds to the RPA arrays, but with greater design flexibility for mixed signal ICs. A wide variety of analog and digital standard cell circuit functions is intended to provide rapid development time.

Raytheon also has GaAs MMIC capabilities for high performance ICs with devices having F_T up to 27 GHz.

Hitachi America Ltd.

Hitachi offers ASIC technology in CMOS and BiCMOS. Somewhat better equipped for high speed digital circuits like PLLs, counters and dividers, Hitachi has developed the greatest number of customers in computer and disk-drive businesses. IC design. Design support is provided by third-party design centers: Locus Inc., Micral, Indiana Microelectronics Center and Digital Equipment Corp.

Harris Semiconductor

The Harris FastTrack design system is the highlight of this company's custom and semi-custom IC program. Combined with high performance bipolar and CMOS processes, the focus is on combining the performance of an IC design with the modularity of RF circuit design. To ease the design process, the software includes numerous RF building blocks that can be used as designed by Harris developers, or modified to optimize performance. One specific feature is scalable transistors, allowing optimization for noise figure, gain, and power handling capability.

Hughes Microelectronics

Hughes ASIC capabilities are centered around their CyberCell library, which provides an extensive selection of analog and digital circuit functions. Included with a complete package of analog and digital cells, which includes nonvolatile EEPROM capabilities, is an RF library with amplifiers, PLLs, quadrature detector, oscillators, Gilbert cell, PN generator and others.

Hughes ASICs have been widely used in the RFID industry, where small size and power consumption are critical design parameters. Spread spectrum applications are also an area where Hughes ASICs have been developed.

Walmsley Microsystems

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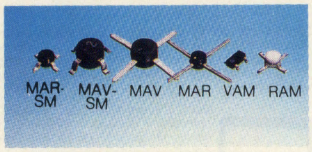

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add suffix SM to model no. (ex. MAR-ISM)	MAR-1 1.04	MAR-2 1.40	MAR-3 1.50	MAR-4 1.60	MAR-6 1.34	MAR-7 1.80	MAR-8 1.75	
	MAV-1 1.15	+MAV-2 1.45	+MAV-3 1.55	MAV-4 1.65				MAV-11 2.15
CERAMIC SURFACE-MOUNT	RAM-1 4.95	RAM-2 4.95	RAM-3 4.95	RAM-4 4.95	RAM-6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

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

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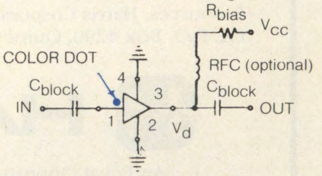
DAK-3: 3 of each MAR, MAR-SM, MAV-11, MAV-11SM (48 pcs) $74.95

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

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

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

Typical Circuit Arrangement



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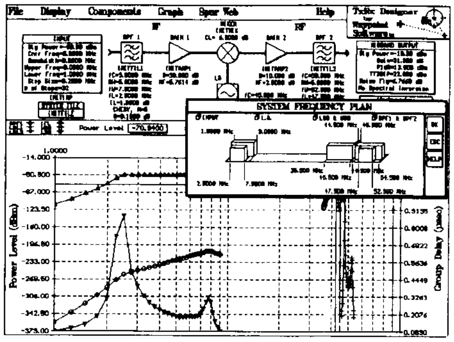

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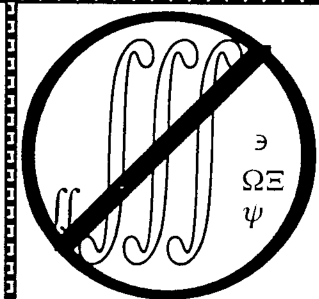

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Advertising Index

RF literature

Frequency Synthesis Catalog

Sciteq's 90-page, 1994-1995 catalog includes tutorials on frequency synthesis, plus technical and application data on the company's DDS, PLL and fractional-N synthesizer products. It also includes a line of microwave prescalers and other components commonly used in synthesizer designs.
Sciteq Electronics, Inc.
INFO/CARD #210

Trim Cap Bulletin

Sprague-Goodman offers Preliminary Engineering Bulletin SG-310, featuring their new GPY series of sapphire dielectric trimmer capacitors. Bulletin SG-310 includes features, specifications, and a detailed outline drawing. The GPY models measure 5.2 x 4.3 x 3.2 mm and are available in capacitance ranges from 0.4 - 2.0 pF to 0.8 - 8.0 pF.
Sprague-Goodman Electronics, Inc.
INFO/CARD #209

Representative Locator

The Electronics Representatives Association (ERA) announces publication of the 1994/95 edition of the *Locator Directory of Electronics Industry Manufacturers' Representatives*. The Locator contains listings of member firms and the territory each covers, categories of products handled, names of company officers and managers, number of personnel, branch offices and additional facilities or services.
Electronics Representatives Association
INFO/CARD #208

Network Analyzer News

The latest version of Hewlett-Packard's *HP 8510/8720 News* includes an article on measuring at rated current densities on-wafer", new product news, and a question and answer column.
Hewlett-Packard Co.
INFO/CARD #207

Amplifier Linearity Note

"Evaluating Amplifier Linearity", is an illustrated, four-page tech note from ENI. The publication explains the different methods commonly used to evaluate the linearity performance of RF power amplifiers. The tech note is available at no charge.
ENI
INFO/CARD #206

Software App. Note

"Using Microwave Harmonica PC to Design and Simulate a Clapp Oscillator" is the title of an application note offered by Compact Software. The eight-page document describes the use of nonlinear analysis at all stages of the design process, from searching for the frequency of oscillation to determining final oscillator performance.
Compact Software
INFO/CARD #205

Circuit Design Book

A reprinted edition of *Circuit Design Using Personal Computers*, by Thomas R. Cuthbert Jr., has bee released by Krieger Publishing. This book is a guide to designing electronic circuits using small computers and programmable calculators. The 512-page, clothbound book sells for $63.95.
Krieger Publishing Co.
INFO/CARD #204

Distribution Systems Literature

K&L Microwave offers a folder containing 18 individual data sheets featuring model specifications, photos and individual product features on switch matrices. Included are: coaxial, solid state, HF, video, audio, digital and hybrid switch matrices.
K&L Microwave, Inc.
INFO/CARD #203

Mixer Catalog

Miteq's 16-page, color short-form catalog summarizes the important input, output and transfer characteristics of eight mixer product groups. Among the product types listed are, single, double and triple balanced mixers; high IP3 mixers; mixer/IF amplifiers; image rejection mixers; LNA/image rejection mixers; biphase, I/Q modulators; biphase, I/Q detectors; and mixer subsystems. The catalog also describes Miteq's customization services and quality assurance testing.
Miteq
INFO/CARD #202

Material Selection Guide

Emerson & Cuming offers an eight-page brochure describing their microwave materials. The materials described in the selection guide range from lossy foams, magnetically loaded rubber sheets and high-loss castable resins to low loss dielectrics.
Emerson & Cuming
INFO/CARD #201

Chip Cap Catalog

A new 24-page surface mount chip capacitor catalog from Johanson Dielectrics covers a wide variety of capacitor types including new MemoryGUARD® decoupling chips with overall heights of 0.018 and 0.015 inches, and MLC's for hybrid circuit applications. Also included is an application note covering SMT manufacturing, and tape and reel information.
Johanson Dielectrics
INFO/CARD #200

Coaxial Adapter Catalog

Now available from Amphenol RF/microwave Operations is a 24-page catalog detailing 159 coaxial adapters and precision phase-matched cable assemblies for use in test, measurement and instrumentation applications.
Amphenol Corp.
INFO/CARD #199

RF guide to editorial coverage

RF software

Simulator Runs in Windows

Compact Software is demonstrating a new version of its Super-Spice time-domain simulator operating under the Microsoft Windows environment. The simulator is fully Windows compliant and features a flexible graphics report writer that allows users to graph different forms of simulation output in multiple graphics windows. Super-Spice for Windows is based on the same 32-bit simulation engine as the workstation version of Super-Spice. Super-Spice includes models of lossy transmission media, accurate models for various discontinuities, and an "electromagnetics module" that allows analysis of multi-layer/multi-strip media.
Compact Software, Inc.
INFO/CARD #195

Vacuum Tube Model Library

Over 40 vacuum tube models are available in a SPICE library from Intusoft. The devices have all been characterized in a laboratory environment using actual devices. The library comes with a number of examples including regulated power supplies, preamps, amplifiers and tube test circuits. In addition, a tube modeling service is available. The library sells for $525.
Intusoft
INFO/CARD #194

Updated Coverage Software

SoftWright LLC has released version 3.0 of the Terrain Analysis Package (TAP™) engineering software. A new batch processing capability allows users to set up multiple projects and let the computer prepare multiple studies without user intervention. The new multi-user capability enable two or more users to access TAP on a local area network. Other new features include the ability to locate the highest topography near a possible transmitter site and a very large library of several hundred antenna patterns.
SoftWright LLC
INFO/CARD #193

Updated System Design

Version 2.10 of TxRx Designer from Waypoint Software offers an innovative 3-D representation of frequencies and cascade parameters, moveable windows and extensive on-line help for every screen. Calculations of dynamic range, filter noise bandwidth, LO and input power leakage to output, as well as spur power calculations are performed. The software comes with a comprehensive manual and costs $149.95.
Waypoint Software
INFO/CARD #192

Test & Measurement Software

Liberty Labs has released a series of software libraries for a variety of measurement applications. The software was developed using National Instruments, LabVIEW for Windows. Among the available program modules are: IEC 801-3 Automated RF Susceptibility, HP Series spectrum analyzer software for emissions/site attenuation, mobile radio/cellular radio software, and impedance measurement. The modules are available as stand-alone executables, or as code along with the LabVIEW for Windows development system. A package including the LabVIEW for Windows development package and two library modules costs $5750, program modules consisting of source code and documentation cost $750, and stand-alone executables cost $500 each.
Liberty Labs, Inc.
INFO/CARD #191

VHDL-A/Verilog-A Analog Simulator

Cadence Design Systems' SpectreHDL™, accepts both VHDL-A and Verilog-A circuit descriptions, as well as SPICE netlists. The package includes a dual-language AHDL engine, and a language compiler for both Verilog-A and VHDL-A modeling. It is available as an option the the Cadence Analog Artist and Analog Workbench environments. SpectreHDL's U.S. list price starts at $10,000 and requires purchase of the underlying Spectre simulator.
Cadence Design Systems, Inc.
INFO/CARD #190

Analog Optimization

Paragon is a new member of MicroSims' Design Center family of products which does analog performance optimization. Paragon can adjust design parameters simultaneously, eliminating the process of manually tweaking each design parameter one at a time. It also offers constrained and unconstrained optimization (including non-linear constraints), interactive circuit exploration and a model parameter fitter. Paragon, and all members of the Design Center support Windows NT. Paragon is priced at $1900 on the PC under MS Windows, and $3900 on the Sun.
MicroSim Corp.
INFO/CARD #189

ASIC Layout for the Mac

Version 5 of Tanner Research's L-Edit and L-Edit Pro mask layout editor and chip verification system for the Macintosh upgrades L-Edit's hierarchical edit features and verification utilities for ASIC design. Chip designers can now take advantage of hierarchical edit-in-place for faster and easier editing, window stretching, cell and layer locking, cut and merge capability, group and ungroup as well as new features and increased performance in design rule checking, parameter extraction, and layout vs. schematic comparison. Pricing for L-Edit 5.0 on the Macintosh starts at $1495 and ranges up to $5295 with the full complement of verification tools.
Tanner Research
INFO/CARD #188