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Engineering RF & Wireless Products . . . . DC to Light

August 1998

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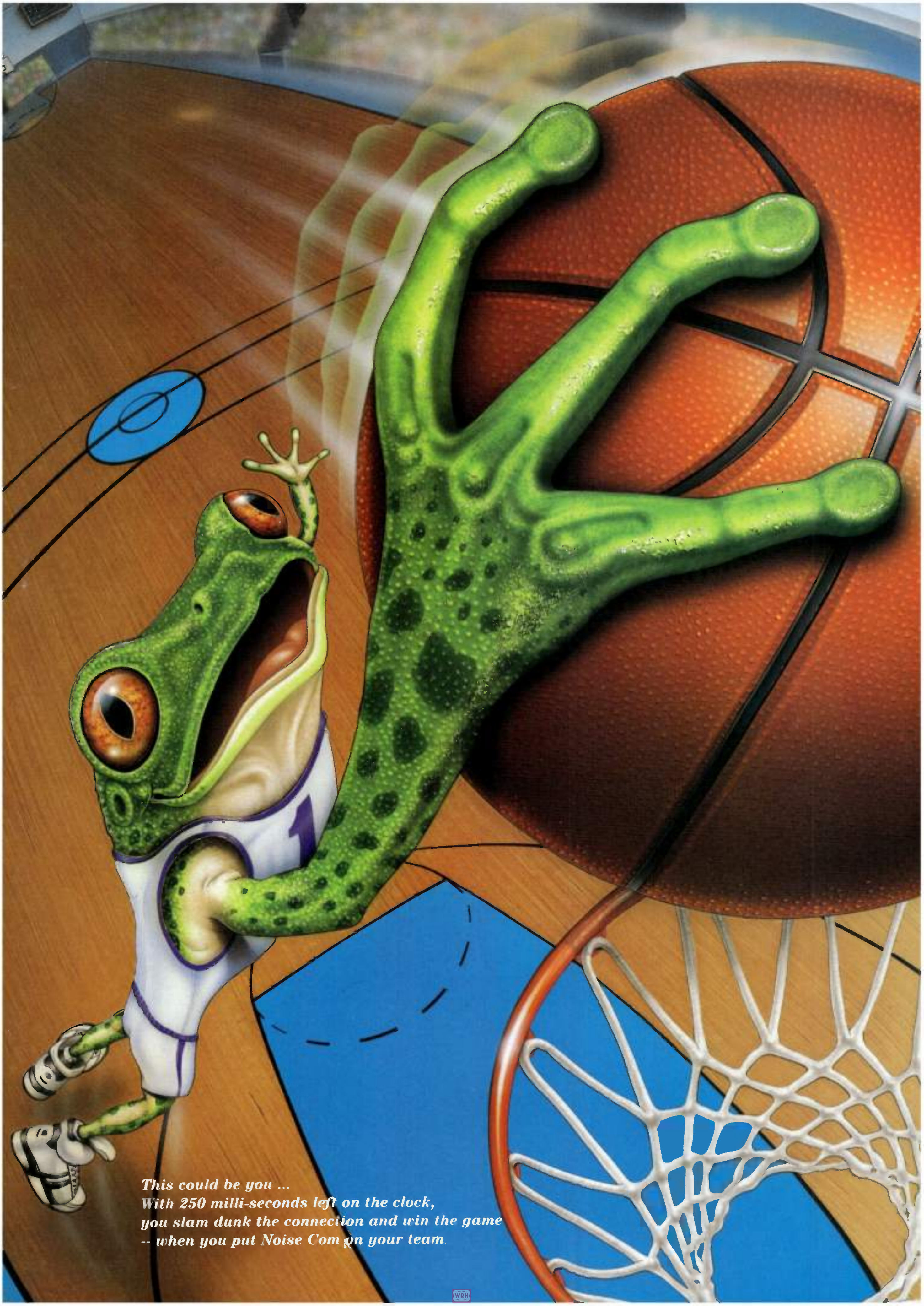
October 19-21, 1998
Santa Clara, CA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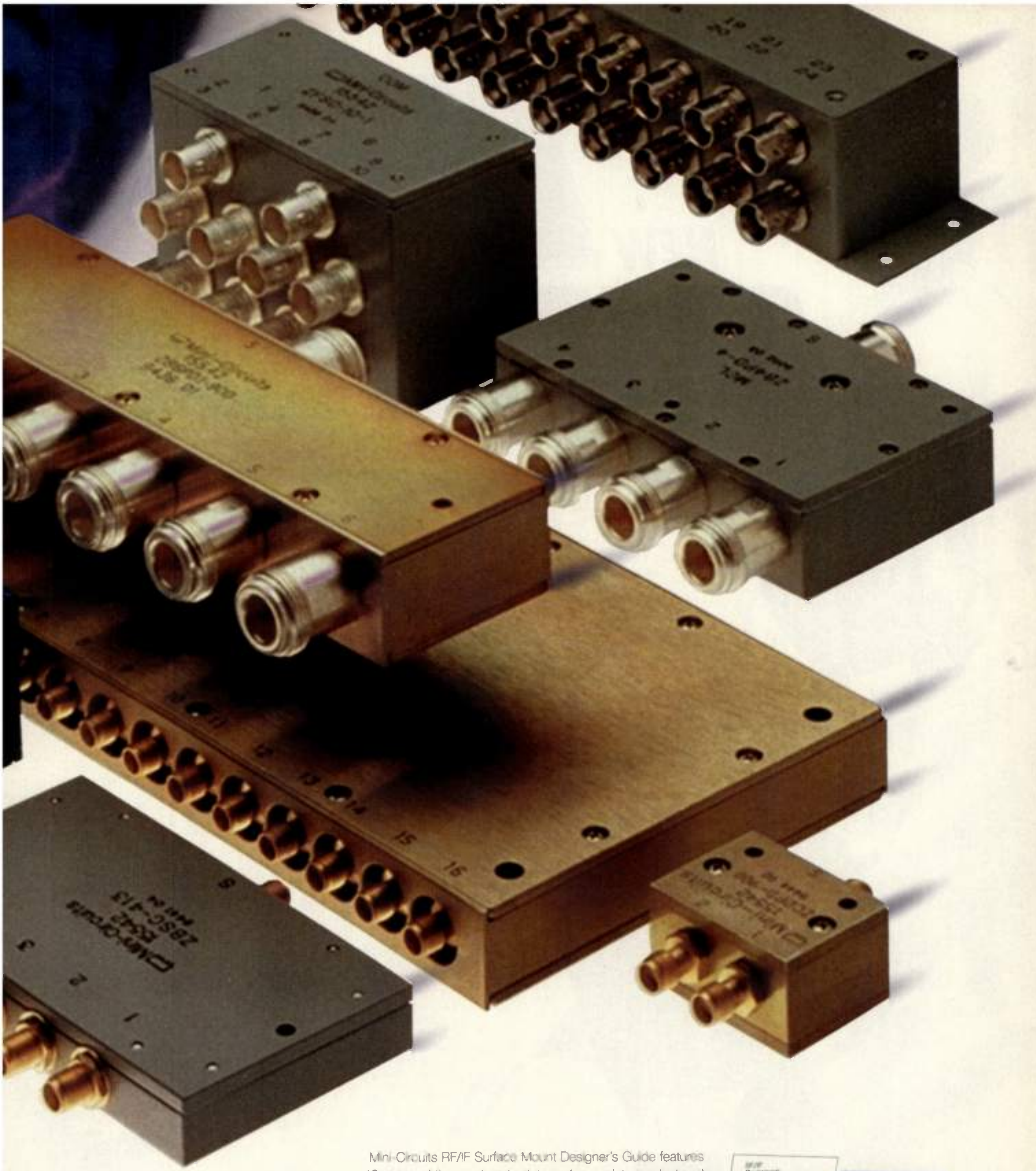

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ERA-2SM	DC-6000	15.2	12.4	4.6	26.0	40	2.00
ERA-3	DC-3000	20.8	12.1	3.8	23.0	35	2.10
ERA-3SM	DC-3000	20.2	11.5	3.8	23.0	35	2.15
ERA-4	DC-4000	13.5	▲17.0	5.5	▲32.5	65	4.15
ERA-4SM	DC-4000	13.5	▲16.8	5.2	▲33.0	65	4.20
ERA-5	DC-4000	18.8	▲18.4	4.5	▲33.0	65	4.15
ERA-5SM	DC-4000	18.5	▲18.4	4.3	▲32.5	65	4.20
ERA-6	DC-4000	11.3	▲18.5	8.4	▲36.5	70	4.15
ERA-6SM	DC-4000	11.3	▲17.9	8.4	▲36.0	70	4.20

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ERA-1 ERA-1SM
ACTUAL SIZE

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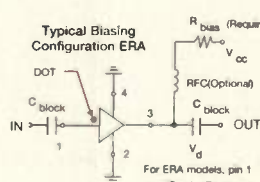

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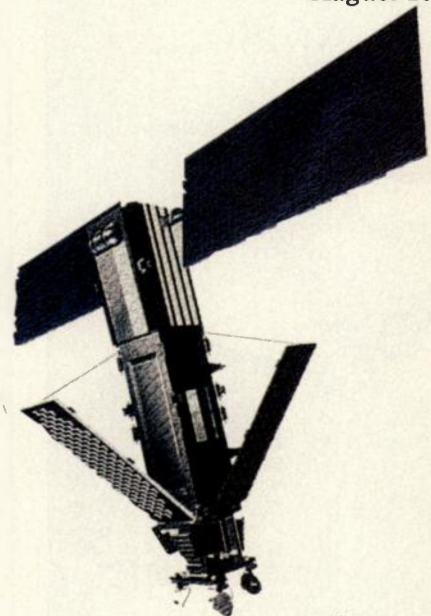

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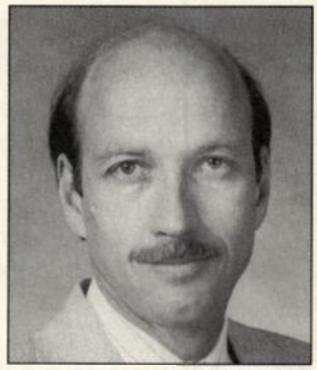
departments

Coming in September

- *Modulation*
- *PCS, DECT*
- *Filters*

Semiconductor Technologies Report Card



By Ernest Worthman
Contributing Editor
ernest_worthman@ieee.org

Due to a death in the family, Ernest Worthman will be writing this month's column instead of Don Bishop.

As I was working on the RF Conference and Expo to be held in San Jose this October, I got a call from last year's keynote speaker, Earl Lum. Earl is now an industry analyst with CIBC Oppenheimer, and works on analyzing trends in the RF market. As our discussion progressed, we found ourselves talking about the performance of various segments of the industry. He mentioned he had an interesting report on the investment health of gallium arsenide (GaAs) and competing semiconductor technologies. I asked him to send me a copy.

I like reading these perspectives. If you put aside that the main purpose of these types of reports is to analyze the players stock and investment positions, you can siphon off a great deal of trend information what the future is likely to bring.

For example, this report brings to light the fact that the competition from silicon (Si), silicon germanium (SiGe), silicon carbide (SiC) and indium phosphide (InP) is heating up.

The competition is coming in the form of price and performance curves. As technology marches on, the demand for longer run times and the 3 V threshold for RF circuits, as well as the trend to miniaturize components—ultimately to the "radio on a chip" level—becomes closer to reality. This means that traditional discrete device applications are falling to monolithic microwave integrated circuit (MMIC) and microwave integrated circuit (MIC) modules as well as exotic heterojunction bipolar transistors (HBTs) and pseudomorphic high electron mobility transistors (PHEMTs).

Additional pressures on the GaAs market stronghold, the RF power amplifiers, are coming from semiconductors such as Si and SiGe. The recent resurgence in these bipolar junction transistor (BJT) areas is becuase of a couple of issues. First, the usable frequency range of these traditional current devices is getting to the 3.0 GHz range, with f_T of 25 GHz. Second, new manufacturing processes can leverage the manufacturing of current wafer technology.

Also, metal oxide silicon field effect transistors (MOSFETs) are heading for the next generation using laterally diffused MOS (LDMOS). Laterally diffusing means that the gate width can be reduced to improve switching speeds, thus improving frequency range.

SiGe is a promising technology similar to the compound semiconductor found in GaAs. With SiGe devices, the base of the transistor is replaced with this material, which has higher electron mobility than silicon. For many applications, the extended frequency is a perfect match for the applications beyond silicon, but below the GaAs regions. SiGe technology also shows promise to work well with the upcoming digital technology.

Finally, there are other emerging technologies that show exciting potential such as silicon on insulator (SOI), SiC and InP. These somewhat untested but promising technologies provide a number of advantages in traditional production as well as offer new avenues for development.

So, what does all of this mean? Well, if you are an investor, it means that you will need to watch these emerging and promising technologies and keep an eye on your money. If you are a designer, it means that you will have even more options to add to that every pervasive list of technologies to choose from. RF

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August 19–21 **Piezoelectric**—*Kansas City.* Information: Pete Walsh, Electronics Industry Association, 2500 Wilson Blvd., Arlington, VA, 22201-3834. Tel. 703-907-7547; Fax 703-907-7547; e-mail *pwalsh@eia.org.*

24–28 **Symposium on Electromagnetic Compatibility–EMC '98**—*Denver.* Information: R. Barry Wallen PO Box 387, County Road #16, Rollinsville, CO 80474. Tel. 303-682-6600; Fax 303-682-6672; e-mail *bwallen@intellistor.com.*

31–September 3 **Wireless Symposium & Exhibition**—*Boston.* Information: Wireless/Portable registration, Penton Media, 611 Route 46 West, Hasbrouck Hts., NJ 07604.Tel 1-888-WireReg ; Fax 201-393-6297

September 2–4 **ISSSTA 98 International Symposium on Spread Spectrum Techniques and Applications**—*Sun City, South Africa.* Information: Dr. Pietre van Rooyen, Department of Electrical and Electronic Engineering, University of Pretoria, Pretoria, 0002, South Africa. Tel. +27 12 420 2291; Fax +27 12 43 3254; e-mail *vroopg@fanella.ee.up.ac.za.*

9–11 **1998 International Symposium on Advanced Radio Technologies**—*Boulder, CO.* Information: U.S. Department of Commerce, Boulder Laboratories, 325 Broadway, Boulder, CO. Tel. Fred McGehan, NIST 303-497-3246; Web site **ntia.its.bldrdoc.gov/meetings/art/art98.html**

13–16 **ICSPAT & DSP World Expo 1998**—*Toronto.* Information: Liz Austin, Miller Freeman, 525 Market St., Suite 500, San Francisco, CA 94105. Tel. 415-538-3848 or 888-239-5563; e-mail *dspworld@mfi.com.*

23–25 **PCS '98**—*Orlando.* Information: Personal Communications Industry Association, 500 Montgomery Street, Suite 700, Alexandria, VA 22314. Tel.703-739-0300; Fax 703-836-1608 Web site **www.pcs98.com/**

October 4–6 **Power '98**—*Santa Clara, CA.* Information:Mary Jean Ahearn. Tel. 800-874-9980; Fax 781-982-1724; e-mail *conferences@gigaweb.com*; Web site **www.gigaweb.com/events/power98.htm.**

14–16 **TelecomLatina '98**—*Miami.* Information: Intertec Trade Shows and Conferences 6300 S. Syracuse Way,

Suite 650, Englewood, CO 80111. Tel. 303-220-0600.

18–21 **MILCOM '98**—*Bedford, MA.* Information: Dr. Mafred Unkauf. Fax 1-508-490-2820; e-mail *Manfred_G_Unkauf@ccmail.res.ray.com*; Web site **www.milicom98.com**.

19–21 **RF Design '98 Conference & Expo**—*San Jose, CA.* Information: Intertec Trade Shows and Conferences, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 800-288-8606 or 303-220-0600; Fax 303-770-0253.

19–21 **RF Design Seminar Series**—*San Jose, CA.* Information: Intertec Trade Shows and Conferences, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 800-288-8606 or 303-220-0600; Fax 303-770-0253.

28–31 **ITA/USMSS Private Wireless Communications Conference & Exhibition**—*Washington, D.C.*. Information: Industrial Telecommunications Association, 1110 North Glebe Road, Suite 500, Arlington, VA 22201. Tel. 703-528-5115; Fax 703-524-1074; e-mail *info@ita-relay.com;* Web site **www.ita-relay.com**.

November 1–3 **Third Annual Wireless Communication Conference**—*San Diego.* Silas Deane, International Microelectronics and Packaging Society and Educational Foundation, 1850 Centennial Park Drive, Suite 105, Reston, VA 20191-1517. Tel. 615-963-1307; Fax 703-758-1066; e-mail *IMAPS@aol.com*.

1–4 **IEEE GaAs IC Symposium**—*Atlanta.* Information: 1998 IEEE GaAs IC Symposium, c/o IEEE, Attn: Ms. Marie Leonardis, 445 Hoes Lane, Piscataway, NJ 08855. Tel 732-562-3875; Fax 732-981-1293; e-mail *m.leonardis@ieee.org*.

1–5 **Embedded Systems Conference**—*San Jose, CA.* Liz Austin, Miller Freeman, 525 Market St., Suite 500, San Francisco, CA 94105. Tel 415-5538-3848 or 888-229-5563; e-mail *esc@mfi.com*

2–4 **IEEE-APS Exhibition on Antennas and Propagation for Wireless Communication**—*Waltham, MA.* Information: APWC98-Secretariat, 52 Agnes Drive, Framingham, MA 01701. Tel. 508-788-5152; Fax 508-788-6226; Web site **www.tiac.net/tuli/apwc98**.

RF courses

RF Design Seminar Series— Oct. 19–22, San Jose, CA.— Information: Intertec Trade Shows and Conferences, 6300 S. Syracuse Way, Suite 650, Englewood, CO 80111. Tel. 303-220-0600 or 800-288-8606; Fax 303-770-0253.

TEC Cellular—*Wireless Systems Overview*—Oct. 5; *Frequency Planning*— Oct. 7; *RF Planning Criteria for Wireless System Design*— Oct. 15; *Wireless System Design Priniciples*— Oct. 16; *Introduction to CDMA*—Oct. 20; *Intermediate CDMA*—Oct. 21; *Advanced CDMA*—Oct. 22, Melbourne, FL. Information: TECC, 7619 Emerald Drive, West Melbourne, Florida, 32904. Tel. 407-952-8300; Fax 407-725-5062; Web site **www.tecc.com**.

CKC Laboratories—*CORE EMC Design*—Sept. 21–22, Redmond, WA; *EMC Design II*, Oct. 19, Fremont, CA; Nov. 12, Orange County, CA; *Worldwide EMC Compliance Routes*—Oct. 19, Fremont, CA; Nov. 12, Orange County, CA; *Immunity to ESD*—Oct. 20, Fremont, CA; Nov. 13, Orange County, CA. Information: CKC Laboratories, 5473A Clouds Rest, Mariposa, CA 95338. Tel. 800-500-4362.

Penn State—*Advanced Modeling in Applied Computational Electromagnetics*—Sept. 28–30, State College, PA. Information: Richard W. Adler, ACES Executive Officer. Tel. 408-656-2352; Fax 408-649-0300; e-mail *rwa@ibm.net*.

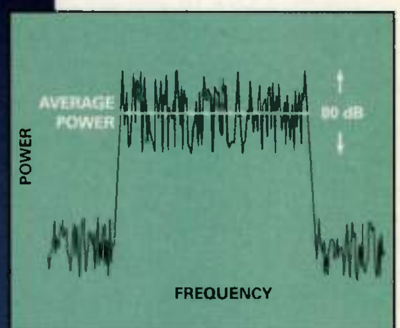
TeleStrategies—*Understanding Telecommunications Technologies for Non-Engineers*— Sept. 17–18, Nov. 5–6, Washington DC; Oct. 22–23, Atlanta; Dec. 3–4, Dallas; Oct 15–16, Chicago; Information: TeleStrategies, PO Box 811, McLean, VA 22101. Tel. 703-734-7050; Fax 703-734-9371.

Besser Associates—*RF and Wireless Made Simple*—Sept. 14–15; *Frequency Synthesis & Applications in Wireless Systems*—Sept. 14–16; *DSP Made Simple*—Sept. 16—18, Dallas; *Applied RF Techniques I*—Sept. 28–Oct. 2; *RF and Wireless Made Simple*—Sept. 28–29, San Diego Information: Besser Associates, 4800 El Camino Real, Suite 210, Los Altos, CA 94022. Tel. 650-949-3300; Fax 650-949-4400; e-mail *info@bessercourse.com;* Web site **www.bessercourse.com**.

UCLA Extension—*Advanced Digital Communications: The Search for Efficient Signaling Methods*—Oct. 12–14; *Digital Signal Processing for Cellular Mobile Wireless Communications*—Oct. 19–21; *Adaptive Filtering in Signal Processing and Communications*—Oct. 26–30, Los Angles. Information: UCLA Extension, Department of Engineering, Information Systems and Technical Management, Short Courses, 10995 LeConte Ave., Suite 542, Los Angeles, CA 90024. Tel. 310-825-3344; Fax 310-206-2815; e-mail *mhenness@unex.ucla.edu*; Web site **www.unex.ucla.edu/shortcourses**

Bellcore—*Wireless Interconnection 98*—Oct. 20–21, Phoenix. Information: Bellcore, 8 Corporate Place, Room 3A184, Piscataway, NJ 08854. Tel. 1-800-521-2673; Fax 732-336-2559; Web site **www. belcore.com**

Giga-tronics Introduces The 8540C Universal Power Meter



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Editorial forum

By Roger Lesser, Senior Associate Editor

Da Bulls?

I love new technology. Who doesn't? I write the *RF Design* News column each month, and enjoy seeing the numerous press releases that define where the industry is heading. (Can editors get paid by the pound of press releases they read?) At various trade shows, I talk to an average of 30–40 companies during a typical three-day event. I find these visits informative and fun. Fun? Yes, those I have visited with can tell you I'm rarely short on opinion and enjoy "stirring the pot" when it comes to issues affecting the industry.

Over the past year, I've been following the debate between advocates of gas-based products, such as gallium arsenide (GaAs) and those who carry the silicon flag. At times, the discussions remind me of debates over which basketball team is better, the modern-day Chicago Bulls or the Larry Bird-led Boston Celtics.

The gas advocates point to the benefits of GaAs with its increased bandwidth potential, while the silicon advocates point to the availability of silicon-based products and the lower cost of silicon-based devices. The gas advocates will suggest that silicon is reaching its limit in technology advances. The silicon supporters will tell you that gas products offer low production yields. They will also point to silicon germanium (SiGe) as the "replacement" for gas technology.

So, which one is better? Which one will dominate? Well, according to some industry observers, the edge goes to gas-based products but the cost of producing gas-based devices will have to drop. On the other hand, I've talked to some industry wizards that believe SiGe is definitely a technology to contend with.

Where do I stand in the debate? To be truthful (and editors always are, right?), can it be possible for the two technologies to co-exist? Do I have to take sides? I mean the marketplace will make the final decision. My job in the debate—stir the pot.

RF news

Tektronix issues voluntary recall of oscilloscopes

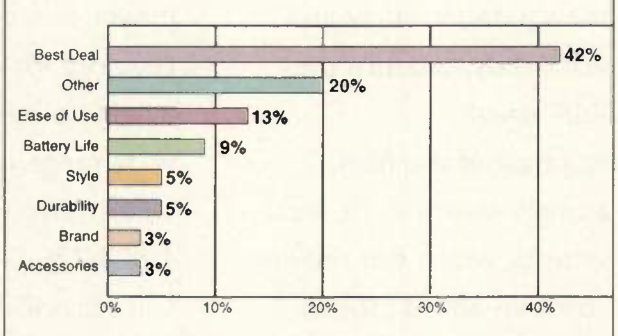
Tektronix, Beaverton, OR, has announced a voluntary recall of its model TDS210 and TDS220 oscilloscopes. The company determined that certain incorrect use of the product could cause the ground connection to fail. Tektronix is unaware of any injuries caused by the misuse.

If a user incorrectly connects a probe ground lead to a voltage source, or incorrectly touches the ground ring near the probe tip to a voltage source, a circuit board trace in the oscillosope's electrical ground path may open.

The recall applies to TDS210 and TDS220 units with serial numbers as follows: TDS210–serial number below BO49400 or CO10880; TDS 220– serial numbers below BO41060 or CO11175. Customers can contact Textronix at 800-835-9433, ext. 2400. Also, visit Textronix Web site at **www.tek.com/measurement**.

Wireless end user study points to cost trend

The Mobile User Survey, from the Yankee Group, Boston, MA, shows that the penetration of wireless phones in the United States has increased from 27–35% from 1997 to 1998. The report finds that personal communications services (PCS) and cellular have become an accepted part of the mainstream communications market. According to Phillip Redman, program manager of wireless/mobile communications, "The depth of wireless phone penetration can be attributed mainly to lower costs for services and hardware, which is the impact of increased competition in the top 50 markets," he says.



Users rank the most important factor when choosing a wireless phone.

The survey found that 42% of respondents rely on getting the best deal from the carrier and are willing to spend around $100 for a new digital phone. Brand awareness among end users is weak, according to the Yankee Group study. "With the increase in competition among manufacturers for mind and market share, building and maintaining brand awareness through price and promotional campaigns will become more important this year as more handset models become available," Redman says. "1998 will be a critical year for manufacturers to get product on the shelf. With the number of competitors coming to the market, they are going to have to drive costs down in order to compete."

The Yankee Group conducts the Mobile User Survey to identify the needs of current and potential mobile users. The survey is divided into two sections: the general user survey and the user specific survey. For more information concerning the survey, check the Yankee Group Web site at **www.primark.com**

R&D spending still important, stays robust

In its annual survey, Inside R&D, a weekly intelligence service, Englewood, NJ, finds that research and development (R&D), is seeing a serious boom compared to the early 1990s. According to the survey, the top 100 United States corporations spent a total of $92.2 billion in 1997, and increase of 13.8% from the 1996 total of $81.1 billion. The increase is seen as a result of the increasingly competitive global economy. Corporations are feeling the pressure to develop innovative products at a faster rate and are turning to internal R&D to provide a competitive advantage.

Harry Goldstein, editor and analyst for Inside R&D sees R&D staying robust. "Companies understand that in a highly competitive atmosphere, copy cat technologies are not going to look good to Wall Street or satisfy increasingly sophisticated consumers," he say. "R&D departments are the creative nexus to today's corporation. Companies that recognize

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this and nurture these seed beds of new ideas and products maintain competitive advantage and flourish. Those who don't fall by the wayside."

Leading the way in the R&D race are electronics and computers. The electronics & electrical sector had expenditures in excess of $19.5 million for 22 companies. Inside R&D notes companies such as National Semiconductor, 3Com, and Qualcomm are replacing past R&D stalwarts, especially in the petroleum sector.

Contracts

CommQuest receives GSM support contract from China—CommQuest, Encinitas, CA, has received a multi-million dollar contract from Truly Telecommunications, China, in support of Truly Telecommunications' effort to design and produce its first global system for mobile communications (GSM) wireless phones. CommQuest will provide its total system solution and GSM-XL chipsets.

Aydin Telemerty receives upgrade contract—Aydin Telemetry, Newtown, PA, has received a contract from the Aermacchi S.p.A, Italy, to upgrade the S2000 Telemerty preprocessor system. The upgrade will provide a link between the S2000 and the S6200 systems allowing direct VME access.

Business Briefs

RF Micro Devices opens GaAs HBT facility—RF Micro Devices (RFMD), Greensboro, NC, has opened a gallium arsenide heterojunction bipolar transistor (GaAs HBT) fabrication facility. The opening completes the transfer of TRW's, Dallas, TX, proprietary GaAs HBT process, exclusively licensed to RFMD for commercial wireless applications less than 10 GHz. The TRW and RFMD processes are the same with the exception of the wafer size. TRW's is three-inch while RFMD is four-inch.

Spectrum Signal acquires Alex Computer Systems—Spectrum Signal, Canada, has acquired Alex Computers, Ithica, NY, as part of its strategy to support Analog Devices' new 32-bit, floating-point, multiprocessing digital signal processor (DSP), the ADSP-21160. Alex Computer products include the Apex-Pro and Apex-Debug.

National Semiconductor and Graychip team form alliance—National Semiconductor, Santa Clara, CA, and Graychip DSP Chips and Systems, Palo Alto, CA, have joined forces to jointly market integrated circuits (ICs) for cellular basestation. The product offering will include Graychips digital down conversion and up conversion ICs.

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Spectrum-analyzer measurements and noise

Noise is an inherent component of any signal. Accurately measuring this noise and noise-like digital communications signals can help improve circuit evaluation.

By Joe Gorin

Noise is the classical limitation of electronics. In measurements, noise and distortions limit the dynamic range of test results. The characteristics of noise and its direct measurement are discussed here, along with the measurement of noise-like signals exemplified by digital code-division, multiple-access (CDMA) and time-division, multiple-access (TDMA) signals. Compensating for the noise in instrumentation while measuring continuous wave (CW) sinusoidal and noise-like signals will also be discussed.

Simple noise—baseband, real, Gaussian

Noise occurs because of the random motion of electrons. The number of electrons involved is large, and their motions are independent. Therefore, the variation in the rate of current flow takes on a bell-shaped curve known as the Gaussian probability density function (PDF) in accordance with the central limit theorem from statistics. The Gaussian PDF is shown in Figure 1.

The Gaussian PDF explains some of the characteristics of a noise signal seen on a baseband instrument such as an oscilloscope. The baseband signal is a real signal—it has no imaginary components.

Bandpassed noise—I and Q

When using spectrum analyzers in RF design work, signals within a passband, such as a communications channel or the resolution bandwidth (RBW, the bandwidth of the final IF) of a spectrum analyzer are measured. Noise in this bandwidth still has a Gaussian PDF, but few RF instruments display PDF-related metrics.

Instead, a signal's magnitude and phase (polar coordinates) or I/Q components are observed. The latter are the in-phase (I) and quadrature (Q) parts of a signal, or the real and imaginary components of a rectangular-coordinate representation of a signal. Basic (scalar) spectrum analyzers measure only the magnitude of a signal. The characteristics of the magnitude of a noise signal are what is of interest.

Consider the noise within a passband as being made of independent I and Q components, each with Gaussian PDFs. Figure 2 shows samples of I and Q components of noise represented in the I/Q plane. The signal in the passband is actually given by the sum of the I magnitude, v_I, multiplied by a cosine wave (at the center frequency of the passband) and the Q magnitude, v_Q, multiplied by a sine wave. In this article, just the I and Q components without the complications of the sine/cosine waves will be discussed.

Spectrum analyzers respond to the magnitude of the signal within their RBW passband. The magnitude, or envelope, of a signal represented by an I/Q pair is given by:

$$v_{env} = \sqrt{(v_I^2 + v_Q^2)}$$

Graphically, the envelope is the length of the vector from the origin to the I/Q pair. It is instructive to draw circles of evenly spaced constant-amplitude envelopes on the samples of I/Q pairs as shown in Figure 3.

Count the number of samples within each annular ring in Figure 3. Notice that the area near zero volts does not have the highest count of samples. Even though the density of samples is highest there, this area is smaller than any of the other rings.

The count within each ring constitutes a histogram of the distribution of the envelope. If the width of the rings were reduced and expressed as the "count" per unit of ring width, the limit becomes a continuous function instead of a histogram. This continuous function is the PDF of the envelope of bandpassed noise. It is a Rayleigh distribution (Figure 4) in the envelope voltage, v, that depends on

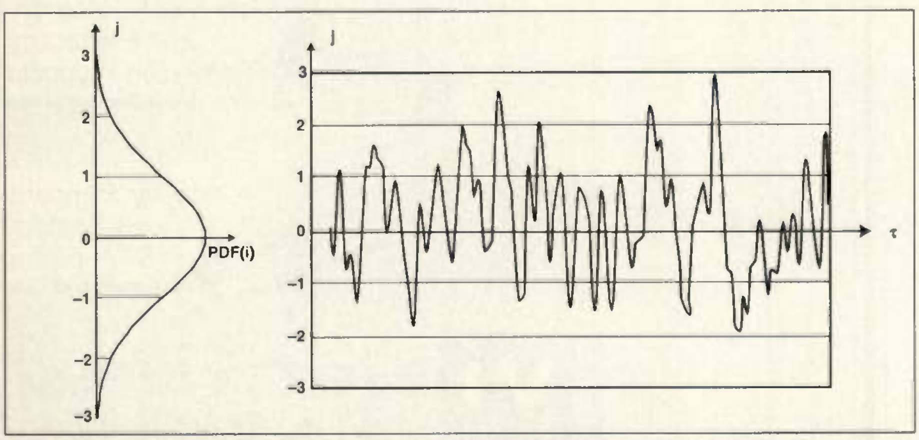

Figure 1. The Gaussian PDF is maximum at zero current and falls off away from zero, as shown (rotated 90°) on the left. A typical noise waveform is shown on the right.

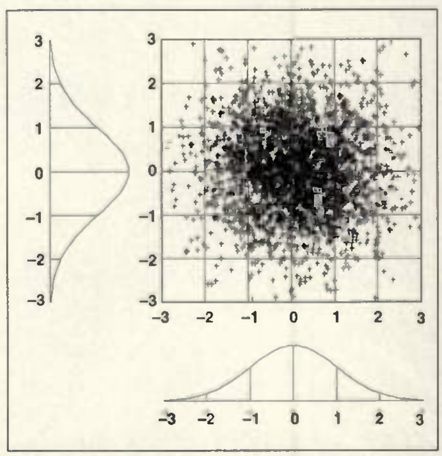

Figure 2. Bandpassed noise has a Gaussian PDF independently in both its I and Q components.

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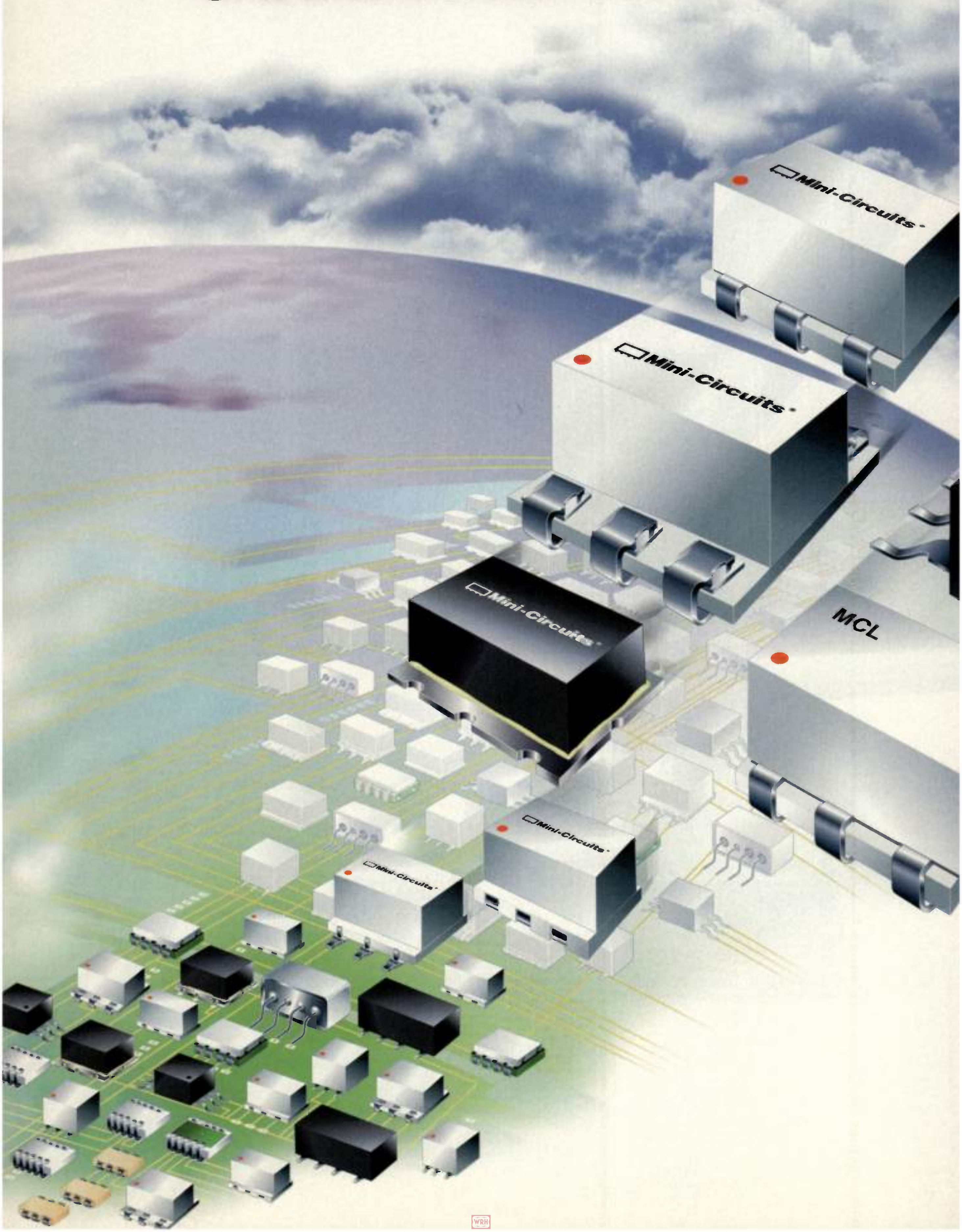

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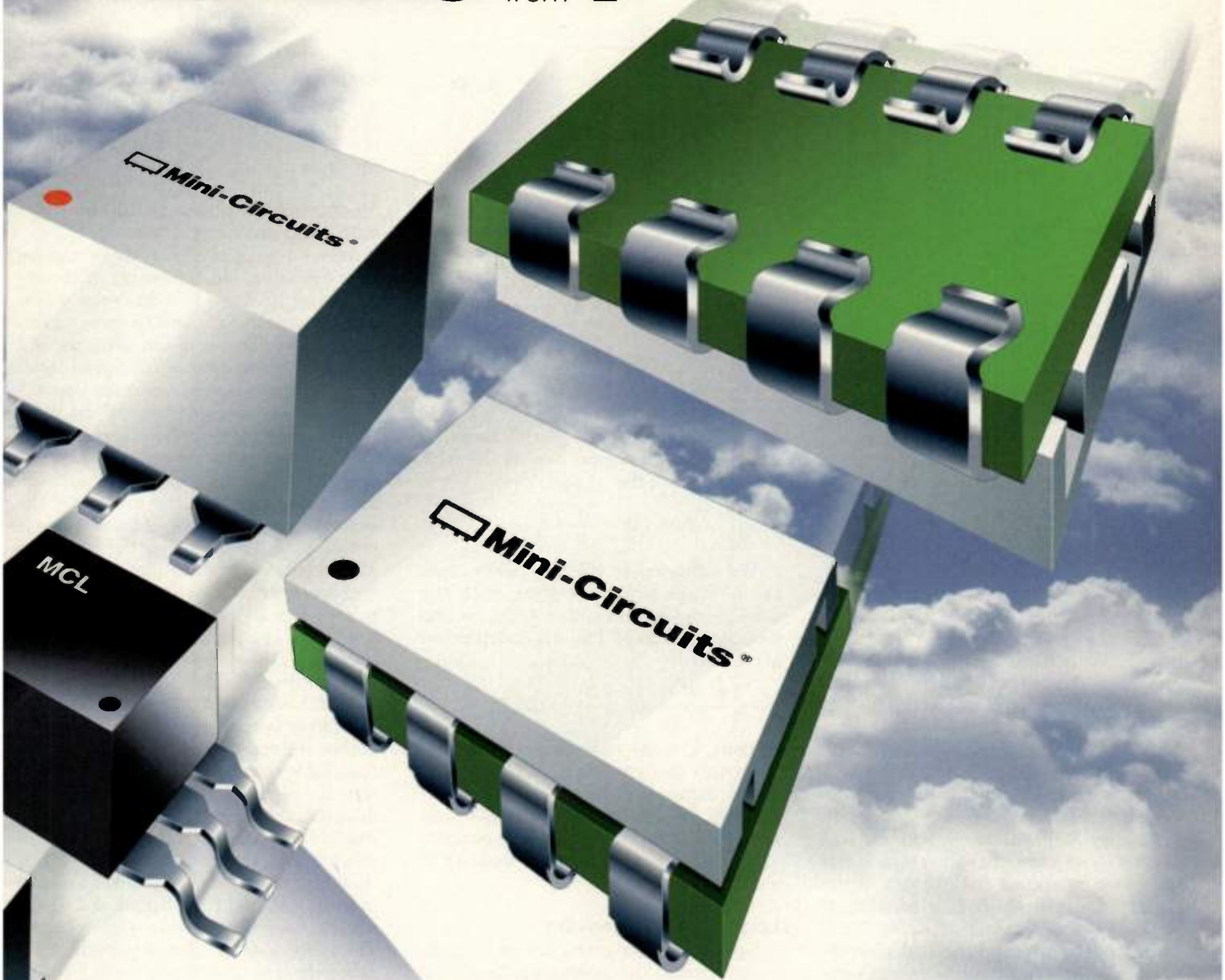

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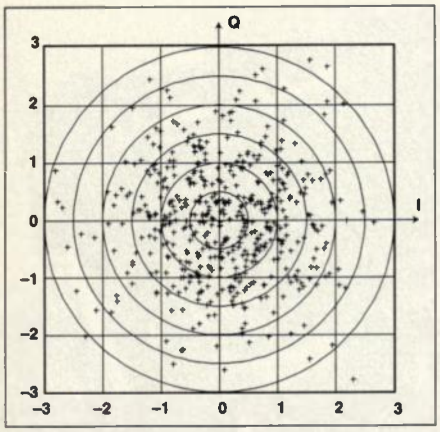

Figure 3. Samples of I/Q pairs shown with evenly spaced constant-amplitude envelope circles.

the sigma of the signal; for $v \geq 0$:

$$PDF(v) = \left(\frac{v}{\sigma^2}\right)\exp\left(-\frac{1}{2}\left(\frac{v}{\sigma}\right)^2\right)$$

Measuring the power of noise with an envelope detector

The power of the noise is the parameter usually measured with a spectrum analyzer. The power is the "heating value" of the signal. Mathematically, it is the average of v^2/R, where R is the impedance of the signal and v is its instantaneous voltage.

At first glance, finding the average envelope voltage and squaring it, then dividing by R might seem logical. But finding the square of the average is not the same as finding the average of the square. In fact, there is a consistent under-measurement of noise from squaring the average instead of averaging the square; this under-measurement is 1.05 dB.

The average envelope voltage is given by integrating the product of the envelope voltage and the probability that the envelope takes on that voltage. This probability is the Rayleigh PDF, so:

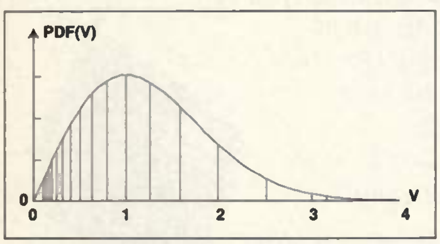

Figure 5. The PDF of the voltage envelope of noise is graphed. 1 dB spaced marks on the x-axis shows how the probability density would be different on a log scale. Where the decibel markings are dense, the probability that the noise will fall between adjacent marks is reduced.

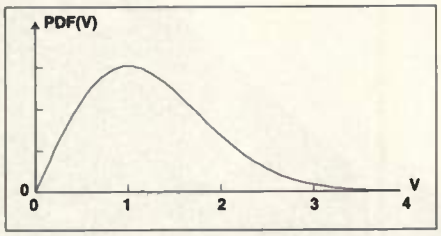

Figure 4. The PDF of the voltage of the envelope of a noise signal is a Rayleigh distribution. The PDF is zero at zero volts, even though the PDFs of the individual I and Q components are maximum at zero volts. It is maximum for v = sigma.

$$\bar{v} = \int_0^\infty v PDF(v) dv = \sigma\sqrt{\frac{\pi}{2}}$$

The average power of the signal is given by an analogous expression with v^2/R in place of the "v" part:

$$\bar{p} = \int_0^\infty \left(\frac{v^2}{R}\right) PDF(v) dv = \frac{2\sigma^2}{R}$$

We can compare the true power, from the average power integral, with the voltage-envelope-detected estimate and find the ratio to be 1.05 dB, independent of σ and R.

$$10\log\left(\frac{\bar{v}^2/R}{\bar{p}}\right) = 10\log\left(\frac{\pi}{4}\right) = -1.05 \text{ dB}$$

Thus, if noise were measured with a spectrum analyzer using voltage-envelope detection (the "linear" scale) and averaging, an additional 1.05 dB would need to be added to the result to compensate for averaging voltage instead of voltage-squared.

Logarithmic processing

Spectrum analyzers are most commonly used in the logarithmic ("log") display mode, in that the vertical axis is calibrated in decibels. Look at the PDF for the voltage envelope of a noise signal, but mark the x-axis with points equally spaced on a decibel scale—in this case with 1 dB spacing. (See Figure 5.) The

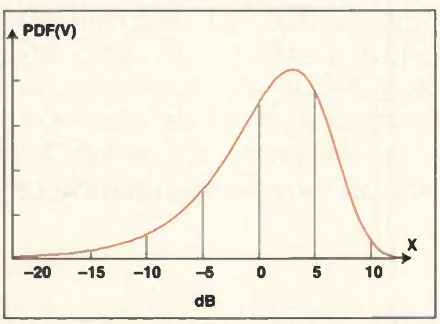

Figure 6. The PDF of logged noise is about 30 dB wide and tilted toward the high end.

area under the curve between markings is the probability that the log of the envelope voltage will be within that 1 dB interval. Figure 6 represents the continuous PDF of a logged signal that was predicted from the areas in Figure 5.

Measuring the power of noise with a log-envelope scale

When a spectrum analyzer is in a log (dB) display mode, averaging of the results can be done in numerous ways. Mechanisms include multiple trace averaging, video filtering of the envelope, and use of the noise marker (discussed later) which averages results across the x-axis.

When the average power of the noise is expressed in decibels, a logarithm of that average power is computed. When the output of the log scale of a spectrum analyzer is averaged, the average of the log is computed. The log of the average is not equal to the average of the log. If the same kinds of computations are used as were previously used in comparing voltage envelopes and power envelopes, the result is that log processing causes an under-response to noise of 2.51 dB, rather than 1.05 dB.

[Some authors artificially state that this factor is because of 1.05 dB from envelope detection and another 1.45 dB from logarithmic amplification, reasoning that the signal is first voltage-envelope detected, then logarithmically amplified. But if the voltage-squared envelope (in other words, the power envelope, which would cause zero error instead of 1.05 dB) is measured and then logged, a 2.51 dB under-response would still result. Therefore, there is no real point in separating the 2.51 dB into two pieces.]

The log amplification acts as a compressor for large noise peaks; a peak of ten times the average level is only 10 dB higher. Instantaneous near-zero envelopes, on the other hand, contain no power but are expanded toward negative infinity decibels. The combination of these two aspects of the logarithmic curve cause noise power to be underestimated.

Equivalent noise bandwidth

Before discussing the measurement of noise with a spectrum analyzer "noise marker," it is necessary to understand the RBW filter of a spectrum analyzer.

The ideal RBW has a flat passband and infinite attenuation outside that passband. But it must also have good time domain performance so that it behaves well when signals sweep through the passband. Most spectrum analyzers use four-

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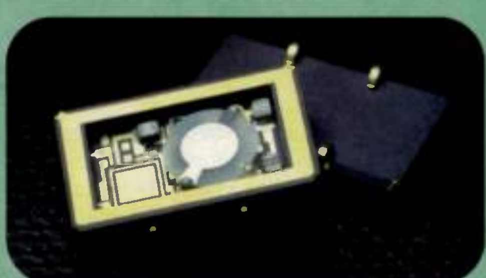

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Spectrum analyzers and envelope detectors

A simplified block diagram of a spectrum analyzer is shown in Figure A. The envelope detector/logarithmic amplifier block is shown configured as they are used in the HP 8560 E-Series spectrum analyzers. This block diagram is better for tutorial purposes because the log amplifier and detector positions are reversed compared to most analyzers. In either case, the important concept to recognize is that an IF signal goes into this pair of circuits, and a baseband signal comes out.

The salient features of the envelope detector are:

1. The output voltage is proportional to the input voltage envelope.
2. The bandwidth for following envelope variations is large compared to the widest RBW.

Figure B shows an envelope detector and peak detector with their associated gains.

If the input signal is continuous wave (CW), a peak detector and an envelope detector act identically. But if the signal has variations in its envelope, the envelope detector with the shown lowpass filter (LPF) will follow those variations with the linear, time-domain characteristics of the filter; the peak detector will follow non-linearly, subject to its maximum negative-going dv/dt limit, as demonstrated in Figure C . The non-linearity will make for unpredictable behavior for signals with noise-like statistical variations.

A peak detector may act like an envelope detector in the limit as its resistive load dominates and the capacitive load is minimized. But practically, the non-ideal voltage drop across the diodes and the heavy required resistive load make this topology unsuitable for envelope detection. All spectrum analyzers use envelope detectors; some are just misnamed.

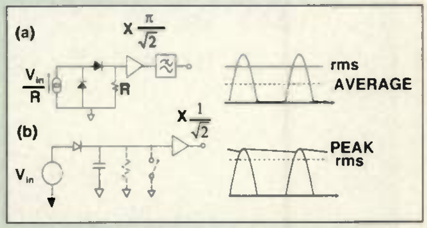

Figure B. A half-wave rectifier (a) acts as an envelope detector. A peak detector (b) is reset by leakage through a resistor or by actuating a switch.

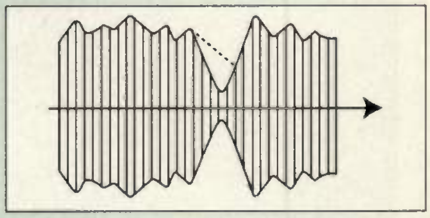

Figure C. An envelope detector will follow the envelope of the shown signal, albeit with the delay and filtering action of the LPF used to remove the carrier harmonics. A peak detector is subject to negative slew limits, as demonstrated by the dashed line it will follow across a response pit.

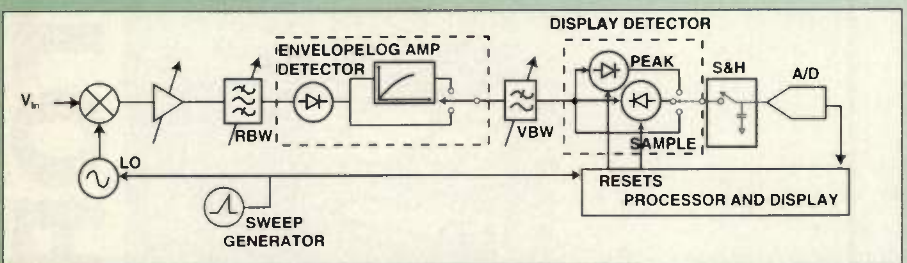

Figure A. Simplified spectrum-analyzer block diagram.

Filter type	Application	NBW/–3 dB BW
4-pole sync	Most SAs analog	1.128 (0.52 dB)
5-pole sync	Some SAs analog	1.111 (0.46 dB)
Typical FFT	FFT-based SAs	1.05 (0.23 dB)

Table 1. The ratio of the equivalent noise bandwidth to the –3 dB bandwidth.

pole synchronously tuned filters for their RBW filters. Plot the power gain (the square of the voltage gain) of the RBW filter versus frequency as shown in Figure 7. The response of the filter to noise of flat power spectral density will be the same as the response of a rectangular filter with the same maximum gain and the same area under their curves. The width of such a rectangular filter is the "equivalent noise bandwidth" of the RBW filter. The noise density at the input to the RBW filter is given by the output power divided by the equivalent noise bandwidth.

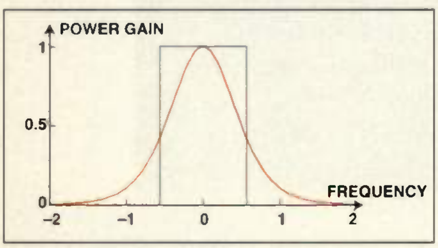

Figure 7. The power gain versus frequency of an RBW filter can be modeled by a rectangular filter with the same area and peak level, and a width of the "equivalent noise bandwidth."

The ratio of the equivalent noise bandwidth to the –3 dB bandwidth (the "name" of the RBW is usually its –3 dB BW) is given by Table 1.

The noise marker

As previously noted, the measured level at the output of a spectrum analyzer must be manipulated to represent the input spectral noise density that is to be measured. This manipulation involves three factors, which may be added in decibel units:

1. Under-response because of voltage envelope detection (add 1.05 dB) or log-scale response (add 2.51 dB).
2. Over-response because of the ratio of the equivalent noise bandwidth to the –3 dB bandwidth (subtract typically 0.52 dB).
3. Normalization to a 1 Hz bandwidth (subtract 10 times the log of the RBW, where the RBW is given in units of Hz).

A further operation of the noise marker in spectrum analyzers is to average 32 measurement cells centered around the marker location to reduce the variance of the result.

The final result of these computations is a measure of the noise density, the noise in a theoretical ideal 1 Hz bandwidth. The units are typically dBm/Hz.

Measuring noise-like signals—digital communications signals

Digitally modulated signals are created by clocking a DAC with the symbols (a group of bits simultaneously transmitted), then passing the DAC output through a pre-modulation filter (to reduce the transmitted bandwidth), then modulating the carrier with the filtered signal. (See Figure 8.) The resulting signal is obviously not noise-like if the digital signal is a simple pattern. It also does not have a noise-like distribution if

Measuring noise with spectrum analyzers

There are three ways noise measurements look perfectly reasonable on the screen of a spectrum analyzer but can be significantly in error.

• *Caution 1, input mixer level*—A noise-like signal of high amplitude can overdrive the front end of a spectrum analyzer although the displayed signal is within the normal display range. This problem is possible whenever the bandwidth of the noise-like signal is much wider than the resolution bandwidth (RBW). The power within the RBW will be lower than the total power by about ten decibels times the log of the ratio of the signal bandwidth to the RBW. For example, an IS-95 code-division, multiple-access (CDMA) signal with a 1.23 MHz bandwidth is 31 dB larger than the power in a 1 kHz RBW. If the indicated power with the 1 kHz RBW is –20 dBm at the input mixer (i.e., after the input attenuator), then the mixer is seeing about +11 dBm. Most spectrum analyzers are specified for –10 dBm continuous wave (CW) signals at their input mixer--the level below that mixer compression is specified to be less than 1 dB for CW signals and usually 5 dB or more above this –10 dBm. The mixer behavior with Gaussian noise is not guaranteed, especially because its peak-to-average ratio is much higher than that of CW signals. Keeping the mixer power below -10 dBm is a good practice that is unlikely to allow significant mixer nonlinearity. Keep the total power at the input mixer at or below –10 dBm.

• *Caution 2, overdriving the log amp*—Often, the level displayed has been heavily averaged using trace averaging or a video bandwidth (VBW) much smaller than the RBW. In such a case, instantaneous noise peaks are well above the displayed average level. If the level is high enough that the log amp has significant errors for these peak levels, the average result will be in error. Figure D shows the error because of overdriving the log amp in the lower right corner, based on a model that has the log amp clipping at the top of its range. Typically, log amps are still close to ideal for a few dB above their specified top, making the error model conservative. But it is possible for a log amp to switch from log mode to linear (voltage) behavior at high levels. In that case, larger (and of opposite sign) errors to those computed by the model are possible. Therefore, keep the displayed average log level at least 7 dB below the maximum calibrated level of the log amp.

• *Caution 3, underdriving the log amp*—The opposite of the overdriven log amp problem is the underdriven log amp problem. With a clipping model for the log amp, the results in the upper left corner of Figure D were obtained. Keep the displayed average log level at least 14 dB above the minimum calibrated level of the log amp.

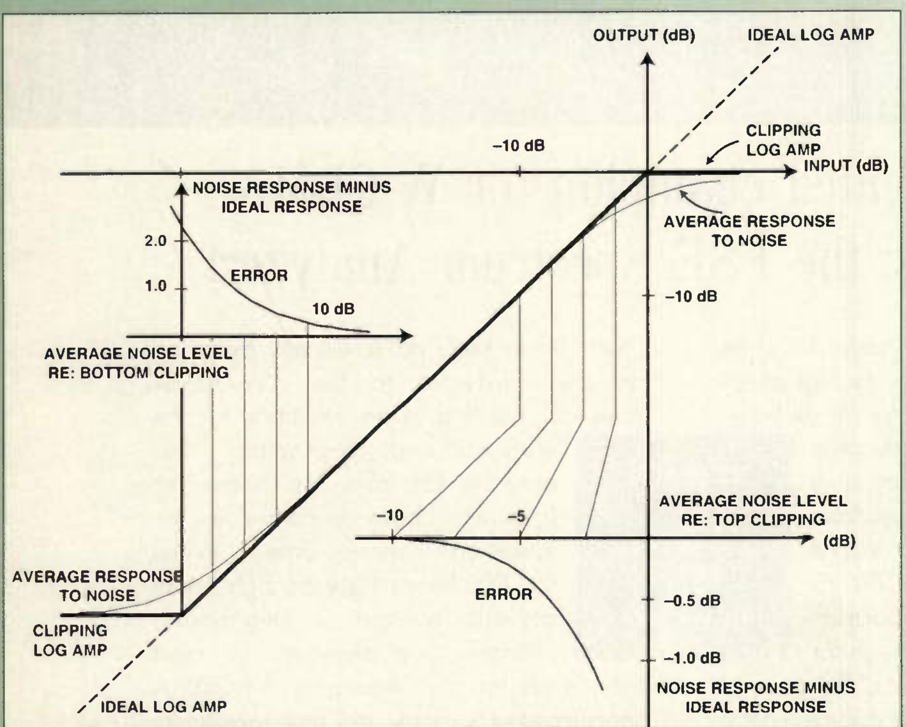

Figure D: In its center, this graph shows three curves: the ideal log amp behavior, that of a log amp that clips at its maximum and minimum extremes, and the average response to noise subject to that clipping. The lower right plot shows, on expanded scales, the error in average noise response because of clipping at the positive extreme. The average level should be kept 7 dB below the clipping level for an error below 0.1 dB. The upper left plot shows, with an expanded vertical scale, the corresponding error for clipping against the bottom of the scale. The average level must be kept 14 dB above the clipping level for an error below 0.1 dB.

the bandwidth of observation is wide enough for the discrete nature of the DAC outputs to significantly affect the distribution of amplitudes.

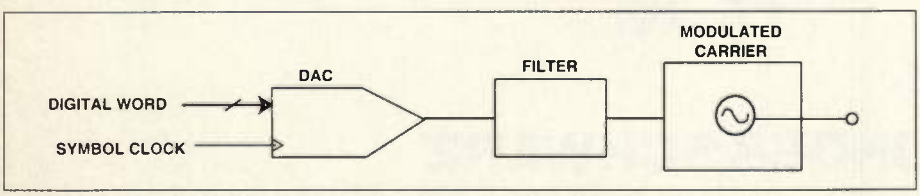

Figure 8. A simplified model for the generation of digital communications signals.

But, under many circumstances, especially test conditions, the digital signal bits are random. And, as exemplified by the "channel power" measurements discussed below, the observation bandwidth is narrow. If the digital update period (the reciprocal of the symbol rate) is less than one-fifth the duration of the majority of the impulse response of the resolution bandwidth filter, the signal within the RBW is approximately Gaussian ac-

Peak-detected noise (and TDMA ACP measurements)

Time-division, multiple-access (TDMA), or burst-RF systems, are usually measured with peak detectors. The burst "off" events are not shown on the screen of the spectrum analyzer to avoid distracting the user. Examples include ACP measurements for personal digital cellular (PDC) by two methods, personal handiphone system (PHS) and North American dual-mode cellular (NADC). Noise is also often peak-detected in the measurement of rotating media, such as hard disk drives and video cassette recorders (VCRs).

The peak of noise will exceed its power average by an amount that increases (on average) with the length of time over that the peak is observed. A combination of analysis, approximation and experimentation leads to this equation for v_{pk}, the ratio of the average power of peak measurements to the average power of sampled measurements.

$$v_{pk} = [10\ \mathrm{dB}]\log_{10}\left[\ln\left(2\pi\tau BW_i + e\right)\right]$$

Tau is the observation period, usually given by either the length of an RF burst, or by the spectrum-analyzer sweep time divided by the number of cells in a sweep. BW_i is the "impulse bandwidth" of the RBW filter, which is 1.62 times the –3 dB BW for the four-pole synchronously tuned filter used in most spectrum analyzers. Note that v_{pk} is a "power average" result—the average of the log of the ratio will be different.

The graph in Figure E shows a comparison of this equation with some experimental results. The fit of the experimental results would be even better if 10.7 dB were used in place of 10 dB in the previous equation, even though analysis does not support such a change.

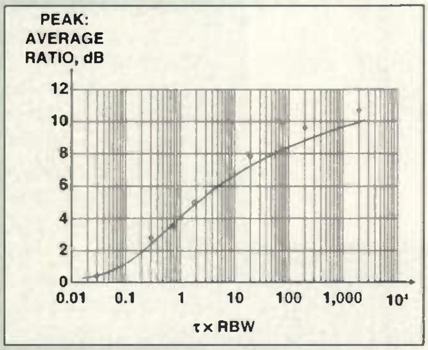

Figure E. The peak-detected response to noise increases with the observation time.

cording to the central limit theorem.

A typical example is IS-95 CDMA. Performing spectrum analysis, such as the adjacent-channel power ratio (ACPR) test, is usually done using the 30 kHz RBW to observe the signal. This bandwidth is only one-fortieth of the symbol clock (1.23 Msymbols/s), so the signal in the RBW is the sum of the impulse responses to about 40 pseudorandom digital bits. A Gaussian PDF is an excellent approximation to the PDF of this signal.

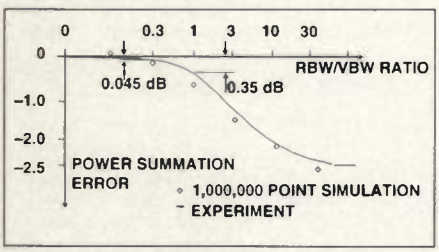

Figure 9. For VBW ≥ 3 RBW, the averaging effect of the VBW filter does not significantly affect power-detection accuracy.

Channel-power measurements

Most modern spectrum analyzers allow the measurement of the power within a frequency range, called the channel bandwidth. The displayed result comes from the computation:

$$p_{ch} = \left(\frac{B_s}{B_n}\right)\left(\frac{1}{N}\right)\sum_{i=n1}^{n2} 10^{\left(\frac{p_i}{10}\right)}$$

where p_{ch} is the power in the channel, B_s is the specified bandwidth (also known as the channel bandwidth), B_n is the equivalent noise bandwidth of the RBW used, N is the number of data points in the summation, and p_i is the sample of the power in measurement cell i in dB units (if p_i is in dBm, p_{ch} is in milliwatts). $n1$ and $n2$ are the end-points for the index i within the channel bandwidth; $N = (n2 - n1) + 1$.

The computation works for continuous wave (CW) signals, such as from sinusoidal modulation. The computation is a power-summing computation. Because the computation changes the input data points to a power scale before summing, there is no need to compensate for the difference between the log of the average and the average of the log as explained previously, even if the signal has a noise-like PDF. If the signal starts with noise-like statistics and is averaged in decibel form (typically with a VBW filter on the log scale) before the power summation, some of 2.51 dB under-response noted earlier will occur. If the signal is of noise-like statistics, and the signal is averaged before performing the summation, adding 2.51 dB to the result will provide an accurate measurement. Plus, the averaging reduces the variance of the result.

When the statistics of the signal are unknown, the best measurement technique is not to average before power summation. Using VBW ≥ 3RBW is required for insignificant averaging, and is recommended. The bandwidth of the video signal is not as obvious as it appears. To avoid peak-bias of the measurement, the "sample" detector must be used. Spectrum analyzers have lower effective video bandwidths in sample detection than they do in peak detection mode because of the limitations of the sample-and-hold circuit that precedes the A/D converter.

Figure 9 shows the experimentally determined relationship between the VBW:RBW ratio and the under-response of the partially averaged logarithmically processed noise signal.

Adjacent-channel power

There are many standards for the measurement of adjacent-channel power (ACP) with a spectrum analyzer. The issues involved in most ACP measurements are covered in detail in an earlier article [2]. A survey of other standards is also available [4].

For digitally modulated signals, ACP and channel-power measurements are similar, except ACP is easier. ACP is usually the ratio of the power in the main channel to the power in an adjacent channel. If the modulation is digital, the main channel will have noise-like statistics. Whether the signals in the adjacent channel are caused by broadband noise, phase noise or inter modulation of noise-like signals in the main channel, the adjacent channel will have noise-like statistics. A spurious signal in the adjacent channel is most likely modulated to appear noise-like too, but a CW-like tone is a possibility.

If the main and adjacent channels are

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Log scale for CW measurements

If one were to "design" a scale (such as power, voltage, log power, or an arbitrary polynomial) to have response to signal plus noise that is independent of small amounts of noise, one could end up designing the log scale.

Consider a signal having unity amplitude and arbitrary phase, as in Figure F. Consider noise with an amplitude much less than unity, r.m.s., with random phase. Let us break the noise into components that are in-phase and in-quadrature with the signal. Both of these components will have Gaussian PDFs, but for this simplified explanation, we can consider them to have values of ±x, where x << 1.

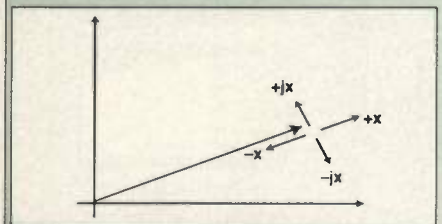

Figure F. Noise components can be projected into in-phase and quadrature parts with respect to a signal of unity amplitude and arbitrary phase.

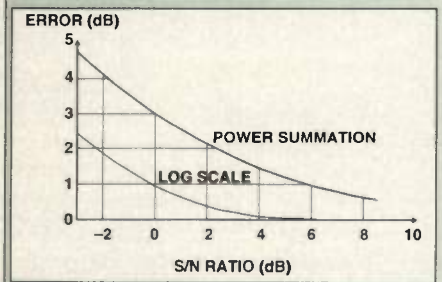

Figure G. CW signals measured on a logarithmic scale show very little effect from the addition of noise signals.

The average response to the signal plus the quadrature noise component is the response to a signal of magnitude:

$$\sqrt{1+x^2}$$

The average response to the signal plus in-phase noise will be lower than the response to a signal without noise if the chosen scale is compressive. For example, let x be ±0.1 and the scale be logarithmic. The response for x = +0.1 is log(1.1); for x = –0.1 is log (0.9). The mean of these two is –0.0022, also expressible as log (0.9950). The mean response to the quadrature components is log(sqrt(1+(0.1)^2)), or log (1.0050). Thus, the log scale has an average deviation for in-phase noise that is equal and opposite to the deviation for quadrature noise. To first order, the log scale is noise-immune. Thus, an analyzer that averages (for example, by video filtering) the response of a log amp to the sum of a CW signal and a noise signal has no first-order dependence on the noise signal.

Figure G shows the average error because of noise addition for signals measured on the log scale and, for comparison, for signals measured on a power scale.

---

both noise-like, then their ratio will be accurately measured regardless of whether their true power or log-averaged power (or any partially averaged result between these extremes) is measured. Thus, unless discrete CW tones are found in the signals, ACP is not subject to the cautions regarding VBW and other averaging noted in the section on channel power previously.

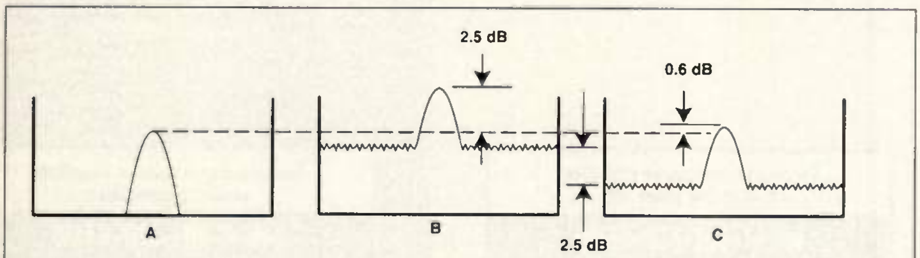

Figure 10. Log averaging improves the measurement of CW signals when their amplitude is near that of the noise. (a) shows a noise-free signal. (b) shows an averaged trace with power-scale averaging and noise power 1 dB below signal power; the noise-induced error is 2.5 dB. (c) shows the effect with log-scale averaging—the noise falls 2.5 dB and the noise-induced error falls to only 0.6 dB.

But some ACP standards call for the measurement of absolute power, rather than a power ratio. In such cases, the cautions about VBW and other averaging do apply.

Carrier power

Burst carriers, such as those used in TDMA mobile stations, are measured differently than continuous carriers. The power of the transmitter during the time it is on is known as the "carrier power."

Carrier power is measured with the spectrum analyzer in "zero span." In this mode, the local oscillator (LO) of the analyzer does not sweep, thus the span swept is zero. The display then shows amplitude normally on the y axis, and time on the x axis. If the RBW is larger compared to the bandwidth of the burst signal, then all the display points will include all the power in the channel. The carrier power is computed by averaging the power of all the signals that represent the times when the burst is on. Depending on the modulation type, this is often considered to be any point within 20 dB of the highest registered amplitude. (A trigger and gated spectrum analysis may be used if the carrier power is to be measured over a specified portion of a burst-RF signal.)

Using a wide RBW for the carrier-power measurement means that the signal will not have noise-like statistics. It will not have CW-like statistics either, so it is still wise to set the VBW as wide as possible. But let's consider some examples to see if the sample-mode bandwidths of spectrum analyzers are a problem.

For IS-95 CDMA, with a modulation rate of 1.2288 MHz, we can anticipate a problem with two typical spectrum analyzer families that have 450 and 800 kHz effective video bandwidths. Experimentally, an instrument with an 800 kHz sample-mode bandwidth experienced a 0.2 dB error, and one with 450 kHz BW had a 0.6 dB error with an OQPSK (mobile) burst signal. For PDC, NADC and TETRA, the symbol rates are less than 25 kb/s, so a VBW set to maximum will work well. It will also work well. It will also work well for PHS and GSM, with symbol rates of 380 and 270 kb/s.

Compensation for instrumentation noise—CW signals and log vs. power detection

When measuring a single CW tone in the presence of noise, and when using power detection, the level measured is equal to the sum of the power of the CW

The noisiness of noise measurements

The results of measuring noise-like signals are, not surprisingly, noisy. Reducing this noise is accomplished by three types of averaging:

- increasing the averaging within each measurement cell of a spectrum analyzer by reducing the VBW.
- increasing the averaging within a computed result like channel power by increasing the number of measurement cells contributing to the result.
- averaging a number of computed results.

Variance and averaging

The variance of a result is defined as the square of its standard deviation, therefore it is symbolically σ^2. The variance is inversely proportional to the number of independent results averaged. Thus, when N results are combined, the variance of the final result is σ^2/N.

The variance of a channel-power result computed from N independent measurement cells is likewise σ^2/N, where σ^2 is the variance of a single measurement cell. But this variance is an interesting parameter.

If the standard deviation of logged envelope noise is measured, it will be 5.57 dB. Thus, the σ of a channel-power measurement that averaged log data over, for example, 100 measurements cells would be 0.56 dB (5.6/sqrt(100)). But averaging log data not only causes the aforementioned 2.51 dB under-response, it also has a higher than desired variance. Those not-rare-enough negative spikes of envelope, such as –30 dB, add significantly to the variance of the log average even though they represent little power. The variance of a power measurement made by averaging power is lower than that made by averaging the log of power by a factor of 1.64.

Thus, the σ of a channel-power measurement is lower than that of a log-averaged measurement by a factor of the square root of this 1.64:

$$\sigma_{noise} = \frac{4.35\text{ dB}}{\sqrt{N}} \quad \text{[power averaging]}$$

$$\sigma_{noise} = \frac{5.57\text{ dB}}{\sqrt{N}} \quad \text{[log processing]}$$

Averaging computed results

If individual channel-power measurements are averaged to get a lower-variance final estimate, it would be unnecessary to convert dB-format answers to absolute power to get the advantages of avoiding log averaging. The individual measurements, being the results of many measurement cells summed together, no longer have a distribution like the "logged Rayleigh," but rather look Gaussian. Also, their distribution is sufficiently narrow that the log (dB) scale is linear enough to be a good approximation of the power scale. Thus, our intermediate results can be dB-averaged.

Swept versus FFT analysis

In the previous discussion, the variance reduced by a factor of N was from independent results. This independence is typically the case in swept-spectrum analyzers, because of the time required to sweep from one measurement cell to the next under typical conditions of span, RBW and sweep time. FFT analyzers will usually have fewer independent points in a measurement across a channel bandwidth, reducing, but not eliminating, their theoretical speed advantage.

For digital communications signals, FFT analyzers have an even greater speed advantage than their throughput predicts. Consider a constant-envelope modulation, such as used in GSM cellular phones. When measured with a sweeping analyzer, with an RBW much narrower than the symbol rate, the spectrum looks noise-like. But in an FFT span wider than the spectral width of the signal, the total power looks constant, so channel power measurements will have low variance.

Zero span

A zero-span measurement of carrier power is made with a wide RBW, so the independence of data points is determined by the symbol rate of the digital modulation. Data points spaced by a time greater than the symbol rate will be almost completely independent.

Zero span is sometimes used for other noise and noise-like measurements where the noise bandwidth is much greater than the RBW, such as in the measurement of power spectral density. For example, some companies specify IS-95 CDMA ACPR measurements that are spot-frequency power spectral density specifications: Zero span can be used to speed this kind of measurement.

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tone and the power of the noise within the RBW filter. Thus, the accuracy of a measurement could be improved by measuring the CW tone first (let's call this the "S + N" or signal-plus-noise), then disconnect the signal to make the "N" measurement. The difference between the two, with both measurements in power units (for example, milliwatts, not dBm) would be the signal power.

But measuring with a log scale and video filtering or video averaging results in unexpectedly good results. As described earlier, the noise will be measured lower than a CW signal with equal power within the RBW by 2.5 dB. But to first order, the noise does not even affect the S+N measurement. Figure 10 demonstrates the improvement in CW measurement accuracy when using log averaging versus power averaging.

To compensate S+N measurements on a log scale for higher-order effects and high noise levels, use this equation where all terms are in dB units:

$$power_{CW} = power_{S+N} - 10.42 \cdot 10^{-0.333(deltaSN)}$$

where $power_{S+N}$ is the observed power of the signal with noise, and *deltaSN* is the decibel difference between the S + N and N-only measurements. With this compensation, noise-induced errors are less than 0.25 dB even for signals as small as 9 dB below the interfering noise. Of course, in such a situation, the repeatability becomes a more important concern than the average error. Excellent results can be obtained with adequate averaging. Also, the process of averaging and compensating, when done on a log scale, converges on the result much faster than when done in a power-detecting environment.

Power-detection measurements and noise subtraction

If the signal to be measured has the same statistical distribution as the instrumentation noise (in other words, if the signal is noise-like), then the sum of the signal and instrumentation noise will be a simple power sum:

$$power_{S+N} = power_S + power_N$$

The units of all variables must be

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power units such as milliwatts, and not log units like dBm, nor voltage units like mV. This equation also applies if $power_S$ and $power_N$ are measured with log averaging.

The power equation also applies when the signal and the noise have different statistics (CW and Gaussian respectively) but power detection is used. The power equation would never apply if the signal and the noise were correlated, either in-phase adding or subtracting. But, that will never be the case with noise.

Therefore, subtract the measured noise power from any power-detected result to get improved accuracy. Results of interest are the channel-power, ACP and carrier-power measurements described previously. The equation would be:

$$power_S = power_{S+N} - power_N$$

Care should be exercised that the measurement setups for $power_{S+N}$ and $power_N$ are as similar as possible. RF

References

1. Nutting, Larry, "Cellular and PCS TDMA Transmitter Testing with a Spectrum Analyzer," *Hewlett-Packard Wireless Symposium*, February 1992.
2. Gorin, Joe, "Make Adjacent Channel Power Measurements," *Microwaves & RF*, May 1992, pp. 137-143.
3. Cutler, Robert, "Power Measurements on Digitally Modulated Signals," *Hewlett-Packard Wireless Communications Symposium*, 1994.
4. Ballo, David and Gorin, Joe, "Adjacent Channel Power Measurements in the Digital Wireless Era," *Microwave Journal*, July 1994, pp. 74-89.
5. Peterson, Blake, "Spectrum Analysis Basics," *Hewlett-Packard Application Note 150, literature part number 5952-0292*, November 1, 1989.
6. Moulthrop, Andrew A. and Muha, Michael S., "Accurate Measurement of Signals Close to the Noise Floor on a Spectrum Analyzer," *IEEE Transactions on Microwave Theory and Techniques*, November 1991, pp. 1182-1885.

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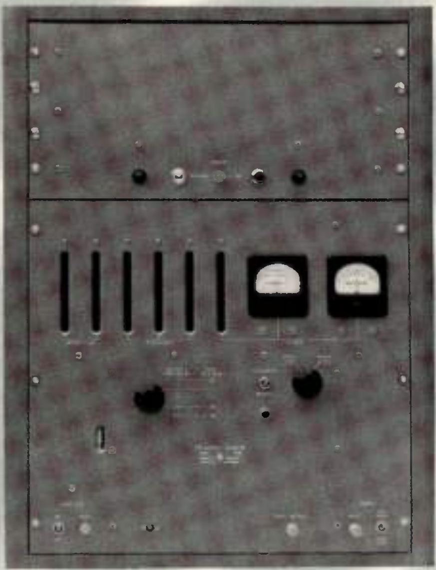

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Expanding Possibilities

Measuring QPSK modulation in personal/mobile satellite communication systems

Big LEO systems are the future for mobile and data communications. However, measuring the QPSK-modulated signals can be a challenge.

By Steve Reyes

A number of emerging personal mobile satellite communications systems are positioned to turn on in the near future. Market drivers for these systems include global mobile telecom users, high-speed data needs (Fax, Internet) and remote stationary locations (rural areas and global small villages). An additional anticipated market is providing global paging services combined with the mobile phone.

One of the satellite options is the Low Earth Orbit (LEO) system that operates in the newly licensed Ka and C bands where wide-data bandwidth are readily available. A major concern of the LEO system engineer is the accurate monitoring of power during operation. Recent advances in power meter design have introduced new measurement techniques that give satellite system operators the ability to monitor the short- and long-term power status under operating conditions.

Two of the new systems, Globalstar and Iridium, are known as Big LEOs. Big LEO systems are satellite systems that provide voice and data communication. Little LEO systems are systems that do not provide voice connections. These systems provide packet data links, or "store and forward" services, for data such as electronic mail, paging, digital messages and other commercial services.

A primary characteristic of the LEO system compared to the traditional geostationary (GEO) system is the low altitude. Low altitude results in the satellites not having a stationary position on the horizon. So, a larger number of satellites are required in multiple planes to maintain connections. Other differences between LEO systems and GEO systems are found in the time delay and the power requirements of the personal mobile phone.

GEO satellites have a typical orbit of more than 35,000 km compared to a typical LEO orbit of 700–1,400 km. Advances in GEO satellite technology have recently reduced the size requirements of the end user terminal and can now be handled by very small aperture terminals (VSATs). A drawback of VSATs in telecommunications is the two-way time delay caused by the altitude of the orbit. The typical voice interaction delay for GEO systems is from 600–1,400 msec, although LEO systems have a typical delay in the 300–500 msec range for local connections and 900 milliseconds for intercontinental connections. Also, the VSATs still are not truly portable and are not considered a personal mobile communication device.

The fixed orbit of a GEO satellite allows a wide-distribution footprint for maximum coverage per satellite. A GEO system requires only three to four satellites for global coverage while the LEO systems need 12–66 satellites for complete coverage. The number varies depending on the altitude of the satellites, the planned capacity of the system and other market objectives. As the number of satellites increase, there is more opportunity to cover a larger area of the globe and to provide a higher average elevation angle. A high-elevation angle reduces the effects of shadowing (blockages of the signal caused by buildings, trees) and results in less likelihood of a dropped call.

Table 1 provides a summary of the big LEO systems with comparison to

	GEO	Globalstar	IRIDIUM
# Satellites	4–6	48	66
# Planes	1	8	6
Altitude (km)	36,000	1,401	785
Modulation	QAM	QPSK	QPSK
Mobile User Uplink (GHz) Downlink (GHz)		1.610–1.6265 2.4835–2.500	1.616–1.6265 1.616–1.6265
Gateway Terminal	C/S Band K band (VSATs)	C Band Uplink / Downlink	Uplink 27.5–30.0 GHz Downlink 18.8–20.2 GHz
Avg. Satellite Connection Time		10–12 min	9 min
Transponder		Bent Pipe	Processing
Two Way Time Delay (millisec.)	600–1,400	300 local 900 intercontinental	300 local 900 intercontinental
Sat Mission Life (yrs)	10–15	7.5	5
Crosslinks	No	No	Yes; 4 crosslinks at 25 Mbps; 22.55–23.55 GHz
Data Rate (kb/s)	2.4 to 1.5 Mb/s	1.2–9.6 (Voice & Data)	4.8 (Voice) 2.4 (Data)
Battery Life		24 hrs standby, 8 hrs @ 5% duty cycle	24 hrs: 1 hr talk, 23 hrs standby

Table 1. Satellite communication systems.

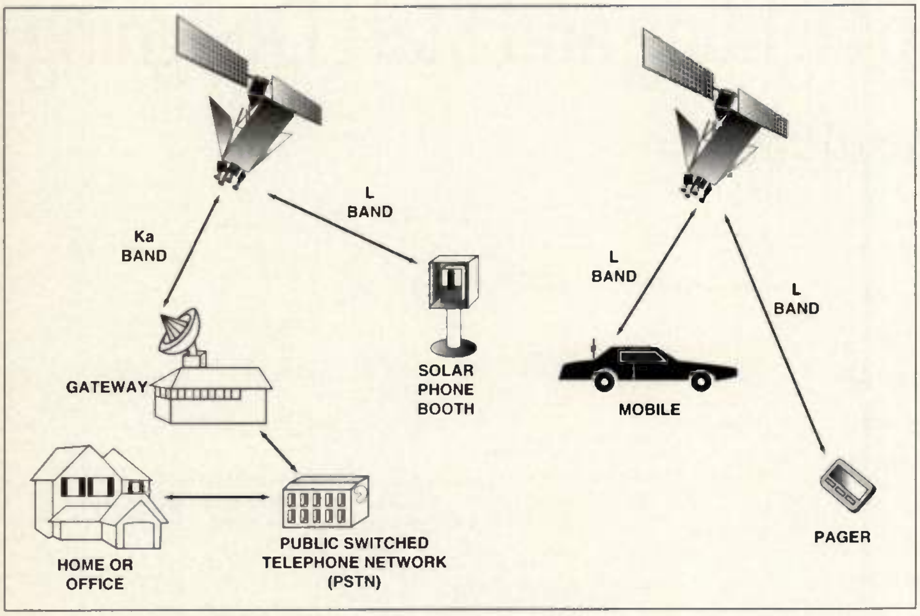
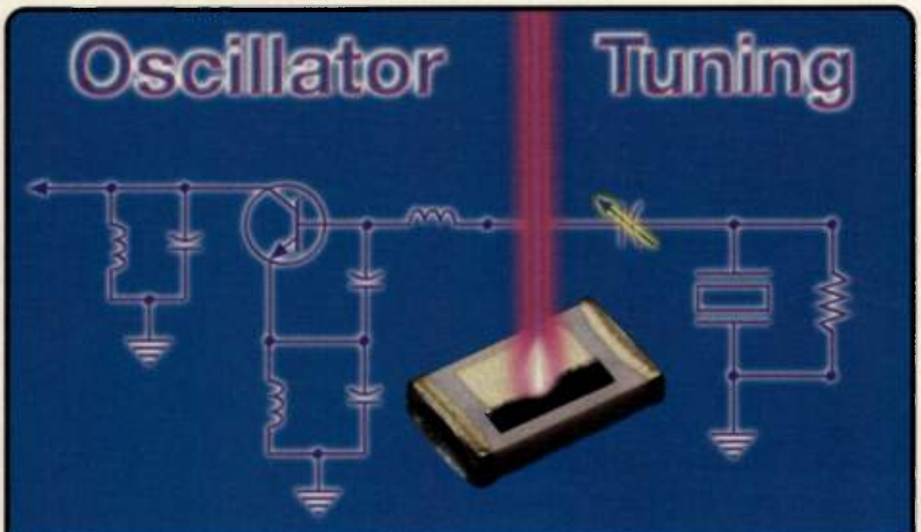


Figure 1. A typical big LEO system.

the traditional GEO systems. The big LEOs establish connections between the earth stations and the satellites in the C and Ka bands, while mobile connections are made via the handsets in the L and S bands. The earth stations may also double as gateways that provide connection to the local public switched telephone network (PSTN). Connections between earth stations are provided either through crosslinks between satellites, as in the IRIDIUM system, or through leased lines in other systems. Figure 1 provides an overview of a big LEO system.

Satellite modulation techniques

LEO systems use quadrature phase-shift keying (QPSK) modulation for maximum channel efficiency. Although there are different variations of QPSK modulation, the basic structure is the use of all four quadrants of the constellation. Figure 2 provides an example of a QPSK modulated signal used in a typical communication system. The four clusters represent the points of data available when using this technique. The tighter the clusters, the lower the bit error rate (BER). As the phase of the carrier signal shifts from one quadrant to another, the



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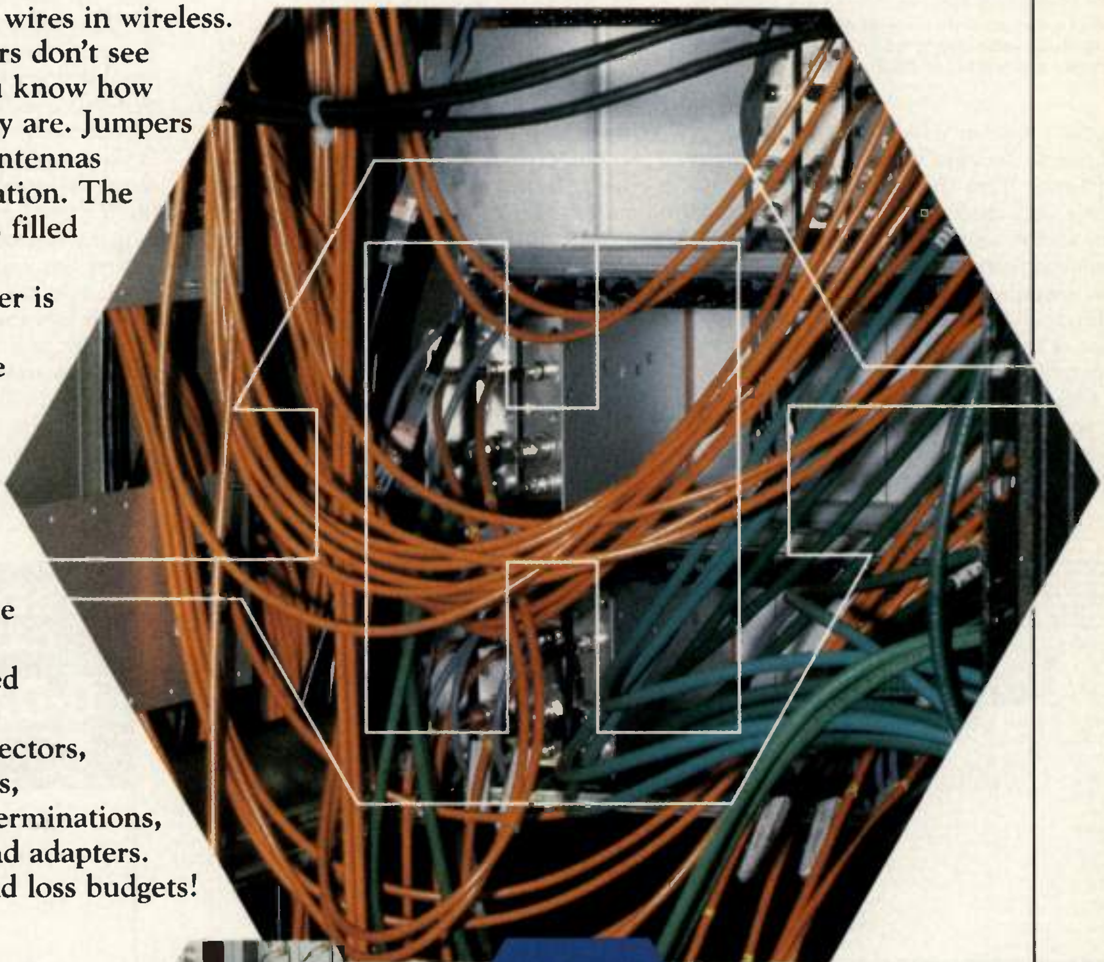

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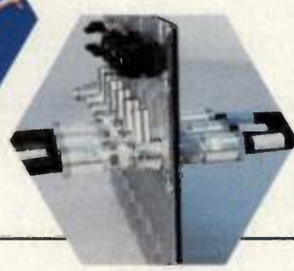

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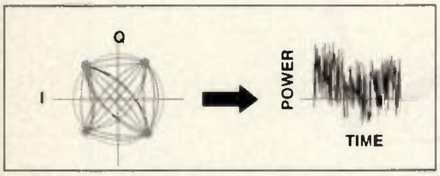

Figure 2. The QPSK-modulated signal experiences random power level fluctuations during the modulation process. The power amplitude chart gives an indication of the wide range of amplitude variations the carrier signal will track under a real-world condition.

signal vector often passes near or through the zero crossing. Because the distance from the zero crossing represents amplitude, Figure 2 indicates that the QPSK modulated signal experiences random power level fluctuations during the modulation process. The power amplitude chart in Figure 2 gives an indication of the wide range of amplitude variations the carrier signal will track under a real-world condition.

In satellite systems, there is a need to constantly monitor the power output of the satellite and ground stations. In low-power portable systems, issues such as building penetration, rain and tree attenuation, and horizon tracking result in the need to establish link budgets at the mobile phone, the satellite and ground station with margins as high as 20 dB or more. Consequently, accurate power measurements are critical to the success of the satellite system.

Power meter measurements

Power meters are ideal for monitoring the power transmission of satellite systems because of their accuracy, stability, and when available, user features. Diode sensors provide the best method for characterizing a complex modulated signal because of their ability of tracking the power envelope.

A diode sensor provides a voltage output proportional to power input within the square-law region of the diode, –70 to –20 dBm. This is often referred to as the linear region of the power sensor. Because diode sensors have a wide RF bandwidth, frequency modulated (FM) or phase modulated (PM) signals can be easily measured by diode sensors either inside the square law region or outside the square law region when non-linear correction factors are applied. However, if the signal is amplitude-modulated (AM), such as in the case of a QPSK modulated signal, then additional factors must be considered. If the power level of the modulated signal is within the square law region, then average power measurements are available when the meter is designed to properly take into account power variations. A properly designed power meter can accumulate multiple power readings of the modulated signal and average the data as long as the power level is within the square law region of the diode.

An additional challenge is encountered when the power level rises above –20 dBm and the diode is no longer in the square law region. In this case, the video bandwidth of the sensor, as well as the analog bandwidth of the meter front-end, must be wide enough to track the amplitude variations. If it is

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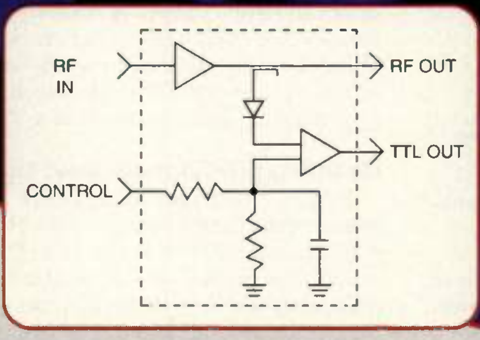

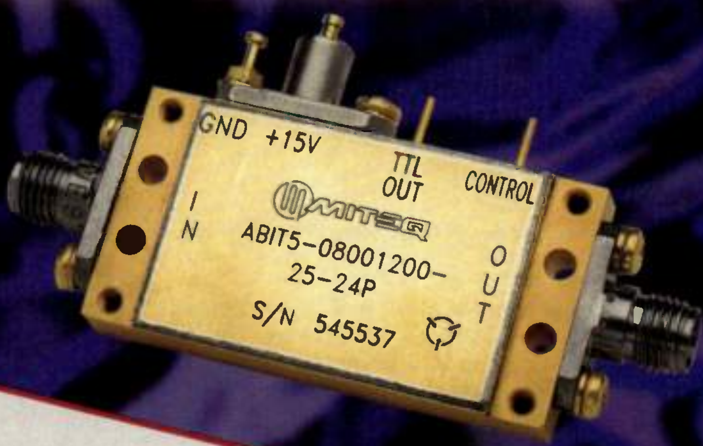

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BIT detection format	TTL single ended	TTL single ended
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*Other levels available via adjustment to the threshold control.

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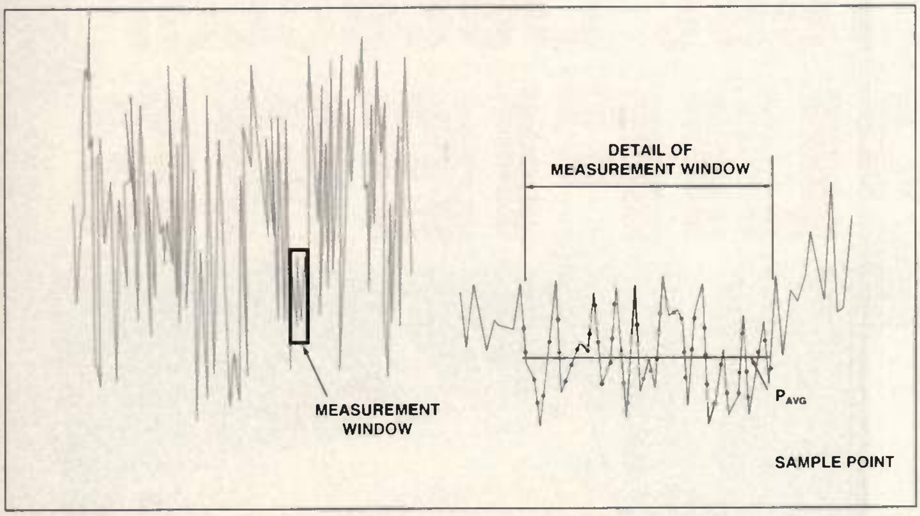

Figure 3. An example of an evenly distributed, random amplitude signal such as that found in a QPSK-modulated signal.

not, then a measurement offset will result. Diode sensors designed with the proper video bandwidth will track the power envelope and provide the power meter with sampled measurements ready for averaging. The bandwidth of the sensor must therefore be high enough to track the highest modulation rate of the communication system being measured. Using this approach provides a method of measuring a modulated signal outside the square law region and thereby providing the maximum dynamic range available for the measurement system.

A consequence of wider bandwidths in the measurement system is a reduction of dynamic range. To optimize measurement accuracy, power sensors with different bandwidths provide the opportunity to match the power sensor to the application while maintaining maximum dynamic range. A wide dynamic range offers the systems engineer the ability to accurately monitor the output of the system over the wide-link budgets typically found in satellite systems.

Measuring QPSK modulated signals

Figure 3 provides an example of an evenly distributed, random amplitude signal such as that found in a QPSK-modulated signal. Because the broad definition of power is the amount of energy per unit of time, the average power of a randomly modulated signal is the average power over the time pe-

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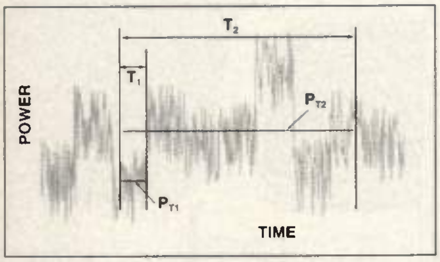

Figure 4. An example of the different levels of transmission that might exist in a communication channel.

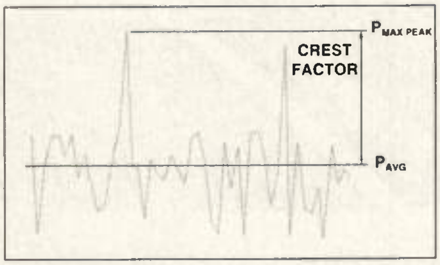

Figure 5. Crest factor is the ratio of the largest peak power encountered to the average power within the same measurement period.

riod of interest.

A diode-based power meter provides power measurements of an AM signal by accumulating sampled measurements over a period of time and providing an average. With random distribution of power, the power meter will arrive at the proper level when enough samples are accumulated. This time period can be indirectly controlled by the "Average N" number used.

Now consider a situation where the average power of the modulated signal varies with time caused by real-world conditions. For example, in a satellite communications system, the average transmitted power will vary with environmental conditions such as cloud cover, rain and changes in temperature. Also, changes in traffic occupancy cause variances in power output. Figure 4 provides an example of the different levels of transmission that might exist in a communication channel. A power measurement over time T1 will be different than a measurement over time T2 because of the difference in the times of the measurement window.

If the objective is to determine the power output of the transmitter at a specific point in time, then the power measurement window will have a relatively short duration. However, the systems operator often needs to analyze both the long-term uninterrupted power as well as the short-term power. In this case, a different method of data accumulation is needed. The difficulty with performing long-term power measurements under remote control is that the power meter often requires housekeeping chores, such as temperature compensation and display updates, that result in measurement gaps between readings. A power meter that takes into account this specific concern can provide an internal measurement mode that will eliminate meaurement gaps in the data.

Another important measurement of QPSK-modulated signals is crest factor. Crest factor is the ratio of the largest peak power encountered to the average power within the same measurement period (Figure 5). The systems engineer uses crest factor to track

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the largest peak power encountered during transmission. Limiting the peak power requirements to levels within the design parameters of the transmitter minimizes clipping or compression of the carrier and thereby minimizes BER during transmission.

Conclusion

The evolution of mobile communication systems has led to the development of personal communication satellite systems for global coverage. The big LEO systems will provide global personal services for voice and data for mobile as well as fixed remote-site access. These systems use QPSK modulation techniques for optimum performance of channel occupancy and data throughput. Accurate power measurements of QPSK-modulated signals can be challenging because of the constantly changing nature of the signal. Techniques have been developed that provide the capabilities necessary for a diode-based power meter to perform these measurements quickly and accurately. *RF*

References

1. T. Mangir, "Satellite Communication Systems for Personal/Mobile Communication and Computation," *WESCON/95: Satellite Communication*, 1995.

2. T. Rappaport, "Wireless Communications," *IEEE PRESS*, New York, 1996.

3. W. Sun, M.N. Sweeting and A. Curiel, "LEO Satellite Constellation for Regional Communications," Centre for Satellite Engineering Research, University of Surrey, Guildford, Surrey, United Kingdom, **www.ee.surrey.ac.uk/EE/CSER/UOSAT/**.

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Steve Reyes is the marketing manager of the Instruments Division at Giga-tronics. He has been with Giga-tronics for four years. Steve has held various design development, sales and marketing positions in the microwave test and measurement industry for the last 19 years. He is a graduate of the University of California, Davis. He can be reached at 4650 Norris Canyon Rd., San Ramon CA 94583; Phone 800-726-4442. The 8540C Universal Power Meter from Giga-tronics provides all the capabilities discussed in this article. For more information, visit their Web site **www.gigatronics.com**.

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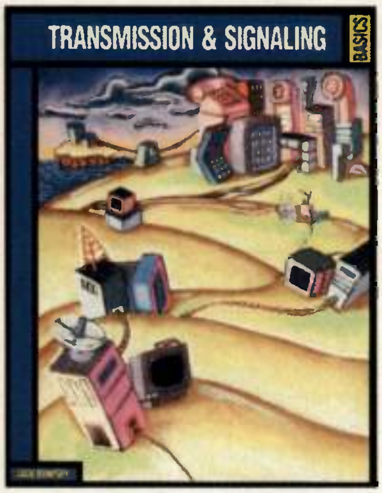

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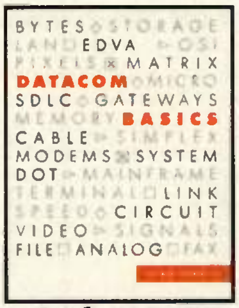

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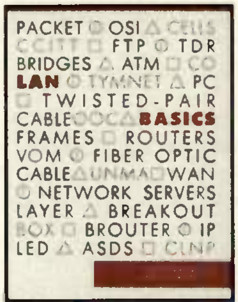

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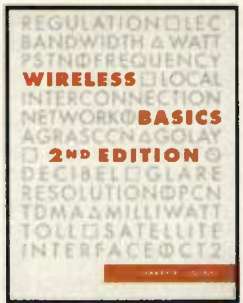

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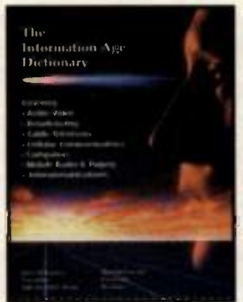

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Signal synthesis and mixed signal technology

"Mixed signal" has become the buzz word of the '90s. So what is mixed signal technology?

By Ken Gentile

Historically, there have been two distinct classes of integrated circuits (ICs); digital ICs and analog ICs. Mixed signal technology combines both digital and analog technologies in a single IC. This is a relatively recent innovation. In the past, most IC manufacturers tended to have two distinct product lines; one analog and one digital. In fact, several manufacturers specialize in producing only analog or digital ICs.

For the engineer who has specialized in either analog or digital design but has not been formally introduced to the world of digital signal processing (DSP), a foundation will be laid that covers the basic concepts of DSP. Some specific design considerations are unique to mixed signal systems. Knowledge of these design considerations will help a designer determine if a mixed signal system is a viable solution and show how to implement a sound mixed-signal design if so determined.

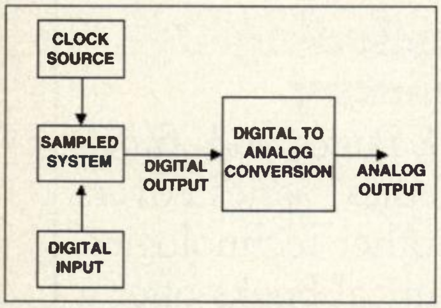

Figure 1. Basic mixed signal synthesis system.

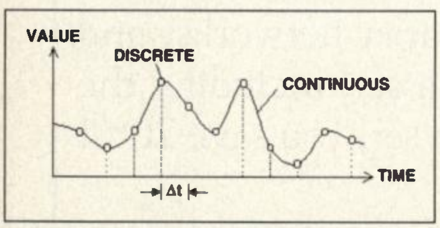

Figure 2. Discrete to continuous translation.

Mixed signal technology can be divided into two major categories: analysis and synthesis. Some systems incorporate both forms. Analysis consists of a mixed signal system that accepts an analog input, converts it to digital and processes it in the digital realm. Examples include some types of electronic measurement equipment, photocopiers and digital cameras. Synthesis internally generates a digital (numeric) version of an analog signal and ultimately yields an analog output. Examples are electronic musical instruments, computer sound cards and certain types of electronic test equipment.

Mixed signal synthesis

A basic mixed signal synthesis system is shown in Figure 1. The fundamental requirement of a mixed signal system is a clock source. This is because any mixed signal system is a sampled system and any sampled system requires a timing element. The clock source may be generated locally by an oscillator or may be provided by some external source.

The digital input is merely the numeric information that models the desired analog output. It can take the form of externally provided real-time data, or data generated by a DSP chip, or data stored in a read only memory (ROM) table. In either case, this information is totally digital.

The sampled system makes use of the clock source and digital input to create a digital output. The digital output is in the form of numeric information and is not useful until it is translated into analog form.

The purpose of the digital-to-analog conversion block is to perform this translation. It takes the numeric information and translates it into its analog representation. Thus, the output is the desired analog product (a sound, a picture, a waveform).

Digital signal synthesis basics

Digital signal synthesis is, at its heart, a time-domain operation. A sampled system operates on one sample at a time, building up the desired output. Numbers are produced from the sampled system at regular intervals, creating a series of discrete numeric values occurring at regular intervals. The digital-to-analog conversion function transforms the sequence of numbers from a series of discrete values to a continuous analog output (effectively filling in the void between the numbers). This is a transformation from the discrete (digital) world to the continuous (analog) world. This process is shown in Figure 2.

The time between successive numeric values is Δt and is known as the sample period (the assumption is made that Δt is uniform). The reciprocal of the sample period is the sample rate or sample frequency, F_s.

$$F_s = \frac{1}{\Delta t}$$

There is a fundamental relationship between F_s and the highest analog frequency that can be faithfully produced at the output using discrete digital values. This highest frequency is known as the Nyquist rate and is given by:

$$\text{Nyquist Rate} = \frac{F_s}{2}$$

This relationship is the keystone of DSP and is of paramount importance in any sampled system. This relationship puts a limitation on the useable bandwidth of the final analog output signal. For example, if the sampled system operates at 10 Msps (mega-samples-per-second), then the maximum analog output frequency must be 5 MHz or less.

To elaborate on this concept, first consider a continuous analog signal in the time domain (Figure 3a). Assume that the spectrum of this signal (frequency domain) is such as shown in Figure 3b. Such a spectrum, one that starts at 0 Hz and covers a finite bandwidth, is called a baseband spectrum. Now, take samples at regular intervals (Δt) of the analog

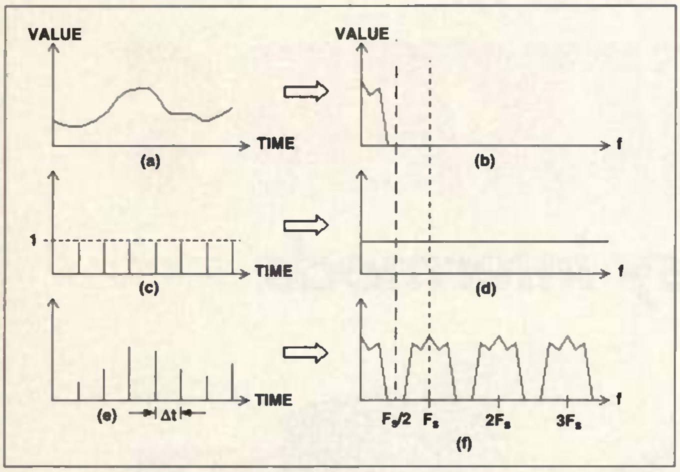

Figure 3. The sampling process from both the time and frequency perspective.

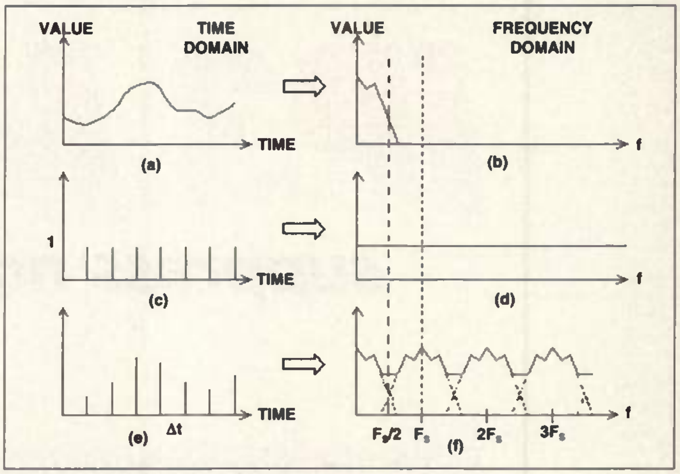

Figure 4. Sampling and alias frequencies.

signal. Or mathematically, multiply the analog signal of Figure 3a by the impulses of Figure 3c. The result (in the time domain) is Figure 3e, and the frequency domain equivalent appears in Figure 3f.

Where did the spectral replicas come from? The answer lies in two subtleties associated with the sampling process. First, each of the individual impulses in Figure 3c has a frequency spectrum that is a horizontal straight line (i.e., it is composed of an infinite number of frequencies). This means that the horizontal line shown in Figure 3d is not a single horizontal line, but actually a composite of horizontal lines superimposed on each other. Each horizontal line is the spectrum of one impulse offset by a frequency of value F_s relative to the spectrum of the previous impulse. The frequency offset is because of the shifting property of the Fourier transform. The second subtlety is the fact that when the two time domain signals (Figure 3a and 3c) are multiplied, the result is their product (Figure 3e). In the frequency domain, however, the spectrum of Figure 3b must be convolved with the spectrum of Figure 3d to arrive at the result (Figure 3f). This, too, is a property of the Fourier transform and can be stated as: *Multiplication in the time domain is equivalent to convolution in the frequency domain, and vice versa.*

Convolving the delayed, horizontal, spectral lines of Figure 3d with the baseband spectrum of Figure 3b yields the replicated baseband spectra in Figure 3f. Notice, also, that the baseband spectrum is mirrored around integer multiples of the sampling frequency, F_s. This mirror effect stems from an assumption that the baseband spectrum was a real signal. A real signal has a spectrum that is symmetric about the vertical axis at f = 0 (that is, it has a negative frequency spectrum that is a mirror image to its positive frequency spectrum). Hence, the spectra centered on multiples of F_s reflect the baseband spectrum and its mirror image about f = 0. To the contrary, a complex baseband spectrum is asymmetric about f = 0. That is, its negative frequency spectrum is not a mirror image of its positive frequency spectrum. So, when a complex baseband signal is sampled, it results in the appearance of the asymmetric baseband spectrum replicated at integer multiples of F_s.

It should be apparent from Figure 3f that if a sampled system is used to generate signals, the spectrum is infinite. Because the goal is to reproduce the baseband spectrum (not its replicas), it is necessary to lowpass filter the output signal. If an ideal filter were used with a cutoff frequency of ½F_s, then the output of the filter would be a reproduction of the original baseband spectrum--a perfect reproduction, as long as the bandwidth of the original baseband spectrum is less than ½F_s. Unfortunately, an ideal lowpass filter is not physically realizable. A realistic filter will have a frequency range in which the attenuation will gradually go from zero (the passband) to some acceptably large value (the stopband). Thus, an attenuation slope will be between the end of the passband and the beginning of the stopband. This leads to a rule of thumb for designing mixed signal systems:

Limit the baseband spectrum to 40% of F_s to allow for a realistic lowpass filter's transition region.

The real importance of the Nyquist Rate does not become evident until the situation in Figure 4 is considered. Assume that the time-domain signal in Figure 4a has a spectrum as shown in Figure 4b. Notice, however, the relationship between Fs and the baseband spectrum; the baseband spectrum spans a range that exceeds ½F_s. As in the previous example, we once again sample at intervals of Δt (the same Δt as in the previous example) and show the spectral results. Notice that the spectral images overlap. In the overlap regions, frequencies from one image are superimposed on the other (a summing operation) resulting in a spectrum that differs considerably from the original baseband spectrum. This mixing of signals is an irreversible process; there is no way to recover the information contained in the overlap regions. Furthermore, those frequencies not originally in the region from 0 to ½F_s but that intrude into that region, are called alias frequencies (or aliases).

It should be obvious from the results shown in Figure 4f that the baseband spectrum must be constrained to half of the system sample rate (½F_s) if a digital signal is to be synthesized.

Digital-to-analog conversion

Digital signal synthesis involves nothing more than the generation of a time series of numbers that represents a desired spectrum in the frequency domain. Unfortunately, a time series of numbers is not useful in the real-world. After all, time appears to progress in a continuous fashion, not in discrete steps (time quanta, so to speak). Certainly, it is desirable to have a means to convert our discrete time series of numbers to a

n	x(n)	D(n)	ε
0	128	128	0
1	197.202	197	0.202
2	244.443	244	0.433
3	254.697	255	-0.303
4	224.736	225	-0.264
5	164.062	164	0.062
6	91.938	92	-0.062
7	31.264	31	0.264
8	1.303	1	0.303
9	11.567	12	-0.433
10	58.798	59	-0.202

Table 1. The computed values of x(n), D(n) and the error ε, for N = 11.

continuous (analog) signal. This is the function of the digital-to-analog conversion portion of a mixed signal system.

The heart of the digital-to-analog conversion block is the digital-to-analog converter (DAC). The DAC is an electronic device that accepts a number as an input and converts this number to some analog representation of that number (a certain amount of current or voltage, for example). Typically, the input to the DAC consists of a group of digital logic input lines. The input circuitry of the DAC is usually configured to decode the group of input lines as a binary number. For example, a DAC with eight inputs (an 8-bit DAC) can decode 2^8 (256) unique input combinations of logical 1s and 0s. Typically, the DAC's internal circuitry is designed to translate the binary weighted number at its input to a linearly scaled voltage or current at its output. For example, for a particular 8-bit DAC, an input number of zero yields an output voltage of –5 V and each unit increment at the input yields a unit increment at the output such that an input value of 255 yields an output voltage of +5 V. This represents a linear input/output relationship, which is what we would expect.

It should be obvious from the previous paragraph that one of the fundamental limitations to using a DAC is the fact that the input is only capable of accepting a fixed range of numbers. Values outside of the range of the input are meaningless. So, any number generating system that precedes the DAC must be constrained to generate numbers within the DAC's input range. In addition to this constraint, several other DAC related factors limit mixed signal performance:

- Quantization noise
- Harmonic distortion
- Clock jitter
- Switching transients
- Zero order hold effects

As previously described, both the input and output of a DAC are quantized—only specific values are allowed (no intermediate values). This fundamental limitation produces an affect known as quantization error. The effect of quantization error becomes obvious when using the DAC to generate a sinusoid. Suppose one cycle of a sine wave consisting of N sample points using the previously described DAC is generated. The sample values would then be given by:

$$x(n) = 128 + 128 \cdot \sin\left(\frac{2\pi n}{N}\right)$$

where n is the sample index (n = 0,1,2...N–1).

However, the DAC can only accept integers between 0 and 255, so the actual DAC input values, D(n), must be constrained to integers. Thus, the DAC input values are given by:

$$D(n) = \mathrm{INT}[x(n)]$$

The INT(x) function simply implies rounding the argument, x, to the nearest integer. Table 1 tabulates the computed values (rounded to three decimal places) of x(n), D(n), and the error ε, for N = 11.

Obviously, the values of D(n) do not represent a perfect sinusoid. If the eleven D(n) values were sequentially fed to the DAC repetitively, the result would be an output waveform that approximates a sinusoid. Its spectrum would consist of a vertical line corresponding to the frequency of the sine wave along with a finite noise floor. It can be shown that, in the absence of all other noise sources, the total noise power (because of quantization) is predictable relative to the power of a full-scale sinusoid at the DAC output. This is often specified as signal-to-quantization noise ratio (SQNR) and is usually expressed in decibel units (dB).

$$\mathrm{SQNR} = 6.02B + 1.76$$

where B is the number of bits associated with the DAC's input section. For our 8-bit DAC, the SQNR is approximately 50 dB, which means that the amount of noise power produced by the quantization error will always be at least 50 dB below the power of a full scale sinusoid at the DAC output. This does not mean that the noise floor will be 50 dB below the signal. Instead, it means that if a wideband measurement is made of a DAC-generated sinusoid, then the sum of all the power in the band (excluding the sinusoid) will be 50 dB below the power contained in the sinusoid (provided the amplitude of the sinusoid spans the full-scale range of the DAC).

It follows from this discussion that the larger the number of DAC input bits, the smaller the ε, and the larger the SQNR (that is, less noise). In the ideal sense, the more bits the better. However, this only applies to ideal DACs. Limitations associated with the physical realization of a DAC puts an upper bound on the number of bits that are attainable for a given application. Incidentally, the number of DAC inputs gives rise to the term "DAC resolution." This is a measure of the smallest incremental voltage or current step at the DAC output. Specifically, the DAC in question would be considered a DAC with "8-bit resolution." This infers that the DAC output consists of 256 equally spaced values. The absolute step size at the output, of course, is dependent on the range of the DAC's minimum and maximum output values, but the resolution is still 8 bits.

The net result of quantization error is that quantization noise represents a theoretical limit on the quality of the signal that a mixed signal system can generate. Even if a perfect DAC could be produced, the best noise performance is defined by the SQNR equation.

Obviously, it is not possible to produce a perfect DAC. Normally, for a given input number, a DAC generates an output level that deviates slightly from the ideal output level. This is usually specified by DAC manufacturers as differential nonlinearity (DNL) and integral nonlinearity (INL). The net result of DNL and INL is that the DAC's input to output relationship is not perfectly linear. This means that the input signal is transformed through some nonlinear process before being produced at the output. The result is that a perfect digital sine wave at the input is transformed at the output to the desired sine wave plus harmonics. Thus, a distorted sine wave is produced at the DAC output. This form of error is known as harmonic distortion. Keep in mind that this error is in addition to the SQNR.

As mentioned earlier, a sampled system is sampled at a specified sample rate, F_s. This, of course, implies that numbers are sent to the input of the DAC at the sample rate, as well. Thus, there must be some system clock source to derive the timing to feed numeric samples to the DAC. Errors in the accuracy of the clock source must be consid-

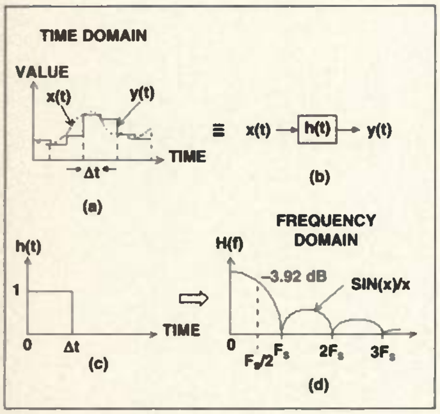

Figure 5. Zero-order hold effects.

ered in the analysis of DAC errors.

Thus far, it has been assumed that the sample clock occurs at precise intervals. In a real-world application, however, this is not the case. There will always be some finite deviation between clock intervals resulting in nonuniform sampling intervals. This deviation between successive sampling instants is known as clock jitter. Clock jitter can be composed of periodic and/or random components. Another way to think of clock jitter is as a time variation in the phase of the clock signal. This, in turn, manifests itself as a time variation in the phase of the output signal and appears as a modulation component in the output spectrum. This is particularly easy to spot with a spectrum analyzer if the clock jitter is periodic. As an example, suppose a DAC is being used to generate a sinusoid of frequency, f_o, but there is periodic clock jitter present with a frequency of $f_o/10$. Normally, the output spectrum is expected to be a single spectral line at f_o along with the expected quantization noise and any harmonic spectral lines because of DAC nonlinearity. The periodic jitter, however, will produce additional spectral lines at $0.9f_o$ and $1.1f_o$ because of the modulation affect of the jitter frequency. Aperiodic jitter is less easily spotted. The result is instead of a sharp spectral line at f_o, a spread out spectral peak centered at f_o is achieved.

Another source of DAC error is caused by switching transients. Ideally, sharp, square edges are desired when the DAC switches between two output levels. In the real-world, however, both fabrication issues and circuit layout issues cause a deviation from the ideal. Some sources of switching transients are:

- Capacitive loading on the DAC's output pin (voltage output DACs, only)
- Timing skew
- Impedance mismatching between the DAC output and the terminating load

For voltage output DACs, capacitive loading causes large switching currents to flow through the DAC output as the load capacitor is rapidly charged and discharged. Each change of output voltage for such a DAC is effectively a step function; i.e., an instantaneous change in voltage. An instantaneous voltage change across a capacitor implies an infinite charging current (limited by circuit resistance in this case). Because these transient currents must be provided by the DAC output, they must originate at the DAC's power or ground connection. Large transient currents give rise to transient voltages at the power or ground connection because of the finite impedance of the connection. These transient voltages, in turn, appear as glitches superimposed on the DAC output. Because these glitches approximate an impulse, the spectral result is broadband noise with an increase in the level of the noise floor.

Timing skew comes from sources internal to the DAC. Variations in timing at the DAC's output switches are the primary culprit. Recall that each of the DAC input lines is weighted in binary fashion. It is also the combination of all the input data signals that determines the final DAC output. If the signal paths internal to the device have asymmetric propagation times, then the output will consist of spikes as the various binary decisions arrive at the output at slightly different times. Thus, the rising and falling edges of the DAC's output signal will contain glitches. These glitches approximate impulses, so the spectral results are broadband noise and an increase in the level of the noise floor.

An impedance mismatch has a different effect. The signal generated by the DAC is an electromagnetic wave that propagates along the path established by the external circuit. As the propagating wave encounters a change in the characteristics of the medium (an impedance mismatch), some of the wave's energy propagates into the new medium and some of the energy is reflected back to the source. The net effect is that the source will have time delayed versions of the signal (echoes) superimposed on the original wave. Because the reflections are related to the physical characteristics of the circuit, they are constant over time and occur periodically. The net result is the appearance in the output of spectral lines corresponding to the periodic nature of the reflections.

The last form of DAC induced error is known as sine-x-over-x [SIN(x)/x] distortion. This error is a fundamental byproduct of a DAC. As numbers are presented to the DAC input, they are held (either internal to the DAC or by the external circuit) until the next number is available. The duration between successive numbers is Δt. At the DAC output, this translates into holding an analog level for a period of Δt before changing to the next value. This process is known as a zero-order hold and can be thought of as passing the desired analog output signal through a filter as shown in Figure 5. Figure 5a shows the desired analog output signal, x(t), and the zero-order hold approximation, y(t), which is the actual DAC output signal. This is identical to passing x(t) through a filter with impulse response, h(t), as shown in Figure 5b and 5c. The Fourier transform of h(t) is H(f) as shown in Figure 5d. Thus, the spectrum of the DAC output is the ideal analog spectrum multiplied by the SIN(x)/x envelope. It should be apparent from Figure 5d that the output level of the DAC is frequency dependent. For instance, if the DAC is generating a sinusoid at a frequency of ½Fs, then the magnitude of that sinusoid will be 3.92 dB less than expected.

Though SIN(x)/x error is an intrinsic DAC error, the fact that it is deterministic makes it possible to correct. One such method is to precede the DAC with a digital finite impulse response (FIR) filter that has a frequency response that is the inverse of the SIN(x)/x envelope. This will effectively flatten the frequency response at the output of the DAC for frequencies as high as the Nyquist frequency (½F_s).

Having covered the systemic and intrinsic errors that affect DAC performance, it is time to introduce a parameter commonly used in industry to denote a more realistic measure of a DAC's capabilities. Recall the formula for predicting quantization noise: SQNR = 6.02B + 1.76. This represents the theoretical maximum in DAC performance and relates the DAC's resolution (B is the number of bits of resolution) to the relative quantization noise power in decibels. The other forms of DAC errors add to the quantization noise. If all these sources of noise are summed up

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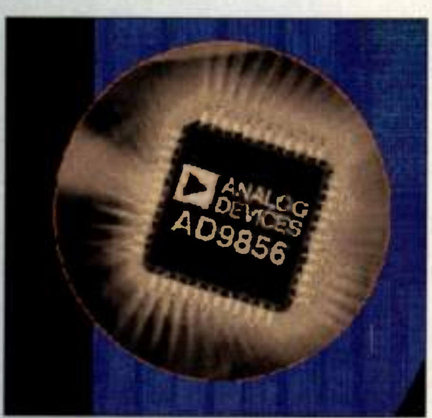
INFO/CARD 3

Upconverter exemplifies mixed-signal technology

Analog Devices' new AD9856AST quadrature digital upconverter device exemplifies state-of-the-art mixed signal technology in action. It integrates a 12-bit high-speed DAC, direct digital synthesizer, interpolation filters and high-speed multipliers/adder onto a single high performance chip. The AD9856AST accepts 12-bit (parallel or serial) complex data words at a rate as high as 45 mega-samples-per-second, in burst or continuous mode. An input demultiplexer splits the data into I/Q paths and an interpolation stage up samples the effective data rate to match the DDS clock rate. Sine/Cosine carriers are modulated with the I/Q data, and finally, the device outputs an analog modulated carrier that is frequency-agile over the range of DC-70 MHz. The AD9856AST targets modulation/upconversion applications in the communication and networking industries where low cost, small size, low power and complete digital control are critical attributes. The AD9856AST provides an interface between the VLSI digital ASIC and the RF output.



AD9856AST device package.

and expressed as dB relative to a full scale signal, then that value can be substituted into the left-hand side of the quantization noise formula and the equation can be solved for B. The result is a value of B less than ideal that represents the effective number of bits (ENOB) of the DAC's performance. So, a 12-bit DAC may be indicated on a data sheet as having an ENOB of 10.9 bits. This indicates that in addition to quantization noise, there is an additional 6.62 dB of noise (6.02×[12–10.9]) because of other sources. In practice, the ENOB rating excludes any error because of SIN(x)/x distortion.

Direct digital synthesis

Digital synthesis is the process whereby the sampled system (Figure 1) generates the time domain numbers required to produce the desired output spectrum. For complicated spectra, where numerous single frequencies must be generated simultaneously, the sampling system must be capable of monumental computing power and will require a DSP chip. At relatively high sample rates however, even a DSP chip can become completely overwhelmed. When the spectrum remains constant over time, using the DSP to precalculate the time domain data and store it in memory can reduce the DSP burden. Then, dedicated hardware can sequentially read from memory and pass the data to the DAC, wrapping back around to the beginning of the data set when the end is reached (without the wrap around feature, the spectrum would only be a burst lasting as long as it takes to exhaust the data set).

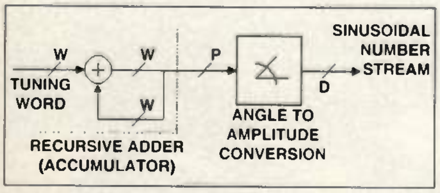


Figure 6. DDS block diagram.

In a wide range of mixed signal applications, however, the requirement is to generate a single sinusoid at any given moment. For such applications, a direct digital synthesizer (DDS) is ideal. A basic DDS block diagram is shown in Figure 6.

The DDS is composed of a W-bit recursive adder (or accumulator) where the P most significant bits are tapped off and routed to an angle-to-amplitude converter (AAC). Furthermore, the accumulator is designed to drop the "carry" and continue accumulating when it performs an addition that causes an overflow (a circular adder). Also, it should be pointed out that the accumulator is updated at the system sample rate, F_s.

The AAC is a 2^P length table of values that represent the amplitude of the corresponding input angle. The precise table values, k_i, are determined by the following equation:

$$k_i = \cos\left(\frac{2\pi i}{2^P}\right)$$

where $i = 0, 1, 2, \ldots, 2^{P-1}$

Remember that the values of k_i presented previously are limited only by the precision of the method used to compute them. In the case of the AAC, the values of k_i are represented at the output with only D bits of resolution (because output of the AAC is typically connected to a D-bit DAC). Thus, the actual values contained in the table are not the high-precision values as computed, but rather the computed values quantized to D bits.

To understand the operation of a DDS, the output of the accumulator is set to zero and the W-bit tuning word is set to some value T, where $1 \le T \le 2^{W-1}$. As the accumulator is updated at the sample rate, it repeatedly adds T to itself. After n samples, the accumulator output is nT. Eventually, the accumulator will roll over, and the long-term output of the accumulator, A(n), is given by:

$$A(n) = (nT)\mathrm{MODULO}(2^W)$$

This implies that the accumulator rolls over every $2^W/T$ samples on average. Because a sample occurs every Δt seconds, the accumulator rolls over every $(\Delta t \times 2^W/T)$ seconds. In terms of the sample rate (F_s), the rollover period of the accumulator is $2^W/(T \times F_s)$. This leads to a rollover frequency, f_o, of:

$$f_o = \frac{TF_s}{2^W}$$

Because the output of the accumulator is routed to the input of the AAC, the output value can be considered as a linearly changing angle. Converting this linearly changing angle to an amplitude effectively generates a numeric sine wave of frequency fo in the time domain. This technique makes it is possible to generate sinusoids with fine frequency resolution simply by selecting the appropriate value of T (the tuning word) as described by the previous equation. For example, if we have a 32-bit ac-

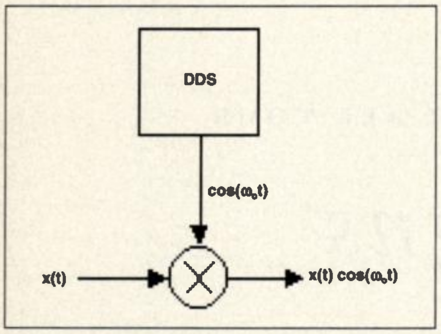


Figure 7. DDS double sideband suppressed carrier modulator.

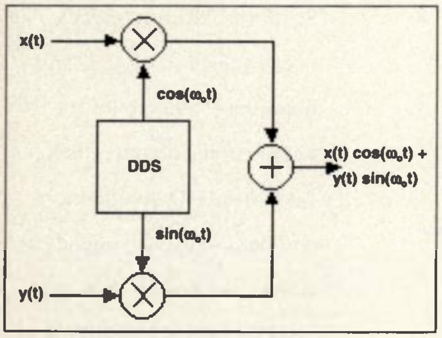


Figure 8. DDS quadrature modulator.

cumulator (W = 32) and a sample rate of 20 MHz ($F_s = 2 \cdot 10^7$), it is possible to generate any frequency as high as 10 MHz with a resolution of 0.00466 Hz.

The previous description shows where a DDS can generate a single sinusoid. With a slight modification, it is possible to use the DDS as the primary building block of a digital modulator (see Figure 7).

All that is required is a DDS tuned to some carrier frequency, ω_0, and a digital multiplier. The only stipulation is that the modulating signal, x(t), must be a digital signal sampled at F_s. With another slight modification, the DDS architecture can be extended to build a quadrature modulator as shown in Figure 8.

Note that both the cosine and sine components of the carrier signal can be generated with a single DDS. This is because the AAC portion of the DDS contains a table that is composed of cosine data. The sine data is automatically obtained by picking up data at an offset of ¼ the length of the table (corresponding to a phase shift of 90°).

DDS architecture also lends itself to phase and frequency modulation schemes (see Figure 9). In the case of a phase modulator, an additional adder prior to the AAC is required. The output of the accumulator generates the time domain carrier frequency as prescribed by the input tuning word. The modulating signal, x(t), is summed with the carrier data. This results in instantaneous modification of the carrier phase information as it arrives at the AAC. This is phase modulation. In the case of a frequency modulator, the addition of an adder is again required, but at the input to the accumulator instead of prior to the AAC. In this scheme, the tuning word is modified by the modulating signal, x(t). Because the tuning word establishes the carrier frequency, instantaneous variations of the tuning word result in instantaneous variations of the carrier frequency. This is frequency modulation. The only stipulation in both cases is that x(t) be numeric samples occurring at the sample rate, F_s.

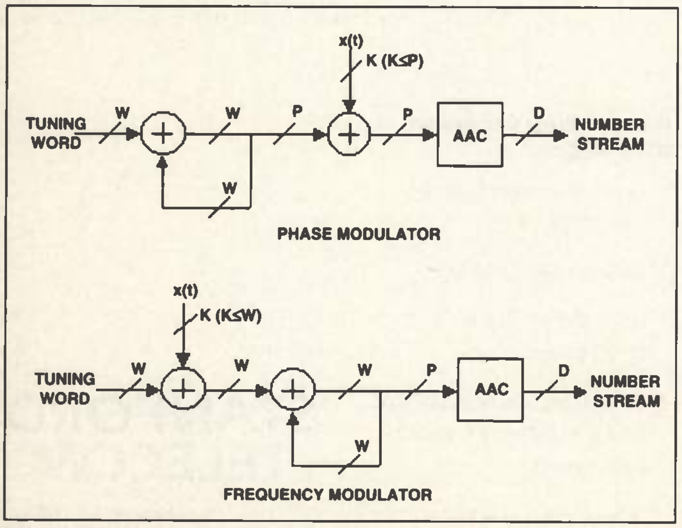


Figure 9. DDS phase and frequency modulator.

The ability to generate sinusoids with extremely fine frequency resolution is the hallmark of a DDS. Unfortunate-ly, the high frequency resolution is compromised by imperfect spurious performance. Spurious performance refers to the appearance of unwanted discrete spectral lines appearing in the output spectrum. For example, if an absolutely pure sine wave is generated, then its spectrum is a single vertical line at the desired frequency. If other spectral lines appear in the spectrum, these are known as spurs and are referred to as spurious noise. So, if spectral purity is required, then it is important to know the limitations of DDS generated sinusoids.

Spurious noise in DDS systems is caused by phase truncation (this is separate from the random noise effects associated with finite word length in the AAC and quantization errors associated with an output DAC). Phase truncation occurs because only a portion of the accumulator's most significant bits are passed on to the AAC (see Figure 6). The purpose of phase truncation is to minimize the amount of hardware required. To demonstrate the need for phase truncation, consider a 48-bit DDS. In this case, the AAC would need a cosine table with 2^{48} (281 trillion) entries. That's an inconceivable amount of hardware. Phase truncation allows us to maintain the phenomenal frequency resolution of the DDS at the expense of spurious noise.

A thorough analysis of spurious noise caused by phase truncation is treated in paper [1]. The results offer two interesting points. First, the distribution of spurs is dependent on the choice of the tuning word, T, and the number of phase truncation bits, B (where B = W – P [see Figure 6]). For choices of T, such that T is an integer multiple of 2^B, there are no spurs at all. All other choices of T result in a distribution of spurs of varying magnitude. The second interesting point is that when spurs are present, the worst case spur magnitude (WCSM) is also dependent on T and B and can be shown to have an upper bound. It turns out that for B > 4 (not at all unreasonable) the WCSM relative to the magnitude of the fundamental sinusoid is closely approximated by:

$$\text{WCSM} = -6.02P \text{ (dB)}$$

This tells the designer the largest spur levels that can be expected based solely on the number of non-truncated phase bits (P) in the DDS design. Not only does the paper predict the magnitude of the WCSM, it also defines the choices of T that produce the WCSM. The worst spurs occur when T is chosen to be an odd integer multiple of 2^{B-1}. All other choices of T result in spurs smaller than the WCSM.

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Main Application	Test Sets	Tele. Sync.	Tele. Sync./GSM	Navigation
Options				
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E. Higher Temp.	-25° to +65C	-25° to +65C	0 to +65C	–
F. Fast Warm-up	Lock in 5 min.	in 7 min.	in 7 min.	–
S. Less Phase Noise	$1x10^{-12}$/100s	$1x10^{-12}$/100s	$1x10^{-12}$/100s	–
Allowed Supply Volt.	24v only	12 or 24v	12 or 24v	24v
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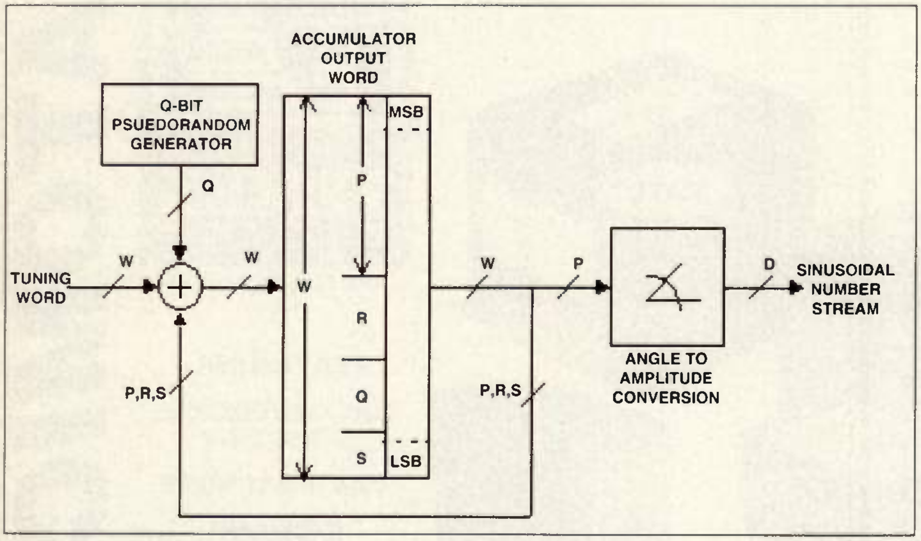

Figure 10. DDS with phase dithering.

DDS using a technique known as phase dithering. This technique is only applicable, however, if one can tolerate a slight reduction in the spectral purity of the desired output sinusoid. Figure 10 demonstrates the modifications necessary to convert the standard DDS architecture to a phase-dithered architecture.

In Figure 10, the W-bit output word of the accumulator has been expanded for clarity. We still pass P bits to the AAC as in the original DDS architecture. However, the truncated bits are divided into three groups (Q, R and S). The Q bits are the dithered bits and the R and S bits are the remainder of the truncated bits above and below the Q bits. Instead of feeding the Q bits back to the adder, they are substituted with a Q-bit random pattern (i.e., the pattern changes with each update of the accumulator). This is the equivalent to randomly phase-modulating the desired sinusoid at the rate of the sample clock. Dithering causes the energy contained in the spurs to be distributed across the spectrum greatly reducing (or completely eliminating) the spurs. This benefit must be paid for by two tradeoffs, however. First, the spectral smearing is indiscriminate, so even the desired sinusoid is smeared. This results in a broadening of the desired sinusoid's line spectrum. Secondly, an artificial noise floor is produced because of the spectral smearing. This is not much of a penalty, however, if the number of dithering bits is small because the noise floor can easily be kept to -90 dBc or less. In fact, Figure 11 shows the result of a MathCad simulation of a DDS system. The system is designed with the following parameters:

F_s = 10 MHz (system sample rate)

f_o = ~550 kHz (DDS output frequency)

W = 32 (accumulator word size)

P = 13 (phase bits)

D = 30 (AAC output bits)

The large value of D was chosen to emulate an ideal 30-bit DAC to prevent the quantization errors associated with the DAC from masking out the spurious effects of the DDS. Figure 11a shows the DDS output spectrum with no phase dithering and the tuning word chosen to yield the worst case spur magnitude. Note the 0 dB output signal near 0.5 MHz and the –75 dB spur near 4.5 MHz. Figure 11b shows the result with two bits of dithering (Q = 2) and the same tuning word. Notice that the spur at 4.5 MHz is completely obliterated. Keep in mind that this was accomplished simply by randomizing two bits. The reduction in spectral purity is also apparent by the noise skirt around the 500 kHz tone. Whether or not this spectral impurity is acceptable is dependent on the particular application where the DDS is to be used. The size and placement of Q affects the tradeoff between spectral purity and spur reduction. The optimal choice is dependent on the system configuration and requires some empirical engineering.

Oversampling

Given a desired output spectrum with maximum frequency f_{max}, we know from sampling theory that a sample rate (F_s) of at least $2f_{max}$ is required to properly reconstruct the sampled spectrum. Oversampling is nothing more than choosing a value of F_s considerably greater than $2f_{max}$. The main reason that oversampling is used is that it greatly reduces the complexity of the lowpass antialiasing filter that ultimately follows the output of a DAC in a mixed signal system. Figure 12 graphically demonstrates how oversampling affects the filter requirements. In Figure 12a, the sample rate is chosen so that the baseband spectrum fits within the range of ½F_s. The filter must rolloff quickly to offer a flat passband over the range of the baseband spectrum and, at the same time, offer significant attenuation at frequencies above ½F_s. This implies a complicated filter. If the same baseband requirement is kept but a higher F_s is chosen, the result of Figure 12b is achieved. The less stringent filter requirement implies a reduction in both complexity and distortion. An additional advantage, is that by choosing a sample rate much higher than necessary, the baseband spectrum can be kept in the fairly flat portion of the SIN(x)/x envelope inherent in the DAC portion of any

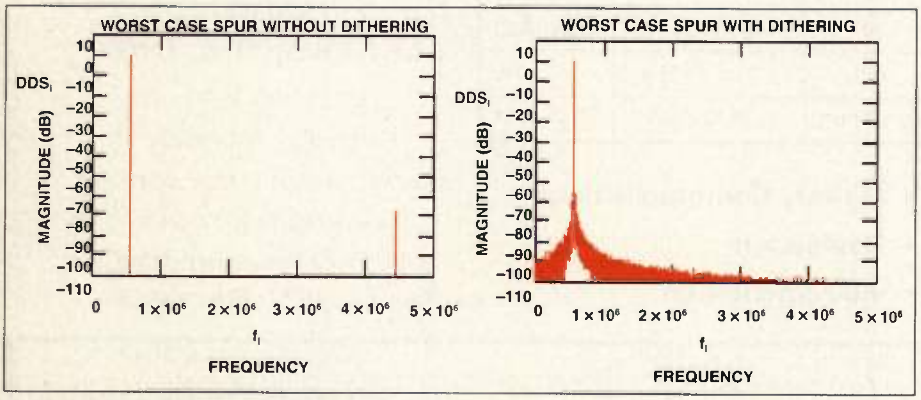

Figure 11. Spectral results caused by dithering.

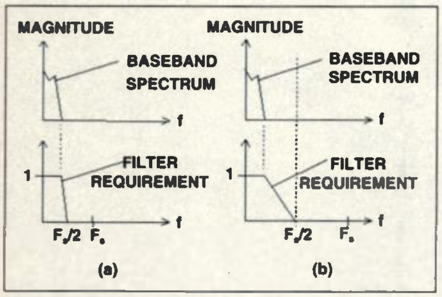

Figure 12. Oversampling.

mixed signal system. This can obviate the need for an inverse SIN(x)/x filter.

One of the drawbacks to oversampling is that for high-speed applications, the required value of F_s can be greater than 100 MHz. This poses a problem for the clock source portion of any mixed signal system. To maintain reasonable drift and jitter performance, a crystal oscillator is usually used. Unfortunately, crystals in the 100 MHz range are not feasible. Though commercial crystal oscillators are available in this range, they use the crystal's harmonic overtones and are relatively expensive. One solution is to use a relatively low-frequency crystal oscillator (in the 10's of megahertz range) and a frequency multiplier circuit using a phase locked loop (PLL) (see Figure 13). The crystal oscillator produces a stable output frequency, f_{XTAL}, that is phase compared to the output of a voltage controlled oscillator (VCO) designed with a nominal operating frequency of N× f_{XTAL}. The output of the phase comparator (ε_f) is a time varying signal that represents the phase error between the two input frequencies. The error signal is passed through a lowpass filter that effectively averages the phase error. The averaged error controls the VCO by causing its output frequency to deviate from nominal in proportion to the control voltage. The VCO output frequency is fed through a divide-by-N frequency divider back to the comparator. Thus, the feedback path back to the comparator operates near the frequency of the crystal oscillator. The feedback results in the loop stabilizing when both inputs to the comparator are phase synchronous and, therefore, frequency locked. Thus, the system clock runs at N times the crystal frequency.

Keep in mind that any intrinsic drift or jitter associated with the crystal oscillator will appear at the VCO output multiplied by N. So, it is important to choose both the crystal and oscillator with sufficiently low drift and jitter to meet the drift and jitter requirements of the system clock.

When designing a mixed signal system, a significant advantage can be realized if the frequency multiplier circuitry can be integrated into the same silicon as the rest of the design. The advantages are twofold. First, there is the reduction in the amount of external hardware required. Secondly, the potential for broadcasting high frequency signals around a printed circuit board via the external frequency multiplier circuitry is eliminated. Both of these advantages make an integrated frequency multiplier an attractive feature.

Conclusion

Mixed signal synthesis offers a wide range of application and flexibility. One of the key features of mixed signal designs is that the signal processing elements (filters, signal sources) are immune to drift caused by thermal effects and variation in component values caused by temperature and aging. These factors wreak havoc in analog designs. Another key feature is the flexibility offered by the programmability of the signal processing building blocks. For instance, if a digital filter is designed so that the filter coefficients can be programmed, then almost any frequency response characteristic can be realized by changing the filter coefficients without the need to modify hardware.

On the down side, there are some considerations that may prevent the use of a mixed signal design. Power consumption probably offers the largest handicap to mixed signal implementations. DSP circuitry tends to be power hungry, especially at high sample rates. However, progress is being made on this front as newer low power, high-speed processes become available in the semiconductor industry. Another drawback is switching noise. Because mixed signal systems are inherently digital, switching transients can be an issue when the final analog output must offer a high signal to noise ratio. However, careful layout in both the silicon that contains the mixed signal elements and on the host circuit board can go a long way toward achieving a high quality analog output signal in spite of digital switching transients. RF

References

1. H. T. Nicholas and H. Samueli, "An Analysis of the Output Spectrum of Direct Digital Frequency Synthesizers in the Presence of Phase-Accumulator Truncation," *41st Annual Frequency Control Symposium*, 1987.

2. J. G. Proakis and D. G. Manolakis, *Digital Signal Processing Principles, Algorithms, and Applications*, Prentice Hall, 1996.

3. V. Oppenheim and A.S. Willsky, *Signals and Systems*, Prentice Hall, 1983.

4. J. D. Gibson, *Principles of Digital and Analog Communications*, Prentice Hall, 1993.

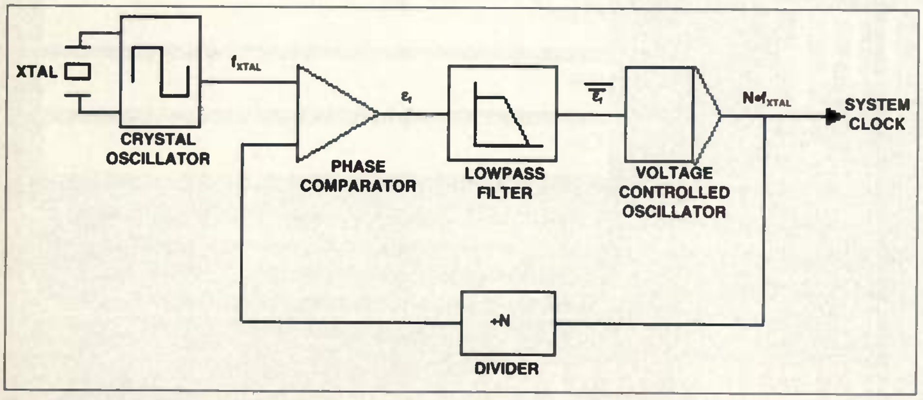

Figure 13. Frequency multiplier.

About the author

Ken Gentile received a B.S.E.E. from North Carolina State University. He currently is a system design engineer at Analog Devices, Greensboro, NC. As a member of the synthesizer team, he is responsible for the system level design and analysis of signal synthesis products. His specialties are analog circuit design and the application of digital signal processing techniques in communications systems. He can be reached at 336-605-4073 or by e-mail at *ken.gentile@analog.com*.

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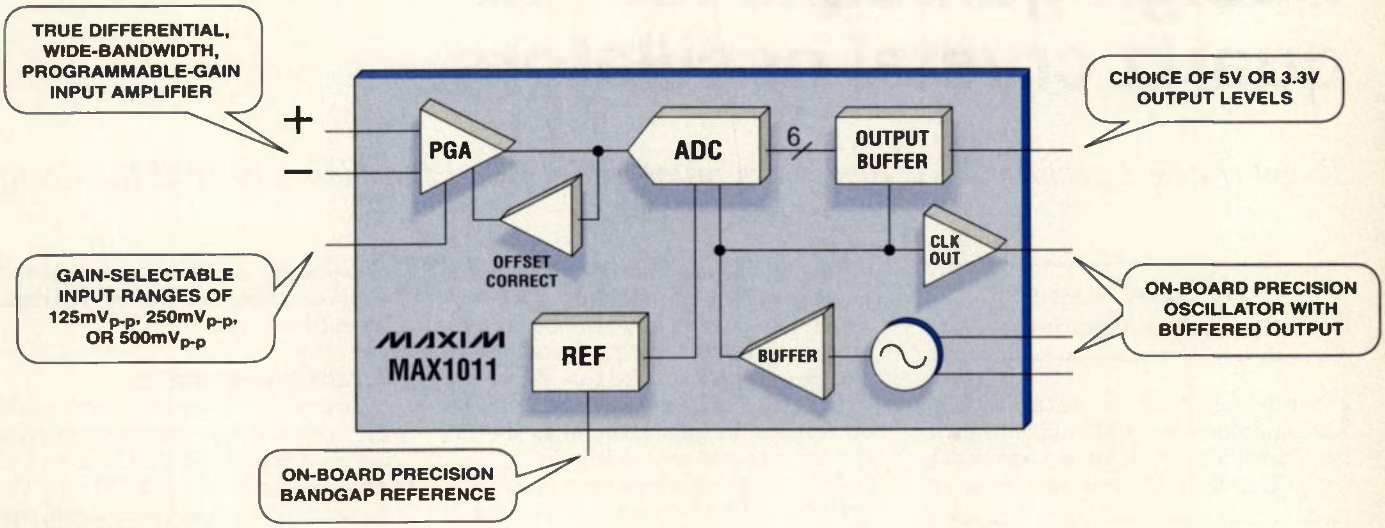

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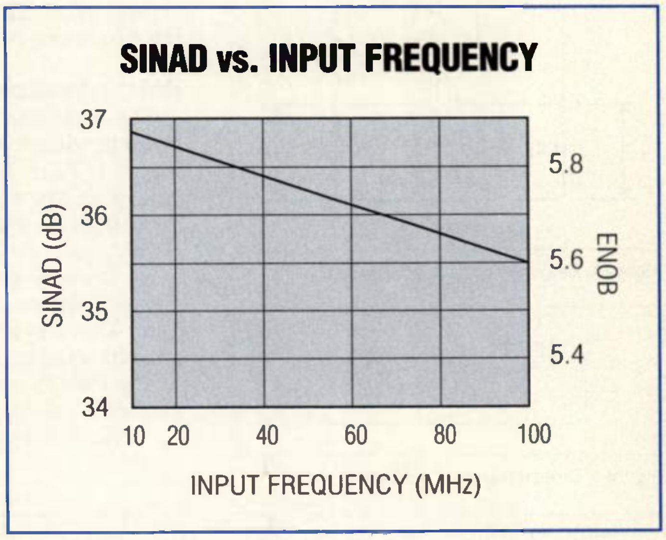

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RF oscillator designs

Design guideline for quartz crystal oscillators

To get the best performance, designers must understand the theory behind the design.

By S.S. Chuang and Jim Varsovia

Complementary metal oxide semiconductor (CMOS) pierce oscillator circuits are well known and widely used. The circuits offer excellent frequency stability and a wide range of frequencies. They are designed for use in small, low-current and low-voltage battery-operated portable products for low-frequency applications [1,2]. Designing with miniaturized quartz crystals requires careful consideration to the frequency, gain and crystal drive level.

The design equations used in a typical crystal-controlled pierce oscillator circuit design are derived from a closed loop and phase analysis. The frequency, gain and crystal drive current equations are derived from this method.

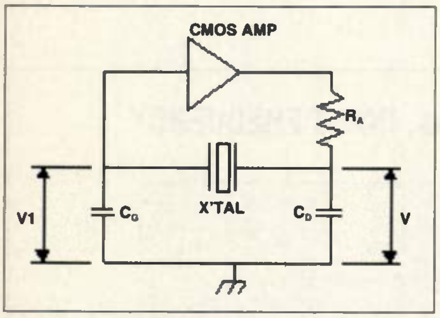

Figure 1. Basic pierce oscillator circuit.

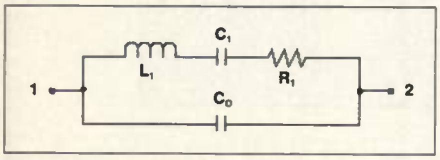

Figure 2. Crystal electrical equivalent circuit.

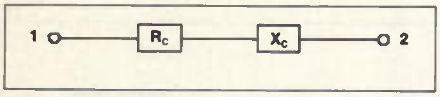

Figure 3. Effective electrical circuit of a quartz crystal.

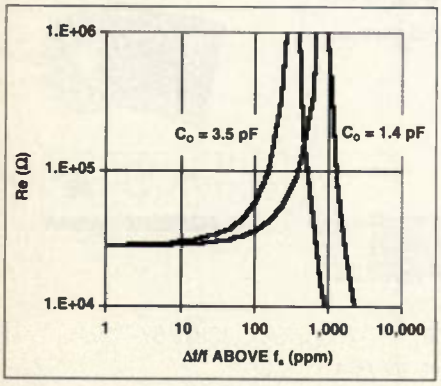

Figure 4. Re (Ω) vs. Δf/f (ppm).

Basic crystal oscillator

The basic quartz crystal CMOS pierce oscillator circuit configuration is shown in Figure 1. The crystal oscillator circuit consists of an amplifying section and a feedback network. For oscillation to occur, the Barkhausen criteria must be met:

a.) The loop gain must be equal to or greater than one.

b.) The phase shift around the loop must be equal to n360°.

The CMOS inverter provides the amplification and the two capacitors, C_D and C_G, and the crystal work as the feedback network. R_A stabilizes the output voltage of the amplifier and is used to reduce the crystal drive level.

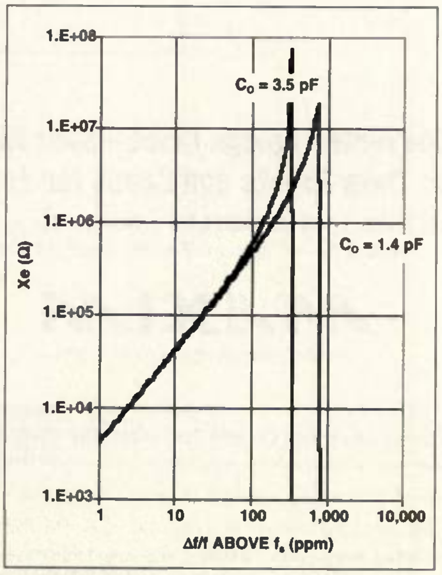

Figure 5. Xe (Ω) vs. Δf/f.

Crystal characteristics

To analyze the quartz crystal oscillator, the crystal itself must be understood. Figure 2 shows the electrical equivalent circuit of a quartz crystal. The L_1, C_1 and R_1 are referred to as the electrical equivalent of the mechanical parameters: inertia, restoring force and friction. These parameters can be measured using a crystal impedance meter or a network analyzer. C_0 is the shunt capacitance between terminals and the sum of the electrode capacitance of the crystal and package capacitance.

This equivalent circuit can effectively be simplified as a resistance (R_e) in series with a reactance (X_e) at a frequency f as shown in Figure 3.

$R_e(f)$ and $X_e(f)$ as a function of frequency are as follows:

$$R_e(f) = \frac{R_1}{\left(\frac{R_1}{X_o}\right)^2 + \left(\frac{X_m}{X_o} - 1\right)^2} \quad (1)$$

$$X_e(f) = \frac{X_m\left(1 - \frac{X_m}{X_o} - \frac{R_1^{\,2}}{X_m X_o}\right)}{\left(\frac{R_1}{X_o}\right)^2 + \left(\frac{X_m}{X_o} - 1\right)^2} \quad (2)$$

where:

$$X_o = \frac{1}{\omega C_o}; \quad X_m = \omega L_1 - \frac{1}{\omega C_1} \quad (3)$$

The series resonant frequency of the crystal is defined as:

$$f_s = \frac{1}{2\pi\sqrt{L_1 C_1}}; \quad \omega_s = \frac{1}{\sqrt{L_1 C_1}} \quad (4)$$

The quality factor Q is defined as:

$$Q = \frac{\omega L_1}{R_1} = \frac{1}{\omega R_1 C_1} \quad (5)$$

From Equations 1 and 2, an example of the magnitude of R_e and X_e as a function of frequency are shown in Figures 4 and 5 respectively for f_s = 32.768 kHz, C_1 = 2.4 fF and R_1 = 28 kΩ. The frequency is ex-

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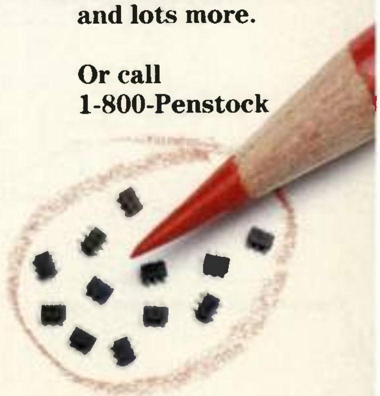

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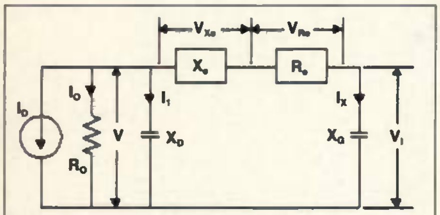

$$I_o = \frac{V}{R_o};\quad I_1 = \frac{V}{X_D};\quad I_D = g_m X_G I_X$$

$$X_D = \frac{1}{\omega C_D} = \frac{1}{2\pi f C_D};\quad X_G = \frac{1}{\omega C_G} = \frac{1}{2\pi f C_G}$$

Figure 6. Pierce oscillator AC equivalent circuit.

pressed in terms of parts per million (ppm) above the series resonant frequency (f_s) of the crystal ($\Delta f/f$). These two graphs are useful in the analysis of the crystal oscillator.

Crystal oscillator design

The AC equivalent circuit of the amplifier and feedback network of a pierce oscillator is shown in Figure 6. For the following analysis, R_A is omitted and will be reintroduced later.

From Figure 6:

$$I_o = \frac{V}{R_o};\quad I_1 = \frac{V}{X_D};\quad I_D = g_m X_G I_X$$

$$X_D = \frac{1}{\omega C_D} = \frac{1}{2\pi f C_D};\quad X_G = \frac{1}{\omega C_G} = \frac{1}{2\pi f C_G}$$

The phase and amplitude relationship of the oscillator voltage, current and impedance are shown in Figures 7 and 8. Assume that the oscillator is oscillating at a frequency f and the amplifier output current I_D is 180° out of phase with the oscillator input voltage V_1.

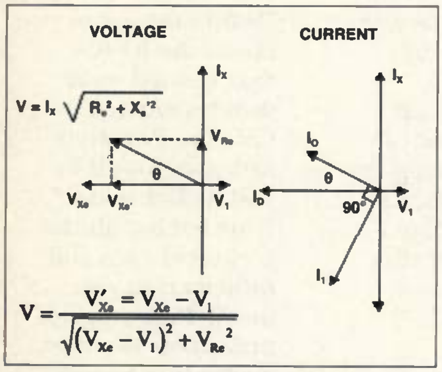

Figure 7. Current and voltage phase diagram.

$$X_e' = X_e - X_G$$

$$\sin\theta = \frac{R_e}{\sqrt{R_e^2 + X_e'^2}}$$

$$\cos\theta = \frac{X_e'}{\sqrt{R_e^2 + X_e'^2}}$$

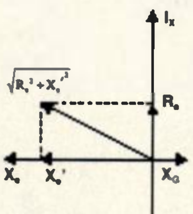

Figure 8. Impedance phase diagram.

Frequency equation

From the imaginary part of the current phase diagram (y-axis):

$$I_1 \cos\theta = I_X + I_o \sin\theta \tag{6}$$

and from the equations derived from the equivalent circuit, the voltage and impedance phasor diagram, Equation 6 becomes:

$$\frac{X_e'}{X_D}\cdot I_X = I_X + I_X\cdot\frac{R_e}{R_o}$$

from:

$$X_e' = X_e - X_G;\quad X_e = X_D\left(1 + \frac{R_e}{R_o}\right) + X_G$$

Then:

$$X_e = \frac{1}{\omega C_D}\left(1 + \frac{R_e}{R_o}\right) + \frac{1}{\omega C_G} \tag{7}$$

Assuming:

$$\left(\frac{R_1}{X_o}\right)^2 << \left(\frac{X_m}{X_o} - 1\right)^2 \text{ and } \left|\frac{R_1^2}{X_m X_o}\right| << \left|\frac{X_m}{X_o} - 1\right|$$

Equation 2 becomes:

$$X_e(f) = \frac{X_m}{1 - \dfrac{X_m}{X_o'}}; \tag{7a}$$

$$X_o' = \frac{1}{\omega C_o'};\quad C_o' = C_0 + C_{SM}$$

Let:

$$X_{C_L'} = \frac{1}{\omega C_L'} = \frac{1}{\omega C_D}\left(1 + \frac{R_e}{R_o}\right) + \frac{1}{\omega C_G} \tag{7b}$$

$$C_L' = \left\{\frac{1}{C_D}\left(1 + \frac{R_e}{R_o}\right) + \frac{1}{C_G}\right\}^{-1}$$

From Equations 7a and 7b, one can obtain:

$$X_m X_o' = X_{C_L'}\left(X_o' - X_m\right)$$

$$X_m = \frac{X_{C_L'} X_o'}{X_o' + X_{C_L'}}$$

Then:

$$X_m = \frac{1}{\omega\left(C_o' + C_L'\right)} \tag{8}$$

From Equations 3 and 4:

$$X_m = \omega L_1 - \frac{1}{\omega C_1} = \frac{1}{\omega C_1}\left\{\frac{(\omega - \omega_s)(\omega + \omega_s)}{\omega_s^2}\right\}$$

$$X_m = \frac{2(\omega - \omega_s)}{\omega^2 C_1}$$

From Equation 8:

$$\frac{2(\omega - \omega_s)}{\omega^2 C_1} = \frac{1}{\omega\left(C_o' + C_L'\right)}$$

$$f - f_s = \frac{f_s C_1}{2\left(C_o' + C_L'\right)}$$

$$f = f_s\left\{1 + \frac{C_1}{2\left(C_o' + C_L'\right)}\right\} \tag{9}$$

Then:

$$f = f_s\left\{1 + \frac{C_1}{2(C_o + C_L)}\right\} \tag{10}$$

where $C_L = C_{SM} + C_L'$

Equation 10 is the oscillating frequency of the crystal oscillator. C_L is called the load capacitance of the oscillator. With a specified C_L, the crystal manufacturer can then match the crystal to the customer's circuit to obtain the desired oscillation frequency. From the C_L equation, the relationship between the other circuit parameters can be established (i.e. C_D, C_G, R_O and C_{SM}) as it relates to the oscillation frequency of the crystal oscillator.

In a typical CMOS oscillator, R_O generally decreases as the supply voltage increases. This causes a decrease in load capacitance and an increase in the oscillation frequency. Figure 9 shows the effective load capacitance (C_L) changes as the output resistance (R_O) changes.

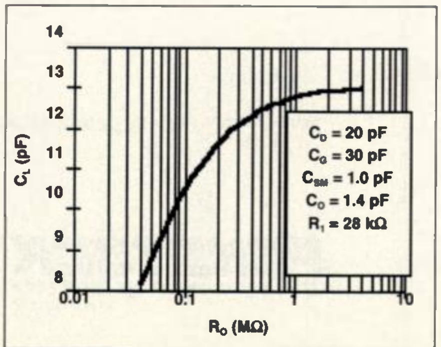

Figure 9. Effective load capacitance (C_L) vs. output resistance (R_O).

Gain equation

From the real part of the current phase diagram (x-axis):

$$I_D = I_o \cos\theta + I_1 \sin\theta \tag{11}$$

and from the equation derived from the voltage and impedance phase diagram, Equation 11 becomes:

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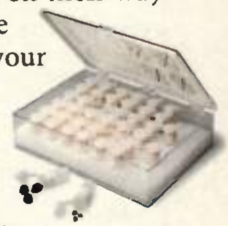

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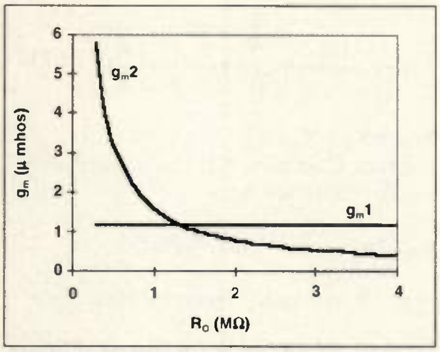

Figure 10. Comparison of minimum g_m requirements vs. amplifier's output resistance (R_O). g_m1 = first term and g_m2 = 2nd term of Equation 12. For C_D = 20 pF, C_G = 30 pF, C_{SM} = 1.1 pF, C_O = 1.4 pF, R_1 = 28 kΩ, f_O = 32.768 kHz and C_L = 13 pF.

$$g_m X_G I_X = \frac{I_x\sqrt{R_e^2+X_e'^2}}{R_o}\cdot\frac{X_e'}{\sqrt{R_e^2+X_e'^2}} + \frac{I_x\sqrt{R_e^2+X_e'^2}}{X_D}\cdot\frac{R_e}{\sqrt{R_e^2+X_e'^2}} = I_x\frac{X_e'}{R_o}+I_x\frac{R_e}{X_D}$$

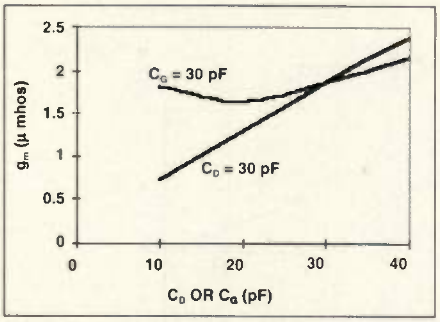

Figure 11. For R_O = 2.5 MΩ, g_m comparison between C_D and C_G, where C_{SM} = 1.1 pF, C_O = 1.4 pF, R_1 = 28 kΩ, f_O = 32.768 kHz.

$$g_m X_G = \frac{X_e'}{R_o}+\frac{R_e}{X_D};\quad g_m = \frac{R_e}{X_D X_G}+\frac{X_e'}{R_o X_G}$$

and from $X_e' = X_e - X_G$ and Equation 7:

$$g_m = \frac{R_e}{X_D X_G}+\frac{1}{R_o X_G}\left[X_D\left(1+\frac{R_e}{R_o}\right)\right]$$

$$g_m = 4\pi^2 f^2 C_D C_G R_e + \frac{C_G}{C_D R_o}\left(1+\frac{R_e}{R_o}\right) \qquad (12)$$

where:

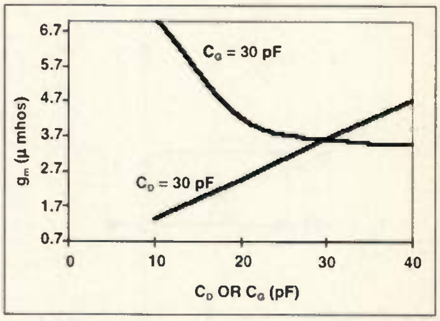

Figure 12. For R_O = 500 kΩ, g_m comparison between C_D and C_G, where C_{SM} = 1.1 pF, C_O = 1.4 pF, R_1 = 28 kΩ, f_O = 32.768 kHz.

$$R_e \approx R_1\left(1+\frac{C_o'}{C_L}\right)^2$$

Equation 12 gives the minimum g_m required for the oscillator to maintain oscillation. In practice, 5–10 times the calculated value is required to insure fast start of oscillation. This equation also aids the designer in selecting the component values for C_D and C_G to match the CMOS amplifier and the crystal.

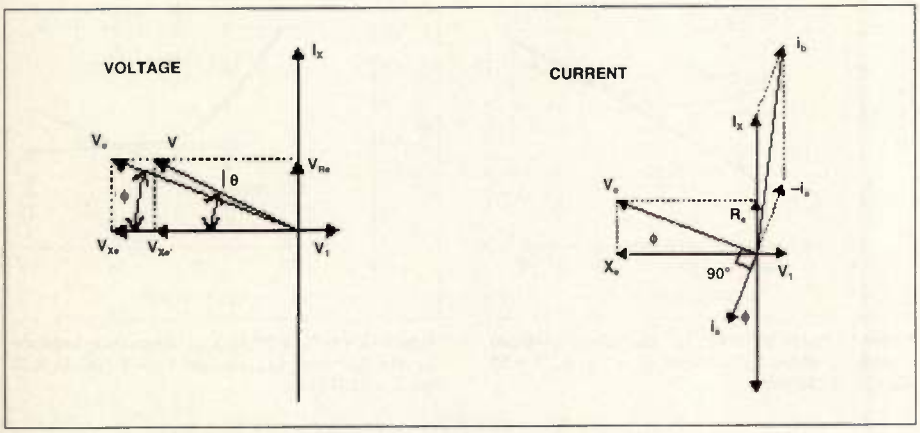

Figure 14. Voltage and current phase relationship with the circuit equivalent.

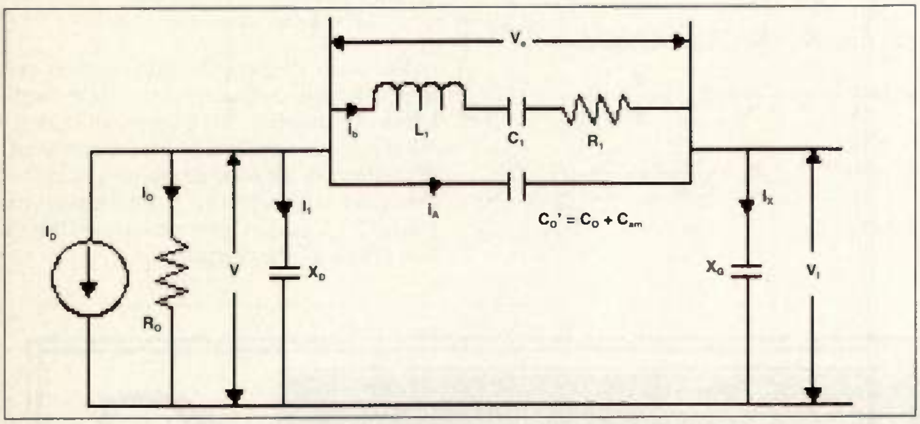

Figure 13. Oscillator AC equivalent circuit with the crystal electrical equivalent circuit.

It is important to note that in most analyses, only the first term of Equation 12 is used. The second term must be taken into account, especially for low-frequency applications where the second term becomes larger than the first term as shown in Figure 10, when R_O is less than 1.2 MΩ.

Using Equation 12, Figures 11 and 12 show the change in the minimum g_m requirements caused by a change in either C_D or C_G, while maintaining the other capacitor constant. For a 32.768 kHz oscillator, as shown in Figure 11, trimming the output capacitor (C_G) will produce more change in g_m than the input capacitor (C_D). As shown in Figure 12, a decrease in the amplifiers' output resistance (R_O) increases the minimum g_m requirement.

Crystal drive current

To analyze the current flowing through the crystal, the AC equivalent circuit from Figure 6 is redrawn to show the crystal's electrical equivalent circuit as shown in Figure 13. The crystal drive current (I_b, and i_a) is the current through the shunt capacitance C_O.

The crystal voltage, current and impedance phase relationships are shown in Figures 14 and 15.

From:

$$|i_a| = \frac{V_e}{X_o} \quad \text{and} \quad V_e = I_x\sqrt{(R_e^2 + X_e^2)}$$

$$i_a = \frac{I_x\sqrt{(R_e^2 + X_e^2)}}{X_o} \qquad (13)$$

where:

$$X_o = \frac{1}{\omega C_o'} = \frac{1}{\omega(C_o + C_{sm})}$$

From the current phase diagram of Figure 14 and the relationship:

$$i_b = \sqrt{(I_x + i_a\cos\phi)^2 + (i_a\sin\phi)^2}$$

and from the crystal impedance phase diagram Figure 15:

$$\sin\phi = \frac{R_e}{\sqrt{(R_e^2 + X_e^2)}}; \quad \cos\phi = \frac{X_e}{\sqrt{(R_e^2 + X_e^2)}}$$

substituting sin φ and cos φ and i_a from Equation 13:

$$i_b = \frac{|V|}{\sqrt{(R_e^2 + X_e^2)}}\sqrt{\left(1 + \frac{X_e}{X_o}\right)^2 + \left(\frac{R_e}{X_o}\right)^2} \qquad (14)$$

where $X'_e = X_e - X_G$

From Equation 14, the crystal drive can be calculated from:

$$P = i_b^2 R_1 \qquad \text{(in Watts)}$$

where R_1 = crystal's motional resistance.

Typical effects of R_A in the oscillator circuit

In many cases, a resistor R_A is introduced between the amplifier output terminal and the crystal input terminal as shown in Figure 1. The use of R_A will increase the frequency stability because it provides a stabilizing effect by reducing the total percentage change in the amplifier output resistance R_O and also increases the effective output impedance by R_A as shown in Figure 9. R_A also stabilizes the output voltage of the oscillator and is used to reduce the drive level of the crystal.

The complete AC equivalent circuit of Figure 1 is shown in Figure 16, where X_d is the total output capacitance of the amplifier. Using the same analytical approach, the frequency, gain and crystal drive current equations with R_A are shown.

The gain equation is:

$$g_m \geq 4\pi^2 f^2 C_G\left[(C_D + C_d)R_e + \left(C_d + \frac{R_e}{R_o}C_d\right)R_A\right.$$

$$+ \frac{C_G}{C_D\left(1 + \frac{R_A}{R_o}\right) + C_D}\left(4\pi^2 f^2 C_D C_d R_A + \frac{1}{R_o}\right) \cdot$$

$$\left(1 + \frac{R_A + R_e}{R_o} - 4\pi^2 f^2 C_D C_d R_A R_e\right)$$

The crystal drive current:

$$i_b = \frac{|V|\sqrt{\left(1 + \frac{X_e}{X_o}\right)^2 + \left(\frac{R_e}{X_o}\right)^2}}{\sqrt{\left[R_e + R_A\left(1 - \frac{X_e'}{X_o}\right)\right]^2 + \left[X_e' + R_A\frac{R_e}{X_D}\right]^2}}$$

Conclusion

Using the closed loop and phase diagram method allows the frequency, gain and crystal drive current equations for a simple quartz crystal pierce oscillator to be derived. As the equations show, the stray capacitance, minimum gain requirements and the output resistance of

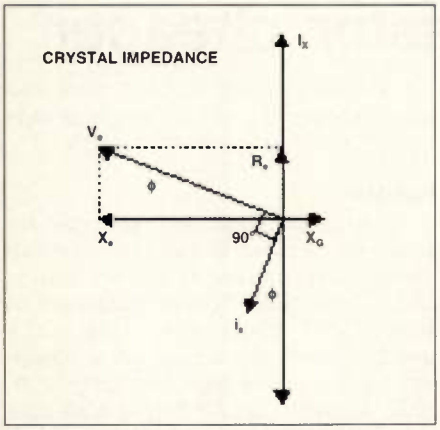

Figure 15. Crystal impedance phase diagram.

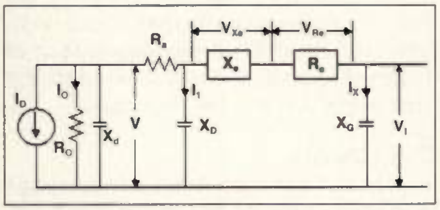

Figure 16. Pierce oscillator AC equivalent circuit with R_s included.

the amplifier must be carefully considered to obtain optimum oscillator performance. The minimum gain requirements should include consideration for the full range of operational temperature and voltage. The stray capacitance (C_{SM}) is especially critical because of the negative feedback effects and will increase the minimum gain requirements of the oscillator [1]. As crystal manufacturers continue to miniaturize the crystal resonator, the oscillator designer must take into account the trade off in the crystal, amplifier and the circuit layout strays to select the appropriate component values to achieve proper crystal drive, start up and a stable oscillation. *RF*

About the authors

Dr. Shih S. Chuang is the chief operating officer of Statek, Orange, CA. He received his Ph.D.E.E. from the University of Rochester, NY. He has earned four patents related to quartz resonators and sensors. He was awarded EIA's David Larson award in 1994 for his contribution in quartz crystal industries.

Mr. Jim B. Varsovia is an engineering manager at Statek where he is responsible for wide process development, equipment design and product yield maintenance. He received his B.S.E.E. from the University of Sto. Tomas, Manila, Philippines.

References

1. S.S. Chuang and E. Burnett, "Analysis of CMOS Quartz Oscillator," *Proc. 9th Int. Congress Chronometry,* Stuttgart, W. Germany, Sept. 1974 paper C2.2.

2. E. Vittoz, "High-Performance Crystal Oscillator circuits: Theory and Application," *IEEE Journal of Solid State Circuits*, Vol. 23, June 1988, pp. 774-783.

RF product forum

Oscillators becoming smaller, faster, cheaper

Each month, the product forum gives companies manufacturing the products used by RF engineers the opportunity to offer their opinions regarding today's marketplace and trends in the industry without editorial interpretation. This month, the product forum highlights oscillators. This information was compiled by Gregg Miller, Technical Editor.

Precision Control

"The trend is better stabilities and smaller sizes, getting down to the half-inch height," says Robert Zeigler, President of Precision Control. "Ovenized or temperature stabilized oscillators have been a real producer of power and also of size, and lately they have gotten down to about a half-inch high." Zeigler also sees a trend toward using SC cut crystals instead of the normal AT cut crystals. "SC cuts gives us approximately a five- to ten-time improvement over temperature than the AT cuts; it also gives us about five- or ten-time improvement as far as aging goes, and the prices are very competitive. This leads to less and less height in the package," Ziegler says.

Temex

"I think we're seeing the same trends that we've seen for the last 20 or so years—smaller, higher frequencies, and less expensive," says Bill Beck, Temex marketing manager for time and frequency products. With more oscillators being manufactured for very specific purposes such as cellular phones, Beck sees technology and miniaturization as being applied to what has traditionally been more custom-type applications. This is because of the great advantage of price and size.

As for the future, Beck thinks the most interesting thing has been the development of the small AT strip crystals that have some inherent advantage over the round AT type crystals. "They seem to do extremely well for aging, hysteresis and activity dips," he says. Beck also sees fundamental crystals in the 200–400 MHz range, which has opened up the ability to do high-pole voltage controlled crystal oscillators (VCXOs) at higher frequencies.

Check out the advertisements from these oscillator manufacturers in this issue:

- Anderson Laboratories, p. 61
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Oak Frequency Control Group

"Customers are asking for smaller, faster, cheaper, and more stability as well," says John Cline, President of Oak Frequency Control Group. "I think board real estate is valuable, and smaller miniaturized devices are very important." Surface mountable, even on the larger, more traditional devices such as oven-controlled crystal oscillators (OCXOs), is also important. Cline also believes devices that have a crystal in them have to withstand robust manufacturing processes. "No longer are they hand-assembled after the rest of the printed circuit board is assembled. Manufacturers like to include this operation all in one-step," he says.

Cline is suprised by the globalness of the frequency control market. "No longer is it a U.S. market. The pressures that we see from the Far East, China and Europe all collaborate with smaller, faster, cheaper," he says.

MITEQ

Dave Krautheimer, MITEQ's director of sales and marketing, is seeing a desire for lower price and quicker delivery. "The customers are really looking for virtually off-the-shelf hardware, but unfortunately, the stuff is being made basically to order." He also sees a larger request for smaller, lighter, more compact, lower current oscillators. High military rail and space requirements are also popular.

As far as the future goes, Krautheimer believes there may be some techniques using microwave monolithic integrated circuits (MMICs) and newer technologies where it would be less value added from the work standpoint. Some of the assembly technologies will be used more and more as opposed to the RF engineer having to "tweak" the oscillator to work.

Sawtek

"A lot of our oscillators right now are designed to cater to the military and higher performance types of applications," says Bob Proulx, manager of Sawtek's RF subsystems. "Some of the trends that we are seeing are a continued push towards high frequency, running around L-band." Proulx also says that military customers are concerned with g-sensitivity. G-sensitivity is an immunity to microphonics, and are notorious for generating side-bands. An oscillator style has been developed that is designed to make the oscillator relatively immune to that kind of phenomena.

CTS Reeves

"One of the more interesting trends that we've seen is the concept of just-good-enough specification performance," notes Terry Luxmore, business development manager for CTS Reeves. "We have a number of customers who feel that they have been overspecing their products. So, we're seeing a conscious effort to lower the specification criterion to reduce the cost but still meet the end applications performance needs," he says.

Luxmore believes there will be more and more semiconductor integration use, as well as miniaturized quartz reducing the size. In packaging, he sees a trend towards more ceramic packaging as the price comes down, where size constraints can be met while still having a reliable, high-quality product.

Vari-L

According to Derek Bailey, Vari-L Vice President of sales and marketing, "The big area is power consumption. We're looking at reduced power consumption modes, ways for people to save power in a stand-by mode where they can actually turn the oscillator off," he says. Reducing its fundamental current to 50%, the oscillator can still generate an application signal a little bit lower in amplitude with a little bit worse phase noise, but Bailey notes it works just fine for signal detection. Bailey says if an oscillator is operating at 2.8 V drawing 6 or 7 mA in a full-up mode, you can turn on the stand-by mode and drop the current to half of that. "As soon as the signal presence is detected, you can go ahead and put it back into full up mode and you'll get the integrity in terms of the output and the phase noise being what it needs to be to be full-function," he says.

ICS Tropical

"The trends that we are seeing are requests for custom parts that are not off-the-shelf and more stringent specifications, such as with phase noise and linear tuning," says Eliot Fenton, Vice President of engineering for ICS Tropical. "Normally, customers are asking for the integration of oscillation into small signal force packages. They are also looking to higher frequencies," he says.

Fenton sees innovations in: quieter and higher frequency semiconductors, smaller packages, improved models and improved software, the developing of new architecture and packaging. He believes all this will improve the performance, the reliability and the repeatability of future products.

Ecliptek

"We see the trend towards programmable oscillators that we could program in house and ship to our customers," says Mark W. Stoner, Ecliptek director of sales and marketing. A programmable oscillator is an integrated circuit (IC) with a set frequency, usually 14.318 MHz, that is prepackaged in any different number of packages, including thru-hole or surface-mount ceramics. The frequency is burned on and the oscillator is shipped to the customer, cutting the lead time down from 12–14 weeks to one day. However, according to Stoner, right now it is not being offered because of the trade-offs in jitter. "The jitter specification is a little bit higher than a standard oscillator. In some applications, it may be a little sketchy," he says.

Monitor Products

"The number one thing on our customers' wish list is programmable oscillators," says Robert Blasier, Monitor Product's western regional sales manager. "They are also looking for surface-mount voltage controlled crystal oscillator (VCXO) and temperature-controlled crystal oscillator (TCXO) solutions. They are looking for small, ceramic or plastic surface-mount packages that can be used in automated assembly," he says. Blasier also sees a lot of transition in the telecommunications side of the business from thru-hole to surface mount technology.

Blasier sees innovations coming mostly out of the semiconductor business, primarily silicon solutions including programmable oscillators and digitally compensated TCXOs.

C-MAC Frequency Products

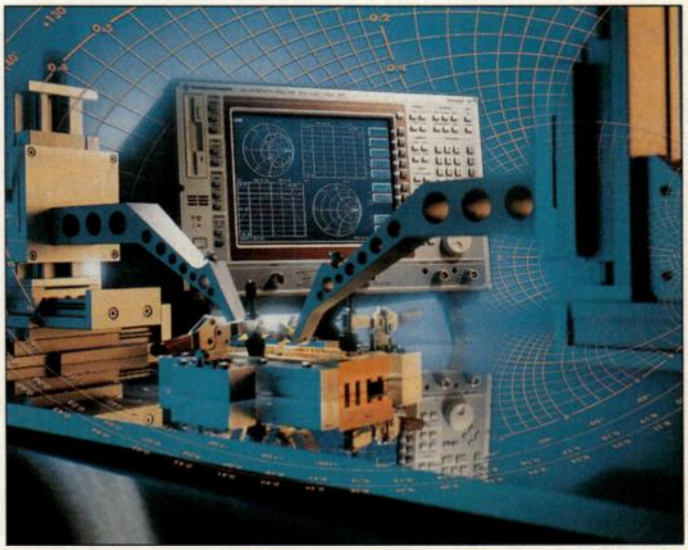
There is a trend in the natural reduction in size to 5 × 7 millimeter packages for TCXOs. "The trend in VCXOs I see is the surface mount and frequencies increasing significantly above 100 MHz," says Bob Pearson, C-Mac Frequency Products' North American sales and marketing manager. Person notes as far as TCXOs are concerned, surface mount packaging is a natural trend and stratum 3 compatibility is becoming "fashionable." OCXOs with precisions of better than 10^{-10} are becoming apparent for base station applications, and at the other end of the scale, miniaturization of OCXOs and surface mount compatibility.

Z-Communications

Chuck Eapen, director of sales and marketing for Z-Commnications, says, "From the perspective of the voltage control oscillator (VCO) market, what we see are greater demands on vendors to develop lower phase noise products." The more exotic modulation schemes necessitate a quiet voltage-controlled oscillator (VCO), more quiet than what is commercially available through present day microstrip designs. In response to that, there are normalized VCO products that offer single sideband performance figures that are about 10–15 dB better than the current market.

Eapen believes other things include a continuing effort on packaging reductions. "There is already plans to find out how we can improve upon the 0.3" × 0.3" package structure," he says. That is where further advances in technology come into play. **RF**

Two vector network analyzers have an extended frequency range of 8 GHz



The ZVC and ZVCE are vector network analyzers that feature wide dynamic range, high measurement speed and accuracy. An important attribute to these analyzers is their extended frequency range of 8 GHz in comparison to 4 GHz with the other models, which enables measurements also on satellite components. To round off the functionalities, a new firmware version includes the optional measurement functions "level calibration" and "measurements on frequency-converting devices." Features include a dynamic range of more than 130 dB at 10 Hz, a high measurement speed of as high as 125 µs/point, and a wide frequency range from 20 kHz to 8 GHz. Both models include two measurement channels and a reference channel. An electronic switch and a second standing wave ratio (SWR) bridge enable bidirectional measurements.

Rohde & Schwarz
INFO/CARD 132

Mini VCO for WLAN market

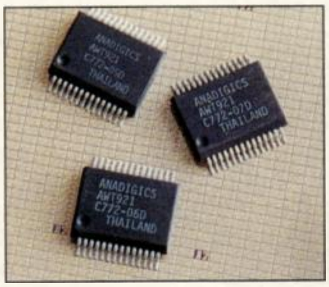
The V630ME13 surface mount mini-voltage controlled oscillator (VCO) has been designed for the wireless local area network (WLAN) market. Designed to ease any phase-locked loop (PPL) designers task, the VCO features a frequency range from 2,700–2,900 MHz within 0.5–4.5 VDC of control. Other features

include a signal source of –95 dBc/Hz typically at a 10 kHz offset while attenuating the second harmonic to better than –15 dBc.

Z-Communications
INFO/CARD 133

High-performance GaAs MMICs

A series of gallium arsenide (GaAs) monolithic



microwave integrated circuits (MMICs) offer high-performance, cost effective options for designers of cellular and personal communications service (PCS) infrastructure applications. The AWT921 (900 MHz range), AWT1921 (1.6 GHz band) and the AWT1922 (1.9 GHz PCS and GSM bands) feature high levels of integration in small, surface-mount packages. All three parts are packaged in wide body 28-pin, enhanced SSOP packages. The AWT921 is priced at $20 while the AWT1921 and AWT1922 are priced at $25 in quantities of 100,000.

Anadigics
INFO/CARD 134

Impedance matching adapter

The TEI 105-1816 impedance matching adapter complements the line of connectors, cable assemblies and adapters already available for military 1553 data bus applications. This adapter uses an embedded transformer to accomplish the impedance step-up/down.

The product offers the engineer a simple, elegant adapter for mismatched data signal devices and interfaces. adapter is available in both male and female inputs and outputs for BNC and TNC type coax and TRB or TRT triax cable. The frequency range is as high as 500 MHz.

Trompeter Electronics
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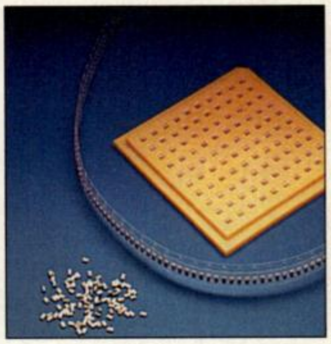
0603 surface-mount capacitors

The ATC 500 series of broad-band microwave surface mount ceramic capacitors provides rugged, surface-mountable, stable NPO temperature-characteristic, laser-



marked devices with high self-resonant frequencies in values as high as 10 pF. These capacitors feature first parallel resonant (FPR) frequencies exceeding 35 GHz for values of 0.1–2.2 pF and exceeding 20 GHz for values as high as 10 pF. The high FPR makes these capacitors suitable for broadband DC blocking/RF coupling. Typical unit pricing is between 20–50 cents for quantities of 100,000.

American Technical Ceramics
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SIGNAL PROCESSING COMPONENTS

Fifth-order, lowpass elliptic filters

The MAX7411 and MAX7415 fifth-order, switched-capacitor, lowpass elliptic filters consume 1.2 mA of current from either a 5 V or 3 V supply. These filters feature a transition ratio of 1.25 and provide 37 dB of stop-band rejection. Corner frequencies are clock tunable from 1–15 Hz. Package options include an eight-pin μMAX or an eight-pin plastic dual-inline package (DIP) with prices beginning at 99 cents.
Maxim Integrated Products
INFO/CARD 137

Switchmode rectifier delivers 100 A at 48 V

The WLR5600 is an ultra-density, microprocessor-controlled switchmode rectifier for distributed- and bulk-power telecommunications applications. Features include delivering 100 A at 48 V, power factor correction and is fan-cooling for efficient and reliable operation. The WLR5600 is also hot-pluggable so that it can be inserted into a live voltage bus without disruption, and is priced at less than 40 cents per watt.
Lambda Electronics
INFO/CARD 138

Inductive proximity sensors with linear output

A line of inductive productive sensors feature a 1–9 VDC linear output ranging in size from 12–30 mm in diameter cylindrical models. All models operate with input voltages from 18–30 VDC with an output current as high as 5 mA. Linear output sensors of this type can be used for positioning, differentiating metal materials and sorting by size, shape or surface texture. Pricing starts at $137 for single quantities.
Altech
INFO/CARD 139

70 MHz LC filters for telecom applications

A line of 70 MHz intermediate frequency (IF) inductive-capacitive (LC) filters for telecom industry applications are designed with bandwidth ranges from 2.5–60 MHz. Available with various insertion loss and shape factors, these filters are available in several package sizes and configurations.
Piezo Technology
INFO/CARD 140

Two-way power divider for LAN applications

The PB-5 two-way power divider is designed for local area network (LAN) applications. Features include a frequency range from 2,200–2,500 MHz and an insertion loss of 0.4 dB typical. Other features include 24 dB typical isolation and amplitude balance of 0.3 dB maximum.
Pulsar Microwave
INFO/CARD 141

Low-phase noise frequency synthesizer

The PSA-770C low-phase noise frequency synthesizer measures 0.94" × 0.94" × 0.232" with a frequency range of 750–790 MHz. Features include spurious suppression better than –65 dBc and second harmonic suppression exceeds –15 dBc. Phase noise is –100 dBc/Hz at 10 kHz offset. The synthesizer operates from a 5 V supply.
Princeton Electronic Systems
INFO/CARD 142

High-current powerline choke

The DC 780 series high-current powerline choke offers current handling capabilities that make them suitable for use in switching regulated power supply applications. Features include current ranges from 100–2.3 A and inductance ranges from 1.0–2,200 uH with current rating of 0.8–11.4 A. The DC 780 series is priced at $1.32 in quantities of 1,000.
API Delevan
INFO/CARD 143

SEMICONDUCTORS

CMOS single-chip RF receiver

The MICRF001, single-chip complementary metal oxide semiconductor

(CMOS) RF receiver that integrates a complete radio receiver onto a single silicon chip. Features include a 300–450 MHz frequency range with seamless interface to standard decoders and microprocessors. Designed for use in remote actuation systems, the MICRF001 is priced at $3,00 in quantities of 1,000.
Micrel Semiconductor
INFO/CARD 144

8-bit, quad-channel voltage-output DACs

The AD7304 and AD7035 quad voltage-output digital to analog converters (DACs) are designed for general-purpose DC and AC gain with offset adjustment in system designs where cost, low-power consumption and a small footprint are the design criteria. Features include a single 3 V or 5 V voltage supply and a reference multiplying-bandwidth of 2.6 MHz. An internal power ON reset places both parts in the zero-scale state at turn ON. The AD7304 and the AD7305 are priced at $3.25 and $3.75, respectively, in quantities of 1,000.
Analog Devices
INFO/CARD 145

SIGNAL SOURCES

Quick-turn clock oscillators

This line of quick-turn clock oscillators feature a frequency range from 0.9–135 MHz with a frequency stability of ±100 ppm over a temperature range of 0–70°C. Features include grounded metal covers that reduce electromagnetic interference (EMI).
International Crystal Mfg.
INFO/CARD 146

Miniature OCXO in a standard four-pin DIP

The QEO 93 is a 1–35 MHz miniature oven-controlled crystal oscillator (OCXO) in a standard four-pin dual-inline package (DIP). Features include a low-aging SC crystal or an economical AT crystal.
Temex Electronics
INFO/CARD 147

VCO delivers better phase noise performance

The CLV1000E voltage-controlled oscillator (VCO) generates frequencies between 900–1,100 MHz within 1–10 VDC of control voltage with an average tuning sensitivity of 27 MHz/V. The wideband oscillator provides a spectrally clean signal of –111 dBc/Hz typically at 10 kHz from the carrier. In addition, the design of this VCO also improves second harmonic attenuation to better than –14 dBc. Designed to enhance phase-locked loop (PLL) designs, the CLV1000E minimizes power consumption by operating off a 5 VDC supply while typically drawing only 22 mA into

a 50 Ω load. The VCO measures 0.5″ × 0.5″ × 0.22″ and is priced at $24.95.
Z-Communications
INFO/CARD 148

TOOLS, MATERIALS & PROCESSES

Thermally conductive epoxy for optoelectronics

Tra-bond 2155 high-performance epoxy has die shear strength of 19 kg on a 100 × 100 mil pad. Developed for microelectronics assembly and packaging, thermal conductivity is more than 0.9 W/mK with thin bond lines, and adhesion is greater than 2,000 psi when cured at room temperature. With a pot life of three hours and a working life of as much as eight hours, this epoxy is easily dispensed.
Tra-Con
INFO/CARD 149

AMPLIFIERS

Amplifiers with a built-in test feature

The ABIT series of amplifiers feature a built-in test feature for monitoring the power output. In addition to the RF output, the unit includes a detected transistor-transistor logic (TTL) compatible output whose threshold can be externally adjusted via a variable voltage source. The amplifier is hermetically sealed kovar, which will meet the rigorous environments of military and space applications. The unit is also available with various electrical options and an assortment of connector combinations.
MITEQ
INFO/CARD 150

CABLES & CONNECTORS

Adapter kit joins universal adapter series

The PT-4000-150 unidapt female-to-female barrel adapter has joined the the universal adapter series. This connector kit comes with two male and two female each of BNC, mini-UHF, N, TNC, SMA and UHF coaxial adapters. Each of these adapters can be mixed and matched to make a different adapter.
RF Connectors
INFO/CARD 151

Right angle adapter for data bus applications

Featuring a completely concentric one-piece design, the ADRMF70 right-angle TRB male-to-female adapter is suited for telemetry and ground-support data bus applications where cable management, strength and security are required. The ADRMF70 features include the ability to mate with any standard 70 series connector, and is

available in two-, three- and four-lug and threaded versions.
Trompeter Electronics
INFO/CARD 152

Backplane connector for high-performance applications

A rugged, shielded, high-density backplane connector is specified to support the high data rates and demanding physical requirements associated with next-generation industrial computer and telephony applications. Four- and eight-slot backplanes in both 3U and 6U formats are available using the Z-Pack 2 mm HM backplane connectors.
AMP
INFO/CARD 153

SUBSYSTEMS

Line of products based on DSP C6000

A line of 14 digital signal processor (DSP) development board-level products have been developed to satisfy the cost and performance requirements based on Texas Instruments' C6000 target markets. These markets include telecommunications, image processing and defense. The product line includes the Quad C6201 PCI and Compact PCI boards targeted at wireless telecommunication systems based on wireless modulation standards. The range includes support products such as analog converter boards and digital down-converter sets.
Blue Wave Systems
INFO/CARD 154

Board-level modem for base station applications

The SynetBase Gaussian minimum shift keying (GMSK) board-level modem using digital signal processing (DSP) technology is configured for 8 kb/s, GMSK3 operation using packetized data and transmit analog baseband interfaces. This modem interfaces with data transmissions from mobile data networks, automatic vehicle location systems and low-earth orbiting satellite (LEOS) applications to tie the base station receive chain using baseband interfaces or intermediate frequency (IF), providing radio hook-up versatility. The receive side of the modem digitizes receive baseband signals and uses DSP algorithms to produce demodulated data based on the received packets of data.
Synetcom Digital
INFO/CARD 155

Charge controller for lithium-ion battery packs

The LM3620 is a highly integrated, low-cost controller for charge and end-of charge control of single-cell and dual-cell lithium-ion battery packs for handheld communication products. Rated at 1.2% regulation accuracy, the LM3620 precisely controls charge voltage from a current-limited DC-DC switching charger or linear charger. In its simplest form, an application circuit using the SOT23-5 sized controller package would consist of a capacitor, a diode, a transistor and a resistor.
National Semiconductor
INFO/CARD 156

DISCRETE COMPONENTS

Chip resonator delivers wide frequency range

The SSR series ultraminiature ceramic chip resonator provides portable electronics design engineers with a high-performance timing device in a surface-mount package that measures 3.2 × 2.1 × 1.5 mm. Designed for clock applications in devices such as cellular telephones, the resonators feature an operating frequency range from 16–60 MHz with several standard frequencies available. Other features include a 100 Ω resonant impedance, with a temperature stability of ±0.3% over the operating temperatures of –20°C to 80°C. Pricing for the resonators is less than 30 cents each in quantities of 100,000.
AVX
INFO/CARD 157

Chip size trimmer capacitors

The JS series of ultraminiature surface-mount chip size trimmer capacitors features a capacitance range of 0.4–1.0 pF. The series features a self resonant frequency at 4 GHz, making it suitable for telecommunications applications. The capacitors also feature high stability and measure 2.8 × 2.2 × 1.0 mm. The JS series is available in tape and reel and priced at less than 60 cents in quantities of 1,000.
Voltronics
INFO/CARD 158

Coaxial resonator design kit

A line of coaxial resonator design kits each contain 40 resonators, giving a variety of mechanical profiles to assist the design engineer. Each kit specifically addresses existing frequency bands from 300 MHz to 4 GHz. Whether used for voltage controlled oscillator (VCO) or filter applications, the kits offer the engineer multiple frequency and mechanical options.
Trans-Tech
INFO/CARD 159

Surface-mount resistor networks

The SMR series of high-reliability, precision resistor networks for fine-pitch, surface-mount applications feature lead pitch of 0.8 mm and are available in 4–16 pin out styles. The standard value range is 2 Ω to 10 MΩ in isolated or common bussed configurations with tolerances to 0.5%. High-reliability construction offers abrasively trimmed resistors for improved stability and power handling as well as reduced noise. The protruding, five-sided, nickel barrier terminations enhance solder attachment and inspection. The footprint for a SMR 8, four resistor network, is a 1206 case size.
Mini-Systems
INFO/CARD 160

Highest-power LDMOS available in market

The GOLDMOS 120 W, 2 GHz transistor is the highest power laterally diffused metal oxide semiconductor (LDMOS) transistor available in the market today. Using an all-gold technology for increased product reliability, features of the product include a 11 dB gain, 42% more power, 120 W pep and low drift I_{DQ}. These product features provide communications systems designers with the maximum RF signal power at a lower cost.
Ericsson Components
INFO/CARD 160

Test software for CDMA-based mobile phones

Noise Com's version 2.1.1 of its code-division multiple-access (CDMA) automated test software (CATS-98A) is designed for testing mobile receivers and transmitters, as specified in IS-98A and J-STD-018. The CATS-98A integrates Noise Com's wireless impairment system (WIS-98A) with a base station simulator for testing of CDMA-based mobile phones.
Noise Com
INFO/CARD 115

DSP design software offers integrated development

HP EEsof offers a new digital signal processing (DSP) product that allows integrated co-development of DSP designs with analog circuits and radio frequency integrated circuits (RFICs). The HP DSP Designer is part of HP EEsof's HP Advanced Design System and includes a development environment for behavioral-level algorithms from synthesis of RTL-level VHDL or Verlog. A new simulation technology, HP Ptolmey, is built in.
HP EEsof
INFO/CARD 116

Software developed to support new DSP

3L Limited's Diamond RTOS software is designed to support digital signal processing (DSP) applications based on Analog Devices' new 32-bit, floating-point multiprocessing DSP, the ADSP-21106. The Diamond multi-DSP real-time operating system offers a parallel programming environment with multitasking, multi-threading and interprocessor communications facilities.
3L Limited
INFO/CARD 117

Electromagnetic simulation for the PC upgrade

Applied Wave Research offers an upgrade to its EMSight 3D electromagnetic simulation software used to analyze the electrical behavior of radio frequency integrated circuits (RFICs), microwave monolithic integrated circuits (MMICs) and other devices. The update includes new functions such as an integrated, schematic-driven, linear circuit simulator, bi-directional AutoCAD and GDSII translators and a number of other features.
Applied Wave Research
INFO/CARD 118

Measurement and control software updated

National Instruments' Measure 2.0 allows users to configure and control data acquisition hardware, as well as serial or GPIB instruments, and drop acquisition results directly into spreadsheets for analysis and graphing. The software adds support for the DAQ Channel Wizard to reduce the time spent on defining signal types, connections and transducer equations before beginning development of a system.
National Instruments
INFO/CARD 119

Book explains FDTD electromagnetic analysis

Advances in Computational Electrodynamics: The Finite-Difference Time-Domain Method, from Artech House is designed to supplement Allen Taflove's 1995 book, *Computational Electrodynamics: The Finite-Difference Time-Domain Method.* The book assembles the latest techniques and results of theoreticians and practitioners of Finite-Difference Time-Domain (FDTD) computational electromagnetic modeling.
Artech House
INFO/CARD 120

EMC encyclopedia features tutorials, terms, formulas

The *1998 EMC Encyclopedia,* from emf-emi control, contains 624-pages of terms, definitions, formulas, design, diagnosis and case histories concerning electromagnetic compatibility (EMC). Also included are 149 tutorials, 452 illustrations and 151 photographs. The encyclopedia is available on CD-ROM.
emf-emi control
INFO/CARD 121

Catalog features bridges, diodes, rectifier assemblies

The 1998 catalog of bridges, diodes and high-voltage rectifier assemblies rom Electronic Devices contains complete specifications and engineering information on more than 1000 items. Details are shown on bridges as high as 100 A, and 12 KV and diodes from 50 to 20,000 V, to 6 V, with recoveries as low as 35 ns. Package styles for these products include standard, miniature, surface mount and special design. The catalog also covers night-vision diodes, high-temperature rectifiers, 32 KV 3-phase bridges and custom rectifiers.
Electronic Devices
INFO/CARD 122

Thermal management brochure

AI Technology offers a brochure that features thermal management solutions for heat sink attachment. The brochure describes features and benefits, availability, shelf life, applications procedure, cure schedules and typical properties of the EG series of heat sink attach epoxy. The brochure specifically addresses the EG7655 , one or two part heat sink attach epoxy. Also described are the epoxy's thermal mechanical analysis, dynamic mechanical analysis. Other descriptions are also provided.
AI Technology
INFO/CARD 123

Brochure details new series of RF coaxial connectors

Tru-Connector's brochures details the company's new series of high-power, low-frequency RF coaxial connectors and complete cable assemblies for sputtering and wafer process systems. The SQS Series Super Quick Coaxial Connector brochure features a line of panel receptacle, in-series and between series adapters and cable assemblies that are rated at 10,000 V and 5,000 W of RF power.
Tru-Connector
INFO/CARD 124

Bulletin introduces fast cure die attach adhesive

Ablebond 8510B die attach adhesive is detailed in a bulletin from Ablestick Electronic Materials & Adhesives. The adhesive is a silver filled epoxy that allows for reduced cycle times by cureing in 15 minutes at 150 C. The adhesive is designed for Ball Grid Array semiconductor packages and is designed to adhere large die to bare laminate, gold, solder mask or copper oxide surfaces.
Ablestick
INFO/CARD 125

Catalog features microwave filters

Lorch offers a catalog that provides a company description, ordering information and filter selection criteria. The catalog features cavity filters, waveguide filters, wireless products, discrete filters, ceramic filters and tunable filters. The catalog also provides specifications, design guides and outline drawings.
Lorch Microwave
INFO/CARD 126

Brochure describes frequency control products

Fox Electronics' brochure describes the company's frequency control products for wireless applications. Included are detailed descriptions of Fox's precision crystals, oscillators, voltage-controlled crystal oscillators (VCXOs) and temperature-controlled crystal oscillators (TCXOs).
Fox Electronics
INFO/CARD 127

Catalog describes three-phase powerline filters

This 24-page catalog from Schaffner describes three-phase powerline filters featuring a range of components from 3 A to 1,200 A. The catalog details technical information and component performance characteristics. The filters are constructed to meet the test requirements of IEC 950. The catalog is available in English, French and German.
Schaffner
INFO/CARD 128

Electrical products catalog features disconnects

Bussmann Circuit Components offers a 31-page catalog that features the Magnum double row terminal blocks, power distribution blocks, quick connect blocks, disconnects and other products. The catalog also details the company's line of DIN rail mounted products including terminal blocks, circuit breakers and fuse holders.
Bussmann Circuit Components
INFO/CARD 129

Power supply catalog offered on CD-ROM

Power Trends' 120-page catalog for its power conversion devices is available on a CD-ROM. The catalog features DC to DC converters and integrated switching regulators.
Power Trends
INFO/CARD 130

On-line

Noise Com Web site adds new features —Noise Com has updated its Web site with a database-driven format that enables the user to find technical specifications on all Noise Com test systems and components. The site also offers application notes and frequently asked questions. The Web address is for the update site is **www.noisecom.com**.
Noise Com
INFO/CARD 131

RF Literature/Product Showcase

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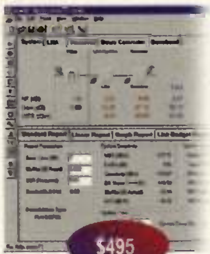

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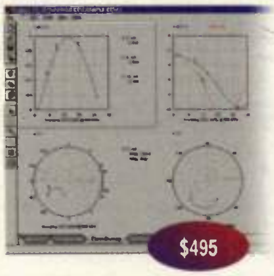

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RF LITERATURE/PRODUCT SHOWCASE

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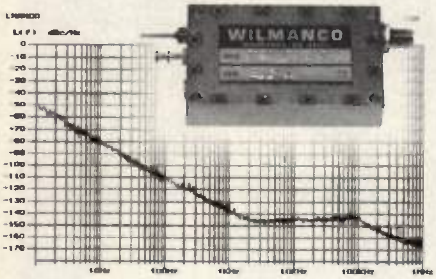

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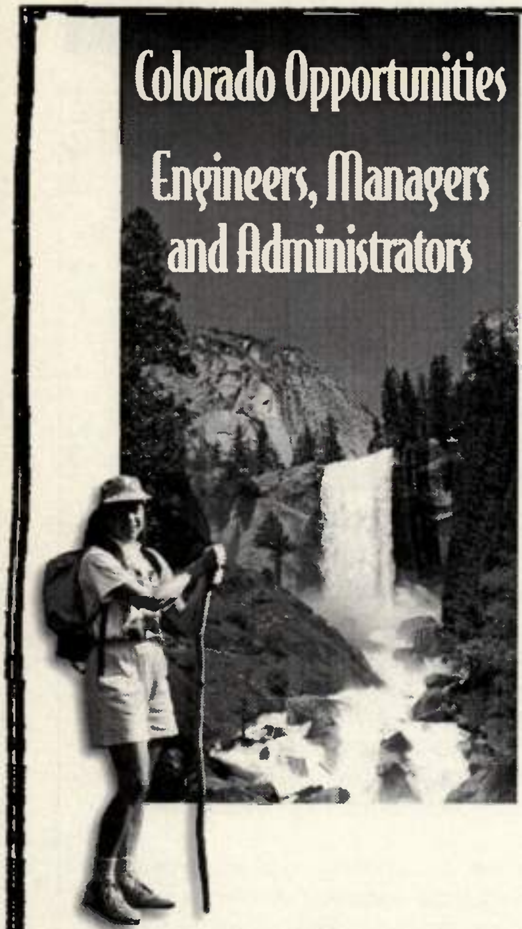

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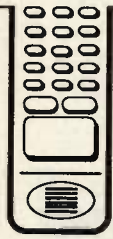

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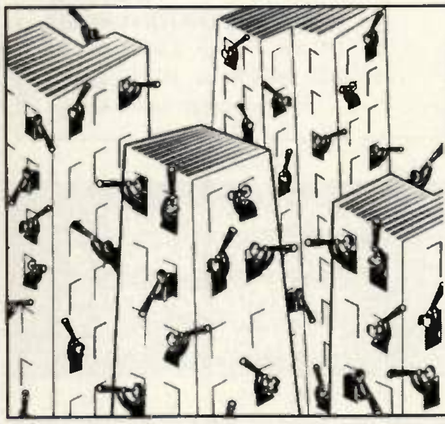

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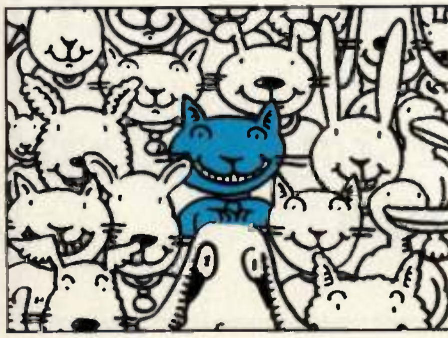

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RF A moment with...

Nicky Lu

president and chief executive officer, EiC

Nicky Lu is the co-founder of EiC, and is the company's president and chief executive officer. Lu co-founded the company after founding Etron, a Taiwan-based semiconductor company. Lu spent seven years with IBM where he was involved in development of dynamic random-access memory (DRAM) related technologies. He co-invented and pioneered the emergence of a 3D-DRAM technology, known as Substrate-Plate Trench-Capacitor (SPT) cell. The technology is used in IBM's 4 Mb and 256 Mb DRAMS.

Lu holds 20 U.S. patents and has published over 50 technical papers and is on the technical program committees of the IEEE International Solid States Circuits Conference (ISSCCC) and the symposium on very large-scale integration (VLSI) circuits. In addition, he has received a number of awards including a Stanford fellowship, three IBM Outstanding Innovation/Technical Achievement awards. He was elected as an AdCom member of the IEEE Solid-State Circuits Society since 1977. He is also a director of the Taiwan Semiconductor Industry Association. Lu received his MS and Ph.D degrees from Stanford University and his BSEE from the Nation Taiwan University.

The interview was conducted by Roger Lesser, Senior Associate Editor and Gregg Miller, Technical Editor.

RF Design: *As a co-founder of a start-up company in the wireless communications industry, what are your impressions of the challenges you have to meet?*

Lu: It is certainly very challenging and rewarding. We have a team spirit that has been the foundation of meeting the goals we have set. Everyone puts in extra effort and hours. This is very common in the Bay area. We have had a lot of challenges, but this is to be expected. We know we are going to face unexpected challenges and problems. The key issue for us is how quickly we can access the situation and come up with a solution. We need to adapt to the changes in the market-place. We have learned to expect the unexpected and adapt to the changes.

RF Design: *What advice would you offer to someone who wants to start a company?*

Lu: Startup requires a lot of hard work and down to earth work. A common saying we have is: It doesn't matter what your title is, the president means the janitor. He needs to serve everyone best. That is the startup spirit. You may see the manufacturing director doing an operators job. You also have to enjoy the work. Not just the management work, but also the real effort it requires to make things happen.

RF Design: *What is EiC's primary business strategy in today's dynamic wireless market place?*

Lu: We are both technology driven as well as customer driven. We want to offer the best technology suitable to the customer. Several of us have worked on cellular or cordless phones including RF design. We have been the customer before, so we know the general attitude of the customer, what they require and what kind of service they want from the manufacturer. At the same time, we believe customers in the RF wireless market need something better than what they can receive now. So we need to offer something that really does advance the technology. This allows the customer to advance their product design as well.

RF Design: *Given that most companies strive to meet customer requirements, what challenges does this present to you, the supplier?*

Lu: Depending on their project, there are several major standards such as code-division mulitple access (CDMA), time-division multiple access (TDMA) and global system of mobile communication (GSM). Now everyone is talking about broadband CDMA in the future. Each standard has different technical requirements so the approach must be different. This presents a communications problem. For example, the CDMA manufacturer may say they care about the spectral regrowth in the transmitter side or have other concerns. How does this translate to the IC designer, who may not know what the application is?

RF Design: *With the need to meet the various challenges each standard has, what common issues do you see?*

Lu: Beyond the communication issue, the general market is looking for smaller IC size, more function, better production and uniformity. We are not committed to one particular standard. We work with the customer to find the right solution.

RF Design: *Your company has functions in both the United States and in Asia. What advantages does this offer?*

Lu: EiC's fab is located in Fremont, CA. Offshore manufacturing offers lower labor cost but less technical expertise in the RF market. Combination of the strength is the management objective. We want to combine the strengths of the Pacific rim including the U.S. West Coast. In the San Francisco Bay area, the overall atmosphere of the people in the industry is very aggressive, very innovative and you can find world class talent here. The labor intensive effort is not as suitable for the Bay area, so we want to use the Pacific Rims strength which is known for its labor quality, turn around time and reduced cost.

RF Design: *There is a real debate between the GaAs advocates and those who believe Silicon is the future of IC. Is there room for both? How do you view the future of GaAs?*

Lu: Each device technology has strength in different applications. The advantage of GaAs is in the high frequency analog circuit including power amplifiers. The mainstream for semiconductors is digital circuits and this will be dominated by Si CMOS. GaAs will not replace that role for sure. GaAs HBT on the other hand offers obvious advantages in the analog circuit operation above 1 GHz. RF

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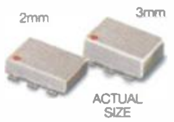

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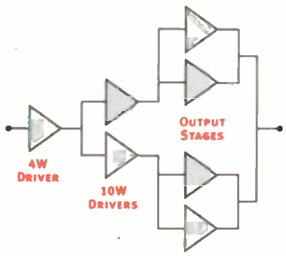

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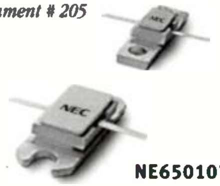

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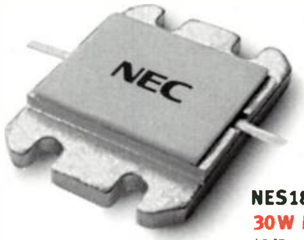

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