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September 2001
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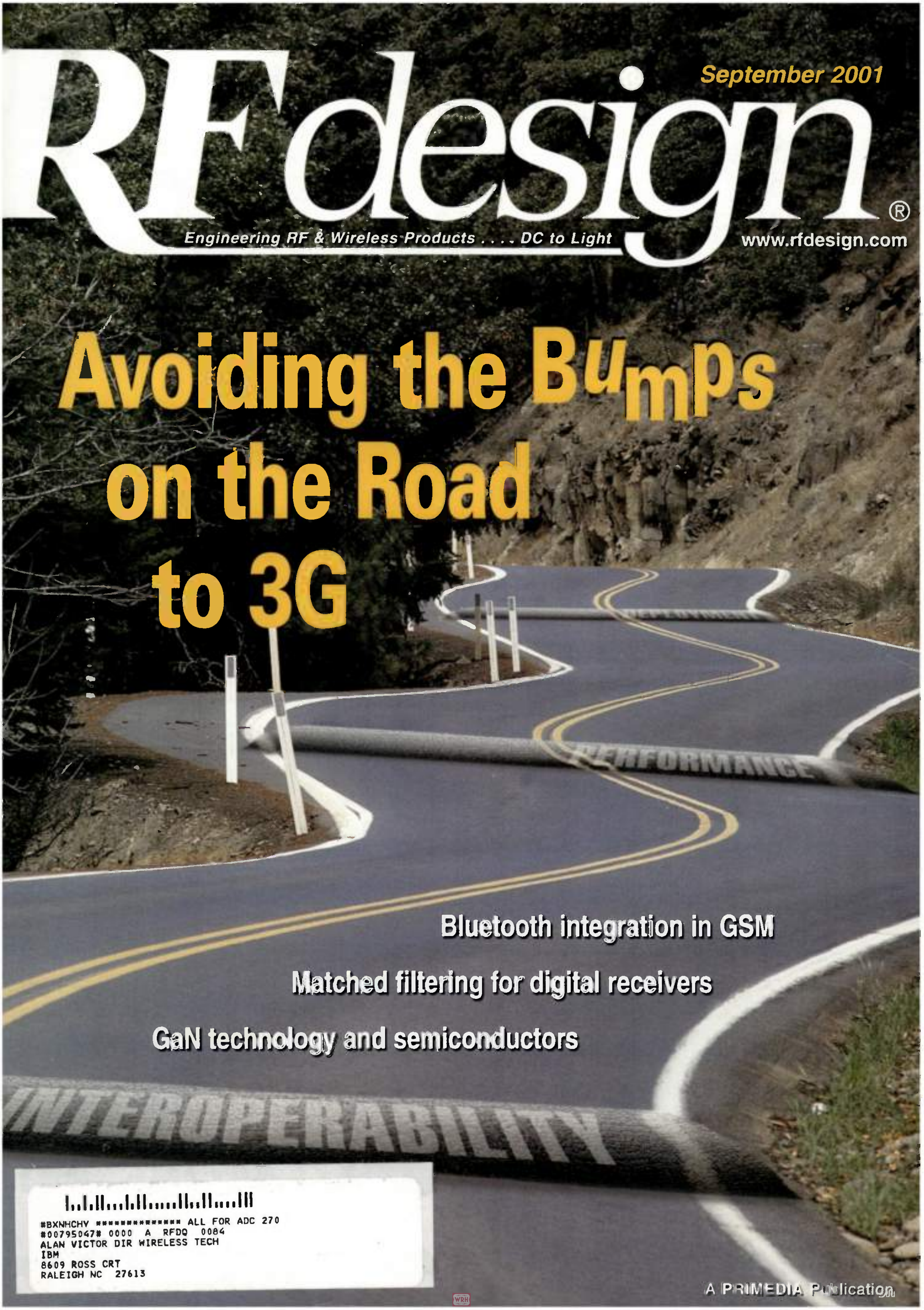

Avoiding the Bumps on the Road to 3G

Bluetooth integration in GSM

Matched filtering for digital receivers

GaN technology and semiconductors

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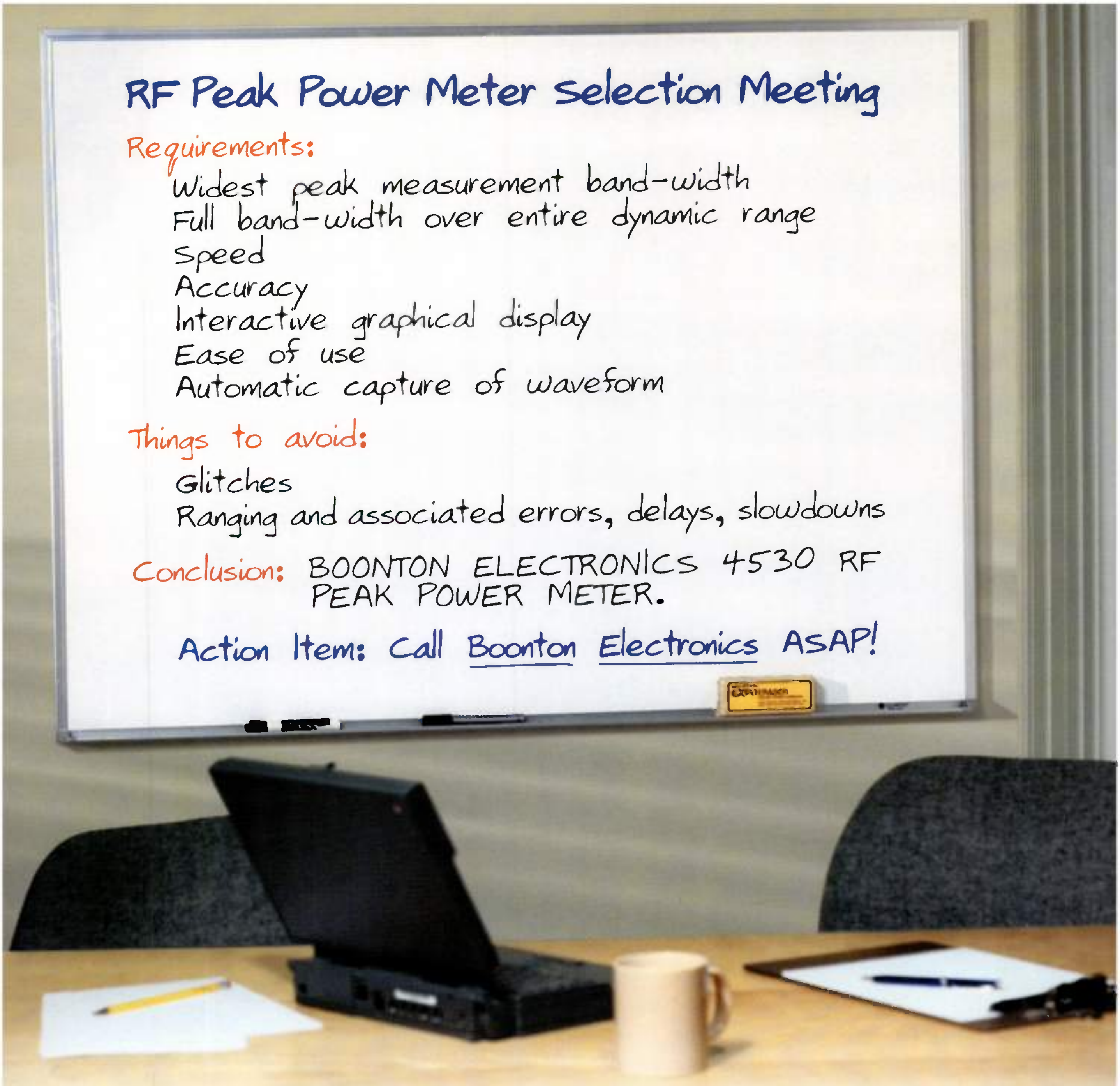
RF Peak Power Meter Selection Meeting
Requirements:
Widest peak measurement band-width
Full band-width over entire dynamic range
Speed
Accuracy
Interactive graphical display
Ease of use
Automatic capture of waveform
Things to avoid:
Glitches
Ranging and associated errors, delays, slowdowns
Conclusion: BOONTON ELECTRONICS 4530 RF PEAK POWER METER.
Action Item: Call Boonton Electronics ASAP!

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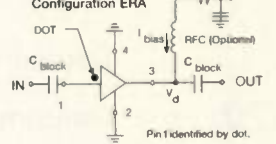
ERA-1SM ACTUAL SIZE

Model	*Freq. (MHz)	Gain (dB)	Max. Power Out (dBm, @1dB Comp)	Dynamic Range NF(dB)	Dynamic Range IP3(dBm)	@Device Current (mA)	(1) Price $ea. (30 Qty.)
ERA-1SM	DC-8000	11.8	11.3	5.5	26.0	40	1.42
ERA-21SM	DC-8000	13.2	12.6	4.7	26.0	40	1.57
ERA-2SM	DC-6000	15.2	12.4	4.6	26.0	40	1.57
ERA-33SM	DC-3000	17.4	13.5	3.9	28.5	40	1.72
ERA-3SM	DC-3000	20.2	11.5	3.8	23.0	35	1.72
ERA-6SM	DC-4000	11.3	▲17.9	▲8.4	▲36.0	70	3.90
ERA-4SM	DC-4000	13.5	▲16.8	▲5.2	▲33.0	65	3.90
ERA-51SM	DC-4000	16.1	▲18.1	▲4.1	▲33.0	65	3.90
ERA-5SM	DC-4000	18.5	▲18.4	▲4.3	▲32.5	65	3.90

Note:
Specs typical at 2GHz, 25°C.
Exception: ▲ indicates typ. numbers tested at 1GHz.
* Low freq. cutoff determined by external coupling capacitors.
(1) Price (ea.) Qty 1000: ERA-1SM $1.19, -2SM or -21SM $1.33, -3SM or -33SM $1.48, -4SM, -5SM, -6SM or -51SM $2.95.

Typical Biasing Configuration ERA



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Who's Fed up?

By Roger Lesser
Editor
rlesser@primediabusiness.com

As a common taxpayer, what would you say your chances are of getting anythir out of the federal government that it didn't want to give you? You are correc sir/ma'am. Zilch. So, how come the government (in this case the FCC) is being aske to give in on two issues?

It's my spectrum. No, it's my spectrum

Like two little kids battling over the last piece of candy, the FCC and NextWav have been locking horns over who owns the spectrum that NextWave purchase before filing for bankruptcy. To bring your scorebook up to date, here is how it wer down: In 1996, NextWave was granted licenses for spectrum to build a PCS networl It was to pay more than $4 billion. But, alas, NextWave payed just $500 millio before seeking bankruptcy.

So, the FCC took the candy away and reauctioned it to a number of players to th tune of $17 billion. NextWave appeals to the courts and loses. But, it wins on appea and now the FCC wants the Supreme Court to rule that it owns the candy and ca sell it to anyone it wants. And to get to this point has taken four years.

The argument from NextWave is the FCC is delaying access to 3G that consumer desperately want (I know I'm holding my breath). The FCC's contention is NextWav can't hide under the bankruptcy laws and will file its request on Sept. 22.

The current purchasers of the now melting candy (which include Verizon Wireless Cingular and Sprint) are pushing the FCC to settle the case.

Can have your candy and eat it too? Evidently. At least that is what the FCC i trying to do. They want the spectrum back for obvious reasons. $4 billion vs. $1 billion. Money talks.

I have to side with the FCC on this one. NextWave assumed the responsibility c paying the FCC for the spectrum and defaulted. Even thought it can now show it ha the backing, it's too late. The FCC took the right action in reauctioning the spectrur to the other players. It got more for it, and in the process is splitting the spectrur (17 licenses have been distributed). In the long run, I think this is better for the con sumer. Instead of having one bull in the china closet, you have many. This shoul mean a faster build-out and lower prices.

Speaking of bull

The other battle the FCC is waging, and one it should control, is the fate of it E9-1-1 mandate. The 1 Oct. deadline for carriers to have E-911 is fast approaching and here come the carriers asking for another extension. AT&T Wireless, Nexte and Verizon are all pleading they need more time. The FCC has already caved, er granted one exception to VoiceStream. Why?

The carriers had the option of implementing technology in the networks or th handsets. For nearly five years some carriers have shown no real interest in makin it happen, depending on yet another extension. No way, (San) Jose.

The need for E 9-1-1 is one of the most important issues facing telecommunica tions and public safety. People are dying (and I have the examples to prove it because of the lack of viable E-911. Stick to the 1 Oct. deadline.

Count me two for two on the side of the FCC.

Roger

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

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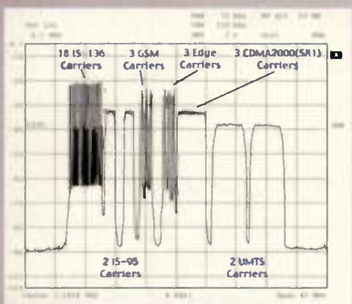

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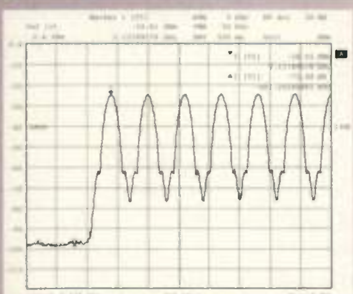
GSM Standard



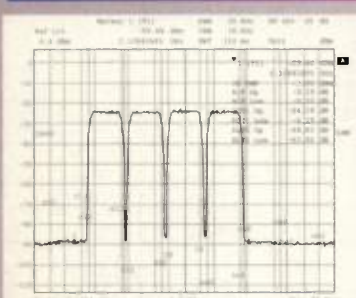
8 GSM Carriers
600 kHz Offset
2.14 GHz Band

-73 dBc IMD

+15 dBm PEP

Direct to IF Vector Signal Generation

UMTS (3.84 MS/s) Standard



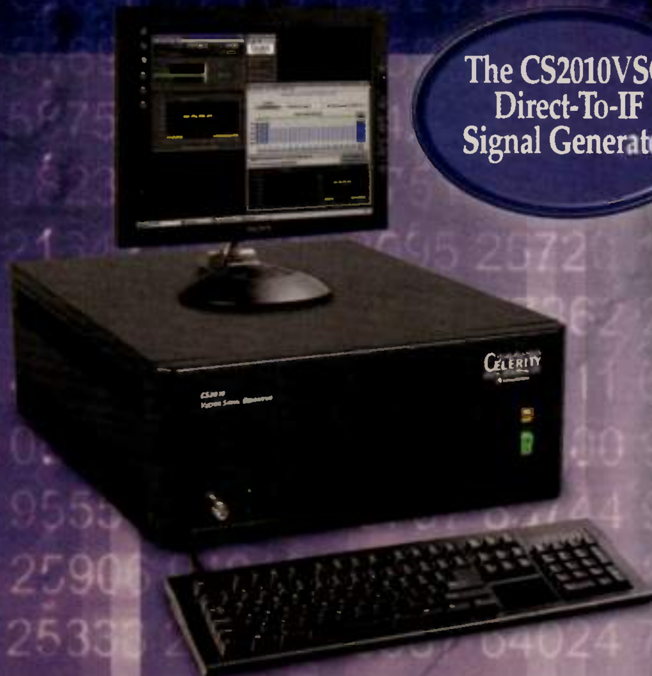
4 UMTS Carriers
Adjacent Channels
2.14 GHz Band

-64 dBc ACPR (eq BWs)

+19 dBm PEP

11.4 dB Crest Factor

Direct to IF Vector Signal Generation



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RF calendar

September

10–13 **CTIA Wireless I.T. and Internet 2001** – *San Diego* – Information: Web site: **www.wirelessIT.com**

19–21 **Voice-Activated Web Content** – *Boston* – Information: Web site: **www.srinstitute.com/ck102**

24–26 **EDA: Front-To-Back** – *Santa Clara* – Information: Penton Media. Tel. 1.888.947.3734.

24–28 **European Microwave Week** – *London* – Information: Web site: **www.eumw.com**

October

1–3 **34th Annual Connector and Interconnection Technology Symposium** – *Anaheim* – Information: Web site: **www.ec-central.org**

1–4 **Communications Design Conference** – *San Jose* – Information: Web site: **www.CommDesignConference.com**

2–4 **Sensors Expo Fall** – Philadelphia – Information: Web site: **www.sensorsexpo.com**

8–11 **Bluetooth Summit 5** – *Vienna, Austria* – Information: Web site: **www.iir-conferences.com/a.cfm?id=382>**

23–25 **Cleveland 2001 Advanced Productivity Exhibition** – *Cleveland* – Information: SME Customer Service. Tel. 800.733.4763. Web site: **www.sme.org/cleveland**

November

13–15 **APOC** – *Beijing* – Information: Web site: **www.spie.org/info/apoc**

December

3–6 **Internet World Wireless West 2001** – *San Jose* – Information: Web site: **www.ccievents.com**

11–13 **Bluetooth Developer's Conference 2001** – *San Francisco* – Information: Web site: **www.key3media.com/bluetooth/**

11–14 **International Radar Symposium India** – *Bangalore* – Information: Web site: **www.irsi2001.com**

January 2002

22–24 **Photonics West** – *San Jose* – Information: Web site: **www.spie.org/exhibitions/pw**

RF courses

Agilent Technologies – *RF and Microwave Fundamentals* – Dec. 4–6; *Network Analysis Measurements* – Oct. 16–17; *Spectrum Analysis Measurements* – Oct. 18–19. Information: Tracey Bull, Eskdale Rd., Winnersh Triangle, Wokingham, UK; Tel. +44.118.927.6741; Fax: +44.118.927.6862; e-mail: *tracey_bull@agilent.com*

Alexander Resources – *3G Wireless: Promises & Realities* – Sept. 24-25, Dallas, Oct. 29-30, Washington DC; *Making Money in the U.S. Wireless Internet Market* – Sept. 5-6, San Jose, Oct. 1-2, Dallas. Information: Jeff Stone, Alexander Resources,15851 N. Dallas Pkwy, Addison,TX 75001; Tel. 972.818.8225; Fax: 972.818.6366; e-mail: *jstone@alexanderresources.com*.

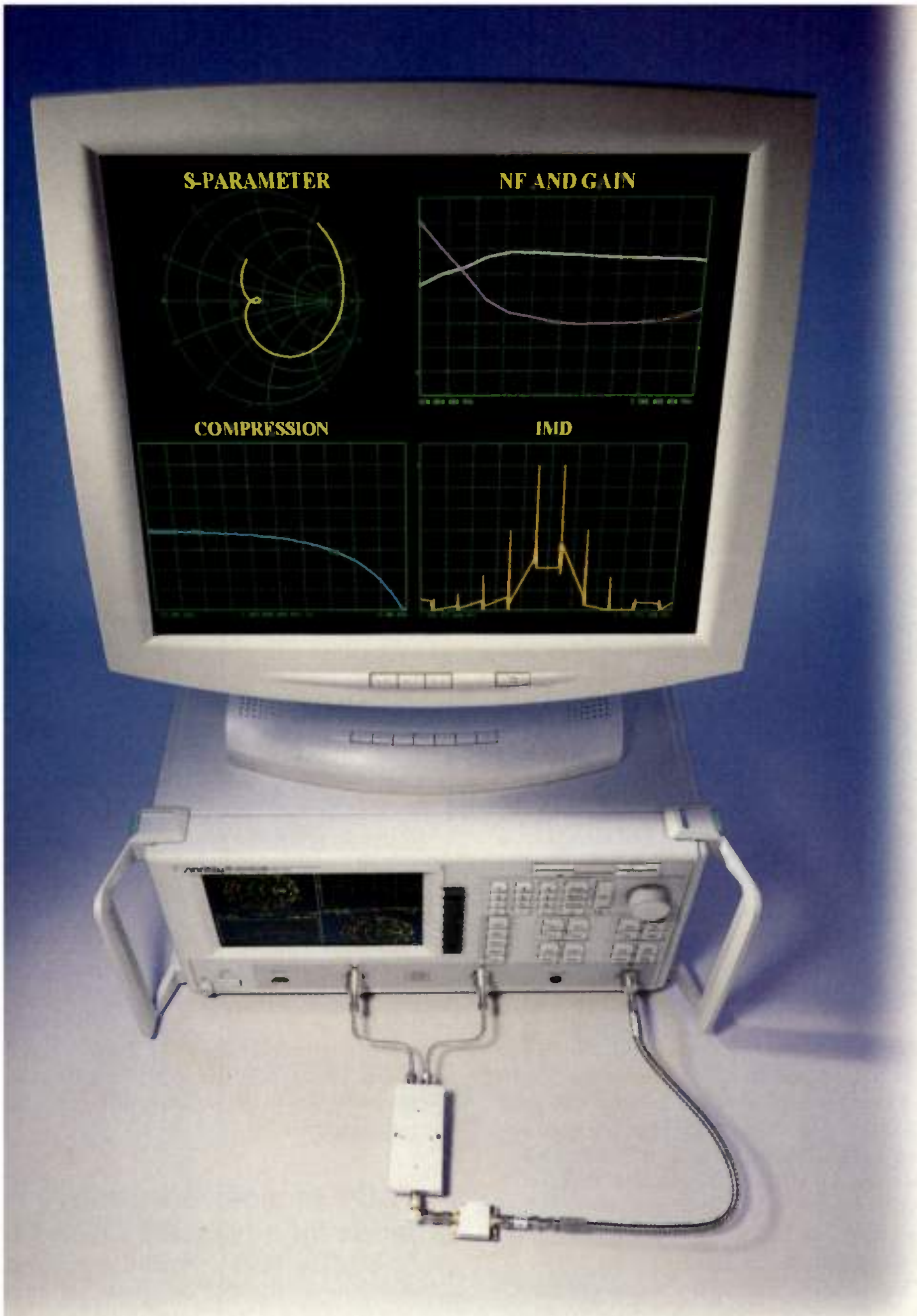
Besser Associates – *RF and Wireless Made Simple* – Oct. 22-23 ; *Fiber Optics Made Simple* – Oct. 30–31, Mountain View, CA. Information: Besser Associates, 201 San Antonio Circle Building E, Suite 280, Mountain View, CA 94040; Tel. 650-949-3300; Fax: 650-949-4400; e-mail: *info@bessercourse.com*; Web site: **www.bessercourse.com**

Georgia Institute of Technology – *Infrared Countermeasures* – Nov. 6–8, Atlanta; Information: Continuing Education, Georgia Institute of Technology, Tel. 404.385.3502; e-mail: *conted@gatech.edu;* Web site: **www.conted.gatech.edu**

R.A. Wood Associates – *Introductory RF and Microwaves* – Sept. 20–21; *RF and Microwave Receiver Design* – Sept. 24–26; *RF Power Amplifiers, Classes A–S: How Circuits Operate, How to Design Them, and When to Use Each* – Sept. 27–28, Lake George, NY. Information: R.A. Wood Associates, 1001 Broad St. Ste. 450, Utica, NY 13501; Tel. 315.735.4217; Fax 315.735.4328; e-mail: *RAWood@rawood.com;* Web site: **www.rawood.com**

UCLA – *Multirate Signal Processing in Transmitter and Receiver Designs* – Nov. 14–16; *Communications Systems, Using Digital Signal Processing* – Nov. 26–30, Los Angeles. Information: Information Systems and Technical Management Short Courses. Tel. 310.825.3344; e-mail: *mhenness@unex.ucla.edu*; Web site: **www.uclaextenstion.org/shortcourses**

University of Missouri-Rolla – *Circuit Board Layout to Reduce Noise Emission and Susceptibility* – Sept. 19, Denver. Information: Web site: **www.umr.edu/-conted>**



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Parameter	MS4623B Measures
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MS4623B Scorpion Vector Network Measurement System

INFO/CARD 1

With mobility and quality for all

By Nikki Chandler
senior associate editor
nchandler@primediabusiness.com

We all need help at times. Wireless technology can now aid not only mobile workers, but the handicapped as well.

In college, I took a political science class in which we studied the Americans with Disabilities Act, along with required readings. One book that I read in this class was written by a handicapped person who stated that being "disabled" was part of a person's identity — just like I am female or you are an engineer. (And don't tell me that "engineer" is not an identity; I am married to one.)

Bluetooth is one technology making progress in aiding the disabled. I know that it hasn't exactly lived up to its expectations in the past, but a company in the UK is doing something remarkable with the technology.

Red-M, based in Wexham Springs, UK, has provided Bluetooth to the National Star College of Further Education in Cheltenham, UK. The network allows the 150 students aged 16 to 25 with physical disabilities or acquired brain injuries to wirelessly access online resources and course content. It also enables them to submit coursework from their laptops, remotely over a Bluetooth connection.

The wireless network at the college is based on Red-M's 3000AS access servers and 1000AP access points, allowing mobile access from Bluetooth-enabled devices. By accessing the network, students can now have an increased level of access to education tools and learning services from a location convenient to them. Further applications under consideration, according to a press release from Red-M, include the ability for staff at the college to wirelessly access student's educational or medical records from personal digital assistants.

Is Bluetooth the best option for this application, though?

Another company based in Rochester, New Hampshire, has essentially done the same thing in Ireland. Enterasys Networks has provided Ireland's Southern Health Board with an IEEE 802.11b Roamabout wireless system for hospitals in Cork and Kerry, Ireland.

The system will be used to support Ireland's first virtual classroom, allowing children to continue learning from their hospital beds. According to a story by Dan McDonough Jr. on Wireless NewsFactor, the health board linked three hospitals within the Cork city area to the Cork University Hospital, the central site of the virtual classroom, using the Roamabout system.

A child who has to spend a lot of time in the hospital can attend his normal classroom by a virtual LAN, accessed and supported via the 802.11b system. Mobile wireless access to the wired LAN is possible using laptops connected via the Roamabout's access card and points.

Whether it is Bluetooth or 802.11b, wireless technology is doing more than making the average consumer's life more convenient with up-to-the-minute stock quotes or information on local restaurants. It is also providing a way for the disabled and the sick to maximize their quality of life. Thank you to all you who make that possible.

Nikki

Wireless still to grow on narrowband, broadband

Wireless is continuing to grow at good pace, despite the economic slow down of the technology industry, accord ing to Allied Business Intelligence (ABI Oyster Bay, NY.

Those involved in the narrowban and broadband wireless industries wi have an increasing volume of sales, AB said, though the upward curve may no match the grandiose predictions mad in 2000.

The wireless narrowband market i evolving as carriers move to 2.5G an 3G networks, upgrading infrastructur from 1999 to 2006. ABI predicts that overall, there will be more than 1.7 bil lion wireless subscribers by year-en 2006, with more than 500 million o those using wireless Internet access The movement into the next generatio of cellular technology will also create larger market for Bluetooth connectivi ty, with module shipments expected t rise from less than 1 million in 2001 t 1.6 billion in 2006.

For broadband wireless, LMDS MMDS and unlicensed band fixed wire less will continue to be used as a solu tion for the local loop. LMDS subscriber will number 3.6 million in 2007, accord ing to ABI, while the MMDS subscribe base will reach about 14 million durin the same period.

FCC examines spectrum bands for advanced wireless

The FCC took action in August t examine additional frequency band to support the introduction o advanced wireless services, includ ing 3G and future generations o wireless systems.

The Commission adopted a Memo randum Opinion and Order (MO&O and a Further Notice of Propose Rulemaking (FNPRM) that explor additional frequency bands. These include bands currently designate for the Mobile Satellite Servic (MSS), the Unlicensed Persona Communications Service, the Ama teur Radio Service, and the Multi point Distribution Service.

Specifically, the FCC seeks com ment on reallocating some spectrum in the 1910-1930 MHz, 1990-202 MHz, 2150-2160 MHz, 2165-220 MHz, and 2390-2400 MHz bands fo new advanced wireless services.

BUSINESS BRIEFS

Microchip Technology forms RF Products Group — Microchip Technology, Chandler, AZ, has formed the Radio Frequency Products Group. The group will design, develop and launch PICmicro microcontrollers with on-chip RF connectivity targeting high-volume embedded applications such as remote sensing, remote control, toys, security and access control.

SiGe Semiconductor awarded Bluetooth contract from CSR — SiGe Semiconductor's PA2423MB power amplifier has been selected by Cambridge Silicon Radio (CSR) for integration on CSR's BlueCore01 modules. The modules are designed to provide a complete, efficient, and low-power solution that accelerates time-to-market for Class 1 Bluetooth-enabled PCs, workstations and PCMCIA cards.

Mitel is reborn as Zarlink Semiconductor — Mitel, Canada, has announced it has changed its name to Zarlink Semiconductor. The company produces analog, digital and mixed-signal products for wired, wireless and optical connectivity markets.

Ansoft, Rohde & Schwarz team — Ansoft, Pittsburgh, announces an agreement with test and measurement equipment manufacturer, Rohde & Schwarz, Germany, to provide links between its popular WinIQSIMŒ communication waveform generation software and Ansoft's communications design products, Serenade and Symphony. The new capability will allow RF designers and system architects to simulate communications systems under the same conditions used in hardware testing and product development.

RF Micro Devices opens China facility — RF Micro Devices, Greensboro, NC intends to open a facility in the Beijing Xingwang Industrial Park, which is located in the Beijing Economic Technological Development Area. The Beijing Xingwang Industrial Park was established in May 2000 by Nokia in conjunction with the Chinese state governments, the Beijing municipal government and representatives of the Beijing Economic-Technological Development Area.

Socket successfully trials Bluetooth with Japanese telecom operator — Newark, CA-based Socket Communications' Bluetooth CompactFlash Cards were successfully used as part of a trial of Bluetooth wireless technology by NTT, a Japanese telecom operator, in partnership with Sumitomo. The cards were a component of a location-based system, including navigation that was recently tested in an Osaka shopping arcade. This trial was designed to demonstrate Bluetooth connectivity between handheld devices and LAN access points.

Xemics selects Conexant for Bluetooth baseband device — Xemics, Neuchâtel, Switzerland, announces that it has selected Mountain View, CA-based Conexant's Bluetooth radio as the preferred radio device to implement its ultra-low-power Bluetooth solution.

Advance, Agilent Technologies partner with CETECOM S.A. for Bluetooth Conformance testers — Agilent Technologies, Palo Alto, CA, and Centro de Tecnologia de las Comunicaciones S.A. (CETECOM), Monte Carlo, announce that CETECOM, an Agilent value-added reseller (VAR), has integrated Agilent equipment into test solutions to help manufacturers meet the industry certification requirements for Bluetooth devices.

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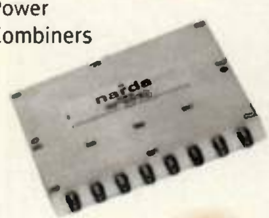

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DARING

INNOVATION

Integrating Bluetooth in the GSM cell phone infrastructure

Embedding a Bluetooth subsystem in a cellular telephone may be the first step toward complete wireless integration

By Steve Brown, Mark Lane, Dino Fernandez

We've all heard the distinct sound in elevators, at restaurants, during meetings, even at church: *the cell phone ring*. The sound pierces through the air as discernible as a mother calling for her children in a supermarket. The reaction is immediate: People dive into their pockets, rummage through purses or reach along belt buckles to check if the intrusion emanates from their person. It seems everybody has one: business people, housewives, janitors, kids, even nuns.

Integrating the future.

Business is won and lost. Personal relationships are strengthened or weakened. It's inescapable. Moreover, it's annoying. Nevertheless, that sound we hear is only a minor irritation. The noise we can't hear or see is the real nuisance. For engineers, it impedes our advancement, another roadblock the evolution of technology must conquer. It makes life difficult for the ones entrusted to make life easier.

One can only wish...

In a perfect RF world, a simple hand-held device such as a cell phone would work seamlessly to transmit and receive information to and from computers. It would open garage doors, set timers on VCRs, change channels on televisions, surf the Internet, and buy a soda from a vending machine — one device, endless possibilities. In a perfect RF world, there would be no wires to connect. In a perfect RF world, PC would communicate with Mac. In a perfect RF world, there would be no such thing as interference or noise. The airwaves would be serene, and everything would co-exist. HomeRF, 802.11x, and Bluetooth would lovingly share the 2.4-GHz band. And, RF would stand for "really friendly."

Currently, Bluetooth wireless technology is being touted as a de facto standard, as well as a global specification for wireless connectivity. It is a cable replacement technology that simplifies the communications between people, as well as mobile PCs, cell phones and other portable devices.

Bluetooth's markets and opportunities

Cell phones are one of Bluetooth's larger potential markets. In fact, Bluetooth's roots are in the global system for mobile communications (GSM) world, and forecasts predict fast growth of Bluetooth in the GSM markets. However, putting a powerful cellular radio next to a low-power Bluetooth radio in a cell phone requires careful design because of the possibility of RF transmit and receive interference between the two radios. Therefore, engineers must develop Bluetooth systems using special radio filters that can function despite internal noise from the GSM cell phone and spurious radio signal interference.

In reality, any Bluetooth module/unit will be exposed to an unfriendly RF environment. The Bluetooth system is designed to have a high tolerance to interference, but is not necessarily designed to have high sensitivity. The 2.4 GHz industrial, scientific and medical (ISM) band, which includes microwave ovens, presents serious forms of interference for Bluetooth communications. The biggest problem in adding Bluetooth to cell phones is the potential for the powerful cell phone transmitter blocking the Bluetooth receiver during transmission. While GSM hand-held transmitters produce 1 to 3 W, the Bluetooth receiver is intended to operate effectively with signals as low as 10 pW, or 1/100,000,000,000 of the power, resulting in the Bluetooth receiver being overwhelmed by its over-

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10dB	DBTC-10-4-75	5-1000	1.4	20
12dB	DBTC-12-4	5-1000	0.7	21
13dB	DBTC-13-4	5-1000	0.7	18
13dB	DBTC-13-5-75	5-1000	1.0	19
		1000-1500	1.4	17
16dB	DBTC-16-5-75	5-1000	1.0	21
		1000-1500	1.3	19
17dB	DBTC-17-5	50-1000	0.9	20
		1000-1500	1.0	20
		1500-2000	1.1	14
18dB	DBTC-18-4-75	5-1000	0.8	21
20dB	DBTC-20-4	20-1000	0.4	21

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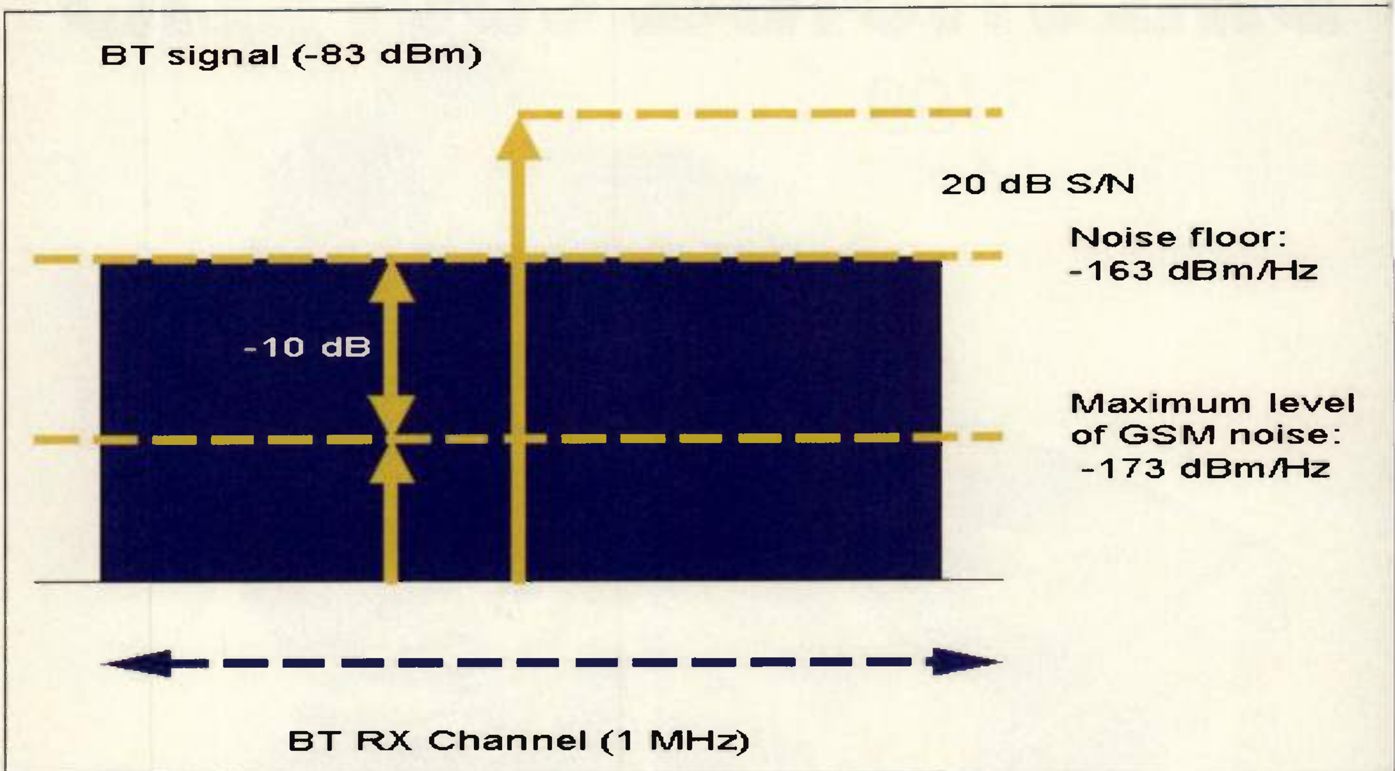

Figure 1. GSM phone interfering with a Bluetooth module.

bearing cell phone neighbor. The GSM transmitter may also generate significant noise, which could limit the range of Bluetooth operations.

The issues — tx/ rx

The fundamental problem is that a cell phone's transmitter transmits not only the required data signal, but a certain level of noise as well. Some of this noise will appear in the Bluetooth band. The level of this noise might be sufficient to interfere or block an incoming Bluetooth signal.

Wideband noise affects half-duplex cellular systems (the cellular radio either transmits or receives, but does not do both simultaneously). Such systems include the time-division-multiple-access-(TDMA) based GSM standard, as well as full-duplex systems (the cellular radio can simultaneously transmit and receive) such as code-division multiple access (CDMA).

To illustrate the problem, consider the situation of a GSM-based telephone and a Bluetooth module. For the GSM standard, three possible bands exist: GSM 900, PCS 1900, and DCS 1800. The output power for each standard is shown in Table 1.

For GSM applications, the biggest source of noise in conventional transmitter architectures is from the RF up-converter. The noise floor of the VCO used in the frequency synthesizer typically dominates this noise. In addition to VCO noise, the non-linearity of the amplifiers used in the transmit chain can result in noise intermodulating in the amplifiers (see Figure 1). This intermodulation can result in a type of spectral re-growth in the output spectrum. This re-growth is reduced in most transmitters by using a bandpass filter to reduce the out-of-band noise. The far-out noise will be a function of the VCO noise, the modulator noise figure, and the amount of rejection achievable in the RF transmit filters.

Plan "B"

GSM designers have recently turned to architectures with no modulator by using translational loops. This relies on a high-frequency PLL. In this case, the VCO noise floor and the attenuation profile of a low-pass filter limit the wideband noise. In all three systems, the wideband noise from the transmitter that falls in the certain bands is restricted.

The specifications

Outside of these bands, all the telephones need to meet the following requirements:

- *ETSI requirements for spurious emissions other than those described above.*
- *<1 GHz: wideband noise must be <–36 dBm.*
- *>1 GHz: wideband noise must be <–30 dBm.*

Although the figures above are encouraging, the wideband noise in the 2.4 GHz ISM band remains undefined. Thus far, the FCC/ETSI requirements ignore the case of having a 2.4 GHz device inside a 900, 1800, or 1900 MHz device.

The Feds say...

The FCC allows users to operate wireless products without obtaining FCC licenses if the products meet certain requirements. For example, there is no limit on antenna gain so long as the radio operates under 1 W of transmitter output power. Because the FCC rules are market-based, they allow for flexibility within the band. This is a good thing because no one model will fit all situations. For example, in rural areas, spectrum interference is lower, but a higher radiation power (for greater range) is required. In urban areas where populations are denser, the need to eliminate interference is great.

The deregulation of this frequency spectrum does away with the need for

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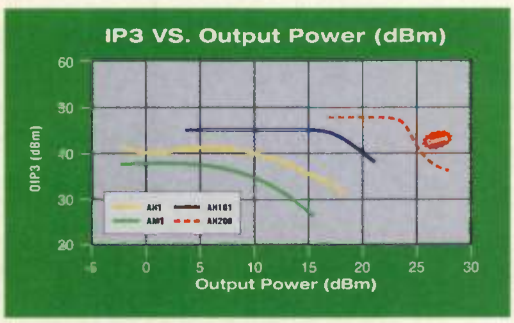

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AH102	350-3000	45	27	200
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AM1	250-3000	37	18	75
AH200	250-6000	47	30	360

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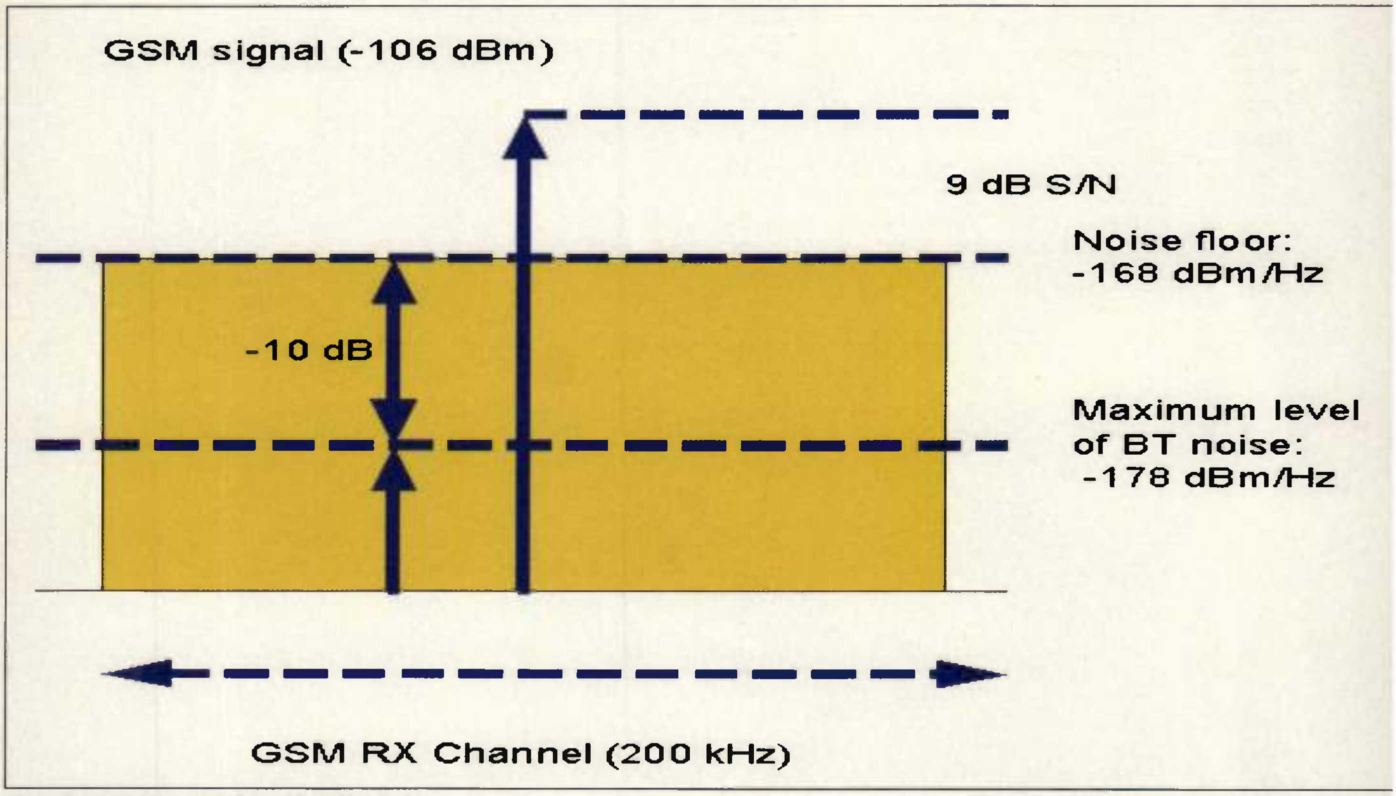

Figure 2. Bluetooth interfering with GSM cell phone.

user organizations to perform costly and time-consuming frequency planning to coordinate radio installations that will avoid interference with existing radio systems.

For companies developing wireless communications, the door is wide open because it allows companies to develop products without worrying about licensing products in new bands and stimulates competition between organizations to bring to market better overall products. More available bandwidth in the higher frequency bands translates into higher data rates. Thus, the creation of ad hoc networks is easier; one of the objectives of Bluetooth.

To ensure that the Bluetooth radio module will operate effectively inside a cell phone, the level of noise from the phone's transmitter must be measured and controlled. This is particularly true if the phone uses a filter at the output. It is important that this filter does not have a spurious response in the 2.4 GHz band.

In addition, designers need to build in a defense against interference. In radio engineering terms, the wideband noise, measured in a 1 MHz-wide band in the 2.4 GHz band, should be less than –100 dBm. If this is not the case, a trap should be placed at the output of the transmitter to attenuate energy in the 2.4 GHz band.

For Bluetooth, this will be relatively easy to add to today's phone designs, but may pose a problem for third-generation (3G) systems operating at 2.1 GHz because their signals are close to the 2.4-GHz band used by Bluetooth. The wideband noise requirements for a GSM transmitter in other bands of interest are given in Table 2. Note that there is no additional requirement for the 2 GHz ISM band.

To ensure that the Bluetooth unit/module will operate effectively inside a cell phone, the noise level from the transmitter of such telephones should be measured. This is particularly true if the telephone uses a filter at the output. It is important that this filter does not have a spurious response in the 2.4 GHz ISM band.

For a spurious emission of –83 dBm in the Bluetooth receiver band, the GSM spurious response requirements are given in Table 3.

System	Rx Freq. (MHz)	Tx Freq. (MHz)	Max. output power (dBm)
GSM 900	935 to 960	890 to 915	33 (3W)
PCS 1900	1930 to 1990	1850 to 1910	30 (1W)
DCS 1800	1805 to 1880	1710 to 1785	30 (1W)

Table 1. GSM output power.

System	935 to 960 MHz	1805 to 1880 MHz	1930 to 1990 MHz
GSM 900	–79 dBm	–71 dBm	–71 dBm
PCS 1900	–79 dBm	–71 dBm	–71 dBm
DCS 1800	–79 dBm	–71 dBm	–71 dBm

Table 2. GSM wideband transmission.

Problem: BT tx blocks GSM

The second problem in the cell phone application is the Bluetooth

Parameter	Specification
Required C/I (carrier-to-interference ratio)	20 dB
GSM spurious emission	–83 dB
Loss between BT and cell phone antenna	20 dB
Power into BT receiver	–103 dBm
Minimum discernable signal	–83 dBm

Table 3. GSM spurious response requirements in the Bluetooth RX band.

transmitter noise blocking the receiver of the cell phone (the "David and Goliath" problem). The Bluetooth transmitter must never interfere with the cell phone operation. This defeats the purpose of the Bluetooth application. Shown below and in Table 4, the level of noise from the Bluetooth transmitter in the relevant bands is calculated based on a maximum output power of 0 dBm. The aim is to keep the transmitted noise from the Bluetooth transmitter of the cellular telephone to ≤ the channel noise (the channel noise has a power spectral density (PSD) of –174 dBm/Hz).

In the GSM band, the Bluetooth transmitter will be able to achieve a PSD of –158 dBm/Hz into the Bluetooth antenna.

This, however, assumes the following:

1. Unfiltered transmitter noise is dominated by VCO phase noise/modulator noise at –125 dBc/Hz as the transmitter approaches a maximum power output of 0 dBm. This translates to –125 dBm/Hz.

2. The noise is attenuated at least 33 dB by the transmit filter.

Finally, if there is at least 20 db of coupling loss between the cell phone and the Bluetooth antenna, the level of the noise in the cell phones receiver will be -178 dB (see Figure 2), which is 10 dB below the noise floor of the GSM receiver. Hence this will cause < 1 dB desense of the GSM receiver. To accom-plish this, it is essential that the Bluetooth filter not have spurious responses at the cell phone receive fre-quencies.

Conclusions

Each cellular standard presents specific challenges to Bluetooth, and this analysis does not account for any other form of injected noise or interference such as that generated by digital logic circuitry, reference oscillators, liquid crystal displays (LCDs), and similar components. To smoothly integrate Bluetooth products into hand-held devices such as cell phones, power consumption must be minimal during active and standby modes and must be small enough to fit comfortably within the device. They must also be cost-effective so not to significantly increase the overall price of the device. Radio performance must have good sensitivity, low IP3 current, effective receiver blocking and transmitter sensitivity, low transmitter spurious response and low transmitter noise.

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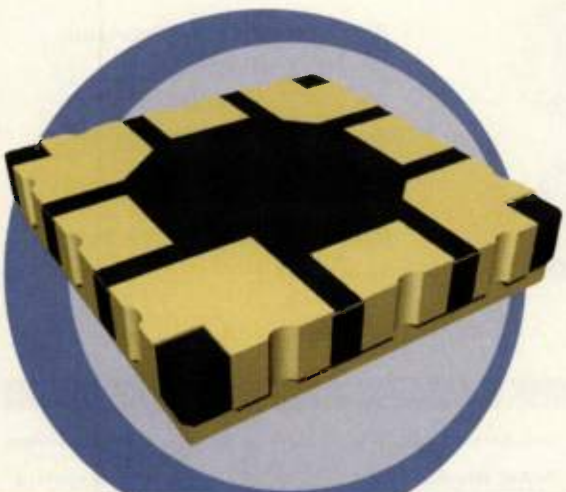

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Band of Interest	PSD Noise	RBW = 30 kHz	RBW = 100 kHz
800 to 900 MHz	–158 dBm/Hz	–113 dBm	–108 dBm
1800 to 1900 MHz	–158 dBm/Hz	–113 dBm	–108 dBm
1400 to 1500 MHz	–158 dBm/Hz	–113 dBm	–108 dBm

Table 4. Transmitted noise levels from the Bluetooth transmitter.

As technology advances further (read: simpler; smaller; cost-effective), today's novelty items will become tomorrow's everyday appliances — domesticated devices that will be second nature. As the world continues to get smaller and communications systems improve, people will trade data and communicate seamlessly via airwaves. The fact that Bluetooth wireless technology is a standard and a technology with an ad-hoc nature makes this possible. Although Bluetooth has an innovative and well-thought-out architecture to survive in this unforgiving radio environment, extensive testing of real radios is the only way to ensure compatible high performance.

RF

1. C/I: carrier to interference ratio.

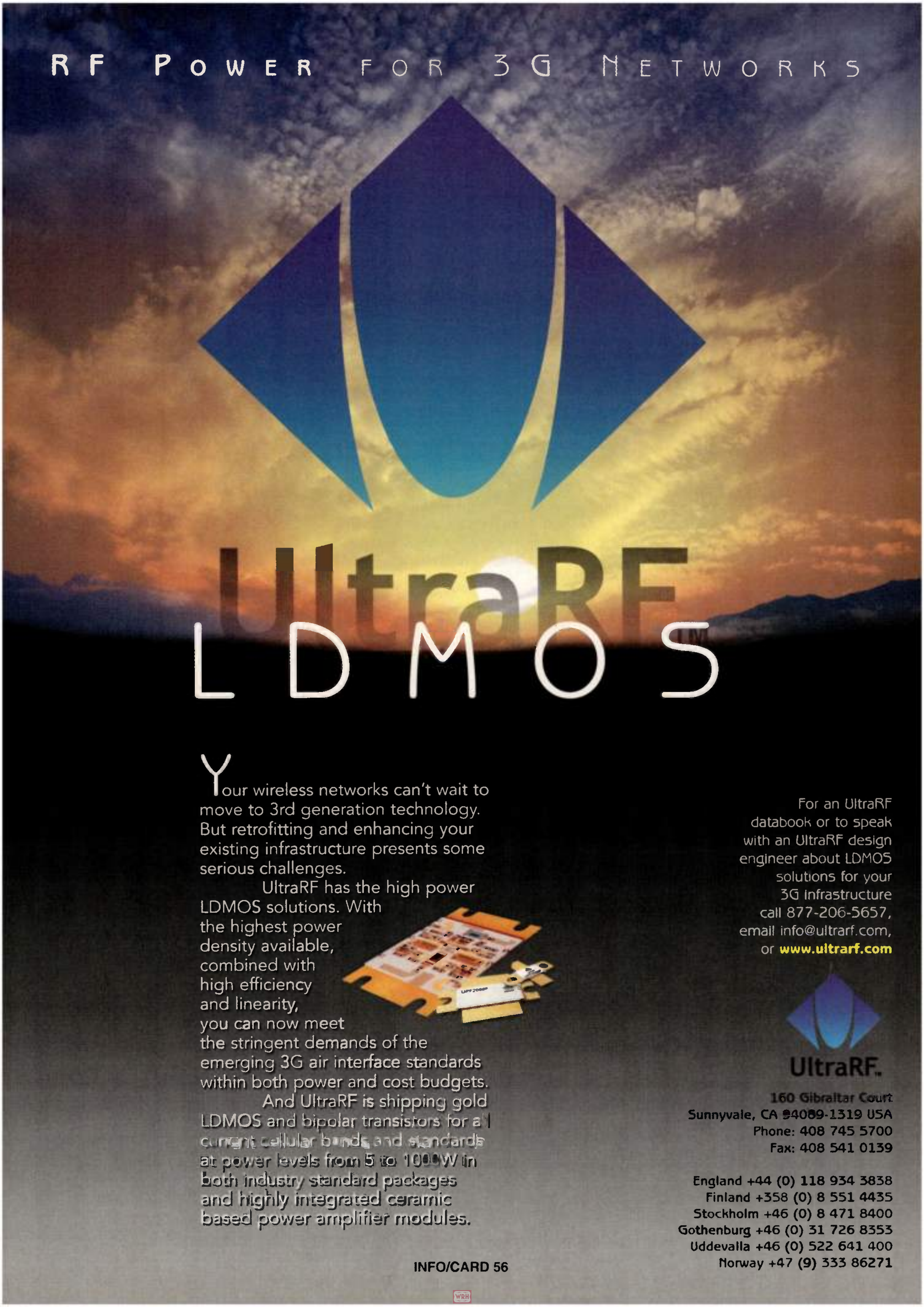
2. For a narrowband system, a bandwidth of 30 kHz for example, the integrated thermal noise floor is –129 dBm. Thus, with a filter rejection of 30 dB and 30 dB of coupling loss, the Bluetooth transmitter noise in the GSM band will be –135 dBm/Hz. This is below the thermal noise floor of the system. Therefore, with a –145-dBm/Hz Bluetooth transmitter noise floor, –30 dB of RF filter rejection in the cell phone receive band, and 30 dB of coupling between the antennas, there should be no desense to the cell phone.

About the author

Steve Brown is VP, general manager Bluetooth products at Silicon Wave. He has more than 10 years experience in design and management and holds a bachelor's degree in electronic and information engineering from Queens University Belfast, Northern Ireland.

Mark Lane is RF systems manager at Silicon Wave. Lane has three years of system design experience with Bluetooth and more than 10 years experience in the wireless industry. He holds a bachelor of electrical and electronic engineering with 1st Class honors from Auckland University New Zealand.

Dino Fernandez is a technical writer at Silicon Wave. Fernandez has been involved with the semiconductor industry for three years with seven years of analog design experience. He holds bachelor's degrees in electrical engineering, applied math, and English from San Diego State University.



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INFO/CARD 56

Matched filtering and timing recovery in digital receivers

A practical look at methods for signal detection and symbol synchronization.

By Louis Litwin

The acquisition of a signal in a digital communications system requires the convergence of several signal processing algorithms before the receiver can output meaningful data. These algorithms are adaptive in nature and need to process multiple received symbols before convergence is achieved. Because of the feedback nature inherent in these algorithms, the various adaptive receiver sections are often referred to as loops. Certain receiver loops depend on other loops. Depending on the algorithm implemented, it is possible that a given loop cannot converge until one or more previous loops have sufficiently converged. The major receiver loops are listed in the order that they typically need to converge, although the order may sometimes vary depending on the implementation.

Stage 1 – AGC

This stage scales the signal to a known power level. Automatic gain control (AGC) is typically handled in the analog domain to properly scale the signal for analog-to-digital (A/D) conversion because A/D converters have a limited dynamic range. If the received signal strength is too high, the A/D conversion process will introduce a type of distortion known as clipping. If the signal strength is too low, the signal variations will toggle only a few bits at the A/D, and distortion will occur because of severe quantization.

The convergence of the AGC loop is also required for several other receiver blocks. Certain parameters and gains for various adaptive algorithms, as well as boundaries for symbol decision regions at the slicer, are based on the signal being at a known power level. In addition to the analog AGC, many receivers implement an additional AGC in the digital domain for fine signal scaling.

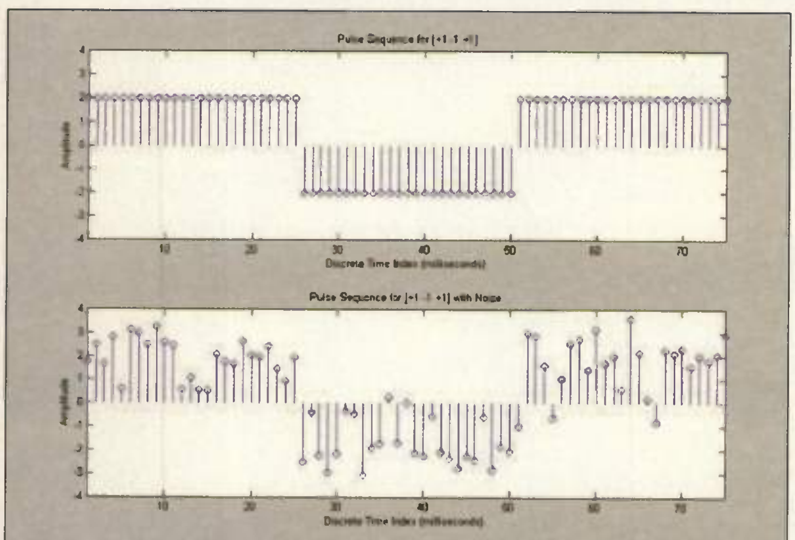

Figure 1. Rectangular pulse train shown with and without noise. The SNR for the lower plot is roughly 5 dB.

Stage 2 – timing recovery

The purpose of the timing recovery loop is to obtain symbol synchronization. Two quantities must be determined by the receiver to achieve symbol synchronization. The first is the sampling frequency. Locking the sampling frequency requires estimating the symbol period so that samples can be taken at the correct rate. Although this quantity should be known (e.g., the system's symbol rate is specified to be 20 MHz), oscillator drift will introduce deviations from the stated symbol rate.

The other quantity to determine is sampling phase. Locking the sampling phase involves determining the correct time within a symbol period to take a sample. Real-world symbol pulse shapes have a peak in the center of the symbol period. Sampling the symbol at this peak results in the best signal-to-noise-ratio and will ideally eliminate interference from other symbols. This type of interference is known as intersymbol interference.

Stage 3 – carrier recovery

An oscillator at the transmitter generates a sinusoidal carrier signal that ideally exists at some known carrier frequency. Due to oscillator drift, the actual frequency of the carrier will deviate slightly from the ideal value. This carrier is multiplied by the data to modulate the signal up to a passband center frequency. At the receiver, the passband signal is multiplied by a sinusoid generated by the local oscillator.

Preferably, the frequency of the local oscillator will exactly match the frequency of the oscillator used at the transmitter. In practice, their frequencies differ and, instead of demodulation bringing the signal to baseband, the signal will be near baseband with some frequency offset. The presence of this frequency offset will cause the received signal constellation to rotate. This "spinning" effect must be removed before accurate symbol decisions can be made. The purpose of the carrier recovery loop is to remove this frequency offset so that the signal can be processed directly at baseband.

Stage 4 – channel equalization

Transmitting a signal through a multipath channel results in a received signal that consists

Continued on page 36

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ADE-3G	3	2300-2700	+7	5.6	36	13	3.45
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ADE-30	3	200-3000	+7	4.5	35	14	6.95
ADE-32	3	2500-3200	+7	5.4	29	15	6.95
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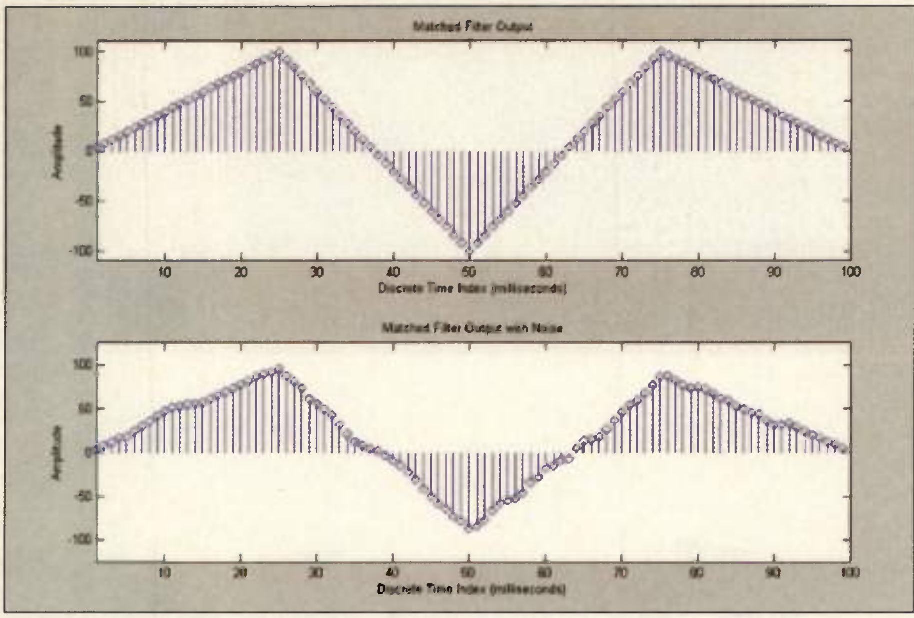


Figure 2. Matched filter outputs for signals in Figure 1.

of several delayed and scaled versions of the transmitted signal. Multiple versions of the signal occur because the receiver may pick up the signal that traveled the direct path from transmitter to receiver, as well as multiple reflected paths. The multipath channel can be viewed as a linear filter. The equalizer is an adaptive filter that attempts to remove intersymbol interference by undoing the filtering effects of the multipath channel.

Timing recovery algorithms adaptively determine the correct time to sample the symbol pulse shape. Thus, before entering into a discussion on timing recovery, some background material will be provided on the topics of matched filtering and pulse shaping.

Signal detection

A basic problem in digital communications is the detection and estimation of a transmitted pulse in the presence of additive white Gaussian noise (AWGN). Imagine the simple case of a rectangular pulse, such as that shown in the top half of Figure 1. A data symbol of +1 is indicated by transmitting a pulse with an amplitude of +2, and similarly, a data symbol of –1 is indicated by transmitting a pulse with an amplitude of –2. The period of these pulses, T, is 25 ms. Note that the one pulse is simply a negated version of the other.

When two pulse shapes are used that have the same energy and a cross-correlation of –1, the signaling set is said to be antipodal. The estimation of the transmitted pulse shape is trivial for the ca of no noise. The receiver simply takes o sample every T seconds and determin whether the sample equals +2 or –2.

Such a scheme no longer works in t presence of AWGN. White noise has in nite average power and can therefore ea ily drown out the received signal that is limited power. The lower half of Figure shows the same pulse sequence for t case of noise with a signal-to-noise rat (SNR) of 5 dB. Note that the noise h severely distorted the signal, even flippi the sign of some samples. Because a practical communications systems ha some non-trivial noise level, a more robu signal estimation scheme is needed.

Matched filtering

Practical receivers estimate t transmitted signal by using a tec nique known as matched filtering. receiver employing such a technique fi ters the received signal with a filt whose shape is "matched" to the tran mitted signal's pulse shape. The outp of the filter is then sampled at time The matched filter's pulse shape is time-reversed version of the transm pulse shape. Thus, if the transmit puls shape $h(t)$ is defined as:

$h(t)$ for $0 \le t \le T$

then the ideal matched filter's respons $h_m(t)$ is:

$h_m(t) = h(T-t)$ for $0 \le t \le T$

Such processing has two advantage One advantage is that typical puls shapes have a low-pass response. By fi tering the received signal with such a fi ter at the receiver, the frequencies co taining the data signal are passed whil the remaining frequencies are attenua ed. This matched filtering limits th amount of the noise spectrum that i passed on to subsequent stages in th receiver. A second advantage is that matched filter correlates the receive signal with the transmit pulse shap over the symbol period T.

Recall that passing a signal $r($ through a filter $h_m(t)$ is a convolutio operation. The convolution of these tw signals can be written as:

$$y(t) = \int_T^0 r(t) h_m(T-t) dt$$

where $y(T)$ represents the output of th matched filter sampled at time However, the matched filter's respons

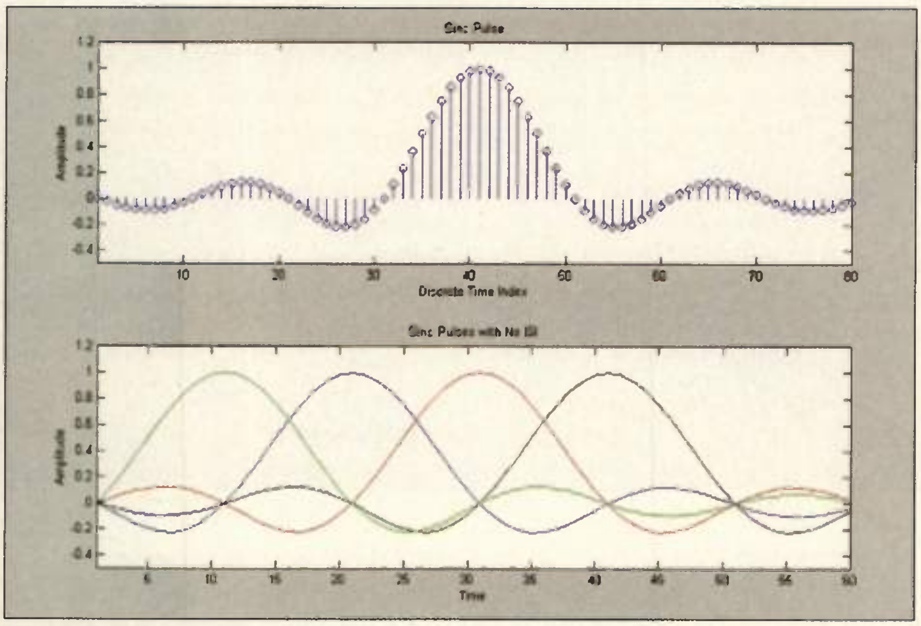
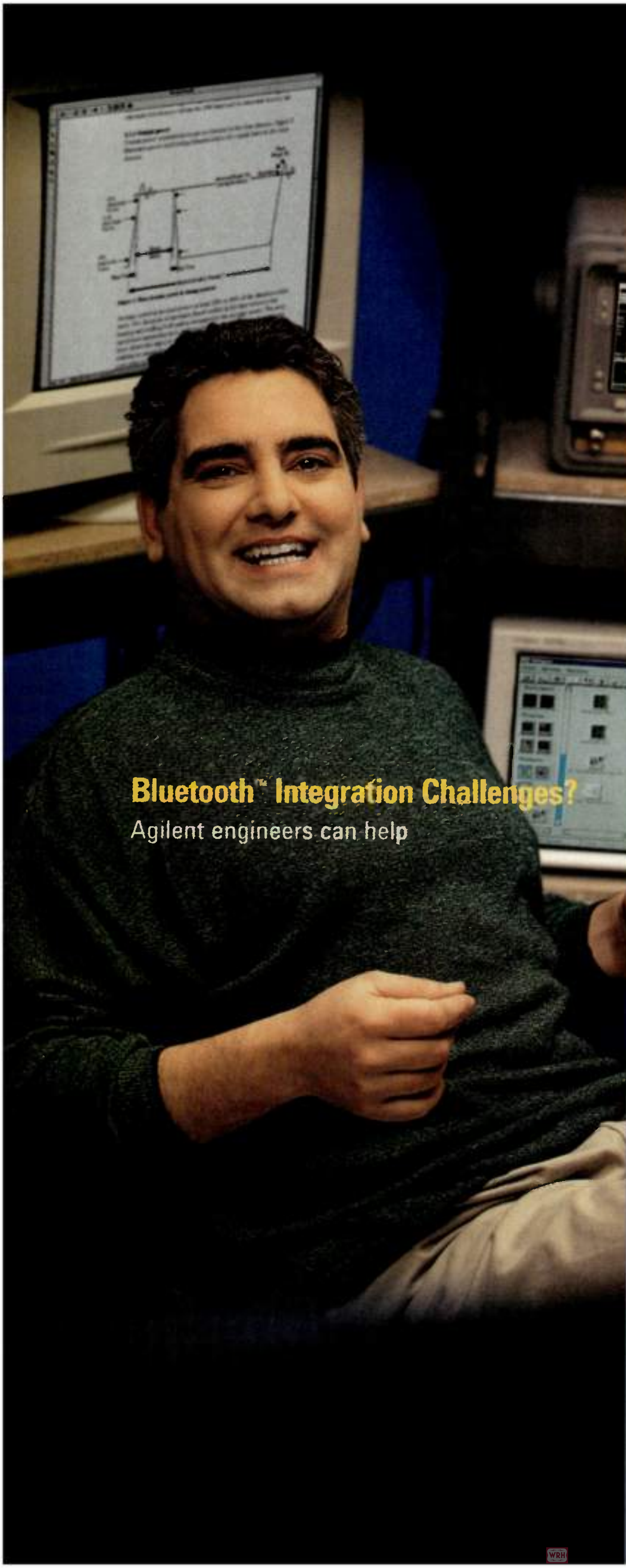


Figure 3. Sinc pulse examples.



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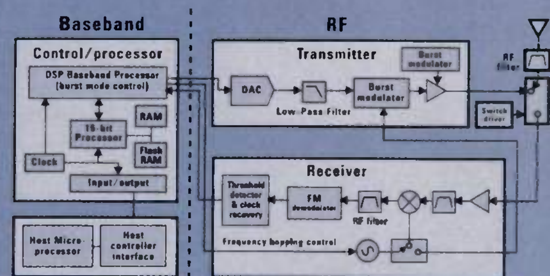

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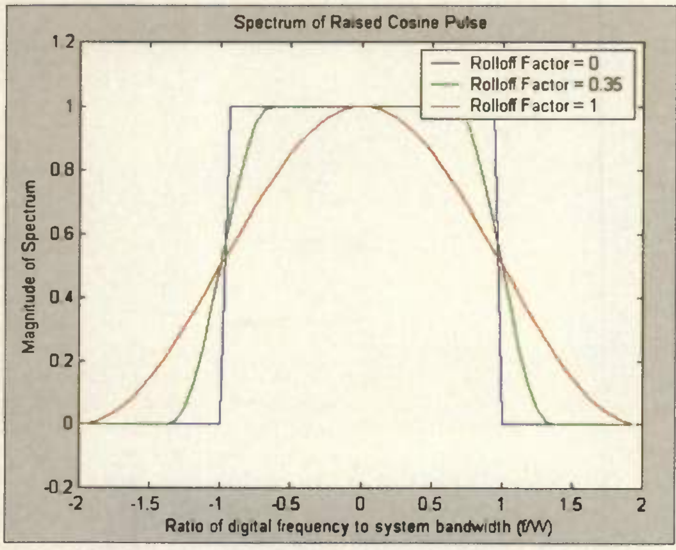


Figure 4. Spectrum of raised cosine pulse for different values of the roll-off factor.

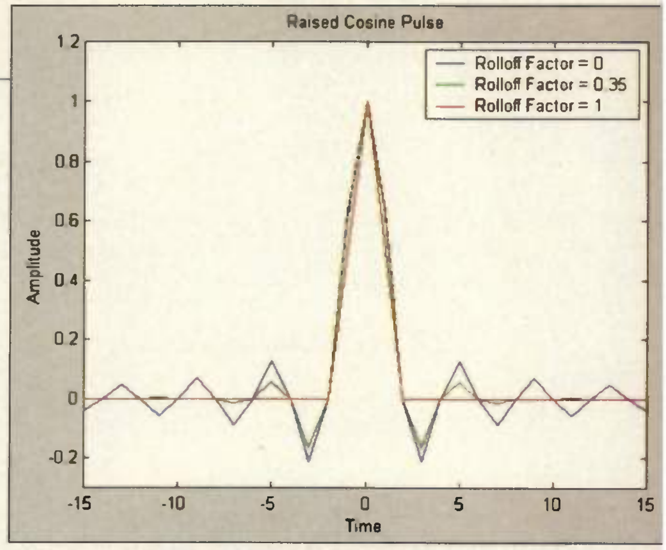


Figure 5. Raised cosine pulse for different values of the rolloff factor.

was defined as $h_m(t) = h(T - t)$. By substituting this definition into the above equation, the following integral is obtained:

$$y(t) = \int_0^T r(t)h(T-(T-t))dt =$$

$$\int_0^T r(t)h(t)dt$$

The above equation is the cross-correlation (sampled at time T) of $r(t)$ with $h(t)$ for a lag of 0. Thus, this simple derivation has illustrated how matched filtering effects the correlation of the received signal with the matched filter. Such processing results in a correlation gain by integrating the received signal energy while averaging out the zero-mean AWGN.

An example of matched filtering is shown in Figure 2. The received signals for the top and bottom halves of the figure are the signals shown in Figure 1. The matched filter used was:

$$h_m(t) = 2 \text{ for } 0 \le t \le T$$

Note that sampling the matched filter output at time T = 25 ms provides the sample with the highest SNR. The samples from Figure 1 had an amplitude of 2, whereas the matched filter output (when sampled properly) has a value of 100. The value of 100 represents the integral, over the time period T, of the received signal pulse shape exactly lined up with the matched filter response. The value of this peak can be calculated as follows:

$$y(t) = \int_0^{25} (2 \bullet 2)dt =$$

$$25(4) - 0(4) = 100$$

This simple example illustrates how matched filtering provides the receiver with a stronger signal to work with compared to directly sampling the received signal. The processing gain of matched filtering is especially apparent for the example with an SNR of 5 dB.

Note that the received signal is severely distorted by noise, but the matched filter's output is still close to its ideal value for the case of no noise. This result is possible because the matched filter filters out the higher frequency noise and then integrates the remaining lower frequency noise over a time period of T ms. Because AWGN is zero-mean, this integration effectively averages out the noise.

As can be seen from Figure 2, it is important to sample the matched filter's output exactly at time T to obtain the sample with the highest SNR. Sampling the matched filter's output at some time $T + \Delta$, (where Δ represents a receiver timing offset) will significantly reduce the effective SNR seen by subsequent receiver blocks. This example shows the importance of keeping Δ as close to zero as possible and thus provides motivation for the inclusion of a timing recovery loop in the receiver.

Before discussing specific timing recovery algorithms, the next sections will first illustrate the problems inherent in using this rectangular pulse shape. A more practical pulse shape known as a root-raised cosine pulse will then be introduced.

Ideal pulse shaping

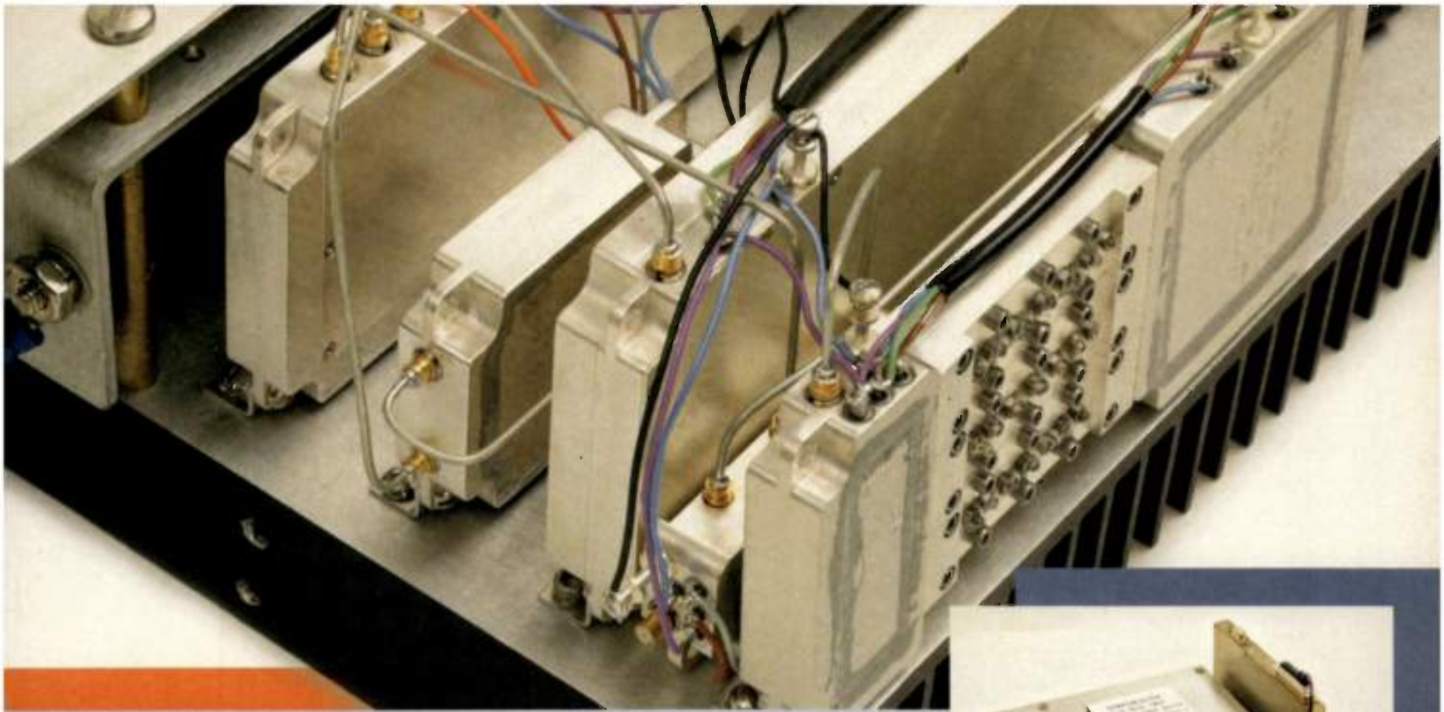
Although the use of matched filtering gives the optimum performance in the presence of AWGN, there is still a problem with using a rectangular pulse shape. Recall from Fourier theory that a rectangular pulse in the time domain is equivalent to a sinc pulse in the frequency domain. Because the tails of the sinc pulse extend to infinity, such pulse shape would require a syste with infinite bandwidth.

The ideal pulse shape should hav two properties. It should have a limite bandwidth to allow transmission o practical band-limited systems. Th pulse shape should also have zero inte symbol interference if sampled at th correct time interval. That is, when pulse train is sampled every T second the value of the sample at time should only be due to the current puls And there should be no interferenc from the other transmitted pulses.

In other words, ideally, $h(t)$ = 1 for = 0 and $h(t)$ = 0 for $t = \pm kT$ where k is non-zero integer. An ideal pulse shap that meets these requirements is time-domain sinc pulse. An example c a sinc pulse for which T = 10 is show in Figure 3. Note that the pulse take on a value of 1 at its peak and its zer crossings occur at intervals of intege multiples of ±10 samples away fro the peak. The lower half of the figur shows a pulse train of four pulses. Thi example illustrates how the peak o any given pulse lines up with the zer crossings of the remaining pulses Therefore, there is no ISI.

Practical pulse shaping

Although the sinc pulse represent the ideal pulse shape, it cannot b implemented in practice because th pulse extends in time for infinite dura tion. The infinite signal duration is du to the discontinuities in the sinc pulse' rectangular-shaped spectrum. Signal with discontinuities in their spectrun are physically unrealizable. However practical pulse shapes can be formed b smoothing the roll-off of the spectrun and allowing it to occupy excess band width beyond that which is needed fo



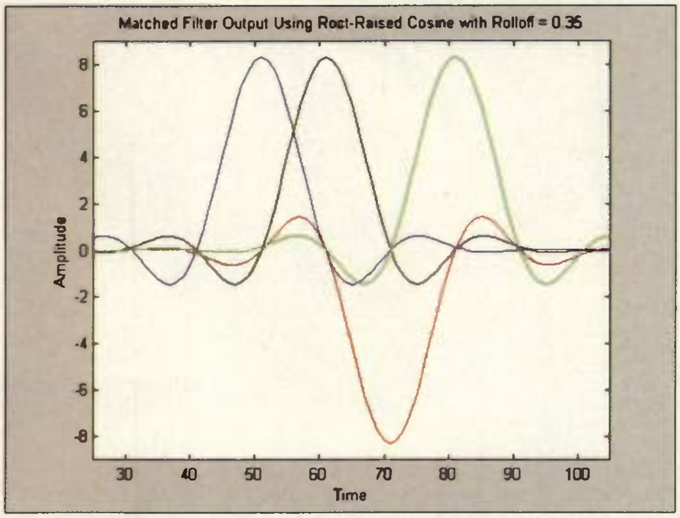


Figure 6. Zero ISI at output of matched filter using a root-raised cosine pulse.

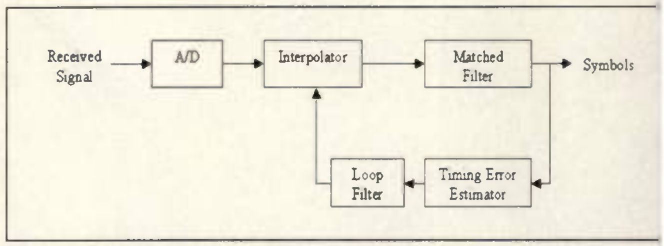


Figure 7. Example of an all-digital timing recovery loop.

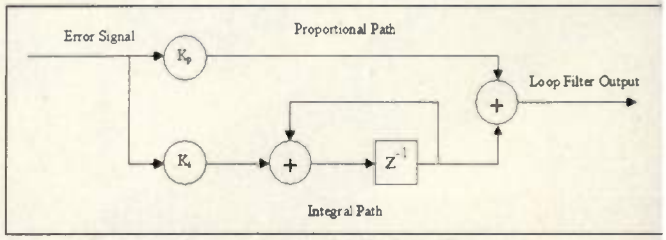


Figure 8. Structure of a typical second-order loop filter.

the spectrum of the ideal sinc pulse.

One pulse shape that has properties similar to the sinc pulse, but without the frequency-domain discontinuities, is the raised cosine pulse. The raised cosine pulse has a parameter known as the rolloff factor. The value of the rolloff factor determines how rapidly the frequency-domain spectrum of the pulse rolls off. The raised cosine pulse is identical to the sinc pulse when the rolloff factor is equal to zero. As the rolloff factor is increased, the spectrum begins to decay more gradually and this increased rolloff causes the pulse to occupy more bandwidth. When the rolloff reaches its maximum value of one, the spectrum requires twice as much bandwidth as the pulse with a rolloff of zero. Practical digital communications systems often use a rolloff factor of between 0.10 and 0.35. A pulse with a rolloff factor of 0.35 occupies 35% more bandwidth than the ideal sinc pulse. Figure 4 shows the effect of the rolloff factor on the pulse's spectrum. Figure 5 contains time-domain raised cosine pulses for the same rolloff factors used in Figure 4.

The pulses in Figure 5 exhibit zero-crossings at integer multiples of the symbol period. Thus, even with non-zero roll-off factors, the raised cosine pulse maintains this desirable (from the standpoint of no ISI) property of the sinc pulse. The choice of the roll-off factor is a trade-off between required bandwidth and the duration of the time-domain pulse. Note that the tails of the time-domain pulse are reduced for higher values of the roll-off factor. The smaller tails are desirable from a timing recovery standpoint because, in the presence of a timing offset, they will contribute less to ISI compared to the larger tails of the sinc pulse.

The most popular pulse shape used in practical communications systems is the root-raised cosine pulse. The root-raised cosine pulse is formed by taking the square root of a raised cosine pulse. This pulse shape is used to split the spectral characteristics of the raised cosine pulse equally between the transmitter and receiver.

By matched-filtering the root-raised cosine pulse and then sampling it at the symbol period, the root-raised cosine pulse is essentially squared. Thus, the output of the matched filter has a raised cosine pulse response.

An example of the matched filter output for a pulse train of root-raised cosine pulses with a rolloff factor of 0.35 is shown in Figure 6. Note that the matched filter output exhibits zero ISI because of the locations of the zero crossings for the case of perfect timing.

Timing recovery

The previous sections have shown how intersymbol interference can be avoided by sampling the matched filter output at its peak, which occurs every T seconds. The purpose of the timing recovery loop is to alter, as necessary, the sampling frequency and sampling phase to sample the matched filter at the peaks. If the timing recovery loop is operating properly, it will provide the downstream processing blocks with symbols that were sampled at the highest SNR points available.

An example of a typical all-digital timing recovery loop is shown in Figur 7. After A/D conversion, the signal i passed through an interpolator. Th interpolator is able to generate sample in between those actually sampled b the A/D (i.e., it interpolates). By gene ating these intermediate samples a needed, the interpolator can adjust th effective sampling frequency and phase

Interpolation is accomplished b first inserting N–1 zeros in betwee the data samples (upsampling by factor of N). The upsampled signa passes through a lowpass interpola tion filter to remove the aliases cause by upsampling. The resulting interpo lated signal is a smoothed version c the original signal and it contains N times as many samples.

Following interpolation, the outpu of the matched filter is sent to a timin error estimator that can use a numbe of different algorithms to generate timing error. The control signal for th interpolator is formed by filtering thi error signal using a standard second order loop filter containing a propor tional and an integral section. A example of a typical second-order loo filter is shown in Figure 8.

The second-order loop filter consist of two paths. The proportional patl multiplies the timing error signal by proportional gain K_p. From control theo ry, it is known that a proportional patl can be used to track out a phase erro however, it cannot track out a frequenc error. For a timing recovery loop t track out a sampling frequency error, loop filter containing an integral path i needed. The integral path multiplie the error signal by an integral gain K

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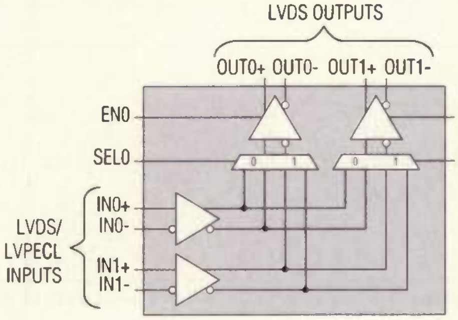

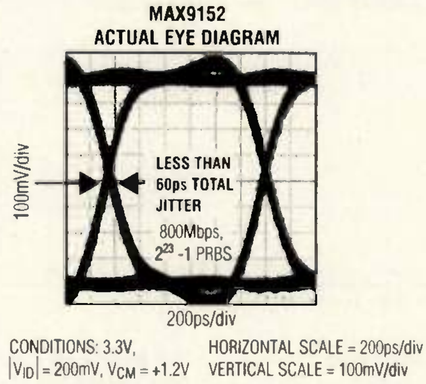

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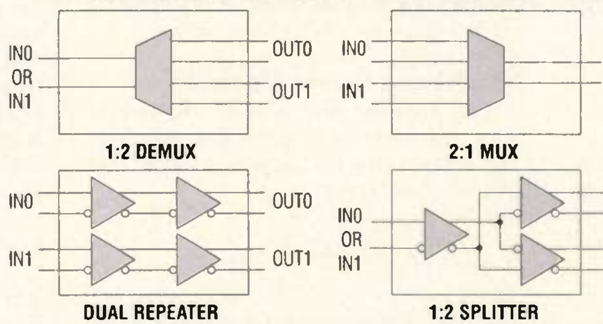

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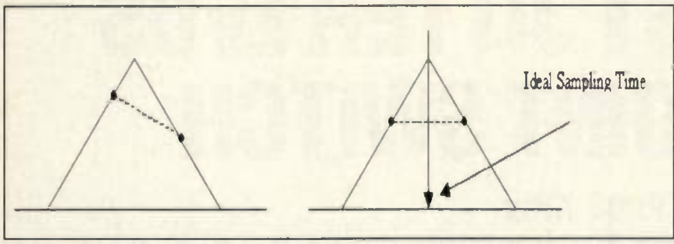

Figure 9. Method of generating error for early-late gate algorithm. The left plot shows where sampling is occurring too late. When sampling occurs at the right time, the early and late samples will be at the same amplitude.

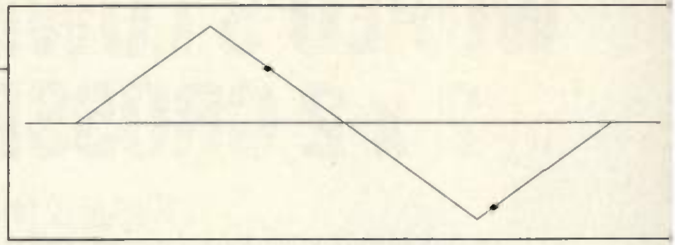

Figure 11. Timing is fast: $e_n = (-0.8 \bullet 1) - (-1 \bullet 0.5) = -0.3$.

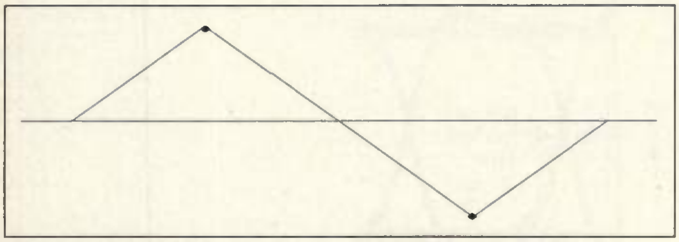

Figure 10. Correct timing: $e_n = (-1 \bullet 1) - (-1 \bullet 1) = 0$.

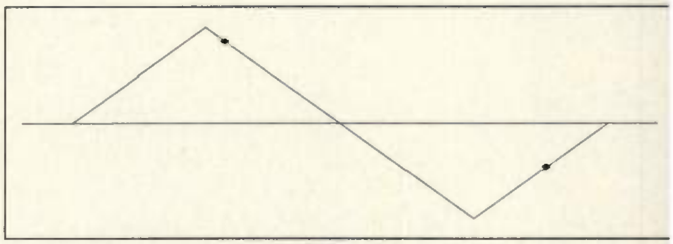

Figure 12. Timing is slow: $e_n = (-0.5 \bullet 1) - (-1 \bullet 0.8) = 0.3$.

and then integrates the scaled error using an adder and a delay block. A second-order filter, such as that shown in Figure 8, can track out both a sampling phase and a sampling frequency error.

Early-late gate algorithm

This timing recovery algorithm generates its error by using samples that are early and late compared to the ideal sampling point. The generation of the error requires at least three samples per symbol. The method of generating the error is illustrated in Figure 9. The left plot is for the case where sampling is occurring late. Note that the early and late samples are at different amplitudes. This difference in amplitude is used to derive an error for the timing recovery loop. Once the timing recovery loop converges, the early and late samples will be at equal amplitudes. The sample to be used for later processing is the sample that lies in the middle of the early and late samples. One drawback of the early-late gate algorithm is that it requires at least three samples per symbol. Thus, it is impractical for systems with high data rates.

Mueller and Muller Algorithm

The Mueller and Muller algorithm only requires one sample per symbol. The error term is computed using the following equation:

$$e_n = (y_n \bullet y_{n-1}) - (y_n \bullet y_{n-1})$$

where y_n is the sample from the current symbol and y_{n-1} is the sample from the previous symbol. The slicer (decision device) outputs for the current, and previous symbol are represented by $\hat{y}_n$ and $\hat{y}_{n-1}$, respectively. Examples of the value for the Mueller and Muller error for the cases of different timing offsets are shown in Figure 10, Figure 11 and Figure 12. One drawback of this algorithm is that it is sensitive to carrier offsets, and thus carrier recovery must be performed prior to the Mueller and Muller timing recovery.

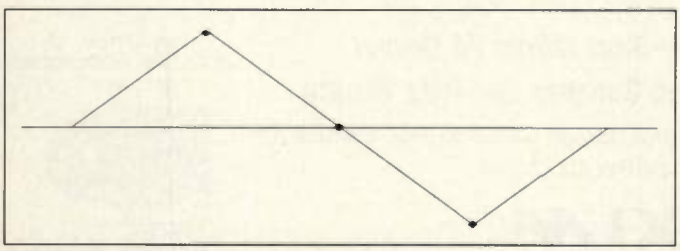

Figure 13. Correct timing: $e_n = (-1 -1) \bullet 0 = 0$.

Gardner algorithm

The Gardner algorithm has seen widespread use in many practical timing recovery loop implementations. The algorithm uses two samples per symbol and has the advantage of being insensitive to carrier offsets. The timing recovery loop can lock first, therefore simplifying the task of carrier recovery. The error for the Gardner algorithm is computed using the following equation:

$$e_n = (y_n - y_{n-2})\, y_{n-1}$$

where the spacing between y_n and y_{n-2} is T seconds, and the spacing between y_n and y_{n-1} is $T/2$ seconds.

The following figures illustrate how the sign of the Gardner error can be used to determine whether the sampling is correct (Figure 13), late (Figure 14) or early (Figure 15). Note that the Gardner error is most useful on symbol transitions (when the symbol goes from positive to negative or vice-versa). The Gardner error is relatively small when the current and previous symbol have the same polarity.

A simulation was run for a timing recovery loop that used the Gardner algorithm and the results are shown in Figure 16 (page 48). The top plot shows the matched filter output samples for the in-phase component of the signal.

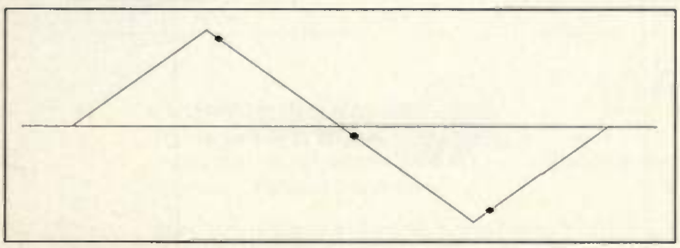

Figure 14. Timing is late: $e_n = (-0.8 -0.8) \bullet (-0.2) = 0.32$.

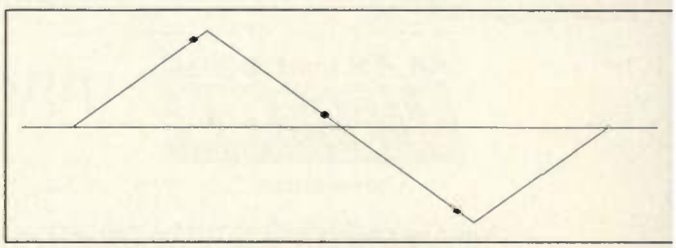

Figure 15. Timing is early: $e_n = (-0.8 -0.8) \bullet (0.2) = -0.32$.

Notice that the timing recovery loop converges after about 600 symbols have been processed. At this point, the output of the matched filter takes on values of +1 and −1. The values are fairly constant because the matched filter output is being sampled near the ideal center point. During the first 600 symbols, when the loop is still converging, the matched filter samples take on a wide range of amplitudes. This variance in the matched filter output is because of ISI caused by sampling the output at points other than the ideal center point. The bottom plot shows the Gardner error e_n vs. time.

Other methods of timing recovery

The ideal case is to have the transmitter and receiver running off of the same clock. Although this situation is typically impossible in a wireless communications system, it can be implemented in some wired systems, such as computer networks. In such an ideal system, a timing recovery loop is not needed because synchronization is explicit.

Another alternative is to have the clock frequency transmitted along with the data. The receiver can recover this clock signal with a narrowband bandpass filter tuned to that frequency. Although this method is used in some practical systems, it is generally inefficient because the transmission of the clock signal consumes both bandwidth and transmitter power that could have otherwise been used for sending user data. In addition, other decision-directed and non-decision-directed algorithms exist for generating an error signal for a timing recovery.

The Gardner's algorithm presented here represents a good starting point for practical implementations because of its robustness to carrier offsets, simple implementation and modest oversampling requirement of two samples per symbol. The interested reader can learn more about timing recovery algorithms by consulting the references listed at the end of this article.

Conclusions

This article presents the problem of detecting pulses transmitted across an AWGN channel. Merely sampling the pulses at the receiver once every symbol period is found to be ineffective because of the signal distortion due to the presence of noise with an infinite bandwidth. The concept of the matched filter receiver is introduced as a way to limit the noise at the receiver, as well as to provide a high SNR sampling point due to the correlation gain. The implementation of symbol timing synchronization is shown to be a vital process in obtaining the best SNR sampling point while also avoiding intersymbol interference.

RF

Acknowledgments

The author would like to thank Kumar Ramaswamy and Paul Knutson (both of Thomson Multimedia) for their help in proofreading this article and also for the numerous (and sometimes late-night) discussions on the topic of timing recovery.

Continued on page 48

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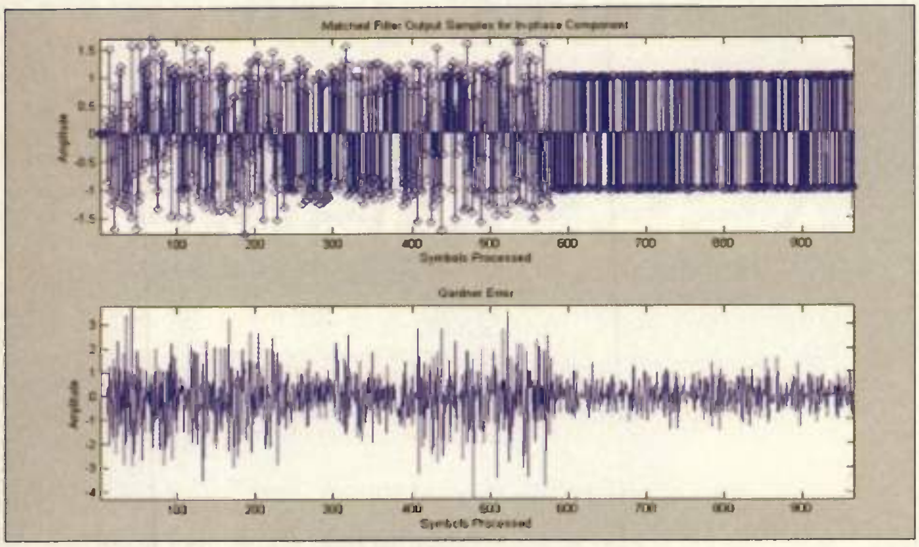

Figure 16. Simulation results using Gardner algorithm on QPSK data.

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About the author

Louis Litwin is a member of the technical staff with Thomson Multimedia Corporate Research where he is working on 3G CDMA technology for mobile applications. He received his M.S. degree in electrical engineering from Purdue University and his B.S. degree in electrical engineering from Drexel University.

Data recording for real-time signal analysis

A new breed of test instrument facilitates field analysis of signals and data.

By John DeMott

Deployment of 2.5G and 3G wireless networks can now be accelerated with an innovative new test equipment architecture — one that enables spectral recording and playback of next-generation communications networks. Through the integration of gigabytes of high-speed memory with highly linear analog-to-digital (A/D), digital-to-analog (D/A), and RF up/down converters, the functionality of real-time RF signal acquisition is combined with direct-to-IF signal generation.

This is made possible by the ability of next-generation test instruments to capture field recordings of RF signals and play them back in the lab. This enables debugging of the system in the presence of real-world fading, interferers and adjacent channels — something that hasn't always been possible, or practical.

In addition, the RF record/playback capability permits capture of the output from prototype transmitters, which can be recreated via the RF signal generation capability. These prototype/proprietary format recordings can be distributed to the development team, enabling concurrent work on successive modules such as amplifiers and linearization circuits.

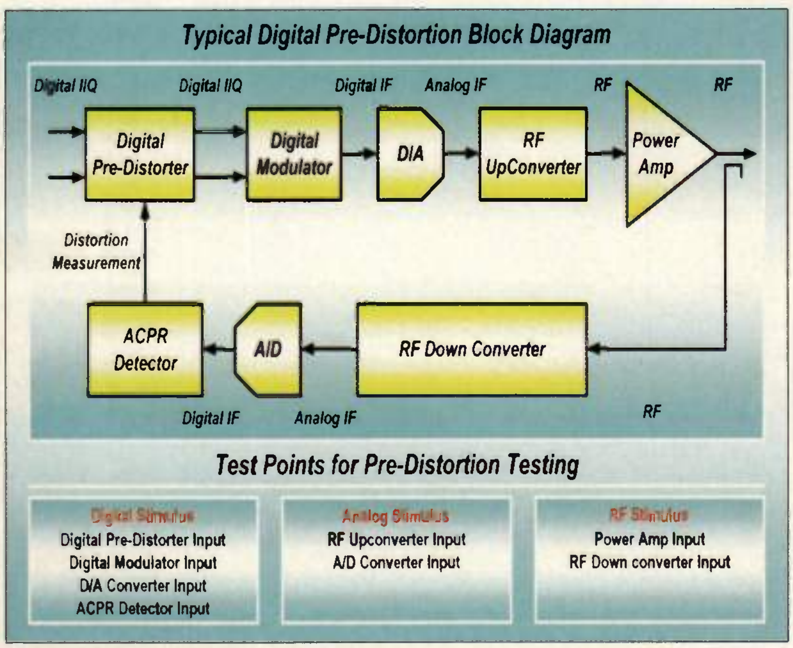

Figure 1. Digital pre-distortion test points.

Digital pre-distortion technique

This unique platform tests pre-distortion algorithms and circuits for next-generation power amplifiers. Its core is the direct-to-IF approach.

Digital pre-distortion is considered the dominant technique for increasing efficiency and reducing cost in the latest 3G power amplifiers. Using this technique, designers can sample the RF output of their power amplifier and down-convert the signal to an IF. A/D converters digitize the IF, and digital signal processor (DSP) circuits implement algorithms to adjust the pre-distortion based on the detected output of the amplifier. Additional parameters affect the digital in-phase and quadrature (I/Q), as well as clipping circuits and lookup tables. These processing chains are used to adjust the digital I/Q stream prior to modulation, analog conversion and RF up-conversion. The goal is to increase power efficiency while keeping the adjacent channel power (ACP) leakage and error vector magnitude to a minimum. The block diagram in Figure 1 illustrates such a signal chain.

The bandwidths of pre-distortion circuits are typically three times the bandwidth of the output channel. This excess bandwidth allows detection and processing of the fundamental, in addition to the distortion products above and below the transmit channel. New instruments that have high output bandwidths (60 MHz and up) are able to accommodate testing of 3G multi-carrier power amplifiers used for universal mobile telecommunications service (UMTS/3GPP) applications; 20 MHz of transmit bandwidth for the four carriers at 5 MHz offset, and 20 MHz each for the upper and lower distortion products.

Deployment and implementation

In an actual deployment, the entire chain illustrated in Figure 1 would be implemented in the power amplifier or digital radio sections of the base station. To assist designers in testing and verifying the algorithms, these wide-bandwidth vector signal generators can be used to simulate portions of the block diagram. Figure 1 indicates the test points in a typical pre-distortion signal chain. Annotations on this diagram illustrate the areas where the instruments can be used to simulate the digital, analog and RF sections of the pre-distortion circuit. Figure 2 shows a block diagram where such points exist.

This 3G equipment closely mimics sections of

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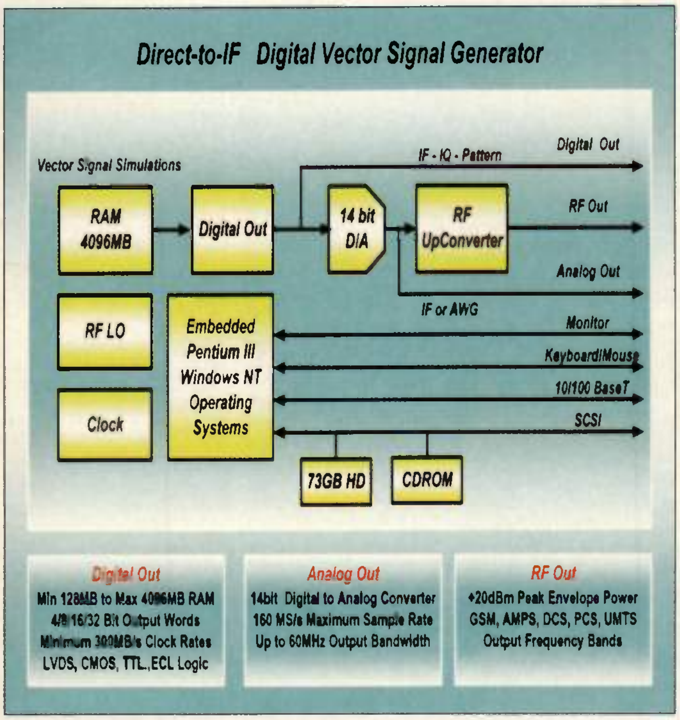


Figure 2. CS2000 Series digital vector signal generator.

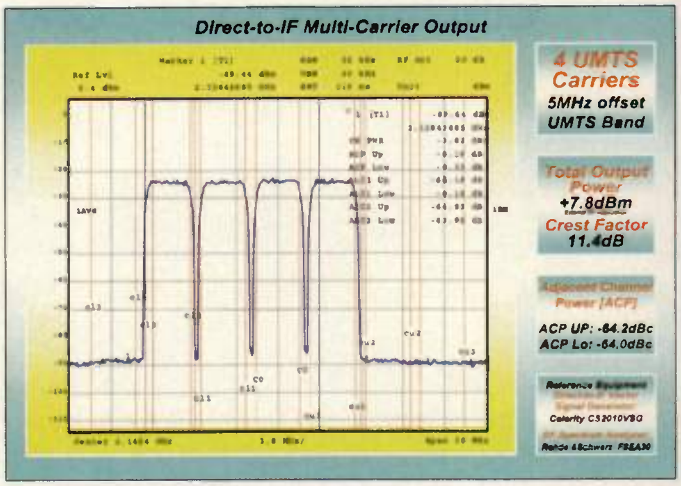
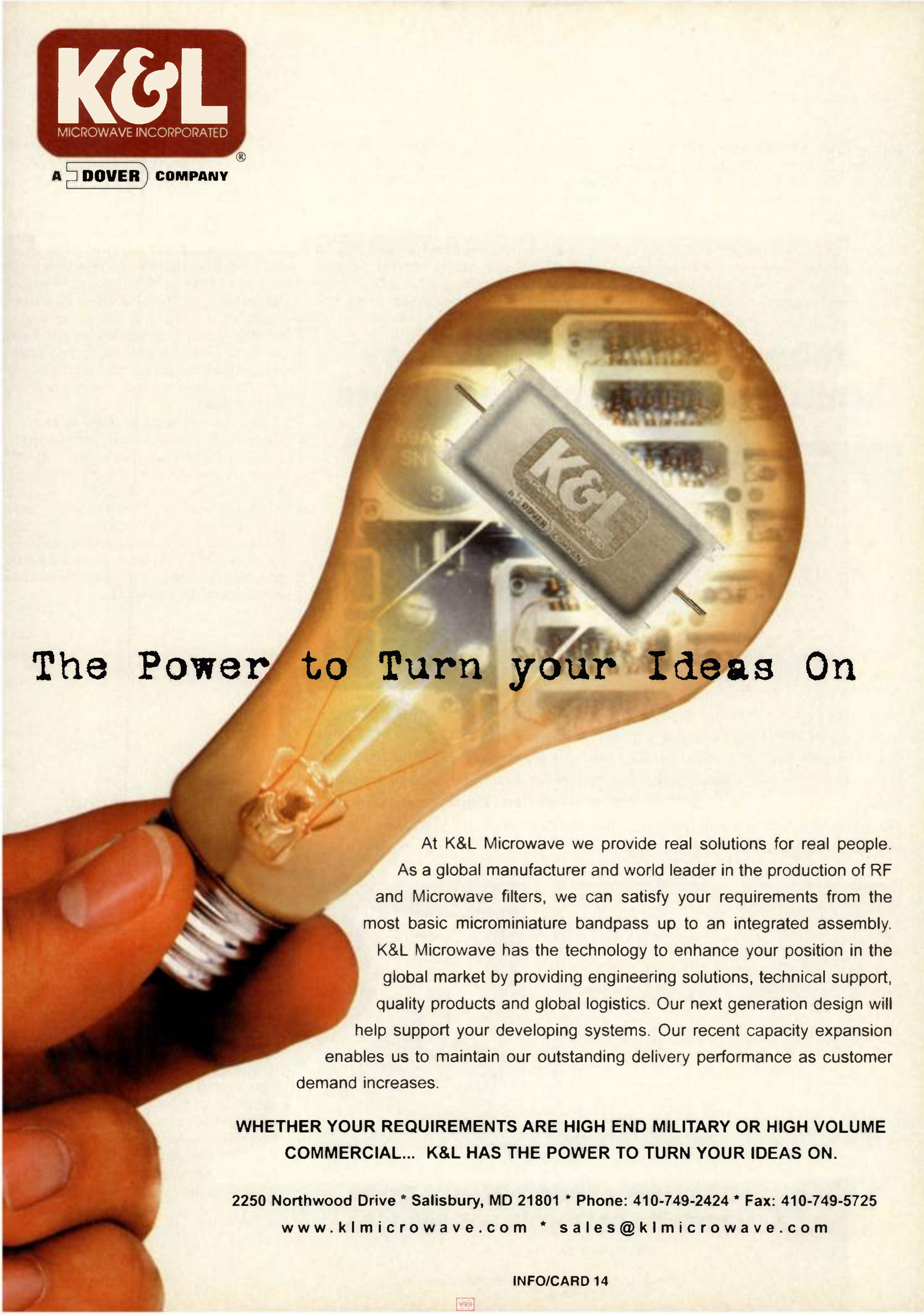


Figure 3. Multi-carrier output.

the signal chain being considered for the pre-distortion circuit. Inserting the equipment in-line with the signal flow accommodates testing of the various portions of the chain. The equipment's modular architecture permits the generation of digital pattern, digital I/Q, digital IF, analog IF, and RF signals.

To ensure accurate measurements, this high-tech test equipment must have specifications that suit digital out-



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put at rates as high as 400 MB/s and beyond. It also needs to be able to handle high-bit-rate D/A converters, in the neighborhood of 14 bit – 160 MS/s digital-to-analog converters and higher.

New innovations in solid-state waveform memory can accommodate simulations in the gigabyte range. Such deep memory is a key requirement in attaining 60 MHz bandwidth at 160 MS/s sampling rates. Such deep memory also allows sufficient recorded time periods to accurately analyze the waveform.

Finally, direct-to-IF architectures are typically used to achieve wideband RF output for multi-carrier performance. An output plot showing four-carrier UMTS simulation (note the ACP performance on the order of –64dBc) is given in Figure 3.

Conclusions

Test and measurement innovations that provide designers with the ability to both record and playback RF, analog or digital signals are effective tools for shortening design cycles and improving the bottom line. Features such as debugging receiver algorithms, acquiring signals in the field for later analysis, and capturing intermittent phenomena for study make the final design much more accurate and reliable.

Such innovations in mass storage — those that offer several hundred gigabytes of memory enhanced with RAID disk arrays for capturing record and playback — can save the designer work and worry. This unique combination of direct-to-IF architecture, wide bandwidth and deep memory capability provides a critical advantage in testing and debugging next-generation communications products.

RF

About the author

John DeMott is vice president of marketing at Celerity Digital Broadband Test. He has years of experience in the test and measurement field and, before going to work for Celerity in 1999, worked with Tektronix for 11 years. DeMott can be reached by e-mail at: *jdemott@celerity.1-3com.com*.

The CS2010 Vector Signal Generator is part of the CS2000 instrument series from Celerity Digital Broadband Test, an L-3 Communications company. It was designed to offer advanced test and measurement solutions for multi-standard, multi-carrier applications. Additional configurations in the series include solutions that provide designers with the ability to both record and playback RF, analog or digital signals.

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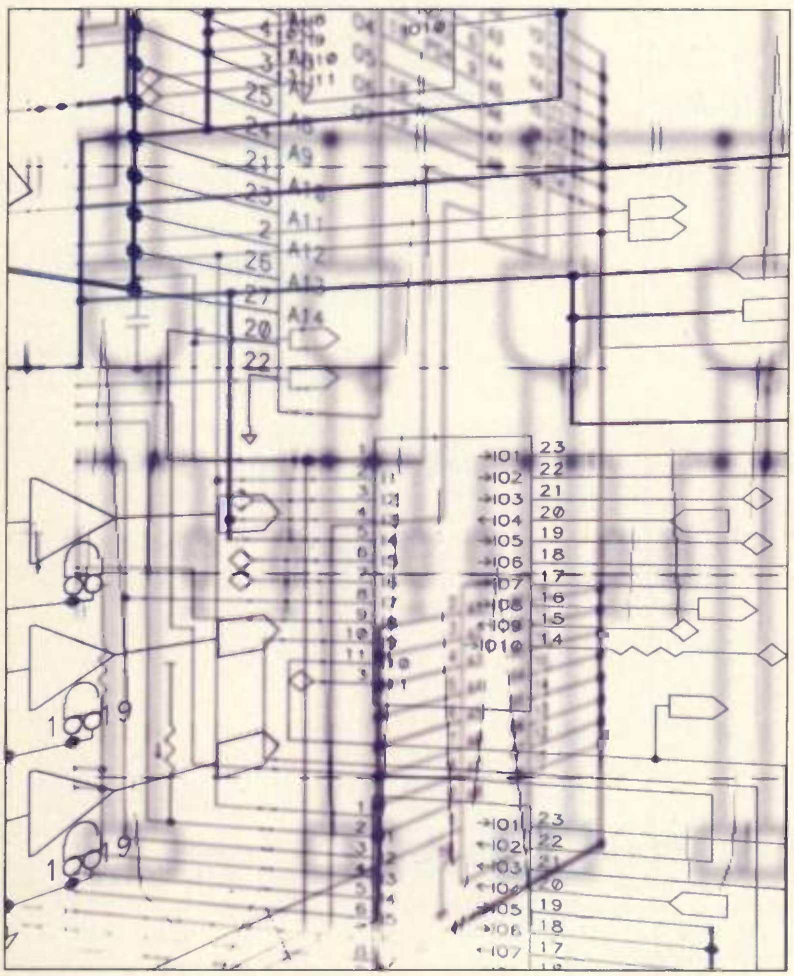
INFO/CARD 22

Switching systems reduce test times

Reducing test times and increasing equipment utilization is tantamount to saving money. Switching systems for DUTs pay off.

By Roland Lowe

To meet the simultaneous goals of high test-system throughput and execution of sophisticated protocols, wireless device manufacturers must use fast automated instruments, such as communications and spectrum analyzers.



Still, production testing of cell phones, pagers, two-way radios, and antennas may take several minutes. Complicated test protocols include a variety of operational checks and adjustments, including:

- Bandwidth
- Carrier frequency
- RF output levels
- Receiver sensitivity
- Antenna gain

A switching system for multiple DUTs

To reduce test time and increase equipment utilization, instruments are often connected to devices under test (DUTs) through a switching system. These systems increase productivity by allowing multiple tests on more than one device. For RF tests, a multiplexed coax switch arrangement can be used to route a number of instrument inputs/outputs (I/Os) to different DUT test points. A matrix topology may also be used, which provides a great deal of flexibility when more than one instrument must be simultaneously connected to different test points. However, attention must be paid to RF signal integrity to avoid compromising measurement system accuracy and product quality, which would offset productivity gains from higher throughput.

Determining the signal's frequency content

In making a product decision, one of the first considerations should be the frequency content of the signals to be switched. This is a critical step because the signal or pulse format determines the operating bandwidth.

For example, the frequency spectral distribution of a 2 GHz sine wave carrier is different from a 2 GHz digital pulse. Preserving frequency harmonics of the digital pulse and power spectral distribution is critical for maintaining signal integrity.

A bit of basic math

For most applications, equation (1) provides a good approximation between the frequency and the rise time or fall time of the signal. In this equation, R_t is the rise time or fall time of the digital signal, in nanoseconds, from the 10% to 90% amplitude level. Bandwidth is defined by the interval between the reference, or zero decibels (dB) amplitude level, and the upper frequency, F, where the signal falls to –3 dB below the passband frequency.

$$F = \frac{35}{R_t} \quad (1)$$

Choosing a switch design

To maintain signal integrity at minimal cost, it is necessary to use appropriate switching system technology. It is generally satisfactory to specify

Configuration	Insertion loss (dB)	VSWR	Crosstalk (dB)
RF coaxial relay	-0.5	1.35	-80
Multiplex switch cards	-9.0	2.75	-30

Table 1. 2 GHz performance comparison of a 1 x 16 multiplexer using coaxial relays and cables and four RF switch cards.

only the maximum values of insertion loss, voltage-standing wave ratio (VSWR), crosstalk, and power handling capability for a system designed to operate at a single frequency. In a wideband switch system, values for all frequencies of interest should be specified. In either case, the switch manufacturer should characterize and verify performance of the product over the desired frequency range regardless of technology used.

Once specifications are complete, the test engineer still has the option of selecting either a coaxial relay or card-based system for applications below 2 GHz, the pertinent frequency for many wireless products.

Switching systems comprised of coaxial electromechanical relays and cables achieve the lowest insertion loss, VSWR, and crosstalk performance. However, systems designed around switching mainframes and surface-mount PC card technologies may also provide acceptable performance.

Coaxial relay designs are often less expensive than switch-card designs for medium to large-size switches. This is because of the limitation of low switch density per card at high frequencies in a card-based system. For any switching configuration, the RF signal performance of a coaxial relay system is unsurpassed, so the cost/performance trade-off is hard to beat.

The coax approach consists of interconnecting precision electromechanical coaxial relays with high-performance RF cables and an appropriate switch controller. Electromechanical relays are available in a variety of contact configurations with 1 x 2, 1 x 4, and 1 x 6 being the most common. With precision mechanical construction, only small impedance mismatches exist between relays, connectors and cables.

For frequencies below 2 GHz, VSWR and insertion loss remain low. Also, because these switch systems are custom-designed, it becomes a simple issue to integrate active and passive signal conditioning components, such as amplifiers and attenuators, into the final product.

In other applications, the card approach may suffice. This design consists of miniature microwave relays, RF connectors and associated control circuitry mounted on an epoxy or microwave laminate. These cards are designed to operate inside an intelligent controller chassis using a VMEbus Extensions for Instrumentation (VXI) or general-purpose interface bus (GPIB).

Because the switching time of a relay limits the speed of most mechanical relay switching systems, GPIB-based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controllers provide adequate speed for these applications and are more cost-effective than VXI controllers.

It all boils down to performance

High performance is achieved in card-based systems by careful impedance matching between the circuit elements and signal transmission lines on the laminate, referred to as striplines or microstrips. In this design, high uniformity of the dielectric constant and dissipation factor of the laminate is essential for high-performance striplines.

Also, optimizing geometrical relationships between the circuit elements is critical. Switch cards are available in simple multiplex configurations and typically contain two to three 1 x 4 multiplexers per card.

Table 1 shows a comparison of the electrical performance at 2 GHz of a 1 x 16 multiplexer constructed from coaxial relays and cables, vs. four switch cards, each containing two 1 x 4 multiplexers. Specifications for the system built from switch cards is an estimate based on the specifications for an individual switch card. As shown in the table, less signal degradation is produced by the system constructed from coaxial cables and relays.

Besides high-quality signals, benefits of a custom-built coaxial relay system usually include an intuitive operator interface and a report from the manufacturer detailing signal transmission characteristics. The measurements of insertion loss and return loss, typically contained in the report, are often used for software-based signal compensation in an ATE system.

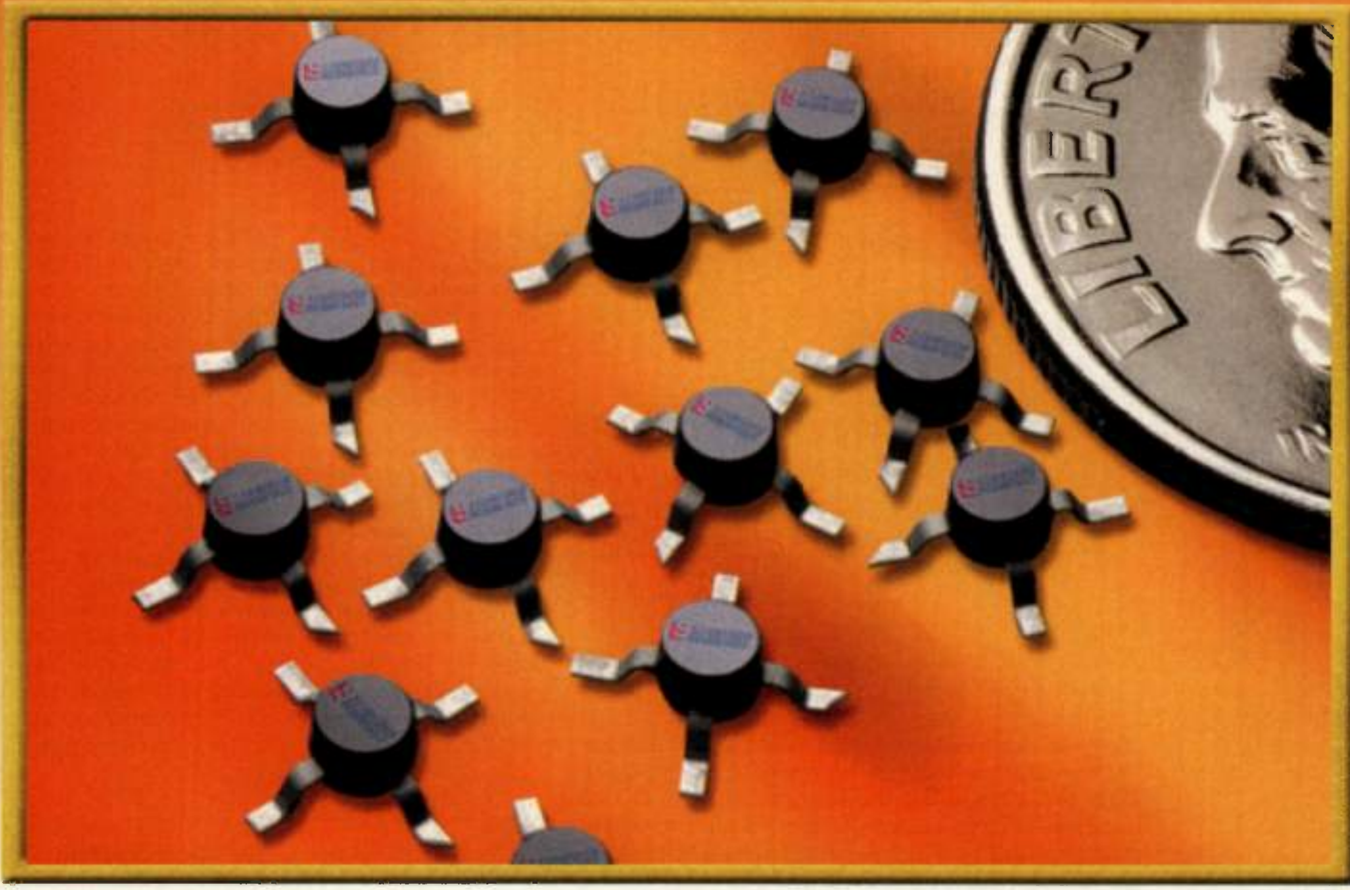
The final decision criterion

As the final design is made, size and integration criteria must be considered. Frequently, an important objective for a test engineer is to reduce the size of the test rack. Depending on whose system is used, a typical card-based matrix switching systems is available for 2 GHz applications in half-rack size units that support as many as 24 channels with six 1 x 4 multiplexers, three on each of two cards. Where higher bandwidth i required, and there is space for a ful rack width, a multiplexed microwav coaxial relay system is available.

RF

About the author

Roland Lowe is the telecom applications engineering manager at Keithley Instruments, Cleveland. He has eight years of experience in ATE system design and construction, including switching systems. Previously, Lowe was with NASA Lewis Research Center. He has a B.S.E.E. degree from Rensselaer Polytechnic Institute and an M.S.E.E. degree from Cleveland State University.



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NGA-286	DC–6.0	15	31.2	15	3.4	4.0, 50	120
NGA-386	DC–4.0	15	27	19	2.7	4.0, 35	144
NGA-486	DC–8.0	17.5	39.5	14.5	4.5	4.2, 80	118
NGA-586	DC–6.0	19	38	19	4.5	5.0, 80	121
NGA-686	DC–4.0	19.2	35	11	6.1	5.9, 80	121

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Testing the 3G infrastructure

cdma2000 may well be the 3G platform of the future. If so, testing its interoperability and performance will be critical to its success.

By Rob VanBrunt

Over the next several months CDMA handset vendors and service providers will work feverishly to deploy initial third-generation (3G) CDMA services in North America. These 3G services will be made possible by a new air interface standard called cdma2000. Offering several clear migration-path benefits, such as increased voice capacity and higher-speed data connections, cdma2000 will look to build on the success and momentum of its 2G predecessor, IS-95. To maximize the success of the cdma2000 rollout, mobile manufacturers and service providers will use the structured approach to testing CDMA mobile devices originally developed for IS-95. Evaluating cdma2000 devices and services generates significant new test methodology challenges.

It's a three-step process

Managing and implementing the successful rollout of a new cellular air interface standard is tricky business. There are many historical examples of the bumps along the road to widespread deployment. In the early 1990s, GSM deployment was delayed in part by a lack of thoroughly tested mobile handsets, prompting the cry "God Send Mobiles." In recent times, the W-CDMA community has been forced to delay the rollout of cdma2000's counterpart 3G technology because of incomplete specifications and test standards. It is worth a look back at how IS-95 deployment largely avoided similar pitfalls through the use of a staged testing methodology.

By the mid-1990s, CDMA supporters had convinced service providers that their IS-95 air interface technology held significant theoretical capacity advantages over competing technologies. However, the task remained of realizing those benefits with commercial equipment on commercial systems. With a goal of minimizing time-to-market, CDMA supporters banned together and formed an international consortium of companies called the CDMA Developers Group (CDG).

Within the CDG, a system test team was formed to focus on developing a test methodology for verifying the performance and interoperability of CDMA equipment and services. This methodology took the form of a three-step process that includes physical layer parametric performance testing of mobile devices, interoperability protocol testing between network infrastructure and mobiles, and mobile field performance testing. These steps are summarized in Figure 1 and are being applied to cdma2000 mobile devices.

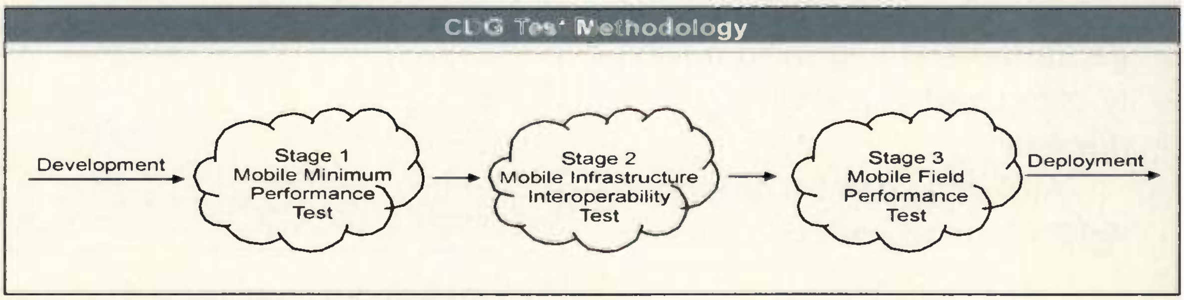

Figure 1. The three stages of test – from development to deployment.

Stage 1: Physical layer parametric performance

The CDG Stage 1 test specification, known specifically as EIA/TIA-98D, Recommended Minimum Performance Standards for cdma2000 Spread Spectrum Mobile Stations, focuses on the parametric physical layer performance of a cdma2000 mobile device. This specification evaluates the performance of the mobile's transmitter and receiver through a series of air interface tests. These tests are usually performed in a cabled environment on laboratory equipment.

To achieve value-added benefits such as increased network capacity and more prolific data connections, cdma2000 employs significant modifications to the IS-95 air interface specification.

Network capacity is increased through the use of a reverse link pilot. Not present in IS-95 mobiles, this signal enables a cdma2000 base station to perform synchronous detection of the mobile and provides a channel for forward-link power control. These features improve forward- and reverse-link performance and enable the CDMA network to allow more users to operate in the same amount of spectrum.

To evaluate the mobile's reverse pilot channel performance, the relative time and phase accuracy between the mobile's pilot channel and other reverse-link code channels must be measured. This

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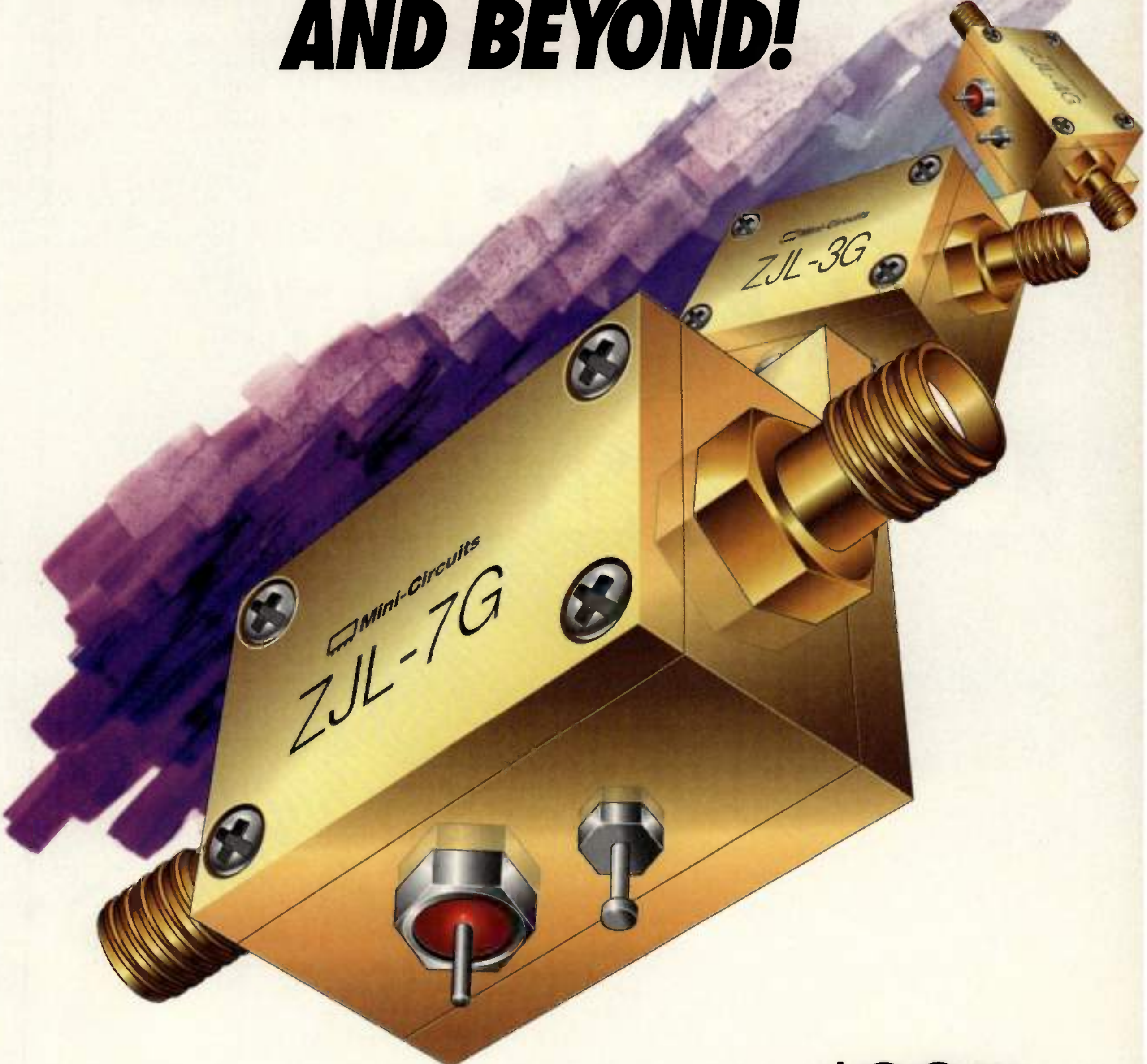

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ZJL-5G	20-5000	9.0	±0.55	15.0	8.5	32.0	80	129.95
ZJL-7G	20-7000	10.0	±1.0	8.0	5.0	24.0	50	99.95
ZJL-4G	20-4000	12.4	±0.25	13.5	5.5	30.5	75	129.95
ZJL-6G	20-6000	13.0	±1.6	9.0	4.5	24.0	50	114.95
ZJL-4HG	20-4000	17.0	±1.5	15.0	4.5	30.5	75	129.95
ZJL-3G	20-3000	19.0	±2.2	8.0	3.8	22.0	45	114.95
ZKL-2R7	10-2700	24.0	±0.7	13.0	5.0	30.0	120	149.95
ZKL-2R5	10-2500	30.0	±1.5	15.0	5.0	31.0	120	149.95
ZKL-2	10-2000	33.5	±1.0	15.0	4.0	31.0	120	149.95
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NOTES:
1. Typical at 1dB compression.
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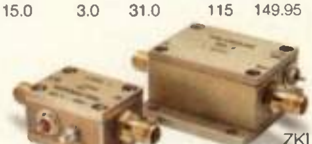

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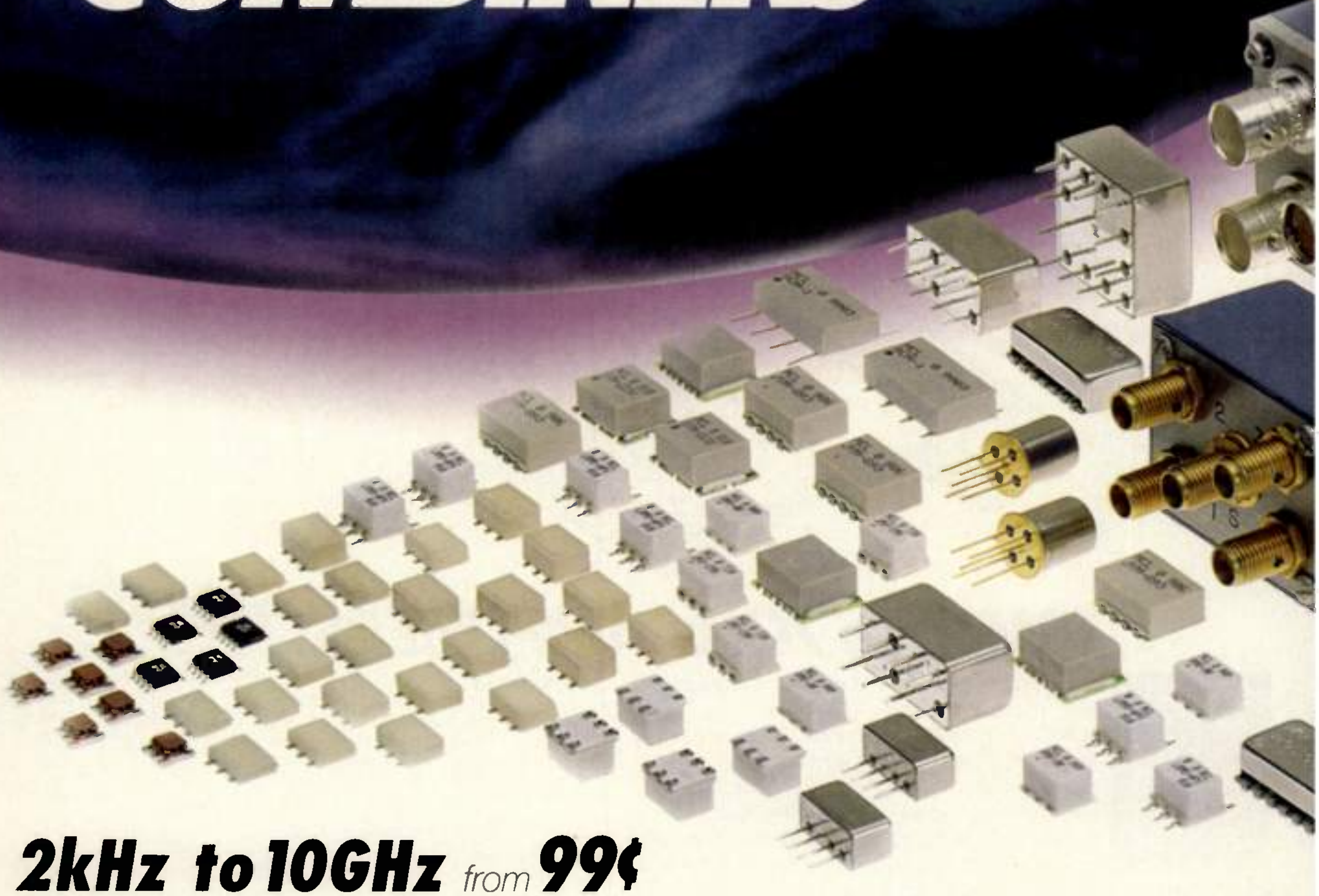

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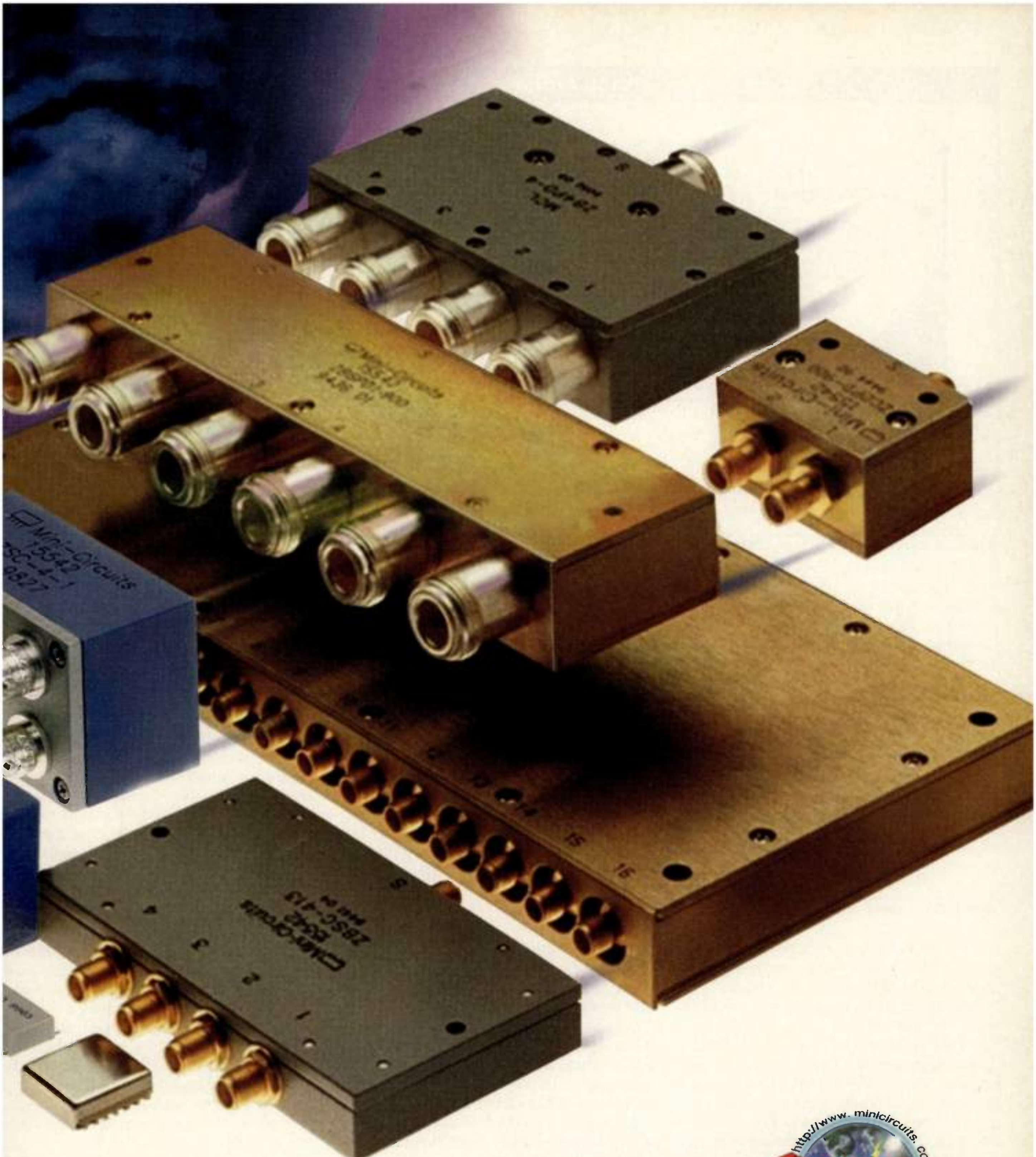
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Effect of CW Phase Noise

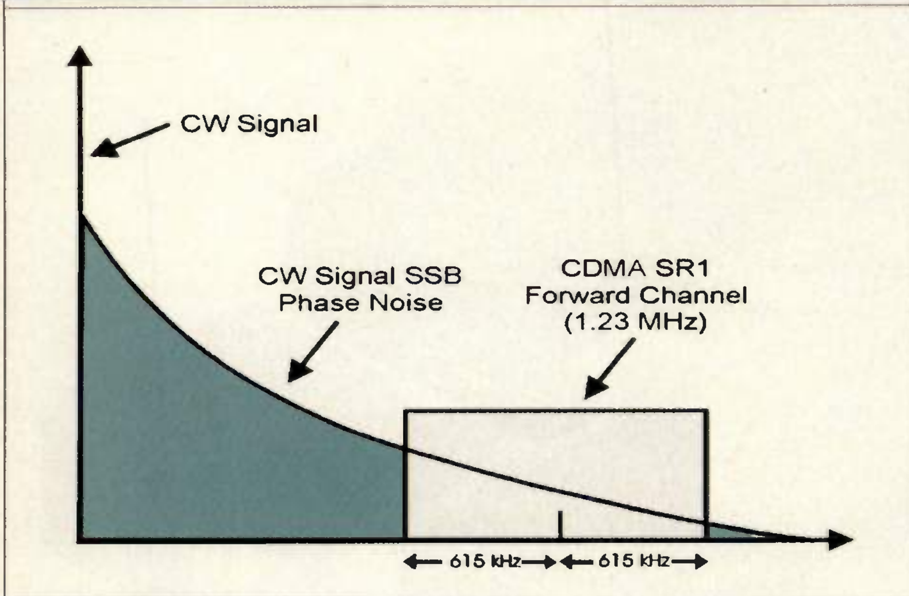

Figure 2. CW phase-noise effects on CDMA signals.

requires the use of a code-domain analyzer. Forward-link power control performance must also be verified, which requires the use of average white Gaussian noise (AWGN) emulation to degrade the forward-link performance and a CDMA network emulator to decode the power control bits on the reverse pilot channel. The network emulator must be able to capture the power control bits and determine if the proper sequence was sent by the mobile.

ence conditions. EIA/TIA-98D places stringent new performance requirements on the continuous wave (CW) adjacent-channel interference source used for single-tone desensitization tests.

In 2G test standards, the phase-noise requirements of the CW interferer were not specified. During an adjacent-channel receiver test, parasitic phase noise can extend into the passband of the received channel and act as an additional co-channel interferer.

Bandclass	*Phase noise*
BC 0, 2, 3, 5 and 7	–144 dBc/Hz@285 KHz offset
BC 1, 4, and 6	–144 dBc/Hz@635 KHz offset

Table 1. CW phase-noise specifications.

The cdma2000 standard also adds support for a much wider variety of data services to be delivered to the phone.

Included in the specification are operating modes that allow simultaneous transmission of voice and data. These services require the mobile to support flexible radio configurations and additional traffic channels, such as a supplemental channel (F/R-SCH). Because the quality of data delivery is a key performance metric, the mobile receiver must be evaluated under a variety of radio channel conditions to test its robustness.

The performance of the receiver is determined by measuring its forward-link frame error rate (FER) under different channel conditions. An RF channel emulator provides multipath channel conditions. An interference emulator generates co- and adjacent-channel interfer-

Parasitic phase noise led to erroneous test conditions in some 2G single-tone desensitization test setups. To solve this problem, IS-98D includes stringent CW phase-noise performance specifications illustrated in Figure 2. A high-performance, application-specific instrument is required to meet these performance standards.

In contrast to 2G test specifications, which included FER tests for just two forward-link data rate sets over a single forward traffic channel, cdma2000 spreading rate 1 (SR1) employs five forward-link radio configurations. Data can be delivered over a combination of forward traffic channel, dedicated control channel, and forward supplemental channel(s). Thus, tests such as single-tone desensitization now involve many more permutations of data delivery vs. channel conditions. Add support for 10 band classes vs. the two found in IS-95, and it is easy to see how the flexibility of cdma2000 generates thousands of additional EIA/TIA-98D test cases. This large increase in the number of test cases reinforces the requirement for automated test procedures.

Stage 2: Interoperability performance

After completing the Stage 1 test phase, mobile devices are subjected to Stage 2 tests.

The CDG Stage 2 interoperability tests focus on evaluating the protocol layer performance of a mobile through a series of mobile base station signaling and call-processing tests. Like Stage 1 tests, Stage 2 tests are performed in a cabled environment. True Stage 2 testing involves performing a series of test scenarios on actual infrastructure equipment at interoperability I/O test labs collocated with major infrastructure manufacturers. New innovations in test equipment make it possible for mobile manufacturers to perform pre-testing in their own labs on in-house test platforms. Although interoperability tests with actual infrastructure equipment will always be required, there is a movement to transfer some portion of the Stage 2 tests from the I/O labs into mobile certification labs to streamline the test process.

Because cdma2000 cells will not be ubiquitous from the start of deployment, CDG Stage 2 must provide for tests that verify the mobile's ability to handle both IS-95 and cdma2000 air interface protocols. Key tests related to this requirement involve evaluating how the mobile handles inter-generation hand-offs between IS-95 and cdma2000 cells. Performing these tests on test instruments requires a CDMA network emulator equipped with the ability to emulate both air interface standards while performing hand-offs between independent RF carriers.

As is the case with EIA/TIA-98D tests, new cdma2000 features and services create new demands on the Stage 2 test process. Another new user benefit of cdma2000 is enhanced mobile battery life.

Battery life is extended using a forward-link, quick-paging channel (QPCH). The QPCH permits a cdma2000 mobile device to keep its receiver signal processing "asleep" a greater percentage of time when in standby more often. A cdma2000 base station now includes a quick page indicator (QPI) in the forward-link trans-

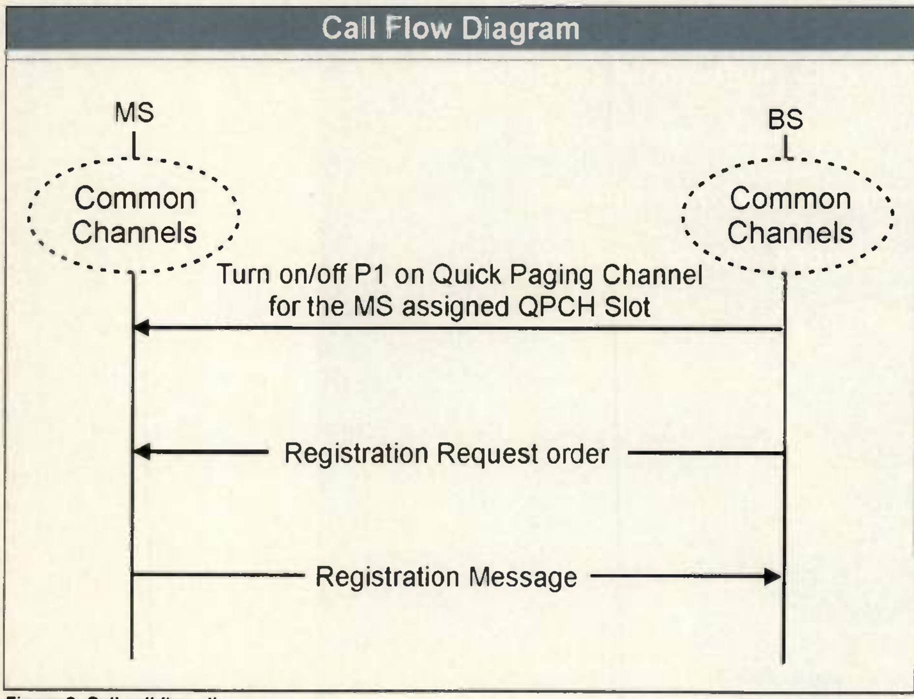

Figure 3. Call cell flow diagram.

mission that can be briefly monitored (no demodulation, just energy detection). If the QPI indicates no impending page message for the mobile, the mobile can immediately fall back to "sleep mode" and ignore the following paging slot. This increased sleep time conserves battery energy.

QPCH performance must be verified to ensure mobile monitors the QPCH slot and reacts correctly to the QP[Proper performance is verified usin both positive and negative scenario tes cases as shown in the call flow diagrar in Figure 3. Positive performance i measured by setting the correspondin mobile QPI to ON and those for al other slots to OFF. The base statio then sends a registration request orde on the paging channel and verifies tha the mobile receives and processes mes sages on its assigned slot. The negativ scenario sets the corresponding mobil QPI to OFF, and those for all othe slots to ON. Similarly, a registratio request order is sent, but this time th test verifies the mobile does not proces messages on its assigned slot Executing these scenarios on tes equipment requires a network emula tor that allows low-level manipulatio of paging-channel parameters.

Stage 3: Field test performance

While Stage 1 and Stage 2 verifie the physical layer and protocol laye performance of the mobile in a cable lab environment, the goal of Stage 3 is t

validate the mobile's ability to perform at both levels in a real-world environment. A mobile manufacturer will typically do this testing in conjunction with the service provider it is selling its product to. These tests involve a series of call processing scenarios that are executed over a set of defined drive routes.

For example, handoff scenarios may be tested while driving through the urban canyons of New York. At one instant, a building may be blocking the mobile's view of all cell sites, but a moment later (as the vehicle clears the building and enters an intersection), strong transmissions may reach the mobile from many cell sites. The ability of the mobile to handle these dynamic situations is essential for a reliable network.

As stated before, one of the major reasons for service providers to aggressively pursue the evolution to cdma2000 is increased capacity.

Through the use of the reverse-link pilot channel, a mobile now has the ability to perform closed-loop power control on the relative traffic channel level transmitted by the base station. This new cdma2000 feature, known as fast-forward power control (FFPC), has the net effect of reducing the code channel power transmitted on the forward link. In a CDMA system, a reduction in transmitted power directly relates to an increase in capacity.

The implementation of FFPC means a mobile is executing power control algorithms nearly as complex as the requirements on a base station. Due to this complicated process and its direct impact on the effectiveness of network deployment, field verification of FFPC is critical. At the same time, effective diagnostic tools must exist to monitor the mobile and ai in analysis of its performance. Because field-testing uses rea network infrastructure, the same level of control and feed back typically available in a lab do not exist. A diagnosti monitor is used to verify that the mobile is sending the cor rect power-control decision bits to the base station based o the received energy-to-noise ratio observed by the mobile.

The mobile diagnostic monitor also automates the contro and reporting mechanisms of a drive test. For instance, on scenario may require the mobile to originate a phone cal periodically throughout the drive. Another situation ma necessitate plotting points every time a call is dropped durin the testing. With the aid of tools such as a built-in scriptin language and a GPS receiver interface, a mobile diagnosti tool simplifies and automates these tasks.

Summary

To minimize time-to-market and ensure a successful roll out, cdma2000 manufacturers and service providers will us a comprehensive three-stage process to validate mobile devic performance. Although this is the same approach used for IS 95 mobile performance verification, the new value-added fea tures and services associated with cdma2000 generate signifi cant new test requirements. Innovative application-specifi tests are required to meet these demands. These tests wil need to be integrated, and will need to incorporate automa tion as well if the large number of new test cases is to be han dled in an efficient manner.

RF

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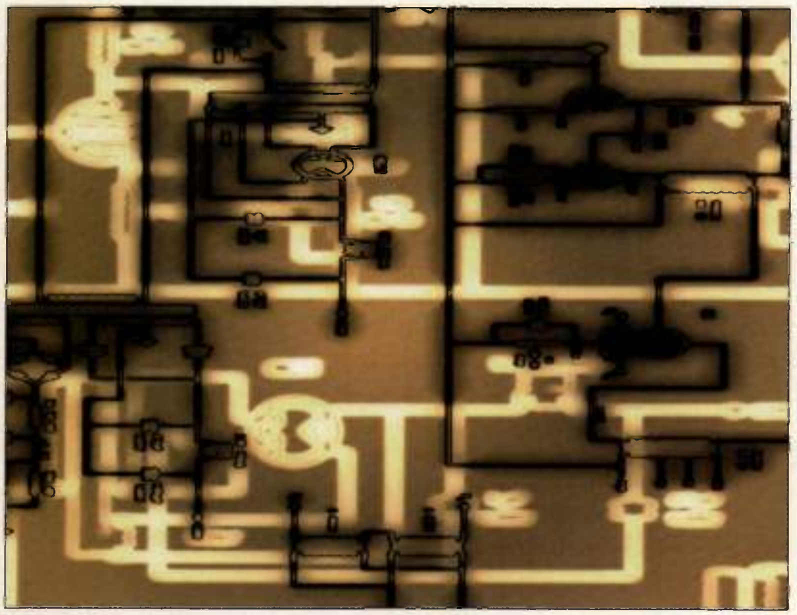
Gallium nitride electronic devices for high-power wireless applications

Could semiconductors based on GaN technology be the answer to tomorrow's hardened high-power wireless systems?

By Ric Borges

Microwave systems designers, no matter which markets their products target, constantly face demands for higher performance, lower costs and faster design turnaround. These challenges are particularly difficult in the race to design wireless infrastructure that can support new wireless communications applications. Such devices demand higher power, improved spectral purity, increased bandwidth and other requirements that tax today's technologies.



High frequency and high power – tomorrow's semiconductors.

For example, in designing the state-of-the-art power amplifiers necessary for the high-power transmitters used in cellular base stations, systems designers are starting from the ground-up and focusing on power transistors.

Power amplifiers are major performance and cost factors in next-generation base stations, and advanced transistors would go a long way toward helping designers meet or exceed their design objectives. This is particularly true because stringent linearity requirements are increasingly difficult and costly to meet using the high-performance power transistors currently available.

It's all about efficiency

One area that systems designers are looking to improve in power amplifiers is power consumption. In amplifying high-frequency RF signals, as much as 90% of the power consumed is lost to heat. This heat results in reliability problems and higher air-conditioning costs and contributes to substantially larger and more expensive base stations.

The search for the holy grail

To address such system-level problems, researchers have focused their attention on the semiconductor materials used in power transistors by searching for a high-performance building block that combines lower costs with improved performance and manufacturability. Of the contenders, gallium nitride (GaN) is emerging as the front runner.

While GaN technology has been in development for more than a decade, it has only been in the last few years that the material has made great strides from laboratory proofs-of-concept to being a true contender for emerging wireless applications. In the most critical breakthrough, advances in epitaxial growth now allow manufacturers to grow GaN layers on a variety of substrates. As a result, microwave designers are finding that the time has come to take a close look at the advantages GaN-based devices may be able to offer.

Due to its long development cycle, GaN has been somewhat of an unknown entity, and its benefits have not been widely understood.

Wide-bandgap semiconductor issues

Though many high-performance semiconductor materials have been successfully commercialized, some of the most promising semiconductors (from a theoretical perspective) have never made it into the mainstream of microwave devices. The wide-bandgap semiconductor families, which include GaN, silicon carbide (SiC) and diamond, have long been touted for their potential superior performance in high-frequency and/or high-power applications. However, they have all have been side-tracked on the road to microwave applications by technical production problems.

Of these promising contenders for microwave super-materials, diamond continues to be plagued with many problems inherent to the material. These problems are reflected in difficulties such as all new!

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GAL-3	DC-3000	22.4	19.1	±1.7	12.5	3.5	25	127	35	3.3	.99
GAL-6	DC-4000	12.2	11.8	±0.3	18.2	4.5	36	93	70	5.2	1.49
GAL-4	DC-4000	14.4	13.5	±0.5	17.5	4.0	34	93	65	4.6	1.49
GAL-51	DC-4000	18.1	16.1	±1.0	18.0	3.5	35	78	65	4.5	1.49
GAL-5	DC-4000	20.6	17.5	±1.6	18.0	3.5	35	103	65	4.4	1.49

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Property	Si	GaAs	SiC	GaN
Suitability for High Power	Medium	Low	High	High
Suitability for High Frequencies	Low	High	Medium	High
HEMT structures	No	Yes	No	Yes
Low Cost Substrates	Yes	No	No	Yes

Table 1. Properties of GaN.

poor doping control and poor ohmic contacts, as well as manufacturing difficulties in creating large areas of high-quality, low-defect material at a reasonable cost.

SiC has been limited to expensive, small and low-quality substrate wafers.

GaN, the potential leader, has been restricted by its limited availability. Until recently, it could only be produced on those same expensive, low-quality SiC substrates or on small, difficult-to-process sapphire substrates.

The quality of GaN layers produced on sapphire or SiC has been inconsistent. The primary problem is that developers are unable to get the defect density, which has a proportional effect on signal quality, below levels that would allow consistently good microwave devices. As a result, the only commercial success for GaN has been in light-emitting diode (LED) applications, which tolerate certain kinds of material defects surprisingly well. But recent advances in the growth of GaN offer the promise of lower defect levels and lower costs, opening the door to practical, high-performance wireless devices.

Material and electronic properties

The excitement about GaN stems from its unique material and electronic properties (see Table 1).

GaN has an energy gap value that approaches 3.4 eV at room temperature,

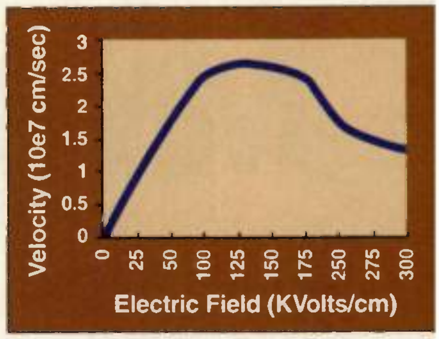

Figure 1. Drift Velocity vs. Electric Field

enabling GaN devices to support peak internal electric fields about five times higher than silicon or gallium arsenide (GaAs). Higher electric field strength results in higher breakdown voltages — a critical attribute for handling high-power requirements and for achieving much higher efficiencies through the use of higher supply voltages.

For high-frequency performance, high electron speeds are necessary to minimize internal device delays. Figure 1 shows how electron velocity is related to the electric field in GaN. The velocity increases linearly with the electric field in low field environments, with the electron mobility serving as the proportionality constant.

As the electric field increases, the electron velocity overshoots and then settles to a steady value. The low field mobility is limited by the presence of doping impurities and lattice vibrations, which scatter the electrons while traveling in the device channel. However, this limitation can be partially removed by growing a modulation-doped heterostructure, as illustrated in Figure 2, physically separating the scattering impurities from the channel.

In this configuration, silicon-doped aluminum gallium nitride (AlGaN) is grown on top of GaN. AlGaN has an even higher energy gap than GaN. The silicon impurities donate electrons to the crystal that then tend to accumulate in the regions of lowest potential — known as a quantum well — just beneath the AlGaN/GaN interface. This forms a sheet of electrons, which constitutes a two-dimensional electron gas (2DEG). Here, the electrons experience higher mobility because they are physically separated from the ionized silicon donor atoms residing in the AlGaN.

The modulation-doped heterostructure described thus far is fairly standard in other semiconductor systems. The 2DEG can be contacted with source and drain metals and modulated

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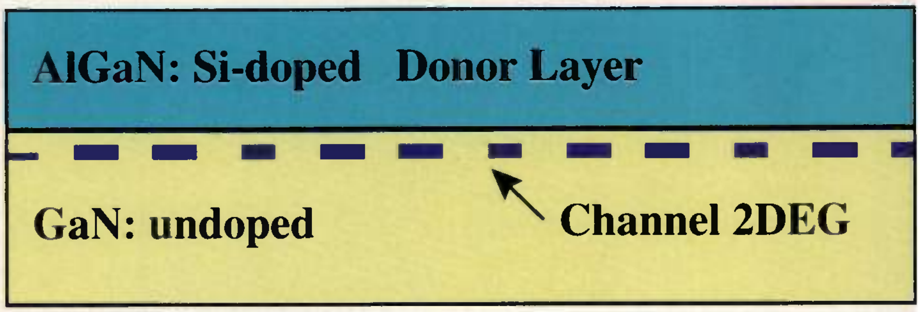


Figure 2. Modulation-doped heterostructure.

with a gate contact to realize a high-electron mobility transistor (HEMT). HEMT devices fabricated in other technologies (e.g. AlGaAs, GaAs) have been in production for many years.

The AlGaN/GaN modulation-doped heterostructure, however, has some unique characteristics. First and foremost, it is the only heterostructure system among the three wide-bandgap semiconductors. This means that AlGaN/GaN can uniquely exploit the power-handling capabilities of wide-bandgap semiconductors, as well as the high-frequency potential of modulation-doped structures. It is this fortuitous combination that makes GaN and its associated compounds so well-suited to high-power, high-frequency applications.

The second unique attribute of the AlGaN/GaN heterostructure is the possibility of building high channel charge. Higher channel charge increases the device's current handling capability. Because GaN is a strongly polar material, the strain resulting from growing lattice-mismatched AlGaN on GaN induces a piezoelectric charge. This supplies additional electrons to the HEMT channel. This total channel charge can top 1x1013 electrons/cm2 — roughly four to five times higher than for AlGaAs/GaAs HEMTs. This piezoelectric property is a unique power-boosting bonus factor for AlGaN/GaN HEMTs.

Substrates, growth and defects

Given these advantages, it is natural to ask why GaN electronic devices have yet to be commercialized. The answer lies in the difficulties associated with crystal growth.

Silicon and GaAs devices are produced on silicon and GaAs substrates of high quality. However, no bulk GaN semiconductor substrates are available. Thus, epitaxial layers must be grown on dissimilar substrates; that is, heteroepitaxially.

Until recently, GaN was grown on either sapphire or SiC. Neither of these substrates is ideal for widespread commercialization. Sapphire is expensive, is limited to four-inch diameter wafers, and is a poor thermal conductor. This virtually eliminates sapphire from any high-power application. SiC, though an excellent thermal conductor, is expensive, available only in small wafer sizes, and fraught with crystal defects.

The most highly refined semiconductor substrates in the world are silicon wafers. Recently, innovations in metal-organic chemical vapor deposition (MOCVD) have enabled the growth of high-quality GaN layers on silicon. The process has been demonstrated on 4″ wafers and can be scaled to larger diameters.

A high-quality epitaxial layer technology on a silicon substrate takes advantage of years of research into wafer fabrication equipment and processing techniques, which are routinely used in CMOS or BiCMOS integrated circuits. This GaN-on-silicon approach yields a low-cost, high-performance platform for high-frequency, high-power products — a potentially exciting combination.

Semiconductor technologies

Over the years, electronic device researchers have proposed various semiconductor ranking methods, or figures of merit, for evaluating semiconductors for high-frequency, high-power applications. These figures of merit for high performance attempt to account for the most relevant material properties and combine them into one number that represents a measure of the relative strengths of the alternative materials.

The Johnson figure of merit takes into account the breakdown voltage and saturated electron drift velocity in defining a measure of value for handling high frequencies. For GaN, the Johnson figure of merit is 790 times that of silicon, about 70 times that of GaAs, and about twice that of SiC.

The Baliga figure of merit is calculat-

ed based on dielectric constant, electron mobility and critical electric field in a measurement that approximates the high-power handling capability. Based on its properties, the Baliga figure for GaN is about 100 times that of silicon, six times that of GaAs and three times that of SiC.

What do these numbers mean? For high-frequency, high-power devices, GaN offers far higher performance possibilities than GaAs and SiC. Here again, the superior breakdown field strength, bandgap, mobility and electron-saturated drift velocity of GaN are the keys.

Device alternatives

How will GaN devices stack up against competing devices?

In a world dominated by silicon transistors, GaAs-based HEMTs and heterojunction bipolar transistors (HBTs) have a well-deserved reputation for high-frequency capabilities. More exotic compound semiconductors, such as indium phosphide, offer advantages in the most demanding high-frequency, low-power applications.

However, for high-frequency, high-power applications, GaAs has two major drawbacks: cost and power dissipation. Both are essentially fundamental to the material. GaAs substrates are more expensive, more difficult to handle and more thermally resistive than silicon. This makes it too difficult to remove heat in high-power applications.

The critical electric field, which is roughly one-fifth that of GaN, is another drawback.

SiC metal-semiconductor field-effect transistors (MESFETs) benefit from the excellent thermal conductivity of the substrate. However, its electron mobility is significantly lower than that of GaN, which is related to the lack of heterojunction technology in this material system. Further, the substrates are costly, limited in diameter and contain micropipe defects that can affect device manufacturing yields. Unless the substrate problems are addressed in the near term, SiC MESFETs will have difficulty competing in cost-sensitive commercial applications.

Recently, silicon germanium (SiGe) HBTs have found applications in many microwave and mixed signal products where they can offer high-performance, yet cost-effective, products previously unavailable on a silicon platform.

However, the SiGe HBT's device structure remains a relatively low-power configuration. The high-frequency performance exhibited by SiGe HBTs is largely a result of decreased minority carrier transit time through the base layer. This is achieved by thinning the base (the SiGe layer allows this at the same time as higher doping to minimize base resistance) and grading the germanium concentration to form a built-in field that pushes the electrons across.

To modify this structure for high-power applications, the collector layer would have to be thickened to a point where most of the gains from reduced base transit time would be washed out by a much larger collector delay. Hence, SiGe HBTs are unlikely candidates for high-power, high-frequency applications.

Silicon laterally diffused metal-oxide semiconductor (LDMOS) devices are an example of a structure that results from pushing the limits of silicon power MOS transistor technology to its high-frequency limits. Silicon LDMOS has steadily carved out the largest share of the base station power amplifier market at the expense of silicon bipolar and GaAs MESFETs. Silicon LDMOS offers excellent cost and performance ratios in this segment. However, its ability to continue addressing this market is questionable given the demanding power, speed and linearity specifications for next-generation systems.

Pushing silicon performance

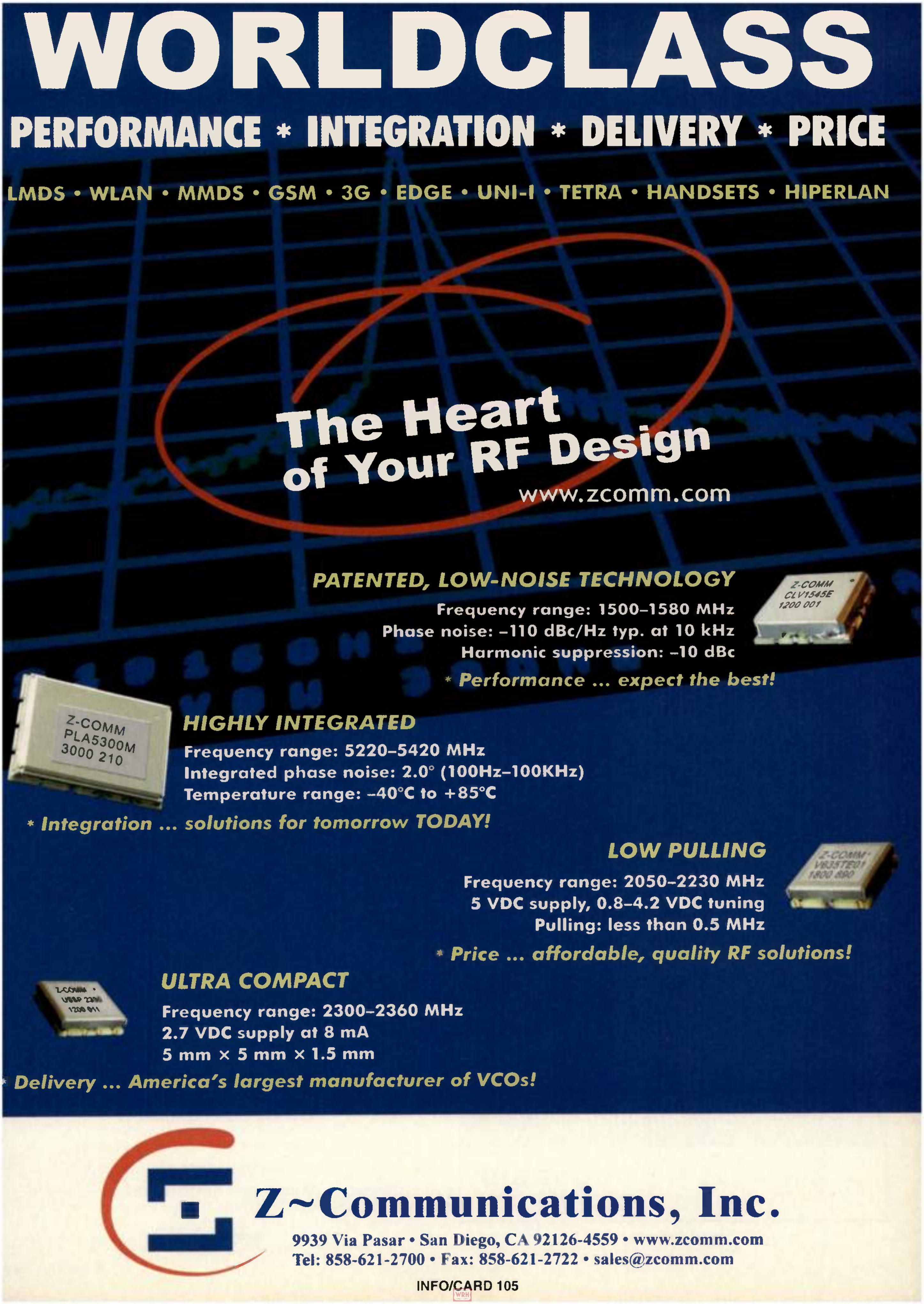
Cellular telephony is now the single largest market for semiconductors, having surpassed the PC-related market. One reason is that RF device prices and performance do not follow Moore's Law — there is no straight-ahead, geometric progression to higher RF performance.

As cellular usage continues to increase and usage becomes more data intensive, the RF infrastructure must provide higher performance. Changes will include:

- Continued migration from 900 MHz to 1.8, 1.9, 2.1 and higher GHz for higher bandwidth spectrum space.
- Higher power levels for higher frequency signals and lower bit error rates.
- Higher linearity to handle complex modulation schemes and provide less adjacent channel spillover.

Some trade-offs

Linearity is the converse of distortion. Low linearity in power amplifiers causes excessive spillover between adjacent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channels, wasting valuable radio spectrum. Demands for higher speeds and more efficient use of radio spectrum are driving linearity specifications to the limit of current device technologies. Linearity requirements are often met only in a tradeoff of output power and efficiency. The material properties of GaN are expected to allow the fabrication of transistors with superior linearity, which in turn will allow power amplifier designers to meet linearity specifications at lower costs. It can be expensive to measure and cancel out distortion with additional circuitry, which typically includes precise distortion cancellation circuits, delay lines and expensive factory tuning operations.

As a result, power amp cost savings of $1,000 or more may be achieved by going to power transistors with significantly higher linearity, higher output power levels and greater efficiency.

Linearity requirements differ among cellular systems. However, even for less stringent linearity specifications, higher transistor linearity is still valuable: Higher linearity at a given power level can allow a design to achieve higher amplifier efficiency while still meeting the linearity specification. Higher power transistor operation efficiency translates to savings in operating costs as well as other benefits, as described below.

Efficiency is the key

Efficiency refers to the ability of the transistor and amplifier to convert electrical power into output power. Excess power appears as heat, which limits the useful power available from the amplifier before it overheats. The excess heat also interferes with other performance characteristics like linearity, which degrades as temperatures rise, and limits the maximum power available from a single amplifier.

GaN devices are expected to offer inherently superior efficiency and greater design freedom to simultaneously achieve higher overall amplifier performance compared to competing devices. One avenue to higher efficiencies using GaN is through higher supply voltages. While silicon LDMO devices cannot take advantage of th approach, GaN devices can.

Efficiency may also be improved b running GaN devices with less backo from peak-power operating points. Du to inherently higher linearity, les backoff is required from the transist power rating to achieve adequate lin earity. This would allow the GaN tran sistor to operate at a higher point o the efficiency/power curve. Given th typical 8% to 10% efficiency levels o power amplifiers, even a small efficien cy increase can be significant. Fo amplifier end-users, higher power eff ciency means savings in capital an operating costs, including utility an air-conditioning costs.

Higher data rate modulatio schemes and multicarrier amplificatio systems currently being designe require high-linearity power amplifier which depend on power transistor with high compression points, excellen thermal stability and increasingly hig frequency response. These require

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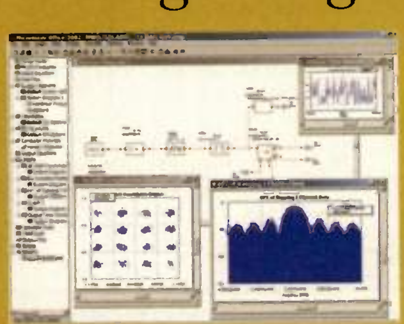

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Microwave Office 2002

INFO/CARD 10

ments in particular are beginning to place severe pressure on LDMOS technology. Designers using LDMOS must typically design-in extra circuitry to allow LDMOS-based power amps to meet linearity specs, which can be as stringent as -65dBc. GaN HEMTs can alleviate many of the problems presented by LDMOS devices, thanks to inherently higher transconductance (which helps linearity), good thermal management and higher cutoff frequencies.

Current directions

The GaN microwave power transistors currently in development can demonstrate as much as four times the theoretical maximum output power density of GaAs. Higher power densities allow smaller chips to handle the same amount of power, resulting in more chips per wafer, and hence, lower costs per chip. Alternatively, the same-sized device can handle higher power, resulting in lower costs per watt of power and lower systems costs. GaN devices are also expected to offer higher impedances, easing input matching and high-bandwidth design challenges.

MOCVD techniques for GaN growth on silicon and other substrates are being refined, and, for the case of silicon substrates, volume manufacturing of GaN power devices is expected within the coming year. Initially, these devices may appear as drop-in replacements for LDMOS or other devices currently used. However, systems designers will likely begin to redesign transmitter systems to fully leverage the performance advantages of GaN high-frequency power devices, which may possibly reduce or eliminate some of the costly linearization circuitry necessary for emerging high-bandwidth wireless systems.

Researchers and developers alike are still realizing the full benefits of GaN-based devices, but all signs are pointing to the commercialization of GaN HEMTs as one of the deciding factors in next-generation wireless communications.

RF

About the author

Ricardo Borges is the director o device engineering for Nitrone Corporation. Borges has more thar 12 years of experience in the design simulation and fabrication of devices for the wireless market. Prior to his work at Nitronex, he was with Alpha Industries, M/A-COM, Cree and Avant. He can be contacted at Nitronex Corporation, 628 Hutton Street, Suite 106, Raleigh, NC 27606. Tel. 919.807.9100 Web **www.nitronex.com**

Catalog features timing products for GPS

Rakon's 2001 catalog is available on both CD-Rom and hard copy. The catalog features detailed specifications, model drawings and photos of Rakon's latest crystals and oscillators, as well as informative technical information. New products highlighted in the catalog include miniaturized 7 x 5mm and 5x3mm SMD temperature-compensated crystal oscillators with performance specifications of ±1ppm temperature stability. These typically consumes only 1.2mA. Company profile information is also included.

Rakon
INFO/CARD 115

Power product resource highlights AC/DC

IFR Systems announces the *Kikusui 2001* product catalog, a resource for users of AC and DC power supplies, electronic loads, power controllers, battery testers and general test and measurement instruments. The catalog highlights new products and provides visual and model numbers for easy ordering. With more than 200 pages, the catalog contains information on Kikusui's selection of AC and DC power supplies, electronic loads, battery testers, power supply controller/GPIB programmers, rack assemblies for power supplies, oscilloscopes, signal generators, electrical safety testers, jitter meters and other general test and measurement instruments. Kikusui offers ISO 9001-compliant products that enable production of test equipment.

Kikusui
INFO/CARD 116

Catalog showcases stocked coaxial cable assemblies

Avnet is stocking more than 150 coaxial cable assemblies for test and measurement and production applications. These cables are suitable for communications infrastructure and test, where performance and repeatability at competitive prices are required. The new Avnet Semflex stocked cable catalog includes coax cables with single, double and triple shielding. Some cables are also available with stainless steel armor. Removable connector heads are another option. Frequency response is as high as 50 GHz on the test and measurement cables and 18 GHz on the production cables. Connector styles include: 2.4mm; 2.9mm; 3.5mm; 7mm; SMA; N; TNC.

Avnet
INFO/CARD 117

Application note focuses on antenna measurement

Giga-tronics' new application note, *Using the 12000A for Antenna Measurements*, was created for use with the company's 20 GHz microwave synthesizer. The note describes and diagrams techniques and equipment requirements for both far- and near-field measurements. While not an actual antenna test, a tutorial on radar cross-section measurement is provided for designers who need to determine reflection characteristics.

Giga-tronics
INFO/CARD 118

Reference book presents basic design concepts

RF Power Amplifiers by Mihai Albulet presents the basic theoretical concepts used in the analysis and design of RF power amplifiers. It covers various amplification classes, circuit topologies, bias circuits and matching networks. In addition to a discussion of the basic concepts used in the analysis and design of RF power amplifiers, detailed mathematical derivations indicate the assumptions and limitations of the presented results. This allows the reader to calculate their usefulness in practical designs.

Noble Publishing
INFO/CARD 119

Product catalog for broadband access, mobile

Conexant's new product catalog is available on-line, in print or on CD-ROM. The catalog is organized to help quickly identify product information. The two main sections, broadband access and mobile communications, each contain six key product categories detailing useful features such as part numbers, product descriptions, comparison charts and diagrams.

Conexant
INFO/CARD 120

On the Web

Diode Web site offers redesigned interface

Micrometrics' new Web site offers several new commercial products, including abrupt and hyperabrupt tuning varactors, surface-mount pin diodes (SOTs), high-frequency mixer/detectors, and ceramic MELFs. In addition to a redesigned user interface that allows visitors to dynamically sort through all products and package types, a feature also allows visitors to view an Inside Micrometrics movie that gives a tour of the entire Micrometrics facility in Londonderry, NH. Application notes for tuning varactors, PIN diodes and step recovery diodes are offered, as well as tips on chip and beam lead handling.

Micrometrics
www.micrometrics.com

Site offers phase shifters reference tool

Sage Laboratories announces a new Web site that functions as a reference tool for designers looking to adjust clocks and data phase in optical networks, compensate component errors in system architectures, or tune final phase in radar systems. The devices are also useful for testing stability of DUTs in production test environments. The site outlines an advanced coaxial technique for low insertion loss and tight phase and frequency accuracy, and also offers information on quality control measures. The site features a case study and a 16-page product catalog as well.

Sage Laboratories
www.phaseshifters.com

Mixed-language simulators offer new enhancements

Cadence Design Systems announces an upgrade to its flagship NC-Sim mixed-language simulators. Cadence NC simulators now include the code coverage analysis functionality of NC-Cov and the interactive training courses of the Cadence Internet Learning Series (iLS). Integrating NC-Cov code coverage analysis into the simulators substantially increases performance while retaining a low overhead. Providing iLS helps NC-Sim users increase productivity by making interactive training available 24 x 7. NC-Sim 3.3 also offers a number of other performance and usability enhancements. Several new features add a new level of simplicity for mixed-language verification. Memory usage has been reduced to support verification of larger designs using existing computing platforms. New language features have been added to support new IEEE standards like 1076.4-2000 and 1364-2001.

Cadence Design Systems
INFO/CARD 121

Software cuts filter tuning time, training

Agilent Technologies introduces a software tool that reduces the time and skill required to tune the coupled-resonator bandpass filters used in wireless base stations. The Agilent N4261A filter-tuning software allows manufacturers of RF and microwave filters to achieve greater production throughput by reducing a filter tuner's training time from more than six weeks to less than one day. In addition, manufacturers can consistently tune each filter to a higher specified level of performance. The software tool runs under the Windows 2000 or Windows NT 4.0 operating system, and operates in conjunction with Agilent's new PNA Series of RF network analyzers, as well as the Agilent 8753 and 8720 family of network analyzers.

Agilent Technologies
INFO/CARD 122

Real-time system available for MIPS32 architectures

Green Hills Software announces its Integrity real-time operating system (RTOS) for the MIPS32 architecture ar compatible processor cores (MIPS32 4K 4Km, and 4Kp). Integrity gives designe of MIPS32-based defense, telecom, ar consumer systems a royalty-free targ environment for deploying their applic tions. The MIPS32 4Kc, 4Km, and 4K cores are high-performance, synthesiz able, 32-bit RISC processor cores for sy tem-on-a-chip applications such as ba tery-operated handheld devices, cab modems, line cards, and set-top boxe Fully compatible with the MIPS32 arch tecture, the 4K family of cores run exis ing R3000 and R4000 user-level cod Integrity is a scalable, ROMable, mem ry-protected, royalty-free real-time ope ating system. Leveraging the hardwa memory protection facilities of th MIPS32 Memory Management Un (MMU), Integrity maximizes securit and reliability by building a "firewal between the kernel and user tasks. I addition, Integrity guarantees the avai ability of system resources in both th time and space domain.

Green Hills Software
INFO/CARD 123

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INFO/CARD 72

Move from 2000 to XP to have low impact on test

Engineers worried that the switch to Microsoft Windows XP may leave existing programming code incompatible with the new standard need not worry.

The Windows XP operating system should have little, if any, effect on existing test routines or future coding initiatives, said Keithley Instrument's David Howarth, who coordinates software strategy for the company's instrument and data acquisition product lines.

Howarth's review of the pre-released technical literature on XP indicates that few features will affect how the underlying code interacts with data acquisition or test sequences.

Windows XP is built on top of the more reliable Windows 2000 and NT frameworks, Howarth said, and is designed by Microsoft to encourage users to upgrade. The infrastructure code under the user interface is changing, he said, but programs written for previous Windows 2000 or NT platforms will run the same.

New features in XP include a redesigned Start menu that favors the user's five most-used programs, a wizard that makes it easier to prepare files for the Web, integrated CD burning and a dual-view feature that allows the running of two monitors off a single computer.

Add-on tool for test engineers, device designers

Nucleus DataMap 1.0 allows wafer test data to be viewed in a user-friendly graphical wafer-map format. DataMap is a suitable add-on tool for test engineers and device designers that currently use or will use the Nucleus 2.0/2.1 Prober Control Software. The DataMap software is a stand-alone package that can be run on a Cascade Microtech S300 or Summit Probe station computer along side Nucleus, or on any PC-based desktop or notebook or computer. Test data can now be viewed at the probe station (to verify pass/fail conditions for example), and then also be quickly viewed by the device engineer remotely to check device par meter data and statistics over the wafer

Cascade Microtech
INFO/CARD 124

Suite increases functionalit compatibility

PC Management Specialists, ar Vector Networks announce the release version 5.03 of their PC auditing ar software distribution product, LANut Suite. Version 5.03 of the Suite builds c numerous product enhancements inclu ed in v.5.02, with the addition of a ne LANdeploy utility that automates th task of rolling out the LANutil Client in multidomain Windows/NT 2000 installa tion. LANutil v.5.03 offers heightene performance and compatibility wit Oracle and SQL Server/Server 200 LANutil Suite supports ODBC-complia databases and enables easy access from range of customer database applicatior and reporting packages.

PC Management Specialists
Vector Networks
INFO/CARD 125

RF PICmicro Controller

Microchip Technology introduces a family of microcontrollers designed to ease the RF design process while reducing component count and board space. The rfPICI2C509AG is an 18-pin PICmicro microcontroller that features an integrated 315/433 MHz transmitter. This low-power, single-chip RF device is the first of 10 planned devices in the new rfPIC family, which targets RF connectivity for high-volume embedded control applications such as remote sensing, remote control, toys, security and access control. The subsystem integrates 1024 words of program memory with 41 bytes of user RAM. The device offers six I/O pins with on-chip clock oscillators, 33 single-word instructions, full-speed 1μs instruction cycle at 4 MHz, seven special function hardware registers, two-level deep hardware stack, eight-bit real time clock/counter with eight-bit programmable prescaler, watchdog timer and direct LED drive. The on-chip 315/433 MHz transmitter enables designs to conform to U.S. FCC Part 15 regulations and European ERC 70-03E and EN 300 220-1 requirements. The transmitter features a VCO phase locked to quartz crystal reference, which allows narrow receiver bandwidth to maximize range and interference immunity. The integrated crystal oscillator and VCO requires a minimum of external components. Additionally, the subsystem features Microchip's in-circuit serial programming (ICSP) technology, which allows the devices to be programmed after being placed in a circuit board. This offers flexibility, reduces development time and manufacturing cycles, and improves time-to-market. ICSP also enables reduced cost of field upgrades, system calibration during manufacturing, the addition of unique identification codes to the system and calibration of the system in the field. The product requires only two I/0 pins for most devices. By integrating several components into the 18-pin single chip subsystem, rfPICI2C509AG is suitable for the following space-constrained applications: home appliances, such as fan control; remote PC peripherals, such as keypads; command and control, such as air-conditioning control, water irrigation systems and toys; wireless sensors, such as temperature sensing, tire pressure sensing, smoke detectors and water level sensors; and home security applications, such as garage door openers and remote infrared detectors.

Microchip Technology
INFO/CARD 126

Microcontroller with integrated transmitter

Vector signal analyzer offers 3G communications capabilities

Agilent introduces the 89600 Vector Signal Analyzer (VSA). The 89600 offers 3G communications capabilities with tighter integration between the VSA and the Agilent Advanced Design System (ADS). Designers of 3G and other digitally modulated radios can perform virtual system evaluation, using dynamic links from the 89600 to the ADS and new links from the ADS to the ESG series signal generator. The VSA can measure either actual hardware or simulated output from the ADS when the system's hardware blocks are incomplete. The ADS links to the ESG signal generator and can take the simulated output of one hardware block's circuit simulation and download it to the signal generator to simulate the next stage's actual hardware. This means design engineers no longer need to wait for all of the hardware stages in a block diagram to come together before they begin looking for system-level problems. Now the VSA can uncover RF and DSP problems throughout the radio block diagram even before hardware exists.

Agilent Technologies
INFO/CARD 127

Bluetooth test set provides full implementation of test-mode signaling

Anritsu Company introduces the MT8850A Bluetooth test set, which conducts measurements in accordance with RF test specification VO.09. The system uses the Bluetooth protocol stack for full implementation of test-mode signaling. The system is designed for production test of Bluetooth chip sets and modules, as well as consumer products using Bluetooth radios. The MT8850A can analyze RF power, frequency, modulation, and receiver sensitivity (BER/FER). The system can be configured to run custom test scripts, and it provides full user control of a variety of test parameters. All measurements can be pre-programmed into the set, so they can be conducted with a single keystroke. A GBIB interface is available for programming in a manufacturing environment. Both GPIB and RS232 interfaces are standard.

Anritsu
INFO/CARD 128

Mobile-radio tester for Bluetooth worldwide

Rohde & Schwarz's CMU200 offers an option that can offer Bluetooth capability to common standards including GSM, AMPS, TDMA and cdmaOne. The device is designed as a multistandard platform, which can test to several standards in parallel. The CMU200 can be upgraded for follow-on mobile-radio standards and perform Bluetooth tests together with those for mobile radio. This functionality, as well as high measurement speed, allows the CMU200 to be used in production testing. The system has been optimized to meet advanced requirements in terms of measurement, accuracy, speed and ease-of-operation. The tester offers temperature-controlled error correction that increases absolute accuracy by a factor of three, thus enhancing repeat accuracy.

Rohde & Schwarz
INFO/CARD 129

WLAN analysis tool for FHSS networks

BVS announces the Cricket 2.4 GHz WLAN receiver. The device is a handheld, wideband, wireless receiver designed specifically for sweeping and optimizing local area networks. The instrument measures coverage of FHSS CDMA networks, which operate on the IEEE 802.11 standard. This allows the user to measure and determine the AP, PER and RSSI signal levels aiding in locating hub and access points throughout a building. It demodulates FHSS signals and is compatible with IEEE 802.11. In addition, the instrument measures narrowband energy and displays other sources of interference such as microwave ovens and DSSS signals. The unit features a built-in display, keypad and two removable battery packs for true portability.

Berkeley Varitronics
INFO/CARD 130

Handheld spectrum analyzer

Bantam Instruments introduces its battery-operated personal spectrum analyzer. The Model 401A covers from 1 MHz to 1024 MHz and functions i both bench-top and field use. It i designed for the measurement of har monic and spurious emissions, identifi cation of unknown or unwanted sig nals, signal monitoring, field strengtl measurements and EMC pre-compli ance testing. Included with the spec trum analyzer is the Model PIO active E-Field Probe for trou bleshooting and EMC measure ments. The Model 401A can display measurements in either dBm or dB

DC-6GHz

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K3-VAT: *2 of Ea. VAT-3, -6, -10 (6 total) $59.95*

Model	Attenuation* (dB) Nominal (±0.3)	Attenuation* (dB) Flatness Midband Typ.	VSWR (:1) Midband Typ.
VAT-1	1	0.20	1.10
VAT-2	2	0.20	1.20
VAT-3	3	0.15	1.15
VAT-4	4	0.15	1.15
VAT-5	5	0.10	1.15
VAT-6	6	0.10	1.15
VAT-7	7	0.10	1.15
VAT-8	8	0.10	1.20
VAT-9	9	0.10	1.15
VAT-10	10	0.20	1.20
VAT-12	12	0.10	1.20
VAT-15	15	0.30	1.40
VAT-20	20	0.75	1.20
VAT-30	30	0.30	1.15

Power: 0.5W at 70°C ambient. Derate linearly 0.015W/°C above 70°C.
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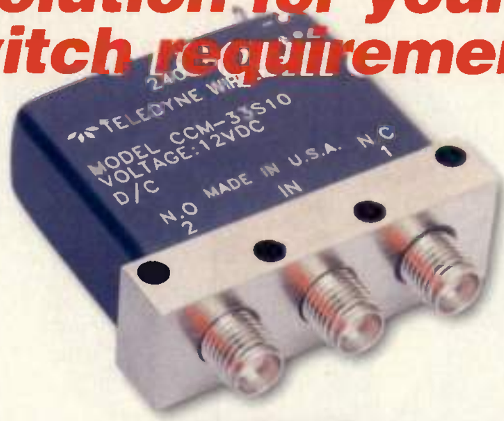

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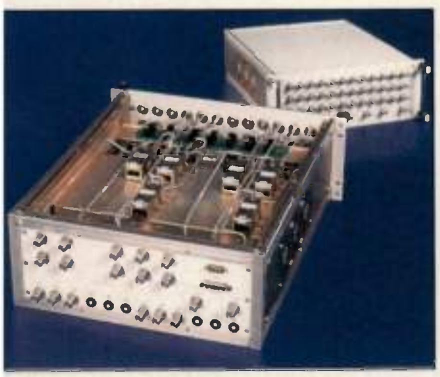
and has a sensitivity of –95 dBm. Three frequency markers are available for signal identification. Internal save/recall capability facilitates the storage of 20 measurement setups and 20 traces. Traces are labeled with the date and time of measurement and measurement setups are tagged with the frequency span and other measurement data for easy identification.
Bantam Instruments
INFO/CARD 131

RF test interface system

Dow-Key Microwave introduces a high-power (5001 and 5002) RF test interface system developed to support the RF testing of WCDMA base stations. The high-power segment of this system is designed to meet the requirement for passive intermodulation. The system routes and conditions RF signals from the inputs and outputs of the DUT to the test equipment, allowing for test



automation. All of the switchable components have internal CANbus controllers, reducing the internal control lines to only two lines. Although the system can be controlled directly via CANbus, and fully supported by ViewLab, an additional internal translator offers an alternative control via standard GPIB interface. The frequency range of the system is 1.5 GHz to 2.7 GHz, and RF power capability is as high as 100 W.
Dow-key Microwave
INFO/CARD 132

Ultra-wideband recording system

Celerity Digital Broadband Test announces the GigaFLASH Ultra-Wideband Recording System. This new instrument system is the latest

advance in snapshot data recording and data playback/waveform generation. Applications include communications analysis, radar analysis, telecommunications processing, high-speed analog-to-digital converter characterization, digital spectrum analysis and high-speed data buffering. Two models are currently available: the GF1500, which offers a sampling rate of 1500

MHz at eight bits and 32 GB of high speed storage; and the downscaled-model, GF 1250. The systems can capture more than 26 seconds of signal data at bandwidths of 600 MHz. High-performance ADCs in the system provide a spurious-free dynamic range of 40 dB over the entire input bandwidth. The analog input bandwidth of 1500 MHz supports direct digital downconversion, eliminating the need for wideband analog downconverters.

Celerity Digital Broadband Test
INFO/CARD 133

Wafer-level laser diode test system

Karl Suss and Labsphere announce an automated laser diode wafer-level test system for vertical cavity surface-emitting lasers (VCSELs). The new system is designed for high-speed wafer device characterization by using a patented Spectralon integrating sphere to minimize reflections and not damage the device under test. The core of the test system is the PA200 semiautomatic probe system, which provides low cost of ownership and reliable, long-term service. The additional components of the system are Labsphere's control-system ProberBench control software. The system is easily configured to provide L-I-V curves, optical power measurements, peak wavelength, full-width half-max, kink voltage/current curves and spectral analysis. The sphere's insensitivity to beam alignment and divergence allows accurate total flux measurements to be taken. Because of the modular design, users can start with a basic system that will grow with their requirements.

Karl Suss/Labsphere
INFO/CARD 134

LMDS ATE test system

The In-Phase Technologies' Model 1011 was developed to address the production test requirements of transceiver-related components found in LMDS system designs. The system is comprised of a combination of commercially available off-the-shelf test equipment (COTS) and various interface and control modules designed in accordance with the specific relevant component specifications. Through an intuitive graphical user interface, the system enables the operator to configure virtually all aspects of the required testing. The basic system operates over the frequency range of 2 GHz to 40 GHz and consists of a spectrum analyzer, vector network analyzer, microwave power meter and associated synthesized signal sources, power sup-

plies, RF switch assemblies and UUT test fixtures. Systems that operate as high as 60 GHz are also available. Typical measurements include gain flatness, return loss, spurious response, IMD, group delay, leakage and detector sensitivity. The standard system has a peak measurement capacity of 213,000 points per hour. At any specific temperature setting, the system will completely characterize a transceiver module in 120 seconds.

In-Phase Technologies
INFO/CARD 135

PA reliability test sets for MMICs and HMICs

Space Electronics debuts its new line of Shason Instruments' Power Amplifier Automated Reliability Test Sets (PAARTS). The systems are capable of performing three-temperature life tests on discrete transistors, monolithic microwave integrated circuits (MMICs), hybrid microwave integrated circuits (HMICs), and RF/microwave module assemblies. The system consists of hardware and software used to initiate, supervise and record temperature, electrical, and RF performance parameters automatically throughout the test duration. The test station is operated through proprietary system software installed on

a PC. A Windows-based graphical user interface provides user-friendly control of the system configuration.

Space Electronics
INFO/CARD 136

Low microphonics, 1 to 23 GHz frequency synthesizers for 128 QAM links

Elcom Technologies' new series of dual output, rugged, frequency synthesizers have ultra-low microphonics and improved phase noise (at least 10 dBc lower than previous models). Designed for high-capacity micro/millimeter wave radios up to 38 GHz, the DFSL series offers lower phase noise and guaranteed zero phase hits. The device meets 16, 32, 128 and 256 quadrature amplitude modulation (QAM) requirements, making the synthesizers suitable for high-speed data transmissions. The series has a tuning bandwidth up to 1000 MHz, and step sizes range from 25 kHz to 10 MHz. DC power consumption for the synthesizers is less than 4 W and offers wide operating temperature between –35 to + 70° C. Packaged in a 3.75" x 4.5" x 1.16" housing, the devices are also available in a low-profile construction of 3.75 x 4.5 x 0.73 inch package. Additional applications include wireless ATM networks and SATCOM converters. The device offers DC power of 12/18 VDC at 250mA, or 8/18 VDC at 250mA and meets operating vibration standard ETSI 300019-1-4 and operating shock standard ETSI 300019-1-4.

Elcom Technologies
INFO/CARD 137

Specifications at a glance:
- 0.5 to 23 GHz
- <25 ms switching speed
- 12 to 18 dBm output power
- –20 dBc harmonics
- <±3 ppm frequency stability

SIGNAL SOURCES

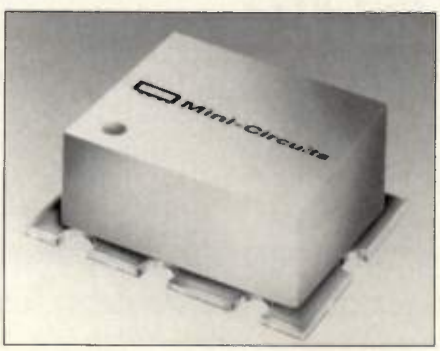
Low phase jitter/phase noise high-frequency VFT5 VCXO

VF Technologies introduces its latest voltage-controlled crystal oscillators: the low phase jitter and phase noise high-frequency VFT5 VCXO. The oscillator is paired with a unique analog circuit. The oscillator uses VF's high-frequency fundamental crystal to achieve frequency stability over temperature of typically ±20 ppm over the industrial temperature range. The design allows for the suppression of subharmonics better than 50 dB, which results in less than 1ps RMS cycle-to cycle phase jitter. Features include: output frequencies from 500 MHz to 1000 MHz; phase jitter less than 1 ps RMS in the 100 Hz to 80 MHz range; ECLiPS compatible logic; complementary outputs; enable/disable feature; and 3.3 or 5 VDC operation.

ValpeyFisher Technologies
INFO/CARD 138

Intermodulation – 5 to 1800 MHz with mixer

Mini-Circuits targets PCS and cellular applications within 5 MHz to 1800 MHz. Typically at center band, the SYM-18H mixer exhibits high 30 dBm 1P3, low 5.75 dB conversion loss, and high 45 dB L-R, 50 dB L-I isolation. Ruggedly constructed in a low-cost plastic package with solder plated terminations.



Mini-Circuits
INFO/CARD 139

Coherent frequency source clock generator

Micro Networks introduces a clock generator designed for clock generation and distribution in optical networks including 10 GB Ethernet fibercom systems and other applications requiring coherent frequency sources. The M250 clock generator provides synchronous output frequencies of 622.08MHz, 311.04MHz, and 155.52MHz. Two output signals indicate "out of lock" and "loss of reference clock" conditions. The

device operates with an input frequency of 19.44 MHz, and an internal reference clock that can be activated by an "input mode select" control signal.
Micro Networks
INFO/CARD 140

Ultra-miniature, voltage-controlled crystal oscillator

The VC-800, VCXO is a quartz-stabilized square wave generator with a CMOS output. It is tested at CMOS and TTL logic levels. The device is hermetically sealed in a 3.2 x 5.0 x 2 mm ceramic leadless chip carrier (LCC) with six contact pads. Selected frequencies between 1.544 MHz and 77.76 MHz are available with a 3.3 or 5.0 supply voltage. Phase jitter performance is better than <6 ps rms for frequencies greater than 12 MHz. The device is suitable for communications applications including xDSL customer premise equipment (CPE), PCMCIA cards, handsets, digital video and ATM/SONET/SDH applications.
Vectron International
INFO/CARD 141

Specifications at a glance:
- CMOS/TTL logic
- 3.3 or 5.0 VDC supply voltage
- <6 ps jitter

TCXO for cellular applicatons

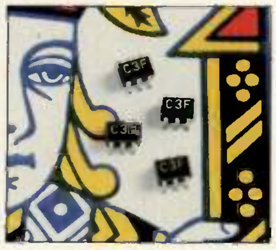
Rakon introduces the IT200U SMD TCXO. The device is a small, SMD TCXO using an analog IC for compensation in combination with a UM-1S crystal for greater stability. Clipped sinewave frequencies range from 10 MHz to 26 MHz. Standard temperature stability choices are ±1 ppm, ±1.5 ppm and ±2.5 ppm over wide temperature ranges. The unit can operate on any supply voltage between 2.7 and 5.5 VDC and consumes only 1.2 mA typically. Wireless applications include GSM/TDMA/AMPS cellular phones, PCMCIA CDPD cards and others.

Rakon
INFO/CARD 142

AMPLIFIERS

2.9 GHz RFIC driver amplifier for mobile communications

California Eastern Labs has added a new medium-power amplifier to its line of NEC Silicon RFICs. The versatile UPC8182TB has an upper operating frequency of 2.9 GHz at 3 dB bandwidth, making it suitable for a variety of mobile communications applications. Designed to drive two-stage PAs, the UPC8182TB also offers 30 dB isolation to minimize a PA's loading effects. It is manufactured using NEC's latest 25 GHz fT UHSO silicon bipolar process, resulting in consistency and reliability. It is housed in a miniature 6-pin SOT-363 package and available on tape and reel.



California Eastern Labs
INFO/CARD 143

Raytheon 5 GHz power amplifier modules

Raytheon has begun to sample the RTPA 5250 5 GHz, 54 Mbp/s power amplifier modules. The RTPA 5250 is a wideband, high-efficiency power amplifier/switching module targeted for high-speed wireless data applications. Designed on a high-performance 0.5 micron PHEMT process technology, it offers high output power, low noise and flat gain linearity to help designers match wired network performance. The module meets IEEE 802.11(a) and Hiperlan 2 standards, while also covering all three UNII bands. It combines a multi-stage amplifier and impedance-matching circuitry with a pair of high-speed, low loss switches in a high-performance low temperature co-fired ceramic (LTCC) package. Other features include process tolerant active bias and a power-down mode for extended talk time.
Raytheon
INFO/CARD 144

High-power, pulsed solid-state amplifier

Aethercomm announces the SSPA 1.35-1.45-80, a high-power, pulsed solid-state amplifier used for military telemetry and data transmission. The device supports pulse widths as high as 100 msec with duty cycles from 0.1% to CW operation. Minimum output power is 80 W at 85° C base plate. The unit will operate from –50° C to +95° C base plate. Gain at saturated output power is > 40 dB across the band. Small signal gain is 45 dB ±2 dB with a gain flatness of ±0.5 dB. Input VSWR is 1.5:1 max. Harmonic levels are >30 dBc at maximum saturated output power. Peak current is 13 amps max. The PA operates from a +28 VDC supply with a quiescent current of 1 amp. All the active devices contain a fully temperature-compensated active bias circuit, which keeps the quiescent current within 10% of its nominal value from –50°C to 95° C.

Athercomm
INFO/CARD 145

SEMICONDUCTOR/ICs

Single-voltage small-signal transistor

Agilent Technologies announces a low-current, single-voltage small-signal transistor based on Agilent's E-pHEMT technology. The ATF-55143 is a single-voltage device, eliminating the need for an additional negative

Specifications at a glance:
- 0.6 dB noise figure
- 17.7 dB associated gain
- +24.2 dBm output IP3
- +6.5 dBm input IP3

(Typical @ 2Ghz, 2.7 VDC)

voltage for biasing. The device can enhance receiver performance in cellular/PCS and WCDMA handsets, mobile devices/data-cards, and other low-current wireless receiver applications in the 450 MHz to 6 GHz frequency range. In addition, the ATF-55143 can be designed into applications above 2 GHz with small degradation in device performance.
Agilent Technologies
INFO/CARD 146

128-Mb mobile RAM in sample quantities

Infineon Technologies announces the availability of sample quantities of its 128-Mbit Mobile-RAM. Designed for use in battery-powered, handheld electronic products, the RAM is a low-power synchronous dynamic random access memory (SDRAM), mounted in a space-saving fine-pitch ball grid array (FBGA) package that is fully compliant with the new joint electron device engineering council (JEDEC) standard. Compared to standard thin small outline package (TSOP) mounted SDRAM, the form factor of the RAM is reduced by more than a factor of three. Power consumption of the RAM is reduced by as much as 80% compared to a standard 128-Mbit SDRAM. This is achieved by a reduced operating voltage of 2.5VDC and I/O voltage of 1.8 VDC or 2.5 VDC, as well as power management.
Infineon
INFO/CARD 147

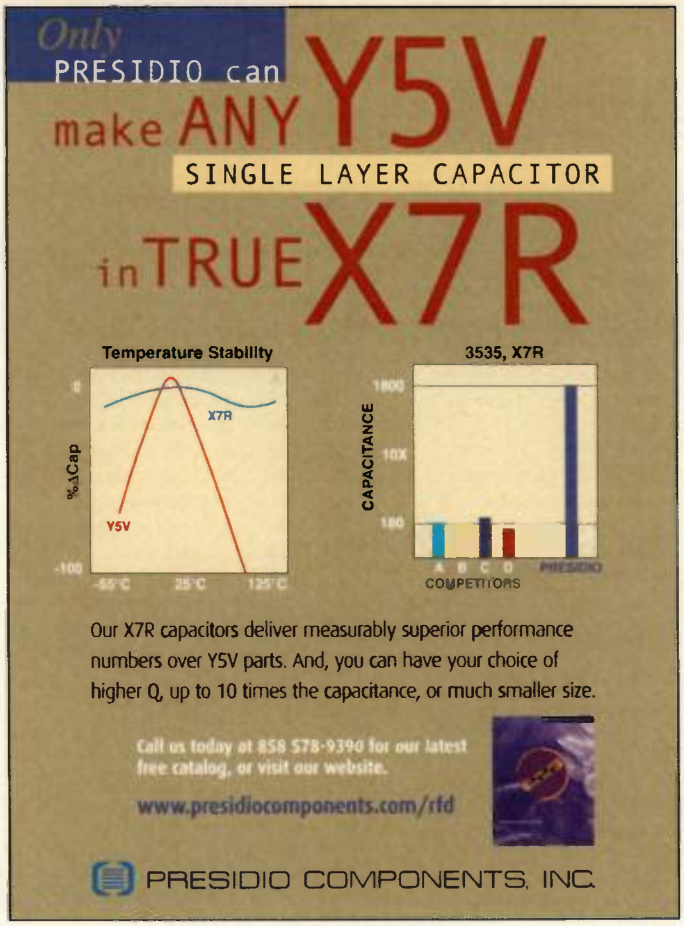
TX/RX

Extended read range RFID transponder coils

Coilcraft introduces a family of high-performance antenna coils designed for RFID applications at 125 kHz. These low-profile transponder coils have an extended length that allows longer read ranges and higher Q. Overall

Specifications at a glance:
- 125 KHz frequency
- 0.4 to 8.1 mH inductance
- extended read range
- high Q

Continued on page 104



INFO/CARD 60

INFO/CARD 6

GLOSSARY OF TERMS USED IN RF DESIGN

2G – second generation wireless systems
3G – third generation wireless systems
A/D – analog-to-digital
AC – alternating current
ACPR – adjacent–channel power ratio
ADC – analog–to–digital converter
AGC – automatic gain control
AMPS – advanced mobile phone system
AODV – ad-hoc on demand distance vector
ASIC – application–specific integrated circuit
ASK – amplifier shift keying
ASP – application service provider
ATM – asynchronous transfer mode
AWGN – additive white gaussian noise
BER – bit error rate
BPSK – binary phase shift keying
CCRR – co–channel rejection ratio
CDMA – code–division multiple access
CDPD – cellular digital packet data
CGI – common gateway interface
CMOS – complementary metal-oxide semiconductor
COTS – commercial off-of-the-shelf
CMRR – common-mode rejection ratio
CPE – customer premise equipment
CW – continuous wave
DC – direct current
DCS – distributed communications system or digital cellular system
DDS – direct digital synthesis
DECT – digital european cordless telephone
DSP – digital signal processor
DUT – device under test
EEPROM – electrically erasable programmable read-only memory
EM – electromagnetic
EMC – electromagnetic compatibility
EMI – electromagnetic interference
ESD – electrostatic discharge
ETSI – european telecommunications standards institute
FCC – federal communications commission
FDD – frequency division duplex
FEM – finite-element method
FER – frame error rate
FET – field-effect transistor
FHSS – frequency-hopping, spread spectrum
FIFO – first-in, first-out
FIR – finite impulse response
FO – fiber optics
FSK – frequency shift keying
FPGA – fine-pitch ball grid array
GaAs – gallium arsenide
GaN – gallium nitride
Gb – gigabit
GB – gigabyte
GFSK – gaussian filtered frequency shift keying
GMSK – gaussian minimum shift keying
GPIB – general-purpose interface bus
GPRS – general packet radio service
GPS – global positioning system
GSM – global system for mobile communications
HBT – heterojunction bipolar transistor
HDR – high data rate
HEMT – high electron mobility transistor
HSCSD – high–speed circuit-switched data
HTTP – hypertext transfer protocol
I and Q – in–phase and quadrature
I/O – input/output
IC – integrated circuit
IF – intermediate frequency
IM – intermodulation
IMD – intermodulation distortion
InP – indium phosphide
IP – internet protocol
IR – infrared
ISM – industrial, scientific, and medical
JEDED – joint electron device engineers council
JSP – java server pages
LAN – local area network
LCC – leadless chip carrier
LDMOS – laterally diffused metal oxide silicon
LMDS – local multipoint distribution service
LNA – low–noise amplifier
LO – local oscillator
LOS – line of sight
LPF – low–pass filter
LSI – large scale integration
LTCC – low–temperature co–fired ceramic
MDS – multipoint distribution systems
MMAC – million multiply accumulate operations
MMDS – multichannel multipoint distribution service
MMIC – monolithic microwave integrated circuit
MOSFET – metal–oxide semiconductor field–effect transistor
MOU – minutes of use
MSPS – million samples per second
NRZ – non–return to zero
NTC – negative temperature coefficient
OEM – original equipment manufacturer
PA – power amplifier
PAR – peak-to-average ratio
PCB – printed circuit board
PCMCIA – personal computer memory card interface assocition (now simply referred to as PC card)
PCS – personal communications system
PDA – personal digital assistant
PDC – pacific digital cellular
PECL – positive emitter-coupled logic
PHEMT – pseudomorphic high-electronmobility transistor
PIM – personal information management
PLL – phase–locked loop
PPM – parts per million
PSK – phase shift keying
QAM – quadrature amplitude modulation
QPSK – quadrature phase shift keying
RFI – radio frequency interference
RFIC – radio frequency integrated circuit
RFID – radio frequency identification
RMS – root-mean-square
ROM – read–only memory
SAR – successive approixmation register
SDH – synchronous digital hierarchy
SDRAM/SORAM – synchronous dynamic random access memory
SEU – single event upset
SiC – silicon-carbide
SIR – serial infrared
SMA – standardization management activity
SMD – short message delivery
SMR –specialized mobile radio
SMS – short messaging service
SMT – surface–mount technology or surface–mount toroidal
SNR – signal–to–noise ratio
SOIC – small-outline integrated circuit
SONET – synchronous optical network
SPDT – single–pole double–throw
SSPA – solid state power amplifiers
TCP – transmission control protocol
TCXO – temperature controlled oscillator
TDD – time division duplex
TDMA – time–division multiple access
TETRA – trans european trunked radio
TSOP – thin small outline package
TTL – transistor –transistor logic
UART – universal asynchronous receiver transmitter
UDP – user datagram protocol
UMTS – universal mobile telecommunications service
UNII – unlicensed national information infrastructure
UTRA – UMTS terrestrial radio access
VCO – voltage-controlled oscillator
VCSEL – vertical cavity surface emitting laser
VCXO – voltage–controlled crystal oscillator
VOFDM – vector orthogonal frequency division multiplexing
VSA – vector signal analyzer
VSAT – very small aperture terminal (satellite service)
VSWR – voltage standing wave ratio
WAP – wireless application protocol
W–CDMA – wideband code–division multiple access
WLAN – wireless local area network
XDSL – another name for an ISDN BRI channel

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dimensions are 11.8 x 3.6 x 3.1 mm. The coil is constructed of ferrite laminated onto a ceramic base. This makes it more rugged and impact-resistant. The 4308TC Series includes 11 models with inductance values from 0.4 to 8.1 mH. Coilcraft can also design coils with different inductance values or for operation at frequencies other than 125 kHz. These transponder coils come packaged in tape and reel with an encapsulated top that ensures reliable pick-and-place operations.
Coilcraft
INFO/CARD 148

Cellular CDMA LNA/PA driver amp, bypass switch

RF Micro Devices introduces the RF2369 LNA and PA driver amplifier. The unit is a 3.0 VDC switchable low-noise amplifier with a bypass switch and high dynamic range designed for

Specifications at a glance:
- 11.5 dBm LNA IP3
- 2 dB bypass loss
- 15.5 dB LNA gain
- 1.6 dB LNA noise figure

digital cellular applications. This device functions as a front-end LNA with an adjustable bias current that can be set externally. This feature allows the designer flexibility to trade-off RF performance vs. current consumption. It features a typical low bypass loss of 2 dB. This bypass performance allows a front end design, which meets all IS-98 requirements including IMD testing, using only two gain states and a single logic control line. In high-gain mode, the device exhibits 15.5 dB LNA gain, 11.5 dBm LNA 11P3, and 1.6 dB LNA noise figure. It is manufactured using a GaAs HBT process technology and is offered in an industry-standard S0T23-6 package.
RF Micro Devices
INFO/CARD 149

Dual-band combiner covers cellular, PCS and GSM

Reactel introduces a new dual-band combiner covering cellular-PCS, and GSM 900 to 1800 for dual-band antennas. The unit is completely sealed for outdoor top-of-the-tower use, and covers the frequency range of 800 to 1000, and 1700 to 2000 MHz. The insertion loss is 0.3 dB max and isolation is 45 dB min. Standard +43 dBm carriers produce less than −140dBc of IMD. Passband return loss is 20dB min. with power handling of 500 W CW. It measures 1.0" x 5.2" x 7.4" and comes with standard connectors of 7/16 DIN female at all ports. Operating temperature is from −40 to +85° C.
Reactel
INFO/CARD 150

Broadband LMDS CPE subscriber antennas

Andrew introduces LMDS CPE antennas designed for broadband applications in the 27.5 GHz to 31.5 GHz frequency band. The lightweight antennas provide a gain of 36.6 dBi at 28.5 GHz. They incorporate shaped Cassegrain optics for high efficiency and optimum pattern control. The antennas are compliant with European Telecommunications Standards Institute (ETSI) TS2 requirements. LMDS CPE antennas are precision-molded from white ASA plastic for toughness and rigidity. The antenna's optical surfaces are coated with high conductivity silver alloy for high reflectance and long life. Antennas can be custom-configured to interface with customer-specified radio equipment.

Andrew Corporation
INFO/CARD 151

SPACE/MILITARY

Prescalers for defense, space applications

Peregrine Semiconductor announces its PE9302 and PE9303 rad hard 3.5 GHz prescalers for space and defense applications. The devices are high-performance monolithic CMOS prescalers with a fixed divide ratio of four and eight, respectively. With an operating

Specifications at a glance:
- 2.0 to 3.5 GHz operation
- 14 ma @3 VDC power draw
- 300 krad radiation immunity
- $<10^{-9}$ SEU tolerances

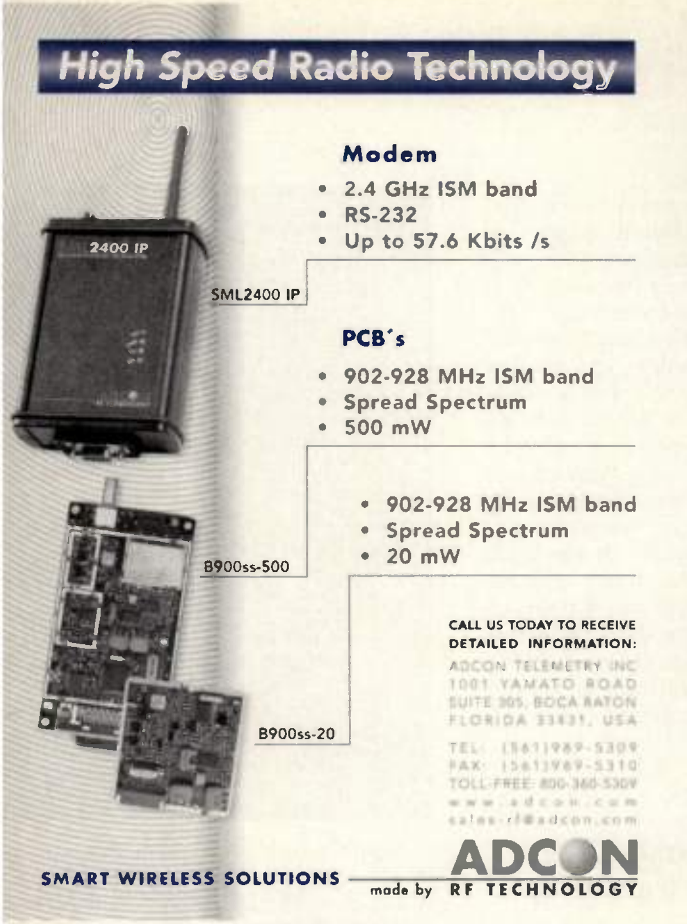
frequency range of 2.0 to 3.5 GHz, the prescalers are designed for low-power operation (14mA @ 3 V across frequency) and operate from a single supply. Built using Peregrine's UTSi CMOS process, the devices can attain 300Krad (Si) total dose tolerance. They are immune to any latch-up and offer single event upset (SEU) tolerances ($<10^{-9}$/bit-day).
Peregrine Semiconductor
INFO/CARD 152

SUBSYSTEMS

Touch screen data converter for wireless devices

Analog Devices introduces the AD7843 and AD7873 sensitive touch-screen digitizers optimized for battery-powered equipment such as personal digital assistants, handheld devices, monitors, point-of-sale terminals, and pagers. The pin-compatible units integrate a 12-bit successive-approximation

register (SAR) ADC architecture with low on-resistance switches for driving touch screens. The AD7873 has added functionality that includes an on-chip temperature sensor from −40 to 85° C, direct battery and touch-pressure measurement, and an on-board reference of 2.5 V. They consume less than 1.4 mW (max) of power with the internal reference off, while operating at a throughput rate greater than 125 ks/s. The parts also have improved electrostatic discharge (ESD) immunity featuring 10-12 KeV ESD protection on analog inputs to



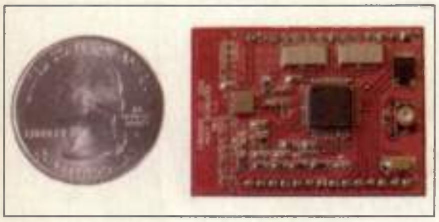
INFO/CARD 5

INFO/CARD 55

prevent damage to critical internal system components. Both low-power devices operate from a single 2.2 VDC.
Analog Devices
INFO/CARD 153

250 channel ISM transceiver

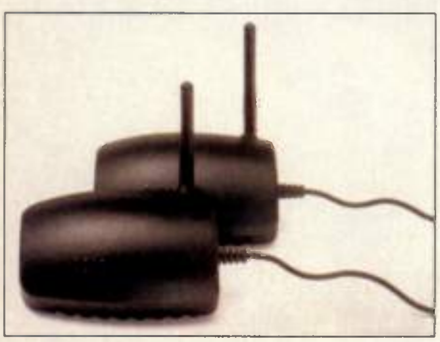
Enrange announces a 1.5" x 1.1" x 0.2" RF transceiver module for ISM band applications. It offers 250+ channels available in 902-928 MHz band. It can use the built-in internal antenna,



which conserves board space, or it can use an external antenna of choice. Its features include adjustable power output levels, data rates up to 38.4 Kb/s, fast power up and channel lock times (under 1 msec). It includes a standby power-saving mode, making it suitable for battery-powered applications. Bi-directional RF communication can be achieved over distances of 500 ft., and it is available off-the-shelf.
Enrange
INFO/CARD 154

Plug-and-play wireless interconnects

AeroComm introduces its ConnexLink packaged transceiver. The plug-and-play device can be set up in minutes to virtually "cut the cables" between standard RS232 devices. It allows users to



quickly upgrade their wired terminals to cordless operation in commercial, industrial and residential applications. The system implements a proprietary communication protocol to provide secure local data transmissions at rates up to 115.2 Kb/s. It uses frequency-hopping spread-spectrum technology in the unlicensed 2.4 GHz band up to 500 feet indoors. Software enables custom configurations based on the user's needs. Any number of remote links can be set up in both point-to-point or point-to-multipoint configurations. Applications include real-time inventory and change monitoring in vending machines and ATMs, quick data upload to electronic signs and scoreboards, timely information retrieval on kiosks and point-of-sale displays, remote data collection from industrial loggers and monitors, and communications to personal and portable computers and hand-held terminals.
Aerocomm
INFO/CARD 155

Revised single-chip UHF low-power data transceiver

Xemics presents the XE1201A, a new revision of its single-chip UHF transceiver. Designed for low-power and low-voltage wireless data link applications. it has a new integrated PA that allows an output power of +5dBm. It is pin-compatible with the XE1201, with any changes for the specifications in receiver mode. It includes a bit synchronizer so that synchronized received data can be directly read by a microcontrolller. It operates in the 300 to 500 MHz frequency range, and is compatible with the ETS300-220 standard for operation in the 433.92 MHz unlicensed frequency band. The XE1201A targets industrial and building control, as well as automotive and remote sensing applications, including but not limited to energy-meter remote reading, remote control, and tire monitoring.
Xemics
INFO/CARD 156

32-Channel A/D converter delivers 2X bandwidth

Pentek introduces a 32-channel A/D converter modular interface extension (MIX) module that offers a 2X performance improvement over existing products. The COTS module features 32 individual sigma-delta A/D converters with 16-bit resolution, sampling rates of 200 kHz and built-in signal conditioning. Complete high-performance,

real-time sub-systems with as many as 96 channels of data acquisition and as much as eight DSPs can be designed for high-frequency sonar, vibration analysis and speech processing.
Pentek
INFO/CARD 157

PASSIVES

Surftrim line of SMT capacitors expanded

Sprague-Goodman has added a new capacitance range to the smallest and thinnest models in its line of SURFTRIM surface-mount trimmer capacitors. The new model is designated GKP6R066 and has a capacitance range of 2.5 to 6.0 pF with drift after setting of less than ± 1%. Q is 200 minimum at 1 MHz. Temperature coefficient of capacitance is NPO ±500 ppm/°C for GKP6R066. Operating temperature range is –25 to +85° C. Voltage rating is 25 VDC and dielectric withstanding voltage is 55 VDC. Insulation resistance is 10^4 MΩ, minimum. Tuning torque is

Specifications at a glance:
- 2.5 to 6.0 pF
- Minimum 200 Q @1 MHz
- ±500 ppm/°C NPO
- 25 VDC working voltage

10 - 100 g-cm (0.2 - 1.39 oz-in.). Models GKP10066 and GKP20066 have capacitance ranges of 3.0 to 10.0 pF, and 4.5 to 20.0 pF respectively.
Sprague-Goodman
INFO/CARD 158

INTERCONNECT/ INTERFACE

Microminiature MMCX PC board receptacles

Applied Engineering Products (AEP) offer design engineers space savings and design versatility. When mounted to a PC board, their mating end is flushed with the edge of the board, allowing boards to be connected in close proximity. The snap-on mating interface of MMCX connectors provides quick, secure connection of PC boards and other components. The receptacles have gold-plated bodies for superior solderability and can be mounted on PC. boards from .031" to .063" thick. Frequency range for the connectors is DC to 6 GHz, and they exhibit low RF leakage throughout their rated service life of 500 mating cycles. They are available individually packaged or preloaded into industry-standard tape-and-reel packaging.
AEP
INFO/CARD 159

MATERIALS/ PACKAGING

High dissipation metal/ceramic packages

Zentrix Technologies announces a new family of ultra-high dissipation metal/ceramic packages for RF and microwave power semiconductor devices. Replacing a conventional RF package with an Ultra Pack can increase the dissipation capability of a high-power LDMOS FET by more than 45% The packs use a tri-metal flange or earless/pill configuration that exhibits enhanced mechanical rigidity and high thermal conductivity (up to 300 W/mK). Ultra Packs address the platform for the next generation of high-power GaAs, GaN, SiC, and LDMOS FETs.
Zentrix Technologies
INFO/CARD 160

FIBER OPTICS/IR

IrDA device combines low-power with low-profile

ZiLOG announces a Slim Line family of IrDA-compliant transceivers with a new low-profile module that will allow designers to add infrared connectivity to even the thinnest PDAs, cell phones and other handheld portable devices. Housed in a miniature 9.1 mm x 3.4 mm package, the ZHX 1810 measures just 2.75 mm high. The ZHX1810 eliminates the trade-off between adding infrared connectivity and maintaining a slim product. And because it occupies the same footprint as many other devices, it's an easy design-in for existing printed circuit board layouts. Designed to operate using the IrDA-Data standard, it combines an IRED emitter, a PIN photodiode detector, a digital AC coupled LED driver and a receiver/decoder in a single package. Just three external components are required for a complete serial infrared solution (SIR). The ZHX 1810 operates with a minimum link distance of 1 meter and supports transmission speeds from 2.4 to 115.2 kb/s. It offers –250 to +850° C operating temperature range, plus mechanical enhancements to the package, to ensure reliable operation in the handheld environment. Built using sheet-cast, optical grade epoxy, the ZHX 1810 features an external metal shield that adds extra RFI/EMI protection and improved mechanical strength.
Zilog
INFO/CARD 161

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RF Engineering Manager: 3-5 years engineering management experience in antenna or RF related products, 5 years design experience in Wireless Communication field, and BSEE required. Manage Engineering Department for Base Station Company RF Engineer who can direct engineering activities to include design, test, prototypes, and interface with manufacturing. Must be hands-on player who can also oversee CAD, EE, ME and test technician functional reports.

RF Power Amp Design: Design and develop high-efficiency low-voltage SiGe power devices and amplifiers for cellular/PCS applications. Requirements include MS or PhD and experience in MMIC or RFIC design and test along with 5+ years experience in bipolar and GaAs power amp design.

RFIC Designers: Hands-on engineers specializing in GaAs, Si, SiGe etc. circuit design. Design centers are located throughout the US and internationally. The companies we represent will sponsor citizenship. All our client companies are successful RFIC technology leaders. All levels of engineering technology positions are open. Design, applications, project engineering, manufacturing/production. BSEE or equal experience minimum.

Senior RF Engineer/fiber-optic communications products: Must be able to design and analyze RF circuits and subsystems in the frequency range from DC to 10 GHZ. Responsible for generating schedules and meeting deadlines. Perform hands-on testing and evaluation of new designs. Provide proper documentation. Transition designs to manufacturing. 10-15 years of relevant "hands-on" experience in circuit /system design and product development BSEE (MSEE preferred) Proficiency with the RF CAD tools, ADS, Series IV, Spice, Touchstone, Eagleware, EM simulators. Familiarity with SONET and Gigabit Ethernet is a plus.

Sr. Scientist SAW Devices: Responsible for the research and development of new or modified process formulations and equipment, requirements and specifications in the manufacturing and evaluation of Surface Acoustic Wave (SAW) devices. Conceive, plan and execute projects involving understanding, defining, and selecting new concepts and approaches for new or improved processes in SAW devices. PhD/MS.

Senior Broadband Modem Design Engineer: Candidate will be responsible for the design and implementation of next generation broadband wireless access modem at speeds of 100 kb/s to 40 Mb/s, using MQAM or OFDM modulation schemes. Required candidate must have a BSEE (MSEE desired) with 5+ years RF data communications designs experience. Knowledge of TDD/FDD/TDMA techniques is preferred.

Principal Design Engineer RF IC design in the Wireless Communications and/or Broadband technologies. Experience in designing on multiple technologies such as HBT GaAs, SiGe, BiCMOS, Bipolar, is highly desirable.

RF Design Engineer Design of RF transceivers used in digital radios in the 2-6GHz frequency range. BSEE minimum, MSEE preferred. 3+ years of board-level RF and analog circuit design experience. Experience with amplifiers, filters, mixers, PLLs and their integration into radio transceivers.

Sr. Filter Design Engineer: 3 plus years experience in the design and development of RF/Microwave filters for the wireless industry. Experience with ceramic, cavity, combline, stripline, low pass, band pass filters a plus. All Filter Designers are encouraged to apply.

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The evolution of toilet talk

by Ernest Worthman
technology editor
eworthman@primediabusiness.com

At last. I think I have discovered the ultimate motivation for deployment of ubiquitous wireless coverage.

I was perusing one of the dozens of magazines I receive each month and found an interesting piece on the latest in toilet technology. While this isn't the first time I've seen this, this time it ignited my creative juices.

It seems that a couple of companies have discovered a way to make your toilet more than just a waste receptacle — Welcome the intelligent appliance. ..

Matsushita Electric Industrial Company of Japan (Why doesn't this surprise me?) and Twyford Bathrooms of Cheshire, England, have, separately, developed a net-enabled toilet embedded with sensitive hormone and nutrient detectors capable of analyzing your waste by-products. It's true. What's more is that it talks to you. And, it can distinguish among multiple users.

This could take some getting used to – But for someone like me, the conversation might be along these lines: (Try to see it in the same vein as the conversation between Dave, the astronaut, and HAL, the on-board computer, in the movie *2001: a Space Odyssey*.)

A Sunday morning conversation –

T: "Good morning, Ern. Rough night, eh? Maybe you ought to reconsider those *Ozzfests* at your age. Would you like me to order up a perk-up special for your breakfast? From your fluid analysis, I'd suggest a megadose of vitamins E, B and C. I'll signal the blender to add that to the protein and fiber cocktail."

E: "Chill out there, Mr. T. I need to get the heart started before I begin to deal with breakfast. How about you tell that finicky coffee pot to brew up a nice, strong pot of Bigbucks finest home-ground Hazelnut-Raspberry-Espresso Blend."

T: "Be nice to that coffee pot, Ern. If you had as much water run through you as it has, you'd be finicky too. But you really should consider cutting out the caffeine. I sense that it will get your heart rate up to a level that is too high for this time in the morning."

E: "Oh, knock it off, Mr. T., and get the darned thing to start cranking."

T: "OK, I'll send it a nice, gentle, low-power wake-up call. It should be ready in a couple of minutes.

"By the way, Ern, It seems your blood pressure and cholesterol are a bit higher than normal this morning. Would you like me to send a quick message to the clinic to make sure you're not out of limits for your age?"

E: "It's OK, Mr. T. I had a super-duper order of macho-nachos with jalapenos, sour cream, refried beans and avocados doused with my usual half-shaker of salt for dinner last night. It's a temporary thing. You can recheck my vitals later and if it's still up, log it."

T: "Beans, eh? Shall I increase the sensitivity of the air quality sensors? Oh...sorry, Ern, we intelligent appliances aren't supposed to have humor. Have a nice day."

Onward to the kitchen – The toilet has the net-enabled coffee pot gently brewing and the net-enabled juicemaster conjuring up a flavorless, colorless, stinky cocktail of vitamins, proteins, fiber, and minerals based on the analysis Mr. T. made of my morning ritual. On the sly, I throw in a cold slice of pizza, hoping to add a bit of flavor to the concoction. I'm sure Mr. T. will have something to say about this later in the day.

I gulp the concoction, wondering why it has this mist rising from it, pour a cup of coffee with three scoops of sugar and read a few sections of the morning paper.

Finally, I head back up to the bathroom to shower and shave. Mr. T. tells me that, upon further analysis, I am pregnant.

"Pregnant?" I retort to Mr. T. "How in the heck can I be pregnant? I'm a guy, you idiot."

"Well, it seems you have a fever and your chemical balance is way off," Mr. T. says. "It almost seems as if you have had a complete change of chemical makeup," the toilet continues.

"You're nuts," I reply.

"No," Mr. T retorts. "I e-mailed the results to a lab to be sure. And it definitely supports my preliminary analysis."

About that time I hear a faint meow as Monte, my tabby male cat walks out of the bedroom.

About this time I'm really sorry I taught Monte to use the toilet.

But, seriously for a moment – Actually, after I got a grip I realized that this could have some significant value, especially in areas such as medicine. Not only can the system talk to you and tell you if you're pregnant, have elevated blood sugar, and have abnormal temperature or blood pressure, but these net-enabled intelligent commodes can e-mail the results to a doctor or other recipient of your choice.

I think once we get past the shock of having a smart toilet and realize what it can do to improve the lives of those who may not always be on top of their health (especially the elderly or infirmed), or finally get a reliable and regular method of monitoring of our vitals, it may not be as errant as it sounds.

Ern

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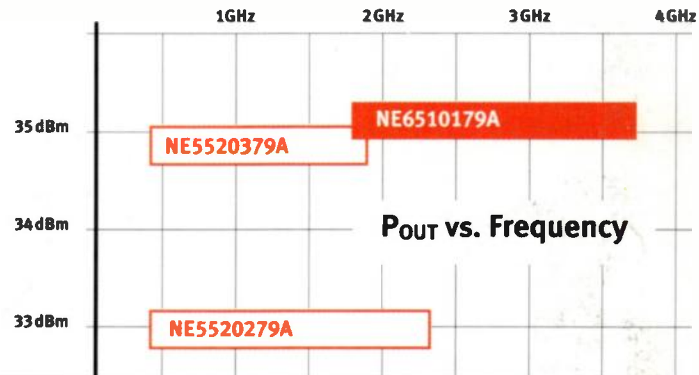

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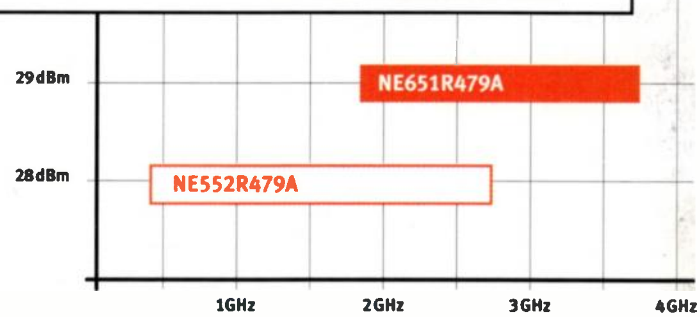

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