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MULTILAYER BALUNS Break Wire-Wound Size Barrier

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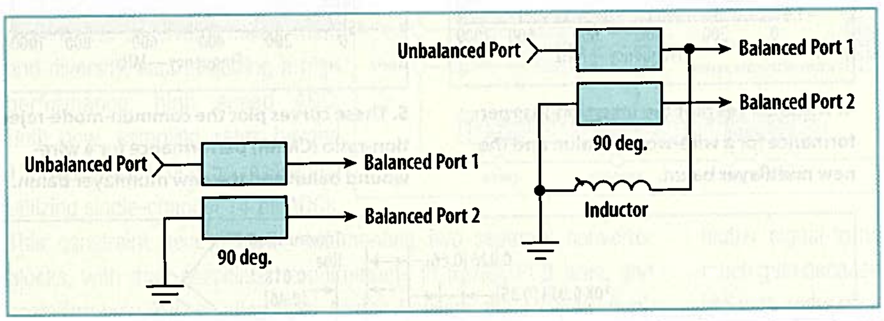
Cover Story

Multilayer Baluns Break Size Barrier

These new baluns not only do away with the ferrite core and size of wire-wound components, they also shave the manufacturing, design, and performance trade-offs associated with traditional transformers.

NIELS KIRKEBY
R&D Manager
Anaren, Inc., 6635 Kirkville Rd., East Syracuse, NY 13057; (315) 433-1917 ext. 218, FAX: (315) 432-9121, e-mail: ccg@anaren.com, Internet: www.anaren.com.

Impedance transformers are one of the necessities of high-frequency design. Unfortunately, when miniaturization is an issue, the wire-wound ferrite components that represent traditional impedance transformers pose three major design challenges. For one thing, the dome-shaped ferrite core is not well suited for high-volume pick-and-place manufacturing equipment and must be used with a plastic cap. For another, the height constraints of modern commercial designs, such as mobile phones and other portable electronic devices, are not well supported by the relatively bulky size of wire-wound impedance transformers, especially when compared to the small size of typical surface-mount-technology (SMT) components. Finally, wire-wound baluns are hampered by the performance limitations inherent in working with nonlinear ferrites. Fortunately, impedance transformers have been improving with time and designers have some alternatives to the traditional wire-wound solution.



1. The basic configurations for the Guanella 1:1 balun (left) and the Ruthroff variation (right) are shown for comparison.

Table 1: Bandwidth comparison of different structures ($BW_{\%} = 200 \frac{|f1 - f2|}{f1 + f2}$)

BALUN TYPE	IMPEDANCE RATIO	TYPICAL BANDWIDTH
Marchand	1:4	115 percent
Marchand	1:1	40 percent
Merrill	1:1	100 percent
Guanella (with ferrite)	1:1	~200 percent
Guanella (without ferrite, Anaren)	1:1	160 percent
Guanella (with ferrite)	1:4	~200 percent
Guanella (without ferrite, Anaren)	1:4	160 percent

For narrowband applications, such as found in wireless consumer products, or medium-bandwidth applications such as satellite-based television, smaller non-ferrite-based balanced-unbalanced (balun) impedance transformers have been developed to save space compared to traditional wire-wound transformers. Implemented using a lattice, Marchand, or Anaren-developed and patented Merrill structure, these solutions are practical where the task calls for no more than about 100 percent bandwidth, but they are not well-suited when a wider bandwidth is needed, such as terrestrial broadcast applications where the bandwidth exceeds 150 percent. ***Table 1*** offers a comparison of typical bandwidths for several narrowband balun structures.

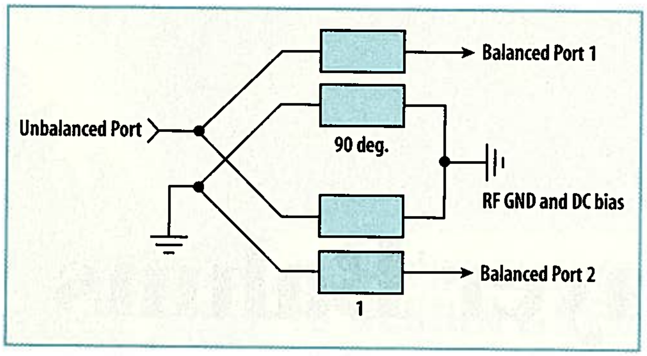
Wire-wound transformers have also gotten smaller over time, with some suppliers offering components as small as 4 × 4 mm with a height profile of 4 mm or less. Even with their recent size reductions, however, the shortcomings of traditional wire-wound baluns remain: they are not well suited for use in high-volume pick-and-place operations, the height of traditional wire-wound transformers is not well suited for low-profile electronic designs, and wire-wound baluns suffer from the material limitations of Ferrite construction with respect to repeatability, temperature stability, and intermodulation distortion (IMD).

To overcome these limitations, Anaren developed a new, non-ferrite transformer based on a patent-pending multilayer approach. The design incorporates the basic impedance-transformation principles first described by Guanella and Ruthroff and applied to wire-wound baluns. But the form factor of the new component is similar to that of ceramic-style SMT baluns.

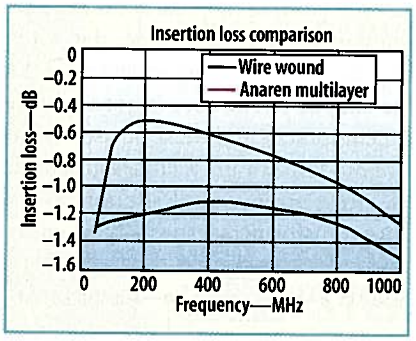
The new design builds upon the Guanella and Ruthroff impedance-transformation structures, using a multilayer circuit fabrication approach to achieve unprecedented small size. ***Figure 1*** shows configurations for a Guanella 1:1 balun (left) and the Ruthroff variation (right) while ***Fig. 2*** shows the configuration for a Guanella 1:4 transformer. The relative performance profiles of the various impedance transformers have been collected in Table 1.

One of the advantages offered by the new multilayer balun is a reduced profile height and 'true' SMT package. These improvements not only make these components much easier to incorporate into a fully automated, pick-and-place assembly environment—for the first time, the design allows lower-frequency baluns to be considered at the design stage for integration into ultraslim consumer handheld products such as modern handheld microcomputers and cellular telephones.

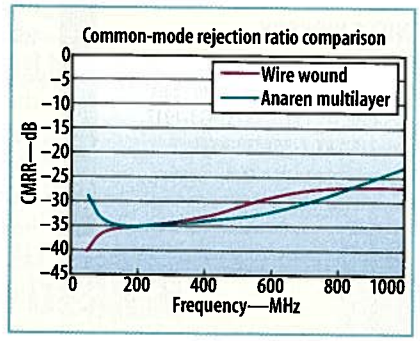
The size difference between a typical wire-wound 1:4 balun and one of Anaren's new 1:4 low-profile baluns for terrestrial broadcast applications is apparent ***(Fig. 3)***, hinting at the savings in printed-circuit-board (PCB) space that might be realized with the new component. The insertion loss ***(Fig. 4)*** and common-mode rejection



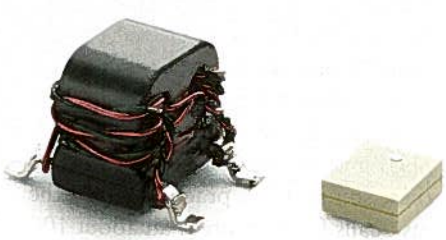
2. This schematic diagram shows the configuration for a Guanella 1:4 transformer.



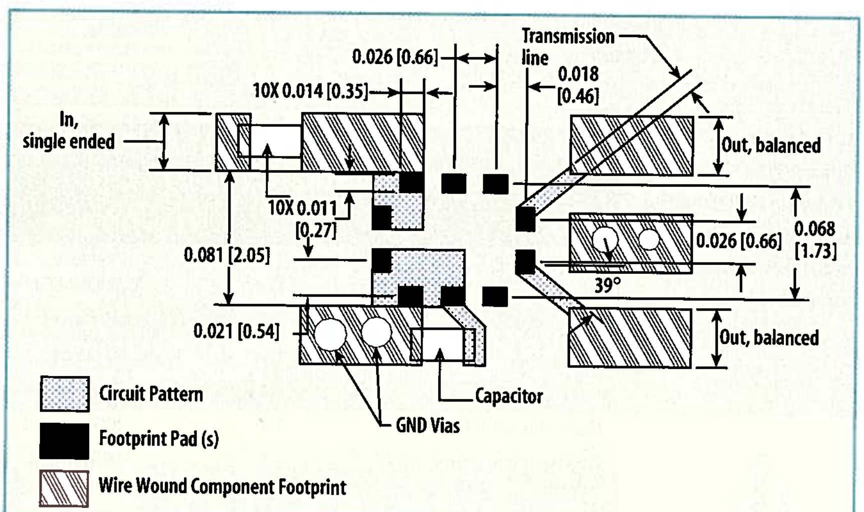
4. These curves plot the insertion-loss performance for a wire-wound balun and the new multilayer balun.



5. These curves plot the common-mode-rejection-ratio (CMRR) performance for a wire-wound balun and the new multilayer balun.



3. A traditional wire-wound balun, which measures 4 × 4 × 4 mm, looms over the much smaller multilayer balun, which measures just 2.5 × 2.0 × 1.0 mm.



6. This layout shows a common footprint that simplifies a performance comparison between a traditional wire-wound balun and the new multilayer balun.

LEADING inside

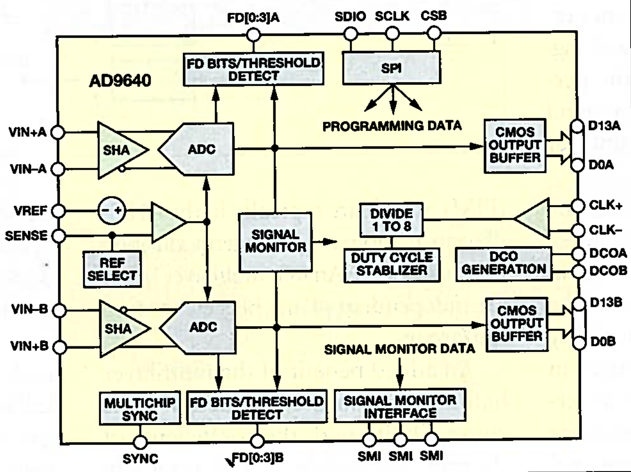
A series of engineering insights by Analog Devices.

Data Converter Function Can Help Solve Cost and Size Design Challenges in 3G and 4G Wireless Infrastructure

As usage and demand for competitive services continue to rise, manufacturers of wireless infrastructure, especially 3G and 4G, must constantly reduce the size and cost of newly installed wireless infrastructure, while holding to high standards of performance, functionality, and quality of service. The data conversion block is a critical function in wireless infrastructure designs, and selecting a converter that is targeted for this application is key to improving the overall system design and breaking through design barriers such as size and cost.

In the main receiver function, the analog-to-digital converter (ADC) is the key block that digitizes the incoming intermediate frequency (IF) signal (after it has been mixed down from the antenna) and then passes the digital data to the digital downconverter. Most architectures require two receivers, called main and diversity, each requiring a high performance, high speed ADC. Until now, sampling rates beyond 135 MSPS could only be realized by utilizing single-channel 14-bit ADCs. This constraint necessitated implementing two separate converter blocks, with their associated requirements in power, PCB area, and cost. The new ADC solution from Analog Devices, the AD9640, dual, 14-bit, 150 MSPS A/D converter, addresses this issue. This dual device enables a 50% reduction in converter board space requirements in the main and diversity architecture. And the AD9640 contains additional attributes that improve wireless infrastructure system design.

14-bit, 150 MSPS ADC in 9 mm × 9 mm 64-lead LFCSP targets wireless infrastructure



A 150 MSPS ADC sampling rate simplifies some of the signal chain complexity and cost associated with a communications design. As sampling rates increase, analog input filtering requirements decrease, and the reduced filtering complexity results in lower cost. Also, because the AD9640 can sample an IF input signal as high as 450 MHz, an analog mix down stage can be eliminated from the receiver input signal chain. This functionality allows savings in board space and cost, and improves performance through the elimination of an analog block and its associated noise contribution.

The power reduction in the AD9640, versus the previous single ADC solutions, provides benefits for base station design. Because many new wireless infrastructure systems are being mounted on outside poles, they cannot utilize active heating and cooling systems as afforded by equipment sheds and buildings. By consuming a relatively low 390 mW/channel, the AD9640 simplifies the mechanical and passive thermal design requirements of the pole-mounted transceiver enclosure.

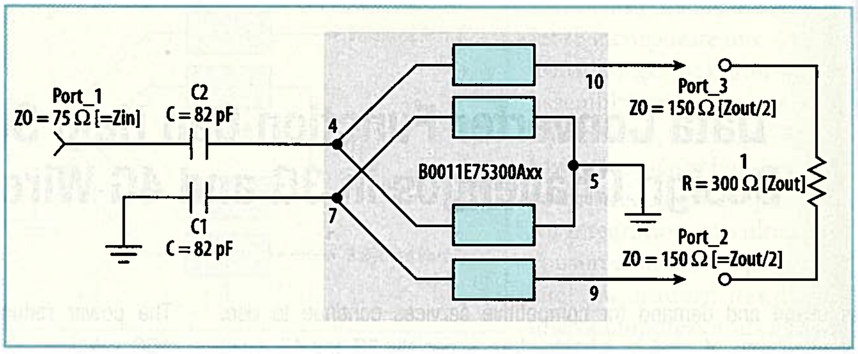
The high performance level achieved by this dual ADC also contributes to significant cost savings in a wireless infrastructure design. Within the radio receiver there is an automatic gain control (AGC) loop that controls the strength of the desired incoming signal. The function of the AGC is to maintain a fixed input signal level to the ADC to ensure that it meets the dynamic range requirements of the system. As a cell phone user moves farther away from the cell tower, the AGC loop increases its gain to ensure adequate reception. If the ADC has a higher signal-to-noise ratio (SNR), the AGC loop does not need as much gain because the ADC can resolve smaller signals and can operate with reduced input levels. Likewise, large interfering signals can cause the ADC to generate spurious components or harmonics. ADCs with higher SFDR performance allow the system to tolerate larger interferers without having to adjust the AGC. In both cases the AGC circuit can be simplified or eliminated with a high performance ADC like the AD9640, which delivers SNR of 72.7 dBFS, and an SFDR of 85 dBc, with a 70 MHz IF input.

Analog Devices offers a wide portfolio of ADCs for communications applications. For data sheets and additional information on the AD9640, visit *www.analog.com/AD9640* or call 1-800-AnalogD. ▶

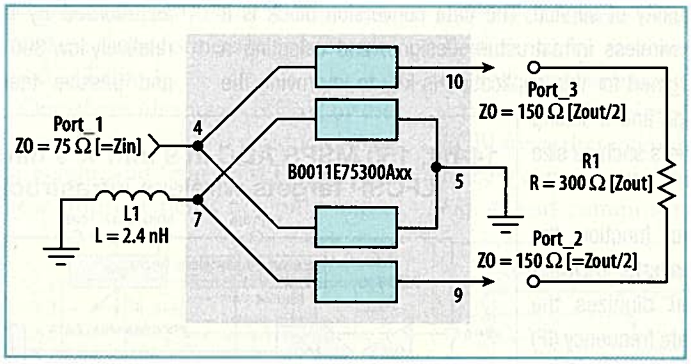
Author Profile: ***Chris Cloninger*** *is the business development manager for Analog Devices' High Speed Signal Processing Product Line.*

ratio (CMRR, ***Fig. 5***) of the two components have also been plotted for comparison. The curves show a significant advantage in insertion-loss performance for the smaller, multilayer balun compared to the wire-wound component, with comparable CMRR performance for the two components.

With its improved insertion loss and equivalent common-mode rejection ration performance, the Anaren multilayer balun can directly replace its wire-wound counterpart for terrestrial broadcast applications. And, because of its more compact form factor—the PCB area taken up by the multilayer balun is less than 40 percent of that of the wire-wound part—it is possible to construct a layout that can fit *either* the wire-wound *or* the Anaren multilayer balun to facilitate easy, in–system performance comparisons and testing. A suggested layout for comparing the performance of a traditional wire-wound balun with that for the new multilayer balun is shown in ***Fig. 6***.



7. Capacitors connected on the single-ended side of the balun improves the insertion loss at the lower end of the band.

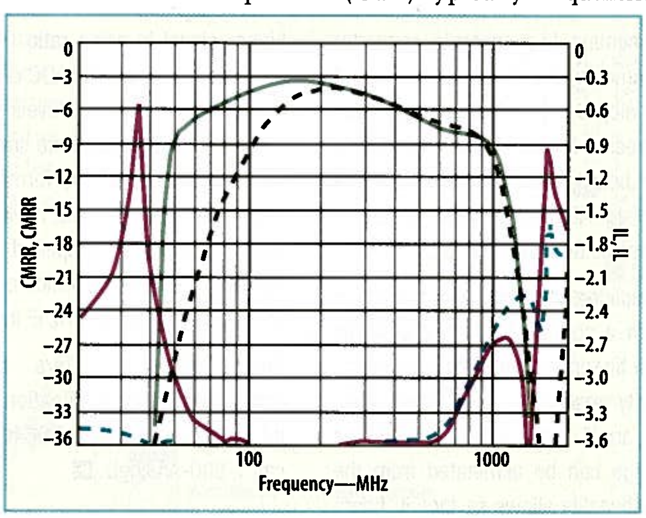


8. An inductor connected on the ground of the single-ended side of the balun improves the balanced performance at the high end of the band.

Beyond its small form factor, the new balun benefits from the non-ferrite softboard circuit-board material used in its multilayer construction. The material, with a relative permeability of 1, is less susceptible to changes in temperature than high-permeability ferrite materials. This stable performance with temperature simplifies system and circuit design, since less performance margin is required over a wide temperature range.

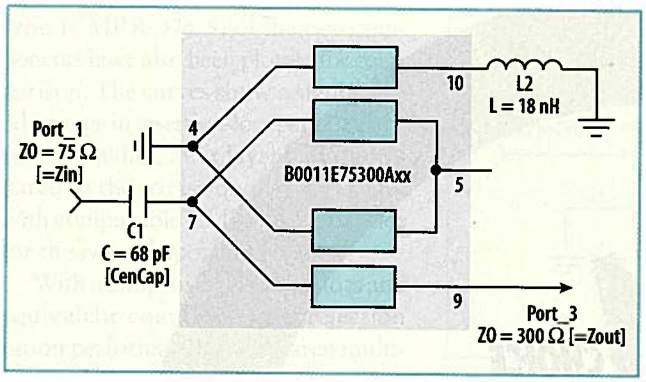
The use of high-permeability materials traditionally used in wire-wound balun construction can also be a concern for the system designer since such materials are inherently nonlinear and, at high-enough power levels, can produce intermodulation distortion products that degrade system performance. Conversely, the new, low-permeability multilayer balun exhibits only intermodulation products caused by dissimilar metals, known as passive intermodulation (PIM), which are typically in the –100-dBc range. Moreover, the intermodulation products for the Anaren multilayer balun are independent of any bias currents in the circuit.

An added benefit of the multilayer balun's softboard construction is its compatibility with the coefficients of thermal expansion (CTE) typically found in PCB materials, so that the PCB and the balun's materials tend to expand and contract at the same rates as a function of temperature. Of course, since low-permeability materials are used in the new balun, there is a practical lower-frequency limit to the design, generally to about 50 MHz. At frequencies below 50 MHz, a wire-wound ferrite-based balun is still an optimum solution.



9. The insertion loss and common-mode rejection ratio performance of the balun (dashed lines) are compared to the same component with capacitors and an inductor (solid lines).

The new multilayer baluns can be matched to accommodate the needs of applications in specific frequency bands using a simple discrete network. A recommended capacitive network ***(Fig. 7)*** improves the insertion loss at the lower end of the band. An inductive network ***(Fig. 8)*** improves balanced performance at the high end. Both can be applied concurrently, if required. However, as with any performance tuning it is a compromise and should be carried out according to the application. ***Figure***



10. This simple schematic diagram shows how a 1:4 balun is used as an unbalanced-unbalanced (unun) transformer.

9 compares the performance of the balun with and without the additional passive circuit elements. The new 1:4 multilayer balun can also be used as a single-ended-to-single-ended impedance transformer (unun) as shown in ***Fig. 10***.

In combination, these performance and form-factor enhancements enable engineers in market segments like terrestrial broadcast system design, that have historically been limited to and by the constraints of wire-wound technology. Facing the same top-level design challenges prevalent in other electronics markets (i.e., miniaturization, the push to reduce PCB costs, etc.), today's terrestrial broadcast designers are charged with market-specific hurdles and functions driven by content- and service-provider demand. These include Internet Protocol Tele-

(continued on p. 110)

Table 2: Anaren multilayer products now available for sampling

MODEL	FREQUENCY	UNBALANCED PORT IMPEDANCE	BALANCED PORT IMPEDANCE	INSERTION LOSS	AMPLITUDE BALANCE	PHASE BALANCE	RETURN LOSS
	(MHz)	(Ω)	(Ω)	(dB)	(dB)	deg. (Δ180 deg.)	(dB)
0922B75-37APR	950 to 2150	75	75	0.8	0.7	10	12
B0922J7575A00	950 to 2150	75	75	1.2	1.4	9	7.9
B0922J7575A50	950 to 2150	75	75	1.1	1.4	9	12
B0011E75300A00	48 to 1080	75	300	1.6	1.5	15	9

(continued from p. 98)

vision (IPTV) and extra hard-drives, as well as incorporating multiple tuners to accommodate watch/record, picture-in-picture (PiP), and other value-added features. Given the new family of true SMT, low-profile non-ferrite broadband baluns from Anaren ***(Table 2)***, design engineers working on terrestrial broadcast electronic solutions need no longer consider the transformer as one of the limitations in a compact design.

In a design environment all but fully migrated to surface mount, miniaturized components—wire-wound baluns have placed limitations on system designers, particularly in the terrestrial broadcast arena. Anaren's new multilayer balun eliminates many of these limitations, and affords the design engineer a new option for developing compact designs suited to today's applications.

The new family of multilayer baluns is an appropriate alternative to wire-wound ferrite transformers for the broadband-communications market. The new baluns offer bandwidths of 20:1, excellent temperature stability, low insertion loss across the full frequency range, good amplitude and phase balance, and a form factor that supports the latest cellular telephones and other slim-profile electronic designs, including set-top digital-television converter boxes and liquid-crystal-display (LCD) televisions. The multilayer baluns are currently available for sampling from the company's website or by contacting Richardson Electronics (www.rell.com), Anaren's exclusive distribution partner for consumer-product components. **Anaren, Inc., 6635 Kirkville Rd., East Syracuse, NY 13057; (315) 433-1917 ext. 218, FAX: (315) 432-9121, e-mail: nkirkeby@anaren.com, Internet: www.anaren.com.**

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2. J. Merrill, "Design of Baluns using Backward Wave Couplers," *Applied Microwave & Wireless*, Vol. 12, No. 4, April 2000.
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4. C.L. Ruthroff, "Some Broad-Band Transformers," *Proceedings of the IRE*, Vol. 47, August 1959, pp. 1337-1342.

Product Technology

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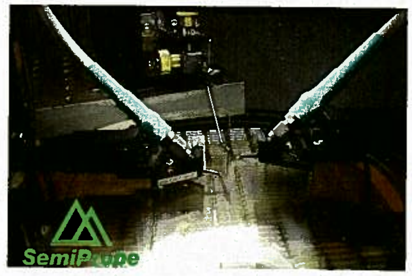
substrates for setting up its probe heads.

Given its proximity to the University of Vermont, it is no surprise that SemiProbe extends a special offer to Universities and educators. The firm provides all Universities and institutions involved in training and education with a 10-percent discount on its products. Systems such as the PS4L Probe System For Life are well suited for university laboratories, giving them a chance to upgrade according to their own budget limitations. In addition, the company's University Referral Program allows any University customer who refers a friend or colleague to SemiProbe to receive "SemiProbe Bucks." These are essentially credits equivalent to 5 percent of the friend or colleague's purchase price, which can then be redeemed for SemiProbe products of the user's choice.

The fledgling company brings more than 50 years of combined test experience to the industry, but many fresh new ideas in terms of practical engineering and even sales. With probe stations that are built to last forever, this is a firm that truly wants to be "the last probe-station company you will ever need." **SemiProbe LLC, Farrell Hall, 210 Colchester Ave., Burlington, VT 05405-1757; (802) 860-7000, Internet: www.semiprobe.com.**



3. SemiProbe installs high-performance Picoprobe probe heads from GGB Industries on its compact probe stations for coaxial measurements through 110 GHz and waveguide measurements through 325 GHz.

Product Technology

(continued from p. 108)

MATLAB and MathCad, to generate advanced waveforms within the instrument itself or to operate with files imported from an external computer. Moving files is easy, since the AWG5000 series instruments feature four Universal Serial Bus (USB) ports along with GPIB and Gigabit Ethernet local-area-network (LAN) interfaces. Generated waveforms are clearly displayed on an XGA-compatible, 10.4-in. color liquid-crystal-display (LCD) touch-screen display.

The AWG5000 Series instruments owe much to their high-performance digital-to-analog converters (DACs), but support these components with an internal reference clock with phase noise of better than –90 dBc/Hz offset 100 kHz from the carrier. The instruments include an internal trigger generator with adjustable range of 1 μs to 10 s and 0.1-μs resolution. The skew between outputs can be controlled over a range of ±5 ns with 5-ps resolution.

The AWG5000 Series of arbitrary waveform generators are self-contained solutions to mixed-signal testing at analog and digital baseband and IF levels. By adding the firm's AWG7000 arbitrary waveform generator, with 20 GSamples/s and 10-b vertical-resolution performance levels, users can create full waveform control over the baseband, IF, and RF levels of a design. P&A: $25,000 and up (AWG5000 Series instruments), $7500 (option 03 for 28 channels of digital data on model AWG5002), $10,000 (option 03 for 28 channels of digital data on model AWG5012), and $7500 to $15,000 (options for increasing waveform memory to 32 Mpoints/channel). **Tektronix, Inc., 14200 SW Karl Braun Dr., P.O. Box 500, Beaverton, OR 97077; (800) 835-9433, Internet: www.tektronix.com.**