cover story

Network Analyzers Simplify Mixer Test

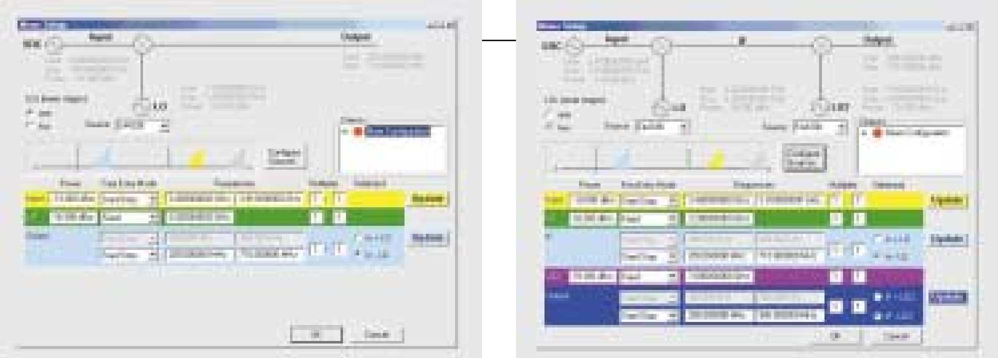
By offering coverage through 67 GHz and a new method for characterizing mixers, these analyzers eliminate many measurement challenges for higher-frequency designs.

DAVID BALLO
Product Manager
Agilent Technologies, 1400 Fountaingrove Pkwy., Santa Rosa, CA 95403; (707) 577-2000, FAX: (707) 577-6070, e-mail: david_ballo@agilent.com, Internet: www.agilent.com.

Mixers are one of the fundamental components of every superheterodyne receiver (Rx), but evaluating them has never been easy, even with powerful vector-network analyzers (VNAs). The techniques employed to characterize the phase and group-delay performance of mixers are especially cumbersome, lengthy, and prone to error. To solve this problem, Agilent Technologies (Santa Rosa, CA) has created new calibration techniques for its PNA Series of VNAs that reduces or eliminates traditional problems inherent in characterization of mixers and converters. It is available for the E8362B, E8363B, and E8364B VNAs, with coverage from 10 MHz to 20, 40, and 50 GHz, respectively, as well as for the new E8361A network analyzer with coverage from 10 MHz to 67 GHz.

The 67-GHz E8361A **(Fig. 1)** should find a following in manufacturers of passive components and subsystems designed for satellite communications, point-to-point digital radio, broadband wireless access, and OC-768 (40 Gb/s) optical-communications systems. The instrument has all of the features and capabilities of previous PNA Series analyzers, including trace noise of less than 0.03 dB at a 1-kHz bandwidth, dynamic range greater than 90 dB at 67 GHz, and measurement speed of less than 26 μs per point. Similar to all of the PNA Series instruments, the E8361A is based on the Windows 2000 operating system,

1. With 67-GHz capability, the E8361A PNA Series VNA is well-equipped for evaluating a wide range of microwave and millimeter-wave components.



2. The dialog box for single-conversion devices (a) and dual-conversion devices (b) allows the user to enter all values in a single place, guided by the instrument to ensure compliance with acceptable limits.

which provides the operator with a familiar operating environment, provides a multitude of connectivity choices, and allows programs to be run inside or outside the analyzer.

The frequency-offset measurement capability is implemented as a hardware and firmware solution in the analyzers. The hardware provides the ability to make basic offset-frequency measurements, including mixer-conversion loss, intermodulation distortion (IMD), and harmonic and spurious responses. The firmware automates the mixer-measurement process, making it possible for users without extensive knowledge of mixer measurement to set up, calibrate, and characterize their devices accurately and quickly. The firmware's advanced calibration choices include vector correction of conversion loss, phase, and group delay, and match-corrected absolute-power measurements, both of which increase the overall accuracy of the process compared to other methods in use today.

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Any mixer-based superheterodyne receiving system requires that the mixers within it have well-controlled amplitude phase, and group-delay responses. Characterizing the amplitude response (conversion gain or loss) is the easiest measurement. Conversion phase and group delay, however, continue to be difficult to measure with high accuracy and repeatability, and the test set-up employed in the process usually requires multiple external components, with many connections and reconnections. This process creates mismatch and connector repeatability errors, and increases the chance that operator error will occur, creating a high level of uncertainty in the measurement results.

Agilent's new vector mixer calibration accommodates conversion loss as well as phase and group delay, resulting in a far more accurate and comparatively simple technique that requires fewer external components and connections. This is best understood by comparing it with two other methods that are commonly employed to characterize mixer phase or group-delay responses.

The first method requires the designer to make three measurements on three pairs of mixers. The amplitude and phase responses of each mixer are calculated by solving the three linear equations created by the three measurements. The technique uses upconversion and downconversion and employs an intermediate-frequency (IF) filter between the mixer pairs to keep the unwanted mixing product from being reconverted. The method also assumes that at least one of the mixers is reciprocal (it has the same conversion loss and group delay in upconversion as downconversion). Its most obvious drawback is the fact that three sets of measurements must be made and the mixer pairs must be reconnected with the filter. Errors can creep into the process due to connector repeatability and the mismatch effects between the filter and mixer pairs, as well as between the mixers and test equipment.

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Fast Scopes and Probes Save Signal Integrity

LON HINTZE

Product Manager, Agilent Technologies

Accelerating clock speeds and ever-faster digital circuits pose extreme challenges for even the best oscilloscopes. To measure clock speeds in excess of 200 MHz and edge rates less than 100 ps, real-time oscilloscopes must have extremely high sampling rates, broad bandwidths, and must be complemented by single-ended and differential active probes with comparable performance. Fast scopes have been available, but high-performance probes have been scarce. Fortunately, the new 6-GHz model 54855A and 4-GHz model 54854A Infinium oscilloscopes and a novel probe architecture known as InfiniiMax from Agilent Technologies (Colorado Springs, CO) effectively address these challenges, delivering sampling rates to 20 GSamples/s simultaneously on four independent channels.

1. The 4-GHz model 54854A and 6-GHz model 54855A Infinium digital oscilloscopes provide sampling rates to 20 GSamples/s simultaneously on four independent channels.

The probes feature a new architecture to ensure full bandwidth even when accessories are used at the probe tip to make the physical connection to the device under test (DUT). Probe amplifiers can be configured for single-ended or differential operation through different probe heads, so a single probe amplifier can be used to make either type of measurement. The two new oscilloscopes **(Fig. 1)** retain all of the features of other Infinium models, including an 8.4-in. (21.34-cm) thin-film-transistor (TFT) color liquid-crystal-display (LCD) screen, 10/100 local-area-network (LAN) Ethernet interface, 10-Gb hard drive, and remote operability from the Internet. However, the operating system has been upgraded to Windows XP, a compact-disc-read/write (CD-RW) drive has been added and there is dual-monitor support for running third-party applications on the oscilloscope. Standard memory is 262 kpoint/channel, which can be increased to 1 Mpoint/channel with no loss of sampling rate, or up to 32 Mpoint/channel at sample rates of 2 GSamples/s and slower. Memory of 1 Mpoint creates a time-capture window of 50 µs per channel at 20 GSamples/s, which is more than adequate for most applications. Acquisition memory of 32 Mpoints at 2 GSamples/s and slower sample rates allows the designer to capture long time windows at high resolution, such as identifying glitches due to a power-supply start-up from reset.

2. The InfiniiMax probe system is designed to provide maximum measurement bandwidth when used with the latest 4- and 6-GHz Infinium digital oscilloscope models.

The ability to maintain a full 20 GSamples/s on all four channels simultaneously when performing either single-ended or differential measurements is unique to the new scopes. All other four-channel scopes require two channels to deliver real-time, full-rate sampling at 6 GHz without aliasing, essentially turning them into two-channel many connections and reconnections. This process creates mismatch and connector repeatability errors, and increases the chance that operator error will occur, creating a high level of uncertainty in the measurement results.

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The other popular method used for characterizing mixer group delay involves measuring mixer return loss with an air line that is terminated with a short, and taking the time-domain transform of the response. The time delay of the response with the short is subtracted from the delay due to the length of the airline by itself, which yields the two-way delay of the mixer. This technique has proven useful only for broadband mixers, and delay resolution is limited by the time-domain resolution. In addition, the delay response is a combination of the response from the sum and difference products, and the measurement requires a reciprocal mixer. On the positive side, the technique does not require additional mixers or locking the local oscillator (LO) to any of the test signals.

Agilent's technique for the PNA Series analyzers is a vector-corrected mixer calibration approach that employs reflection measurements to fully characterize a reciprocal calibration mixer/filter pair, without any additional mixers. This calibration mixer/filter pair is then used in conjunction with short, open, load, and through standards to calibrate a test system that can then be used to measure the conversion loss, conversion phase, and absolute group delay of any mixer or converter under test. The method can be used to measure both reciprocal or nonreciprocal mixers and converters, and the calibration process and control of external test equipment [such as signal sources for the LOs of the device under test (DUTs)] is highly automated.

Previously, in addition to the tedious nature of the mixer-characterization process, the instrument interface from which the designer must work has typically added to the confusion of an already-difficult task. To remedy this, Agilent's new frequency-conversion firmware presents a clear picture without requiring the user to enter obscure and confusing values. All values are set up on a single screen. By entering values into a single dialog box (shown in **Fig. 2a** for single-conversion devices and **Fig. 2b** for dual-conversion devices),

Fast Scopes and Probes *(continued)*

instruments. The independent channels provide an important advantage, since in many measurement situations at least three signals must be viewed in relationship to each other to accurately determine performance margins.

In addition to the scopes and probes, Agilent has introduced an optional jitter-analysis package that will be useful for designers of high-speed clock circuits. It is integrated into the scope-application suite, and includes a setup wizard that guides the user through the jitter-measurement process, including tips on the various types of measurements and when to use them. Measurements include cycle-to-cycle, n-cycle jitter, and period jitter, as well as time-interval error, setup and hold time, measurement histograms, trending, and jitter spectrum.

While the bandwidth and sampling rates of the 54855A and 54854A are impressive, the use of a conventional probe architecture would have made these specifications almost meaningless. This is because the performance of traditional active probes drops precipitously at high frequencies as wire accessories are added to the probe tips to facilitate physical connection to the circuit. For example, a 2-in. (5.08-cm) long wire attached to the end of a probe with specified 6-GHz bandwidth will reduce the probe's effective bandwidth to only 1.5 GHz, rendering any additional scope bandwidth useless. In addition, as the maximum operating frequency of the probe increases, the size of the probe decreases, which can make it extremely difficult to use when "browsing" by hand from point to point in the circuit.

The new InfiniiMax architecture eliminates these drawbacks. In a conventional active probe, a length of transmission line in the measurement path (such as the aforementioned wire accessories) becomes a tank circuit at high frequencies that can resonate causing unwanted oscillation, variations in impedance, and reduced bandwidth. In contrast, the transmission line in the InfiniiMax probe circuit path is well-controlled, properly terminated, and compensated by the probe amplifier.

As a result, the InfiniiMax probe system **(Fig. 2)** offers the highest performance available for any use model—browsing, solder-in, socket or probe holder. To maintain usability of these small probes, Agilent has designed a sleeve that fits over the probe head, making it easier to hold for long periods of time in a "browsing" fashion. The company offers a considerable number of probe choices to meet customer needs ranging from low cost to the highest performance. Probe amplifiers with 3.5-, 5.0-, and 7.0-GHz bandwidths are available. Combined with "connectivity kits," these probes are capable of either single-ended or differential measurements, or both if two types of kits are selected. The kits contain a small browser (and sleeve), a socketed probe head, a solder-in probe head, and fully characterized performance plots for all of its various probe heads. These performance plots include swept-frequency response, common-mode rejection versus frequency, impedance versus frequency, time-domain probe loading, and time-domain probe tracking.

The InfiniiMax probe architecture circumvents issues that have plagued active probes for years. Since conventional probe designs have not been able to keep pace with bandwidth requirements, they have limited performance of even the fastest scopes to the maximum speed of the probe itself. In addition, these probes cannot achieve their specified performance when any wire accessory is attached to them, a situation that worsens rapidly as wire length is increased. Finally, as measurement frequencies have increased, probe designs have become smaller and smaller, which has made the probe difficult to hold. This is compounded by the task of inserting probes into the fine-pitch geometries of integrated circuits (ICs). All of these problems are successfully addressed by the new InfiniiMax architecture. P&A: 54854A (4 GHz) $49,995.00, 54855A (6 GHz) $58,995.00, InfiniiMax probes $3850.00 to $8550.00, Jitter Analysis Software $3995.00. **Agilent Technologies, (395 Page Mill Rd., Palo Alto, CA 94303, (800) 452-4844, www.agilent.com.**

all the values are presented in a single place. The firmware ensures the values are within acceptable ranges and provides help when requested.

The vector-mixer-calibration technique is conducted in two steps. The user characterizes a mixer/filter pair with reciprocal properties first, and this mixer then becomes an additional through standard with which to calibrate the test system. With this step completed, the test system can characterize nearly any reciprocal or nonreciprocal mixer or converter without the need for reconnection of the calibration mixer. Information is also provided about the input and output match of the calibration mixer, which can be used to remove mismatch errors at the input and output of the test system. Since there is no need for multiple mixer connections during the mixer-calibration process, connector repeatability is eliminated as a source of measurement error.

Measurement systems that use traditional techniques for measuring group delay are inherently not well-matched, requiring generous use of attenuators to reduce mismatches of the test system. These attenuators cause serious degradation of the test system's dynamic range and calibration stability. Until the introduction of Agilent's vector-mixer-calibration technique, no method had been proposed to correct for the calibration or reference mixer's input and output mismatch, and thus they have been impossible to determine. The vector-calibration technique is currently one of the only commercially available methods that corrects for input- and output-mismatch effects of the entire test system, providing accurate transmission and reflection measurements of the mixer or converter under test.

To show the viability of the technique, a classic network-analyzer procedure can be used. In this process, a mixer is measured by itself and then with an air line, which is a low-loss, well-matched delay line. In an ideal measurement, the test system should show the conversion loss of the mixer reduced by exactly the loss of the air line, and mismatch effects should introduce minimal ripple on the measurements. The results of measurements performed with an air line scalar and vector calibrations show that ripple in the scalar measurement is nearly an order of magnitude greater than that of the vector-calibrated measurement. P&A: $139,000.00 (E8361A 67-GHz PNA Series VNA), $19,500.00 (frequency-offset measurement capability, typical mixer option configuration); now available for order. **Agilent Technologies, Test and Measurement Organization, 5301 Stevens Creek Blvd., MS 54LAK, Santa Clara, CA 95052; (800) 452-4844, Internet: www.agilent.com/find/PNA.**

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