RF-CHANNEL SIMULATORS

bring reality's challenges to your prototype

Channel simulators let you replicate the varying and troublesome characteristics of the RF channel at your workbench, so you can assess and quantify the performance of your communications system.

BILL SCHWEBER, TECHNICAL EDITOR

In the beginning of wireless, there was just "noise," and life was simple. Engineers soon called this noise additive white Gaussian noise (AWGN), but even this title was not enough to capture all the idiosyncrasies of a real-world RF channel. Then, engineers, scientists, and mathematicians got involved, and they soon gave names to more subtle effects, such as Rayleigh fading, Ricean fading, impulse noise, cyclostationary noise, and intersymbol interference, to name just of few of the newer noise-family members. All these noises were in addition to basic channel difficulties of signal attenuation and loss.

Your problem is that when you need to see if your RF-based system meets expectations and test its tolerance to channel impairments, the real channel is uncooperative. Although you can set up your prototype system in an environment that (you hope) is typical and representative of the real world, it's extremely difficult to achieve consistency, repeatability, and precision in the attenuation factors and in the various noise types and parameters. One day, you have a relatively quiet real channel; the next day, it is noisy and unpredictable. It's a challenge to measure the nature and complexity of this real-world noise. And when you need to test your system against some industry standard, you must provide a channel with better documentation of its characteristics than you can informally lash together.

The channel simulator can make your life easier. This test instrument, which is usually a self-contained box, provides

@a glance

- If you're working with RF-channel-based links, consider how you'll evaluate your prototype system under realistic, consistent channel conditions of noise and fading.
- Simulators can implement basic yet essential SNR modeling or more complete fading-based models, and you'll probably need both.
- Some instruments combine both signal-source and channel simulation and are fine for some applications at the system level but may be unsuitable for your initial subsystem-stage performance characterization.

Photo courtesy Telecom Analysis Systems Inc

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known, programmable channel impairments for your RF link. It lets you repeatedly establish attenuation factors as well as noise type and magnitude. Some simulators require you to provide the signal source separately; thus, they can support proprietary signals, formats, and modulations, such as those for RFID, keyless-entry systems, and specialty wireless LANs. Other simulators are integral to a larger signal- and data-generator unit. Some units are designed for general-purpose applications, such as long-distance RF links. Still others target the noise patterns relevant to more tightly constrained systems, such as cell phones, which you must test against defined standards.

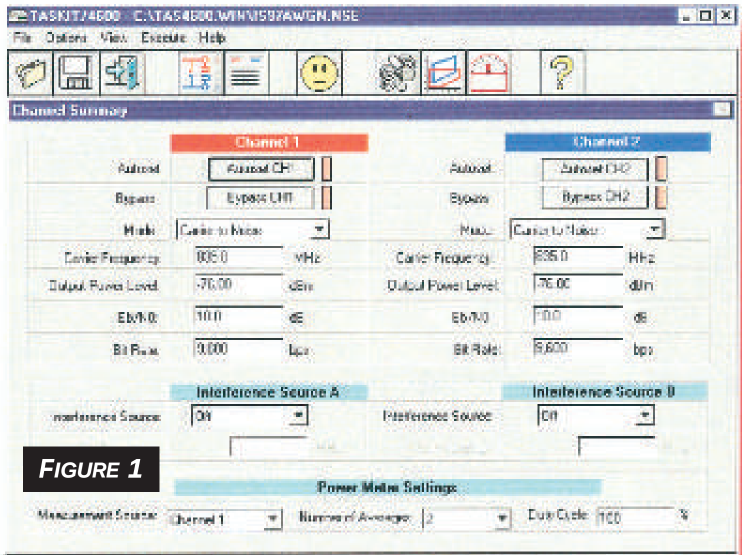

FIGURE 1

The Windows-based application software for the TAS 4600A noise and interference emulator provides graphical user control in addition to vendor-defined configurations.

Deal with SNR first

SNR and carrier-to-noise ratio (CNR) (or the similar ratio of carrier energy to noise energy (E_b/N_o) are the oldest and most common communications-related parameters—and with good reason. Usually expressed in decibels, these ratios capture the relative strength of the desired signal versus undesired noise (usually, AWGN).

Though computer-based simulation is a step toward predicting your system's performance **(Reference 1)** you'll soon need to go to the real world. Before you get involved with sophisticated forms of noise and channel impairments (see **sidebar** "Channel models define various realities"), you need to assess your system's ability to handle this basic Gaussian noise and various SNRs and CNRs. The reasons for making this assessment are, first, that every channel has AWGN problems and, second that, if your system can't handle basic AWGN problems, it's highly unlikely that it will be able to successfully handle more complex noise.

To address this problem, several vendors offer stand-alone instrumentation, which replicates basic channel characteristics. The TAS-4600A noise and interference Emulator from Telecom Analysis Systems (TAS), for example, is a two-channel unit that measures the power of your applied RF signal and then adds an amount of AWGN or interference that you specify. It lets you scale the input carrier over a 120-dB range, so that you can perform critical SNR testing at low carrier levels, in which front-end noise in your receiver becomes a significant factor.

Although you can control the unit via its front panel, you can also use the provided Windows applications software to set up tests, store test parameters and results, and use the supplied test configurations for cellular systems, PCs, and IMT-2000 bands (**Figure 1**). Because the software supports two independent channels, you can use it for

WHEN BAD CHANNELS HAPPEN TO GOOD DESIGNS

Unfortunately, a noisy or an ill-behaved channel can make it difficult for you to achieve acceptable performance, even with a carefully conceived and well-executed RF design. If your system doesn't meet your performance goals—as measured by bit-error rate, reliability, throughput, or some other characterization of acceptable performance—the good news is that you have many choices to explore for improvement.

The bad news is that marketing-specified goals, regulatory strictures, and design constraints often prevent you from seriously considering of many of these choices. If you assume that you can't change or improve the channel itself, which is usually the situation, then consider each of these options and rule out the ones that don't fit. Concentrate on the options that can help, but also weigh the technical and design cost of each, as there are rarely "cost-free" choices:

- Increase the transmitter power;
- Reduce the specified operating distance;
- Use a more directional antenna, which provides some gain and reduces interference, or use multiple antennas in a diversity arrangement;
- Reduce the noise in your receiver's front end by adding filtering or going to a lower noise front-end design;
- Implement a more error-tolerant data algorithm and error-detection/correction scheme;
- Reduce the data rate or channel bandwidth;
- Switch to more noise-resistant modulation techniques;
- Consider shifting to another frequency band, or using frequency diversity.

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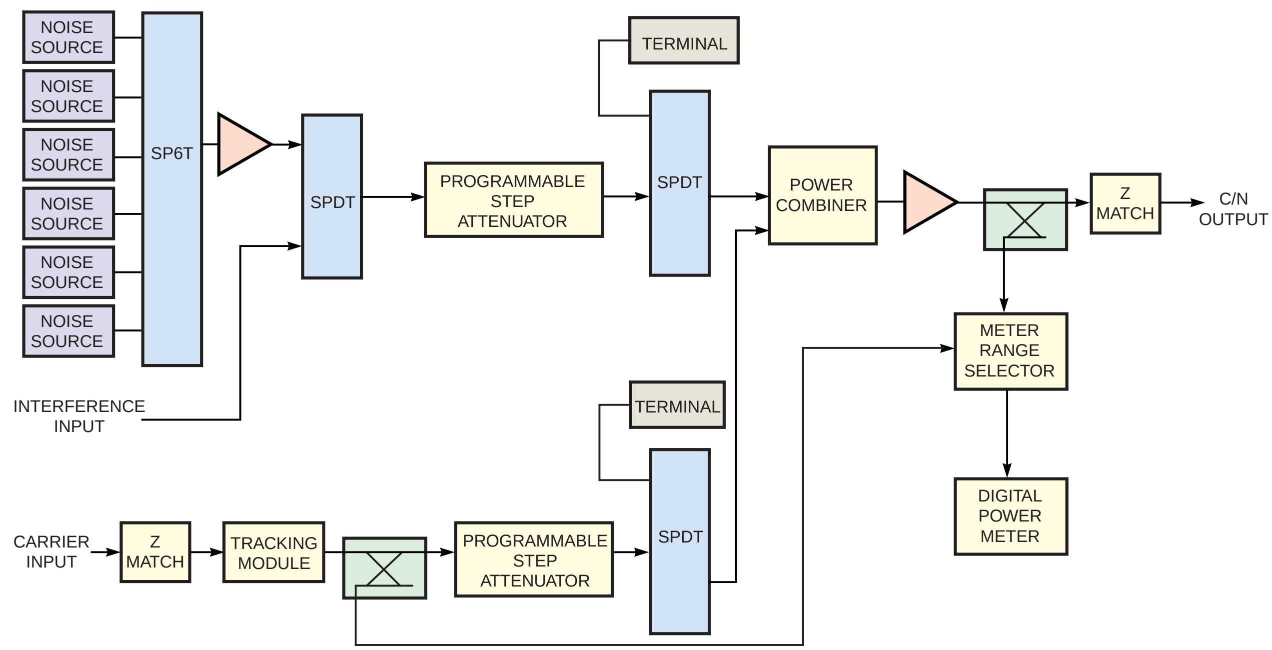
FIGURE 2



With the UFX-BER signal-to-noise generator from Noise Com, you can blend your transmitted signal with precisely measured noise factors.

duplex or diversity-path testing.

Noise Com's UFX-BER similarly strives to maintain an accurate ratio between a user-supplied carrier and an internally generated noise source (**Figure 2**). You can set this ratio in one of five ways: as CNR carrier-to-noise density (C/N_o), bit-energy to noise density (E_b/n_o), carrier to interferer (C/I), and true rms power meter. Output power settings range from –55 to +5 dBm. The instrument is available in a variety of models with frequency ranges tailored to specific applications, such as 5 to 45 MHz for high-definition TV, 650 to 850 MHz for Iridium phones, and 5 to 90 MHz for general-purpose applications. The UFX-BER has a four-line 3 20-character-per-line display. It can operate as a stand-alone device, or you can interface it to a controller via an IEEE 488 or RS-232C/422/423 interface.

Once you establish basic SNR or CNR performance, you'll probably have to look at more realistic channel simulations that include various fading and multipath scenarios. The PC-controlled HP 11759C from Hewlett-Packard is a 40- to 2700-MHz channel-propagation simulator designed for testing digital cell phones under RF multipath conditions with fast-fading, slow-fading, and Doppler-shift parameters. You provide the signal source as well as a local-oscillator (LO) signal, which sets the operating frequency.

The HP 11759C has two independent RF channels, each with three signal paths. The six paths allow you to meet the basic multipath-replication conditions that most cell-phone-testing standards require. These conditions model the complex multipath reality by using the sum of only a limited number of paths. (Note that six paths provide a good approximation.) The unit lets each path be Doppler-shifted or faded and delayed relative to the others. You can simulate various types of fading and multipath environments by establishing a correlation coefficient between the path pairs in the two channels. You can also jointly control two HP 11759C units to meet the 12-path (also called 12-ray) test requirement of Global System for

FIGURE 3

The TAS 4500 Flex unit provides fading and other channel perturbations to your signal.

Mobile communication (GSM) and DCS1800 standards. The available Doppler shift range is ±425 Hz, which corresponds to relative handset-to-base-station speeds as high as 509 km/hour at 900 MHz.

In addition to the TAS 4600 noise and interference emulator, TAS also offers a channel emulator that goes beyond basic SNR or CNR channel simulation. The TAS 4500 Flex4 unit lets you establish multipath fading, log-normal fading, delay, and path-loss conditions with a user-supplied signal (**Figure 3**). The TAS 4500 translates your input signal down to an IF range via an internal LO, performs the channel-emulation signal processing, then upconverts the signal back to the original RF (**Figure 4a**). Each IF block has three independent signal-processing paths, which prove the delay, path loss, and other channel characteristics you require (**figures 4b** and **c**). Because each system channel has as many as two IF modules, you can get a maximum of six paths per channel and 12 paths per unit.

Like the TAS 4600, the TAS 4500 is normally controlled via a PC that has vendor-supplied application software. This software sets the TAS 4500 for configurations that meet the requirements of standards such as code-division multiple-access (CDMA), time-division multiple-access (TDMA), GSM, and PHS, as well as cellular modems. You can combine the two TAS units in series to provide both SNR and channel-fading emulation.

Noise Com's 30- to 2500-MHz MP-2700 multipath fading emulator is available in 6-MHz narrowband and 24-MHz wideband models, with one-channel/six-path, two-channel/six-path, and two-channel/12-path versions (**Figure 5**). Again, you provide the LO, which can range to 140 MHz above RF. The self-contained unit has a full QWERTY keyboard and screen plus floppy disk and implements Nakagami, Rayleigh, delay, Doppler, Ricean, Suzuki, and log-normal channel models.

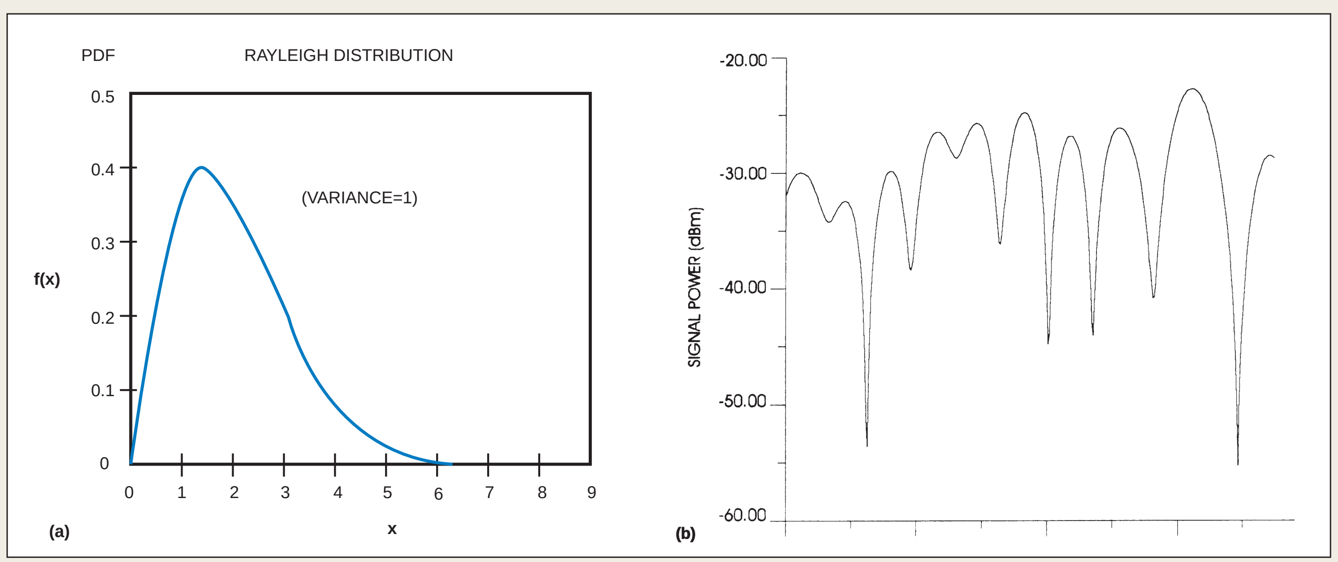
If your application encompasses high-frequency (HF) or very-high-frequency (VHF) paths, a system such as the Signatron S-250C radio-channel simulator can help you avoid the practical difficulties of obtaining repeatable, meaningful measurements that include nonfading-groundwave and multipath-

CHANNEL MODELS DEFINE VARIOUS REALITIES

The channel model and corresponding channel simulation that you need to invoke depends on the electronic environment and the nature of your application. Certainly, some environments are electrically nastier and noisier than others or have noise attributes (impulse noise, fixed-frequency interference sources) that others do not. In addition, some types of channel degradations are not a factor in all situations. For example, a fixed point-to-point link is less affected by the multipath, fluctuations, and fading that a moving cell phone endures when it changes location but maintains contact with several base stations.

Noise and channel models begin with additive white Gaussian noise (AWGN, called the "normal" distribution in statistics). Such noise is present in all systems and forms the major noise constituent in some, such as space links. Unfortunately, the relatively well-defined and easy-to-analyze Gaussian noise model does not adequately characterize the fading and widely varying channels that many communication systems endure. Some channels have slow fading with propagation drifts over a time period of many symbols or bits, which results from atmospheric changes or landscape- and topography-based change. Others have fast fading, with fast transitions during one bit period or frame period and which can wipe out a string of consecutive symbols. Neither fast nor slow fading is the same as impulse noise from lightning or a nearby motor's starting up.

The Rayleigh-noise-distributed channel is named for mathematics developed by English physicist John William Strutt (Lord Rayleigh) in the late 1800s. In this channel, the transmitted signal travels to the receiver along multiple independent paths. The receiver sees a constructive and destructive interference sum of numerous random variables. The typical received signal clusters around a most likely value, but the signal at any time deviates narrowly or widely from this most likely value, depending on the statistics of the channel (**Figure A**). The range and likelihood of deviation approximate the fading



The probability-distribution function of a Rayleigh-faded signal (a) leads to shallow and deep fades in received-signal strength as multipath signals add and subtract, typified in (b) for a 900-MHz carrier, 100-Hz Doppler frequency, taken over a 75-msec window.

channel you observe in mobile communications. Rayleigh fades of 10 to 30 dB are common and can range to 50 dB, making a successful receiver and data-recovery algorithm quite a challenge.

Ricean fading (after Stephen O Rice, a Bell Labs researcher who worked on this concept in the 1940s and 1950s) molds Rayleigh fading into a more realistic situation. In this situation, there is a strongly dominant path—typically, the line-of-sight path—plus the multiple random paths. The Rayleigh model is usually associated with outdoor propagation, and the Ricean model is more closely associated with indoor paths.

Your model may also have a slow variation in the field strength, which can occur when the receiver moves steadily away from the source or when there is a temporary physical block, such as a hill between source and receiver. This blockage adds a less-than-unity coefficient to the path loss and is identified mathematically as log-normal shadowing or fading.

Rayleigh and Ricean fading characterizes the multipath phenomena that leads to intersymbol interference (ISI) caused by relative path delay. Because some of the waves arrive later than others, one version of an early data bit can actually arrive at the receiver simultaneously with—or even after—a later data bit that came by a shorter, more direct path. Thus, the first bit interferes with subsequent bits. This form of ISI has a different underlying cause than ISI caused by time-smearing of bits as they pass through a bandwidth-limited channel.

Gaussian, Rayleigh, and Ricean channels share one characteristic: They are what mathematicians call "stationary." This term means that, although you cannot assign a known, specific value to the noise or channel impairment at any instant (after all, you're describing a random process) and you can describe these factors only by the statistics of the probability distribution function, the function's moments as defined by these statistics don't change. In other words, the mean is constant, and, in many cases, the higher order moments are also constant. In an engineering context, these statistical descriptions may in fact change slowly, but they are constant over a relatively large number of bit periods.

Not all noise processes are stationary. In a cyclostationary process, the process statistics are not constant but instead have a periodicity of their own. For example, a rotating antenna sees Gaussian noise, but the Gaussian mean itself varies at every angle of the antenna as a result of what the antenna is pointing at (such as the sun, local noise sources, and blockages). If you graph the mean noise of this rotating antenna channel, you would get an AWGN function with a mean that cycles from 0 to 360°.

Don't forget Doppler shift, either. (You do remember your basic physics, don't you?) The amount of carrier-frequency shifting that the receiver observes is a function of both the relative speed between source and receiver and the nominal carrier frequency. The shift is approximately 1 kHz in most earth-bound applications but can be far greater for satellite links, which have much higher relative velocities.

As if these many types and noise sources aren't enough to make system design a challenge (and we haven't looked at Nakagami or Suzuki fading models), you also have to contend with self-sourced noise or interference resulting from an adjacent signal's spilling into the desired signal frequency, intermodulation distortions in your circuitry, and digital crosstalk. But these conditions result from less-than-perfect circuit designs and implementations and are not the fault of the RF channel itself.

If you think you are hearing noises in your head all the time, you may be right. Noise, along with its effects and the ways to compensate for it, is the most analyzed subject in communication engineering—from the undergraduate through the postdoctoral level—and with good reason. Noise is a major factor in the reliability, consistency, and throughput of a link. Additionally, noise makes engineers' jobs more difficult and thus keeps more engineers employed. To further pursue the meanings of noise and see the underlying equations if you desire, look into various textbooks for mathematical analysis (**References A** and **B**) as well as trade publications (**Reference C**) for a more intuitive approach.

References

A. Papoulis, A, *Probability, Random Variables, and Stochastic Processes*, McGraw-Hill, 1991

B. Beckmann, Petr, *Probability in Communications Engineering*, Harcourt, Brace and World, 1967.

C. Howald, Rob, "The Fuss about Fading," *Communication Systems Design*, April 1998.

TABLE 1—CHANNEL SIMULATION

Vendor	Model	Description	Price
Hewlett-Packard Co Palo Alto, CA www.hp.com Circle No. 301	HP 11759C	RF channel simulator, 40 to 2700 MHz	$57,650
IFR Systems Inc Wichita, KS 1-316-522-4981 fax1-316-522-1360 www.ifrsys.com Circle No. 302	Marconi 2050, 2051, 2052	Signal generator with multipath fading 10 kHz to 1.35 GHz (2050), 2.7 GHz (2051), 5.4 GHz (2052)	$24,000, $26,000, $40,000
Noise Com Inc Paramus, NJ 1-201-261-8797 fax 1-201-261-8339 www.noisecom.com Circle No. 303	UFX-BER MP2700	C/N precision generator, Multipath fading emulator	$22,000 to $45,000, $45,000 to $90,000
Signatron Technology Concord, MA 1-978-371-0550 fax 1-978-371-7414 www.signatron.com Circle No. 304	S-250C	HF/VHF radio-channel simulator	$50,000 (narrowband), $225,000 to $500,000 (wideband)
Tektronix/Rohde & Schwarz Portland, OR 1-800-426-2200 fax 1-503-222-1542 www.tek.com/measurement Circle No. 305	SMIQ02, SMIQ03	Signal generator with optional multipath fading 300 kHz to 2.2 GHz (SMIQ02), 3.3 GHz (SMIQ03)	$27,950 (SMIQ02), $30,950 (SMIQ03)
Telecom Analysis Systems Eatontown, NJ 1-732-544-8700 fax 1-732-544-8347 www.taskit.com Circle No. 306	4500 Flex 4600A	RF channel emulator with fading, Noise and interference emulator	$37,950 $44,950

fading-skywave components. This waveform-independent unit is primarily designed for testing frequency-hopping radios (128 frequencies, 1000 hops/sec) with dual diversity-reception and full-duplex operation, although its applications extend beyond that type of operation (**Figure 6**).

The S-250C incorporates propagation models for a 2- to 90-MHz range and operates under the control of a PC that includes software for sophisticated real-time modeling of the channel characteristics. The software is based on basic link parameters that you enter. The six-ft-high, 19-in., rack-mount unit can also include jamming waveforms if your application requires them. Its RF bandwidth is 80 kHz, and it supports a 300-Hz to 40-kHz baseband audio-channel interface.

If you are reaching for distance, the Noise Com SCS250 satellite-channel simulator represents available units for testing links that encompass low-Earth orbits, medium-Earth orbits, or geostationary orbits. (Sorry, if you're into deep-space satellites, you'll have to build a custom system.) The SCS250 implements functions that are similar to those needed for shorter terrestrial paths but with larger parameter values. The signal delay range is as much as 2000 msec, and the Doppler-shift range is ±500 kHz. An optional data-generation software package, Satgen, provides satellite orbital factors, including ground path trace and horizon display based on azimuth and elevation angles.

Because many applications involve standardized, regulatory-specified tests, channel-impairment vendors do what their IC counterparts have done: They integrate the signal generator and impairment-simulation functions into one application-specific instrument. The use of one box results in lower overall cost, easier interconnection, and reduced benchtop space requirements, but there's a trade-off in general-purpose flexibility. It's ironic that the signal-generator vendors first devote considerable design effort to producing

WHAT IF YOU'RE "WIRED"?

The wireless RF channel is the greatest challenge as a communications link, because of its many beyond-your-control sources of degradation and its inconsistencies. If you are using a wired link, either copper or fiber, you naturally have a much easier challenge in link simulation and system testing. Yet, although you can loop several thousand feet of fiber or copper in your lab, it's an inelegant and awkward approach that severely limits your ability to quickly change path lengths.

For fiber-optic links, attenuation and dispersion, rather than noise and other time-variant behaviors, are the dominant channel problems. You can get started with a basic optical attenuator, available from many instrumentation vendors. If your work is voiceband telephony-related, look at **Reference A**. Many telephony-specific vendors now offer line simulators for wideband loop applications, such as xDSL, along with performance-evaluation software.

Reference

A. Schweber, Bill, "Testing the telephony interface," *EDN*, March 28, 1996, pg 73.

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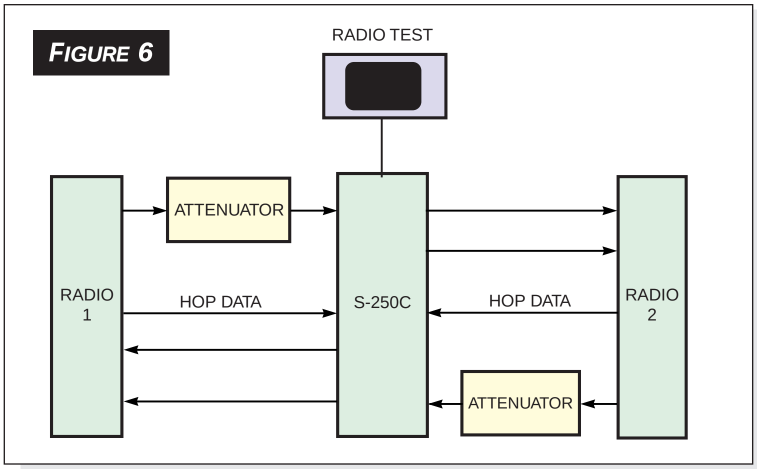
ever-more-perfect waveforms and then devote effort to corrupting them, but such are the mandates of the application. The integrated units produce the complex I/Q waveforms that nearly every advanced communication system requires and provide other application-specific modulations.

IFR Systems (which recently bought Marconi Instruments) offers the Marconi 2050 series of digital/vector signal generators. In addition to the signal sources, the instruments in this series have built-in Rayleigh and Ricean fading simulation. The high-end member of the family covers carriers from 10 kHz to 5.4 GHz.

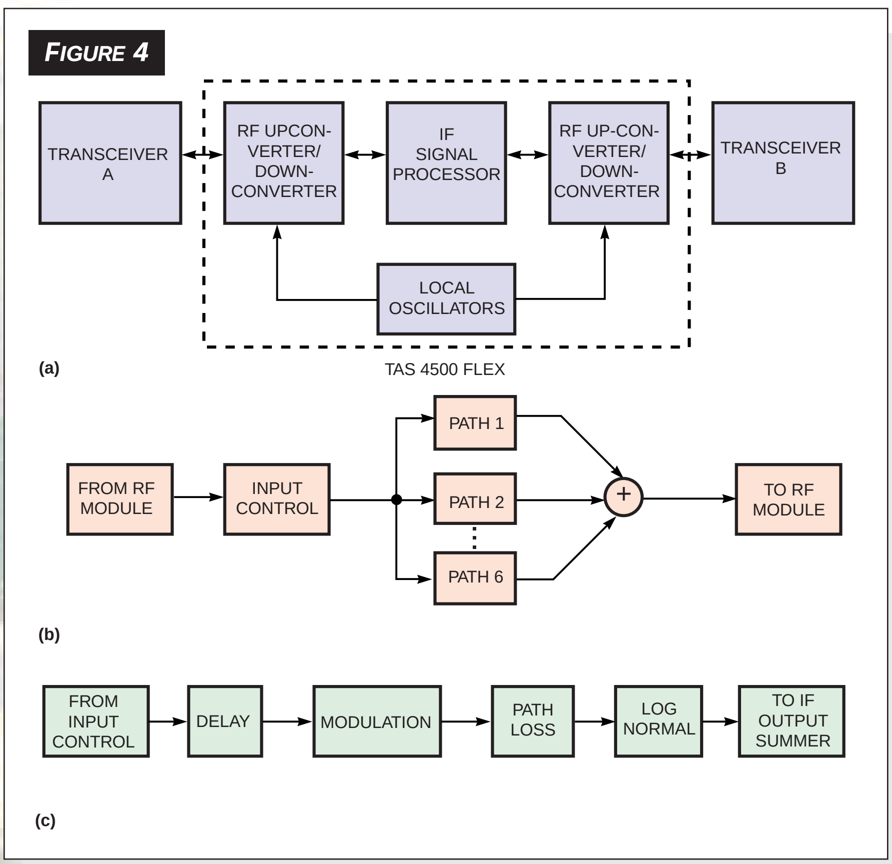
Ranging from 300 kHz to either 2.2 GHz in its SMIQ02 version or 3.2 GHz in its SMIQ03 version, the SMIQ vector signal generators (**Figure 7**) available from Tektronix/Rohde & Schwarz in North America (and directly from Rohde & Schwarz in Europe) produce TDMA and CDMA signals that correspond to all major mobile-radio standards (**Figure 7**). The SMIQ family provides both analog and digital modulation, as well as digitally modulated signals as fast as 7M symbols/sec.

You can add the optional SMIQB14 fading module, which gives the SMIQ series six propagation paths, with Rayleigh, Rice, log-normal, and Suzuki profiles, as well as Doppler shift. If you want to go to the full 12-ray fading simulation, you can add a six-path fading module to the first. Additional optional coders support a wide family of modulation types, such as FSK, Gaussian-filtered minimum-shift keying, binary phase-shift keying, quadrature phase-shift keying, 32 quadrature amplitude modulation (QAM), 64QAM, and others. When fitted with the appropriate coders and data generators, the SMIQ's signals conform to various mobile-radio standards. You operate the SMIQ instruments from front-panel controls, or via the IEEE-488 bus interface.

Although combined dedicated signal generators with impairment testing may be viable choices for your final sys-



Signatron's S-250C HF/VHF channel simulator lets you test radios, RF modems, and channel-hopping systems with AWGN and propagation-simulation noise.



With the TAS 4500, a downconverter and upconverter bracket the IF signal processor (a), which consists of multiple signal paths (b), each with independent parameters (c).

FIGURE 5 The Noise Com MP2700 wideband multipath fading emulator simulates a long list of fading models on the user-supplied signal.

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tem test, you may find that separate boxes provide an equally effective prototype test configuration. These multibox setups allow you to perform essential general-purpose subsystem functional tests on your design in the early stages of the design cycle before you are ready for compliance-level testing. Alternatively, you can reuse instruments in the multibox configuration for RF systems, which have different needs. Nearly all vendors of general-purpose impairment and simulation boxes offer complete test and evaluation configurations linked by the IEEE 488 bus and by application software; thus, the vendors provide a seamless instrumentation package. You have to add the features, benefits, flexibility, ease of use, and cost factors to determine which approach best fits your immediate and long-term needs.

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Reference

1. Schweber, Bill, "Communication-simulation software smoothes system design," *EDN*, Aug 3, 1998, pg 87.

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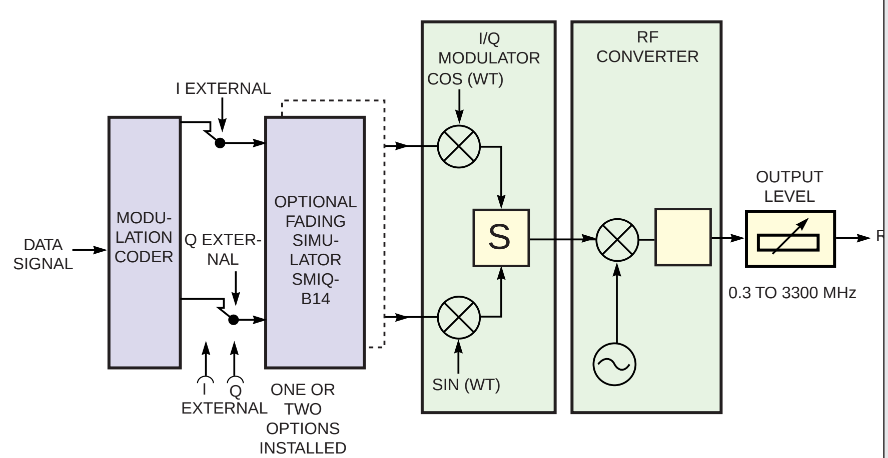
FIGURE 7

(a)



(b)

The Tektronix/Rohde & Schwarz SMIQ vector-signal generator (a) includes sources for TDMA and CDMA signals, analog and digital I/Q modulation, and an optional fading simulator for six (or 12) fade paths (b).