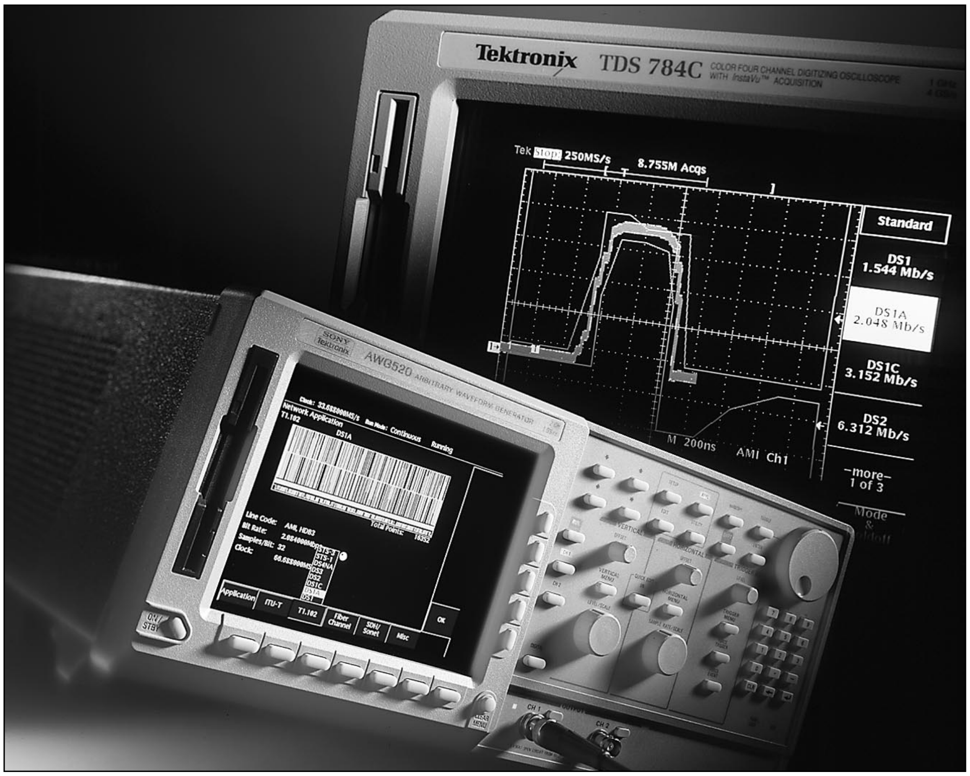
Tektronix

Application Note

Arbitrary Waveform Generators Solve Physical Layer Test Problems



Simulation is at the heart of every design program these days. Telecommunication products on every scale, from IC devices to complete transmission systems, undergo comprehensive evaluation in the CAD environment. But eventually, every new circuit or system emerges into the real world, where it must be tested for conditions not foreseen in simulation. This step usually involves exhaustive protocol layer testing with a Bit Error Rate Tester (BERT) and protocol analyzer.

All is well until, say, the BERT detects an error. While it's certainly important to know that an error exists, it's equally important to understand why it exists – only then can you trace the error back to the design flaw that caused it. Unfortunately, conventional BERTs and protocol analyzers don't provide these critical "why" details. This information is embedded in the device's electrical signals, within the physical layer. BERTs and protocol analyzers are basically error counters that typically look for valid binary levels and timing relationships. They are not troubleshooting tools; they can't characterize the nature and degree of signal impairments at the physical layer.

Troubleshooting at the physical layer requires a pairing of stimulus and measurement instruments. The oscilloscope is, of course, a versatile tool for capturing and observing device responses of all kinds. But what about the signal source? Ultimately, many design problems – even in purely "digital" circuits – are a result of analog phenomena. Often it's necessary to feed a circuit with signals having specific analog impairments superimposed on complex bit streams.

Many RF signal generators offer a wealth of frequency ranges and built-in modulation options, but have no means of creating transient spikes and sub-threshold "runt" pulses. Likewise, most data generators are limited to producing steady streams of 1s and 0s, with nothing in between. Traditional pulse generators lack wave-shaping features and require cumbersome external modulation hardware.

Only one type of signal source, the Arbitrary Waveform Generator (AWG), adapts to all the real-world signal needs of today's telecom components. The AWG accepts a waveshape definition, stores the digitized image in its memory, and outputs the analog equivalent via its digital-to-analog converters. The AWG's signal output doesn't care about periodicity, binary logic levels, or operational cycles. It simply puts out a continuously changing series of voltage levels (each equivalent to a point stored in its memory) to trace out any imaginable waveform or bit pattern.

The most advanced AWG models deliver frequencies up to 250 MHz, concurrent analog and digital outputs, and other functions essential for testing to established telecom standards ranging from DS-1 (1.5 MHz) to SONET/SDH (155 Mb/s). Their 10-bit resolution delivers the detail needed to emulate complex signal formats. AWG record length, formerly a limitation, is now sufficient to allow reconstruction of complete word-length waveforms. Lastly, some AWGs provide special telecom-oriented test features that make troubleshooting faster, easier, and more repeatable. Figure 1 is a simplified block diagram of a state-of-the-art AWG. The balance of this application note discusses the ways in which this instrument, the Tektronix AWG 520, addresses telecom test requirements.

Single Pulse Testing for Design Characterization

Characterizing a new wireless design calls for driving the Unit Under Test (UUT) with both nominal and impaired signals. The creation of these variants is a particular strength of the AWG architecture.

Exercises known as single-pulse tests are designed to push the template limits specified in Bellcore standards. The AWG 520 offers a special “application” function that provides waveforms for single-pulse testing. Its built-in standard waveform library includes nominal pulses for almost 30 physical layer standards, including DS1A, DS3, STS-1, etc. The instrument’s equation editor provides a tool for modifying these standard pulses into wide, narrow, and other anomalous pulses. If modifications are needed, or if new standards arise, it’s a simple matter to edit pulse waveforms while viewing the changes on the instrument’s built-in waveform display.

In addition, the Bellcore standard defines three timing variations for the wide pulse. Therefore, the AWG 520 includes range selections to determine the placement of the pulse in time, with respect to the template window.

Using its internal processor, the AWG 520 convolves the single pulse with a predetermined data sequence (which may be a standardized test sequence or vectors downloaded from a simulator) to produce a composite waveform that contains impairments. Figure 2a shows the unmodified data signal, while Figure 2b shows the effect of the impairments (Figure 2c is a closeup of this impaired signal). This data becomes the input to the UUT. The UUT’s response to the impaired signals is monitored on a BERT while the AWG loops on the data pattern. By this means, the correlation between data errors and various types and degrees of impairment can be tracked. Thus, the AWG is a fundamental tool for characterizing a telecom device’s performance limits.

The AWG also lends itself to a variation of this procedure that is useful for both design characterization and troubleshooting applications. Paired with a suitable DSO (such as the Tektronix TDS 784C), the AWG 520 can reconstruct signal anomalies suspected of causing bit errors. In this instance, the TDS 784C monitors the UUT input. When an output error occurs, the scope captures the “slice” of input data that prompted it. With the AWG 520, a simple procedure is used to copy that waveform directly from the scope via GPIB. The final

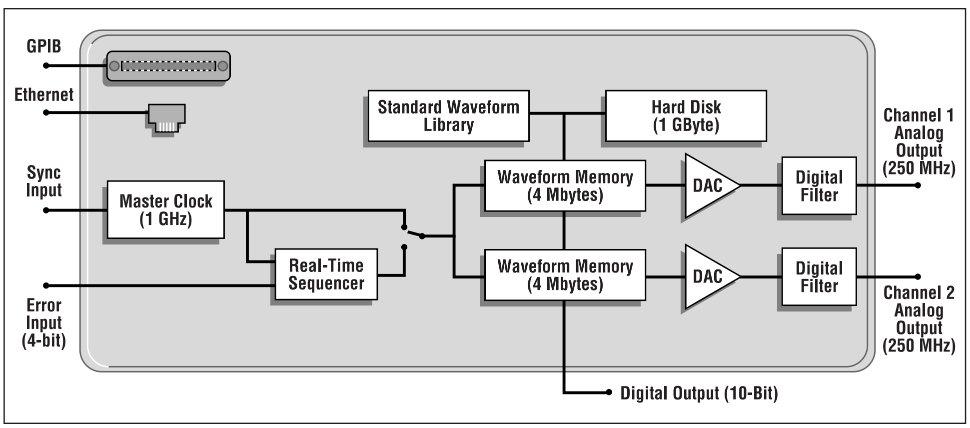


Figure 1. AWG architecture block diagram.

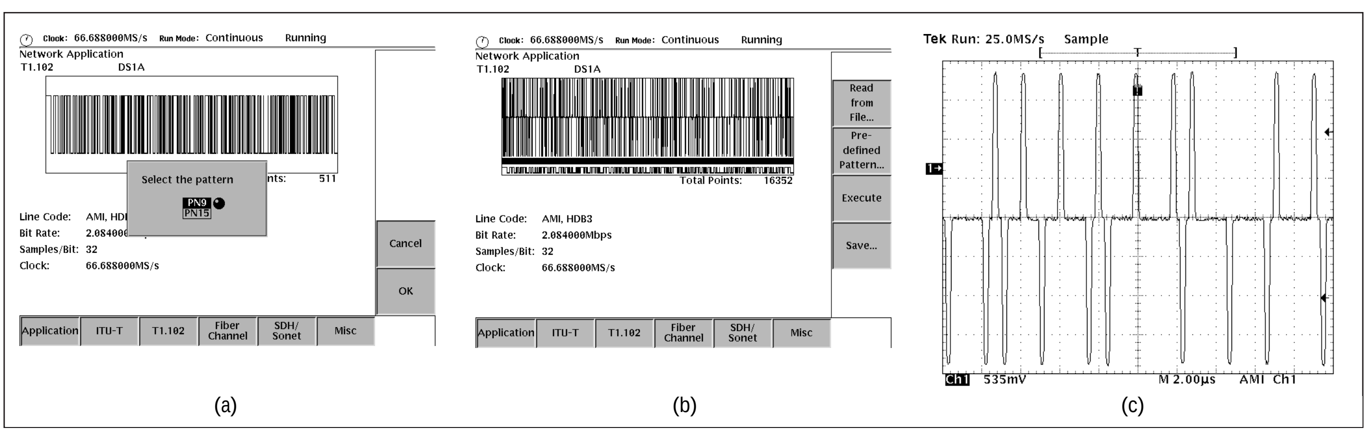


Figure 2. (a) A data waveform prior to addition of impairments; (b) the same data after convolving with an impaired waveform; (c) a closer look at the composite data/impairment signal.

step is to loop repeatedly through the data while examining the UUT response with a BERT. It may be necessary to repeat the process with several data segments in order to pinpoint the actual failing vector. Of course, this process requires an AWG that is tightly coupled to the scope (as is the AWG 520), with compatible waveform data formats and interface features.

Sequencers Help Catch Infrequent Errors

An AWG's sequencer is one measure of its overall flexibility and appropriateness for complex physical layer testing chores. Basic sequencers execute simple instructions such as loops, repeating limited segments of the waveform memory. More advanced sequencers are also adapted for producing complex modulated signals. It may be necessary, for example, to assemble a waveform by concatenating many small segments, and to repeat that complex waveform – with variations – for long "marathon" test runs consisting of days, weeks, or even months of operation. Rudimentary sequencers require their content to be compiled and stored in the waveform memory. To execute 100 repetitions of a waveform segment, for example, conventional sequencers compile and store 100 copies of the segment in the waveform memory. Ultimately there's a limit (the capacity of the memory) that bounds the sequence length. As telecom standards and modulation types continue to evolve, that limit might stand in the way of detecting irregular pattern-dependent errors and co-symbol interference.

A more modern architecture is embodied in the programmable real-time sequencer of the AWG 520. It's an uncompromised conditional sequencer capable of executing not only loops but also jumps, gotos, and similar instructions. On the face of it, it's obvious that this approach is far more memory-efficient. It's also the key to effectively infinite pattern length. For example, any of the 8,192 lines of sequencer code can contain a loop instruction. And any loop can circulate up to 65,535 times through the points of an individual stored waveform component. The product of these two numbers is a concatenated waveform stream made up of over 500 million segments!

Massively long patterns are valuable when trying to accumulate a history of bit errors for analysis. Conversely, it's also possible to insert deliberate anomalies minutes, hours, or days apart. Long patterns are essential when running long-term stress tests.

A true real-time sequencer offers yet another advantage: the ability to respond immediately to error prompts returning from the UUT (via the BERT). In the case of the AWG 520, a dedicated 4-bit error input provides up to 16 trigger states for the sequencer, which can be programmed to respond with jumps to subroutines in the waveform memory. These might contain alternate pattern segments with different signal impairments, for example. Thus a whole characterization procedure can be designed around a sequencer program that iteratively widens a nominal pulse toward a template violation; when it finally causes an error, the sequencer responds by jumping to a routine that gradually narrows the pulse toward a violation. Or, the sequencer might be programmed to jump to a troubleshooting routine. In either case, the AWG 520 brings a uniquely high level of automation to everyday characterization tasks.

Jitter with a Purpose

Most of the foregoing explanation relates to procedures that identify "analog" problems – amplitude and rise-time errors that cause failures in digital devices. But telecom circuits, especially components with high bit rates and complex output streams, are equally susceptible to "digital" errors. Chief among these are the effects of jitter. Jitter problems plague many new designs. But ironically, when you want jitter (when evaluating a circuit's jitter tolerance, for example), it's rather difficult to create and control.

The AWG architecture offers a potential solution for this problem. It involves thinking in terms of individual samples (points). By applying minute, controlled shifts in amplitude to each successive point on an edge, that edge is effectively moved in time. Figure 3 depicts a jittery waveform created with this technique. Here, one region of the waveform has been selected and treated with point-by-point amplitude shifts. Each repetition of the waveform exhibits a small time shift relative to those surrounding it.

It's important to note that this approach simply isn't practical with an ordinary AWG.

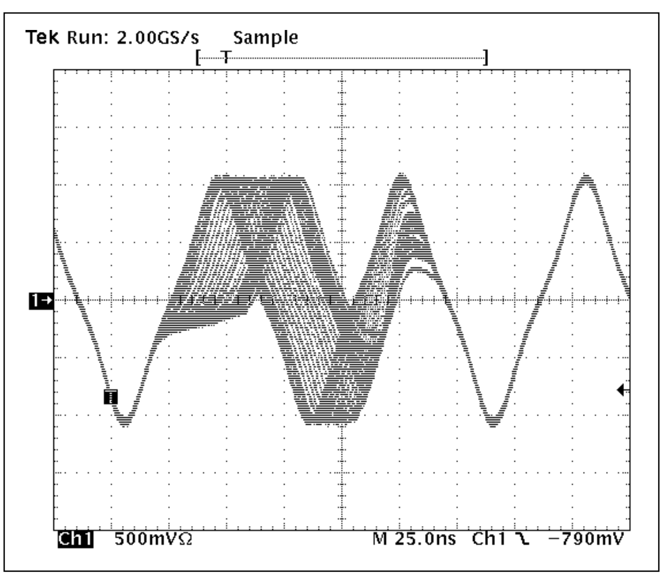


Figure 3. Jitter produced with the Quick Edit function and the internal real-time sequencer.

Since the shifts affect many thousands of points, it would be an impossibly cumbersome task to implement jitter this way unless the instrument was equipped with specific features for that purpose. The AWG 520's capability is just such a feature, and more. Using Quick Edit in conjunction with its real-time sequencer, the AWG 520 produces realistic jitter phenomena with 5 ps resolution on waveforms having rise-times as low as 4 ns. When used in this fashion, the Quick Edit function operates similarly to the Tektronix AWG 2000 Series, except that waveforms can be changed at the output in real time. The instrument can produce low-frequency, high-frequency, single-bit, and overall jitter, emulating the timing and amplitude impairments that arise from these conditions.

"Random" Noise and Filtering Mimic Real-World Environments

Among digital instruments of all kinds, creating realistic noise signals is a challenge. Digital noise attempts to approximate analog "randomness," but is, by nature, repetitive not random. In typical compiled AWG noise, the degree of randomness is constrained by record length and clock resolution. Thus it's not possible to test a telecom device exhaustively for its response to natural random noise with a conventional AWG. Ordinarily this test procedure forces the engineer to choose between using an external, dedicated random noise generator or accepting the limitations of the AWG's built-in digital noise source. When testing a device for noise susceptibility, this may not be a satisfactory choice.

Some AWGs provide true random noise in addition to the usual pseudo-random digital noise. Their random noise output can be any value, at any time (unlike digital noise, which will by definition be within a fixed range of values). The AWG 520 includes a true random noise generator that provides an accurate model of the real-world noise encountered in high-frequency telecom devices.

Filtering is another issue that sometimes gets overlooked in AWG architecture. Filtering can be used to shape (modify the frequency content) of noise signals. It's equally useful for modifying almost any type of data stream. By programming a controlled amount of frequency roll-off, for example, it's possible to emulate the effects of cable degradation. The input of the UUT receives a filtered signal that appears to have passed through a marginal cable. Astute application of filtering is the key to creating a whole battery of realistic tests for UUT response to high-frequency loss, frequency-dependent amplitude variations, transients, and more. The AWG 520 includes a built-in digital filter to implement such tests.

Where Analog Meets Digital

The "main" output of an AWG is, of course, its analog output. Even when the waveform is essentially a binary stream, the whole point of using an AWG is to introduce analog characteristics into the waveform for test purposes.

Frequently a telecom device has, in addition to the specific functional input under test, other digital inputs that must be driven with binary codes concurrently. These inputs may need the binary equivalent of the instantaneous analog input, as in convertor architectures. Or they may need an entirely different data set. In either case, the AWG is often called upon to provide analog information as well as purely digital data with the word widths and speeds necessary to match demanding telecom data rates.

The AWG 520 meets this requirement with a dual waveform memory scheme that provides analog and digital outputs simultaneously. The two 4 Mbyte memories are independent in content, though under the control of the same 1 GHz master clock. The digital output provides 10-bit parallel data at speeds up to 1 GHz. The 4 Mbyte memory behind the digital output can be used (optionally) to support a second analog output instead.

The AWG: Insurance for Dependable Physical Layer Testing

The arbitrary waveform generator is a general purpose tool with many special attributes that benefit physical layer test applications. The AWG's unique ability to produce edges, pulses, noise, and irregular waveshapes – virtually without limit – ensures that, whatever the physical layer requirement, instruments such as the Tektronix AWG 520 will deliver utterly realistic signals to a unit under test. There is no better way to support the quality of the final product.

For further information, contact Tektronix:

World Wide Web: http://www.tek.com; **ASEAN Countries** (65) 356-3900; **Australia & New Zealand** 61 (2) 888-7066; **Austria, Eastern Europe, & Middle East** 43 (2236) 8092-0; **Belgium** 32 (2) 725-96-10; **Brazil and South America** 55 (11) 3741 8360; **Canada** 1 (800) 661-5625; **Denmark** 45 (44) 850700; **Finland** 358 (9) 4783 400; **France & North Africa** 33 (1) 69 86 81 08; **Germany** 49 (221) 94 77-400; **Hong Kong** (852) 2585-6688; **India** 91 (80) 2275577; **Italy** 39 (2) 250861; **Japan** (Sony/Tektronix Corporation) 81 (3) 3448-4611; **Mexico, Central America, & Caribbean** 52 (5) 666-6333; **The Netherlands** 31 23 56 95555; **Norway** 47 (22) 070700; **People's Republic of China** (86) 10-62351230; **Republic of Korea** 82 (2) 528-5299; **Spain & Portugal** 34 (1) 372 6000; **Sweden** 46 (8) 629 6500; **Switzerland** 41 (41) 7119192; **Taiwan** 886 (2) 722-9622; **United Kingdom & Eire** 44 (1628) 403300; **USA** 1 (800) 426-2200

From other areas, contact: Tektronix, Inc. Export Sales, P.O. Box 500, M/S 50-255, Beaverton, Oregon 97077-0001, USA (503) 627-1916

ISO 9001

Tektronix

2/98 TD/XBS 76W–11933–0