

Keysight Technologies

# Complex Modulation Generation with Low-Cost Arbitrary Waveform Generators

## Keysight's Trueform Architecture for Wireless Applications

White Paper

### Abstract

The purpose of this white paper is to show how the Keysight 33500B Series Trueform waveform generators can be applied to generate complex modulated signals. The Keysight 33500B Series Trueform waveform generators offer a very cost-effective solution for generating many modern, complex, baseband IQ digital communication signals. This white paper demonstrates the Keysight 33500B Series Trueform waveform generators producing today's complex digital wireless protocols like W-CDMA, DVB, and OFDM.



## Introduction

Digitally modulated signals fill space and travel through almost every wired and optical network. Today, almost all wireless services use a plethora of complex carrier modulation schemes. The continuous improvement in modulation technologies and components and advances in error-correction codes have increased channel capacity close to the fundamental limit as set by the Shannon-Hartley theorem.

Capacity and efficiency have been improved even more through the development of new transmission strategies such as MIMO (Multiple-In-Multiple-Out) antenna technology and the implementation of extremely flexible multiple-access schemes in the time, frequency, and code domains. Additionally, more and more products and services with decreasing prices rely on the capability of one or more wireless technologies to operate properly.

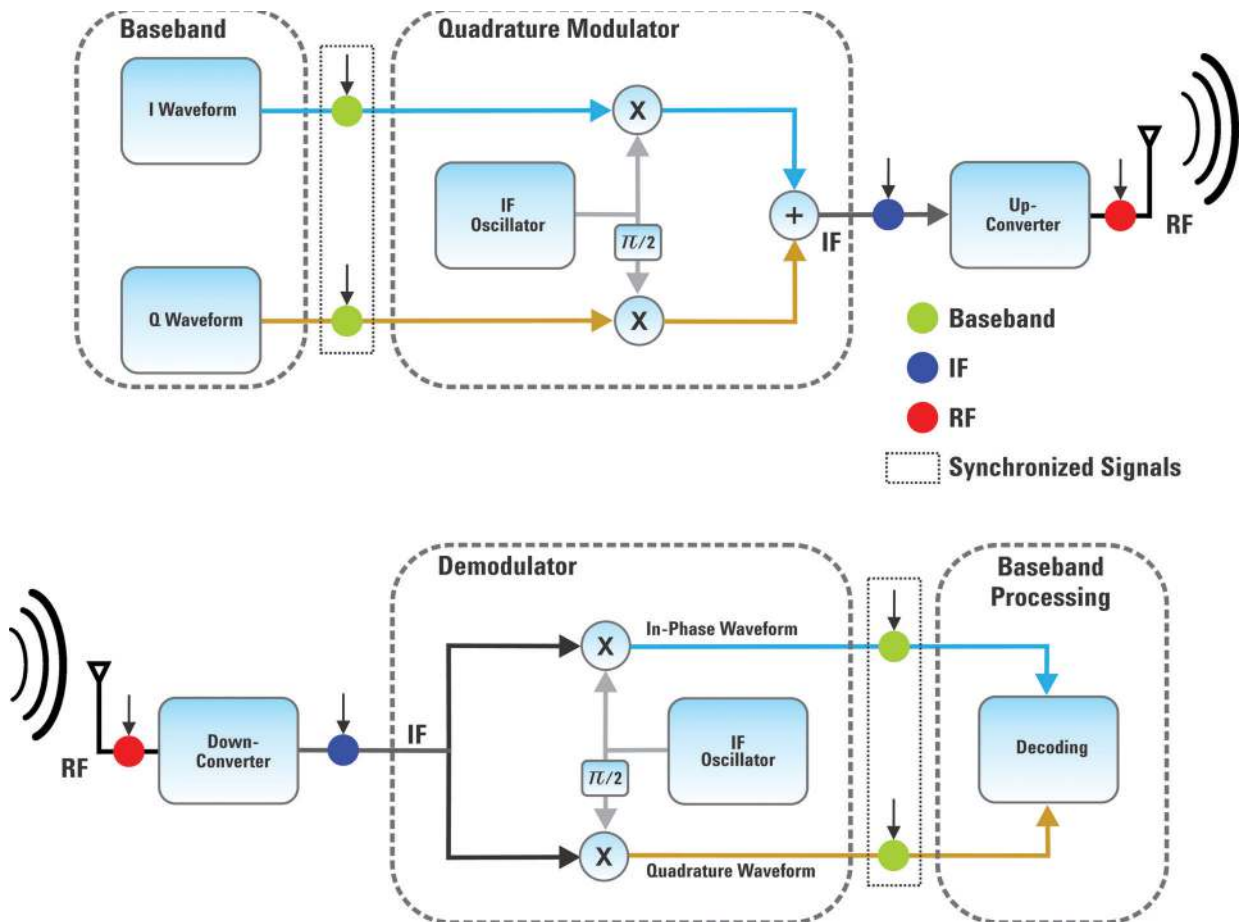
This level of complexity and interoperability is made possible only through extensive testing during all the phases of the life of a product or service—from basic technology research to device manufacturing or network deployment. Test equipment flexibility is paramount to successfully address those needs. The overall cost of test equipment is also important so team leaders can make sure the equipment is available to all engineers throughout the entire project.

Traditionally, test equipment for wireless applications has been specifically designed for the task, and the introduction of new modulation technologies and signal bandwidths, which often come together, resulted in the need for new equipment or costly upgrades. For analysis, the main tool available to wireless designers is the vector signal analyzer (VSA), a piece of equipment capable of measuring the spectrum of a signal and its evolution over time and capable of keeping complete amplitude and phase information. For stimulus, the tool of choice is the vector signal generator (VSG), which is capable of generating one or multiple carriers and controlling in real time their respective amplitudes and phases over time. Although some tests must only be performed exactly at the RF carrier frequency, many others must be performed at lower frequencies (IF or intermediate frequency) or even at baseband level.

Arbitrary waveform generators (AWGs) have been used for a long time to supply baseband signals to analog quadrature modulators in most VSGs. Sometimes these baseband generators are implemented inside the RF VSGs, while other solutions are based on the use of external AWGs. To be useful for many tests and operators, RF signal generators must have enough frequency range and a minimum level of performance in terms of modulation and spectral quality. As a result, there are limitations in terms of modulation bandwidth and cost. Although state-of-the-art generators still maintain this architecture, modern high-performance AWGs can easily supply high-quality baseband and IF (and even RF) signals at a fraction of the cost so they can be made widely available to all designers while maintaining their ability to generate other analog and digital signals out of reach of conventional RF generators. Low-cost AWGs are typically based on the convenient and flexible direct digital synthesis (DDS) architecture. Unfortunately, some fundamental limitations of DDS technology render AWGs based on it almost useless to generate high-quality (or even usable) IF/RF signals or high-bandwidth baseband signals. Keysight, with its new Trueform technology, has dramatically changed the low-cost wireless signal generation landscape. The purpose of this white paper is to show how the Keysight 33500B Series Trueform waveform generators can be used to generate complex modulated signals.

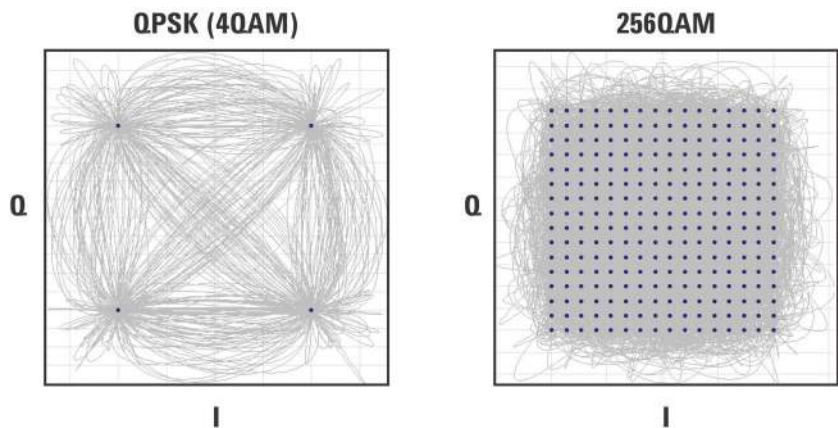
## Digital Modulation Basics

Figure 1 shows the block diagram of a digital wireless transmission system. The carrier is modulated in amplitude and phase simultaneously. A quadrature modulator implements both modulations by applying two baseband signals to two orthogonal carriers (90° relative phase). Each baseband signal can be seen as the real and imaginary part of a complex signal. The real part is called the “I” (in-phase) signal, while the complex part is known as the “Q” (or quadrature) signal.



**Figure 1. Simplified block diagram of a digital wireless system.** Most modern modulation schemes are based on quadrature modulation, in which two orthogonal carriers transport portions of a digital message. This figure also shows where signal generators can be applied during transmitter and receiver testing.

Many modulation schemes are based on assigning different modulation states to a finite set of symbols, typically made of a number of coded bits, in a process known as *symbol mapping*. As a result,  $N$  bits require  $2^N$  different modulation states. A convenient way to represent graphically the location of the modulation state is in an  $I$  versus  $Q$  Cartesian coordinate system that directly shows the amplitude and phase for each symbol (see Figure 2). This representation is known as a *constellation diagram*. This diagram is also useful for analysis purposes, as it gives direct visual clues to any anomalies or distortions applied to the signal during modulation and transmission.



**Figure 2. Phase/constellation diagrams are a convenient way to show modulation schemes.** They are basically an  $I$  versus  $Q$  Cartesian representation that directly translates to a polar (magnitude versus phase) representation of the carrier state of modulation. In this figure, constellations (blue dots) of QPSK and 256QAM modulations are shown. While QPSK carries just two bits per symbol, 256QAM carries six bits per symbol, although the bigger distance between different symbol locations makes QPSK more resilient to noise or lower-accuracy components.

The more complex the constellation, the more bits per symbol will be transmitted. However, a higher-order modulation requires more complex and accurate transmission and reception systems, and it will be more sensitive to noise and other distortions as the distance between symbol locations will be shorter for the same power level. A QPSK modulation scheme (two bits per symbol) will be more resilient to noise than a 256QAM (eight bits per symbol). On the other hand, the 256QAM signal will transport four times more information than a QPSK signal with the same symbol rate (measured in baud or symbols/second). Many other criteria influence the selection of a given modulation scheme. Power efficiency and cost considerations, for example, will influence the choice of GMSK as the modulation scheme for GSM, given that constant power modulation allows for the usage of very efficient, nonlinear low-cost power amplifiers in the UE (user equipment or mobile phones).

Spectrum is a scarce commodity that must be efficiently used since it must be shared among multiple users and services. This is true for wired applications (such as CATV), optical applications (such as DWDM), and especially, wireless communication applications. Considering that any given signal must occupy a limited bandwidth (a channel), the symbol rate must maintain a limit, and the signal must pass through a band-pass filter to make sure it doesn't interfere with adjacent or distant channels. Filtering can be implemented directly at the RF frequencies, or more commonly, applied to the modulating (baseband) signals before quadrature modulation. This process is known as pulse shaping, and it consists in the application of a convenient low-pass filter to both I and Q components.

Raised-cosine filters (also known as Nyquist filters) are probably the most popular type of filter for QPSK/QAM modulation, as they produce bandwidth-limited signals with no intersymbol interference. In most communication systems, the overall raised-cosine response is obtained by splitting filtering evenly between the transmitter and the receiver, resulting in the square root raised cosine filter. For FSK modulation schemes, in which the amplitude is constant and data being transmitted controls the carrier frequency, Gaussian filters are commonly applied to the modulating signal (not the RF signal). Raised-cosine filters are fully defined by two parameters: symbol rate and the roll off parameter (known as  $\alpha$ , alpha). Gaussian filters are defined by symbol rate and the BT (bandwidth, B; symbol period, T) product parameters. The alpha and BT parameters influence the roll-off shape, thus affecting the occupied bandwidth parameter among other signal characteristics.

Modulated signals may be subject to different linear and non-linear distortions. The lack of accuracy at the transmitter may result in quadrature error (phase between the orthogonal carriers) and imbalance (unequal amplitude between the I and Q components), and carrier leakage (DC offset resulting in a residual carrier). Non-linear errors such as AM-AM and AM-PM distortions result from saturation (and even clipping) in the transmitter RF power amplifiers. Non-linear distortions are especially dangerous as they cause spectral growth. Modern transmitters use precorrection techniques to compensate for such distortions.

The transmission path is also a source of errors and distortions. These errors can come in the form of interferences, fading, and multipath distortions, as signals typically arrive at the receiver from various sources with differing amplitudes and delays. Even worse, transmission path induced distortions vary over time, so they must be compensated at the receiver through adaptive equalization techniques. The effects of multipath distortions dramatically increase with symbol rate, as delayed copies of the signal will interfere with later symbols in the same signal. Some modulation techniques have been specifically designed to gracefully compensate for, and even benefit from, multipath distortions.

Orthogonal Frequency Division Multiplexing (OFDM) consists of using 10s, 100s, or even 1,000s of close carriers to transport the message after splitting the data among all the carriers. As a result, the symbol time will decrease in the same proportion. Carrier spacing is chosen to be the inverse of the symbol rate, so the carriers will not interfere with each other (i.e., they will be orthogonal). Some additional components in the OFDM signal are designed to ease signal channel estimation and receiver synchronization, while some cyclic redundancy is added to eliminate the interference caused by previous symbols. All these advantages have made OFDM the modulation of choice for most modern wireless and wired communication systems such as terrestrial broadcast, WiFi, UWB, LTE, WiMAX™, etc. OFDM signals do, however, have some drawbacks, | as the increased complexity and accuracy (with respect to phase noise) required to handle them and the high peak-to-average-power ratio (PAPR) make them sensitive to nonlinearity at the transmitters.

OFDM techniques combined with MIMO and beam forming are the basis for the 4G mobile communications technologies. MIMO can increase capacity by exploiting spatial diversity obtained through the use of multiple transmitting and receiving antennas, thus allowing for the transmission of multiple signals over the same band. Beam forming increases capacity by steering the signal directly to the receiver using phase-array antennas, so the same frequency may be reused for other users located in a different azimuth angle.

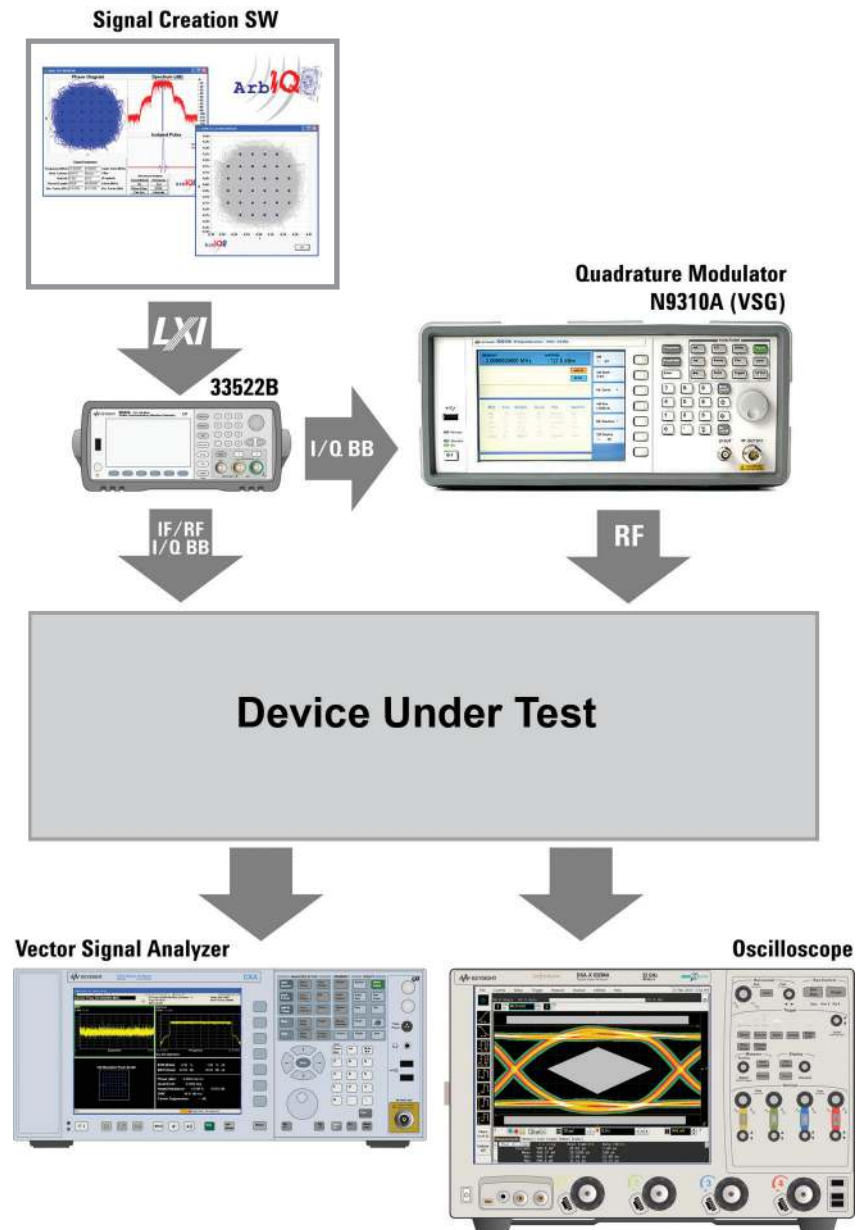
## RF Signal Generation Using AWGs

The rapid evolution and growing complexity of modulation schemes and coding systems make wireless testing a significant challenge. Generators must be capable of supplying multiple standard signals, sometimes even simultaneously, while simulating complex linear and nonlinear distortions so receiver designs and components can be properly validated. Arbitrary waveform generators have been the foundation of most RF and wireless vector signal generators (VSGs). Two-channel external or internal AWGs typically supply high-precision baseband IQ signals to feed a quadrature modulator (see Figure 3).

**Figure 3. AWGs can generate RF modulated signals through two basic methods. Two-channel instruments can generate I and Q baseband signals that can be applied to an external quadrature generator. Single-channel instruments with sufficient sampling rate can directly generate a modulated carrier at IF or even RF frequencies.**

*Note: All the signals shown in this white paper have been generated using the Keysight 33522B waveform generator, except for the DDS waveform shown in Figures 4 and 5. The signals in those figures were created using a commercially-available arbitrary waveform generation package.*

*The generated signals have been validated and analyzed using a Keysight CXA vector signal generator and a Keysight MSO7014B DSO.*



This working scheme allows for the complete control of both the amplitude and phase of a carrier such that any analog or digital modulation scheme, distorted or not, is feasible within the bandwidth limitations of the system. AWGs are ideal since no special hardware is required for either a given modulation scheme or a modulation standard, and the addition of new ones depends only on the availability of adequate external software. As sampling rate and spurious free dynamic range (SFDR) performance in AWGs have dramatically improved over time, direct generation of multiple, dissimilar, modulated IF/RF carriers is now feasible (see Figure 3).

AWGs, alone or in conjunction with a quadrature modulator or up-converter, can be applied as signal sources to many different test points within a RF transmitter or receiver (see colored dots in Figure 1). In general, baseband signal generation requires two synchronized channels while IF/RF signal generation requires just a single channel. More channels will be required if MIMO or beam forming scenarios are to be emulated. Baseband signals can be easily generated by low-cost AWGs since bandwidth requirements are moderate for most digital modulation standards, in the order of a few megahertz. However, any difference between the two channels implementing the two baseband signals (I and Q) in terms of amplitude, frequency response, or delay will result in a noticeable modulation quality reduction as they will create quadrature error and imbalance.

A flat frequency response and a good channel-to-channel match are highly desirable. AWGs may add some problems of their own as a typical frequency response is usually optimized for time-domain pulse response and image reduction. In fact, images can generate spurious out-of-band signals that may interfere with nearby channels after modulation. Most low-cost AWGs are based on the flexible and inexpensive DDS architecture. This generation technique causes jitter intrinsically. While some level of jitter may be acceptable for some time-domain signals, its nonlinear nature will cause spectral growth and in-band noise (including phase noise) affecting modulation quality dramatically.

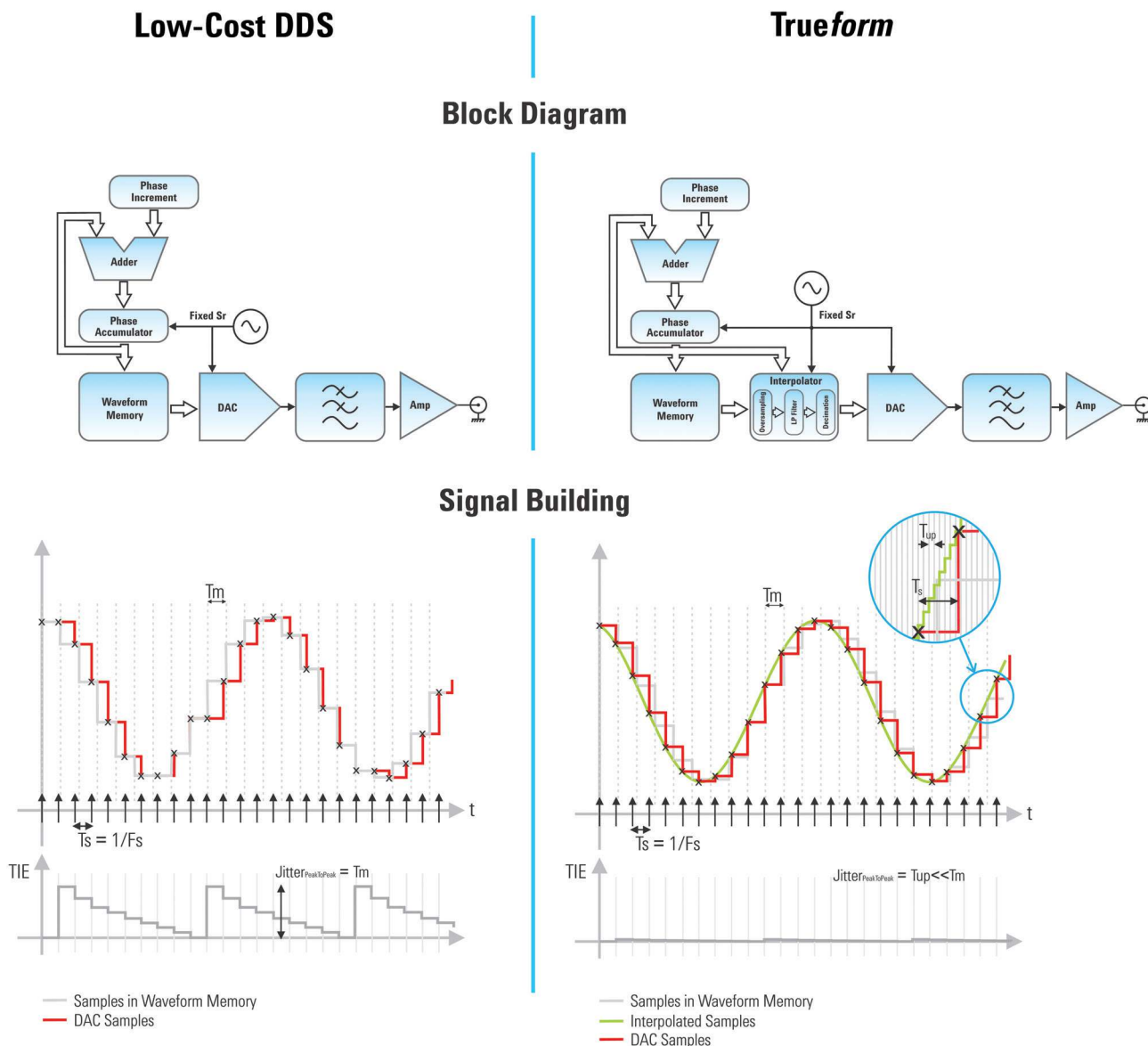
Generating most modulated signals exactly at the final RF carrier frequency may not be possible for most low-cost AWGs. Most receivers and many transmitters, however, do not directly process the modulated signal at its final frequency; they use a much lower intermediate frequency (IF) signal instead. Typical IF frequencies are in the 10s of MHz so they can be handled by many AWGs. Imbalance between the I and the Q baseband components of the signal is no longer a problem, since they exist only in the mathematical domain. Frequency response flatness is still an issue, however, especially for wideband modulations. The influence of jitter generated by the DDS architecture will be even more significant since it now affects the carrier as well, resulting in unacceptable levels of signal distortion and spectral growth.

Record length (the size of the available waveform memory) is also an important specification to consider. Many modulated signals require a minimum time window (i.e., a complete frame) to be properly recognized by a receiver under test. For example, a DVB-T signal requires a minimum of 68 OFDM symbols (the length of a TPS frame that carries information about the signal modulation) or approximately 70 ms. For a 100-MSa/s waveform generator, this time window requirement translates into a minimum record length of 7 MSample. Since the maximum record length for most DDS-based, low-cost AWGs is below 1 MSample, it is not possible to generate many complex modulated signals.

The introduction of the Keysight 33500B Series waveform generators with Trueform architecture has extended performance available previously only in high-end generators. Trueform technology gives the arbitrary waveform generator the ability to generate high-quality baseband and IF signals at a much lower price.

### Keysight's Trueform Architecture

Keysight's new 33500B Series waveform generators built on the Trueform architecture offer the flexibility and advantages of DDS-based waveform generators without any of the drawbacks (see Figures 4 and 5).

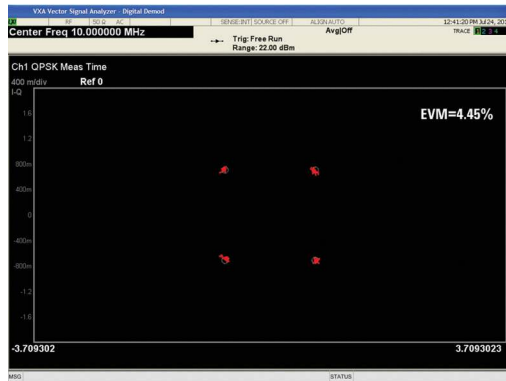


**Figure 4. DDS versus Keysight's Trueform technology.** The way traditional DDS architectures (left) access waveform memory results in an unacceptable level of jitter for modulated signal generation. Keysight's new Trueform architecture (right) eliminates the jitter, as the signal stored in memory is filtered, interpolated, and resampled in real-time.

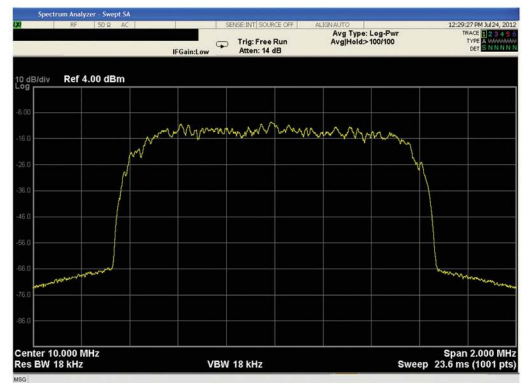
## Low-Cost DDS

## Trueform

### Constellation



### Spectrum

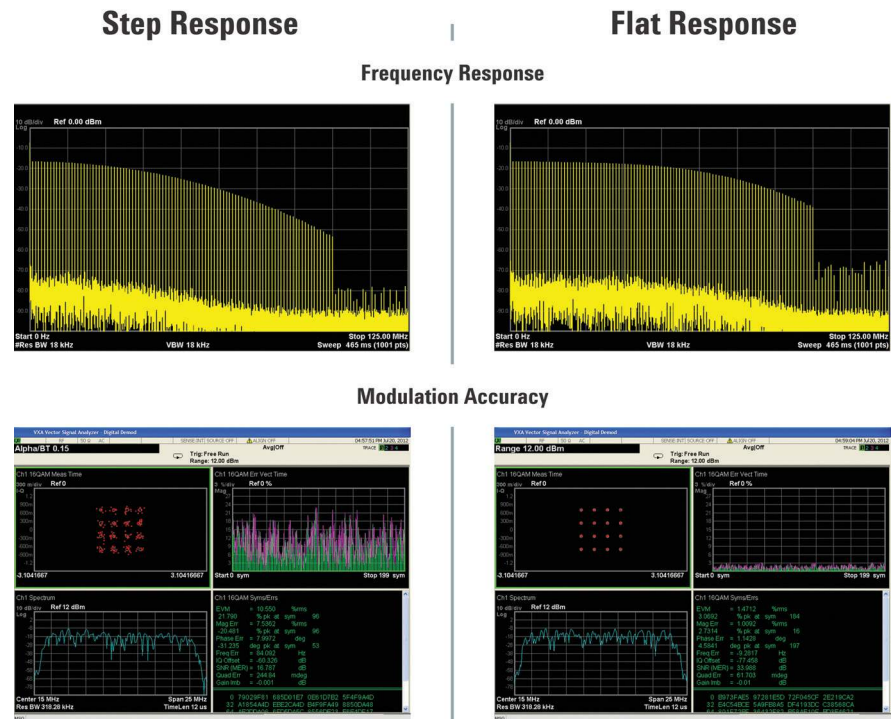


**Figure 5. DDS versus Keysight's Trueform technology constellation and spectral diagram.** In this figure, the same QPSK signal is generated by DDS and Trueform generators. The differences are significant in terms of modulation quality (EVM, error vector magnitude) and spectral quality (notice the 20-dB difference in dynamic range). The elliptical distribution of dots (in red) in the DDS constellation diagram shows jitter as phase noise in the modulation domain; pure noise (Gaussian noise) will make the constellation dots be circular in shape, as can be seen on the Trueform generator output. Spectral growth is a consequence of the sample jitter produced by the DDS architecture.

With the Trueform architecture, improved performance is obtained by interpolating the samples stored in the waveform memory in real-time through a DSP block, including a FIR low-pass filter. In this way, the jitter associated with time mapping of the samples stored in the waveform memory can be virtually eliminated without having to increase their original resolution, so valuable waveform memory is saved and potential time windows extended. The filter cut-off frequency and shape are adjusted so the frequency contents of the resulting signal can be reproduced accurately by the instrument's DAC. Finally, the filtered, up-sampled signal will be decimated to match the DAC fixed sampling rate. This arrangement can be seen as a real-time resampling system and will always use all the available samples in the process, since all samples will be fed to the processing block. Fast features in the signal that would be skipped randomly or misplaced in traditional DDS-based generators will now be shown consistently with very small jitter. This architecture offers a much longer equivalent record length thanks to the real-time interpolation process.

The low-pass digital real-time filter can also be used to improve the time or the frequency response of the output. For example with the Keysight 33500B Series, the combination of a high sampling rate related to the instrument bandwidth (oversampling) and a good analog interpolation filter at the output, results in clean, image-free signals. Its digital filter is designed to compensate for the DAC's frequency response, and two filtering modes are available—"brick-wall" filtering for flat frequency response (e.g., for IQ, multitone, or IF signal generation) or "Bessel" filtering to obtain a step response with fast rise times but without any ringing (e.g., for pulse or pattern generation). The flat response is a better fit for modulated signal generation since flatness is extremely important to obtain good modulation accuracy (see Figure 6).

**Figure 6. Trueform architecture can optimize the waveform generator frequency response for flatness or step response.** Regular AWGs are typically optimized for step response. In this figure, a 100-tone signal covering the range from 1 MHz to 100 MHz has been used to assess frequency response in both filter modes (top). Generating a 20-MBaud 16QAM signal and analyzing its quality in the two modes shows the importance of flat response for high-quality wideband modulation generation (bottom). With a sampling rate of 250 MHz and the Trueform signal generation technique, the usable digital bandwidth is much larger than it is with other forms of generation, which can be normalized with software for flatness as high as 100 MHz.



Ringings is not an issue for modulated signals, either baseband or IF/RF, since signals are already band-limited and, as a consequence, they show some ringing of their own. A flat response makes unnecessary any signal correction in most situations; it also increases dynamic range and improves channel-to-channel matching, which is an important feature for baseband signal generation. Generation of multicarrier signals is also improved, as modulation quality and/or amplitude levels are more consistent throughout all the channels.

The Trueform architecture is extremely useful for the generation of signals where the frequency and modulation domain quality is important for a variety of reasons (see Table 1):

- Real-time resampling removes jitter from the signal, no matter the sampling rate selection.
- The low-pass FIR cut-off frequency prevents any aliasing from showing up in the output signal.
- The DSP-corrected flat frequency response allows for good quality modulated signal generation (both baseband and IF/RF) without the need for signal precorrection and cumbersome frequency response calibration.
- The high oversampling (250 MSa/s sampling rate for a 30 MHz bandwidth), the real-time resampling process to keep sampling rate for the DAC constant, and the quality of the low-pass analog reconstruction filter, result in image-free, spurious-free signals.
- The matching and synchronization between the two channels are excellent, which makes high-quality baseband generation possible.
- The excellent fixed-rate sampling clock performance minimizes phase-noise in the signal.

Table 1. DDS versus Keysight’s Trueform for modulated signal generation

	Low-cost DDS	Trueform	Comments
<b>Jitter phase noise</b>	Poor	Excellent	Phase jitter greatly impacts modulation accuracy performance and spectral behavior. DDS-generated modulated waveforms do not reach a minimum acceptable quality level.
<b>Selectable frequency response</b>	No Step only	Yes Step/flat	Non-flat frequency responses degrade modulation quality performance, especially for wideband signals. Generation of good quality signals requires mathematical correction after careful generator calibration to obtain a flat response.
<b>Record length</b>	<1 MSample	16 MSample	Payload emulation, channel coding, and implementation of channelization schemes require long sequencing of symbols and, as a consequence, very long record length for implementation. OFDM and noise signal generation also result in long record length requirements.
<b>Sequencing</b>	No	32 sequences	Sequencing is necessary to implement protocols or low-repetition-rate bursts. It also helps to dramatically improve automatic testing throughput.

Unlike traditional low-cost DDS-based generators, the Keysight 33500B Series generators can be handled just like “true-arb” generators. This allows users to set any desired sampling rate for the DAC, but with the advantage of the real-time oversampling architecture (and the corresponding image-free output signal) and the convenience of being able to change the signal repetition rate without stopping the signal play-back, which is not possible using DDS architecture. Like DDS-based waveform generators, the DAC in Trueform generators always operate at a fixed rate (its maximum). In this way, the sampling clock system is greatly simplified and jitter and cost are minimized. Sampling clock jitter is directly transferred to modulated signals as phase noise.

## Example Applications

The characteristics of the Keysight 33500B Series allow its use in multiple modulated and RF signal generation applications:

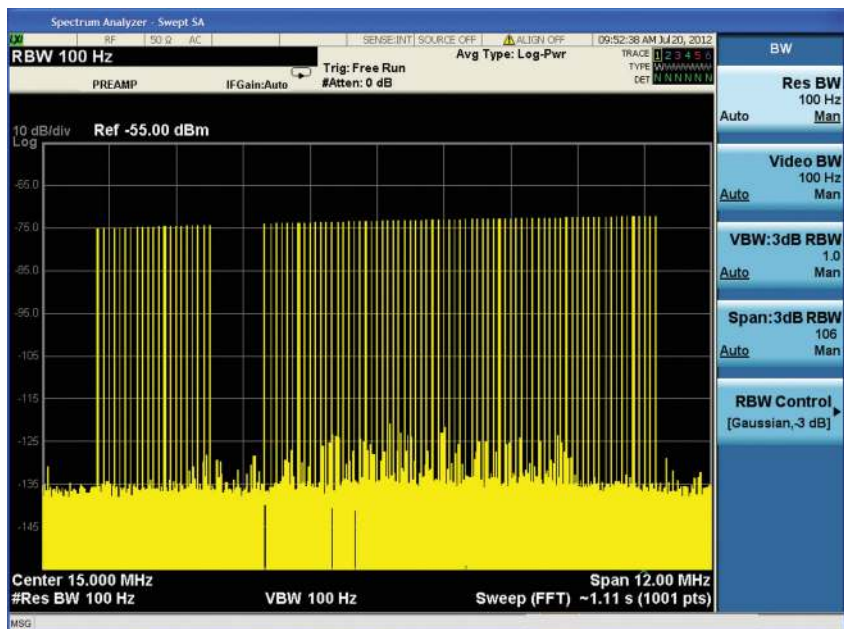
### Multitone signal generation

Multitone signals are made of a set of equally spaced unmodulated carriers. These signals are useful for characterizing both linear (i.e., frequency response) and nonlinear (i.e., intermodulation) responses from any device. Flatness and dynamic range are the most valuable multitone signal characteristics. Phase noise introduced by sampling clock jitter or by traditional DDS architectures may render the signal useless—the Trueform architecture is ideal for generating these types of signals. Noise power ratio (NPR) testing is a particular multitone signal designed to measure in-band intermodulation by removing some carriers (see Figure 7).

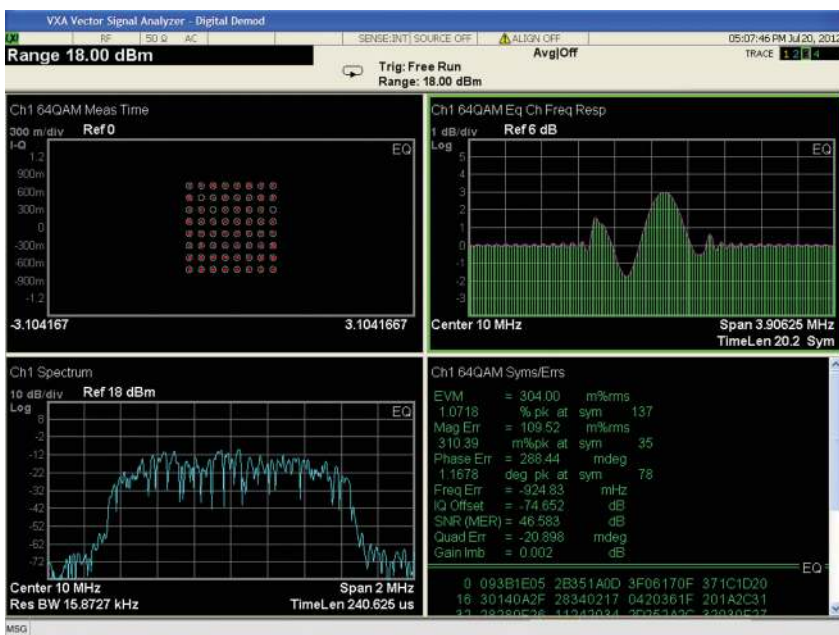
The level of intermodulation added by a modulator or amplifier can be assessed by looking at the level of the unwanted intermodulation products within the notch that will show up at the location of the removed carriers.

**Figure 7. Multi-tone signals are useful for assessing the linear and non-linear performance of a system.** These signals consist of a set of equally spaced unmodulated carriers with the same amplitudes. Phase must be random in order to optimize the peak-to-average power ratio (PAPR) and improve the average power.

Non-linear behavior can be established by adding a notch and looking for intermodulation products in the empty band, as shown. The generation of a noise-free notch or the SFDR of > 55 dB in the notch is important for finding various inter-modulation distortions.



High-quality general-purpose modulated signal generator  
 Satellite communications, radio links (see Figure 8), cordless phones, CATV head-ends, legacy WiFi networks, low-power wireless communications (e.g., Zigbee or RFID), and many other devices use a relatively simple single-carrier modulation scheme. The Keysight 33500B Series, with its excellent performance in terms of flatness, linearity, and dynamic range, can create modulated signals with high modulation quality and excellent frequency domain performance. Available bandwidth makes it feasible to generate signals with up to 60 MHz of modulation bandwidth (33522B).

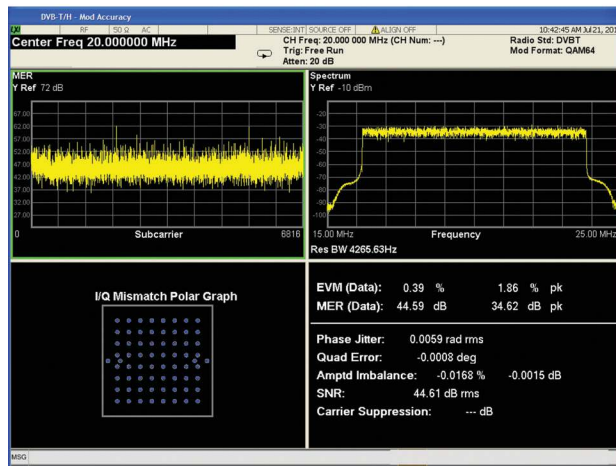


**Figure 8. Modulation and spectral quality define the performance of any modulated signal generator.** The ability to simulate linear and non-linear distortions caused by transmission equipment and the signal path is also important. In this figure, a radio-link 64QAM with multipath distortion is generated using a Keysight 33522B waveform generator. The adaptive equalizer in the Keysight CXA analyzer (top right) shows the corresponding channel response. Modulation quality for the corrected signal is excellent (0.3%).

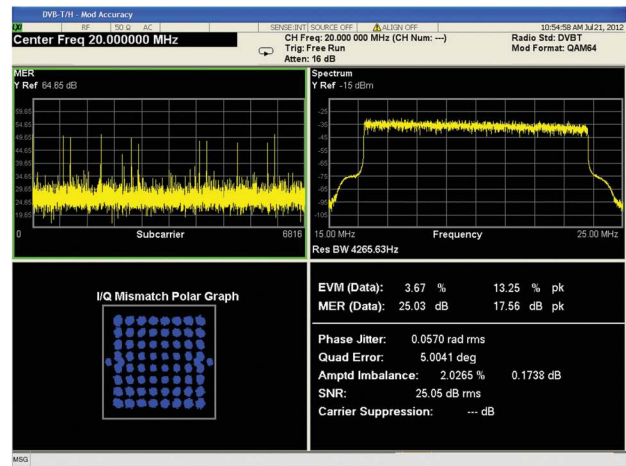
## OFDM

Generation of high-quality OFDM signals is especially demanding since these signals show a high peak-to-average power ratio and are very sensitive to phase noise and non-linearity. Additionally, statistically useful signals require sequences with as many different symbols as possible. Given the long duration of each OFDM symbol, statistically valid OFDM signals require much longer record lengths than single-carrier modulations. The Keysight 33500B Series, with its high amplitude levels, 16-bit DAC resolution, and 16-MSamples record length, is ideal for OFDM signal generation. Terrestrial broadcasting (DVB-T/T2, ISDB-T, DTMB, DAB, DRM), WiFi (802.11a/g/n), WiMAX, and LTE are just some of the applications that can be addressed with the Keysight 33500B Series generators (see Figure 9).

### Not Impaired



### Quadrature Impairments

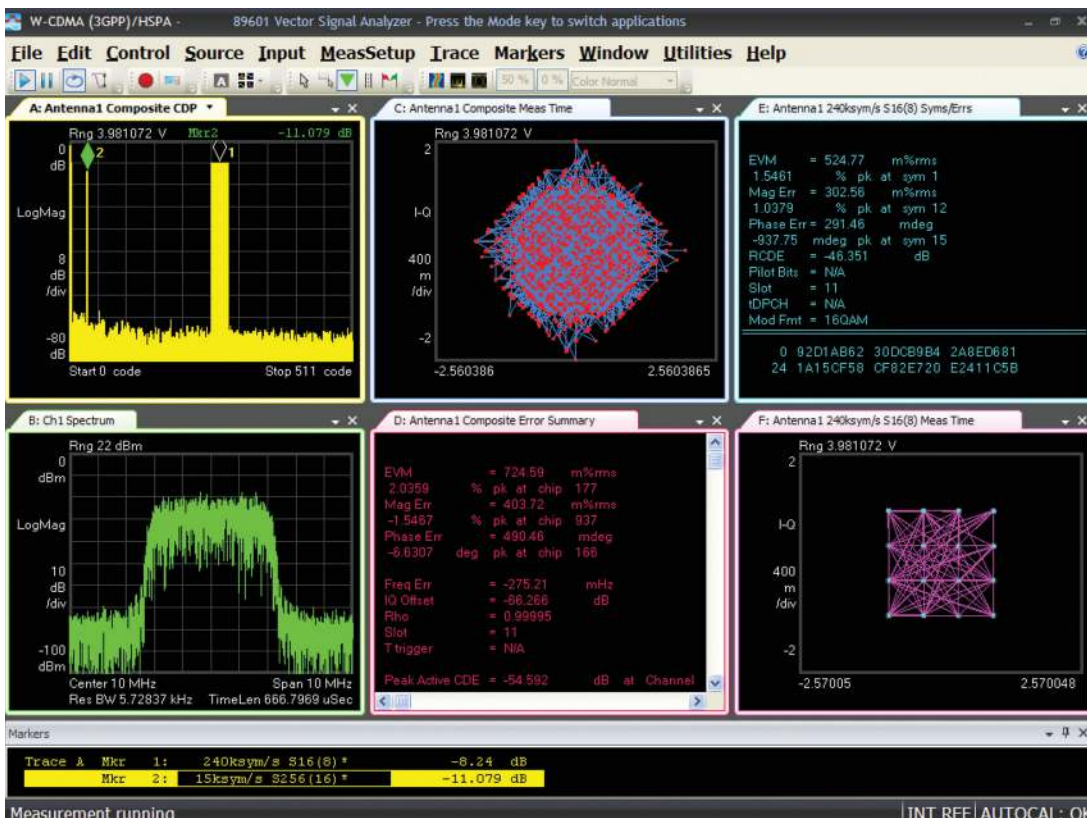


**Figure 9. OFDM signal generation not only requires good waveform generator performance, but it often requires long record lengths, as well. This DVB-T signal (8K mode) requires several MSamples to store the minimum 68 OFDM symbols necessary to carry the TPS information receivers need to properly demodulate the signal.**

In this figure, a perfect signal (left) generated by a Keysight 33522B waveform generator shows excellent modulation quality performance (MER > 45 db). As shown on the right, some quadrature error (5°) and imbalance (2%) have been mathematically added to the signal. The analyzer shows the accuracy of the impairments generated through accurate AWGs. Note that the quadrature errors show square dots within the constellation and not a circular cloud, as happens with additive noise.

## Support for channel coding and meaningful payloads

Most wireless communication standards use channel coding (i.e., error correction codes). Some tests require generating signals with properly coded signals and, in some cases, transporting specific payloads. In many cases, symbols are organized in frames of a given length and/or information is interleaved (i.e., the order of the data being sent is changed). For example, a typical CATV digital signal (DVB-C) may consist of a QAM (16 to 256) modulated carrier, but a meaningful frame requires sending a sequence of 8 MPEG2 packets (188 payload bytes + 16 bytes Reed-Solomon error protection bytes). The same considerations apply to mobile telephony (such as UMTS shown in Figure 10) or wireless networks (such as WiFi).



**Figure 10. A 3GPP (UMTS) WCDMA downlink IF signal generated by a Keysight 33522B waveform generator.** This is a complex signal, since it carries different data and synchronization channels.

The Keysight 89601B software running in a CXA shows the signal in multiple domains: Code (top left) domain power diagram—4 channels, (two of the channels are located next to 0 Hz, which are effectively sync codes). Number 2 is the first signal that would simulate voice, which is QPSK modulated. Number 1 is a 16QAM signal that would represent a data transmission: modulation (top center), frequency (bottom left), and channel (bottom right).

The channel undergoing analysis is an HSDPA, 16QAM channel. The composite signal constellation is of the entire signal (upper center); note the ~0.5% EVM showing that the Keysight 33500B Series can generate multiple modulations while maintaining excellent jitter and noise performance.

Generating such signals requires storing many thousands of symbols in the waveform memory and often requires record lengths well over 1 MSample, leaving them out of the reach of most low-cost generators. The Keysight 33500B Series, with its 16 MSamples waveform memory for each channel, can support virtually any realistic channel-coding requirement. The 33500B Series' record length granularity of just one sample gives users total freedom when adjusting record lengths, ensuring higher accuracy in all timing parameters, including carrier frequency and symbol rate.

## Multiple signal generation

Testing a receiver under real-life conditions requires the addition of distortions (i.e., multipath) and additive white Gaussian noise (AWGN). Since the available spectrum is often shared by multiple services, and since those services may be shared by many operators and users, a realistic emulation may require generating multiple modulated signals simultaneously, especially those located in adjacent channels, as occurs with CATV head-end emulation (see Figure 11).

**Figure 11. Three DVB-C 64QAM carriers generated simultaneously by a Keysight 33522B.** Tests are performed in the central channel, but all are channel coded following the DVB-C standard—although the data is uncorrelated to avoid artificially high power peaks in the combined signal. The DVB-C analysis shows the modulation quality obtained (EVM = 0.35%). Since the signal is properly channel coded, it is possible to perform BER tests with it. BER can be calculated by checking the corrected and uncorrected errors before and after Reed-Solomon decoding.



Note the following important points from Figure 11:

- Very good signal and flat frequency response.
- Notch is very good, 50 dB from signal.
- The signals are three DVB 64QAM modulated carriers transporting actual MPEG streams.
- BER is very good but the generated signal must have the length appropriate for the error correction type.

Some wireless standards are even designed to operate within the same band simultaneously. For example, wireless services such as WiFi and *Bluetooth*® may share the ISM band located around 2.450 GHz, and both services must keep operating under interference conditions. Today, devices emitting and receiving multiple wireless standards (for example, any smart phone can handle GSM, UMTS, WiFi, *Bluetooth*, and GPS signals at the same time) are common, and interoperability is a very important design requirement. More and more power amplifiers in transmitters (e.g., UMTS Node-B or DVB-T) are designed to handle multiple channels simultaneously to save money and reduce size. AWGs are ideal to generate such complex scenarios, since multiple similar or dissimilar signals can be mathematically added and simultaneously generated. Signal amplitude, frequency-domain flatness, record length, and dynamic range are important to generate such multiple signal scenarios and the Keysight 33500B Series excels in all these aspects.

### Burst signal generation

Most advanced wireless services require complex protocols to attach devices for communication or to handle handovers. Some may be based on noncontinuous transmissions with relatively long inactive periods between bursts of information. Inactive periods can be as short as microseconds (or even less) or as long as several seconds. The only way to handle such signal emulation scenarios with commercial waveform generators is to use a feature only available in high-end, true-arb architecture AWGs, which is sequencing. Traditional DDS-based low-cost waveform generators do not support sequencing, as the way in which memory is accessed does not allow seamless linking between different segments. The Keysight 33500B Series, with its Trueform architecture, does not suffer from this limitation; every sample in the waveform memory is read and seamless sequencing of segments is made possible. The 33522B can store up to 32 sequences of up to 512 segments.

## Conclusion

The Keysight 33500B Series is the first low-cost waveform generator family capable of creating high-quality baseband and IF/RF modulated signals. Keysight's exclusive Trueform architecture keeps all the advantages of DDS while removing all the drawbacks, especially with respect to low-jitter signal generation, which is a must for wireless applications. The Trueform architecture is even superior to the true-arb architectures used in high-end AWGs, since DSP-based oversampling and filtering allow users to obtain image-free signals and select the best frequency and transient response for a given application.

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