

Calibrate, Characterize and Emulate Systems Using RFXpress® in AWG Series

Introduction

System designers and device manufacturers so long have been using one set of instruments for creating digitally modulated RF signals for testing their device, and another set of instruments to characterize their system. With high bandwidth and high sampling rate Tektronix AWG7122B along with RFXpress® software, test signals and device characterization can now be done with one set of general purpose instruments up to 9.6 GHz.

RFXpress software allows user to calibrate, emulate s-parameter and characterize devices using high bandwidth and high sampling rate Tektronix AWG Series arbitrary waveform generators.

System calibration allows users to create good quality signals with flat amplitude and low phase distorted signals in the frequency band of interest.

S-parameter emulation tools provide users the flexibility to emulate a device/system as a black box even when the device/system is not physically available.

DUT characterization feature in RFXpress allows users to characterize the device/system in the frequency domain.

This paper describes the features system calibration, DUT characterization and s-parameter emulation in RFXpress.

System Calibration

Signal generators generating test signals for wide band RF communication application would require to generate signals with flat amplitude and linear phase response in the frequency band of interest.

It would mean that the distortions caused due to inherent characteristics of the signal generators, the cables, connectors and any other external device used like amplifiers, mixers etc need to be de-embedded from the signals before sending it to the device under test. A typical test setup with AWG7122B is shown in Figure 1. To achieve the same the signal needs to be calibrated/ pre-distorted by first finding the system characteristics without the DUT and correcting for the influences mentioned above.

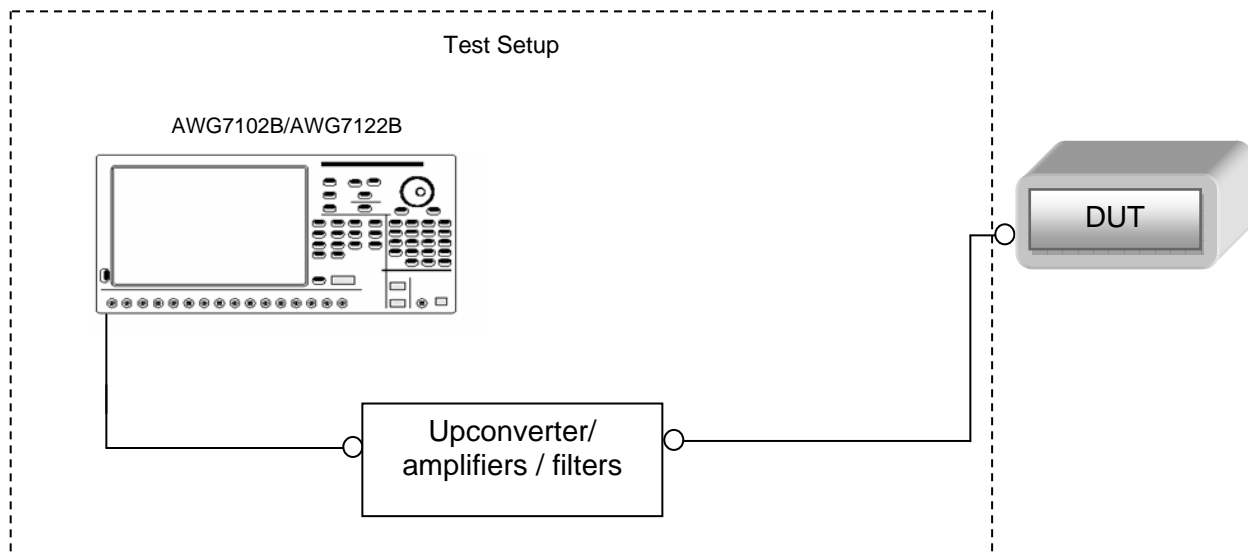


Figure 1: Test setup

Arbitrary waveform generator AWG7122B is a digital:analog synthesis instrument using a high-speed digital to analog converter (DAC) based system. While creating wide band signals the source for distortions of the signals could be:

- The well known $\sin(x)/x$ roll off of the DACs. In any DAC based system, the frequency response of the signals are not flat through out the Nyquist but is influenced by the $\sin(x)/x$ roll off.
- The analog components after the DAC within the AWG have their own bandwidth which again would influence the signal frequency response.
- External devices like amplifier/attenuators, cables and the connectors would have influence on the signal characteristics.
- Frequency translating devices, like mixers/up-converters, have influence on the frequency response of the signal created.

RFXpress provides three types of system calibration:

- RF Calibration
- Image Calibration
- IF signal Calibration

The first step would be to identify the system and create the correction to be applied to the signal used for testing DUT.

The idea here is to create a known stimulus signal (golden signal) generate and pass through system which needs to be de-embedded. This signal is captured on the oscilloscope, compared captured waveform with the stimulus. From the compared data the magnitude and the phase characteristics of the system is obtained. An inverse filter is then created using this correction data. Figure 2 shows the setup for system calibration.

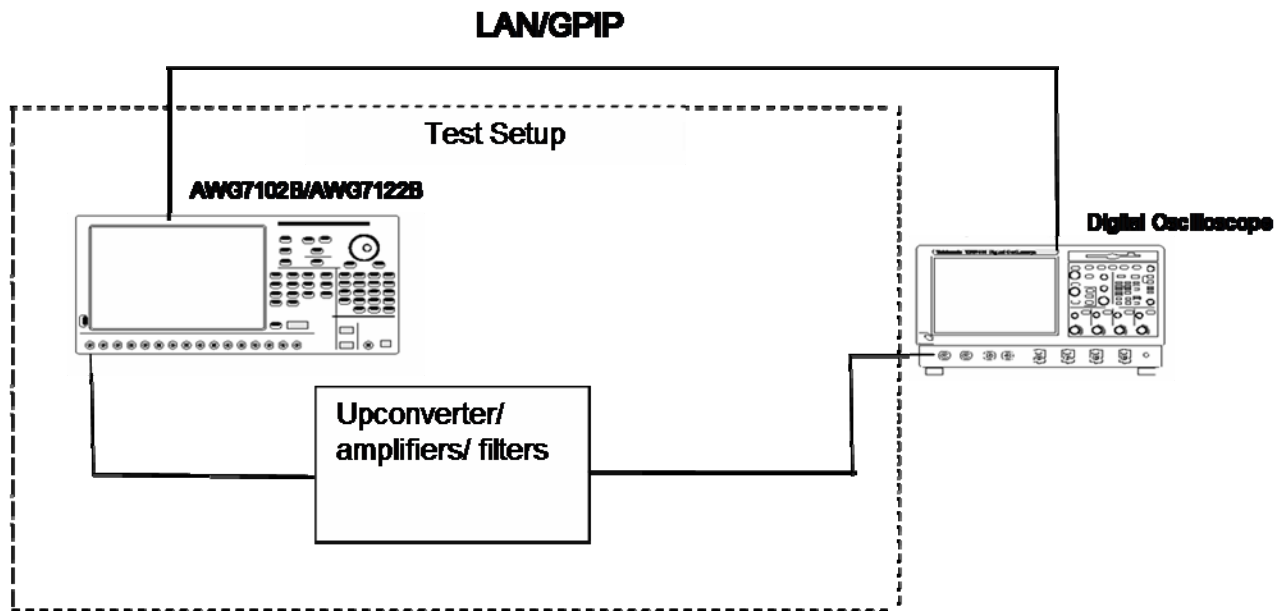


Figure 2: System calibration setup

The first goal involves identifying a stimulus waveform. The stimulus waveform should have a known magnitude and phase characteristics. Additionally the signal should have a limited peak to average ratio so as to increase the overall power of the signal and the signal to noise ratio.

Orthogonal multi-tone signals in the band of interest are one such signals and which has been chosen in the RFXpress. The tones are created in the band of interest with the required resolution.

The signal created from the AWG needs to be captured and analyzed for characterizing the system. The instrument that needs to acquire/capture the signal should have a bandwidth higher than our band of interest and also should not add its own artifacts or distort the signal which would be characterized. Tektronix high-performance DPO/DSA Series oscilloscopes with enhanced bandwidth features suit this requirement. DPO/DSA Series oscilloscopes with sampling rate and high bandwidth would be ideally suited for calibrating the system.

The captured signal is now transferred through LAN/GPIB to the AWG where in the analysis is done.

Frequency analysis is done on the captured signal using FFT method. The time domain flat top window is first applied on the signal. Flat top window provides a very good magnitude and phase response by removing undesired scallop effect. Obtaining the magnitude response would be straight forward by looking into the frequency bins of interest.

Phase response requires a time reference for the acquired signal. Thus before taking the FFT of the acquired signal proper timing alignment of the signal needs to be done. Correlation is done to acquire the right time alignment of the acquired signal. As the acquired signal is captured with a different sampling rate than generated, the stimulus signal needs to be re-created with a sampling rate of the acquired signal.

Time aligned signal is now analyzed in the frequency domain by taking the FFT of the signal. From the real and imaginary parts of the FFT, the magnitude response and phase response is obtained. Magnitude and the phase responses at the exact bins of transmitter signals are examined for measuring the distortions.

While calibrating in the IF mode, the stimulus signal from AWG would be the Intermediate Frequency and it would then be converted to required RF using mixers/upconverters.

RFXpress software provides for calibrating signals for the whole signal path to the output of mixer (up-converter) plus filters if any. Both the lower side band (Local Oscillator – IF) and the upper side band (Local Oscillator + IF) can be calibrated using the software.

The normalized magnitude response of the captured signal is compared with the normalized magnitude of the stimulus and the difference is obtained giving us the magnitude distortions.

An inverse magnitude and phase response is obtained from the measured magnitude and phase response. Using IFFT an inverse filter is thus obtained. The impulse response thus obtained would be applied on the signals the designer would like to create using RFXpress software.

Super Nyquist Signal Creation and Calibration

It is well known that DAC based system can generate signals from zero to Nyquist frequency (Sampling rate/2). The output signals are often confined to this frequency band. The normal approach would be to use an anti-aliasing (smoothing) filter to remove spectral components above Sampling rate/2. It is also well known that the DAC based system also generates spectral images well beyond the Nyquist rate.

When a digital signal is converted to an analog signal through the DAC, the signal spectrum will repeat every harmonic of the sampling rate (F_s). The spectrum of the reconstructed signal will show the signal spectrum and its image around the sampling rate. These images can be well utilized to create high frequency signals provided the system has enough bandwidth and the SNR. This amounts to creating under-sampled or Super Nyquist signals.

Note that the images will be affected by the $\sin(x)/x$ roll of the DAC, thus the images would be attenuated. Not only that the images would be attenuated but for images in even Nyquist zone would be spectrally inverted.

Using RFXpress Images could be made use by the users to create RF signals with known bandwidth. I and Q can be swapped and inverted using the software. Calibrating this signals provides users an opportunity to good quality waveforms for communication system.

In RFXpress calibration can be done to signals in the first image (Sampling rate – signal frequency)

The calibration procedure mentioned in the previous section is again used here, but in the analysis the image frequencies are analyzed. The correction are now applied by swapping the frequency bins and inverting the phase

DUT Characterization

RF Communication systems require characterizing the devices used in the transmitter and receiver. This is basically required by the system designers in understanding if the devices used meet their design specification. Device manufactures require characterizing the device to create the specification of the component

System designers require characterizing a system instead of individual device when the devices are cascaded like a combination of filters and mixers etc. Even though individually the characteristics of the devices would be available, the designers would be interested in characterizing the system itself.

RFXpress provides for characterizing the devices and the system for both frequency translating devices like mixers and non- frequency translating devices like amplifiers, filters etc.

DUT characterization involves three steps in RFXpress:

- Step 1: Signal path calibration without the DUT
- Step 2: Pre-distort the stimulus to de-embed the measuring instrument characteristics
- Step 3: Measure the magnitude and phase response of DUT

Step 1: Applying the same procedure as in system calibration. The setup would consist of the test setup without the DUT. The aim would be to de-embed or remove the characteristics or influence of the test setup while measuring the characteristics of the DUT.

After identifying the system without the DUT as in step 1, the inverse magnitude and phase response of the test setup is obtained.

Step 2: Applying the correction coefficients created in step 1 to the stimulus.

Using IFFT an inverse filter is created from the magnitude and phase correction factors obtained in step 1. Note the DUT needs to be characterized at the same sampling rate at which the AWG was characterized.

The stimulus signal is generated again but this time the stimulus is pre-distorted to remove the characteristics of AWG and the cables.

Note the step 1 and step 2 is done in the blocks of 1 GHz so as to get a good system characteristics. This basically helps in keeping the stimulus with high SNR (i.e. if we have to compensate for the whole bandwidth of the AWG at one shot, the lower frequencies would have to be reduced in power by more than 10 dB which would affect the SNR of the stimulus itself).

Step 3: Finding the magnitude and phase characteristics of the device. The DUT which needs to be characterized is to be now connected to the setup as shown in Figure 3. The pre-distorted stimulus is now passed through the system to identify the characteristics of the DUT. The output from the DUT is captured on the oscilloscope and time aligned for phase reference. The magnitude and phase characteristics are obtained for the DUT as in step 1 for the test step up. The magnitude and phase characteristics are plotted and stored as a S_{21} data in a .txt file.

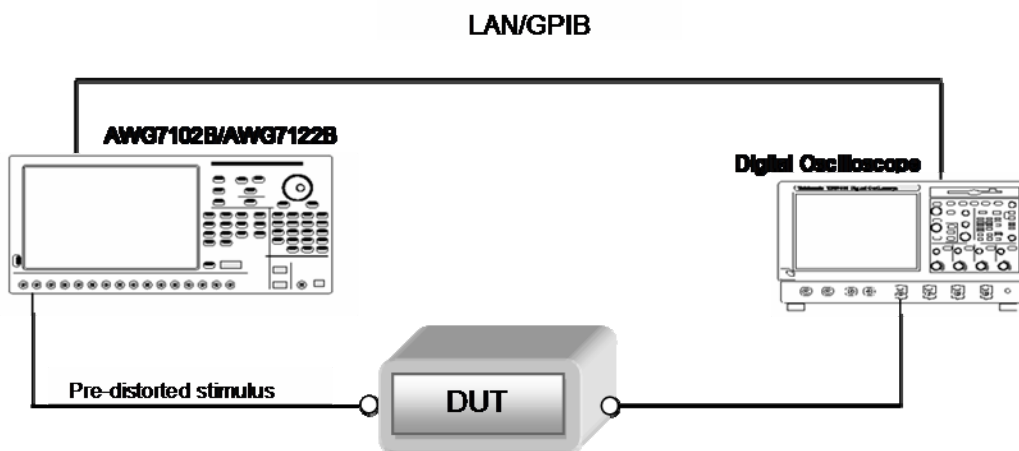


Figure 3: DUT characterization setup

S-parameter Emulation

S-parameter emulation tool in RFXpress allows user to make use of the s-parameter characteristics of the device provided in the touch tone files.

This feature allows users to emulate the device characteristics from the s-parameter files over frequency range of interest. This feature also allows user to emulate cascading of devices without physically having the devices. System designer would require to de-embed or equalize the characteristic of a channel or of the test setup when their characteristics are known. RFXpress provides user to invert or equalize for the s-parameter provided.

S-parameter provides the magnitude and phase response for a set of frequency values for different combination of input output of the device. Each combination of the input output defines different characteristics of the device. In RFXpress, these magnitude and phase response are used to create of filter using IFFT. Note a 4096 tap filter is created in RFXpress by linearly interpolating the values.

IFFT requires that the all the frequencies be equally spaced and we need to have values from 0 Hz to Nyquist (sampling rate/2). If the s-parameter file does not have information on the 0Hz or does not have values till Nyquist, a constant interpolation (i.e. the closest value is chosen).

Example of System Calibration, DUT Characterization and S-parameter Emulation

We will now take a setup and illustrate the above three features of RFXpress. Let us take a setup consisting of an AWG7122B and a Low pass filter with 6.4GHz cut off as shown in Figure 4

We will create a QPSK digital modulated signal with symbol rate of 2 GHz (BW of 2 GHz) and carrier of 5 GHz. The signal would lie in the roll off region of the filter.

We will observe the frequency spectrum and the EVM of the signal using SignalVu™ Vector Signal Analysis software installed on a DPO72004.

Next we will calibrate the system with and again observe the spectrum and EVM.

Next we will replace the physical filter with the s-parameter file of the component and observe the EVM.

We will also characterize the filter using DUT characterization feature of RFXpress and compare results with the one provided by manufacturer.

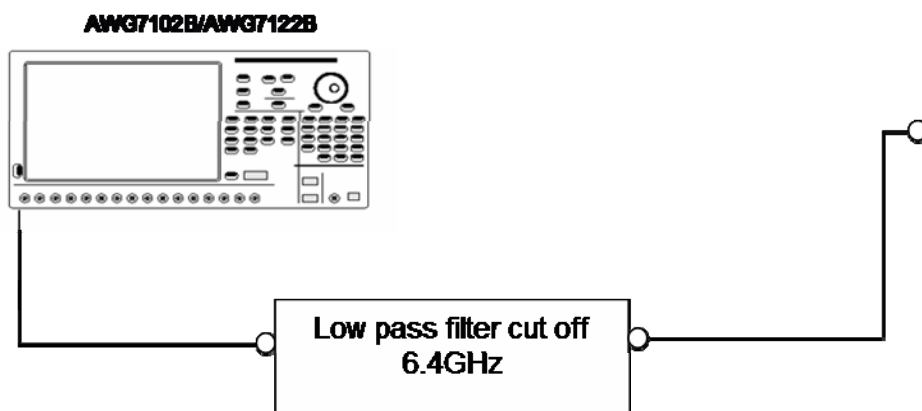


Figure 4: DUT characterization setup

The Low pass filter has the magnitude characteristics as provided in Figure 5. This characteristic is as provided by the component manufacturer.

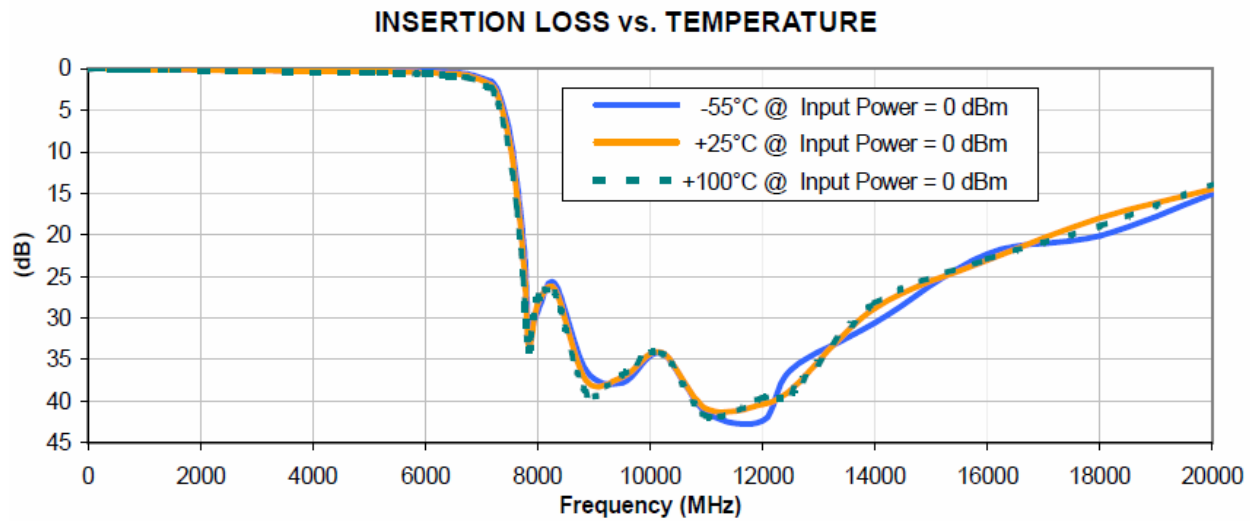


Figure 5: S21 magnitude characteristics of the filter

A QPSK signal with a 5 GHz carrier and symbol rate of 2 GHz using RFXpress is shown in Figure 6.

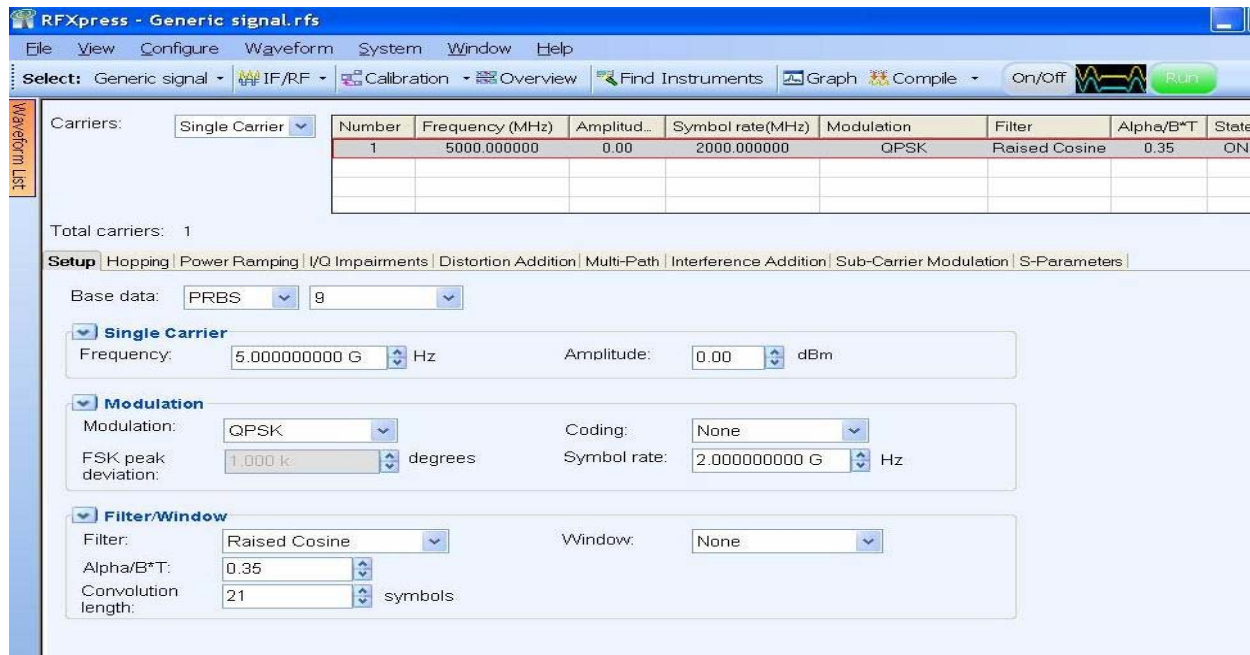


Figure 6: RFXpress setup

The spectrum and the EVM was observed using SignalVu software on the oscilloscope and is shown in Figure 7. The EVM measured is around 12%.

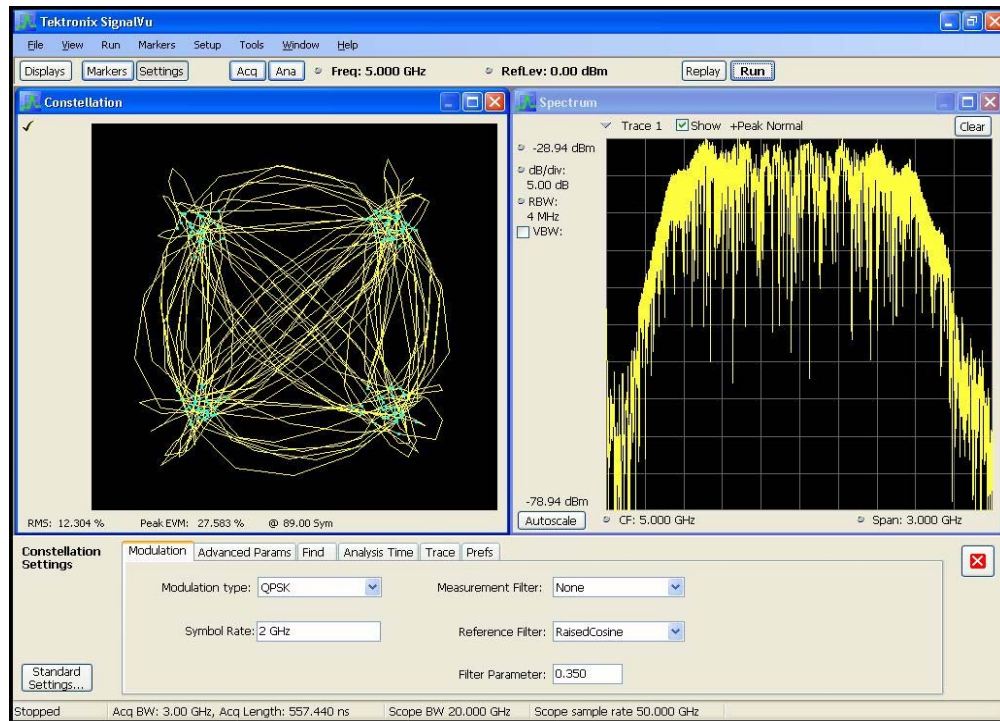


Figure 7: SignalVu analysis of non-calibrated signal

System Calibration of Example Setup

The system (including the external filter) is now calibrated using RFXpress system calibration. RF calibration is chosen and the Start Frequency and End Frequency is provided. Note the sampling rate for identifying the system characteristics and thus correction file has to be the same which will be used for final signal generation as the DAC roll off is affected by the Sampling rate.

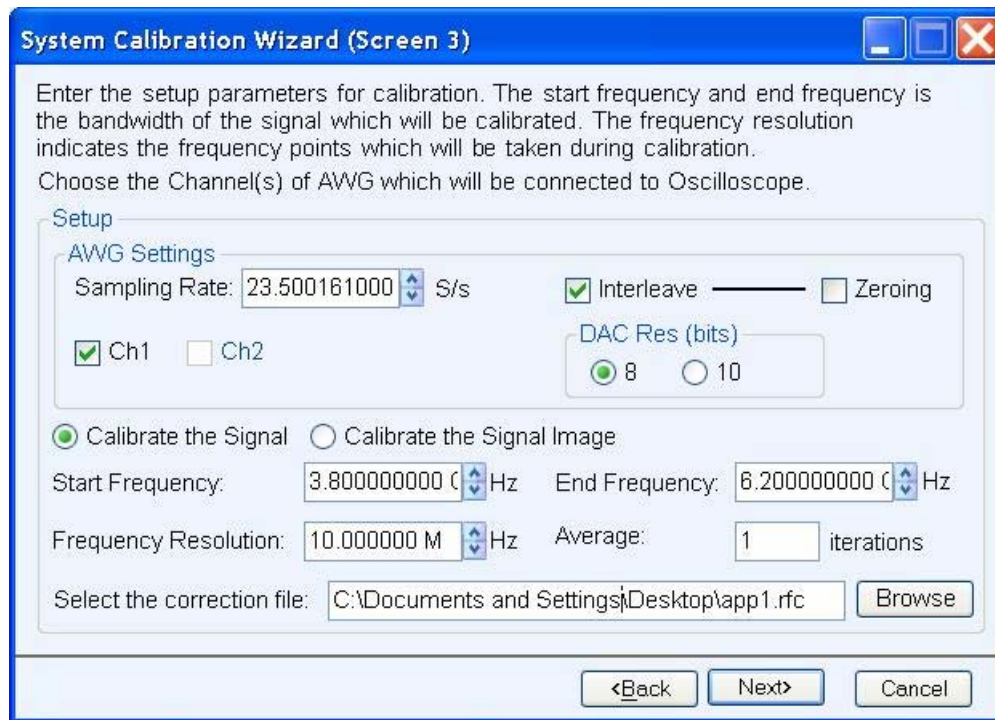


Figure 8: RFXpress setup for system calibration

The QPSK signal is then re-created now pre-distorted with the correction coefficients calculated in the calibration procedure above. The spectrum and the EVM was again observed using SignalVu software on the oscilloscope and is shown in Figure 9. We see a significant improvement in the EVM of the signal and also a flat magnitude response. The EVM measured is around 6%.

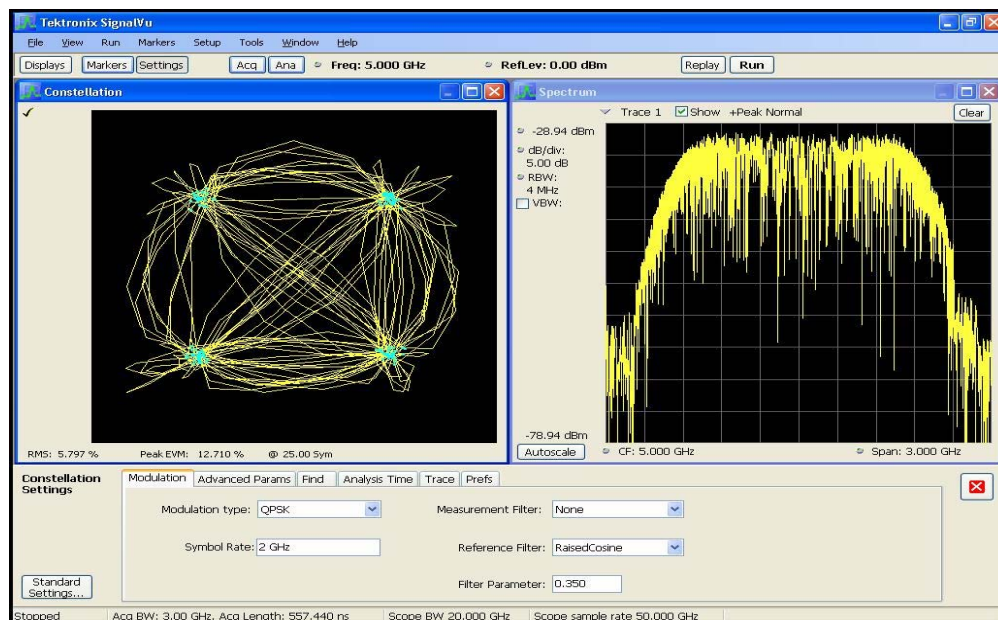


Figure 9: SignalVu analysis of calibrated signal

S-parameter Emulation of the Filter

Next the physical filter is removed from the test setup. The s-parameter of the component is provided as input to RFXpress. RFXpress now emulates the Low Pass Filter. The signal generated is pre-distorted using the correction file created earlier.

Waveform List

Carriers: Single Carrier

Number	Frequency (MHz)	Amplitud...	Symbol rate(MHz)	Modulation	Filter	Alpha/B*T	State
1	5000.000000	0.00	2000.000000	QPSK	Raised Cosine	0.35	ON

Total carriers: 1

Setup | Hopping | Power Ramping | I/Q Impairments | Distortion Addition | Multi-Path | Interference Addition | Sub-Carrier Modulation | **S-Parameters**

S-Parameters

Select the mode: Non-Cascading ☐ Apply Inversion ☒ Turn On

Filter Bandwidth

☐ Auto ☒ Full Bandwidth ☐ Manual 1.000000000 G Hz

Read from file: E:\Sparamaters\filters\Lowpassfilter.S2P

Touchstone 2-Port S-Parameter Selection

Select the location of the channel transmission data in the Touchstone File:

☐ S₁₁ ☐ S₁₂
☒ S₂₁ ☐ S₂₂

Figure 10: RFXpress setup for s-parameter emulation

The spectrum and the EVM was again observed using SignalVu software on oscilloscope and is as shown in Figure 11. We see that the signal quality is same as with the physical filter in place. EVM is 6% as before.

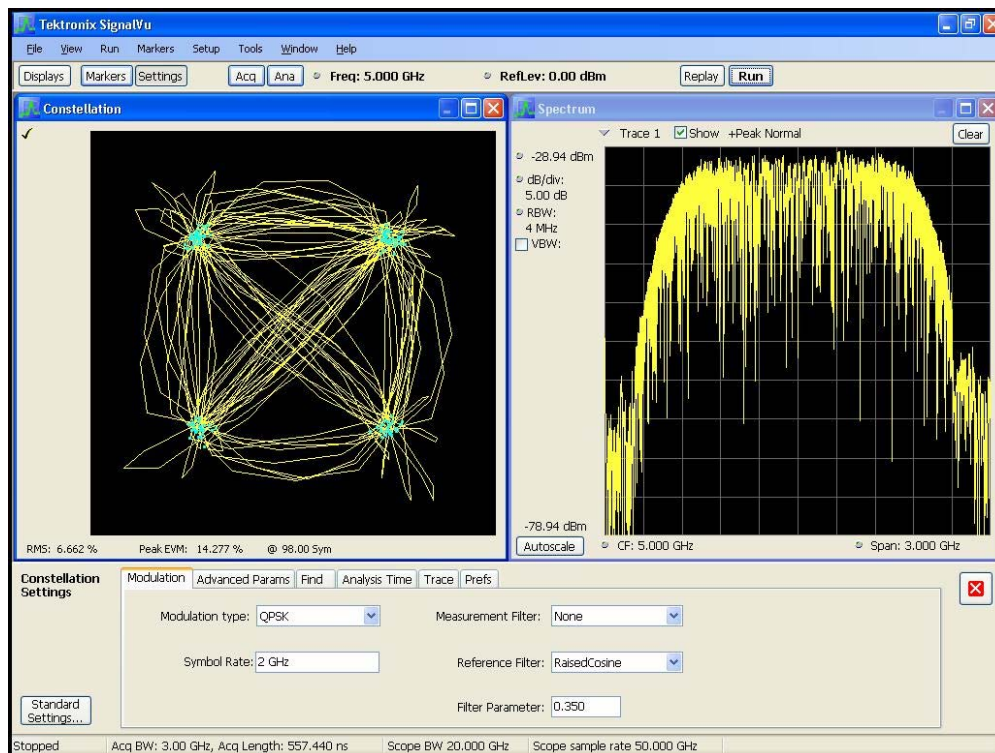


Figure 11: SignalVu analysis of emulated hardware

Characterizing the Filter Using RFXpress

The S_{21} characteristics of the filter are now obtained using DUT characterization feature in RFXpress. In this example, the AWG is set to maximum sampling rate (24 GS/s) and the span from 10 MHz to 11.7 GHz was considered. The resolution of measurement was set to 10 MHz.

The setup is shown in Figure 12:

DUT Characterization Wizard (Screen 3)

Enter the setup parameters for calibration. The Start and End frequency is the bandwidth of the signal which will be generated from AWG and calibrated. The frequency resolution indicates the number of frequency points being considered within the bandwidth. The time taken to calibrate will depend upon the frequency resolution and number of iterations.

Choose the Channel of AWG which will be connected to Oscilloscope.

Setup

AWG Settings

Sampling Rate: 24.000000000 G S/s ☒ Interleave ☐ Zeroing

☒ Ch1 ☐ Ch2

DAC Res (bits)

☐ 8 ☒ 10

Start Frequency: 10.000000 M Average: 1 iterations

End Frequency: 11.760000000 G

Frequency Resolution: 10.000000 M

<Back Next> Cancel

Figure 12: RFXpress setup for s-parameter emulation

The amplitude and the phase characteristics of the filter case are plotted as shown in Figure 13 at the end of characterization.

Note the data is also stored in a .txt file for further use.

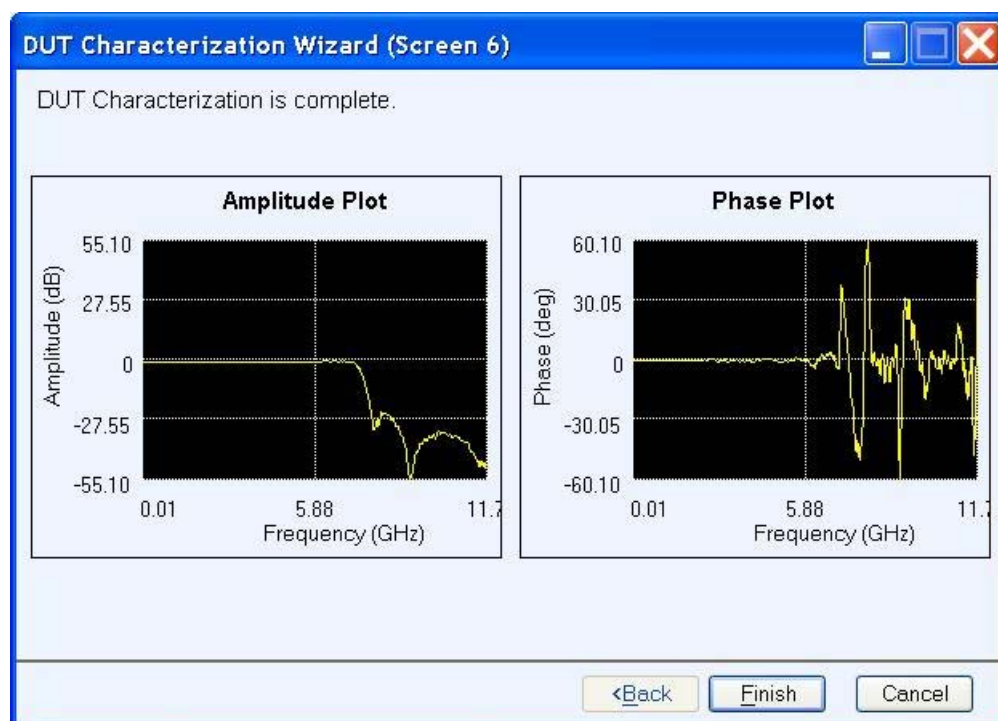


Figure 13: Filter characteristics plot in RFXpress

Conclusion

The Tektronix AWG7000B Series set a new industry standard for advanced RF signal generation, by delivering an exceptional combination of high sample rate, wide analog bandwidth, and deep memory. With a sample rate of up to 24 GS/s and 9.6 GHz analog bandwidth, the AWG7000B Series can directly generate RF signals never before possible from an AWG. In instances where IQ generation is desired, the AWG5000B or AWG7000B offer the ability to over-sample the signal, thereby improving signal quality. RFXpress software fully utilizes the wideband capabilities of the AWG providing ultimate flexibility to create complicated pulsed radar waveform.

The complex, fast-changing environments that RF receivers must operate create significant test challenges, particularly around simulating the real-world environment in the lab. Software-based tools combined with high-performance AWG instruments provide an easy, effective way to ensure that RF receivers are able to handle these environments. Moreover, with the flexibility to pre-distort the signals to create waveforms with minimum distortions enable receiver testing with confidence. The feature to emulate hardware reduces the time spent waiting for the actual device to be delivered for testing. DUT characterization enables users to obtain the actual device characteristics.

Techniques for system calibration, s-parameter emulation and DUT characterization have been demonstrated, using RFXpress software. It also covered the direct digital synthesis of these waveforms using an AWG and analysis using the SignalVu software on the oscilloscope.