

# AWG70000 Series Precompensation for improved frequency flatness and phase linearity

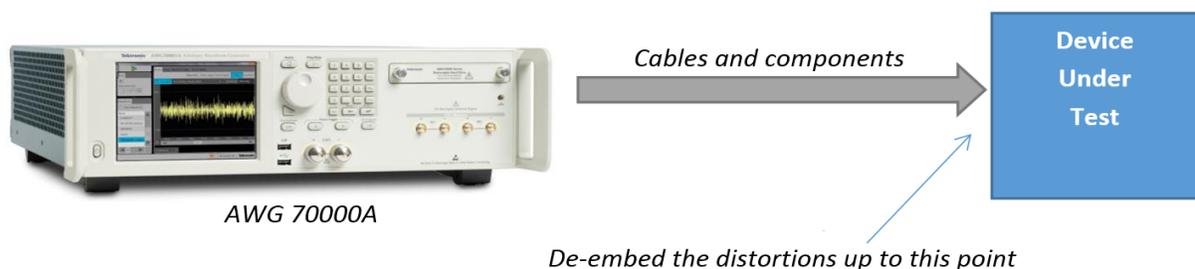
One of the main challenges while testing a Device Under Test (DUT) is to make sure the test equipment generating the signals is of better quality than that of the Device Under Test.

Thus the signal generators, Arbitrary Waveform Generators (AWGs) in this case, generating test signals for wide band communication applications, require the generation of waveforms with minimum EVM, flat amplitude and linear phase response in the band of interest. Wide band signals created from signals generators are limited by the bandwidth of the instruments frequency BW roll off, distortions caused due to inherent characteristics of instrument and distortions created by the cables, connectors etc. This means that the influence of the AWGs and the cables on the signals which could distort the signals needs to be de-embedded from the signals before sending it to the DUT.

The challenge is to first characterize the test set up which includes the test equipment, the connectors, cables and any external device like amplifiers and mixers used.

The typical generator for these applications is an AWG such as the Tektronix AWG70000 series that is a Digital to Analog Converter (DAC) based system. When creating wideband signals, the source for distortions of the signals could be:

1. The well-known  $\sin(x)/x$  roll off of the DACs. *(In any DAC based system, the frequency response of the signals is not flat throughout the Nyquist band but is also influenced by the  $\sin(x)/x$  roll off.)*
2. The analog components after the DAC within the AWG have their own bandwidth characteristics which again would influence the signal's frequency response.
3. External devices like multiplexers, amplifiers, attenuators, cables and the connectors influence the signal characteristics.



One of the main advantages of using a DAC based generator is that the output waveform can be pre-compensated to remove some of these analog effects that are part of the signal path that includes cables, connectors and other devices in the signal path of the DUT to be tested.

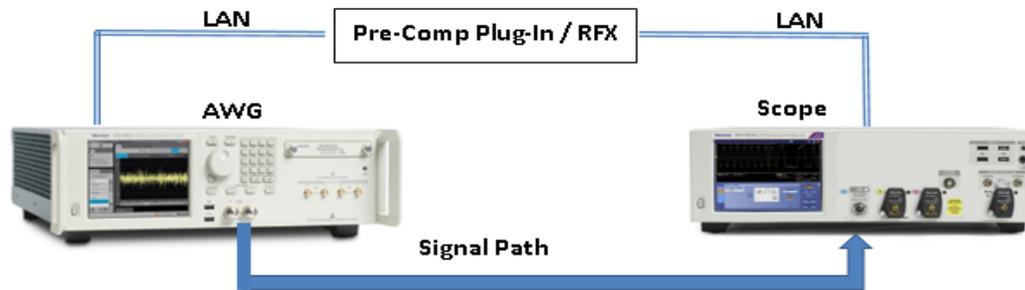
To create this precompensated waveform and effectively de-embed components, cables and connectors, the signal path needs to be evaluated by measuring the amplitude and phase of the signal to determine where the loss is and then a correction file created and applied to the test waveform.

# AWG70000 Precomp Technical Brief

## System Identification/Generating Correction Factors

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

A known stimulus signal (Golden Signal) will be passed through the complete system which needs to be de-embedded. This wide band multi-tone signal is created and generated out of the AWG and fed through the signal path to an oscilloscope which replaces the DUT. The resulting signal is analyzed and the magnitude and the phase characteristics of the system are obtained. An inverse filter is then created and saved as a correction file.



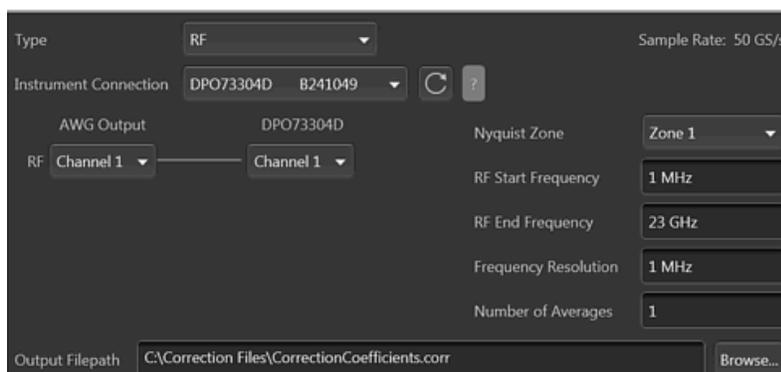
## Compensation Types

The Precompensation plug in for the AWG70K series or SourceXpress® offers several types of compensation methods depending on the application and if the AWG is a dual or single channel instrument. With dual channel AWGs the user can select from RF, IF, IQ with Modulator or Direct IQ. Single channel instruments only allow RF or IF compensation.



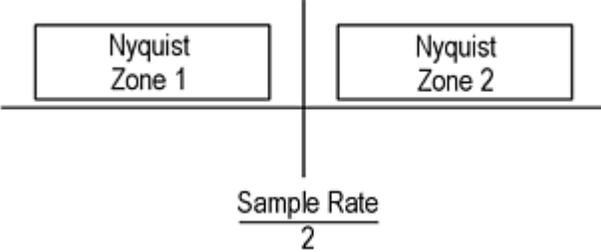
## RF coefficients

The RF coefficients are for a single RF signal from the AWG to the device under test (DUT). In the example shown, the RF signal is being output from channel 1 of the AWG and input to channel 1 of the connected oscilloscope (DPO73304D). Use the connection diagram pull-down lists to select the proper output and input channels of your setup. For RF type coefficients, you can connect to either an oscilloscope or a real time signal analyzer (RSA) to capture the waveform.

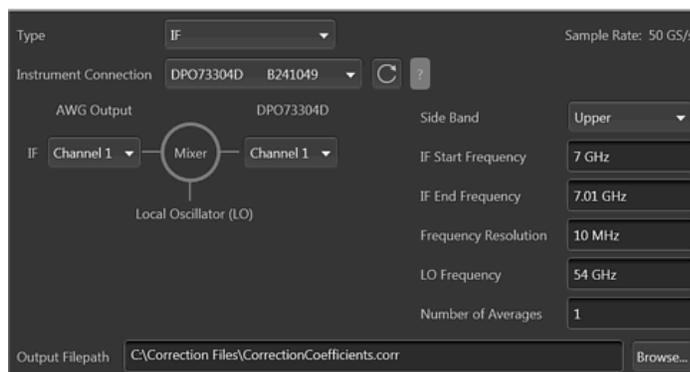


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The settings for the RF type include:

Item	Description
Sample Rate:	The Sample Rate displays the current AWG's clock rate. It is not adjustable from the Precompensation plug-in, but is adjustable from the setup clock menu.
Nyquist Zone	Choose Nyquist Zone 1 or Zone 2. 
RF Start Frequency	Used in conjunction with the RF End Frequency setting, select the frequency range you want to create a correction file.  Start and Stop Frequency settings are based on $\frac{1}{2}$ the available Sample Rate of the AWG and the Nyquist Zone selection.
RF End Frequency	Used in conjunction with the RF Start Frequency setting, select the frequency range you want to create a correction file.  Start and Stop Frequency settings are based on $\frac{1}{2}$ the available Sample Rate of the AWG and the Nyquist Zone selection.
Frequency Resolution	Enter the frequency resolution of the signal to determine the number of frequency points between start and end frequencies that coefficients will be created.
Number of Averages	Enter the number of times the software sends and captures the signal through the user defined configuration to create an average.  Increasing the number of averages reduces the noise level but increases processing time.

### IF Coefficients



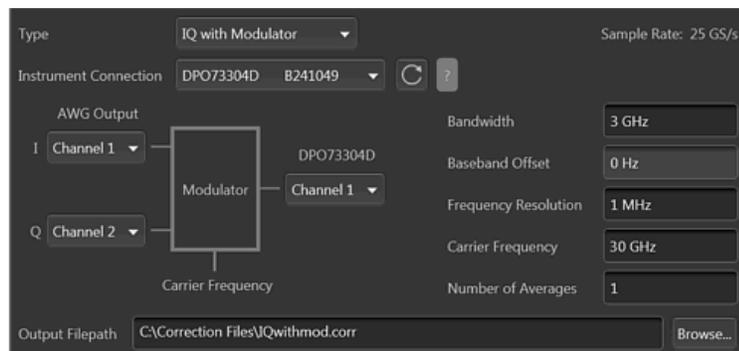
This can be used when an AWG is used as an IF signal generator and the signal is up-converted using a mixer.

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The settings for the IF type includes:

Item	Description
Sample Rate:	The Sample Rate displays the current AWG's clock rate. It is not adjustable from the Precompensation plug-in.
Sideband	Select the frequency band (Upper or Lower) which is to be calibrated.
IF Start Frequency	Used in conjunction with the IF End Frequency setting, select the frequency range you want to create a correction file.
IF End Frequency	Used in conjunction with the IF Start Frequency setting, select the frequency range you want to create a correction file.
Frequency Resolution	Enter the frequency resolution of the signal to determine the number of frequency points between start and end frequencies that coefficients will be created.
LO Frequency	Enter the frequency of the local oscillator to be mixed with the IF signal
Number of Averages	Enter the number of times the software sends and captures the signal through the user defined configuration to create an average.  Increasing the number of averages reduces the noise level but increases processing time.

### IQ with Modulator coefficients



The IQ with modulator coefficients are individual I and Q signals from the AWG and modulated with a carrier frequency to provide a single RF signal to the device under test (DUT). In the example shown, the I and Q signals are being output from channels 1 and 2 of the AWG, modulated with a 30 GHz carrier frequency, and input to channel 1 of the connected oscilloscope (DPO73304D).

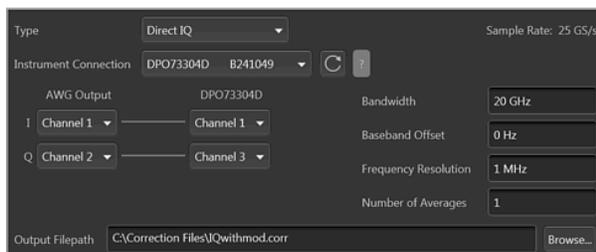
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The settings for the IQ with modulator type include:

Item	Description
Sample Rate:	The Sample Rate displays the current AWG's clock rate. It is not adjustable from the Precompensation plug-in.
Baseband Offset	The default signal is centered at the Carrier Frequency. The Baseband Offset changes moves the signal center + or – from the carrier frequency.
Frequency Resolution	Enter the frequency resolution of the signal to determine the number of frequency points between start and end frequencies that coefficients will be created.
Carrier Frequency	Enter the carrier frequency of the modulator to create the RF signal.
Number of Averages	Enter the number of times the software sends and captures the signal through the user defined configuration to create an average.  Increasing the number of averages reduces the noise level but increases processing time.

### Direct IQ coefficients

The Direct IQ coefficients are individual I and Q signals from the AWG and connected directly to the device under test (DUT). In the example shown, the I and Q signals are being output from channels 1 and 2 of the AWG and input to channels 1 and 3 of the connected oscilloscope (DPO73304D). Use the connection diagram pull-down lists to select the proper output and input channels of your setup. For Direct IQ coefficients, you must connect to an oscilloscope to capture the waveform since two channels are required.



The settings for the Direct IQ type include:

Item	Description
Sample Rate:	The Sample Rate displays the current AWG's clock rate. It is not adjustable from the Precompensation plug-in.
Bandwidth	Enter the bandwidth of the signal.  The available bandwidth setting is dependent on the AWG's sample rate and the Frequency Resolution setting.
Baseband Offset	The default signal is centered at the Bandwidth Frequency. The Baseband Offset changes moves the signal center + or – from the bandwidth frequency.
Frequency Resolution	Enter the frequency resolution of the signal to select the number of samples between start and end frequencies.

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## Creation of Correction file

### Stimulus Signal

The first goal involves creating 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 use the full dynamic range of the instrument.

Orthogonal Multi-Tone signals in the band of interest are the type of signals which have been chosen in the Pre-compensation routine. The tones are created in the frequency band of interest with the required resolution. These tones are made orthogonal by making sure it has complete cycles of all the tones in the time window.

Basically, the time window of the signal to be generated should be  $\frac{1}{(\text{resolution between the tones})}$  or multiples of the same.

### Analysis

In order to characterize the system, the signal generated by the AWG must be properly captured and analyzed. The instrument performing the acquisition of the signal should have a bandwidth higher than the band of interest. The measuring/capturing instrument should not add any of its own artifacts or distort the signal which would be characterized. Thus a near ideal capturing instrument would be required. Tektronix wide bandwidth oscilloscopes suit these requirements. Scopes with sampling rates as high as 200Gs, bandwidth up to 70GHz and low noise ADCs are ideally suited for doing this pre-compensation of the AWG signals. The scopes also provide the ability to capture large record lengths which will give better frequency resolution for the analysis.

The acquired signal is then transferred to the pre-compensation application where 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. Obtaining the magnitude response is then calculated 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. Correlation is done between the acquired signal and the stimulus signal. As the acquired signal is captured with a different sampling rate than what is generated, the stimulus signal needs to be re-created with a sampling rate of the acquired signal.

The 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.

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. The phase response is unwrapped and the phase distortions are obtained. The difference in the stimulus phase and the stimulus signal phase is compared and the difference is captured. This provides the phase distortion in the captured signal. Group delay distortions are derived from phase information.

An inverse frequency response is obtained and stored in the correction factor file.

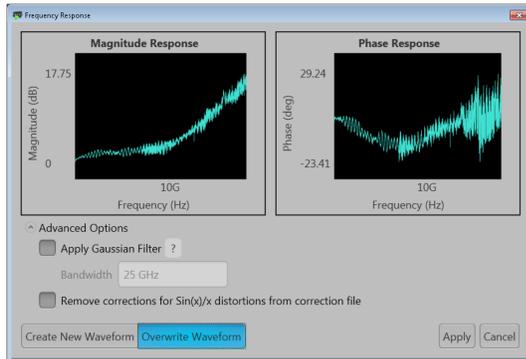
Next the impulse response is obtained by a frequency sampling method, by taking the IFFT of the correction factor. This impulse response is convolved with the signal of interest to obtain pre-compensated/de-embedded signal.

Once the calculations have been done the correction file .corr is saved. This .corr file is similar to a S1P touchtone file and can be used as such.

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## Applying the correction to the test signal

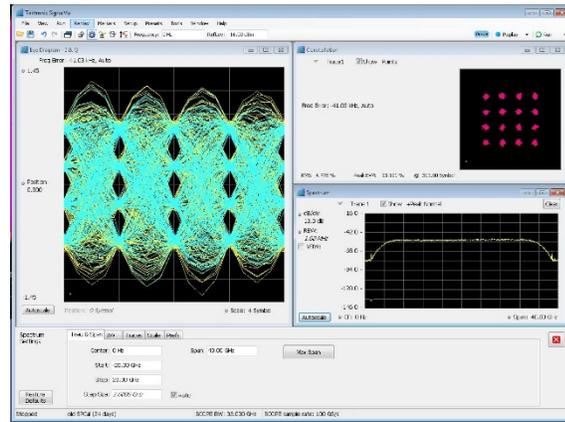
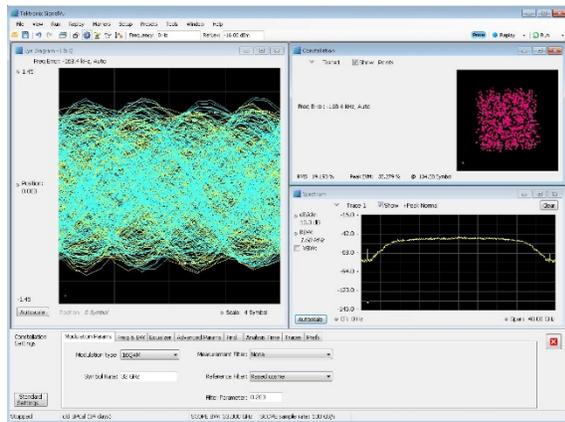
Once the correction file has been calculated it can then be applied to any waveform in the AWG waveform list. To apply, the user just needs to right mouse click on the waveform that they want to apply it to and then select the correction file. The specific waveform for the test can be created using any of waveform generation tools available, such as the AWG70K series waveform generation plugins, RFXpress, SerialXpress and MATLAB just to name a few.



If the waveform is a NRZ type waveform, the user also has the option of turning off the sin(x)/x corrections or applying a Gaussian filter to the file when the correction is applied.

*Note: it is also important that the correction was done at the same sample rate as the desired output waveform, so that the time and phase relationship is maintained. This may require changing the properties of the waveform sample rate attribute so that it matches the compensation file sample rate.*

## Correction example using a 16QAM 32GBaud waveform



### Before Compensation

### After Compensation

Not only can these corrections be applied to the test waveform, but if other s-parameter files are available for other components (modulators or amplifiers) in the signal path, they can also be applied. This allows for a complete pre-compensation from the output of the AWG all the way to the DUT. *(This feature will be available at a later time)*

## Conclusion

As signal requirements increase, the effects of signal magnitude and phase distortions due to analog characteristics can be dramatically reduced using pre-compensated waveforms. This capability provides the best signal quality at the device to be tested and removes external influences that can degrade outcome of the required testing. Having a simple process to create these correction coefficients enables testing engineers to use their time more effectively, thus improving their efficiency during these complex testing experiments.

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