

# InstaView™ Technology Demystified

## APPLICATION NOTE



# Introduction

Arbitrary function generators (AFGs) are used to generate many different types of electrical waveforms, such as sine waves, square waves, triangular waves and arbitrary waveforms. Most electrical engineers use an AFG as a reference source for their devices under test (DUTs). The latest Tektronix AFG31000 Series Arbitrary Function Generators support at least 20 different standard function waveforms, allow adjusting the relative amplitude from 1 mV<sub>p-p</sub> to 10 V<sub>p-p</sub>, and have a relative frequency range from DC to 250 MHz. This wide frequency range covers DC, the audio frequency band, the video frequency band and the radio frequency band. Impedance matching is required to maximize the power transfer and minimize signal reflection.

The signal source's output impedance should be equal to the load impedance or characteristic impedance. For example, in audio systems, 600 Ω is used as the characteristic impedance; 75 Ω is used as the characteristic impedance in video systems. For the radio frequency band, the most common characteristic impedance is 50 Ω, which is the compromise value between minimum loss and power handling capability. For Tektronix AFG products, we chose 50 Ω as our characteristic impedance because of its wideband high-frequency capability and universality. Almost all of the analog/RF parameters listed in the specification are measured under 50 Ω load matching conditions.

What will happen if the load impedance is not 50 Ω? Do we know whether the actual output waveforms of a signal generator are still ideal waveforms under non-50 Ω load impedance conditions? The answer depends on the degree of mismatch. **Figure 1** is a simple signal generator's Thevenin equivalent circuit under DC or low frequency or short cables conditions.

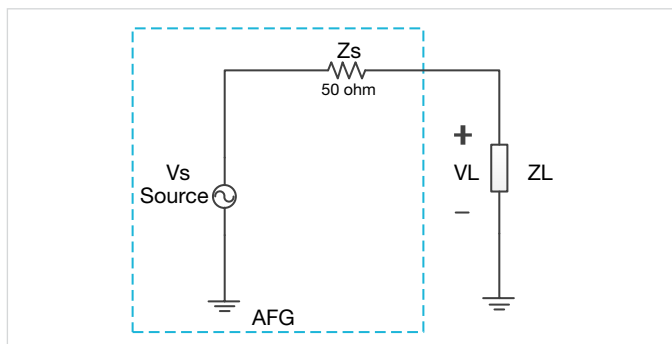


Figure 1. AFG output Thevenin equivalent circuit.

According to Ohm's law and Kirchhoff's circuit laws, we could get:

$$V_L = V_S * \frac{Z_L}{Z_S + Z_L} \tag{1-1}$$

We assume  $Z_S$  is 50 Ω, and  $V_S$  is 2 V<sub>p-p</sub> amplitude:

When  $Z_L$  is equal 50 Ω, the  $V_L$  should be 1 V<sub>p-p</sub>, half of the  $V_S$  amplitude.

When  $Z_L$  is 1 MΩ or infinite resistance, the  $V_L$  will be 2 V<sub>p-p</sub>, the same as the  $V_S$  amplitude.

We can see that the actual output waveform's amplitude changes based on the different load impedance under low-frequency conditions.

As the frequency increases, the system circuit models become more complex. It's necessary to regard the cable as a transmission line and consider reflection and complex load (not only resistance, but also inductance or/and capacitance). The actual output waveform's amplitude and shape could be largely different from the ideal source output under certain mismatching conditions. The following sections analyze it in detail.

That is to say, if mismatched load impedance or mismatched long cables are used, whether intentionally or not, the actual output waveforms will not be the ideal ones that one might think they are. The bad reference waveforms could cause test/measurement errors and misleading conclusions and could even damage the DUT under extreme conditions.

There are two main ways to identify the actual signal waveform. The first is to use an oscilloscope to probe the load of the AFG or the input of DUT. The other way is to use the Tektronix InstaView™ function to calculate the actual load waveform and display it on the AFG's LCD screen. The user can just push the InstaView button and enter the cable parameters in the menu; the waveform will appear on the display immediately and continuously. This offers a convenient and quick way to confirm the matching degree of the load impedance. By the way, if mismatch problems are discovered and debugging is necessary, an oscilloscope is still the preferred tool.

# What's InstaView Technology?

InstaView is an abbreviation of the phrase “instantaneous view.” It provides a view of the actual waveform at the load of the AFG31000 in real time. The traditional AFG products display only the setting parameters or ideal waveforms. In order to see the actual waveform on the load of the generator or the input of the DUT, an oscilloscope is needed to probe the related test points.

With the patented InstaView technology, the AFG31000 Series can measure and display the actual waveform at the DUT, rather than just the ideal waveform set on the AFG, with no need for any other instrument. All that's needed is just the cable between the AFG output and the DUT, which is already in place. **Figure 2** shows the simplified test connection when using the InstaView function. The waveform shown changes in real time, along with the settings like frequency, amplitude and waveform shape changes or the impedance change at the device under test.

## The principle of InstaView Technology

**Figure 3** shows the standard AFG test connection. It includes three main parts: the AFG instrument, a 50 Ω BNC coaxial cable and the DUT (the oscilloscope is used as the DUT in this photo). The following sections cover building equivalent system models based on **Figure 3** and performing the mathematical calculations.

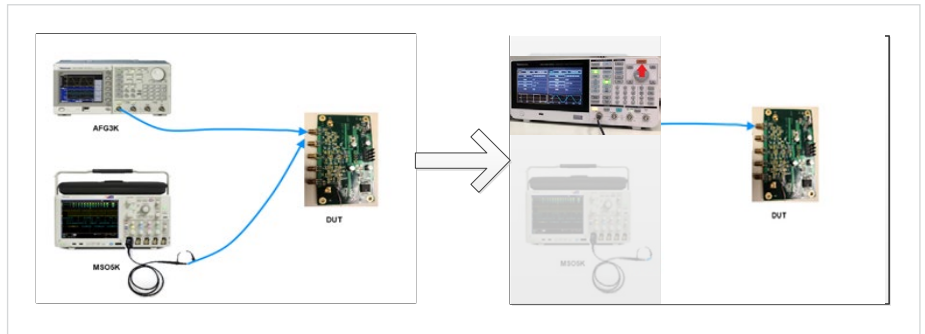


Figure 2. Simplified test setup via InstaView

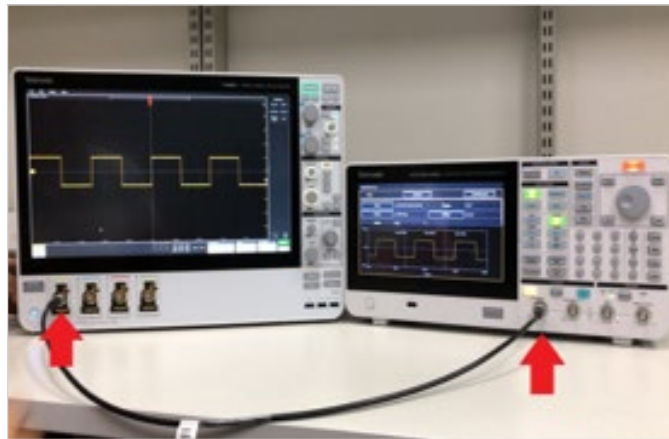


Figure 3. Standard AFG test connection

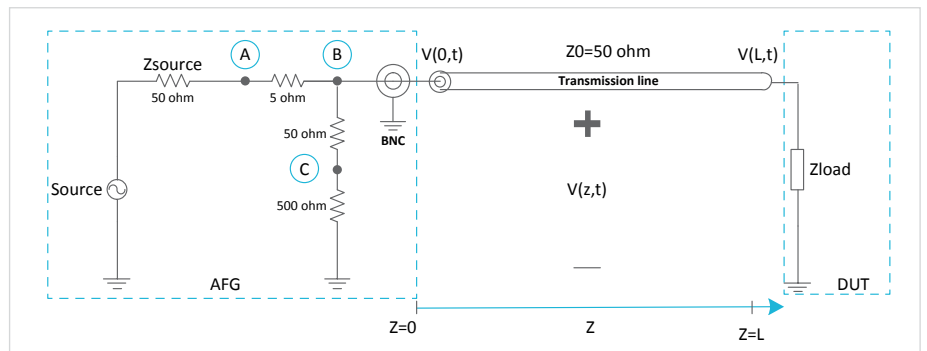


Figure 4. Test system equivalent models

**Figure 4** depicts the equivalent system models. We could simplify AFG circuits as ideal voltage source with series 50 Ω source resistors. These three resistors compose a unidirectional bridge. We acquire sampling data through it; after arithmetic calculation, we can finally get the actual load waveform. The transmission line is represented by the symbol of the coaxial cable

with length  $L$ , which should have a 50 Ω characteristic impedance. The DUT is the device under test with a load impedance,  $Z_{load}$ , which could be pure resistance, inductance, or capacitance or a combination of them. The arrow represents the incident waveform propagation direction. The reflection waveform will propagate in the reverse direction.

The following sections are a step-by-step analysis of this system:

## 1. DC or low-frequency range

The transmission line is composed of two conductors: one is regarded as the signal path, the other is used as the return path. The PCB traces on multilayer boards, such as the microstrip and stripline, could be transmission lines.

The coaxial cables could be transmission lines as well. Whether the traces and cables could be regarded as transmission line depends on the maximum signal frequency or the fastest rise/fall time compared to the cable's physical length.

In equation (2-1) and (2-2),  $L$  represents cable length,  $\lambda$  represents wavelength,  $v$  represents propagation velocity,  $f_{max}$  represents maximum frequency,  $TD$  represents transmission delay,  $\tau_r$  represents rise time.

When the cable length ( $L$ ) is smaller than 10 times the wavelength ( $\lambda$ ), or waveform's rise time ( $\tau_r$ ) is larger than 10 times the transmission delay ( $TD$ ), the transmission line effect can be ignored. We can regard the cable as ideal lossless line with no attenuation and no phase delay.

$$L < \frac{1}{10} * \lambda = \frac{1}{10} * \frac{v}{f_{max}} \quad (2-1)$$

$$\tau_r > 10 * TD = 10 * \frac{L}{v} \quad (2-2)$$

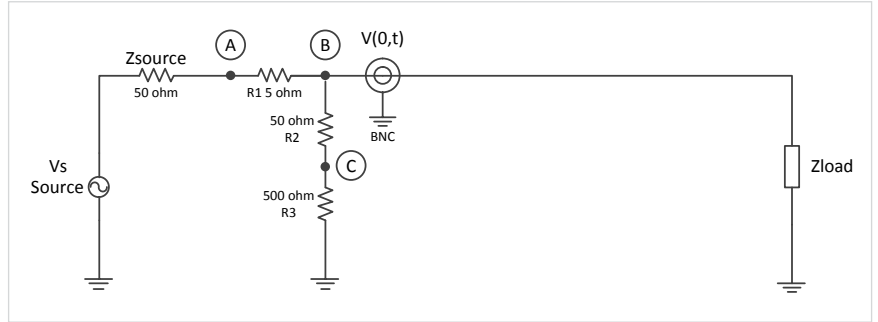


Figure 5. Simplified diagram under low-frequency condition

To simplify the equations, we can use light speed,  $c$ , to replace propagation velocity,  $v$ , when we calculate in hand.

Figure 5 shows the simplified equivalent models diagram in which the transmission line is replaced by an ideal line.

Based on Kirchhoff's laws:

$$\begin{aligned} V_A &= V_S * \frac{(R2 + R3) * Zload}{R2 + R3 + Zload} \\ V_B &= V(0,t) = V_S * \frac{\frac{(R2 + R3) * Zload}{R2 + R3 + Zload}}{Zsource + R1 + \frac{(R2 + R3) * Zload}{R2 + R3 + Zload}} \\ V_C &= V_S * \frac{\frac{(R2 + R3) * Zload}{R2 + R3 + Zload}}{Zsource + R1 + \frac{(R2 + R3) * Zload}{R2 + R3 + Zload}} * \frac{R3}{R2 + R3} \end{aligned} \quad (2-4)$$

$Z_{load}$  is the load impedance and unknown value.

$V_S$  is the amplitude of the source. We could regard it as unknown value.

$V_A$ ,  $V_B$  and  $V_C$  are test points.

When  $Z_{load} = 50 \Omega$

$$V_B = V(0,t) = V_S * \frac{5}{11} \quad (2-6)$$

There is no reflection signal, so the B point waveform is same as the load's; it could be considered as the initial incident waveform.

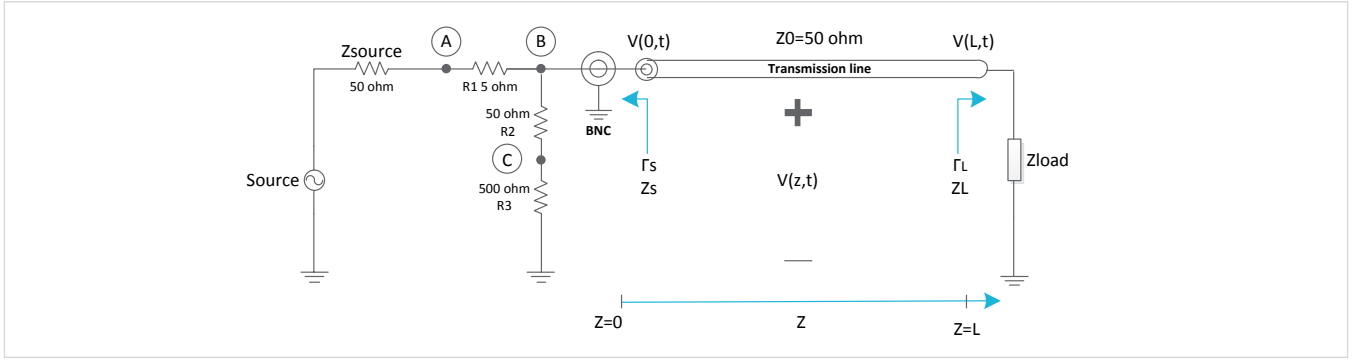


Figure 6. System models with lossless transmission line.

## 2. High-frequency range with lossless transmission line

As frequency increases, the transmission line effect should be considered. But when the cable length is not very long and frequency is not very high, the transmission line's attenuation elements  $R$  (distributed resistance) and  $G$  (distributed conductance) are small and could be neglected. Under these conditions, we could consider the coaxial cable as a lossless transmission line. The signal's amplitude on a lossless transmission line will stay constant; only propagation delay occurs. Figure 6 shows the system models with a lossless transmission line.

The reflection will occur when impedance mismatch happens. The reflection coefficient,  $\Gamma$ , is defined as:

$$\Gamma = \frac{V_{ref}}{V_{inc}} = \frac{Z_{load} - Z_0}{Z_{load} + Z_0} \quad (2-7)$$

So we could get the source reflection coefficient and load reflection coefficient:

$$\Gamma_L = \frac{Z_{load} - Z_0}{Z_{load} + Z_0} = \frac{Z_{load} - 50}{Z_{load} + 50} \quad (2-8)$$

$$\Gamma_S = \frac{Z_S - Z_0}{Z_S + Z_0} = \frac{50 - 50}{50 + 50}$$

$$\Gamma_L = \frac{Z_{source} + R1 * (R2 + R3)}{Z_{source} + R1 + R2 + R3} = 50 \, \Omega \quad (2-9)$$

When  $Z_{load} \neq 50 \, \Omega$ , the  $\Gamma_L$  will not be zero; that means there is a signal being reflected. The reflected signal will propagate along the reverse  $z$ -axis to reach source terminator  $Z_S$ .

$\Gamma_S$  is equal to 0; that means no reflection will occur when the signal reaches source terminator  $Z_S$ .

So we can consider this system as one reflection case. Only load mismatched impedance could cause reflection. The reflected signal will propagate to source  $Z_S$ . No second reflection will occur because the value of  $Z_S$  is  $50 \, \Omega$ . The voltage at any point along the transmission line could be considered to be the sum of the incident waveform and the reflection waveform.

$$V(z,t) = V_{inc}(t - z/v) + V_{ref}(t + z/v) \quad (2-10)$$

$V_{inc}$  represents the incident waveform or forward-traveling waveform.

$V_{ref}$  represents the reflection waveform or backward-traveling waveform.

$v$  represents the propagation velocity

$z$  represents the distance along cable

At point B

$$V_B = V(0,t) = V_{inc}(t) + V_{ref}(t) \quad (2-11)$$

At point A

$$V_A = V_{inc}(t) * \frac{(Z_0 + R2 + R3) * R1 + (R2 + R3) * Z_0}{R3 + R2} + V_{ref}(t) * \frac{Z_{source}}{R3 + R2} \quad (2-12)$$

At point C

$$V_C = V_{inc}(t) * \frac{R3}{R3 + R2} + V_{ref}(t) * \frac{R3}{R3 + R2} \quad (2-13)$$

We could determine the  $V_{inc}(t)$  and  $V_{ref}(t)$  based on the preceding equations. The load waveform  $V(L,t)$  is the composite of the delayed propagation  $V_{inc}(t)$  waveform and the advancing propagation  $V_{ref}(t)$  waveform. The delayed or advancing phase value is calculated by  $L/v$ , or measured, before the calculation of load waveform. So, at the load:

$$V(L,t) = V_{inc}(t - L/v) + V_{ref}(t + L/v) \quad (2-14)$$

Figure 7 shows an example of how to process and calculate the waveform based on the above principles and equations. As shown, after capturing the waveform data on any two points, we can calculate the actual incident waveform and reflection waveform. Finally, we can get the actual load waveform based on equation 2-14 and display it on the LCD. We can compare this calculated waveform data with the measured waveform data via oscilloscope to get the accuracy result.

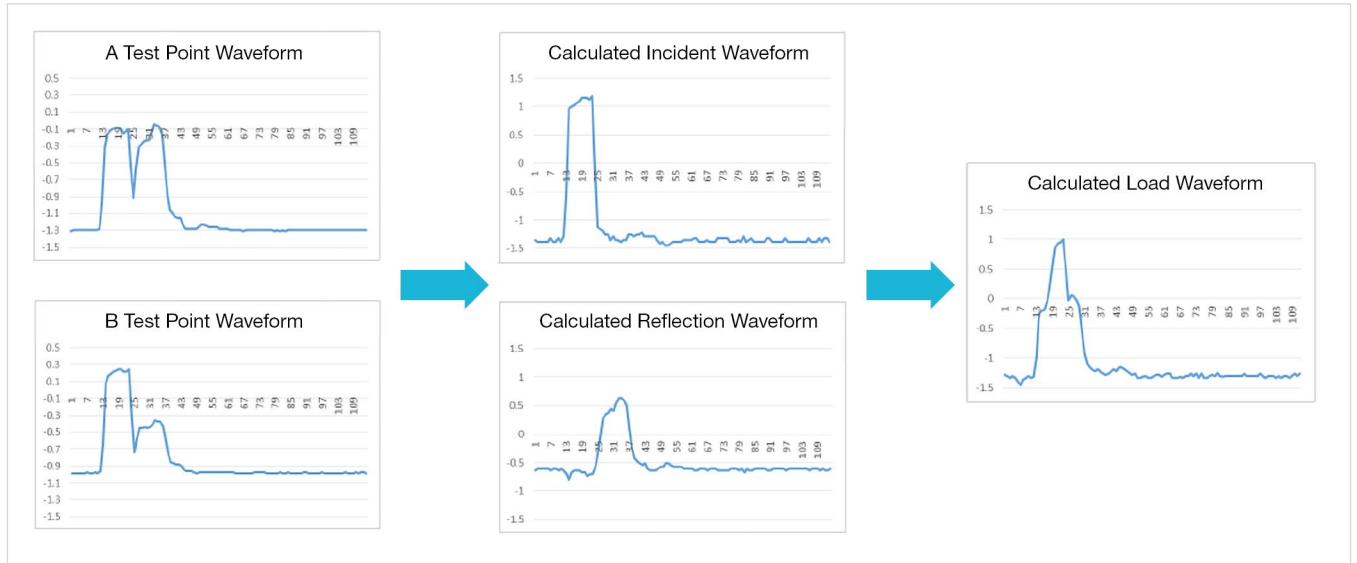


Figure 7.

## InstaView test result

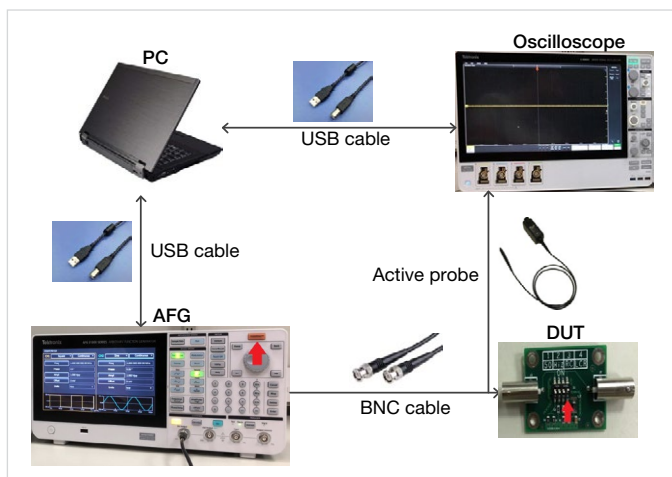


Figure 8. InstaView test setup diagram

Figure 8 illustrates the InstaView test setup. A computer controls the oscilloscope and AFG equipment. An oscilloscope acquires waveform data from the DUT via a probe. The AFG's InstaView function is enabled and the load waveform appears on the AFG's display in real time. The DUT is a demo board, which could provide many different type of loads (matching, non-matching). Finally, the computer is used to get the acquired data from the oscilloscope and the calculated data from InstaView, and to compare them to determine the error. For DC or low AC frequency, the oscilloscope is replaced with a DMM to get better measurement accuracy.

In the following figures, the X-axis represents the setting in Vdc and Vpp. The orange curves are the voltages measured by InstaView, and the gray curves are the voltages measured by a digital multimeter.

### DC accuracy

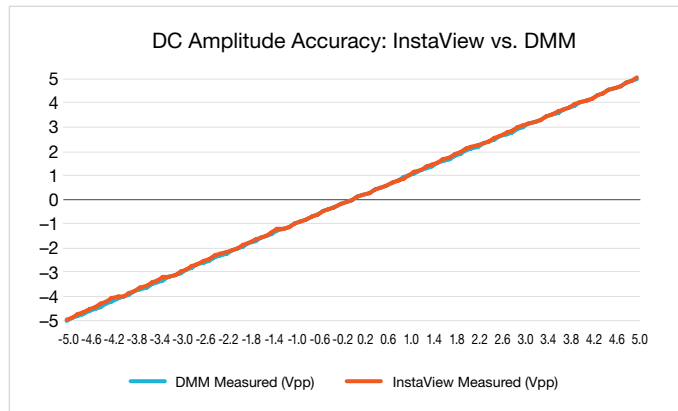


Figure 9. DC accuracy error with DMM (50 Ω terminator + 90 cm BNC RG-58 cable)

### AC accuracy

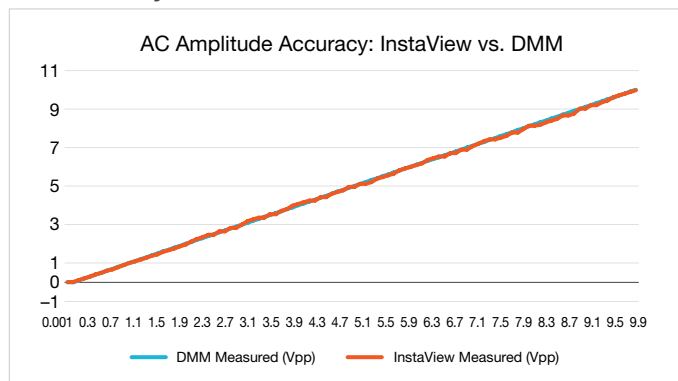


Figure 10. 1 kHz AC accuracy error with DMM (50 Ω terminator + 90 cm BNC RG-58 cable)

### Flatness within bandwidth

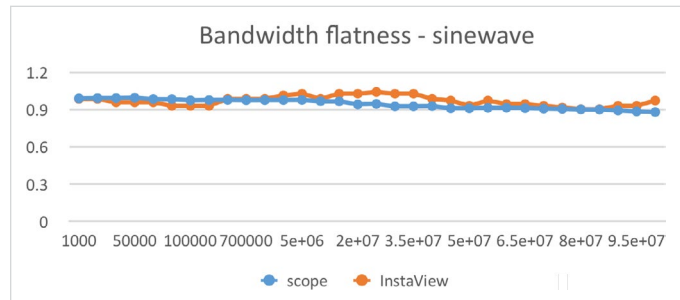


Figure 11. Flatness error within analog bandwidth

### 50 Ω match

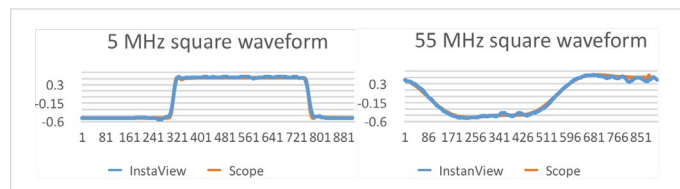


Figure 12. Square waveform under 50 Ω match condition

### 1 MΩ mismatch

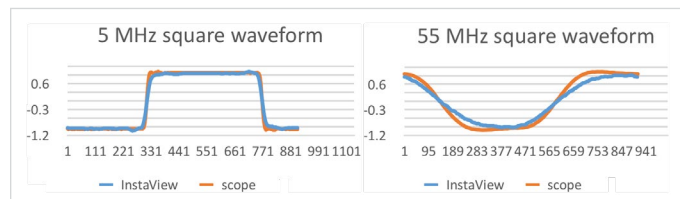


Figure 13. Square waveform under 1 MΩ mismatch condition

### Complex mismatch

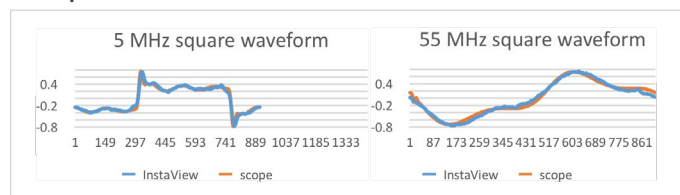


Figure 14. Square waveform under complex mismatch condition (combination of R, L and C)

## How to use the InstaView function with the Tektronix AFG31000

Set up InstaView on the AFG31000

1. Press “InstaView™” on the front panel to call up the setting window.

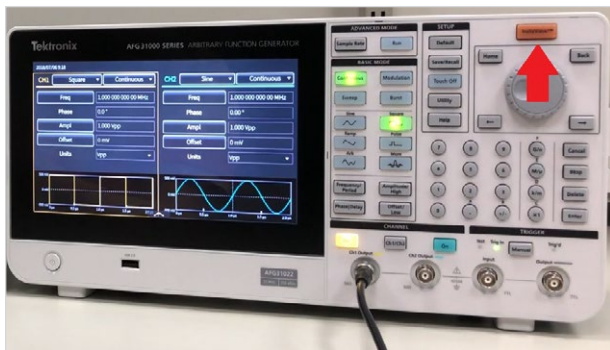


Figure 15. AFG31000 InstaView setup

2. Measure or manually enter the BNC cable delay. We will use this value to do phase shift when we calculate the load waveform.

If choosing Auto measure, please connect the BNC cable between the channel port and trigger out port and press the Run button. The delay value will be automatically added.

If choosing Manual input, you can enter the BNC cable delay value directly.

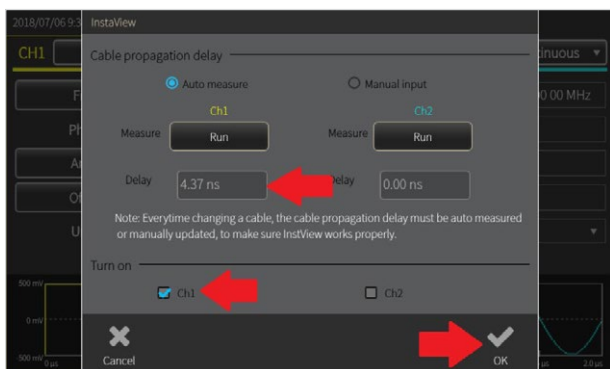


Figure 16. AFG30000 Series' InstaView parameters input menu

3. After setting the delay, choose the channel to measure and press the OK button. The load waveform will appear on the display.



Figure 17. AFG31000 Series InstaView display user interface

## Conclusion

The InstaView function is a quick and convenient way to determine whether the actual reference waveforms are what's needed or not, whether the load impedance or input impedance of the DUT matches or not, and how bad it is if it doesn't.

It is also a good diagnostic tool for the researcher and designer in the lab. If there are questions about the input reference waveforms or the input impedance of the DUT, all it takes is a simple push of the InstaView button to see the result on the display.

The InstaView function also serves as a good demonstration in educational settings, providing students with visual feedback on the waveforms under matching and mismatching conditions.