

# MEASUREMENT TIPS

Volume 10, Number 1

## Creating Differential Signals with a Two-Channel Arbitrary Waveform Generator



### Snapshot

**Single-ended signals** are referenced to a common level, such as ground, that they can share with other signals, so a single-ended signal requires only a single path or wire. Differential signals are made up of a pair of paths that are both dedicated to a single signal at any given time. One path is used at a higher potential than the other. Differential signals do add complexity, since they require two wires instead of just one, but they provide a number of performance advantages over single-ended signals.

Differential signal advantages include better signal-to-noise ratio, fewer timing errors, and less crosstalk. These advantages make differential signals common in applications such as ADC inputs, instrumentation amplifiers, measurement sensors (like accelerometers), and communication signals. When engineers design and test devices that use differential signals, simulating the differential signals for testing can be challenging. These challenges are caused by the fact that most function/arbitrary waveform generators (FAWGs) have single-ended outputs; instruments that can generate differential signals tend to be fairly costly. To create a differential signal using a single-ended instrument requires custom hardware to turn the single-ended signal into a differential signal. In this measurement brief, we will explain how to use a two-channel FAWG to produce an accurate differential signal at a low cost.

A maker of electronic monitoring equipment for industrial applications was designing a circuit to monitor vibration and wanted to simulate the output conditions of the vibration sensor to test the circuit. The design team used a balanced differential output accelerometer as a vibration sensor. They fed the differential output of the accelerometer into their prototype input conditioning circuit, which consisted of an instrumentation amplifier, some filtering, and finally, an ADC. To properly set the offset and gain and tune the bandwidth of the design, the team needed to simulate the output of the accelerometer under various vibration scenarios. They collected accelerometer output data with a digitizer, then downloaded the digitized data into a .csv file.

Using a USB stick, they loaded the .csv file data into an Agilent Technologies 33522 two-channel function/arbitrary waveform generator. Using the tracking function on the 33522A, the team created a single differential channel with the 33522A's two single-ended channels.

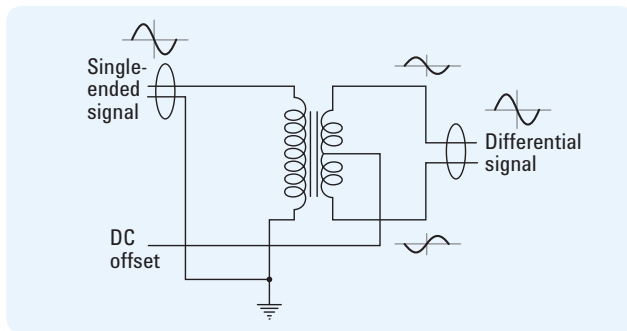
From there, they were able to easily test and tune the input signal conditioning of their vibration monitoring circuit.



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## Turning a single-ended signal into a differential signal

There are two common ways to use custom hardware at the output of a single-ended source to create a differential signal. You can use a differential amplifier circuit design; we will cover this method in more detail shortly. The other method is to use a transformer circuit like the one in **Figure 1**. Using custom hardware to generate differential signals takes additional setup time, adds complexity, and reduces signal quality. The reduced signal quality is a result of the non-ideal nature of the custom hardware. When you generate differential signals to test a device like an ADC or an instrumentation amplifier, the added distortion created by the custom hardware limits the accuracy of the test. Also, it makes establishing test specifications challenging, since you must identify and quantify every source of error in the custom hardware.



**FIGURE 1. Single-ended-to-differential converter**

## Using a two-channel FAWG to create differential signals

FAWG's with two single-ended channels can have the channels combined into a single differential signal channel. To do this, you need to tie together the two "low" or "common" connections of each channel. The "high" of one channel must be used as the high signal path of the differential channel and the "high" of the other channel must be used as the inverse return wire or low signal path. In addition to the two channels, you also need channel tracking capability, which is lacking in most two-channel waveform generators. This feature gives you the ability to create an inverted mirror image of the output signal

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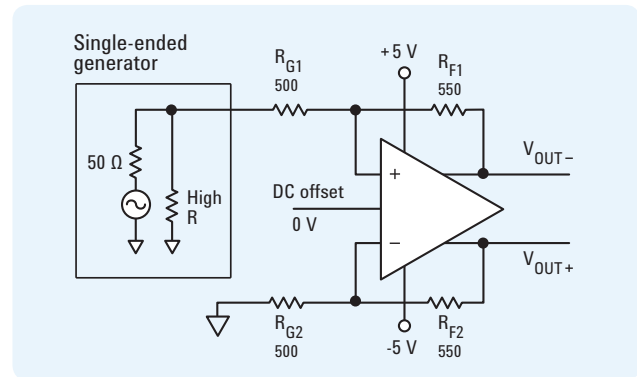
**Using a two channel FAWG** that does not have tracking capability will lead to timing errors between the channel outputs causing increased distortion on your differential signal. Channel settings, such as turning the outputs on or making a frequency change, would have to be done on each channel simultaneously or else the timing and phase between the outputs will be off. To change settings simultaneously typically requires hardware and software triggering adding to the complexity of the setups. Even with triggering added there will still be small timing differences between the channels causing the outputs to drift. To compensate for this drift a scope should be used to monitor timing differences between the outputs so you can make adjustments when necessary. FAWGs that have tracking capability, like the 33522A, eliminate these issues.

from channel one onto channel two, which is exactly what is needed to create a differential signal. Also, this capability means you only have to set up the arb or built-in waveform on one channel and the inverted version of the waveform automatically tracks to the other channel.

The Agilent 33522A two-channel function/arb waveform generator has the tracking feature that allows you to create a differential signal channel using its two single-ended channels. The following section provides example differential signals. One set of differential signals was created using a single-ended FAWG combined with a custom differential amplifier circuit. The other was created using the two-channel 33522A FAWG

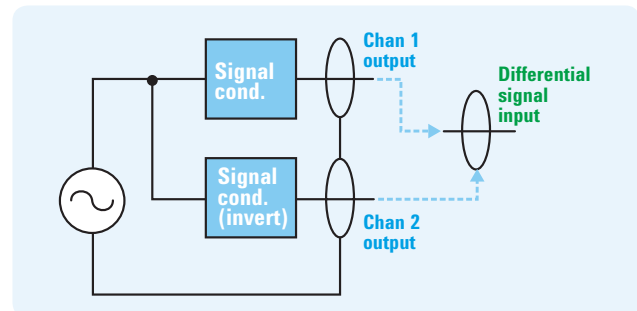
## Two-channel FAWG vs. single-channel FAWG with custom hardware

A high-quality single-ended FAWG was used as the differential amplifier input. **Figure 2** shows a schematic diagram of the setup.



**FIGURE 2. Single-ended generator with differential amp circuit**

In Figure 2, we chose the resistors in the differential circuit to achieve a gain value of 1. We set the DC offset to 0 V. When we built the circuit, we were careful to keep signal paths and wiring as short as possible for better signal integrity. **Figure 3** shows the 33522A setup.



**FIGURE 3. Simplified view of 33522A outputs in tracking mode**

In **Figure 3**, the BNC or low side of each channel is represented by a black circle. The BNCs are connected inside the 33522A. The 33522A is configured for channel 2 to track channel 1, so you need to set up only one signal on channel 1, and the output of channel 2 will be a synced and inverted version of channel 1.

For this example, we measured and captured three signals with a differential input high-resolution digitizer. The example signal we used was a squarewave at 500 KHz. **Figure 4a** shows a digitizer screen shot of the signals. The three signals:

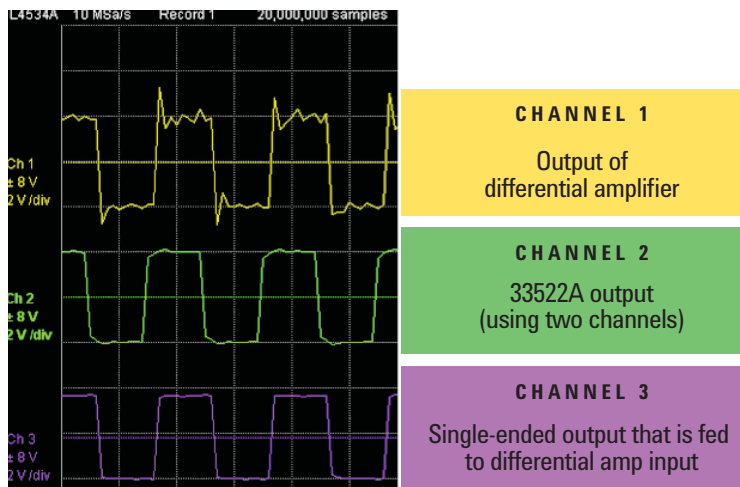
- **Signal in yellow** is a differential signal from the output of the differential amplifier connected to the single-ended FAWG
- **Signal in green** is the differential signal output created by the two channels from the 33522A
- **Signal in purple** is the output of the single-ended FAWG before the differential amplifier input

From the screen shot in Figure 4a, we can easily see the differential amplifier signal output is filled with noise and ringing. We can see the signal input to the differential amplifier (in purple) is not distorted, so we know that the distortion comes from the differential amplifier circuit. The differential amplifier used had a bandwidth of 300 MHz, and we can see that this is not a bandwidth problem since the amplitude is not attenuated. For better signal integrity, a larger ground plane and some

bypass capacitors were added to the differential amplifier circuit in Figure 2. The result of the differential circuit signal integrity improvements can be seen in **Figure 4b**.

As you can see in Figure 4b, when we put more time and engineering effort into the differential amplifier circuit, we were able to eliminate a noticeable amount of noise from the signal, but there still is a great deal of ringing in the signal. Now we could continue to tune the circuit with various analog engineering techniques and circuit components to get better signal quality. But this will take more time and increase circuit complexity; keep in mind that in this example we are just looking at a single waveform at a single frequency. The added engineering complexity for the custom hardware is not going into the design—it simply enables us to perform a small subset of testing for the design.

This example illustrates how you can save time and achieve superior accuracy using a two-channel FAWG with tracking capability instead of a single-channel FAWG with custom hardware.



**FIGURE 4a:**  
*Example signal outputs 1*



**FIGURE 4b:**  
*Example signal outputs 2*

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**Another advantage** of using a two-channel FAWG is when a DC offset is needed in the differential signal. When using custom hardware, to create a DC offset in the signal additional equipment is required such as a power supply or DAC. This is avoided when using a two-channel FAWG with tracking capability since the offset capability is built-in.

## Conclusion

Using a two-channel function/arb waveform generator provides an accurate low-cost method for creating differential analog and digital signals. To create the differential signal using two channels, the high side of one channel serves as the differential high and the high side of the other serves as the differential low. Also, the isolated commons of each channel must be at the same potential. In addition to two parallel channels, the FAWG needs to have channel tracking capability to create the inverted mirror image of one channel on the other channel output, matched in frequency and phase. The 33522A FAWG has the two channels and the tracking capability needed to create accurate differential signals easily. As we saw in the example, using the 33522A lowers complexity and provides more flexibility and better signal quality than using a single-ended instrument with custom hardware.

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Printed in USA, July 1, 2010

5990-5897EN



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