Generating Complex ECG Patterns with an Arbitrary Waveform Generator
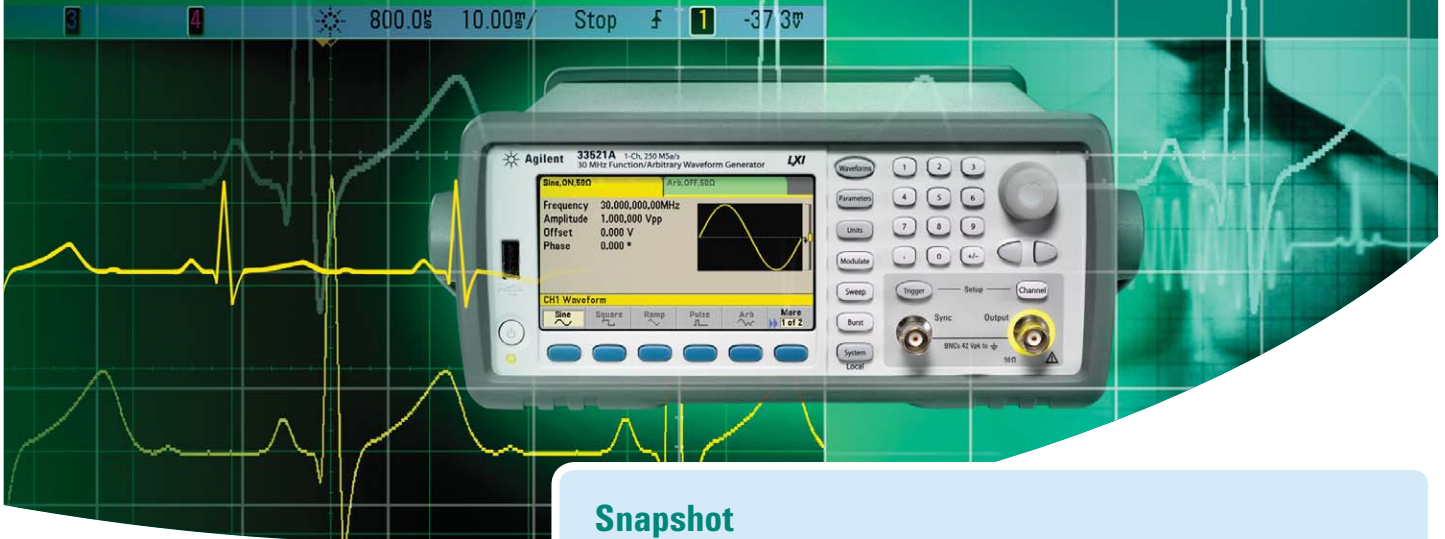
Using an electrocardiogram (ECG) is an invaluable way to identify various physical ailments. To conduct an ECG, medical personnel place leads on a patient's skin and measure the electrical activity of the heart over one beat cycle. The outputs of the leads are combined to create an ECG signal. Variations in the signal amplitude and timing provide indications of various ailments such as myocardial infarction, hypocalcaemia, and emphysema. Today there is a wide array of cardiac equipment that displays and interprets ECG signal patterns. Medical equipment designers need a flexible way to seamlessly generate accurate ECG signal patterns to verify and test their designs. In this measurement brief, we will discuss how to generate complex ECG signal patterns with an arbitrary waveform generator (AWG).

Snapshot

A maker of cardiac monitoring equipment needed to test its latest design's ability to capture and interpret ECG signals. The company's design engineers wanted to simulate gradually changing sequences of normal and abnormal ECG signals to test and tune the design's input signal conditioning hardware and the firmware interpretation algorithms to ensure their design did not produce false positives or life-threatening false negatives. To simulate the ECG signals, the engineers used the Agilent 33521A function/arbitrary waveform generator. They chose the 33521A because of its arbitrary waveform sequencing feature. This feature allowed them to seamlessly switch across various ECG signals stored in arbitrary waveform memory. With this functionality, they were able to simulate the gradual onset of various ECG signal abnormalities without any discontinuities in their test. Also, the 33521A's 1-million-point arbitrary waveform memory allowed them to store a large library of various ECG signals.

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ECG waveform

A typical 12-lead ECG waveform is shown in **Figure 1**.
Key waves and intervals are labeled.
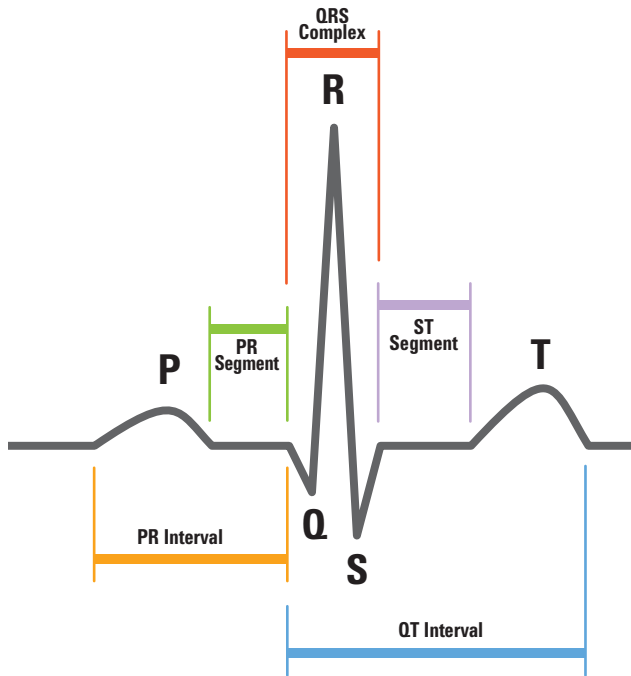
In this measurement brief, we will use the 12-lead ECG waveform as an example to show you how you can use an AWG to create complex cardiac signal patterns. Of course, an AWG can be used to simulate other lead-count ECG waveforms or to simulate a single-lead signal. The purpose here is to show how an AWG can be used to create complex cardiac signal patterns.

ECG waveform

There are three methods to create and store an ECG on an AWG:

1. You can use a device such as a digitizer or oscilloscope to capture an actual ECG signal from a patient. Then you upload the digitized points to the AWG. With modern AWGs, there are many ways to accomplish this, including using a .csv file and a memory stick.

2. You can use mathematical software to create an ECG signal. There may be custom software for the AWG that can do this, or you could use a standard software package, such as MATLAB®.

3. If your instrument has this capability, you can use your AWG's built-in typical ECG waveform. The Agilent 33521A has this capability.

The example ECG waveforms used later in this measurement brief were based on the 33521A's built-in ECG waveform, which is shown in **Figure 2**. An easy way to create a whole library of different ECG waveforms is to combine method 1 and 2 or method 3 and 2 together. You can access and manipulate the points in the built-in ECG waveform (method 3) to create other non-typical or abnormal ECG signals for testing cardiac monitoring equipment. One way to do this on the 33521A is directly on the instrument using the large, front-panel display. Another way is to use a mathematical software tool (method 2). That is how methods 2 and 3 can be combined to create a library of different ECG waveforms, and of course, methods 1 and 2 could be combined in the same manner.
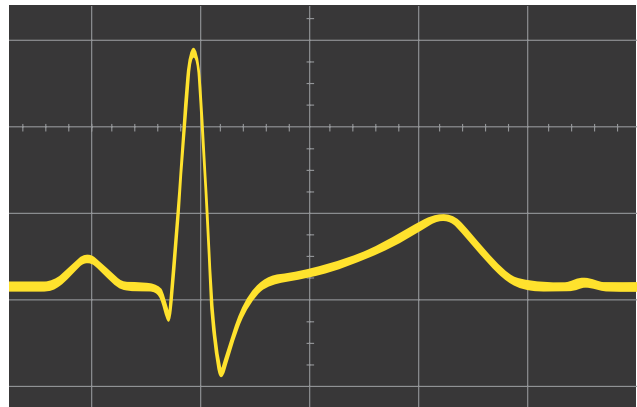
MEASUREMENT TIP

You can download and use an ECG simulator program created in MATLAB®. You can find the ECG simulator download and instructions at

http://www.mathworks.com/matlabcentral/
fileexchange/10858-ecg-simulation-using-matlab

or type "ECG MATLAB" into a search engine and it should be at the top of the results. The program creates ECG waveforms using multiple Fourier series summed together. A Fourier series is used for each distinct wave shape in the ECG waveform, such as the P wave, T wave, etc. The program allows you to adjust various ECG waveform parameters to simulate various cardiac conditions.

Using an AWG's arb sequencing capability to simulate complex ECG patterns

AWGs that have arb sequencing ability, like the 33521A function/arb waveform generator, can seamlessly transition from one arb waveform stored in memory to another without any discontinuities in the output. **Figure 3** shows an example using the 33521A's arb sequencing feature on three different ECG waveforms stored in different places in memory.
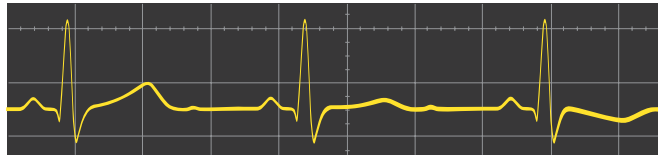
FIGURE 3. *Example ECG waveform sequence*

The first ECG waveform cycle is the 33521A's built-in ECG waveform. The other two were based on the first one but were changed in a systematic way using MATLAB software. Notice the second ECG waveform has a flattened T wave. In the third ECG waveform, the T wave is inverted.

The 33521A's sequencing capability provides flexibility for controlling when it sequences from one waveform to another. One way to control sequencing is to specify how many cycles each waveform is run before sequencing to the next. Sequences can also return to a waveform that was used previously in that sequence.

Combining the 33521A's arb sequencing feature with its large arb memory, 1 million points per channel standard with 16 million optional, gives you the ability to simulate complex ECG patterns for thorough testing of your cardiac monitoring equipment design. For example, the three waveforms shown in Figure 3 each were created with about 500 points. You could store up to 2,000 different ECG waveforms of this size in the 33521A's standard arb memory. The 33521A allows arb sequences to contain up to 512 steps, allowing you to create complex ECG patterns for thorough testing.

MEASUREMENT TIP

You can control arb sequences on the 33521A asynchronously by using triggers to control waveform transitions instead of cycle counts. This provides you with the ability to continuously cycle a waveform for some undetermined time period until it receives a software trigger or external trigger or front-panel trigger. Once it receives the trigger, the 33521A transitions to the next waveform in the sequence. You can also mix the two ways of transitioning through a sequence, specifying a count and using triggers.

MEASUREMENT TIP

Real-world cardiac signals are typically very low in amplitude, often only a couple of millivolts or even less. This poses a problem for simulation using AWGs because typically their lowest amplitude setting is between 10 mV and 1 mV (the 33521A's lowest amplitude is 1 mV), and when they are used at their lowest amplitude, the AWG's signal-to-noise ratio can become a problem. One way to overcome these drawbacks is to use a voltage divider at the output of the AWG. Since ECG signals are at such low frequencies, the divider only needs resistors, as reactive effects can be ignored. When you construct the voltage divider, remember the amplitude accuracy of the divider's output signal is dependent on the precision of the resistors used in the divider. For example, a voltage divider that uses a 10-kohm resistor and a 10-ohm resistor will reduce amplitude of 1 V down to 1 mV, as shown in **Figure 4.**
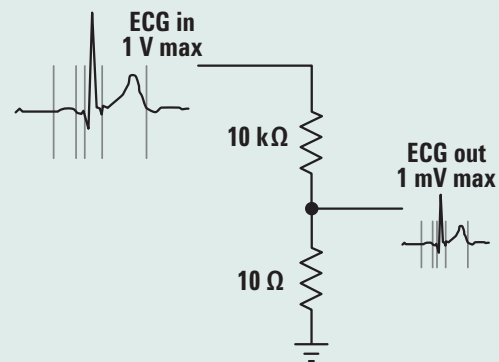
FIGURE 4. *Simple voltage divider*

Conclusion

Human lives are at stake, so thorough testing of cardiac monitoring equipment designs is critical. To ensure your design properly characterizes and interprets various ECG waveform conditions, you need accurate testing simulations of complex ECG signal patterns. AWGs, like the 33521A, that have arb sequencing capability and deep arb memory provide an excellent solution for ECG simulation. The sequencing provides the ability to seamlessly transition through various ECG signal conditions. The deep arb memory complements the sequencing capability by allowing you to store a large library of ECG waveforms. This allows you to add subtle changes from waveform to waveform for high-resolution testing of your design.

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