# Advantages of Using the Direct Digital Synthesis (DDS) Option in Arbitrary Waveform Generators

*The arbitrary waveform generator (AWG) is among the most powerful and flexible signal sources available for electronic testing. AWGs can generate an almost infinite number of waveforms within the generator's bandwidth and the length of its waveform memory. Once you have the AWG you will need to fill it with useful waveforms. Applications support software for AWGs allows waveforms to be created analytically with great precision using equations or captured, using digitizers or digital oscilloscopes, and replayed. The cost of creating, capturing, modifying, and transferring test waveforms can be very expensive so any tool that simplifies the process is very valuable.*

Spectrum Instrumentation has released a direct digital synthesis (DDS) firmware option for its range of 16-bit Arbitrary Waveform Generators (AWGs). DDS is a method for generating periodic waveforms from a single, fixed-frequency reference clock. Spectrum Instrumentation's DDS option for AWGs uses multiple 'DDS cores' to generate a multi-carrier (multi-tone) signal with each carrier having a well-defined frequency, amplitude, and phase. Figure 1 shows the architecture of the DDS signal generation on the M4i.66xx series AWG with up to 1.25 GS/s and 400 MHz signal bandwidth.

The DDS option signal routing allows different connections between available DDS cores and the output channels giving maximum flexibility. On the first released DDS option for the M4i.66xx series this results in 23 DDS cores in total with up to 20 DDS cores being routable to a single channel.
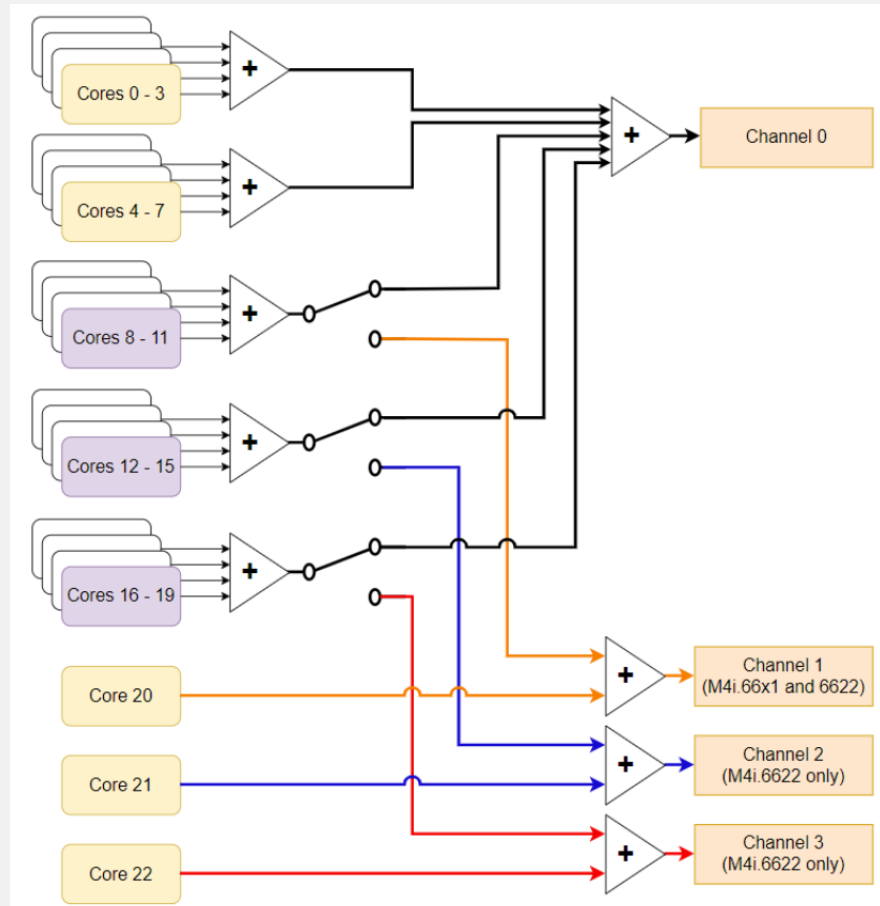


*Figure 1: The DDS option, shown as an example in a four-channel AWG M4i.6622-x8, is implemented by adding multiple DDS Cores to generate multi-carrier (multi-tone) signals to the AWG outputs each with independent control of frequency, amplitude, and phase.*

## Programming sine wave outputs

The DDS option offers a significant advantage in waveform creation. The AWG waveforms must be described on a point-by-point basis. If you have a 1 Mega-sample waveform every voltage value of that waveform must be calculated and stored in the waveform memory. In comparison, the DDS sinewaves are described by simple commands. Figure 2 provides an example of how to generate a 100 MHz sine wave.
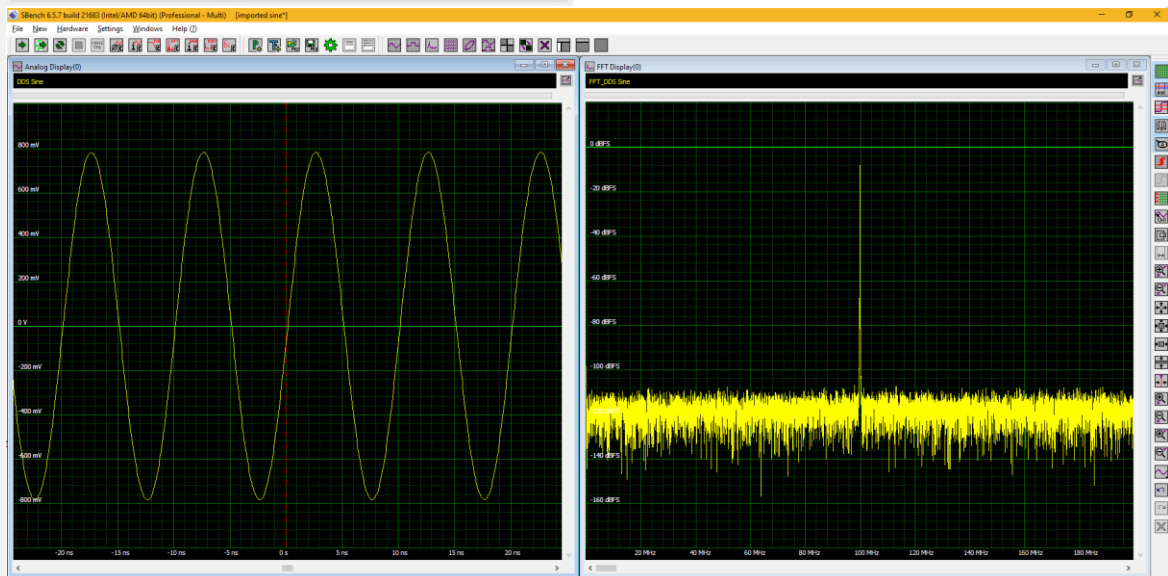


*Figure 2: An example of the C++ commands to create a 100 MHz sine wave using the DDS option.*

These simple text-based source commands, after being compiled, are sent to the DDS firmware in an even more concise form, requiring far less memory than an equivalent AWG waveform. In this example, the sine frequency and amplitude are specified. Commands can be written in Python, C/C++, MATLAB, LabVIEW, and many other programming environments.

The amplitude, frequency, and phase of each carrier can be set. Additionally, linear variations in the sine frequency or amplitude can be specified. As an example, to generate a five MHz radar chirp for a 250 MHz carrier the DDS core commands are:

```
// Chirp, 10µs duration, linear frequency sweep starting at 247.5 MHz to 252.5 MHz
CORE0_FREQ = 247.5 MHz
CORE0_FREQ_SLOPE = 5/10 MHz/µs
CORE0_AMP = 1.0 // 100% Amplitude
TRG_SRC = TIMER
TRG_TIMER = 10µs
CMD = EXEC_AT_TRG
```

The frequency starts at 247.5 MHz and linearly increases to 252.5 MHz over 10 µs. The FFT spectrum of the signals is shown in Figure 3.

Computing this same waveform in the AWG, using equations, requires calculating the voltage values of 12500 samples at 1.25 GHz sampling rate.

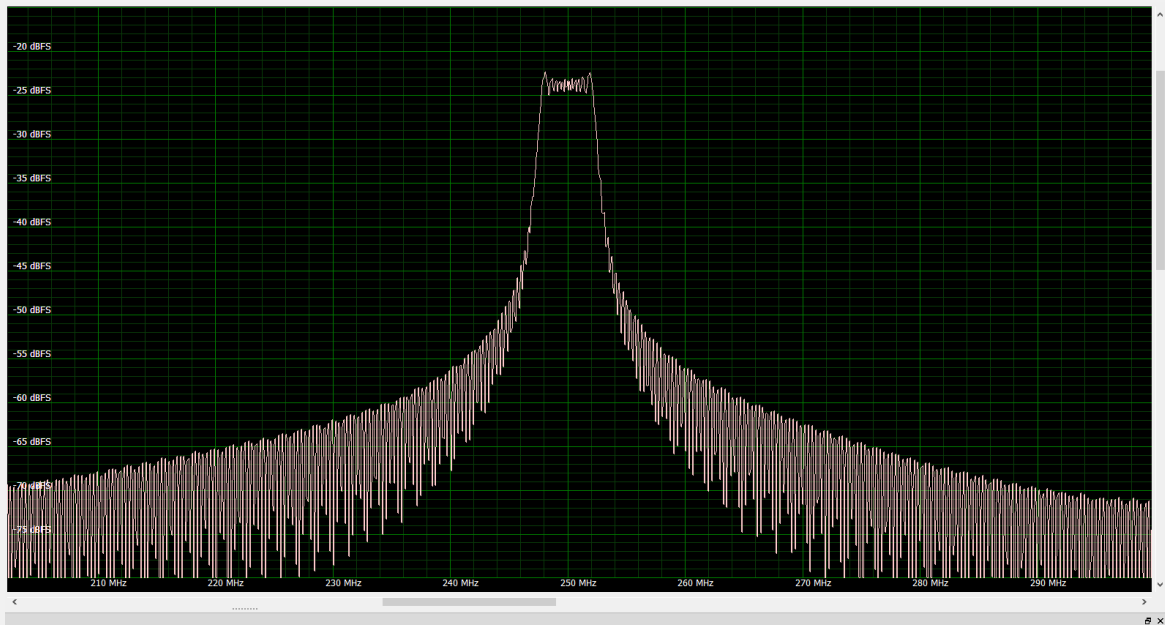## Application Note Using DDS Mode in different Applications



*Figure 3: the FFT spectrum of a radar chirp shows the linear variation of frequency from 247.5 to 252.5 MHz.*

In contrast, the DDS core generates the same signal using just six commands. Furthermore, these commands are sent to the AWG via an optimized driver, that fits each of these into just 64 Bits, or 8 Bytes. This allows to store up to 500 million commands in an AWGs 4 GB on-board memory!

DDS commands are executed synchronously with a user-specified trigger event. Trigger events include those generated in the AWG card's internal trigger logic or, as in this case, the use of an internal timer. Careful design means the DDS output can be synchronized with any external trigger event, or the programmable timer, with a resolution of just 6.4 ns.

Each core can generate its own modulated sine wave. Another radar example is to generate a radar pulse train with a 250 MHz carrier, at a 10 kHz pulse repetition frequency (PRF), and a 10 µs pulse width. The DDS command queue is as follows:

```
// Initial Settings
PHASE_BEHAVIOR = JUMP
CORE0_FREQ = 250 MHz
TRG_SRC = TIMER
for(i = 0; i < pulse_count; i++){

        // Switching on for 10 µs
        CORE0_PHASE = 0 // Start at Phase 0 each Cycle
        CORE0_AMP = 1.0 // 100% Amplitude
        TRG_TIMER = 10µs
        CMD = EXEC_AT_TRG

        // Switching of for 90µs to get 10kHz repetition Rate
        CORE0_AMP = 0
        TRG_TIMER = 90µs
}
```

## ▶ Application Note Using DDS Mode in different Applications

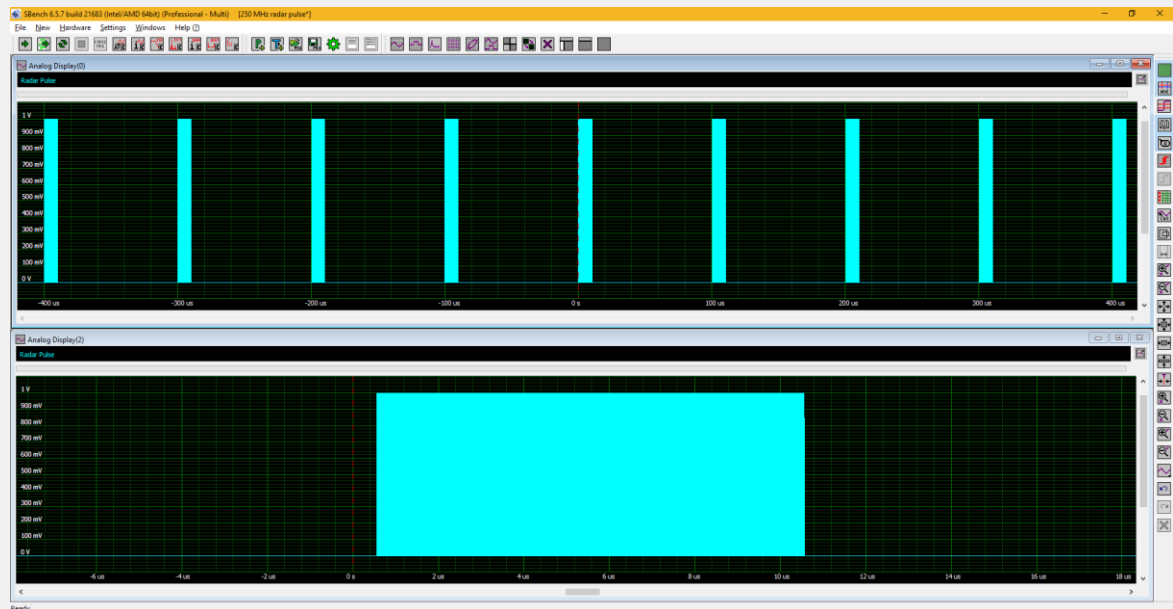The resultant pulse stream is shown in Figure 4:



*Figure 4: A radar pulse with a 250 MHz carrier, 10 kHz PRF, and a 10 μs pulse width, created with the DDS option, shown with horizontal scales of 100 μs (above) and 2 μs (below) per division.*

This shows the ability to gate the sine carrier. Setting the carrier amplitude to zero turns it off. The same technique of setting the amplitude can be used to amplitude modulate the carrier.

## Dual tone waveforms

The DDS option can create multiple summed carriers. The most common usage of multi-carrier waveforms is in intermodulation distortion (IMD) testing. Dual-tone waveforms, sinewaves with different carrier frequencies, are summed and applied to a device. Non-linearities in the device give rise to mixing products at specific frequencies. The output spectrum of the device will contain the original signal frequencies, the sum and difference frequencies, and the intermodulation products, which are multiples of the sum and difference frequencies. The IMD level is the ratio of the power of the intermodulation products to the power of the desired output signal, expressed in decibels (dB). The lower the IMD level, the better the device performance. Figure 5 provides an example of a two-tone test.
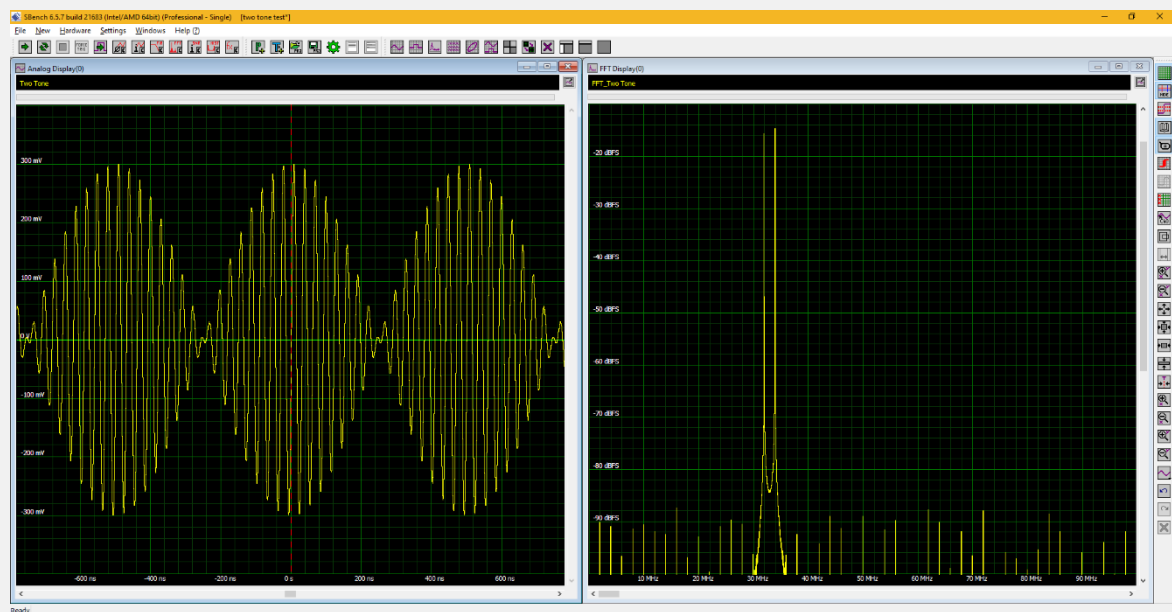


*Figure 5: Dual sinewaves at 32 and 34 MHz are summed for an IMD test. The output spectrum of the device shows the original two frequencies along with harmonic and intermodulation products spaced every two MHz.*

The two tones used are at 32 and 34 MHz. The summed signals, shown on the left periodically interfere and reinforce each other resulting in a beat note. The spectrum shows the two original frequencies and all the mixing and intermodulation products. They are spaced at the 2 MHz difference frequency.

## Multi-tone waveforms

Multi-tone sinewaves can be used for a quick evaluation of an analog-to-digital converter (ADC) performance. The right-hand table shows the frequency and amplitude of the components of a test waveform consisting of fifteen summed sinewaves.

The resultant waveform, viewed on a spectrum analyzer is shown in Figure 6:

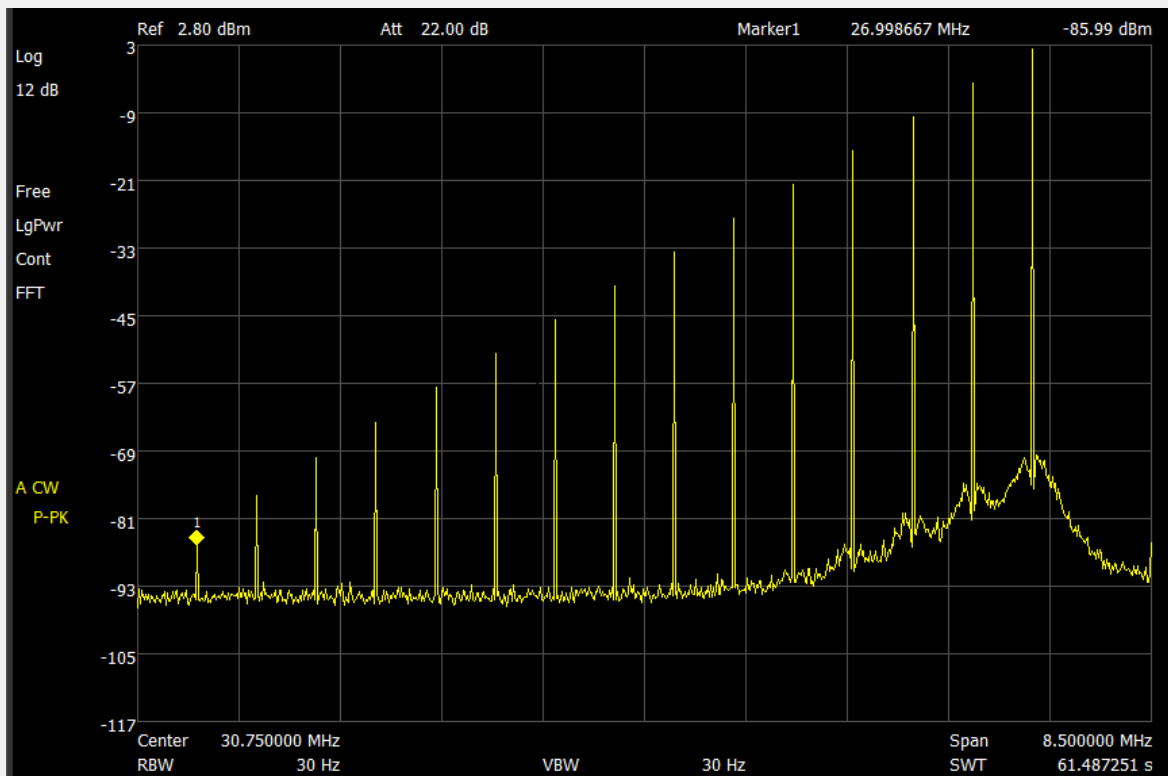| Frequency (MHz) | Amplitude (%) | Relative Amplitude (dB) |
|---|---|---|
| 34.0 | 50 | 0 |
| 33.5 | 25 | -6 |
| 33.0 | 12.5 | -12 |
| 32.5 | 6.25 | -18 |
| 32.0 | 3.125 | -24 |
| 31.5 | 1.562548 | -30 |
| 31.0 | 0.781274 | -36 |
| 30.5 | 0.390637 | -42 |
| 30.0 | 0.195318 | -48 |
| 29.5 | 0.097659 | -54 |
| 29.0 | 0.04830 | -60 |
| 28.5 | 0.024415 | -66 |
| 28.0 | 0.012207 | -72 |
| 27.5 | 0.006104 | -78 |
| 27.0 | 0.003052 | -84 |



*Figure 6: The fifteen-tone waveform viewed on a spectrum analyzer.*

## ▶ Application Note Using DDS Mode in different Applications

The spectrum analyzer shows the linearity of the tone amplitudes.

Applied to a digitizer the resultant display in Figure 7 shows the dynamic range and linearity of the digitizer.
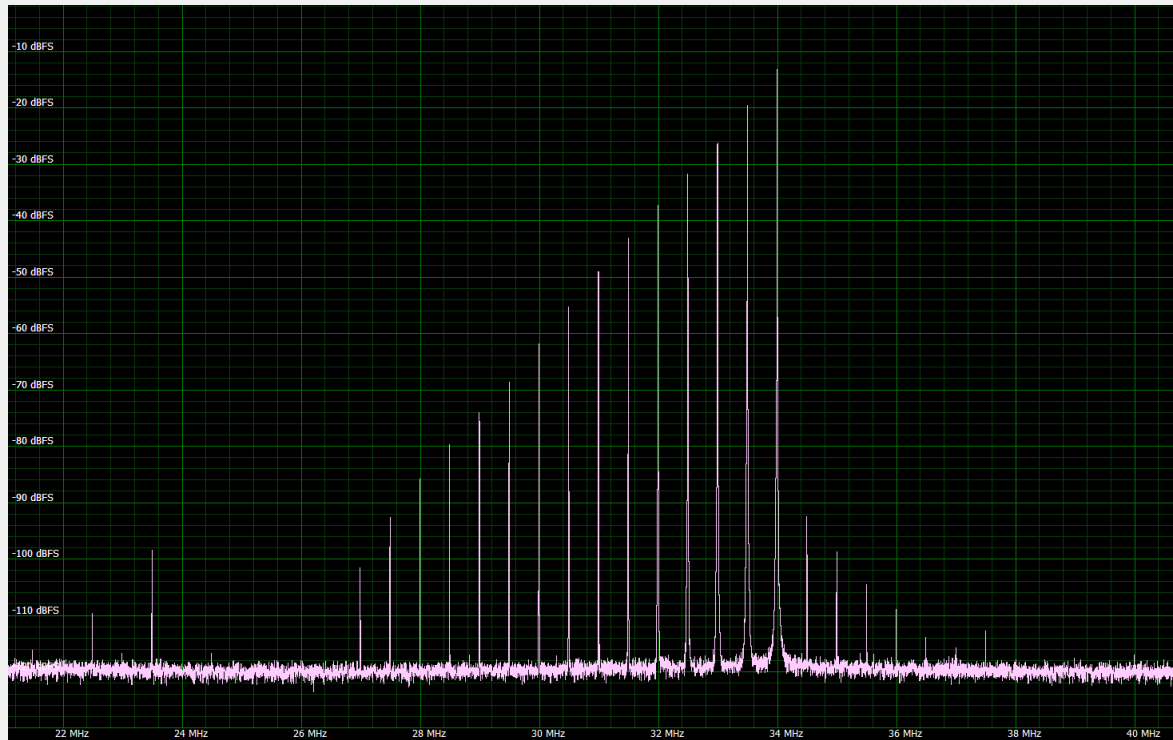


*Figure 7: The response of a digitizer to the fifteen-tone test waveform.*

The digitizer response does an excellent job of reading the tone amplitudes. Some intermodulation components appear with amplitudes well below -90 dB. This simple waveform provides a quick insight into the high quality of the digitizer response.

## Multi-tone multi-output applications

The multi-tone signals described so far are summed and are output through a single channel. It is also possible to output single sinewaves through multiple channels. Applications like driving a phased array system use the amplitude and phase control of individual sinewaves to steer or focus the wavefront of an array of antennas or transducers. Figure 8 provides a simplified view of this functionality.
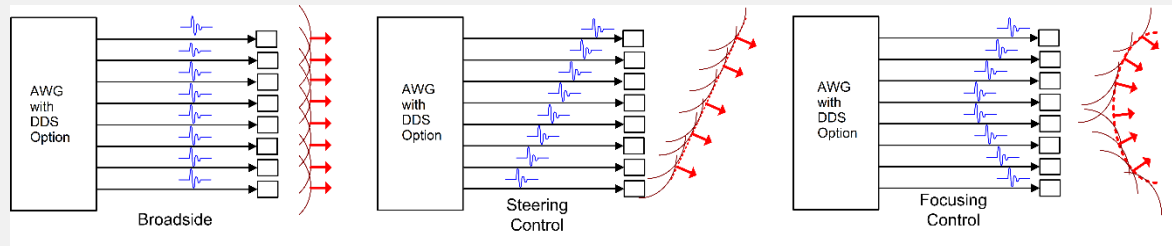


*Figure 8: Controlling the phase and amplitude of individual sources driving an antenna or transducer array permits steering or focusing the emitted wavefront.*

If the waveforms arrive at the emitters with the same phase, then the wavefront has a flat or broadside shape. By phase delaying the waveform linearly across the emitters, the wavefront can be steered. Finally, by phasing the waveforms so that emitters near the center arrive first and outer emitters are driven later the array can be focused.

Figure 9 shows the waveforms for driving an eight-element phased array for a broadside or undirected alignment and for the directed wavefront steered 45 degrees downward.
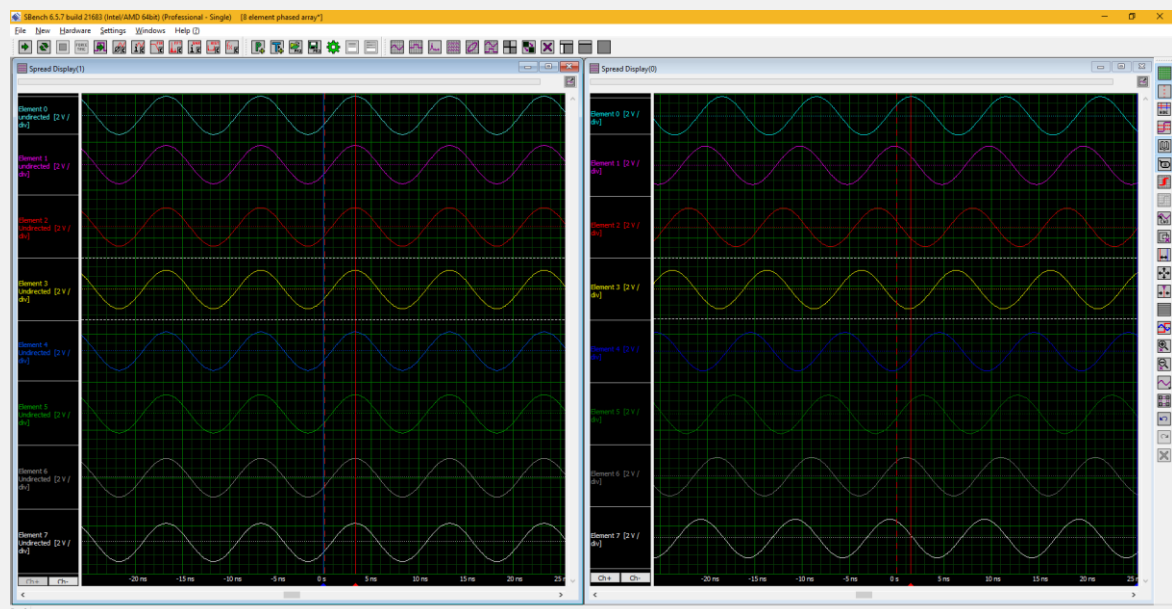


*Figure 9: Comparing the signal phasing for a broadside (left) with a zero-phase shift and a directed (right) alignment with a progressive phase shift for an eight-element phased array.*

The red cursor marks the peak of the third cycle of the element 0 waveform in both instances. All the waveforms in the undirected instance have the same phase and the cursor falls on the third cycle peak of all the element waveforms. The directed waveform element shows the element phase progressively retarded for each successive element.

## ▶ Application Note Using DDS Mode in different Applications

This example uses eight channels, which can be accomplished using two four-channel M4i.6622-x8 AWGs, synchronized with the Star-Hub option. Systems using up to 8 PCIe cards, or with 32 channels, can be built in the same way. If an LXI/Ethernet based instrument is preferred, DN series generator NETBOX units, with up to 24 channels are also available.

## Quadrature modulation

The DDS option also permits the generation of phase-modulated signals. Quadrature modulation is based on phase modulation and is used in data communications systems. Quadrature phase shift keying (QPSK) is a modulation scheme that encodes two bits per transmitted symbol. It is generated by creating two binary phase shift keyed (BPSK) data streams, called the in-phase (I) and quadrature (Q) data streams. The I and Q signals are summed in quadrature to produce the QPSK signal. These signals encode the two binary states with a 180-degree difference. The DDS option can easily produce these waveforms as shown in Figure 10.
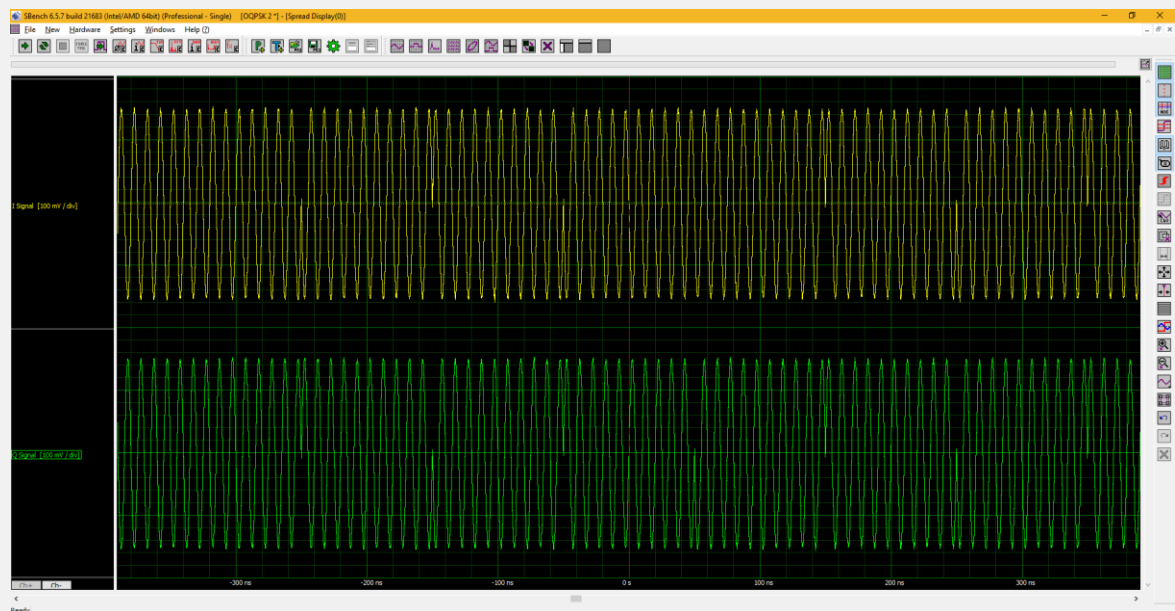


*Figure 10: The I and Q components of a QPSK-encoded signal are combined to produce a signal with four data states.*

```
// I Signal on Channel 0, CORE 0
// Q Signal on Channel 1, CORE 20


PHASE_BEHAVIOR = SHIFT
CORE0_FREQ     = 100 MHz
CORE0_AMP      = 1.0

CORE20_FREQ    = 100 MHz
CORE20_AMP     = 1.0


// 10 MHz Sampling Rate by using the Timer
TRG_SRC        = TIMER
TRG_TIMER      = 0.2µs

bool iq_data[64][2];    // 64 QSPK Symbols with 1 I and 1 Q Bit
                        // n'th I-Bit at Index [n][0], Q-Bit at Index [n][1]
```

▶ **Application Note Using DDS Mode in different Applications**

```
// Fill IQ Data with 128 Bit of a Pseudorandom Binary Sequence
iq_data = generate_PRBS_data(128)

for (i = 0; i < 64; i++)
{
    CORE0_PHASE    = 0°  + iq_data[i][0] * 180°
    CORE20_PHASE   = 90° + iq_data[i][1] * 180°
    CMD            = EXECUTE_AT_TRIG
}
```

The two BPSK signals, each of which have only two binary states, are combined in the modulator to form a four-state QPSK signal. This example phase modulates a 100 MHz carrier at a 5 MHz symbol rate with plus and minus 180-degree phase shifts corresponding to the transmitted 1 and 0 states of the binary data.

## Conclusion

The Spectrum Instrumentation DDS option for AWGs increases the versatility of AWG products by adding multiple sinewave outputs, that are simple to generate and control, to the AWG capabilities. The simple text-based commands of the DDS option control the amplitude, frequency, and phase of the sinewaves and replace more voluminous sample value-based AWG waveforms for sinewaves for more responsive control.

The DDS option can be applied in applications that use fast frequency switching, fine frequency, phase, and amplitude control including communications, medical, imaging, and industrial systems.