

Optimizing Arduino and the AD9851 DDS signal generator

Steve Sandler - February 10, 2016

Arduino has taken the product “maker” world by storm and one of the more popular Arduino modules is the Analog Devices [AD9851](#) DDS waveform generator. An Internet Web search for “Arduino DDS” showed more than 100,000 results, while the same video search turned up many dozens of videos. Internet forums are filled with discussions related to two specific issues. One issue is that the output amplitude is not constant with frequency, requiring a level control loop. The second issue is that the distortion gets pretty horrific, particularly at higher output frequency settings. In this article, we’ll show how to correct these issues, as well as providing some additional tips for improving the quality of the output.

DDS basics

While this article concentrates on the AD9851 device, Analog Devices produces many others that operate in a similar fashion. The devices combine a clock reference with a digital divider and a phase locked loop to provide a sinewave output with very fine resolution. In the case of the AD9851, the digital divider is 32 bits and the clock frequency is typically 125 MHz. This results in a frequency resolution of approximately 30 milli-Hz. A single resistor, Rset controls the current output level and therefore the output voltage level.

The digital nature of the DDS process results in an output signal and many signal images. The images follow a $\sin(x)/x$ envelope. This envelope is shown in the Analog Devices website and is shown in **Figure 1**.

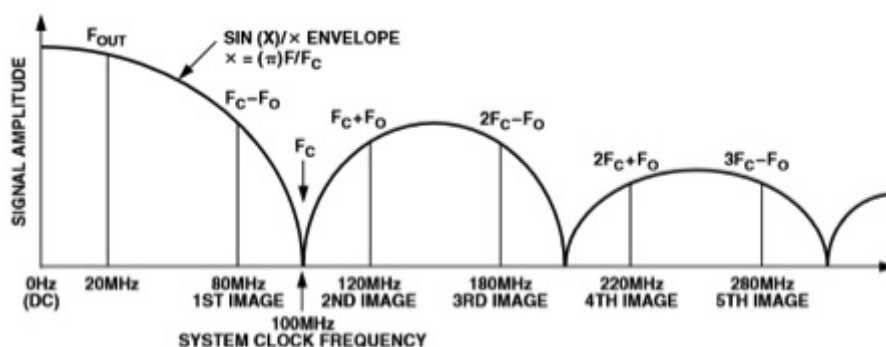


Figure 1 Sin(x)/x envelope from the AD9851 datasheet.

From this **figure** it is easy to see that as the output frequency increases the first system image and the output frequency move closer together, while at the same time the amplitude of the image increases. The AD9851 DDS board is shown connected to an Arduino in **Figure 2**. The Arduino is used to set the DDS output frequency. A DC block, the Picotest J2130A (shown in the figure, www.picotest.com) or the P2130A 500Hz - 8GHz Blocker, is used to connect the DDS output to a

50Ω oscilloscope port to view the spectral response. The unfiltered AD9851 output is measured so that we can see the digital spectrum rather than the filtered output.

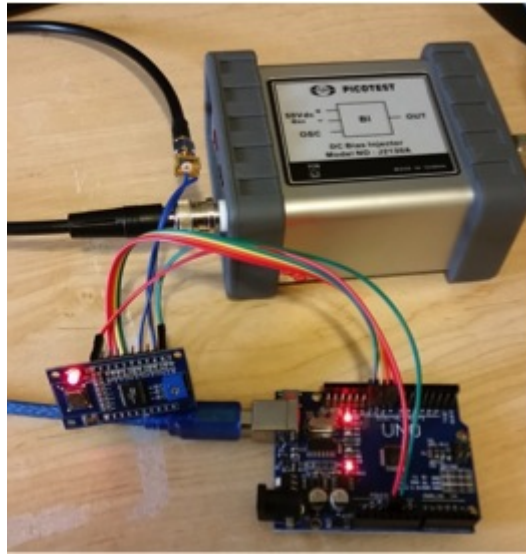


Figure 2 A popular AD9851 DDS module from Ebay is shown connected to an Arduino UNO via the Picotest J2130A DC blocker. The Arduino is used to set the output frequency of the AD9851.

The output frequency is set to 3 MHz and the unfiltered output spectrum is shown in **Figure 3**. As expected we can see the 3 MHz fundamental as well as the first and second images at 122 MHz and 128 MHz, respectively. The clock feedthrough is also visible in this measurement at 125 MHz. The images are far from the 3 MHz fundamental making them simple to filter using a low pass filter.

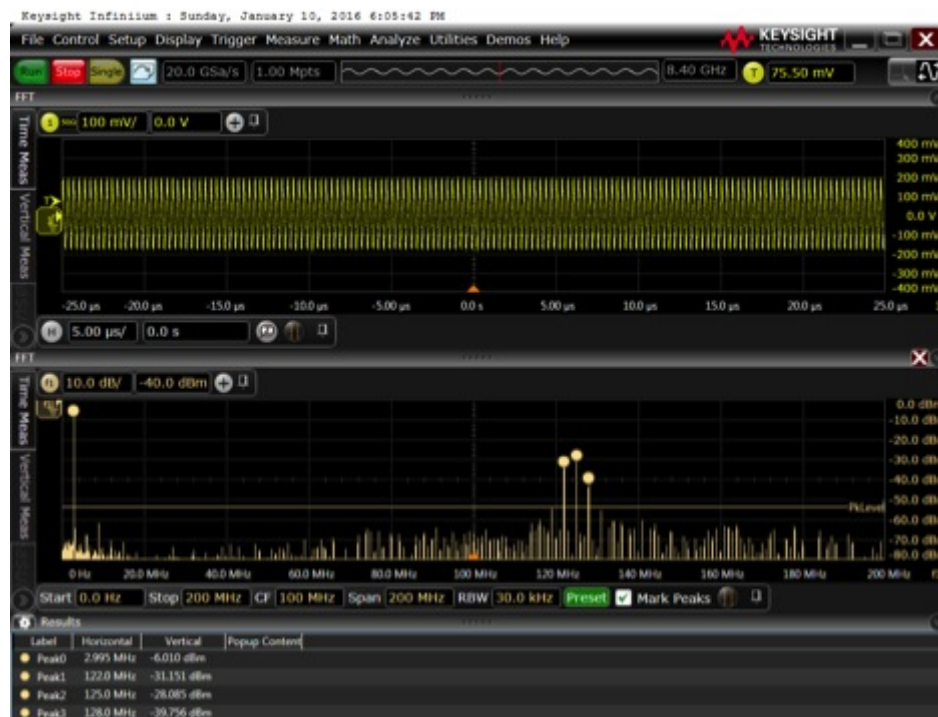


Figure 3 The DDS unfiltered output spectrum with a 3 MHz output frequency.

The output frequency is set to 50 MHz and the unfiltered output spectrum is shown in **Figure 4**. Now we can see the first and second images appear at 75 MHz and 175 MHz respectively, as expected. The first image amplitude is only 2.5 dB lower than the fundamental and also less than an octave from the fundamental, making it difficult to filter.



Figure 4 The DDS unfiltered output spectrum with a 50 MHz output frequency.

Further increasing the frequency to 60 MHz the unfiltered output spectrum is shown in **Figure 5**. Now we can see the first and second images appear at 65 MHz and 185 MHz respectively, again as expected. Now the first image amplitude is only 0.5 dB lower than the fundamental and very close to the fundamental, making it even more difficult to filter.

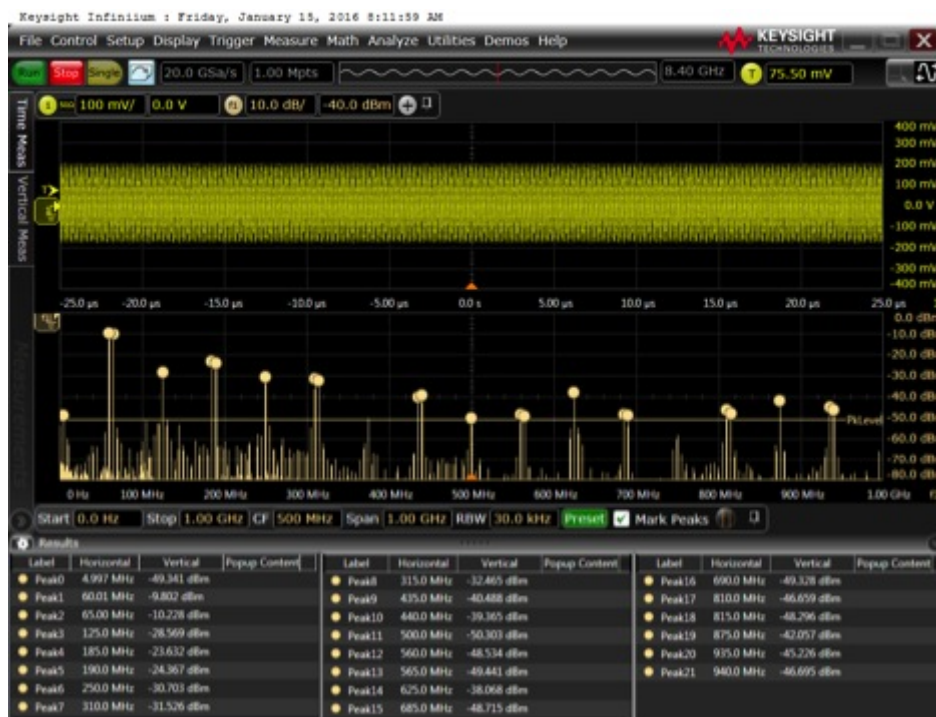


Figure 5 The DDS unfiltered output spectrum with a 60 MHz output frequency.

The output filter
The output filter

The Analog Devices evaluation board and the Ebay board both use the same 7th order elliptical output filter design. The filter is published in the datasheet and is shown in **Figure 6**.

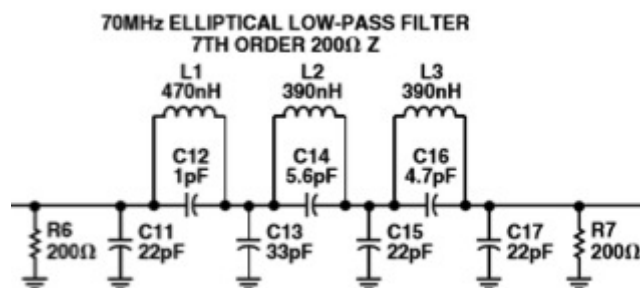


Figure 6 70 MHz elliptical filter used in Ebay board and shown in the Analog Devices datasheet.

While the elliptical filter is sharp, the 70 MHz filter cutoff is too high for the 125 MHz clock, resulting in poor image rejection at 50 MHz, as seen in **Figure 7**.

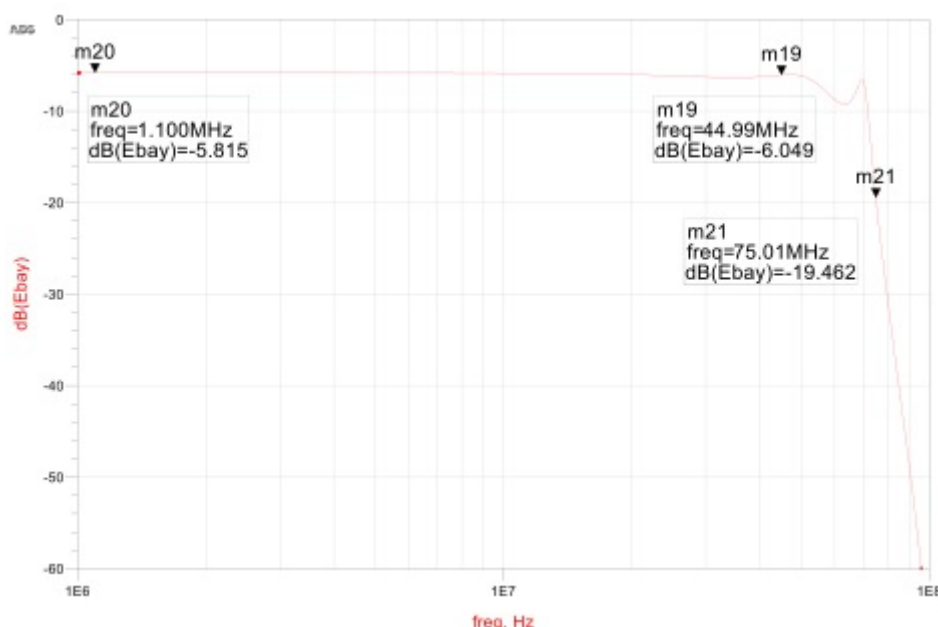


Figure 7 ADS simulation of the 70 MHz filter shown in Figure 6.

A Chebyshev low pass filter with a 65 MHz trap is shown in **Figure 8**. The filter is designed to mate directly with a 50 Ω load, though with a reduced amplitude. The sharp trap significantly reduces the images at higher output frequencies, while also using fewer components.

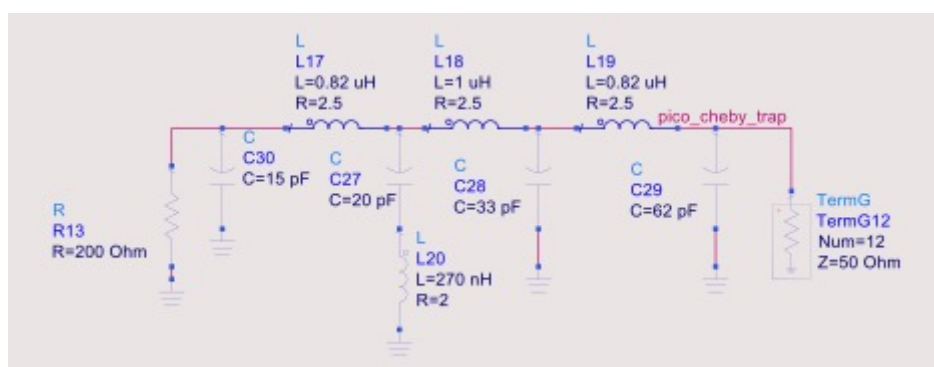


Figure 8 Reduced component count Chebyshev low pass filter incorporating a 65 MHz trap.

The improved filter provides nearly 50 dB better image rejection at 50 MHz. The amplitude can be restored to the prior level using the Rset amplitude adjustment resistor. A comparison between the 70 MHz elliptical filter and the improved Chebyshev low pass filter incorporating a trap is shown in **Figure 9**.

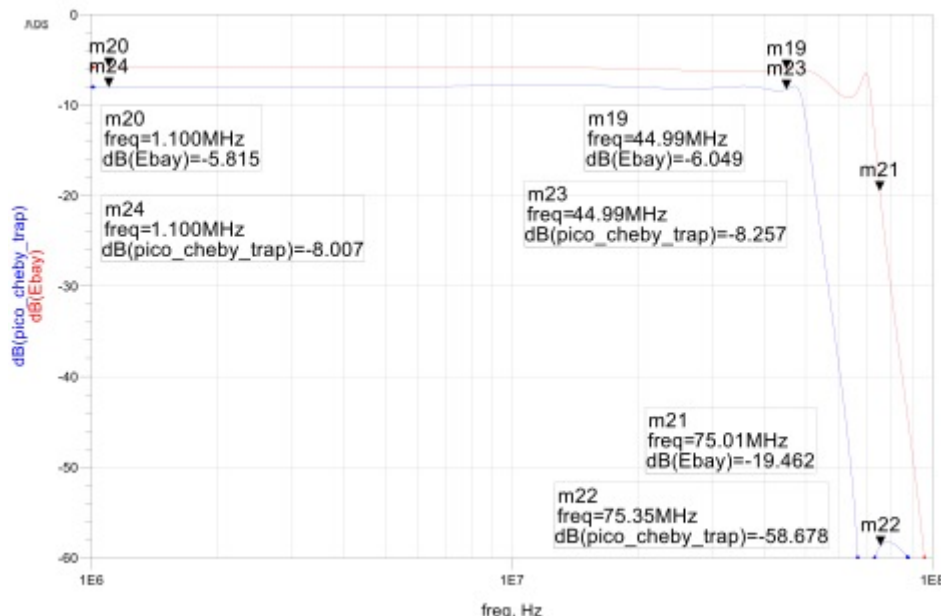


Figure 9 Comparison between the 70 MHz elliptical filter and the improved Chebyshev low pass filter. The Chebyshev filter is designed to be -3 dB at approximately 50 MHz.

The signal amplitude is reduced a bit using the Chebyshev filter due to the $50\ \Omega$ output loading. While the amplitude can be adjusted by reducing the value of the Rset resistor doing so will significantly increase both the odd and even low order harmonics of the output waveform. The spectral content of the filtered output is shown for both filters in **Figure 10**.

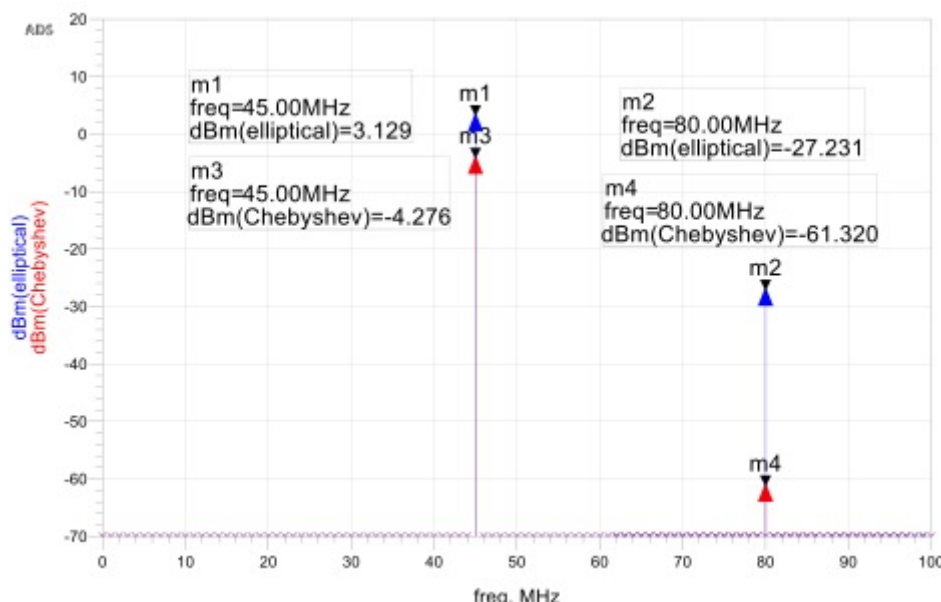


Figure 10 With a 45 MHz output signal the elliptical filter indicates an image only -24 dBc for the elliptical filter while the reduced component low pass Chebyshev filter results in nearly -65 dBc improving the performance by 40 dB while also improving the amplitude flatness and reducing component count.

The filter was assembled on a PCB board, shown in **Figure 11**. The filter was connected

differentially across the two AD9851 outputs and connected to a 50 Ω oscilloscope using a wide bandwidth DC block. The DC block eliminates the 50 Ω DC loading on the AD9851.

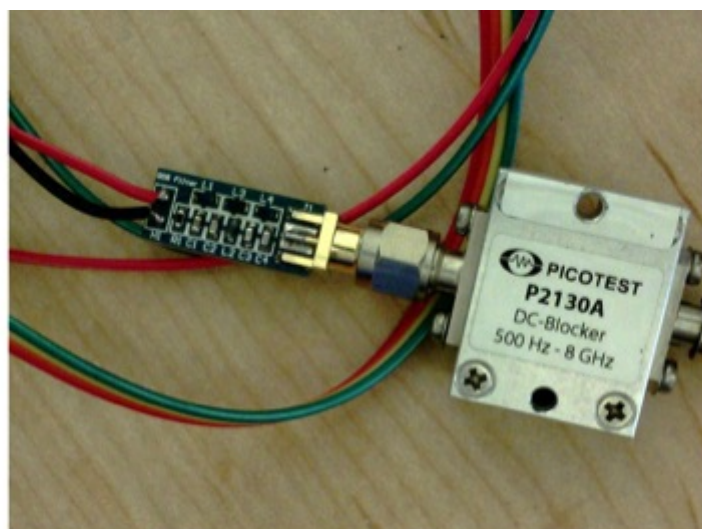


Figure 11 The reduced component count Chebyshev filter was constructed on a PCB and connected to a 50 Ω oscilloscope input using the Picotest P2130A (500Hz - 8GHz) DC block.

The 40 MHz time domain response shown in **Figure 12** is clean, even at high frequency output owing to the filter trap. The amplitude roll-off is very sharp above 47 MHz.

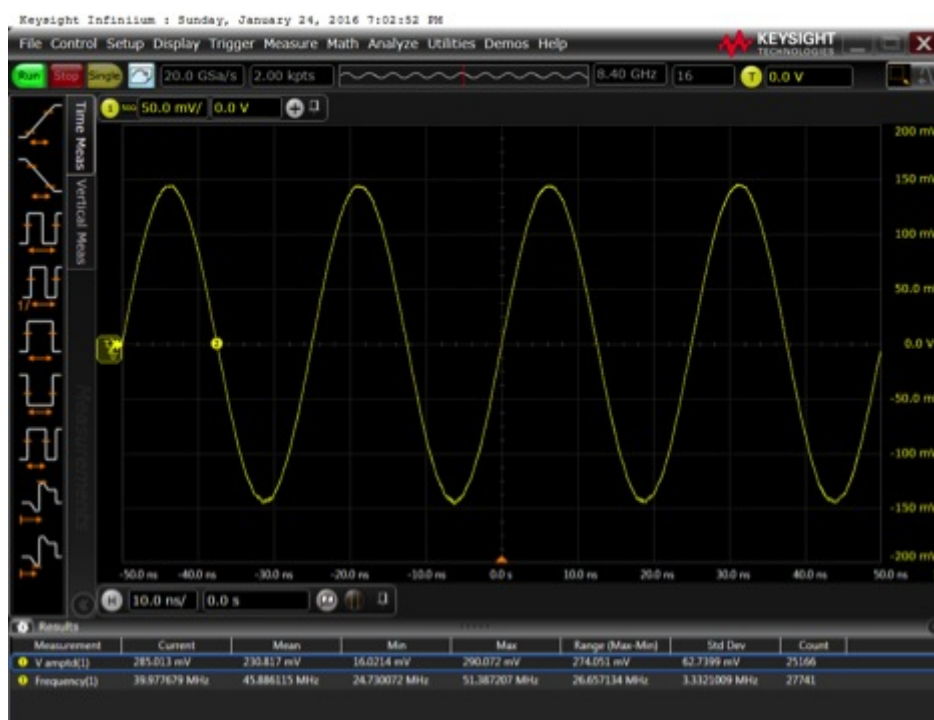


Figure 12 The 40 MHz time domain response shows a clean output and not quite –3dB from the low frequency output. The amplitude roll-off is very sharp about 47MHz.

Figure 13 shows the spectral content for a 45 MHz output, where the images would be most severe. The first signal images are below –60 dBc. The residual 125 MHz clock and the clock harmonics are the largest spurs. The spurs are all below about –47 dBc up to 500 MHz.



Figure 13 The first signal images are below -60 dBc. The residual 125 MHz clock and the clock harmonics are the largest spurs. The spurs are all below about -47 dBc up to 500 MHz.

Conclusion

A Keysight ADS harmonic balance simulation model was used to improve the performance of the AD9851 DDS waveform generator while also reducing the output filter component count. A Chebyshev low pass filter, incorporating a 65 MHz trap was designed for a $50\ \Omega$ output, taken differentially across the two AD9851 outputs. The filter was designed to provide optimum gain flatness while improving the first signal image by nearly 40 dB at 45 MHz. The output measured -3 dB at approximately 46 MHz, very close to the 50 MHz design goal, with the error likely being due to the chip inductor tolerances. The spectral content could likely be further improved by reducing the signal level via Rset. The $50\ \Omega$ output simplifies wideband connections using coax cable and is also compatible with additional RF amplifiers and filters.

The DDS waveform generator can also be used in narrow band applications using a bandpass filter. The output signal can also be obtained from signal images rather than the fundamental signal, allowing operation well above the 125 MHz clock frequency. Perhaps we'll look at these applications in a future article.

Also see:

- [A cheap DDS signal generator](#)
- [DDS and converter form signal generator](#)
- [Arduino: embedded engineering for all](#)
- [Intuitive sampling theory](#)
- [DDS design](#)
- [*duino meets chipmakers: What's all this then?](#)

