

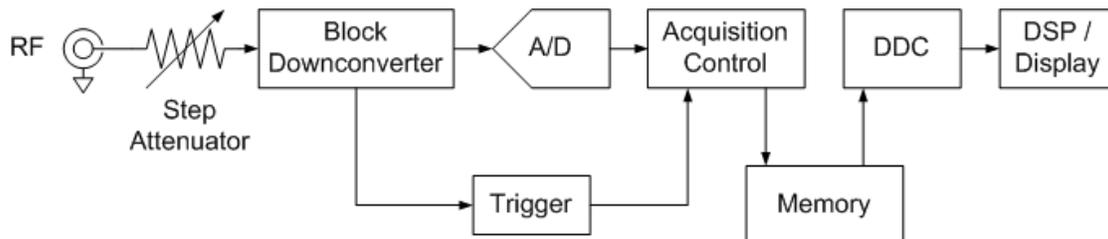
The Secrets Behind the MDO4000C Series Spectrum Analyzer Performance

Learn how:

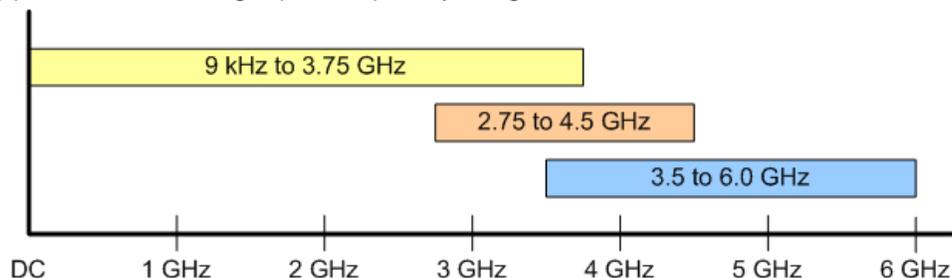
- The MDO4000C Series leverage oscilloscope acquisition technology to achieve better spectral fidelity than entry-level spectrum analyzers.
- The design techniques used in the MDO4000C Series allow them to achieve spectral fidelity far in excess of that provided by the typical FFT feature found in other oscilloscopes.

Block Diagram

In order to understand the topics discussed below, it is important to have a basic understanding of the acquisition architecture of the spectrum analyzer in the MDO4000C. A simplified block diagram is presented below:



At the core of the MDO is the same Tektronix-proprietary A/D converter used in most Tektronix oscilloscopes. This 8-bit A/D converter samples at 10 GS/s and has an input bandwidth in excess of 5 GHz. In order to extend the input frequency response in the 6 GHz MDO models, a downconverter is used before the A/D. This downconverter supports the following input frequency ranges:



After data is acquired to memory, a combination of hardware and software techniques are used to do a digital downconversion (DDC) to greatly enhance signal fidelity. Further spectral processing, using a Discrete Fourier Transform (DFT) allows the display of spectral data.

This is essentially the same architecture used by modern spectrum analyzers. The main differences are:

- A significantly higher sample rate and, therefore, capture bandwidth
- A small number of fixed downconversion ranges

The remainder of this document discusses the various techniques that have been used to improve spectral fidelity throughout the signal path.

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A Dedicated, Integrated Spectrum Analyzer Provides Better Fidelity

Because the spectrum analyzer is dedicated to RF measurements, the design of the signal input is optimized for improved spectral fidelity. Improvements include:

- The BNC is replaced by a higher fidelity N connector and better interconnect to the circuit board.
- Unlike a typical oscilloscope input, the spectrum analyzer input does not need to pass DC signals, nor does it need to provide offset capabilities. This allows the use of attenuator and amplifier components that are optimized for use in spectral applications.
- Significantly improved shielding is provided.

Processing Gain Provides Improved Sensitivity

There might appear to be an inconsistency between the use of an 8-bit A/D converter and the desire to view signal details that can be more than 100dB below full scale. This inconsistency stems from the formula that relates A/D resolution to Signal to Noise Ratio (SNR):

$$SNR = 6.02N + 1.76dB$$

Where N is the number of bits of resolution. For an 8-bit A/D converter, the noise floor is, at best, about 50dB below full scale. This would seem to eliminate any possibility of viewing signals below this level.

The important thing to understand is that the noise predicted by this equation is broadband and typically spread uniformly across the bandwidth of the A/D converter. By using a combination of DDC and DFT to reduce the bandwidth of the data that is actually processed and displayed, the noise floor is lowered, allowing visibility of small signals. This effect is called *Process Gain*¹, and improves the SNR as follows:

$$Process\ Gain = 10 \log_{10} \frac{fs}{2 * RBW}$$

Where fs is the sample rate and RBW is the resolution bandwidth of the DFT. As an example, for a 10 MHz span and an RBW of 10 kHz (given the MDO4000C sample rate of 10 GS/s), this improves SNR by roughly 57dB, to about 107dB².

It is interesting to note that with an A/D sampling at 20 MS/s, which is typical for an entry level spectrum analyzer, it would require at least 12.5 bits of resolution to achieve this same SNR performance.

Recall that the Displayed Average Noise Level (DANL) specification for a spectrum analyzer is given in units of dBm/Hz. This is because the system noise is broadband. The level of noise seen at a particular setting is determined by the RBW setting. This phenomenon is demonstrated on a typical spectrum analyzer when the noise floor is reduced by 10dB for every 10X reduction in the RBW. Process gain is simply a manifestation of this phenomenon.

¹ Suggested reading for more information: Analog Devices MT-001 Tutorial; www.analog.com

² Other noise sources cause the MDO4000C to fall short of this theoretical performance, see data sheet for details.

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Another important point in understanding noise performance is that, in a typical spectrum analyzer (using a 14 or 16-bit A/D), the downconverter noise output is well above the A/D noise floor. This is due to the high gain between the mixer and the A/D converter. The high gain is required because the downconverter mixer input level has to be kept low in order to keep its distortion below that of the high resolution A/D. In the MDO4000C, the input level of the downconverter can be higher because its distortion only has to be kept below that of the 8-bit A/D. In this case, the noise floor is much closer to the A/D converter itself. The net result is that the DANL specification for the MDO4000C is very similar to a typical spectrum analyzer.

Dither Provides Improved SFDR

There also appears to be an inconsistency between the use of an 8-bit A/D and the desire for high Spurious Free Dynamic Range (SFDR) needed for spectral measurements.

In an A/D converter, Differential Nonlinearity (DNL) errors show up as spurs in the frequency domain³. Lower resolution A/D converters generally have higher DNL errors, resulting in a correspondingly lower SFDR.

In a typical A/D converter, the DNL errors are not uniformly distributed but, rather, affect only a subset of the A/D codes. Because of this, dither can be used to significantly reduce DNL errors and improve SFDR. Dither is a random signal that is added to the input signal to smear its energy across multiple A/D codes, effectively averaging the individual DNL errors across all the codes.

The result of adding dither is that the spurs, caused by DNL errors, are pushed closer to the noise floor.

In the MDO4000C, dither is added above the cutoff of the 3.75 GHz IF filter, but below the 5 GHz Nyquist frequency for the A/D. The added dither signal is outside the span of interest and is filtered out during the downconversion process.

As an aside, the MDO4000C specification for residual spurious response is limited by a spur at 2.5 GHz. This spur is caused by gain and offset mismatch between the four 2.5 GHz quadrants that make up the 10 GS/s A/D and, as such, is not impacted by the addition of dither. It is important to note that this spur is fixed in frequency and is located above the 2.4 GHz ISM band most commonly used for low-cost radio and wireless communications. Dither improves the SFDR performance at all other frequencies.

³ Suggested reading for more information: Analog Devices AN-410 Application Note; www.analog.com

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Summary

While using oscilloscope technology to build a high-fidelity spectrum analyzer is a significant break from tradition, there are techniques that allow it to be done effectively. These techniques include:

- The use of a dedicated spectrum analyzer input to improve fidelity
- The use of DDC and DFT techniques to leverage process gain for improved sensitivity
- The use of dither to improve SFDR

By using these techniques, the MDO4000C achieves the fidelity needed to make spectral measurements, while reaping the benefits that oscilloscope technology provide. These benefits include:

- Wide capture bandwidth of at least 1 GHz at any center frequency and up to 3.75 GHz in specific instances.
- The ability to view RF time domain data beyond the typical zero span provided by a spectrum analyzer.
- Time correlation with analog and digital channels

For a more in-depth understanding of the capabilities and architecture of the MDO4000C Series products, refer to the *Fundamentals of the MDO4000C Series Mixed Domain Oscilloscope*, available at: www.tektronix.com/mdo4000.

MDO4000 Series Mixed Domain Oscilloscope

The world's first oscilloscope with a built-in spectrum analyzer.

For the first time ever;

- You can capture time-correlated analog, digital and RF signals for a complete system view of your device.
- See both the time and frequency domain in a single glance.
- View the RF spectrum at any point in the time to see how it changes with time or device state.
- Solve the most complicated design issues, quickly and efficiently, with an oscilloscope as integrated as your design.

Transforming the way you test. Only from Tektronix.

Learn more: www.tektronix.com/mdo4000b

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