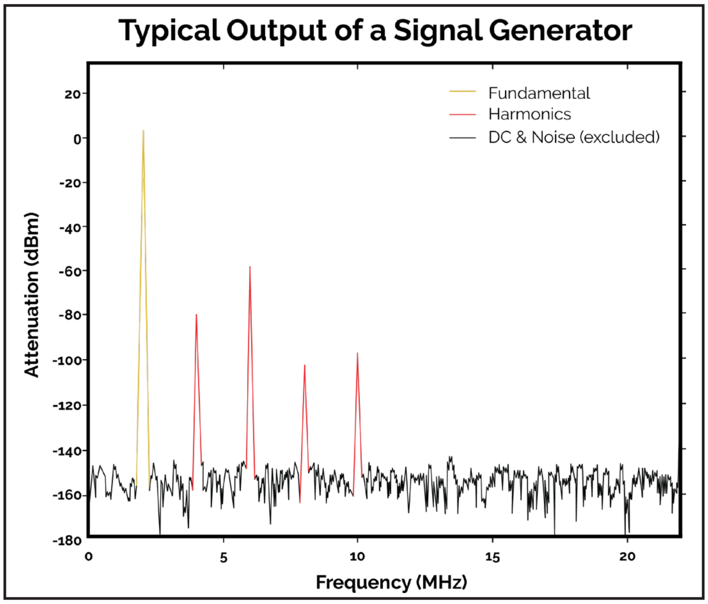
The Benefits of Low THD Filters for ADC/DAC Testing

Gowanda Components Group provides high quality microwave and RF passive filters with improved Total Harmonic Distortion (THD) characteristics. This improvement (lowering of THD) is achieved by using unique component structures along with high Q inductors and capacitors. GCG's low distortion lowpass, highpass, bandpass and band rejection filters are utilized in industry to clean signal sources or test generators by removing the harmonics of the test signal that otherwise would interfere with test results. This document reviews the basics of harmonic distortion and the benefits provided by low THD filters when used in conjunction with Analog to Digital Conversion and Digital to Analog Conversion (ADC/DAC) testing.

Total Harmonic Distortion Defined

In order to understand Total Harmonic Distortion it is best to first understand a harmonic and the fundamental frequency. A harmonic is any member of a repeating signal such as a sinusoidal wave. Harmonics are described as a positive integer multiple of the original wave. This means that the original wave is considered the fundamental frequency (sometimes referred to as the 1st harmonic). Subsequent waves are known as higher harmonics. For example, if the original frequency is 50MHz, this would be the fundamental frequency or 1st harmonic. The first three harmonics after that are 100MHz (2nd harmonic), 150MHz (3rd harmonic), and 200MHz (4th harmonic). Subsequent harmonics will occur in similar 50MHz intervals.

The frequency supplied by a signal generator will be the fundamental frequency. The harmonic distortion from that signal generator is a level of output signal in the higher value harmonics that is greater than the floor of the spectrum analyzer. The power levels of the individual harmonic values are usually expressed in decibel format. There are two units that can be used: dBc, which is relative to the fundamental carrier power level, or dBm, which is absolute power. The simplest measurement unit for harmonic measurement is dBm. See typical output of a signal generator to the right.



The Total Harmonic Distortion can then be calculated by taking the root sum of the squares of the first five or six harmonics for the fundamental frequency. There is a negligible error in most situations when only the second and third harmonics are included, but only if the higher harmonics are three to five times smaller than the largest harmonic. The following equations are utilized to calculate THD.

Equations for THD Calculation:

$$\text{THD (\%)} = 100 \times \sqrt{\frac{P_2 + P_3 + P_4 + \ldots + P_n}{P_1}}\text{, where } P_n \text{ is in Watts}$$

$$\text{THD (\%)} = 100 \times \sqrt{\frac{V_2^2 + V_3^2 + V_4^2 + \ldots + V_n^2}{V_1}}\text{, where } V_n \text{ is in RMS Voltage}$$

$$\text{THD (-dB)} = 20 \log \sqrt{[10^{(2nd\ Har/20)}]^2 + [10^{(3rd\ Har/20)}]^2 + \ldots + [10^{(nth\ Har/20)}]^2}\text{, where Har is in -dB}$$

$$P(W) = 0.001 \times 10^{P/10}\text{, where P is in dBm}$$

$$V_{RMS} = \frac{V_{pk}}{\sqrt{2}}\text{, to convert peak voltage to RMS voltage}$$

In the equations above, "n" is the harmonic number. If n = 1 then that is the fundamental frequency of the test signal applied.

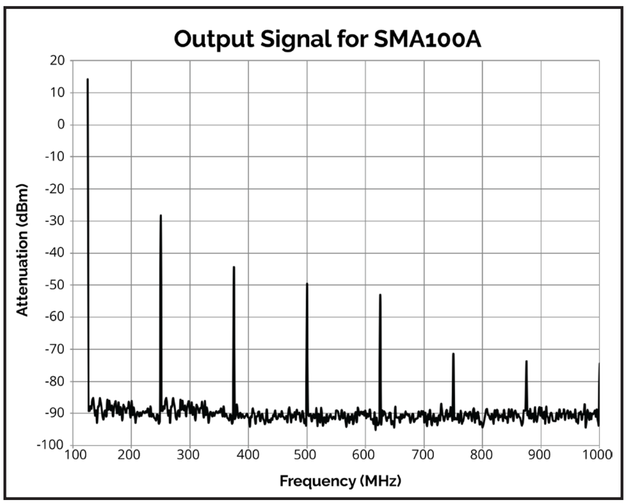
Benefits of Low THD Filters for ADC/DAC Testing

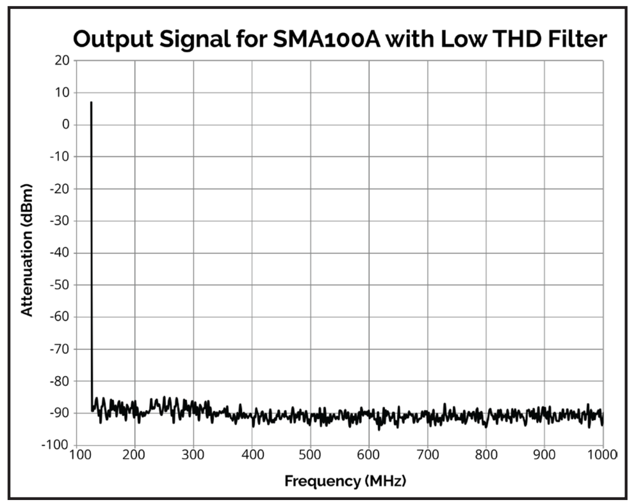
Many testing applications require a clean harmonic-free signal in order to provide the best results. However, typical high quality signal generators and frequency synthesizers will have harmonics present at the output up to the 6th or 7th harmonic. This is not acceptable for most ADC/DAC testing applications.

Harmonic distortion can be measured using a Rhode & Schwarz FSU Spectrum Analyzer and a Rhode & Schwarz SMA100A Signal Generator. In this example, a 125MHz signal at 15dBm was output from the generator. The signal generator is high quality but still produces high level harmonics up through the 9th harmonic. Using the THD equations above results in a calculated THD of -28.12dB (0.76%). Refer to output signal graph below left.

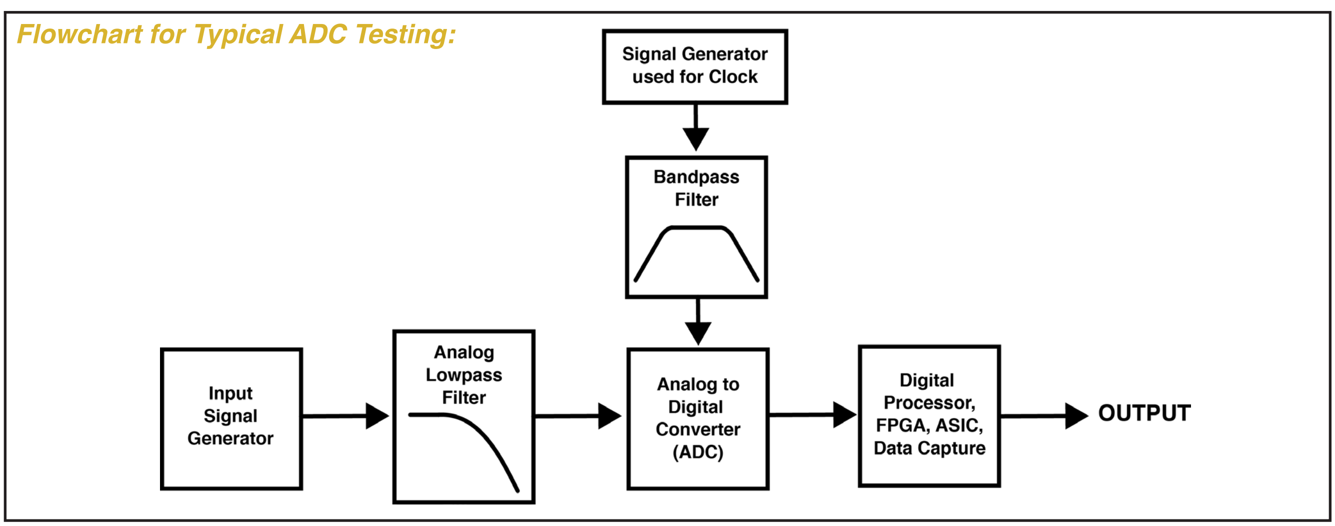
The signal can be cleaned up by simply adding a passive filter after the signal source. By adding, for example, a KC4TR-125M-3P-50-69A filter (a low THD filter from GCG's affiliate TTE Fitlers*) in between the signal generator and the spectrum analyzer, all harmonics are dropped below -80dBm, resulting in a calculated THD of -80.31dB (0.004%). This reduction in THD is significant and will enhance the quality of ADC/DAC testing. Refer to output signal graph below right.

**Please note that there are many other low THD filters available from TTE Filters. Please refer to the "Helpful Information' section on page 4.*





For reference, the flowchart below depicts a typical setup for performing ADC/DAC testing.

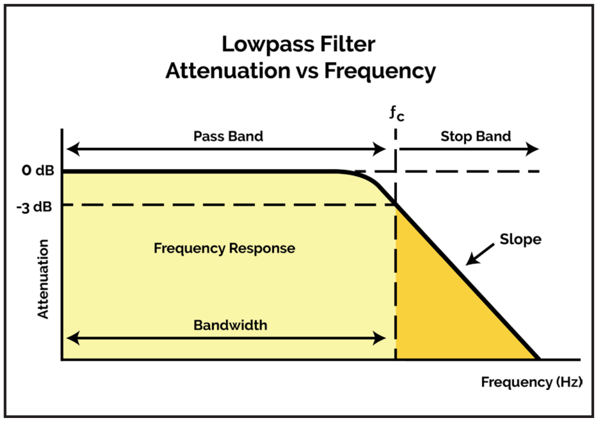


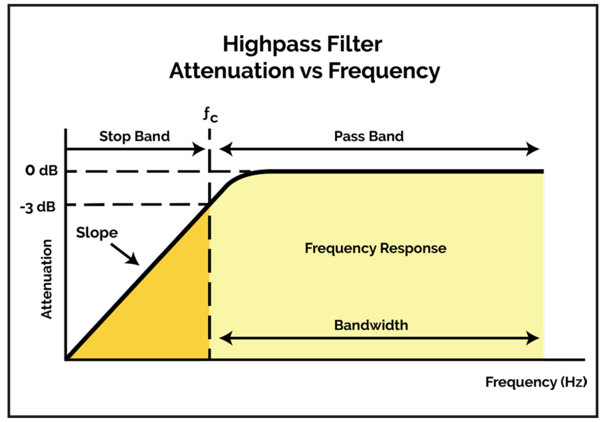
Adding a low distortion filter can help to improve the dynamic range and selectivity of all spectrum analyzers for harmonic distortion and intermodulation measurements. Also, adding a filter in the clock helps reduce spurs and improve performance. There are a variety of low THD filter types that can be used depending on the application. These include lowpass, highpass, bandpass and band rejection filters, such as those offered by GCG.

Choosing the Correct Filter Type

Lowpass Filters are designed to pass the fundamental frequency and remove (attenuate) all harmonics. These filters will pass all frequencies below the fundamental frequency as well. These filters have low insertion loss in the passband, which allows the greatest amount of power to pass through. They are an ideal filter for providing a low harmonic distortion signal from the test generator. Refer to lowpass filter graph below left.

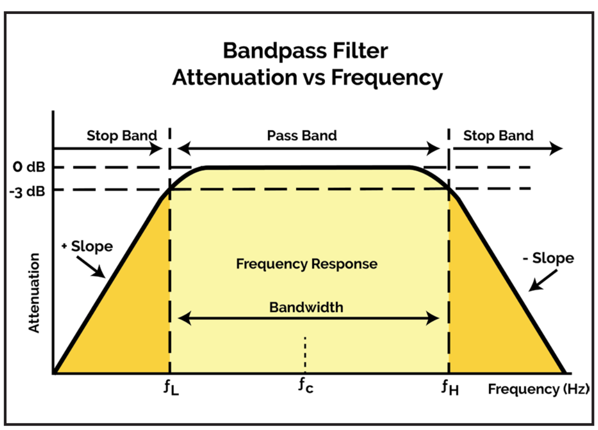
Highpass Filters are designed to attenuate the fundamental frequency and pass all higher harmonics. Similar to the lowpass filter this filter type has low insertion loss in the passband. Using a highpass filter will provide a path for all harmonics from the generator. Refer to highpass filter graph below right.

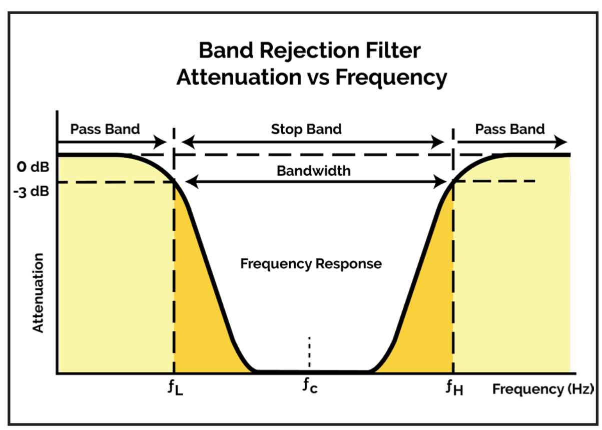




Bandpass Filters are designed to pass the fundamental frequency as well as a range of frequencies around it. These filters will attenuate all harmonics as well as the sub-harmonics below the passband. The bandpass filter is the most common filter application but often provides the highest insertion loss at the fundamental frequency. Refer to bandpass filter graph below left.

Band Rejection Filters, also known as notch filters or bandstop filters, are designed to attenuate the fundamental frequency and pass lower and higher frequencies, which includes the harmonics. These filters are also used to improve the dynamic range of any spectrum analyzer. Refer to band rejection filter graph below right.





The filters mentioned above can also be combined to create diplexers, triplexers or multiplexers. The combination of filter types to create multiplexers provides a low-loss means of splitting or combining two or more signals of different frequencies at a common port. They also provide isolation between the signal ports. Multiplexers can be cascaded together to increase their stop band attenuation.

The Role of Filter Topologies

GCG can provide different filter types in conjunction with different topologies which include, Bessel, Butterworth, Chebyshev, Elliptical and Gaussian. GCG also uses multiple technologies that help provide a wide range of frequencies.

Bessel Filters have a maximally flat response in both magnitude and phase. They provide a linear phase response in the passband. Bessel filters are used to reduce the nonlinear-phase distortion inherent in all Infinite Impulse Response (IIR) filters.

Butterworth Filters exhibit a nearly flat passband with no ripple. The roll-off is smooth and monotonic, with a lowpass or highpass roll-off rate of 20dB/decade (6dB/octave) for every pole. They also offer a reasonably good phase response.

Chebyshev Filters achieve a faster roll-off which is achieved by allowing ripple in the passband. As ripple increases (bad), the roll-off becomes sharper (good). The Chebyshev response is an optimal trade-off between these two parameters. Chebyshev filters offer a poor phase response.

Elliptical Filters provide the sharpest roll-off but they have ripple in both the passband and the stopband. The phase response for these filters is also very non-linear. The benefits of elliptical filters is that they provide the lowest order as long as the primary concern is to pass frequencies within a certain band and reject frequencies outside the band, regardless of phase shifts or ringing.

Gaussian Filters are similar to Bessel filters except they provide a lower time delay and minimum rise. They are considered ideal time domain filters.

In Conclusion

The addition of a low distortion filter after a signal source significantly reduces harmonic distortion and improves the quality of test results with ADC/DAC testing. GCG's low THD filters are designed for such applications and offer versatility with multiple filter types and topologies. The company's expertise with custom designs adds value for application-specific requirements.

Helpful Information:

GCG's TTE Filters affiliate offers the following series with low THD characteristics:

- **RC Series** - Band Rejection Chebyshev Filter
- **KB Series** - Bandpass Butterworth Filter
- **KC Series** - Bandpass Chebyshev Filter
- **Q Series** - Bandpass Elliptical Function Filter
- **HC Series** - Highpass Chebyshev Filter
- **HE Series** - Highpass Elliptical Function Filter
- **H Series** - Highpass TTE Design Filter
- **LC Series** - Lowpass Chebyshev Filter
- **LE Series** - Lowpass Elliptical Function (Anti-Aliasing) Filter
- **J Series** - Lowpass TTE Design Filter

For links to additional information on the low THD series above, please go to http://www.tte.com/search-for-low-thd-filters/. To access additional filter products from GCG please go to sister affiliates Microwave Circuits and Instec Filters.

To access downloadable versions of this and prior technical tips please **click here**.

If you have any questions about this Technical Tip, suggestions for future Technical Tips, or need assistance with our standard or custom products, please contact us.

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