Understanding the HI5721 D/A Converter Spectral Specifications

Introduction

Data converters have, and continue to be one of the basic building blocks in data acquisition systems. However, with the growing dependance on D/A converter spectral purity in today's applications, it is becoming increasingly important for system level designers and IC manufacturers alike to understand the effect of spectral non-uniformity in these complex applications. The performance of a given D/A converter under a specific set of conditions provides the system designer with the data he or she needs to determine whether the converter will meet the requirements of the system.

Discussion

Although there are a variety of definitions for Spurious Free Dynamic Range (SFDR), one which is commonly accepted is that SFDR is the difference in power between the fundamental and the highest spur over the full Nyquist bandwidth. SFDR is specified in dBc (decibels below carrier). Some variations of this specification include: a) the definition of a frequency window of interest around the fundamental and b) the exclusion of harmonics in the calculation of SFDR. Though sound arguments can be made to justify any of these definitions for SFDR, particular attention must be paid to what is actually being defined in each case.

Depending on the glitch impulse characteristics of the D/A converter, noise within a band limited range of frequencies (or window) can be dominated by its effects. Glitch impulse, which is a measure of the glitch area created by switching transients during converter updates, will generate high frequency spurs that fold back in band and cannot be filtered. This noise, which resides close to the fundamental, can define "windowed" SFDR.

Therefore, while the definition of a window around the fundamental provides useful information regarding the nature of the noise floor, it provides too limited a scope. Unless the user filters the output signal in a similar fashion to that being used to test the converter, the effect of the remainder of the noise floor on the application is unknown. The same can be said of defining SFDR using harmonics. Since harmonic distortion typically exceeds noise in the D/A converter's spectrum (as seen in Figure 1), little information about the characteristics of the noise floor are obtained. Figure 2 graphically illustrates this point. As one can see, dramatically different SFDR specifications can arise depending on the method used for its definition. Specific system requirements will dictate which of the outlined methods will best suit your needs. However, by using method 2 (as shown in Figure 2) and determining the peak non-harmonically related noise generated by the converter in combination with total harmonic distortion (which defines noise generated by harmonics only), a better determination of the D/A converter's overall spectral purity can be obtained.

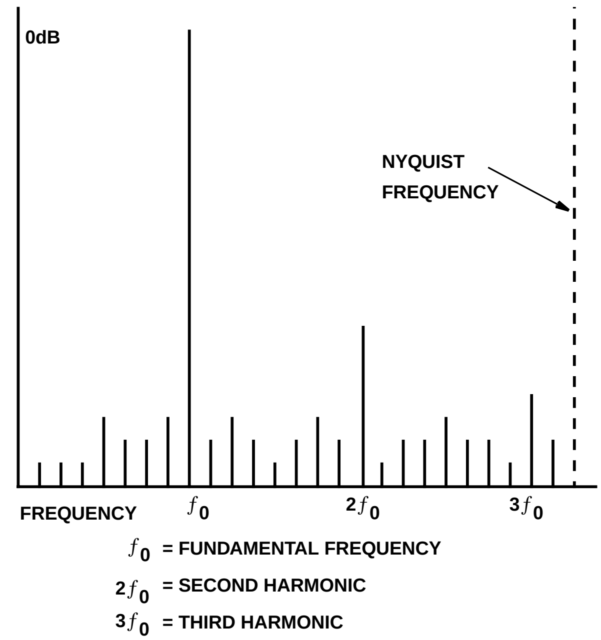
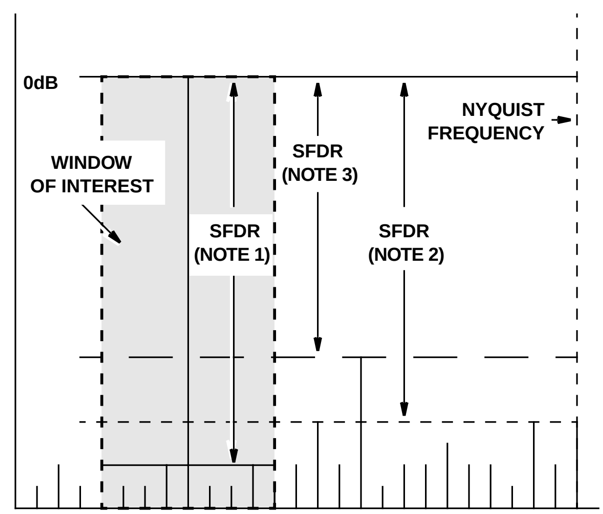


FIGURE 1. TYPICAL D/A CONVERTER SPECTRUM



NOTES:
1. SFDR as Defined In 'Window'
2. SFDR to Nyquist Without Harmonics
3. SFDR to Nyquist Including Harmonics

FIGURE 2. DEFINING SFDR

Total Harmonic Distortion (THD) is defined as the difference in power between the fundamental and the RMS contribution of all harmonics in band (to Nyquist), and is specified in dBc. While harmonics in general are dominated by any repetitive sources of error in a given converter, the shape of the transfer curve, or more specifically, the combination of integral non-linearity (INL), which is specified as the worst case deviation from the straight line approximation of a given converter's transfer function, and differential non-linearity (DNL), which is the worst case deviation from an ideal step size between adjacent codes along the transfer curve, will dominate the harmonic content of the spectrum.

Analysis of the Fourier series expansion of a given function reveals that:

$$f(t) = \frac{a_0}{2} + \sum_{n=1}^{\infty} a_n \cos(n\omega_0 t) + \sum_{n=1}^{\infty} b_n \sin(n\omega_0 t)$$

where

$$a_n = \frac{2}{T}\int_T f(t)\cos(n\omega_0 t)$$

$$b_n = \frac{2}{T}\int_T f(t)\sin(n\omega_0 t)$$

and $\frac{a_0}{2}$ is the DC value of the waveform $f(t)$[1].

When a function is even (or $f(t) = f(-t)$),

$$b_n \equiv 0 \quad a_n = \frac{4}{T}\int_0^{\frac{T}{2}} f(t)\cos(n\omega_o t)\ dt$$

only even harmonics are generated.

Similarly, when a function is odd (or $f(t) = -f(-t)$),

$$a_n \equiv 0 \quad b_n = \frac{4}{T}\int_0^{\frac{T}{2}} f(t)\sin(n\omega_0 t)\ dt$$

and only odd harmonics are generated.

In order to apply these equations, we must first establish the evenness or oddness of a given function. If we analyze the typical converter transfer functions shown in Figure 3, and prove the periodicity of these functions by superimposing them on to a sine wave, we now become free to apply the visual test for evenness or oddness[2]. Figure 4 graphically illustrates this procedure. The results of this test determine that the characteristic ‘bow’ function is even, while the ‘S’ function is odd.

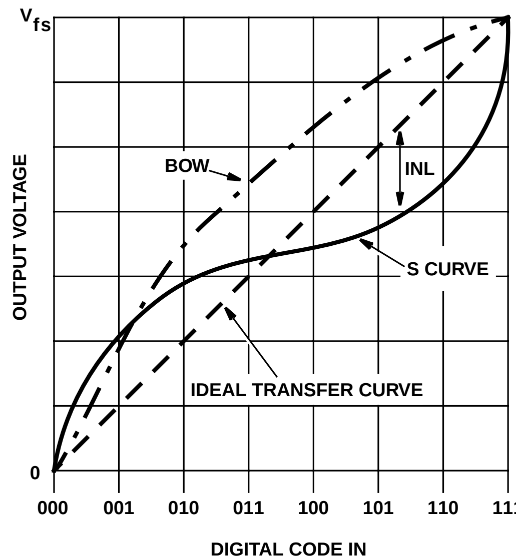


FIGURE 3. TYPICAL D/A CONVERTER TRANSFER FUNCTIONS

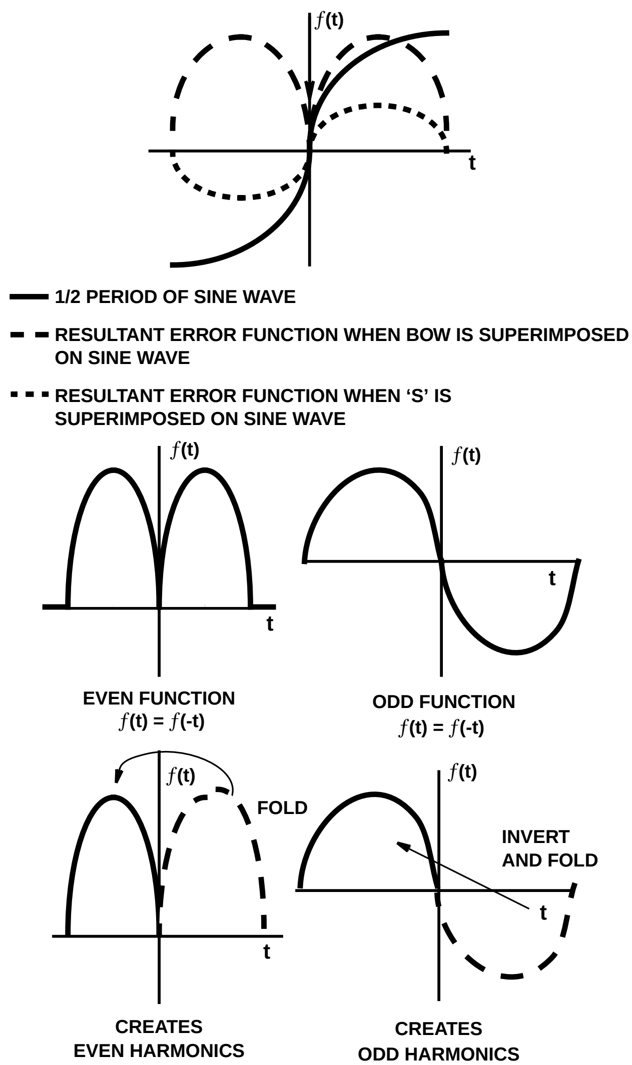


FIGURE 4. VISUAL TEST FOR EVENNESS OR ODDNESS

Applying this knowledge, we can determine that a ‘bow’ characteristic will generate dominant second harmonic, and an ‘S’ characteristic will generate a dominant third.

While this analysis assumes that functions are perfectly even or perfectly odd (which rarely occurs), it does provide an intuitive feel for the nature of harmonic distortion in data converters.

Signal to Noise + Distortion (SINAD) is the ratio of the power of the fundamental to RMS noise including harmonics (depending on the manufacturer, this specification may also be called Signal to Noise Ratio), and is specified in dB. Since this specification encompasses all noise in band (both harmonically and non-harmonically related over the full Nyquist bandwidth), it defines the overall effective resolution of the converter being tested. Once SINAD has been computed, the effective number of bits (ENOB) of a given converter is defined by the following equation:

$$\mathrm{ENOB} = \frac{(\mathrm{SINAD} - 1.76)}{6.02}$$

Signal to Noise Ratio (or SNR) is defined as the ratio of the power of the fundamental to RMS noise (the RMS value of the entire noise floor, minus harmonics, over the full Nyquist bandwidth), and is specified in dB. While this specification does not include any harmonic contributions, it does provide insight to the overall characteristic of its noise floor. Therefore, the combination of this specification with THD provides the user with more information about the nature of both harmonically and non-harmonically generated distortion than SINAD alone can provide.

Conclusion

Since these specifications define the level of resolution for a given converter, it is important to understand the test conditions used when defining these parameters, and their applicability to the system being designed. Also, since not all manufacturers guarantee a minimum level of dynamic accuracy on their converters (usually given as typical values, if at all), it has been shown that careful analysis of the DC specifications can yield relevant spectral information. The nature of the converter’s transfer function (which outlines the linearity performance of the converter) as well as specifications such as settling time and glitch impulse can assist the designer in anticipating the nature of both harmonic and noise floor degradation, which will limit the overall resolution of the converter.

References

[1] R.J. Mayhan, “Discrete-Time and Continuous Time Linear Systems”, 1984, pp. 398-402.

[2] R.W. Ramirez, “The FFT Fundamentals and Concepts”, 1985, pp. 41-46.