RF Engines Limited

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Contents

Comparison of Dither Methods for A to D Converters

1. Overview.

The object of this short document is to compare wideband and band-limited methods when using dither noise to reduce quantisation spurs in A/D converters. The basic problem is that, when applying a ‘clean’ sine-wave input to the A/D, spurs appear at fixed frequencies depending on the exact input and clock frequencies and at levels depending on the number of effective bits in the A/D. These spurs are caused by the regular interaction between the input sine-wave and the quantisation levels. Under normal conditions, with system noise present, these interactions are ‘dithered’ by the noise itself which tends to ‘smear’ out the spurs into the noise floor. With clean signals, however, such as might occur with large signals and AGC which pushes the system noise floor below that of the A/D, the spurs can become a problem.

Fortunately, a solution is to deliberately add random noise, or ‘dither’, of sufficient level at the A/D input. This subject is dealt with in some detail in Ref [1] below. The object here is to compare two possible methods of achieving this and is particularly centred on 12 bit A/D devices such as the Analog Devices AD9430

2. Results with No Dither.

Figure 1 below shows the effect of a signal at a frequency of Fin =132 MHz, a level of –0.5 dB full scale and a sample rate of Fs=176 Msps which has been down-converted to complex baseband (LO = -132 MHz). The spectrum of this signal, using a 16K point complex FFT, shows no spurs because it happens to lie at the exact centre of the second Nyquist zone of 3Fs/4.

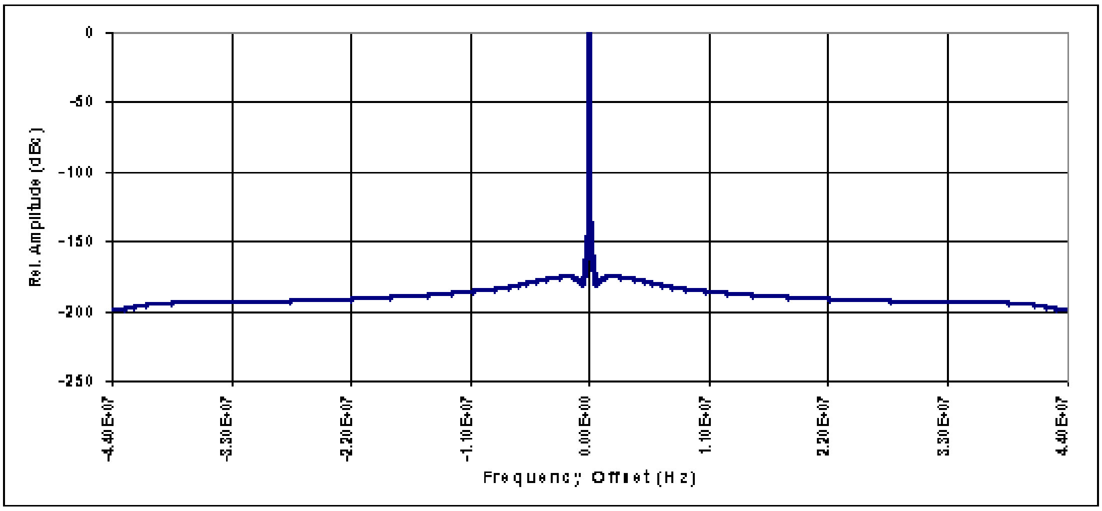

Figure 1. Spectrum of A/D Output after Conversion to Zero IF- Input at 132 MHz

Figure 2 and 3 below show the cases for inputs at Fs = 137.5 MHz (Fs/32 offset) and Fs = 132.6875 MHz (Fs/256 MHz offset). Spurs now appear and increase in number as the offset reduces and the highest spur levels are in the region of –80 dBc. It will be helpful to ask, “what was the *expected* quantisation noise level?”

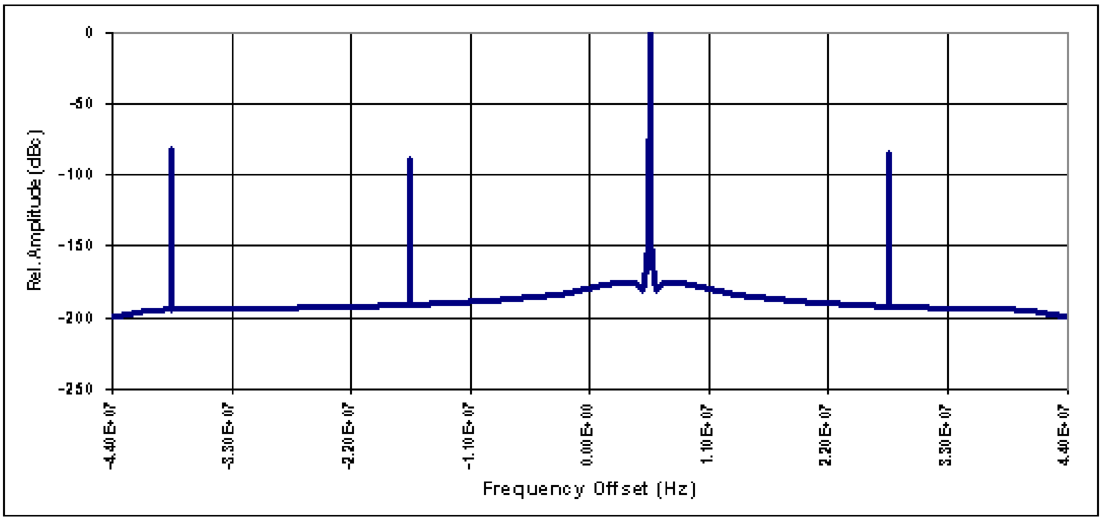

Figure 2. Spectrum of A/D Output after Conversion to Zero IF- Input at 137.5 MHz

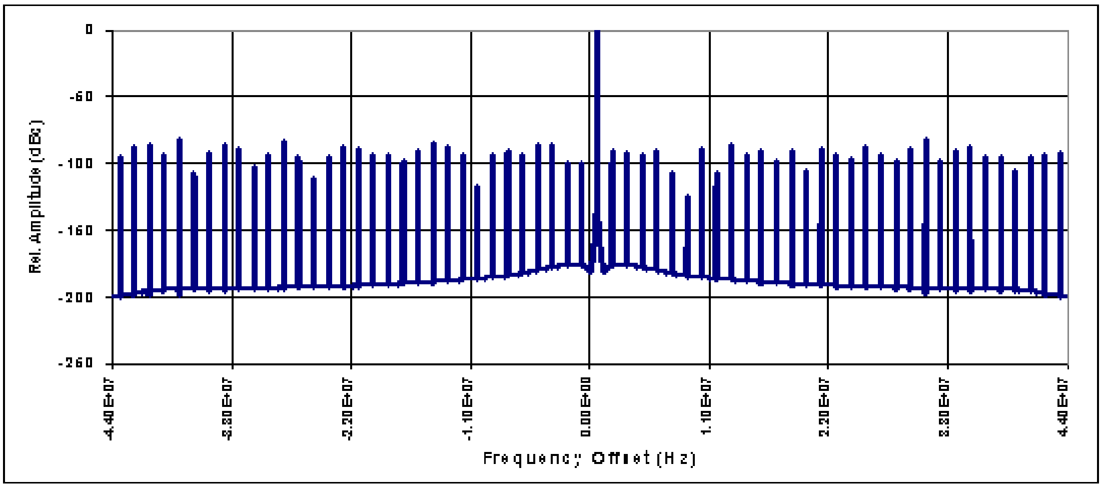

Figure 3. Spectrum of A/D Output after Conversion to Zero IF- Input at 132.6875 MHz

This subject is dealt with in most standard texts giving a theoretical result :-

RMS Signal / RMS Quantisation Noise = 1.2247 * 2^N

Where Signal is at full scale and N is the number of bits. Thus, for a perfect 12 bit A/D, the overall signal to noise is:-

20*Log10 {1.2247*2^12} = 74 dB

To this must be added a figure of approximately 10*Log10{16384) to allow for the noise power density reduction in the 16K point FFT, giving an overall figure of:-

RMS Signal / RMS Quantisation Noise Power Density = 116.1 dB

Clearly, the spurs we see in Figs. 2 and 3 above are considerably higher than this due to the energy being collected up into discrete spectral lines

3. Addition of Wideband Dither.

The first, and probably the easiest solution, is to add wideband noise to the signal ahead of the A/D. This can be done very simply by using a noise diode (e.g. one of several different devices from NoiseCom) and some form of broadband combiner. Figure 4 below shows the effect of adding a small amount of dither, corresponding to +/- 1 output quantisation levels (+/- 1 ‘codes’ or ‘quanta’). It may be seen that the *average* noise floor level is raised to around the 116.1 dB theoretical level but that there are still significant spurs at around –85 dBc, so the level of dither in not enough.

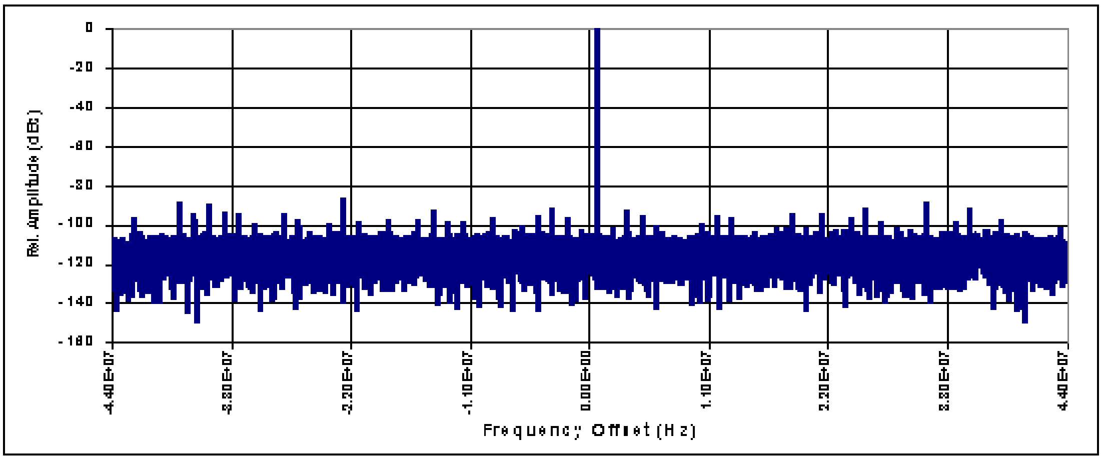

Figure 4. As Figure 3 but with Addition of 2 Quanta Pk-Pk of Wideband Dither

In Figure 5 it may be seen that, by raising the input noise level by some 8 dB to give at least +/- 2 quanta of dither, the spurs have been reduced to around the average noise level. This is also an RMS level of 0.486 quanta which, for the AD9430, equates to 0.158 mV RMS at the A/D input. The only problem is that the overall noise floor is now the sum of the inherent A/D quantisation noise and the input dither and is raised at least 3 dB above the theoretical level, thereby reducing the overall dynamic range (in a 16K transform) to around 113 dB.

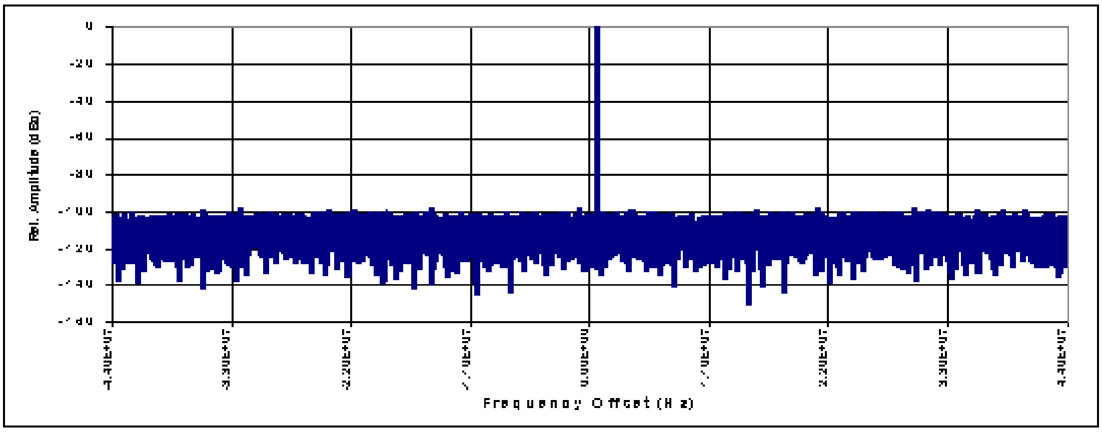

Figure 5. As Figure 3 but with Addition of 4 Quanta Pk-Pk (0.158 mV rms) of Wideband Dither

For many applications, this may not matter but, for more demanding situations, it is possible to ‘wring’ the last few dB of dynamic range out of the A/D, as described next.

4. Addition of Narrow-Band Dither.

It is impossible to make use of the whole Nyquist zone of the A/D because it is necessarily preceded by an anti-alias filter. This, as its name suggests, is needed to exclude frequencies from outside of the chosen Nyquist region from folding in or 'aliassing'. All filters have a finite cut-off rate so there will be a small region where aliassing does take place and is unusable for normal signals. Typically, about 20% of the Nyquist zone is unusable and can, therefore, be used for the addition of dither noise. Using the above example of a sample rate of 176 Msps, the Nyquist zones are half of this (88 MHz) leaving some 8.8 MHz at either end of a zone for dither. The most obvious place to use is the region from DC to 8.8 MHz, using a low-pass filter which cuts off any dither noise to the system noise floor by 8.8 MHz.

Figure 6 below shows the effect of using 2 MHz narrow-band dither giving +/- 1 quanta dither. In this case, the spurs are reduced more than was the case for this level of wideband dither and are at around –93 dBc. The average noise level is close to the theoretical value of around –116 dBc

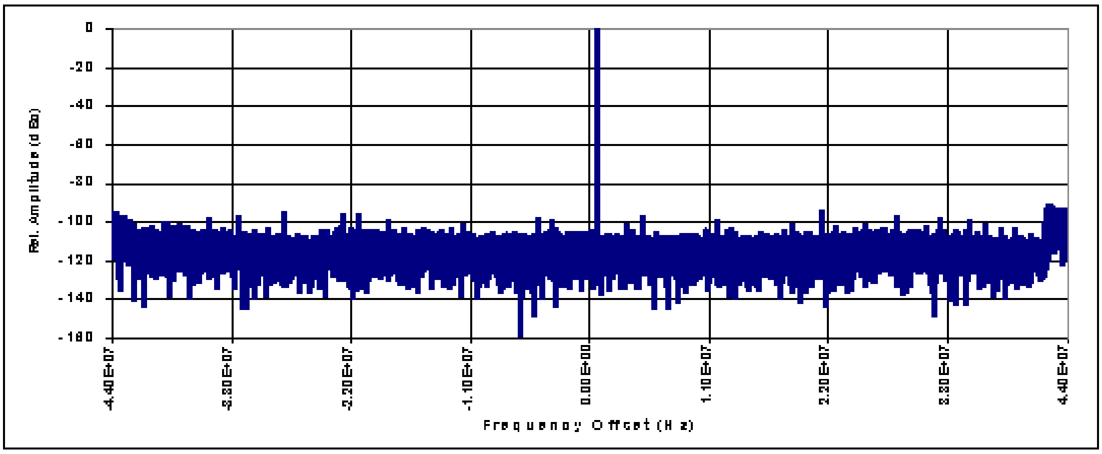

Figure 6. As Figure 3 but with Addition of 2 Quanta Pk-Pk of Narrowband Dither

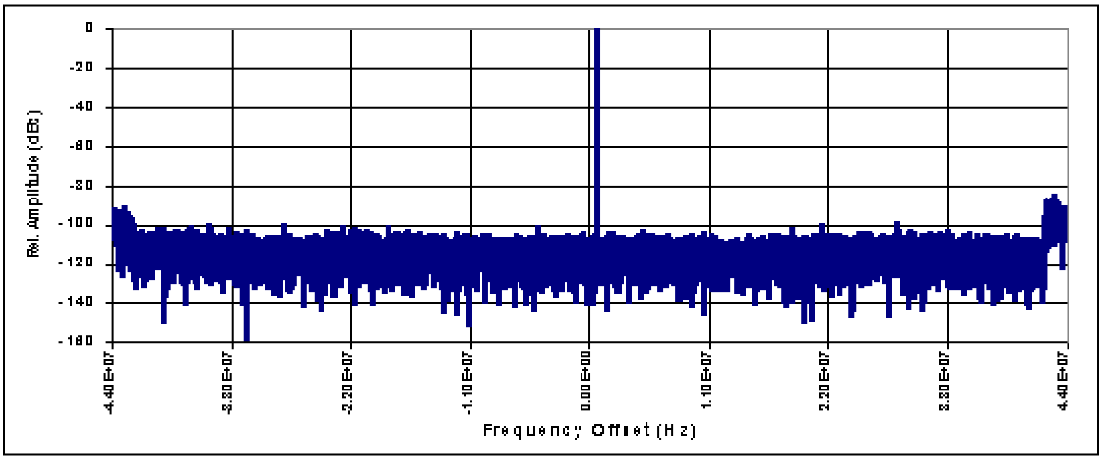

Figure 7. As Figure 3 but with Addition of 5 Quanta Pk-Pk (0.261 mV rms) of Narrowband Dither

In Figure 7 above, the effect of adding more narrowband dither is clearly seen. With 5 quanta Pk-Pk, equivalent to 0.261 mV rms at the input, the spurs are reduced to around –98 dBc with no increase in the in-band noise level. Finally, in Figure 8 below, increasing the noise by a further 6 dB gives 9 quanta Pk-Pk, equivalent to 0.507 mV rms at the input. This results in the spurs being reduced to the peak noise level of around –102 dBc whilst the mean in-band noise remains at a level of around –116 dBc since all of the additional noise appears in the unusable zones.

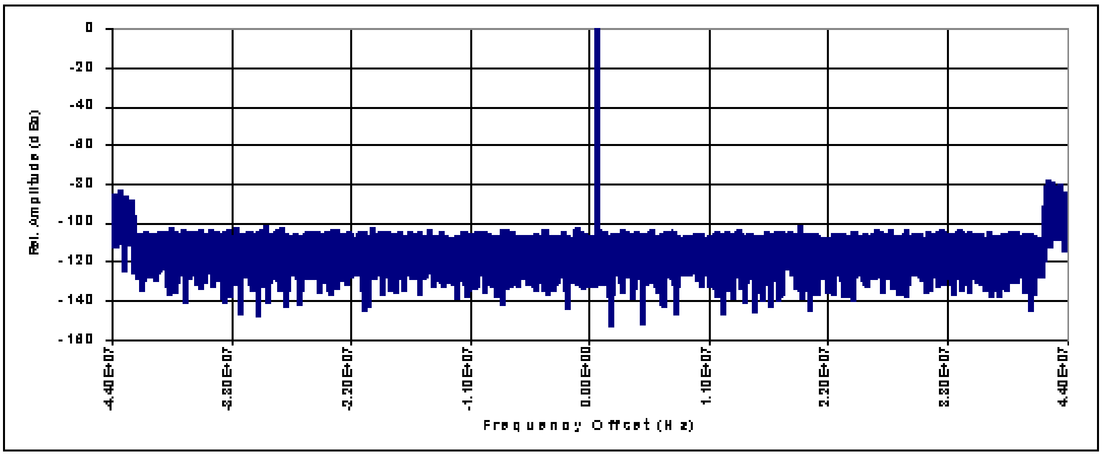

Figure 8. As Figure 3 but with Addition of 9 Quanta Pk-Pk (0.507 mV rms) of Narrowband Dither

5. Example Calculation.

A simple calculation for the wideband dither case may help as an illustration. Taking the case given in Figure 5 above, we require a dither level of 0.158 mV rms into the A/D. Assuming that the load impedance seen by the noise diode is 50 ohms (which may be different from the A/D input impedance, as illustrated in Figure 9 below) and that there is a 6 dB loss then we require a level of 0.316 mV (2x0.158 mV) from the noise diode which is equivalent to a power level of –57 dBm. Assuming an analogue input bandwidth to the AD9430 of 700 MHz, the required Excess Noise Ratio (ENR) from the diode is calculated as follows:-

KTB = -114 dBm / MHz
= -114+10 Log10(700) dBm / 700 MHz
= -85.6 dBm / 700 MHz
ENR = (85.6 – 57)dB
= 28.6 dB

This may be readily achieved by using, for example, the NoiseCom NC302L diode which has an available bandwidth of 3 GHz and an ENR of 30 to 35 dB.

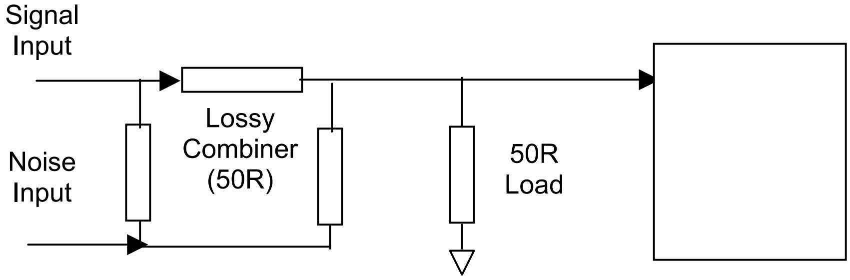

Figure 9. One Possible Wideband Dither Arrangement

6. Conclusions.

It may be readily concluded that the addition of dither noise at the A/D input makes a significant improvement to the quantisation spurs. It most systems, the natural system noise will produce the required effect but in situations where high signal levels cause the AGC to drive down the system noise floor below that of the A/D then spurs will occur. A typical example of this might be in instrumentation where high level CW signals may be used for test and calibration purposes.

The addition of wideband noise can certainly help but, to reduce the spurs below noise level, the amount of noise present will add to the inherent A/D noise and reduce dynamic range by at least 3 dB. The advantage of this method, however, is its simplicity since it only requires the addition of a noise diode of the correct level and bandwidth at the A/D input. NoiseCom produce a range of such diodes and the method is to be recommended if adequate performance can be achieved in this way.

For ultimate performance, narrowband dither is highly recommended. Spurs may be driven down to close to system noise level without adding to the average noise level. The main disadvantage is the requirement for additional low-pass filtering and amplification since filtering the noise also reduces its level. It must also be remembered that placing an additional filter at the output of the main anti-alias filter also affects the load impedance. It is normal, therefore, to design such a structure, carefully taking account of these effects.

References.

[1] Analog Devices Application Note AN-410, “Overcoming Converter Nonlinearities with Dither.