



APPLICATION NOTE 3716

Folded-Frequency Calculator

Abstract: The following application note provides a fast, easy-to-use tool to determine true and aliased frequency locations of image signals and harmonics in a typical frequency spectrum. Such data is used to analyze the dynamic performance of analog-to-digital (ADC) and digital-to-analog (DAC) converters. The calculator tool was created in Excel and can be downloaded through the link provided in the application note.

This Excel®-based, easy-to-use, Folded-Frequency Calculator provides a quick way to locate integral harmonics of the fundamental frequency in the first Nyquist zone of a sampled data system. The calculator is independent of the sampling process and works for Nyquist-, over-, and undersampling. This tool is useful for users interested in locating various harmonics in the first Nyquist zone of folded frequency spectrum of ADCs and DACs.

This application note discusses the algorithm used for the calculation of folded-frequency locations in the first Nyquist zone, and includes a step-by-step guide for the [Folded-Frequency](#) Calculator. Additionally, to lend a deeper insight, this application note briefly discusses the concepts of [aliasing](#) and [Nyquist](#) in sampled data systems in general, and in data converters in particular.

Aliasing and Nyquist

Aliasing in a sampled data system is a well-known phenomenon. Aliasing occurs whenever a signal is sampled at a rate below its Nyquist rate, i.e. twice the signal frequency bandwidth. A real-world signal-frequency spectrum contains harmonics of the fundamental frequency, as well as in-band and out-of-band noise frequencies. Inherent device and sampling process nonlinearities manifest themselves in the form of harmonics of the desired fundamental frequency in the output waveform. Any higher order harmonics with frequencies greater than $f_{\text{SAMP}}/2$, with f_{SAMP} being the sampling frequency, fold back into the first Nyquist zone (**Figures 1a** and **1b**) due to aliasing.

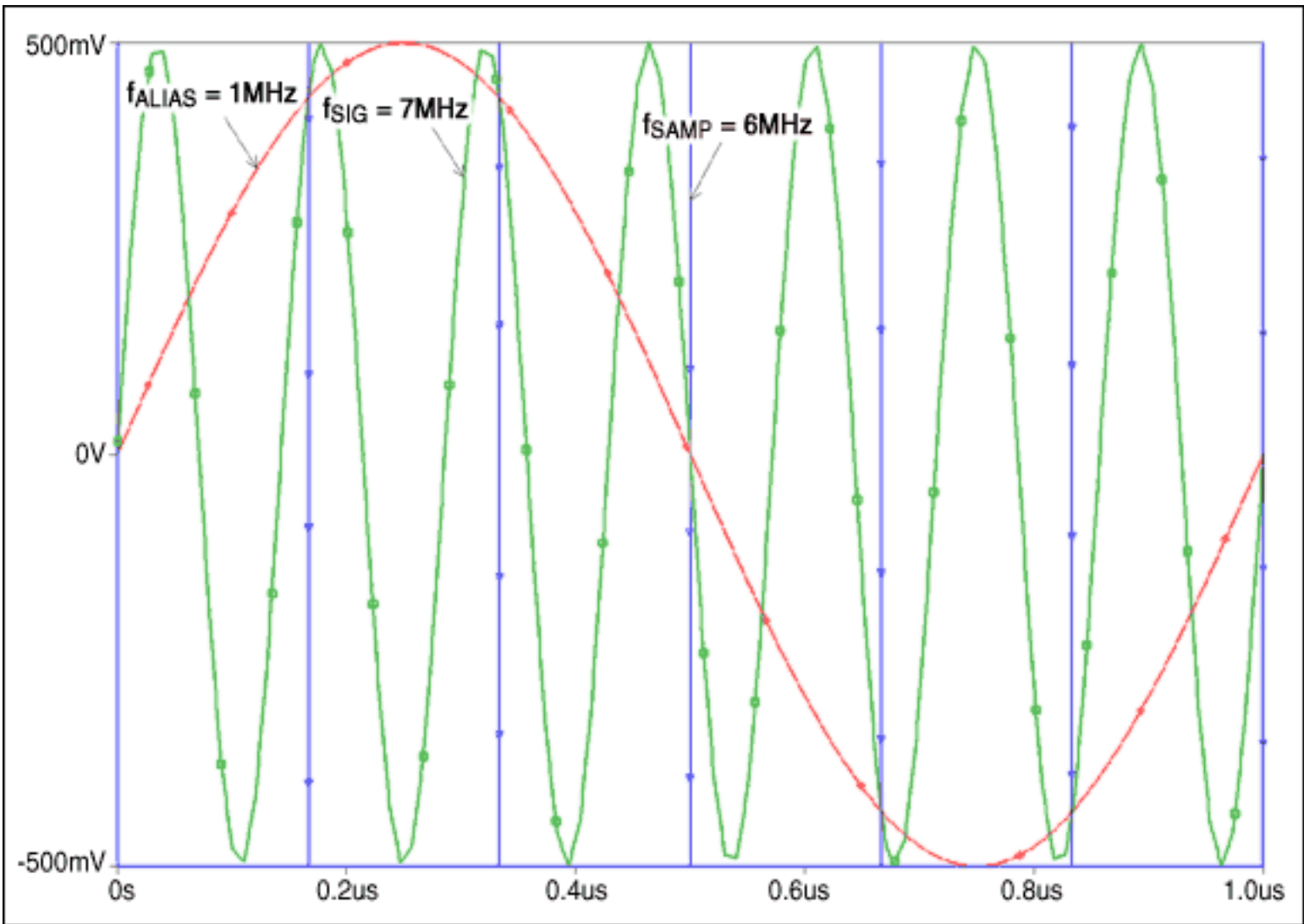


Figure 1a. Aliasing in the time domain.

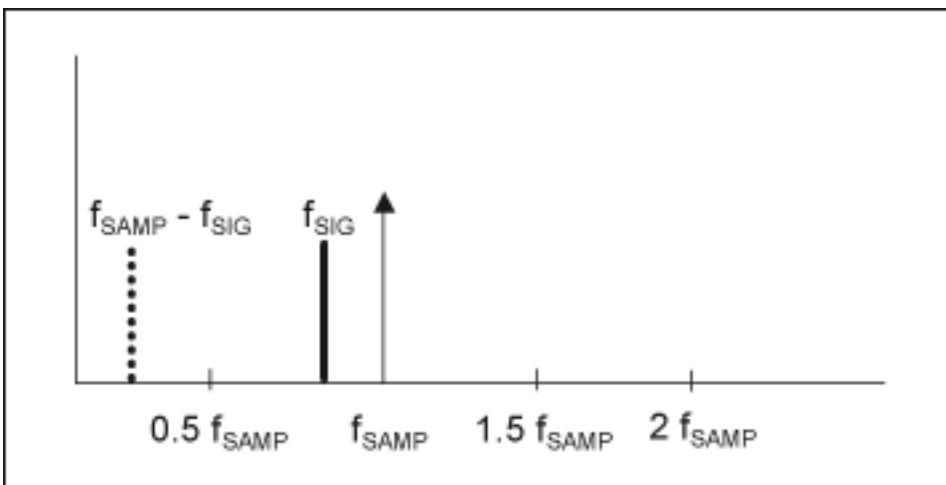


Figure 1b. Aliasing in the frequency domain.

The fast Fourier transform (FFT) frequency spectrum of a discrete time signal can be divided into an infinite number of $f_{\text{SAMP}}/2$ frequency bands, also known as Nyquist zones. The frequency spectrum between DC and $f_{\text{SAMP}}/2$ is known as the first Nyquist zone. The frequency spectrum repeats itself over different Nyquist zones. Note that the even Nyquist zones appear as mirror images of the odd Nyquist zones (**Figure 2**).

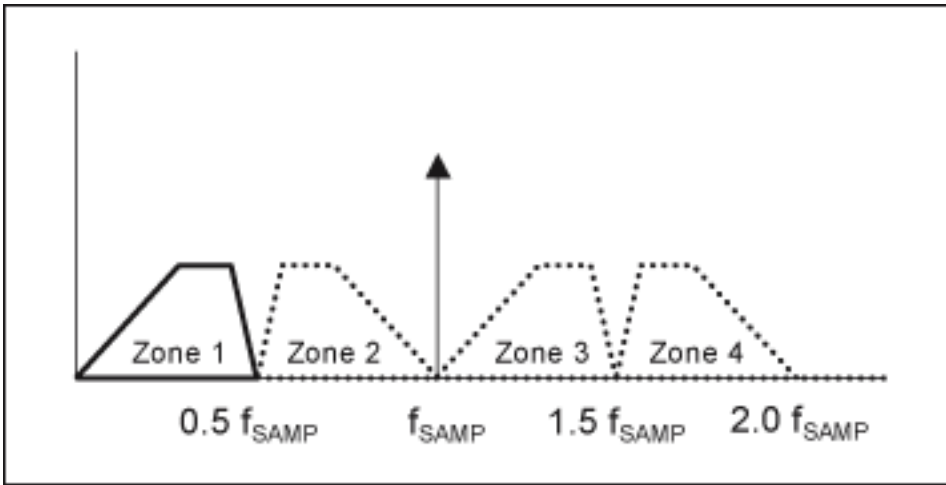


Figure 2. Display of various Nyquist zones.

Aliasing in ADCs and DACs

Aliasing in ADCs is a ramification of the track-and-hold (T/H) processing of the analog signal at the input stage. In the digital signal processing (DSP) domain, T/H processing is equivalent to convolution of the frequency spectrum of the impulse train (due to the sampling clock) with the frequency spectrum of the analog input. This convolution results in periodicity of the frequency spectrum that is observed over various Nyquist zones, as previously explained. When the input signal contains frequency components above the Nyquist frequency ($f_{SAMP}/2$), the adjacent Nyquist zones start overlapping and result in aliasing.

Aliasing in DACs is a consequence of the zero-order-hold (ZOH) processing (used to avoid code-dependent output glitches) of the discrete time samples at the output stage. ZOH processing in the DSP domain is equivalent to convolution of the $\sin(x)/x$ type of frequency spectrum (of the rectangular function appearing due to holding discrete time samples) with the DAC core's output-impulse train frequency spectrum (of varying amplitude, in general). As in the case of ADCs, the periodicity of the output spectrum over different Nyquist zones can be attributed to this convolution.

Calculator

Mathematically, any frequency component below $f_{SAMP}/2$ will be present in the frequency spectrum without aliasing. However, due to aliasing, any harmonic component (f_{HARM}) above $f_{SAMP}/2$ will also appear as an image frequency at $|\pm K \times f_{SAMP} \pm f_{HARM}|$, where $K = 1, 2, 3$, and so on.

The following algorithm can be used to locate various harmonics in the first Nyquist zone:

```

f_NYQ = f_SAMP/2;
f_HARM = N x f_FUND; //N is an integer
If (f_HARM lies in an odd Nyquist zone) then
f_LOC = f_HARM % f_FUND; //% is the modulus operator
else
f_LOC = f_FUND - (f_HARM % f_FUND);
End;
```

where: f_{NYQ} is the Nyquist frequency, f_{SAMP} is the sampling frequency, f_{FUND} is the fundamental frequency of the signal, f_{HARM} is a harmonic frequency of the signal, and f_{LOC} is the location of a harmonic in the first Nyquist zone.

Finding the location (f_{LOC}) of various harmonic frequencies (f_{HARM}) using a simple electronic calculator may require certain iterations. An Excel spreadsheet titled "[Folded-Frequency Calculator](#)" is available for download to simplify the process.

The Folded-Frequency Calculator requires two input variables: the sampling frequency (f_{SAMP}) and the fundamental frequency of the signal (f_{FUND}). Using these two variables, the Folded-Frequency Calculator calculates the value of Nyquist frequency (f_{NYQ}), absolute values of various harmonic frequencies (f_{HARM}), and locations of various harmonics in the first Nyquist zone of a folded-frequency spectrum. **Table 1** shows an example of a folded-frequency calculation.

Table 1. Folded-Frequency Calculation with Inputs $f_{\text{SAMP}} = 500.000000$ and $f_{\text{FUND}} = 29.96826172$

N	f_{NYQ} (MHZ)	f_{HARM} (MHZ)	f_{LOC} (MHZ)
1	250.000000	29.96826172	29.96826172
2		59.93652344	59.93652344
3		89.90478515	89.90478515
4		119.8730469	119.8730469
5		149.8413086	149.8413086
6		179.8095703	179.8095703
7		209.777832	209.777832
8		239.7460937	239.7460937
9		269.7143555	230.2856445
10		299.6826172	200.3173828
11		329.6508789	170.3491211
12		359.6191406	140.3808594
13		389.5874023	110.4125977
14		419.5556641	80.44433595
15		449.5239258	50.47607423

References

Downloadable version of [Application Note Coherent Sampling Calculator](#)

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Application Note 3716: www.maxim-ic.com/an3716

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