EVLA Memo 130

The Effects of Fraction Truncation in Direct Digital Synthesis

M. Luce (NRAO), K. Morris (NRAO)

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Abstract

EVLA modules that employ Direct Digital Synthesis (DDS) are vulnerable to unintended frequency offsets arising from the truncation of the fractional part of frequency tuning commands. The modules affected include, but are not limited to, the L302 2nd LO Synthesizer and the L351 Master Offset Generator. The underlying mechanism is the same in both cases, but the effects on science manifest differently and the two modules will be treated separately in this paper.

1 Introduction

In general, a DDS can synthesize frequencies between 0 and $f_{clk}/2$ Hz, where f_{clk} is the frequency, in Hz, of the driving clock. The Analog Devices AD9852 DDS, which is used in both the L302 and the L351 employs a 48-bit frequency tuning word. This word is represented as a hexadecimal integer between zero and $2^{48} - 1$. The frequency tuning word (FTW) is calculated as

$$FTW = \frac{f_{output}(Hz)}{f_{clk}(Hz)} \times 2^b, \mathrm{b} = 48$$

eq 1

In order that the DDS output frequency is exactly the desired frequency, the FTW must be an integer. The least increment of tuning frequency can be calculated as

$$\Delta f_{output} = \frac{f_{clk}(Hz)}{2^{48}}$$

eq 2

In the case of the L302,

$$\Delta f_{output} = \frac{128MHz}{2^{48}} = 0.455\mu\text{Hz}$$

eq 3

and in the case of the L351,

$$\Delta f_{output} = \frac{256MHz}{2^{48}} = 0.905\mu Hz$$

eq 4

The output frequency will therefore be an integer multiple of this quantity. When the output frequency is not an integer multiple of the least increment of the tuning frequency, the error in numeric representation will manifest as an unintended frequency offset. The magnitude of the frequency offset can be calculated as

$$f_{offset}(Hz) = \frac{Frac\{FTW\} \times f_{clk}(Hz)}{2^{48}}$$

eq 5

The error could manifest as either truncation (floor) or rounding (either floor or ceiling), depending on how the particular MIB software treats floating point numbers.

2 L351 Master Offset Generator

The Master Offset Generator produces a constant frequency from its DDS, which serves the Round Trip Phase Monitor (RTPM) and nothing else. When this frequency is not integer-divisible according to equation 1, the result is an unintended phase slope in the round-trip phase measurement. For an offset frequency of 128Hz, the DDS output frequency is 64.000016MHz, and the frequency error at the RTPM is 323nHz, or approximately 28ps of phase per day. The L351 offset frequency was adjusted to allow for more precise duty cycle control in the RTPM, and currently stands at 200Hz. However, this frequency is actually less desirable than the original 128Hz in terms of frequency offset, which is now 5.05μHz, or 436ps per day. This unintentional offset is measurable in field RTPM data, which shows a measured average phase slope of 450ps per day, though this slope includes the "natural" phase slope imposed by the annual buried fiber temperature slope. The natural phase slope is approximately +/- 25ps per day, averaged over a 6-month period.

3 L302 10.8 – 14.8Ghz Synthesizer

The L302 main loop DDS is also subject to errors caused by truncation of the frequency tuning word. Errors in the DDS frequency are directly represented in the output frequency of the L302. As shown in Figure 1, the main loop DDS frequency varies across the 128MHz spacing between comb lines.

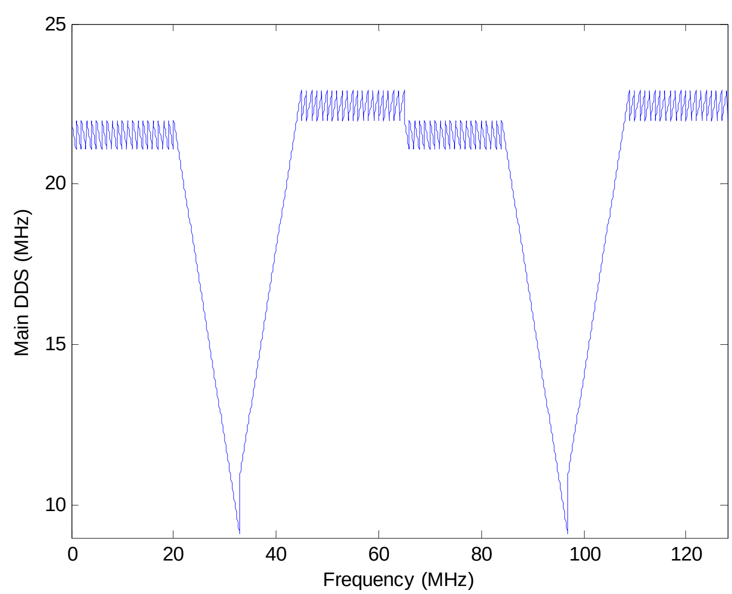

Figure 1: Main loop DDS frequency

Similarly, the tuning word truncation error varies across the comb spacing. For any given comb interval, the maximum error for the main loop DDS is ~441nHz, while the mean error is ~218nHz with a standard deviation of ~132nHz. Figure 2 illustrates the frequency tuning error for output frequency commands within 200kHz of 12.8GHz.

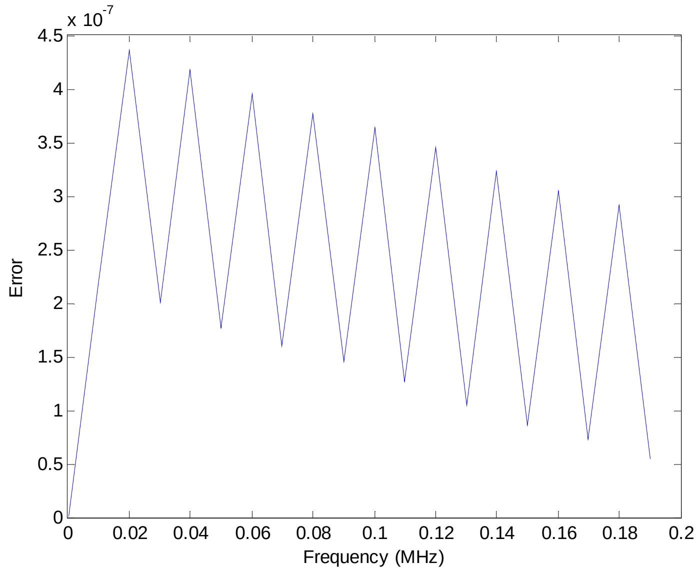

Figure 2: Frequency tuning error

4 Conclusions

Frequency errors are introduced in the EVLA digital synthesizers through two mechanisms. Floating point number representations causes errors through lack of precision, and the choice of frequency introduces errors by requiring non-integer frequency tuning words. The precision errors can be mitigated by increasing the bit depth available in the floating point mantissa. In some cases the frequency error due to non-integer frequency tuning words can be eliminated through careful frequency selection. When the error cannot be avoided, it can be characterized and removed.