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To: Broadband Development Group

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Subject: Phase Cal Channel-to-Channel Phase Discontinuities

Overview

When the phase cal rail spacing is not an integer multiple of the frequency channel width (i.e. 32 MHz), a phase discontinuity is introduced between the phase cal phase estimates of adjacent channels. This note is intended to address the source of these discontinuities and offer a method with which they may be calculated and subsequently removed using manual phase cal adjustment during fringe fitting.

Phase Discontinuities

For the purpose of this note, we may consider the broadband hardware as an ideal transmission line which exhibits perfectly linear group delay. Driving our fictitious network is the phase cal generator possessing matching impedance and the transmission line is terminated with a phase detecting receiver (i.e. the UDC, DBE, and correlator) also with matching impedance. The functional form of the complex time signal, comprising all rails, at the output of the network is:

$$s(t) = \sum_m e^{j2\pi m \Delta f_r \left(t - \frac{d}{c} \right)} \quad \text{Eq (1)}$$

where m is the rail harmonic number, Δf_r is the rail spacing frequency (now 5 MHz for BBDev), d is the length of the ideal transmission line, and c is the speed of light. The Fourier series coefficients corresponding to the signal given by Eq (1) are:

$$S(m\Delta f_r) = e^{-j\frac{2\pi d}{c} m \Delta f_r} \quad \text{Eq (2)}$$

Since Eq (2) defines Fourier series coefficients, and therefore the spectrum of the phase cal signal, $S(m\Delta f_r)$ also defines the phase of each rail.

As a result of processing $S(m\Delta f_r)$ with the UDC and DBE, each rail's RF frequency, $m\Delta f_r$, is translated to a channelized baseband spectrum $S_{bb}(f)$ through the process:

$$S_{bb}(f) = [S(m\Delta f_r) H(f - f_{LO} \pm nB_c)] \otimes \delta \left(f + f_{LO} \pm \left(\frac{1}{2} - n \right) B_c \right) \quad \text{Eq (3)}$$

where f is baseband frequency, f_{LO} is the effective local oscillator frequency (see next section), B_c is the channel bandwidth¹, n is the DBE channel number², and $H(f)$ is the idealized lowpass function³ spanning the interval $[-B_c/2, B_c/2]$. Substituting ‘+’ for the \pm operator performs lower sideband (LSB) detection and ‘-’ performs upper sideband (USB) detection. The \otimes symbol is the convolution operator and performs the RF to IF baseband conversion. A graphical representation of the processing described here is shown in Figures 1 and 2. Through the processing that is described by Eq 3, the relationship of rail m ’s baseband frequency, f_{bb}^{mn} , given that it is in channel n is:

$$f_{bb}^{mn} = m\Delta f_r - \left(f_{LO} \pm \left(\frac{1}{2} - n \right) B_c \right) \quad \text{Eq (4)}$$

where the \pm operator maintains its’ convention regarding USB and LSB detection. Since the bandwidth of the baseband filter is B_c , if f_{bb}^{mn} is outside the range $[0, B_c]$ for USB or $[-B_c, 0]$ for LSB, it is rejected by the filter $H(f)$ and is not detectable in that receiver channel.

If we consider a single rail of the phase cal signal having phase defined by it’s Fourier series coefficient given in Eq (2), the effect of the processing described by Eq (3), as long as the rail falls within the specified channel, is to simply shift the rail’s frequency from $m\Delta f_r$ to f_{bb}^{mn} . Based on this development, the phase of the baseband rail is given by:

$$S_{bb}(m\Delta f_r) = e^{-j\frac{2\pi d}{c} f_{bb}^{mn}} \quad \text{Eq (5)}$$

Based on Eq (4), as long as $B_c / \Delta f_r = \text{integer}$, there will exist a rail in every channel for which $f_{bb}^{mn} = \text{constant}$. This being the case, the phase of these rails according to Eq (5) will also be constant since f_{bb}^{mn} and d are constants.

For example, with $\Delta f_r = 1 \text{ MHz}$ rail spacing and $B_c = 16 \text{ MHz}$ channel bandwidth, the $f_{bb}^{mn} = \text{constant}$ condition was satisfied since $B_c / \Delta f_r = \text{integer}$. Currently, the BBDev system is configured for $\Delta f_r = 5 \text{ MHz}$ in order to avoid saturation of receiver components, particularly the LNA, by the peak power level of the pulse. This being the case, $B_c / \Delta f_r = \text{non-integer}$, and the condition $f_{bb}^{mn} = \text{constant}$ cannot be satisfied. As a result, a phase discontinuity is observed between adjacent channels and the magnitude of the discontinuity, according to Eq (5) is a function of both the difference in the baseband frequency of the rail’s in the adjacent channels and the group delay through the receiver network. Unfortunately, we do not have apriori information of d and herein lays the problem.

¹ Channel bandwidth for BBDev is 32 MHz

² Valid channel numbers for BBDev are 1,3,5,7,9,11,13,15

³ The actual filter function is not important for the purposes of this note so I implement an ideal filter to simplify the development

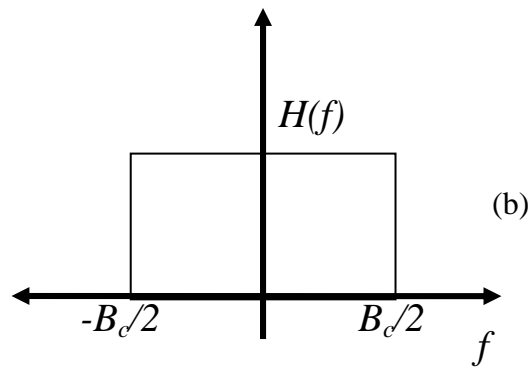
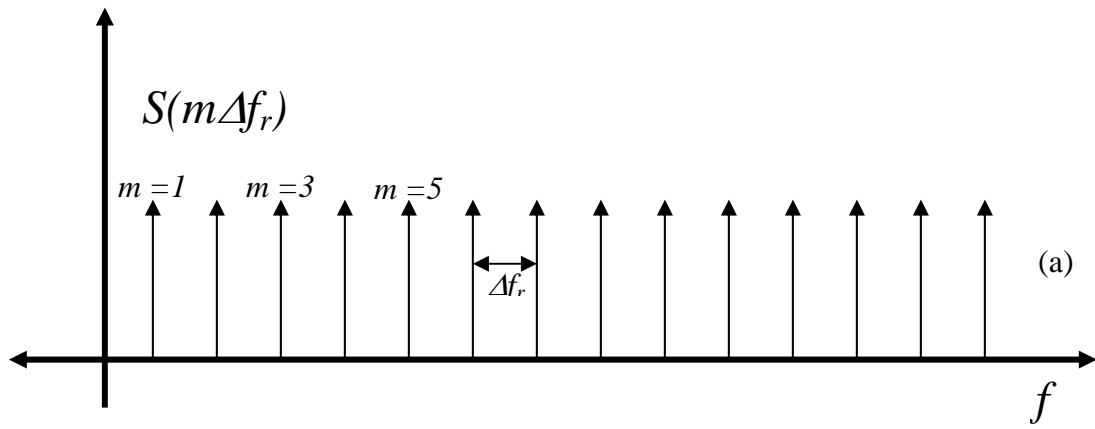


Figure 1: Graphical Representation of $S(m\Delta f_r)$ (a) and $H(f)$ (b)

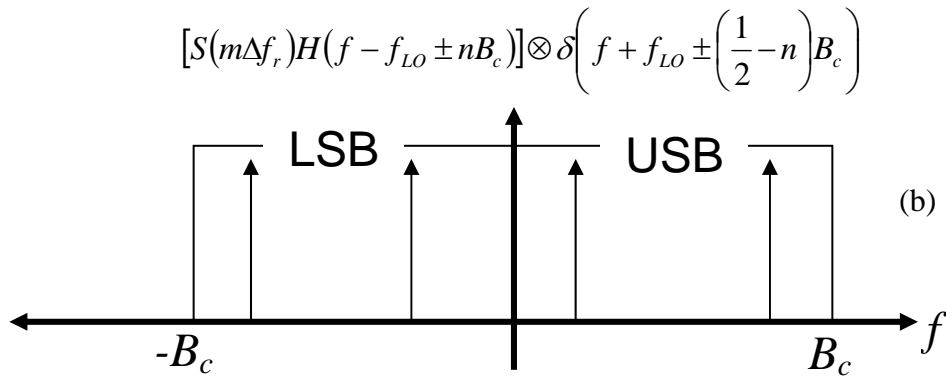
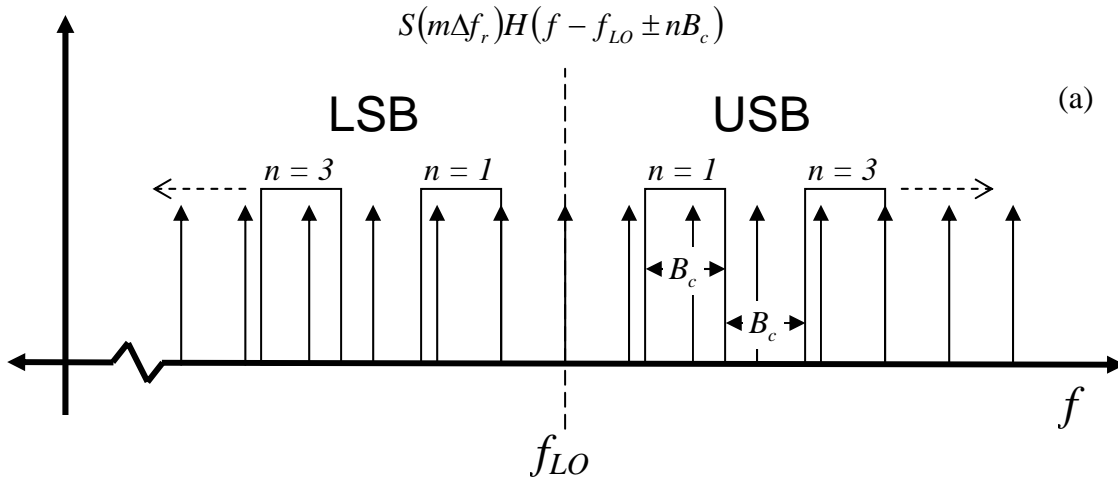


Figure 2: Graphical Representation of Channelized Phase Cal Tones (a) and Phase Cal Tones after Baseband Conversion (b)

Fortunately, multiple rails exist in any given channel. Therefore, from the frequency diversity of the phase cal phase in a given channel it is possible to estimate the group delay, due to the hardware alone, and estimate the expected phase discontinuity so that it may be removed with manual phase cal correction during fringe fitting. In analyzing Eq (5), one can develop an estimate for d if given various f_{bb}^{mn} values and their corresponding phases by fitting the phase vs. frequency to a line, the slope of which provides the estimate of d . With an estimate for d in-hand, the phase discontinuity can be calculated given the baseband frequency of the tones in the adjacent channels.

Calculating Effective LO Frequency for BBDev Receiver

The DBE is “hard-wired” such that Nyquist zones 1 and 3 are always USB and Nyquist zone 2 is always LSB. Furthermore, Nyquist zone 2 and Nyquist zone 3 are a LSB/USB pair since they share the same f_{LO} . From the UDC (Luff) LO frequency, the effective LO frequency, as described in the previous section, is given as follows:

For Nyquist Zone 1:

$$f_{LO} = 4 f_{UDC} - 22500$$

For Nyquist Zone 2,3:

$$f_{LO} = 4 f_{UDC} - 21476$$