GC5016 Application Note:
Digital Down Converter Mode Gain Settings

February 25, 2004

Setting the GC5016's gain in the DDC mode

The objective in the DDC mode is to set the gain variables to prevent overflow in the CIC and PFIR and then to adjust G to achieve the desired overall gain. The cmd5016 program calculates the optimal gain settings based on the desired overall gain. The desired overall gain is set using the cmd5016 keyword *overall_gain*.

Gain is almost always added in the down convert mode. The input data is usually a composite of multiple carriers plus interferers. Once a single carrier has been isolated and all other carriers or interferers (blockers) have been removed, the signal strength can be boosted to optimize the signal's dynamic range in the output data. Six dB of gain is also added if the input data is real, such as data coming from an analog to digital converter (ADC).

The desired amount of gain is usually a combination of a fixed gain component that is a function of the strongest possible signal strength and any fixed RF and IF gains in the system, and a variable gain component that is a function of the minimum signal strength and any variable RF or IF gains in the system. The fixed portion of the gain is set using the *overall_gain* keyword in the cmd5016 input file. The variable portion of the gain is either absorbed by the dynamic range of the output data's word size, or the signal strength is monitored using the GC5016's power meter and the final gain is adjusted by an external controller, or the GC5016's automatic gain control (AGC) circuit is used to adjust the final gain.

Typically the overall gain is set so that the strongest input signal will be output with the correct output crest factor. For example, assume the input signal to the GC5016 is a wideband spectrum containing four carriers and each DDC in the GC5016 will be extracting one of the carriers. Assume also that the front end RF and IF gains are set so that ADC data has a crest factor of 13dB when all four carriers are at full strength, i.e., the RMS level of the four carrier input signal is 13 dB below full scale. If the desired DDC output crest factor is 8dB, then the overall gain should be set to:

+6dB because the input is real,
add another +6dB because each carrier is one-fourth the input power,
add another +5dB for the difference in crest factors.

This means that the overall gain should be +17dB, which is achieved by setting overall_gain = 7.08 = $10^{(17/20)}$.

Note that the overall gain includes an additional 6dB of gain because the input data is real, such as data coming from an ADC converter. The gain of 6dB compensates for the loss of 6dB when tuning a signal down to DC and filtering out its negative image. Mathematically this is illustrated by using an example input signal s(t) modulated up to a frequency of "w". The input is defined as:

$$d(t) = s(t) * \cos(wt) = s(t) * (e^{jwt} + e^{-jwt})/2$$

If this is mixed down to DC using e^{-jwt}, the result is:

$$\begin{aligned} y(t) &= d(t) * e^{-jwt} \\ &= s(t) * (1 + e^{-j2wt})/2 \\ &= s(t)/2 + s(t)e^{-j2wt}/2 \end{aligned}$$

Which, after low pass filtering becomes:

$$y(t) = s(t)/2$$

Hence a gain of 2 (6dB) is required to bring s(t) back to full scale.

How CMD5016 Calculates the Gain settings

Definitions:

NOTE: All variables in italics are key words for the cmd5016 program
overall_gain: User's desired overall gain for each channel, defaults to 2.0
rinf_zpad: Amount of input zero padding, defaults to 0
cic_rshift: Used to extend the CIC decimation range, should always use the default value of 1
cic_dec: Decimation in the CIC, set by the user
cic_shift: Gain adjustment in the CIC, will be set by cmd5016
fir_dec: Decimation in the PFIR, set by the user
fir_shift: Gain adjustment at the output of the PFIR, will be set by cmd5016
gain_msb: 3 MSBs of the AGC gain "G", will be set by cmd5016
gain_lsb: 16 LSBs of the AGC gain "G", will be set by cmd5016
G: 19 bit unsigned fixed AGC gain value, see the keywords above
ZPAD_GAIN: The RMS gain through the zero pad circuit
MIX_GAIN: A fixed gain of ½ in the mixer, prevents overflow in complex input data
RSHIFT_GAIN: A fixed gain of 1 when *cic_rshift*=1, otherwise 0.5.
CIC_GAIN: The RMS gain through the CIC after *cic_shift* is applied
PFIR_SUM: Sum of the PFIR taps, used to give the RMS gain through the PFIR
FIR_GAIN: The RMS gain through the PFIR after *fir_shift* is applied
AGC_GAIN: The nominal gain in the AGC when AGC is turned off
OVERALL_GAIN: The overall gain in the chip (should be equal to *overall_gain*)

The user is required to set *overall_gain*, *cic_dec* and *fir_dec* and the file name containing the PFIR filter taps. The cmd5016 program will use these keywords to calculate the gain settings.

The DDC gain is set by cmd5016 using the following algorithm:

1) Set ZPAD_GAIN=1/(*rinf_zpad*+1)
2) Set MIX_GAIN=0.5
3) Set RSHIFT_GAIN=$2^{(cic\_rshift-1)}$
4) Set *cic_shift* to prevent overflow in the CIC, let N=*cic_dec*
    a. *cic_shift* = floor(40-*cic_rshift*-$\log_2$(N^5*MIX_GAIN/(1+*rinf_zpad*)))
    b. if rinf_zpad > N, then use
       cic_shift = floor(40-*cic_rshift*-$\log_2$(N^4*MIX_GAIN))
    c. If the PFIR filter is symmetric, then use
       cic_shift = *cic_shift*-1
    d. If *cic_shift* <=0, then set *cic_shift*=0 and set *cic_rshift*=0.
    e. Limit *cic_shift* to be between 0 and 39
5) Set CIC_GAIN = $N^5 2^{(cic\_shift-39)}$
6) Set *fir_shift* so that the overall gain is within a factor of 2 of *overall_gain*
    a. *fir_shift* = floor(21-$\log_2$(PFIR_SUM*CIC_GAIN*RSHIFT_GAIN*MIX_GAIN*PAD_GAIN/*overall_gain*))
    b. Limit *fir_shift* to be between 0 and 7
7) Set FIR_GAIN=PFIR_SUM*$2^{(fir\_shift-21)}$
8) Set G = 4096*overall_gain/(FIR_GAIN*CIC_GAIN*RSHIFT_GAIN*MIX_GAIN*ZPAD_GAIN)
   Note: G will be 4096 or greater if the gains are set correctly.
9) Set AGC_GAIN = G/4096
10) Set OVERALL_GAIN = AGC_GAIN*FIR_GAIN*CIC_GAIN*RSHIFT_GAIN*MIX_GAIN*ZPAD_GAIN

OVERALL_GAIN should equal overall_gain.