Response of the 2 Pass Filter with integer tap weights

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Abstract

Effects of truncation on tap coefficients for the 2 Pass Filter proposed for ALMA are examined. It is shown that performances well within specifications can be achieved using 8 bit taps for the first step filter, and 9 bits for the second. Overall stopband rejection is better than 47 dB everywhere, apart from a few channels near the sub-band edges where it is better than 40 dB, and is much better over most of the stopband.

1 Introduction

The 2GC filter is composed of two prototype low-pass filters cascaded together. The response is then moved to an arbitrary point across the input 2 GHz band using a tunable complex mixer.

Each filter uses a conventional FIR design, with exact multipliers at each tap. These multipliers, implemented as look-up tables, produce the integer product of the integer input by a constant tap value. The tap is represented by an integer in a finite range, and thus the filter response is degraded with respect to an ideal FIR with real valued tap weights. Since the filter linearity is preserved, however, tap truncation does not produce other ill effects, as, for example, are caused by data quantization. Moreover, the effect is exactly quantifiable by computing the theoretical response of the actual FIR function used.

For the 2GC filter, tap weights have been computed using standard techniques, and then the real valued weights rounded to N bit integer values, with N chosen in order to produce an acceptable response. Results are examined in the following chapters.

2 First stage filter

The first stage filter has been computed using the Misell algorithm, imposing the passband and stopband limits shown in tab. 1.

	Begin	end	weight
Passband	0.0	$f_s/64$	0.4
Stopband	$3f_s/64$	$f_s/2$	5.0

Table 1: Specifications for the first pass filter. f_s is the sampling frequency (4 GHz). Weight is higher for the stopband, in order to have a better stopband rejection at the expense of more in-band ripple.

The resulting response is equiripple, with a stopband rejection of 50 dB, and a passband ripple of 1 dB. The FIR tap weights have then been truncated to 7, 8, 9 and 10 bit accuracy, obtaining the responses shown in fig. 1. The minimum attenuation was respectively 43, 47, 47.5, 48 and 49.5 dB. 8 bit tap weights give a reasonable compromise between performance degradation and filter complexity.

3 Second pass filter

The second filter response has been computed using a minimization fit program. The goal function to be minimized is the difference of the cascaded response of the two filters, using the actual 8 bit taps chosen

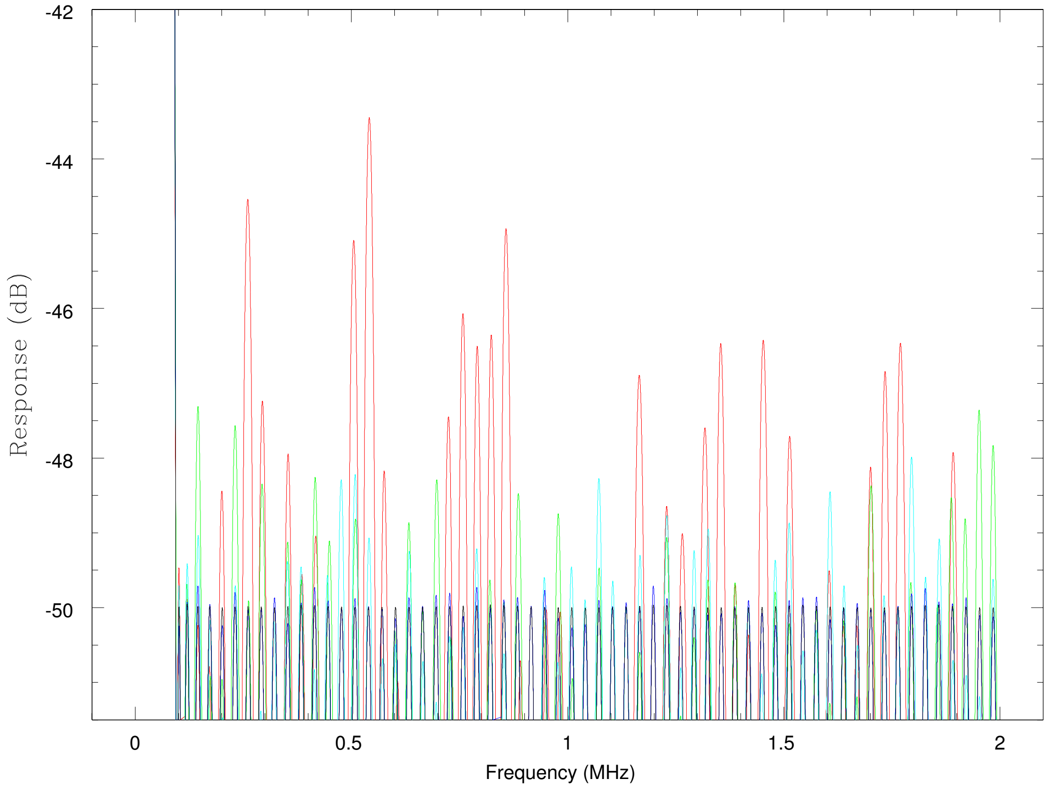

Figure 1: Stopband response of first pass filter. Tap quantization is: red 7 bit, green 8 bit, cyan 9bit, blue 10 bit, black full precision.

for the first filter, and of the response specified in tab. 2. The difference is raised to the 4_{th} power, to give a performance intermediate between an equiripple design and a least square design. In this way, a better stopband attenuation is obtained, at the expense of a slight degradation in the frequencies adjacent to the passband. The minimization is done only in the down-sampled band (0 to 62.5 MHz), as the more critical parameters can be evaluated in this region.

	Begin	end	weight
Passband	0.0	$15/64\,f_s$	1.0
Stopband	$17/64\,f_s$	$f_s/2$	2.0

Table 2: Specifications for the second pass filter. f_s is the re-sampled frequency (125 MHz)

The tap weights have then been truncated to 8, 9 and 10 bits. The resulting passband and stopband responses are plotted in fig. 2. The passband ripple is 0.2 dB ($\pm$0.1 dB) for the full precision tap weights, and is degraded to 0.3 dB for 8 and 9 bit weights. Going to 10 bit improves ripple to almost the full precision result.

Stopband rejection is very bad for 8 bit tap weights. For 9 bit tap quantization the rejection is higher than 40 dB after 2 channels from band edge, higher than 42 dB after 4 channels, and better than 47 dB after 7.5 channels (broken line in fig. 2 right). This is comparable to the rejection from nearby channels due to Hanning tapering. Going to 10 dB improves by 1-1.5 dB the performances in the region near the sub-band edge. The rejection from the folded sub-bands is always better than 48 dB, and is nearly identical irrespective of tap truncation (fig. 3). Due to the two pass architecture, about half the stopband has a total rejection in excess of 90 dB,

Choosing 9 bit tap weight quantization greatly simplifies the filter design, as the Altera FPGAs have

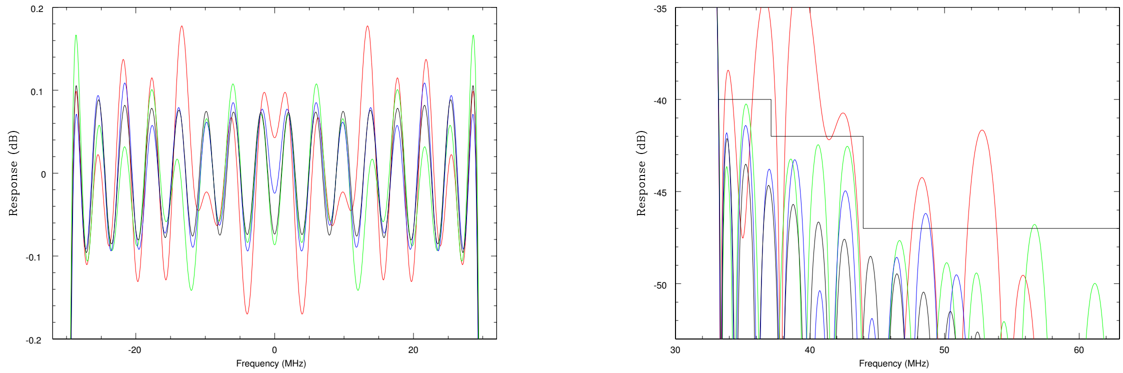

Figure 2: Passband (left) and stopband response of cascaded filters. Different colors refer to quantization in second stage filter taps (first stage taps always 8 bit). red 8 bit, green 9 bit, blue 10 bit, black full precision. Broken line on right plot indicates approximate response for the 9 bit case

hardware multipliers of this size. For this reason, and considering the modest degradation in performance, 9 bit tap weights have been chosen.

4 Conclusions

Tap coefficient truncation to 8 bit and 9 bit for the first and second stage filters degrade the filter performance by an acceptable amount. In-band ripple is raised from 0.2 dB to 0.3 dB peak-to-peak. Minimum stopband attenuation is always better than 40 dB, and better than 47 dB after a few spectral channels from the sub-band edge, compared to 50 dB for a full precision filter.

A Tap coefficent tables

The tap weigths actually used in the first and second stage filters are given in the following tables. Values are listed for positive lags only, as a function of the lag expressed in samples. Taps are evaluated at semi-integer samples, in order to obtain a symmetric filter with an even number of taps.

τ	tap	τ	tap	τ	tap	τ	tap	τ	tap	τ	tap	τ	tap	τ	tap
0.5	127	1.5	127	2.5	126	3.5	125	4.5	123	5.5	121	6.5	119	7.5	116
8.5	113	9.5	110	10.5	107	11.5	103	12.5	99	13.5	95	14.5	90	15.5	86
16.5	81	17.5	76	18.5	71	19.5	67	20.5	62	21.5	57	22.5	52	23.5	47
24.5	43	25.5	38	26.5	34	27.5	30	28.5	26	29.5	22	30.5	18	31.5	15
32.5	12	33.5	9	34.5	6	35.5	4	36.5	2	37.5	0	38.5	-2	39.5	-4
40.5	-5	41.5	-6	42.5	-7	43.5	-8	44.5	-9	45.5	-9	46.5	-9	47.5	-9
48.5	-9	49.5	-9	50.5	-9	51.5	-9	52.5	-8	53.5	-8	54.5	-7	55.5	-7
56.5	-6	57.5	-6	58.5	-5	59.5	-5	60.5	-4	61.5	-4	62.5	-3	63.5	-8

Table 3: Tap weigths for first stage filter

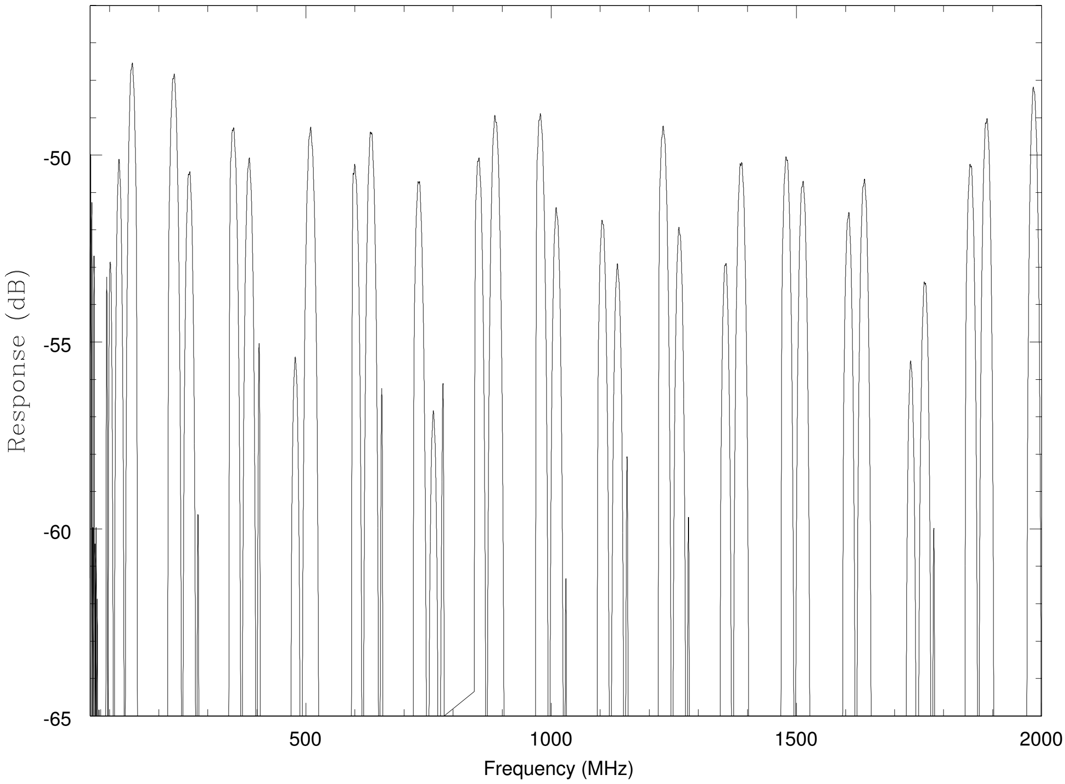

Figure 3: Stopband rejection over the full 2 GHz band for the cascaded filter. First and second stage use 8 bit and 9 bit taps

τ	tap	τ	tap	τ	tap	τ	tap	τ	tap	τ	tap	τ	tap	τ	tap
0.5	255	1.5	80	2.5	-56	3.5	-36	4.5	31	5.5	24	6.5	-21	7.5	-17
8.5	15	9.5	13	10.5	-12	11.5	-11	12.5	9	13.5	9	14.5	-7	15.5	-7
16.5	6	17.5	6	18.5	-5	19.5	-5	20.5	4	21.5	4	22.5	-3	23.5	-3
24.5	2	25.5	3	26.5	-2	27.5	-2	28.5	1	29.5	2	30.5	-2	31.5	-2

Table 4: Tap weigths for second stage filter