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HIGH-QUALITY LOW-COST LOW-FREQUENCY FILTER FOR ADC TESTING

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Abstract – This paper deals with the generation of low-distortion sine wave signal by means of low-cost filter for the purpose of ADC testing at the signal frequency of 20 kHz. The design and manufacture of such a filter is proposed and the functionality of a prototype is verified on a top digitizer.

Keywords: ADC testing, low-distortion signal, signal filtering

1. INTRODUCTION

All dynamic ADC test methods standardized so far assume spectrally pure test signal or the test signal distortion at least 10 dB lower than that of the tested ADC [1], [2]. This condition presented no problems several years ago for the testing of low-resolution low-performance ADCs but it can be hardly fulfilled for the testing of up-to-date digitizers of which harmonic distortion is extremely low. In fact there are two basic ways how to solve this problem.

1. Distorted signal is filtered to the quality satisfying standardized test conditions.
2. Alternative test signals or alternative evaluation algorithms have to be applied.

The first way seems to be apparently easier and more reliable because standardized methods can be applied. However, the design of a filter has to consider several important requests on filter parameters: high linearity, low wide-band noise and impedance matching at filter input and output. High Q parameter is advantageous but not critical; it is mostly sufficient if the second harmonic component is attenuated by the filter enough.

The first point of view is the usage of active or passive design. Although up-to-date operation amplifiers offer good parameters, the maximal reachable THD of active amplifiers is only about –90 dB, which is not sufficient for the testing of many up-to-date ADCs. Thus, passive filters are more advantageous for ADC testing.

The applications of special low-distortion passive band-pass filters have already been successfully proved. They dealt either with a cryogenic filter [3], which main disadvantage is its high operational cost, or with crystal filters [4], where some problems of impedance matching and of low allowable signal amplitude occurred.

Passive RC and RL filters cannot reach high Q and impedance matching of RC filters is problematic, too. These problems are solved by LC filters but on the other hand particularly the design and manufacture of coils bring other problems in general (sensitivity to external disturbances, selection of the core with regard to temperature dependence, linearity and permeability) as well as at low frequencies (mechanical dimensions) and at high frequencies (parasitic capacities).

These problems have already been analyzed in the articles focused on the design of LC filters at MHz frequencies [5], [6]. The prototypes of these filters reached excellent THD (about –140 dB), high resistance to external disturbances, high Q (about 35), low attenuation of the fundamental harmonic component (about –3 dB) and high attenuation of higher harmonic components (about –80 dB). Nevertheless, the components and the manufacture of these filters are relatively expensive and they would also be problematically applicable at low frequencies because of the lack of appropriate capacitors.

In this paper, the design of a low-frequency filter based on the design of high-quality high-frequency LC filters [5] is introduced and the substitution of expensive components for low frequencies is proposed. The suitability of these components and the overall filter performance is verified by experimental results on a prototype of the band-pass filter at the frequency of 20.19 kHz. The application of the filter for high-quality ADC testing is verified on the top NI PXI 5922 digitizer and two generators (ultra low-distortion SR DS360 generator and arbitrary waveform generator HP 33120A).

2. DESIGN OF FILTER PROTOTYPE

The diagram of the filter is presented in Fig. 1. It is a simple 6th order design with 3 resonant LC circuits and

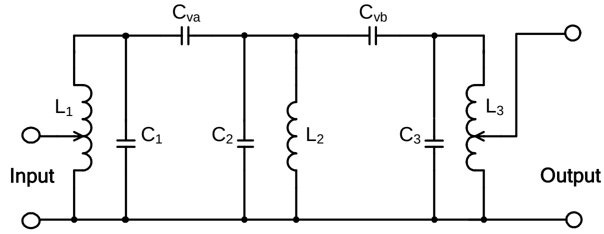


Fig. 1. Diagram of the band-pass filter

capacitive coupling [5] (see Fig. 1). Impedance matching is solved there by a low-impedance branch of the input and output coil.

Components' values were computed for Chebyshev 0.1 dB approximation using known band-pass frequency and capacitors C_1–C_3. The band-pass frequency of 20.19 kHz was chosen witch respect to an existing band-stop filter that could be used for the measurement of the band-pass filter. Polypropylene capacitors 220 nF / 1250V= / 600V~ with metal foil electrodes and 5% tolerance were selected because of their low price, high capacity and high voltage. High nominal voltage of capacitors is needed because of good linearity in low voltage working range. Capacitors with higher capacity could also be used and the inductances needed in resonant circuits could be decreased but this would also decrease the Q_L of coils because $Q_L = \omega L / R_L$, $L \approx N^2$, $R \approx N$. All values of filter components are shown in Table 1.

Table 1. Components' values

C_1–C_3	L_1, L_3	L_2	C_{va}, C_{vb}
220 nF	282 µH	277 µH	4.16 nF

The coupling capacitors of the same type like resonant capacitors were used (polypropylene capacitors 4.7 nF / 1250V= / 600V~ with metal foil electrodes and 5% tolerance).

The most critical part of filter design is the choice of coil cores. With respect to maximal filter linearity the cores must not consist of any ferromagnetic material and their mechanical dimensions must not be very temperature dependent. Taking these requests and also the price into account, glass bottles were chosen for the first prototype. In order to reduce coils' resistances, thick ø 1.5 mm isolated wire was used – the maximal diameter for almost 100% coverage of bottle cylinder surface. The wire was fixed to the bottles by glue and all components were also glued to a board (see Fig. 2).

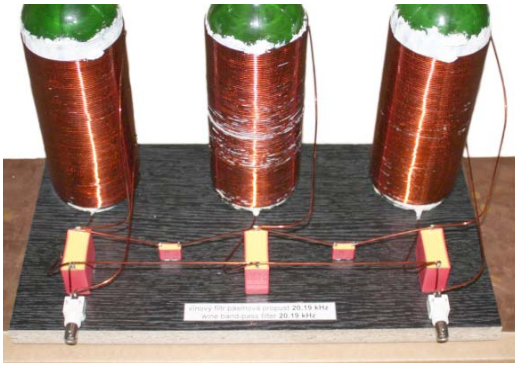


Fig. 2. Prototype of the band-pass filter

Since the capacities are fixed, the tuning of the filter had to be accomplished by means of inductances. Exact resonant frequency of each LC circuit was tuned separately and observed by means of a spectrum analyzer. The low-impedance branches were also adjusted at the end so that maximal accuracy of impedance matching could be reached.

The first filter prototype was designed mainly with the aim of the suppression of parasitic higher harmonic components and with regard to minimal price. Thus, the shielding of each coil as well as of whole filter was not manufactured. This implies an inductive coupling among coils and consequently lower attenuation in band-stop band as well as higher sensitivity to external distortion.

3. FILTER PARAMETERS

Experimental measurements on the filter prototype were performed. In all measurements, the filter was placed so that the distance to surrounding ferromagnetic parts could be enlarged. Copper plate at the bottom of the filter suppressed the most significant external disturbances. The effect of eddy currents in the copper plate was negligible at the operational frequency of the filter.

Measured values of filter attenuation are shown in Table 2. The attenuation is a flat line until 4.5 MHz where parasitic components begin deforming the characteristics. Note that if each of the coils is shielded, the coupling among the coils is reduced and higher attenuation could be expected. Q of the filter was about 19. The most problematic measurement was filter linearity. Although the dynamic range of about 130 dB of the measurement setup was reached by the application of the band-stop filter, maximal amplitude of a generator and minimal digitizer range, higher harmonic content was not measurable.

Table 2. Filter attenuation

harmonic component	1	2	3	4	5	6	7	8	9
attenuation (dB)	6	71	73	73	72	72	71	71	70

4. APPLICATION FOR ADC TESTING

The measurements on the top NI PXI 5922 digitizer and with two different generators (SR DS360 and HP 33120A) were performed. The SR DS360 generator and the NI PXI 5922 digitizer provide high THDs but considering the nominal THD of the digitizer, the generator seems not to be spectrally pure enough for the testing of this digitizer (see Table 3). To verify this hypothesis, the digitizer was tested both directly by the signal from the generator and by this signal passed through the filter (see Fig. 3).

Table 3. Levels of harmonic components of SR DS360 generator

harmonic comp.	1	2	3	4	5	6	7	8	9
level (dBc)	0	−104	−110	−127	−118	−127	−123	−135	−129

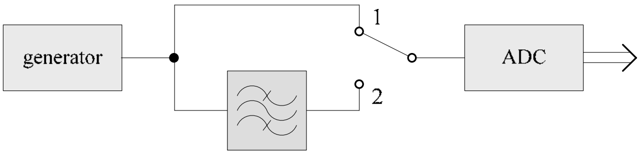
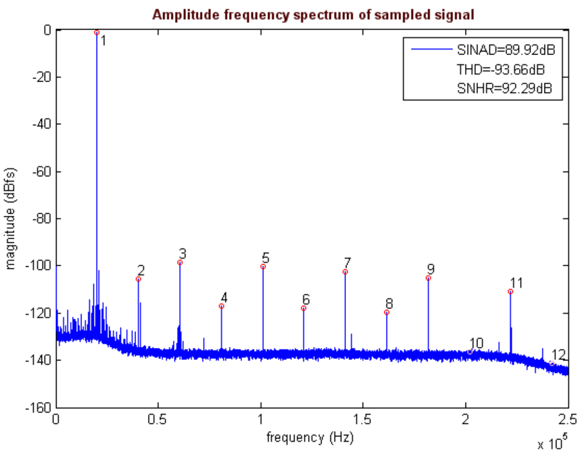
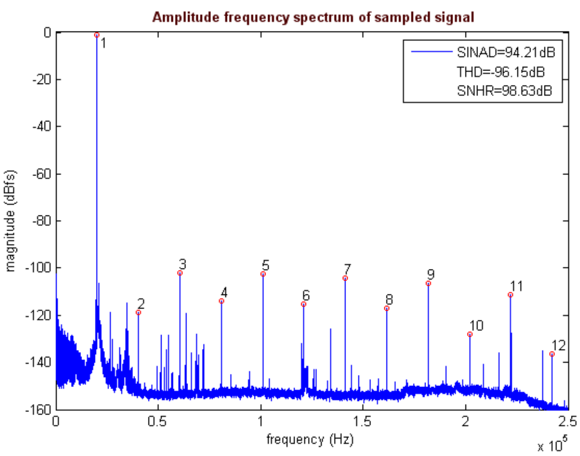


Fig. 3. Measurement setup

Apparently the filter decreased harmonic distortion of the test signal (this is obvious particularly on the second harmonic component) but also significantly reduced wide-band noise. Consequently the measured values of all the SINAD, THD and SNHR are better when using the filter. These values correspond to the actual digitizer performance at the sampling frequency of 500 kHz. The noise at low frequencies and some spurious components that appeared in the amplitude frequency spectra 4b) are caused by improper shielding of the filter; these could be suppressed when the filter is placed into non-ferromagnetic shielding case. In this measurement setup the measured values of the SNHR and consequently the SINAD could be still higher.



a) without filter



b) with filter

Fig. 4. Measured amplitude frequency spectra – SR DS360 generator (Welch average 31×64 kSa, 50% overlapping)

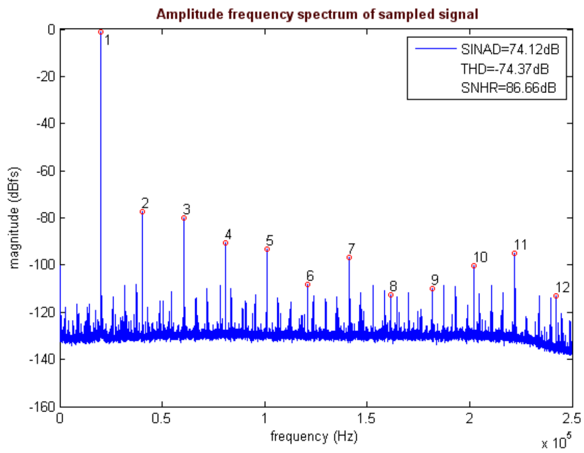
Table 4. Levels of harmonic components

harmonic comp.	1	2	3	4	5	6	7	8	9
without filter (dB)	–1	–105	–99	–117	–100	–118	–102	–119	–105
with filter (dB)	–1	–119	–102	–113	–102	–116	–104	–117	–107

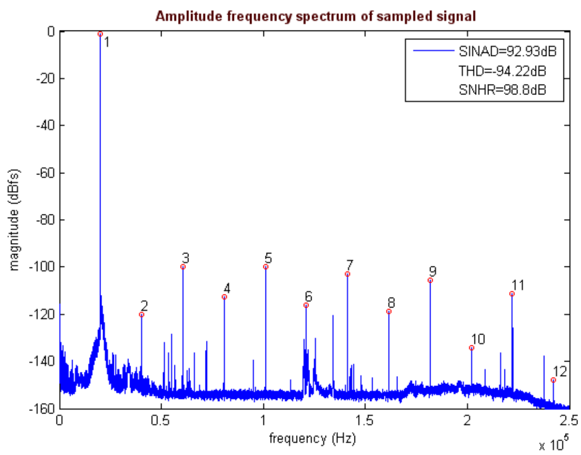
The applicability of the filter was also tested on an arbitrary waveform generator HP 33120A. The parameters of this generator are obviously not sufficient for top digitizer testing but the filtering enables the application of such common generator (see Table 5 and Fig. 5).

Table 5. Levels of harmonic components – HP 33120a

harmonic comp.	1	2	3	4	5	6	7	8	9
without filter (dB)	–1	–77	–80	–90	–93	–108	–96	–112	–110
with filter (dB)	–1	–119	–100	–112	–100	–116	–102	–119	–105



a) without filter



b) with filter

Fig. 5. Measured amplitude frequency spectra – HP 33120A generator (Welch average 31×64 kSa, 50% overlapping)

The distortion of the digitizer was also obtained applying the method of frequency spectrum correction [7] and the generator HP 33120A. The frequency spectrum computed by this method (see Fig. 6) shows practically the same level of harmonic components as in Fig. 4 and 5. Spurious components do not appear in Fig. 6 because of proper shielding but an increased noise appears at low frequencies due to the weakness of this method. This is the reason of slightly decreased values of the SNHR and consequently of the SINAD.

Table 6. Levels of harmonic components computed by the frequency spectrum correction method

harmonic comp.	1	2	3	4	5	6	7	8	9
level (dB)	–2	–113	–106	–112	–104	–115	–106	–116	–108

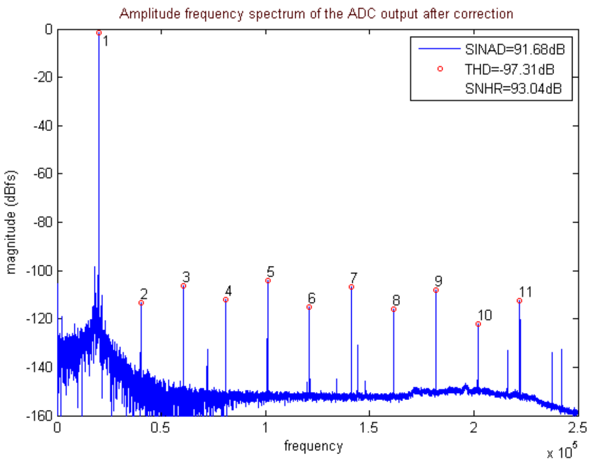


Fig. 6. Amplitude frequency spectrum computed by frequency spectrum correction method – DS 360 generator (Welch average 100×41.5 kSa, 50% overlapping)

5. CONCLUSION

Low-cost prototype of a band-pass filter at the frequency of 20.4 kHz was designed and manufactured. Experimental measurements confirmed the suitability of this filter for the evaluation of harmonic distortion of very linear digitizers (THD > –130 dB). The applicability of this filter was successfully verified by the measurements on the top digitizer NI PXI 5922 with the ultra low-distortion generator SR DS360 and the arbitrary waveform generator HP 33120. The results were in agreement with the results of the frequency spectrum correction method. Slight deviations in results were caused particularly by long-term and temperature instabilities because the measurements were performed at different times.

On the other hand the lack of shielding of this filter caused a rise of many spurious components in the measured frequency spectra. Thus, a new version of this filter with proper shielding is planned. However, the shielding increases the complexity of filter manufacture as well as filter price.

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