Passive Notch Filter: Construction and Application Notes

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August 2, 2018
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1 Introduction

Distortion measurements on a low distortion oscillator are very challenging. The distortion contribution of the analyzer cannot be separated from the actual oscillator distortion. In particular cancellation between oscillator and analyzer distortion may occur, leading to overly optimistic results. For reliable measurement results, the distortion analyzer must have lower distortion than the oscillator to be measured.

I have designed the passive notch filter discussed here particularly for this task. It consists of a RC filter (Hall type) that is preceded by a switchable resistive input attenuator. At the output of the notch filter the fundamental frequency is much more attenuated than the harmonics of the input signal. Thus the dynamic range is reduced and distortion from the following signal chain (e.g. a commercial audio analyzer, or a low-noise post-amplifier plus soundcard) far less likely to be significant.

If activated, the input attenuator reduces the internal operating level of the notch filter. This minimizes the distortion contribution of the filter and allows operation even with high input levels.

To avoid any distortion contribution e.g. from trimmers the notch filter is not tunable. So for each center frequency a separate filter with different capacitor values is required. For my personal use I have built a decadic set with center frequencies ranging from 10 Hz to 100 kHz. To bring the notch filter close to the nominal center frequency, certain resistors are selected during the construction of the circuit. Also capacitors can be matched to minimize degradation of the notch depth.

The passive filters show a rather wide (low-Q) notch response. Particularly the 2^{nd} harmonic distortion of the source is thus significantly attenuated too. A correction factor for each harmonic must thus be applied in post processing.

It is very difficult to estimate the distortion contribution of the notch filter. According to my basic calculations I'd expect the capacitors to be the dominant distortion source. If the internal operation level is set below +10 dBu (see section 3), then the resulting distortion should be well below −140 dBu. Two independent engineers with experience in low distortion measurements have kindly tested my personal set of notch filters. Neither has found detectable distortion contribution at the measurement limites of their setups, which provides some support (but surely no proof) for my assessment. Partially defective components (e.g. resistors with unusually high voltage coefficient), board leakage, slightly oxidized contacts in the switches or input connectors, presence of ferromagnetic materials and other subtle issues could possibly limit the performance further.

Like any specialized tool, these notch filters should be used with careful consideration, and any measurement result interpreted with appropriate caution.

2 Construction Notes

You can find the schematics and Gerber files on my website:
www.nanovolt.ch/resources/low_distortion_oscillators/

- Shown capacitor values are for a 10 Hz center frequency. 10 nF gives 100 Hz etc.
- Resistors are metal/thin film MiniMELF. R11–R14, R18 and R19 shall have 0.1% precision, the others may be standard 1%.
- Capacitors are ceramic C0G, 1206, 50 V or higher. 1% precision is preferred. 100 nF 1% is expensive, so I've used 5% here and distributed them such that the the sum of C1–C10 equaled about that of C11–C20 and C21–C30.
- R15–R17 and R20–R23 are selected to tune the exact notch frequency. First measure the notch frequency without them, then select R15, R16, R20 and R21 such that the notch frequency is just slightly below the desired value. Re-measure and select remaining resistors.
- Switches are e.g. Mouser 633-M2022S2A2G40-RO and 633-M2012S2A2G40-RO.
- BNCs are e.g. Mouser 571-1-1337494-0 (with 571-1-1634816-0 and 571-1-1634817-0).
- Case is e.g. Mouser 546-1457C801E (there's an equivalent without the EMI/RFI seal, which is cheaper).

I recommend that you clean the board after soldering such that no flux or other contamination remains. Particularly in humide and hot climates this could otherwise cause subtle distortion issues.

3 Application Notes

- For very low distortion measurements I recommend that the input attenuator is set such that the level to the actual filter is below +10 dBu. A second measurement with 10 dB higher attenuation may serve to gain higher confidence in the measurement result.
- I've measured the frequency response of each filter (in every attenuation setting, including the post-amplifier and using a suitable source impedance) and use this for software correction. But of course you can just use calculation/simulation if you don't need best accuracy.
- I'm using a battery powered, OPA827/AD8001 based, 40 dB post amplifier. The design is not yet optimal and I want to do a redesign first before sharing. But any reasonably low distortion/low noise design should work.