The CALF: A Selectable Audio Filter

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Introducing the CALF

An audio filter is a useful accessory for any receiver lacking desired selectivity, or as a building block in a direct conversion receiver. Particularly in many vintage and home brew receivers it has been a steady theme to consider adding audio filtering. In the case of the direct conversion receiver, the lack of an intermediate frequency implies that all filtering must be accomplished at audio after the product detector. Active filters using operational amplifiers (‘op amps’ for short) are ideal for providing needed audio selectivity, in some cases in conjunction with providing most of a receiver’s gain. The Configurable Audio Limiter Filter (CALF) provides a selectable filtering solution with a unique do-it-yourself theme where you can choose your filters.

Some may critique that op amp filters are an old technology which indeed is true. However, in surveying the available technologies (Table 1) op amp filters have discriminating attributes that merit their use especially in low cost applications and those seeking low current consumption. While at first glance the SCAF and DSP solutions have appeal for their inherent adjustability, a small bank of op amp filters provides adequate selection for most operating. I find that for CW operating in the shack I tend to favor only a couple selections from my larger rigs, such that the CALF still provides luxury in offering many bandwidth settings. While those operating HF rightly favor high selectivity over audio fidelity, when the bands are not so crowded there is enjoyment of a more pleasant sound from a good direct conversion receiver. Those building simple field friendly rigs can conclude that including a couple op amp audio filter selections will serve them well.

The CALF, developed and kitted by author KC9ON, does the heavy lifting in providing a robust selectable audio filtering platform. The circuit board hosts six audio filters as well as a limiter that is useful for ear protection, reducing the level of static crashes, and as an aid in weak signal detection. Moreover, the circuit board is arranged so that the builder can also design and install audio filters of their own design. These features attracted author WB8YYY to the CALF as an improved audio filtering solution for use with my HW8 and HW16 receivers. This article integrates the candid review of the builder as well as further insight from the CALF designer. Our intent is to guide you into creating the audio filtering that you wish to operate with.

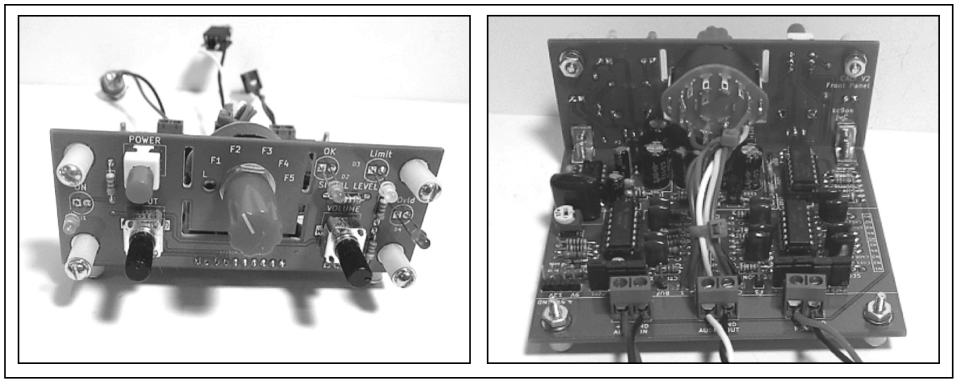


Figure 1—The Configurable (or CW) Audio Limiter Filter is realized with two high quality PC boards and nice front panel controls.

Alternative	Advantages	Disadvantages
Op Amp Filter	Ability to optimize filter shape for best reception fidelity. Easy to design with modern on-line tools.	Few. Need a separate stage for each setting but these are very low cost.
Switched Capacitor Audio Filter (SCAF)	Tunable and easy to design from manufacturers information.	Higher noise lends them to back end stages. Lower fidelity than optimized fixed filters.
Digital Signal Processing (DSP)	Usually many bandwidth selections and other features.	Tends to be higher current and higher cost.

Table 1—Three excellent IC based filtering technologies are available to amateurs.

This article describes experience in building the CALF, and applying it as an accessory or a receiver building block. The CALF was developed due to discussions on filtering by author KC9ON with Glen, KK4LPG who provided valuable assistance in designing the CALF active audio filters.

Building the CALF

The CALF (Figure 1) consists of a main PC board and a second board hosting the front panel. All parts are provided by the kit available from KC9ON, also including mating connectors for power and audio. On the front panel are:

- a nice rotary switch that selects from 6 different audio pass bands
- input and output audio level potentiometers
- LED indicators that convey the amount of limiting that is occurring
- a power switch, which bypasses the audio when turned off

The main board hosts op amp stages with the integrated limiter and provides a LM386 final audio amplifier. A unique feature is providing three IC sockets that are available for the builder to install various audio filters. The kit contains the components for 6 band pass filters that range from supporting AM signals to narrow CW filtering. The socket arrangement allows any of these 6 filters to be replaced by filters of the builder’s design. The well laid-out PC boards convey the experience of the designer and employ high quality construction including full solder masks. In contrast to many projects the authors have completed, the front panel circuit board greatly simplifies the wiring which is

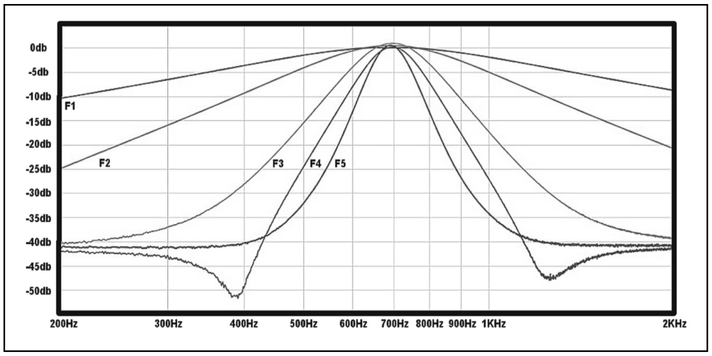


Figure 2—Graph of the stock filter responses. The kit contains parts for these six selectable filters, and also contains sockets to allow builders to design and modify filters of their own design.

appreciated. The few wires needed are for connecting the switch terminals to the main PC board and for the 3 connectors, using diversely colored wires supplied in the kit. The user only needs to supply a case, if desired, and any capacitors/resistors required to implement custom filters.

Characteristics of Op Amp Based Audio Filters

Audio filters historically have been built with inductors and capacitors, commonly called LC filters. Some excellent filters can be realized with this technology but they require rather large inductors and capacitors. The active audio filter now more commonly used relies on the behavior of electronic operational amplifier (op amp for short) circuits to realize good filters with only resistors and capacitors. Additionally, the very high input impedance of op amps gives very high isolation when cascading filter stages, greatly simplifying design. The specific arrangement of RC components in an active filter determine whether the network is a low pass, high pass, band pass or band reject filter. For our applications both low pass and band pass filters tend to be the more useful versions. The authors suggest skimming one of these excellent tutorials on op amp active filters to appreciate the background, but it is not essential to comprehend all of this background to design useful filters when led to stay within the appropriate boundaries.

Op amp active filters are clearly an old technology. They were the mainstay of direct conversion transceivers of an earlier era, and commonly available as an accessory for older receivers lacking selectivity. Articles in *QST* and other journals prescribed how to home brew one of these filters. Since then, higher performing op amp devices with much lower noise are widely available and very low cost. The authors advocate determining the filter characteristics that you desire and implementing them, either in your home brew design or in using the CALF.

In addition to op amp based audio filters that tend to be fixed in their behavior, another technology known as the switched capacitor active filter (SCAF) has emerged. SCAF devices lend themselves to easily realized tuning. A popular example in the QRP community is the NESCAF. While the SCAF is an effective filter for reducing receive bandwidth (and thereby the received total noise level), it has very different attributes than an op amp filter which allows the designer to create a better frequency

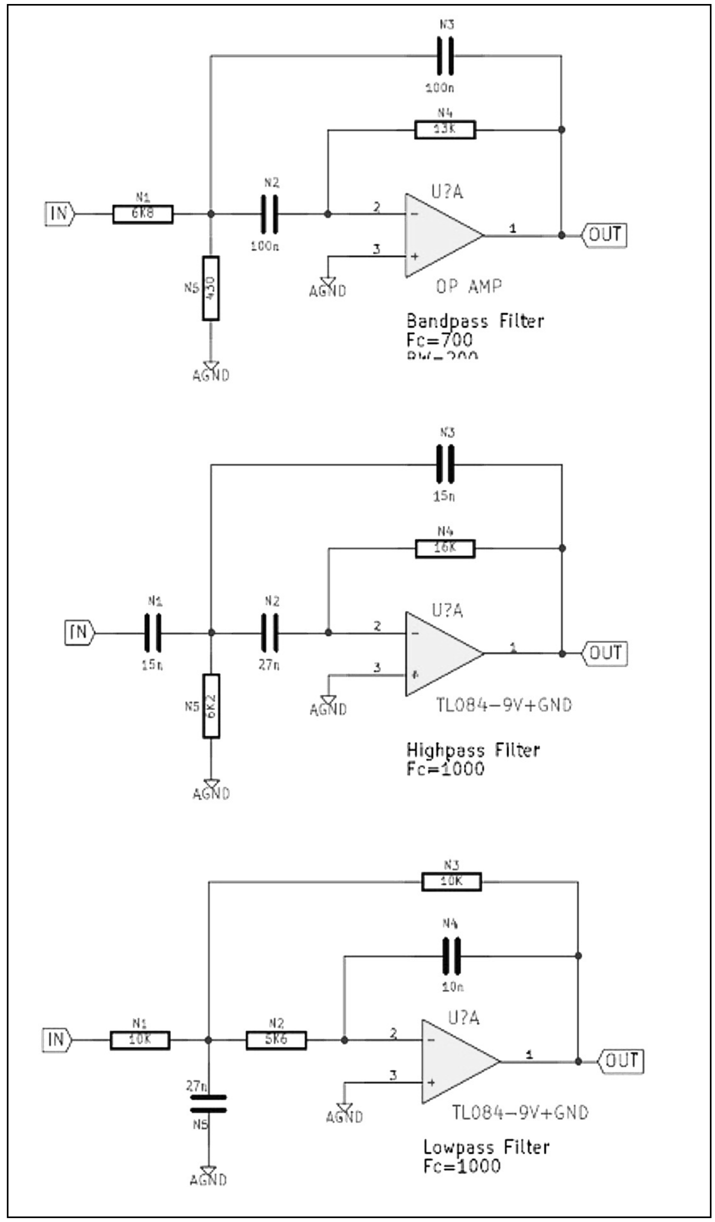


Figure 3—These active filtering networks can be transformed between low pass, high pass and band pass networks by the arrangement of resistors and capacitors. The CALF supports installing all three types of filters.

response at a given bandwidth. SCAF filters add appreciably more noise than a modern low noise op amp filter, and hence should be placed close to the end of the audio chain. A nice receiver example is the NC2030 that integrates both fixed op amp and tunable SCAF filtering. After experiencing both a SCAF and the switchable fixed filters within the CALF—one may indeed prefer the latter approach for its cleaner receiving sound.

You Too Can Design Good Audio Filters

Indeed the enterprising amateur can design useful active audio filters, with only a little guidance needed. These can be hosted within the CALF, or built with any appropriate construction approach. Unlike RF filters, the stages in these active filters are well isolated by the op amps so they can be designed as simple,

component	bank 1	bank 2
N1	2.67 kΩ	1.74 kΩ
N2	2.21 kΩ	1.18 kΩ
N3	5.36 kΩ	3.48 kΩ
N4	10 nF	10 nF
N5	33 nF	68 nF

Table 2—The CALF was reconfigured with 2 low pass filters designed for SSB reception, an easy design using the referenced design tool. The remaining stock filter narrower settings are used at WB8YYY for CW reception.

individual filters. Each individual stage can be low pass, high pass or band pass. Note the arrangement successively cascades these stages, so they should be arranged from wider to narrower bandwidth in their sequence. The CALF circuit board is designed to accept two-pole filters of multistage topology, implying that each filter will be realized with 6 discrete components. While these filters may be designed using equations, it is much easier to employ a freely available design tool—TI's Filter Pro.

The following steps will allow the builder to evaluate other filter designs for installation within the CALF:

1. Use a computer tool that designs active audio filters, such as TI's 'Webench Designer' (an on-line tool) or their previously developed 'FilterPro' (a downloadable design tool).

2. Select the type of filter, such as low pass or band pass.

3. Select the center frequency, pass band and rejection characteristics.

4. For use on the CALF circuit board, select the Multiple Feedback topology.

5. The filtering characteristic is also selectable. The authors suggest using a Bessel characteristic to obtain the best sounding response for pulsed (on off keying of CW) signals. Alternatively if you have a stronger preference for sharper rejection consider the Chebyshev characteristic instead.

6. Select the desired gain level for the individual filter stage. Since the CALF consists of cascaded stages, it is recommended to set each for unity gain, or a slight gain such as 2.

7. The design program allows selecting one of the capacitors, which can be a convenient value from your available parts. 10 nF is often a good value to use, but this can be iterated to see what other component values are generated.

8. Execute the program to obtain the component values required for the desired filter characteristic, and iterate the design as required around parts required and performance.

Note that the CALF circuit board arrangement is successively switched, meaning that it is generally best to locate the widerst filter first and then each filter could be chosen to be narrower in bandwidth than the prior filter. However, one can also try differing center frequencies and other creative ideas for successively cascading filters. This is why CALF has the experimenting jumper blocks in the rear to reconfigure the order of any installed filters.

A few tips from the CALF designer in realizing your own filters: 1) Keep gain <10 per stage; 2) Keep the Q <10 per stage to avoid ringing and other distortion. 3) Make use of the capacitor/resistor tolerance settings in FilterPro to suit the parts you have on hand. Typically John uses E24 (5%) resistor values and E12 (10%) capacitor values; 4) When changing the capacitor value, try to also keep resistance as low as possible. Large megohm values will increase the noise.

Deciding the provided narrow filters 3 through 6 were just fine as is, author WB8YYY chose to focus on the first 2 filters. John realized these as band pass filters, while I decided it would be interesting to explore low pass filters with SSB signals in mind. Based upon John's suggestion I decided to design these first two filters as one 4 pole cascade seeking my intended bandwidth—knowing the first stage can also be individually selected with wider bandwidth. Staring at the CALF schematic, each stage in the stock filters has a gain of approximately 2, the ratio of N3/N1, which is a little to make up for component losses. The selected characteristics: gain equal to 4, a 1.8 kHz passband, –45 dB rejection at 5 kHz, and a Bessel filter characteristic. Within the tool one chooses a 'seed' capacitor which I set for 10 nF. Knowing that these wide filters are a bit forgiving I did not fret with tolerances. I had close values for all but the N3 parts—these were still within about 5 or 6 percent which is adequate for these wide filters. The resulting wide bandwidth filters sound very nice in receiving SSB.

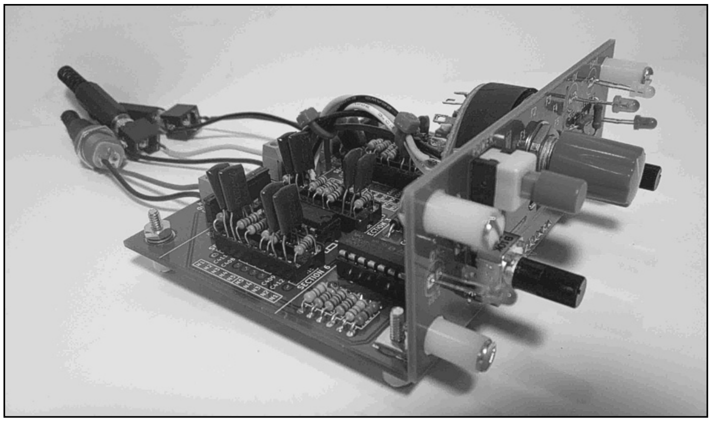
Evaluating the CALF

This section contains the candid review of builder WB8YYY. The CALF was first constructed with its stock filters. No unusual issues were noted in construction, well, except for learning how to read an additional color stripe in the included 1% tolerance resistors. Upon assembly it was noted a much higher loss when a particular filter was selected, and because of the cascaded architecture it then affects every subsequent filter selection. This is a clue that an improper resistor may have been installed. As the gain of each stage is determined by the ratio of the feedback (N3) resistor to the input resistor (N1), this is an obvious disruption to keep in mind when troubleshooting. This allowed me to quickly locate where my mistake was made.

The builder may directly mount the 'stock' CALF filters to the board, but it is more fun to mount the included IC sockets that allow 'plug-and-play' of various filters that the builder can design (Figure 4). These sockets worked well for parts with thick leads, but the supplied 1% resistors have rather thin leads—these were difficult to install and some were found to be a bit intermittent in making contact. I finally decided it was easier to mount the filter parts into a second socket, and then mate these with the circuit board sockets. After listening carefully to each of the filters, I decided to solder the parts to the upper socket to avoid any future problems with intermittent connection. If I ever wish to experiment with different filters the only cost is another IC socket.

After successful assembly the CALF was plugged into the HW8 headphone output. As my HW8 is entirely stock, it suffers from poor selectivity as well as distorted receive audio (made worse by directly plugging in modern low impedance headphones as the HW8 was intended to use high impedance headphones). I did make one modification to the CALF, deciding that I prefer locating the headphone jack on the front panel and replacing the provided mono jack with a stereo one. Not finding a suitable location on the CALF's nice PC board front panel, I took a thin strip of material and loosened the mounting hardware on the rotary switch. This thin front panel extension stays in place when the rotary switch is reinstalled.

My immediate impression in using the CALF was "Wow". I discovered that lurk-



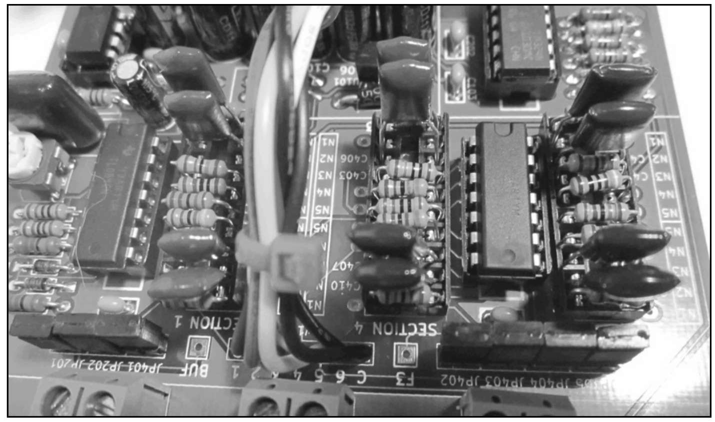


Figure 4—The CALF circuit board design features available sockets (there are 3 of them next to the ICs) that can be used to experimentally reconfigure the 6 selectable filters.

ing inside the HW8 is a very clean sounding, direct conversion receiver when a better audio chain such as the CALF is attached. In using the CALF, it is best to reduce the audio gain of the HW8 to a very low setting thereby reducing the drive to its final audio amplifier. My first exposure to a clean sounding direct conversion receiver was the excellent Fort Tuthill transceiver by K7VE. My own subjective assessment of the HW8 plus CALF is that it sounds nearly as good. Moreover, the ability to select 6 different pass bands may be a bit extravagant—the ability to gradually dial down the bandwidth is very nice. Literally, the CALF transforms the HW8 from a mediocre receiver to a very nice one in both selectivity and pleasant sounding signals. When a direct conversion receiver is appropriately designed and built, its audio quality cannot be matched by typical superhet receivers whose crystal filtering, while nice for selectivity, introduces distortion. A brief note about the limiter function: with careful adjustment of the CALF's input audio level control and noting the useful front panel LEDs that convey when the limiter is being engagedthe operator can optimally set the level into the CALF. I find that I keep the rig's audio gain at a low fixed level and exclusively use the CALF's input and output audio controls.

Applying the CALF

The CALF has multiple uses:

1) accessory audio filter
2) receiver audio section
3) test bed to evaluate audio filters for use in homebrew receivers.

Its use with the HW8 as an enhanced audio section has already been noted. Another application is using it to implement the back-end audio stages of a direct conversion receiver by adding a product detector front end. Perhaps the builder could build the VFO and receiver front end on a separate un-etched board and place it in an enclosure along with a CALF. Finally, the CALF is a platform that can evaluate audio filter designs against actual signals prior to including it in your next rig design. Possibly this nifty, very affordable configurable audio limiter filter would be very useful in your shack.

References

1. WB8YYY regularly employed a MFJ-720 with his HW16 to improve its selectivity and also eliminate a little residual power supply hum, plus a SCAF audio filter with his HW8. KC9ON developed the CALF to add selectivity with his HW8 and IC725 transceivers.

2. Dan Tayloe, http://www.azscqrpions.org/Tuthill_filter_presentation_08-09.pdf Briefing on the Fort Tuthill Transceiver describes applying op amp filters introducing TI's provided design tool.

3. CALF kits and other related notes are available from KC9ON at http://3rdPlanetSolar.com

4. Tips and tricks to using the CALF: http://kc9on.com/ham-radio/code-reception/

5. KC9ON discussions with KK4LPG were hosted on the HW-8 Yahoo Group. Glen has a wealth of info with his own AFX project http://geocities.ws/glene77is/Articles_ET-2.html.

6. Thomas Kugelstadt, Active Filter Design Techniques, chapter 16, Literature Number SLOA088 from Texas Instruments (available on line).

7. Analog Devices, Op Amp Applications, an on-line text book with a wealth of history, theory and practical design using these devices.

8. Dan Tayloe, N7VE, "Using Active Filter Design Tools," *2014 ARRL Handbook,* Chapter 11, Companion CD.

9. Doug DeMaw, W1FB, *QST* April 1983, describes theory and construction of an example audio filter oriented toward beginners. (WB8YYY note: I built this filter years ago, and plugged it into a portable shortwave receiver for listening to CW. I remember a narrow filter with a dreadful sound resulting from both the filter being too sharp and the noisy op amps that were inexpensive in that era. The author did warn that the filter would work better in front of the final audio amplifier. That board may be in my junk somewhere).

10. Howard Berlin, W3HB, *QST* June 1977, describes theory behind multiple-feedback topology active filters and guides application.

11. Jim Kocsis, WA9PYH, *QST* June 2006, describes designing a compact audio filter for use in the MFJ-9040 transceiver.

12. Using information on the MF10 SCAF data sheet the resulting noise figure is estimated to be around 33 dB.

13. http://www.norcalqrp.org/nc2030.htm

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