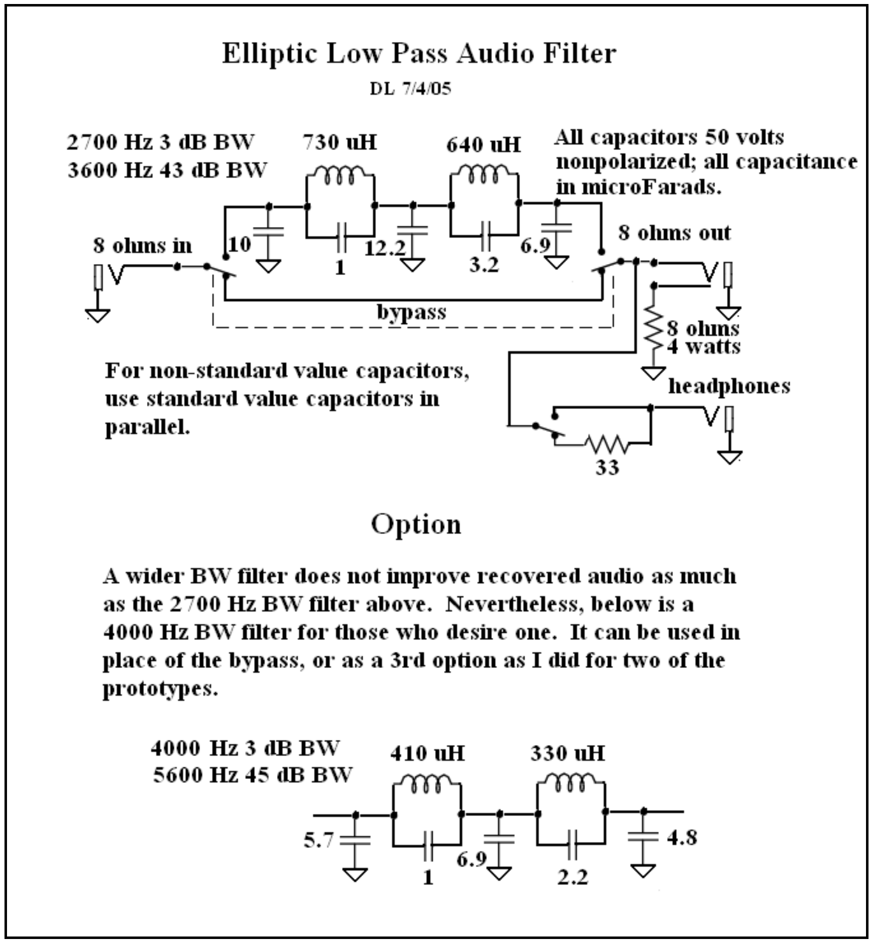
Elliptic Low Pass Audio Filters

Dallas Lankford, 7/4/05, rev. 5/26/08

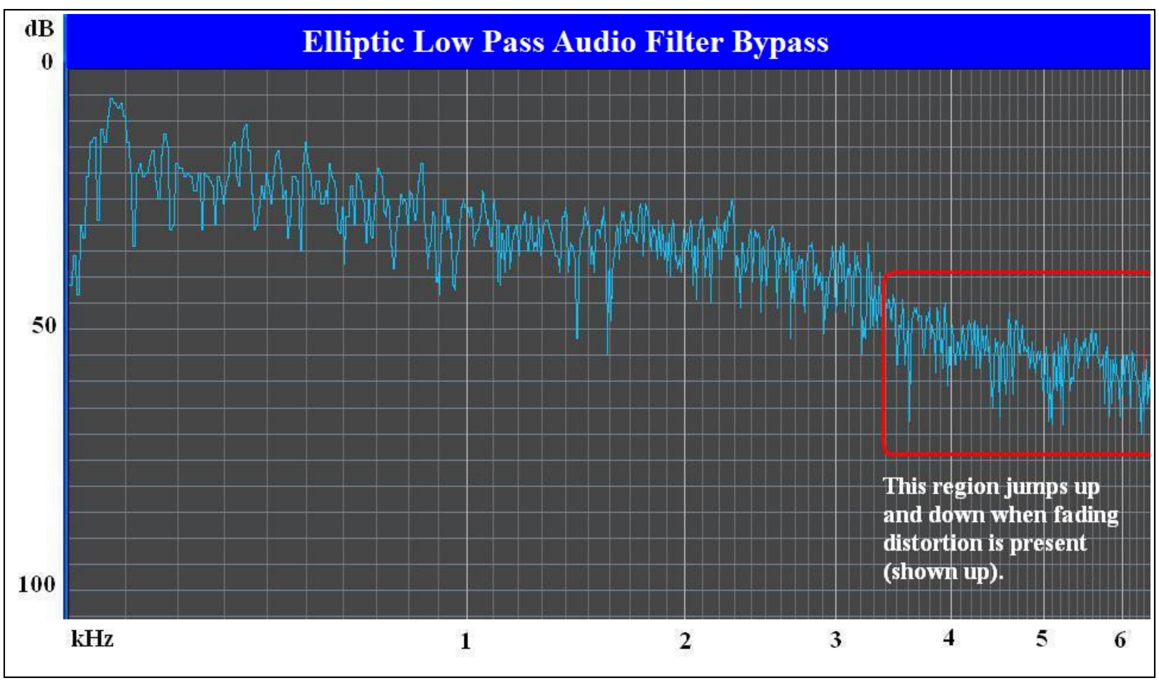
There are a number of different accessories which claim to improve recovered audio from strongly fading MW and SW signals, including various audio filters and AM synchronous detectors, and for which designers, sellers, and users have often given glowing praise. But according to my ears there is only modest improvement due to these kinds of devices when the receiver used with these devices has a suitably slow AGC release time and the signal is off tuned. The distortion which one hears from strongly fading MW and SW signals manifests itself as high frequency sound akin to noise. So it would seem that an appropriate low pass audio filter should substantially improve the audio quality of strongly fading MW and SW signals. However, the audio filters I tried did not. I suspected that either the cutoff frequencies of the filters were not appropriate, or the shape factors (roll off) of the filters were not appropriate, or both, or that other factors were responsible for the lack of significant improvement of the audio. For example, many audio filters roll off the low frequencies, giving the audio a tinny sound, which degrades audio quality in my opinion. And some digital filters, such as the Timewave DSP-599zx filter, have annoying digital artifacts. Rather than spend thousands of dollars for audio filters with variable cutoff frequencies and steep attenuation roll off, such as the Stanford Research 640, which still might not be satisfactory and which might require additional circuits, I decided to design and build such audio filters myself; see the schematics above.



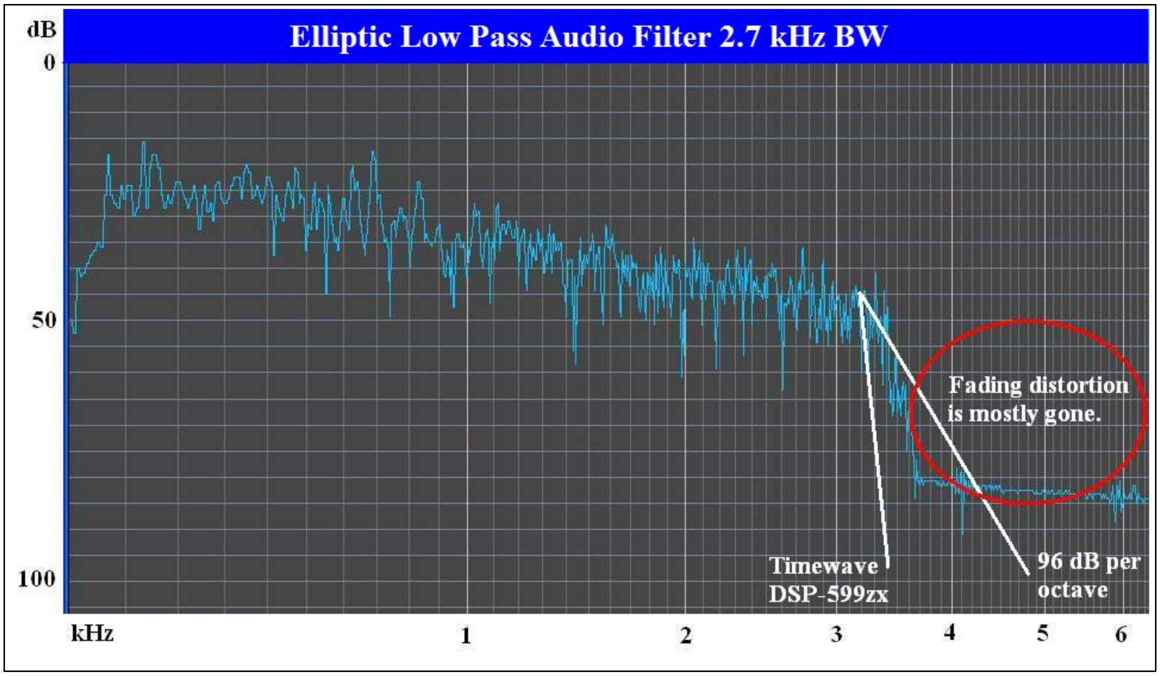
After considering possible kinds of audio filters, it seemed to me that elliptic filters, if the inductors and capacitors could be scaled to practical values, might provide the sufficiently sharp cutoff I wanted. Also, elliptic filter tables (in ARRL Radio Amateur's Handbooks) allowed me to easily determine component values for whatever cutoff frequencies I wanted, and to scale the values for 8 ohms. As it turned out, the component values for 2.7 kHz and 4.0 kHz cutoff frequency elliptic low pass filters were practical. The voltage for 2 watts into 8 ohms is 4 volts, so I used 50 volt non-polarize capacitors for greater power handling capability. The current for 2 watts into 8 ohms is 500 mA, but I could not find any high Q and suitably high current off-the-shelf inductors. So I wound the inductors on Amidon FT-82-61 toroids (µ = 125) using #24 enameled copper wire. Because there is no formula for calculating the number of turns for multilayer toroids, the numbers of turns were found by trial and error using an AADE inductance meter (L/C Meter IIB; www.aade.com).   I used between 2 and 3 (close wound on the inside circumference) layers of #24 enameled copper wire, about 95 turns for 740 µH and about 89 turns for 640 µH. Between 5 and 6 feet of #24 wire was used for each inductor, which provided excess wire (better too much than not enough). For 410 µH and 330 µH the turns were 72 and 65 respectively. The 8 ohm resistor at the output (which is switched by the 1/4 inch plug) provides the necessary 8 ohms filter termination when a speaker is not used. ***The filter input of the filter should be connected to the 8 ohm speaker output of the receiver. Otherwise the shape of the filter may be degraded. (***However, after after much subsequent testing I have found no cases where using the headphone output of a receiver degraded the filter performance, although signal levels may not be adequate without amplification.) Originally switched 33 ohm and 330 ohm resistors were used for low and high impedance headphones. However, it has been found that for some receivers, such as the ICOM- 746Pro, these resistors in the headphone signal path cause severe audio distortion at high volume levels. For this reason a different switching arrangement has been implemented, where one headphone signal path contains no resistor; see the schematics above and below.

An audio spectrum analyzer was used to examine the shape factors of the elliptic low pass audio filters and to study the nature of fading distortion. The best audio spectrum analyzer I found for these purposes was WavePad; see www.nch.com.au/wavepad . Two "snapshots" of the WavePad spectrum display are given below. The receiver used for these measurements was an R390A with a (modified) 6 kHz BW and FAST AGC.

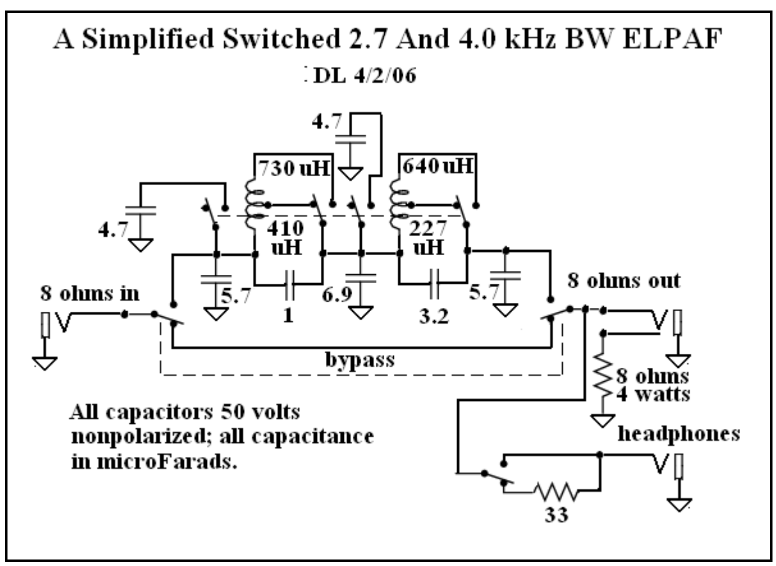
The first spectrum snapshot below, without filtering, shows where most of the fading distortion occurs, namely in the frequency range above about 3500 Hz.



The second spectrum snapshot below shows the audio typically obtained with the 2.7 kHz BW elliptic low pass audio filter. The rolloff of the 2.7 kHz BW elliptic filter appears to be better than 96 dB per octave, but not as good as the Timewave DSP-599zx (which is indicated on the snapshot). Also, the stopband of the 2.7 kHz elliptic filter is not nearly as deep as the Timewave DSP-599zx. But based on performance, the the elliptic filter stopband, both in the 2.7 and 4.0 BW's is more than adequate; cf. the comparisons with AM synchronous detectors below.



Winding four toroids with between 65 and 96 turns of #24 enameled copper wire is quite tedious. So I thought about how I could implement the 2.7 and 4.0 kHz BW filters using only two toroids with taps. As it turned out it can easily be done in an obvious manner (using two tapped toroids, and switching capacitors) with the with a 6 pole double throw toggle switch. But I could find none in my catalogs. A high quality 6 pole double throw rotary switch is available for about $30, Electroswitch part # D4G0603N (Mouser 690- D4G0603N), so the switched filter can be implemented that way. By taking some minor liberties with the filters designs, a 4 pole double throw toggle switch can be used. I used Allied Electronics 676-3280 large lever C&K toggle switches, about $16, rated at 100,000 make and break cycles. The bypass shown in the schematic at right is optional. Because there is no 5th toggle switch position, the 2.2 and 3.2 µF capacitors cannot be switched for the simplified filter; so the 330 µH inductor was decreased to 227 µH (about 55 turns) to give the same resonant frequency for that parallel LC. And because there is no 6th toggle switch position, the output capacitor cannot be switched for the



simplified filter; so the intermediate value of 5.7 µF was used in place of switching 4.7 µF and 6.9 µF.

I have been using an elliptic low pass audio filter with switched 2.7 and 4.0 kHz BW's for almost a year now and have compared it with many AM synchronous detectors on numerous cases of fading and other distortion. All of the comparisons were made with the receivers set for FAST AGC release so that the AM synchronous detectors would have the maximum potential for improving recovered audio. The ELPAF 4.0 kHz BW reduced fading distortion much more than the AM synchronous detectors used in the Racal receivers RA6790, RA6793(A), and RA6830, in the NRD-525 receiver, and the external AMSD-2. In fact, the AM synchronous detectors in those receivers and in AMSD-2 reduced fading distortion very little, if any. The ELPAF 4.0 kHz BW reduced fading distortion almost as much as the AM synchronous used in the Drake R8B and the Watkins Johnson WJ-8711A (the mil version of the HF-1000A). Both the R8B and the WJ-8711A (HF-1000A) appear to have some audio filtering built in, and I have found no way to defeat that built in audio filtering. So the comparison of those AM synchronous detectors to the 4.0 kHz BW ELPAF was probably not a fair comparison, with the unfair advantage going to the R8B and WJ-8711A (HF-1000A). The ELPAF 2.7 kHz BW reduced fading and other forms of distortion almost as much as and in some cases more than the R8B and WJ-8711A (HF-1000A) in tough AM DX situations, such as for MW splits, for nighttime MW graveyard channels, and for foreign MW signals on domestic frequencies with domestics deeply phased.

Of course, ELPAF's never growl or otherwise lose lock because they are not AM synchronous detectors. And, of course, the receiver with which ELPAF's are used can be tuned so that either the upper or lower sideband of the AM signal (or any contiguous segment of the AM signal containing the AM carrier) is selected (to minimize adjacent interference), which is not possible with the WJ-8711A (or HF-1000A). ELPAF's were not designed as accessories for program listening, but rather for DXing. Nevertheless, the 4.0 kHz BW has quite good fidelity and is as good as or better than most, if not all, AM synchronous detectors for program listening.

It has been almost 3 years since I designed and built these ELPAF's and wrote most of this article (above), and I am still as satisfied with my elliptic low pass audio filters today as I was then. An amplified version, which I currently use regularly, is described in the article below. It is made with off the shelf inductors and includes an excellent amplifier, which simplifies and improves the basic design.

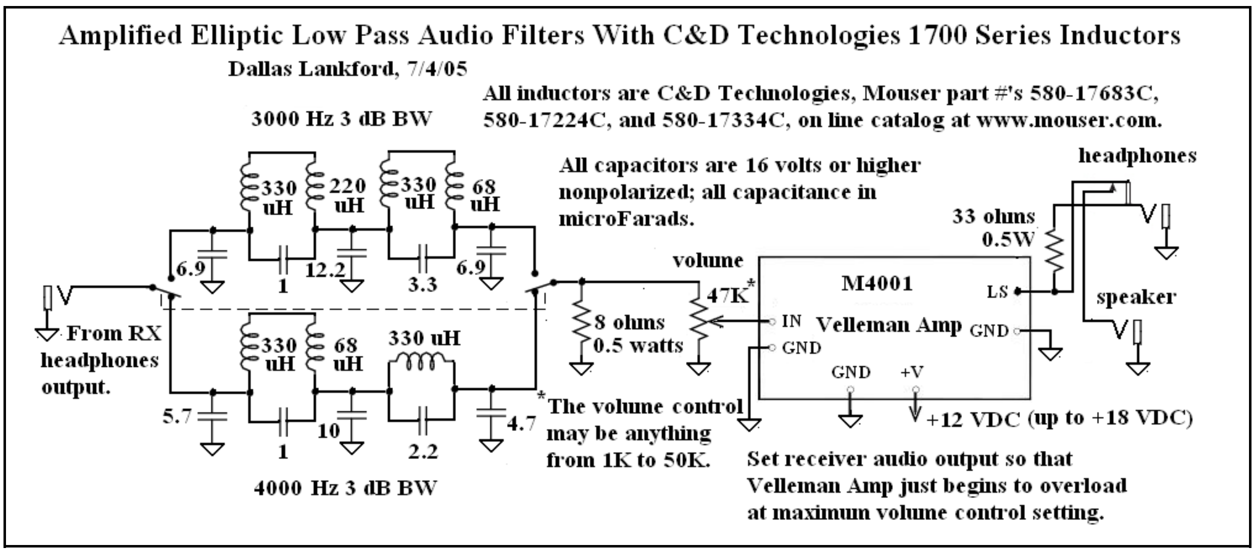
Amplified Elliptic Low Pass Audio Filters

Simplified And Improved

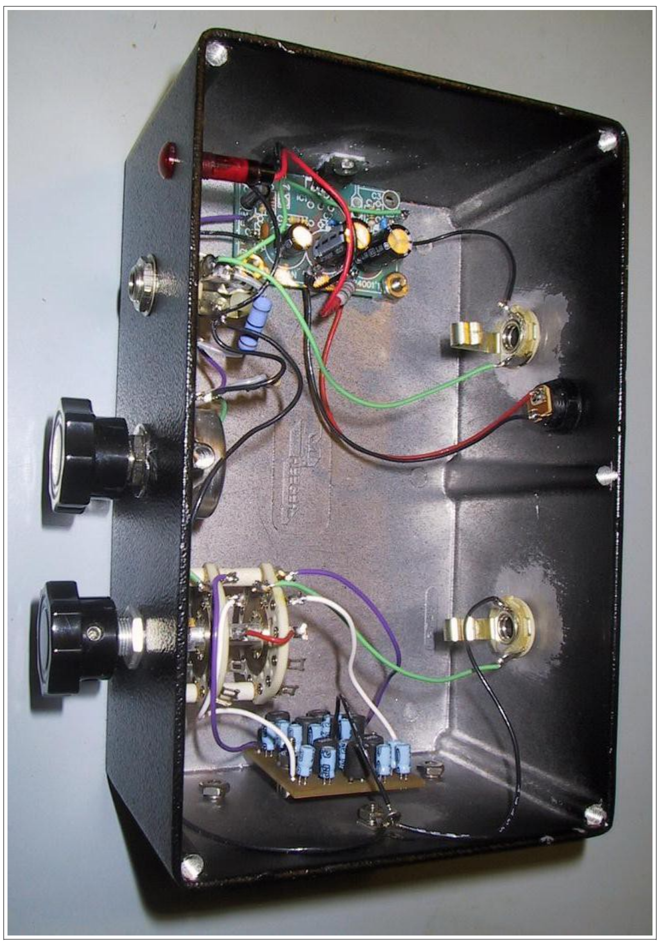
Dallas Lankford, 5/29/06, rev. 5/26/08

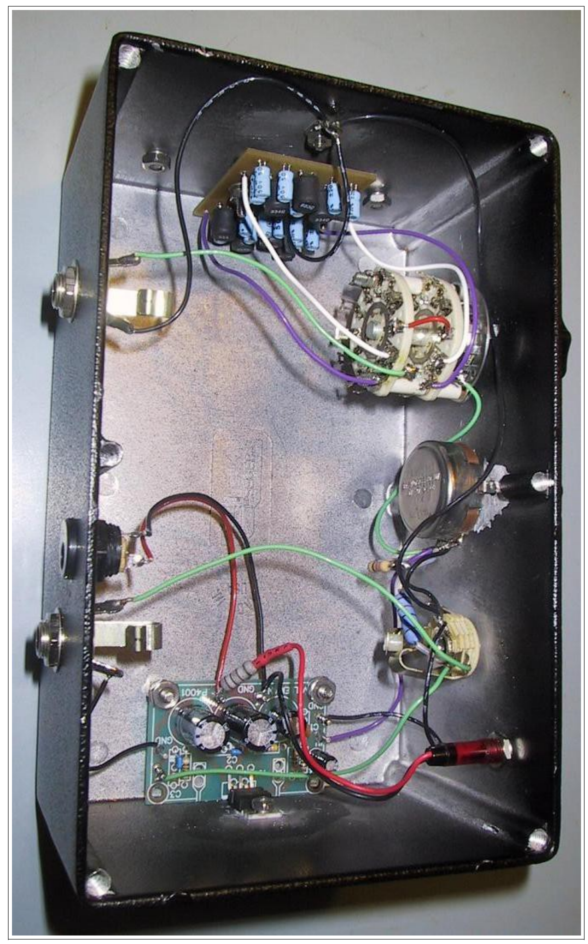
My original elliptic low pass audio filters (above) were not amplified because they used the receiver speaker output which provided adequate audio power for headphones and sufficient audio power for a speaker at moderate listening levels. However, with that approach it is fairly easy to overload the elliptic filter, observed as audio distortion at higher volume levels. If greater undistorted audio output is wanted, the elliptic low pass audio filters should be driven by the lower level headphones output, and the output of the filters should be amplified. An excellent audio amplifier for this application is the Velleman M4001 (7 watts into 4 ohms), which is capable of 2 watts output into 8 ohms with a 15 VDC power supply at 500 mA. Its frequency response is 20 to 20,000 Hz (- 3dB) with nominal 0.05% THD (1 kHz @ 1W). I bought my Velleman amp assembled from Parts Express . The assembled version is discontinued, but the kit version is still available. I think that the kit model is CK4001. You will have to search the Parts Express web site for Velleman products to find the amplifier. They currently sell it for $18.

With amplified filter output and lower level audio input from a receiver headphones jack, overload distortion is no longer a potential problem for the off the shelf inductors which I used. Below is a schematic of a prototype of such a filter which uses C&D Technologies 1700 series inductors. Nonstandard capacitor values are made by paralleling standard values (for example, 12.2 = 10 + 2.2). Several different narrow bandwidth filters were tested with the goal of increasing the narrow bandwidth while maintaining the same amount of fading (and other) distortion reduction as the 2700 Hz filter of previous designs. The 3000 Hz BW filter in the schematic here accomplished that goal; it was designed using the scaling method of the RSGB Radio Communications Handbook, 1994, to scale the 4000 Hz BW filter below to 3000 Hz. A 5000 Hz filter was evaluated, and while it was quite good, the 4000 Hz filter was retained because it lets through noticeably less fading distortion than the 5000 Hz filter. A Switchcraft type 13E headphone jack (Mouser 502-13E) was used so that the speaker would be turned off when a headphone plug was inserted in the headphone jack. Or you may do without the fancy Switchcraft E13 and use ordinary headphone jacks with the speaker jack connected directly to the LS output of the Velleman amplifier. To turn off the speaker you simply unplug the speaker cable. Or you may add a toggle switch to turn the speaker off. ***Be sure to set the receiver headphone audio output so that the Velleman Amp just begins to overload at maximum ELPAF volume control setting.***



Below are photos of the amplified ELPAF. A black Hammond 1590E aluminum box, an Allen Bradley (now Honeywell) 47K ohm 2 watt linear Type J pot, and Teflon hook up wire were used. Occasionally you can find these new old stock on eBay (do not buy used ones). Buy only those with 2 inch shafts which you can hack saw down to the desired length for the knob that you use. Most of the ones I see on eBay have shafts that are too short for a knob. If you can't find an AB type J pot on eBay, I have no idea what to recommend. The heat sink of the Velleman M4001 amp was removed and the IC metal tab was attached to the side of the box with a machine screw, split ring washer, and nut. For good thermal contact the paint on the inside of the box behind the IC tab was sanded to bare metal and heat sink compound was used liberally. A PB board was laid out using free software available from http://www.expresspcb.com/ . The PC board was quite small, namely 1.5" W by 1.75" H. It is laid out for 4-40 mounting screws with 0.25" standoffs, but is small enough that it can be mounted directly to whichever kind of switch is used, rotary or toggle. To make the PC board compact all capacitors were 4 mm diameter radial lead, Mouser part #'s 140-MLNP50V1.0, ... 50V2.2, ... 50V3.3, ... 35V4.7, and ... 16V10. Switching was done with a 2 wafer ceramic rotary switch (which is what was on hand) so that the filters could be bypassed during testing and performance verification. If bypassing is not wanted, a good quality DPDT toggle switch may be used. Or if bypassing is wanted, a 2 pole 6 position ceramic rotary switch may be used, such as an Electroswitch, Mouser part # 690-D4C0206N. The C&D Technologies 1700 series inductors are high Q at 100 kHz and have fairly high maximum current ratings. Other inductors may not give good performance. Center mounting of the volume control was implemented by grinding away part of an internal support. Other layouts may be used. Originally all capacitors used were rated at 50 volts. But such high ratings are not needed when the filters are driven from lower power headphone outputs. For 2 watts RMS the maximum voltage drop is 4 volts RMS across 8 ohms, or about 12 volts peak to peak. The headphones output of a receiver is much less, generally no more than 300 mV peak to peak maximum. According to the M4001 specifications the amp can draw as much as 500 mA at 15 VDC. Any well filtered 12 – 18 VDC power supply rated at 1 amp or greater should be satisfactory. I recommend a Pyraid PS-3KX 13.8 VDC 2.5 amp continuous. It is well made, has no mechanical hum (= no mechanical buzz), and causes no 60 Hz hum in the audio output of the Velleman amp. It is about $22 plus shipping from Universal Radio. I briefly tried a Radio Shack 12 VDC (15. 3 VDC under load) 1 amp wall wart, but it was poorly filtered and produced audible 60 Hz hum in the output of the Velleman amp which could be heard when ambient man made noise was low. You might find that acceptable; I don't.





Why I have spent so much time improving the original ELPAF's? Simple. They provide about as much reduction of fading distortion and reduction of flutter (including sub-audible hetrodyne) distortion as the very best AM synchronous detectors, such as the Drake R8B. At the same time ELPAF's also reduce high frequency splatter, which AM synchronous detectors do not reduce. And there is no waiting around for the AMSD to lock. When you tune in an AM signal with an ELPAF you start listening immediately. I have spent many hours listening to some of the best AM synchronous detectors around on fading and fluttering AM signals, both weak with and without interference, and strong with and without interference, and I have yet to find one that I would recommend over an ELPAF when used with the technique of off tuning and a suitable AGC release time. For these reasons I wanted to make these ELPAF's as good as possible.