A straightforward, cost effective line pre-amp based on the National Semiconductor LM4562 dual audio op-amp

‘X-Altra Mini One’ Line Pre-Amp

- CD Input, 2 line Inputs and optional phono input
- Relay input signal selection
- 16dB Gain on line inputs
- Headphone Amplifier Output
- DC Coupled Line in to Line out
- Low distortion
- Low noise

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Safety

As with most audio projects, this project involves wiring up circuits to the AC mains.

Unless you have the experience wiring up AC mains circuits, do not undertake this project. Alternatively, ask a professional to help you.

Project Level

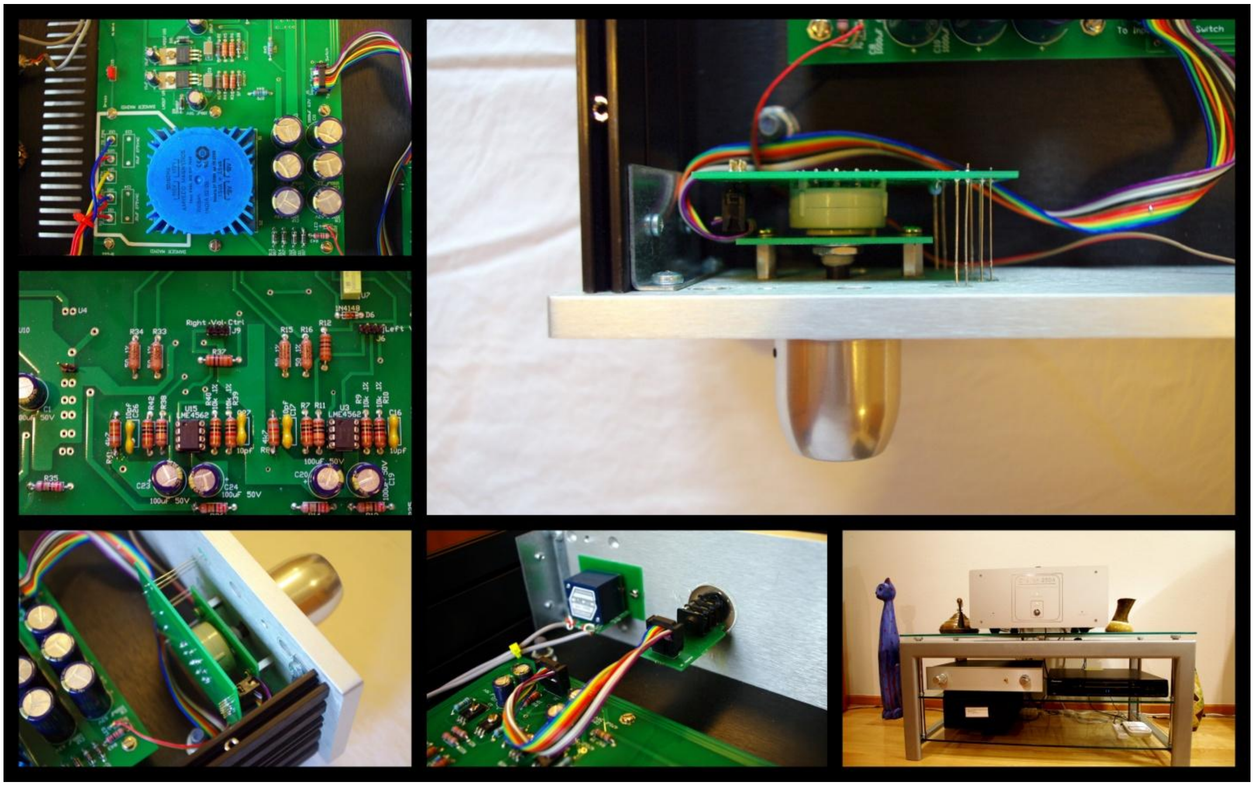
Although not a complex pre-amp, this project is aimed at the reasonably experienced constructor and assumes a solid knowledge of basic electronics.

Copyright

Acknowledgements

My thanks to Akifumi 'Tedd' Okano for doing the measurements on the AP SYS2722 Audio Analyzer and then pointing out how dire my original headphone amp design was along with the fact that I had the L and R channels swapped on some inputs. Corrections thanks to his inputs have been made and incorporated into this document.

’X-Altra Mini One’ Line Pre-amp



1. Introduction

The X-Altra Mini One preamp was borne out of the necessity for a no nonsense control amplifier to drive a 250W per channel stereo amplifier. Why ‘Mini’? Well, this pre-amp dispenses with anything superfluous and just does the basics. I originally planned to start developing a full feature high end pre-amp, spanning perhaps 2 years or more, and did not want to continue with my interim solution, which was to tap off the pre-amp outputs from my Marantz PM7000 integrated amp to drive the big power amp. I was looking for a quick solution that would offer a clear step up in sound quality and allow me to really hear what the power amp and my B&W 703’s could deliver. I soon came up with the overall concept, which was to provide for up to 3 inputs (CD player, Tuner and possibly a decent music server), an optional phono input stage, a headphone output and single ended line output. Good output drive capability was another clear design goal. Personally, it’s quite difficult for me to constrain the urge to add features and complexity, and therefore cost and time, but I am pleased to say I managed to do so on this project.

The result is a pre-amp that does only what it needs to do: - select an input source, adjust the volume, then amplify it by c. 16dB, and finally send it to a line output connector and headphone amp.

The main line gain stage is based around the relatively new National Semiconductor LM4562 dual audio op-amp (OPA), the other option here being the NE5532. On straight distortion and PSSR performance the newer National Semiconductor part excels, although with source impedances upwards of 5k it is not quite as good at the NE5532 on noise performance when both noise voltage (V_{en}) and noise current (I_{en}) are considered, despite the fact the NE5532 is over 30 years old now. However, the LM4562 features much lower input bias currents, lower offset, and improved slew rate and bandwidth performance. The open loop gain is a good deal higher, which is one of the reasons for the dramatically lower distortion compared to the NE5532/4. I looked at quite a few other op-amps, but after examining their performance and cost, it was clear there weren't any other suitable candidates. The LM4562 (and its single equivalent the LME49710) and NE5532 (NE5534 single) are really are in a class of their own when it comes to the important parameters for audio: distortion, PSSR, noise and output drive capability. The other outstanding candidate is the AD797, but it should be noted, this is a single device and is very expensive. For those of you interested in exploring op amp performance for audio applications, take a look at Samuel Groner's study here on opamp_distortion.

The LM4562 dual OPA's used feature 20K THD (i.e. THD at 20KHz)of about 800 ppb (parts per billion) at 3V RMS out into 2k Ohms , power supply rejection at 20KHz that exceeds 70dB on the –ve rail and is over 100dB on the positive rail. The output of this pre-amp can drive a 600 Ohm load to 6VRMS at under 20ppm 20k THD. S/N approaches -120dB referred to 1V RMS out, and response of the unit (line input) is DC to 20KHz –0.2dB, and -3dB at 150KHz. Since the LM4562 features very low input offset and drift characteristics – typically 100uV (700uV max), this design is completely DC coupled and does not rely on any type of servo circuit to achieve this either. Worst-case output offset is in the region of 4mV, but is typically much less than this. This allows omission of any DC blocking caps and therefore makes for a very simple and elegant signal chain. Additional offset arising from the LM4562's bias current flowing through the 10k volume pot amounts to around 100uV at the max volume setting with the inputs open, so with a subsequent gain of c. 16db, contribution of this will still be under a mV. All told therefore, the *typical* output offset you are likely to see with this design is around 2-3mV, and worst case about 4mV. That's easily catered for in direct coupled power amplifiers that incorporate an output offset servo, and its of course of no consequence if the power amp uses capacitive input coupling.

These are not 2nd rate performance specifications by any standards and the use of the LM4562 means no design or performance trade-off's are required in the main gain stage component. Note that it is not possible to use the NE5532 in this design without adding DC blocking capacitors on the input between the potentiometer wiper and R11 and R38 – this is required to prevent wiper noise arising from the very high input bias currents on the 5532. Further, since the output offsets on the NE5532 are considerably higher, a DC blocking capacitor would have had to be inserted between R15 and the output and R35 and the output (see Fig 24 – Circuit Diagram).

2. Which is best: A Discrete or IC Op Amp based Circuit?

Many audio designers prefer discrete designs, feeling that they sound altogether better than IC designs. However, there is another school that believes IC based designs offer the best balance of performance and cost. This is not a debate which will be resolved in the short term nor in this document. If, like me, you are looking for the best cost/performance ratio, then the LM4562 really is quite outstanding (as is the NE5532). With a discrete design, you are going to have a hard time approaching anything like the LM4562's electrical performance. So, as a designer, you have to make a choice and accept that some folks will love your handy work, while others won't. To each to his own, and so be it.

If you're considering the difference in 'sonics', integrated solutions may sound different to their discrete cousins because of overall topology, coupling methods, power supply, layout etc. Most modern mixing desks in recording studios use op-amps exclusively in the small signal chain (microphone amplifiers however usually use discrete input circuits). Typically a microphone through to the recorded signal (now days usually stored on a hard disk after A-D conversion) might pass through as many as 80 to 100 IC op-amp stages[1] and as many signal coupling electrolytic capacitors – there are even companies that specialize in re-capping studio mixer analog boards. One or two op-amps (or electrolytics for that matter) in the stage just before the power-amp in the listeners room I can assure you will not

[1] See Douglas Self's 'Small Signal Audio Design' for an expose on mixing desks . . . op-amps, electrolytics and all.

alter the sound irretrievably for the worse. The much larger impact of speakers (model, response characteristics, positioning in the room, listener's position etc) and room interaction dominate the system 'sonics' and electrical performance by at least one to two orders of magnitude more compared to the amplifier signal chain i.e. 1-2% total system distortion vs 0.1 or 0.01 for the amplifier and pre-amplifier combined. Between your CD disc proper and the analog output, almost all players (including the very high end) incorporate IC D-A converters and op-amp based filters along with an integrated op-amp or two to buffer and clean things up a bit. Any decent system should let you easily discern good recordings from bad, not adding any of its own character, a key characteristic the X-Altra Mini One easily fulfills. From the above, I guess its easy to conclude that my philosophy when it comes to hi-fi amplification: I don't expect and don't want anything in the amplifier signal chain to alter what's coming off the source.

3. Overview

On the front panel, you will find a selector switch with input select LED indication, a volume control and an LED power indicator along with a standard 5mm headphone socket. There is no power ON/OFF switch on the front panel and since the power draw is <5W in operation, I am quite comfortable leaving this pre-amp powered up continuously. If you're a little more eco-conscious than me, then the recommended power socket does have a switch but this is located on the rear panel. Of course, if you build the X-Altra Mini One, you can always fit a switch on the front panel if you like. On the rear of the unit is the switched IEC mains socket and 10[2] high quality Neutrik style panel mount RCA sockets and an earth binding post for the optional phono inputs. That's it – minimalist and focused on re-producing the input signal as accurately as possible.

All the main components are mounted on a large THP FR4 PCB, including a low noise, 15W linear regulated power supply, which connects to the mains via a high quality, fused and switched 3 pin IEC socket. I elected to mount the input connectors, headphones, selector and volume control off board using small adaptor PCB's to allow some flexibility in the type of housing that could be employed.

Input signals are selected via quality small signal sealed Panasonic AGN relays mounted at the rear of the PCB, close to the input sockets. These relays are driven by the front panel mounted rotary switch, avoiding long signal cable or PC trace runs inside the pre-amp, which would have been the case had I elected to use a switch for input selection. The use of dual contact relays to switch both the L and R channels could be raised as a fair criticism on this design as it does impact channel separation. However, in my defence, I have to re-iterate that this is a minimalist design. Completely separating the input selection relays into a left and right bank would provide at least an additional 10 to 15dB of channel separation improvement, but would make this pre-amp more complex (and raise the cost), which is something I tried hard to control on this project. Note also that this design eschews a switched tape loop input/output signal routing in the interests of simplicity.

The X-Altra Mini One is equipped with a simple but extremely effective diamond buffer output headphone amp, capable of easily driving a pair of 32 Ohm headphones to uncomfortably high volume levels. The headphone stage has a gain of 6dB (i.e. about 2x), and I found that with the standard 16 db pre-amp gain this is quite adequate with most headphones, requiring the volume control to be set at approximately the same position used when playing music through the power amp and speakers in my case.

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[2] On the pictures you will note a set of XLR connectors. These were originally intended for a balanced output, but I later decided to settle on single ended outputs only, making these redundant. Not wanting unsightly holes on the rear panel, I elected to leave them in-situ to preserve the cosmetics.

4. Circuit Description

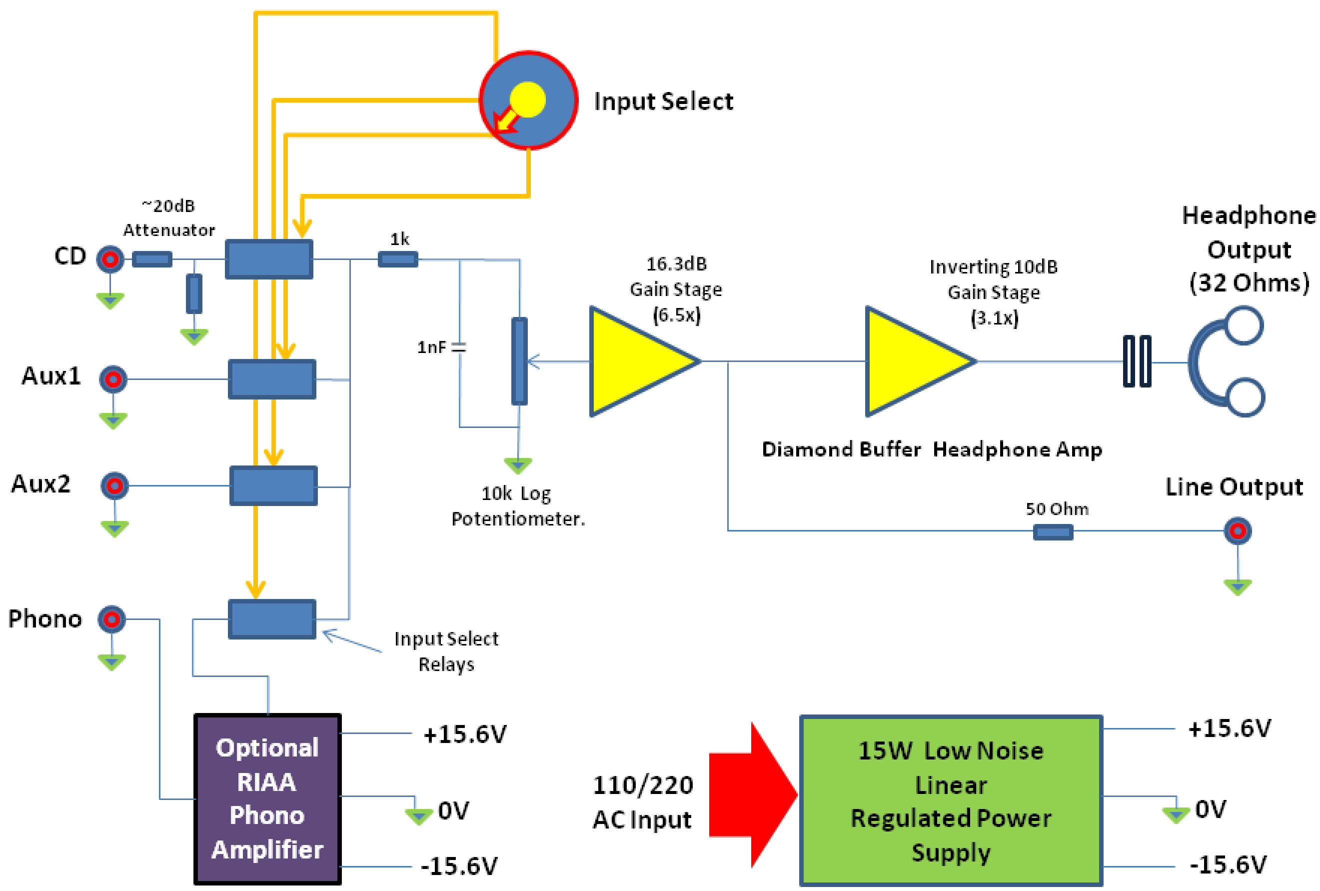


Figure 1 - X-Altra Mini One Block Diagram

4.1 Power Supply

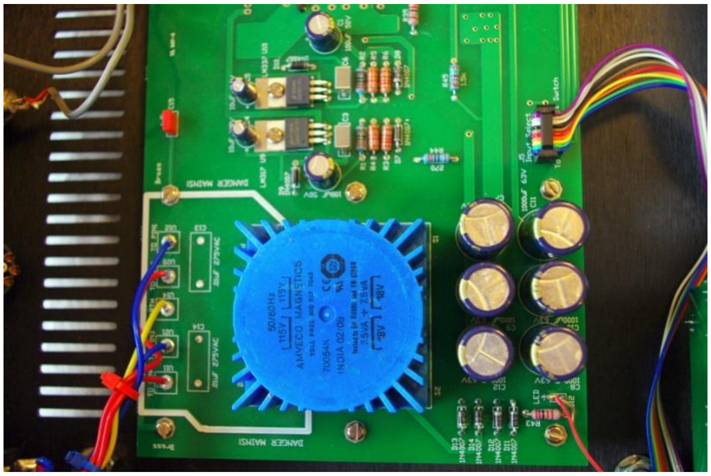


Figure 2 – View of the Power Supply Section

Refer to Fig 1 (top level block diagram) for an overview, and Fig. 24 (circuit diagram) for a detailed description of the circuit. The power supply is fed from an Amveco 15VA (PT # 70054k 18-0-18 VAC) PCB mount dual secondary transformer (T15 on the circuit diagram) and a standard bridge rectifier made up using 1N4007 1A rectifiers (D11 to D14) which then feed into a bank of 6 off 1000uF 63V capacitors. Regulation for the + and – rails is provided by the industry standard LM3xx TO220 regulators – U9 LM317 for the positive rail, and U10 LM337 for the negative rail. C4 and C5 provide additional decoupling of these IC's internal references, improving their wideband noise performance by about 10dB. D7, D8, D9 and D10 provide reverse polarity protection, while C1, C2, C3 and C6 provide local decoupling to ensure the lowest possible noise for these regulators. A discrete shunt regulator was considered for this design, of which there are many fine examples on diyAudio.com, but when the complexity and costs are considered, and the outstanding PSRR of the LM4562 is factored in, there is very little benefit to be had – the LM317 and LM337 offer the best cost –performance solution, and are importantly very easy to apply. The output voltage of the power supply stage is +-15.6VDC and feeds all of the amplifier stages. You will note that each LM4562's + and – rail is decoupled with a series 22 Ohm resistor and a 100uF capacitor. I did this to ensure that there was additional HF filtering at higher frequencies – exactly where the op-amp PSRR performance starts to taper off. Assuming a typical load of 2K Ohms for the stages, for the capacitors used (Panasonic 50V types, with an ESR of around 0.25Ohms), a useful additional 24db is provided at 1KHz, while at 20KHz it is around 40dB. Of course, simply slapping decoupling caps around op-amp gain stages without thinking about the layout is a waste of time. Therefore, the ground return tracks are thick and wide to minimize inductance. Above about 100KHz, the localized decoupling starts to become less effective due to the ground trace inductances. Trace inductance in this layout starts to make itself felt from about 100Khz upwards.

R45 is simply a load balancing resistor for the relays, since they are powered off of the V+ rail only. R44 (270 Ohm) is a dropper resistor, since the pre-amp uses 12V relays.

4.2 Input Selection and Signal Routing

Let's move on now to the input selection stage, comprising J1, J2, J3 and J10 (the phono input socket - more about that later) and their associated relays. I used Panasonic AGN ultra miniature small signal switching relays which are ideal for this type of application. They are sealed, so there are no problems with pollution upsetting the contacts, they are very small, and importantly, they are specifically designed to switch low level signals. I also liked the fact that they require very little actuation power. Although the relays are switched in and out by means of a mechanical switch (see Fig. 23 for the input selector circuit diagram), I still placed flyback diodes (D4 through D6) in very close proximity across each of the relay coils to ensure there is minimal EMI generated when de-energizing the relays. Relay coil flyback voltage spikes generate a lot of RF – you either need to clamp them very close to the source as done in this circuit, or place an RC snubber across the coil. On the CD input, around 20dB of attenuation is provided, since most CD players output 2VRMS, which is about 10x higher than tuner and tape output levels. Note also that most DVD audio output signals are in the 200mV range – CD output levels are really very high compared to most other signal sources, and thus need some attenuation to bring them into line with the other source equipment levels.

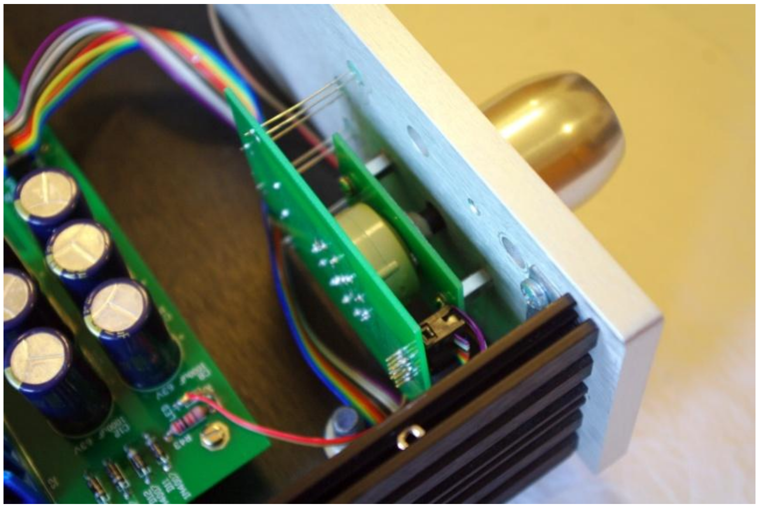


Figure 3 - Input Selector Switch Assembly

4.3 Line Amplifier Stage

The common contacts from the input selection stage feed the line gain stages around U3 (Left Channel) and U15 (Right Channel). Operation of both channels is exactly the same, so we will only look at the circuitry around U3 to explain operation. Inputs from the relay selection stage are fed through a low pass filter consisting of R12 and C25. This provides about –3dB of attenuation at 150KHz, helping to ensure RF and hash picked up on the inputs is not amplified, and separately, that the signal rise times into the pre-amp are controlled so as to minimize overshoot and possible ringing. CFL lamps, laptop adaptors, monitors and TV's, despite all the EMI and RFI compliance certifications printed on their labels, wreak havoc in audio systems, so excessively wide bandwidths are an invitation for noise problems. The filter corner frequency will be affected by the source impedance of the selected input, so anything up to 2K is ok, but beyond that, there will be some roll off of the very high-end audio frequencies. However, in most modern equipment (CD and DVD players, tuners and music servers) the output impedance is less than 1k, so I don't envisage any problems here. See the Measurements section for some further details on this specific point.

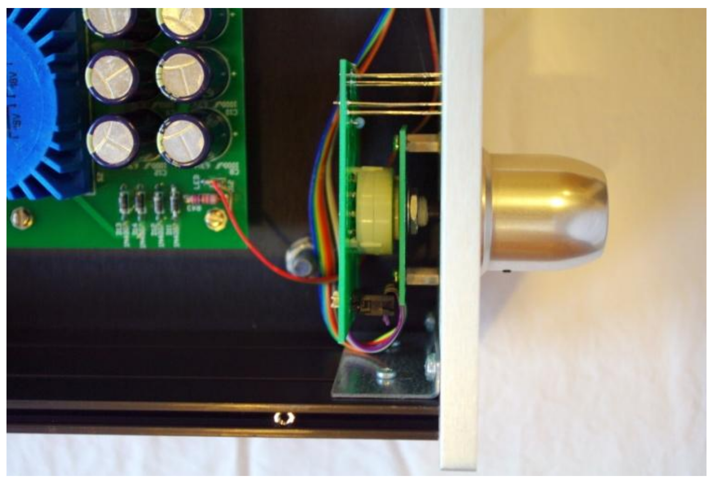


Figure 4 - Another View of the Selector Switch Assembly

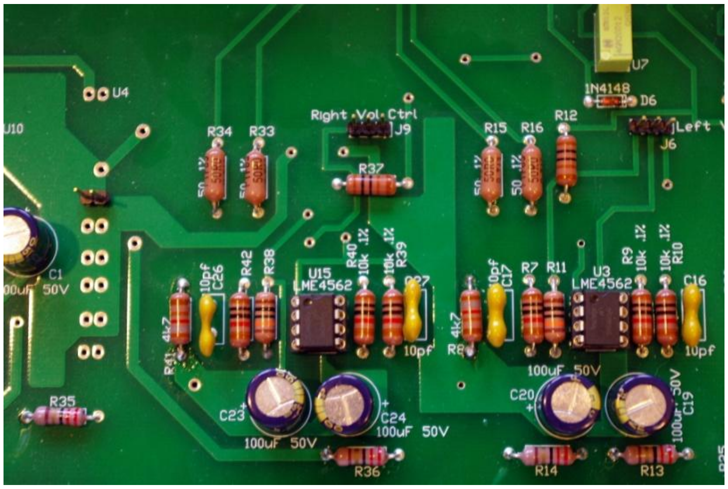


Figure 5 - The Line and Headphone Amp Stage

The output from the filter feeds a 10k log [Alps RK27 Blue Velvet](#) potentiometer. The Alps is a fine potentiometer and is very quiet with a good tactile rotational feel. As mentioned earlier in this document, I have not used DC blocking caps after the potentiometer as a precaution against noise caused by wear on the pot track when there is DC current flowing through it. This is a particular problem in low cost carbon film pots, and in most cases, these will be noisy 'out the box' with any sort of DC flowing through them. Provided the DC current through them is reasonably low, the Alps RK27's used in this design don't have that problem – these are very high quality pots, and coupled to the low input bias currents on the LM4562 (10nA at 25C – so similar to the leakage on an electrolytic cap at room temperature), will make for a very long, noise free operational life. By way of contrast, the NE5532 input bias current (typical) is 200nA – 40x higher – and it can be as high as 1uA.

The potentiometer is connected via J6 (J9 for the RH Channel). I elected in this design to mount the pots off board as this allowed some flexibility in the mechanical layout. With hindsight, mounting the volume control on the PCB and/or at the back of the pre-amp near the input selection relays would have given me better measured results, but this of course would have come at the cost of some flexibility in the mechanical layout. The wiper of the pot feeds into the non-inverting input of U3A, the main line amp stage. This stage is configured for a gain of around 16dB by R7 and R8. A 10pf cap (C17) across R7 provides additional HF roll-off, and reduces any overshoot caused by response peaking. Pin 1 of U3 is routed to the line out connector via R15, a 50 Ohm series resistor. It is not advisable to route outputs from op-amps to external equipment without considering the effects of capacitive loading, hence the reason for the 50 Ohm series resistor. Driving a capacitive load directly from the output of an op-amp causes excessive phase shift in the op-amp's output stage, and under worst case conditions, can cause oscillation. The 50 Ohm resistor isolates the op-amp output from capacitive loads, and ensures minimal peaking and no oscillation. Although there are techniques that can be applied to maintain the near zero output impedance of the op-amp with feedback without resorting to the series output resistor, the approach I used is foolproof, and the standard way of solving the problem; ideal for the X-Altra Mini One.

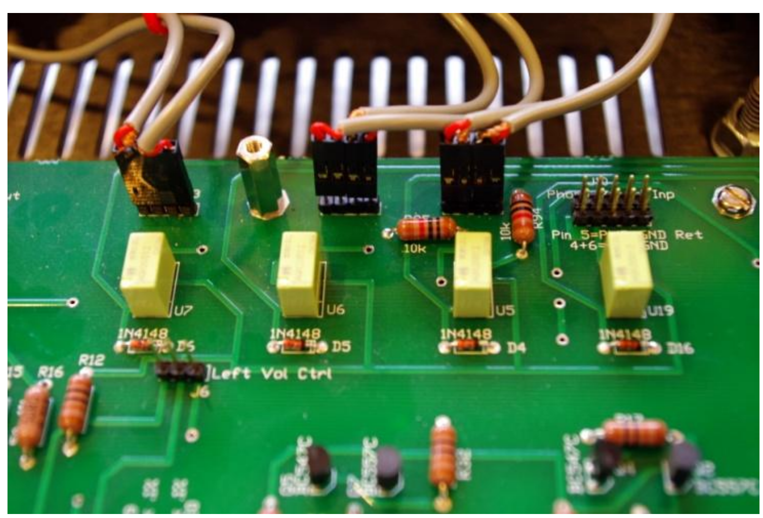


Figure 6 - Input Selection Relays

4.4 Headphone Amplifier

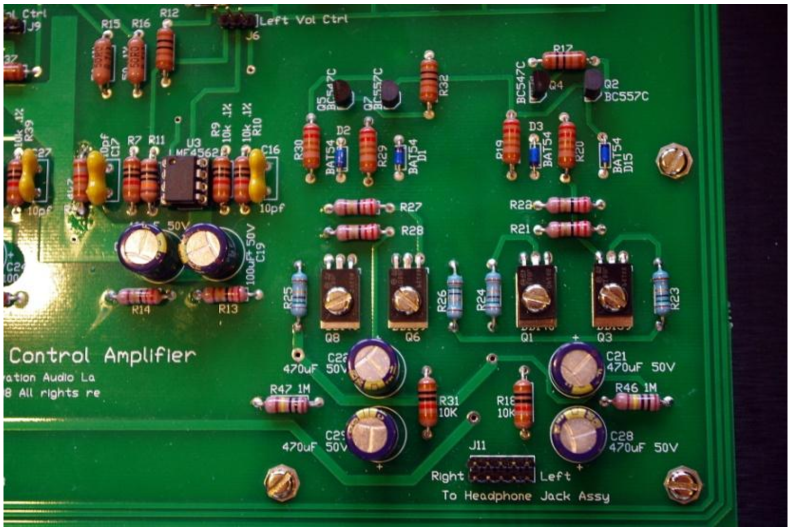


Figure 7 - Headphone Buffer Stage

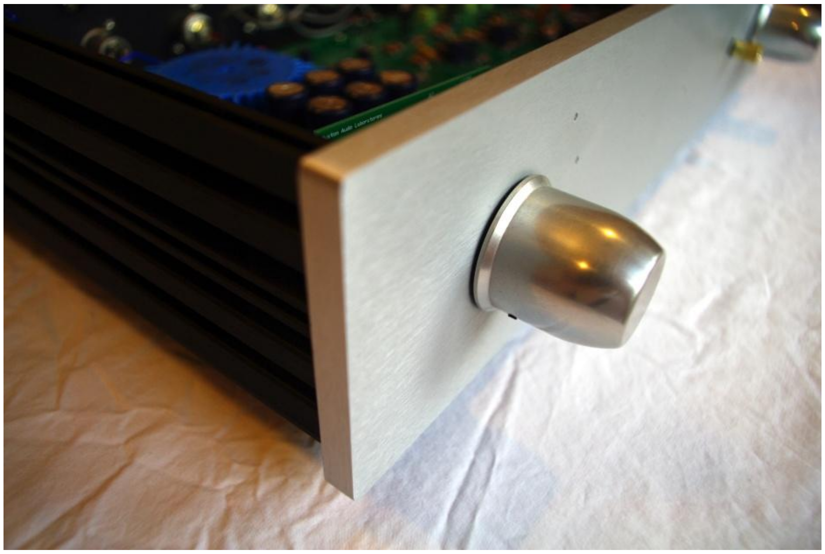
U3B is used for the headphone amplifier and is fed via R10 (3.3k) from the output of the line amp stage U3A. This stage inverts the signal from the line amp providing a gain of around 2x. Why is this stage inverting? Well, originally, I designed the X-Altra Mini One for a balanced output, with an open loop, unity gain headphone buffer stage but later ditched this in favour of an unbalanced output, and a headphone amplifier with gain and feedback. Not wanting to change something I know works very well, I left the inverting stage as is. The output from U3B feeds a diamond buffer stage via R17 (47 Ohms), Q1 and Q4 simply buffer the input signal, which appears at their emitters, and offset it by 1 diode voltage drop. The emitters of these two transistors are tied to their respective supply rails by a 68 Ohm and 10k Ohm resistor with the BD139/140 output device bases tapped off at the junction of the two resistors. R21 and R22 provide local emitter degeneration for the output devices, and set up the output stage quiescent current (measured at 20mA on this design). R121 (3.3 Ohm) provides a small amount of isolation from the headphone cable capacitiance and ensures the headphone amp remains stable. Feedback is taken from the junction of R21 and R22 via R9. The gain of this stage is 2x and is set by R9 and R10, and C16 rolls th e op-amp's response off above 100KHz, ensuring that the headphone amplifier is completely stable. Note, if this cap is not fitted, the headphone amp will oscillate! The output runs in class A up to about 300mV RMS output, after which is transitions to class AB.

4.5 Phono Input

The X-Altra Mini One incorporates the facility for an add on phono card via J10, which is located towards the rear right hand side of the main PCB. J10 provides a +-15VDC supply and output signals which feed into relay U19. Inputs to the phono amp are wired directly from the rear panel to the phono card. Design of this card has not yet started, but in keeping with this pre-amps 'design to a cost point' but don't compromise on performance philosophy, it is going to be op-amp based, and because of the noise requirements, will use a single NE5534 gain stage. Switched R and C cartridge loading will be provided for.

5. Specifications

1.	Output	1VRMS nominal into 600Ohms; 9VRMS into 600 Ohms max (onset of clipping)
2.	Output Impedance	50 Ohms (line output)
3.	Inputs	2 off Auxiliary inputs; 1 off CD input; provision for phono amplifer
4.	Input Sensitivity	150mV RMS for 1VRMS output on aux inputs; 1.65VRMS on CD input
5.	Input Impedance	11k Ohms at 1KHz
6.	Input Source Selection	Via Panasonic AGN small signal relays
7.	Distortion	10ppm 20Hz to 20KHz 1VRMS into 600 Ohms <70ppm 20Hz to 20KHz 6.5VRMS into 600 Ohms (see distortion graphs)
8.	Frequency Response	DC to 20KHz +0dB, -0.2dB; DC to 150KHz +0dB, -3dB
9.	Headphone Output	Class A to 0.3VRMS; 3.5RMS max into 32 Ohms Distortion <0.01% 20Hz to 20KHZ at 3.5VRMS out into 32 Ohms; Headphone amp gain is 2x
10.	Power Consumption	5W nominal, 15W maximum
11.	Front Panel controls	Input select, volume and headphone socket
12.	Weight	4Kgs



6. Measurements

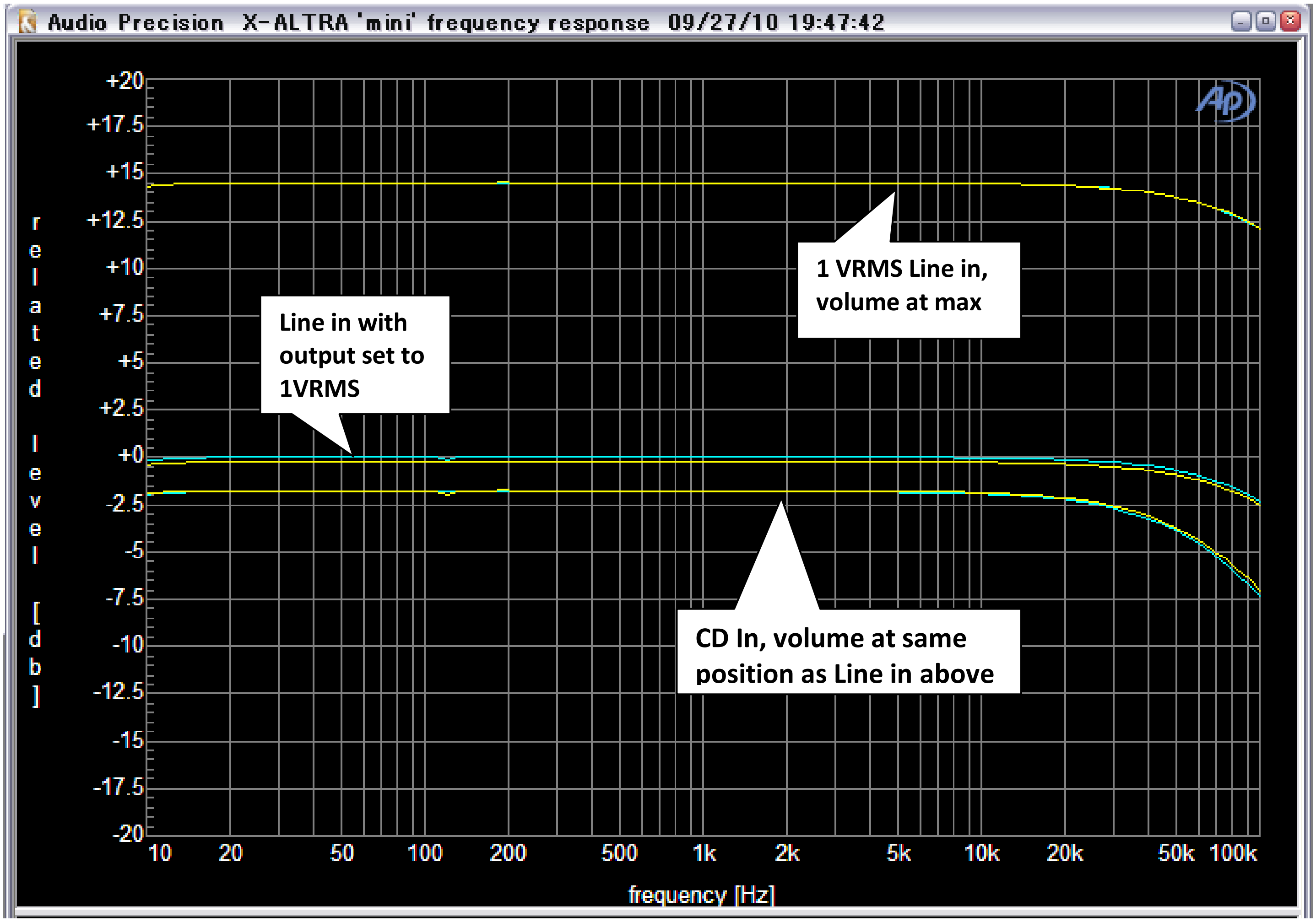


Figure 8 - X-Altra Mini One Line Out Frequency Response

Source impedance for the above measurements was 600 Ohms, as was the pre-amp output load. This graph shows the Line output frequency response for various input and output levels on both the Line inputs and CD input. Worst case it is down at 20KHz by 0.2dB. Note that the CD response rolls off a little more quickly due to the action of the input attenuator which adds around 2k Ohms to the normally 1k Ohm minimum source impedance seen by the filter. This is a compromise between using lower attenuator resistor values (e.g. 2.2k and 470 Ohms) versus minimizing loading the CD source by using 10k and 2.2k Ohms which is what I ended up doing.

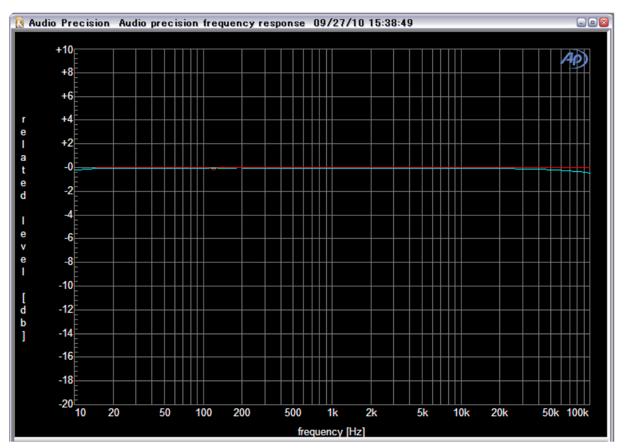


Figure 9 - AP SYS 2722 Reference Frequency Response

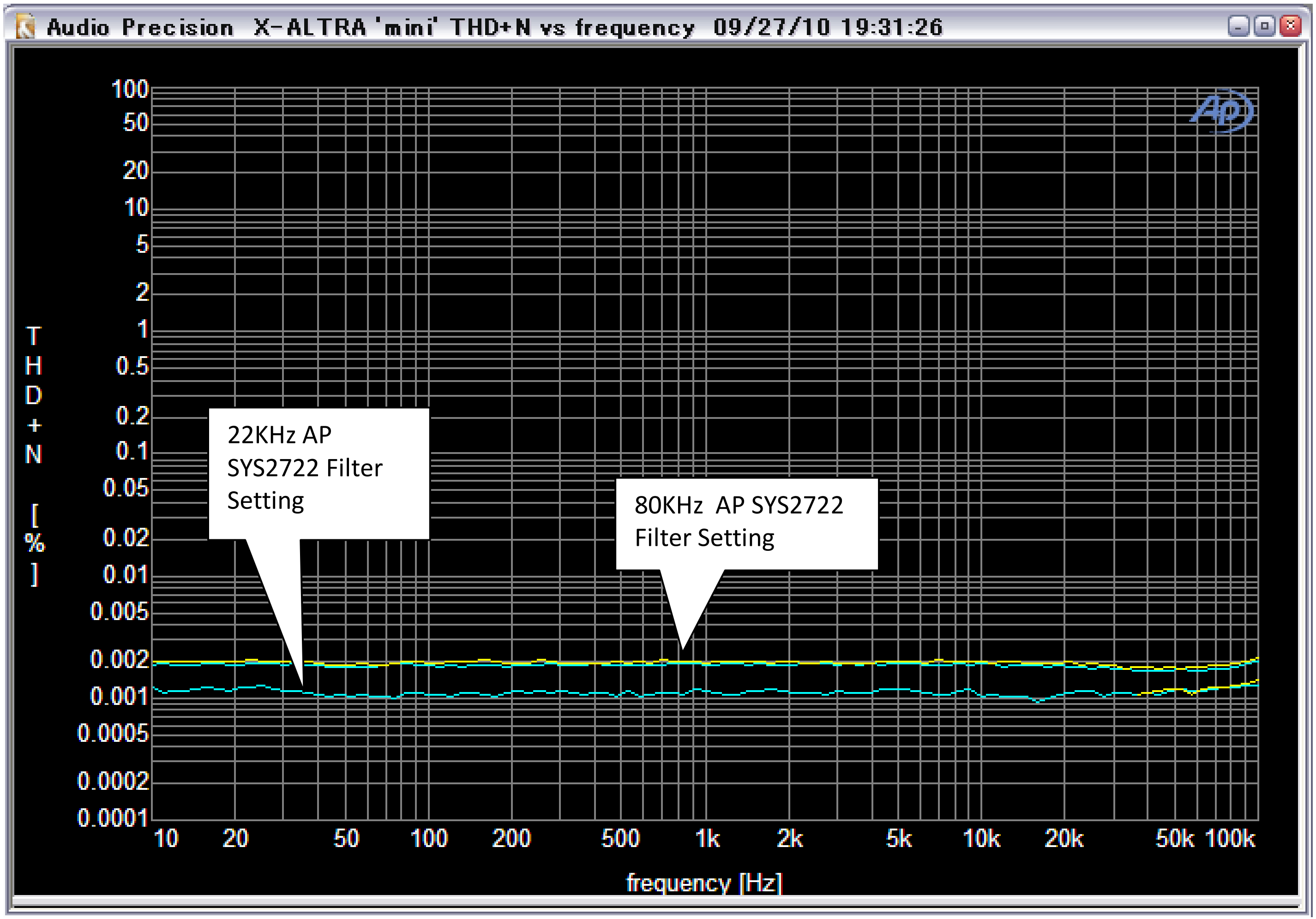


Figure 10 - Output Distortion vs Frequency into 600 Ohms Ref 1VRMS Output

Above is the 1VRMS output THD vs Frequency Plot into 600 Ohms. On 500KHz AP distortion bandwidth measurement (upper set of traces), the THD is 20ppm from 20Hz through to 20KHz, while with the 22KHz bandwidth measurement, it is about 5-6dB lower at c. 10-12ppm. Note that the distortion is flat right across the audio band. This distortion plot represents the typical maximum operating output level for this pre-amp since most power amps require between 1 and 2VRMS for full power output.

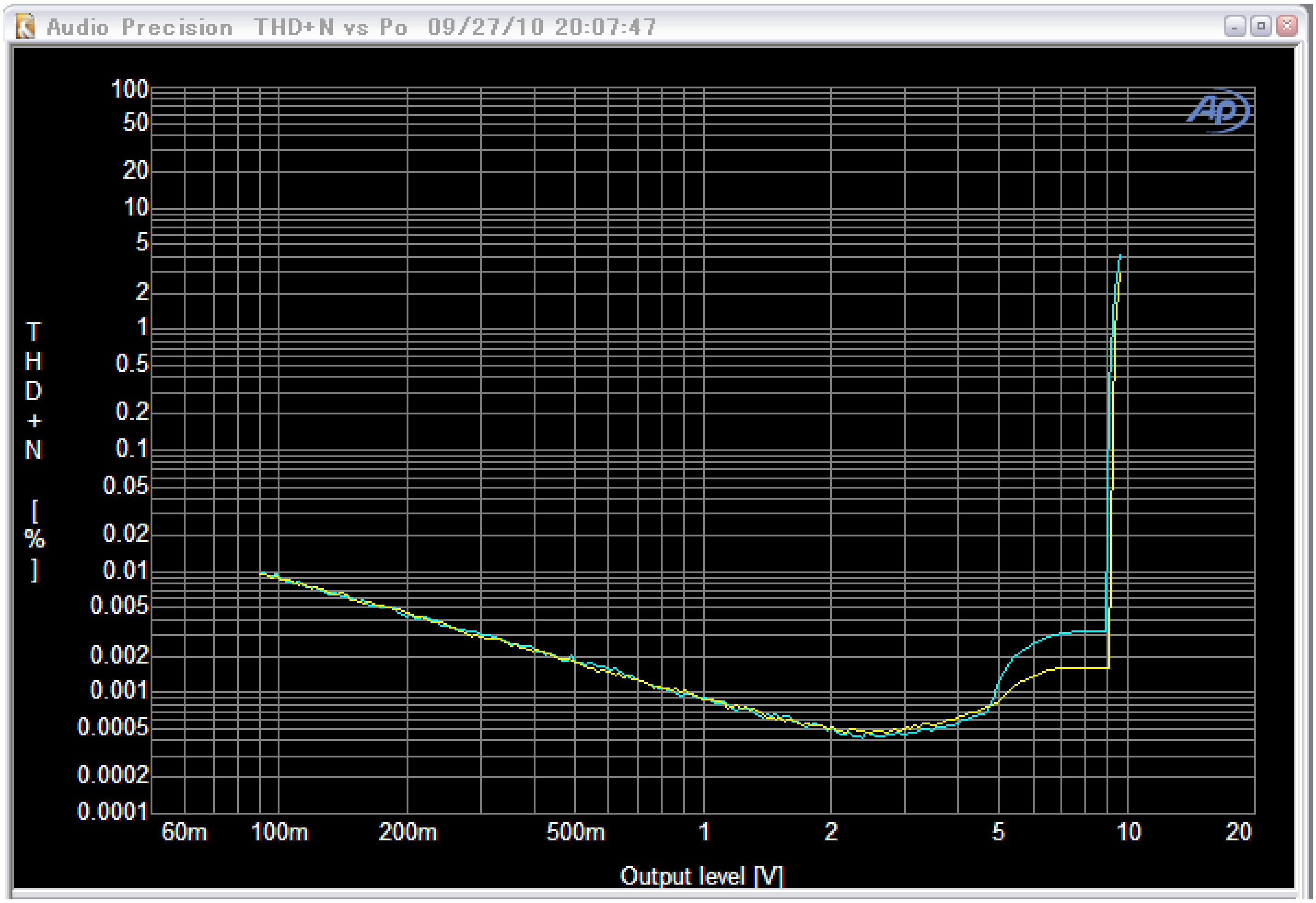


Figure 21 - Distortion at 1KHz vs Output Level. Clipping takes place at 9VRMS output

Fig 11 shows the 1KHz distortion vs Output signal level into 600 Ohms. At 9Vrms out the distortion is better than 35ppm (0.0035%). At the normal 1-2VRMS output levels to drive a power amp, the distortion is under 10ppm (0.001%), and, due to the pre-amps noise floor, and the noise floor of the AP system, the lowest distortion in PPM terms on this plot is around 2.5V – 3V RMS, where it approaches 4ppm (0.0004%) – all of these figures into 600 Ohm load.

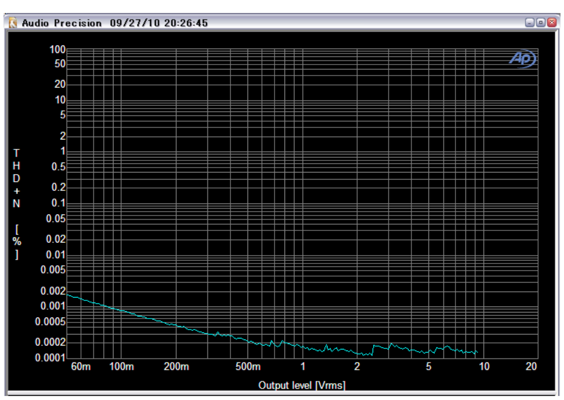


Figure 12 shows the AP SYS2722 distortion into 600 Ohms vs Output Level. Above 1V out, it lies between 1 and 2 ppm. Below this, the instruments noise floor limits the performance, such that at 100mV, it is about 8ppm.

Figure 12 - AP SYS 2722 Distortion Reference into 600 Ohms

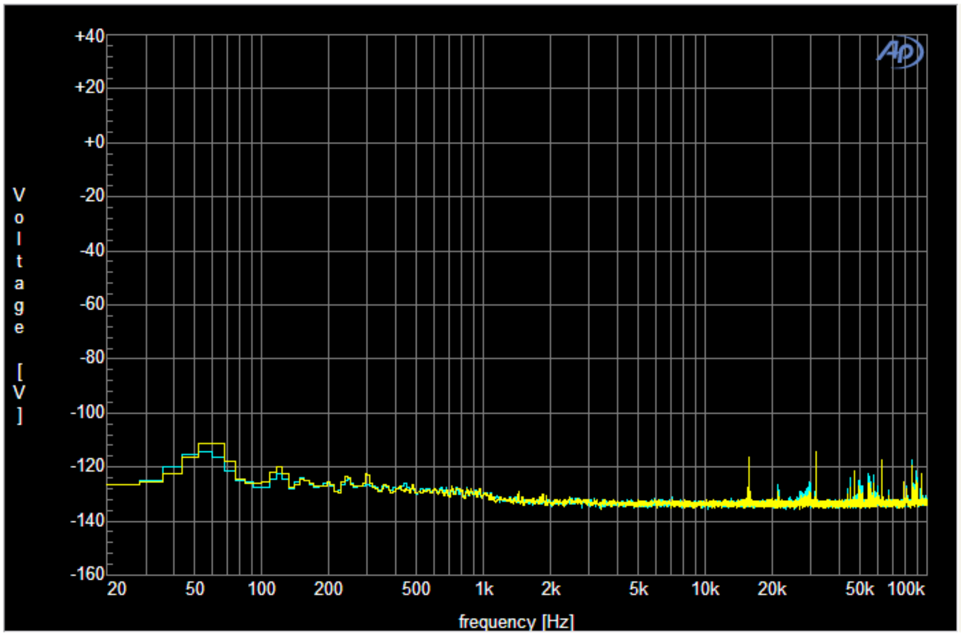
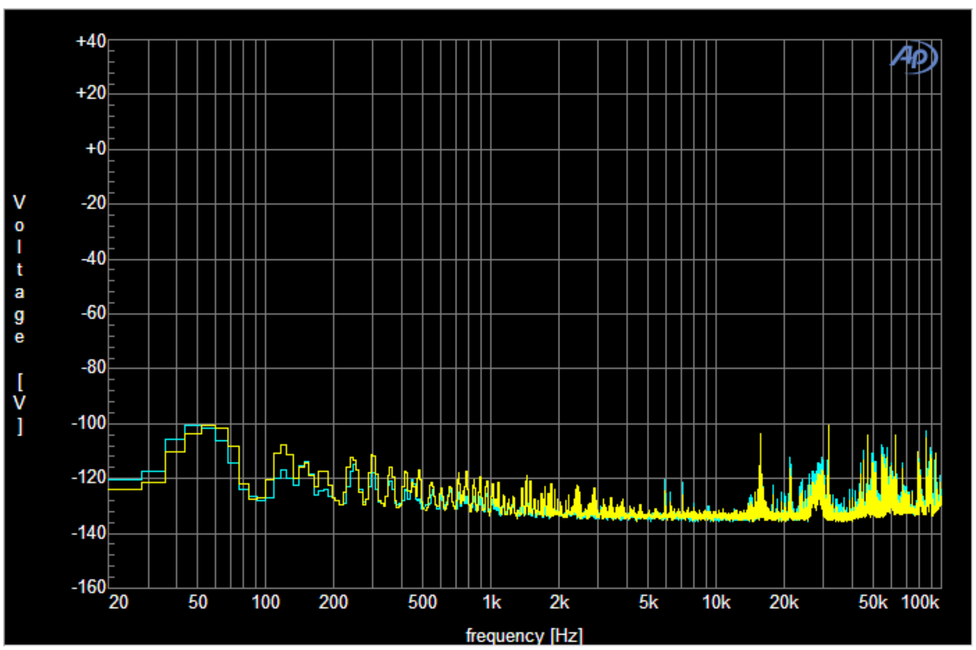


Figure 13 - X-Altra Mini One Noise at Unity Input-Output Gain (Line input)

This plot shows the preamp with the volume control set to the physical mid point (with the input open circuit, so source impedance into the op-amp is therefore about 1k), which gives 1VRMs out for 1VRMS input (Line in). Noise is consistently below -120dB, with a 60Hz mains peak at -110dB. The spikes and to the right hand side of the plot are noise sources from the various SMPS', CFL lamps, LED lamps and LCD TV's and other equipment running in the lab. I was unfortunately not able to get any of these tests done in one of the shielded chambers in the lab, as they were both occupied at the time, but my bet is all round the noise floor would have been a bit better for both the AP and the X-Altra Mini One. The reading was averaged 64 times in the above plot.



This plot shows the output noise with the volume control set to maximum (so source impedance at 1KHz about 10k Ohms) with the input open circuit. Here the noise floor has come up below 2KHz by about 10-20db, and the mains at 60Hz shows up at about -100db, with related harmonics below -110dB. No doubt some part of this noise was just getting picked up on the test bench, but it's a pretty reasonable result in my view. The reading was averaged 64 times in this plot.

Figure 3 - Noise at Maximum Volume

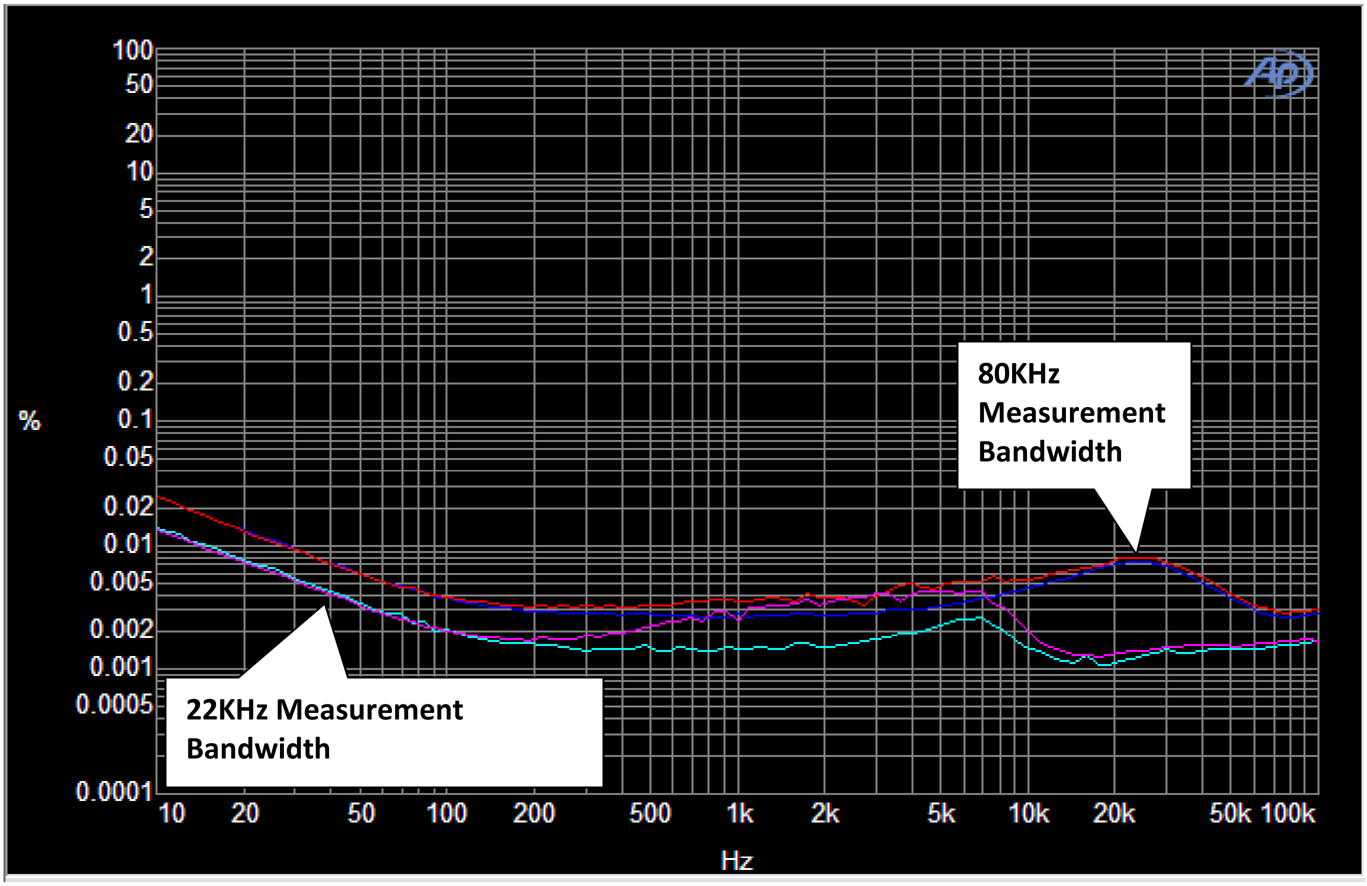


Figure 45 - Headphone Output Distortion at 1VRMS into 32 Ohms

Here is the headphone output performance into 32 Ohms vs frequency. On a typical pair of 32 Ohm headphones, 300-500mV is more than enough for normal listening levels. I use a pair of Bose headphones most of the time and they are very 'bassy' to my ears, so I used 2 x 470uF in series with the output to limit the lower frequency response a bit (on my iPod I simply turn the 'Bass Reducer' on). Of course, we know from Cyril Bateman's work on capacitors that electrolytics distort if any AC voltage is allowed to develop across them, and this manifests itself above as distortion starts rising below about 150Hz. Nevertheless, into a 32 Ohm load above 50Hz distortion remains well below 0.01%. If you are using 'phones with a more normal response, the output caps should be fitted as shown in the circuit – 2 x 1000uF 35V in series per channel. The distortion below 150Hz will be about 6dB better.

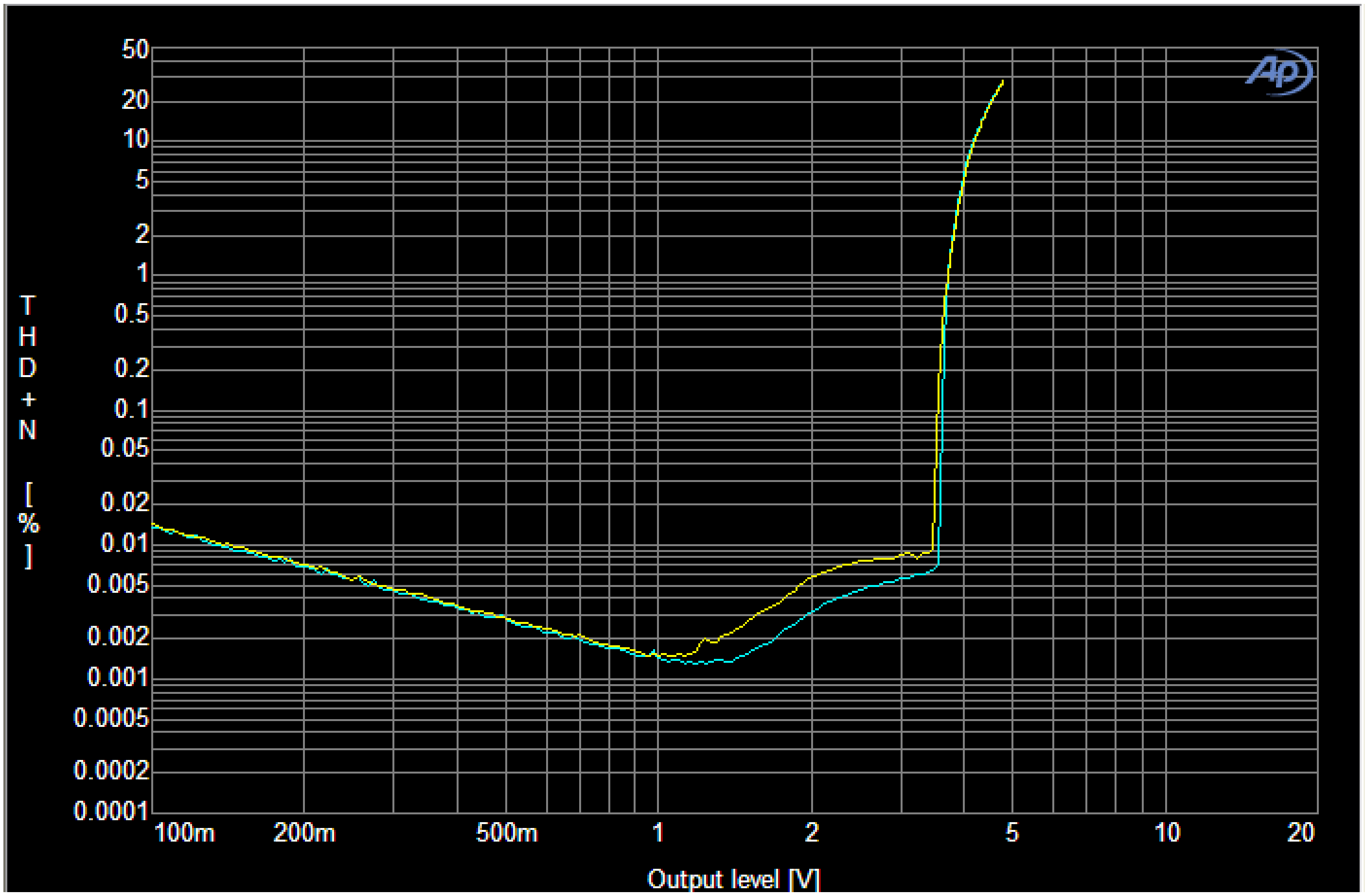


Figure 56 - Headphone Distortion vs Output Level at 1KHz

Fig 16 is the distortion performance into a 32 Ohms load at 1KHz vs output and remains below 0.015% up to 3.5VRMS, with the lowest at about 20ppm at 1VRMS out

7. Component Selection

I used good quality components throughout this line amp. Resistors are Vishay Dale CCF-60 series from Mouser, which offer low noise and importantly low voltage coefficients. When designing with an op-amp that can achieve sub 1ppm distortion performance, even resistors have to be selected carefully in order not to contribute non-linearity to the final performance. Now, if you are working to a tight budget, you can use lower cost general purpose resistors (carbon film) and still get very good performance. Just make sure the ones highlighted in yellow on the circuit diagram (Fig 24) are good quality metal film types. For capacitors, I almost always use Panasonic or Nichicon for the electrolytics because I've found they are specified well and they have a good range of values. For the critical input filter capacitors (C25 and C28), I used 1nF 50V polyester film types. Avoid ceramics in this position, unless they are NP0 which are ok. For the caps across the line amp and headphone amp stage feedback resistors(C26, 27,16 and 17), I used silver mica. Again, NPO ceramics can also be used as an alternative.

For the power supply transformer, I used an Amveco 15VA unit. I found the Amveco transformers to be mechanically very quiet, and can recommend them for this type of application. I tried Block from Germany on a previous project and was disappointed with the high level of mechanical noise. At first I thought it was because there was DC on the mains, but in the end it turned out it was just a noisy transformer, period. In a pre-amp, it's important that the transformer is absolutely quiet – no buzzing and humming is permissible.

A word about the volume control is necessary at this point. The standard unit uses an Alps Blue Velvet dual 10K log taper pot, but you can also fit a Goldpoint Mini V 24 way switched attenuator as an option. This will set you back about $128 for a stereo version, and might well be worth the extra outlay in my view because it has very low noise and extremely accurate tracking between channels, especially at lower volume levels (although this is not a problem with the Alps). Let me add, I have not personally tried the Goldpoint, but I've heard it's a nice product.

I used a 2U 'Slimline' housing with optional 3mm thick Aluminum top and bottom cover plates (rather than the standard 1mm mild steel) from Modushop, who are based in Italy. They have a nice website where you can order the stuff, and they will ship worldwide – prices are not cheap nowadays, but the product is solid and the service is good. The contact is Andrea Bettazoni who runs the business. I had the 10mm front panel machined by Modushop and also the back panel holes for the connectors pre-drilled. The knobs you see are also from Modushop and I can tell you they are beautifully made – solid aluminum and very heavy – no plastic. My only regret is that I ordered the 38mm diameter ones and not the bigger 49mm versions. On audio gear, the bigger the knob the better as this gives a smooth rotational action.

All the components are sourced from RS, Digikey and Mouser with a few of the connectors and caps coming from Akihibara, Tokyo - I currently live in Japan, so this is a convenient place for me pick up this kind of stuff and great place to hunt for tubes! I did not skimp on parts selection, or construction methodology. If you go 'all out' as I did, this pre-amp will cost about $300 to build, most of the cost in the housing and PCB's which I had made by PCB Cart (http://www.pcbcart.com/). If you are a slick hand at making your own double sided PCB's (no absolute need for THP – just make sure you solder the appropriate double sided connections on both sides) and can pull together a decent housing, I reckon you can build this pre-amp for about $100 all in. Some folks are experts at getting free samples – for you guys, make that $80!

8. Assembly and Interconnections

All of the connections between the selector switch and the main board, and between the headphone socket and the main board, are made using 10way ribbon cables and IDC connectors. Once you get the hang of assembling IDC interconnects with a small vice and a length of 10mm (0.4") square wood, my bet is you will never go back to multiple soldered connections between boards for your DIY projects. This construction technique makes for a neat finish and quick assembly/dis-assembly for trouble shooting – the only real effort is in the initial PCB design. A piece of cake.

The pre-amp PCB set comprises 7 PCB's – the main board, and then in Fig 17 below, from top left to top right, the headphone connector PCB, the selector switch mounting PCB, the headphone mounting PCB, the volume control connector PCB, the volume control mounting PCB and finally, the selector switch connection PCB. What are all these mounting PCB's for? Well, I used PCB's to mount switches and connectors to aluminum front plates – its much easier, more accurate and takes less effort than trying to drill, file and polish pieces of aluminum. If you like to use 10mm front plates as I do, then drilling and tapping 3mm x 6mm blind holes is a cinch and the result is a flawless looking job. Of course, if you are getting your boards made professionally, then this approach costs money, so proceed as your pocket allows.

The headphone socket, volume control and the input selector switch all have 10 way IDC male connectors on them to allow connection to the main board via 10 way ribbon cable.

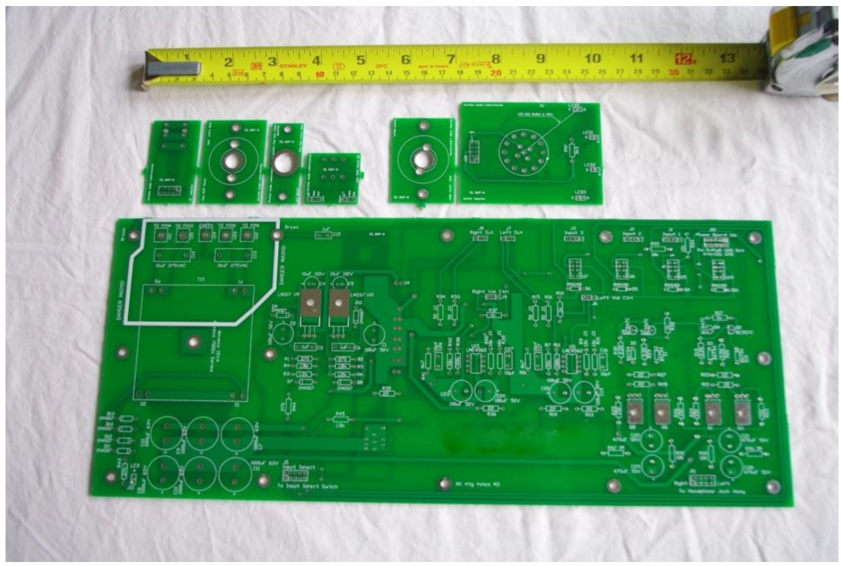


Figure 17 - Complete set of X-Altra Mini PCB's

Before assembling any of the boards, mark out all the holes required on the back of your front plate, and the mounting holes for the main board. Drill and tap the holes as required on the rear of the front plate – in my case, all M3 x 6mm deep. All the mounting PCB's are designed to accommodate 3mm diameter machine screws. Make sure the mounting PCB's align with your holes and you can screw them fully into place before you start any PCB assembly work – trying to do this with an assembled board usually results in components being damaged.

There is no particular order required in the assembly of the PCB, but I usually start with the flattest components first, which in this case is the resistors. The last things that should go in are the op-amps. In my version of this pre-amp, I socketed the op-amps expecting some debugging and trouble shooting (no need – it worked first time), but this is not usually considered good practice due to possible stability problems (and an absolute no-no by the way for high speed work). I never found any problems during testing.

Once all the boards are assembled, construction of the complete system can begin. Note, the final artworks are slightly different from the ones shown in the pictures because I made a few corrections.

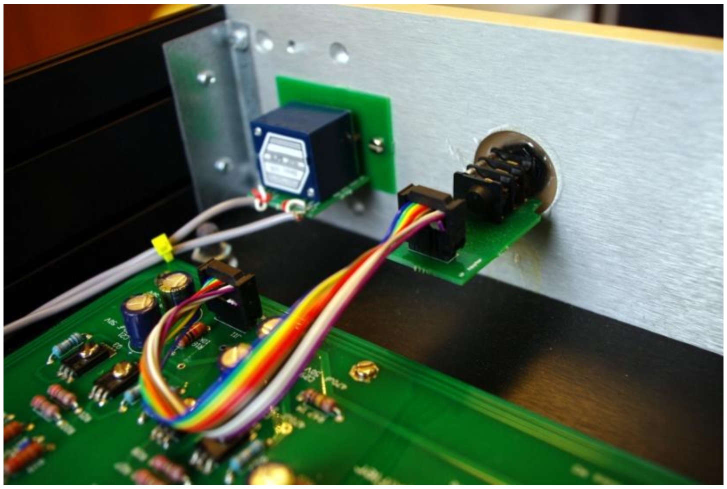


Figure 18 - Volume control and Headphone Socket Mounting

Mount all the input and output sockets. For the headphone socket, I actually glued this into place with 2 part epoxy and did not use the headphone mounting PCB. Note in Fig 18 that the headphone socket is actually recessed into the front plate. You can also see from the pictures that the headphone socket juts out about 1.5mm beyond the front plate surface – this is intentional and ensures the headphone jack plug does not make mechanical contact with the front plate when being inserted, which would end up scratching it. Assemble the input selector switch, making sure the IDC cable is plugged into it before you mount the assembly onto the front plate – you will not be able to plug the cable in once it's mounted.

Note, whatever type of headphone socket you use, the socket common must not make electrical contact with the front plate – for this reason I recommend you use a plastic molded type socket (see parts list). If you use a metal socket and it connects with the chassis, a ground loop will be created, leading to hum and noise – the only way the headphone socket 0V must connect to the preamp PCB 0V is via the ribbon cable! This, by the way, also applies to all the input and output sockets – they must NOT make any electrical contact with the metalwork – again, the 0V on the socket must connect to the PCB 0V via the screened cable. If any of the sockets (input, output or headphone) connect to the chassis other than through the cabling, your pre-amp will sing at 50/60Hz and harmonics thereof. Not the most delightful sounding choir on the block, I can assure you.

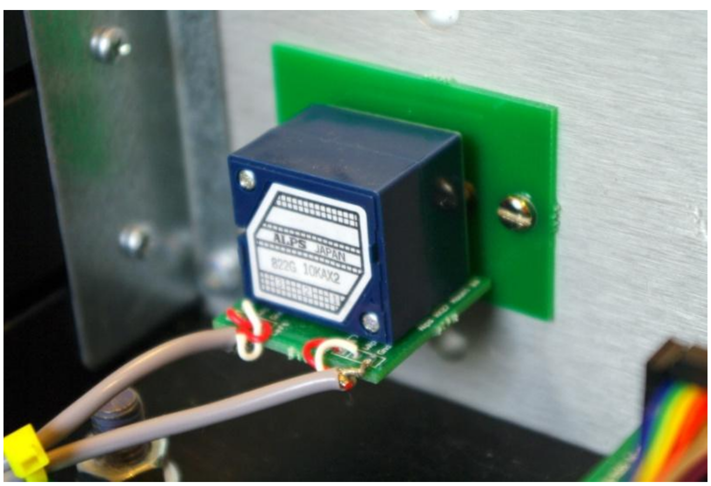


Figure 19 - Volume Control Mounting Detail

Fig 19 shows how the volume control pot is mounted on the front plate. The mounting PCB screws to the 10mm front plate by means of 2 3mm x 6mm long machine head screws. Fig 20 below shows how the selector switch is mounted to the front plate. As with the volume control pot, 2 x 3mm x 6mm long machine head screws are used.

Note that it is very important that the metal housing of the volume control is solidly connected to ground. If this is not done, noise is capacitively coupled from the shaft into the pot tracks, and if you are using a solid aluminum knob as I did, you will get hum. If you use a metal housing and the mounting PCB I have designed for this job, the connection is made for you. Of course, if you mount the pot conventionally to the front plate, this problem will be solved without any effort from your side. I used the mounting method shown to allow all mounting hardware to be located on the rear of the front panel, and to avoid having to cut the potentiometer shaft - always a messy job that can cause damage if you are not very careful.

Make sure there is a solid connection between the housing and the star ground (see Fig 24 Circuit Diagram). This is required for noise, and very importantly, safety. In the pictures, it's the green wire connected from the earth binding post on the rear panel to the star ground point on the PCB. The mains earth on the power inlet must also be connected separately and solidly to the metal chassis as well. Keep this cable short and make the connection near the inlet receptacle.

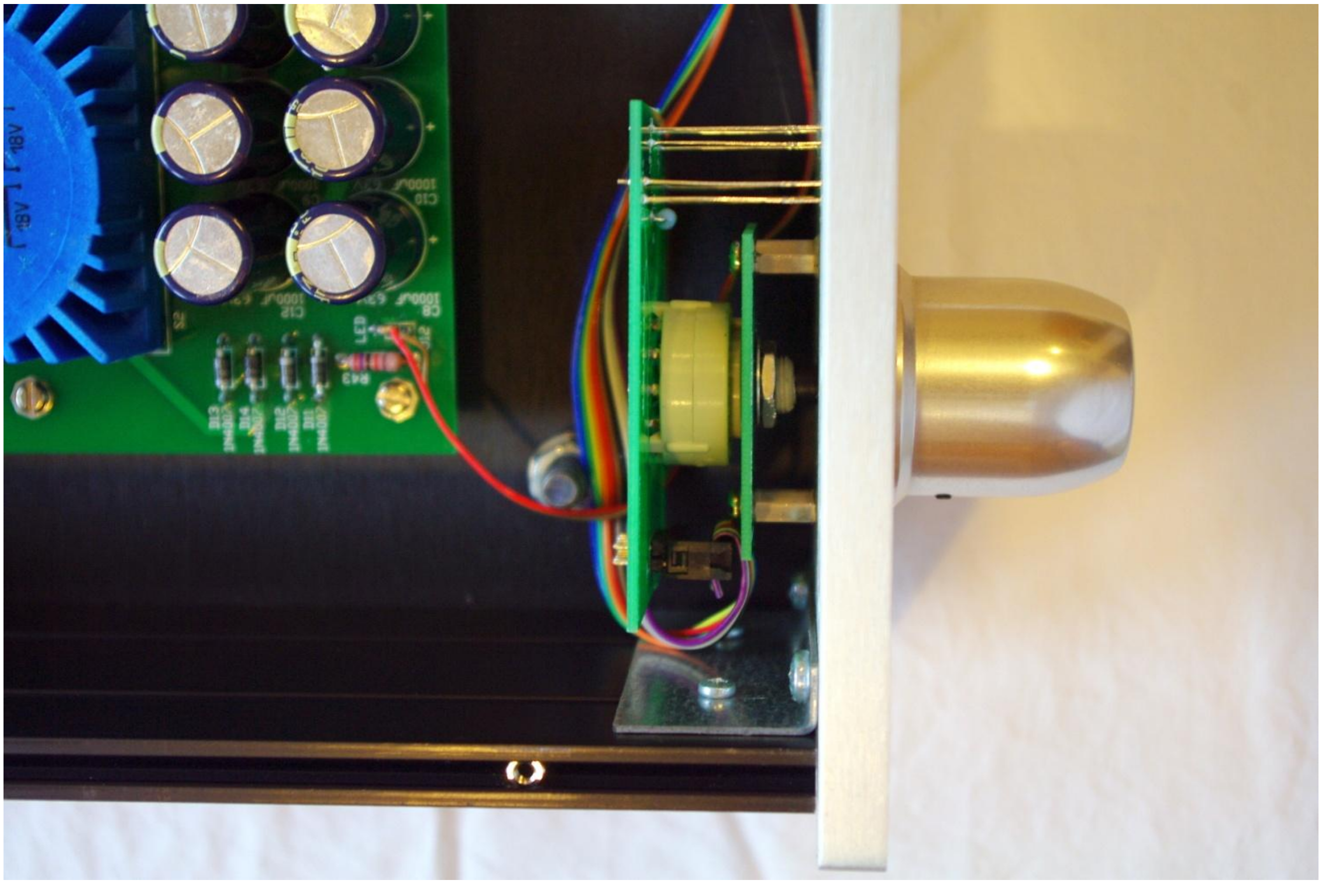


Figure 20 - Close-up of Input Selector Switch Selector Assembly

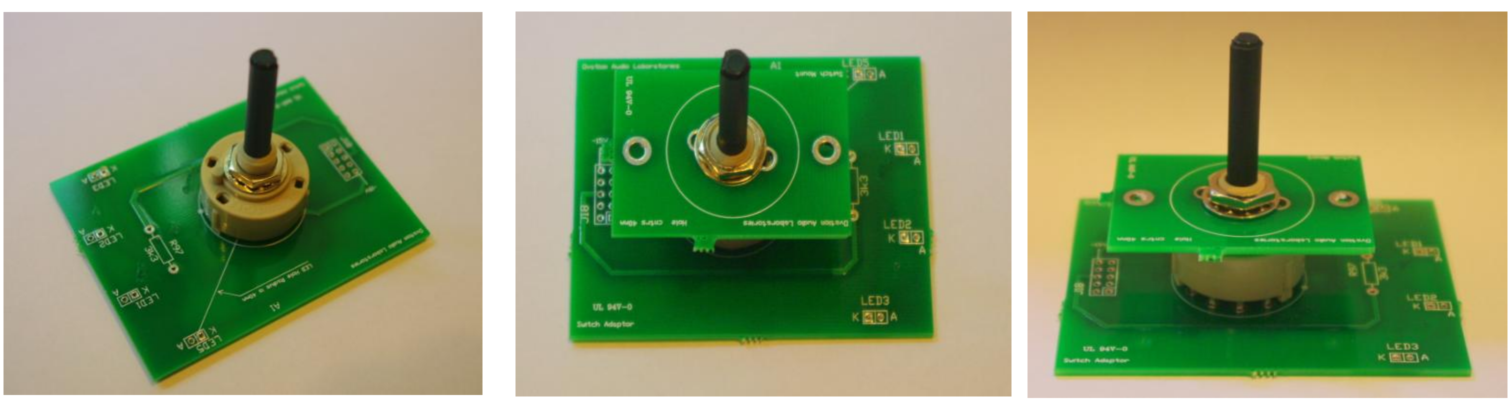


Figure 21- Various views of the selector switch PCB showing how it fits together. Make sure pins ‘A’ and ‘C’ on the switch line up with the holes marked ‘A’ and ‘C’ on the bottom PCB.

Figure 22 details the general wiring arrangement. You may **not** use the pre-amp if it is not EARTHED. All parts of the metal chassis must have a solid connection to EARTH.

For the internal signal wiring, use good quality screened cable. The cheap stuff simply bundles stranded copper next to the inner core and this has very inferior noise rejection properties. The screen must be of the woven type to provide good rejection of any external noise and to reduce cross talk.

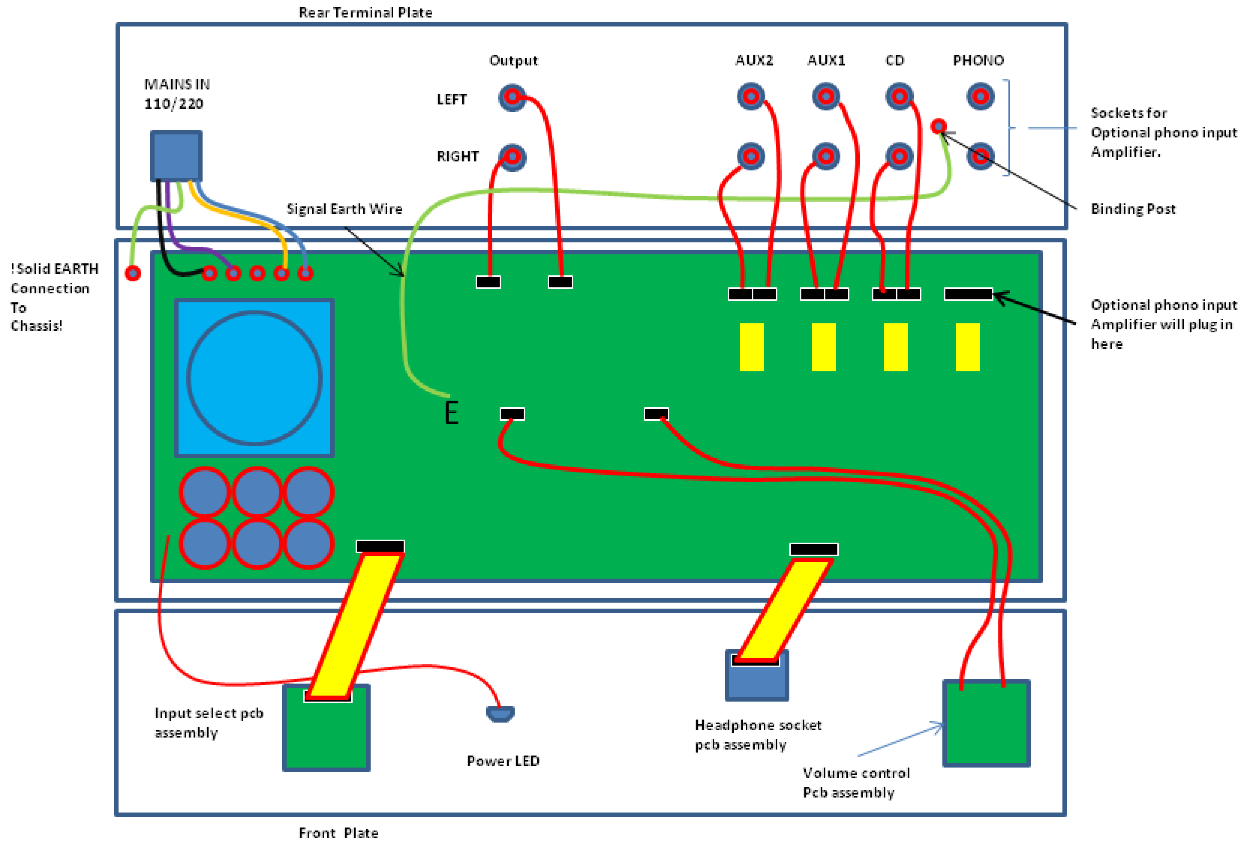


Figure 22 - General Wiring Diagram

9. Sound Tests and Conclusions

I have been using the X-Altra Mini One in my system for well over a year now and have had absolutely no problems. After the initial tests, I had to make a few tweaks like the CD level attenuator which I increased from about -14dB to about -20dB to bring it more in line with the other inputs. The headphone amp also underwent some design changes as well (all these changes have been reflected in the circuit diagram and PCB layout in this document). My system currently consists of a pair of B&W 703's (B&W 703 Review), a Pioneer multi-format CD/DVD/SACD player, and the power amp is a 250W fully balanced topology stereo unit that I designed and built, completing it about three and a half years ago. All connections in my system are currently unbalanced.

I listen to any and everything from rock, pop, classical, jazz and world music and have about 500 CD's (my LP collection of around 300 is in storage with my turntable at present).

After I completed the power amp a few years ago, I started to use it instead of the Marantz PM7000, which is about 95W per channel, to drive the B&W's. In terms of bass grip, sound staging and top end, going from the PM7000 power amp stage to the 250W per channel amp was a very significant step up, even though I was still using the pre-amp section of the Marantz. Big power amps do sound good. I had to doctor the Marantz slightly in order to do this by adding two output phono sockets and connecting these to the Marantz pre-amp output inside the case via 100 Ohms in series with each output. Later on, I also tried feeding the Marantz CD player directly into the power amp. This was possible since the Marantz CD player has a 6 step attenuator that can be controlled by the remote.

I listen to a lot of CD's, but I have listed some of the ones below that allowed me to ascertain the difference between the Marantz pre-amp section and the Marantz CD player direct connection to the power amp versus using the X-Altra Mini One to drive the power amp using the Pioneer and the Marantz CD player as sources.

- Eliane Elias 'Something for You' - great recording of some Bill Evans classics by one of the preeminent jazz pianists around today with clean open sound, although sound staging is not quite as good as some of the CD's below.
- George Benson and Al Jareau 'Giving it Up' ; really crisp, punchy recording with a lot of energy. (great performance by Stanley Clarke on one of the tracks - I had the good fortune of seeing him live at the Blue note in Tokyo about a year ago)
- Diana Krall 'Live in Paris' – a very atmospheric recording with great L to R sound staging and good depth as well. I like the ambience of this recording and the audience applauses really bring it to life.
- Breakfast Baroque – A selection of Baroque pieces from Classic FM in the UK - violins in a small chamber music piece are a great way to assess the mid band and the top end. Some of the recordings on this CD are very well done with good sound staging.
- Fabrizio Bosso's 'Sol Latin Mood' and 'Five High For Five Fun' – a fantastic Jazz combo. Two of the best CD recordings I have picked up over the last 2 years or so – great sound stage, bass and fantastic brass 'attack' on the recordings with loads of energy.

- The Royal Philharmonic's Berloiz recording. This recording is great and the faint background noises, including traffic, you can hear in some of the quiet passages adds to the realism. When the whole orchestra is playing, it's easy to pick out the position of the various instruments and how far back they are. Big natural sound stage.
- Finally, Joe Sample's Old Places Old Faces CD. Open, uncluttered sound. Clifton's Gold (3rd track) is a wonderful sax piece that's raw and gritty with a huge range in level.

The danger here is that I might wax lyrical about my design effort, since there is understandably a natural bias towards my creation. But, let me try to be objective. No, my jaw did not drop off, and I was not staggered by any fundamental new musical insights. Neither was I able to walk around a 3D holographic acoustic sound stage. What I did hear was a very nice sound: clean, open and with zero hiss or hum.

Comparing the Marantz pre-amp driving the power amp to that of the X-Altra Mini One driving the power amp with the Marantz CD player and the Pioneer player as sources I could detect differences:-

1. The bass is crisper and it goes much deeper compared to the Marantz PM7000 or the direct CD connection to the power amp combo. The Marantz PM7000 bass is to my ears, 'sloppy' – its there, but it lacks real 'snap' compared to the X-Altra Mini One driving the power amp.
2. Midrange - very clear and natural. The Marantz sounds polite and has a soft sound in general, especially on big, densely recorded classical pieces. The situation improves when I drive the power amp directly from the Marantz CD player, but it's still not as good as when the amp is fed by the pre-amp with the Marantz CD player as the source. There is a very big step up in the midrange quality going to the Pioneer player – I can discern individual instruments more clearly on all of the CD's mentioned above.

3. Top end. Preamp driving power amp has the best sound. On the Eliane Elias recording, the drummer (Joey Baron) does quite some work on the cymbals and you can hear the fantastic whooshSHSHSsss of the cymbals which with the other combos aren't there – they are a bit flat and lifeless by comparison. Having had the pleasure of seeing Eliane Elias live at the Blue Note in Tokyo a while back, I know what those cymbals should sound like.
4. I listened carefully for the sound stage both front to rear and width. Clearly, not all recordings are made equal in this area, so this is a point that has to be considered when choosing a CD for this assessment. I mainly used the Fabrizio Bosso, Royal Philharmonic and Diana Krall CD's to ascertain this aspect . Its a great sensation when, on good recordings, you get instruments well to the left and the right of the speakers,

and the sound stage is layered front to back – I do not get that to the same degree on any of the Marantz combos. The 'Breakfast Baroque CD also has some tracks that have really good sound staging. I would say the top end on this pre-amp is clean and clinical and you get what goes in. The sibilance isn't exaggerated either which is important.

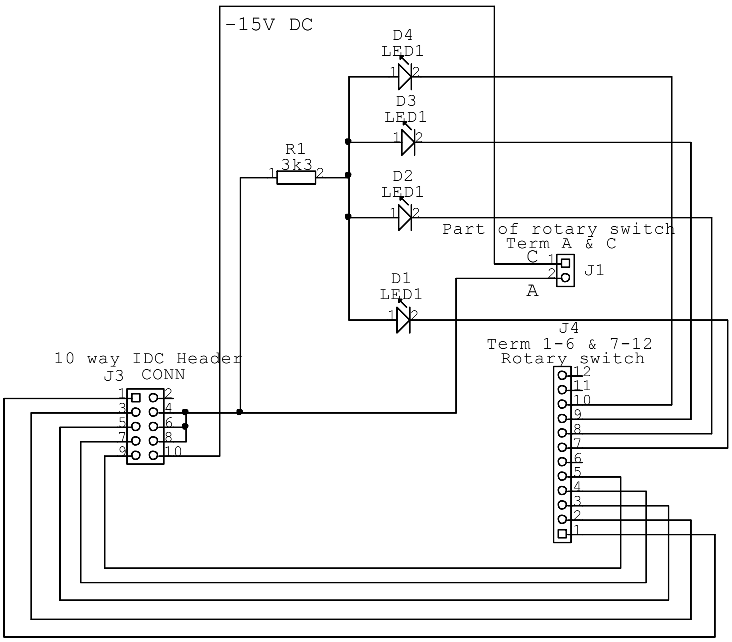
In conclusion, the X-Altra Mini One was built to a minimalist feature spec and to a tight, self imposed budget for the signal chain components. As I mentioned in the construction notes, if you are really careful, you can probably build it for $80. I am extremely pleased with the final result as measured on the AP SYS2722 and the subjective listening tests over the last year or so. There is also no doubt that the LM4562 is a wonderful audio op-amp, which I am sure will go on to replace the 'venerable but still great' (to paraphrase Douglas Self) NE5532, although there is the slightly higher noise spec to consider in some applications. I probably spent a bit too much on professionally made PCB's, knobs, connectors and the chassis, but what the hell – it looks good and sounds great!

Picture of the X-Altra Mini driving the 250W per Channel power Amp. The speakers look a little 'bent' but that's just the wide angle lens that I used to take this shot.

10. What Next?

A DIY Audio fanatic's work is never done. Once one project ('program of work') comes to an end, there is another to think about (along with a fresh round of excuses to the partner as to why attending some dinner party or function on Saturday nights is not a good idea) and I have already started on something altogether more ambitious, but enough of that here. Specifically, for the X-Altra Mini One, I will live with it for another 2 or so years and then, retaining the existing housing, will re-design it from the ground up with fewer restrictions on myself on complexity and cost of the signal chain components. As I mentioned at the beginning, this really was a 'quick 'n dirty' project, to get out of having to use the Marantz pre-amp- stage. There are significant opportunities to improve on the headphone amplifier (e.g. full class A, lower distortion, more headroom). The L/R separation on this pre-amp can also be improved by the use of separate relays on for each channel, and back grounding inputs to increase isolation. For the volume control, there is the prospect of using the Goldpoint Mini 'V', and I'd like to source a really nice selector switch – the Lorlin I used on this pre-amp is good enough, but it has end stops rather than simply rotating back around to the beginning again, and I think the rotational feel can definitely be improved upon. Noise can also be improved and I'm thinking better than 120dB worst case should be another target. The CD attenuator stage can be improved with some buffering, and a tape loop is a useful function. Finally, I will also add fully balanced outputs. You can bet there'll be plenty of SMD's on the board!

11. Circuit Diagrams, Mechanical Drawings and BOM List



J1 pin 1 is Rotary Switch pin C
J1 pin 2 is Rotary Switch pin A

J4 is pins 1-12 on Rotary Switch

Pins 1-4 are used to switch input select relays individually to 0V

Pin 5 is connected out via J3 as a spare but is not used

Pins 7-10 switch LED's D1-D4, indicating which input relay is activated.

LED Anode's commoned and connected to 0V via 3K3 resistor

Cathodes are individually switched to -15V (pin 10 on J3)

Figure 23- Input Selector Switch Circuit Diagram

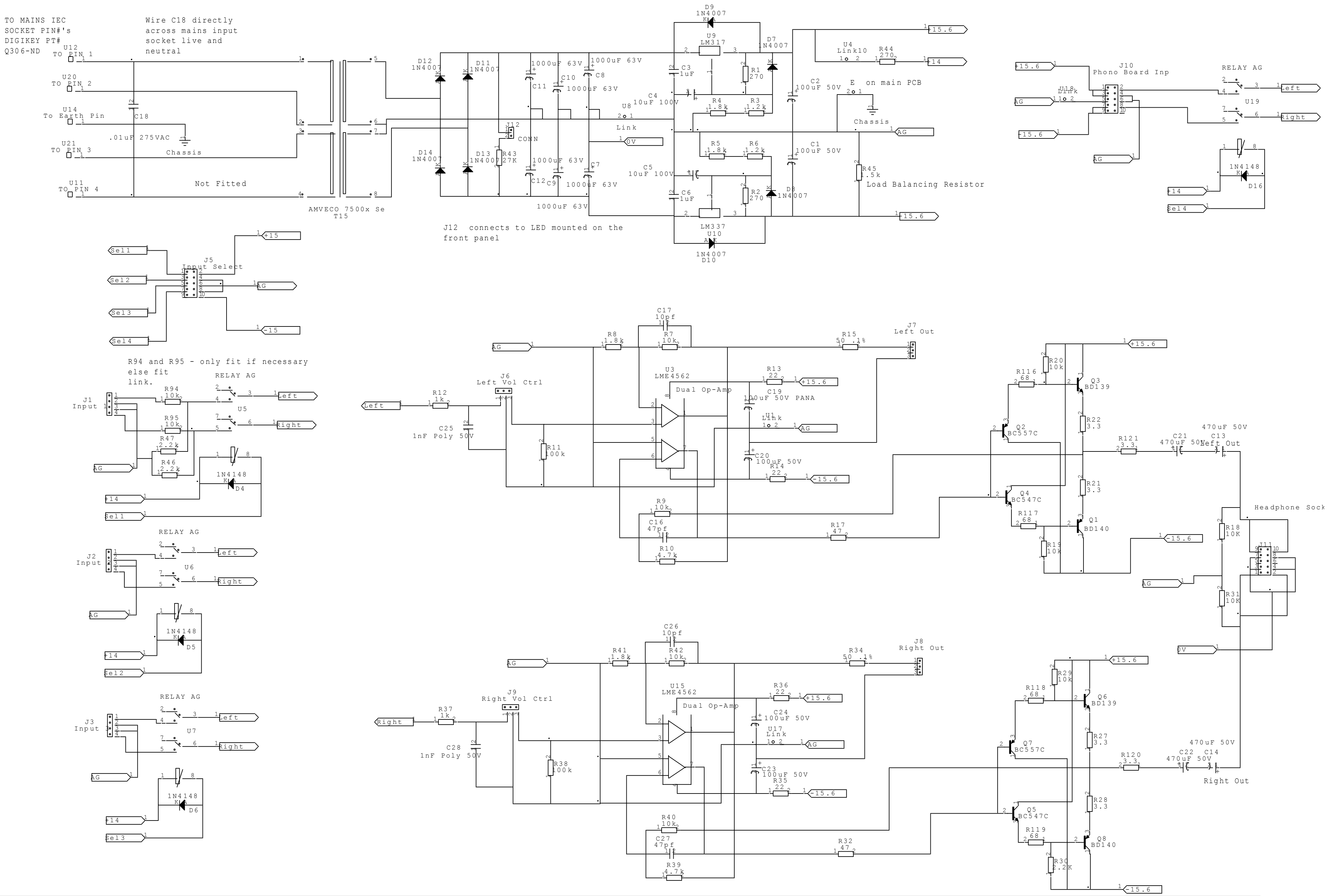

TO MAINS IEC
SOCKET PIN#'s
DIGIKEY PT#
Q306-ND
Wire C18 directly
across mains input
socket live and
neutral
.01uF 275VAC
Chassis
Not Fitted
AMVECO 7500x Se
T15
J12 connects to LED mounted on the
front panel
Load Balancing Resistor
on main PCB
Phono Board Inp
RELAY AG
Input Select
R94 and R95 - only fit if necessary
else fit
link.
Left Vol Ctrl
Right Vol Ctrl
Dual Op-Amp
Left Out
Right Out
Headphone Sock

Figure 24 - X-Altra Mini One Main Circuit Diagram

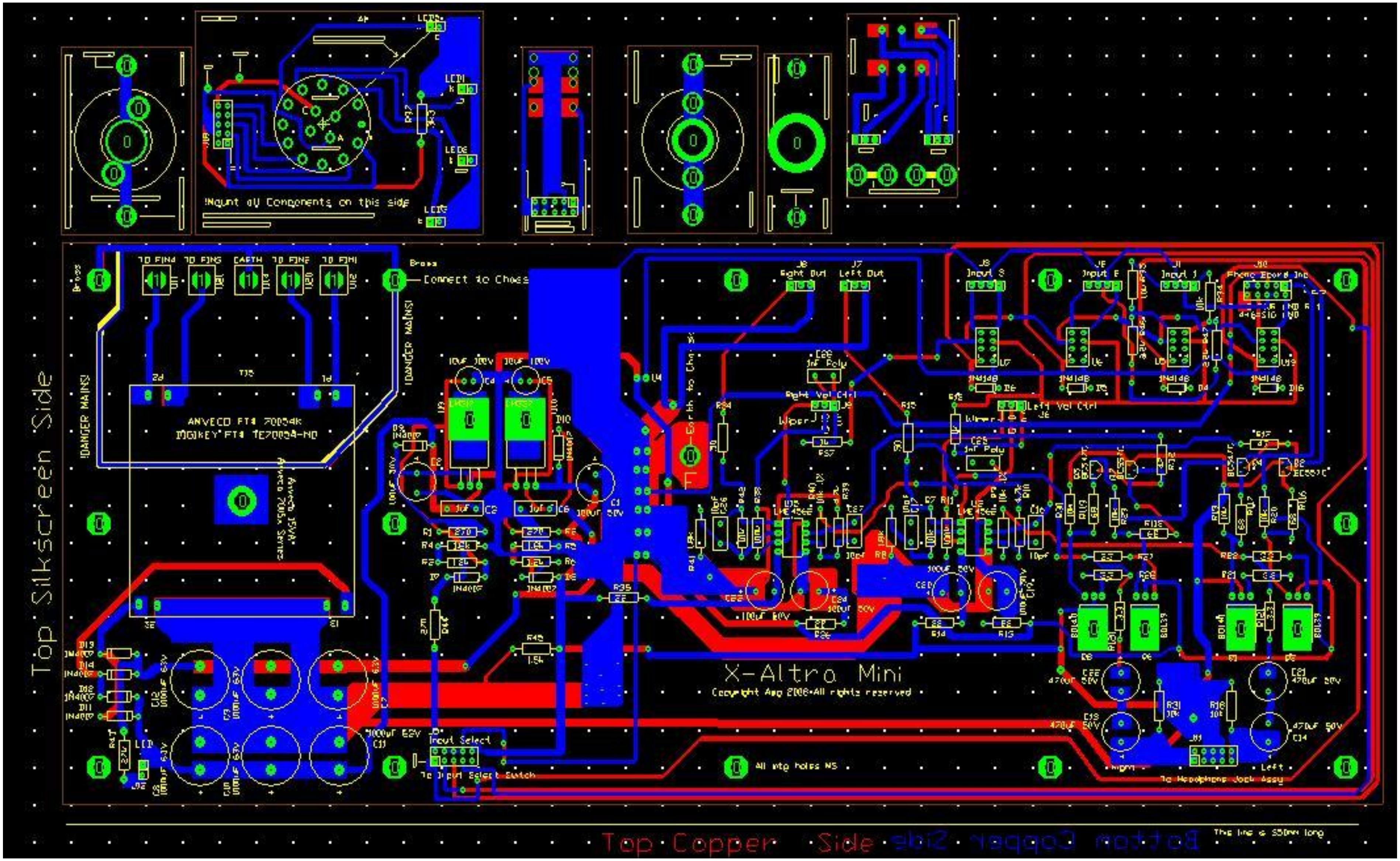


Figure 6 - Printed Circuit board Set

Item	Count	Label-Value	DESCRIPTION	Designation
1	2	100uF 50V	Panasonic FC Series	C1,C2
2	2	1uF	1uF Stacked Foil 100V BIC Vero	C3,C6
3	2	10uF 100V	Panasonic FC Series	C4,C5
4	6	1000uF 63V	Panasonic FC Series	C7,C8,C9,C10,C11,C12
5	4	470uF 50V	Panasonic FC Series	C13,C14,C21,C22
6	2	47pf	Silver Mica	C16,C27
7	2	10pf	Silver Mica	C17,C26
8	1	.01uF 275VAC	Panasonic ECQ-UV	C18
9	4	100uF 50V PANA	Panasonic FC Series	C19, C20,C23,C24
10	2	1nF Poly 50V		C25,C28
11	4	1N4148	GP Small Signal Diode	D4,D5,D6,D16
12	8	1N4007	1A GP Rectifier Diode	D7,D8,D9,D10,D11,D12,D13,D14
13	2	BD140	PNP 1 A GP Audio Transistor	Q1,Q8
14	2	BC557C	PNP GP small signal T0-92 transistor	Q2,Q7
15	2	BD139	NPN 1 A GP Audio Transistor	Q3,Q6
16	2	BC547C	NPN GP small signal T0-92 transistor	Q4,Q5
17	3	270		R1,R2,R44
18	2	1.2k		R3,R6
19	4	1.8k	All YELLOW Resistors are 0.5W Metal Film 1%	R4,R5,R8,R41
20	11	10k	R7 and R42 must be metal film	R7,R9,R18,R19,R20,R29,R31,R40,R42,R94,R95
21	2	4.7k		R10,R39
22	2	100k		R11,R38
23	2	1k		R12,R37
24	4	22		R13,R14,R35,R36
25	2	50	ok to use 47 1% MF Ohm here as well	R15,R34
26	2	47		R17,R32
27	6	3.3		R21,R22,R27,R28,R120,R121
28	3	2.2K		R30,R46,R47
29	1	27K		R43
30	1	1.5k		R45
31	4	68		R116,R117,R118,R119
32	1	AMVECO 750054	AMVECO 15VA TRANSFORMER 18-0-18 VAC output	T15
33	2	LME4562	National Semiconductor	U3,U15
34	1	LM317	National Semiconductor	U9
35	1	LM337	National Semiconductor	U10
36	3	10 Way IDC Header	2.54mm pitch, available from Digikey	J5, J10, J11
37	1	36 way single row header	2.54mm pitch from Digikey. Break off 3 and 4 way as required for connections	J1, J2, J3, J6, J7, J8, J9, J12
38	4	Relay AGN 12V	Panasonic Type AGN20012	
39	4	LED 3mm Green		
40	1	LED 3mm Red		
41	1meter	Ribbon cable 10way multicolor		
42	1	Alps 'Blue Velvet' RK27 Dual Gang 10k Log pot		
43	1	Lorlin 2 x 6 way Rotary Switch. Digikey Pt # EG1953-ND		
44		IEC Switched Mains Input Receptacle. Digikey Pt# Q306-ND		
45	10	Phono Sockets. I used expensive Neutrik panel mount types, but any reasonable quality		
		types will be ok. No part of the socket must make electrical contact with the chassis, so make		
		sure whatever type you end up using complies with this requirement.		

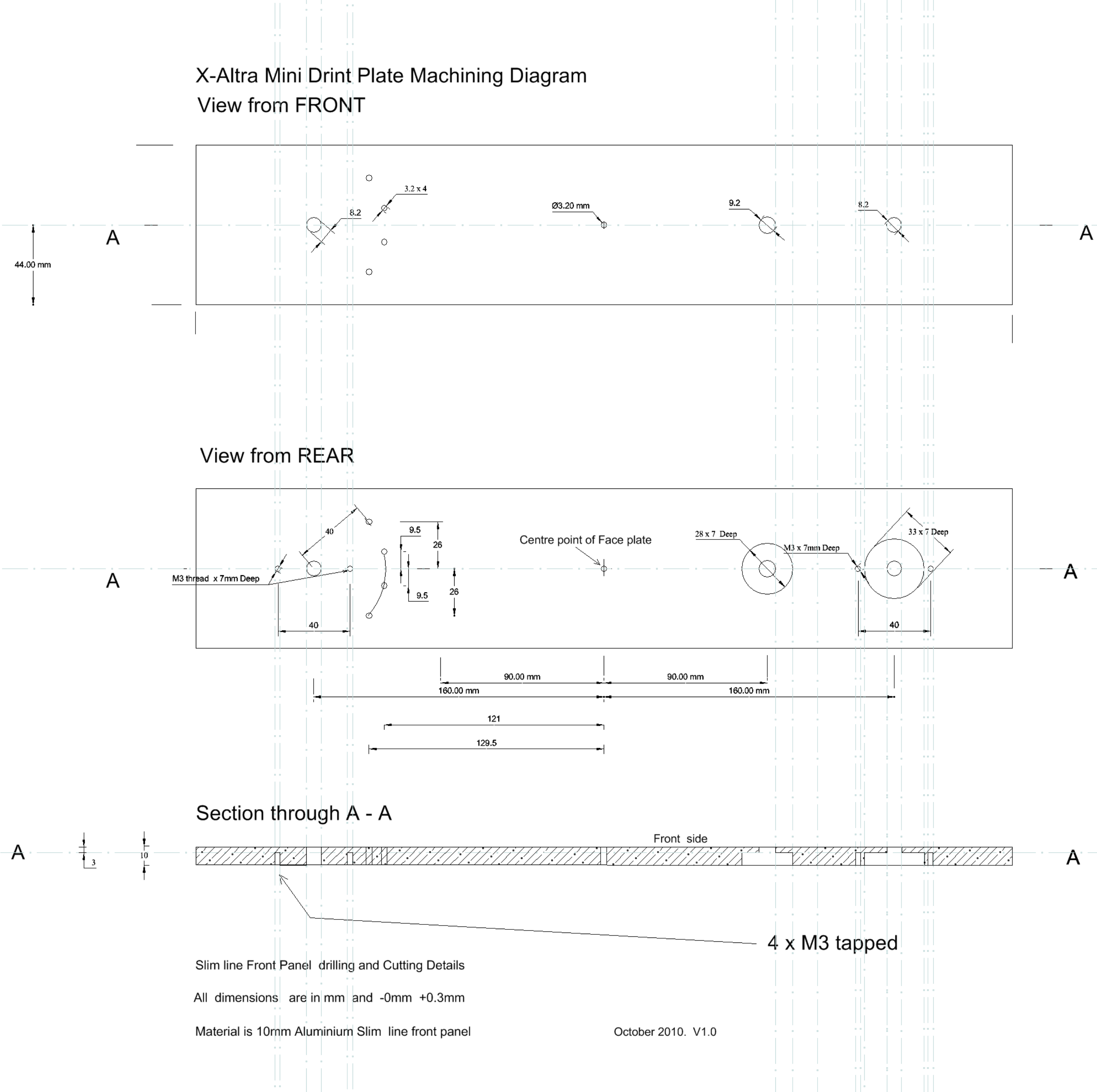


Figure 26 - Front Panel Machining details for the Modushop 'Slimline' Case

Note that I manually countersunk all the LED holes 6.2mm diameter x 6mm deep from the rear of the front panel. This allows the LED's to be positioned in the countersunk holes and improves indication as viewed from the front. See Fig 11 also.

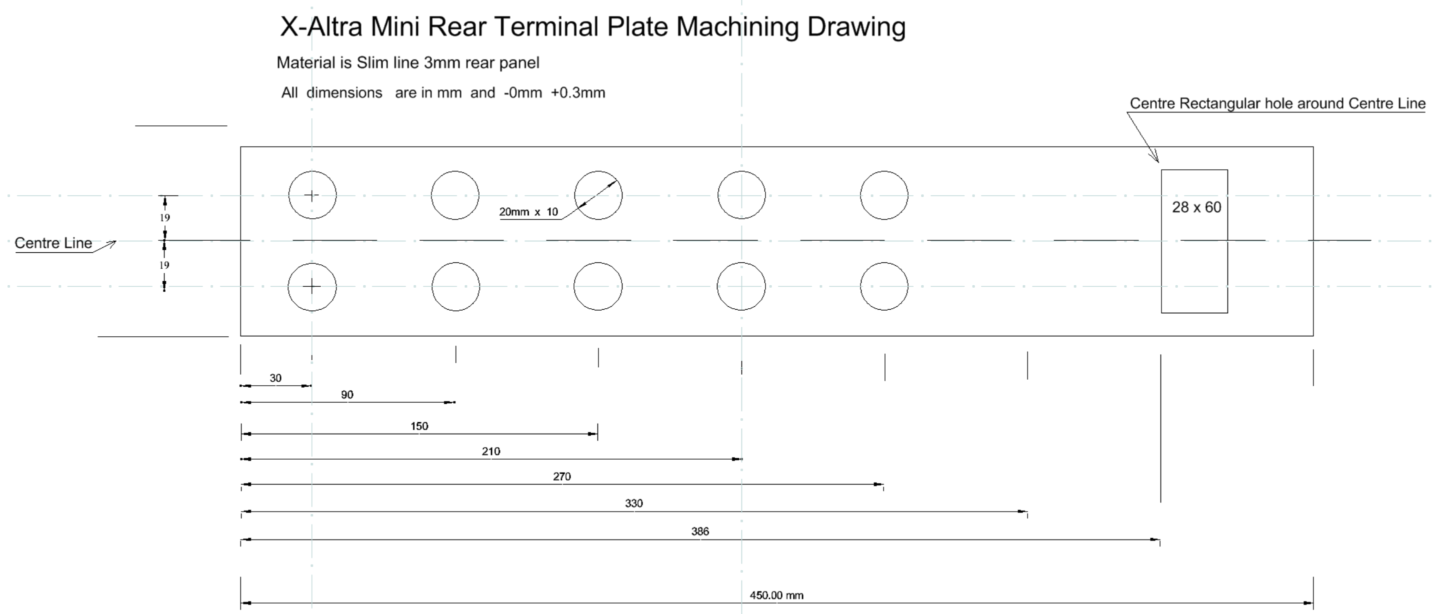


Figure 27 - Rear Panel Machining Detail for the 'Slimline' Case

Document Update History

Date	Change	Page
20 October 2010	Clarified input, output and headphone socket wiring	20
20 October 2010	Corrected H/P Class A spec	11