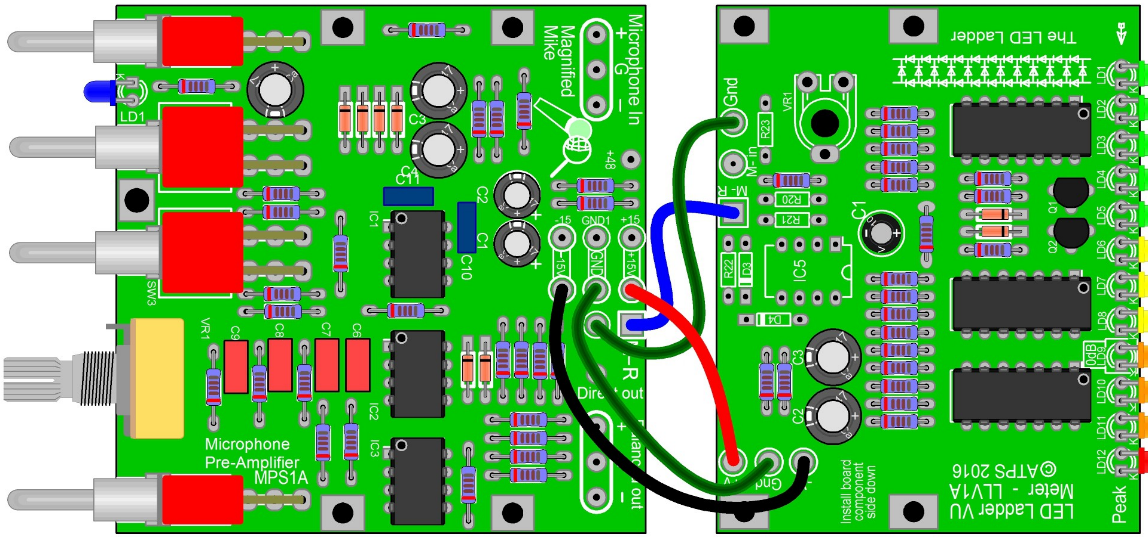
Australian Technical Production Services

Microphone Pre-amplifier with level meter



Revision history:

13/9/2012	created
20/2/2016	Adapted to SSM Pre-amplifier
10/04/2016	Corrections, Construction notes and Errata section
24/01/2017	Parts list correction R5 and R6
10/03/2021	Increase R1 and R2 in VU meter to 51 Ohm due to reports of some LM339es saturating

Credits

This Article contains contributions by:
Richard Freeman

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Microphone pre-amplifier

This microphone pre-amplifier was designed originally for portable recording (although it would be equally at home in a studio, or mixing desk). To this end (with the exception of the high pass filter) it is as neutral* as possible, and has no EQ as it is expected that any processing or EQ is done in post production.

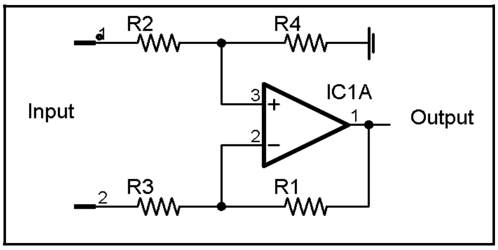
Design considerations

A microphone pre-amplifier needs to meet several almost contradictory criteria in order to be useful.

Firstly, a good pre-amplifier needs to have low distortion and produce very low levels of noise.

Secondly a good Pre-amplifier needs variable gain so it can accommodate a wide variety of signals. This characteristic alone has made pre-amp design challenging over the years. Earlier pre-amplifiers (from the valve era) typically had fixed, high gain stages with a variable attenuator between the signal source and the pre-amplifier. While this could work reasonably well, it meant that noise and distortion from the amplifying stage, (the bane of any high gain electronics), was fixed, could be high, and did not decrease with gain.

Thirdly a good pre-amplifier needs very little 'colouration' (i.e. have a flat frequency response), while it would be more fair to consider this to be more a characteristic of the microphone, the loading that the pre-amplifier presents to the microphone will often affect its character. Typically a lower impedance pre-amplifier will dull the sound of a microphone presenting a warmer, richer (muddier, duller) sound while a higher impedance pre-amplifier will give a crisper, clearer (harsher, more strident) sound. While the output impedance of a typical balanced microphone is in the order of 150 ohms or so, the ideal input impedance of a microphone pre-amplifier is somewhere around 1500 to 5000 ohms.
A Microphone pre-amplifier also needs to have a balanced* input with high Common Mode rejection Ratio (CMRR) to minimise interference.



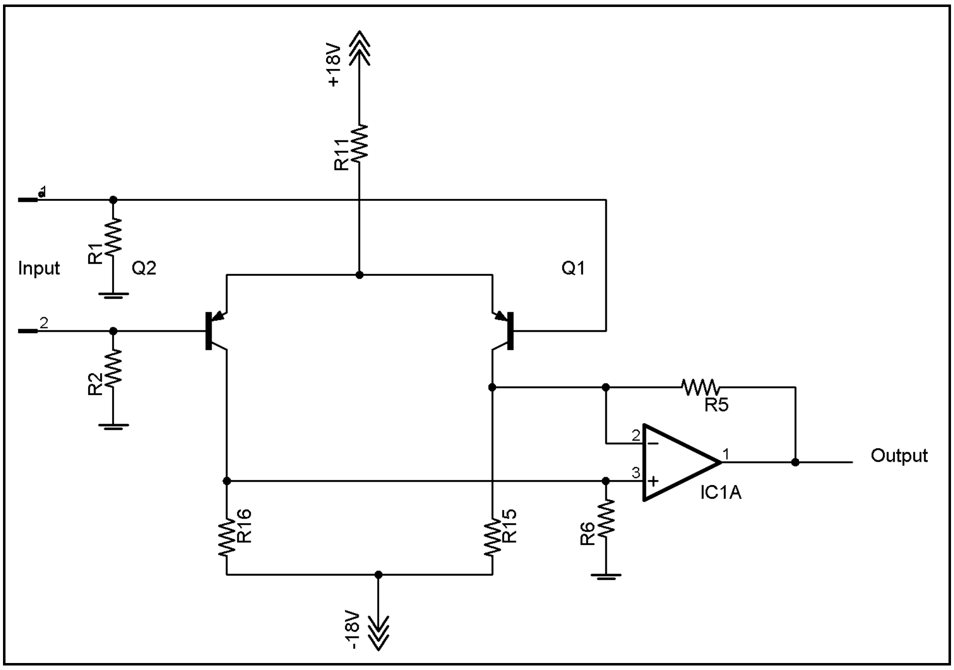
The easiest modern approach would be to use an Op-amp set up as a differential amplifier like this:

if we make the gain setting resistors (say R4 and R1) variable, we have what we want right?

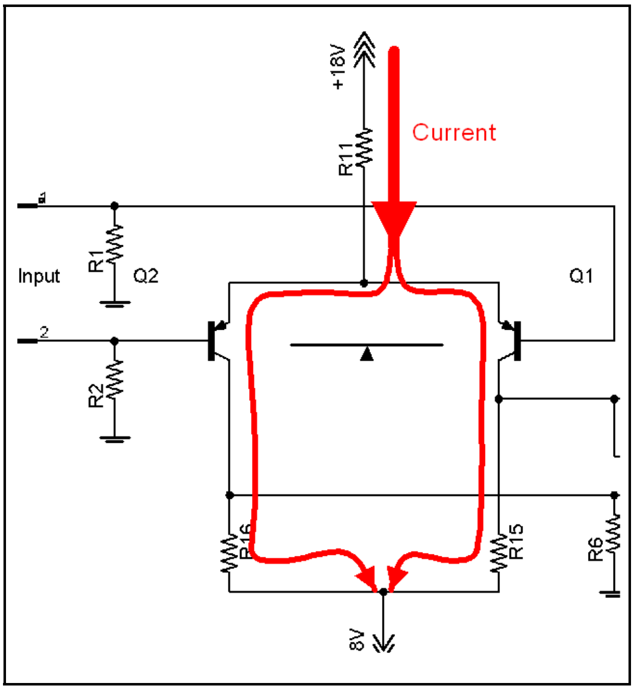
There are unfortunately a couple of problems with this circuit that make it unsuitable for this application: the biggest problem is that Op-amps tend to be rather noisy at higher gain – too noisy in fact, for this job, next variable resistors (especially less expensive ones) do not usually track accurately enough, and any mismatch between R1 and R4 (or R2 and R3) will decrease the CMRR.

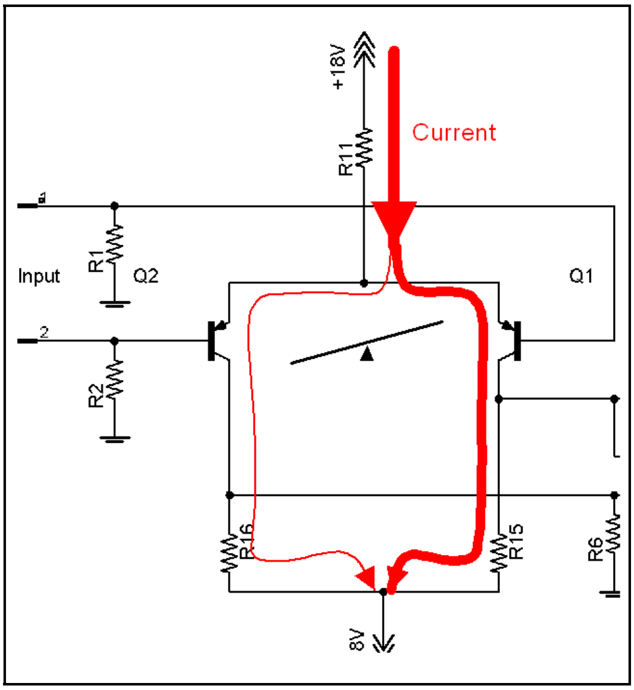
Discrete input (Long tailed pair)

This is why, it is more common to use a couple of medium power (i.e. low noise) transistors in a configuration called a long tailed pair, to provide a high gain stage in front of an Op-amp, like this:



This circuit, where Q1 and Q2 share a common resistor (R11) can be thought of as working a bit like a see-saw, at idle (i.e. no signal input) Q1 and Q2 share the current equally, so that current through R15 is the same as the current through R14, this in turn means that the voltage at the junction of R15+R5 is the





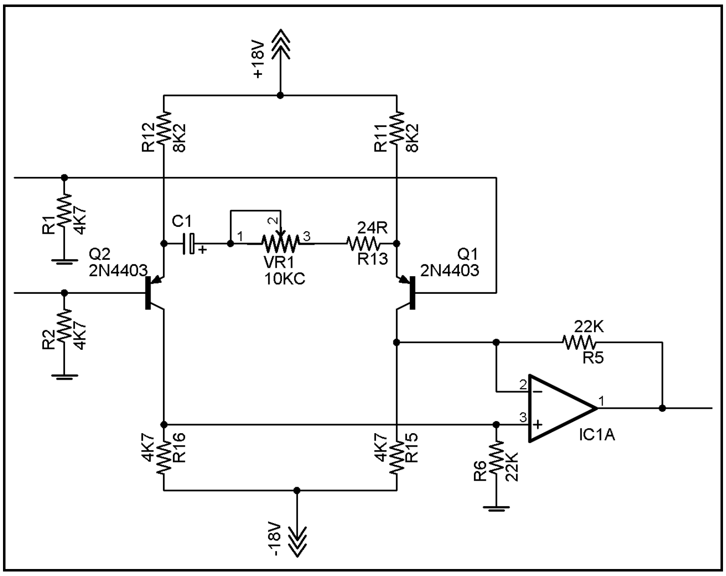
same as the voltage at the junction of R16+R6 and so the output from the op-amp (IC1A) is 0V.

When the signal into the pre-amplifier turns one transistor on (e.g. Q1 in the diagram on the right) that Transistor draws more current, which in turn takes current from the other transistor, turning it off. Likewise when one of the transistors is turns off, this pushes the other transistor harder on.

So the gain of a long tailed pair is dependant on the interaction between the two transistors, and if we now split R11 into two resistors (R11 and R12) and separate the two halves of the circuit with a variable resistor (VR1) as shown in the picture below, we can now vary the gain of the circuit using VR1.

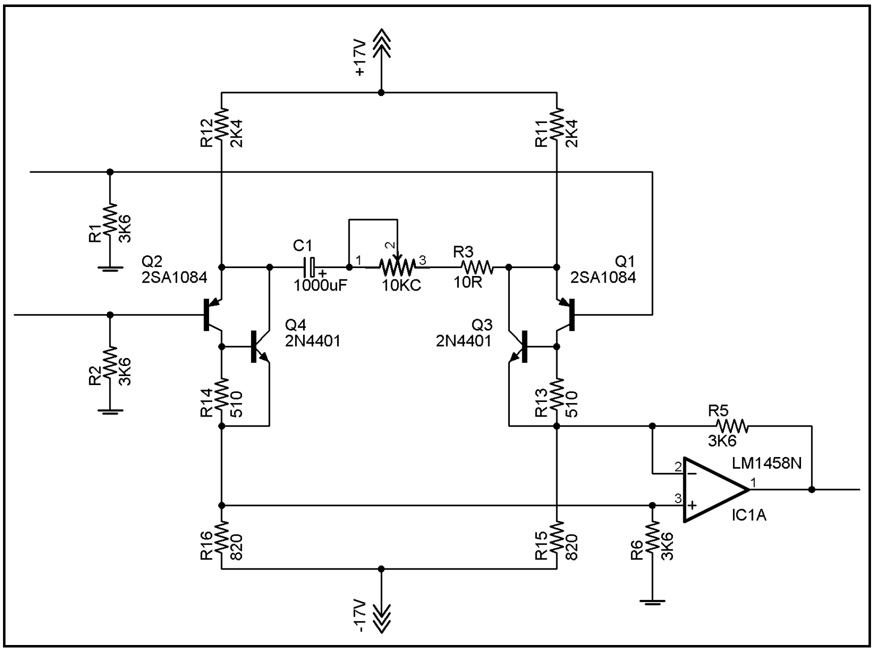
As this is a high gain amplifier, any minor variations between the two transistors, or input circuitry could result in a large DC offset so capacitor C1 is there to reduce DC gain.

Variations of this circuit are commonly used in most popular mixing desks and Microphone Pre-amplifiers.



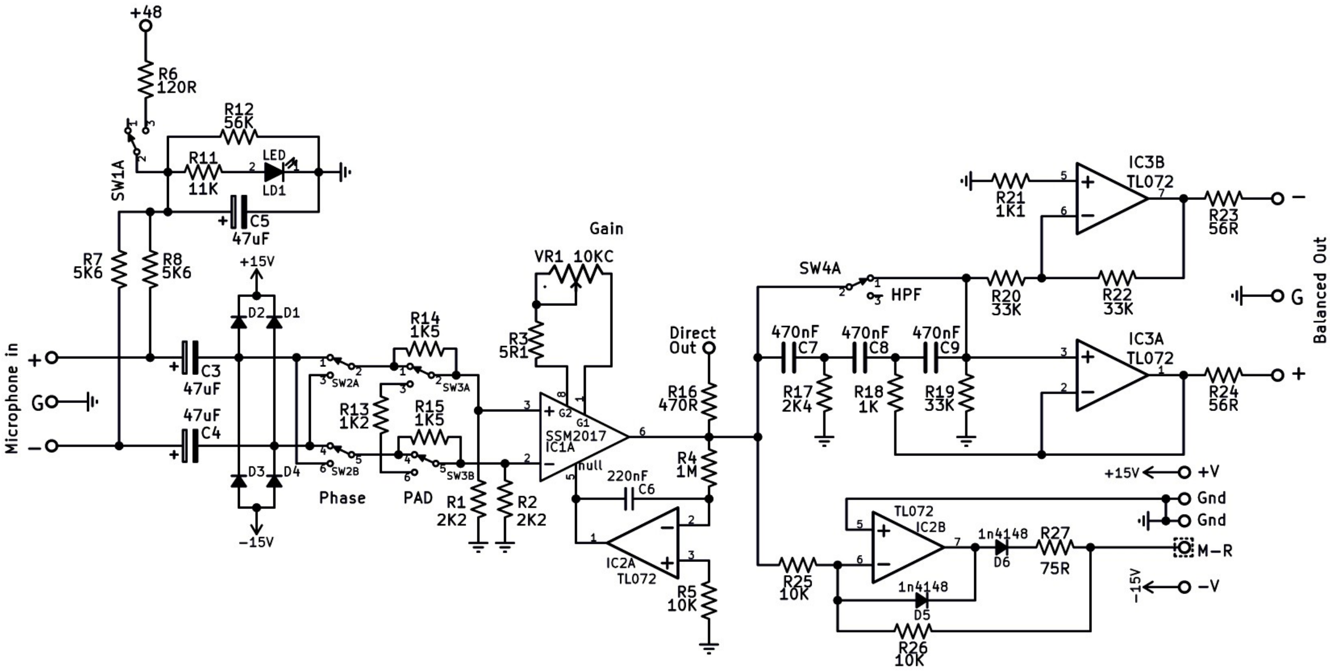
Complementary feedback pair

An higher gain alternative to the simple long tail pair replaces each transistor with a Complementary feedback, or Sziklai pair. This has gain close to a Darlington pair, but with lower distortion (due to

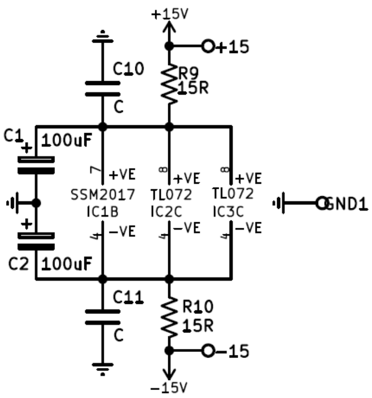


inherent negative feedback), however it is more complex and can be more of a challenge to get working nicely.

So enough back ground, lets just get to the Circuit:



er, ok I 'cheated' and used an Integrated circuit, the SSM2017, Burr-Brown INA217 or THAT semiconductor 1512 these offer levels of performance, which it would take a lot of effort to improve on in discrete form. The internal circuitry of both devices use the Szliski Complementary feedback pair in a (as discussed earlier) as well as a current feedback loop to bring THD down further still.



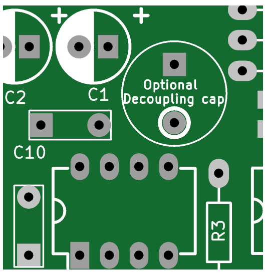
The power supply is decoupled via R9 and R10 with C1 and C2. R9 and R10 significantly reduce noise current from any power supply and stop this noise being injected into the Pre-amplifier Earth.

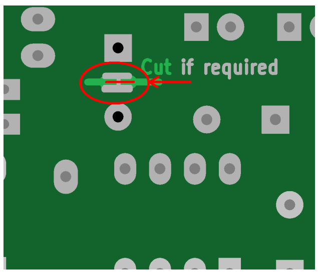
Phantom power is supplied via R6, R7 and R8 while Capacitor C5 provides additional smoothing and acts as a low pass filter, to reduce turn on 'thump' if/when phantom power is turned on, while capacitors C3 and C4 block phantom power from damaging the pre-amp. While Diodes D1-D4 clamp the input to protect the pre-amp against damage.

R13, R14 and R15 are a pad for high level signals when needed. If you do not want the pad, leave out switch 2 and R14 and R15 with wire links.

C7, C8, C9, R17, R18 and R19 in conjunction with IC2A provides a third order Butterworth high-pass filter set at 100Hz while IC3A and IC3B also act as an output buffer. If you do not want the High pass Filter and balanced output, you can leave IC3 out along with C7 to C9 and R17 to R24 and take the (unbalanced) output from the Direct out pad.

IC2A, C6 and R4 is the servo nulling circuit – this is basically a low pass filter which feeds the offset circuitry of the SSM2017 to compensate for any DC offset resulting from small differences in the input circuitry, which after a high gain stage could become significant. Servo nulling means that a decoupling capacitor shown as C1 in earlier circuits is not needed in series with the gain potentiometer.





I did find in testing that initially turning phantom power on resulted in a DC offset beyond what the nulling circuit could handle, this settled down after a short period of time however, and did not reappear. So I suspect that it may have been due to the new blocking capacitors C3 and C4 needing to be 'formed'. I did however decide to add an option to fit a decoupling capacitor if needed – this is marked on the board as 'optional decoupling capacitor' (as shown, in the picture on the left) and needs to be a 2200uF 6.3v Capacitor, since the normal DC voltage across this capacitor is so low, a regular electrolytic may be used and polarity won't matter. Note you will also need to cut the track underneath this capacitor if you decide to use it (as shown, previous page, circled, and marked in red on the picture on the right).

IC2B is a half-wave rectifier for the LED Ladder VU meter, since the other half of IC2 is available.

The VU meter connection comes before the High pass filter, as a meter after the High pass filter may not show low frequency noise (such as wind rumble etc.) and the pre-amplifier could be driven into clip without the meter indicating it.

Finally R1 and R2 provide bias for the Input Transistors in the SSM2017 which also effectively sets the input impedance of the pre-amplifier.

A few words about notation

You may have noticed on the schematic I use component values like 4u7, 2K2, 8R2 and 51R, so what's this about?

In the 'old days' of paper schematics, (yes OK I still prefer to work using print outs, I must be a follower of Ned Lud) diagrams could knock about a workshop for some time getting dirtier and more tattered as time goes by, or alternatively they would be photo-copied time and time again (and indeed some of the schematics in my library are copies of copies of copies). This meant that after a while, it could become difficult to distinguish small, but vitally important characters such as the decimal point (**.**) due to everyday wear and tear, dirt or just noise in one of the copies. To get around this it was decided to replace the decimal point with the multiplier.

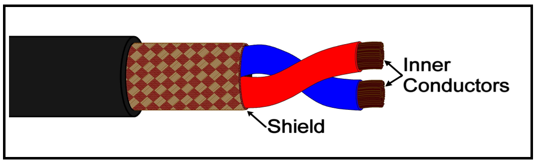
So 2,200 Ohms becomes 2.2K Ohms, then we replace the decimal point with the multiplier (in this case K) to give us 2K2 Ohms. Since resistors are usually measured in Ohms, the word ohms (or the symbol Ω) is redundant and only takes up valuable real-estate, so we drop it to end up with 2K2.

Likewise with Capacitor values, 4.7uF changes to 4u7F, and then we drop the redundant F to end up with 4u7.

So what about 51Ω? Well the standard ASCII character set does not include the Ω symbol, so instead R is often used to denote Ohms (much like u is used, instead of µ or mu), also Resistors frequently have values greater than 100Ω so we need to clarify that that this is 51 Ohms, rather than say, 51 KΩ, so as an exception to the dropping the unit of measurement rule above, we express this as 51R.

Likewise with 8.2Ω, since we have no multiplier, a decimal place can go missing, and want to avoid using the Ohms symbol, R is used instead giving us 8R2.

* Balanced?

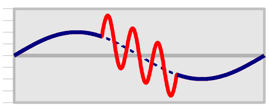


Balanced cabling consists of two signal wires – one commonly called 'in phase' and the other 'out of phase'

(these names are a tad misleading and I only use them here as this reflects common usage) surrounded by a shield. as before the shield is there to stop the signal wires picking up electrical interference but why are there two signal wires?

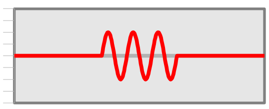
For the sake of this explanation, think of the 'in phase' circuit as carrying the signal while 'out of phase' has no signal (out of phase will often, but not always, have an equal but opposite signal to 'in phase', but it is easier to understand this way).

Both conductors are twisted together, so that any interference or noise is picked up equally by both wires, now, if the receiving electronics takes the difference between the two signals (i.e. subtracts the out of phase signal from the in phase signal) since interference is common to both circuits it is cancelled out.



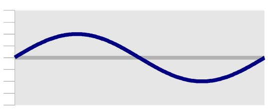
'In phase' (Signal + noise)

Minus



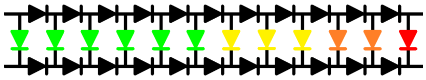
'Out of Phase' (noise only)

Equals



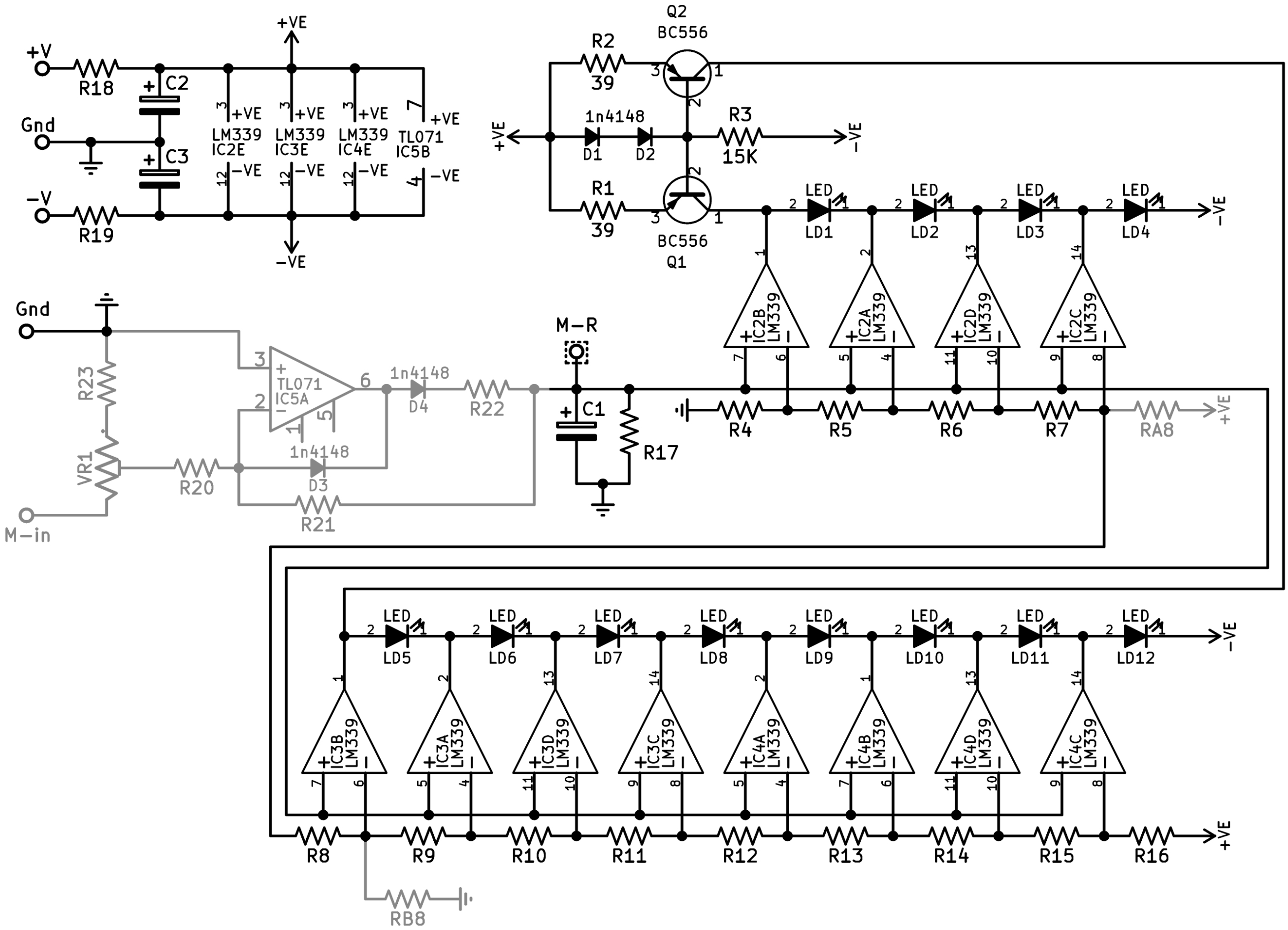
Desired Signal

LED Ladder VU meter



To set Gain properly, you need to be able to meter the output from the Pre-amplifier. The companion board to the Microphone Pre-amplifier is for a LED Ladder VU meter for this purpose.

This has been designed so you can set it up as either a 4, 8 or 12 Led meter, and while the Mic pre-amp does have a rectifier on board, I have also included one on this board for use with other projects.



Circuit description

Shown above is the full 12 LED meter, note greyed out components are for other options,such as the rectifier, which is not needed, so leave out IC5, R20-24, D3,4 and VR1.

C1 acts as a filter, it will rapidly charge up to the peak voltage but discharge much more slowly through R17. So the meter will be peak responding. Q1-2, R1-3, and D1-2 act as two constant current sources (or current limits) they limit to somewhere between 12 and 15 mA (more than enough to drive most LEDs).

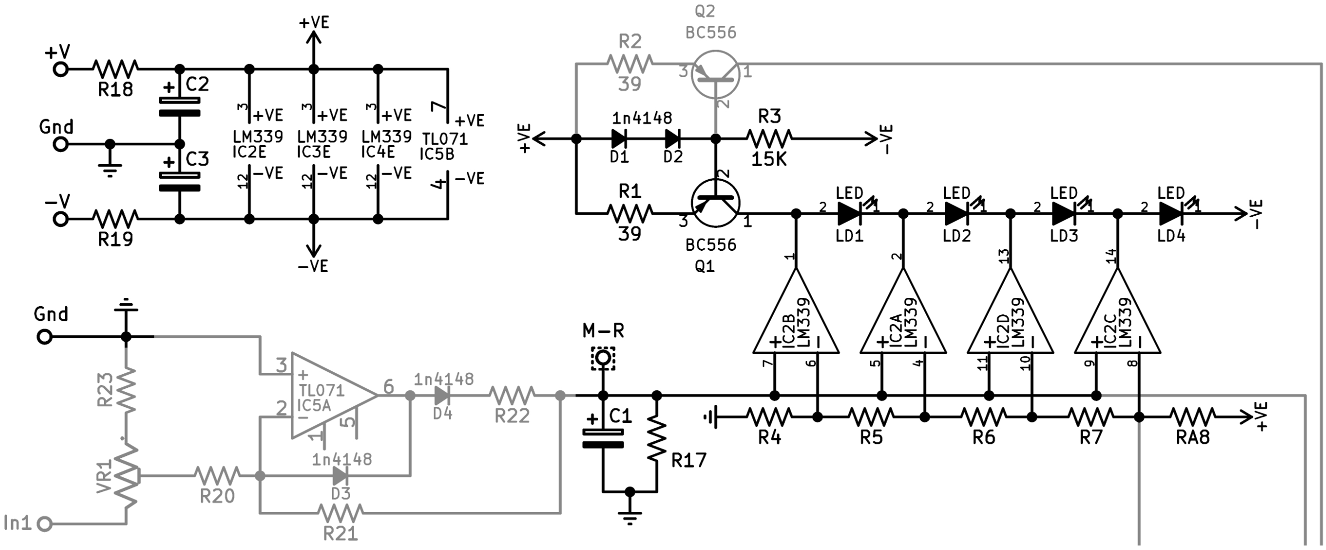
IC1-3 are comparators with open collector outputs, so in the 'off' state they shunt current to the -VE rail. Resistors R4-R16 act as a voltage divider between the positive supply rail and ground.

As the signal input exceeds the reference voltage provided by the voltage divider, the output of the comparator will turn 'on' (or go open circuit) this in turn will let current flow through the LED immediately following that comparator.

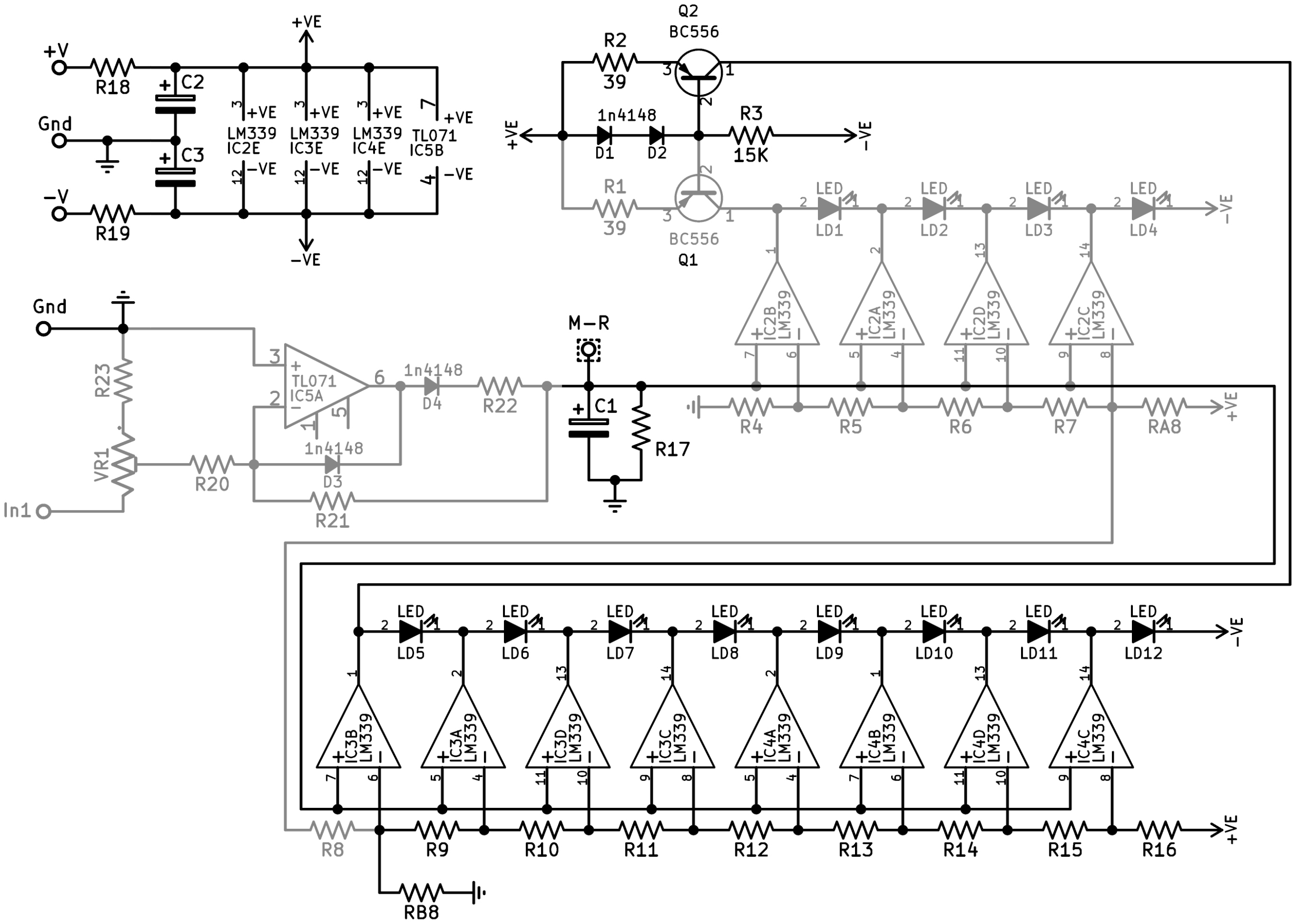
The benefit of using a constant current followed by a chain of LEDs is twofold; firstly it reduces variation in current draw from the supply, in turn reducing noise, particularly at high gain. Secondly it reduces the maximum current draw of the circuit, by around 150mA.

I have allowed for, and present here, several options for this meter, from the full 12 LED display, to 8 or 4 LED meters.

If you only want a 4 LED meter, then use IC2 and associated resistors and LEDs along with Q1, R1 etc. as in the following diagram;



while for the 8 LED version, use IC 3 and IC4 and associated components;



Usage

The purpose of the meter is to let you know what the Pre-amplifier is doing, and there are two critical levels we need know; We need to know when the pre-amplifier is being driven almost into clip, and we need to know when the pre-amplifier output is at nominal level (or '0dB').

Clip should be very straightforward, you might guess that would be at the supply rail, but there is a problem with this, most Op-amps etc. cannot drive their outputs rail to rail for example the INA217 has an output specified as going to 1.8V less than the supply rail, so for a 15 Volt supply, the peak output will go between +13.2V and -13.2V. Ideally though, we want warning before distortion becomes audible, so we want another volt or so before this. I suggest setting peak at around +20dBu (or 1.5dB before clip).

Nominal Level is usually 0dBu, or about 1.1V peak, although you can play around with this value, maybe drop it to -6dBu on the grounds that it is driving a balanced output (and therefore twice the voltage i.e. 6dB more), but really so you can claim more headroom than other manufacturers. 0dBu though, is generally a good level aim for, you still have over 20dB before clipping, and it is a healthy level to be at.

Very useful indications would be around 10dB above nominal 0, I would expect to see this lighting from time to time, while nominal 0 should be lighting a lot. While a signal present LED around -30dBu or so can also be a useful indication of a signal present, you may just need more of it.

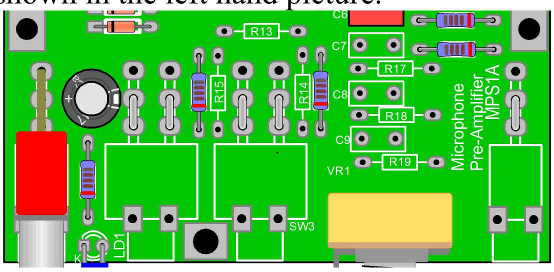
As a bare minimum, I would want 4 indicators; at +20dBu (or peak), +10dBu, 0dBu and -30dBu

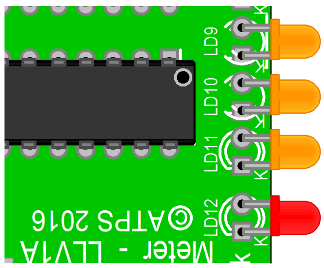
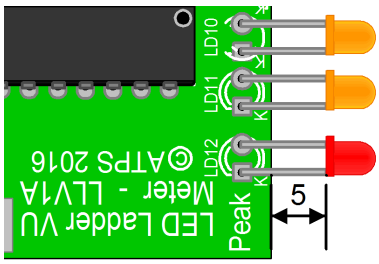
Of course more indicators give you a much better idea of what is happening, I would prefer at least 8 LEDs if not all 12. With most of the extra LEDs below 0, although there is always room for another LED between 0 and peak. So as a suggestion (and a handy setting chart) when the musicians are playing;

4 LED	8 LED	12 LED	Comments
+20dBu	+20dBu	+20dBu	You never want to see this one light.
		+15dBu	Barely want to see this one light, if at all.
+10dBu	+12dBu	+10dBu	Should only light from time to time, on peaks, power chords etc.
	+6dBu	+5dBu	This one should flash regularly.
0dBu	0dBu	0dBu	Want to see this one on a lot, most of the time in fact.
	-6dBu	-5dBu	If they haven't warmed up yet, sound check vocals to around here.
		-10dBu	Almost there, just need a smidge more gain....
	-12dBu	-15dBu	You still want to think about more gain.
	-20dBu	-20dBu	Comfort LEDs – you can see stuff is happening, you just need more of it.
		-25dBu	
-30dBu	-30dBu	-30dBu	Yep, there is something on this channel, but if it's only reaching here, there is either way to little gain, or a fault.
		-35dBu	

If you want to choose other levels, I have a handy open office spreadsheet, for calculating different resistor values at www.atps.net/Projects/VU_Calc.ods

It is usually best to start with the lower lying components, resistors diodes etc. and then go on to larger components such as the capacitors, then finishing with the switches and potentiometer. I recommend using IC sockets – particularly if you are less certain of your soldering ability.
If you wish to leave an option off, insert a wire link in the front two pads of the associated switch as shown in the left hand picture.

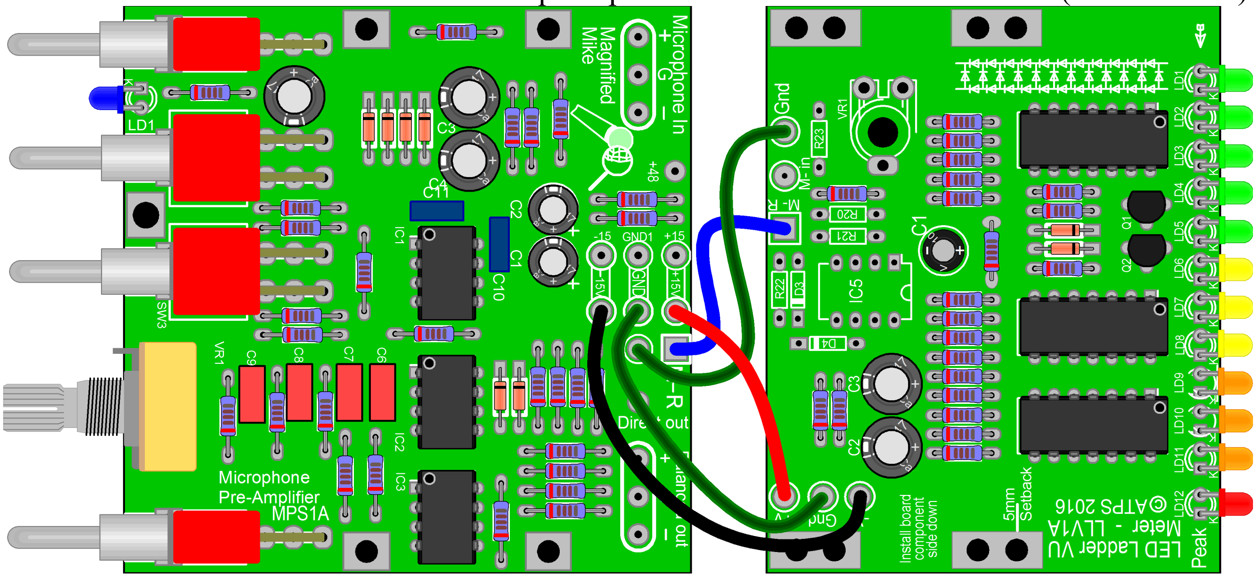


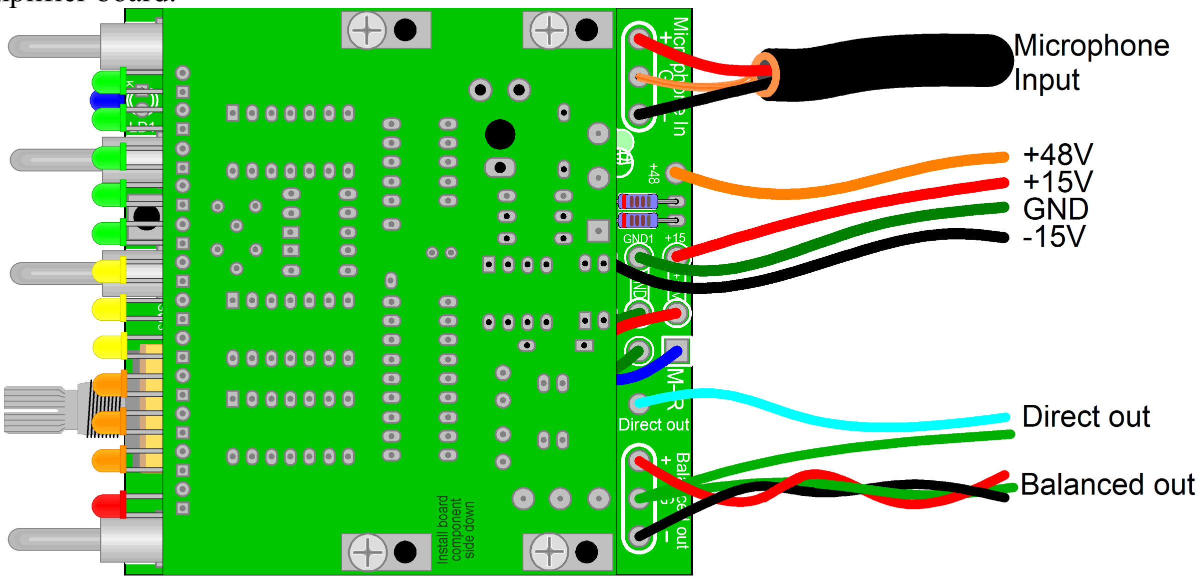
The LEDs on the meter board may either be mounted against the edge of the PCB (as per the middle picture), or extended 5mm from the board (as per the picture on the right), extending the LEDs allows a bigger margin of error as regards the holes for the LEDs in the front panel. There are two sets of mounting holes on the VU meter PCB to allow for either option.

Connections

There are 5 wires between the Pre-amplifier board and the level meter. Three are for the power supply and two for the signal and signal ground. As we are using the rectifier on the pre-amp board, the connection between the two boards uses the square pads marked M-R as shown below (the blue wire).



The LED level meter board is designed to be mounted upside down above the Pre-amplifier board using 25mm spacers. As the level meter board is shorter, you can still access the rest of the connections on the pre-amplifier board.



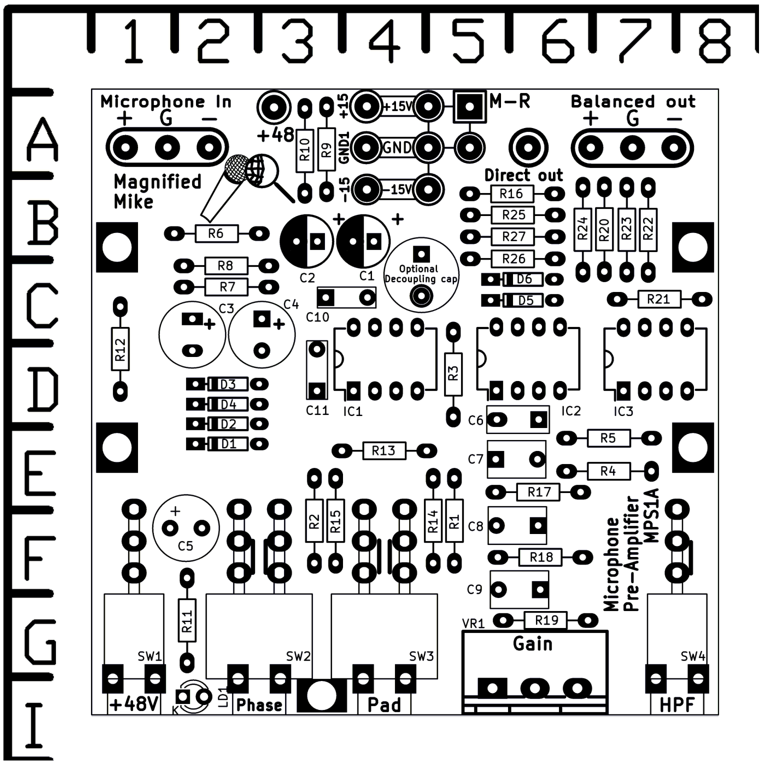
If you only require unbalanced output, but still want access to the switch-able High pass filter, then use the + leg of the balanced output and ground (G).

Important Notes

The output of this circuit does not have any DC decoupling, so inadvertent connection of the balanced output to phantom power would likely result in the destruction of IC3. If this is being used as a standalone pre-amplifier, then I strongly recommend using 100uF 63V capacitors between the balanced output from the PCB and any output connectors.
Also note switches are mounted as per common Australian/UK usage, with up = off and down = on if you prefer US style, you will need to mount the meter board the other way up, and the pre-amplifier board component side down. Note, if you do this you may want to mount the electrolytic capacitors on the VU meter board at right angles to keep a lower profile.

Mic-Pre Construction

Layout

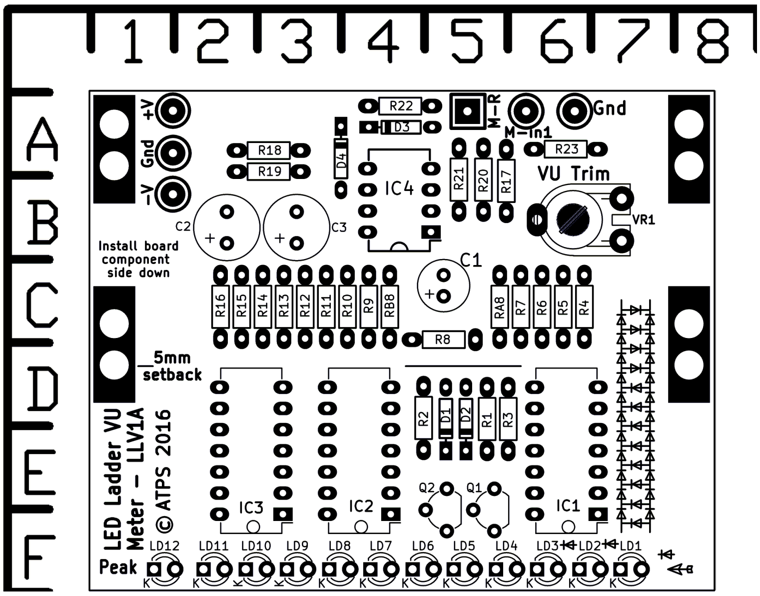


Parts locator

Part	Location	Description	Part	Location	Description
R1	F5	2K2 1% Metal film resistor	**R27**	B5	75R 1/4W resistor
R2	F3	2K2 1% Metal film resistor	**C1**	B4	100uF 25V Electrolytic capacitor
R3	D5	5R1 1% Metal film resistor	**C2**	B3	100uF 25V Electrolytic capacitor
R4	E7	1M 1/4W resistor	**C3**	C1	47uF 63V Electrolytic capacitor
R5	E7	10K 1/4W resistor	**C4**	C2	47uF 63V Low leakage Electrolytic capacitor
R6	B2	120R 1/4W resistor	**C5**	F2	47uF 63V Low leakage Electrolytic capacitor
R7	C2	5K6 1% Metal film resistor	**C6**	E6	220nF Capacitor
R8	C2	5K6 1% Metal film resistor	**C7**	E6	470nF Monolithic Capacitor
R9	A3	15R 1/4W resistor	**C8**	F6	470nF Monolithic Capacitor
R10	A3	15R 1/4W resistor	**C9**	F6	470nF Monolithic Capacitor
R11	G1	11K 1/4W resistor	**C10**	C3	220nF Capacitor
R12	D1	10K 1/4W resistor	**C11**	D3	220nF Capacitor
R13	E4	1K2 1/4W resistor	**D1**	E2	1N4148 Diode
R14	F5	1K5 1% Metal film resistor	**D2**	E2	1N4148 Diode
R15	F3	1K5 1% Metal film resistor	**D3**	D2	1N4148 Diode
R16	B5	470R 1/4W resistor	**D4**	D2	1N4148 Diode
R17	E6	2K4 1/4W resistor	**D5**	C6	1N4148 Diode
R18	F6	1K 1/4W resistor	**D6**	C6	1N4148 Diode
R19	G6	33K 1/4W resistor	**IC1**	D4	INA217, THAT1512, SSM2017, or SSM2019
R20	B7	33K 1/4W resistor	**IC2**	D6	TL072 or equivalent, Op-amp
R21	C7	15K 1/4W resistor	**IC3**	D7	NJM4558 or equivalent, Op-amp
R22	B7	33K 1/4W resistor	**LD1**	I2	3mm Blue LED
R23	B7	56R 1% Metal film resistor	**SW1**	G1	SPDT PCB RA miniature toggle
R24	B6	56R 1% Metal film resistor	**SW2**	G3	SPDT PCB RA miniature toggle
R25	B6	10K 1/4W resistor	**SW3**	G7	DPDT PCB RA miniature toggle
R26	C6	10K 1/4W resistor	**VR1**	I6	10K 'C' taper (reverse log)

LED VU meter Construction

Layout



Parts Locator

I have left the LEDs out, because they are all in order across the front of the board (from F7 back to F2) so should be easy to find.... Greyed out components aren't used in this version.

Part	Location	Description	Part	Location	Description
C1	C5	4.7uF 25V Electrolytic capacitor	**R8**	D5	120R (12 LED) 1% Metal film
C2	B2	220uF 25V Electrolytic capacitor	**RA8**	C5	1k8 (4 LED) 1% Metal film
C3	B3	220uF 25V Electrolytic capacitor	**RB8**	C4	51R (8 LED) 1% Metal film
D1	E4	1N4148	**R9**	C4	220R (12 LED) 110R (8 LED) 1% Metal film
D2	E5	1N4148	**R10**	C4	390R (12 LED) 240R (8 LED) 1% Metal film
D3		1N4148	**R11**	C3	680R (12 LED) 390R (8 LED) 1% Metal film
D4		1N4148	**R12**	C3	1K2 (12 LED) 750R (8 LED) 1% Metal film
IC2	E6	LM339	**R13**	C3	2K2 (12 LED) 1K5 (8 LED) 1% Metal film
IC3	E4	LM339	**R14**	C2	3K9 (12 LED) 3K3 (8 LED) 1% Metal film
IC4	E2	LM339	**R15**	C2	6K8 (12 LED) 10K (8 LED) 1% Metal film
IC5		TL071	**R16**	C2	6K2 (12 LED) 6K2 (8 LED) 1% Metal film
Q1	F5	BC556	**R17**	B5	15K ¼ Watt
Q2	F4	BC556	**R18**	A3	15R ¼ Watt
R1	E5	51R ¼ Watt	**R19**	B3	15R ¼ Watt
R2	E4	51R ¼ Watt	R20		10K 1% Metal film
R3	E5	15K ¼ Watt	R21		10K 1% Metal film
R4	C6	30R (12 LED) 16R (4 LED) 1% Metal film	R22		75R 1% Metal film
R5	C6	22R (12 LED) 470R (4 LED) 1% Metal film	R23		10K 1% Metal film
R6	C6	39R (12 LED) 1K1 (4 LED) 1% Metal film	VR1		5K
R7	C5	68R (12 LED) 3K3 (4 LED) 1% Metal film			

The parts lists are arranged by component values, and include the different options, so for example, from the following section of the parts list, if you want to go with the 12 LED meter, you would need 2 x 51 ohm resistors, which would be R1, R2 1 x39 Ohm for R6, and a 30 Ohm for R4, While for 4 LEDs, you would need 1 x 39 Ohm resistor as R1 and for 8 LEDs you want still want a single 39 ohm resistor but it is now R2.

	1	R4	30R 1% Metal film	(12 LED)
	1	R1	51R ¼ Watt	(4 or 12 LED)
	1	R2	51R ¼ Watt	(8 or 12 LED)
	1	R6	39R 1% Metal film	(12 LED)

Highlight your requirements before going shopping.

Part lists

Pre-amplifier

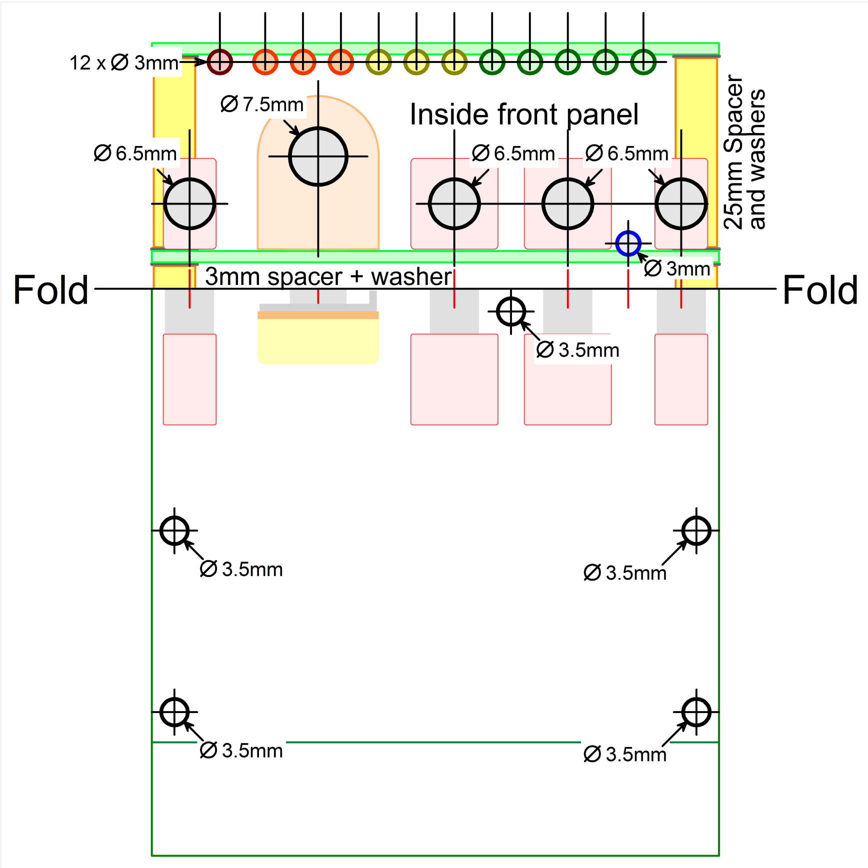
	QTY	Reference	Description	Notes
	2	C1, C2	100uF 25V Electrolytic	
	3	C3, C4, C5	47uF 63V Low leakage Electrolytic	
	3	C6, C10, C11	220nF 63V MKT	
	3	C7, C8, C9	470nF 63V MKT	(HPF)
	6	D1-D6	1N4148	
	1	IC1	INA217, THAT1512, SSM2017, or SSM2019	
	1	IC2	TL072 or equivalent	
	1	IC3	NJM4558 or equivalent	(HPF)
	1	LD1	3mm LED (Blue?)	(48V)
	1	R3	5R1 1% Metal film resistor	
	2	R9, R10	15R 1/4W resistor	
	1	R23, R24	56R 1% Metal film resistor	
	1	R27	75R 1/4W resistor	
	1	R6	120R 1/4W resistor	
	1	R16	470R 1/4W resistor	
	1	R18	1K 1/4W resistor	(HPF)
	1	R13	1K2 1/4W resistor	(PAD)
	2	R14, R15	1K5 1% Metal film resistor	(PAD)
	2	R1, R2	2K2 1% Metal film resistor	
	1	R17	2K4 1/4W resistor	(HPF)
	2	R7, R8	5K6 1% Metal film resistor	
	4	R5, R12, R25, R26	10K 1/4W resistor	
	1	R11	11K 1/4W resistor	
	1	R21	15K 1/4W resistor	
	1	R19	33K 1/4W resistor	(HPF)
	2	R20, R22	33K 1/4W resistor	
	1	R4	1M 1/4W resistor	
	1	SW1	SPDT Right angle PCB switch	(48V)
	1	SW4	SPDT Right angle PCB switch	(HPF)
	1	SW2	DPDT Right angle PCB switch	(Φ)
	1	SW3	DPDT Right angle PCB switch	(Pad)
	1	VR1	10KC (reverse Log) 16mm Potentiometer	

LED VU meter

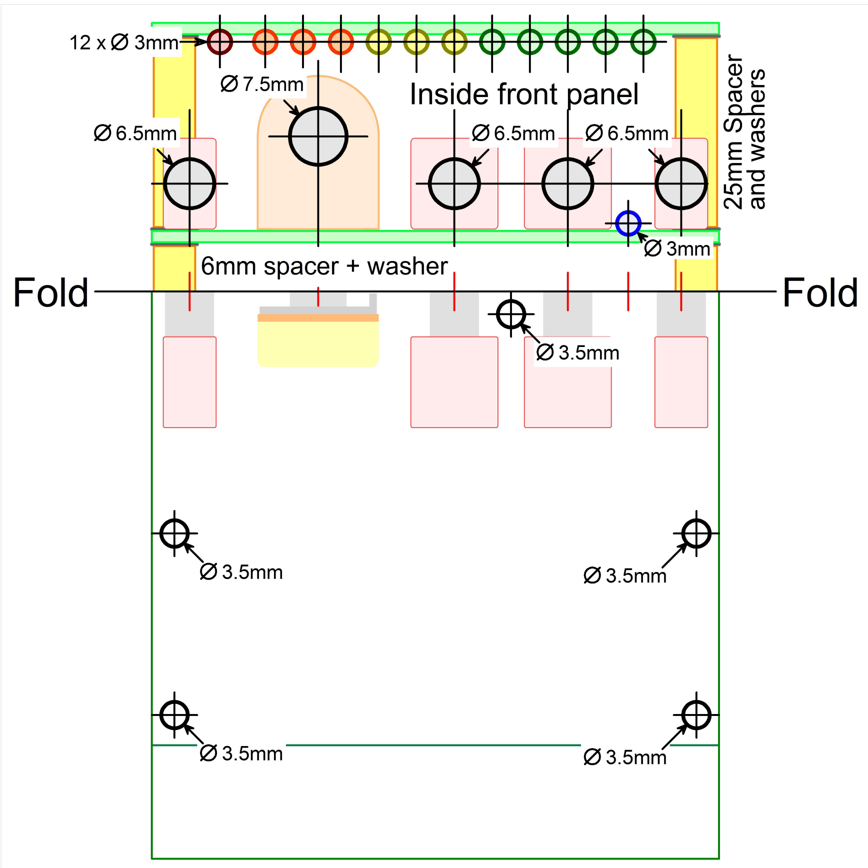
	QTY	Reference	Description	Notes
	1	C1	4.7uF 25V Electrolytic	
	2	C2 - C3	220uF 25V Electrolytic	
	2	D1 - D2	1N4148	
	1	IC2	LM339	(4 or 12 LED)
	2	IC3 - IC4	LM339	(8 or 12 LED)
	1	LD12	Red 3mm LED	(8 or 12 LED)
	1	LD4	Red 3mm LED	(4 LED)
	1	LD3	Orange 3mm LED	(4 LED)
	2	LD10-11	Orange 3mm LED	(12 LED)
	1	LD11	Orange 3mm LED	(8 LED)
	1	LD2	Yellow 3mm LED	(4 LED)
	3	LD7-9	Yellow 3mm LED	(12 LED)
	3	LD8-10	Yellow 3mm LED	(8 LED)
	1	LD1	Green 3mm LED	
	5	LD2-6	Green 3mm LED	(12 LED)
	2	LD5-6	Green 3mm LED	(8 LED)
	1	Q1	BC556	(4 or 12 LED)
	1	Q2	BC556	(8 or 12 LED)
	2	R18 - R19	15R ¼ Watt	
	1	R4	16R (4 LED) 1% Metal film	(4 LED)
	1	R5	22R 1% Metal film	(12 LED)
	1	R4	30R 1% Metal film	(12 LED)
	1	R1	39R ¼ Watt	(4 or 12 LED)
	1	R2	39R ¼ Watt	(8 or 12 LED)
	1	R6	39R 1% Metal film	(12 LED)
	1	RB8	51R 1% Metal film	(8 LED)
	1	R7	68R 1% Metal film	(12 LED)
	1	R9	110R 1% Metal film	(8 LED)
	1	R8	120R 1% Metal film	(12 LED)
	1	R9	220R 1% Metal film	(12 LED)
	1	R10	240R 1% Metal film	(8 LED)
	1	R10	390R 1% Metal film	(12 LED)
	1	R11	390R 1% Metal film	(8 LED)
	1	R5	470R 1% Metal film	(4 LED)
	1	R11	680R 1% Metal film	(12 LED)
	1	R12	750R 1% Metal film	(8 LED)
	1	R6	1K1 1% Metal film	(4 LED)
	1	R12	1K2 1% Metal film	(12 LED)
	1	R13	1K5 1% Metal film	(8 LED)
	1	RA8	1k8 1% Metal film	(4 LED)
	1	R13	2K2 1% Metal film	(12 LED)
	1	R14	3K3 1% Metal film	(8 LED)
	1	R7	3K3 1% Metal film	(4 LED)
	1	R14	3K9 1% Metal film	(12 LED)
	1	R16	6K2 1% Metal film	(8 or 12 LED)
	1	R15	6K8 1% Metal film	(12 LED)
	1	R15	10K 1% Metal film	(8 LED)
	2	R3, R17	15K ¼ Watt	

Drill Template

Internal Template allowing for 3mm spacers



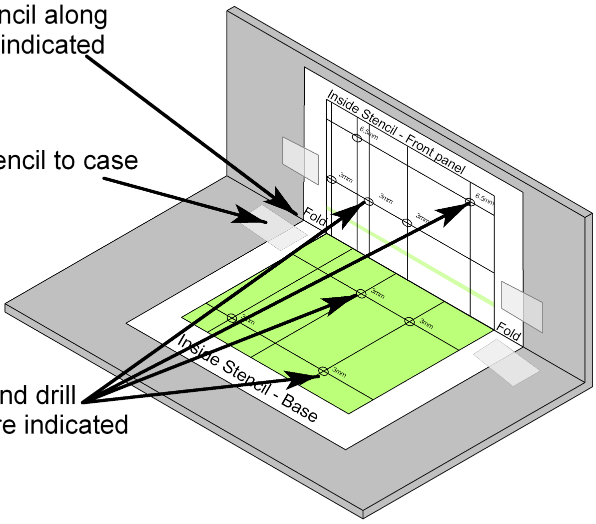
Internal Template allowing for 6mm spacers



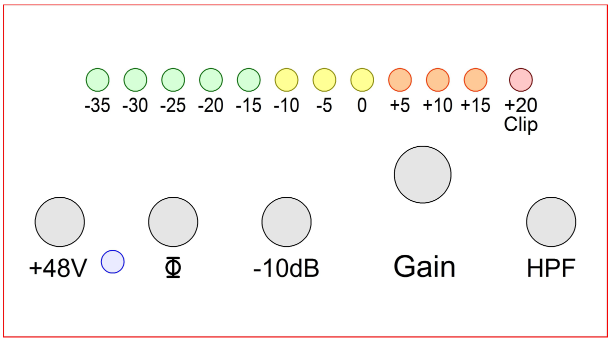
Using Drill template/Stencil

Note print PDF as "Actual size" DO NOT "Fit" " Shrink oversized pages" or "Custom scale".

1) Cut out around the template (allow plenty of room), and fold along line indicated.
2) Tape **inside** the box or bracket (as shown below).
3) Use a centre punch to mark the centre of the holes where indicated on the Template, and drill holes to specified size.

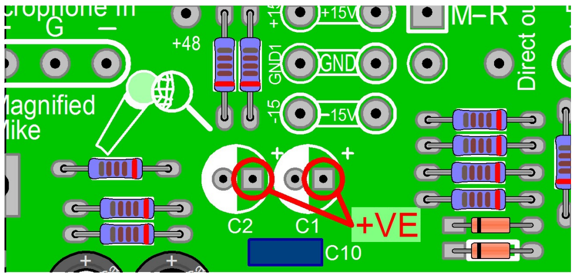


Front panel layout and suggested labelling:



Construction notes and Errata

C1 C2



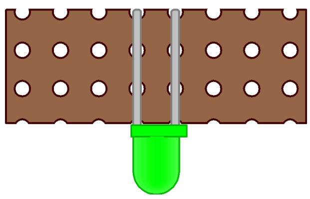
I made this error twice, so I have realised the polarity for C1 and C2 may not be as clear as I would hope.

The square pad is positive, while the round pad on the white side of the capacitor is the negative terminal.

LED mounting

When bending the LED legs a scrap piece of Vero-board can be used for forming the leads to a consistent length (this would be when mounting the LEDs 5mm off the board).

Cut along two rows of holes, spaced four apart (as in the picture) this will allow a spacing of about 7.5mm (2.5mm to the edge of the board, and 5mm off the board). File one edge nearly flat but leave the notches in the other side.



Hold the LED against the flatter edge, and bend the legs at the notches on the other side of the board. Hold the Legs flat on the board, with a pair of pliers when bending, to form a cleaner/sharper bend.