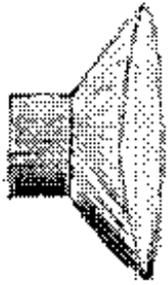


GCSE Electronics Project 1997 - 98



Electronic Volume Meter

By
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1. Problem Statement:

I have a portable CD player, radio, cassette player, a couple of microphones and PC sound card. I am feeding these into the inputs of an audio mixer the output of which is attached to a pair of active loudspeakers. I want to be able to monitor the signal levels going in and coming out of my audio mixer to make sure that I am not overloading the next stage. This could be a tape recorder if I were to record a CD for example.

The audio mixer has four inputs each of which have a volume control. There is also a master volume control on the output amplifier. The reason for using an audio mixer is so that I do not have to swap wires around just to listen to the output from another device. I can have the output of four devices each driving an input of my mixer. I can then adjust the volume of each of the inputs so I can only hear, say, my CD player instead of my radio.

1.1 Problem Analysis:

Table 1 shows some of the audio devices that I have found in the house. I have listed the name of the device, the maximum output voltage and the impedance it expects to drive. From this I can decide how sensitive the meter needs to be and what the input impedance needs to be.

Device	Maximum Line Out Signal (V RMS)	Maximum Headphone Output Signal (V RMS)	Load Impedance For Line Out Socket	Load Impedance For Headphone Socket
Portable CD Player [1]	0.7 @ 50 k Ω	0.48	Minimum 10 k Ω Recommended 50 k Ω	16 Ω
CD Player [2]	2	-	Not Specified	-
Cassette Deck [3]	0.435 @ 50 k Ω	0.775	Minimum 10 k Ω Recommended 50 k Ω	8 Ω
Radio Cassette-Recorder [4]	-	6.3	-	16 - 68 Ω
PC Sound Card [5]	Not Specified	4	Not Specified	4/8 Ω
Reel to Reel Tape Deck [6]	0.775	Not Specified	100 k Ω	8 Ω
Audio Mixer	5.6 (With $\pm 9\text{v}$ supply)	-	Minimum 5 k Ω	-

The number in brackets is the reference number. See section 5 for reference list

Figure 2 below shows the three main stages that the meter consist of:

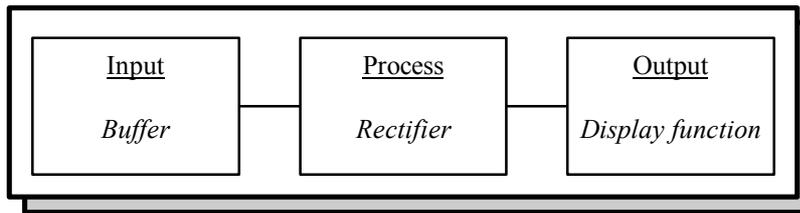


Figure 1 - Three Stages Of The Meter

The input consists of a buffer that may provide any gain or attenuation needed. It also provides the required input impedance for the source. The rectifier will turn the audio input signal into a d.c. voltage to feed into the display function.

1.2 Input Impedance

The meter will need to be A.C. coupled so that in the event of there being any D.C. on the output of the source, then the meter will not detect it.

The meter will be connected in parallel with the load impedance that is being driven by the source. This means that the total impedance that the source will see will be lower than the load impedance of the device that is being driven. If the total impedance is too low then distortion can occur because the source is trying to drive too much current. Even if the impedance of the meter is similar to that of the load then the total impedance will be reduced by half. Ideally, by making the input impedance of the meter ten times greater than the highest load then any distortion on the signal being measured will be minimised and a higher signal level can be achieved.

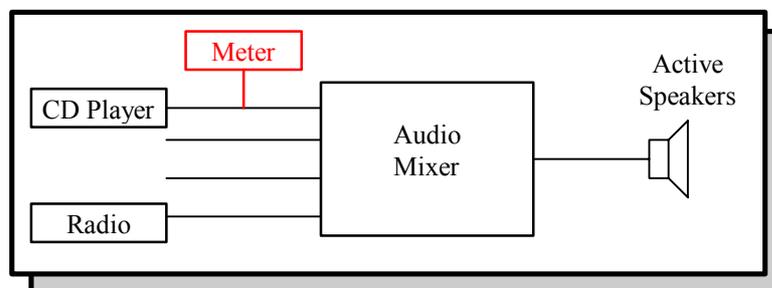


Figure 2 - Typical setup

The highest load impedance for the devices listed in Table 1 is 100 k Ω . This is for the Reel to Reel Tape Deck which I rarely use, so the next biggest load impedance is 50 k Ω . If I multiply this by ten to find the input impedance for the meter, it would need to be 500 k Ω . With this in parallel with a 50 k Ω , then the impedance that the source will be driving is 45 k Ω . An impedance of 50k Ω would result in an effective load of 25k Ω . The lowest tolerable load for the sources is 10k Ω but this is not recommended. This means that a design impedance of 50k Ω or greater will provide an adequate margin.

1.3 Input Sensitivity

Looking at Table 1, the output levels for the different devices are quite different, so there can not be a single reference level. I have decided that I want two selectable reference levels, these will be:

- 0.150v - This would typically drive a pre-amp to full output
- 0.775v - This would typically drive a power amplifier to full output

Another requirement is the range of frequencies that the meter will respond to. For this meter the frequency response needs to be the Hi-Fi range, which is 20Hz → 20kHz. The range of the meter will be -20dB to +13dB. A level of -20dB (one tenth of the 0dB voltage) will provide an acceptable lower threshold, whereas an upper (overload) level of about 12dB will give a good margin of headroom for peaks.

1.4 Meter Characteristics

One way of measuring audio frequency signals is to use an audio millivoltmeter. I have looked up a circuit for a millivolt (mV) meter, and it has the following characteristics:

- Three ranges; 10mV, 100mV and 1v RMS
- Input impedance of 110 kΩ.
- Frequency range of 20Hz → 20kHz

The meter uses a moving coil meter which means that it will not be quite so responsive as the needle has to move back and forth rapidly. Moving coil meters that are purpose-designed for audio use are expensive and difficult to obtain. The circuit mainly consists of a three step attenuator and a full-wave rectifier driving a moving coil meter. A key disadvantage of this meter for my application is that it has a linear scale whereas decibels are based on a logarithmic scale.

Source: *“Operational Amplifier User’s Handbook - R.A. Penfold”, page 109*

There are two types of meter specifically designed for audio use. A VU (Volume Unit) meter, commonly found on domestic audio recorders, displays the average volume level of an audio signal. A PPM (Peak Program Meter), used in professional audio equipment, displays the peak volume level of an audio signal. For a steady sine wave, the difference between the average level (VU) and the peak level (PPM) is about 3dB. But for a complex audio signal, such as speech or music, the difference between the average and peak can be between 10 and 12dB. This means that peaks may be four times larger than the average level. The VU meter and PPM also have different acceleration/deceleration rates. If a 1kHz steady tone is fed into a VU meter, it takes 300 milliseconds for the meter to stabilise. However, the PPM stabilises within 10 milliseconds. The VU meter is slower because it reads the average, and so it must “sample” the audio signal over a longer period of time than the PPM.

The VU meter closely corresponds to the characteristics of the human ear (The human ear does not respond to signals in a linear fashion). This means that it provides a useful indication of the subjective loudness of different programs and is very useful when matching levels between programs. But the VU meter does not give an accurate indication of the peak signals as it is only measuring the average signal level which could cause distortion or overload a device during a recording.

The VU meter also has the following characteristics:

- Logarithmic scale, normally calibrated around -20dB to +6dB
- The 0dB point corresponds to 0.775v rms

Source: *“VU and PPM Audio Meters: An Elementary Explanation - Shure Technical Bulletin”*
<http://www.shure.com/app-meter.html>

I have decided that my meter will be a peak program meter (PPM) to enable me to see the peaks of the signal that might cause distortion on a recording.

1.5 Power Supply

For maximum flexibility and ease of use, the meter will be built as a stand-alone unit. The easiest ways of powering the meter are by using batteries or mains power adapters. The meter will handle a maximum signal of +13dB with respect to 0dB (0dB is equal to 0.775v RMS in this example). +13dB is equal to a voltage of 3.5v RMS which is about 9.9v peak to peak. This shows that a supply greater than 9V would be needed. 12V would be suitable.

A single 9V battery, such as a PP3, has a nominal voltage of 9V, but this will decrease throughout its life. Rechargeable PP3 batteries have a voltage just under 9V (around 8.2V) and so would not be able to drive the meter. Two series connected rechargeable PP3s would provide a voltage supply of about 16.4V. A 12V regulator chip could then be used to ensure a stable supply rail. Mains power adapters (unregulated and regulated) are available with 15V output which could also feed through the regulator chip. A suitable mains adaptor is available from Maplin.

1.6 Housing Constraints



As the meter will have its own power supply it will be built in a separate box from the audio mixer. The box should be black so as to match with the colour of the other equipment. Suitable cases are available from Maplin. I have chosen the ABS Plastic instrument case H2502 as it is a suitable size and is the same as that of my audio mixer.

1.7 Specification

Looking at the information on the previous pages I have drawn up a specification for my meter.

- The input impedance for the meter will ideally be 500 k Ω , but any value above 50 k Ω will be acceptable
- The meter will have a selectable 0dB point of 0.15v and 0.775v RMS
- The meter will measure signals up to +13dB and down to -20dB
- The frequency response will be that of the Hi-Fi range, which is 20Hz \rightarrow 20kHz.
- The power supply will be either two Rechargeable PP3s giving 16.4V or a 15V mains adaptor. This will be regulated down to 12V.
- The meter will be housed in a suitable black plastic box.
- The meter should be portable so it should be of a suitable size.
- The meter will be a Peak Program Meter (PPM).

2. Possible Solutions:

The rectifier could just be one that uses diodes, such as in a power supply, but there is the 600mV drop across the diode which means that any part of the signal less than 600mV would be lost. What is needed is a “*perfect rectifier*” that does not have a forward voltage drop. A way of achieving this is through use of a precision rectifier in which the diode is incorporated within the feedback loop of an operational amplifier. A basic half-wave precision rectifier circuit is shown in Figure 3. The

capacitor and resistor provide a peak detection function. The input signal starts off at 0V so the output from the op-amp and the output from the diode are both 0V. As the input signal rises very slightly, say by 1 μ V, the output from the op-amp will rise very rapidly due to the very large open loop gain of the op-amp (typically 10^5 - 10^6) towards 1V. The diode will become forward biased and as there is now very low resistance in the feedback loop the gain is reduced to 1. This means that the output voltage from the diode tracks the input signal. When the input signal falls below say 0.6nV the output from the op-amp will be less than 0.6V, the diode will no longer be forward biased and the output voltage will be 0V.

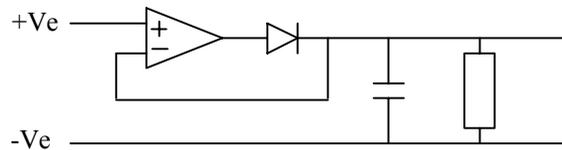


Figure 3 - Basic half-wave precision rectifier

This circuit only provides rectification for the positive half cycles of the input. An audio signal may contain a significant negative going peak which would not be registered. Therefore, for my design I will use a full-wave precision rectifier circuit.

2.1 Solution 1 - Analogue Meter

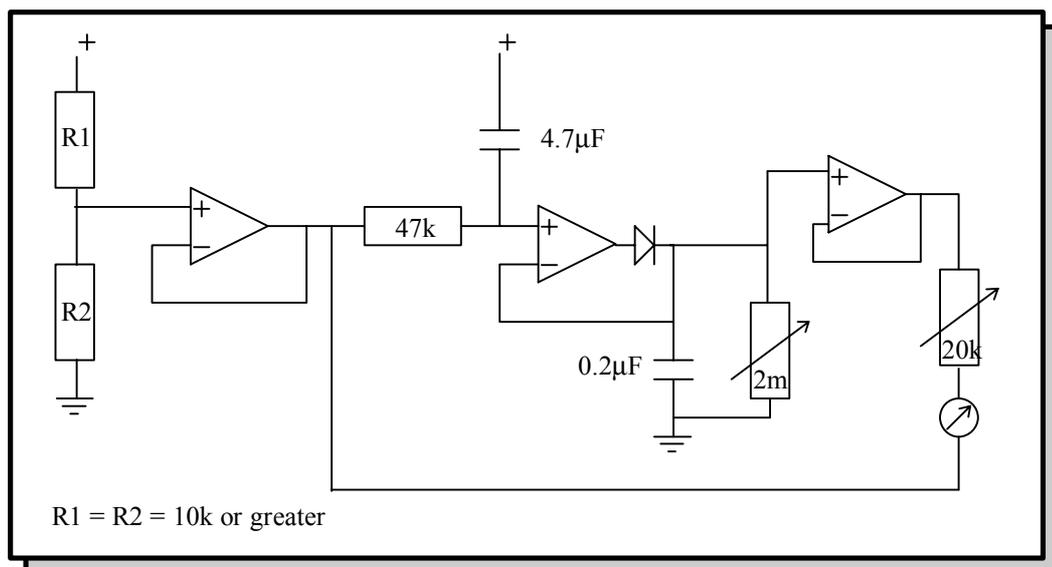


Figure 4 - Simple PPM Meter

The circuit in Figure 4 was suggested to me by my tutor. It has been tested and proven to work. Although this circuit seems simple and cheap to build it suffers from several limitations:

- The rectifier is only a half-wave precision rectifier and not a full-wave precision rectifier.
- The meter is only an analogue meter and a meter built to VU or PPM specifications, with correct acceleration/deceleration rates, would be expensive. A simple instrumentation-type meter, such as ones available from Maplin, could be used instead but it would be inaccurate and not give a true reading.

Also, this circuit is incomplete; a coupling capacitor is needed on the input at the junction of R1 and R2 as a d.c. condition may exist there. To get the required input impedance needed the values of R1 and R2 should be 1 M Ω because these two resistors appear in parallel to a.c. as the power supply has a very low impedance.

2.2 Solution 2 - Using an LED Display Driver

This solution uses two LM3916 Dot/Bar Display Drivers from National Semiconductor. The two main features of this IC are that it is a fast responding electronic VU/PPM meter and it is able to drive LEDs. The LM3916 has a range of -20dB to +3dB, the steps of which are -20dB, -10dB, -7dB, -5dB, -3dB, -1dB, 0dB, +1dB, +2dB and +3dB. The IC also has a selectable dot or bar mode. When in bar mode all the LEDs are illuminated up to the peak and when in dot mode just the peak LED is illuminated. This allows the current drain to be decreased if running on batteries for a lengthy period.

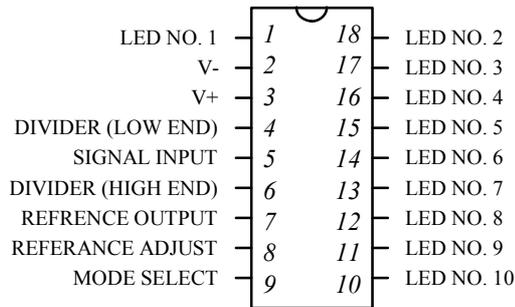


Figure 5 - Pin Connections For LM3916

2.3 Chosen Solution

The solution that I have decided to build is the second solution. Although the first solution looks quite simple, which means not so much skill is needed, I have chosen the second solution because it will be cheaper than the first assuming that a moving coil meter built to PPM specifications is used. The second solution works to PPM specifications and it uses LEDs for the display which are cheap. As well as the Display Driver IC a buffer and a peak wave rectifier will feature in the circuit.

3. PPM Meter Using The LM3916:

I have been obtained a data sheet for the LM3916 IC that will be used in this circuit. I was able to get this from the National Semiconductor WWW site at <http://www.national.com>. I was also able to find an article in the Maplin magazine (Electronics and beyond - October 1997 - [11]) about the Velleman VU Meter kits that also use the LM3916.

3.1 Design

3.1.1 Buffer Stage

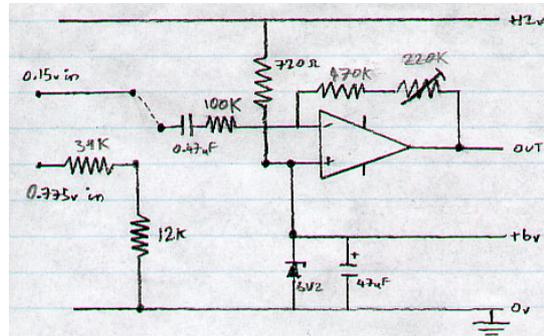


Figure 6 - Circuit Diagram For Buffer Stage

The buffer stage needs to present the required input impedance and provide the gain required to meet the specified sensitivity for the meter. The original circuit diagram is shown in Figure 6. In order to run the op-amp from a single supply rail, one of the inputs needs to have a bias voltage of about half the supply. A 6.2V zener diode has been used to provide a stable bias line that is used throughout the meter circuit. The op-amp is used in inverting mode and the input impedance is set by the 100k input resistor. For a 150mV input voltage, a gain of approximately 6.1 is required to drive the display stage to the 0dB level. This is done with a feedback resistance of approximately 600k. To allow for variations in actual component values, the feedback resistance is composed of a 470k resistor in series with a 220k preset. This gives an adjustable gain range from 4.7 to 6.9. DC isolation is provided by a 0.47µF input capacitor. This value is large enough to set the low-frequency cut-off well below 20Hz, which is the bottom end of the Hi-Fi range. The op-amp used for this stage is the LF351. I have chosen this because it was recommended in the data sheet, they offer greater performance than the 741 and they have a greater gain-bandwidth.

To handle the 775mV input requirement, I originally decided to use an input attenuator consisting of two resistors ahead of the input to the buffer. The resistors used provide the required attenuation of 5.16 whilst maintaining an input impedance of 100k. However, this arrangement make switching quite complex and requires two input sockets. An easier approach is to use two additional input resistors of 330k and 230k in series with the 100k resistor to reduce the gain of the buffer. This approach is simpler, but does cause the input impedance to rise slightly. The additional resistors are shorted out when 150mV sensitivity is selected and only one input socket is now needed.

3.1.2 Rectifier Stage

The circuit for the full wave rectifier that is to be used is one that has been suggested in the data sheet for the display driver. The only change that I have made is to connect both the non-inverting inputs of the op-amps to the +6v rail as the circuit below is designed to work with a split supply rail. The rectifier has unity gain and features the LF352 which is the dual version of the LF351. The circuit diagram for the rectifier is shown in Figure 7.

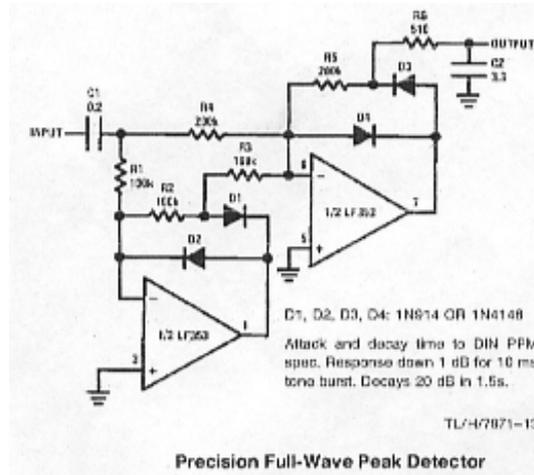


Figure 7 - Circuit Diagram For Rectifier Stage

3.1.3 LED Display Stage

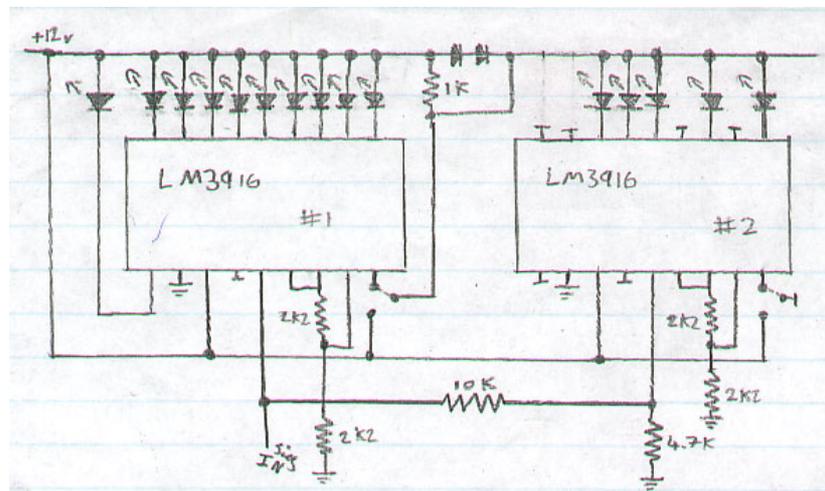


Figure 8 - Circuit Diagram For LED Display Stage

Figure 8 shows the circuit diagram for the LED display stage of the meter. The display consists of 15 LEDs, the steps for which are: -20, -10, -7, -5, -3, -1, 0, +1, +2, +3, +5, +7, +9, +11, +13. The circuit is set up so that either dot or bar mode may be selected. To extinguish the 10th LED when the 11th LED on the second IC is illuminated the 11th to 15th LEDs are tied to the +12v rail through the two series-connected diodes. The diodes are shunted with a 1k resistor to provide a path for driver leakage current. If the circuit were to be permanently used in bar mode then the diodes would not be needed but they do not effect the display if present.

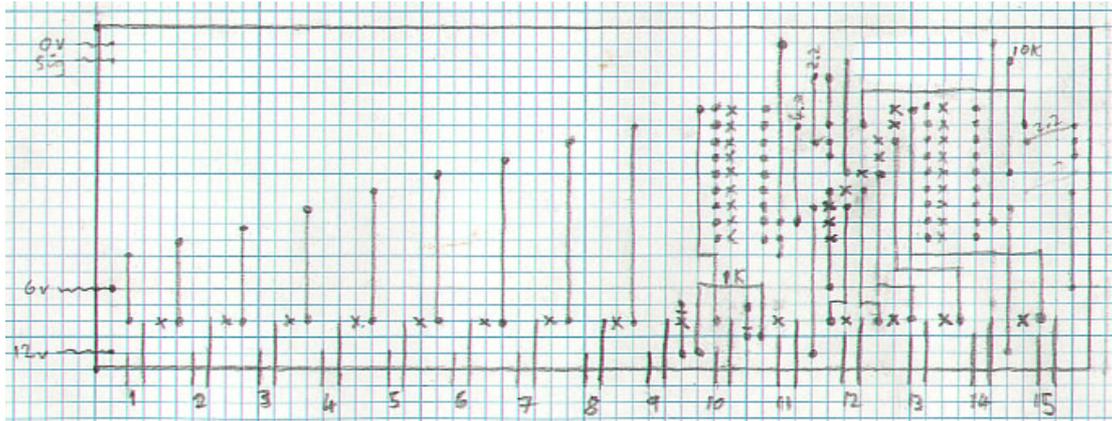


Figure 13 - Veroboard Layout For LED Display Stage

The buffer stage worked first time on veroboard so I then added on the rectifier and linked the two together. The buffer and rectifier now failed to work but this was down to a track not being cut causing the zener diode to be shorted out. The track was cut the first two stages of the meter worked correctly.

3.3 Measured Performance

3.3.1 LED Display Stage Calibration

A static DC test was carried out to test the calibration of the LED display stage. The meter was powered from one power supply and the output from another was connected straight onto the signal rail which feeds pin 5 on both chips. The voltage on the second power supply was gradually increased from 0v and the voltage at which each LED illuminated was recorded. The voltage was measured using a digital multimeter. The Signal Level is the voltage on pin 5 minus the 6.24v DC offset.

Indicate dB Level	Voltage On Pin 5	Signal Level	Actual dB Level
+13	9.72	3.48	12.45
+11	9.03	2.79	10.53
+9	8.47	2.23	8.58
+7	8.04	1.8	6.72
+5	7.68	1.44	4.79
+3	7.41	1.17	2.98
+2	7.29	1.05	2.04
+1	7.18	0.94	1.08
0	7.07	0.83	0.00
-1	6.98	0.74	-1.00
-3	6.84	0.6	-2.82
-5	6.72	0.48	-4.76
-7	6.63	0.39	-6.56
-10	6.52	0.28	-9.44
-20	6.33	0.09	-19.30

3.3.2 Buffer Gain Test

The gain of the buffer stage was tested to check that it had the required gain of 6.7 for the 0.15mV input and 1.2 for the 0.775mV input. The output from a signal generator was connected to the input of the buffer. The output voltage of the generator and the output of the buffer were measured using a digital multimeter. The table below shows that the measured results match the expected results.

Input Voltage (mV)	Output Voltage (V)	Gain
<i>145.6</i>	<i>0.979</i>	<i>6.7</i>
<i>151.0</i>	<i>1.026</i>	<i>6.7</i>
<i>149.0</i>	<i>1.024</i>	<i>6.8</i>
<i>773.0</i>	<i>0.948</i>	<i>1.2</i>
<i>774.0</i>	<i>0.943</i>	<i>1.2</i>

3.4 Component & Price List

(Using Maplin Catalogue)

In the table below I have put together a price list for the components used to make the meter. Included are the sockets and black plastic case. If the circuit is not to be mounted in a box then the cost is quite a bit cheaper.

Component	Price	Quantity	Total Cost
<i>LM3916 Dot/Bar Display Driver</i>	£3.19	2	£6.38
<i>12V 1A Regulator</i>	£0.86	1	£0.86
<i>Green 5mm LED</i>	£0.08	4	£0.32
<i>Yellow 5mm LED</i>	£0.07	3	£0.21
<i>Red 5mm LED</i>	£0.09	11	£0.99
<i>LF351 Op-Amp</i>	£0.53	1	£0.53
<i>LF353 Op-Amp</i>	£0.70	1	£0.70
<i>6.2V 500mW Zener Diode</i>	£0.10	1	£0.10
<i>GenElect 47uF 16V</i>	£0.10	1	£0.10
<i>GenElect 470uF 16V</i>	£0.19	1	£0.19
<i>Tant 3.3uF 35V</i>	£0.40	1	£0.40
<i>0.47uF Poly Layer</i>	£0.49	1	£0.49
<i>0.22uF Poly Layer</i>	£0.29	2	£0.58
<i>0.1uF Poly Layer</i>	£0.29	1	£0.29
<i>Carbon Preset 220k</i>	£0.25	1	£0.25
<i>Metal Film 0.6w Resistor 510Ω</i>	£0.07	1	£0.07
<i>Metal Film 0.6w Resistor 720Ω</i>	£0.07	1	£0.07
<i>Metal Film 0.6w Resistor 1k</i>	£0.07	1	£0.07
<i>Metal Film 0.6w Resistor 2k2</i>	£0.07	2	£0.14
<i>Metal Film 0.6w Resistor 4k7</i>	£0.07	2	£0.14
<i>Metal Film 0.6w Resistor 10k</i>	£0.07	1	£0.07
<i>Metal Film 0.6w Resistor 100k</i>	£0.07	4	£0.28
<i>Metal Film 0.6w Resistor 120k</i>	£0.07	1	£0.07
<i>Metal Film 0.6w Resistor 200k</i>	£0.07	2	£0.14
<i>Metal Film 0.6w Resistor 330k</i>	£0.07	1	£0.07
<i>Metal Film 0.6w Resistor 470k</i>	£0.07	1	£0.07
<i>1N4148 Diode</i>	£0.08	6	£0.48
<i>160mm X 100mm VeroBoard</i>	£2.90	2	£5.80
<i>18 pin IC holder</i>	£0.19	2	£0.38
<i>8 pin IC holder</i>	£0.11	2	£0.22
<i>Stereo 3.5mm Chassis Socket</i>	£0.55	2	£1.10
<i>2.1mm Socket Single-Hole-Fixing</i>	£0.90	1	£0.90
<i>SPST Toggle Switch</i>	£0.99	1	£0.99
<i>Two Part ABS Black Plastic Box</i>	£5.60	1	£5.60
<i>TOTAL COST:</i>			£30.05

I have chosen to use 16V capacitors as next value below this is 10V and the value above is 25V. As the supply rail is only 12V, 16V capacitors are adequate. I have also chosen to use 0.6W resistors because this is all that is needed and I have a big selection of 0.6W resistors.

4. Evaluation:

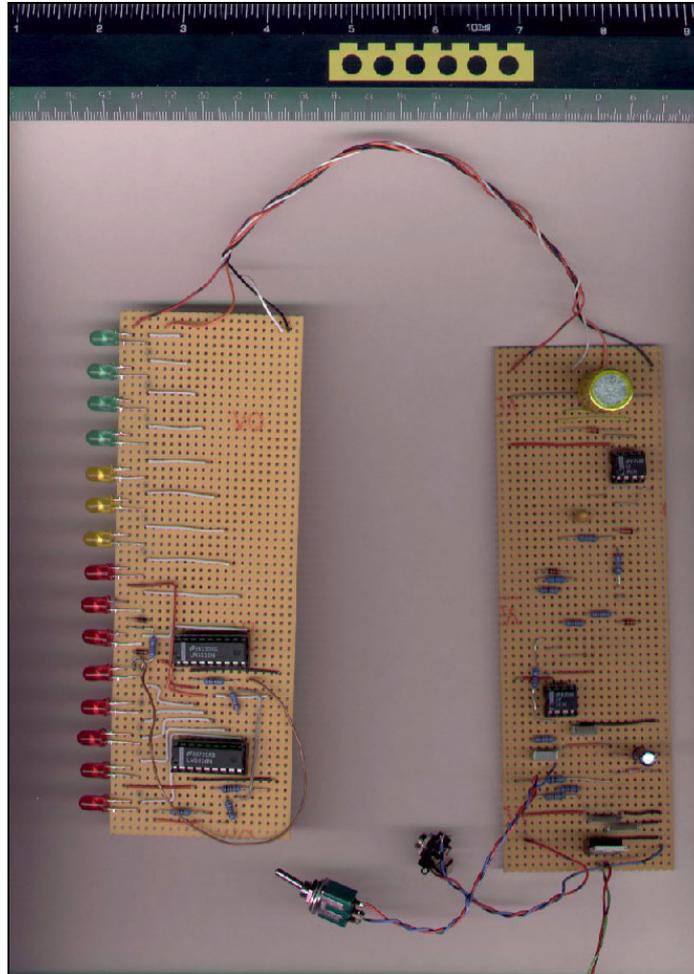


Figure 14 - Picture Of Finished Meter

The meter has now been built on veroboard and has been left running for over an hour perfectly without any problems. The meter has been tested and found to work on two PP3 batteries, and supplies of 14 - 20v. The specification for the regulator says that it can take between +14.5 - +30v. I can only check this up to 20v as this is the limit of the power supply. The meter should be quite reliable, the only minor problems are the wires connecting the two boards and the wires to the switch and sockets, but if the meter is in a case then this should not be a problem. Also if the meter is run for a long time with a large input signal causing the meter to read very close to full scale then the first IC on the display board will get quite hot and this could decrease its working life. A minor modification that has been added to the meter is a diode in series with the supply so that the meter is protected if the supply is connected the wrong way round.

5. References

- [1] *Sony D-240 CD Player Manual*
- [2] *Philips CD-150 CD Player Manual*
- [3] *Sony TC-K61 Stereo Cassette Deck Manual*
- [4] *Sony CFS-205L Radio Cassette-Recorder Manual*
- [5] *Sound Blaster AWE32 Sound Card Manual*
- [6] *Sony TC-366 Reel to Reel Tape Deck Manual*
- [7] *Operational Amplifier User's Handbook - R.A. Penfold*
- [8] *VU and PPM Audio Meters: An Elementary Explanation - Shure Technical Bulletin*
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- [10] *The Maplin Magazine - Electronics and beyond. October 1997, No. 118*
Article on Velleman VU Meters.
- [11] *Maplin Catalogue - September '97 to February '98*