Project 458

LED level meter features simultaneous peak & average display plus 60 dB dynamic range

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This project is, in effect, the first part of the construction articles for the Series 5000 Control Preamplifier. The LED level meter described here, though originally designed for the Series 5000 Preamp, is ideal for any application requiring a wide dynamic range level display. Naturally, two are required for stereo applications.

THE MOST common instrument used to measure audio signal level is the VU meter (VU stands for volume unit). Before the introduction of the VU standard however, ordinary meter movements were used. A full-wave rectifier converted the applied audio signal to dc suitable for driving a voltmeter, usually fitted with a dB scale. Although this is completely suitable for steady sinewave measurement it is entirely unsatisfactory for measurement of constantly changing voltages such as audio signal level. The biggest problem is overshoot of the meter movement. If a 1 kHz sinewave, for example, is applied to this type of meter, the movement can overshoot the correct reading by nearly 80%, indicating a transient that is in fact not present. The VU standard was introduced to overcome these problems. It does this by defining the 'ballistics' of any meter movement to be used in audio signal level measurement. A comparison of VU and ordinary meter movement ballistics is shown in Figure 1. The amount of overshoot of the VU meter is specifically defined by the standard to be not less than 1% and not greater than 1.5%. This characteristic is achieved by carefully modifying the shape of the meter pole pieces and counterweighting the pointer. These techniques ensure that the movement stabilises in the shortest possible time, around 0.3 s (300 ms) for the case shown in Figure 1. The VU meter still displays dB (i.e: 1 VU = 1 dB), but its reaction to transient signals is significantly better than the ordinary meter movement.

Nevertheless, the VU meter is still very slow. It indicates something between the average and the real peak of the signal voltage depending on the complexity and transient nature of the particular input signal. The 0.3 s rise time of the meter will hide all but the most repetitive peaks, so a VU meter could be indicating a signal voltage of say −15 dB when the peaks of the signal are actually overloading an amplifier. Another disadvantage of most VU meters is their limited dynamic range. Usually they display only the 'top' 23 dB of the total range (i.e: −20 to +3 dB) and with the ever increasing dynamic range of modern recording techniques this is not sufficient.

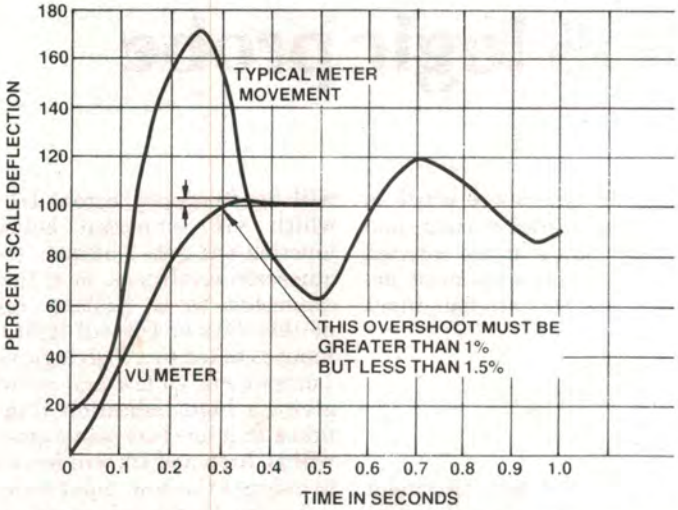
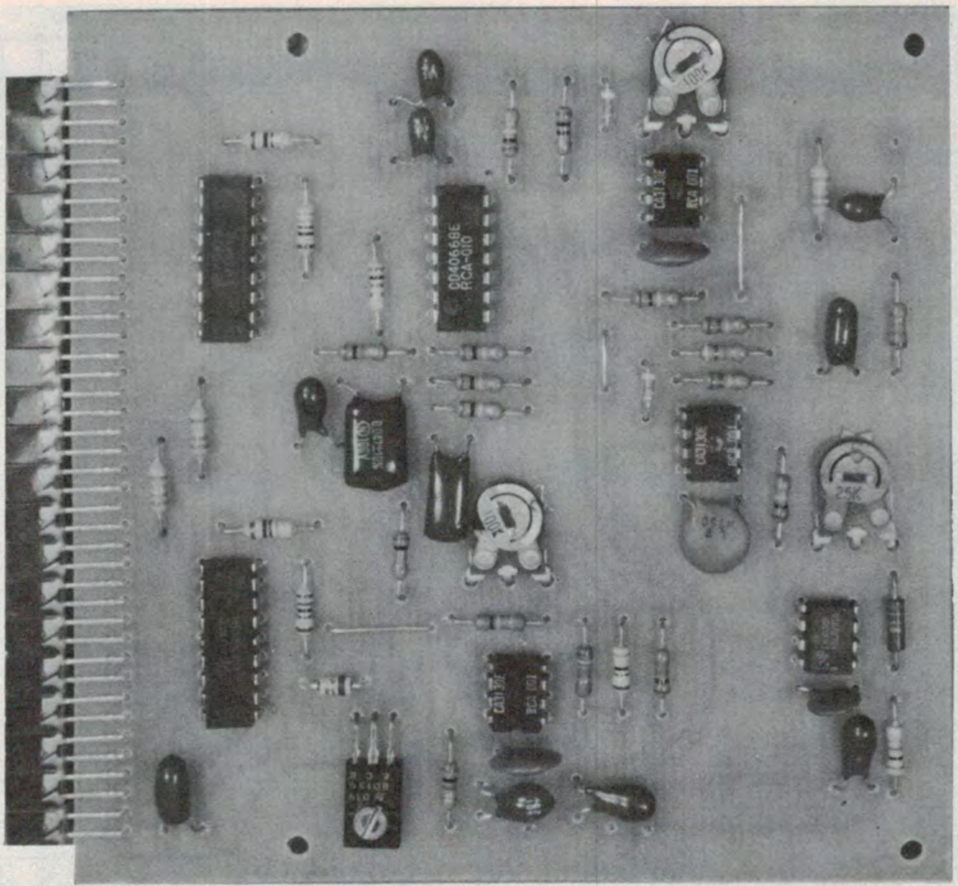


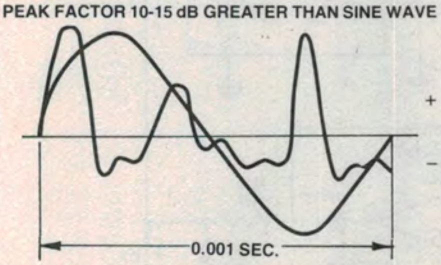
Figure 1. **'Ballistics' of a VU meter compared to conventional moving-coil meter.**

The ETI-458 overcomes these problems by replacing the meter movement

pk/av LED level meter



Full-size reproduction of the completed project. Note the components are laid flat to permit close stacking of two boards for a stereo display.



A typical 'music' signal may have a completely different peak-to-average ratio compared to a sinewave, and the peaks are often not symmetrical in amplitude about the zero axis. The duration of peaks may be as short as 50 microseconds.

with a row of light emitting diodes driven by a pair of dB LED display drivers. Twenty LEDs are used, with 3 dB between each LED, so the total dynamic range displayed is 60 dB. The circuit monitors both the true peak and the average signal level and displays both simultaneously. The difference between the peak and the average voltages of a sinewave is around 3 dB, so with a sinewave applied consecutive LEDs will light. With music applied however, the difference between the two LEDs will be substantially greater, depending on the transient nature of the signal applied. ▶

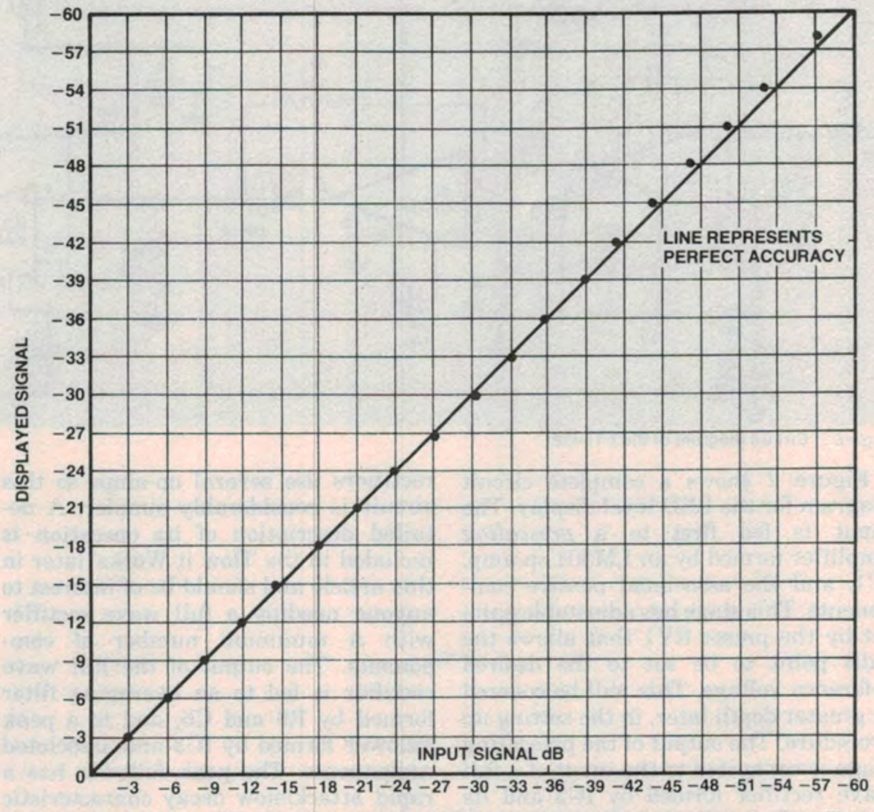


Figure 4. Accuracy of the ETI-458 LED level meter display (dots) compared to 'perfect accuracy' (line).

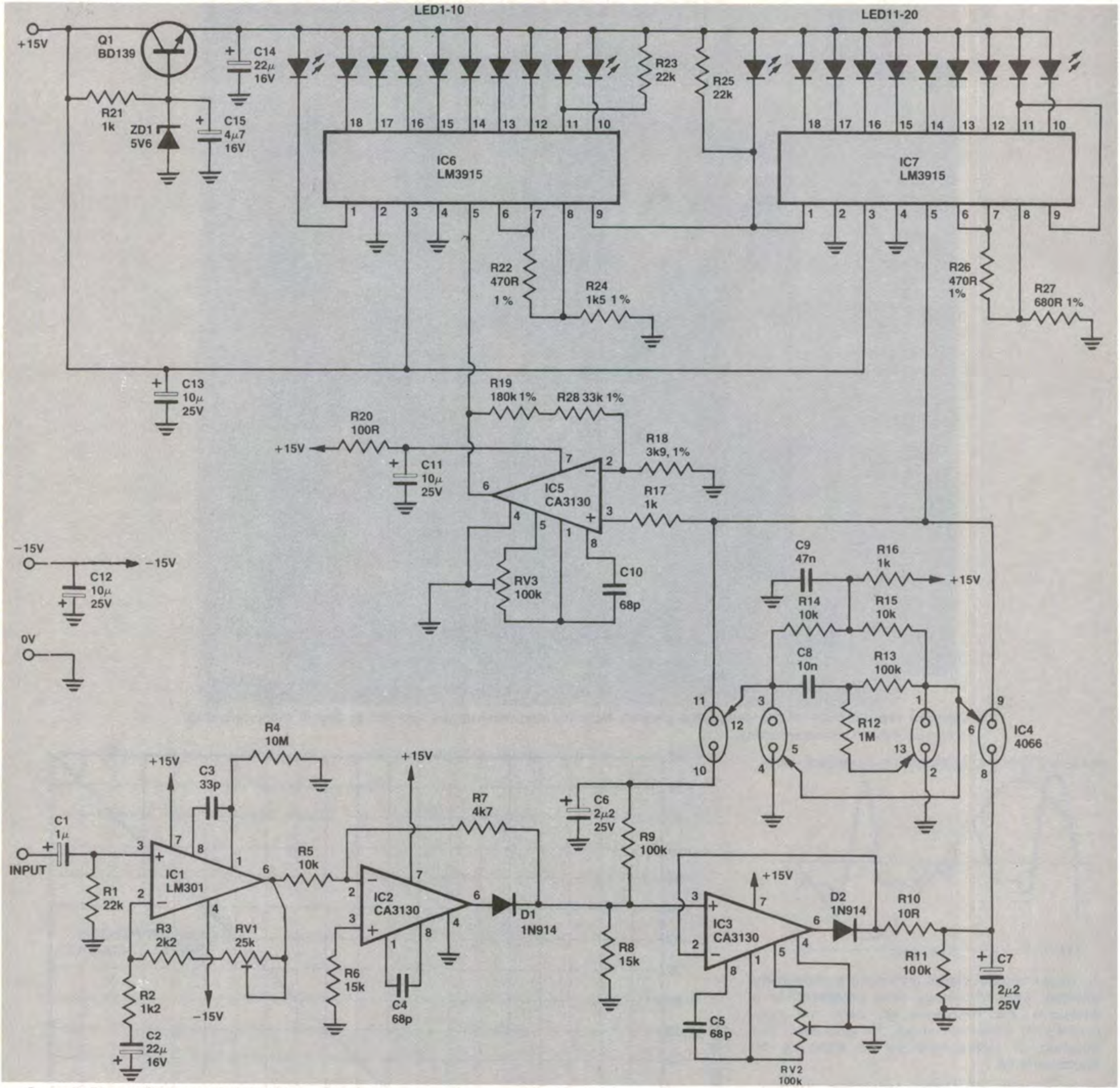


Figure 2. Circuit diagram of the ETI-458.

Figure 2 shows a complete circuit diagram for the LED level display. The input is fed first to a *prescaling* amplifier formed by an LM301 op-amp, IC1, and the associated passive components. This stage has adjustable gain, set by the preset RV1 that allows the 0 dB point to be set to the desired reference voltage. This will be covered in greater depth later, in the setting up procedure. The output of the prescaling stage is connected to the input of a full wave rectifier formed by IC2 and its associated components. Most full wave rectifiers use several op-amps so this circuit is considerably simpler. A detailed description of its operation is included in the 'How it Works' later in this article and should be of interest to anyone needing a full wave rectifier with a minimum number of components. The output of the full wave rectifier is fed to an averaging filter formed by R9 and C6, and to a peak follower formed by IC3 and associated components. The peak follower has a rapid attack/slow decay characteristic so that it responds quickly to any transients but decays slowly so the transient can be seen easily on the display. The outputs from the peak follower and the averaging filter are connected to the inputs of two CMOS analogue switches. The outputs of these switches are connected together and go to the input of the LED display. Two more CMOS switches are used to form a square wave oscillator. This oscillator has out of phase outputs used to drive the signal-carrying analogue switches alternately off and on at a relatively high frequency. When the switch connected to the output of the averaging filter is on, the average signal voltage is connected to the input of the LED display. This switch is subsequently turned off by the oscillator and the other analogue switch turned on, connecting the output of the peak follower to the LED display. So, only one of the two LEDs is on at any instant, but the rapid switching speed between them and the persistence of vision make them both appear to be on.

Input signals to the LED display portion of the circuit are fed simultaneously to the LM3915 driving the upper 30 dB display and via a voltage amplifier to the lower 30 dB display. The biggest problem in the design of an audio level meter with a 60 dB dynamic range arises from the fact that 60 dB below typical 0 dB input voltages could be around 2 mV. This is well below the dc offset voltage of most op-amps so special precautions have been taken in the design to ensure that dc offset errors can be reduced to negligible levels. This is the purpose of the presets RV2 and RV3. These are dc offset controls. Adjustment of these is covered in the setting up procedure. The sensitivity of the LM3915 can be adjusted by changing the voltage between pins 6/7 and ground. The IC maintains a voltage of 1.25 V across R22. The current through R22 will be 1.25/470 or approximately 2.67 mA. A further 75 uA is supplied from pin 8 of the device, so the total current through resistor R24 to ground will be 2.67 mA + 75 uA or approximately 2.73 mA. The voltage drop across R24 will therefore be around 2.73 mA x 1.5k or 4.1 V. Adding the 1.25 volts across R22 gives a total of 5.35 V between pins 6/7 and ground.

HOW IT WORKS — ETI 458

The input stage consists of a variable gain amplifier formed by IC1 and its associated components. This is a conventional IC amplifier circuit in which the gain is determined by the values of the components RV1, R3 and R2. Specifically:

$$A_V = \frac{R2 + R3 + RV1}{R2}$$

So the bigger the value set on RV1, the greater the gain. Capacitor C2 has the effect of decreasing this gain for very low frequencies, or dc, decreasing the dc offset on the output.

The second stage is the full wave rectifier or 'absolute value generator'. As mentioned in the text, most full wave rectifiers require more than a single op-amp, so this stage will be of use in any application requiring a full wave rectifier with minimum component count. For negative-going signals the stage functions as an inverting amplifier with a gain of 0.5. This is determined by the values of R5 and R7. When the input signal goes positive the output is driven hard against its negative supply voltage, which in this case is 0 V. So the output stage is turned off, and has a relatively high output impedance. In this state the resistors R5, R7 and R8 form a potential divider and connect the input signal to the output directly. Again, the output voltage is one half of the input voltage. In order for this circuit to work, the output stage in the op-amp must be CMOS so that the output can go completely to 0 V and have an output impedance high enough not to short out the signal voltage from the potential divider. This is the reason the CA3130 is used. Furthermore, this is a relatively fast device which ensures that the full wave rectifier will have a frequency response that covers the entire audio spectrum. The one disadvantage of the circuit is that it requires a high load impedance since the output signal for positive-going input signals is obtained from the potential divider and not from the op-amp itself. In this application the load is around 100k (R9) which causes negligible error.

The output of the full wave rectifier is fed simultaneously to an average filter formed by R9 and C6, and to the peak hold circuit formed by IC3 and its associated components. The peak hold circuit is really nothing more than a 'precision diode' that charges a capacitor to the peak voltage. The precision diode is formed by including a conventional signal diode in the feedback loop of a fast op-amp. If an input signal is applied which is less than the forward voltage drop of the diode, the stage is effectively in open loop gain (around 320 000 for the CA3130). The output voltage will rise very quickly, turning the diode on. Since the output of the diode is connected to the inverting input of the op-amp, the stage functions with unity gain once the diode has been turned on. Capacitor C5 ensures stability of the stage while preset RV2 allows adjustment of dc offsets due to this stage. The output of the peak hold circuit charges capacitor C7 through resistor R10. The combination of R10 and C7 defines the attack rate of the peak detector.

As shown, the value of R10 is 10 ohms and this is small in comparison to the output impedance of the CA3130, but is included in case some applications require the peak detector to have a slower attack rate. With the values shown, the LED level meter will display single 50 uS pulses accurately and this is entirely adequate for any audio application.

Resistor R11 discharges the capacitor and its value of 100k dictates a decay rate of around one second. This gives the level meter its rapid attack, slow decay characteristic and enables even short transients to be spotted.

As explained in the text, both the average and the peak levels of the signal are displayed simultaneously. This is accomplished by multiplexing the outputs of the peak and average detectors. This is done by switching between the output of these two circuits at a relatively high frequency (say a few hundred Hertz). In the circuit, this is done with CMOS transmission gates. The 4066 was chosen mainly because its on resistance is a little lower than the older 4016 and this enables the remaining two gates in the package to be used as the driving oscillator. The oscillator is formed by resistors R12 to R15 and capacitor C8, with the associated two transmission gates. The frequency of the oscillator is determined by the values of R13 and C8 at around 150 Hz.

IC5 functions as an amplifier stage as discussed in the text. Once again dc offset adjustment is provided, this time by RV3. Capacitor C10 provides the necessary compensation to ensure stability. Details of the two LED drivers and the amplifier formed by IC5 are in the main text.

The transistor Q1 and the associated components R21, C15 and ZD1 form a simple 5V regulator to power the LM3915s. Capacitor C16 is essential for stability of the LED drivers and must be mounted close to the LEDs.

This means that the topmost LED driven by IC6 will light when the input voltage to the device is 5.35 V. Now, 30 dB below this is:

$$\frac{-30}{20} = \log \frac{x}{5.35}$$

or 1.17 V, which is well above the voltage expected on the output of IC5 due to the dc offset. The reference voltage used was chosen specifically to ensure that this would be the case. Now the easiest way to cascade two LM3915s would be to simply set the reference voltage of the second LM3915 the same as that of the first and precede the first one by a 30 dB gain amplifier. However, with the recommended supply voltage of +/−15 V the maximum peak signal voltage that can be delivered by IC1 will be around 6 V. The operation of the absolute value generator (full wave rectifier, IC2) further divides this by two, so the maximum peak signal voltage available will be around 3 V and the top several LEDs would never be lit. To overcome this problem the reference voltage of IC7 is decreased so that the top LED will be lit by a 3 V input signal, and the gain of the amplifier formed by IC5 is changed accordingly.

The resistors R26 and R27 set the reference voltage of IC7 at 3.1 V and 30 dB below this voltage is

$$\frac{-30}{20} = \log \frac{x}{3.1}, \text{ or } 98\text{ mV}.$$

Now, the top LED driven by IC6 must correspond to this voltage, so the required gain around IC5 is 5.34/98 mV or 54.6. The values of the resistors R19 and R18 set this gain at (180+33+3.9)/3.9 or around 56 which is a good enough approximation, amounting to an error of less than 0.5 dB. ▶

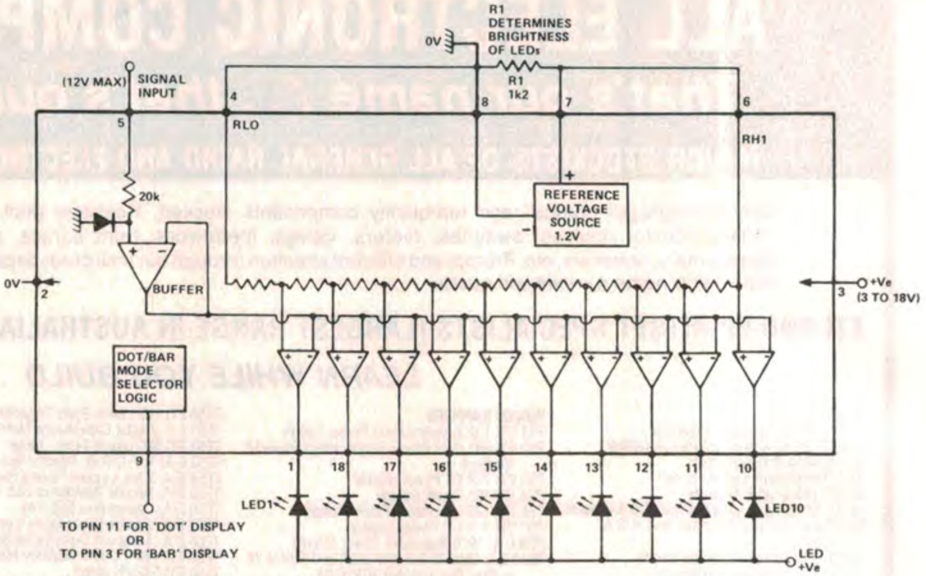
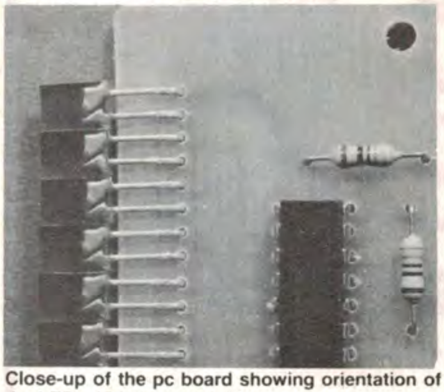


Figure 3. **Internal block diagram of the LM3915.**

Internally, the LM3915 consists of a string of comparators; each one compares the input signal to a reference voltage it derives from a ten-way potential divider (see Figure 3). The accuracy of the LM3915 is determined by these internal resistors and is therefore very good. To ensure the display is accurate over the entire 60 dB range it is only necessary to ensure that the changeover from one LM3915 to the other is accurate. Resistors R18, R19, R22, R24, R26, and R27 have been specified as 1% tolerance types for this reason. This is probably unnecessary for most applications. I have built the unit using 5% types and the error was only around 1.5 dB which is effectively hidden by the 3 dB increments between LEDs. Figure 4 shows the accuracy of one of the prototype units built with 1% resistors in the places specified. If the accuracy were perfect, all the dots would lie on the straight line. The deviation from the line is only small, so the unit is very accurate over the entire 60 dB dynamic range.

Transistor Q1 forms a simple voltage regulator delivering 5 V to the LEDs. This decreases the power dissipation in the LM3915s. The current consumption from the positive rail is around 100 mA while the negative rail needs only several milliamps. If the display is to be used from an existing power supply in a preamplifier for example, care should be taken to ensure that the relatively high positive rail current does not upset the preamplifier performance. In the Series 5000 preamp a separate positive rail is used for the display to decrease any possibility of interaction between the display and the audio signal voltages in the preamp.



Close-up of the pc board showing orientation of the LEDs. IC7 at lower right.

Construction

The pc board is virtually essential for this project, particularly if you are constructing it as part of the Series 5000 Control Preamp.

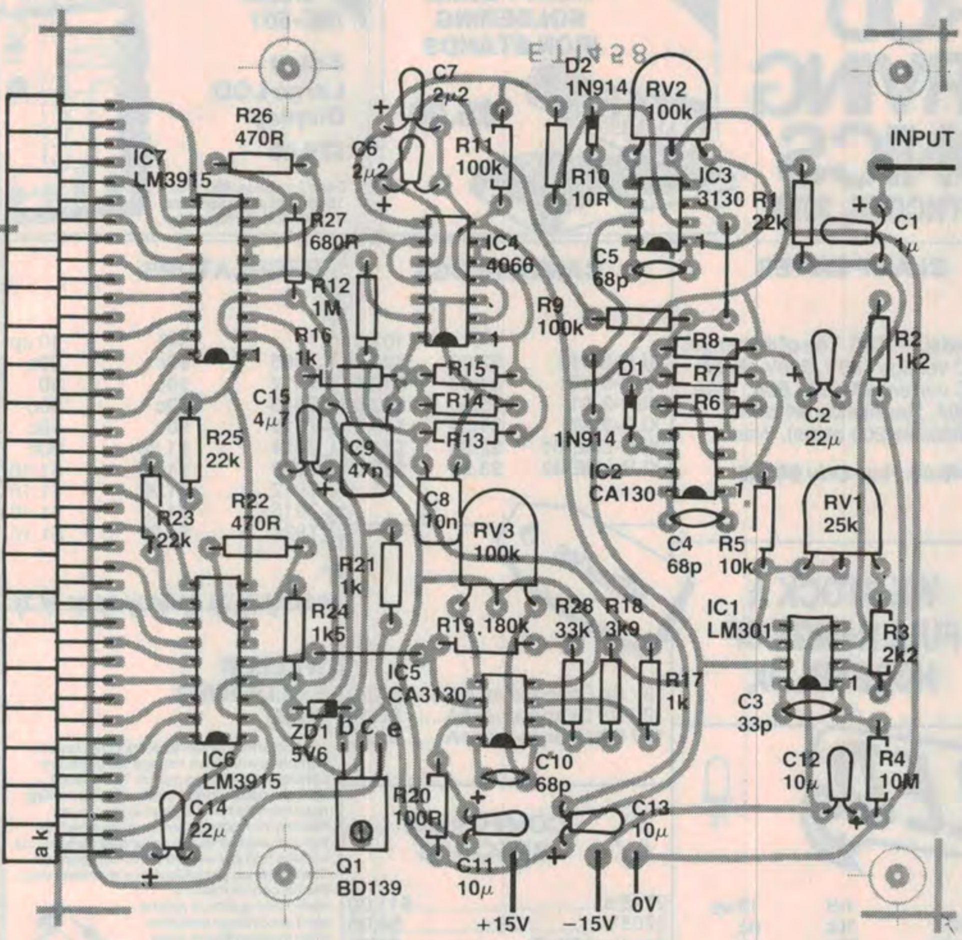
Start construction by mounting the LEDs. This is by far the most difficult part of the project. The LEDs must be inserted evenly and with equal heights, and this is *not* easy. Furthermore, the LEDs must be inserted the right way around. The longer of the leads represents the anode of the LED. Check the orientation of each LED against the overlay, before soldering. The best way I found to mount the LEDs is to start by inserting the first LED on one end of the display. Bend this LED flush against the *edge* of the pc board. Now solder the leads and bend the LED upright again. Insert the next LED and ensure that its height on the board is identical to the first. Now solder the second LED into position. Continue like this for the remaining eighteen LEDs, checking the orientation of each one as you go. After all the LEDs are soldered into position check that the heights are all even and make any adjustments needed now by reheating the appropriate solder joints. Be careful when soldering the LEDs that you do not overheat the leads; this will damage the device and is very easily done. Once all the LEDs are even bend the whole line down against the circuit board as shown in the photographs.

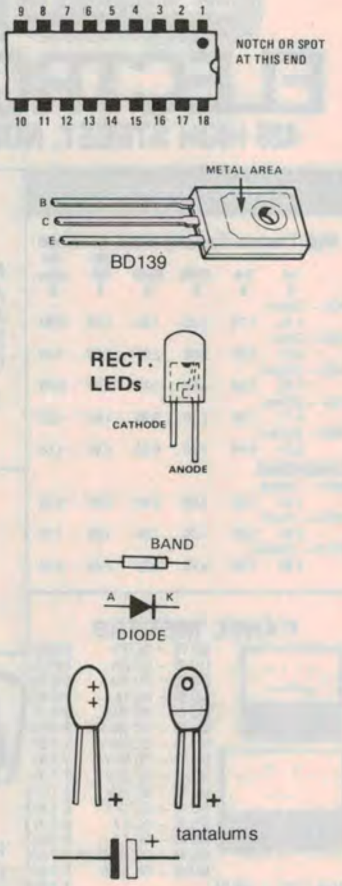
Now all the other components can be mounted. The order of mounting is not really important although it is good general practice to solder the passive components first (resistors and capacitors). And then solder the ICs and transistors. In the Series 5000 Preamp the LED level displays are mounted directly above one another, so all components should be mounted as close as possible to the pc board. The presets are mounted against the circuit board and this is best done by bending their leads at right angles first, and then soldering. Similarly, many of the larger capacitors, such as the greencaps and ceramics, may have to be folded against the board. Leave sufficient lead on the components so that this can be done. Alternatively, bend the component over before soldering. Be careful with the orientation of all polarised components, such as transistor Q1 and the electrolytic and tantalum capacitors. Tantalum capacitators, for example, are very intolerant of reverse biasing.

Setting up proceedure

Once all the components have been mounted on the pc board and checked, the unit can be switched on. Ensure that the power supply you are using has sufficient current capability for the positive rail and that it is correctly connected to the supply points on the circuit board. If the input is touched with a finger two LEDs should light and move up the display. If all is well the dc offsets can now be adjusted. The preset RV2 adjusts the dc offset of the peak follower. This will be adjusted to equal the dc level of the average filter, i.e: that from the output of the full wave rectifier. The overall dc offset can be nulled by RV3.

First connect the input of the LED level meter to earth on the board. This ensures that no signal voltage will be present when the adjustments are made. Now turn both RV2 and RV3 fully clockwise; both LEDs should run off the bottom of the display. Turn RV3 slowly anticlockwise until the second LED from the bottom has just turned on. If RV2 is now turned anticlockwise also, a second LED will light on the display. This is the peak level LED. Adjust RV2 to superimpose this LED





onto the second bottom LED. Now adjust RV3, turning it clockwise again until the LED has just run off the bottom of the display.

The final stage in the setting up procedure is to align the meter for the appropriate 0 dB level. Preset RV1 varies the gain of the prescaling amplifier stage formed by IC1. Adjustment of this preset will vary the input voltage required to light the top LED between 260 mV and 2.5 V. If your application requires 0 dB to be a higher voltage than 2.2 V, use a potential divider at the input to decrease the input signal voltage. If more gain is required increasing the value of the preset from 25k to 100k will decrease the necessary input voltage to around 70 mV, which should be sufficient for most applications.

In the Series 5000 amplifier the top LED is designated +9 dB, so the fourth LED from the top is 0 dB. Calibration of the 0 dB reference is best left until the preamp is finished and the procedure will be described in the Series 5000 Preamp construction article, coming soon. ●

PARTS LIST — ETI 458

Resistors	all ½ W, 5% unless marked otherwise
R1, 23, 25	22k
R2	1k2
R3	2k2
R4	10M
R5, 14, 15	10k
R6, R8	15k
R7	4k7
R9, 11, 13	100k
R10	10R
R12	1M
R16, 17, 21	1k
R18	3k9 1%
R19	180k 1%
R20	100R
R22, R26	470R 1%
R24	1k5 1%
R27	680R 1%
R28	33k 1%
RV1	25k min. trimpot
RV2, RV3	100k min. trimpot

Capacitors	
C1	1μ/6V tant.
C2, C14	22u/16 V tant.
C3	33p ceramic
C4, 5, 10	68p ceramic
C6, C7	2u2/25 V tant.
C8	10n greencap
C9	47n greencap
C11, 12, 13	10u/25 V tant.
C15	4μ7/16 V tant.

Semiconductors	
IC1	LM301, 8-pin DIL
IC2, 3, 5	CA3130, 8-pin DIL
IC4	4066
IC6, IC7	LM3915
D1, D2	1N914 or sim.
ZD1	5V6 zener diode
Q1	BD139
LED1 - 20	Siemens LD80-2 or sim.

Miscellaneous

ETI-458 pc board (double-sided); one 6 BA bolt and nut.

Price estimate

We estimate the cost of purchasing all the components for this project will be in the range:

$38 — $44

Note that this is an **estimate** only and **not** a recommended price. A variety of factors may affect the price of a project, such as — quality of components purchased, type of pc board (fibreglass or phenolic base), type of front panel supplied (if used) etc — whether bought as separate components or made up as a kit.