DESIGNING AND MAKING A SUPER SENSITIVE SENSOR SYSTEM

We have all encountered electronic systems that sense changes in in the environment and cause output devices to be activated. For example a buzzer might come on to warn you that the temperature of the water in a fish tank is too high. This type of circuit is a two state output circuit in which a single output is high for a certain range of input conditions and low for another range.

Quite often it is desirable to sense a number of ranges of input condition and indicate each of these ranges. For example a gardener may wish to know at a glance by reading a display whether the soil in a greenhouse is very dry; dry; moist; wet or saturated with water.

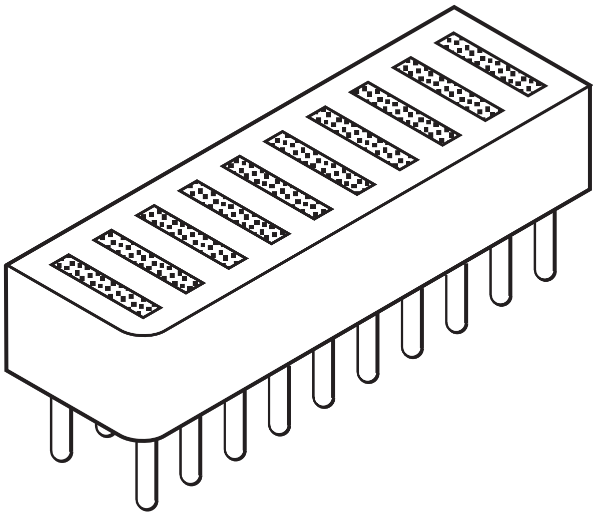
DESIGN BRIEF

Design and make an electronic sensing system that will indicate several levels of input condition. The system should be adaptable to enable it be used for sensing a number of different environmental conditions.

DESIGNING THE SYSTEM

OUTPUT BLOCK

This will give a readout indicating the state of the input. Since several levels of input conditions are required to be displayed a LED array will be appropriate. See Study File 2 which considers LED arrays. The sketch of a LED array is shown below.

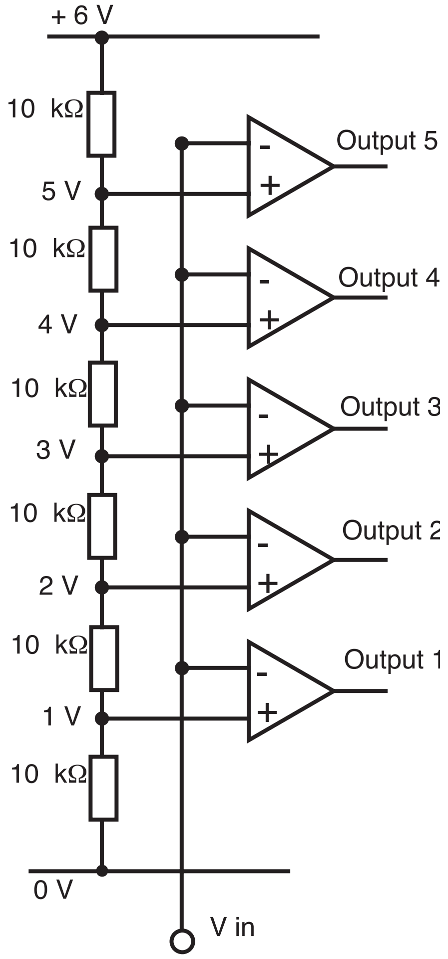


PROCESS BLOCK

The process block will receive information from the input block and will switch several LEDs on or off depending on the magnitude of the signal received from the input.

In study file 7 we considered how several comparators could be interconnected to indicate a number of different levels of an input signal.

The circuit diagram below shows how 5 comparators can be interconnected to indicate different levels of input condition.

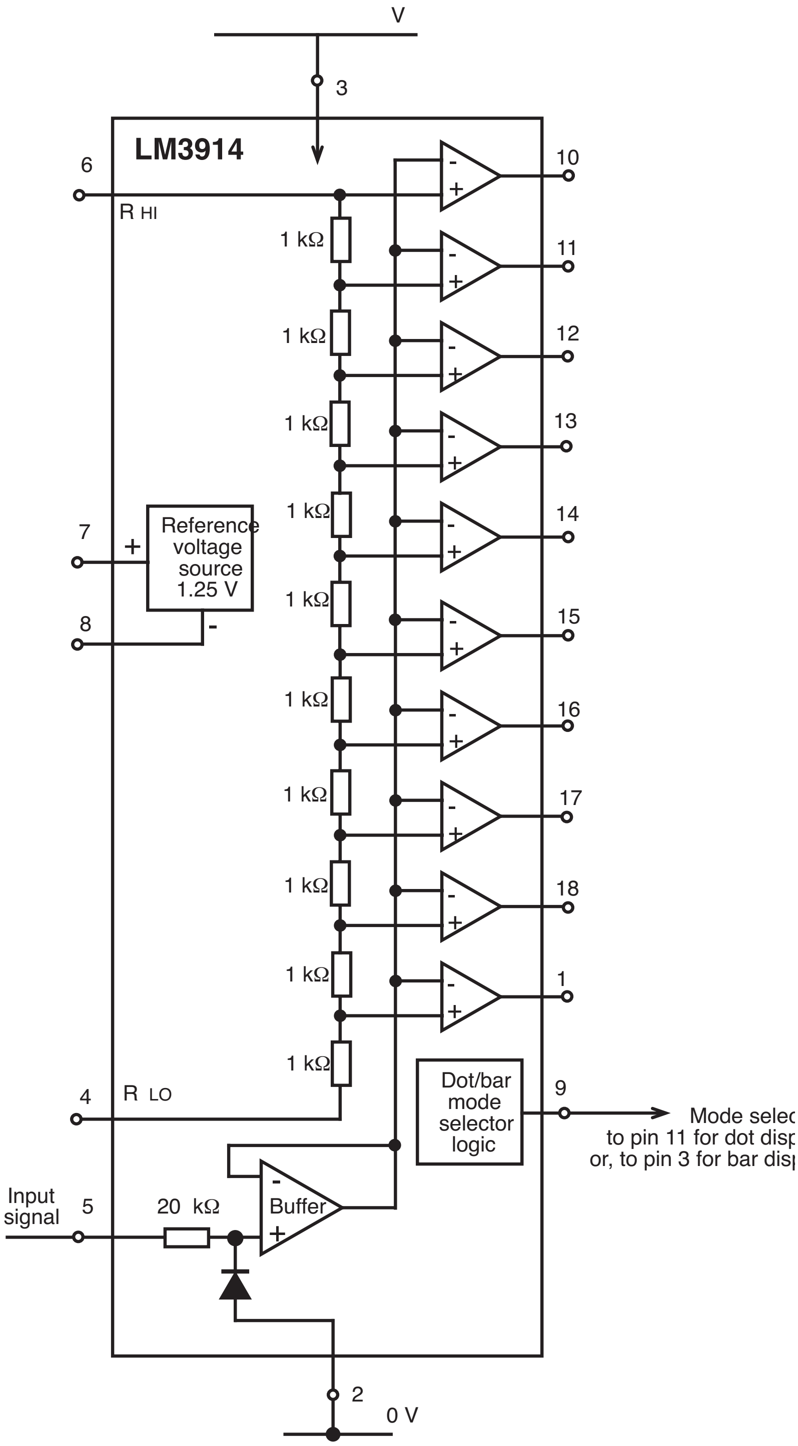


Obviously as the number of comparators is increased so does the ability of the system to distinguish between input conditions which are close to one another but not equal. This is referred to as the resolution of the sytem. The main difficulty with increasing the resolution is that as the number of comparators is increased both the complexity of the wiring and the cost also increase.

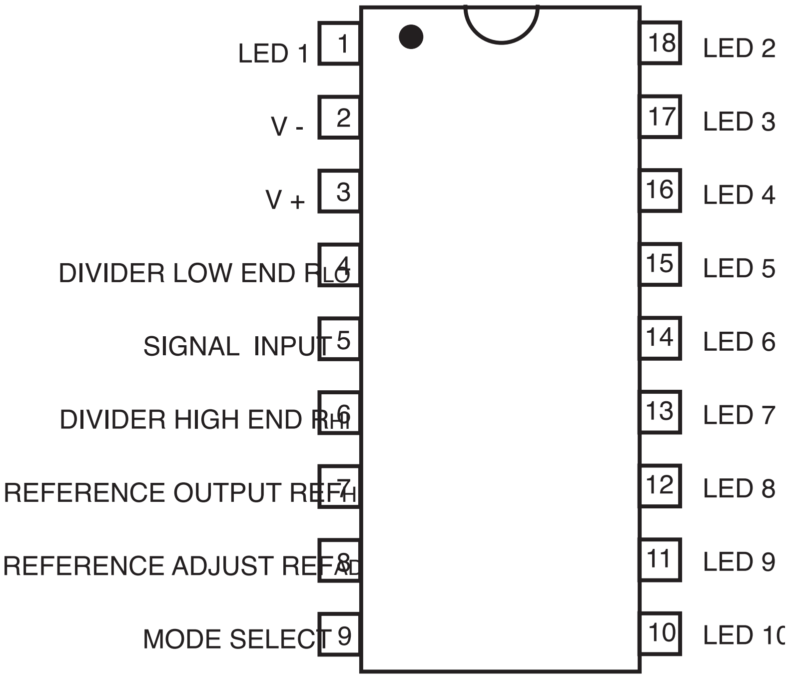
Several specialist ICs are available which have a number of comparators and a resistor chain on a single DIL package.

One of the more sophisticated of these is the LM3914 LED bar graph driver IC. It is available in an eighteen pin DIL package and can drive up to ten LEDs.

The following schematic diagram shows the internal circuitry of the LM3914

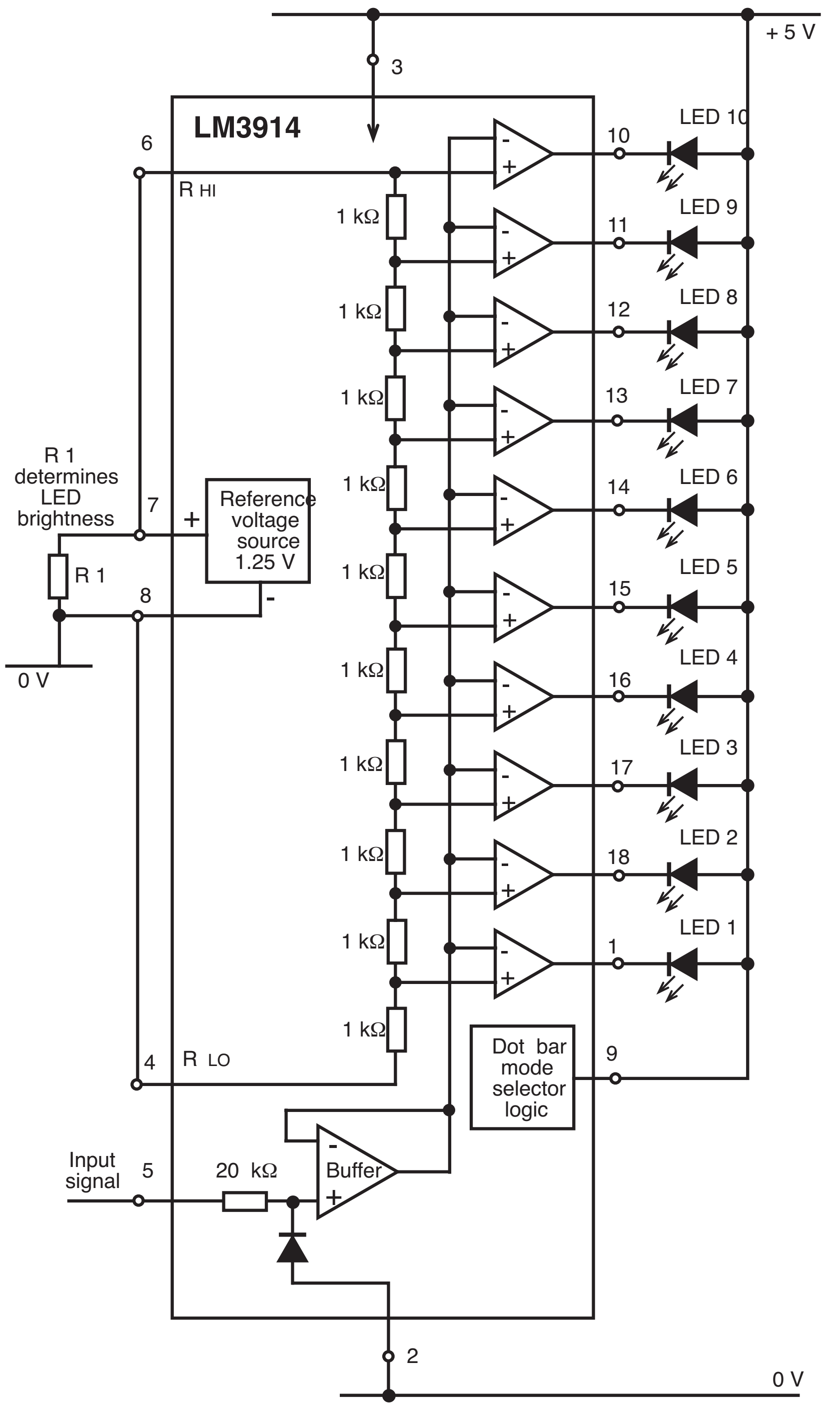


The pin out diagram is given below.



You will notice that the IC contains ten voltage comparators, a ten stage precision potential divider chain and an inbuilt reference voltage. See Study File 7, which looks at comparators in some detail.

Pins 4, 6, 7 and 8 can be interconnected both to each other and to external resistors for different applications. The simplest means of interconnection is shown in the following diagram.



The 1.25V reference voltage is connected across the ten 1K resistors that make up the potential divider chain. Thus 0.125V is applied to the non inverting or reference input of the first comparator, 0.25V to the reference input of the second comparator and so on. If an input signal whose value is slowly rising from 0V is applied to the signal (inverting) input then as the value of the input signal reaches 0.125V the first comparator output goes low and LED1 is illuminated. As the value of the input signal passes each of the comparators' reference voltages the corresponding LED will illuminate. Eventually when the input voltage rises above 1.25V all ten LEDs will be on. The table below summarises the switching action.

LED number	Threshold voltage
1	0.125 V
2	0.250 V
3	0.375 V
4	0.500 v
5	0.625 V
6	0.750 V
7	0.875 V
8	1.000 V
9	1.125 V
10	1.250 V

Table 1

The system has a resolution of 0.125V per display LED.

The value of resistor R1, determines the maximum current that each comparator output can sink, which is approximately ten times the current flowing through R1.

For example if R1 = 1 kΩ
Current through R1 = 1.25V/1kΩ = 1.25mA
Max. current through all output LEDs =
10 × 1.25 mA = 12.5mA.

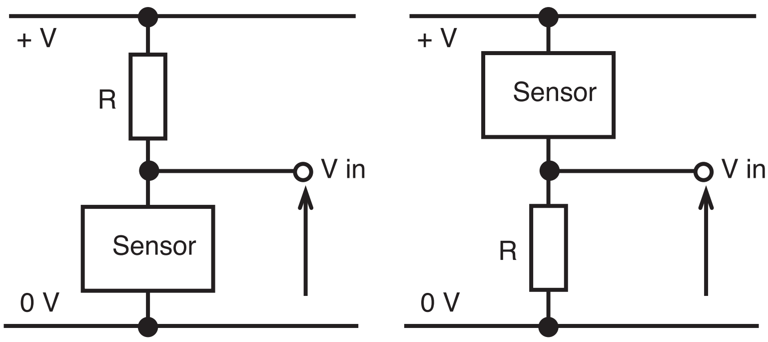
If the LED array consists of Super Red LEDs then a 10kΩ resistor will give adequate illumination.

When the LM3914 is set for dot mode rather than bar mode only one LED will be illuminated at any one time.

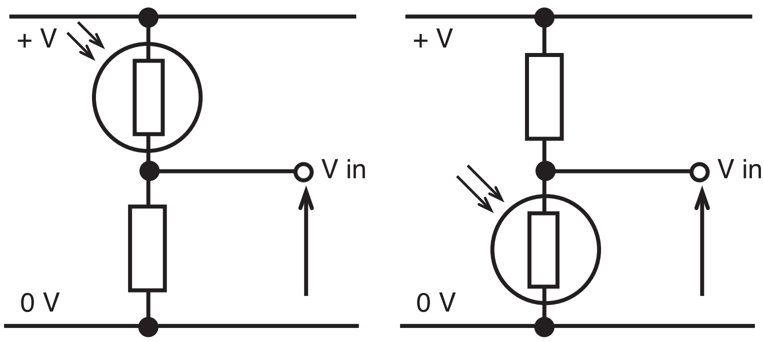
INPUT BLOCK

The input block will consist of a sensor connected in series with a resistor to form a potential divider.

The sensor may be placed in the top or the bottom of the potential divider depending on the application.



For example, if the input block uses an LDR

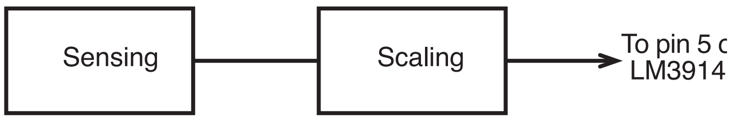


In this case, V in decreases as the light intensity increases

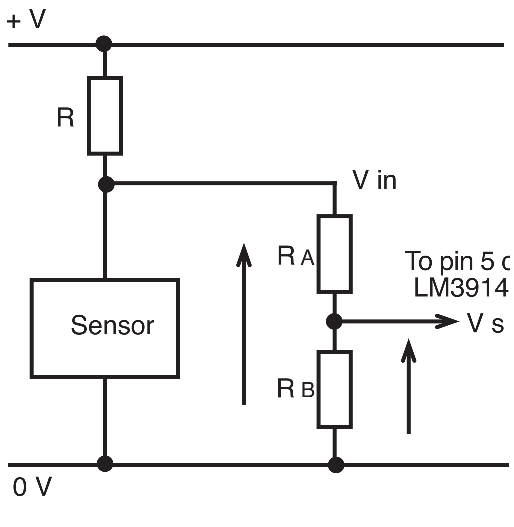
In this case, V in increases as the light intensity increase

Thus by simply interchanging the position of the LDR and resistor we can reverse the way in which the system responds to changes in light level. The left hand input block will cause more LEDs to illuminate as the light level increases whereas the right hand input block will cause fewer LEDs to be illuminated as the light level increases. Obviously this principle can be applied to other sensors.

The basic LM3914 circuit only indicates input signals that are in the range 0 to 1.25V. It would be impossible to ensure that different sensor circuits always produce a signal Vin, in the range 0 to 0.125V. Thus the input block has to be modified to produce a scaled down signal range. The input block can now be represented by two sub-systems.



This can quite easily be achieved by using a second potential divider.



We shall now consider how to choose values for R_A and R_B. The explanation is quite complicated so do not be too concerned if you cannot completely follow it.

You will have learnt from Study File 1 that for the above circuit:

$$V_s = \frac{R_B}{R_A + R_B} \times V_{in} \qquad \textit{Equation 1}$$

We can rearrange equation 1 to get:

$$V_{in} = \frac{V_s (R_A + R_B)}{RB} = V_s\left(1 + \frac{R_A}{R_B}\right) \qquad \textit{Equation 2}$$

Now the maximum value of V_{in} (V_{in} max.) that can be encountered in the environment in which the sensor is being used should just illuminate all ten LEDs and V_s must equal 1.25V when this occurs:

Substituting in equation 2.

$$V_{in}\ max = 1.25\left(1 + \frac{R_A}{R_B}\right) \qquad \textit{Equation 3}$$

Obviously V_{in} max. will be a different value for different sensing sub systems but cannot be greater than the supply voltage V.

We shall be using a 5V supply thus the absolute maximum value of V_{in} max. is 5V.

Substituting in equation 3.

$$5 = 1.25\left(1 + \frac{R_A}{R_B}\right) \qquad \textit{Equation 3}$$

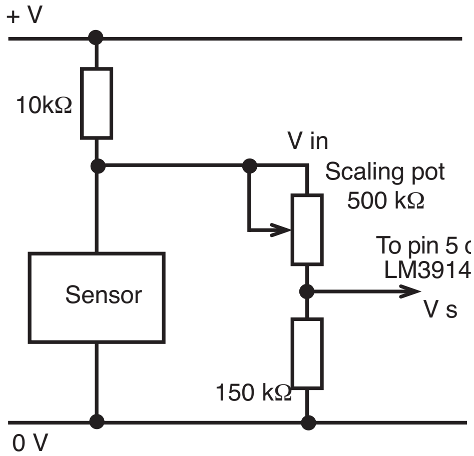
$$\frac{5}{1.25} = 1 + \frac{R_A}{R_B}$$

$$4 = 1 + \frac{R_A}{R_B}$$

$$\frac{R_A}{R_B} = 3$$

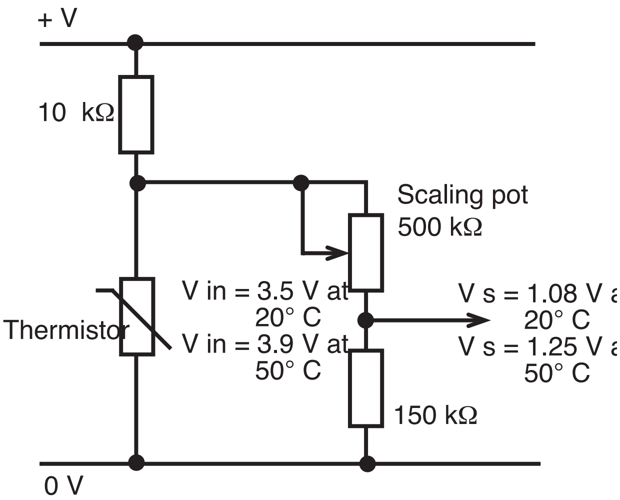
Therefore for the maximum possible input voltage of 5V the resistance of R_A would have to be three times that of R_B. To enable the system to process input signals from a variety of different sensing sub-systems the ratio of R_A to R_B would also need to be variable.

We shall choose high values of resistance for R_A and R_B so that they have a minimal effect on the performance of the sensing sub-system. The circuit diagram for the input block is shown below:



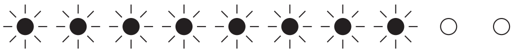
The values of resistance chosen for the input block will allow the system to cope with a wide range of sensors such as thermistors, LDRs and moisture sensors.

Consider the following example of a temperature sensing system. The voltage V_{in} has been measured at the two required temperature extremes of 20°C and 50°C. At 20°C V_{in} = 3.5V. At 50°C V_{in} = 3.9V. The scaling pot is adjusted to produce a value of Vs = 1.25V at the maximum temperature to be indicated (50°C). Consequently the value of Vs at 20°C will be scaled proportionally to a value of 1.08 V.
(i.e. Vs at 20°C = 3.5 × 1.25/3.9 = 1.08V)

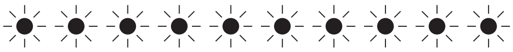


On connecting the input block to a LM3914 and LED array the following results were obtained.

at 20°C Vs = 1.08V   8 LEDs illuminated



at 50°C Vs = 1.25V   10 LEDs illuminated

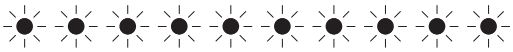


The resulting display is as shown because the resolution of the system is still 0.125V/LED and at 20°C, Vs is equal to 1.08 volts. If you look at table 1 you will see that this corresponds to 8 LEDs illuminated.

We need to expand the resolution of the system so that for the example given

at 20°C   0 LEDs illuminated

at 50°C   10 LEDs illuminated

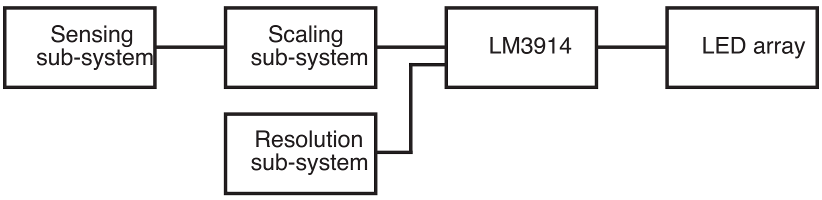


In this case the resolution would be

(1.25 - 1.08) / 10 = 0.017 V/LED

We require a method of expanding the resolution of the system to correspond with the different minimum values of Vin.

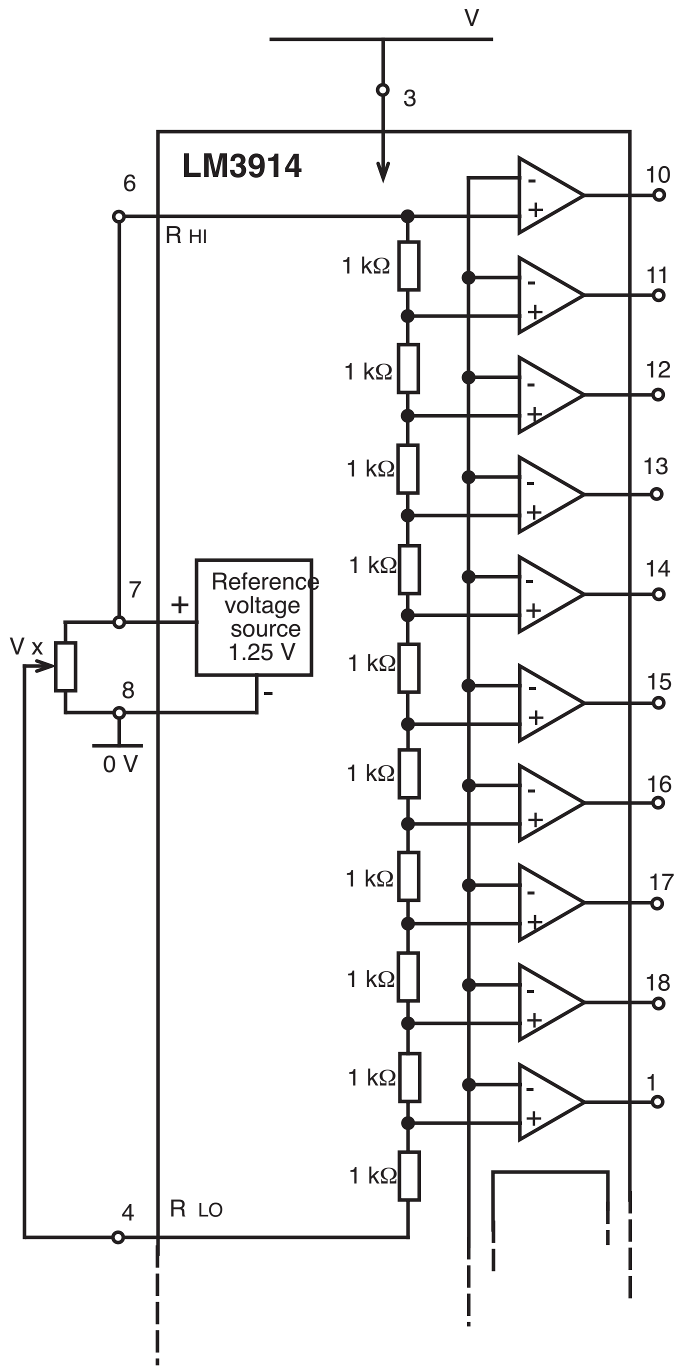
The block diagram for the system is now.



RESOLUTION

A variable resolution can be achieved by applying a voltage, equal to the minimum value of Vs provided by the scaling sub-system to the bottom end of the LM3914 internal potential divider chain. This voltage will depend on both the sensor being used and the range of environmental conditions being monitored.

The following circuit diagram shows how the 1.25V reference voltage can be used to apply a voltage Vx, equal in value to Vs min, to the internal potential divider chain.

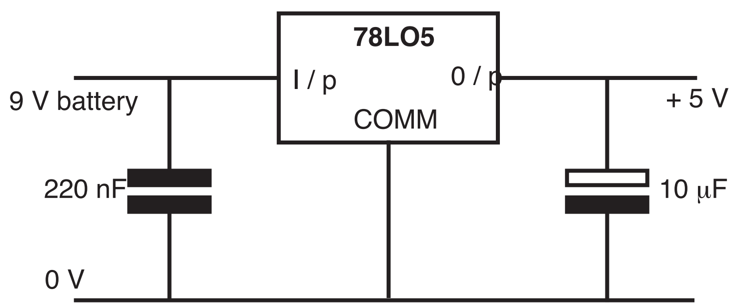


The fixed value of R should be chosen to give the required level of LED brightness as described earlier. The wiper of potentiometer R is connected to the bottom end of the internal potential divider, allowing a fraction, Vx of the 1.25V reference voltage to be applied to it. The potential difference across the ten 1kΩ resistors that make up the potential divider chain is now equal to 1.25 - Vx. The system thus has a variable resolution equal to:

(1.25 - Vx) / 10.

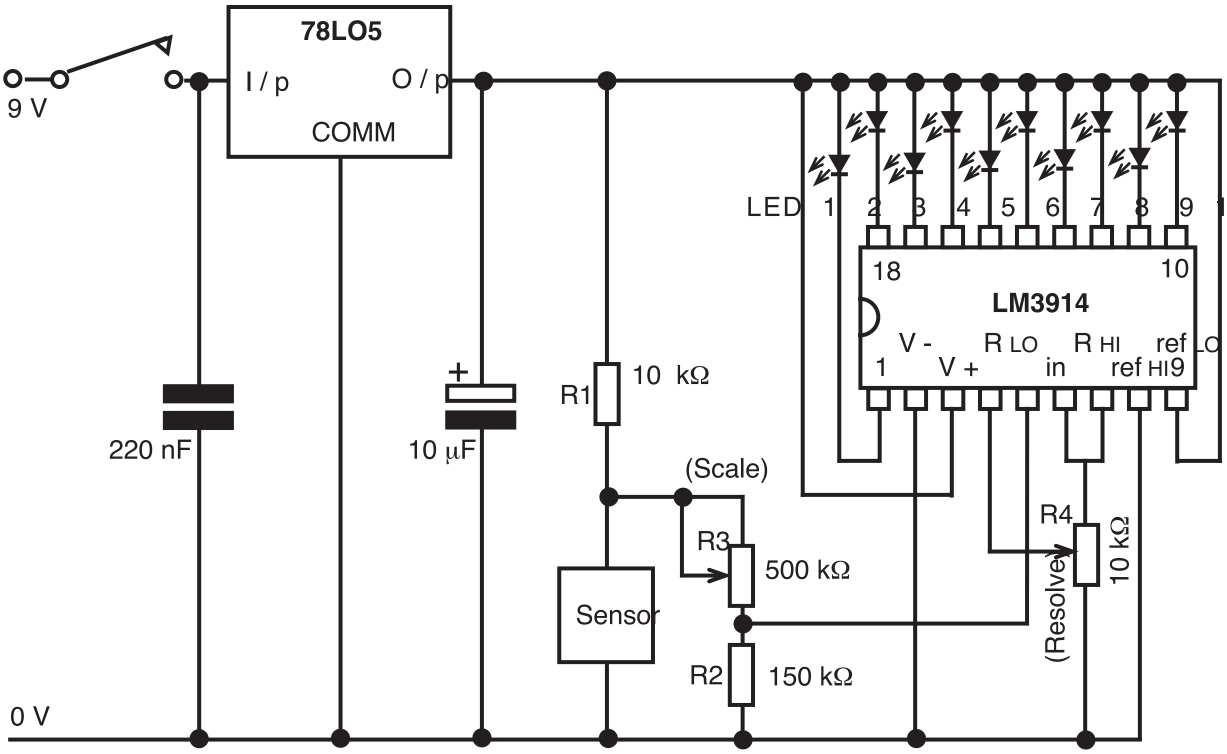
POWER SUPPLY

For the value of the voltage signals Vin and Vs to be independent of the condition of battery being used to power the system the terminal voltage of the battery must remain constant. A new 9V battery will have a terminal voltage of approximately 9.5V. This value will decrease as the battery is being used and is dependent on the current drawn from it. A battery is said to be an unregulated power supply. A voltage regulator can be used with a battery to provide a regulated power supply. A 5 volt regulated supply can be obtained using a 78LO5 voltage regulator which will maintain a constant voltage output of 5V as long as the terminal voltage of the battery does not drop below 7 volts. The circuit and pin out diagrams of a 78LO5 regulated supply are shown below:



PUTTING IT ALL TOGETHER

The circuit diagram for the complete system is shown below.

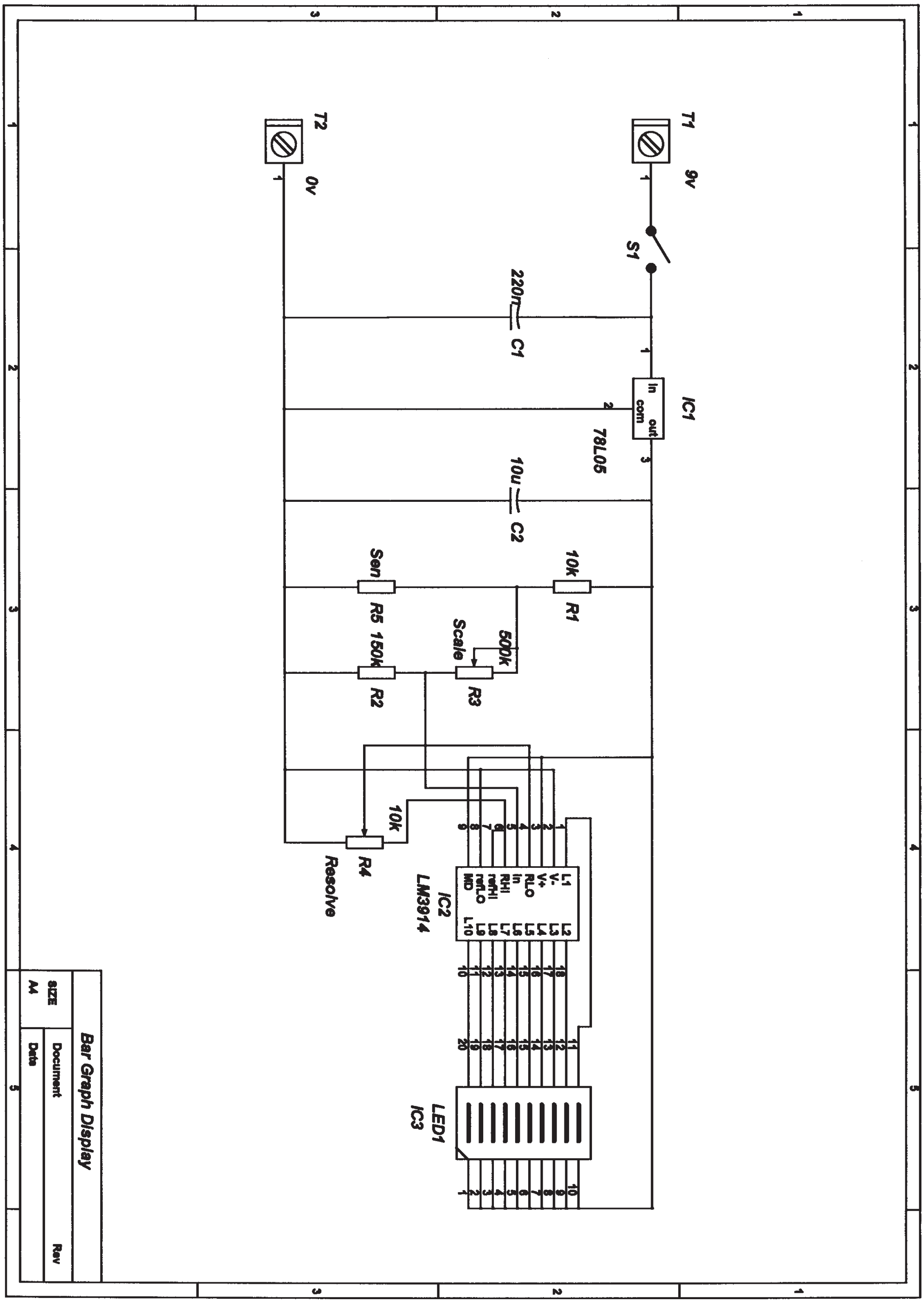


Note: The positioning of the sensor and R1 may be interchanged if the effect obtained on the LED array needs to be reversed.

You will need to make a printed circuit board (PCB) onto which to mount the components. To find out about this see Study File 8 (Making a PCB).

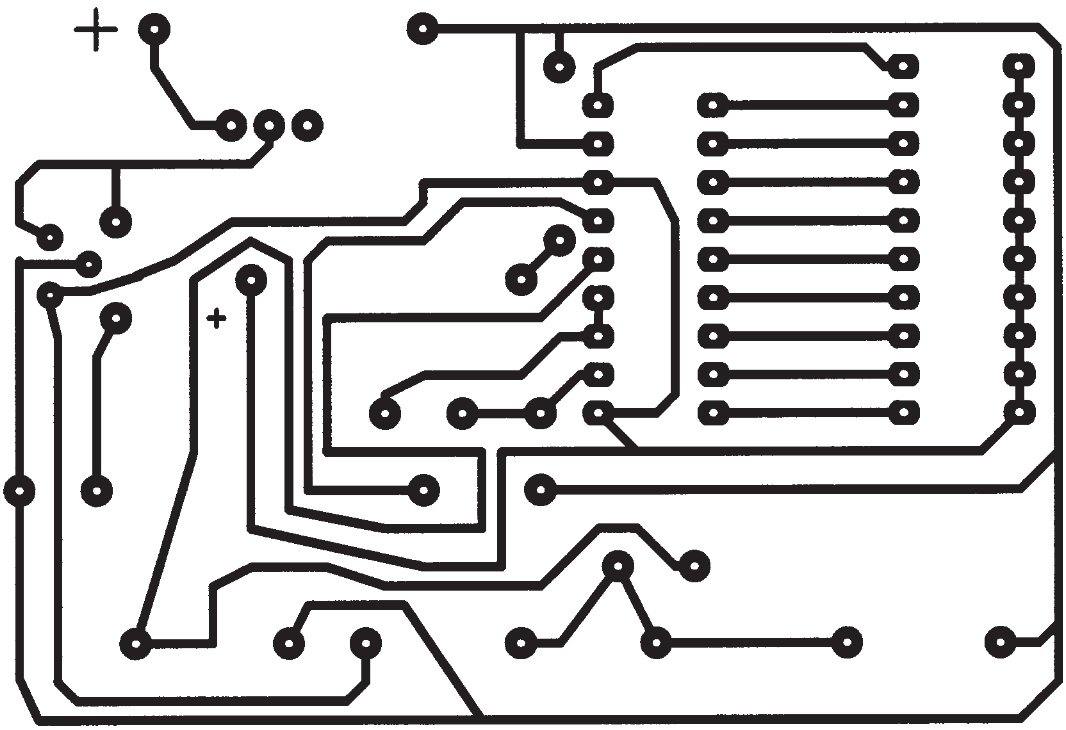
The following four drawings have been produced on a PCB design software package. A disk is also supplied containing a file which includes all four drawings. More information about the PCB design software is given in Study File 8.

SCHEMATIC CIRCUIT DIAGRAM



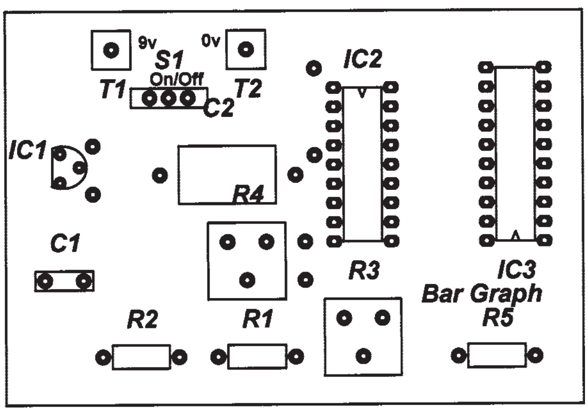
This is the circuit diagram for the complete system redrawn by the design software. The software uses the diagram to create the other three diagrams.

PCB LAYOUT DIAGRAM



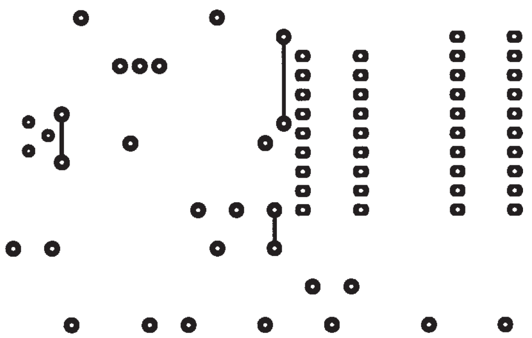
This diagram is used to create the PCB mask on an acetate sheet as described in Study File 8. The diagram is supplied twice normal size so the photocopier should be set to 50% reduction when producing the mask.

COMPONENT LAYOUT DIAGRAM



The diagram shows you where each of the components is to be mounted on the PCB.

WIRE LINK DIAGRAM



This diagram shows you where wire links have to be inserted.

It is advisable to mount all the IC socket holders first. You can then check with a multimeter set to the 200Ω range to ensure that solder has not spilt on any tracks which pass between adjacent pins.

TESTING

When you have built the circuit, you will need to test it to see if it works correctly.

The system cannot be properly tested until it has been calibrated although a quick functional test can be carried out with a LDR used as a sensor.

Before inserting the LM 3914 and LED array, check that the voltage between pins 2 and 3 of the LM 3914 socket is 5V. Confirm that the voltage between pins 2 and 5 of the LM 3914 can be varied by adjusting R3.

Finally check that the voltage on each of the pins 1 to 10 of the LED array socket is 5V.

Insert the LM 3914 and LED array and try covering and uncovering the LDR for various positions of R3 and R4. Some or all of the LEDs should come on and go off as you cover the LDR.

If this functional test works you can now calibrate the system.

If the circuit does not work, follow the simple Fault Finding procedure below:

1. Check that no tracks or pads are bridged or broken. Repair if necessary (see Study File 8).
2. Check that all solder joints are good.
3. Check that all components are mounted correctly. Pay particular attention to the ICs. It is quite easy to plug them in the wrong way around.
4. If all this fails try changing the ICs.

CALIBRATING THE SYSTEM

Adjust the 500kΩ scaling potentiometer (R3) so that the voltage on pin 5 of the LM 3914 is at a maximum.

Monitor the voltage at pin 5 at both extremes of the environmental condition to be encountered and note which of the two extremes produces the higher voltage at pin 5.

Set up the extreme of the environmental condition that produced the higher voltage and carefully adjust R3 until the voltage at pin 5 is 1.25 volts. If the value of the voltage is significantly less than 1.25 volts at the required environmental condition, change the value of R1 from 10kΩ to 4.7kΩ and repeat the procedure.

The scaling is now set and no further adjustment of R3 is necessary.

Set up the extreme of the condition that produced the minimum value of Vin and record the value

Vin min. =

Adjust the 10kΩ resolution potentiometer (R4) until the voltage at pin 4 is equal to the value of Vin min. recorded above.

The system is now calibrated with optimum sensitivity for the range of environmental conditions that are of interest to you. Outside your chosen range the LEDs will either be all off or all on.

EVALUATING THE SENSING SYSTEM

There are a number of things you need to consider when evaluating the system.

1. How well does it work?
   Is the system sensitive enough?

2. Will it work in the situation for which it was designed?
   Can the system be calibrated easily?
   Can you improve the calibration method?

3. Is the system robust enough?
   Can different sensors be easily interchanged?