Project 256

Electronic humidity meter can double as a controller

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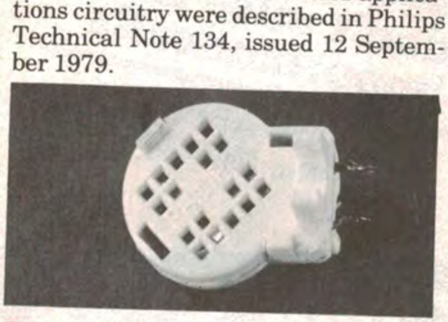
This project can be built to give a readout of relative humidity either on a LED dot-mode display or a conventional meter. In addition it can be used with a following project as a controller to turn on and off a water mist spray in a hothouse, for example.

MEASURING environmental parameters such as temperature, wind speed and direction, etc, are relatively simple problems in electronics. But when it comes to humidity — or relative humidity — a stumbling block arises. The Bureau of Meteorology, and most other agencies or people interested in measuring relative humidity ($H_{rel.}$), employ wet bulb/dry bulb thermometer instruments and a conversion table. Attempts to emulate the wet bulb/dry bulb technique electronically have been tried, using thermistors, in the past but the technique has not met with a great deal of acceptance. It's "fiddly" and offers few advantages — other than a direct readout of relative humidity — over the wet bulb/dry bulb method.

Now, doubtless many an electronics engineer and hobbyist has turned their mind to the problem of a suitable electronic sensor over the years — finally turning to more stimulating things after running up a number of frustrating blind alleys. Not so the Philips organisation. Somewhere along the line they ran up an alley that bore fruit (. . . pomegranates and paw-paws, but that's another story entirely!). In 1979, Philips released a 'capacitive humidity sensor for consumer applications', type number 2322 691 90001. The device characteristics and applications circuitry were described in Philips Technical Note 134, issued 12 September 1979.



The capacitive humidity sensor.

A view of one of our prototype humidity meters featuring the LED display. Note the sensor mounted on the board at the left, adjacent to the battery clip.

This project has been designed to use that sensor and employs a measurement technique described in that Technical Note. To cater for as wide a range of readers' interests and applications as possible, we have designed this project to display the relative humidity reading either on a conventional moving-coil meter or on a dot-mode LED display, using the ubiquitous LM3914 to drive seven LEDs indicating relative humidity over the range 35% to 100%. For those who wish to employ the project in an automatic humidity control system, it can be coupled to our Universal Relay Driver project, ETI-257, also described in this issue.

This project is not intended as a true scientific instrument as accuracy of the sensor is only a few per cent, but for most general domestic applications it should prove more than adequate.

The sensor

A humidity sensor to suit the applications described must meet two major objectives: it must have predictable behaviour and good long-term stability. In addition, the sensor must be ruggedly constructed for reliable operation and be simple to operate and maintain.

Philips claim their capacitive humidity sensor meets the above requirements, and our experience with them would bear this out.

The device consists of a perforated plastic case containing a membrane of non-conductive foil coated on both sides with gold, the membrane and coating forming, respectively, the dielectric and electrodes of a parallel plate capacitor.

Changes in relative humidity cause a change in the sensor's capacitance. With suitable circuitry, this change can be converted into a dc voltage that can be used to give a direct reading of relative humidity, or to serve as the monitoring signal of an automatic humidity control system.

The sensor is designed to measure relative humidity between 10% and 90% and has the advantage that its long-term characteristics are unaffected by condensation of water on the foil surface.

The relationship between relative humidity and capacitance for the sensor is somewhat non-linear. To obtain a direct indication of humidity, either a non-linear scale must be employed on the readout or the circuitry output signal must first be processed by a linearising circuit.

The sensor will not respond immediately to a very rapid, large-scale change in relative humidity. For example, if the relative humidity jumps from 10% to 43%, it will take the sensor round three minutes to again provide a stable reading, according to the Philips data.

If the relative humidity exceeds 90%, even slight temperature variations can lead to condensation of water on the sensor foil; this will cause measurement errors and a considerable increase in response time. The sensitivity of the sensor is not specified below a relative humidity of 10%, although it would be feasible to measure values below this.

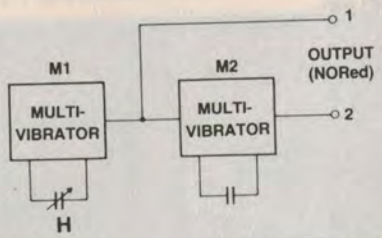


Figure 1. **Block diagram of the circuit technique employed in the humidity meter. Two synchronised multivibrators provide an output signal which varies proportional to variations in relative humidity. 'H' is the humidity sensor.**

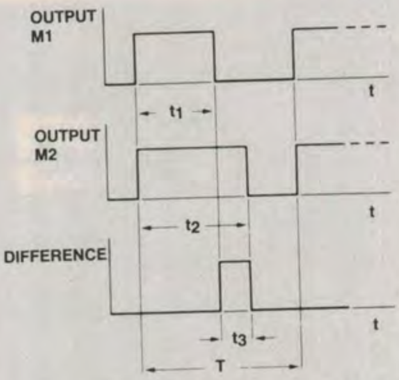
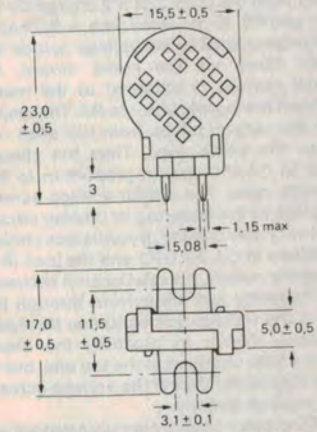


Figure 2. **Illustrating how the output signal, t_3, is obtained. If t_2 is fixed and t_1 varies with variations in humidity, t_3 will vary in direct relation to it.**

The circuit

We've used a circuit technique suggested in Philips' Technical Note 134. The operating principle is based upon measuring the pulse width differences between two synchronised multivibrators (see Figure 1). M1 is controlled by the capacitive humidity sensor, the output pulse width varying as the humidity varies. The second multivibrator, M2, has a fixed pulse width, set by a fixed capacitor. The output of each capacitor is combined in a NOR gate which produces an output signal that varies in width proportional to the difference between the multivibrator output pulse widths (see Figure 2). This is very convenient as the difference signal will be virtually independent of temperature and voltage, provided the characteristics of both multivibrators are identical and the fixed capacitor controlling M2 has a temperature coefficient as close as possible to the capacitive humidity sensor. The first requirement is easily met as both multivibrators employ two gates from a 4001 quad NOR gate package.

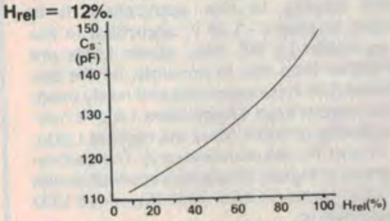
To provide M2 with a temperature characteristic closely matching that of the humidity sensor, several positive temperature coefficient ceramic capacitors in parallel are used. A small value trimmer capacitor permits adjustment of this multivibrator to calibrate the ▶



The relationship between H_{rel} and C_s (sensor capacitance) can be approximated by:

$$C_s/C_s(12\%) = 0.985 + 0.34(H_{rel}/100)^{1.4}$$

where $C_s(12\%)$ is the capacitance at H_{rel} = 12%.



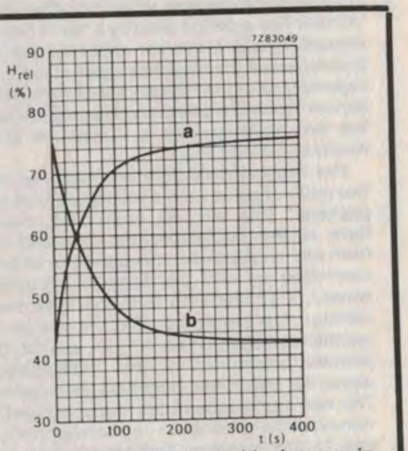
Relationship between relative humidity, H_{rel}, and sensor capacitance, C_s.

Characteristics of the humidity sensor

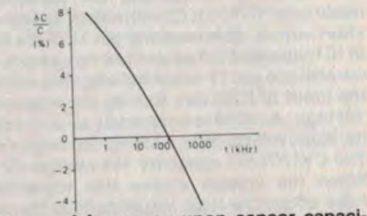
Capacitance ($T = 25°C$, $H_{rel} = 43\%$, $f = 100$ kHz)	122pF ± 15%
Sensitivity ($H_{rel} = 43\%$)	(0.4 ± 0.05)pF/%
Operating frequency range	1 kHz to 1 MHz
Temperature dependence (over operating frequency range)	≈ 0.1%/K
Measuring range	H_{rel} between 10% and 90%
Operating temperature range	0°C to 60°C
Maximum operating voltage (ac or dc)	15 V
Dielectric loss (tan δ) (at $T = 25°C$, $f = 100$ kHz)	‹ 35 x 10^{-3}
Response (90% value) within the range of H_{rel} = 10% to 43%	‹ 3 min.
within the range of H_{rel} = 43% to 90% ($T_{amb} = 25°C$, in circulating air)	‹ 5 min.
Hysteresis at one cycle (H_{rel} ⧫ 10% ⧫ 90% ⧫ 10%)	≈ 3% (H_{rel})

Capacitance of the humidity sensor at four different frequencies (nominal values)

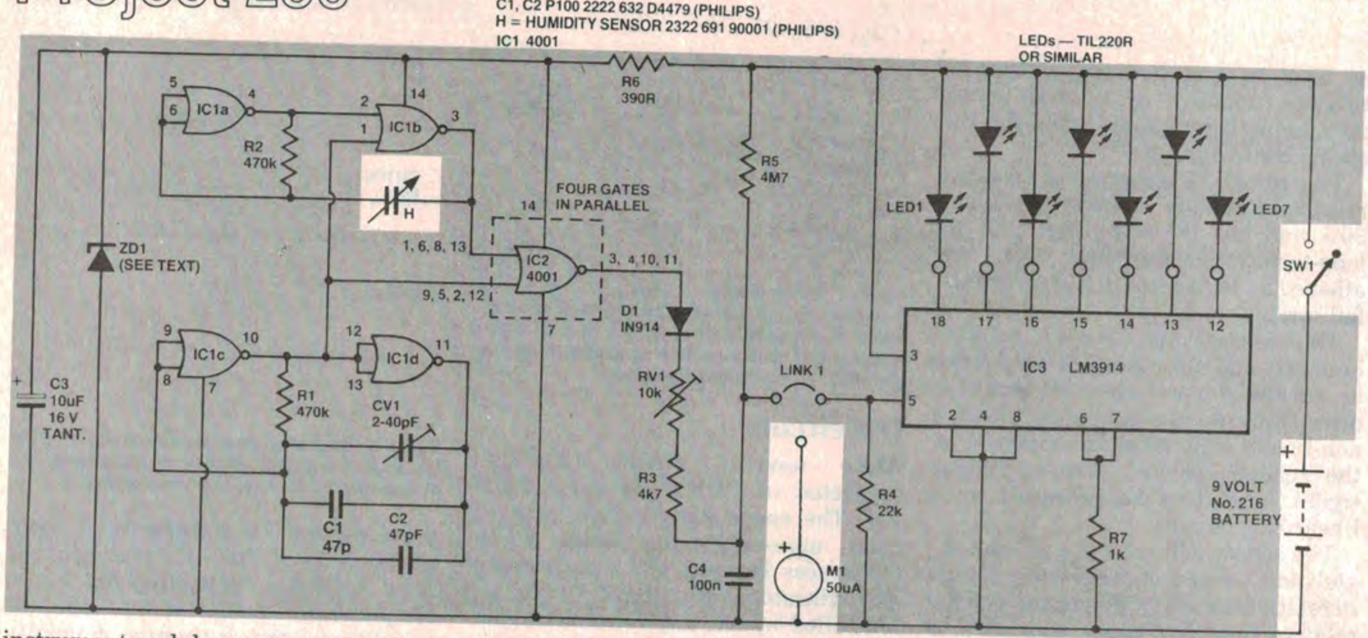
frequency f (kHz)	C_0 (pF) (H_{rel} = 0%)	ΔC (12%) (pF)	ΔC (100%) (pF)
1	116.1	3.6	45.5
10	112.7	3.5	44.2
100	109.0	3.3	42.7
1000	104.6	3.3	41.0



Response of sensor to rapid changes in humidity: (a) from 43% to 75%, (b) from 75% to 43%.



Influence of frequency upon sensor capacitance, C_s, based upon a reference frequency of 100 kHz. (Note this curve also represents the influence of frequency on ΔC and C_0.)


C1, C2 P100 2222 632 D4479 (PHILIPS)
H = HUMIDITY SENSOR 2322 691 90001 (PHILIPS)
IC1 4001

instrument and does not greatly affect the temperature coefficient.

The output voltage from the NOR gate used to combine the two pulses is obviously directly related to the supply voltage, so we have used a simple zener regulator circuit to avoid supply voltage variations affecting the accuracy of the instrument.

Readout can be on a conventional meter or via a LED dot-mode display. A linearising circuit has been employed, as suggested by Philips, to prevent 'cramping' of the readout scale — regardless of whether a meter or the LED circuit is used. Its operation is explained in 'How It Works'. The LED display provides relatively coarse steps but can be

HOW IT WORKS — ETI 256

Two synchronised multivibrators are employed and their outputs compared to provide a signal proportional to relative humidity. This output signal is first 'linearised' and then used to drive either a moving-coil meter or a LED dot-mode display employing an LM3914 dot/bar-mode display driver IC. One multivibrator has a period fixed by a set of ceramic capacitors and a trimmer capacitor (for calibration) while the other has a period set by the capacitance of the Philips capacitive humidity sensor. Thus the difference in period between the two multivibrators is a measure of the relative humidity, $H_{rel.}$.

The two multivibrators are made up from two pairs of gates from a 4001 quad NOR gate package. This ensures both multivibrators have similar characteristics. IC1a and IC1b form one multivibrator, the period of which is controlled by 'H', the capacitive humidity sensor. IC1c and IC1d form the other multivibrator, the period of which is set by the parallel combination of CV1, C1 and C2. CV1 permits adjustment of this multivibrator's period for calibration purposes (zero setting). The two multivibrators are 'synchronised' — turn on at the same time — by having pins 1, 12 and 13 tied together. To illustrate how each multivibrator works, we shall examine that using IC1c and IC1d.

When power is applied, the capacitance made up of CV1, C1, C2 will initially appear as a short circuit, thus coupling pin 11 to the input of IC1c (connected as an inverter), pins 8, 9. If we assume pin 11 is low initially, this will hold the input of IC1c low, forcing the output (pin 10) high. As IC1d is connected as an inverter, its input will be high, holding the output low. The CV1/C1/C2 capacitor will charge via R1. When the voltage across this capacitance rises above the logic low threshold, the input of IC1c will be high and its output will go low. This brings the input of IC1d low, and its output (pin 11) will go high. This will now charge the CV1/C1/C2 capacitor in the reverse direction, via R1. When the voltage across R1 drops to the logic low level, the input of IC1c will again be low and its output (pin 10) will go high. This drives the input of IC1d high, driving its output low, and the whole cycle repeats.

The multivibrator involving IC1a and IC1b is synchronised to the other by having one input (pin 2) of IC1b tied to the output of IC1a. Only when both inputs of IC1b are high can the output of IC1b (pin 3) go low. Thus the outputs of both multivibrators (pins 3 and 11) go low together.

The humidity sensor has a positive temperature coefficient of about 100 parts per million. Accordingly, so that the other multivibrator has a similar characteristic, positive temperature coefficient capacitors with a rating of 100 ppm are used. The characteristic of CV1 has little effect.

The outputs of both multivibrators are combined in a NOR gate to provide positive-going pulses, the width of which will vary depending on the difference in pulse widths between the two multivibrators. As H varies with relative humidity, the pulse width at the output of IC2 will vary in direct relationship. The four gates in IC2 are connected in parallel to provide a low impedance output to drive the 'linearising' circuit. This part of the circuit is shown in Figure 4 here, and for the sake of explanation the meter circuit output is included.

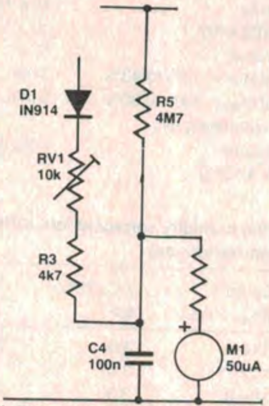


Figure 4. The linearising circuit. The meter is included for the sake of explanation. R4 replaces Link 1.

Pulses from the output of IC2 charge C4 via D1, RV1 and R3. At the same time, a discharge current proportional to the voltage across the capacitor flows via the meter circuit. An additional current is supplied to the meter circuit from the supply line, via R5. The amplitude of the output pulses from IC2 does not vary, but the width does. Thus the charge supplied to C4 will vary in proportion to the pulse width ratio. The output voltage across C4 supplied to the metering or display circuit will thus vary non-linearly. By judicious choice of the values of C4, RV1/R3 and the load (R4, including the meter), the relationship between relative humidity and the current through R4 (and thus the voltage across it) can be made substantially linear. In practice, the scale becomes a little cramped at the top end, but is considerably better than if the voltage across C4 were read off directly.

The LED display circuitry simply employs an LM3914 LED dot/bar-mode IC, operated in the dot mode here. This is partly to conserve battery current (prolonging battery life) and partly because it gives a much more convenient display in this application. It is arranged to read 0 - 1.25 V, according to the bias provided by R7. Only seven LEDs are used rather than the 10 possible, as the low scale one (pin 1) is inaccurate and rarely used, and the output from C4 provides 1 V at a relative humidity of 100% (thus the highest LEDs, pins 11 and 10, are unnecessary). The calibration graph in Figure 3 indicates at which levels each LED turns on and what $H_{rel.}$ each LED corresponds to.

Supply is derived from a 9 Vdc source and the supply rail for IC1 and IC2 is zener regulated to 4.7 V.

PARTS LIST — ETI 256

Resistors	all ½W, 5%
R1, R2	470k
R3	4k7
R4	22k
R5	4M7
R6	390R
R7	1k
RV1	10k miniature trimpot
Capacitors	
C1, C2	47p ceramic (see text)
C3	10u/16 V tantalum
C4	100n greencap
CV1	2-40p film or ceramic trimmer
Semiconductors	
IC1, IC2	4001
IC3	LM3914
LED1-7	TIL220R or any suitable LED
D1	1N914, 1N4148 silicon diode
ZD1	400 mW or 1 W zener, see text
Miscellaneous	
H1	Philips humidity sensor type 2322 691 90001

ETI-256 pc board, pushbutton switch (momentary action); battery clip to suit No. 216 9 V battery.

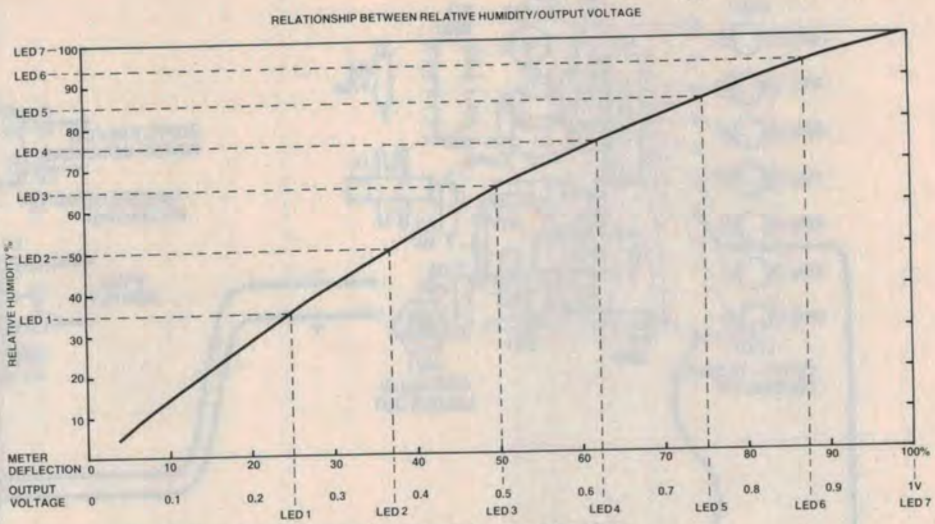


Figure 3. **LED display and humidity readings against meter deflection.**

read at a glance. The indication is somewhat ,non-linear; that is, the interval between each LED is not the same, as the linearising circuit is not perfect. The interval decreases with increasing humidity. Between LED1 and LED2, the change indicated in relative humidity is 15%, from 35% to 50%. At the opposite end of the scale, the change indicated in relative humidity between LED5 and LED6 is less than 10%. The reading indicated by LED6 is only accurate to a few per cent in any case. If you want to read the humidity to within 5% over most of the range between 10% and 90%, we suggest you opt for a meter readout. A calibration graph is given in Figure 3. To employ the project as part of an automatic environment control system, the LED readout circuitry is necessary.

Our prototype operates from a No. 216 9 V battery. To conserve battery life, we used a pushbutton switch to operate the unit, and the reading stabilises very shortly after the circuit is switched on.

Construction

The unit is quite easy to assemble. We've not given any details of housing the completed project as this is likely to vary widely according to individual requirements. Generally, the components may be assembled in any order. Take care with the orientation of the three ICs, the LEDs, C3 and the two diodes, D1 and ZD1. The humidity sensor is not polarised and may be connected any way round. Solder its leads quickly to avoid affecting its performance. The photograph of our unit shows the sensor mounted on the pc board, but we did this principally for convenience. It can be mounted off the board but it is necessary to keep the leads short and ensure they have little capacitance. We would recommend you mount the sensor no more than about 50 or 60 mm away from the pc board and use 22 gauge tinned copper wire spaced the width of the sensor's pins apart (about 5 mm). A twisted pair of hookup wire is not recommended.

If the unit is to be used in a very humid environment (in a hothouse, for example), mount the electronics in a sealed box with the sensor mounted externally, and pass the sensor's pins through a hole in the box, sealing the box with Silastic or a similar sealing compound so that the humid atmosphere does not affect the electronics.

Note that positive temperature coefficient (PTC) capacitors are specified for C1 and C2. *No substitutes can be made* without adversely affecting the operation of the instrument. We have given Philips part numbers but other manufacturers do make PTC ceramic capacitors. It is necessary to ensure you purchase capacitors having a positive temperature coefficient of 100 parts per million (i.e: P100) of the nominal capacitance specified (47 pF).

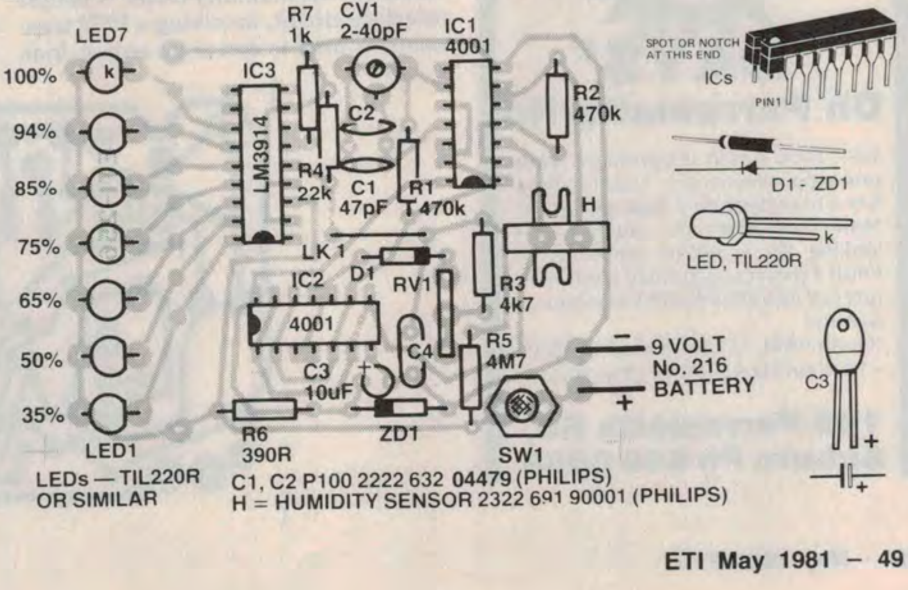
Alignment

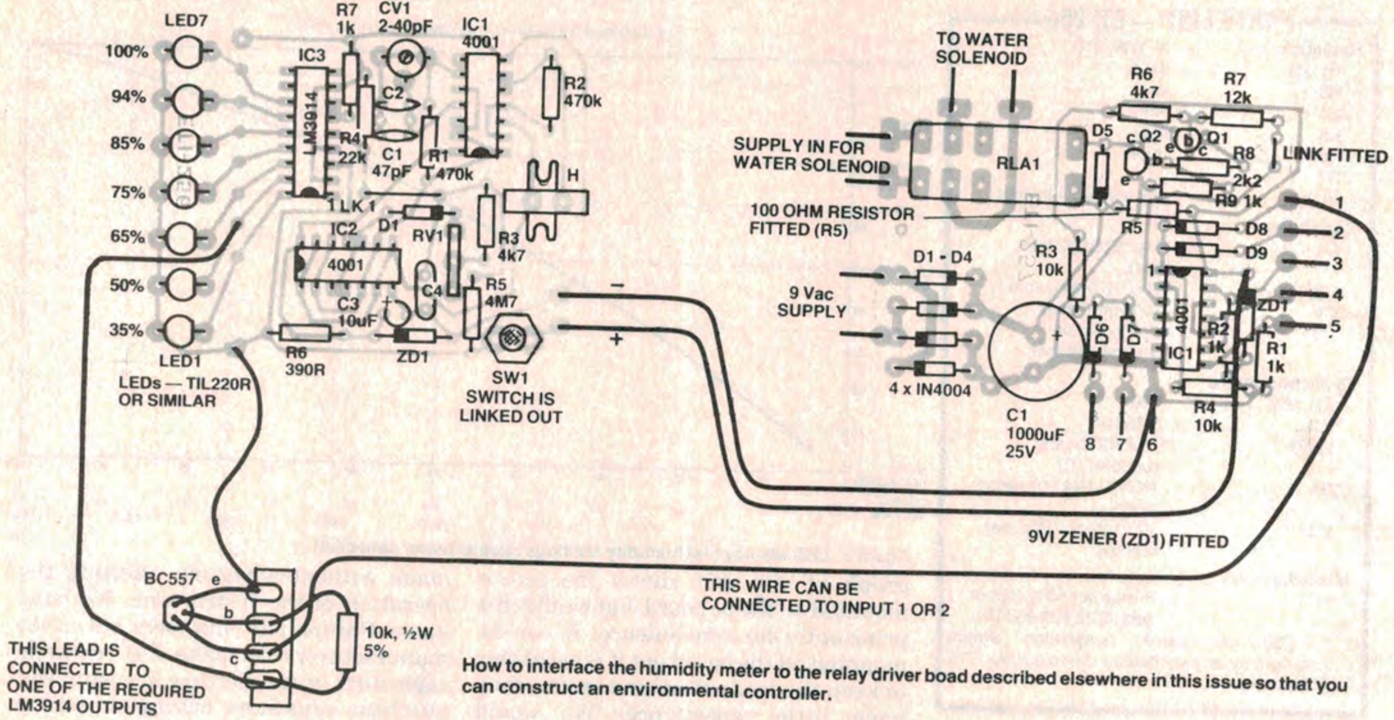
To obtain optimum performance, the following adjustment procedure is recommended:

If you are using the LED display, connect a high impedance voltmeter (input impedance of 1M or greater) between pin 5 of the LM3914 (IC3) and 0 V. Set RV1 at minimum resistance.

1) Replace the humidity sensor by a combination of capacitors to make up a value of 118 pF (a 100 pF, 15 pF and 3p3 in parallel). Turn the unit on and adjust CV1 to produce minimum out-

Component overlay. If you want meter readout, leave out IC3, the LEDs and R7, put R4 in place of Link 1 and connect the meter between the pin 5 pad of IC3 (+) and 0 V.





How to interface the humidity meter to the relay driver boad described elsewhere in this issue so that you can construct an environmental controller.

put. You should be able to get this down to about 0.09 V (90 mV). A slight zero offset reading occurs due to the current supplied by R5. Turn the unit off after adjustment.

2) Replace the 118 pF capacitor network substituted for the sensor by one of 160 pF (150p and 10p in parallel). Turn the unit on again and adjust RV1 to produce a reading of one volt on your voltmeter. LED7 should light.

If you are using a 50 uA meter for readout instead of the LM3914 and LEDs, repeat steps (1) and (2), but this time connect your high impedance voltmeter across C4. In step (2) adjust for full-scale deflection on the meter.

As a controller

The humidity meter can be used as a controller in conjunction with the ETI-257 Universal Relay Driver Board described elsewhere in this issue. It is necessary to use the LED display version of the humidity meter. A simple interface circuit, involving a PNP transistor, is used to derive an output from one of the LEDs on the humidity controller and drive a 'pull high to operate' input on the ETI-257 relay driver board. The accompanying diagram shows how it's done.

The switch on the humidity controller board is not used and the pads on the board are linked. A BC557 is mounted on a tagstrip, along with a 10k, ½W resistor, and this provides the interface between the humidity meter and relay driver boards. The appropriate humidity level is selected by connecting a lead from the cathode of the appropriate LED to the base of the interface transistor, via the 10k resistor.

Power supply for the humidity sensor is obtained from the relay driver board. Don't forget to install Link 1 on the latter board.

In this application the sensor should be placed so that it takes a reading unaffected by the source of water vapour.●