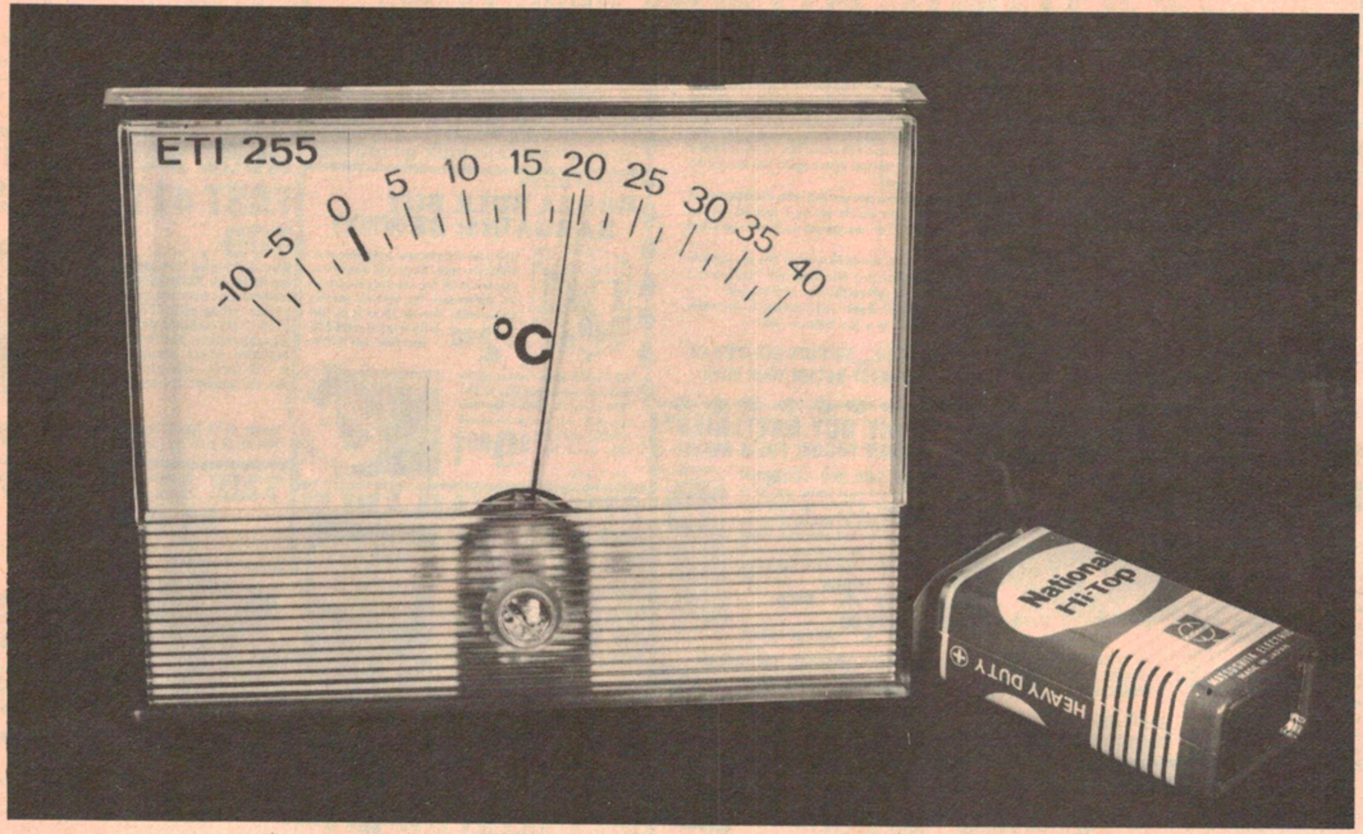


Electronic temperature meter is easy to read and easy to build

Jonathan Scott

This handy little thermometer can be used for local or remote indication of temperatures.

THIS TEMPERATURE meter project can stand alone or you can mount it in a desk top or even in the dash of your car if you don't mind cutting a hole for it. (If you've built all the ETI projects for motorists your dash must look like a piece of swiss cheese by now, so one more hole won't matter!)

Why an electronic thermometer, you may ask ? What's wrong with the ordinary mercury-in-glass type that's been with us for hundreds of years? It's hard to read, that's what. You have to go right up close to see the scale. And mercury thermometers are fragile, too.

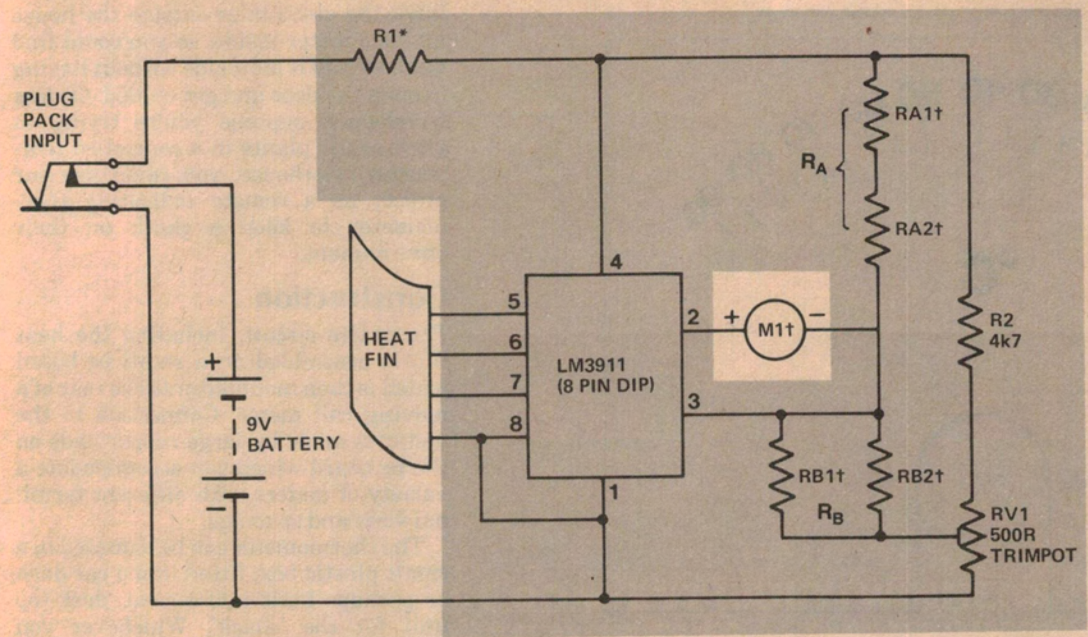
If you want to be able to read off temperature on a nice clear dial you need some kind of electric or electronic sensing element. There are several kinds of sensors you might use, including thermocouples, thermistors and diodes, all of which have their own advantages and drawbacks.

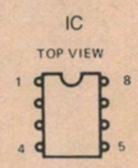
We chose to use a temperature sensing IC, the LM3911, recently introduced by National Semiconductor. There's a more detailed description of it on page 40, but basically it relies on the well-known fact that a transistor's base-emitter voltage varies with temperature — the warmer the transistor gets the greater the b-e voltage.

Because the LM3911 chip includes its own amplifer, it's very easy to use it to drive a meter. Apart from the IC and the meter, the only components in this project are five resistors and a trimpot. By choosing different values of resistors, you can build this temperature meter so that it indicates any temperature range you choose as long as it's between −25°C and +85°C.

We've specified resistor values to make the meter read from −10°C to +40°C, which should be fine for most locations, but in case you live somewhere like Birdsville we've also given values for a temperature range of −10°C to +90°C. But you don't have to stick to the ranges we suggest. Opposite you'll find formulae for calculating the necessary resistance values for any temperature range.

One more useful feature of this project ▶





*R1 = 470R (¼W or ½W) for 9 V operation; 1k8 for 12 V battery (11 - 15 V) operation.
†See table below for resistor values to suit different meter ratings.

HOW IT WORKS — ETI 255

Almost all the functions take place inside the LM3911 chip. Pins 5 - 8 are thermally connected to an internal temperature sensor circuit and transmit the external temperature from a small sheet of copper. The copper fin will generally be at air temperature.

An internal voltage reference, connected between pins 1 and 4, regulates the supply rail to 6.8 volts for the chip and external circuitry. The dropping resistor R1 sets the current to about 3.5 mA, maintaining about 1.2 mA to the IC and about 2.5 mA to the external circuit. It is desirable to keep the current into the IC as low as possible to prevent excessive temperature rise in the chip giving rise to inaccurate readings.

An internal op-amp sinks current from pin 2 in order to hold the voltage on pin 3 at a level which is linearly proportional to the temperature on the sensing pins. The meter, M1, monitors the current into pin 2 giving a reading which is directly proportional to temperature. The resistors R_A and R_B are calculated to give the required zero reading and full-scale temperatures. We have included a table with suitable values as well as formulae so you can roll your own.

The meter reading is linear with temperature and is calibrated to cover the desired range.

The trimpot RV1, compensates for variations between different ICs as well as compensating for temperature rise within the chip.

SUGGESTED VALUES

Range (°C)	Meter F.S.D.	R_{A1}	R_{A2}	R_{B1}	R_{B2}
0 to +100 (note: 85 max.)	100 μA	10k	6k8	27k	270k
0 to +50	50 μA	10k	6k8	27k	270k
−10 to +90	100 μA	8k2	8k2	27k	480k
−10 to +40	50 μA	8k2	8k2	27k	480k
−10 to +40	100 μA	8k2	zero	82k	15k

NOTE: maximum rated temperature is 85°C; minimum is −25°C.

Other temperature ranges can be covered, within the specified limitations of the LM3911, the required range resistor values being calculated from these formulae:

$$R1 = \frac{V_s - 6.9}{0.0035} \quad \ldots\ldots (1)$$

V_s = supply voltage

$$R_A = R_{A1} + R_{A2} \quad \ldots\ldots (2)$$

$$R_B = \frac{1}{1/R_{B1} + 1/R_{B2}} \quad \ldots\ldots (3)$$

$$\text{Let } T_1 = T_0 + 5 \quad \ldots\ldots (4)$$

using equation (4), calculate 'M'

$$M = \frac{T_1}{685} \quad \ldots\ldots (5)$$

where T_0 = zero scale reading in °K
and T (°C) = T(°K) − 273 ...... (6)

$$\text{then } R_B = \frac{10^4}{M.s} \quad \ldots (7)$$

$$\text{and } R_A = \frac{10^4}{s(1-M)} \quad \ldots (8)$$

where s = meter sensitivity in μA/°C
(For example; if you choose a 100 μA meter and wish to cover a range of 50°C, then s = 2 μA/°C)

is that the meter doesn't need to be closely connected to the IC and the rest of the circuitry. You could, for example, have the electronics outside the house and the meter inside, so you could find out how cold it is outside without having to open the door and get chilled. Or less frivolously, suppose you're trying to grow exotic plants in a controlled temperature hothouse, you could use our project as a remote indicating thermometer to keep a check on their environment.

Construction

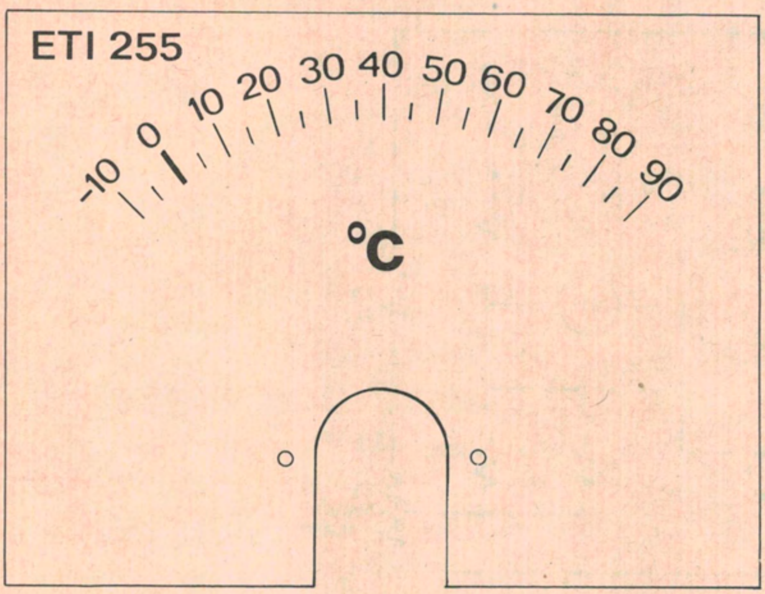
The entire circuit, including the heat fin, is assembled on a small pc board which is then mounted onto the rear of a moving coil meter. Connection to the meter is made by large copper pads on the pc board which can accommodate a variety of meters with different terminal sizes and spacings.

The thermometer can be mounted in a small plastic box, fitted into a car dash or perhaps built into a neat, desk-top unit for the 'shack'. Whichever you choose, be sure to leave a large enough hole in the box to allow free air flow across the heat fin so the meter reads the room air temperature and not that inside the box. If a remote reading unit is required the pc board can be mounted away from the meter.

The first job is to drill the holes into the pc board to suit the type of meter you have. Next fit all the components as shown in the overlay, taking care with the orientation of the IC and the polarity of the battery or power supply connections. The value of R1 is different depending on whether the unit is operated from a 9 V supply (battery or plugpack) or a 12 V supply (vehicle battery or plugpack). Values are beneath the circuit. The values of R_A and R_B are selected from the table for the required temperature range and meter used. Note that R_A consists of two resistors in series (R_{A1} and R_{A2}), while R_B consists of two resistors in parallel (R_{B1} and R_{B2}). Either 2% tolerance or selected 5% tolerance metal film resistors should be used for the sake of accuracy.

Power from a plugpack is applied through a shorting type socket so the unit can be battery operated when the plugpack lead is removed.

The 50 mm by 20 mm heat fin is cut from a small piece of 0.25 mm thick copper shim. Solder it to the pc board track connected to pins 5 - 8 of the IC (see overlay photo). A larger size fin may be used, but we found this one works nicely. In fact, the circuit will work well without any heat fin, but has a longer response time. Make sure the



Full size artwork for meter scale covering −10°C to +90°C. Note that the limit for the LM3911 is +85°C.

THE LM3911 — HOW IT WORKS

The LM3911 is a highly accurate temperature measurement IC for use over a —25°C to +85°C temperature range. Fabricated on a single chip it includes a temperature sensor (pins 5 — 8), stable voltage reference (pins 1 and 4) and an operational amplifier.

The output voltage on pin 2 is directly proportional to temperature in degrees Kelvin having a sensitivity of 10mV/°K. By using the appropriate external resistors with the internal op-amp, any temperature range can be selected.

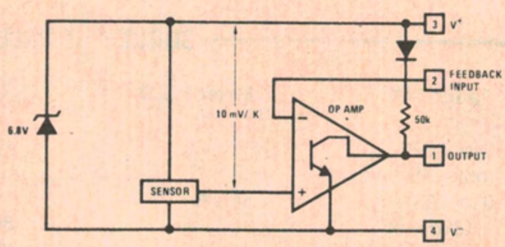
An active shunt regulator across the supply pins provides a stable 6.8 volt reference for the sensing circuitry, and allows the use of any supply voltage with the correct dropping resistor.

The input bias current is low and relatively constant with temperature to ensure high accuracy when a high source impedance is used. The output pin can be returned to a supply up to 35 volts to allow the circuit to drive lamps or relays.

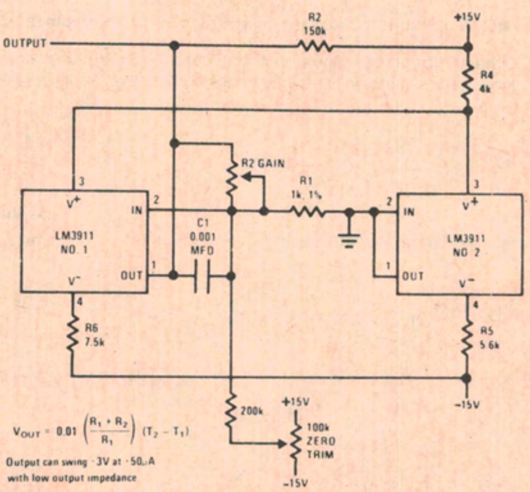
The temperature sensing element uses the difference in base-emitter voltages of two transistors operating at different current densities. Since this output depends only on transistor matching, very good stability and reliability can be obtained.

The op-amp can either be connected as an amplifier to give a linear temperature/voltage output or as a comparator to switch the output at a preset temperature. Therefore, the device can be used either as a measuring instrument or as a temperature controller.

The output can be calibrated for degrees Celsius, Fahrenheit or Kelvin.

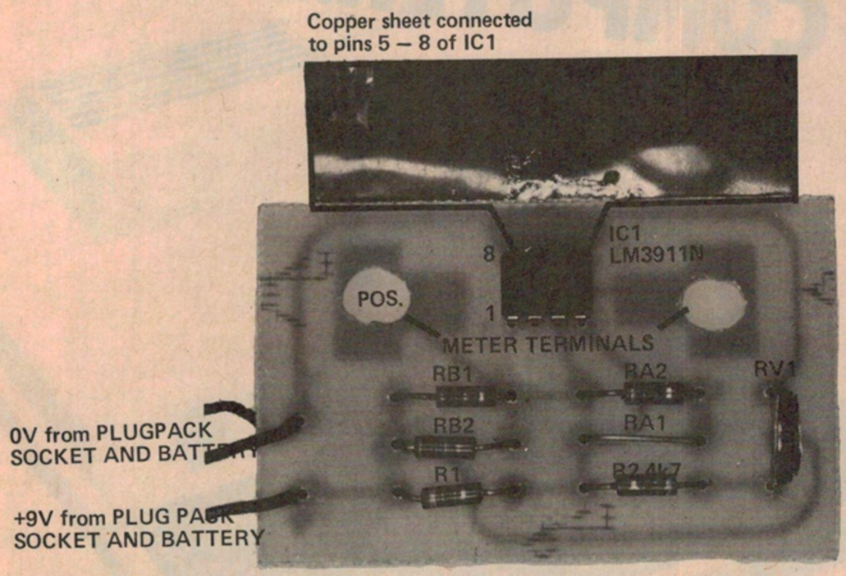


Internal block diagram of the LM3911.



*The 0.01 in the above equation is in units of V/°K or V/°C and is a result of the basic 0.01 V/°K sensitivity of the transducer

Two LM3911s can be configured as a differential thermometer.



Rear view of the instrument showing general assembly. You may prefer to use a rechargeable NiCad type, rather than the dry battery shown, for battery operation of the unit.

fin is not touching any other part of the circuit.

Finally, fit the meter after cleaning the meter pads on the pc board. The spring washer supplied with the meter should be assembled on the copper side of the board so it digs into the surface of the copper for good contact. If this is not done the meter connections may become a high resistance when the copper tarnishes after use.

PARTS LIST — ETI 255

IC1	LM3911N
R1	470R or 1k8
RA1	See table
RB1	"
RA2	"
RB2	"
R2	4k7

All resistors should be 2% or selected 5%, ¼W or ½W metal film types.

RV1	500R miniature vertical mounting trimpot
M1	50 or 100 microamp meter (to suit range). University TD 106 or similar.

ETI-255 pc board; case (if required); plug pack adaptor socket and 9V Plug Pack (Ferguson PPA-9/500 or similar); 9V battery (No. 216) and battery clip if required; small piece of 0.25 mm shim copper.

Apply power and adjust the zero set trimpot which should be capable of adjusting the reading about +/−10°C.

Calibration

Place the unit and a reference thermometer (choose a good one) in a cool place close together and after a few minutes note the difference in readings. Adjust the trim pot for the correct reading.

Two different meter face scales have been included for two temperature ranges, —10°C to 40°C and −10°C to 90°C. Values have also been calculated for 0°C to 50°C and 0°C to 100°C scales to allow standard scales on 50 μA and 100 μA meters to be used. ●

Full size artwork for meter scale covering −10°C to +40°C. Scotchcal meter scales will be available from suppliers — see Shoparound on page 83.