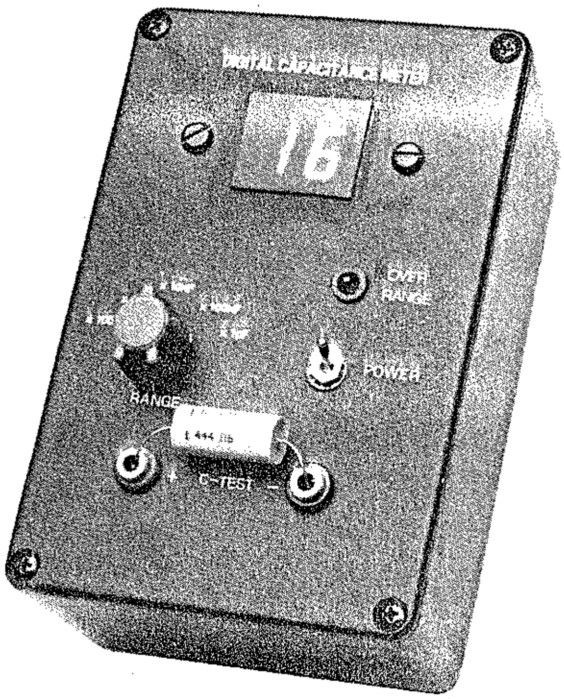
DIGITAL CAPACITANCE METER

Have you just invested in a large bag of capacitors with incomprehensible, little or no markings? Then read on. The instrument described here has five capacitance ranges covering a total range of 100 pF to 100µF, can be powered from a single 9-V battery, and has a built-in over-range indicator to prevent ambiguous readings. So, build this capacitance meter before even opening your bag…



E. Barrow

UNMARKED capacitors can be bought very cheaply, but they often remain unused for years because one is not certain of their value. A low-cost capacitance meter to check out the values quickly and with acceptable accuracy is described here. The instrument is simple to build and based on commonly available components.

A bit of theory

If mathematics gives you a migraine you might like to skip this section and jump to the bottom line.

Consider a capacitor C charging through a resistor R from a supply voltage U_s as shown in Fig. 1.

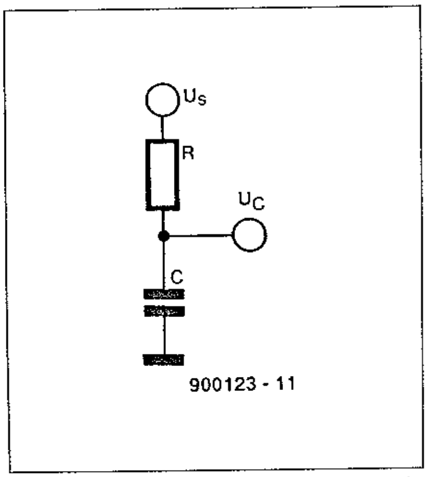


Fig. 1. Basic capacitor charging circuit. Both U_s and U_c are measured w.r.t. ground.

The voltage on the capacitor, U_c, may be written as

$$U_c = U_s(1 - e^{-t/RC})$$

where e is the base of natural logarithms, or 2.718282. Rearranging,

$$1 - \frac{U_c}{U_s} = e^{-t/RC}$$

rearranging and taking natural logarithms

$$R \ln\left(\frac{U_s}{U_s - U_c}\right) = \frac{t}{C}$$

If we make R, U_s and U_c constants, then the left-hand side of the equation becomes a constant term. So,

$$\frac{t}{C} = \text{constant} \qquad \text{or} \qquad C = k\,t$$

In other words, by measuring the time taken for an unknown capacitor to be charged to a certain voltage by a fixed potential (see Fig. 2), we can calculate its capacitance if we know the value of k. An even better way is to set the value of k to some round number by altering R. This allows us to measure the charge time and take this value directly as capacitance.

To cover wider values, range switching is done by changing the charging resistor and so k, by a factor of 10. To keep the resistance within manageable levels, i.e., between 1 kΩ and 1 MΩ, we also switch the clock frequency used to measure the charge time to ⅒th of its value. Thus we get a total range of 5 decades.

The main problem comes when we measure electrolytic and tantalum bead capacitors. These tend to have relatively large leakage currents as their dielectrics are not good insulators like, for instance, polystyrene. So, as the idea postulated by Fig. 1 no longer holds true, it has to be redrawn as in Fig. 3.

To eliminate the error that would arise from the presence of the parallel resistor, the charging resistor can be made smaller to increase the charging current. This minimizes the effect of the leakage resistance R_L.

The standard by which the charge time is measured is a fixed clock. This clock is also

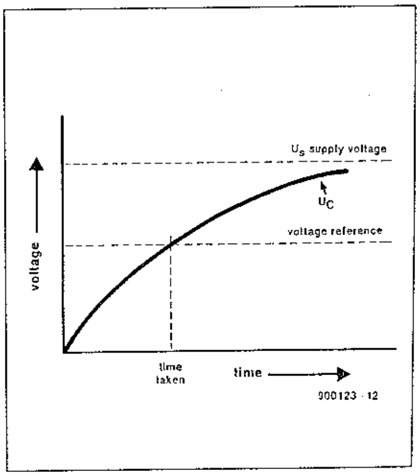


Fig. 2. The charge voltage of a capacitor is essentially a logaritmic (e-) curve.

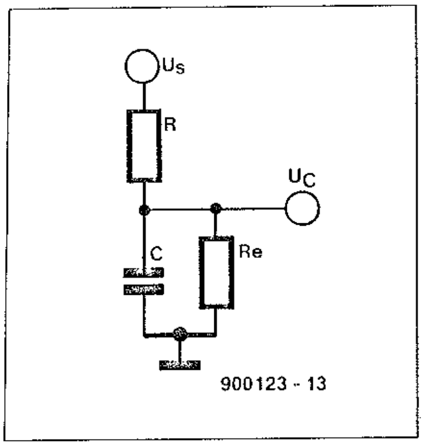


Fig 3. **Accounting for leakage resistance of electrolytic and tantalum capacitors**

divided by 100 to give a second reference as mentioned above. After being selected, one of the reference clocks feeds another two counters. The first one is used along with a D-type bistable configured to divide by 2 to generate all the timing signals, i.e. to reset the counters and the display, and charge and discharge the capacitor. The second counter feeds the display drivers. The whole operation is shown in the block diagram in Fig. 4.

How it works

The practical circuit of the digital capacitance meter is shown in Fig. 6. A timer Type 555 in astable mode generates the fixed clock, which has a frequency of about 20 kHz. This is also divided by a 4518 dual decade counter, IC$_2$, to give a second clock of 200 Hz. One of these frequencies is selected by S$_{1A}$, and divided by 100 (IC$_3$) and subsequently by 2 (IC$_{4A}$). The complementary outputs Q and $\overline{Q}$ are used for all timing operations.

To understand the operation of the circuit, let us assume that it has been running a while, and output Q is about to go high for the next 100 clock pulses. On this positive edge, a positive pulse is sent to the display counter, IC$_7$, resetting it to the zero state. The bilateral switch, IC$_{5C}$ is now closed, charging the test capacitor through the charging resistor selected by S$_{1B}$. A simple voltage reference for the task has been built around zener diode D$_1$.

If the capacitor has a value within the selected range, it will be charged to half the reference voltage within 100 clock pulses. When it reaches this voltage, the output of comparator IC$_6$ goes high, sending a pulse to the latches of the display drivers. This pulse latches the current value of counter IC$_7$, which now appears on the display.

As we have chosen the value of the charging resistors, the value on the display is also equal to the capacitance. After the 100 clock pulses have elapsed, output Q goes low and $\overline{Q}$ goes high. This opens the charging bilateral switch, IC$_{5C}$, and closes the discharging one, IC$_{5B}$. So, for the next 100 clock pulses the capacitor is discharged. A clock timing diagram of the operation is shown in Fig. 5.

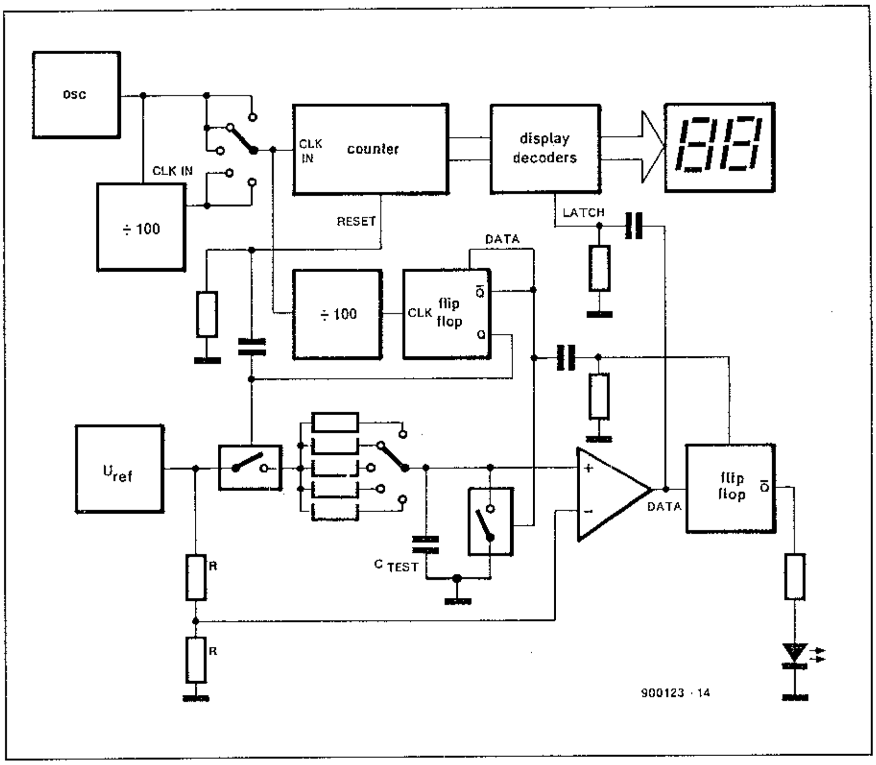


Fig. 4 **Block diagram of the capacitance meter.**

Although the capacitor under test will never totally discharge, the amount of charge left in the worst possible case is unlikely to affect the accuracy, as it will be less than 1% of the total, and the system is only accurate to 1 count.

When the discharging cycle is started, the output of the comparator is sampled by bistable IC$_{4B}$. If the output is low, the capacitor is outside the selected range, and the 'over-range' LED lights. If the comparator output is high, the capacitor is within the selected range, and the LED is turned off.

Both IC$_8$ and IC$_9$ are BCD-to-7 segments decoders, set to drive common-cathode LED displays. Note that capacitors C$_9$ and C$_{10}$ are essential to prevent the glitches produced by

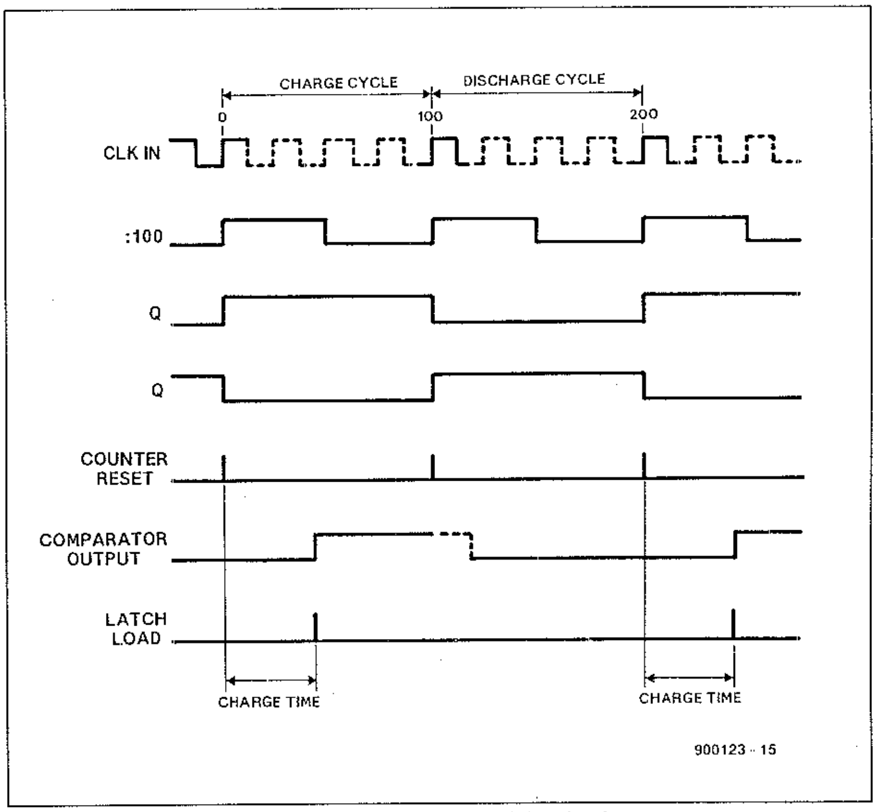


Fig 5 **Timing diagram to illustrate the operation of the circuit**

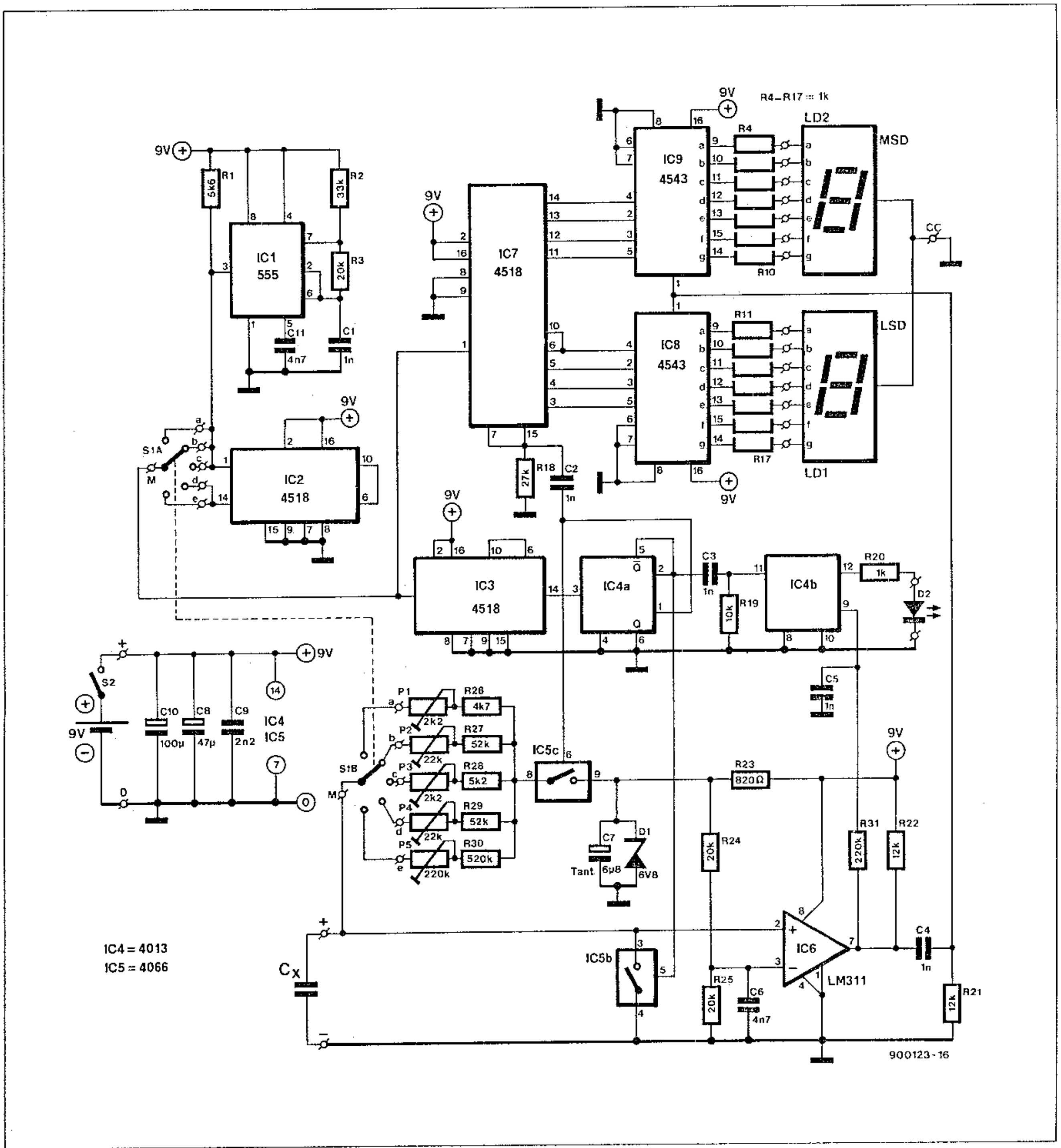


Fig 6. Circuit diagram of the digital capacitance meter. Although two LED displays are shown, a dual type may also be used.

the digital clocks upsetting the timing of the circuit

Construction

The author's design for a printed-circuit board is shown in Fig 7. Firstly, solder the link wires, resistors and the zener diode (remember to get the polarity right). In the prototype, all resistors used were 5% types. Because of the compact nature of this project, use a pencil nose soldering bit and a lot of care (watch out for bridging tracks). Next, fit the capacitors, IC sockets and the presets (vertically mounted types are used here). It is recommended to use polyester capacitors especially for timing purposes (e.g., C1) as these are stable. The presets are a tight fit and the solder pads are small, so that their legs may need a little filing to fit the holes. Next comes the 2-pole rotary range selecting switch, which is fitted on the front panel of the enclosure. Ribbon cable is suggested to connect the display to the main board. In the prototype, a small off-cut of veroboard was used to mount the display, and a small non-reflective bezel to improve the readability. The display can be almost any dual common-cathode LED type. Four bolts are used to hold the board in place, and a clip or a piece of two-sided adhesive tape to stop the battery from rattling around in the case. Two 4-mm sockets, one red (for +) and one black (for 0 volts), are fitted on the cover plate to connect the unknown capacitor.

Note that if IC sockets are used, C2 and C3 become tight fits, so use disc ceramic types here.

Testing

The completed printed-circuit board may be tested after it has been connected to the battery and the external controls. To test the instrument, a voltmeter is required and, if you

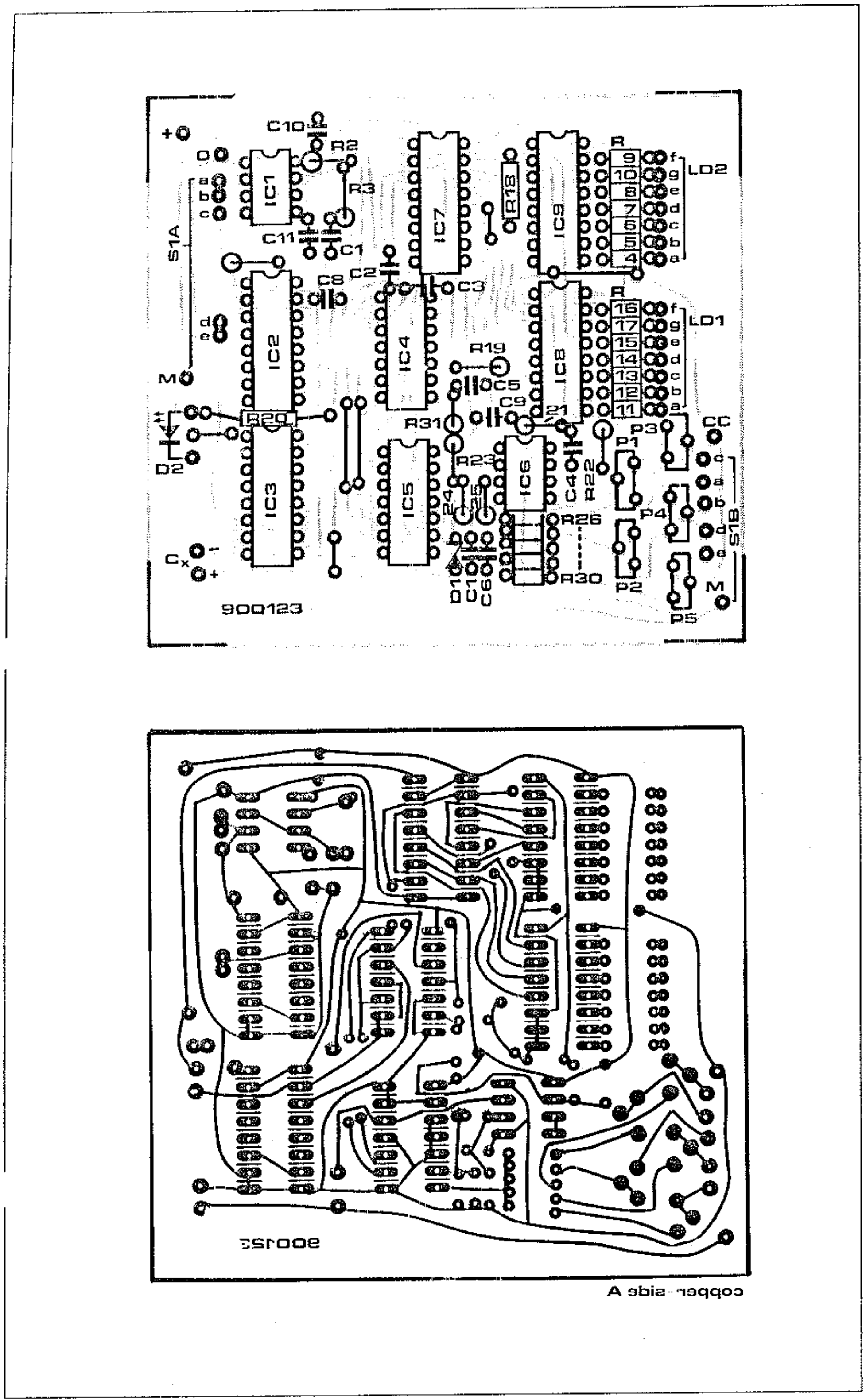


Fig. 7. Author's design of a printed-circuit board for the capacitance meter.

have one, an oscilloscope.

First check that pin 3 of IC$_1$ is supplying a 20-kHz signal. This check is best made with an oscilloscope, although it is possible, if you have bat-like hearing, to try use a pair of headphones and a series resistor. Also check pin 14 of IC$_2$, which should supply a 200-Hz signal.

Set the range switch to the highest range (100 µF) when pin 14 on IC$_3$ should be toggling at about 2 Hz. Finally, check pins 1 and 2 of IC$_4$, which should be toggling at 1 Hz, out of phase with each other.

To check the charging and discharging mechanism you need a voltmeter. Check that there is a stable 6.8 V across the zener diode. Connect a 68-µF capacitor to the unit. The voltage across it should rise and fall regularly. Similarly, the output of the comparator, pin 7 of IC$_6$, should also be pulsing regularly. If the capacitor is changed by one whose value falls outside the range, the comparator's output should remain low, and the LED turn on.

Setting up

This requires a bit of common sense as each range needs calibration separately. Needless to say that access to a set of reference capacitors or another capacitance meter would make life easy.

COMPONENTS LIST

Resistors:

1	5kΩ6	R1
1	33kΩ	R2
3	20kΩ	R3;R24;R25
14	1kΩ	R4 – R17
1	27kΩ	R18
1	10kΩ	R19
1	1kΩ	R20
2	12kΩ	R21;R22
1	820Ω	R23
1	4kΩ7	R26
1	52kΩ	R27
1	7kΩ5	R28
1	82kΩ	R29
1	820kΩ	R30
1	220kΩ	R31
2	2kΩ2 preset V	P1;P3
2	22kΩ preset V	P2;P4
1	220kΩ preset V	P5

Capacitors:

5	1nF	C1 – C5
2	4nF7	C6;C11
1	6µF8 tantalum	C7
1	47µF	C8
1	2nF2	C9
1	100µF	C10

Semiconductors:

1	NE555	IC1
3	4518	IC2;IC3;IC7
1	4013	IC4
1	4066	IC5
1	LM311	IC6
2	4543	IC8;IC9
1	6V8 0.4W zener diode	D1
1	LED 5-mm dia	D2
1	dual CC LED display	LD1;LD2

Miscellaneous:

1	2-pole 5-way rotary switch	S1
1	miniature on/off switch	S2
1	PP3 battery connector	

For the low ranges, setting up is fairly easy as 1% and 2.5% polystyrene capacitors are widely available. Note that the tolerance of your reference capacitor determines the overall accuracy of the final setting. A good choice is 6.8 nF (1% or 5%) for the first range.

Connect the capacitor and adjust P$_1$ until the display reads the expected value, in this case 68. If you have a few different capacitors lying around, use an average to adjust the preset. Follow the same procedure for the other ranges, so for the second range try a 68 nF capacitor, and a 680 nF one for the third range.

The top two ranges are a little difficult to calibrate as the type of reference capacitor is practically limited to an electrolytic or a tantalum one. Unfortunately, both these types have a tolerance of typically 20%. Here, it is best to use a mix of available capacitors and average out the readings to get a consensus. Obviously, all polarized capacitors must be connected the right way around. ■