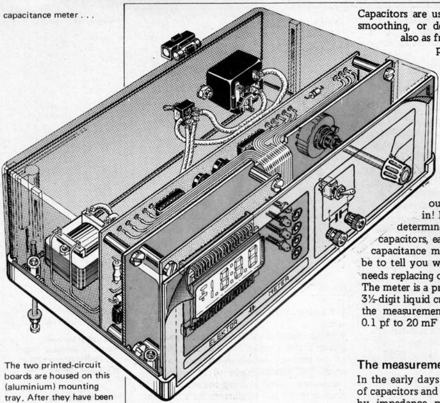


The two printed-circuit boards are housed on this (aluminium) mounting tray. After they have been interconnected, the metering board is connected to the front panel. The resulting entity can then conveniently be slid into the grooves provided in the case.

Capacitors are used mainly as blocking, smoothing, or decoupling elements, and also as frequency determining components in HF and AF engineering. If capacitors are to be used in filters, they should be as close as possible to the calculated value. That normally means the use of high stability capacitors, but the precise value can of course, be determined by some sort of measuring instrument, and this is where our capacitance meter comes in! It will enable you to determine the exact value of the capacitors, easily and conveniently. The capacitance meter will, of course, also be to tell you whether a suspect capacitor needs replacing or not.
The meter is a precision instrument with a 3½-digit liquid crystal display which enables the measurement of capacitances from 0.1 pf to 20 mF in six ranges.

### The measurement of capacitance

In the early days of electronics, the values of capacitors and inductors were determined by impedance measurement in bridge circuits. Such measuring bridges contained, apart from an oscillator, power supply, and sensitive meter amplifier, also very precise and therefore very expensive reference capacitors or inductors. Furthermore, operating these bridges correctly was not a simple matter. None the less, there can be no doubt about the superiority of them. For instance, they make possible the quick determination of factors other than the value, such as the Q factor and inherent losses, which are equally important for the calculation of the impedance of a circuit. However, these factors are not normally of great importance to us.

# capacitance meter...

## . . . to find those elusive farads!

- Measuring ranges: 200 pF; 20 nF; 2 μF; 200 μF; 2000 μF; 20 mF (all f.s.d).
- Accuracy: 1 per cent (if calibrated with a 1% reference capacitor — otherwise larger); 10 . . . 15 per cent in the 20 mF range.
- Read-out on 3½-digit liquid crystal display (LCD).
- Capacitor leakage current does not affect reading.
- Measurement of capacitances below 1 pF.
- Measurement of capacitance of varicaps.
- Measuring time not greater than 1 s.
- Measurement at nominal frequency according to manufacturers' specification (except in the 20 mF range).
- Can be used with test leads (except in the 200 pF range).

Simple and easy-to-operate capacitance meters usually require the unknown capacitor, $C_x$, to be inserted into an oscillator circuit. The frequency of the resulting signal is measured with a frequency counter or a voltmeter (after conversion to a proportional voltage). An appropriately calibrated scale on these instruments makes it possible to read off the value of the capacitor directly (see, for instance, Elektor, December 1981: 'capacitance meter module' page 12-18).
A different method of measurement is illustrated in figure 1. The point of this method is that the unknown capacitance, $C_x$, after differentiation of the input signal (by $C_x/R_s$), is determined by a voltage measurement. By making the value of $R_s$ much smaller than the impedance $X_C$,

the value of $C_x$ can be calculated from

$$C_x = U_1/2\pi f_o R_s U$$

in which $\pi$, $f_o$, $R_s$, and U are known constants, so that only the value of the measured voltage, $U_1$, needs to be inserted.
You don't, of course, want to be bothered with pen, paper, and pocket calculator every time you measure a capacitor, but want to read off its value directly. The diagram of figure 1 is therefore extended into that of figure 2.
The triangular output of the generator is passed to $C_x$ which has been connected in a differentiating circuit. The output of this circuit is a square wave of which the amplitude is proportional to the value of $C_x$ (like $U_1$ in figure 1). The square wave is rectified in a phase-selective synchronous rectifier: the level of the resulting voltage is measured by a digital voltmeter.
The phase-selective rectifier operates as follows. The square-wave output of the differentiator is applied to electronic switch ES5 in phase with the rectangular output of the generator, and to electronic switch ES6 in antiphase with the rectangular output of the generator. The switches are synchronized with the triangular waveform and only pass the positive portions of the square waves. The two resulting square waves are added to provide a d.c. voltage.
The relationship between the waveforms is illustrated in figure 3. The 'rooftops' on the rectangular waveshapes are caused by the leakage current through $C_x$. This current, which is caused by the triangular output of the generator, does not affect the measurement. Firstly, it largely disappears in the build-up of the average level (figure 3B), and, secondly, it is not accepted by the phase-selective rectifier because it is 90° out of phase with the triangular current. In an ideal circuit, the triangular signal superimposed onto the d.c. voltage (figure 3C) does not rise at all.

## The circuit diagram

The waveform generator is built up from two opamps: a Schmitt trigger (IC1) and an integrator (IC2). When the output of the integrator reaches the upper trigger level of the Schmitt trigger, the input to the integrator is inverted. The output level of IC2 then decays until the lower trigger level of the Schmitt trigger is reached. In this way, IC1 produces a rectangular signal and IC2 a triangular one.
The output voltage of IC2 is the test signal for $C_x$ and is connected to the inverting input of the differentiator IC3. The output of the differentiator is therefore a rectangular voltage, the level of which is proportional to the value of $C_x$.
The phase-selective rectifier consists of electronic switches ES5 and ES6 which obtain their signals direct from IC3 and inverted from IC4. The control signal for the switches is taken from IC1 and fed direct to ES5 and inverted (by ES4) to ES6. The output signals of ES5 and ES6 are added and taken to the digital voltmeter via R20 (see figure 5).

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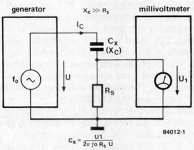


Figure 1. Illustration of how a voltage measurement may be used to determine the value of a capacitance. For instance, if U = 3 V, $f_o$ = 1 kHz, $R_s$ = 100 Ω, and $U_1$ (measured) = 3 mV, $C_x$ = 1.6 nF.

2

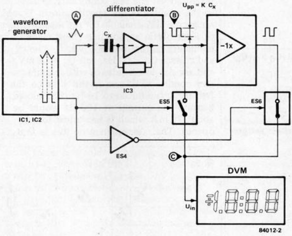


Figure 2. This set-up functions in a similar way to that in figure 1, but a phase-selective rectifier and digital voltmeter have been added.

3

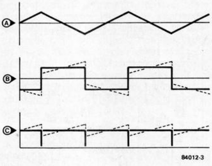


Figure 3. The triangular voltage A is generated by a waveform generator. After this has been differentiated by $C_x$, a rectangular voltage B results which may have a superimposed component (dashed lines) caused by leakage currents. The rectified voltage C is almost free of this leakage-induced component which is largely removed by the rectifier circuits.

The low-pass filter formed by P1, R6, and C2 derives a small triangular signal from the square-wave output of IC1, which is applied to the input of IC3 via C3. As the test signal is in antiphase with this voltage, the unavoidable parasitic capacitance at the test terminals is simply 'spirited away'. In practice this means: adjust P1 with open test terminals so that the DVM reads '0'.
If the wrong measuring range has been selected, IC5 switches on electronic switch ES7 at a certain input level. When that happens, a large d.c. voltage is applied to

the DVM via R21 and the meter shows an overflow.
When the value of $C_x$ is too high for the selected measuring range, IC3 no longer functions as differentiator but rather as comparator for the triangular signal at its input. The result is that a rectangular signal appears at the output of IC3 which is 90° out of phase with respect to the signal which would have appeared under correct conditions. The rectifier will then not have an output, and the DVM reads '0'.
Some more points about the measuring ranges and the test signals. Switch S1 is the range selector. For capacitors between 0 and 2 μF, the amplitude of the triangular signal is about 1.8 $V_{pp}$ at a frequency of around 1000 Hz. Switches ES1 and ES2 are then closed. This enables the measurement of all non-electrolytic capacitors in three ranges: the test conditions conform to the manufacturers' specifications. Three ranges are also available for the measurement of electrolytic capacitors. These measurements are carried out at lower frequency and voltage (f = 100 Hz, and $U_1$ = 18 $mV_{pp}$) and are also in accordance with manufacturers' conditions of test. In the 'f' range, the frequency is reduced to 10 Hz (ES3 closed), because the current at 100 Hz would be about 72 mA which is too much for the opamp. The consequence of this is that the accuracy in this range is only 10 . . . 15 per cent. Fortunately, this is not so bad, because the exact value of electrolytics in this range is normally not very important. If it is required to measure an electrolytic capacitor in range 'c', switch S2 raises the test signal by about 1.5 V to ensure that the test voltage in this range is always positive. In the other ranges, the very small negative voltage of about 9 $mV_{pp}$ causes no harm.
The circuit of figure 5 is basically that of the 'LCD panel meter' featured in the October 1981 issue of Elektor. However, in the present circuit the decimal point is switched by S1b and associated diode matrix. Moreover, the selected range is indicated by LEDs D3 . . . D7.

$$f_{a\ldots c} = \frac{R_2}{4R_1C_6(P_2+R_8)}$$

$$f_{d,e} = \frac{R_3}{4R_1R_7C_6}$$

$$f_f = \frac{R_3}{4R_1R_7(C_4+C_5+C_6)}$$

## Construction

First of all, mount (but do not solder) all resistors up to and including R11 and all capacitors up to and including C9 onto the metering board shown in figure 6. It's best to use soldering pins for this to simplify the soldering after calibration.
Next, fit all components (except R1 and R7) to the display board shown in figure 7. The display and LEDs must be located on the track side: solder the LEDs so that they are well separated from the display. For

4

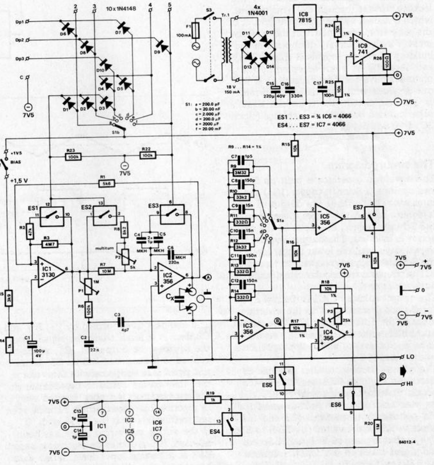


Figure 4. In this circuit of the meter board the waveform generator consists of IC1 and IC2, the differentiator of $C_x$ and IC3, and the phase-selective rectifier of ES4, ES5, ES6, and IC4. Switches S1 and ES1 . . . ES3 provide range selection. Switch S2 provides an off-set voltage at the $C_x$ (test) terminals. IC5 and ES7 together form an 'overflow' detector.

5



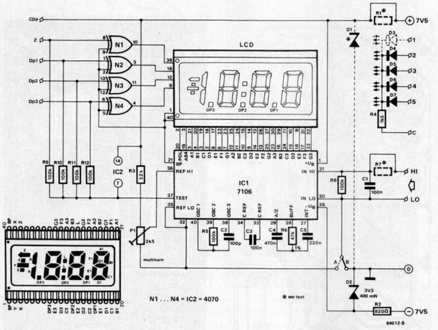

Figure 5. The digital voltmeter in the familiar configuration with IC1 and an LCD. This circuit can be used independently as an LCD panel meter.

the time being, substitute wire bridges for R1 and R7. Do not yet solder diodes D1 and D3. Lastly, fit wire bridge B.

The mechanical construction is best carried out with an eye on the sketch in figure 8. We have used a Vero case into which the aluminium mounting tray can simply be inserted after the calibration. Both printed-circuit boards are mounted onto this tray: the display board at the front and the meter board at the rear. This method also ensures the screening of these circuits from one another.

Terminals with identical markings on the two boards should be interconnected with short lengths of wire, but keep terminals '1', 'CDp', and 'Z' on the display board free. The terminals for connecting $C_x$ should be connected to the meter board by twin screened cable. The screen should be soldered ONLY to the common earth terminal (⊥) near the $C_x$ pins.

Finally, the time has come to connect S2 to the meter board and the earth terminals on the front panel and mounting tray to earth. Then mount the mains transformer, mains on/off switch, and the fuse carrier and fuse in the case. Keep the transformer as far away as possible from the meter board. After sticking the transfer onto the front panel, this and the mounting tray may be inserted into the grooves provided on the case.

## Calibration

First, set the range selector, S1, to position 'f' and adjust preset P3 for zero reading of the display. Next, set S1 to 'a' and adjust preset P1 on the meter board for zero reading of the display.

Switch off the mains supply to the capacitance meter and solder a high stability (1%) resistor of 330 kΩ in the R12 position and a capacitor of 150 pF in the C10 position (both on the meter board). Then connect a 1.5 µF (not electrolytic!) capacitor to the $C_x$ terminals. Set S1 to 'd', switch on the mains supply, and note the indicated value. Then set S1 to 'c', and adjust P2 so that the display indicates the same value as just noted. The position of the decimal point is irrelevant. Remove the 330 kΩ resistor and 150 pF capacitor and solder a 3.3 kΩ resistor and 15 nF capacitor in their place. Finally, connect a 10 nF, 1% tolerance, capacitor across the $C_x$ terminals, set S1 to position 'b', and adjust P1 on the display board so that the display reads exactly 10.00 nF. If the 10 nF capacitor used has a larger tolerance, measuring results will also have a larger tolerance. This completes the calibration; all components should now be soldered into place.

## Applications

The capacitance meter can also be used as interface for a digital voltmeter: the display board is then, of course, not required. Resistor R20 should be 100 kΩ instead of 1 MΩ and a multi-turn preset of 1 MΩ should be connected between terminals HI and LO. The wiper of this preset becomes the output of the interface. The new preset will be used instead of P1 (on the display board) for calibrating the circuit. There is only one (minor) snag: the decimal point is not in the right position! So, remember this!

It is also possible to use the capacitance meter for the measurement of varicaps, but it will then have to be provided with a variable voltage source. A design for

**Meter board:**
- P1 sets display to '0' in range a
- P2 calibrates ranges c and d
- P3 sets display to '0' in range f

**Display board:**
- P1 calibrates to reference value

6

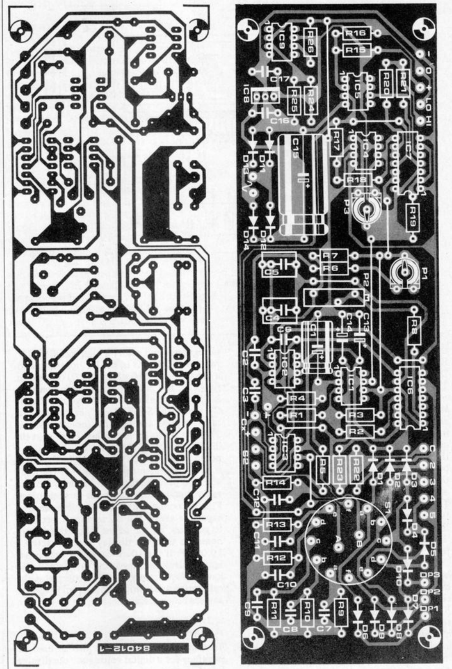


**Figure 6. Component layout and track side of the printed-circuit board for the metering unit. The range selector is soldered onto this board to reduce parasitic capacitances.**

**Parts list — metering board**

Resistors:
R1 = 5k6
R2 = 47 k
R3 = 4M7
R4, R19 = 1 k
R5 = 3k9
R6, R22, R23 = 100 k
R7 = 10 M
R8 = 8k2
R9 = 3M3, 1%
R10 = 33 k, 1%
R11, R13, R14 = 330 Ω, 1%
R12 = 3k3, 1%
R15, R16, R21 = 10 k
R17, R18, R24, R25 = 10 k, 1%
R20 = 1 M
R26 = 100 Ω
P1 = 1 M preset
P2 = 5 k multi-turn preset
P3 = 25 k preset

Capacitors:
C1 = 100 μ/4 V
C2 = 22 n
C3 = 4p7
C4, C5 = 1 μ
C6 = 220 n
C7 = 1p5
C8 = 150 p
C9, C10 = 15 n
C11, C12 = 150 n
C13, C14 = 1 μ/16 V
C15 = 220 μ/40 V
C16 = 330 n
C17 = 100 n
Capacitor 10 nF ± 1% (for calibration)

Semiconductors:
D1 . . . D10 = 1N4148
D11 . . . D14 = 1N4001
IC1 = CA 3130E
IC2 . . . IC5 = LF 356N
IC6, IC7 = 4066
IC8 = 7815
IC9 = 741

Miscellaneous:
S1 = printed-circuit switch, 2 pole, 6 way
S2 = SPST switch
S3 = DPST mains switch
Tr1 = mains transformer, 18 V/150 mA secondary
F1 = 100 mA slow blow mini fuse with carrier
Case, Vero 202-21035F
Printed-circuit board 84012-1
Transfer for front panel

this is shown in figure 9. The indicated capacitance is proportional to the applied voltage which makes it possible to determine the diode characteristic. Care should be taken not to apply a voltage below 2 V, otherwise the diode may conduct. Because of the metering a.c., the measurement may show an error of a few per cent. Since pin 6 of IC3 is connected to the pole of S1a, it would, of course, be possible to run a wire from there to a 'varicap' terminal on the front panel.

## Important!

Before connecting any capacitor, more especially electrolytics, to the $C_x$ terminals, make sure that it is completely discharged by connecting a resistor in parallel with it! Do not use test leads on the lowest range ('a')!

7

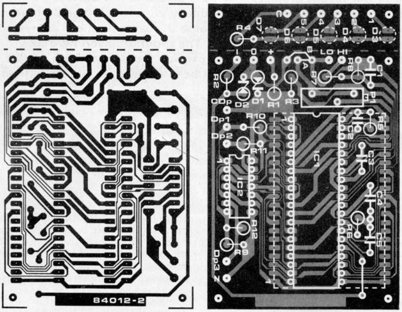


**Figure 7. Component layout and track side of the display unit. The LCD and LEDs are fitted to the track side. Diodes D1 and D3 are not required here.**

**Parts list — display board:**

Resistors:
R1, R7 = wire bridge
R2 = 820 Ω
R3 = 22 k
R4 = 1k5
R5, R8 . . . R12 = 100 k
R6 = 47 k
P1 = 2k5 multi turn preset

Capacitors:
C1, C3 = 100 n
C2 = 100 p
C4 = 470 n
C5 = 220 n

Semiconductors:
D1, D3 = not used
D2 = zener diode 3V3/0.4 W
D4 . . . D7 = LED
IC1 = ICL 7106
IC2 = 4070
LCD = liquid crystal display type NDP530-035A-S-RF-P1C

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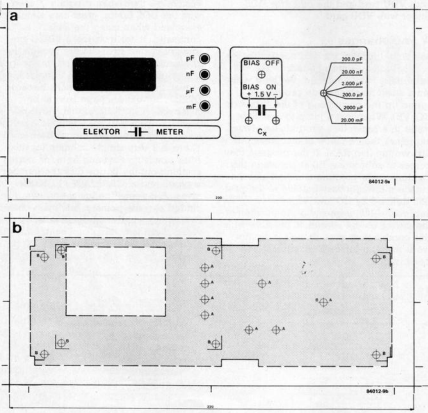


**Figure 8. The mounting tray and front panel. It is, of course, possible to use a different (or no) mounting tray if the case shown in the parts list is not used.**

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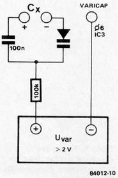


**Figure 9. Test circuit for the determination of the characteristic of varicap diodes.**

## Summarizing . . . .

. . . some of the outstanding points of the capacitance meter:

- All capacitances are measured at the correct frequency.
- Leakage currents have negligible influence on the measurement results.
- The effect of wiring capacitances has been reduced to such an extent that capacitance values smaller than 1 pF may be measured.
- After the capacitor under test has been connected, the display indication will appear in less than one second: this remains true for values up to 1000 µF!

*Sources: 'Capacitance-to-voltage converter', W.B. de Ruyter, Wireless World, June 1983, page 68.*
*'LCD panel meter', Elektor, October 1981, page 10-32.* U.K.