INDUCTANCE-CAPACITANCE METER

FRONT COVER PROJECT

based on a design by H. Kühne

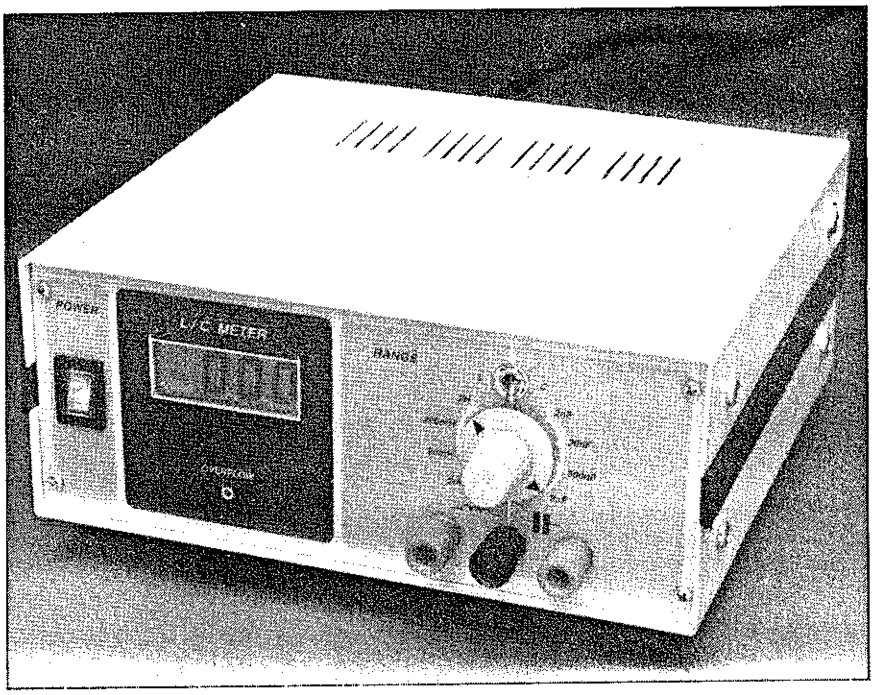
When the value of a capacitor or inductor is measured, it is imperative that ohmic losses do not affect the result. The principle of measurement used in the meter presented here ensures that the influence of ohmic losses is reduced to nil.

BASICALLY, there are two problems in measuring inductance or capacitance: ohmic losses and frequency-dependence of the component. The effect of ohmic losses has been nullified in this design, while the frequency-dependence is, as usual, negated by choosing a measurement frequency that lies in the range in which the component is to operate. In the present design, the frequency lies in the audio range.

The principle of the design is shown in Fig. 1. The value of an inductance, L_x, is determined by passing a sinusoidal current of constant amplitude through the inductor and measuring the resulting voltage across it. The value of a capacitance, C_x, is determined by applying a constant-amplitude sinusoidal voltage across the capacitor and assessing the resulting current through it by measuring the voltage drop across R_C. In either case, that voltage (measured at A) is directly proportional to the inductance or capacitance plus the loss resistance. How that resistance is removed from the measurand (measured quantity) will be discussed later.

We will now consider how the current through the inductance, or the voltage across the capacitance, is held constant. The inverting input of the differential amplifier at the input of the circuit is fed with a sinusoidal measurement signal, U_E, and the non-inverting input with part of the voltage at G, U_A. Since the gain of the amplifier is unity, the voltage at B is $U_A - U_E$. The potential difference between A and B is $U_A - (U_A - U_E)$, which is U_E. Assuming that U_E is a constant-amplitude sinusoidal voltage depending on the setting of switch S_2, a constant voltage exists across R_L or C_x. This causes a constant current through R_L and thus through L_x. Since a constant current flows through the inductance or a constant voltage exists across the capacitance, the loss resistances, R_L and R_C, have no effect on the measurement.

The signal at G consists of two components: a sinusoidal voltage that is *in phase* with U_E and a sinusoidal voltage that is 90° *out of phase* with U_E (cos U_E). Added together, the components form a sinusoidal voltage that is x° out of phase with U_E. The components are separated by synchronous rectification of the signal. The rectifier is driven by a square wave (F) that is shifted 90° with respect to sinU_E. That means that only the cosine component in the signal is rectified: the resulting mean value is directly proportional to the inductance or capacitance, whereas rectification of the sine component yields a mean value of zero.



TECHNICAL DATA

Measurement frequency	1 kHz
Measurement ranges:	
inductance	2, 20, 200 mH, 2 H
capacitance	2, 20, 200 nF, 2 µF
Accuracy (calibrated with 1% capacitor)	
with moving-coil meter	±(1.5% of reading + 2% of FSD)
with 3.5 digit digital voltmeter	±(1.5% of reading + 1 digit)

The various signals encountered in this process are shown in Fig. 2. Figure 2a shows the situation when a perfect inductance or capacitance is being measured. Since ideal components are considered, both the measured signal, U_A, and the square-wave voltage, U_F, driving the rectifier are 90° out of phase with U_E. This means that the rectifier will switch exactly at the zero crossings of the measured signal, which results in a voltage whose mean value is directly proportional to the measured reactance.

If a resistance is substituted for the inductance or capacitance—Fig. 2b—the measured signal will be in phase with U_E. The rectifier then switches exactly at the peaks of the signal, resulting in a mean voltage whose value is zero.

Although practical inductors and capacitors have parasitic or stray resistance, the effect of this is nullified in the synchronous rectification. When a practical inductor or capacitor is measured, the phase shift between the measuring signal, U_E, and the measured signal, U_A, will be somewhere between 0° and 90°. This means that the signal is neither wholly rectified nor reduced to zero: the resulting mean value will be representa-

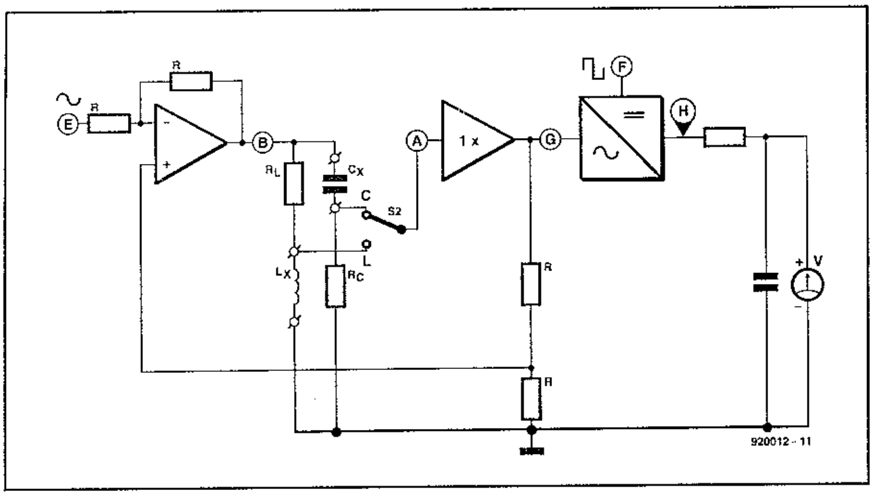


Fig. 1. Principle of the design of the meter.

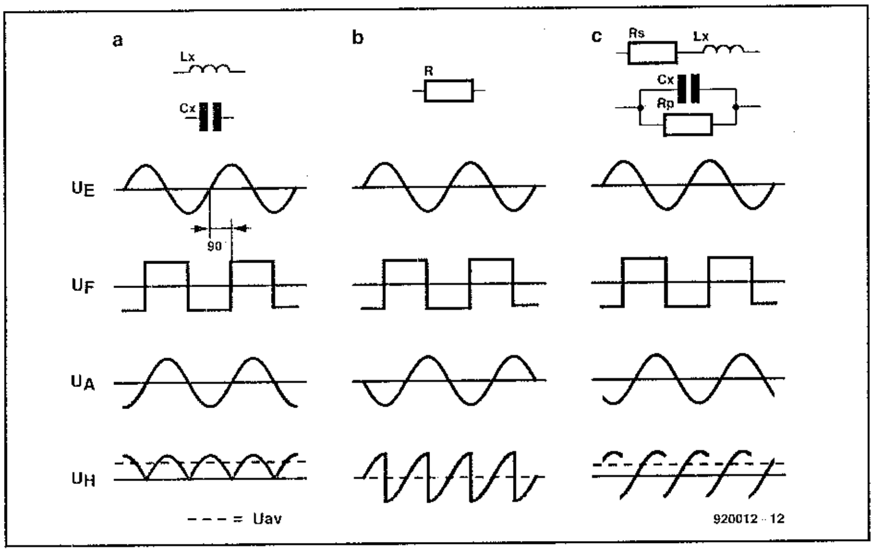


Fig. 2. Waveforms associated with the measurement process.

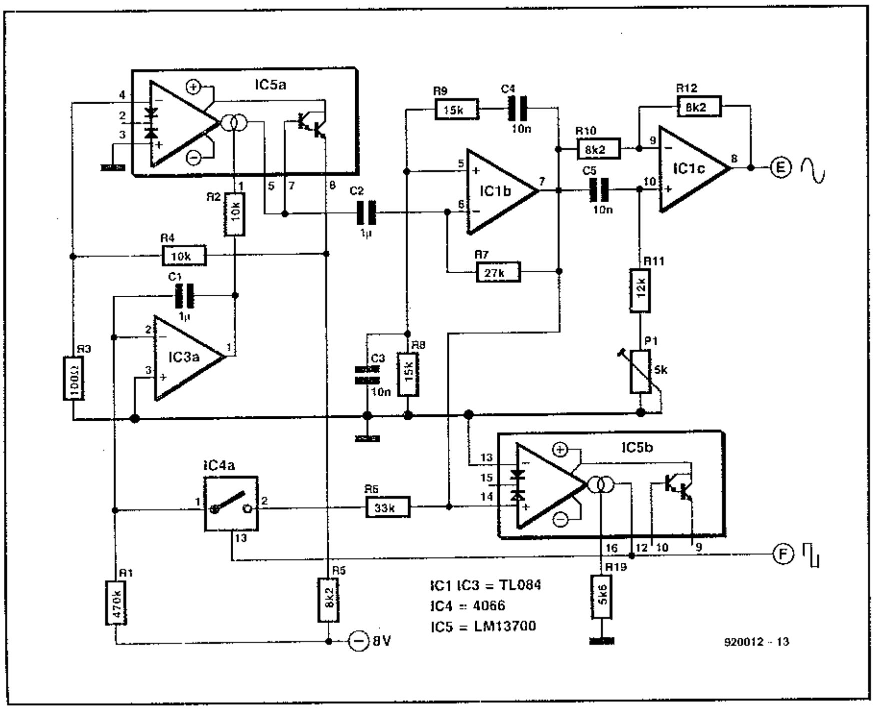


Fig. 3. The oscillator circuit.

tive of the real inductance or capacitance.

Returning to Fig. 1 for a moment, the rectifier is followed by an *RC* network which averages the rectified voltage before that is applied to a meter.

Oscillator

The measurement signal, U_E, and the square wave voltage, U_F, that drives the rectifier are generated by a Wien-bridge oscillator, IC_{1b}—see Fig 3. The sinusoidal output of this stage is converted into a square-wave voltage by IC_{5b}, an operational transconductance amplifier (OTA) connected as comparator. Since the square-wave and sinusoidal signals are in phase, the latter is applied to phase shifter IC_{1c}. The required 90° phase difference between the two signals is set with P_1.

The remainder of the circuit in Fig 3 serves to stabilize the level of the oscillator output. To that end, the output, pin 5, of IC_{5a} is used as a preset resistance in the feedback loop of IC_{1b}. That resistance is determined by the current entering via the control input, pin 1. This current, provided by integrator IC_{3a}, can be used to influence the gain of IC_{1b} and thus the amplitude of the sinusoidal signal. Its level is in turn determined by the amplitude of the positive halves of the sinusoidal signal. The negative halves are not passed by switch IC_{4a} since that is closed by IC_{5b} only during the positive halves of the signal.

Regulation is arranged so that the gain of IC_{1b} diminishes when the amplitude increases and vice versa. Ultimately, the amplitude stabilizes around a value of 1.2 V.

Measuring circuit

Basically, of course, the measuring circuit in Fig. 4 is similar to Fig 1 with the rectifier and meter omitted.

The differential input amplifier consists of IC_{1d}. Its output current is doubled in IC_{1a}, since the peak level should be about 15 mA, which a single TL084 cannot provide. The design ensures that the level of the voltage across R_{17} is identical to that across R_{16}. Consequently, the currents through these resistors are also identical. Observe that one half of the current fed to the measuring circuit is provided by IC_{1d} and the other half by IC_{1a}.

Range switch S_1 is provided with a section, S_{1c}, that enables the decimal points of a digital meter module, if used, to be controlled. In case of an LCD module, the pole of S_{1c} must be fed with the back-plane (BP) signal or, if an LED display is used, with a logic high or low, depending on the type of the display.

The various ranges are determined with the aid of 0.1% resistors. This has two advantages: calibration of only one range suffices and the tolerance of the resistors has a negligible effect on the total accuracy of the meter (if the tolerance were 1%, the meter accuracy would deteriorate by at least 1%). Note that the 1% resistors in parallel with R_{43}, R_{47}, and R_{48}, can be ignored since their tolerance is tiny compared with that of the parallel-connected low-value resistors.

Rectifier and power supply

The remainder of the circuit, that is, rectifier, meter, power supply and overflow indicator, is shown in Fig 5

The rectifier proper, IC_{2d}, is preceded by an amplifier, IC_{2c}, because the output of the metering circuit at full-scale deflection (FSD) is only 150 mV (assuming a perfect inductance or capacitance) and that is not enough to ensure a mean voltage of 2 V to the meter The rectifier elements are not diodes, but two electronic switches, IC_{4b} and IC_{4d}, that are operated by the square-wave signal in step with the sinusoidal output of the oscillator An inverter based on IC_{4c} controls IC_{4d}, so that IC_{4b} and IC_{4d} are alternately opened and closed. When IC_{4b} is closed, IC_{2d} amplifies ×1; when IC_{4d} is closed, IC_{2d} amplifies ×−1 This ensures operation in step with the square-wave signal

The output of the rectifier is smoothed by network R_{27}-C_7. Because this network can be loaded only lightly, the potential across C_7 is buffered by IC_{2a} before the signal is applied to the meter The meter may be a digital or an analogue type. The digital type may be connected directly to buffer IC_{2a} Series resistors and protection diodes for a moving coil meter are provided

At first glance, an overflow indicator may seem superfluous, since the meter, M_1 or DM_1, shows immediately if the meter range is exceeded. That is true enough but consider that if the meter range is grossly exceeded, IC_{2c} will clip and the resulting mean value of the rectified voltage may then fall *under* 2 V, that is, *in* the meter range. The meter reading then means nothing and this would not be evident without the overflow indicator

The indicator is based on IC_{3b} (connected as comparator) and IC_{3c}. The output of the rectifier is compared by IC_{3b} with a voltage set with P_5 to a level of 4 V If the rectified output exceeds the set level, buffer capacitor C_8 is charged via D_3 This results quickly to the output of IC_{3c} changing state and D_4 lighting

Construction and calibration

There should be no particular difficulties in the construction of the instrument if the PCB shown in Fig 6 is used As usual, start with the lowest-lying components, that is, the wire links When the highest protruding components, that is, electrolytic capacitors, IC_6 and IC_7 and the mains transformer, have been fitted, wire up those components that are not fitted on the board

The low-tolerance resistors should be soldered direct to the range switch, S_1 It is, therefore, advisable to use a type of switch that has solder eyelets and not

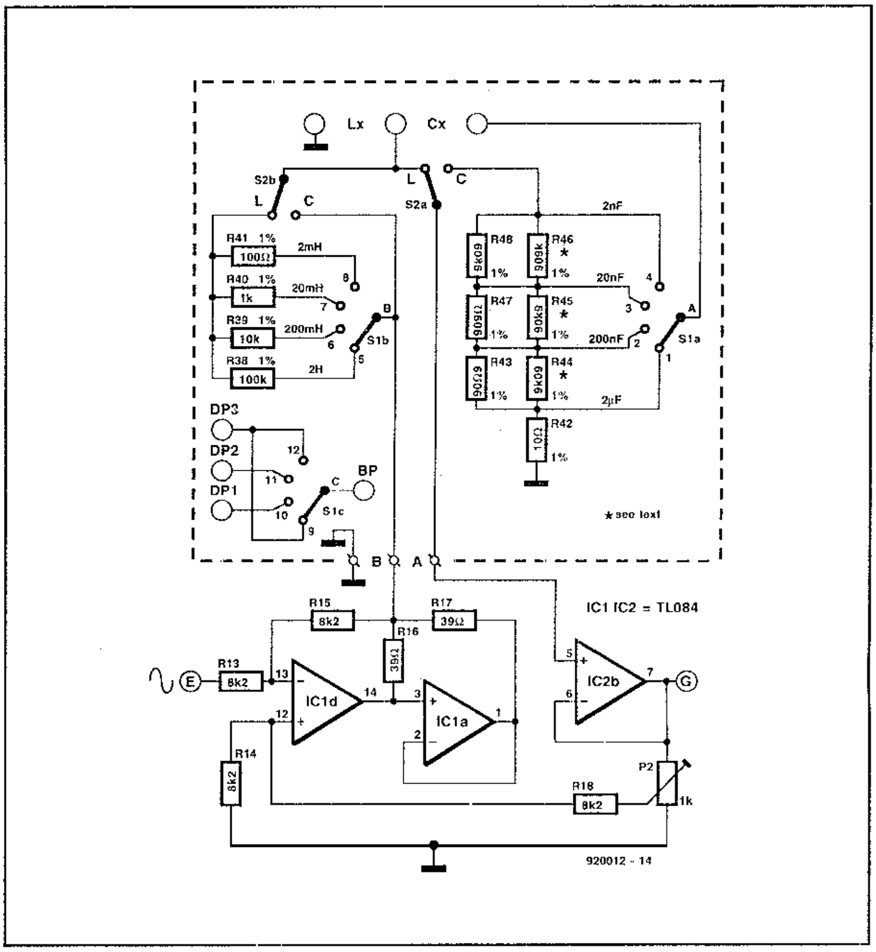


Fig. 4. The metering circuit proper.

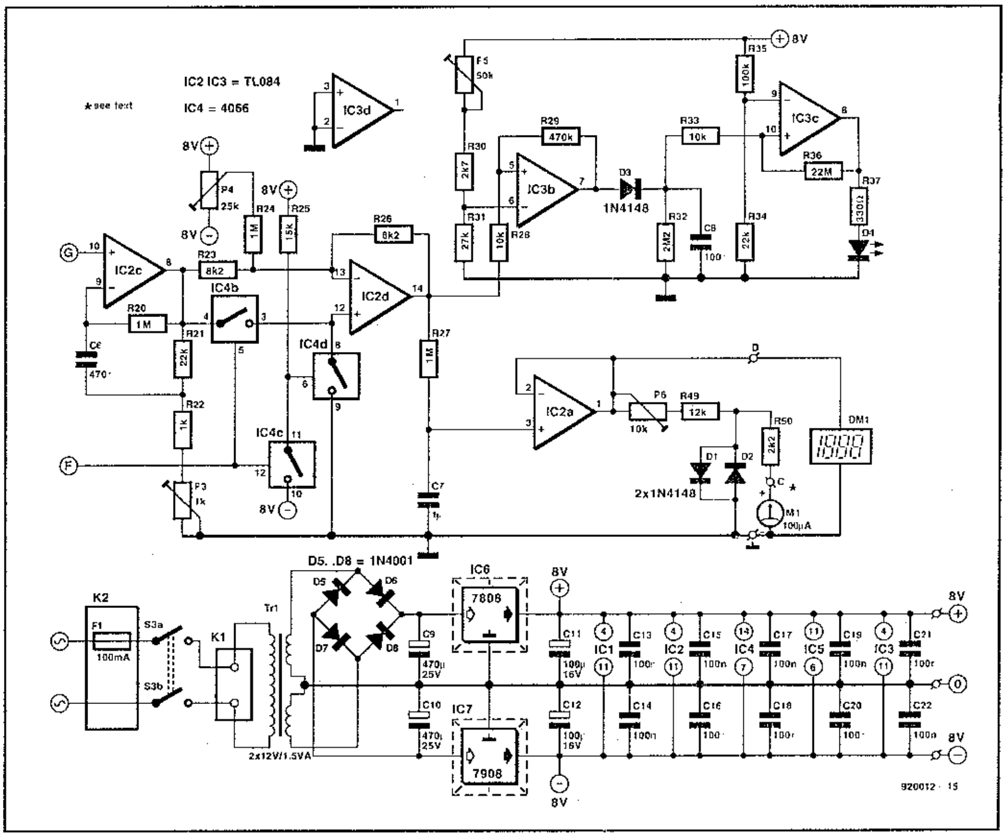


Fig. 5. Circuit of the rectifier, power supply, meter and overflow indicator.

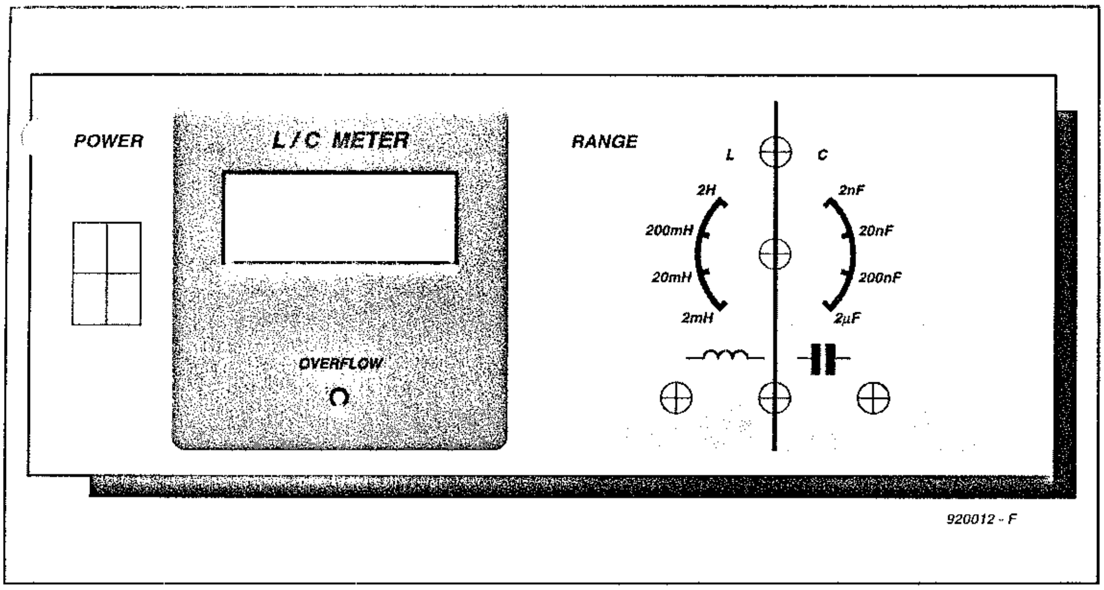


Fig. 6. Proposed front panel layout (foil Type 920012–F).

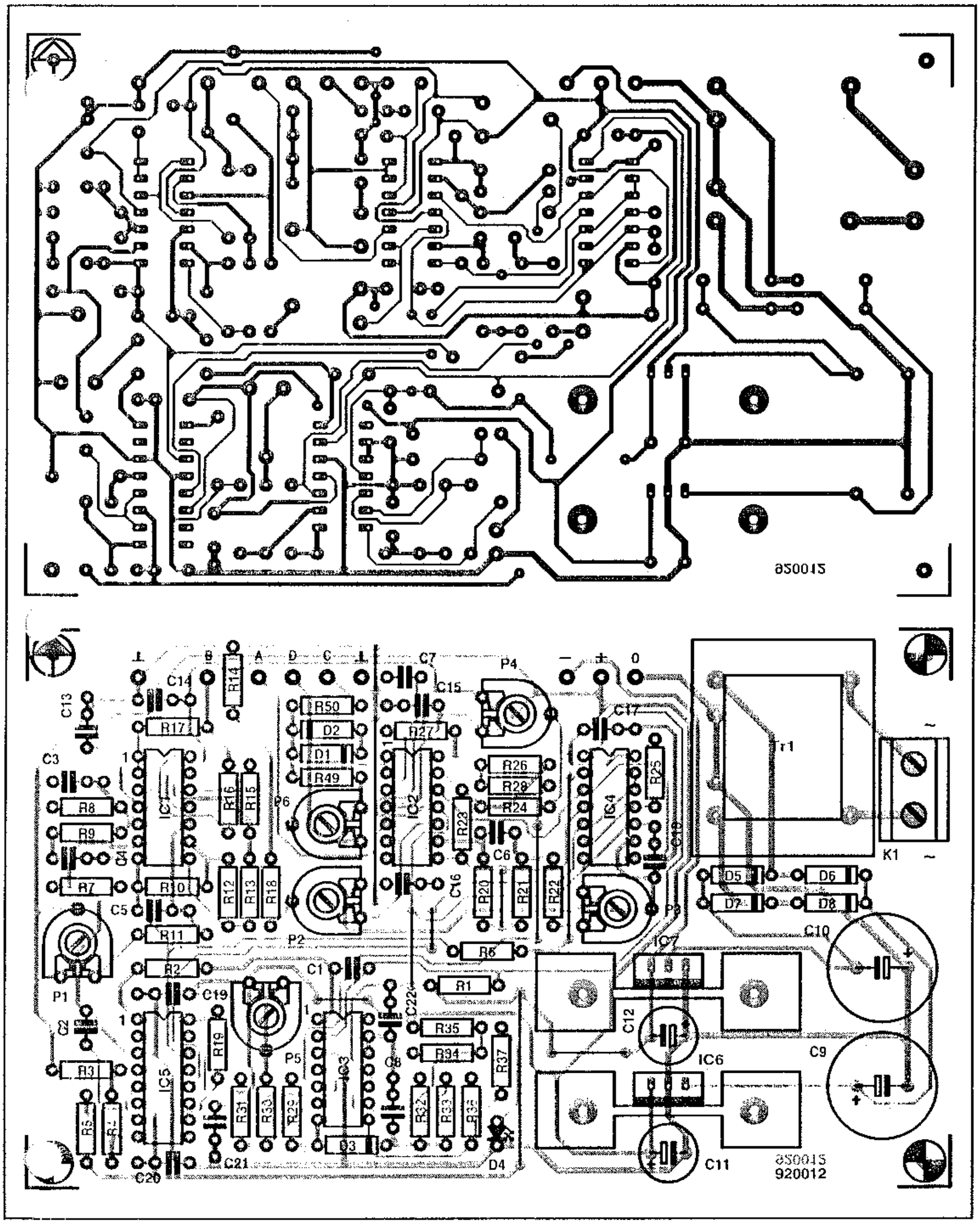


Fig. 7. Printed-circuit board for the inductance-capacitance meter – Type 920012.

PARTS LIST

Resistors:
R1, R29 = 470 kΩ
R2, R4, R28, R33 = 10 kΩ
R3 = 100 Ω
R5 R10, R12–R15, R18, R23, R26 = 8.2 kΩ
R6 = 33 kΩ
R7, R31 = 27 kΩ
R8, R9 = 15 kΩ
R11 = 12 kΩ
R16, R17 = 30 Ω
R19 = 5.6 kΩ
R20, R24, R27 = 1 MΩ
R21, R34 = 22 kΩ
R22 = 1 kΩ
R25 = 15 kΩ
R30 = 2.7 kΩ
R32 = 2.2 MΩ
R35 = 100 kΩ
R36 = 22 MΩ
R37 = 330 Ω
R38 = 100 kΩ, 0.1%
R39 = 10 kΩ, 0.1%
R40 = 1 kΩ, 0.1%
R41 = 100 Ω, 0.1%
R42 = 10 Ω, 0.1%
R43 = 90.9 Ω, 0.1%
R44 = 9.09 kΩ, 1%
R45 = 90.9 kΩ, 1%
R46 = 909 kΩ, 1%
R47 = 909 Ω, 0.1%
R48 = 9.09 kΩ, 0.1%
R49 = 12 kΩ
R50 = 2.2 kΩ
P1 = 4.7 kΩ preset
P2, P3 = 1 kΩ preset
P4 = 25 kΩ preset
P5 = 47 kΩ preset
P6 = 10 kΩ preset

Capacitors:
C1, C2, C7 = 1 µF
C3–C5 = 10 nF
C6 = 470 nF
C8, C13–C20 = 100 nF
C9, C10 = 470 µF, 25 V, radial
C11, C12 = 100 µF, 16 V, radial
1×180 nF, 1%) for calibrating
2×100 nF, 1%) meters

Semiconductors:
D1–D3 = 1N4148
D4 = 5 mm LED, yellow
D5–D8 = 1N4001
IC1–IC3 = TL084
IC4 = 4066
IC5 = LM13700
IC6 = 7808
IC7 = 7908

Miscellaneous:
K1 = 2-way terminal block for PCB mounting, 7.5 mm pitch
K2 = mains panel plug with integral fuse holder and fuse, 100 mA delayed action
K3–K5 = banana socket
S1 = 3-pole, 4-position rotary switch with solder eyelets
S2 = 2-pole change-over switch
S3 = double-pole, double-throw switch with integral lamp
Tr1 = mains transformer, 2×12 V, 1.5 VA
M1 = 100 µA moving-coil meter
DM1 = 3.5 digit digital voltmeter, 2 V
Heat sinks for IC6 and IC7
PCB 920012
Front panel foil 920012-F

one for PCB mounting. It may be possible to bend these eyelets slightly outwards to give more space for the resistors.

If a digital meter module is used, do not forget to wire switch section S_{1c}, which controls the decimal points.

In spite of there being six preset potentiometers, the calibration of the instrument is fairly straightforward. Start with setting all the presets to the centre of their travel.

If a moving coil meter is used, connect a voltmeter between D and earth. With the instrument switched off, zero the moving-coil meter manually. When a digital meter is fitted, an external voltmeter is not required.

Set S_2 to position C(apacitor) and leave the input terminals open. Adjust P_4 till the voltmeter (or internal digital meter) reads 0. This arranges the offset compensation.

Connect two 100 nF in parallel to the input terminals and set the range switch to 200 nF. The value of these capacitors need not be accurate, since this test only serves to set the gain of IC_{2c}. This is done by adjusting P_3 until the voltage at D is 2 V. Because of R_{27} and C_7 ($\tau = 1$ s), this voltage rises only slowly; P_3 should, therefore, be adjusted slowly also. When P_3 has been adjusted as required, connect a resistor of 10 kΩ in parallel with the 100 nF capacitors. Then adjust P_1 to return the voltage at D to 2 V. This arranges the phase difference between sinusoidal and square-wave signals at 90°.

Next, remove the 10 kΩ resistor, but not the capacitors, from the input terminals. Ideally, P_2 should be set with its wiper at the output of IC_{2b}. This would, however, create a positive feedback loop with a gain of ×1: not exactly conditions for oscillation, but very nearly so. It is, therefore, necessary to connect an oscilloscope to the output of IC_{2b} and adjust P_2 so that oscillation just does not set in. If an oscilloscope is not available, set P_2 to about ¾ of its travel, that is, 750 Ω between wiper and earth.

If, apart from an oscilloscope, a function generator that provides a triangular output is available, P_2 can be adjusted even more accurately. To that end, R_{13} must be unsoldered from IC_{1c} and a 3-V, 1 kHz triangular signal applied across it. An oscilloscope connected to the output of IC_{2b} will then show a square wave-form (because of the integrating action of the capacitors at the input). Adjust P_2 so that this wave-form is 'clean', that is, shows no overshoot.

Connect two 100 nF, 1%, capacitors (if a moving coil meter is used) or an 180 nF, 1%, capacitor (if a digital display is used) to the input terminals and adjust P_6 (moving-coil meter) or P_3 (digital display) until the correct value is read. ■

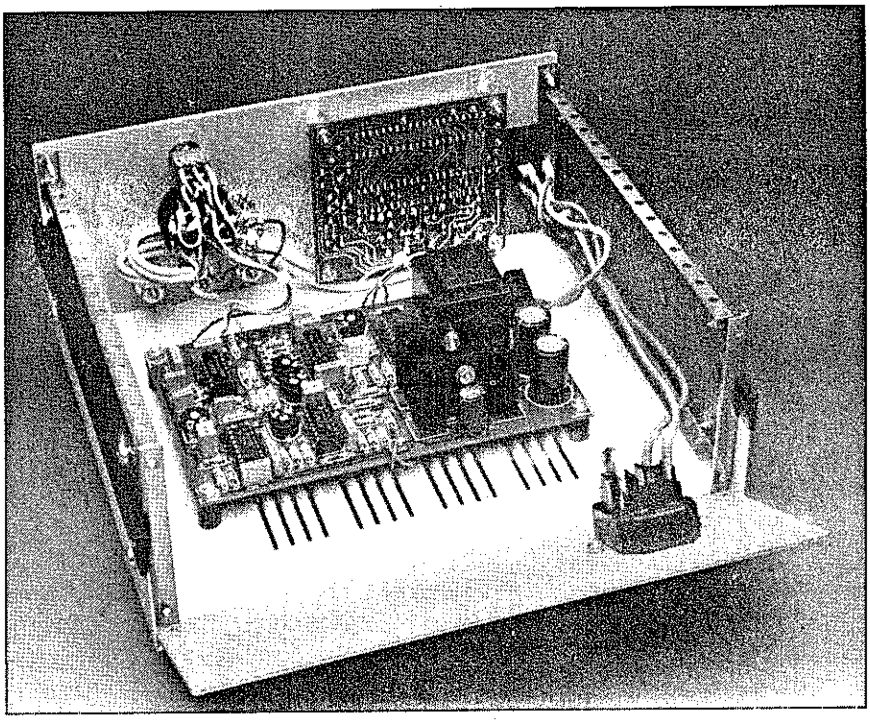


Fig. 8. Inside view of meter with top panel removed and rear panel hinged down

MEASUREMENTS ON POWER SUPPLIES

by our technical staff

How do you know whether your precious laboratory/workshop power supply unit is still working to specification? How do you measure the parameters of the PSU you have just built or purchased for fitting into an electronic apparatus and what do you specifically have to look out for? The answers to these and many other questions connected with the testing of power supplies are given in this practice-based article.

THE requirements of a laboratory/workshop power supply unit are exacting. Not only the output voltage and current, but also the dynamic and static internal resistance, noise, overshoot and thermal stability, to name but a few, are important. *Any electronic apparatus is only as good as its power supply* is an adage that remains true.

The extent to which a power supply can be tested depends primarily on the available test equipment. Normally, the output voltage can be measured with a simple multimeter.

But even this measurement may be more complicated than appears at first sight. Imagine, for instance, that you have obtained a 6 V mains adapter to replace the batteries in a normally battery-operated apparatus, which is not only less expensive in the long run, but also more sensible from an ecological viewpoint. To your surprise, when you measure the output voltage, it is 9–11 V. The first question that pops into your mind is: "Is it safe to connect to the equipment?" Practical considerations show that there is no harm in that whatsoever. The explanation for this statement is that such a simple mains adapter usually consists of a small transformer, rectifier and reservoir capacitor, nothing more. For all sorts of reason, small transformers generally have a fairly high internal resistance—