

RADIOMETER

Capacitance Bridge

type CMB1

Elektriske måleapparater

**til videnskabelig og
industriel anvendelse**



INSTRUCTION AND OPERATING MANUAL
FOR

CAPACITANCE BRIDGE

Type CMB1

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Capacitance Bridge type CMB1/OSF1

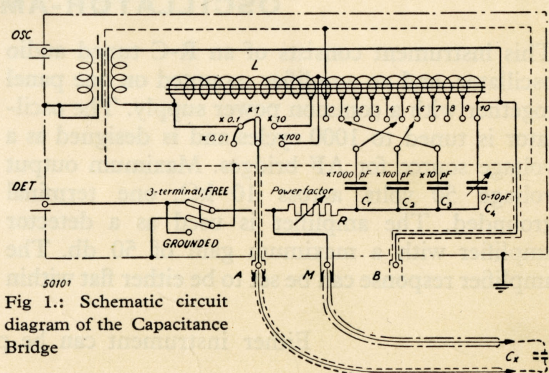
Introduction:

The above illustration shows the Capacitance Bridge type CMB1 (lower panel) combined with the Oscillator Amplifier type OSF1 (upper panel). The type CMB1 bridge is a direct-reading precision instrument for capacitance measurements at audio frequencies. At one frequency, 1000 cycles in the standard model, the bridge is also direct reading in power factor. Bridges with 800 cycle power factor calibration, type CMB1L, can be supplied on request. The capacitance range is remarkably wide, viz. 0.001 pF to 1.1 μ F. Condensers with one terminal grounded, as well as three-terminal condensers can be measured without any extra accessories. A special shielding system is used so that shielded cables can be used between the bridge and the unknown capacitor, without taking the cable capacitances into account, even when very small capacitances are measured.

A notable characteristic of the bridge is its ability to measure directly, without any accessories, the single capacitance components of a complex capacitance network. Due to this property the bridge is able to measure e. g. interelectrode capacitances in vacuum tubes or the separate direct and ground capacitances of multi-conductor cables. The bridge is a convenient instrument for measuring the temperature coefficient of even small condensers because the shielding system makes it possible to place the specimen under test in a thermostat controlled oven of conventional design.

Description:

The diagram fig. 1 shows the circuit of the bridge. Instead of ratio resistors the bridge employs a tapped ratio-inductor L of special design with very low leakage coefficients. The tapped inductor holds the following advantages over ratio resistors: The accuracy of the voltage ratios is very high (better than 0.001%). Therefore the measuring accuracy depends exclusively on the accuracy of the standard condensers. Further the inductor offers a high impedance to the oscillator voltage, but the series impedances in theappings are very low so that the voltage ratios are practically unaffected by loading. This makes possible the special shielding and switching system of the bridge. The capacitance standard consists of 3 stable mica standards C_{1-3} and a variable air condenser C_4 . The standards C_{1-3} are connected to the inductor tap-



pings through decade switches. Therefore the bridge behaves as if the standard arm were built up of 3 capacitance decades (10×1000 , 10×100 , and 10×10 pF) and a variable standard (0–10 pF). Power factor balance is obtained by means of the resistor R. Fig. 2a shows how to measure the direct capacitance C_{1-2} between two cable conductors, and fig.

2b shows the connections when measuring the ground-capitance C_1 of one conductor. It is seen that the unwanted capacitance components have no influence on the bridge balance as they are shunted across either the detector or the left half of the inductor which does not affect the voltage ratios on account of the very low series impedance.

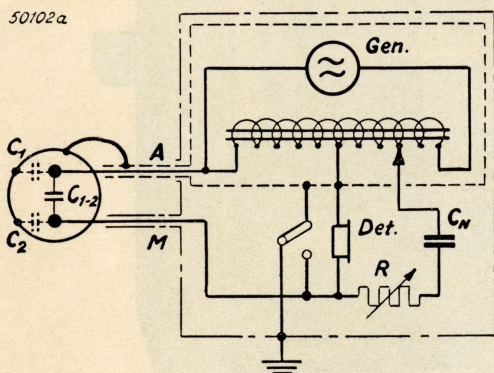


Fig. 2a: Measuring a direct capacitance

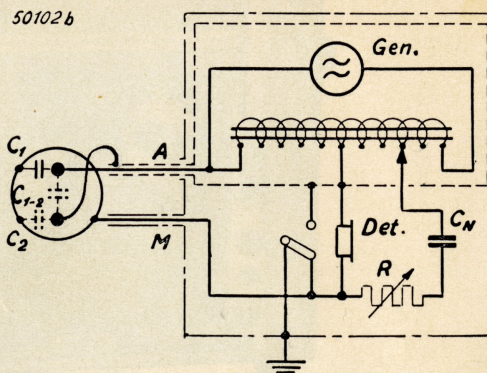


Fig. 2b: Measuring a ground capacitance

SPECIFICATIONS:

Capacitance range and accuracy: 0.001 picofarad to 1.111 microfarads absolute, in 5 ranges:

Range $\times 0.01$: 0–0.1 picofarad by means of the continuous standard alone. Accuracy ± 0.0005 pF.

Range $\times 0.1$: 0–1111 picofarads. Accuracy $\pm 0.1\%$ ± 0.005 pF

Range $\times 1$: 0–11110 picofarads. Accuracy $\pm 0.1\%$ ± 0.05 pF

Range $\times 10$: 0–0.1111 microfarads. Accuracy $\pm 0.1\%$ ± 0.5 pF

Range $\times 100$: 0–1.111 microfarads. Accuracy $\pm 0.1\%$ ± 5 pF

Frequency range: The bridge can be used with full accuracy on the range 200 to 5000 cycles. At 50 and 10,000 cycles the accuracy is reduced to about 0.2%. At frequencies over 2 kc the maximum capacitance which can be measured with full accuracy is $4/f^2$ microfarads where f is the frequency in kilocycles.

Power factor range and accuracy: The power factor dials cover the range $0-110 \times 10^{-3}$ with an accuracy

of 2% or 0.5×10^{-3} whichever is the larger. This applies to capacitances above 100 pF. Below this value the accuracy decreases. The calibration applies to one frequency only, in the standard model 1000 cycles.

Input: Asymmetrical, high impedance (about 10 k Ω at 1000 cycles). The input voltage should not exceed 50 volts. For frequencies below 500 cycles the voltage should not exceed 0.1 volt per cycle.

Accessories supplied: Two 1 m long shielded cables which fit the shielded terminals: 1 double-shielded cable type C1A11, and 1 single-shielded cable type C1A10.

Mounting: Metal cabinet finished in grey enamel and with etched panel cover.

Dimensions: Type CMB1, panel height: 222 mm, in cabinet, over-all: H: 250, W: 570, D: 260 mm. Type CMB1/OSF1 in a single cabinet, over-all: Height: 380 mm, Width: 570 mm, Depth 260 mm. Panels fit a 19" relay rack.

Weight: CMB1/OSF1 25 kilos

OSCILLATOR-AMPLIFIER type OSF1

This instrument consists of an R-C tuned audio oscillator, and an amplifier mounted on one panel together with a common power supply. The oscillator is tuned to 1000 cycles and is designed as a voltage source for AF bridges. Maximum output voltage 50 volts across 10 k Ω , one terminal grounded. The amplifier is used as a detector amplifier with a maximum gain of 50 db. The amplifier response can be set to be either flat within

the AF-range or to be selective to the oscillator frequency. A built-in limiter prevents the output voltage from exceeding 2 volts. Power supply: 110, 127, 150, 200, 220, 240 volts, 50–60 cycles. Consumption 40 watts. The front panel fits a 19" relay rack. Panel height: 133 mm. Dimensions when supplied in separate cabinet, H: 160 mm, D: 215 mm, W: 500 mm.

Either instrument can be purchased and used separately.

Data subject to change without notice.





Capacitance Bridge type CMB1/OSF2

Introduction:

The above illustration shows the Capacitance Bridge type CMB1 (lower panel) combined with the Oscillator Amplifier type OSF2 (upper panel). The type CMB1 bridge is a direct-reading precision instrument for capacitance measurements at audio frequencies. At one frequency, 1000 cycles in the standard model, the bridge is also direct reading in power factor. Bridges with 800 cycle power factor calibration, type CMB1L, can be supplied on request. The capacitance range is remarkably wide, viz. 0.001 pF to 1.1 μ F. Condensers with one terminal grounded, as well as three-terminal condensers can be measured without any extra accessories. A special shielding system is used so that shielded cables can be used between the bridge and the unknown capacitor, without taking the cable capacitances into account, even when very small capacitances are measured.

A notable characteristic of the bridge is its ability to measure directly, without any accessories, the single capacitance components of a complex capacitance network. Due to this property the bridge is able to measure e. g. interelectrode capacitances in vacuum tubes or the separate direct and ground capacitances of multi-conductor cables. The bridge is a convenient instrument for measuring the temperature coefficient of even small condensers because the shielding system makes it possible to place the specimen under test in a thermostat controlled oven of conventional design.

Description:

The diagram fig. 1 shows the circuit of the bridge. Instead of ratio resistors the bridge employs a tapped ratio-inductor L of special design with very low leakage coefficients. The tapped inductor holds the following advantages over ratio resistors: The accuracy of the voltage ratios is very high (better than 0.001 %). Therefore the measuring accuracy depends exclusively on the accuracy of the standard condensers. Further the inductor offers a high impedance to the oscillator voltage, but the series impedances in the tapplings are very low so that the voltage ratios are practically unaffected by loading. This makes possible the special shielding and switching system of the bridge. The capacitance standard consists of 3 stable mica standards C_{1-3} and a variable air condenser C_4 . The standards C_{1-3} are connected to the inductor tap-

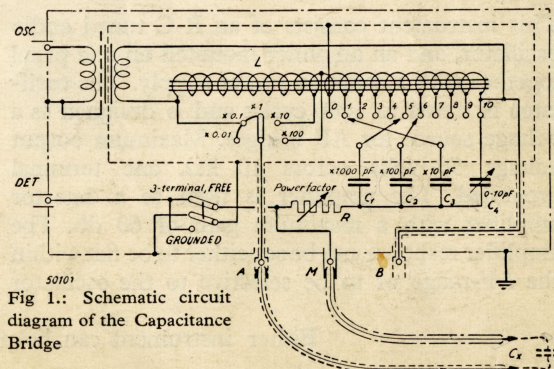


Fig 1.: Schematic circuit diagram of the Capacitance Bridge

pings through decade switches. Therefore the bridge behaves as if the standard arm were built up of 3 capacitance decades (10×1000 , 10×100 , and 10×10 pF) and a variable standard (0–10 pF). Power factor balance is obtained by means of the resistor R. Fig. 2a shows how to measure the direct capacitance C_{1-2} between two cable conductors, and fig.

2b shows the connections when measuring the ground-capitance C_1 of one conductor. It is seen that the unwanted capacitance components have no influence on the bridge balance as they are shunted across either the detector or the left half of the inductor which does not affect the voltage ratios on account of the very low series impedance.

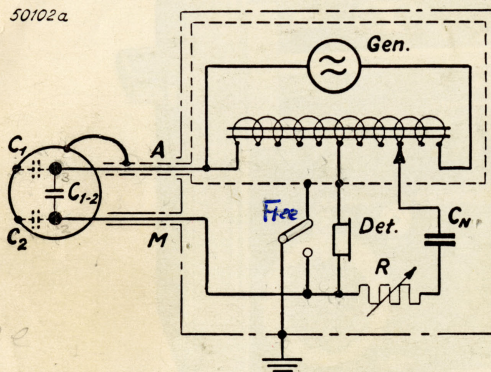


Fig. 2a: Measuring a direct capacitance

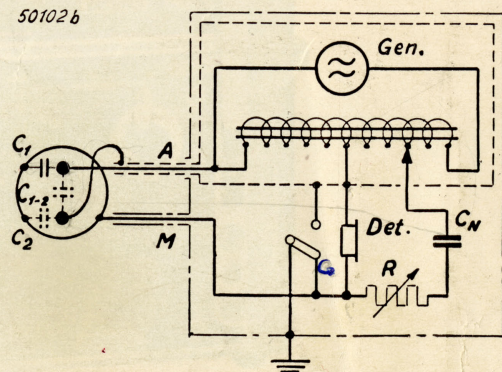


Fig. 2b: Measuring a ground capacitance

SPECIFICATIONS:

Capacitance range and accuracy: 0.001 picofarad to 1.111 microfarads absolute, in 5 ranges:

Range $\times 0.01$: 0–0.1 picofarad by means of the continuous standard alone. Accuracy ± 0.0005 pF.

Range $\times 0.1$: 0–1111 picofarads. Accuracy $\pm (0.1 \% + 0.005 \text{ pF})$

Range $\times 1$: 0–11110 picofarads. Accuracy $\pm (0.1 \% + 0.05 \text{ pF})$

Range $\times 10$: 0–0.1111 microfarads. Accuracy $\pm (0.1 \% + 0.5 \text{ pF})$

Range $\times 100$: 0–1.111 microfarads. Accuracy $\pm (0.1 \% + 5 \text{ pF})$

Frequency range: The bridge can be used with full accuracy on the range 200 to 5000 cycles. At 50 and 10,000 cycles the accuracy is reduced to about 0.2 %. At frequencies over 2 kc the maximum capacitance which can be measured with full accuracy is $4/f^2$ microfarads where f is the frequency in kilocycles.

Power factor range and accuracy: The power factor dials cover the range $0-110 \times 10^{-3}$ with an accuracy

of $2\% + 0.5 \times 10^{-3}$. This applies to capacitances above 100pF. Below this value the accuracy decreases. The calibration applies to one frequency only, in the standard model 1000 cycles.

Input: Asymmetrical, high impedance (about 10 k Ω at 1000 cycles). The input voltage should not exceed 50 volts. For frequencies below 500 cycles the voltage should not exceed 0.1 volt per cycle.

Accessories supplied: Two 1 m long shielded cables which fit the shielded terminals: 1 double-shielded cable type C1A11, and 1 single-shielded cable type C1A10.

Mounting: Metal cabinet finished in grey enamel and with etched panel cover.

Dimensions: Type CMB1, panel height: 222 mm, in cabinet, over-all: H: 250, W: 570, D: 260 mm. Type CMB1/OSF2 in a single cabinet, over-all: Height: 380 mm, Width: 570 mm, Depth 260 mm. Panels fit a 19" relay rack.

Weight: CMB1/OSF2 25 kilos

OSCILLATOR-AMPLIFIER type OSF2

This instrument consists of an R-C tuned audio oscillator, and an amplifier mounted on one panel together with a common power supply. The oscillator is tuned to 1000 cycles and is designed as a voltage source for AF bridges. Maximum output voltage 50 volts across 10 k Ω , one terminal grounded. The amplifier is used as a detector amplifier with a maximum gain of 60 db. The amplifier response can be set either to be flat within the AF-range or to be selective to the oscillator

frequency. The output from the amplifier can be switched to a built-in magic eye or to a pair of output jacks. A built-in limiter prevents the output voltage from exceeding 1 volt. Power supply: 110, 127, 150, 200, 220, 240 volts, 50–60 cycles. Consumption 40 watts. The front panel fits a 19" relay rack. Panel height: 133 mm. Dimensions when supplied in separate cabinet, H: 160 mm, D: 215 mm, W: 500 mm.

Either instrument can be purchased and used separately.

Data subject to change without notice.



INTRODUCTION

The type CMB1 Capacitance Bridge is a direct reading precision bridge which measures capacitance at audio frequency. The measuring range covers about 0.001 pF to 1.111 μ F in 5 ranges. The bridge is balanced by simultaneously balancing capacitance and loss. At one frequency (generally 1000 cycles) the power factor can be read directly.

The design of the bridge permits the unknown capacitance to be connected through shielded cables, the capacitance of which in most cases does not affect the result of the measurements.

The principle of the bridge makes possible direct measurement of the individual capacitance components, grounded as well as direct, of complex networks.

SECTION I

OPERATING PRINCIPLE AND PRINCIPAL COMPONENT PARTS

1-1 THE VOLTAGE DIVIDER

Fig. 1 of plan 1 shows the operating principle of the type CMB1 Capacitance Bridge. By means of a tapped ratio inductor (autotransformer) the voltage V_2 is varied across the fixed standard capacitor C_N . A potentiometer and a rotary switch varies the resistance R in series with C_N . The voltage across the detector will be zero when the products of voltage and admittance are equal for both bridge arms.

The voltage divider consists of 2 ratio inductors. Inductor No. 2 is connected to the center tenth of inductor No. 1. This makes it possible to obtain ratios of up to 1:100.

A properly designed ratio inductor will be extremely accurate and rigid against loading. In the inductor used in the CMB1, which has 2×10^5 sections, the error in the voltage division is of the order of 1 in 10^5 , so that the measuring accuracy is exclusively dependent on the accuracy of the standard capacitor. While the inductor offers a high impedance to the oscillator voltage, the rigidity against loading is the same as that of a voltage divider consisting of $10 \times 1.2\Omega$.

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This rigidity enables the bridge to select the individual capacitance components of a network. Fig. 2 of plan 1 shows how to measure C_1 of the capacitance triangle $C_1 - C_2 - C_3$. The junction of C_2 and C_3 is connected to the same inductor tap (D) as the detector. By this means the left half of the inductor is shunted by C_2 , which will practically not affect the voltage division as long as C_2 is kept within reasonable limits. C_3 will shunt the detector and at most reduce its sensitivity. Therefore only C_1 remains to be outbalanced.

1-2 THE SHIELDING OF THE BRIDGE

Fig. 3 of plan 1 shows how the bridge is shielded. The inductor with the switching arrangement is totally enclosed in a shielded compartment (dot-and-dash line) to which the center (D) of the inductor is connected. The shielded compartment is insulated from the chassis which must be grounded. It will be seen how the shield of the measuring cables has been connected to the shielded compartment and the chassis, so that the cable capacitances are not included in the measurement.

When measuring grounded objects, M is connected to the chassis. When measuring free objects, the shielded compartment and the chassis are interconnected. This is illustrated in fig. 4 and 5 which show an example of measuring the single capacitance components in a shielded-pair transmission line. For convenience the figures show a built-in oscillator. In practice, however, the generator current is fed to the bridge through a built-in double-shielded transformer, as shown in fig. 3.

1-3 THE CAPACITANCE STANDARD

The detailed circuitry of the bridge appears from the complete wiring diagram No. 450-A2 appended to the instructions. The capacitance standard consists of 3 fixed standards, 10,000 pF, 1000 pF and 100 pF plus a variable standard (VK8) of about 4-14 pF. The minimum capacity of the variable standard is outbalanced by means of an adjustable condenser (ZERO) so that the apparent variation will be 0-10 pF.

The 3 fixed standards can be shifted to the various decades by means of switches. They are shielded mica standards of a recognized make. Their capacitance at 20°C has been adjusted with an accuracy better

than 0.05%. The bridge is so designed that the standards appear free from losses at one frequency, generally 1000 cycles.

The variable standard (VK8) and the balancing condenser (ZERO) are designed as three-terminal condensers and are therefore practically free from losses. The arrangement for eliminating the losses of the fixed standards, however, causes a small negative power factor of the order of 0.4×10^{-3} to the VK8. This is the reason why the POWER FACTOR dial does not read zero when the zero of the bridge is being adjusted.

1-4 THE MEASURING RANGES

The 5 measuring ranges are produced as follows:

- x100: The unknown is connected to the 1/100 tap to the left. The 3 fixed standards use the decade on the right-hand side of inductor No. 1. Full voltage across VK8.
- x10: The unknown is connected to the 1/10 tap to the left. Otherwise as for x100.
- x1: Full voltage across the unknown. Otherwise as for x100 and x10.
- x0.1: Full voltage across the unknown. The 3 fixed standards use the decade on the right-hand side of the transformer No. 2. 1/10 voltage across VK8.
- x0.01: Full voltage across the unknown. The 3 fixed standards are inoperative. 1/100 voltage across VK8.

1-5 POWER FACTOR

The phase alignment is made by means of the variable resistor R shown in the various figures of plan 1. R consists of a continuous part which covers the range $0-10 \times 10^{-3}$ in series with a decade that covers the range $0-100 \times 10^{-3}$. The adjustment applies to one frequency only, generally 1000 cycles.

In the range x0.01 where the fixed standards are disconnected, R is practically ineffective. Therefore the calibration of the power factor scale does not apply to the range x0.01 and has been supplemented by an arrangement which is mechanically coupled to the continuous power factor dial shown in the diagram 450-A2.

In the ranges $\times 0.1$, $\times 1$, $\times 10$ and $\times 100$ this arrangement will have practically no influence, so upon the whole the two phase-alignment devices are complementary to each other without one disturbing the other.

The calibration of the power factor scale does not apply to the range $\times 0.01$.

1-6 RESIDUAL GROUND BALANCE

When measuring grounded capacitances, residual leakages between the interior of the bridge and ground will appear as an equivalent displacement of the zero of the bridge. The equivalent zero displacement in itself is very small, a few hundredths of a pF. These leakages can be compensated for by setting the RESIDUAL GROUND BALANCE (by means of the slotted shafts behind the label on the front panel.)

1-7 THE JACK B

is intended for use in limit-measurements against external standard, differential measurements, etc.

SECTION II

OPERATING PROCEDURE

2-1 OSCILLATOR AND DETECTOR

Any good oscillator may be used. An oscilloscope, a vacuum-tube voltmeter or an amplifier with headphones may be used as a detector. If an accuracy of about 1% is sufficient, headphones alone will do, provided that the measurement is made in quiet locations.

The type OSF1 Radiometer Oscillator-Amplifier incorporates a line operated oscillator and a selective 50 db amplifier. Both are designed for use in conjunction with measuring bridges. The amplifier is provided with a magic eye detector. If, however, acoustic detection is wanted, a pair of headphones can be connected to the amplifier.

If a separate oscillator and/or a separate detector is used, connect the units by means of short shielded cables. The resistance of the cable shield should be low. As the shield of the input jack is insulated from the bridge unit, it is also necessary to interconnect the oscillator and the bridge units with a low-resistance strap. Only the bridge proper should be grounded. This should be done to avoid direct coupling between oscillator and detector which will give rise to a wrong balance.

2-2 CHECKING THE ZERO

Ground the bridge and couple it to the oscillator and the detector. (Only the measuring bridge proper may be directly grounded. The oscillator and the detector are grounded through their connections to the bridge.)

Remove the measuring cables, if any, so that the jacks A, M, and B are open. Set the switch C_x to position FREE and the switch MULTIPLY C_x BY to position $\times 1$. Set all other switches and dials to zero position and check the zero of the bridge. If required, readjust the zero with the slotted screw marked ZERO.

In order to obtain a sharp minimum it may be necessary to adjust the continuous dial POWER FACTOR $\times 10^{-3}$ a little (see the section on the capacitance standards).

2-3 SETTING OF THE RESIDUAL GROUND BALANCE

Switch to the range $\times 0.01$. The minimum is reestablished by readjusting the POWER FACTOR dial and the pF dials. Now set the switch C_x to position GROUNDED. By means of the 2 slotted screws behind the label RESIDUAL GROUND BALANCE the equivalent zero displacement is outbalanced until silence is obtained anew. (The latter adjustment is not necessary unless very small (< 10 pF) grounded capacitances are measured).

2-4 MEASURING PROCEDURE

Connect the unknown through 2 shielded cables which are inserted in the jacks A and M. Measurements should always be made with the range switch in the position that has the smallest multiplication factor possible.

If a complex capacitance is being measured, unwanted components can be eliminated by connecting their junction to the internal chassis = the shield of the A-cable. See plan 1 fig. 2 and the text at the top of page 1-2.

Set the switch C_x to position GROUNDED or FREE according as the unknown is grounded or free. M is grounded in position GROUNDED. A has the lowest impedance referred to ground in position FREE. Therefore, whenever possible the side of C_x which is most exposed to picking up hum should be connected to the jack with the lowest impedance referred to ground.

When interchanging the unknown, the detector can be short-circuited by setting the C_x switch to position 0.

2-5 DETERMINING THE POWER FACTOR

At one frequency (generally 1000 cycles) the power factor dials are direct reading, except on the range $\times 0.01$ and at small capacitances. See below.

At other frequencies there is no simple relation between the power factor read and the true power factor. It is therefore recommended to determine the power factor by a substitution measurement.

- Note: When measuring large capacitances ($0.05 \mu\text{F}$) on the range $\times 100$, the resistance in the tap of the inductor to which C_x is connected, causes an apparent increase in the power factor.

The following correction applies at 1000 cycles:

$$\text{true power factor} = \text{power factor read} - 4.5 \times 10^{-3} C_x$$

C_x being the capacitance of the unknown in microfarads.

It should be noted that even small resistances in series with large capacitances will increase the apparent power factor heavily. Therefore, take care that your cables are in a good condition.

2-6 TEST VOLTAGE

At 1000 cycles the oscillator voltage should not exceed 50 volts. At frequencies lower than 500 cycles the oscillator should not exceed 0.1 volt per cycle. The input transformer is so dimensioned that in the ranges

$\times 0.001$, $\times 0.1$ and $\times 1$	the oscillator voltage =				the voltage across C_x			
$\times 10$	"	"	"	= $10 \times$	"	"	"	"
$\times 100$	"	"	"	= $100 \times$	"	"	"	"

2-7 SUMMARY OF MEASURING RANGES AND ACCURACY

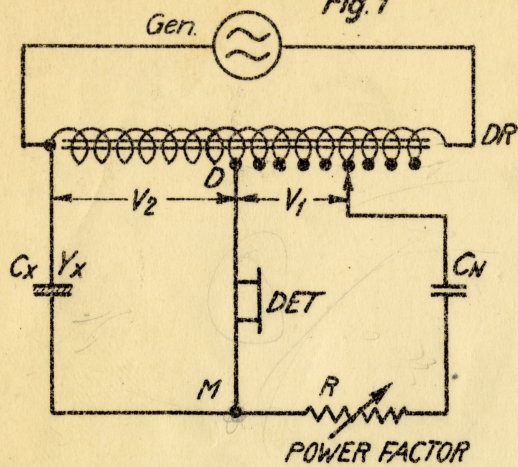
Range $\times 0.01$:	0-0.1 pF with the continuous pF dial alone:		
	Accuracy ± 0.0005 pF		
Range $\times 0.1$:	0-1111 pF.	Accuracy $\pm(0.1\% + 0.005 \text{ pF})$	
Range $\times 1$:	0-11.11 nF	" $\pm(0.1\% + 0.05 \text{ pF})$	
Range $\times 10$:	0-0.1111 μF	" $\pm(0.1\% + 0.5 \text{ pF})$	
Range $\times 100$:	0-1.111 μF	" $\pm(0.1\% + 5 \text{ pF})$	

The accuracies apply to the frequency range 200-5000 cycles, however with the slight modification stated below. At 50 cycles and 10 kilocycles the accuracy has dropped to 0.2%. The highest capacitance that can be measured over 2000 cycles with full accuracy is $4/f^2$, f being the frequency in kilocycles.

The calibration of the power factor dials is within $\pm(2\% + 0.5 \times 10^{-3})$ for capacitances greater than 100 pF, when the correction for large capa-

capacitance is taken into consideration. This applies only when the range switch is set at the position that has the smallest multiplication factor possible. Comparison of power factors for approximately equal capacitance values can be made with a much better accuracy, provided that the same bridge ratio is used.

Fig. 1



Plan 1

Zero condition:

$$\frac{V_1}{V_2} = Y_X (R + j\omega L)$$

Fig. 2

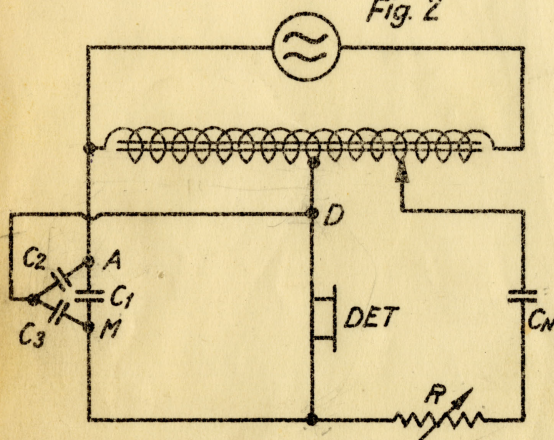


Fig. 3

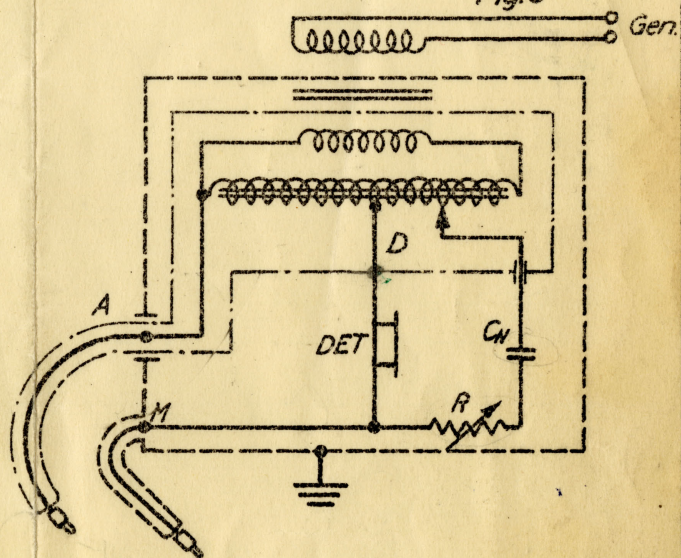
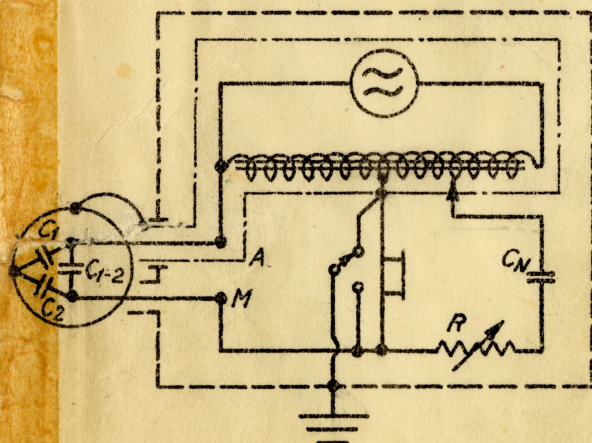
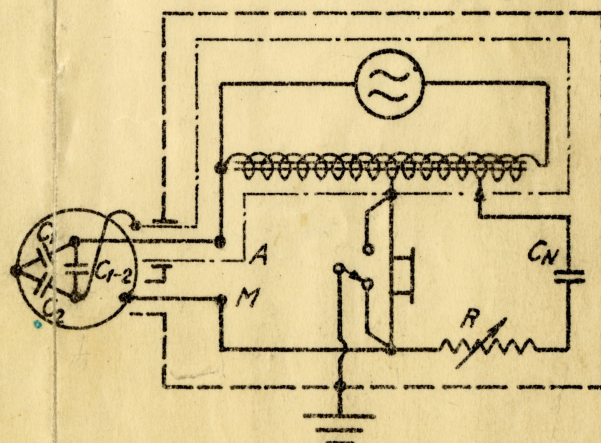


Fig. 4



Direct capacitance (C1-2)

Fig. 5



Ground cap. (C1)

