

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, generally 1000 cycles, 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 has been developed 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 from 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 special 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-

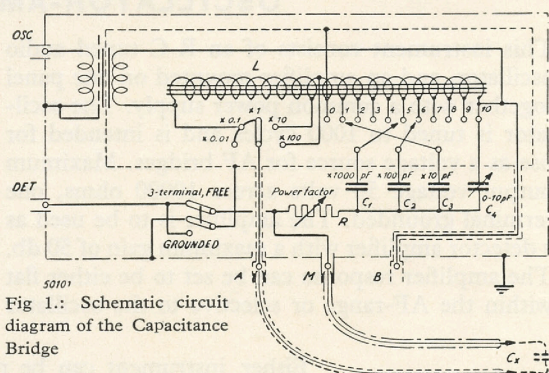


Fig 1.1: Schematic circuit diagram of the Capacitance Bridge

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.

The bridge is switched from measurement of 3-terminal to grounded condensers by switching the ground from the inductor-centre to the unknown-standard junction.

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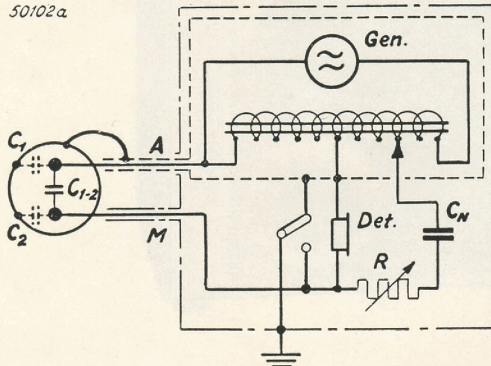


Fig. 2a: Measuring a direct capacitance

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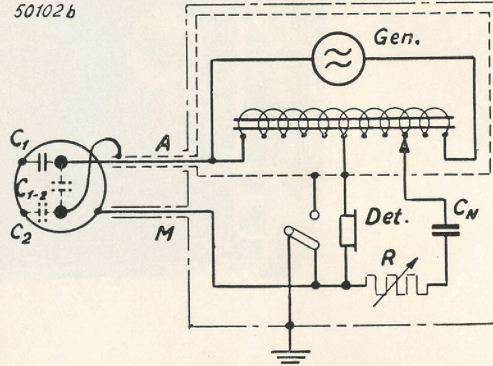


Fig. 2b: Measuring a ground capacitance

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 ± 0.1 % or 0.005 pF whichever is the larger.

Range $\times 1$: 0–11110 picofarads. Accuracy ± 0.1 % or 0.05 pF whichever is the larger.

Range $\times 10$: 0–0.1111 microfarads. Accuracy ± 0.1 % or 0.5 pF whichever is the larger.

Range $\times 100$: 0–1.111 microfarads. Accuracy ± 0.1 % or 5 pF whichever is the larger.

Frequency range: The bridge can be used with full accuracy on the range 200 to 5000 cycles. At 50 and 10000 cycles the accuracy is reduced to 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 1 % or 0.2×10^{-3} whichever is the larger. The calibration applies to one frequency only, generally 1000 cycles. A type CMB1L bridge with 800 cycle power factor calibration can be supplied on request.

Input: Asymmetrical, high impedance (about 10000 ohms 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 fitting the shielded terminals: 1 double-shielded cable type C1A11, and 1 single-shielded cable type C1A10.

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

Finish: Grey enamel. Etched panel cover.

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 intended for use as a voltage source for AF bridges. Maximum output voltage 50 volts across 10000 ohms, one terminal grounded. The amplifier is to be 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 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 is drilled to fit 19" relay racks. Panel height: 133 mm. Dimensions when supplied in separate cabinet, H: 160 mm, D: 215 mm, W: 500 mm. An Oscillator-Amplifier for 800 cycles, type OSF1L, can be supplied on request.

Either instrument can be purchased and used separately.

Data subject to change without notice.



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Introductory

The type CMB1 Capacitance Bridge is a direct reading precision bridge for measuring capacitance at audio frequency. The measuring range covers about 0.001 pF to 1.111 μ F in 5 ranges. The balancing is made by simultaneously balancing capacitance and loss. At one frequency, generally 1000 cycles (possibly 800cps) the power factor can be read directly.

The bridge is so designed that the component to be tested can be connected through shielded cables without their capacitance being included in the result of the measurement. By this means it is possible in most cases to leave the cable capacitances out of account.

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

Description

Operating principle and principal component parts

The principle on which the type CMB1 is based is shown in plan 1, fig. 1. By means of a tapped transformer L, which serves as a voltage divider, the voltage V_2 is varied across the fixed standard capacitor C_N , the resistance R being varied at the same time. The voltage across the detector will be zero when the products of voltage and admittance are equal for both bridge arms.

A voltage divider of the type in question will, if suitably designed, be extremely accurate and rigid against loading. In the transformers used in the CMB1, which have 20 sections, the error in the voltage division is of the order of 1 in 10^5 , so the accuracy is exclusively determined by the accuracy of the standard capacitor. While the autotransformer offers a high impedance to the oscillator voltage, the rigidity against loading is the same as that of a voltage divider consisting of $20 \times 0.8\Omega$.

This rigidity provides for the ability of the bridge to select the individual capacitance components from a network. An example of this is shown in fig. 2, plan 1. From the capacitance triangle $C_1-C_2-C_3$ it is desired to measure C_1 alone. The junction of C_2 and

C_3 is connected to the same transformer tap, D, as the detector. By this means the left half of the autotransformer is shunted by C_2 , which will practically not affect the voltage division as long as C_2 is kept within reasonable limits. (See the section on measuring ranges and accuracy). C_3 will shunt the detector, which, at most, will reduce its sensitivity. Therefore, only C_1 remains to be outbalanced.

The shielding of the bridge

The principle of the shielding of the bridge is shown in plan 1, fig. 3. The autotransformer and the switch arrangement is enclosed in an internal chassis (dot-and-dash line) to which the center of the autotransformer D is connected. The internal chassis is suspended in, but insulated from the external chassis (dotted line) which is kept grounded. It is seen how the shields of the measuring cables are connected to the internal and the external chassis, respectively, so that the cable capacitances are not included in the measurements.

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

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

The voltage divider consists of 2 autotransformers, transformer No. 2 being coupled to the center tenth of transformer No. 1. This makes it possible to obtain ratios of up to 1:100.

By means of switches the 3 fixed standards can be switched around the voltage decades.

The 5 measuring ranges are obtained as follows:

- x100: The unknown is coupled to the 1/100 tap to the left. The 3 fixed standards use the decade on the right-hand side of transformer No. 1. Full voltage across VK8.
- x10: The unknown is coupled 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 out of action. 1/100 voltage across VK8.

Phase alignment (power factor) is made by the variable resistor R shown in the figures of plan 1. It consists of a continuous part which covers the range $0-10 \times 10^{-3}$ in series with a decade that covers the range from $0-100 \times 10^{-3}$. The adjustment applies to one frequency only, 1000 (or 800) cps.

In the range x0.01, where the fixed standards are disconnected, R is practically ineffective. Therefore, it is supplemented by the arrangement shown in the diagram 450-A2 which is mechanically coupled to the continual power factor dial. In the ranges x0.1, x1, x10, and x100 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. It should be noted that the calibration of the power factor scale does not apply to the range x0.01.

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 slotted shafts RESIDUAL GROUND BALANCE which are accessible behind a label on the front panel

The capacitance standards. The 3 fixed standards are shielded mica standards of a recognized make. Their capacitance at 20°C is adjusted with an accuracy better than ~~0.5%~~ ^{0.05%}. The bridge is so designed that the standards appear free from losses at 1000 cps (or 800 cps).

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.

The autotransformers have already been mentioned in the first section of the description, page 1.

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

General comments on the use of the CMB1

Oscillator and detector: Any good oscillator may be used. An amplifier and headphones (possibly a vacuum-tube voltmeter ^{or oscilloscope}) may be used as a detector. In case an accuracy of about 1% is sufficient headphones alone may do, if the measurement is made in a quiet place.

Direct coupling between oscillator and detector should be avoided by means of an adequate shielding, as it will give rise to errors in measurement.

The type OSF1 Radiometer Oscillator-Amplifier which incorporates a line operated oscillator and a selective 50 db amplifier is especially designed with a view to use with measuring bridges.

Checking the zero: Ground the bridge and couple it to the oscillator and the detector. Only the measuring bridge proper may be directly grounded, while the oscillator and the detector are grounded through their connections to the bridge. Remove 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 x1. Check the zero of the bridge with all other switches and dials in zero position. If neces-

sary, make an adjustment 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 (confer the section on the capacitance standards).

Setting the RESIDUAL GROUND BALANCE: Then switch to the range $\times 0.01$. The minimum is reestablished by readjusting the POWER FACTOR and the pF dials. Now set the switch C_x to position GROUNDED. By means of the 2 slotted screws accessible 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 to be measured).

Connecting the unknown. The unknown is connected through 2 shielded cables which are inserted in the jacks A and M. If a complex capacitance is being measured, unwanted components can be eliminated from the measurement by connecting their junction to the internal chassis = the shield of the A-cable. Confer plan 1 fig. 2 and the text on page 1 below.

As the unknown is grounded or free the switch C_x is set to position GROUNDED or FREE. M is grounded in position GROUNDED. In position FREE A has the lowest impedance referred to ground. The side of C_x which is most exposed to picking up hum should therefore as far as possible be connected to the jack that has 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.

Determining the power factor

At 1000 cycles (or 800 cycles) the power factor dials are direct reading, except in the range $\times 0.01$ and at very small capacitances. See below.

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

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

The following correction applies at 1000 cycles:

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

C_x being the capacitance of the unknown in microfarads.

At 800 cycles the correction is:

$$\text{actual power factor} = \text{power factor read} - 3.6 \times 10^{-3} C_x$$

(< 0.0001 μ F)

When measuring small capacitances ~~xxxxxx~~ the supplementary arrangement mentioned in the introduction requires a correction:

$$\text{actual power factor} = \text{power factor read} \left(1 + \frac{2.2 \times 10^{-6}}{C_x} \right)$$

micro

C_x being the capacitance of the unknown in ~~xxxx~~ microfarads. This correction applies to the ranges x1 and x0.1 only. In the range ~~x0.001~~ the power factor is just

$$\text{power factor read} \times \frac{2.2 \times 10^{-6}}{C_x}$$

The terms stated here apply to 1000 cycles. At 800 cycles it is necessary to reckon with ~~a factor of~~ 2.8×10^{-12} instead of 2.2×10^{-12} .

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

x0.01, x0.1, and x1 the oscillator voltage = the voltage across C_x

x10	"	"	"	=10x	"	"	"	"
x100	"	"	"	=100x	"	"	"	"

Summary of measuring ranges and accuracy

Range x0.01: 0-0.1 pF with the continuous pF dial alone:
accuracy ± 0.0005 pF

Range x0.1: 0-1111 pF. Accuracy $\pm 0.1\%$ or ± 0.05 pF

Range x1: 0-11,110 nF. Accuracy $\pm 0.1\%$ or ± 0.05 pF

Range x10: 0-0.1111 μ F. Accuracy $\pm 0.1\%$ or ± 0.5 pF

Range x100: 0-1.111 μ F. Accuracy $\pm 0.1\%$ ~~or~~ ± 5 pF

The accuracies stated here only apply in the frequency range 200-5000 cycles, however, with the slight modification stated below. At 50 cycles and 10 kilocycles the accuracy has fallen 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.

2%
~~1%~~ or 0.2×10^{-3}

The calibration of the power factor dials is within ~~$1\% + 0.1 \times 10^{-3}$~~
for capacitances greater than 100 pF, when the correction for
large capacitances is taken into consideration. For very small
capacitances (< 10 pF) the accuracy is somewhat poorer, the error
increasing to $10\% + 0.5 \times 10^{-3}$.