

INSTRUCTION MANUAL

Type CMB1/OSF2
CAPACITANCE BRIDGE

3rd Edition



RADIOMETER

**ELECTRONIC MEASURING INSTRUMENTS
FOR SCIENTIFIC AND INDUSTRIAL USE**

1

INSTRUCTION AND OPERATING MANUAL
FOR

Type CMB1/OSF2
CAPACITANCE BRIDGE

3rd Edition

These instructions apply to type
CMB1 /OSF2 instruments only

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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 1,000 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 does not affect, in most cases, 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 1

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_1 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 $10 \times 0.7 \Omega$.

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 means of this the left half of the inductor is shunted by C_2 , which will have practically

no effect on 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. 1078-A2, appended to the instructions. The capacitance standard consists of 3 fixed standards, 10,000 pF, 1,000 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 22°C has been adjusted with an accuracy of better than 0.05%. The bridge is so designed that the standards appear free from losses at one frequency, generally 1,000 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 0.7×10^{-3} to the VK8. This is why VK8 is connected to the voltage divider through an RC circuit ($R_1 C_8$). The voltage across VK8 gets there at a phase delay which compensates for the above negative power factor.

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 the same as for x100.
- x1: Full voltage across the unknown. Otherwise the same 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 only one frequency, generally 1,000 cycles.

In the range x0.01 where the fixed standards are disconnected, R is almost ineffective. Therefore the calibration of the power factor scale does not apply to this range and has been supplemented by an arrangement which is mechanically coupled to the continuous power factor dial shown in diagram 1078-A2.

In the ranges x0.1, x1, x10 and x100 this arrangement is disconnected, so that on 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 x0.01.

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

The bushing of Jack B is connected to the center of the transformer No. 1 and the center contact to the right-hand side. It is intended for use in limit-measurements against external standard, differential measurements, etc.

With an unknown capacitance C_x connected to "A" and "M", and an external standard C_e connected to "B", the bridge will be balanced when the following equations are satisfied (C_i being the settings of the internal standards):

$$\text{Range switch position } \times 100: \quad C_x = 100 \times (C_i + C_e)$$

$$\text{Range switch position } \times 10: \quad C_x = 10 \times (C_i + C_e)$$

$$\text{Range switch position } \times 1: \quad C_x = C_i + C_e$$

$$\text{Range switch position } \times 0.1: \quad C_x = 0.1 \times C_i + C_e$$

$$\text{Range switch position } \times 0.01: \quad C_x = 0.01 \times C_i + C_e$$

It may be necessary to introduce additional losses in the external circuits to obtain balance since the power factor arrangement has no effect when only external standards connected to Jack B are used.

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 a quiet location.

The type OSF2 Radiometer Oscillator-Amplifier incorporates a line operated oscillator and a selective 60 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 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 would give 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 switch MULTIPLY C_x BY to position 1. Set all other switches and dials to zero position and check the zero of the bridge. If necessary, readjust the zero with the slotted screw marked ZERO.

The ZERO balance of the bridge is independent of the position of the dial $\text{POWER FACTOR} \times 10^{-3}$.

2-3 SETTING THE RESIDIAL 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 again. (The latter adjustment is not necessary unless very small (less than 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 corresponding to 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 depending on whether 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 1,000 cycles) the power factor dials are direct reading, except on the range $\times 0.01$.

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 (more than $0.05 \mu\text{F}$) on the range x100, the resistance in the tap of the inductor to which C_x is connected causes an apparent increase in power factor.

The following correction applies at 1,000 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 the cables are in good condition.

2-6 TEST VOLTAGE

At 1,000 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 the oscillator voltage = 10x the voltage across C_x
 x100 the oscillator voltage = 100x the voltage across C_x

2-7 SUMMARY OF MEASURING RANGES AND ACCURACY

Range x0.01:	0-0.1 pF with the continuous pF dial alone	Accuracy $\pm 0.0005 \text{ pF}$
Range x0.1:	0-1111 pF	Accuracy $\pm (0.1\% + 0.005 \text{ pF})$
Range x1:	0-11110 pF	Accuracy $\pm (0.1\% + 0.05 \text{ pF})$
Range x10:	0-0.1111 μF	Accuracy $\pm (0.1\% + 0.5 \text{ pF})$
Range x100:	0-1.111 μF	Accuracy $\pm (0.1\% + 5 \text{ pF})$

The accuracies apply to the frequency range 200-5,000 cycles, however with the slight modifications stated below. At 50 cycles and 10 kilocycles the accuracy has dropped to 0.2%. The highest capacitance that can be measured over 2 kc with the above accuracy is $4/f^2 \mu\text{F}$, f being the frequency in kilocycles.

The calibration of the power factor dials is within $\pm (2\% + 0.5 \times 10^{-3})$

when the correction for large 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.

SECTION 3

TYPE OSF2 OSCILLATOR-AMPLIFIER

3.1 DESCRIPTION

3.11 Construction

The instrument consists of an RC phase-shift oscillator and an amplifier mounted on a common panel with a common power supply. The oscillator is tuned to 1 kc and is intended as voltage source for the type CMB1 Capacitance Bridge or other AF bridges. The amplifier is used as a detector amplifier with a max. amplification of about 60 dB. The frequency response may be either flat within the audio-frequency range or selective with a resonance at the oscillator frequency. Either a pair of headphones (2x2 k Ω) or a built-in tuning indicator (EM 34) may be used as null indicator. The terminals for the connection of the headphones are provided with a voltage limiter which prevents the voltage from exceeding 0.5 - 1.0 volts.

3.12 The Oscillator

The phase shift oscillator is a special design of an RC generator. It operates with only one vacuum-tube. A three-mask network is connected between the anode and the grid of an amplifier tube and is so dimensioned that the total phase shift between the anode and the grid is 180° at the desired frequency (generally 1 kc). When the amplification is adjusted by means of the potentiometer REGENERATION so that the oscillations are just maintained, an almost purely sinusoidal output voltage is obtained (the distortion is less than 2%). At the same time the stability of the frequency also becomes very good.

3.13 The Amplifier

The amplifier consists of a low-noise pentode in the input followed by a double triode. By means of a switch, feedback can be introduced in one section of the double triode from the anode to the grid via a double T-network. Thus the feedback ratio becomes dependent on the frequency and gets a minimum at a specified frequency depending on the values of the components in the double T-network. In the standard model the network is so dimensioned that minimum

negative feedback (and accordingly maximum amplification) is obtained at $f = 1 \text{ kc}$.

By means of the switch AMPLIFIER FLAT - SELECTIVE the double T-network can be switched off and the anode resistance in the input tube can be reduced to $22 \text{ k}\Omega$. By this means the amplifier gets an almost straight frequency response within the audio-frequency range with almost the same amplification as the maximum amplification obtained in the selective position.

The other section of the double triode is used as an output tube with the anode coupled to the output jack marked PHONES or to a magic eye (EM34).

The EM34 has two sections with different sensitivity. At maximum amplification (about 60 dB) a voltage of about 2 mV must be fed to the input to make the lower sensitive section close entirely, while the upper section requires about 10 mV to close entirely. The minimum voltage that gives a visible deflection in the sensitive section is about $100 \mu\text{V}$.

3.2 OPERATING PROCEDURE

3.21 Connecting the Instrument to the a - c Line

The instrument is adjusted to 220 volt line voltage when leaving the factory. The voltage selector can be set to 110-115-127-200-220 and 240 volt line voltage. It is accessible when the cover plate on the back of the instrument has been removed.

When the instrument has warmed up for 5-10 minutes, adjust the slotted potentiometer REGENERATION so that the oscillator just oscillates constantly. With the potentiometer OSCILLATOR OUTPUT fully turned on, the output voltage will be 30-40 volts when the load is 10 kilohms. The distortion factor will be about 1.5%. If the potentiometer REGENERATION is turned too much to the right, the distortion factor increases. At 50 volt output it will thus be about 2%. The output impedance of the oscillator is about $25 \text{ k}\Omega$.

3.22 Connecting the Oscillator to the Bridge

When making bridge measurements it is generally preferred to

ground one of the terminals at the zero-indicator. It will therefore be necessary to connect the oscillator to the bridge through a double shielded transformer. Thus the type CMB1 Radiometer Capacitance Bridge is provided with a built-in double shielded transformer.

- 3.23 Adjusting the Output Voltage and the Amplification
If the bridge is far from balanced, it may, due to the limitation of the voltage, often be difficult to ascertain in which direction the components of the bridge must be changed in order to obtain balance. It will then be necessary to reduce either the oscillator voltage or the sensitivity of the amplifier until the limitation ceases. As the bridge approaches balance the voltage and the sensitivity increase again to obtain the highest possible accuracy of the adjustment of the bridge.

3.3 MAINTENANCE

To remove the instrument from the cabinet, remove the 4 set screws along the edge of the cabinet.

At the end of the manual is a wiring diagram stating the normal operating voltages. V_{dc} indicates d-c voltage to chassis, and V_{ac} indicates a-c voltage to chassis, when a 1,000 c/s voltage of 1 mV r-m-s is fed to the amplifier input and the potentiometer AMPLIFIER GAIN has been turned to the extreme right. The values indicated are average values for measurements on various series. The measurements have been made with a vacuum-tube voltmeter with negligible consumption.

3.31 Tube Replacement

All tubes are replaceable without making any changes in the internal adjustments of the instrument.

3.32 Adjusting the potentiometers P_1 , P_2 and P_3

When the instrument leaves the factory, the P_1 , P_2 and P_3 potentiometers are correctly adjusted and lacquered. Generally it will not be necessary to readjust these potentiometers later on. They are only slightly influenced by tube replacement.

When defective components are replaced in the phase shift network or in the double T-network, a readjustment may be neces-

sary. It should be made as follows:

3.33 Adjusting the P_1 Potentiometer

In the first place the P_1 potentiometer influences the frequency of the oscillator, but to some degree it also influences the amplitude. When adjusting the frequency and amplitude, the procedure is as follows:

Measure frequency and amplitude on the output jack of the oscillator (marked "1,000 CYCLES OUTPUT") which loading is 10 k Ω . Turn the potentiometer OSCILLATOR OUTPUT to the extreme right. Then turn the potentiometer REGENERATION to the right until the oscillator oscillates with an output voltage of about 40 volts. If the frequency is too low, turn the P_1 potentiometer a little to the right, and readjust the amplitude by turning the potentiometer REGENERATION a little to the right. If the frequency is too high, turn the potentiometers in the opposite direction.

At an output voltage of 30 volts, the distortion factor will be about 1.5%. If the output voltage is increased to 50 volts by means of the potentiometer REGENERATION, the distortion factor will increase to about 2% and the frequency by about 3 c/s.

3.34 Adjusting the P_2 and P_3 Potentiometers

The P_2 and P_3 potentiometers are intended for fine adjusting of the double T-network so that the amplification will be maximum at the correct resonant frequency without making the amplifier unstable.

P_3 determines the resonant frequency, while P_2 determines the maximum amplification.

However, it is inexpedient to adjust P_2 and P_3 to maximum output because this can easily result in a wrong position in which so great a phase shift occurs in the double T-network that the amplifier becomes unstable and begins oscillating at a frequency near 1,000 c/s. The adjustment should therefore be made as follows:

Feed a 1,000 c/s voltage of 5-10 mV to the amplifier input. This voltage can be drawn from the oscillator of the instrument proper

through an appropriate voltage divider. Set the switch AMPLIFIER FLAT - SELECTIVE to its mid position. Connect a vacuum-tube voltmeter to the tag on the switch which is connected to the double T-network ($68\text{ k}\Omega$ and 2.5 nF). Then adjust P_2 and P_3 until the vacuum-tube voltmeter gives minimum deflection. The instrument should be grounded and if possible mounted on an L-shaped grounded iron plate to reduce hum, if there is any. It is important that the vacuum-tube voltmeter does not load the double T-network too much.

When P_2 and P_3 have been adjusted, check the amplification at $1,000\text{ c/s}$. It should be about 60 dB , and the 3 dB bandwidth should be about $\pm 100\text{ c/s}$. The amplification at 2 kc should have dropped by about 19 dB .

SECTION 4 SPECIFICATIONS

CAPACITANCE BRIDGE

0.001 pF to 1.111 μ F absolute in 5 ranges, viz.:

0-0.1 pF
0-1111 pF
0-11110 pF
0-0.1111 μ F
0-1.111 μ F

ACCURACY

0.1% of reading +0.005 pF above 0.1 pF

0.0005 pF below 0.1 pF

The bridge can be used with full accuracy from 200 cps to 5,000 cps.

At 50 cps and 10,000 cps the accuracy has decreased to about 0.2%.

The maximum capacitance which can be measured with full accuracy decreases above 2 kc according to the expression $C_{\max} = 4/f^2$, where f is the frequency in kc and C_{\max} is the capacitance in μ F.

POWER FACTOR AT 1,000 cps

Range: 0 to 110×10^{-3}

Accuracy: 2% of reading +0.5 $\times 10^{-3}$.

The accuracy stated applies to values above 100 pF; at lower values the accuracy is somewhat lower.

In the $\times 0.01$ range, balance can be achieved, but power factor measurements cannot be made.

INPUT

Unbalanced, high impedance (about 10 k Ω at 1,000 cps).

The maximum input voltage is 50 volts but at frequencies below 500 cps it should not exceed 0.1 volts per cps.

OSCILLATOR

Frequency: 1,000 cps ± 10 cps.

Output: 0 to 50 volts continuously adjustable when connected to the bridge.

Distortion: About 2% at 50 volts output across 10 k Ω .

Hum: Below 20 mV

Output impedance: Approx. 25 k Ω

AMPLIFIER

Amplification: 0 to 60 dB continuously adjustable.

Selective Response: 3 dB down at ± 100 cps.

Flat Response: 3 dB down at 200 cps and 9 kc.

Hum: Below 1 mV with selective response.

Below 5 mV with flat response.

Output Impedance: Approx. 10 k Ω

Output: Limited to 0.5-1 volt.

INDICATOR

Built-in electron ray indicator with two sections of different sensitivity.

POWER SUPPLY

Voltages: 110, 115, 127, 200, 220, 240 volts.

Line frequencies: 50 to 60 cps.

Consumption: 40 watts.

TUBES

1 ECC83 (12AX7)

2 EF86 (6267)

1 EL83 (6CK6)

1 EM34 (6CD7)

MOUNTING AND FINISH

The capacitance Bridge and the Oscillator-Amplifier are mounted on separate front panels but are inserted in a common cabinet. The two units are connected by shielded wires. The front panels are compatible with a 19" standard rack.

DIMENSIONS

Height	Width	Depth
380	565	260 mm
15	22	10 1/4 inches

WEIGHT

25 kilos net (55 lbs.)

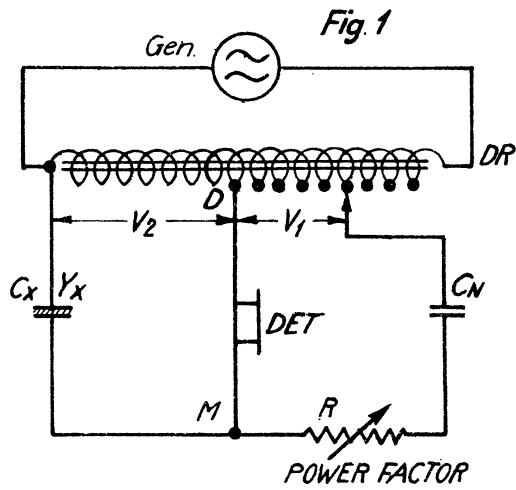
ACCESSORIES SUPPLIED

1 type 1A10 single-shielded cable, 1 m long.

1 type 1A11 double-shielded cable, 1 m long.

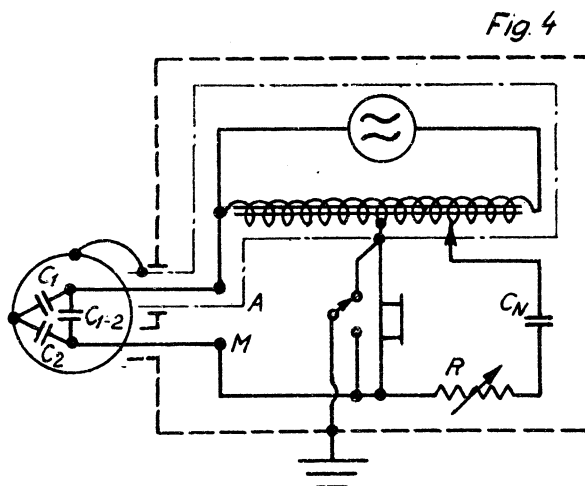
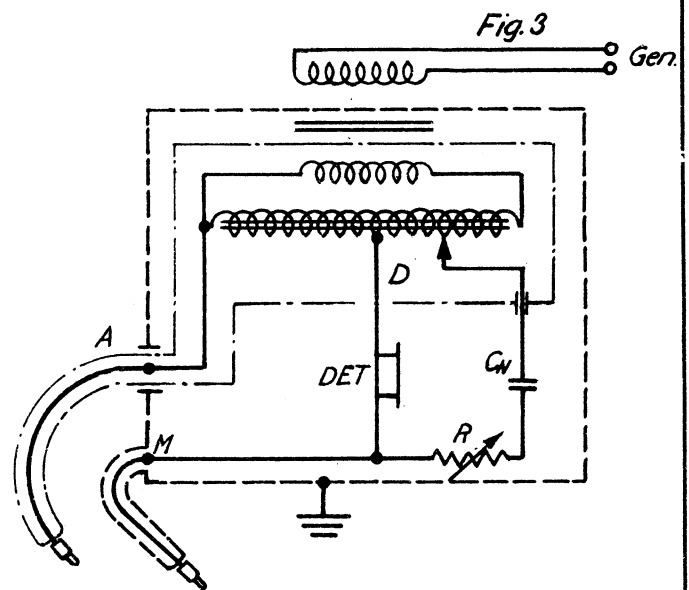
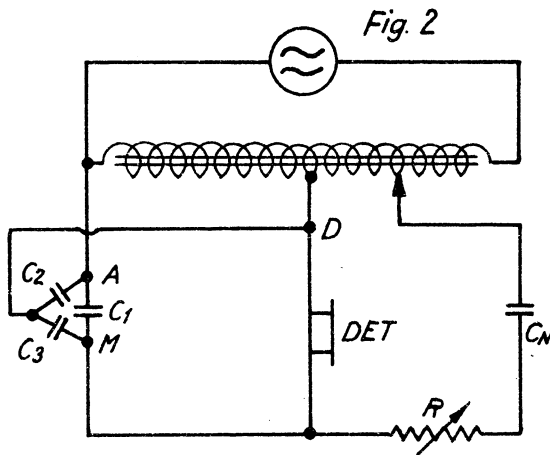
Both cables fit into the shielded outlets from the Capacitance Bridge.

1 type 12G19-1.5 power cord.

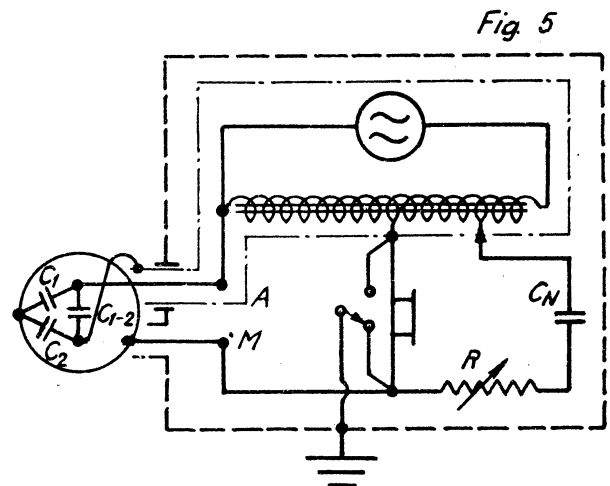


Zero condition:

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



Direct capacitance (C1-2)



Ground cap. (C1)

