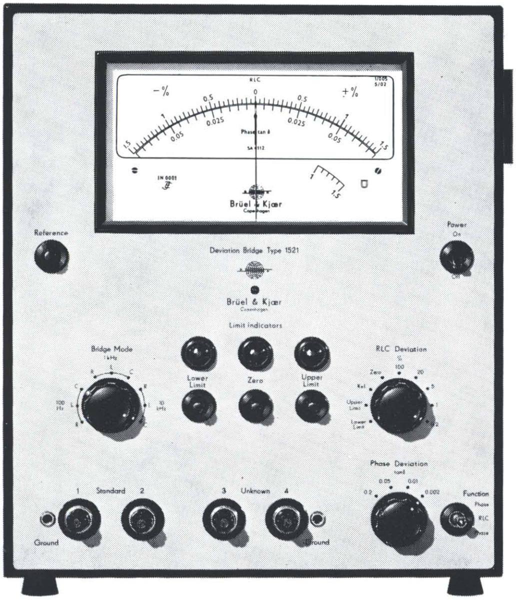
1521

Instructions and Applications



Deviation Bridge Type 1521

A comparator designed principally for checking and sorting of resistors, inductors and capacitors. It can be adapted for many purposes involving comparative measurements. Operation frequencies are 100 Hz, 1 kHz, and 10 kHz.

BRÜEL & KJÆR

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DEVIATION BRIDGE TYPE 1521

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CONTENTS

1. INTRODUCTION

The Deviation Bridge is designed as an updated version of the earlier Brüel & Kjær Deviation Bridges Types 1503, 1504. Operating at either of the frequencies of these earlier instruments, 100 Hz and 1 kHz respectively, the 1521 adds higher precision, and a third operating frequency of 10 kHz. The 1521 is suited principally for non-earthed measurements, but can be used for earthed measurements under certain conditions. A second Brüel & Kjær Deviation Bridge, Type 1519 operates at a frequency of 100 kHz (therefore replacing Type 1506) and is suitable for both earthed and non-earthed measurements.

The principal applications of the 1521 Deviation Bridge will be found in sorting and comparison work on assembly lines. It can be used for:

differentiation between satisfactory and sub-standard components,
comparison of resistors, inductances or capacitors with pre determined standards,
fast and accurate measurements of impedance or admittance giving both absolute value and phase,
controlling automatic sorting equipment,
measurement of differences in lengths, angles, pressures, or temperatures, when used with appropriate transducers.

2. CONTROLS

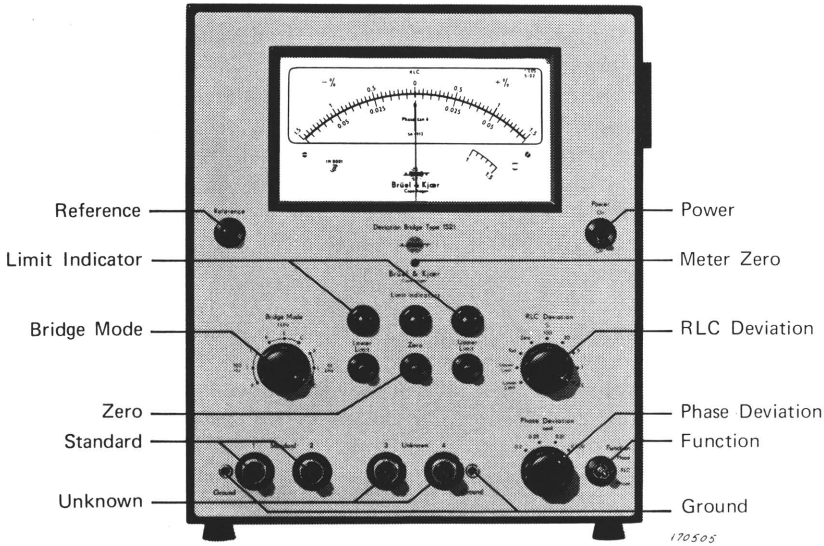


Fig.2.1. Front panel of Deviation Bridge Type 1521

POWER:	Mains switch. On – off. Mechanical zero setting of the indicating instrument. Only to be corrected with the equipment switched off.
REFERENCE:	With this control the oscillator voltage is set to its reference value.
BRIDGE MODE:	The 9 positions of the switch are divided into three groups which relate to the operating frequencies 100 Hz, 1 kHz and 10 kHz. Each group has three sub-positions R, L and C, which are assigned to the familiar symbols for resistances, inductances and capacitors.

LIMIT INDICATORS: "Lower Limit": This is set with left-hand control when the RLC DEVIATION switch is at the position of the same name. If only the red lamp to the left lights during operation, the pointer deflection is below the set limit.

"Upper Limit": This is set with the right-hand control, when the RLC DEVIATION switch is at the position of the same name. If only the red lamp to the right lights during operation, the pointer deflection is above the set limit.

Green lamp: When only the green lamp lights during operation, the pointer deflection is inside the set limits.

During calibration, all three lamps are lit. This also happens in the case of overload. The three lamps are also connected to the output socket LIMIT SIGNAL on the rear panel.

ZERO: Electrical zero setting. This control is for drift compensation. It is not one of the limit indicators.

RLC DEVIATION: Difference in magnitude. The values given 0.2 – 1 – 5 – 20 and 100% relate to the calibration points of the interchangeable scales.

"Zero": In this position the instrument indicates the drift which is to be compensated with the "Zero" control underneath the green lamp.

"Upper Limit", "Lower Limit": In these positions the instrument indicates the limits which can be set with the controls of the same name. During calibration, all three lamps are lit.

"Ref": In this position the oscillator voltage can be set to its reference value by means of the REF potentiometer.

PHASE DEVIATION: Difference in phase angle. The specified tanδ values relate to the calibration points of the interchangeable scales.

FUNCTION: Switch for reading giving difference in magnitude or phase angle. From the lower position "Phase" the switch automatically returns to the middle position "RLC", while the upper position "Phase" locks in. The middle position is neutral except when the contacts 1 and 3 of the EXT. PHASE KEY socket are connected together. In this case an internal relay switches to the "Phase" mode.

STANDARD – UNKNOWN: Terminals for connecting the standard and the unknown components. The terminals 1 and 4 are connected to the oscillator, and their threaded sockets are earthed together with the GROUND socket on the inner bridge midpoint. The terminals 2 and 3 are connected to one another internally. They lead to the input of the impedance transformer. Their threaded sockets are earthed in operating mode "L", and in operating modes "R" and "C" they are connected to the output of the impedance transformer. Screened cables can be connected via the screening covers DB 1065 and plugs JP 0101 supplied.

MAINS CONNECTION: For connection of the power supply. To turn the selector to the correct voltage it is first necessary to unscrew the central fuse. A wide bladed screwdriver or a small coin can then be used.

METER OUTPUT: Analogue output. The plug required is JP 4705. At contact 5 a D.C. voltage proportional to the pointer deflection is brought out, which amounts to +1.1 V at full scale deflection. It originates from a low-impedance source but for short circuit protection it is separated from this by a 220 Ω resistor. Ground on pin 6. The meter of the Deviation Bridge can

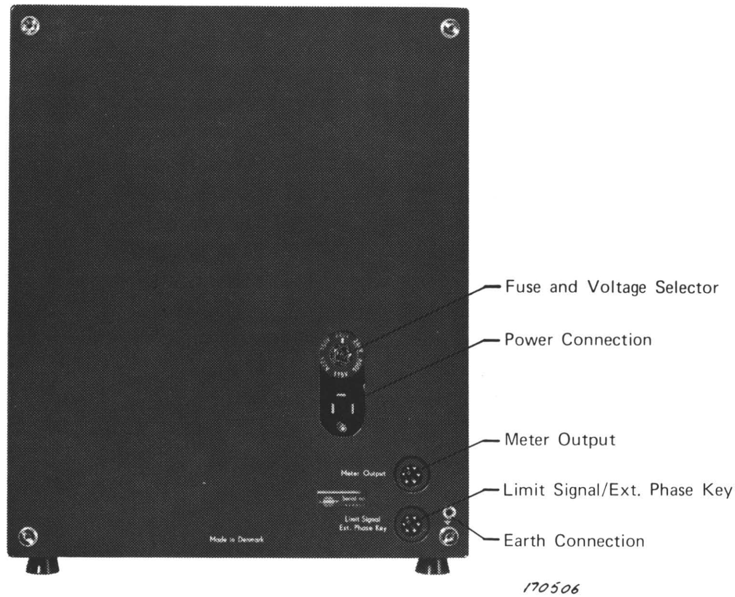


Fig.2.2. Rear panel of Deviation Bridge Type 1521

be switched off by short-circuiting the contacts 4 and 6. The voltage at the analogue output contact 5, is not affected by this. Unnecessary stress on the meter during automatic measurements can be avoided by this means.

LIMIT SIGNAL
EXT.PHASE KEY: The plug required is JP 4705. This socket allows:

a) Control of an automatic machine via 6 V relays, which are activated together with the lamps:

Red Lamp LOWER LIMIT	Contact 2 – 4
Green Lamp	Contact 2 – 5
Red Lamp UPPER LIMIT	Contact 2 – 6

For short-circuit safety the current flowing in the common contact 2 is limited to 0.5 A by means of a PTC resistor. On reaching the load limit the voltage and current break down abruptly to low values, without the lamps ceasing operation. After a brief short-circuit, the voltage starts again after a short delay.

The internal circuit operates with controlled diodes which are operated with an unsmoothed, rectified voltage from the mains transformer. Distortions in the wave shape by externally connected reactances can impair the quenching of the controlled diodes. For this reason, capacitive loads are to be avoided. In the case of inductive loads (relays, motor) a semiconductor diode should be connected in parallel with the loads at contact 2 – 4, 2 – 5 and 2 – 6 in each case. The diodes should be connected with their cathodes at contact 2.

b) Parallel connection of a remote-control switch via contact 1 – 3 to the RLC – PHASE switch. The operating mode RLC corresponds to the open switch function, and the PHASE operating mode to the closed switch function. When using the remote switch, the built-in switch must be fixed on position RLC. The connected lead is isolated from the other circuits of the deviation bridge by a relay.

3. PRINCIPLES OF OPERATION

3.1. SCALE DIVISION

Considering the output stage of the Deviation Bridge and identifying parameters as in Fig.3.1, the vector diagram of Fig.3.2 can be drawn.

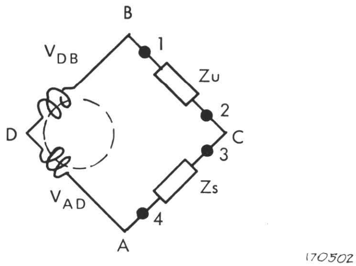


Fig.3.1. Output stage of the Deviation Bridge

V_{AD}, V_{DB}	= voltages on the two halves of the secondary winding of the bridge transformer (= V_o)
V_s, V_u	= voltage on the standard and the unknown
Z_s, Z_u	= impedance of the standard and unknown
V_{DC}	= voltage over the bridge diagonal

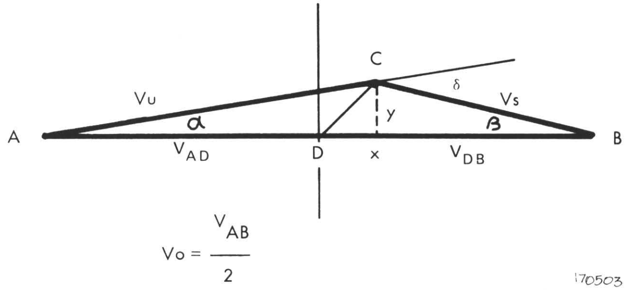


Fig.3.2. Vector diagram of the bridge voltage

x = projection of V_{DC} to V_{AB}. This is the quantity measured in operating mode "R" and "L", with opposite sign measured in operating mode "C"

y = projection of V_{DC} to V_{AB}. This is the quantity measured in operating mode "Phase".

The following relations exist:

1. $V_s + V_u = V_{AB}$ (complex vectors)

2. $$\frac{V_s}{V_u} = \frac{Z_s}{Z_u}$$

If we put $V_{AD} = V_{DB} = 1/2\ V_{AB} = 1$, then

3. $$|V_u| = \sqrt{(1+x)^2 + y^2}$$

4. $$|V_s| = \sqrt{(1-x)^2 + y^2}$$

The relative difference in magnitude between the impedances of unknown and standard, relative to the standard, (i.e. the deviation) is calculated as follows:

5. $$p = \frac{Z_u - Z_s}{Z_s} = \frac{Z_u}{Z_s} - 1 = \frac{V_u}{V_s} - 1$$

6. $$p = \sqrt{\frac{(1+x)^2 + y^2}{(1-x)^2 + y^2}} - 1$$

If $y^2 \ll 1$, we can write:

7. $$p = \frac{1+x}{1-x} - 1 = \frac{2x}{1-x}$$

8. $$x = \frac{p}{2+p}$$

The divisions of the RLC % scales are calculated on the basis of the results 7. and 8. For the reference values of the various measuring ranges the results are:

p%	x_{ref}
0.2	0.000999
1	0.004975
5	0.024390
20	0.090909
100	0.333333

The numerical values listed under x_{ref} give in each case that part of the voltage V_{AD} which produces the reference deflection (red scale mark) in the associated measuring range. The relative difference in magnitude of the admittance of unknown and standard, relative to the standard, is calculated:

9. $$p_a = \frac{\frac{1}{Z_u} - \frac{1}{Z_s}}{\frac{1}{Z_s}} = \frac{Z_s}{Z_u} - 1$$

similarly to 5., 6., 7. and 8. we obtain

10. $$p_a = -\frac{2x}{1+x} \qquad x = -\frac{p_a}{2+p_a}$$

In the operating mode "C", where p_a is measured, x is indicated with reversed sign, so that the same scale can be used as in the operating modes L and R.

The tangent of the phase difference between unknown and standard is obtained from the following calculation:

If α is the phase angle between V_u and V_{AB}
β is the phase angle between V_s and V_{AB}
δ is the phase angle between V_s and V_u

then

11. $$\delta = \alpha + \beta \text{ and}$$

12. $$\tan\delta = \frac{\tan\alpha + \tan\beta}{1 - \tan\alpha \tan\beta}$$

From the vector diagram it follows:

13. $$\tan\alpha = \frac{y}{1 + x} \quad \text{and} \quad \tan\beta = \frac{y}{1 - x}$$

14. $$\tan\delta = \frac{2y}{1 - x^2 - y^2}$$

If $x^2 \ll 1$, it is possible to simplify as follows:

15. $$\tan\delta = \frac{2y}{1 - y^2} \qquad y = \frac{1}{\tan\delta} \left(\sqrt{1 + \tan^2\delta} - 1\right)$$

The division of the tan δ scale is calculated in accordance with this function. For the reference values of the measuring range switch the results are:

tan δ	y_{ref}
0.002	0.001
0.01	0.005
0.05	0.025
0.2	0.099

3.2. UNCERTAINTIES

By neglecting the component y in equation 7) the indicated deviation p^* with a difference in phase is greater than the actual deviation p, but the error for $\tan\delta < 0.2$ and $p < + 20\%$ is on the average less than 1%. The division of equations 7. : 6. gives the following approximation:

16. $$\frac{p^*}{p} = 1 + \tan^2 0.5\delta^* \quad (1 + 0.5\, p^* + 0.16\, p^{*2})$$

The reciprocal of the error is shown in Fig.3.3. It corresponds to the correction factor K by which the indicated deviation p^* is to be multiplied if the true deviation is being sought.

By neglecting the component x in equation 15) the indicated angular deviation δ^* for unequal amounts is smaller than the true angular deviat-

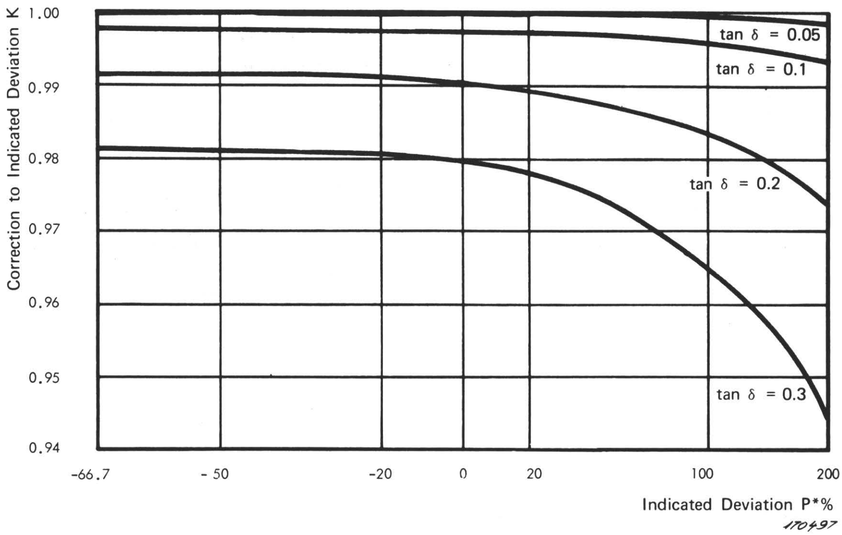


*Fig.3.3. Influence of phase angle tan δ on the indicated difference in amount p**

ion δ, but the mean error for $p < 20\%$ and $\tan\delta < 0.3$ remains below 1%. By division of the equations 15. : 14. the following solution is obtained:

17. $$\frac{\tan\delta^*}{\tan\delta} = 1 - \frac{x^2}{1 - y^2} = 1 - \left(\frac{p^*}{2 + p^*}\right)^2 \cdot \frac{1}{1 - \tan^2 0.5\,\delta^*}$$

The reciprocal of the error is shown in Fig.3.4. It corresponds to the correction factor K_δ by which the indicated angular deviation $\tan\delta^*$ is to be multiplied if the true angular deviation $\tan\delta$ is being sought.

The errors described above are due to the process of measurement, they cannot be avoided by technical countermeasures.

If $x \ll y$ or $y \ll x$, the smaller component is only conditionally measurable, because the amplifier has to process the complete signal $\sqrt{x^2 + y^2}$. Overload occurs if $x \geqq 20\, y_{ref}$ or $y \geqq 20\, x_{ref}$, and in this case the three warning lamps light. It should also be noted that there are technical limits to the separation of the two components. With zero deviation (x = 0)

18. $$x^* \leqq \pm 0.006\, y, \quad p^* \leqq \pm 0.012 \tan 0.5\delta^*$$

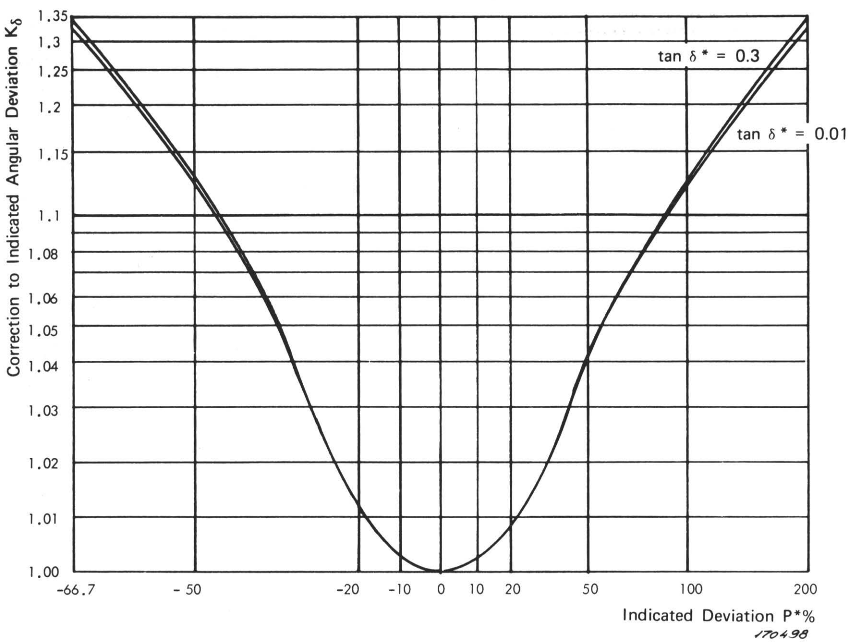


*Fig.3.4. Influence of the deviation p, on the indicated tan δ **

With zero angular deviation (y = 0, tan δ = 0) the indicated value is

$$19. \qquad y^* \leqq \pm\, 0.006\ x, \ \tan\delta^* \leqq \pm\, 0.012 \cdot \frac{p^*}{2 + p^*}$$

The reason for this error is differences in transit time between the signal and reference channel (see 5.6, 6.5, 6.6). Equations 16. and 18. are of particular importance when inductive or capacitive reactances are to be compared with pure resistances, see section 3.16. Here the difference in angle is 90°, tan δ = ∞ is outside the range of indication, tan 0.5 δ = 1 causes doubling of the deviation indication. Accordingly the measurement objects can differ by a maximum of 0.6% when the deviation indication is zero. With careful adjustment in accordance with section 6.5, a smaller uncertainty can be expected.

3.3. ERRORS IN HIGH IMPEDANCE MEASUREMENTS

In the case of high-impedance measurement objects (resistances > 2 MΩ in operating mode R – 100 Hz, capacitors < 500 pF in operating mode

C – 10 kHz), the input impedance Z_e causes losses which can be compensated in accordance with the calibration instructions (4.3 – 4.8, 4.20) by correcting the oscillator voltage by the factor $K = 1 + 0.5 \frac{Z_s}{Z_e}$. Here the resistance of the outer bridge arm Zs / / Zs (1 + p) is dependent on the unknown measurement p. The relationship with the indicated percentage difference in impedance p^* is obtained from the equation:

20. $$\frac{2}{p} - \frac{2}{p^*} = \frac{1}{K} - 1$$

In this the following are interchangeable with change of sign: P with p^*, p with p_a, p_a with p_a^* (p_a = percentage difference in admittance), and K with K / (2K – 1), see the following equations and examples:

For operating mode R and L:

21. $$p^*/p = 1 - 0.5\, p^* + 0.5\, \frac{p^*}{K}$$

$$p/p^* = 1 + 0.5\, p - 0.5\, \frac{p}{K}$$

For operating mode C:

22. $$p_a^*/p_a = 1 + 0.5\, p_a^* - 0.5 \frac{p_a^*}{K}$$

$$p_a/p_a^* = 1 - 0.5\, p_a + 0.5\, \frac{p_a}{K}$$

Examples:

Measurement object	Operating mode	Correction factor	Measured value	True value
Resistances	R – 100 Hz	1.5	25% –24%	24% –25%
Capacitances	C – 10 kHz	1.5	24% –25%	25% –24%
Inductances	L or R	0.75	24% –25%	25% –24%

For small (deviations, below) about 5%, the indication error can usually be ignored. If high-impedance measurement objects have to be sorted in classes of more than 5% width, at least the limit indicator must be set with allowance for the calculated indication error:

1. It is assumed that the indication sensitivity was set in accordance with the calibration instructions (sections 4.3 – 4.8). If the correction factor K has not already been noted, this can be remedied as follows:

2. RLC DEVIATION "Ref"
   Select FUNCTION "RLC"
   Read the pointer deflection in relation to the auxiliary scale 1 . . . . 1.5. If the measured value is smaller than 1, use the (linearly divided) 0.01 tan scale (x 100). The result is between the numerical values 0.2 and 1.5.

3. Put the instrument back into its original modes and note the selected RLC scale range and the RLC DEVIATION switch position. Find the associated amplification coefficient from Table 3.1.

RLC DEVIATION Swtich position	RLC magnitude scale 0.2%	1%	5%	20%	100%
0.2	1	4.98	24.4	91	333.7
1	0.201	1	4.9	18.27	67.0
5		0.204	1	3.72	13.7
20			0.268	1	3.67

Table 3.1. Amplification coefficient

4. Multiply the results 2. and 3. together. The result corresponds to K.

5. Consider the given limits as "true values" and calculate the associated "measured values" to which the limit indicators must be set. Compare with the examples given above, see also Table 3.2. In Table 3.2, column K = 1 corresponds to the true deviation when the other columns are related to the indicated differences in resistance in operating mode R. In operating mode C the opposite signs will apply. In operating mode L the values of K in brackets are to be used together with a change in sign.

Correction factor to oscillator voltage, K							
1	1.1	1.2	1.5	2.5	5	25	90
100	96.65	92.31	85.71	76.92	71.43	67.57	66.91
75	72.53	70.59	66.67	61.22	57.69	55.15	54.71
50	48.89	48.00	46.15	43.47	41.67	40.32	40.09
30	29.60	29.27	28.57	27.52	26.79	26.22	26.12
25	24.72	24.49	24.00	23.26	22.72	22.32	22.25
20	19.82	19.67	19.35	18.87	18.52	18.25	18.20
15	14.90	14.81	14.63	14.35	14.15	13.99	13.96
12.5	12.43	12.37	12.24	12.05	11.90	11.79	11.77
10	9.96	9.92	9.83	9.71	9.62	9.54	9.53
7.5	7.48	7.45	7.41	7.33	7.28	7.24	7.23
5	4.99	4.98	4.96	4.93	4.90	4.89	4.88
2.5	2.50	2.50	2.49	2.48	2.48	2.47	2.47
2	2.00	2.00	1.99	1.99	1.98	1.98	1.98
−2	−2.00	−2.01	−2.01	−2.01	−2.02	−2.02	−2.02
−5	−5.01	−5.02	−5.04	−5.08	−5.10	−5.12	−5.13
−7.5	−7.53	−7.55	−7.59	−7.67	−7.73	−7.78	−7.79
−10	−10.05	−10.08	−10.17	−10.31	−10.42	−10.50	−10.52
−12.5	−12.57	−12.63	−12.77	−12.99	−13.16	−13.30	−13.32
−15	−15.10	−15.19	−15.38	−15.71	−15.96	−16.16	−16.20
−20	−20.18	−20.34	−20.69	−21.28	−21.74	22.12	−22.19
−25	−25.29	−25.53	−26.09	−27.03	−27.78	28.41	−28.53
−30	−30.41	−30.77	−31.58	−32.97	−34.09	35.05	−35.22
−50	−51.16	−52.17	−54.54	−58.82	−62.50	65.77	−66.42
K = 1 (1)	1.1 (0.92)	1.2 (0.86)	1.5 (0.75)	2.5 (0.625)	5 (0.56)	25 (0.51)	90 (0.5)

Table 3.2. Measurement of high impedance items

An indication error of similar magnitude also occurs in the PHASE operating mode where the following equation applies:

23. $$\frac{\tan\delta^*}{\tan\delta} = \frac{1 + \frac{p^*}{2K}}{1 + \frac{p^*}{2}}$$

in which p^* is again interchangeable with $-p_a{}^*$. For $p^* = \pm 25\%$ and $\tan\delta = 0.25$ the measured values are $\tan\delta^* = 0.241$ and 0.262. If the systematic error is also taken into account in accordance with equation 17., the measured values are then $\tan\delta^* = 0.238$ and 0.258. (The higher value relates in each case to the negative value of p^*).

If high-ohmic resistances are being tested, the input capacitance C_e produces a phase angle $\tan\Phi = 0.5\ \omega\ R_s\ C_e$, which is not troublesome if R_s, R_u are pure resistances. Similar to equation 18), however, a difference in phase angle $\tan\delta^* \cong p^* \tan\Phi$ is incorrectly shown when $\tan\delta = 0$. When there is a true difference in phase angle $\tan\delta$, the magnitude indication is uncertain by $p^* = \tan\delta\ .\ \tan\ \Phi$. Therefore in the calibration instructions 4.5 and 4.7 an ohmic resistance is connected in parallel with the input capacitance, which reduces the phase angle.

3.4. POTENTIOMETRIC MEASUREMENT

If we pass the voltage between terminal 1 and the earth socket GROUND via a voltage divider R_1 / R_2 to the input, we obtain in operating mode R or L.

24. $$x = \frac{R_1}{R_1 + R_2} = \frac{p}{2 + p}$$

and the indication is $$p = \frac{2\ R_1}{R_2}$$

in operating mode C, x is negative and

25. $$p = \frac{1}{1 + \frac{R_2}{2\ R_1}}$$

The potentiometric measurement methods in 4.9, 4.10 and 4.11 as well as Table 5.1 are based on 24).

If we replace the resistance R_2 by a capacitance decade C, the output voltage in the PHASE mode is

$$y = \omega RC$$

and the phase indication $$\tan\delta = \frac{2}{\frac{1}{\omega RC} - \omega RC}$$

The output voltage in the operating mode RLC corresponds to

$$x = \frac{1}{2} - \sqrt{\frac{1}{4} - (\omega RC)^2}$$

For x, y $\ll 1$, we have

$$p \cong \frac{\tan^2 \delta}{2}$$

These relations are used in section 6.5.

3.5. LOGARITHMIC CLASSIFICATION

If we put the RLC differences in the form $\log Z_u/Z_s$, we can conveniently break down their spread in classes of the same relative width $10^{l/m}$, the centres of which form the sequence.

26. $p(n) = 10^{n/m}$

and their limits the sequence

27. $q(n) = 10^{\frac{n-1/2}{m}}$

where m is the number of classes per power of ten and n is the ordinal number of the class. Accordingly it is expedient to graduate the standards in accordance with the sequence p(n) and to divide the scale of the pointer instrument in accordance with the sequence q(n).

The solutions m = 6, 12, 24 or 48 correspond roughly to the class widths ±20, ±10, ±5 or ±2.5%, their sequences are known under the international designations E6, E12, E24 and E48.

The solutions m = 5, 10, 20, or 40 correspond to the class widths ±2, ±1, ±0.5 and ±0.25 dB, their sequences are known under the international designations R5, R10, R20 and R40 (Renard numbers).

Both the E-sequences and the R-sequences contain exclusively irrational numbers if the powers of ten are ignored, but those of the R-sequences can be approximated surprisingly accurately by easily marked natural numbers, as log 2 = 0.30103, approximated by 0.3, is a term of the R 10 sequence, and $2^{10} = 1024$ only differs by 2.4% from 1000. Thus, by continued doubling, the sequence 2..4..8..16..32..64 arises, and by continued halving, the sequence 50..25..12.5..6.25..3.125, for comparison the R10 sequence: 1 – 1.25 – 1.6 – 2 – 2.5 – 3.15 – 4 – 5 – 6.3 – 8 – 10.

In order to divide the scale of the indicator instrument in accordance with the sequence q(n), we use the blank scale SA 0027 and Table 3.5. On the empty scale we find a linear division of 0—100° which forms the scale for the tabulated values. Here is an example:

m	6	12	24	48	96	p (n)	6	12	24	48	96	p (n)
n	0	0	0	0	0	100 000	3	6	12	24	48	316 228
					1	102 428					49	323 904
				1	2	104 914				25	50	331 767
					3	107 461					51	339 821
				2	4	110 069			13	26	52	348 070
					5	112 741					53	356 519
				3	6	115 478				27	54	365 174
					7	118 281					55	374 039
		1	2	4	8	121 153		7	14	28	56	383 119
					9	124 094					57	392 419
				5	10	127 106				29	58	401 945
					11	130 192					59	411 702
			3	6	12	133 352			15	30	60	421 696
					13	136 589					61	431 933
				7	14	139 905				31	62	442 418
					15	143 301					63	453 158
	1	2	4	8	16	146 780	4	8	16	32	64	464 159
					17	150 343					65	475 426
				9	18	153 993				33	66	486 967
					19	157 731					67	498 789
			5	10	20	161 560			17	34	68	510 897
					21	165 482					69	523 299
				11	22	169 499				35	70	536 002
					23	173 613					71	549 014
		3	6	12	24	177 828		9	18	36	72	562 341
					25	182 145					73	575 992
				13	26	186 566				37	74	589 975
					27	191 095					75	604 296
				14	28	195 734			19	38	76	618 966
					29	200 485					77	633 991
				15	30	205 352				39	78	649 382
					31	210 337					79	665 145
	2	4	8	16	32	215 443	5	10	20	40	80	681 292
					33	220 673					81	697 831
				17	34	226 030				41	82	714 770
					35	231 517					83	732 122
			9	18	36	237 137			21	42	84	749 894
					37	242 894					85	768 098
				19	38	248 790				43	86	786 744
					39	254 830					87	805 842
		5	10	20	40	261 016		11	22	44	88	825 404
					41	267 352					89	845 441
				21	42	273 842				45	90	865 964
					43	280 490					91	886 986
			11	22	44	287 298			23	46	92	908 518
					45	294 273					93	930 572
				23	46	301 416				47	94	953 162
					47	308 733					95	976 300
	3	6	12	24	48	316 228	6	12	24	48	96	1000 000

Table 3.3. E Series

m	5	10	20	40	80	p (n)	5	10	20	40	80	p (n)
n	0	0	0	0	0	100 000		5	10	20	40	316 228
					1	102 920					41	325 462
				1	2	105 925				21	42	334 965
					3	109 018					43	344 747
			1	2	4	112 202			11	22	44	354 813
					5	115 478					45	365 174
				3	6	118 850				23	46	375 837
					7	122 321					47	386 812
		1	2	4	8	125 893	3	6	12	24	48	398 107
					9	129 569					49	409 732
				5	10	133 352				25	50	421 697
					11	137 246					51	434 010
			3	6	12	141 254			13	26	52	446 684
					13	145 378					53	459 727
				7	14	149 624				27	54	473 151
					15	153 993					55	486 968
	1	2	4	8	16	158 489		7	14	28	56	501 187
					17	163 117					57	515 822
				9	18	167 880				29	58	530 884
					19	172 783					59	546 387
			5	10	20	177 828			15	30	60	562 341
					21	183 021					61	578 762
				11	22	188 365				31	62	595 662
					23	193 865					63	613 056
		3	6	12	24	199 526	4	8	16	32	64	630 957
					25	205 353					65	649 382
				13	26	211 349				33	66	668 344
					27	217 520					67	687 860
			7	14	28	223 872			17	34	68	707 946
					29	230 409					69	728 618
				15	30	237 137				35	70	749 894
					31	244 062					71	771 792
	2	4	8	16	32	251 189		9	18	36	72	794 328
					33	258 523					73	817 523
				17	34	266 073				37	74	841 395
					35	273 842					75	865 964
			9	18	36	281 838			19	38	76	891 251
					37	290 068					77	917 276
				19	38	298 538				39	78	944 061
					39	307 256					79	971 628
		5	10	20	40	316 228	5	10	20	40	80	1000 000

Table 3.4. Reynard Numbers

Capacitors are to be arranged in accordance with the E24 series. Under m = 24 on Table 3.5 the number 10.61..26.38... to 89.39 are found, which are entered on the empty scale as radial graduations. In between the ordinal numbers are written in the same sequence as indicated in the table. At 80° a red reference mark should be made.

The RLC measuring range switch is set to 20% as shown in Table 3.5 under m = 24. A standard from the E24 sequence should be selected, which must correspond approximately to the centre of the spread of the capacitors to be classified. For example, with 2.61 nF the unknowns can be arranged in sorting boxes marked as follows:

n	–3	–2	–1	0	+ 1	+ 2	+ 3
nF	2.15	2.15	2.37	2.61	2.87	3.16	3.16

If different graduations from those given in the tables are required, the following method of calculation can be given:

The numerical sequence q(n) is taken by the bridge voltages

28. $$x_{q(n)} = \frac{q(n) - 1}{q(n) + 1}$$

and the following positions on the empty scale:

29. $$\alpha_{(n)} = \alpha_o + \frac{x_{q(n)}}{x_{ref}} (\alpha_{ref} - \alpha_o)$$

It should be noted that

30. $$x_{q(n)} = -x_q \; (-n)$$

x_{ref} is to be found under 8. and

31. $$\alpha_o \quad 50^\circ, \; \alpha_{ref} = 80^\circ$$

m	6	12	24	48	96
Ref	100 % 80°	100 % 80°	20 % 80°	20 % 80°	5 % 80°
n					
---		93.52		93.28	
+ 5					
---		86.61		85.48	
+ 4					
---	+	79.13	+	77.64	+
+ 3					
---	90.14	71.18	89.39	69.76	86.88
+ 2					
---	75.21	62.86	73.62	61.87	72.13
+ 1					
---	58.61	54.31	57.92	53.96	57.38
0					
---	41.39	45.69	42.18	46.04	42.62
- 1					
---	24.79	37.14	26.38	38.13	27.87
- 2					
---	9.86	28.82	10.61	30.24	13.12
- 3					
---	-	20.87	-	22.36	-
- 4					
---		13.39		14.52	
- 5					
---		6.48		6.72	

m	5	10	20	40	80
Ref	100 % 80°	100 % 80°	20 % 80°	20 % 80°	5 % 80°
		+			
---		92.86		92.50	
+ 4					
---	+	84.42	+	83.13	+
+ 3					
---	96.75	75.20	97.16	73.70	94.23
+ 2					
---	79.91	65.39	78.42	64.24	76.55
+ 1					
---	60.32	55.18	59.50	54.75	58.85
0					
---	39.68	44.82	40.50	45.25	41.15
- 1					
---	20.09	34.61	21.58	35.76	23.45
- 2					
---	3.25	24.80	2.84	26.30	5.77
- 3					
---	-	15.58	-	16.87	-
- 4					
---		7.14		7.50	
		-			

Table 3.5. Limits of the series calculated for SA 0027, in accordance with equation 28).

4. OPERATION

4.1. COMMISSIONING

1. Check that the accessories supplied are complete:
   1 wooden box with 8 plug-in scales, 1 power cable, 2 screening covers DB 1065 and 2 JP 0118 plugs.

2. Select a scale suited to the intended measurements and plug it into the slot in the housing on the right.

3. If pointer deflection deviates from zero although the plug-in scale is put in properly, adjust with a 4 mm screwdriver on the adjusting screw above the green lamp.

4. Select the BRIDGE MODE:
   R for resistances, L for coils, C for capacitors

   The operating mode "L" differs from the mode "R" only in that the compensation for the input capacitance is switched off. Coils for which the overload indicator does not light can be tested with advantage in the operating mode R.

   The following are reasons for the selection of the operating frequency:

   The most suitable frequency is that at which the component to be tested is to operate later. This applies particularly to coils, whose properties can be very dependent on frequency. In special cases it may be necessary to produce a different frequency from that offered, by modifying the oscillator or by using a B & K Beat Frequency Oscillator Type 1022.

   Unless otherwise required, select 100 Hz operating frequency for resistors. For other components, select an operating frequency for which the favourable range of 100 Ω to 10 kΩ is not unnecessarily far removed.

5. Put RLC DEVIATION switch to position"Zero" and the FUNCTION switch to position "RLC".

6. Check the mains voltage selector at the back of the instrument. If the mark deviates from the mains supply voltage, remove the fuse and correct the setting. Connect the instrument to the mains. If a protective earth is required use a special cable with an earthed contact plug. In this case, however, earthed unknowns may not be measured.

7. Set the POWER switch to "On". Connect the standard to the terminals 1 and 2, the unknown to terminals 3 and 4 (Fig.4.1). If the impedance of the unknown is higher than 100 kΩ or lower than 100 Ω, note the appropriate precautions in the following sections.

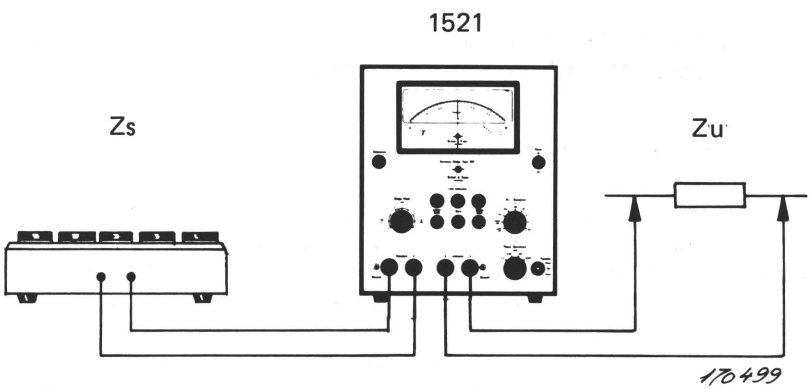


Fig.4.1. Typical use of the 1521. Unknown impedance Z_u is to be compared with the standard Z_s

8. If the pointer is away from zero, adjust with the ZERO control. (The RLC DEVIATION switch should still be set at position "Zero").

9. Set RLC DEVIATION switch to position "Ref". If pointer is away from reference value, correct with the REFERENCE control. The reference value corresponds to the red scale or the value 1 on the auxiliary scale. For unknowns with a particularly high or low impedance there are special calibrating instructions, which are explained in the following sections.

10. Set the RLC DEVIATION switch to the "Upper Limit" position. The pointer deflection corresponds to the point when the right-hand red lamp will light. If necessary, correct the UPPER LIMIT INDICATOR potentiometer.

11. Set the RLC DEVIATION switch to "Lower Limit". The pointer deflection corresponds to the point at which the left-hand red lamp lights. If necessary, correct with the LOWER LIMIT INDICATOR potentiometer.

12. Set the RLC DEVIATION switch and PHASE DEVIATION switch to the positions which correspond to the reference values of the chosen scale.

13. The percentage deviation can be read off the upper scale.

14. Set FUNCTION switch to "Phase" position. The difference in phase angle can be read off the lower scale.

4.2. EARTHING AND SCREENING

It is recommended that the underside of the work bench be lined with aluminium foil and this connected to the casing of the Deviation Bridge. The EARTH CONNECTION socket is on the back of the instrument (Fig.2.2). Essential power cables should be laid at a sufficient distance from the working surface and below the aluminium foil, non-essential ones should be completely removed. In the case of non-earthed unknowns, the casing of the deviation bridge should be earthed, and in the case of earthed unknowns it should be isolated from earth together with the aluminium foil. The earthed pole of an unknown may only be connected to terminal 4. If both the standard and the unknown are earthed, both earthed poles can be connected to terminals 2 and 3. In this case only low-impedance objects can be measured, otherwise the deviation bridge type 1519 is recommended. These suggestions are summarised in Fig.4.2.

The working surface under the outer bridge arm should also be fitted with two boards of insulating material each 300 x 500 x 1 mm, between which a metal foil is sandwiched. This should be conductively connected to the threaded socket of terminal 2 or 3, but insulated from all other objects. For this base it is possible to use the same material from which the boards for printed circuits are made.

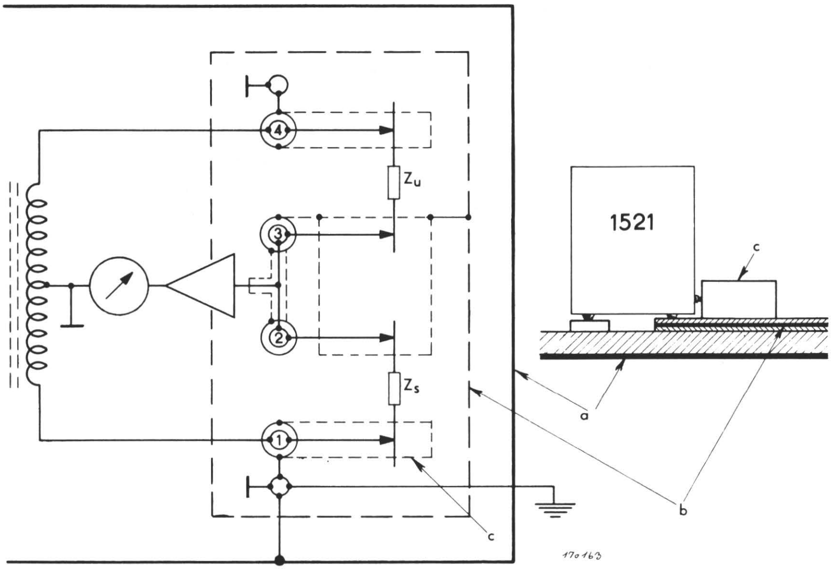


Fig.4.2. Screening:
a) earthed aluminium foil on the underside of the work bench
b) screened working surface made of printed circuit board material, conductively connected to the threaded sockets of terminals 2 and 3, insulated on both sides, area about 300 x 5000 mm
c) screening of contacts, conductively connected to the threaded sockets of the terminals involved. The screening of terminals 2 and 3 should be insulated with respect to earth and casing

Insulated screening of the measured objects is always to be connected to the threaded socket of terminal 2 or 3. Example: the metal casing of an adjustable resistance decade. In this way the undesirable capacitance between the outer bridge mid-point and earth is reduced by one order of magnitude.

Screening which forms a pole of the measured object may only be connected to terminals 1 or 4.

If the outer bridge arm has high impedances, e.g. resistors above 1 MΩ capacitors below 50 pF, the parts connected to terminals 2 and 3 must be screened with respect to the parts connected to terminals 1 and 4. The screening is connected to the threaded sockets of the terminals concerned, and that of terminals 1 and 4 can also be connected to the adjacent GROUND sockets.

If the two halves of the outer bridge arm are at a great distance from the instrument, only one screened cable needs to be connected to terminal 2 or 3, and the leads of terminals 1 and 4 can be laid as a twin cable.

4.3. CALIBRATION FOR COMPARISON OF RESISTORS 2 MΩ to 20 MΩ

1. Note the suggestions for screening in section 4.2.

2. Connect 0.5 R_s between terminals 1 and 2.
   R_s = reference standard, 0.5 R_s can be produced by parallel connection of an unknown which deviates less than 5%, as in Fig.4.3.

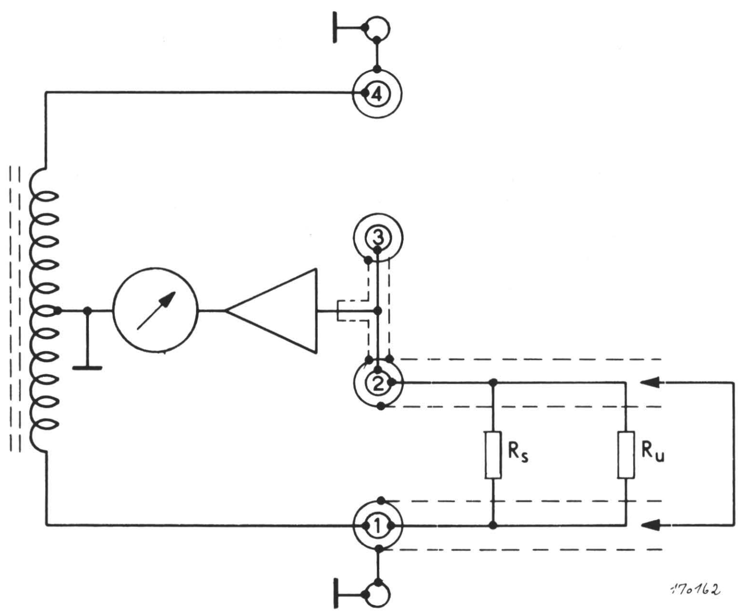


Fig.4.3. Calibrating circuit for resistors of 2 MΩ to 20 MΩ. The pointer deflection is set to 1 (auxiliary scale) in the 100% measuring range with the REFERENCE control. After short-circuiting the measured objects the pointer deflection rises by the correction factor K, with which the oscillator voltage has to be corrected

3. Select BRIDGE MODE "R – 100 Hz"
   RLC DEVIATION "100%"
   METER SCALE 1%, tan 0.01
   FUNCTION "RLC"

   Set the pointer deflection to 1% with the REFERENCE control.

4. Select PHASE DEVIATION "0.2"
   FUNCTION "Phase"

   Read off pointer deflection with respect to tan $\delta = 0.01$ and multiply by the scale factor 30, note result as tanΦ

   Example: If the scale reads tan $\delta = 0.0125$, tan $\Phi = 0.0025 \times 30 = 0.075$.

   If the result is higher than 0.1, try to reduce the capacitance between terminals 2 and 3 with respect to earth by better screening, or use the calibrating procedure given in section 4.5 for resistances above 20 MΩ.

5. Set FUNCTION switch to "RLC" and adjust meter deflection to exactly 1%. Connect terminal 1 to terminal 2 (short-circuit), note pointer deflection with respect to 1% as K factor. Example: if meter reads 1.25, K = 1.25.

6. Set RLC DEVIATION to "Ref". Reproduce the pointer deflection K with the REFERENCE control.
   The instrument is now calibrated.

7. Remove the short-circuit from terminals 1 and 2.
   Replace 0.5 R_s by R_s.
   Select any scale with the exception of the 100% scale.
   Set the measuring range switches RLC DEVIATION and PHASE DEVIATION to the reference values of the selected scale. The instrument is now ready for operation.

8. Note the comments about errors in section 3.3. and the alternative procedure in 4.18.

4.4. CALIBRATION FOR COMPARISON OF CAPACITORS 15 pF to 500 pF

1. Note the suggestions for screening in section 4.2.

2. Connect 2 C_s with terminals 3 and 4. (Fig.4.4).
   C_s = capacitance of the reference standard. 2 C_s can be formed by parallel connection of an unknown which deviates less than 5%.

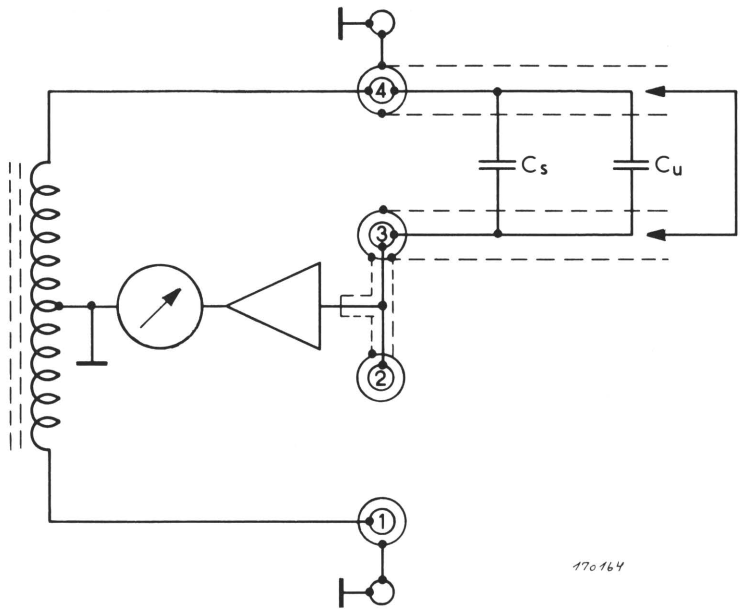


Fig.4.4. Calibrating circuit for capacitances from 15 pF to 500 pF. The pointer deflection is set to 1 (auxiliary scale) in the 100% measuring range with the REFERENCE control. After short-circuiting the measurement objects, the pointer deflection rises by the correction factor K with which the oscillator voltage has to be corrected

3. Select

Select	BRIDGE MODE	"C 10 kHz"
	RLC DEVIATION	100%
	METER SCALE	any, excluding 100% scale
	FUNCTION	RLC

   Set the pointer deflection to 1 (auxiliary scale) with the REFERENCE control.

4. Connect terminal 3 to terminal 4 (short-circuit).
   Note pointer deflection (auxiliary scale) as K factor.

5. Set RLC DEVIATION to "Ref".
   Reproduce pointer deflection K with the REFERENCE control.
   The instrument is now calibrated.

6. Remove the short-circuit from terminals 3 and 4, also remove 2 C_s.
   Connect C_s to the terminals 1 and 2.

   Set the measuring range switch to the reference values of the scale.
   The instrument is now ready for operation.

7. Note the comments about errors in section 3.3. and the alternative calibration procedure in section 4.18.

4.5. CALIBRATION FOR COMPARISON OF RESISTORS 20 MΩ to 100 MΩ

1. Note the suggestions for screening in section 4.2.

2. Connect 0.5 R_s with terminals 1 and 2 (Fig.4.5.).
   R_s = reference standard, 0,5 R_s can be formed by parallel connection of an unknown which deviates less than 2%.

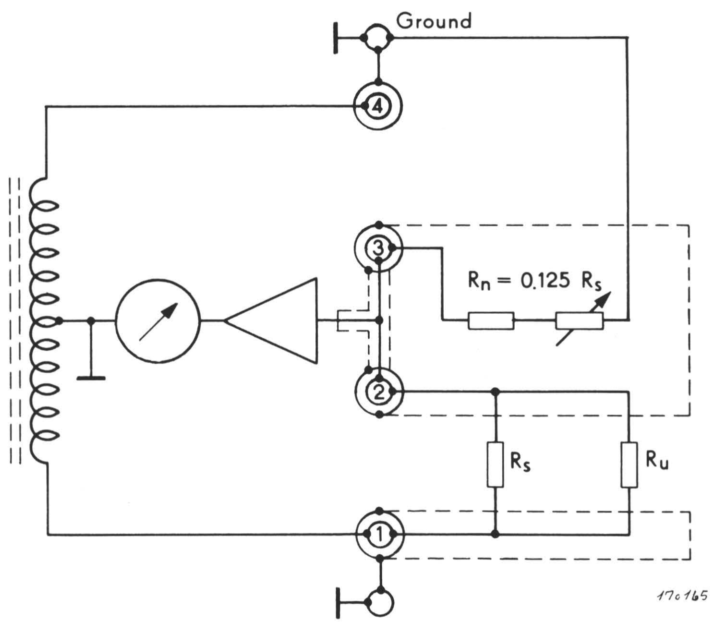


Fig.4.5. Calibration circuit for resistances of 20 MΩ to 100 MΩ

3. Connect a resistance $R_n = 0.125\ R_s$ to terminal 2 or 3 and one of the two earth sockets GROUND.

4. Select BRIDGE MODE "R – 100 Hz"
   RLC DEVIATION "100%"
   FUNCTION "RLC"

5. Use one of the scales in column 1 of Table 4.1, set the pointer deflection with the REFERENCE control to the reference value given in column 2 which is calculated for the lowest magnitude error. If more value is placed on a more accurate phase angle indication, use the reference value given in the last column of the table or avoid the 20% scale.

Scale	% reference value	RLC–DEV	PHASE–DEV.	tan reference value
1% – tan 0.01	0.6%	0.2%	0.002	0.006
1% – tan 0.05	0.6%	0.2%	0.01	0.03
5% – tan 0.01	3%	1%	0.002	0.006
5% – tan 0.05	3%	1%	0.01	0.03
5% – tan 0.2	3%	1%	0.05	0.15
20% – tan 0.05	15.8%	5%	0.01	0.03
20% – tan 0.2	15.8%	5%	0.05	0.15

Table 4.1. Reference values for calibration for resistive measurements in the range 20 MΩ to 100 MΩ and capacitive measurements 2 pF to 15 pF

R_n is selected with sufficient accuracy if the meter deflection is between 0.9 and 1.5 relative to the graduation of the auxiliary scale, after switching the measuring range switch to position REF.

If the pointer deflection is too small, correct R_n.

If the angle Φ is of interest, follow instruction 6, otherwise ignore it.

6. RLC DEVIATION "100%". Set the pointer deflection to the tan reference value of column 5 Table 4.1. with the REFERENCE control. Then set PHASE DEVIATION to "0.2" and the FUNCTION switch to "Phase".

Read off the tan pointer deflection, multiply by the scale factor 0.3 and divide by the tan reference value of column 5, note the result as $\tan\Phi$ (The pointer deflection is to be related to the tan value of the scale, column 1. Example: tan scale 0.05, pointer deflection 0.008, $\tan\Phi = 0.08$). If the result is higher than 0.1, check the input capacitance or use the calibration procedure given below for resistances above 100 MΩ, otherwise set the FUNCTION switch to "RLC" and reproduce the pre-set pointer deflection in accordance with instruction 5.

7. Set the two measuring range switches RLC DEVIATION and PHASE DEVIATION to the positions given in columns 3 and 4, which are one stage more sensitive than the scale reference values in column 1. Replace 0.5 R_s by R_s. The instrument is now calibrated and ready for operation.

   The measuring range is determined by column 1, not 3 or 4.

8. Note the comments about errors in section 3.3. and the alternative calibration procedure in section 4.18.

4.6. CALIBRATION FOR COMPARISON OF CAPACITORS 2 pF to 15 pF

1. Note the suggestions for screening in section 4.2.

2. Connect 2 C_s with terminals 3 and 4 (Fig.4.6).
   C_s = capacitance of the reference standard. 2 C_s can be formed by parallel connection of an unknown which deviates less than 2%.

3. Connect a trimmer C_n with terminal 2 or 3 and one of the two earth sockets GROUND. Guide value: $C_n = 4\,C_s - 12$ pF. Use a low-loss type for preference, e.g. a trimming capacitor with air as dielectric.

4. Select

	BRIDGE MODE	"C 10 kHz"
	RLC DEVIATION	"100%"
	FUNCTION	"RLC"

5. Set the pointer deflection with the trimmer C_n to the reference value shown in column 2 of Table 4.1, which is calculated for the lowest magnitude error. If more value is placed on a more accurate indication of phase angle, use the value given in column 5 of the table or avoid the 20% scale.

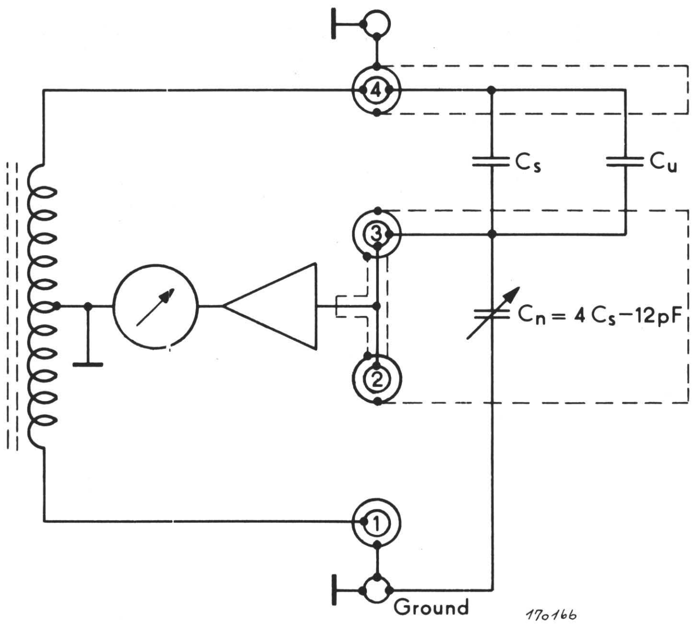


Fig.4.6. Calibration circuit for capacitances from 2 pF to 15 pF

If C_n cannot be set accurately enough, correct with the REFERENCE control. C_n is satisfactory if the meter indication is between 0.9 and 1.5 on the auxiliary scale after switching the measuring range switch to the REF position.

6. Set the two measuring range switches RLC DEVIATION and PHASE DEVIATION to the positions given in columns 3 and 4 of Table 4.1, which are one stage more sensitive than the scale reference values in column 1. The measuring range corresponds to column 1, not 3 or 4.

   Replace 2 C_s by the unknown, connect C_s to terminals 1 and 2. The instrument is now calibrated and ready for operation.

7. Note the comments about errors in section 3.3. and the alternative calibrating procedure in section 4.18.

4.7. CALIBRATION FOR COMPARISON OF RESISTORS 100 MΩ to 500 MΩ

1. Note the suggestions for screening in section 4.2.

2. Connect R_s to terminals 1 and 2. (Fig.4.7).
   R_s = reference standard. Note the difference from the procedures given above, where half the value was used.

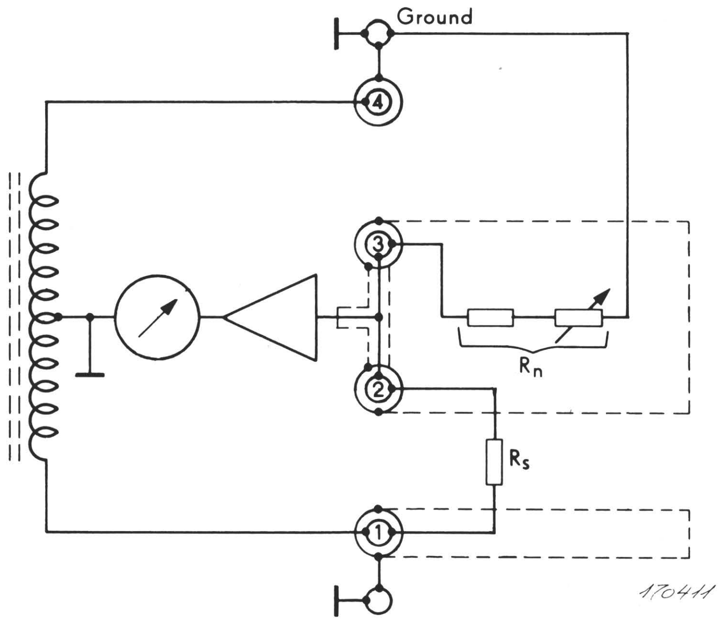


Fig.4.7. Calibration circuit for resistances from 100 MΩ to 500 MΩ

3. Connect a resistance R_n to the terminal 2 or 3 and one of the two earth sockets GROUND. R_n is determined according to the scale:
   R_n = 0.021 R_s for the 5% scale,
   R_n = 0.029 R_s for the 20% scale.

   It is recommended that a value 0.5 MΩ smaller be connected in series with a 1 MΩ potentiometer, the fixed resistance being connected to the terminal 2 or 3, the potentiometer to the earth socket, both being arranged within the screening, which surrounds all the parts connected to terminals 2 and 3 and is to be connected to the threaded sockets 2 or 3.

4. Select BRIDGE MODE "R – 100 Hz"
   RLC DEVIATION "Ref"
   FUNCTION "RLC"

   Set the pointer deflection to the red scale mark (normal sensitivity of indication) with the REFERENCE control.

5. Set RLC DEVIATION to 5%. Set the pointer deflection to the reference value given in column 2 of Table 4.2, which is calculated for the lowest magnitude error, using R_n (see instruction 3). If more value is placed on a more accurate phase angle indication, use the reference value of the last column of the table or avoid the 20% scale.

Scale	% reference value	RLC DEV.	PHASE DEV.	tan reference value
5% – tan 0.05	4.3%	0.2%	0.002	0.041
5% – tan 0.2	4.3%	0.2%	0.01	0.21
20% – tan 0.05	23.4%	1%	0.002	0.041
20% – tan 0.2	23.4%	1%	0.01	0.21

Table 4.2. Reference values for calibration for resistive measurements in the range 100 MΩ to 500 MΩ and capacitive measurements 0.3 pF to 2 pF

   If R_n cannot be set finely enough, the pointer deflection may be a little lower and corrected by turning the REFERENCE control. The adjustment error is about 1% if the REFERENCE control has to be turned to its extreme position.

   The angular error does not need to be measured as the input capacitance at 100 Hz always has a very much higher impedance than R_n.

6. Set the measuring range switch to the values given in columns 3 and 4 of Table 4.2. The measuring range is determined only according to column 1. The instrument is now calibrated and ready for operation.

7. Note the comments about errors in section 3.3. and the alternative calibrating procedure in section 4.18.

4.8. CALIBRATION FOR COMPARISON OF CAPACITORS 0.3 pF to 2 pF

1. Note the suggestions for screening in section 4.2.

2. Connect C_s to terminals 3 and 4 (Fig.4.8).
   C_s = reference standard.

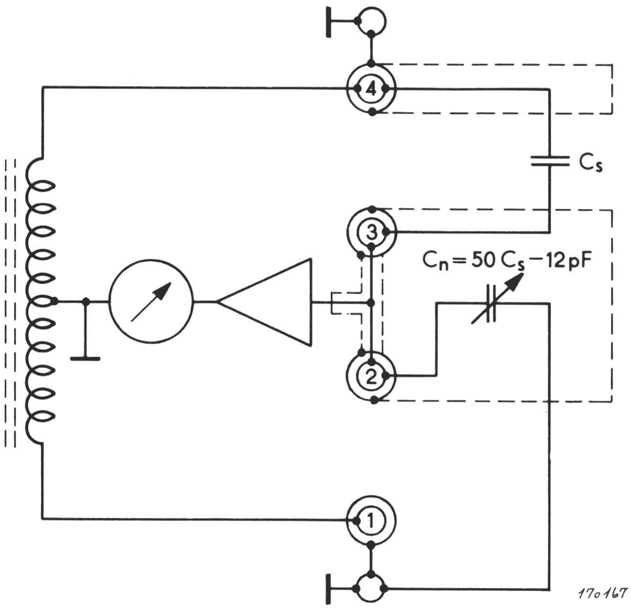


Fig.4.8. Calibration circuit for capacitances of 0.3 pF to 2 pF

3. Connect a low-loss trimmer $C_n = 50\,C_s - 12$ pF to terminal 2 and earth socket GROUND. (Within the screening of range 2 – 3).

4. Select

BRIDGE MODE	"C 10 kHz"
RLC DEVIATION	"Ref"
FUNCTION	"RLC"

   Set the meter deflection with the REFERENCE control to the red scale mark (normal sensitivity indication).

5. Set RLC DEVIATION to "5%". Set C_n in accordance with instruction 4.7.5. and follow to 4.7.7.

4.9. USE AS A CAPACITANCE METER

1. Connect the unknown capacitor C_n to terminals 3 and 4 (Fig.4.9).

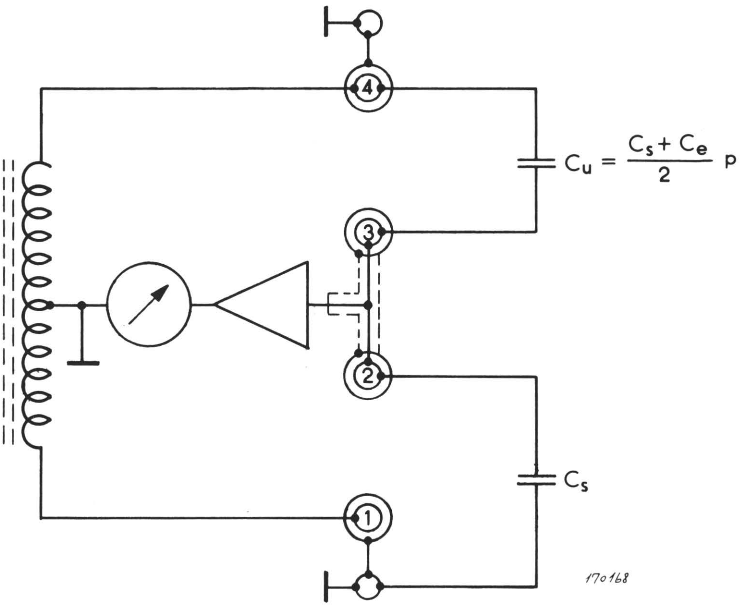


Fig.4.9. Potentiometric measuring circuit for capacitances

2. Connect a capacitance decade to terminal 2 and earth socket GROUND. Use the following values for preference: $C_s + C_e$ = 20 pF, 200 pF, 2 nF, 20 nF, 200 nF, 2 μF, 20 μF .... etc.
   C_s = capacitance decade, C_e = input capacitance (12 pF without cable).

3. Measure the magnitude reading p in operating mode C.
   Select operating frequency 10 kHz for C_n below 1 μF, 1 kHz for C_n from 1 – 10 μF, 100 Hz for C_n from 10 – 100 μF.

4. Calculate: $C_u = 0.5\,(C_s + C_c) \cdot p$

Examples:

	$C_s + C_e$	p	C_u
a)	200 nF	1.3%	1.3 nF
b)	20 nF	0.1%	10 pF
c)	10 nF	0.24%	12 pF
d)	20 pF	0.05%	0.005 pF

Notes: c) for easier reading in position RLC DEVIATION "0.2%" it is permissible to use the 1% scale, which makes for a more convenient reading.

Note that $C_n = C_s + C_e$ when p = 200%. The pointer deflection for 200% coincides with factor 1.5 on the auxiliary scale. If we use a calibrated sample for C_n, we can determine $C_s + C_e$ or C_e in this way. Regarding d): Note the following section 4.10.

4.10. FEMTOFARAD METER

In Section 4.9. it is clear that with $C_s + C_e = 20$ pF it is possible to measure very small capacitances of a few femtofarads (a thousandth of a picofarad). In this case it is necessary to exclude stray capacitances and to calibrate the input capacitance:

1. Screen all 4 terminals with screening sockets DB 1065 (Fig.4.10).

2. Use screened cable AO 0014 at terminals 3 and 4.
   Screen the free plugs with 14 mm diameter screening covers which only have a small opening at the bottom to reach the plug pins or the attached contact clamps. Surround plug and cover with an insulating tube, so that the screens of cables 3 and 4 cannot touch one another.

3. Select

BRIDGE MODE	"C 10 kHz"
RLC DEVIATION	"100%"
FUNCTION	"RLC"

4. Connect a capacitor C = 20 pF to the plugs ends of cable 3 and 4. C can be measured previously against a reliable larger capacitance standard in accordance with section 4.8.

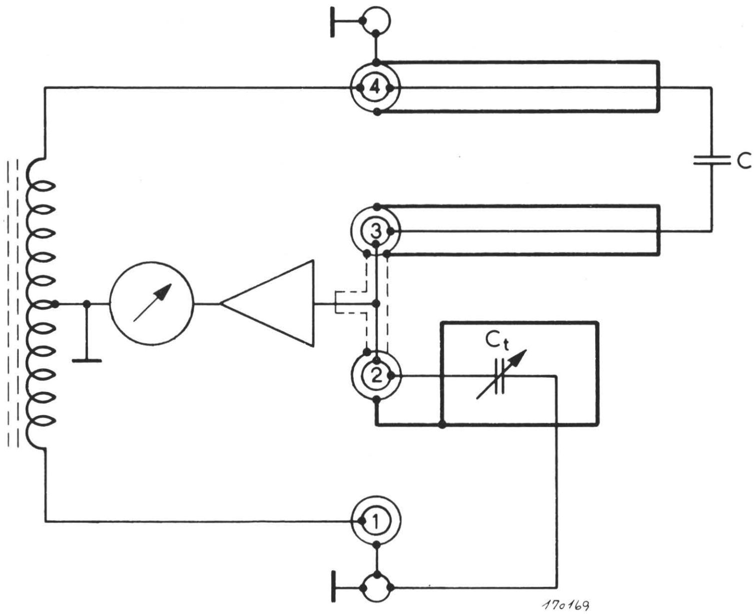


Fig.4.10. Use as a Femtofarad Meter

5. Connect a 2 pF trimmer capacitor C_t to terminal 2 and the earth socket GROUND and adjust it to pointer deflection 1.5 (auxiliary scale) or p = 200%. If the pointer deflection is already lower than 1.5 without the trimmer, repeat the experiment with a shorter cable. Normally the input capacitance without cable is 12 pF, the cable capacitance of AO 0014 (1.2 m) without active screening is 85 pF, with active screening it is 6 pF. A 2 pF trimmer can be made by twisting two insulated wire ends. When the required pointer deflection has been set, test again as follows:

6. Use a 1% scale, set the meter deflection to 0.5% with the REFERENCE control, bridge the 20 pF capacitor C by short-circuiting. The pointer deflection must now be exactly 1%. Then reset the REFERENCE control to the calibrated condition.

7. Replace the 20 pF capacitor C by the capacitance C_n to be measured, select a suitable measuring range and calculated $C_n = p \cdot 10$ pF.

8. Remove C_n without altering the position of the cable ends, determine

the residual indication C_o and subtract from the value of C_n measured previously.

4.11. OHMMETER

1. Connect the unknown R_u to terminal 2 and the earth socket GROUND adjacent to terminal 1 (Fig.4.11).

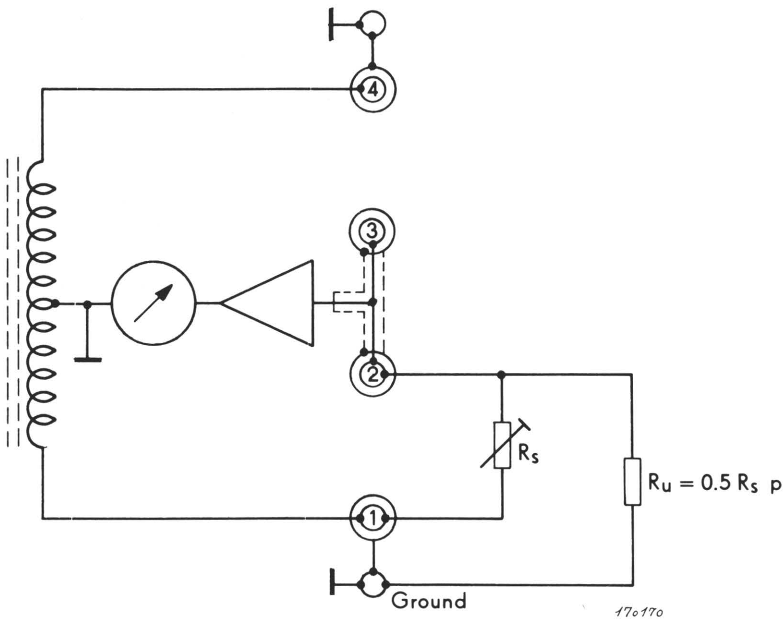


Fig.4.11. Use as Ohmmeter

2. Connect a resistance decade R_s to the terminal 1 and 2 or 1 and 3.

3. Use the following preferred values for R_s: 20 Ω – 200 Ω – 2 kΩ ... 2MΩ.

4. Measure the magnitude reading p (%), use BRIDGE MODE "R 100 Hz".

5. Calculate $R_u = 0.5 \cdot R_s \cdot p$

Examples:

R_s	p	R_u
2 MΩ	25%	250 kΩ
200 kΩ	7%	7 kΩ
200 Ω	16%	16 Ω
20 Ω	0.2%	20 mΩ

Note: Resistances of less than 20 mΩ can be measured by the method above. However, a correction value, made up of the line resistances, the contact resistances and the internal resistance of the earth socket, has to be deducted from the reading. The total correction value is obtained very easily by replacing the unknown with a resistanceless simulation (short-circuit) with the same contact quality. It must be taken into account that even short laboratory cables can have a few milliohms of resistance. The internal resistance of the earth socket is about 10 mΩ. It is recommended that the resistances of all cables and contacts which are used in connection with standards or unknown with an impedance of less than about 25 Ω should be examined by this method.

In this connection it must not be forgotten that the screened cables AO 0013 and AO 0014 have a resistance of about 100 mΩ, and are not suitable for measurement objects below about 100 Ω impedance for which line resistances of 10 mΩ should be the aim.

4.12. GENERAL INSTRUCTIONS FOR COMPARING IMPEDANCES IN THE RANGE 1 Ω to 10 Ω

1. During calibration the bridge is to be operated in the loaded condition, as high currents affect the oscillator voltage.

2. The leads used should be short and have the same resistances. Connect the standard and unknown outside the instrument in series, so that the bridge current does not have to overcome the detour via terminals 2 and 3. The line resistance between terminal 2 and the nodal point has no effect.

3. Measure the line and contact resistances in accordance with section 4.11.

4. Test electrolytic capacitors in the discharged state only.

5. Note section 4.15. "Divided contacts".

4.13. GENERAL INSTRUCTIONS FOR COMPARING IMPEDANCES IN THE RANGE 0.1 Ω to 1 Ω

1. Reduce the oscillator voltage in accordance with instruction 4.14.

2. Note recommendations 4.12.

4.14. REDUCTION OF THE OSCILLATOR VOLTAGE

A reduction in the oscillator voltage is advisable in the following cases:

When impedances in the range 0.1 Ω to 1 Ω are to be compared.

When semi-conductors are to be compared. In this case it is a prerequisite that no rectification occurs at reduced partial voltage (about 75 mV). The wave shape of the voltage at the terminals 2 and 3 should not differ greatly from that which is found in ohmic bridge elements, and this must be checked by means of an oscilloscope. (Note also point 8 below).

The loss in sensitivity of indication is compensated by turning the measuring range switch through one stage. Details can be found from the following calibration instructions:

1. Turn the REFERENCE control counter-clockwise until it comes to the stop.

2. Short-circuit terminals 1 and 2 when modes R and L are to be used or terminals 3 and 4 for operating mode C.

3. Connect the terminals 1 and 4 to the standard and the unknown, which are to be connected in series using terminals 2 and 3.

4. Select FUNCTION "RLC"
   RLC DEVIATION "100%"

5. Follow instruction 4.5.5., in which Table 4.1 gives reference values to which the pointer deflection must be set with the REFERENCE control. To Table 4.1 should be added the reference value 75% for the 100% scale, which could be of interest in testing electrolytic capacitors up to 8000 μF.

6. Set the two measuring range switches RLC DEVIATION and PHASE DEVIATION to the positions indicated in columns 3 and 4 of Table 4.1, which are one stage more sensitive than the scale reference values. The measuring range is now determined by the switch position.

   When using the 100% scale the RLC DEVIATION switch must be set to 20%.

   Remove the short-circuit and connect the nodal point of unknown and standard to the terminals 2 and 3.

7. The accuracy of measurement is not affected by the measures taken, except the change in the operating modes RLC PHASE in the scale ranges 20%, 100% and tan 0.2, in which the attenuation stages of the measuring range switches are different. The error table given in section 3.3. does not apply to the measuring procedure used here.

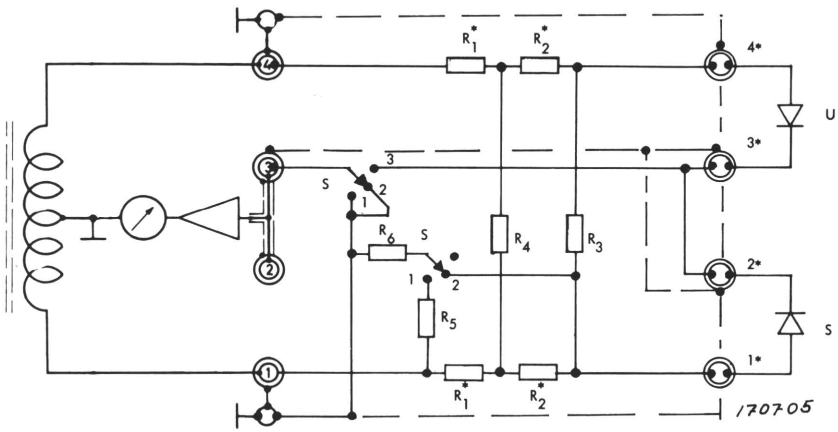


Fig.4.12. Symmetrical reduction of bridge voltage for measurements on semiconductors

8. For measurements on semi-conductors the oscillator voltage can be reduced with a symmetrical divider which takes over the function of the attenuator RLC Deviation (Fig.4.12). For calibration there is an

auxiliary divider R_5, R_6, which at the normal sensitivity of indication in circuit S_1 produces the reference deflection $p = 2\ R_6/R_5$.

In circuit S_2 and position 0.2% (RLC DEVIATION) the measured value p must be reproduced by adjusting R_3 or altering the calibration control REFERENCE. If the auxiliary divider R_6/R_5 is accurately designed, circuit 1 can be omitted.

In circuit 3 the measurement objects can be connected to the auxiliary terminals 1 – 4. The divider resistances are to be selected in accordance with the following table:

Magnitude scale	5%	20%	100%
R_1*	10Ω	10Ω	10Ω
R_2*	0Ω	10Ω	10Ω
R_3	0.85Ω	0.85Ω	0.85Ω
R_4	∞	7.3Ω	1.6Ω
R_5	40 kΩ	40 kΩ	40 kΩ
R_6	1 kΩ	4 kΩ	20 kΩ
V_g	30 mV	8 mV	2 mV

*R_1 and R_2 are to be balanced in pairs to the best possible agreement.

4.15. DIVIDED CONTACTS

When the outer bridge arm has very low impedances (below 20 Ω), differences in resistance of the leads and contacts make the results uncertain. In this case divided contacts can help, the parts a and b of which do not touch one another, see Fig.4.13. The bridge current flows as follows: Terminal 1, contact 1a, reference standard Z_s, contacts 2b and 3b, unknown Z_n, contact 4a. Auxiliary contacts 1b and 4b, which are arranged in the vicinity of the current-carrying contacts 1a and 4a, connect the first bridge arm to the second bridge arm, which has resistances R_1 and R_2 of the same size. Values between 200Ω and 500Ω are suitable, which are sufficiently different from the contact resistances (about 10 mΩ).

Similar auxiliary contacts 2a and 3a are connected to a third bridge arm, which consists of resistances of the same size R_3 and R_4 and distributes the voltage drops at the contacts 2b and 4b equally to both halves. Values between 100 Ω and 1 kΩ are suitable.

In operating mode R, terminal 4 must be loaded with an adjustable 5 kΩ resistance which balances the resistance of the reference channel. In operat-

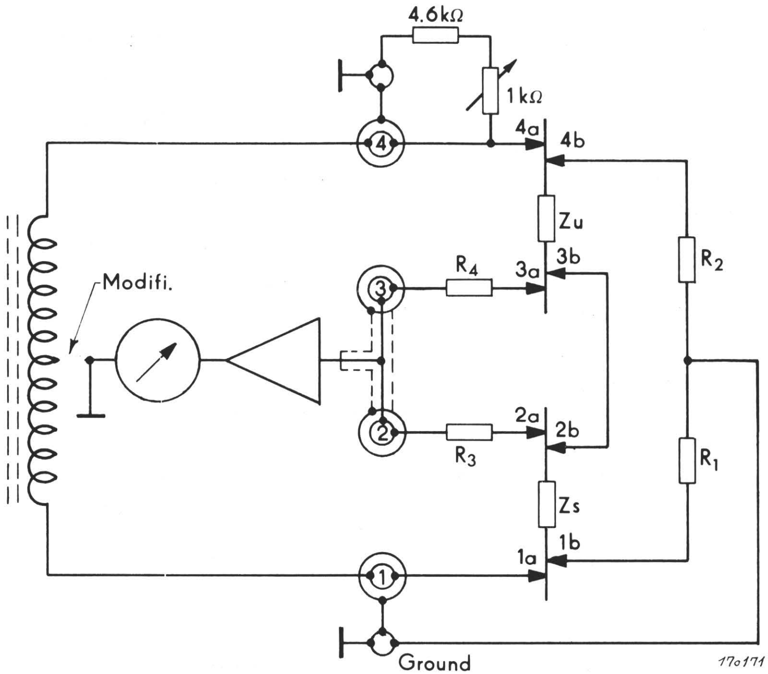


Fig.4.13. Divided contacts for measurement objects below 20 Ω

ing mode C the balance resistance belongs to terminal 1, but one of the two operating modes is sufficient for both types of unknown, if the standard and unknown in the unsuitable one are changed over. The resistance is correctly balanced when with terminals 1 and 4 open the mid-point of the bridge transformer is without voltage. It can be connected during adjustment to terminal 2 or 3. In the case of inaccurate adjustment, neither the bridge symmetry nor the reference voltage are suitable.

The resistances R_1 and R_4 are previously compared in pairs in the 0.2% range. A correction resistance (R / p), which is selected on zero magnitude indication, is connected in parallel with the larger one. For R_1, R_2 only stable wire or metal film resistances can be considered, preferably 2 W types.

Fitting note: The inner bridge mid-point must be unsoldered: remove 4 screws from the back, pull off casing. The bridge transformer is in a cylindrical screening can behind the terminals 2 – 3, the earthed connection consists of two twisted wires, which are earthed at the middle lug of the impedance transformer circuit board. After unsoldering, the ends must remain connected together and covered by an insulating sheath.

The modifications described are only of value for resistances below 20Ω, capacitors above 100 μF at 100 Hz, 10 μF at 1 kHz and 1 μF at 10 kHz.

They are also only effective when the components are connected directly to the contacts. Additional leads and switchable standards nullify the advantages. As the bridge arm R_1, R_2 has a resistance four orders of magnitude higher than the original circuit, unequal stray capacitances affect the bridge symmetry to a greater extent.

4.16. ZERO INDICATOR FOR COMPARING INDUCTIVE OR CAPACITIVE IMPEDANCES WITH PURE RESISTANCES

If a reactance is compared with an effective resistance, the difference in phase angle is 90° and its tanget is infinite and lies outside the range of indication. Under these circumstances the dynamic range is still sufficient for the magnitude range 20%. The magnitude indication is about twice as sensitive as with equality of angle, see the error table below:

p*	−20%	−5%	0	+5%	+20%
p	−10.56%	−2.53	0	+2.47%	+9.54%

p* = indicated, p = true difference in magnitude for $\tan \delta = \infty$

Because phase is not identical, a ±0.6% zero point uncertainty also has to be taken into account. This relates to measurements with the normal oscillator voltage (reference deflection 1).

In spite of these limitations, the deviation bridge does good service as a zero indicator in the determination of inductances and capacitances:

1. Connect the resistance decade R_s to the pair of terminals 3 and 4, connect the casing of the decade to the threaded socket of terminal 3.

2. Connect the reactance to be measured to the pair of terminals 1 and 2.

3. Select BRIDGE MODE "R 100 Hz", "R 1 kHz", or "R 10kHz"
   FUNCTION "RLC"
   RLC DEVIATION "20%"
   METER SCALE 20%

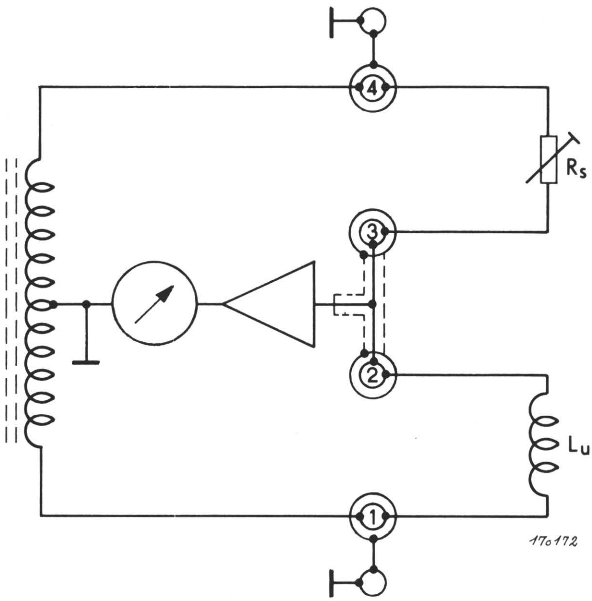


Fig.4.14. Comparison of inductive or capacitive impedances with resistances

4. Set the meter deflection to zero with the resistance decade. Set the FUNCTION switch to "Phase" and note the direction of the indication as the sign in conjunction with the R_s value found.

   Example: $R_s = 2\ k\Omega$, $\tan\delta = -\infty$ $Z = -j\ 2\ k\Omega$.

5. In the case of low-loss measurement objects the measured impedance can be equated with the reactance. From this it is possible to calculate:

   a) The capacitance of a capacitor

$$C = \frac{1}{j\omega Z} = \frac{159}{|Z|\ f}$$

   Units will be nF if $|Z|$ is in kΩ and f in kHz

   Example: $Z = j\ 2\ k\Omega$, $f = 1\ kHz$, $C = 79.6\ nF$.

b) The inductance of a coil

$$L = \frac{Z}{j\omega} = 159 \frac{|Z|}{f}$$

Units will be mH if $|Z|$ is in kΩ and f in kHz.

Example: Z = j 400 Ω, f = 10 kHz, L = 6.36 mH.

Note the values are approximate as in the table above.

The following uncertainties are to be taken into account:
±0.6% zero point uncertainty, caused by incomplete phase congruence, see sections 6.5 and 6.6.
±1% frequency error, see section 6.4. (The true operating frequency can be determined with a frequency meter).

If the effective resistance of the coil is not negligible, this must be taken into account with the relation:

$$L = \frac{1}{\omega} \sqrt{|Z|^2 - R^2}$$

In the case of coils with air cores R corresponds as a first approximation to the D.C. resistance, and in the case of coils with an iron core R is dependent on frequency. The effective resistance R can be determined in the series resonance condition by the following method.

Balance a resistance decade R_s with the impedance of the coil as described in items 1 – 4 of this section.

Replace the coil by a finely adjustable capacitance decade C and adjust this to the impedance R_s (Zero magnitude indication).

Connect the coil L in series with the capacitor C and set the magnitude indication to zero with R_s. Then set the phase indication to zero with C. Repeat both settings, which affect one another, until the magnitude and phase difference is zero. The set value R_s corresponds to the effective resistance of the coil.

The calculation of the inductance is also uncertain when the capacitive reactance of the coil is not large enough compared with the inductive reactance. This condition is not satisfied when there is a negative sign in the phase test according to item 4. Doubt exists when the measured impedance

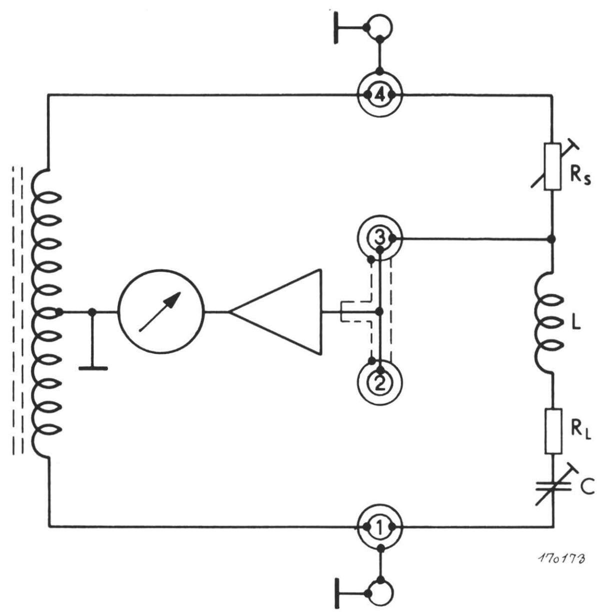


Fig.4.15. *Measurement of the effective resistance R_L by the resonance method. R_S balances the magnitude, and C the angle*

is greater than about 30 kΩ, as higher values are not generally feasible as pure inductive reactances in the case of coils.

The capacitive reactances can be eliminated by calculation if the impedances are measured at two different frequencies. Then

$$L = \frac{n^2 - 1}{\omega \left(\frac{n^2}{Z_1} - \frac{n}{Z_2}\right)}$$

if Z_1 was the impedance measured at the angular frequency ω Z_2 at $n.\omega$.

So for n = 10

$$L = \frac{99}{\omega \left(\frac{100}{Z_1} - \frac{10}{Z_2}\right)}$$

This formula does not take into account the influence of the effective resistance, and therefore it only applies when $Z_1 \gg R$, and Z_1 and Z_2 must be small compared with the resonance resistance (parallel resonance), as this also depends on the effective resistance. Z_2 may be measured above the resonance frequency, giving a negative sign for the measurement in item 4.

The capacitance of a coil can be determined as follows:

Connect the coil in series with a low resistance at the low-resistance output of an audio-frequency oscillator. The voltage drop at the resistance is observed with a sensitive voltmeter. Then the frequency ($= 2\,\pi/\omega$) is set to the minimum of the voltage drop. The capacitance of the coil is

$$C = \frac{1}{\omega^2 L}$$

Coils which contain an iron core alter their inductance with the current, the frequency and the pre-magnetisation. Mechanical forces also influence the electro-magnetic properties of the iron core.

The dependence on the premagnetisation is apparent when the coil comes too near to the indicating instrument which contains a permanent magnet. After a temporary premagnetisation the original inductance is only gradually restored.

4.17. GENERAL INSTRUCTIONS FOR COMPARISON OF INDUCTANCES

The unknown and standard must be sufficiently decoupled, otherwise the measured results will depend on the mutual orientation of the coil axes, which can easily be checked. Precautions which should be taken to ensure decoupling are an adequate distance separation between the coils and closed screening.

Instead of BRIDGE MODE "L" in many cases it is possible to use the mode "R" to obtain the benefit of a lower input capacitance, except when the three warning lamps are lit.

Many coils can only be tested in a narrow frequency range. In this connection the oscillator frequency can be modified between 80 Hz and 16 kHz. Instead of the built-in oscillator it is also possible to use a B & K Beat Frequency Oscillator Type 1022, see section 5.2.

The measured differences in magnitude may only be interpreted as differences in inductance under the following conditions:

a. The inductive reactance must be large compared with the effective resistance.

b. The inductive reactance must be small compared with the capacitive reactance of the winding capacitance.

c. The inductive reactance must be small compared with the capacitive reactance of the input and cable capacitance.

Generally a ratio of about a factor of 5 is sufficient. Whether the conditions are satisfied depends essentially on the choice of a suitable test frequency. In case of doubt the following tests are recommended:

Measurement of the D.C. resistance with an ohmmeter,
Measurement of the impedance at all three operating frequencies in accordance with section 4.16.

Example: Suppose measurements on a coil according to 3.15. gave the results:
Z at 100 Hz = 2 kΩ, Z at 1 kHz = 20 kΩ, Z at 10 kHz = 680 kΩ,
R = 320 Ω.

For this coil, condition a) is satisfied at all three operating frequencies, but condition b) only for 100 Hz and 1 kHz. (In the case of a pure inductance the measured value of Z at 10 kHz given in the example would not be 680 kΩ, but 200 kΩ).

To clarify condition c) the following test may be used:

1. Connect terminal 1 to terminal 2.

2. RLC DEVIATION "100%"
   Set FUNCTION RLC
   Set the meter deflection to 1 (auxiliary scale) with the REFERENCE control.

3. Separate terminal 1 from terminal 2 and connect both to the parallel circuit Ls//Lp using the original cable, the contribution of which to the input capacitance may not be ignored.

4. Select BRIDGE MODE to "L 1000 Hz" and "L 10 kHz" in turn (or to the corresponding R positions if these guarantee a stable operation).

Condition c) is considered as satisfied if the preset pointer deflection 1 is restored.

Below the series resonance the pointer tends towards the positive end, above the series resonance it tends towards the negative end. At high frequencies the pointer deflection is always less than +1. In none of these cases is condition c) met.

If the test gives a low positive deviation within the auxiliary scale and values 1 to 1.5, it can be corrected by a corresponding reduction in the oscillator voltage:

Set the pointer deflection back to 1 with the REFERENCE control,
Connect terminal 1 to terminal 2 and note the meter deflection, which is smaller than previously.
Set RLC DEVIATION to "Ref".
Reproduce the last pointer deflection observed with the REFERENCE calibration control,
Separate terminal 1 from terminal 2 and connect both to the standard L_s.
The instrument is now calibrated.

The correction is dependent on the scatter between samples of the unknown and on the cable capacitance of leads 2 and 3.

4.18. AN ALTERNATIVE CALIBRATION METHOD FOR HIGH–IMPEDANCE MEASUREMENT OBJECTS

An alternative calibrating circuit for high-impedance measurement objects is given in Fig.4.16. Here the oscillator is divided by the resistances R_1, R_2 between the terminals 1 and 4. In the operating modes R and L with the switch S closed (Z_s, Z_n =0) the positive reference deflection $p = 2\ R_1/R_2$ and the phase indication zero is produced. A negative reference deflection $-p = 2/(2 + R_2/R_1)$ is obtained by switching to operating mode C or by changing terminals 1 and 4.

If R_1 and R_2 are calibrated resistances, the reference deflection p only needs to be measured after completion of the correction measures described below, i.e. the switch S can be omitted. The values R_1, R_2 and p are to be taken from Table 6.1.

If R_1 and R_2 are uncalibrated resistances, or if a continuously adjustable

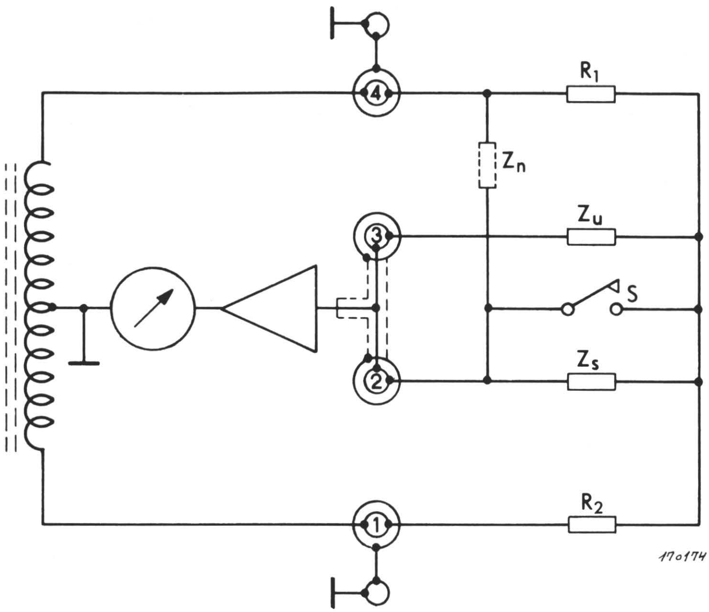


Fig.4.16. Universal calibration circuit for all high-impedance measurement objects

potentiometer is used, the reference value p must be measured before correction with the switch S closed and at the normal sensitivity of indication.

With switch S open, different measured values are indicated $p^* = p / K$ and $\tan \delta^* = p^* \tan\Phi$ as a result of the attenuation. The following measures are suitable for corrections:

a) Selection of a more favourable oscillator frequency:
100 Hz for resistive and inductive measurement objects,
10 kHz for capacitive measurement objects.

b) Alteration of the calibration control REFERENCE.
This measure is only logical if $\tan \delta < 0.1$.

In the case of inductive measurement objects it must also be assumed that $0.7 < K \leq 1$, i.e. the difference in magnitude must be capable of being offset by a small reduction in the oscillator voltage. Otherwise the series resonance is only slightly above or even below the oscillator frequency.

c) Alteration of the two measurement range switches.

d) Shunting the input by means of Z_n, see Fig.4.16.

These two measures can only be used for the following ohmic and capacitive measurement objects:

20 MΩ <	R_s, R_u	< 100 MΩ	c) + 1 stage,	d) $R_n \approx 0.125\ R_s$
100 MΩ <	R_s, R_u	< 500 MΩ	c) + 2 stages,	d) $R_n \approx 0.02\ R_s$
2 pF	C_s, C_u	15 pF	c) + 1 stage,	d) $C_n \approx 4$, $C_s = 12$ pF
0.3 pF	C_s, C_u	2 pF	c) + 2 stages,	d) $C_n \approx 50$, $C_s = 12$ pF

The residual error can be compensated with Z_n or by altering the calibration control REFERENCE. After completing the correction, the same reference value p should be indicated with switch S open as before the correction with switch S closed.

In sections 4.4 to 4.8 the same correction measures are described in more detail in connection with a simplified calibration method which dispenses with the voltage divider R_1/R_2.

4.19. CALIBRATION FOR USE WITH INDUCTIVE DISPLACEMENT PICKUPS

In conjunction with an inductive displacement pick-up (differential transformer) the deviation bridge can be used as a micrometer.

Inductive displacement pick-ups consist of a cylindrical coil, Fig.4.17, which is divided into two halves by a centre tapping. The inductances vary in opposite directions with the setting of a moving core. Depending on the lengths of the core and the coil, it is possible to establish two limit positions between which the ratio L_1/L_2 is proportional to the distance. In conjunction with the deviation bridge there is a linear connection with the graduation of the uncalibrated scale SA 0027.

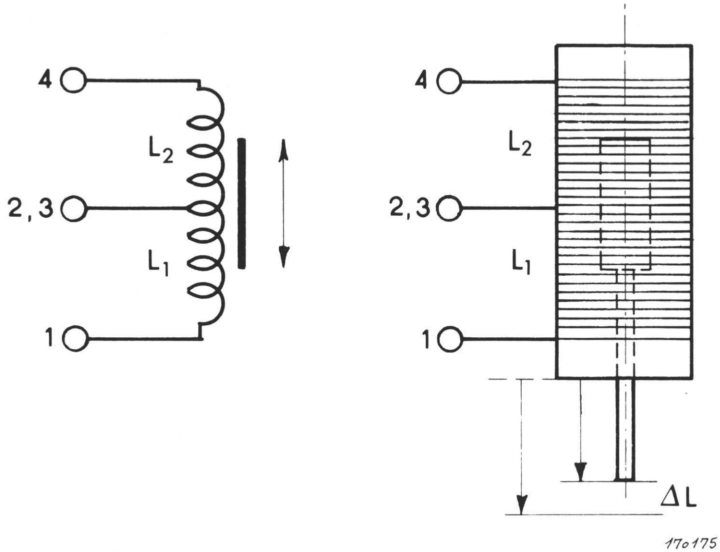


Fig.4.17. Principle of the inductive displacement pick-up. The inductance ratio $L_1 : L_2$ is a measure of the change in length $\Delta 1$ by which the core has been moved from its middle position

The scale SA 0027 can be calibrated and marked in accordance with the following instructions:

1. | | |
   |---|---|
   | BRIDGE MODE | "L 1 kHz" |
   | RLC DEVIATION | "5%" |
   | Select FUNCTION | "RLC" |
   | METER SCALE | SA 0027 |

2. Connect the ends of the coil to the terminals 1 and 4, the centre of the coil to terminal 2 or 3, set the core to pointer deflection 50^{o} (zero point on the normal RLC scales).

3. Move the core by means of a calibrated mechanical arrangement (micrometer, slip gauge) by the reference distance s, until the pointer points to the scale sector 72^{o} to 90^{o}. The ratio between s and its unit should preferably correspond to a numerical value in the series ... 0.08 – 0.1 – 0.2 – 0.4 – 0.8 – 1 – 2 – 4 – 8 – 10 – 20 ....

   Examples: S = 0.4 mm, 2 = 0.02 inch.

4. Set the pointer deflection with the REFERENCE control to 90°.

Scale SA 0027	RLC DEVIATION RANGE (%) 0.2	1	5	20	100
	μm	μm	mm	mm	mm
0	50	250	1.25	5	20
10	40	200	1.00	4	16
20	30	150	0.75	3	12
30	20	100	0.50	2	8
40	10	50	0.25	1	4
50 (0)	0	0	0.00	0	0
60	10	50	0.25	1	4
70	20	100	0.50	2	8
80 (Ref)	30	150	0.75	3	12
90	40	200	1.00	4	16
100	50	250	1.25	5	20
Calibration factor K/K*	1	1.004	1.024	1.099	1.2

Table 4.3. Calibration of inductive displacement transducers

The calibration factor K/K* is obtained from the percentage graduation of the measuring range switch. The correction factor K* = s/s* is obtained from experimental comparison of the distance s and indication s*.

5. Switch RLC DEVIATION to REF, read the pointer deflection off the auxiliary scale, example 1.25. Note result as $K_{5\%} = 1.25$. Calculate the calibration factors for the other ranges as follows. (See last column of Table 4.3).

$$K_{0.2\%} = K_{5\%} : 1.024 = 1.22$$
$$K_{1\%} = K_{0.2\%} \cdot 1.044 = 1.23$$
$$K_{20\%} = K_{0.2\%} \cdot 1.099 = 1.34$$
$$K_{100\%} = K_{0.2\%} \cdot 1.2 = 1.47$$

Note: the 100% measuring range is only reasonable if the distance between the end positions of the displacement pick-up is greater than the distance indication range.

6. Multiply the distances given in the table by the factor s/l mm found in accordance with 3.

Examples	Distances according to table:	0 – 50 – 100 – 150 μm
	Reference distance 0.4 mm	0 – 20 – 40 – 60 μm
	Reference distance 0.02 inch	0 – 1 – 2 – 3 in. 10^{-3}

7. Mark the scale SA 0027 with the calculated results, example:

Original graduation: 0 – 10 – 20 – 30 – 40 – 50 – 60 ....
80 – 60 – 40 – 20 – 0 – 20 m

Measuring range: 1%, $K_{1\%}$ = 1.23
(This scale is only valid for the 1% measuring range when the calibration value $K_{1\%}$ = 1.23 is set in switch position "Ref" with the REFERENCE control).

4.20. COMPARISON OF COMPONENTS IN NETWORKS

In a series of similar networks (Fig.4.18) the resistances Z_1 are to be compared. The node C opposite Z_1 is connected to the threaded socket S_2 (or S_3) of the terminal pair 2, 3 (Fig.4.19), so that Z_2 only loads the input and Z_3 only the oscillator.

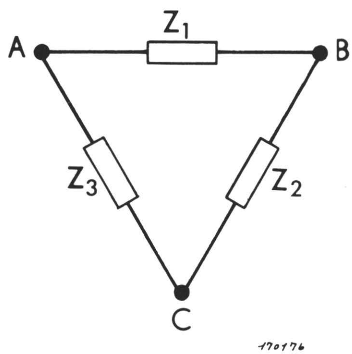


Fig.4.18. Simple network with the measurement object Z_1

Z_2 has no effect on the bridge balance but it can reduce the bridge output voltage and turn its phase. To compensate this the same measures as listed in section 4.3 are appropriate.

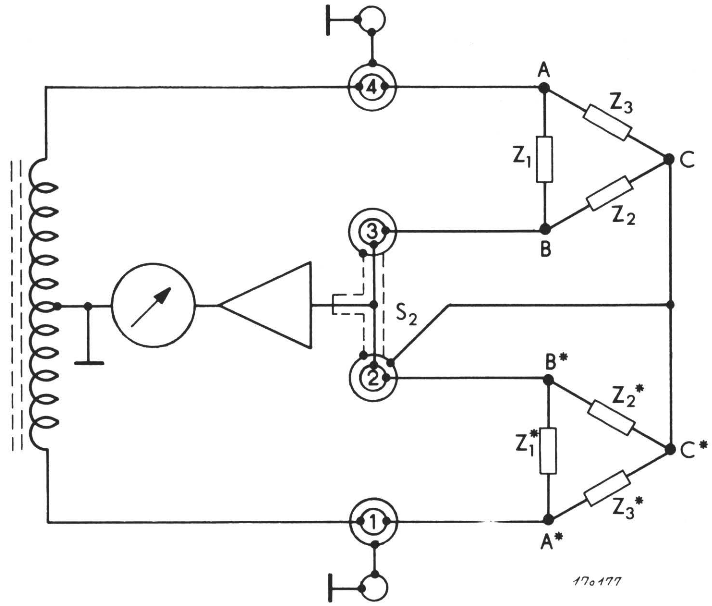


Fig.4.19. Resistances Z_1 in similar networks are compared

When $Z_1 \sim Z^*_1$, $Z_2 \sim Z^*_2$, the attenuation is

$$K = 1 + n\, Z_1/Z_2,$$

with n = 0.07 in operating mode R or C, n = 1 in operating mode L.

If Z^*_2 is removed from the network used as the "standard" then

$$K = 1 + 0.5\, n\, Z_1/Z_2$$

Via Z_3 a current flows from the oscillator into the internal resistance of S_2, S_3, which in operating mode R or C is about 17 Ω in series with 50 μF, in operating mode L about 10 mΩ. If Z_3 is not large enough compared with the internal resistance, the scatter of Z_3 acquires an influence on that of the bridge balance, which can be tested as follows:

Separate Z^*_1 and Z_1 from the terminals 1 and 4, and connect instead with the earth socket GROUND as in Fig.4.20, note the magnitude and phase of the measured values. Vary Z^*_3 within in scatter range, e.g. by parallel connection of a second sample ($Z^*_2/2$) or by separation ($Z^*_3 = \omega$).

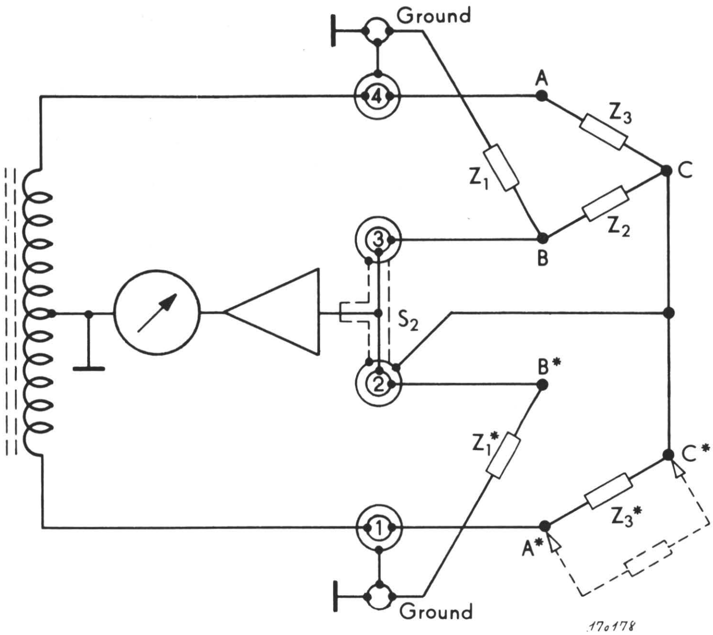


Fig.4.20. Influence of scatter of samples of Z_3

The measured values found correspond to the zero point uncertainty which has to be taken into account in testing the other samples Z_1.

The attenuation K can also be found experimentally:

Separate Z_1, Z_2 from the earth socket and connect both to the node of a voltage divider R_1, R_2 (Fig.4.21), which can be designed in accordance with Table 6.1 when $R_1 \ll Z_2$. When Z_1, $Z_2 = 0$ (short-circuit), the amount $p = 2\ R_1/R_2$ is indicated. Without short-circuit the indication is

$$p^* \cong p/K, \quad \tan\delta \cong p^* \tan\Phi$$

The magnitude indication can be corrected with the REFERENCE calibration control when $1 < K < 1.5$, and $\tan\Phi < 0.1$. If this condition is not met, a shunt Z_4 should be inserted instead of Z^*_2, and it should be dimensioned so that the indication p is produced by turning the measuring range switch.

If $\tan\Phi < 0.1$, the quotient Z_4/Z_1 should be real and Z_4 at least so small

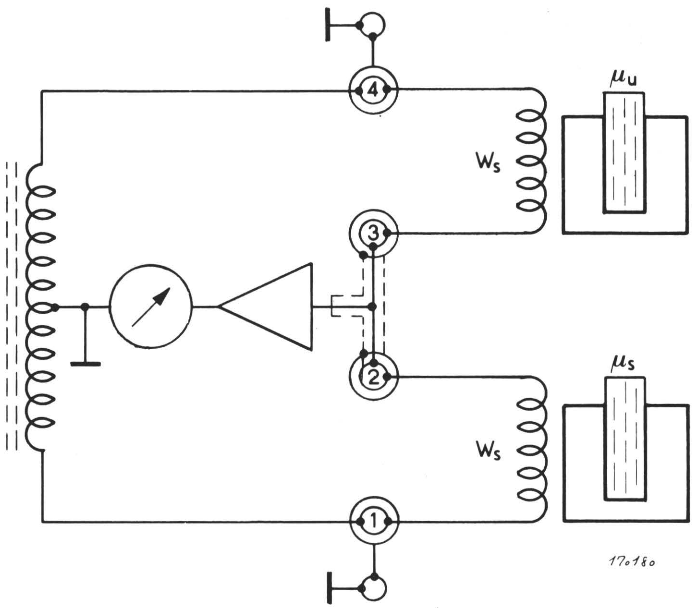


Fig.4.21. Calibration Circuit

that tan $\Phi < 0.1$. (The measuring range switch PHASE DEV. is to be turned in the same way as the switch RLC DEV.)

If tan $\Phi > 1$, the quotient Z_4/Z_2 should be real and Z_4 at least so small that tan $\Phi > 10$. In this case the operating modes RLC and PHASE are to be transposed, but not the scales. The two measuring range switches are on Pos. 0.002 and 0.2%, and the scale 5%/tan 0.05 is recommended. If the direction of indication is reversed, the terminals 1 and 4 must be transposed.

The reliability of the correction measures taken can be checked by setting various values for R_2. Finally $Z_1{}^*$ is to be connected to terminal 1 again. When changing the unknowns, three connections are to be made in each case.

4.21. RELATIVE SYNCHRONISM OF TANDEM POTENTIOMETERS

Tandem potentiometers, which are used as volume controls in stereophonic transmission systems, must have similar control characteristics. Logarithmically divided scales, which can be entered on the empty scale

± 10 dB. Set RLC DEVIATION to "100%"		
dB	SA 0027	
	+	–
0	50	50
0.5	52.59	47.41
1	55.18	44.32
1.5	57.75	42.25
2	60.32	39.68
2.5	62.86	37.14
3	65.39	34.61
3.5	67.89	32.11
4	70.36	29.64
4.5	72.80	27.20
5	75.21	24.79
5.5	77.58	22.42
6	79.91	20.09
6.5	82.19	17.81
7	84.42	15.58
7.5	86.61	13.39
8	88.74	11.25
8.5	90.83	09.17
9	92.86	07.14
9.5	94.83	05.17
10	96.75	03.25
Ref.: 80.00 = 100%		

± 2.5 dB. Set RLC DEVIATION to 20%	
SA 0027	
+	–
50	50
59.49	40.51
68.97	31.03
78.42	21.58
87.83	12.17
97.17	02.83
Ref.: 80.0 = 5%	

Table 4.4. Calibration of scale SA 0027 relative to a dB scale

SA 0027 in accordance with one of the two tables Table 4.4 are suitable for testing.

If $R_1 = f_1\ (\alpha)$ and $R_2 = f_2\ (\alpha)$ are the resistance characteristics of the two potentiometers, the indicated measuring value when using the logarithmic dB scale corresponds to the expression

$$F\ (\alpha) = 20 \log \frac{f_1\ (\alpha)}{f_2\ (\alpha)}$$

The relative synchronisation error corresponds to the difference

$$F(\alpha) \quad - F(\alpha_1),$$

where α_1 is the reference angle at the setting of which the two stereo channels are to be tuned to the same level. Unless expressly agreed otherwise, $\alpha_1 = \alpha_{max}$ is the stop angle at which the attenuation is zero.

For small reference values $F(\alpha_1)$ the numerical subtraction can be avoided if the zero point is adjusted accordingly with the ZERO control, as the graduation of the dB scale is almost linear. The following suggestions arise from this for the design of an automatic sorting arrangement:

The measured value $F(\alpha_1)$ can be passed as an analogue output voltage from the METER OUTPUT socket to a storage circuit. After loading the store, the analogue output voltage $F(\alpha)$ is compared with the stored voltage. The difference between the two voltages can be used to control the limit indicators. If the agreed error limits are themselves a function of the angle of rotation, the difference voltage must be passed via a voltage divider, the attenuation of which is automatically varied.

4.22. SOME EXAMPLES OF SPECIAL APPLICATIONS

1. For balancing two resistances, connect the l/p-times value in parallel with the larger sample. Instead of this it is also possible to connect the p-times value in series with the smaller sample.

2. If it is desired to make an individual standard component, secondary standards can be established by comparison with a single calibrated reference standard. By connecting similar samples in parallel or in series, half or double values are obtained. By continued repetition of this procedure it is possible to produce a complete series of standards.

3. For the calibration of L or C reference standards, the process mentioned in section 4.16, with which reactances and effective resistances can be compared, is often sufficient.

4. Tandem potentiometers reveal their synchronisation errors when one part is measured as "standard", the second as "unknown", see section 4.21.

5. Multiple potentiometers for T-elements contain two equal divisions and a third with half the resistance. First the equal divisions are measured and then they are connected in parallel and compared jointly with the third.

6. Ferrite cores for LF coils can be sorted with the aid of the deviation bridge. From two similar coils one is fitted with a reference core, the other with the core to be investigated. A suitable arrangement holds the core in a reproducible position. Pot cores must be held together under a reproducible pressure. Fig.4.22.

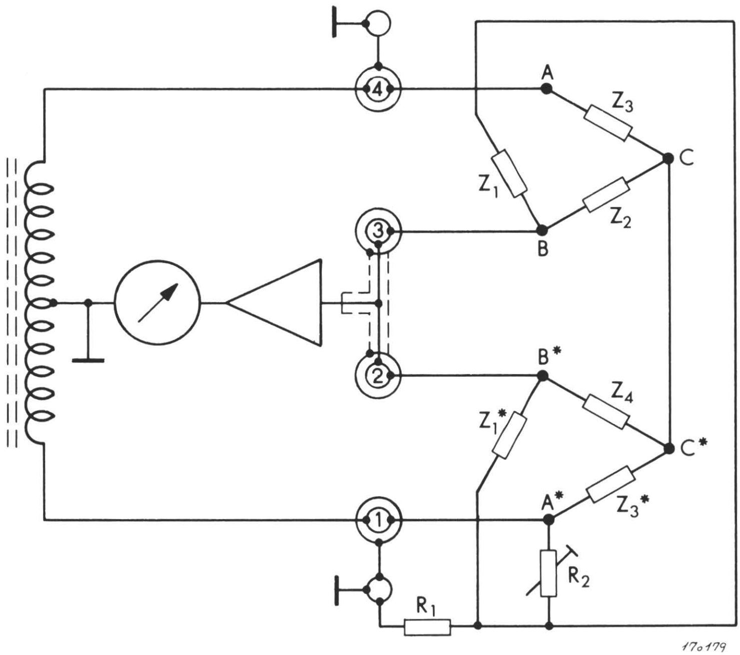


Fig.4.22. Measuring circuit for coil cores

7. Short-circuited turns are detected as follows:
   One of two coils is provided with a ferrite rod core (antenna), on to which the coil to be tested is also placed. The second coil is in a closed pot core. Short-circuited turns are revealed as a difference in phase angle. The sensitivity of indication is tested by short-circuiting a turn. The most suitable oscillator frequency is usually 10 kHz. Fig.4.23.

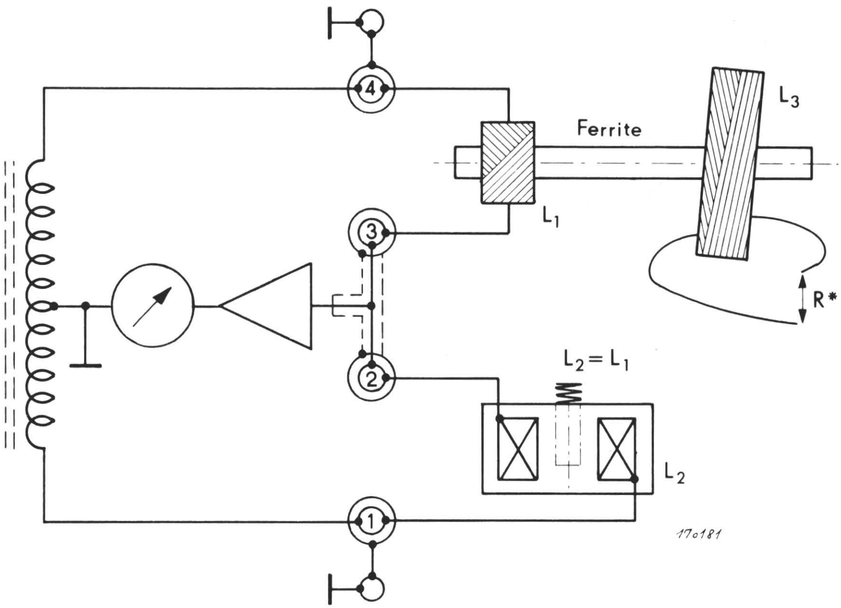


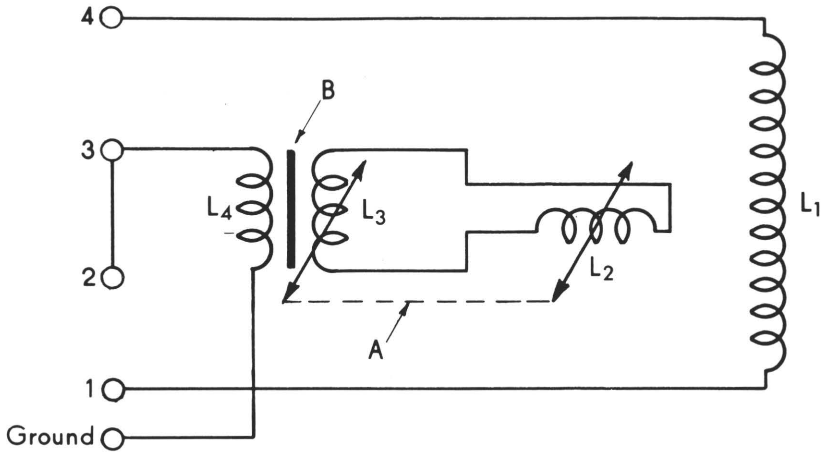
Fig.4.23. Detection of short-circuited turns

8. Magnetic heads (for magnetic tape recording equipment) are measured by various manufacturers during grinding. With the aid of the limit indicator the grinding process can be automatically interrupted when the impedance has reached the desired value.

9. Permanent magnets can be sorted with the aid of a field plate. The field plate alters its resistance under the effect of the magnetic field strength.

10. Differences in length can be measured with an inductive displacement pick-up, see section 4.19.

11. Angular differences are measured with an inductive goniometer, see Fig.4.24. A short cylindrical coil L_2 is pivoted in the field of a longer cylindrical coil L_1. L_1 is fed from the oscillator terminals 1 and 4 with 10 kHz, and the output voltage of L_2 is dependent on the sine of the angle of rotation. For small angles up to 5^o, the linear scale SA 0027 can be calibrated in the same way as described in section 4.19.



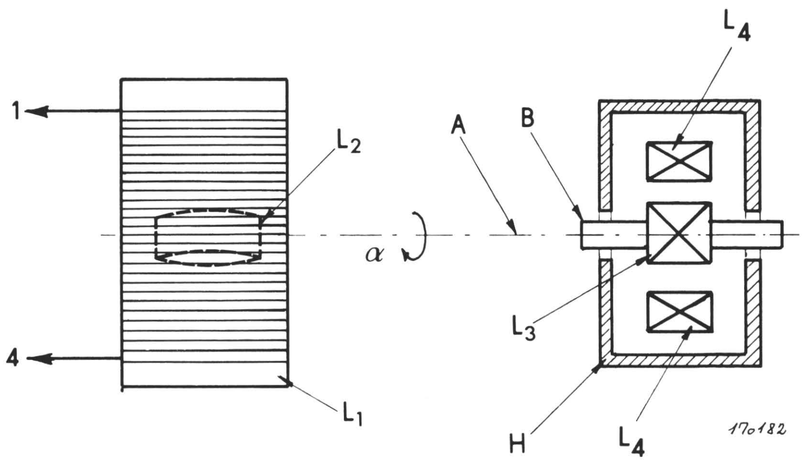


Fig.4.24. *Principle of the inductive angle meter. The goniometer coil L_2 receives a voltage $V = k \sin \alpha$ which is passed via the transformer L_3/L_4 to the input. L_4 can be turned jointly with the core B and the axis A, while L_3 and the ferrite shell H are fixed. In place of the transformer L_3/L_4 a flexible lead can be used, but this limits the rotation of the axis*

12. Forces can be determined with strain gauges.

13. Temperatures can be measured with NTC resistors, PTC resistors or barium titanate capacitors. For calibration purposes the electrical thermometer can be placed together with a standard mercury thermometer in a heatable, oil-filled vessel. The centre of the measuring range is determined by means of an adjustable resistance, Fig.4.25.

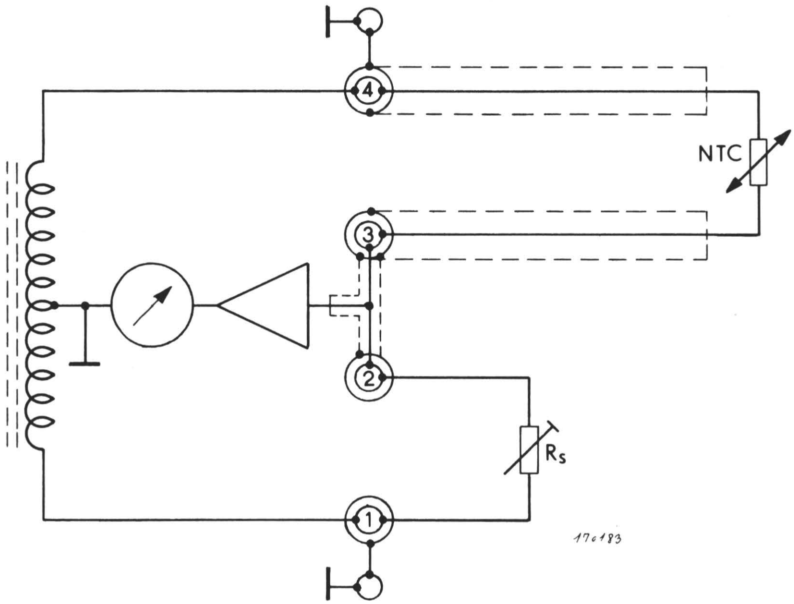


Fig.4.25. Electrical Thermometer

14. Differences in brightness are measured with cadmium sulphide photoconductive cells. Fig.4.26.

15. Variations in the magnitude or phase angle indication can be recorded with a D.C. recorder. Fig.4.27.

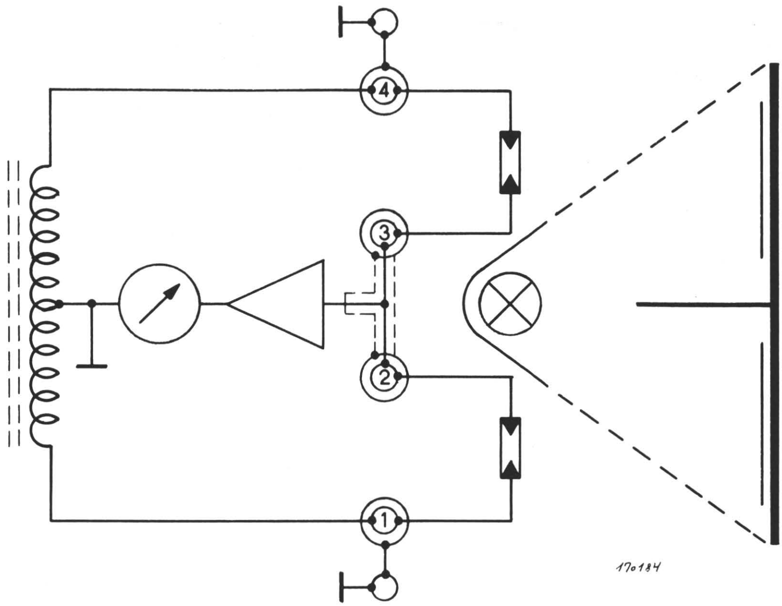


Fig.4.26. *Measuring circuit with two photoconductive cells. The light reflectance of two sample plates is being compared*

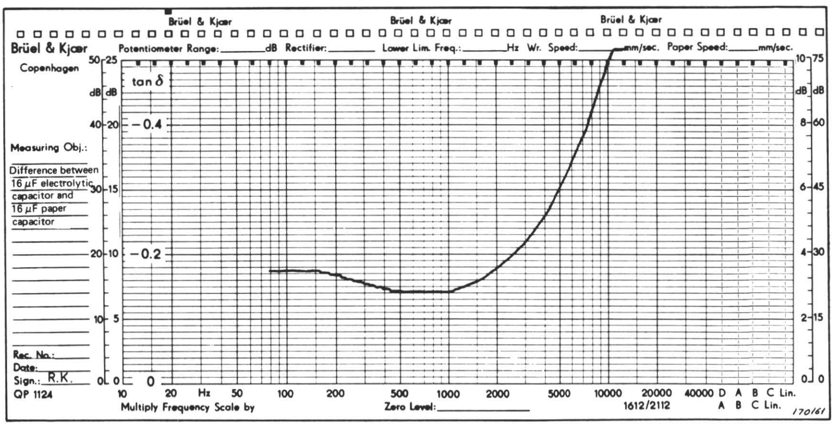


Fig.4.27. *Difference in phase angle between a 16 μF electrolytic capacitor and 16 μF paper capacitor as a function of frequency. The built-in oscillator of the 1521 was replaced for the measurement by the B & K Beat Frequency Oscillator Type 1022. The 2305 Level Recorder was used for recording*

5. DESCRIPTION

5.1. METHOD OF OPERATION

The two components to be compared, which will be referred to as the "Unknown" and the "Standard" are connected in series via the terminals 2 – 3 and joined to a bridge transformer via the terminals 1 – 4. The transformer is supplied by an oscillator whose operating frequency can be switched to 100 Hz, 1 kHz and 10 kHz. Where there is dissimilarity, a voltage is produced between the (earthed) mid-point of the bridge transformer and the pair of terminals 2 – 3. This voltage is compared by the receiving system with the terminal voltage 1 or 4. The magnitude and phase of the voltage ratio are measured and the ratio related as follows to the standard in the various operating modes:

In operating modes "R" and "L" the percentage difference of the impedances is indicated. The sign of the indicated values is positive if the impedance of the unknown is greater than that of the standard.

In operating mode "C" the percentage difference of the admittance is indicated. The sign of the indicated value is positive, if the admittance of the unknown is greater than that of the standard.

In the operating mode "Phase" the tangent of the phase difference is indicated. The sign of the indicated value is positive if the loss factor of the unknown is greater than that of the standard.

When using loss-free standards, the differences in magnitude can be interpreted as RLC differences, and the phase differences as loss factors of the unknowns. Interchangeable scales are supplied for the different measurement ranges.

The instrument is equipped with electronic tolerance indicators, by means of which automatic equipment can be controlled. The following conditions are signalled by warning lamps:

1. The unknown is acceptable (green lamp),
2. The unknown is too small (red lamp, left),
3. The unknown is too large (red lamp, right),
4. The measured result is not usable (all three lamps).

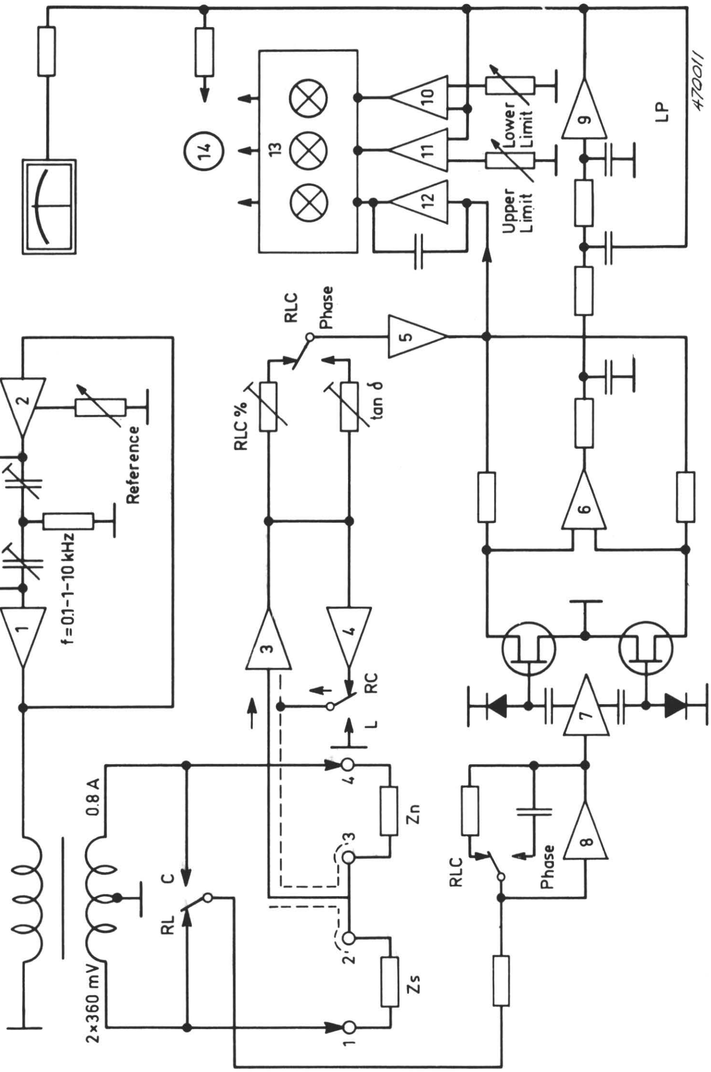


Fig.5.1. Circuit principle of the 1521. Items referred to in the text are: 1) and 2) Oscillator and Bridge Amplifier, 3) FET Input Stage, 4) Emitter Follower, 5) Signal Amplifier, 6) Controlled Rectifier, 7) Controlling Amplifier for 6), 8) Integrator, 9) Low Pass Filter, 10) and 11) Limit Comparators, 12) Overload comparator, 13) Indicator lamps 14) Meter signal output

Apart from these signals, a D.C. voltage proportional to the pointer deflection is available at a rear panel socket. This can be used for a second pointer instrument, for a recording instrument or for the analogue process control.

Further details are discussed in the following sections with the aid of a diagram of the circuit (Fig.5.1).

5.2. OSCILLATOR

The oscillator supplies the primary side of the bridge transformer. It has three operating frequencies, namely 0.1, 1 and 10 kHz, which are determined by two balanced capacitors of a T-filter in each case. The amplitude is kept constant by a sensitive control circuit, but this does not take into account the losses at the internal resistance of the bridge transformer for reasons of short-circuit safety. Therefore, the bridge has to be calibrated in the closed condition when impedances under 5 Ω are to be compared. During calibration, the indicator is set with the calibration control REFERENCE to the reference value at which the voltage measured between the oscillator terminal 1 or 4 and the earth socket GROUND is about 360 mV. The current consumption is limited to about 0.8 A where sudden distortions occur. In the case of measurement objects below 0.5 Ω impedance it is advisable to check the wave shape by means of an oscilloscope. The oscillator voltage can also be reduced by a factor of 5 with the calibration control REFERENCE, so that the outer bridge arm consumes correspondingly less current. The resultant reduction in sensitivity is compensated by the measuring range switch, as in section 3.14. By this method impedances down to 0.1 Ω can be measured but limits are then set to the accuracy by the contact resistances of the terminals.

In the case of high-impedance measurement objects the oscillator voltage may be raised by a factor of 1.5 to balance out capacitive losses, see sections 4.3 – 4.8. If operating frequencies other than those offered are needed for any reasons, the following modifications are possible.

In place of the built-in capacitors, other balanced pairs may be used whose capacitance must each be 0.1/f μF/kHz, for example: f = 0.8 kHz, c = 0.125 μF. It is advisable to test the two samples beforehand to 0.5% agreement with the deviation bridge. If the operating frequency remains within the limits 80 Hz – 16 kHz, the phase congruence only varies slightly (cf. 6.7, 6.8).

In place of the built-in oscillator it is also possible to connect the B & K Frequency Oscillator Type 1022 to the primary side of the bridge transformer, THE MATCHING IMPEDANCE of the 1022 should be set to 4 V/6 Ω. There are spare contacts available for this modification on the METER OUTPUT socket. The operating frequency can be continuously varied by means of the Beat Frequency Oscillator.

5.3. BRIDGE TRANSFORMER

The secondary winding of the bridge transformer consists of two similar parts which form the inner bridge arm. They are wound in the form of two twisted wire tails, the ends of which are brought out of the stray field together via a narrow opening in the otherwise hermetically sealed screening can. At this point the partial voltages are identical in the unloaded condition, and at terminals 1 and 4 they differ by a maximum of 10^{-4} at no load and by about 2×10^{-4} at the maximum permissible current consumption. The internal resistance, measured from one of the two terminals 1 or 4 to the earthed mid-point, is no greater than $32 \cdot 10^{-3}\ \Omega$ with an inductive component of 2.5 Ω at 1000 Hz the difference in resistance being about $10^{-4}\ \Omega$. In view of the low internal resistance, there is no objection to connecting terminal 4 to the earthed pole of an unknown, by which it will be loaded on one side with the housing-to-earth capacitance ($\approx$200 pF). In this case it is only necessary for the housing to remain non-earthed, and the parts connected to terminals 2 and 3 must be screened.

Capacitors which have stored more than 1 W should not be discharged at terminals 1 and 4. Higher energies endanger the bridge transformer, the oscillator and the power supply, and lower energies are absorbed by a VDR resistor on the primary side. The inner ends of the two parts of the winding are twisted and brought out of the screening can and earthed on the central lug of the impedance transformer printed circuit board. They can be unsoldered for constructing other bridge circuits, taking into account the operation of the reference channel, see section 4.15.

5.4. FET INPUT STAGE

A field-effect transistor carries the measurement voltage from terminals 2 and 3 near no-load conditions via a current-amplifying transistor to the attenuators RLC DEVIATION and PHASE DEVIATION. Two low-capacitance diodes and a coupling capacitor protect the sensitive input against voltages up to 500 V. Nevertheless, it is better to measure capacitive measurement objects in the discharged condition, because transient phenomena in the coupling elements delay the indication. The resistive component of the input impedance is about 400 MΩ.

An emitter follower transfers the output voltage to the impedance transformer in modes R and C to the threaded socket of terminals 2 and 3, which can be connected via the screening DB 1065 and plugs JP 0118 to the screens of the outer bridge mid-point. Its voltage is only about 7% lower than the measurement voltage at the terminals, and displacement currents between the outer bridge mid-point and the screen are therefore about 14 times smaller than with an earthed screen. Its internal resistance is about 17 Ω in series with 50 μF capacitance. An overload or short-circuit to earth merely makes the feedback ineffective, but without endangering the emitter follower or influencing the properties of the impedance transformer. D.C. voltages of more than 10 V can endanger the coupling capacitor.

In operating mode L the feedback is eliminated for reasons of stability, the threaded sockets of terminals 2 and 3 are separated from the emitter follower and earthed on the internal bridge mid-point instead. Otherwise, inductive measurement objects can cause the impedance transformer bridged with the cable capacitance to vibrate as an oscillator. Under these circumstances the signal amplifier is overloaded and the three warning lamps light up. Conditions of stability still exist for the majority of the coils which could be examined so that instead of operating mode L, the mode R can be used to obtain the benefit of a more favourable input capacitance, as long as the three warning lamps do not light.

The input capacitance is about 12 pF in modes R and C, and mode L it it about 30 pF.

5.5. SIGNAL AMPLIFIER

Of the two outputs of the attenuators RLC DEVIATION and PHASE DEVIATION, one is connected to the signal amplifier at any given time. Switching is done by a relay which is operated by means of the toggle switch FUNCTION or by shirt-circuiting the contacts 3 and 1 at the socket EXT. PHASE KEY (rear panel). The output of the signal amplifier is connected to the controlled rectifier and the overload indicator.

5.6. REFERENCE CHANNEL

Via the BRIDGE MODE switch, the oscillator terminal 1 is connected to the reference channel in operating modes R and L, and the oscillator terminal 2 is connected to this channel in operating mode C. This channel contains a voltage comparator which reacts to the polarity change of the supply voltage and with the aid of a phase reversal stage produces two square wave voltages offset by 180^{o}, which in turn control the rectifier. Ahead of the input to the voltage comparator there is an auxiliary amplifier which operates as an integrator in the PHASE mode. It delays the polarity change by one quarter period. Although the output voltage of the integrator decreases in proportion to the operating frequency, the dynamic range of the reference channel allows the oscillator voltage to drop by a factor of 5 or rise by a factor of 1.5. The limited switching speed of the comparator results in varying transit times which, at an operating frequency of 10 kHz can differ by $\pm 0.4 \mu$ s or $\tan\Phi = \pm 0.025$. As the signal amplifier does not transmit completely without a delay either, the phase congruence at the three operating frequencies is individually balanced for the normal oscillator voltage setting (cf. 6.7, 6.8).

Defective phase congruence is apparent in cases where very small differences in amount are to be measured in the presence of large phase differences. Such conditions occur where the impedance of a capacitor is compared with a pure resistance (cf. 4.16). For dynamic reasons this is only possible in the 20% measuring range, the zero point uncertainty being ±0.6%. The error can reach the ±1% limit if the oscillator voltage or frequency is modified. Errors of this magnitude have no effect on the magnitude reading if the measurement objects have the same or similar phases.

The simple construction of the reference channel gives the instrument the following characteristics:

1. The phase congruence is unaffected by the load of the bridge transformer, even when the maximum permissible current is being taken.

2. By using a Beat Frequency Oscillator Type 1022 in place of the built-in oscillator, the operating frequency can be continuous varied. The resistive and reactive components can be recorded as a function of the frequency.

3. The operating frequency of the oscillator can be modified relatively easily.

The reference channel also has a calibration divider which in switch position "Ref" delivers a reference voltage to the signal amplifier. The calibration divider has two resistors which are set to the ratio 1000 with the internal adjustment control (cf. 6.1).

5.7. CONTROLLED RECTIFIER

The output voltage of the signal amplifier passes via two voltage dividers to the two inputs of a differential amplifier. Two field-effect transistors form the terminal resistances of the voltage dividers; they are made alternately conductive by the square wave voltages of the control amplifier, the voltage dividers assuming a high attenuation.

If there is no phase difference between the signal and control voltage, the positive half-waves of the signal only reach the non-inverting input and the negative ones only reach the inverting input, so that at the output of the differential amplifier both half-waves appear in the positive direction. In operating modes "R" or "L" this condition means that the impedance of the unknown has a greater magnitude but the same phase angle as the standard. On reversing the difference in amount the phase shifts through

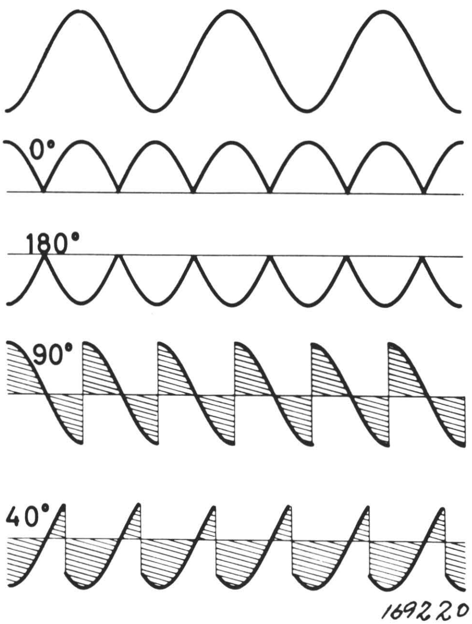


Fig.5.2. Output voltage of the controlled rectifier with various phase differences between control and signal voltage

180^{o} and the half-waves at the output of the differential amplifier are negative. The same happens on switching to mode "C" where the control voltage is rotated through 180^{o}. In this case the direction of the indication is reversed, so that it is not the difference in impedance which is measured but the difference in admittance.

In the operating mode "Phase" the integrator turns the phase of the control voltage 90^{o}, but positive and negative quarters of the signal now appear at the output of the differential amplifier and cancel each other out as long as the phase angles of the unknown and the standard are the same. In the case of dissimilar phase angles, the parts of the positive half-waves and the remains of the negative half-waves do not cancel each other out, as in Fig.5.2. Their arithmetic mean is $\frac{2A}{\pi}\cos\Phi$, where A is the signal amplitude and Φ is the phase difference of the signal relative to the control voltage.

The output voltage of the differential amplifier is passed through an active low-pass filter for the purpose of integration, and this forms the arithmetic mean within 50 ms.

5.8. LIMIT INDICATOR

The output of the low-pass filter is coupled to a voltage comparator, the reference voltage of which is set with the LOWER LIMIT control. If the measured voltage drops below the reference value, the output voltage of the comparator abruptly changes from the negative to the positive state and lights the red lamp "LOWER LIMIT" via a thyristor. The thyristor is operated by the unfiltered positive half-waves of a 6—V_{eff} full-wave power rectifier, the intervention of which terminates tbe lit condition within a half period of the mains frequency when the measured voltage exceeds the reference value in the positive direction.

During calibration in the "Lower Limit" switch position, the set limit is measured by the indicating instrument. The red lamp is lit in this case together with the other lamps. The low-pass filter is separated from the controlled rectifier and connected directly to the pick-up of the LOWER LIMIT control.

The second voltage comparator operates in the same way, but the inputs are reversed. It lights the "UPPER LIMIT" lamp when the measured voltage rises in the positive direction above the reference voltage.

A third thyristor is combined with the two limit indicators by logic circuits, and this lights the green lamp when neither the lower limit is passed nor the upper limit reached.

5.9. OVERLOAD INDICATION

A monostable multivibrator holds all three thyristors in the conducting state for about 8 ms as soon as the output voltage of the signal amplifier reaches the negative overload point. Hence when all three lamps are lit, this is a sign of overload with the meaning "Measured result not usable". The following causes can initiate this signal:

1. Open terminals, e.g. during changing of the unknowns.

2. The difference in magnitude or phase angle is too great for the measuring range.

3. The measured object has a break or a short-circuit.

4. In the case of high-impedance measured objects: external voltages as a result of defective or incorrect screening and earthing measures, see section 4.2.

5. In the case of inductive measured objects: series resonance, feedback, see section 4.17.

At 100 Hz operating frequency and 50 Hz mains frequency the response threshold fluctuates about 1 dB. In this range the lamps light periodically, but they burn continuously when the signal amplitude has indisputably reached the overload point.

For unsymmetrically distributed spurious signals the overload indicator does not operate reliably, because only one of the two signal directions is monitored. Signals of this kind can be caused by commutator motors or electromechanical switchgear, in the vicinity of which even radio reception and the operation of other electronic equipment will be affected.

5.10. POWER SUPPLY

The power supply contains two symmetrical, electronically controlled branches for plus and minus 16 V operating voltage. Mains voltage fluctuations up to ± 10% affect the indicated measured value by a factor of (1 ± 0.005) at the most, without altering the zero point.

A mains voltage selector adjacent to the mains connection can be switched to the following mains voltages when the fuse is unscrewed beforehand:

115 – 127 – 150 – 220 – 240 V (50 Hz – 400 Hz).

The fuse used (0.2 A medium-slow, 5 x 20 mm, DIN 41 41,571) is designed for all the mains voltage settings. For 220–V mains it is also possible to use 0.1 og 0.125 A fuses which react sooner in the case of a fault.

The power consumption is 15 – 20 W.

The mains cable supplied has no protective earth, but the plug socket is also suitable for plugs including a protective earth. The earthing contact is connected to the casing. Protective earthing is only possible if the measured objects are insulated with respect to earth.

6. TESTING

Despite careful handling, faults can develop due to ageing or to rough treatment in transport. The following procedure can be used to detect them.

6.1. CALIBRATION OF THE DEVIATION SCALE

1. BRIDGE MODE "R 100 Hz"
   FUNCTION "RLC"

2. Connect a resistance decade R_1 to terminal 2 and earth socket GROUND.

3. Connect a second resistance decade R_2 to the terminals 1 and 2.

4. Set R_1 and R_2 to the values given in columns 2 and 3 of Table 6.1, and test the scale deflection in the positive direction.

5. Use BRIDGE MODE "C 100 Hz" and columns 2 and 4 for the negative direction.

Differences may be due to the following:

a. R_1, R_2 are not pure resistances (to be detected in the PHASE operating mode); are inaccurately calibrated; $R_1 = 10\Omega$ inaccurate due to excessive contact resistances.

b. If the error is in the same direction in all measuring ranges and can be reduced by a different setting of the REFERENCE calibration control: defective adjustment of the internal control P 404, defective resistance R 403 (refer to Service Instructions).

c. If the error is limited to a few measuring ranges, but is within the admissible limit in the 0.2% range: graduation error in the measuring range switch.

p%	R_1 Ω	R_2 Ω +% "R"	R_2 Ω –% "C"
0,05	10	40 000	39 980
0,1	10	20 000	19 980
0,15	10	13 333	13 313
0,2	10	10 000	9 980
0,25	10	8 000	7 980
0,3	10	6 667	6 647
0,4	10	5 000	4 980
0,5	10	4 000	3 980
0,6	10	3 333	3 313
0,8	10	2 500	2 480
1,0	100	20 000	19 800
1,2	100	16 667	16 467
1,5	100	13 333	13 133
2	100	10 000	9 800
3	100	6 667	6 467
4	100	5 000	4 800
5	100	4 000	3 800
6	100	3 333	3 133
7	100	2 857	2 657
8	100	2 500	2 300
10	1000	20 000	18 000
12	1000	16 667	14 667
15	1000	13 333	11 333
20	1000	10 000	8 000
25	1000	8 000	6 000
30	1000	6 667	4 667
50	1000	4 000	2 000
100	1000	2 000	-
150	1000	1 333	-
200	1000	1 000	-

Table 6.1. Calibration of the % scale

Note: For positive magnitude indication, $R_2 = 2\,R_1/p$.
For negative magnitude indication in operating mode C

$$R_2 = 2\,R_1\left(\frac{1}{p} - 1\right).$$

6.2. OVERLOAD INDICATOR

In the RLC measuring range 0.2% test with R_1 = 10 Ω the ignition point of the overload indicator by varying R_2 until all three lamps are lit. Theoretical value of R_2 = 500 Ω (± 10%).

6.3. CALIBRATION OF THE PHASE DEVIATION SCALE

1. BRIDGE MODE "R" or "C" – "10 kHz"
   Select RLC DEVIATION "20%"
   STANDARD
   (terminals 1 – 2) A resistance R, say 10Ω/1 W, in parallel with a 100Ω variable potentiometer.
   UNKNOWN
   (terminals 3 – 4) A low-loss synthetic foil capacitor, C = about 2 μF.
   FUNCTION "RLC"

2. Set the resistance R to give a scale deflection of zero.

tan	R_1 (Ω)	R_2 (Ω)	tan	R_1 (Ω)	R_2 (Ω)
0,0005	10	39 990	0,02	200	19 802
0,001	10	19 990	0,03	200	13 136
0,0015	10	13 323			
			0,04	400	19 608
0,002	20	19 980	0,05	400	15 608
0,0025	20	15 980	0,06	400	12 944
0,003	20	13 304	0,07	400	11 044
0,004	40	19 060	0,08	1000	24 040
0,005	40	15 960	0,1	1000	19 050
0,006	40	13 292	0,12	1000	15 727
			0,15	1000	12 418
0,008	100	24 900			
0,01	100	19 900	0,2	2000	18 198
0,012	100	16 567	0,25	2000	14 246
0,015	100	13 234	0,3	2000	11 626

Table 6.2. Calibration of the tan δ scale

3. Separate the nodal point R C from terminals 2 and 3, connect an adjustable resistance decade R_1 to terminal 2 and the earth socket GROUND, and a second resistance decade R_2 to terminal 2 and the nodal point RC.

4. Set the FUNCTION switch to "Phase". Set R_1 and R_2 to the values given in Table 6.2. Repeat the test with the various phase angle scales. Set the measuring range switch PHASE DEVIATION to the reference values corresponding to the scales. Repeat test in both operating modes "R" and "C" – "10 kHz".

6.4. OSCILLATOR FREQUENCY

The oscillator frequency can be checked between terminal 1 and earth socket GROUND (voltage 360 mV) with an electronic meter. Error sources: components of the bridged T-filter inside the oscillator circuit.

6.5. PHASE CONGRUENCE IN RLC MODE

1. Connect a resistance $R_1 = 20\,\Omega$ to terminal 2 and earth socket GROUND.

2. Connect a capacitance decade C_2 to terminals 1 and 2.

3. PHASE DEVIATION "0.05"
   Select FUNCTION "Phase"

4. Set the pointer deflection C_2 to $\tan \delta = 0.03$.

5. Select FUNCTION "RLC"
   RLC DEVIATION "0.2%"
   The magnitude indication should be 0.045% (half the square of the phase angle). Tolerance: ±0.018%.

   On switching to operating mode C (same operating frequency) the indication should be of the same magnitude but opposite in sign.

6. Repeat instruction 5 at all three operating frequencies.

7. Error sources: differences in transit time in the signal or reference channel, changes in capacitance in the coupling capacitors.

Adjustment possibilities: P 401/100 Hz, P 302/1 kHz, P 403/10 kHz. Refer to the Service Instructions.

6.6. PHASE CONGRUENCE IN PHASE MODE

Switch PHASE DEVIATION to "0.2, FUNCTION switch to "Phase" connect terminal 1 to terminal 2 (or terminal 3 to terminal 4). The pointer deflection should be less than ±0.012 in all positions of the BRIDGE MODE switch. Error source: integrator. Adjustment possibility: C 401 at 10 kHz. Refer to the Service Instructions.

6.7. LIMIT INDICATORS

Reproduce in accordance with section 6.1 the same pointer deflections to which the limit indicators were previously set. Deviations from the expected ignition points can be compensated with the internal adjustment controls P 603 (LOWER LIMIT) or P 604 (UPPER LIMIT). Refer to the Service Instructions.

6.8. INPUT IMPEDANCE

1. Connect the "hot end" of an air trimmer capacitor C = 0 – 30 pF to terminal 3.

2. Put screening covers on terminals 1 and 4, connect a screened cable to terminal 4, connect the free end to terminal 2.

3. Select

Select	SCALE	"1% tan 0.01"
	BRIDGE MODE	"C – 10 kHz"
	RLC DEVIATION	"100%"
	PHASE DEVIATION	"0.2"
	FUNCTION	"RLC"

4. Set the pointer deflection to 1% with the REFERENCE control.

5. Separate the cable from terminal 2 and connect it to the "cold end" of the trimmer C.

6. Adjust C to give a pointer deflection 0.5%. C is now equal to the input capacitance C_e.

7. Switch BRIDGE MODE to "R – 100 Hz". Set the meter deflection to 1% with the REFERENCE control.

8. Set FUNCTION switch to "Phase". Read the meter deflection relative to 1%, example 0.55, multiply by scale factor 0.3, note result as tan Φ. Example tan $\Phi = 0.165$.

9. Switch BRIDGE MODE "C – 10 kHz"
RLC DEVIATION "Ref"
FUNCTION "RLC"
Set meter deflection with REFERENCE control to 1%.

10. Connect a capacitor $C_n = 10$ nF to terminal 2 and the earth socket GROUND.

Set measuring range switch RLC DEVIATION to 0.2%. Read the meter deflection relative to 1%, example: 1.2% / 1% = 1.2, multiply by scale factor 10 pF, note $C_e = 12$ pF. This is the input capacitance in operating modes R and C.

11. Calculate the input resistance.

$$R_e = \frac{1}{\omega C_e 2 \tan \Phi}, \quad \omega = 2\pi \quad 100\,\text{Hz}, \tan \Phi \text{ (see 8.)}$$

$$\text{Example: } \frac{796 \times 10^{-6}}{12 \times 10^{-12} \times 0.165} = 402\,\text{M}\Omega$$

12. Repeat instruction 1 – 6, and 9 and 10 in BRIDGE MODE L – 10 kHz, where the typical input capacitance is 30 pF.

7. SPECIFICATIONS

Operating frequencies: 100 Hz – 1 kHz – 10 kHz.

Bridge voltages: 2 x 360 mV at standard calibration.

Ranges of application with suitable choice of operating frequency:

1. For comparison measurements at standard calibration:
   R: 1 Ω – 2 MΩ, C: 500 pF – 3000 μF, L: 20 μH – 500 H.

2. For comparison measurements when observing special calibration instructions in accordance with instructions for use:
   R: 0.1 Ω – 500 MΩ, C: 0.3 pF – 30,000 μF.

3. For potentiometric measurements:
   R: 100 mΩ – 1 MΩ, C: 0.002 pF – 10 μF.

Indication ranges: Interchangeable scales

for RLC deviations:

Reference value %	Scale limit values +%	–%
0.2	0.3	0.3
1	1.5	1.5
5	7.6	7
20	32	24
100	200	65

for phase deviations:

Reference value tan δ	Scale limit values $\pm$ tan δ
0.002	0.003
0.01	0.015
0.05	0.075
0.2	0.3

Overload

Overload occurs if the difference between the Standard component and the Unknown component exceeds a factor of 15 times the full scale deflection. In the overload condition all three indicator lamps are lit.

Measuring ranges		Overload at:		
RLC %	tan δ	+%	–%	tan δ
0.2	0.002	4	4	0.04
1	0.01	22	18	0.2
5	0.05	200	65	1.5
20	0.2			

Bridge circuit

Two similar windings of a transformer form the inner bridge arm, the mid-point of which is connected to the two earth sockets GROUND and to the housing. The outer bridge arm is formed by the measurement objects (unknown, reference standard).

Connections

Four screw terminals for laboratory plugs, cable eyes or wires, when using the screening covers DB 1065 also suitable for screened cables with B & K plugs JP 0101. The cable capacitances measured between the terminals 2, 3 and the earth sockets GROUND, can be made about 93% ineffective by feedback in operating modes R and C.

Internal impedance of the oscillator, measured between terminal 1 or 4 with respect to the earth sockets: $32 \cdot 10^{-3}\ \Omega$ with inductive component $2.5 \cdot 10^{-3}\ \Omega$ at 1 kHz. Difference in resistance between the two halves of the inner bridge arm: about $0.1 \cdot 10^{-3}\ \Omega$.

Input resistance, measured between terminal 2 or 3 and the earth sockets, about 400 MΩ.

Input capacitance: about 12 pF in operating mode R or C,
about 30 pF in operating mode L.

Feed-back: In operating mode R or C the voltage at the threaded socket of terminals 2 and 3 is about 7% lower than the input voltage. The internal impedance is about 17 Ω with capacitive component 3.2 Ω at 1 kHz. In the case of overload or short-circuit to earth, the input impedance assumes the characteristics of operating mode L where the threaded socket are earthed. The threaded sockets of terminals 1 and 4 are earthed in all operating modes.

Calibration:

The RLC DEVIATION switch bas, in addition to the 5 measuring range positions. 4 other positions, "Zero", "Reference", "Upper Limit" and "Lower Limit". In the "Zero" position the residual unbalance is compensated by the ZERO control. In "Reference" position the pointer deflection is set to the red scale mark with the aid of the REFERENCE control. In the case of a change of scale, the two settings do not need to be repeated.

Limit indication:

Three lamps give the following information:

1. The unknown is usable (green lamp).
2. The unknown is too small (red lamp, left).
3. The unknown is too large (red lamp, right).
4. The measured result is unusable (all three lamps).

Uncertainties:

With symbols:

p^* (x 100%) = indicated,
p (x 100%) = true difference in magnitude
δ^* = indicated,
δ = true difference in phase angle

Error of symmetry:

$p^*, \tan\delta^* < 10^{-4}$, when $p, \delta = 0$.

As a result of 10% mains voltage variation:

$p^*/p = 1 \pm 0.005\,(1 + 0.5\,p^*)$,
$\tan\delta^*/\tan\delta = 1 \pm 0.005$.

Graduation error in measuring range switch:

$$p^*/p = 1 \pm 0.02\,(1 + 0.5\,p^*),$$
$$\tan\delta^*/\tan\delta = 1 \pm 0.02.$$

Uncertainty of pointer instrument:

$$p^*/p = 1 \pm 0.015\,(1 + 0.5\,p^*).$$
$$\tan\delta^*/\tan\delta = 1 \pm 0.015.$$

Uncertainty of phase congruence:

$$p^* = \pm 0.012 \tan 0.5\,\delta^* \text{ when } p = 0$$
$$\tan\delta^* = \pm 0.012\,p^* : (2 + p^*), \text{ when } \delta = 0.$$

Systematic error of method of measurement:

$$p^*/p = 1 + \tan^2 0.5\,\delta^*\,(1 + 0.5\,p^* + 0.16\,p^{*2})$$
$$\tan\delta^*/\tan\delta = 1 - \left(\frac{p^*}{2 + p^*}\right)^2 : (1 - \tan^2 0.5\,\delta^*)$$

Indication error for resistances 2 MΩ and above in operating mode R 100 Hz:

$$p^*/p = 1 - 0.5\,p^* + 0.5\,(p^*/K)$$
$$\tan\delta^*/\tan\delta = \left(\frac{1 + 0.5\,p^*/K}{1 + 0.5\,p^*}\right)$$

K = correction factor by which the sensitivity of indication must be calibrated to cancel out the input losses, if the resistance of the outer bridge arm is replaced by half the value of the standard.

Indication error for capacitances 500 pF and below in operating mode C 10 kHz:

$$p^*/p = 1 + 0.5\,p^* - 0.5\,p^*/K,$$
$$\tan\delta^*/\tan\delta = \left(\frac{1 - 0.5\,p^*/K}{1 - 0.5\,p^*}\right)$$

Zero point uncertainty for high resistances:

$$p^* = \tan\delta^* \tan\Phi, \text{ when } p = 0$$
$$\tan\delta^* = p^* \tan\Phi, \text{ when } \tan\delta = 0$$
Φ = phase angle of input loss, $\tan\Phi = 0.5\,\frac{R_s}{Z_e}$

Z_e = input impedance.

Plug-in scales supplied:

Phase angle difference tan δ	RLC Difference (%)				
	100	20	5	1	0.2
0.2	SA 0109	SA 0110	SA 0112		
0.05	SA 0109	SA 0110	SA 0111	SA 0112	
0.01			SA 0111	SA 0113	SA 0114
0.002				SA 0113	SA 0114

2 scales SA 0027 for special markings. Graduation 0 — 100 in grey print.
5 = negative scale limit, 50 = scale mid-point,
95 = positive scale limit.

Power:

115, 127, 150, 220, 240 Volts
50 to 400 Hz
18 VA

Dimensions:

Height	33 cm	(13 in)
Width	28 cm	(11 in)
Depth	20.5 cm	(8.1 in)

B & K INSTRUMENTS:

ACOUSTICAL....
Condenser Microphones
Piezo-Electric Microphones
Microphone Preamplifiers
Microphone Calibration Equip.
Sound Level Meters
(general purpose-precision-
and impulse)
Standing Wave Apparatus
Tapping Machines
Noise Limit Indicators

ELECTROACOUSTICAL....
Artificial Ears
Artificial Mouths
Artificial Mastoids
Hearing Aid Test Boxes
Telephone Measuring Equipment
Audiometer Calibrators
Audio Reproduction Test Equip.

STRAIN....
Strain Gauge Apparatus
Multipoint Panels
Automatic Selectors
Balancing Units

VIBRATION....
Accelerometers
Accelerometer Preamplifiers
Accelerometer Calibrators
Vibration Meters
Magnetic Transducers
Capacitive Transducers
Vibration Exciter Controls
Vibration Programmers
Vibration Signal Selectors
Mini-Shakers
Complex Modulus Apparatus
Stroboscopes

GENERATING....
Beat Frequency Oscillators
Random Noise Generators
Sine-Random Generators

MEASURING....
Measuring Amplifiers
Voltmeters
Deviation Bridges
Megohmmeters

ANALYZING....
Band-Pass Filter Sets
Frequency Spectrometers
Frequency Analyzers
Real-Time Analyzers
Slave Filters
Psophometer Filters
Statistical Analyzers

RECORDING....
Level Recorders
(strip-chart and polar)
Frequency Response Tracers
Tape Recorders

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