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1 MHZ MODULE TRANSFORMER BRIDGE

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Abstract: A transformer bridge to study low-loss dielectrics at the frequency 1 MHz is developed. The main components of the bridge: a ratio transformer and variable measuring standards of capacitance and conductance are made in the form of removable modules. The bridge measurement range by loss angle tangent D is 10^{-6} - 10^{-3} with the capacitance 1-1000 pF. Measurement uncertainty D is ± (2-3)$\times 10^{-6}$, k=2.
Keywords: transformer bridge, loss angle

1 INTRODUCTION

The novel non-contact method and measuring cell (MC) to study solid dielectric specimens were described previously [1], which made it possible to reduce the uncertainty of measurement of dielectric permittivity at the frequency 1 MHz down to 0,1%, but had insufficient accuracy when measuring low loss angles. In the method described the loss angle is “diluted” with the capacitance of air gaps between a specimen and electrodes and at D < $5 \cdot 10^{-5}$ a device is required with the sensitivity at the level 10^{-6}. The resolution by D of commercial produced capacitance meters (MCE-17A, Russia; HP 4278A, US) is in the range of 10^{-5} - 10^{-4} and the uncertainty of measuring D is by a factor of 10 greater for them.

In the proposed transformer bridge the main components are made in the form of removable modules, that makes it possible to improve the accuracy of their calibration and simplify the readjustment of the bridge measurement range. The transformer bridge is designed on the basis of binary dividers. A new variable coaxial capacitor with an improved stability, linear scale and minimum initial capacitance, is designed to balance the bridge by capacitance. A device based on a T-circuit with a fixed resistor and two capacitors compatible in design, is developed to balance the bridge by conductance. A symmetrical earth connection used in the bridge circuit helps to improve the accuracy.

2 ELECTRIC CIRCUIT AND DESIGN OF THE BRIDGE

Electrical circuit of the bridge (Fig. 1) is of the same type as the circuit of the Lynch bridge [2] and contains a generator, input transformer T, two microvoltmeters V_1 and V_2, ratio transformer RT, variable capacitor C_1, variable conductance device ($-G_1$), conductance box G_2 and symmetrical earth connection S.

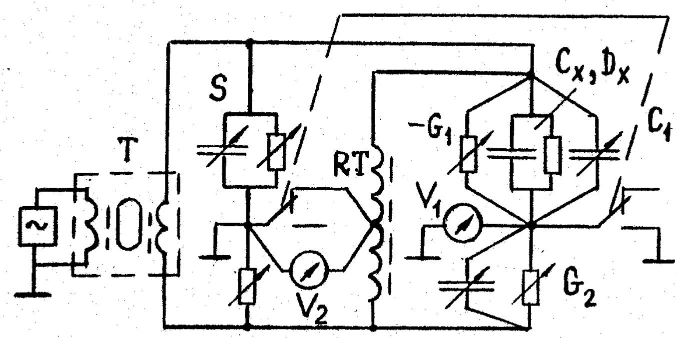


Figure 1. Transformer bridge

The design of the bridge presents a polyterminal connector with the built-in input transformer, conductance box and symmetrical earth connection resistors; the other components are removable. The input transformer matches symmetrical input of the bridge to the asymmetrical output of the generator. It is a separating transformer and comprises two windings of 30 turns each, wound on separate ferrit cores. The transformer is located in a closed cavity of a brass cup, a central rod of which forms a volume coupling turn between the windings. The volume turn limits electromagnetic fields of the windings, considerably reduces their leakage inductance and eliminates the capacitance between them. The RT allows to obtain ratio coefficients from 0,1 to 1; the transformer is assembled on sections, each of which divides an applied voltage in the ratio 2:1. In the present work a measurement method has been applied in which ratios of RT are not used and therefore the design of RT and its calibration are not considered here. The conductance box is intended for initial balancing the bridge by G and for measuring $D > 1{\cdot}10^{-4}$ as well as of lower values of D when the capacitance is higher than 100 pF. It contains four decades with multiples from 1 nS up to 1 µS. Two smaller decades have been made in a smooth form on the basis of a resistive T- circuit; and greater decades present a set of resistors, assembled on switches of the carrousel type. The switches are provided with additional circuit boards which give the opportunity to short-circuit unconnected resistors to the body. This permits the box capacitance to be kept constant in the range of 0,1 pF.

The symmetrical earth connection is a resistor - capacitor one. It is intended for eliminating the effect of capacitance and conductance leakage from the bridge tops that bypass the transformer arms. At low frequencies the effect of leakage is usually neglected providing that magnetic coupling between windings is hard; it is accomplished with magnetic permeability of the core being $\mu_r \geq 10^5$. At high frequencies (HF) this condition is not managed to meet as μ_r of the used ferrite cores is no more than 10^3. Besides, the bypass effect of the capacitance leakage increases proportionally with frequency. Taking into account that the bypass effect of impedances in the HF transformer bridge is substantially reduced, the symmetrical earth connection can be balanced with a much lower accuracy than balancing the bridge. To make this underbalance unaffected for balancing the bridge the arms of the symmetrical earth connection should be connected in parallel with the transformer arms, as shown in Fig.1. The capacitors of the symmetrical earth connection are removable and the maximum value of the adjustable resistors is 15 kΩ. A high degree of stability is not needed from these capacitors and resistors. The generator and microvoltmeters are made commercially; a high sensitivity being required only from microvoltmeter V_1 used as a null detector of the bridge. The selective microvoltmeter, type SMV -11 (Germany), is used for this purpose. The sensitivity of microvoltmeter V_2 can be lower by the order of 3-4. In the polyterminal connector there are two and three-terminal coaxial sockets. Variable measures (and if it is necessary fixed ones) are connected to three-terminal sockets for balancing the bridge by C and G; variable capacitors of the symmetrical earth connection are connected to two-terminal sockets. All parts and circuits, having potential of the body, except T-circuits in the conductance box, come together at a single point to avoid the appearance of spurious closed current circuits that interact with other branches of the bridge circuit. An object of measurement, if it is equipped with a three-terminal coaxial connector, is put onto the corresponding socket of the bridge, or connected to the bridge by a special short five-terminal cable.

3 VARIABLE CAPACITOR

When measuring D with an uncertainty of $1{\cdot}10^{-6}$, the capacitance in the bridge should be balanced and stable in the range of $1{\cdot}10^{-6}$. Therefore, considerable attention has been given to the development of the HF variable capacitor possessing a high resolution and rather high stability. The Woods variable coaxial capacitor with a movable electrode of floating potential [3] was taken as a basis because of the lack of a sliding contact and the possibility of a precise calculation of its frequency dependence (uncertainty is less than 0,01 % at the frequency 1 MHz). But the Woods capacitor had a significant initial capacitance, nonuniformity of the scale and small gaps between electrodes (about 0,1 mm) which resulted in instability of its capacitance value. Besides, the above capacitor was two-terminal but to use in a transformer bridge it should be three-terminal. The new variable coaxial capacitor is free of above drawbacks. It comprises (Fig. 2) internal 1 and external 2 stators, manufactured as cylindrical packs, and movable electrode 3, located in screening body 4. Screen 5 is placed between the stators that eliminates their initial capacitance. Movable electrode 3 is mechanically connected through isolator 7 to guide 6 of a mechanism providing for displacement.

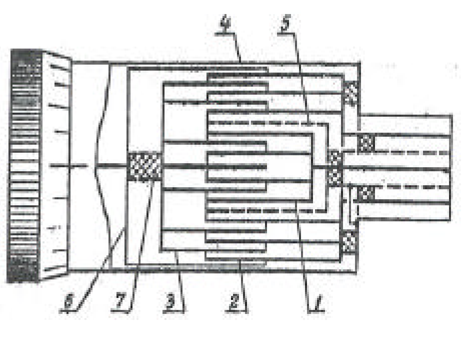


Figure 2. Design of variable capacitor

When movable electrode 3 is immersed into the space between stators 1 and 2 at the depth h, working capacitance C_{12} is generated, which consists of two capacitances C_1 and C_2 connected in-series, each oh them being proportional to h (Fig.3a).

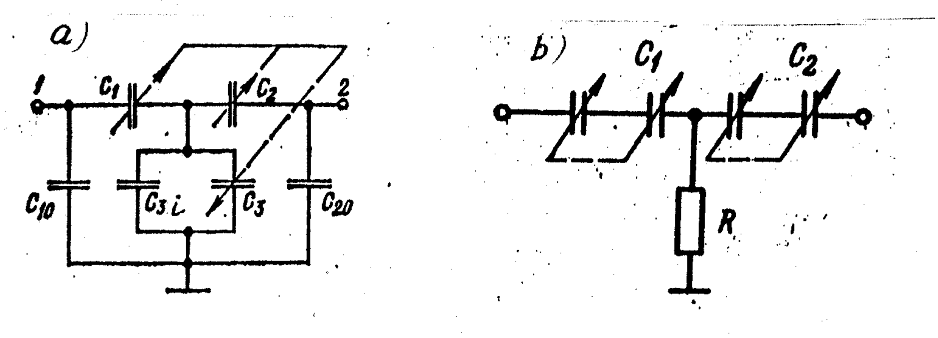


Figure 3. Electrical circuit of : a) variable capacitor; b) variable conductance device

The working capacitance depends also on capacitance of moving electrode 3 relative to body 4 and screen 5. This capacitance consists of a variable part C_3 which is also proportional to h, and a fixed part C_{3i} , caused by isolator 7 and an incomplete immersion of the movable electrode. The presence of the fixed part breaks the scale linearity. To eliminate this drawback, an initial overlap h_1 is introduced between internal stator 1 and movable electrode 3. Then, with the proviso that

$$h_{1i} = \frac{C_{3i}}{C_2' - C_3'} \tag{1}$$

the linear dependence of the working capacitance C_{12} on the depth of immersion h is afforded:

$$C_{12} = h \frac{C_1' C_2'}{C_1' + C_2' - C_3'} \tag{2}$$

where C_1', C_2' and C_3' are corresponding single (per length unit) capacitances.

The capacitors are designed for the maximum capacitance 10, 60 and 100 pF with the initial capacitance not more than 0,5 pF and a scale division is 0,0026; 0,015 and 0,029 pF. The initial overlap between the movable electrode and the internal stator makes up 3,6; 5,6 and 4,8 mm. The gaps between the movable electrode and stators are established in the range of 0,3-1 mm, and the single capacitance is increased mainly due to the increased number of cylindrical electrodes rather than due to decreasing of gaps between them. Besides, the developed capacitor provides for a comparatively small value of capacitances C_{10} and C_{20} of the stators relative to the body and their constancy. Thus, C_{10} =35 pF, C_{20} =101 pF for the capacitor 100 pF and their variations do not exceed 6 and 1 pF, respectively. This property is especially useful when capacitors are used in the bridge with a symmetrical earth connection, since it shortens time of balance achievement. A variable capacitor with a capacitance of 0,1 pF has also been made to balance the bridge fine (when the resolution of the capacitor 10 pF is not enough). It is not a readout device and is made as a micrometric screw covering the opening in the screen between the electrodes.

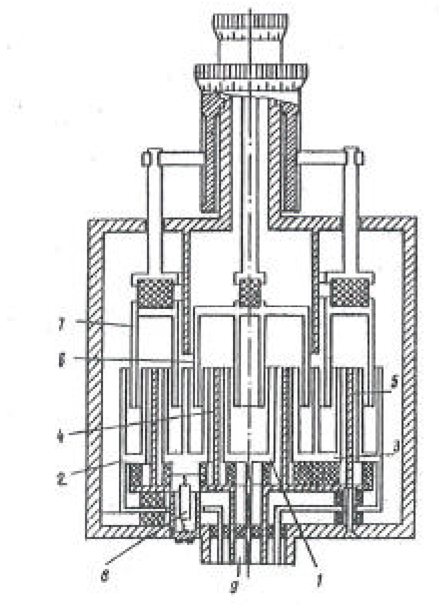
4 VARIABLE CONDUCTANCE DEVICE

To balance the bridge by conductance, a special device is developed on the basis of a T-circuit, which contains two in-series connected variable coaxial capacitors with a non-contact movable electrode and a resistor, connected between the middle point of capacitors and the body (Fig.3b). The capacitors and resistor are combined into one design [4], comprising three stators 1,2 and 3, separating screens 4 and 5, which are located between them, and two movable electrodes 6 and 7, made as cylindrical packs (Fig.4). The middle stator 3 is common to both movable electrodes, resistor 8 is set up between the end wall of stator 3 and the body, and the internal and external stators are connected to output connector 9. The direct conductance of the T-circuit and parallel to it capacitance C_p , provided that $[\omega R(C_1 + C_2)]^2 < 0{,}01$, are determined:

$$G = - \omega^2 RC_1C_2 \tag{3}$$

$$C_p = \frac{C_1 C_2}{C_1 + C_2}[wR(C_1 + C_2)]^2 \qquad (4)$$

where $\omega = 2\pi f$, f - is frequency.



Quantities R and C_2 in Formula (3) are used to change the scale division of the device while capacitance C_1 is proportional to G. The parallel capacitance C_p is very small and fluctuates within 0,001-0,01 pF.

Owing to the use of the removable resistor and variable capacitors with a large factor of overlapping, the device has an extended G range and its accuracy at HF is mainly determined by calculation uncertainty of the capacitance value of the capacitor with a movable non-contact electrode; as mentioned above this uncertainty is very small. One-sided location of the stators allows the device to be provided with a coaxial three-terminal connector without lengthening current - carrying conductors. The device developed is characterized by: C_1 = 0,1-5,6 pF, C_2 = 0,9-26 pF, R = 30-200 Ω. Range G makes up 10 pS -1 μS at the frequency 1 MHz. It makes possible to cover the range D = 10^{-7} -10^{-4} with the capacitance 1-100 pF. If D and C exceed these values, the conductance box is used.

Figure 4. Design of variable conductance device

5 EXPERIMENTAL RESULTS

Measurements of the capacitance and conductance of MC with or without a specimen are carried out in the same arm of the bridge by the substitution method. The value D of the specimen is determined using the same formulas [1], but substituting ΔD increments for values $\Delta G/\omega C$ in them.

The bridge response by D is $1 \cdot 10^{-6}$ with the capacitance 10 pF and the generator voltage 2V. For the specimens made of synthetic quartz glass, the D values are $(3 - 10) \cdot 10^{-6}$, the measurement uncertainty being $u = \pm (2 - 3) \cdot 10^{-6}$, k = 2.

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