HIGH FREQUENCY CAPACITY METER

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I. Introduction

The rapid development in the scientific and technical life of our age requires the same rapid development in the field of the measuring technics. The different physical and chemical quantities must be measured with an ever higher sensibility and accuracy and this fact requires very serious stability characteristics from our instruments. In the last few years such requirements have appeared in physico-chemical measurments with the dielectric constants of materials, the more, because the measuring results so obtained can be used quite well in the research of material structures, on instrumental analysis and in several control works in the industry.

At misture adsorption and material structure research, as well as for analytical investigations, in our institute it was necessary to measure the dielectric constants of liquids in a wide frequency range with high sensibility and accuracy. In our investigation the different capacity measuring methods were compared and the analysis of the problems to be solved has brought about a new electric measuring circuit.

2. Comparison of capacity measuring methods

For measuring capacity the properties of the condenser on the effect of alternating current can be used. The more important measuring methods are outlined as follows.

a) The impedance of the measuring condenser can immediately be determined by the voltage-current measuring principle. The precision is not too high, in case of a simple device a precision of $0{,}2 \cdot 10^{-2}$—$1 \cdot 10^{-2}$ can be attained.

b) A high precision measurement is made possible by applying different bridging methods. In precision also a value of 10^{-5}—10^{-6} can be attained, however, it decreases in case of an increase of frequency owing to the inevitable difficulties encountered in earthing and to scattering, so that bridges cannot be used over 15—20 MHz even in the case of a particular building up.

c) For higher frequencies only such measuring methods can be taken into account, in which the measuring condenser is set into an oscillating circuit.

c) 1. A resonance measuring method is used the most frequently. By a loose joining an oscillating circuit is excited at a high frequency, its resonance frequency is determined, then, connecting the measuring capacity into the oscillating circuit, also the new resonance frequency is measured. The precision of the measuring can be increased only by a very careful building up until 10^{-4} value and the precision depends to a great extent on the quality of the oscillating circuit.

c) 2. Another possibility is to connect the oscillating circuit to an oscillator. Then, if correctly executed, the frequency of the oscillator depends only

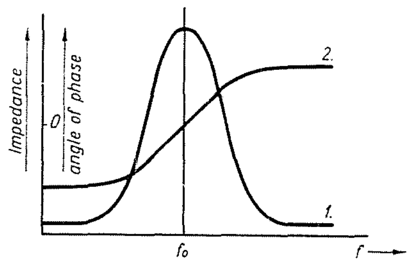

Fig. 1. Impedance and phase characteristics of an oscillating circuit. Curve 1: impedance characteristics. Curve 2: phase characteristics

on the resonance point of the oscillating circuit; measuring the frequency resp. the frequency change, the capacity can be calculated.

This task can be solved properly by using two oscillators, then by mixing, their oscillations a differential frequency is produced and this change is measured. In general, the precision of the measuring depends only on the stability of the two oscillators in respect to each other, in case of a careful building up a precision of 10^{-5} can be attained in the short wave band, too.

As the oscillating circuit measuring method seems to be the best, let us, therefore, examine more closely some fundamental questions referring to this method.

Measuring with the resonance method (according to point *c*/1.) the resonance frequency of the oscillating circuit is generally determined by using the impedance characteristics of the oscillating circuit, then the change, after connecting the unknown capacity should be measured and from these two data the value of the capacity sought for can be calculated. In general, the resonance point can be determined by observing the voltage maximum, it must be stated, however, that the observation of maximum can be done only under very unpleasant circumstances because of principal hindrances. Examining the shape of the impedance characteristics of the oscillation circuit (curve 1 in

Fig. 1), it can be seen, that it has a horizontal tangent on the resonance frequency, so, in case of differentially small capacity changes no impedance change can be observed in principle, either. There is no hope in using the more rapidly declining intervals of the impedance characterstics, because here the impedance values depend to a high degree on the losses of the oscillating circuit. So the place of the voltage maximum must be determined (namely its place depends practically only on the LC product of the circuit). The precision of the measurement can be improved only by "sharpening" the impedance characteristics of the oscillating circuit i. e. by improving the quality of the circuit, by a condenser having losses (measuring non-isolating liquids), hower this task often cannot be solved.

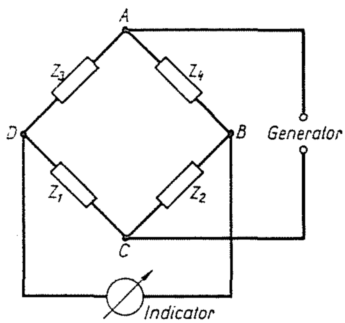

Fig. 2. Coupling in theory of an a. c. bridge

The resonance frequency can be determined very exactly with the aid of the phase characteristics of the oscillating circuit. Between the voltage and the current of the oscillating circuit there is 0° phase displacement at the resonance frequency. The phase characteristics go through this point linearly (curve 2 in Fig. 1), this is a very favourable peculiarity from the point of view of measuring. On the whole the method with an oscillator after point $c/2$ conforms to the measuring on these characteristics, because if the losses of the oscillating circuit cease, it will oscillate undamped on the resonance frequency corresponding to the 0° phase angle. A frequency change can be attained at a differentially small change of the capacity of the oscillating circuit, too. In our measuring method the favourable form of the phase characteristics is used to increase the sensibility.

3. Review of the applied connections

On the basis of the aforesaid a solution has been worked out in our experiments on the electronic connection of the capacity meter, where the phases of two uniform oscillating circuits are compared with a phase recording indicator.

The principal operation of the connection is as follows: building up the usual bridge circuit from four oscillating circuits (Fig. 2) and feeding the bridge at points A, C from a high frequency generator, a phase equality is to be found between points B, D (the bridge will be equalized in phase) if

$$\frac{Z_1}{Z_2} = \frac{Z_3}{Z_4}$$

relation is valid.

If e. g. the LC products of the oscillating circuits Z_1 and Z_2 are identical, then in case of the identity of Z_3 and Z_4 the phase equalization arises. It can

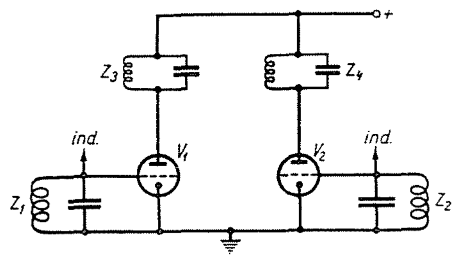

Fig. 3. Scheme of coupling of a bridge containing two circuit members with inner excitation

adequately be observed with an oscilloscope leading the signal of point B to the horizontal, and that of point D to the vertical deviating system. In case of a phase accordance a stable ellypsis is to be seen on the oscilloscope. In order to avoid earthing problems care should be taken to earth one pole of each of the four applied oscillating circuits. Then two points of the bridge (A, C) must be earthed and the bridge cannot be fed from outside. The energizing of the oscillating circuits can be ensured by compensating the losses of oscillating circuits with inner energizing. This task has been solved building up a T. P. T. G. oscillator-connection. The applied circuit works in the following manner (Fig. 3).

The oscillating circuits Z_3 and Z_4 are tuned to an about 3% higher frequency than the resonance frequency of the oscillating circuits Z_1 and Z_3 in the grids. Thous, owing to the amplification and the Miller effect, the tubes (V_1, V_2) transform the impedance of inductive character in the plates to a negative resistance into the grid circuits, and there the two oscillating circuits are energized on their own resonance frequencies. The signals of the two grids are led into a phase sensitive indicator (oscilloscope or coincidence tube). In case of small detunings the change in the frequency of the oscillating circuits will correspond and be proportional to the change in the capacity of the oscillating circuit, the grid oscillating circuits are not influenced by the plate impedances.

Let us examine the role of the single elements from the point of view of the measuring bridge after Fig. 2 (Fig. 4). The points A and C are earthed according to the term; points B and D have fallen into 2—2 independent points. But this independence is not a real one, because in our case the "hot points" of the oscillating circuits Z_1 and Z_3 resp. Z_2 and Z_4 are bound on the grids resp. plates of electron tubes. The electron tube performs a phase drive between its grid and plate, but this phase drive is always constant, namely 180°, so, from the point

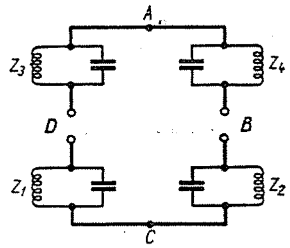

Fig. 4. Scheme of coupling to investigate the work of a bridge grounded at two points

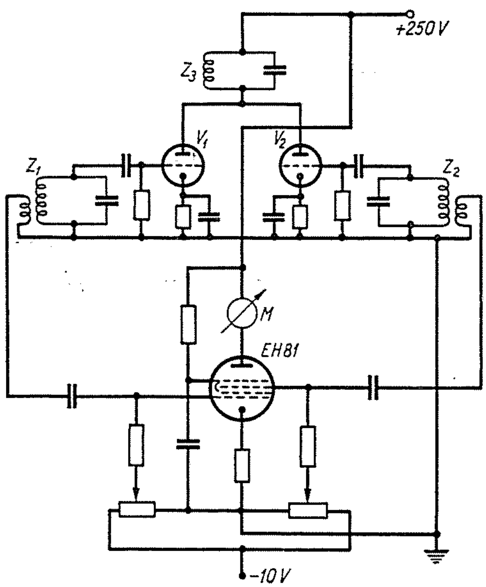

Fig. 5. Simplified bridge-scheme uniting the Z_3 and Z_4 comparison circuit members, with coincidence coupling as indicator

of view of high frequency it is equivalent to the case, when the points in question are connected galvanically (then the phase drive is also constant, namely 0°).

But the great advantage of the electron tube connection against the galvanical one is, that it does not affect the work of the bridge, making the oscillating circuits self-oscillating, so the outer generator is unnecessary, considering that in case of compensation ($Z_1 = Z_2$ and $Z_3 = Z_4$) there are signals of the same amplitude and phase at the hot points of Z_3 and Z_4 i. e. on the plates of the tubes, the two plates can be connected galvanically, too. This does not at all affect the equality, on the other hand it has its advantage, that instead of two oscillating circuits only one can be applied, so $Z_3 = Z_4$ as a matter of course is ensured. (The coupling modifies the behavior of the connection in an unequalized case, but this will not be treated here, only mentioned, that it has an increasing effect on stability.) The so formed connection can be seen on Fig. 5 using coincidence connection as indicator.

The signals of the two grids are coupled to the two bias levelled grids of an EH 81 coincidence tube. The tube leads a maximal plate current, when the two

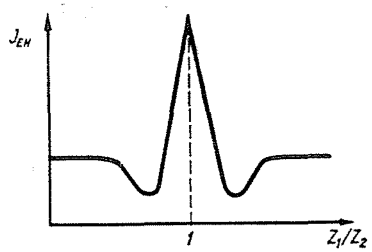

Fig. 6. Characteristics of the indicator in Fig 5. function of detuning. (I_{EH} = anode current of the coincidence tube read on a microampermeter.)

oscillating circuits are in identical phase. The measurings can the most adequately be carried out by substitution. The change in the plate current of the coincidence tube is illustrated as the function of the detuning (Fig. 6). It can easily be seen, that the characteristics of the indication is rather declined in case of small detunings. The sensitivity of the circuit is about the value 10^{-5}. Its longwearing stability depends on the stability of the two oscillating circuits with respect to each other.

The deficiency of this circuit is, that the change in capacity cannot be directly read, the measuring result can be obtained by looking for the extreme value of the amplitude on the instrument measuring the plate current of the coincidence tube. As the immediate readings are often important requirements, a variant of this connection has been worked out showing the change in capacity immediately.

As a matter of fact the circuit is built up as a system of two bridges: a high-frequency bridge and a direct current one (Fig. 7).

The direct current bridge consist of resistances R_1 and R_2 and tubes V_3 and V_4, these are coincidence tubes (EH 81). Their internal resistances are increased or decreased according to the phase position of the oscillating circuits Z_1 and Z_2 with respect to the phase position of the oscillating circuit of the common plate circuit. The characteristics of the system are illustrated in Fig. 8.

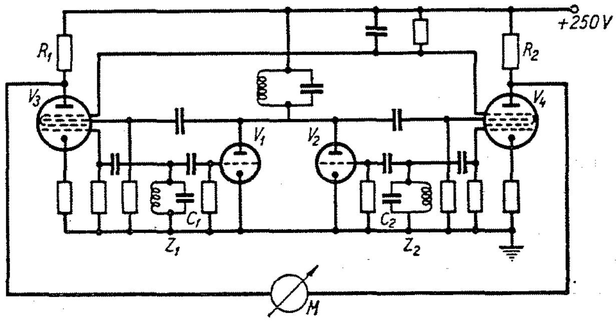

Fig. 7. Scheme of a bridge system indicating immediately the change in capacity. The members of the d. c. bridge used as indicator are R_1 and R_2 resistances, V_3 and V_4 coincidence tubes, resp.

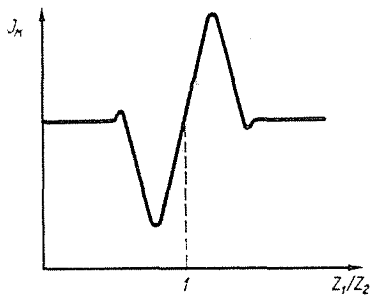

Fig. 8. Characteristics of the indicator in Fig. 7 in function of detuning. (I_M = the bridge current of the d. c. unbalanced bridge read on the M measuring instrument.)

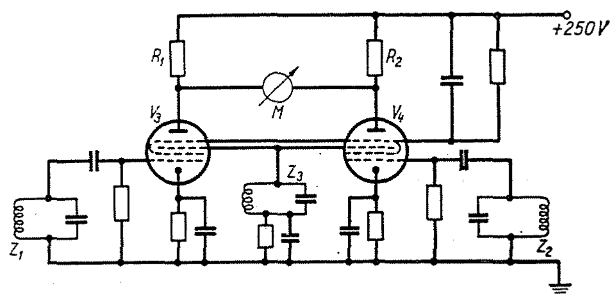

Fig. 9. Simplified bridge-system used on frequencies less than 30 MHz. The coincidence tubes V_3 and V_4 supply the excitation of the measuring circuits Z_1 and Z_2

Applying long life tube it is possible to attain a better sensitivity value than 10^{-5}. The stability here, too, depends on the stability of the two oscillating circuits (Z_1, Z_2) in relation to each other. By the detuning of Z_3 only the linear tuning range of the characteristics is decreased, neither a slope change, nor a characteristics deplacement is caused by it. The detuning of the two measuring oscillating circuits can be restricted from each other to an order 10^{-5}—10^{-6} without using a special liquid thermostat. This can be achieved by an exact mechanical building up and placing it into a thermically common system. The temperation of the liquid naturally brings about further advantages.

Up to the range of 30 MHz the exciting tubes (V_1, V_2) can also be substituted by the corresponding grids of the tube E81H. The simplified solution is shown in Fig. 9. This circuit can be realized with such two control grid tubes, where between the first and third grids of which there is a big enough amplification. Thus, the task of the excitation as well as the coincidence formation is fulfilled by the two tubes. The circuit under 30 MHz has the same properties, as the preceding alternative. It proves to be particularly advantageous for measurings in plant where there is a continuous production control.

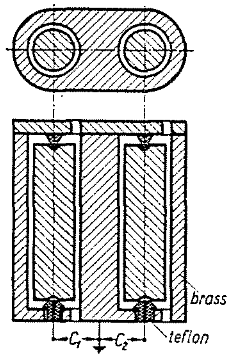

Fig. 10. Twin measuring condenser for measuring the dielectric constants of liquids. C_1 and C_2 are the capacitive elements of the measuring circuits Z_1 and Z_2 in the previous figures

4. Measuring cells

It should be mentioned, that the sensitivity of the electronic connection is higher than the stability of the usual measuring condensers. A good measuring cell must be totally screened from outside, mechanically solid and stable. The cylindrical condensers with corrosion resistant brass plating proved to be satisfactory, which can be filled up from above and discharged at their lower orifices. The system can be washed and dried through the two orifices. The condensers must be fixed onto the panel of the instrument, because the slightest mechanical deformations can cause a high error in measurings.

When measuring in plants small tube condensers built into closed tubings can be used well, in case of adequate fixing they work accurately. In this case the outleading of the internal armature must be brought through the wall of the earthed outer tube, the outleading wire is long and the spread capacity will be even greater. The diminishing in sensibility caused in this way can be eliminated by coupling the circuit immediately to the tubing. Then the indicating direct current instrument can be placed anywhere. The errors caused by unsteadiness in temperature can be diminished and so can to a certain extent be those caused by the mechanical deformation using a twin measuring condenser, in such the external armature of the measuring condensers is a common metallic body (Fig. 10). In this case the internal armature of measuring condensers are coupled to the active points of the oscillating circuits Z_1 resp. Z_2. If the geometries of the two condensers are completely identical, it is possible to determine directly the dielectric constant of a material to be investigated with respect to that of air (the material to be tested goes into one of the measuring condensers, leaving the other one free), or to determine the dielectric constant of a liquid with respect to that of another, to that of the standard.

This arrangement can also be well used for the determination of binary mixtures. In this case one of the components goes into one of the measuring

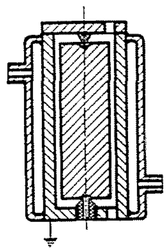

Fig. 11. Measuring condenser with thermostating jacket

condensers and the mixture into the other. The advantage of using twin conderses is, that the measuring condenser itself does generally not need to be thermostated, because the identical changes in the geometries of the measuring condensers do not appear because of the symmetry of the system. (The temperature coefficients of the dielectric constants of two similar materials, too, in general hardly differ.)

The temperature dependence of the dielectric constant of the material can be measured only in a well thermostated measuring condenser, then the external armature of the condenser gets a wrapping (Fig. 11), in which the thermostating liquid circulates.

The absolute value of the dielectric constant of the liquid to be measured can be so measured, that the twin measuring condenser thermostated fitted to that of variable capacity, thus measuring of 10^{-5}—10^{-6} precision can be done in interval of $\varepsilon = 1—100$. The planning of such an instrument is progressing.

5. Specification data

The specification and setting of the instrument used in analytical application of the circuit was:

Measuring frequency: 8 MHz

Measuring range: 117.5—145 pF
Sensitivity: $1 \cdot 10^{-3}$ pF
Precision: $2 \cdot 10^{-3}$ pF
Weight of the instrument: cc. 10 kg.
Empty capacity of the measuring condenser $C_0 = 65$ pF
Insultation resistence of the measuring condenser $R = 10^6—10^7$ MΩ.

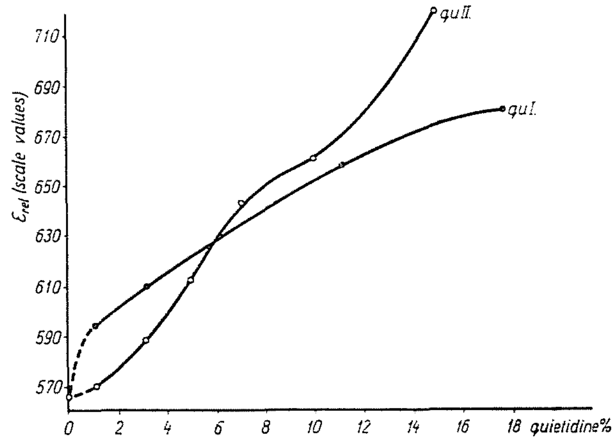

Fig. 12. Dielectric constant of the benzene solutions of two quietidine isomers (I—II) in function of concentration

6. An analytical application of the circuit

The applicability of the measuring instrument built according to scheme in fig. 9 is shown, for solving an analytical problem:

Quietidine (N, N'-di-phenylisopropyl-piperazine) used as a sedative has two isomers (I and II) emering in the production. Their melting points are 56 resp. 98°C, their dielectric properties slightly differ from each other. The dielectric constant of the benzenic solutions of the two isomers are plotted in function of the concentration in Fig. 12. It can be seen, that

a) The sensitivity of the instrument makes possible the determination of a concentration to an accuracy of 0.1%.

b) The characters of the curves of the two isomers are rather different. The cause of this lies in the different dielectric constants of the two isomers and in the differences of the benzene — quietidine interactions.

c) The first sections of the curves are of special interest. In the area of small quietidine concentration (c = 0—1%) the relations in steepness are inverted to those in the area of high concentration. Assumedly the reason is that the solvent was not pure enough. Namely, benzene usually contains some water which is rather difficult to remove. In the present case the applied drying method was single distillation from sodium, the freshly dried benzen, too, can contain 0.01% water. This impurity which is small compared to the quantity of benzene, but highly polar, can interact with the two quietidine isomers before the benzene but having different affinities. The benzene-quietidine interactions are weaker than this and enforces only by a greater quantity of quietidine, and though they have a measurable effect, they do not greatly influence the concentration function of the dielectric constant of the solution.

According to these the character of the course of the curve in the small concentration is determined by the effect of the polar impurity of the benzene.

At a concentration higher than about 1%, where the molecules of the water impurity are already "occupied", there can be no never water-quietidine interactions, so the benzene-quie idine interaction becomes dominants.

7. Summary

A new bridge measuring capacity in 1—100 MHz frequency range has been described. The self excited, phase-sensitive bridge circuit and the symmetrical building up gives about 10^{-5} sensibility and stability.

The instrument measures the impedance and can be used for measuring small inductivity and capacity changes.

With different condensers the dielectric constants of liquids, even of gases, can be measured on gradually variable frequencies. On account of its great sensibility it is good for measuring dipole moment or e. g. for the analysis of mixtures in those cases when the components are very similar even in their dielectric properties.

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