NOVEL CIRCUIT FOR THE RAPID MEASUREMENT OF DIELECTRIC CONSTANT WITH ULTRA PRECISION OVER A WIDE RANGE OF FREQUENCIES

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A simplified instrument is designed for dielectric constant measurements of liquids and gases over a wide range of frequencies by using 6*J*5 as variable oscillator and 6*E*5 electron-ray tube for mechanical resonance indication with the quartz crystal of various frequencies. Measurements with the proposed new circuit are simple, rapid and accurate.

Dielectric constant is an important parameter for determining molecular structures. Dielectric properties are also of some value in analytical work as very pure compounds exhibit their characteristic dielectric constants. There are several methods[1] of measuring dielectric cell capacitance C_s which is needed for determining dielectric constant 'E' of a material. Resonance methods[2] and bridge techniques[3] for measuring reactance are especially suitable for liquids or solutions having high electrical conductance. For solutions with low conductance, Chein[4] heterodyne beat method is very accurate. Alexander[5] and Bender[6] have developed the use of electron-ray tube as an indicator of high frequency resonance.

Ordinary resonance method used for liquids is useless since the point of resonance given by any sensitive indicator is not sharp enough to exhibit the small alterations of capacitance due to small dielectric constant as in the case of gaseous dielectrics, photo-dielectric materials. The purpose of the present paper is to suggest a new modified circuit suitable for high and low conduction (loss) materials, with an added advantage of simplicity, accuracy and rapidity.

NOVEL EXPERIMENTAL TECHNIQUE

The present circuit makes use of piezo-electric effect. The piezo-electric effect may be utilized to fix the frequency of a vacuum tube oscillator[7,8] with an accuracy of better than 1 part in 1,000,000 to 5,000,000. Certain crystalline materials, notably Rochelle salts, quartz and tourmaline exhibit piezo-electric effect.

The crystal block is adjusted to correct desired frequency by sawing it slightly over size and then reducing the thickness by grinding and polishing, using the best techniques that have been developed for the construction of precision lenses and similar optical devices. When this crystal is set in vibrations by suitable application of alternating potentials, mechanical resonance will occur at the desired frequency.

The new circuit is presented in Fig. 1. The condenser C_s containing the dielectric sample is included with a standard variable precision condenser C_p and a coarse condenser C_v, in the circuit of the modified Hartley oscillator by using 6*J*5.

A reference frequency can be found out which will correspond to the natural frequency of the quartz crystal employed at which the mechanical resonance will occur. The actual critical frequency at which the crystal will resonate in a given case depends upon the piece of quartz employed[9] and is given by

$$f = 2370/x,$$

Where f is in kilocycles/Sec., and x is the thickness in mm.

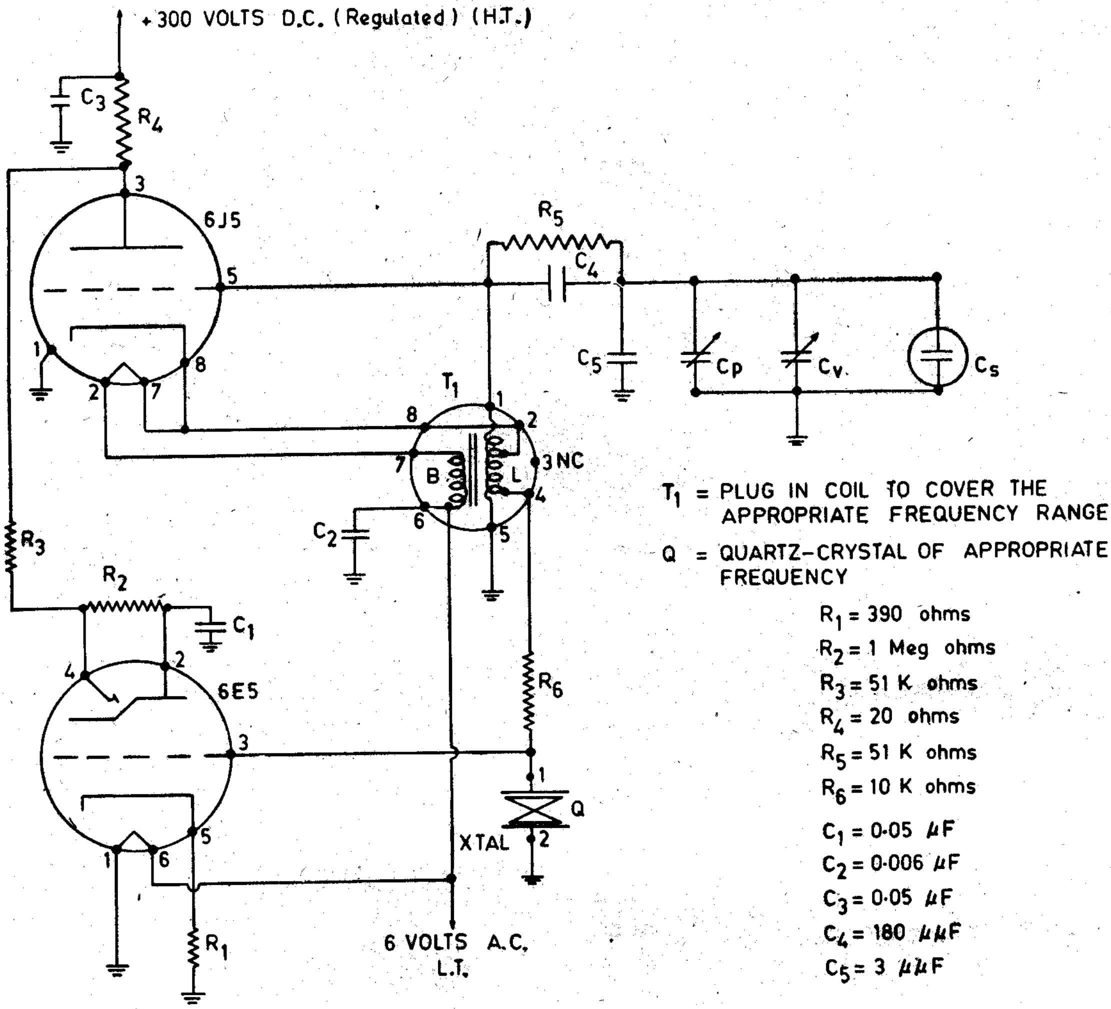

Fig. 1—Circuit for the rapid measurement of dielectric constant with ultra precision over a wide range of frequencies.

Resonance is indicated by a very sharp absorption of energy, made evident by the changes of anode current in 6E5 as shown in Fig. 2 by the curve β. The width of the resulting crevasse is of the order of 1/5 pF and the variable oscillator 6J5 can be tuned to a definite frequency and changes in C_s or C_p of the order. 0.0002 pF can be detected. Readings are taken on ascending and descending sides of crevasse and their mean is regarded as a reference point.

The critical capacitance setting at which the shadow angle in the tuning indicator tube 6E5, abruptly widens, corresponds to the condition of resonance, and is taken as the reference point for capacitance measurements.

The frequency generated by the variable oscillator is given by.

$$f = 1/2\,\pi\,(LC)^{\frac{1}{2}} \quad (1)$$

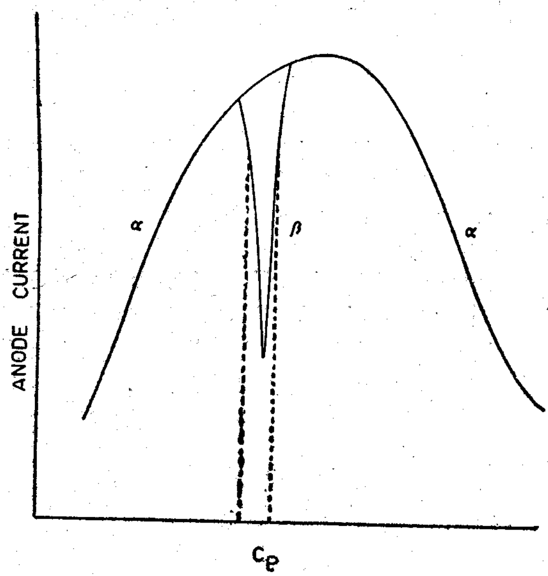

Fig. 2— β-curve indicating change in anode current signifies resonance.

Where L and C, are the inductance and capacitance respectively in its tuning circuit.[10] So long as f and L are held constant, the resonance condition corresponds to a constant value for,

$$C = C_s + C_p + C_v = \text{Constant} \quad (2)$$

If the system is initially at resonance and then C_s is changed, the change in C_s can be measured by finding the change in C_p required to restore the condition of resonance.

The $6J5$ acts as a variable oscillator and the piezo-electric quartz crystal in the grid circuit with $6E5$ tuning eye tube is used to fix the frequency of the oscillator with accuracy.

The Dielectric constant ϵ is given by

$$\epsilon = \frac{C_s}{C_o} \quad (3)$$

Where C_s is the capacitance of a condenser when the dielectric medium is the solution or gas and C_o is the capacitance of the same condenser when medium is a vacuum.[11]

In order to circumvent difficulties due to stray capacitance, it is convenient to use a dielectric cell which is so arranged that the measurements are made of capacitance difference between two fixed positions (a and b) of rotor plates of a variable capacitor, a two position cell of a proven design[12] can be used. The dielectric constant of fluid sample is then obtained from the equation,

$$\frac{C_{liq}}{C_{ref}} = \frac{C_{b,liq} - C_{a,liq}}{C_{b,ref} - C_{a,ref}} \quad (4)$$

Where $C_b,liq—C_a,liq$ is the capacitance increment between positions a and b measured with plates immersed in fluid sample and $C_{b,ref} - C_{a,ref}$ is the corresponding increment measured with plates immersed in a reference substance of known dielectric constant.

It is possible to build plug-in-coil units— T_1, T_2, T_3, T_4, T_5 and T_6 to cover the frequency range from 1 to 9 Megacycles.

The plug-in-units are built to cover the ranges of frequency as shown in Table 1.

TABLE 1

S. No.	Plug-in-coil unit	Frequency range covered by plug-in-coil units in Megacycles
1	2	3
1	T_1	1—2
2	T_2	2—3
3	T_3	3—4
4	T_4	4—5.3
5	T_5	5.3—7
6	T_6	7—9

By choosing any plug-in-coil unit from T_1 to T_6 to cover the appropriate frequency range and also the quartz crystal of the desired frequency, it is possible to scan the dielectric sample over the entire range of frequencies.

DISCUSSION

It is well known that the principles of resonance method are employed in a number of common electronic instruments such as the grid-dip-meter and Q-meter. These can be used for rapid measurements of dielectric properties over a wide range of frequencies when high accuracy is not required. But the resonance method in the present apparatus has all the aforestated merits and also very high accuracy, i.e. the circuit can be used for rapid measurements of dielectric properties over a wide range of frequencies with ultra precision.

The potential accuracy of the present set up is very high. Differentiation of the frequency determinating relation (1) gives us (for constant L),

$$\frac{\Delta f}{f} = -\frac{1}{2}\frac{\Delta C}{C} \quad (5)$$

Since, the frequency of the oscillator can be fixed as accurately as 1, in 1000,000, the detectable change of capacitance in the circuit is 1 part in 500,000.

In Heterodyne Beat method, high precision is possible, since changes in beat frequency of much less than 1 cycle are easily detected and with f about 10^6 cycles one can detect a change in capacitance of a few parts per million. Thus the accuracy is comparable to the accuracy given by present set up.

The accuracy attainable with Schering circuit is $\pm$ (0.2%+0.04pF) in capacitance. This circuit may be used beyond 1 MHz by employing a micrometer—electrode system, but at the expense of increased error in the capacitance measurement[13].

A two terminal impedance bridge designed for use at radio frequencies is the Hewlett Packard 250 A RX meter. The operating range is 500 KHz to 250 MHz. Reported accuracy is $\pm$ (0.5+ $0.5f^2$ $C_x \times 10^{-5}$) %$\pm$ 0.15 pF in capacitance.

A bridge for use with highly conducting materials at low frequencies has been described by Schwan and Sittel[14]. The operating range is 10 Hz to 200 KHz. The bridge accuracy is $\pm 0.1\%$ in capacitance.

The introduction of the heterodyne beat circuit of Chein[4] for the determination of the dielectric constant made possible for the first time really accurate determination of the electric moments of gaseous molecules. However with the ultra accuracy obtainable by the present instrument it is possible to study the effects of non-polar solvent on the magnitude of the measured electric moment of a given solute molecule. The dipole moments of less polar molecules such as chloroform can be determined but careful attention to detail is required for accurate results in such work. Different extrapolation procedure may be used.

For accurate measurements, the precision capacitor C_p must be calibrated. The procedure described by Smyth for use with the Heterodyne Beat Method can also be adopted for use with this novel equipment.

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REFERENCES

1. SMYTH, C. P., 'Determination of Dipole Moments', in 'Technique of organic Chemistry', *ed.* Weissberger, Vol. I, part III, (Interscience, N. Y.), 1960, pp. 2599.

2. LE FE'VRE, R. J. W., 'Dipole Moments' (Methuen, London) Chapter II, 1964, 47.

3. LE FE'VRE, R. J. W., 'Dipole Moments' (Methuen, London) Chapter II, (1964), 36.

4. CHEIN, J. Y., *J. Chem. Educ.*, **24** (1947), 494.

5. ALEXANDER, F. C., *Electronics*, **18** (1945), 116.

6. BENDER, P., *J. Chem. Education*, **23** (1946), 179.

7. AUSTIN, V. EASTMAN, M. S. 'Fundamentals of Vacuum Tubes' 3rd edition, (Mc Graw Hill Book Company, New York, Toronto, London), 1949, 468.

8. Electronic Training Staff Cruft Laboratory, Harward University, 'Electronic Circuits and tubes', (Mc Graw Hill Book Company, INC.,), 1947, 502.

9. LE FE'VRE, R. J. W., 'Dipole Moments' (Methuen, London) Chapter II, 1964, 38.

10. CLAPP, J. K., *Proc. Inst. Radio Engrs.*, **136** (1948), 356.

11. BITTER, F., 'Currents, Fields & Particles', (Technology Press, Cambridge, Mass), 1956.

12. BENDER, P., University of Wisconsin, Madison, Wisconsin.

13. FIELD, R. F. in 'Dielectric Materials and Applications', *ed.* A Von Hippel, (MIT Press, Cambridge, Mass), 1954.

14. SCHWAN, H. P. & SITTEL, K. Trans. Am. Inst. Elect. Engrs. 72, 1953, 114.