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 6J5 as variable oscillator and 6C5 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 of measuring dielectric cell capacitance \( C_s \) which is needed for determining dielectric constant \( \varepsilon \) of a material. Resonance methods and bridge techniques for measuring reactance are especially suitable for liquids or solutions having high electrical conductance. For solutions with low conductance, Chenn\(^4\) 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, 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.

\[ f = \frac{2370}{x}, \]

Where \( f \) is in kilocycles/Sec., and \( x \) is the thickness in mm.
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 $\beta$. 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:

$$f = \frac{1}{2 \pi} \sqrt{\frac{1}{LC}}$$

(1)

Fig. 2—$\beta$-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 piezoelectric 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 \( \varepsilon \) is given by

\[
\varepsilon = \frac{C_s}{C_o} \quad (3)
\]

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,

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

**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 aforesaid 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 \( L \)),

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

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>
<thead>
<tr>
<th>S. No.</th>
<th>Plug-in-coil unit</th>
<th>Frequency range covered by plug-in-coil units in Megacycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>( T_1 )</td>
<td>1—2</td>
</tr>
<tr>
<td>2</td>
<td>( T_2 )</td>
<td>2—3</td>
</tr>
<tr>
<td>3</td>
<td>( T_3 )</td>
<td>3—4</td>
</tr>
<tr>
<td>4</td>
<td>( T_4 )</td>
<td>4—5.3</td>
</tr>
<tr>
<td>5</td>
<td>( T_5 )</td>
<td>5.3—7</td>
</tr>
<tr>
<td>6</td>
<td>( T_6 )</td>
<td>7—9</td>
</tr>
</tbody>
</table>

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.

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 ± (0.5 + 0.5f² C x 10⁻⁸ ) % ± 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 ± 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 C₀ 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

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