Installation for measuring the dielectric anisotropy of liquid crystals at low frequencies by the bridge method with constant displacement

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Abstract. Installation designed to measure the dielectric anisotropy in laboratory studies of liquid crystal polymer films is described. The installation operates on the principle of a balanced alternating current (AC) bridge, allowing the application of a direct external current (bias) to the liquid crystal cell. The internal resistance of the direct current (DC) source, which affects the equilibrium condition of the bridge, is compensated. The frequency of the AC current feeding the bridge and the offset voltage of the cell is regulated within a wide range, which makes it possible to study various functional dependences of the dielectric parameters of liquid crystals and their modifiers.

1. Introduction

The theoretical and applied significance of liquid crystals is well known. An external influence, for example, an electric field, causes a change in some of its physical properties. Therefore, liquid crystals (LC) have found wide application as an anisotropic medium in scientific research, information display devices, optical-control devices, and even microwave technology [1]. Nowadays, many LC is known and synthesized, modification of LC films with various micro and nanoparticles is developing [2], which makes it possible to improve the properties of LC, for example, their speed.

LC, being dielectrics, are polarized when an electric field is applied to them; the reorientation of molecules leads to a change in their dielectric constant. Therefore, the dielectric anisotropy of LC is an important characteristic. The possibility of investigating the functional dependence of the dielectric anisotropy of LC on the strength of the electric field applied to them and on the frequency of the alternating current, using which the cell impedance is measured, makes it possible to subtly study LC and their interaction with various modifiers that improve their properties. For example, there is a hysteresis of the dielectric anisotropy (and, consequently, the cell capacity) of LC from the applied voltage, modified by some nanoparticles [4], making it possible to create liquid crystal cells with particular properties.

There are various methods for measuring the dielectric anisotropy of LC or their films: resonance, bridge, beat methods, determination of the time constant of an RC circuit, and various versions of microwave methods [5]. Often, however, it is important to measure the dielectric anisotropy of LC in the absence of high-frequency currents or high-frequency electromagnetic radiation. All methods for
measuring dielectric anisotropy at low frequencies or direct current are reduced to consider the change in the cell capacitance of LC with different orientations of their molecules. The direction of molecules is usually set by using orienting layers of various configurations in a liquid crystal cell [6]. However, this method has significant drawbacks; for example, it is impossible to quickly measure the parameters of its optical speed and its dielectric anisotropy for the same cell, which reduces the statistical volume of experimental data and the reliability of research. Forced reorientation of liquid crystal molecules by applying a constant electric field when measuring the cell capacitance followed by calculating the dielectric constant based on the formula for a flat capacitor is inapplicable to most methods for measuring capacitance. So, the most common modern impedance meters are based on determining the time constant of an RC circuit - the time required for the voltage across a capacitor to reach 63.2% of its voltage when fully charged. Applying an external voltage to the measured cell will lead to the fundamental impossibility of measuring capacitance with this method.

The most suitable method for measuring the capacitance of a cell of LC at different orientations of their molecules due to the electric field created by applying a constant voltage to the cell is an AC bridge. This method has high accuracy, is insensitive to a continuous bias on one of its arms, and allows you to combine the measurement of dielectric anisotropy and opto-temporal properties of LC in one setup.

2. Brief theoretical remarks
The determination of the capacitance by an AC bridge is based on the measurement of the electrical impedance of the measured two-terminal, in our case, a liquid crystal cell. Size of the impedance of LC, however, and liquid dielectrics or electrolytes, in general, are almost always associated with the need to separate the impedance components [7]. In polar dielectrics, which fully include LC, one can note the impedance of the volume of their layer and the impedance of a thin layer near the electrodes of the liquid crystal cell. The volume impedance is determined not only by the oriented molecules of LC but also disadvantageous, by a contribution to it by the conductivity of the liquid crystal layer itself or their film. The latter depends on the presence and concentration of ions in the coating, their charge and mobility [7]. The near-electrode impedance is mainly associated with forming an electric double layer at the surface of the cell electrodes.

For a complete description of the electrical properties of a liquid crystal cell, you can use an equivalent electrical circuit, which, however, in our case, neglects the capacity of the electric double layer (figure 1). \( R_{el} \) is the resistance of the cell electrodes; this also includes the resistance of the contacts of the sample holder and other circuit elements up to the capacitance meter; \( C_{LQ} \) – capacitance of a cell with a dielectric in the form of LC; \( R_{LQ} \) is the volume resistance of LC in the cell gap and \( R_{tr} \) is the active resistance to the current flowing due to the transfer of charges from the external electrical circuit through the electrode to the liquid crystal layer and the extraction of leads from this layer through the electrode back to the outer course. The resistance \( R_{tr} \), the active and reactance of the electric double layer are dielectric losses; they are responsible for the imaginary part of the dielectric constant.

![Figure 1. Equivalent circuit diagram of a liquid crystal cell.](image)

As a result, by measuring the capacitance \( C \) of the cell by the AC bridge, it is possible to calculate the real part of the dielectric constant \( \varepsilon ' \) of LC using the well-known formula:

\[
\varepsilon ' = \frac{Cd}{\varepsilon_0 S}
\]
where \(d\) is the thickness of the liquid crystal layer in the cell, \(S\) is the area of one of its electrodes.

To calculate the imaginary part of the dielectric constant \(\varepsilon''\), it is necessary to measure the tangent of the dielectric loss angle \([6]\):

\[ \varepsilon'' = \varepsilon'_\tan\delta, \]

Thus, an AC bridge, allowing the measurement of cell capacitance, dielectric loss tangent and at the same time insensitive to the DC bias, is best suited for determining the dielectric constant of LC.

1. Device and principle of operation

A balanced AC Schering bridge was chosen for the study of LC. Unbalanced bridges, although they are more convenient to use without additional automation tools and allow a direct report from the indicator, are still less accurate \([8]\).

A simplified diagram of an AC bridge is shown in Figure 2. The bridge is powered by alternating current from the Gen 1 generator through the TV1 transformer. The generator allows you to change the frequency of the current over a wide range. Directly the bridge arms are composed of elements \(R1\), \(R2\) and \(R4\), \(C2\) and a \(CL1\) liquid crystal cell. The balancing of the bridge is performed by the variable resistor \(R1\). The reference capacitor of bridge \(C2\) is precision. The variable resistor \(R4\) connected in series allows balancing the bridge relative to the dielectric losses in the liquid crystal cell by its position. Thus, the tangent of the dielectric loss angle can be read.

Like many liquid dielectrics, even well-purified LC have a noticeable ionic conductivity, the existence of which is undesirable, since the presence of a current through the cell, on the one hand, leads to the accumulation of electric charges, on the other hand, to their relaxation near the electrodes, which can worsen both the quality of the cell and the accuracy of measuring its capacity.

Amplifier \(U1\), rectifier \(VD1\)-\(VD2\)-\(R6\)-\(R7\) and microammeter \(P1\) are used as a zero indicator, according to the readings of which the bridge is balanced. Using a two-half-period rectifier based on Schottky diodes with the replacement of two arms with resistors allows minimizing the voltage drop and, accordingly, increasing the null indicator's sensitivity. When measuring the parallel component of the dielectric constant, a DC bias is applied to the LC cell \(CL1\) from a variable current source \(BP1\) through a resistor \(R3\). This resistor is necessary to significantly increase the internal resistance of the DC source so that it has a minor effect on the balance of the bridge. When measuring the standard component of the dielectric constant, a resistor \(R5\) is connected in parallel to the liquid crystal cell instead of the current source by the switch \(SA1\), the resistance of which is equal to the source's internal resistance \(R3\). Thus, when measuring both components of the dielectric constant, the exact resistance is connected in parallel to the cell, which avoids distortions in the bridge reading when switching measurement modes. The capacitor \(C1\) prevents the zero-indicator of the constant bias from reaching the input of the amplifier; the variable resistor \(R6\) adjusts the amplifier's sensitivity. The amplifier is powered by a separate current source to eliminate parasitic circuits.
The equilibrium condition of the considered bridge circuit can be expressed as follows:

\[
\frac{1}{\omega C_1} = \frac{R_1}{R_2}, \quad \frac{R_{3,5}}{\omega C_2 R_{3,5} + 1} = \frac{R_1}{R_2} = \frac{\omega C_2 R_{3,5}}{\omega C_2 R_{3,5} + 1} = \frac{R_2}{R_1},
\]

\[
C_{L1} = C_2 \frac{R_1}{R_2} - \frac{1}{\omega R_{3,5}}, \tag{1}
\]

where \(R_{3,5}\) is the resistance of the resistor \(R3\) or \(R5\) connected in parallel with the measured cell. From formula (1) it can be seen that the capacity of a liquid crystal cell in the case of its parallelization by an active circuit with a finite resistance depends on the frequency of the current at which the bridge operates. Therefore, if the bridge's scale is linearly graduated, then when measuring the dependence of the cell capacitance on frequency, an error will occur, determined by the second term of formula (1). Graphically, the value of this deviation in determining the capacitance \(\Delta C\) for a natural bridge, depending on the value of the frequency of its power supply, is shown in Figure 3. Only in a separate frequency range (from \(\sim 10\) kHz) can this dependence be considered linear and relatively insignificant (based on the capacity of a typical laboratory liquid crystal cell, the error is no more than 2-5%).

![Figure 3. Dependence of the error in determining the capacitance \(\Delta C\) on the current frequency \(\nu\).](image-url)

The tangent of the dielectric loss angle in the liquid crystal cell based on the bridge circuit can be determined as follows:

\[
tg \delta = \omega C_2 R_4.
\]

In an actual design, the bridge is combined with equipment for measuring the optical and temporal properties of LC in electric and magnetic fields (the external view of the setup is shown in Figure 4), which makes it possible to measure various parameters for the same cell sample quickly. The report of the capacitance in the AC bridge is carried out from a vernier connected to a variable multiturn resistor \(R3\) and representing two drums with scales, one of which, serving for a rough reading, rotates due to the planetary gear ten times slower than the second, which helps for accurate reading (Figure 5). The SA1 switch is made in the form of an electronic trigger controlled by a push-button controller and having a light indication of the bridge operation mode.
The bridge is calibrated taking into account the active resistance and capacitance of the lead wires and contacts to the liquid crystal cell using exemplary capacitors.

The measurement limits of the cell capacitance by the presented device are 100-500 pF; the loss tangent is up to 0.05, the maximum applied constant electric displacement to the cell is up to 320 V.

2. Conclusion
The above design of the installation for calculating the dielectric anisotropy by measuring the capacitance of a cell of LC meets the tasks set and can be used in other experimental studies in laboratory practice. The installation is quite simple, it uses the available elements, which simplifies its manufacture and requirements for the experimental conditions.

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