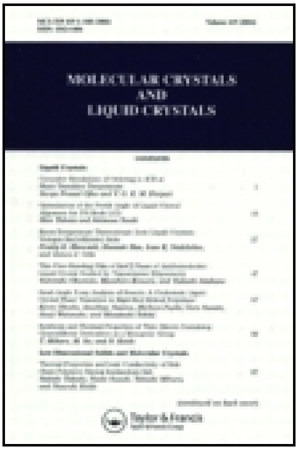

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Noise and Dielectric Measurements on an Antiferroelectric Liquid Crystal

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Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 367, pp. 719-726
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Noise and Dielectric Measurements on an Antiferroelectric Liquid Crystal

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We present a new characterization technique applicable to ferroelectric liquid crystals. This non perturbative technique allows the determination of the real and imaginary parts of the complex permittivity from current and voltage noise measurements. A current noise measurement set-up is described. The method is validate on an antiferroelectric liquid crystal from simultaneous dielectric and noise measurements.

Keywords: complex permittivity; current noise; voltage noise; antiferroelectric liquid crystal

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I. INTRODUCTION

The dielectric measurements are generally performed with an impedance analyzer. The complex permittivity $\varepsilon^* = \varepsilon' - j\varepsilon''$ is calculated at each frequency from the measured device capacitance C_m and conductance G_m. Musevic *et al.* [1] recently performed noise measurements on a commercial ferroelectric liquid crystal and showed that the current noise spectral density $S_i(f)$ is connected with dielectric losses $\varepsilon''(f)$. Noise measurement method is interesting as it is non perturbative. In this paper, we demonstrate that the real and imaginary parts of the complex permittivity can be determined from current and voltage noise densities $S_i(f)$ and $S_e(f)$. A current noise measurement set-up and an application of the method to an antiferrolectric liquid crystal are successively presented. The method is validated from simultaneous dielectric and noise measurements. Dielectric and voltage noise measurements are performed with previously reported experimental devices [2,3].

II. CURRENT NOISE MEASUREMENT SET-UP

The current noise measurement set-up and the corresponding noise circuit model are presented Figure 1. It includes the cell, a Keithley 428 current amplifier and a Hewlett Packard HP 89410A signal analyzer used for the voltage noise measurement [3]. The cell filled with the sample is modeled as a Norton equivalent circuit. The 428 current amplifier converts a small input current into an output voltage. The amplifier gain is adjustable by decade increments from 10^3V/A to 10^{11}V/A. To calculate $S_i(f)$ from the measured voltage density $S_v(f)$, we use the simplified noise circuit model given in Figure 1 to take into account the parasitic elements. These parasitic elements have been previously [3] measured for the HP89410A. Their influence are found to be negligible in our case and disregarding correlation between the different noise sources, one gets :

$$S_i(f) = \frac{S_v(f)}{A_\Omega^{\,2}} - S_{i_g}(f) \qquad (1)$$

where A_Ω is the current amplifier gain and $S_{i_g}(f)$ is determined with the cell replaced by an open circuit. Both quantities are measured for different calibers in the working frequency range.

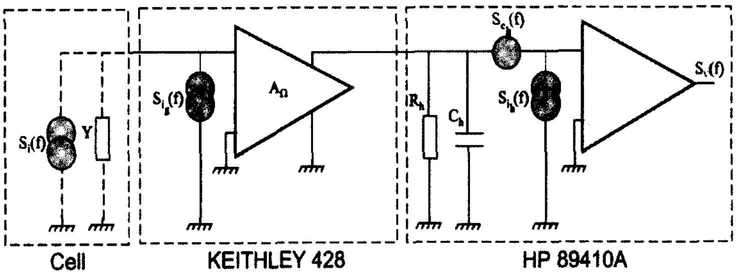
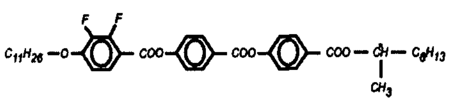


Figure 1. Noise model for the current measurement set-up.

We have studied the homologous n=11 of the following benzoate series. The chemical formula and the phase sequence are presented in Figure 2 [4]. The measuring cell is a plan capacitor cell conceived in our laboratory and described in a previous paper [2].



K 58.8 S^*_{CA} 70.5 S^*_{CFI1} 71.4 S^*_{FI2} 80.5 S^*_{C} 108.6 $S^*_{C\alpha}$ 109.5 S_A 127.7 I

Figure 2. Chemical formula and phase sequence of the investigated compound.

Figures 3 and 4 show $\frac{S_v(f)}{A_\Omega^2}$ and the corresponding corrective term $S_{i_g}(f)$ for the ferroelectric S^*_C phase (at 90°C) and the paraelectric S_A phase (at 110°C) respectively. In the S^*_C phase (Figure 3), two calibers were used to optimize measurements : 10^8V/A in the frequency range 10Hz–1kHz and 10^7V/A at high frequencies. This explains the discontinuity for the parasitic term $S_{i_g}(f)$ observed at 1kHz. The measured noise current density $\frac{S_v(f)}{A_\Omega^2}$ is about one decade higher than the parasitic term $S_{i_g}(f)$. Thus, in this phase $S_i(f)$ is determined in good conditions. The limiting measuring frequency is about 30kHz and corresponds to the current amplifier cut-off frequency of the gain. In the S_A phase, the measured noise current density slightly depends on frequency and only one caliber (10^7V/A) is necessary for the measurement. The accuracy on $S_i(f)$ is lower in the S_A phase where the parasitic term $S_{i_g}(f)$ is nearing the measured noise current density $\frac{S_v(f)}{A_\Omega^2}$.
The frequency range is thus reduced at 4kHz.

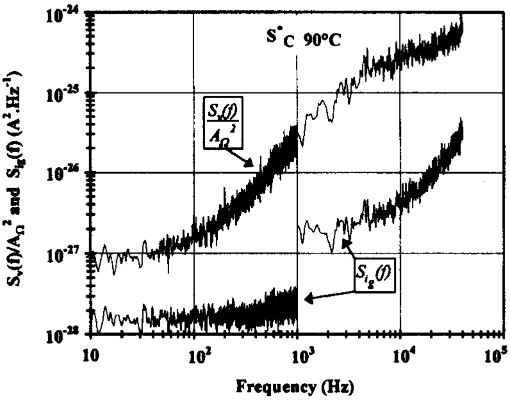


Figure 3. Evolution of the sample measured noise current spectral density $\frac{S_v(f)}{A_\Omega^2}$ and of the corrective term $S_{i_g}(f)$ *versus* frequency for the ferroelectric S^*_C phase.

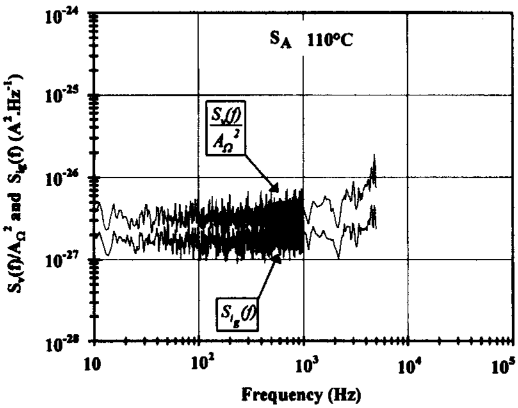


Figure 4. Evolution of the sample measured noise current spectral density $\frac{S_v(f)}{A_\Omega^2}$ and of the corrective term $S_{i_g}(f)$ *versus* frequency for the paraelectric S_A phase.

III. COMPLEX PERMITTIVITY DETERMINATION FROM CURRENT AND VOLTAGE NOISE MEASUREMENTS

In our case, measurements are performed using a plan capacitor cell [2]. It is well known that the complex permittivity $\varepsilon^* = \varepsilon' - j\varepsilon''$ can be determined from the measured cell capacitance C_m and conductance G_m :

$$\varepsilon' = \frac{C_m}{C_0} \quad (2) \qquad \varepsilon'' = \frac{G_m}{2\pi f C_0} \quad (3)$$

where f is the frequency and C_0 the "empty" cell capacitance. According to the generalized Nyquist theorem [5], the measuring cell only exhibits thermal noise assuming that no bias is applied. In this case, the current and voltage noise spectral densities are given respectively by :

$$S_i(f) = 4k_B T Re(Y) \quad (4) \qquad S_e(f) = 4k_B T Re(Z) \quad (5)$$

where k_B is the Boltzmann's constant, T the sample temperature, $Re(Y)$ is the real part of the admittance Y and $Re(Z)$ is the real part of the impedance Z. Using relations (2) to (5), one gets :

$$\varepsilon'' = \frac{S_i(f)}{8k_B T \pi f C_0} \quad (6) \qquad \varepsilon' = \sqrt{\frac{S_i(f)}{(2\pi f C_0)^2 S_e(f)} - \varepsilon''^2} \quad (7)$$

These relations show that the complex permittivity can be determined from current and voltage noise measurements. To valid this method, we have performed simultaneous noise and dielectric measurements. Voltage noise and dielectric measurements are performed with a previously described experimental set-up [2,3]. An example of comparison between ε' and ε'' values determined from dielectric measurements (relations (2) and (3)) with those calculated from noise measurements (relations (6) and (7)) is given in Figures 5 and 6.

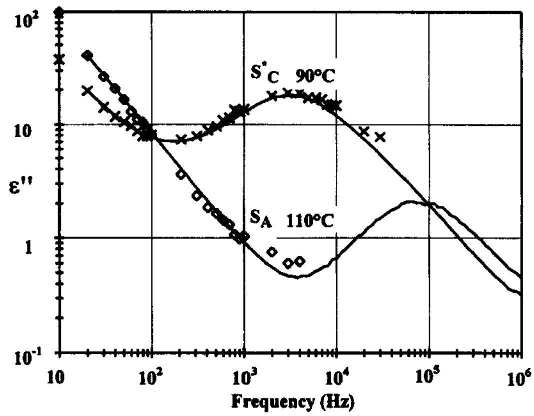


Figure 5. Imaginary permittivity ε'' for the paraelectric S_A phase and for the ferroelectric S^*_C phase : determined from dielectric measurements (thick line); determined from noise measurements (x and ◇).

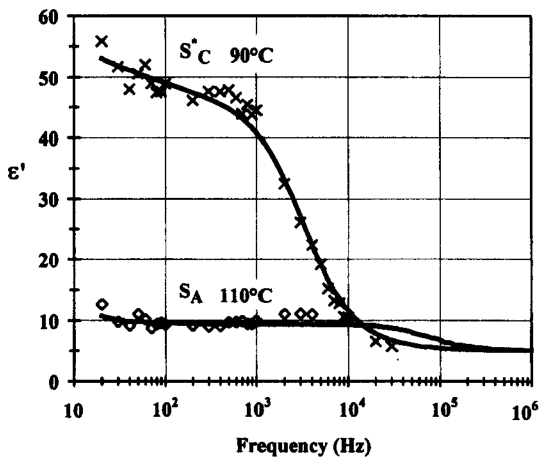


Figure 6. Real permittivity ε' for the paraelectric S_A phase and for the ferroelectric S^*_C phase : determined from dielectric measurements (thick line); determined from noise measurements (x and ◇).

IV. DISCUSSION

For ε'' a good agreement is observed in Figure 5 as long as $S_i(f)$ can be determined with a low correction level *i.e.* under 30kHz for the S^*_C phase and 4kHz for the S_A phase. For ε' (Figure 6) the accuracy is reduced due to the sensitivity of this quantity to both $S_i(f)$ and $S_e(f)$ incertitudes.

These first results highlight the interest of the method but also the necessity to improve the bench sensitivity as the noise level remains much lower than in an active amplifying device.

Acknowledgments

This work has been supported in part by the « Conseil Régional Nord-Pas de Calais ».

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