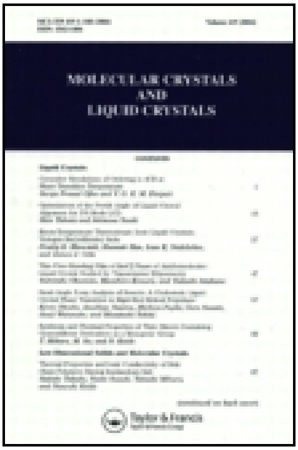

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Liquid Crystals Applications to R.F. and Microwave Tunable Components

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We present an experimental procedure for dielectric characterization of liquid crystals in the frequency range $10^3 - 10^{10}$ Hz. This procedure is based an open-end strip line measuring cell and a 2D S.D.A. electromagnetic simulation software. Effective permittivities and tensor permittivity elements are determined for a commercial nematic liquid crystal. An application to an electrically tunable microwave phase-shifter is also presented. Transmission coefficient phase variations of about 0.5°/cm length are obtained per GHz showing the liquid crystals potentialities for such applications.

Keywords: Electrical characterization method; dielectric permittivity; dielectric anisotropy; microwave tunable devices; strip line structures

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I. INTRODUCTION

Radiofrequency (R.F.) and microwave tunable devices (phase shifters, filters ...) are interesting for device miniaturization and present applications in the field of telecommunications. Up to now, such devices are mainly based on strip-line structures with modification of the guided wavelength. This modification is achieved with diodes (varactor, PIN, Schottky) or with specific substrate materials (ferroelectric ceramics, ferrites ...). In the former case, the permittivity or permeability of the substrate material is driven with an external electric or magnetic field. Liquid crystals are known as anisotropic materials which optical axis orientation is modified with surface treatments or with an external field. Such properties can be used to realize microwave frequency tunable components [1][2].

In this paper, we describe a R.F. and microwave complex permittivity measurement method based on an open-end strip line measuring cell and a 2D S.D.A. electromagnetic simulation software. Experimental results on a commercial nematic liquid crystal are given. These results are used to develop an application to a liquid crystal tunable phase shifter. This original structure and the performances are presented.

II. DIELECTRIC CHARACTERIZATION METHOD

We have built a measuring cell based on the strip-line configuration given in figure 1. A 750µm width and 9mm length microstrip line is realized on a copper metallized (thickness 17.5µm) PTFE glass fiber substrate (ε_r = 2.2 and thickness 254µm). The active part of the cell is obtained in adding a 7mm length top ground plane in order to make a cavity where the liquid crystal is inserted by capillarity.

This cavity concentrates the electromagnetic field in the sample. The cavity thickness is controlled with standard spacers and is fixed to 100µm. For measurements, the sample is orientated by an external magnetic field.

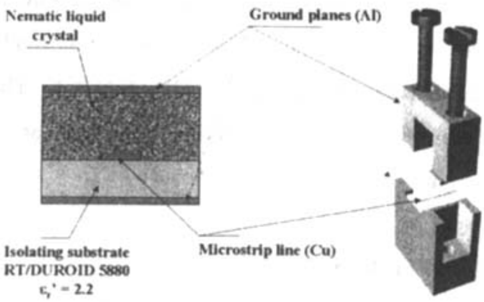

Figure 1 : Exploded and cross-section view of the measuring cell.

The remaining 2mm access line is used to connect the cell to the measurement set-up : HP4284A and HP4291A impedance analyzers with a SMA standard connector for measurements up to 2GHz; a HP8510 vectorial network analyser with Wiltron 3680K probes test fixture in the frequency range 1GHz-10GHz. The reflection coefficient S_{11} is measured in the input plane of the active part after a calibration procedure in order to take into account transitions, SMA or K connector and the access line. The complex effective permittivity ε^*_{eff} of the structure is obtained at each measuring frequency by using quasi-TEM approximation [3][4]:

$$\frac{1-S_{11}}{1+S_{11}}=\frac{Y_{cv}}{Y_c}\sqrt{\varepsilon^*_{eff}}\,th\left(j\frac{2\pi}{\lambda_0}\sqrt{\varepsilon^*_{eff}}\,L\right) \qquad (1)$$

where L is the active part length, λ_0 is the vacuum wavelength, Y_{cv} is the characteristic admittance of the empty cell and $Y_c = 1/50\Omega$ is fixed by the measurement set-up.

An electromagnetic simulation software has been developped to determine the characteristic admittance Y_{cv} and the material permittivity tensor [5][6]. This numerical software is based on integral full wave equations method including the metallic losses, the subtrate anisoptropy, the radiation and the surface waves. The resolution is made with two dimensions spectral domain approach (2D S.D.A.). The material permittivity tensor is obtained in fitting measured and calculated reflection coefficients.

III. EXPERIMENTAL RESULTS

For example, we present in figure 2 the effective complex permittivity results obtained at room temperature with a nematic liquid crystal (Merck K15) for two orientations of the optical axis (**n**) : parallel and perpendicular to the R.F. measuring electric field ($\mathbf{E}_{rf}$). The frequency dependence of the real and imaginary parts of the permittivity can be explained by the existence of dipolar relaxation process connected with molecular dynamics [7].

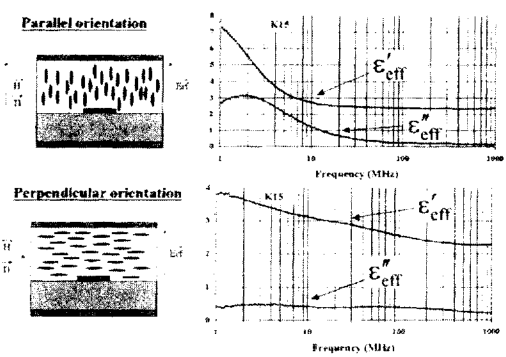

Figure 2 : Effective permittivities measured for two orientations of K15.

A significant parameter for applications to R.F. and microwave tunable devices is the effective dielectric anisotropy : $\Delta\varepsilon'_{eff}=\varepsilon'_{eff//}-\varepsilon'_{eff\perp}$. The figure 3 shows the frequency dependence of this parameter. For applications, the high dielectric anisotropy, present at low frequency, is used for electrical driving of the molecular orientation with a DC or low frequency bias voltage. At microwave frequencies, the anisotropy is much lower but high enough for tunable device applications. The permittivity tensor determination shows that the K15 dielectric anisotropy is equal to 0.2 at 10GHz.

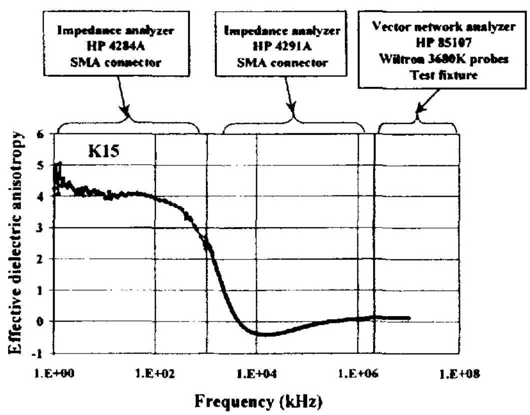

Figure 3 : Effective dielectric anisotropy of K15 nematic liquid crystal.

IV. APPLICATION TO R.F. AND MICROWAVE TUNABLE MICROSTRIP PHASE SHIFTER

For dielectric characterization, we used a magnetic field to orientate the liquid crystal molecules. As part of applications, we used a electrical driving field to tilt the director **n** from perpendicular to parallel orientation (to the R.F. electric field). An initial perpendicular orientation is obtained by a surface treatment. A polyimide is deposited on microstrip line and top ground plane. It is annealed and brushed in order to give a planar orientation to the liquid crystal without driving field.

We present in figure 4 the original structure used to realize a liquid crystal tunable phase-shifter. This structure includes a coplanar waveguide for the two access and a central cavity of 3cm length and 180μm height where the liquid crystal is inserted by capillarity. Dimensions were designed with HFSS-Ansoft electromagnetic simulation software using previous dielectric characterization results. A characteristic impedance near to 50Ω was maintained in the whole structure. The simulations show a microstrip propagation mode in the cavity.

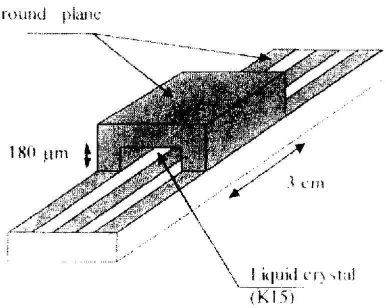

Figure 4 : Phase shifter structure.

To characterize this phase-shifter, we used a WILTRON probes test fixture 3680K in coplanar configuration connected to a vectorial network analyzer HP85107. Measurements were carried out in the 2-18GHz frequency range. We studied the phase variation of the S_{21} transmission parameter of the scattering matrix. As we can see in figure 5, when a bias voltage is applied to the structure the phase of the S_{21} parameter shifts.

Under bias, the modification of the liquid crystal orientation breeds to dielectric permittivity and guided wavelength changes.

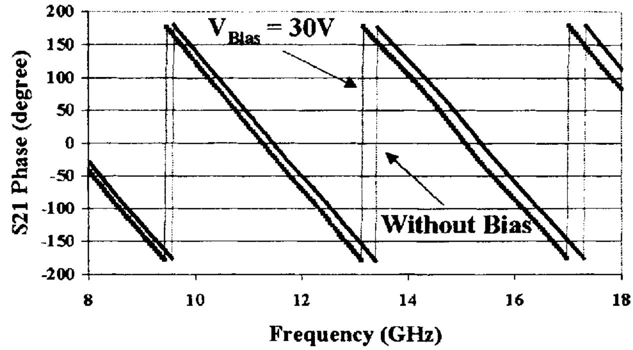

Figure 5 : Phase of the S_{21} parameter for 0 V and 30 V bias voltage.

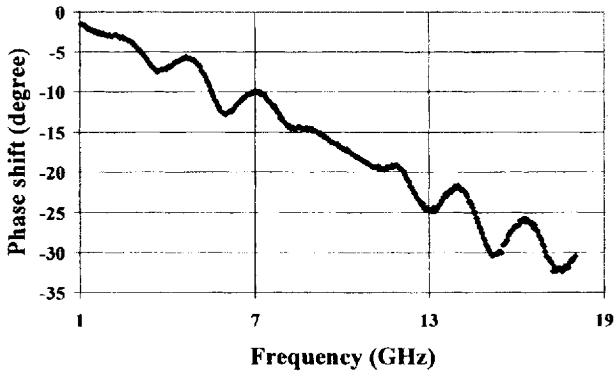

Figure 6 : S_{21} phase shift with 30 V bias voltage (reference 0 V).

The S_{21} phase difference observed between measurements without and with bias voltage versus frequency is given in figure 6. We obtained at 18GHz a maximum phase shift of 30° with an active line of 3cm. The slope average measured is 0.56°/GHz/cm. The figure 7 presents the phase shift versus the bias voltage for different frequencies. 90% of the phase agility is obtained for a DC bias of 10V.

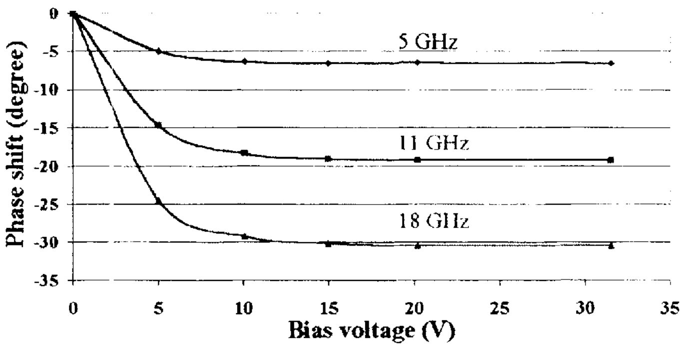

Figure 7 : Variation of the phase shift with the DC bias voltage.

V. CONCLUSION AND PERSPECTIVES

On the basis of dielectric characterization results presented, we have realized a tunable phase shifter with 0.56°/GHz/cm shift. Liquid crystals seem to be good candidates for R.F. and microwave tunable components applications. Future works will focus on others applications circuits (filters, antennas...), comparison between different nematic crystals and increase of the frequency range for millimeter wave applications.

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