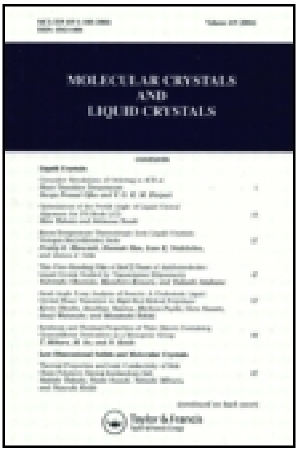

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Dielectric Characterization of Polymer Dispersed Liquid Crystal in Microwave Range - Material Integration in Specific Electronic Devices

Freddy Krasinski [a b c] , Bertrand Splingart [a b c] , Frédéric Dubois [a b c] , Ulrich Maschke [a d] & Christian Legrand [a b c]
[a] Université Lille - Nord de France, Lille, France
[b] Université du Littoral Côte d'Opale, UDSMM, Calais, France
[c] CNRS, EAC, Lille, France
[d] Université des Sciences et Techniques de Lille, UMET (UMR 8207-CNRS), Villeneuve d'Ascq, France

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Dielectric Characterization of Polymer Dispersed Liquid Crystal in Microwave Range – Material Integration in Specific Electronic Devices

FREDDY KRASINSKI,[1,2,3] BERTRAND SPLINGART,[1,2,3] FRÉDÉRIC DUBOIS,[1,2,3] ULRICH MASCHKE,[1,4] AND CHRISTIAN LEGRAND[1,2,3]

[1]Université Lille – Nord de France, Lille, France
[2]Université du Littoral Côte d'Opale, UDSMM, Calais, France
[3]CNRS, EAC, Lille, France
[4]Université des Sciences et Techniques de Lille, UMET
(UMR 8207-CNRS), Villeneuve d'Ascq, France

We present an original way to obtain reconfigurable microwave devices, filled with a polymer dispersed liquid crystal (PDLC). We study the dielectric parameters of the material in the microwave range, using an original cell. Then, we manufacture a microwave tunable device using the PDLC.

The purpose of our work is to cancel the polymer alignment layer used in microwave devices filled with pure liquid crystals. Actually, the difference in thickness between metallic parts and non-metallic parts of some specific microwave devices do not allow this polymer alignment layer deposit.

Keywords Dielectric characterization; liquid crystal; microwave; polymer; tunable device

1. Introduction

The needs of the new electronic industry, for example in the telecommunications domain, are now to miniaturize and make faster electronic components. Thus, some electronic functions (dephasors, filters...) are embedded, and manufactured with components whose characteristics can be modified by an external command. In the microwave domain, we talk of "reconfigurable devices" or "agile circuits". In our laboratory, part of our studies concerns anisotropic materials like ferroelectric materials, or nematic liquid crystals (LC), in a large range of temperatures and frequencies, with or without the application of an external magnetic or electric driving field [1,2]. In case of LC, to avoid both the characterization cells waterproof problems, and the pre-orientation of the molecules with a polymer alignment layer, we will try to shut up the liquid crystal droplets into the chemically crosslinked

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Address correspondence to Freddy Krasinski, Université Lille – Nord de France, F-5900, Lille, France. Tel.: 0033 0321465779; Fax: 00 33 0321465778; E-mail: freddy.krasinski@univ-littoral.fr

polymer network, by applying a polymerization induced phase separation technique. Then we will obtain a polymer dispersed liquid crystal (PDLC). Thanks to the high anchoring forces between the liquid crystal molecules and the polymer matrix, it will be useless to pre-orientate the molecules with a polymer alignment layer. A high external electric driving field will steer those liquid crystals molecules, in order to modify the composite permittivity, and thus the electromagnetic behaviour of the devices [3,4]. Actually, the propagation velocity of the electromagnetic waves through the anisotropic materials will be modified by the molecules orientation, whether they are perpendicular or parallel to the microwave electromagnetic field [5].

This paper presents three parts: we first present how to obtain a PDLC in a cell by an U.V. polymerization, and also how to characterise the material. Secondly, we will present the dielectric characterization of several known materials in the microwave range, to test the cell behaviour, and the dielectric characterization of a PDLC, with or without the application of a high external electric driving field by means of the cell. Thirdly, we will present its integration into a specific application, and the most important microwave behaviours of this microwave device.

2. Different Ways to Characterize Materials

2.1. *Dielectric Characterizations Already Used*

Several measuring cells are used in our laboratory. In Figure 1, we present a measuring cell which allows the dielectric characterizations of liquids (in particular liquid crystals), between 1 and 10 GHz.

This cell is connected to one port of a calibrated vector network analyser, by means of microwave probe set. We deduce the dielectric constant by measuring the reflection coefficient of a filled cell. Notice that we can apply a magnetic field to steer the liquid crystal molecules, but we cannot apply a high external electrical driving field (2 V/µm), without destroying the cell by an electrical short cut. That is why this kind of cells cannot be used to characterize a PDLC. In Figure 2, we present the photograph of a capacitive interdigital cell which is used to deduce the dielectric constant of thin ferroelectric films covered with a gold transmission line, using masking and evaporating techniques [6].

We have tried to dispose gold on a PDLC film in the same way. Because of the spongy aspect of the PDLC, it was impossible to obtain perfect gilded layers. In Figure 3, we note many cracks on the deposit surface, which prohibits good electrical connections.

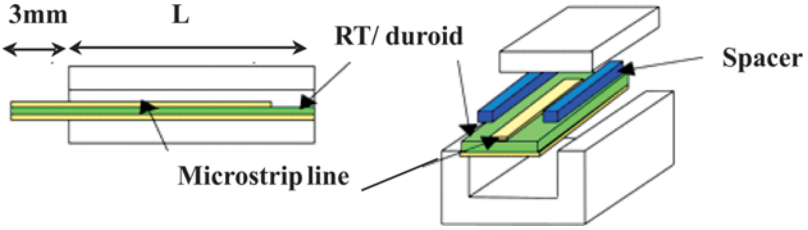


Figure 1. Reflection coefficient measuring cell (1–10 GHz range). (Figure appears in color online.)

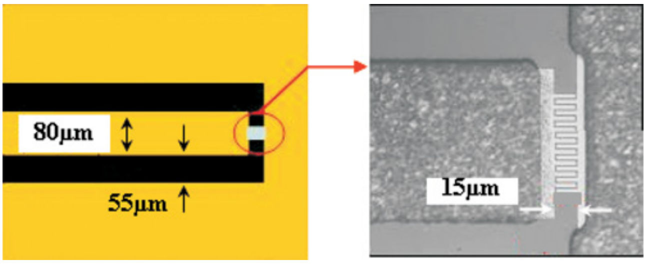


Figure 2. Photographs of a coplanar line and an end-interdigital capacitor. (Figure appears in color online.)

In Figure 4, we present another dielectric liquid characterization technique, using a waveguide section cell filled with the liquid.

The two ports of a network analyser are connected to the two waveguide accesses. The S-parameters (S_{ij} of the scattering matrix) measurements allow us to determine the complex liquid permittivity, in the range of the Ka-band frequencies. To do this, we have developed an original characterization method without calibrating the analyser [5], where no cell disassembling is necessary. But in this cell, we cannot polymerise a mixture of polymer and liquid crystals filled into the cell by an UV beam, because of the lightproof property of the cell.

2.2. *The Original Planar Cell to Both Obtain and Characterize the PDLC*

We have to manufacture an "open-cell" which will permit the UV beam to polymerise the mixture of liquid crystal and polymer. This cell should allow us both to apply the microwave electromagnetic field to the PDLC after polymerizing the mixture, and also to apply a high electric driving field (4 V/µm) by means of a bias. We have chosen to manufacture a planar cell, by machining half the diameter of Radiall SMA connections, by means of a milling machine (Fig. 5).

This machined cell is placed on an earthed part used as a support. In Figure 6, we present the complete cell.

To avoid electric damages on the two connected ports of the network analyser, we will use waveguide accesses. They will disconnect the polarization voltage applied by the bias between the central conductor of the Radial connection and the ground. We present the complete operating bench experiments in Figure 7.

A commercial simulator (Sonnet) has given us the simulated impedance results of either an empty cell, or filled with a known material (we chose paraffin oil, for

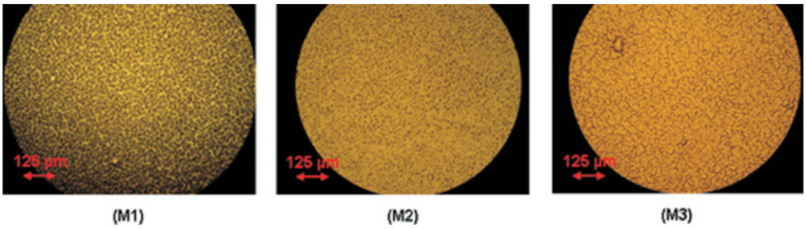
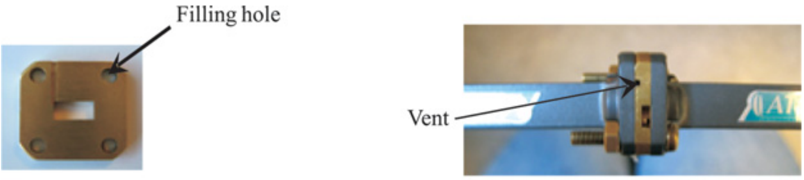


Figure 3. Photographs of the gold deposits on PDLC layers. (Figure appears in color online.)



7.112×3.556mm
Cell

Thickness : 2.48mm
Cell between 2 waveguides

Figure 4. Photographs of the measuring cell to determinate permittivity of liquids a in the range of Ka-band frequencies. (Figure appears in color online.)

which the real part of the dielectric permittivity is taken usually at 2.15, and the imaginary part at 0.02, in the X-band) [5]. The simulated impedance of the device has lead us to know the simulated reflection coefficients. The cell was mechanically adjusted using a technique which gave us the measured reflection coefficient (known as the "Time Domain Reflectometry"), because this measured coefficient has to be in accordance with the simulated reflection coefficient, for each port of the cell. After this study, we can affirm that the effective dielectric permittivity of the cell is equal to the dielectric permittivity of the cell filling material, for dielectric permittivity values between 2 and 4. The PDLC dielectric permittivity will be in this interval, so we consider that the cell is well-adapted to characterise the PDLC.

In the X-band range, we obtained the S-parameters of the empty cell. Then, we filled the cell, without disassembling it. We obtained the S-parameters of the device before, during, and after polymerization, with or without an electric driving field. From these S-parameters, the same characterization method gave us the dielectric parameters of the material filling the cell.

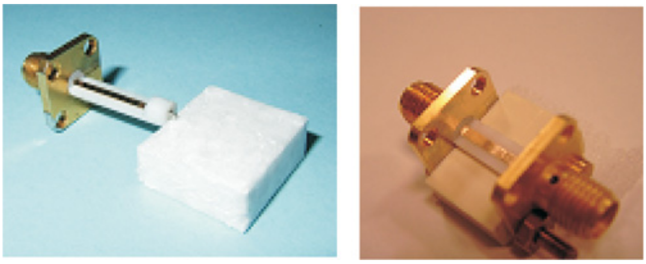


Figure 5. Photographs of the cell in the manufacturing time. (Figure appears in color online.)

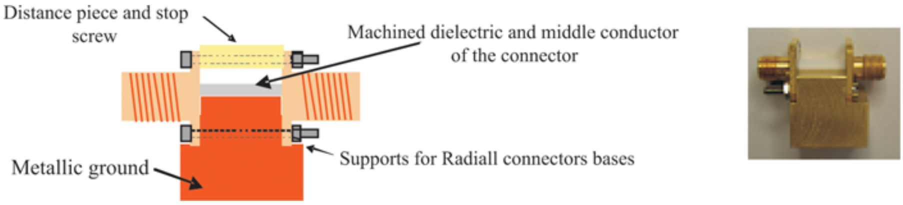


Figure 6. Photograph and design of the accomplished cell. (Figure appears in color online.)

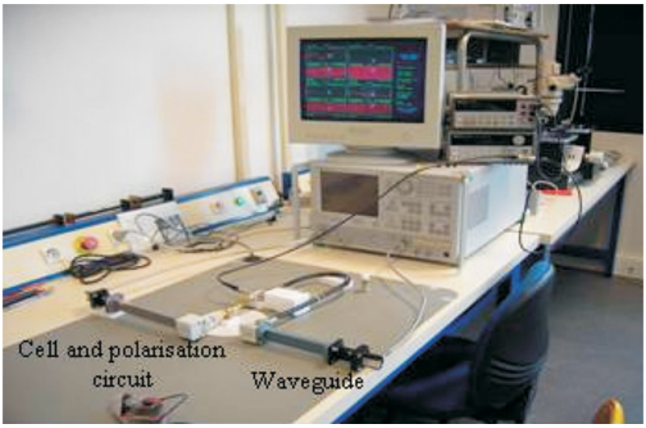


Figure 7. Photograph of the complete operating bench experiments. (Figure appears in color online.)

3. Microwave Dielectric Characterizations with the New Cell

3.1. *Measurements of a Known Liquid*

For each measurement, we have verified that the cell was in good working order by testing it with paraffin oil. In Figure 8, we present the real part of its complex permittivity, in the X-band frequency range.

The experimental value (2.15) is in perfect agreement with values obtained by other experimental methods. The imaginary part of the complex permittivity can be considered as equal to 0.015. Those measurements prove that the all the device dielectric characterizations parameters (accesses, cell, filling cell, connections...) are in good working order.

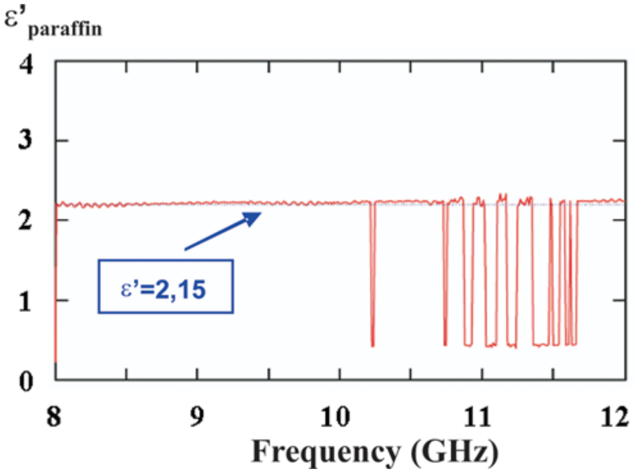


Figure 8. Real part of the dielectric permittivity for the paraffin oil versus frequency. (Figure appears in color online.)

3.2. *Microwave Dielectric Characterization of PDLC*

A PDLC has been obtained by means of a U.V. beam, focused on the balanced mixture of a monomer (NOA65, Norland) and a liquid crystal (5CB, Merck), pre-filled within the cell. Without disassembling the cell, it was been possible to obtain its dielectric permittivity, and then to deduce the material anisotropy by applying a high external electric driving field (2 V/μm).

First, in Figure 9, we present the real part of permittivity for the NOA65-5CB mixture versus exposure time, at 10 GHz.

The initial value (3.07) is between the value for the pure NOA65 (3.35), and the value for the pure 5CB (for isotropic configuration: 2.80). After a complete polymerization process, the real part of the permittivity for the NOA65-5CB mixture can be considered as equal to 2.90. The imaginary part of the permittivity for this PDLC can be taken between 0.12 and 0.18. Those values are higher than the values for a pure liquid crystal (0.05 for a parallel configuration, and 0.08 for a perpendicular configuration). We think it will be necessary to choose a polymer which presents lower losses in the microwave range.

Secondly, we present the dielectric permittivities for the NOA65-5CB polymerized mixture, versus the electric driving field, at 10 GHz, in Table 1. The dilutions of the liquid crystal into the polymer, and the high anchoring forces within the polymer matrix, have caused the anisotropy to decrease to 0.07 (instead of 0.35 for the 5CB pure liquid crystal, at the same frequency). We think this anisotropy value will be sufficient if we choose to develop electronic circuits in the highest frequencies.

Thirdly, we present the phase displacement $\Delta\varphi$, measured at 10 GHz, presented by the PDLC, in situ in the cell, versus the electric driving field E_c (Fig. 10).

In this curve we can notice the first part, until −1.5°: some liquid crystal molecules in the polymer may not be gripped to the polymer walls. In the second part of the curve, until −2.6°: we can suppose that the liquid crystal molecules have become smaller and well-gripped. In the third part of the curve, all the liquid crystal molecules steer: we reach a saturation point.

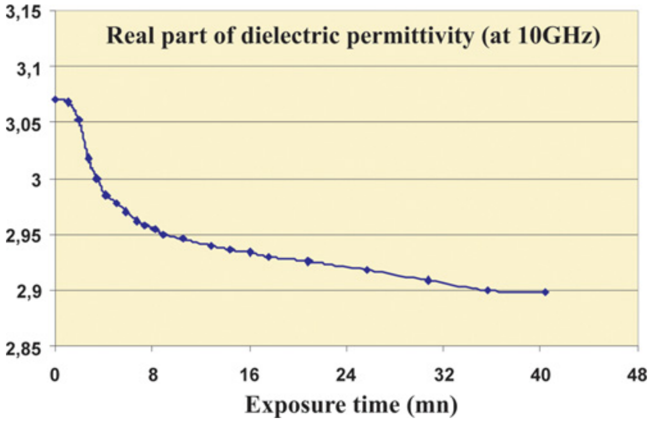


Figure 9. Real part of the dielectric permittivity for a mixture (NOA65-5CB) versus U.V. exposure time. (Figure appears in color online.)

Table 1. Dielectric permitivity of PDLC material with and without electric driving field

PDLC : NOA65/5CB (50%-50%)	ε'	ε'' (estimation)
Without driving field	2,90	$150 \cdot 10^{-3}$
With driving field (4 V/μm)	2,97	$100 \cdot 10^{-3}$

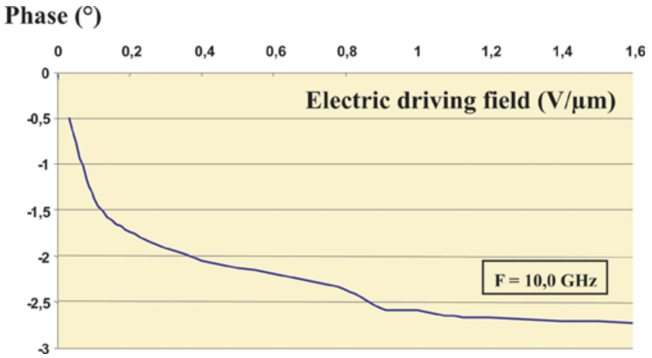


Figure 10. PDLC phase displacement versus electric driving field. (Figure appears in color online.)

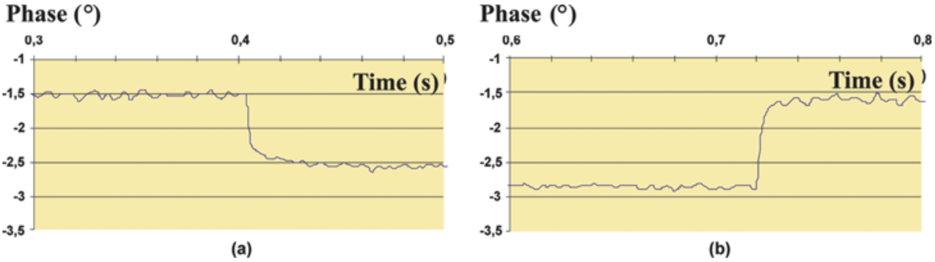


Figure 11. PDLC rising time and falling time. (Figure appears in color online.)

We determined the rising time/falling time, by the application/extinction of a saturation driving field. Figure 11 shows that the falling time is faster with a PDLC than with a pure liquid crystal (for which it would take about a few minutes).

All those PDLC behaviours confirm their possible use for a tunable electronic device, in the microwave range.

4. Specific Application of the PDLC in a Microwave Device (Ka Band)

To easily apply an external driving field, and to obtain a better U.V. polymerization, we have chosen a planar circuit device. The gaps between the metallic zones were filled with the mixture to be polymerised, by means of a perpendicular U.V. beam. The edges of the filled gaps have contributed to create the driving field, to steer the

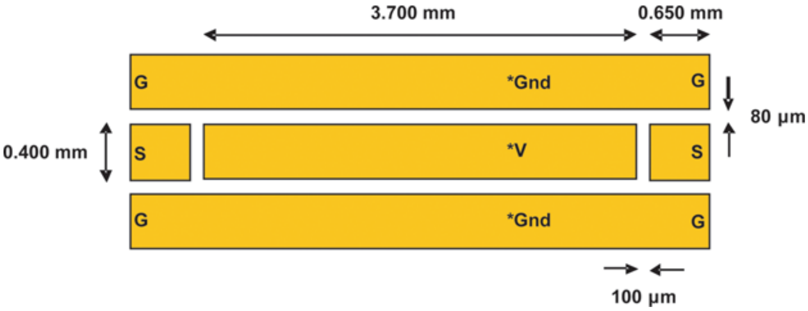


Figure 12. Coplanar resonator design. (Figure appears in color online.)

liquid crystal molecules included in the polymer. The design of the chosen coplanar resonator is presented on Figure 12.

The resonator was designed for an operating frequency of about 30 GHz. The gaps were filled with the mixture studied before (a balanced mixture of the monomer NOA65 with the liquid crystal 5CB, in grey on Fig. 12). Thanks to "Plateforme de Technologie de l'Université du Littoral Côte d'Opale", this design was manufactured on a 381 µm thickness Duroïd substrate, covered with a 35 µm thickness copper layer. At both ends of the resonator, it was necessary to design an access to apply the microwave coplanar probes connected to the network analyser (Fig. 13).

In fact, the gap between two pins must not exceed 125 µm. Besides, we have had to design two contacts to connect the external voltage, and to link them to the metallic zones of the resonator with 30 µm diameter aluminium wire. All those geometrical considerations are visible on the resonator photograph in Figure 14.

After applying and polymerizing the mixture, the resonant frequencies F_0 were measured, with and without an external voltage. On Figure 15 and Table 2, we present the best results for such a structure: the transmission coefficient $|S_{12}|$, the resonant frequency shift ΔF_0, and the quality factor Q.

When a driving field is applied to the structure, the frequency shift ΔF_0 equals about 117 MHz. We prove that such a structure is a tunable microwave device,

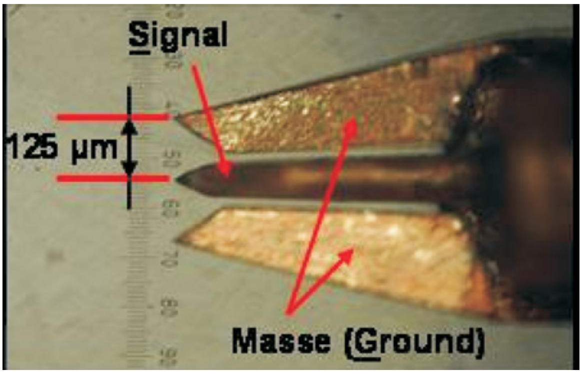


Figure 13. Photograph of the coplanar test probe (40 GHz range). (Figure appears in color online.)

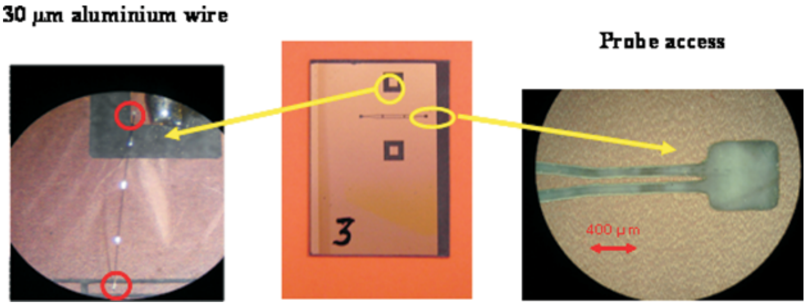


Figure 14. Photographs of the resonator (access, aluminium wire, and soldering). (Figure appears in color online.)

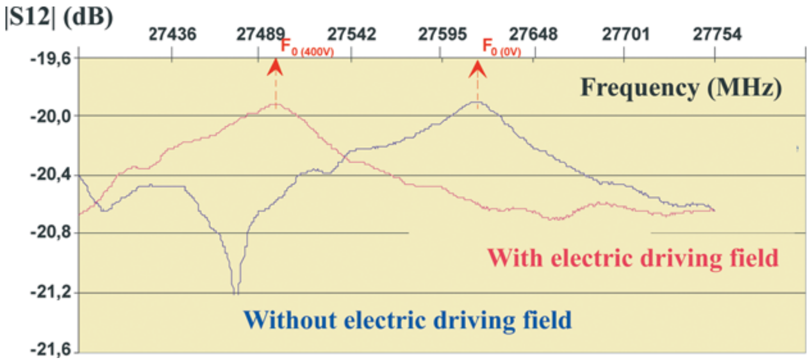


Figure 15. Transmission parameters of the resonator with and without electric driving field.

Table 2. Best results for coplanar resonator (30 GHz)

	Without driving field	With driving field (4 V/µm)
F_0 (GHz)	27,615	27,498
$\lvert S_{12}\rvert$ (dB)	−19,8	−19,9
ΔF_0 (MHz)	965	1050
Q	29	26

even if the quality factor Q ($26 < Q < 29$) has to be upgraded using more precise manufacturing techniques.

5. Conclusion and Perspectives

We have made and perfected a microwave characterization cell which allows us to obtain dielectric characterizations of PDLC composites after an in-situ polymerization. We have also demonstrated not only a simplified way to use liquid crystals in reconfigurable microwave devices by using PDLC materials, but also the uselessness to use polymer alignment layer. It is relatively easy to obtain PDLC materials. Their physical properties (rising time and falling time, anisotropy…) encourage us to apply those materials to improve microwave devices: a resonator has been manufactured, in the Ka band, employing a PDLC.

We think that a good control of PDLC obtaining techniques, and improvements in the microwave circuits processes, can allow the manufacture of devices with better microwave behaviours.

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