

Frequency resonant behaviour of the effective permittivity for a polyvalent liquid crystal in microwave range

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We consider a thermotropic polyvalent liquid crystal, which presents different local orders for different temperature ranges. The aim of our paper is to perform a material study, illustrating its specific characteristics. We determine the effective permittivity of the material, in the microwave frequency range, where the practical results are difficult to obtain. We follow these steps: structure simulations using a high level program, measurements for punctual frequencies in the microwave range, and theoretical calculation based on the Rayleigh bi-dimensional model. The effective permittivity curves plotted against frequency are obtained. The curves illustrate the frequency dependence of the determined quantity, which is not predicted by the existing theories, and indicate the resonances, which are of great interest in practice as they represent breakups of electrical properties of the material.

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1. Introduction

Materials presenting more than one components have physical properties depending on their internal structure. The material parameters have effective values, characterizing the mixture and presenting physical and geometrical resonances.

Our material study is performed for a polyvalent liquid crystal, which is a mixed structure with applications in electronics and physics. The material, which presents properties of a liquid crystal for specific temperature ranges [6], has two special aspects: it has two types of macro-molecules, and it is a thermotropic liquid crystal, however its local order changes with the temperature.

For our study some mixtures of *p-cyanobenzilidene-p'-butylaniline*+ *p-hexyloxybenzimidene amino benzonitrile* have been considered. An unusual phase transition sequence was observed by Cladis in these mixtures: the nematic phase is followed by smectic and reentrant nematic phases when the temperature is decreased. These are known as the reentrant nematic mixtures. We mention that there are also other several compounds identified with the same behaviour.

It is interesting that modifying the concentration of the two types of molecules, the limits of the temperature domains (where the mixture presents the properties of a liquid crystal) do not change, but its optical anisotropy intensity changes, as we expected. Resonances of the material parameters do not change their position on frequency scale. No details are given about the concentration of molecules, as this is not relevant for our study.

The electrical properties of the mixture, illustrated by its electric effective relative permittivity are analyzed. These values were determined for a frequency range specific to the microwave domain and the magnitude

of resonances was obtained using a simulation program. The results were confirmed by punctual frequencies measurements and theoretical estimation.

In our contribution, some new determinations of resonances, which are usually difficult to perform at high frequencies, are presented. The resonances are very important for an efficient utilization of the material, because a resonant behaviour at a well-known frequency indicates a special response of the material to the external electromagnetic stress.

The results are compared with those obtained in our previous work [4], in the case of the bivalent monomolecular HAB liquid crystal (also see Table 1). When the temperature increases, the HAB substance evolves: isotropic, smectic liquid crystal, then nematic liquid crystal, and finally the local order disappears (is thermal 'broken') and the HAB is isotropic again.

2. Effective permittivity determination strategy

We use a triple strategy for determining the values of the effective permittivity and the electric resonances for the mixture with liquid crystal properties:

- simulations, in a continuous frequency domain, with frequency sweeping between 7.8 ÷ 12.4 GHz, and determinations of the first ten resonances in microwave range;

- measurements for a group of punctual frequencies up to 12.4 GHz, for confirming the resonant frequencies in the case of each analyzed structure;

- theoretical calculations, using the Rayleigh bi-dimensional theory, for estimating the direct current value of the effective permittivity.

The details are given in the following.

The simulations are performed using the High Frequency Structure Simulator program (Ansoft Technologies), oriented to HF determinations of the quantities characterizing the electromagnetic field interactions with the structures. The mixed material samples are simulated inside a rectangular waveguide, with the cross-section of 22.86 x 10.16 x 10 mm, at an excitation level of 1W incident normalized power at each port, defined on opposite samples faces. The oscillation mode inside the waveguide is TE₁₀. The direction of propagation of the testing field was considered parallel and transverse on the long molecules, for illustrating the anisotropy (see Figure 1). Every sample was structured of approximately 106 basic cells, with the same orientation of the long molecules inside. The dimensions of the basic cells are approximately one order greater than the molecular dimensions order, as shown in Figures 2 - 4, for the analyzed states of the mixture: isotropic, nematic liquid crystal and smectic liquid crystal. The two types of molecules in the mixture are represented with different colors and dimensions.

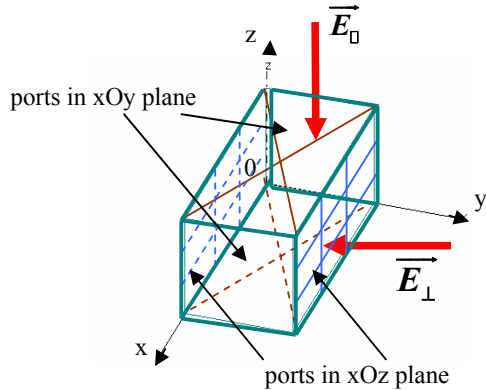


Fig. 1. Sample exposed to the testing field.

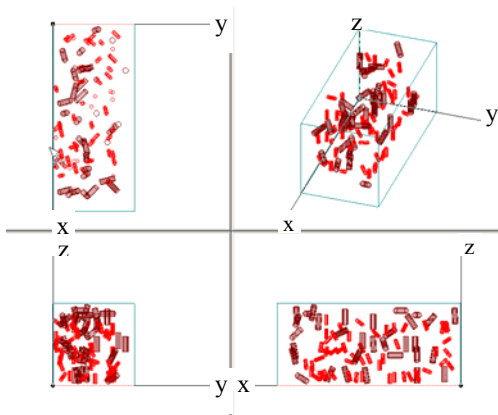


Fig. 2. The basic cell for the isotropic state of the analyzed mixture. Two types of different molecules can be observed.

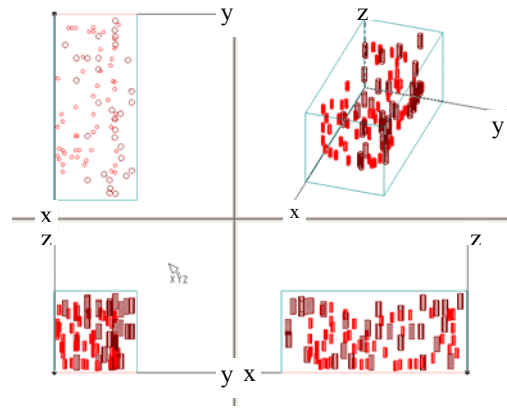


Fig. 3. The basic cell for the nematic liquid crystal state of the analyzed mixture. Two types of different molecules are arranged parallel, with their symmetry centers randomly placed in samples volume.

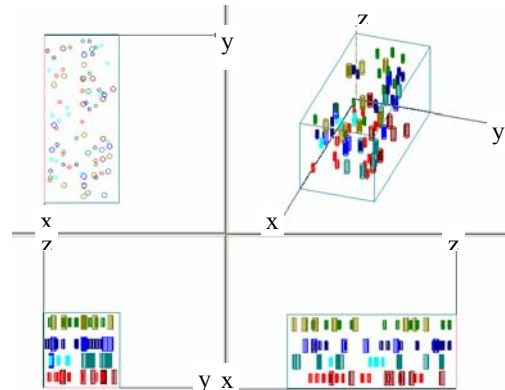


Fig. 4. The basic cell for the smectic liquid crystal state of the analyzed mixture. The two types of different molecules are arranged in parallel equidistant planes, with their symmetry centers placed randomly in these planes.

For samples which are exposed to the testing field inside the rectangular waveguide, we have developed a method for the determination of *S* parameters, and for the calculation of the effective permittivity [1], [3]. As a result, at a frequency *f*, the effective permittivity of the mixed material sample, $\epsilon_{r,ef}$ is given by

$$\epsilon_{\Gamma,ef} = \frac{\beta^2 + (\pi/a)^2}{\epsilon_0 \mu_0 \cdot (2\pi f)^2} \quad (1)$$

where we have denoted: β - the propagation constant of the testing field inside the sample, *a*- the length of the waveguide cross-section, ϵ_0 and μ_0 - electric permittivity and magnetic permeability of the free space, respectively.

The measurements for the effective electric permittivity are performed using the experimental arrangement presented in Fig. 5. The main part of the

installation is represented by the multi-function block HP Agilent 4396B, which includes the variable frequency microwave generator and the module for S-parameters determination. Before every set of samples measurements, the calibration of the installation was done with a calibration kit, available with the 43961A module, and with APC-7 connectors. After the determination of S parameters, the authors have used the same algorithm based on physical considerations for computing the effective permittivity.

The analyzed substance (liquid crystal) was introduced in a parallelepiped recipient, with 0.2 mm thick Teflon walls, which fills the cross-section of the rectangular waveguide considered before. The long molecules are oriented homeotropic, planar homogeneous, respectively, using chemical ingredients, which are applied on the recipient walls. The measurements were done in the microwave laboratory of the L'Ecole Nationale Supérieure de l'Electronique et de ses Applications (ENSEA), Cergy, France.

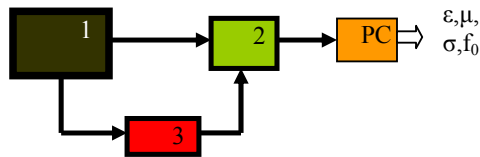


Fig. 5. Block diagram of the experimental arrangement for effective permittivity measurements: 1 - variable frequency microwave generator; 2 - module for S parameter determination; 3 - waveguide with sample.

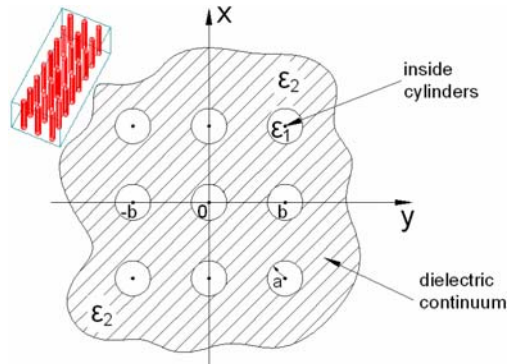


Fig. 6. The Rayleigh model of mixed dielectric.

The theoretical calculation was performed using the Rayleigh bi-dimensional theory [5], which gives the effective electric permittivity for mixed materials with structures similar with those considered by us (Figure 6). One supposes a finite array of equidistant infinite long cylinders, with permittivity ϵ_1 , radius a , and distance b between basis centers, placed in a homogeneous dielectric with permittivity ϵ_2 .

We have to consider some differences between the theoretical model and the real structures, such as:

- our structures (liquid crystals basic cells) do not have infinite long cylinders, because the cylinders are represented by the long molecules, with finite length;

- the inside cylinders are not equidistant. Their symmetry centers are randomly placed in parallel equidistant planes (for smectic structures) or in the volume of the samples (for nematics);

- in the case of the liquid crystal mixture not all the long molecules are of the same kind, but of two categories: *p-cyanobenzilidene-p'-butylaniline* molecules and *p-hexyloxybenzoinidene amino benzonitrile* molecules, respectively.

The theoretical expression for the relative effective permittivity of structures described by the Rayleigh bi-dimensional theory is the following

$$\epsilon_{r,ef} \cong \epsilon_2 \left(1 - \frac{2\beta_{2,1} \tilde{w}_4}{1 + \beta_{2,1} \tilde{w}_4 - \delta_{2,1} \tilde{w}_4^4 - \gamma_{2,1} \tilde{w}_4^8} \right) \quad (2)$$

where one denotes

$$\beta_{2,1} = \frac{\epsilon_2 - \epsilon_1}{\epsilon_2 + \epsilon_1}, \quad \tilde{w}_4 = \pi \left(\frac{a}{b} \right)^2 \quad (3)$$

and

$$\delta_{2,1} = 0.30583 \beta_{2,1}^2, \quad \gamma_{2,1} = 0.013361 \beta_{2,1}^2 \quad (4)$$

The most important limit of the theory is that it does not describe the dependence of the effective permittivity on frequency. The value of the effective permittivity given by the Rayleigh formula represents a DC value. Using this formula, we have no possibility to predict resonances. Another limit of the theory is that anisotropy is not considered. Even if the formula gives the better results for mixtures with this kind of geometry, we have to consider its limits when the material works in a HF electromagnetic field. An important and complete formula was given by us in our previous work [4].

3. Results and interpretation

For the considered mixture, the effective permittivity curves are obtained by simulation, describing its evolution with frequency (Fig. 7). The results are presented for each state of the mixed material: isotropic, nematic liquid crystal and smectic liquid crystal, when the testing field propagates with the \vec{E} vector parallel and transverse on the long molecules, respectively. In this way, the anisotropy is illustrated. A frequency domain of 7.8 - 12.4 GHz was selected, where the precision of the method is the best.

We point out that the curves describe the dependence of the effective permittivity on frequency, which was not predicted by the existing theories, and indicate the resonances. The obtained curves can be extended to higher frequencies by extrapolations. These extrapolations are acceptable as they include the resonances, determined with the HFSS program up to 45 GHz.

One can notice that the resonances appear in the considered frequency domain on all the curves

characterizing the mixture states. All of them are geometrical resonances, corresponding to a geometrical parameter of the sample and strongly dependent of its internal order. The resonances of the isotropic state have a lower magnitude than the resonances of the liquid crystal state, because an effect of too strong or too week polarization cannot be found in an isotropic material. On the other hand, a multitude of resonances appears on the curves which correspond to the smectic liquid crystal state, characterizing an inhomogeneous material.

We have also computed the optical anisotropy of the material, defined as

$$\Delta\epsilon = \epsilon_{\parallel} - \epsilon_{\perp} \tag{5}$$

where ϵ_{\parallel} is the parallel effective permittivity and ϵ_{\perp} is the transverse one. For the anisotropic states of the material (nematic and smectic), the anisotropy curves plotted against frequency are given (Fig. 8).

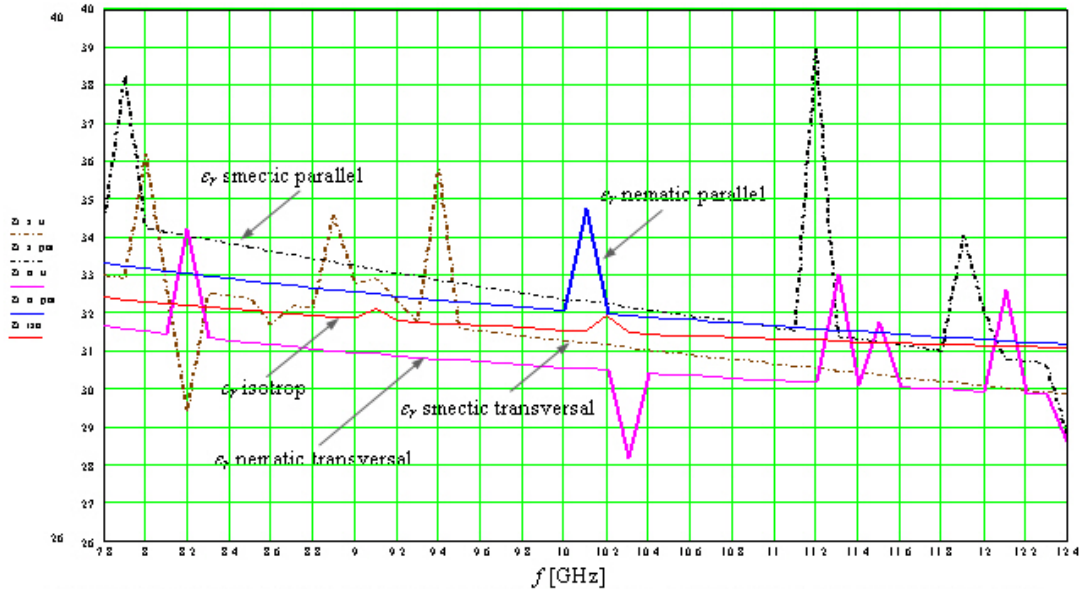


Fig. 7. Electric relative effective permittivity curves versus frequency for the mixture: *p*-cyanobenzilidene-*p*'-butylaniline + *p*-hexyloxybenzoinidene amino benzonitrile, for each state of the material: isotropic, nematic liquid crystal and smectic liquid crystal, for two propagation directions of the testing field.

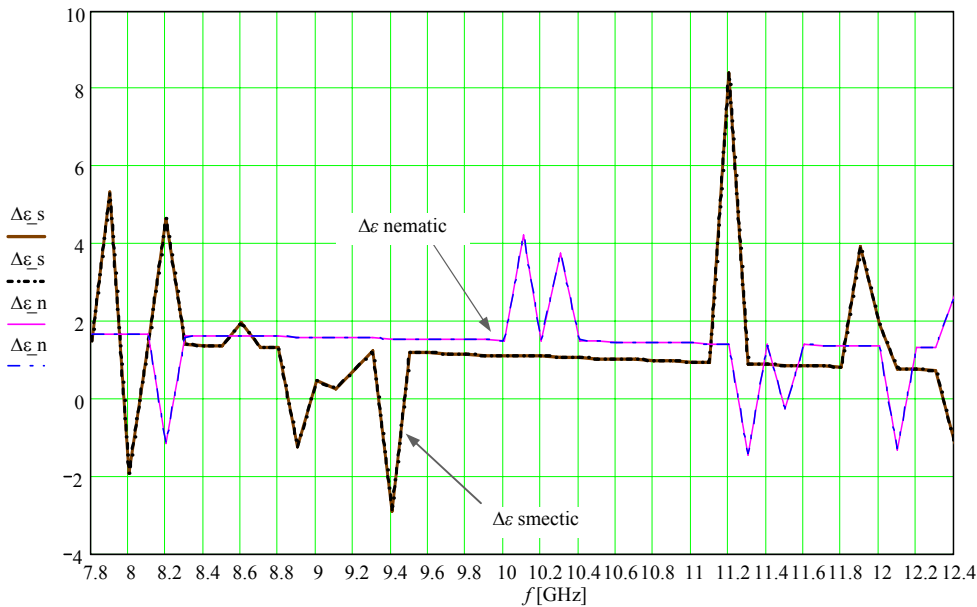


Fig. 8. Optical anisotropy, $\Delta\epsilon$, for the anisotropic states of the mixture.

One emphasizes a particular property of the mixture concerning the optical anisotropy. If the resonances are not considered, the anisotropic states of the mixture are optical positive. Related to some resonances zones, the optical anisotropy becomes punctual negative and the behaviour of the field interaction with the structure is radically changed. Therefore, it is very important to localize with high precision these particular resonances on the frequency scale. This behaviour is never observed in an anisotropic material, with only one type of long molecules.

For the analyzed mixture, the first ten resonances in microwave range were determined, using the special module of the HFSS program. Every state of the mixture was considered (isotropic, nematic and smectic liquid crystal), in two cases of exposure to the external field:

with the \vec{E} vector parallel and transverse on the long

molecules, respectively. For describing the resonant behavior of the mixture, three classes of thermotropic liquid crystals were considered: nematic, smectic and polyvalent (see Table 1 and Table 2). For our purpose, nematics and smectics were used. With the aim of exemplification, two families were chosen: the nematic *nytril* (CN) family and the smectic *diphenyl-bora-trioxadecalines*, because the liquid crystals belonging to the same family have similar properties. The well-known *p-azoxyanisol* (PAA) and *p-metyloxibenziliden-p'-butylaniline* (MBBA) were considered as etalon substances. Another polyvalent liquid crystal was also studied. It presents the same thermotropic states (nematic and smectic) like our mixture, but evolving in inverse order when the temperature increases.

Table 1. First ten resonances, in microwave range, for the nematic and smectic liquid crystals, obtained by simulations.

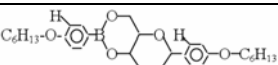
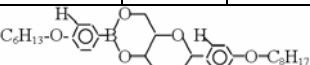
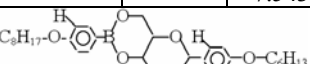
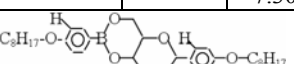
Chemical formula	f_0 [GHz]	f_1 [GHz]	f_2 [GHz]	f_3 [GHz]	f_4 [GHz]	f_5 [GHz]	f_6 [GHz]	f_7 [GHz]	f_8 [GHz]	f_9 [GHz]	
Nematic liquid crystals											
p-azoxyanisol (PAA): $\text{CH}_3\text{-O-}\langle\bigcirc\rangle\text{-N=N-}\langle\bigcirc\rangle\text{-O-CH}_3$											
	\parallel	2.130	4.001	4.708	5.998	6.042	7.101	7.197	7.287	7.447	7.729
	\perp	1.593	2.781	3.423	3.637	3.909	4.569	4.991	5.231	5.750	6.204
p-metyloxibenziliden-p'-butylaniline (MBBA): $\text{CH}_3\text{-O-}\langle\bigcirc\rangle\text{-CH=C-}\langle\bigcirc\rangle\text{-CH}_2\text{-CH}_2\text{-CH}_2\text{-CH}_3$											
	\parallel	10.275	11.834	12.237	12.634	13.951	14.643	15.901	16.582	17.964	19.463
	\perp	6.468	8.273	9.681	10.224	10.837	12.463	14.084	15.138	16.431	17.228
n-C ₄ H ₉ -O-⟨⊙⟩-CH=⟨⊙⟩-C≡N											
	\parallel	5.057	6.467	8.823	9.082	9.423	9.822	9.971	10.084	10.379	10.577
	\perp	3.469	5.284	6.184	6.826	7.026	7.565	7.961	8.316	8.613	9.237
C ₇ H ₁₅ -C-O-O-⟨⊙⟩-CH=⟨⊙⟩-C≡N											
	\parallel	9.127	9.972	10.112	15.545	16.130	16.592	17.069	17.561	17.693	17.938
	\perp	5.422	7.901	9.672	10.164	10.643	11.098	15.455	16.125	17.625	17.749
C ₆ H ₁₃ -O-⟨⊙⟩-CH-⟨⊙⟩-C≡N											
	\parallel	4.013	5.671	6.893	7.206	10.221	14.002	14.881	16.683	17.086	17.442
	\perp	3.142	4.061	4.965	6.213	6.986	8.726	9.172	11.581	13.675	15.863
Smectic liquid crystals (diphenyl-bora-trioxadecalines):											
 C ₆ H ₁₃ -O-⟨⊙⟩-B-⟨⊙⟩-O-C ₆ H ₁₃											
	\parallel	8.604	11.256	12.180	12.212	12.864	13.123	13.404	13.465	14.480	14.894
	\perp	6.227	8.046	8.873	9.614	10.115	10.912	11.381	11.574	11.849	12.648
 C ₆ H ₁₃ -O-⟨⊙⟩-B-⟨⊙⟩-O-C ₆ H ₁₇											
	\parallel	10.372	11.486	12.618	13.497	13.953	14.601	15.026	15.832	16.598	17.381
	\perp	7.543	9.013	10.228	10.851	11.443	11.961	12.683	13.146	13.875	14.349
 C ₈ H ₁₇ -O-⟨⊙⟩-B-⟨⊙⟩-O-C ₆ H ₁₃											
	\parallel	10.748	12.054	13.198	13.876	14.683	14.992	15.321	16.471	17.173	17.996
	\perp	7.301	9.046	10.284	10.779	11.586	12.264	12.826	13.947	14.782	15.082
 C ₈ H ₁₇ -O-⟨⊙⟩-B-⟨⊙⟩-O-C ₆ H ₁₇											
	\parallel	12.445	14.071	15.403	16.182	16.896	17.549	17.973	18.284	18.659	19.358
	\perp	9.876	11.218	12.796	13.543	13.874	14.631	14.928	15.741	16.294	17.641

Table 2. First ten resonances, in microwave range, for the polyvalent liquid crystals, obtained by simulations. The values written with bold fonts represent the resonances obtained by measurements, up 12.4 GHz.

Chemical formula	f_0 [GHz]	f_1 [GHz]	f_2 [GHz]	f_3 [GHz]	f_4 [GHz]	f_5 [GHz]	f_6 [GHz]	f_7 [GHz]	f_8 [GHz]	f_9 [GHz]		
Polyvalent liquid crystals												
HAB: <chem>C7H15-O-C6H4-N=N-C6H4-O-C7H15</chem>												
T ↑	nematic		15.555	16.129	18.893	19.584	20.682	21.471	21.671	21.782	21.852	23.529
		⊥	10.831	11.962	12.223	14.648	15.831	16.796	16.981	17.286	17.875	21.106
			10.761	11.914	12.106	-	-	-	-	-	-	-
	smectic		16.148	19.002	19.640	20.725	21.402	21.707	23.535	24.010	24.317	27.734
		⊥	11.431	13.862	14.323	15.648	16.831	17.796	19.581	20.286	20.875	24.106
			11.267	-	-	-	-	-	-	-	-	-
isotropic		15.683	16.114	19.123	19.525	20.633	21.550	21.881	23.941	24.336	28.486	
Mixture: p-cyanobenzilidene-p'-butylaniline + p-hexyloxybenzoinidene amino benzonitrile												
T ↑	smectic		7.873	11.163	11.947	12.023	12.402	12.620	12.630	12.706	12.868	13.097
			7.742	11.108	11.893	11.934	-	-	-	-	-	-
		⊥	4.329	7.219	8.083	8.169	8.608	8.876	8.966	9.062	9.154	9.453
		3.962	6.985	7.864	7.947	8.409	8.677	8.768	8.874	8.986	9.308	
	nematic		10.063	13.485	14.506	15.050	15.580	15.603	15.907	15.957	16.206	16.682
			9.952	-	-	-	-	-	-	-	-	-
		⊥	8.236	10.281	11.286	11.503	12.117	12.425	12.776	12.885	13.041	13.326
		7.998	10.146	11.214	11.383	11.978	-	-	-	-	-	
	isotropic		5.564	9.123	10.157	12.467	13.173	13.580	13.792	14.061	14.242	14.829
		5.287	8.923	9.975	-	-	-	-	-	-	-	

We have also illustrated in a graph the first ten resonances for the two polyvalent liquid crystals (Figs. 9). When the temperature increases, on each line of the

graphs, the resonances of a state (isotropic, nematic liquid crystal, etc.) are represented.

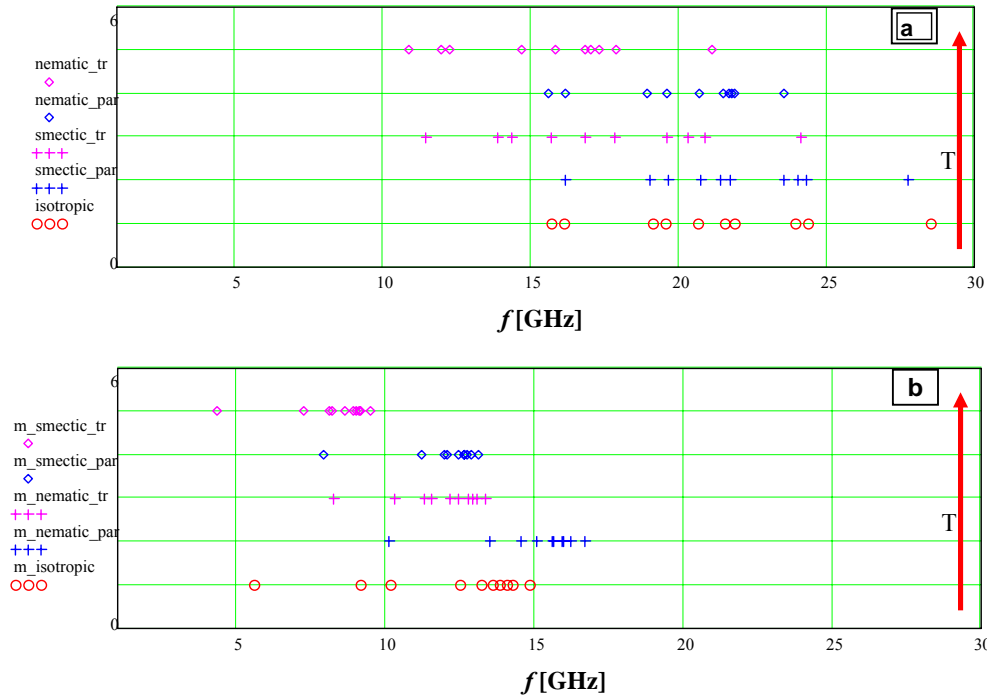


Fig. 9. First ten resonant frequencies by simulation for the HAB substance (a) and mixture (b).

One can remark that the mixture presents resonances at lower frequencies than the HAB substance. These are geometrical resonances, depending on the geometrical parameters of the material, such as: length and width of long molecules, the distance between two successive molecular layers for smectic structures, etc. The connection between resonances and the geometrical parameters which determine these resonances are easily made by an artificial modification of the parameters, and monitoring the resonance shifts and their magnitude.

One notes that the resonant frequencies corresponding to the liquid crystal states decrease when the temperature increases, if we consider the same direction of the testing field. If the resonant frequency values are inverse proportional with the corresponding geometrical parameters, one concludes that the geometrical parameters have higher values when the temperature increases. In this way, the local order is modified.

The study of the distribution of the resonant frequencies on the frequency scale gives interesting results. For the same material, the displacement between a resonant frequency and the successive one is

approximately the same when the material changes its internal order. This is a consequence of the fact that the connections between the most of geometrical parameters remain the same, even the internal order is changed. The differences are due to the new parameters introduced with each change in the local order (for example, at the mixture change from nematic to smectic, we have to consider a new geometrical parameter, which was not defined for the previous isotropic and nematic states: the spacing between two successive molecular layers). The magnitude of resonances depends on the nature of material constituents, and not only on its geometry. This dependence is shown in the graphs of the effective permittivity versus frequency.

For the analyzed liquid crystal materials, the fundamental resonant frequencies, in the microwave domain, are plotted on the same graph (Figure 10). One sees that lower fundamental resonant frequencies can be found at nematic liquid crystals, rather than to smectic liquid crystals, but depending on substance nature (see MBBA, with its fundamental resonant frequencies even higher than some *diphenyl-bora-trioxadecalines*).

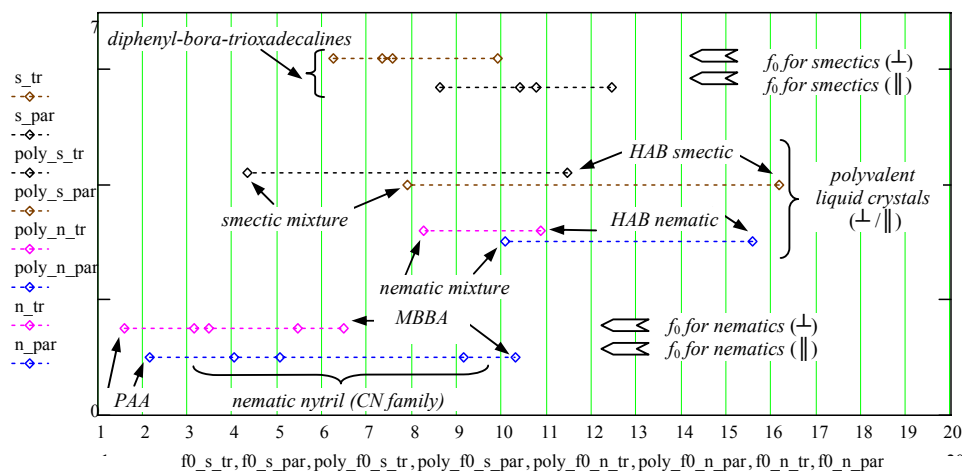


Fig. 10. Distribution of fundamental resonant frequencies, f (GHz), for three categories of liquid crystals: nematic, smectic and polyvalent, on the same graph.

The polyvalent liquid crystals seem to present high values for fundamental resonant frequencies, corresponding to the geometrical parameters attached to the long complex molecules. The values of these frequencies can be consistently reduced when the polyvalent liquid crystal is a mixture, as shown in the Figure 10. For all the liquid crystals, an exposure field with its \vec{E} vector transverse on the long molecular axes determines fundamental resonances, having lower values than in the case when a parallel field is applied. This is a consequence of the fact that resonances correspond to a combination of geometrical parameters characterizing the structure and not to only one parameter [3,4].

We also studied the resonant frequency displacement for our mixture. For each state of the mixture, the

displacements between each resonant frequency and the fundamental frequency are calculated. The displacements are represented against the resonant frequency values in Fig. 11. The graphs never intersect, as we expected.

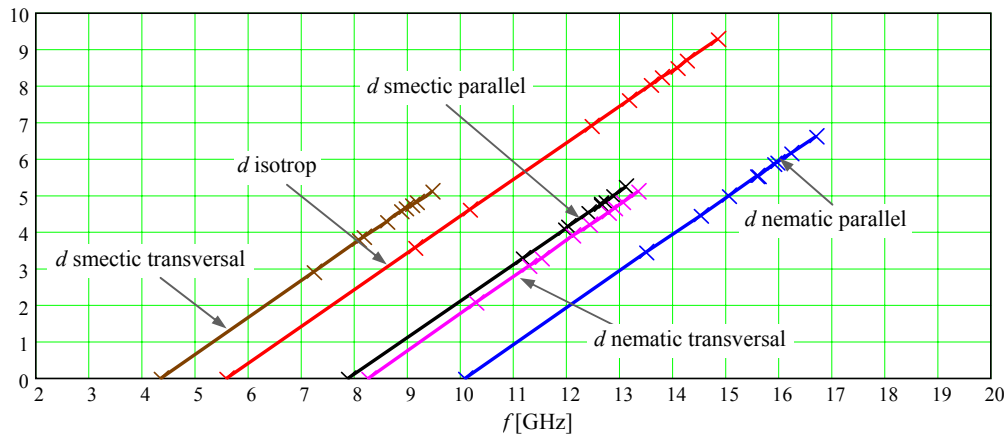


Fig. 11. Resonant frequencies displacements vs. resonant frequency values, for all states of the mixture: isotropic, nematic liquid crystal and smectic liquid crystal.

The experiments confirm the values of the resonant frequency, obtained for punctual frequencies in the domain of 0.3 - 12.4 GHz. For the considered polyvalent liquid crystals the results obtained by simulation for the resonant frequencies, are also given in Table 2 (written with bold fonts). There is a good coordination between the results obtained by measurements and those by simulation. Similar experimental checks were done for resonant frequencies of liquid crystals classified in other categories (like PAA, MBAA, etc.) [1], [3]. If we compare the results of the simulation with the experimental data, a systematical negative absolute error occurs. This situation will be discussed separately.

We also present the results obtained for the relative effective permittivity in direct current, which are given in Table 3. The theoretical calculation of the effective permittivity is based, as we have mentioned in our previous considerations, on the Rayleigh bi-dimensional theory. Following the theoretical predictions [5], [7], the DC effective permittivity values are higher than those obtained in microwave range.

Table 3. The DC values of the effective permittivity (Rayleigh bi-dimensional theory).

Material	ϵ_r, ef
Nematic liquid crystals	
p-azoxyanisol (PAA)	63.268
p-metyloxibenziliden-p'-butylaniline (MBBA)	74.627
nematic nytril (CN family) 1	25.486
nematic nytril 2	18.453
nematic nytril 3	22.178
Smectic liquid crystals (diphenyl-bora-trioxadecalines)	
diphenyl-bora-trioxadecaline 1	34.843
diphenyl-bora-trioxadecaline 2	39.596
diphenyl-bora-trioxadecaline 3	41.243
diphenyl-bora-trioxadecaline 4	44.657
Polyvalent liquid crystals	
HAB	14.371
Mixture	
p-cyanobenzilidene-p'-butylaniline + p-hexyloxybenzimidene amino benzonitrile	36.285

4. Discussion

In this section, the main aspects of our work are presented:

- the resonances of the electrical relative effective permittivity characterize the electrical behaviour of the samples. The resonance analysis imposes the study of the resonances position on the frequency scale, connected to the properties of the material (structure, local order, nature of components and geometry);
- the comparison between resonances characterizing different structures can help us to choose the suitable structure for a concrete practical situation;
- the optical anisotropy of the inhomogeneous mixtures can vary in the vicinity of some resonances, even changing its sign. This effect is not found at materials with a single component;
- the analysis of the first ten resonances in the microwave range for different types of thermotropic liquid crystals, yields the relationship between the resonant frequencies and the geometrical parameters of each sample. This is obtained by an artificial modification of the parameters and monitoring the resonance shifts and their magnitude;
- an increasing of temperature determines a modification of the internal local order in such a manner that the resonance frequencies decrease;
- for the same material, the displacement between successive resonant frequencies is approximately the same when the material changes its internal order;
- the magnitude of the resonances is also influenced by the nature of the material constituents, and not only by its geometry;
- for all the liquid crystals, an exposure field with its \vec{E} vector transverse on the long molecular axes determines fundamental resonances, having lower values than in the case when a parallel field is applied. This is a consequence of the fact that resonances correspond to a combination of geometrical parameters characterizing the structure and not corresponding to only a singular parameter;

- the displacements between the resonant frequency and the fundamental present a linear evolution against resonant frequencies, as we expected;
- there is a good coordination between the results obtained by measurements and those by simulation. The concordance between these results sustains the importance of the method;
- the analysis of the obtained results for the DC effective permittivity sustains the usefulness of this model;
- the limits of the theoretical model for mixed structures have to be considered. The models does not have an exact geometrical match. It cannot describe the frequency evolution of the material parameters or illustrate the resonances, and it doesn't consider the material anisotropy.

5. Conclusions

In this contribution, an extensive analysis of the frequency resonance behaviour for a thermotropic polyvalent liquid crystal is performed. This presents different local orders for different temperature ranges and has many applications in electronics and physics. The breakups of the electrical properties occur at frequencies corresponding to the resonances, and determine a particular behaviour of the samples in external fields.

For performing our study we followed these steps: structure simulations using a powerful program, measurements for punctual frequencies in the microwave range, and theoretical calculation based on the Rayleigh bi-dimensional model. The effective permittivity curves plotted against frequency were obtained.

Some remarks are needed:

- the resonances appear at frequencies which correspond to the geometrical parameters of the samples, and are strongly influenced by the internal order. The nature of the components influences the magnitude of resonances;

- our method yields important results and covers a frequency domain where is difficult to work using other methods;

- the existing theoretical models present limitations, which limit their applicability area.

In conclusion, our method is useful for the study of the electrical effective permittivity of a polyvalent liquid crystal, in the microwave frequency range, where practical results are difficult to obtain.

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