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Study of the Electromagnetic Characteristics of a Composite Metamaterial Transmission Line (CRLH) CPW in Coplanar Technology

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Abstract: *The electromagnetic characteristics of the transmission lines represent the important factor in the design of the various microwave circuits. Several solutions have been proposed to improve the electrical qualities of these circuits. In this work, we study the electromagnetic characteristics of a new type of transmission line which is the composite Right / Left handed line (CRLH) CPW obtained from metamaterials components. Our basic cell which is studied in coplanar technology, is composed by a coplanar interdigital capacity (CID) CPW and parallel inductance. For the (CID) CPW, we use five (05) fingers and for the shunt inductance, we use two parallel stubs short-circuited to the ground plane. To study the electromagnetic characteristics of our coplanar metamaterial line, we determine the propagation regions in the overall structure. The substrate used to have the Right / Left handed behavior is the dielectric FR_ Epoxy of dielectric constant* ($\varepsilon_r = 4.4$) *and loss tangent* ($\delta = 0.02$)*. Since our overall structure is complicated, we use the HFSS simulator.*

Keyword: (*CID) CPW, (CRLH) CPW, HFSS, Metamaterial, Microwave, Stub*

1. INTRODUCTION

Previously, left-handed metamaterials [1], whose permittivity and permeability are both negative [2-3] , have been a great topic for microwave and millimeter-wave societies due to their unusual unique phenomena which cannot be seen in nature, such as backward wave propagations, refractions with a negative refractive index [4], and generation of surface plasmon.

The composite line "Right / Left Handed", often noted (CRLH), is a line that includes both the elements of the Right handed (RH) and Left handed (LH) lines. This line represents the real case of the combined propagation (right / left) and can represent by a quadrupole that has an elementary length [5].

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The coplanar Right / Left handed (CRLH) CPW line represents the basic tool in the design and realization of microwave circuits [6]. The basic cell of such a line (CRLH) CPW is composed by discontinuous coplanar lines; these discontinuities can realize open circuits and also short circuits. Generally, an open circuit is of capacitive nature and the short circuit is of inductive nature (for a series-parallel connection) respectively.

In this article, we will represent a parametric study of the electromagnetic characteristics of the Right / Left handed (CRLH) CPW line. This study is based on the primary parameters of the (CRLH) CPW, in particular the dispersion parameters. In the design methodology, we will associate a (CID) CPW of five (05) fingers with a parallel inductance of two shunted stubs at the upper ground plane.

The etching of each device will be on the upper plane of the selected substrate which is the FR_Epoxy. Several geometric dimensions of each device (CID and parallel inductance) have been proposed to have our parametric study.

2. THE (CRLH) CPW ANALYSIS

2.1 The (CID) CPW design

2.1.1 Description of the Proposed (CID) CPW

The interdigital capacity is a planar structure of which can contain N thin parallel conductive bands, these bands are often called "fingers" and alternately connected to one or the other of the two bands, of total length W, which are perpendicular to them. The whole elements are deposited on the upper face of a dielectric substrate.

The first calculation of this kind of capacity proposed by Gary. Alley [7] showed values of (CID) CPW commonly of the order of 0.1 to 15 pF, but these calculations are valid only if the thickness of the dielectric is sufficiently important (>1mm). The interdigital capacity (CID) CPW is represented by the Figure 1.

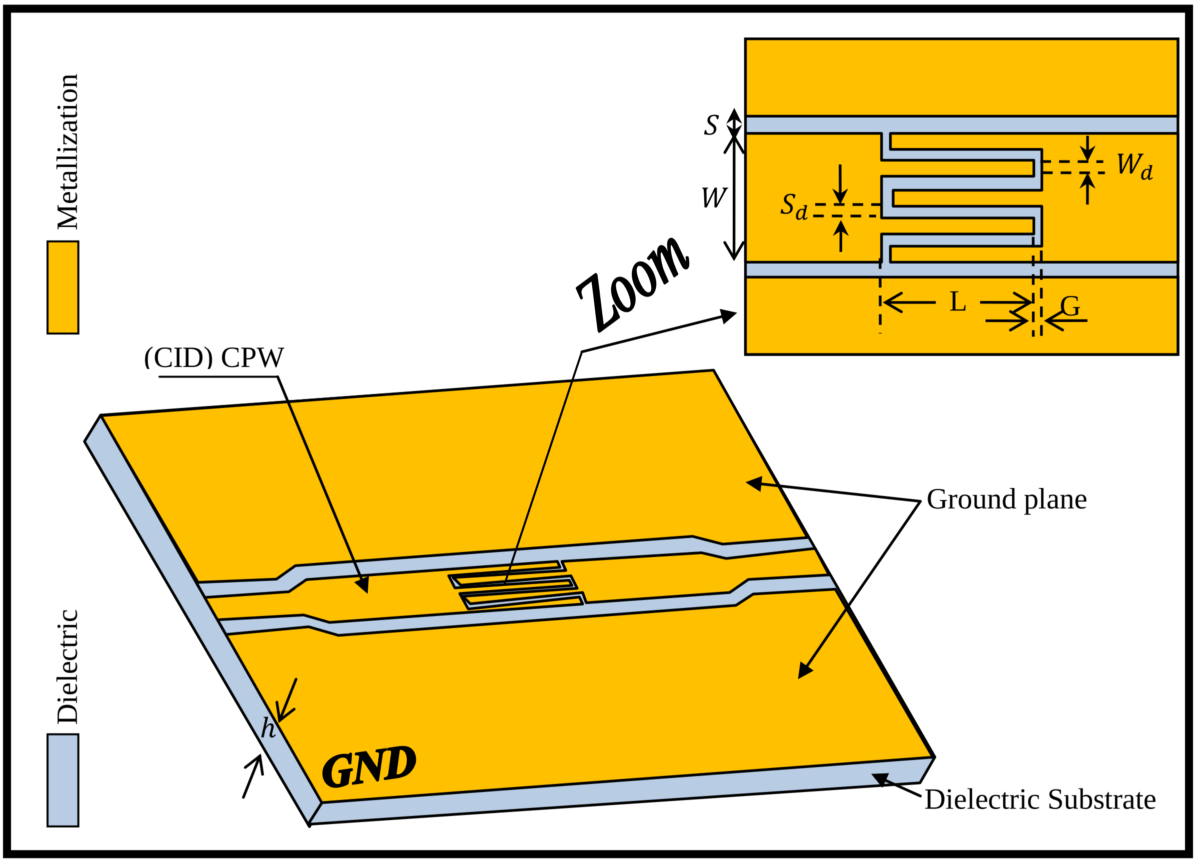

Figure 1 Representation of the (CID) CPW.

In Figure 1, we have indicated the geometric parameters of the (CID) CPW, with:W= total width of the (CID) CPW, S = width of the slot, L = finger length, G = gap width at the end of each finger, w_d = finger width. s_d = spacing between the fingers and metallization respectively.

2.1.2 Equivalent electrical circuit

The equivalent electrical circuit of the (CID) CPW is represented by two capacitances C_{p1} and C_{p1} which are parallel parasitic capacitances. The circuit contains another capacity series which is C_s. Several calculation models to determine the value of the (CID) CPW,

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have been proposed in various researches. These calculations differ from one another according to the nature of the geometrical parameters of the structure, in particular the two parameters (h, t). The equivalent electrical circuit of the (CID) CPW is represented by Figure 2.

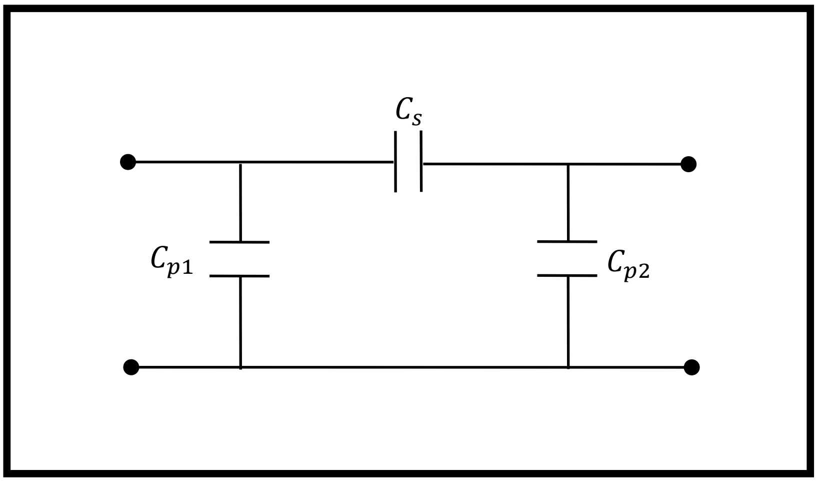

Figure 2 Equivalent electrical schema of the (CID) CPW.

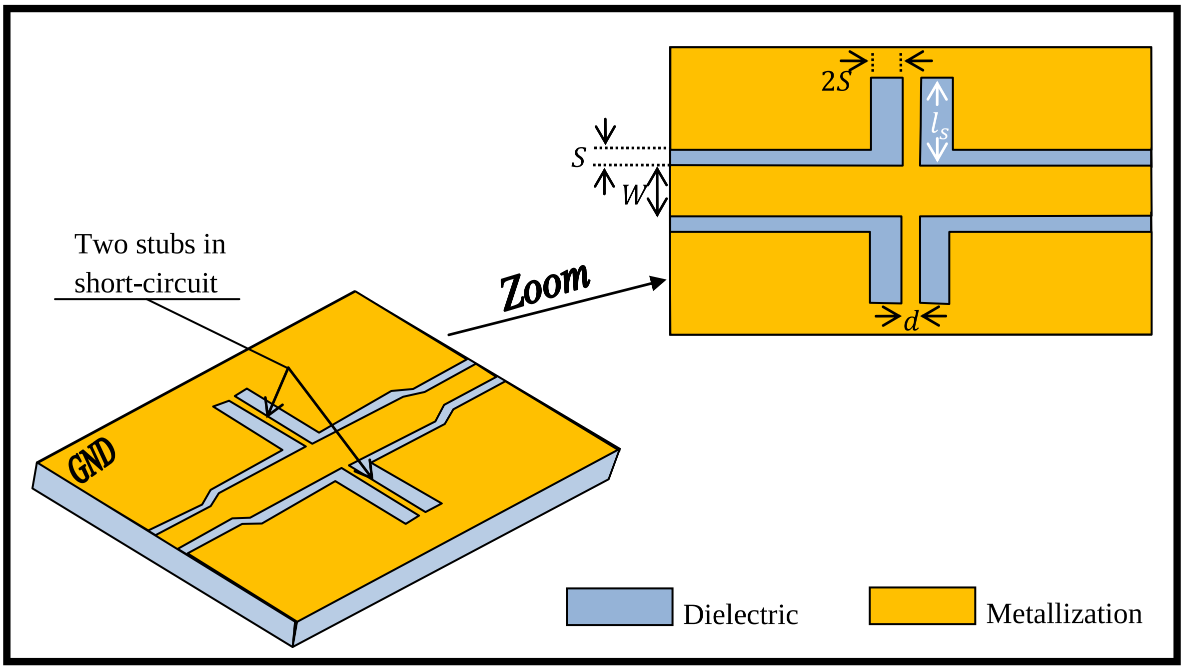

Figure 3 Representation of parallel CPW inductance.

For a metallization of thickness that is t, Spartak. Gevorgian has defined the effective width of the fingers by [8].

$$w_{deff} = w_d + \frac{t}{\pi}\left[1 + ln\left(\frac{4\pi w_d}{t}\right)\right] \quad (1)$$

The values of the series and parallel capacities are given by the following relation.

$$\begin{cases} C_s = \frac{2}{j\omega}\left[\frac{S_{21}}{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}\right] \\ C_p = \frac{1}{j\omega}\left[\frac{(1+S_{11})(1-S_{22}) + S_{21}(S_{12}-2)}{(1+S_{11})(1+S_{22}) - S_{12}S_{21}}\right] \end{cases} \quad (2)$$

2.2 Parallel inductance design

2.2.1 Description of the proposed shunt inductance

Inductive discontinuities are usually obtained from short-circuited stubs at the ground planes. Parallel coplanar inductances are realized from these stubs in association with strip conductors. Figure 3 shows a parallel coplanar inductance.

2.2.2 Equivalent electrical circuit

The equivalent electrical circuit of the parallel CPW inductance is represented by two series inductors L_s and another parallel inductance which is

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L_p. The inductance L_p of the parallel branch can be determined by two approximate Equations [9, 10].

$$\begin{cases} L_p = l_s\left[\ln\left(\frac{2\pi l_s}{d}\right) - 1 + \frac{d}{\pi l_s}\right] \\ L_p = l_s\left[\ln\left(\frac{1+\sqrt{1+\theta^2}}{\theta}\right) + \theta - \sqrt{1+\theta^2}\right] \end{cases} \quad (3)$$

With: $= d/4l_s$, the series inductance L_s increases proportionally as a function of the width of the stub [11]. The values of the two inductances are given by the following Equations.

$$\begin{cases} L_p = \frac{2}{j\omega}\left[\frac{S_{12}}{(1-S_{11})(1-S_{22}) - S_{12}S_{21}}\right] \\ L_s = \frac{S_{12}}{j\omega S_{21}}\left[\frac{(1+S_{11})(1-S_{22}) + S_{21}(S_{12}-2)}{(1-S_{11})(1-S_{22}) - S_{12}S_{21}}\right] \end{cases} \quad (4)$$

The equivalent electrical circuit of the parallel induce CPW is shown in Figure 4.

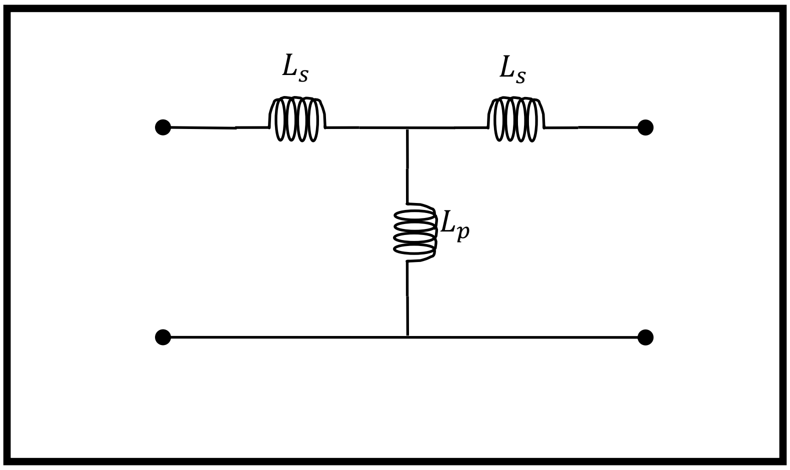

Figure 4 Equivalent electrical schema of the parallel CPW inductance.

2.3 (CRLH) CPW modeling

The design of a (CRLH) coplanar line can articulate on several parameters (geometric and physical). In our design, the most important factor in these parameters is the nature of the substrates that is dielectric. For geometric parameters, we can perform several simulations if we vary these various parameters, but in our case, we will vary only two parameters which are the length (l_c) of the cell (CRLH) CPW and the length of the shorted stubs (l_s).

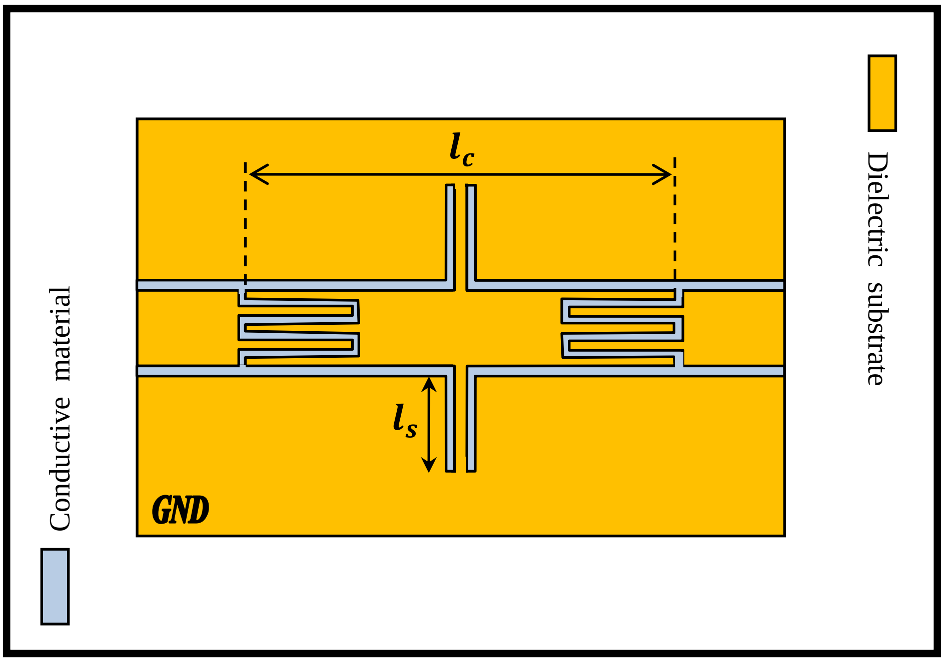

Figure 5 Basic Cell for (CRLH) CPW line.

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3. SIMULATION RESULTS

3.1 (CID) CPW simulation

The most important parameter for the study of (CID) CPW is the parameter L which represents the length of the fingers. For the simulation of our (CID) CPW, we will choose three cells of the same number of fingers (N=5), the same substrate of FR_Epoxy (h = 0.8 mm) and thickness of the conductor ($t = 5\ \mu m$), but for different values of L. We will keep the same value for the gap (G = 100µm). The characteristics of the three interdigital capacities to be simulated are summarized in Table I.

TABLE I DIMENSIONS OF THE THREE INTERDIGITAL CAPACITANCES

(CID) CPW	*W (mm)*	*S (mm)*	*L (mm)*	s_d *(mm)*	w_d *(mm)*
(CID) 1	0.9	0.3	1.5	0.1	0.1
(CID) 2	0.9	0.3	2.0	0.1	0.1
(CID) 3	0.9	0.3	2.5	0.1	0.1

One of the three proposed interdigital capacitances (for a finger length that is 2.5mm for example) can be represented by Figure 6.

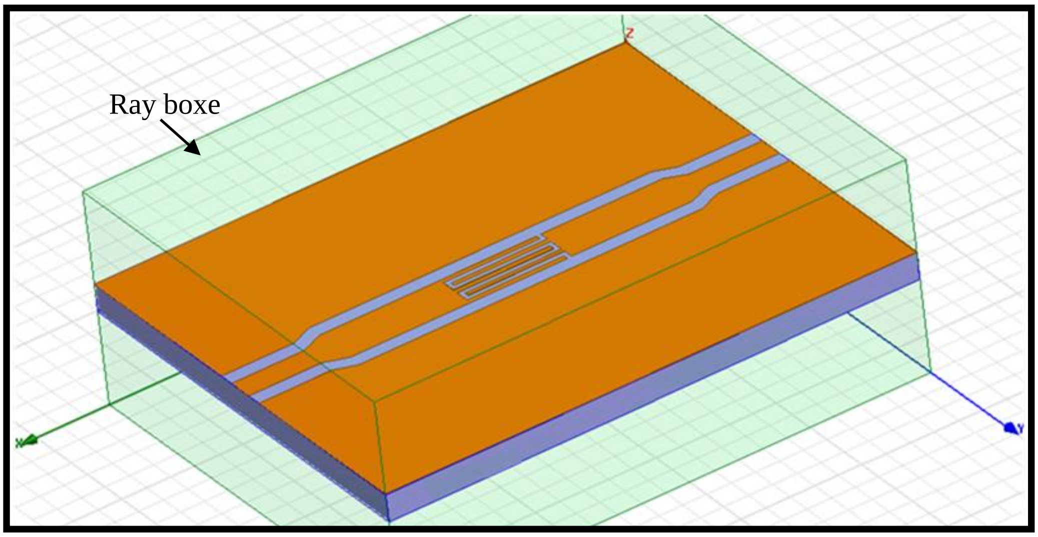

Figure 6 (CID) CPW for 5 fingers.

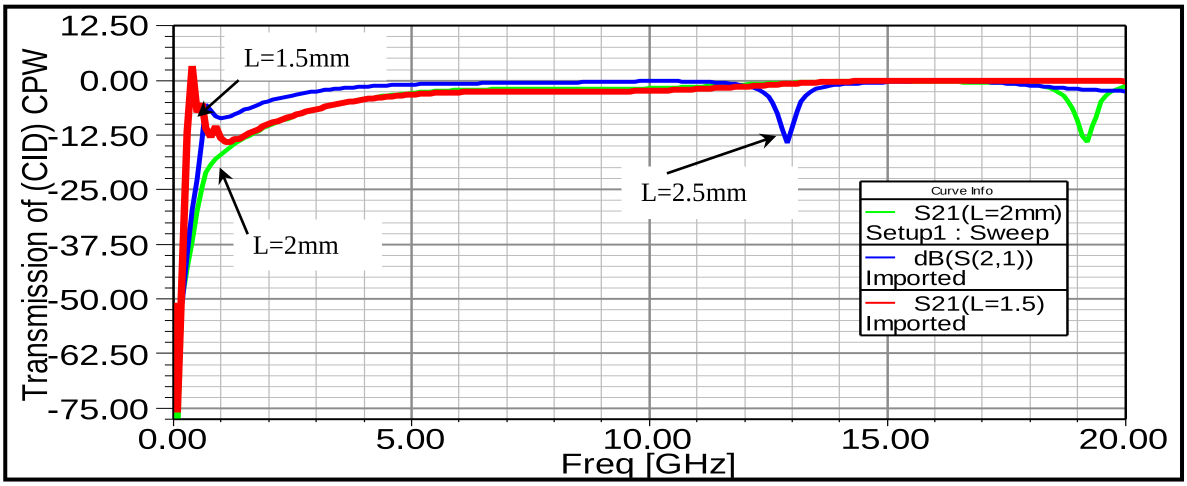

Figure 7 Transmission coefficients for the three (CID) CPW.

Figure 7 shows the transmission of our (CID) CPW for the three finger lengths. Figure 7 shows the transmission coefficients for the three interdigital capacitances, according to the three values of the fingers length, it is noted that the coefficients S_{21} are proportional to these lengths (L). Always, from the formula

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(2) we can deduce the value of the capacity (CID) CPW which is (C_s). On the HFSS simulator, the various values of the capacitance Cs can be visualized for the two values of the fingers length (L = 1.5mm and L = 2.5mm). Figure 8 below shows these values of the (CID) CPW.

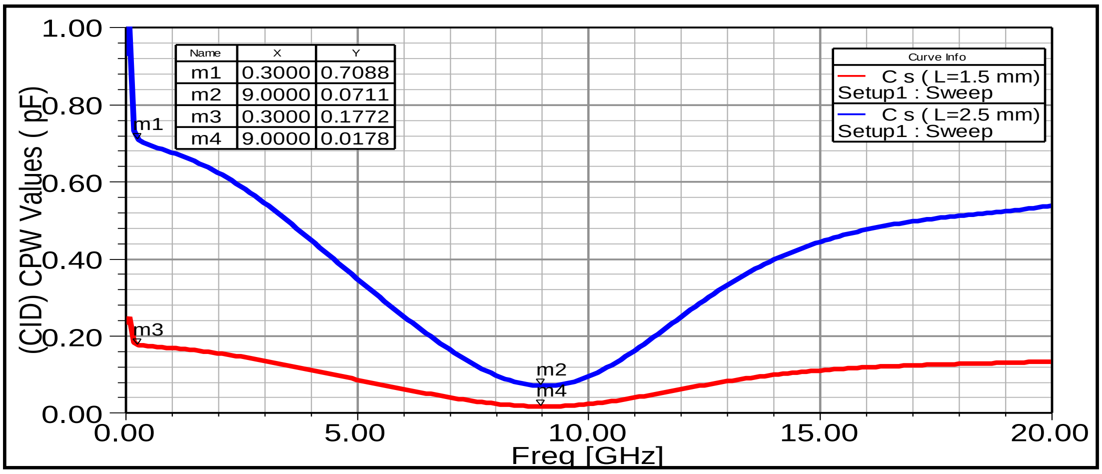

Figure 8 (CID) CPW values.

Figure 8 shows the two values of each capacity (CID) CPW for (L=1.5mm et L=2.5mm). For the first length of the finger (L=1.5mm) we can notice that the value of Cs varies between 0.017pF and 0.177 pF. For the second length (L=2.5mm), the values of the capacity are between 0.071pF and 0.708pF. So, we notice that the value of the (CID) CPW capacity increases as the length of the fingers increases.

3.2 Simulation of the parallel CPW inductance

The study of parallel CPW inductances can also articulate on various parameters such as (W, S, h, d, t), but the most important parameter in the various studies of this type of inductance is the parameter l_s which represents the length of the shunted stubs.

For our simulation, we will choose three CPW inductance cells different from each other (according to l_s values). We kept the same width of the stubs (d =0.2mm) for the same substrate. The characteristics of the three CPW inductances to be simulated are summarized in Table II.

TABLE II DIMENSIONS OF THE THREE INDUCTANTES

Inductance CPW	*W(mm)*	*S (mm)*	*ls(mm)*
CPW 1	0.8	0.2	1.2
CPW 2	0.8	0.2	1.5
CPW 3	0.8	0.2	1.8

The parallel CPW inductance is shunted to the ground planes by the two stubs of identical lengths (ls). One of the three proposed inductors (for a length of stubs which is 1.5 mm for example) can be represented by Figure 9.

After applying the boundary conditions on our structure, the three [S] parameter responses for the three lengths of the proposed stubs can be represented by Figure 10.

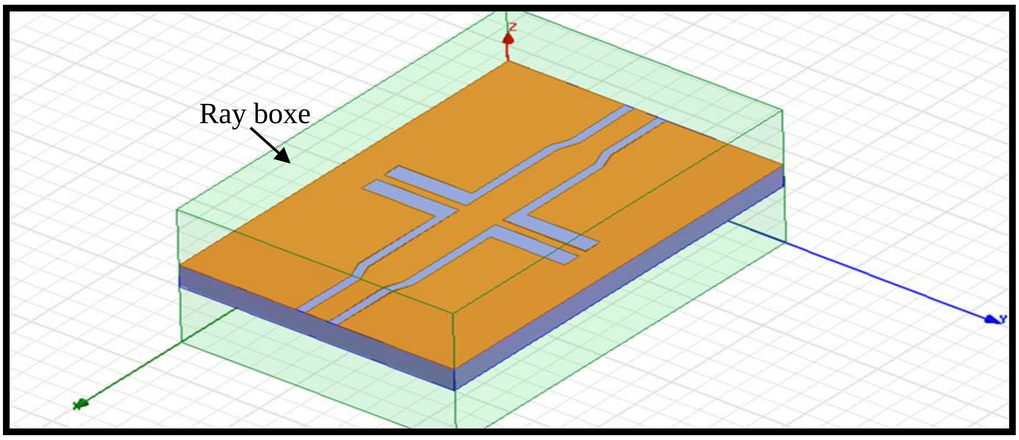

Figure 9 Inductance parallèle à stubs court-circuités (ls =1.5mm).

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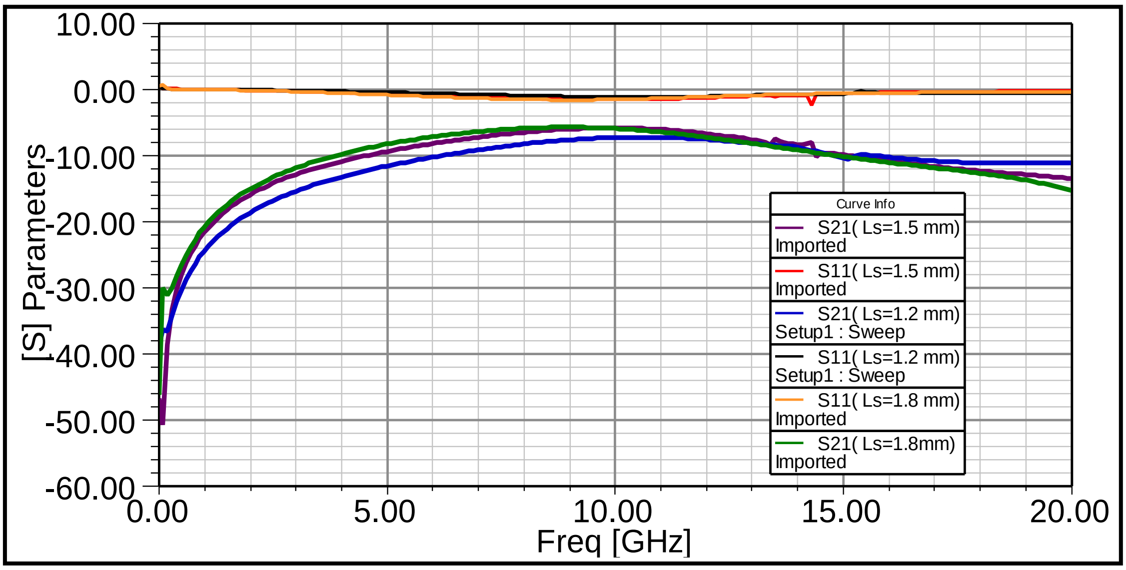

Figure 10 [S] parameters for shunt inductances.

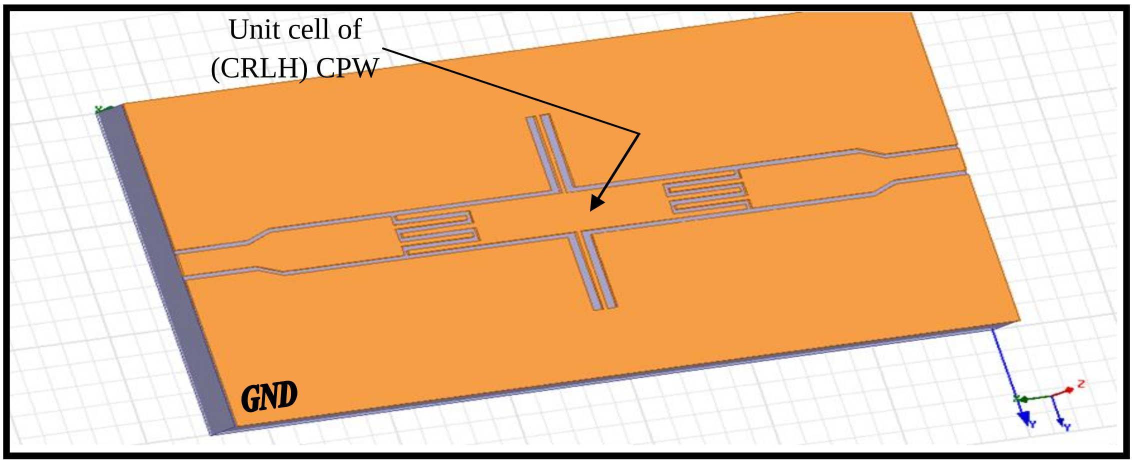

Figure 11 Unit cell of (CRLH) CPW on HFSS 3-D Modeler..

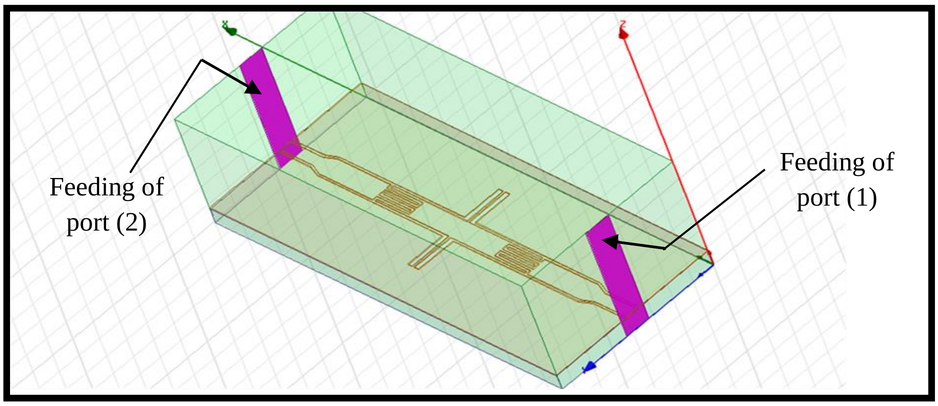

Figure 12 Port excitation procedure for (CRLH) CPW .

Figure 10 shows the transmission and reflection coefficients for the three parallel inductances according to the three values of the length of the stubs. We notice that the coefficients S_{11} and S_{21} are proportional to the length (*ls*).

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3.3 Simulation of (CRLH) CPW

It is proposed to simulate a line (CRLH) CPW composed of an interdigital capacity (CID) CPW and a parallel CPW inductor. The dimensions of this structure (for two values of *ls* and *lc*) and for (W=0.5 mm) are summarized in Table III.

TABLE III DIMENSIONS OF THE TWO (CRLH) CPW

CRLH	CRLH1	CRLH2
L(mm)	1.5	1.5
S(mm)	0.1	0.1
G(mm)	0.1	0.1
l_s *(mm)*	1.8	1.5
l_c *(mm)*	7	9
d(mm)	0.1	0.1

We choose different lengths for (CRLH1) CPW and (CRLH2) CPW. The first (CRLH1) CPW line is represented on the HFSS 3-Modeler by Figure 11. The reflection and transmission coefficients are shown in Figure 13.

Figure 13 shows the reflection and transmission coefficients of the (CRLH) CPW line composed of an interdigital capacitance (CID) CPW and a parallel CPW inductance. We can notice that for each configuration, there are three propagation regions (Left hand propagation LH, Electromagnetic bandgap EBG and Right hand propagation RH). Table IV shows the three regions according to the frequency variation. The electromagnetic characteristics of our (CRLH) CPW cell can be summarized in the dispersion diagram shown in Figure 14.

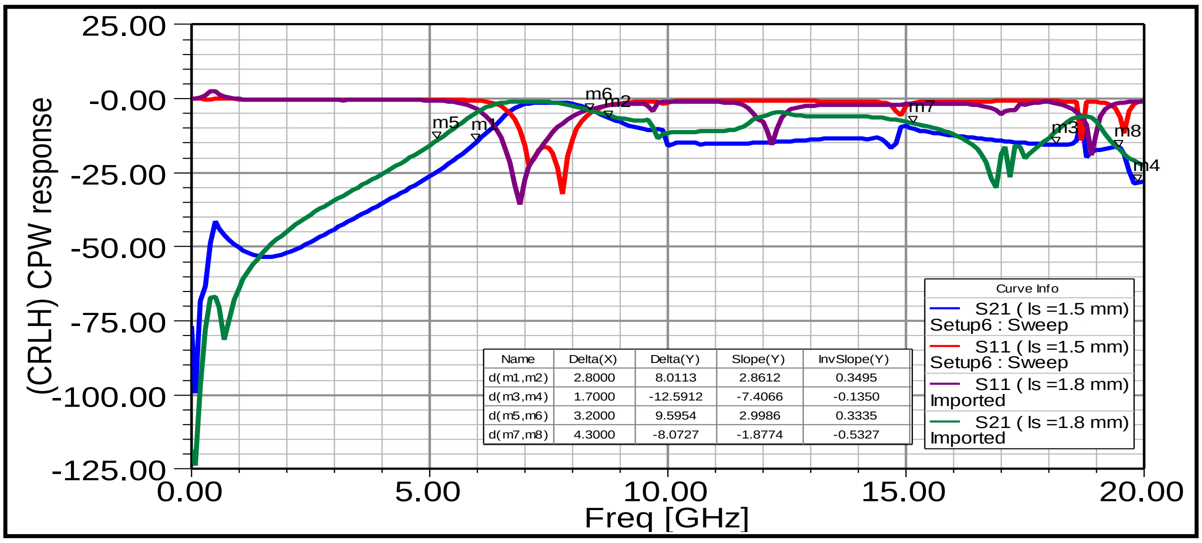

Figure 13 [S] parameters for the first (CRLH) CPW.

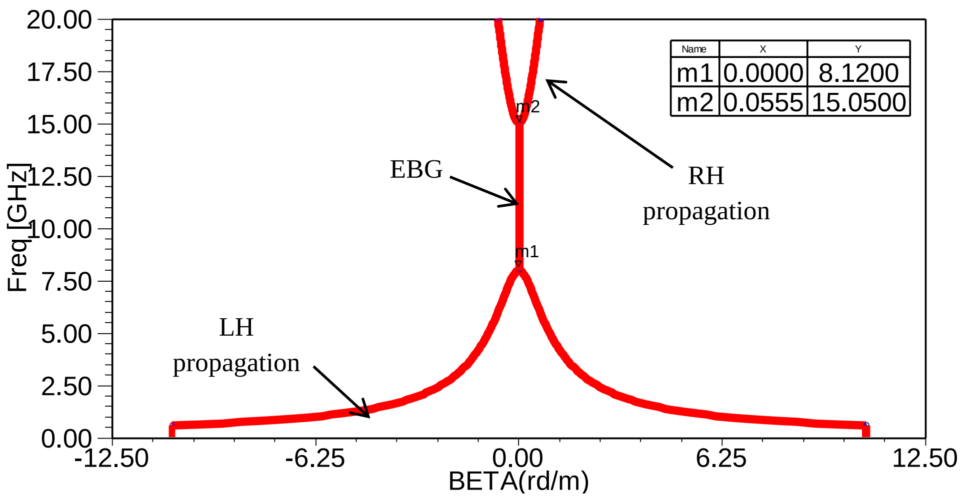

Figure 14 Dispersion diagram of the (CRLH1) CPW.

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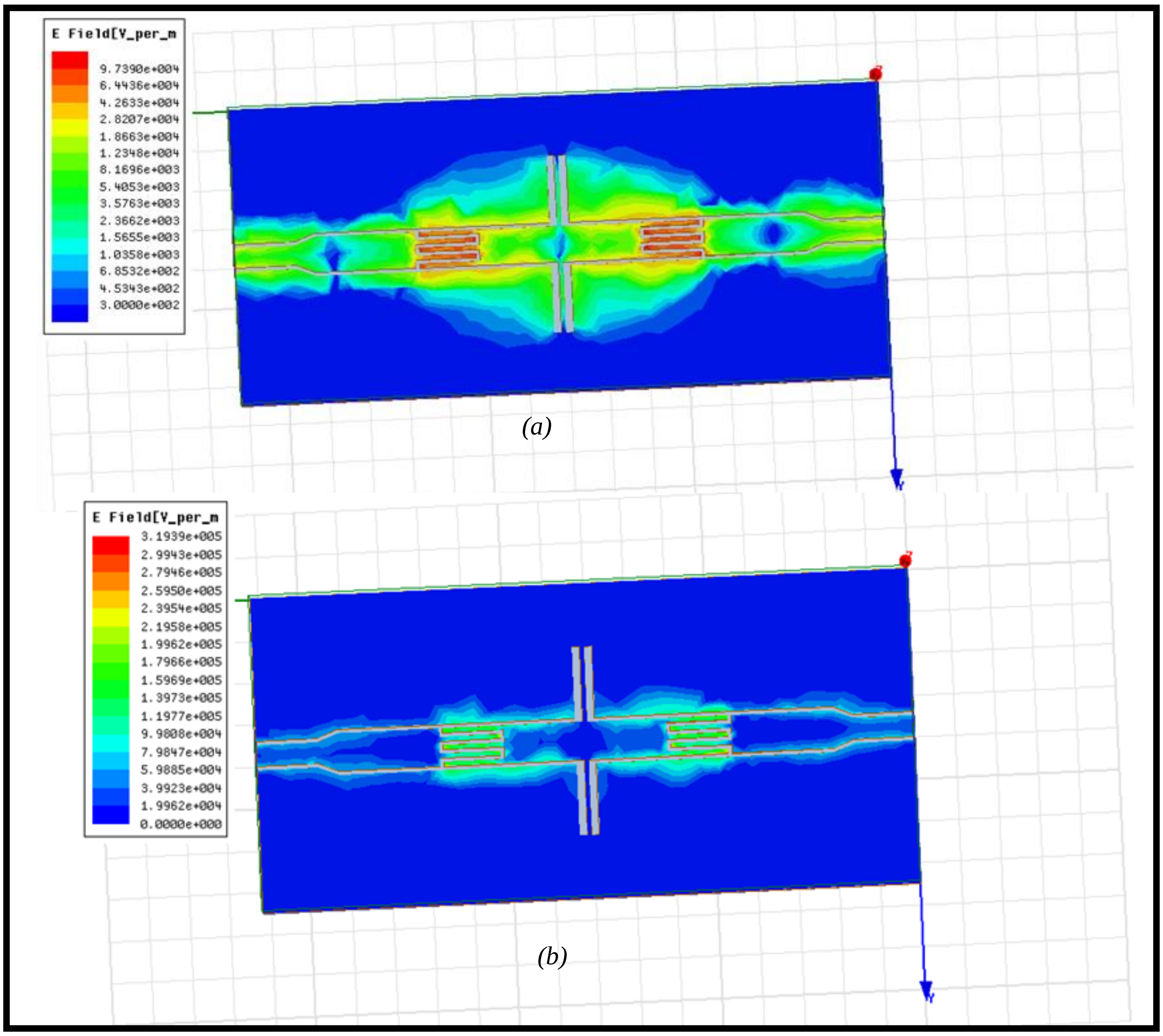

Figure 15 Electric field distributions on the (CRLH1) CPW line, (a) at 8.12 GHz, (b) at 15.05 GHz.

TABLE IV PROPAGATION REGIONS OF (CRLH) CPW

Région(GHz) / CRLH	LH	EBG	RH
CRLH1 (*lc* = 7*mm*)	3.4	6.7	4.4
CRLH2 (*lc* = 9*mm*)	2.8	9.2	1.7

Figure 14 shows the dispersion diagram of the co-planar (CRLH1) line composed of an interdigital capacitance and a parallel CPW inductance. We note that there are also three propagation regions inside the (CRLH) CPW cell, the LH region ($\beta < 0$), the RH region ($\beta > 0$) and the frequency region [8.12 -15.05] GHz which represents the EBG. The distribution of the electric field on our transmission line outside the EBG band is represented by Figure 15.

In Figure 15, we note that on the line (CRLH1) CPW, the electric field is more condensed between the fingers of the (CID) CPW at the first resonance, which justifies the capacitive effect of the overall structure. At the second resonance, we can say that the electric field is distributed slightly over the whole structure (with larger values near the fingers of the (CID) CPW always).

4. CONCLUSION

A composite (CRLH) CPW line is studied for co-planar technology in this work. A combination of an interdigital capacity (CID) CPW which have five fingers and a parallel inductance for two shunted stubs at ground plane allowed us to obtain our global (CRLH) CPW transmission line. We have shown all the electromagnetic characteristics of our composite line from two cells of different geometric dimensions, so three propagation regions are envisaged for each cell which shows the new behavior of our transmission line based on left-handed (LH) metamaterials.

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The substrate used in our study is a soft substrate which is the FR_Epoxy. According to our results, we can say that our proposed structure can contribute to the design of several microwave circuits.

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