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An Electrical Equivalent Circuit of Slotted Metamaterial Antenna for Mobile Handsets

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Abstract- This paper presents the reactance component of the impedance of metamaterial antenna covering GSM, PCS, DCS and WIBRO. The equivalent circuit of antenna is drawn for the individual elements of the antenna pattern of the design. The input impedance, reflection coefficient and return loss are presented. The response of the reactance shows the resonant frequency.
Key words: Metamaterial, equivalent circuit, impedance, S-SRR, CRLH and slot.

Introduction:

Structure: The prototype is having meander structure printed on both sides with CRLH-TL, S-SRRs. The antenna of size, $40 \times 60 \times 0.762$ mm^3, with a printed type on a substrate of RT Duroid 5880LZ (ε_r=2.2) and edge feeding and slots of different sizes are introduced in it to increase the number resonant frequencies. However, to achieve the multi-band response, slots with unequal dimensions are introduced. Slot with dimensions 14 mm is introduced in 24.75mm patch and the other slot of 6mm is introduced on the 11.5mm patch as shown in Fig 1. These slots are so placed in the patches, so as to give good resonance characteristics [1]. The combination of patches with slots and SRRs achieve high magnetic coupling at resonance. The presence of the rings leads to an effective negative-valued permeability in a narrow band at resonance. Mechanical etching was used for the antenna. This dimensional variation in turn makes antennas to resonate with different central frequencies. Analytically 'equivalent' antenna is determined for the prototype.

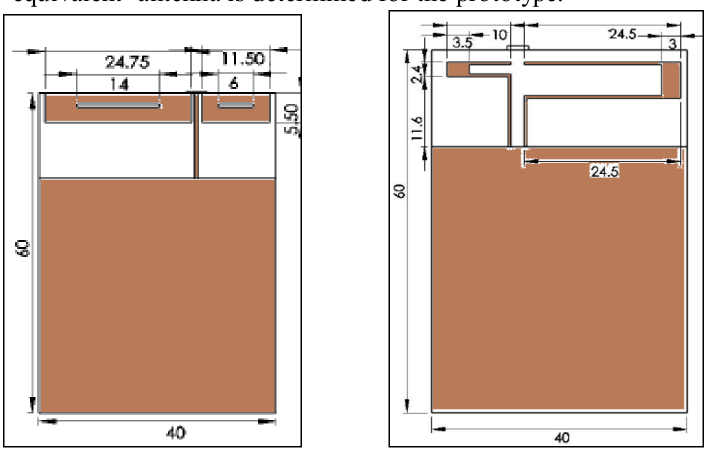

Fig 1 Front and back views of Antenna

Related Work

Photograph of fabricated Antenna with slot:

Fig 2 Photograph of the Antenna

The metamaterial transmission line allows the existence of backward waves, in other words, negative propagation constants. Thus, two different frequencies can have the same propagation constant (in the sense of absolute value) through this dispersion relation. As a consequence, the same mode and current distribution are achieved in the two different frequency bands. This property is utilized in this work to design a dual band antenna, where Zc is the characteristic impedance of the feeding line. In order to have the ring resonate at another frequency f2, it can be written as following based on the negative propagation constant of the CRLH transmission line:

$$Zc = \sqrt{\frac{L_R'}{C_R'}} = \sqrt{\frac{L_L'}{C_L'}} \quad (1)$$

$$\omega_{r1}, \omega_{r2} = \frac{1}{\sqrt{L_R C_L}}, \frac{1}{\sqrt{L_L C_R}} \quad (2)$$

$$\beta_2 = -\frac{2\pi}{L} = \omega_2\sqrt{C_R' L_R'} - \frac{1}{\omega_2\sqrt{L_L' C_L'}} \quad (3)$$

The minus sign indicates that the CRLH transmission line is supporting a backward wave at the second frequency f_2. It's clear that the propagation constants at these two frequencies

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have the opposite signs but the same absolute values. Thus, the current distributions at these two frequencies are the same. It consists of the CRLH transmission line in which the series inductance and capacitance and shunt inductance and capacitance exist and resonate for two frequencies named f_L and f_H . The antenna, on the other hand, in fact, on its other side of PCB, has ring resonators, which also resonate at f_L. The patch on the side which has transmission line resonates in both frequencies. The resonant frequency of the prototype antenna is 1.9 GHz and 4 GHz. These two frequencies represent the low and high frequencies of CRLH which are the resonant frequencies of SRR and complement wires on the other side of PCB antenna. The values of the inductance and capacitance of equivalent circuit are derived from the MURTA CHIPS DATABASE. The equivalence in terms of circuits gives the input impedance of the antenna, which is to be analyzed in the MATLAB. The circuit represents the current flow from source to ground. Analytical analysis deals with the equivalent circuit of an antenna. The equivalent circuit of individual components, SRR, CRLH and patch with slot are shown in Fig1. The input impedance, reflection coefficient and return loss have been computed and expressions are given below. Design consists of unsymmetrical cells with combination of different sized patches to resonate in the frequency range mobile applications. Considering with the 'equivalence' of individual elements, for all the main elements including CRLH, S-SRR, and PATCH with slot of the prototype having slots on one side, the equivalent circuit of an antenna is drawn. The input impedance for analysis is derived from the overall circuit according to current from feed point to ground. The reactance component of input impedance is then plotted to obtain the resonating frequency. The individual parts of antenna are considered and their circuit equivalent is presented to derive the overall impedance of the circuit, as shown in Fig 3. The CRLH TL, radiating patches and SRRs were the main elements to promote the radiation. The circuit is connected with the above mentioned elements according to Fig 4 to derive the impedance.

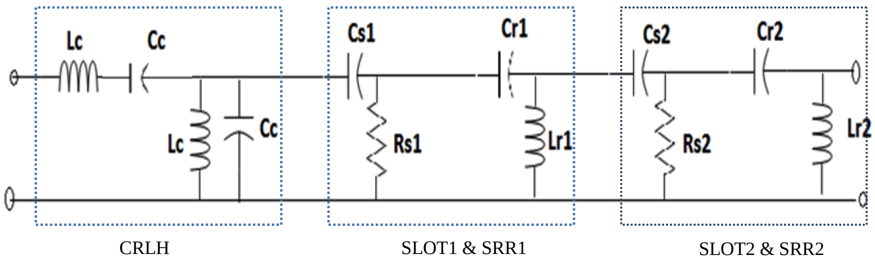

Fig 3 Over all Equivalent Circuit

The CRLH-TL is basically the combination of conventional and dual of conventional transmission line. Examples are series inter-digital capacitors and shunt stub inductors, which are introduced in a microstrip transmission line, as by a nonlinear equation mentioned in Eq3 where β is the propagation constant, ω is the angular frequency, and L_R, C_R, L_L, C_L are characteristic inductances and capacitances of the CRLH transmission line. The characteristic inductances and capacitances, L_R, C_R, L_L, C_L are equal to L_C, C_C, L_C, C_C respectively as shown in Fig 3. The resonant frequency is given by the equations Eqn1 and Eqn3.

Input Impedance

The equivalent circuit of an antenna is drawn considering all the main elements of the prototype having slots on one side. The input impedance is derived from the overall circuit according to current from feed point to ground. The reactance component of input impedance is then plotted to observe the resonating frequency. The input impedance equation is represented in terms of S, where is S = jω.

The impedance of the antenna equivalent is calculated or derived by above cited equations and the reflection coefficient is related to the input impedance as

$$\Gamma = \frac{Z_{in} - Z_o}{Z_{in} - Z_o} \qquad (5)$$

The response of the (i) input impedance (reactance) (ii) reflection coefficient and (iii) return loss is obtained for the frequency range from1GHz to 5GHz. It may be noted that metamaterial concepts like CRLH were proposed and applied for enhancement of antenna characteristics. They are basically the dual of traditional transmission lines and follow the same analysis as that for the conventional transmission line. Substituting the equation Eqn 4 in the Eqn 5, the reflection coefficient is obtained.

Equation 7 gives the reflection Coefficient for the antenna. Return Loss can be determined by substituting Eqn 7 in the Eqn 6.The return loss can also calculated by the relation as

$$S_{11} = \frac{1}{1-\Gamma} \qquad (7)$$

$$Z_{11} = \frac{50\times10^{-94}s^9 + 12.5\times10^{-80}s^8 + 99.5\times10^{-75}s^7 + 5.23\times10^{-54}s^6 + 17.4\times10^{-54}s^5 + 2.4\times10^{-24}s^4 + 2.4\times10^{-33}s^3 + 2.16\times10^{-21}s^2 + 13.2\times10^{-12}s + 1}{49.8\times10^{-85}s^8 + 12.4\times10^{-73}s^7 + 17.4\times10^{-45}s^6 + 2.4\times10^{-45}s^5 + 17.4\times10^{-45}s^4 + 6.42\times10^{-30}s^3 + 14.3\times10^{-24}s^2 + 1.08\times10^{-12}s} \qquad (4)$$

$$\Gamma = \frac{50\times10^{-94}s^9 + 12.5\times10^{-80}s^8 + 99.5\times10^{-75}s^7 + 5.23\times10^{-54}s^6 + 17.4\times10^{-54}s^5 + 2.4\times10^{-24}s^4 + 2.4\times10^{-33}s^3 + 2.16\times10^{-21}s^2 + 13.2\times10^{-12}s + 1 - 50}{49.8\times10^{-85}s^8 + 12.4\times10^{-73}s^7 + 17.4\times10^{-45}s^6 + 2.4\times10^{-45}s^5 + 17.4\times10^{-45}s^4 + 6.42\times10^{-30}s^3 + 14.3\times10^{-24}s^2 + 1.08\times10^{-12}s + 50} \qquad (6)$$

$$S_{11} = \frac{49.8\times10^{-85}s^8 + 12.4\times10^{-73}s^7 + 17.4\times10^{-45}s^6 + 2.4\times10^{-45}s^5 + 17.4\times10^{-45}s^4 + 6.42\times10^{-30}s^3 + 14.3\times10^{-24}s^2 + 1.08\times10^{-12}s + 50}{-50\times10^{-94}s^9 - 12.5\times10^{-80}s^8 + 12.4\times10^{-73}s^7 + 17.4\times10^{-45}s^6 + 2.4\times10^{-45}s^5 - 2.4\times10^{-24}s^4 + 6.42\times10^{-30}s^3 - 2.16\times10^{-21}s^2 + 11.2\times10^{-12}s + 99} \qquad (8)$$

The return loss of the antenna is given by the Eqn 8.
The response for the (i) input impedance (reactance) (ii) reflection coefficient and (iii) return loss S_{11} are obtained and analyzed. The standard set of equations for conversion between VSWR, return loss, and reflection coefficient (Γ) are also used for the purpose. Analytical equivalent of the antenna is determined by the equivalence of individual elements. The main elements include CRLH, S-SRR and PATCH with slot. The input impedance is derived from the overall circuit according to current flow from the feed point to ground. The reactance component of input impedance is then plotted to observe the resonating frequency.

Input Impedance of Antenna

The graph for input impedance for the antenna prototype, shown in Fig 5, is obtained from the MATLAB code after considering the individual values of components of the antenna prototype. This graph shows the reactive term of the input impedance [2] [4].

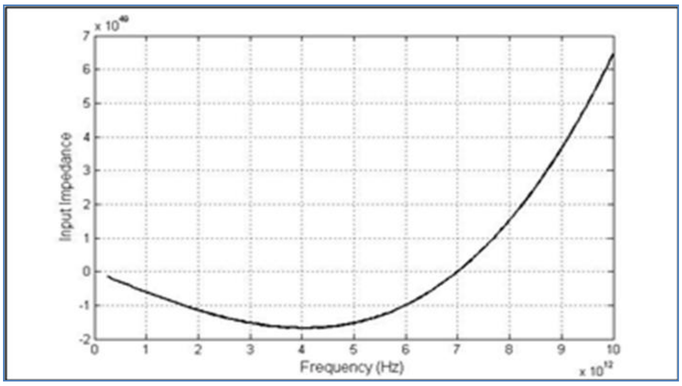

Fig 5 Input Impedance of the Antenna

The input impedance value is derived from equation 4, considering the individual 'nutshells' of the antenna equivalent considering CRLH, SRR and Patch, with the slot on the either side of the two sided prototype antenna. The order of the nutshells of antenna indicates the current flow from source to sink. From this graph, it is seen that the reactance crosses exactly at frequency value of 1.9 GHz, that is, the resonant frequency value that has already been obtained from Fig 5. The result is also similar to the result presented in the paper [3].

Table 4. 1 BW of Antenna on RT Duroid and with slot

S_{11}	BW1 (GHz)	BW2 (GHz)	BW3 (GHz)	BW4 (GHz)
simulated	1.6-2.05	2.3-2.45	3.3-3.4	4.4-4.5
Tested	1.6-2.05	2.35-2.5	3.4-3.5	4.45-4.6
Center frequency	1.9	2.4	3.35	4.462

The comparison between simulated and tested values of return loss at four resonances of the antenna is presented in Fig 6.

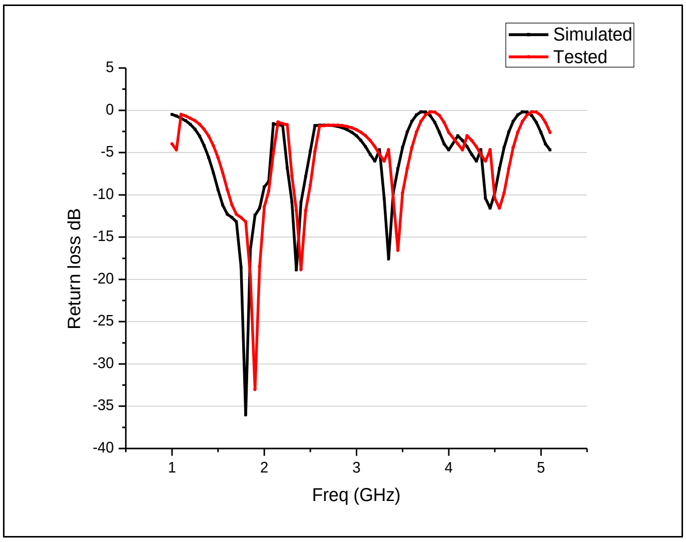

Fig 6 Return loss of Antenna

Conclusion

Reactance component of the proposed antenna is presented by considering the equivalent circuit. The reactance response of mobile handset antenna is in agreement with the return loss response at 1.9 GHz. The reactance equivalent derived is used to control the frequency response of the proposed antenna.

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