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Numerical analysis of the concentric ring number for electric field sensing with a Split-Ring Resonator metamaterial

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Abstract. Wireless communications have experienced a tremendous development during the last decade. The interaction of the electromagnetic waves as a function of the frequency and intensity with physical objects remains largely unknown. This poses the challenge to study the physical mechanisms involved to actually quantify the impact of the interaction with other objects caused by various electromagnetic waves-emitting sources. Here, we proposed the design of a plane SRR (Split-Ring Resonator) with metamaterial circular rings for S-Band frequency range. To guide the construction of the SRR prototype, simulations of the bandwidth were conducted using the Finite Integral technique. A logarithmic function describes the dependence of the simulated resonant frequency. The maximum simulated bandwidth of the SRR can be reached with an even number of concentric rings.

1.Introduction

Metamaterials with electrical negative indexes have had a great impact in the field of optics and electromagnetism [1]. These artificially metal-dielectric composites with periodic structures whose maximum dimension is less than the wavelength of interest have had a major impact in communications systems. In particular, the development of miniaturized antennas to improve the directivity, radiation pattern and efficiency has gained a great deal of interest due to the growing demand of more efficient communications systems. Multiband antennas can be designed with different structures such as the Split Ring Resonators (SRR) [2-5]. The experimental development of this type of antennas has been not fully investigated. In this paper, a metamaterial effect was obtained using a pair of concentric circles having a slot, one ring geometrically opposite to the other [6-7], and we studied the dependence of the number of concentric ring pairs for a flat SRR, the bandwidth and resonance frequency. The proposed design could be employed for electric field sensing in communications working in the S-Band (2-4GHz).

2.Methods and Results

A flat SRR metamaterial with circular rings was designed. This geometry minimizes the leakage currents caused by discontinuities at right angles. Figure 1 shows the schematics of an elementary structure. Table 1 summarizes the dimensions of the antenna prototype. The Finite integration technique (FIT) was used to simulate the S11-parameters with the Software Tool CST (CST Microwave Studio,

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Darmstadt, Germany). This software is able to determine the reflection coefficients based on a time domain solver, which obtains the frequency response due to a temporary stimulus. Table 1 data was also used for all electromagnetic simulations. Figure 2 shows the simulated S11-parameter for the resonance frequency as a function of the number of concentric ring pairs.

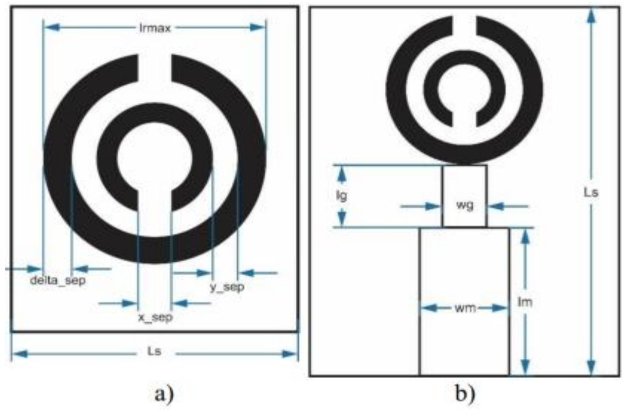

Figure 1. Design of the flat metamaterial SRR with circular rings. a) primary structure, b) current feeding microstrip.

Table 1. Physical characteristics of a flat metamaterial SRR used for the numerical analysis of finite integration in the time domain (FITD), and a FR4 substrate with an electrical permittivity ε_r=4.3.

Name	*[mm]*	Description
delta_sep	0.3	Separation of the track
h	2	Height of the substrate
lg	1.0	Length of the wave-guide
lm	5.0	Length of the Microstrip-line
lrmax	17.0	Length of the maximum radius
Ls	40.0	Length of the substrate
Mt	0.035	Thickness of the microstrip-line
wg	0.5	Width of the wave guide
wm	1.8	Width of the microstrip-line
x_sep	2.0	Separation of the split ring
y_sep	0.1	Separation between each pair of rings

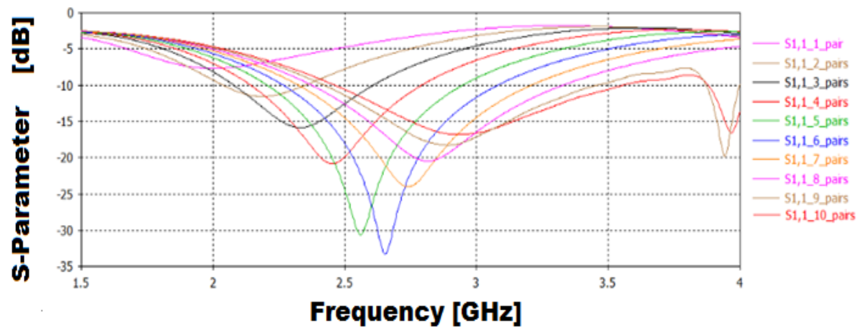

Figure 2. Attenuation plot of the resonance frequency as a function of the number of pairs of concentric rings.

From the Figure 2 data, it was obtained the S11 parameter, the bandwidth (BW) at 3 dB and summarized in Table 2. The dependence of the number of concentric ring pairs on the resonance frequency was plotted in Figure 3. Additionally, a plot of number of pairs of concentric rings vs**.** bandwidth is shown in Figure 4.

Table 2. Bandwidth calculation data for the number of concentric ring pairs tested.

Rings	F central [GHz]	S11 [dB]	F1 [GHz]	F2 [GHz]	BW [GHz]
1	1.9975	-8	1.6708	2.4647	0.7939
2	2.1875	-12	1.984	2.4166	0.4326
3	2.33	-16	2.1853	2.4834	0.2981
4	2.4525	-21	2.3843	2.5222	0.1379
5	2.56	-31	2.5375	2.5827	0.0452
6	2.6525	-33	2.6245	2.6824	0.0579
7	2.74	-24	2.6529	2.8289	0.176
8	2.815	-20	2.6569	2.9801	0.3232
9	2.89	-18	2.6707	3.1193	0.4486
10	2.93	-17	2.6922	3.2106	0.5184

It is noted that as the number of pairs of concentric rings (*Npac*) increases toward the inside of the maximum ring, the resonance frequency (*Fr*) increases up to a certain limit, presenting a logarithmic behavior that can be modeled by the following equation:

$$Fr = (0.4201)\ln(Npac) + 1.921 \quad Npac \in \{1,\ldots,10\} \qquad (1)$$

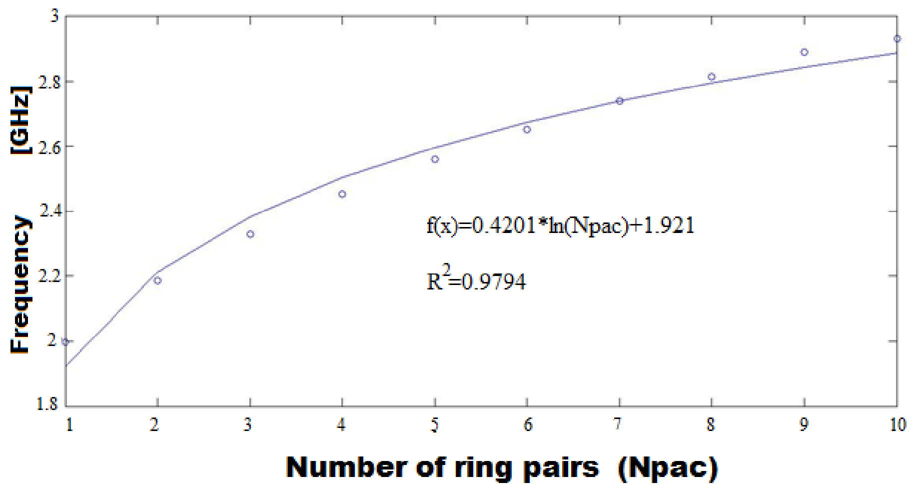

Figure 3. Relationship between the **Npac** with the**Fr**.

On the other hand, by increasing the *Npac*, the BW reaches its minimum value (ring pair 5), and after this value the BW increases again. Figure 4 shows a parabolic behavior for the simulated BW when the *Npac* is varied.

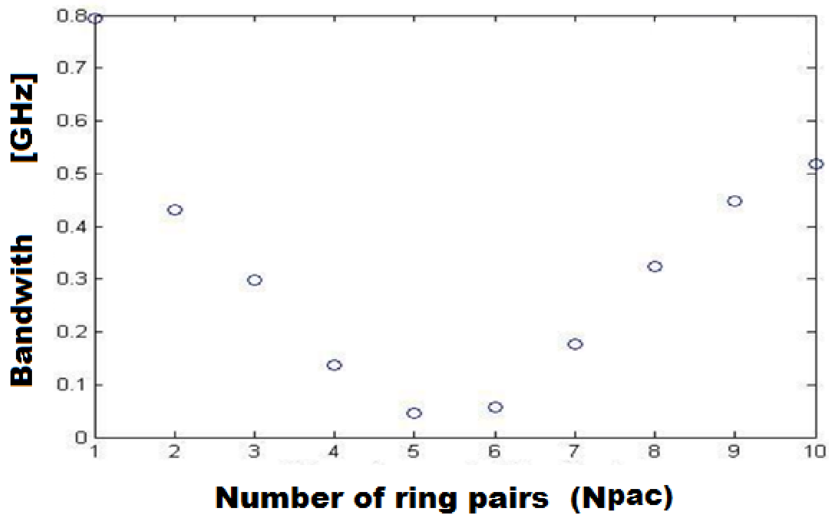

Figure 4. Relationship between the *Npac* and the simulated BW.

A symmetrical pattern can be appreciated indicating that the same BW can be achieved for different *Npac*. This also implies that a greater *Npac* is necessary to obtain a high BW, in the frequency of interest for electric field sensing**.**

3.Conclusions

The simulation results showed that the relation between the number of concentric rings and the resonance frequency of the SRR metamaterial with circular rings can be fitted to a logarithmic function. This allows us to compute the concentric ring number that must be added to a primary structure for a specific resonance frequency in the microwave band from 2 to 4 GHz, which is actually used in many of the devices found in home, industry and healthcare centers. The present sensor could be used for monitoring the electric field emitted by the devices and for improving the reported safe values for electric field exposure. One of the principal problems for Electric Field Sensor at high frequencies is the limited bandwidth; almost all have to be a resonant or multi-resonant structure with a restricted range of frequencies. The simulation shows that the dimensions of the antenna do not restrict its operation in the microwave band, so this antenna can be fully integrated with circuits that operate at high frequencies. These simulated data offer the means to be able to compute the bandwidth for a specific working frequency to perform the electric field sensing at certain points in the space. It is still remain to perform an experimental comparison with an actual SRR metamaterial.

4. Acknowledgments

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5. References

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