HIGH EFFICIENT DIPOLE ANTENNAS BY USING LEFT-HANDED SUPERSTRATES

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Abstract: This paper deals with pass band properties of Left Handed Media (LHM) to enhance dipole antenna performances. The LHM properties' have been used in order to make high directivity antennas with good return loss features. The LHM structure is used as superstrate and placed over a dipole antenna. This superstrate is determining the characteristics of radiation patterns. Simulations of different types of LHM configurations are presented. The improvements of the radiation and matching parameters for each configuration are presented. High efficient antennas are obtained with this technique.

INTRODUCTION

Since Veselago predicted the existence of left-handed media (LHM) in 1968 [1], many attempts have been made to construct this type of structure. LHMs denote artificially constructed materials having electromagnetic properties not generally found in nature, such as having negative permittivity and negative permeability.

Ziolkowski designed different types of LHM-media based on substrates with embedded capacitively loaded strips (CLSs) that produce a strong dielectric-like response, and split ring resonators (SRRs), that produce a strong magnetic material-like response [2]. These LHM-medias were formed by unit cells which were characterised with ANSOFT's High Frequency Structure Simulator (HFSS). That configuration acted as a LHM at the X band. From Maxwell equation, it is envisaged that these types of structures can be physically scaled in order to tune the operational band of frequencies at which they act as a LHM.

This paper analyzes the behaviour of one of these unit cells at different bands of frequencies. As it will be shown, these cells have transmission and non-transmission bands that will be used in order to create a structure that acts as a filter. Therefore, power is only going to be transmitted in the pass band of the cells, i.e. at the transmission peak in the S_{21}. Out of these bands, power will be reflected. This property will be used to place a LHM media as a super-strate of a dipole antenna to enhance its radiation features. High efficiency antennas with directivity patterns and low back radiation are obtained.

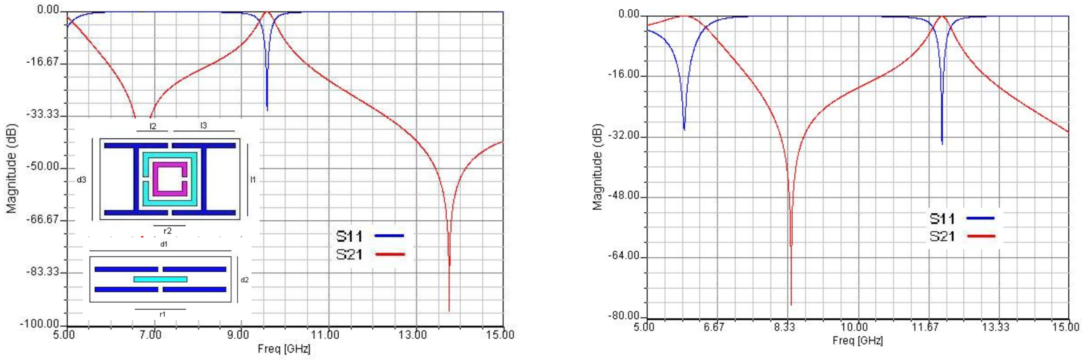
LHM MEDIA

The LHM unit cell consists of one SRR between two pairs of CLSs (see inset Fig. 1). The width of all the gaps and lines were 0.254 mm, the unit cell in the z direction was d_1=7.366 mm, the x length d_2=2.3622 mm and the y length was d_3=4.318 mm. The height of the CLS inclusions was l_1=3.81 mm, the length of the full capacitive strips was l_2=3.556 mm and the length of the half strips was l_3=1.778 mm. The length of the outer SRR was r_1=2.794 mm and the inner was r_2=1.778mm. The dielectric has a permittivity of ε_r=2.2.

This kind of unit cell will be used as a super-substrate and placed over a dipole antenna. As it will be presented later on, two different physical size unit cells will be combined on top the dipole antenna. The large one will have a pass band in a certain frequency range and the smaller one will have its pass band at a higher frequency. Therefore, when the larger cell allows the power to be transmitted, the smaller will reflect it, and vice-versa. In particular, the smaller configuration will be scaled 0.8 times the larger one (dimensions given previously).

The larger structure (see Fig. 1) was simulated with the normal incidence unit cell PEC-PMC (PerfectElectricConductor-PecfectMagneticConductor) waveguide configuration in HFSS. The HFSS-predicted values of S_{11} and S_{21} are shown in Fig 1 (a) and (b). The (a) response exhibits only one resonant value at 9.5782 GHz within the frequency band (5 to 15 GHz). The (b) case presents two resonant frequencies can be observed at 5.88 and 11.98

GHz. The 9.5782 GHz frequency peak has been moved to 11.98 GHz (1.25 times larger than the resonant frequency of the bigger cell).



(a) (b)

Fig. 1. HFSS predicted S parameters for (a)the larger unit cell (b) the smaller one.

DIPOLE SUPERSTRATE CONFIGURATION

Once the response of this unit cell is known, different types of superstrate configurations will be studied and analysed in order to determine the radiation pattern features of the whole configuration (dipole+LHM media).

First of all, a simple $\lambda/2$ dipole working at 9.57 GHz (resonant frequency of the larger LHM unit cell) has been modelled. The dipole has a length of 10.5422 mm and it is placed in the middle of a substrate of ε_r=2.2 and d=1.4478 mm in thickness without a ground plane. The dipole is fed by a gap source HFSS and its impedance has been optimised to have a good return loss parameter (-20 dB @ 9.57 GHz). This impedance has a value of 51.6 Ω.

Dipole antenna with a uniform superstrate

As starting point, the radiation properties of the dipole with a uniform superstrate over it were analysed (see inset Fig. 2). The superstrate is formed by 18 unit cells as described in previous section. The size of the structure in λ terms is about l_x=0.75 λ in x direction, l_y=0.62 λ in y direction and l_z=0.245 λ in z direction. As the structure is symmetrical, it has been analysed by taking into account its electromagnetically symmetry properties to reduce computation time under Ansoft-HFSS software.

If the resonant frequency of the whole structure is analysed, a shift with respect to the resonant frequency of the dipole and the LHM unit cell can be observed. The reason for this is that the unit cell was analysed under normal incidence condition and now a dipole antenna has been used as feeding structure. The interaction between both structures produces this deviation into the resonant frequency. The S_{11} and directivity values of this configuration as function of the frequency are plotted in Fig. 2. The best matching is about –9.76 dB at 9.8 GHz and the maximum directivity obtained is 7.6 dB at 9.92 GHz. Theoretically the maximum directivity that the whole configuration can achieved is around 7.66dB. This means that the efficiency of this radiation system is close to 100%.

Fig. 2 b shows a comparison between the H-plane radiation pattern of the dipole alone together with the radiation of the LHM+dipole at resonant frequency. Only H-plane patterns are presented as being the most restrictive in terms of side radiation for dipole antennas (see Fig. 2a).

A set of H-pane radiation patterns for this LHM+dipole configuration for other frequencies is presented in Fig. 3.a. Although the directivity is very good, it will be seen that these radiation patterns are worse than radiation patterns achieved in the following section. In this case, a considerable amount of back radiation is obtained for all the frequencies shown in Fig. 3 with smaller values where maximum directivity is achieved. It is observed that minimum S_{11} and maximum directivity frequency points do not coincide. Further investigations to match both parameters are in progress.

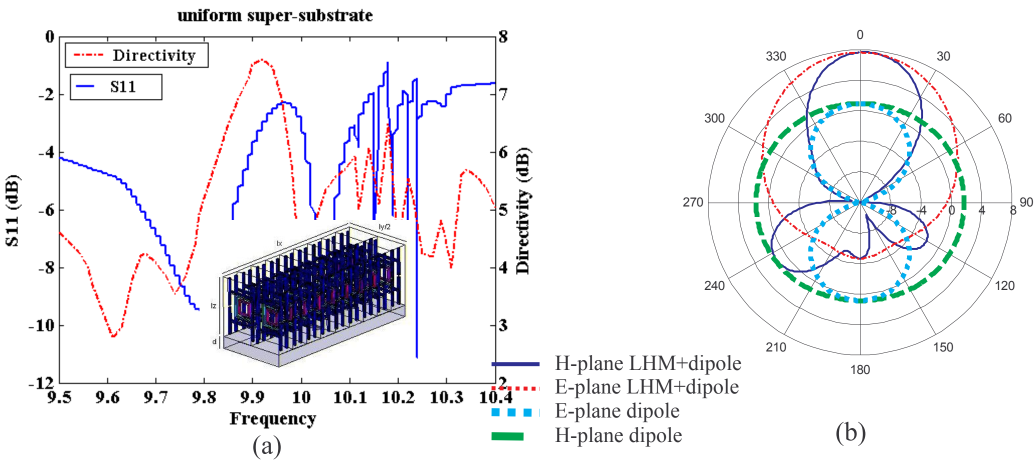


Fig. 2. (a) Directivity and S_{11} vs frequency. Configuration within the inset. (b) H-plane radiation pattern of a dipole antennas versus LHM+dipole.

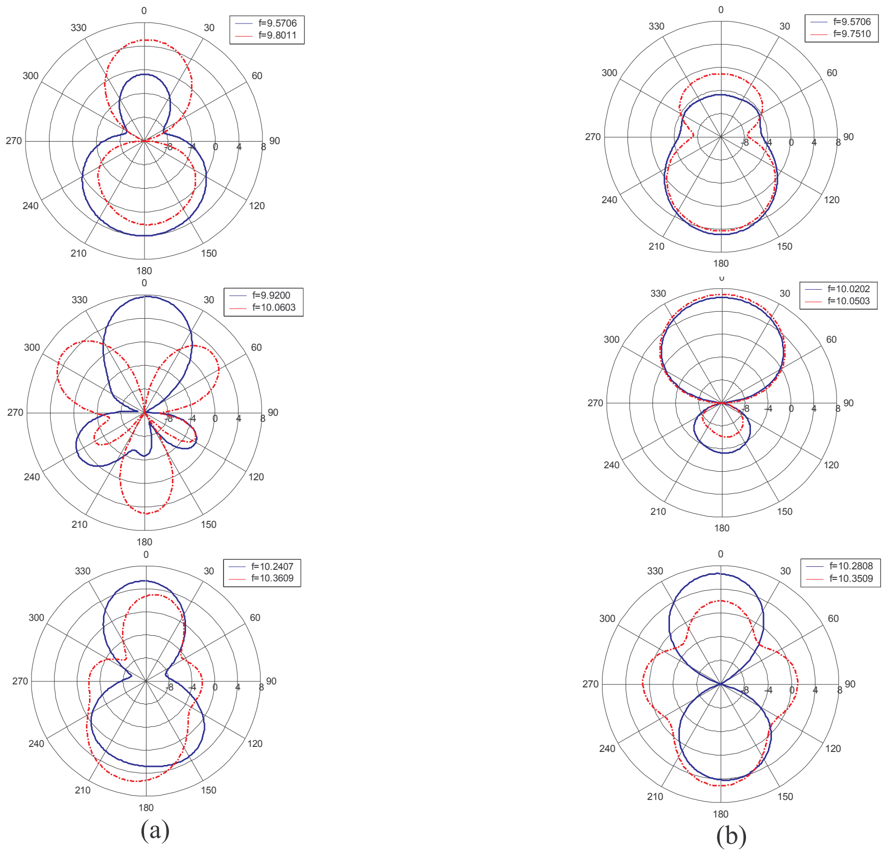
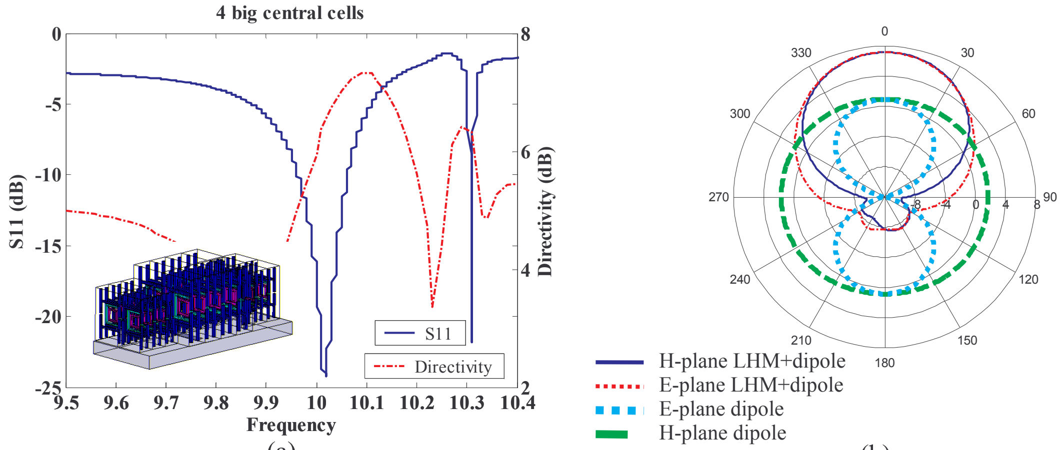


Fig. 3.Radiation patterns at different frequencies. (a) For the uniform super-strate. (b) For the modified super-strate.

In order to control the radiation properties of this configuration, the physical size of the cells placed over the dipole can be modified. In this way, the transmitted power together with the radiation pattern shape can be changed.

Dipole antenna with a modified superstrate

Placing larger size cells just on top of the dipole and smaller ones at corner sides (see Fig. 4), improved radiation patterns can be obtained (i.e., less back radiation). This is because of the fact that the obtained matching (S_{11} parameter) is better than in the previous case with approximately the same directivity. The number of central cells has been varied from one to five and they have been enclosed with small cells that reflect the power. The best properties correspond with the case of four large central cells surrounded by six small ones. This configuration has a physical size given by l_x=0.72 λ in x direction, l_y=0.59 λ in y direction and l_z=0.25 λ in z direction.



(a) (b)

Fig. 4. (a) Directivity and S_{11} vs frequency with inset dipole antenna with the selected superstrate. (b) H-plane radiation pattern LHM+ dipole compared with the dipole alone.

The S_{11} behaviour together with the directivity dependence with frequency is plotted in Fig. 4.a. The whole structure exhibits a resonant frequency that occurs at 10.02 GHz. For this case, the matching of the whole structure (LHM+dipole) is better than the previous configuration. Maximum directivity values around 7.3 dB are obtained at 10.1 GHz (see Fig. 4.b). If they are compared with the maximum theoretically directivity that this structure can exhibited (7.3dB), a 100% antenna efficiency has been obtained. For this configuration a better match between the best S_{11} and the maximum directivity frequency points is achieved when compared with the previous case. Anyway, this matching is not complete and investigations to coincide these two parameters are currently in progress.

Analysing the radiation pattern features for different frequencies (Fig. 3.b), it can be observed that when the frequency is out of the resonant frequency, the power is reflected and a high back radiation is observed. However, when the frequency is around the resonant frequency, most of the power is radiated to bore-sight direction with low back radiation levels.

CONCLUSIONS

In this work, pass band property of left handed materials have been used to achieve high efficient radiation systems. It has been demonstrated that by playing with the different types of cells with pass band or stop band properties over the dipole, radiation patterns with enhanced properties at bore-sight direction can be obtained.

As this paper presents only very promising results, more studies have to be done in order to obtain the best combination of LHM unit cells together with antennas. This work is being extended to array configurations.

ACKNOWLEDGEMENTS

The research presented in this paper has been financially supported by the Navarra Government under resolution 17/2004.

REFERENCES

[1] V.G. Veselago, "The electrodynamics of substances with simultaneously negative values of ε and μ", Sov. Phys. Usp. 10, 509 (1968).
[2] R. W. Ziolkowski, "Design, Fabrication, and Testing of Double Negative Metamaterials", IEEE Transactions on Antennas and Propagation, Vol. 51, No. 7, July 2003.
[3] R. Marqués, J. D. Baena, J. Martel, F. Medina, F. Falcone, M. Sorolla, F. Martín, "Novel small resonant electromagnetic particles for metamaterial and filter design" Proc. of Int. Conf. on Electromag. In Advanced App. (ICEAA'03), pp. 439-442, Torino (Italy) 2003
[4] R. Chantalat, T. Monédière, M. Thévenot, B. Jecko, P. Dumon, "Multibeam antenna with interlaced focal feeds byusing a 1-D dielectric EBG resonator" Proceedings of the 27th ESA Antenna Technology Workshop on Innovative Periodic Antennas: Electromagnetic Bandgap, Left-Handed Materials, Fractal and Frequency Selective Surfaces, Santiago de Compostela (Spain) 2004