Investigation of metamaterial structure influence on selective properties of microwave waveguide sensor

Katarína Isteníková, Dagmar Faktorová

Faculty of Electrical Engineering, University of Žilina, Univerzitná 1, 010 26 Žilina, e-mail: katarina.istenikova@fel.uniza.sk, dagmar.faktorova@fel.uniza.sk

Abstract **The paper proposes the possibility of metamaterial structure using for the transmission properties of open waveguide probe changing and the possibility of microwave open waveguide sensor tuning with metamaterial structure to be used for non-destructive testing of dielectric materials properties. The aim of our work was to develop a frequency selective sensor in microwave frequency band sensitive to changing of dielectric properties of investigated dielectric material. In the paper we describe the new approach with incorporation metamaterial structures with negative permittivity and permeability in the volume of waveguide sensor in order to create the stop-band properties of designed sensor. The optimal number of metamaterial units and metamaterial structures inserted into waveguide volume were numerically optimized and experimentally verified for chosen frequency band from microwave frequencies region.**

Keywords **Microwave sensor, metamaterial, complex permittivity, stop-band filter.**

I. Introduction

Microwave waveguide sensors can measure properties of materials based on microwave interaction with matter and they can be used to provide information about dielectric properties of investigated dielectric material characterized with complex permittivity and with that knowledge can afford information about moisture content, density, structure and even chemical reactions [1]. Microwave sensor offers many advantages in comparison with traditional sensor such as rapid and nondestructive measurement [1-3]. Nowadays, a great interest has been devoted to the sensing applications of metamaterials [1].

II. Theory of metamaterials

Metamaterials which are defined as effectively homogeneous electromagnetic structure exhibiting unusual electromagnetic properties especially the backward wave and negative refraction not readily available in nature, represent a new paradigm in electronics and photonics. The currently available artificial structures are realized by using planar structures with specific topology in *x-y* plane [3].

In the paper we study the influence of negative permeability and permittivity medium on the performances of frequency selective properties of rectangular open waveguide sensor. Metamaterial structure used for conventional waveguide sensor tuning consists of arrays of unit cells of split resonators (SR) and wire structure which was designed by Pendry et al. [4]. Split resonators behave as LC resonant circuits which can be excited by a time-varying electromagnetic field with a non-negligible component applied parallel to the split resonator axis [4].

III. Sensor for dielectric properties investigation

A lot of methods and sensors have been proposed for dielectric properties of materials investigation. In our paper we describe the design of microwave waveguide sensor tuned with metamaterial structure (MMS).

Our idea at frequency selective waveguide sensor suggestion was to design sensor capable to complex permittivity change. This fact can be observed via changes of distribution parameter α in the Cole - Cole equation [5]

$$\dot{\varepsilon}_{\mathrm{r}} = \varepsilon_{\infty} + \frac{\varepsilon_{\mathrm{s}} - \varepsilon_{\infty}}{1 + \left(\mathrm{j}\omega\tau\right)^{1-\alpha}}, \qquad (1)$$

where ε_s and ε_∞ are static and infinite permittivity respectively, ω is angular frequency, τ is the mean relaxation time for dielectric and distribution parameter α is a constant for dielectric having a value $0 \le \alpha \le 1$. The distribution parameter characterizes the width of relaxation spectra of investigated dielectric material [2], [6]. The changes of investigated material permittivity induce also the changes of distribution parameter α.

We proposed the waveguide sensor with metamaterial structure which induces the band-stop properties sensor. The MMS can be designed for chosen frequency band to be capable to the value of investigated dielectric material complex permittivity. In the case, that dielectric characteristic of investigated material change, the sensor start work with another value of distribution parameter α and will change the frequency band to which is sensor capable. The frequency spectrum of reflected signal from the investigated dielectric can be investigated and its changes respond to dielectric properties of investigated material.

IV. Numerical and Experimental Results

The metamaterial structure was designed with the spit ring resonators (SRR) on one side of substrate ROGERS RT/DUROID 5870 (ε_r = 2.33, tanδ = 0.0012) and with disrupted wires on the other side of substrate, Fig. 3.

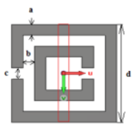


Fig. 1. Metamaterial unit - SRR and wire on the substrate

The designed MMS is strongly resonant around the magnetic plasma frequency ω_m which is induced by the currents and split which imitates magnetic poles. This resonant behaviour is due to the capacitive element such as splits, and in turn results in very high positive and negative values of permeability close to the magnetic plasma frequency [7].

The SRR would yield a negative value of permeability and the wire structure a negative value of permittivity. The resonant behaviour and band-stop properties of MMS were numerically simulated and experimentally observed by measuring the transmission through the waveguide with inserted MMS. The proposed metamaterial unit, Fig. 1 [8], interaction with electromagnetic field can be numerically study through frequency dependence of scattering parameters S_{11} a S_{21}, Fig. 2. Figure 2 shows the band-stop properties of one metamaterial unit.

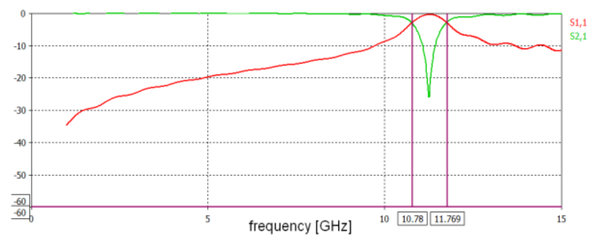
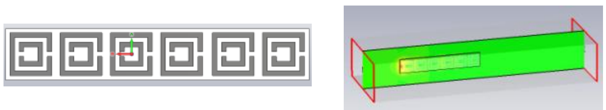


Fig. 2. The S_{11} and S_{21} – parameters of band-stop filter characteristics for one metamaterial unit

The optimal number of metamaterial units on substrate for chosen frequency stop-band is six, Fig. 3a); optimal number of substrates with MMS inserted to the volume of waveguide is three. The numerical result of stop-band properties of waveguide tuned with one metamaterial structure created from six MMS units is in Fig. 3b).



a) b)

Fig. 3. The optimization of waveguide sensor tuned with band-stop filter a) MMS with six units, b) stop-band filter simulation results with one MMS inserted in waveguide volume (f = 8 GHz)

The numerical results for scattering parameters S_{11} and S_{21} of designed stop-band filter (the bandwidth Δf = 1.85 GHz, low frequency f_l = 10.48 GHz, high frequency f_h = 12.33 GHz) are in Fig. 4.

The measurements of sample dielectric properties changes were performed on the standard laboratory microwave measuring set in the X frequency band with 1 kHz modulation and the reflected signal from the dielectric sample was detected by the selective amplifier [2], [8].

The experimental results have validated the numerical results and have confirmed that the new sensor tuned with MMS is possible to use for material dielectric properties changes investigation. The measurement of frequency dependence of reflected and transmitted signal through the waveguide sensor have shown that the selective properties of waveguide sensor tuned with MMS has the stop-band properties for the frequency band - low frequency f_l = 10.4 GHz, high frequency f_h = 12.3 GHz.

The precise metamaterials structure with frequency selective properties for investigated dielectric material can be designed and can be used for tuning of waveguide sensor which can be used for dielectric properties of dielectric material changing investigation.

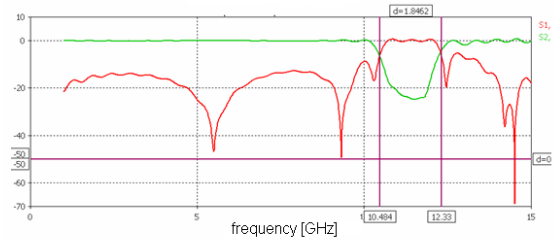


Fig. 4.The S_{11} and S_{21} – parameters of stop-band filter characteristics for designed waveguide sensor with three MMS

V. Conclusion

The numerical and experimental results have shown the new approach to the investigation of material dielectric properties changing. We have shown that the sensor tuned with designed metamaterial structure has the frequency selective properties.

The next work will be directed to the numerical calculation of material dielectric parameters changes by using the values of distribution parameter connected with the frequency band shift.

VI. Acknowledgements

This work has been supported from Ľudmila Čuchranová Memorial Stipend Program and from Slovak Research and development agency APVV Bilateral project SK-RO-0015-10.

VII. References

[1] Huang, M., Yang, J.: "Microwave sensor using metamaterials", Wave Propagation, 1st ed., InTech, 2011.

[2] Faktorová, D.: "Dielectric Materials Parameters Characterisation Using Waveguide Probe Tuned with Metamaterial", Proc. of ISMOT 13th International Symposium on Microwave and Optical Technology, 2011, pp. 4.

[3] Caloz, CH., Itoh, T.: "Metamaterials for High Frequency Electronics", Proc. of IEEE, Vol. 93, No. 10, 2005, pp. 1744-1752.

[4] Pendry, J. B. *et al*: "Magnetism from Conductors and Enhanced Nonlinear Phenomena", IEEE Trans. Microwave Theor. Tech., Vol. 47, No. 6, 1999, 2075-2084.

[5] Grosinger, J. *et al*: "Determining the dielectric properties of a car tire for an advanced tire monitoring system", Proc. of IEEE 70th Vehicular Technology Conference Fall, Anchorage, 2009, pp.5.

[6] Faktorová, D., Omelka, P., Isteníková, K.: "Antenna parameters enhancement by using artificial magnetic structure", Journal of Electrical Engineering, Vol. 61, No. 7/s., 2010, pp. 156-159.

[7] Aydin, K., Ozbay, E.: "Identifying magnetic response of split-ring resonators at microwave frequencies", Opto-Electronic Review, Vol. 14, No. 3, 2006, pp. 193-199.

[8] Faktorová, D.: "Microwave characterisation of frequency and temperature dependence of beef bone dielectric properties using waveguide measurement system", Proc. of the Measurement '09 Conference, 2009, pp. 402-405.