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The Fabrication and Test of Paraffin-based Dielectric Lenses Using the Free-Space Method for 10-18 GHz



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Abstract

In this study to make sure that the paraffin wax lens can handle higher frequencies, instead of big reflectors for metamaterial measurement set up, two dielectric lenses is fabricated. The proposed lens are fabricated using a molding paraffin wax process for 10-18 GHz using the free-space method. The fabricating paraffin wax based lenses guarantee low cost and ease of implementation compared to the other machining and material methods. To verify the proposed lens performance, the two similar paraffin lens are used to measure the S-parameters of a conventional spiral metamaterial unit cell. This experiment confirms a good agreements of simulation and measurement results.

Introduction

- In all of the previously reported works, the main part of the metamaterial medium design is the fabrication and test process to validate the simulation results for the unit-cell.
- The S-parameters resulting from a metamaterial cell or medium prototype should be measured.
- Various methods are used to carry out this type of measurement including the free-space method, waveguide method and a series of single-cell methods.
- Here, we propose a low-cost yet effective method to measure the S-parameters using the free-space method.

Objective and Goals

- How much we can increase the frequency range?
- The lens can handle higher frequencies, instead of big reflectors.
- Using smaller reflectors with the 12-inch diameter to make the molding process much more accurate.
- Control that the surface of the lens is smooth enough, which is necessary for high-frequency applications.
- Analysis of Paraffin Wax as a alternative option with the material that usually is used to fabricate a dielectric lens: **Polystyrene microwave plastic** or **Rexolite**.



Fig.1. The molding process of a dielectric paraffin lens and the fabricated paraffin wax lenses

Fabrication Process

- The paraffin wax was used in a molding process as an alternative approach for the lens design and implementation.
- This material has the permittivity of 2.55, which is very close to **Rexolite** with better mechanical characteristics to ease the fabrication and shaping.
- The density is around 0.88 g/cm³ that makes the structure around 20% lighter compared to plastic based lenses.
- The molding process, which is proved to be an effective method for the frequency range of 1-4 GHz.

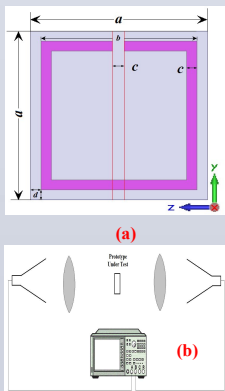


Fig.2. (a) The proposed metamaterial Single cell (b) Block diagram of the free-space measurement method and (c) Test setup located in INRS-EMT

Measurement and Discussions

- The S-parameters of three conventional SRR (Split-Ring Resonator) and line combinations with different dimensions for three frequency bands are measured.
- These bands are 1-4 GHz, 5-13 GHz and 10-18 GHz that we name them “**low-frequency**”, “**middle-frequency**” and “**high-frequency**”, respectively.

Results

- The **low-frequency** unit cells is in the range of 1-4 GHz
- The **middle frequency** expanded range is up to 12.5 GHz
- and finally we conducted the measurements up to 18 GHz for High frequency band
- This experiment confirms a good agreement between simulation and measurement results.

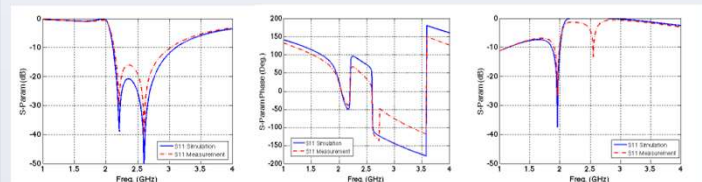


Fig. 3 (a) Magnitude and Phase of S11, and S21 for low-frequency SRR; For low-frequency design: a=18, b=15, c=1.5, d=1.5

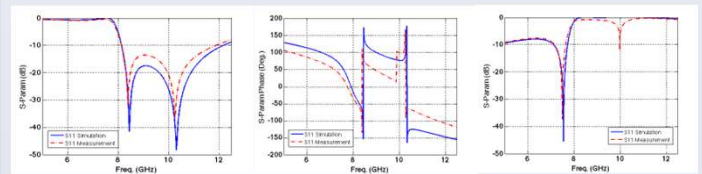


Fig. 3 (b) Magnitude and Phase of S11, and S21 for middle-frequency SRR; For middle-frequency design: a=4.5, b=3.75, c=0.375, d=0.375

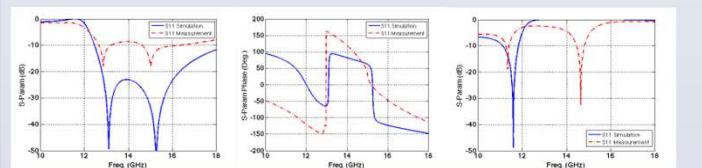


Fig. 3 (c) Magnitude and Phase of S11, and S21 for High-frequency SRR; For high-frequency design: a=3, b=2.5, c=0.25, d=0.25

Advantageous and Drawbacks

- As plotted in Figures 3 a-c, in the **low and middle frequency bands** there is a very good correlation between the simulation and measurement.
- In the **high frequency band**, the difference between measurement and simulation becomes more significant.
- Large dimensions of the horn which causes the spill-over problem in high frequency.
- The inherent loss of the paraffin material at higher frequencies.
- The cost of the project would be too high to justify this method at high frequency > 20GHz.

Importance

- The phase of the S-parameters are as important as the magnitude and it is necessary to measure them too because in the extraction with **Kramers–Kronig** algorithm.
- The S-parameter as a complete complex number to be able to calculate the effective constitutive parameters.
- Compared to the previous set of lenses made in the group (in the range of 1-4 GHz), we used smaller structures and the fabrication process was done much more accurate and the results are acceptable up to 15 GHz.

Conclusions

- Two paraffin-based lenses for metamaterial measurement is fabricated.
- With increasing the frequency (up to 18 GHz which is the horn upper frequency limit) the measurement results show a significant difference compared to the simulations.
- The large dimensions of the horn which causes the spill-over problem and also the inherent loss of the paraffin material used for this application.
- Nevertheless, we enhanced the previous design from 4 GHz to 15 GHz and it seems that it is the limit and if we wanted to go higher the cost of the project would be too high.