Reflection/Transmission Measurement System For Planar Materials And Verification By Thin Wire Grids

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Abstract

This paper describes a measurement system to evaluate the reflection and transmission (R/T) properties of planar materials have been constructed within the Open-Range EM Laboratory (ASEMLAB) of Gebze Institute of Technology. This manuscript describes this measurement system, calibration process, and the results of an application - measurement of the R/T coefficients of a thin wire mesh. In order to check the measured R/T coefficients of the thin wire mesh a periodic method of moments (PMM) code has been developed. The currents that leave one periodic cell and enter the next are handled in a novel way.

1. Introduction

With the widespread use of high frequency electromagnetic (EM) waves, new product families to screen, deflect, or absorb these EM waves are being researched. A variety of fabrics, deflection fences, paints, and light construction materials such as dry-walls form a certain class of these products. A measurement system designed for the reflection and transmission (R/T) properties of these materials has been constructed within the Open-Range EM Laboratory (ASEMLAB) of Gebze Institute of Technology. This manuscript (i) describes this measurement system, (ii) outlines its calibration process, and (iii) reports the results of an application - measurement of the R/T coefficients of a thin wire mesh. Solution of electromagnetic wave scattering from wire mesh structures can be achieved by using a variety of methods such as method of moments (MoM) [1]. For 2-D periodic array of repeating unit cells containing metal shapes, it is required to use PMM [2]. In this paper, in order to check the measured R/T coefficients of the thin wire mesh a periodic method of moments (PMM) code has been developed. The currents that leave one periodic cell and enter the next are handled in a novel way. The rest of the paper is organized as follows: First, the measurement system is going to be described. Next, the PMM code will be explained. Finally, the comparison results for the thin wire mesh will be presented.

2. The R/T Measurement System

The aim of the measurement system is to determine the polarization dependent reflection and transmission coefficients of a material at normal incidence. A basic drawing of the system is given in Fig. 1. The main chamber, whose dimensions are 240×120×120 cm, consists of two identical sections separated by a sliding window. The sample is loaded to the sliding window, which is made out of aluminum and has an aperture of 40×40 cm. Both parts of the chamber (including the doors) are EMI isolated. When an aluminum sheet is placed as the sample, the isolation between the two chambers is measured to be in excess of -40 dB throughout the 2 – 18 GHz operation band. The inner walls of the chamber are covered with microwave pyramid absorbers. The transmit and receive antennas are Satimo type SH-2000 dual-ridge horn antennas. The antennas can be rotated so that all four polarization type measurements can be carried out. The calibration of the system is carried out in four steps. The first step is to do a port calibration of the network analyzer. For this purpose, the short, open and matched loads are connected in

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place of the horn antennas. In the second step, a 2 mm thick aluminum sheet is placed at the sample window and S11 and S21 parameters are recorded. This case corresponds to full reflection and zero transmission. Then the window is left open with no samples and S11 and S21 are recorded. This case corresponds to zero reflection and full transmission. In the fourth step, a $10\,mm$ thick polyethylene sheet with a relative dielectric constant of 2.25 is placed as the sample and the R and T coefficients are compared to the theoretical values. If the theoretical and measured values match, the calibration is completed. The measurement of the sample follows a similar procedure except that the polyethylene sheet is replaced with the measurement sample. The R and T coefficients are calculated as

$$|R| = \left| \frac{S_{11}^{sample} - S_{11}^{open}}{S_{11}^{metal} - S_{11}^{open}} \right| \quad \text{and} \quad |T| = \left| \frac{S_{21}^{sample} - S_{21}^{metal}}{S_{21}^{open} - S_{21}^{metal}} \right| \tag{1}$$

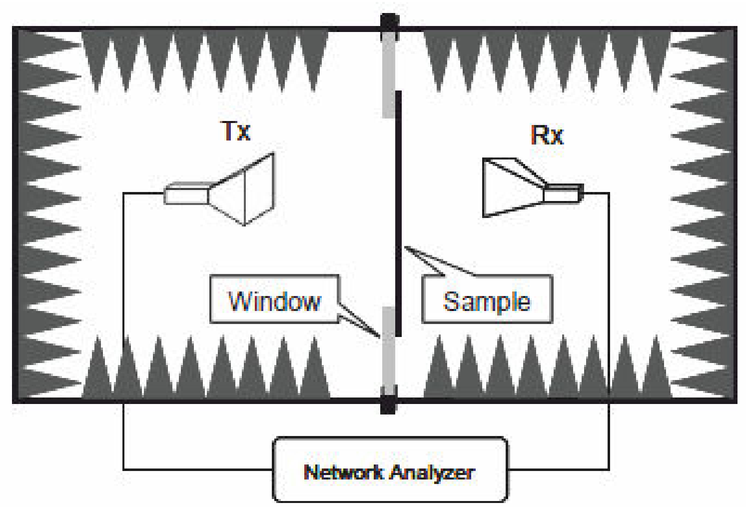

Figure 1. Measurement system.

3. The PMM Algorithm for Thin Wire Mesh

For 2-D periodic array of repeating unit cells containing metal shapes, it is required to use PMM [2]. This kind of structures can be characterized only by describing a reference basic unit cell (see Fig. 2) which is repeated in two directions across the plane of the array to make the periodic structure. Blackburn and Arnaut have used a PMM with thin-wire kernel for modeling wire loop-type periodic arrays [3]. For such arrays, according to Floquet's theorem, the currents vary according to a phase factor of the incident plane wave along the array:

$$I_{qm} = I_{00} \exp(-j\beta q D_x s_x) \exp(-j\beta m D_z s_z) \tag{2}$$

where I_{00} denotes reference element current which is located at origin $(0,0,0)$ while I_{qm} refers to the current of an arbitrary element located in cell (q,m). D_x and D_z denote element spacing in the x and z directions, respectively. If the cells have wire connection with the neighboring cells (such as Fig. 2(c)), current flowing from one cell to the next must be modeled appropriately. In this work, according to Eq. (2), the current leaving a cell and entering the next is modeled with the same current magnitude except a phase shift. This has been implemented in the computer program by using one basis function which connects the exit point on one side to the entry point on the other side. The rest of the formulation used follows that of [3]. The implementation is tested by computing the reflection coefficient for a dipole array by first centering the dipole in the unit cell and then by splitting the dipole across adjacent elements. The dipole array consisted of $4\,mm$ long dipoles with diameter $a = 100\,\mu m$ spaced $D_x = D_z = 6\,mm$ and was illuminated by a normally incident plane wave. Once the agreement between the two cases (split and unsplit cases) has been shown to be perfect, analysis of wire meshes has been conducted.

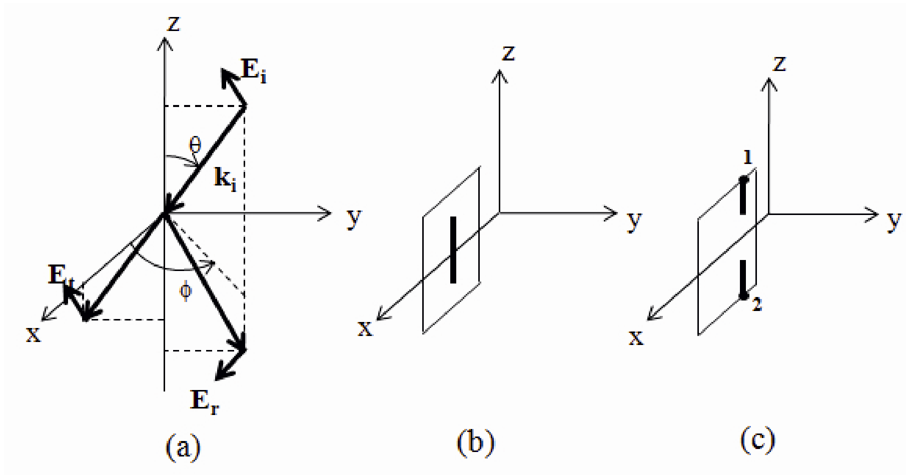

Figure 2. (a) plane wave incident, (b) unit cell for unsplit dipole, (c) unit cell for split dipole.

4. Comparison of Measurement and Computed Results

The unit cell structure given in the inset of Figure 3 when placed periodically forms a mesh grid. Here, wire diameter is $a = 140\,\mu m$ and $D_x = D_z = 3.75\,mm$. By using the PMM code described above, the reflection and transmission coefficients are calculated for normal incidence for both Horizontal/Horizontal (HH) and Vertical/Vertical(VV) polarizations. The obtained results are compared with the results of the measurements. The results are given in Fig. 3. As seen from Fig. 4, numerical results for VV and HH polarizations are the same as expected. For, reflection coefficients, difference between numerical and experimental results are in the limit of ten percent error range except for the frequency range of 2 – 3 GHz and 17.5 – 18 GHz for VV polarization and 2 – 3 GHz for HH polarization. For transmission coefficients, differences between numerical and experimental results are in good agreement for the whole frequency range of 2 – 18 GHz for both VV and HH polarizations. In Fig. 4, how the wire radius effects the R/T coefficients have been studied. Wire diameters of $50, 63$ and $140\,\mu m$ have been used. As expected, the reflection coefficients shows direct proportion with the diameter while the transmission coefficient inverse proportion with the diameter.

5. Conclusions

A measurement system for determining the reflection and transmission coefficients from sheet materials have been introduced. The calibration procedure for this system has been outlined. Verification of the system have been made with reflection and transmission coefficients measurements of thin wire meshes. In order to compare the results, a PMM code has been developed. A novel formulation for modeling currents across adjacent cells has been introduced. The comparison of measurement and computational results show that the initial accuracy of the measurement system is about 10% for the transmission coefficient. There seem to be discrepancies in the lower frequency regime. Suggestions and further developments of the system will be presented in the meeting.

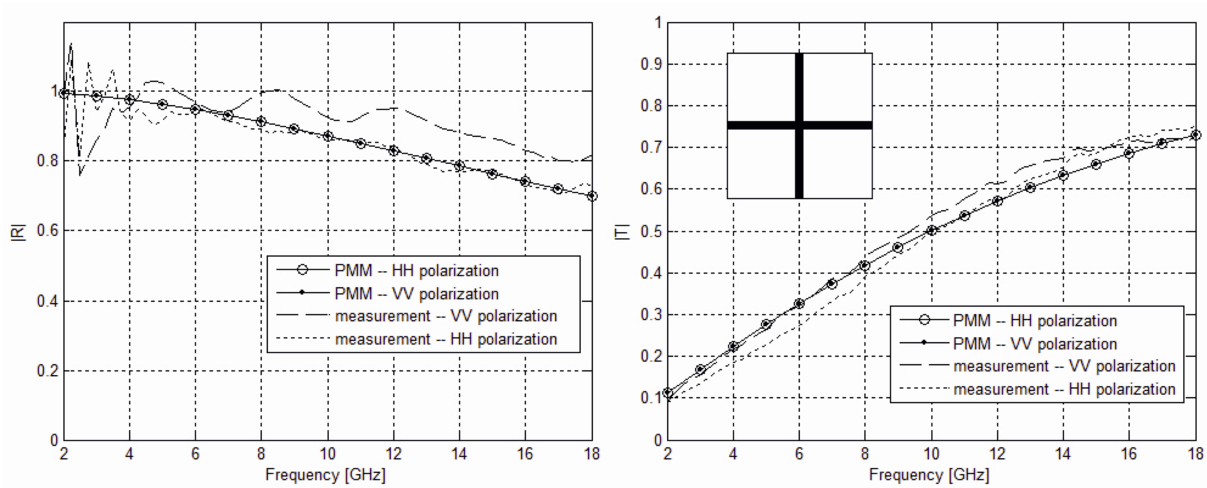

Figure 3. Reflection and transmission coefficients for wire mesh with a = 140 μm.

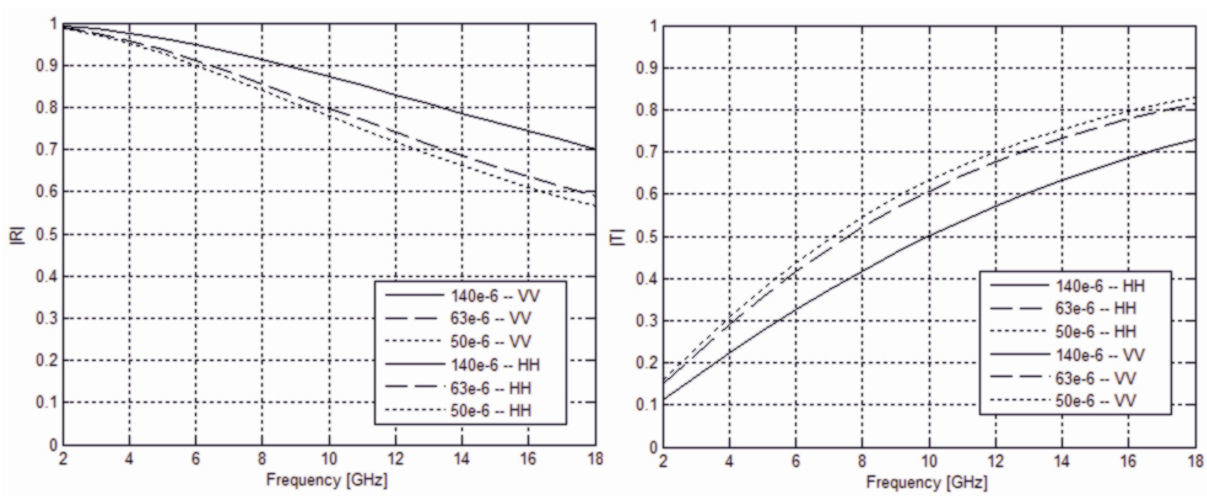

Figure 4. Reflection and transmission coefficients for different wire diameters.

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