Tunable EM-wave Absorber Below 1 GHz using Diode Grid and its Evaluation by Large Stripline

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***Abstract*— An electrically-controllable EM-wave absorber panel is developed which employs a simple structure of planar diode grids as a metamaterial layer. To evaluate the reflectivity of the absorber panel that is smaller than the wavelength, we developed a measurement system with a large stripline that is usable for frequencies lower than 700 MHz. The absorber panel is shown to achieve reflectivity of less than –10 dB, and the abosrbing frequency is tunable between 500 MHz and 600 MHz by varying the reverse voltage bias.**

Key words: EM-wave absorber, metamaterial, artificial material, variable capacitor diode, large stripline.

I. Introduction

EM-wave absorbers as countermeasure devices for reducing the unwanted reflection have been utilized for many applications over the years, such as the internal lining of anechoic chamber, or as the partition between lanes at the toll-collecting gates working with ITS (intelligent transportation system).

Traditional EM-wave absorbers have been based on well-prepared lossy materials such as the carbon-composite materials or the ferrite-composite materials as well as the bulk ferrites. However, obtaining a suitable material and keeping the material characteristics within the tolerance is generally not an easy task.

On the other hand, the circuit-based metamaterials have been proposed and applied to the new types of EM-wave absorbers [1], [2], [3], [4], [5], [6], [7], [8], [9], [10], [11]. They have a distinctive feature of electrically-controllable material characteristics. Thanks to the variability, the metamaterial-based EM-wave absorbers can be flexible for different wave incidence conditions such as different frequencies, incident angles, or wave polarizations. The possibility has been shown not only for microwave frequencies, but also for VHF or UHF frequencies [10], [11].

In this paper, a new EM-wave absorber working in frequencies below 1 GHz is investigated with a simple planar grid structure [11] as the metamaterial layer. To evaluate the manufactured absorber panel that is smaller than the wavelength, a large stripline is utilized for the reflectivity evaluation.

II. EM-Wave Absorber Panel using Diode Grid

A. Structure

Figure 1 shows the EM-wave absorber panel under test. It consists of a front board, a metal plate in the back, and 20 mm spacing between them. The front board is a dielectric board having conductor grids on its both sides. The conductor grid is formed with square patterns having 47 mm side length. It is formed with 2 mm wide copper strips, and the middle point of each side of the square pattern is loaded with a SMD-type variable capacitor diode. The copper strips make angles of 45° with the sides of the panel for the sake of easy bias application. The diodes on the front side of the front board are biased with reverse voltages, while those on reverse side are biased with forward currents.

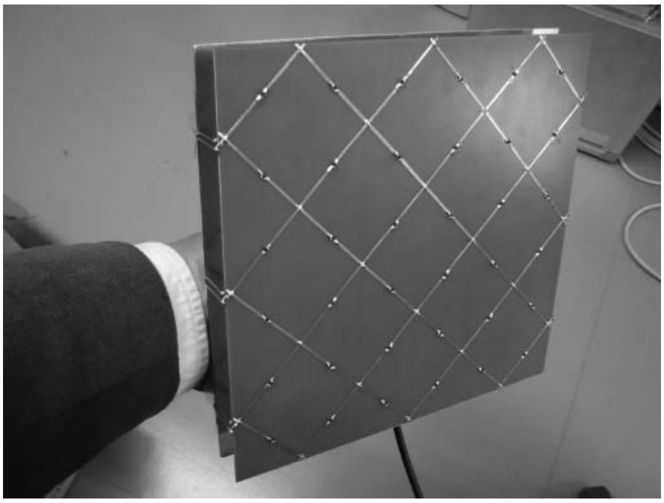

Fig. 1. Tunable EM-wave absorber panel.

B. Variable capacitor diode

The variable capacitor diode used here, when applying reverse voltages, typically have capacitances varying between 2 pF to 20 pF. According to the measurement, the capacitance vastly increases up to 10000 pF in the forward current bias condition. In the forward bias condition, the parallel conductance also increases up to 0.1 S. Therefore, by combining two independently-biased diodes in parallel, one of them being biased with a reverse voltage and the other with a forward current, it is expected that the conductance and susceptance can be electrically controlled in a certain region.

III. Experiment

A. Setup

Figure 2 illustrates the reflectivity measurement system for the EM-wave absorber panel. The measurement system consists of a large stripline, a vector network analyzer, a balun (180° hybrid coupler with matched load termination at Σ port) and a coaxial cable connecting them, and DC voltage and current sources. The reflectivity of the EM-wave absorber panel is measured at one end of the stripline. A voltage source and a current source are used to appliy DC bias to the panel. The large stripline has a tapered end, and the balun connects the tapered end of the stripline with the vector network analyzer via a coaxial cable.

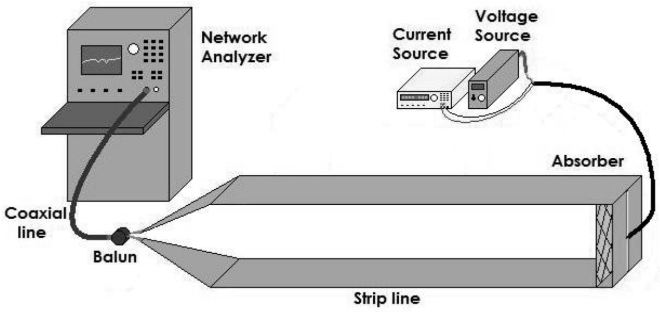

Fig. 2. Reflectivity measurement system.

B. Large stripline

Since the test frequency is below 1 GHz, the wavelength is longer than the panel size. Therefore, the free-space reflection measurement is not adequate for evaluating the absorber panel. So, we adopted the large stripline for the measurement. The stripline has conductor width and spacing both equal to 200 mm. The length of the stripline's straight section is approximately 1800 mm and additional 230 mm for the tapered portion.

C. Reflectivity measurement

The theoretical characteristic impedance of the stripline is calculated to be 177 Ω, while the balanced port of the balun has 100 Ω port impedance. Therefore, the reflection occures not only at the absorber panel at the end, but also at the connection part between the balun and the stripline. To separate the former from the latter, the time domain function of the vector network analyzer is utilized.

D. Evaluation of large stripline

The Short-Open-Load calibration is performed at the test-port cable end. It is connected to the unbalance port of the balun to obtain the S_{11} parameter. Figure 3 shows the time-domain representation of the S_{11} parameter. Here, a movable short metal plate is placed at three different positions and measured. The first peak in the left side represents the reflection at the balun-taper-stripline connections. The other three peaks represent the reflection from the movable short plate set at the different distances (shown in the figure) from the taper-to-stripline connection point. Applying the time gate

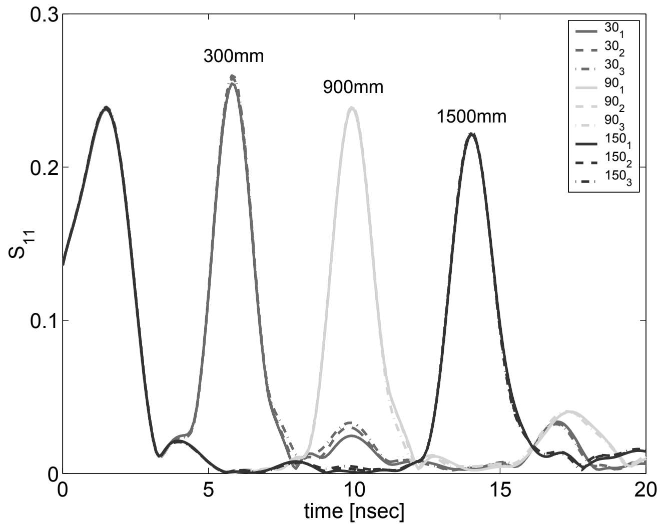

Fig. 3. Time-domain reprsentation of S_{11} for several short plate position.

to each reflection from the movable short plate, and observing in the frequency domain, Fig. 4 is obtained. It can be seen that the amplitude rapidly attenuates as distance increases at frequencies above 750 MHz. The transmission loss of the

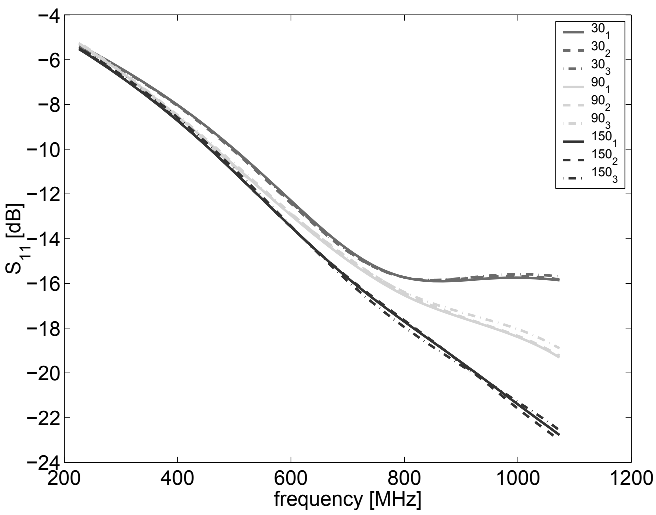

Fig. 4. Time-gated S_{11} for the reflection by the short plate.

stripline calculated from Fig. 4 is shown in Fig. 5. The transmission loss is less than 1 dB/m up to 700 MHz, while it rapidly increases afterwards. This is consistent with the cut-off frequency of higher-order mode, which is expected to be around 750 MHz where the conductor separation is equal to the half wavelength. Above 750 MHz the single mode condition does not hold, which may result into the radiation loss of the stripline to increase. From this result, we assume that the stripline can be used to evaluate the reflectivity at frequencies up to 700 MHz.

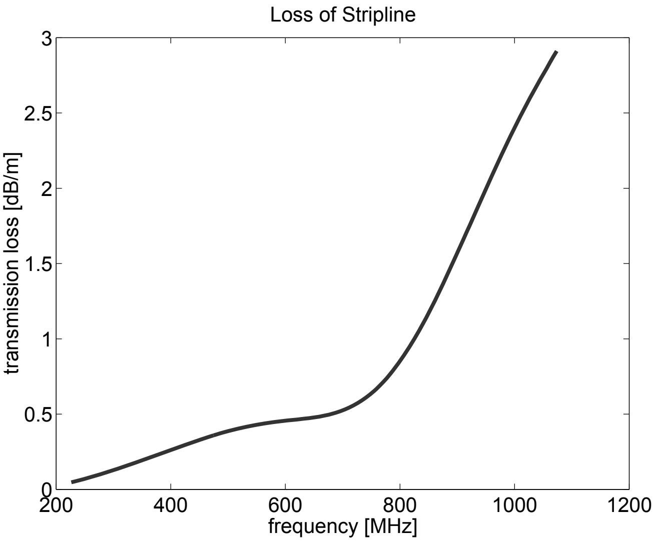

Fig. 5. Estimated transmission loss of stripline.

E. Reflectivity of the abosrber panel

Figure 6 shows the S_{11} parameter of the large stripline simply loaded with a short plate at the end. The reflected wave from the end of the stripline is time gated which experienced the round trip propagation. This data is used as the reference level to define 0 dB reflectivity.

Figure 7 shows the reflectivity of the absorber panel, while varying the reverse voltage V_r between 0 V to 180 V and fixing the forward current I_f to 20 mA. The frequency giving the minimum reflectivity (referred to as the absorbing frequency) increases from 200 MHz to 600 MHz as applied V_r increases. This is due to the decrease of the susceptibility of the front board because of the decrease of the capacitance of diodes. Note that the voltage applied to each diode is $1/6$ the value of V_r, because of the 6-series and 6-parallel connection of the diode network. For absorbing frequencies between 500 MHz and 600 MHz, the minimum reflectivities achieve values as low as -10 dB.

Figure 8 shows the reflectivity of the absorber panel, while varying the forward current I_f between 1 mA to 70 mA and fixing the reverse voltage V_r to 144 V. In this case, the absorbing frequency is almost constant and the minimum reflectivity varies. However, the variation of the minimum reflectivity is smaller than expected. If the conductivity is to

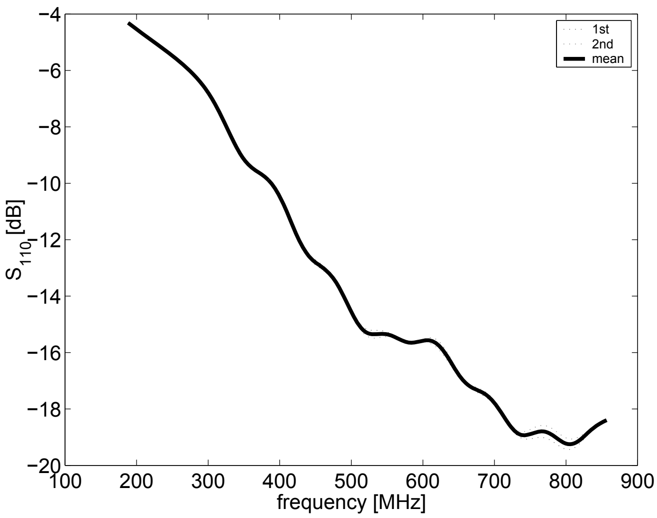

Fig. 6. Reference level of reflectivity $= 0$ dB.

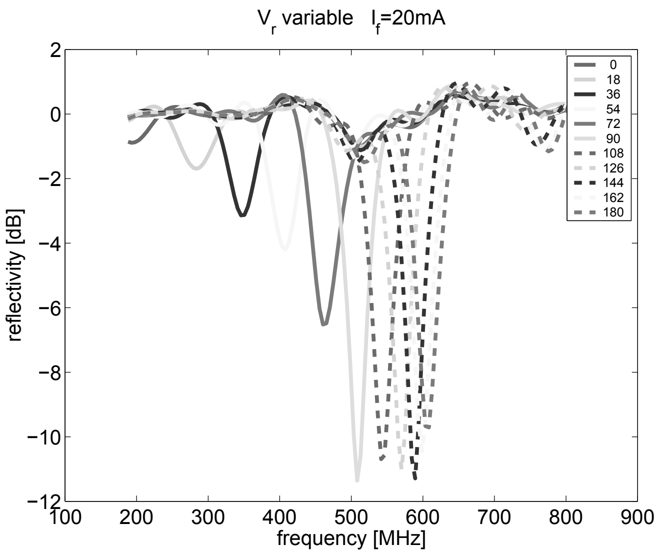

Fig. 7. Reflectivity of EM-wave absorber while varying bias voltage V_r.

vary as expected from the measured result of the impedance of the diode with bias applied, smaller reflectivity would be achieved. Figure 9 shows the minimum reflectivity as a function of I_f. As shown, the good matching as low as -20 dB or less is not achieved even at the optimum bias (around 15 mA). Currently, we are seeking for the cause of this result and working on achieving better reflectivity.

IV. Conclusion

We have developed a new EM-wave absorber panel with a simple structure having planar diode grids on both sides of a dielectric plate as a metamaterial layer. To evaluate the reflectivity of the absorber panel which is smaller than the wavelength, we have developed a measurement system employing a large stripline. The stripline system is shown to be applicable for frequencies lower than 700 MHz.

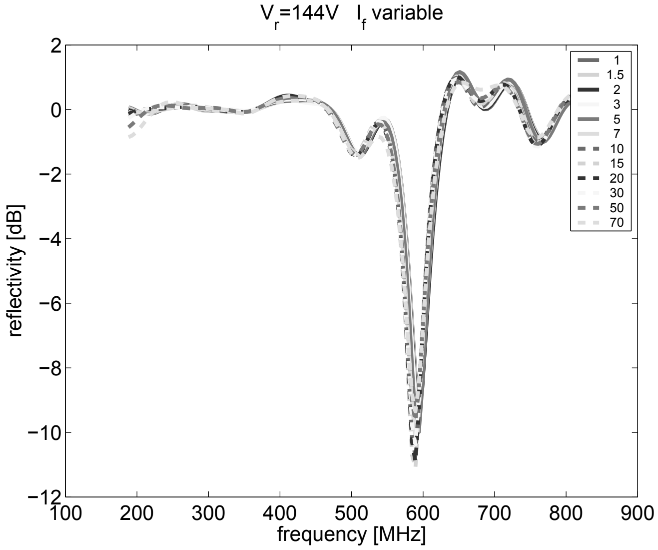

Fig. 8. Reflectivity of EM-wave absorber while varying bias current I_f.

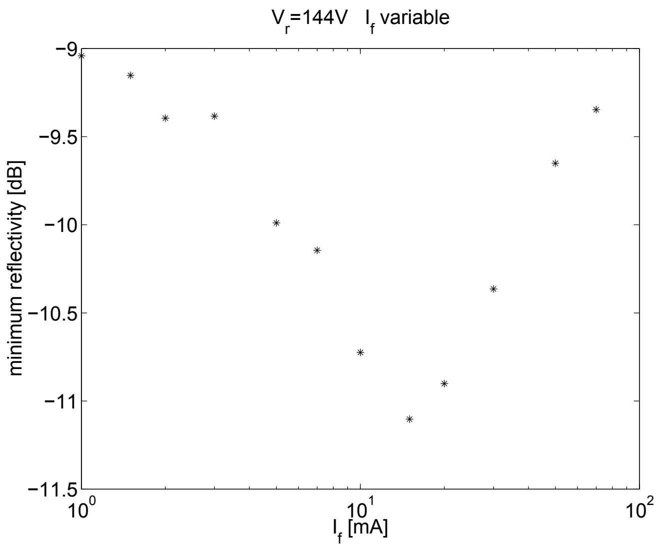

Fig. 9. Minimum reflectivity as a function of bias current I_f.

We have experimentally shown that the absorber panel achieves reflectivity of less than -10 dB at the end of the stripline. The abosrbing frequency is tunable between 500 MHz and 600 MHz by varying the reverse voltage bias. We are working on achieving better matching with reflectivity lower than -20 dB which may be achieved by appropriately adjusting the conductivity of the front board.

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