Metamaterial Wave Absorber to Improve Oblique Incident Characteristics

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***Abstract*— We propose novel RH-metamaterial structure of the Z-chip for improving the oblique incidence characteristics as an electromagnetic wave absorber. The basic characteristics of a wave absorber using a Z-chip is calculated by FDTD simulation at an oblique incidence. To demonstrate the efficiencies of the chip, a unit cell like a Z-chip was introduced to an actual computer controlled metamaterial electromagnetic wave absorber. The free space method is applied to measure the oblique incident reflection coefficient of the absorber. As a result, it is shown that the TM oblique incidence characteristics were improved the by structural improvement of the chip.**

Key words: wave absorber, metamaterial, reflection coefficient, electromagnetic compatibility, oblique incidence.

I. INTRODUCTION

Recently, several numbers of studies about metamaterial and its application for EMC or microwave technology have been reported. An original idea reported an electromagnetic absorber realized by using surface-printed patterns[1]. By using the integrated circuit elements, absorber showed broadband characteristics[2]. Introducing the functional cell concept, that absorber become computer controllable [3][4][5][6][7]. These absorbers are constructed of computer controlled metamaterial that has the capability of autonomous response to incident electromagnetic waves[8]. However, several subjects remain for study such as oblique incidence characteristics, polarization characteristics, or higher mode diffraction, and others. In this report, first, we propose a Z-chip unit cell for wave absorbers to improve the TM wave oblique incidence. The basic absorbing characteristics calculated by simulations are shown. Next, examples of a wave absorber using Z-chip are presented. The oblique incidence characteristics of the absorber are investigated by experiments. The proposed wave absorber has good characteristics for both TE and TM incidents.

II. Z-CHIP FOR WAVE ABSORBER

A. Concept of the Z-chip

Fig. 1 shows the geometry of the proposed unit cell of a Z-chip. In an actual wave absorber, a lot of Z-chip are periodically arranged in both *x* and *y* directions. The basic concept of the Z-chip is to absorb both TE and TM oblique incident wave efficiently. As shown in the figure, the Z-chip has a vertical (*y*-direction) main metal element and two horizontal (*x*-direction) metal fins. A lumped impedance element (*R*) is placed at the center of the main element. This type of a Z-chip has four tunable parameters. These are, a: Length of the fins, b: Length of the main element, d: periodic length, R: impedance of the lumped element. Although there may exist a lot of variations for the tunable parameters, we limited our stady to these values for simplicity in this report. The basic objective in introducing the Z-chip is to efficiently absorb oblique incidences that magnetic field is parallel to the main element of the chip.

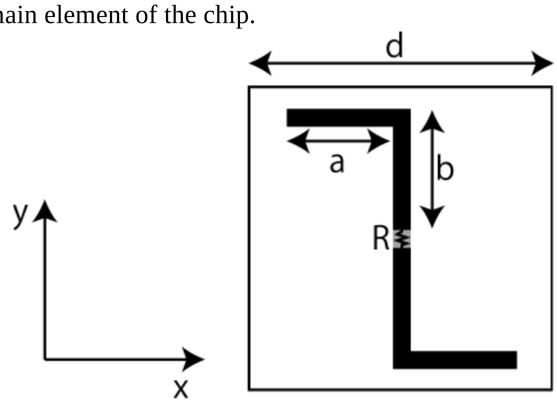

Fig. 1 Unit cell of the Z-chip

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B. FDTD simulation for the wave absorber using Z-chip

In this report, we used FDTD simulations to calculate the basic characteristics of the wave absorber using the Z-chip.

Fig. 2 shows geometry of the FDTD simulation. To calculate oblique incidents of the periodic structure, we used a Sine-Cosine FDTD algorithm shown in Ref [4]. Calculations are performed using three-dimensional FDTD method. The perfect electric conductor (PEC) is used as a short metal at the back end of the absorber. The 30 layers perfect matching layer (PML) is located at the incident side of the absorber to cancel the reflection from the boundary. The remaining boundaries are set as periodic boundary conditions. The unit structure is repeated with respect to the periodic length *P* in *x* and *y* direction. The Z-chip plane is placed at length *d* from the short metal like a λ/4 type wave absorber. The incident plane wave can be excited at arbitrary incident angles. To efficiently calculate the scattered field, the scattered field formulation of the FDTD is used. An observation plane is located at 240mm from the short metal. A two dimension Fourier transform is applied to the electric fields at the observation plane. As a result, diffraction coefficients of the plane wave expansion are obtained. We used a 0-th order diffraction coefficient as a reflection coefficient of the absorber. Although the higher order diffraction coefficient of propagating mode exists, we omit the higher coefficients for simplicity in this report.

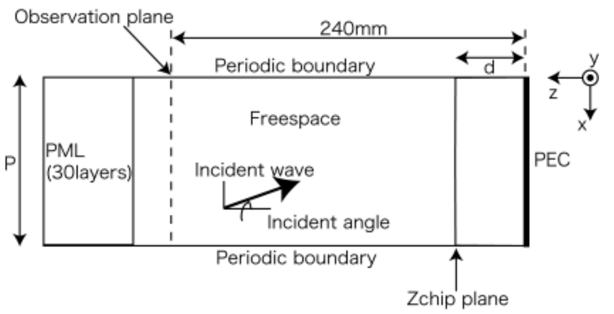

Fig. 2 Geometry of the FDTD simulation of Z-chip absorber.

TABLE 1 shows dimensions of the Z-chip absorber. The parameters are described in Fig. 1 and Fig. 2. Actually, lumped element impedance can have a reactance that is realized by using capacitor, inductor, or other electric parts. In this calculation, simple pure resistor is used.

TABLE 1
Dimensions of calculated Z-chip absorber

Fin length	a	14 mm
Main element length	b	16 mm
Periodic length	P	40 mm
Space between back metal	d	20 mm
Lumped element impedance	R	1kΩ

The incident angle of plane wave is 45 deg. The magnetic field of the incident wave oriented parallel to the *y* axis. Thus the incident is considered as a TM oblique incidence.

Fig. 3 shows the simulation result of the wave absorber using the Z-chip. The horizontal axis shows calculation frequency in GHz. The vertical axis shows reflection coefficient in dB. The solid line shows the reflection coefficient of main polarization reflection (magnetic field alongs the *y* axis). The dotted line shows the cross polarization reflection (electric field alongs the *y* axis).

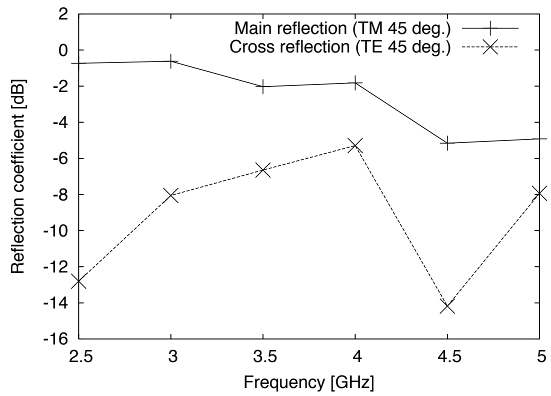

Fig. 3 Simulation result of Z-chip for wave absorber (45 deg. TM incident).

III. APPLICATION OF THE Z-CHIP

C. Actual wave absorber using Z-chip like cell unit

To investigate the effect of the Z-chip, it is applied to reduce deterioration of matching characteristics in TM wave oblique incident case when a microwave absorber was composed of a kind of Right-handed metamaterial (RHM).

Fig. 4 and Fig. 5 shows a three dimensional metamaterial absorber which is the focus of this paper[6]. This absorber is composed of unit cells with PIN diodes and microchip capacitors. PIN diodes and microchip capacitors are mounted on the middle of both side of a rectangular conductive circuit respectively. These PIN diode impedances can be controlled by feeding DC bias voltages with a pair of feeders connected a power source. Capacitors are mounted to control DC PIN diode currents. By introducing an idea of false wirings with capacitors, the wiring number of one substrate with 144 wirings in our initial absorber can be reduced to only two. In this microwave absorber construction, a conductive plate is placed behind the unit cells, keeping a spacing distance *d*. Each dimension of this absorber is tabulated in TABLE 2.

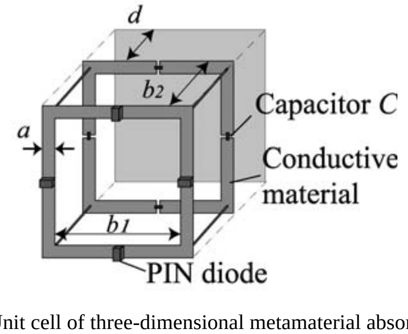

Fig. 4 Unit cell of three-dimensional metamaterial absorber.

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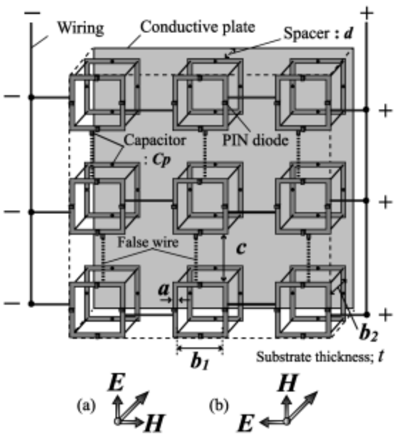

Fig. 5 Three dimensional metamaterial absorber.

TABLE 2

DIMENSIONS OF ABSORBER

a	2.0mm	b_1	20.0mm	b_2	12.0mm
c	25.0mm	*d*	5.0mm	*C*	1.0pF

The principle of the present absorber can be simply explained by introducing an equivalent transmission line with a parallel circuit composed of a series of *R*, *C*, and *L* component, and a short circuit with distance *d* as shown in Fig. 6.

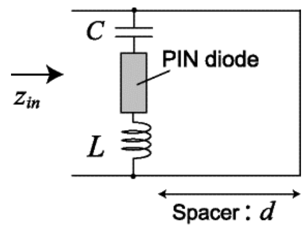

Fig. 6 Equivalent transmission line with a microwave absorber.

That is, the fundamental principle is based on the construction of a *C*, *R*, and *L* circuit using unit cells. If a normalized input impedance z_{in} (= Z_{in}/Z_c, Z_c: transmission line characteristic impedance) looking through the absorber can be adjusted to have the value of 1.0 by controlling the PIN diode bias voltage, matching conditions are satisfied. This configuration, however, has had a problem that the matching characteristic of oblique incidence of TM wave has been degraded, compared with that of TE wave. This is caused by the fact that magnetic fields cannot fully couple with this unit cells and cannot fully activate the PIN diodes in the TM wave oblique incidence case.

Fig. 7 and Fig. 8 shows an example of matching characteristics for both TE and TM waves at the incident angle of 45 deg. Present matching frequency is 5.2 GHz. As shown in Fig. 8, the matching can't be taken for the TM wave case where the incident wave is at the angle of 45 deg. Therefore, to improve the TM wave oblique incidence characteristics, a new configuration of the unit cell using Z chips is introduced.

D. New configuration of the Z-chip wave absorber

Fig. 9 shows the new configuration of the unit cell of the wave absorber. To couple with magnetic fields, the concept of Z-chip is introduced to 2D rectangular conductive circuits. The fin sizes are written in Fig. 9 and other sizes are the same as in Table 1. In this configuration, small square conductive patches (2x2 mm) are attached on the substrate to control the matching characteristic.

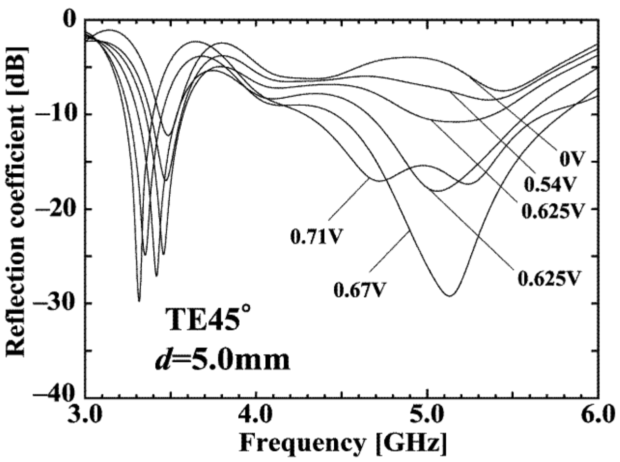

Fig. 7 Oblique incident matching characteristics at 45° both for TE wave.

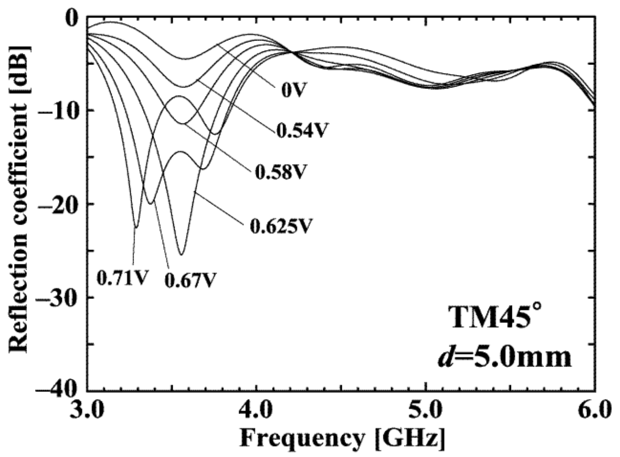

Fig. 8 Oblique incident matching characteristics at 45° both for TM wave.

Fig. 10 shows experimental results of matching characteristics at 3.46GHz both for the normal incidence and for the oblique incidence of TE and TM waves at angle of 45°. It becomes clear that the matching characteristic of oblique incidence for TM wave is improved by introducing the Z-chip concept.

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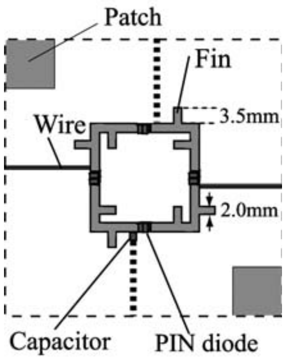

Fig. 9 New configuration of the unit cell.

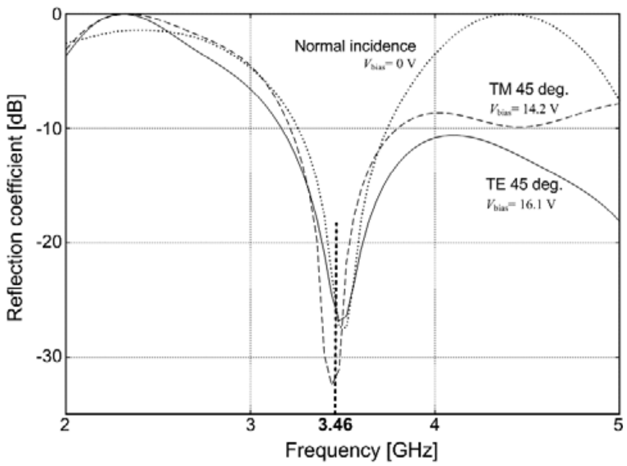

Fig. 10 Matching characteristics of the absorber.

IV. Conclusion

In this report, we proposed a novel RH-metamaterial structure of the Z-chip for improving the oblique incidence characteristics as an electromagnetic wave absorber. The basic characteristics of a wave absorber using a Z-chip is calculated by FDTD simulation at an oblique incidence. To demonstrate the efficiencies of the chip, a unit cell like a Z-chip was introduced to an actual computer controlled metamaterial electromagnetic wave absorber. The free space method is applied to measure the oblique incident reflection coefficient of the absorber. As a result, it is shown that the TM oblique incidence characteristics has improved the by structural improvement of the chip.

There are many study themes for this kind of metamaterial. For example, following items are left for further study that are directly related to results of this report.

- Investigating detailed characteristics of Z-chips by FDTD simulation, such as polarization characteristics or higher mode diffraction coefficients.
- Designing the wave absorber using Z-chip by simulation that can be used for oblique incidences.
- Fabricating and measuring an actual computer controllable wave absorber that has an autonomical behavior.
- Investigating applicability of the Z-chip for near field absorption devices.

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