EM-Wave Absorber Composed of Periodic Patch Antennas Designed for Both H- and V-polarized Waves at 2.4GHz Band

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Abstract—We proposed EM-wave absorber with periodic patch antennas. It has two feed points on a square patch. We simulated electromagnetic field of patch antennas having infinite periodic structures by using FDTD method and designed at 2.4GHz band. Then, we manufactured and measured the EM-wave absorber for 2.45GHz. As a result, both H- and V-polarized waves could be absorbed at 2.4GHz.

Keywords—Wave absorber, Patch antenna, FDTD method, Meta-material

I. INTRODUCTION

EM-wave absorber is widely used to improve the wireless environment, such as for RFID or wireless LAN to work properly. EM-wave absorber is typically made from carbon and ferrite etc. However, since absorbing characteristics is determined by those materials, their design is restricted by the materials [1].

For improving this problem, we proposed a new type of EM-wave absorber composed of periodic patch antennas on a printed circuit board [2]. The length of periodic structure is shorter than the half-wave length. If we can make EM-wave absorber using a printed circuit technique, unlike the design depending on material, it can be designed only by adjusting loads or size of structure.

Furthermore, this EM-wave absorber is used by a printed circuit board, so it may be mass-produced like IC tag, with lighter weight. In these points, it can be advantageous both in applicability and cost.

We designed the absorbing frequency by choosing patch antenna’s size and designed EM-wave absorber for all polarized waves of vertical incidence wave. In addition, we considered the optimum load that consumes maximum power when connected to the feed points of the patch antenna. The EM-absorber’s structure is shown in Fig.1. In this research, we simulated electromagnetic field of patch antennas having infinite periodic structures by using FDTD method and designed at 2.4GHz band. Then, we manufactured and measured the EM-wave absorber for 2.45GHz. As a result, both H- and V-polarized waves could be absorbed at 2.4GHz.

II. PERIODIC PATCH ANTENNAS

A. Unit Periodic Structure

We describe an unit periodic structure of patch antenna’s EM-wave absorber. It has two feed points on a square patch for any polarized waves of normal incidence wave. By arranging two feed points, as shown in Fig.2, it can be designed to absorb both horizontal and vertical polarization. In Fig.3, when the incident wave’s electric field \( E \) has a polarization angle, it can be divided into horizontal and vertical polarization. Thus, polarization which has any angle can be absorbed. Here, \( \theta = 0^\circ \) represents horizontal polarization, and \( \theta = 90^\circ \) represents vertical polarization.

B. Equivalent Circuit Model

Unit periodic structure of patch antenna’s EM-wave absorber including load circuit is expressed by the equivalent circuit as Fig.4. The left-hand side of port 1,2 represents the patch antenna, and the other side represents the load circuit. When microwave enters to EM-wave absorber, open voltages appear at each ports. These voltages are replaced by source of voltages \( e_1, e_2 \). Also, the left-hand side of voltage sources represents the source impedance of the antenna \( Z_S \) and the right-hand side of them represents the load impedance \( Z_L \).
From the maximum power transfer theorem, when the load impedance is satisfied with
\[
Z_L = Z_S^*,
\]
where * is a complex conjugate transposition, the maximum power is consumed by the load circuit [3]. In this case, we can express each impedances by symmetry Π-type circuit.

III. NUMERICAL ANALYSIS

A. Analysis Model

To compute the source impedance of EM-wave absorber of periodic patch antennas, we simulated the electromagnetic field with the FDTD method. The analysis model is shown in Fig.5. The cell size \( \Delta x = \Delta y = \Delta z = 0.8\text{mm} \), and time step \( \Delta t = 1.53\text{ps} \).

A patch and a ground plane is set as perfect electric conductors (PECs). In the dielectric area, the permitivity is set to \( \varepsilon_r = 4.7 \) (glass epoxy). Also, the thickness of a printed circuit board is 1.6mm. To assume the infinite periodic structure, periodic boundary condition (PBC) is set to top and bottom surface, and behind and front surface. By exciting the Gaussian pulse \( i(t) \) whose bandwidth is 5GHz at the port 1, the output voltage \( v(t) \) is calculated. Source impedance is obtained by calculating \( V(f)/I(f) \), where \( I(f), V(f) \) are the DFT of \( i(t) \) and \( v(t) \).

\( a \) is the length of a square patch, \( p \) is the length of the structure, and \( d \) is the distance from a center of patch to the port, both distance of ports is same length from a center of patch.

We analyzed the change of frequency characteristics of source impedance by changing each parameters, \( a, p, d \).

B. Source Impedance by the Length of the Structure \( p \)

We examined the change of the frequency characteristics of source impedance by changing \( p \). It is desirable that \( p \) is much shorter than wavelength, but under the condition that Bragg diffracted ray doesn’t occur in worst case, it is set to \( p < \frac{\lambda_0}{2} \), where \( \lambda_0 \) is the shortest wavelength. At this time, it is set to \( a = 25.6\text{mm}, d = 12.8\text{mm}, \) and \( p = 40.0, 49.6\text{mm} \) (< \( \frac{\lambda_0}{2} = 60.0\text{mm}, \) at 2.5GHz). Fig.6, 7 shows the frequency characteristics of self-impedance when \( p = 40.0\text{mm} \) and \( p = 49.6\text{mm} \), where self-impedance is calculated by \( V(f)/I(f) \) at the port 1.

C. Relation between \( a \) and Resonance Frequency

Fig.8 shows the relation between the side length of a patch, \( a \), and resonance frequency. In addition, we compared \( a \) with \( f_r = \frac{c}{2a\sqrt{\varepsilon_r}} \) (\( f_r \) : resonance frequency, \( c \) : speed of light). It seems that the effect which the resonance wave oozes out of the patch makes the resonance frequency lower than the approximation. Thus, it is expected that half wavelength of the resonance wave is longer than the length of a patch.
Fig. 7. Imaginary part of self-impedance by \( p \)

Fig. 8. The relation between \( a \) and resonance frequency

D. Absorbing Characteristics

Since the source impedance of periodic patch antenna’s EM-wave absorber were calculated, we calculated the absorbing characteristics when loads are connected to the antenna. Parameters are set as \( a = 25.6 \text{mm}, d = 12.8 \text{mm} \), and we compared absorbing characteristics with changing \( p \). As shown in Fig.9, we calculated absorbing characteristics by connecting pure resistances that match at the resonance point. \( R_b \) is ignored because of high negative resistance.

Fig. 9. Equivalent circuit model (pure resistance at the resonance point)

Fig.10 shows the absorbing characteristics of symmetry mode and anti-symmetry mode when \( p = 30.4 \text{mm} \) and \( p = 49.6 \text{mm} \). Here, symmetry mode is excited with same amplitude and same phase on two ports, and anti-symmetry mode is excited with same amplitude and opposite phase on two ports. In terms of polarization of Fig.3, symmetry and anti-symmetry modes correspond to \( \theta = 45^\circ \), and \( \theta = -45^\circ \), respectively. Here, we define the fractional bandwidth as the band which satisfies \(-20\text{dB}\) or less reflection, divided by a resonance frequency.

Fig.11 shows the relation between \( p \) and the fractional bandwidth. When \( p \) gets smaller, the fractional bandwidth becomes larger, but it is about 1\% narrow bandwidth. When \( p = 30.4 \text{mm} \), the fractional bandwidth is 1.03\% at 2.43GHz. Though it is a narrow bandwidth, any polarized waves can be absorbed at the absorbing frequency.

IV. EXPERIMENT

A. Measurement Environment

We manufactured the EM-wave absorber sample which has \( 5 \times 6 \) patch antennas on double-sided FR4 printed circuit board (PCB), vertical 250 mm, width 200 mm, and 1.6 mm in thickness as shown in Fig.12. With FDTD method, we determined each sizes of unit periodic structure as shown in Table.I for 2.45GHz. Also, a reference metal plate was double-sided FR4 raw PCB of the same size, whose edge was covered with the copper tape to prevent internal resonance.

Fig.13 shows the measurement system. We used fixed ridge horn antenna and a movable sample stand to move sample. We did 1-port SOL calibration with VNA, and measured \( S_{11} \) at the port of antenna, with of no sample, with a reference plate, and with the EM-wave absorber sample. Frequency range is from 1GHz to 5GHz, interval is 10 MHz, and we measured at a total of 401 point frequencies. Moving a movable stand at the interval of 5mm from the position 0.5m away from the...
antenna aperture, we measured $S_{11}$ at a total of 12 positions. EM-wave absorber reducing the reflection from a wall or a floor was not installed in the room. When we measure $S_{11}$ with this method, their trajectories on complex plane have a similarity relationship. After nullating these trajectories’ center of gravities, they are pattern-matched with respect to the amplitude and phase. As a result, we obtain complex reflection coefficient. With this measurement, we can receive stronger reflection signal at antenna’s near field, as well as the elimination of spurious reflection signal [4].

**V. CONCLUSION**

With FDTD method, we simulated EM-wave absorber of periodic patch antennas. As a result of simulation, it absorbed 1% fractional bandwidth at 2.43GHz only by connecting pure resistances. In the experiment, we confirmed that it absorbed $-15\text{dB}$ at 2.4GHz for both H- and V-polarized waves, so it could absorb the target frequency. It is important to increase the fractional bandwidth because proposed EM-wave absorber has narrow bandwidth. We are considering the improvement of bandwidth by adding parasitic patches. Furthermore, the angular characteristics should be investigated.

**REFERENCES**


