LETTER

Fabrication of Alternating-Phase Fed Single-Layer Slotted Waveguide Arrays Using Plastic Materials with Metal-Plating

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SUMMARY Lightweight single-layer slotted waveguide array antennas are fabricated using plastic materials with metal-plating. A plastic material that has good heat-radiation properties is investigated. Three types of antennas are fabricated by milling, using ABS resin, heat-radiating plastic, and aluminum alloy. In measurements, all three types of antennas are confirmed to have almost the same VSWR and gain in the 25 GHz frequency band.

key words: *fixed wireless access (FWA), slotted waveguide array, plastic material, metal-plating*

1. Introduction

Wireless IP Access System (WIPAS), which offers low costs to home subscribers, is a point-to-multipoint (P-MP) fixed wireless access (FWA) system at 26 GHz frequency band for areas with low subscriber density [1]. The reduction in size and cost of the wireless terminal (WT) is indispensable to WIPAS service deployment in rural areas. Development of an alternating phase-fed single-layer slotted waveguide array [2]–[4] and a Microwave Monolithic IC (MMIC), which are the key components of the WT equipment in WIPAS, led to successful reductions in both cost and weight of order 1/10 and 1/5, respectively. The weight reduction of the antennas would further contribute to simpler installation of WTs. As the antenna also acts as a heat sink for RF, IF and baseband circuits integrated on the back of the waveguide base, the heat-radiating capabilities of the antenna materials are important for the materials of antennas.

The alternating phase-fed single-layer slotted waveguide array installed in WT consists of a slotted plate and a grooved waveguide base as shown in Fig. 1. These two components are mass-produced from aluminum alloy by a pressing and a die-casting process, respectively. Since rigorous electrical contact between the waveguide base and the slotted plate is in principle not required, they are fixed up only by screws, together with a choke surrounding the periphery. In this antenna, the slotted plate and the grooved waveguide base are quite different in thickness, but should be fabricated with the same material in view of robustness against thermal distortion.

This is the first report of the successful fabrication of full plastic single layer slot antennas with the performance comparative to that made from metal. In addition to the popular ABS resin, the heat-radiating plastic with higher thermal conductivity are tested. As the trial fabrication of plastic antennas, a milling process instead of injection molding [5] is adopted. For the direct comparison of the potential of materials in antenna application, three types of antennas made of ABS resin, heat-radiating plastic and the conventional aluminum alloy are designed and fabricated using the same parameters. Almost the same antenna performances are achieved except the slight change in the beam tilting angle for the heat radiating plastics due to the non-negligible thickness of the plating which is indispensable to suppressing surface roughness.

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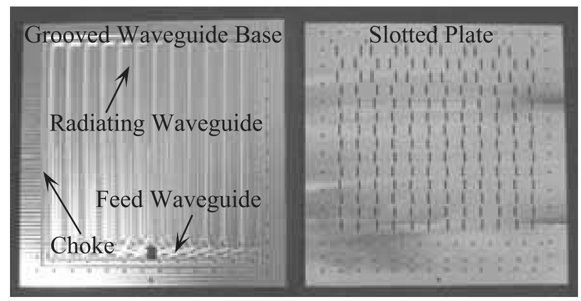

Fig. 1 Alternating phase-fed single-layer slotted waveguide array made from aluminum alloy.

2. Characteristics of Antenna Materials and Metal-Plating

When investigating possible antenna materials, ABS (Acrylonitrile Butadiene Styrene) resin is first considered, since it has a very low weight and is easy for metal-plating. To realize similar heat-radiating capabilities as the aluminum alloy, also a heat-radiating plastic is investigated. The physical properties of the selected antenna materials are summarized in Table 1. The relative density of ABS resin is 1.04, which is only 39% of that of the aluminum alloy, but the allowable temperature limit 85°C is too low to be used inside WT for WIPAS. On the other hand, the heat-radiating plastic exhibits a higher allowable temperature limit of 126°C together with a relative density of 1.60, which is 60% of that of the aluminum alloy. The thermal conductivity is the property of a material that indicates its ability to conduct heat. It is defined as the flux of heat (energy per unit area per unit time) divided by a temperature gradient (temperature difference per unit length). The heat-radiating plastic has a much

Table 1 Physical properties of antenna materials.

	Aluminum alloy	ABS resin	Heat-radiating plastic
Relative density	2.68	1.04	1.60
Allowable temperature limit		85°C	126°C
Thermal conductivity	137 W/mK	0.2 W/mK	7 W/mK

Table 2 Parameters for the metal-plating of the plastic antennas.

	ABS resin	Heat-radiating plastic
Plated metal	Nickel (Ni)	Copper (Cu)
Electric conductivity	15×10^6 S/m	58×10^6 S/m
Skin depth at 25 GHz	0.82 μm	0.42 μm
Plating thickness δ	10±5 μm	45±5 μm

higher thermal conductivity than the ABS resin, when the ratios between the plastic materials and the aluminum alloy are considered.

In this paper, three types of antennas, one made from aluminum alloy, one from ABS resin and the other from heat-radiating plastic, are fabricated and compared. At the present stage of the trial manufacture, a milling process instead of die-casting is applied to both the slotted plates and the grooved waveguide bases. Conventionally, a plastic waveguide base is combined with a metal slot plate. They have different thermal expansion coefficients, so the antenna may be distorted due to temperature variations. After milling, in the metal-plating process a layer of nickel with the thickness of 10±5 μm is deposited on the components of plastic antenna made from the ABS resin, and similarly a layer of copper with the thickness of 45±5 μm is deposited on the components of plastic antenna made from the heat-radiating plastic. The parameters for the metal-plating are summarized in Table 2. The plating thicknesses δ are much thicker than the corresponding skin depths for both plated metals at 25 GHz, which are calculated in the condition of smooth surface. Relative thick metal-plating is necessary, because the asperity will lead to the degradation of electric conductivity. However, a larger value of δ will result in a considerable variation in antenna dimensions. This disadvantage is not included in the trial fabrication and all three types of antennas are manufactured to the same dimensions prior to the metal-plating. This difference results in the difference of beam-tilting direction discussed in the next section.

3. Antenna Fabrication and Measurement

The design frequency is 25.0 GHz. The cross-sectional dimensions of the radiating waveguides are a = 8 mm in width and b = 3 mm in height. There are 12 radiating waveguides arranged side by side and 14 slots cut in each broad wall of the waveguides. The thickness t of the slotted plate is increased to 2mm, to make the fabrication easier

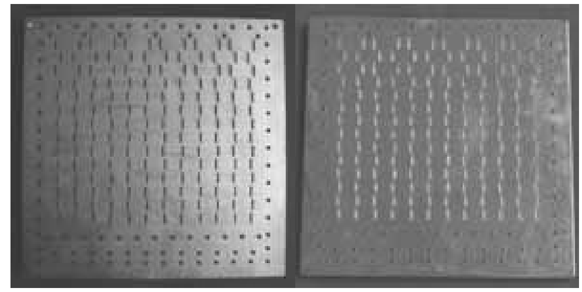

Fig. 2 Plastic antennas with metal-plating: (left) ABS resin with nickel plating; (right) heat-radiating plastic with copper plating.

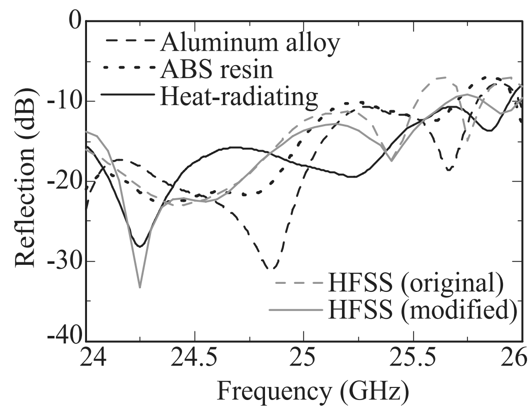

Fig. 3 Frequency characteristics of reflection at antenna input.

in milling process of plastics. In order to suppress the reflection from the slots as well as to decrease the slot spacing below half guided wavelength, backward beam-tilting technique is adopted in the design of the slot array [4], [6].

The fabricated antennas made from the aluminum alloy and the plastic materials with metal-plating are shown in Figs. 1 and 2, respectively. These antennas are fed by a coaxial cable through a coaxial-waveguide adapter connected to the bottom. The reflections measured at the antenna input for all three antennas are shown in Fig. 3. As can be easily observed, all antennas have almost similar characteristics, and the envelope curves below −10 dB almost coincide to each other. The aperture field illuminations are measured in the near-field measurement system. The two-dimensional (2-D) aperture distributions of amplitudes and phases at the design frequency are compared in Fig. 4. The main beam of heat-radiating antenna is at −7.0 degrees tilted from the boresite, whereas that of other two antennas is at −7.5 degrees. Since these beam shifts are identified as the effects of a large plating thickness and could be removed by introducing revised dimension parameters easily, the potential of the material or uniformity of aperture phase would better be extracted by subtracting the phase taper associated with the corresponding beam-tilting angles. The distributions of phase in Fig. 4 indicate the results after above treatment. After this modification in phase, the uniformity of the aperture distribution for all the antennas can be virtually compared. As the result, we concluded that three antennas

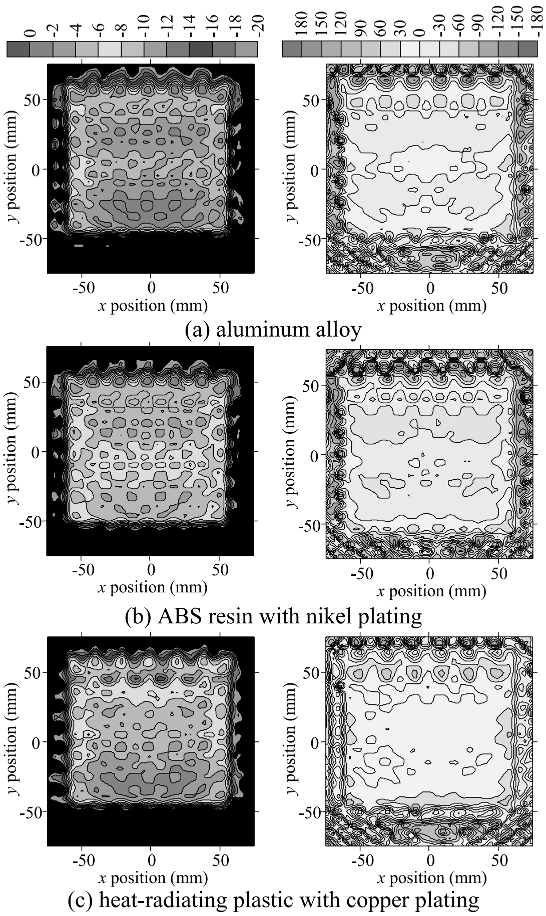

Fig. 4 2-D aperture distribution in amplitude and phase.

show similar characteristics both in amplitudes and phases, and similar potentials for antenna application.

The antenna gains are measured in an anechoic chamber, and the results are summarized in Fig. 5. The graphs for the antennas made from the aluminum alloy and the ABS resin agree well with each other. However, for the heat-radiating plastic antenna the frequency of the maximum gain has shifted. It is because of the variation of the antenna dimensions due to the larger plating thickness of $45\pm5\,\mu$m. Such thick plating is unfortunately inevitable to smooth the surfaces of the heat-radiating plastic, since this material is not easy for metal-plating as the ABS resin. The relation between this frequency shift and the antenna dimensions is qualitatively demonstrated using an FEM-based simulator HFSS (High Frequency Structure Simulator) [7] by only modifying the waveguide width a to $a - 2\delta = 7.91$ mm and the slot thickness t to $t + 2\delta = 2.09$ mm, and leaving the other parameters unchanged. These simulation results are also shown in Fig. 5. Similar frequency shift phenomenon is observed in the HFSS results. The variations of antenna dimensions should be taken into account during fabrication to improve the design. Alternatively, the improvements in metal-plating for heat-radiating plastic with small thickness or the investigation for new materials is the solution to enhance the antenna performance. As for the antenna gain, the

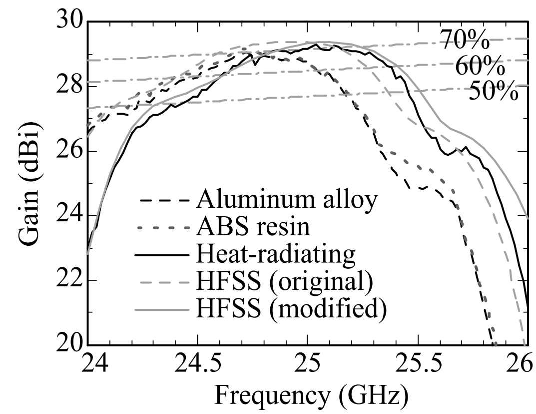

Fig. 5 Frequency characteristics of antenna gain.

antennas made from plastic materials with metal-plating exhibit performances comparable to aluminum alloy antenna. The potential of single-layer plastic antennas has been fully confirmed.

4. Conclusion

To realize weight savings in single-layer slotted waveguide arrays, plastic materials with metal-plating are adopted for fabrication. Furthermore, a plastic antenna with heat-radiating properties is also investigated. Two plastic antennas made from ABS resin and heat-radiating plastic show reasonable antenna performance compatible with the aluminum alloy antenna. As the future work, the cost and the mass-production of plastic antennas should be investigated further.

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