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

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Abstract

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 in milling process, using ABS resin, heat-radiating plastic, and aluminium alloy. In measurements, all three types of antennas are confirmed to have almost the same VSWR and gain around 25GHz frequency band.

1. Introduction

Wireless IP Access System (WIPAS) with a low cost for home subscribers, is a point-to-multipoint (P-MP) fixed wireless access (FWA) system at 26 GHz frequency band for the area 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 single-layer slotted waveguide array [2-5] 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 alternating-phase fed single-layer slotted waveguide array [4, 5] 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 aluminium 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.

Reducing the weight of the antennas would further contribute to simplifying the 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. In this paper, the authors present new lightweight antennas made using plastic materials that have good heat-radiating properties. For comparison, antennas made from conventional aluminium alloy and plastic materials together with metal-plating are also fabricated.

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

In this paper, three types of antennas, one made from aluminium 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 antennas 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 antennas 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 25GHz, 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.

3. Antenna Fabrication and Measurement

The design frequency is 25.0GHz. The cross-sectional dimensions of the radiating waveguides are a = 8mm in width and b = 3mm 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 slot plate is increased to 2 mm, to make the fabrication easier 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 [5, 6].

The fabricated antennas made from the aluminium alloy and the plastic materials with metal-plating are shown in Figures 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 Figure 3 (a). As can be observed from the figure, all antennas have almost similar characteristics, and the envelope curves below -10dB coincide. The aperture field illuminations are measured in the near-field measurement system. All the antennas show similar characteristics, except for the main beam of heat-radiating antenna, which is at -7.0 degrees, whereas for the other two antennas it is at -7.5 degrees.

The antenna gains are measured in an anechoic chamber, and the results are summarized in Figure 3 (b). The graphs for the antennas made from the aluminium 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±5 μm. The surface roughness on slotted plate and grooved waveguide base are measured at the centre point through laser microscope as shown in Figure 4 for different plating thickness δ. Such thick plating of 45μm is unfortunately inevitable to smooth the surfaces of the heat-radiating plastic, since it 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-2δ= 7.91 mm and the slot thickness t to t+2δ = 2.09mm, and leaving the other parameters unchanged. These simulation results are also shown in Figure 3 (b). 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. After all, the antennas made from plastic materials with metal-plating exhibit comparable operation properties with the aluminium alloy antenna in terms of reflection and gain.

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 similar antenna performance with the aluminium alloy antenna.

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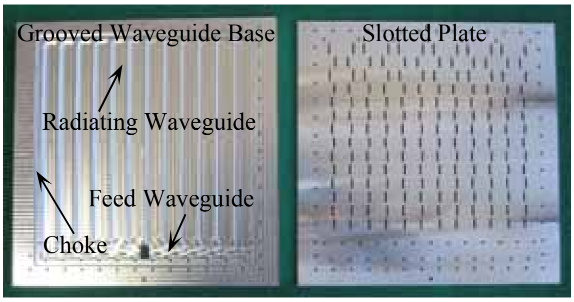

Figure 1: Single-Layer Slotted Waveguide Array Made from Aluminium Alloy

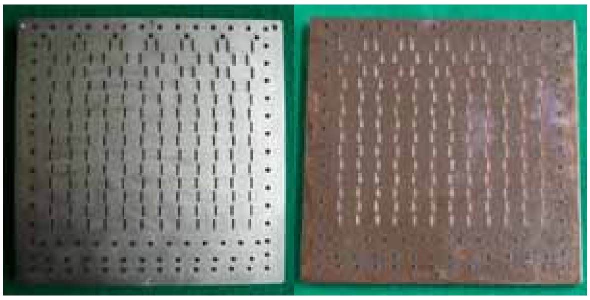

Figure 2: Plastic Antennas with Metal-Plating, (left) ABS Resin with Nickel Plating; (right) Heat-Radiating Plastic with Copper Plating

Table 1: Physical Properties of Antenna Materials

	Aluminium alloy	ABS resin	Heat-radiating plastic
Relative density	2.68	1.04	1.60
Allowable temp. limit		85°C	126°C
Thermal conductivity	137W/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	15×10^6S/m	58×10^6S/m
Skin depth @ 25GHz	0.82 μm	0.42 μm
Plating thickness δ	10 ± 5 μm	45 ± 5 μm

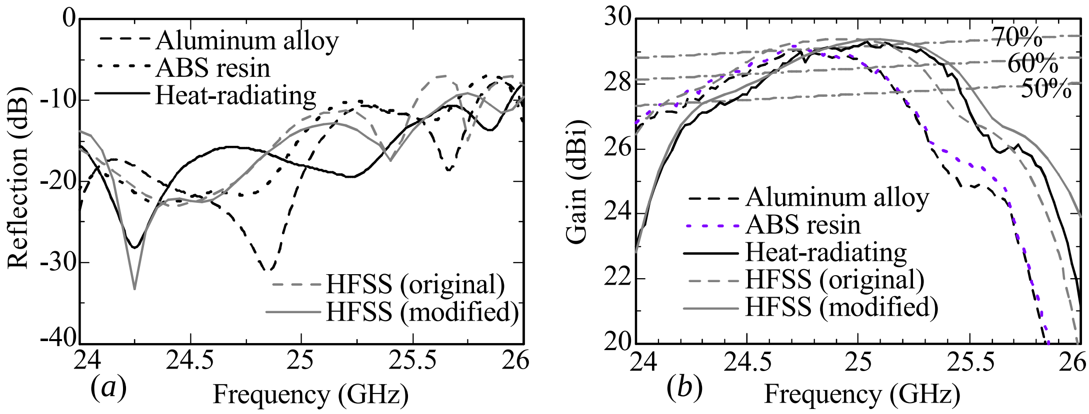

Figure 3: Frequency Characteristics of Reflection and Gain for Fabricated Antennas

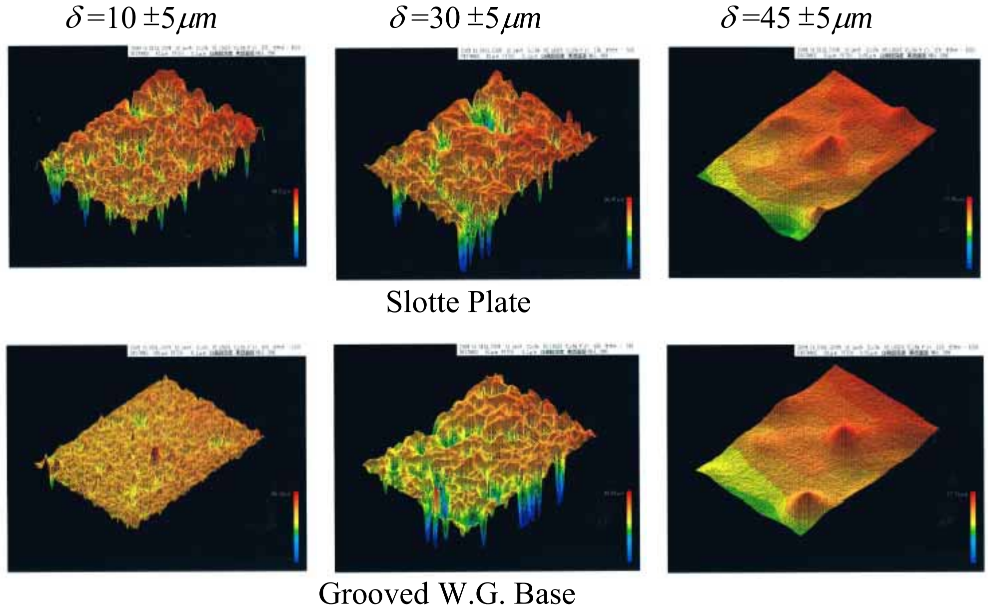

Figure 4: Surface Roughness Measured through Laser Microscope for Different Plating Thickness δ.

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