A 94GHz-Band Monopulse-Feed Slotted Waveguide Antenna by Stereolithography and Metal-Plating

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Abstract

We design a 94GHz-band monopulse-feed antenna. The reflections for both inputs are suppressed below -15 dB over a 4 GHz bandwidth. A high isolation of more than 50 dB is estimated over the frequency range of 90 ~ 98 GHz. This prototype antenna is ready to be fabricated by applying stereolithograpy and plating.

Keywords : stereolithography metal-plating monopulse-feed antenna waveguide slot array

1. Introduction

The highly functional antenna and radar systems associated with feeding networks always have complicated structures. The integration of the antennas and the feeding circuits can lead to the reduction in both insertion loss and manufacture cost. However, the traditional processing technology such as milling and etching can not be easily applied to the realization of multi-layer structures. In this study, a new fabrication technique by applying the stereo-lithograph of plastics and metal-plating is introduced to the realization of a mono-pulse antenna in 94 GHz band. Stereolithography is a three-dimensional (3-D) fabrication process to make solid objects by successively "printing" thin layers of the UV curable photopolymer resin [1]. On each layer, the laser beam traces a part cross-section pattern on the surface of the liquid epoxy resin. By applying stereolithography, even the complicated 3-D structure can be fabricated cheaply and fastly with a light weight. In this paper, a 94GHz-band monopulse-feed antenna with symmetric feeding circuit and slot array arrangement is designed and to be fabricated by stereolithograpy and metal-plating.

2. Fabrication Technique using Stereolithograpy and Metal-Plating

2.1 **Process of Stereolithography and Metal-Plating**

The process procedure is briefly illustrated as follows. In a word, a 3D structure is built slice by slice from bottom to top in a vessel of liquid UV curable photopolymer resin. Starting from a 3-D CAD data, the model is cut into thin horizontal slices and programmed into the stereolithography 3-D printing machine. This machine then uses a computer controlled laser to draw the bottom cross section onto the surface of a liquid proxy resin that hardens where struck by the laser. The part is then lowered to a depth corresponding to the section's thickness and the next cross section is then drawn directly on top of the previous one. This is repeated until the whole model is finished. At present, the minimum thickness of sections' thickness is 0.1mm. It must be taken into account during the design that the vertical thickness should be the multiple of 0.1mm, while basically there are no limitations in the horizontal dimensions. After the stereolithography, metal-plating on both the inner and outer surfaces is the key to realize the waveguide structure so as to reduce the transmission loss even in the millimeter-wave band. Here, chemical plating together with electroplating and other techniques are under investigation. There are a lot of advantages of fabricating the antenna using stereolithography with metal-plating. For examples, it will be extremely lightweight and the complex 3-D structure antenna integrated with its feeding circuit can be precisely realized without further insertion loss.

2.2 **Hollow Waveguide Realized by Applying Stereolithography and Plating**

The hollow waveguide fabricated by using stereolithography with metal plating in 94GHz band is investigated first. The dimension of cross-section is modified as 2.54 mm x 1.27 mm, whose thickness is different from the standard waveguide WR-10. Figure 1 shows the photographs a 2-inch hollow waveguide fabricated by using stereolithography with two types of metal plating. The first one is the chemical plating together with electroplating [2]. As the preprocessing, all the surfaces are roughened to some extent for easy chemical plating. However, a relative large plating thickness is necessary to smooth that roughness. Here, the thicknesses for chemical plating and electroplating are 2μm and 10μm, respectively. The second one is the molecular adhesive plating, where the preprocessing to roughen the surfaces is not necessary. A smoother surface and a smaller plating thickness are anticipated. As the initial try, the plating thickness is set up at only 1μm. Figure 2 shows the measured frequency characteristics of the 2-inch waveguide produced in different methods. The waveguide by applying molecular adhesive plating exhibits larger transmission loss than that by applying chemical plating together with electroplating. This is because the plating thickness in molecular adhesive plating is only 1μm. Nonetheless, almost identical transmission characteristics compared with chemical plating together with electroplating can be expected by only increasing the plating thickening to 2 or 3 μm.

3. Structure and Design of the Monopulse-Feed Antenna

The monopulse radar system [3] enables the measurement of angle in current beam position during one pulse. It has high accuracy of angle detection because of the small time fluctuation. The elements in antenna array are divided into two halves. These two separate sub-arrays are placed symmetrically in the focal plane on each side of the axis of the radar antenna. In the monopulse system, a Σ-pattern is synthesized by feeding both sub-arrays in-phase, while a Δ-pattern is realized by feeding them with a phase difference of 180 degrees out of phase.

In this study, we are going to realize the symmetric structures in both the feeding and radiating parts. Moment method analysis is applied in the antenna element design, and the finite element method based electromagnetic simulator HFSS is applied in the full-structure analysis and further optimization. The feeding circuit is designed first. It is well known that, those two sub-arrays can be easily fed with same amplitudes and in-phase through an H-plane T-junction, while they can be fed with same amplitudes and in alternating-phase through an E-plane T-junction. Magic-T is just the unique structure characterized as the combination of H-plane and E-plane T-junctions with high-isolation. As illustrated in Figure 3, two radiating waveguides in the monopulse-feed antenna is fed by using the Magic-T together with one pair of H-plane bends at a right angle [3]. Firstly, the key components of the H-Plane, E-Plane T-Junction and H-plane bend are designed separately. After that, they are combined together and are fine-tuned again by applying HFSS with higher-order modes taken into account. The center frequency is 94 GHz. Waveguide height b is 1.1 mm, and the waveguide widths a_1, a_2 are 2.2 mm in common. Other structural parameters are shown in Figure 3. Conducting post is the typical structure fabricated in a substrate for reflection suppression [3], but it can not be easily realized in a hollow waveguide. This time, the reflection in the feeding circuit is mainly optimized by changing d. The frequency characteristics of reflection and transmission are summarized in Figure 4. The reflection is suppressed below -30 dB at the neighborhood of center frequency, and a high isolation of more than 70 dB is estimated over the frequency range of 90 ~ 98 GHz.

Longitudinal slots are introduced as the radiating elements. Each sub-array has five slots cut in the broad wall of radiating waveguide with symmetry along the center axis. This two-dimensional 2x5-slot array is designed using the combination of a full-wave MoM analysis and an equivalent circuit model [4]. We are going to realize a uniform excitation for maximum directivity. The standing-wave excitation associated with the slot spacing equal to $\lambda_g/2$ is adopted for reflection suppression maintaining the mainbeam at the boresight. The spacing between the last slot to the short is $\lambda_g/4$. To keep the stableness in the process of stereolithography, the thicknesses of slots and sidewall between two radiating waveguides are set at 0.5 mm. As the initial design, the slot width is selected as 0.4mm, even though a wider slot may be preferred to plate the antenna more easily. As illustrated in the design procedure [4], the slot spacing and admittance are designed in the equivalent circuit as summarized in Figure 3. The slot spacing is perturbed from the initial value of $\lambda_g/2$, to compensate the phase deviation due to the reflected wave from all slots. To realize an input admittance equal to 1 for input matching, basically the conductance is nearly equal to 0.2 in the five-element array. The desired real part (conductance) and the imaginary part (susceptance) of admittance will be realized by adjusting the slot offset and length iteratively. The slot length and slot offset determined by applying full-wave MoM analysis are summarized in Figure 3. The interesting thing is that, the radiating slots located in neighbor waveguides have opposite offsets for symmetric arrangement. It means, those two radiating waveguides arranged side-by-side provides us with a Σ-pattern by adopting the alternating-phase feed. The slot parameters are determined for the alternating-phase fed array and they are not futher optimized for the in-phase fed one. The reflections for both the alternating-phase and in-phase fed arrays are summarized in Figure 5.

After designing the feeding circuit and the radiating slot array, they are united together and analyzed by applying HFSS. Figure 6 shows the designed frequency characteristics of reflections and transmissions in the 94GHz-band monopulse-feed antenna. At the center frequency of 94 GHz, the reflection at Ports 1 and 2 are -16.8 dB and -16.3 dB, respectively. Over a 4 GHz bandwidth, both reflections are suppressed below -15 dB. A high isolation of more than 50 dB is estimated over the frequency range of 90 ~ 98 GHz, with the effects of slot array taken into account. Figure 7 shows the E-plane radiation patterns of monopulse-feed antenna for both inputs from Ports 1 and 2. A relative deep null at the boresight for the Δ-pattern is estimated because of the symmetric structures in both the feeding and radiating parts. The prototype monopulse antenna designed in 94 GHz band is now ready for fabrication by applying stereolithography and metal-plating. As illustrated in Figure 8, the antenna connection with the WR-10 flanges is also taken into account.

4. Conclusion

A new process by applying stereolithography and metal-Plating is introduced to the realization of 3-D structures for light-weight, fast manufacture and low insertion loss. A monopulse-feed antenna is designed in 94GHz band. The symmetric structures in both the feeding and radiating parts are the key to realize high performance especially in radiation patterns. Magic-T like structure is introduced in the feeding circuit, and the longitudinal slots with mirrored arrangements are adopted as the radiating elements. The reflections for either input are suppressed below -15 dB over a 4 GHz bandwidth. A high isolation of more than 50 dB is estimated over the frequency range of 90 ~ 98 GHz. This antennas operates properly even by checking the E-plane radiation patterns for both the Δ-pattern and Σ-pattern. Now, we are ready to fabricate the prototype antenna applying stereolithography and metal-plating .

References

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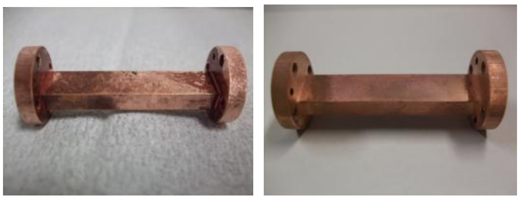


chemical plating together with electroplating

Molecular Adhesive Plating

Figure 1: WR-10 fabricated by using two type plating

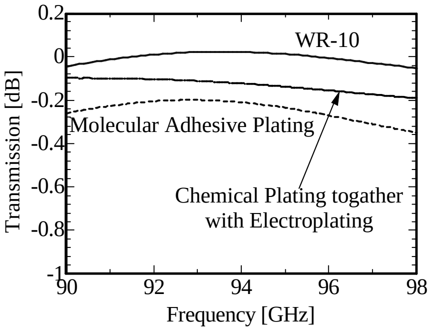
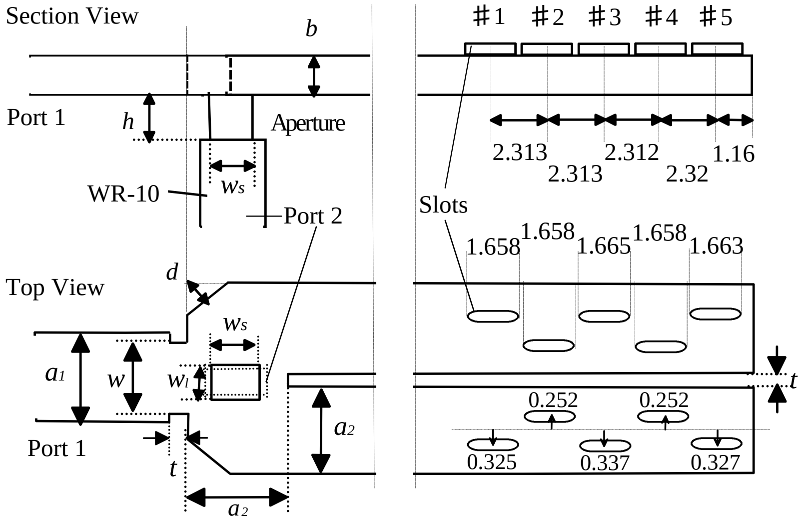


Figure 2: Reflection S parameters of WR-10 (experiment)



[mm]

a_1	2.2
a_2	2.2
b	1.1
d	1.63
w	1.82
w_l	1.62
w_s	1.78
h	1.4
t	0.5

Figure 3: Monopulse-feed antenna and structural parameters

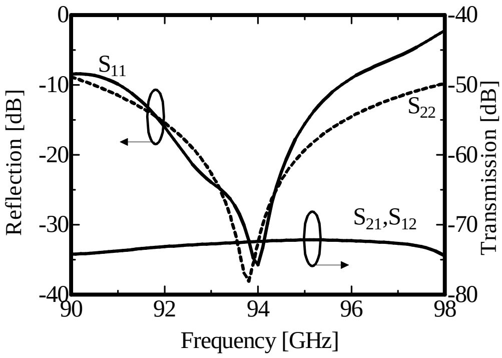


Figure 4: S-parameters of feeding circuit

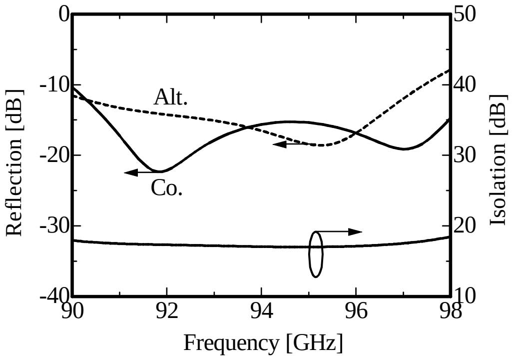


Figure 5: Reflection and isolation of waveguide slot array

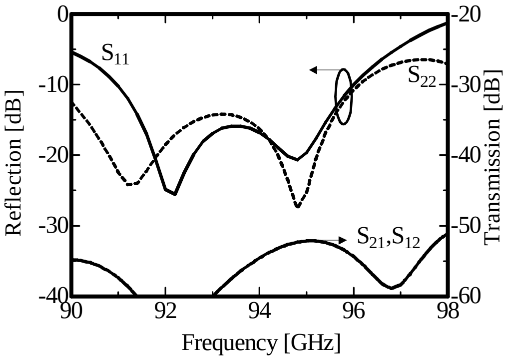


Figure 6: S-parameters of monopulse-feed antenna

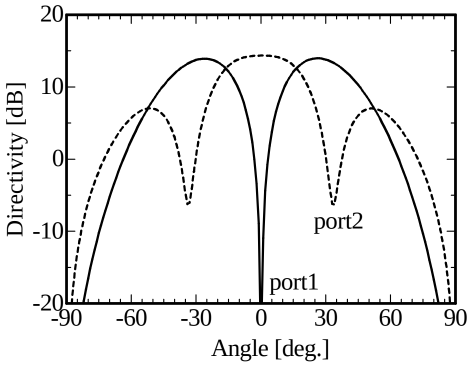


Figure 7: E-plane radiation pattern of monopulse-feed antenna

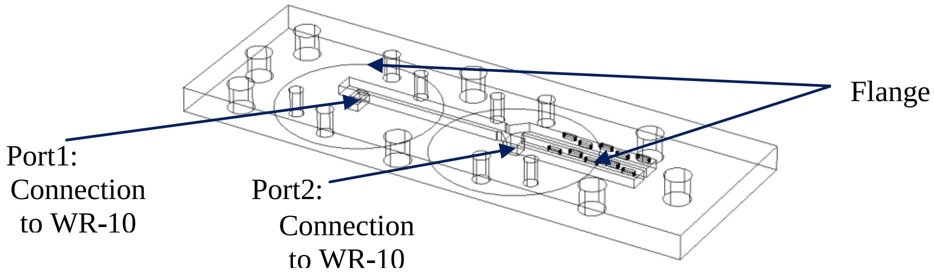


Figure 8: Image of monopulse-feed antenna