Design of a Substrate Integrated Waveguide Aperture Antenna with Electromagnetic Band Gap Structure

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Abstract—In this paper, a novel antenna with vertical polarization and low profile in vertical direction was designed base on substrate integrated waveguide (SIW) and Electromagnetic Band Gap (EBG) structure. The radiation performance and the standing-wave ratio (SWR) were optimized via stepped transition structure. The gain and the front-to-back ratio were increased via the Electromagnetic Band Gap structure. This antenna with wide bandwidth and wide radiation lobe was base on Printed Circuit Board (PCB), and it was easy to be produced and easy for integration.

Keywords—EBG; E-plane stepped transition; low profile; SIW

I. INTRODUCTION

Rectangular waveguide aperture antenna is widely used and performs well in the field of the microwave. A E-plane stepped transition aperture antenna is designed in X band using Substrate integrated waveguide (SIW) and Electromagnetic Band Gap (EBG) technology. Substrate integrated waveguide (SIW) is a waveguide-like structure using Printed Circuit Board (PCB) technology where two periodic rows of metallic vias are used in to replace the narrow wall of traditional waveguide. This is a vertical polarization antenna with low profile in vertical direction due to the SIW technology[1,2].

Because of the low profile of the antenna, there’s much more impedance mismatch then standard waveguide aperture antenna at the aperture plane. The most-commonly-used design for the problem is H-plane sectoral horn antenna which uses the sectoral horn as a transition structure to remit the impedance mismatch and improve the radiation pattern in H-plane. However, because of the sectoral horn structure, the size of the antenna is much more bigger. And due to the low profile in E-plane of the antenna, it’s much hard to adjust the pattern in E-plane, not in H-plane[3-5].

In this paper, the E-plane stepped transition structure replaces the H-plane sectoral horn which only brings little size increase. But it can efficiently reduce the influence of the impedance mismatch and improve the radiation pattern in E-plane. And to improve the radiation pattern further, the Electromagnetic Band Gap (EBG) structure is loaded on the surface of the antenna. The EBG structure can efficiently restrain the backward radiation in E-plane and improve the gain of the antenna[6,7].

II. DESCRIPTION OF ANTENNA DESIGN

The fabrication of the proposed SIW E-plane aperture antenna is shown in Fig. 1. (a), composed of 3 pieces of PCB. And according to function it can be divided as two parts: the SIW Antenna Part and the EBG Part which is represented in Fig. 1. (b).

![Fig. 1 Structure of the antenna](image)

A. SIW Antenna Part

The SIW Antenna Part includes the full medium layer and the right area of the top layer and the bottom layer. The left area of medium is a typical SIW structure, and the right area of the 3 layers constitutes a bigger SIW structure. And there is a stepped discontinuity appeared naturally between the two different SIW structure.
SIW is a waveguide-like structure and the SIW Antenna Part can be equivalent to a stepped transition waveguide which is shown in Fig. 2. \( K_1 \) is the fundamental wave transmitting in the SIW. At the end of the structure, the electromagnetic wave \( K_1 \) is radiated to the free space. But a part of wave, which is called reflected wave and marked \( K_2 \), run back to the SIW because of the impedance mismatch between the edge of the SIW and the air. The reflected part is a large proportion of wave \( K_1 \) and the performances of the antenna without stepped transition structure are diminished when the substrate thickness is much smaller than the wavelength. But at the stepped discontinuity plane, the reflect wave \( K_2 \) generates a new reflect wave \( K_3 \). The new reflect wave \( K_3 \) has a same direction with \( K_1 \). Adjust the length of the bigger SIW as following:

\[
2L + \lambda_g \cdot (\theta_1 + \theta_2) / 2\pi = \lambda_g
\]

Where \( L \) is the length of the bigger SIW; \( \lambda_g \) is the waveguide wavelength; \( \theta_1 \) is the phase mutation between \( K_1 \) and \( K_2 \); \( \theta_2 \) is the phase mutation between \( K_2 \) and \( K_3 \).

The wave \( K_1 \) and \( K_3 \) get the same phase and vectorial superposition. Due to the stepped transition, there’s more energy radiated to the free space and less back to the antenna, the efficiency of the antenna is increased and the Standing Wave Ratio (SWR) reduced.

![Fig. 2 Equivalent structure of the SIW Antenna Part](image)

### B. EBG Part

The EBG Part includes the left area of the top layer and the bottom layer. They are mushroom-like EBG structure, the EBG structure can suppress the surface wave.

When the substrate thickness is much smaller than the wavelength, the diffraction of the electromagnetic wave can’t be ignored. The diffraction wave will energize the surface wave on the up surface and the bottom surface. The surface wave spreads backward and take a part of energy away from the main radiative direction. Fig. 3. (a) shows the surface wave on the surface of the antenna, and the surface energizes wave spreading against the main radiative direction.

The EBG structure has a nice effect for suppressing the surface wave. The EBG structure can turn the surface wave back and let the energy come back to the main radiative direction shown in Fig. 3. (b). Due to the suppression of the surface wave, the gain get increased obviously (about 4 dB increased) and the front-to-back ratio get increased hugely (about 18 dB increased).

### III. RESULTS

In order to get the difference between the antenna with stepped transition and EBG structure and without them, two control groups are established in HFSS, comparing in stepped transition and EBG structure respectively.

Fig. 4. shows the S parameter between the antenna with and without stepped transition. It can be seen that the stepped transition decreases the reflection coefficient (S11) greatly. And the bandwidth is about 4GHz.

![Fig. 4 Simulated S parameter](image)

![Fig. 5 Simulated E-plane Radiation pattern](image)
Fig. 5 shows the radiation pattern in E-plane, and Fig. 6 shows the radiation pattern in H-plane. It can be seen that the gain gets increased about 4 dB and the front-to-back ratio gets increased about 18 dB.

IV. CONCLUSION

A novel SIW E-plane aperture antenna has been designed by using EBG structure. The simulation results show that the reflection coefficient is decreased greatly due to the stepped transition structure, the gain and the front-to-back ratio get increased 4 and 18 dB due to the EBG structure. As a vertical polarization antenna, the polarization ratio of the antenna is great.

REFERENCES


