Novel Miniaturized Satellite Navigation Antennas Based on Substrate Integrated Waveguide

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Abstract— In this paper, two novel miniaturized satellite navigation antennas based on substrate integrated waveguide are proposed in this paper. A single-layer SIW annular slot antenna is studied and designed at first. Then through overlay a patch on top layer, a multi-layer SIW antenna is designed. The first antenna covers the Beidou satellite navigation system (BDS) B1I band with circular polarization (CP) and the second one covers the BDS B1I and B2I band with dual circular polarization. Performance has been proved to be better than microstrip navigation antennas in gain and front-to-back ratio (FBR) with the similar size. Both simulation and test results are given respectively.

1. INTRODUCTION

Antenna is one of the most important components in satellite navigation receiver. Patch antenna, which is small in size, easy to machining, and convenient to realize CP, is widely used in the navigation antenna. Patch navigation antenna using dual feed with multi-layers or slotting in single layer are given in [1] and [2]. These entire patch antennas have their shortcoming of big loss, and big back lobe, which is difficult to overcome.

Recently, the substrate integrated waveguide (SIW) causes a wide attention. Its application on antenna, has partly replaced patch antenna in millimeter wave. Etching quadrature slot on SIW cavity is the most popular method to realize CP and dual-band, which has a detailed application in [3]. However, because of its miniaturization is hard, related applications in satellite navigation antennas are rare.

In this paper, two novel miniaturized satellite navigation antennas based on SIW are proposed in this paper. By loading annular slot on the SIW cavity, the antenna can realize the radiation principle similar with patch antenna. Due the contribution of the SIW backed cavity, its gain and FBR is higher than patch antenna.

2. ANTENNA I: SINGLE LAYER STRUCTURE

This section gives the research on single layer structure at first, by loading annular slot on the top layer of SIW cavity and using the coupler to realize dual feed.

2.1. Antenna Configuration

The antenna configuration is shown in Figure 1 and Figure 2. Because the antenna has three layers structure, both configuration of each layer and 3-Dimension are given.

The principle of the proposed antenna is similar with patch antenna. In patch antenna, electromagnetic wave is driven through the slot between the patch and the ground then radiate power. The annular slot in the antenna uses field discontinuity on both sides of the slot to radiate, which is equivalent to move the slot onto the top layer of the SIW cavity. Consequently, circularly polarized radiation is produced when the radiations from the orthogonal slot pairs combine in the far field.

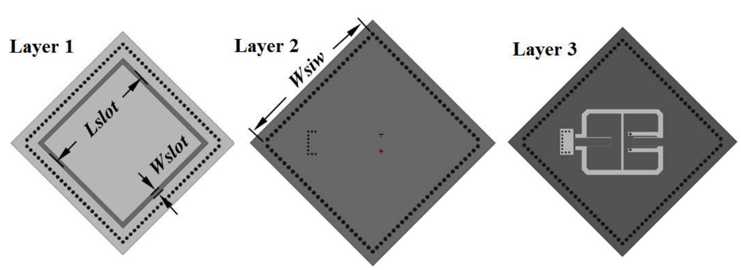


Figure 1: Configuration of Antenna I on each layer.

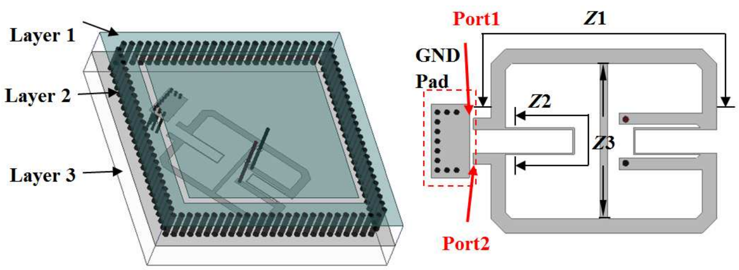


Figure 2: 3-D configuration of Antenna I and the coupler in details.

The resonant frequency is mainly determined by the length of the slot:

$$f = \frac{c}{2 \times Lslot \times \sqrt{\varepsilon_r}} \tag{1}$$

where $Lslot$ is the length of the slot, and ε_r is the relative permittivity. $Wslot$ is the width of the annular slot, which affects the impedance match and the radiation efficiency.

The coupler on the bottom layer is a wideband device which is studied in [4]. It is composed of the main line and three branch lines, whose impedance are $Z1$, $Z2$ and $Z3$ respectively. Rogers 5880 with a thickness of 1.508 mm, a relative permittivity of 2.2 is used as the dielectric substrate. The dimensions of Antenna I are listed in Table 1 with Ansoft HFSS simulation and optimization.

Table 1: Geometrical parameters of Antenna I (Units: mm).

Wsiw	**Lslot**	**Wslot**	**l1**	**w1**	**l2**	**w2**	**l3**	**w3**
44.00	41.50	1.10	51.25	2.26	27.40	0.24	26.40	1.15

2.2. Simulation Results and Analysis

Figure 3 shows the S parameter and axial ratio (AR) of the antenna with the 3-branch coupler in simulation. A resonant point of S_{11} can be viewed in BDS B2I band (1206 MHz), which also appears in S_{21}. That means the antenna is in radiation condition in this frequency, rather than straight-through from port 1 to port 2. This can also been proved by the following radiation pattern. A good axial ratio is shown in operation bandwidth, which is lower than 3 dB.

The simulated radiation patterns of the proposed antenna are shown in Figure 4. It is seen that the proposed antenna is a right hand circularly polarized (RHCP) antenna which can rightly receive the navigation signal. The antenna has a good RHCP gain in BDS B2I band which achieves 4.24 dB and a good FBR larger than 7 dB. The FBR is better than traditional patch navigation antennas due to the contribution of SIW backed cavity.

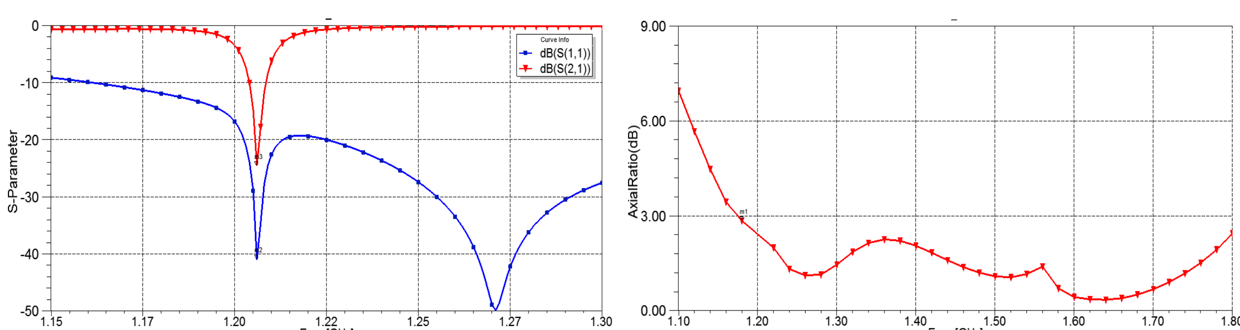


Figure 3: S-parameters and AR of Antenna I with 3-branch coupler. (a) S-parameters, (b) AR.

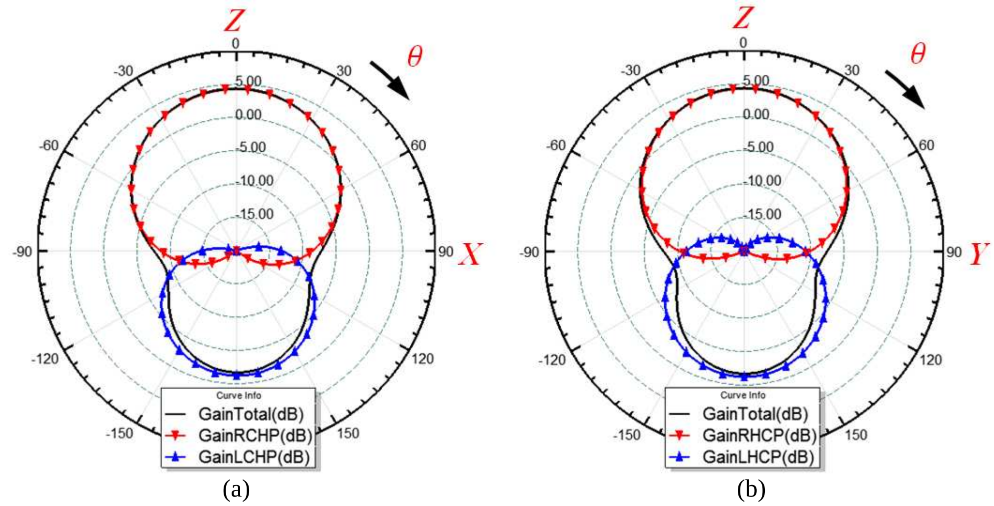


Figure 4: Radiation pattern of Antenna I at 1206 MHz. (a) X-Z plane, (b) Y-Z plane.

3. ANTENNA II: MULTILAYER STRUCTURE

From December, 2013, BDS has started to offer civilian dual-band service in B1I and B2I band, which demands antennas to have a capability of dual band operation. This section gives the design of a multilayer structure which can realize dual band radiation.

3.1. Antenna Configuration

The antenna configuration of 3-D veiw and top view is shown in Figure 5. The antenna has four metal layers in total. Because the same coupler on bottom layer serves as the feeder, detailed configuration on each layer is not given.

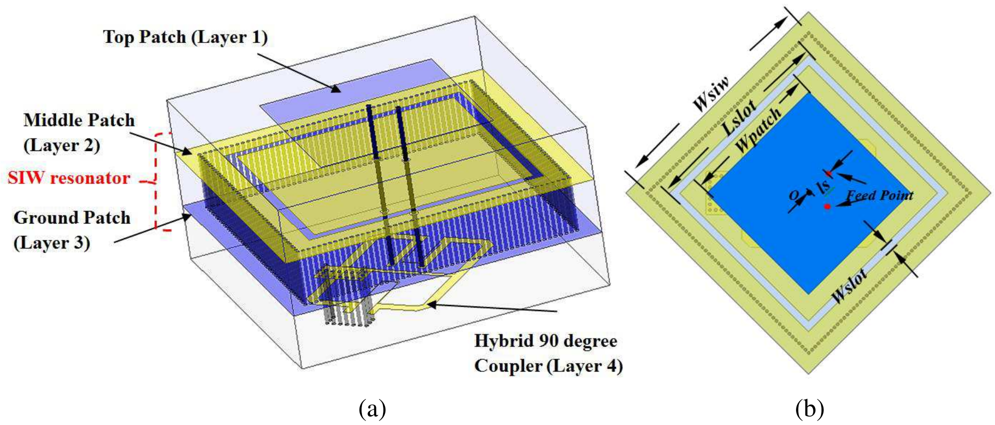


Figure 5: Configuration of Antenna II. (a) 3-D view, (b) top view.

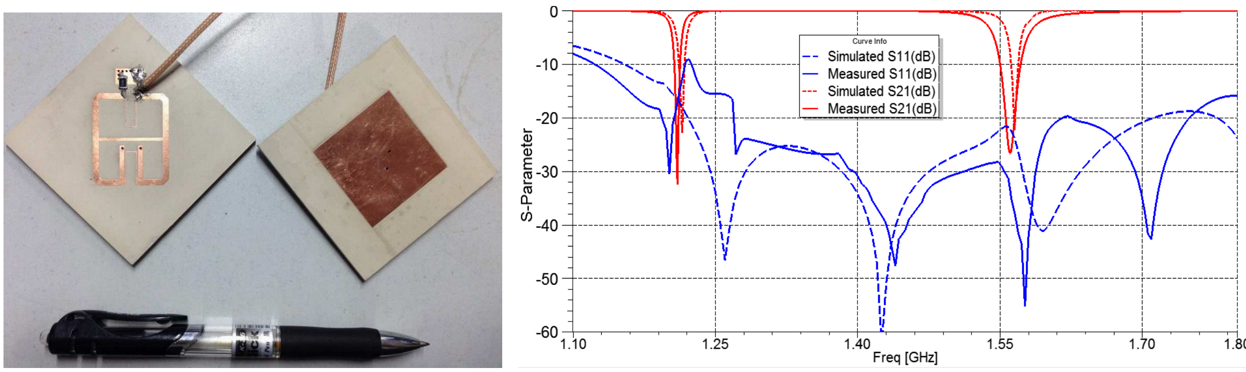
In Antenna II, radiation on higher frequency is realized by the patch on top layer. The coupler feed the patch via the probe and coupling to the cavity through the aperture outside the probe. Antenna radiates power in lower frequency through the annular slot on SIW cavity, while through the top patch in higher frequency. The resonant frequency can be tuned by tuning the size of the patch and the annular slot, respectively. By using the same substrate in Antenna I, the dimensions of the Antenna II are listed in Table 2 with Ansoft HFSS simulation and optimization.

Table 2: Geometrical parameters of Antenna II (Units: mm).

Wsiw	Lslot	Wslot	Wpatch	ls	l1	w1	l2	w2	l3	w3
44.00	41.50	37.25	9.70	4.80	51.25	2.26	27.40	0.24	26.40	1.15

3.2. Simulation and Measurement Results with Analysis

The proposed antenna (Antenna II) has been fabricated on a multilayer PCB substrate and their photographs are shown in Figure 6, which has its top view and bottom view.



(a) (b)

Figure 6: Antenna II. (a) Fabricated photo, (b) simulated and measured S-parameter.

The measured and simulated reflection coefficient is shown in Figure 7. From 1.1 GHz to 1.8 GHz, the S_{11} of the proposed antenna is blow -10 dB. Furthermore, resonant frequency of S_{21} can be viewed in BDS B1I and B2I band (simulated in 1206 MHz and 1561 MHz). That means the antenna is in radiation condition in these two frequencies, rather than straight-through from port 1 to port 2. The center frequency shift between the measured and simulated results is only about 5 MHz in lower frequency and 7 MHz in higher frequency.

Table 3 shows the performance comparison for the simulated and measured results of Antenna II. The peak gain in both frequencies has all exceed 3.5 dB, with the AR below 3 dB. Due to the contribution of SIW backed cavity, the lower frequency gain has remarkably increase, which is higher than traditional dual-mode satellite navigation antenna designed.

Table 3: Performance comparison for simulated and measured results of Antenna II.

Frequency (MHz)	**1206**	**1561**
Sim. Peak Gain (dB)	3.92	4.54
Meas. Peak Gain (dB)	3.25	4.03
Sim. Axial Ratio (dB)	1.71	1.87
Meas. Axial Ratio (dB)	2.33	2.41

4. CONCLUSION

Two novel miniaturized satellite navigation antennas based on SIW are proposed in this paper. The antennas have the advantages of small size, high gain and FBR, which is better than patch satellite navigation antenna. The measured results are satisfied at each operating band, and demonstrate good agreements with simulated results.

ACKNOWLEDGMENT

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