A Novel Compact Wideband TSA Array for Near-Surface Ice Sheet Penetrating Radar Applications

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Abstract. A novel compact tapered slot antenna (TSA) array for near-surface ice sheet penetrating radar applications is presented. This TSA array is composed of eight compact antenna elements which are etched on two 480mm×283mm FR4 substrates. Each antenna element is fed by a wideband coplanar waveguide (CPW) to coupled strip-line (CPS) balun. The two antenna substrates are connected together with a metallic baffle. To obtain wideband properties, another two metallic baffles are used along broadsides of the array. This array is fed by a 1×8 wideband power divider. The measured S11 of the array is less than -10dB in the band of 500MHz-2GHz, and the measured gain is more than 6dBi in the whole band which agrees well with the simulated results.

1. Introduction

It is reported that the sea level has been rising at the rate of about 2mm per year in the last century, and this can be partly ascribed to the melting of polar ice sheet [1]. The influence of ice sheet on rising of sea level can be quantified by investigating the mass balance of ice sheet. Icecap detection radar can be used to obtain the data on near surface internal layers of polar ice sheet so as to estimate the accumulation rate of ice.

Icecap detection radar is a kind of ultra-wideband radar which operates in frequency modulation continuous wave (FMCW) mode. It is reported that near-surface ice sheet detection radar was developed at the University of Kansas [1]. With an operating bandwidth of 500MHz-2GHz, data in depth of 200m with a resolution of 10cm was obtained in Greenland [2].

Near-surface ice sheet penetrating radar is also developed in our laboratory to detect Antarctic shallow icecap. To radiate and receive such wideband signals, antennas with high gain and broad bandwidth are necessary. Frequency independent antennas such as spiral antennas or LPDA antennas, whose structure are specified by only angles, have continuous scaling of performance with frequency [3]. Although the practical antenna structures are truncated, and the effects of feeding balun must be considered, FI antennas can still maintain very broadband bandwidth. However, gain of these antennas may not be high enough, and it will be complicated and costly to fabricate the antennas. Horn antennas have not only wide bandwidth but also high gain [3], but they are large, heavy and costly in this operating band. Otherwise, grating lobes will appear in high frequencies.

Tapered slot antenna is a kind of travelling wave antenna which has broad bandwidth, moderate gain and low sidelobes [4]. The bandwidth of this antenna is mainly dependent on the size of the tapered slot open and the transition between the antenna slot and the feeding configuration. This antenna is easy and inexpensive to fabricate. To obtain higher gain, TSA array can be used. In this

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paper, a novel compact tapered slot antenna array operating in the band of 500MHz-2GHz is designed and fabricated. It is used as the radiating and receiving antennas of Near-surface ice sheet penetrating radar.

2. Design of the antenna array

The array is composed of eight compact tapered slot antenna elements. Due to the size limit of fabricating equipment, every four antennas are etched on one FR4 substrate of 480mm×382mm. Then two substrates are connected together with a metallic baffle, and another two mental baffles are placed along the sides of edge elements. Each element is fed by a CPW to CPS transition which is coplanar with the tapered slot configuration. The whole array is fed by a 8-way broadband power divider.

2.1. Design of the CPW to CPS transition

Various planar transitions have been designed to feed tapered slot antennas, and coplanar waveguide to slot-line transition and microstrip to slot-line transition are two kinds of most widely used. Normally, wideband open or short stubs are used to guarantee the wideband properties of transitions. In this paper, a novel coplanar waveguide to coupled strip-line transition is used as the feeding balun.

This CPW to CPS transition was reported in [5], and it has been used to feed different types of antennas [6,7]. The characteristic impedance of coupled strip-line is designed to be comparable to that of slot-line. Then the coplanar waveguide is designed to be a 4 section Chebyshev transformer which can transform the characteristic impedance of coupled strip-line to 50Ω. A wideband short stub which will show an open circuit to confine the field between the two coupled strip-lines is utilized. The configuration parameters of the CPW to CPS transition are shown in table 1.

Table 1. Configuration parameters of the CPW to CPS Transition.

		CPW						CPS	Slot-line
		Z_0	Z_1	Z_2	Z_3	Z_4	Z_5	Z_{CPS}	Z_{SL}
Designed impedance (Ω)		50	54.7	60	66.6	73	80	80	80
Simulated impedance(Ω)		49.5	54.6	62	69	74	80.4	86	83.3
Configuration parameters(mm)	Strip width	3.2	3.0	2.7	2.4	2.2	1.9	3.0	
	Gap width	0.3	0.4	0.55	0.7	0.8	0.95	0.4	0.4
	Strip Length	3	3	3	3	3	3	15	

To investigate the wideband properties of the CPW to CPS transition, a model of two back-to-back connected transitions was built and simulated using HFSS10.0. The transition model, the simulated transmission and reflection properties are shown in figure 1.

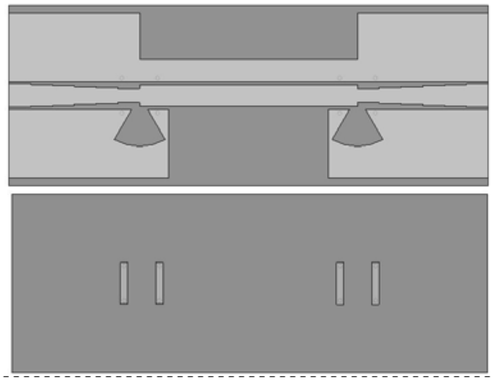

Figure 1. Configuration of the CPW to CPS transition.

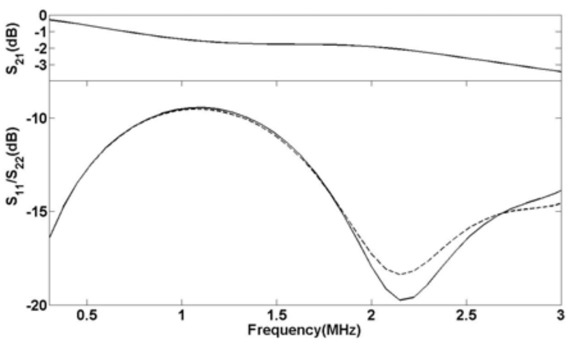

Figure 2. Simulated transmission loss and return loss.

To avoid using bond wires near the stub, two strips are placed on the back side of substrate. Each strip is used to connect the two ground strips of CPW together through two via holes. In figure2, it is shown that the transmission loss of each transition is less than 1dB in the band of 0.5GHz-2GHz.

2.2. Design of the array

For array design, to avoid the appearance of grating lobes in visible region, the element spacing in array should satisfy the condition [8]

$$\frac{d}{\lambda} \leq \frac{1}{1+\sin\theta} \tag{1}$$

where d is the element spacing, λ is the operating wavelength, θ is the scanning angle.

For our application, the array is designed to radiate in endfire direction, so the scanning angle is $\theta = 0^\circ$. This means that the element spacing should satisfy $d \leq \lambda$. According to conventional theory of travelling wave antenna, the width and length of TSA antennas should be larger than half a wavelength at the lowest operating frequency [9]. Researchers found that the size of TSA could be about a quarter of lowest operating wavelength [4]. It is obvious that the size of antenna slot open must be less than a quarter of wavelength at 0.5GHz for a array. For an infinite array, the mutual coupling between elements can improve the input return loss of individual element. In reality, the elements in array must be confined to a reasonable number. To compensate the truncation effect of a finite array, metallic baffles could be used to mimic an infinite array [2].

In our design, the width of TSA open is designed to be 120mm which is 0.8λ at 2GHz. And the length of TSA is chosen to be 250mm. When using this TSA as element, 8 antennas are sufficient to build a array to obtain desired low input return loss, high radiating gain, narrow beam width, low sidelobe level and moderate array size. Three metallic baffles of 300mm×120mm are used to improve the operating properties of array element. The array model is depicted in figure3.

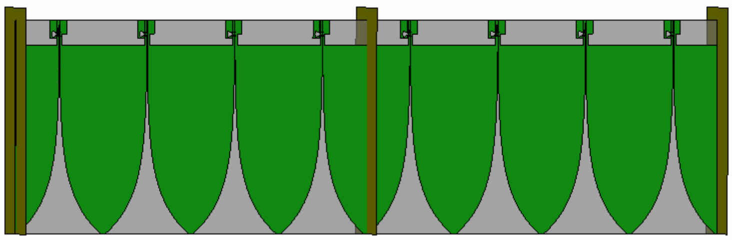

Figure 3. Array antenna model.

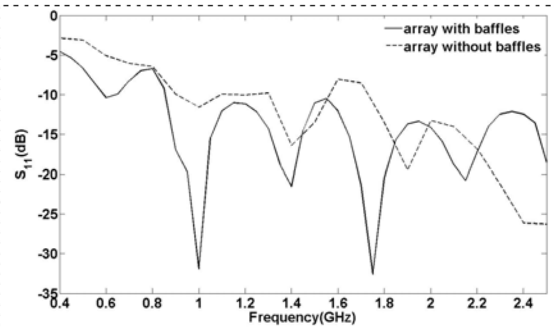

Figure 4. Return loss of the first element in array with/without baffles.

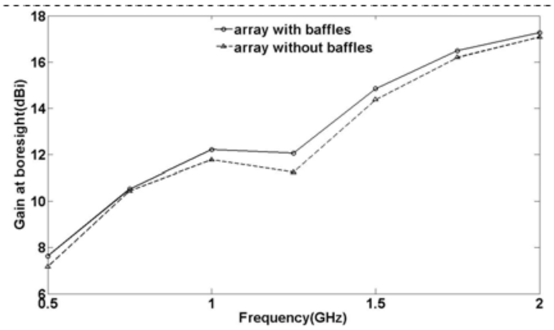

Figure 5. Gain at boresight of the array with/without baffles.

In figure 4, it is revealed that the input return loss of the first element in array with baffles is improved to some extent than that of the array without baffles at low frequencies. As shown in figure 5, gain at boresight of the array with baffles is slightly improved than that of the array without baffles

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in the whole band. The normalized radiation patterns on E plane are shown in figure 6, and it is evident that the half power beam width of the patterns are less than 30° . At frequencies higher than 0.5GHz, side-lobe level and back-lobe level are both lower than -15dB. At 0.5GHz, these two levels are lower than -10dB.

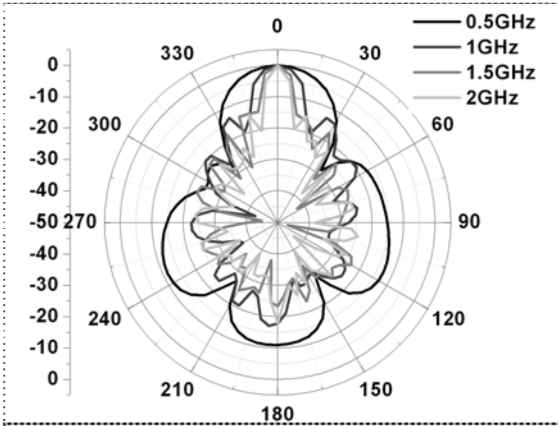

Figure 6. Normalized radiation patterns on E plane at different frequencies.

3. Measured results

The array was fabricated according to the design, and other auxiliary structures were also machined to strengthen the stability and reliability of the TSA array. The complete array is shown in figure 7. Transmission loss of the feeding 8-way power divider is typically 0.8dB, and worst situation is 1.7dB at 2GHz.

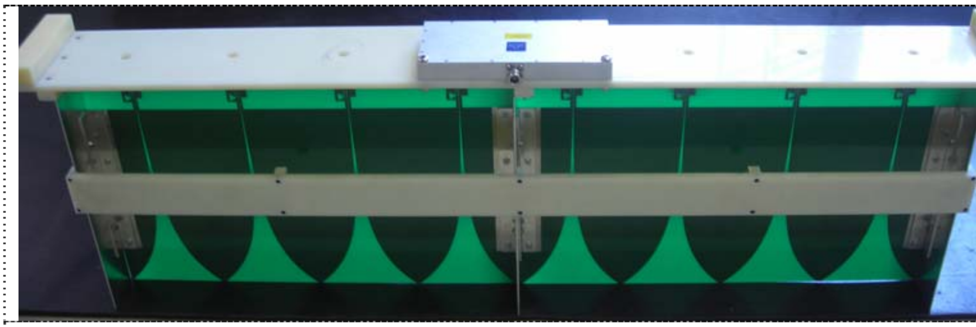

Figure 7. The complete TSA array.

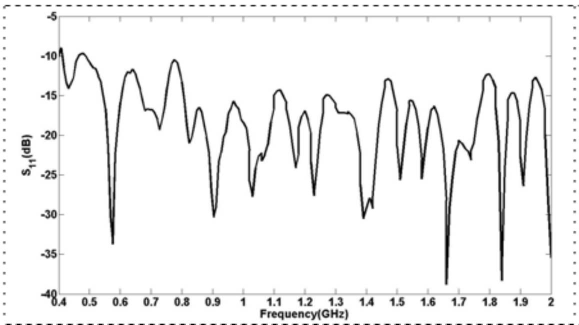

Figure 8. Measured return loss of the array.

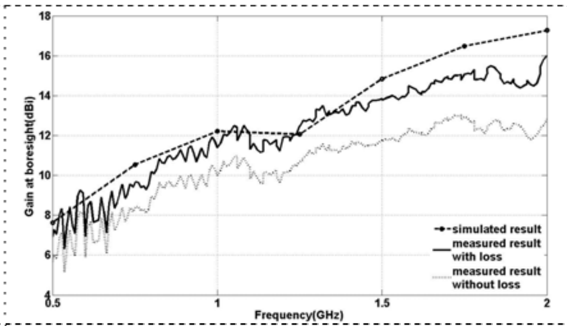

Figure 9. Measured gain compared with simulated result.

Return loss and radiation gain were measured on open site, and the results are shown in figure 8 and 9. It is clear that the measured return loss is lower than -10dB in the whole operating band. Including the transmission loss of power divider and cables, the measured radiation gain at boresight is comparable to the simulated results. The difference may be ascribed to the effects of measurement site. And the radiation gain is higher than 6dBi in the band of 0.5GHz-2GHz which can satisfy the requirement of near-surface ice sheet penetrating radar.

4. Conclusion

To satisfy the requirement of near-surface ice sheet penetrating radar, a compact tapered slot antenna is designed. The size of array element is smaller than normal TSA antennas due to the mutual coupling between the elements. A novel coplanar CPW to CPS transition is used to feed each array element. To improve the wideband properties and enhance the stability of the array, three mental baffles are utilized to connect two 4-element antenna boards. Other non-metallic structures are used to strengthen the reliability of the array. Simulated and measured results show that radiation gain of the array is higher than 6dB, and pattern beam-width is less than 30° which means the array concentrate most of energy at boresight. Measured array input return loss is less than -10 dB which is a general standard to evaluate ultra-wideband antennas. The array can satisfy the requirements of near-surface ice sheet penetrating radar well. It will be used together with the radar to map the near surface layer details of Antarctic ice sheet.

Acknowledgments

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