

DEVELOPMENT OF THE RADIATING PART OF AN ULTRA-WIDEBAND TAPERED-SLOT ANTENNA FOR GPR APPLICATIONS

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Abstract

This paper presents some techniques of improving characteristics of planar ultra-wideband antennas based on the tapered slot line. Different antenna openings based on the elliptical taper with additional metal flares, smooth and corrugated bent blades had been studied. Several planar antennas with dimensions of 23 to 12 centimeters have been simulated using electromagnetic simulation software, and then designed, fabricated and tested. Results of computer simulations and measurements of the ultra-wideband antenna characteristics are presented.

Keywords: Ultra-wideband, tapered-slot antenna, antenna opening, ground penetrating radar.

1. INTRODUCTION

The ultra-wideband (UWB) antennas always attracted attention of researchers and are used in different applications in communications, various kinds of antenna test ranges, microwave imaging.

Ground penetrating radar (GPR) is important practical application where ultra-wideband antennas are employed, too. Requirements to the antennas may differ depending on particular application due to compromise between penetration depth and resolution. So, antennas in archeology operate typically in the frequency range of 0.01 to 2 GHz, in civil engineering – 0.3 to 4 GHz, in medical imaging of 1 to 10 GHz. Besides, there exist other specific requirements to the GPR antennas such as good impedance matching over full frequency range of operation, sufficient directivity (gain, front-to-back ratio etc.). The geometrical size is also an important parameter.

The tapered-slot antenna (TSA) was presented by Gibson for the first time in 1970's [1]. TSA known also as notch antenna is the end-fire traveling wave antenna and exploits guiding properties of the slot line when the latter extends to region where the edge separation exceeds a half of the wavelength. Such antenna has very low profile in purely planar implementation; it is lightweight and may be easily fabricated by photo etching technology. TSA demonstrate multi-octave bandwidth, moderate gain (6-11 dB) and relatively symmetric radiation patterns in E- and H-plane for classical tapered-slot antenna design. The beamwidths are approximately equal in both planes.

2. SOME DESIGN ASPECTS OF THE ANTENNA OPENING

A typical TSA consists of a balun and a tapered-slot section formed by gradual widening of a slot line. The opening angle at the beginning of the antenna flare influences the antenna input impedance.

The slot section in the radiation region can assume different geometric shapes such as nonlinear taper, linear taper or constant width. The beamwidth of TSA with constant width is known to be typically the smallest that could be considered as an advantage. However, in this case it is necessary to take into account reflection from the antenna edges and contribution to formation of a high level of side lobes [2]. That is why various nonlinear tapers of TSA are more popular in subsurface radar.

The radiation performance of the TSA is directly affected by the following parameters: antenna length, width of the antenna opening and the substrate thickness. The electromagnetic wave in the antenna substrate propagates closely to the metal edges in the slot line. Initially, when for most taper profiles the separation is relatively small, the wave is closely bound to the tapers. As the taper separation increases, the electromagnetic wave becomes progressively less attached to the metal taper. This continues until the taper separation reaches approximately a half of the wavelength and the guided wave starts to radiate into free space. This means that the width of the opening must exceed a half of the wavelength in any TSA design for effective radiation.

In GPR applications compact antennas are of particular interest as at low operating frequencies standard

antennas may become too large and inconvenient in use. That is why the geometrical size of ultra-wideband antennas is minimized often deliberately neglecting the basic requirements to the antenna design and thus worsening the characteristics.

In this paper, TSA with nonlinear elliptical profiles have been studied. Such profile provides a smooth transition in area of the antenna opening and reduces reflection from it (Fig. 1).

Reduced size of a radiating part of the antenna results in deteriorating some characteristics. So, at the ends of the frequency range the antenna gain drops whereas return loss and reflection of the radiated wave from opening increase. The radiation pattern is too wide at low frequencies while at high frequencies more sidelobes arise. To avoid additional deterioration at the ends of frequency range, an ultra-wideband balun with the frequency band of operation a bit wider than required in the application was developed [3]. As a result, satisfactory antenna characteristics over the frequency range of interest have been attained.

The purpose of further research is to improve the radiation properties of the antenna at low frequencies.

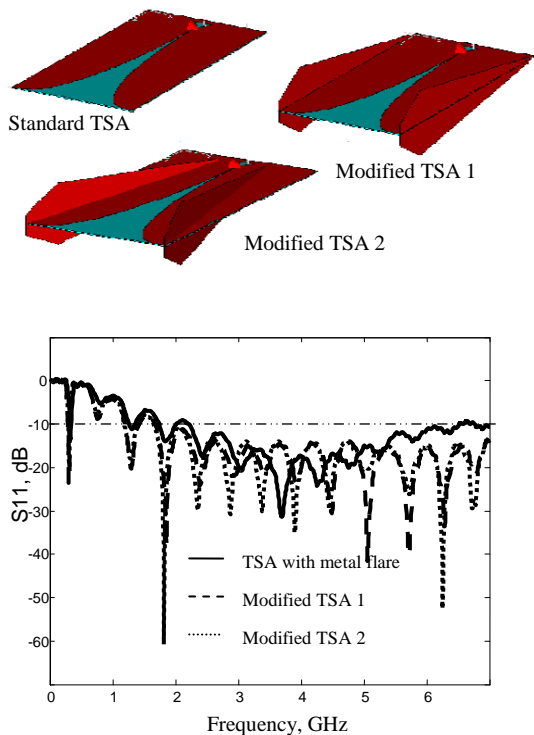


Fig. 1. Simulation results for a standard TSA and TSA with additional flares.

The tapered-slot antennas with the size of 230 mm to 120 mm on the FR-4 substrate with the thickness of 1 mm have been studied using the CST Microwave Studio electromagnetic simulation software. In Fig. 1, S_{11} parameters for a standard TSA and TSA modified by inserting additional metal flares orthogonal to main flares are shown. Simulation data demonstrate that these flares increase directivity and gain of the antenna.

For example, at a frequency of 2.5 GHz the gain increases from 9 dB to 9.8 dB, radiation efficiency from 0.31 to 0.95 and the level of side lobes is reduced from -5 dB to -10.3... -12 dB. At the same time, position of the metal flares does not affect considerably the S -parameters of the antenna.

Using metal flares of special design in the area of opening as shown in Fig. 2 leads to increase of the effective size of the opening. Thus, even a slight expansion of metallization at the opening of the antenna results in reduction of reflection at low frequencies over the operating frequency range.

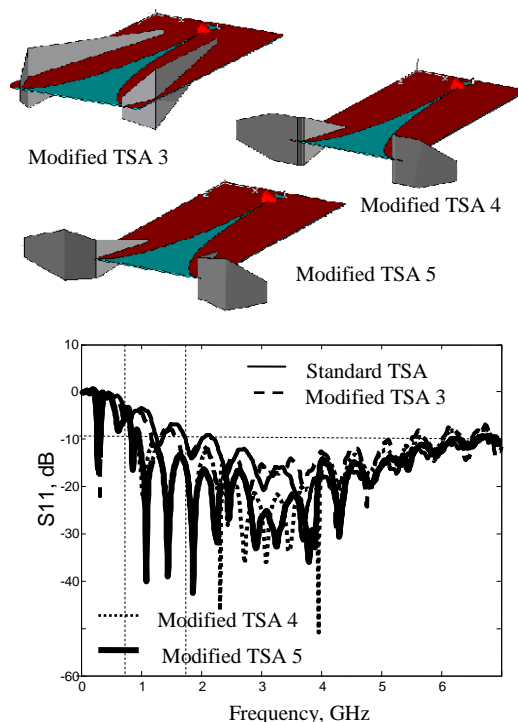


Fig. 2. Simulation results for a standard TSA and antennas with extra directing flares in the antenna opening area.

Fig. 2 shows that the use of small metal blades leads to considerable improvement of S -parameters of the antenna in range of 0.8 to 1.8 GHz in comparison with the standard TSA. The level of side lobes is reduced from -3 dB to -4.7 dB, the gain is increased from 3.9 dB to 6 dB, and radiation efficiency is increased from 0.28 to 0.94 for modified TSA 5.

By the way, in above simulations we did not use any absorbers, resistive cards or corrugated surfaces. The interest was to improve the antenna characteristics by additional metal flares only.

One more aspect of the study is influence of the substrate with high dielectric permittivity. In this work, usual FR-4 with the permittivity of 4.2 was used. That may be important especially at high frequencies as high contrast between the supporting dielectric layer and free space may cause considerable reflection back into the antenna. Besides, this reflection usually enhances

side lobes of the radiation pattern. That is why an antenna was simulated where dielectric substrate is left only in the beginning of antenna whereas the opening is formed by free metal flares. Fig. 3 demonstrates results of such cutting off the dielectric substrate by 2/3 of total length of the antenna.

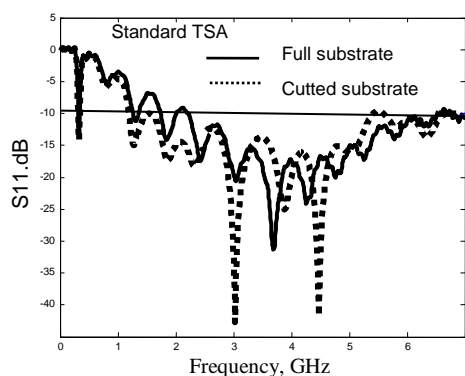


Fig. 3. Simulation results for standard TSA with metal flare with total and topped substrate.

3. EXPERIMENTAL RESULTS

Experimental investigation of TSA with different configurations of the opening had been carried out using vector network analyzer Agilent E5071B in the frequency range of 0.5 to 8 GHz and double-ridged horn Schwarzbeck BBHA 9120A, frequency range of 0.75 to 5.2 GHz, as a test antenna. A standard TSA, antennas with additional metal flares like modified TSA 1 and TSA 3 (Figs. 1,2) and TSA with metal blades like modified TSA 5 (Fig. 2) had been tested.

Measured results of S -parameters for standard tapered-slot antenna and antenna with bent metal blades show that the frequency range of the antenna can be extended by about 0.5–1 GHz to low frequencies (Fig. 4) if the level of -10 dB is accepted as criterion of the antenna operability.

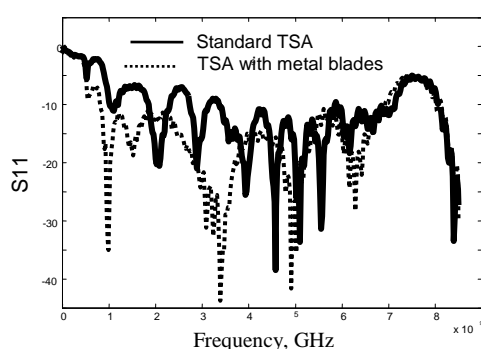


Fig. 4. Measured S_{11} parameters for a standard TSA and TSA with metal blades.

For further evaluation, we used commercial double-ridged horn BBHA 9120A as a test antenna. Distance between the horn antenna and the TSA under test (size of 230 to 120 mm, frequency range 0.5 of 6.5 GHz) and was selected of 60 cm. Fig. 5 shows the measurements

results for the standard antenna, TSA with metal flares and TSA with metal blades. Besides, in our experiments the surface of blades was bent slightly.

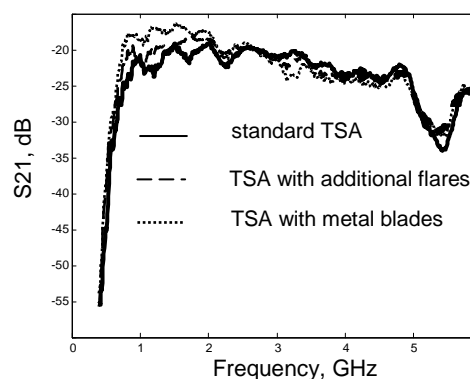


Fig. 5 Measured S_{21} parameters for double-ridged horn Schwarzbeck BBHA 9120A and different modifications of TSA.

One can see that the measured transmission coefficient at low frequencies increases considerably due to proposed modifications of the antenna opening. The best results had been obtained for TSA with metal blades.

4. CONCLUSION

In this paper, the effect of the different antenna flare design on the tapered-slot antenna characteristics has been studied. It is shown both theoretically and experimentally that the modifications of the antenna by additional flares enhances the antenna bandwidth and transmission coefficient at low frequencies without considerable increase of the geometrical size.

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