DEVELOPMENT OF UWB PLANAR DIPOLE FOR NEAR SURFACE APPLICATIONS

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Abstract

In the paper the results of numerical and experimental studies of ultra-wideband dipole radiator and optimized CPW-to-CPS transformer (balun) are presented. Such dipole is used in GPR scanning system based on the Agilent E5071B VNA, and is located in direct proximity to object surface. Different theoretical models were developed to optimize and analyze the 50 to 100 Ohms balun with passband 1-7 GHz. The special attention was paid to matching antennas open with properties of the media under test. All numerical results were performed using CST Microwave Studio software.

Keywords: wideband, coplanar waveguide, coplanar stripline, transformer, balun, antenna, dipole, antenna radiation pattern, gain, side lobe

1. INTRODUCTION

Subsurface radar is specific application using ultra wideband antennas. Those sensors are the part of a GPR system demanding attention because the imaging quality depends strongly on the radiation characteristics of the antenna. The antennas are located on or just above the ground or the object surface and should have stable performance over different types of media with various dielectric properties. Because of this reason, only few types of antennas found application in GPR: wideband bow-tie and loaded dipoles, TEM-horn, spiral and tapered-slot antennas Vivaldi type, and their various modifications.

The antenna parameters to be optimized depending on a solved task include bandwidth, radiation pattern, phase centre location, gain and radiation efficiency. And at the same time, it is necessary to take into account that antennas are usually designed for free space applications. In a GPR an antenna has to meet completely different requirements since it is often located very close to the ground to receive strong target signals. Therefore GPR antennas should be optimized taking the environment into account.

In this paper, a design of a popular planar bow-tie (bifin) antenna widely applied for years in subsurface radar is proposed [1,2]. Main drawbacks of this antenna are related to multiple reflections inside the antenna and from flare ends, and to the poor wideband impedance matching. We will consider some choices of antenna design to suppress these sources of clutter as well as some features of work.

2. ANTENNA DESIGN

2.1. DESIGN OF FEEDING

Transition structures employed to transform electromagnetic energy between balanced and unbalanced transmission lines are used in different types of antennas structures and microwave circuits. The coplanar waveguide (CPW) -to- coplanar stripline (CPS) transformer is a planar structure, that makes it simple and cheap, but always there is a problem of minimization of geometrical sizes.

In many cases considered transformer is made on high dielectric permittivity substrates reducing the size and bringing the losses on the higher frequencies for a wideband balun. It compels to compromise between the geometrical sizes of the transformer and transmission losses for the high frequencies in the range. At the same time, it should be noted that the CPW and CPS, as media for hybrid and monolithic microwave circuits, both have the advantages of small dispersion, less sensitivity to substrate thickness and simple realization.

To guarantee smooth transformer, not only the impedance match, but also the field match should be

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sustained. Sometimes a transformer can attain the field match and / or impedance match only in a narrow frequency band only, and would exhibit high insertion losses elsewhere. We are looking for a CPW-to-CPS thansition that maximize the bandwidth and minimize the insertion loss [4-6].

In this work for analyze of the transformer, CST Microwave Studio software was used to simulate the performance of the printed balun for frequency range 1-7 GHz, transforming 50 Ohms from a coaxial cable to 100 Ohms on an antenna open, in terms of the s-parameters, as well as the current distribution on the surface of the transition structure, which is useful to identify areas of greatest reflections. Fig.1 represents simulation model of transformer with the impedance transformer and equivalent-circuits model.

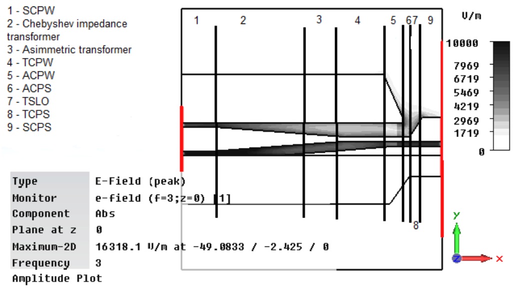


Fig.1. Layout CPW to CPS transformer. Physical configuration with simulation results for the electric field amplitude and equivalent-circuits model.

The structure is a wideband transformer, that can be decomposed into 9 parts for theoretical modeling: SCPW–symmetric coplanar waveguide; Chebyshev impedance transformer; asymmetric transformer; TCPW– Coplanar waveguide tapered linearly in the lower slot; ACPW– Asymmetric coplanar waveguide tapered linearly in the upper ground strip; TSLO– Unterminated slotline open; TCPS–Asymmetric coplanar stripline tapered linearly in the upper strip; SCPS– Symmetric coplanar stripline.

The Chebyshev’s multi-section matching transformer was in use as the impedance transformer. Twenty cells per wavelength and edge cells were used to simulate the balun structure. Results of the simulation demonstrate the dependence of the bandwidth on the length of sections that form the transformer. Maximum of losses occurs at a lower frequency whereas the length of sections increases – just because of this reason sections of transformer of Chebyshev were most minimized.

By the next step, three structures were modeled together, resulting in a 50 Ohms (CPW) to 100 Ohms (CPS) transformer through Chebyshev’s transformer. Besides, it was the important task of geometrical minimization of the balun. Initially, the original length of transformer was 60 mm, the final length was 40 mm. The question of the influence on losses of gradual shortening 50- and 100-Ohms parts of the transformer was studied. Simulated results for S-parameters for wideband transformer 60 mm long and short-cut to 5 mm 50-Ohm part (CPW) and frequency response are shown in Fig.2, where a performance decline at lower frequency can be noticed as the return loss become smaller than -10 dB.

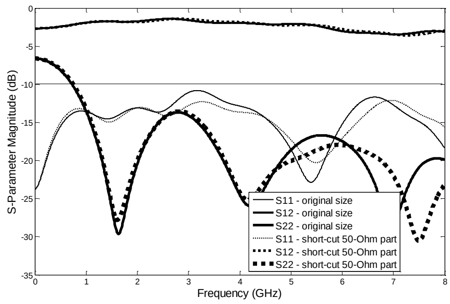
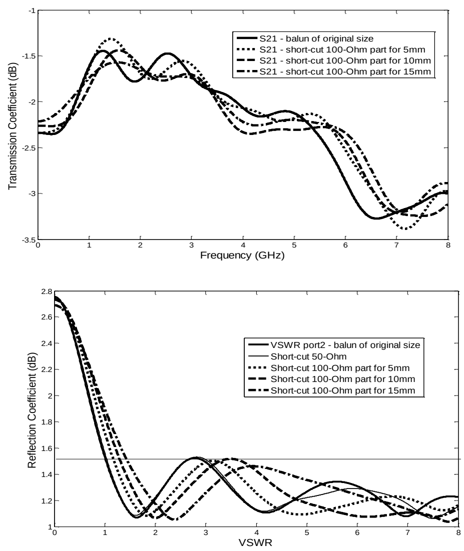


Fig.2. Simulated S-parameters of the transformer.

The next results of simulations that have been performed show how the bandwidth is influenced by the length of the sections that form the CPS (Fig. 3).



a)

b)

Fig. 3. Simulated results. a)-transmission coefficient obtained for transformers with different length of CPS; b)- VSWR for port 2 of balun with different length of CPS.

For longer lines, there are not critical changes in lower frequencies, but at a frequency of 6 GHz the losses increase to -3dB. Restrictions in the higher part of frequency range taking into account properties of a substrate material are corrected by length reduction of CPS. Consequently, it’s necessary to use a short CPS line to connect balun and antenna, for obtaining a good bandwidth. Obviously, maximum losses value is higher for long lines. For short lines, maximum losses are lower and at higher frequencies.

2.1. ANTENNA FEATURES

Performance of a V-shaped bow-tie antenna with corrugated edges are presented in [3]. Complete length of antenna is λ/2 at the lower frequency 1GHz in the band. In the design process it was taken into account that antenna have its own unwanted reflections between the antenna's plate and the screen as well as between the antenna aperture and the first boundary (for example, air-soil). That is why it is desirable to decrease such reflections by providing a smooth radiation of a the wave to objects under test. The 7 mm thick dielectric with permittivity 2.4 was used as a matching layer between radiating part of the antenna and the studied medium. Simulation task was a study of the field behavior of the antenna placed on objects with dielectric permittivity of 4 and 41.5 (imitation of the biological tissue) [7]. Fig.4 shows the field formation for the bow-tie dipole with the dielectric layer in the aperture and without it. The layer helps to focus a field and reduces the lateral radiation of the antenna. The analysis of directional patterns showed increase of gain from 3.6 dB at an average frequency of range to 5.3 dB with minimization of side lobs from -12 to -18 dB.

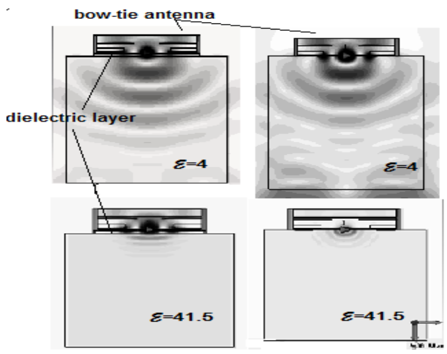


Fig. 4. Simulation results. Electric field amplitude for the bow-tie dipoles with (left) and without (right) the dielectric layer in the aperture at frequency of 2 GHz.

3. EXPERIMENTAL RESULTS

The CPW-to-CPS transmission line and bow-tie antennas flare was made in a dielectric substrate FR-4. The experimental investigations of antennas have been carried out using network analyzer Agilent E5071B in the frequency range from 1 to 7 GHz and antennas with matched transformer and matched aperture as well as with antennas without the aperture matching. The quality of an antenna is assessed by a series of B-scans for typical targets – 8 mm diameter metal rods, shallowly buried at the depth 2 cm in the sand box. Fig. 5 presents B-scan after performing inverse discrete Fourier transform with 6-th order Kaiser window to convert frequency data to the smoothed time-domain signal. The aperture matching allows the best subtract of the first boundary and more exactly detection of shallowly buried objects.

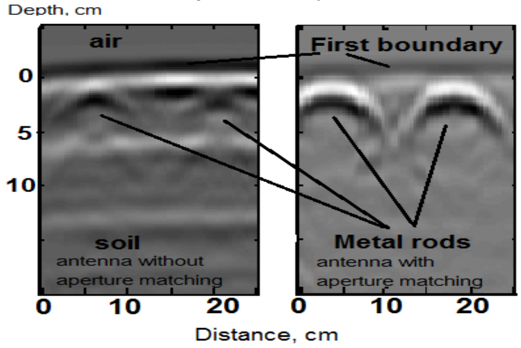


Fig. 5. Experimental results for antennas without (left) and with (right) aperture matching.

4. PERMISSION TO PUBLISH

The authors are responsible for all material contained in the manuscript they submit and agree to the submission of the paper.

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