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The effects of source impedance on the time-domain performance of UWB bowtie antennas

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Abstract— Ultra-wideband (UWB) antennas have been widely used in short range radar applications such as ground penetrating radar (GPR). There are numerous reported studies addressing the design of different types of antennas, loading methods and feed structures to achieve the required UWB performance. However, there are few reports on the relationship between the source impedance of the antenna feed and the UWB performance. This paper investigated the effects of the source impedance (changing from 50 ohms to 350 ohms) on the time-domain performance of bowtie antennas. The results were validated by both simulation and experiment. For bowtie antennas, the time-domain signal settles quicker with the increasing source impedance from the output of the balun structure, however the signal magnitude was reduced. A good compromise source impedance was found to be around 250 ohms.

Keywords: ground penetrating radar (GPR), Ultra-wideband (UWB), source impedance, bowtie antenna

1. INTRODUCTION

Ultra-wideband (UWB) technology has been widely investigated for communications, radar and imaging where the large bandwidth provides high resolution [1]. For radar system like Ground Penetrating Radar (GPR), a short time-domain signal enables the reflections from the ground and the reflections from the near-surface targets to be more effectively distinguished [2]. In UWB technology, the antennas are a key element of the system, and these act as a wide-band filter to radiate and receive the UWB signals. The design and performance of UWB antennas has attracted much research attention, which can mainly be divided into three categories: changing antenna shape, antenna loading, and antenna balun design.

Numerous antenna configurations have been investigated for UWB radar, including bowtie, Vivaldi, horn, and spiral structures [3]. To optimise the pulse response of bowtie antennas, various shapes have been studied, for instance, triangular, round-ended triangle, teardrop, end folded and so on [4]. The standard method to achieve a short impulse response is to series load the antenna or to place absorbers at the end of the antenna to absorb the outward propagating energy and dampen unwanted reflections [5][6]. This includes resistive, RC or RL loading and shunt loading designs.

Various types of baluns have been designed to connect the unbalanced transmission lines to balanced antennas, and structures like a transformer and inductive baluns, waveguide and microstrip baluns, and LC balun have been widely applied [7][8][9][10]. However, designing a high-efficiency UWB antenna and balun structure is still a challenge, and the balun structure, its proximity to the antenna design all affect the radiation of the antenna both in time and space.

This study considers the effect of source impedance on the time-domain performance, signal amplitude and settling time of UWB bowtie antennas and shows that these parameters are significantly affected. Furthermore there is an optimum source impedance to minimise the signal settling time while keeping the amplitude high.

The paper is organised as follows: firstly, the background for the UWB antennas are introduced, and then the design and the simulation setup of the antenna and active balun are presented. Finally, results are shown to illustrate the effects of the source impedance on the time-domain performance of the UWB bowtie antennas.

2. METHODOLOGY

The simulation software adopted in the experiment was CST and gprMax [11] and the result from both of these simulation packages were compared whenever possible. The key features that were used in the CST and gprMax simulations are shown in Table 1.

For the experimental measurements, a Copper Mountain S5065 vector network analyser (VNA) was used with step frequency continuous wave (SFCW) technology. Key parameters that were used in these measurements are shown in Table 2.

Table 1: Summary of the key simulation features in CST and gprMax.

CST Parameters	Summary
Problem types	High frequency
Solver	Time domain
Boundary condition	Open(add space)
Mesh tpye	Hexahedral
Frequency	0-6 GHz
gprMax Parameters	Summary
Frequency range	20 MHz to 6 GHz
Time domain range	10 ns
Cell size	2 mm
Input signal format	Gaussian signal
Input signal amplitude	1 V
Input signal central frequency	1.5 GHz
Perfect matching layer thickness	10 cells

Table 2: Summary of the VNA parameters.

VNA Parameters	Summary
Number of steps	201
Frequency step size	32.3 MHz
Start frequency	32.3 MHz
Stop frequency	6500 MHz
Intermediate frequency bandwidth	1 kHz

2.1. Antenna Setup

The bowtie antenna was chosen to be examined in this paper, as it is the most widely used antenna tpye in GPR. The initial antenna dimensions, for both simulation and measurement, are shown in Figure 1.

In the simulation, the antenna is represented by a sheet of perfect electrical conductor (PEC), using the surface of the appropriate voxels. The antennas were fed by a transmission line that can change the impedance in the simulation. In the measurement, the material of the bowtie antenna was copper, and the thickness of the copper on the PCB layer was 35 m. The antennas were fed by an active balun device that can transform the antenna source impedance.

Figure 1: Dimensions of the solid bowtie antenna.

2.2. Active Balun Design

The active balun was designed according to the datasheet of a fully differential amplifier LMH3401 [12] to control the source impedance that feeds the antenna. The active balun can transform the unbalanced signal in the cable to the balanced signal in the antenna and can change the source impedance of the antenna from 50 Ω to the desired value by changing the output resistors of the circuits. The balun was designed on a 0.8 mm thick 2-layer FR4 printed circuit board (PCB) board and mounted directly on the back of the bowtie antennas as shown in Figure 2. Both the transmitting and receiving circuits are powered from a ± 2.5 V supply.

Figure 2: Active balun design.

2.3. Face-to-face Setup

This simulation consists of two antennas facing each other with a separation of 100 mm, of which one is a transmitter, and the other is a receiver, as is shown in Figure 3a. In the CST simulation, each antenna was fed from a 50 ohms impedance and was connected with two resistors seated between the source and two perfect electrical conductor (PEC) triangles. In the gprMax simulation, the 50 ohms source was connected to the antennas through two parallel short conductive edges, of which the conductivity of the edge were adjusted according to the desired source resistance.

In the measurement, an antenna was connected to a 50 ohms transmission cable via the active balun device. Radar absorbing material (RAM) was placed around the antennas to reduce the interference, such as unwanted reflection from the background. The measurement setup is shown in Figure 3b.

Figure 3: Face to face configuration. (a) Simulation (b) Measurement

3. RESULTS AND DISCUSSION

3.1. Source Impedance Effect

Source impedance simulation results in CST and gprMax are shown in Figure 4, and measurement results are shown in Figure 5. The simulation and measured results demonstrate that with the increase of the source impedance, the settling time of the signal was reduced and the energy radiated was decreased. Late time ringing causes self-clutter in the radar system, which can degrade the range resolution. Low-amplitude signals reduce the signal to noise ratio (SNR). Therefore, in a real implementation, the source impedance needs to be a compromise to get a relatively high range resolution and a high SNR.

Figure 4: Source impedance effect - simulation. (a) CST (b) gprMax

Figure 5: Source impedance effect - measurement.

3.2. Effect of Bowie Antenna Flare Angle

The results shown in Figure 4 and 5 were from the bowtie antenna dimensions described in section 2.1. Further simulations using gprMax were carried out to investigate the effect of source impedance on bowtie antennas with different flare angles. Additional experiments adopted the face-to-face setup described in section 2.3 but changing the face-to-face distance from 100 mm to 500 mm, in order to adapt all antenna flare angles. In the investigations, the antenna length was kept at 100 mm while changing the flare angles of the bowtie antenna from 20 to 100 degrees listed in Table 3. Figure 6a and 6b show how the antenna time-domain signal changed with different flare angles, at source impedance of 100 ohms and 250 ohms respectively. The results demonstrate that increasing the source impedance decreased the settling time and the signal energy for antennas with different flare angles.

The antenna time-domain performance did change a little with different flares angles. Bigger flare angle bowtie antenna generated a signal with slightly less late-time ringings. However, in a real implementation, the choice of the antenna flare angle needs to be optimised according to the radar head dimension.

Table 3: Bowtie antenna flare angle investigations.

Parameters	Range
Source impedance	100, 250 ohms
Flare angle	20,40,60,80,100 degrees
Antenna length	100 mm

Figure 6: Changing flare angle of an antenna with a length of 100 mm. (a) 100 ohms source impedance (b) 250 ohms source impedance

3.3. Effect of Bowie Antenna Length

Further simulations using gprMax was implemented to investigate the effect of source impedance on bowtie antenna with different dimensions. The setup of the simulation still adopted the face-to-face setup described in section 2.3 but changing the face-to-face distance from 100 mm to 500 mm, in order to adapt all antenna dimensions. Table 4 lists different antenna dimensions, keeping the antenna flare angle at 43.6 degrees while changing the antenna length from 20 mm to 400 mm. Figure 7a and 7b show how the antenna time-domain signal changed with different dimensions, at source impedance of 100 ohms and 250 ohms respectively. The results demonstrate that increasing the source impedance reduced the late-time ringings and the signal magnitude for all antenna dimensions.

Changing the antenna length changed the antenna time-domain performance significantly. Longer antennas radiated at lower frequency, and tended to extend the time-domain signal. However, they radiated more energy compared to the short antennas. In a real implementation, antenna length needs to be optimised according the requirement of the resolution and the signal energy.

Table 4: Bowtie antenna length investigations.

Parameters	Range
Source impedance	100, 250 ohms
Antenna length	20,50,100,200,400 mm
Flare angle	43.6 degrees

Figure 7: Changing antenna length at a flare angle at 43.6 degrees. (a) 100 ohms source impedance (b) 250 ohms source impedance

4. CONCLUSION

Source impedance has a considerable effect on the time-domain performance of UWB bowtie antennas. Increasing the source impedance for bowtie antenna tends to reduce the settling time of the time-domain signal transferred and thus get a better UWB performance. However, increasing the source impedance will also reduce the signal energy, which can reduce the signal to noise ratio. A compromise needs to be considered when choosing the source impedance for UWB bowtie antennas. Future work will include investigating the physics and the theory of the source impedance effect and implementing more measurements to verify the simulations and theories.

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