A Thorough Analysis of Wire Bow-Tie Antenna

Parisa Fallah[1], Bijan Zakeri[2], Amirashkan Darvish[3]
1- Department of Electrical Engineering, Noshirvani University of Technology, Babol, Iran.
Email: df.aapd@yahoo.com
2- Department of Electrical Engineering,Noshirvani University of Technology, Babol, Iran.
Email: zakeri@nit.ac.ir
3- Department of Electrical Engineering,Noshirvani University of Technology, Babol, Iran.
Email:amir.darvish70@yahoo.com

Received: October 2017 Revised: October 2017 Accepted: December 2017

ABSTRACT:
Ground penetrating radar (GPR) is one of the most important instruments in some cases such as remote sensing, non-destructive evaluation and microwave imaging. The radiation component (antenna) in these radars is very important. Features and constraints such as high impedance bandwidth, stable radiation patterns, minimum distortion of the antenna end reflections and consequently sending high-precision pulses makes many challenges in construction and design of the antenna. In addition, the antenna size, which is expected to cover both low frequencies and portability, adds to the difficulty of designing this antenna. In this paper, four possible modes of wire bowtie antenna, which is known as one of the most common antenna in impulse GPR applications are introduced and investigated. To this regard, late-time-ringing effect of the transmitted UWB waveform, pattern characteristics and impedance bandwidth of the proposed structures have been analyzed and compared. The results show that the other modes can be replaced to the original one in most cases.

KEYWORDS: Bowtie antenna, Ground penetrating radars, Wire structures, UWB pulse radiation, GPR antenna, input impedance, GPR pulses, radiation pattern.

1. INTRODUCTION

Ground penetrating radar (GPR) has been widely used in subsurface probing applications [1], [2]. Antenna is an important part of GPR equipments and wide bandwidth is an inseperable requirements for a GPR antenna [3]. Wideband characteristics of bowtie antenna was reported by many investigators comprising of Brown and Woodward [4], and Carrel who was the first to show analytically that the bandwidth of bowtie antenna depends on the bowtie flare angle [5]. Then, Lambert et al. [6] and Lee and smith [7] improved Carrel's analytical solution. shlager et al.[8] and Leat et al.[9] developed a numerical model for a bowtie antenna. Their analysis involves the use of the finite-difference time-domain (FDTD) method for modeling fully three-dimensional antennas. These issues also include the use of a simple feed model and the staircasing of the edges of the antenna. Solid bow-tie antenna have long been used due to the wideband characteristics it provided [8, 10]. However, in most cases, using wire bowtie antennas is more advantageous as introduced in [11] and [12]. In wire structures, the following characteristics can be achieved by varying the wire geometry in real time.

Improving pulse radiation: Generally, one of the important characteristics of the GPR antenna is the ability to send differential Gaussian pulses with a width of 0.8 nanoseconds. But, because of the limitation in length, the waves reaching the end of the antenna, return and disturb the transmitted wave. This phenomenon is called late-time-ringing. It creates undesired pulses and leads to errors in target detection. For this reason, minimizing this factor in antenna design is crucial. Creating travelling waves in the antenna can prevent this phenomenon and the created distortion at the antenna end. Using resistive loads or plates can be considered as a suitable strategy for creating travelling waves [13]. But this solution greatly affects the antenna radiation efficiency, and in turn, the antenna would not have feasible radiation performance. Therefore, providing alternative solutions for improving the pulse radiation performance is always admirable. In Fig. 1 these pulses are plotted in time and frequency. As shown in Fig. 1(a), the desired pulse has a duration equal to 0.8 nanosecond, which according to the Fig. 1(b) has frequency components from very low frequencies to frequencies near 4.5 GHz. Therefore, from the frequency point of view, the coverage of a wide range of 0 to 4 GHz is essential for this antenna in a way that exceeding this domain can prevent radiation of intended frequency components. Wire bowtie structures has shown a reliable

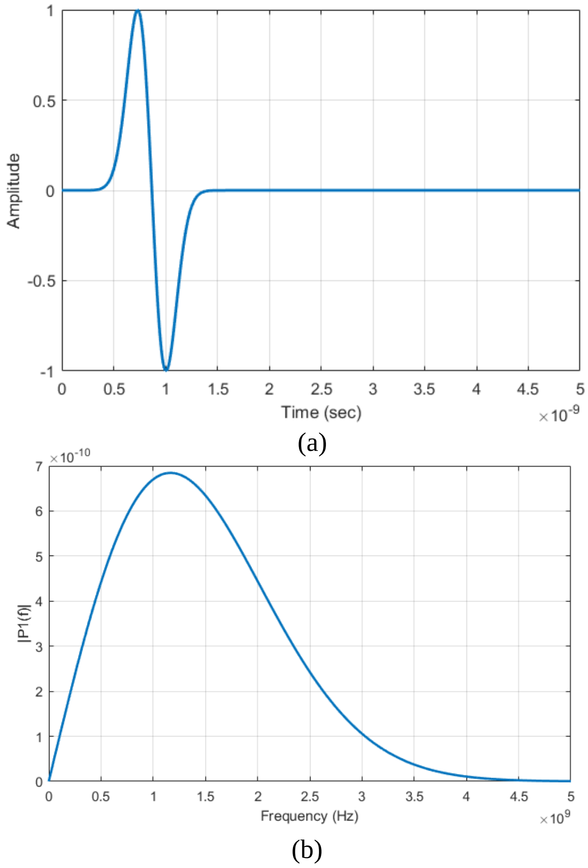


Fig. 1. Transmitted waveform. (a).time domain. (b).frequency domain

capacity of covering the frequency range.

Achieving resistive impedance: The second essential characteristic of GPR antenna is its impedance bandwidth, especially suitable for impedance of 50 ohms and 100 ohms. In other words, the simultaneous acquisition of zero reactance and resistance of 50 (or 100) ohms is the second challenge of designing a PR antenna. One of the effective ways to increase the impedance bandwidth is creating a suitable condition for deflection of electric current in different lengths. In other words, the structures in which the surface currents experience more changes can demonstrate more impedance bandwidth. It has been proved that wire bowtie structures can possess this feature [14].

Having simple and changeable structure: Another factor that can be obtained through using a wire bowtie antenna is its compact, simple, cheap and portable structure. In other words, if we consider GPR antennas in the frequency range from 0.01 to 5 GHz, by dividing this range to smaller ones we can have several application of GPR antennas. Since abovementioned frequency band is a large frequency band, without considering any special antenna, the maximum dimensions required for such antenna would be about 30 meters. As a result, a wire bowtie structure is necessary to reduce the dimensions of the antenna. This maximum reduction is possible by selecting appropriate modes for the antenna.

In this paper, we introduce and analyze *four* possible configurations of a common wire bowtie structure which had been designed for an impulse GPR application. At first, the structures are described in detail. The analysis procedure consists of three main parts. *Input impedance comparisons* are presented in section 3. Then, in section 4, pulse radiation analysis is conducted regarding to some recent studies. Finally, in section 5, we will compare the radiation patterns of the intended structures.

2. THE STRUCTURES UNDER STUDY

The original geometry of the wire-based antenna which is studied in this work can be seen in Fig. 2 that have identical wire elements, a common feed point and same angular seperation between wires, as suggested in [14].

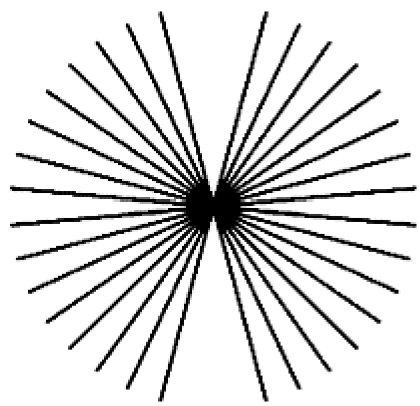


Fig. 2. Geometry of proposed antenna

As shown in Fig. 2, the case study has two positive and negative poles. The feed point is on PVC support and bow-tie poles are placed near eachother. The structure consists of 16 wires in each pole each of which separated with the angular distance of 10°. All wires have same length. In addition, there is a 2mm gap between two poles. It has been demonstrated that such a wire structure is a good approximation of a solid bow-tie antenna. By changing the wire length and intensity of the original antenna various modes of the structure can be created. Considering the point that all of the wires diameters are the same and just the length of them and number of wires are varing in this study, the following

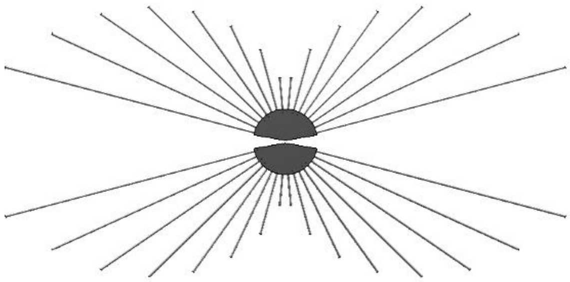


Fig. 3. Shematic ascending wire bowtie antenna.

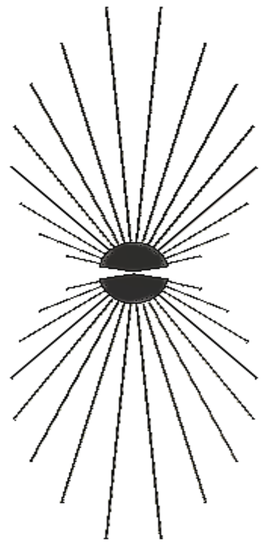


Fig. 4. Shematic of descending wire bowtie antenna

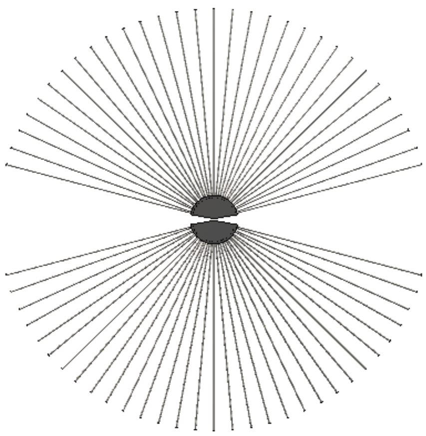


Fig. 5. Shematic of extra wire bowtie antenna.

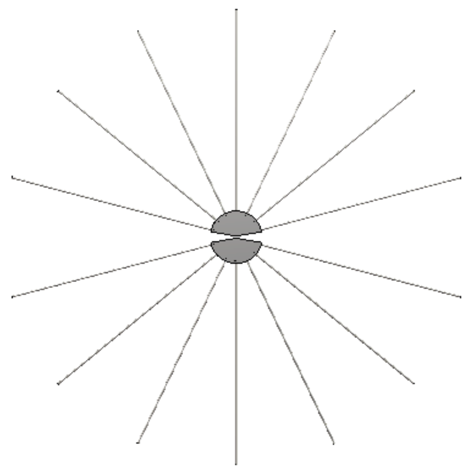


Fig. 6. Shematic of less wire bowtie antenna.

four antenna can be introduced.

1- *Ascending wire bowtie antenna*: This mode has 16 wires in each pole as the original one, but the length of the wires are changing linearly in an ascending manner. It has been shown in Fig. 3. Indeed, in each quarter, there are 8 wires with the lengths that are increasing linearly from 50mm (in center) to 225mm (in corner). The common difference for this arithmetic progression is 25mm.

2- *Descending wire bowtie antenna:* Fig. 4 illustrates this mode. This structure is similar to the previous one except that the wires are decreasing linearly from 225mm (in center) to 50mm (in corner). The common difference is 25mm.

3- *Extra wire bowtie antenna:* This structure has been shown in Fig. 5. In this mode the number of wires of the original design has been increased. As a result, each pole consists of 31 wires with angular separation of 5°.

4- *Less wire bowtie antenna:* Fig. 6 illustrates the antenna which has lower number of wires than the original one. As a result, each pole has 7 wires with angular separation of 25°.

The feeding mechanism used in all of these simulations are the same. Their feed can be hold with PVC support such as the original shape of antenna.

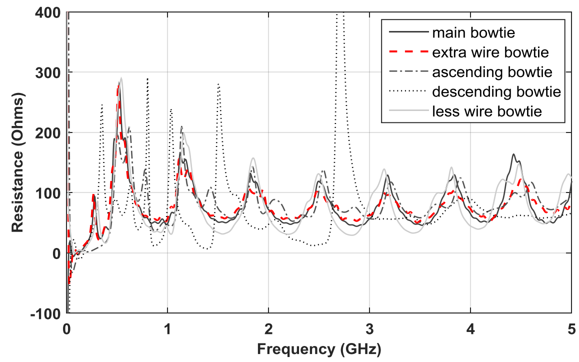
It should be mentioned that all of the newly proposed antennas are assymetric in both directions X and Y same as the original design.

3. INPUT IMPEDANCE ANALYSIS

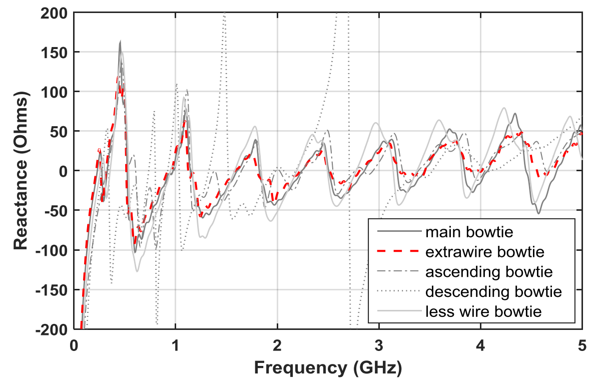
In this section we want to analyze the computed input impedance of the original bow-tie antennas (in free space) with greatest flare angle and compare it with the other version of the antenna that have some alternations than the main antenna [14]. Fig. 7, indicates the computed input resistance and reactance of the intended antennas. As shown in Fig. 7, at frequencies below 1 GHz, there is higher impedance level and fluctuations for all modes. At higher frequencies the impedance behaves oppositely, the fluctuations is lower. Specially, ascending wire antenna has lower fluctuations than others. Also, the antenna with descending wires, have the highest fluctuation among these antennas, so, have the worth condition for matching. It can be observed that, extra wire bowtie antenna has slightly less fluctuations than other antennas. It is more clear in higher frequencies, so this antenna has better match condition than other antennas.

4. PULSE RADIATION ANALYSIS

In impulse GPR applications the waveform of the transient fields transmitted into the ground should exactly be known to improve imaging of subsurface. It is important first to observe the shape of the transmitted main pulse (the pulse which is radiated directly from the feed point) because it mainly determines the waveforms transmitted by the antenna into the subsurface. The radiated waveform can be divided to two different parts. The main pulse waveform, which should be enhanced and the late-time-ringing part, which should be diminished. In Fig. 1 we observe the shape of the transmitted pulse with duration of 0.8 ns for GPR applications. For this test, we use field probe in 25 cm at the broadside direction of the antenna. Fig. 8 shows the radiated pulse of all antannas under test. It can be infered that, the ascending wire bowtie antenna has a radiated pulse with higher amplitude and less late-time-ringing in comparison to other antennas which makes it more desired for impulse GPR applications. It also shows that the most of the feeding power is concentrated to the main pulse radiation. As a result, the antenna recuires less post-processes for obtaining desired information from the waveform [15].



(a)



(b)

Fig. 7. Comparison among the computed input impedance of various type of proposed antenna: (a) resistance (b) reactance.

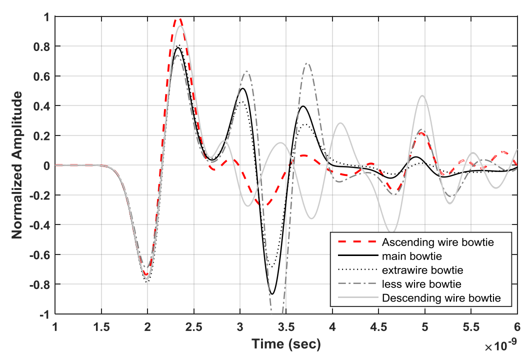


Fig. 8. A comparison among the computed pulse radiations.

On the other hand, the extra wire bowtie antenna shows the unchanged characteristics in the main part, but its *maximum amplitude* in the late-time ringing part has been enhanced over the main bowtie. In [16] a modified bowtie antenna using a resistively loading section has been introduced in order to improve the pulse radiation. Fig. 9 shows the comparison of pulse radiation between the proposed antenna [16] and the ascending wire antenna introduce in this paper. The waveform radiation of the latter comprises of an intact differential gaussian pulse with stronger extremums. In addition, the late-time-ringing section of the ascending wire bowtie transmitted pulse has lower amplitude in comparison to the modified bowtie.

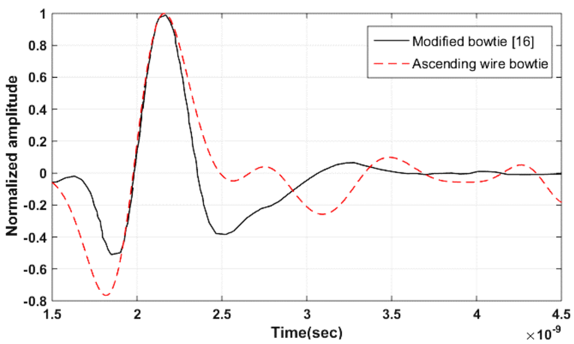


Fig. 9. A comparison between the computed pulse radiation of the proposed bowtie antenna [16] and ascending wire bowtie antenna.

5. RADIATION PATTERN ANALYSIS

In GPR applications, we need a directive radiation pattern which is stable during a wide frequency range. It is important due to the fact that the desired monopulse has non-zero frequency components through 0 to 3.5 GHz as shown in Fig. 1(b). A broadband characteristic for radiation pattern ensures that all of the frequency components can be transmitted in a directive manner. An essential criterion for this analysis is that the main beams of the patterns are pointed in the broadside direction. The simulated radiation patterns of the wire bowtie antenna at 6 different frequencies from 0.5 to 3.3 GHz are presented in Fig. 10. The results demonstrate the directive property of the antennas, especially in extra wire and ascending wire bowtie antenna. Moreover, the figure shows that the main beams of the extra wire and ascending wire bowtie antenna are relatively stable for all frequency samples. However, descending wire bowtie and less wire bowtie antenna has shown less stable patterns which makes them less attractive for GPR.

6. FURTHER DISCUSSIONS

Among the proposed structures, ascending wire bowtie has several advantages which makes it pioneer for impulse GPR applications. Higher quality of the transmitted waveform (the similiarity between excitation signal and the transmitted one), higher efficiency (stronger amplitude at the main pulse section), stable radiation pattern as well as smaller size are the reasons that makes it more desirable. It should be noted that lower performance of the extra wire bowtie antenna in radiation of UWB pulses overshadows its good impedance characteristics.

As a future work, better impedance characteristics of the ascending wire bowtie antenna can be achieved using loading techniquese as utialized in [3]. Resistive loading and capacitive loading are two common tools that can properly enhance the antenna bandwidth.

7. CONCLUSION

Four different modes of wire bowtie antenna have been introduced and analyzed for GPR applications. The proposed designs can be achieved by changing the intensity and the length of the wires. From the impedance matching viewpoint, extra wire bowtie antenna has more reliable impedance characteristics than other antennas with less fluctuations. Ascending wire bowtie antenna however behaves same as the main bowtie, it is a good choice for adaptive applications. In the pulse radiation analysis, ascending wire bowtie shows stronger transmission of the main pulse with more reduction of end reflections. In the comparison between the ascending wire bowtie antenna and the recently introduced modified bowtie antenna, it is obvious that ascending wire bowtie antenna has a good main pulse amplitude with lower late-time-ringing. This characteristic makes this antenna suitabe for impulse GPR applications. In the final test, radiation characteristics of the proposed antennas have been compared through the bandwidth. Extra wire bowtie antenna and ascending wire bowtie antenna have shown more stable results over the desired frequency.

8. ACKNOWLEDGMENT

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

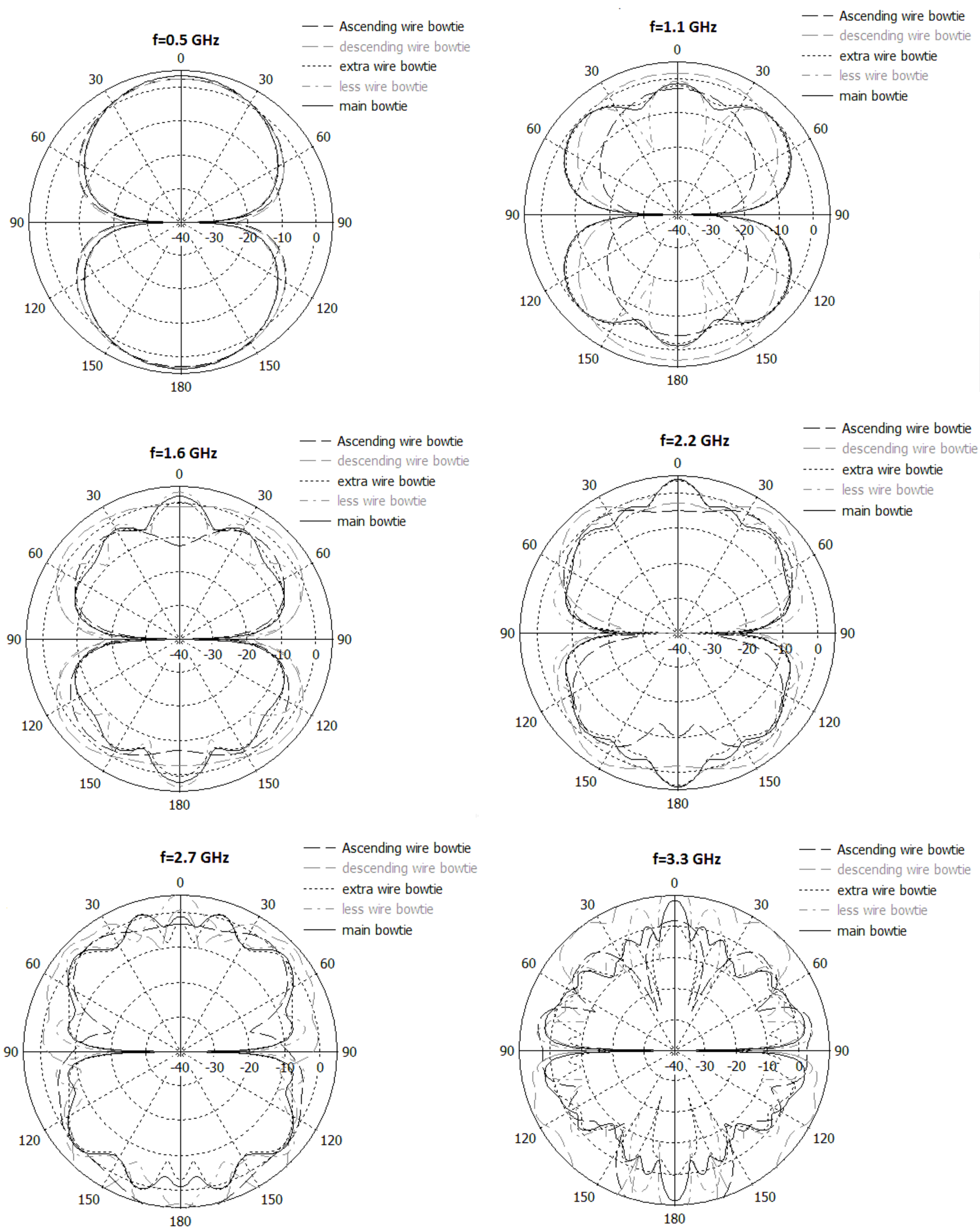


Fig. 10. Radiation patterns of the *RC* loaded bow-tie antenna for different frequencies, measured in dBi.

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