A Novel wideband VHF antenna for impulse GPR applications

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(Manuscript Received on December 11th, 2013; Manuscript Revised September 05th, 2014)

ABSTRACT:

A novel wideband VHF antenna for the impulse ground penetrating radar (GPR) system at 200 MHz central frequency is presented in this article. The antenna improves the impulse GPR system for increasing ability penetration. By using the Lemniscate curve, this novel structure of the proposed antenna achieve better radiation than other bow-tie antennas. In addition, this article also proposes the UWB balanced-to-balanced (balun) transformation line is designed to feed the antenna. The balun is an important element for improving the bandwidth of the antenna. The fabrication of the antenna is only simple but also low cost with FR4 substrate and copper patch. The proposed antenna is designed and fabricated with the successful results.

Keywords: *Impulse ground penetrating radar (GPR) system, Lemniscate curve, balanced-to-unbalanced (balun), bow-tie antenna, Novel wideband VHF antenna.*

1. INTRODUCTION

Ground penetrating radar (GPR) is sometimes called georadar, ground probing radar, or subsurface radar. GPR uses electromagnetic wave propagation and scattering to image, locate and quantitatively identify contrasts in electrical and magnetic properties in the ground. [1]. Detectability

of a subsurface feature depends upon contrast in electrical and magnetic properties, and the geometric relationship with the antenna. Quantitative interpretation through modeling can derive from ground penetrating radar data such information as depth, orientation, size and shape of buried objects, density and water content of soils, and much more. Important component in any GPR system are the transmitter and receiver antennas [2]. Antennas radiate electromagnetic energy in the microwave band (UHF/VHF frequencies) when there is a change in the acceleration of the current on the antenna. Antennas also convert electromagnetic waves to currents on an antenna element, acting as a receiver of the electromagnetic radiation by capturing part of the electromagnetic wave [3].

The depth range of GPR system depends on not only the electrical conductivity of the ground but also the transmitted central frequency. The lower frequency will make the deeper penetration. So, the GPR systems requite the designed antenna that has a low central frequency in VHF range. Recently, there are many researches for improving the deeper penetration of the impulse GPR system. The antenna is situated above dry sand with relative dielectric permittivity in the 500 MHz–3 GHz range and with very small conductivity [4]. The antenna has a broadband and makes the GPR system to high resolution. However, the UHF central frequencies of this antenna don't improve the range of depth for the impulse GPR system. Besides, ZOU Aimin, LI Jicai, WANG Keke and CHENG Defu have experimental results show that voltage standing wave ratio (VSWR) of the loaded antenna is less than 2.5 in the band 0-300 MHz [5]. However, the value of VSWR make performance of the antenna is not good and it is the trouble for processing signals in the receiver. In addition, Chen Guo and Richard C.Liu provided Shielded antenna system [6]. Although they make a good Transmitting signal with shielding and absorbing materials, their designed antenna is used in a GPR system working at 400MHz central frequency.

In this article, we propose a novel wideband VHF antenna to improve the deep penetration for the impulse GPR system. Unlike the above bow-ties antenna in [5], [6] and [7], the antenna is based on Lemniscate curve to achieve a good radiation. The proposed balun has a broadband and makes a good matching impedance. The dimension of the antenna is smaller than other bow-tie antennas at the same central frequency. The antenna is successfully optimized by CST MICROWAVE STUDIO software. The proposed antenna has the return loss is less than -10 dB and VSWR is less than 2 in band 176-232 MHz. The results show good agreement between simulation and measurement.

2. THE PROPOSED LEMNISCATE ANTENNA

The proposed antenna has FR4 dielectric substrate and copper patch for the impulse GPR system. We use the Lemniscate cure to create the structure of the antenna. This curve of the patch of antenna is shown in Figure 1. The locus of the point P on the Lemniscate curve can be determined from two focal points F and F' such that 2OF.OF' = a2 (where a is the distance from O to the center focal point F). The equation of Lemniscate curve in Cartesean coordinate is shown [7]:

$$(x^2+y^2)^2-2a^2(\mathrm{x}^2-\mathrm{y}^2)=0 \qquad (1)$$

And the form in plolar coordinate is shown:

$$r^2=2a^2\cos(2\theta) \qquad (2)$$

The curve Lemniscate of the proposed antenna has length La = 541.3 mm, width Wa = 182 mm, and the gap between the two wings of the antenna is 5 mm, as shown in Figure 2.

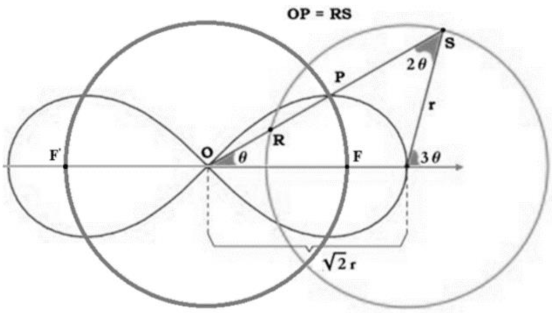

Fig 1. The Lemniscate curve

The curve Lemniscate of the proposed antenna has length La = 541.3 mm, width Wa = 182 mm, and the gap between the two wings of the antenna is 5 mm, as shown in Figure 2.

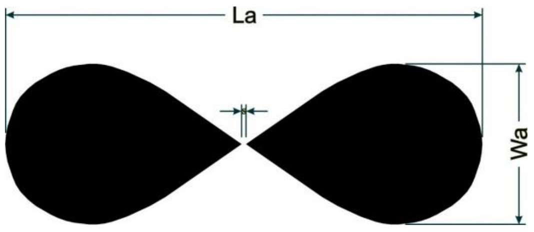

Fig 2. Geometry and configuration of the proposed antenna

The distance of Lemniscate curve for this antenna is $\sqrt{2}r = 268.15$ mm and OF = 186.61 mm. Like the dipole antenna, the feed line of Lemniscate antenna is located in middle of the wings at S opened point. The proposed antenna uses FR4 dielectric material which has a length Ls = 546.3 mm, width Ws = 192 mm, the thickness of FR4 dielectric substrate h = 1.6 mm, dielectric constant εr = 4.6, loss tangent tan δ = 0.02, and the thickness of the copper patch t = 35 micrometers, shown in Figure 3.

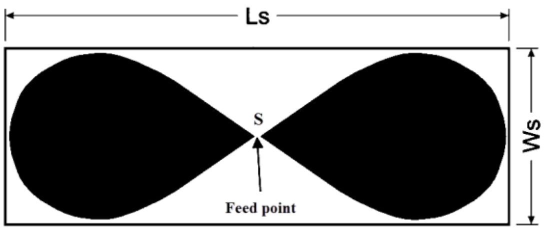

Fig 3. Geometry and configuration of the proposed antenna is based on substrate with feed point

The microstrip taper balun is designed to transform from the unbalanced structure of the coaxial cable 50 Ω impedance to the antenna structure balance in the 200 MHz frequency, is shown as Figure 4. This taper-line balun has two sections: the balanced line portion which matches the antenna impedance to 50 Ohm and a portion which actually performs the mode transduction. The dimensions of balun are shown in Figure 5 and its values are shown in Table I.

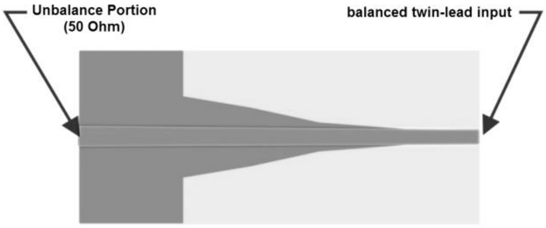

Fig 4. Configuration of the microstip taper balun

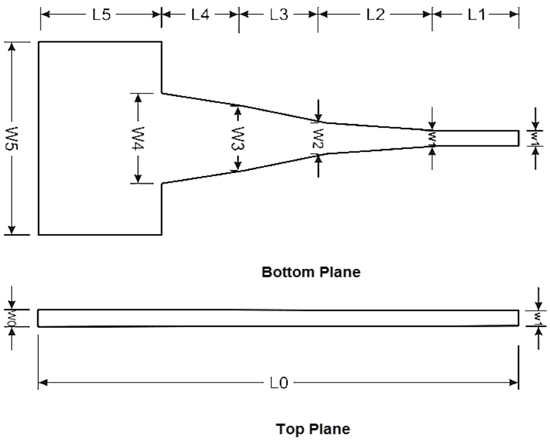

Fig 5. The dimensions of balun

Table 1. The dimension values of balun

n	Wn (mm)	Ln (mm)
0	3	300
1	3	60
2	6	90
3	12	60
4	25	60
5	40	30

We firstly simulate the antenna without balun. The value of reflection coefficient S11 = - 21.1 dB. S11 is less than - 10 dB and VSWR is less than 2 in the frequency range from 221.6 MHz to 184.38 MHz, as shown in Figures. 6 and 7. Input impedance of the antenna Z = 42.52 + 3.24*j Ohm at frequency 200 MHz. The real part and the imaginary part of the impedance respectively are presented in Figures 8 and 9.

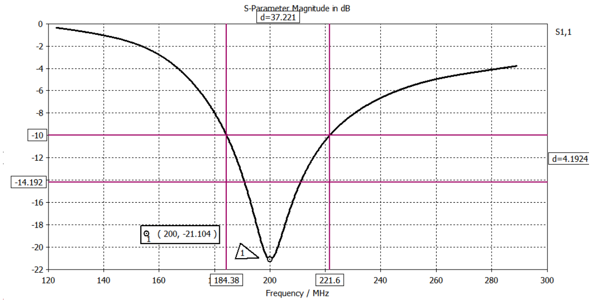

Fig 6. Return loss S11 of the antenna without balun

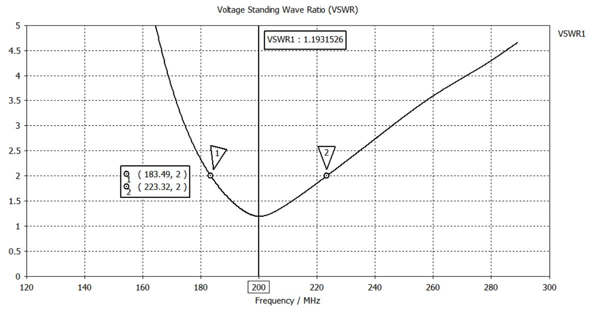

Fig 7. VSWR of the antenna without balun

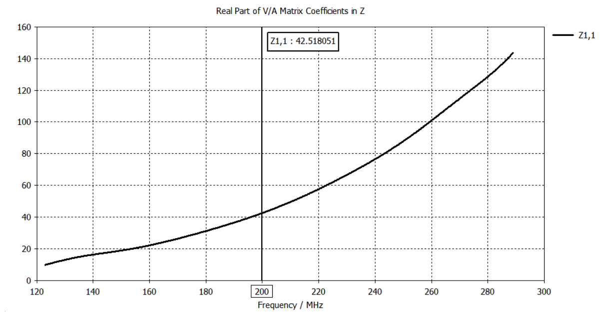

Fig8. The real part of the impedance

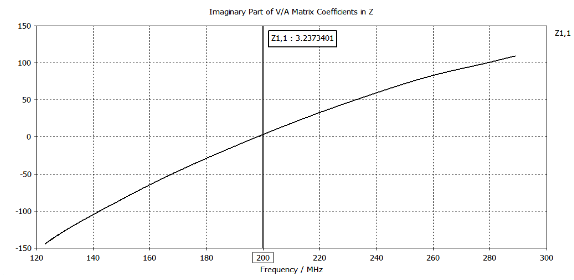

Fig 9. The imaginary part of the impedance

We use the balun to feed the antenna, make good match impedance and increase performance of antenna, is shown Figure 10. The simulation results of antenna with balun are show in Figures 11, 12, and 13.

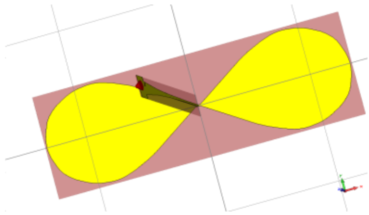

Fig 10. Antenna with balun in simulation environment of **CST** software

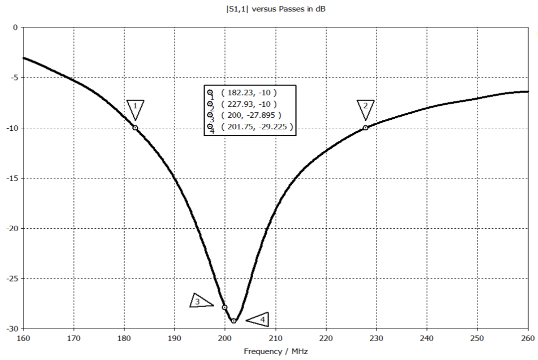

Fig 11. Return loss of antenna with balun

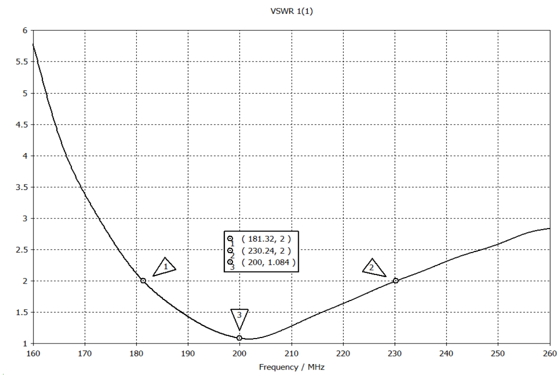

Fig 12. VSWR of the antenna with balun

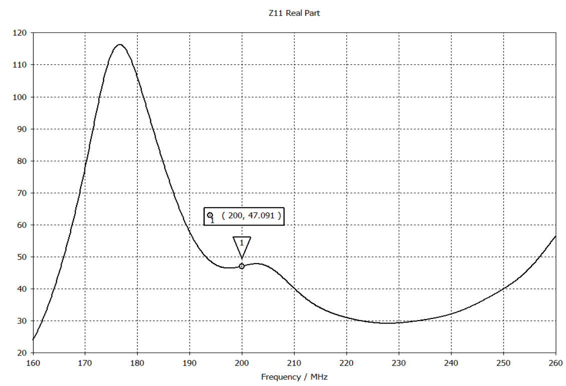

Fig 13. The real part of impedance in case the antenna with balun

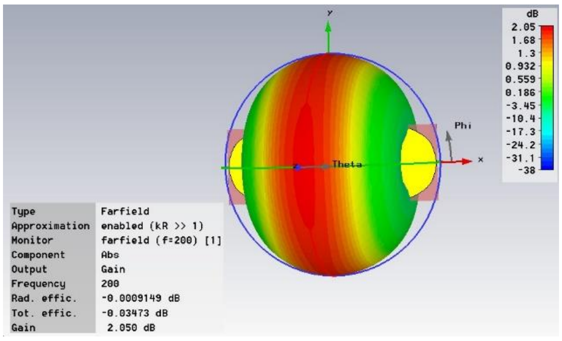

Fig 14. 3D radiation pattern of antenna at 200 MHz

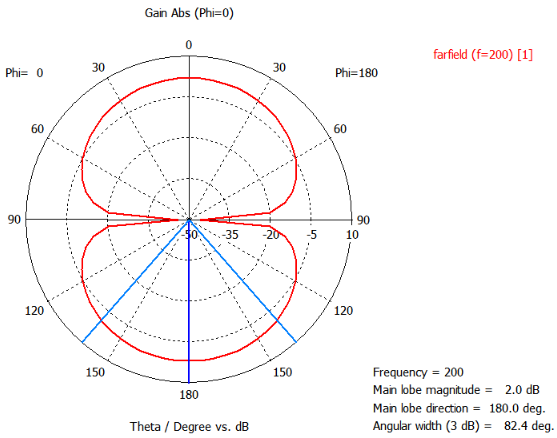

Fig 15. Radiation pattern of antenna at 200 MHz in polar coo

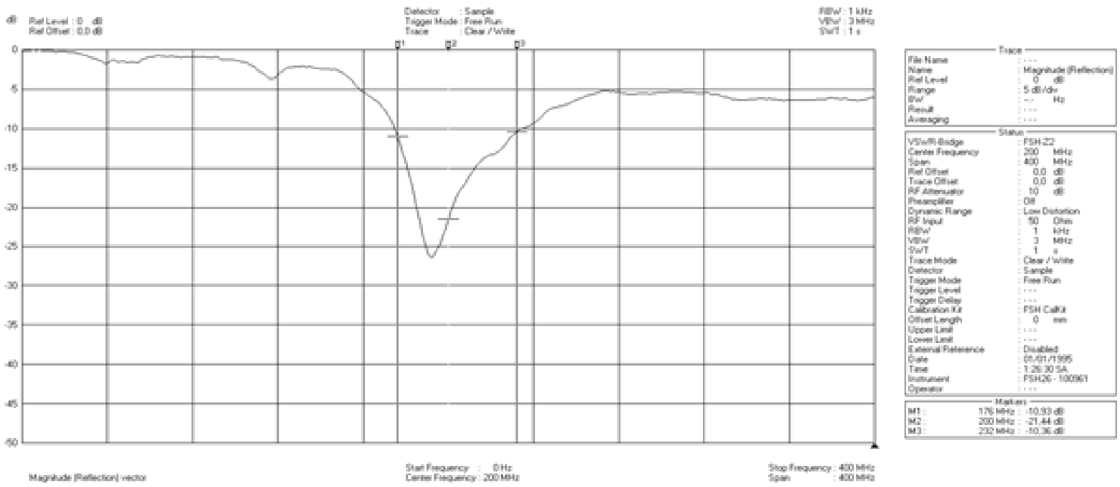

Fig 16. Measured reflection coefficient S11

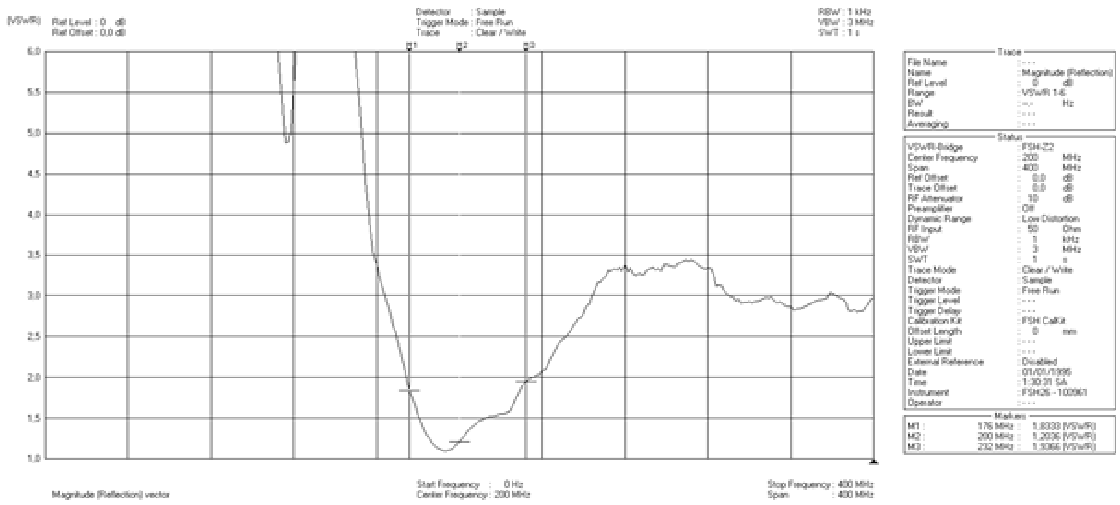

Fig 17. VSWR measurement

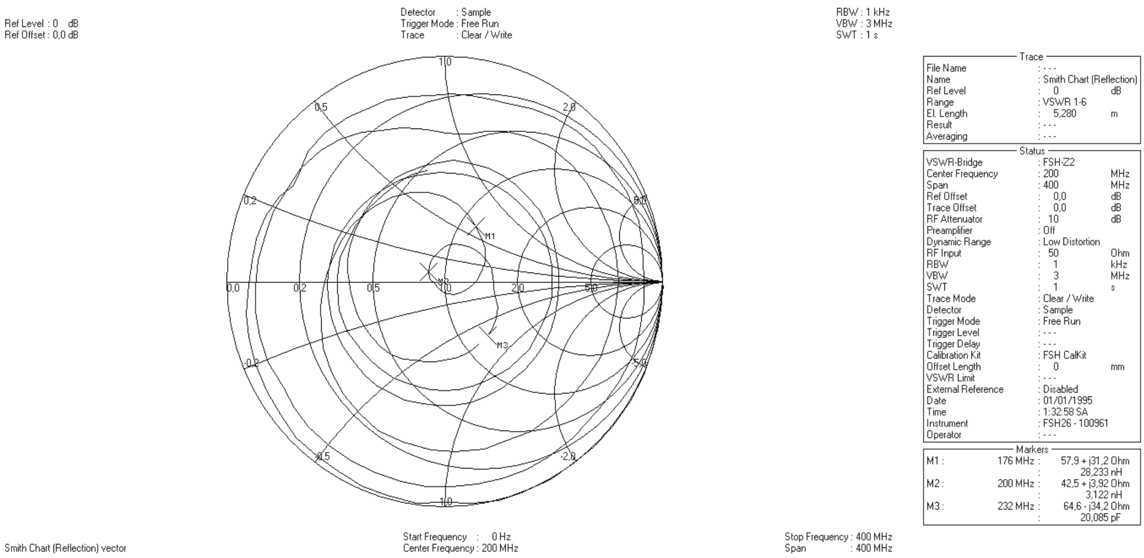

Fig 18. Smith Chart measurement

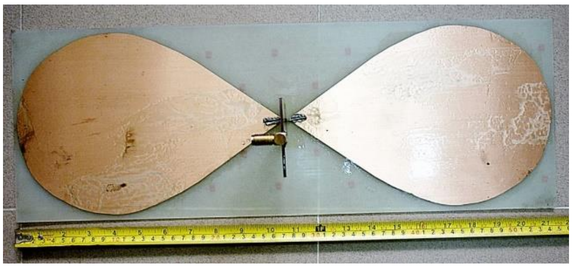

Fig 19. Geometry of the implemented antenna

According to the above simulation results at the central frequency from Figure 11 to Figure 15, S11 is less than -25 dB and the real part of the impedance is 47 Ohm. The bandwidth is 49 MHz, equivalent to 25% of the central frequency 200 MHz. The simulation results show that matching impedance in case of the antenna with the balun is better than the case of the antenna without the balun. So, the designed balun helps to increase the performance of antenna.

Radiation pattern in 3D and polar coordinate of the proposed antenna at 200 MHz are shown in Figure 14 and 15, respectively. Radiation pattern focuses on two directions, which is suitable for applications need narrow beam width and GPR system is an example application. The low central frequency and the stability of radiation improve for the deeper penetration.

3. EXPERIMENTAL RESULTS

In this section, we present the measured results of the proposed antenna. The implemented antenna is shown in Figure 19. Figure 16 and 17 show the measured reflection coefficient S11 and VSWR with the wideband balun transformer line. The Smith Chart measurement of the proposed antenna is also shown in Figure 18. It proves that the antenna has a good matching impedance. The Table II and Table III compare the results of S11 and VSWR. The results of comparison show good agreement between simulation and measurement.

Table 2. Comparison results between simulation and measurement of S11

Frequency (MHz)	Simulated S11 (dB)	Frequency (MHz)	Measured S11 (dB)
182.23	-10	176	-10.93
200	-27.9	200	-21.44
227.93	-10	232	-10.36

Table 3.Comparison results between simulation and measurement of VSWR

Frequency (MHz)	Simulated VSWR	Frequency (MHz)	Measured VSWR
181.32	2	176	1.833
200	1.084	200	1.204
230.24	2	232	1.972

4. CONCLUSIONS

The novel wideband VHF antenna is successfully designed and measured for the impulse GPR system. The measured results show that the proposed antenna has a bandwidth from 176-232 MHz, equivalent to 28% of the central frequency 200 MHz. The wideband balun makes a good matching impedance of the antenna. The structure of patch antenna is the Lemniscate curve. This structure is new way of designing antenna for the industrial production antennas. The implement of antenna is extremely low cost. Besides, the antenna is also suitable for other applications in VHF range. In future, the proposed antenna can be used to make an antenna arrays for the purpose of increasing performance and making a multi-channel GPR system.

ACKNOWLEDGEMENT: *This research is supported by National Key Laboratory of Digital Control and System Engineering (DCSELAB), HCMUT, VNU-HCM under grant number B2012-20b-01TĐ.*

Đề xuất một loại Anten băng rộng mới cho hệ thống radar xuyên đất dạng xung trong băng tần VHF

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TÓM TẮT:

Trong bài này, chúng tôi đưa ra một kiểu thiết kế mới cho anten băng rộng, ứng dụng cho hệ thống Radar xuyên đất (GPR) ở băng tần VHF. Với tần số trung tâm là 200 MHz, anten vi dải được thiết kế có thể đạt được độ xuyên sâu tối đa 5 m cho hệ thống Radar xuyên đất dạng xung. Anten được thiết kế theo kiểu anten bow-tie và kiến trúc được tạo theo dạng đường Lemniscate. Kiến trúc này giúp cho anten có được bức xạ tốt hơn so với các anten bow-tie hoạt động cùng tần số. Ngoài ra, một balun băng rộng được thiết kế để giúp anten phối hợp trở kháng tốt và tăng hiệu suất bức xạ. Việc thi công anten rất đơn giản và cực kỳ giảm chi chi phí với một lớp điện môi FR4 và một dải kim loại bằng đồng phía trên. Anten được mô phỏng, thiết kế và đo đạc thành công với sự phối hợp trở kháng tốt, độ lợi và sự bức xạ ổn định.

Từ khóa: *Impulse ground penetrating radar (GPR) system, Lemniscate curve, balanced-to-unbalanced (balun), bow-tie antenna, Novel wideband VHF antenna.*

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