Research Article

VHF/UHF Wideband Slim Monopole Antenna with Distributed Matching Structures

Dongjie Qin and Baohua Sun

Key Laboratory of Antennas and Microwave Technology, Xidian University, Xi’an 710071, Shaanxi, China

Correspondence should be addressed to Baohua Sun; bhsun@mail.xidian.edu.cn

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This paper presents a wideband monopole antenna with distributed matching structures operating on VHF/UHF bands. The antenna consists of a slim rectangular metal strip with a T-type slot etched on the upper half, two rectangular slots on the lower half, and two rectangular plates soldered with the bottom end of the main strip. The antenna is installed on a metal case which serves as ground. To achieve a wide bandwidth, an impedance matching network consisting of the distributed structures, which are composed of two metal plates and a metal thin strip, is devised and integrated with the main radiating strip. The T-type slot near the top tip of the main strip is used for the miniaturization of the antenna. The proposed antenna is fabricated and measured, and the measured results are in good agreement with the simulated results. The sizes of the proposed antenna and the case are 0.19\(\lambda_{\text{max}}\) \times 0.014\(\lambda_{\text{max}}\) and 0.17\(\lambda_{\text{max}}\) \times 0.1\(\lambda_{\text{max}}\) \times 0.034\(\lambda_{\text{max}}\), respectively. The operating bandwidth is from 203.7 to 516.9 MHz (2.54 octaves) with the condition of VSWR \(\leq 3:1\). This antenna has a slim structure, a wide bandwidth covering partially VHF and UHF bands, and omnidirectional radiation patterns, so it can be the candidate for the applications of backpacked radio stations in military communication scenarios.

1. Introduction

Whip antennas, with slim shapes and omnidirectional radiation patterns in the horizontal plane, are the traditional antennas for backpacked radio stations [1] operating on VHF and UHF bands with wide applications in military communication, civilian rescue, and other fields [2]. The relative impedance bandwidth of the a-quarter-wavelength whip monopole antennas is narrow [3] and unable to satisfy the need for wideband communication nowadays. Cage antennas, biconical antennas, discone antennas, planar antennas, and sleeve antennas have wide bandwidths but with big sizes that are not suitable for the backpacked radio stations [4]. For example, Souny and Morlaas design a monopole antenna loaded with a cage in [5] achieving the bandwidth of 480–900 MHz but with a diameter of 0.8\(\lambda_{\text{max}}\) in [7]. Yadam et al. design an ultrawideband conical monopole antenna that covers the band from 0.5 to 3 GHz to detect partial discharges [8]. The antenna is with a big volume of 0.183\(\lambda_{\text{max}}\) \times 0.25\(\lambda_{\text{max}}\) \times 0.25\(\lambda_{\text{max}}\). Omar and Shen present a wideband monopole antenna composed of a cone loaded with two thin and short parasitic posts and a top ring that is shorted to the ground with four meandered lines [9]. This antenna achieves a bandwidth of 4.861 : 1 but with a diameter of 0.34\(\lambda_{\text{max}}\). Dzagbletey et al. present a planar monopole with a cone ground that exhibits a relatively wide bandwidth of 0.56 to 8.2 GHz [10]. With the trident-branches feed, the monopole antenna is well matched in the low-frequency region but with a diameter of 0.42\(\lambda_{\text{max}}\). Johnson et al. present a monopole antenna loaded with the capacitive top circular patch which is designed to improve matching and pattern roundness for satellite applications on the VHF and UHF band with retractable supporting...
structures [11]. But the diameter of the proposed antenna is 0.1λ_{max}. Zhang et al. propose a wideband sleeve monopole antenna without the ground plane [12]. But the overall size of the sleeve antenna is large. Zhang et al. present a monopole antenna with two sleeves achieving a bandwidth from 730 to 3880 MHz with a diameter of 0.3λ_{max} in [13] that is too large for a backpacked radio station. Zhao et al. propose an ultrawideband monopole with the bandwidth of 210–2000 MHz with a diameter of 0.426λ_{max} in [14]. Huang et al. present a planar monopole with etched grates and concave ground in [15] achieving the bandwidth of 450–950 MHz but with a dimension of 0.352λ_{max} × 0.044λ_{max} that is relatively large. Monopole antennas with resistive, capacitive, or inductive loadings have wide bandwidths [4]. Amani et al. propose a 173cm-high dipole loaded with LR loads that achieve the bandwidth of 30–512 MHz but with low gains of −20 dBi at 30 MHz and −2 dBi at 512 MHz [16]. Ding et al. present a 1.47m-high wire monopole antenna with LR loading [17] that covers the bandwidth of 30–520 MHz, but the lowest efficiency is 35% due to the loss of resistance. Werner and Werner present a whip monopole loaded with stubs in [18] to achieve miniature, but the bandwidth is narrow. The normal mode helix antenna has a slim size [4], but the bandwidth is narrow.

Figure 1: The structure of the proposed antenna.

Figure 2: The dimensions of the proposed antenna. (a) The front view of the antenna (the left inset is the magnifying view of the slim strip and the rectangular plates near the feed point of the antenna, and the right inset is the magnifying view of the T-type slot on the upper half of the radiated strip). (b) The left view of the antenna.
Kim et al. present a monopole composed of a cylindrical helix and an extendable rod to achieve miniaturization but with the bandwidth of 174–230 MHz that is relatively narrow [19]. Mobile phone antennas have been widely researched, and the techniques of miniaturization and bandwidth broadening are abundant but are not suitable for the applications in the VHF band because the size of mobile phones is small. So, the antennas with whip shapes, wide bandwidths, omnidirectional radiation patterns, and high efficiencies or high gains applied in the VHF/UHF band becomes an urgent need for backpacked radio stations.

This paper presents a wideband slim monopole antenna. A middle slim strip in the main radiator and two rectangular plates (near the feed point) together form the matching network to achieve good impedance matching. A T-type slot in the upper half of the main radiator is used to miniaturize the size of the proposed antenna. The antenna is fabricated with copper foil with a thickness of 0.2 mm which makes the monopole antenna occupy little transverse space. The metal case on which the monopole antenna is mounted has a similar shape to an Oxford Dictionary which can not only serve as the ground of the monopole antenna but also can be a container for the relevant circuit boards, batteries, and other devices of the backpacked radio station. The monopole antenna covers the bandwidth of 225–400 MHz with horizontal omnidirectional radiation patterns which can be used in military communication applications.

This paper is organized as follows. Section 2 introduces the structures of the proposed antenna. Section 3 presents the operating principle which includes three parts: (1) Performance comparison of the traditional monopole antenna and the proposed antenna with identical outer sizes. (2) The equivalent circuit of the distributed matching network of the proposed antenna. (3) Surface currents and the 3D radiation patterns. Section 4 shows the effects of the key parameters on the performance of the proposed antenna, and explanations with Smith charts are given below the corresponding VSWR results of every parameter study. Fabrication and the measured results of the

![Figure 3: The simulated VSWR of Ant. 1 and Ant. 2.](image1)

| Variables | Values (mm) |
|-----------|-------------|
| $h_1$     | 250         |
| $h_2$     | 280         |
| $h_3$     | 70          |
| $h_4$     | 100         |
| $h_5$     | 10          |
| $h_6$     | 50          |
| $h_7$     | 220         |
| $g_1$     | 5           |
| $w_1$     | 150         |
| $w_2$     | 20          |
| $w_3$     | 2           |
| $w_4$     | 2           |
| $w_5$     | 5           |
| $w_6$     | 20          |
| $w_7$     | 50          |
| $w_8$     | 93          |

Table 1: The values of the variables of the monopole antenna.

![Figure 4: The simulated Smith charts of Ant. 1 and Ant. 2.](image2)

![Figure 5: The equivalent circuit of the proposed antenna.](image3)
Figure 6: The simulated VSWR of Ant. 1 and Ant. 2 with the matching circuit composed of $L = 36.4$ nH and $C = 1.7$ pF.

Figure 7: The surface currents (with the feed of 0 deg) of the proposed antenna. (a) 200 MHz, (b) 350 MHz, and (c) 500 MHz.
proposed antenna are shown in Section 5. Section 6 gives a brief conclusion of this paper.

2. Antenna Structure

The proposed antenna is in a slim (the width of 20 mm and the length of 280 mm) and thin (the thickness of 0.2 mm) form that takes up only a little space, which is installed on a metal case served as ground, shown in Figure 1. Loaded with a middle slim rectangular strip (the width of 2 mm and length of 70 mm) and two rectangular plates (the width of 12 mm and the length of 20 mm), the proposed antenna is well matched. The T-slot etched at the upper half of the radiated strip relatively miniaturizes the size of the monopole antenna. The metal box in a form with a shape and size similar to an Oxford Dictionary serves as the ground of the proposed antenna. The specific dimensions of the wideband monopole antenna are shown in Figure 2. Table 1 lists the values of the variables of the proposed antenna.

3. Operating Principle

3.1. Performance Comparison. To show the improvement of the VSWR bandwidth of the proposed antenna with the middle slim strip, the rectangular plates, and the T-type slot, comparisons between the traditional monopole antenna (without the slim strip, the rectangular plates, and the T-type slot and with other sizes equal to that of the proposed antenna) and the proposed antenna are presented in this part. The traditional monopole antenna is named Ant. 1, and the proposed antenna is named Ant. 2. The 3D structure simulation is by HFSS 2021R1 software. The VSWR curves of the two antennas are depicted in Figure 3. The VSWR bandwidth (VSWR ≤ 3 : 1) of Ant. 1 and Ant. 2 are 215.6–303.2 MHz (33.8%) and 203.7–516.9 MHz (86.9%), respectively. With the overall sizes of the antenna and the ground unchanged, the VSWR bandwidth of the proposed antenna is greatly improved from 33.8% to 86.9%. Ant. 1 is unmatched in the range of 300 to 500 MHz seen in Figure 4 because the part in this frequency region of the blue line is far away from the central matching point of the Smith chart. However, Ant. 2 is matched with 50 Ω in the whole frequency range from 200 to 500 MHz that the red curve in Figure 4 curls around the matching point.

3.2. Equivalent Circuit. The operating principles of the proposed monopole antenna can be well explained with the equivalent circuit model, shown in Figure 5. The middle slim strip loaded near the feeding port serves as an inductor in

Figure 8: The 3D radiation patterns of the proposed antenna. (a) 200 MHz, (b) 350 MHz, and (c) 500 MHz.
series with the antenna port. The length and the width of the slim strip determine the value of the inductor. The two rectangular plates soldered with the bottom tip of the copper strip play the role of two capacitors parallel with the antenna port. The gap between the plates and the ground and the area of the plates both determine the value of the capacitor. The optimal values of the inductor and capacitor are 36.4 nH and 1.7 pF, respectively, which are obtained by the optimization in the circuit simulation with ADS 2020 software. The simulated VSWR curves of Ant. 1 and the Ant. 2 with $L = 36.4$ nH and $C = 1.7$ pF (with the circuit form in Figure 5) are shown in Figure 6. The differences between the two curves in Figure 6 can be easily seen that the bandwidth of the Ant. 1 loaded with $L = 36.4$ nH and $C = 1.7$ pF is much

**Figure 9:** (a) VSWR curves and (b) Smith charts with different values of $h_3$ with other variables unchanged.

**Figure 10:** (a) VSWR curves and (b) Smith charts with different values of $g_1$ with other variables unchanged.
wider than that of Ant. 2. The corresponding sizes of the slim strip and the plates can be tuned when the tendency of the VSWR curve is identical to the red one in Figure 6.

3.3. Surface Current Distribution and 3D Radiation Pattern. The surface currents of the proposed antenna are shown in Figure 7. The currents on the main strip at 200, 350, and 500 MHz are stronger than those on the ground, while the directions of the currents on the ground are different at these three frequencies. At 200 MHz, the currents on the ground have the same directions as those on the main strip. At 350 MHz, only about the upper one-fifth part of the currents on the ground have the same directions as those on the main strip. At 500 MHz, the case is complicated. The currents on the upper-right part and the upper-left part of the ground have the same directions as those on the main strip. The currents with directions perpendicular to those of the currents on the middle part of the ground appear. The 3D polar radiation patterns at 200, 350, and 500 MHz are shown in Figure 8. The shape of the 3D radiation pattern of the proposed monopole antenna at 200 MHz is normal and is similar to that of the traditional monopole. The shape at 350 MHz has a little deformation because antidirection currents appear on the ground. The shape at 500 MHz deforms a lot because the currents on the ground become complicated and the asymmetric position of the monopole antenna makes the 3D radiation patterns deform. But the omnidirectional patterns on the horizontal plane of the monopole antenna at the range of 200–500 MHz are stable, and the proposed monopole antenna is capable of the applications of omnidirectional communication.
4. Parameter Analysis

The changes of VSWR curves with different values of the variables are just the phenomena of the matching state. The corresponding Smith charts can give more clear and visual guidance to find the values of the equivalent inductor and capacitor by tuning the size of the slim strip and the rectangular plates. Relatively good results will be obtained by attempting several combinations of different variables. The criterion of the optimization is that the curve in the Smith chart is in the circle of $VSWR = 3:1$. The following studies of different variables are based on a relatively good
combination of variables listed in Table 1. Although the variables may be independent of each other, the effects of the different values of one variable on the VSWR of the antenna can show that how a relatively good result is found. This part will present how the equivalent inductor, capacitor, the size of the T-type slot, and the size of the ground affect the performance of the proposed antenna.

**4.1. Equivalent Inductor.** The length ($h_3$) and the width ($w_1$) of the slim strip determine the values of the equivalent inductor. With $h_3$ increasing from 30 mm to 90 mm, the VSWR at 450 MHz drops from 5 : 1 to 1.2 : 1 as shown in Figure 9(a), and the points on the curves in the Smith chart shift from the lower part ($0.8 - 1.8j$) to the middle part ($1 + 0j$) as shown in Figure 9(b). Meanwhile, the VSWR at

**Figure 14:** (a) VSWR curves and (b) Smith charts with different values of $h_6$ with other variables unchanged.

**Figure 15:** (a) VSWR curves and (b) Smith charts with different values of $w_1$ with other variables unchanged.
200 MHz drops from 5:1 to 2.5:1 shown in Figure 9, and the points on the curves in the Smith chart shift from (0.5 - 1j) to (0.4 - 0.2j) are shown in Figure 9(b). Curves in the Smith chart get tighter and shift from the lower-left to upper-right part with \( h_3 \) increasing, showing that the equivalent inductor increases at the same time.

4.2. Equivalent Capacitor. The values of the equivalent capacitor of the rectangular plates are determined by the gaps \((g_1)\) between the plates and the ground and the area of the plates \((w_5 \times w_6)\). The narrower the gap and the bigger the area of the plates, the higher the values of the equivalent capacitor. As shown in Figures 10–12, with smaller \( g_1 \), bigger \( w_5 \), and \( w_6 \) (i.e., the bigger equivalent capacitor), the VSWR curves shift to the left end (i.e., the lower band), and the curves in Smith charts get tighter and focus on the matching point (Figure 11).

4.3. T-Type Slot. The effects of the loaded position \((h_7)\) and the opening of the slot \((h_6)\) on the performance of the antenna are studied. By analyzing Figures 13 and 14, the T-type slot mostly affects the higher frequency range and slightly causes changes in the lower frequency range. The bigger \( h_7 \) (i.e., the slot is farther away from the feeding port) and the bigger \( h_6 \) (i.e., the farther position of the opening of the T-type slot away from the feeding port) will obtain the
smaller values of the VSWR in the higher frequency region and the tighter curves in Smith charts, but bring a slight shift to the left of the lower frequency region.

4.4. Ground. The effects of the size of the ground (the height \( h_1 \) and the width \( w_1 \)) on the performance of the antenna are studied. The thickness \( w_7 \) is not studied because the ground is supposed not too thick to affect the portability.

The effects of \( w_1 \) on the VSWR are shown in Figure 15(a). The width of the ground \( w_1 \) affects the middle frequency region that the value of the VSWR is high when \( w_1 = 50 \text{ mm} \), while the value stays stable when \( w_1 \) is bigger than 150 mm. So, we choose \( w_1 = 150 \text{ mm} \). From the Smith chart in Figure 15(b), the middle part of the curve when \( w_1 = 50 \text{ mm} \) is a little far away from other curves showing not well matched. The effect of the height of ground \( h_1 \) on VSWR is shown in Figure 16(a). The low and middle-frequency region of the VSWR is more affected. With \( h_1 \) getting higher, the values of VSWR are below 3:1 when \( h_1 \) is bigger than 250 mm. So, \( h_1 = 250 \text{ mm} \) is chosen. The Smith chart in Figure 16(b) is obvious that the curves tightly focus on the matching circle when \( h_1 \) is greater than 250 mm which means good matching.

5. Validation

The simulated model with the values of the variables listed in Table 1 is fabricated (shown in Figure 17) and measured. The measured VSWR bandwidth is from 199.4 to 507.6 MHz.
shown in Figure 18(a), which is in good agreement with the simulated one. The trivial differences are caused by manufacturing errors and interferences in the measuring environment. The measured gain curve is shown in Figure 18(b). The differences between the measured gain and the simulated gain are less than 1 dB which can be accepted as a valid measurement. For the passive antenna with omnidirectional radiation and overall size under $0.25\lambda$, the gain of around 2 dBi is enough for communication applications. The measured H-plane radiation patterns at 200, 350, and 500 MHz of the wideband monopole antenna are presented in Figure 19 which are compared with the simulated results simultaneously. The differences between the measured and simulated results are caused by the measuring environment, but the omnidirectional radiation in the azimuth plane of the wideband monopole can be seen.

Table 2 gives the comparisons between this paper and other works. Compared with ref. [11, 12], the proposed antenna has a smaller size. Compared with ref. [16, 17, 19], the proposed antenna has higher efficiencies. Compared with [18], the proposed antenna has wider bandwidth.

6. Conclusion

This paper presents a wideband monopole antenna with a slim whip-shaped form, omnidirectional radiation patterns, wide bandwidth (204–517 MHz), and high efficiency, which is suitable for the applications of backpacked radio stations. Using distributed matching structure replacing the lumped elements can eliminate the electrical breakdown of the lumped capacitors used in the matching network circuits and provide a method for designing instinctively wideband antennas without extra matching network circuits.
Data Availability
All data included in this study are available upon request to the corresponding author.

Conflicts of Interest
The authors declare that there are no conflicts of interest regarding the publication of this article.

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