LETTER

VHF/UHF Wideband Slim Monopole Antenna with Meander Line Loading and Slot-Modified Ground Designed by Characteristic Mode Analysis

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Abstract This letter presents a wideband slim monopole antenna operating on very-high-frequency (VHF) and ultra-high-frequency (UHF) bands. The monopole antenna is composed of a slim strip and a meander line loading. The monopole antenna is vertically mounted on the case of the radio station which is served as ground and modified with slots. The method of characteristic mode analysis (CMA) is used to design the proposed antenna. By loading the meander line, the resonant frequency of the characteristic mode 1 of the proposed antenna moves to the lower band and higher modes are effectively excited at the higher band, which leads to a wide impedance bandwidth. Moreover, by loading the slots on the case, the inverse currents of characteristic mode 3 on the case at higher band, having bad effects on radiation patterns, are canceled out. Hence, the gain at horizontal plane at higher band is improved. A prototype of the proposed antenna with a slim structure is fabricated and measured. The bandwidth (VSWR≤3:1) is 200-550 MHz (93.3%). The gain is greater than 0.5 dB in the working band. The proposed antenna has omnidirectional radiation patterns and is suitable for backpacked radio station applications.

Key words: Characteristic mode analysis (CMA), monopole antenna, UHF antenna, VHF antenna, wideband antenna.

Classification: Microwave and millimeter wave devices, circuits, and hardware

1. Introduction

Wideband antennas with omnidirectional radiation patterns have extensive applications in communications. Especially, with the development of technologies of frequency-hopping and spread-spectrum communications, the wideband antennas with slim structures are necessary for backpacked radio stations in very-high-frequency (VHF) and ultra-high-frequency (UHF) bands. However, with the restrictions of the paradoxical relationships among the bandwidth, gain, and volume of a specific antenna, the wideband antennas with slim structures are not easy to achieve. Traditional monopole antennas with a quarter wavelength are slim and with whip shapes, and are often used in radio stations. But they have narrow bandwidths which are not suitable for current broadband applications. Normal-mode helical antennas [1, 2, 3, 4] are with slim and short structures, while their bandwidths are also narrow.

In addition, there are lots of wideband but not slim antennas. For example, planar-type antennas which are printed on the dielectric slabs have wide bandwidths. [5] presents a monopole antenna with an ultra-wide bandwidth. [6] proposes a monopole antenna for automotive communications with a broad bandwidth. [7] presents a monopole antenna with a meander line exhibiting an ultra-wide bandwidth. [8, 9] propose UWB antennas with defective ground in planar forms. [10] presents a dual-band E-type monopole antenna for laptop computers. [11] proposes an UWB antenna with band-notched function. [12] presents a wideband dipole antenna with elliptical shapes and loaded with parasitic strips for 5G. [13] proposes a wideband microstrip antenna loaded with parasitic strips. [14] presents a microstrip-fed monopole antenna with parasitic patches to achieve wideband characteristics. [15] presents a planar wideband monopole antenna with two asymmetrical ground planes. [16] proposes a wideband antenna composed of two planar monopole antenna. [17] presents a wideband U-type monopole antenna with unidirectional radiation patterns. [18] proposes a wideband circular monopole antenna with three notched bands. Volume-type antennas occupy cylindrical volumes with relatively thick diameters to achieve relatively low heights and wide bandwidths. For example, gradually thickening the radiator [19], monopole antenna loaded with a cage [20], 3D structures composed of loops and top hat [21], conical monopole antenna [22], loaded with sleeves [23, 24], 3D knot shape [25] or a cone filled with liquid [26]. Additionally, wideband antennas are extensively used in mobile communications. [27] presents a wideband monopole antenna derived...
Fig. 1. The model of the proposed antenna. (a) The 3D model, the inset is the magnified view of the meander line. (b) The specific sizes marked with variables.

Fig. 2. (a) Ant. 1: common monopole antenna. (b) Ant. 2: common monopole antenna with meander line loading. (c) Ant. 3: common monopole antenna with meander line loading and slots on the case (the proposed antenna).

Table I. Variables of the Proposed Antenna

| Variables | Values (mm) | Variables | Values (mm) |
|-----------|-------------|-----------|-------------|
| 1         | g           | 4         | w_5         | 90          |
| 2         | g           | 20        | w_6         | 5           |
| 3         | h           | 250       | w_7         | 25          |
| 4         | h           | 280       | w_8         | 20          |
| 5         | h           | 100       | w_9         | 40          |
| 6         | w           | 46        | w_{10}      | 50          |
| 7         | w           | 30        | w_{11}      | 2           |
| 8         | w           | 40        | w_{12}      | 2           |
| 9         | w           | 150       |             |             |

Backpacked radio station applications. A wideband slim monopole antenna is presented in this letter. The proposed antenna consists of a slim strip and a meander line loading. The monopole antenna is vertically mounted on the case of the radio station which is served as ground and modified with U-type slots. Assisted by the method of characteristic mode analysis (CMA), by loading the meander line, a wide bandwidth is achieved, and by etching two U-type slots on both sides of the case, radiation patterns at higher band are improved. This letter is organized as follows. Part 2 presents the design details of the proposed antenna. The operating principle of the proposed antenna explained with the CMA method is presented in Part 3. Part 4 shows the validation of the prototype and measured results. A concise conclusion is given in Part 5.

2. Design of the Proposed Antenna

The structure of the proposed antenna is shown in Fig. 1. Fig. 1 (a) shows the 3D view of the proposed antenna. A slim strip is vertically mounted on a dielectric slab by soldering with the left end of the meander line. The feed is located on the right-lower end of the meander line, shown in the magnified view of the meander line in Fig. 1 (a). The meander line has 6 turns, and the length of every element equals to the width of the strip. Two U-type slots are etched on both sides of the case. Fig. 1 (b) shows the left side view and the front view of the proposed antenna, and the magnified top view of the meander line, with sizes marked with variables. The variables with values are listed in Table I. The thickness of the dielectric slab is 4 mm, the relative permittivity is 2.25, and the loss tangent is 0.001. The strip and the ground are made of the copper foil with a thickness of 0.2 mm.

3. Operating Principle Explained With CMA

This part will present the operating principles of the meander line and the slots on the case. Three antennas, Ant. 1 (the common monopole antenna without the meander line loading), shown in Fig. 2 (a), Ant. 2 (the common monopole antenna with the meander line loading, with other sizes equaling to those of Ant. 1 except the meander line), shown in Fig. 2 (b), and Ant. 3 (Ant. 2 with slots on the case, with other sizes equaling to those of Ant. 2 except the slots), shown in Fig. 2 (c), are studied. The modal significance (MS) and the modal weighting coefficients (MWC) of the three antennas are calculated by CMA with the software CST Studio Suite 2021. The values of MS of different modes show the intrinsic potential of every mode of an antenna that are irrelevant to the excitation. Properly choosing a feed, the modes of our interest will be excited. The values of

from a Vivaldi antenna for mobile communications applications. Broadband monopole antenna used in mobile phones is presented in [28]. [29] proposes a wideband mobile-phone antenna consisting of two L-shaped radiators. [30] presents a loop-monopole mobile antenna with multiple bands. Although the above techniques are very advanced and have wide applications, these antennas are not slim and not suitable for
MWC show the excited states of every mode with the present feed of an antenna. MS and MWC are used to analyze the characteristic modes of the proposed antenna and provide the guide to manipulate the characteristic modes to achieve the desired performance.

3.1 The Problem of the Common Monopole Antenna
The bandwidth of the common monopole antenna (Ant. 1) is relatively narrow. To find the reason why the bandwidth of a common monopole antenna is narrow, the MS and MWC of Ant. 1 are calculated. The MS and MWC results of Ant. 1 are shown in Fig. 3 (a) and (b), respectively. The resonant frequency (MS=1) of the mode 1 and mode 2 is 240 and 550 MHz, respectively, seen from Fig. 3 (a). MS of mode 3 reaches to 0.61 at 550 MHz. The maximum MWCs of mode 1, mode 2, and mode 3 are 0.96, 0.31, and 0.08, with frequencies of 230, 400, and 365 MHz, respectively, seen from Fig. 3 (b). The reason why the bandwidth of Ant. 1 is narrow is that only mode 1 at lower band is effectively excited (with MWC≥0.707) and the higher modes at higher band are not.

3.2 The Function of the Meander Line
To effectively excite the higher modes at higher band, the meander line is designed. The specific design of the meander line is shown in Fig. 1 (b) and the sizes of it are listed in Table. I. The MS and MWC results of Ant. 2 are shown in Fig. 4. (a) and (b), respectively. The resonant frequencies of the mode 1, mode 2, and mode 3 are 200, 520, and 550, respectively. The maximum MWCs of mode 1, mode 2, and mode 3 are 1.17, 1.12, and 0.73, with frequencies of 200, 533, and 500 MHz, respectively, seen from Fig. 4 (b). The mode 1 is enhanced and moves to lower band. Mode 2 and mode 3 are effectively excited after loading the meander line. The VSWR of Ant. 1 and Ant. 2 is shown in Fig. 5 to validate the effect of the meander line loading. The VSWR bandwidths (VSWR≤3:1) of Ant. 1 and Ant. 2 are 212-294 and 200-540 MHz, respectively. The VSWR bandwidth is improved from 32.4% to 91.9%.

The reason why a wide bandwidth can be obtained with the meander line loading, in tradition, can be explained with an equivalent circuit to some extent. It is noted that the equivalent circuit cannot forecast the currents modes of an antenna. Assisted by the CMA method, the currents of different characteristic modes can be demonstrated and manipulated to achieve the desired impedance bandwidth and radiation patterns. Seen from Fig. 4 (b), the MWC of mode 3 reach the maximum values at 500 MHz and the MWC of mode 2 is greater than 0.707. There is a doubt that whether both the mode 2 and mode 3 contribute to the total radiation patterns at 500 MHz. By observing the 3D characteristic radiation patterns of mode 2 and mode 3 of Ant. 2 at 500 MHz in Fig. 6, the radiation pattern of mode 2 is of our
3.3 The Function of the Slots on the Case

To cancel out the reverse currents on the case of the mode 3, the U-type slots are etched on both sides of the case of Ant. 3, shown in Fig. 2 (c). The MS and MWC results of Ant. 3 are shown in Fig. 7 (a) and (b), respectively. The MSs of mode 1 and mode 3 of Ant. 3 are nearly unchanged compared to those of Ant. 2. The maximum MS of mode 2 move from 500 to 436 MHz. The MS at 500 MHz drops from 1 to 0.32, which shows mode 2 is not the resonant mode at 500 MHz. The MWC of mode 3 at 500 MHz increases from 0.73 to 1.15. So the mode 3 is reinforced at 500 MHz. Fig. 8 shows the characteristic surface current distribution and radiation pattern of mode 3 at 500 MHz of Ant. 3. The radiation pattern of mode 3 at 500 MHz is greatly improved compared with that of Ant. 2.

The U-type slots have two effects. Firstly, with the transverse slot on the center of the case, the currents on the upper half case are cut off. Secondly, with the vertical slots at the two ends of the transverse slot, the currents on the edges of the lower half case have inverse direction of the currents within the U-type slots. The currents on the case of Ant. 2 are mostly cancelled out by loading the U-type slots on the case. So the characteristic radiation pattern of mode 3 at 500 MHz is improved. The simulated H-plane radiation patterns of Ant. 2 and Ant. 3 at 500 MHz are shown in Fig. 9. The gain is improved at least 1 dB at horizontal plane.

To sum up, by loading the meander line, the mode 1 moves to the lower band and the higher modes are effectively excited, so the wide bandwidth is achieved. By loading the U-type slots on the case, the reverse currents on the case of the mode 3 at higher band are canceled out, so the radiation patterns at higher band are
4. Validation of the Proposed Antenna

The proposed antenna is fabricated and measured. Fig. 10 shows the prototype of the proposed antenna. Simulated and measured VSWR and realized gain are shown in Fig. 11. The measured bandwidth (VSWR≤3:1) is 200-550 MHz (93.3%). The gain is between 3.1 and 0.5 dBi. The radiation efficiency is above 95% in the working band mainly due to the conduction loss of copper. The simulated and measured E-plane and H-plane normalized radiation patterns at 200, 350, and 550 MHz are shown in Fig. 12. The proposed antenna is with omnidirectional radiation patterns.

5. Conclusion

This letter presents a wideband slim monopole antenna loaded with a meander line and vertically mounted on a modified case with slots. The method of CMA is adopted to analyze the three main characteristic modes of the proposed antenna. With the meander line loading and the slot-modified ground, the three main characteristic modes are manipulated to achieve a wide bandwidth and improved radiation patterns. The proposed antenna with a slim structure has a wide bandwidth (VSWR≤3:1) of 200-550 MHz (93.3%). The gain of the proposed antenna is greater than 0.5 dBi. The proposed antenna has omnidirectional radiation patterns and is suitable for backpacked radio station applications.

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