Improved Resistively-Loaded Vee Dipole for Ground-Penetrating Radar Applications

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I. Introduction

A typical resistively-loaded vee dipole (RVD) consists of two straight arms, each of which is loaded with the Wu-King resistive profile [1]. The RVD is suitable to use in a short-pulse ground-penetrating radar (GPR) application because it can radiate a short pulse into a small spot on the ground, while having a low radar cross section (RCS) [2]. It is also light and has an appropriate structure to be used in an array; thus, it can be used in a hand-held system with a small number of antenna elements or in a vehicle-mounted system with a large number of antenna elements.

A GPR antenna must perform well over a broad range of frequency to maximize the ability of the GPR to find buried objects. To improve the performance of the RVD, e. g., gain, voltage standing wave ratio (VSWR), and front-to-back ratio (F/B), two methods are applied in this work. First, the resistive profile is modified from the Wu-King profile to lower the resistance around the drive point. Second, curved arms are used instead of straight arms to make the transition from the feed line to the antenna smooth. The improvements are shown numerically in the following section.

The improved RVD can easily be realized according to the method described in [3], i.e., printing the antenna arms on a thin Kapton film and loading surface-mount chip resistors such that they approximate the continuous resistive profile. While the antenna realized in [3] was attached to a thick FR-4 frame to enhance the mechanical stability, in this work, the antenna is inserted between two blocks of Styrofoam. The resulting structure is more robust and easier to handle than the antenna attached to a thick FR-4 frame because all the delicate components are protected by the Styrofoam instead of being exposed.

II. Antenna Design

The Wu-King resistive profile (R') can be written as the resistance per unit length as:

$$R'(r') = \frac{R_0}{1-(r'/h)}, \tag{1}$$

where R_0 is the resistance per unit length at the drive point, r' is the distance along the arms from the drive point, and h is the length of the arm. Because of the discontinuity in the resistance at the drive point, the incident power is reflected in the feed line. To reduce this reflection, one can lower R_0. However, this will lower the entire resistance

This work is supported in part by the US Army RDECOM CERDEC Night Vision and Electronic Sensors Directorate, Countermine Division and in part by the U. S. Army Research Office under Contract Number DAAD19-02-1-0252.

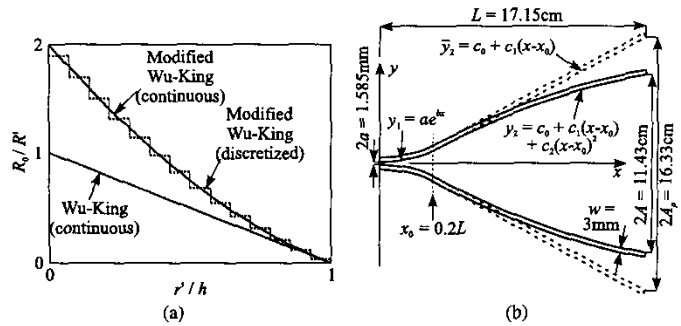

Fig. 1. (a) Comparison of loading profiles. (b) Diagram of the improved RVD.

profile and result in a reflection from the open end of the antenna. To lower the resistance per unit length at the drive point while maintaining small open-end reflection, a modified Wu-King profile (R'_m) is considered, which can be written as

$$\frac{1}{R'_m(r')} = \frac{1-(r'/h)}{R_0} + \frac{[1-(r'/h)]^2}{R_{0m}}, \tag{2}$$

where R_{0m} is a parameter that modifies the resistive profile. This equation is equivalent to Eq. (1) when $R_{0m} = \infty$. For a finite and positive R_{0m}, the resistance per unit length is lower than R_0 at the drive point and infinite at the open end. In this work, $R_{0m}h = R_0h = 467.1\Omega$ is chosen, where h is the length of the arm. The loading profile is compared with the Wu-King profile in Fig. 1 (a).

The abrupt change in the geometry between the feed line and the antenna arms also causes the power to be reflected at the drive point. This can be alleviated by using a curve that varies smoothly from the feed line. The selected curve is shown in Fig. 1 (b), which can be expressed as:

$$y = \begin{cases} y_1 = ae^{bx}, & 0 <= x < x_0, \\ y_2 = c_0 + c_1(x - x_0) + c_2(x - x_0)^2, & x_0 <= x <= L. \end{cases} \tag{3}$$

The curve grows exponentially over the interval $0 < x <= x_0$ and grows at a slower rate over the interval $x_0 <= x <= L$, where L is the length of the antenna. The parameter a is determined such that the characteristic impedance of the arms is equal to the characteristic impedance of the feed line (Z_0) at the drive point. The parameters b, c_0, c_1, and c_2 are determined according to the following relations:

$$\begin{aligned} &ae^{bx_0} = c_0, && y_1 = y_2 \text{ at } x = x_0, \\ &abe^{bx_0} = c_1, && y_1' = y_2' \text{ at } x = x_0, \\ &c_0 + c_1(L - x_0) = A_p, && \bar{y}_2 = A_p \text{ at } x = L, \\ &c_0 + c_1(L - x_0) + c_2(L - x_0)^2 = A, && y_2 = A \text{ at } x = L, \end{aligned} \tag{4}$$

where A_p is a half of the aperture size if the curve were straight over the interval $x_0 <= x <= L$, and A is a half of the aperture size. For this work, the chosen parameters are $Z_0 = 200\Omega$, $2A = 11.43$cm, $2Ap = 16.33$cm, $L = 17.15$cm, and $x_0/L = 0.2$. The

width of the strip is chosen to be 3mm. Thus, the coplanar strip geometry at the drive point requires $2a = 1.585$mm to have $Z_0 = 200\Omega$. The parameters determined from Eqs. (3) and (4) are $b = 67.34$, $c_0 = -0.007976$, $c_1 = 0.5371$,and $c_2 = -1.302$.

Fig. 2 compares the responses of the improved RVD with those of the typical RVD with straight arms. The results are obtained numerically using a method of moments code. Here, the RVD with straight arms has the same length and aperture size as the improved RVD and is loaded with the Wu-King profile (Eq. (1)). The figure also shows the responses of the improved RVD whose continuous resistive profile is approximated by 14 resistors (Fig. 1 (a)). The results are obtained with 200Ω feed line.

In Fig. 2 (a), the gains of the antennas are graphed against frequency. The figure shows that the improved RVD's have higher gains than the RVD with straight arms. The discretization of the loading profile does not seem to affect the gain much for frequencies less than 8GHz. Fig. 2 (b) shows the F/B's in dB-scale. The F/B is improved for most frequencies with use of curved arms and modified Wu-King profile. The improvement is significant around 2GHz for both continuous and discretized versions of modified Wu-King profile. Fig. 2 (c) shows the VSWR's of the antennas with a 200Ω-feed line. The VSWR is significantly lowered at low frequencies, essentially extending the lower end of the bandwidth. The VSWR for the RVD with discretized profile is slightly worse than the other antennas for frequencies higher than 8GHz. Fig. 2 (d) shows the monostatic RCS's observed at the front of the antenna. The RCS is improved significantly at most frequencies with use of the curved arms and continuous modified Wu-King profile. However, the RCS is deteriorated by the discretization of the continuous profile, which does not affects gain, F/B, and VSWR significantly. Note that the RCS for the RVD with curved arms and discretized modified Wu-King profile is still comparable to the RCS for the RVD with the straight arms and continuous Wu-King profile over the frequency range $1.5\text{GHz} < f < 7\text{GHz}$.

To realize the antenna, one efficient way is to print the antenna arms on a Kapton film and load each arm with surface-mount chip resistors. The antennas can then be packaged between two blocks of Styrofoam to enhance the mechanical strength and protect the chip resistors from the environment. Fig. 3 shows the new RVD on a Styrofoam blocks, which will be covered by another Styrofoam block.

III. Conclusion

A new RVD has been designed. The new RVD has curved arms and loaded with a modified Wu-King resistive profile. The RVD showed improved responses in a broad range of frequency, which make it more suitable to use in a GPR system than a typical RVD. One way of implementing the antenna was shown.

References

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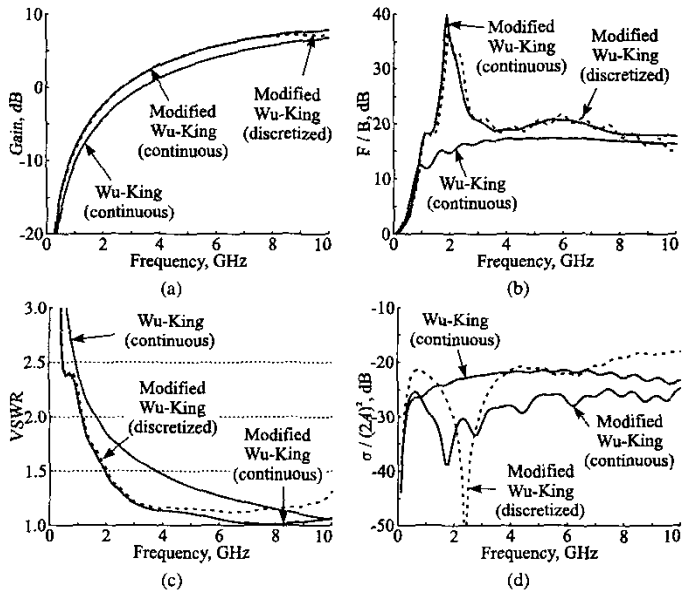

Fig. 2. Comparison of the responses from the RVDs: (a) Gain, (b) F/B, (c) VSWR, and (d) RCS. The feed line impedance is 200Ω.

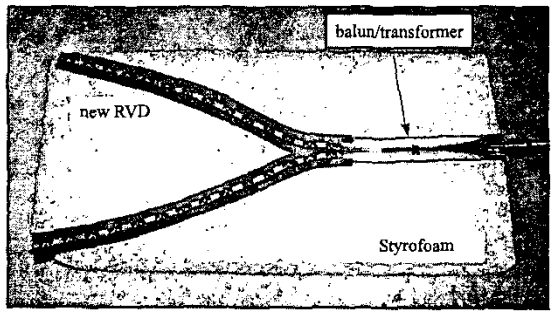

Fig. 3. Realization of the improved RVD. Another Styrofoam block of the same size as the one shown in the figure is used to cover the antenna.