

A Moderate Gain Extremely Short HF Monopole Antenna

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Abstract— An extremely short HF monopole antenna with moderate gain is presented. The height and lateral dimension of the proposed antenna are $\lambda/300$ and $\lambda/100 \times \lambda/100$ at 20MHz, respectively. The antenna is designed using two short in-phase vertical elements. To achieve in-phase radiation from the short vertical pins a modified T-type 180 degree phase shifter utilizing a capacitive impedance inverter is used [1]. An important advantage of the proposed antenna is omnidirectional radiation pattern and high gain. It is found that the gain of the proposed antenna is about 6dB higher than that of the conventional spiral-shaped inverted-F antenna on high dielectric-constant substrate ($\epsilon=10.2$) occupying the same volume but about 200 times heavier.

Keywords—Short monopole, HF antennas, in-phase vertical elements

I. INTRODUCTION

In many near-ground communication scenarios, the use of monopole antennas providing vertical polarization and omnidirectional radiation pattern is essential [2]. The need for vertical polarization stems from the fact that near-ground propagation path loss between two near-ground antennas for vertically oriented antennas is by many orders of magnitude lower than any other antenna orientation configurations. In fact, this is the main reason $\lambda/4$ monopole antennas with vertical polarization and omnidirectional radiation pattern are prevalent in many communication devices working near the ground. Since the size of the conventional $\lambda/4$ monopole antenna is prohibitively large for many applications, different types of low profile inverted-F antennas have been prevalent. However, the drawback of such antennas depending on the required miniaturization is significant decrease in gain corresponding to their vertically polarized radiation. Therefore, it is imperative to further investigate methods of realizing extremely short monopole antennas with very small lateral dimensions, while maintaining high radiation efficiency. This will allow ease of integration of such antennas with the package or platform of small wireless devices that are emerging.

Recently, a novel high-gain low-profile miniaturized antenna with omnidirectional vertically polarized radiation, similar to a short dipole was reported [3]. In [3], the gain and polarization improvement are achieved by isolating the feed structure from a miniaturized resonant radiating structure composed of an in-plane capacitor and a structurally embedded transformer. Although the antenna with low profile of

$\lambda/40\sim\lambda/50$ level can provide high gain comparable to an ideal short dipole, further size reduction for extremely short monopole antennas with height values of less than $\lambda/100$ results in serious gain drop due to ohmic and dielectric losses. Therefore, it is imperative to further investigate methods of improving the gain of extremely short monopole antennas with very small lateral dimension ($<\lambda/100$).

In this paper, a moderate gain extremely short HF monopole antenna is presented. The proposed antenna is designed using two short in-phase vertical elements. In effect, this doubles the effective height of the short dipole without physically increasing the height [4]. To achieve in-phase radiation, the short vertical pins should be $\lambda/2$ away from each other. To minimize the $\lambda/2$ transmission line a modified T-type 180 degree phase shifter with a capacitive impedance inverter is used. To avoid the suppression of vertically polarized radiation due to the conduction current flowing along a capacitive impedance inverter, the inverter is substituted by an open stub [1]. In the T-type 180 degree phase shifter, the values of two inductors and geometry of the open stub are chosen for antenna miniaturization. The height and lateral dimension of the proposed antenna are $\lambda/300$ and $\lambda/100 \times \lambda/100$ at 20MHz, respectively. The gain of the proposed antenna is discussed, compared to the conventional spiral-shaped inverted-F antenna on high dielectric-constant substrate ($\epsilon=10.2$).

II. SIZE REDUCTION OF $\lambda/2$ TRANSMISSION LINE FOR ANTENNA MINIATURIZATION

A short-circuited $\lambda/2$ transmission line resonates and the shorting pins with large electric current can radiate vertically polarized field. The most important issue in designing two in-phase elements is to reduce the length of the $\lambda/2$ transmission line. A new miniaturized technique using a modified T-type 180 degree phase shifter with a capacitive impedance inverter was presented [1]. Fig. 1(a) shows two vertical elements which are $\lambda/2$ away from each other. Currents flowing on two vertical pins are in phase because of 180 degree phase shift from the $\lambda/2$ transmission line. Its circuit model is shown in Fig. 1(b), assuming that small inductances from two vertical pins with very low profile ($\lambda/300$) are ignorable. Black arrows depict the direction of currents flowing at each probing point.

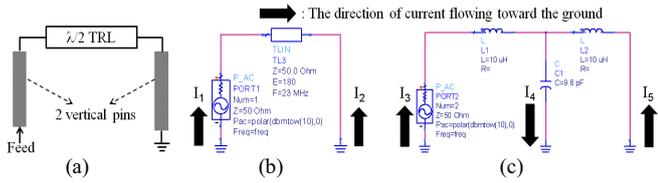


Figure 1. (a) Two vertical elements put $\lambda/2$ away from each other, (b) its circuit model and (c) a circuit model for a T-type 180 degree phase shifter.

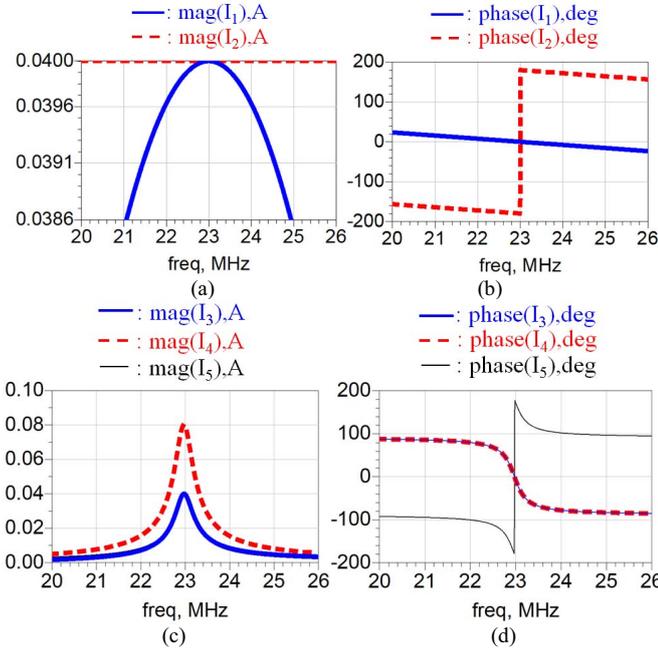


Figure 2. (a) Magnitudes and (b) phases of currents I_1 and I_2 , and (c) magnitudes and (d) phases of currents I_3 , I_4 and I_5 shown in Fig. 1.

To reduce lateral dimension of antenna structure, using a meandered metallic trace causes not only high ohmic loss but also perturbs the required omnidirectional radiation. This leads to low radiation efficiency and polarization purity.

To minimize the $\lambda/2$ transmission line a T-type 180 degree phase shifter with an impedance inverter can be used, as shown in Fig. 1(c). However, it is pointed out that without modifying its schematic the topology cannot be applied to the design of vertically polarized antennas because a conduction current flowing along a short-circuit connected to a capacitor is out of phase as indicated by a black arrow shown in the middle point of schematic shown in Fig. 1(c). Fig. 2 shows the magnitude and phase of currents at each probing point in Fig. 1. As expected, at 23MHz I_1 and I_2 have the same magnitude but 180 degree phase difference. However, at 23MHz the phase of I_4 is 0 degree, which is out of phase compared to the phase of I_3 or I_5 . The magnitude (0.08A at 23MHz) of I_4 is twice that (0.04A at 23MHz) of I_3 or I_5 as shown Fig. 2(c) and (d). It means that radiated fields from the vertical current I_4 exactly cancel out radiated fields from two vertical currents at I_3 and I_5 , resulting in no vertically polarized radiation. Therefore, in order to utilize this schematic for antenna miniaturization it is a key to eliminate the conduction current

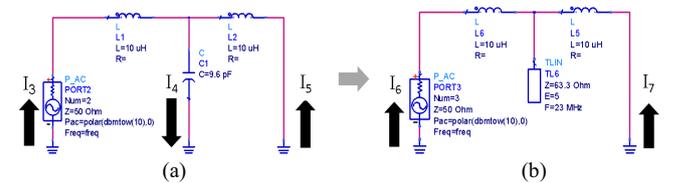


Figure 3. (a) The circuit model for a T-type 180 degree phase shifter, (b) the circuit model employing an open stub instead of a shorted capacitor in (a).

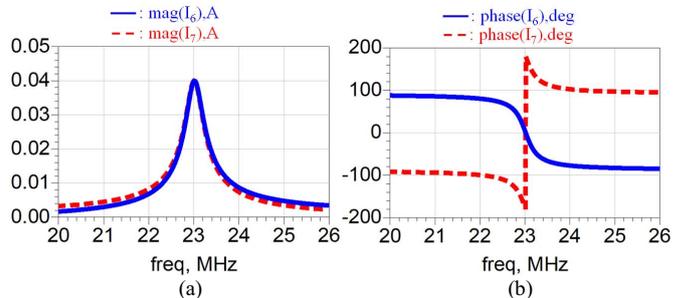


Figure 4. (a) Magnitudes and (b) phases of currents I_6 and I_7 shown in Fig. 3.

path at I_4 , while maintaining the 180 degree phase shift required for I_3 and I_5 that radiate in phase.

In this study, a shorted capacitor generating an out-of-phase conduction current is substituted by an open-stub as shown in Fig. 3(b). Characteristic impedance and length of the open stub in the circuit schematic is appropriately chosen to achieve the required 180 degree phase shift at 23MHz. Fig. 4 shows the magnitudes and phases of I_6 and I_7 , indicating the same magnitude and 180 degree phase difference.

III. EXTREMELY SHORT MONOPOLE ANTENNA EMPLOYING TWO IN-PHASE VERTICAL ELEMENTS

Based on the analysis of the equivalent circuit shown in Fig. 3(b), a low-profile miniaturized HF antenna with two in-phase elements is designed. Fig. 5 shows the top view and side view of the proposed antenna. The lateral dimension and height of the proposed antenna are 150mm ($\lambda/100$) and 50mm ($\lambda/300$), respectively. The substrate used in this design is air to obtain low dielectric loss. In order to consider actual ohmic loss, the conductivity of copper is used in all metallic traces and vertical pins in the full-wave analysis. Fig. 5(b) shows the geometry of the optimized open stub and two inductors.

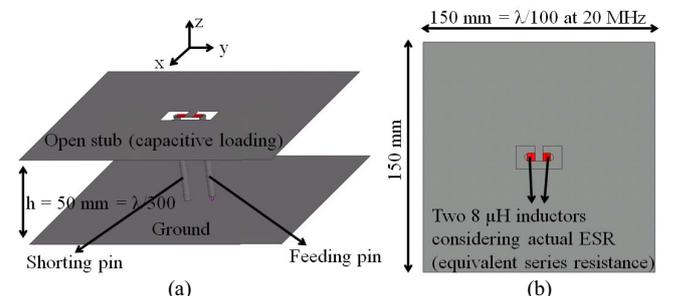


Figure 5. (a) Side view and (b) top view of the proposed HF antenna.

In order to consider actual equivalent model of the inductors used in this design, equivalent series resistances (ESR) are extracted at 20MHz and added to the simulation model. By changing the distance between the shorting pin and the feeding pin, the input impedance can be controlled. The geometry of the open stubs on the top plate is chosen to be symmetric in terms of XZ and YZ planes and the positions of the two pins are at the center of antenna structure, enabling ideally omnidirectional pattern.

IV. GAIN AND WEIGHT COMPARISON

To examine the advantages of the proposed antenna, its performance must be compared with that of a conventional Inverted-F antenna. The small inverted-F antenna can be fabricated using a $\lambda/4$ open-ended transmission line. At 20MHz and in free space, one wavelength (λ) is 15m and thus $\lambda/4$ is 3.75m. To fit a $\lambda/4$ ($=3.75m$) inverted-F antenna on the small area of 0.15m X 0.15m ($\lambda/100$ X $\lambda/100$), the use of a substrate with high dielectric constant ($\epsilon=10.2$) and spiral topology are needed (see Fig. 6). However, the spiral metallic trace causes high ohmic loss, leading to significant gain reduction of antenna gain. Fig. 7 shows simulated S_{11} and 3D radiation pattern of the aforementioned spiral-shaped inverted-F antenna. As expected, the gain is very low (-33.4 dBi) at 26.1MHz due to high ohmic and dielectric losses. However, it is shown that the radiation efficiency of the proposed antenna is much higher than that of the Inverted-F antenna of similar size due to multiple vertical elements and the fact that the parasitic loss from two inductors in the proposed topology is much lower than the ohmic loss from the $\lambda/4$ spiral metallic trace. Fig. 8 shows S_{11} and 3D radiation patterns of the proposed antenna. At the resonant frequencies the gain of the proposed antenna is about 6dB higher than that of the Inverted-F antenna.

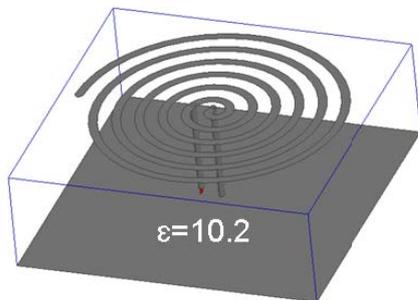


Figure 6. Conventional spiral-shaped inverted-F antenna on high dielectric-constant substrate ($\epsilon=10.2$).

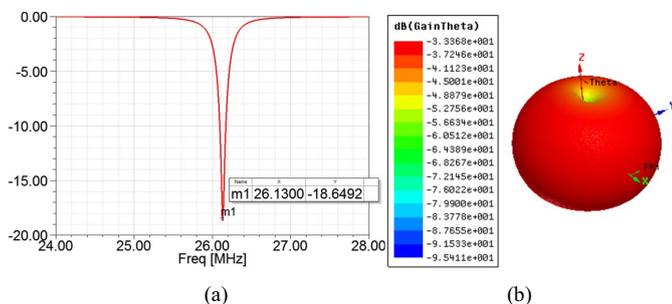


Figure 7. Simulated (a) S_{11} and (b) 3D radiation pattern of conventional spiral-shaped inverted-F antenna on high dielectric-constant substrate ($\epsilon=10.2$).

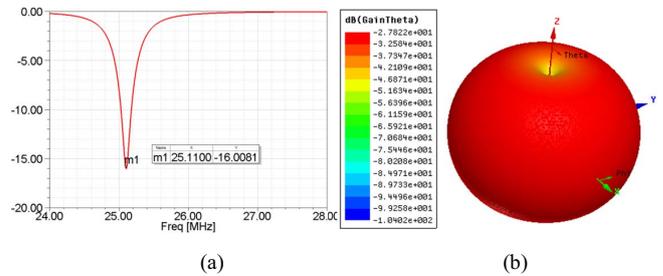


Figure 8. Simulated (a) S_{11} and (b) 3D radiation pattern of the proposed HF antenna.

Another advantage of the proposed antenna over the Inverted-F antenna is its much lower weight. In order to reduce the physical dimension of the $\lambda/4$ inverted-F antenna a high dielectric-constant material must be used as the substrate. However, the higher the dielectric constant of the substrate material is, the heavier the antenna is due to high density of high dielectric-constant materials. However, the proposed antenna does not require high dielectric-constant materials because its topology is based on a T-type 180 degree phase shifter, not the open-ended very long transmission line. Table I shows the actual weights of all the materials used to fabricate the $\lambda/4$ inverted-F antenna with high substrate ($\epsilon=10.2$) and the proposed antenna without any substrate. Amazingly, the total weight of the conventional inverted-F antenna including the substrate with $\epsilon=10.2$ is about 200 times heavier than that of the proposed antenna which is just 15.8g. Fig. 9 shows fabricated HF antenna with the weight of 19g. The top plate is supported by Styrofoam posts. The difference between the total sum (15.8g) of weights of all the components and actually measured weight (19g) is due to weights added by solder lead and superglue.

TABLE I. WEIGHTS OF EACH PART OF THE PROPOSED ANTENNA WITHOUT THE SUBSTRATE (=AIR) AND THE $\lambda/4$ INVERTED-F ANTENNA WITH HIGH SUBSTRATE

Inverted-F antenna (g) on the substrate ($\epsilon=10.2$)		The proposed antenna (g)	
One 50mm RO6010	3501	Two 50um ULTRALAM 3850 LCP	13.293
		Styrofoam to support a top-plate	0.3524
Two inductors	0.1	Two inductors	0.1
One copper post	1.4	Two copper posts	2.0204
Total weight (g)	3502		15.8

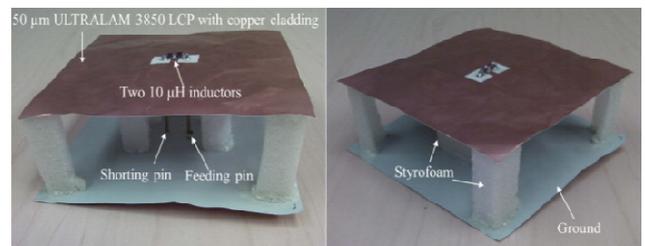


Figure 9. Fabricated HF antenna with the weight of 19g.

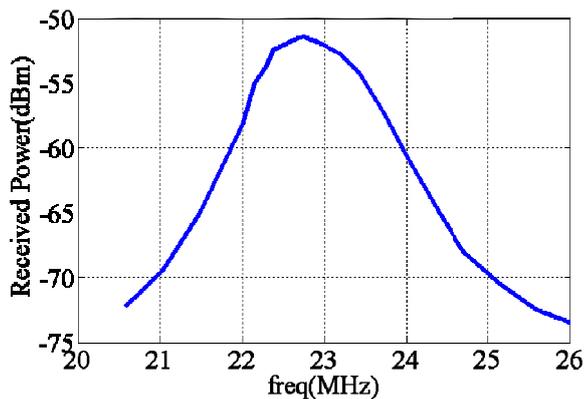


Figure 10. Outside measurement result: Received power using a $\lambda/10$ dipole antenna.

It should be discussed that in order to measure the fabricated HF antenna very large anechoic chamber is needed. Since the chamber is enclosed by the metal wall and filled with absorbing materials, at HF band it is seen just as a metallic waveguide. If the dimension of the chamber is very small in terms of a wavelength, there is no wave propagation inside the chamber because the operating frequency of test antenna is below the cutoff frequency of the waveguide. Because of this problem, the anechoic chamber with the dimension of 5m X 5m X 15m in the University of Michigan couldn't be used at 20MHz. Instead of using the chamber, outside measurement in open space is conducted. Fig .10 shows the received power using a $\lambda/10$ dipole antenna. Although the exact gain couldn't be characterized due to near-ground propagation effects, the operating frequency of the proposed antenna is clearly found at 22.8 MHz showing good agreement with simulated S_{11} in Fig. 8 (a). Measurement setup

for identifying exact gain and measurement results will be discussed in the presentation.

V. CONCLUSION

A moderate gain extremely short HF monopole antenna with vertical polarization and omnidirectional radiation pattern is presented. The antenna operation is accomplished by substituting an impedance inverter capacitor which produces the required 180 degree phase shifter with an open stub. In this approach, no conduction current in the opposite direction to the radiating pins is generated. The lateral dimension and height of the proposed antenna are $\lambda/100$ and $\lambda/300$, respectively. The gain of the proposed antenna is about 6dB higher than that of the conventional spiral-shaped inverted-F antenna on high dielectric-constant substrate ($\epsilon=10.2$). Moreover, it is shown that the total weight of the conventional inverted-F antenna including the substrate with $\epsilon=10.2$ is about 200 times heavier than that of the proposed antenna which is just 15.8g.

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