# Miniaturized Multi-Element Monopole Antenna

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## I. INTRODUCTION

Monopole antennas have widely been employed in various mobile and ground-based communication systems due to its simple topology and moderate efficiency. In addition, the omnidirectional radiation pattern of a monopole antenna is advantageous in situations where communication system modules are deployed in a random fashion or for terrestrial applications and non-line-of-sight conditions. However, the practicality of monopole antennas is oftentimes problematic below VHF and UHF bands due to its large vertical dimension. This is especially detrimental for applications such as security monitoring or military surveillance where evading unwanted detection is highly desired. Various studies have been done to reduce the vertical height of the monopole antenna [1]-[3]. However, achieving low vertical profile below the UHF band remains unresolved. In this paper, a new class of antenna with radiation characteristics similar to the traditional monopole antenna is proposed and discussed. The basic structure of the low-profile antenna is composed of microstrip resonators fed by a single probe at a proper location. Quarter-wave elements are shorted to the ground plane and the open-circuited segments are wound around in a spiral-shaped fashion for miniaturization. The overall lateral dimension of the multi-element miniaturized monopole antenna is minimized to 0.08 $\lambda \times$ 0.08 $\lambda$. The proposed antenna features a vertically polarized omnidirectional radiation behavior while having a vertical height less than 0.03 $\lambda$. The miniaturized multi-element monopole antenna is further modified to enhance the bandwidth and achieve multi-resonance behavior. The fabricated antennas feature low levels of cross-polarizations, sufficient gains and omnidirectional radiation patterns in the horizontal planes of the antennas.

## II. ANTENNA DESIGN

The relatively large vertical dimension of a monopole antenna is typically reduced by modifying its geometry to various shapes such as the meander-line or helically loaded monopole as shown in Figure 1. Height reduction using this technique is limited to $\lambda/8$ - $\lambda/10$. The second problem is difficulty in matching these antennas. The single-element inverted-F tip monopole antenna no longer features a purely vertically polarized omnidirectional radiation pattern. Instead, in addition to vertically polarized radiation, the increased lateral dimension of the antenna results in horizontally polarized radiated fields. Therefore, additional modification of the antenna is required to achieve the radiation characteristics of a traditional monopole antenna.

The miniaturized multi-element monopole antenna is designed based on the single-element monopole antenna as shown in Figure 2. First, an additional element is added to the single-element design. Both elements are fed using a single coaxial feed. The two-element monopole antenna is designed to eliminate the undesired horizontal radiation fields. By aligning the two elements in opposite directions in the horizontal plane, the horizontal currents of the antenna are cancelled in the far field region. As a result, the

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vertical currents flowing on the shorting pins are left to radiate, enabling the antenna to exhibit a vertically polarized radiation. Additional elements are added to provide electrical symmetry and mechanical stability to the proposed antenna. A four-element monopole antenna is illustrated in Figure 3. The elements are aligned to cancel the horizontal currents similar to the two-element monopole antenna. However, as the vertical height of the multi-element monopole antenna is greatly reduced, the lateral dimension increases. The lateral dimension of the multi-element monopole antenna is reduced by folding each element in spiral-shaped geometry. The reduced four-element monopole antenna is presented in Figure 4. The antenna is designed and simulated using Ansoft HFSS and the final topology is shown Figure 5. Input impedance matching is achieved by adjusting the lengths of the inserted short-circuited narrow slot-lines. The lateral dimension of the antenna is 56 mm × 56 mm (0.08 λ). The height of the final topology is 20 mm (0.027 λ).

## III. MEASURMENT RESULTS AND DISCUSSIONS

The miniaturized multi-element monopole antenna is fabricated using a 1 mm thick RO5880 substrate with dielectric constant of $\varepsilon_{ra} = 2.2$. The upper and lower side of the antenna geometry is printed on the front and back side of the substrate respectively. Via holes are used to establish an electrical connection between the two layers. The antenna is then placed on a 200 mm × 200 mm metallic ground plane. The input reflection coefficient of the antenna is measured using a calibrated vector network analyzer and the results are presented in Figure 6. The fabricated antenna features 1% 2:1 VSWR bandwidth. The co- and cross polarized E-plane and H-plane radiation patterns of the fabricated antenna are measured and the results are shown in Figure 8. Cross-polarized radiations are mainly caused by the induced currents on the coaxial cable connected to the antenna feed. Overall, the cross radiation levels are found to be lower by more than 10 dB in all angles of interest. The fabricated miniaturized multi-element monopole antenna exhibits an omnidirectional radiation pattern in the horizontal plane of the antenna, similar to a typical vertically oriented monopole antenna. A radiation null can also be observed at $\theta = 0^\circ$ in the E-Plane as well. However, the height of the proposed antenna is much smaller in magnitudes compared to a typical monopole antenna. The gain of the antenna is measured in the anechoic chamber at the University of Michigan and is measured to be 2.9 dBi.

The bandwidth of the miniaturized multi-element monopole antenna is further enhanced to feature a dual-band or broadband behavior. The dual-band miniaturized multi-element monopole antenna is designed by combining two multi-element monopole antennas using parasitic coupling mechanism. Such method prevents possible transmission zeros from occurring, making it easier to merge two resonances. Each multi-element monopole antenna is fabricated on the front and back side of a substrate, identical to its single-band counterpart. The two substrates are then vertically stacked with a fixed distance. The vertical distance between the two substrates can be adjusted to merge or split the two resonances. The miniaturized dual-band multi-element monopole antenna is designed and fabricated to feature an identical vertical height, gain and radiation patterns as that of the original miniaturized multi-element monopole antenna. A picture of the fabricated miniaturized dual-band monopole antenna is presented in Figure 7. Additional parametric studies and measurement results will be discussed in the symposium.

## IV. CONCLUSIONS

An electrically small antenna has been developed, presented and discussed. The featured antenna is derived from the traditional monopole antenna. Additional elements are combined and the topology is further modified to display a radiation characteristic similar to a vertically oriented monopole antenna. The antenna is further miniaturized for enhanced mobility and compactness. The miniaturized multi-element monopole antenna is less than 0.03 $\lambda$ in vertical height. 2:1 VSWR bandwidth of the proposed antenna is measured to be similar to a typical electrically small monopole antenna. However, the antenna features excellent radiation efficiency and is easily matched to a 50 ohm feed line. To further enhance the bandwidth of the antenna, a dual-band multi-element antenna is designed by combing two multi-element antennas through parasitic coupling. The miniaturized dual-band multi-element antenna displays improved bandwidth, omnidirectional radiation patterns, and excellent gain.

## REFERENCES

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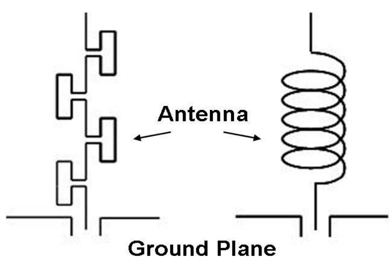


Fig. 1. Height-reduced monopole antennas.

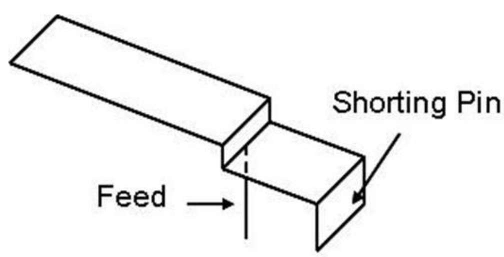


Fig. 2 Single-element monopole antenna. Ground plane is not shown.

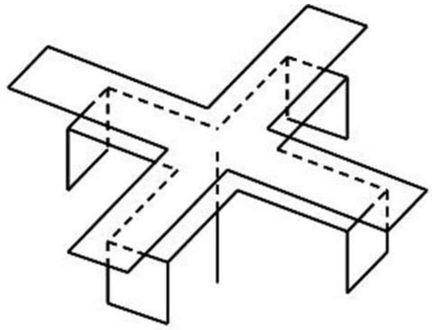

Fig. 3 Four-element monopole antenna. Ground plane is not shown.

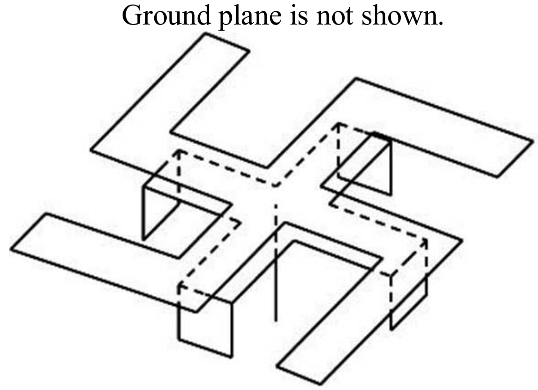

Fig. 4. Miniaturized four-element monopole antenna. Ground plane is not shown.

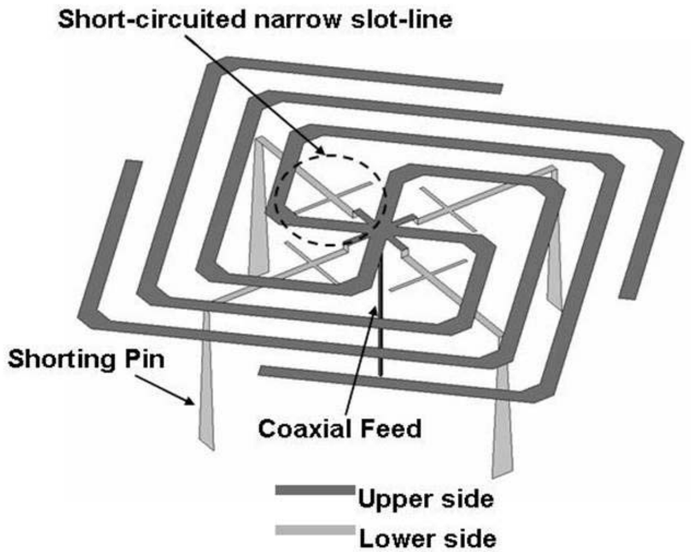


Fig 5. Topology of the miniaturized multi-element monopole antenna. Ground plane is not shown.

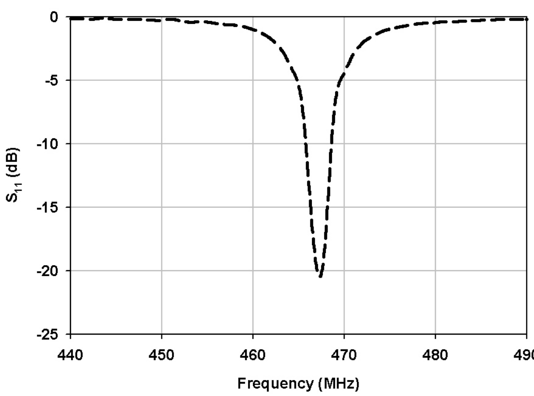


Fig 6. Measured $S_{11}$ of the miniaturized multi-element monopole antenna.

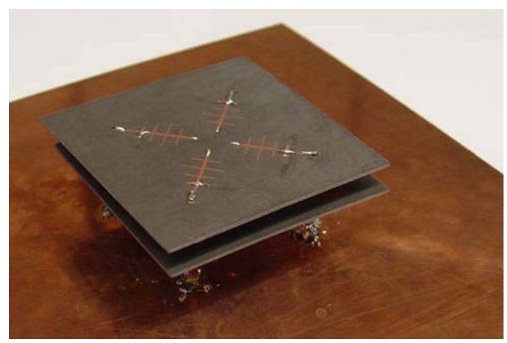

Fig 7. Photo of the fabricated miniaturized dual-band multi-element monopole antenna.

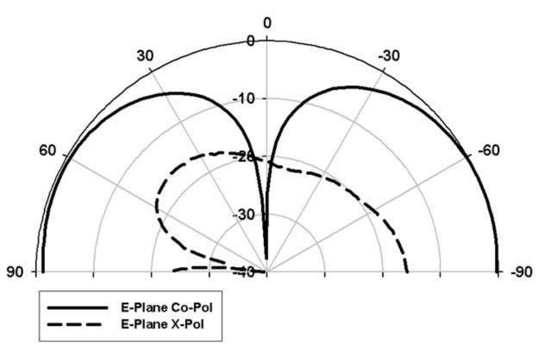


Fig 8.(a) Measured E-Plane of the miniaturized multi-element monopole antenna at 467 MHz.

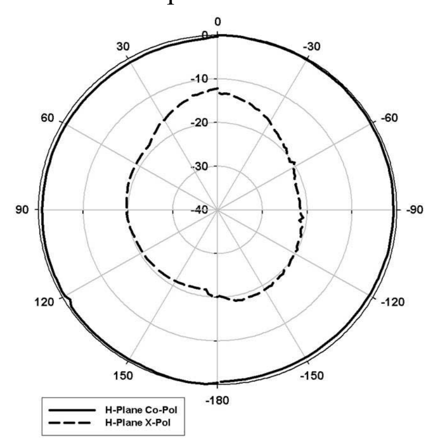


Fig 8. (b) Measured H-Plane of the miniaturized multi-element monopole antenna at 467 MHz.