Low-Profile Wearable UHF Antenna for Portable Radios and Radar Applications

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Abstract

A low profile, electrically small wideband array antenna suitable for the portable radio and radar applications has been developed. The availability of low-loss high-permittivity ceramic materials ensures that the antenna element can be designed to cover lower UHF band in 300-1000 MHz, with only about tenth of the longest wavelength in length, while providing very stable radiation characteristics. The eight-element linear array has been tested over the same frequency range, which includes a multi-function box to conduct SAR imaging or implement beamforming. The antenna element can be inserted into the manpack or integrated with the tactical vest for personal radios or short-range radars.

I. Introduction

Recently, significant endeavors have expanded applications of portable radar and sensor technology to anti-terrorism, law-enforcement, security operation, and rescue equipments [1-2]. It is pursuing to have all hardware be integrated in one manpack, such as the radar system, antennas, and associated switches and cables, as shown in Figure 1 [3]. For personal radio or communications, single or a few antenna elements are usually feasible to satisfy the system requirement. For radars or sensors providing high-resolution, real-time, and in-situ hazard monitoring, it requires miniaturized wideband antenna unit. To be an efficient radiator, an antenna should have dimensions comparable to the wavelength (e.g., $\lambda/4$ to $\lambda/2$). However, the wavelength at VHF-UHF frequency bands is relatively large ranging from 10 meters at 30MHz. Thus, most antennas used at these frequencies are electrically small antennas but with relatively large physical dimensions, and hence are not suitable for portable applications [4-5]. Theoretical limits to antennas prove that in an electrically small antenna, a tradeoff between efficiency, size, and bandwidth exists. Therefore, to design an electrically small antenna that covers a wide frequency, a comprehensive optimization must be performed to achieve the best solution that provides maximum bandwidth and efficiency while requiring a minimal antenna profile.

Figure 1 A portable radar system fitting into the manpack, including all RF modules and antennas.

Figure 2 A wearable antenna array deployed on the tactical vest with capability of conducting the beam steering in the horizontal plane.

To date, many ceramic materials with large permittivity/permeability (high contrast) but low loss are available, which can effectively reduce the physical size of the antenna [6]. However, most of such materials suffer from narrow operational bandwidths, high losses, and significant frequency dispersions. Therefore, the theoretical advantages promised by the use of high-contrast ceramic materials have yet remained to be achieved. In this work, low-profile, electrically-small, wideband UHF antennas are developed for the portable radios. Figure 2 shows the concept of the wearable array which can provide simultaneous transmitting and receiving functions. The array includes couples of the wideband antenna unit and is capable of providing the beamforming function to enhance the system performance and detection reliability while all required hardware are inside the manpack. The proposed antenna unit is able to integrate with the outer tactical vest and the manpack, as a body wearable antenna, after optimization of the antenna radiation for future short-range radios and portable radar systems.

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II. Single Radiator Design

Miniaturization of antennas can be implemented using high-contrast materials because the guided wavelength within that material is smaller so the lowest operation frequency of the antenna can be reduced as the dimension of the substrate is unchanged. This has not been become popular due to higher dielectric loss and cost. However, recently commercial available and affordable ceramic materials with low loss, light weight, and thin thickness may solve those concerns. It has been successfully applied the high-contrast ceramic materials to design a wearable wideband antenna in the lower UHF band, as shown in Figure 3. This elliptical monopole antenna is able to be integrated with the military uniform or tactical vest for both transmit and receive purpose, which can be rescale to operate at high end of VHF band. The elliptical patch antenna is printed on a high-contrast low-loss commercial ceramic substrate consisting of anatase titanium dioxide, with a relative dielectric constant of about 100, a loss tangent of 4.5×10^{-4}, and a thickness of 3.05 mm. All of these parameters have a tolerance of 5%. The dimension of the ceramic substrate is 10.2×10.2 cm^2. At this time, this antenna, including the substrate, has a dimension of $0.11\lambda_L\times0.11\lambda_L\times0.003\lambda_L$ (λ_L = 92 cm at 325 MHz), and thus is a physically small antenna and almost an electrically small antenna according to the Chu limit.

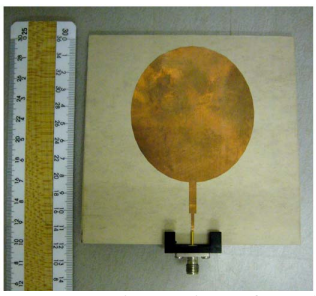


Figure 3 The antenna unit consists of an elliptical patch antenna on the front side, with the impedance transformer, and a partial notched ground plane on the backside.

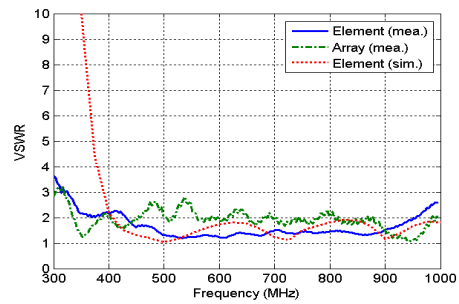
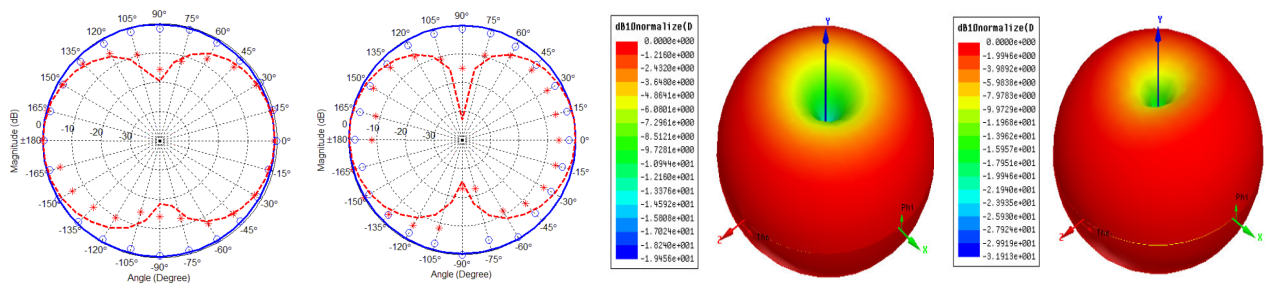


Figure 4 Simulated and measured return losses of the wideband ceramic antenna element and the 8-element linear array.



(a) (b) (c) (d)

Figure 5 Simulated and measured radiation patterns of the elliptical patch antenna at (a) 400 MHz and (b) 800 MHz (Solid/dash line: simulated xz-/xy-plane pattern; circle/star: measured xz-/xy-plane pattern); (c) and (d) show the simulated 3-D patterns at 400 MHz and 800 MHz, respectively.

Simulated and measured VSWR of this antenna are shown in Figure 4 where the measured results follow the trend of those simulated. The measured results shows, with VSWR < 2.5, the bandwidth is about 100%, from 325 MHz to 1000 MHz. These results demonstrate that this monopole antenna design is sufficient and has capability for the desired bandwidth. The measured average gain is about −5 dBi. One reason for this lower gain is because of significantly reduced effective radiation aperture. The antenna diameter has been reduced to about $0.1\lambda_L$, which causes a corresponding gain reduction of about 10 dB to regular patch antennas as the gain is proportional to the effective radiation aperture. Furthermore, the ceramic substrate with a high dielectric constant also confines electric fields to radiate outside the dielectrics and thus results in gain loss. Since this wideband antenna can be viewed as a type of vertical monopole antenna, its radiation pattern should be similar to those of regular monopoles. This has been verified in both the simulation and measurement, as shown in Figure 5, where all patterns are qualitatively similar to the monopole antenna and retain good stability within the whole operation frequencies.

III. Portable Array Antenna Design

One of the goals of this work is to have an array antenna which can enhance the system performance of the portable radars. The single wideband radiator has been used to build a linear array prototype for the wearable antenna system, as shown in Figure 6. Considering the available straight-line distance on an average human body, the radiation aperture of the wearable array antenna is chosen as 175 cm, which is approximately equal to the maximum extension distance between the right and left hands of an adult. The element spacing is chosen as 25 cm with eight elements, while the grating lobe effect is not significant theoretically. Wearable antennas limit the deployment of the array antenna as more elements are planned to use. Figure 6 shows how the elliptical patches are assembled to form an eight elements array, which are combined by a multi-function box including a switch set (two SP4T switches) and an 8-to-1 power combiner. When the switch set is used, the array antenna system can perform discrete scanning for radar imaging. When eight elements are connected through the power combiner, beamforming and array synthesis can be implemented. The measured VSWR of the 8-element array antenna is shown in Figure 4 and it can be seen the results are acceptable for most radar applications.

The array patterns on the horizontal plane (xz-plane) are shown in Figure 7. As the frequency increases, the beamwidth becomes narrower and more sidelobes appear. At the lower frequency, the measured results including mainlobes and sidelobes follow the trend of the calculated patterns. As the frequency increases, sidelobes become less recognizable and their magnitudes become larger. Because of the degradation of the sidelobes, the beamwidths of the mainlobes become wider and the grating lobes are more significant.

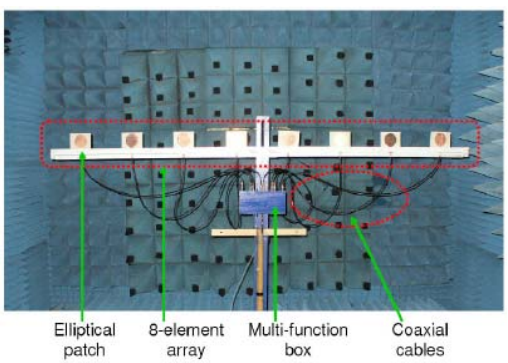


Figure 6 A wideband array antenna prototype for the wearable antenna system.

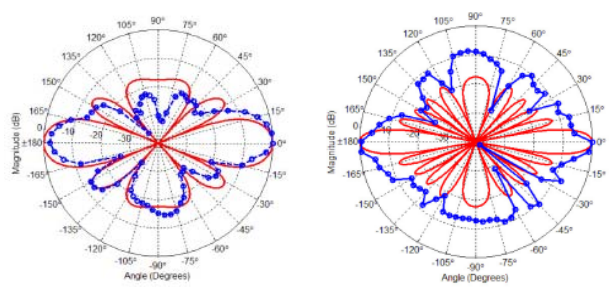


Figure 7 Radiation patterns of the array antenna with a uniform distribution: (a) 400 MHz, and (b) 800 MHz. (Solid line: calculated results; circles: measured results.)

Despite that the shielding effect of the ground plane of the individual patch antennas reduces the influence of the human body on the antenna pattern, it is still expected that the center frequency of the antenna will change by over 1%, and the antenna efficiency will decrease by over 10% due to the presence of the human body. Since the outer tactical vest has a different topology from the human body, the arrangement of the antennas on it still needs further investigation. One of the best ways to determine the antenna array arrangement is to apply electromagnetic simulation with a well-defined human model. This would be part of the future work.

IV. Potential Antenna Capability

Obviously the wearable antenna has interaction with the human body while in use. For example, as the antenna is right above part of the human body such as the breast, the VSWR and hence radiation characteristics change. Figure 8 shows the lowest frequency of operation decreases to 200 MHz (VSWR = 2.5), compared to 3250 MHz as the antenna is in free space. While the antenna may radiate maximum power of couple watts, it may generate high specific absorption rate (SAR) resulting safety and health issue to the user, which should be considered in the antenna design so that the SAR issue is brought into the RF performance in the beginning stage.

The proposed antenna can be fit for both the tactical vest and the manpack, as shown in Figure 9. Due to the advantages of electrically small and physically small, the antenna can be easily inserted into the improved outer tactical vest. Figure 9(a) shows two currently available high-contrast ceramic antennas for L-band (covering 1-2 GHz) and UHF band. Thin and soft low-loss cables are used to connect the antennas to realize the antenna diversity.

This is very convenient to use, and beneficial to implement maintenance and replacement of the antenna once damaged. The proposed antenna can also be integrated with the manpack or any kind of backpacks, as shown in Figure 9(b). The same concept for the vest can be also applied here. Then the antenna can be hidden in the pocket of the vest or manpack, while the connecting cables is also put inside the vest/manpack, as shown in Figure 9(c). This way, the antenna becomes invisible and the user will not entangled by the antenna or cables.

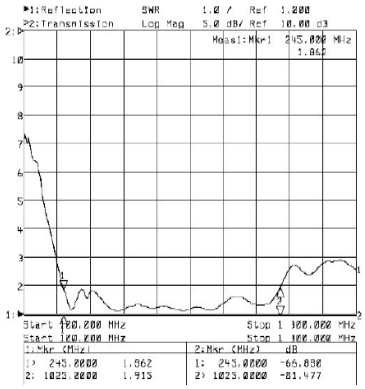
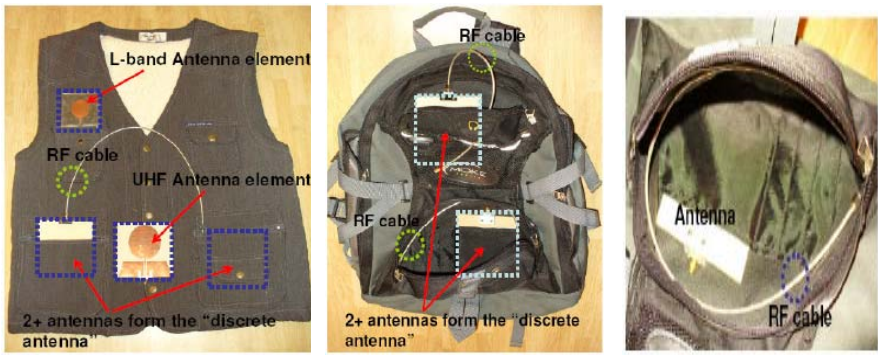


Figure 8 Measured VSWR of the antenna unit when it is right above the human breast.



(a) (b) (c)

Figure 9 Proposed electrical small wearable antenna configuration and possible antenna placement: (a) on/inside the tactical vest; (b) inside the manpack; (c) inside the inner pocket.

V. Conclusion

Intending to integrate with the tactical vest and the manpack, wideband wearable antenna using a high-contrast ceramic material has been designed to improve the usage inconvenience of the whip antenna, avoiding issues of entanglement and cable connecting. The proposed antenna can provide enough bandwidth covering voice and data transmitting, more antenna elements can be used for the radio or sensor as the array antenna. This concept has been partly verified by an UHF wideband radar system with 8-element linear array distributed on the human body. Unlike conventional UHF antennas, the proposed antenna could be invisible and does not require repeatedly and complicated cable connection. This simplifies the antenna systems and also shortens the preparation time for the communications.

VI. Acknowledgements

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VII. References

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