Antenna for Hand-Held, Ultra-Wideband Transceiver in UHF Band

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Introduction

Ultra-wide bandwidth (UWB) communication systems have found many new applications such as short range links that may require operation in a low interference or detection environment. In order to obtain the desired ultra-wide instantaneous bandwidth using a physically small antenna, most of these systems operate at microwave frequencies (>1 GHz). However, propagation losses (including penetration through walls and foliage) can significantly limit link distance at those frequencies. A UWB system that operates across the UHF band will have better sensitivity and longer range, but at the expense of a physically larger antenna because of the longer wavelengths. While electrically small (in wavelengths) antennas can operate efficiently, they are relatively narrow band and must be tuned. An antenna has been designed for a hand-held radio terminal that is equivalent to the size of the terminal's case and provides efficient operation across the UHF band.

Design Constraints and Approaches

A UHF communication system has been designed to operate from 225 to 700 MHz. Its antenna must operate efficiently over that band with low dispersion and have uniform gain coverage in the azimuth plane (relative to the horizon). The antenna is mounted on the case of a hand-held wideband terminal and for operational reasons its overall size was constrained to be no larger than the case of the terminal ($20 \times 10 \times 5$ cm). Therefore, the antenna becomes electrically small within the lower half of the band. Because of this size constraint, the metal terminal case must become the counterpoise of a monopole antenna that is attached to it. This meant that the antenna is attached so its axis is collinear with the longest dimension of the case. (An integrated/conformal antenna mounted on the case is not feasible for ultra-wideband UHF operation.) The downside of this is that the human operator holding the case couples to the antenna affecting its performance by altering the impedance and the pattern.

For an antenna that is not electrically large, there are fundamental tradeoffs with respect to volumetric size, efficiency and radiation bandwidth. (The volumetric size is defined as the smallest sphere that encloses the antenna.) These were quantified many years ago by Chu and Harrington [1]. The antenna pattern will be relatively constant across the band since the antenna is electrically small or near its first resonance. Consequently, for a given size antenna, there are two options for increasing its bandwidth. One is to place impedances (resistive and/or reactive) at critical locations along the antenna. The second is to optimize the shape of the antenna within the constraints of a manageable overall volume for it. Computer simulations used the MoM Patch code [2] to model the antenna performance and identify preferred configurations. These were built and tested.

Impedance Loading

The simplest antenna is a 20 cm long monopole with the case as its electromagnetic counterpoise. Over the band of interest, the input impedance of the antenna (and consequently the power transferred through it on transmit and receive) varies significantly. One option considered for mitigating this variation is to place a distribution of discrete impedances along the length of the monopole. Also considered was a 20 cm folded monopole to provide options for more locations to place the loads. Least square optimization was used to choose the impedance loading.

If the impedances are reactive, this could provide distributed tuning while not degrading efficiency. However, the required bandwidth is too large and the number of effectively independent reactances that can be distributed is too small to provide the needed improvement. Consequently, the optimization did not converge to a viable solution.

Distributing resistors along the length of the antenna can reduce the reflection of the current from the end of the antenna and make it appear less frequency sensitive. The resistors reduce the radiation efficiency of the antenna. This technique is reasonable when the overall length of the antenna is $\geq\lambda/2$. Optimization studies for this antenna did not yield results with acceptable efficiencies.

Volumetric Shaping

Within a given specified volume, the performance of an antenna can be modified and improved by shaping. Here the objective is to minimize the variation of the input impedance over the operating band and both the magnitude and variation of the input reactance. Many configurations were examined including a fat monopole, flat fans and cones. Wire models of the latter two were examined initially to reduce the weight.

The conical shape with 20° half angle provides better performance than the fan. Also, the desired impedance levels are achieved more effectively when the conical shape is approximated by more wires (e.g., 4 vs. 8 vs. 16 wires). These results are to be expected since there is more filled effective volume and the results approach a solid cone. The predicted power transfer loss $(1-|\Gamma|^2)$ through different models of these antennas is shown in Figure 1.

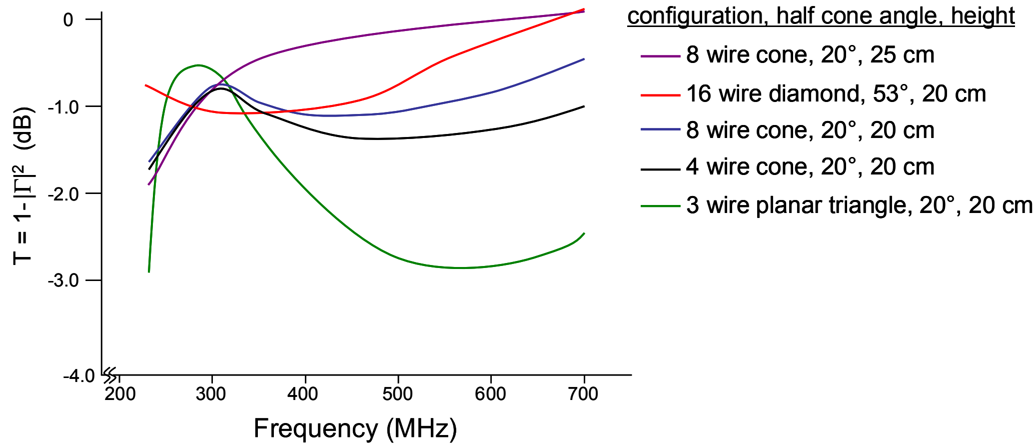

Figure 1. Power Transfer Through Antenna (from the Source, to the Load)

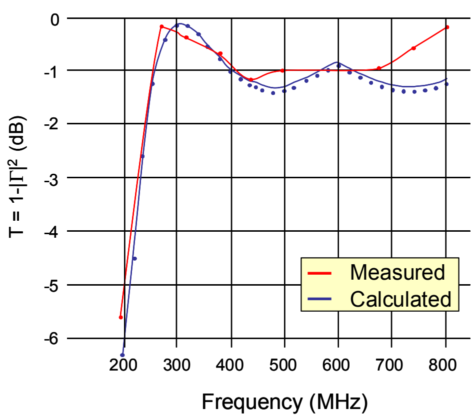

Figure 2. Transmission Loss of “Fat” Monopole on Terminal

Figure 3. “Fat” Monopole Mounted on Radio Case and Showing Internal Copper Lining

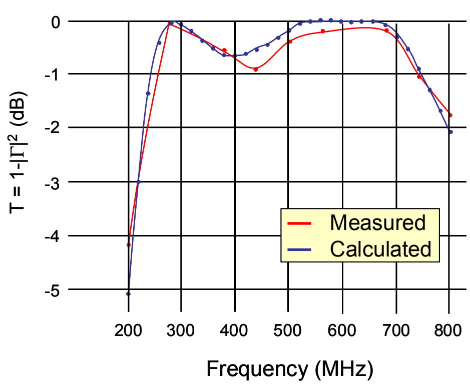

Figure 4. Transmission Loss of “Fat” Monopole on Terminal with 15 nh Series Tuning Inductor

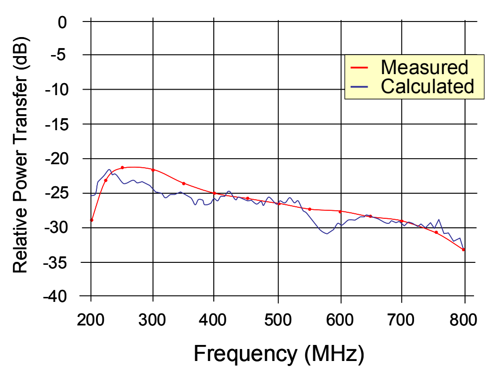

Figure 5. Relative Power Transfer Between Two “Fat” Monopole Antennas

The large width of the conical structure is not operationally preferred and a narrower cone angle has more mismatch. Therefore, two approaches were combined, a fat (4 cm diameter) cylindrical monopole with a cone transition to the feed point on the case. The power transfer loss shown in Figure 2 is less than 1.5 dB across most of the band. Figure 3 shows the antenna mounted on the radio case in the antenna range and the internal copper lining in the case to form the counterpoise.

Reactance Matching

The input reactance of this antenna is capacitive and its calculated and measured frequency dependence indicated that a series inductor placed at the feed point of the monopole further reduces the mismatch across the band. The presence of the terminal case counterpoise for the antenna modifies the reactance, in comparison with the typical dipole shape, to make this feasible. A 15 nh inductor provides the best match across the band. The experimental model of this antenna and terminal case with the matching inductor at the feed point is shown in Figure 3. The power transfer loss is now reduced to less than 1 dB across the UHF band (Figure 4).

A duplicate of this antenna and the terminal case was built and the total power transfer was calculated and measured between the two antennas. The two antennas were placed at the same height above the ground and their separation precluded any significant effect of multipath. The pattern across the UHF band is essentially the same as a small dipole because of the combined electrical size of the monopole and case. As shown in Figure 5, the power transfer decays approximately as $1/\text{freq.}^2$, as predicted for the Friis, free-space transmission formula.

Summary

An antenna has been designed that is relatively small (approximately $\lambda/6$ at the bottom of the band) while operating efficiently and with negligible dispersion over a very wide bandwidth. This is achieved by increasing its volumetric size while maintaining its maximum linear dimension. Because of the asymmetric configuration of the monopole antenna and its counterpoise, series inductive tuning provides further improvement. These results are scalable (e.g., antenna less than one inch long for 3 to 10 GHz band operation).

Reference

1. R. C. Hansen, "Fundamental Limitations in Antennas," *Proceedings of the IEEE*, Vol. 69, No. 2, February 1981, and references therein.

2. W. A. Johnson, D. R. Wilton, and R. M. Sharpe, "Modeling Scattering From and Radiation by Arbitrary Shaped Objects with the Electric Field Integral Equation Triangular Surface Patch Code," *Electromagnetics*, 10:41-63, 1990.