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14. ABSTRACT
This is a proposal for an effort to assess and develop critical technology for clandestine RF communication systems for unmanned autonomous vehicles (UAV). Under a previous ONR grant titled "Clandestine RF Communications for Autonomous Unmanned Vehicles," Applied Research Laboratories, The University of Texas at Austin (ARL:UT) developed and tested a preliminary design of an electronically that has been achieved to date for a wire antenna. System level issues were also assessed, such as data rates, propagation effects, and overall system impacts for a wide variety of communication methods. This proposed effort consists of two parts. The first part addresses the further development of electrically small antennas needed for clandestine communications operating over-the-horizon (OTH). The second part addresses the required modulation schemes and hardware for the communication link, as well as assessing the concepts for expendable transmitters.

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Clandestine ELOS/OTH RF Communications for Unmanned Underwater Vehicles

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LONG-TERM GOAL

The long term goal of this research is to identify fundamental issues and required technological developments for small, long-range communications systems utilizing HF ground wave propagation that can be used in extended-line-of-sight and over-the-horizon (ELOS/OTH) communications. Because ELOS/OTH transmission over water requires HF frequencies, the sizes of standard antennas, such as quarter wave monopoles, are too large for UUV operation. Therefore, a major focus of this effort is on the development of electrically small antennas.

OBJECTIVES

The objectives of this effort are to assess small antenna designs, and the fundamental mechanisms for radiation, tuning, and dissipation losses. A further objective is to determine the scalability of various designs so that antenna size can be traded for bandwidth as required.

APPROACH

Under previous ONR funding, an assessment was made about a variety of OTH communications techniques [1]. HF groundwave propagation was determined to be an effective and robust mode of communication over a seawater path. The most significant issue for UUV's is the antenna size. In order to address this, a new type of small antenna, the folded conical helix (FLEX) antenna, shown in Figure 1, was developed. This antenna provides excellent electrical performance as well as a robust design that can be made retractable or collapsible. Several other designs were also assessed, and the folded conical helix was determined to provide the best bandwidth-efficiency-size combinations that could be obtained for a wire antenna. Because of the initial success of the FLEX antenna this effort focused on determining the scalability of the antenna and reducing the size of the antenna. Our approach, therefore, has focused on size reduction of the FLEX antenna, and the measure of SWR and efficiency.

Accurate measurement of efficiency of an antenna is difficult. It is roughly analogous to trying to measure the output of spray from a sprinkler head that is leaking and determining the fraction of outflow that is leaking. The basic Wheeler cap method is widely accepted as being a very accurate method provided the basic assumptions are met. As a check on this measurement, we compare measurements of the relative gain of the antenna to a reference antenna. The relative gain method,

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sometimes referred to as the substitution method, is a technique in which the gain of the antenna under test is compared by substituting for it an antenna with a known gain. For the 10-meter antenna we referenced the gain to a quarter wave monopole.

The Wheeler cap method involves making a free-field measurement and a capped measurement. The capped measurement is made when we place the antenna in an electromagnetically "tight" chamber, which is assumed to cut off the radiated energy while not disturbing the currents on the antenna. Although a hemispherical cap is ideal for this type of measurement, we use cylindrical caps because of the complexity of the construction of a large hemisphere. This method measures the efficiency of the antenna excluding mismatch losses. This method directly compares the radiation resistance with the ohmic loss in the antenna. In fact, the cap does change the currents slightly in the antenna and shifts the resonance frequency as well. This effect increases as cap size is decreased and wavelength is increased, so it is important to use a sufficiently large cap. At present we have used two different sized caps in our measurements.

WORK COMPLETED

A size reduction of more than a factor of 4 relative to a wavelength has been completed. This results in an antenna of a $kr = 0.2$, where k is the wave number as midband, and r is the maximum linear extent (in radius) of the antenna. Equivalently, this can be characterized as a 0.03λ size antenna. SWR and efficiency measurements have been made on these antennas. The half power (SWR = 5.8) bandwidths of these antennas are shown in Figure 2 where they are compared to the Chu and Wheeler half power bandwidth limits for small antennas [2,3]. Also, high bandwidth small monopole antennas are shown [4,5,6].

Efficiency measurements using the relative gain method as well as the Wheeler cap method were made. We also improved the mechanical construction techniques to allow more designs to be tested with a minimum amount of re-fabrication for each antenna. Measurements were performed using a variety of sizes and types of wire to optimize matching and efficiency. We further tested several different lumped element-loading schemes to determine the effects of shifting the transmission line resonance with respect to the antenna mode resonance.

Modeling of this type of antenna is difficult and programs such as NEC are of limited use because this type of antenna has many closely spaced parallel wires that NEC does not model accurately. Consequently, we have primarily used static models so far to determine the optimum flare angle of the cone. Static models suggest that the minimum Q is achieved when the flare angle is around 40 degrees.

RESULTS

This effort was successful in achieving a 4-fold reduction in size of the antenna ($kr = 0.2$) while maintaining efficiencies of about 80% or higher. The efficiency and SWR for a $kr=0.2$ antenna is shown in Figure 3. This antenna is indicated as antenna 3 in Table 1. The small cross on the efficiency curve denotes the point at which the reactance for the uncapped data is zero. From a rigorous point of view, this is the only point at which the efficiency calculation is valid. The efficiency data was collected with the large cap (described below), and the bandwidth is about 550KHz, or about 1.9 percent. Figure 2 indicates this is the approximate loaded 2/Q limit for a second order antenna.

Measurements of efficiency were made using both relative gain and the Wheeler cap methods (see Table 1). Originally we used a cap that was made from a 55-gallon drum that was 22" in diameter and 34" tall. It appeared that as the frequencies were decreased, the cap was becoming too small compared to a wavelength in order to provide accurate results. Therefore, a larger cylindrical cap that was 4' tall and 4' in diameter was constructed and later used to test the 10-meter wavelength (kr=0.2) antennas. A shift in the resonance frequency of the antennas under test was observed when they were placed in the cap. When the large cap was used, the shift in the resonance frequency was much less than the smaller cap. In the case of the kr = 0.2 antennas, the larger cap caused a shift in the antenna resonance frequency of about 500KHz, while the smaller cap would cause shifts in the antenna resonance of about 1.7MHz. A larger cap that will be 6' in diameter is currently being designed. We have used two different methods to correct for the observed resonance shift. Initially, we used a method called phase rotation [7]. However, we now simply shift the data in frequency until the resonance of the capped antenna aligns with the resonance of the uncapped antenna. This method gives us an efficiency of about 83% for the 10-meter (kr=0.2) antenna, which is in closer agreement with the relative gain measurements. Using the phase rotation method we calculated about 90% efficiency at resonance. The Wheeler cap efficiency data in Table 1 was obtained with the large cap.

For the relative gain measurement, the antennas were placed about 100 yards apart in the clearest area available. The quarter wave monopole was set up as the transmitter and was measured. We also measured the gain of a center loaded whip and the kr = 0.2 FLEX antenna. The smallest measurable signal change with our equipment was about 0.5 dB. According to our measurements the center loaded whip was about 0.5 dB below the quarter wave monopole, and the kr=0.2 flex antenna was 1dB below the center-loaded whip, thus 1.5dB below the quarter wave monopole antenna. This is a limited precision method and the estimates obtained have an uncertainty between +/- 0.5dB (10 percent) to +/- 1dB (20 percent). Unlike the Wheeler cap method, this method with which the measurements have been obtained, have to be corrected for mismatch losses. It also requires that the patterns of the antenna under test be identical with the reference antenna.

The SWR of the quarter wave monopole near 30MHz is about 1.5 or better (less than 4% reflected power). The relative gain difference between the small antenna and the quarter wave antenna was measured to be 1.5 dB. The SWR on the small antenna is about 2 to 1 at the measured frequency which means about 10% of the power is reflected. 1.5 dB implies that the signal power from the small antenna is about 71% of the quarter wave monopole. Thus, the estimated efficiency is about 76% after correcting for the difference in reflection losses.

We observed a number of other important properties of this antenna. First, as the antenna size is reduced, it becomes much more difficult to maintain effective double tuning with the transmission line mode of the fold. It is also difficult to modify the transmission line impedance sufficiently to compensate for this. Second, the efficiency curve in Figure 3 is curious since it suggests the antenna is efficient out of the resonance band. We were able to make limited tests of this using an amateur radio transceiver and a tuner. The 10-meter amateur band is near the resonance of the antenna, and we were able to match the antenna to the transmitter out of the resonance band of the antenna at approximately 29.6MHz. At this frequency, we were able to contact stations in New York from Austin, Texas (1600 miles) with good signal characteristics using a 20-watt FM transceiver. Although no quantitative results can be derived from this, it does suggest that narrow band tuning could allow the antenna to operate outside its inherent resonance range.

Table 1. Efficiency measurements for kr=0.2 antenna (0.03λ)

Antenna	Wheeler Cap Efficiency	Date	Efficiency relative to a quarter wave monopole	
Antenna 1	87%	7-09-01	76% +/- 10% minimum	August, 01
Antenna 2	80%	8-06-01	None	
Antenna 3	83%	8-07-01	None	

The half-power bandwidths achieved for the kr = 0.36 and kr = 0.2 antennas are shown in Figure 2. The kr = 0.2 antenna appears to be very close to the Q/2 limit for a second order antenna. This is not surprising since it is difficult, if not impossible, to maintain the double tuning as size is decreased. This is because the transmission lines are in parallel, and their characteristic impedance is reduced as more lines are added. This does not include cross-coupling effects to mutual capacitance and mutual inductance between the lines.

We are further assessing whether or not additional size reduction is possible. We currently have a design that has a size of kr = 0.09. However, the efficiency is about 40%. We are working on several different methods such as increasing available conductor cross-section, modifying the overall antenna shape, and adding more conductors to improve this efficiency.

IMPACT/APPLICATION

Efficient wideband small antennas will make possible long-range (30-150 miles) point-to-point communication for UUVs. Because the FLEX antenna is a wire antenna, it can be made retractable and robust in a maritime environment. The impact will be to provide comparatively high data rate communications, and provide a critical component for an HF radio WAN for small UUVs over paths that are ELOS/OTH. This will make it possible to have point-to-point UUV communication while they perform long-range missions such as maritime reconnaissance and mine identification.

TRANSITIONS

This effort is well suited for the AOFNC effort to develop organic mine clearance systems. This is especially appropriate for the communication-navigation vehicles that are being contemplated to relay information from underwater acoustic communications across long distances to the main command ship.

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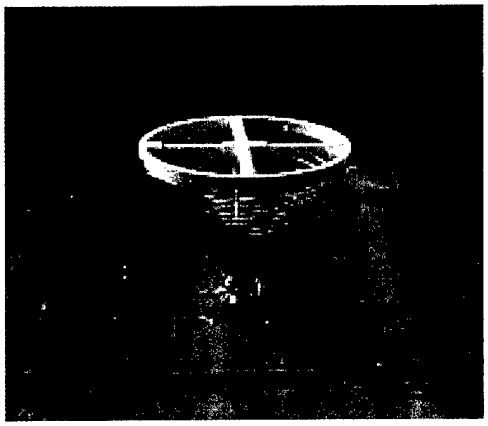

Figure 1. kr = 0.2 (0.03λ) FLEX antenna for 30MHz. Antenna is about 1 ft in height above the ground plane.

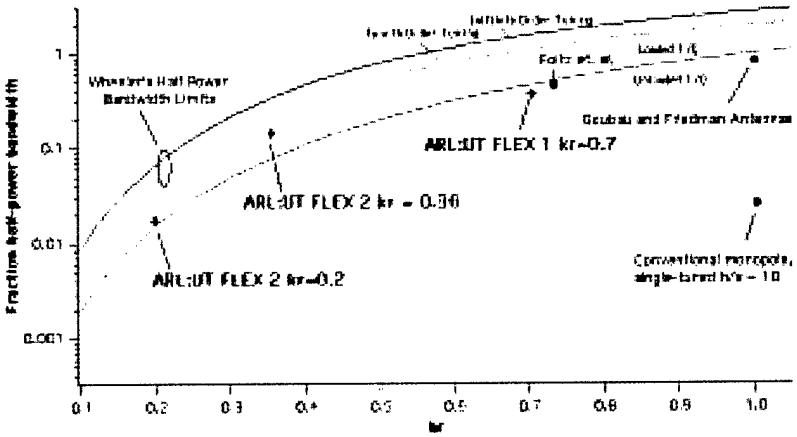

Figure 2. Comparison of FLEX antennas at various sizes to Chu and Wheeler limits.

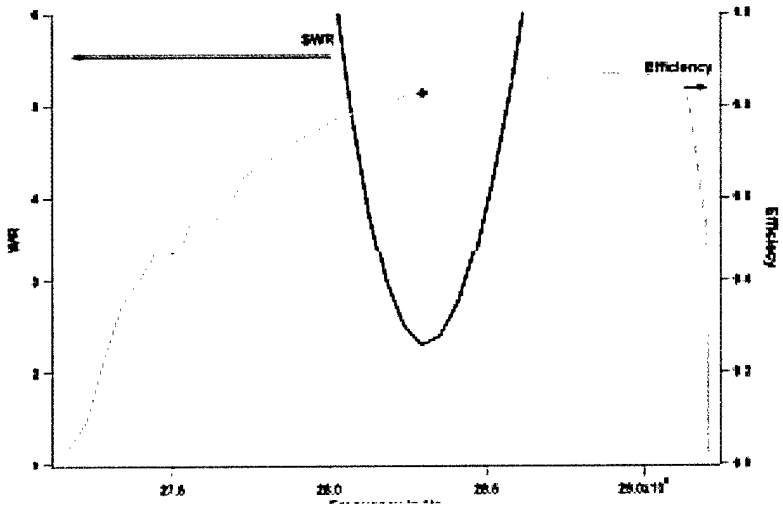

Figure 3. SWR and Efficiency (Wheeler Cap) for the kr=0.2 Antenna.