A STUDY OF ANTENNA AND RADIO FREQUENCY TRACKING SYSTEM

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INTRODUCTION

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The information contained in this report summarizes the technical findings, conclusions, and recommendations made in the performance of the referenced contract by the Electrical Engineering Department of Auburn University.

Work has been performed under this subject contract on the study of antenna and radio frequency tracking systems. Three major areas related to a study of the phase stability of VLF propagation, the design and development of an electronically scanned tracking antenna subsystem, and a study of an inverted r-f tracking system have been investigated. A summary of the work completed in the performance of these investigations is enclosed.

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Enclosure 1: VERY LOW FREQUENCY PROPAGATION STUDY

A study of the phase stability of VLF propagation was initiated as a partial requirement for the performance of this contract. A system for the measurement of the phase stability of a VLF signal radiated over a short distance, which is independent of the incidental phase errors of the associated transmission equipment and is a function only of the propagation medium, was proposed. In addition, amplitude stability of the VLF signal can be measured as well as the inherent phase errors introduced by transmitting antennas due to wind loading, temperature, etc., utilizing the proposed system.

The results of this investigation indicate that a required radiated power of 100 to 200 milliwatts is sufficient for communications over a proposed path of 320 km at approximately 20 kc/s with available receiving systems. It was also determined that if a constant power is radiated from a short vertical radiator the unattenuated field strength is independent of antenna height. Thus, extremely short vertical radiators can be utilized for VLF communications; however, the antenna efficiency decreases as the antenna height is decreased.

A study of scaled model umbrella antennas indicated that a 300-foot vertical radiator with a 12-rib, 300-foot umbrella should be a feasible antenna structure for this work. The measured capacitance is large enough to reduce the antenna base voltage to a reasonable value and minimize the tuning inductance requirements.

An investigation to determine the effect of the ground system on the antenna efficiency indicates that the effective loss resistance due to the ground conduction currents is much smaller than originally expected for reasonable ground wire lengths. This study is based on the determination of the equivalent resistance of the ground as calculated from the power dissipated in the radial ground wire system, the earth adjacent to the ground wire system, and the power dissipated in the earth beyond the ground system. This study shows that the required ground wire lengths for extremely short vertical radiators is much less than the 0.3λ to 0.5λ lengths recommended for a satisfactory radial ground wire system at higher frequencies.

A survey of the effects of the finite conductivity of the earth on the antenna radiation characteristics is presented as related to short path propagation. The receiving antenna requirements are determined based on this survey and the characteristics of the VLF propagation medium for the proposed path of communications.

A detailed discussion of the work performed on this investigation is presented in Technical Report Number 9 entitled "An Investigation of the Design Criterion for a Phase Stability Study System of VLF Propagation Over Short Distances."

Enclosure 2. ANTENNA SUBSYSTEMS

Another phase of the performance requirements of this contract was to develop an electronically scanned antenna. The initial phase of this investigation began with the design and construction of an array of helices which could be electrically scanned by changing the phase to each element of the array using ferrite phase-shifters. Experimental models of this type antenna with phase-shifters were constructed and tested. Various parameters were investigated experimentally and an extensive study of the antenna radiation characteristics was accomplished.

The construction of an outdoor antenna test facility was initiated and completed to facilitate the design and development of experimental antennas pursuant to contract requirements.

Due to certain disadvantages of the array of helices, a study directed toward the design of an antenna which consists of an array of crossed slots developing a 30° circular beam that is electronically steerable over a hemisphere was made. Linear arrays as well as square arrays were considered in Technical Report November 4,"An Analytical Evaluation of the Mills Cross and the Two-Dimensional Matrix Antenna Array." Investigations of a Mills Cross antenna, formed from the perpendicular intersection of two linear arrays, revealed that a pencil beam may be obtained; however the gain of the array is low due to electronic rejection. As a result only the square matrix arrays were considered since a minimum gain of 7 db is required of the array. The gain of the matrix array is dependent only on the number of elements. A theoretical investigation of matrix antenna performance versus number of elements and element spacing was performed and a digital computer study performed to determine the field patterns of 5 x 5 array of crossed slot antennas throughout a hemisphere. An experimental investigation was initiated to develop a suitable array element. The element ideally would be circularly polarized and have a hemispherical radiation pattern. A crossed-slot, cavity-fed element was designed and tested. The test results indicate this to be a usable element since it has the desired radiation characteristics, may be circularly polarized, and is easily matched with regard to feed-point impedance. Further investigations indicate that a 6 x 6 element matrix array is necessary to obtain the desired antenna gain.

Development of a r-f direction finder was initiated and an electric-magnetic dipole was built to be used as a direction finding element. This element is circularly polarized and will respond to a linearly polarized signal regardless of orientation. In addition, an investigation of a phase comparison array of dipoles to be used as a direction finder has been made. These dipoles may be combined and properly phased to provide the necessary characteristics which were obtained from an analytical investigation of phase comparison direction finding systems. This study consisted of design and construction of a suitable array and determining mutual coupling between elements and investigating various properties of this array.

Enclosure 3: R-F TRACKING SYSTEMS

A study of an inverted r-f range and orbital tracking system was made according to the requirements of this contract. This phase of work was related to the preliminary system definition and certain areas pertinent to the over-all system design such as basic logic requirements, SNR limits, operational procedures, etc.

An investigation of various phase-lock receiver configurations has been made. One receiver configuration described in Technical Report Number 1 utilizing a form of double sideband modulation was investigated analytically and found to exhibit a series of points of possible false phase lock. An experimental simulation of this modulator scheme substantiated the analytical treatment. Another analytical investigation of a phase lock receiver utilizing differential phase feedback was made. A mathematical model of this system was formulated and an analysis of this model was made to determine basic design criteria. This model, which consists of a multiple loop feedback control system with a non-linear gain component in one loop, was programmed on a computer to verify system characteristics. A report on this work is presented in Technical Report Number 8, "An Analysis of the Effects of Differential Phase Feedback on a Type 2 Feedback Control System as Applied to Phase-Lock Receivers."

A study of the phase shift incurred by a sinusoidal wave in passing through a crystal mixer was made which is treated from a causal viewpoint both analytically and empirically in Technical Report Number 2. The results obtained from these two approaches are in good agreement with respect to the form of phase shift as a function of the controlled variables, while fair quantitative agreement between the two approaches is obtained. From the results of this investigation, an operating condition is obtained that minimizes the change in phase shift through a crystal mixer for reasonable variations in the controlled variable.

An investigation of a real time data extrapolation technique designed to minimize reacquisition time of a phase-lock receiver following a signal interruption as well as to "replace" the data lost during the interruption was initiated to facilitate design of the proposed system. From the results obtained, it is evident that extrapolations can be made with a high degree of accuracy for slowly changing data. For rapidly changing data, the extrapolations deviate from the true data rapidly so that accuracy is unreliable after three or four extrapolations. However, the extrapolation technique should reduce the probability of loss of phase lock during a period of signal loss even for rapidly changing signals as reported in Technical Report Number 5, " AROD Real Time Data Extrapolation."

A comparative study of balanced and single-ended mixers in the presence of local-oscillator noise was made to determine the most feasible configuration for utilization in frequency synthesis with crystal mixers. This comparison was made both analytically and experimentally in

Technical Report Number 7 and in all cases the balanced mixer significantly reduced the amount of noise introduced in the mixer output for the two types of local oscillator noise investigated.