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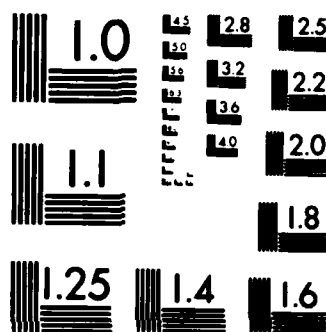
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RADC-TR-84-218  
Final Technical Report  
November 1984



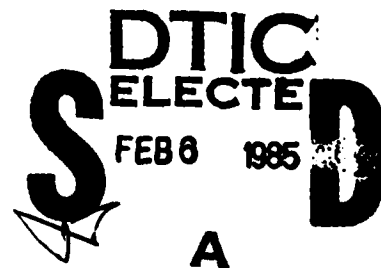
## ***SURVIVABLE PROPAGATION***

**Megapulse, Inc.**

**Frederick M. Tingley**

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**ROME AIR DEVELOPMENT CENTER  
Air Force Systems Command  
Griffiss Air Force Base, NY 13441-5700**

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RADC-TR-84-218 has been reviewed and is approved for publication.

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## REPORT DOCUMENTATION PAGE

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18. Subject Terms (Continued).

Transverse Magnetic  
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# TABLE OF CONTENTS

| <u>Section</u> |                                                                               | <u>Page</u> |
|----------------|-------------------------------------------------------------------------------|-------------|
|                | INTRODUCTION                                                                  | 3           |
| A              | SURVIVABILITY OF TRANSVERSE ELECTRIC PROPAGATION                              | 4           |
| B              | INSTRUMENTATION FOR THE INVESTIGATION OF THE<br>VLF/LF VERTICAL FIELD PROFILE | 6           |
| C              | METEOR BURST COMMUNICATIONS                                                   | 7           |
| D              | RADIATION PROPERTIES OF CORONA DISCHARGE                                      | 9           |
| E              | MAINTENANCE OF THE VLF/LF SOUNDING EQUIPMENT                                  | 11          |
| F              | NOISE NULLING SPACED ARRAYS                                                   | 12          |
| G              | POWERLINE ANTENNA PARAMETERS                                                  | 14          |
| H              | MISCELLANEOUS                                                                 | 15          |

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## INTRODUCTION

Megapulse is pleased to submit this Final Technical Report describing the studies performed under this contract with Rome Air Development Center. This program is a combination of related projects, each dealing with an aspect of the propagation of electromagnetic waves. Comprehensive technical reports describing the work done and the study results were prepared as each phase was completed; some were submitted to RADC to become "Interim Technical Reports" while the others remain Megapulse reports and were distributed only within the company and the Survivable Propagation Section (EEPS) of RADC. Rather than republish all of these works in a single binder, we have chosen to summarize each of the contracted projects briefly, and list the relevant reports.

#### A. SURVIVABILITY OF TRANSVERSE ELECTRIC PROPAGATION

Because Low Frequency TE-polarized waves are difficult to excite from antennas on the earth's surface, and because they may reflect differently from the ionosphere than waves in the TM-polarization, they offer possibilities for improved anti-jam and propagation characteristics. Studies were initiated to investigate these possibilities.

An abandoned elevated power line at Thule Air Base, three kilometers in length, was converted to a large horizontal dipole antenna. It was fitted alternately with two transmitters, one with continuous wave output and the other pulsed. The former, a commercial unit, was capable of producing 8 kw into a 50 ohm load at 35 kHz. The latter was especially designed and built by Megapulse for this project, as were coupling circuits for matching the transmitters to the antenna. Two receivers, one for CW and the other for pulsed signals, were obtained and calibrated.

The Powerline antenna transmits both TE and TM polarized waves. To observe the ionospheric reflectivity for TE waves at near grazing incidence, a medium-long propagation path is needed, and the path direction should be along the TM null of the transmitting antenna to avoid confusion with TM waves. Due to the limited availability of convenient potential receiving sites in the arctic, only two sites were considered: Sondrestrom, Greenland and Goose Bay, Labrador. Preliminary tests at Sondrestrom indicated difficulties in separating TE and TM waves in that direction. Goose Bay is much more nearly in the TM null, but theoretical analysis indicated that the TE signal strength there might be too low to permit large absorption conditions to be measured. Because of these discouraging predictions, no TE receiving experiments were made in the Goose Bay area.

The following pieces were prepared to describe the project:

"A Wave-Excitation Model for the 35 kHz Powerline Antenna at Thule Air Base, Greenland"; E.A. Lewis, J.L. Heckscher (RADC). Contract Report, Dec. 1982.

"Daytime Signals Expected at Sondrestrom and Goose Bay from the Powerline Antenna at Thule Air Base", E.A. Lewis, J.L. Heckscher (RADC), P.K. Kossey (RADC). Contract Report, 4 Oct. 1982.

"Exact Solution for the Electromagnetic Fields of a Uniform Line-Current Parallel to a Flat Homogeneous Earth"; E. A. Lewis, J. L. Heckscher (RADC). RADC-TR-82-92, April 82.

"An Example of Field and Power-Loss Calculations for a Uniform Radio Frequency Current in a Tunnel in Resistive Material"; E.A. Lewis, J.L. Heckscher (RADC). Contract Report.

## B. INSTRUMENTATION FOR THE INVESTIGATION OF THE VLF/LF VERTICAL FIELD PROFILE

Ground based monitoring instrumentation was designed, built and tested under this program. This equipment took the composite signal from the S-band tracking system, demodulated it, and separated the TE and TM VLF signals for processing and data reduction. It also produced permanent records of the VLF signals for analysis at RADC. In addition, this equipment was used to measure Doppler shift (1,000 Hz) phase data for the rocket range measurement.

### C. METEOR BURST COMMUNICATIONS

This major project was begun with a literature search to discover the state of the art in this method of VHF communication. As a meteoroid from space enters the earth's atmosphere it leaves a trail of ions which reflects radiowaves at these frequencies back to earth. The random occurrences of meteors permits intermittent propagation between points well beyond line of sight. From the study of past work a program was designed with the prime goal of discovering the characteristics of the communications technique at high latitudes and its survivability under high ionospheric absorption conditions. A test link was established in Greenland with a 1 kw transmitter at Sondrestrom A.B. and a receiver at Thule A.B., both of which are virtually unmanned. The transmitter and receiver automatically and synchronously step through four frequencies at 45, 67, 101 and 150 MHz, leaving intervening periods of no transmission for the measurement of noise and calibration of the receivers. When a signal is detected, the receiving system automatically records the waveform in digital form on magnetic tape, and measures and records key parameters.

The waveforms, recovered by playback in the laboratory, are displayed graphically, classified as to type (overdense and underdense meteor, sporadic E, auroral, and artifact) and further measurements are made and printed. Statistical parameters are calculated for various ensembles and printed and graphically displayed. These include waiting times for a selection of message lengths, probabilities of reflections with various information capacities and measures of capacity using different modulation and coding techniques. All of this data is outputted by the computer in a form suitable for publication.

An analytical model of the geometry of meteor reflection links was developed and programmed for a digital computer. For any given shower of

meteoroids with a common radiant, the computer program selects and counts those whose trails have the correct positions and orientations to specularly reflect VHF waves between selected points on the earth. The number of meteors satisfying the geometric conditions is expressed as a "crosssection" for communications connectivity, typically measured in thousands of square kilometers. These computations were made for the geometry of the Greenland link, and the results presented in a form similar to the familiar directional patterns of an antenna. If the direction distribution of the incoming meteoroids is known, either from measurement or from astronomical scenario, it could be folded into the present model.

The same model was used to determine the response to specular reflection from columns of electrons aligned with the earth's magnetic field lines, a situation which occurs in auroral conditions. The field line orientation with respect to the Greenland testbed was found to be incompatible with such reflection.

The technical reports prepared for this project are:

"Geometric Crosssections for Specular Point-to-Point Reflections from Meteor Trails"; E.A. Lewis. Contract Report.

"A Numerical Search for Sondrestrom-Thule VHF Propagation Paths via Specular Reflecting Field-Aligned Ionization Columns"; E.A. Lewis. Contract Report.

"The RADC Meteor Scatter Testbed in Greenland; Sondrestrom Thule Link"; Jens Ostergaard. Contract Report.

#### D. RADIATION PROPERTIES OF CORONA DISCHARGE

Starting with corona discharges on small negatively charged pins mounted on a ground plane, Megapulse made detailed theoretical and experimental studies of the corona process and the resultant pin currents and radiated fields. Waveforms of the currents at the bases of the pins were photographically recorded from a dc to 1 GHz oscilloscope display. The shape of the pulses remained fairly stable with time, but the amplitude varied widely. The shortest pins (about 1 cm.) produced single uni-polar pulses but longer pins created damped oscillatory currents. The waveforms are in agreement with those computed from traveling wave theory.

Using simple radiation theory, the radiated electric fields resulting from these pin currents were calculated. Measurements of the fields were made with monopole antennas mounted on the same ground plane as the pins and photographically recorded. The spectra of the measured and the derived fields compared well. The frequency of current oscillation was found to correspond to the pin length, and the damping rate to the pin length to diameter ratio.

The electromagnetic model was expanded to include relativistic effects, which allows predictions of radiation patterns from various shapes and sizes of corona excited antennas.

Using similar experimental and theoretical techniques, the study continued into the characteristics of the radiation from longer (to 3 meters) and complex shapes. As expected, these produced lower frequency and multi-peaked spectra. The resultant fields at relatively large distances were predicted and compared to noise when processed by near optimum antenna and receiver systems.

The work on this project produced the following reports:

"Electromagnetic Radiation from Negative Point Corona"; E.A. Lewis, F.M. Tingley, J.B. Donahoe, R.C. Kahler. RADC-TR 84-39, June 1984.

"Possibilities for Corona Detection Using Upward-Looking Receiving Antennas"; E.A. Lewis. RADC-TR 84-152, June 1984.

"Electromagnetic Fields from the Generation and Absorption of Discontinuous Linear Current-Fronts"; E.A. Lewis. RADC-TR 84-153, June 1984.

"Orange Airport Field Tests, Corona", F.M. Tingley. Contract Report.

#### E. MAINTENANCE OF THE VLF/LF SOUNDING EQUIPMENT

The ionosounder system located at three sites in northern Greenland (two at Thule A.B. and one at Qanaq) has been operating very well and has not required as much maintenance as was anticipated. The magnetic tapes from the receiver site at Qanaq are delivered to RADC/EEP and are used to determine D region electron density profiles during polar cap absorption (PCA) events. The profiles are of special interest in connection with LF, HF and VHF programs.

The maintenance of this system has been incorporated into trips for other purposes, i.e., the meteor burst experiment. In the fall of 1983 the meteor burst receiving site was installed at Thule A.B. and a site survey was made at Qanaq. Therefore, maintenance was done on the ionosounder system at that time. Routine maintenance including general cleaning of the electronic equipment and cycling of the cesium beam battery backup system was performed. In addition, a Kennedy 1600 tape recorder was substituted at Qanaq, replacing a worn out Cipher, and the auto start option was repaired. Also, at South Mountain, a new Fluke Data Logger was installed and a Kennedy 9800 tape recorder was substituted for a Kennedy 1600.

After termination of the Powerline project, the equipment was removed and the two joined shelters were moved to South Mountain to house the meteor burst equipment.

## F. NOISE NULLING SPACED ARRAYS

With proper design and operation, the nulls of a spaced array can be steered to the direction of noise and interference sources while maintaining the maxima near the desired source with a resultant substantial improvement in signal-to-noise ratio. The equations for the antenna patterns of combinations of two and three steerable loops were derived and computer calculated for various separations and both TE and TM propagation. The parameters were then optimized for noise uniformly distributed in azimuth and for some irregular noise direction situations.

An array of two manually steerable loops separated by 11.75 km was assembled, with the signal connection provided by a microwave telemetry link. Because this link proved marginal and because the large separation resulted in antenna patterns too complex for this simple initial testing, the separation was reduced to 4.1 km. Numerous antenna patterns were machine generated for the range of controlling parameters and three frequencies. With these and a display of current noise source directions (Watson-Watt direction finder), the operator was able to steer the nulls to the directions of the worst noise. The system was demonstrated using an aircraft transmitting at frequencies near 35 kHz through a long trailing wire antenna as a source. In spite of many noise source directions, some surrounding that of the aircraft, a 12.8 db improvement in signal-to-noise ratio over that available from an omnidirectional antenna was achieved.

The analytical work was described in:

"Potential Improvement in the Reception of TM and TE Polarized LF Waves with Two and Three Spaced Antennas on the Ground"; E.A. Lewis, J.A. Heckscher (RADC). Contract Report.

The experimental portion was described in:

"An Experimental Investigation of the Improvement in the Reception of TM-Polarized LF Waves with a Two Element Spaced Array"; F.M. Tingley, R.C. Kahler, E.A. Lewis. RADC-TR 84-91, May 1984.

#### G. POWERLINE ANTENNA PARAMETERS

Careful measurements of the wave transients in the antenna, input impedance, and local radiated magnetic fields were made in northern Greenland. These were coupled with the analytically derived electromagnetic description and a fairly consistent picture of its behavior emerged. The real part of the input impedance is 30 ohms, but the efficiency is only about 0.4%. Questions remain as to the accuracy of some of the other parameters.

The project was described in:

"Electrical Properties of the Thule Powerline Antenna"; E.A. Lewis, R.C. Kahler, J.B. Donahoe, J.L. Heckscher (RADC). Contract Report.

## H. MISCELLANEOUS

On a few occasions, Megapulse was asked to consult on special projects.

This resulted in the following papers:

"Ionospheric Propagation"; E.A. Lewis. Contract Report.

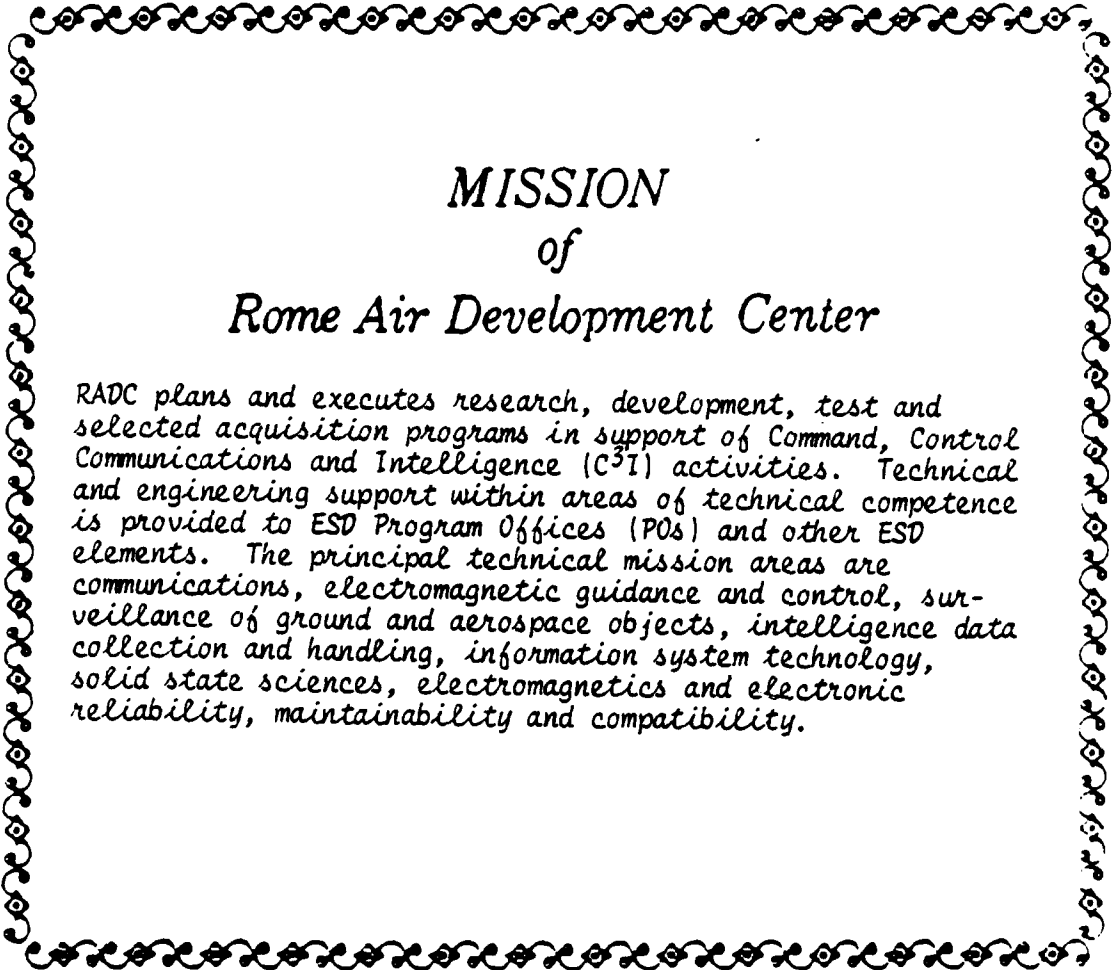
"Groundwave Propagation"; E.A. Lewis. Contract Report.

"VHF/UHF Ionospheric Scintillations in the Far North";

E.A. Lewis. Contract Report.

"Determination of Height Gain by Ray Tracing for Powerflux I or II";

P.K. Enge. Contract Report.



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