SPONSORED PROJECT TERMINATION SHEET

Date: August 16, 1983

Project Title: Antenna System Development Task
Project No: A-3442
Project Director: J. A. Woody
Sponsor: U.S. Army Missile Command

Effective Termination Date: 3/19/83
Clearance of Accounting Charges: 5/19/83

Grant/Contract Closeout Actions Remaining:

- [x] Final Invoice and Closing Documents
- [ ] Final Fiscal Report
- [x] Final Report of Inventions
- [x] Govt. Property Inventory & Related Certificate
- [ ] Classified Material Certificate
- [ ] Other ____________________________

Assigned to: ECSL (School/Laboratory)

COPIES TO:
Administrative Coordinator
Research Property Management
Accounting
Procurement/EES Supply Services
Research Security Services
Reports Coordinator (OCA)
Legal Services (OCA)
Library
EES Public Relations (2)
Computer Input
Project File
Other ____________________________
7 February 1983

Systems Simulation and Development Directorate  
U.S. Army Missile Command  
Redstone Arsenal, AL 35898

Attention: Dr. M. M. Hallum  
DRSMI-RDF

Subject: Monthly Technical Report No. 1, Project A-3442,  
Delivery Order No. 0063 under Contract No. DAAH01-81-D-A003, "Antenna System Development Task" covering the period from 6 December 1982 to 31 January 1983.

Gentlemen:

The objectives of this program are to (1) determine the performance characteristics of a proposed antenna configuration which is simpler, lighter, and less costly than an existing antenna configuration and (2) evaluate the effects on the performance characteristics of selected modifications to the proposed antenna configuration. The proposed (original) antenna configuration is a vertical monopole with three ground radials. The monopole is $\frac{5}{8}\lambda$ long at 78 MHz and is base-loaded for impedance matching. The ground radials are 36-inches long and decline at a 15-degree angle from the horizontal. The selected modifications to the original configuration are as follows:

(1) The lengths of the ground radials increased to 42, 48, and 54 inches (radial lengths increased by 6, 12, and 18 inches, respectively).

(2) The decline angles of the ground radials relative to horizontal increased to 45 and 60 degrees.

(3) The number of ground radials increased to four and eight.

(4) The ground radials removed and the monopole mounted on metal and on wood masts.

During this reporting period, a method of implementing the modified configurations was developed and measurements were performed on the original and each of the modified configurations. A new base plate/mounting bracket (i.e., metal bracket at the base of the monopole which is used to mount the ground radials and to mount the complete antenna to a mast) and additional ground radials were constructed to permit changing of the radial decline angle.
and the number of radials. The lengths of the ground radials were changed by adding extensions to the existing radials on the original monopole. For each configuration (original and nine modified), azimuth and elevation patterns were measured at 68, 79, and 88 MHz. Also, the gain was measured for each configuration at 68, 73, 79, 83 and 88 MHz.

The resulting pattern and gain data are currently being reduced and analyzed. Based on preliminary analysis of this data, it appears that the modifications to the original monopole configuration do not improve its performance characteristics. In fact, the majority of the modifications significantly degrade the performance at the upper frequencies. Further analysis of the data is required before definitive conclusions can be formulated.

In addition to the data reduction and analysis, the impedance/VSWR is also currently being measured for each configuration from 68 to 88 MHz. It is anticipated that during the next month the measurements, data reduction, and data analysis will be completed and preparation of the letter-type final report will be initiated.

Respectfully submitted,

[Signature]
Jimmy A. Woody
Project Director

Approved:

[Signature]
Hugh W. Denny, Chief
Electromagnetic Compatibility Division
Gentlemen:

The objectives of this program are to (1) determine the performance characteristics of a proposed antenna configuration which is simpler, lighter, and less costly than an existing antenna configuration and (2) evaluate the effects on the performance characteristics of selected modifications to the proposed antenna configuration. The proposed (original) antenna configuration is a vertical monopole with three ground radials. The monopole is \( \frac{5}{8} \) \( \lambda \) long at 78 MHz and is base-loaded for impedance matching. The ground radials are 36-inches long and decline at a 15-degree angle from the horizontal. The selected modifications to the original configuration are as follows:

1. The lengths of the ground radials were increased to 42, 48, and 54 inches (radial lengths increased by 6, 12, and 18 inches, respectively).
2. The decline angles of the ground radials relative to horizontal were increased to 45 and 60 degrees.
3. The number of ground radials were increased to four and eight.
4. The ground radials were removed and the monopole was mounted on metal and on wood masts.

The technical activities this month included the completion of all measurements on the original and modified antenna configurations, the presentation of a technical briefing, an analysis of the measured data, and a theoretical analysis of a few modifications whose effects were not measured. The complex input impedance of the original and each modified antenna configuration was measured from 68 to 88 MHz in 1-MHz steps. These impedance data were then converted to VSWR in a 50-ohm system. Analysis of these data...
indicates that the antenna must be tuned to maintain a low VSWR. Analysis of
the gain, azimuth and elevation pattern, and VSWR data for all the measured
configurations indicates that the original monopole provides better overall
performance than any of the modified configurations.

On 9 February 1983, a project review meeting was held at Georgia Tech.
Attending this meeting were Mr. Peter Johnson of MICOM, Mr. Dave Carey of
Tech. At this meeting, Georgia Tech personnel gave a technical presentation
describing this program and the measurement results obtained to date. These
results as well as the remaining effort on the program were discussed in
detail.

As an adjunct the measurement effort, a limited number of other
modifications to the original monopole have been modeled using a Method of
Moments (MOM) computer program. These theoretical models include decreasing
the lengths of the ground radials and decreasing the ground radial decline
angle. Preliminary analyses of the results from these models indicate that
decreasing the lengths of the ground radials does not significantly effect the
performance of the antenna. In contrast, decreasing the ground radial decline
angle to zero degrees (i.e., horizontal) does appear to improve the gain and
elevation pattern characteristics by as much as 1 dB at the tuned frequency.

Preparation of the final report for this program was also initiated
during this reporting period. It is anticipated that the data analysis and
final report will be completed next month.

Respectfully submitted,

Jimmy Woody
Project Director

Approved:

Hugh W. Denny, Chief
Electromagnetic Compatibility Division
13 January 1983

Systems Simulation and Development Directorate
U.S. Army Missile Command
Redstone Arsenal, AL 35898

Attention: Dr. M. M. Hallum
DRSMI-RDF


Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated reporting period.

Sincerely,

[Signature]

Jimmy A. Woody
Project Director

Approved:

Hugh W. Denny, Chief
Electromagnetic Compatibility Division

Enclosure
PERFORMANCE AND COST REPORT

CONTRACT NUMBER: DAAH01-81-D-A003
D.O. 0063

DATE: 13 January 1983

CONTRACTOR: Georgia Tech - EES

CONTRACT VALUE: $21,000

NO. OF LABOR HOURS: 712

COMPLETION DATE (TECHNICAL REPORT): 19 May 1983

<table>
<thead>
<tr>
<th>TASK/PROGRAM</th>
<th>Expended This Month</th>
<th>Cumulative To Date</th>
<th>% of Total L/H Spent To Date</th>
<th>% of Total Funds Spent To Date</th>
<th>Cumulative % of Work Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L-Hours</td>
<td>Funds</td>
<td>L-Hours</td>
<td>Funds</td>
<td>This Month</td>
</tr>
<tr>
<td>Antenna System Development</td>
<td>77</td>
<td>$2442</td>
<td>77</td>
<td>$2442</td>
<td>11</td>
</tr>
</tbody>
</table>

Are remaining labor hours sufficient to complete each task? **yes**
If not, which tasks have insufficient labor hours? 

Are remaining funds sufficient to complete each task? **yes**
If not, which tasks have insufficient funds? 

**Antenna System Development**

| L-Hours   | Funds   |%
<table>
<thead>
<tr>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>77</td>
<td>$2442</td>
</tr>
<tr>
<td>77</td>
<td>$2442</td>
</tr>
<tr>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

- Antenna System Development: 10% of total funds spent to date, 10% of work completed.
7 February 1983

Systems Simulation and Development Directorate
U.S. Army Missile Command
Redstone Arsenal, AL 35898

Attention: Dr. M. M. Hallum
DRSMI-RDF

Subject: Cost and Performance Report No. 2, Project A-3442,
Delivery Order No. 0063 under Contract No. DAAH01-81-D-A003, "Antenna System Development Task" covering
the period from 1 to 31 January 1983.

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated
reporting period.

Sincerely,

Jimmy A. Woody
Project Director

Approved:

Hugh M. Denny, Chief
Electromagnetic Compatibility Division

Enclosure
**PERFORMANCE AND COST REPORT**

**CONTRACT NUMBER** DAAH01-81-D-A003

**DATE** 7 February 1983

**CONTRACTOR** Georgia Tech - EES

**D.O.** 0063

**CONTRACT VALUE** $21,000

**NO. OF LABOR HOURS** 712

**COMPLETION DATE (TECHNICAL REPORT)** 19 May 1983

**TASK/PROGRAM**

<table>
<thead>
<tr>
<th>TASK/PROGRAM</th>
<th>Expended This Month</th>
<th>Cumulative To Date</th>
<th>% of Total L/H Spent To Date</th>
<th>% of Total Funds Spent To Date</th>
<th>Cumulative % of Work Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L-Hours</td>
<td>Funds</td>
<td>L-Hours</td>
<td>Funds</td>
<td></td>
</tr>
<tr>
<td>Antenna System Development</td>
<td>228</td>
<td>$6268</td>
<td>305</td>
<td>$8710</td>
<td>43</td>
</tr>
</tbody>
</table>

Are remaining labor hours sufficient to complete each task? **Yes**

If not, which tasks have insufficient labor hours? _______  

Are remaining funds sufficient to complete each task? **Yes**

If not, which tasks have insufficient funds? _______  

3 March 1983

Systems Simulation and Development Directorate
U.S. Army Missile Command
Redstone Arsenal, AL 35898

Attention: Dr. M. M. Hallum
DRSMI-RDF

Subject: Cost and Performance Report No. 3, Project A-3442,
Delivery Order No. 0063 under Contract No. DAAH01-81-D-A003, "Antenna System Development Task" covering
the period from 1 to 28 February 1983.

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated
reporting period.

Sincerely,

[Signature]
Jimmy A. Woody
Project Director

Approved:

Hugh W. Denny, Chief
Electromagnetic Compatibility Division

Enclosure
PERFORMANCE AND COST REPORT

DAAH01-81-D-A003

CONTRACT NUMBER  D.O. 0063       DATE  3 March 1983       CONTRACTOR  Georgia Tech - EES

CONTRACT VALUE $21,000       NO. OF LABOR HOURS  712       COMPLETION DATE (TECHNICAL REPORT) 19 May 1983

Expended
This Month
L-Hours | Funds  | Cumulative
        |        | To Date
L-Hours | Funds  | % of Total
        |        | L/H Spent
        |        | To Date
% of Total
Funds Spent
To Date
Cumulative % of Work
Completed
This Month | To Date

<table>
<thead>
<tr>
<th>TASK/PROGRAM</th>
<th>Expended</th>
<th>Cumulative</th>
<th>% of Total</th>
<th>% of Total</th>
<th>Cumulative</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>This Month</td>
<td>To Date</td>
<td>L/H Spent</td>
<td>Funds Spent</td>
<td>Work</td>
</tr>
<tr>
<td></td>
<td>L-Hours</td>
<td>L-Hours</td>
<td>To Date</td>
<td>To Date</td>
<td>Completed</td>
</tr>
<tr>
<td>Antenna System Development</td>
<td>265</td>
<td>570</td>
<td>$7419</td>
<td>$16,129</td>
<td>77</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>35</td>
</tr>
</tbody>
</table>

Are remaining labor hours sufficient to complete each task? Yes
If not, which tasks have insufficient labor hours?

Are remaining funds sufficient to complete each task? Yes
If not, which tasks have insufficient funds?
1 April 1983

Systems Simulation and Development Directorate  
U.S. Army Missile Command  
Redstone Arsenal, AL 35898

Attention:  Dr. M. M. Hallum  
DRSMI-RDF

Subject:  Cost and Performance Report No. 4, Project A-3442,  
Delivery Order No. 0063 under Contract No. DAAH01-81-D-A003, "Antenna System Development Task" covering  
the period from 1 to 31 March 1983.

Gentlemen:

Please find enclosed the Cost and Performance Report for the indicated  
reporting period.

Sincerely,

Jimmy A. Woody  
Project Director

Approved:

Hugh W. Denny, Chief  
Electromagnetic Compatibility Division

Enclosure
## PERFORMANCE AND COST REPORT

**CONTRACT NUMBER** DAAH01-81-D-A003  
**DATE** 1 April 1983  
**CONTRACTOR** Georgia Tech - EES  
**D.O.** 0063  

** CONTRACT VALUE** $21,000  
**NO. OF LABOR HOURS** 712  
**COMPLETION DATE (TECHNICAL REPORT)** 19 May 1983

<table>
<thead>
<tr>
<th>TASK/PROGRAM</th>
<th>Expended This Month</th>
<th>Cumulative To Date</th>
<th>% of Total L/H Spent To Date</th>
<th>% of Total Funds Spent To Date</th>
<th>Cumulative % of Work Completed</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>L-Hours</td>
<td>Funds</td>
<td>L-Hours</td>
<td>Funds</td>
<td></td>
</tr>
<tr>
<td>Antenna System Development</td>
<td>215</td>
<td>$4624</td>
<td>785</td>
<td>$20753</td>
<td>110</td>
</tr>
</tbody>
</table>

Are remaining labor hours sufficient to complete each task? **Yes**  
If not, which tasks have insufficient labor hours? 

Are remaining funds sufficient to complete each task? **Yes**  
If not, which tasks have insufficient funds?
EVALUATION OF PROPOSED ANTENNA
AND SELECTED MODIFICATIONS

Contract No. DAAH01-81-D-A003
Delivery Order No. 0063

By

J. A. Woody

March 1983

Submitted to

U.S. ARMY MISSILE COMMAND
Systems Simulation and Development Directorate
DRSMI-RDF
Redstone Arsenal, AL 35898

Prepared by

Electromagnetic Compatibility Division
Electronics and Computer Systems Laboratory
Engineering Experiment Station
Georgia Institute of Technology
Atlanta, Georgia 30332

A Unit of the University System of Georgia
1.0 INTRODUCTION

As a result of discussions between Mr. E. E. Johnson and Mr. Tom Pierce of the U.S. Army MICOM and members of Georgia Tech's Engineering Experiment Station (EES), the Electronics and Computer Systems Laboratory (ECSL) of EES was tasked (Delivery Order No. 0063) under Contract DAAH01-81-D-A003 to assist in the preliminary development of a proposed antenna system. The purpose of the proposed antenna configuration is to provide a simpler, lighter, and less costly replacement for an existing antenna system. The specific objectives of this task were to (1) determine the electrical performance characteristics of the proposed antenna configuration and (2) evaluate the effects on the performance characteristic of selected modifications to the proposed configuration.

From 6 December 1982 to 28 February 1983, ECSL personnel designed and fabricated the modifications to the original configuration of the proposed antenna; measured the electrical performance characteristics of the original antenna and of each of the modified configurations; analyzed the measured data; and theoretically analyzed additional modifications. The results of these efforts indicate that the performance of the originally proposed configuration, which is simple, lightweight, and inexpensive, is better than the performance of any of the modifications that were measured. Additional investigations are required to finalize the design of the optimum configuration for the desired electrical and mechanical performance.

Subsequent sections of this report define the original antenna configuration and the selected modifications which were measured, describe the measurements performed and the test procedures employed, present the resulting data and conclusions, and set forth the additional investigations recommended for the final design of the optimum antenna configuration.

2.0 ANTENNA CONFIGURATIONS

The electrical performance characteristics of ten (10) antenna configurations were investigated on this task. These configurations include the originally proposed antenna and nine (9) modifications to the original antenna. The original configuration consists of a vertical monopole with
three (3) ground radials. The radiating element is 5/8 wavelength ($\lambda$) long at 78 MHz and is base-loaded for impedance matching. Each of the three ground radials are 36 inches long and decline at an angle of 15 degrees relative to horizontal.

The modifications to the original monopole include changes in the lengths, decline angle, and number of the ground radials. The ground radial lengths were modified by attaching extensions to the original 36-inch radials. The extensions consisted of tubes with an inner diameter slightly larger than the outer diameter of the original radials. Three (3) modified ground radial lengths of 42, 48, and 54 inches (i.e., the original radial length of 36 inches was increased by 6, 12, and 18 inches, respectively) were evaluated.

In order to implement the modifications to the decline angle and number of ground radials, a new antenna baseplate/mounting bracket and new 36-inch ground radials were fabricated. Using these new parts, the original ground radial decline angle of 15 degrees relative to horizontal was increased to 45 degrees and then to 60 degrees. In a similar manner, the number of ground radials was changed from three to (1) four, (2) eight, (3) no radials and the radiating element on a metal mast, and (4) no radials and the radiating element on a wood mast.

Each of these nine modifications to the original monopole (three increases in ground radial lengths, two increases in ground radial decline angles, and four changes in the number of ground radials) were made one at a time so that the effects of the modifications could be independently evaluated. Thus, the electrical performance characteristics of each of the ten antenna configurations were measured and compared.

3.0 ANTENNA MEASUREMENTS

Antenna gain, azimuth and elevation patterns, and impedance/voltage-standing-wave ratio (VSWR) characteristics were measured for each of the ten antenna configurations. The gain measurements were performed at 68, 73, 79, 83, and 88 MHz. (Originally, measurements were planned at 78 MHz; however, because of the presence of a local TV video carrier at 77.25 MHz, this test frequency had to be changed to 79 MHz to avoid interference.) Azimuth and elevation patterns were measured at 68, 79, and 88 MHz. The input impedance
of each antenna configuration was measured at 1 MHz increments from 68 to 88 MHz.

The antenna gain and pattern measurements were performed on a 28-acre antenna test site located approximately 20 miles from Atlanta in a low RF-noise environment. This test site was designed for antenna measurements at HF, VHF, and UHF. Major features of the test site include:

- A concrete block instrumentation building with no metal in the walls and ceiling;
- Two remote test pads at distances of 595 feet and 915 feet from the instrumentation building; and
- Underground cabling on the site.

The gain and pattern measurements were made on the 595-foot range using the configuration illustrated in Figure 1. Signal substitution was used (dotted line in Figure 1) to determine the power level at the input of the receiver. The gain at zero degrees elevation of each antenna configuration was measured relative to a half-wavelength dipole, i.e., the received power from the antenna-under-test was compared with the received power from the dipole when both were exposed to the same radiated field. The gain of the antenna-under-test in dB relative to an isotropic antenna, dBi, was then determined by adding 2.15 dB (the gain of a half-wavelength dipole relative to an isotropic antenna) to the difference between the power levels received from the antenna-under-test and from the dipole.

It should be noted that the gain measurements were performed at zero degrees elevation relative to horizontal with the antenna-under-test mounted in its normal operating orientation (i.e., monopole was vertical). Therefore, the measured gain corresponds to the level on the elevation pattern at zero degrees and is not necessarily the maximum level (gain) in the elevation plane.

The impedance/VSWR measurements for each antenna configuration were performed by measuring the magnitude and phase angle of the complex input impedance of each configuration. These impedance measurements were made with an HP 4815A RF Vector Impedance Meter. The input impedance was recorded at each test frequency and then used to calculate the VSWR in a 50-ohm system.
Figure 1. Measurement Setup for Antenna Gain and Pattern Measurements.
4.0 MEASUREMENT RESULTS

The measured gains of the ten antenna configurations are tabulated in Tables 1, 2, and 3 for various lengths, decline angles, and number of ground radials, respectively. To facilitate analysis, these gains are also plotted as a function of frequency in Figures 2, 3, and 4. The gain of the original monopole configuration is included in each table and figure to simplify comparisons.

The data in Table 1 and Figure 2 indicate that increasing the lengths of the ground radials generally degrades the gain (at zero degrees elevation) of the antenna. At the low frequency end of the 68 to 88 MHz band, lengthening the ground radials has essentially no effect on the antenna gain; however, increasing the radial length decreases the gain by larger amounts for each higher test frequency. At 88 MHz, each additional 6-inch extension decreases the gain by 2.6 to 4.8 dB.

In a similar manner, the data in Table 2 and Figure 3 indicate that increasing the decline angle of the ground radials relative to horizontal also degrades the gain of the antenna. Again, the degradation is less than a dB at 68 MHz and as much as 5.8 dB at 88 MHz.

The gain data in Table 3 and Figure 4 indicate that changing the number of ground radials from three to four or to eight has very little effect -- the resulting change in gain is generally less than 1 dB. Removing the ground radials, however, has a dramatic effect on the gain. The gains of the antenna configurations with no ground radials are approximately 10 dB better than the original monopole at 88 MHz. At 79 MHz, the gain of the configuration with no radials on a wood mast is degraded by more than 6 dB. Also, the gain of the configuration with no radials on a metal mast has 3.6 dB or less variation over the entire frequency range. On initial inspection, this last configuration appears to have the best gain characteristics because of the uniformity of the gain as a function of frequency. However, after further consideration, it was concluded that this configuration with no ground radials was not desirable because, without a ground plane of some kind, changes in the size and location of metal objects below the antenna have a much greater potential for affecting the electrical performance characteristics.
### TABLE 1
EFFECTS OF GROUND RADIAL LENGTH ($l$) ON GAIN

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Original Monopole</th>
<th>$l = 36$ inches</th>
<th>$l = 42$ inches</th>
<th>$l = 48$ inches</th>
<th>$l = 54$ inches</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>3.0</td>
<td>3.2</td>
<td>3.0</td>
<td>3.2</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>4.2</td>
<td>3.8</td>
<td>3.2</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>5.8</td>
<td>3.8</td>
<td>2.8</td>
<td>1.2</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>2.0</td>
<td>0.0</td>
<td>-1.8</td>
<td>-3.2</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>-5.6</td>
<td>-8.2</td>
<td>-11.0</td>
<td>-15.8</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 2
EFFECTS OF GROUND RADIAL DECLINE ANGLE ($\theta$) ON GAIN

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Original Monopole</th>
<th>$\theta = 15$ degrees</th>
<th>$\theta = 45$ degrees</th>
<th>$\theta = 60$ degrees</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>3.0</td>
<td>2.8</td>
<td>2.2</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>4.2</td>
<td>3.0</td>
<td>3.0</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>5.8</td>
<td>4.8</td>
<td>3.4</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>2.0</td>
<td>-0.8</td>
<td>0.0</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>-5.6</td>
<td>-9.6</td>
<td>-11.4</td>
<td></td>
</tr>
</tbody>
</table>

### TABLE 3
EFFECTS OF NUMBER OF GROUND RADIALS ON GAIN

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Original Monopole</th>
<th>3 Radials</th>
<th>4 Radials</th>
<th>8 Radials</th>
<th>No Radials Metal Mast</th>
<th>No Radials Wood Mast</th>
</tr>
</thead>
<tbody>
<tr>
<td>68</td>
<td>3.0</td>
<td>3.0</td>
<td>2.8</td>
<td>2.0</td>
<td>4.4</td>
<td></td>
</tr>
<tr>
<td>73</td>
<td>4.2</td>
<td>3.8</td>
<td>4.2</td>
<td>1.8</td>
<td>1.8</td>
<td></td>
</tr>
<tr>
<td>79</td>
<td>5.8</td>
<td>5.4</td>
<td>4.6</td>
<td>4.8</td>
<td>-1.4</td>
<td></td>
</tr>
<tr>
<td>83</td>
<td>2.0</td>
<td>1.8</td>
<td>1.8</td>
<td>5.4</td>
<td>1.0</td>
<td></td>
</tr>
<tr>
<td>88</td>
<td>-5.6</td>
<td>-4.8</td>
<td>-5.0</td>
<td>4.4</td>
<td>5.2</td>
<td></td>
</tr>
</tbody>
</table>
Figure 2. Gain as a Function of Frequency for Different Lengths of Ground Radials (3 Radials).
Figure 3. Gain as a Function of Frequency for Different Ground Radial Decline Angles (3 Radials).
Figure 4. Gain as a Function of Frequency for Different Numbers of Ground Radials and No Radials (Radials 36 inches long).
The azimuth and elevation patterns for each antenna configuration are presented in Appendices A and B, respectively. The azimuth patterns are copies of the rectangular plots made by the SA 1525 Pattern Recorder. The elevation patterns were recorded in rectangular form and then replotted in polar format to facilitate interpretation. Each elevation pattern is normalized to the maximum level measured.

The azimuth patterns for the original monopole (Figures A-1 through A-3) indicate that the maximum azimuthal variation is less than 1 dB. Figures A-4 through A-12 indicate that increasing the length of the ground radials (1) decreases these variations at 68 MHz, (2) produces negligible effect on these variations at 79 MHz, and (3) increases these variations at 88 MHz. With an increase in ground radial lengths to 54 inches, the azimuthal variations at 88 MHz increased by more than 1.5 dB to approximately 2.5 dB.

Figures A-13 through A-18 indicate that increasing the ground radial decline angle below horizontal reduces the maximum variations in the azimuth pattern at 68 MHz and has no significant effect on these variations at either 79 or 88 MHz.

Figures A-19 through A-24 indicate that increasing the number of ground radials to four or eight has effects on the azimuth patterns similar to those of increasing the length of the ground radials. The maximum azimuthal variations decrease, remain the same, and increase slightly at 68, 79, and 88 MHz, respectively. Removing the ground radials completely has different effects depending on whether a metal or wood mast is used. On a metal mast (Figures A-25 through A-27), the variations decrease at 68 and 88 MHz and remain unchanged at 79 MHz. On a wood mast (Figures A-28 through A-30), these variations increase slightly at 68 MHz and decrease slightly at 88 MHz. At 79 MHz, these variations increase significantly to approximately 3.5 dB.

The elevation patterns for the original monopole (Figures B-1 through B-3) indicate that the angle of maximum gain is greater than 20 degrees above horizontal and that this angle increases with increasing frequency. (It is noted that the measured gain discussed previously was measured at zero-degrees elevation angle, i.e., at horizontal). Also, at the higher test frequency, the beam begins splitting in the elevation plane and the gain at horizontal decreases significantly. In order to quantify the elevation patterns, selected characteristics are tabulated in Table 4. From this table, it is obvious that the best performance (highest gain, lack of beam splitting, etc.) is obtained at the tuned frequency.
TABLE 4
ELEVATION PATTERN CHARACTERISTICS OF ORIGINAL MONOPOLE CONFIGURATION

<table>
<thead>
<tr>
<th>Frequency (MHz)</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal</td>
<td>Gain (dBi)</td>
</tr>
<tr>
<td>68</td>
<td>21</td>
<td>4.2</td>
</tr>
<tr>
<td>79</td>
<td>26</td>
<td>7.9</td>
</tr>
<tr>
<td>88</td>
<td>39</td>
<td>1.5</td>
</tr>
</tbody>
</table>

TABLE 5
EFFECTS OF GROUND RADIAL LENGTH (\( \lambda \)) ON ELEVATION PATTERN CHARACTERISTICS AT 68 MHz

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal</td>
<td>Gain (dBi)</td>
</tr>
<tr>
<td>Orig. Monopole (( \lambda =36 ) inches)</td>
<td>21</td>
<td>4.2</td>
</tr>
<tr>
<td>( \lambda =42 ) inches</td>
<td>22</td>
<td>4.5</td>
</tr>
<tr>
<td>( \lambda =48 ) inches</td>
<td>20</td>
<td>3.9</td>
</tr>
<tr>
<td>( \lambda =54 ) inches</td>
<td>20</td>
<td>4.1</td>
</tr>
</tbody>
</table>
The elevation patterns for each of the modified configurations are given in Figures B-4 through B-30. Again, the selected characteristics of these patterns have been tabulated to facilitate analysis and are given in Tables 5 through 13. In each table, the appropriate original monopole data are repeated to permit direct comparisons.

Tables 5 through 7 indicate that increasing the length of the ground radials does not improve the elevation pattern characteristics. At 68 MHz, no significant changes are noted with increases in radial lengths. At 79 and 88 MHz, each increase in radial length degrades the performance characteristics by increasing the elevation angle of maximum radiation, decreasing both the maximum and horizontal gains, and decreasing the minimum gains within ±15 degrees of horizontal.

Tables 8 through 10 indicate that increasing the decline angle of the ground radials relative to horizontal also degrades the elevation pattern characteristics of the monopole antenna. At all three test frequencies, increasing the decline angle decreases the gain at horizontal and decreases the minimum gain within ±15 degrees of horizontal. At 68 and 88 MHz, increases in the ground radial decline angle has very little effect on the angle of maximum gain; however, at 79 MHz (the approximate tuned frequency), the angle of maximum gain increases significantly when the decline angle is increased.

Tables 11 through 13 indicate that changing the number of ground radials does not improve the elevation characteristics of the monopole. Increasing the number of ground radials to 4 or 8 either has no significant effect on the gain at horizontal and on the minimum gain within ±15 degrees of horizontal or decreases these gains depending on the test frequency. Completely removing the radials degrades the performance at the tuned frequency and appears to improve the elevation pattern characteristics at the other two test frequencies. However, this improvement is expected to change (possibly even to degradation) as the location and/or number of metal objects below the antenna change. Therefore, a monopole antenna without any ground radials is not considered an acceptable configuration for stable and repeatable performance characteristics.

The VSWRs of the ten antenna configurations are plotted versus frequency in Figures 5, 6, and 7 for various lengths, decline angles, and number of ground radials, respectively. The VSWR was calculated from the measured
### TABLE 6

**EFFECTS OF GROUND RADIAL LENGTH (χ) ON ELEVATION PATTERN CHARACTERISTICS AT 79 MHz**

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal (degrees)</td>
<td>Gain (dBi)</td>
</tr>
<tr>
<td>Orig. Monopole (χ=36 inches)</td>
<td>26</td>
<td>7.9</td>
</tr>
<tr>
<td>χ=42 inches</td>
<td>36</td>
<td>5.7</td>
</tr>
<tr>
<td>χ=48 inches</td>
<td>42</td>
<td>5.4</td>
</tr>
<tr>
<td>χ=54 inches</td>
<td>45</td>
<td>4.7</td>
</tr>
</tbody>
</table>

### TABLE 7

**EFFECTS OF GROUND RADIAL LENGTH (χ) ON ELEVATION PATTERN CHARACTERISTICS AT 88 MHz**

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal (degrees)</td>
<td>Gain (dBi)</td>
</tr>
<tr>
<td>Orig. Monopole (χ=36 inches)</td>
<td>39</td>
<td>1.5</td>
</tr>
<tr>
<td>χ=42 inches</td>
<td>41</td>
<td>3.8</td>
</tr>
<tr>
<td>χ=48 inches</td>
<td>43</td>
<td>0.1</td>
</tr>
<tr>
<td>χ=54 inches</td>
<td>45</td>
<td>-2.4</td>
</tr>
</tbody>
</table>
### TABLE 8

**EFFECTS OF GROUND RADIAL DECLINE ANGLE (θ) ON ELEVATION PATTERN CHARACTERISTICS AT 68 MHz**

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal (degrees)</td>
<td>Gain at Horizontal (dBi)</td>
</tr>
<tr>
<td>Orig. Monopole (θ=15 degrees)</td>
<td>21</td>
<td>4.2</td>
</tr>
<tr>
<td>θ=45 degrees</td>
<td>22</td>
<td>4.3</td>
</tr>
<tr>
<td>θ=60 degrees</td>
<td>24</td>
<td>4.1</td>
</tr>
</tbody>
</table>

### TABLE 9

**EFFECTS OF GROUND RADIAL DECLINE ANGLE (θ) ON ELEVATION PATTERN CHARACTERISTICS AT 79 MHz**

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal (degrees)</td>
<td>Gain at Horizontal (dBi)</td>
</tr>
<tr>
<td>Orig. Monopole (θ=15 degrees)</td>
<td>26</td>
<td>7.9</td>
</tr>
<tr>
<td>θ=45 degrees</td>
<td>39</td>
<td>9.2</td>
</tr>
<tr>
<td>θ=60 degrees</td>
<td>35</td>
<td>8.5</td>
</tr>
</tbody>
</table>
### TABLE 10

EFFECTS OF GROUND RADIAL DECLINE ANGLE ($\theta$) ON ELEVATION PATTERN CHARACTERISTICS AT 88 MHz

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within $\pm15^\circ$ of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal Gain</td>
<td>Gain at Horizontal Gain</td>
</tr>
<tr>
<td>Orig. Monopole ($\theta=15$ degrees)</td>
<td>39 1.5</td>
<td>-5.6</td>
</tr>
<tr>
<td>$\theta=45$ degrees</td>
<td>39 5.8</td>
<td>-9.6</td>
</tr>
<tr>
<td>$\theta=60$ degrees</td>
<td>36 7.5</td>
<td>-11.4</td>
</tr>
</tbody>
</table>

### TABLE 11

EFFECTS OF NUMBER OF GROUND RADIALS ON ELEVATION PATTERN CHARACTERISTICS AT 68 MHz

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within $\pm15^\circ$ of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal Gain</td>
<td>Gain at Horizontal Gain</td>
</tr>
<tr>
<td>Orig. Monopole (3 Radials)</td>
<td>21 4.2</td>
<td>3.0</td>
</tr>
<tr>
<td>4 Radials</td>
<td>20 4.1</td>
<td>3.0</td>
</tr>
<tr>
<td>8 Radials</td>
<td>22 4.1</td>
<td>2.8</td>
</tr>
<tr>
<td>No Radials Metal Mast</td>
<td>17 2.5</td>
<td>2.0</td>
</tr>
<tr>
<td>No Radials Wood Mast</td>
<td>24 4.5</td>
<td>4.4</td>
</tr>
</tbody>
</table>
TABLE 12
EFFECTS OF NUMBER OF GROUND RADIALS ON ELEVATION PATTERN CHARACTERISTICS AT 79 MHz

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal (degrees)</td>
<td>Gain (dBi)</td>
</tr>
<tr>
<td>Orig. Monopole (3 Radials)</td>
<td>26</td>
<td>7.9</td>
</tr>
<tr>
<td>4 Radials</td>
<td>32</td>
<td>7.2</td>
</tr>
<tr>
<td>8 Radials</td>
<td>35</td>
<td>6.7</td>
</tr>
<tr>
<td>No Radials Metal Mast</td>
<td>32</td>
<td>8.5</td>
</tr>
<tr>
<td>No Radials Wood Mast</td>
<td>34</td>
<td>7.3</td>
</tr>
</tbody>
</table>

TABLE 13
EFFECTS OF NUMBER OF GROUND RADIALS ON ELEVATION PATTERN CHARACTERISTICS AT 88 MHz

<table>
<thead>
<tr>
<th>Antenna Configuration</th>
<th>Maximum Gain</th>
<th>Minimum Gain Within ±15° of Horizontal</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Angle Above Horizontal (degrees)</td>
<td>Gain (dBi)</td>
</tr>
<tr>
<td>Orig. Monopole (3 Radials)</td>
<td>39</td>
<td>1.5</td>
</tr>
<tr>
<td>4 Radials</td>
<td>43</td>
<td>5.2</td>
</tr>
<tr>
<td>8 Radials</td>
<td>42</td>
<td>4.3</td>
</tr>
<tr>
<td>No Radials Metal Mast</td>
<td>32</td>
<td>11.8</td>
</tr>
<tr>
<td>No Radials Wood Mast</td>
<td>22</td>
<td>8.9</td>
</tr>
</tbody>
</table>
Figure 5. VSWR as a Function of Frequency for Different Lengths of Ground Radials (3 Radials)
Figure 6. VSWR as a Function of Frequency for Different Ground Radial Decline Angles (3 radials).
Figure 7. VSWR as a Function of Frequency for Different Numbers of Ground Radials
(Radials 36 inches long)
complex input impedance assuming a 50-ohm characteristic impedance. The VSWR for the original monopole, which is included on each figure to facilitate comparisons, is less than, or equal to, 2.5:1 over approximately a 4 MHz frequency spread; it is less than, or equal to, 1.8:1 over approximately 2 MHz. Both of these frequency ranges are centered about the minimum-VSWR frequency which is slightly greater than 78 MHz.

Figure 5 indicates that increasing the length of the ground radials lowers the frequency at which the minimum VSWR occurs. However, changing the ground radial lengths does not significantly change the 2.5:1 and 1.8:1 VSWR frequency spreads. Similarly, Figure 6 indicates that increasing the decline angle of the ground radials decreases the minimum-VSWR frequency slightly. Also, the frequency spreads over which the VSWR's are less than, or equal to, 2.5:1 and 1.8:1 increase by approximately 0.5 MHz. Finally, Figure 7 indicates that increasing the number of ground radials lowers slightly the frequency of minimum VSWR and increases slightly the 2.5:1 and 1.8:1 VSWR frequency spreads. In contrast, removing the ground radials increases the minimum-VSWR frequency by 5 to 6 MHz and increases the frequency spreads over which the VSWR's are less than, or equal to, 2.5:1 and 1.8:1 by approximately 1 MHz. Analysis of all the VSWR graphs in Figures 5, 6, and 7 indicates that the modifications to the original monopole either degrade the VSWR performance characteristics or result in a slight improvement in these characteristics. The small improvements provided by some modifications (e.g., increasing the decline angle of the ground radials) are not large enough to justify these modifications, especially considering their resulting degradation in gain and elevation patterns.

In summary, the results of the gain, pattern, and VSWR measurements on the ten antenna configurations indicate that the original monopole exhibits very good performance at the tuned frequency with some degradation at lower frequencies and, in general, significant degradation at higher frequencies. The modifications to the original configuration either degrade the performance characteristics of the antenna or have no significant effect on these characteristics. There were not any instances in which a modification improved all of the antenna's performance characteristics relative to the original configuration. Generally, the modifications made little difference at 68 MHz, degraded the overall performance near the tuned frequency, and significantly degraded the overall performance at 88 MHz. Based on specific
analyses of the measured gain and VSWR data as a function of frequency, the performance of all the antenna configurations (including the original) is degraded at frequencies more than 1 to 2 MHz off the tuned frequency. This degradation increases as the test frequency gets further away from the tuned frequency. Therefore, to achieve optimum performance at all operating frequencies, the final antenna configuration should include an adjustable-length radiating element such that the antenna can be tuned to the operating frequency.

5.0 THEORETICAL ANALYSIS

As a supplement to the measurement effort presented in the preceding sections, a limited number of additional modifications to the original monopole were investigated by modeling them using a Method of Moments (MOM) computer program. These theoretical models include decreasing the lengths of the ground radials to 30 inches and to 24 inches (i.e., decreasing the original length by 6 and 12 inches, respectively) and decreasing the ground radial decline angle to zero degrees (i.e., horizontal).

First, the original monopole configuration was modeled to illustrate the correlation between the measured and theoretical results. Both the measured and theoretical elevation patterns are plotted in Figures 8 and 9 for 79 MHz and 88 MHz, respectively. The patterns in these figures indicate good correlation near the tuned frequency and correlation within a few dB at other test frequencies.

The theoretical elevation patterns indicate that decreasing the length of the ground radials from 36 inches to 30 or 24 inches does not significantly affect the performance of the antenna. For these three lengths, there is no difference between the elevation patterns at 68 MHz; less than 0.2 dB difference for elevation angles from -18 to 66 degrees at 78 MHz, and less than one dB difference at 88 MHz (see Figure 10).

The theoretical elevation patterns for ground radials with zero degrees decline angle relative to horizontal are presented in Figures 11, 12, and 13 for 68, 79, and 88 MHz, respectively. The patterns for the original monopole (15 degree decline angle) are also given for comparison. Figure 11 indicates that changing the decline angle from 15 to zero degrees at 68 MHz changes the elevation pattern less than 1 dB and has practically no effect on the gain
Figure 8. Elevation Pattern of Original Monopole at 79 MHz.
Figure 9. Elevation Pattern of Original Monopole at 88 MHz.
Figure 10. Theoretical Elevation Patterns for Different Lengths of Ground Radials (3 Radials) at 88 MHz.
Figure 11. Theoretical Elevation Patterns for Different Ground Radial Decline Angles at 68 MHz (3 Radials).
Figure 12. Theoretical Elevation Patterns for Different Ground Radial Decline Angles at 78 MHz (3 Radials).
Figure 13. Theoretical Elevation Patterns for Different Ground Radial Decline Angles at 88 MHz (3 Radials).
within ±15 degrees of horizontal. Figure 12 indicates that, near the tuned frequency, changing the ground radial decline angle relative to horizontal from 15 to zero degrees changes the elevation pattern by approximately 1 dB; however, this change is of significance within ±15 degrees of horizontal where it improves the gain. In fact, at zero degrees elevation (i.e., horizontal) changing the decline angle from 15 to zero degrees improves the gain by almost 1 dB. Figure 13 indicates that changing the ground radial decline angle from 15 to zero degrees also improves the antenna's performance near horizontal at 88 MHz. Specifically at zero degrees elevation, the gain is improved by almost 3 dB.

A final theoretical analysis was performed to evaluate the effect on the azimuth pattern when a metal surface is placed below the antenna. The MOM program was used to model the original monopole configuration (three 36-inch ground radials at 15 degrees below horizontal) with a 7-foot by 18-foot metal surface 10 feet below the base of the antenna. In the model, the metal surface was placed horizontally and the mast for the antenna was placed on one of the long sides of the surface. If the metal surface has any effect on the antenna, the azimuth pattern should become more directive over the surface. The resulting data from the model indicates that the variation in the azimuth pattern is less than 0.5 dB at 68 and 78 MHz and is less than 1 dB at 88 MHz. These theoretical azimuthal variations are comparable in magnitude to those measured when the metal surface was not present (see Figures A-1 through A-3). Therefore, it appears that the ground radials effectively isolate the antenna from metal surfaces below the radials such that a 7-foot by 18-foot metal surface 10 feet below the base of the antenna does not affect the antenna's azimuthal performance.

6.0 CONCLUSIONS

A 5/8-wavelength monopole is a simple, light, and inexpensive antenna configuration; it can provide comparable, or better, performance characteristics than the existing antennas. This task was conducted to evaluate the performance of a 5/8-wavelength monopole and of selected
modifications. Based on the results of the measurements and theoretical analysis, the following conclusions have been formulated:

- The original monopole configuration (three 36-inch ground radials with a decline angle of 15 degrees below horizontal) has better overall performance characteristics than any of the modified configurations that were measured. That is, increasing the length, decline angle, or number of ground radials degrades the antenna's performance.

- It appears theoretically that decreasing the length of the ground radials below 36 inches has no significant effect on the performance of the antenna. In contrast, the theoretical analysis indicates that decreasing the ground radial decline angle to zero degrees (horizontal) improves the antenna's performance near resonance. It is recommended that both of these observations be verified experimentally.

- The ground radials should not be completely removed from the monopole configuration since they provide required isolation between the antenna and conductive surfaces which may be located below the antenna.

- It is obvious from the gain and VSWR data near resonance that the final design of the antenna will have to incorporate a tunable radiating element such that the length of the monopole can be maintained near 5/8-wavelength at each operating frequency. With such a tuned antenna configuration the gain should exceed 4 dBi in the horizontal plane and the minimum gain within ±15 degrees of horizontal should exceed 1.5 dBi.

- It is recommended that additional investigations be performed on the tunable antenna concept to design the tuning mechanism, to determine the number and spacing of tuning increments, to ensure that 36-inch ground radials are optimum for each tuned frequency, and to verify the overall performance of the tunable antenna throughout its operational frequency range.
APPENDIX A

The azimuth patterns for the various measured antenna configurations are given in this Appendix. Figures A-1 through A-3 are the patterns for the original monopole. Figures A-4 through A-12 are the patterns for antenna configurations with increased ground radial lengths. Figures A-13 through A-18 are the patterns for antenna configurations with increased ground radial decline angles. Figures A-19 through A-30 are the patterns for antenna configurations with different numbers of ground radials. Three consecutive figures which present the patterns for 68, 79, and 88 MHz are included for each antenna configuration.
Figure A-1. Azimuth Pattern of Original Monopole at 68 MHz.
Figure A-2. Azimuth Pattern of Original Monopole at 79 MHz.
Figure A-3. Azimuth Pattern of Original Monopole at 88 MHz.
Figure A-4. Azimuth Pattern of Monopole with 42-inch Ground Radials (length extended 6 inches) at 68 MHz.
Figure A-5. Azimuth Pattern of Monopole with 42-inch Ground Radials (length extended 6 inches) at 79 MHz.
Figure A-6. Azimuth Pattern of Monopole with 42-inch Ground Radials (length extended 6 inches) at 88 MHz.
Figure A-7. Azimuth Pattern of Monopole with 48-inch Ground Radials (length extended 12 inches) at 68 MHz.
Figure A-8. Azimuth Pattern of Monopole with 48-inch Ground Radials (length extended 12 inches) at 79 MHz.
Figure A-9. Azimuth Pattern of Monopole with 48-inch Ground Radials (length extended 12 inches) at 88 MHz.
Figure A-10. Azimuth Pattern of Monopole with 54-inch Ground Radials (length extended 18 inches) at 68 MHz.
Figure A-11. Azimuth Pattern of Monopole with 54-inch Ground Radials (length extended 18 inches) at 79 MHz.
Figure A-12. Azimuth Pattern of Monopole with 54-inch Ground Radials (length extended 18 inches) at 88 MHz.
Figure A-13. Azimuth Pattern of Monopole with Ground Radial Decline Angle of 45 degrees at 68 MHz.
Figure A-14. Azimuth Pattern of Monopole with Ground Radial Decline Angle of 45 degrees at 79 MHz.
Figure A-15. Azimuth Pattern of Monopole with Ground Radial Decline Angle of 45 degrees at 88 MHz.
Figure A-16. Azimuth Pattern of Monopole with Ground Radial Decline Angle of 60 degrees at 68 MHz.
Figure A-17. Azimuth Pattern of Monopole with Ground Radial Decline Angle of 60 degrees at 79 MHz.
Figure A-18. Azimuth Pattern of Monopole with Ground Radial
Decline Angle of 60 degrees at 88 MHz.
Figure A-19. Azimuth Pattern of Monopole with 4 Ground Radials at 68 MHz.
Figure A-20. Azimuth Pattern of Monopole with 4 Ground Radials at 79 MHz.
Figure A-21. Azimuth Pattern of Monopole with 4 Ground Radials at 88 MHz.
Figure A-22. Azimuth Pattern of Monopole with 8 Ground Radials at 68 MHz.
Figure A-23. Azimuth Pattern of Monopole with 8 Ground Radials at 79 MHz.
Figure A-24. Azimuth Pattern of Monopole with 8 Ground Radials at 88 MHz.
Figure A-25. Azimuth Pattern of Monopole with No Ground Radials on Metal Mast at 68 MHz.
Figure A-26. Azimuth Pattern of Monopole with No Ground Radials on Metal Mast at 79 MHz.
Figure A-27. Azimuth Pattern of Monopole with No Ground Radials on Metal Mast at 88 MHz.
Figure A-28. Azimuth Pattern of Monopole with No Ground Radials on Wood Mast at 68 MHz.
Figure A-29. Azimuth Pattern of Monopole with No Ground Radials on Wood Mast at 79 MHz.
Figure A-30. Azimuth Pattern of Monopole with No Ground Radials on Wood Mast at 88 MHz.
APPENDIX B

The elevation patterns for the various measured antenna configurations are given in this Appendix. Figures B-1 through B-3 are the patterns for the original monopole. Figures B-4 through B-12 are the patterns for antenna configurations with increased ground radial lengths. Figures B-13 through B-18 are the patterns for antenna configurations with increased ground radial decline angles. Figures B-19 through B-30 are the patterns for antenna configurations with different numbers of ground radials. Three consecutive figures which present the patterns for 68, 79, and 88 MHz are included for each antenna configuration.
Figure B-1. Elevation Pattern of Original Monopole at 68 MHz.
Figure B-2. Elevation Pattern of Original Monopole at 79 MHz.
Figure B-3. Elevation Pattern of Original Monopole at 88 MHz.
Figure B-4. Elevation Pattern of Monopole with 42-inch Ground Radials (length extended 6 inches) at 68 MHz.
Figure B-5. Elevation Pattern of Monopole with 42-inch Ground Radials (length extended 6 inches) at 79 MHz.
Figure B-6. Elevation Pattern of Monopole with 42-inch Ground Radials (length extended 6 inches) at 88 MHz.
Figure B-7. Elevation Pattern of Monopole with 48-inch Ground Radials (length extended 12 inches) at 68 MHz.
Figure B-8. Elevation Pattern of Monopole with 48-inch Ground Radials (length extended 12 inches) at 79 MHz.
Figure B-9. Elevation Pattern of Monopole with 48-inch Ground Radials (length extended 12 inches) at 88 MHz.
Figure B-10. Elevation Pattern of Monopole with 54-inch Ground Radials (length extended 18 inches) at 68 MHz.
Figure B-11. Elevation Pattern of Monopole with 54-inch Ground Radials (length extended 18 inches) at 79 MHz.
Figure B-12. Elevation Pattern of Monopole with 54-inch Ground Radials (length extended 18 inches) at 88 MHz.
Figure B-13. Elevation Pattern of Monopole with Ground Radial Decline Angle of 45 degrees at 68 MHz.
Figure B-14. Elevation Pattern of Monopole with Ground Radial Decline Angle of 45 degrees at 79 MHz.
Figure B-15. Elevation Pattern of Monopole with Ground Radial Decline Angle of 45 degrees at 88 MHz.
Figure B-16. Elevation Angle of Monopole with Ground Radial Decline Angle of 60 degrees at 68 MHz.
Figure B-17. Elevation Pattern of Monopole with Ground Radial Decline Angle of 60 degrees at 79 MHz.
Figure B-18. Elevation Pattern of Monopole with Ground Radial Decline Angle of 60 degrees at 88 MHz.
Figure B-19. Elevation Pattern of Monopole with 4 Ground Radials at 68 MHz.
Figure B-20. Elevation Pattern of Monopole with 4 Ground Radials at 79 MHz.
Figure B-21. Elevation Pattern of Monopole with 4 Ground Radials at 88 MHz.
Figure B-22. Elevation Pattern of Monopole with 8 Ground Radials at 68 MHz.
Figure B-23. Elevation Pattern of Monopole with 8 Ground Radials at 79 MHz.
Figure B-24. Elevation Pattern of Monopole with 8 Ground Radials at 88 MHz.
Figure B-25. Elevation Pattern of Monopole with No Ground Radials on Metal Mast at 68 MHz.
Figure B-26. Elevation Pattern of Monopole with No Ground Radials on Metal Mast at 79 MHz.
Figure B-27. Elevation Pattern of Monopole with No Ground Radials on Metal Mast at 88 MHz.
Figure B-28. Elevation Pattern Of Monopole with No Ground Radials on Wood Mast at 68 MHz.
Figure B-29. Elevation Pattern of Monopole with No Ground Radials on Wood Mast at 79 MHz.
Figure B-30. Elevation Pattern of Monopole with No Ground Radials on Wood Mast at 88 MHz.