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CANADIAN AERONAUTICAL SATELLITE TESTS USING THE ATS-6 SATELLITE – JANUARY 1976

by

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ABSTRACT

A series of tests were conducted to complement those tests conducted in the previous year, using the ATS-6 satellite to compare the performance of several voice modulation techniques and two antenna systems installed in an airborne terminal. For these tests, improved versions of a voice modulation technique based on a delta encoding/PSK modulation and a technique based upon the transmission of the PSK modulated zero-crossing transitions of the audio signal were tested against a reference narrowband frequency modulation system under varying conditions of carrier-to-noise density ratio and carrier-to-diffuse multipath ratio. The delta and zero-crossing encoding units proved to be very reliable and yielded exceptionally good intelligibility scores. The aircraft antenna system included a nine-element linear phased array mounted on the top centerline of the aircraft and two cavity-backed slot dipole antennas mounted on the shoulders of the aircraft. A significant improvement over previous testing was the incorporation of an automatic beam steering unit which worked in conjunction with an onboard inertial navigation system. After some improvements to speed-up the updating algorithm, this unit functioned perfectly, providing a medium gain, highly reliable antenna system.

1. INTRODUCTION

In the first year after the launch of the ATS-6 satellite, Canada, in collaboration with the National Aeronautics and Space Administration, the U.S. Federal Aviation Administration and the European Space Agency conducted an extensive set of experiments designed to evaluate, in an operational environment, the performance of a linear phased-array aircraft antenna, and four voice modulation techniques which had been proposed for the AEROSAT system. Following an analysis of the data acquired during these tests[1], an evaluation was made of what further data would be required. As a result, a limited number of tests were planned and performed with the ATS-6 satellite in January 1976.

This report presents the results of these tests, and indicates how they complement the results of the 1975 tests.

2. TEST OBJECTIVES

2.1 VOICE TESTS

The results of the 1975 tests showed conclusively that, of the four voice modulation techniques evaluated, the 16 Kbps Delta and the PZC (zero-crossing) modem* performed the best in terms of percent intelligibility[1]. However, the models of the modems actually tested were prototypes in different stages of development. The Delta codec consisted of a modem, built by SED Systems Limited of Saskatoon, working in conjunction with a lab-built bit-synchronization integrate-and-dump circuit and squaring-loop bit-recovery circuit. The PZC modem was an advanced breadboard which included an agc circuit to correct for deficiencies in the performance of the zero-crossing detector circuit.

During the year following the 1975 tests, an improved commercial model of the Delta modem was produced by SED. In addition, an improved zero-crossing detector had been developed for the PZC modem. The new detector had a sufficiently large dynamic range that the agc circuit could be eliminated, thereby considerably reducing the complexity of the modulator, and greatly increasing the attractiveness of the PZC modem as a low-cost, high-reliability modem for the AEROSAT system.

After reviewing the voice modulation techniques evaluated by other experimenters, it was felt that the two techniques selected were very competitive in terms of performance. However, it was considered important to demonstrate that the changes that had been made to the modems did not degrade their performance. Therefore, one objective of the January 1976 tests was to evaluate the performance of the improved versions of the PZC and delta modems.

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* *In this report, for brevity, the term 'modem' is used to describe the complete channel unit used in the experiments, including coder/decoder and PSK modulator/demodulator.*

2.2 ANTENNA TESTS

A significant result of the 1975 tests was the good performance of the linear phased-array L-band antenna mounted on the aircraft. However, during the 1975 tests, all beam steering was done manually, using a look-up table and a beam selector switch. This is, of course, not suitable for an operational antenna, and so an automatic beam-steering unit was developed by Canadian Marconi Company Limited under contract to the Department of Transport. This unit takes, as input, the data from an inertial or doppler navigation system along with the spacecraft sub-latitude, and ensures automatically the proper array element phasing while the aircraft is manoeuvered. A second objective of the January 1976 tests was to evaluate the performance of this beam-steering unit.

3. EXPERIMENTAL CONFIGURATION

Since the ATS-6 satellite was located at 35 degrees east longitude it was not possible to conduct these tests using a ground station location in North America. Several potential sites in Europe were investigated followed by the acceptance of an offer from the European Space Technology Experimental Centre (ESTEC) to establish a ground terminal at their location in Holland.

A 15 foot diameter parabolic antenna was transported to Holland with the assistance of the Canadian Armed Forces. This antenna was used with a 110 watt TWT amplifier during the experiments.

Figure 3-1 is a photograph of the terminal installed at ESTEC. Figure 3-2 contains a block diagram of the transmit facility while a block diagram of the receive facility is presented in Figure 3-3. The six-foot diameter antenna used with the receiver was provided by ESTEC.

The experiments were conducted with the aircraft in three different regions. The first test area was at 48°N latitude, 10°W longitude where the spacecraft elevation angle was 18 degrees. For these tests the aircraft flew out of Shannon, Ireland. The second test area was at 62°N latitude, 10°W longitude where the elevation angle was 10 degrees. Prestwick was used as the aircraft base for these flights. Reykjavik, Iceland, was used as a base for flights in the areas of 67°N latitude, 15°W longitude (satellite elevation of 5 degrees) and 68°N latitude, 27°W longitude (satellite elevation angle of 0 degrees). These test locations relative to the ground terminal location at ESTEC are shown in Figure 3-4.

For the tests out of Shannon the fan beam of ATS-6 was used, but in order to have increased power, the spot beam antenna was used during the low-elevation-angle tests.

The test equipment carried in the aircraft was designed to receive the signals from the satellite, process these signals in various ways, and record relevant parameters so as to facilitate subsequent detailed analysis on the ground. The equipment used in the previous flight trials was described in the report on that experiment[1]. However, for the experiments to be described here, certain additions were made. A block diagram of the equipment as used during the flight trials of January 1976 is shown in Figure 3-5.

Automatic selection of the phased-array beam requires knowledge of aircraft position, heading and pitch, and also sub-satellite longitude. The aircraft parameters were obtained from the inertial navigation system for the antenna digital processor unit. Provision for two sub-satellite longitudes was allowed for and these were entered manually into the satellite selector unit. The antenna drive unit controlled the phase of the signal supplied to the radiating array elements such that the beam calculated by the digital processor was produced. The antenna control unit permitted either automatic or manual selection of beams as well as self-testing of the digital processor and the phase shifters.

To permit recording on magnetic tape the number of the selected beam, a unique analogue voltage is produced for each beam number. Different voltage polarities are used for manual and automatic beam selection. Thus, during the subsequent data analysis, both beam number and mode of selection could be determined.

A major addition to the airborne equipment for the 1976 experiments was the inclusion of a 50 watt L-band transmitter to permit direct voice communications between the aircraft and the ground station. The airborne upconverter is shown schematically in Figure 3-6. As no diplexer was available, a remotely activated switch was used to disconnect the receiver and connect the transmitter as required.

A diagram showing the equipment rack layout is shown in Figure 3-7.

4. TEST RESULTS

The series of tests was, unfortunately, marred by a wide range of equipment difficulties, the most notable being intermittent failures of the tape recorder and receiver. As a result, 50 percent of the potentially available data was invalid, or in some cases, was not recorded at all. This equipment problem severely affected our ability to meet the test objectives.

4.1 VOICE TEST RESULTS

Primarily due to the intermittent failure of the tape recorder, only six voice tests were successfully completed. All of the tests used the MRT intelligibility test, which is described in[1]. The data acquired during these tests are summarized in Table 4-1.

Figures 4-1 through 4-3 show the data from Table 4-1 for the modems along with a curve representing the average for all tests conducted in 1975.

4.2 CONCLUSIONS FOR VOICE TESTS

In comparing the 1976 results with the 1975 results, two factors should be kept in mind:

(a) The curve shown for the 1975 tests is an average of many data points (see [1]);

(b) The experimental carrier-to-noise density ratio has a possible error of ± 0.5 dB.

Keeping these points in mind, it appears that there is no evidence in Figures 4-1 and 4-2 that the changes made to the Delta and PZC modems caused any significant change in their performance. The results for the FM modem were intended to act as a reference to the 1975 tests. Since only one data point was acquired, it is not particularly significant although it is reassuring that the result lies within the experimental error of the 1975 test result.

TABLE 4-1

Summary of Voice Test Results

Modem	Date	Elevation (°)	C/N_0	Mean Int (%)	σ	95%
Delta	20/1/76	18	46	90.0	2.3	1.7
		18	43	85.3	2.7	2.0
	27/1/76	05	43	88.8	2.3	1.6
		05	41	79.4	2.9	2.0
PZC	15/1/76	18	40	79.2	5.1	3.6
FM	21/1/76	10	49	91.1	2.2	1.5

5. ANTENNA GAIN RESULTS

Due to failures in the Aircraft Attitude Position Indicator Multiplexer (AAPIM) and in the receiver a.g.c. circuits during the flight trials, data recorded on magnetic tape could not be processed to obtain antenna gains.

Fortunately, strip-chart recordings were made during all flights of analogue a.g.c. voltage and aircraft heading. The information on the strip charts was subsequently digitized and recorded on cassettes using an H.P. 9830A calculator equipped with a digitizer table. The program used to analyze the data from the previous trials was modified for use with the digitized data. Unlike the analysis of data recorded on magnetic tape, the accuracy of the results obtained from strip-chart records depends to a large extent on the care taken during the manual digitizing process.

Samples of a.g.c. and aircraft heading voltage were taken at each three-second mark on the chart. For chart records made during level flight on headings incremented 10° at 1.5 minute intervals, approximately 25 valid samples per heading were obtained. These data, along with an estimate of the aircraft longitude, latitude, pitch and roll permitted a good estimate of the antenna gain to be made by the analysis programme. During level flights at constant heading, the roll is equal to 0°, and the other parameters can be accurately estimated. During bank turns the aircraft positional parameters change rapidly, making estimation difficult. In addition, sample density is low during bank turns. For these reasons, data acquired during such turns were not used.

TABLE 5-1

Geographical Locations for Antenna Gain Measurements

Date	Initial Aircraft Position
20 January 1976	48°N 10°W
23 January 1976	68°N 27°W
27 January 1976	67°N 15°W

Plots of mean gain and standard deviation, as a function of azimuth and elevation angle, are shown for the phased array in Figures 5-1 to 5-3 and for the slot dipole in Figures 5-4 to 5-6.

The gain values for the phased array are shown on a polar azimuth-elevation plot in Figure 5-7. The gain of the slot dipole is similarly displayed in Figure 5-8.

5.1 ANTENNA BEAM-SELECTION RESULTS

The performance of the automatic beam-selection mechanism of the phased array was monitored throughout the antenna experiments. Unfortunately, due to problems with the AAPIM, beam numbers recorded could not be related to aircraft position. Nevertheless, it was observed during some tight turns that loss of signal did occur momentarily, indicating that antenna beams were not being switched fast enough to keep up with the aircraft's rapidly changing attitude with respect to the satellite.

Analysis has shown that this lag was caused by a switching time delay circuit which had been included in the driver box for use with the manual switching controller. Following the test flights, modifications were made which provided for the bypassing of this circuit when in the auto-tracking mode. At the same time, the algorithm used for calculating the beam steering parameters was considerably speeded up by making incremental calculations of the steering parameters rather than the full calculation for each update.

On two separate occasions messages were transmitted from the aircraft via ATS-6 to the ground station where they were recorded. One of these messages was a continuous commentary from the aircraft during a landing procedure. No noticeable gaps are present in this message, indicating that voice communications can be maintained during aircraft landing manoeuvres.

The second message that was transmitted was a monitored conversation between the aircraft pilot and an Air Traffic Controller in Iceland. The satellite elevation angle during this conversation was very low (5°), as was the received C/N_0. Consequently, the quality of the recorded voice message is poor, and because the conversation was not continuous, little information could be gained regarding the operation of the antenna beam-selection process.

5.2 CONCLUSIONS FOR ANTENNA TESTS

Examination of Figures 5-1, 5-2 and 5-3 show the very good agreement between the values of gain measured on the aircraft with those measured by the manufacturer in an anechoice chamber. Figure 5-1 shows higher gain than expected at forward end-fire for 15° elevation. High gain in this direction was also measured in previous experiments.

As a result of the manner in which this gain data was retrieved from chart recordings, no information on maximum and minimum gain at each heading was obtained. However, examination of the standard deviation of the gain gives an indication of the amount of multipath interference present. For instance, from Figure 5-2, the gain between 0 and 5 degrees elevation has large values of standard deviation, indicating the presence of considerable multipath interference.

The polar plot, which depicts gain of the phased-array versus azimuth and elevation, shows some evidence of asymmetry between the 45° - 225° plane and the 135° - 315° plane. This asymmetry was also evident in previous results.

The gain values measured for the slot-dipole are much as expected and tie in quite well with those values previously measured. Low values of gain with correspondingly high values of standard deviation are apparent in the forward and aft directions, where there is poor coverage with the two-slot-dipole antenna system.

Figures 5-9 and 5-10 show an overall measured gain plot for the phased-array and slot-dipole antenna systems. These plots represent the results of both the 1975 and the 1976 tests.

The results of the phased-array automatic beam-steering system evaluation are not conclusive. From observations, it appeared that the beam-selection lagged behind the aircraft position during rapid manoeuvres. However, voice tapes indicated that continuous communication between aircraft and ground was possible during take-off and landing manoeuvres. Further evaluation of the beam-steering system will be required before firm conclusions may be drawn.

6. CONCLUSIONS

As a result of the many equipment failures, much of the originally planned experiment was not successfully carried out. However, from the results obtained the following important conclusions can be made:

1) The changes made to the voice modems after the 1975 tests had no significant effect on the intelligibility score;

2) Considerably more gain data were obtained for the phased-array and the slot-dipole antenna system;

3) While the automatic beam-steering unit for the phased-array antenna generally worked well, it was observed to lag slightly during rapid manoeuvres. It is recommended that the updating algorithm be speeded-up.

7. ACKNOWLEDGEMENTS

In an experiment of this nature, the success of the project is critically dependent upon the support of many agencies and personnel. In this case, we would like to express out appreciation to the National Aeronautics and Space Administration for making available to us their facilities, and to the personnel of the European Space Agency at ESTEC who gave freely their time and expertise.

This program was carried out jointly by the Aeronautical Satellite Studies Program of the Communications Research Centre, Department of Communications and the TACD branch of the Department of Transport. The efforts and support of all involved personnel of these groups is greatly appreciated. Special thanks are also due to the staff of Flight Services Division, Department of Transport, for their co-operation and help in implementing the flight trials.

8. REFERENCES

1. Chinnick, J. and D. Burtt. *Canadian Aeronautical Satellite Tests Using the ATS-6 Satellite, 1974-1975*. Communications Research Centre Report No. 1308, February 1978.

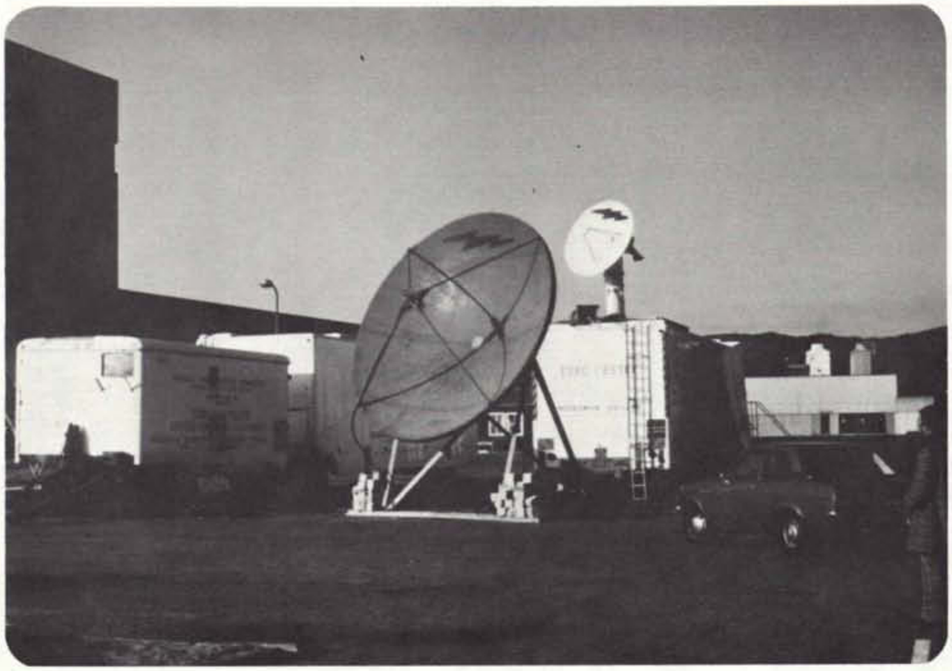

Figure 3-1. Photograph of Ground Terminal at ESTEC

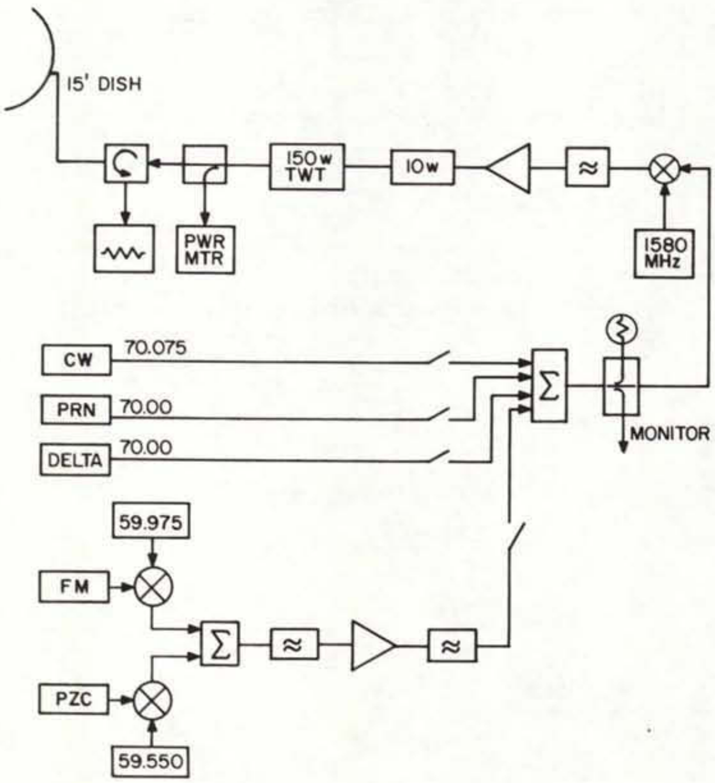

Figure 3-2. Block Diagram of Transmit Equipment Configuration at ESTEC

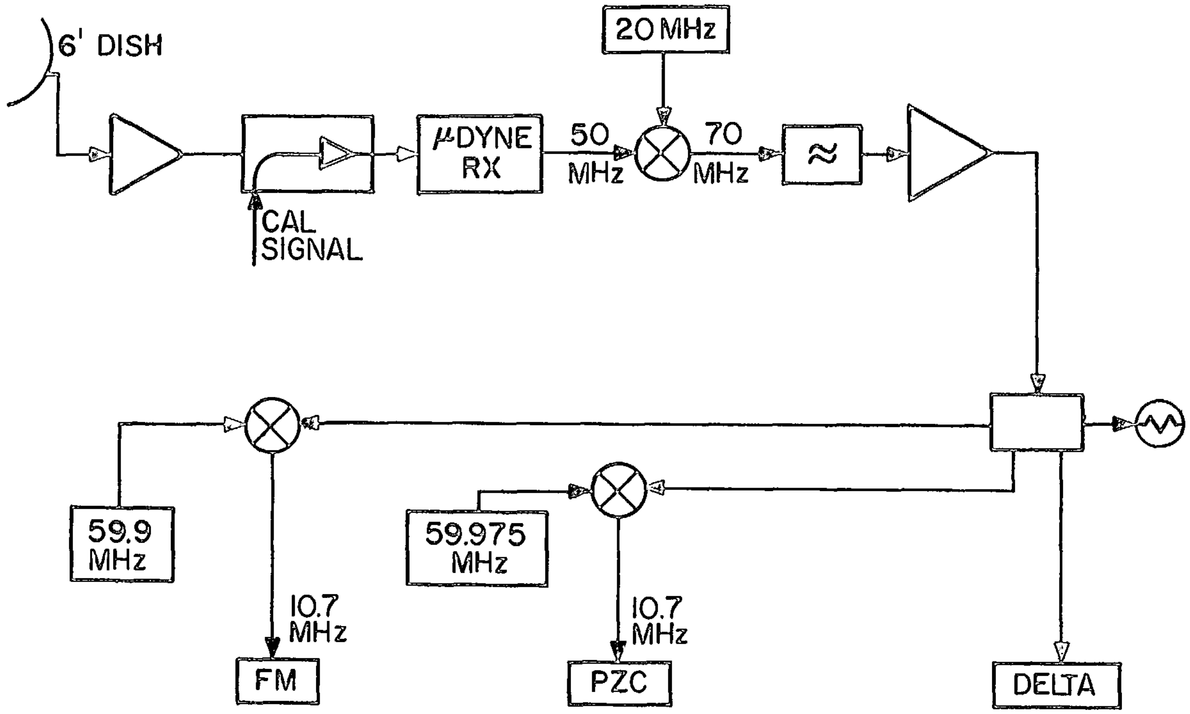

Figure 3-3. Block Diagram of Receive Equipment at ESTEC

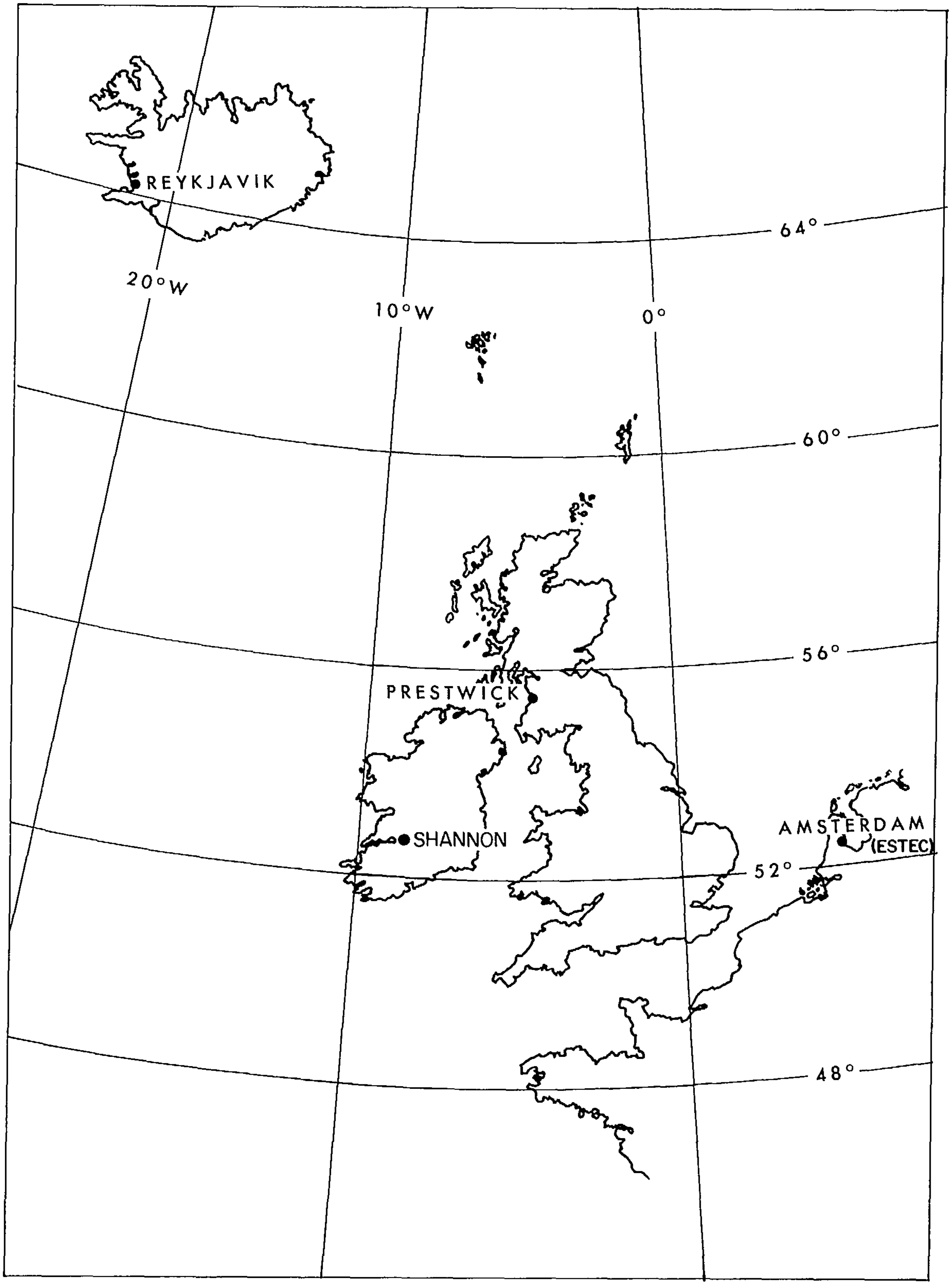

Figure 3-4. Test Locations Relative to ESTEC Ground Terminal

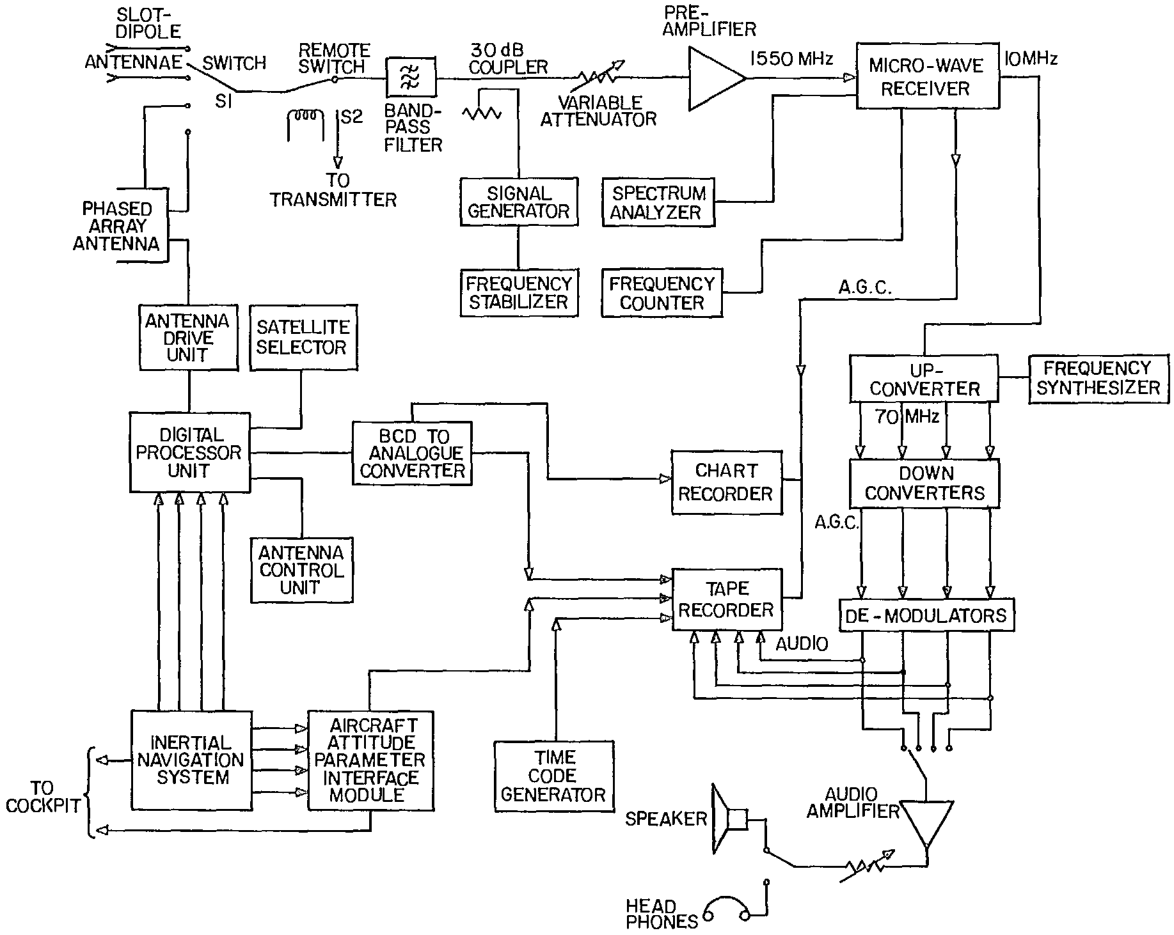

Figure 3-5. Block Diagram of Down-Converting and Recording Equipment on the Aircraft

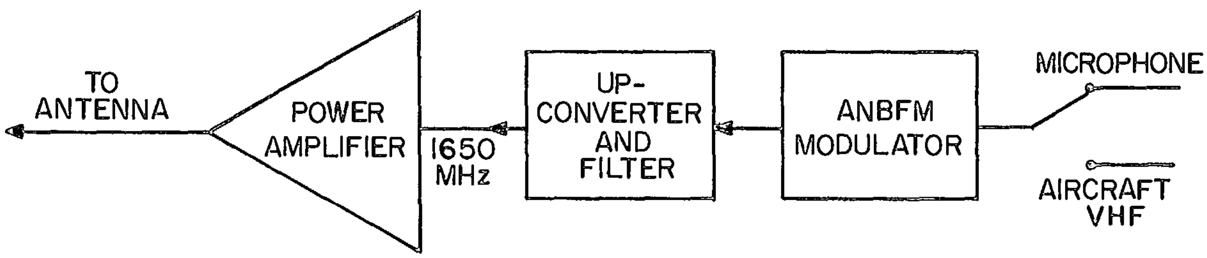

Figure 3-6. Block Diagram of Airborne Upconverter

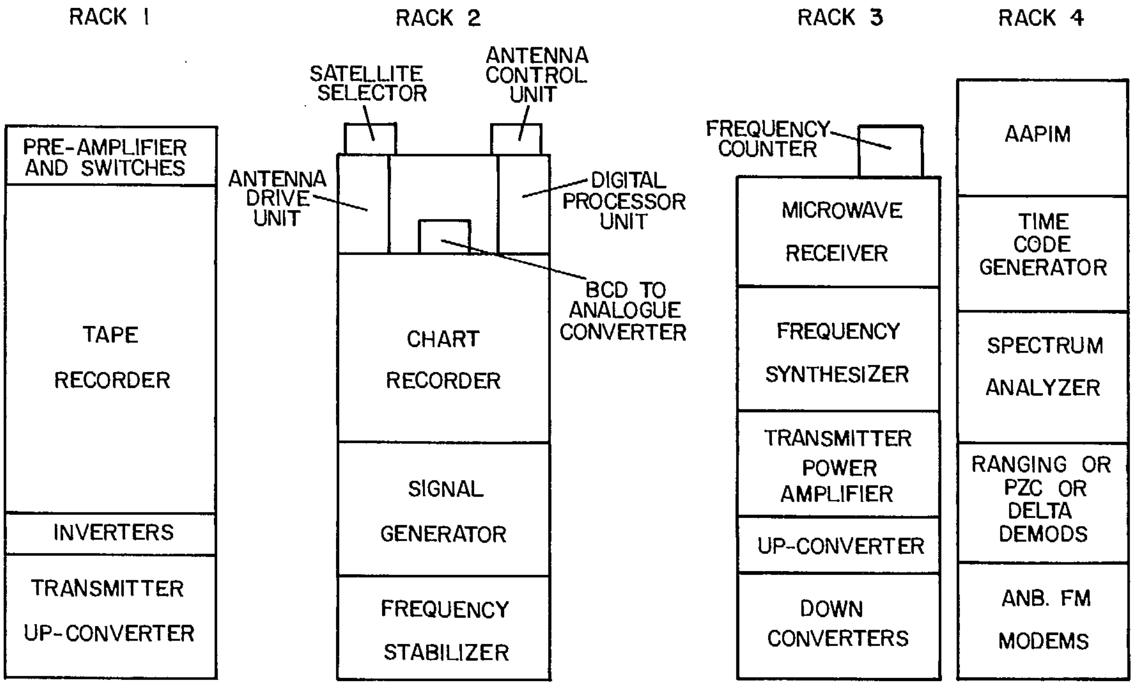

Figure 3-7. Rack Layout of Airborne Equipment

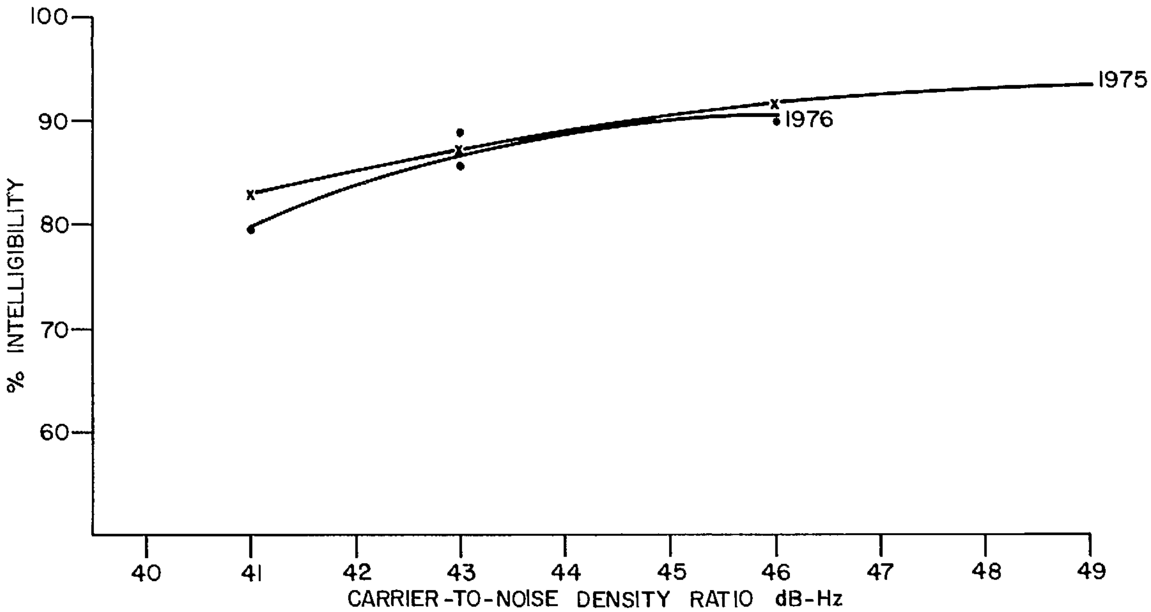

Figure 4-1. Comparison of 1975 and 1976 Voice Data Acquired using Delta Modem

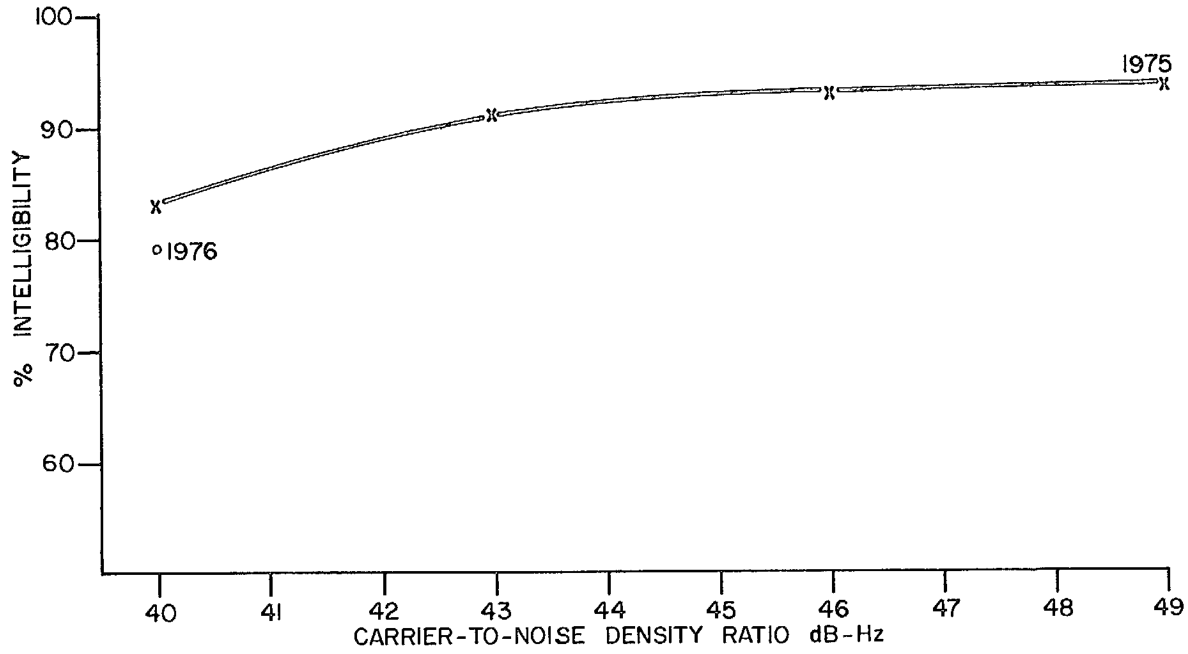

Figure 4-2. Comparison of 1975 and 1976 Voice Data Acquired using PZC Modem

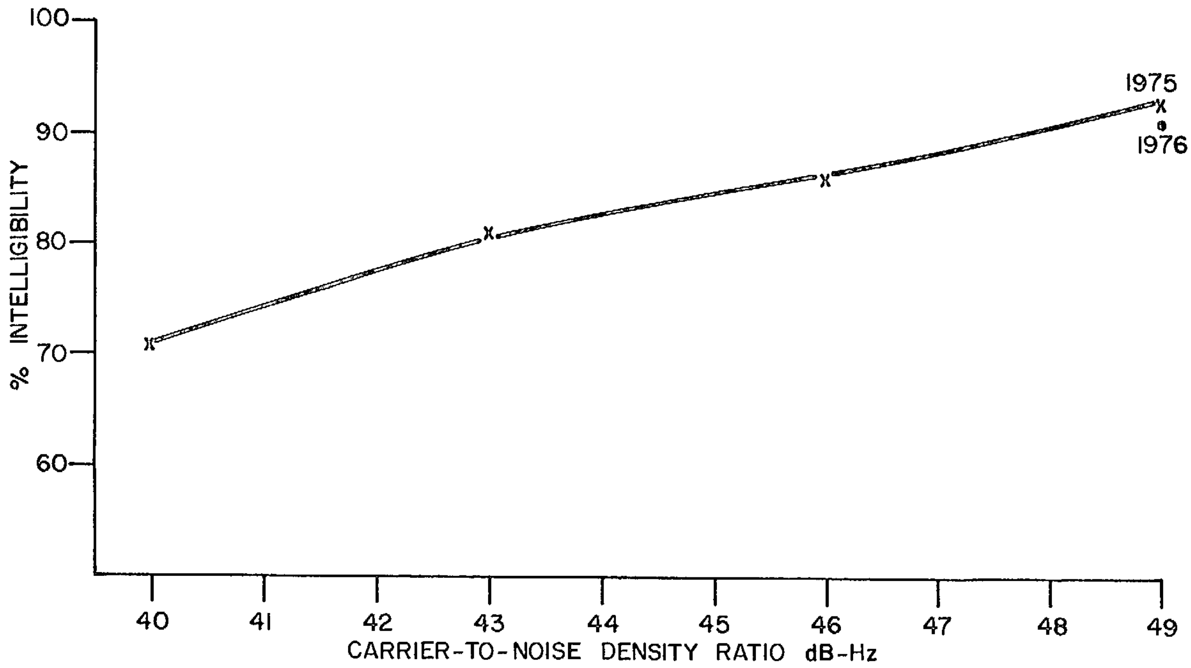

Figure 4-3. Comparison of 1975 and 1976 Voice Data Acquired using ANBFM Modem

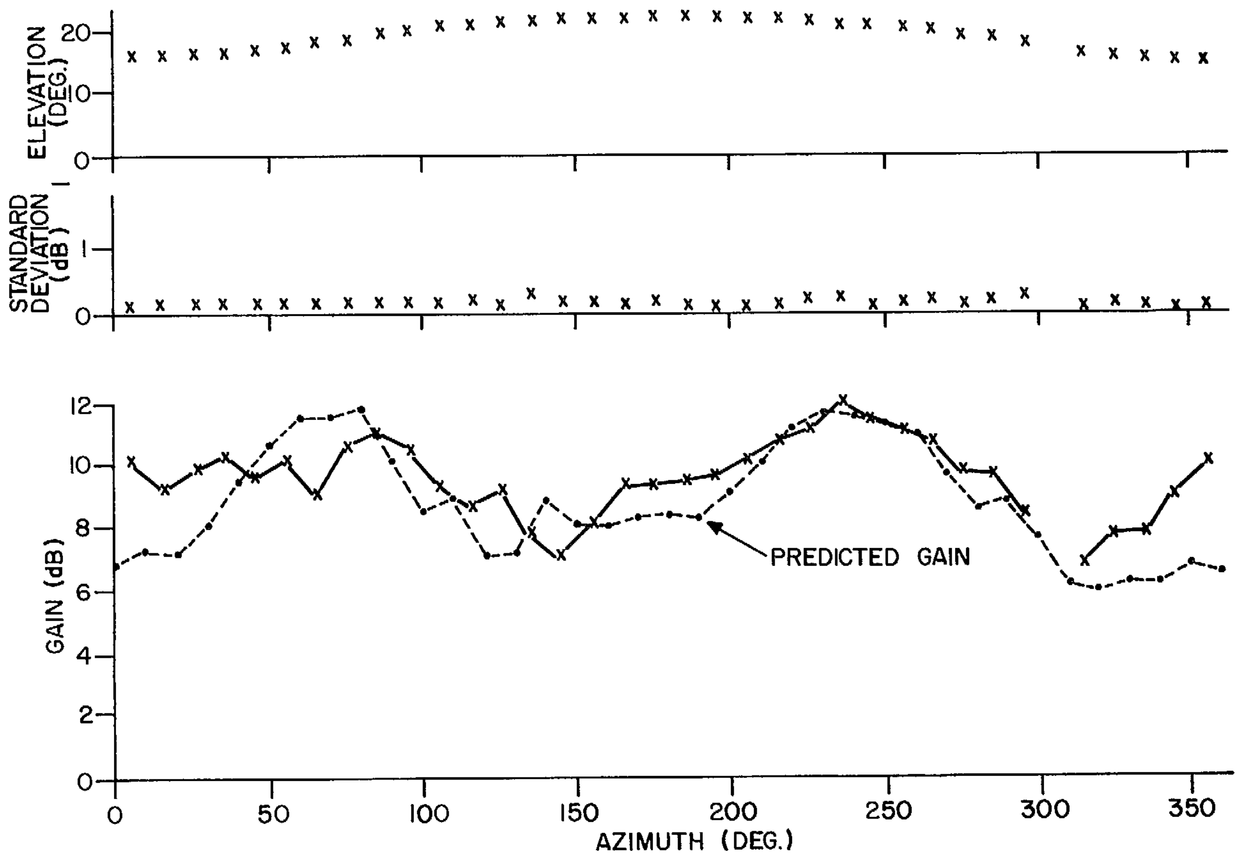

Figure 5-1. Phased-Array Antenna Data for 20 January 1976

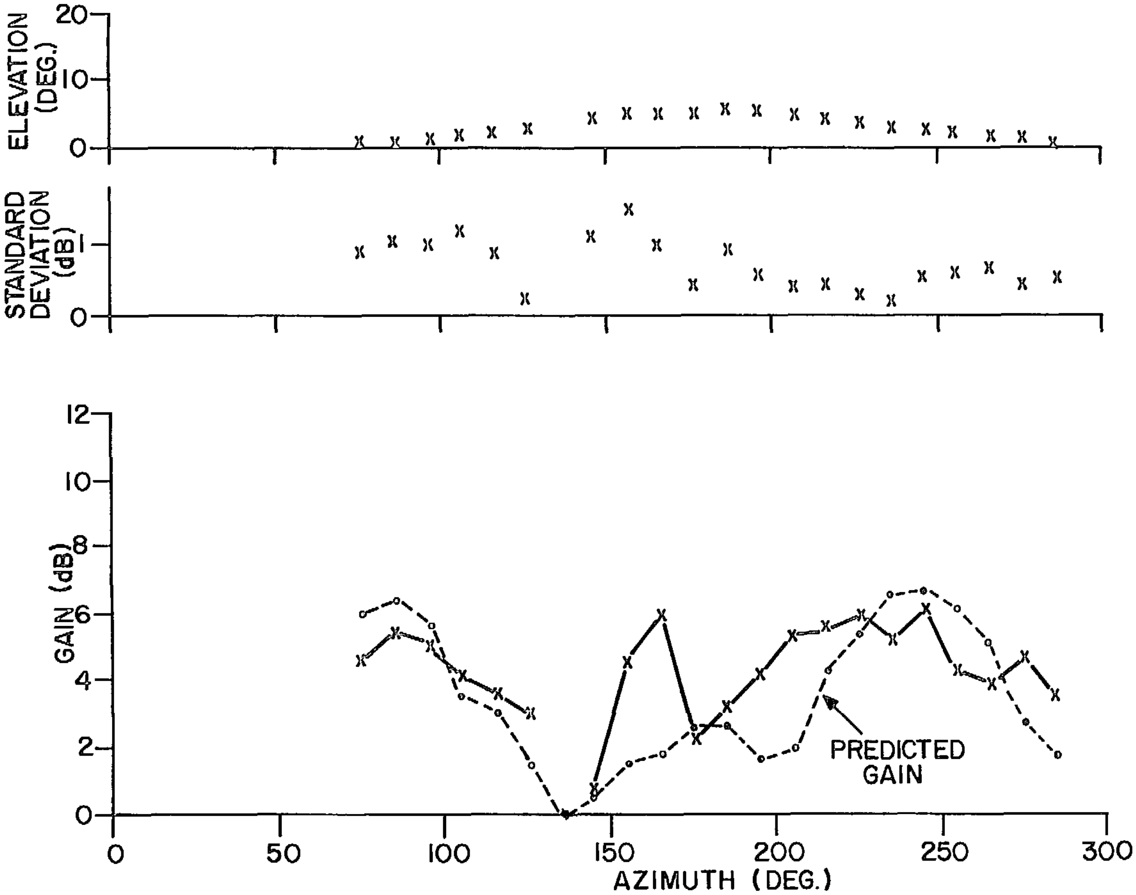

Figure 5-2. Phased-Array Antenna Data for 23 January 1976

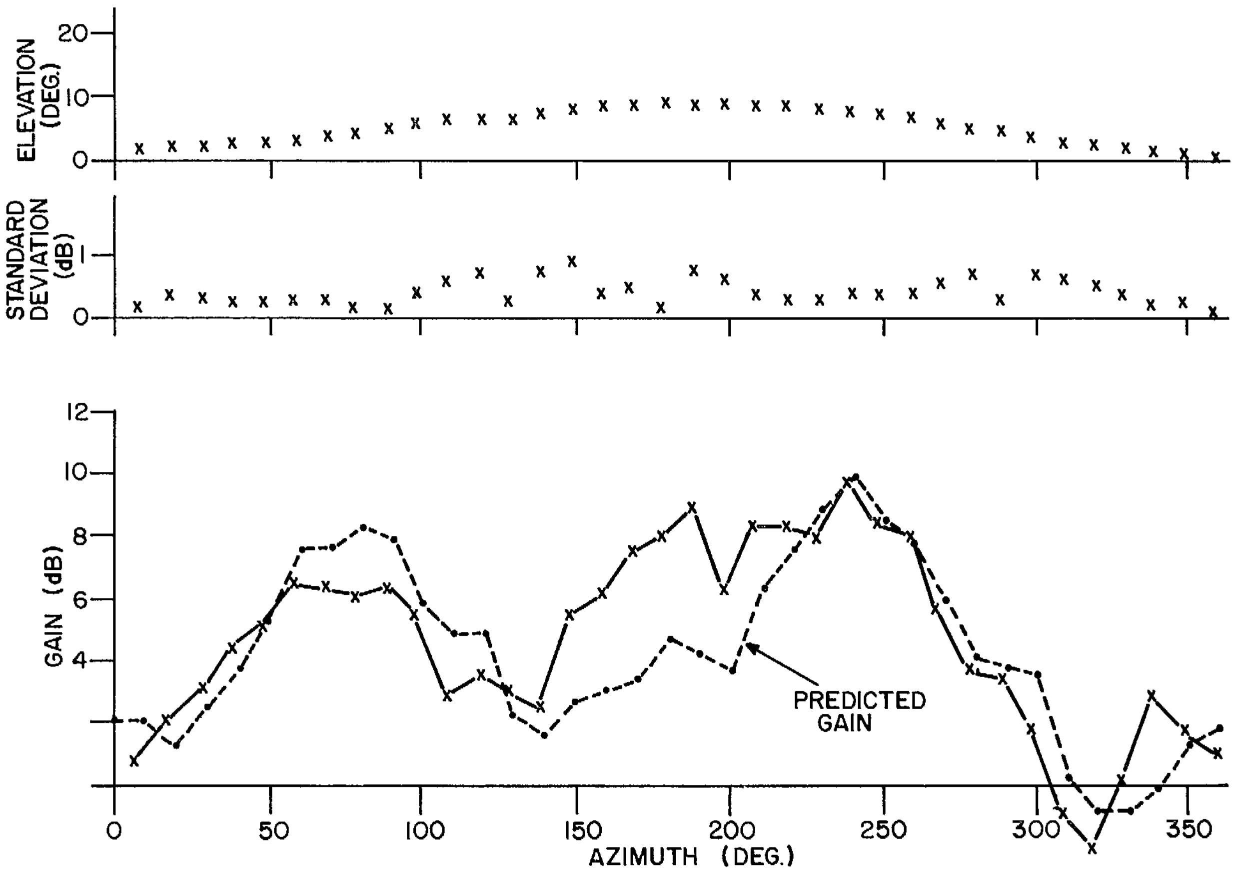

Figure 5-3. Phased-Array Antenna Data for 27 January 1976

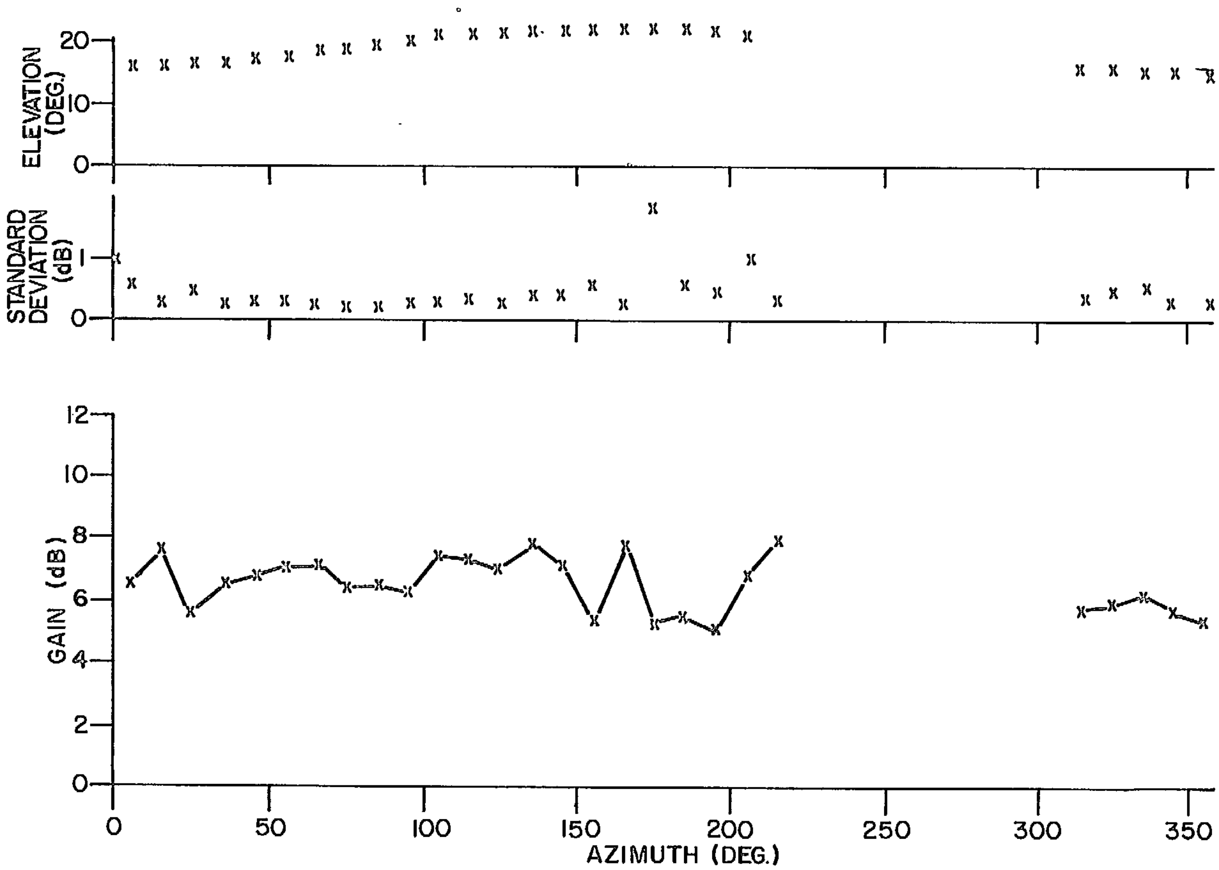

Figure 5-4. Slot-Dipole Antenna Data for 20 January 1976

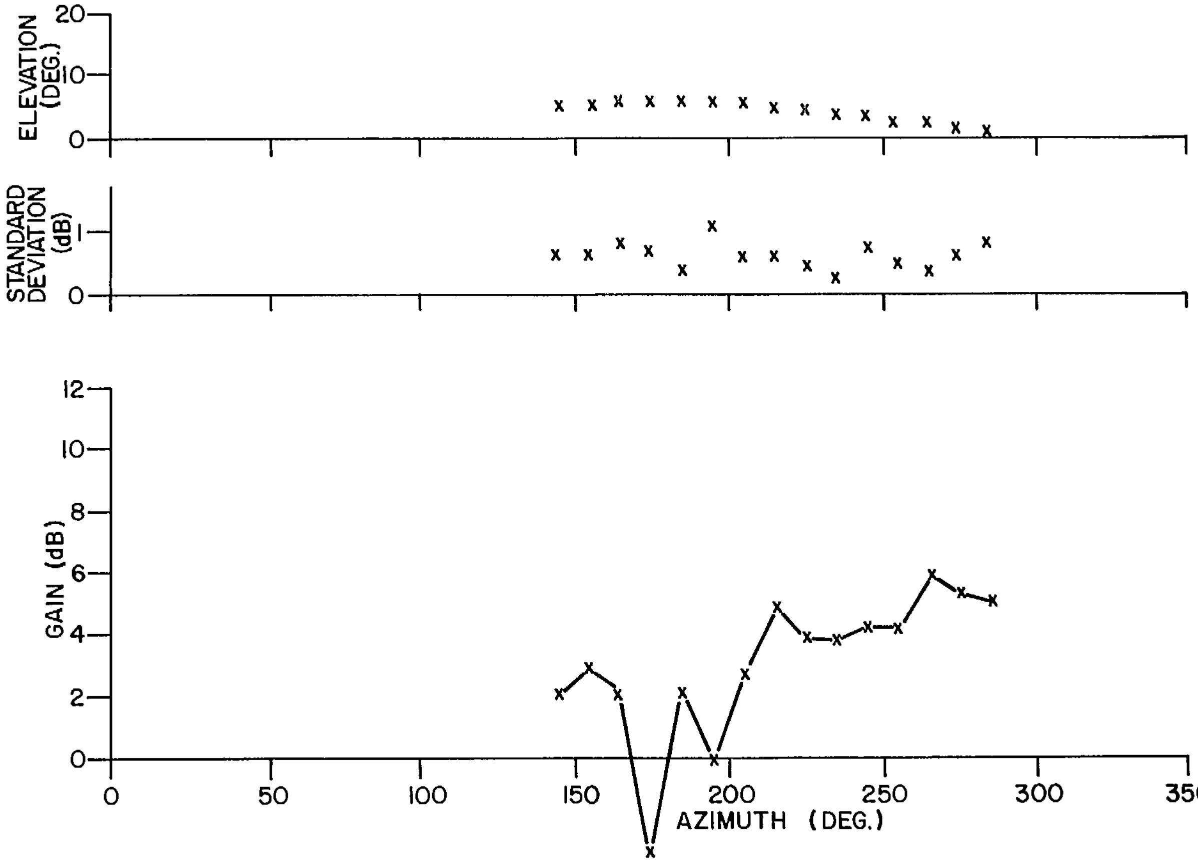

Figure 5-5. Slot-Dipole Antenna Data for 23 January 1976

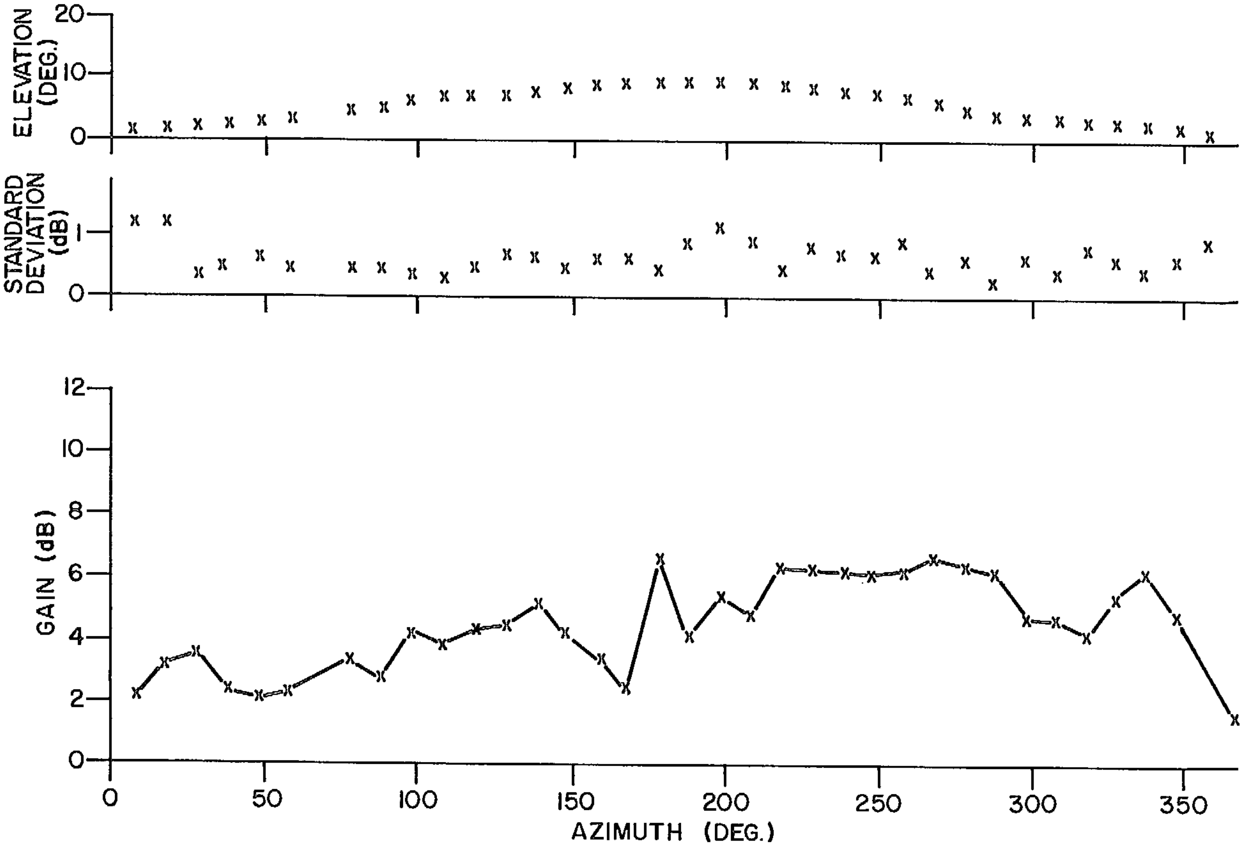

Figure 5-6. Slot-Dipole Antenna Data for 27 January 1976

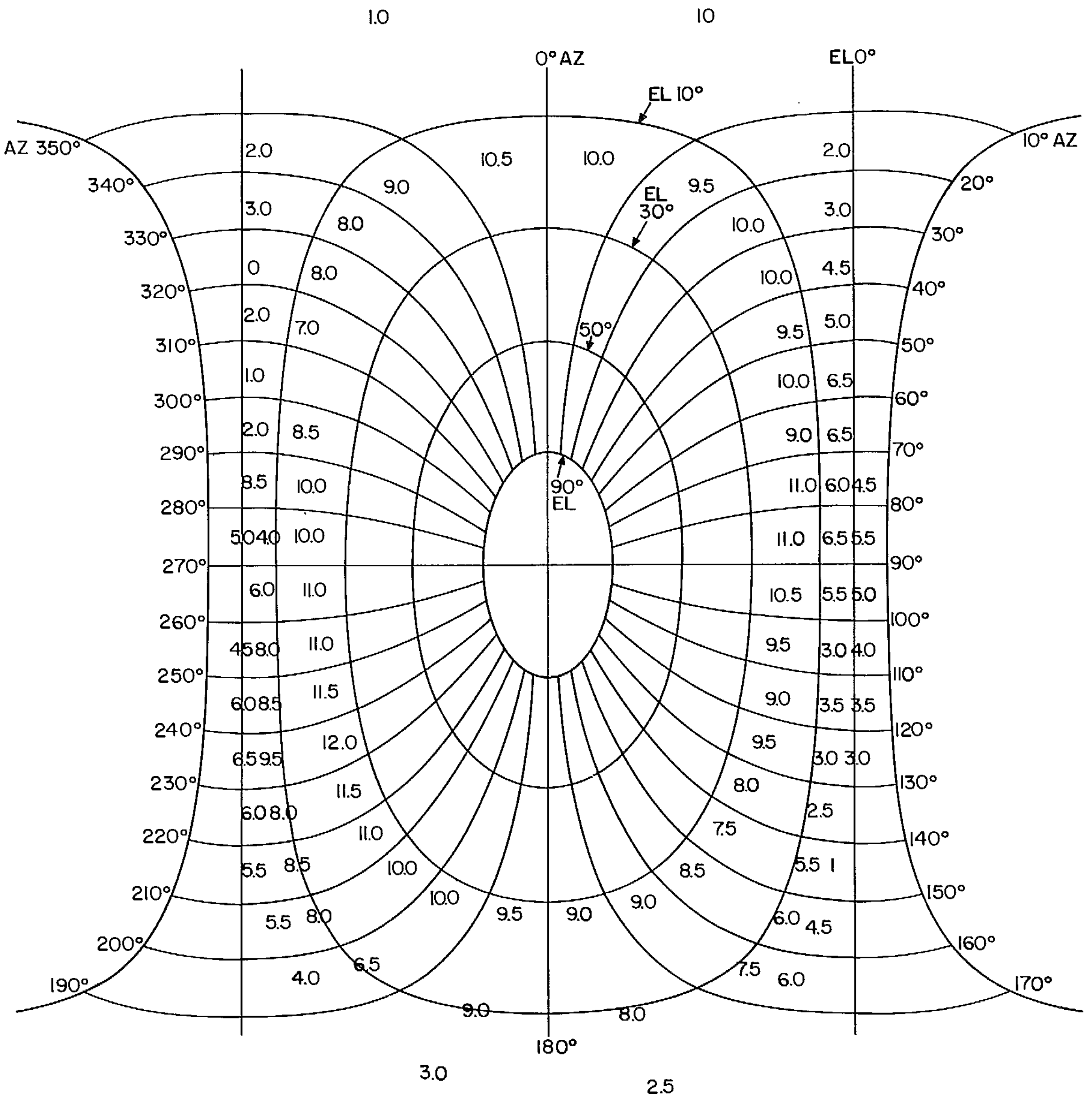

Figure 5-7. Azimuth vs Elevation Plot of Mean Measured Phased Array Gain for 1976 Trials

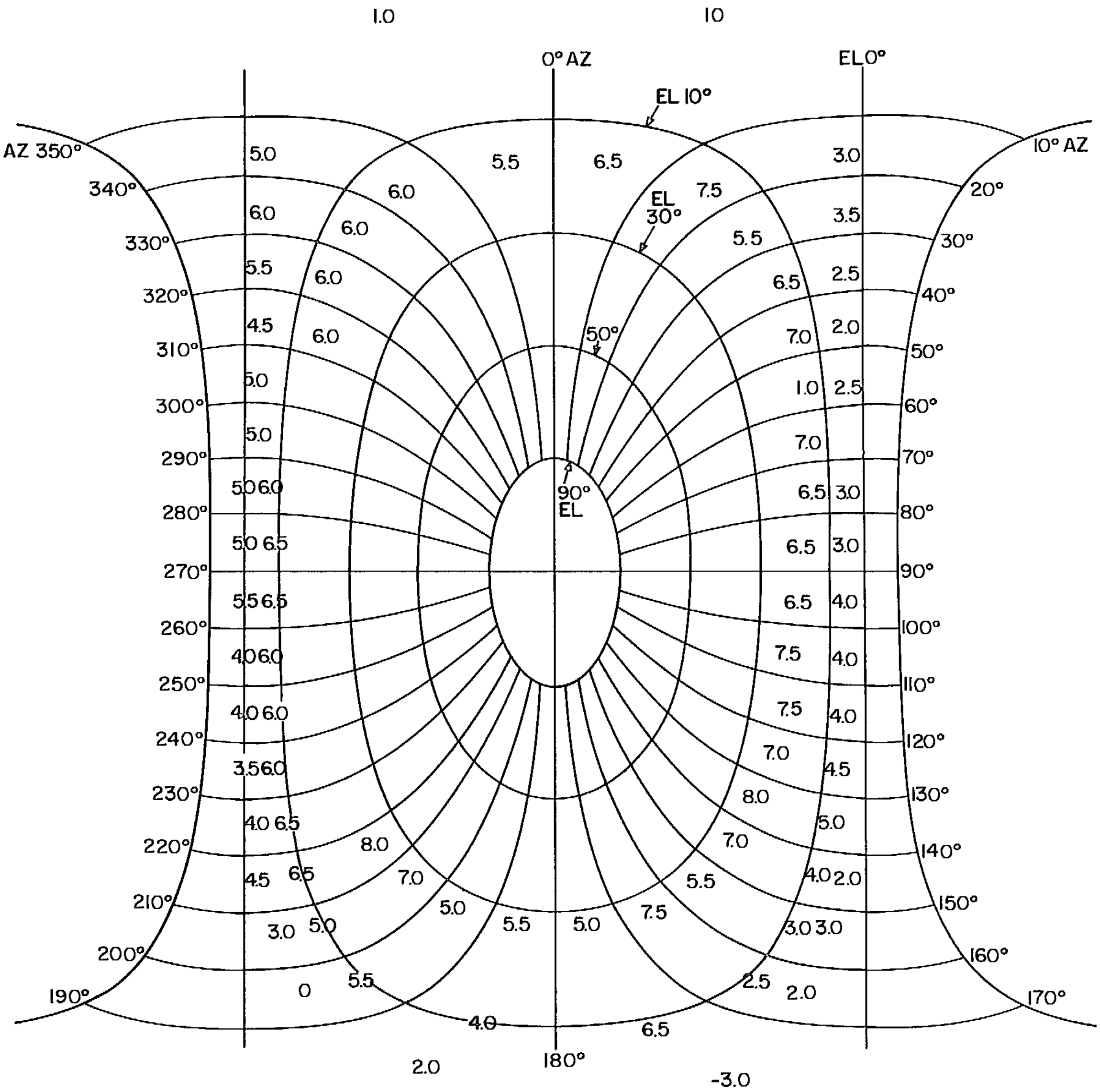

Figure 5-8. Azimuth vs Elevation Plot of Mean Measured Slot-Dipole Gain for 1976 Trials

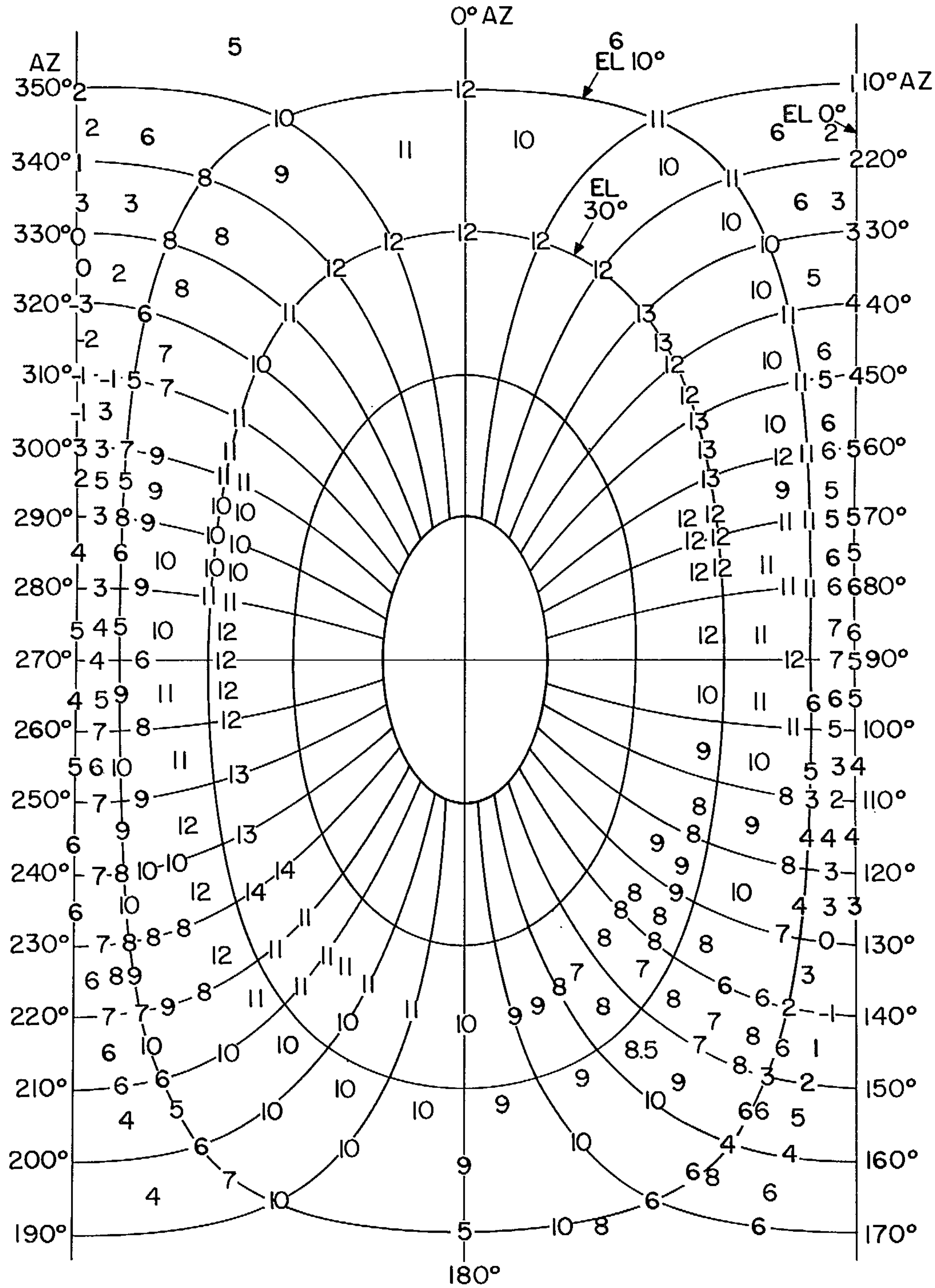

Figure 5-9. Summary of Measured Gain Results for Phased Array Antenna from 1975 and 1976 Tests

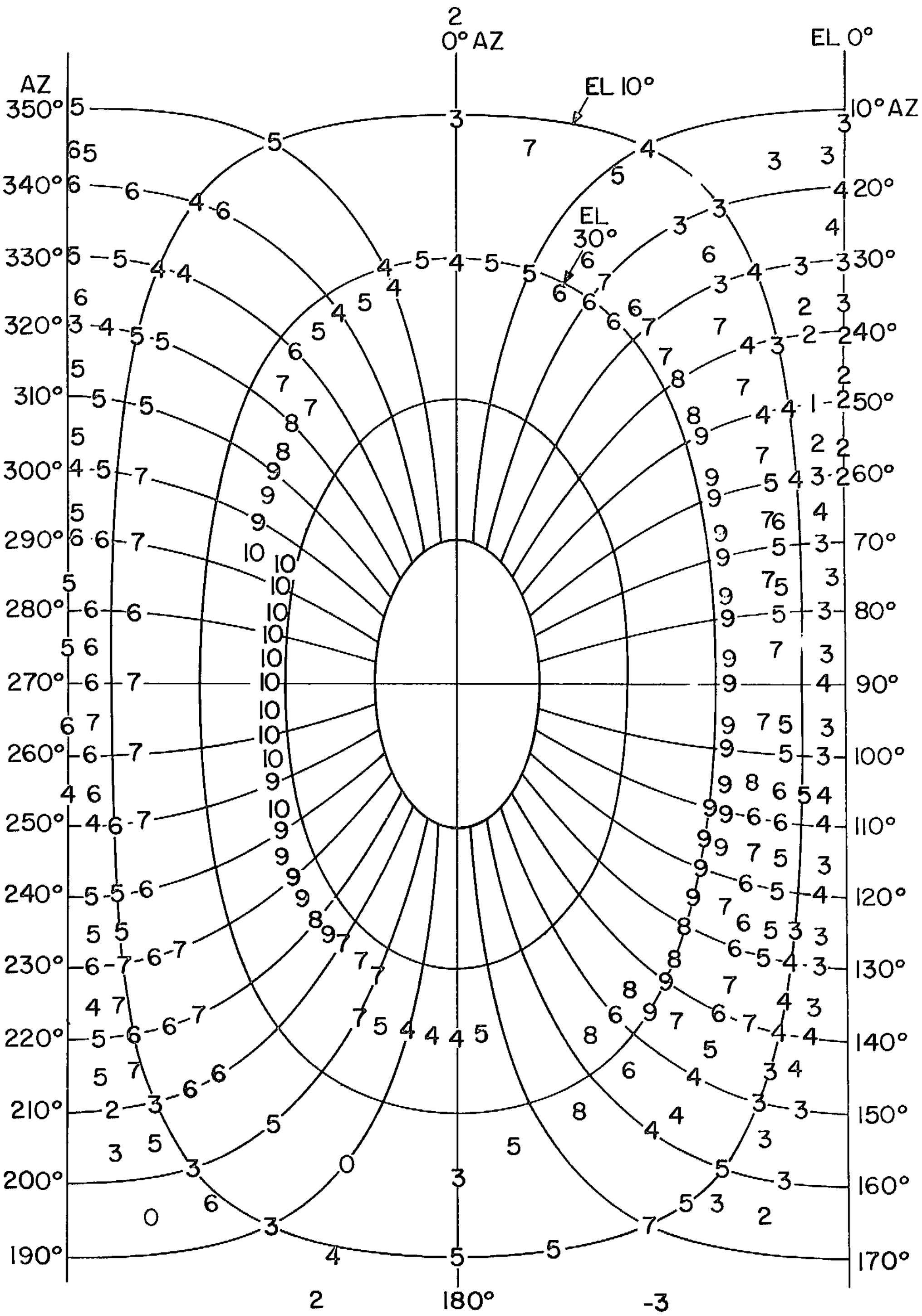

Figure 5-10. Summary of Measured Gain Results for Slot-Dipole Antennae from 1975 and 1976 Tests

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8. **ABSTRACT:** A series of tests were conducted to complement those tests conducted in the previous year, using the ATS-6 satellite to compare the performance of several voice modulation techniques and two antenna systems installed in an airborne terminal. For these tests, improved versions of a voice modulation technique based on a delta encoding/PSK modulation and a technique based upon the transmission of the PSK modulated zero-crossing transitions of the audio signal were tested against a reference narrowband frequency modulation system under varying conditions of carrier-to-noise density ratio and carrier-to-diffuse multipath radio. The delta and zero-crossing encoding units proved to be very reliable and yielded exceptionally good intelligibility scores. The aircraft antenna system included a nine-element linear phased array mounted on the top center-line of the aircraft and two cavity-backed slot dipole antennas mounted on the shoulders of the aircraft. A significant improvement over previous testing was the incorporation of an automatic beam steering unit which worked in conjunction with an on-board inertial navigation system. After some improvements to speed-up the updating algorithm, this unit functioned perfectly, providing a medium gain, highly reliable antenna system.

9. **CITATION:**

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