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Final Technical Report
March 1972

Prepared By
Rome Air Development Center
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Griffiss Air Force Base, New York 13440

PROJECT SECEDE

RF BEACON GROUND STATIONS DISPERSIVE-PHASE/DIFFERENTIAL DOPPLER MEASUREMENT SYSTEM

Electrac, Inc.
Anaheim, California

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13. ABSTRACT

In support of the SECEDE II barium release RF Beacon Test Series, Electrac, Inc., designed, fabricated, installed and operated on site, four Dispersive-Phase/Differential Doppler Measurement Systems. The experiment's primary purpose was to further the diagnostic objective of obtaining descriptive information about the barium ions produced in the test series. The cloud parameter to be measured was the integrated electron density along a line-of-sight as a function of the line's cloud penetration position. Of prime interest were integrated density striations.

This report describes the measurement system, including design criteria and final configuration of the four systems as installed in the field. Three of the four systems were configured to receive the four rocket-borne beacon emissions at 145.7, 291.5, 437.3 and 874 MHz. The fourth system installed with the U.S. Army Ballistic Research Lab system was configured to also receive at 36 MHz. A tape recorder was utilized to record both real time data (amplitude and phase) and raw data. "Quick Look" system status was provided by simultaneous recording of the amplitude and phase data on strip chart recorders. Additional provisions were included for control, display and field calibration of each system.

Typical data is presented to show real time system performance under cloud occultation conditions. All systems were operational and provided the requisite data during each of the scheduled events.

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DIFFERENTIAL DOPPLER MEASUREMENT						
ELECTRON DENSITY MEASUREMENT						
DOPPLER TRACKING						

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RF BEACON GROUND STATIONS
DISPERSIVE-PHASE/DIFFERENTIAL DOPPLER
MEASUREMENT SYSTEM

Raymond W. Honey

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Program Manager: Irwin J. Weber
Project Engineer: Raymond W. Honey
Phone: 714 879-6021

Project Engineer: Vincent J. Coyne
Phone: 315 330-3107

Contract Engineer: Richard Carmen
Phone: 315 330-2478

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PUBLICATION REVIEW

This technical report has been reviewed and is approved.

RADC Project Engineer

Richard W. Carman
RADC Contract Engineer

ABSTRACT

In support of the SECEDE II barium release RF Beacon test series, Electrac, Inc. designed, fabricated and fielded four Dispersive-Phase/Differential Doppler Measurement Systems. The experiment's primary purpose was to further the diagnostic objective of obtaining descriptive information about the barium ions produced in the test series. The cloud parameter to be measured was the integrated electron density along a line of sight as a function of the lines cloud-penetration position. Of prime interest were integrated density striations.

This report describes the measurement system including design criteria and final configuration of the four systems as installed in the field. Three of the four systems were configured to receive the four rocket borne-beacon emissions at 145.7, 291.5, 437.3 and 874 MHz. The fourth system installed with the U. S. Army Ballistic Research Lab system was configured to also receive at 36 MHz. A tape recorder was utilized to record both real time data (amplitude and phase) and raw data. "Quick-Look" system status was provided by simultaneous recording of the amplitude and phase data on strip chart recorders. Additional provisions were included for control, display and field calibration of each system.

Typical data is presented to show real time system performance under cloud occultation conditions. All systems were operational and provided the requisite data during each of the scheduled events.

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1 -- INTRODUCTION

1.1 BACKGROUND

Extensive measurements of high altitude barium releases in the presence of sunlight have given considerable information on the shapes of the neutral and ionized barium clouds as well as their motion in the atmosphere. In early times, both the neutral and ionized clouds have simple shapes and can be explained in terms of diffusion away from the initial core. Sunlight ionizes the neutral barium in a multistep process. Calculation of the rate of ionization of the barium has proved difficult because large barium clouds are optically thick (in the important absorbing lines) to the solar radiation. Thus one cannot calculate the ionization distribution even for the simple shape during the quiescent early times.

The SECEDE II release series was conducted in the northern Gulf Coast of Florida in January of 1971. Six barium releases were made, at heights ranging from 150 through 250 km. Barium mix payloads are 48 kg on five releases and 352 kg on one release. A rocket-beacon was used to transmit through the barium ion plasma to ground sites.

The beacons were aimed to pass behind the barium clouds and nearly transverse to the geomagnetic field lines as seen from the receiving sites.

The well known dispersive-phase technique takes advantage of the dispersive nature of UHF-VHF propogation in an ionized medium to measure the phase-path deflect, or shortening of the phase-path length between a transmitter and receiver. Under several assumptions, the phase-path deflect is accurately proportional to the integrated electron density or electron content, N_t, along the path.

1.2 OBJECTIVE

During the series experiments were conducted to measure integrated electron density along a line of sight as a function of the linear cloud-penetration position, including integrated-density variation in space due to the presence of plasma density striations. This line integral, sometimes referred to as "total electron content", was measured by means of ground observations of signals transmitted from a radio beacon carrier behind the ion cloud on a sounding rocket.

The technique for measuring total electron content involved observing the differential-Doppler shift (dispersive phase) on two coherent CW signals that pass through the plasma. The choice of frequencies depended upon the content anticipated. To cover a wide range of electron densities, the Doppler shift of 146, 292 and 437 MHz was measured with respect to 875 MHz. Phase-path differences and amplitude were measured. Four ground receiving stations were included to increase the probability that the beacon rocket would pass behind the barium cloud as viewed from at least one ground site.

The differential phase measurement is referred to the lower of the two frequencies. Thus, if the frequencies are f and nf, and the phase difference, ϕ_d, is computed (effectively) at f, the error tolerances are specified on the recovered phase shift at f, ϕ_f, where

$$\phi_f = \frac{n^2}{n^2 - 1} \phi_d$$

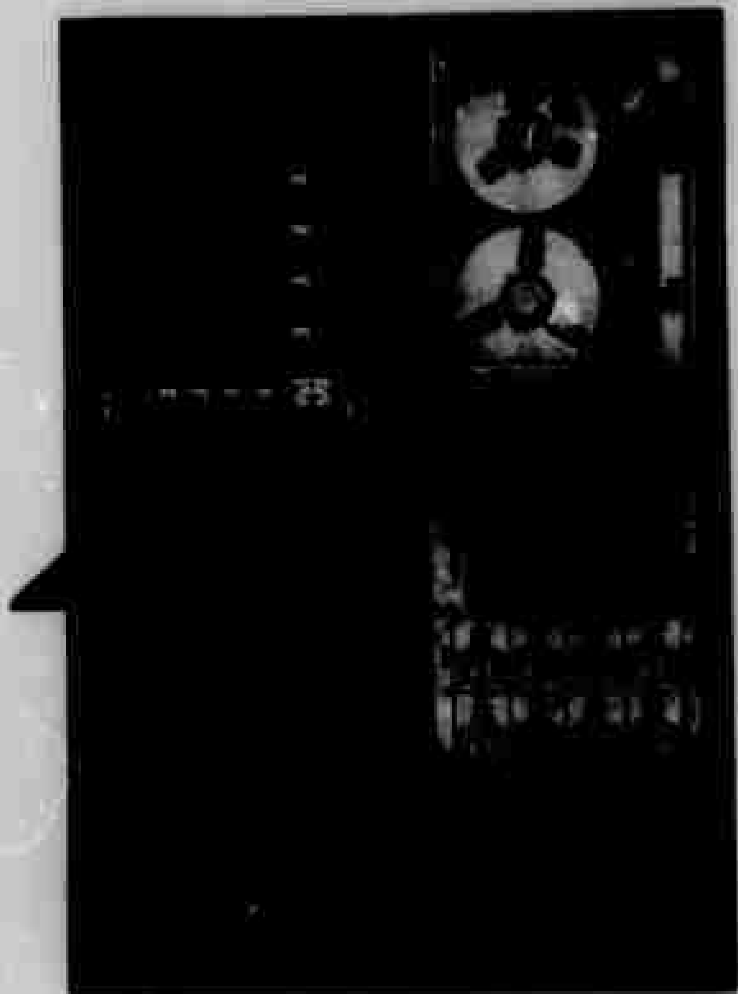
The 874.59 MHz signal is the upper frequency for all the measurement pairs. Amplitude measurements are made at all frequencies.

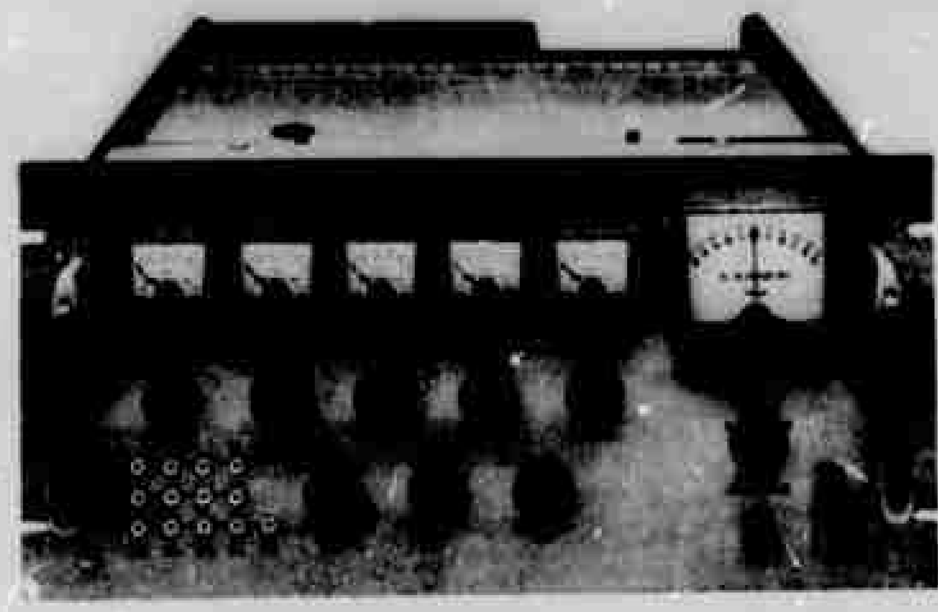
2 -- INSTRUMENTATION

2.1 The Electrac Dispersive-Phase Differential Doppler Measurement System is used for the measurement of signal amplitudes and differential phase of four or five coherent frequencies in the range of 36 to 874 MHz. The system is configured as shown in Figures 2-1 and 2-1a and consists of the equipments listed in paragraph 2.2. The system interfaces with magnetic tape and/or strip chart recorders for display or recording of both real-time and raw output data.

In a typical installation scenario (see Figures 2-2, 2-3, and 2-4), each system is placed approximately 20 km apart parallel to a rocket trajectory. System design criteria includes line-of-sight distance to the launch site of at least 150 km and rocket apogees of 250 to 400 km. Ion clouds (typically a Barium mix) are placed separately at 185 km on the down leg of the trajectory. The rocket path profile is specified as falling 85 km behind the cloud. The rocket borne coherent frequency transmitters are tracked from launch to impact. Typical strip chart data is illustrated in Figure 2-5. For this presentation, the chart has been cut into three segments.

Differential phase measurements are made continuously with the system by comparing the lower received frequencies with the received highest frequency as a reference. To resolve differential phase advance or retardation in a dispersive environment,





DISPERSIVE-PHASE/DIFFERENTIAL DOPPLER MEASUREMENT SYSTEM

Figure 2-1

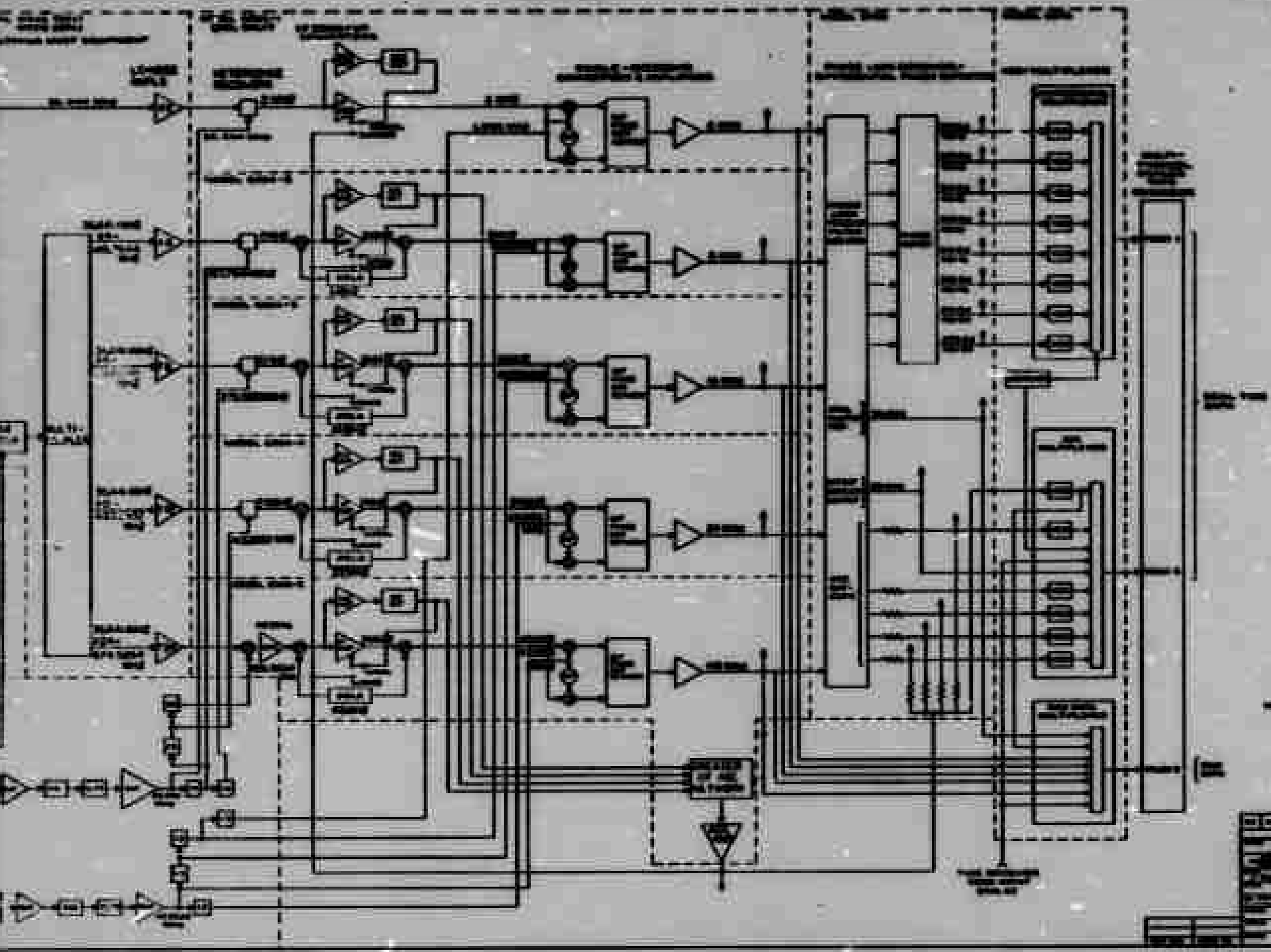
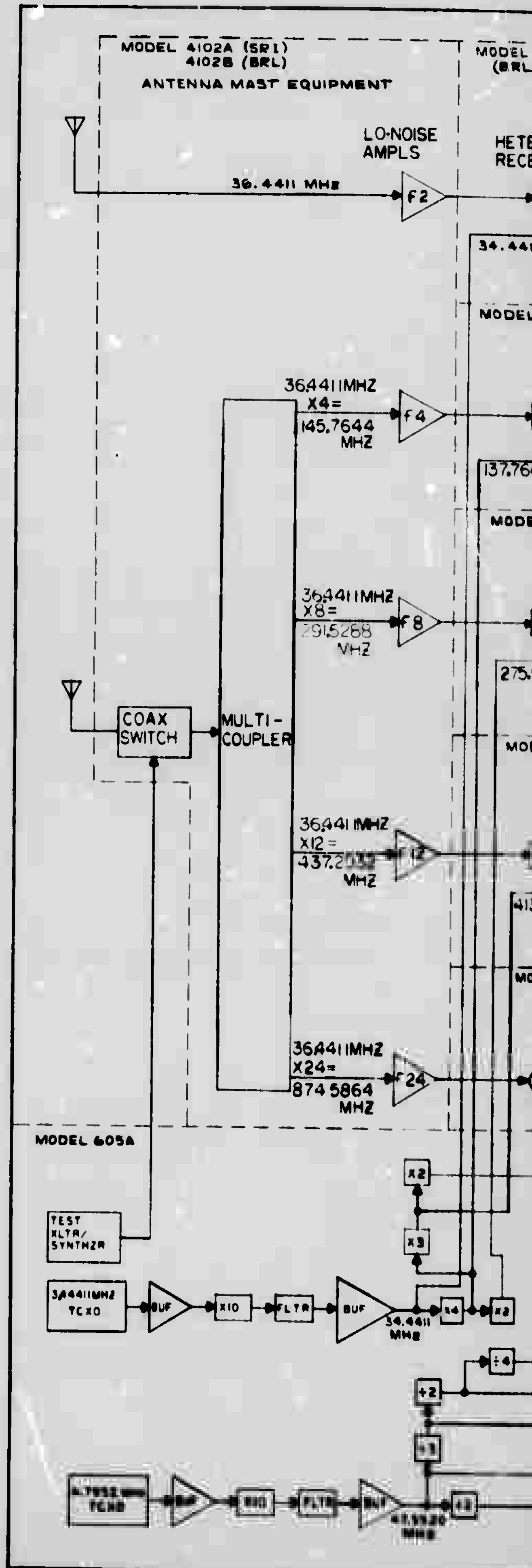
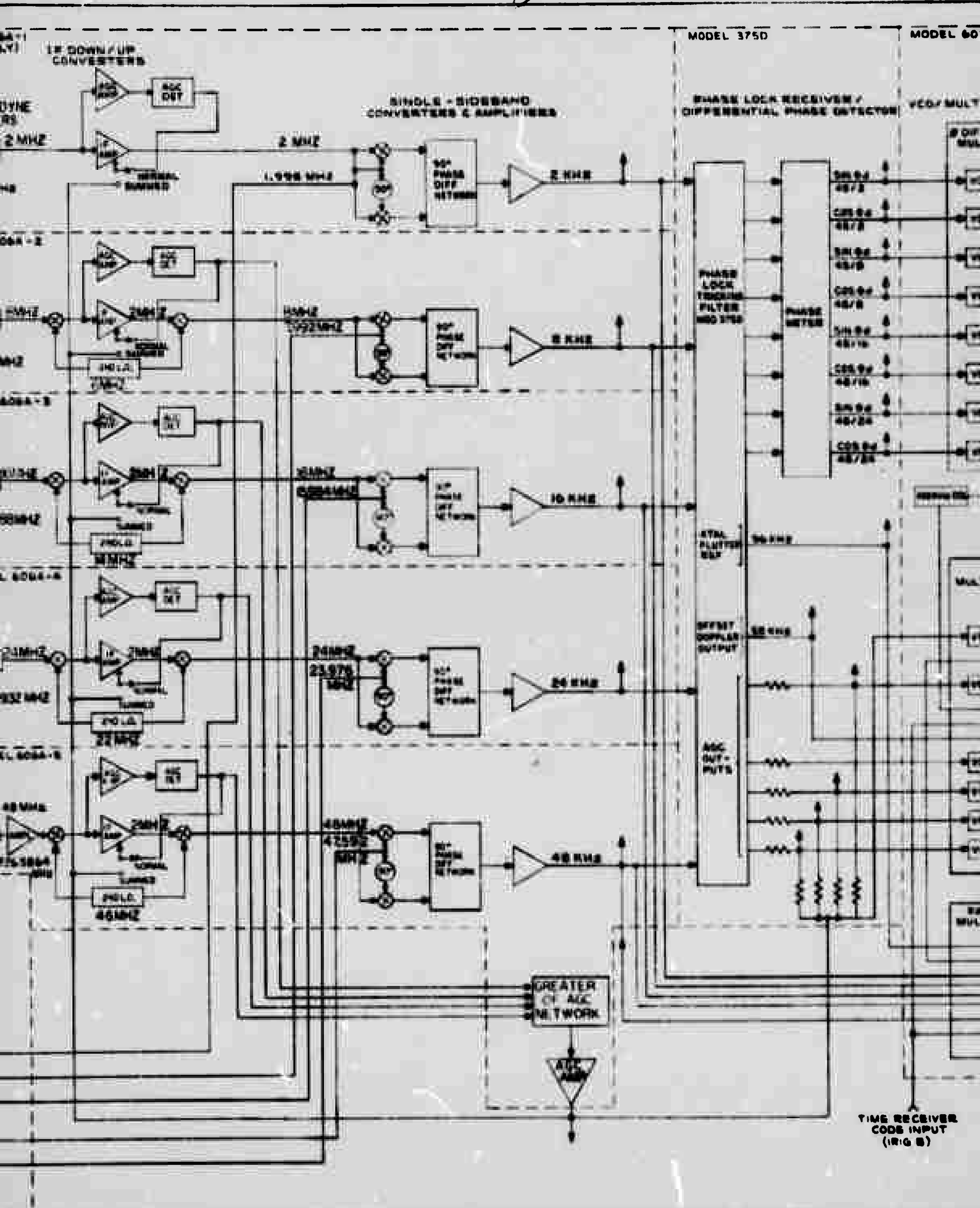


Figure 3-1a

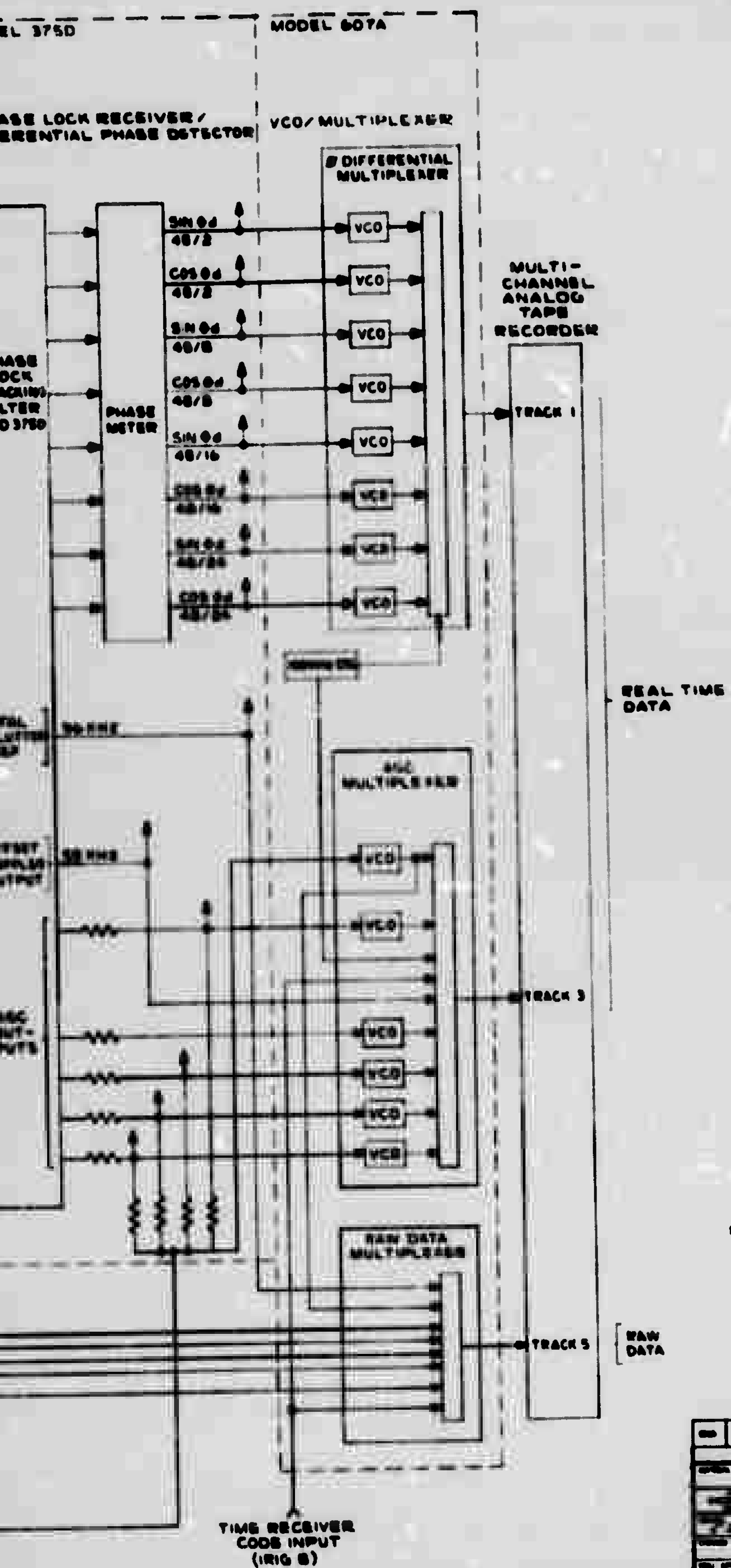


MODEL 4102A (SRI)
4102B (BRL)
ANTENNA MAST EQUIPMENT
LO-NOISE AMPLS
36.4411 MHz
F2
36.4411MHZ X4= 145.7644 MHZ
F4
36.4411MHZ X8= 291.5288 MHZ
F8
COAX SWITCH
MULTI-COUPLER
36.441 MHZ X12 = MHZ
36.4411MHZ X24= 874.5864 MHZ
F24
MODEL 605A
X2
X3
TEST XLTR/ SYNTHZR
TCXO
BUF
X10
FLTR
BUF
X4
X2
÷4
÷2

B



MODEL 375D
IF DOWN/UP CONVERTERS
SINGLE - SIDEBAND CONVERTERS & AMPLIFIERS
PHASE LOCK RECEIVER / DIFFERENTIAL PHASE DETECTOR
2 MHZ
2 KHZ
8 KHZ
16 KHZ
24 KHZ
48 KHZ
24MHZ
48MHZ
22MHZ
46MHZ
PHASE LOCK TRACKING FILTER
PHASE METER
GREATER OF AGC NETWORK
TIME RECEIVER CODE INPUT (IRIG B)



NOTE:
605A DOWN CONVERTER FOR HPI RECEIVER SYSTEM ONLY

6772 B

Figure 2-1a

REVISED & REDRAWN

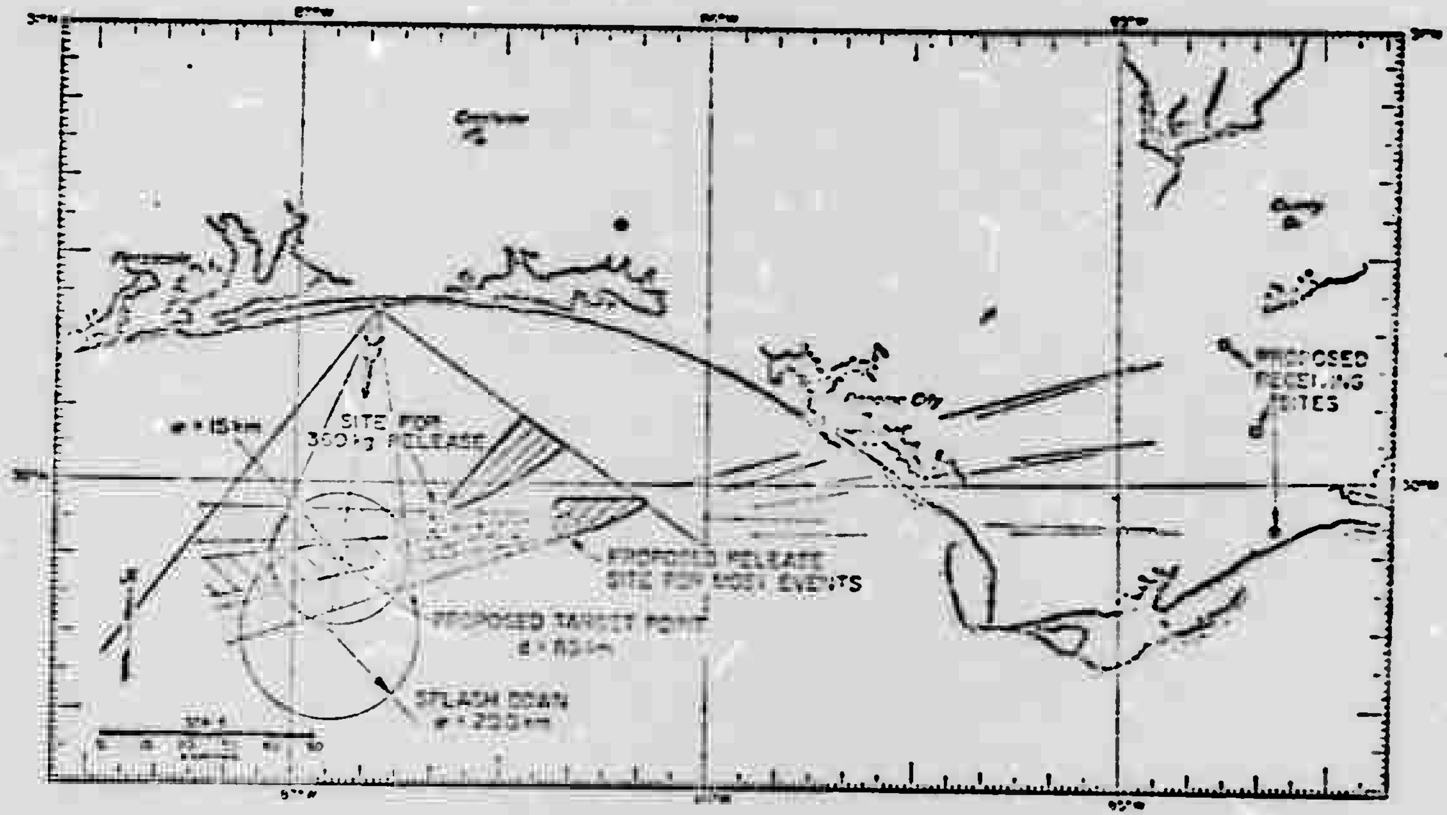
BLOCK DIAG - SECEDE II RECEIVER SYSTEM

ELECTRAC, INC.

16154 R 6772 B

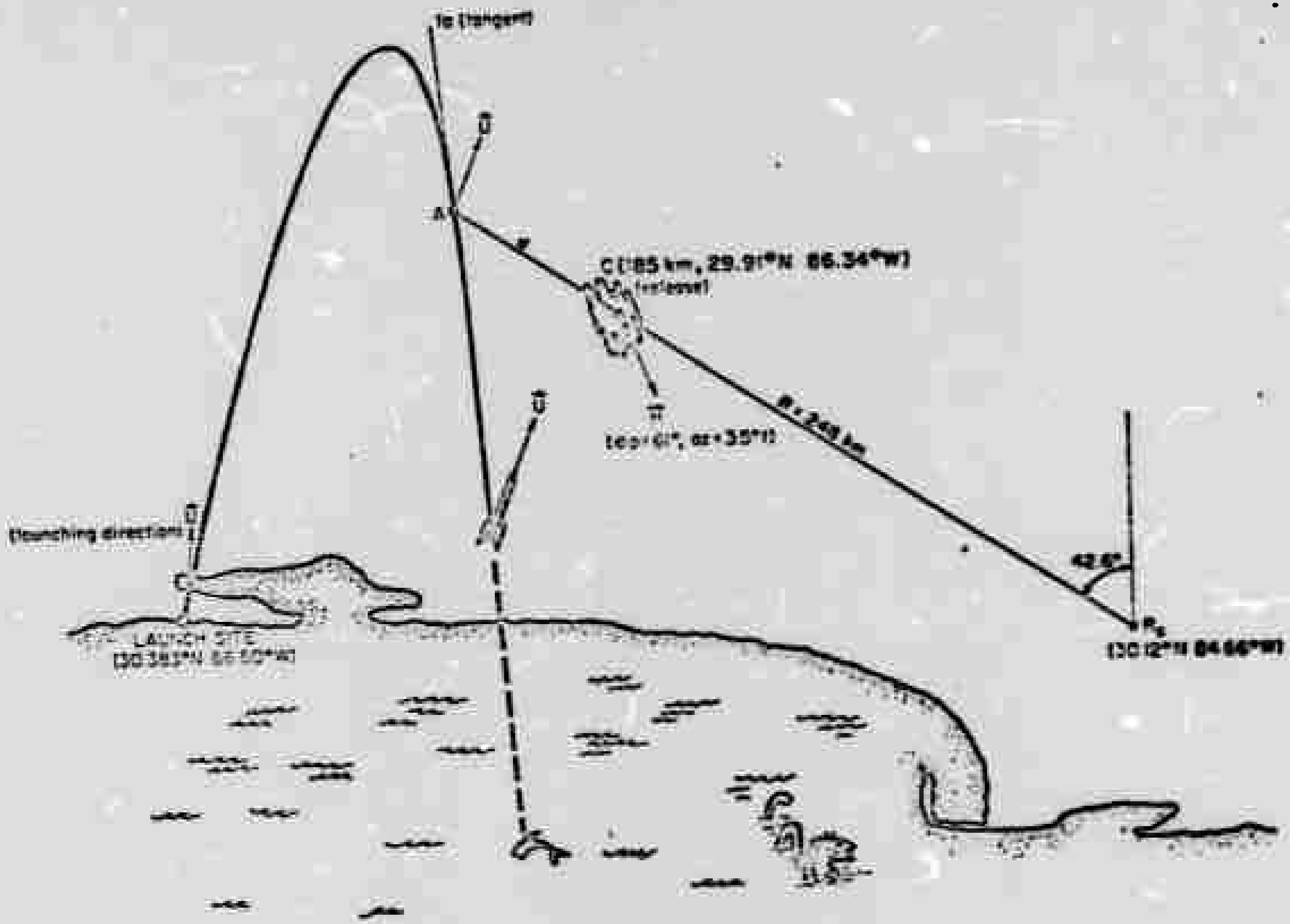
NEXT ASSY | MODEL NO

9342-180



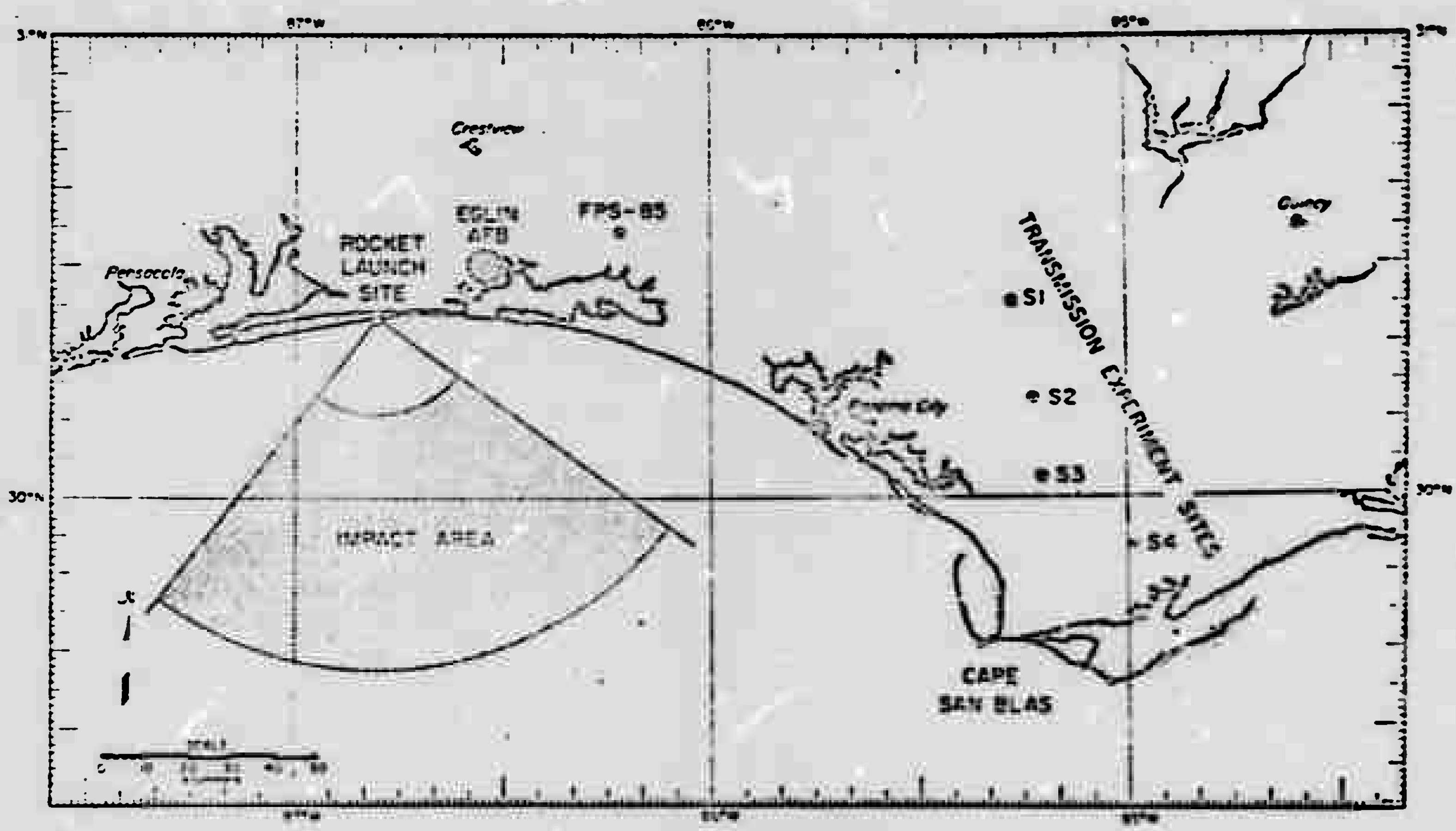
RECOMMENDED GEOMETRY AND RESULTING VALUES OF DISPERSION (U)

Figure 2-2



VALUES OF INTEREST IN SECEDE GEOMETRY (U)

Figure 2-3



MAP OF TEST AREA (U)
Figure 2-4

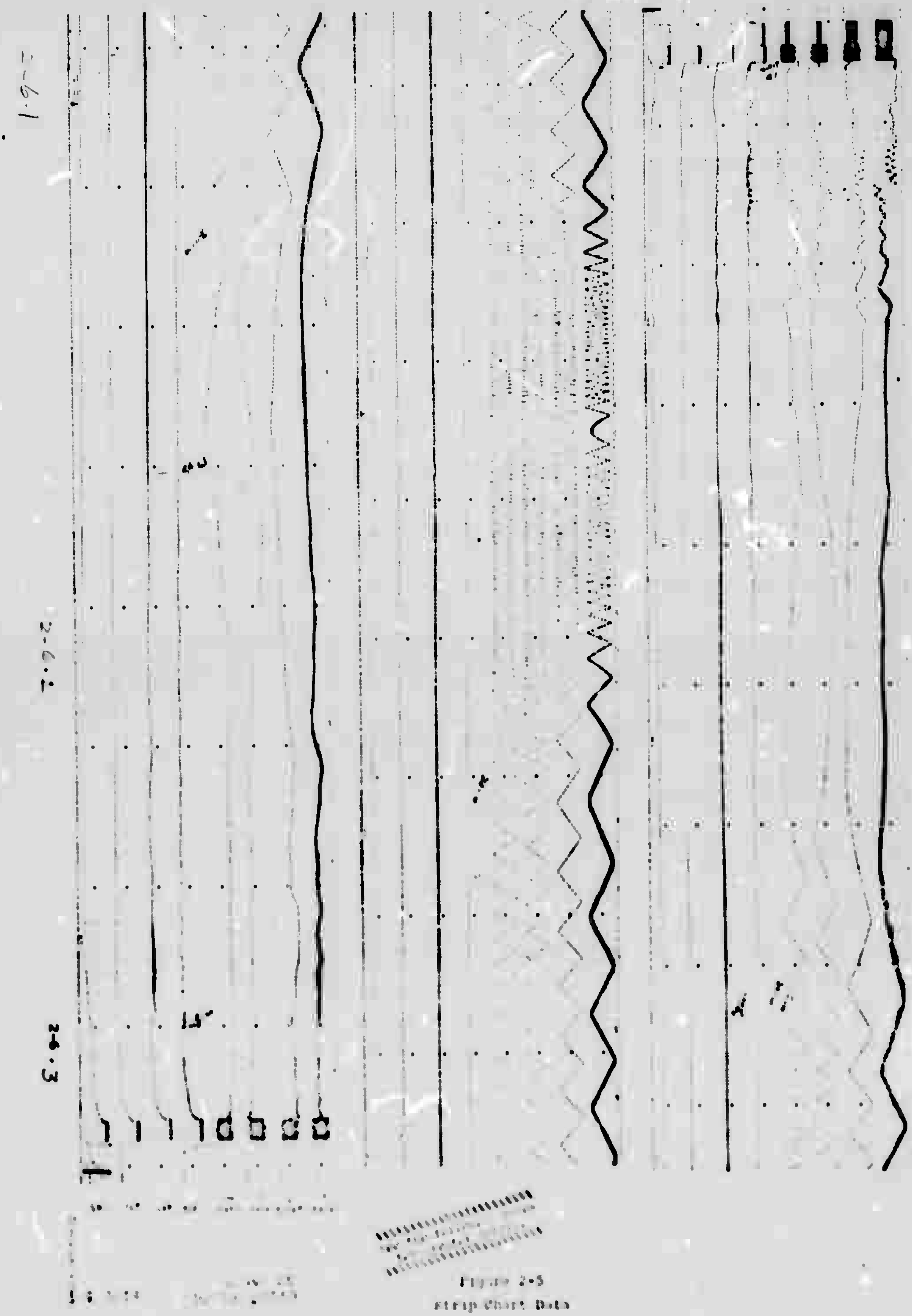
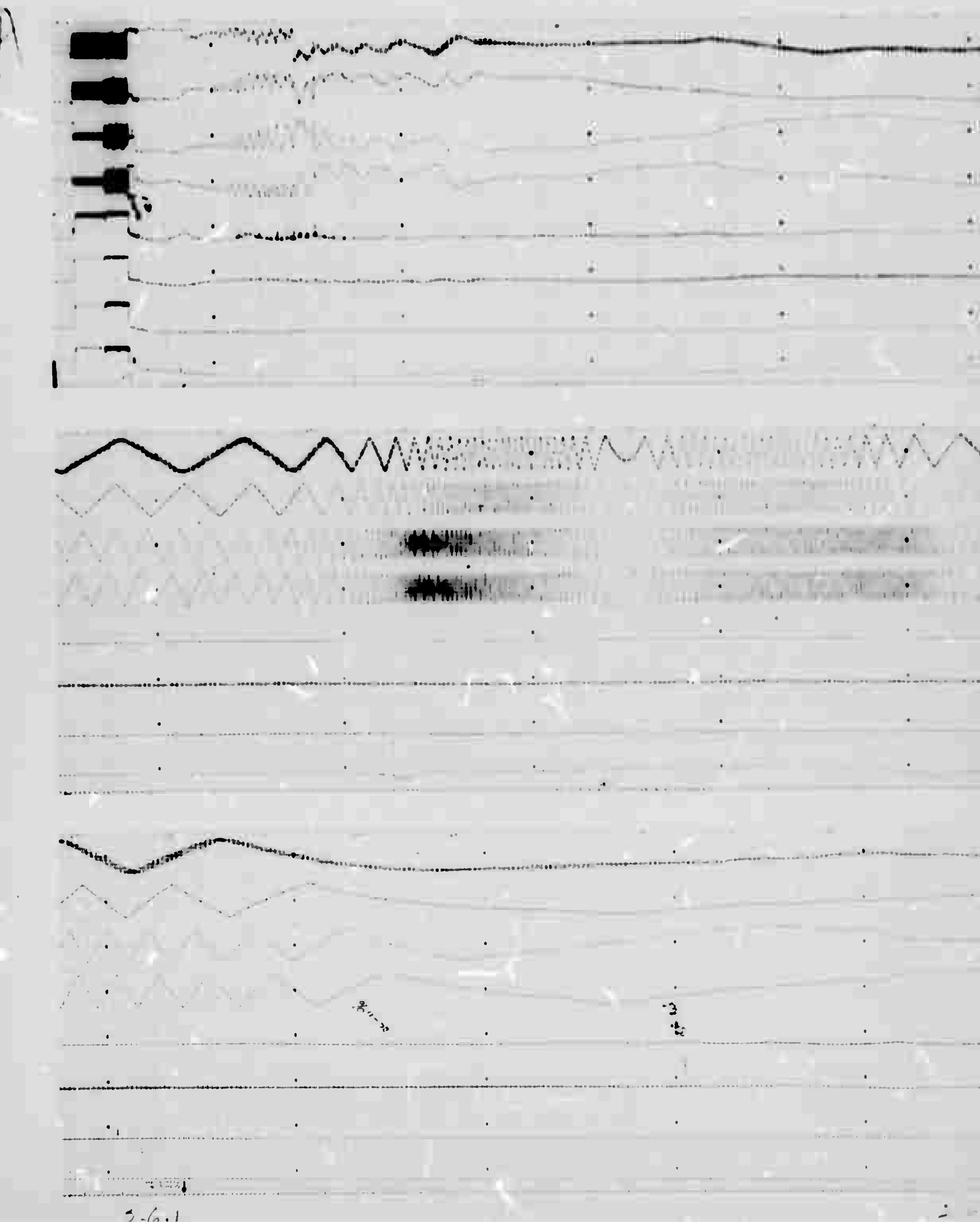


Figure 2-5
Strip Chart Data



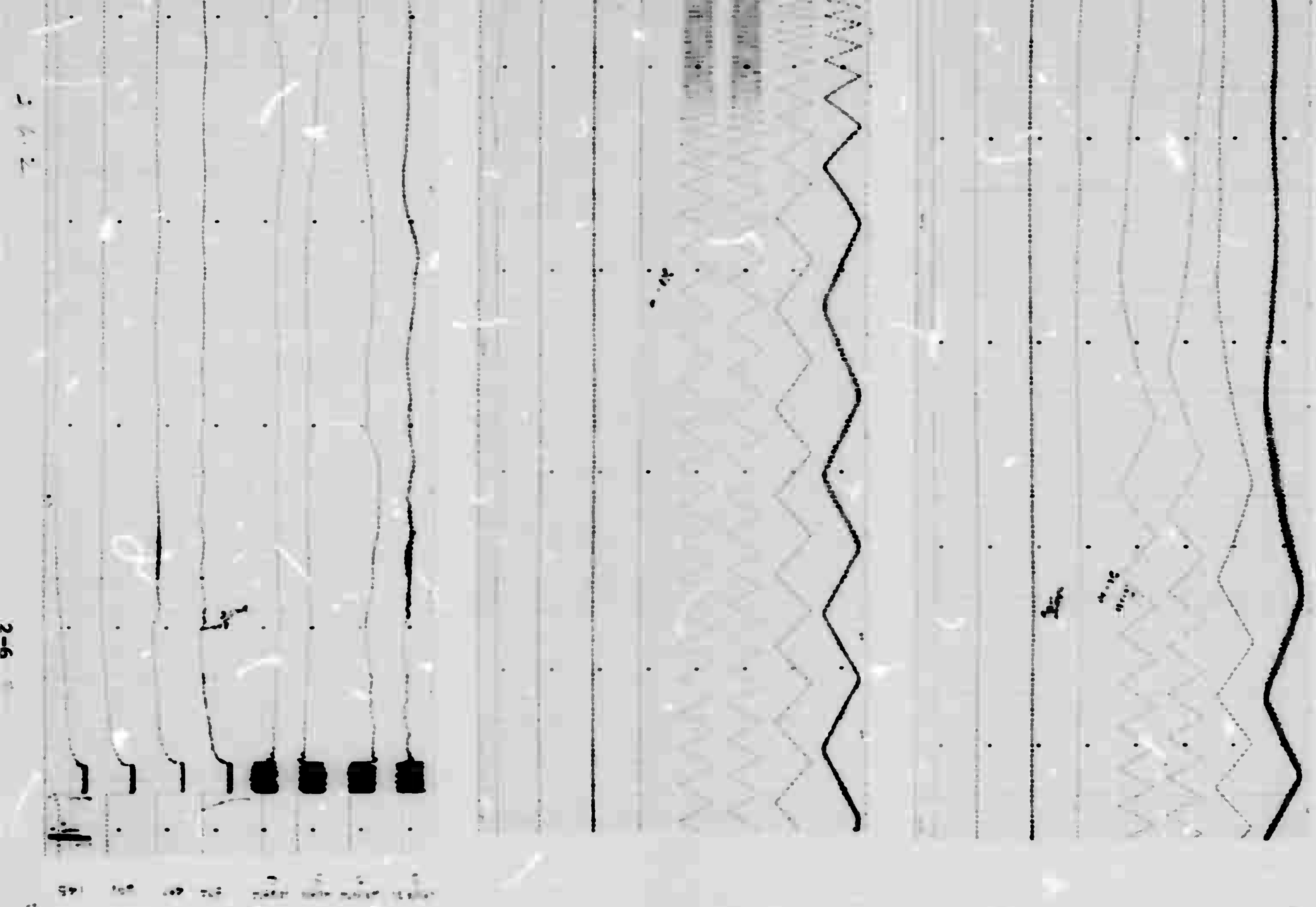


Figure 2-5
Strip Chart Data

both the sine and cos of differential channels are available. Simultaneously, amplitude measurements are made on each of the transmitted carriers. As shown in Figure 2-5, the upper four tracks represent the amplitudes of the received signals at approximately 145.7, 291.5, 437.3 and 874.6 MHz. The lower four tracks are indicative of the following differential phase measurements:

a) 145.7/874.6 sin

b) 145.7/874.6 cos

c) 291.5/874.6 sin

d) 437.3/874.6 sin

A notable achievement of this measurement system is its capability to track a spinning target. This is shown as a 3 rps rate of the booster/payload prior to destaging and a subsequent speed up to 8 rps after destaging. The phase data is "self calibrating" in that the difference is presented as a triangular pattern with a peak-to-peak excursion corresponding to -90 and +90 degree phase change.

Quite evident in Figure 2-5 are the ionosphere differential phase count up and the resultant speedup due to occultation with highly dense ion clouds as well as the diffractive effects on the amplitude of the lower frequency signals. This data can thus be utilized to determine the "total electron content" of the ion cloud.

2.2 EQUIPMENT CONFIGURATION

The Electrac developed system for one (1) ground station is shown in Figure 2-1, and consists of the following:

Antenna Mounted Units

Electrac Model 4108B, Crossed Log-Periodic Antenna

Electrac Model 4102A, 4 Channel RF Preamplifier and Multicoupler

Electrac Model 4102B, 5 Channel RF Preamplifier and Multicoupler

Rack Mounted Units

Electrac Model 606A-1, 36 MHz/2 kHz Down Converter

Electrac Model 606A-2, 145 MHz/8 kHz Down Converter

Electrac Model 606A-3, 291 MHz/16 kHz Down Converter

Electrac Model 606A-4, 437 MHz/24 kHz Down Converter

Electrac Model 606A-5, 874 MHz/48 kHz Down Converter

Electrac Model 605A, Frequency Synthesizer

Electrac Model 607A, VCO Multiplexer

Electrac Model 375D, Four Channel Tracking Filter or Model 375D-215, Five Channel Tracking Filter

The equipment was supplied to the U. S. Air Force, Rome Air Development Center in the four-channel configuration and to the U. S. Army Ballistic Research Laboratories in the five-channel configuration.

The four-channel configurations included a Bell and Howell Magnetic Tape Recorder/Reproducer, Model VR3360 as shown in Figure 2-1. Also shown is a typical installation with a strip chart recorder.

A set of typical antenna patterns is included as Appendix A. Data includes cuts taken in both orthogonal planes as well as circularity measurements.

3 -- SYSTEM ASSEMBLY CALIBRATION AND CHECKOUT

After the Electrac instrumentation system had been initially mechanized, it was found that the required system AGC recovery time necessitated redistribution of the non-coherent and coherent AGC control. It was also necessary to add band pass filters between the first and second mixers to correct very high order harmonic cross-talk. The harmonic relation between the various channels made it necessary to modify the tracking filter to minimize false lock-up on adjacent channel harmonics. Finally, it became necessary to change from "greatest of" AGC to independent channel AGC, in order to eliminate channel to channel cross-talk in amplitude measurements.

As originally planned, all channels were to operate at the same gain in the 2 MHz "identical" IF amplifiers. With matched amplitude and phase characteristics, the differential effect would have been minimized. The largest signal channel controlled the gains of all channels. This non-coherent AGC signal was added to the individual coherent AGC voltage. If all channels, both coherent and non-coherent, were sufficiently matched in slope, an increase in the strongest channel resulted in all other channels being suppressed and their coherent AGC changing to cancel the change in non-coherent AGC. In actual operation, it was not possible to maintain sufficient slope matching and an increase in one channel coupled in varying degrees to all channel AGC outputs.

A switch was added to allow each channel to be operated independently, eliminating the cross coupling. This, however, resulted in some sacrifice in phase accuracy since each non-coherent AGC operated at its own level depending on its signal strength and the common mode cancellation was lost.

These changes were carried out concurrently with equipment fabrication and assembly because of schedule pressure.

In its final configuration, the phase-lock tracking filter drove phase detectors that provided triangular-wave outputs of dispersive phase between each of the measurement frequencies and the reference. Since there is a 180° ambiguity in the output of this type of phase detector, a second detector at each measured frequency provided an output shifted by 90° to resolve this ambiguity. These outputs represented the prime data, and were recorded on magnetic tape. In addition, the amplitude of the received signals was also recorded, as well as timing signals and "raw" received signals. The latter were low-frequency IF signals that drove the tracking filter and this could be directly recorded.

Variations of the phase and amplitude outputs were also put on strip chart records to act primarily as quick look data for field evaluation of operations and results.

Prior to beacon launch, and after the last beacon splash down, calibration signals were recorded, primarily to establish the AGC calibration. A stability recording preceded and followed the beacon flights; the stability test signals simply consisted of a steady input to the receivers. Acquisition of the beacon signals typically occurred within three to five seconds after launch.

4 -- FIELD INSTALLATION AND OPERATION

Three systems were built in the four-channel configuration and one system in the five-channel version. The following equipment deliveries were made:

One Antenna to Ballistic Research Labs	30 Nov. 70
Three Antennas to Tyndall AFB	14 Dec. 70
One Experimental Model, four-channel version, to Tyndall AFB	14 Dec. 70
One Experimental Model, five-channel version, to Tyndall AFB	24 Dec. 70
One Experimental Model, four-channel version, to Tyndall AFB	31 Dec. 70
One Experimental Model, four-channel version, to Tyndall AFB	02 Jan. 71

In addition to the above items, operating spares were shipped to Tyndall AFB on 08 January 1971; and to Stanford Research Institute (SRI) on 19 February 1971 and 08 March 1971. Data chart records for the Nutmeg, Plum and Redwood events were shipped to SRI on 16 March 1971. Chart records from other events were delivered to SRI informally at the test site. Original data tapes were hand carried to SRI by Dr. A. Burns.

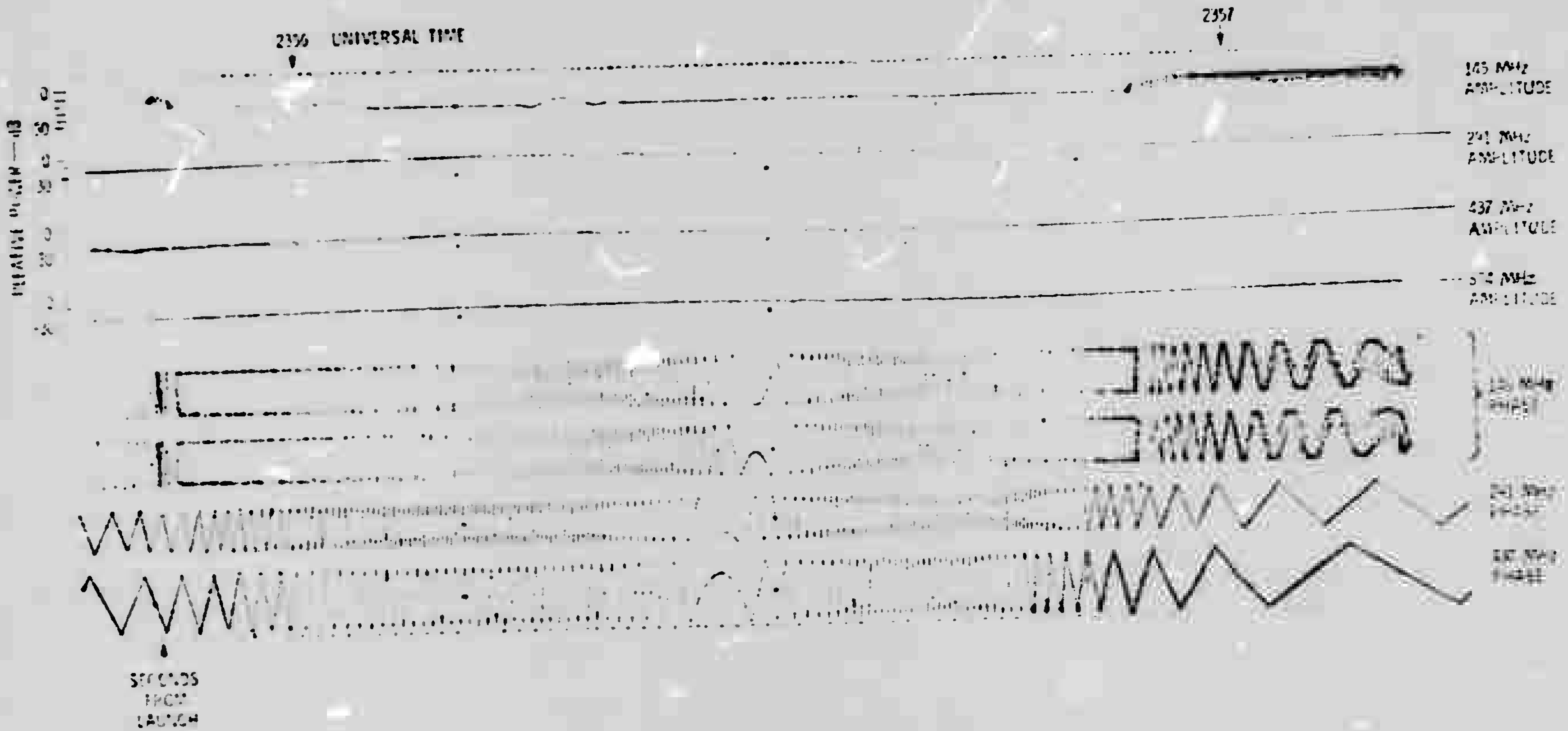
The Acceptance Test Procedure was delivered informally to the test site with the equipment, together with test data taken at the Electrac plant. The procedure was incorporated in preliminary operating instructions prepared for Electrac field personnel.

Electrac field personnel left Anaheim for Tyndall AFB 12 December 1970 and arrived at the test site 17 December 1970. The installation and test work was completed 6 January 1971. First flights were begun 7 January 1971 with a helicopter beacon checkout flight. The operation and maintenance phase of the work continued from that date until 2 February 1971. Three days were required to clean up the various sites and pack the equipment for shipment. Electrac personnel departed the test area 5 February 1971 and arrived at Anaheim 10 February 1971.

5 -- SECEDE II OPERATIONS

The Electrac Dispersive-Phase Differential Doppler Measurement Systems were all operational during the beacon experiment. Data were collected on all of the Secede II releases except REDWOOD, where both beacons failed to pass behind the cloud with respect to the receiving stations. During the NUTWOOD event, failures (due to beacon antenna breakdown) of both the main reference frequency (874 MHz) and the alternate reference (437 MHz) prevented obtaining dispersive phase data, although there is some hope of making a phase comparison between 145 MHz and 291 MHz with the "raw" recorded signals. On the other releases, at least two of the dispersive-phase sites received cloud-affected signals from at least one beacon. Considerable high quality data, corresponding to spatially separated slices through the clouds, were thus obtained, particularly for the early-time smooth (non-striated) clouds. The Spruce data are for the period just after striations developed and represent all the striation data obtained.

Figure 5-1 shows the chart record from a typical early-time, smooth-cloud occultation, in this case for Beacon 1 and S-3 on Event OLIVE. The top four channels show the signal amplitudes; the rest are dispersive-phase records, including the 145-MHz quadrature phase output. Each full cycle in the latter set of records represents 360° of dispersive-phase change, with the phase reference in each case being the 874-MHz signal.



BEACON (Dispersive-phase) RECORDS FROM SITE 3, OLIVE EARLY-TIME BEACON (U)

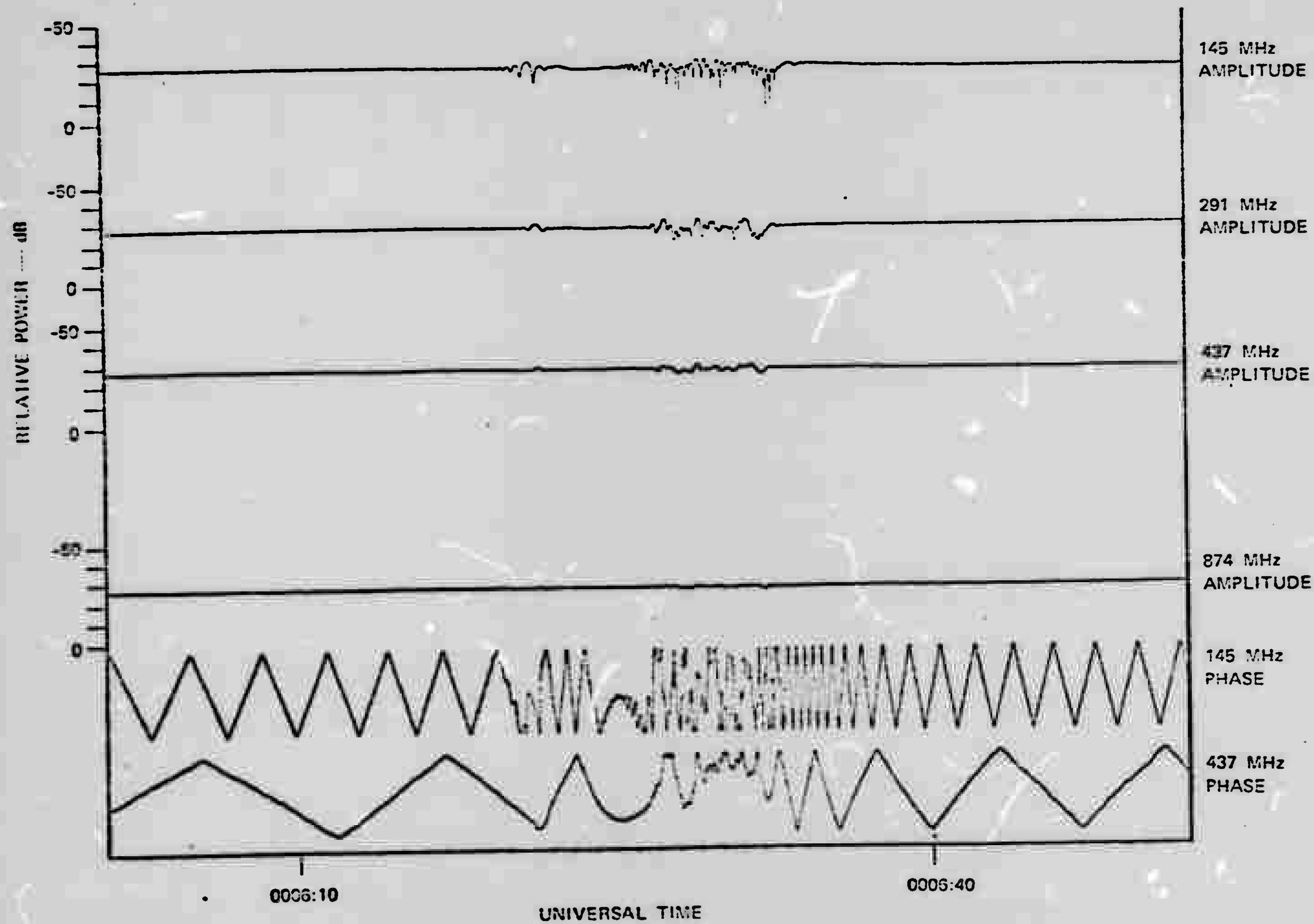
Figure 5-1

The triangular, phase-detector output waveforms at the right and left ends of the record resulted from the ionospheric contribution to N_t. The obvious increase in rate of dispersive-phase change through the middle portion of the record is the contribution of the early-time (about 150 seconds after release) OLIVE ion cloud. Near the center of the record, N_t reaches its maximum, where the slope of dispersive-phase change is zero. Note that refraction caused N_t to reach its maximum value at different times on different frequencies.

A different sort of occultation record appears in Figure 5-2, obtained at S-1 about 14 minutes after the SPRUCE release. The top four records are of the four signal amplitudes and the bottom two are of the 14[illegible]-MHz/874-MHz and 437-MHz/874-MHz dispersive phases.

Although missing the main body of the ion cloud, the beacon line-of-sight crossed the portion of the cloud that had begun to show striations. Thus, most of the regular (triangular) phase changes seen are due to the ionosphere.

The 437-MHz records afford the best description of the occultation. At the beginning there is an abrupt change in the dispersive-phase slope, followed by a relatively rapid increase in N_t to a maximum four seconds later. Following this maximum, considerable small-scale structure is visible, much of it below 100 m in size, a rough estimate based on the time duration of the small features and an estimated rocket velocity of about 500 m/sec.



BEACON (Dispersive-phase) RECORDS FROM SITE 1, EVENT SPRUCE (U)

Figure 5-?

6-- CONCLUSION AND RECOMMENDATIONS

Electrac, Inc. designed, fabricated, and fielded four Dispersive-Phase/Differential Doppler Measurement Systems. Experiments were conducted to provide data on integrated electron density and wavefront distortion. All systems were operational and provided a considerable amount of high-quality data.

The systems were designed to provide data on amplitude as well as phase. Since both the amplitude and phase readouts are directly affected by non-linearity and/or phase shift in the AGC attenuators, it is felt that although the attenuators were sufficient for these experiments, improvements could be made. In particular, the non-coherent attenuators are in need of additional design effort to make the system more accurate at strong signal levels (greater than -95 dBm wherein the non-coherent AGC begins to operate).

Since the phase comparators in the model 375D involve several dividers with no provision for presetting, each time the system is turned on and locked, even for repeated runs on the same tape data, the phase outputs start at any one of several random fixed offsets. Although this can be taken out in data reduction as a constant offset, it might be more convenient to consider providing reset signals or a means of advancing or retarding the signal count so that particular phase points could be chosen at the start of a record.

The system as used had poorer noise figures than anticipated particularly in the 437 MHz channel and future systems should consider means of reducing the noise figure and as a consequence improve the system threshold.

ACKNOWLEDGEMENT

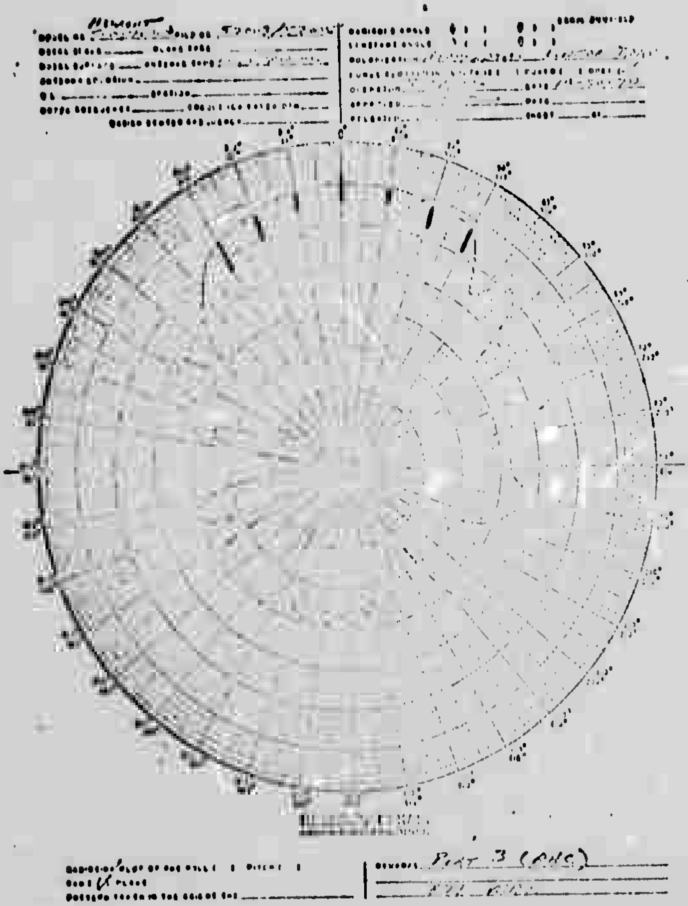
To the many people who contributed so greatly and with much extra effort in order to enable us to get into the field operationally and on time, our sincerest thanks. Key Electrac personnel involved in the various phases of the program included the following:

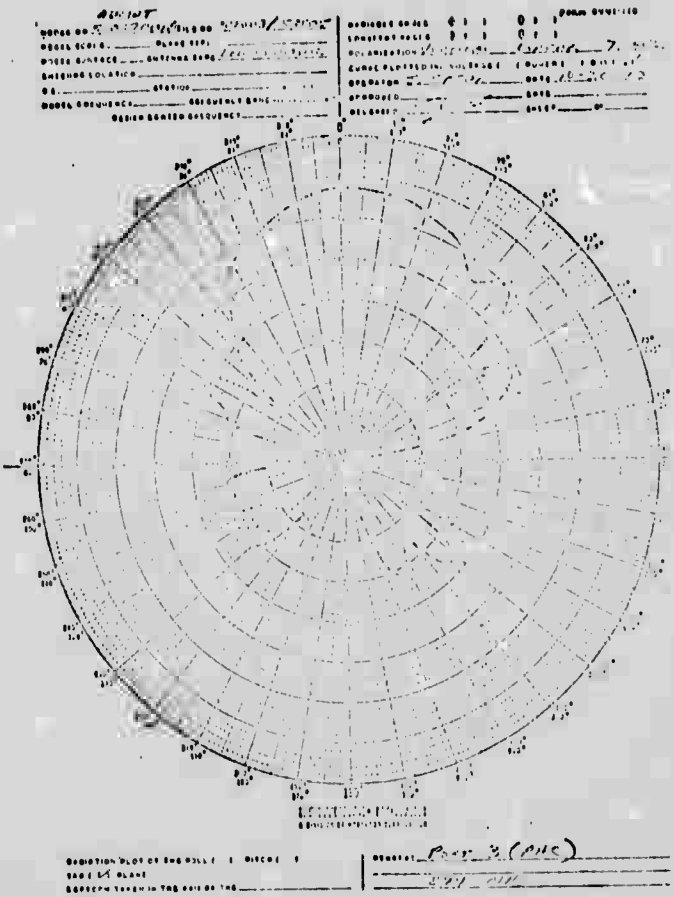
System Design	Hardware Design	Field Operations	Final Report
L. Katz	R. Honey	I. Weber	R. Honey
I. Weber	L. Wells	J. Gebel	
R. Honey	J. App	R. Terrell	

Consultant: Dr. A. J. Mallinckrodt

APPENDIX A
ANTENNA PATTERNS

6..3


Part 3 (AHS)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