

UNCLASSIFIED

AD NUMBER: AD0861196

LIMITATION CHANGES

TO:

Approved for public release; distribution is unlimited.

FROM:

Distribution authorized to US Government Agencies only; Export Control; 30 Sep 1969. Other requests shall be referred to Naval Ship Engineering Center, Hyattsville, MD 20782.

AUTHORITY

USNSEC ltr dtd 27 Aug 1973

THIS PAGE IS UNCLASSIFIED

AD 861196

# LF TO VHF SHIPBOARD DIRECTION FINDING RESEARCH

T.C. Green

R. Lorenz

W.M. Sherrill



INTERIM DEVELOPMENT REPORT FOR THE PERIOD  
1 JULY 1969 — 30 SEPTEMBER 1969  
NAVY DEPARTMENT CONTRACT NR. N00024-69-C-1205  
DATE OF REPORT 30 SEPTEMBER 1969



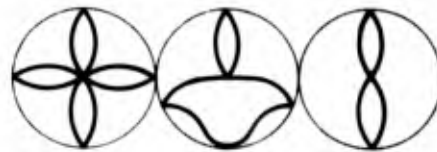
**SOUTHWEST RESEARCH INSTITUTE**  
SAN ANTONIO HOUSTON

Reproduced by the  
CLEARINGHOUSE  
for Federal Scientific & Technical  
Information Springfield Va. 22151

# LF TO VHF SHIPBOARD DIRECTION FINDING RESEARCH

T.C. Green  
R. Lorenz  
W.M. Sherrill

**STATEMENT #2 UNCLASSIFIED**  
This document is subject to special export controls and each transmittal to foreign government or foreign nationals may be made only with prior approval of Naval Ship Engineering Center  
Code 6176B  
Center Bldg. Prince Georges  
Hyattsville Md 20782



Code 6176-B

INTERIM DEVELOPMENT REPORT FOR SHIPBOARD RADIO  
DIRECTION FINDING DESIGN, STUDY AND DEVELOPMENT.  
PERIOD COVERING 1 JULY 1969 to 30 SEPTEMBER 1969.  
DATE OF REPORT 30 SEPTEMBER 1969. PREPARED FOR NAVY  
DEPARTMENT, NAVSEC. CONTRACT NR. N00024-69-C-1205.

APPROVED:

*Douglas N. Travers*

Douglas N. Travers, Director  
Department of Applied Electromagnetics

D D C  
RECEIVED  
NOV 12 1969

## ABSTRACT

The ferrite core crossed spaced loop antenna was installed at the simulated ship site in anticipation of a DF evaluation over the 2- to 32-MHz range.

Assembly and checkout of the interferometer diode switch and digital sequencer assembly was completed. The interferometer was operated automatically with a remotely located computer to obtain sky wave DF measurements at the simulated ship site, using known medium and short range stations. The computed azimuth and elevation angles were consistent with measurements obtained by a clean site interferometer on the same stations. Elevation angle data spread is examined for the presence of one- and two-hop mode scintillation phenomena.

A bearing corrector system to be implemented in the final contract quarter utilizing the existing DF calibrator and interferometer digital sequencer is described. The calibration data storage and corrected bearing computation will be accomplished by an on-line remote computer utilizing the dial telephone network.

## TABLE OF CONTENTS

|  | <u>Page</u> |
|--|-------------|
| LIST OF ILLUSTRATIONS  | iv          |
| I. PURPOSE   | 1           |
| II. WORK PERFORMED   | 2           |
| A. Phase I - Ferrite Core Crossed Spaced Loop Antenna            | 2           |
| B. Phase II - Shipboard Interferometer                           | 2           |
| 1. Digital Instrumentation                                       | 2           |
| 2. Calibration and Operation Procedures                          | 7           |
| 3. Preliminary Sky Wave Measurements                             | 12          |
| C. Phase III - Automatic Shipboard Bearing Corrector             | 16          |
| III. CONCLUSIONS   | 19          |
| IV. RECOMMENDATIONS  | 20          |
| V. PROGRAM FOR THE NEXT INTERVAL                                 | 21          |
| APPENDICES   | 22          |
| I. Simulated Ship Site Interferometer Bearing Calculator Program | 22          |
| II. Disc File Loading Procedures                                 | 30          |
| III. Manual Loading Procedures                                   | 32          |
| IV. TTY Control of Ship Site Interferometer                      | 34          |

## LIST OF ILLUSTRATIONS

| <u>Figures</u> |  | <u>Page</u> |
|----------------|--|-------------|
| 1              | Ferrite Core Crossed Spaced Loop Antenna<br>at Simulated Ship Facility | 3           |
| 2              | Detail Block Diagram - Ship Site<br>Interferometer                     | 4           |
| 3              | Schematic - TTY/Coupler Buffer Circuit                                 | 6           |
| 4              | Digital Sequencer Timing Diagram                                       | 8           |
| 5a             | RF and Digital Sequencer   | 9           |
| 5b             | Ship Site Interferometer Equipment Group                               | 9           |
| 6              | DDP-516 Computer and Disc File   | 11          |
| 7              | Typical Ship Site Interferometer TTY Printout                          | 13          |
| 8              | Simulated Ship Site Interferometer Sky Wave<br>DF Performance          | 15          |
| 9              | Automatic Bearing Corrector Simplified<br>Block Diagram                | 17          |

## I. PURPOSE

It is the purpose of this contract to design, develop, and evaluate prototype DF antennas, special DF techniques, and DF calibration circuits which provide practical state-of-the-art solutions to the shipboard direction-finding requirements in the HF and low VHF range. Prototype DF systems and calibration techniques are to be evaluated in a realistic reradiation environment at the SwRI ship simulation site. Experimental results will be combined with fundamental theoretical analysis to provide detailed recommendations as to the optimum DF system for specific Navy DF requirements.

Project Phase I--Continue development of a ferrite core crossed spaced loop antenna and associated electronics for shipboard direction-finding applications in the 2- to 30-MHz range. Evaluate a prototype ferrite core DF antenna at the simulation site over the design frequency range and compare to other existing DF techniques.

Project Phase II--Design and develop a feasibility demonstration model DF interferometer for shipboard application. Develop techniques and circuitry for demonstrating automatic bearing computations at a remote located computer. Perform an initial test at the SwRI ship simulation site to compare the simulated shipboard performance of the interferometer to similar land-based performance data previously obtained.

Project Phase III--Modify existing DF calibrator circuits to demonstrate automatic corrected bearing computations and readout for any observed bearing on a polar CRT display. Emphasize development of circuits and techniques for storage and recall of calibration data for automatic computation of the corrected relative bearing using local TTY control of remotely located computer equipment.

## II. WORK PERFORMED

### A. Phase I - Ferrite Core Crossed Spaced Loop Antenna

The ferrite core crossed spaced loop antenna was moved from the DF tower site where previous tests were conducted to the simulated ship site facility. The antenna is mounted at the 40-ft level with a 4-in. copper mast connecting the antenna to the screen room laboratory at the base of the tower. Figure 1 shows the ferrite core antenna installed at the simulated ship site with the "ship" superstructure shown in the background. Since DF performance was improved using a balanced preamplifier termination in the antenna<sup>1</sup>, the ferrite core antenna will be terminated in balanced preamplifiers and utilize a balanced output to the goniometer scan direction finder in the screen room laboratory.

It is planned to obtain a complete set of DF calibration curves for the ferrite core antenna at the simulated ship site over the 2- to 32-MHz range. These curves will be compared to the previously obtained calibration curves for the same antenna at the clean site facility and, in addition, will be evaluated for no bearing possible regions and multivalued re-entrant curves. This performance data will provide an important reference for future ferrite spaced loop antenna development.

### B. Phase II - Shipboard Interferometer

#### 1. Digital Instrumentation

The digital instrumentation for the interferometer at the simulated ship site was completed during the past interim reporting period. The digitally instrumented crossed baseline interferometer at the ship site facility was operated automatically with the remotely located DDP-516 computer. A detailed block diagram of the complete interferometer is shown in Figure 2 and is discussed in the following paragraphs. Detailed descriptions of the interferometer can also be found in the previous interim reports<sup>1, 2</sup> for this contract.

The five single-ended RF outputs from the simple loop interferometer antennas are routed via phase matched cables to diode RF switches.

<sup>1</sup>Green, T. C., and Sherrill, W. M., "LF to VHF Shipboard Direction Finding Research, " Interim Development Report for Contract No. N00024-69-C-1205, Southwest Research Institute, June 30, 1969.

<sup>2</sup>Green, T. C., and Sherrill, W. M., "LF to VHF Shipboard Direction Finding Research, " Interim Development Report for Contract No. N00024-69-C-1205, Southwest Research Institute, March 31, 1969.



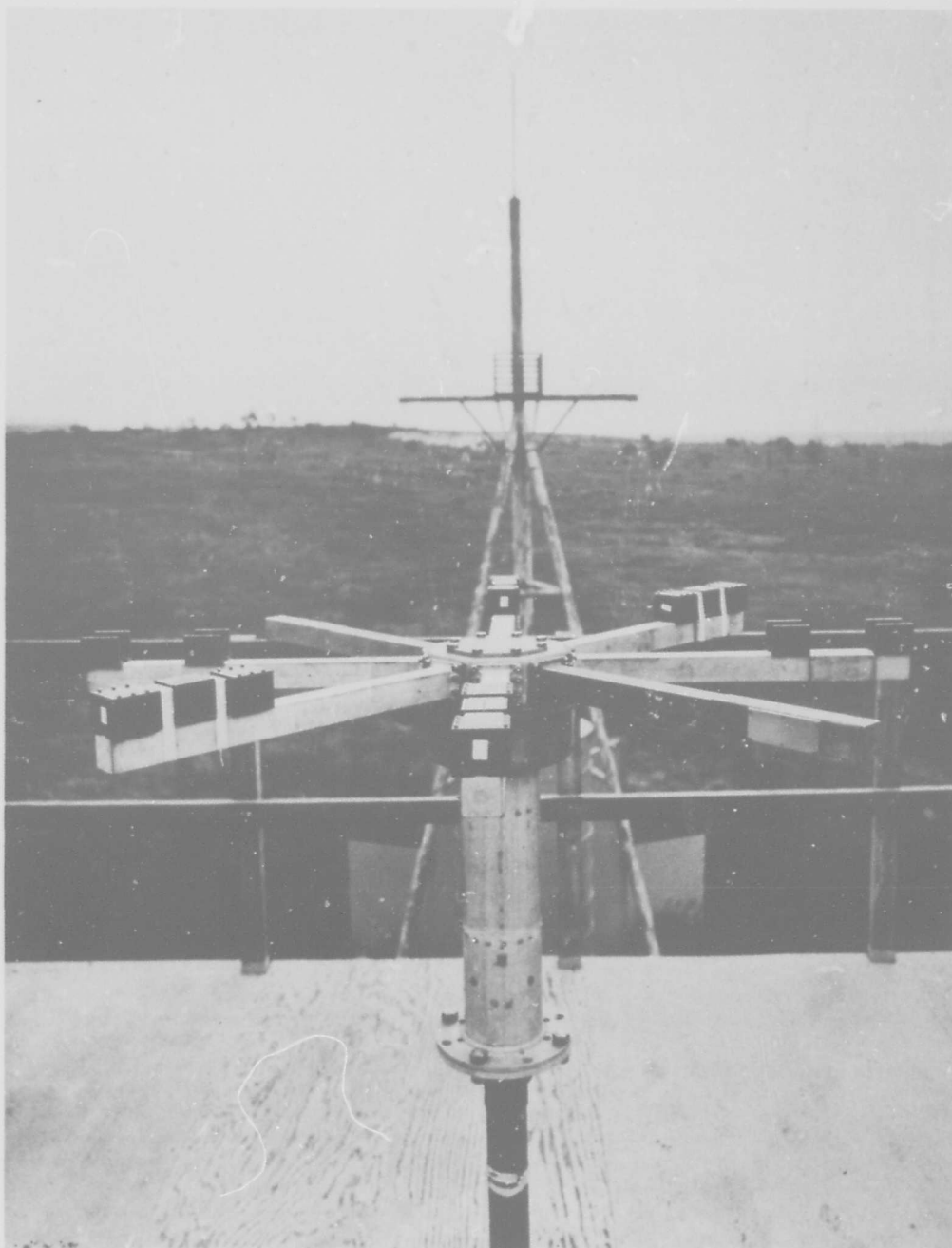


FIGURE 1  
FERRITE CORE CROSSED SPACED LOOP ANTENNA  
AT SIMULATED SHIP FACILITY

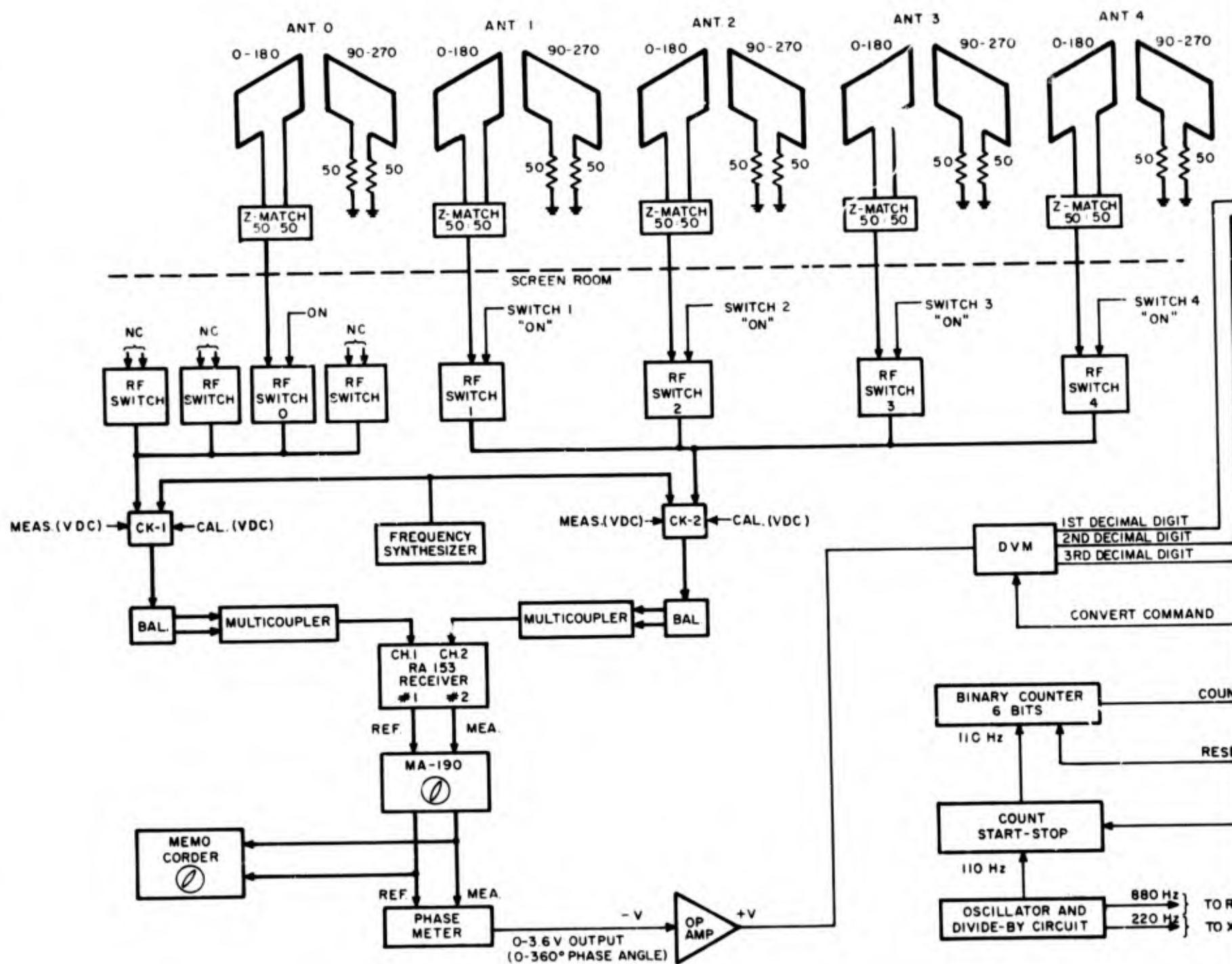


FIGURE 2  
DETAIL BLOCK DIAGRAM OF SIMULATED SH

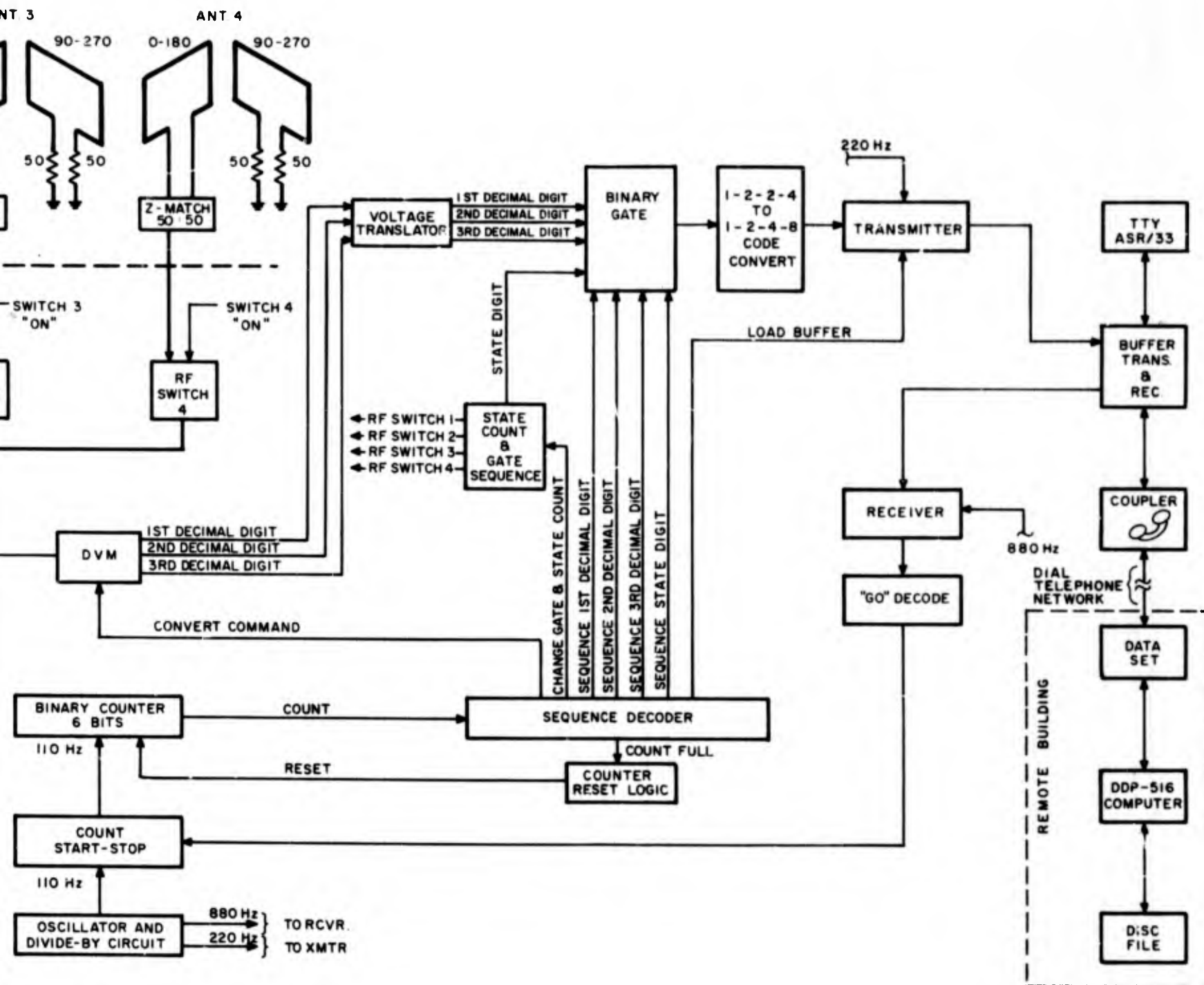


FIGURE 2

F SIMULATED SHIP SITE INTERFEROMETER

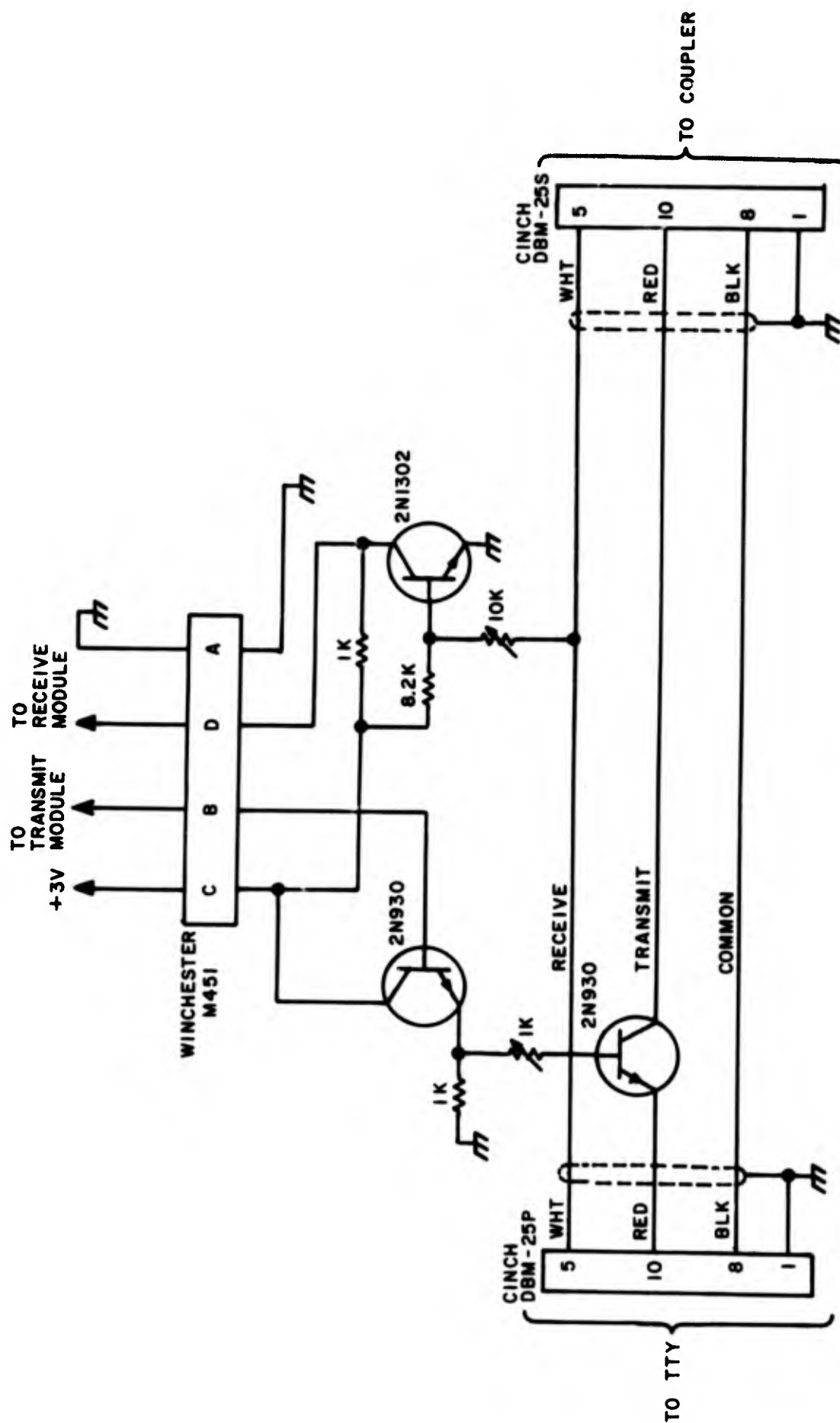
12

RF switches 1 through 4 have a common RF output which is fed to coaxial relay CK2 while the reference RF switch (0) output is commoned with three identical RF switches which are in the OFF mode. The parallel output configuration of the reference RF switch provides phase matching with the RF output of switches 1 through 4. Coaxial relays CK1 and CK2 select either the RF inputs from the diode switches or a CAL RF signal from a frequency synthesizer depending on the position of a front panel switch. Each RF output from the coaxial relays is routed through the twin-channel receiver via multicouplers to isolate the receiver input from the preceding circuitry.

The IF outputs from the twin-channel receiver are amplified in the MA-190 unit which, in addition, provides phase adjustment for calibration requirements. A 0- to 360-degree phasemeter measures the relative phase between the two IF signals and produces an analog output from 0 to -3.6 volts proportional to the relative phase angle. An operational amplifier is used to change the negative polarity of the phasemeter output to the positive voltage input requirement for the digital voltmeter. Upon command from the sequence decoder, the digital voltmeter samples the analog input and registers the amplitude in BCD digital form. The three most significant decimal digits are utilized providing 1-degree phase resolution of the system. The decimal digits are in a 1224 BCD format and are routed in parallel form to a binary gate via a voltage translator circuit. In addition to the decimal digits, a state count consisting of a number from 1 to 4 is present at the binary gate representing the antenna pair associated with the phase measurement.

The complete interferometer measurement and data transfer sequence is started by the DDP-516 computer generating a GO character which is transmitted over the conventional dial telephone network. A data set is used to couple the information into the telephone line at the computer facility and a TTY acoustic coupler is used to receive (and transmit) at the simulated ship site laboratory. The coupler converts the tone modulated information to electrical pulses and transfers the information to the transmitter and receiver buffer and in addition to the ASR/33 TTY.

A schematic diagram of the transistorized buffer circuit is shown in Figure 3. A simple transistor switch is used in the transmit section of the buffer circuit to open or close the 20-mA TTY/coupler transmit line. Activation of the transistor switch by the transmitter card module results in identical space/mark levels being furnished to the coupler as would normally be originated by the TTY transmit circuit. The switch is normally closed allowing use of the TTY when the sequencer is not transmitting. The receive portion of the buffer circuit detects the presence of mark and space levels on the TTY/coupler interface and furnishes the levels to the sequencer receiver. This receiver buffer does not affect the normal TTY receive capability.



**FIGURE 3**  
**SCHEMATIC-TTY/COUPLER BUFFER CIRCUIT**

The GO command generated by the computer is a lower case "m" in the ASCII code which prints on the TTY as a capital "M." The receiver module converts the serial pulses from the buffer to parallel eleven-bit characters which are routed to the diode decode circuit.

When the GO character (m) is detected by the decoder, a start command is furnished to the output gate on the master oscillator which allows the 110-Hz sequence frequency to pulse the six-bit binary counter. The six-bit binary count is furnished to a decode matrix consisting of 22 six-input nand gates. Each nand gate is coded to activate on a specific six-bit count providing sequence command outputs at appropriate intervals of the binary count. As the counter proceeds through the six-bit count, each decimal digit and the state count are sequenced out individually in a four-bit binary format. Each four-bit number is, therefore, sequenced through the gate/code converter to the transmitter modules which converts the parallel binary number to a serial form and transmits it upon command (load buffer) from the sequence decoder. The 1224 BCD format is converted to the conventional 1248 BCD code before being routed to the transmitter module.

The transmitter output is an eleven-bit character with the number incoded in the eight-bit ASCII code format. Each character represents either one of the three decimal digits from the DVM or the state count and is transmitted in serial form via the dial telephone network to the DDP-516 computer.

The computer is programmed prior to the start of the measurements to take N sets of four phase angles and then average the phase measurements before computing the average elevation and azimuth angles of arrival. Upon completion of receiving a set of four phase measurements, the computer generates an additional GO command requesting another set of four phase angle measurements until N sets have been sent. The computer then calculates the azimuth and elevation angles of arrival and transmits the information to the ASR/33 TTY unit. A timing diagram of the transmission sequence is shown in Figure 4. The interferometer sequencer with RF diode switches is shown in Figure 5(a).

## 2. Calibration and Operation Procedures

The basic program used in the DDP-516 computer to compute the azimuth and elevation angles of arrival for the ship site interferometer is almost identical to the program used in the existing Army interferometer work under contract DAABD7-67-C-0198.<sup>3</sup> Some program modifications

<sup>3</sup>Travers, D. N., Sherrill, W. M., Martin, P. E., Mathews, R. B., and Dodge, C., "Interferometer Direction Finder System for 2- to 10-MHz," Final Report for Contract No. ECOM-0198-F, Southwest Research Institute, March 1969.

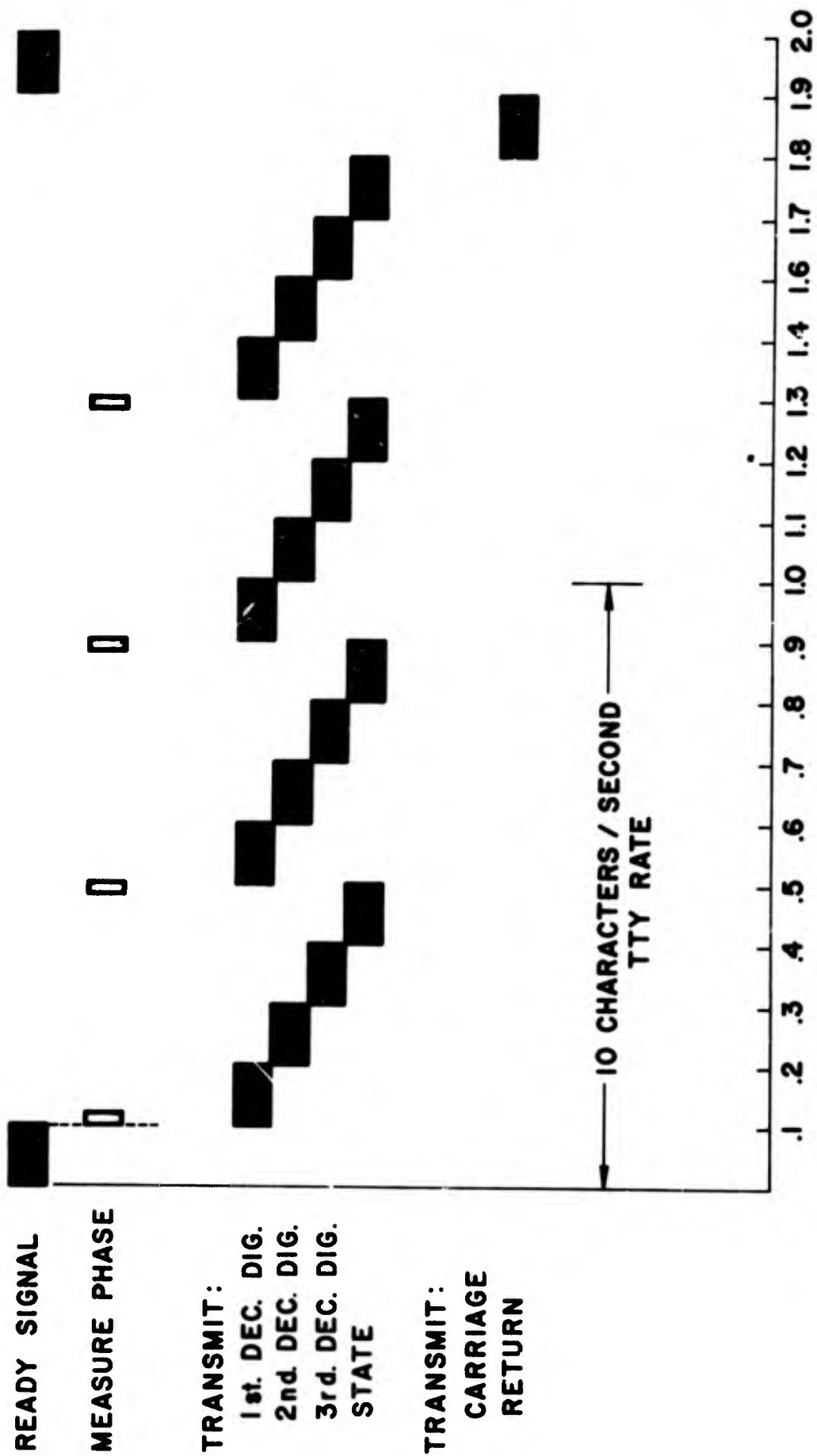
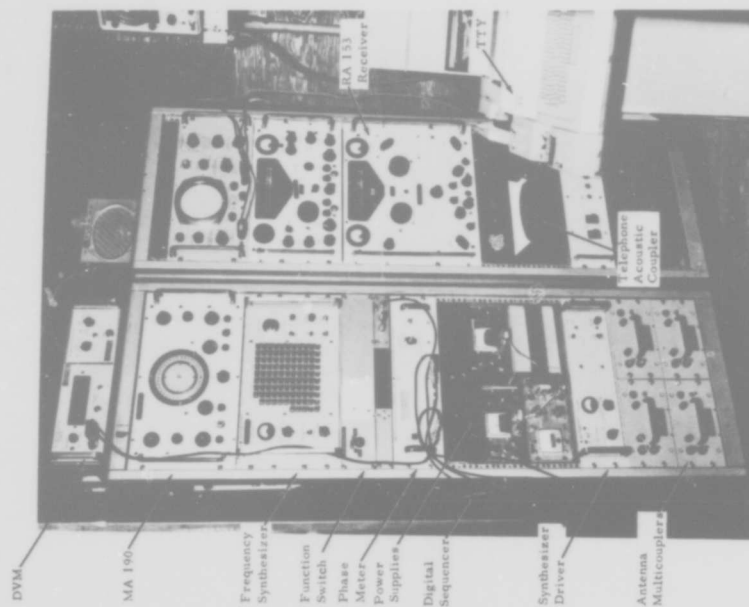
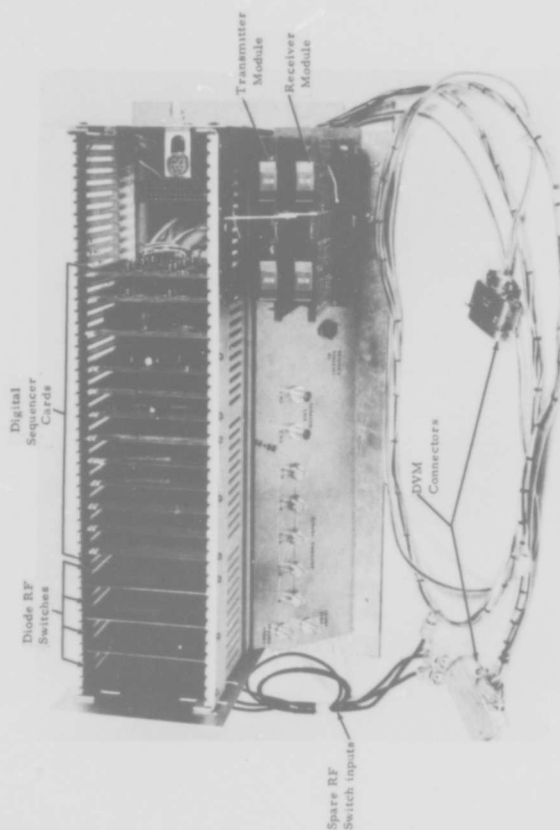


FIGURE 4  
DIGITAL SEQUENCER TIMING DIAGRAM





(b) SHIP SITE INTERFEROMETER EQUIPMENT GROUP



(a) RF AND DIGITAL SEQUENCER

FIGURE 5



were required to change the input data format to be compatible with the output data form from the ship site interferometer sequencer. In addition, the program was changed to generate the GO command and the use of a 0- to 360-degree phasemeter output rather than the  $\pm 180$ -degree phasemeter output used in the Army interferometer work. A teletypewriter printer listing of the complete program is shown in Appendix I.

To operate the interferometer at the simulated ship site, the program described above must be loaded from a disc file to the computer core memory. These units are located at the remote computer facility and the program transfer is accomplished with a minimum of procedural steps as described in Appendix II. An alternate method of loading the DDP-516 computer with the program for the ship site interferometer is to utilize the paper tape version of the program and load it manually into the computer. Procedures for accomplishing this loading technique are described in Appendix III. Figure 6 is a photograph of the DDP-516 computer and peripheral equipment at the remote facility.

Once the computer is loaded with the proper program, the remainder of the interferometer setup procedures and operation can be accomplished from the ship site laboratory area. The initial procedure is to calibrate the receiving circuits at the appropriate frequency of interest. This is accomplished using a frequency synthesizer preset for the frequency of interest and the mode selection switch in the CAL position. The calibrated signal is fed with equal amplitude and equal phase into both channels of the receiving circuits as shown in Figure 2. Since the twin-channel receiver and the other RF/IF circuitry are not perfectly phase and gain matched, compensating adjustments must be accomplished. By adjusting the phase and amplitude controls in the MA-190 unit, the Watson-Watt display can be set for equal amplitude and zero relative phase ( $\pm 1$ -degree resolution on the CRT in phase). The complete interferometer laboratory equipment group and the individual component identification are shown in Figure 5(b).

The remote computer is connected to the interferometer circuits by dialing the telephone number of the computer data set and placing the telephone receiver into the acoustic coupler when the answering tone of the computer data set is audible. When the connection is established, the computer program immediately transmits header questions displayed on the TTY printout. The header questions are answered by the interferometer operator and includes the following information; frequency, station call number, station call sign, operator number, time, selection criteria, and number of measurements to be performed. The answer to most of these questions is readily apparent; however, the last two header input requirements are explained in more detail below.

The program allows the operator to select the number of complete sets of phase measurements to be obtained by the computer before

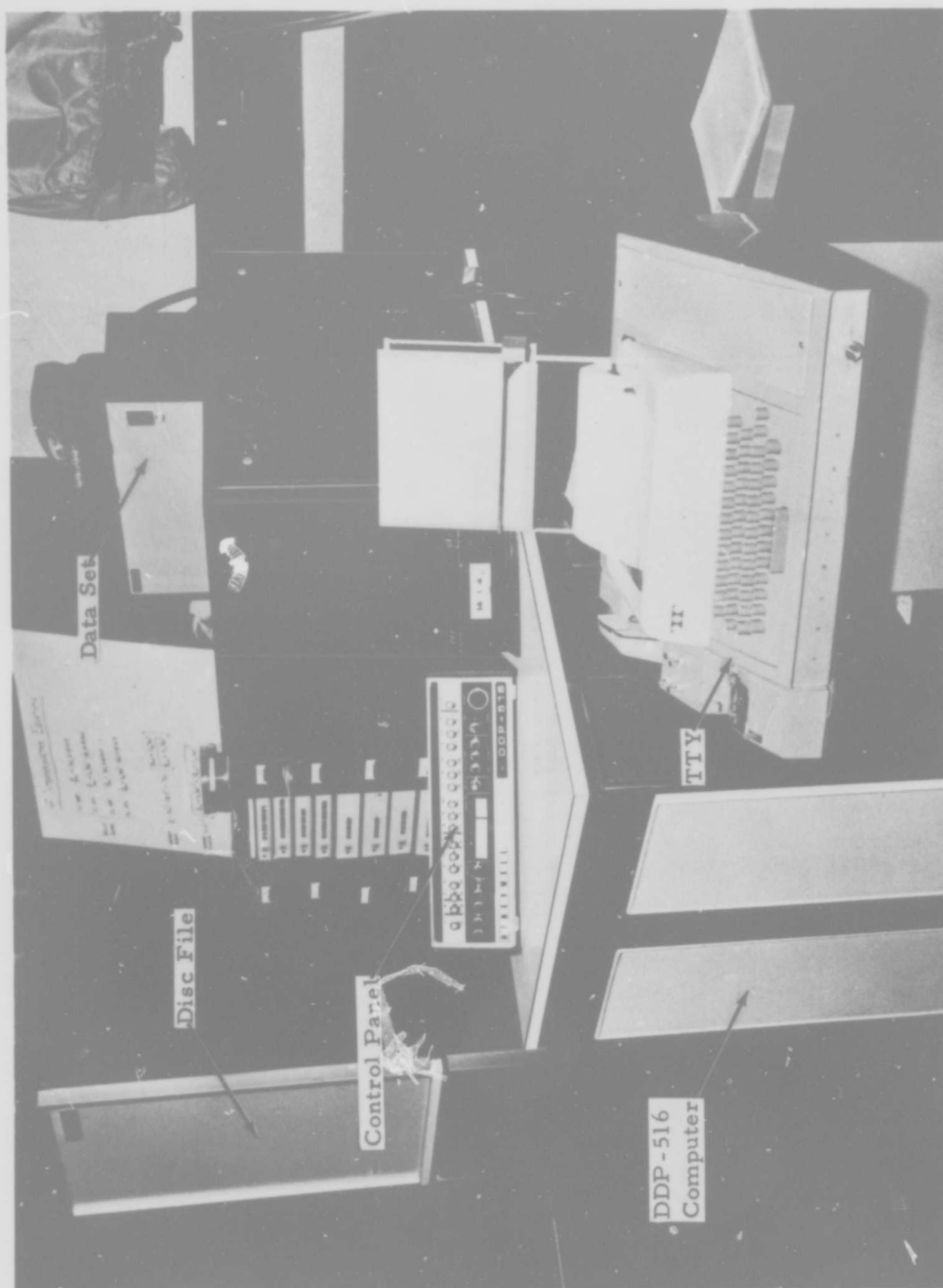


FIGURE 6  
DDP-516 COMPUTER AND DISC FILE

averaging these phase angles and computing the average azimuth and elevation angles of arrival. In addition, the program allows the operator to select the number of times this averaging sequence will be performed before further instructions.

A selection criterion option is also available to the operator which tells the computer whether to accept all frames of phase measurement data and compute the average azimuth and elevation angle of arrival or to accept only those frames of phase data which compute an elevation angle between 0 and 90 degrees. This selection option is necessary since during periods of severe multipath or wave interference effects across the interferometer aperture, the measured phase angles can compute elevation angles outside of the 0- to 90-degree quadrant, which is an obvious error. In order to eliminate these bad data computations from the averaging solution, the selection mode can be selected which rejects such data.

A typical TTY printout for the operation of the ship site interferometer on WWV at 10 MHz is shown in Figure 7. The header information is illustrated and several types of averaging options are shown. Note that the first set of data shown is for ten snap bearings (one set of four phase angles per bearing computation) on WWV at 10.0 MHz. The selection code P instructs the computer to accept all phase measurements regardless of the elevation angle computation. Elevation angles which are computed outside of the 0- to 90-degree quadrant are shown as -1 on the data printout. The computed azimuth angles are seen to vary from 312 to 342 degrees compared to the true great circle bearing (GCB) of 337 degrees for WWV from SwRI. The second data set results are for ten "good" phase angle sets (Q criteria) and the computed azimuth and elevation angles are realistic. It should be noted that the ten phase angle set average bearing solution can normally be obtained in 20 to 30 sec using the Q criteria. Since the TTY receiver is not blinded during the sequencer transmission, the state code and phase angle numbers are printed on the typewriter as they are sent over the dial telephone network to the computer. Figure 5 shows the format of this number group. Appendix IV lists the complete procedures for entering the header information into the computer.

### 3. Preliminary Sky Wave Measurements

The interferometer at the simulated ship site was operated briefly on sky wave signals in the automatic mode using the remote computer. The header information was set for the computer to obtain ten frames of valid phase angle measurements (Q criteria) and compute the average azimuth and elevation angle of arrival. In addition, the computer was pre-set to obtain sixty of the ten frame averages resulting in continuous data acquisition and computation on a specific frequency for approximately 30 min. WWV of Ft. Collins, Colorado was used as a medium range target (857 statute miles) at a true great circle bearing of 336.7 degrees from

FREQ. IN DESIRED  
COMPUTER FREQ.

FREQ. (MHz) 10.000: 10.0  
RUN NO. 3 16003: 000116000  
CALL NO. 777: DESIRED STATION  
CALL SIGN: CALL SIGN  
OPERATOR NO. 52:30  
TIME 1133

AZI ELEV. NO. NO. 0000000000  
MUTR FREQ. AVG. STOR: 0000000000

| SEL. NO. | NO.  | TIME |
|----------|------|------|
| 334.1    | 27.0 | 1    |
| 311.1    | 24.1 | 1    |
| 331.7    | 15.1 | 1    |
| 331.5    | -1.0 | 1    |
| 323.2    | -1.0 | 1    |
| 337.7    | 31.9 | 1    |
| 336.1    | 31.5 | 1    |
| 325.0    | 13.0 | 1    |
| 349.5    | -1.0 | 1    |
| 327.0    | -1.0 | 1    |

M120820533294262  
M128820533884088

| 334.1   | 36.4      | 10  | 1236 | 1053 | 2546 | 330  |
|---------|-----------|-----|------|------|------|------|
| AZIMUTH | ELEVATION | NO  | NO   | NO   | NO   | NO   |
| ANGLE   | ANGLE     | AVG | STOR | STOR | STOR | STOR |

FREQUENCY (MHz) 10.000:  
RUN NO. 3 16003: 000116000  
CALL NO. 777:  
CALL SIGN: :  
OPERATOR NO. 52:30  
TIME 1009

AZI ELEV. NO. NO. 0000000000  
MUTR FREQ. AVG. STOR: 0000000000

M1218203533014081  
M1207204833184322  
M1233208533334126  
M1254210032584175  
M1241208633124040  
M1255231732674237  
M1253204233164213  
M1230203533164036  
M1225203632884209  
M1221216333224171  
M1210206033004221

335.9 31.2 10 2081206204632164344  
M1275206133114128  
M128820533884088  
336.1 24.6 10 308116323178714341  
M128820533884088  
329.2 31.5 10 2081114914232114227  
M128820533884088  
328.1 29.2 10 2081114914232114227  
M128820533884088  
327.8 31.5 10 6081247211711111  
M128820533884088  
339.2 15.1 10 7581255911503554102  
M128820533884088  
335.3 35.7 10 081225204633014240  
M128820533884088  
333.8 29.4 10 058123123423314027  
M128820533884088  
340.1 31.9 10 113:

NOT REPRODUCIBLE

FIGURE 7  
TYPICAL SHIP SITE INTERFEROMETER TTY PRINTOUT

Southwest Research Institute. The station was monitored successively on the north-south oriented simple loops and the east-west oriented loops for approximately 30 min each between 1100 and 1300 hours CDT.

A linear plot of the computed azimuth angle ( $\phi$ ) and elevation angle ( $\psi$ ) is shown in the upper curves of Figure 8. The computed azimuth angles of arrival for both sets of loops show a tight grouping in a 10-degree region from 330 to 340 degrees GCB with the average being very close to the true GCB of 337 degrees. The east-west oriented loops have the maximum antenna response in the direction of the fore-aft line of the simulated ship superstructure and, therefore, are more susceptible to reradiation from the superstructure than the north-south oriented loops. A slightly increased scatter in azimuth for the east-west loops compared to the north-south loops could indicate some effect of the ship's superstructure on the east-west data. However, the scatter could equally arise from increased interference fading during the east-west loop measurement period (due to sky wave mode interference).

The computed elevation angle data for WWV show a distribution of angles primarily between 20 and 48 degrees. These results can be analyzed in terms of the presence of both one- and two-hop modes of varying uncorrelated amplitudes across the interferometer aperture. For example, if one takes the average low computed elevation angle (Figure 8) as approximately 25 degrees constituting a one-hop mode from Ft. Collins, Colorado, a midpoint ionospheric reflection height of 333-km is computed. Using the 333-km reflection height for a two-hop mode, a computed elevation angle is 43 degrees which is near the average high computed elevation angles. Therefore, the grouping of the computed elevation angles is consistent with the one-hop and two-hop analysis and would appear to be plausible for a midday measurement.

A second set of interferometer measurements was performed on WKB-20 in New Orleans at 10.46 MHz. This is an FSK station located on a GCB from Southwest Research Institute of 81.5 degrees at a distance of 534 statute miles. It should be noted that the GCB of 81.5 degrees is approximately in line with the fore-aft line of the ship superstructure (at 90 degrees true bearing). Therefore, the superstructure and reradiators were directly between the incident wave and the interferometer antennas.

For the WKB-20 data, the computed azimuth and elevation angles are shown in the lower curves of Figure 8. The azimuth angles are seen to be very closely grouped around the GCB of 81.5 degrees for both the north-south and east-west oriented loops. In addition, the elevation angle data show a tight grouping around an angle of approximately 33 degrees. The east-west oriented loops show slightly greater spread in elevation angle than the north-south oriented loops which might be attributed to the reradiation susceptibility of the east-west loops. The tight grouping of elevation

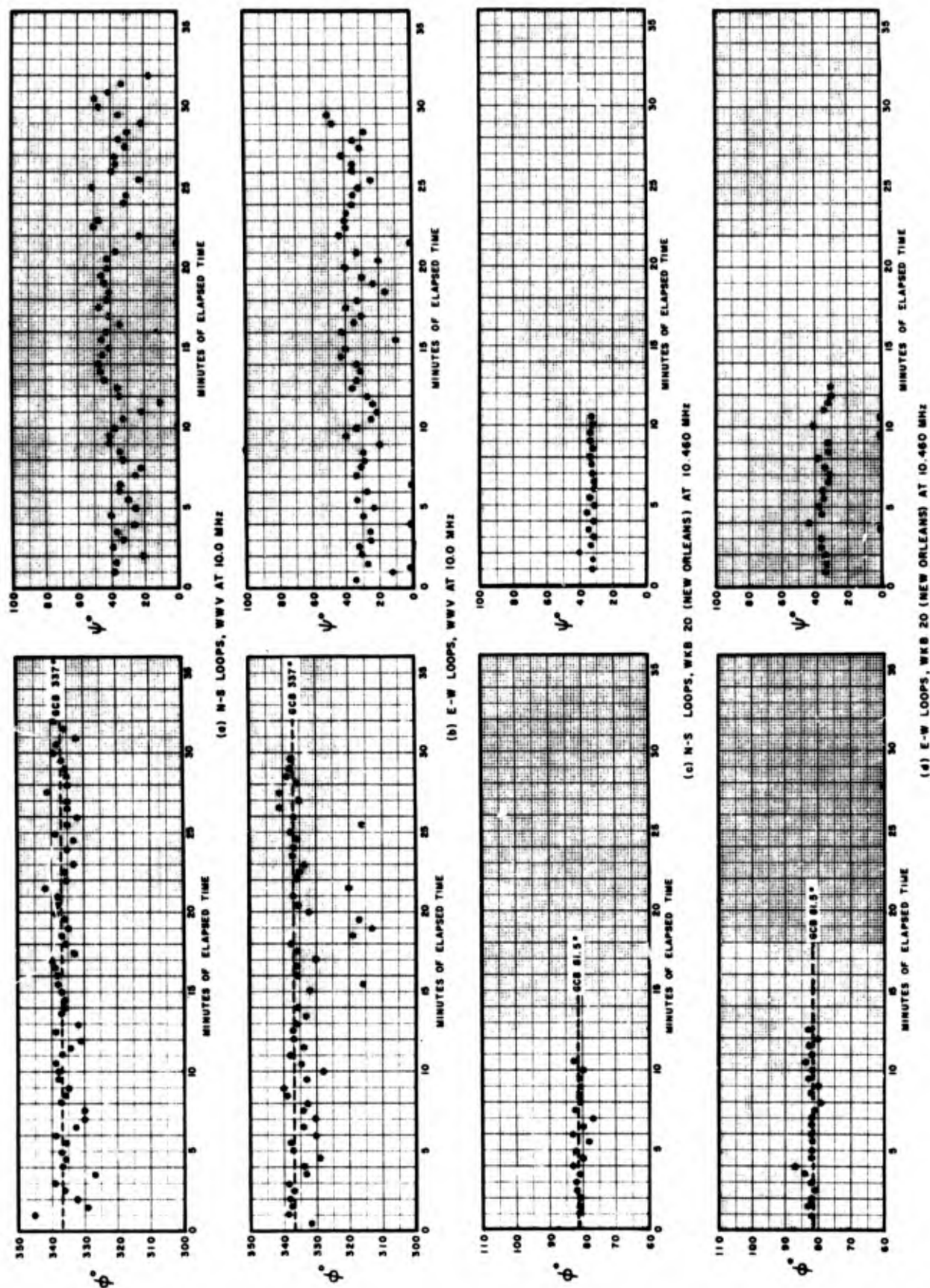


FIGURE 8  
SIMULATED SHIP SITE INTERFEROMETER SKYWAVE DF PERFORMANCE



angle data indicates a one-hop mode reception and stable propagation conditions during the measurement. Using an average elevation angle value of 33 degrees (Figure 8), a midpoint reflection height of 290 km is derived. This compares favorably with the 333-km reflection height computed in the WWV measurements at 10.0 MHz. These results demonstrate that the ship site interferometer operating at a frame rate of once per 2-sec period can provide sky wave DF performance in the presence of a ship's superstructure. The effects of the ship's superstructure were not apparent in this preliminary data analysis.

### C. Phase III - Automatic Shipboard Bearing Corrector

A simple demonstration of bearing correction technique for a polar CRT display is planned for the next interim reporting period. The technique will utilize extensively the digital sequencer and data transfer circuits developed for the simulated ship site interferometer and discussed previously in this report. In addition, the DDP-516 computer at the remote Army interferometer facility will be utilized on a noninterference basis. A simplified block diagram of the planned bearing corrector unit is shown in Figure 9.

The SwRI DF calibrator will be used in its normal mode with the observed bearing (OB) input from a cursor driven synchro at the CRT DF display. Similarly, the relative bearing (RB) input is fed from a synchro transmitter driven by an optical follower which manually tracks the target transmitter. The DC potentiometer outputs from the DF calibrator representing the instantaneous OB and DEVIATION will be fed in parallel to the calibrator X-Y plotter and to an analog FET multiplexer. Channel selection (OB or DEV) at the multiplexer is identical to the diode RF switch selection for the interferometer. Figure 9 illustrates the data output format with the OB and DEV alternately transmitted to the computer. Since the sequencer rate is designed to transmit one four-state decimal number word in 2 sec, the calibration storage rate will be one word (OB and DEV) per sec.

A program for the DDP-516 computer will be written to provide the store calibration data operation and the bearing correction calculation. For a simple demonstration, it is planned to store only one calibration data set for a specific frequency and then perform the bearing correction on any arbitrary OB for that frequency. The entire system operation will be performed from the simulated ship site facility with the corrected bearing readout shown on the teletypewriter printout.

The use of a remote computer and the relatively slow serial data transmission over telephone lines is necessitated by the amount of remaining project funds and the readily available equipment.

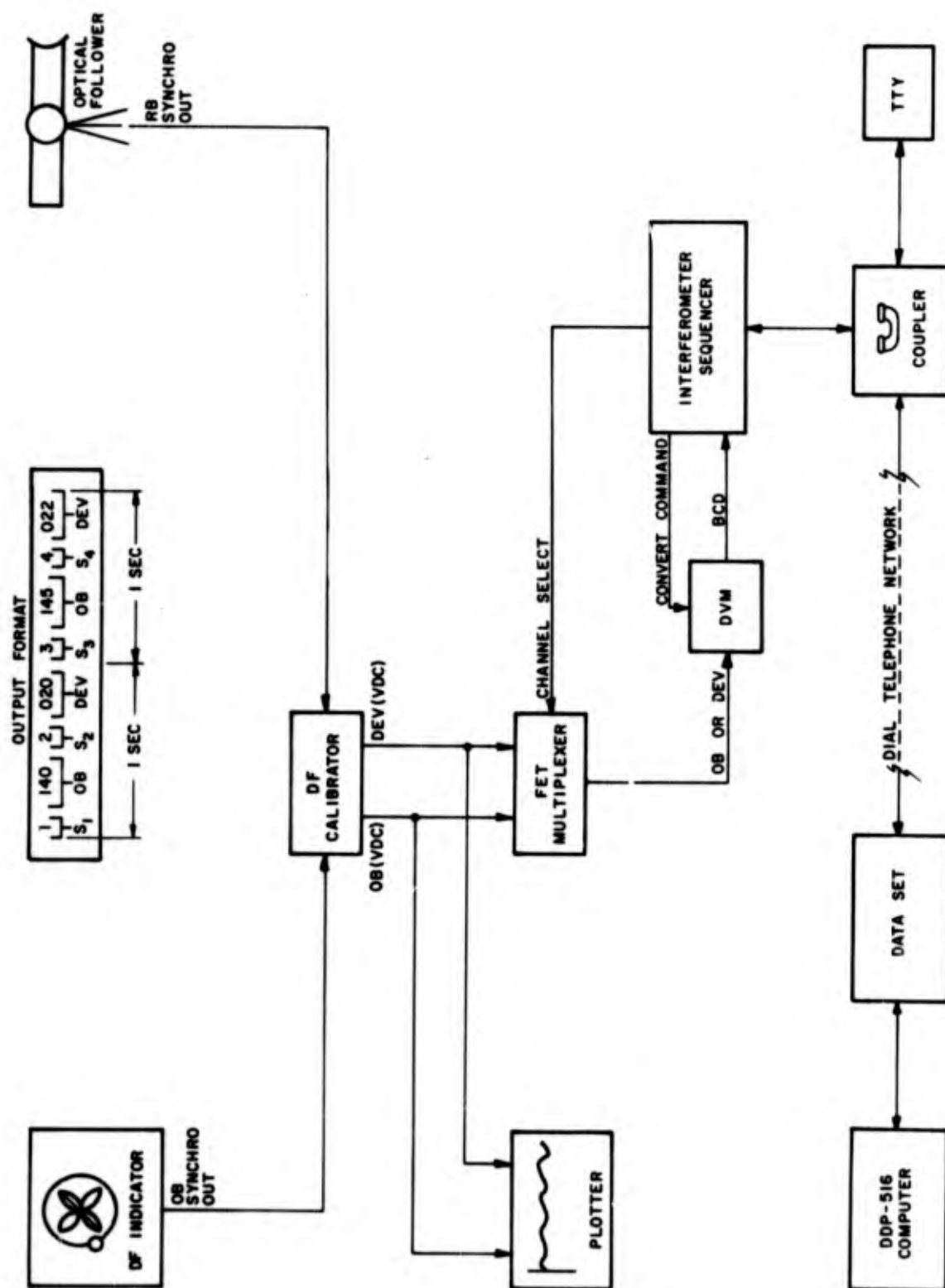


FIGURE 9  
AUTOMATIC BEARING CORRECTOR SIMPLIFIED BLOCK DIAGRAM



It is important to note that the operation of the existing DF calibrator and its integral digitizing circuits<sup>4</sup> with an on-site small computer such as the PDP8/L is considered by SwRI to be the optimum technique for the automatic bearing corrector. However, the electrical hard-wire interface of the existing calibrator to a computer is straightforward and well understood. On the other hand, the computer program for calibration data storage and observed bearing correction is unique to the bearing corrector development task. The program developed for the DDP-516 computer during the remaining contract period for the bearing corrector system demonstration will be directly usable\* in a small computer for future proposed work. Therefore, the development of bearing corrector computer program under this contract will greatly expedite the development of the proposed bearing corrector unit with an integral small computer.

---

<sup>4</sup>Sherrill, W. M., Lorenz, R., and Solberg, R., Jr., "LF to VHF Shipboard Direction Finding Research," Final Report for Contract No. NObsr 89167, Southwest Research Institute, June 30, 1968.

\*Slight modification of the program will be required since the proposed small computer will be operated directly in parallel data format with the DF calibrator rather than in serial data format over dial telephone lines.

### III. CONCLUSIONS

- The automatic operation of a five-element interferometer was successfully demonstrated in a simulated shipboard environment and included on-line bearing readout using a remotely located computer.
- Azimuth and elevation angle data for sky wave signals measured on the simulated ship site interferometer have shown accuracy consistent with known ionospheric lateral deviation effects.
- Azimuth error attributable to the ship's superstructure with the interferometer in its present aft position and baseline dimensions is estimated as less than  $\pm 5$  degrees for all sky wave signals measured.
- The data transfer rate of one phase angle set (four phase angles) per 2-sec period is adequate under most propagation conditions for CW or FSK sky wave signals. A faster data transfer rate and input editing circuits are mandatory for successful operation against sky wave signals with other modulation schemes.

#### IV. RECOMMENDATIONS

The following are recommendations regarding the ship site interferometer development:

1. Install an improved omnidirectional antenna element in the DF array. A quadrature-fed, crossed simple loop element is recommended for this application.
2. Install input data editing circuits on the interferometer for improved performance against communication modulations and wave interference conditions.
3. Perform exhaustive sky wave and airborne transmitter measurements with the interferometer in its present site to determine the effects of the ship's superstructure.
4. Obtain DF performance data for less optimum antenna element sites about the ship's superstructure using both on-the-air sky wave signals and local airborne target signals.
5. Investigate mast mounted DF antenna techniques for sky wave performance including the rotating spaced loop antenna and small aperture phase interferometers using crossed loop antennas.

## V. PROGRAM FOR THE NEXT INTERVAL

During the final period of this contract, the following work areas will be emphasized:

### Phase I - Ferrite Core Crossed Spaced Loop Antenna

DF calibration curves for the 2- to 32-MHz range will be obtained for the ferrite core spaced loop antenna installed at the simulated ship facility and compared to previously obtained clean site calibration curves.

### Phase II - Shipboard Interferometer

Work is completed on this project phase.

### Phase III - Automatic Shipboard Bearing Corrector

An automatic bearing corrector system utilizing the existing DF calibrator and interferometer digital sequencer will be designed and implemented. Emphasis will be on programming the remote DDP-516 computer for the calibration data acquisition and storage, and the bearing correction computation.

APPENDIX I

SIMULATED SHIP SITE INTERFEROMETER  
BEARING CALCULATOR PROGRAM

# APPENDIX I SHIP SITE INTERFEROMETER BEARING CALCULATION PROGRAM

```

INTEGER CALS,BLNK
COMMON/FLAG/IPQ,IUV,IDATE(3),KBL,KIT,IBL,BLNK
DIMENSION XX(4)
DIMENSION CALS(5),III(5),IVD(3)
DATA IS/1HB/,FREQ/6.3/,IRUN/0000/,ICAL/999/,CALS(1),CALS(2)
1,CALS(3),CALS(4),CALS(5)/5*2H  /,L1/1/,ITM/2400/
CALL CSASR
301 WRITE(1,103)FREQ
    READ(1,203)X
    IF(X) 403,403,402
402 FREQ = X
403 IRUN = IRUN +1
    WRITE(1,104)IRUN,(IDATE(I),I = 1,3)
    READ(1,204)K,(IVD(I), I = 1,3)
    IF(K) 404,405,404
404 IRUN = K
405 IF(IVD(L1) .EQ. BLNK) GO TO 325
    DO 324 K = 1,3
324 IDATE(K)= IVD(K)
325 WRITE(1,105)ICAL
    READ(1,204)K
    IF(K) 407,407,406
406 ICAL = K
407 WRITE(1,106)(CALS(K),K = 1,5)
    READ(1,205)(III(K),K=1,5)
    IF(III(L1) .EQ. BLNK) GO TO 321
    DO 322 K= 1,5
322 CALS(K) = III(K)
321 WRITE(1,107)IOP
    READ(1,206) IOPP
    IF(IOPP)408,409,408
408 IOP = IOPP
    ITM = KTME(ITM)
409 WRITE(1,108) ITM
109 FORMAT(5H0 AZI2X26HELEVA NO. NO. YM0REC0TIME/
1 20H MUTH TION AVG STOR,A2)
    WRITE(1,109)IBL
    KIT =1
366 READ(1,207) K1,IOPP,ICC,ITMM
    K = 1
    IC=1
    IF(K1 .EQ. 1H&) GO TO 367
    IF(K1 .EQ. 1HN) GO TO 301
    IF(K1 .EQ. 1HY) GO TO 362
    IF(K1 .EQ. 1HP) GO TO 310
    IF(K1 .EQ. 1HQ) GO TO 312
368 WRITE(1,110)IBL
110 FORMAT(20XA2)
    GO TO 366
310 IPQ = 1

```

```

      GO TO 362
312 IPO = 0
362 IF(IOPP)410,368,410
410 K = IOPP
367 IF(ITMM)411,412,411
411 ITM = ITMM
412 KBL = IBL
      IF(ICC)360,360,413
413 KBL = BLNK
      IC = ICC
360 CALL BESUB(ISC,FREQ,K,IRUN,ITM,ICAL,CALS,IOP)
      IF(K) 368,368,370
370 IC = IC -1
      IOPP = 2
      IF((IC .EQ. 1) .OR. (IOPP .EQ. 1)) KBL = IBL
      IF((IC .LE. 0) .OR. (IOPP .EQ. 1)) GO TO 366
      GO TO 360
101 FORMAT(6HREADY:)
103 FORMAT(14HFREQUENCY(MHZ),F6.3,1H:)
104 FORMAT(7HRUN NO.,I5,2X3A2,1H:)
105 FORMAT(8HCALL NO.,I5,1H:)
106 FORMAT(10HCALL SIGN ,5A2,1H:)
107 FORMAT( 13HOPERATOR NO.  I2,2H: )
108 FORMAT(5HTIME I4)
203 FORMAT(F!0.2)
204 FORMAT(I4,3A2)
205 FORMAT(5A2)
206 FORMAT(I2)
207 FORMAT(A1,I4,I3,I4)
      END
SO
      SUBROUTINE BESUB(ISC,FREQ,K,IRUN,ITIME,ICAL,CALS,IOP)
      INTEGER CALS,BLNK
      DIMENSION SSP(4)
      COMMON ITM(150),SP(4,150)
      COMMON /FLAG/IPO,IUV,IDATE(3),KBL,KIT,IBL,BLNK
C:BEARING PROGRAM
      DIMENSION P(4),D(4),CALS(5),ALFA(2)
      DATA D(1),D(2),D(3),D(4)/12.2,32.,12.2,82.2/,RAD/57.29578/
      1,ALFA(1),ALFA(2)/180.5,270.5/
      DATA ISTORE/150/
      KK = 0
      KP = 0
      IF(KIT .EQ. 1) GO TO 309
      IF(K) 299,300,307
300 K=1
309 ICNT = -1
C  STORE UNAMBIGUOUS PHASE ANGLES
      KIT = 2
307 HLF=150./FREQ

```

```

301 IF(KK - K)451,320,320
451 ICNT = ICNT +1
    KK = KK+1
    KS = MOD(ICNT,ISTORE)+1
    ITM(KS) = ITIME
    CALL BEAR(SP(1,KS),IRR,ISE)
    IF(IRR-1)302,310,302
310 CALL PHIPSI(DMY,TMP,SP(1,KS),D,RAD,HLF,ALFA)
    IF(IPQ)452,452,301
452 IF(TMP) 453,301,301
453 ICNT = ICNT-1
    KK = KK-1
    KP = KP+1
    IF(KP -33) 301,301,302
302 K =KK
    IF(K)370,370,320
370 XBEA = -1.
    ELV = -1.
    KBL = IBL
    GO TO 371
320 DO 321 I=1,4
321 SSP(I) = 0.
    KF = 1
    IMK = ICNT -K +1
    IMK = MOD(IMK,ISTORE)+1
    I = IMK
    J = KS
    IF(KS-IMK)454,333,333
454 KF = 2
    J = ISTORE
    GO TO 333
343 I =1
    J = KS
    KF =1
333 DO 340 M = I,J
    DO 340 N = 1,4
340 SSP(N) = SP(N,M)+SSP(N)
    GO TO (342,343),KF
342 XT = K
    DO 344 I = 1,4
344 P(I) = SSP(I)/XT
    GO TO 597
299 KGZ = IABS(K)
    IF((KGZ .GT. ISTORE) .OR. (ICNT-KGZ+1 .LT. 0))RETURN
C   KS EXIST FROM PREVIOUS ENTRY AND IS LOCATION OF MOST RECENT
C   ITEM IN STORE.
C   LOCATE EARLIEST ITEM TO BE PUNCHED OUT.
    WRITE (2,399)IRUN,FREQ,ISE,ICAL,(CALS(I), I = 1,5),IOP,KGZ,D
    1,ALFA,(IDATE(I) , I = 1,3)
399 FORMAT(I4,F7.3,1XA1,I6,1X5A2,I3,I5,4F7.2/2F7.2,1X3A2)

```



```

      KF = 1
      IMK = ICNT -KGZ +1
      IMK = MOD(IMK,ISTORE)+1
      I = IMK
      J = KS
      IF(KS - IMK)355,360,360
355  KF = 2
      J = ISTORE
      GO TO 360
361  I = 1
      J = KS
      KF = 1
360  WRITE(2,400)(ITM(M),(SP(N,M),N = 1,4),M=I,J)
400  FORMAT(14,1X,4F11.3)
      IF(KF- 2)356,361,356
356  CALL PUNOF
      RETURN
597  CALL PHIPSI(XBEA,ELV,P,D,RAD,HLF,ALFA)
      KP = ICNT+1
371  IF(ICNT .GE. ISTORE -1) KP = ISTORE
      WRITE(1,72)XBEA,ELV,K,KP,KBL
      RETURN
72  FORMAT(2F6.1,2I4,A2)
      END
SO
      SUBROUTINE BEAR(PA,IER,ISEO)
      INTEGER CHNL,STATE,BLNK
      COMMON/FLAG/IPQ,IUV,IDATE(3),KBL,KIT,IBL,BLNK
      DIMENSION P(4)
      DIMENSION KIA(4)
      DIMENSION IP(4),KZ(4),A(4)
      EQUIVALENCE (KZ(2),KIA(1))
      DATA KIA(1),KIA(2),KIA(3),KIA(4)
      9/2,3,4,1/
      DATA KZ(1),KZ(2),KZ(3),KZ(4)
      2/1,2,3,4/
1   DO 23 IC = 1,4
      P(IC) = 0.
23  IP(IC) = 0
      ITS = -1
      KT = 0
      KDLAY = -1
      KIC = 0
      K = 1
      I = 2
26  CALL ANIN(KIC,IV,IER,STATE)
      IF(IER .EQ.1) GO TO 22
17  IER = 3
      RETURN
22  IF(STATE)17,26,24

```

```

24 IF(ITS)29,31,31
29 D0 299 IC = 1,4
   IF(STATE .EQ. KIA(IC))G0 T0 300
299 CONTINUE
   G0 T0 26
300 ITS = STATE
   I0R = STATE
   G0 T0 26
31 IF(STATE .EQ. I0R) G0 T0 50
   IF(STATE .NE. KIA(I0R)) G0 T0 26
   IF(STATE .NE. ITS) G0 T0 49
   D0 60 IC= 1,4
   IF(IP(IC) .NE.0)G0 T0 60
C   SC = SHORT CYCLE; START.
C   THE SEQUENCE FROM HARDWARE DID NOT PROVIDE THE PHASE
C   ANGLES EXPECTED BY THE PROGRAM.
   G0 T0 1
60 PA(IC) = P(IC)/FLOAT(IP(IC))
   RETURN
49 I0R = STATE
   IF (KT .EQ. 0) ITS =STATE
   KT = -1
   KDLAY = KDLAYV
50 IF(KDLAY)26,51,52
52 KDLAY = KDLAY-1
   G0 T0 26
51 KS = KZ(STATE)
   IF(KS .EQ.0) G0 T0 20
   V = IV
   P(KS) = P(KS)+V
   IP(KS) = IP(KS)+1
20 CONTINUE
   G0 T0 26
   END
S0
SUBROUTINE PHIPSI(PHI,PSI,PM,DIS,DMY,HLEWV,ALPHA)
DIMENSION PM(4),DIS(4),N(4),ALPHA(2)
DATA RAD/57.2957795/
D0 110 L=1,4,1
IF (PM(L) .GT. 180.) PM(L)=PM(L)-360.
110 CONTINUE
D0 16 J=2,4,2
TEST = PM(J-1)*DIS(J)/DIS(J-1) - PM(J)
IF(TEST .LT. 0.)TEST =TEST -360.
T =TEST/360.+0.5
N(J) = T
16 CONTINUE
P2 = PM(4)+360.*FLOAT(N(4))
P1 = PM(2)+360.*FLOAT(N(2))
TEST = P2*DIS(2)*COS(ALPHA(1)/RAD )-P1*DIS(4)*COS(ALPHA(2)/RAD )

```

```

TESTL = P1*DIS(4)*SIN(ALPHA(2)/RAD)-P2*DIS(2)*SIN(ALPHA(1)/RAD )
PHI=AMOD(360.-ATAN2(TEST,TESTL)*RAD,360.)
TEST = SQRT((DIS(4)*P1)**2 +(DIS(2)*P2)**2 -2.*DIS(2)*DIS(4)
1      *COS(ALPHA(2)/RAD-ALPHA(1)/RAD))/(180./HLFW*DIS(2)*DIS(4)
2      *SIN(ALPHA(2)/RAD-ALPHA(1)/RAD))
IF ((TEST .GT. 1.) .AND. (TEST .LT. 1.001)) TEST=1.
IF (TEST .LE. 1.) GO TO 23
GO TO 17
23 PSI=ACOSF(TEST)*RAD
RETURN
17 PSI=-1.
RETURN
END
FUNCTION ACOSF(X)
ACOSF=ATAN(SQRT(1./X/X-1.))
RETURN
END
SO
SUBROUTINE ANIN(NS,IPM,IER,K)
DIMENSION KS(4),IP(4)
NS = NS +1
IER = 1
GO TO (1,2,2,2,2,3),NS
1 IPM = 0.
K = 4
READ(1,34)(KS(I),IP(I),I = 1,4)
34 FORMAT(4(I1,I3))
RETURN
2 IPM = IP(NS-1)
K = KS(NS-1)
RETURN
3 IPM = 0.
K = 1
RETURN
END
SO
SO
SUBROUTINE CSASR
C THIS ROUTINE INSERTS A LINE FEED TO CONTINUE TYPING FROM THE KEY
C BOARD AFTER LEFT ARROW.
CALL OSAP
RETURN
END
SO
BLOCK DATA
INTEGER BLNK
COMMON/FLAG/ IPO,IUV,IDATE(3),KBL,KIT,IBL,BLNK
DATA IPO,IUV/2*0/,IDATE(1),IDATE(2),IDATE(3)/2H09,2HJL,2H69/
1,BLNK/2H /,IBL/-17785/

```

```
END  
$0  
FUNCTION KTME(K)  
KTME = K  
RETURN  
END  
$0
```

**APPENDIX II**  
**DISC FILE LOADING PROCEDURES**

## APPENDIX II

### DISC FILE LOADING PROCEDURES

These procedures are accomplished at the DDP-516 facility. Switch functions are accomplished at DDP-516 control panel.

- (1) Remove Bootstrap tape from library and place on load reel.
- (2) Switch DDP-516 control to Single Instruction (SI).
- (3) Place tape leader in paper tape reader and close gate.
- (4) Depress Master Clear Switch.
- (5) Select Register P.
- (6) Depress Octal 1 (Bit 16) on Display Register.
- (7) Switch DDP-516 control to Run.

After tape loading is completed, the program should be selected from the Disc File as follows:

- (8) Switch DDP-516 control to SI.
- (9) Depress Master Clear.
- (10) Place Octal 17700 into Display Register.
- (11) Switch DDP-516 control to Run.
- (12) Depress Start Switch.

The TTY printout and operator answers are shown below:

TTY: Select I, U, P, L

Operator: L

TTY: Select R, W, other (CR)

Operator: SHIPIN

TTY: Ready

Operator then depresses Start on DDP-516 Control Panel and program is started. Remote operation can then be implemented.

APPENDIX III  
MANUAL LOADING PROCEDURES

### APPENDIX III

#### MANUAL LOADING PROCEDURES

These procedures are accomplished at the DDP-516 facility. Switch functions are accomplished at DDP-516 Control Panel.

- (1) Remove SHIP I tape from library and place on load reel.
- (2) Switch DDP-516 control to Single Instruction (SI).
- (3) Place tape leader in paper tape reader and close gate.
- (4) Depress Master Clear Switch.
- (5) Select Register P.
- (6) Depress Octal 1 (Bit 16) on Display Register.
- (7) Switch DDP-516 control to Run.
- (8) Depress Start Switch.

After tape loading is completed, the program should be started as follows:

- (9) Switch DDP-516 control to SI.
- (10) Depress Master Clear.
- (11) Place Octal 1000 (Bit 7) into Display Register.
- (12) Switch DDP-516 control to Run.
- (13) Depress Start Switch.
- (14) TTY printer should print out Frequency:. Computer can then be operated from simulated ship interferometer TTY unit.



APPENDIX IV  
TTY CONTROL OF SHIP SITE INTERFEROMETER

## APPENDIX IV

## TTY CONTROL OF SHIP SITE INTERFEROMETER

The following paragraphs describe the operator's response to the TTY header questions for operating the ship site interferometer using the remote computer.

(1) Frequency (MHz) - If the intercept to be taken is on the same frequency as the previous intercept, confirm the frequency by pressing RETURN. To change to a new intercept frequency, type the frequency in MHz, taking care to enter a decimal point, and then press RETURN.

(2) RUN NO. - The RUN NO. which is the four digits following the period is increased by one each time the START command is given. The data follow, e. g., 26AU68. The date or run number may be changed by simply typing the desired run number--date combination after the colon, such as: 123427AU68 (no spaces between run and date when typed), followed by a RETURN. Such a command would result in the following characters appearing after the RUN NO. on the next run: 1235 27AU68. The general rule is: confirm the run number and date by pressing return, or change the run number by entering a four-digit number and change the date by entering a new six-character date. The run may be changed without retyping date; date will then remain the same.

(3) CALL NO. - This is the arbitrarily assigned call number for station being monitored. This four-digit integer provides a frequency station identification number and will remain the same until the operator goes to a new intercept and types in a new identification number followed by a RETURN.

(4) CALL SIGN - Confirm the station call sign if the intercept to be taken is the same as previously taken by pressing RETURN or enter up to 10 characters for the new intercept call sign and then press RETURN.

(5) OPERATOR NO. - If the same operator has remained at the console, confirm the previous operator identification by pressing RETURN, or change the operator number by typing any two digits.

(6) TIME - The operator should enter a new four-digit number indicating the time of a 24-hr day at which the bearing collection is started. Press the RETURN key and the teleprinter will type a two-line heading followed by a colon to left of the heading YMORECONTIME.

The first two columns of the heading are the bearing (an azimuth and elevation). In the third column titled NO. AVG is the number of sets of four phase angles which were averaged to obtain the bearing. The fourth column

is the total number of sets of phase angles stored in the computer memory. (The computer is programmed to hold the latest 150 sets; if an operator attempts to exceed this limit, the oldest sets are replaced by those taken most recently.)

Under the heading YMORECONTIME, the operator types information commanding the machine to take more bearings, print some or all of the bearings on a paper tape, or abort the task. In any case, the operator types the necessary information and the computer starts the task as soon as the operator presses the RETURN key.

If it is desired to take more bearings, type a P following the colon followed by a four digit number under MORE which instructs the computer how many sets of phase angles to average before computing the bearing. Follow this averaging instruction with a three-digit number to instruct the computer to CONTinue the instruction under MORE\_\_\_ times. Beneath TIME, enter the 24-hr time at which the intercept is initiated. Then press RETURN and the computer will start its task. The P designation instructs the computer to accept all sets of phase analysis. A Q may be used in place of P to instruct the computer to reject those phase sets which compute elevation angles outside the 0- to 90-degree quadrant.

If some of the bearings are to be punched on paper tape for analysis, type a Y- followed by a three-digit number (up to 150) describing how many of the most recent stored bearings are to be punched on tape. Once the RETURN key is pressed, the paper punch will start.

If the task is to be aborted, type N beneath the Y in the YMORECONTIME heading and press the RETURN key. The computer will return to READY command.