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Final Report

RADC TRINIDAD-ROME SATELLITE COMMUNICATION LINK

Rodney C. Pratt

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Communications Research Branch
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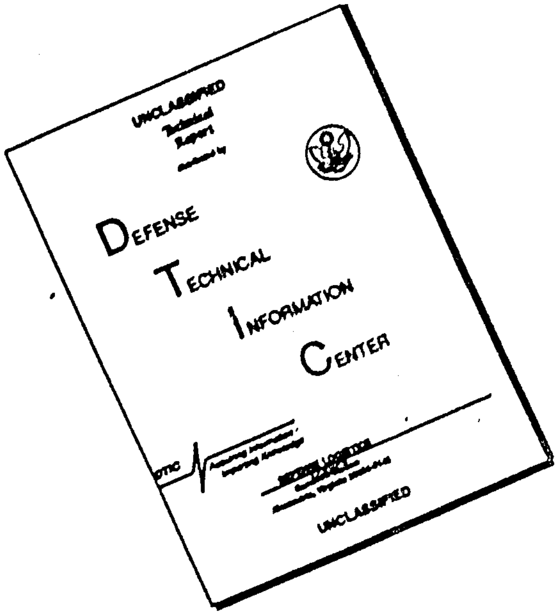

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RADC TRINIDAD-ROME SATELLITE COMMUNICATION LINK

Rodney C. Pratt

FOREWORD

The author wishes to express his appreciation for the work accomplished by the members of the CTS crew who manned the Floyd and Trinidad Sites and performed the many tasks necessary to place the equipment in working order.

This technical report has been reviewed and is approved.

Approved: PHILIP T. DUESBERRY, Major, USAF
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Colonel, USAF
Chief, Communications Division

FOR THE COMMANDER: IRVING J. GABELMAN
Chief, Advanced Studies Group

ABSTRACT

This report describes the facilities at Rome and Trinidad which are used to perform communication experiments using the Echo type satellites. These facilities have undergone many modifications over the past five years and this report describes the facility as it presently exists. The Rome and Trinidad facilities provide a duplex communication link when used with passive satellites. The communication for this link is accomplished at S band while tracking at Trinidad is dependent upon a 427 mc radar set. There have been some unique developments in providing this capability with work continuing on a high power dual frequency feed. The Trinidad facility will be closed down by 30 June 1965 but the Floyd facility will be retained for future work.

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INTRODUCTION

The first satellite communication experiments were conducted at RADC at the launching of the Echo I satellite. The test bed for these experiments was a simplex space communication link with the transmitting terminal located at Trinidad, West Indies, and the receiving terminal located at the RADC Floyd Site located near Griffiss Air Force Base, New York. The original facilities were constructed under Contract AF30(602)-2016, "Space Communications Techniques," by the Philco Corporation. The facilities, as they existed at that time, are described in RADC-TN-60-59 by Mr. James E. McFee and later by three technical notes submitted by the Philco Corporation in November 1960. The report on "Experimental Passive-Satellite Communication Link," RADC-TN-60-281A, gives some of the results of the Echo I experiments such as received signal level analysis and the results of TTY, tone and voice modulation tests.

After a period of testing, using the Echo I satellite, both sites were closed down to permit a modification program designed to increase the versatility of the link. A contract was awarded to Page Communications Engineers, Inc., to carry out the new work under Contract AF30(602)-2403. The modifications made under this contract include the following:

1. Making the simplex link into a duplex link.
2. Installation of boresight cameras at each tracking antenna to provide records of satellite tracking accuracy.
3. A pulse mode transmitting and receiving capability, at Trinidad, to allow self checking of the antenna pointing accuracy.
4. A track on communication signal capability for the Floyd terminal.
5. An optical tracking capability for the Floyd terminal.
6. Two gc receivers installed at each site with increased sensitivity over the previous equipment.
7. Frequency measuring equipment of increased accuracy to measure the doppler effect.

An analysis of the tracking accuracies achieved at the Trinidad and Floyd Sites was made using the new boresight cameras. The result of this analysis is contained in the Page Communications Engineers, Inc. final report, RADC-TDR-63-111, which is Reference 5.

In the course of making the above modifications, it has been possible to retain all of the original capability of the link. This report will deal with a description of both Space Communications Terminals as they exist at this time.

Analysis of the type of data collected in the performance of the doppler effect measurement using Echo II is contained in a technical documentary report by Edward Cossette. This report is entitled "Analysis of Doppler Data from Echo II," RADC-TDR-64-444 which is Reference 7.

EXPERIMENTAL DUPLEX SATELLITE COMMUNICATION LINK

The two terminals of the experimental link are located at the Trinidad Atlantic Missile Range Tracking Station at the U.S. Naval Station, Chaguaramas, Trinidad and Tobago and the RADC Floyd Site located approximately five miles from Griffiss AFB. Transmission from Trinidad to Floyd is accomplished at 2270 mc and from Floyd to Trinidad at 1840 mc. Both terminals use common antennas for transmission and reception of signals with specially constructed feeds and filters used to allow the duplex operation.

The transmitters are both of the AN/FRC-56 type using frequency modulation and having 10 kw average power output. The receivers at both terminals have parametric amplifier first stages with a noise figure of approximately 1.5 db. There are two complete receivers at both terminals which provide information outputs from both the vertically and horizontally polarized received signals plus an IF combined output.

The tracking of the satellite from the Trinidad terminal is accomplished entirely by the BMEWS type radar tracker. The communication feed is mounted in this tracker dish so that the radar and communication patterns are concentric. The tracking from the Floyd terminal is accomplished by a choice of the following three methods:

1. Monopulse tracking of the radar signal scattered from the satellite which is illuminated from Trinidad.
2. Conical scan tracking of the communication signal scattered from the satellite which is illuminated from Trinidad.
3. Optical tracking of the satellite by use of a Mark 51 gun director which controls the antenna mount. (This can be accomplished only when the satellite is illuminated by the sun at night and the weather is favorable.)

At Trinidad, the tracking accuracy can be further checked by transmitting in the 2 gc pulse mode and peaking up on the return.

The data at the two sites is recorded on a combination of chart recorders, tape recorders and digital printers. At Floyd, an additional 14-channel FR-100 tape recorder is used to duplicate the chart recorded data to aid in rapid analysis.

The experiments run on the Floyd-Trinidad link include:

1. Path loss measurement

2. Doppler effect measurement
3. Sig' al statistics measurements
4. Noise statistics measurements
5. Modulation tests

Figure 1 is a diagram showing configuration of the Trinidad-Floyd link.

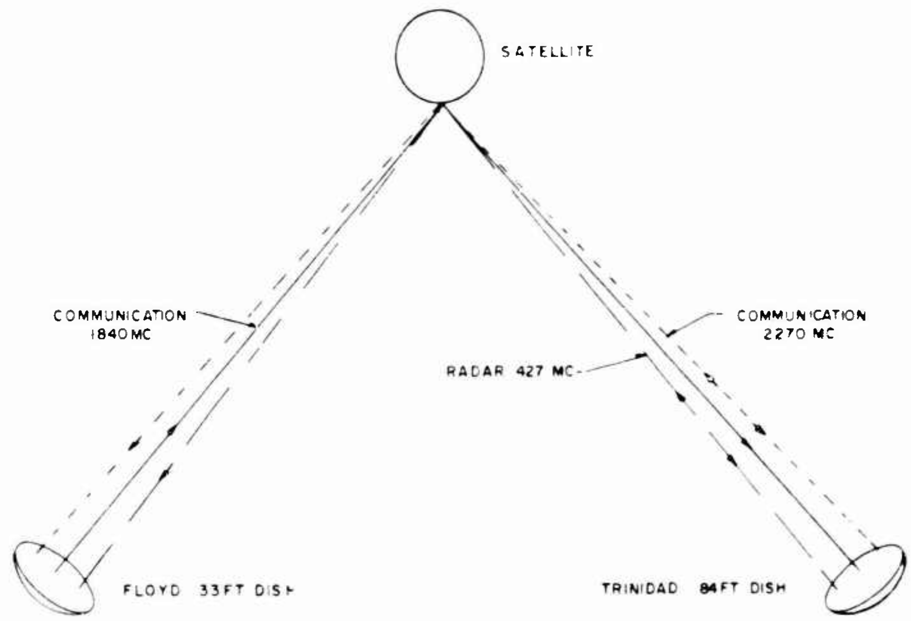

Figure 1 - Diagram of Trinidad-Floyd Link

Description of the Floyd Terminal

I. Parabolic Reflector and Mount

The reflector at the Floyd terminal is a 400-inch diameter paraboloid having an F/D ratio of 0.425. The construction is made up of 20 main radial ribs with 20 radial half ribs in the outer portion of the dish. The assembly is laced together with aluminum tubing to add rigidity. The skin covering is made up of 1/4 inch aluminum open mesh which is riveted to the supporting framework. The surface tolerance, as measured at the factory, deviated from a true paraboloid by not more than $\pm 1/16$ inch. The surface has not been remeasured since assembly and erection at the Floyd site. The antenna system has 3 db beamwidths at the following frequencies of interest:

Receiving at radar frequency of 427 mc - 5^{o} 36'
Receiving S-band frequency of 2270 mc - 55'
Transmitting S-band frequency of 1840 mc 1^{o} 2'

The mount used with this r·flector is a converted mark 32 Model 4 Twin 5 inch/38 caliber gun mount. The mount has been modified such that the maximum angular rate in azimuth and elevation which can be reached is ten degrees per second. The maximum acceleration in azimuth and elevation is three degrees per second per second.

The reflector and gun mount are mounted upon a 35 foot high concrete tower. Access to the tower is gained by use of a steel ladder fastened to the inside wall of the tower.

A photograph of the Floyd antenna system is shown in Figure 2.

Antenna Feed System

The feed system for the Floyd antenna has some unusual requirements since, like the Trinidad feed, it must receive on two S-band frequencies plus track on the 427 mc radar frequency. This feed has the added requirement that it must provide for tracking of reflected signals from satellites at the communication frequency of 2270 mc.

The arrangment for the S-band feed is a four-horn cluster in a square formation mounted at the focal point of the 400-inch antenna. The radar tracking utilizes four spiral antennas, in a monopulse configuration, mounted directly around the S-band feed. Tracking at S band is accomplished by use of an artificial conical scanning system while the radar tracking uses monopulse tracking.

The characteristics of the feed system are as follows:

1. The S-band portion of the feed system has a frequency range from 1700 to 2400 mc.
2. Transmitted signal is horizontally polarized with a minimum power rating of 10 kw average power. (Transmit beam does not scan and is on axis.)
3. May receive both horizontally and vertically polarized signals at 2 gc.
4. May track either horizontally or vertically polarized signals at 2 gc.
5. Transmission at 1840 mc and reception at 2270 mc may be performed simultaneously.
6. Operation of the 427 mc monopulse feed is not affected by use of S-band feed.

Figure 3 is a photograph of the feed package.

2 Gc Tracking System

The 2 gc tracking system is unusual in that it is a conical scan system where the scanning is accomplished synthetically. The feed configuration, as described above, is identical to the type used in a monopulse system but electrically the effect is the same as with conical scan tracking. The scanning is generated by a rotating phase shifter inserted in the difference

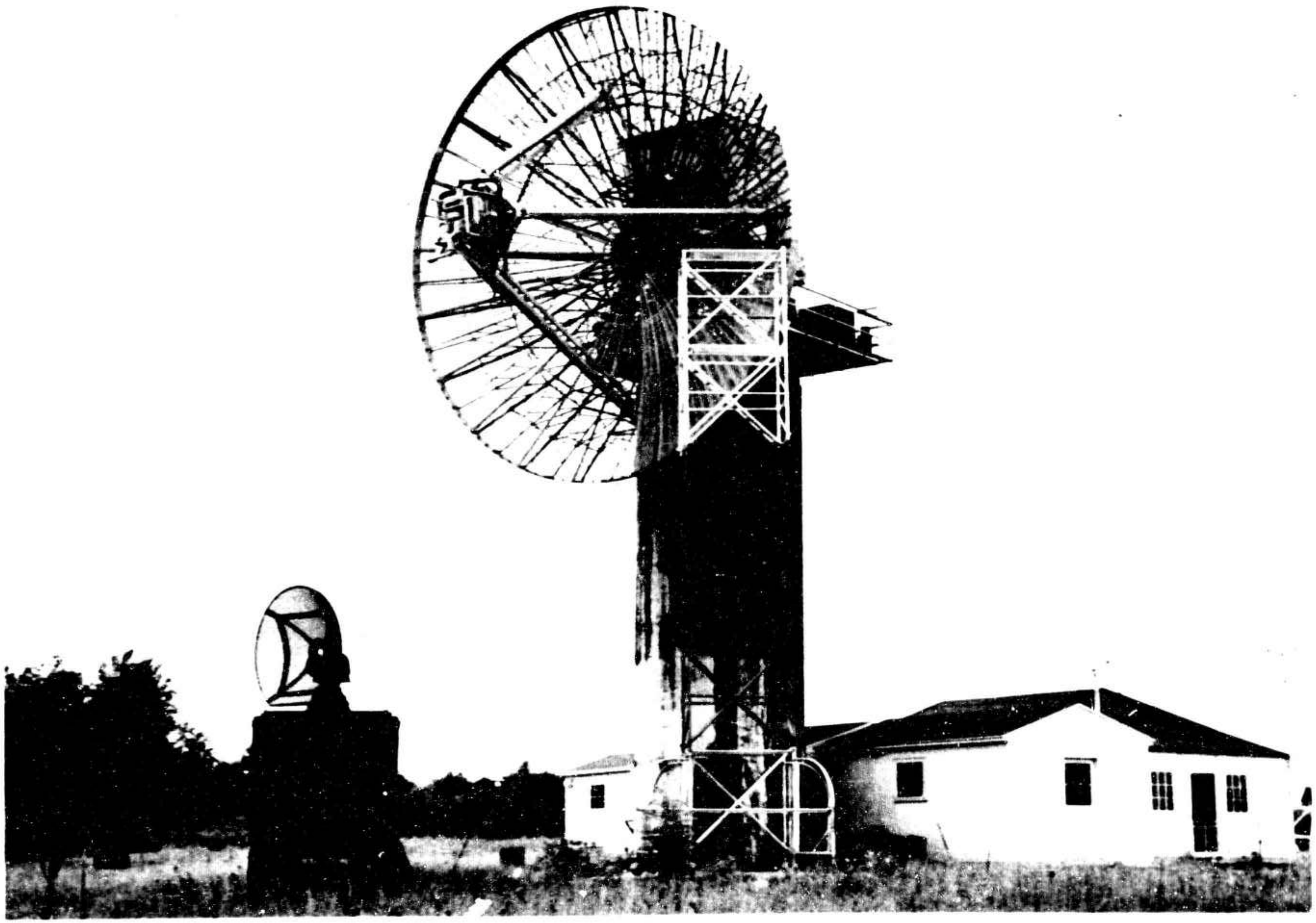

Figure 2 - Photograph of Floyd Antenna System

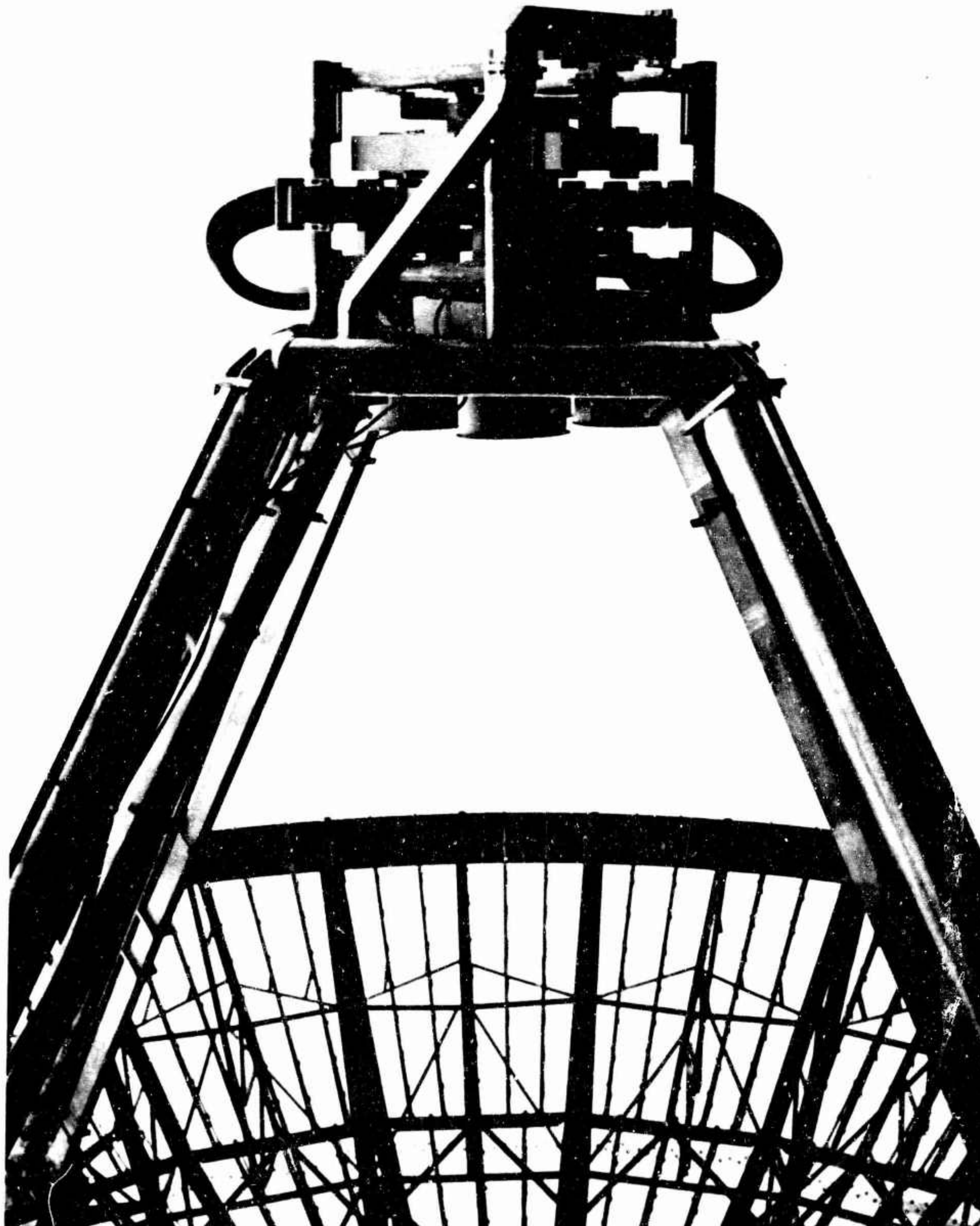

Figure 3 - Photograph of Floyd Feed Package

channel which gives the effect of a continuous scan and not sequential lobing. Sequential lobing would be unsatisfactory for this purpose as this channel is also used for communication and lobing would put holes in the information.

Synthetic conical scan has the advantage over conventional conical scan in that the feed has no moving parts and therefore does not cause vibration to degrade tracking. It has the same advantage over monopulse as conventional conical scan; only one receiver is required rather than three. A block diagram for the synthetic conical scan system is shown in Figure 4. A detailed explanation of the S-band tracking circuitry is given in Appendix B.

Radar Tracking System

A monopulse tracking system is available, at the Floyd facility, which will allow tracking of a passive satellite when illuminated by the Trinidad radar set on a frequency of 427 mc. A block diagram of this system is shown in Figure 5.

The feed system for the monopulse tracker consists of four spiral antennas with stripline hybrid units mounted at the back. The three pre-amplifiers are tube type having a noise figure of 5 db and a gain of 40 db. The output of each of the difference channels go to balanced modulators and are modulated by 10 and 15 kc signals. The three channels are then added together and connected to a single receiver chain consisting of a Nems Clark type REV-100 and at an IF frequency of 60 mc a Nems Clark type 131A. The signals are again separated to drive the servo system by use of audio band-pass filters.

Optical Tracking System

For tracking targets which are optically visible from the Floyd Site, an optical tracker may be used. To accomplish this, a U.S. Navy gun director originally designed to work with the Mark 32 gun mount is used. The nomenclature for the gun director is a U.S. Navy Mark 51 gun director.

The optical tracker is located approximately 700 feet North-Northwest of the 400-inch diameter parabolic antenna. It is mounted on a 10 x 10 x 1 foot concrete pad. A wooden wind break is constructed around the tracker to give the operator protection from the wind.

The gun director has been modified to hold two telescopes which the operator may use to track the target. The first telescope is used to acquire the target and is a Bausch and Lomb Balscope Sr. type providing a 2.7 degree field of view and 15X magnification. The second telescope is used for tracking and is a Bausch and Lomb Balvar 24 which is adjustable in magnification from 6X to 24X. For most operations requiring an optical track,

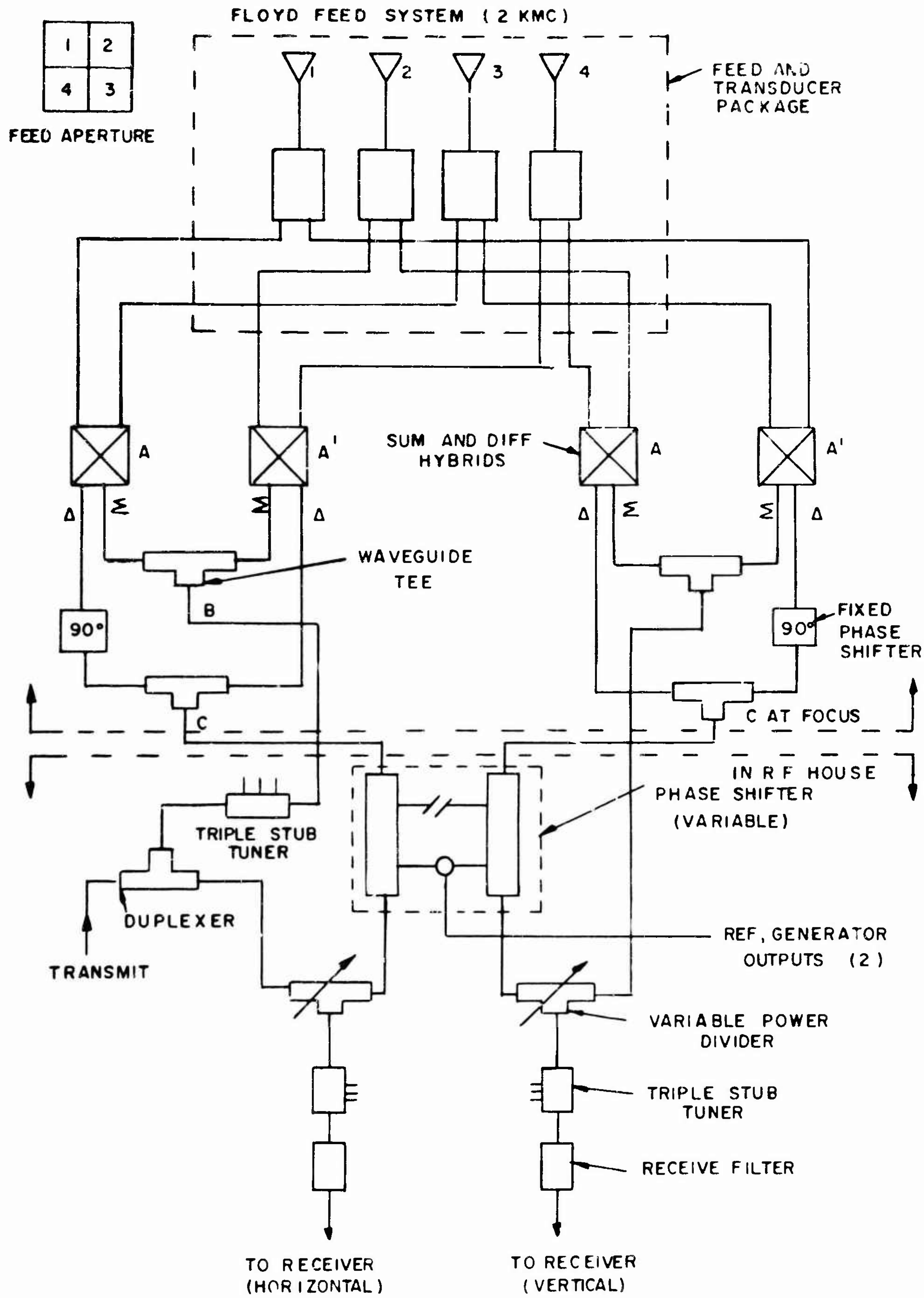

Figure 4 - Block Diagram of S-Band Tracking System

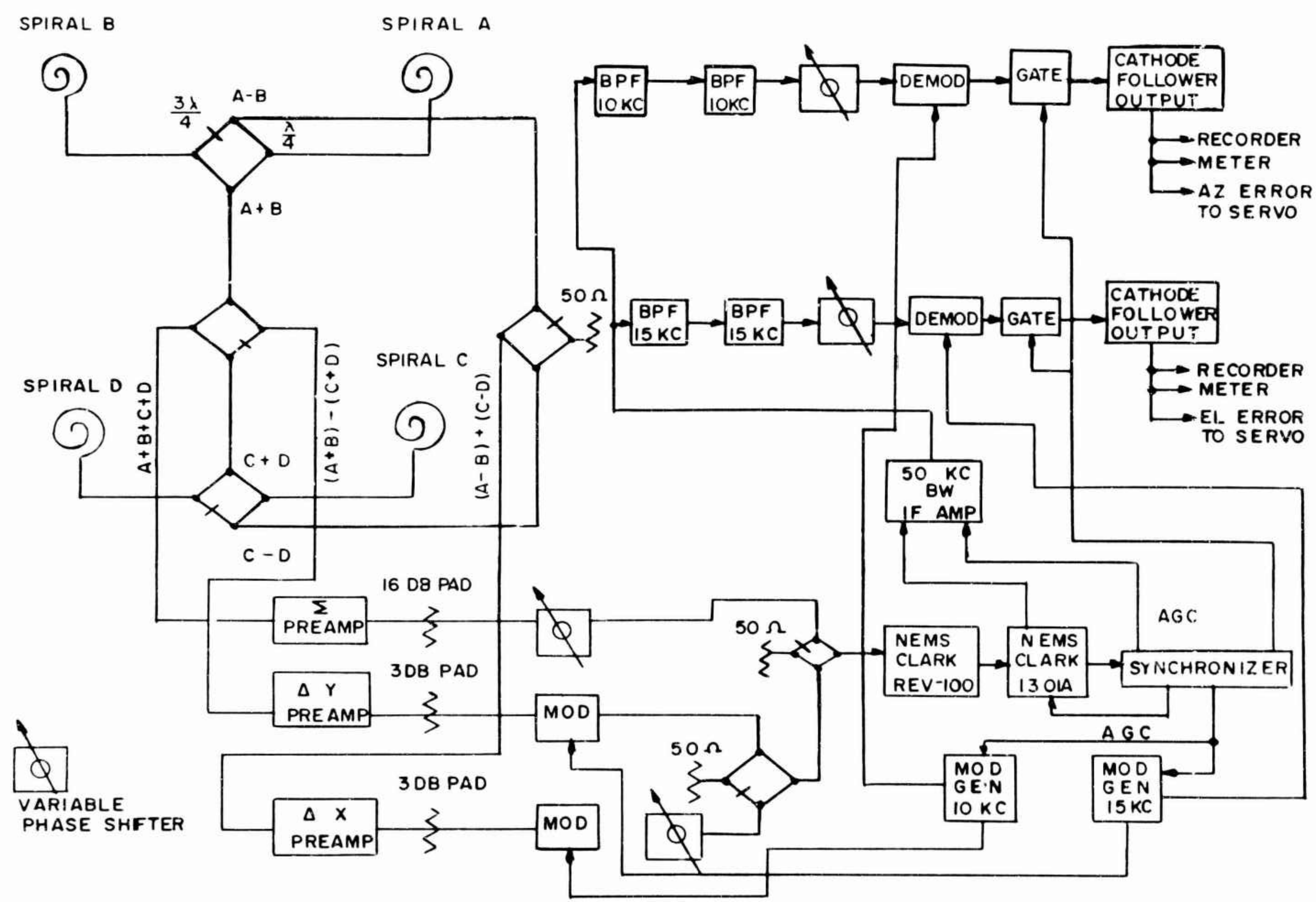

Figure 5 - Radar Tracking System

this scope is operated using a magnification of 6X.

Tracking, using the optical tracker, has been to an accuracy of approximately 0.1 degree. The tests, to measure these accuracies, were made under adverse weather conditions so the results can be considered realistic for all optical tracks.

Parametric Amplifiers

The parametric preamplifiers used for both terminals of the Floyd-Trinidad link were developed by Airborne Instruments Laboratory. There are two channels for each site so as to keep the horizontally and vertically polarized signals separate. The varactors of the preamplifiers are liquid nitrogen cooled in order to obtain a very low noise figure.

The cryogenic cooling incorporates an open loop liquid nitrogen system which is designed to essentially cool the varactor only. The nitrogen is supplied from a 7 1/2 liter tank which will allow approximately four hours of operation on one charge.

The noise figure for the paramps run typically at 1.5 db when cooled to 78° K. The paramps may also be used uncooled but the noise figure under that condition is degraded to approximately 2.5 db.

The 3 db bandwidth of the units is approximately 30 mc at the S-Band frequencies and this is at a gain of 20 db. The 1 bd bandwidth of the units average 14 mc.

The parametric amplifiers for Floyd and Trinidad are similar except that the Floyd unit has separate pumps for each channel and the Trinidad unit has a common pump. Also the Floyd units are tuned to receive the 2270 mc signal from Trinidad and the Trinidad units are tuned to the 1840 mc frequency of the Floyd transmitter. The pump frequency used for the paramps is 18 gc.

The Floyd parametric amplifier is located in the antenna mounted RF house to minimize the line loss from the feed. The Trinidad unit is also mounted on the antenna but in a smaller enclosure.

Converter-Amplifier

The converter-amplifiers for both sites are similar except for their operating frequencies. At both sites the converters are located near the parametric amplifiers.

The converter-amplifiers were constructed by the Microphase Corporation especially for this application. These units also have two channels each in order to preserve the capability of separate reception of horizontally and vertically polarized signals.

The converter-amplifier is a two-channel superheterodyne receiver fed by a common local oscillator chain. Each receiver contains a wideband balanced mixer and an IF preamplifier. The local oscillator chain consists of a UHF amplifier, harmonic generator, and power splitting hybrid. The L. O. chain is driven by an external RF source at one fourth the mixing frequency. The RF source is derived from the site standard to preserve the frequency accuracy required in order to allow accurate doppler shift measurements to be made.

The noise figure of these units run between 6 and 7 db. The output frequency of these units is nominally 29.5 mc in order to allow use of Collins R-390 HF receivers for IF amplifiers.

Available for backup equipment for the Floyd Site is an AN/FRC-56 two-channel receiver. These units work satisfactorily but with a slightly higher noise figure.

Dual Diversity Phase Lock Receiving System

This section will deal with that portion of the 2 gc receiver which follows the converter-amplifier at an IF frequency of 29.5 mc. This circuitry is designed to perform the following:

1. Amplify and demodulate the vertically and horizontally polarized received signals.
2. Provide a combined vertically and horizontally polarized output.
3. Track the doppler shift of the received signal to keep it within the IF bandpass.
4. Provide an accurate output for measurement of the amount of doppler shift. The basic receiver used is a Collins R-390A HF receiver for each channel. These receivers have been modified in that the high frequency oscillator has been disconnected and replaced by an external voltage controlled oscillator (VCO).

Figure 6 shows a block diagram of the phase lock receiver which is described in Appendix C.

Transmitter

The transmitter used at the Floyd Site is an AN/FRC-56 (v) power amplifier and REL type 867C exciter. The transmitter is designed to operate with an output of 10 kw in the frequency range from 1.7 to 2.4 gc. The type of modulation used is FM, with an index of one.

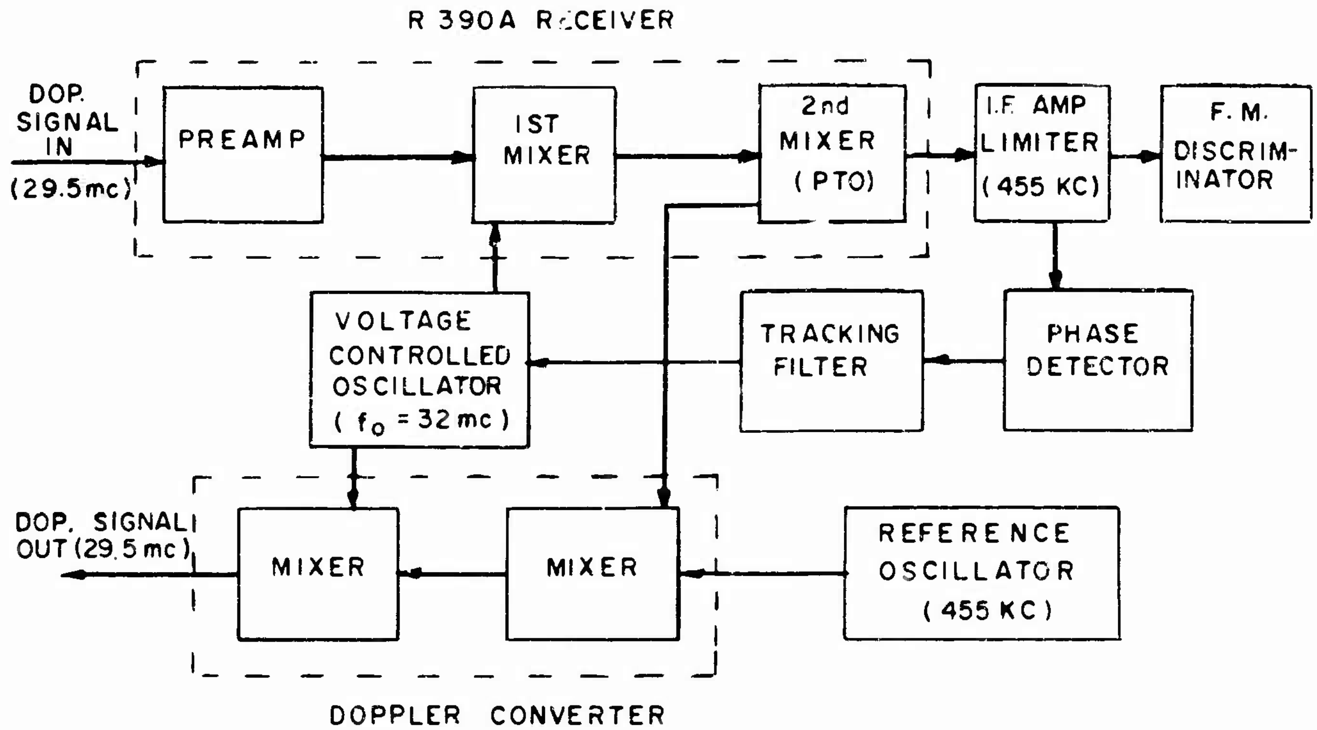

Figure 6 - Block Diagram of Phase Lock Receiver

The power amplifier uses a Varian type VA 800 klystron which operates at a power gain of 40 db and requires approximately 0.25 watts of drive. The 50 ohm input uses a type N connector and the output connects to a WR-430 waveguide flange.

The exciter is similar to an AN/FRC-56 (v) exciter, except that it is designed to operate from an external frequency synthesizer rather than internal crystals. The exciter is frequency controlled from the site standard in order to preserve the doppler shift measurement capability of the link. The exciter has a 50 ohm output of 5 watts (an attenuator in the power amplifier is used to regulate the drive to the final stage).

Performance characteristics of the AN/FRC-56 transmitting equipment are as follows:

Power Amplifier

Frequency range	1.7 - 2.4 gc
Power output	10 kw
Power gain	40 db
Input	Type N connector, 50 ohms nominal, SWR 1.2 maximum
Output	WR-430 waveguide flange
Primary power	208 VAC $\pm 5\%$

Primary power (continued)

	60 ± 3 cps, 3-phase
	120 VAC ± 5%
	60 ± cps, 1-phase
	4 - wire
Bandwidth	± 500 kc at 0.5 db
	± 3.5 mc at 3.0 db
Driving power	2 watts maximum

<u>Exciter</u>

RF frequency range	1.7 - 2.4 gc
RF power output	5 watts
External frequencies required	2 mc (+20 dbm)
	50.0 mc (+13 dbm)
	85-105 mc (+13 dbm)
Input impedance	50 ohms
Output impedance	50 ohms
Modulating frequency	250 cps to 70 kc
Modulation input impedance	150/600 ohms balanced/unbalanced
Test tone peak deviation	140 kc in flat portion of pre-emphasis characteristics nominal ±32 kc for -26 dbm input.
Baseband pre-emphasis	12 sec
Deviation capability	±500 kc peak max.
Modulation frequency	±1 db 500 cps to 8 kc
	±2 db 250 cps to 70 kc
Intermodulation distortion	-50 db max. using 50% random noise loading
Residual AM	-50 db max.
Residual FM	65 db below test tone level per 4 kc channel.

<u>Site Frequency Standard</u>

Although the transmitter and receiver at the Floyd Site were originally designed to work with a Cesium frequency standard (National Atomichron NC 1001), a conversion was made to a Rubidium Standard. The Rubidium Standard being used is the General Technology Corporation Model 304-B with special outputs at 10 mc and 100 mc's in order to duplicate all of the frequencies previously produced by the atomichron. The performance characteristics of the 304-B standard are as follows:

<u>Output</u>

Initial frequency setting $\pm 1 \times 10^{-10}$ ($\pm 2 \times 10^{-11}$ if set at National

	Bureau of Standards)
Accuracy	After initial setting, accuracy is determined by long term stability.
Long-term stability	1×10^{-10} (Standard Deviation) 5×10^{-11} (Standard Deviation) for ninety days in a controlled environment.
Short-term stability	1×10^{-11} (Standard Deviation) for one second averaging time.
Magnetic	Less than 5×10^{-12} for any orientation in the earth's magnetic field.
Tunability	At least $\pm 1 \times 10^{-9}$ about the initial frequency setting; total range 4×10^{-9}. A calibration chart of frequency change vs tuning control dial setting is provided.
Frequencies	100 mc, 10 mc, 5 mc, 1 mc and 100 kc.
Level	10 dbm at 50 ohms, each output.
Spectrum	Equivalent bandwidth 1 cps at 24 gc/sec. AC line frequency sidebands more than 100 db below carrier. Nonharmonically related signals more than 70 db below carrier.

Input

Voltage	85 - 130 VAC, 50 - 400 cps, single phase, or 23-31 VDC. If both are applied, PC source provides power only if AC fails.
Power operating	35 watts AC, 30 watts DC.
Warmup	58 watts AC, 50 watts DC.

In order to supply an accurate local oscillator frequency to the converter-amplifier, a synthesizer must be used to provide a frequency of 560.125 mc which is controlled by the Rubidium Standard. For this purpose a Shomandl type FD-3 synthesizer is used. The FD-3 synthesizer is operated with inputs at 100 kc and 5 mc (from standard) and is tuned to give the 560.125 mc output.

To supply the accurate frequencies to the AN/FRC-56 (v) transmitter a second synthesizer is needed. For this purpose a Page Communication Engineers, Inc. synthesizer, type F, is used. This synthesizer was developed especially for use to control the Floyd transmitter for transmission at 1840 mc. The signal input requirements for this unit are as follows:

Frequency	Source Impedance	Level
1 mc	50 ohms	10 dbm (0.7 v)
10 mc	50 ohms	10 dbm

100 mc	50 ohms	10 dbm

The signal outputs available from this unit are as follows:

Output No.	Frequency	Output Impedance	Level
1	1 mc	50 ohms	10 dbm (0.7 v)
2	1 mc	50 ohms	10 dbm
3	1 mc	50 ohms	10 dbm
4	2 mc	50 ohms	30 dbm (7.07 v)
5	50 mc	50 ohms	20 dbm (2.24 v)
6	89.111 mc	50 ohms	20 dbm

Transmission Lines

2 Gc

At the focal point of the dish are located the feed and transducer package, sum and difference hybrids, and two waveguide ties. All of these components are interconnected with WR-430 waveguide. From the focal point to the antenna mounted RF house are four WR-430 waveguides which run along the back of the feeds spars for transmission of the following channels: 1. a vertically polarized sum channel; 2. a vertically polarized difference channel; 3. a horizontally polarized sum channel; and 4. a horizontally polarized difference channel.

Inside the RF shack, the duplexer, phase shifter, variable power divider, receive filters, and directional couplers are interconnected with WR/430 waveguide. From a transition in the directional couplers, a short run of heliax cable is used to connect the horizontal and vertical channels of the parametric amplifier.

From the transmit leg of the duplexer, WR-430 waveguide is run to the AN/FRC-56 transmitter with the exception of the flexguide used around the elevation and azimuth joints. A short piece of flexible waveguide is used to allow elevation travel of the gun mount through its entire range of -15^{o} to 85^{o} elevation. A 28 foot section of flexible waveguide is suspended down the center of the concrete tower which is allowed to twist to give a maximum azimuth rotation of the mount of ± 540 degrees.

The IF frequency lines are RG-9/U coaxial cable and are also suspended down the center of the tower. These lines do not further restrict rotation of the antenna.

The entire waveguide run is pressurized with dry air. This includes all components in the line so that no air bypasses are required from the transmitter to feed.

Duplexer

A duplexer is used to allow simultaneous transmission at 1840 mc and reception at 2270 mc. This branching filter consists of sharply tuned receiver band and transmitter band filters and a common junction between filters and antenna. The filters are constructed of WR-430 waveguide with inductive irises and capacitive tuning screws forming four in-line resonant cavities in each filter arm. The rejection of the transmit frequency in the receiver arm is greater than 100 db while the transmit arm has a receive frequency rejection of more than 80 db. The receive filter in the vertically polarized channel is of the same construction as the duplexer.

427 Mc

The monopulse tracking system utilizes RG-9/U coaxial cable throughout. Sum and difference channels are connected to the preamplifier with coaxial cables which are banded to the feed spars. The preamplifier outputs are connected to the 427 mc receiver with cables which are suspended in the center of the tower in the same fashion as the 29.5 mc IF lines of the 2 gc receiving system.

Boresight Installation for Floyd Terminal

A boresight signal source for use in alignment of the 33 foot tracking antenna at 427 mc and 2270 mc is provided at a New York State owned water tower. The tower is located on the grounds of the Marcy State Hospital, Marcy, N. Y. The 427 mc and 2270 mc feeds are located at the 140 foot level of the tower and are clamped to the railing around the catwalk at that level. The look angles to the boresight from the Floyd antenna are 0.8 degrees elevation and 125.8 degrees azimuth. The distance to the boresight is 2.67 miles.

The feed to provide a 427 mc signal from the boresight is a dipole antenna mounted in the horizontal plane.

The feed to provide a 2270 mc signal from the boresight is a horn having a gain of 15 db. Provision is made for mounting this horn for vertical or horizontal polarization. This is to make it compatible with the vertical or horizontally polarized channels of the Floyd installation. Also the horn may be mounted at an orientation of 45 degrees for use with either polarization and the loss in gain is calculated to be 3 db.

The signal generator to provide the 427 mc signal is a Hewlett Packard Model 608C. This equipment has a built-in variable attenuator and is preset to give the desired level of signal. The generator is connected to the dipole by styrofoam coaxial cable.

The signal generator to provide the 2270 mc signal is an American Electronic Laboratories crystal controlled oscillator with a varactor multiplier chain. The crystal frequency of the oscillator is 85 mc. The maximum power output at 2270 mc is 20 milliwatts with fixed attenuators available to set the power to the desired output. This generator is connected to the horn antenna with styrofoam coaxial cable.

Both signal generators are remotely controlled from the Floyd Site by use of the high powered S-band transmitter. Three pulses at a frequency of 1840 mc or 2270 mc within a 30 second period will turn on both signal sources for a period of time set on timers. There are separate timers to control the 427 mc and 2270 mc signal generators. The S-band horn is connected to a crystal detector and a sensitive relay to start the timers. The S-band horn is switched to the signal generator when the triggering function is completed. The timers may be separately preset for from 1 to 60 minutes duration.

Record Capability

I. Floyd Site

Chart Recorders

Two model Brush RD 1684 chart recorders are used to record much of the data of the space communication terminal. These recorders are of the pen type and have eight calibrated channels plus a time marker and an event marker. The time marker is referenced to WWV to give a record of time with all data. The event marker is operated from the control desk where a running log of events is recorded. The 16 channels' total would typically be utilized in this way:

1. Vertical polarized AGC voltage
2. Horizontal polarized AGC voltage
3. Azimuth error of track
4. Elevation error of track
5. Coarse elevation position
6. Fine elevation position
7. Coarse azimuth position
8. Fine elevation position
9. Radar AGC voltage
10. Transmitter output power
11. Transmitter frequency deviation
12. Azimuth speed
13. Elevation speed
14. Mode of track-radar, communication, optically, manually.

15. Spare
16. Spare

Tape Recorders

Two model 960 Ampex tape recorders are available and are mounted in pull out drawers in one of the rack cabinets. The recorders will normally be used to record the following:

Recorder #1 - Channel 1 - Horizontal rcvd audio
Channel 2 - Vertical rcvd audio
Recorder #2 - Channel 1 - Combined horizontal and vertical audio
Channel 2 - WWV.

Three model 600 or 601 Ampex single-channel tape recorders utilized in the following way:

1. One channel for intercom conversation
2. One channel for beacon receiver
3. One channel for transmitter modulation.

One FR-100 tape recorder (Ampex) having 10 channels DC record and four channels direct record. This machine will be used in a different way for nearly all tests performed. However, a typical arrangement would be to duplicate the data on the Brush recorders to facilitate data analysis. This recorder has isolation amplifiers on all inputs to avoid loading down of circuits. All of the inputs to this tape recorder, inputs and outputs to isolation amplifiers, and outputs from receiving and transmitting equipment are brought to a pair of patch panels, using BNC connectors, to allow rapid connections to be made for the various tests.

Doppler Frequency Recorder

The doppler frequency is recorded on a Hewlett Packard Digital Printer HP 560A which, in turn, operates from a Hewlett Packard Electronic Counter HP 524D. The printer will operate over a large range of intervals and is referenced to WWV with the interval recorded to give running time reference. A plus doppler shift would be indicated by a doppler output of 29.5 mc plus the amount of shift. A negative doppler shift would be shown by a reading of 29.5 mc minus the amount of doppler shift. The HP 524D is connected directly to the doppler output described under the Phase Lock Receiver Section.

Cameras

Boresight Camera

A camera mounted on the backup structure of the 33 foot parabolic antenna is used to measure accurately the error of track on visible targets. This camera is a Robot Recorder 24 C which has a capacity of 200 feet of 35 mm film. This camera takes time sequential pictures during track which is triggered by either a timing unit operating from 1 to 30 sec per frame or from a 1 sec pulse from the HP 524D counter. Besides taking a picture of the satellite on each frame, azimuth and elevation look angles, frame number, and lights indication type of track are recorded. This gives a reference to the other recorded data for each picture taken.

Scope Camera

A scope camera is used to take photographs of an oscilloscope represented trace of the received radar signal. This gives an additional recording of the received radar pulses. (The AGC voltage is recorded on chart recorder).

Philco S. L. V. T.

This unit is a signal level totalizer which provides 22 channels of recording. The totalizer works on the DC levels of received signals so that the percentage of time the signal exceeds each of the preset levels can be determined. This equipment is used on an experiment to determine signal statistics.

Teletypewriter

In the case of transmission of teletype signals over the link, the teletypewriter is used to print out the received signal directly. The same information is also recorded on an audio tape recorder and punched into tape for later playback.

For tabulated and graphical data on Floyd terminal see Appendix A

II. Description of the Trinidad Terminal

Tracking System

The Trinidad terminal of the space communication link is located at the Atlantic Missile Range Station which is situated at the U. S. Naval Station of the island. The 2 gc communication equipment is integrated with a FPS-5 radar tracker such that the radar and communication equipment use an 84 foot parabolic antenna in common. All tracking of satellites is accomplished by the radar set for the Trinidad terminal.

As of 30 June 1965, The Trinidad Space Communication Facility will be disbanded with most of the equipment being sent to RADC for use at other facilities. At the present time, the radar terminal at Trinidad is undergoing modifications to the antenna which may render the site inoperative until such time that the communication equipment must be shipped out. There has been much effort spent in the development of a dual frequency feed system which is described in the Feed System section below. If it proves impossible to test the final feed system at Trinidad, it is anticipated that the feed will be tested at the RADC Newport Antenna Range and the RADC High Power Laboratory. Completion of this feed development can provide a useful technique for future antenna design.

Feed System

The radar portion of the feed system uses a front feed which has a conical scanning horn. The aperture of the circular radar horn is 25-inch diameter with the center being 6 inches from the mechanical center for the conical scan. This radar equipment operates on a frequency of 427 mc when used to accomplish tracking of the communication experiments. The communication portion of the feed system uses a Cassegrainian type of feed and is arranged so that it does not hinder the radar operation. The communication feed is designed to operate at S-band.

The design of the communication feed has been a difficult problem as it has the stringent requirement that it cannot in any way degrade or change the operation of the radar equipment. Two types of feeds have been used prior to the present design but both had deficiencies.

The first feed used was a Canoga Model 8405 splash plate feed placed directly under the radar horn. This feed had the disadvantage that it did not provide optimum illumination of the 84 foot dish. This was partly due to the fact that the location of the radar feed did not allow the Canoga feed to be placed close enough to the focal point of the dish. The second limitation was that a feed of the proper disign to illuminate the 84 foot dish was not available and therefore a compromise had to be made in picking the model.

The second feed used was a grid feed which consisted of a flat Cassegrainian reflector made up of parallel rods for the reflecting material. This feed gave increased antenna gain over the splash plate feed as the

Cassegrainian configuration can be placed at the optimum position. The gain of the over-all antenna system using the grid feed was improved by 2.5 db bringing the gain to 48.5 db. The disadvantage of the grid feed is that it disables one polarization of both the radar and communication receive channels. To meet the requirement of not causing degradation to the radar capabilities, this feed has to be removed for all operations not involving the communication equipment.

A new feed system has been designed to correct the deficiencies of the previous feeds. This feed uses the Cassegrainian approach of the grid feed but is constructed so as not to be polarization sensitive. This new design shows promise in providing a method of illuminating a dish at two frequencies but so far there has been a problem in survivability. The models installed so far have shown good electrical properties but have eventually broken down under the high peak power of the radar transmitter. A last attempt is being made to provide a subreflector which will survive in this environment. The grid feed is presently being used until this feed is completed.

The new feed, presently under construction, is designed to meet the following requirements:

1. Be reflective to horizontal and vertical polarizations at the receive frequency of 1840 mc.
2. Be reflective to horizontal and vertical polarizations at the transmit frequency of 2270 mc.
3. Be transparent to all radar frequencies from 400 - 450 mc and not restrict the use of different polarizations at these frequencies.

The configuration of the over-all feed system is shown in Figure 7. The subreflector is constructed of materials of high dielectric constant so as to minimize the effect upon the radar beam. Styrofoam and fiberglass are the materials used for this purpose. To allow the structure to be reflective at 1840 and 2270 mc, aluminium rings which approach the resonant region were placed on the subreflector surface closest to the S band horn. Since the ring dimensions are small compared to a wavelength at 427 mc, they appear nearly transparent at this frequency. A second surface of the subreflector also has rings placed upon it which presents the same admittance, to the radar horn, as the first surface. The two surfaces are spaced 1/4 of a wavelength at 427 mc so the small amount of reflection from one surface is effectively cancelled out by reflections from the second surface. A cross sectional view of the subreflector is shown in Figure 8.

The difficulties which have been experienced with this feed system can be placed in the following categories: 1. excessive heating of the materials; and 2. voltage breakdown between adjacent rings. The first model of this type of feed was quite successful but failed after eight months of operation.

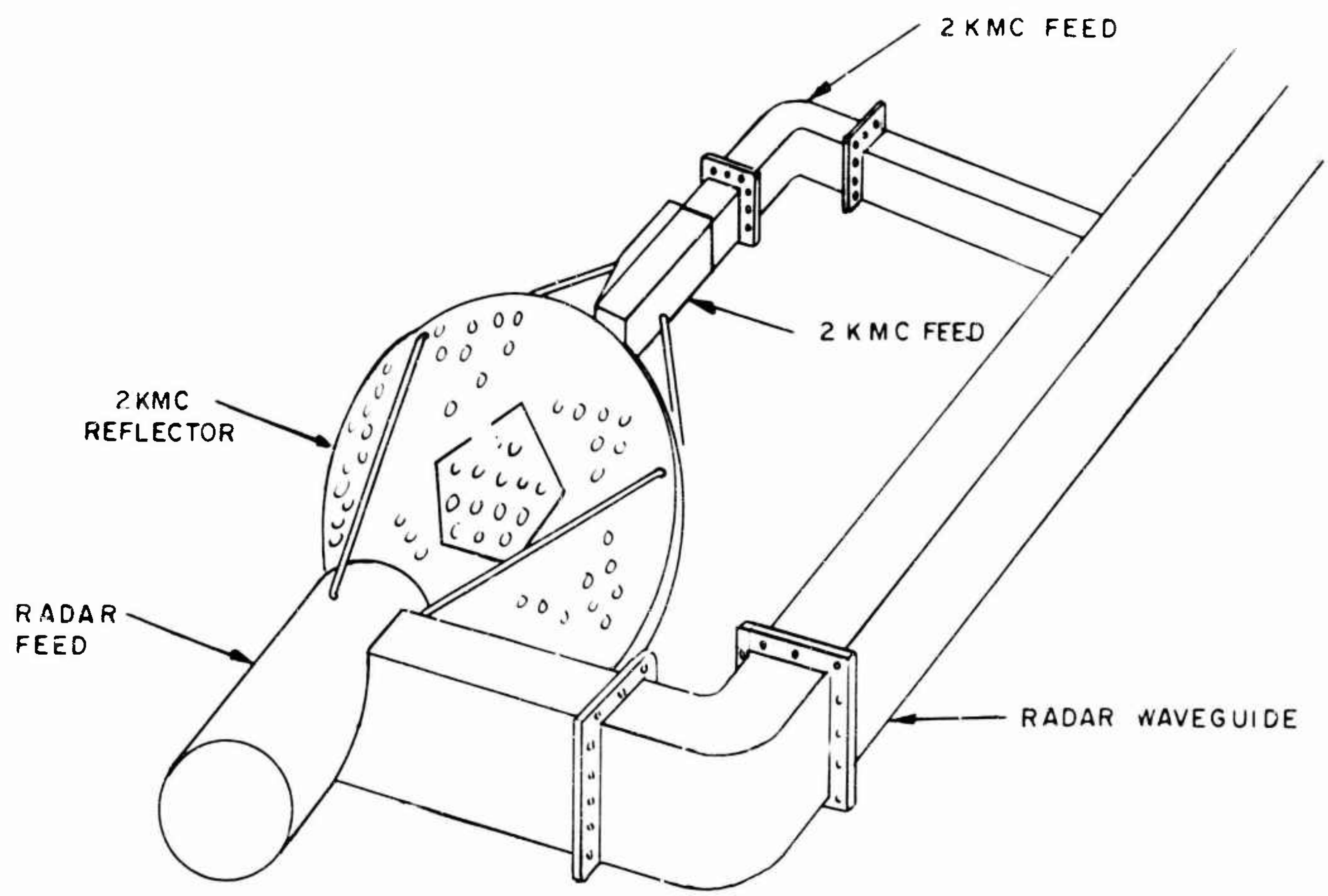

Figure 7 - Dual Frequency Feed System - Trinidad

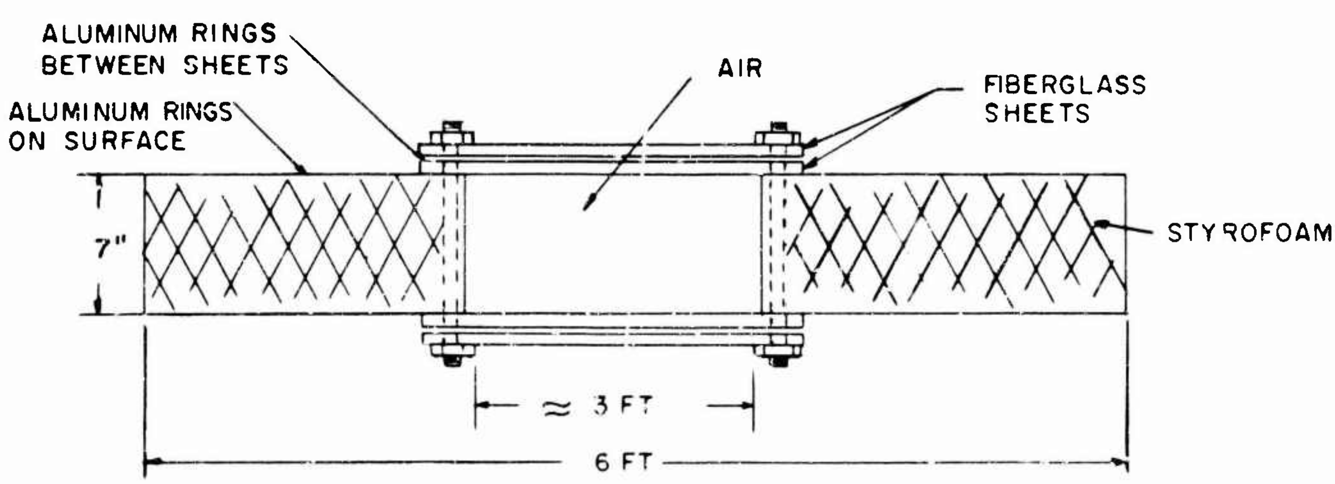

Figure 8 - Cross Section of Trinidad Cassegrainian Subreflector

The subreflector of this feed was constructed with the rings placed between layers of fiberglass such that there was an air space between rings. This feed was damaged by arcing between rings with the reason being that the inside surfaces of the fiberglass had collected dirt and moisture thus reducing the breakdown voltage between rings.

The next model was designed to eliminate this problem but unfortunately created a second problem. The subreflector for this feed completely enclosed the rings in fiberglass so as to control the dielectric between rings keeping the breakdown voltage constant. The difficulty with this feed was that the rings reached an operating temperature which exceeded the melting point of the resin and the feed was destroyed through heating.

The final model, which is presently ready for testing, has been designed to avoid all of the known problems. The rings have been made with a circular cross section, rather than flat, to increase the breakdown voltage between rings. The rings are mounted between strips of fiberglass so that the rings will be air cooled. Since arcing and heating has occurred only between rings in the direction of the polarization of the radar transmitter, the fiberglass has been arranged so that the areas causing prior trouble are completely in air. If this final model of the feed is successful, it will no doubt be the subject of a separate report.

The subreflector described above has the following measured characteristics:

1. 98% transmissivity of the radar energy.
2. 80% reflectivity of S band energy at 1840 and 2270 mc.
3. No noticeable change in VSWR of the radar feed line when reflector is placed in front of the horn.

A drawing of the method of illuminating the 84 foot dish is shown in Figure 9.

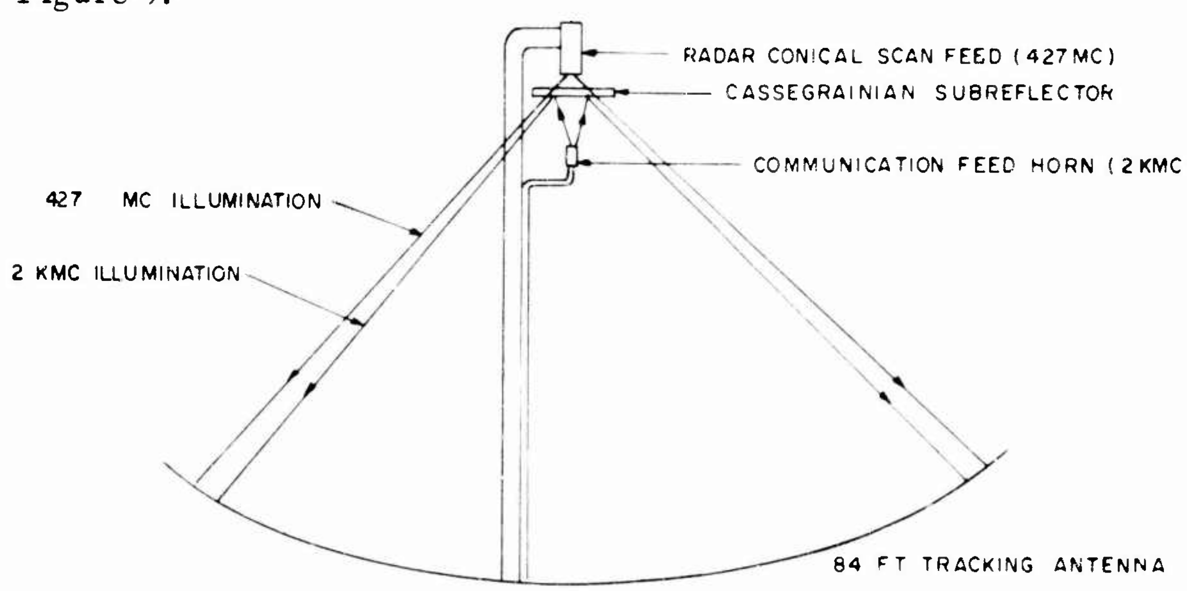

Figure 9 - Dual Feed Arrangement - Trinidad

The measured over-all antenna gain at the S band transmit frequency is 52 db. The 3 db beamwidth is measured to be 26 feet.

Transmission Line

The original radar tracker had no provision for additional transmission lines through the elevation and azimuth joints over those needed for the radar operation. This presented the only major problem to the installation of WR-430 waveguide for the 2 gc feed line.

The elevation joint was solved by the insertion of a rotary joint on the center line of the elevation torque tube. The WR-430 connects to this joint at the center of the torque for the run down the tower, and at one end of the torque tube for the run to the feed.

The azimuth joint was a more difficult problem since the radar equipment took up all of the area along the axis of rotation. Flexible waveguide was used here which is arranged so it winds and unwinds like a watch hair spring as the tracker is rotated. In order to restrict the movement of this flexguide so that it would not get entangled with objects inside the tracker tower, a trough with a roller bottom was installed. This trough holds the flexguide in a horizontal loop position and confines it to a minimum inner diameter and a maximum outer diameter. This azimuth arrangement restricts the azimuth travel of the tracker to 375^{o} and it was necessary to install limit switches to avoid destruction of the flexguide. The flexguide is disconnected during noncommunication experiments to remove the 375^{o} restriction.

The waveguide run is under pressure of dry air to keep the moisture from the transmission line.

The loss of the transmit line is 2.3 db. The loss in the receive line, which only goes to the parametric amplifier located just below the elevation joint, is 0.7 db.

Duplexer

A duplexer and receive filter, of the same type used at the Floyd Site, are mounted near the elevation joint. The transmit and receive frequencies are reversed for the Trinidad installation. (2270 mc transmit, 1840 mc receive).

Parametric Amplifier

See Parametric Amplifier for Floyd Site. Differs in that a common pump is used in Trinidad and the receive frequency is 1840 mc.

Converter-Amplifier

See Converter-Amplifier for Floyd Site. Differs only in receive frequency.

Dual Diversity Phase Lock Receiving System

See same for Floyd Site.

Transmitter

See transmitter for Floyd Site.

Site Frequency Standard

In order that very accurate doppler shift measurements may be made, the transmitter and receiver must be held to a close frequency tolerance. The frequency standard for the Trinidad Site is a National Company Model NC 1001 Atomichron.

The only site standard controlled frequency in the receiver is the local oscillator of the S band receiver. All other locally generated frequencies are cancelled out as far as doppler frequency measurements are concerned. A Schomandl synthesizer is used to provide the input to the converter for multiplication to the local oscillator frequency. This frequency is 452.625 for the Trinidad Site.

For control of the AN/FRC-56 transmitter a specially built Page Communications Engineers, Inc. synthesizer is used. The frequency outputs for the Trinidad transmitter are 50 mc, 2 mc and 101.0555 mc.

The atomichron itself has a frequency accuracy and long term stability of 1 part in 10^{-10}. The standard frequency outputs of the NC 1001 are 100 kc, 1 mc, 5 mc, 10 mc and 100 mc. The Schomandl sythesizer, used in the receiver, utilizes the 100 kc output. The Page synthesizer used in the transmitter uses the 100 mc, 10 mc and 1 mc outputs. The atomichron is a primary standard and therefore as long as it is properly locked in, the frequency accuracy is assured.

Boresight

The boresight at Trinidad utilizes a tower located upon Mt. Catherine which is three miles distance from the tracker. The electronic equipment is not permanently installed at this boresight and therefore must be taken to the site for antenna checkouts.

Record Capability - Trinidad Site

Chart Recorder

A brush Model RD 1664 chart recorder is used at the Trinidad installation. This instrument differs from the Floyd recorders in that it has only 6 analog channels. A typical utilization for this instrument is as follows:

Channel number
1. Horizontally received signal AGC voltage
2. Vertically received signal AGC voltage
3. Transmitter 2270 mc power output
4. Transmitter FM deviation
5. Tracker azimuth position
6. Tracker elevation position

Also two event markers are used to record time and events.

Ampex 960 Stereo Tape Recorders

There are two of these recorders and they are of the same type as used at Floyd. The four channels are used in the following way:

Channel number
1. Vertically polarized received signal (audio)
2. Horizontally polarized received signal (audio)
3. Transmitter modulation inputs.
4. Transmitter modulation inputs.

Doppler Frequency Recorder

This is accomplished in the same way as at the Floyd Site. The doppler shift is recorded on a Hewlett Packard Digital Printer HP 560A which operates on the output of a Hewlett Packard Counter HP 524D.

Boresight Camera

This installation is the same as the Floyd installation. The camera is mounted in its waterproof enclosure at the back up structure of the 84 foot dish. Its position is approximately 34 inches above the horizontal axis and approximately 40 inches to the right of the vertical axis of the dish.

Teletype

Although there is no teletypewriter located at the Trinidad terminal, there is a provision for transmitting and receiving teletype signals with a converter and tape recorders.

Communication Between Sites

So that the on-the-air testing can be well coordinated, a HF communication link has been established between the Floyd and Trinidad Sites. The equipment used for this purpose consists of a Technical Material GPT-750 transmitter and a Collins R-390 receiver at each terminal. The mode of transmission used is single sideband-supressed carrier modulation. The frequency used is 19.390 mc with 14.650 being used as backup.

CONCLUSIONS AND RECOMMENDATIONS

As of June 1965, the Trinidad facility, described in this report, will be dismantled. The components of this facility will be shipped to RADC and will be available for incorporation into other facilities, including the Floyd terminal, in order to allow for other work. The two terminals described in this report are very versatile in that they are comprized of many components with standard interfaces rather than one over-all unit. This means that by substituting preamps, converters, feeds, etc., these terminals can be easily modified to perform a multitude of tasks. The extensive recording facilities are such that they are almost universal for collection of data in many areas of communication. As an example, the Floyd facility was recently modified to include the capability of acting as the receiving station for air-ground experiments performed in conjunction with Wright Field, and this modification was made in only one month's time with minimum expenditure of funds.

There are many experiments presently being carried on at the Floyd facility, such as, Air-Ground microwave experiments, Balloon Boresighting techniques, Radiometric Boresighting Techniques, VHF experiments. The facility also has a capability for conducting tropospheric scatter experiments and experiments with other space vehicles. Therefore, it can be seen that even though the Trinidad facility is being closed, the Floyd facility will continue to be used for testing experimental techniques, thus giving the site a high rate of utilization for a long time to come.

APPENDIX A

MEASURED PARAMETERS OF FLOYD FACILITY

1. ANTENNA

ANTENNA GAIN

FREQUENCY	MODE	POLARIZATION	GAIN (DB)
2.27 Gc.	RECEIVE	HORIZONTAL	45.25
2.27 Gc.	RECEIVE	VERTICAL	45.65
1.84 Gc.	TRANSMIT	HORIZONTAL	44.1

ANTENNA 3 DB BEAMWIDTH

FREQUENCY	PLANE	POLARIZATION	BEAMWIDTH	SIDELOBE
2.27 Gc.	VERTICAL	VERTICAL	1.3°	-13 DB
2.27 Gc.	HORIZONTAL	VERTICAL	0.8°	-9 DB
2.27 Gc.	VERTICAL	HORIZONTAL	0.9°	-13 DB
2.27 Gc.	HORIZONTAL	HORIZONTAL	0.9°	-16.5 DB
427 Mc	VERTICAL	CIRCULAR	5° 42'	-4 DB
427 Mc	HORIZONTAL	CIRCULAR	4° 42'	-8 DB

2. PARAMETRIC AMPLIFIER

	HORIZONTAL POLARIZATION	VERTICAL POLARIZATION
GAIN	20 DB	20 DB
NOISE FIGURE (COOLED)	1.5 DB	1.5 DB
NOISE FIGURE (UNCOOLED)	2.3 DB	2.3 DB
BANDWIDTH	28.0 Mc	24.4 Mc
DYNAMIC RANGE	25 DB	DB
FREQUENCY	2.27 Gc	2.27 Gc

NOTE - Plots shown in figures 10 thru 14 this section.

3. CONVERTER

	HORIZONTAL POLARIZATION	VERTICAL POLARIZATION
GAIN	16.0 DB	16.0 DB
NOISE FIGURE	7.5 DB	6.0 DB
BANDWIDTH	500 Kc	450 Kc
FREQ. IN	2.27 Gc	2.27 Gc
FREQ. OUT	29.5 Mc	29.5 Mc
L. O. IN	2240.5 Mc	2240.5 Mc
DYNAMIC RANGE	80 DB	80 DB

4. R-390'S (I. F. RECEIVERS)

	HORIZONTAL POLARIZATION	VERTICAL POLARIZATION
NOISE FIGURE 29.4 Mc	10.7 DB	11.9 DB
NOISE FIGURE 29.5 Mc	12.0 DB	11.2 DB
NOISE FIGURE 29.6 Mc	13.6 DB	11.3 DB
BANDWIDTH (455 Kc I. F.)	8.4 Kc	7.7 Kc
DYNAMIC RANGE	45 DB	45 DB

5. LINE LOSSES

LINE	FREQUENCY	POLARIZATION	LOSS
TRANSMITTER TO ANTENNA	1.84 Gc.	HORIZONTAL	1.65 DB
ANTENNA TO PARAMP.	2.27 Gc.	HORIZONTAL	1.8 DB
ANTENNA TO PARAMP.	2.27 Gc.	VERTICAL	1.8 DB
PARAMP TO CONVERTER	2.27 Gc.	HORIZONTAL	1.1 DB
PARAMP TO CONVERTER	2.27 Gc.	VERTICAL	1.1 DB
CONVERTER TO R-390	29.5 Mc.	HORIZONTAL	3.1 DB
CONVERTER TO R-390	29.5 Mc.	VERTICAL	3.9 DB
(FOLLOWING CABLES FROM ANTENNA HOUSE TO CONTROL ROOM)			
SPARE CABLE NO. 1	29.5 Mc.		2.3 DB
CALIBRATE CABLE	29.5 Mc.		2.3 DB
CALIBRATE CABLE	2.27 Gc.		18.25 DB
SPARE CABLE NO. 3	2.27 Gc.		13.75 DB
SPARE CABLE NO. 4	2.27 Gc.		11.75 DB

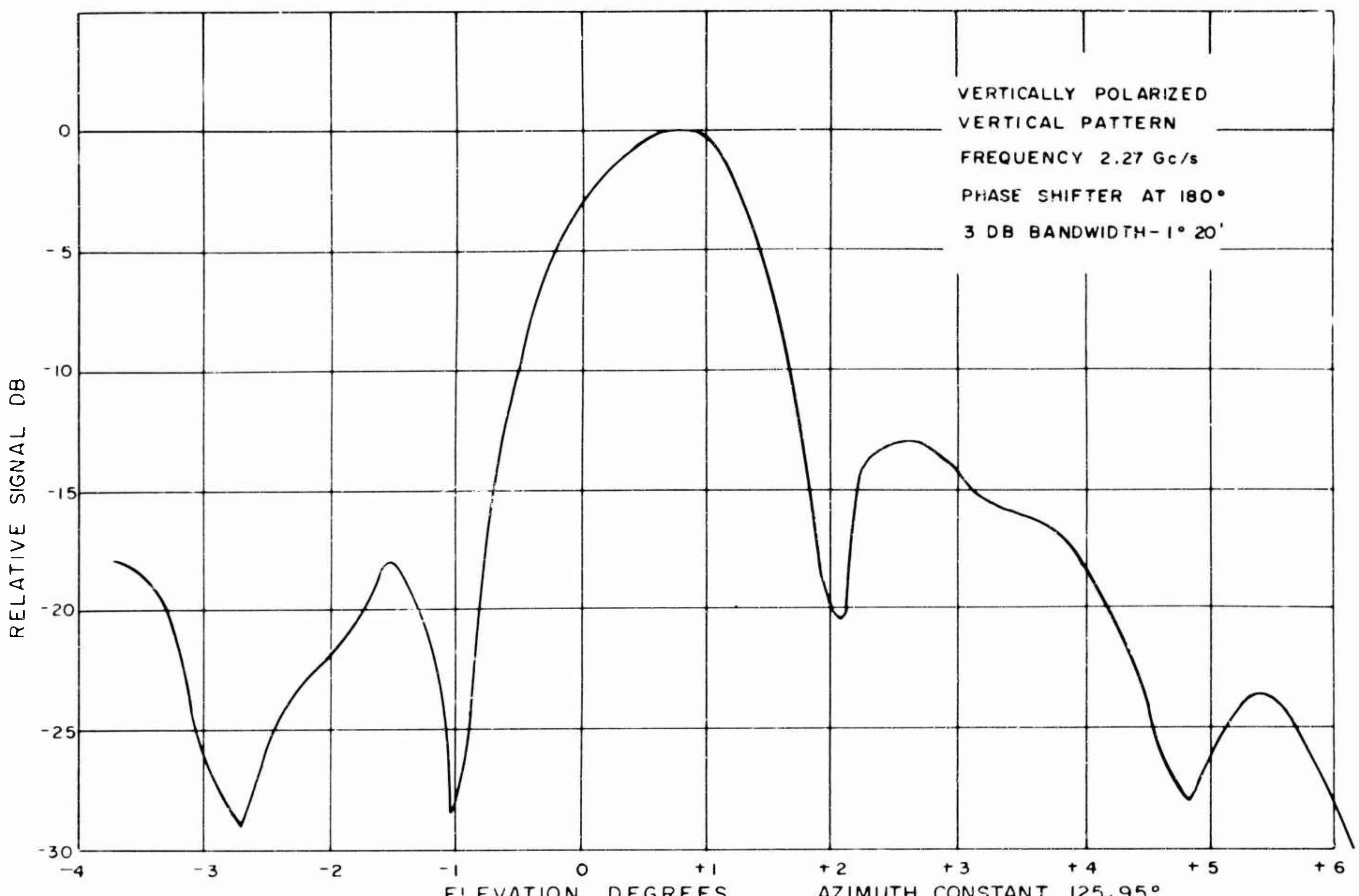

Figure 10 - Vertically Polarized Floyd S-Band Antenna Pattern - Vertical Cut

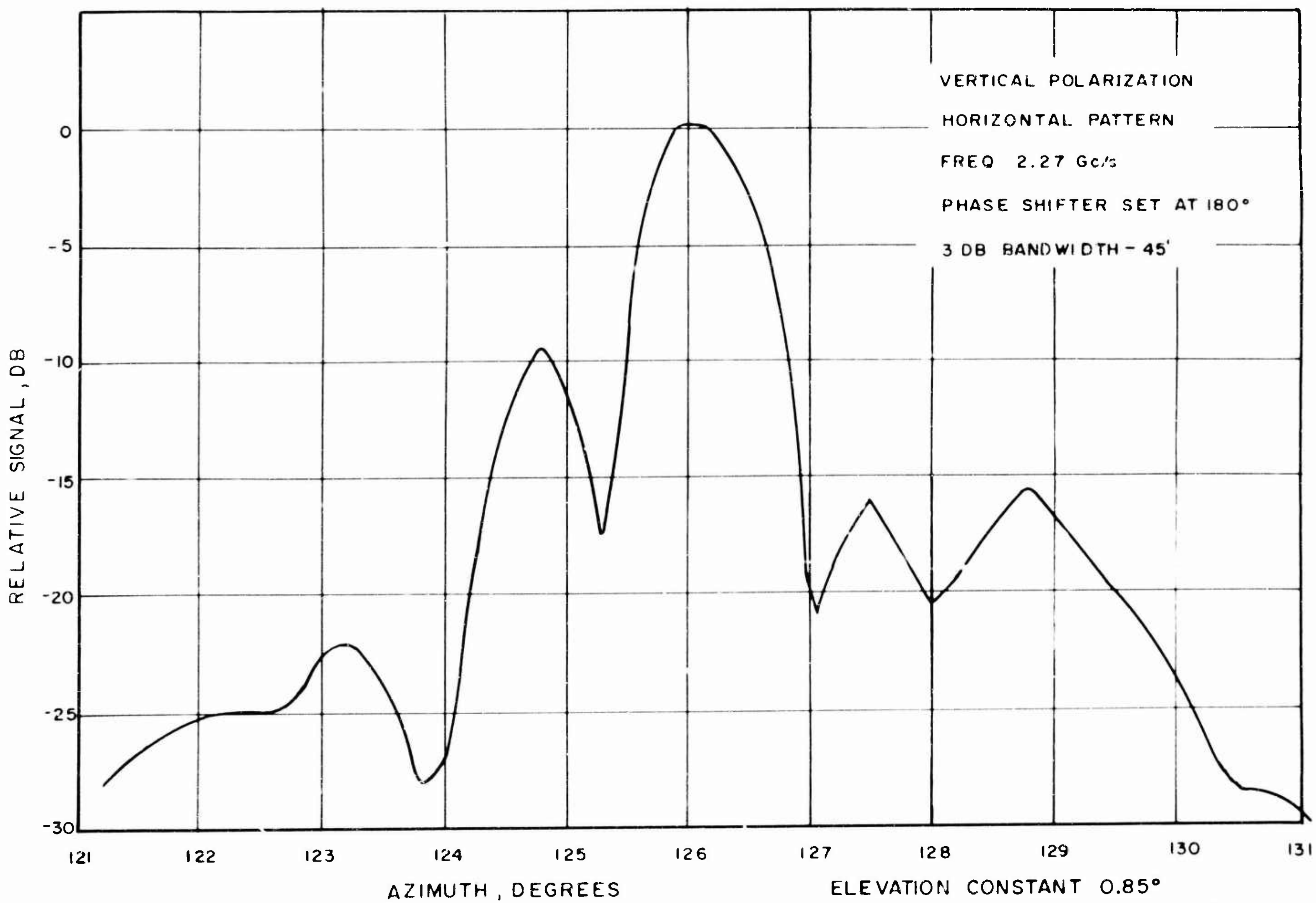

Figure 11 - Vertically Polarized Floyd S-Band Antenna Pattern · Horizontally Cut

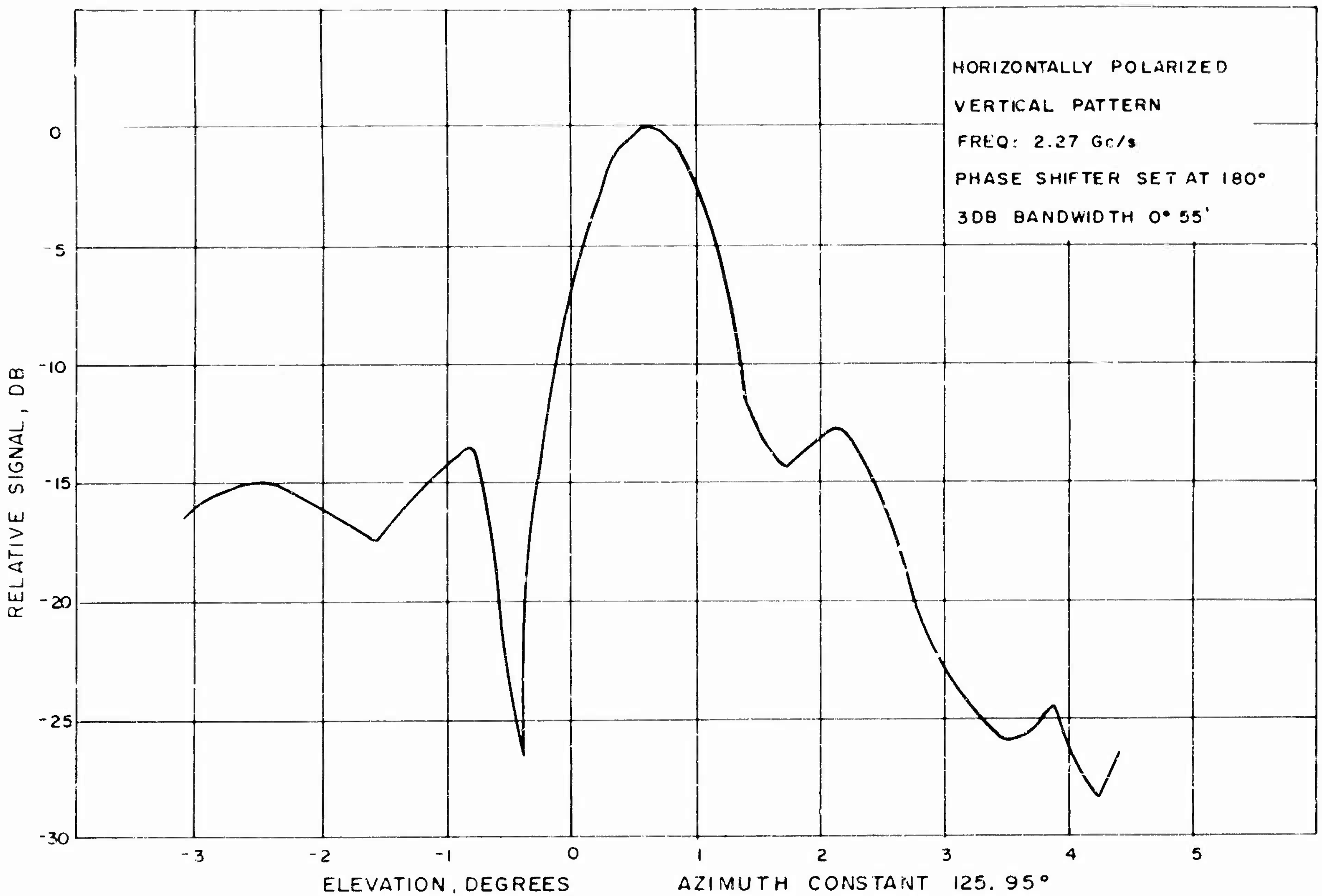

Figure 12 - Horizontal Polarized Floyd S-Band Antenna Pattern - Vertical Cut

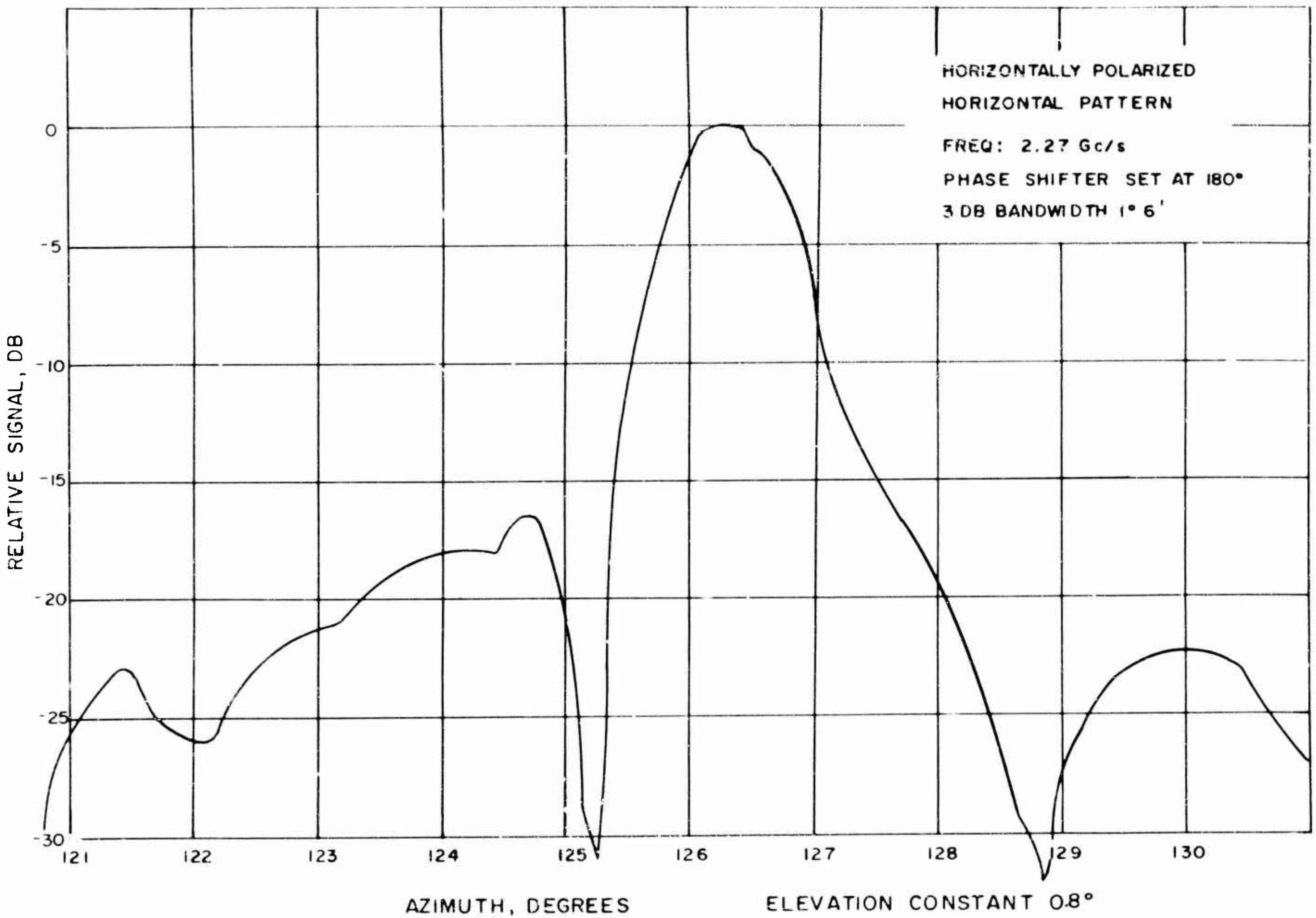

Figure 13 - Horizontally Polarized Floyd S-Band Antenna Pattern - Horizontal Cut

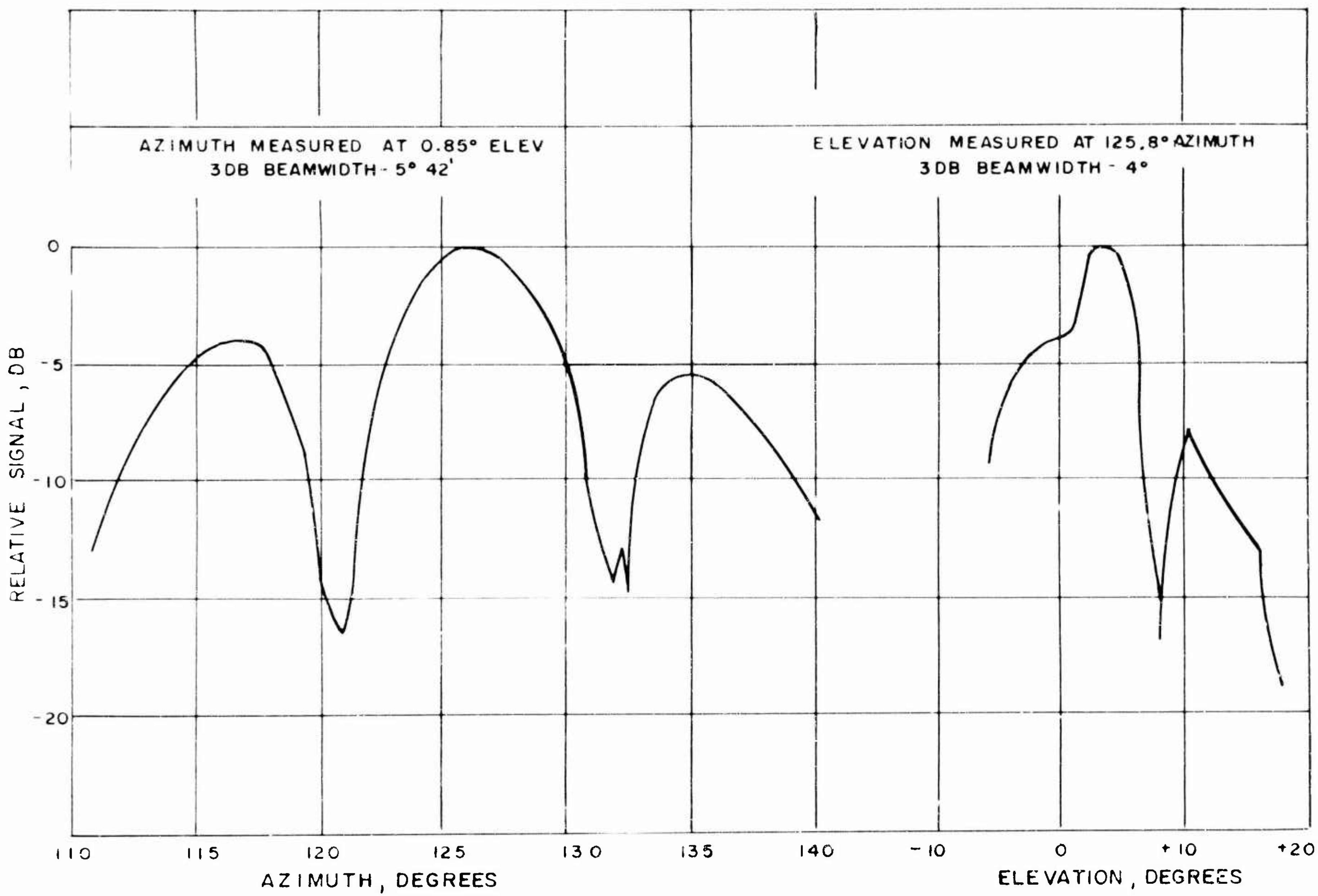

Figure 14 - Floyd Monopulse Antenna Pattern - 427 Mc

APPENDIX B

2 GC TRACKING SYSTEM

Tracking at 2 gc may be accomplished using either horizontally or vertically polarized signals. The circuitry is identical for both channels, therefore this discussion will be limited to the horizontal channel. This discussion will make reference to Figure 4 which is a block diagram of the tracking system.

The Sum Channel

The sum channel is used in the tracking system to provide a means to adjust the effective skew of the conical scan to be a compromise of pull-in range and loss of sensitivity of the received signal. This adjustment is made at the variable power divider and is presently made to scan about the 0.5 db point of the beam pattern. The horizontally polarized sum channel is also used in the transmit mode to provide for on-axis radiation of the 10 kw S-band signal.

Feeds 1 through 4 are S-band horns arranged in a square configuration and are located at the focal point of the dish. Feeds 1 and 3 are connected to hybrid A and feeds 2 and 4 to hybrid A', all through equal lengths of WR-430 waveguide. The sum channel outputs of the hybrid therefore give signals of equal amplitude and phase when the antenna is oriented exactly at the signal source. The outputs of the hybrid are combined in waveguide tee B to give the desired sum channel signal. This signal is then transmitted to the duplexer through WR-430 waveguide which is tuned using a triple stub tuner. The receive leg of the duplexer is connected to the variable power divider at which the crossover point of the conical scan is adjusted.

The transmitter feed line is connected to the transmit leg of the duplexer and going through the same circuitry described above in reverse order provides the on-axis radiated beam, dividing the power equally in the four horns.

The Difference Channel

The difference output from hybrid A is the combined signals of feeds 1 and 3 but with a relative phase shift of 180°. In the case of reception of an on-target signal there would be zero output. In case of a tracking error the difference output would contain phase information proportional to a component of the tracking error. The hybrid A' will treat the signals of feeds 2 and 4 in the same manner. The difference channels from hybrids A and A' are then combined in waveguide tee C except that the signal for a goes through an additional 90° phase shift. The output of waveguide tee C now contains all of the necessary phase information to extablish the tracking error channel.

The error channel is then transmitted through WR-430 to the rotary phase shifter. This type of phase shifter consists of a rotating half wave section sandwiched between two fixed in-line quarter wave sections. The phase shift rotation is exactly equal to twice the mechanical rotation of the half wave polarizer. In this unit the difference channel signal undergoes an electrical phase rotation at a 28.75 rate.

The output of the phase shifter is then combined with the sum channel at the variable power divider which is adjusted to give the effective 0.5 db cross over. The output of the power divider is then connected to the 2 gc receiver.

Reference Generator

The rotating phase shifter also contains a reference generator which provides a signal of 28.75 cps which is synchronized mechanically to the rotating phase shift of the difference channel. This signal is used to modulate a 400 cps carrier and is then transmitted to the conical scan demodulator. This signal is demodulated and split into two 28.75 signals, one of which undergoes a 90 degree phase shift.

The demodulated signal from the 2 gc receiver still contains the rotating phase of the phase shifter but differs in phase from the reference generator signal depending upon this phase relationship of the signal hitting the four feeds. This signal is compared with the two reference generator signals with the phase difference being converted to DC voltages. The reference generator is adjusted so that one DC voltage represents the azimuth error. The DC signals are then fed to the servo amplifier which drives the antenna to perform automatic tracking.

APPENDIX C

DUAL DIVERSITY PHASE LOCK RECEIVING SYSTEM

The phase lock receiving system is used to obtain automatic frequency tracking of the received signal. This is necessary because of the doppler shift if the noise bandwidth of the receiver is to be kept narrow. A secondary purpose of the phase lock loop is to provide means of recording the doppler shift on a digital printer. The following description makes use of the block diagram of Figure 6.

The 455 kc of the R-390A receiver is fed to a limiter-amplifier, the output of which goes to a FM discriminator and audio amplifier. The output of the limiter-amplifier is also compared in phase with a 455 kc crystal reference oscillator. The error signal is then filtered, to remove the modulation, and is connected to the VCO to provide doppler tracking within the R-390A.

The output of the reference oscillator is mixed in turn with the second oscillator of the R-390A and the VCO to give a 29.5 mc output containing doppler information. This output is the one used for measurement using the Hewlett Packard 524 frequency counter.

Each channel of the receiver (horizontal and vertical) is identical in circuitry. The reference oscillator at 455 kc is common to both channels. The doppler shift can be measured, using the frequency counter in either of the two channels. A digital printer is used to provide a permanent record of the doppler shift. The doppler shift is the amount the IF frequency varies from the 29.5 mc center frequency. The circuit is designed such that all errors cancel for the purpose of measuring doppler shift and the doppler output is therefore the same frequency as the doppler input. The accuracy of measurement is therefore determined by the accuracy of the local oscillator of the converter-amplifier which is controlled by the site frequency standard.

The combiner utilizes a signal out of the external IF amplifier on each of the R-390A's and has its own limiter, discriminator and audio amplifier. Since the horizontal and vertical received signals are phase locked to a common oscillator, they are also maintained in phase with each other which permits the use of predetection diversity combination.

To give an indication of phase lock, a one inch cathode ray tube is used to provide a Lissajous pattern. This scope can be used to compare the 455 kc output of each receiver with the reference oscillator or the two receivers with each other.

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