UNATTENDED SPACE-DIVERSITY TELEMETRY TRACKING ANTENNA SYSTEM

W. C. Turner and R. A. Potter
Electro-Magnetic Processes, Inc.
Chatsworth, California

ABSTRACT

A remotely-operated ground telemetry tracking and receiving station is described. The station, operating in a space-diversity mode, is capable of reception and tracking both at VHF and at UHF. The station can be configured and operated from a distance of 240 km using a wide-band land data link. Uplink command at VHF is included as part of the station.

KEY WORDS

"Remotely-operated, Space Diversity, Telemetry, Tracking Antennas."

INTRODUCTION

A remotely-operated telemetry ground station commissioned by the Japan Air Self Defense Forces (JASDF) of the Japanese Defense Agency (JDA) is the result of a joint effort by Nippon Electric Company (NEC), Mitsubishi Electric Corporation (MELCO) and Hitachi. Called the Flight Test and Control System (FTCS), the location of this station makes possible the extensive use of a newly-developed flight test range over the Sea of Japan (Zone G of Figure 1) for the F15 and for the FSX aircraft test programs.

The new telemetry antenna ground terminal is located at Wajima, 545 meters up the northwest side of a mountain rising 3,000 meters above sea level. A wide-band (6 Mbps) landline, supplied by Hitachi, links Wajima with the data reduction center of the Air Development Test Wing (ADTW) located at Gifu, 240 km to the southeast. Site development and equipment supplied at Wajima is due to MELCO and its supplier Electro-Magnetic Processes, Inc. (EMP). Site development and equipment supplied at Gifu is due to NEC and its supplier Loral EMR. The two sites communicate with each other via a 9600 baud half-duplex RS-232 link.

ANALYSIS

EMP undertook a considerable amount of multipath analysis and provided it to MELCO before a final antenna design configuration for the Wajima site was determined. Trade-off analyses were performed in order to optimize the system configuration at S-band: polarization diversity, space diversity, frequency diversity and combinations of all were considered. Although the S-band antennas provide both senses of circular polarizations, economical considerations dictated the elimination of frequency and polarization diversity as candidates, and only right-hand circular polarization (RHCP) is used. For space diversity, analysis showed the optimum vertical spacing (at S-band) to be to be 11 feet (3.35 meters). Figure 2 shows the carrier-to-noise ratio versus range (100 to 120 nautical-mile segment) for three cases: polarization diversity only; three antennas space diversity only; and polarization diversity with space diversity of two antennas. Figure 3 shows the carrier-to-noise ratio over a 20 to 120 nautical-mile range and Figure 4 shows the coverage of altitude vs. range for the low-gain antenna (dotted line) and for the high-gain antenna (solid line); both curves are for polarization and space diversity of two antennas. The curves of Figure 4 are the locus of points for a 13 dB carrier-to-noise (C/N) ratio when the aircraft is radiating an effective isotropic radiated power (EIRP) of 1 watt; anything inside of the curve represents a C/N greater than 13 dB. The parameters for the data presented in these curves are:

Frequency	2,350 MHz
IF Bandwidth	6.0 MHZ
Beamwidth	7.4 Degrees
Beam Tilt	2.0 Degrees up
Antenna Heights	1,776, 1,787 and 1,798 feet above mean sea level (MSL)
Vehicle Altitude	5,000 feet above MSL
Surface Roughness	0.5 feet (Sea State 1)

WAJIMA SITE

The systems at Wajima can provide simultaneous tracking of -- and telemetry data retrieval from -- two aircraft under test either at P-band (280-330 MHZ) or at S-band (2300-2400 MHZ). Two identical tracking systems provide coverage to a range of 120 nautical miles. Each system is composed of two single-axis (azimuth only) tracking antennas operating at both bands stacked one above the other as shown in Figure 5. A second identical radome-protected system (two antennas) is located adjacent to the first. Table 1 provides system specifications.

Although tracking of two aircraft with a single system is possible, the more conventional use of the facility utilizes the two tracking antennas simultaneously to provide space diversity at both bands. Although some improvement may have been realized through the use of polarization diversity (receiving RHCP & LHCP simultaneously) the cost of additional receivers and diversity combiners did not seem justified. For the space diversity operation only one of the two tracking antennas is put into the autotrack mode (the one receiving the stronger signal), while the second one is slaved to the tracking unit so that both are pointing at the aircraft under test. The system also has the capability of simultaneously transmitting as much as 25 watts of power on the P-band uplink.

Two systems were delivered. A system comprises two "antennas," each consisting of one UHF High Gain Antenna (4-foot diameter paraboloidal antenna), a 4-element UHF Low Gain Antenna, and a two-helix VHF array; all three antennas are mounted on an azimuth-only rotator/pedestal. A receiver per band (UHF and VHF), plus diversity combiners (UHF and VHF -- shared with the other antenna of the system) complete the "antenna." A simplified block diagram of the RF subsystem is shown in Figure 6.

Figure 7 is a partial block diagram of a "system." Only Pre-Detection combining, both for UHF and for VHF receivers, was provided. From the figure it may be inferred (triangle, note 1) that Post-Detection combining may be added at a future date; this is true: receivers, as delivered, were not fitted with FM Demodulators for Pre-Detection combining. Use of the new Microdyne Model 3220-PC combiner permits installation of the Model 1444-D FM Demodulator in the combiner itself for demodulation of pre-detection combined signals. If post-detection combining is desired, two additional demodulators may be installed in the receivers simply be removing a plate covering the place for normal demodulator installation, and removing a single jumper cable inside.

The FTCS is intended for totally unattended operation at the Wajima site. The EMP Model GTS-ACU-6-1H Antenna Control Unit (ACU) permits complete remote configuration of the antenna system, including modes (Autotrack, Search, Auto-Acquire, Rate Memory, etc.); configuration of all receivers and combiners, including frequency selection, IF bandwidths, AGC time constants, etc., is also possible remotely via the dedicated link from Gifu.

Referring again to Figure 5, the configuration and outline of one of the two systems is shown. The four-dipole array is the low-gain ("acquisition aid") antenna. The UHF high gain antenna feed is the EMP Radscan feed, mounted at the focal point of the four-foot diameter paraboloidal reflector. The feed is supported by the "clamshelled" radome (the radome and the reflector, joined at the outer edges of their circumferences, constitute a "clamshell"). The two helical antennas, each with its own ground screen, form a two-element VHF array with asymmetrical beamwidths: the elevation beamwidth is broad, while the azimuth beamwidth is narrow.

GIFU SITE

Control of the two space diversity antenna/rotator systems at Wajima is via the keyboard of a single computer located at GIFU. All commands that can be initiated via the ACU-6 antenna control unit's front or side panels can be initiated by the computer operator. The system menus and displays are in the Japanese language.

The Flight Test Telemetry System at GIFU consists of redundant EMR System 90 high-speed acquisition, real-time parallel processing, storage and display systems. As shown in Figure 8, each system is built around the EMR 8715 Preprocessor.

Data inputs from the aircraft, directly or by tape playback, are IRIG-standard PCM streams, each conditioned and synchronized by an EMR 8320 PCM Bit Synchronizer and decommutated by a D20 module within the 8715. This pair of units handles data at rates to 20 Mbps, preparing each word for preprocessing in the 8715. To guard against loss of data, redundant preprocessor units are used.

This system is configured with the O/S90 architecture, and accepts both MIL-STD-1553 data (IRIG Chapter 8) and PCM telemetry data. Data can be displayed at any workstation in many formats. The O/S90 was delivered with a variety of graphic display formats including strip chart, bar chart, crossplots, and alphanumeric. A software editor is available to create new displays (such as annunciator panels, artificial horizons, heads-up displays, flight director layouts, power-spectral displays, etc.). Parameter assignments can be changed while viewing data, as can display characteristics such as axis scaling, time span, update rate, colors, limit checking. etc.

SYSTEMS CAPABILITY

Each of the antennas is identical, and each is capable of autotracking, independently of any outside information, at VHF or at UHF. Although in normal operation, one antenna is designated the Master, and the other is designated the Slave, either of the antennas is capable of tracking (and acting as the Master) with the other antenna slaved to it. This includes one antenna in the system tracking at VHF (and slaving the other), with the other receiving at UHF (S-band). In short, either antenna of an FTCS system can track any signal that it is capable of receiving, and slaving the other antenna to it.

REMOTE CONTROL OPERATION

For the following discussion, Local refers to the site at which the antennas are located (Wajima), and Remote refers to the site at which the "Remote Control" equipment is located (Gifu). ACU's are referred to as "ACU-6's." Parallel control is referred to either as "GPIB" or as "IEEE-488"; serial control is referred to as "RS-232C." Master refers to the ACU at Wajima that is in control; the Master can be in control in any mode: Autotrack, Manual, Search, etc. The Antenna/Pedestal that is not in control at Wajima is referred to as the Slave. The Slave Antenna/Pedestal follows the Master Antenna/Pedestal at all times; its primary function in this mode is only to "Receive" signals from its diverse Space Position and to provide these signals to the "Diversity Combiner" for combining with the signals received by the Master Antenna/Pedestal.

Each of the antennas is capable of independent remote control from the Gifu site. Complete control, including mode of operation, frequency/band of operation, etc. is possible. Systems at Wajima report back status and operating parameters to the Remote station at Gifu over the 6 MHZ data link.

The two Local ACU-6's are interconnected to each other through an RS-232C interface cable for slaving and for status purposes. The present position and mode status of each antenna is transmitted from one unit to the other. Each of the ACU-6's is provided with a Master switch. There is a confirmation cycle of three (3) seconds for changing from Master to Slave mode in each ACU-6. If both of the ACU's are put in Master mode, each ACU will operate independently, controlling its own antenna/pedestal; if one Master switch is turned off, that ACU will automatically "slave" to the other one. If one ACU is tracking, the other will be slaving, and conversely. The two ACU's cannot be in the Slave mode at the same time.

RECEIVER/TRANSMITTER

Operating in the Space Diversity mode, signals received by each of two identical antennas, separated in space, are fed to a Diversity Combiner. Operation in this mode permits an increase in signal-to-noise ratio (S/N) of 2.5 dB over that attainable with a single system (for signals that are approximately equal at each of the antennas).

The two VHF antennas per system are co-located with the UHF antennas. Each VHF antenna is identical to all of the others, and is capable not only of autotracking, but of transmitting up to 25 watts of c-w RF power. Since transmitting and receiving occur on different frequencies in the VHF band, provision is made for the transmission of signals on one antenna (radome) complex, while receiving signals at the other frequency at the opposite antenna (radome) complex. Transmit and receive frequencies are in the bands 282-286 MHZ and 326-330 MHZ.

DIVERSITY OPERATION

Diversity combining is a technique for coping with the problem of signal fading. In a telemetry link, the signal received from the telemetry source at the telemetry receiving system will undergo amplitude fluctuations (fades) for a number of reasons. These include changes in the gain and polarization of the source antenna due to vehicle maneuvering, multipath interference with the direct signal, and atmospheric effects. Fades from these causes can easily reduce the received signal at one of the two antennas in the system by 20 dB or more. Fortunately, the fading due to these causes at (say) antenna #1 is not correlated with the fading at (say) antenna #2, and this is one of the advantages of space diversity.

In diversity combining, two or more receiver outputs are added in the combiner to provide one continuous output. Diversity combining depends on a physical difference in the path to each receiver so that deep fades are uncorrelated, i.e., occur at different times in different channels. The types of diversity used to achieve this essential difference in the two (or more) receiver channels are space diversity, frequency diversity, polarization diversity, time diversity, and angle diversity. The type selected depends on the source of the fading problem. Space diversity, which is utilized in the proposed system, is best for suppressing fades due to multipath reflections. Polarization diversity suppresses fades caused by changes in source antenna polarization due to vehicle maneuvering; polarization diversity, combined with space diversity, was originally proposed for the FTCS Program but current requirements have eliminated the polarization diversity portion of the system -- which seriously diminishes each system's capability to provide an optimum signal-to-noise ratio (S/N) under all conditions

The Microdyne Model 3220-PC combines two receiver channels. Two combiner modes are available: pre-detection mode and post-detection mode. Pre-detection mode means that the two signals are combined, prior to detection, at the receiver's second IF frequency; this requires that the signal carriers in each receiver output be in-phase, and at the same frequency when combined. This is accomplished through a phase-lock loop in the combiner. Post-detection combining does not require this since the signals are combined after final detection where only the modulating signal (baseband) is present. This might seem simpler, but post-detection combining (which is not currently being provided in this program) has other disadvantages, beyond the scope of this discussion, which make pre-detection combining preferable if only one is to be used.

The 3220-PC combiner is an "optimal-ratio" combiner; this means that the two signals are not simply added, but are weighted in an optimal manner before addition to provide the best output carrier-to-noise ratio. The weight is the amplitude ratio of the two signals to be added. Optimum weighting involves using more of the signal with the better C/N ratio than the signal with the poorer C/N ratio (1).

CONCLUSION

To meet the flight testing challenges of current and future generation aircraft, the Japanese Air Self Defense Forces have purchased and commissioned a state-of-the-art telemetry receiving and data reduction facility with extensive expansion capability. By utilizing dual-band tuners in their receivers, they can cover L-band as well as S-band without changing the antenna. Their data rates can be increased to 12 Mbps with no changes to the ground station. By adding additional receivers and combiners they can embrace polarization diversity in addition to the existing space diversity. The option to operate the entire system locally or from miles distant adds to the flexibility of JASDF planning.

ACKNOWLEDGMENTS

Many thanks to C. W. Chandler of EMP for generating the curves used here.

REFERENCES

(1) Lennox, William M., Improved Radio Frequency Communications Through The Use of Diversity Combiners, Microdyne Corporation, Ocala, Florida. January 1984.

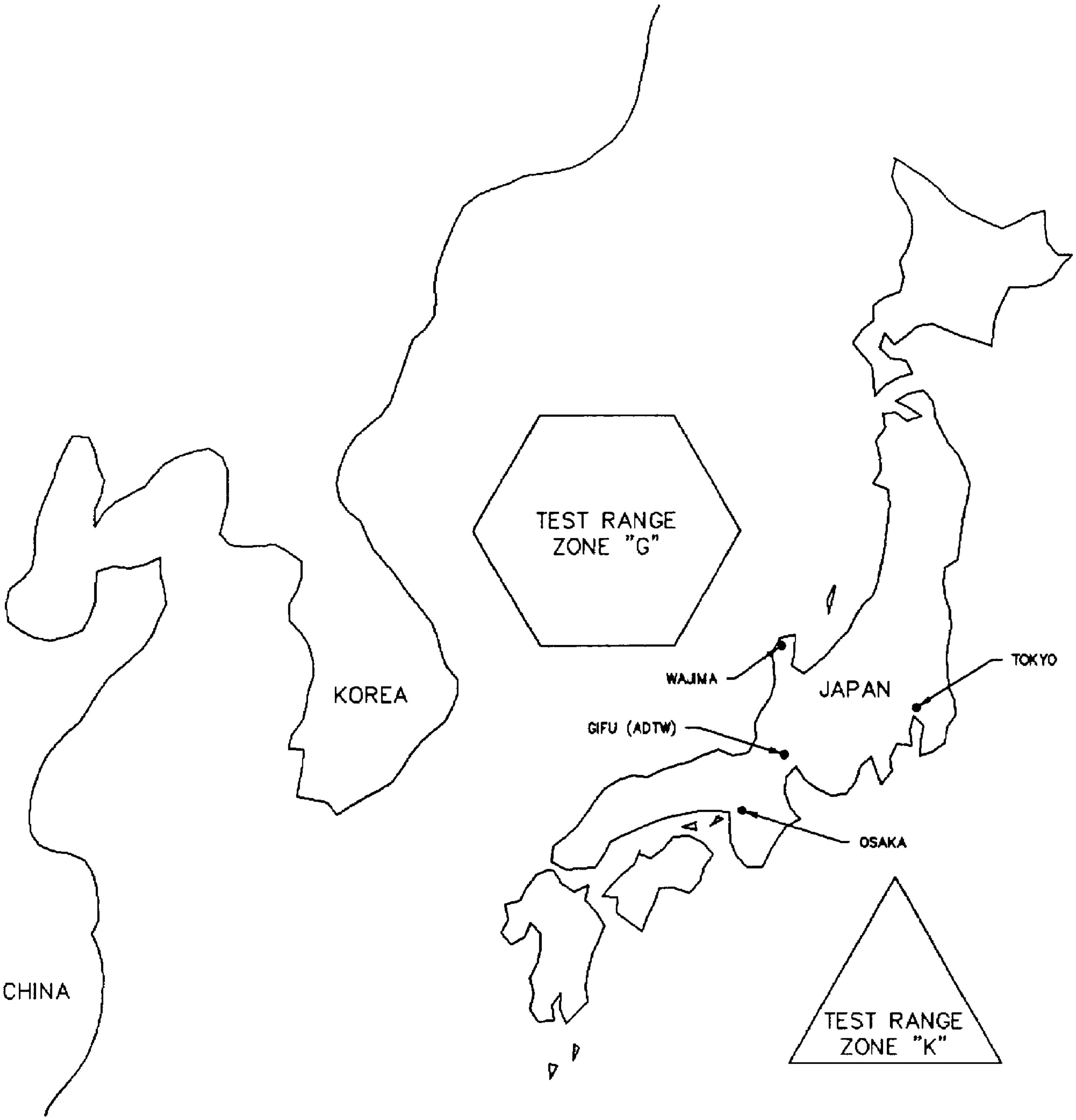

TEST RANGE
ZONE "G"
KOREA
CHINA
WAJIMA
GIFU (ADTW)
JAPAN
TOKYO
OSAKA
TEST RANGE
ZONE "K"

Figure 1

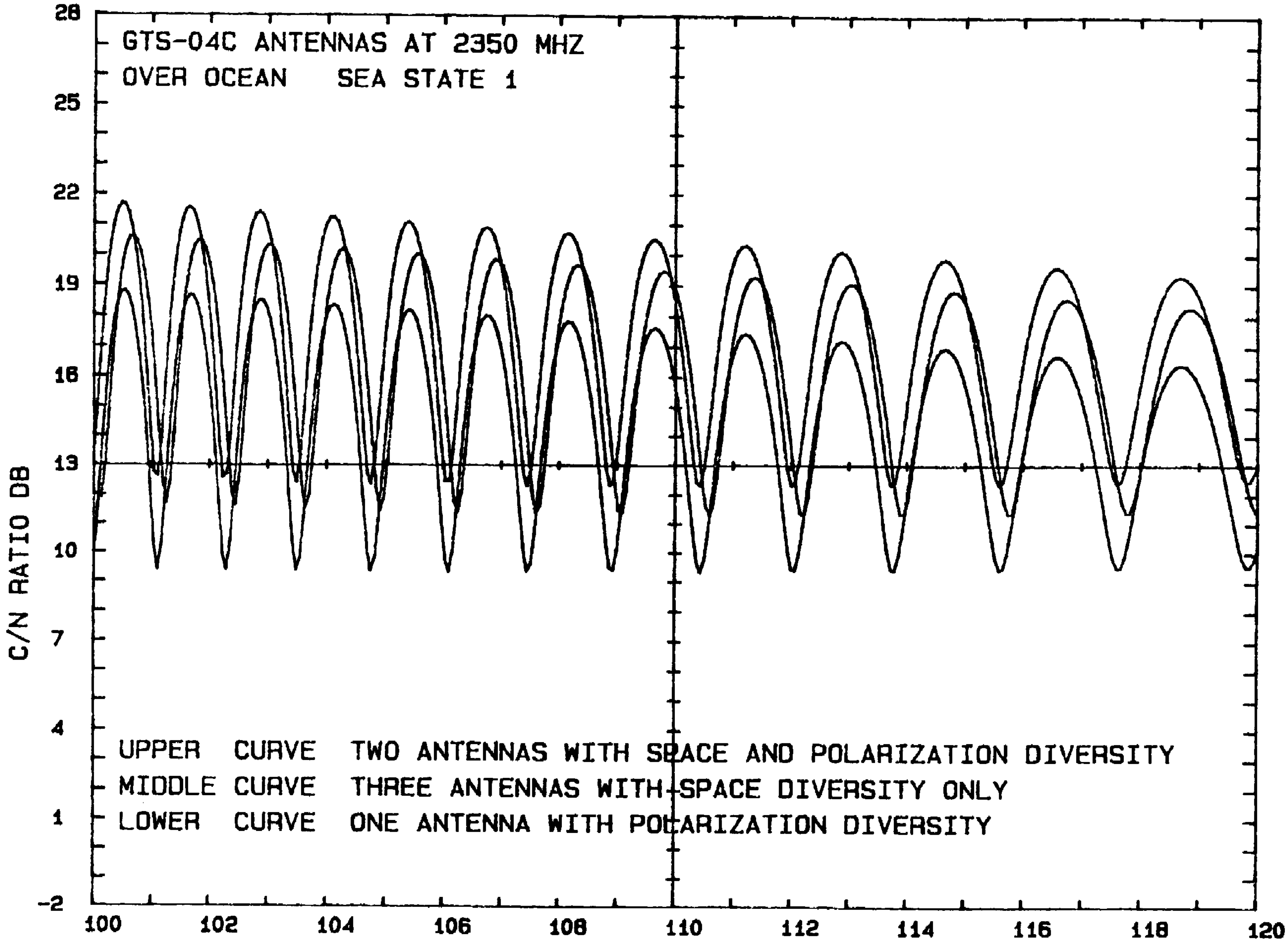

GTS-04C ANTENNAS AT 2350 MHZ
OVER OCEAN SEA STATE 1
UPPER CURVE TWO ANTENNAS WITH SPACE AND POLARIZATION DIVERSITY
MIDDLE CURVE THREE ANTENNAS WITH SPACE DIVERSITY ONLY
LOWER CURVE ONE ANTENNA WITH POLARIZATION DIVERSITY
C/N RATIO DB
28
25
22
19
16
13
10
7
4
1
-2
100
102
104
106
108
110
112
114
116
118
120
RANGE NAUTICAL MILES

FIGURE 2

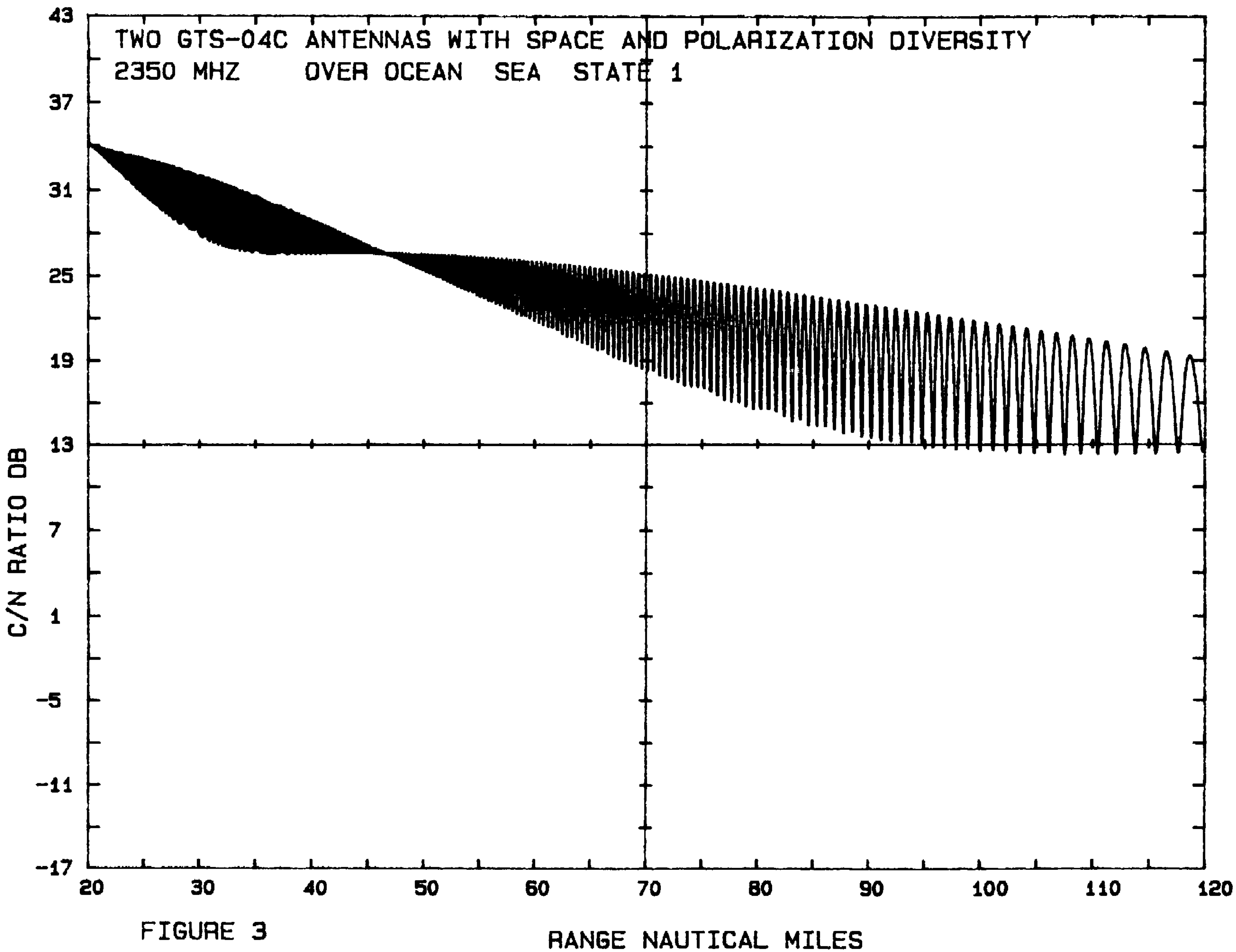
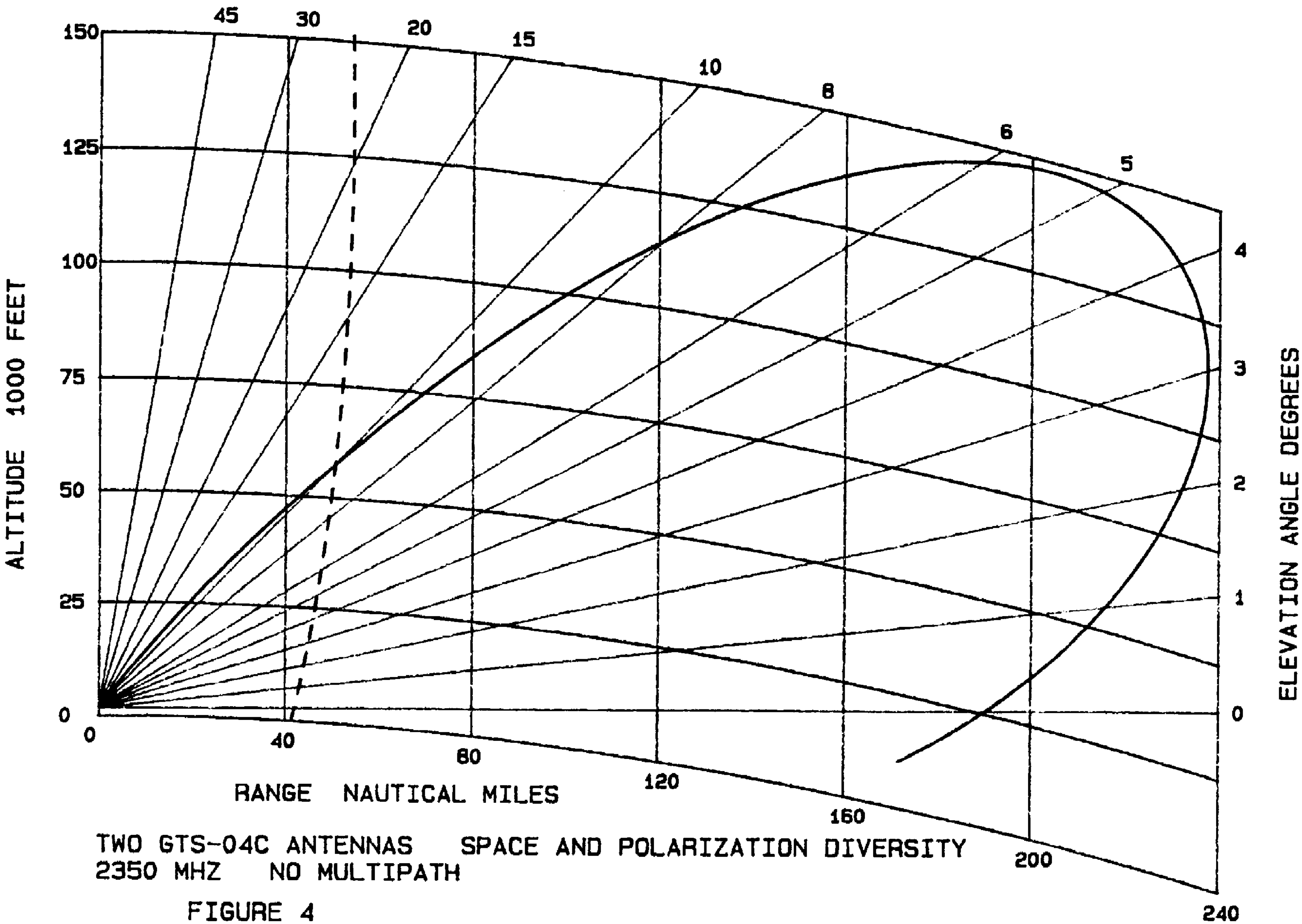

TWO GTS-04C ANTENNAS WITH SPACE AND POLARIZATION DIVERSITY
2350 MHZ OVER OCEAN SEA STATE 1
C/N RATIO DB
43
37
31
25
19
13
7
1
-5
-11
-17
20
30
40
50
60
70
80
90
100
110
120
RANGE NAUTICAL MILES

FIGURE 3



TWO GTS-04C ANTENNAS SPACE AND POLARIZATION DIVERSITY
2350 MHZ NO MULTIPATH

FIGURE 4

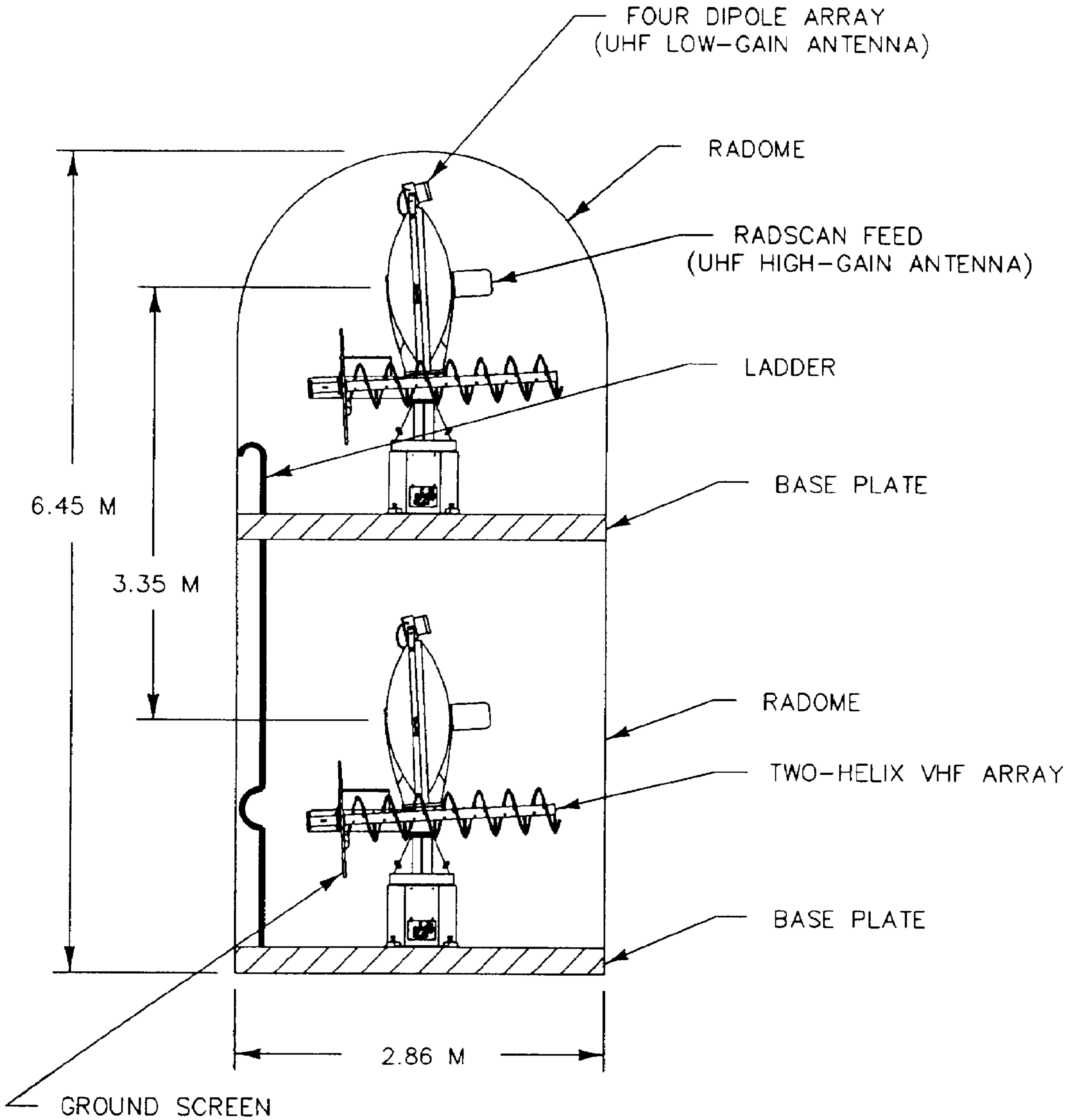


Figure 5 SPACE DIVERSITY ANTENNA SYSTEM

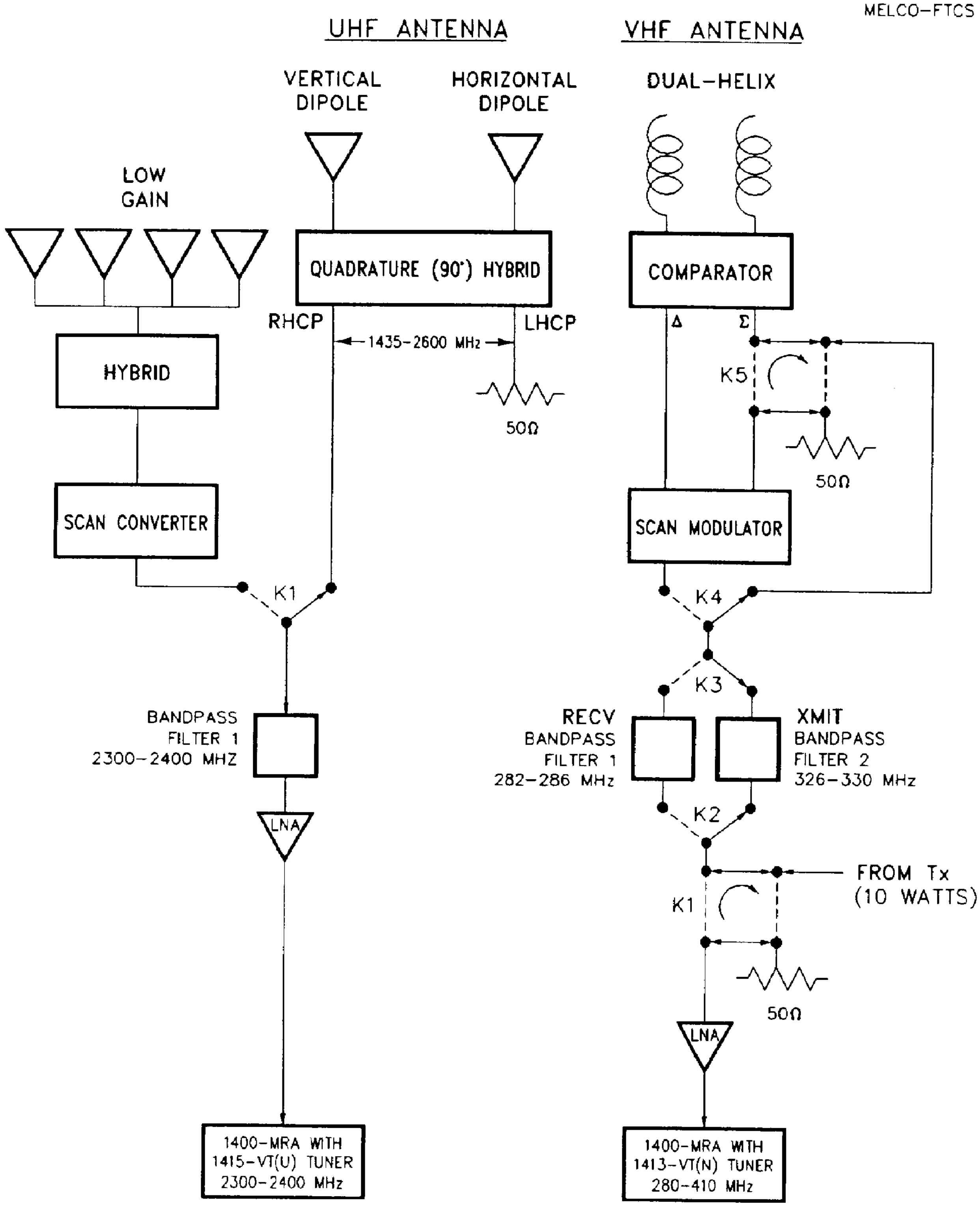


Figure 6 SIMPLIFIED BLOCK DIAGRAM, RF SUBSYSTEM, S-BAND AND VHF
VHF SYSTEM SHOWN IN TRANSMIT MODE.
ONE OF TWO ANTENNA/PEDESTALS PER SYSTEM.

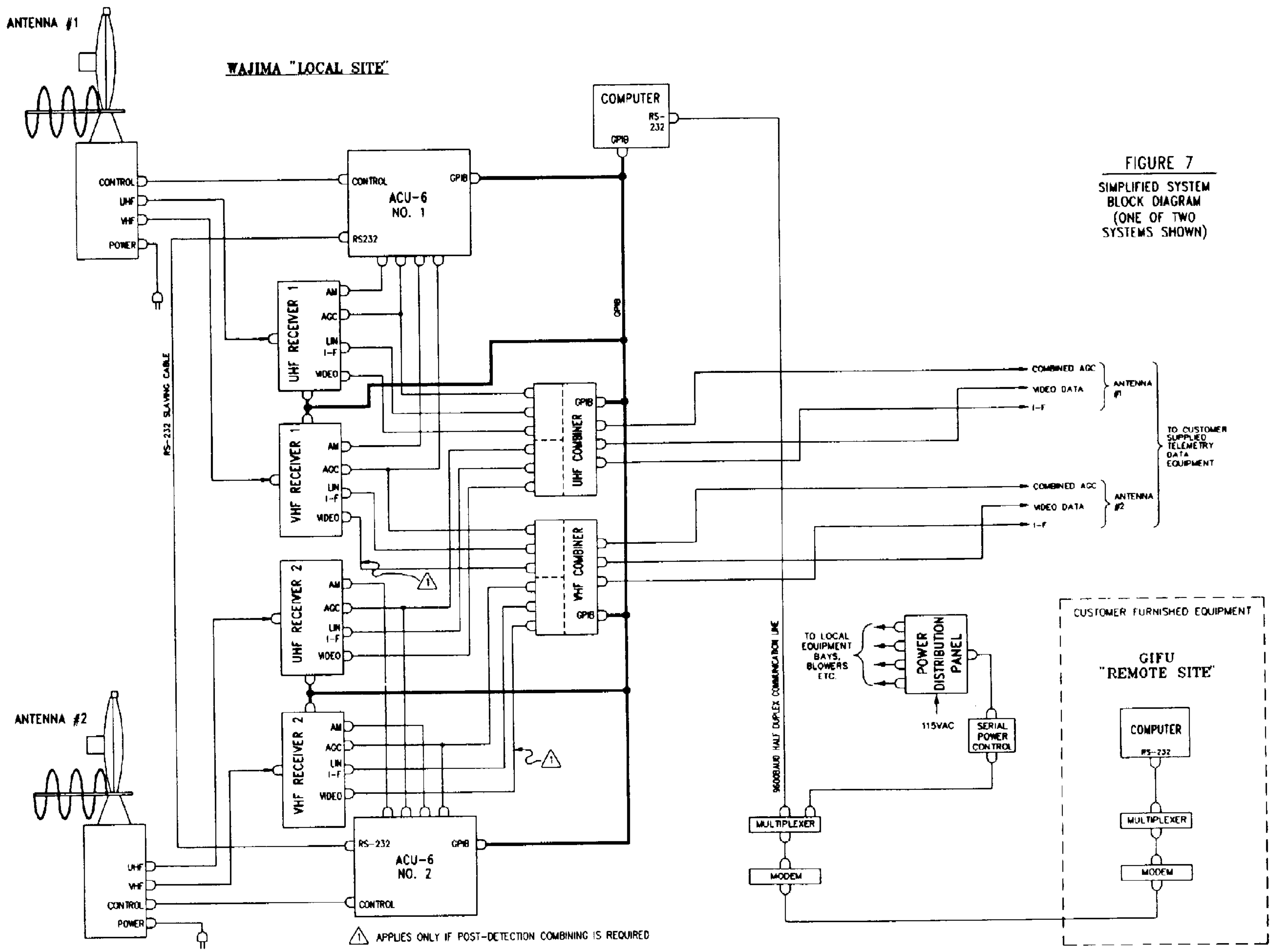


FIGURE 7
SIMPLIFIED SYSTEM BLOCK DIAGRAM (ONE OF TWO SYSTEMS SHOWN)

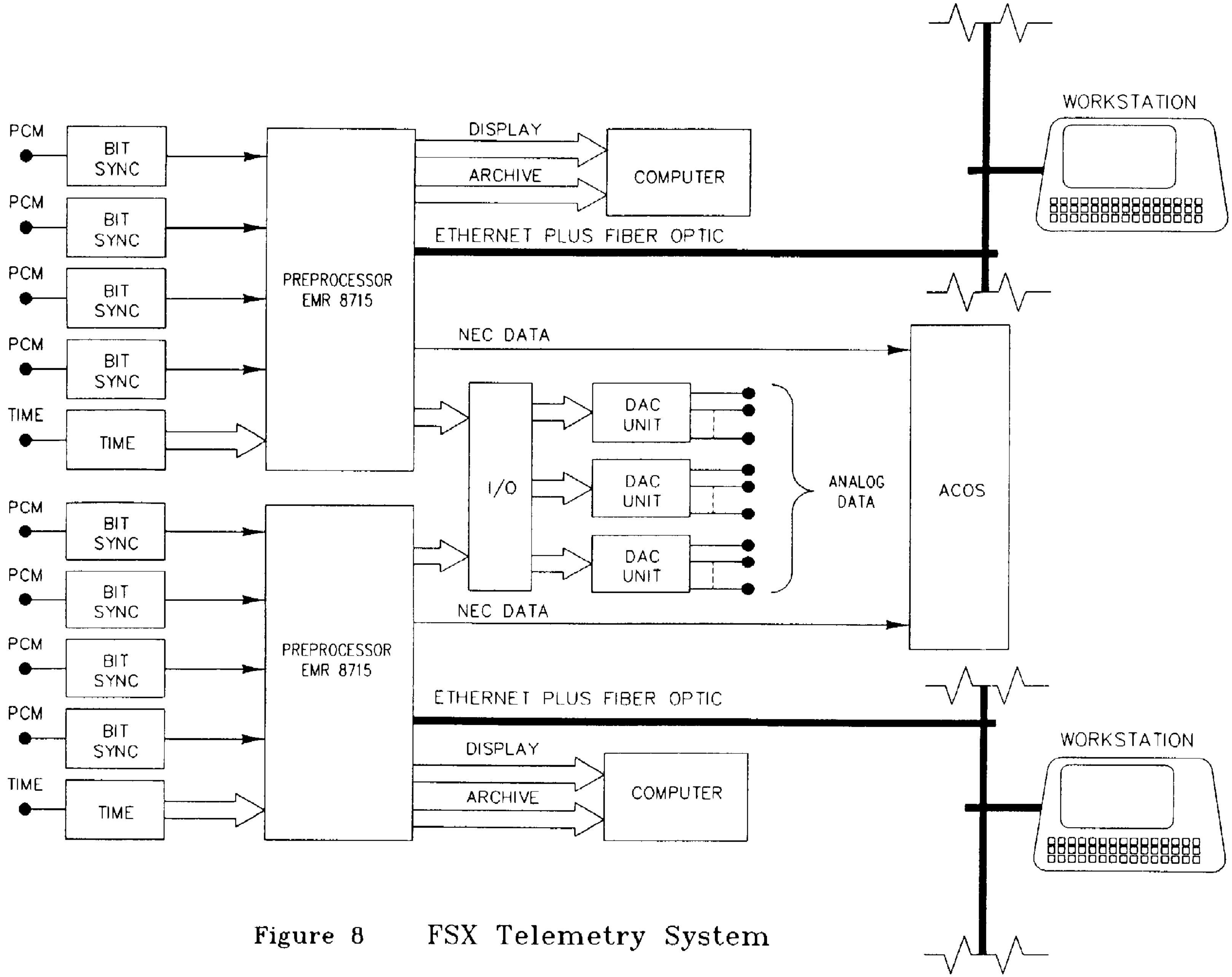


Figure 8 FSX Telemetry System

TABLE 1

SYSTEM SPECIFICATIONS
SPACE DIVERSITY TELEMETRY TRACKING ANTENNA SYSTEM

	UHF	VHF
Antenna Configuration (Two Antennas, Space Diversity)	4-ft Reflector	Two 7-Turn Helices
Low-gain UHF Antenna	4-Cup Dipole Array	None
Tracking Mode (Az Only)	Hi-gain: Conscan Lo-gain: Single-Channel Monopulse	Single-Channel Monopulse
RF Frequencies, MHz	2300-2400	282-286 & 326-330
IF Bandwidths, MHz	3.3, 6 & 12	0.3, 0.5 & 1.0
C/N Required for Data	13 dB	13 dB
Source EIRP	+30 dBm	+30 dBm
Antenna Gain, Hi-gain	24 dBi Min	12 dBi Min
Lo-gain	14 dBi Min	---
Beamwidths, Hi-gain	7.4°Az 7.4° El	21°Az 35°El
Beamwidths, Lo-gain	13°Az 52°El	---
Acquisition Angle	±13°	±20°
Polarization, Hi-gain	RHCP*	RHCP
Lo-gain	RHCP*	
LNA Noise Figure	1.0 dB (75°K)	5.0 dB (627°K)
LNA Gain	33 dB Min	33 dB Min
Loss, Antenna to LNA	1.0 dB Max	1.0 dB Max

*LHCP available but not used.