"KU-BAND COMMUNICATION SUBSYSTEM"

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ABSTRACT

The Ku-Band subsystem for NASA's Space Shuttle Orbiter is a combined radar and communications system that provides either radar-aided rendezvous capability or high-rate two-way communications via a synchronous-orbit TDRS relay satellite. This paper describes the architecture of the Ku-Band system and focuses on several unique aspects of the design. Communication capabilities are described in detail.

INTRODUCTION

Other papers on the Ku-Band subsystem have given a great amount of detail on specific components of the system. This one gives an overview, with emphasis on certain unique design aspects of the Ku-Band subsystem that enable components to be used for both radar and communication functions.

The Ku-Band subsystem is not designed like most spacecraft subsystems. Because of the nature of the shuttle mission, redundancy is not required. Repair or replacement of failed components can be easily accomplished after landing, while in the meantime the S-Band backup system can be used. Secondly, ease and speed of repair are a major consideration. Component modules must be interchangeable from unit to unit without affecting overall system performance. This forces a design approach that incorporates level control of signals at many interfaces throughout the Ku-Band system.

The Ku-Band system is divided into four line-replaceable units (LRUs). These units are designed to be replaceable at the shuttle integration facility, with no further testing required to assure full system performance. Each LRU is divided into several shop-replaceable units (SRUs) which can be replaced quickly at a Ku-Band repair facility.

The first of the LRUs, the deployed assembly, or DA, contains upconverters, downconverters, and all RF electronics. The DA also includes the 3 foot diamter dish antenna and its azimuth/elevation gimbal mechanism. The DA's RF equipment is shared between radar and communication functions in a rather intricate switching arrangement that minimizes the amount of single-function hardware in the DA. The DA is mounted on the "sill" at the front of the shuttle's payload bay on a boom that can swing out when the doors are open. (See Figures 1 and 2). This gives the antenna a relatively unobstructed view to either synchronous orbit or to a rendezvous radar target. In the stowed position the DA is relatively flat and rests just inside the payload bay doors. This configuration avoids intrusion into the payload volume.

The other three LRUs are mounted inside the shuttle in the avionics bay. They look like 3 identical black boxes although their functions are quite different. (See Figure 3).

The signal processor assembly (SPA) performs all the baseband processing for the communication function. For the receiving function it performs bit synchronization, frame synchronization, and data decommutation, although a bypass mode, called Mode 2, can be used to allow bit detection to be performed by a payload. For the transmitting function the SPA selects three of eleven data sources and constructs a 1.875 GHz modulated IF signal which is fed to the Ku-Band upconverter in the DA.

Electronics Assembly Two (EA-2) is the radar processor box. It interfaces with the DA through a 78 MHz radar IF. The inphase and quadrature components of the received signal are detected and converted from analog to digital form for processing. Control lines from EA-2 to the DA allow the EA-2 to adjust pulse repetition frequency, pulse duration, and the transmit/receive frequency. Pulse to pulse coherence is maintained to improve performance. The upconverter/downconverter in the DA is capable of accommodating five different RF's. The EA-2 cycles among all 5 frequencies and averages the result to improve immunity to target scintillation.

Electronics Assembly One (EA-1) contains the antenna positioner servo, a microprocessor for mode control, plus several communication functions that didn't fit in the SPA. Because of its controlling microprocessor, the EA-1 can be considered the "heart" of the Ku-Band system. Although the SPA is turned off in radar mode and the EA-2 is turned off in communication mode, the EA-1 is always active (as is the DA).

MONOPULSE TRACKING

In both radar and communication modes, the antenna must be able to point at a moving target, even though the shuttle may be rotating underneath the deployed assembly. This autotracking function is accomplished using a 5-feed time-shared single channel monopulse tracking system. A central feed at the focus of the dish antenna is surrounded by four weakly coupled feeds. Opposite pairs of these weakly coupled feeds are added

180° out of phase. The result (see Figure 4), is a signal whose amplitude is proportional to the antenna pointing error over an angular range of about ± 2 degrees.

A pair of PIN diodes (see Figure 5) control whether the error signal is (A+C) - (B+D) or (A+B) - (C+D). This time-sharing capability allows a single receiver to be used for both azimuth and elevation errors (see Figure 6). A selectable 0/180 degree downconversion phase shift is used to modulate the RF error signal.

The error signal is then added to the sum, or main channel, signal. The relative phasing of the two channels is such that the error signal will add to or subtract from the primary signal amplitude. The 0/180 degree modulation of the Δ channel phase therefore appears as AM on the comm track and radar IF's. The magnitude and phase of this AM give a direct linear measure of the antenna pointing error in either azimuth or elevation (whichever is selected by the PIN diode bias). The antenna control servos for communication and for radar translate AM into gimbal motor drive current to cancel the measured error.

Shuttle motion is taken out by an inner servo loop that operates on gyro error signals. The gyro package is mounted on the antenna side of the gimbal assembly. The inner servo loop acts to maintain the gyro's orientation in inertial space by driving the gimbal motors to counteract shuttle rotation. In effect the gyro and the monopulse feed system each produce error signals which are added and used to drive the gimbal motors.

RADAR MODE OPERATION

In radar mode, the DA, EA-1, and EA-2 are active. The SPA is turned off. The transmitted RF signal consists of a pulse train originating from a coherent synthesized frequency source in the DA. Pulse width, pulse repetition rate, and carrier frequency are all controlled by the radar processor in the EA-2. Moreover, the EA-2 selects which antenna or combination of antennas will be used. Transmission occurs only through the main (dish) antenna, but for reception either a widebeam horn or an azimuth/elevation monopulse error signal is available in addition to the primary (sum) signal.

During radar search acquisition, for maximum sensitivity only the sum channel is used. When a target is detected, a sidelobe test is performed by comparing the received signal level from the widebeam horn (which is pointed in the same direction as the dish antenna) with that from the dish. This is done by switching the difference (Δ) channel to the widebeam horn then alternately blanking the Δ and Σ receivers. If the widebeam horn signal is not substantially weaker than the received signal from the dish, the radar processor concludes it has detected the target on a sidelobe of the main beam (see Figure 7). The receiver gain is ratcheted down and the search continues. If the widebeam horn signal is substantially weaker, a target detection is declared, and the radar enters its tracking mode. The difference receiver is switched over to the monopulse az/el error signal and the radar processor commands the sequence $\Sigma + \Delta az$, $\Sigma - \Delta az$, $\Sigma + \Delta el$, $\Sigma - \Delta el$ for each of the five frequencies in turn. This set of received signals constitutes a “frame” of data which is used to determine error signals for the angle tracking loop. Simultaneously three range gates are used for the range and range rate tracking loops. Range, range rate, angle, and angle rate estimates are output to the orbiter’s computers for use in making a fuel-efficient rendezvous with the target.

The preceding discussion dealt with the passive target radar, which is what one normally thinks of when one hears the word radar. The Ku-Band system also includes an active target radar mode, for which the radar target carries a special transponder. Although this greatly extends the radar range, there are no spacecraft at present which carry such a transponder.

COMMUNICATIONS MODE OPERATION

In communications mode, the DA, EA-1, and SPA are active. The EA-2 is turned off. The TDRSS K-band single access service is used. This provides nearly full-time communication independent of whether a ground station is in view from the orbiter.

RETURN LINK

The SPA multiplexes three of eleven possible data sources onto a modulated 1.875 GHz carrier which is fed to the DA for upconversion and transmission to TDRS.

The return link, from Orbiter Ku-Band system to TDRS to ground, has two modes of operation. Mode 1 features a high rate digital data channel denoted channel 3, of 2 to 50 Mbps. This data is rate one-half convolutionally encoded, giving a symbol rate of 4 to 100 Msps and doubling the signal bandwidth. The encoded high-rate channel 3 data modulates the carrier as the I channel of an unbalanced QPSK modulator. (See Figure 8). The unbalanced modulation gives 80% of the power to the I channel, leaving 20% for the Q channel. The Q channel input to the 1.875 GHz modulator is itself a modulated 8.5 MHz subcarrier.

The modulated 8.5 MHz subcarrier is formed by unbalanced QPSK modulation of an 8.5 MHz square wave. (See Figure 9). Channel 1, which consists of orbiter operations data, gets 27% of the subcarrier power, while Channel 2, one of five possible sources, gets the remaining 73%. Because the subcarrier is a squarewave, it gives a true binary input to the 1.875 MHz QPSK modulator.

For Mode 2, the subcarrier is formed the same way except that it is filtered to become a sine-wave subcarrier. Channel 3 is selected from five sources. The baseband data stream from Channel 3 is added to the subcarrier (using frequency isolation), then the resulting video is frequency modulated using a 1.875 GHz VCO. Figure 10 illustrates the modulation implementation for both modes, with a 1.875 GHz switch selecting the modulator to be used. The complete set of possible return link data sources is shown in Table 1.

The 1.875 GHz modulated IF signal from the SPA is upconverted to 15.003 GHz in the DA, using an LO of 84 x 156 MHz. A TWT provides 50 watts of RF power for transmission from either the widebeam horn (acquisition) or the dish antenna (when angle tracking begins).

FORWARD LINK

In the receiving, or forward link function, the DA downconverts an incoming 13.775 GHZ signal to 647 MHz, using the 84 x 156 MHz LO. As explained in the section on monopulse tracking there are actually two receivers. The sum receiver carries a signal from the central feed of the dish to the 647 MHz data channel output. A combination of the sum and difference receiver outputs gives the 647 MHz communication angle track output (see Figure 11). The angle track output is fed to an AGC circuit and envelope detector in EA-1. The detected percent AM gives a measure of the angle errors (alternating azimuth and elevation at a 370 Hz sample rate). Error voltage for azimuth and elevation are fed to the servo, which provides motor drive until the error voltages are nulled.

The DA’s data channel output at 647 MHz is downconverted to a 21.88 MHz second IF inside the EA-1 (see Figure 12). The signal is then passed through an automatic gain control stage which acts on a narrowband noise sample 3 MHz from the carrier. This AGC stage establishes a fixed noise density independent of signal level. Next comes an automatic level control (ALC) which uses variable attenuation to establish a fixed signal level. The AGC is only needed to ensure that the ALC’s square law detectors operate at their designed levels, (see Figure 13).

Since the received signal from TDRS usually includes a 3.028 megachip per second pseudonoise spectrum spreading code, the next operation in the receiver is to strip off this PN code if it is present. A tau-dither loop performs this function, (see Figure 14). The loop’s error signal is of the form $I^2 - Q^2$, where I^2 is the in-phase power and Q^2 is the quadrature power. The $I^2 - Q^2$ difference is actually formed by time-sharing the square law detector, using the dither signal. When $I^2 - Q^2$ reaches a large enough value, the PN loop is considered locked and the sweep shuts off. The “on-time code” is used to despread the data at the input to the Costas loop, which demodulates the data, (see Figure 15).

The SPA receives the demodulated bit stream, up to 216 Kbps, from EA-1. In forward link Mode 1 the SPA performs bit synchronization, frame synchronization, and bit detection. In Mode 2 the data is not processed at all, but is amplified and filtered before being output to the orbiter. Mode 2 will be used primarily for payload support, where the payload contains its own bit synchronizer and bit detector.

ANTENNA SWITCHING

The use of two antenna systems for both radar and communication modes is unique to the Ku-Band system. Figure 16 shows the interconnection scheme for these antennas. In radar mode the four-port crossover switch is not used. It is left in the straight-through position. Since radar transmissions are at 13.779 to 13.988 GHz, as compared to the communication transmit frequency of 15.003 GHz, diplexer filters can be used to separate and recombine the radar and communication transmission paths. This is not done for the usual reason of permitting simultaneous operation at two frequencies, but rather to allow the insertion of a ferrite switch assembly in the radar transmission signal path. Unlike the TWT, the ferrite switch is not a wideband device. It is not capable of operation over both radar and communication bands. The radar signal is always transmitted from the central feed of the dish antenna. This gives maximum angular selectivity and helps to prevent unwanted signal returns.

Radar receiving requires two different antenna configurations. During acquisition, the difference receiver is connected to the widebeam horn. The difference receiver is blanked while the sum receiver listens for a target return. When the EA-2 (the radar processor box) detects a target, it alternately blanks the sum and difference receivers and compares the signal levels. This “guard/main sequence” is designed to weed out sidelobe returns. In radar tracking mode the difference receiver is connected to the az/el error output of the dish antenna, allowing continuous angle tracking of the target.

In communication mode, the widebeam horn is never used for receiving. However it is used for transmitting during acquisition. The transmission from the widebeam horn will reach the TDRS as long as the initial pointing of the antenna assembly is within 15 degrees of the true TDRS line of sight. The four-port crossover switch allows the transmitter output at the communication frequency to reach the widebeam horn, while permitting the sum receiver to “listen” on the dish antenna. When the TDRS receives the 15.003 GHz Ku-Band transmission from the widebeam horn, it determines the direction to the shuttle and transmits a 13.775 GHz signal to the Ku-Band system. When the EA-1 detects this signal coming out of the sum receiver, it switches the system into tracking mode, which includes selecting the az/el error signal to the difference receiver. The two waveguide switches must be thrown in the correct order (crossover switch before widebeam select switch) to avoid transmitting 50 watts into the az/el error output and destroying the PIN diodes. Switch timing was a difficult interface area in the Ku-Band system.

CONCLUSION

The functions of the shuttle Ku-Band integrated radar and communication subsystem have been described, with emphasis on the communication mode and on the integration of radar functions into the hardware. The monopulse tracking and antenna switching functions have also been covered.

The radar function provides a fuel-saving rendezvous capability, while the communication function allows virtually uninterrupted two-way multichannel communication between ground and the orbiter.

REFERENCE

A good comprehensive reference is “Orbiter Ku-Band Integrated Radar and Communications Subsystem”, by Ralph R. Cager, Jr., David T. LaFlame, and Lowell C. Parode. It appeared in the November 1978 IEEE Transactions on Communications. The author thanks Mr. Parode for providing some of the figures from his 1978 paper for use in this paper.

TABLE 1
RETURN LINK DATA SOURCES

Source	Type	Rate or Bandwidth
CHANNEL 1 (MODE l/MODE 2)		
Operations data - Network signal processor (1,2)	Digital	192 kbps (biphase)
CHANNEL 2 (MODE l/MODE 2)		
Payload Recorder	Digital	25.5 - 1024 kbps (biphase)
Operations recorder	Digital	25.5 - 1024 kbps (biphase)
Payload low data rate	Digital	16 - 2000 kbps (NRZ) 16 - 1024 kbps (biphase)
Payload interrogator (1,2) low data rate	Digital/ Analog	16 - 2000 kbps (NRZ) 16 - 1024 kbps (biphase) 1.024 MHz (PSK or FM)
CHANNEL 3 (MODE 1)		
Payload max	Digital	2 - 50 Mbps (NRZ)
CHANNEL 3 (MODE 2)		
Payload interrogator (1,2) high data rate	Digital/ Analog	16 - 4000 kbps 0 - 4.5 MHz
Payload	Analog	0 - 4.5 MHz
Payload high data rate	Digital	16 - 4000 kbps
Television	Analog	0 - 4.5 MHz

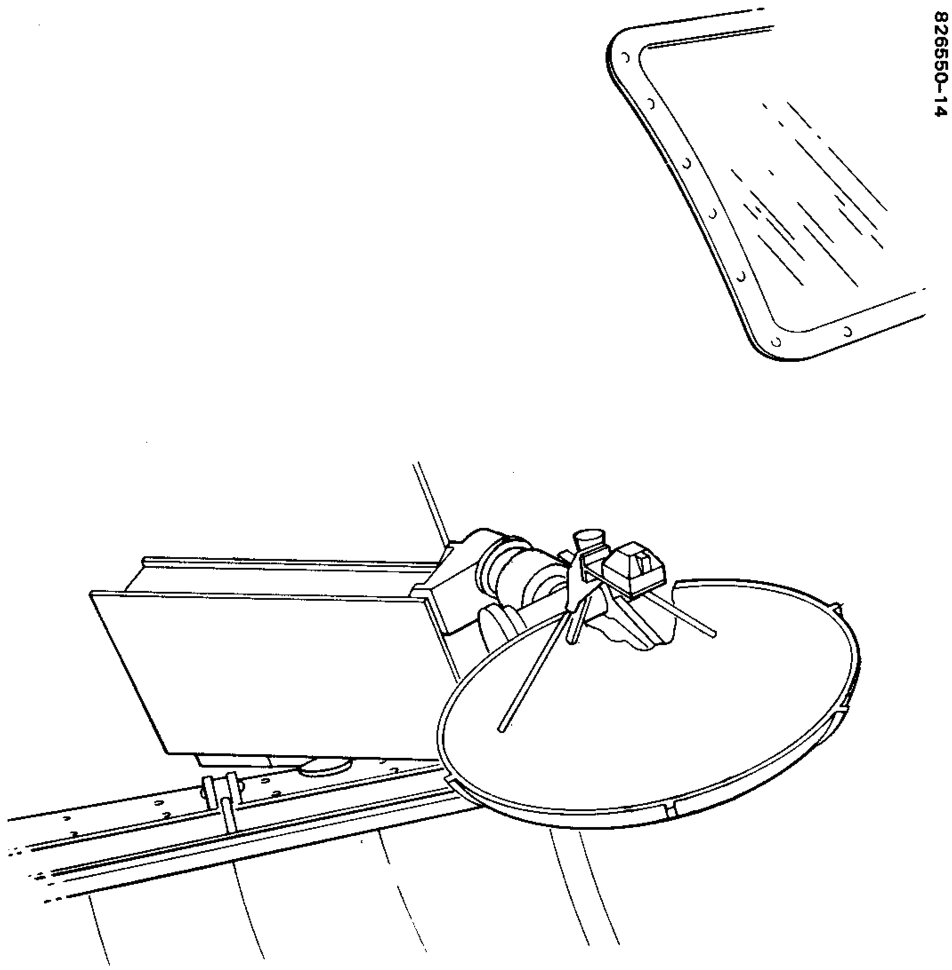

FIGURE 1. DEPLOYED ASSEMBLY

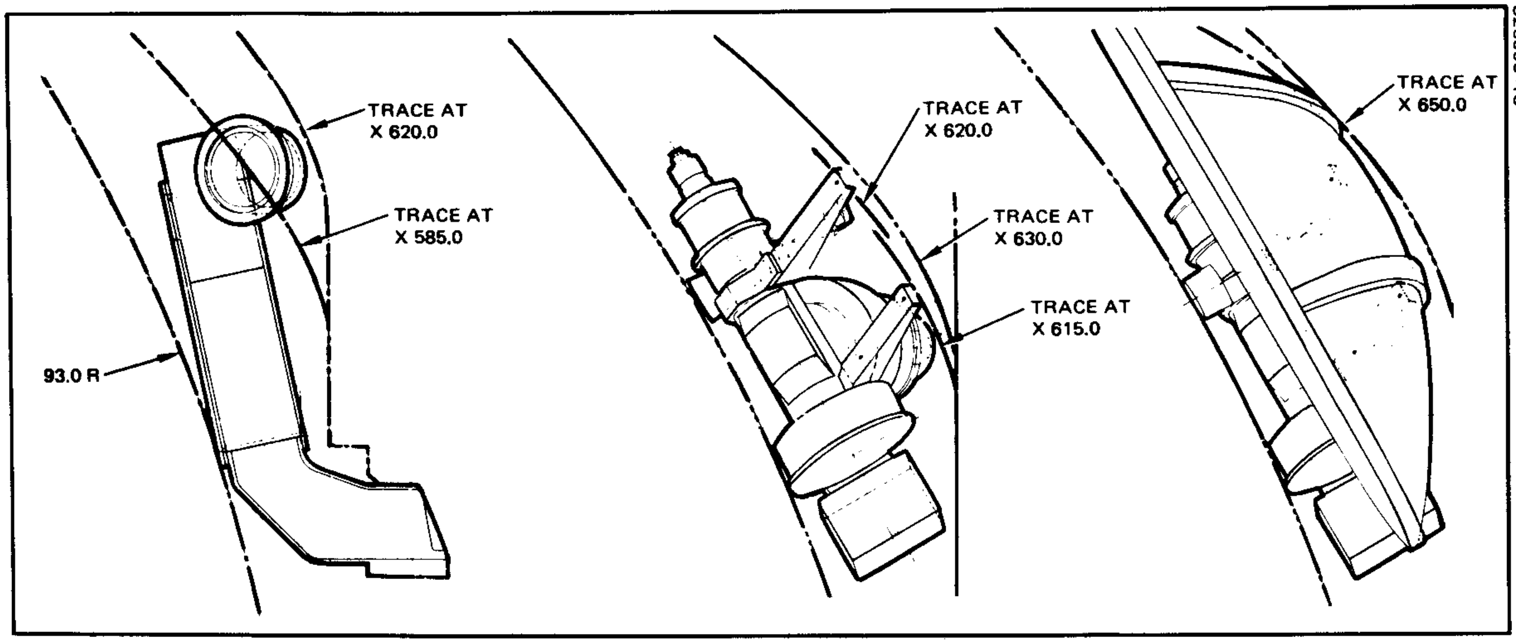

FIGURE 2. STOWED ANTENNA WITH PAYLOAD BAY DOORS CLOSED

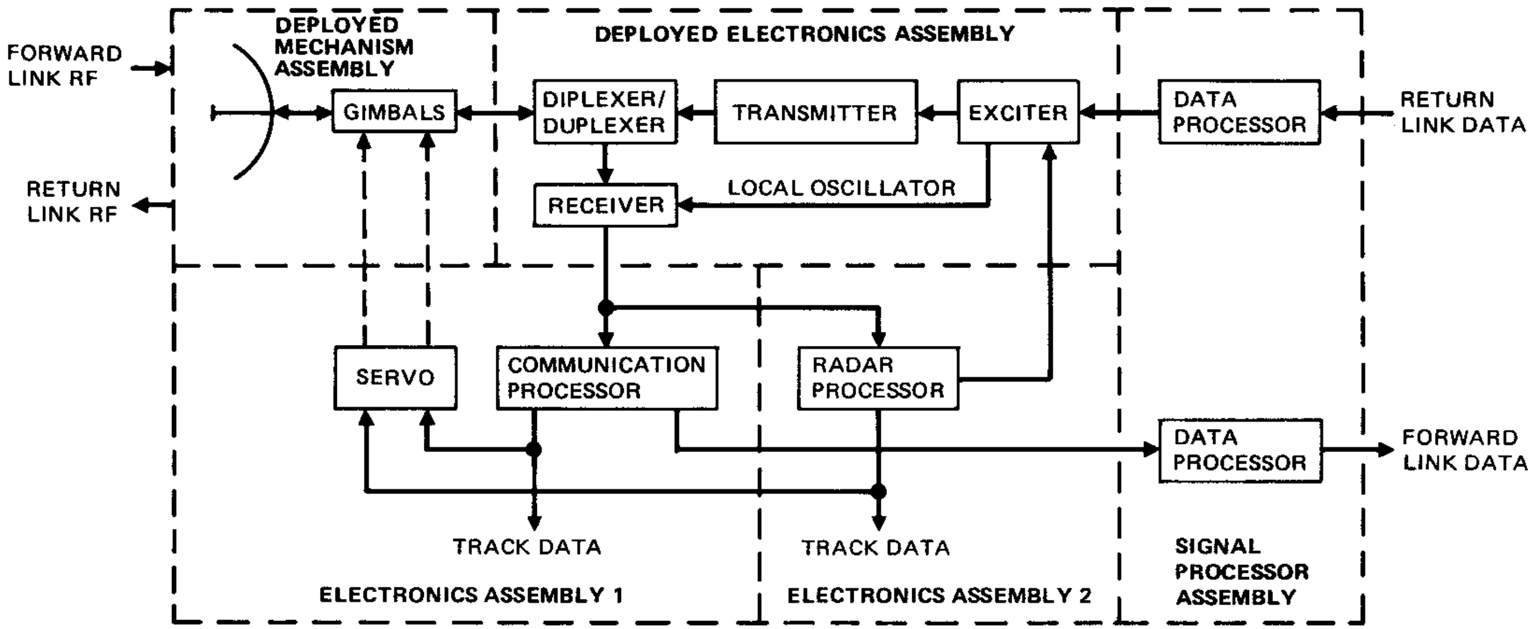

FIGURE 3. Ku BAND SYSTEM BLOCK DIAGRAM

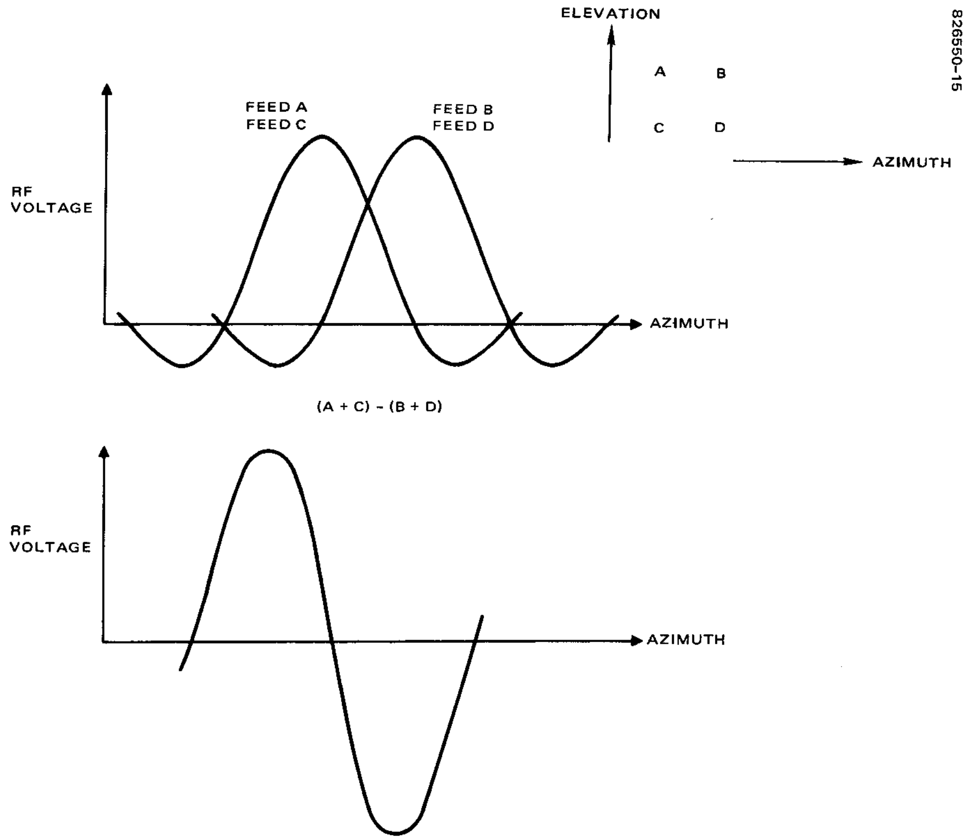

FIGURE 4. MONOPULSE ERROR SIGNAL GENERATION

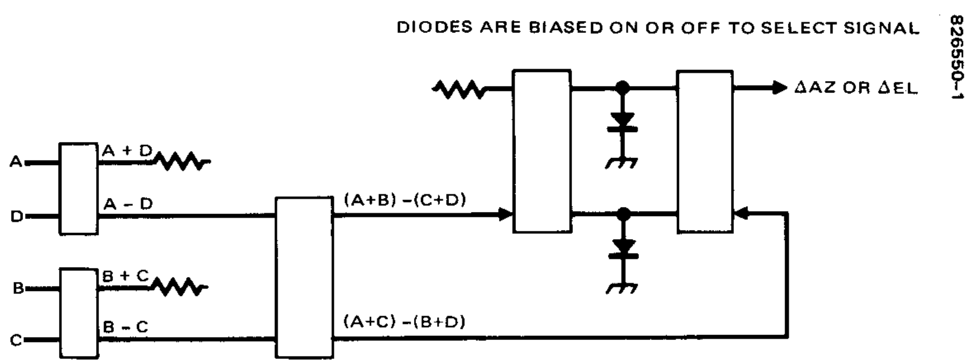

FIGURE 5. AZ/EL DIFFERENCE NETWORK

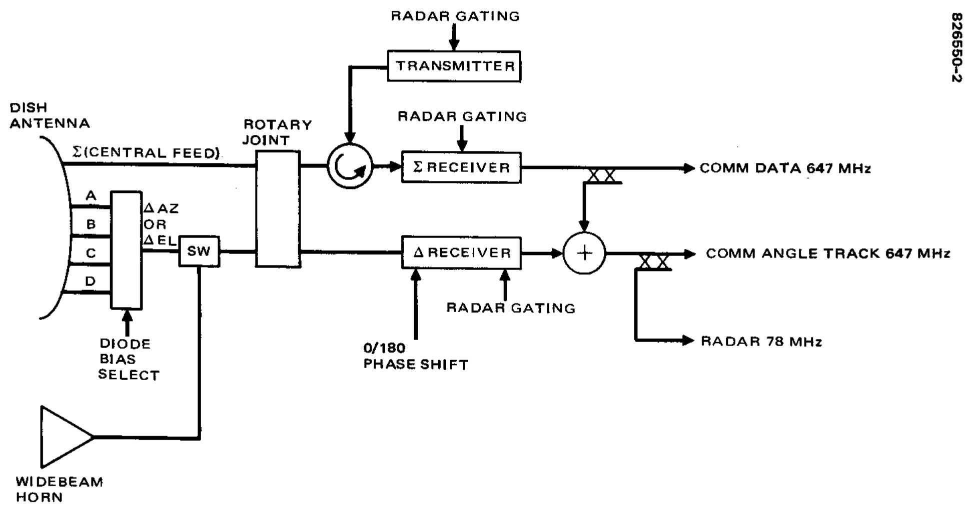

FIGURE 6. DEPLOYED ASSEMBLY FUNCTIONAL BLOCK DIAGRAM

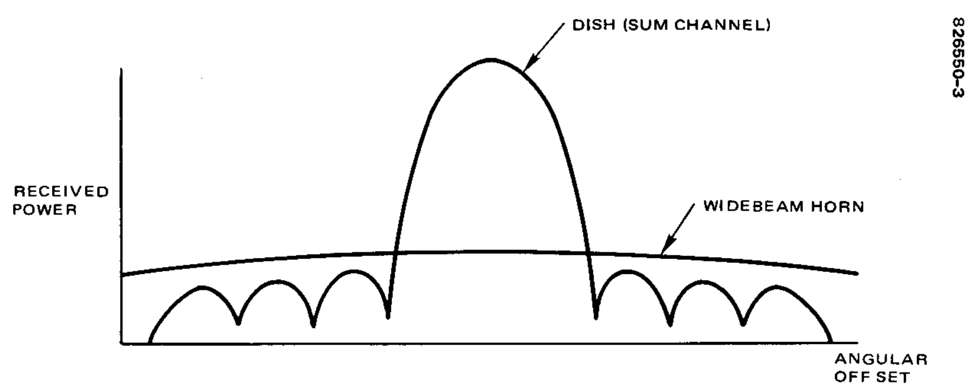

FIGURE 7. SIDELOBE DISCRIMINATION, PERFORMED BY COMPARING RECEIVED LEVELS FROM TWO ANTENNAS

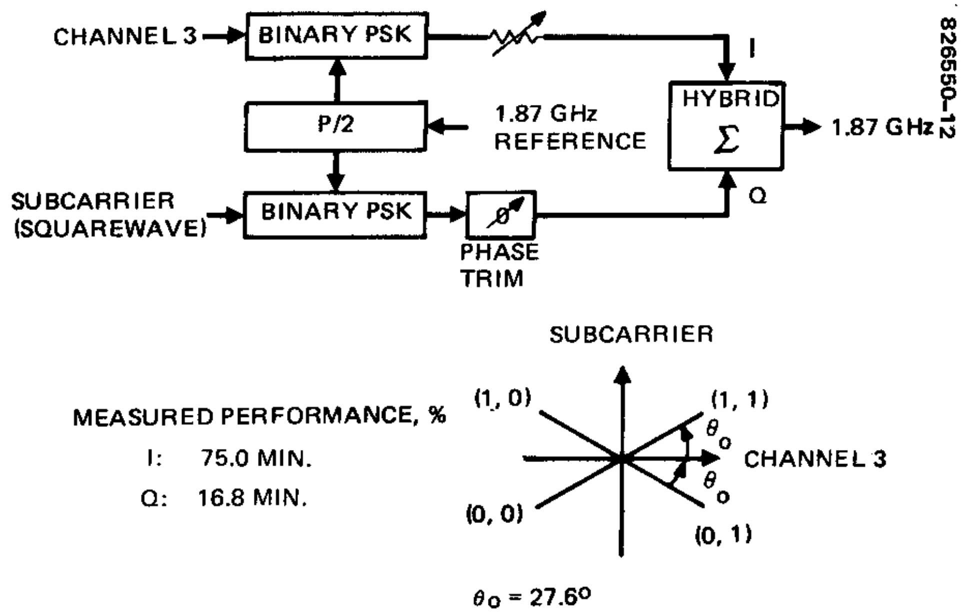

FIGURE 8. RF UNBALANCED QPSK MODULATOR FOR MODE 1

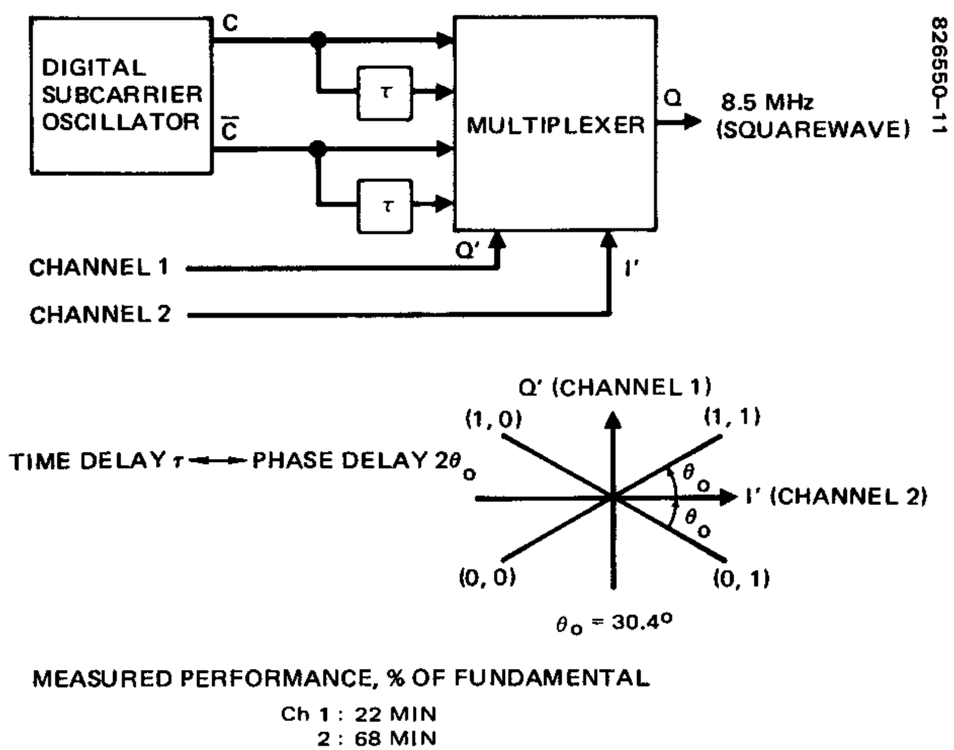

FIGURE 9. SQUARE WAVE SUBCARRIER UNBALANCED QPSK MODULATOR

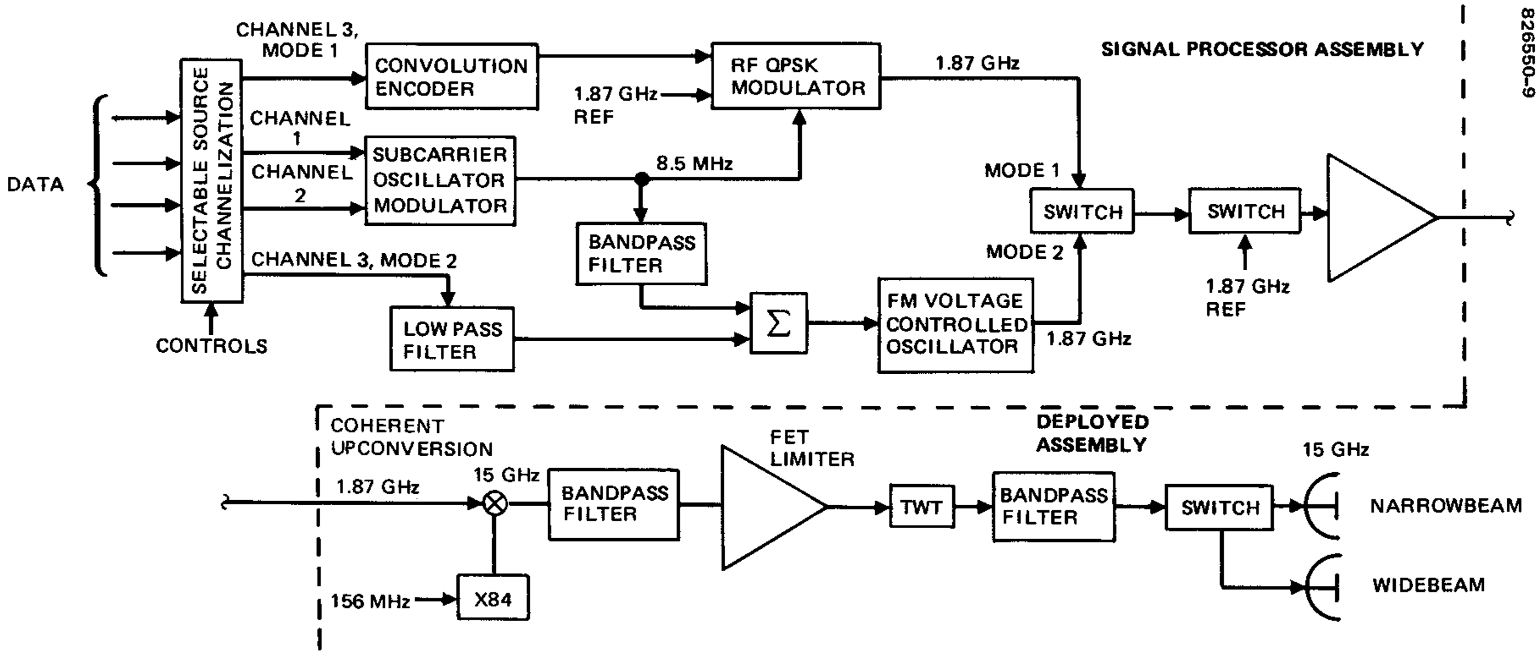

FIGURE 10. RETURN LINK COMMUNICATIONS SUBSYSTEM

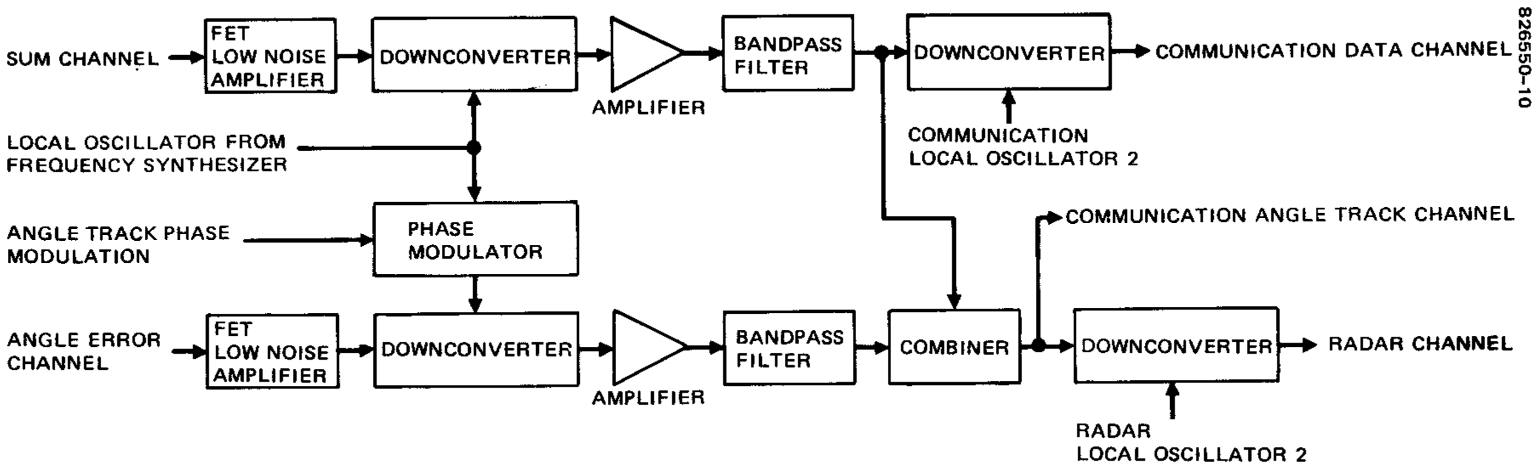

FIGURE 11. TWO-CHANNEL DOWNCONVERTER

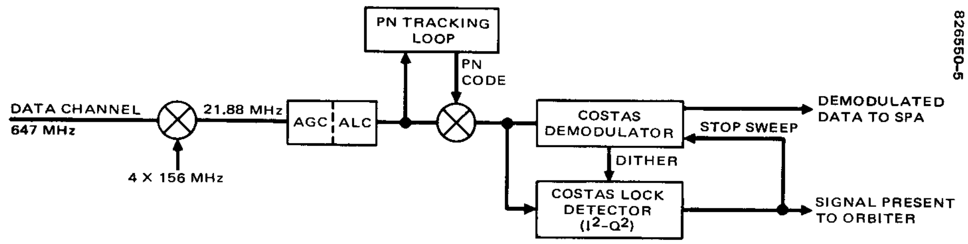

FIGURE 12. EA-1 FORWARD LINK FUNCTIONS

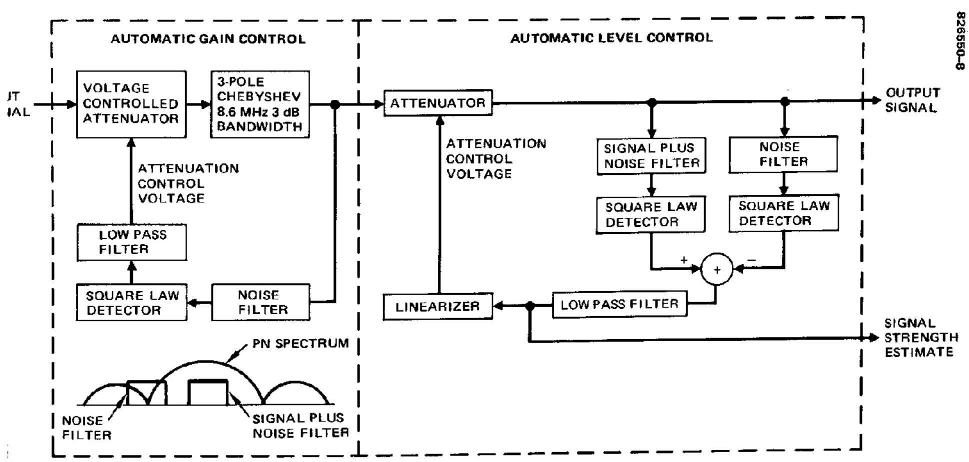

FIGURE 13. AUTOMATIC GAIN AND LEVEL CONTROL CIRCUITS

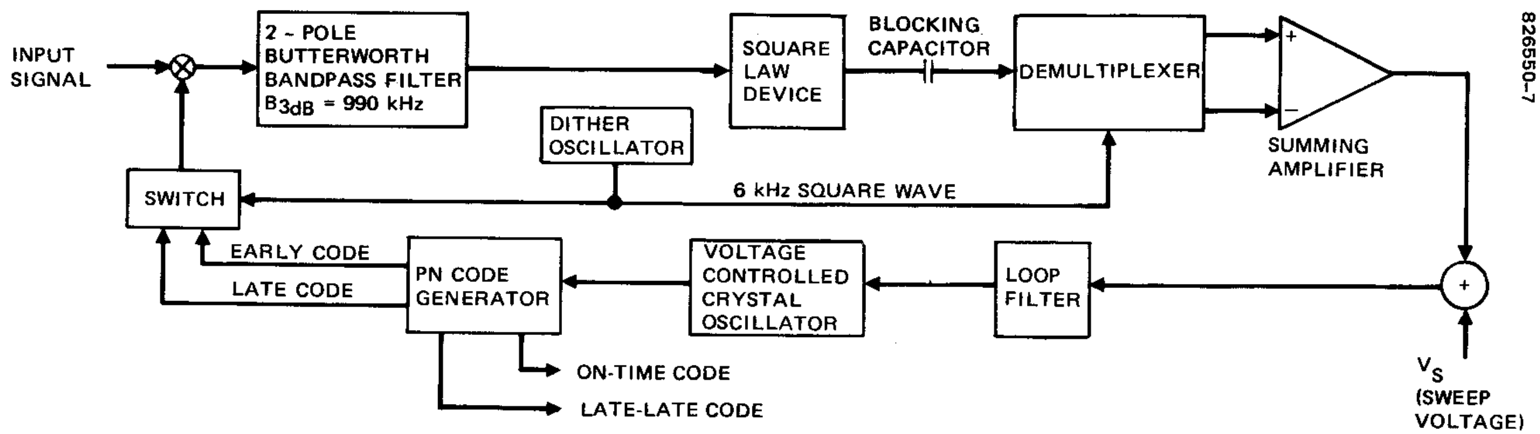

FIGURE 14. TAU-DITHER PN TRACKING LOOP

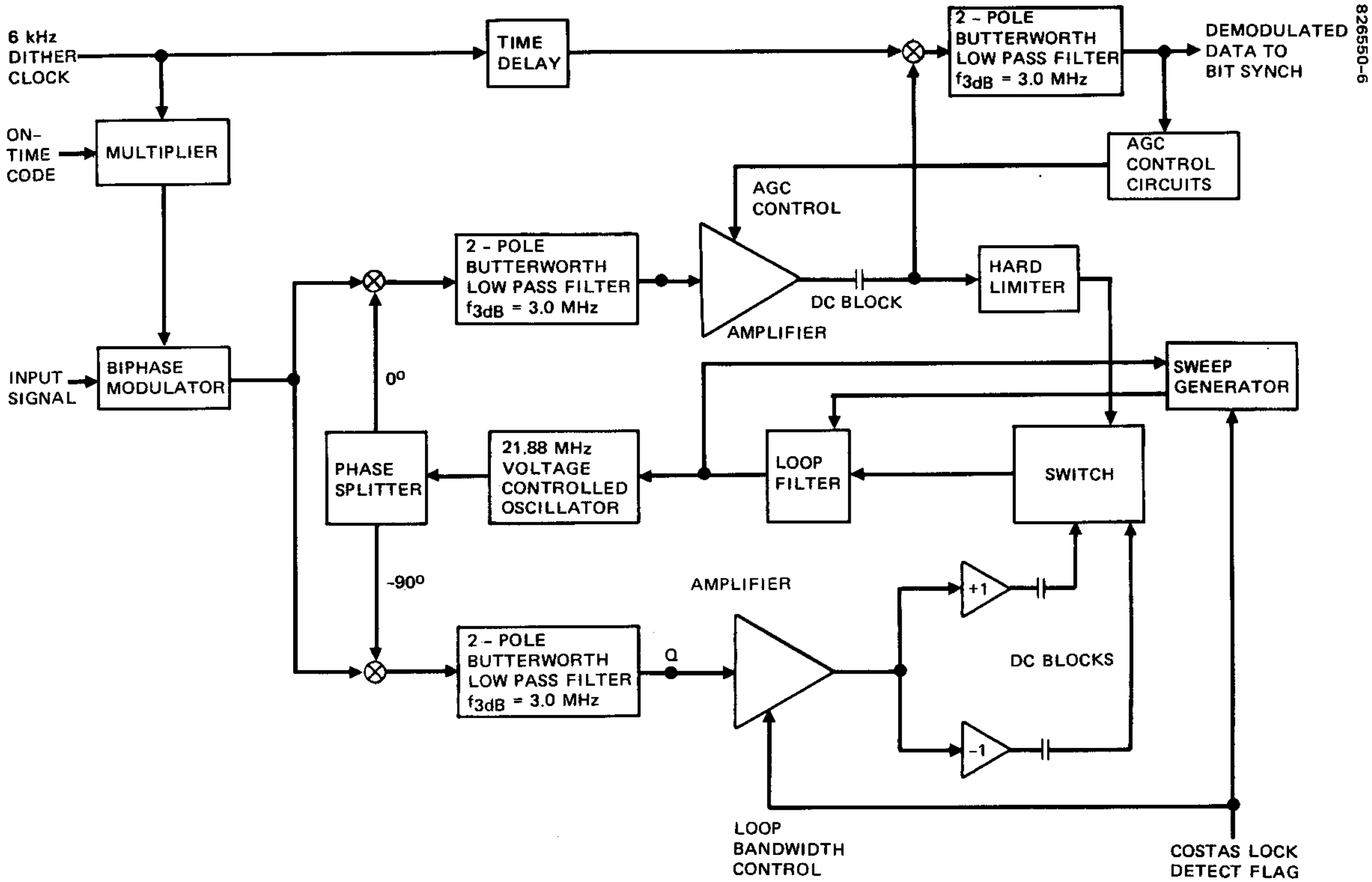

FIGURE 15. COSTAS DEMODULATOR

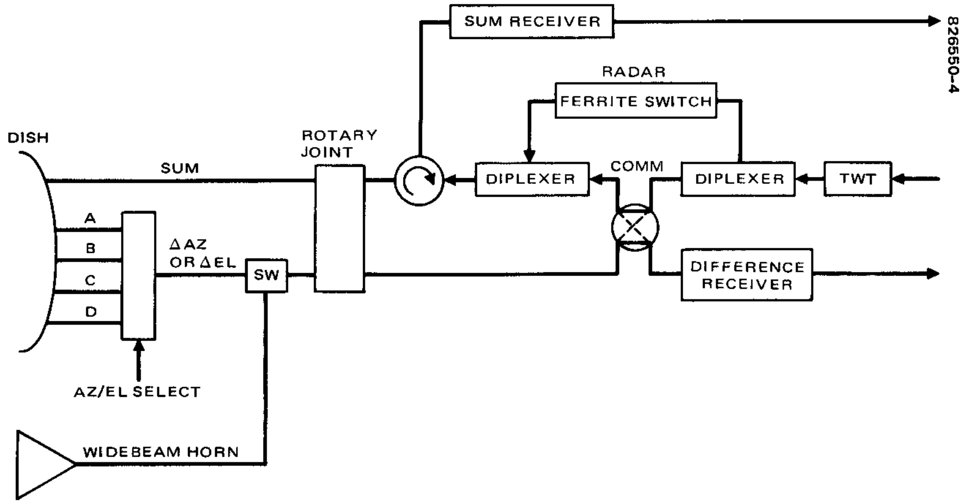

FIGURE 16. ANTENNA SWITCHING