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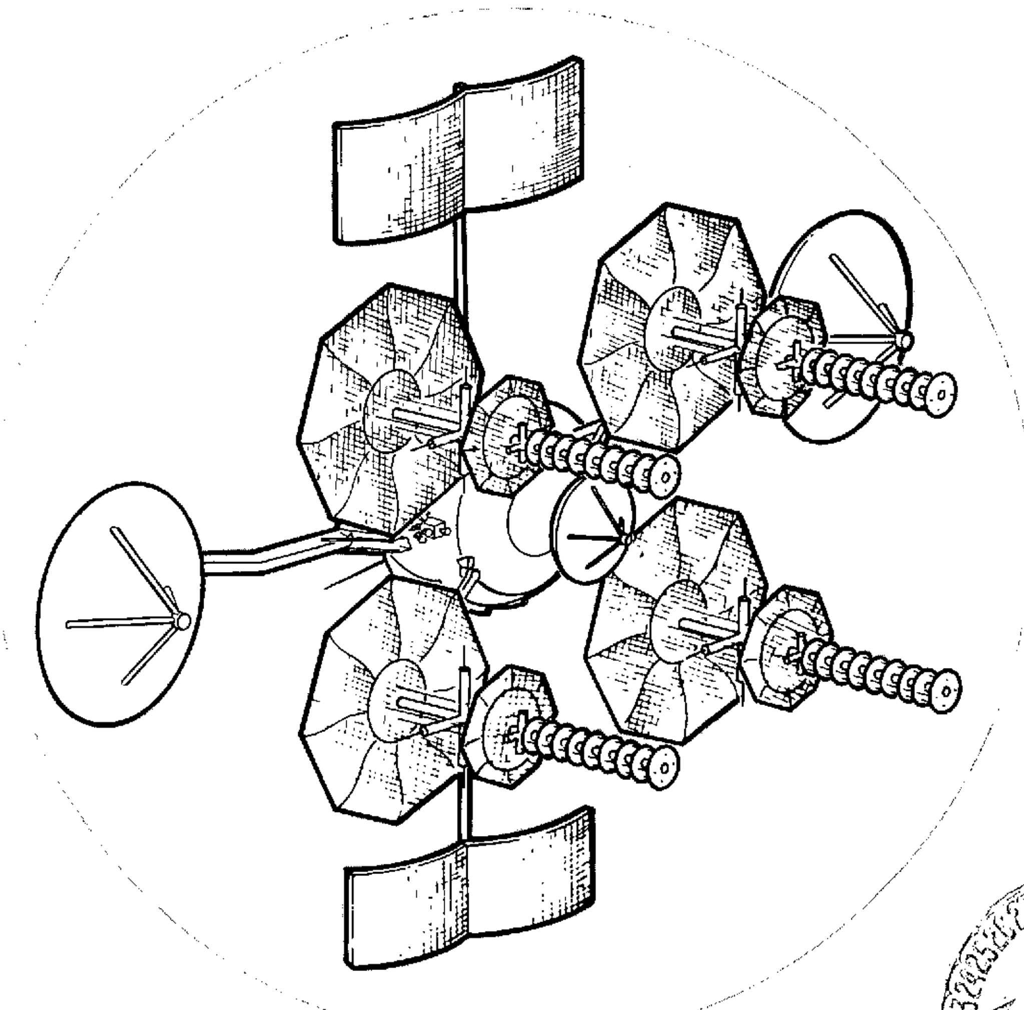
PART I FINAL REPORT

TRACKING & DATA RELAY SATELLITE SYSTEM CONFIGURATION & TRADEOFF STUDY

VOLUME V USER IMPACT & GROUND STATION DESIGN



OCTOBER 1972

SUBMITTED TO
GODDARD SPACE FLIGHT CENTER
NATIONAL AERONAUTICS & SPACE ADMINISTRATION

Space Division
North American Rockwell

IN ACCORDANCE WITH
CONTRACT NAS5-21705

12214 Lakewood Boulevard, Downey, California 90241

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PART I FINAL REPORT

TRACKING & DATA RELAY SATELLITE SYSTEM CONFIGURATION & TRADEOFF STUDY

VOLUME V
USER IMPACT & GROUND STATION DESIGN

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FOREWORD

This report summarizes the results of Part I of the study conducted under Contract NAS5-2107, Tracking and Data Relay Satellite Configuration and Systems Trade-off Study - 3-Axis Stabilized Configuration. The study was conducted by the Space Division of North American Rockwell Corporation for the Goddard Space Flight Center of the National Aeronautics and Space Administration.

The study is in two parts. Part I of the study considered all elements of the TDRS system but emphasized the design of a 3-axis stabilized satellite and a telecommunications system optimized for support of low and medium data rate user spacecraft constrained to be launched on a Delta 2914. Part II will emphasize upgrading the spacecraft design to provide telecommunications support to low and high, or low, medium and high data rate users, considering launches with the Atlas/Centaur and the Space Shuttle.

The report consists of the following seven volumes.

1.	Summary	SD 72-SA-0133-1
2.	System Engineering	SD 72-SA-0133-2
3.	Telecommunications Service System	SD 72-SA-0133-3
4.	Spacecraft and Subsystem Design	SD 72-SA-0133-4
5.	User Impact and Ground Station Design	SD 72-SA-0133-5
6.	Cost Estimates	SD 72-SA-0133-6
7.	Telecommunications System Summary	SD 72-SA-0133-7

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G. Shaushanian	"	User Transponder Design

TABLE OF CONTENTS

VOLUME I

VOLUME II

VOLUME III

Section | Page

VOLUME IV

Section		Page

VOLUME V

VOLUME VI

VOLUME VII

Section | Page

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ILLUSTRATIONS

TABLES

11.0 USER SPACECRAFT IMPACT

The configuration of the user satellite transponder can be designed in a number of ways, three of which are:

1. A transponder designed to be compatible with the optimum design of the TDRS
2. A compromise design of both TDRS and user transponder resulting in an overall minimum cost system
3. A system design resulting in a user transponder design with a minimum impact on the user

Because of the limited specific information regarding the current user transponder designs or proposed designs, a detailed evaluation of the impact on the user could not be made. However, conclusions could be drawn based on the limited user information available and the operational constraints imposed by the TDRSS because of its geographic access.

In defining the impact on the user, the general operational requirements imposed on the user must be defined. The operational requirements result from the configuration of the TDRSS and the information transfer requirements of the users. These requirements are shown in Table 11-1.

Even with the incorporation of the TDRSS in the NASA reporting network, the users must be compatible with both TDRSS and STDN. In the LDR user each of the two TDRSs will use two unique carrier frequencies in the UHF band (400.5 to 401.5 MHz). Therefore each user must be capable of receiving the four frequencies and the STDN VHF (148-149 MHz) carrier frequency. This requirement for STDN interface is an option to the user as a backup to the primary TDRSS connection. All MDRs will be assigned a unique S-band carrier frequency which may be handed over from one TDRS to another. In the MDR case again compatibility with STDN is an option to the user which should be considered.

11.1 USER SPACECRAFT TRANSPONDER CONCEPTS AND TRADES

The LDR and MDR user transponders will differ somewhat for several basic reasons. Therefore the concepts for each of the user types will be discussed separately.

11.1.1 LDR Transponder

The requirements for the LDR user transponder are listed in Table 11-2.

The LDR concept presented here is the result of determining the functions to be performed and considering the manner in which these functions could best be accomplished.

Table 11-1. User Spacecraft Transponder Requirements

LDR:

- Compatibility with both TDRS and STDN
- Tuneable to one of four UHF receiver frequencies (TDRS) and one VHF frequency (STDN)
- PN modulation necessary for multipath rejection on both forward and return links and signal density reduction in the forward link

MDR:

- Compatibility with both TDRS and STDN
- One S-band receiver frequency (TDRS) and one S-band frequency (STDN)
- Compatibility with USB modulation
- PN modulation necessary on forward link to reduce signal energy density

Table 11-2. LDR User Spacecraft Transponder Requirements

Forward Link	
• Data rate	100 bps to 1000 bps
• Carrier frequency	400.5 to 401.5 MHz (4 channels)
• PN modulation	167 Kchips/sec
• Code length	Short - 2047 chips (Gold sequence) Long - Eleven 2047 (Gold sequences in serial)
• One PN code sequence to all users	
Return Link	
• Data rate	100 bps to 10,000 bps
• Carrier frequency	136 MHz (1 channel)
• PN modulation	1 Mchip/sec
• Code length	Short - 2047 chips (Gold sequence) Long - Sixty-six 2047 (Gold sequences in serial)
• Unique code sequence for each user (TDRSS access is CDMA)	

The LDR transponder must be capable of receiving command, transmitting data, and providing PN code coherence in the LDR so that a ranging computation can be performed on the ground. For a number of reasons discussed in Section 3.5.4, a PN code modulation is used in both the forward and return links to the LDR, therefore before any function can be performed a connectivity must be established by synchronizing to the received PN code both in the user transponder and at the TDRS GS and by properly tuning the user receiver to the one of four TDRS to user carrier frequencies being used. Having established connectivity the transmission of data in both directions can be accomplished. Tracking is accomplished by computing the transit time of the signal from TDRS to user to TDRS. This feature establishes the minimum code length of the PN sequence for a given code rate. The minimum code rate is established by the amount of band-spreading required.

Tuning to the proper carrier frequency is accomplished by selecting the proper injection frequency at the mixers. Three obvious techniques were considered:

* 1. Programmed from the ground station at the termination of the previous transmission.

2. A quiescent injection frequency at the first and possible second mixers followed by narrowband filters and envelope detectors which are continuously monitored for exceedence of a threshold. For example, a 10 kHz filter bandwidth will result in a 3 dB increase in total energy at the minimum expected signal energy.

3. Toggle between the four injection frequencies. The receiver will dwell at one injection frequency for a period of time equal to the maximum time necessary to synch. If synch is not achieved the system will switch to the next injection frequency and repeat.

The command message transmitted to a user will contain the instruction directing the proper tuning for the next transmission after the present communication is completed. The advantage of this technique is that very little hardware is required to implement the operation.

The concept for PN code acquisition is more involved. The need for PN comes from the need to spread the TDRS to user transmission such that IRAC requirements are met, to discriminate against the multipath, to provide modulation for code division multiplexing of the user transmissions, and for tracking. In Section 3.5.4 a discussion of the code acquisition and tracking illustrates the problems involved and the concept eventually selected for this system. In short, a short code is transmitted for the initial acquisition phase of the communication in order to get a reasonable acquisition time (40 sec). The resultant code sequence configuration resulted in ambiguous ranging information, therefore a two mode coding technique was used: a short code (2047 chips), for acquisition, and a long code (11 x 2047 in the forward link and 66 x 2047 in the return link) for the tracking mode with the switching taking place in both

* Selected approach

the user and TDRS GS upon command so that coherence in the user and TDRS G/S receiver would not be lost and sync could be maintained in the user and TDRS G/S during the switch. The PN code acquisition requires a search of frequency uncertainty and time uncertainty regions. Aside from the serial time and frequency search two techniques were considered which allowed a faster search of the uncertainty ranges: digital matched filter and digital spectral analysis.

The voltage output from a digital matched filter when the input is mistuned in frequency by an amount $\Delta\omega$ is given.

$$\frac{\sin\ (\Delta\omega\ T/2)}{(\Delta\omega\ T/2)}$$

where $\Delta\omega$ is the tuning error and T is the matched filter time window or the length of the pseudo-random sequence for which the matched filter is designed. Thus the digital matched filter rapidly resolves the time ambiguity but must be properly tuned in frequency for optimum performance. The latter requirement can be attained by moving the local oscillator preceding the digital matched filter in incremental steps to perform the necessary frequency search.

In addition to the losses associated with mistiming, there is an inherent signal suppression loss, i.e., if the interference is Gaussian a 3 dB suppression can be incurred under poor signal-to-noise conditions. If the interference is CW the suppression can be as high as 6 dB under poor signal-to-interference conditions. The above losses are typical when the digital matched filter uses hard limiting in the input to the digital shift registers. To avoid these suppressions quantization of two or three bit PCM is often used. This increases the complexity associated with the implementation of the digital matched filter since it increases the number of registers by a factor of two or three, depending on whether 4-level or 8-level quantization is employed. In some instances an additive dither signal is employed to reduce the suppression losses. This technique also results in a signal-to-noise loss of about 2 dB.

To avoid these losses and/or complexity an alternate approach to synchronization is advisable. This alternate approach involves an all-digital discrete Fourier transform which minimizes synchronization time resulting from doppler uncertainties. In this case, the time uncertainty is searched (1/2 chip increments) over the pseudonoise code length and for each increment the total doppler uncertainty is searched in real time. A simplified functional diagram of the real time doppler uncertainty resolver is illustrated in Figure 11-1. Where the digital matched filter is essentially a fast time search technique the digital spectral analysis (doppler processor) is a fast frequency search approach. A more detailed discussion of the parameters of the code acquisition is presented in Section 3.5.4.

After synchronization is achieved at the TDRS GS and user receivers, the shift to the long code is accomplished by initiating a command at the TDRS GS which instructs the user reference PN code generator to go to a prescheduled feedback switching mode at the next all 1's loading of the code generator. Since this is the code sequence being transmitted up, the received and reference codes remain in sync. The feedback switch mode generates a different

2047 sequence each time one 2047 sequence is completed until 11 such sequences have been serially generated. Then the entire 11 x 2047 sequence is repeated. Since the return link chip rate is 6 times faster, 66 serially aligned 2047 codes are used in the return link. To instruct the TDRS GS of the switch to long code, an instruction is added to the command verification message similar to the instruction added to the command message.

Convolutional encoding is applied to the data for error control and then Δ coded so that the phase ambiguity introduced by the Costas loop (which mathematically is equivalent to a squaring loop) may be resolved in the demodulation process.

11.1.2 MDR Transponder

The requirements for the MDR user transponder are listed in Table 11-3.

Table 11-3. MDR User Spacecraft Transponder Requirements

Forward Link	
• Data rate	100 bps to 1000 bps
• Carrier frequency	2025 to 2120 MHz (2 channels)
• PN modulation	5M chips/sec
• Code length	Short - 16383 chips (Gold sequence) Long - forty 16383 (Gold sequences in serial
• PN code sequence Common to both users	
• Ranging code	Rate - 500 K chips/sec Length - 65535 chips
Return Link	
• Data rate	10 kbps to 1000 kbps
• Carrier frequency	2200 to 2300 MHz
• PN ranging code is transponded	500 K chips/sec
• Unique frequency channel for each of two users	

The MDR concept is similar to the LDR concept with a few exceptions. The MDR transponder is required to perform the same operational functions, but because of the difference in operating frequency the number of users accommodated, and the difference in the user and TDRS antenna characteristics, the method of implementing these operational functions are different. The PN code modulation also is used in the MDR case for stated reasons (see Section 3.5.4) in both the forward and return links. Therefore, in establishing connectivity a code acquisition must be accomplished.

One unique S-band carrier frequency is assigned to each MDR user. Since the TDRS for this case is a simple translating repeater, the unique carrier frequency for any of the MDR users can be selected on the ground and transmitted through either of the two TDRSs.

The concept for code acquisition is somewhat different. The reason for PN code modulation for the MDR user is to derive tracking information and to spread the signal energy in the TDRS to user link to conform to IRAC requirements. The basic circuitry is the same as the LDR case for the same reasons, i.e., using a doppler processor, early-late gate tracker, and basic short code length.

A short code (16383 chips) is transmitted from the TDRS G/S to the user. The 16383 chip code length will require a maximum of 33 seconds lock up time in the user. After synchronization in the user, the TDRS ground station transmits a command instructing a switch to long code. The long code will be a serial sequence of 40 different 16383 length codes. A slow code (500 K chip/sec) of length 2^{16}-1 (or 65535 chips) is modulo-two added to the long code. The switch to long code will be made at a specific 16383 sequence of the long code with the slow (500 K chips/sec) code starting at a predetermined point in the slow code starting at a predetermined point in the slow code sequence. For example, if the all 1's point in the slow code (500 K chips/sec) is used as the index point, then the 16 ones in the 65535 slow code will be made time coincident with a specific and unique 160 chip sequence in one of the 40 16383 codes of the long code when the two codes are modulo-two added. This time relationship between the fast long code and the slow code is determined by the relative initial setting of the two PN code generators in the user. (This initial setting in the user can be established by a reset command). Since the time relationship of the slow and fast codes at the TDRS GS and user are the same, the user essentially transponds the slow code to the TDRS GS for ranging purposes even though the PN code in the return link is generated in the user.

The command message (MDR case) and digital voice (manned case) can be extracted from the in-phase side of the Costas loop and processed as shown in the block diagram of Figure 11-1.

In the return link the PN code is not added to the data to form the modulating signal because the data rate is comparable to the code rate, and since the PN code is being transmitted only for tracking purposes, the PN code is trated like an additional data signal. The PN code bi-phase modulates an IF carrier which is then added to an IF carrier modulated by the data. The summed signal is then translated to the transmission frequency.

Another difference is that the manned user case must also support voice transmissions. The concept used here is to time division multiplex (TDM) the data with the digitized (Δ Mod) voice to form a single data stream.

11.2 USER SPACECRAFT TRANSPONDER MECHANIZATION

The mechanization of the LDR and MDR transponder are illustrated in Figures 11-1 through 11-4 in the form of functional block diagrams. There are a number of functions being performed in these designs which will be described in this section.

11.2.1 LDR Transponder

The block diagrams for the LDR receiver and transmitter are shown in Figures 11-1 and 11-2 respectively.

11.2.1.1 Receiver

The receiver is shown segmented into RF, code tracking loop, carrier tracking loop, doppler processor, decoder, and frequency synthesizer sections. There also is a controller from which signals will be directed to segments to initiate specific functions and receive signals to maintain operational status of the receiver and transmitter.

The RF segment consisting of the RF and IF circuitry is straightforward, except for the need to switch to the appropriate injection frequency at the first or second mixer to tune the receiver to the proper channel to receive the command. The procedure used here is to transmit in the command message an instruction to the frequency synthesizer selecting the proper injection frequency for the next transmission such that at the end of the current transmission the injection frequency will be switched to the proper channel. To insure against the synthesizer switching frequency in the case of inadvertent loss of lock, the frequency synthesizer will only switch to the new programmed injection frequency upon command from the controller. The switch command from the controller will be generated after some N code acquisition cycles have been performed by the receiver assuring that loss of lock was due to end of communication.

The 16.25 MHz IF signal is split into two channels one going to the carrier tracking loop and one going to the clock tracking loop.

The carrier tracking loop (Figure 11-1) is a Costas loop (mathematically equivalent to a squaring loop). The function of this loop is to reduce the signal to baseband and strip the data off at the output of the in-phase low pass filter. The signal output of the loop filter is the error signal denoting the difference between the reference 1.25 MHz and the 1.25 MHz IF. This error signal is used to vary the VCO to the proper injection frequency to account for frequency uncertainties. But the magnitude of the doppler uncertainty will require unreasonable pull-in times even with large acquisition bandwidths, therefore a frequency search mode is provided to quickly sweep the loop VCO to within a reasonable error frequency (equivalent to the reciprocal of the data rate). This is accomplished by means of the doppler processor.

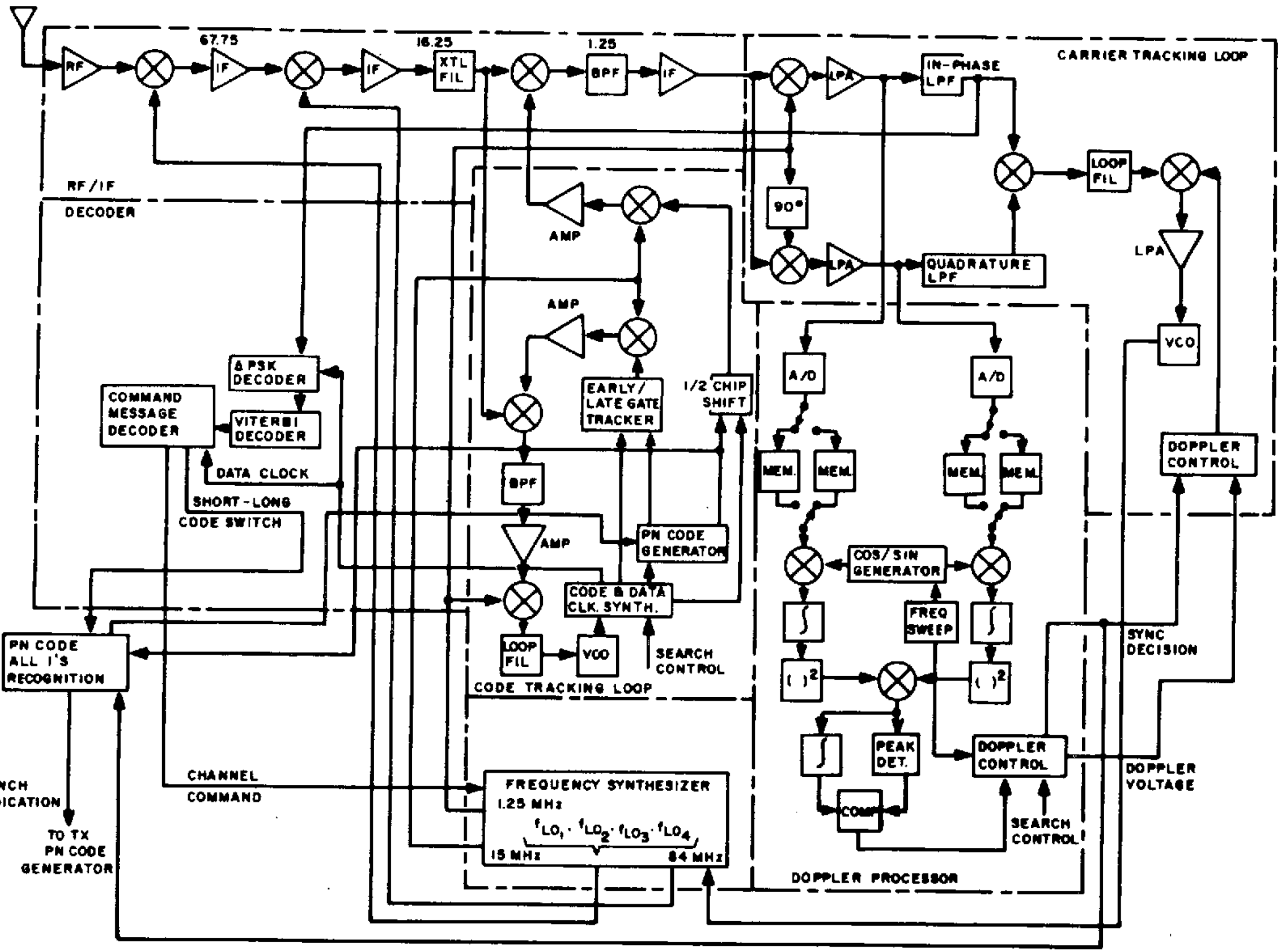

Figure 11-1. LDR Receiver

The doppler processor (Figure 11-1) provides a correction voltage to the carrier loop VCO which is then used as one of the two reference frequencies in the frequency synthesizer. In this way the doppler correction is injected in all frequencies where the doppler correction is necessary. The processor will also indicate code acquisition. The inputs to the doppler processor are taken from the in-phase and quadrature signals in the carrier tracking loop following the low pass amplifiers which have bandwidths equivalent to the reciprocal of the data rate. Therefore when the codes are out of sync the signal energy in the data bandwidth will be small. When the codes are in sync, the signal energy in the data bandwidth will increase by the PN process gain. Therefore the doppler processor will indicate a "hit" or signal presence in a 100 Hz frequency cell when the PN codes are in synchronism because of the threshold exceedence. On every frequency sweep, the average energy level over the entire frequency uncertainty region is computed. This value is used as the floating reference point. The threshold is established by selecting a margin by which the maximum signal must exceed the floating reference. This margin is the threshold factor.

The first step in the process is to bandpass filter the signal-plus-noise using a filter of bandwidth 2W centered at $\omega_c/2$ Hz. The principal operation next performed is the computation of the Fourier coefficients of the filtered signal-plus-noise on the interval (O,T). A pulse of unknown frequency can be represented as

$$P(t) = A \cos \left[(\omega_c + \omega_a)t+\theta\right] \qquad o < t < T \qquad (11\text{-}1)$$

where ω_c is the nominal center frequency, is unknown, uniformly probable over the range $\pm 2\pi W$ and T is the data bit period. Assume WT to be an integer, M; if necessary by over-estimating W slightly.

In particular, it is desired to compute the power in each component corresponding to frequencies in the filter passband. These quantities are the values of C_n^2 where

$$C_n = \frac{1}{T} \int_o^T f(t) \exp(-j2\pi n/T)dt \qquad (11\text{-}2)$$

for values of n in the region $\frac{\omega_c T}{2\pi} \pm WT$, where f(t) is P(t) + noise. Alternatively, C_n^2 can be obtained through

$$C_n^2 = a_n^2 + b_n^2 \qquad (11\text{-}3)$$

$$a_n = \frac{1}{T} \int_o^T f(t) \cos 2\pi nt/T \, dt$$

$$b_n = \frac{1}{T} \int_o^T f(t) \sin 2\pi nt/T \, dt$$

In the mechanization it is necessary to store f(t) at the filter output. This is conveniently done by resolving f(t) into its quadrature components, sampling and quantizing so that digital memory can be used. The quadrature components of f(t) with respect to a carrier at w_c are $f_c(t)$ and $f_s(t)$) such that

$$f(t) = f_c(t) \cos \omega_c t + f_s(t) \sin \omega_c t \tag{11-4}$$

where

$$f_c(t) = A \cos(\omega_a t + \theta) + n_c(t)$$

$$f_s(t) = -A \sin(\omega_a t + \theta) + n_s(t)$$

in which n_c and n_s are indpendent Gaussian noise processes of zero mean, the same power, both bandlimited to the frequency interval (-W, +W). On the basis of sampling theory, it would be adequate to sample f_c and f_s at the rate of 2W samples/second, however, as a practical matter sampling should be at 3W to 4W samples/second to allow for non-ideal filtering and to improve the accuracy of the numerical approximations to the integrals. Call the actual sampling rate R, such that RT is a convenient integer. Amplitude quantization of the samples can be performed as crudely as one bit. However, this entails a loss of nearly 2 dB in output signal-to-noise. The use of 3-bit (8 level) quantization reduces this loss to a few tenths of a dB. The sampled, quantized values of $f_c(t)$ and $f_s(t)$ will be represented by $F_c(m/R)$ and $F_s(m/R)$ where the range of the integer m is 1 to RT corresponding to the range of t: $0<t<T$.

Before writing a final expression for a_n and b_n, it is useful to note certain symmetries in the expressions for values of n spaced equally above and below the midband value, $\omega_c T/2\pi$. To make these evident, let $n = k_c + k$ where $k_c = \omega_c T/2\pi$. The range of k which is of interest is $\pm$WT. Making these changes in notation, approximating $f_c(t)$ and $f_s(t)$ by their sampled, quantized counterparts, and approximating the integrals by sums, we obtain:

$$a_{\pm k} = \frac{1}{2RT} \sum_{m=1}^{RT} F_c\left(\frac{m}{R}\right) \cos \frac{2\pi km}{RT} \pm \frac{1}{2RT} \sum_{m=1}^{RT} F_s\left(\frac{m}{R}\right) \sin \frac{2\pi km}{RT} \tag{11-5a}$$

$$b_{\pm k} = \frac{1}{2RT} \sum_{m=1}^{RT} F_s\left(\frac{m}{R}\right) \cos \frac{2\pi km}{RT} \pm \frac{1}{2RT} \sum_{m=1}^{RT} F_c\left(\frac{m}{R}\right) \sin \frac{2\pi km}{RT} \tag{11-5b}$$

Having computed the 2WT pairs of coefficients, a_k and b_k, the 2WT coefficients C_k^2 are formed. Since only one signal is sought, it is the maximum of all the C_k^2 which need be compared to a threshold to make the detection d decision. Since the threshold setting should be proportional to the noise power, it may be convenient to set the threshold as a fixed fraction, β , of the noise power as estimated by the sum of all of the C_k^2.
β is chosen to achieve a given false alarm rate, or a given detection probability for a given signal-to-noise ratio, or some similar basis.

The computation of a_k and b_k are performed in two modes (data rates of 100 bps and 1000 bps):

1. R = 32,000 sample/sec, T = 10 msec, and k ranges from -159 to +160. This is equivalent to having 320 filters each 100 Hz wide to cover the frequency uncertainty of $\pm$ 16 kHz.

2. R = 32,000 samples/sec, T = 1 msec, and k ranges from -15 to +16. This is equivalent to having 32 filters each 1 kHz wide to cover the frequency uncertainty of $\pm$16 kHz.

In the following, only mode 1 is described since 2 is operationally identical to 1.

The first section of the mechanization concerns obtaining and storing the F_c data. The F_c and F_s signals are the I (in phase) and Q (quadrature) channel outputs, respectively, from the baseband signal processing module. These signals are converted to 3-bit words and sampled at the rate of 32,000 samples per second. Thus, for RT = 320, a batch of data characterizing the signal over 10 milli-second is obtained (i.e., 320 words each of 3 bits). The memory is of shift register type and consists of four 320-word x 3-bit sections, 2 for F_c and 2 for F_s. The two memory registers for each signal component are organized such that while one memory register is being loaded (gathering new data), the other is recirculating at accelerated rate for processing (computing a_k and b_k). The recirculating rate is 10,240 Hz so that 320 pairs of a_k and b_k are computed in 10 msec, which is the required time interval to gather a new batch of data by the other memory register. Thus, by alternating the two memory register's functions, input signals are continually processed until the unknown frequency is found.

The computation of a_k and b_k requires the multiplication of data samples, $F_c(\frac{m}{R})$ and $F_s(\frac{m}{R})$ by the value of $\cos(\frac{2\pi km}{RT})$ and $\sin(\frac{2\pi km}{RT})$ and summing the products. $F_c(\frac{m}{R})$ and $F_s(\frac{m}{R})$ are read out serially from the circulating memory register. The arguments for the sine and cosine are generated by decoding the 4 most significant bits of a 7-bit accumulator which starting at zero accumulates the value of k as m indexes from 1 to 320 (k increments each time m cycles until k ranges from -159 to +160.) At the end of the computation for a particular k, (i.e., at m = 320) the $C_k^2 = a_k^2 + b_k^2 \simeq (\sum R_m)^2 + (\sum J_m)^2$ is obtained and is presented to the "auctioneer." This is a register and comparator arrangement which is preset to zero at the start of each data batch and thereafter compares the present content of its register with the newly computed C_k^2. Whichever is greater is then stored in the register. Thus, at the end of a k cycle (i.e., as k goes through the range from -159 to +160), the greatest value of C_k^2. seen is left in the auctioneer. A final comparison is then made with the sum of C_k^2, which is accumulated in a separate register, to make the detection decision.

Having detected the presence of a signal as the doppler processor scanned the frequency range in one pass, the doppler processor employs a further decision strategy, whereby two out of three consecutive detections, called hits in the block diagram, are required to be declared a valid hit. This increases the true detection probability and decreases the false alarm rate under the threshold condition of 10 dB S/N in 100 Hz. At the conclusion of a valid hit, an analog voltage corresponding to the detected doppler frequency is sent to the carrier and code loop VCO's. This voltage effectively drives the local oscillator frequency to the input carrier for rapid acquisition.

After each sweep, if the presence of a signal is not detected, then the reference PN code is retarded by 1/2 chip in the code tracking loop and the entire frequency search process repeated in the doppler processor.

After code acquisition is detected then the controller will perform a number of functions indicated as search control in the block diagram:

1. The 1/2 chip retard function is stopped, and the early-late gate tracker is activated.

2. Activate the output gate of the all 1's recognition register such that the transmitter PN code generator start pulse is outputted to the transmitter

3. Activate the transmitter power amplifier

4. Initiate loss of lock count in the frequency synthesizer in case of inadvertant loss of lock

The early-late gate tracker has now been activated in the code tracking loop. The 16.25 MHz IF signal is mixed with a reference IF modulated by the reference PN code through the code tracker.

The frequency synthesizer will generate a number of frequencies from two reference sources. The injection frequencies in the RF/IF segment of the receiver are generated from a stable source while the 1.25 MHz injection frequency for the carrier tracking loop is derived from the carrier tracking loop VCO making the value of the 1.25 MHz injection frequency doppler corrected.

The receiver is now ready to receive a command message transmitted from the TDRS GS. The data is taken off the in-phase side of the carrier tracking loop and applied to a ΔPSK decoder to remove the differential coding and a Viterbi decoder to remove the error correction coding. The command message is then applied to the message decoder and the various instructions identified. The instructions of concern to the mechanization of the transponder are the injected frequency selection for the next communication and the short code to long code instruction. This is applied to the all 1's code recognition register and at the next all 1's loading of the PN code generator, the switch to long code is made in the PN code generator. The output of the all 1's recognition register following the "switch to long code" instruction is also transmitted to the transmitter PN code generator to switch the transmitter PN code generator to long code.

11.2.1.2 Transmitter

The LDR transmitter is shown in Figure 11-2. The functioning of the transmitter is rather straightforward except for the control signals from the receiver.

The PN code generator is an 11-stage code generator with logic to change the feedback logic such that six different 2047 codes are generated in serial. This is done to produce a non-repeating code length equivalent in time to the length of the PN code in the forward link. Initially the PN code generator is set to a known feedback logic (code sequence) with an all 1's loading in the register so that the all 1's points in both the transmitter and receiver code generator are time coincident. When the start pulse from the receiver all 1's recognition register is received, the transmitter code generator is started and the transmitter activated.

The PN code is transmitted to the TDRS ground station. After the code acquisition is achieved in the ground station, the command message is transmitted to the user on short code. An instruction in the command message indicates that a switch in the forward link code from the short to long code has been made and at what point in the short code the switch has been made. The all 1's point is a convenient index point although any point in the code is equivalent. After the instruction is read, the all 1's point is recognized in the all 1's register and the short to long code switch is made in the receiver code generator without loss of synchronization.

The switch must also be made in the transmitter PN code generator and in the TDRS GS receiver at the proper times. The switch to long code in the transmitter code generator is made at the same time the switch is made in the receiver code generator. After receipt of the command message in the user, a command verification message is formatted and transmitted to the TDRS GS. The command verification message informs the ground station that the short code-long code switch is being made in the user. Since the position in the forward link code where the switch is made is known to the ground station and since the relative position of the forward and return link codes in the user is also known, then the ground station receiver can identify the point in the return link short code where the switch to long code must be made.

The data is added to the PN code and modulated on to the carrier after a long code synch verification has been received from the TDRS ground station.

11.2.1.3 LDR Transponder - Size, Weight, and Power Estimates

The estimates for size, power, and weight have been made with the assumption that the LDR will have a transmit power of 37 dBm (5 watts). Additional assumptions made are as follows:

1. No secondary power supply
2. Hardware is 1974 technology
3. micropower logic
4. No hybrid technology
5. No radiation hardening

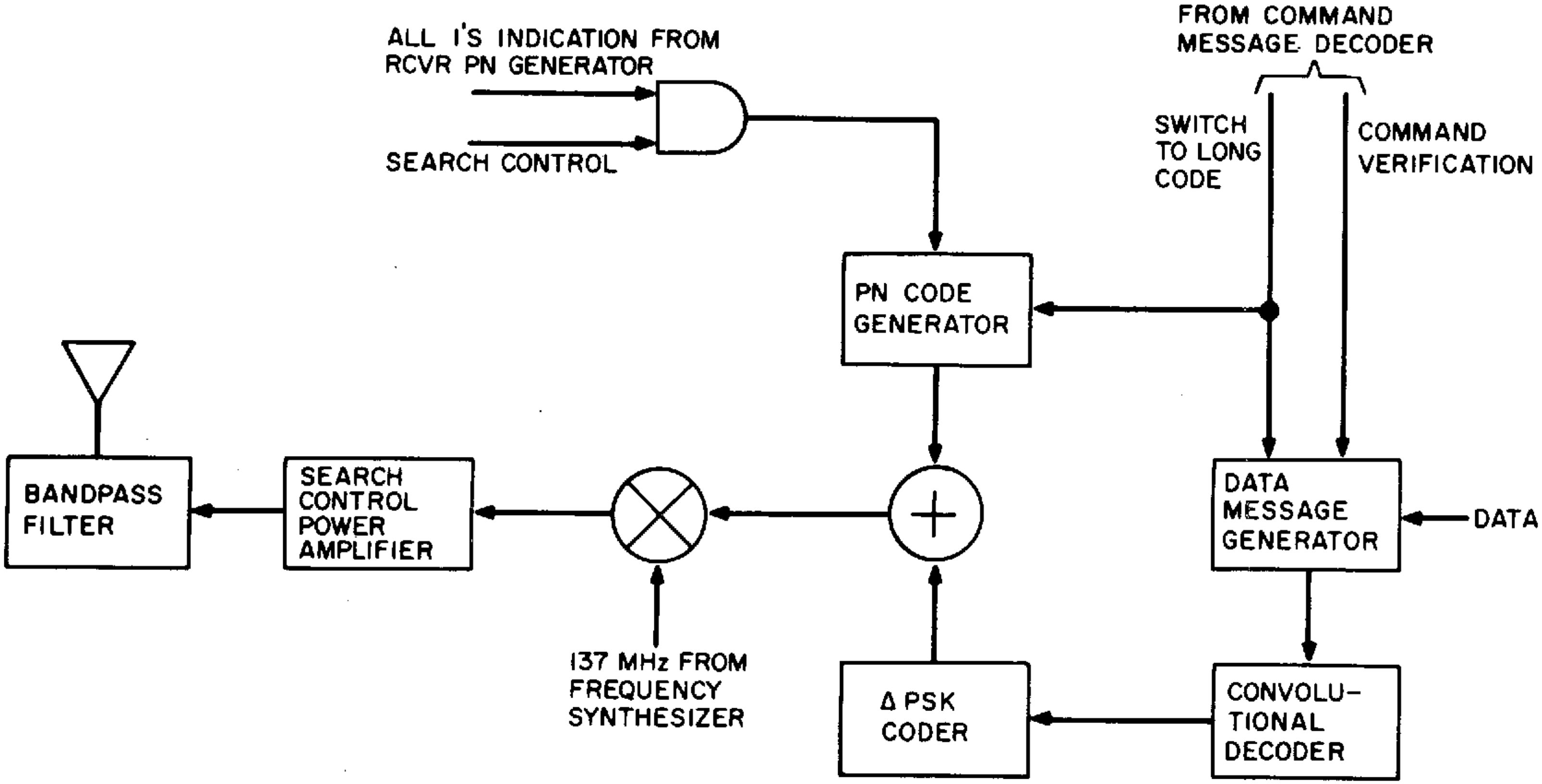

Figure 11-2. LDR Transmitter

The transponder size and power are distributed as follows:

Item	Size (cm^3)	Size ($in.^3$)	Power (watt)
Receiver:			
RF/IF assembly	490	30	1
Local ref. correlator	490	30	1
Costas demodulator	740	45	3
Doppler resolver	246	15	2
Coder/clock	246	15	1
Controller	246	15	1
Data processor	246	15	1
RF synthesizer	490	30	2
Transmitter:			
RF powr amp (40.8 dBm)	2460	150	10
Modulator	490	30	2
Data processor	246	15	1
RF synthesizer	490	30	3
Total	6900	420	28

The weight distribution is: transmitter - 4 pounds (1.8 Kg)
receiver - 6 pounds (2.7 Kg)

11.2.2 MDR Transponder

The block diagrams for the MDR receiver and transmitter are shown in Figures 11-3 and 11-4.

11.2.2.1 Receiver

The receiver is shown segmented into RF, code tracking loop, carrier tracking loop, data and voice decoder, and doppler processor. There is also a controller from which signals will be directed to segments to initiate specific functions and receive signals to maintain operational status of the receiver and transmitter.

The RF segment consisting of the RF and IF circuitry is rather straightforward. The output of the 16.25 MHz IF is split into two channels, one going to the carrier tracking loop and one going to the code tracking loop. The carrier tracking loop is a Costas loop. The function here is to reduce the signal to baseband and to extract the data and voice for further processing in the decoder segment. The functional description of the Costas loop was given in Section 11.2.1.

The code acquisition function is essentially the same as that used in the LDR case except for some small modifications which will be discussed here. The code acquisition operation is started by the TDRS GS repeatedly transmitting a single 16,383 chip sequence. In the user, the receiver will first search the

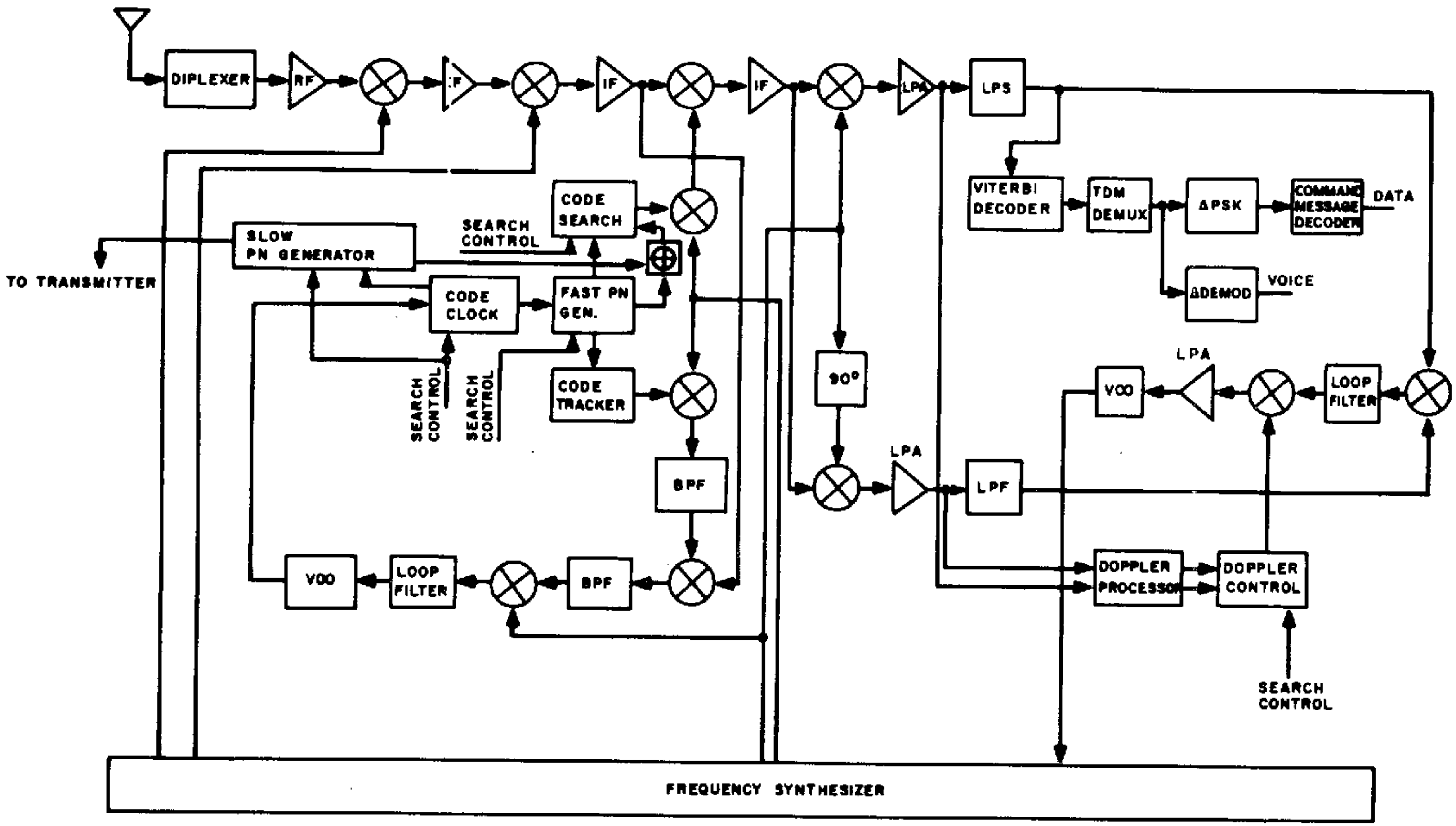

Figure 11-3. MDR Receiver

frequency uncertainty band. If a signal is not detected, the reference PN code is retarded by 1/2 chip and the frequency search repeated. This procedure is continued until code acquisition is achieved. The frequency search is performed by the doppler processor.

The functional description of the doppler processor is also given in Section 11.2.1 but the mechanization parameters must be changed to accommodate the MDR case. The computation of the a_k and b_k Fourier coefficients are performed in one mode (1000 bps). For this Mode:

R = 120,000 samples/sec, T = 1 msec, and K ranges from -59 to 60. This is equivalent to having 120 filters and 1 kHz wide to cover the frequency uncertainty of ± 60 kHz.

Each frequency search will take 1 msec. The maximum synch time is equal to a search through 16,383 chips at 1/2 chip per frequency search with 1 msec required for each frequency search or a synch time of approximately 33 seconds.

After the code has been acquired, a synch-acquired message is transmitted to the ground. Then a command message is transmitted to the user with a short code to long code instruction. The long code is composed of 40 different 16,383 chip codes in serial, each one generated by a change in the feedback logic of the code generator after each 16,383 code sequence has been generated. After 40 of these sequences are generated, the total of 40 codes is repeated. At the time the switch is made to long code, a 500 K chip/sec slow code is modulo two added to the fast code to implement the ranging modulation. The codes are modulo two added at specific points in the two codes corresponding to the time relationship in the two PN generators in the user. This code is 65,535 chips in length to provide unambiguous ranging over the 40,000 km unknown range. The code generators in the user are time related such that the relative code position of the two code generators is maintained. During the code acquisition phase the slow PN code generator, although it is continuously running to maintain the proper code position, is not added to the fast PN code generator until a synch indication is received from search control. After synch indication has been received and the proper point in the long or fast code is present, the slow code is modulo two added to the fast code to form the composite reference PN code. At this point the 500 K chips/sec PN code generators in the TDRS GS and in the user are displaced by the one way transit time. The output of the slow PN code generator is now applied to the transmitter for the retransmission to ground.

11.2.2.2 Transmitter

The MDR transmitter block diagram is shown in Figure 11-4. The 500 K chip/sec PN signal modulates an IF carrier which is added to a second IF carrier modulated by the data.

For the manned user case, the data and voice are time division multiplexed to form a serial data stream.

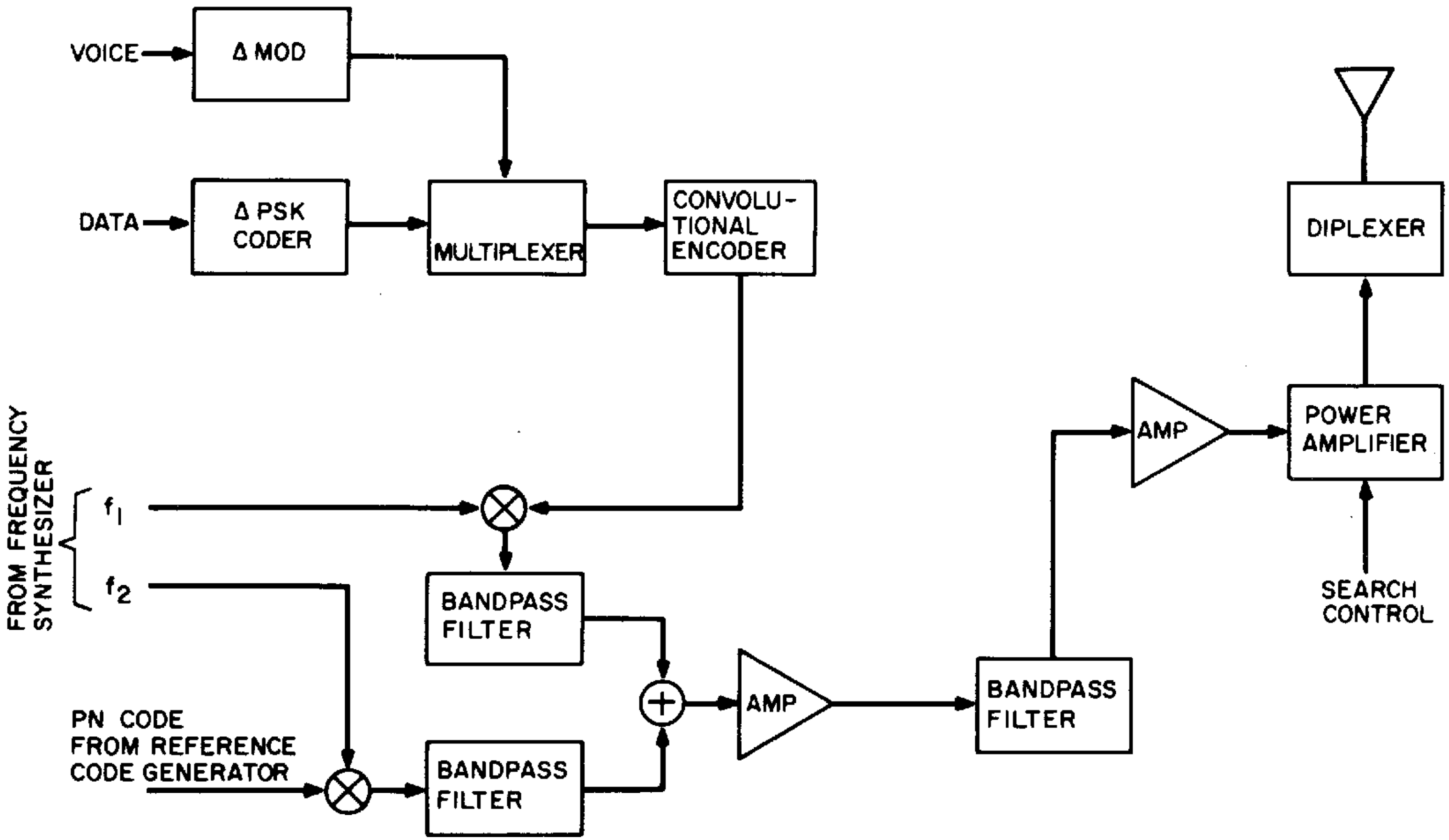

Figure 11-4. MDR Transmitter

11.2.2.3 MDR Transponder Size, Weight, and Power Estimates

The estimates for size, power, and weight were made assuming the MDR has a transmit power of 40.8 dBm (12 watts). Additional assumptions made were:

1. No secondary power supply
2. 1974 technology hardware
3. Micropower logic
4. No hybrid technology
5. No radiation hardening

The transponder size and power are distributed as follows:

Item	Size (cm^3)	Size ($in.^3$)	Power (watt)
Receiver:			
RF/IF assembly	740	45	1
Local ref. correlator	490	30	1
Costas demodulator	740	45	3
Doppler resolver	246	15	2
Coder/clock	246	15	1
Controller	246	15	1
Data processor	246	15	1
RF synthesizer	490	30	2
Transmitter:			
RF power amp (40.8 dBm)	2460	150	25
Modulator	490	30	2
Data processor	246	15	1
RF synthesizer	740	45	5
Total	7300	445	45

The weight distribution is: transmitter - 4 pounds (1.8 Kg)
receiver - 8 pounds (3.6 Kg)

11.3 CONCLUSIONS

The conclusions presented here are only those relating to the impact on the user spacecraft brought about by the communication relay service through TDRSS. Although the specific information on the configuration of the user spacecraft which TDRSS must support is somewhat limited, conclusions nave been reached based on that limited information.

The use of an orbiting relay platform introduces problems not present with STDN Ground Network, which necessitate added hardware in the user. Specifically, the need for PN modulations results for three primary reasons:

1. Distribution of the signal energy emanating from the TDRS to the user over a bandwidth such that the signal flux density at the earth will conform to the IRAC requirements

2. Discriminate against the multipath signal which will exist in the LDR case

3. Provide code division multiplexing from up to 20 users on the return link per TDRS.

The PN code requires hardware in the user which is not needed with the ground network data collection system. The impact in both LDR and MDR users is unavoidable when the basic need for PN modulation is coupled with the necessity to develop a reasonable system in terms of lock-up time, code lengths for unambiguous ranging, and the amount of bandspreading required to conform to the IRAC requirements for a given level of performance. The amount of the impact can only be defined qualitatively due to the limited knowledge of specific user hardware. A qualitative comparison can be drawn by referring to Figure 11-4. In this block diagram, the segments of the LDR block diagram shown which would not be required for the ground network system are the doppler processor, code tracking loop, a small portion of the carrier tracking loop (doppler control portion) and the synch and code search control signals.

Because of the shift to UHF in the TDRS to user forward link, two receiver channels (one UHF) are required if compatibility with STDN is required. The need to tune to any one of four carrier frequencies is a direct result of the visibility of TDRS to a large coverage area.

In the transmitter, the PN code generator and the associated control signals are an added hardware requirement in the user due to the necessity for PN modulation.

In addition to the hardware, the operational sequence and command message formatting required to achieve connectivity between the TDRS GS and the user is complicated by the need for code acquisition.

In the MDR case the need for two PN codes with different rates is due to the band spreading (8 MHz), the unambiguous ranging, and a reasonable lock-up time (33 seconds). This mechanization again is unavoidable if the requirements are to be met. The doppler processor, code tracking loop, doppler control portion of the carrier tracking loop and the control signals of the block diagram in Figure 11-3 will not be necessary for the ground network. The added complexity in the transmitter and the operational sequence and command message formatting necessary to achieve connection between the TDRS GS and the user is comparable to that in the LDR case.

12.0 TDRS GROUND STATION DESIGN

This section describes TDRS ground station system which is configured to satisfy or exceed TDRSS requirements. A simplified block diagram of the GS is shown in Figure 12-1. Ground station requirements and constraints, trade-offs, and concept description are discussed.

The TDRS system ground station is the unifying element in the overall system design. All commands, tracking, and voice signals pass through it and emanate from it to the two relay satellites. It also is the central gathering facility for the downlink telemetry, tracking, and voice before these are processed and sent to the users.

The TDRS ground station is a fully automated facility. All switching, frequency selection, antenna patching, data transmission interfaces, modem selection and patching, power control, antenna pointing and tracking, etc., will be computer-controlled with supervisory override to minimize the number of station personnel. The central processing unit (CPU) used to perform the controlling function is under the command of NOCC. A manual override mode is provided so as to maintain the system functioning, although, at a reduced level in the case of CPU malfunction.

The equipment configuration request necessary to support a particular user is put into a format which can be recognized by the CPU. After an execute order is given, the CPU selects the ground station equipment, the equipment parameters, and the interconnection layout. A check is automatically performed on the final configuration by means of local simulation units and monitoring of the subsystem outputs prior to transmission. Upon successful completion of test and transmission, a message status is forwarded to TDRSNET and the user. If there is a malfunction or degradation anywhere within the system, this fact is relayed to NOCC for action.

12.1 REQUIREMENTS AND CONSTRAINTS

12.1.1 Uplink Requirements and Constraints

The TDRSS Ground Station must be capable of sending to the relay satellites all necessary command, tracking, and voice signals.

12.1.1.1 Command Signals

Two basic types of commands exist: commands for the relay satellites themselves, and those to be ultimately received and processed by the various user spacecrafts. The commands for TDRS are generated at the ground station under the control of TDRSCON. The commands for the users can be generated at the ground station under NOCC control or can be received over the communications/data lines (NASCOM) and transmitted directly to TDRS. The source of commands in this case is the user control center.

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The bit rates for the commands can range from 100 to 1000 bps; therefore, normal voiceband data lines can be used for remote source commanding. The only hardware constraints foreseen are the availability of the necessary lines for remote sources and the necessary command generators for local sources.

Operational constraints enter into the picture due to the two channel/ TDRS uplink configuration. Commands will have to be scheduled along with any required handover from TDRS No. 1 to TDRS No. 2.

12.1.1.2 Tracking Signals

The need for range and range rate data on user spacecraft implies a need to know the location of both relay satellites within accuracies which yield the specified range and range rate accuracy on any user. The approach proposed is a trilateration technique (three code/three ground station process) as shown in Section 3.5.3 for TDRS and a one code process on each user. In terms of the ground station, then, all code generation will be performed locally at the ground station by means of pseudonoise (PN) codes applied to the appropriate uplink carriers.

Due to the complexity of the tracking (i.e., the multiple relay method from ground to TDRS to user to TDRS to ground), the code processing will be accomplished by the ground station as opposed to user processing; however, provision is made to forward raw data to the user control center.

12.1.1.3 Voice Signals

The medium data rate (MDR) user can have the requirement of real time voice. The source of the voice can be local, but in most cases it will be received over communications lines by means of modems connected to the user control center. Of course, any facility with access to the communications lines can talk to the user. As example of this might be TDRSCON, MSC/Shuttle, or a special Presidential message.

Normally the voice link will be over the S-/Ku-band channel from TDRS to the user. However, a back-up link will be provided over the UHF channel to the user. The ground station, then, must incorporate the switching and other units necessary for the primary/back-up voice.

12.1.2 Downlink Requirements and Constraints

The TDRSS ground station must be capable of receiving from the relay satellites all telemetry, tracking, and voice signals required by the network along with attendant intermediate data handling or processing.

12.1.2.1 Telemetry Signals

As in the case of command signals, there are two categories for the network telemetry. The first is the telemetry from the TDRS spacecraft and the second is that originating from the sundry users. The TDRS will be transmitting housekeeping data, command verifications, etc., which must be received and interpreted by the network so as to ascertain the operating status or condition of the system. As for the users, each will upon command transmit similar telemetry.

In the case of TDRS telemetry, data will be received and handled by the ground station so that TDRSCON and TRDSNET will be able to receive display signals via communications/data lines which reflect the system condition. For the users there will be a minimum of handling/processing performed at the ground station. Instead, the telemetry will be formatted for transmission to the individual users where it can be reduced per their unique requirements.

12.1.2.2 Tracking Signals

A tracking system employing relay satellites to transponder user satellite ranging codes necessarily incurs more errors than a ground to user to ground system. The added errors are due to the range and range rate uncertainty of the relay itself. To obtain sufficient user tracking accuracy these relay errors must be made negligible relative to those of the user. This is accomplished by constraining the relay tracking scheme to one of trilateration as analyzed in Section 3.5.3 of this report.

Basically, TDRS tracking consists of the following. A PN code is generated at the ground station and transmitted to TDRS. The code is then turned around to the ground station, detected, and processed. Simultaneously, it is transmitted from TDRS to two spatially separated remote ground locations. These remote locations receive the code, generate new codes (one for each), and transmit them to TDRS, where they are relayed to the ground station for processing. Trilateration is then used to pinpoint the locations of the TDRS spacecrafts.

Simultaneously, each user satellite will return a code which must be received. Since the location of the user is intimately related to the location of the relays, the range and range rate processing will have to be performed at the ground station before range and rate counts can be transmitted to the user control center.

12.1.2.3 Voice Signals

Both primary and back-up voice is required. Consequently, the proper switching, detection, and voice routing will have to be provided at the ground station. Both local and remote voice will be obtainable.

12.2 TDRS GROUND STATION

The basic elements of the ground station shown in Figure 12-1 are described in this section.

12.2.1 <u>TDRS GS Antenna Subsystem</u>

The TDRS GS antenna subsystem consists of two 60 ft (18.3m) dia. parabolic reflectors mounted on an elevation over azimuth wheel and track pedestal and three VHF helicies to support two operational spacecraft and an in-orbit spare.

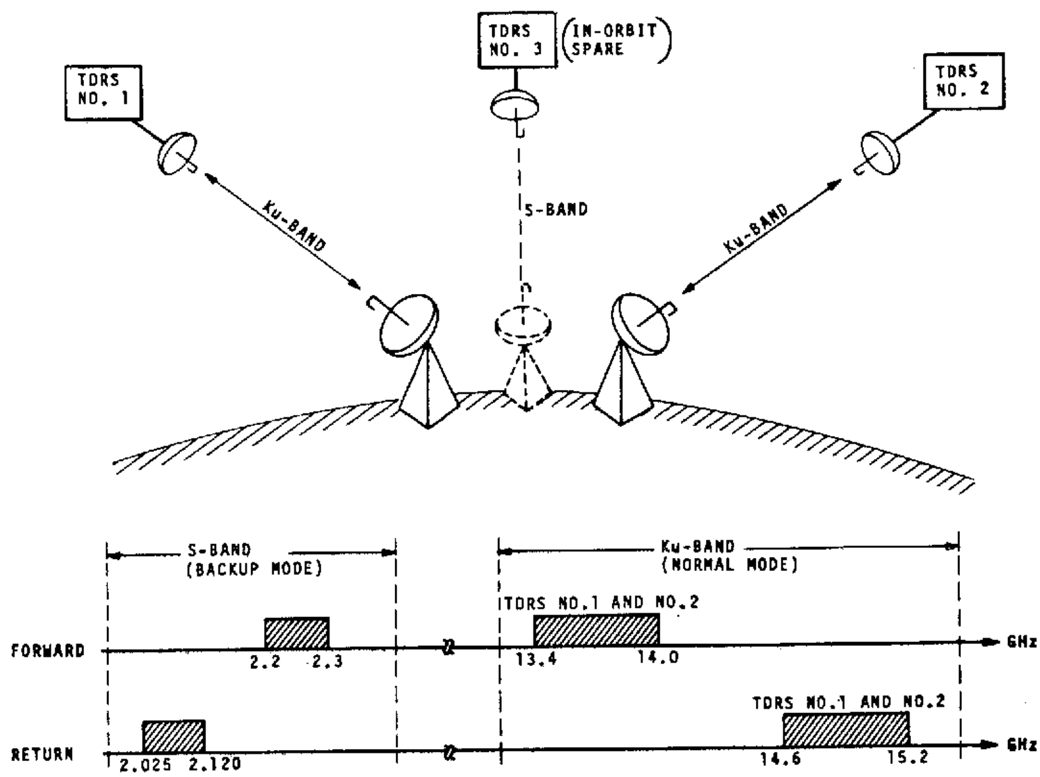


Figure 12-2. Frequency Plan for Ground Station

The 60 ft(18.3m) dia.antennas are high efficiency (>67%) Cassegrains using shaped reflectors and subreflectors. A horizontally stabilized RF equipment room is attached over the azimuth bearing. The RF room houses the four-horn feed assembly (including the monopulse bridge and diplexer), parametric amplifier and associated wiring and cabling. This design approach is a scaled down version of field-proven COMSAT station equipment and provides high reliability and low maintenance.

12.2.2 Antenna Site Analysis

The 60 ft(18.3m) dia. antennas supporting the TDRS operational spacecraft utilize identical frequency spectra, Figure 12-2. It is, therefore, necessary to insure that the space-to-earth links have sufficient isolation to eliminate cross-service interference. Link computations indicate that overall transponded signal must operate with CNR's of 19 dB and 5.2 dB for the MDR and LDR links, respectively, for a system error probability of 10^{-5} or less. This performance requires that the cross channel interference beween the space-to-earth links be approximately 30 dB. This isolation is obtained by:

1. Physical site separation
2. Reflector design techniques to minimize side lobe spillover
3. Special site preparation

Physical site separation to provide natural geographic and/or geological shielding barriers is inconsistent with efficient operational control and maintenance.

12.3 ANTENNA SITE ISOLATION ANALYSIS

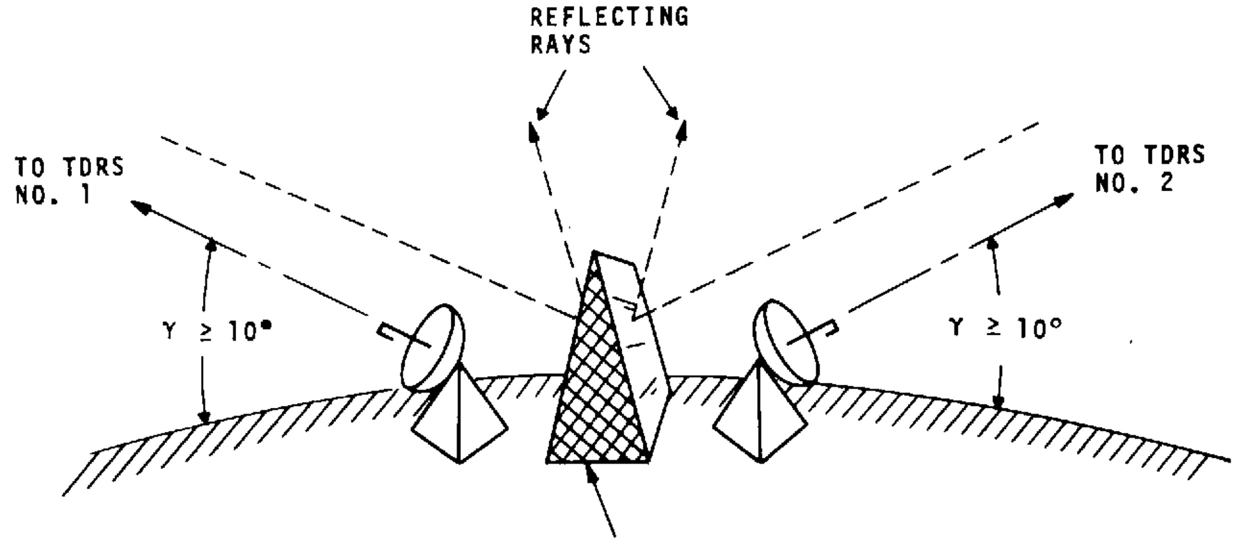
To provide satisfactory performance, the cross channel interference requirements be ween the two space-to-earth links must be maintained 5 to 10 dB below the C/N of 19 dB, or approximately 30 dB. Since the two GS antennas are effectively located back-to-back, its front-to-back lobe levels must be designed to provide the above margin. Antenna techniques are available which can provide front-to-back ratios as high as 75 dB using specially designed skirts about the dish perimeter to minimize all side lobe spillovers. In addition since the two antennas are essentially back-to-back, it is possible to use special site preparation as shown in Figure 12-3 to reduce cross link isolation.

By combining efficient antenna designs with high front-to-back ratios with either of the proposed ground site preparations, it is expected that 60 to 75 dB isolations can be assured between the two space-to-earth links.

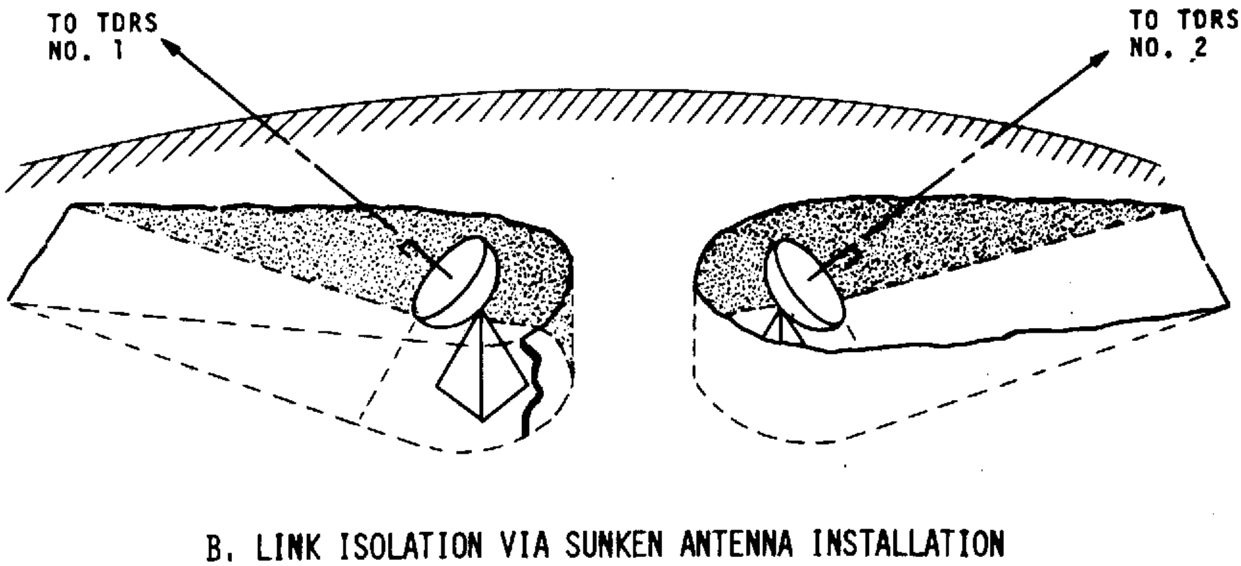
Although it is not now planned to use the in-orbit spare TDRS satellite as an operational vehicle, it is possible to provide new full relay performance capability in this TDRS satellite by employing the functionally redundant S-band back-up mode that has been included into the basic design. Referring to Figure 12-2, this third, space-to-earth link can operate in S-band back-up mode and still provide full LDR plus one MDR user support. By operating this link at S-band this will not cause interference in the other two links. To implement this capability for full time use, it will be necessary to add a third antenna operating at S-band with a complete GS transceiver. Alternatively, (on a periodic, time-shared basis), it will be possible to use a dual S/Ku-band feed on one of the 60 ft (18.3m) antennas and tap into one of the two GS transceivers at a convenient S-band level. This alternate operational capability for the in-orbit spare TDRS satellite has not been included in the design or in the cost estimate for the TDRS Ground Station.

12.4 Ku-BAND GROUND STATION ANTENNA

The feed to be used would be a square pyramidal horn fed by four square wave guides at the throat, providing monopulse tracking and circular polarization. This design is similar to that developed for the Haystack radar. The feed is a multi-mode corrugated horn and allows for accurate control of primary feed illumination to attain the high efficiencies of a doubly-shaped reflector antenna system. These techniques, particularly the use of multi-mode monopulse feeds, are limited to narrow band systems. The referenced Haystack feed horn has a bandwidth design objective of 7.5 percent and has achieved a 10 percent bandwidth. Ku-band frequencies, as they are presently conceived, span the range of 13.4 to 14.2 GHz for transmit operation and 14.4 to 15.25 GHz for reception from the spacecraft. The total bandwidth (13.4 to 15.25 GHz) approaches 12.6 percent bandwidth. Philco WDL has attained 75 percent efficiency for a 35-foot antenna operating from 3.7 GHz to 4.2 GHz, a 12.5 percent bandwidth. This performance was achieved using a corrugated



A. LINK ISOLATION VIA ABSORBENT/REFLECTION WALL



B. LINK ISOLATION VIA SUNKEN ANTENNA INSTALLATION

Figure 12-3. Antenna Installation at Ground Site to Ensure Good Link Isolation throat conical horn primary feed. It is assumed that the multi-mode monopulse horn design could be improved to cover a 12.6 percent total bandwidth (±2.9 percent in transmit) with the design optimized for the ground station receive mode at the expense of the ground station transmit function.

A 60'(18.3m) dish with a total efficiency of 75 percent would provide a nominal gain of 67.0 dB on transmit and 67.9 dB on receive. This design with a total antenna efficiency of 75 percent implies nominal first and second side lobe levels 17 and 24 dB below the peak of the beam. The back lobe would be 10 to 15 dB below the gain of the feed and approximately 60 dB below the peak of the main beam. Back lobe level could be reduced to the order of 70 dB with the use of a cylindrical shield about the periphery of the dish.

12.4.1 TDRS Ground Station Receiver Front End

The space-to-ground link is designed for a system noise temperature of 23.3 dB and a sky temperature of approximately 30°K. This means that the receiver temperature is about 300°K as measured at the antenna input port. A receiver which corresponds to this consists of a diplexer with an input insertion loss of approximately 2dB followed by two paramps each having a gain of 15 dB. Both paramps are uncooled and have a noise temperature of 100°K. Each paramp is backed up by a redundant paramp. Following the paramps the signal is mixed down to 2072.5 MHz, and amplified in an S-band amplifier to 0 dBm. This signal is then sent by cable to the central GS.

12.4.2 TDRS Ground Station FM Demodulator and Demultiplexer

The 2072.5 MHz signal from the antenna substation is filtered and amplified upon entering the main station. This signal is 600 MHz wide since it is five channels at different frequencies, all of which have frequency modulated the carrier (FDM/FM). The next operation is to demodulate the carrier using a phase lock loop with a VCXO at 2072.5 MHz, and a 600 MHz bandwidth. The resulting signal as baseband is 46.5 MHz wide if there is no TV on MDR-2. With TV, MDR-2 is 100 MHz wide rather than 10 MHz wide, and the total bandwidth is 154 MHz. In either case, 500 MHz is added to the signal to move it to a frequency where it is easier to separate the signals with filters.

The LDR channels are each 1 MHz and spaced 2.5 MHz apart. The 19.5 MHz LDR band is mixed down to 100 MHz, filtered, and routed to the AGIPA processors. Channel MDR-1 is 10 MHz wide, but the information is not necessarily centered in the band. Therefore, the 356 MHz L.O. signal is made variable in 0.1 MHz steps so that the information in the MDR channel can be centered. The same is true for the 392.5 MHz L.O. signal for MDR-2. However, when MDR-2 is receiving a TV signal, the 100 MHz bandpass filter is used and the L.O. is fixed at 455 MHz, since the TV channel requires the full 100 MHz. The order wire signal is mixed down to 150 MHz from 515 MHz, and is filtered with a 1 MHz filter. The remaining channel is the TDRS telemetry data. When the VHF transponder is operating, the telemetry is received at 137 MHz. To reduce the number of conversions required, minimize equipment and simplify the switching network, the Ku-band telemetry signal is also mixed down to 137 MHz.

12.4.3 TDRS Ground Station LDR Processing

The 19.5 MHz wide LDR band consists of eight 1 MHz channels spaced 2.5 MHz apart with 1 MHz guard. These channels are the received signals from the four vertical and four horizontal antenna elements at the satellite. If the eight signals are combined with the proper relative phasing and amplitudes, then the detected signal to interference ratio for one user will be optimized. It is the function of the AGIPA processor to find the optimum weights for a particular user, combine the eight channels, and send that result to a demodulator. In the TDRS system the 40 individual users are identified by orthogonal pseudonoise codes which allows the 20 users to occupy one eight-channel group. The PN code corresponding to the desired user is employed to detect that user, and unweighted and weighted samples are sent to a mini-computer for comparison. The computer changes the weights until the optimum weights are obtained.

During handover the spare processors are employed. The LDR downlink selector routes the signal from the new relay satellite to an unused processor while the main computer assigns the correct PN code to that processor. The mini-computer at the new processor optimizes the signal, and indicates that the signal is ready to be demodulated. The CPU now switches the user's demodulator over to the new processor and no data is lost. The AGIPA processor deactivated during handover becomes a back-up processor.

12.4.4 TDRS Ground RF Transmitter

The transmitter consists of 3 RR power amplifiers providing 25 watts each. Two amplifiers are used for the MDR#1 and MDR#2 command data, and the third amplifier is a linear amplifier to transmit the two LDR, TDRS pilot reference, and the TDRS command data. The outputs are multiplexed in a multicoupler. The RIRP for each channel is 80.9 dBm.

12.4.5 TDRS Ground Station FDM Multiplexing

The forward link data from ground station to TDRS contains six channels, of which four are data to be relayed to users. The fifth channel is the pilot frequency used as a reference for the frequency synthesizers in the TDRS satellite. These five channels are sent up together by frequency division multiplex.

Two of the uplink channels are MDR channels for two MDR users. The channels start out at 150 MHz and, at present, are only 1 MHz wide. The signals are mixed to a predetermined frequency with 0.1 MHz resolution anywhere within a 100 MHz bandwidth. The new frequency is determined by the particular MDR user to be serviced. The TDRS system transmits the entire 100 MHz band for each MDR user.

The two LDR channels are 1 MHz wide and start out at 150 MHz. They are mixed down to 55 and 60 MHz and then go to a VHF combiner. Also entering the combiner is the pilot frequency at 65 MHz and the telemetry command link. Telemetry starts as 149 MHz with 1 MHz bandwidth because this is the same frequency the VHF transmitter uses to transmit it. Mixing with 99 MHz brings the telemetry down to 50 MHz. The four low bandwidth signals next are assembled in a VHF frequency combined and then the entire 15.5 MHz band is translated to S-band and sent to the transmitter site.

12.4.6 TDRS Ground Station Frequency Source

The ground station frequency source serves as a source for almost every frequency in the system. This serves to make all of the signals coherent and stable to the degree that the atomic reference used for a primary reference is stable. The synthesizer does not produce every frequency required for two reasons. The demodulators must be locked to the incoming users signal which use a different frequency reference. Therefore, VCXO's are used in phase lock loops in the demodulators. The other frequencies not directly produced by the synthesizer are produced indirectly by remote units.

This leaves the main frequency synthesizer to produce 23 low-level signals. Further study should reduce this number. These low-level signals serve to lock loops at the point where a signal is needed. In the case of variable sources such as those required for the MDR channels the lowest frequency desired can be mixed with multiples of 100 kHz to produce desired frequencies in 100 kHz steps. The multiplying can be performed by a programmable counter which allows the entire process to be computer-controlled.

12.4.7 TDRS Ground Link Backup Modes

The main links for data and information relay between TDRS and the ground occur at Ku-band. Should there be a temporary failure (or even a catastrophic failure), there is an alternate link available, although it forces a slightly reduced capability. At the satellite, one of the TDRS-to-user MDR link is converted into a ground link at S-band or Ku-band.

The main limitation of this configuration is loss of an MDR channel. Secondly, the frequency allocation at S-band is only 90 MHz wide for the downlink rather than 600 MHz wide. By using FDM only and chopping 30 MHz off of the remaining MDR channel, the rest of the channels are transmitted just as before. When received, the S-band link is not translated in frequency at the receiver site, but is transferred right to the demultiplexer in the main station. The use of 6.5-foot (2m) transmitting antenna allows a much less elaborate receiver on the ground at S-band.

For the uplink in S-band backup mode, only one TWT is needed. The power required is only 0.5 kw and the bandwidth has been reduced to 100 MHz. However, the bandwidth is now 5 percent of the frequency being transmitted so that a Kylstron cannot be used. Since there no longer are two high-power MDR signals producing intermodulation products as in the Ku-band transmitter, the channels can be combined at low power.

The backup mode ground equipment is much less involved than the main channel. However, the capability of the system is reduced when in backup mode.

12.5 DESIGN CONSIDERATIONS

This section presents factors affecting the proposed ground station design along with the rationale for choosing the present approach. The discussion here will be in terms of the signal processing from reception at the antenna to the required destination.

12.5.1 Signal Categories

The signal processing categories at the ground station are:

1. LDR command/tracking (uplink)
2. LDR telemetry
3. LDR/MDR tracking (downlink)
4. MDR command (P/BU)*/uplink voice (P/BU)/tracking
5. MDR telemetry (P/BU)
6. MDR order wire
7. MDR downlink voice (P/BU) (Manned user)
8. TDRS command/tracking (P/BU)
9. TDRS telemetry (P/BU)
10. TDRS tracking (downlink) (P/BU)
11. Grd. sta./network communications

Section 12.6 contains a block diagram and a discussion of each of these categories. In the following subsections the tradeoffs used to arrive at the design are presented.

12.5.2 LDR Command/Tracking (Uplink)

For the low data rate (LDR) user, provision must be made for locally generated or remote real time command. For remote command (Figure 12-4) the maximum data rate of 1000 bps allows the use of normal voiceband lines and low speed modems. In the non-real time mode command data will be generated and processed in the central processing unit (CPU) (minicomputer) and will be the end result of programming by TDRSNET under orders from a user. Since the CPU is needed for configuration control, data processing, etc., this added function has a negligible impact on the design.

The local reference referred to in Figure 12-4 is just one output of a frequency synthesizer provided at the ground station for modulation/demodulation purposes. Given the need for several references, any additional output is readily added with very little extra hardware.

*(P/BU) = (Primary/Backup)

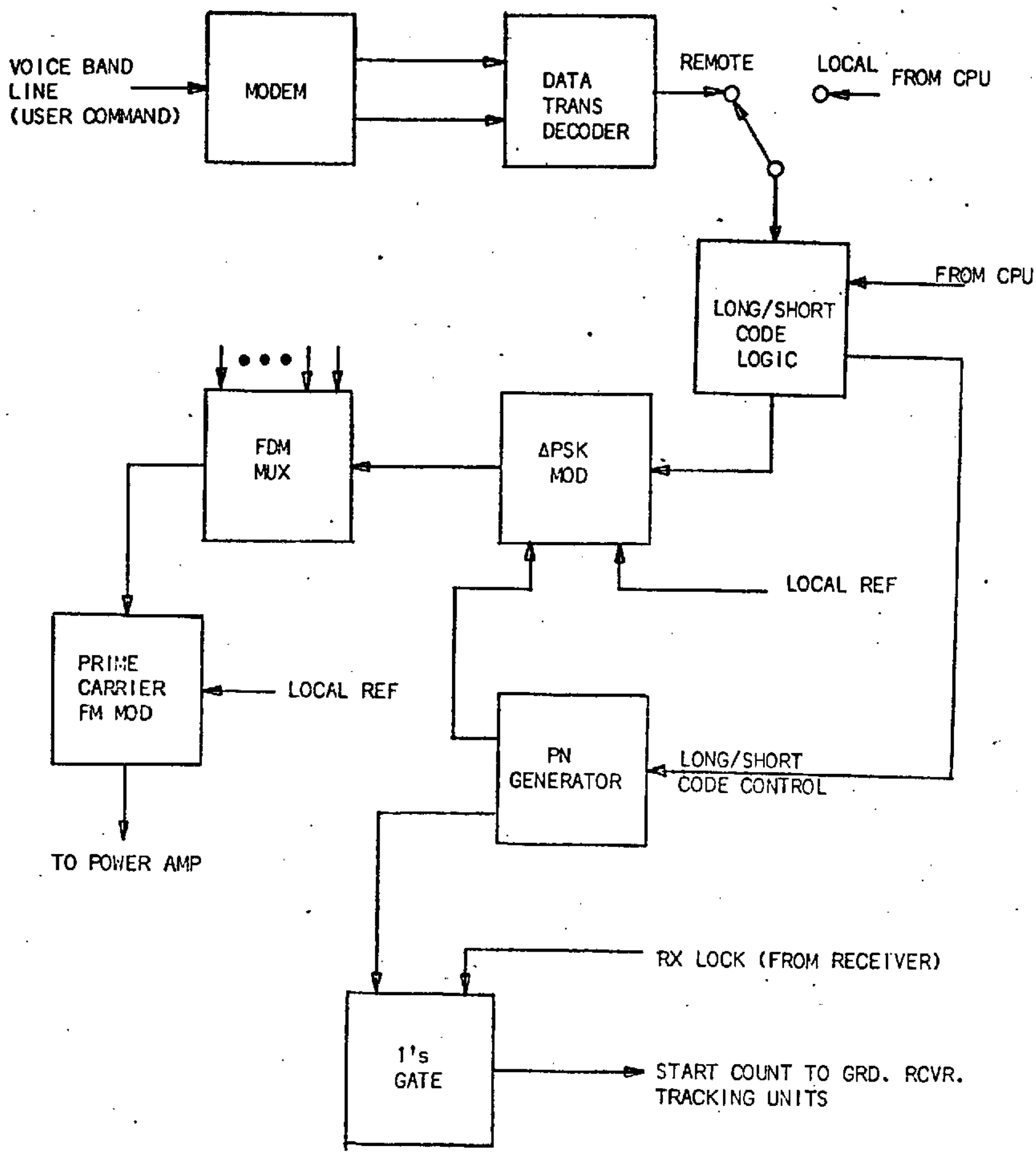


Figure 12-4. LDR Command/Tracking (Uplink)

The PN generator is used for tracking; therefore, it will require correlation with the received code. This is implemented by the 1's gate. A short code is used to "synch up" the system due to the long acquisition time needed for the tracking code. When ranging is required the user and ground station switch to a long code.

12.5.3 LDR Telemetry

Each LDR user signal is processed through AGIPA and the telemetry is stripped off. Raw data (unconditioned) may be desired by the user; hence, this option is made available. Provision also is made for full data conditioning and/or forward error control decoding. A functional block diagram of LDR telemetry is shown in Figure 12-5.

All data is recorded at the ground station to provide a backup in case of loss in the transmission to the user. This recording also allows a playback at slower rates. A graphic recorder is provided for quicklook purposes as a gross check on system operation. The cost impact of this option is negligible in contrast to the operational flexibility afforded by the ability to check some of the outgoing data. Also these recorders are available for TDRS housekeeping data quicklook, thus serving a dual purpose.

Wideband lines are chosen as the real time TDRSS to User Control Center medium due to the maximum bit rate requirement of 10 kbps. However, the option of voice band lines for tape recorder playback is provided.

12.5.4 LDR/MDR Tracking (Downlink)

The implementation of this category is straightforward and is shown in Figure 12-6. The only major tradeoff was the choice of doing the range and doppler count processing at the ground station. This processing is performed in the GS due to availability of the CPU (normally used for station control) and the relative complexity of the user range and doppler count extraction which involves determining the TDRS location parameters. The CPU output is the counts that are equivalent to a standard (non-relay) system. These are time shared and sent to each user.

12.5.5 MDR Command (P/BU)/Uplink Voice (P/BU)/Tracking

The considerations for this mode of operation (see Figure 12-7) are as follows. Voice band lines are used in the remote command mode since these lines will handle the 1 kbps maximum bit rate required. As in the LDR case, local command is provided via the CPU. The manned user has the option of simultaneous voice by time division multiplexing (TDM) the voice with the commands. Provision is made for either local or remote voice for the two available voice channels.

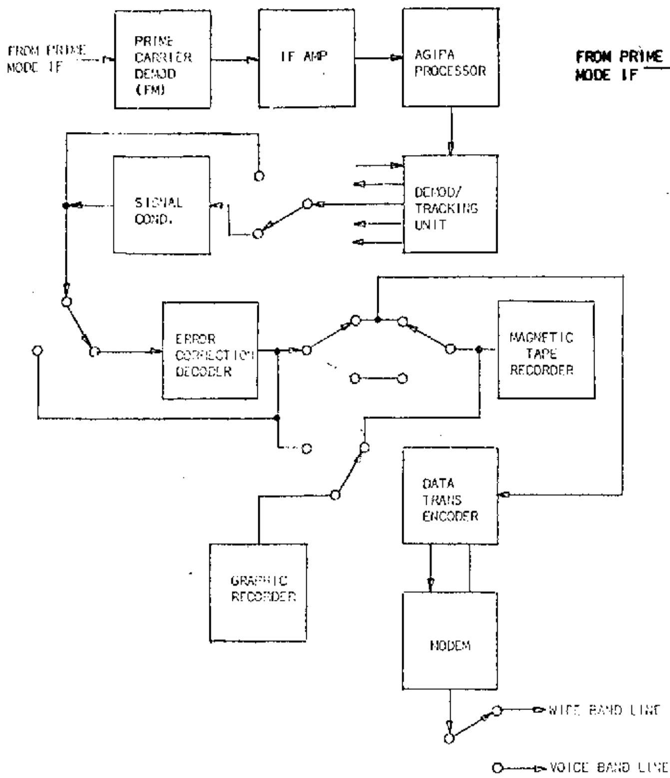


Figure 12-5. LDR Telemetry

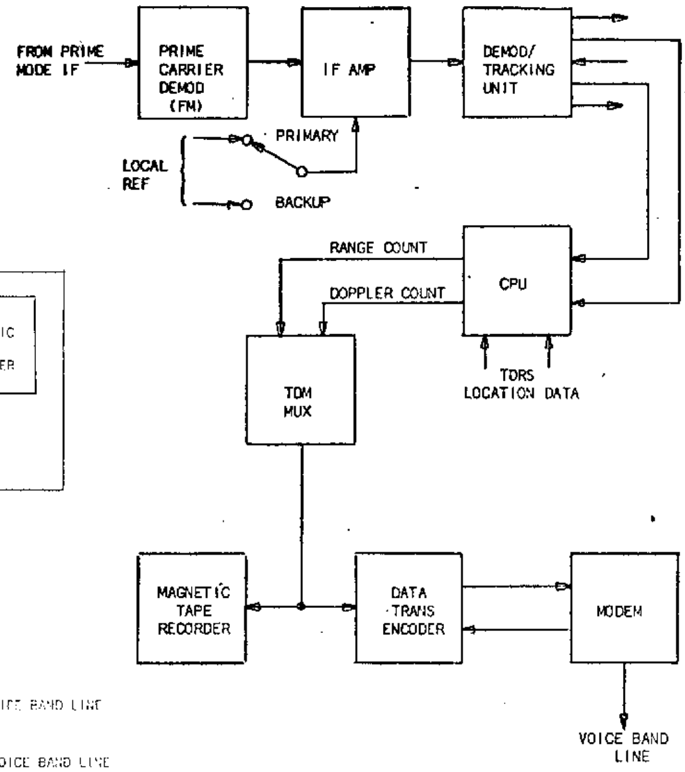


Figure 12-6. LDR/MDR Tracking (Downlink)

The rationale for the PN configuration and tradeoffs involved are the same as those of the LDR.

12.5.6 MDR Telemetry (P/BU)

TDM was selected for manned MDR user telemetry/voice service. For backup the source frequency is switched to shift the subcarrier frequency to the VHF band. In this mode the receiver multiplexer is switched to demultiplex only one voice channel. The MDR telemetry system is shown in Figure 12-8.

As in the LDR case, either raw or conditioned data is available and can be recorded and/or sent to the user in real time as well as low bit rate playback over voice band lines.

12.5.7 TDRS Order Wire

The downlink order wire (Figure 12-9) is used to notify the ground station of service requirements needed by the MDR. It also serves the dual purpose of bringing down one of the three TDRS location codes. No major tradeoffs were performed.

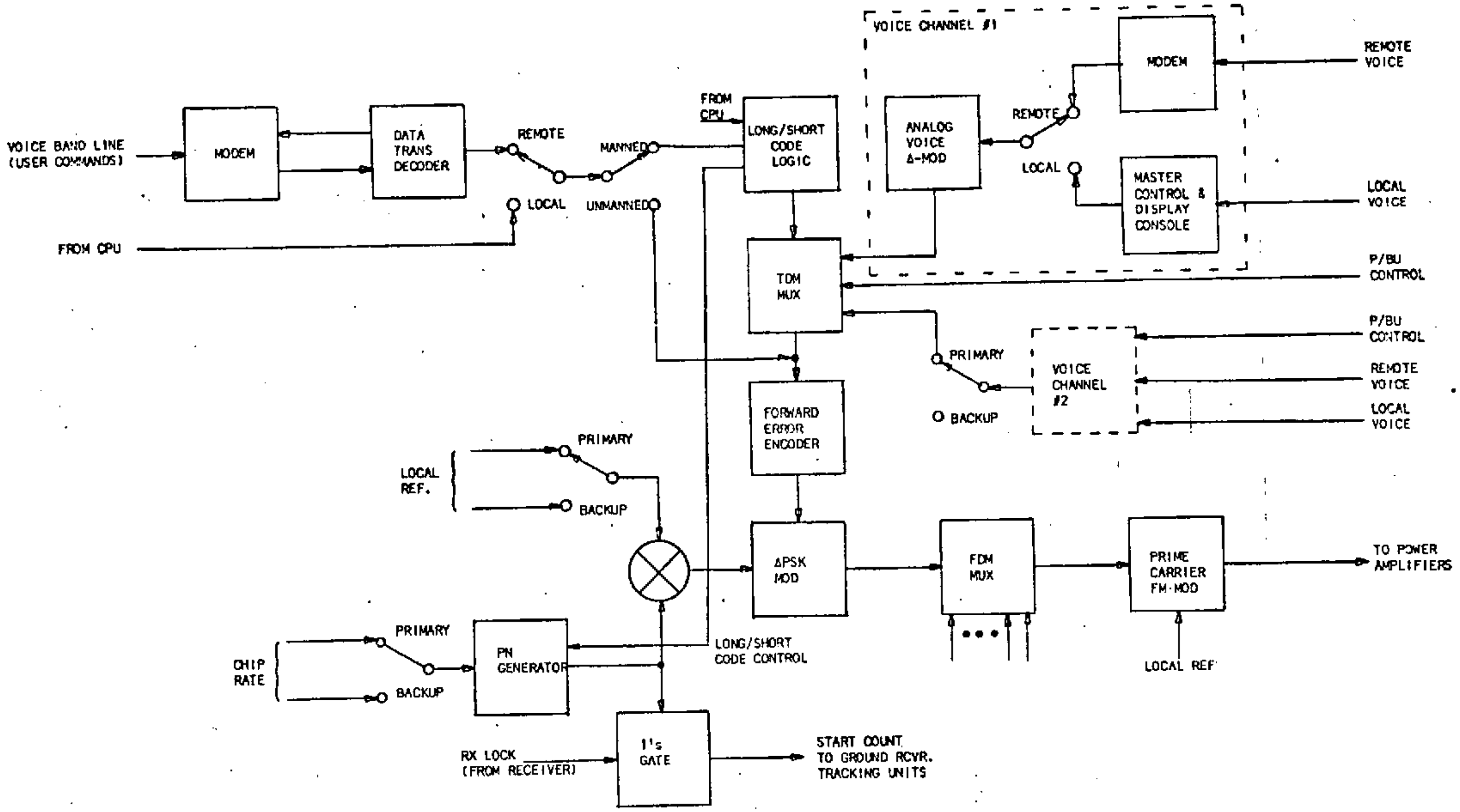


Figure 12-7. MDR Command (P/BU)/Uplink Voice (P/BU)/Tracking

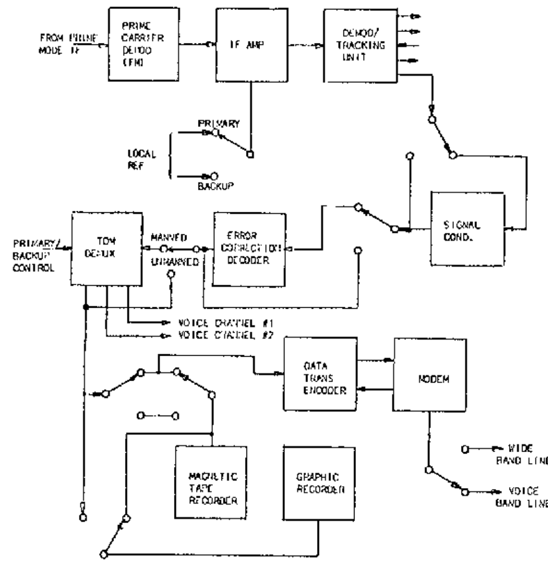


Figure 12-8. MDR Telemetry (P/BU)

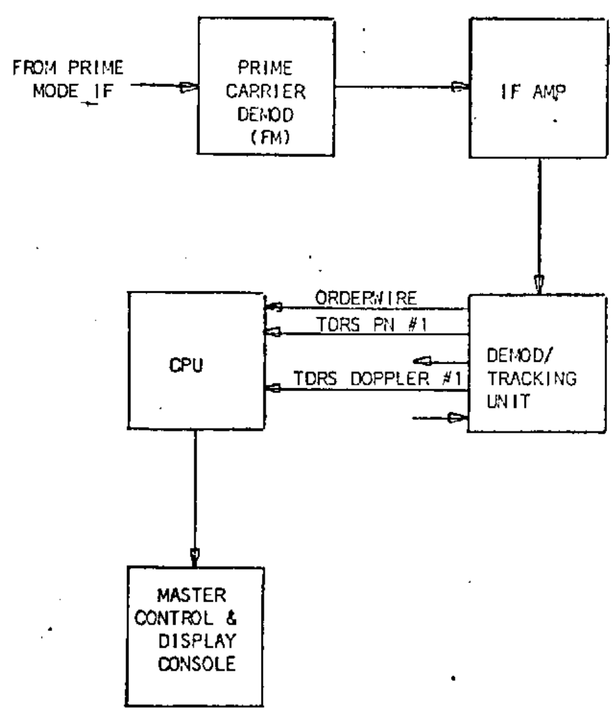


Figure 12-9. TDRS Order Wire

12.5.8 MDR Downlink Voice (P/BU) (Manned User)

For the manned user, the decision was to provide two voice channels in the primary mode and one in the backup mode (see Figure 12-10). Also, soft decision forward error decoding is used in both modes. Provision is made for recording voice on magnetic tape for purpose of GS backup.

The option of monitoring each voice channel is included in the design in that the hardware can also be used for duplex voice communications with MDR users. A local voice input allows communication with the user in case of loss of remote voice capability.

Consideration was given to routing raw delta modulated voice directly to the user, but this would require wide band lines and the option was deemed to be unnecessarily costly for the minimum flexibility added. This option was, therefore, not incorporated in the design.

12.5.9 TDRS Command/Tracking (P/BU)

The design of the TDRS command/tracking (Figure 12-11) is straightforward. It incorporates a backup VHF transmission capability to supplement the primary transmission mechanism. Either the PN commands for TDRS are frequency division multiplexed onto the Ku-band uplink along with the other (user) channels or they can be translated into VHF and transmitted over a separate antenna. In the case of TDRS the long/short code system is not needed.

The approach selected for the tracking of TDRS is one PN generator and three range gates. This technique was chosen over other configurations mainly for its simplicity and minimum cost.

12.5.10 TDRS Telemetry (P/BU)

A separate dedicated channel is provided for TDRS telemetry (see Figure 12-12). The data received is conditioned, recorded and/or applied to the local status equipment. Since many signal conditioners are available for other purposes (users) conditioned rather than unconditioned data was chosen.

The status equipment will be a combination of hardware and software (from the CPU). Provision also is made for sending the status to TDRSCON. A voice-band line is chosen since the status data will be of a "housekeeping" nature (except during launch/injection) and hence low in rate.

12.5.11 TDRS Tracking (Downlink) (P/BU)

The tradeoffs of TDRS tracking include a capability of tracking in a backup mode (see Figure 12-13). In this case the CPU makes use of only one demodulation tracking unit for calculating the TDRS location. In the backup mode only PN_1, i.e., one PN code, is turned around. The other two codes from the remote ground stations are not transmitted.

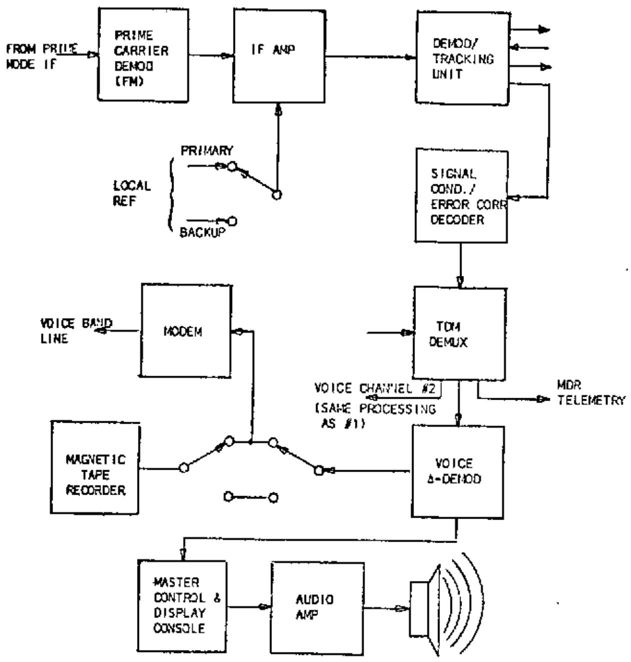


Figure 12-10. MDR Downlink Voice (P/BU)

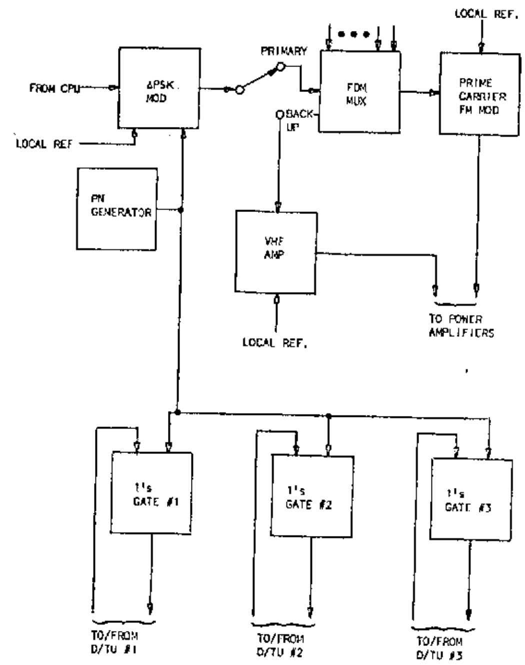


Figure 12-11. TDRS Command/Tracking (P/BU)

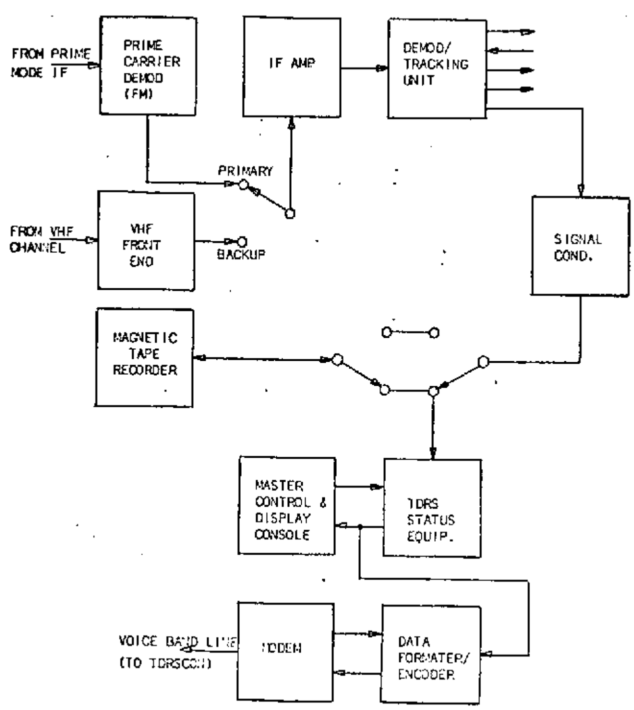


Figure 12-12. TDRS Telemetry

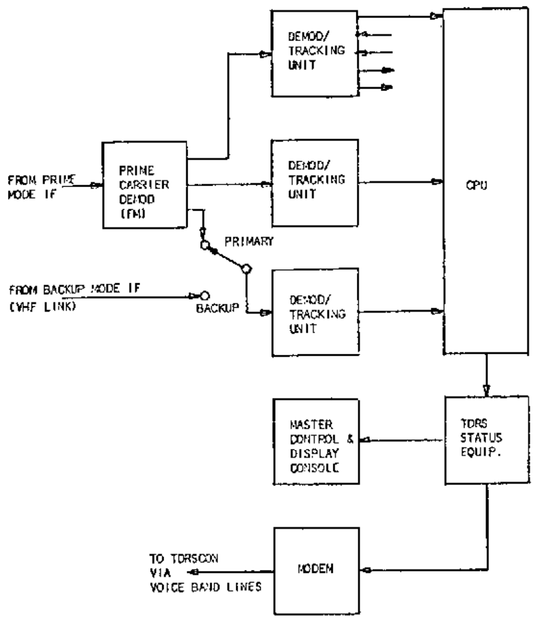


Figure 12-13. TDRS Tracking (Downlink) (P/BU)

As in the case of the TDRS, telemetry provision is made for local display together with the standard TDRSCON display data sent via voice band lines.

12.5.12 Ground Station/Network Communications

The choice of a combination of voice band lines for voice and wide band lines for data was made for GS/network communications (see Figure 12-14). Since it is desirable to be able to control all location operations by means of a central unit, the voice and data required for ground station to outside facility communication is designed to pass through the master control and display console for routing by TDRSNET via NASCOM. This also allows the option of automatic control via the CPU or manual control via the master console.

12.6 CONCEPT DESCRIPTION

While the tradeoff analysis in Section 12.5 describes the various segments of the ground station concept, it does not cover some aspects of the design (where no major tradeoffs were involved). In this section each category will be discussed with the purpose of explaining the reasoning behind the chosen design.

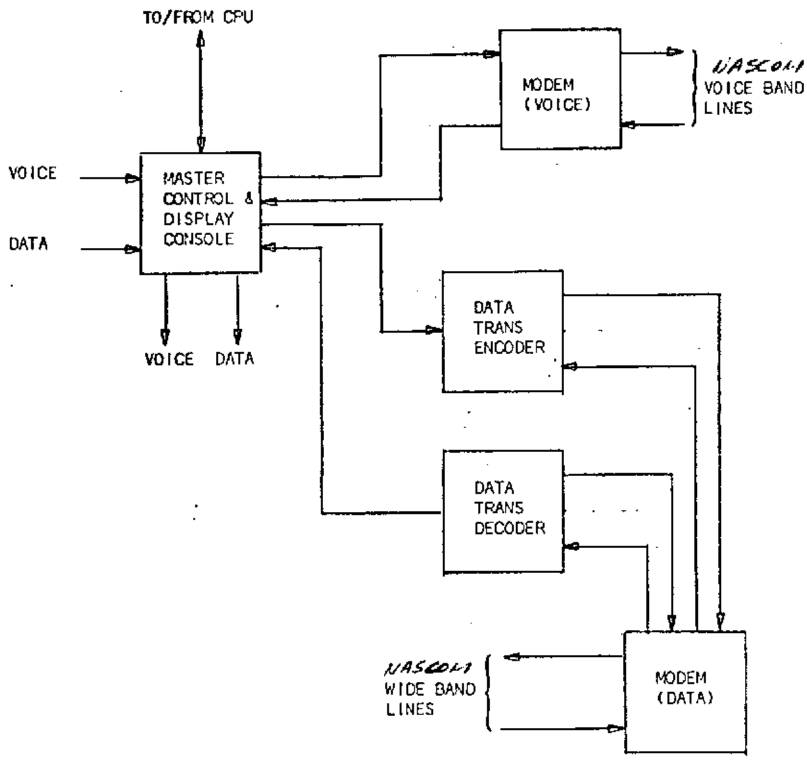


Figure 12-14. Ground Station/Network Communications

12.6.1 LDR Command/Tracking (Uplink)

Commands can originate either locally at the GS or in real time from the user control center via NASCOM. The correct command source is selected at the ground station, used to ΔPSK modulate a subcarrier which has been PN modulated previously, and added to other subcarriers in the frequency multiplexer. The FDM output is then translated to Ku-band, amplified, and transmitted to TDRS.

The output of the PN generator also drives a 1's gate which, when enabled by the receiver (upon obtaining code synchronization) sends a "start range count" pulse to the receiver. The term "1's gate" implies that the sequence of all ones must be obtained before range count is started (the receiver then measures the time needed to receive the all ones back at the ground). Ranging requires a long code; acquisition requires a short code. This is implemented by the appropriate logic. (See LDR transponder for details.)

12.6.2 LDR Telemetry

All LDR telemetry signals are received on one of five FDM subcarriers. The entire LDR band is AGIPA processed and then the particular LDR of interest is selected by the demodulation tracking unit which recognizes the appropriate code. Upon lock of code and carrier, the unit sends unconditioned data to a switch that provides the option of conditioning and/or error decoding. The added option of using a hard or soft decision signal conditioner is also available. The data is then sent to the user control center over wide band lines at rates up to 10 kbps. It is also recorded on magnetic tape as a real time transmission failure backup. The magnetic tape record mode is also provided to enable slow speed playback over voice band lines in non-real time.

The option of graphic recording is provided as a quick look. This can be used for fault isolation and/or as a quality check by GS personnel.

12.6.3 LDR/MDR Tracking (Downlink)

The input to the demodulation tracking unit is selected by switching and filtering. Although the detail of the demodulation tracking unit is not shown here*, suffice it to say that the unit is gated so as to accurately measure the doppler frequency shift in the carrier which is related to the satellite orbital velocity (range rate) and also the round trip PN code delay which is related to the range of the satellite. These outputs are sent to the CPU where the TDRS position and rate data is available. The CPU then computes the range count and doppler count as if no relay was involved (removes the relay parameters). The user then can use this data to determine orbits, etc.

The range and doppler counts are TDM and routed to the user via NASCOM. The backup of recording is used here to preclude any loss of data due to transmission malfunction.

12.6.4 MDR Command (P/BU)/Uplink Voice (P/BU) Tracking

As in the LDR case, the MDR command source is selected. The commands and/or TDM voice (for manned users) phase shift (delta coded) modulates a subcarrier, is added to other inputs, translated to Ku-band and transmitted to TDRS.

The voice is delta modulated and has two possible sources; i.e., one from the master control and display console and the other from a remote user via a modem/voice line set.

Provision is made for a primary and a backup mode of operation. The major differences in the backup mode are the chip rate is reduced, the number of voice inputs is decreased, and the subcarrier is changed from S-band to VHF.

As before, the PN generator output is fed to a 1's gate for ranging purposes, and the discussion previously given applies here as well.

12.6.5 MDR Telemetry (P/BU)

MDR telemetry received by the demodulation tracking unit is selectable. In the primary mode it comes down on an S-band subcarrier; in the backup mode it arrives via a VHF link. The telemetry (plus one or two channel voice for manned users) is stripped off the subcarrier. The telemetry is then either conditioned or not conditioned, demultiplexed, and then routed to the MDR user control center over NASCOM wide band lines.

*See Section 12.6.12

As in the LDR telemetry case the option of either magnetic or graphic recording or both is provided. Also, it is possible to record at the normal bit rate and play back over voice band lines at a reduced rate. The wide band mode, however, will be the primary link to the user.

12.6.6 TDRS Order Wire

The order wire link is used for three purposes. The first is to send one of the TDRS ranging codes from TDRS to the ground station. The second is to notify the network of a need for service. The third is to provide MDR's with an S-band beacon. The demodulation tracking unit extracts the range and doppler counts and also the modulation representing the service order. All of this is sent to the CPU for interpretation.

While the CPU uses the range and doppler counts in conjunction with other information to determine the location of TDRS, it also decodes the order wire data and routes it to the master console for action by ground station personnel (if such is the configuration at the time). An automatic response may be programmed into the CPU for standard order wire reactions by the ground station. Operation of the order wire link will be configured automatically by the CPU to provide mission support and will be powered down during slack periods.

12.6.7 MDR Downlink Voice (P/BU) (Manned User)

For the manned user delta modulated voice is time division multiplexed with the MDR telemetry. After the digital bit stream is detected in the demodulation tracking unit, it is conditioned, forward error control decoded, and sent to the demultiplexer. The demultiplexer strips off the voice channel or channels from the telemetry. Each channel is then converted to analog voice by the "voice delta-demod.". The output of the demodulator has the option of being locally amplified and produced at the ground station and/or sent to user control centers via NASCOM line. The option of magnetic recording is also provided.

12.6.8 TDRS Command/Tracking (P/BU)

The commands for the TDRS are generated in the CPU, ΔPSK modulated on a subcarrier which has been PN. The choice of either adding it to the other FDM subcarriers and transmitting on the Ku-band uplink or just amplifying the subcarrier (carrier in this case) and transmitting it to TDRS over the completely separate VHF system is available.

It should be noted that the PN generator output is applied to three 1's gates. This is because of the tri-code location scheme used for TDRS. The enabling of the three gates by their respective code loops allows each loop to be triggered by the transmitted all ones which, in turn, calculate range and doppler as described previously for the single loop.

12.6.9 TDRS Telemetry (P/BU)

Selection of the demodulation tracking unit source is determined by a switch. The two sources are either that which arrives over the primary Ku-band downlink or by the separate VHF backup link from TDRS to the ground station.

The TDRS telemetry is extracted by the demodulation tracking unit, conditioned and sent to the TDRS status equipment. The status equipment interprets the data and generates display data which is applied to the master console. The status data also is routed to a special data formatter and encoder/modem set. These units are connected to a voice band line which is dedicated to TDRSCON for purposes of displays.

12.6.10 TDRS Tracking (Downlink) (P/BU)

As mentioned previously, a three-code system is used to locate TDRS. In the primary mode, one code is derived from the order wire tracking unit; the other two are extracted by two separate tracking loops. The three range and doppler counts are sent to the CPU where the TDRS location is computed.

In the backup mode only the PN_1 code is used. This one comes down from TDRS via the VHF link. In this case more uncertainty is incurred.

The range and doppler processed data is outputted to the TDRS status equipment for generation of the orbital display data. As before, a dedicated line to TDRSCON is also fed by the status equipment.

12.6.11 Ground Station/Network Communications

For the routine data and voice communication between the ground station and outside facilities both voice band and wide band lines along with their respective modems will be used. All of the traffic is routed through the master console to the NASCOM and can be either automatically (CPU) or manually controlled.

12.6.12 Demodulation Tracking Unit

The demodulation tracking unit shown in Figure 12-15 extracts an NRZ-L bit stream from the PN-ΔPSK input. It also incorporates all the necessary functions for determining the code delay and doppler shift due to the input source's range and range rate.

Several of these units and units with essentially the same objectives are used to process the various subcarriers throughout the ground station system. The following is a description of the unit depicted in Figure 12-15.

The PN-ΔPSK carrier (VHF band) is applied to the first mixer of the unit and is combined with a PN local reference. The bandpass filter isolates the difference frequency. At this point (until PN lock has been obtained) there is a noise-like waveform into the Costas loop phase detectors. The loop cannot possibly lock up to the carrier so the loop searches in vain for a predetermined period of time allotted for carrier lock.

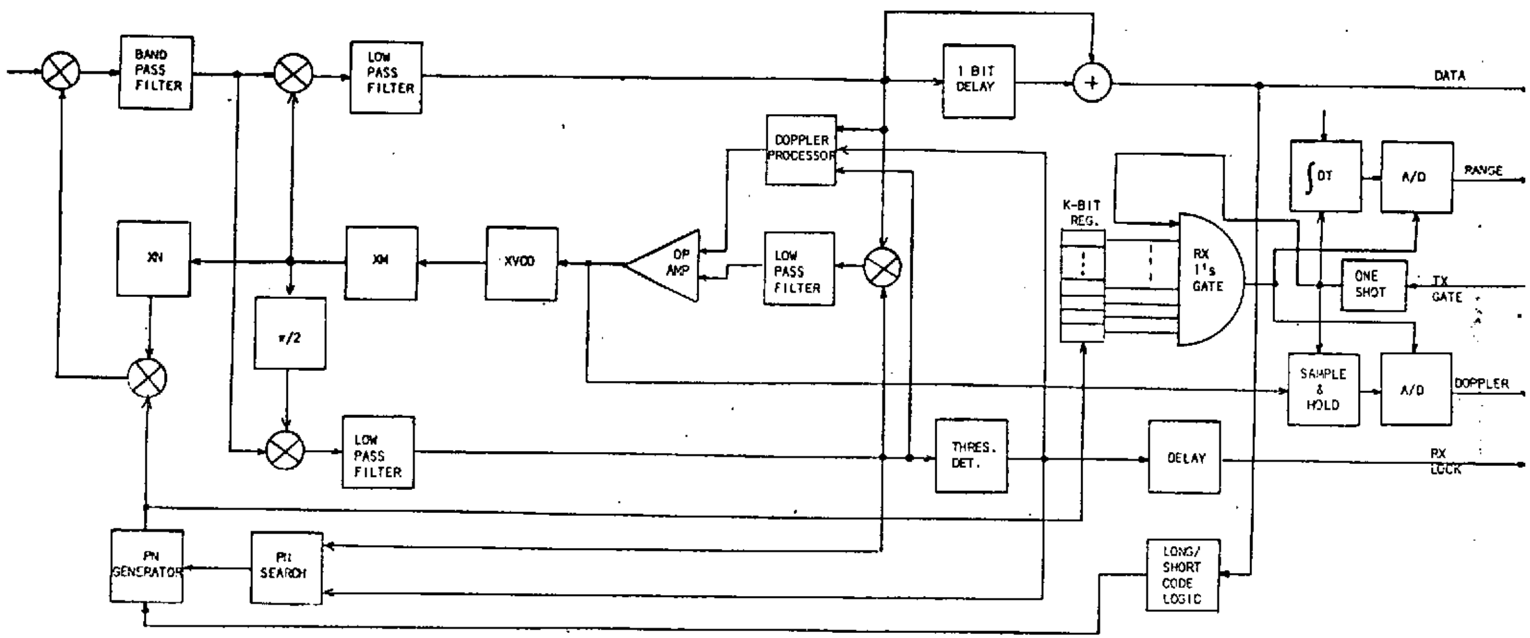


Figure 12-15. Demodulation/Tracking Unit

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North American Rockwell

The PN search block provides a half chip delay coarse search after each carrier search time slot. At some point the local PN code comes within a half chip of perfect synchronization with the received code. The output of the bandpass filter now contains sufficient carrier for the loop to lock.

To obtain carrier lock the doppler processor resolves the doppler shift and applies an error signal (proportional to the shift) to the operational amplifier which drives the crystal oscillator. Since the loop is now within pull range it tracks the carrier. This having occurred, the threshold detector inhibits the doppler processor, the coarse PN search, and after a delay sufficient to obtain fine lock on the PN code, sends an indication of the receiver lock (RX lock) to the transmitter.

Range delay is obtained as follows. The RX lock enables the transmitter (TX) 1's gate. The first time an all ones transmitter code condition occurs the TX gate fires the "one shot" which enables the receiver (RX) 1's gate. It also starts the integrator and causes the sample and hold to sample the error voltage to the XVCO. When an all ones receiver code condition occurs (the receiver generator is locked to the incoming code) the integration is stopped, converted to a digital word and sent to the CPU for processing. Simultaneously the doppler error voltage is A/D'ed and also sent to the CPU.

The purpose of the 1 bit delay and mod-2 adder is to convert the delta coded bit stream to NRZ-L. Also, when the user switches into the ranging mode, that is, from a short to a long code, a special message is sent downlink. The long/short code logic recognizes the message and switches the PN generator to a long sequence configuration.

As an added note, the one shot prevents a stop count output from the RX gate unless a start count has occurred. Also the RX gate is enabled only for a period of time sufficient for maximum expected delay. This prevents accidental triggering outside the delay window.

12.6.13 Modulation Unit

The modulation unit shown in Figure 12-16 is the basic modulator for all uplink data and/or digital voice.

The NRZ-L data stream is converted to delta coded PCM, PN coded, and bi-phase modulated onto the appropriate subcarrier. The composite waveform is then filtered and the output sent to an uplink multiplexer or other uplink processor.

The TX 1's gate provides a start pulse for the receiver tracking circuits when all ones condition occurs in the PN code generator output, and the code length control input chooses the long or short code under the command of the ground station.

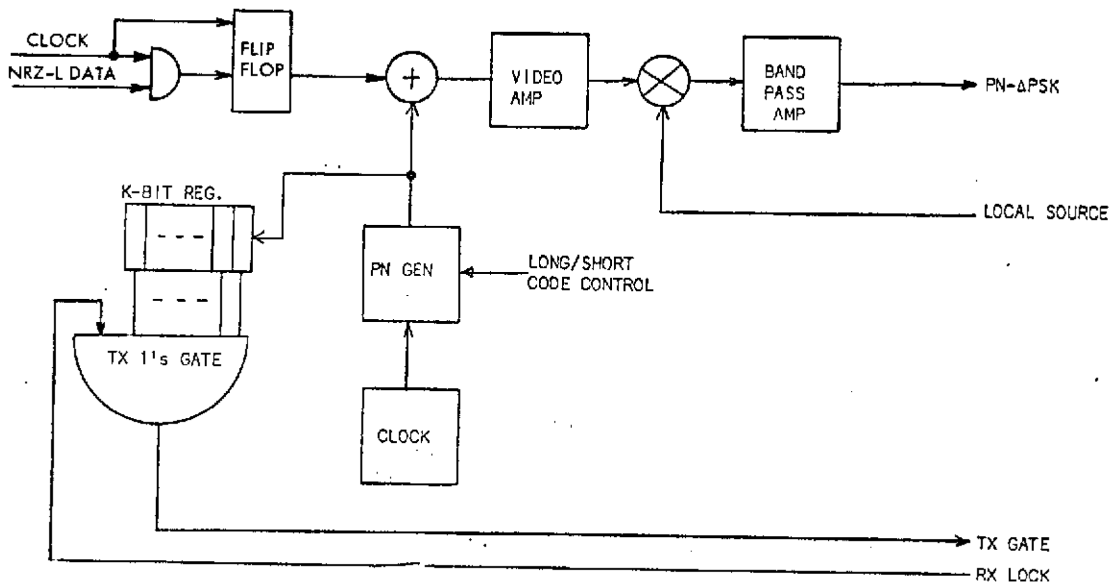

Figure 12-16. PN/ΔPSK Modulator

12.6.14 Control and Monitor Subsystem

This automated subsystem provides both local control and monitoring (at equipment) and remote control and monitoring (control console). Each equipment or subsystem will have a complete local control and monitor panel. These local panels will provide full operational control of all circuits, metering of all critical and adjustable voltages and currents, and fault/status indicators that permit fault isolation to the chassis level for maintenance. The remote control and monitoring capability will be provided by the CPU and status display on the control console, as discussed in the following paragraphs.

12.6.14.1 Control and Monitor Console

The basic objective will be to provide a station control center so that the entire system and segments thereof can be operated entirely from that center (Figure 12-17). The control center will be configured to accommodate two operators through use of a semi-wrap-around console. All control and display functions necessary to effectively operate the system, such as system status, intercom, power, antenna, transmit-receive and performance monitor, will be provided at the control center console. The controls and displays will be positioned within the reach/visibility limitations imposed by the design and the more critical functions will be give location priority. The console will be treated as an entity wherein overall uniformity will be accomplished through standardization of components, markings, control action, and

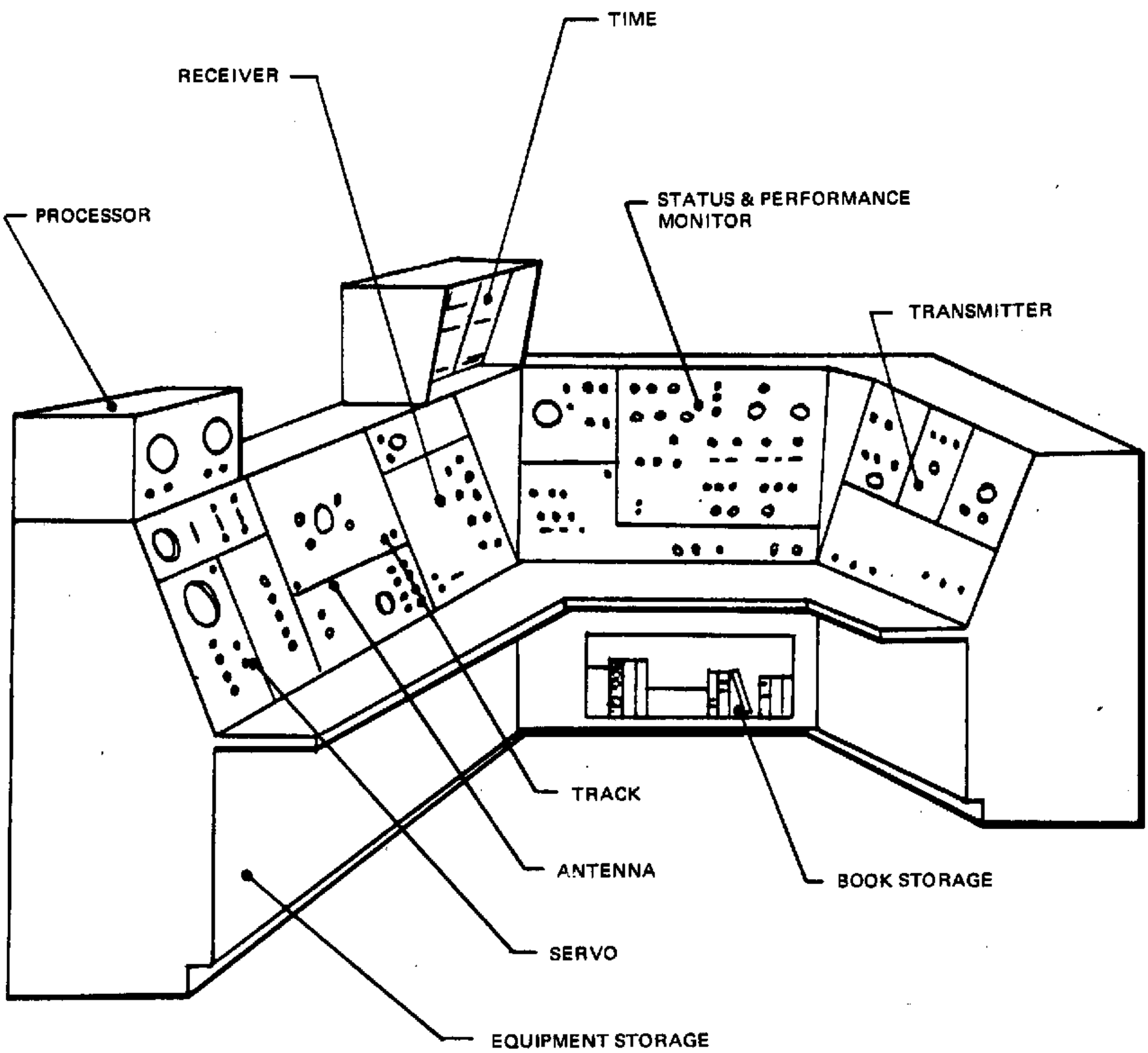

Figure 12-17. Control and Monitor Console

component functional use. Thus, the various control panels will provide the operator with a readily understandable, easy to operate, system. However, display/control panels will also be physically arrange so that each panel segment may be removed with its equipment. This will aid in display/control functional grouping and permit repair of defective components without interrupting on-line equipment.

Of prime importance in achieving automated control of the system will be the system status panel provided at the control override console. This panel will provide the operator with the use or availability status of each major segment of equipment, the mode of operation of the system, the equipment flow path of the operational mode, and ongoing maintenance.

Another basic function provided at the control console will be an intercom center through which the operator can communicate with segments of the system located remotely from the GS control center.

Other major control center override functions provided at the control console will be transmission, reception, antenna, power, and performance analysis for applicable operating sections.

The major panels which will be located in the control console are:

1. Transmitter monitor and control panel
2. Microwave receiver monitor and control panel
3. Antenna monitor and control panel
4. Tracking receiver monitor and control panel
5. Fault and system status panel
6. Performance monitor panel
7. Power generator monitor and control panel (behind control console)

These panels will provide controls and status for the required functions as noted in the following paragraphs. In addition to the panels, some of the data acquisition system will be located at the control console.

Power Generation Monitor and Control Panel. The functions of the power generation monitor and control panel are shown in Table 12-1.

12.6.14.2 Alarm and Status Subsystem

The basic purpose of the alarm and status subsystem is to monitor measurement status from various equipment, perform a high- and low-limit check, alarm those measurements that are out of limits, and provide a malfunction CPU printout automatically. The data acquisition subsystem required to perform this task will be described in the following paragraphs.

Table 12-1. Power Generation Monitor and Control Panel Functions

Description	Function
Control--generator control 4-position rotary (three required, one per generator)	Provides manual setup of automatic control of electrical power generation and automatic source switching. Position 1 - Off Position 2 - Standby--logic on, heaters on, etc., ready for start Position 3 - Ready--start and engine operating, no load applied Position 4 - On-line--engine operating and generating power
Control--power analyisis 9-position rotary	Enables operator at console to analyze power characteristics. Position 1 - Generator 1, phase 1 volts, amps and frequency Position 2 - Generator 1, phase 2 volts, amps and frequency Position 3 - Generator 1, phase 3 volts, amps and frequency Positions 4,5, and 6 - Same as positions 1,2, and 3 for generator 2 Positions 7,8, and 9 - Same as positions 1,2, and 3 for generator 3
Control--pushbutton cup guarded	Emergency disengagement of all power into entire system
Indicator--pointer-type voltmeter	Readout of voltage of selected generator and phase
Indicator--pointer-type ammeter	Readout of amps of selected generator and phase
Indicator--vibrating reedmeter	Readout of frequency of selected generator and phase
Indicator--lighted-type	On commercial power
Indicator--lighted-type	On generator power
Display--legend-type indicator light for generator 1	Four indications shown: on-line, standby, backup and source interrupt. This indicator shows actual automatic generator control status for generator 1. This light will reflect actual switch positions for initial operating sequence selection, but after an automatic control system function will not match actual switch position unless operator updates switch position to match indicator. If the switch associated with this light were placed in the on-line position, the light would so indicate until a fault occurred that reduced power. Then Generator 1 would automatically switch off the line, and this indicator would read "source interrupt." This generator would not then be automatically placed in backup again unless the switch associated with this light were placed in that position manually. Automatic generator control will sequence generators from backup to standby to on-line source interrupt, if required.
Display--legend-type indicator for generator 2	Same as for generator 1
Display--legend-type indicator for commercial power and generator 3	Same as for generator 1 except commercial power

Data Acquisition Subsystem. This subsystem will provide the following capabilities:

1. Continuous monitoring of critical measurements of both on-line and redundant equipments
2. Equipment fault isolation and detection
3. Equipment fault location and display
4. Audible and visual alarms on out-of-limit measurements
5. Remote system/equipment status (control console)
6. Local equipment status (equipment racks)
7. Automatically provide system (terminal) status information to an external user
8. Fault isolation to the replaceable module level dependent upon the particular faulted measurement
9. Automatic CPU printout of faulted measurements with supporting information
10. Control capability

Automatic transfer of redundant equipment will not be controlled by the data acquisition subsystem. This transfer will be controlled by switching logic within the redundant equipments themselves. The data acquisition system will, therefore, not be in the critical communications path or major failure category. Therefore, any fault or failure within the data acquisition system will be classified as a minor failure of non-traffic carrying equipment. The data processor will have this output control capability available, if required.

System measurements will orientate from internal sensors or monitor points located within the individual equipments or subsystems. These measurements will be both analog and contact sense (discretes). The majority of indicator measurements routed to the control console will also be routed to the data acquisition subsystem. Additional measurements from the individual equipments will also be routed to the data acquisition subsystem to aid in fault isolation to the replaceable module or isolation to a group of modules depending upon the measurement. Measurements will be provided in the following categories:

1. Provide terminal status data for transmission to an external user
2. Provide fault isolation and detection to the chassis level and where feasible to the module level
3. Fault detection of critical functions

4. Equipment monitoring for detection of parameter degradation and status for both "on line" and stand-by equipments

12.7 CONCLUSIONS AND RECOMMENDATIONS

The overall tracking and data relay satellite system ground station design is relatively straightforward. The impact of a relay type system as opposed to a set of ground stations ringing the globe is that one complex station (one incorporating relay transmit/receive plus normal user satellite functions) is required rather than several simpler hardware/software-wise stations.

In terms of hardware, the need to have equipment which can track, command, and receive telemetry (TT&C) from TDRS, together with the formatting and de-formatting of user TT&C is essential. This added hardware is not really a major item since the main complexity comes in the signal processing of user TT&C. This, however, occurs after the user data has been separated out or before the user commands have been integrated into the relay uplink format.

The conclusion is that the complexity of the ground station is for the most part simply the addition of commonly used hardware/software in sufficient quantities to handle the number of users. The amount of TDRSS unique equipment is small in comparison.

An essential item in the ground station is the CPU. It is involved in all aspects of the ground station, if only in a switch controller capacity. The CPU is literally the "heart" of the ground station and its efficient operation depends on the CPU.

The recommendation here then is that reliability be a major factor in the CPU design.

Since real time telemetry is a prime objective of the TDRS system the need for wide band lines to deliver the user data is essential. With proper multiplexing these wide band lines also can be used for voice band and/or bit rate applications, thus eliminating entirely the requirement for voice band lines. As of this date, however, the cost of doing this seems to be prohibitive, hence a hybrid of voice and wide band lines is recommended. An added consideration here was that 9600 bps rates are presently available over conditioned voice band lines and so it is expected that higher rates will be forthcoming (20,000 bps has been mentioned) by the time the ground station design is implemented.