MANNED SPACE FLIGHT NETWORK UNIFIED S-BAND SYSTEM 1970

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Introduction The Unified S- Band (USB) communication system installed at MSFN tracking stations around the world in 1965 and 1966 was provided to meet the then known and anticipated requirements of an Apollo lunar landing program. Such functions as precision two-way doppler and ranging measurements dictated the need for a highly stable carrier, a narrow deviation, phase modulation transmit/receive system. From the equipments available during the early 1960's, it was decided to use the Jet Propulsion Laboratory (JPL) receiver/exciter/ranging system as it met all the basic requirements for Apollo spacecraft communications and represented a proven hardware concept through its use in the JPL Deep Space Network (DSN).

As initially implemented, the USB system consisted of 30-foot or 85-foot cassegrain antenna systems driven by an X- Y mount, low-noise parametric amplifiers, the JPL receiver/exciter/ranging system, and a data demodulator system. Supporting equipments, including a tracking data processor, an antenna position programmer, and a precision timing system were also installed, but these equipments are not discussed. The basic ground communications system is shown in Fig. 1. The amount of equipment and the size of antennas varied depending on the particular tracking station, but all other significant system characteristics were the same. Table 1 lists the main features of the originally implemented S-Band system.

In the following text, a discussion concerning the evolution of an improved, more versatile S-Band system from the originally conceived system is presented. Emphasis will be placed on the receive portion of the system as little in the way of new requirements or equipment difficulties have been encountered in other areas. Finally, a tabulation of system parameters available to the 1970 user is given.

Early System Operation During the next two years following completion of the MSFN for support of Apollo, only minor changes were made affecting system performance or capabilities. Tracking of the early Apollo earth-orbital launches proved the basic system for mission support. But, continued operation of the S-Band system and continuing test programs dealing with spacecraft/ground station compatibility began to provide information which led to two significant equipment changes; one primarily to improve system reliability and the other to improve signal detection sensitivity.

Failure reports and general feedback from station operating personnel indicated that reliability of the hot parametric amplifiers was quite low. The problem covered the gamut of short life from the reflex klystron pump source, poor gain stability, and alignment difficulties. These shortcomings eventually led to a decision to replace the unit. A market search and review of the state-of-the art in hot paramp development indicated that paramps could be provided with much improved performance. The most noteworthy change in new unit procured for the network was use of a Gunn oscillator pump source operating at 23.6 GHz versus the reflex klystron pump source operating at 15.5 GHz in the original unit. A comparison of paramp characteristics is contained in Table 2. Another feature of the new paramp is the provision of three channels thus allowing an improvement in receiver angle tracking sensitivity.

The second change (to improve signal detection sensitivity) concerned replacement of the 50 MHz modulation tracking demodulator which is part of the Data Demodulator System previously discussed. Both the CSM and LM spacecraft transmit a frequency modulated (FM) carrier as well as a phase modulated (PM) carrier. The FM carrier is used primarily for transmission of television but also serves to transmit voice and telemetry data. Several of the FM transmission modes from the CSM include playback of voice and telemetry information recorded while the spacecraft is behind the moon and out of contact with the earth-based tracking stations. Peak carrier deviation for playback voice was and still is a mere 60 kHz versus 600 KHz for telemetry. Tests simulating lunar distance communication conducted at the Manned Spacecraft Center compatibility facility indicated that the reception of playback voice would be below intelligibility standards with the existing spacecraft-to-ground communications system Since the spacecraft design was frozen attention centered around improving the sensitivity of the ground receiver. The 50 MHz FM demodulator being used at that time was a modulation tracking phase lock loop design. But, the design did not offer sufficient threshold extension to allow for positive signal margin in the case of playback voice. In an effort to resolve the problem two new FM demodulator designs were investigated. One employed an advanced phase lock loop[1] and the other employed frequency feedback for threshold extension. Test results indicated that either design would meet the requirements. Simplicity and lower cost to produce the phase lock demodulator resulted in its adoption for the network. The signal-to-noise curves of Fig. 2 illustrate the superior performance of the new demodulator.

A third significant system change is about to take place within the USB system. This change has resulted primarily from problems encountered in the use of patching to route signals and configure systems for mission support. Appreciation of the problem is easily gained by describing the number of signals involved. An MSFN station equiped with an

85-foot antenna contains four receivers. Each receiver has three outputs-PM video, voice, and 50 MHz IF. A nearby DSN facility is also equipped with four receivers having identical outputs. The signals from these eight receivers are routed to four Data Demodulator Systems.

Receivers and demodulator systems may be configured in various combinations to support the two Apollo spacecraft. Each demodulator system has typically 20 outputs which include voice, PCM telemetry, television, and baseband video. The demodulator serves as distributor for all these signals to various users as depicted in Fig. 2. Patching and verifying all inputs and outputs prior to mission support represents a formidable task. Real-time changes in configuration can be even more formidable. Typical problems that have been encountered include incorrect patches, improper patch seating, open patch cables, and improperly terminated signal paths. All of these problems can result in loss of data.

In order to relieve these cumbersome equipment interfaces matrix switching systems are being procured. Figure 3 depicts the matrix As it applies to the USB equipment. Matrix switching is also being incorporated in other areas of the MSFN tracking station. Its application in these areas is discussed in the paper dealing with MSFN Telemetry Systems. The main features of the USB matrix switching system are contained in Table 3. Obvious advantages of this switching approach include ease of operation, configuration control, and maintenance. Overall signal path reliability is also greatly increased with the need to manually patch and unpatch no longer existent.

Impact of the “J” Mission Advent of the Apollo “J” mission series has introduced many new acronyms such as LCRU, SDS, PFS that represent communication and data systems each with specific communications requirements. The LCRU will transmit and receive S-Band signals directly from the eard; during lunar exploration the SDS contained in the service module will transmit a new group of subcarriers, and the PFS will transmit a third new data link. But, the varied requirements of these new signal sources do not significantly impact the USB system configuration. All three systems time-share existing Apollo frequency assignments. Through the use of the matrix switching system and the existing receiver/demodulator capability all the new spacecraft-to-ground signals can be detected and routed to the desired users. The same statement is not true for the uplink. Addition of the ground-to-LCRU communications link has required implementation of a new subcarrier for voice transmission to the astronauts. Integration of this additional subcarrier equipment into the existing transmission system is not difficult. The result will be a transmit system capable of being modulated by various combinations of ranging data directly on the carrier, a voice modulated 30 KHz; subcarrier, a voice or PSK command modulated 70 KHz subcarrier, and a voice modulated 124 KHz; subcarrier. Modulation of the transmitter by other yet to be defined signals falling within the bandwidth of the modulator is also possible.

Support of Other NASA Programs Possible availability of a world-wide S-Band communications network for support of existing and future space flight programs has resulted in requirements for tracking, receiving, and demodulating signals throughout the 2200 to 2300 MHz band. The present special purpose S- Band receiving system with its limited 2270 to 2300 MHz tuning range, does not have the capability to support an increasing number of these requirements. Formal requirements exist for support of OAO, Mariner, and ERTS missions. Support requirements have been indicated from such programs as IMP, OSO, ATS, Planetary Explorers, Pioneer and Viking. A general increase in requirements is resulting from the gradual withdrawal of users from the VHF telemetry band.

To allow support of all these requirements dictated that modifications be made to the antenna feed system and receiver down conversion circuitry. Addition of equipment to the angle tracking portion of the receiver was also necessary.

It was previously indicated iii Table 1 that the design passbands of the feed were 2090 to 2120 MHz for transmit and 2270 to 2300 MHz for receive. Basically the feed, less its diplexer and receive filters, has a much wider bandwidth. Therefore, all that was required to obtain the 2200 to 2300 MHz receive capability was replacement of the diplexer and receive filter components of the feed with redesigned units covering the desired frequency band. Although simple enough to perform, careful attention had to be given in preparation of specifications. In at least the ERTS support application, extremely wideband signals are received. Such signals are quite easily distorted. Therefore, specifying such parameters as group delay and pa ssband ripple became very important.

This same attention was required in consideration of modifications to the receiver down conversion circuitry. JPL’s design of the receiver system was based partly on its use in narrow band phase lock applications with tuning done by crystal VCO selection. Use of the receiver to receive and track signals throughout a 100 MHz band with bandwidths from tens of kilohertz to tens of megahertz required a significant modification. At the same time it was necessary to preserve the existing equipment capabilities. Figure 5 illustrates the makup of the basic receiver. Only the reference channel is shown for simplification. All shaded-corner blocks of the receiver had to be replaced. With the modification, a general upgrading of receiver specifications was also accomplished. Tuning by selection of the appropriate VCXO was deleted. A synthesizer /VCXO combination is used instead. Carrier frequency selection in 1 KHz increments may now be made directly through front panel mounted thumbwheels. A single VCXO is retained for carrier acquisition and tracking. Table 4 gives a performance comparison of new and old receiver down-convertors. In order to meet the image response specification a double conversion process was employed with an intermediate frequency at 340 MHz for best spurious response. Thus, the overall receiver is now triple conversion.

A final user requirement not met by the S- Band system was the ability to angle track FM carriers. Most FM transmissions do not provide either a sufficiently stable carrier or sufficient carrier power for phase lock tracking. To meet this requirement, a new fixed frequency receiver is being procured. This receiver will connect directly to 50 MHz I.F. reference and angle channel outputs of the new down-convertor. Cross-correlation detection is used to accomodate signals without a recognizable carrier. Carriers with modulation bandwidths from less than 100 KHzto20 MHz can be detected and error voltages derived for angle tracking of the transmitting source.

Summary It can be clearly seen from the foregone discussion that, in the five years since its inception, the role and characteristics of the Unified S-Band system have changed considerably. These changes have followed these basic guidelines for network implementation:

1. Sustaining the networks' capability for reliable mission support.
2. Increasing effectiveness and efficiency in manned space flight support.
3. Incorporation of new equipment to meet new program support requirements.

New S-Band parametric amplifiers and new FM demodulators have replaced the original equipment to sustain the networks' performance in the latter case and to provide more effective, efficient support in the former. The addition of matrix switching undoubtedly will provide for more effective, efficient system support. Redesign of the JPL receiver down-convertor and provision for cross-correlation tracking satisfy new program support requirements. Taken together these changes have transformed an almost single purpose system into a general purpose S-Band communications system capable of supporting a variety of users with widely varying requirements. A tabulation of pertinent characteristics available to these users are resented in Table 5.

Future Improvements Future improvements and modifications under consideration at the present time fall mainly in the area of receive system sensitivity through the use of maser prearnplifiers and demodulators providing additional threshold extension.

References

1. S. C. Gupta, J. W. Bayless, and D. R. Hummels, "Threshold Investigation of Phase- Locked Discriminators", IEEE Transactions on Aerospace and Electronic Systems, November, 1968, pages 855-863.
2. NASA SP-87, Proceedings of the Apollo Unified S-Band Technical Conference., July, 1965.
3. NASA TN D-2208, Unified S-Band Telecommunications Techniques for Apollo, March, 1965.

Table 1.-Early USB System Characteristics

1.	Antenna	-	30 ft. or 85 ft. diameter parabola on X-Y mount.
2.	Feed	-	Cassegrain, RCP or LCP, Monopulse Transmit: 2090 MHz to 2120 MHz Receive: 2270 MHz to 2300 MHz
3.	Paramps	-	Cooled, 35°K, single channel Hot, 170°K, single channel
4.	Receiver	-	Double conversion, phase lock, crystal VCO controlled. Outputs: PM Video (4 MHz) 50 MHz IF (5 MHz) Doppler (1 MHz bias) Range code (PRN)
5.	Transmitter	-	Power output: 20 KW Modulation (PM): PRN range code, Voice, Command
6.	Data Demod	-	Demodulates 1.024 MHz and 1.25 MHz subcarriers, and 50 MHz L F
7.	Ranging Subsystem	-	Max Range: 800,000 km Accuracy: 15 m Resolution: 1 m
8.	Doppler Subsystem	-	Accuracy: 20 mm/sec Resolution: 0.65 mm/sec

Table 2.-Comparison of Hot Paramp Characteristics

Function	Old Unit	New Unit
Frequency Range	2270-2300 MHz	2200-2300 MHz
Noise Temperature	170°K	100°K
Gain	20± 1 db,	20 + 0.5 db
Stability	±1 db/24 hrs?	±0.5 db/24 hrs
Outputs	5	7
Channels	1	3
Weight	63 lbs	41 lbs

Table 3.-USB Matrix Switching System Capabilities

1. Thumbwheel selection-Any RCVR to any DEMOD
2. Dedicated data line sets- Prime and Alternate
3. Thumbwheel selection-Any DEMOD to either data line set
4. Magnetically latched reed crosspoints
5. Display and confirmation of all signal paths selected.
6. Front panel monitoring of all matrix inputs and outputs.
7. Termination of all unswitched signals.

Table 4.- Comparison of Old and New Down-Convertors

Specification	New	Old
Freq. Range	2200-2300 MHz (Synthesizer)	2270-Z300 MHz- (Plug-in crystal)
Noise Figure	8 db, max.	11 db max.
Bandwidth 50 MHz IF	30 MHz min.	8 MHz min.
Spurious	-70, db min.	-40 db min.
Images	-60 db min.	-30 db min.

Table 5.-USB System Characteristics-1970

1.	Antenna	-	30 ft. or 85 ft. diameter parabola on X-Y mount.
2.	Feed	-	Cassegrain, RCP or LCP, Monopulse Transmit: 2090 to 2120 MHz Receive: 2200 to 2300 MHz
3.	Paramps	-	Cooled: Single channel, 35°K Hot: Three channel, 100°K
4.	Receiver	-	Triple conversion, phase lock or cross correlation tracking. Synthesizer tuning in I KHz steps Outputs: PM Video (4 MHz) 50 MHz IF (30 MHz) Doppler (1 MHz bias) Range code (PRN)

Note: All other system charactersitics have not changed significantly.

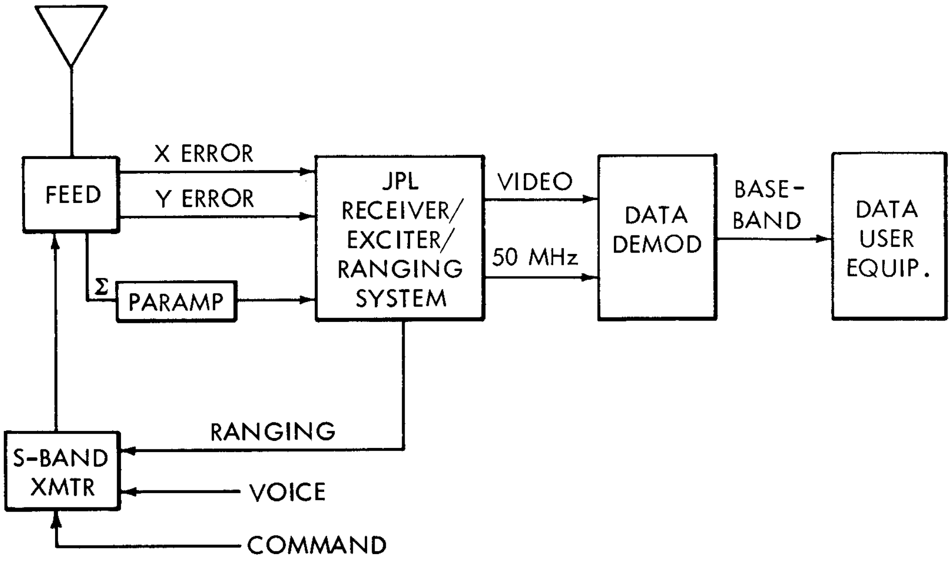

Fig. 1 - Basic USB Communication System

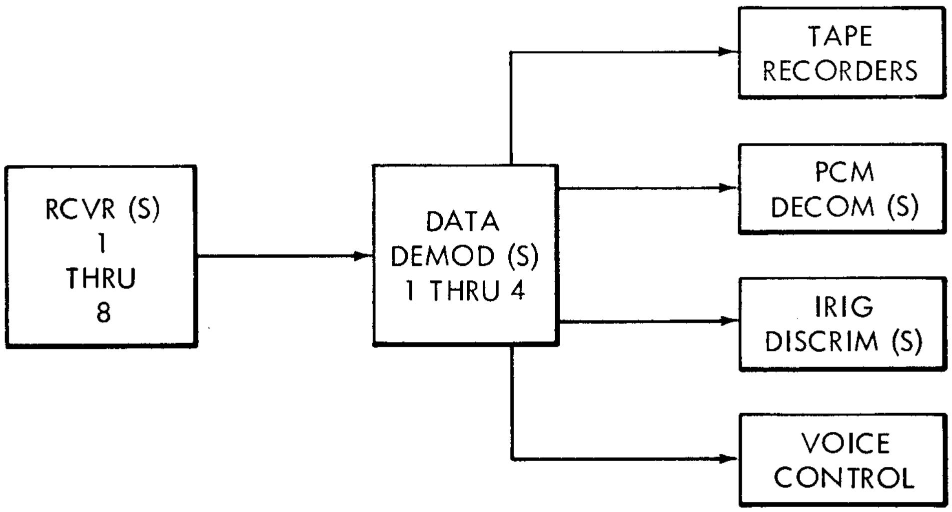

Fig. 2 - USB System Interface with Patching

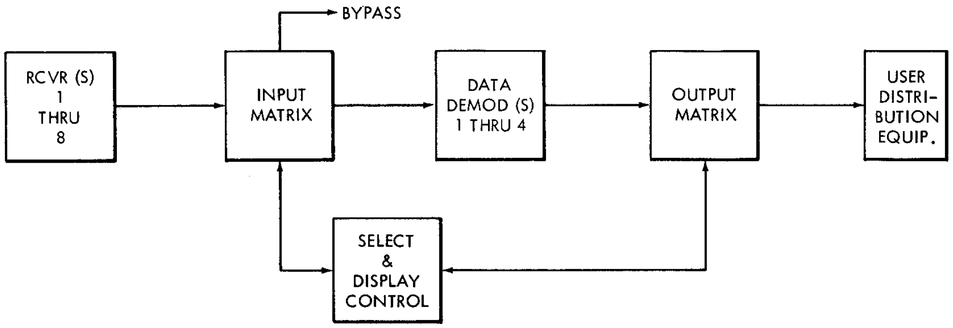

Fig. 3 - USB System Interface with Matrix Switching

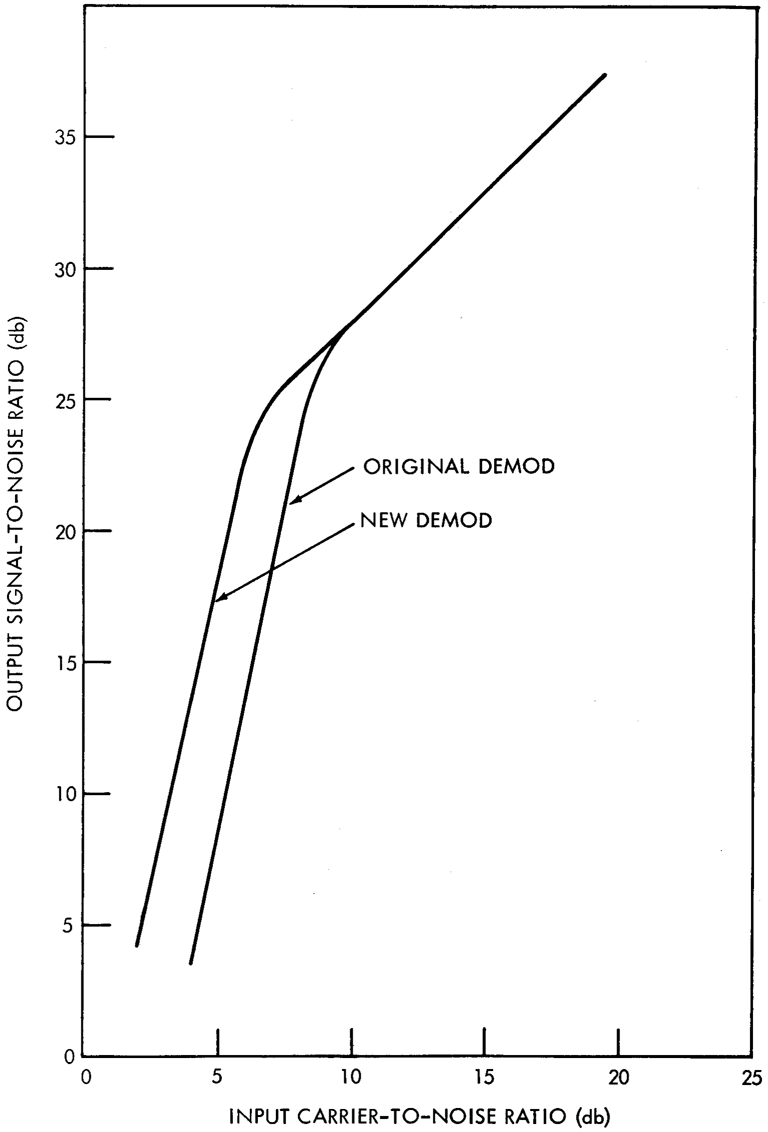

Fig. 4 -

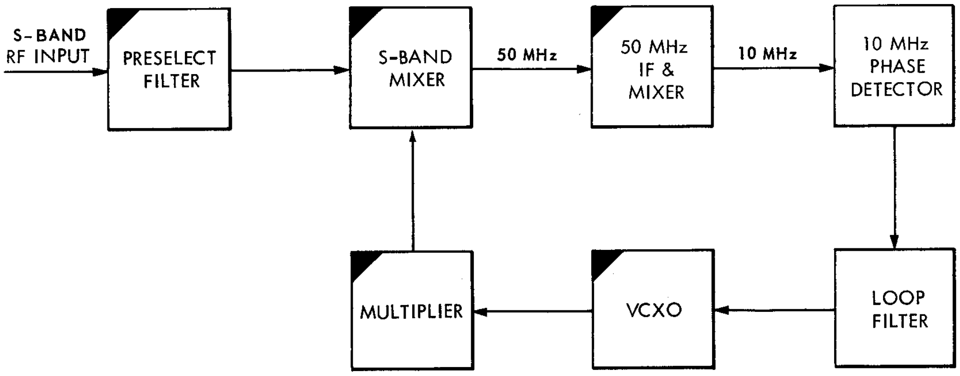

Fig. 5 - Basic JPL Receiver