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MULTI-EVA COMMUNICATIONS
SYSTEM ANALYSIS

FINAL REPORT

JUNE 30, 1972

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ABSTRACT

A NASA Multi-EVA Communications concept is analyzed to establish requirements of a confident candidate system for Space Shuttle. Conceptual baseline configurations, EVA's-to-Spacecraft via PCM/FDM and Spacecraft-to-EVA via PAM/FM, and respective functional performance requirements are discussed. The baseline system is analyzed to determine link characteristics, EMI levels at various frequency bands, and determination of desirable spectrum. Selected L -and S-Band links are analyzed to ascertain signal design parameters. A trade-off is performed, which establishes L-Band frequency as the best compromise from standpoint of applicability to EVA type hardware. Detailed performance requirements are established, and a design approach is identified which employs adaptive RF power technique to accommodate link dynamic range of one foot to 10 nautical miles from EVA to 10-channel spacecraft receiver. The results of the analysis along with the reliability/safety aspects and physical characteristics of the candidate system, indicate that the initial baseline concept meets functional requirements, but is poor from standpoint of overall Space Shuttle program cost. Recommendations are provided which indicate that Time Division Multiple Access (TDMA) employing a single EVA channel, is a more desirable approach from Space Shuttle Programmatic vantage point.

SECTION 1

INTRODUCTION

This Final Report contains the results of the analysis performed by RCA during the study of the Multi-EVA Communications System. This effort was accomplished in accordance with the Statement of Work, Exhibit "A" of Contract No. NAS 9-12092 under cognizance of the NASA Engineering and Development Directorate.

The contents are arranged to present a concise summary of the major efforts accomplished and their conclusions, then procedes to describe the NASA Candidate System as RCA interprets the information provided, and details the functional and performance requirements. The Candidate System is examined and the areas requiring analysis are identified. Analysis and trade-offs are accomplished. The link is optimized and preliminary performance parameters are established. Specific design approaches to meet the performance parameters are discussed, and the study conclusions and recommendations are detailed. This information leads to the definition of areas for future study.

SECTION 2

SUMMARY

2.1 OBJECTIVE

The objective of this study is to perform ana analysis of the Multi-EVA Communications System concept presently being considered by the National Aeronautics and Space Administration. This System is described in Paragraph 3 and Block Diagram 3-2. The Study is to lead to an enhanced definition of, and confidence in the Candidate System, which will allow Prototype Hardware Design and Fabrication to proceed. The Study is to optimize the System Design and recommend changes that will enhance performance, simplicity or reliability. Details of the system concept which are not included in the Baseline Description are to be defined as part of the study.

2.2 TECHNICAL CONSIDERATIONS

The Multi-EVA FDM 10-channel conceptual baseline was analyzed to determine a suitable candidate for fulfillment of the Space Shuttle mission functional requirements. The candidate system to fulfill those requirements must be free of EMI from earth-based emitters, allow operation over omni-directional antenna patterns, and permit development of lightweight hardware to minimize Shuttle overhead weight.

A preliminary analysis considered a system in the VHF band, assumed the Shuttle orbiting 200 NM altitude above the earth, and EVA/SC separation range at 10 NM maximum. These conditions indicated a 26 dB power advantage of an EVA-to-SC link over an earth-to-SC link due to the 200 to 10 mile range differential. Thus, if a 15 dB desired-to-interference ratio in the receiver IF bandwidth is considered, then the integrated interference from terrestrial sources in the receiver bandwidth must be less than 11 dB above the EVA/SC transmitter power. For a representative EVA power of 27 dBm, the RFI level should then be less than 38 dBm. The LES-5 and LES-6 data indicate RFI power levels within 255 to 315 MHz were 6 to 32 dB above the required 38 dBm. The International Frequency List (IFL) indicates that 156 to 214 MHz and 386 to 454 MHz are unuseable because of radars within these bands. The IFL lists disclosed that available bands free of EMI occur within the frequency bands of 1219-1240, 1289-1300 MHz (L-Band) and 2359-2375/2399-2410 MHz (S-Band).

Frequency spectrum alternates evaluated included VHF through Ku-Band; however, emphasis was placed on L and S-Band, since below L-Band EMI sources are high and above S-Band the power requirements become excessive.

To define the system characteristics relative to the various bands to obtain minimum EVA transmitter power (and resultant lower weight) the receiver noise figure and noise bandwidth were identified. The SC receiver configuration required channel separation of 1 MHz and channel filters of 3 dB bandwidth of 100 KHz to provide rejection to the adjacent channels. These filters require low center frequency, which requires down-conversion of the input frequency. The resultant receiver noise figure determines the minimum signal levels and intermodulation products the maximum usable signal levels.

Since mission conditions may place one EVA at a 10-mile distance and nine EVA's close to the SC, a wide dynamic range is required by the spacecraft receiver. An automatic EVA transmitter adapative power level control is recommended to overcome the dynamic range problem. Based on the analysis and tradeoff in the aforementioned areas, L-Band was selected for EVA/SC and SC to EVA links.

Examination of the system basebands indicated that the multiplexing, modulation, and audio handling techniques were basically standard. The pulse amplitude commutation of the ten voice channels has been evaluated in the bast and proven to provide good quality voice using the minimum of spectrum space. Alternate techniques were considered, e.g., digital voice using delta modulation; this, however, required the additional hardware for analog-to-digital and digital-to-analog conversion as well as requiring increased bandwidth to handle the higher bit rates involved.

It was concluded that the candidate system is feasible to accommodate most of the required functions, except that certain baseline criteria exhibit distinct disadvantages to enable the design of a low-cost optimized system. The use of dedicated multiple RF channels wastes spectrum, dictates the need for 10 backpacks of different frequencies (plus spares) which is poor logistics design, increases Shuttle overhead weight by about $10 million, and impacts the growth factor of communication links yet to be determined for the Shuttle systems. The use of microwave frequencies for the baseline concept results in bulky hardware, since directive antennas cannot be employed due to the nature of the EVA missions. Thus, the microwave band results in excess prime power consumption due to propagation loss over omni-directional patterns. To achieve satisfactory link performance for the variations of signal level due to the simultaneous ranges involved, wide dynamic receiver front end design is required as well as a form of adaptive power control. The adaptive power control technique could, however, introduce a potential single point failure at the critical maximum range, depending on design and redundancy considerations. Although the FDMA baseline was analyzed from a standpoint of a single spacecraft antenna, it is recognized that multiple antennas are required to accommodate EVA's in different quadrants around the Shuttle. This, further burdens the propogation problem since power splitting and/or phasing of signals is required.

The overall FDMA system does not lend itself to commonality with other Shuttle systems to enable overall program cost savings. Whereas a common design could allow for a multi-purpose system.

Multiple access communications is best achieved by departure from the classical Frequency Division Multiple Access (FDMA) technique. Time Division Multiple Access (TDMA) techniques, which can employ existing technology, offer a low-cost alternative. TDMA overcomes the RFI from Earth radiations by providing higher S/N at the receiver low average transmission power; adaptive power control is not needed for wide dynamic range, due to the avoidance of inter-channel interferences; the EVA equipment is simple and identical for all EVA's, and ranging can easily be accomplished with the same equipment at little additional cost. All communication channels can be compressed within two narrow VHF bands thus allowing use of omni-antennas at low power consumption.

The TDMA technique can utilize hardware such as a low duty cycle 100 watt VHF transmitter already developed by RCA for the Apollo 17 Lunar Sounder, plus portions of the existing EVCS.

It is recommended that the TDMA approach be considered over the FDMA approach in lieu of severe budget restrictions invoked on the Space Shuttle. A study is required to determine the best TDMA technique to fit the overall Shuttle functional requirements.

SECTION 3

GUIDELINES AND CONSTRAINTS

3.1 GENERAL

The Guidelines and Constraints along with the objectives establish the area of bounds within which the study must be conducted. In the case of the Multi-EVA Communications System Study the area is defined by the Work Statement, a Block Diagram of the Candidate System (Figure 3-2) provided by NASA, and descriptions resulting from NASA Technical Interchange Meetings. The majority of the Analysis Material contained in Sections 4 and 6 are based on the above information. Late in the study additional detail was obtained on the system concept from NASA Multi-EVA Communications System Contractor Report TCSD 2026 dated February 1972. The basic concepts contained in this document are identical to those shown in Figure 3-2, with the exception of the configuration of the audio matrix and the interfaces with the Shuttle Intercommunications and Data Subsystems.

The following paragraphs define the mission objectives, the functional and performance requirements and describe the NASA Candidate System concept provided for analysis and refinement to meet the requirements.

3.2 MISSION OBJECTIVES

The basic purpose of Multi-EVA operations is to support Space Shuttle and/or Space Station Missions requiring the placement of two or more men in the space environment to perform work not ordinarily accomplished automatically or remotely. This effort could consist of:

- The insertion or retreival of complex satellites into or from earth orbit.
- Servicing or fueling satellites in Earth Orbit
- Construction of Space Stations or Large Satellites in Earth Orbit
- Assisting in Earth Orbit Rescue Missions
- Conducting or Supporting Earth Orbit Environmental experiments

3.2 (Continued)

The above missions can only be accomplished by maintaining communications contact with the EVA base spacecraft and other EVA's concerned.

3.3 EVA COMMUNICATIONS LINK REQUIREMENTS

The RF Communications required to support EVA Missions are shown in Figure 3-1. EVA Communicates Voice and Data directly to only the EVA Base Station, this in most instances will be the space shuttle or a sortie module. To accomplish a specifc mission EVA may be required to talk to various mission or technical experts in other space craft or on earth. This must be accomplished by relay through the base space craft in order to minimize the complexity, weight and power required for the EVA backpack communications equipment.

3.4 SYSTEM FUNCTIONAL REQUIREMENTS

3.4.1 GENERAL

The functional requirements of both the EVA personal communications backpack and the EVA base spacecraft equipment are based on the information contained in the NASA Multi-EVA Communications System description and RCA's interpretation of the system concepts.

3.4.2 MULTI-EVA COMMUNICATIONS SYSTEM FUNCTIONS

The Candidate System should satisfy the following functional requirements:

- The system shall be capable of transmitting voice and data simultaneously from each of ten EVA's to the Base Station.
- The Base Station shall be capable of receiving voice and data simultaneously from each of Ten EVA's.
- The Base Station shall be capable of transmitting base station voice and relayed voice to each of the ten EVA's simultaneously.

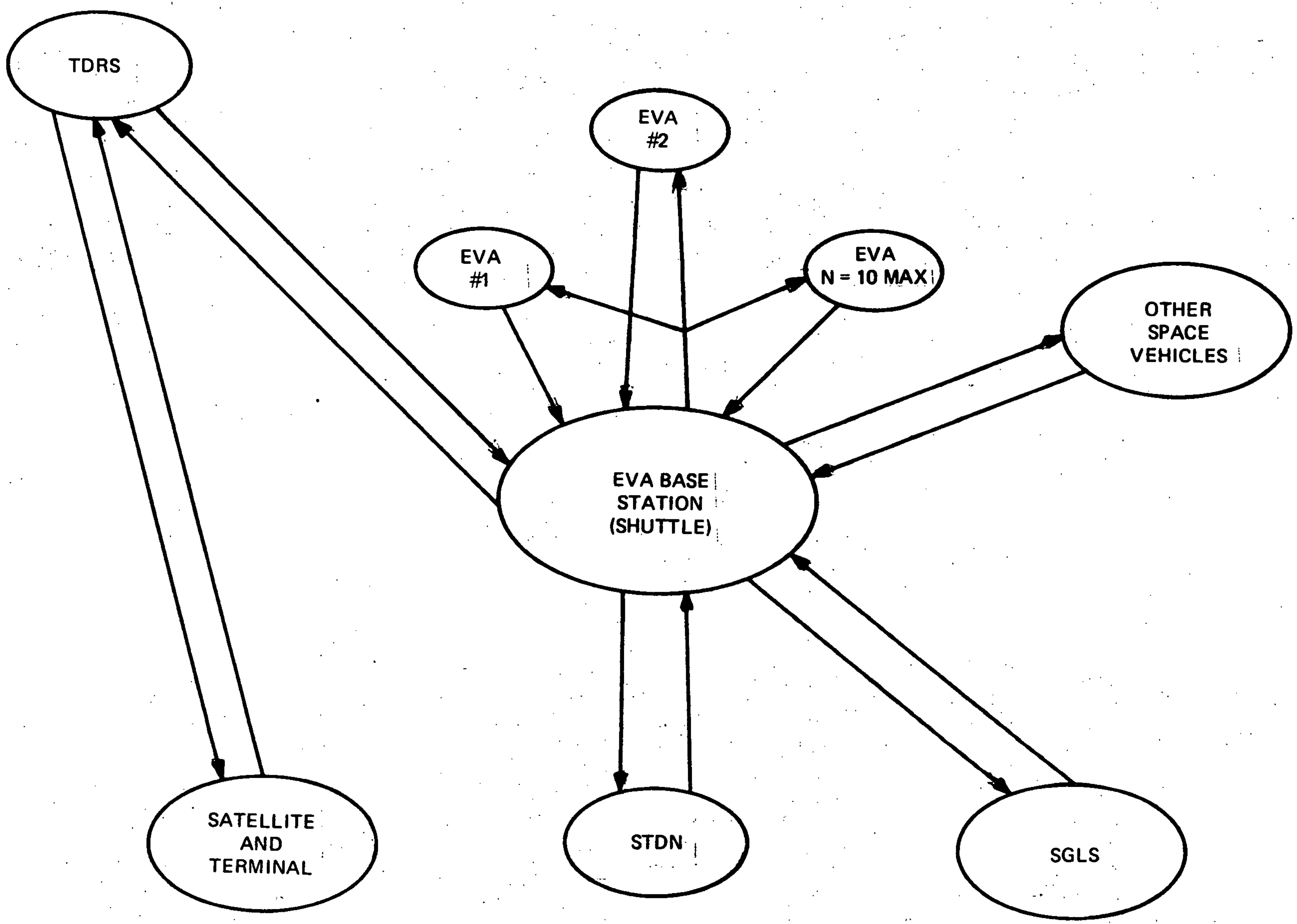


Figure 3-1. EVA Communications and Relay Links

3.4.2 (Continued)

- The system shall be capable of up to ten simultaneous conversations These conversations shall be independent in every respect.
- Each conversation shall be among any number of parties from one (Broadcast) to twenty-five, ten of which are EVA's.
- Participants: Parties involved in the conversations shall include EVA's, Base Station crewman (via ICS), crewman of nearby spacecraft (via Base Station RF Relay), ground controllers (via Base Station RF Relay) and other sources of audio on-board the base station spacecraft.
- Access: An EVA crewman shall have the capability of entering or exiting a conversation at will, solely under his control.
- Paging: The system shall allow announcements which are heard by all EVA crewman regardless of the conversation in which they are participating.
- Telemetry: The system shall provide continuous biomedical and life support system telemetry from all EVA crewman.

3.4.3 MULTI-EVA BACKPACK FUNCTIONS

The following functions are to be performed by the communications equipment carried by the Astronaut during Extra Vehicular Activities.

- Voice Generation and Processing for RF Transmission
- Telemetry data generation consisting of the following items.
    - Astronaut Biomedical Data
    - Space Suit Data
    - Environmental Life Support Data
    - Communications Channel Select Data
    - Equipment Performance Data
    - Self Test or Auto Test Data

3.4.3 (Continued)

- Signal Conditioning for the above data.
- Warning Tone Generation
- PCM Encoding for TLM Data
- Multiplex Function for Voice and PCM Data
- RF Power Generation
- RF Reception and Detection of Base Station Signals
- Demultiplexing of Selected Received Channels
- Self Test or Auto Test Function
- Associated Manual Control

3.4.4 BASE STATION DETAILED FUNCTIONS

In its relation to the Multi-EVA Backpack the base station equipment must perform the following functions.

- Reception and detection of the Voice and Data Signals from as many as 10 EVA's simultaneously
- Separation of Voice and Data
- PCM Data Decoding
- Channel Selection Data Separation and Encoding.
- Audio Channel Recognition and Activation
- Intercommunications access and mixing
- Paging Access and Mixing
- Audio Channel Multiplexing
- RF Generation and Transmission

3.5 SYSTEM PERFORMANCE REQUIREMENTS

The following are the established system performance requirements for the candidate system. These are to be considered design goals. Performance requirements based on system and link analysis are contained in paragraphs 4 and 5.

- Voice Performance: Worse Case Voice to Noise Ratio Shall be 26 db.
- Distortion: Worse Case end to end distortion of Voice Signals shall be 10%
- Frequency response of the end to end system shall be ±4 dB of the 1 KHz response.

3.5 (Continued)

- o Telemetry Bit error rate: Worse case shall be less than 10^{-6}.
- o Range: Maximum of 10 N.M. line of sight.

3.6 MULTI-EVA BASELINE CONCEPT DESCRIPTION

The baseline concept description is based on the NASA Candidate System as defined in Figures 3-2, 3-3 and 3-4, as interpreted by RCA to accomplish the functional and performance requirements of paragraphs 3.4 and 3.5.

3.6.1 EVA to Base Station Communications

When an EVA task is created and the number of crewman determined to accomplished it, each establishes his idenity by choosing the backpack communicator he will use. Idenity is based on the fact that each EVA transmitter operates on a different permanently assigned frequency, and as a result all EVA's can transmit Voice and Data simultaneously.

Each EVA can determine by received channel selection who he wants to listen to, this also automatically selects the same channel in the Spacecraft for him to talk on. This effectively establishes a simplex communications link since both EVA's talk and listen on the same communications channel. The automatic channel selection is accomplished by including the channel select code in the telemetry data and decoding it in the spacecraft for switch activation.

The following signal flow description refers to Block Diagram Figure 3-3. EVA Voice is picked up by the mike amplified to the AGC control level, activating a VOX Switch, is then clipped and filtered above the AGC Control Level. The Voice is then mixed with the PCM Subcarrier Oscillator at a level to deviate the FM transmitter ±12 KHz peak for voice.

Data including Biomed, Life Support, Equipment Performance and Channel Selection information is conditioned to the proper levels and scale factors, converted from analog to Digital form then PCM encoded. The Serial PCM Data Biphase modulates a subcarrier oscillator whose center frequency is 8192 Hz. The PCM SCO is mixed with the Voice Signal and deviates the FM Transmitter ±8 KHz Peak.

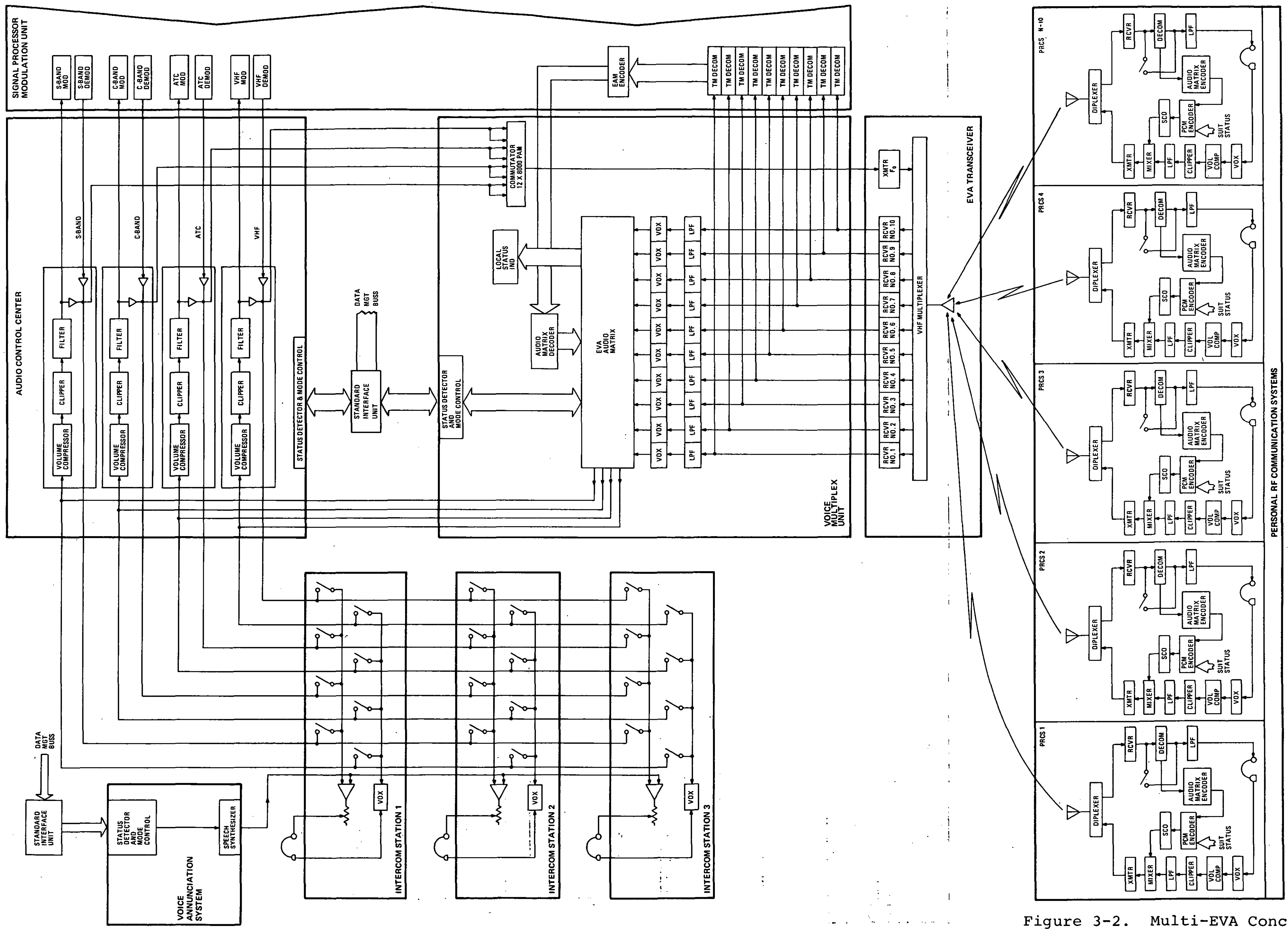


Figure 3-2. Multi-EVA Concept Block Diagram

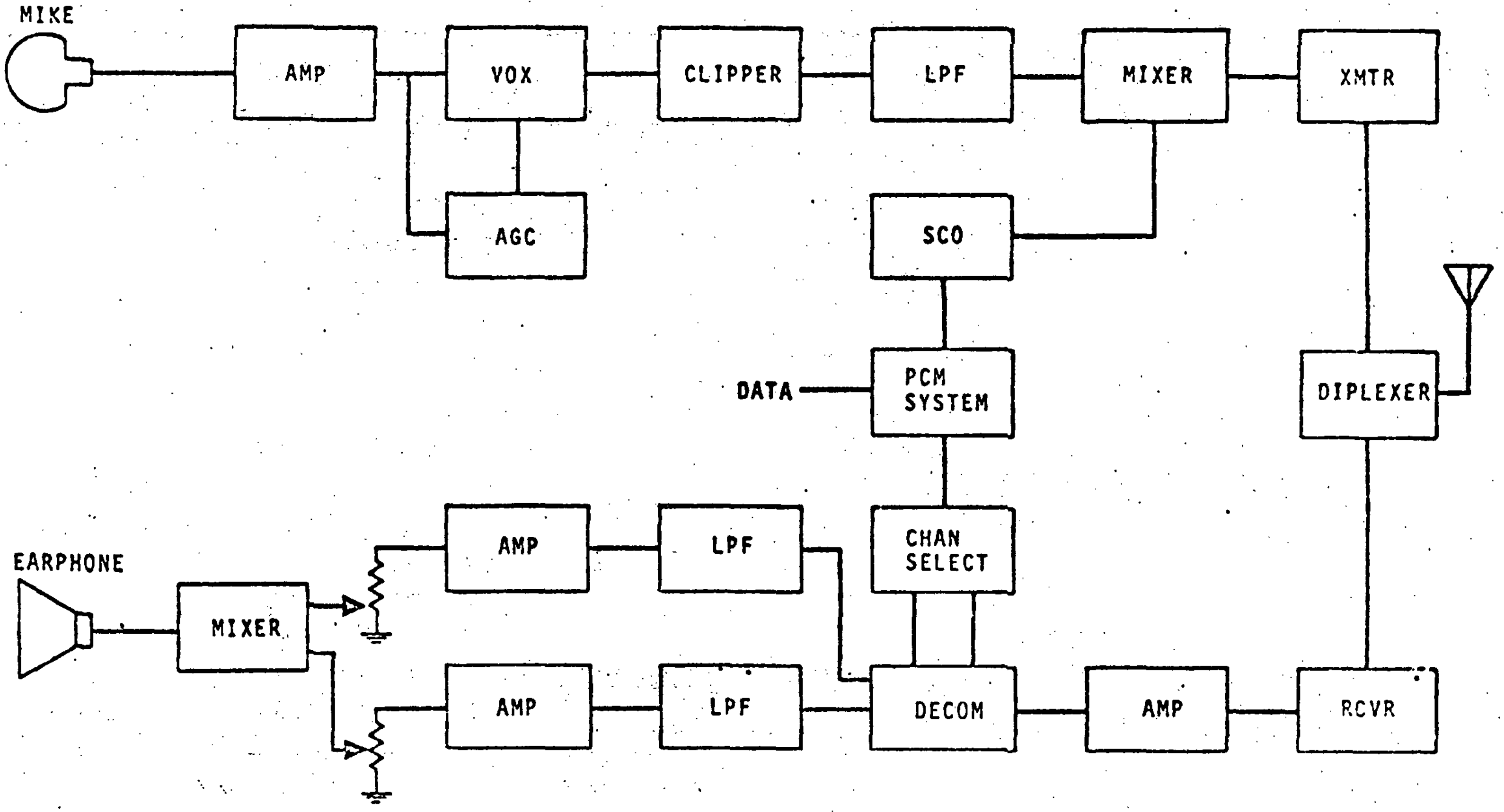


Figure 3-3. Multi-EVA Personal RF Communicator Block Diagram

The PCM Bit Rate is 256 bits per second composed of 32 eight-bit words. Two words are utilized for frame synchronization; the remaining thirty are data words. Each word is sampled once per second establishing the frame rate at one per second.

The bandwidth of the EVA antenna is sufficient to permit common operation of both transmit and receive functions. A diplexer is utilized to permit common operation and to provide the necessary isolation between received and transmit bands. The RF received signal is FM modulated by a pulse amplitude modulated wave train containing time division multiplexed samples of the ten base station EVA Communications channels. This signal is detected by the Receiver, amplified, and routed to the PAM Decommutator. The Decommutator establishes synchronization and gating pulses for control of the communications channels to be selected. Each EVA can select two of the ten communications channels to listen to simultaneously. These channels are gated out of the demux, filtered, amplified and mixed, then routed to the earphone. Each of the two audio channels has its own volume control.

3.6.2 Base Station to EVA Communications

The Multi-EVA Base Station candidate configuration is shown in Figure 3-4. This figure does not show the interfaces to external systems in detail, particularly in the areas of PCM data demodulation and shuttle intercom processing and control. Figure 3-2 does shown the PCM decommutation and an intercom interface that reflects an early configuration of the shuttle avionics. These areas will be discussed in Paragraph 4.1.

The RF signals are received at the base station from each EVA simultaneously and detected by a receiver with pass band frequencies assigned individually to match each EVA transmitter. The outputs of the receiver consist of up to 10 multiplexed signals containing EVA voice and PCM data subcarrier.

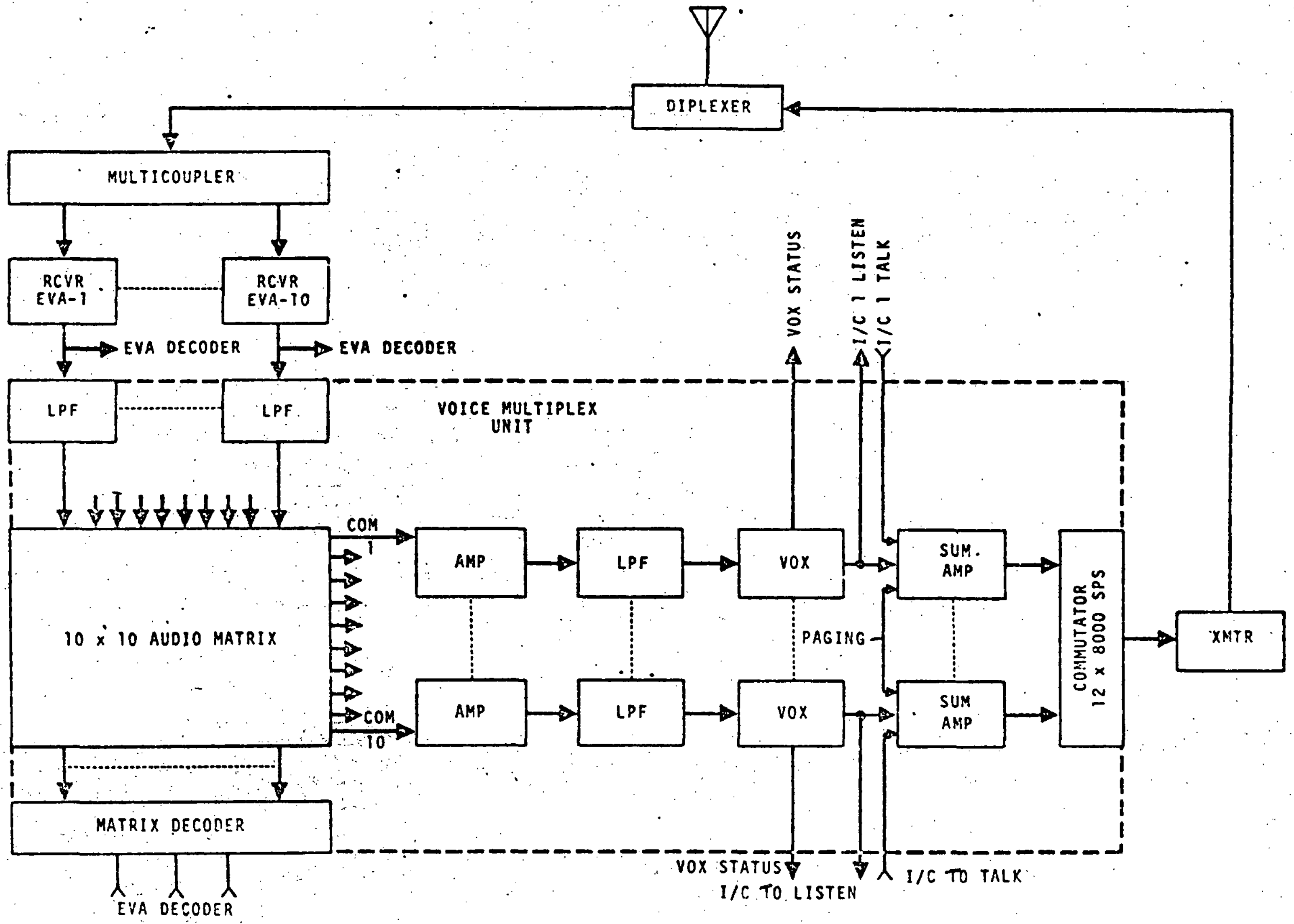


Figure 3-4. Multi-EVA Base Station Block Diagram

The Voice signals are separated from the subcarrier oscillators by a series of low pass filters. The voice signals are fed to individual bus lines of a 10 x 10 audio matrix where remotely controlled switch selection of the transmit communications channel is accomplished. Voice on the selected comm channel is amplified, filtered, and activates a Voice operated switch placing the voice on one point of the 12 x 8000 SPS PAM commutator. This time division multiplexed signal containing up to ten conversations FM modulates the base station transmitter. The frequency assigned to this transmitter is the same as the receivers carried by all EVA's. This completes the talk-listen cycle for conversations between EVA's.

The Base Station receiver outputs are also routed to a bank of 10 subcarrier discriminators where the 8192 Hz subcarrier is band pass filtered from the voice signals and the biphase PCM modulation detected. The output is the PCM data from each EVA which is routed to the decoders which separate the audio channel select word and route the remaining PCM data to the shuttle data handling subsystem. The channel select words are tagged with ID indicating the receiver channel from which they originated. This information is then routed to the matrix decoder which detects the code word and supplies the switch signal to the proper points in the 10 x 10 audio matrix, establishing EVA—to—EVA audio patching, via remote control.

3.6.3 EVA/CREWMAN COMMUNICATIONS

EVA Communications with shuttle crewman is through the shuttle intercommunications system (ICS). The ICS interface with the EVA base station occurs at two points for each EVA comm. channel, one for listening and the other for talk. The ICS listen lines are after each VOX circuit eliminating receiver noise with no signal present. The talk lines are mixed with the conversation taking place on the selected PAM channel. Voice talk and listen paths are not duplex, except for the fact they are handled on separate RF frequencies. Access for ICS is controlled by the Shuttle Crewman assigned to EVA coordination.

3.6.4 EVA RELAY COMMUNICATIONS

Access by EVA's to the shuttle radio equipment for communications with earth sites or other space vehicles must take place through the Intercommunications System under control of shuttle crewman.

3.6.5 SHUTTLE/EVA PAGING

Voice announcements from the shuttle to all EVA's simultaneously is accomplished by mixing the paging output with each EVA comm channel being commutated for transmission to all EVA's. This effectively parallels all EVA's and selected ICS channels placing paging voice on top of existing conversations.

SECTION 4

SYSTEM ANALYSIS

4.1 EXAMINATION OF THE BASELINE SYSTEM

A detailed examination of the NASA Candidate System was made with respect to the concepts and techniques employed to accomplish the mission and functional requirements. This assessment was made considering the details of the Multi-EVA System described in Section 3 of this report.

A preliminary examination indicated that the multiplexing, modulation, and audio handling techniques were basically standard and in most cases directly related to IRIG definition. One exception is the pulse amplitude commutation of the ten voice channels. This, however, has been evaluated in the past and proven to provide good quality voice using the minimum of spectrum space. Alternate techniques were considered involving digital voice using Delta Modulation; this, however, required the additional hardware for analog-to-digital and digital-to-analog conversion as well as requiring increased bandwidth to handle the higher bit rates involved. Before considering these techniques acceptable, a system link and end-to-end analysis had to be accomplished and analized to determine compatibility with modulation and multiplexing techniques. The first items requiring determination to accomplish this analysis were the frequency assignments or at least the associated bands. The indication was that Apollo VHF frequencies may not be available and that lower VHF bands were troubled by severe multi-path and electromagnetic interference problems. Frequency spectrum alternates were evaluated including VHF, UHF, L, S, X and Ku-Bands, with the details and results contained in paragraph 4.2. The frequency analysis indicated L-Band as being satisfactory alternate, and the detailed link evaluation was performed using it as the basis in comparisons with other bands. The detailed analysis is contained in paragraph 4.3.

The unique portions of the Multi-EVA Communications were then determined to be the receivers, transmitters, audio matrix and the data and ICS interface with the Shuttle Subsystems. This selection is based on the link analysis and the requirements for communications with ten EVA's simultaneously, 10 miles range, remote multiple access by all EVA's and the definition of Shuttle interfaces.

The receivers present a design problem with respect to the wide dynamic range necessary to handle EVA signals close in as well as those at 10 miles simultaneously. Frequency allocation, front end design alternates, mixers and filters are discussed in Section 6. A solution at L-Band to dynamic range may require EVA RF transmitter output control based on received signal strength as well as wide range receivers.

One of the major disadvantages of the frequency multiplex of EVA transmissions is the fact that each transmitter operates on a different assigned frequency. This makes each EVA backpack unique, requiring 10 units to provide a backup spare. An alternate would be time division multiplex which has distinct advantages but requires a revised concept for voice and data modulation.

Shuttle Subsystem Interfaces are unique only in the stability of their definition. Design problems are not anticipated unless a voice multiplex bus is used on the shuttle; then it remains one of compatibility.

The candidate system appears capable of meeting all of the basic requirements with one possible exception.

There is one required function that the candidate system as defined does not meet. This states that an EVA crewman shall have the capability to enter or exit a conversation, solely under his control. The EVA has the capability to select any EVA communications channel for talk and listen purposes, which provides control over conversations with any EVA crewman. This, however, does not provide access for conversations involving the Shuttle Intercommunications System. Control of EVA conversations with internal Shuttle Crewman or access to the radio equipment for relay communications must be under the control of the shuttle mission specialist, since the only interface shown for remote EVA control is for channel selection of the audio matrix. Remote control could be provided EVA to accomplish 100% access using any one of several techniques described as follows. One approach is to assign specific channels of EVA communications to the specific intercom buses related to the access desired. For example, EVA wishes to communicate with earth; he selects channel 10 which has been assigned to provide access to the earth transceiver via VOX control. This type of assignment presents two operational problems. The first is that it reduces the number of EVA to EVA channels by three at the very least, since simultaneous usage must be considered. The three simultaneous conversations would be between EVA Group 1 and Earth, EVA Group 2 and "Other Space Vehicle," and EVA Group 3 and internal crewman. This leaves seven channels for EVA to EVA Communications. The second problem is that it now becomes difficult for one EVA to locate the channel of a second he wishes to converse with, since 10 EVA's are listening to only seven channels. The simplest method for location is again to assign a specific channel to each EVA with the ground rule that he always listens to that channel as well as the one he selects to talk on. With only seven channels available a prearranged channel assignment must be made to double up three EVA's when ten are required to be out.

An alternate method of 100% access would be to let a computer recognize the EVA selection code and monitor each comm channels use, store the identity of the users and update based on changes.

audio matrix to select the proper channel called for. The same type of control would be used to activate the shuttle intercomm system as well as the access to radio equipment for relay. This technique is complex and costly unless the Shuttle ICS uses it and EVA just adds a function. If an on-board crewman controls access to the radio equipment, a reverse paging system is desirable or a communication channel assigned specifically for ICS which is continuously monitored by the crewman.

The paging concept as shown in Figure 3-4 places the paging voice simultaneously on each commutated EVA channel over the top of any conversation in progress. An alternate method of paging that provides a backup communications path in the event of an EVA decommutator failure should be considered during the redundancy vs. backup reliability trade-off. This concept would be to remove the commutator wave train as modulation for the base station transmitter and substitute paging voice modulating the carrier directly. The EVA backpack units would recognize the loss of the commutator signal and automatically bypass the decommutator placing audio directly into the EVA headset amplifier.

The EVA operations will include multiple tasks simultaneously, which may place EVA crewman in any quadrant with respect to the shuttle vehicle. This being the case, Figure 3-4 whould be modified to include additional antennas for coverage purposes as well as the incorporation of a coax antenna switch and/or power splitters. If operations can be in any quadrant simultaneouly, the base transmitter power may have to be increased to handle the power split.

4.2 FREQUENCY SPECTRUM ALTERNATIVES

4.2.1 RFI Investigations

Initially the RFI investigations involved discussions with the RCA Frequency Bureau personnel. They indicated that caution must be exercised in selecting any "clear" (use), but assigned frequencies or channels. Such channels will probably be used by those to whom assigned prior to the Multi-EVA operational era and, perhaps, at a high level of interference. It is generally better to select occupied channels where the interference level is acceptable as the user power level(s) probably will not be increased.

A review of the final documents resulting from the World Administrative Radio Conference for Space Telecommunications (WARC-ST) (held in Geneva) yielded the following:

A new regulation of interest which states "308A: The bands 240-328.6 MHz and 335.4-399.9 MHz may also be used for mobile satellite service. The use and development of this service shall be subject to agreement among the administrations concerned and those having services operating in accordance with the tables which may be affected."

The tables referred to show basic allocations in these bands for Fixed Mobile, Space Telemetering, Aeronautical Radionavigation and Radio Astronomy.

Most of these reports also examine the multipath problem which exists for the User/TDRS link, and propose modulation and special processing solutions to combat both the RFI and multipath.

The earth multipath problem does not exist for the Multi-EVA operation, and the use of sophisticated modulation techniques to combat RFI to impact hardware (size, weight, primary power) more or less than that from change to a carrier frequency where the interference levels are tolerable. This matter is examined further later on in this report.

It should be noted that Article 1 of the Radio Regulations defines Mobile Satellite Service as "A radiocommunication service:

- between mobile earth stations and one or more space stations; or between space stations used by this service;
- or between mobile earth stations by means of one or more space stations;
- and if the system so requires, for connection between these space stations and one or more earth stations at specified fixed points."

It was concluded that nothing in these WARC-ST documents precludes our use of VHF.

LES 5 and LES 6 Experiments

RFI measurements were made by these two Lincoln Experiment Satellites (LES), and the resultant data are given in the report listed as Reference 1. This MIT document was reviewed during this reporting period and a summary of the findings is given in the following paragraphs.

LES-5 Description and Results

This satellite was launched July 1, 1967 into a nearly-circular, almost equatorial, quasi-synchronous orbit. In this orbit the satellite "drifts" to provide full earth coverage, exclusive of the polar regions, in about eleven days. The satellite RFI package is designed to monitor the frequency band of 255 to 280 MHZ by stepping from 283 down to 253 MHZ in 256 steps of 120 KHZ bandwidth, dwelling 2.56 sec at each step. Thus, a complete frequency scan is completed in approximately 11 minutes. LES-5 will be turned off automatically by a timer in April 1972.

The nominal receiving system sensitivity is about -120 dBm at 255 MHz and 20 dB poorer at 280 MHz due to the antenna design. This receiver measures average RF power in each 120 KHz bandwidth step, and can accommodate a dynamic range of 60 dB, but not exceeding 0 dBm at the receiver input. Capability is also included in the experiment for measuring a Peak/Average ratio wherein: (a) the Peak is the highest short term average power in a 600 KHz bandwidth centered on each frequency step, and (b) the Average is the average power measured in the corresponding 120 KHz band. A low P/A value implies a strong CW signal, an intermediate value (about 15 dB) implies noise in both bandwidth "windows", and a high value (40 dB or greater) implies a pulsed signal or strong CW lying in the wide (600KHZ) bandwidth, but outside the narrow (120 KHZ) bandwidth. However, Reference 1 states that little effort was devoted to reduction of this Peak/Average data.

Measurements at six selected frequencies in the band of interest for twelve different scans over the period from July 4, 1967 to February 12, 1968 are summarized in Table 4-1. Average or mean values and standard deviations (sigma) were calculated and are also given in the table. These values were used to plot Figure 4-1, which provides a reasonably accurate representation of the mean and ± 1 σ boundaries of power levels measured across the entire LES-5 band. Graphs of Reference 1 show the power measurements to be a continuous

TABLE 4-1

MEASURED DATA FROM LES-5

DATE OF SCAN	SCAN #	AVERAGE POWER (-dBm) MEASURED AT FREQ. (MHZ) SHOWN					
		255	260	265	270	275	280
7-4-67	1	120	115	112	110	103	98
8-1-67	2	115	117	112	108	105	100
9-25-67	3	117	117	110	107	102	100
10-17-67	4	120	118	111	108	102	98
10-31-67	5	120	118	112	108	105	100
11- 1-67	6	120	118	112	110	105	100
11- 6-67	7	120	120	112	108	105	100
11-22-67	8	122	120	115	112	108	105
1-24-68	9	120	125	116	112	105	105
2- 6-68	10	122	123	115	112	105	105
2-12-68	11	125	125	115	115	107	105
3-18-68	12	122	120	116	110	110	102
⊙MEAN VALUES TO NEAREST dBm		120	120	113	110	105	102
⊙STD. DEV. (σ)		2.5	3.2	2.1	2.4	2.3	2.8

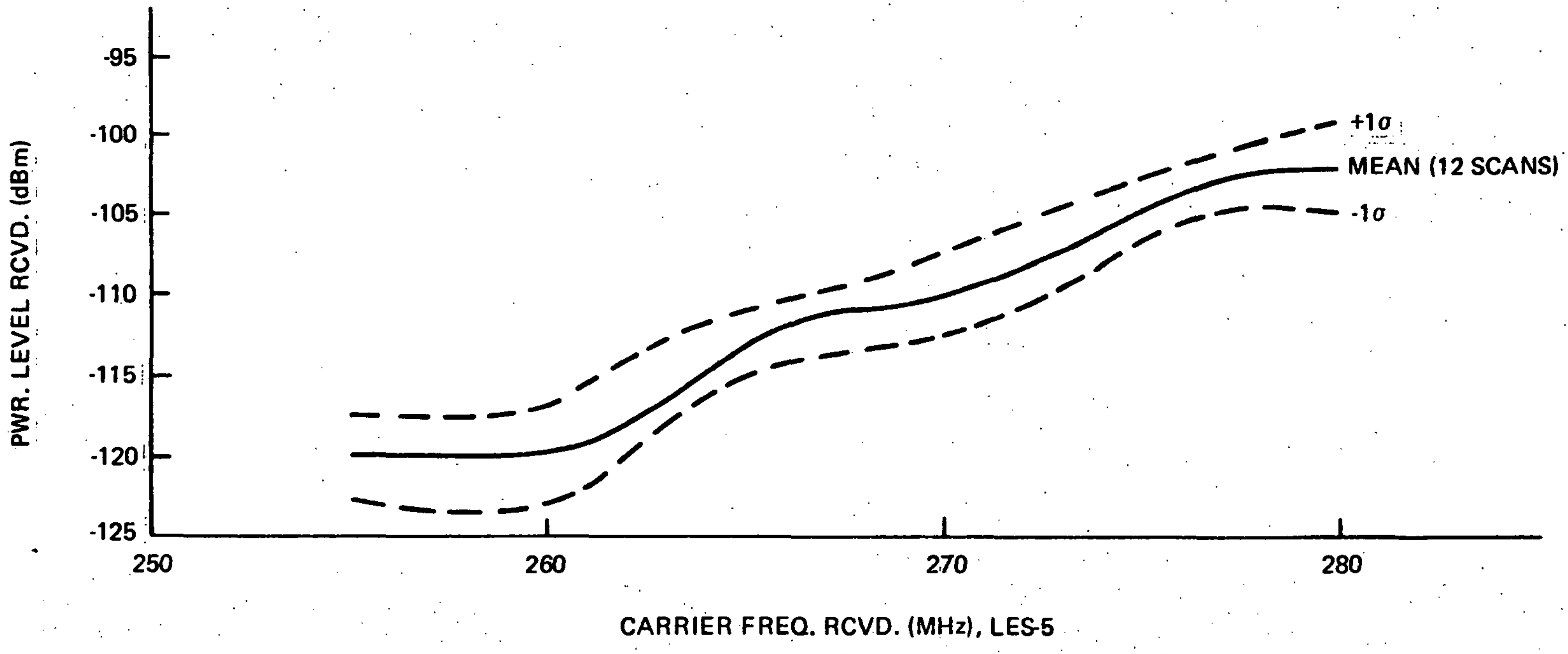


Figure 4-1. LES-5 Composite Measurements

LES-5 Description and Results: (continued)

function in this band from 255 to 280 MHz such that the bandwidth of any one earth RF source does not have to be determined for comparison with the expected spacecraft receiver bandwidth for Multi-EVA operation.

Conclusions regarding the significance of these data are combined with conclusions relating to LES-6 data a subsequent paragraph.

LES-6 Description and Results

This satellite was launched September 26, 1968 into a nearly circular almost equatorial, synchronous orbit where it was "anchored" at 90°W longitude for all measurements given in the MIT report, Reference 11. (It was moved later to 38°W longitude). Using a design similar to that of the LES-5, LES-6 monitors the band 290 to 315 MHz with a receiver sensitivity about 6 dB improved over that of the LES-5. No "turn-off" timer is provided on this satellite, so the terminal date for data availability will be that of an LES-6 failure, or decision to halt ground reception of the transmissions.

This satellite has provided more total data than the LES-5, but it is limited in geographical coverage due to the fixed

2. LES-6 Description and Results: (continued)

position relative to the earth. Average measurements determined from ten different scans are given in Table 4-2 and a plot of the data, prepared as described above for LES-5, is given in Figure 4-2.

3. Conclusions

Table 4-3 lists the average or mean values determined in 1 and 2 above, and translates these to Effective Earth EIRP levels by adding path loss values for the frequencies shown. These levels are then compared with the +38 dBm earth source EIRP maximum derived in Reference 2. This is the maximum value permitted if a Desired/Interference signal power ratio of 15 dB minimum is to be maintained at the spacecraft receiver under other conditions described in Reference 2.

As shown in Table 4-3, all average values for the full frequency range covered by LES-5 plus LES-6 exceed the +38 dBm reference level. The excess ranges from 13 to 32 dB and 5 to 11 dB for the LES-5 and -6 frequency spans respectively.

Table 4-3 shows Effective Earth EIRP values range from 20 watts to 10 KW. As stated in Reference II, the carrier frequencies associated with a number of the higher power cases indicated

TABLE 4-2

MEASURED DATA FROM LES-6

DATE OF SCAN	SCAN #	AVERAGE POWER (-dBm) MEASURED AT FREQ. (MHZ) SHOWN					
		290	295	300	305	310	315
11-4-68	1	130	130	131	130	129	126
11-5-68	2	130	130	132	131	132	127
12-9-68	3	130	130	132	130	132	128
12-10-68	4	131	130	132	127	132	122
4-10-69	5	130	126	125	125	128	125
4-11-69	6	127	128	130	125	128	127
6- 2-69	7	125	125	120	130	127	120
6- 3-69	8	125	128	130	129	128	125
9-30-69	9	128	127	130	130	128	120
10- 1-69	10	125	127	128	128	128	125
⊙MEAN VALUES TO NEAREST dBm		128	128	129	129	129	124
⊙STD. DEV. (σ)		2.4	1.9	2.8	2.2	2.0	2.9

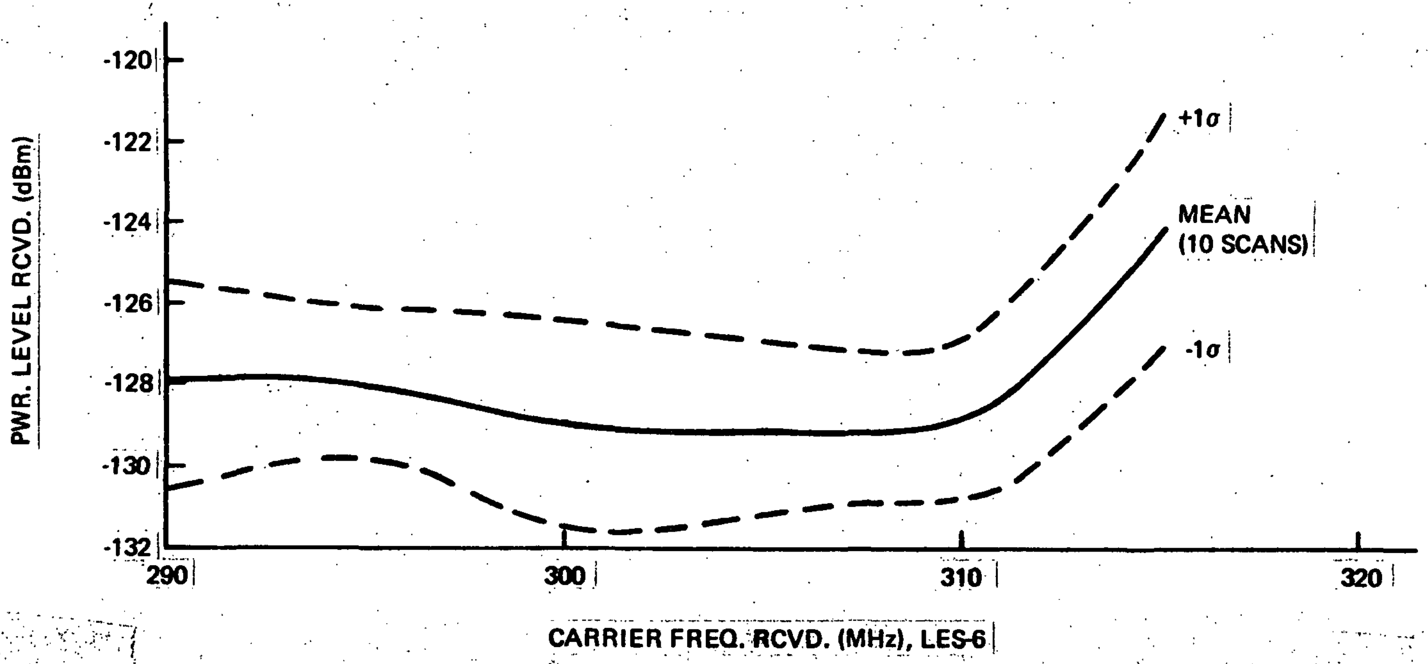


Figure 4-2. LES-6 Composite Measurements

LES-5, -6/MULTI-EVA INTERFERENCE EVALUATION

FREQUENCY (MHZ)		AVERAGE PWR. LEVEL REC. (dBm)	PATH LOSS CORRECTION (dB)	EFFECTIVE EARTH EIRP (dBm)	EFFECTIVE EARTH EIRP (Watts)	EXCESS OVER +38dBm (dB)
255	LES-5	-120	171	+51	126	+13
260		-120	171	+51	126	+13
265		-113	171	+58	630	+20
270		-110	171	+61	1260	+23
275		-105	172	+67	5000	+29
280		-102	172	+70	10,000	+32
290	LES-6	-128	172	+44	25	+ 6
295		-128	172	+44	25	+ 6
300		-129	172	+43	20	+ 5
305		-129	173	+44	25	+ 6
310		-129	173	+44	25	+ 6
315		-124	173	+49	80	+11

Conclusions: (continued)

the likelihood that LES-5 was receiving transmissions from AN/FRT-49 TDDL transmitters. The EIRP from such sites, corrected with reference to RHC polarization corresponding to the LES-5 antenna design, is 40 KW. (20 KW transmitter output and 3 dB effective antenna gain). The 10 KW value shown at 280 MHz in Table 4-3 corresponds best with this TDDL EIRP level.

A brief re-examination of the IFL-International Frequency List - (see Monthly Progress Report #3) was made for comparison of EIRP values with those measured by LES-5 and 6. No EIRP values corresponding to TDDL site power output levels were observed in the list, which indicates how one could be misled using this limited IFL reference as a single data source for this study. The highest EIRP observed in this IFL for the frequency range corresponding to LES-5 and 6 measurements was 1.25 KW. Most of the sites listed showed EIRP levels only 50, 100 or 200 watts.

The high power levels measured by LES-5 and -6 suggested examination of alternate carrier frequencies for Multi-EVA.

Review of Additional Documents

The reports listed as Reference 2 through 10 were reviewed as additional sources of data and analysis pertinent to this RFI problem. Brief summaries of each reference and comments on their applicability to the Multi-EVA Study are as follows:

Reference 2: This report relates primarily to the use of satellites for Ground/Satellite/Ground relay communications and frequency allocations for same. Little RFI information is contained in the report.

Reference 3: This article contains an overall view of the RFI problem and a plot of approximate power spectral densities acorss the range from 10 MHz to 10 GHz. An appreciation of the basic severity of the RFI problem in the VHF band can be gained from calculations based on the information provided. However, the scales used for plotting the data are too coarse to permit examination of individual carrier channels or a band of channels of interest. (For example, 270 to 280 MHz or any similar spread of 10 MHz.)

References 4 through 10: These reports all examine RFI difficulties for the case of low earth orbit "user" satellites communicating with ground sites via a geostationary satellite such as the TDRS planned by NASA. Values for interference levels are given for selected ranges within the VHF band planned for telemetering from the users or for commands to the users. Most of the data were derived from the ECAC data bank, and are applicable for our study. However, the entire range from 200 MHz to 399 MHz is not evaluated and most of the data pertain to the bands 136-138 MHz and 148-150 MHz.

REFERENCES

1. "The Results of the LES-5 and LES-6 RFI Experiment" - W.W. Ward et al.
   Lincoln Laboratories, MIT, 6 February 1970.

2. "Radio Spectrum Utilization in Space," A Report of the Joint Technical Advisory Council of the IEEE and the EIA, September, 1970; Volume XXXIII.

3. "How to Deal with RFI in Space", E. Dusina, EDM Magazine, July 1, 1969.

4. "RFI Characteristics of a Data Relay Satellite System," John W. Bryan, GSFC, International Telemetering Conference of 1969 Proceedings, Volume V.

5. "The Effects of Multipath and RFI on the Tracking and Data Relay Satellite System", ESL TM-215 of 18 March 1971.

6. "A VHF Communication System for a Low Altitude Satellite Utilizing a Data Relay Satellite System", Hughes Aircraft Company, November 1970.

7. "A Space Shuttle Communications System Signal Design Study (VHF Relay through TDRS)", NASA, MSC, May 26, 1971.

8. "A Multiple-Access Satellite Relay System for Low Data Rate Users", Hefferman and Gilchriest of NASA, GSFC.

REFERENCES: continued

9. "Final Report for Multipath (Modulation Study - Adaptive Techniques)", Hekimian Laboratories, Inc., (Study done for NASA, GSFC).

10. "Final Report for Multipath/Modulation Study for the TDRS", Magnavox Company, (Study done for NASA, GSFC).

4.2.2 Carrier Frequency Recommendations

All three regions of the International Frequency List (Figure 4-3) were reviewed covering the frequency span from 450 MHz to 2500 MHz. The review included the regular IFL and the recapulative supplements which provided additional listings through August 1971.

Important factors in the search for suitable carrier frequencies included: (a) effective radiated power spectral densities of interferring sources as low as +16 dBm/KHz, and (b) one band at least 10 MHz wide to accommodate 10 separate Multi-EVA carriers for transmission EVA/Spacecraft.

The IFL study disclosed no 10 MHz bandwidth (continuous or in reasonably separated portions) which met the maximum interference level requirement where listings of emitters existed. Therefore, attention was directed at "holes" or empty portions of the 450-2500 MHz spread of interest.

Following are the lists of such empty spots (at least approximately 10 MHz wide). The second columns of these lists present the classes and bandwidths of emissions operating at the lower limit of the empty spot. The bandwidths are given in kHz. For example, a listing of 1020-1030 in the first column indicates that no other emissions are present (according to the IFL) in the 1020-1030 MHz band, except those at 1020 MHz and 1030 MHz frequencies. The listing in the second column of 1000 P9 indicates that the widest bandwidth of all transmissions at 1020 MHz is 1000 kHz, and it extends from 1020 MHz to 1021 MHz. Hence, the actual unoccupied band is 1021-1030 MHz. Symbol P9 is the internationally agreed designation of the class of emission. (For these symbols, see Reference Data for Radio Engineers; Fifth Edition, March 1969; pages 1-16 and 1-17.)

Region 1

Empty Frequency Bands	Bandwidth, Class of Emission
1020-1030	1000 P9
1215-1240	650 P9
1287-1300	2000 P9
2304-2312.5	3000 F9
2330-2355	3000 F9
2355-2375	4000 F9
2376-2395	6000 F9
2395-2410	4000 F9
2410-2424	3000 F9
2424-2438	3000 F9
2438-2450	3000 F9

Region 2

Empty Frequency Bands	Bandwidth, Class of Emission
713- 725	6000 A5
1106-1114	650 P9
1130-1146	650 P9
1218-1247.5	1000 F9
1247.5-1330	1000 F9
1300-1362	1000 F9
1362-1395	1000 F9
2295-2375	1000 F3
2375-2398	?
2398-2450	8 A3
2455-2468	1 AD1

Region 3

Empty Frequency Bands	Bandwidth, Class of Emission
498.98-530.1	36 F3
539-551	200 F3
551-588	200 F3
635-650	6000 A5C
695-710	40 F3
710-722.5	40 F3
725-740	40 F3
755-770	40 F3
770-785	40 F3
785-800	40 F3
815-866	650 F3
1209-1315	500 PO
1317-1400	3000 PO
1420-1665	2000 ?
1700-1720	5600 PO
1751-1767.5	2000 F9
1855-1867.25	1920 F3
1895-1912.5	1920 F3
2009.5-2024	5000 P3F
2053-2067	36 F3
2193-2222	5860 F3
2285-2375	25,000 F3
2375-2450	?
2450-2650	?

Examination of all three regions of the world permits one to derive the following residual bands as most suitable for Multi-EVA based on this RFI consideration:

1219 MHz (bounded by Region 2) - 1240 MHz (bounded by Region 1)
1289 MHz (bounded by Region 1) - 1300 MHz (bounded by Region 1)
2359 MHz (bounded by Region 1) - 2375 MHz (bounded by Region 1)
2399 MHz (bounded by Region 1) - 2410 MHz (bounded by Region 1)

Link analyses contained in Monthly Report #1 show the following EVA transmitter power output requirements based on use of low gain (omni type) antennas on both the EVAs and the spacecraft.

Carrier Frequency	EVA Transmitter Power Required Without AFC*	With AFC*
VHF (280 MHz)	.02 Watts	.02 Watts
S (2000 MHz)	5 Watts	1.5 Watts
X (8000 MHz)	314 Watts	27 Watts
K (13000 MHz)	2000 Watts	110 Watts

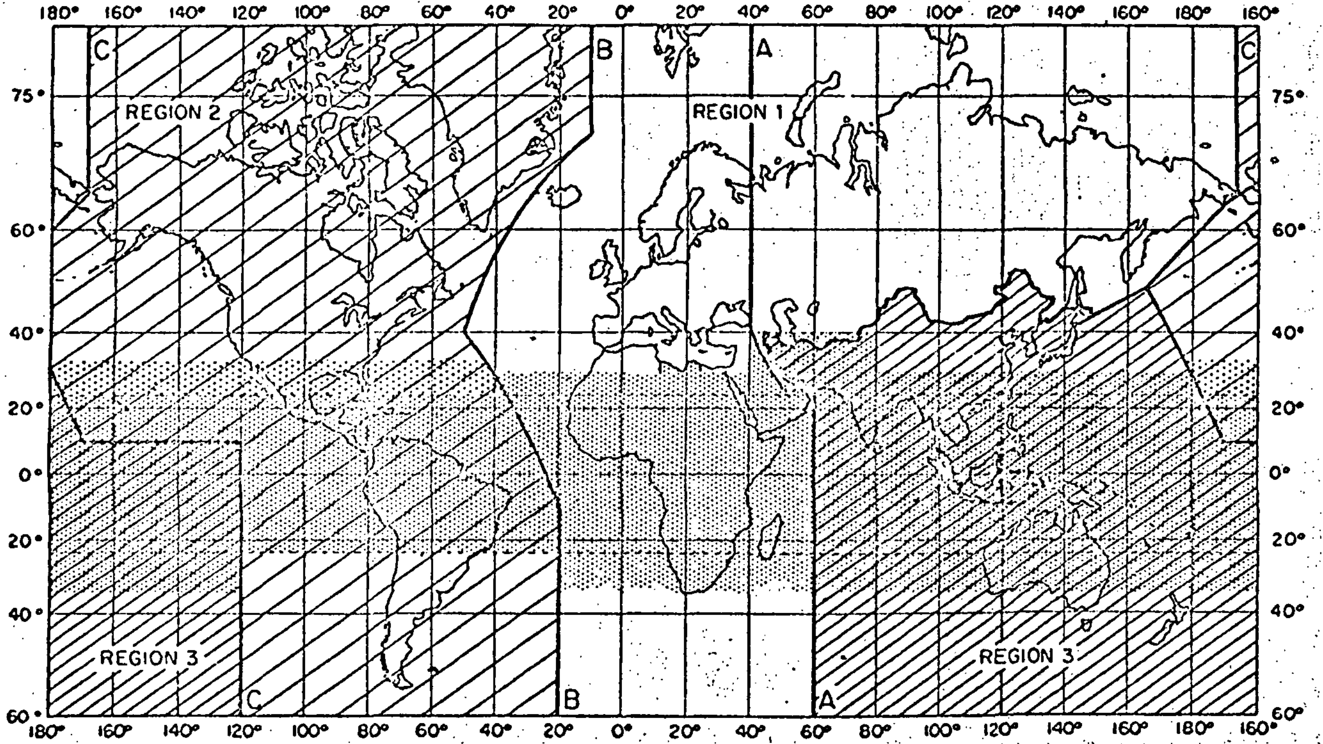
*Automatic Frequency Control in Spacecraft receivers.

Since all electrical power requirements associated with the astronauts' extra-vehicular activities would be supported by batteries, it is highly desirable that the transmitter power requirements be minimized.

Assuming the same link parameters used for the S-Band (2000 MHz) analysis prevail for the 1219 to 2410 MHz range tabulated above, theoretical EVA transmitter power requirements would be as follows:

	Without AFC	With AFC
1219-1240 MHz	1.9 Watts	0.6 Watts
1289-1300 MHz	2.1 Watts	0.6 Watts
2359-2375 MHz	7.0 Watts	2.1 Watts
2399-2410 MHz	7.3 Watts	2.2 Watts

From the standpoint of minimizing primary power requirements, the obvious preferred bands are 1219-1240 and 1289-1300 MHz. One example configuration would place the 10 EVA transmitter carriers in the 1219-1240 band and the Spacecraft transmitter carrier in the 1289-1300 MHz region. It is recognized, however, that other considerations should be included such as equipment availability, commonality and cost.



The shaded part represents the Tropical Zone as defined in Nos. 135 and 136

Figure 4. 3. Mercator Chart of Regions Pertaining to Frequency Allocations

4.3 PRELIMINARY LINK PERFORMANCE EVALUATIONS

Link performance analyses were completed to determine the required EVA transmitter power for satisfactory communications of voice and the data subcarrier from an EVA to the spacecraft. The analysis compared use of VHF, S, X and K-band carriers, but excluded consideration of interference from terrestrial sources. This can be a major problem and warrants detailed evaluation. This is planned for the next reporting period.

Most of the parameters used in the analysis were those characteristics of the "baseline" Multi-EVA Communications System, and other values were selected as typical for the equipments involved.

A. Assumed Values

The specific numerics used in the link evaluations were as follows:

1. Nominal Carrier Frequencies

VHF	280 MHz
L-Band	1250 MHz
S-Band	2000 MHz
X-Band	8000 MHz
K-Band	13,000 MHz

	VHF	L	S	X	K
2. EVA Line Losses	2db	2db	2db	2db	2db
3. Receiver Noise Figure	5db	7db	7db	8db	10db

	VHF	L	S	X	K
4. Spacecraft Multicoupler Loss	3db	3db	3db	3db	3db
5. Spacecraft Line Loss	2db	2db	2db	2db	2db

Receiver noise figures can be reduced by using parametric amplifiers, but such designs were not assumed for this initial analysis since interference considerations can obviate the advantages resulting from lower noise figure. This will be taken into account after consideration of the interference problem.

The multicoupler loss value estimated assumes separation of the 10 EVA channels is done at the IF, rather than RF frequency.

6. Modulation Levels (FM) of Carrier

Voice: 12 KHz peak deviation

Data Subcarrier: 8 KHz peak deviation

7. Frequency Instabilities	VHF	S, X, & K Bands
EVA Transmitter	±.005% max.	±.0025%
Spacecraft Receiver	±.005% max.	±.0025%

8. Spacecraft receiver IF bandwidth to accommodate baseband, modulation and R/T instabilities: 75 KHz.

9. CNR required in IF bandwidth: 10 db

10. Voice SNR required in post detection bandwidth of 3 KHz: 28db p-p/rms for speech clipped 12db below peak.

11. Data subcarrier SNR required in assumed 2 KHz pre-detection bandwidth: 16db. (This high level chosen to accommodate SNR degradation due to relay over an SC/MSFN link, for example, and still provide an E/No adequate for a BER no less than 10^{-6} at the earth demodulator.)

12. Imposed Margin: 9db. This value includes 3db polarization loss assuming linearly polarized antenna on the astronaut or experiment module and a circularly polarized antenna on the spacecraft, 3db for unfavorable antenna orientations, and 3db for worst case tolerance accumulation for other equipment characteristics.

B. Results

Link calculations were based on the CNR requirement of 10db in the IF bandwidth, as this is more demanding than either the voice or subcarrier SNR values. (These SNR requirements are exceeded when the 10db CNR is achieved due to the FM indices used and the large IF/post-detection bandwidth ratios.)

Key results are as follows:

	EVA Transmitter Power Required	
	Without AFC	With AFC
VLF	.02 watt	.02 watt
L	1 watt	0.4 watt
S	5 watts	1.5 watts
X	314 watts	27 watts
Ku	2000 watts	110 watts

Note that with AFC, VHF provides at least 19db advantage over S-band and the other frequencies. Without AFC, this advantage is increased to 24db. It is impractical to provide the power outputs indicated at X - and K-bands by solid-state means in either case. Five watts of power at S-band can be realized by solid-state means at the present time. However, the size, weight and input power of a 5-watt transmitter at S-band is considerably greater than that required at VHF for a comparable power level. A 5db reduction in power at S-band can be achieved by using AFC. However, the AFC receiver is considerably more complex and will result in increased size, weight and input power.

X-and K-bands were considered because of the smaller physical size antennas which could be flush-mounted on the spacecraft, and they offer a somewhat lower interference problem probability. However, these considerations are more than offset by the higher transmitter power levels required as shown above. These could be reduced by using parametric amplifier receivers and antennas on the spacecraft with small gain (such as 3 to 6db), which would not reduce coverage seriously.

4.3 continued

Carrier Frequency Selection

The RFI investigation describes two 10 MHZ windows at "L" Band and "S" Band which were approved by the MSC Technical Monitor. An analysis of these two frequency bands follows.

For omni-directional antennas at EVA and SC antenna gain is assumed to be 0db.

$$P_T = L_1 + L_2 + L_3 + F + P_N + N_{BW} + CNR + M$$

P_T = Required transmitter power (dBm)

L_1 = Combined EVA/SC line loss (dB)

L_2 = Combined EVA/SC Duplexer loss (dB)

L_3 = Propagation Loss (dB)

F = Receiver noise figure (dB)

P_N = Thermal Noise ($F = 0$ dB) (dBm/KHz)

N_{BW} = Noise Bandwidth (kHz)

CNR = Carrier-to-noise ratio (dB)

M = Margin (dB)

Representative values are as follows:

$L_1 = 4$ dB

$L_2 = 3$ dB

$P_N = 144$ dBm/KHz

$CNR = 10$ dB

$M = 9$ dB

$$P_T = 4 + 3 + L_3 + F + (-144) + N_{BW} + 10 + 9$$

$$= L_3 + F + N_{BW} - 118$$

The noise bandwidth (N_{BW}) is determined by the required information bandwidth plus additional bandwidth for frequency instability due to tolerances on transmitter and local oscillator frequency as well as tolerance on center frequency and bandwidth of the channel selection filters. If major instability is due to EVA frequency tolerance, then for a tolerance of ± 0.003% (± 30 KHz/GC) the added bandwidth will be as follows:

BAND	"L"	"S"
Freq. (GC)	1.25	2.35
F (KHz)	37.5	70.5
F (KHz)	75	141

Thus, if information bandwidth is 75 KHz for EVA to SC link and 750 KHz for SC to EVA link, the noise bandwidth becomes:

BAND	"L"		"S"	
Link	EVA/SC	SC/EVA	EVA/SC	SC/EVA
Info BW (KHz)	75	750	75	750
Δ BW (KHz)	75	75	141	141
Total (KHz)	150	825	216	891
dB (re 1 KHz)	21.8	29.2	23.4	29.5

Propagation loss for 10 nautical miles is:

$$\alpha = 97 + 20 \log f + 20 \log d$$

where α = dB

f = Gc

d = statute miles

= 0.869 nautical miles

α dB = 97 + 20 Log f + 20 log 11.50

= 97 + 20 log f + 21.2

= 118.2 + 20 log f

Freq. (Gc)	1.25	2.35
α dB	120.2	125.6

For "L" Band (1.25 Gc)

EVA to SC Link

P_T = 120.2 + F + 21.8 - 118 dBm

P_T = 24 + F dBm

SC to EVA Link

P_T = 120.2 + F + 29.2 -118

= 31.4 + F dBm

For "S" Band (2.35 Gc)

EVA to SC Link

P_T = 125.6 + F + 23.4 -118

P_T = 31 + FdBm

SC to EVA Link

P_T = 125.6 + F + 29.5 - 118

= 37.1 + F dBm

Assuming equal receiver noise figures at "L" and "S" band, the required EVA transmit power at "S" band is 31-24 = 7 dB or 5 times that required at "L" band. The SC power ratio is 37.1 - 31.4 = 5.7 dB or 3.7.

"L" Band is therefore selected for the following reasons:

a) Less power output required

b) Higher DC/RF power conversion efficiency

c) Less multiplication required in frequency generation chains

For a noise figure of 7 dB. The transmitter power output at 1,25 Gc i

24 + 7 = 31 dBm or 1.25 Watts for EVA

31.4 + 7 = 38.4 dBm or 6.9 watts for SC

The minimum per channel receive level at the SC receiver output will b

31 - 120.2 - 4 - 3 = 96.2 dBm

For an assumed 15 dB minimum loss between transmit and receive antenna the maximum per channel receive level at SC will be:

-96.2 + 120.2 - 15 = +9 dBm

Therefore, where on EVA is at maximum distance from SC and nine EVA's are close to SC, the total mean power at SC receiver input is:

+ 9 + 10 log 9 = +9 +9.5 = 18.5 dBm

The instantaneous to mean power for nine channels is 12 dB, therefore instantaneous power at receiver input is 18.5 + 12 = 30.5 dBm or about one watt.

Mixers are not available to operate at such input power therefore the per channel maximum levels must be reduced preferably without a reducti in maximum range.

4.4 MAJOR TRADE-OFF CONSIDERATIONS

4.4.1 Performance Characteristics

The RF frequencies to be used for the links between the EVA's and SC should be selected by considering the following goals:

a) Minimum EVA transmitter power to permit minimum battery size.

b) Maximum protection from EMI primarily from earth-based emitters.

c) Minimum size and weight for EVA equipment.

d) Omnidirectional antenna patterns for EVA and spacecraft.

Minimum transmitter power is achieved by minimizing receiver noise figure, propagation loss, and receiver noise bandwidth if only thermal noise is considered. Since antenna gain is near unity because of omnidirectional requirements, the increased propagation loss with an increase in frequency cannot be compensated by an increase in antenna gain. Noise figure decreases as frequency is decreased, and less additional noise bandwidth is required to be added to compensate for oscillator frequency tolerences. When external noise or interference is considered, the higher frequencies are preferred due to lower emitter population density.

The selected approach, therefore, was to assume representative values of receiver noise figure, noise bandwidth, propagation loss, cable/diplexer loss, etc., to determine the external noise (EMI) which could be tolerated. The tolerable EMI level could be increased by decreasing receiver sensitivity, but the EMI plus the lowered receiver sensitivity makes this approach unacceptable. The bands selected were therefore based on external noise problems.

The bands selected were based on data extracted from International Frequency List (IFL), which indicates that emission-free windows exist at L-band and S-band frequencies. Subsequent analysis of power requirements indicates the L-band frequencies should be used for multi-eva communications.

In order to define the equipment characteristics and achieve minimum EVA transmitter power, it was necessary to establish the receiver noise figure and noise bandwidth. The SC receiver configuration has individual channel bandwidths in the order of 100 KHz, and the desired channel separation is about 1 MHz. The channel filters should, therefore, have a 3 dB bandwidth of 100 KHz and provide sufficient rejection to the adjacent channels. Filters such as this require a relatively low center frequency, which means that the input frequency must be down converted. At the frequency selected, a passive mixer is required which introduces added loss into the system..

The resulting receiver noise figure will set the minimum signal levels. Intermodulation products will set maximum usable signal levels.

Since the condition could exist of one EVA at a 10-mile distance and nine EVA's close to the SC, the dynamic range required by the spacecraft receiver is excessive. Therefore, an automatic power level control feature is recommended to overcome the dynamic range problem. This adaptive power level control is discussed in detail later in this report.

4.4.1.1 ASSUMED SYSTEM PARAMETERS

The following parameter values were used for the system analysis:

(a) EVA-to-SC information bandwidth 75 KHz maximum.

(b) SC information bandwidth 750 KHz maximum.

(c) CNR of 10 dB will result in acceptable SNR.

(d) A margin of 9 dB is imposed.
This value includes a 3 dB polarization loss, assuming linearly polarized antenna on the astronaut or experiment made, and a circularly polarized antenna on the spacecraft; 3 dB for unfavorable antenna orientations; and 3 dB for worst-case tolerence accumulation for other equipment characteristics.

(e) Unity antenna gain for omnidirectional pattern.

(f) Additional parameter values were assumed as required.

(g) Frequency selection

4.4.1.2 SELECTION OF FREQUENCY BAND

The following values were assumed as representative for the various frequency bands to be considered. Range is 10 nautical miles and antennas have unity gain.

Band	VHF	L	S	X	K
Frequency (Gc)	0.28	1	2	8	13
EVA Cable Loss (dB)	2	2	2	2	2
Receiver Noise Figure (dB)	5	7	7	8	10
SC Multicoupler Loss (dB)	3	3	3	3	3
SC Cable Loss (dB)	2	2	2	2	2
Carrier-to-Noise (dB)	10	10	10	10	10
Margin (dB)	9	9	9	9	9
Freq. Instability (±%)	.005	.005	.0025	.0025	.0025
Required EVA Transmit Power					
Without AFC (Watts)	0.02	1	5	314	2000
With AFC (Watts)	0.02	0.4	1.5	27	110

These transmitter powers are based on receiver thermal noise only and show that due to lack of antenna gain, the VHF band results in minimum EVA power. Since the orbiting spacecraft may be in an orbit as low as 200 NM in altitude above the earth, and the maximum EVA/SC separation range is 10 NM, there is only a 26 dB power advantage of an EVA-to-SC link over an earth-to-SC link due to this range differential. For a 15 dB ratio in desired-to-interference ratio (where the interference is an integration of all likely "in-band" sources) in the receiver IF bandwidth. Thus, the integrated interference (RFI) from terrestrial sources in the receiver bandwidth must be less than 26-15=11 dB above the EVA/SC transmitter power. For EVA power of 27 dBm, the RFI level should be less than 38 dBm.

From LES-5 and LES-6 data the RFI power levels in 255 to 315 MHz range were 6 to 32 dB above the required 38 dBm. Electromagnetic Compability Analysis Center (ELAC) data was not available; the only wideband source was the International Frequency List (IFL) published by the International Telecommunication Union, which contains data on earth transmitter sites. Bands from 156 to 214 MHz and 386 to 454 MHz were eliminated because of radars in these ranges.

The IFL was used to investigate the span from 450 to 2500 MHz for effective radiated power spectral density of earth radiated interfering sources greater than 16 dBm/KHz and a band of at least 10 MHz. The IFL lists disclosed no 10 MHz bandwidth (continuous or in reasonably separated portions) which met the interference level requirements where listing showed emitters. Attention was therefore directed at "holes" or empty portions of the 450 - 2500 MHz range. Holes were found in the following frequency bands: 1219-1240/1289-1300/ 2359-2375/2399-2410 MHz.

Based on the above data L- and S- band were investigated for the EVA/SC communication links.

4.4.2 PHYSICAL TRADE-OFF CONSIDERATIONS

The baseline system has been examined for a standpoint of frequency band, EMI, signal performance, etc. However, in light of the end use of the multi-EVA System it is important to consider the applicability relative to hardware, e.g., power drain, size, weight, what is its impact to Space Shuttle overhead, to the anticipated EVA missions.

The baseline system was analyzed to evaluate the power, size and weight factor as they applied to a VHF, L-Band, and S-Band system. The EVA equipment considered included the anticipated prime power source based on a four hour mission with a two hour safety factor. The sizing projection considered a rechargeable configuration for the battery and the use of proven space hardware factored for a 1975 type design.

Although the VHF equipment has significant problems when considering spectrum and EMI, it is considered here as a baseline reference so that the difference in weight and power may be highlighted and its impact on vehicle costs estimated.

MULTI-EVA

The following tables provide an estimate of the physical characteristics for the EVA hardware. The following guide lines were used in arriving at the values presented.

1. A four hour mission with two hour reserve.
2. Batteries for the mission should be reuseable. (i.e., rechargeable)
3. Batteries including cells will be specifically designed for this application. (28V nominal is assigned).
4. Antenna is a quarter wave omni mounted either on the set or on the helmet.
5. Estimates are based on known state-of-the art space hardware.
6. Package dimensions were established by using known subassembly sizes, iterated until a reasonable efficient layout was obtained.
7. Thermal isolation is assumed. That is, the EVA package will be responsible for its own thermal management, such as radiators, phase-change material, insulation and heat sinking.

In comparing baseline EVA equipment in the three frequency bands the most significant item is the transmitter, its efficiency and its power level. The need for higher transmitter power at higher frequency is reflected in transmitter weight; thus the lower efficiency is reflected in the size and weight of the unit case, battery, and thermal radiator. These items account for about 75% of the weight difference between VHF and L-Band equipment and over 90% of the difference between L-Band and S-Band equipments. New techniques might decrease the S-Band transmitter weights and improve the transmitter efficiency thus reducing radiator, case and battery weight, but correcponding improvements could also be projected for L-Band. Only the use of directive antenna could effectively equalize the weight factor, and that approach is unacceptable from other considerations.

EVA POWER BUDGETS

ITEM	VHF	L-Band	S-Band
	Power Estimated in Watts		
Rec.	1.2W	1.00	1.00
Trans.	4.2W	12.00	53.0
Processing	1.0	1.0	1.00
Regulator	2.5	3.0	4.00
Watts/HL	8.9	17.0	59.00
		Watt Hours	
Requirements for 4 Hr. + 2 Hr. Res.	53.3	102.0	353.00

EVA SIZE ESTIMATES

	VHF	L-BAND	S-BAND
Width	7.0"	7.0"	7.0"
Length	14.0"	8.0"	16.0"
Height	2.75"	4.75"	4.75"

WITH REDUNDANCY

	VHF	L-BAND	S-BAND
Width	7.0	7.0	7.0
Length	17.0	11.5	19.5
Height	2.75	4.75	4.75

EVA WEIGHT BUDGET

ITEM	VHF	L-Band	S-Band
	Weight Estimated in Lbs.		
Rec.	.5	1.7	1.5
Xmtr.	.5	3.1	4.5
Diplexer	.25	1.25	1.0
Antenna	.25	.25	.25
Regulator	.25	.30	.45
Processing	1.0	1.0	1.0
Connector and Wire	.75	.75	.75
Case and Cover	2.4	4.1	6.7
Radiator	.5	1.0	3.0
Battery	2.11	3.15	10.3
TOTAL:	8.51 lbs.	16.60 lbs.	30.45 lbs.

EVA WEIGHT BUDGET, REDUNDNAT

ITEM	QTY.	VHF	L-BAND	S-BAND
		Weight Estimated in Lbs.		
Rec.	2	1.00	2.4	3.0
Xmtr.	2	1.00	6.2	9.0
Diplexer	2	.50	2.5	2
Antenna	1	.25	.25	.25
Regulator	2	.50	.6	.9
Processing/Tel.	2	2.00	2.0	2.0
Connector and Wire	2	1.50	1.5	1.5
Case and Cover	1	3.1	5.3	8.6
Radiator	1	.5	1.0	3.0
Battery	1	2.1	3.2	10.3
TOTAL:		12.45 lbs.	24.95 lbs.	40.55 lbs.

SPACECRAFT CONSIDERATIONS

The estimate for spacecraft equipment is based on the following assumptions:

1. Power will be supplied by the spacecraft.

2. Cooling will be supplied by the spacecraft, either air or cold plate.

3. Audio processing and distribution within the spacecraft and for relay to and from ground is a responsibility of the spacecraft audio system.

4. Two antennas are assumed but antenna cables and power distribution lines are not included in the estimate because of the range of weight variation dependency on location within the spacecraft.

5. Sealed designs are assumed to increase anticipated equipment operating life by restricting the exposure to humidity, salt spray, and foreign particle contamination.

The transmitter weight is a smaller percentage of the total weight. The weight penalties of the thermal controls , due to the transmitter are not included here since it is assumed these are supplied as part of the spacecraft. These items are not treated here because their values are affected by total spacecraft capacity and the time phasing of spacecraft electrical and cooling loads. These factors would alter the conclusion but would only increase the differences established by the items considered.

SPACECRAFT EQUIPMENT ESTIMATED WEIGHT IN POUNDS

ITEM	VHF	L-BAND	S-BAND
Rec.	3.5	4.5	4.2
Xmtr.	.75	2.5	7.1
Diplexer	.5	1.30	1.1
Antenna	2.0	2.2	2.0
Regulator	.3	.45	.65
Signal Processor/Commutator	2.0	2.0	2.0
Audio Matrix (10 x 10)	1.10	1.10	1.10
Decommutator	3.20	3.20	3.20
Case and Cover	2.8	3.05	3.85
Cable and Wiring	1.0	1.0	1.0
TOTAL:	17.15	21.30	26.20

SPACECRAFT REDUNDANT EQUIPMENT ESTIMATE - Weight in Pounds

	34.30	42.60	52.40

CONCLUSIONS

Figure 4-4 displays the estimated communication system and subsystem weights. Although weights were estimated for three frequency points and although projection beyond these points is risky, it is safe to conclude that the higher the frequency the greater the weight penalty, and it becomes prohibitive if pursued much beyond S-Band. VHF provides a 30.8 lb. weight advantage over L-Band but is not recommended from a Spectrum and EMI point of view. As L-Band system would provide 24.4 lb advantage over an S-Band system and no forseeable technique advancement would significantly remove the advantage. On a weight projection above, not considering the spacecraft power penalty the weight overhead cost advantage of VHF over L-band for space shuttle is about 10 million dollars. This is based on a $32,000 per pound penalty on the Shuttle program (delivery into orbit of all Multi-EVA hardware plus spares) spread over 100 missions.

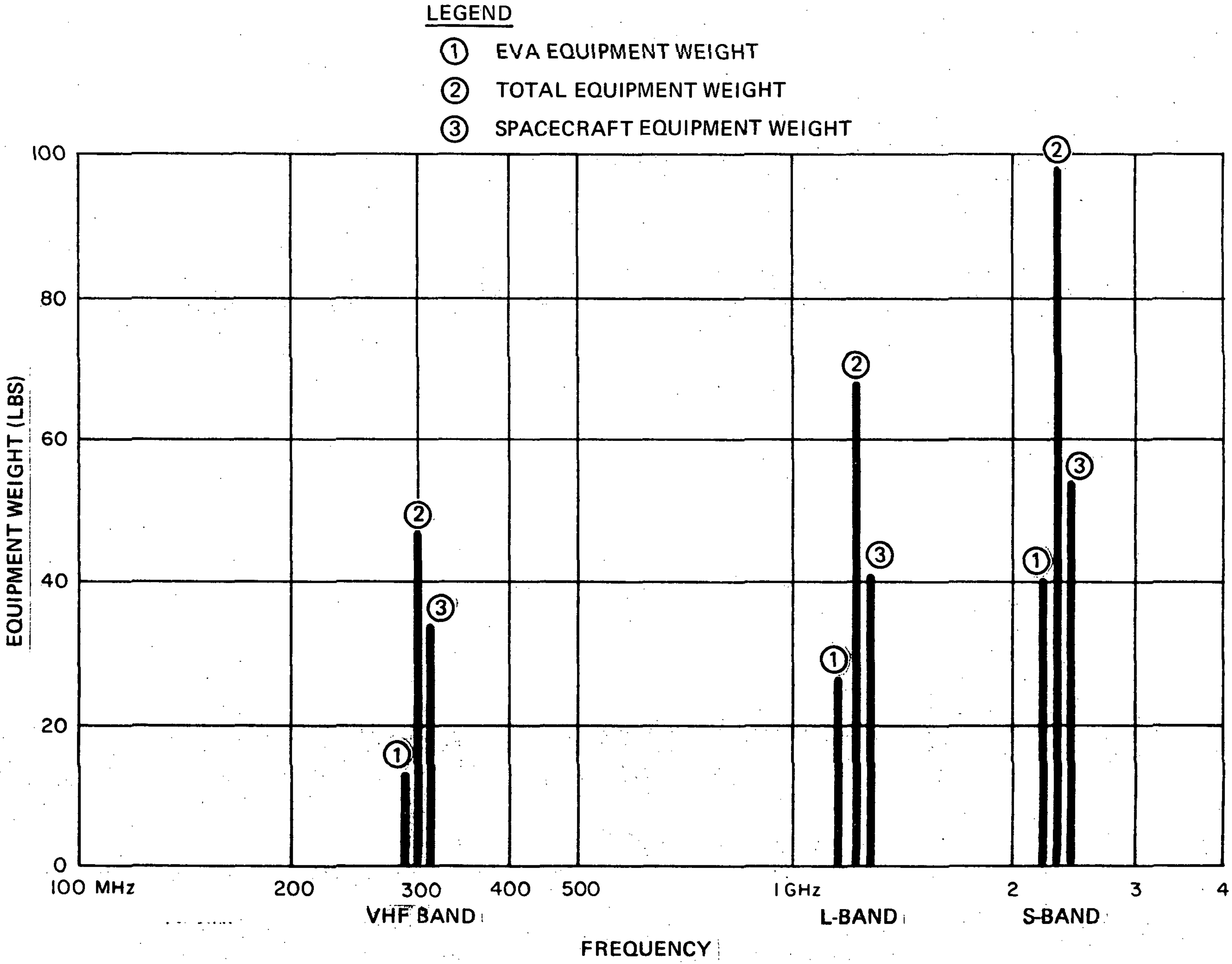


Figure 4-4. Equipment Weight vs. Frequency

SECTION 5

DETAILED REQUIREMENTS

The candidate system has been analyzed for functional requirements, frequency allocation, frequency assignments, signal performance, dynamic range, interfaces and physical applicability. The results of these analyses are collected and organized as related to Space Shuttle applications. The organized material is arranged as preliminary specifications as part of this report. Appendix A contains the EVA backpack portion and Appendix B the Spacecraft portion.

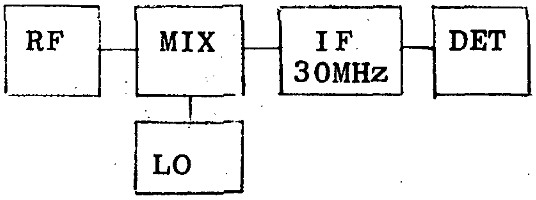
These specifications are intended to provide the detailed requirements but have been organized in a preliminary specification format to provide a basis for preparation of a final document. This final document will be dependent on detailed information relative to the Space Shuttle - EVA mission profile, signal interfaces both internal and external, mechanical and thermal interfaces and weight-power payload restrictions.

SECTION 6

DESIGN APPROACH

6.1 PRESELECTION

For small RF channel spacing, a multipole filter design is required for channel selection. For bandwidths of approximately 100 KHz, crystal filters in the frequency range of 5 to 40 MHz are practical. A contiguous or comb filter is more practical in the range from 20 to 35 MHz. For single-conversion receiver design:



the image response is at:

$$F_{RF} \pm 2F_{IF} = F_{RF} \pm 2(35) = F_{RF} \pm 70 \text{ MHz}$$

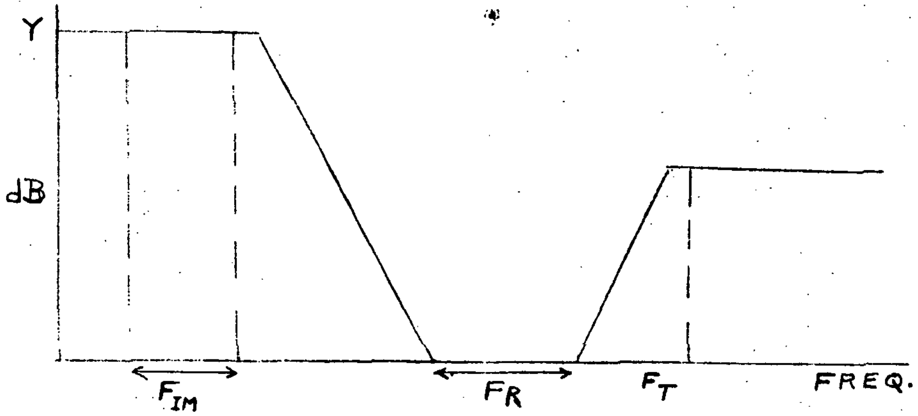
the low-side LO injection,

$$F_{IM} = F_{RF} - 70 \text{ MHz}$$

$$F_{RF} = 1250 \text{ MHz}, \; F_{IM} = 1250-70 = 1180 \text{ MHz}$$

$$F_{RF} - 2350 \text{ MHz} \; F_{IM} = 2350-70 \text{ MHz} = 2280 \text{ MHz}$$

The preselector (receive portion of diplexer) should reject the image, transmitter, and local-oscillator frequencies.



The following parameters are assumed for comparison purposes:

Band	F_R	F_{IN}	F_T
L	1250±5	1180±5	1300
S	2350±5	2280±5	2400

BW

0.1 dB = 10 MHz

At L-Band $BW_X = 2\ (1300 - 1250) = 100$ MHz

$BW_Y = 2\ (1255 - 1180) = 150$ MHz

At S-Band $BW_X = 2\ (2400 - 2350) = 100$ MHz

$BW_Y = 2\ (2280 - 2355) = 150$ MHz

$$\frac{BW_X}{BW_{0.1}} = \frac{100}{10} = 10$$

$$\frac{BW_Y}{BW_{0.1}} = \frac{150}{10} = 15$$

The required attenuation at transmit frequency (X), and attenuation at the image frequency (Y) must be known to determine the filter complexity.

A spurious response rejection of 80 dB is typical; therefore, assume Y = 80 dB. To reduce the level of a 2-watt (+33 dBm) transmitter to a level of -20 dBm which should not overload the receiver, requires an attenuation of 33+20 = 53 dB; therefore, assume X = 50 dB.

Therefore: $\frac{BW_{50}}{BW_{0.1}} = 10 \qquad \frac{BW_{80}}{BW_{0.1}} = 15$

For:

$$\frac{V_P}{V_V} = 0.1 \text{ dB (i.e. Ripple 0.1 dB)*}$$

	$\frac{BW_{50}}{BW_3}$	$\frac{BW_{80}}{BW_3}$	$\frac{BW_{0.1}}{BW_3}$	$\frac{BW_{50}}{BW_{0.1}}$	$\frac{BW_{80}}{BW_{0.1}}$
3	6	19.2	0.72	8.3	26.6
4	3.3	8	0.83	4.0	9.65

Therefore a minimum of 4 poles is required.

Local oscillator is 35 MHz from desired frequency: therefore:

$$\frac{BW_X}{BW_{0.1}} = \frac{2(70)}{10} = 7$$

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*Reference Data for Radio Engineers, Fourth Edition, page 193

For 4-pole filter:

$$\frac{BW_X}{BW_{0.1}} = \frac{BW_X}{BW_3} \quad \frac{BW_3}{BW_{0.1}} = 7$$

$$\frac{BW_X}{BW_3} = 7 \qquad \frac{BW_{0.1}}{BW_3} = 7\ (0.83) = 5.8$$

Therefore: $X \approx 68$ dB.

To keep local-oscillator radiation at antenna 40 dB below 1 μv or -107 dBm , the local-oscillator power must be limited to $-107 + 68 + X = -39 + X$ = isolation between mixer local oscillator and RF parts.

For $X = 30$ dB

Max LO power $= -39 + 30 = -9$ dBm

If LO power is higher, additional isolation is required in the mixer or a more complex preselector will be required.

Previous estimates of the number of resonators or poles in the preselector were based on selectivity characteristics. The minimum insertion loss may be less if additional poles are used.

Figure 6-1* is based on approximations such that the accuracy will increase as (LA)s increases and as the product $Q_u W_s$ increases in size. It shows that for minimum passband loss, the number of resonators is determined by the required reject band attenuation. This decreased passband loss is achieved at the expense of increased volume required by the added resonators.

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*Microwave Filters Impedance - Matching Networks, and Coupling Structures, Mattihaei, Young, Jones, 1964, page 679.

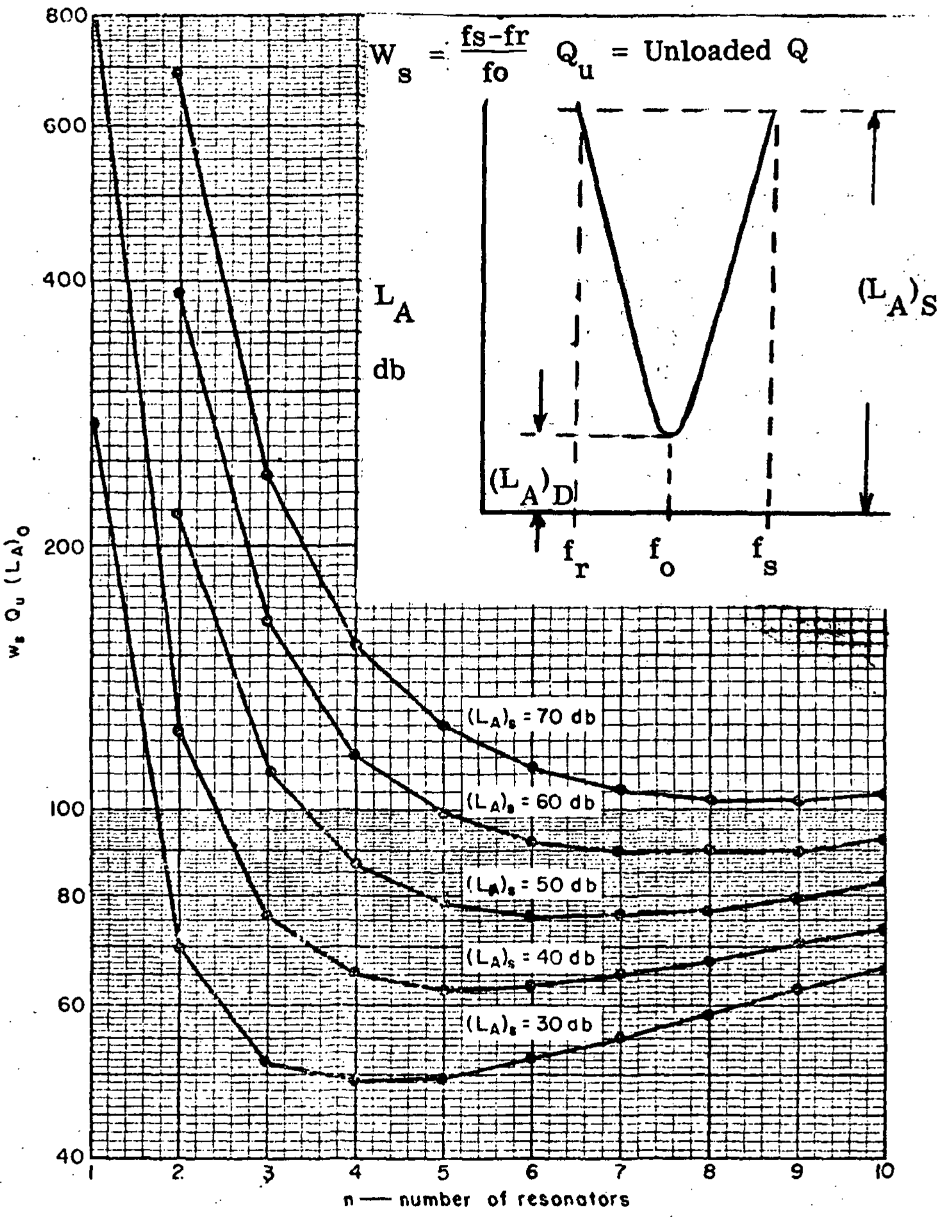

FIG. 6-1. DATA FOR DETERMINING THE PERFORMANCE OF BAND-PASS FILTERS DESIGNED FROM EQUAL-ELEMENT PROTOTYPES

Microwave Filters, Impedance - Matching Networks, and Coupling Structures by Matthaei, Young, Jones, 1964.

6.2 CHANNEL SELECTION FILTERS

Assume two-step channel selection:

(a) Two-pole (0.1) db ripple) comb filter to keep insertion loss low before IF gain.

(b) Remaining filtering (reject adjacent channels) after some IF gain.

Assume total noise BW of 150 KHz. Use comb filter $BW_{1dB} = 150$ KHz

Post amplifier $BW_{2dB} = 150$ KHz

For two-pole 0.1 dB ripple BPF and $BW_1 = 150$ KHz, at BW of 2 MHz what is attenuation? *

$$\frac{BW_1}{BW_3} = 0.75 \qquad \frac{BWx}{BWs} = \frac{2}{BW_1/0.75} = \frac{1.5}{BW_1} = \frac{1.5}{0.15} = 10$$

$X = 29 + 12 = 41$ dB

At BW = 4 MHz, $\frac{BWx}{BW_3} = \frac{4(0.75)}{0.15} = 20$

$X = 29 + 12 + 12 = 53$ dB

At BW = 6 MHz $X = 29 + 12 + 12 + 12 = 65$ dB

Therefore for desired signal at 0 dB

Channel n @ 0 dB

Channel (N-1) & (N+1) @ -41 dB

$$\left.\begin{array}{ll}\text{Channel (N-2) \& (N+2)} & @\ -53\text{ dB}\\ \text{Channel (N-3) \& (N+3)} & @\ -65\text{ dB}\end{array}\right\} 52.75\text{ dB}$$

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* Reference Data for Radio Engineers, Fourth Edition, page 193.

The total power due to channels N-3, N-2, N+2 and N+3 compared to power in channels N-1 and N+1, is negligible. Total undesired power is, therefore, -41 + 3 = -38 dB above desired channel when all channels are at the same input power level. When adjacent channels are 105 dB above desired signal, an additional attenuation of 105-28 = 67 dB is required to equalize desired and undesired levels. To reduce undesired adjacent channels to noise level an additional 19 dB is required or 67 + 19 = 86 dB.

For 150 KHz @ 2 dB

2 MHz @ 86 dB or greater

For 0.1 dB ripple filter

N = 3 $\frac{BW_{86}}{BW_2} = ?$ $\frac{BW_{50}}{BW_3} = 6$ $\frac{BW_{86}}{BW_2} = 9\ (2)\ (2) = 36$

$\frac{BW_2}{BW_3} = 0.95$ $\frac{BW_{86}}{BW_2} = \frac{BW_{86}}{BW_3}\ \frac{BW_3}{BW_2}$

$= \frac{36}{0.95} = 38$

BW_{86} dB = 38 (.150) = 5.7 MHz

N = 4 $\frac{BW_{62}}{BW_3} = 4.8$ $\frac{BW_{86}}{BW_3} = 4.8\ (2)$ $\frac{BW_2}{BW_3} = 0.96$

$\frac{BW_{86}}{BW_2} = \frac{9.6}{0.96} = 10$

BW_{86} = 10 (0.15) = 1.5 MHz

6.3 NOISE BANDWIDTH

The SC 75 KHz bandwidth must be increased because of frequency instability of the EVA transmitter, SC local oscillator, and channel selector filters. For an EVA transmitter stability of ±0.003% or ±30 KHz/GC, at 1.25 GC the receiver bandwidth must be increased by 75 KHz and at 2.35 GC by 141 KHz. The receiver bandwidth would thus be 75 + 75 = 150 KHz at L-Band and 75 + 141 = 216 KHz at S- Band. SC local-oscillator instability can be effectively eliminated by use of temperature-controlled crystals, and the drift of the channel selection filters will also be small compared to EVA instability.

Based on these noise bandwidths and previously assumed parameters, the following link analysis shows that L-Band is preferred due to lower power requirements.

EVA-To-SC Path

	1.25 GC	2.35 GC
Propagation Loss (10 NM) (dB)	120.2	125.6
EVA/SC Line Loss (dB)	4.0	4.0
EVA/SC Diplexer Loss (dB)	3.0	3.0
Total Loss (dB)	127.2	132.6
Receiver Noise Figure (dB)	7.0	7.0
Thermal Noise (F=0 dB) (dbm/KHz)	-144	-144
Receiver Noise (dbm/KHz)	-137	-137
Rec. Level (19 dB C/N / BW=1 KHz)(dBm)	-118	-118
Transmitter Power (NBW = 1 KHz)(dBm)	9.2	14.6
Transmitter Power (NBW = 75 KHz)(dBm)	27.9(0.6W)	33.3(2.1W)

EVA-to-SC Path (Cont'd)

	1.25 GC	2.35 GC
Transmitter Power (NBW=150 KHz)(dBm)	30.9(1.2W)	-
(EVA Freq. ± 0.003%) (NBW=215 KHz)(dBm)	-	37.9(6.2W)

SC-to-EVA Path

	1.25 GC	2.35 GC
Propagation Loss (10 NM) (dB)	120.2	125.6
EVA/SC Line Loss (dB)	4.0	4.0
EVA/SC Diplexer Loss (dB)	3.0	3.0
Total Loss (dB)	127.2	132.6
Receiver Noise Figure (dB)	7.0	7.0
Thermal Noise (dbm/KHz)	-144	-144
Receiver Noise (dbm/KHz)	-137	-137
Rec. Level (19 dB C/N/BW=1 KHz)	-118	-118
Transmitter Power (NBW=1 KHz)(dBm)	9.2	14.6
(NBW=750 KHz)(dBm)	37.9(6.2W)	43.3(21.4)
Transmitter Power (NBW=800 KHz)(dBm)	38.5(7.1W)	-
(EVA Freq. ±0.003%)(NBW=890 KHz)(dBm)	-	44.8(30W)

The EVA transmitter frequency instability could be compensated by the use of signal seeking automatic frequency control in the SC receiver. The AFC control must be derived after channel selection; two possible configurations are shown in Figures 6-2 and 6-3.

The principle problems associated with signal seeking AFC are:

(a) Lock on adjacent channel instead of desired channel.

(b) Complexity

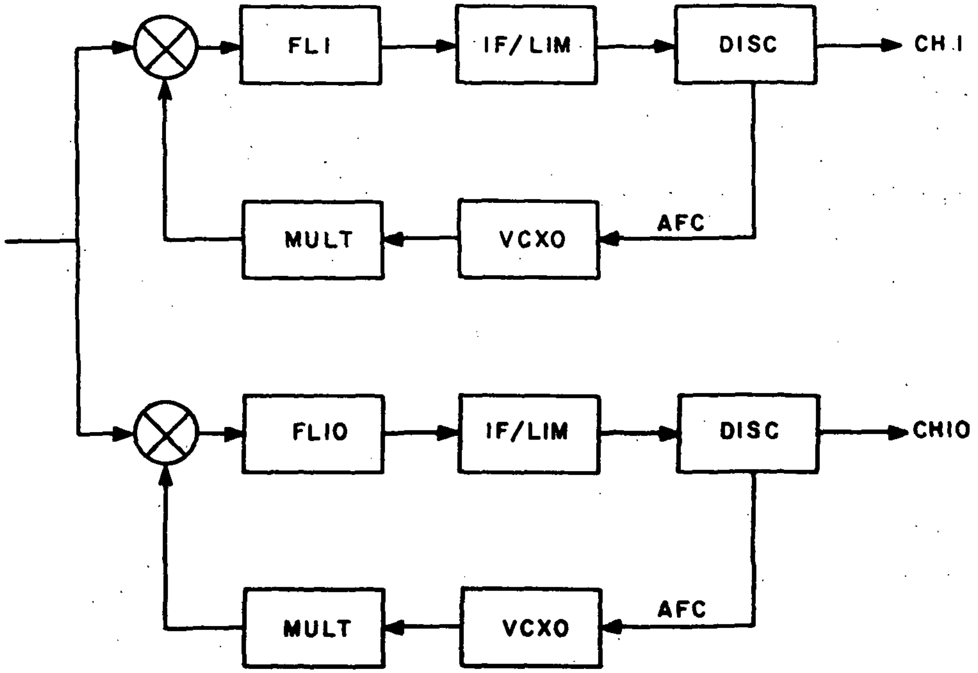


Figure 6-2. Signal Seeking AFC Type 1

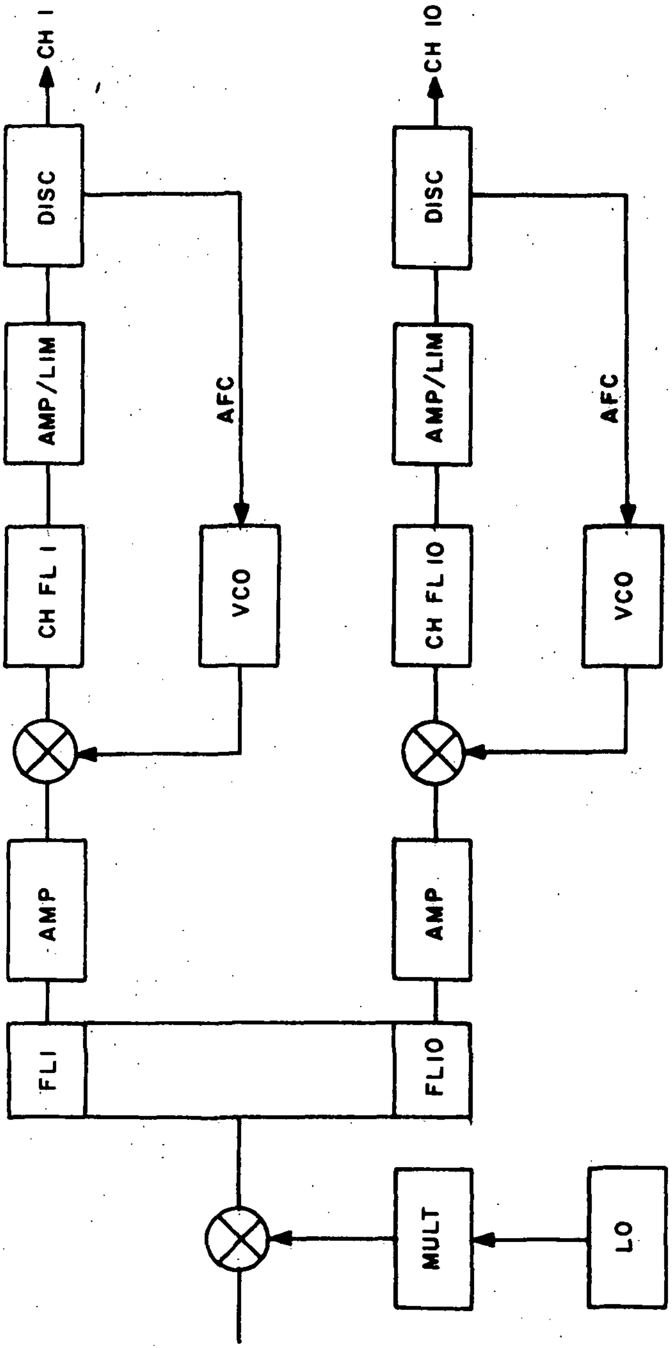


Figure 6-3. Signal Seeking AFC Type 2

6.4 RECEIVER NOISE FIGURE

Figure 6-4 shows two receiver configurations with parameters designated which determine the receiver noise figure.

The first configuration provides filtering ahead of the first gain element, so that only the mixer is exposed to all 10 input carriers. This should result in the mixer characteristics determining dynamic range.

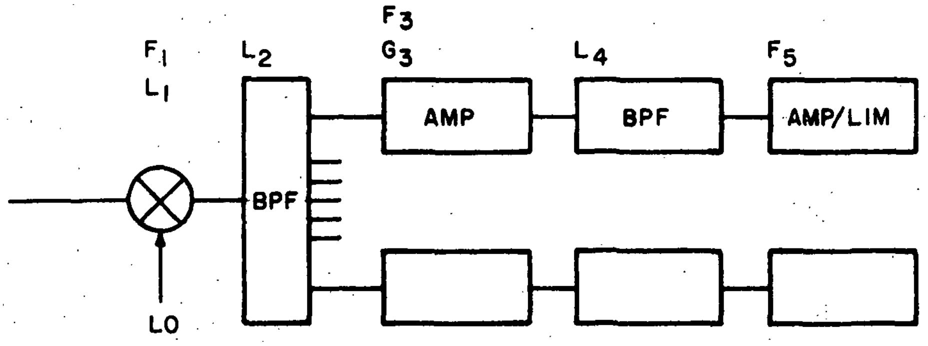
The second configuration exposes the mixer and IF amplifier to all 10 channels; therefore, both will generate intermodulation products which will limit the dynamic range. Investigation of various approaches to high dynamic range has illustrated that diode mixer circuits can be made having overload characteristic superior to solid-state amplifiers. Modern Schottky - barrier diodes in balanced mixers, in the frequency range being considered, have conversion loss of about 9 dB when measured in a 50-ohm system. The noise figure is usually no more than one 1 dB greater than the conversion loss, and therefore, approximately equal.

IF filter insertion loss will be set by filter complexity. 3 dB is assumed as a conservative estimate for a simple filter, 6 dB for more complex, and 10 dB for most complex.

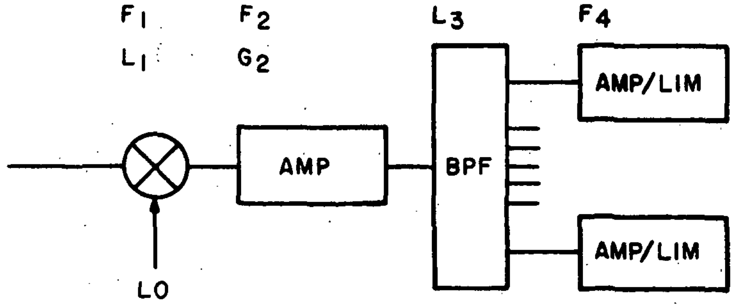
Amplifier noise figures of 1.5 dB are assumed which may be too optimistic, since filters precede the amplifiers which results in a potential conflict due to:

(a) Most filters require a matched output in order to obtain desired selectivity.

(b) An IF amplifier must be optimally mismatched to obtain the minimum noise figure.



① $F_{TOT} = F_1 + L_1(L_2 - 1) + L_1 L_2 (F_3 - 1) + \frac{L_1 L_2}{G_3}(L_4 - 1) + \frac{L_1 L_2 L_4}{G_3}(F_5 - 1)$



② $F_{TOT} = F_1 + L_1(F_2 - 1) + \frac{L_4}{G_2}(L_3 - 1) + \frac{L_1 L_3}{G_2}(F_4 - 1)$

Figure 6-4. Channel Filter Configurations

From the equations in Fig. 6-4 and the following assumed values of the various parameters,

For configuration (1)

L_1 = 9 dB (X8) L_2 = 3 dB (X2) G_3 = 10 dB (X10)

F_1 = 10 dB (X10) F_3=F_5=1.5 dB (X1.41) L_4 = 6 dB (X4)

$$F_{tot} = 10 + 8\ (2-1) + 8(2)(1.41-1) + \frac{8(2)}{10}\ (4-1) + \frac{8(2)(4)}{10}\ (1.41-1)$$

$$= 10 + 8 + 6.55 + 4.8 + 2.62$$

$$= 31.97$$

$$= 15 \text{ dB}$$

For configuration (2)

F_1 = 10 dB (X10) F_2=F_4=1.5 dB (X1.41) L_3 = 10 dB (X10)

L_1 = 9 dB (X8) G_2 = 10 dB (X10)

$$F_{tot} = 10 + 8\ (1.41-1) + \frac{8}{10}\ (10-1) + \frac{8(10)}{10}\ (1.41-1)$$

$$= 10 + 3.68 + 7.2 + 3.68$$

$$= 24.56$$

$$= 13.9 \text{ dB}$$

6.5 MIXER CONVERSION LOSS

Conversion loss within a diode mixer is a complex process due to the non-linear nature of a mixer. A broadband mixer produces a multitude of frequency terms, most of which are undesired, and the circulation of these unwanted currents through resistive source, output, and pump impedances produces power losses chargeable to the mixing process. It is these losses which are responsible for the above quoted conversion loss figures, plus the resistive losses associated with the various currents circulating through the diodes.

A technique exists whereby essentially only the desired signal, local oscillator, and IF currents are allowed to circulate in their respective source and load resistances with the remaining undesired frequencies (or at least the larger amplitude of these) terminated at the various ports with lossless reactances. This mixer configuration is commonly referred to as an image-terminated mixer, and is discussed analytically in a number of books and technical papers.*

The doubly-balanced mixer is to considered on the basis of its superior dynamic range, especially when selected diode quads are used.

The analyses show the expected theoretical conversion losses of doubly-balanced mixers for various frequency-dependent termination impedance at the signal, image, and output ports. (Signal and image ports are physically identical but mathematically separated for analysis.) Of the multitude of possible configurations of

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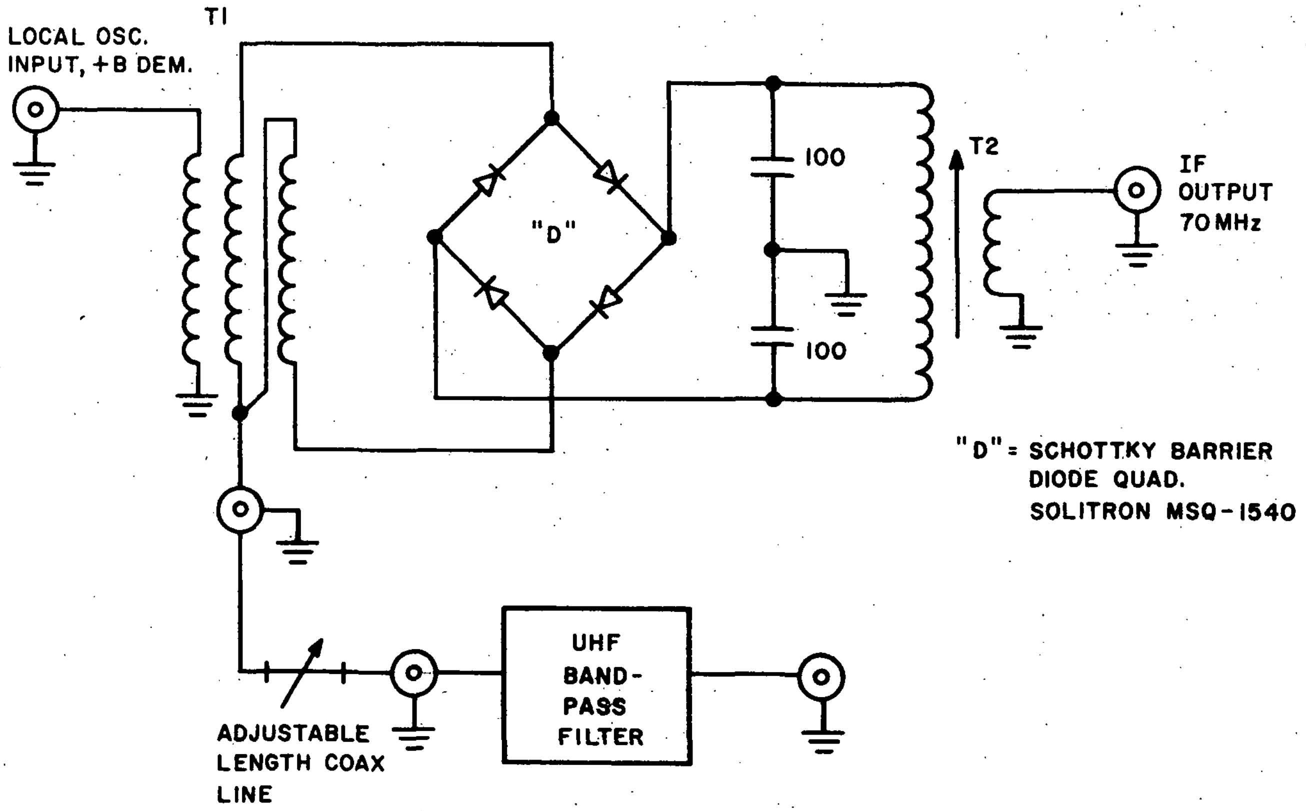
* See bibliography

the ring type mixer are shown to provide minimum theoretical conversion loss. These require signal input and output frequency-dependent terminations providing an open circuit at all undesired frequencies at the input port and a short circuit at all undesired frequencies at the output port, or the converse. Of the two choices, the first configuration is the more practical. Other analyses indicate that this configuration also minimizes the additive noise of the mixer.

To provide the required termination condition, bandpass filters can be used at each port to pass the desired frequencies unperturbed and block the other terms with purely reactive terminations which can be adjusted in magnitude and phase at the mixer terminals.

An indication of the performance of such a circuit at UHF was obtained as part of another contract. An experimental mixer was fabricated by initially using the components of a commercial Lorch mixer, and later using a matched Solitron Schottky diode quad when it was received.

The circuit tested is shown in Figure 6-5. The input transformer is the one used in a Lorch FC-200 unit. The output transformer was designed to resonate at the IF output, 70 MHz, and the coupling was adjusted for best conversion efficiency. The output load impedance found best for minimum loss, with a 200-ohm effective drive impedance, was about 400 ohms. This agrees well with the theoretical factor of 2.47 given by Caruthers for the ratio of load to source resistance for optimum conversion, using terminations



T1; 6T # 34 TRIFILAR
WOUND ≈ 1/8" DIA. POWDERED
IRON TOROID.

T2; CTC 2501 FORM PRI.
4T # 30 1/4" LONG
SEC. 3T # 24 CLOSE WOUND
(ADJ. SPACING BETWEEN
COILS)

Figure 6-5. Image Terminated Mixer

of an input open circuit at the image frequency and an output short circuit at other than IF. The output IF tank circuit appears as a low reactance at all but 70 MHz, thus fulfilling the output terminating condition.

The signal input bandpass filter provides a reactive impedance at the image frequency when viewed from the mixer signal terminals (assuming the bandpass does not extend into the image frequency). By adjusting the length of transmission line between the filter and mixer, the image frequency impedance seen by the diode quad can be made to appear as an open circuit as required. A tunable lab filter, Telonic ITF-250-5-3EE, having a 0.5 dB insertion loss, was used for this unit.

It is shown in the references that it is most important to provide this termination condition at the image frequency. The other frequency term of interest is the sum of input and pump frequencies. Both sum and image are potentially of equal magnitude, but the diode barrier capacity tends to short the higher frequency sum term, thus reducing its importance. If both terms were equally large, it would be desirable to provide an open circuit termination at both frequencies to minimize losses.

Tests were made at 290 MHz signal frequency, and the circuit was adjusted for minimum loss using a swept input signal. The minimum conversion loss attainable was measured as an insertion loss of 3.5 dB, including 0.5 dB filter loss. Therefore, the conversion loss attributable to the mixer alone is 3.0 dB, an improvement of about 5 dB over a broadband mixer.

To investigate bandwidth possibilities, a fixed-tuned Telonic TBF-290-20-4XX2 barrel filter (20 MHz bandwidth, 290 MHz f_o) was used in place of the tunable unit. Under these conditions, the conversion loss of the mixer alone varied from 3-4 dB across the 280-300 MHz bandwidth with the line stretcher set for optimum passband.

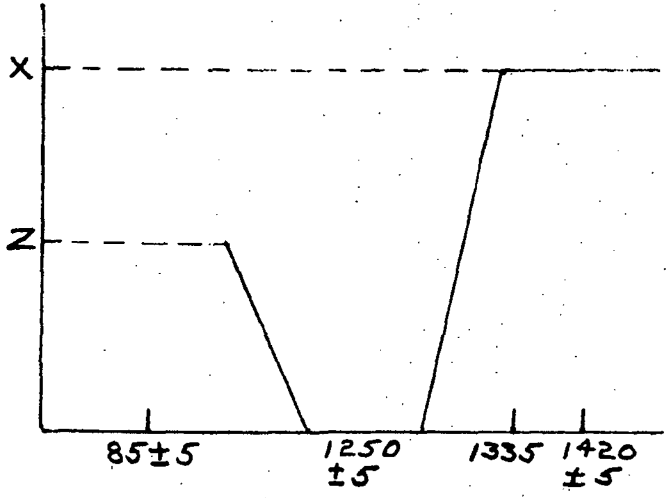
6.6 UPCONVERTER OUTPUT FILTER

1335
±85 ±5

1250 ±5
1420 ±5

Pass 1250 ± 5

Reject 1420 ± 5
1335
85 ± 5



$F_o = 1250$

$BW_{0.1} = 10$ MHz

$BW_X = 2(335 - 1250) = 170$ MHz

$BW_Y = 2(1415 - 1250) = 330$ MHz

$BW_Z = 2(1250 - 85) = 2330$ MHz

For mixer L_o @ +20 dBm and isolation of 20 dB L_o @ output port will be +20 - 20 = 0 dBm. For mixer with 2 dB compression at +19 dBm assume conversion loss of 11 dB. Desired signal will be +19 - 11 = +8 dBm.

For L_o signal A dB below +8, the filter must provide A dB of attenuation. The value of A can be set by spurious output requirements of transmitter.

For A = 60 dB $BW_X = BW_{60}$.

Filter complexity will be determined by:

$BW_{0.1} = 10$ MHz

$BW_{60} = 170$ MHz

$BW_{60}/BW_{0.1} = 17$

For 0.1 dB ripple filter

	2	3
$BW_{0.1}/BW_S$	0.52	0.72
BW_{60}/BW_S	4(7.5)	2(4.3)
$BW_{60}/BW_{0.1}$	58	12

Therefore, three poles will be sufficient.

6.7 LOW-NOISE AMPLIFIER AND FILTERS

The IF amplifier design is one of the more critical circuits of a system without RF amplification. Since the preselector and the mixer introduce loss into the system, it is most critical that the IF display the lowest possible noise figure. The dynamic range of the IF amplifier should also be comparable to that of the quad mixer so that the amplifier does not degrade the performance of the overall system. Low-noise figures on the order of 1 dB have been obtained with both bipolar and FET amplifiers. The FET amplifier displays significantly better dynamic range than the bipolar amplifier and, therefore, is first considered for this task.

The filter between the mixer and the first gain element must also have extremely low loss since its loss will add directly to the overall noise figure of the system. A crystal filter was chosen due to the high unloaded Q of its elements.

Preceding the IF amplifier with a crystal filter presents a problem: a normal crystal filter requires a matched output in order to display its proper passband characteristic. An IF amplifier must be optimally mismatched to display its best noise figure. It is believed that a filter can be designed which operates into the high-impedance load of an FET while displaying a lower impedance source to that transistor.

The following results were obtained during the design on another contract:

F_O = 17 MHz
BW @ 0.5 dB = ± 75 KHz min.
BW @ 30 dB = ± 150 KHz max.
Power Loss = 1 dB max.

This filter plus a cascade amplifier provided a measured noise figure of less than 2 dB. A typical specification for a crystal filter meeting the requirements for this application, is contained in Appendix C.

6.8 SPACECRAFT SIGNAL LEVELS

For a noise bandwidth of 150 KHz the thermal noise will be!

$$P_n = F_{dB} - 144 \text{ dBm/KHz} + 10 \log 150$$

$$= F_{dB} - 144 + 21.8$$

$$= F_{dB} - 122.2$$

For 19 dB C/N, the received signal level will be:

$$P_{s_{dbm}} = F_{dB} - 122.2 + 19$$

$$= F_{dB} - 103.2$$

For configurations shown in Figure 6-4,

For ① $P_s = 15 - 103.2 = -88.2$ dBm min.

② Ps = 13.9 - 103.2 = -89.3 dBm min.

These power levels must be provided when propagation loss is 120 dB. When loss, decreases to 10-20 dB at minimum separation, the above levels will increase by 100 - 110 dB. Thus, the single-carrier power level at the mixer input will vary as follows:

For ① -88 to +17 dBm

② -89 to +16 dBm

For nine equal level signals, the total power will be 10 log 9 or 9.5 dB above each signal.

Assumed gains and losses are as shown in Figure 6-6.

In ① the first BPF rejects adjacent channels by 41 dB; therefore, at the filter output, each adjacent channel signal level will be:

+17-9-3-41 = -36 dBm (Two channels -33 dBm)

While the desired signal level will be:

-88-9-3 = -100 dBm

The calculated levels are also shown in Figure 6-6 for amplification before filtering.

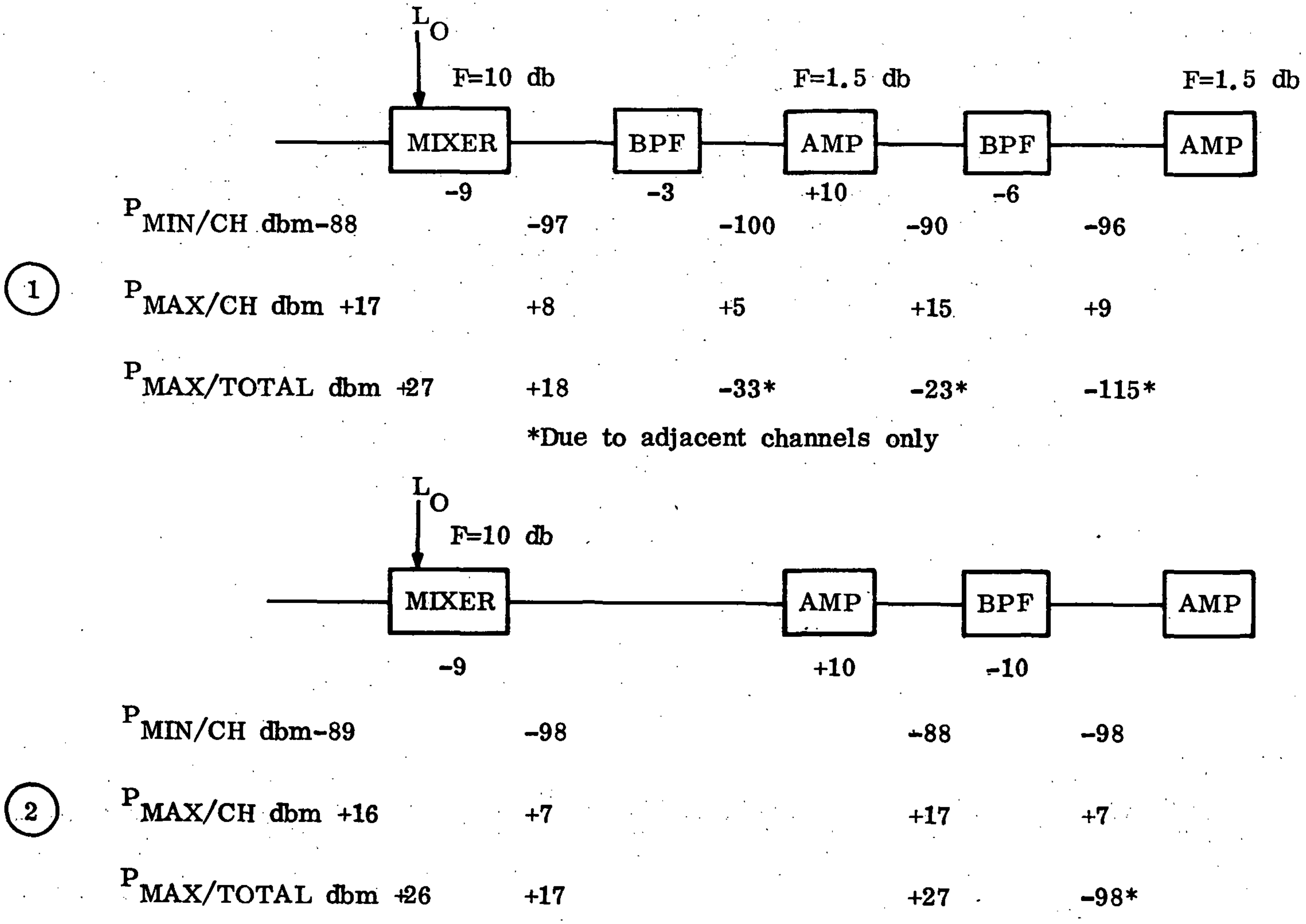


Figure 6-6. Spacecraft Signal Levels (L Band)

6.8 (Continued)

In ① the degree of small signal compression in the presence of high-level signals and the intermodulation products due to high-level signals falling in the weak signal band, will be determined almost entirely by the mixer linearity, since the first bandpass filter will effectively eliminate all channels except for the desired and two adjacent channels.

In ② both the mixer and amplifier are exposed to all signals and have approximately equal power levels. The mixer signals levels are, however, about 1 dB lower than in ① due to the lower system noise figure. The mixer in either case must accept a total signal input power of +27 dBm and simultaneously pass a low-level signal of -88 dBm. This will require a local-oscillator power in the order of +30 dBm or 1 watt to maintain linearity of conversion loss.

6.9 INTERMODULATION PRODUCTS

Third - and fifth - order intermod products fall close to the desired passband, and therefore can cause interference. The third-order products are usually higher in level than the fifth order.

Third-order products are of the form:

$$f_x = 2\,f_a - f_b$$

and $f_x = f_a + f_b - f_c$

where f_x is the intermod frequency

and f_a, f_b, f_c are the original frequencies.

For equal channel separation of ΔF starting at frequency f_o,

$$f_a = f_o \pm \Delta F$$

$$f_b = f_o \pm 2\,\Delta F$$

$$f_c = f_o \pm 3\,\Delta F$$

for $2f_a - f_b$ products

$$2\,(f_o \pm \Delta F) - (f_o \pm 2\,\Delta F) = f_o$$

for $f_a + f_b - f_c$ products

$$(f_o \pm \Delta F) + (f_o \pm 2\,\Delta F) - (f_o \pm 30F) = f_o$$

Thus channels N ± 1 and N ± 2 produce channel N as do channels N ± 1 plus N ± 2 plus N ± 3.

To avoid on-channel intermodulation products in a multi-frequency system, the allocation of channels must be based on a technique of staggering where the spacing between any two channels is not repeated.

6.9 (Continued)

The following table shows an example of third-and fifth-order intermodulation avoidance.

Channels Required	Channels Available	Operating Channels having no on-channel 3rd order intermodulation interference
3	4	1,2,4
4	7	1,2,5,7
5	12	1,2,5,10,12
6	18	1,2,5,11,13,18
7	26	1,2,5,11,19,24,26
8	35	1,2,5,10,16,23,33,35
9	46	1,2,5,14,25,31,39,41,46
10	62	1,2,8,12,27,40,48,57,60,62
11	78	1,17,18,24,28,43,56,64,73,76,78

Channels Required	Channels Available	Operating Channels having no on-channel 3rd and 5th order intermodulation interference
8	137	1,2,8,12,27,50,78,137

If 10 channels are to be limited to a bandwidth to a bandwidth of 10 MHz, then to avoid th third-order products 62 channel assignments are required and only 10 are used. The channel spacing is reduced from:

$$\frac{10\text{ MHz}}{10} = 1.0\text{ MHz to } \frac{10\text{ MHz}}{62} = 0.16\text{ MHz, or the bandwidth increases to}$$

$$\frac{62}{10} = (10) = 62\text{ MHz}$$

Thus the channel separation filters become quite complex or the 10-channel bandwidth becomes excessive.

6.10 REDUCTION OF DYNAMIC RANGE

Dynamic range can be reduced by lowering maximum power per channel and by reduction in the number of channels.

A high-level mixer is the Lorch Model FC-2342/235Z which has the following characteristics for L-band operation:

Noise Figure: within 1 dB of conversion loss
Conversion Loss: 9 dB
Nominal Lo Power: +20 dBm
Compression Level (-2 dB): +19 dBm
Two-Tone IM

$$\left.\begin{array}{l}\text{-30 dBm}\\ \text{each tone}\end{array}\right\}\begin{array}{l}\text{3rd order: 130 dB}\\ \text{5th order: 135 dB}\end{array}$$

$$\left.\begin{array}{l}\text{0 dbm}\\ \text{each tone}\end{array}\right\}\begin{array}{l}\text{3rd order: 70 dB}\\ \text{5th order: 75 dB}\end{array}$$

For third-order intermodulation products equal to the minimum channel level, the products must be down by an amount equal to the dynamic range of 105 dB. Since third-order products are reduced 30 dB for each 10 dB reduction in each of two input signals, the relative change at the output is 2 dB per 1 dB change.

Thus if two 0 dBm signals produce products 70 dB down, then for 105 dB the input levels must be reduced by

$$\frac{105 - 70}{2} = \frac{35}{2} \approx 17 \text{ dB or to } -17 \text{ dBm per tone}$$

Two tones at -17 dBm each produces an instantaneous power of -17 dBm +3 ±6 = -8 dBm

If this level is not to be exceeded for 10 tones, then per-channel level must be limited to -8 dBm -10 -13 = -31 dBm.

If third-order products were reduced to noise level, rejection must be increased by 19 dB, which will limit maximum per channel level to $-31 \text{ dBm} - \frac{19}{2} = -41 \text{ dBm}$

From the level diagram the calculated per-channel level for 10 miles is +17 dBm. If this is reduced to -31 dBm, range will be

$$20 \log \frac{10}{X} = 48 \qquad \frac{10}{X} = 250$$

$$\log \frac{10}{X} = 2.4 \qquad X \pm \frac{10}{250} = 0.04$$

for -41 dBm, range will be

$$20 \log \frac{10}{X} = 58 \qquad X = \frac{10}{800} = 0.0125$$

This reduction in range is not acceptable; therefore, alternate methods of reducing dynamic range must be considered.

When the first gain stage is exposed to all 10 channels and the maximum per channel level is limited to -31 dBm, then the per-channel input level will be -31 -9 = -40 dBm for a 9 dB mixer loss. The instantaneous peak power for the channels will be

$$-40 + 10 + 13 = -17 \text{ dBm}$$

For two channels and the same peak power, the per-channel level will be

$$-17 - 3 - 6 = -26 \text{ dBm}$$

The power outputs of third-order products (P_3) is equal to 3(I-F) dB below the intercept point, where I and F are the values of the intercept point and fundamental signal levels, expressed in dBm.

For $P_3 = 120$ dB

$$F = 26 \text{ dBm} + G \text{ where } G = \text{Stage gain}$$

$$I = 1/3\, P_3 + F = 1/3\ (120) + (-26 + G) = 14 \text{ dBm} + G$$

For the gain of 10 dB assumed for noise figure calculations, intercept point for IF amplifier exposed to 10 channels will be

$$14 \text{ dBm} + 10 = 24 \text{ dBm}$$

6.11 ADAPTIVE EVA TRANSMITTER POWER CONTROL

The dynamic range required of the SC receiver can also be reduced by control of the EVA transmitter power output.

When the EVA-to-SC separation is large, the received signal level at EVA receiver will be low. This condition is sensed and used to set the EVA transmitter power to the maximum level required for EVA-to-SL link. When the EVA-to-SC separation is minimum, the EVA receiver level is high, and this condition is sensed and used to reduce EVA transmitter power output. In theory this adaptive power control would result in constant power at to SC from each EVA independent of EM-to-SC separation. From calculations of maximum signal levels which can be tolerated for a state-of-the-art mixer, the dynamic range must be reduced by +15 - (-31) = 46 db ≈ 50 db

This requires that the EVA transmitter power be capable of a 50-dB reduction from maximum. The EVA transmitter power could be reduced by bypassing the PA and then switching in an attenuator. The power control sequence could be as follows:

1. When EVA/SC range decreases from 10 miles to 1 mile, EVA and SC receive levels increase by 20 dB if transmitter power remains constant.
2. This 20-dB increase in EVA receive power is sensed, and causes EVA transmitter power to decrease by, say, 10 dB. This will result in a 10-dB decrease in SC receive level, resulting in SC input power change of only 10 dB for the 10:1 range reduction.
3. When EVA/SC range changes from 0.01 mile to less than 0.01 mile, the EVA and SC receive level increases by 20 dB or greater. This 20 dB or greater increase in EVA receive power is sensed and causes the EVA transmitter to decrease by another 40 db which will decrease SC receive level by 40 db. This level control is illustrated in Figures 6-7 and 6-8.

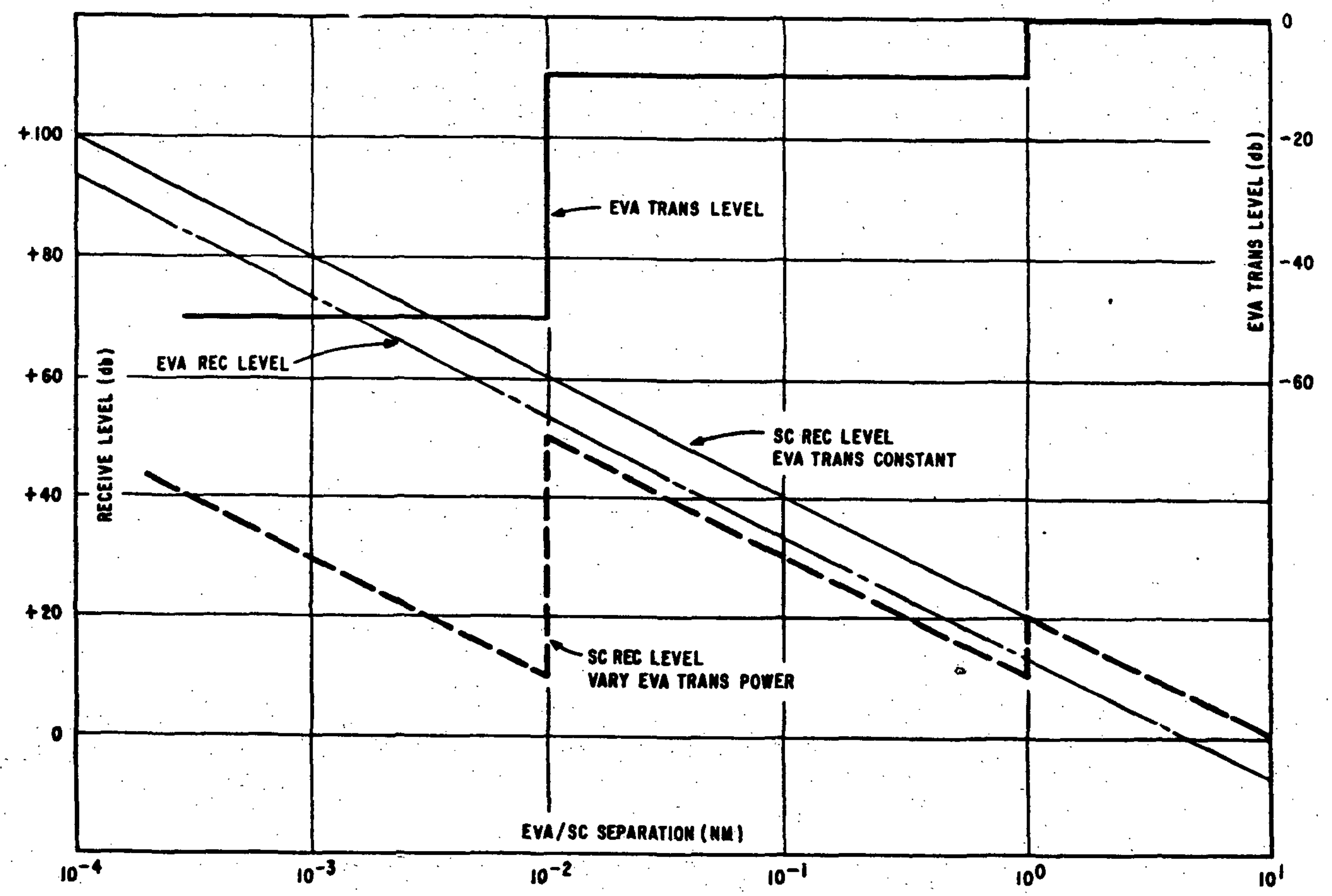


FIGURE 6-7. ADAPTIVE POWER LEVEL CONTROL

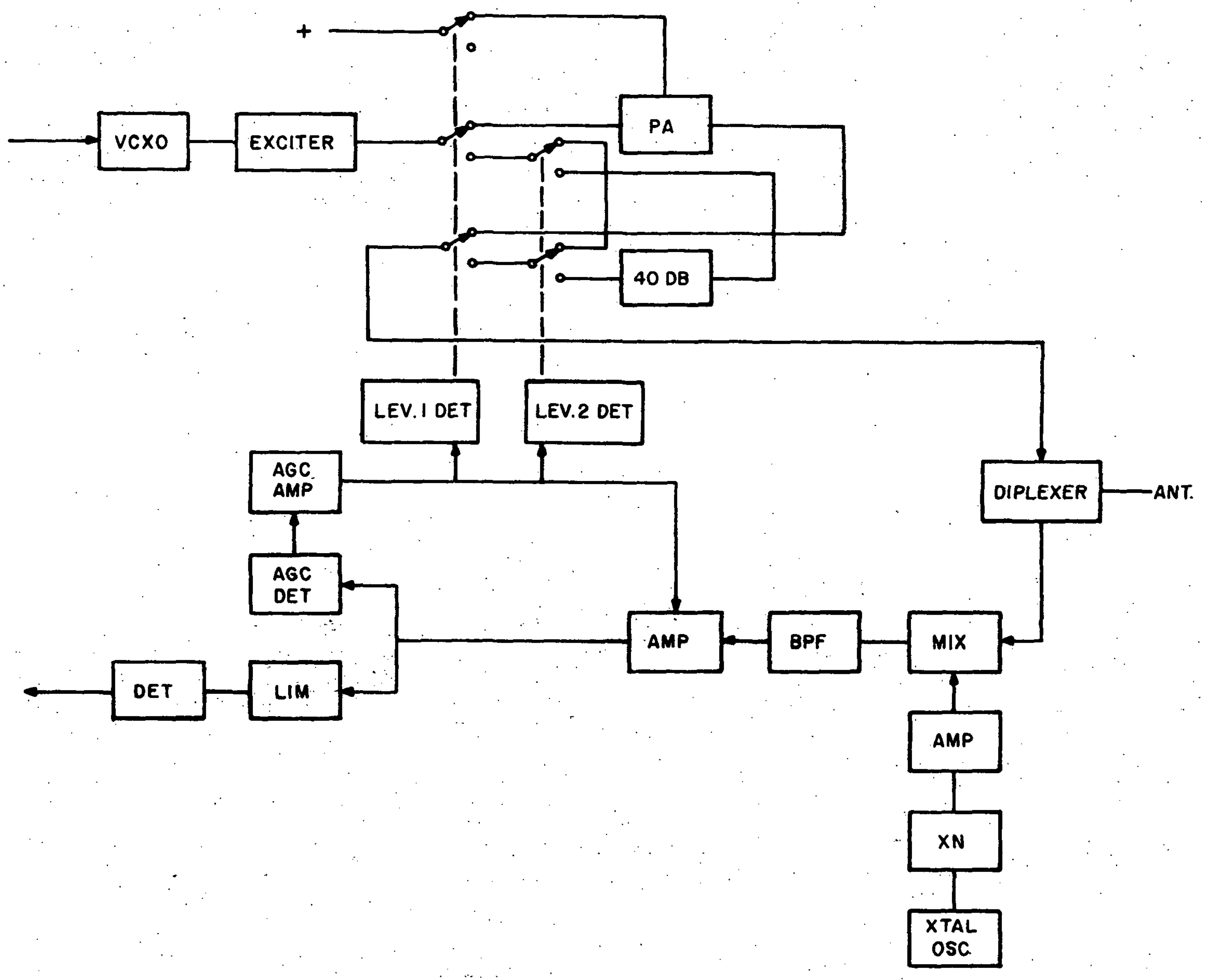


Figure 6-8. EVA Power Level Control

6.12 MINIMUM REQUIRED EVA POWER OUTPUT VARIATION

If an RF amplifier can be constructed having an intercept point equal to that of a balanced mixer, an RF amplifier should be used to reduce system noise figure and therefore required transmitter power. The third-order products (P_3) will be 3(I-F) dB below the intercept point (I); F is the fundamental level in dbm.

Thus $P_3 = 3(I-F)$

For P_3 equal to the dynamic range which is Pmax - Pmin, then

$$P_{max} - P_{min} = 3(I - P_{max})$$

$$P_{max} = \frac{3I + P_{min}}{4}$$

Pmin will be determined by the system noise figure, etc.

For an RF amplifier having equal response at the desired and image frequencies, a filter must follow the amplifier to reject the image noise.

From Figure 3-9,

$$F_{tot} = \frac{F + 36.8}{G_1}$$

For $F_1 = 4.5$ dB (x 2.8) G = 27 dB (x 500)

$$F_{tot} = 2.8 + \frac{36.8}{500} = 2.8 + 0135$$

$$= 2.87$$

$$F_{tot} = 4.6 \text{ dB}$$

From previous calculation (para. 6.8) the minimum carrier level for SNR = 19 dB, etc.

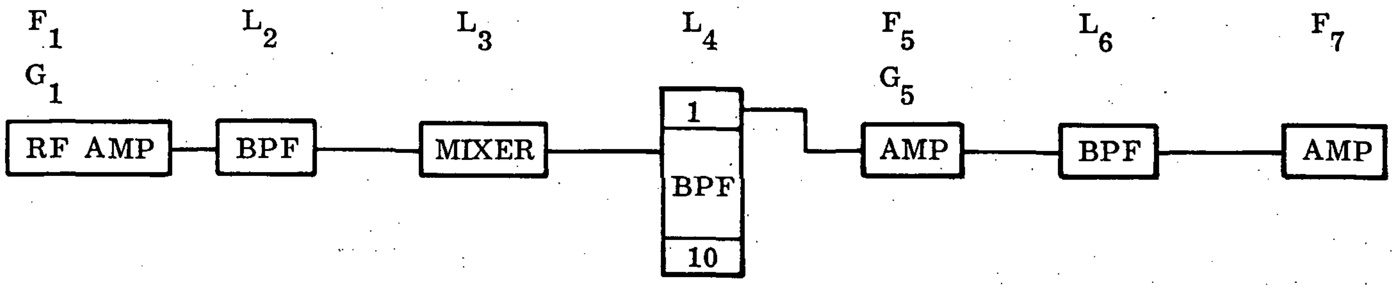
Pmin = FdB -103.2 dBm

For F = 4.6

Pmin = -98.6 dBm

Since $P_{max} = \frac{3I + P_{min}}{4} = \frac{3I + (-98.6)}{4}$

$$= 0.75 \; I - 24.7$$



$$F_{TOT} = F_1 + \frac{L_2 - 1}{G_1} + \frac{L_2}{G_1}(L_3 - 1) + \frac{L_2 L_3}{G_1}(L_4 - 1) + \frac{L_2 L_3 L_4}{G_1}(F_5 - 1) + \frac{L_2 L_3 L_4}{G_1\ G_5}(L_6 - 1) + \frac{L_2 L_3 L_4 L_6}{G_1\ G_5}(F_7 - 1)$$

For $L_2 = 1$ db (x1.26) $L_4 = 3$ db (x2) $G_5 = 10$ db (x10) $F_7 = 1.5$ db (x1.41)

$L_3 = 9$ db (x8) $F_5 = 1.5$ db (x1.41) $L_6 = 6$db (x4)

$$F_{TOT} = F_1 + \frac{1}{G_1}\left[(1.26-1) + 1.26(8-1) + 1.26(8)\ (2-1) + 1.26(8)\ (2)\ (1.41-1) + \frac{1.26(8)(2)}{10}(4-1) + \frac{1.26(8)(2)}{10}(1.41-1)\right]$$

$$= F_1 + \frac{1}{G_1}\left[0.26 + 1.26(7) + 1.26(8) + 1.26(8)(2)(0.41) + 1.26(8)(0.2)(3) + 1.26(8)(0.2)(4)(0.41)\right]$$

$$= F_1 + \frac{1}{G_1}\left[0.26 + 8.8 + 10.1 + 8.25 + 6.05 + 3.3\right]$$

$$F_{TOT} = F_1 + \frac{1}{G_1}\left[36.8\right]$$

Figure 6-9. Noise Figure Model

6.12 (Continued)

For an amplifier with I = +20 dBm

$$\begin{aligned} \text{Pmax} &= 0.75\ (20) - 24.7 \\ &= 15 - 24.7 \\ &= -9.7\ \text{dBm} \end{aligned}$$

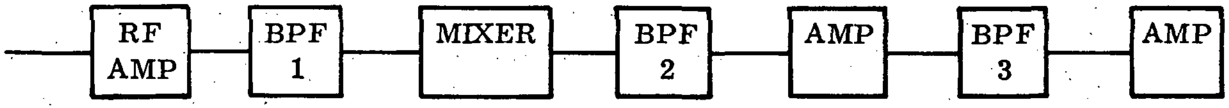
Two signals each at -9.7 dbm, produce an instantaneous power of

$$-9.7\ \text{dBm} +3 +6 = -0.7\ \text{dBm}$$

In order for the channels not to exceed -0.7 dBm, the per-channel level must be less than -0.7 -10 -13=-23.7 dBm at the amplifier output. The input level will therefore be 27 dB below -23.7 dBm or -50.7 dBm. To prevent maximum signal level from exceeding -50.7 dBm, provisions must be made in the EVA transmitter to reduce power by -50.7 -(-98.6) = 47.9 dB.

This reduction in dynamic range from 105 dB to 48 dB also permits use of less complex channel selection filters.

A level diagram for this configuration is shown in Figure 6-10. The EVA-to-SC link analysis is given in Table 6-1.



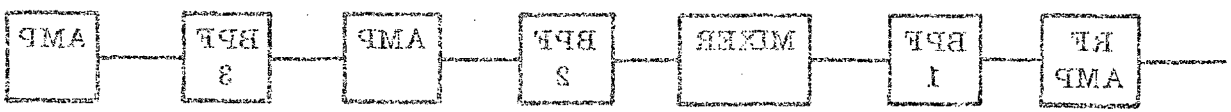
	RF AMP	BPF 1	MIXER	BPF 2	AMP	BPF 3	AMP
GAIN (db)	+27	-1	-9	-3	+10	-6	
$P_{MIN/CH}$ (dbm)	-98.6	-71.6	-72.6	-81.6	-84.6	-74.6	-80.6
$P_{MAX/CH}$ (dbm)	-50.7	-23.7	-24.7	-33.7	-36.7	-26.7	-32.7
P_{TOT} (dbm)	-40.7	-13.7	-14.7	-23.7	-70.7	▷1 -60.7	-80.6 ▷3
P_{INST} (dbm)	- 27.7	-0.7	-1.7	-10.7	-64.7	▷2 -54.7	-80.6 ▷3

▷1 -33.7-40+3 = -70.7 dbm from CH N-1 & N+1 @ -40 db

▷2 -70.7 + 6 = -64.7 dbm

▷3 BPF 3 REJECTS CH N.1 & N-1

Figure 6-10. SC Level Diagram (With EVA Trans Power Control)



	RF AMP	BPF 1	MIXER	BPF 2	AMP	BPF 3	AMP
GAIN (db)	+27	-1	-9	-3	+10	-6	
$P_{MIN/CH}$ (dbm)	-98.6	-71.6	-72.6	-81.6	-84.6	-74.6	-80.6
$P_{MAX/CH}$ (dbm)	-50.7	-23.7	-24.7	-33.7	-36.7	-26.7	-32.7
P_{TOT} (dbm)	-40.7	-13.7	-14.7	-23.7	-70.7 △1	-60.7	-80.6 △3
P_{INST} (dbm)	- 27.7	-0.7	-1.7	-10.7	-64.7 △2	-54.7	-80.6 △3

△1 -33.7-40+3 = -70.7 dbm from CH N-1 & N+1 @ -40 db

△2 -70.7 + 6 = -64.7 dbm

△3 BPF 3 REJECTS CH N,1 & N-1

Figure 6-30 SC Level Diagram (With EVA Trans Power Control)

TABLE 6-1. EVA-TO-SC LINK ANALYSIS

			1.25 GC	2.35 GC
Propagation Loss (10 mm)		(dB)	120.2	125.6
EVA/SC Line Loss		(dB)	4.0	4.0
EVA/SC Diplexer Loss		(dB)	3.0	3.0
Total Loss		(dB)	127.2	132.6
Thermal Noise (F = 0 dB)		(dBm/KHz)	-144	-144
Noise Figure		(dB)	4.5	4.5
Receiver Noise		(dBm/KHz)	-139.5	-139.5
Rec. Level for 10 dB CNR		(dBm/KHz)	-129.5	-129.5
Rec. Level (9 dB margin)		(dBm/KHz)	-120.5	-120.5
Total Loss			127.2	132.6
Transmit Power		(dBm/KHz)	+6.7	+12.1
EVA Transmit Power	(BW = 75 KHz)	(dBm)	+25.4	+30.8
EVA Transmit Power	(BW = 150 KHz)	(dBm)	+28.4 (0.69w)	-
(EVA Freq. ±0.003%)	(BW = 216 KHz)	(dBm)	-	+35.4 (3.5w)
SC Transmit Power	(BW = 750 KHz)	(dBm)	+35.4	+40.8
SC Transmit Power	(BW = 800 KHz)	(dBm)	+35.7 (3.7w)	-
(EVA Lo ±0.003%)	(BW = 890 KHz)	(dBm)	-	+41.5 (14.1w)

6.13 SC-TO-EVA LINK

This link is subject to the assumed 105 dB variation in received power level, since the EVA receiver is subject to a single carrier, instead of a multiplicity of carriers. Automatic gain control(AGC)can be used to prevent receiver overload. To minimize SC transmitter power requirements, the EVA receiver noise figure should be minimized.

Figure 6-11 illustrates the levels which would exist for linear operation with and without an RF amplifier. The noise figure is degraded 9 dB when an RF amplifier is not used, which requires that the SC transmit power be increased by 9 dB (X 9.5).

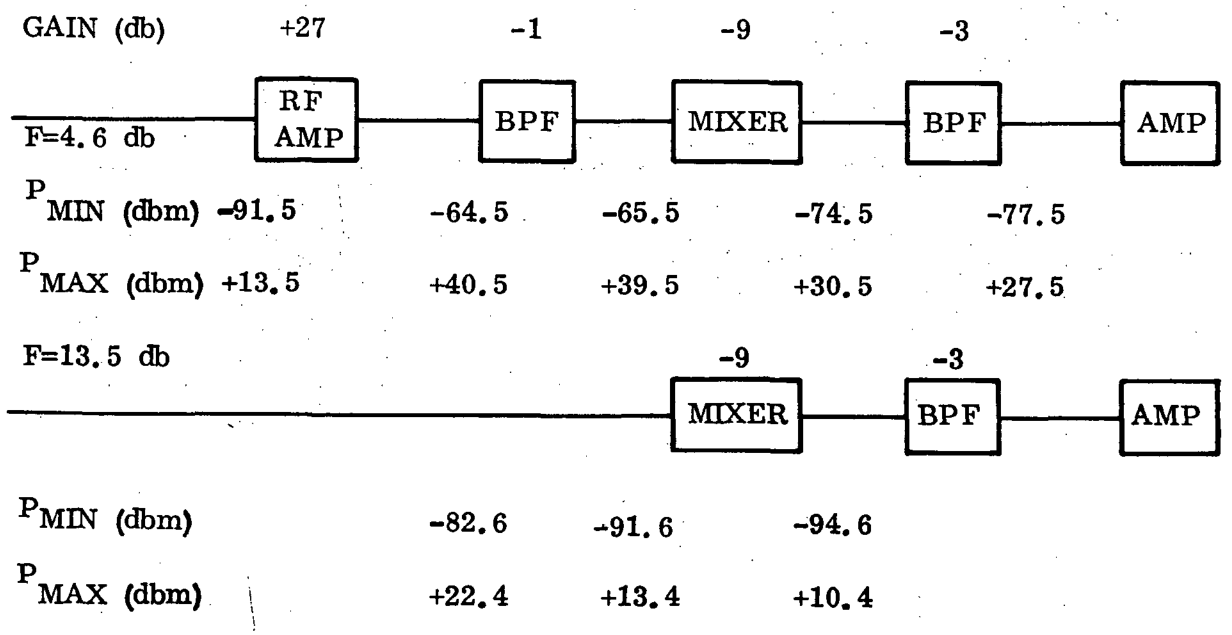


Figure 6-11. EVA Level Diagram (Linearity Assumed)

6.14 SC CONCEPTS

Figure 6-12 shows the transmitter consisting of a VCXO multiplied up to the final RF frequency. The receiver local oscillator is provided by a crystal oscillator multiplied up to the required RF frequency. For a frequency deviation of ±100 KHz at the final RF frequency, the deviation relative to RF frequency is $\pm 100\ (10)^3/1300(10)^6 \times 100\% = \pm 0.008\%$. Incidental FM can result in a low signal-to-noise ratio due to this low percent deviation.

The circuit shown in Figure 6-13 generates the FM signal at a relatively low frequency (85 MHz) and is upconverted to the final RF frequency. This approach permits use of a common local oscillator and the percent deviation is $\pm 100(10)^3/85(10)^6 \times 100\% = 0.12\%$.

Figure 6-14 shows the proposed SC block diagram.

6.15 EVA CONCEPTS

Figure 6-15 shows the multiplied VCXO approach which results in a percent deviation of $\pm 20\ (10)^3 \times 100\% = \pm 0.002\%$. Figure 6-16 shows the upconverted common local oscillator approach which results in ±0.02 percent deviation.

Figure 6-17 shows the proposed EVA block diagram.

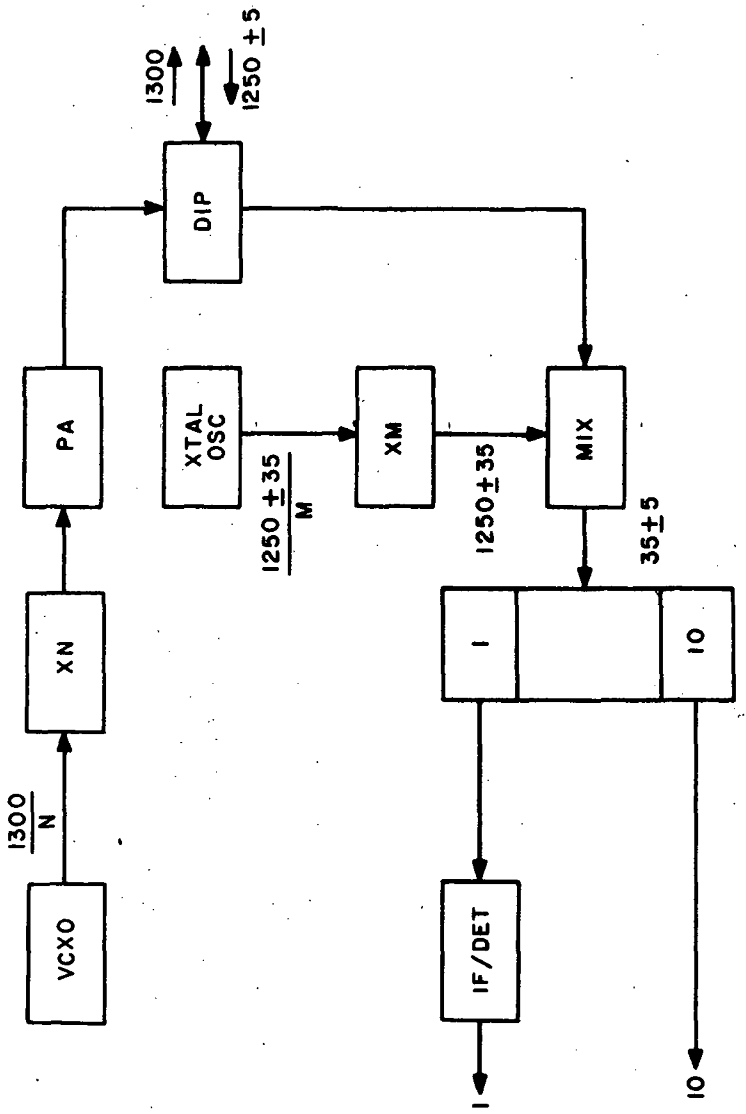


Figure 6-12. Spacecraft Concepts (1)

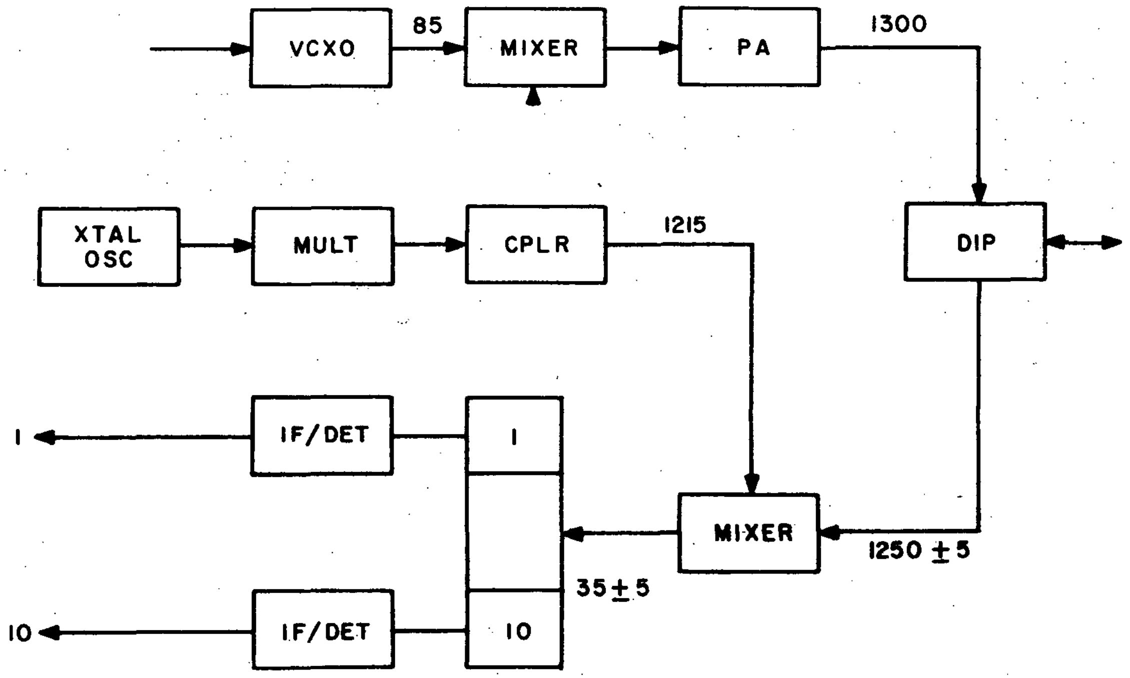


Figure 6-13. Spacecraft Concepts (2)

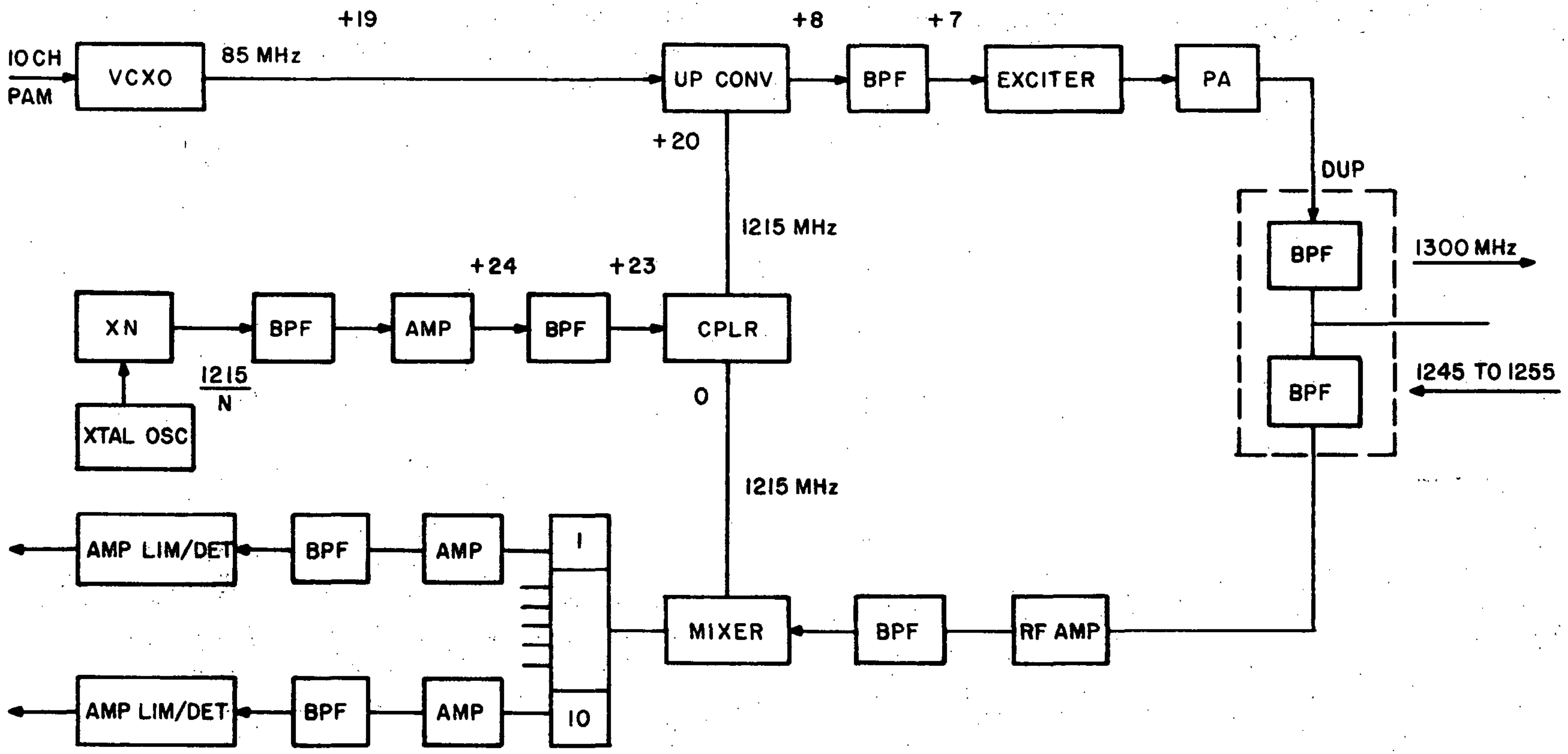


Figure 6-14. Spacecraft Block Diagram

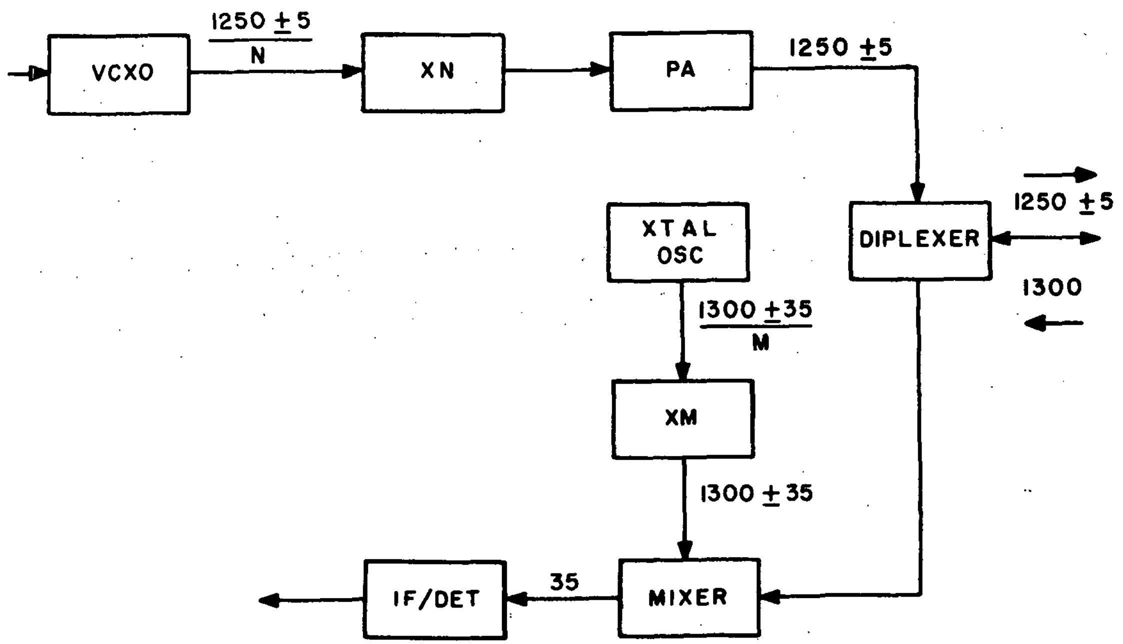


Figure 6–15. EVA Concept Type 1

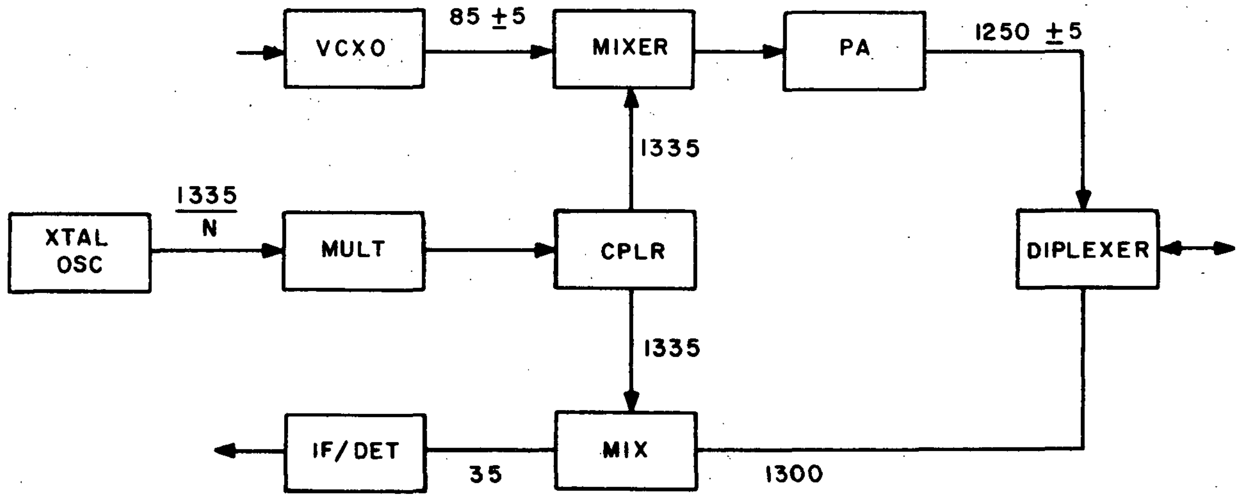
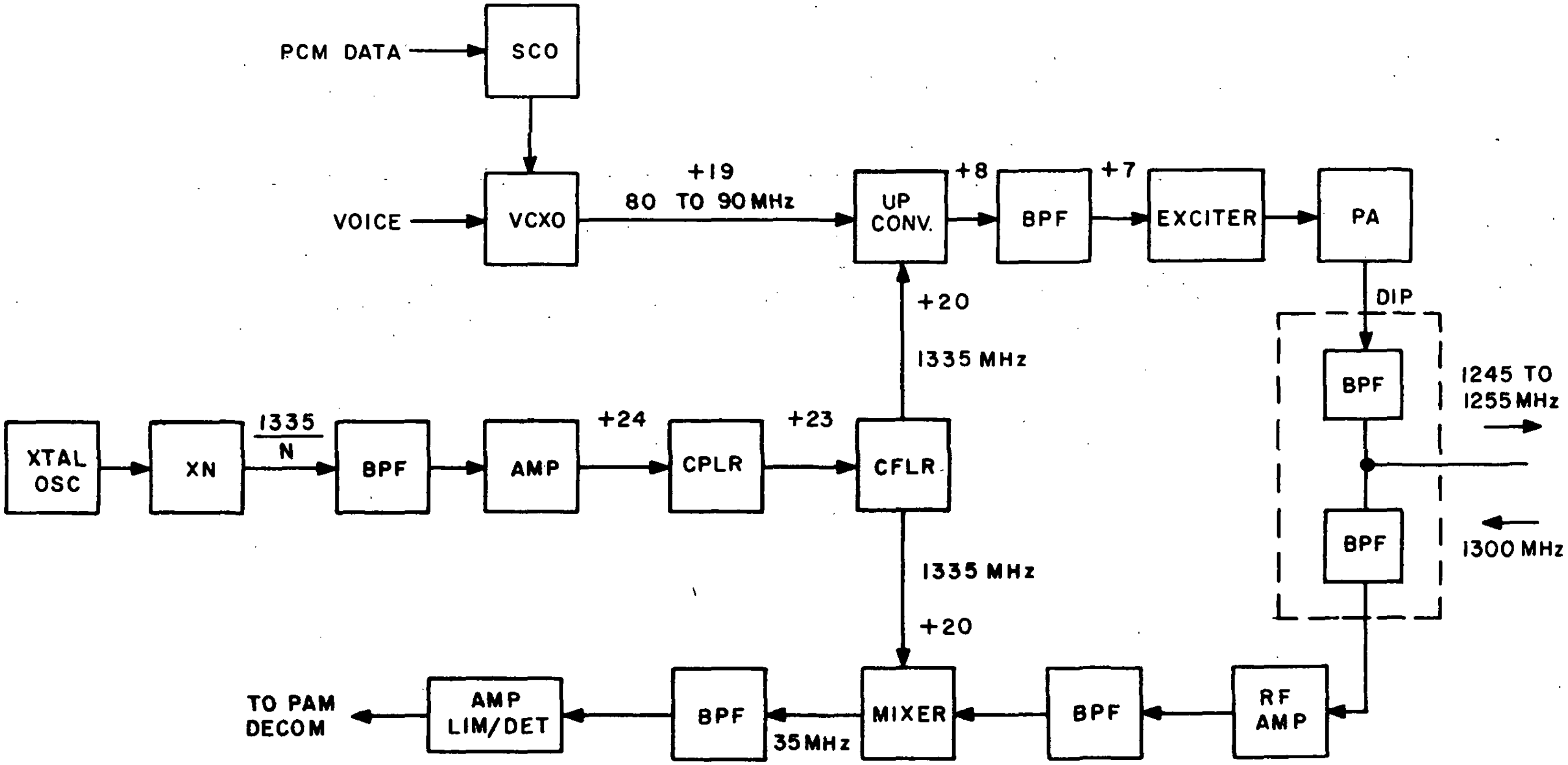


Figure 6-16. EVA Concept Type 2



ALL EVA EQPT THE SAME EXCEPT FOR VCXO FREQUENCY

Figure 6-17. EVA Block Diagram

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IMAGE TERMINATED MIXERS

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SECTION 7

SYSTEM RELIABILITY AND SAFETY

This section summarizes the results of the reliability and safety aspects of the study effort. The reliability and safety factors are presented together because of their natural overlap duringthe system evaluation/definition phase. Subsequent phases should focus separate attention on the techniques and specific aspects associated with reliability and safety, detailed FMEA, reliability modeling and prediction, component/part selection, hardware and astronaut safety (sharp edges, voltage levels, etc.).

7.1 RELIABILITY AND SAFETY FACTORS INCLUDED IN SYSTEM STUDY

The purpose of the Multi-EVA Communications System (MECS) is to provide voice communications between Extra Vehicular Astronauts (up to 10) and the Shuttle Space Craft (SC) and conversations with other parties (ground controllers other orbiting spacecraft up to 25 total) and to provide EVA biomed data to the SC.

For purposes of this study only the EVA/SC/EVA link was evaluated.

The main objective of the study effort was to determine a feasible system. Part of this effort included selection of suitable frequencies because of the VHF Band restrictions. In obtaining a first cut at weight/powers estimates for the selected L-band frequency system a single thread system was evaluated. That is, the weight/power estimates were obtained without any consideration toward reliability/safety improvement via redundancy, back-up modes, etc.

In evaluating the baseline system from a Reliability/Safety standpoint the following criteria were applied:

1. EVA Transmission to Spacecraft includes:
    a. Voice (2 way)
    b. Biomed Data
    c. Primary Life Support System Status: i.e., Consumables status, battery voltage, pressure, temperature, etc.

2. The failure of any EVA PRCS constituted a failure of the mission, i.e., EVA/SC communications is mission critical and crew safety critical.

Based upon the above criteria/assumptions the baseline system was evaluated to determine suitability, feasibility, alternative operational procedures, back-up modes, and hardware redundancy.

7.2 SYSTEM EVALUATION

A flow diagram of the required operating modes for the Multi-EVA Communications System (MECS) as described in paragraph 1.3.3.1 of Exhibit "A" is depicted in Figure 7-1. The personal RF Communicator System (PRCS) to be used by each EVA is shown in Figure 7-2. The system as shown was evaluated first on the basis of L-Band frequency implementation and secondly from a generic standpoint which is independent from hardware implementation and would apply in most cases.

Table 7-1 presents a summary of the critical areas and recommended improvements including redundant features. The detailed supporting rationale is described in the following paragraphs.

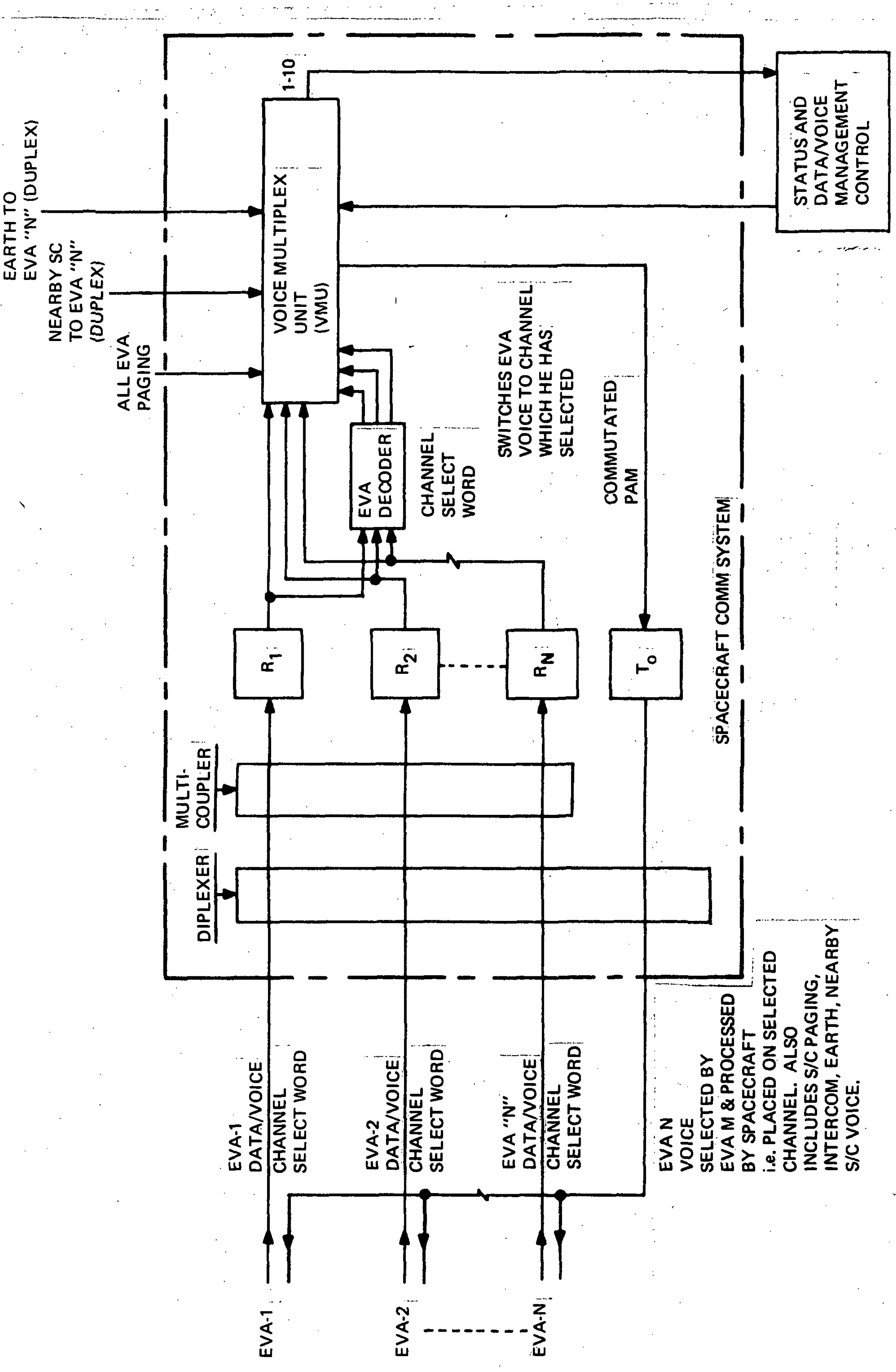

Figure 7-1. Multi-EVA Functional Diagram

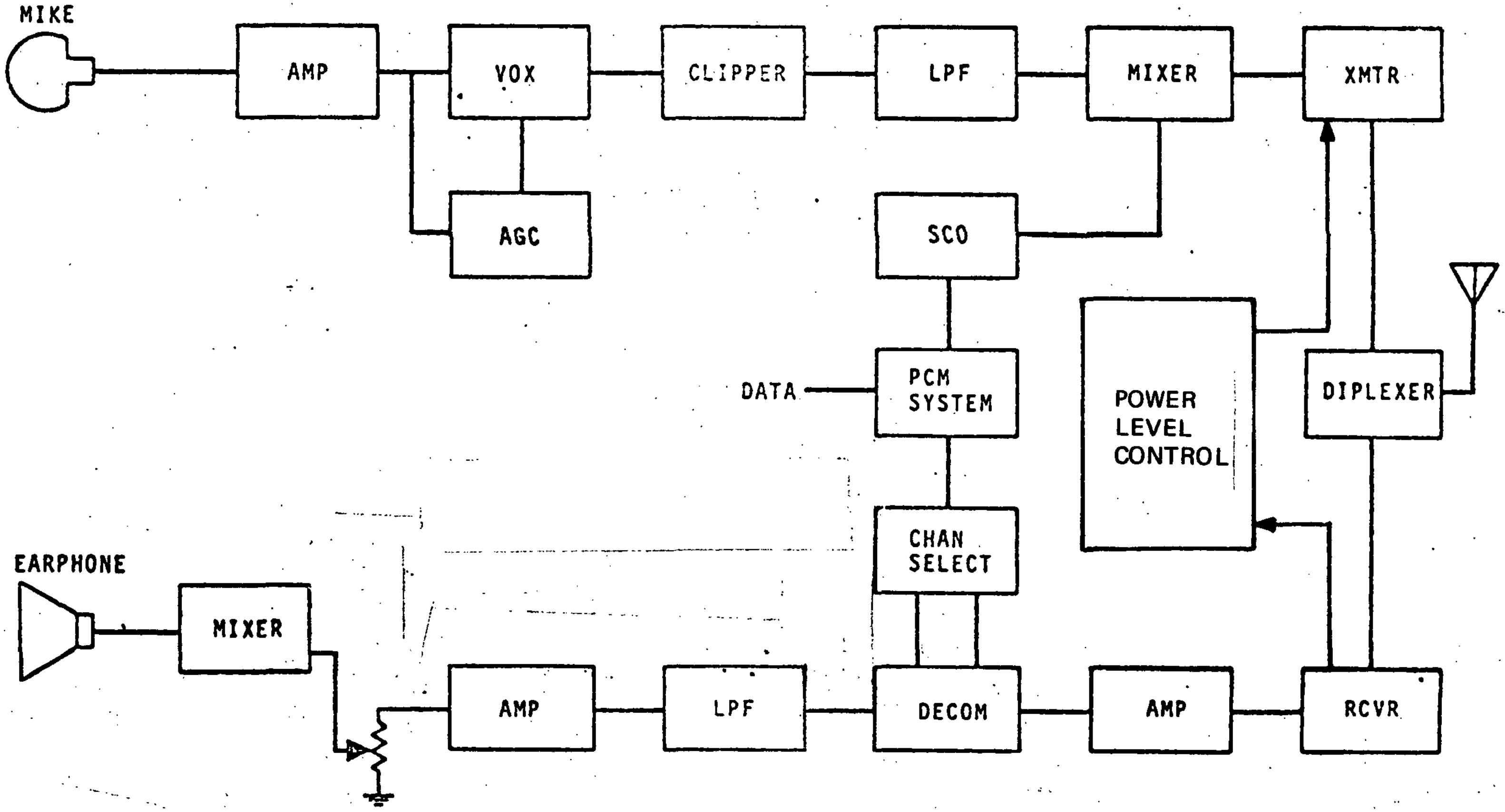

Figure 7-2. Personal RF Communicator System

TABLE 7-1. CRITICAL RELIABILITY/SAFETY FACTORS

HARDWARE/FUNCTION	FAILURE EFFECT	RECOMMENDED IMPROVEMENT
EVA PRCS Receiver/Transmitter	Loss of Communications between EVA N and Spacecraft	Redundant Receivers/Transmitters: Parallel or standby with switching ar fault detection.
EVA PRCS Voltage Regulators	Loss of Communications between EVA N and Spacecraft	Parallel VR's either of which could carry full load in the event of single failure.
EVA PRCS Commutator	Loss of Voice/Data to Spacecraft	Double Commutator channel capacity Cross strap all channels or a select few - Also provides growth capabilit
SC Receivers	Failure of Rn results in loss of communications with all EVA's	1. Redundant Receivers: Either parallel or standby with switching an fault detection. 2. Several spare frequency tunable receivers
SC Transmitter	Failure of transmitter results in loss of communications with all EVA's	Redundant transmitters either paralle standby with switching and fault detection
Status and Data/Voice Management Control	Failure could result in loss of communications with all EVA's	LSI design incorporating error detect and correction majority rating and se test for fault isolation.
EVA/SC Communications	Failure such that EVA communications is precluded	Separate CW Beacon tone from separ SC transmitter would permit EVA to return to SC via increasing tone intensity.

7.2.1 FREQUENCY SELECTION

The system as shown is more or less generic in nature and insensitive to hardware implementation. When interpreted from the results of the system study several undesireable implications are apparent.

The SC receivers as shown in Figure 7-1 are indeed individual to accept the separate EVA transmission frequencies but they are not necessarily independent. The L-Band frequency selection necessitated a multi-channel filter arrangement for separate IF channels. The multicoupler shown in Figure 7-1 can actually be considered as a common receiver RF front-end and the "separate" receivers shown (R_1, R_2, ----R_N) are the separate IF filters. From a reliability/safety standpoint this is undesirable. The common front-end represents a single-point failure. Also, the separate IF's are not necessarily independent, and a failure of any single IF filter channel would affect all others unless sufficient isolation were included via hybrids or other means.

The PRCS shown in Figure 7-2 includes an adaptive RF power control. This enables communications with "close-in" and remote EVAs (10 miles max) simultaneously and is necessitated because of the L-Band wide dynamic range requirements. This feature also presents a potential single-point failure depending upon the failure mode, i.e., catastropic or non-catastropic. Failure could occur such that a near-in EVA could preclude communications from other EVA's (non-catastrophic) or an individual EVA could be disabled (catastropic). The non-catastrophic situation could be remedied by an operational procedure via the SC. The catastrophic failure situation could be remedied via a redundant PRCS or by including the capability to "switch-out" the failed Adaptive Power Control and following the operational procedure for the non-catastrophic failure mode. This would also necessitate a failure sensing device or a self-test feature.

The L-Band selection, to permit optimum use would require the use of directional antennas. From an operational standpoint this is undesirable because it would severely restrict EVA space orientation. Since directional antennas cannot be used, the resultant hardware would be bulky and would have excess power requirements and be inherently less reliable than a more compact low-power system.

The inclusion of redundancies or spare modules, which will be required will further compound the size/power problem.

7.2.2 STATUS AND DATA VOICE MANAGEMENT CONTROL (SMC)

The MECS as depicted in Figure 7-1 is essentially a single thread system. As such virtually every point of the system is a single-point failure. Of particular concern is the Status and Data Voice Management Control. While this function is not defined in Exhibit A, it will be required in order to implement the conversation patching/switching task for 25 conversations, 10 of which may be EVA's.

This function can be performed manually, automatically or a combination thereof. If automated it will involve a computer system. A preliminary evaluation indicates that the SMC could be executed in terms of four or five plug-in modules each about 2" x 2" x 0.5" using Large Scale Integration (LSI) technology. Several attractive aspects could thus be achieved. LSI technology would permit inclusion of such reliability features as error-detection and correction, fault detection and correction (majority voting techniques) and self-test features for fault isolation. LSI technology would permit carrying spare plug-in modules thus providing extremely high reliability per missions for a very small or insignificant weight penalty. Although the SMC is not shown as part of the SC Communications equipment this is recommended, as it would significantly reduce cabling and routing and would permit use of LSI plug-in modules.

7.2.3 PERSONAL RF COMMUNICATOR SYSTEM

The PRCS as shown in Figure 7-2 is also a single thread reliability system. The single-point failure aspects of the adaptive power control portion was discussed earlier under Frequency Selection.

In addition consideration should be given to some form of redundancy of the receivers, transmitters, power sources (voltage/regulator) or an entire PRCS.

Parallel redundancy while less reliable than standby redundancy relieves the astronaut of going through a fault detection, isolation and switching routine. These could be automated but the automation itself constitutes a single-point failure which should also be designed fail-safe. The decision regarding level of redundancy would also depend upon weight limitations. Tradeoffs which would guide such decisions should be accomplished in later program phases.

Another approach would be a single PRCS per EVA with spares being carried on the S.C. There are several constraints associated with this. First the EVA would have to have the capability of monitoring critical PLSS and Biomed status via visual means attached to the space suit while returning for a spare unit. Secondly, all PRCS units should be common for optional sparing.

The last approach considered would be for the EVAs to be working in teams, thus permitting failure of voice communications for most tasks. EVA PLSS/Biomed self-monitoring would be necessary for this or a redundnat transmitter for data transmittal only.

7.2.4 OPERATIONAL CONSIDERATIONS

From a safety standpoint a warning tone should be provided to indicate to the EVA critical PLSS status (expendable) and Biomed Status. This capability is included in the existing Apollo EVCS equipment.

Also from an operational safety standpoint the EVA should have a means of locating and returning to the spacecraft in the event of SC communications failure. This could be implemented via a separate SC cw transmitter which would put out a constant cw tone and a pick-off of the PRCS receiver AGC to a variable intensity tone to the EVA.

SECTION 8

CONCLUSIONS

The study objective was to provide an analysis of the NASA "candidate" Multi EVA Communications System intended for use on programs such as Space Shuttle and Space Station. The end product (report) is to provide "an enhanced definition of, and a confidence in the candidate system, allowing prototype hardware development to proceed."

To accomplish the objective, an analysis of the candidate system was conducted resulting in trade-offs in several major areas. First, selection of an available frequency band to accommodate an interference "free" link resulted in L-band for RF transmission. Signal power was examined to accommodate the L-band propogation loss and also the wider bandwidth oscillator instabilities. The spacecraft communication links with "close in" and remote EVA's simultaneously (Dynamic Range) resulted in EVA Terminal adaptive RF power control. The spacecraft receiver mult-channel filter IM product analyses led to an unusual selection of channel allocation within the EVA/spacecraft band and a complex filter configuration. Finally, the candidate system was considered with respect to equipment utility, commonality, mission usage, physical characteristics, power requirements, reliability and safety, and program costs to the Space Shuttle.

It is concluded that the candidate system accommodates most of the required functions. However, certain criteria within the baseline concept do not permit the design of a low-cost optimized system. First and foremost, the use of dedicated multiple RF channels dictates a frequency management problem, creates a complex equipment logistics problem ($10 Million Shuttle weight overhead costs), and impacts the Shuttle communications systems growth capability.

Second, baselining of a microwave frequency band (where omni antennas are employed) results in costly and bulky hardware. Directive antennas cannot be employed here due to the nature of the EVA missions. Thus, the microwave band results in higher prime power consumption because of propagation loss coupled with omni-direction patterns.

Third, the wide dynamic range dictates the need for adaptive RF power control which introduces a serious single-point failure during the most critical portion of an EVA's mission (at long range from his base station).

Finally, the overall Multi-EVA system is not consistent with other Shuttle communications systems. Whereas a common design could allow for modular packages for communications between Multi-EVA to Shuttle and Shuttle to other spacecrafts*, those encountered during the 1977 to 1990 time frame.

A method for overcoming the disadvantages cited here is discussed in the next Section of this Report.

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*Data Communications and ranging for rendezvous as required with unmanned satellites.

SECTION 9

AREAS FOR FUTURE STUDY

The Multi-EVA Communications System Analysis Study has highlighted several items that require further detailed study prior to prototype hardware fabrication. These items fall into two basic categories, those associated with the L - Band frequency multiplexed system (FDMA) or the VHF time division multiple access system (TDMA) these categories with their associated items are listed below with descriptions of the recommended effort to be accomplished in future studies.

9.1 L - BAND MULTI-EVA SYSTEM (FDMA)

Operational complexity with respect to the number of EVA's, frequency assignment and comm channel selection.

Base Station Receiver Design and Breadboard construction

Receiver/Transmitter compatibility with respect to multiple signals, dynamic range and adaptive power control.

Remote automatic operation of the audio matrix for EVA access to Shuttle ICS and Radio Equipment.

Space Shuttle Interfaces with EVA Base Station Equipment in the areas of:

- Control
- IC's
- EVA Data Monitoring
- Performance Monitoring
- On-Board Checkout
- Prime Power
- Antennas and RF Losses
- Power Splitting/Phasing
- Direct Paging

9.1.1 Reliability and Safety

Follow-on phases of the Multi-EVA Communications System definition should include effort in the area of trade-off studies to support final configuration definition, analyses to determine reliability/safety requirements for redundancies, repair and back-up modes and requirements definition to guide hardware design.

a. Configuration Definition - Effort to further define the Multi-EVA Communications System in terms of hardware definition should be accompanied by trade-off analyses to select the optimum reliability/maintainability for the EVA Comm mission. Operational criticality will have to be established. For example, if EVA's work in teams a single EVA Voice Communications failure may be tolerable. Also, the hardware execution may permit carrying two PRCS equipments or the operational situation may permit an EVA to return to the SC for a replacement PRCS. Further, if the EVA's work as teams each PRCS could have a low power back-up xmit/receiver mode with either EVA acting as a relay to the SC.

Regarding the spacecraft system a decision to carry spare tunable Receivers or spare computer modules will significantly effect hardware complexity.

b. Analyses

More detailed FMEA/single-point failure analyses down to lower levels will be required to permit definition of back up modes and lower level redundancies.

Also during hardware definition/design the selection of components and parts or design approaches should be based upon achieving optimum reliability.

c. Requirements Definition

As a result of the trade-off and FMEA analyses and component/design selection effort a definition of the system reliability/maintainability requirements should be developed for inclusion in the system specification.

9.2 TIME DIVISION MULTIPLE ACCESS SYSTEM

Determine the optimum system configuration relative to channel loading, earth based EMI, pulse width and repetition rate, guard channels, and flexibility to allow for expansion.

Analyze synchronous vs non-synchronous techniques. Determine frequency selection, separation between transmit and receive channels, and trade-off diplexing vs. T/R switch.

Perform a duty factor trade-off to optimize link performance vs. input power drain.

Analyze applicable data redundancy coding techniques (assume 19.2 Kb/sec is baseline to be compatible with SGLS requirements). Trade-off delta modulation techniques such as delta mod, delta sigma, variable slope, to determine optimum performance vs. complexity.

Determine methodology for implementing EVA range read out.

Determine methodology for universal TDMA application toward other Shuttle functions such as S/C to S/C voice and data, S/C to S/C ranging, multi-spacecraft and multi-EVA environment.

Investigate applicability of a TDMA scheme to TDRS to overcome multi-path, a voice data link, employ range measurements for S/C's.

Evaluate use of ATC 100-watt radio components (e.g., ARC-152 for use as S/C equipment because of higher duty cycle required.

Synthesize a multi-purpose TDMA comm system which employs a single TDMA technique to accommodate all S/C and EVA functions for voice, data and ranging to encompass the following:

ORB/OSV
ORB/EVA
ORB/TDRS

Select an optimum TDMA system, define the requirements, develop and demonstrate a breadboard.

APPENDIX A

SPECIFICATION
FOR
PORTABLE RADIO COMMUNICATIONS SYSTEM

EXHIBIT A

PRELIMINARY

SPECIFICATION
FOR
PORTABLE RADIO COMMUNICATIONS SYSTEM
(PRCS)

(PART OF MULTI EVA COMMUNICATIONS SYSTEM)
30 JUNE 1972

TABLE OF CONTENTS

1.0 SCOPE

This specification describes the electrical and environmental requirements of a Portable Radio Communications System (PRCS) which is part of the Multi EVA Communications System used for EVA (Extravehicular Activity). The specifications are considered to be the minimum requirement and require that the components described herein shall be entirely compatible with each other. Any portion of the specifications which would create any incompatibility within the system shall be brought to the attention of the Contracting Officer in writing and subsequent corrective action awaited. No deviations shall be permitted without the full written permission of the NASA Contracting Officer or his authorized representative.

2.0 GENERAL

The Multi EVA Communications System shall consist of a maximum of 10 Portable Radio Communication Systems and one (1) Spacecraft Multi EVA Communication Unit. The system shall provide for communications of each astronauts voice and continuous biomedical and Life Support data to the Spacecraft with the Spacecraft being able to decode the data and provide voice communications including conference capability not only with the EVA's and spacecraft's and paging intra vehicular crewman (via the spacecrafts intercom system, crewman of nearby spacecrafts (via air-to-air RF links) ground controller via air-to-ground RF links) and recorded or synthesized speech generated on board.

Each astronauts PRCS unit shall provide a capability of conversation with the spacecraft and selection of conference capability on one channel in addition to his assigned channel. Each PRCS biomedical and PLSS data shall be provided to the Spacecraft on a continuous basis.

The spacecraft EVA Communications unit shall provide voice including conference capability with the participants above and be able to decode the astronauts selection of voice channel to permit conversation accordingly. In addition capability shall be provided to allow announcements which are heard by all EVA crewmen regardless of the conversation in which they are participating.

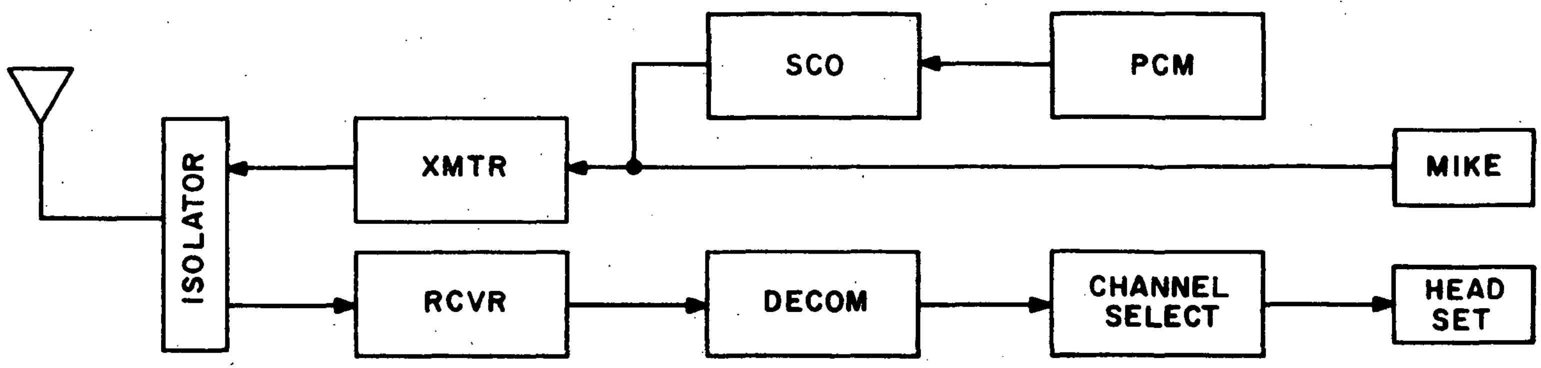

Figure 1. Portable RF Communications System (PRCS), Block Diagram

3.0 OPERATION (Reference Figure 1)

Each Portable RF Communications Unit (PRCS) shall be capable of transmitting the astronauts voice and continuous PLSS data including biomed to the spacecraft. Provisions shall be made for selection by the astronaut of two out of ten voice channel received via the spacecraft 12 channel commutated voice transmission system.

Continuous PLSS and biomedical data shall be combined along with channel selection into a 32 word per frame telemetry which is applied to an 8192 Hz subcarrier. This telemetry input is then combined with the astronauts voice which deviates the FM carrier at ±12KHz for transmission to the spacecraft.

The spacecraft PAM Commutator 12 voice channel information is received by the PRCS and based upon the selection by the astronaut (possible 2 out of 10) the selected voice channel(s) are routed to the headset. All conversations are via the spacecraft.

PRCS Astronaut Controls include power and backup switching, volume control and the selection of any two of the ten channels for conversation.

Provisions are also made for a telemetry/PRCS warning tone which is applied to the headset in the event of a significant malfunction in the PLSS or the PRCS.

3.1 Transmission

3.1.1 Voice

The voice input circuitry shall be:

Nominal Input Voice Level:	0 dBm (microphone)
Dynamic Range of Voice	-9dBm to +12 (with +25 dBm as a Design Goal)
Noise Level:	-30 dBm nominal, with an expected maximum of -24 dBm

3.1.2 Frequency Response

The frequency response of voice shall be 200 cps to 2.0KHz ±2dB referenced to 1 KC with filter roll off more than 40 dB per octave above 2 KHz.

3.1.3 VOX

The voice operated switch shall switch the voice input to transmitter.

3.1.3.1 VOX Attack and Release Time

The Attack and Release times shall be set for intelligible voice communications. Attack and Release times shall be less than .5 Msec. at 1 KHz. Release time shall be between .4 and .6 seconds. The VOX must be capable of recycling within 1 millisecond after release.

3.1.3.2 VOX Sensitivity

The VOX shall actuate with a sine wave signal level of (±2dB) as adjusted by a fixed internal accessible resistor.

3.1.4 Automatic Volume Control (AVC)

The Microphone voice signal shall be VOX enabled and shall hold a constant output level (±2dB) at the clipper input over an input range from TBD dBm to TBD dBm. The no signal gain of the AVC shall be a maximum of TBD dB. The attack and release times shall be set for intelligible voice communications.

3.1.5 Clipper

The 12 dB maximum of peak clipping shall be provided. This shall be adjustable (within ±1dB) by an internal accessible fixed resistance. A low pass filter shall follow the clipper with a response sufficient to provide a demodulated subcarrier data output equivalent to a BER of 10^{-6} or better. This applies for any specified voice input.

3.1.6 Telemetry

Each telemetry, subsystem shall consist of a PCM coded system and a 8/92 Hz subcarrier. The input impedance of the commutator and VCO shall be a minimum of 1 megohm.

3.1.6 continued

Each telemetry and associated subcarrier Oscillator shall be as follows:

Telemetry/Subcarrier Oscillator

Frame Length: 32 words per frame

Word Length: 8 bits per word

Bit Rate: 256 bits per sec ±.005%

Format: Word 1 and 2 Frame Sync - 0000010111001111, MSB First

Word 3 PAM decommutator channel select.

Bits 1 thru 4 - selected channel, binary positive true logic.

Bits 5 thru 8 - inverse of bits 1 thru 4

Words 15 and 16 - automatic test words

15 - 01101111

16 - 10010000

Words 4 thru 14, 17 thru 32-binary data

Modulation - 8192 Hz ±.005% coherent phase shift

Key (PSK) split phase - S(SO-S). 8192 Hz 180°

Phase Shift Change at SO-MID signal crossing.

3.1.6 continued:

Output Level: The 8192Hz subcarrier shall deviate the FM transmitter 8 KHz peak maximum.

The PCM signal must be of a quality and format such that it can be easily decommutated in any Space Shuttle Orbiter or Space Base. These requirements shall be met under all conditions specified in this document.

3.1.7 Transmitter Output

Each PRCS transmitter frequency shall be selected from the frequency band of 1219 to 1240 MHz. The frequency shall be selected to provide a maximum isolation and rejection with the respective band and those related in the receive band of 1289 to 1300 MHz.

Each of the ten selected frequency shall have the following transmitting characteristics:

Frequency Stability:	±0.005%
Output Power:	0.7 watts minimum
Modulation:	True FM
Deviation:	Voice 12 kHz peak Subcarrier 8 kHz peak
Modulation Distortion:	3% maximum
Incidental FM:	Less than 2 KHZ pp dc to 5 KHZ
Spurious Emission:	Meets IRIG 106-70

3.2 Reception

3.2.1 Receiver Frequency

The Receiver Frequency shall be selected within the band of 1289 to 1300 MHZ and shall be common to all PRCS unit. The frequency shall be selected to provide a maximum isolation and rejection with the respective frequency band and those related in the transmit frequency band.

In addition the receive shall have the following characteristics:

Center Frequency Stability:	±0.005%
Sensitivity:	96dBm carrier provides 20 dB quieting
Modulation:	True FM
Dynamic Range:	113dB

3.2.2 Squelch

The receivers shall be squelched when the RF carrier is absent or below a useful level. The squelch level and unsquelch level shall be TBD.

3.2.3 PAM Voice Commutator Output

The 12 x 8,000 sample per second RZ received commutator voice input must be routed by channel selection to the astronauts headset for reception. Choice of any two out of ten channels made by the astronaut shall be routed accordingly.

3.4.2.5 Telemetry Voice Crosstalk

The telemetry shall be filtered out of the audio input to the headset such that the TM is at least 30dB below the received voice level.

3.3 Sidetone

Attenuated voice modulation of the transmitter shall be mixed with the audio output. The sidetone (or pseudo-sidetone) shall be 10 ±3dB below the received voice level as adjusted by the volume control.

3.4 Warning System

The warning system shall consist of a 1.5kc audio tone (modulated by 15 cps) that is remotely activated by a switch with contact resistance of 0 to 1,000 ohms. The output of the tone generator shall be 2 ±.5 milliwatts into a 300 ohms balanced load.

3.5 Antenna

The omni-directional antenna (nominal impedance of 50 ohms) will be subject to shorting to the spacecraft structure during on-board checkout and egress operations. The unit shall be designed to withstand open or short circuit antenna conditions; without permanent damage for up to 4 hours; and allow performance within specification with VSWR's of up to 10:1 at any phase angle. (The radiated power is allowed proportional reduction as a function of voltage standing wave ratio). The antenna shall be shared simultaneously with up to

3.5 continued

two transmitters and up to two receivers. Each transmitter or receiver must be sufficiently isolated from each other to allow system performance, as specified in this done

3.6 Range

The spacecraft Multi-EVA Communications unit shall be capable of meeting the specified performance herein when used in the Multi EVA Communication System with the Portable Radio Communications Systems (PRCS) operating at physical distance of 1 foot from spacecraft antenna up to 10 nautical miles - away-line of sight.

The above applicable specifications also apply to the backup and primary links. These specifications shall be met under all conditions specified in this document without violating the IRIG Standards, dated March 1966.

3.7 Electromagnetic Interference

The unit shall meet the requirements of MSC-IESD Document 19-3A. The audio conducted susceptibility requirement shall be 1.1 volts peak-to-peak over a frequency range of 30 Hz to 17 KHz.

3.8 Power

The maximum input power requirements for each PRCS shall not exceed TBD amperes (not including regulated power delivered to the transducers) under any combination of environmental conditions and over a voltage range of ____ to ____ VDC. Reverse polarity protection is required on the power input within the PRCS.

3.9 Controls

All controls shall be remote to the PRCS and shall be astronaut operated. A mode selector switch shall control the operational modes which are: (1) Off, Test, Primary and (2) Secondary. A push-to-talk (PTT)/voice operated transmit (VOX) switch will select a PTT mode or a VOX operation of the voice input to the primary transmitter or secondary transmitter carrier, as shown in Figure 2. Volume control of each receiver output shall be provided by a remote 10,000 ohm potentiometer. The receiver output power shall be delivered to a 600 ohm balanced load and shall be adjustable from .1 milliwatts maximum at the minimum setting to 50 ±10 milliwatts at the maximum setting. In addition external controls shall provide capability to select any two of 10 channels for voice communications, thereby permitting conversation with others including astronauts on a selected basis.

3.10 Headset

The headset that will be used with the PRCS is Government equipment and will have the following characteristics.

3.10.1 Microphones

3.10.1.1 Output Impedance

600 ohms balanced.

3.10.1.2 Frequency Response

300 cps to 5Kc. (Response of Microphone)

3.11 Earphones

3.11.1 Input Impedance

600 ohms balanced.

3.11.2 Maximum Audio Input

60 milliwatts.

3.11.3 Warning Tone Input Impedance

300 ohms balanced.

3.12 Signal Conditioning

Each PRCS shall be required to supply separate regulated voltages to TBD groups of up to TBD transducers each. Each regulator shall provide short circuit protection to the battery by limiting the transducer current to 3 times nominal.

3.12.1 Transducer Output Signal

All transducer measurements initiated within the PRCS shall be conditioned to 0-5 volts for modulation of the telemetry channels.

All transducer measurements initiated external to the PRCS shall be conditioned to 0-5 volts at the external interface.

3.13 Physical Configuration

The Physical Configuration shall be in accordance with the outline and mounting drawing TBD. The unit including connectors and connector protective covers, shall be a maximum of ______ lbs.

Heat dissipation from the unit will be primarily by conduction through its mounting interfaces. Sufficient cooling shall be provided to maintain the unit at no greater than a maximum unit mounting base temperature of 120°F.

3.14 Connectors

The connector selection, location, and pin assignments shall be in accordance with the outline and mounting drawing.

3.15 Environmental

The system shall be capable of meeting all specifications defined in this document under the following environmental conditions.

3.15.1 Temperature

The unit shall operate as specified over the temperature range of +20°F to +120°F, (130°F for 1 hour) as measured at the baseplate. Each unit shall survive storage temperatures of -65°F and +180°F.

3.15.2 Pressure/Vacuum

No structural damage, performance change, or electrical arcing shall occur over the pressure range of from 21 psia down to 10^{-14} millimeters of mercury.

3.15.3 Acceleration

The unit shall perform as specified under acceleration of 20 g's for 2.5 minutes per direction both direction of each of three perpendicular axes.

3.15.4 Shock

The unit shall perform as specified while being subjected to a 15g shock. The specified shock levels apply to each of three mutually perpendicular axes and shall have a trapezodal waveform with a 10 - 11 millisecond rise time and 0 - 1 millisecond decay time.

3.15.5 Vibration

The unit shall operate as specified while being subjected to the following vibration tests:

Vibration Levels

A. Resonance Search

TBD

B. Launch and Boost

The Launch and Boost vibration levels shall be determined from the mounting and second structures levels of the space vehicle where in the units are stowed during the mission.

3.15.6 Oxygen Atmosphere

The unit shall be unaffected by a 95 - 100% O_2 atmosphere at 5 psia to 21 psia for up to 30 days. The unit shall not support combustion under these conditions.

3.15.7 Humidity

The system shall be operative and unaffected by 100% humidity in a temperature range of 26°C to 70°C cycled as in MIL-STD-810A (USAF), Method 507.

3.15.8 Salt Fog

The unit shall perform as specified while being subjected to a salt fog (1% by weight) as described in MIL-STD-810A, Method 509.1, Procedure 1.

3.15.9 Shelf Life

The systems shall be capable of meeting all specifications for a period of ten (10) years of storage including 1,000 operating hours after delivery to the Government.

3.16 Interfaces

Interfaces are to be in accordance with the outline and mounting drawing.

4.0 CERTIFICATION TEST REQUIREMENTS

The requirements of ASPO-RQA-11A, applicable to this contract, are only those sections of ASPO-RQA-11A that relate to electronic equipment. The manner in which these requirements are implemented shall be in accordance with the detailed test plan for qualification test to be prepared by contractor and approved by the NASA Contracting Officer. Any deviation from this document must have prior approval of the Contracting Officer. The intent of the following subparagraphs is to define the environmental test conditions to be imposed within the scope of ASPO-RQA-11A. Unless otherwise indicated, the equipment shall be continuously operated and all modes of operation monitored.

4.1 Design Proof Qualification

4.1.1 Thermal/Vacuum (Operating)

The PRCS shall be subjected to a pressure of 10^{-5} mm of mercury for the test duration. The temperature of the chamber and heat sink shall be 20°F for TBD hours and 120°F for TBD hours. The unit is to be turned off and the chamber temperature increased to 130°F. After the unit is allowed to stabilize, the unit shall be turned on and operated for TBD hour.

4.1.2 Shock

This test is to be conducted per MIL-STD-810, Method 516, Procedure I. Modify the shock pulse to a sawtooth with a 40g

4.1.2 continued:

peak and an 11 ±1 m. sec. rise and 1 ± 1 m. sec. decay on both directions of each of three axes.

4.1.3 Vibration (Operating)

Vibration shall be as specified in paragraph 3.16.5 for a duration of five minutes per axis.

4.1.4 Leak Rate (Non-Operating)

A leak rate consistent with the Shuttle mission requirements shall be demonstrated at a vacuum of 10^{-4}mm of mercury.

4.1.5 Corrosive Contaminants, Oxygen and Humidity

The unit shall be subjected to 1% (by weight) salt fog in accordance with MIL-STD-810 for one hour. Then, the chamber is back filled (from 20mm of mercury) with commercial oxygen (95 ± 5%) to 5.0 ± .2 psia. The temperature of the chamber is held at 120°F ±10°F for 12 hours. With the oxygen environment at 5 psia, introduce a relative humidity of 95% ± 5% for a temperature of 100°F ± 10°F for a duration of 50 hours.

4.2 Mission Simulation

These tests are to be performed in the sequence listed.

4.2.1 Extreme Temperatures (Non-Operating)

Following acceptance test, the unit is to be lowered to -20°F for TBD hours; then, the temperature increased to 110°F for TBD hours.

4.2.2 Prelaunch Operation (Operating)

The unit is to be operated for 50 hours under ambient conditions.

4.2.3 Launch Vibration (Non-Operating)

The unit is to be subjected to TBD minutes per axis of vibration as specified in paragraph 3.16.5.

4.2.4 Thermal/Vacuum

This test will be conducted as specified in paragraph 4.1.1, except the temperature extremes shall be 0°F and 130°F. The unit will not be operated for the first TBD hours. During this period the test item shall be subjected to the temperature extremes specified above alternately for TBD hour periods. The unit will then be operated for an additional TBD hours at a chamber and heat sink temperature of 70°F.

4.2.5 Descent Vibration (Non-Operating)

The unit shall be subjected to random vibration as specified for TBD minutes per axis.

4.2.5 continued:

Levels are to be established on these in paragraph 3.16.5 of this specification.

4.2.6 Shock (Operating)

The unit is to be subjected to shock as described in paragraph 4.1.2.

4.2.7 Electrical/Mechanical Functional Check

The unit shall be functionally checked out both for electrical performance and mechanical inspection.

4.2.8 Second Mission Cycle

Repeat paragraphs 4.2.3 through 4.2.7.

4.3 Acceptance Test

4.3.1 Thermal/Vacuum (Operating)

The unit shall be subjected to a pressure of 10^{-5}mm of mercury for the test duration. The temperature of the chamber and heat sink shall be 20°F for 2 hours after equipment stabilization and 120°F for 2 hours after equipment stabilization.

4.3.2 Vibration (Operating)

The unit shall be subjected to random vibration as specified below for 1 minute per axis.

The levels are to be derived from the vibration levels established under paragraph 3.16.5 with appropriate factors applied to reduce the levels suitable for acceptance testing.

5.0 RELIABILITY, QUALITY ASSURANCE, AND CONFIGURATION CONTROL

5.1 Quality Assurance

The contractor shall establish, implement and maintain a Quality Assurance Program in accordance with NASA Quality Publication NPC-200-2"Quality Provisions for Space System Contractors". The Quality Plan to be submitted for NASA review will, after NASA review and unless disapproved, represent the agreement between NASA and contractor for the implementation of the Quality Requirements.

5.2 Reliability

The reliability program to be implemented shall meet the requirements of NPC 250-1 "Reliability Program Provisions for Space Systems Contractors."

The Reliability Plan to be submitted for NASA review will, after NASA approval, represent the agreement between NASA and Contractor for the implementation of the Reliability Requirements.

5.3 Configuration Control

A Configuration Control Plan is to be prepared by the Contractor and submitted to NASA for review, which after NASA approval, will represent the agreement between NASA and the contractor for the implementation of the Configuration Control requirements. NPC-500-1, MSC Supplemental Number 1 shall be used as a

5.3 continued

guide in the preparation of the contractor's Configuration Control Plan, and as a guide in the conduct of Reviews and Inspections.

5.4 Subcontracts

The reliability and quality assurance requirements set forth herein shall be included in any subcontracts. The Contractor agrees that he will include in every subcontract a provision in which the subcontractor agrees to allow the Contracting Officer or his designated representative(s) to perform Engineering, Reliability and Quality Assurance Reviews at the subcontractor's plant(s).

APPENDIX B

SPECIFICATION

FOR

SPACECRAFT MULTI-EVA COMMUNICATION UNIT

EXHIBIT B

PRELIMINARY

SPECIFICATION
FOR
SPACECRAFT MULTI-EVA COMMUNICATION UNIT

(PART OF MULTI-EVA COMMUNICATIONS SYSTEM)
30 JUNE 1972

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1.0 SCOPE

This specification describes the electrical and environmental requirements of a Spacecraft Multi-EVA Communication Unit which is part of the multi EVA Communications System used for EVA (Extravehicular Activity). The specifications are considered to be the minimum requirement and require that the components described herein shall be entirely compatible with each other. Any portion of the specifications which would create any incompatibility within the system shall be brought to the attention of the Contracting Officer in writing and subsequent corrective action awaited. No deviations shall be permitted without the full written permission of the NASA Contracting Officer or his authorized representative.

2.0 GENERAL

The Multi-EVA Communications System shall consist of a maximum of 10 Portable Radio Communication Systems and one (1) Spacecraft Multi EVA Communication Unit. The system shall provide for communications of each astronauts voice and continuous biomedical and Life Support data to the Spacecraft with the Spacecraft being able to decode the data and provide voice communications including conference capability not only with the EVA's and spacecraft's and paging intra vehicular crewman (via the spacecrafts intercom system, crewman of nearby spacecrafts (via air-to-air RF links) ground controller via air-to-ground RF links) and recorded or synthesized speech generated on board.

Each astronauts PRCS unit shall provide a capability of conversation with the spacecraft and selection of conference capability on one channel in addition to his assigned channel. Each PRCS biomedical and PLSS data shall be provided to the Spacecraft on a continuous basis.

The spacecraft EVA Communications unit shall provide voice including conference capability with the participants above and be able to decode the astronauts selection of voice channel to permit conversation accordingly. In addition capability shall be provided to allow announcements which are heard by all EVA crewmen regardless of the conversation in which they are participating.

3.0 OPERATION (Reference Figure 1)

The spacecraft Multi-EVA Communication Unit shall be capable of receiving up to 10 EVA's combined voice and telemetry data, deliver the data for use by the data management system and decode each EVA's channel select word to permit routing of each EVA's voice to the 10 x 10 voice matrix unit where the filtered audio signal is mixed with other conversation.

The output of the voice multiplex unit for each channel is amplified; VOX applied and filtered to form outputs to the spacecraft intercom system. It is also mixed with inputs from the spacecraft intercom system and an input from a paging system. This mixed signal is then gated into the 12 channel 8,000 sample per second time division PAM multiplex which is transmitted to the individual PRCS units.

3.1 Transmission

3.1.1 Voice (S/C Interface)

The voice input circuitry shall be:

Nominal Input Voice Level: 0 dBm (microphone)

Dynamic Range of Voice: -9 dBm to +12 (with +25dBm as a Design Goal)

Noise Level: -30 dBm nominal, with an expected maximum of -24dBm

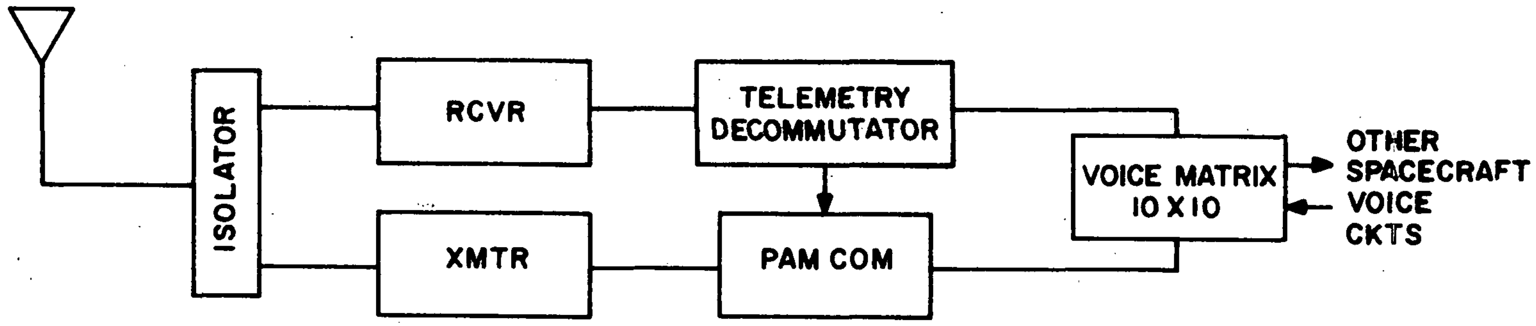


Figure 1. Spacecraft Multi-EVA Communication Unit, Block Diagram

3.1.2 Frequency Response

The frequency response of voice shall be 200 cps to 2.0 KHz ±2dB referenced to 1 KC with filter roll off more than 40 dB per octabe above 2 KHz.

3.1.3 VOX

The voice operated switch shall switch the voice input to the transmitter.

3.1.3.1 Attack and Release Time

The Attack and Release times shall be set for intelligible voice communications. Attack and Release times shall be less than .5 Msec. at 1 KHz. Release Time shall be between .4 and .6 seconds. The VOX must be capable of recycling within 1 millisecond after release.

3.1.3.2 Sensitivity

The VOX shall actuate with a sine wave signal level of (±2dB) as adjusted by a fixed internal accessible resistor.

3.1.4 Automatic Volume Control (AVC)

The Microphone voice signal shall be VOX enable and shall hold a constant output level (± 2dB) at the clipper input over an input range from TBD dBm to TBD dBm. The no signal gain of the AVC shall be a maximum of TBD dB. The attack and release times shall be set for intelligible voice communications.

3.1.5 Clipper

The 12dB maximum of peak clipping shall be provided. This shall be adjustable (within ±1dB) by an internal accessible fixed resistance. A low pass filter shall follow the clipper with a response sufficient to provide a demodulated subcarrier data output equivalent to a BER of 10^{-6} or better. This applies for any specified voice input.

3.1.6 PAM Commutator Output

The PAM output of the mixed audio for transmission shall be as follows:

Level: 3 volts peak-to-peak

Format: 12 x 8,000 sps RZ, 50% duty cycle

Output Impedance: Less than 500 ohm

Rise and Fall Time: Less than 1.2 usec

3.1.7 Transmitter Output

RF Output

The transmit frequency shall be selected within the band of 1289-1300 MHz and shall provide maximum isolation and rejection with respect to the receiver frequencies (reference paragraph 3.2.1).

3.1.7 continued:

Center Frequency Stability:	±0.005%
Output Power	3.7 watts minimum
Distortion	3% maximum
Modulation:	True FM
Incidental FM	Less than 2 KHz pp dc to 5 KHz
Spurious Emissions:	IRIG-106-70

3.2 Reception

3.2.1 Receiver(s) Frequencies

The receiver frequencies shall be a maximum of 10 bands within the 1219 to 1240 MHz band. The frequencies shall be selected to provide a maximum isolation and rejection within the respective frequency bands and those related in the transmit frequency bands. (see paragraph 3.1.7).

Frequency Stability:	±0.005%
Sensitivity:	96dBm carrier provides 20 dB quieting
Modulation:	True FM
Deviation:	Voice 12 khz peak Subcarrier 8 khz peak
Dynamic Range:	113dB
Channel Separation:	40dB minimum

3.2.2 Squelch

The receivers shall be squelched when the RF carrier is present or below a useful level. The squelch level and unsquelch level shall be TBD.

3.2.3 Receiver Output Level

The receiver's output levels shall not change more than 9dB for voice over the full dynamic range of the receiver sensitivity, at the earphone interface.

3.2.4 Frequency Response

The frequency response of voice shall be 200 cps to 2.0 KHz ±2dB referenced to 1 KC with filter roll off more than 40 dB per octave above 2 KHz.

3.2.5 Voice (To S/C Interface)

The backup voice circuitry shall be redundant to the primary mode voice circuitry.

Nominal Input Voice Level:	0 dBm (microphone)
Dynamic Range of Voice:	-9 dBm to +12 (with +25 dBm as a Design Goal)
Noise Level:	-30 dBm nominal, with an expected maximum of -24 dBm

3.2.6 Telemetry Decoding Subsystem

The telemetry subsystem for decoding each EVA's data shall consist of a PCM decommutation system and a 8192 Hz subcarrier discriminator.

Each EVA telemetry channel shall be capable of processing the following information.

Telemetry/Subcarrier Discriminator

Frame Length:	32 words per frame
Word Length:	8 bits per word
Bit Rate:	256 bits per sec ±.005%
Format:	Word 1 and 2 Frame Sync - 0000010111001111, MSB First Word 3 PAM decommutator channel select. Bits 1 thru 4 - selected channel, binary positive true logic. Bits 5 thru 8 - inverse of bits 1 thru 4 Words 15 and 16 - automatic test words 15 - 01101111 16 - 10010000 Words 4 thru 14, 17 thru 32 binary data Modulation - 8192 Hz ± .005% coherent phase shift.

Key (PSK) split phase - S(SO-S).
8192 Hz 180°

Phase Shift Change at SO-MID signal crossing

The PCM signal must be of a quality and format such that it can be easily decommutated in any Space Shuttle Orbiter or Space Base. These requirements shall be met under all conditions specified in this document.

3.2.7 Channel Select Word Decoder and Voice Routing

The channel select word decoder shall be (audio matrix) capable of decoding the channel select word and routing the voice information to the appropriate interface either for PAM Commutator for transmission and/or to other spacecraft voice interfaces.

3.2.8 Telemetry/Voice Crosstalk

The telemetry tones shall be filtered out of the audio input to the headset such that the EVA's data subcarriers are at least 30 dB below the received voice level.

3.3 Sidetone

Attenuated voice modulation of the transmitter shall be mixed with the audio output. The sidetone (or pseudo-sidetone) shall be 10 ±3dB below the received voice level as adjusted by the volume control.

3.4 Electrical Isolation

The unit design shall provide sufficient isolation between the various functional units and shall achieve the required performance under all operating modes specified herein.

3.5 Antenna

The omni-directional antenna (nominal impedance of 50 ohms) will be subject to shorting to the spacecraft structure during on-board checkout and egress operations. The unit shall be designed to withstand open or short circuit antenna conditions; without permanent damage for up to 4 hours; and allow performance within specification with VSWR's of up to 10:1 at any phase angle. (The radiated power is allowed proportional reduction as a function of voltage standing wave ratio). The antenna shall be shared simultaneously with up to two transmitters and up to two receivers. Each transmitter or receiver must be sufficiently isolated from each other to allow system performance, as specified in this document.

3.6 Range

The spacecraft multiple EVA Communications unit shall be capable of meeting the specified performance herein when used in the Multiple EVA Communication System/with the Portable Radio Communications System (PRCS) operating at physical distance of 1 foot from spacecraft antenna up to 10 nautical miles - away-line of sight.

3.6 continued:

The above applicable specifications also apply to the backup and primary links. These specifications shall be met under all conditions specified in this document without violating the IRIG Standards, dated March 1966.

3.7 Electromagnetic Interference

The unit shall meet the requirements of MSC-IESD Document 19-3A. The audio conducted susceptibility requirement shall be 1.1 volts peak-to-peak over a frequency range of 30 Hz to 19 KHz.

3.8 Power

The maximum input power requirements for each unit shall not exceed TBD amperes (not including regulated power delivered to the transducers) under any combination of environmental conditions and over a voltage range of TBD to TBD VDC. Reverse polarity protection is required on the power input within the unit.

3.9 Controls

All controls shall be astronaut operated. A mode selector switch shall control the operational modes which are: Test, Off, Primary and Backup.

3.10 Physical Configuration

The Physical Configuration shall be in accordance with the Outline and Mounting drawing TBD. The unit including connectors and connector protective covers, shall be a maximum of ________ lbs.

3.10 continued:

Heat dissipation from the unit will be primarily by conduction through its mounting interfaces. Sufficient cooling shall be provided to maintain the unit at no greater than a maximum unit mounting base temperature of 120°F.

3.11 Connectors

The connector selection, location, and pin assignments shall be in accordance with the outline and mounting drawing.

3.12 Environmental

The system shall be capable of meeting all specifications defined in this document under the following environmental conditions.

3.12.1 Temperature

The unit shall operate as specified over the temperature range of +20°F to +120°F, (130°F for 1 hour) as measured at the baseplate. Each unit shall survive storage temperatures of -65°F and +180°F.

3.12.2 Pressure/Vacuum

No structural damage, performance change, or electrical arcing shall occur over the pressure range of from 21 psia down to 10^{-9} millimeters of mercury.

3.12.3 Acceleration

The unit shall perform as specified under acceleration of 20 g's for 2.5 minutes per direction both direction of each of three perpendicular axes.

3.12.4 Shock

The unit shall perform as specified while being subjected to a 15g shock. The specified shock levels apply to each of three mutually perpendicular axes and shall have a trapezodal waveform with a 10 - 11 millisecond rise time and 0 - 1 millisecond decay time.

3.12.5 Vibration

The unit shall operate as specified while being subjected to the following vibration tests.

Vibration Levels

A. Resonance Search

TBD

B. Launch and Boost

The Launch and Boost vibration levels shall be determined from the mounting and second structures levels of the space vehicle where in the units are located during the mission.

3.12.6 Oxygen Atmosphere

The unit shall be unaffected by a 95 - 100% O_2 atmosphere at 5 psia to 21 psia for up to 30 days. The unit shall not support combustion under these conditions.

3.12.7 Humidity

The system shall be operative and unaffected by 100% humidity in a temperature range of 26°C to 70°C cycled as in MIL-STD-810A (USAF), Method 507.

3.12.8 Salt Fog

The unit shall perform as specified while being subjected to a salt fog (15% by weight) as described in MIL-STD-810A, Method 509.1, Procedure 1.

3.12.9 Shelf Life

The systems shall be capable of meeting all specifications for a period of ten (10) years of storage including 1,000 operating hours after delivery to the Government.

3.13 Interfaces

Interfaces are to be in accordance with the outline and mounting drawing.

4.0 CERTIFICATION TEST REQUIREMENTS

The requirements of ASPO-RQA-11A, applicable to this contract, are only those sections of ASPO-RQA-11A that relate to electronic equipment. The manner in which these requirements are implemented shall be in accordance with the detailed test plan for qualification test to be prepared by contractor and approved by the NASA Contracting Officer. Any deviation from this document must have prior approval of the Contracting Officer. The intent of the following subparagraphs is to define the environmental test conditions to be imposed within the scope of ASPO-RQA-11A. Unless otherwise indicated, the equipment shall be continuously operated and all modes of operation monitored.

4.1 Design Proof Qualification

4.1.1 Thermal/Vacuum (Operating)

The unit shall be subjected to a pressure of 10^{-5}mm of mercury for the test duration. The temperature of the chamber and heat sink shall be 20°F for TBD hours and 120°F for TBD hours. The unit is to be turned off and the chamber temperature increased to 130°F. After the unit is allowed to stabilize, the unit shall be turned on and operated for TBD hour.

4.1.2 Shock

This test is to be conducted per MIL-STD-810, Method 516, Procedure I. Modify the shock pulse to a sawtooth with a 40g

4.2.1 Extreme Temperatures (Non-Operating)

Following acceptance test, the unit is to be lowered to -20°F for TBD hours; then, the temperature increased to 110°F for TBD hours.

4.2.2 Prelaunch Operation (Operating)

The unit is to be operated for 50 hours under ambient conditions.

4.2.3 Launch Vibration (Non-Operating)

The unit is to be subjected to TBD minutes per axis of vibration as specified in paragraph 3.16.5.

4.2.4 Thermal/Vacuum

This test will be conducted as specified in paragraph 4.1.1, except the temperature extremes shall be 0°F and 130°F. The unit will not be operated for the first TBD hours. During this period the test item shall be subjected to the temperature extremes specified above alternately for TBD hour periods. The unit will then be operated for an additional TBD hours at a chamber and heat sink temperature of 70°F.

4.2.5 Descent Vibration (Non-Operating)

The unit shall be subjected to random vibration as specified for TBD minutes per axis.

Levels are to be established on these in paragraph 3.16.5 of this specification.

4.2.6 Shock (Operating)

The unit to be subjected to shock as described in paragraph 4.1.2.

4.2.7 Electrical/Mechanical Functional Check

The unit shall be functionally checked out both for electrical performance and mechanical inspection.

4.2.8 Second Mission Cycle

Repeat paragraphs 4.2.3 through 4.2.7.

4.3 Acceptance Test

4.3.1 Thermal/Vacuum (Operating)

The unit shall be subjected to a pressure of 10^{-5} mm of mercury for the test duration. The temperature of the chamber and heat sink shall be 20°F for 2 hours after equipment stabilization and 120°F for 2 hours after equipment stabilization.

4.3.2 Vibration (Operating)

The unit shall be subjected to random vibration as specified below for 1 minute per axis.

The levels are to be derived from the vibration levels established under paragraph 3.16.5 with appropriate factors applied to reduce the levels suitable for acceptance testing.

4.1.2 continued:

peak and an 11 ±1 m. sec. rise and 1 ± 1 m. sec. decay on both directions of each of three axes.

4.1.3 Vibration (Operating)

Vibration shall be as specified in paragraph 3.16.5 for a duration of five minutes per axis.

4.1.4 Leak Rate (Non-Operating)

A leak rate consistent with the Shuttle mission requirements shall be demonstrated at a vacuum of 10^{-4}mm of mercury.

4.1.5 Corrosive Contaminants, Oxygen and Humidity

The unit shall be subjected to 1% (by weight) salt fog in accordance with MIL-STD-810 for one hour. Then, the chamber is back filled (from 20mm of mercury) with commercial oxygen (95 ± 5%) to 5.0 ± .2 psia. The temperature of the chamber is held at 120°F ±10°F for 12 hours. With the oxygen environment at 5 psia, introduce a relative humidity of 95% ± 5% for a temperature of 100°F ± 10°F for a duration of 50 hours.

4.2 Mission Simulation

These tests are to be performed in the sequence listed.

5.0 RELIABILITY, QUALITY ASSURANCE, AND CONFIGURATION CONTROL

5.1 Quality Assurance

The contractor shall establish, implement and maintain a Quality Assurance Program in accordance with NASA Quality Publication NPC-200-2"Quality Provisions for Space System Contractors". The Quality Plan to be submitted for NASA review will, after NASA review and unless disapproved, represent the agreement between NASA and contractor for the implementation of the Quality Requirements.

5.2 Reliability

The reliability program to be implemented shall meet the requirements of NPC 250-1 "Reliability Program Provisions for Space Systems Contractors."

The Reliability Plan to be submitted for NASA review will, after NASA approval, represent the agreement between NASA and Contractor for the implementation of the Reliability Requirements.

5.3 Configuration Control

A Configuration Control Plan is to be prepared by the Contractor and submitted to NASA for review, which after NASA approval, will represent the agreement between NASA and the contractor for the implementation of the Configuration Control requirements. NPC-500-1, MSC Supplemental Number 1 shall be used as a

5.3 continued

guide in the preparation of the contractor's Configuration Control Plan, and as a guide in the conduct of Reviews and Inspections.

5.4 Subcontracts

The reliability and quality assurance requirements set forth herein shall be included in any subcontracts. The Contractor agrees that he will include in every subcontract a provision in which the subcontractor agrees to allow the Contracting Officer or his designated representative(s) to perform Engineering, Reliability and Quality Assurance Reviews at the subcontractor's plant(s).

APPENDIX C

CRYSTAL FILTER SPECIFICATION

CRYSTAL FILTER SPECIFICATION

A tentative specification for the 10-channel comb filter is presented below.

1.0 SCOPE

1.1 This specification covers the requirements for a 10-channel comb filter for use in a multichannel receiver. A low insertion loss with an output mismatch is a primary requirement for this filter bank.

2.0 REQUIREMENTS

2.1 Electrical

2.1.1 Center Frequency (f_o) to be:
25, 26, 27, 28, 29, 30, 31, 32, 33, and 24 MHz.

2.1.2 Bandwidth at 1.0 dB shall be ±0.75 KHz minimum.

2.1.3 Deleted

2.1.4 Bandwidth at 40 dB shall be ±1.0 MHz maximum.

2.1.5 Spurious responses shall be -40 dB maximum.

2.1.6 Ultimate rejection shall be 40 dB minimum.

2.1.7 Source impedance (R_g) shall be 2000 ohm ±10% with L/C tuning.

2.1.8 Filter output impedance (R_o) shall be 2000 ±10% with L/C tuning.

2.1.9 Load impedance shall be 40K ohm ±10% in parallel with 8 pf ±3 pf.

2.1.10 Power insertion loss shall be 1 dB maximum.

2.1.10.1 Insertion loss is defined as the available power ratio, $\frac{P_{AI}}{P_{AO}}$

2.1.10.2 Available power in, P_{AI}, is defined as: $P_{AI} = \frac{E_G^2}{4R_G}$

2.1.10.3 Available power out, P_{AO}, is defined as: $P_{AO} = \frac{E_O^2}{4R_0}$

2.1.10.4 Voltages are open circuit voltages.

2.1.10.5 Filter output impedance is R_O.

2.1.10.6 Source impedance is R_G.

2.1.11 A signal ±1.0 MHz of center frequency of +27 dBm or an inband band signal of +80 dBm shall not cause distortion of pass band or shift in center frequency.

2.1.11.1 Crystal filter shall not be irreversibly damaged by an inband signal +27 dBm.

2.1.12 Third-order intermodulation response. Two 0 dBm signals spaced +200 kHz and +400 kHz or -200 kHz and -400 kHz from 17.0 MHz applied to the input of the crystal filter, shall produce a third-order product at 17.0 MHz no greater than -120 dBm.

2.2 Mechanical

2.2.1 Materials and workmanship shall be of the best quality available. Construction shall be sturdy and durable, and of maximum simplicity compatible with other requirements of the specification.

2.2.2 Volume is desired to be less than (TBSL) cubic inches.

2.2.3 Service conditions - No tests need be performed as long as unit is guaranteed to operate under normal laboratory use.

2.2.4 Vibration and Shock - No tests need be performed as long as unit is guaranteed to operate under normal laboratory use.

3.0 PREPARATION FOR DELIVERY

3.1 Preparation for delivery shall be in accordance with best commercial practice. Packaging shall be such as to preclude damage during shipment.

3.2 Documentation - To be supplied later.

3.3 Test Data - Pertinent data taken during testing shall be supplied with units. To include: attenuation characteristics, test fixtures used other than herein specified, and intrinsic impedances of unit.

APPENDIX D

TIME DIVISION MULTIPLE ACCESS SYSTEM (TDMA) TECHNIQUES

INTRODUCTION

In the Multi-EVA system, operation in the VHF band is preferable to minimize battery size. These frequencies result in lower losses which is very important since omnidirectional antennas are required. However, a maximum protection against EMI, primarily from Earth-based emitters, is necessary. Furthermore, the near-far problem is very severe, since some EVA receivers may be only a few feet away from the spacecraft, while others are permitted to have ranges up to ten nautical miles.

The multiple access problem is best solved by departure from classical methods such as Frequency Division Multiple Access (FDMA). It is believed that Time Division Multiple Access techniques, which can use existing technology, offer a low cost solution. They overcome the RFI from Earth radiations by having a considerably higher S/N at the receiver with low average transmission power; no power control is needed for large differences in range, due to the avoidance of inter-channel interferences; the EVA equipment is simple, and ranging can easily be accomplished with the same equipment at little additional cost.

This Appendix explains the TDMA technique in general, presents solutions to the multi-EVA problems, and describes the equipment configuration. Critical hardware, such as a low duty cycle 100 watt VHF transmitter has already been developed by RCA for the Apollo 17 Lunar Sounder.

1. General Description of TDMA

Time Division Multiple Access (TDMA) is defined as the time-sequenced entry at a receiver of information-modulated signals which emanate from different sources. A TDMA signal of a channel occupies a certain time slot for a duration τ, and the next pulse of the same channel occurs after T seconds. A synchronous system which has a time slot assigned for each channel can accommodate $\frac{T - tg}{\tau}$ channels, where tg is the time within T, taken by the guardbands.

In TDMA, the transmissions of different links are separated in time such that each link has sole use of the receiver as specified times. The simpliest scheme is a repetititve sequence of time slots where an access-channel consists of the same time slot in each frame. Any form of modulation compatible with the pulsed nature of the waveform (such as pulse width, pulse position, PSK or FSK) may be used.

The TDMA may be random or synchronous. A synchronous scheme requires network synchronization in the form of a time-reference signal which can be generated at the main stations (or repeater). This time reference is needed by transmitting terminals to accurately pulse their transmissions so that they occur during their allocated time slot. Receiving terminals require the time reference to synchronize the gating.

The synchronous TDMA technique has the advantage that no interference is produced due to intermodulation products, since only one signal is present in the spacecraft repeater at any time. The exclusive use of the spacecraft repeater power by a single link at any time also eliminates the requirement of power control for different ranges of links. Furthermore, the pulsed nature of the signals permits each link transmitter to operate at its peak power. Thus, due to the peak power transmission, S/N at the receiver will be improved (20 dB improvement is easily achievable). This is of a very great importance in those cases, where the outside system interference creates problems. (For example, RFI at low altitude spacecraft from radiation sources on Earth.)

2. TDMA For Multi-EVA System

2.1 Operation Characteristics

The main characteristics of the Multi-EVA system operation are: required simplicity, RFI problem, large differences in ranges between the spacecraft and individual EVA sets. The minimum number of links is ten, and the information to be transmitted consists of voice and data. The RFI environment requires strong signal, thus peak power transmissions are desired. Power control due to range difference complicates the equipment. Simultaneous transmissions on many links produce intermodulation interference at the spacecraft. These problems can be solved or significantly simplified by the use of TDMA techniques.

2.2 Information Modulation

The type of information to be transmitted by the Multi-EVA system is voice and low rate telemetry. For a TDMA system, voice must be digitized. A Δ - modulation scheme with 19.2 kbt/s rate has been proved to be one of the most convenient schemes, and modulators-demodulators have been perfected. It has been established that a binary error rate up to 1.6% will maintain acceptable speech quality, and that an error rate of 1% produces good results. To avoid fine phase and frequency controls, non-coherent binary FSK modulation will be used to transmit digitized voice and telemetry. For non-coherent FSK modulation, in case of voice, 1% error rate requires E/No = 9 dB; for non-coherent FSK modulation, in case of data, 10^{-5} error rate is obtained with E/No = 13 dB.

The 19.2 kbt/s voice determines the duration of a time frame in a TDMA system, since this is the highest information rate to be transmitted. Thus,

$$T = \frac{1 \text{ Sec.}}{19.2 \times 10^{3}} = 0.0521 \times 10^{-3} \approx 52 \text{ usec.}$$

The voice and data (if both types of information are present) from each EVA will be transmitted intermittently in each frame. Thus, 19.2×10^3 pulses representing telemetry will be transmitted each second. If, for example, the telemetry information rate is 300 bits, this will result into a redundancy of $19.2 \times 10^3/300 = 64$; this redundancy, by means of post-detection integration, will result into a S/N improvement (at least 9 dB). At the spacecraft, each frame has to accommodate, in case of ten links, twenty time slots for reception (ten pulses of voice and ten pulses of data) and ten slots for transmission. To avoid a strict time control, guards of one pulse duration will be left between slots, these considerations and the fact that binary numbers are easier to work with will determine the pulse duration, . If one divides the frame duration by 2^7, one obtains:

$$\tau = \frac{T}{2^7} = \frac{52 \text{ usec}}{128} = 0.407 \approx 0.4 \text{ usec}$$

This pulse duration of 0.4 usec will result in 16 channels with the above mentioned time guards between slots.

A synchronous TDMA scheme for N channels with frame T, pulse duration and with guards between individual slots is shown for illustration purposes in Figure 1. Examples of timing at EVA's and spacecraft are presented in Figure 2. (For simplicity, only one pulse is transmitted by EVA, either voice or data.)

In Figure 2A, the range between EVA and spacecraft is X miles. EVA 1 transmits a pulse which arrives at the spacecraft with a delay due to the range of X miles. Then, the spacecraft transmits the synchronization pulse and after some delay, the message pulse to EVA 1. The timing difference between the synchronization and information pulses is constant, and it indicates the slot assigned for EVA 1 within the frame. Again, the synchronization and message pulses arrive at EVA 1 with additional delay due to the range.

Figure 2B depicts the same story where the range from the spacecraft to EVA 1 is twice as long as in Figure 2A.

Figure 3 shows time frames at the spacecraft and EVA transmitters. In Figure 3A, the synchronization signal followed by ten transmissions to EVA's (no data is sent to EVA's) are indicated. In Figure 3B, the time frame of the EVA transmitter consists of a voice pulse and a data pulse separated by T/2. Thus, time separation permits the transmitter to build up its power between voice and data pulses.

2.3 Clock Rate and Bandwidth

The EVA's transmitters transmit 19.2 kbt/s of voice and 19.2 kilopulses

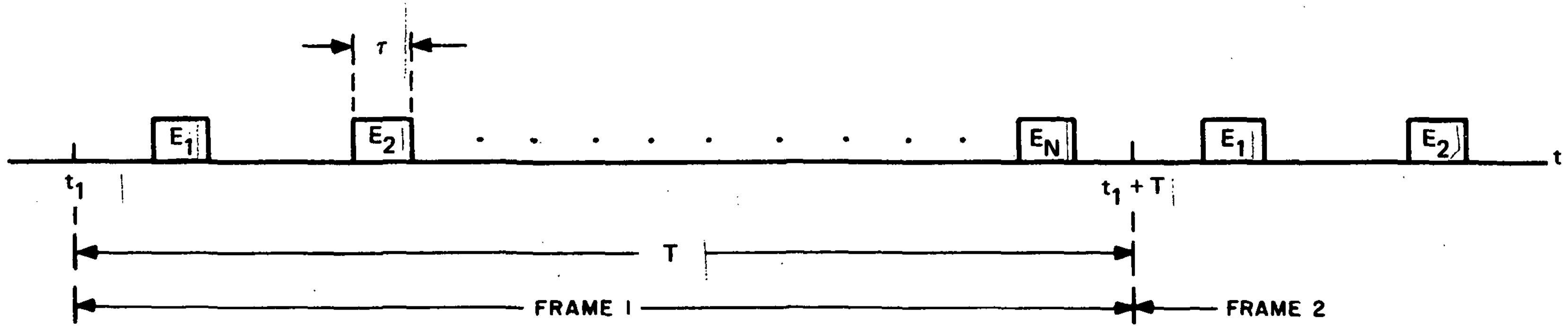


Figure 1. Synchronous TDMA Scheme

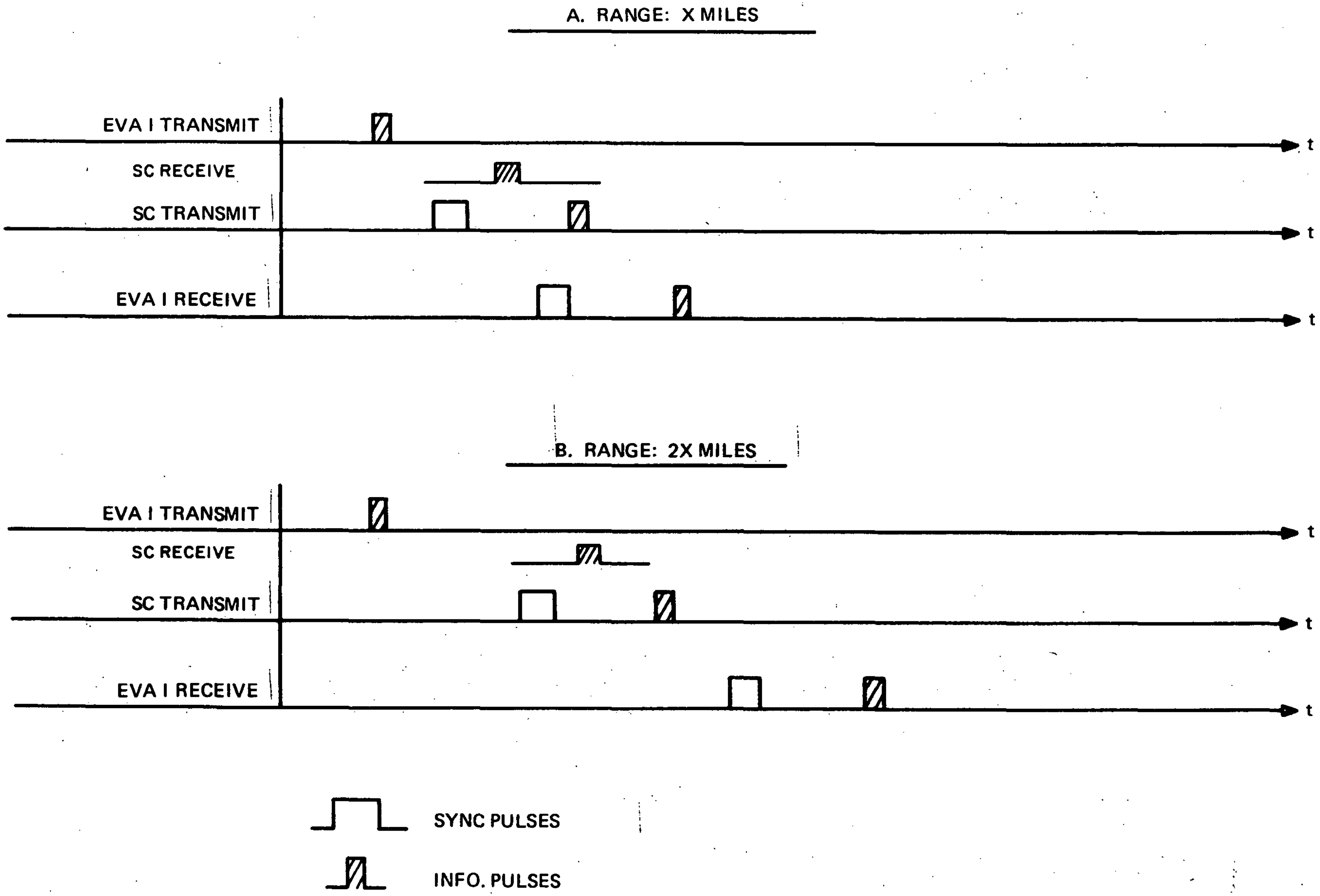
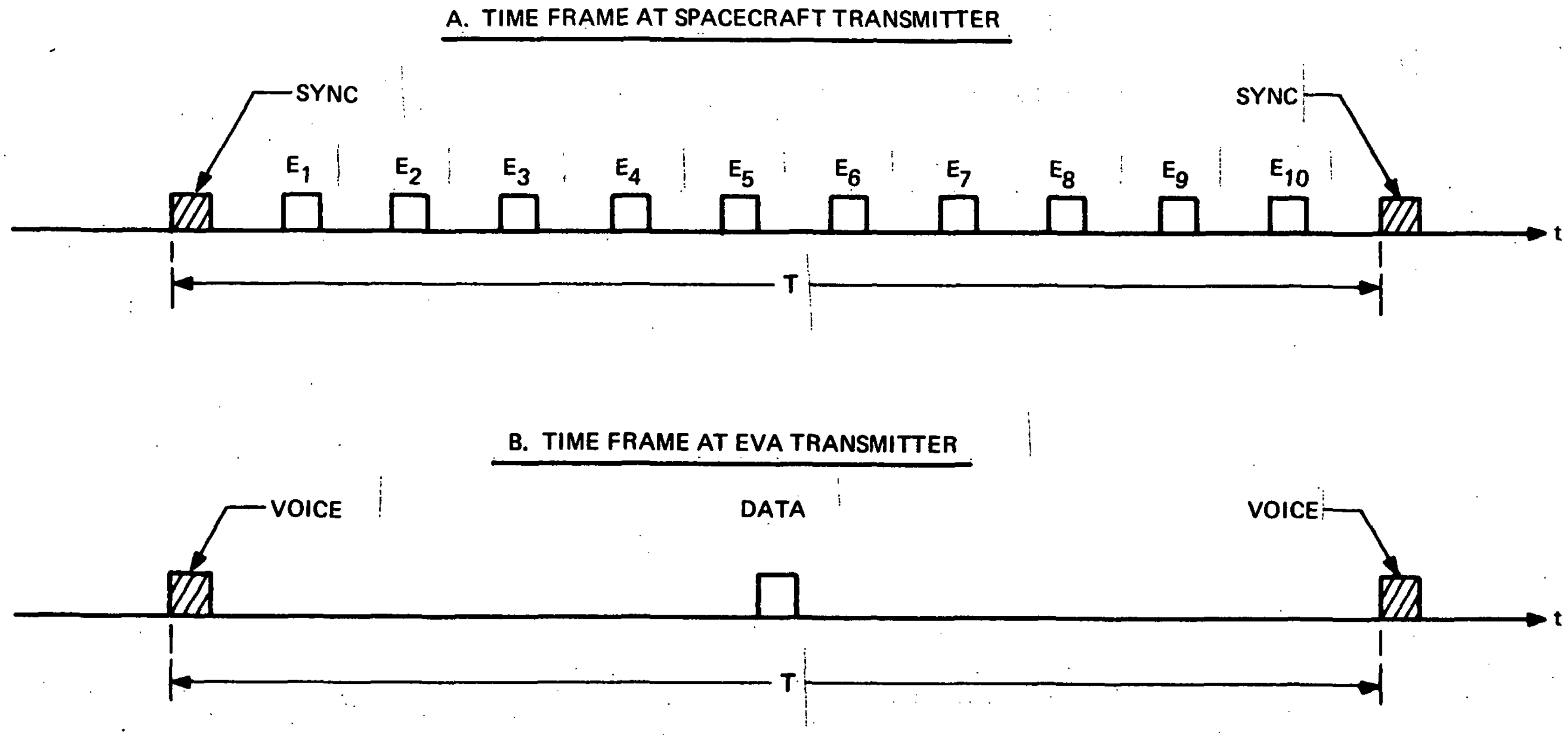


Figure 2. Examples of Timing at EVA's and Spacecraft


A. TIME FRAME AT SPACECRAFT TRANSMITTER

B. TIME FRAME AT EVA TRANSMITTER

Figure 3. Time Frames at Spacecraft and EVA Transmitters

of data (with redundancy) each second. Thus, the clock rate required at EVA's is 38.4 kbt/s. The pulse duration is 0.4 usec, and the bandwidth needed to transmit one pulse is $\frac{2}{4 \times 10^{-7}} = 5$ MHz. Since the FSK modulation requires one channel for space and one channel for mark symbol, the total bandwidth amounts to 10 MHz.

However, a filter narrower than null-to-null can reduce this bandwidth and possibly improve reception, especially in a high interference environment.

It should be noted that voice and telemetry data are transmitted on the same carrier. The distinction between these two types of information is accomplished by time gating. Due to the FSK modulation, frequency stability requirements are significantly reduced. For a carrier frequency of 300 MHz and $\tau = 0.4$ usec., a frequency stability of 0.01% is more than needed and no additional noise bandwidth at the receiver is produced.

The bandwidth occupancy of a TDMA, FSK modulated, system presents no problems. The RFI from earth sources is overcome by the increased S/N due to the peak power transmission and by the fact, that the receiver is gated off when no signals are expected.

The wideband nature of the modulation results in a very low power density (0.1 watt/MHz average) so that the EVA transmitters will not interfere with earth based receivers.

2.4 Synchronization Procedure

The synchronization procedure is simple because the pulsed nature of the signals permits an accurate determination of range from the spacecraft to the EVA's. The spacecraft transmits a sync signal, and all EVA's lock up to it. Each EVA signal is assigned a time slot which has a constant delay (different for each EVA) relative to the sync signal. By means of a tracking loop the propagation time is determined. Say this propagation time is t_p, and the assigned slot at the SC receiver is t_d after the sync signal. The time for EVA to transmit its pulse, t_t, is:

$$t_t = t_s + t_d - t_p$$

where t_s is the time of sync signal. This procedure is illustrated in Figure 4.

A detailed timing sequence of the signals as they occur at the spacecraft is shown in Figure 4A. The sync signal and the time slots for the first three EVA's are indicated. The sync signal is transmitted first by the spacecraft transmitter. Then 0.8 microsecond after the transmission of the sync pulse, the spacecraft receiver is gated on for a period of .4 microsecond. The signal from EVA 1 should be received during this period. Since this signal is FSK modulated, either a mark or a space will be received at the spacecraft. This information is stripped from the signal, and used internally in the spacecraft to demodulate the EVA 1 voice or data signal. A digitized voice signal intended for EVA 1 is transmitted 0.8 microsecond after the receiver was gated on. The transmitted signal has a duration of .4 microsecond and will be sent as either a mark or space, depending on the information bit to be conveyed to EVA 1. After a .4 microsecond guard space, the spacecraft receiver is gated on again, to allow the signal from EVA 2

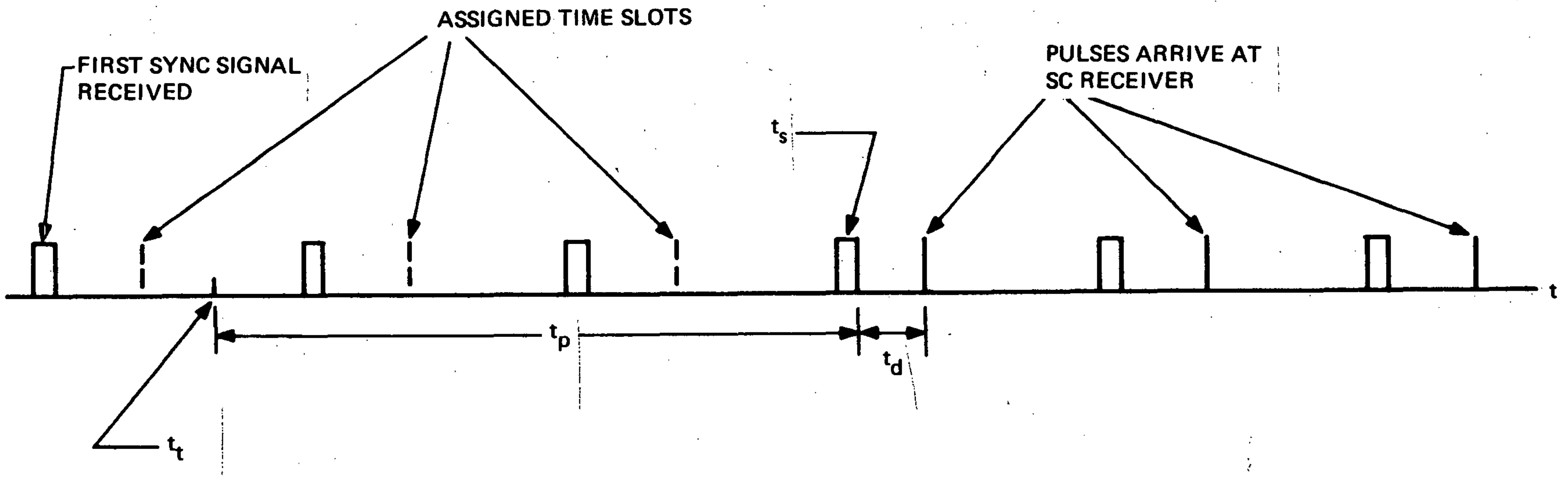


Figure 4. Transmission Time

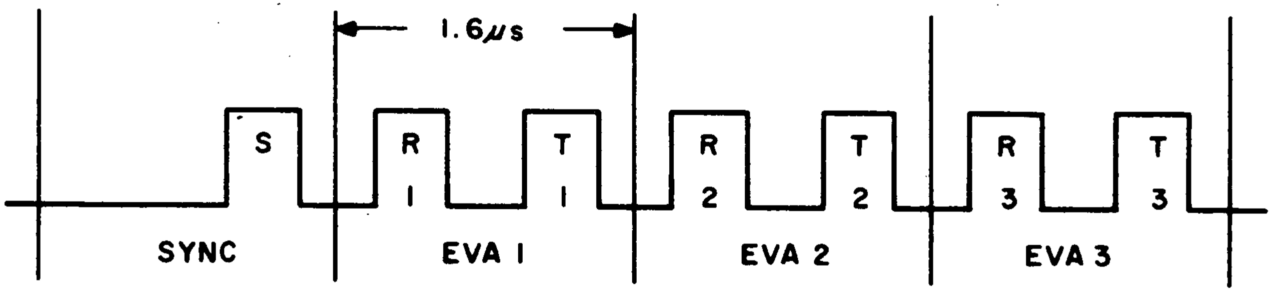


Figure 4a. Time Sequence at Spacecraft

to be received. It is demodulated and the information sent to a signal processor while information intended for EVA 2 is modulated onto the carrier during the pulse period labelled T2. This represents the transmission period for EVA 2; this process is repeated for EVA 3, EVA 4, etc. The total timing sequence allows 32 EVA's to be serviced. However, since voice and data are received from each EVA, this number has to be reduced to 16. Furthermore, the sync pulse occupies a time slot and the active number of EVA's under this timing scheme is limited to 15. It should be noted that if the spacecraft does not receive a signal during the receiver "on" periods, identified by R1, R2, R3, etc., the spacecraft will not transmit .8 microsecond later. Consequently, there will only be transmissions when the received signal appears in the proper time slot. This feature reduces total system interference.

Synchronization by the EVA equipment is achieved as follows. The EVA receiver searches for the unique synchronization pulse. While this pulse appears once per frame, it can easily be identified by a unique mark-space coding.

Each EVA tracks the synchronization pulse and gates the receiver on at the specified delayed period, such as the time delay between the sync pulse and T1, or the sync pulse and T2, etc. Next the EVA starts to transmit a stream of pulses; even when the astronaut is not talking and there is no voice signal, there will be a delta modulation idle pattern which is alternating mark and spaces. The time of transmission from EVA will be changed automatically, till it is sufficiently ahead of the spacecraft receive slot to compensate for the propagation delay.

When the EVA transmitter reaches the correct time of transmission, the spacecraft will receive the signal in the proper time slot. The spacecraft will then start to transmit the signal in the appropriate transmit time slot. This signal will now appear at the right time in the gated EVA receiver, and it can now be used to close the tracking loop around the transmit timing generator. The tracking loop will keep the EVA transmitter moving in time as the range is changed. This will assure that the EVA transmission will always arrive at the designated receive time slot at the spacecraft. Since the duty cycle of the transmitted pulse from EVA is less than 1 percent, the out of sync transmitter will have less than 1 percent of probability of interferring with another EVA channel. This small probability does not degrade voice intelligibility significantly, and it does not affect the data performance due to the large amount of redundancy. Of course, once all EVA transmitters are properly locked to the designated time slot, there will be no mutual interference whatsoever. The total synchronization procedure should not take much more than one second, since a fairly wide loop bandwidth can be used. This will be borne out by the following link analysis.

2.5 Link Analysis

A link analysis of a synchronous Multi-EVA system with TDMA is presented below. Firstly, carrier-to-noise ratio is computed for an environment free of RFI. Secondly, the level of tolerable RFI is determined. The frequency assumed is 280 MHz, antennas are considered to be of unity gain, and the maximum range of 10 n. miles is used. It should be noted, that no SC multicoupler loss is included. This is due to the fact that only one receiver is used at the SC because of the TDMA technique.

Propagation loss (f = 280 MHz; R = 10 n. m.)		107. 1 dB
EVA cable loss		2. 0 dB
SC Cable Loss		2. 0 dB
	Total Loss:	111. 1 dB
Receiver Noise Figure		5. 0 dB
kTB (B = 5 MHz)		-137. 0 dB
Receiver Noise		-132. 0 dBW
P_T (peak power = 100 w)		20. 0 dBW
C/N		40. 9 dB

Thus, C/N under no RFI conditions amounts to 40. 9 dB, which corresponds to E/N_o = 43. 9 dB. It was mentioned before, that Δ - modulated FSK voice requires 9 dB of E/N_o, and telemetry requires 13 dB of E/N_o. This is an indication that a high level of RFI can be overcome by the system.

In determining this level, the natural receiver noise can be entirely neglected. On the other hand, because of high redundancy in telemetry transmissions, voice is the limiting factor. Thus C/N required is 6 dB, and the amount of interference tolerated in the receiver is -97. 1 dBW. Considering the spacecraft at a 200 n. m. altitude and the difference of the free space loss, the total integrated interference from terrestrial sources is 40 dBW (or 70 dBm). This is the maximum RFI power level registered by LES-5 and LES-6 in the 255-315 MHz range.

3. Random TDMA System

For purposes of illustration, a random TDMA method is presented here. It has disadvantages, since at the receiver of any channel two or more signals may occur during the same gating period, and interference will be caused.

This interference may be small, if the period T is long, and the number of channels is small. The peak power gain by pulsing the signals may be of a greater significance than the S/N reduction due to the occasional overlapping of two or more time slots. To avoid interference of two channels on two or more consecutive pulses, the period T must be slightly different for each channel, and these individual channel periods cannot be multiples of each other. In this case, the mutual interference become random, and its effects are the same as those of noise.

3.1 An Example Analysis

Consider ten channel system and random (non-synchronous) transmissions. Let pulse duration τ = 1 usec. The periods T_i are approximately 100 usec, but each slightly different, say, by 1 usec (T_1 = 96 usec; T_2 = 97 usec; T_3 = 98 usec, etc.). Thus, the probability that at any gating period two signals will share the same time slot by any time portion (between zero and τ) is 0.1. The cumulative probability vs. the percentage overlap (of τ) is shown in Figure 5.

The interference of more than two channels will be of higher order, and is neglected here. Furthermore, for simplifying this analysis, we assume that the average overlap is 50%, which has the probability of 0.01.

Consider that the information modulation is a binary FSK. Thus, when mark overlaps mark and space overlaps space, no errors occur. When space overlaps mark and vice versa, the probability of error is 0.5. Therefore, the probability of error, when overlaps occur, is 0.25 for FSK modulation.

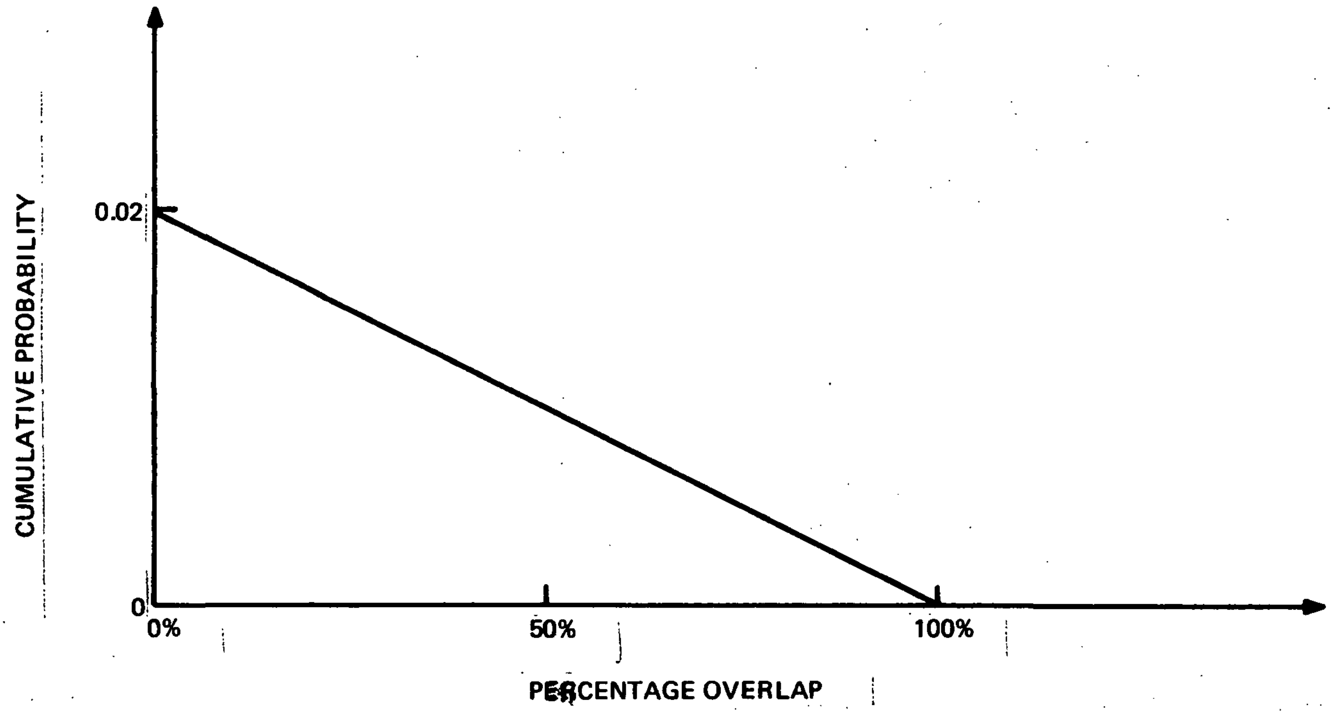


Figure 5. Cumulative Probability vs Percentage Overlap

The total probability of error is

$$P_T = \frac{1}{4} \quad 1 - (1 - \frac{\tau}{T})^{n-1}$$

where τ is pulse duration, T is average period and n is the number of channels. For τ = 1 usec, T = 100 usec and n = 10, $P_T \approx 2 \times 10^{-2}$.

This error rate is low enough for voice transmission. However, it will be further reduced by the filtering, which is directly proportional to the ratio of the transmission bandwidth to the voice bandwidth.

For digital data, consider 2 kbt/sec information to be transmitted by each channel. If $T \approx 100$ usec and τ = 1 usec, the bandwidth ratio will produce 7 dB additional gain. The final error rate for a binary FSK information modulation will be reduced to 10^{-6}.

4. Equipment Description

Two types of EVA communication systems will be described. The first uses synchronous time division multiple access, the second uses a non-synchronous or random TDMA approach.

The synchronous TDMA Multi-EVA System is illustrated in simplified form in Figure 5A. On the left, the basic EVA configuration is shown while on the right the spacecraft equipment is illustrated. The EVA equipment includes a receiver and a sync tracker. This will receive and track the synchronization pulse transmitted by the spacecraft. It will also gate on the receiver at the designated time delay with respect to the synchronization pulse. At this delayed time slot, the delta modulated voice signal will appear if the transmitter is synchronized. For this purpose a transmit tracker

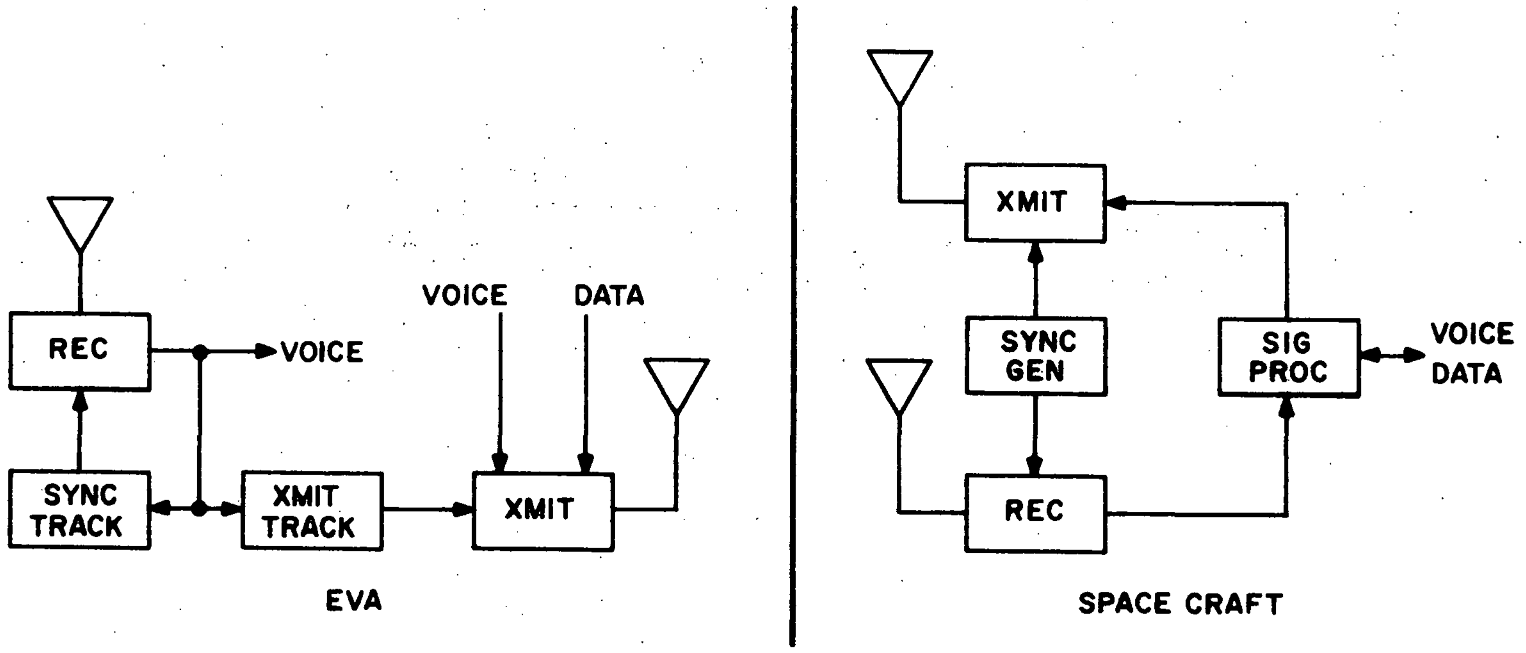


Figure 5a. Synchronous TDMA Multi-EVA Configuration

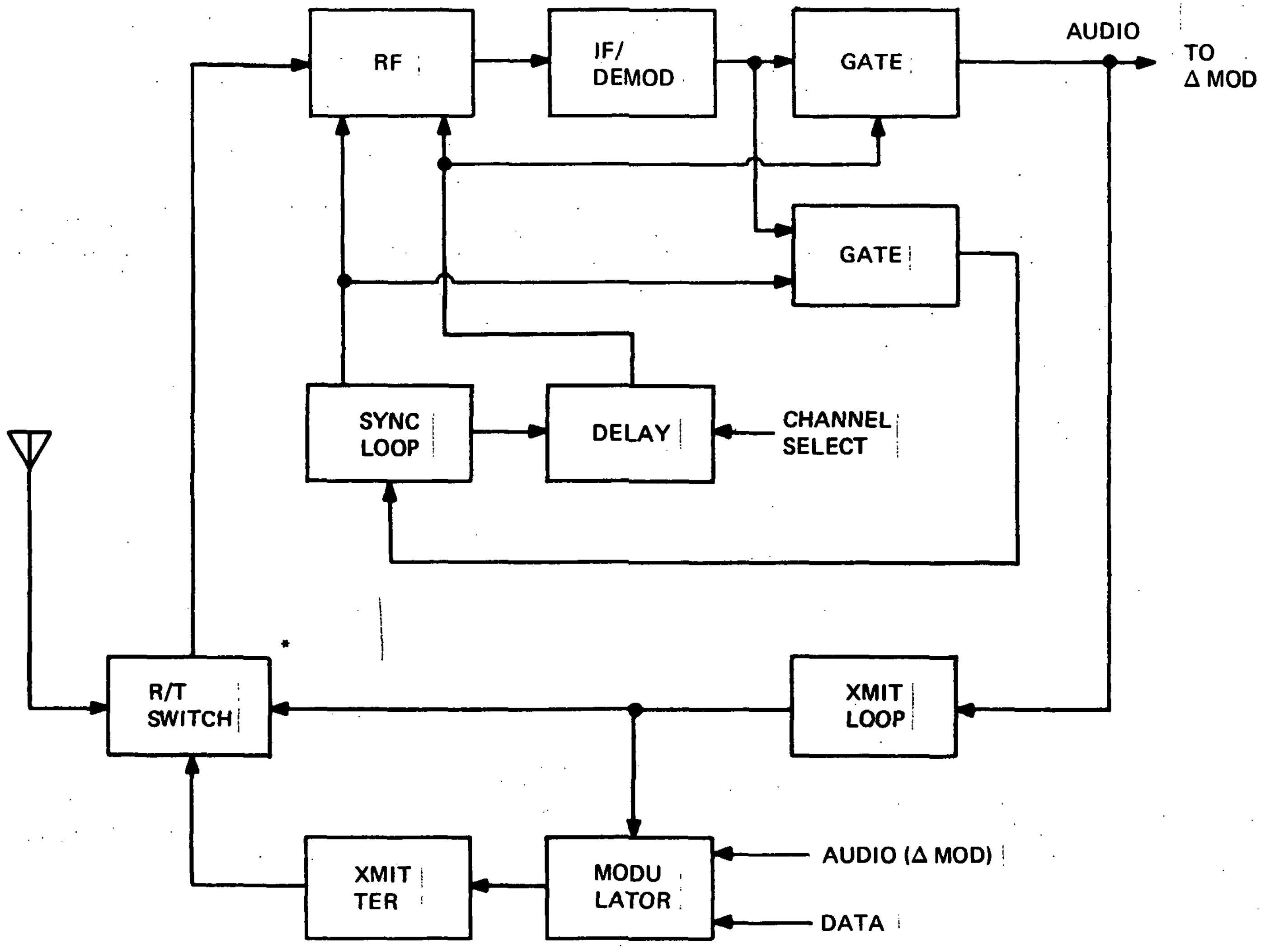
is used which controls the time when the transmitter sends out its .4 microsecond pulse. The voice or data input controls whether this pulse is sent on the mark or space frequency.

The spacecraft complement consists of a sync generator which triggers the transmitter and which produces a regular train of sync pulses. The sync generator also produces a series of gating signals for each of the expected receive and transmit time for each of the EVA's.

For example, an enabling gating pulse will turn the spacecraft receiver on when a signal from EVA 1 is expected. If the signal is present, it will be demodulated and sent to the signal processor. This in turn will modulate the transmitter on the succeeding transmit slot, with the appropriate voice information, which is then sent out to the EVA.

4.1 Synchronous TDMA

The synchronous TDMA EVA system is illustrated in simplified block diagram form in Figure 6. The signal from the spacecraft is received by the antenna and passed on to an TR switch or diplexer. This normally feeds a gated RF amplifier. The RF amplifier is gated at the time when the synchronization pulse is expected from the spacecraft. The RF amplifier is also gated at a specified number of microseconds after the sync pulse since this corresponds to the time slot assigned to that particular EVA receiver. When the RF amplifier is gated on the signal is then passed on to a limiting IF amplifier and FSK demodulator. The output of this demodulator is gated again at the appropriate time so that only the desired synchronization pulse or information pulse is passed to the appropriate processing circuits. The



*DIPLEXER COULD BE USED

Figure 6. Synchronous TDMA EVA System

synchronizing pulse is passed by the synchronizing gate and it is fed to the sync tracking loop. This tracking loop will search, acquire, and track the synchronization pulse transmitted by the spacecraft. The particular EVA information channel is obtained by adding a fixed delay following the sync pulse. The delay is adjusted in each receiver to make the desired channel selection. After the sync pulse is delayed by the specified value the receiver is gated on again and this time the output of the receiver is gated and fed to the audio circuits which include a delta mod demodulator and since the EVA system controls the position of the time slot relative to the spacecraft synch pulse, the audio channel output pulses are also applied to a transmit tracking loop. This transmit tracking loop provides pulses at the appropriate time for the modulator and the TR switch. One output pulse from the transmit loop is used to gate the audio signal in the form of delta modulation to the transmitter and via the RT switch to the antenna. The alternate pulse from the transmit loop gates the data signal through the modulator and transmitter and the TR switch to the antenna. The relative time position of the transmit loop with respect to the sync loop is controlled by the received audio output pulses. As the EVA distance increases with respect to the spacecraft the transmit loop must be moved in relative time to assure that the desired signal is still received in the proper time slot; that is, the specified number of microseconds after receipt of the synch pulse. Since the relative position of the transmit loop and the sync tracking loop is only a function of range very little additional circuitry would be required to read out the phase difference of these two tracking loops and obtain a very accurate range measurement. A resolution of the order of 60 feet is easily obtainable.

Figure 7 shows an example of the sync tracking loop and also the communications tracking loop. A voltage controlled crystal oscillator (VCXO) drives an early/late jitter circuit which merely adds in a small amount of delay at periodic intervals. The output of this circuit is then divided by 128 to provide 128 time slots per frame. One frame represents about 52 microseconds so that a delta modulation rate of 19.2 kilobits per second can be used. The output of the divider is gated with the input to produce a pulse with a duty cycle of 1 unit in 128. This pulse is used to gate the RF amplifier and the demodulated video. The divide by 128 circuit also drives a divide by 4 circuit and this controls the early/late jitter. It also drives an early/late switch, which, during the early portion passes the video signal directly, while it inverts the video signal during the late phase of the cycle. Consequently, an early minus late signal is generated; this is filtered in a loop filter which drives the VCXO in such a direction so that proper track in the loop will be maintained. The concept of early/late gating and tracking in the front end of the receiver has been used successfully in the Apollo VHF Ranging System. It can be implemented with very simple circuitry especially when only a single loop is involved. An example of such a loop is found in the Apollo Range Tone Transfer Assembly (RTTA). Since practically all the circuitry is digital in nature, it lends itself very well to extreme miniaturization by means of MSI and LSI techniques.

A multichannel synchronous TDMA spacecraft receiver is shown in Figure 8.

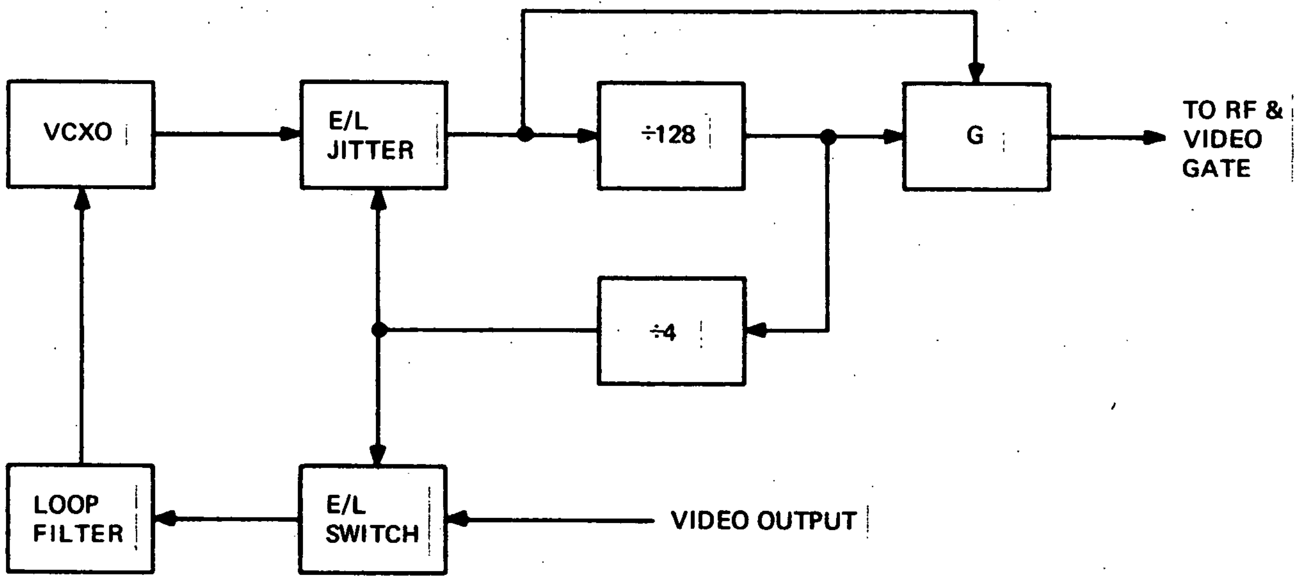


Figure 7. Synch and Communications Tracking Loops

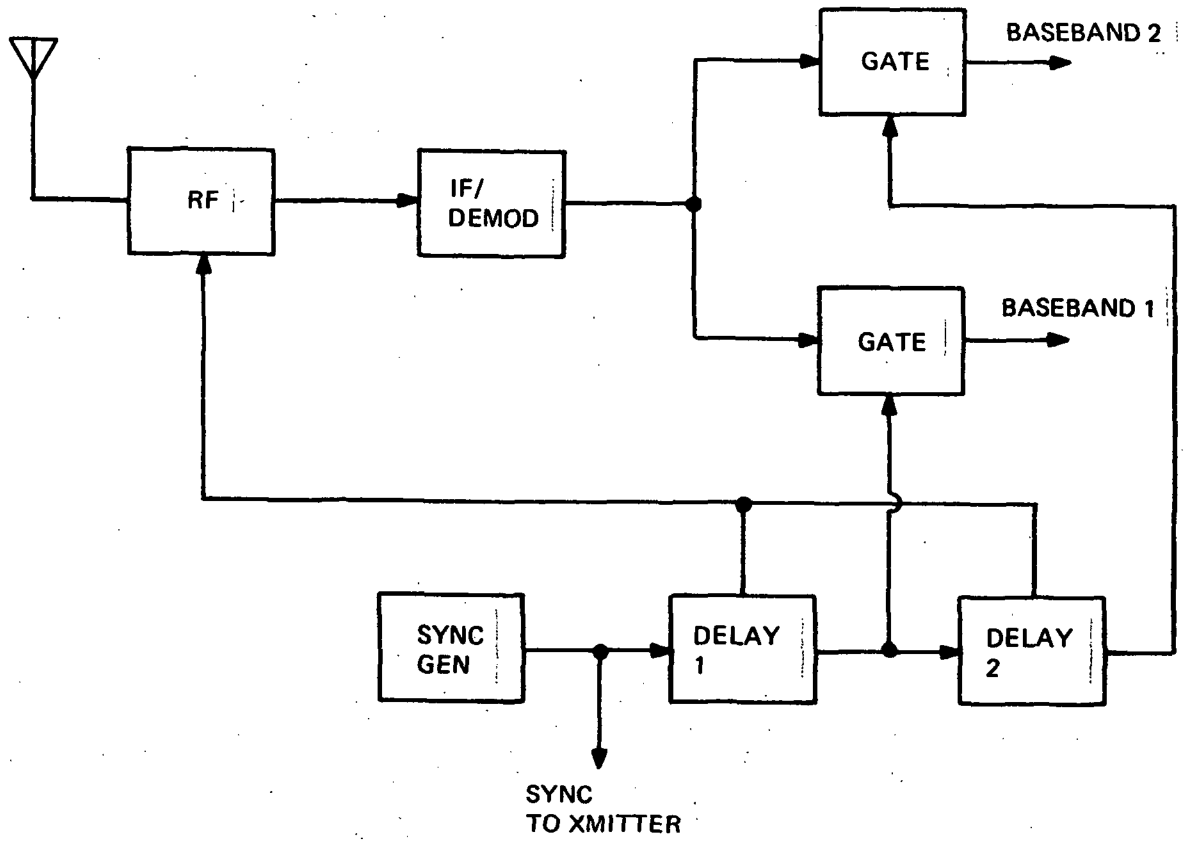


Figure 8. Synchronous TDMA Spacecraft Receiver

The signal is received by the antenna and sent to a gated RF amplifier. This amplifier is gated on only for the duration of each expected signal. Its output is further amplified and limited and then demodulated. From there, it is applied to a number of gates, two of which are shown in the diagram. The receiver gating is produced by a sync generator which also provides the spacecraft sync pulse to the spacecraft transmitter. The sync pulse is delayed by the spacing of the channels for each successive EVA signal. For example, EVA-1 will cause his signal to reach the spacecraft a specified number of microseconds after the synch pulse has been transmitted. Consequently, at the time of the EVA-1 signal, the RF amplifier is turned on and the demodulator output is gated on the channel 1 baseband signal path. Similarly, when the signal from EVA-2 is expected the front end of the receiver is gated on and the demodulated signal is gated on to a baseband 2 circuit. This process can readily be extended to 10 or more voice channels and also an equal number of data channels. In the case of the data channels, there may not be a need to separate the signals since they are already multiplexed for use in the computer, or other link from the spacecraft to earth.

4.2 Random TDMA Equipment Description

Figure 9 shows the Random TDMA EVA system. In this case, the transmitter is essentially free running under control of a pulse generator. This pulse generator gates the transmitter modulator on and allows either audio or data modulation to take place. The modulator then drives the transmitter and the RT switch passes the transmitted signal on to the antenna. The random

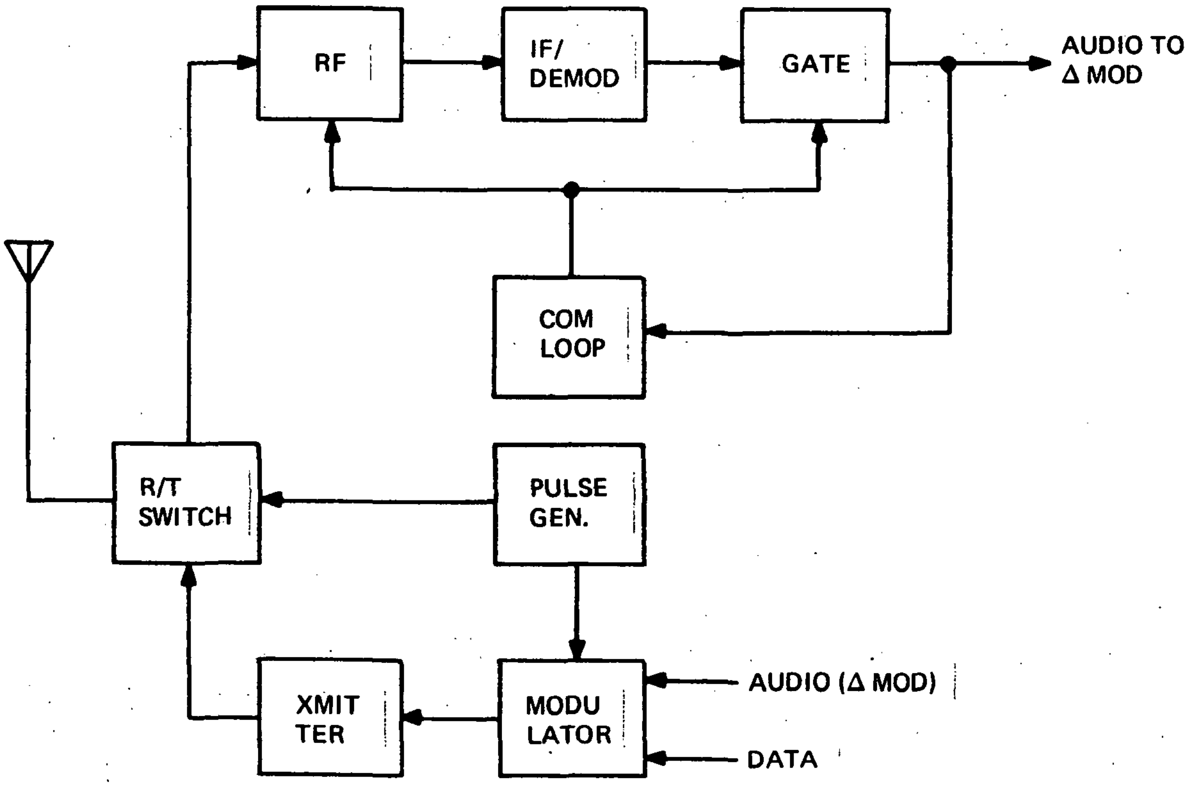


Figure 9. Random TDMA EVA System

TDMA receiver can be completely independent of the transmitter. The incoming signal is received by the antenna and passed via the TR switch to a gated RF amplifier. The signal is then sent to a limiting IF amplifier and demodulator and it is gated again under control of the communications tracking loop. The tracking loop receives its error signal from the audio output of the receiver and by means of early/late gating maintains the receiver gate in the proper time phase. It should be noted that channel selection in the receiver is accomplished by selecting the PRF of the comm tracking loop. The loop itself is implemented in the same fashion as the loops used for the synchronous scheme except that a variable division ratio is used instead of the divide by 128. Each channel uses a relatively prime number as a means of uniquely identifying the channel and effecting the channel selection.

Figure 10 shows a random TDMA dual channel receiver. The concept could readily be expanded to a ten channel receiver for use in the spacecraft. The various signals are received by the antenna and applied to the gated RF amplifier. The amplifier is gated on at the time whenever a signal is expected. Once the signal is passed and amplified it is sent to the intermediate frequency amplifier which includes a hard limiter and the FSK demodulator. The output after the demodulator is gated on to a number of baseband channels. Since each channel uses a unique pulse repetition period, separate tracking loops are provided for each channel. For example, loop #1 gates the RF amplifier and the video gate on at the time when a signal is expected from EVA 1. Similarly, tracking loop #2 gates on the RF amplifier and the output of the demodulator when a signal is expected from EVA 2.

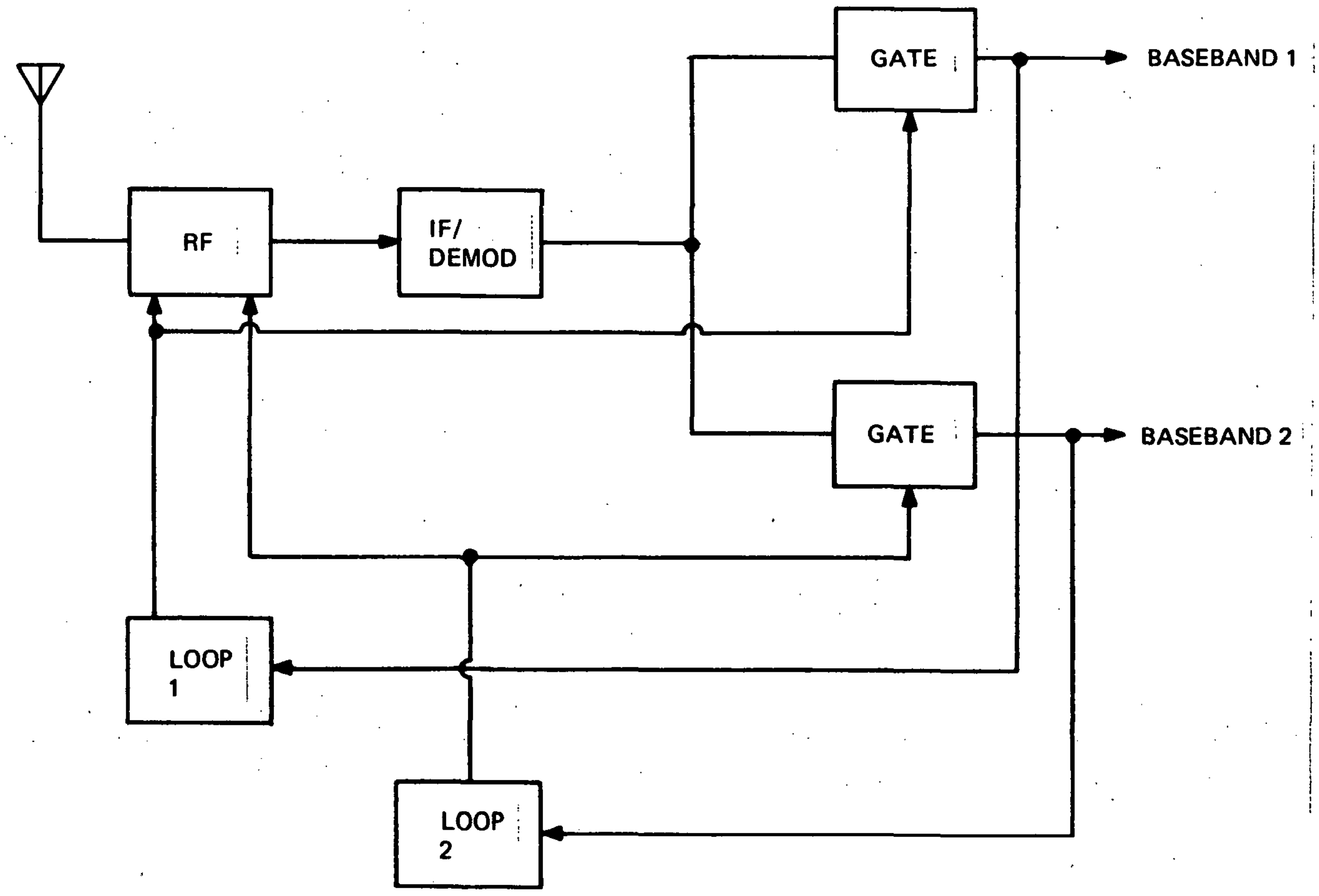


Figure 10. Random TDMA Dual-Channel Receiver

However, the outputs are separated onto different signal lines so that separate signal processing can be applied. In the random TDMA system, the receivers and transmitters are completely independent and there is no need for crossconnection except for control of the TR switch. Because of the independence of the transmit and receive functions it is not possible to extract range information from a random TDMA system.

5. Conclusions

The following conclusions can be drawn about a TDMA Multi-EVA system:

a. TDMA pulses systems result in higher S/N ratios; the RFI from Earth radiations of an integrated level of 70 dBm can be overcome, and therefore the VHF band can be used as well as microwave.

b. The system equipment is simple, since no power control is needed, channel selection is accomplished by digital control and frequency stability requirements are trivial.

c. All EVA transmitters and receivers are identical (in FDMA, different filters and crystals are needed).

d. All technology to build such a system exists from the Apollo Ranging and CSAR programs, and 100 w peak power VHF transmitters with a 1.6% duty cycle have been developed for Apollo 17.

e. The S/N ratio, in addition to the peak power transmission, is further increased by the elimination of the multicoupler loss, since only one receiver and transmitter is needed in the spacecraft.

f. The RFI is rejected by the peak power and by gating off the receiver when no signals are expected.

g. The total bandwidth required is less than that for an FDMA system.

h. A random TDMA system, according to the preliminary analysis, can achieve the transmission accuracies desired, although further evaluation is required.

i. Range information is obtained as part of the synchronization process in synchronous TDMA and it can be displayed at little additional cost.