THE LUNAR COMMUNICATIONS RELAY UNIT SYSTEM DESIGN*

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Summary Lunar Surface Exploration by Early Apollo Astronauts was limited by the range capabilities and configuration of the surface communications. To permit greater scientific yield from manned lunar exploration, it was necessary to provide improvements in crew mobility plus communications compatible with extended extravehicular activity.

Expansion of EVA** and video communications capability was constrained by the requirement of interfacing with existing earth and lunar surface facilities, vehicle payload requirements, and crew operational considerations. Various trade-off s were conducted to permit rapid development of a feasible communication's system which are described herein.

The revision of the EVA mission profile necessitated establishment of new signal design parameters compatible with mobile and fixed site relay configurations. The design approach selected required strict discipline to enable integration of the electrical, mechanical, thermal and human factor fields.

The resultant design of the Lunar Communications Relay Unit is a portable communications package to provide relay-to-earth of voice, data and color television from lunar surface locations far beyond the LM landing site and relay of ground voice to the EVA crew.

Introduction During the Apollo XI and XII missions the lunar surface activity of the crew was limited to line-of -sight position relative to their communication relay station. The configuration of EVA-LM-MSFN facilities are described to identify existing constraints and functions required for system expansion. During these missions the crew

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** Refer to the Glossary (Appendix I) for all terms and abbreviations.

was provided with the communications facilities as shown in Figure 1. The EVA to MSFN communication system provides the following links:

(1) S-Band Duplex, LM to MSFN
(2) S-Band Duplex, CSM to MSFN
(3) VHF AM EVA_1 to LM and to EVA_2
(4) VHF EM EVA_2 to EVA_1
(5) VHF AM LM to EVA_1 and EVA_2

The LM Communications Subsystem provides relay between the EVA's and the MSFN earth stations, and between the EVA's and the CSM (via the MSFN). EVA_1 provides the intermediate relay function between EVA_2 and the LM. The television camera, when utilized, is hardlined directly into the LM.

The back pack communications (EVCS) carried by the LMP (EVC-2) and the LM-CDR (EVC-1) initiate the voice and data down link transmissions as shown in Figure 2. The FM carrier (279.0 MHz) is modulated by the following three channels:

(1) Baseband Voice
(2) 3.9 KHz subcarrier carrying EKG data
(3) 7.35 KHz subcarrier carrying 30 x 1.5 commutated PLSS status data.

The EVA_1 demodulates the received EVA_2 composite FM carrier and combines the received baseband signals with EVA_1 composite baseband so that five channels amplitude modulate the 259.7 MHz carrier as follows:

(1) Baseband Voice (EVA_1 or EVA_2)
(2) 3.9 KHz subcarrier, EVA_2 EKG
(3) 5.4 KHz subcarrier, EVA_1 EKG
(4) 7.35 KHz subcarrier, EVA_2 PLSS status
(5) 10.5 KHz subcarrier, EVA_1 PLSS status

The EVA_1 VHF signal is received by the LM which demodulates the composite baseband from the 259.7 MHz carrier. The voice and subcarriers are then processed to enable modulation of the S-Band carrier (2282.5 MHz) as follows:

(1) Phase modulate carrier by composite baseband, or
(2) Frequency modulate carrier by 1.25 MHz subcarrier; subcarrier frequency modulated by composite baseband.

Since both down link signals are processed similarly at the MSFN ground station, it is desirous that the SNR of the received signals maintain a balanced discipline whether the signal received from LM is PM or FM.

Therefore, the modulation indices of the EVCS down link signal must be conditioned by the premodulation signal processor to provide the MSFN

Signal	EVA-1 % AM	Tolerance in % of Value	Ratio of Input Modulation Levels	SNR Required at MSFN	MSFN Pre-dection NBW in Hz
Voice	36.5	12 (EVC-1) 18 (EVC-2)	4.35	14.0 dB	3000
3.9 KHz S. C.	8.4	18	1.0*	8.5 dB	655
5.4 KHz S. C.	9.3	12	1.1	8.5 dB	905
7.35 KHz S. C.	16.2	18	1.93	11.0 dB	1232
10.5 KHz S. C.	19.0	12	2.26	11.0 dB	1763

*Reference

The phase modulated (or frequency modulated) S-band carriers are transmitted to the MSFN from the LM. The received signal at the MSFN demodulates the 1.25 MHz subcarrier from the S-Band carrier. The composite I baseband is demodulated from the 1.25 MHz subcarrier, the four data subcarriers separated from the composite by bandpass filters and the voice through a low pass filter. The four data subcarriers are reduced to analog by the respective channel discriminators.

It should be noted that the LM communications subsystem serves a dual purpose. During deep space flight the S-band link is employed for voice, data, and video communications, plus vehicle tracking. The VHF link is employed for voice and data communications between LM and the CSM in addition to ranging during rendezvous.

The flight requirements include doppler correction, dynamic antenna steering (S-Band) to maintain link acquisition for various vehicle attitudes, and phase lock transponding for ranging. Although the characteristics employed to meet the above requirements are desirable during in-flight operation, these features become superfluous for extravehicular exploration when the LM is placed on the lunar surface to serve as unattended relay station. Communications at the lunar base is conducted line-of-sight between EVA's and the LM (1 to 1.5 nm dependent on terrain). Video communications is limited to the length of cable between the TV camera and the LM. Therefore, the exploration at the lunar base is limited to about a six mile perimeter around the spacecraft without television, or a six hundred (600) foot perimeter with TV.

To increase the scientific yield from each manned lunar mission necessitates improvements in EVA/Video to MSFN communications to enable crew activity limited only by their life support systems. The capability provided must provide functions similar to the LM communications subsystem as employed during an EVA sortie.

It is obvious that the desired system take the form of a portable package, i.e., a miniaturized LM communications subsystem. Such a device will require its own prime power source, environmental control, antenna farm and facilities for handling TV, as does the LM.

Requirements For Improving System Capability The necessary capabilities required to improve the EVA to earth communications system are highlighted in the following general requirements:

(1) The Lunar Communications Relay Unit (LCRU) shall be a portable, self - contained communications relay terminal providing:
  - (a) EVA communications capability on the lunar surface when beyond line -of - sight conditions of the Lunar Module, while hand carrying the LCRU.
  - (b) A direct Lunar-to-Earth voice-data link via the LCRU during extended lunar explorations while the EVA is traversing the lunar surface on the Lunar Rover Vehicle (LRV).
  - (c) Direct Lunar-to-Earth color TV transmission via the LCRU from a fixed- site location while installed on the LRV.
  - (d) Voice transmissions from earth initiated by the Manned Spaceflight Network (MSFN) to EVA.
  - (e) Command subcarrier transmission and hardline to GCTA.
  - (f) On-off commands from GCTA during remote/standby operations.
  - (g) Compatibility of LCRU stowage and removal from the MESA compartment in the LM descent stage, and stowage on LRV.
  - (h) Replacement of batteries while on the lunar surface by a suited astronaut.

(2) The LCRU must provide interface with LRV prime power source.

(3) Produce the LCRU engineering model within six months and flight model within one year.

Since the LCRU system is scheduled for Apollo 15 an extremely short term development program was evident. The schedule economy dictated maximum use of off -the-shelf designs for the LCRU components and essentially zero impact to the MSFN ground station and/or MCCH. It was obvious that the VHF link must be exactly compatible with EVCS since the crew hardware would be utilized with both the LM and LCRU. The

S-Band links would be similar to the LM but modified to enable useage of less sophisticated equipment since volume and weight appeared extremely limited due to stowage and payload constraints of both the LM spacecraft and LRV. Crew interface was, obviously, a formidable task since the EVA is required to assemble, hand carry, and manipulate the LCRU in a suited environment. The design approach had to minimize crew effort to avoid reduction of their scientific task capability.

The major requirements established for the LCRU (for the sake of this discussion) are:

(1) Input-output performance
(2) Thermal requirements
(3) Allocated volume

The output performance, particularly the transmission EIRP to span deep space, is a product of antenna gain times transmitter power. Since the LCRU is to be utilized in a mobile mode (as well as fixed site relay), the wide coverage desired will necessitate a low gain antenna, resulting in appreciable transmitter power. Since prime power will be required for approximately a six hour sortie, both the thermal requirements (due to transmitter dissipation) and allocated volume (due to size of battery and transmitter) are affected by EIRP. The transmitter dissipation will contribute most of the heat input to the LCRU.

The amount of internal heat generated establishes the major factors for environmental control. The transmitter and battery volumes are the major contenders for packaging space. (The LCRU is allocated an envelope of only 16 x 22 x 5 inches, irregular in shape.)

The external thermal requirements for the LCRU are established by the LCRU time lines of projected mission profile. A sample timeline is shown in Figure 3. The LCRU thermal mission is indicated as 64 hours. The upper curve denotes the sun angle to LCRU (sun at zenith = 90°). The hot case indicates higher initial sun angle and low duration shaded areas during a sortie. The cold, case denotes low initial sun angle and long periods of shade during a sortie. To establish the total thermal requirements for the LCRU, calls for a third curve of total LCRU internal power dissipation plotted against the same timeline. The dissipation is a design trade-off factor.

The LCRU input-output requirements consist of the following:

(1) LCRU to MSFN S-Band down link interfaces
(2) MSFN to LCRU S-Band up link interfaces
(3) EVCS and LCRU uplink-downlink VHF interfaces
(4) GCTA and LCRU hardline uplink and downlink interfaces.

The EVCS to LM interface required operation over a lunar surface path loss of 119 dB. Since the EVA's will conduct their activity in close proximity to the LCRU the path loss of the VHF link was reduced to 105 dB.

If EVCS link performance is employed over the reduced path loss, then the SNR of the VHF link will be greater than 30 dB. Therefore, for the purposes of this paper the VHF requirements will be omitted.

The GCTA signal interfaces with LCRU are limited to the following:

(1) GCTA video output-DC coupled with a nominal bandwidth of 2 MHz, and SNR of 35 dB
(2) LCRU 70 KHz subcarrier output - 10 dB SNR in 20 KHz NBW.

The LCRU to MSFN S-Band down link requirements are tabulated in :Appendix II and the MSFN to LCRU S-Band uplink in Appendix III. The major worst case signal parameter requirements for design of a relay terminal compatible with the MSFN include:

A. Down link: space path loss, MSFN antenna gains, noise power and SNR for required carrier performance, subcarriers, voice and video channels.

The listed down link parameters were selected from available MSFN configurations to accommodate the following operational mode s:

(1) Wide band PM - voice/data on 1.25 MHz subcarrier
(2) Narrow band PM - voice /data baseband
(3) Wide band FM - voice/data on 1.25 MHz subcarrier and video baseband

B. Uplink: space path loss, MSFN antenna gains, MSFN EIRP, voice subcarrier deviation (124 KHz) and post detection SNR, command subcarrier deviation (70 KHz) and predetection SNR.

The LCRU antenna farm requirements include a vertically polarized omnidirectional VHF whip and two S-Band antennas. A narrow beam antenna is required to attain high EIRP for video transmission when the LCRU is operated from a fixed site. A wide beam antenna provides a conical beamwidth of 60° for downlink transmission, and 120° for uplink reception. The wide coverage is necessary to maintain earth link acquisition during mobile operation with the LCRU.

System Design Trade-Offs Upon initial investigation the system design of the EVA-LCRU-GCTA-MSFN complex appeared as a nightmare in engineering disciplines. Each of the engineering tasks apparently was interrelated with another task and yet the tasks were serial in nature. Packaging form factor was fixed by LM spacecraft maximum stowage volume and also LRV payload stowage. Internal electronic subassembly configurations were dependent on signal design, which depended on choice of antenna, but transmitter power determined battery watt hour capacity, which determined mission capability, etc., ad infinitum. The total number of trade-offs performed to develop the LCRU baseline design is beyond the scope of this paper. A list of pertinent trade-offs is provided in Appendix IV. The major area of interest covered in this section will include the signal design needed to accommodate the uplink and downlink requirement covered in the preceding section.

A dual downlink carrier was considered to permit transmission of baseband video on one carrier and voice-data over the second carrier via the 1.25 MHz subcarrier. This approach appeared promising since it permitted use of a low power transmitter for the voice-data channel. The use of the low power channel would enable prime power management by cycling the TV channel on and off during long periods of fixed site operation. The major disadvantages to this approach include the following:

(1) Single antenna port for both high and low antennas required numerous manual antenna switchings by the crew during a sortie.
(2) Required two receiver down link frequencies (for LCRU) for every ground station.
(3) Created a major single point failure at switch, and redundancy caused excessive packaging waste due to triplexer size. Close channel spacing of available frequencies (within 27 MHz) contributed to excessive triplexer size. Since the spacing was only 1% of carrier frequency the triplexer filter design (for required insertion loss and isolation) dictated the need for a volume incompatible with the available LCRU envelope.

Redundant S-Band transceivers (one down link frequency) were considered to permit hardlining of the antennas to their respective transceivers. This approach simplified crew procedure, eliminated the single point failure, was compatible with packaging and required only one LCRU down link frequency at the ground stations.

If these redundant units were configured with dual modulators, the down link carrier channels could be configured for the three MSFN modes:

(1) PM narrow band-voice-data baseband
(2) PM on carrier wideband-baseband FM on 1.25 MHz subcarrier
(3) FM wideband-video baseband and 1.25 MHz subcarrier, both FM on carrier.

The preceding section discussed down link requirements which were based on non-optimum conditioning of the received signals from EVCS. This means the EIRP was established on worst case modulation indices of the EVA voice-data channels.

Optimizing of these indices and the index of the 1.25 MHz SC would permit a practical reduction of the EIRP by approximately 2 dB. The signal processing for optimization of the EVCS indices would require individual channel division of the subcarriers and voice from the composite signal, individual AGC, and recombination.

The trade-off of a complex signal processor to the 2 dB reduction in EIRP appeared as a poor design choice since the EIRP requirements were obtained from an overall worst case analysis. An off the shelf transmitter design was available which provided a power dissipation timeline (Figure 4) compatible with the thermal profile and allowed development of a feasible environmental control system.

The transmitters were selected based on the following:

(1) projected LCRU circuit losses
(2) available state of the art high gain antenna of 23 dB
(3) available state of the art wide beam width helix antenna for mobile operation with LCRU - antenna gain of +6.5 dB min. over 60° beamwidth (downlink mode) and -5 dB gain over 120° beamwidth (uplink).

Resultant LCRU Design The LCRU system design provides the link capabilities shown in Figure 5. Commonality is provided with the EVCS since the LCRU accepts inputs from EVA on the 259.7 MHz carrier and transmits to EVA_1 and EVA_2 on 296.8 MHz. The MSFN-LM uplink S-Band carrier (2101.8 MHz) is shared for the MSFN-LCRU uplink for voice and commands. The downlink S-Band carrier (2265.5 MHz) transmissions include voice/data or TV/voice data.

The down link system configuration (Figure 6) emphasizes the versatility of the LM and LCRU deployed as relay terminals between the EVA's and the MSFN. Access into the MSFN is accomplished by selecting LM or LCRU receiver frequency and Mode configurations (i.e., PM-WB, PM-NB) at the MSFN by selection of predetection bandwidth. These features enable both the ground controller and the crew (via procedure) to employ the LM during EVA activity adjacent to the spacecraft, and utilization of the LCRU beyond line of sight of the LM. During the latter, a fifth subcarrier (14.5 KHz) provides the LCRU status of temperature and up-link received battery voltage. The two measurements modulate the subcarrier on a time shared basis, and is combined with the EVA voice and four EMU subcarriers. Mode selection of the down link channels is provided via a multiposition switch located on the LCRU control panel available to the crew. The S-Band FM transmitter, and the companion SCO are capable of on-off control by ground command over the MSFN-LCRU uplink utilizing the 70 KHz subcarrier.

The MSFN-LCRU-EVA uplink is identified in Figure 7. Access to the LM or LCRU uplink voice channel is provided by selection of the 30 KHz or 124 KHz subcarrier respectively, on which the voice baseband is frequency modulated. The uplink digital commands frequency modulate the 70 KHz subcarrier. LM or LCRU are selected by discrete code. The composite 70 and 124 KHz subcarriers phase modulate the uplink S-Band carrier which is received by the LCRU. The carrier is demodulated and the two subcarriers are separated. The uplink voice is retransmitted to the two EVA's over the VHF link at 296.8 MHz. The 7 0 KHz subcarrier is hardlined to the GCTA from the LCRU. This GCTA is capable of command operation by ground controllers to execute pan, tilt and zoom functions with the television camera in addition to camera on-off control.

The LCRU subsystem configuration is functionally illustrated in Figure 8.

Three antennas are utilized in the LCRU system each handlined into the respective transceivers.

A VHF ommi whip antenna is used for the link between the LCRU and EVA's. Two S-Band antennas provide for communications between the LCRU and MSFN. The wide beamwidth low gain helical antenna is used for voice/data communications between MSFN and LCRU during the mobile mode. The narrow beamwidth high gain parabolic dish is used for TV/voice-data coverage when the LCRU is stationary.

The paths between the VHF transceivers and the S-band transceivers include the signal processing functions to condition the uplink and downlink baseband signals. The processing employed enables establishment of the modulation indices for each of the modulation signal parameters (Appendices II and III). To provide simplicity, the down link EVA input signals are retained in composite baseband of voice and four subcarriers. The AGC obtained from the VHF receiver is utilized to maintain signal level within I dB. This approach was possible since the input signal dynamic range is low enough to allow flat output due to the high received signal strength at the LCFU. Thus the down link processing is reduced to four simple functions:

- Combining the fifth subcarrier with EVA inputs.
- Setting baseband modulation indices for narrow band PM.
- Shaping baseband for desired FM indices for 1.25 MHz subcarrier.
- Mixing video and voice/data.

The choice of dual modulators was employed to provide redundancy at each S-band antenna port in the event of damage to an antenna during a sortie. In addition this approach allowed simplicity in mode switching utilizing DC controls rather than coaxial devices.

The up-link channel employs two identical 8 dB noise figure dual conversion FM receivers to receive voice and/or voice and command data from MFSN. The composite baseband signals consist of voice on a 124 KHz SC and command data on a 70 KHz SC. The voice subcarrier is separated from the composite. The voice outputs of the receivers are coupled through a 3 dB coupler. Squelch is provided for receiver quieting in the event carrier or subcarrier are not acquired. The uplink 70 KHz subcarrier is processed for output level only and hardlined to the GCTA. The uplink voice VOX keys the VHF transmitter during the presence of voice. The voice is processed to set the modulation index at a level sufficient to override crew intercommunication. A summary of the worst case circuit margin is provided in Appendix V. The circuit margins analyzed include three down links-PM wide band, PM narrow band, television voice-data; and the uplink. The analysis is summarized to include the S-band links between LCRU and MSFN. The VHF up and down links are not included since the SNRI s are high enough to appear negligible in the overall analysis. For several of the parameters, two values are provided; the higher value denotes use of the 210-foot MSFN dish, the lower value denotes use of the 85-foot MSFN dish. Since the circuit margins shown were developed for all worst case conditions of LCRU operations, several margins appear low. In the practical sense the margins will be 3 to 4 dB higher since positioning of the low gain antenna by the crew will result in lower “off -boresight angle” than used in the analysis. In addition the sum of circuit losses, modulation losses, transmitter power, etc. will not all occur at worst case extremes.

The LCRU hardware is designed principally for use when the crew conducts an extended sortie with the LRV, Figure 9. The LCRU is mounted on the front cross member of the vehicle.

The high gain antenna and GCTA are located on either side of the LCRU. The low gain S-Band antenna is located adjacent to the LRV control panel to provide crew access during traverse. This enables the EVA to orient the antenna toward the earth as required. The LCRU is packaged in a nominal 16 x 22 x 5 inch envelope. Approximately two thirds of the envelope houses the electronics within a pressure vessel containing dry nitrogen. The pressurization approach is employed primarily to prevent ignition of corona. within the RF modules. The remaining compartment houses the prime power source, a replaceable (silver zinc, 400-watt hour) battery, and miscellaneous cables, switches and terminal boards associated with the control panel.

The temperature control system for the LCRU is a combination radiation and change of phase system. There are three major components to this temperature control system. The primary mode of heat rejection from the equipment is through the radiator which is located at the space-looking side of the LCRU. This radiator is constructed using second surface mirrors which allow it to operate with minimum solar absorption (a= 0.10) while effectively radiating in the infrared spectrum. During extended mission timelines it became impossible to provide enough radiator surface within the present envelope of the equipment to permit complete rejection of energy dissipated and absorbed in the unit. If the equipment begins an operating period at a temperature below the maximum allowable for reliable operation, a certain amount of energy can be stored in the specific heating of the components of the equipment. Obviously, since the radiator cannot reject the required amount of heat, the equipment can never reach thermal steady state without reaching an excessively high temperature. The design also allows control of the amount of effective radiator exposed during the periods between operation to something less than that required during operation to prevent overcooling.

Utilizing the combination of radiation cooling plus specific heating of the equipment, provides an inadequate amount of cooling to include the many uncertainties that are encountered in the thermal environment (such as the effect of lunar dust on the radiator, the orientation of the radiator during a traverse, and the fact that the lunar and solar inputs onto the equipment change as mission time proceeds). These factors have resulted in a design in which the radiator and the multifoil insulating blanket that covers the radiator during periods of no thermal dissipation is supplemented by an additional component which is a change of phase package. This package contains a wax material which changes from solid to liquid at a temperature low enough that the heat required for the phase change can be absorbed from the electronic equipment. As shown in Figure 10, the LCRU equipment consists of the case completely surrounded by a thermal blanket to minimize the absorption of heat from lunar or solar sources. This thermal blanket is removable at the top and can be removed in two pieces. When the blanket is removed, it exposes a radiation panel which is the primary cooling mechanism in the system. The radiation panel is mounted on a change of phase package located on top of the LCRU. Two additional phase change packages are provided, one external and the other in the unpressurized compartment.

A typical thermal profile of the LCRU is presented in Figure 11. The curve represents the thermal transients for a 70-hour lunar mission during a hot traverse (full sunlight). Notice the clipping at 120°F due to phase change of the wax material. The damping which occurs subsequent to phase change accounts for the heat transfer back into the LCRU due to refreezing of the wax. Thus the temperature on the LCRU radiator for this profile is limited between 60°F and 120°F.

The LCRU/LRV enables the Apollo crew to conduct three long term sorties, of a nominal duration of five hours each. At the beginning and end of each sortie when in line-of-sight of the spacecraft, the LM communications is employed. During the traverse of a long range sortie the low gain S-Band antenna is manually positioned for earth (MSFN) acquisition to maintain the duplex link employing the transceiver which includes the PM wide band functions. Down link transmission is satisfactory over a beam width of up to 60°; and up link over a beam width of 120°.

The television link is designed for fixed base (vehicle stopped) operation. To initiate television transmission requires boresighting of the high gain antenna to the earth within a 5° beamwidth. To simplify crew procedure the parabolic dish assembly includes an optical viewfinder and ball joint fastened positioning control.

Subsequent to optical earth acquisition the crew switches the LCRU mode selector to the FM/TV-voice mode employing the other transceiver. Two TV modes are available to the crew, manual control of the camera or remote ground control operation. During remote operation the ground controller is capable of positioning the camera for pan and tilt, operate the zoom lens to maximum and minimum focal length, switch the camera on and off, and switch the voice/data 1.25 MHz subcarrier on and off. Thus the crew is provided with a "hands off" television capability during the numerous tasks they conduct on a sortie. The two transceivers are employed during a sortie consistent with the traverse/stop cycle required of various scientific tasks conducted by the crew.

Subsequent to each sortie the LCRU is switched off and thermal controls adjusted consistent with the local sun angle. At the beginning of second and third sorties a fresh battery is installed in the LCRU prior to initiating the traverse.

Following the final sortie the LCRU is switched to LRV internal power and set for remote TV, which allows for standby operation of LCRU and GCTA at minimum power. During the standby period (14 hours) the up link is operable via the high gain transceiver port. While the LCRU is dormant, the ground controller may command "on" the LCRU periodically to enable down link data to check status of LCRU battery voltage and heat sink temperature.

Immediately prior to lift off of the LM, the ground controller may energize the LCRU and GCTA for remote television operation. The camera may be positioned for optimum view of the LM ascent and subsequent to lift-off the ascent stage may be optically tracked until beyond resolving capability of the camera.

APPENDIX I
GLOSSARY

AGC	Automatic Gain Control
AM	Amplitude Modulation
BPF	Bandpass Filter
BW	Bandwidth
CDR	Lunar Module Commander (EVC-1) or (EVA_1)
CNR	Carrier-to-noise Power Ratio
CSM	Command and Service Module
db	Decibel
dbw	Decibel, referenced to 1 watt
EIRP	Effective Isotropic Radiated Power
EKG	Electrocardiogram
EMU	Extravehicular Mobility Unit (Spacesuit and PLSS)
EVA	Extravehicular Astronaut (or activity)
EVCS	Extravehicular Communications Systems
FL	Filter
FM	Frequency Modulation
GCTA	Ground Controlled Television Assembly
HG	High Gain Antenna
Hz	Hertz
IF	Intermediate Frequency
IRIG	Inter-Range Instrumentation Group
KHz	Kilohertz
LCRU	Lunar Communications Relay Unit
LG	Low Gain Antenna
LM	Lunar Module or LM Communication Subsystem
LMP	Lunar Module Pilot (EVC-2) or EVA_2)
LPF	Low Pass Filter
LRV	Lunar Rover Vehicle
MCCH	Mission Control Center, Houston
MHz	Megahertz
MSFN	Manned Space Flight Network
NB	Narrow Band
NBW	Noise Bandwidth
NM	Nautical Miles
PA	Power Amplifier
PLSS	Portable Life Support System
PM	Phase Modulation
RAD	Radians
RMS	Root-Mean-Square

SC	Subcarrier
SCO	Subcarrier Oscillator
SNR	Signal-to-noise Power Ratio
VCO	Voltage Controlled Oscillator
VHF	Very High Frequency
VOX	Voice Operated Transmissions
W	Watt
WB	Wide Band

APPENDIX II. LCRU TO MSFN DOWN LINK REQUIREMENTS
A. RF POWER LEVELS

MODE	Req'd EIRP For at Least 0 Margin in All Channels		Required Carrier & Subcarrier Powers for Each Channel and 0 Margin (DBW)							
	85' ANT (dBW)	210' ANT (dBW)	Carrier NBW: 50 Hz	1.25 MHz NBW: 48 KHz	Voice NBW: 3 KHz	3.0 KHz NBW: 720 Hz	5.4 KHz NBW: 995 Hz	7.35 KHz NBW: 1355 Hz	10.5 KHz NBW: 1939 Hz	14.5 KHz NBW: 2680 Hz
PRIMARY VOICE (FM/PM)	12.3*	NA	-176.4	-148.6	-156.3	-168.3	-166.9	-163.1	-161.5	-162.6
SECONDARY VOICE (BASEBAND PM)	12.9**	NA	-176.4	NA	-156.6	-168.3	-168.9	-163.1	-161.5	-162.6
TV/VOICE # (TV FM; VOICE FM/FM)	28.9##	21.4##	NA	-148.8	-156.3	-168.3	-166.9	-163.1	-161.5	-162.6

\# TV Predetection NBW: 5.3 MHz; post detection NBW: 1.7 MHz

\## EIRP determined by TV predetection treshold requirements

* EIRP determined by 1.25 MHz subcarrier

** EIRP determined by 14.5 KHz subcarrier

APPENDIX II. LCRU TO MSFN DOWN LINK REQUIREMENTS (cont.)
B. MODULATION PARAMETERS

1. 25-MHz Subcarrier Deviations - FM/FM Mode			
Voice	(4. 35)	6. 6 kHz	±15% Each Channel for LCRU, ±25% Each Channel for EVCS/LCRU Overall Tolerance*
3. 9-kHz Subcarrier	(1. 0)	2. 7 kHz	
5. 4-kHz Subcarrier	(1. 1)	3. 0 kHz	
7. 35-kHz Subcarrier	(1. 93)	5. 2 kHz	
10. 5-kHz Subcarrier	(2. 26)	6. 1 kHz	
14. 5-kHz Subcarrier		7. 6 kHz	
Carrier Deviations - FM/PM Mode			
1. 25-MHz Subcarrier		1. 85 Rad	±10%
Carrier Deviations - Baseband			
Voice	(4. 35)	0. 98 Rad	±15% Each Channel for LCRU, ±25% Each Channel for EVCS/LCRU Overall Tolerance*
3. 9-kHz Subcarrier	(1. 0)	0. 23 Rad	
5. 4-kHz Subcarrier	(1. 1)	0. 25 Rad	
7. 35-kHz Subcarrier	(1. 93)	0. 43 Rad	
10. 5-kHz Subcarrier	(2. 26)	0. 51 Rad	
14. 5-kHz Subcarrier		0. 40 Rad	
Carrier Deviations - TV Mode (Color)			
Television		1. 7 MHz	4% (9% TV/LCRU)
1. 25-MHz Subcarrier		400 kHz	10%

*Based on nominal ratio signal set received from EVA-1, shown in parentheses.

APPENDIX III. MSFN TO LCRU UPLINK REQUIREMENTS

A. RF POWER LEVELS

Required Predetection Power (dBw) In Carrier and Subcarrier for 0 dB Margin* (MSFN EIRP = 90.5 dBw)					
Carrier NBW = 494 KHz		124 KHz S.C. NBW = 29 KHz		70 KHz S.C. NBW = 24 KHz	
H.G. Ant.	L.G. Ant.	H.G. Ant.	L.G. Ant.	H.G. Ant.	L.G. Ant.
-147.8	-120.5	-151.7	-126.2	-152.4	N/A

*For Post Detection SNR = 14 db

B. MODULATION PARAMETERS

Carrier Deviations (S-Band)		
(1) 124 KHz Voice Subcarrier	1.1 Rad	±10%
(2) 70-KHz Command Subcarrier	.8 Rad	±10%
(2) 124-KHz Voice Subcarrier	.8 Rad	±10%
(3) 30 KHz Voice Subcarrier	1.1 Rad	±10%
(3) 70 KHz Command Subcarrier	1.1 Rad	±10%
124 KHz Subcarrier Deviation	±7.5 KHz	±10%
70-KHz Subcarrier Deviation	±5.0 KHz	±10%
Carrier Modulation (VHF)	70%	±10%

NOTE:

(1) Up Link Voice MSFN to LCRU

(2) Up Link Voice MSFN to LCRU and Up Link Commands MSFN to LCRU/LM

(3) Up Link Voice MSFN to LM and Up Link Commands MSFN to LCRU/LM

APPENDIX IV
PERTINENT DESIGN TRADE-OFFS

High Gain Antenna:

- Phased helix array
- Solid parabolic dish
- Petal section parabolic dish
- Planar phased array
- Cassegrain fed inflatable dish
- Single fold ribbed mesh dish,* cup helix fed, 5° beamwidth, 23 db minimum gain, deployed dish diameter of 38 inches, optical sight for pointing aid, antenna assembly ball joint mounted for positioning capability.

Prime Power Source:

- Varied trades of voltage from 17 to 32 volts, varied trades of cell packaging configuration for form factor.
- Silver-zinc battery,* potassium hydroxide electrolyte, 19 cells, 29 volt, 400 watt hour capacity, 18 day activated wet life.

Environmental Control System:

- Boiler
- Sublimator
- Radiative coatings, paints, platings
- Second surface mirrors
- Change of phase materials (waxes)
- Multifoil blanket
- Hybrid system* - second surface mirrors plus change of phase packets plus multifoil blanket.

Deployed Configuration Design:

- Human engineering of -
    - LCRU and ancillary parts assembling
    - LCRU Control Panel
    - High gain antenna deployment and pointing mechanisms
    - Low gain antenna pointing mechanism
    - Hand carry attitude

*Selected for LCRU

APPENDIX V
WORST CASE LINK MARGIN SUMMARY

LINK PARAMETER	PMI/WB	PMI/NB*	FM/TV	UPLINK
TRANSMITTER POWER:	7.1w	7.1w	8.7w	10kw
EFFECTIVE ANT. GAIN:	6.5db	6.5db	23.0db	50.5db
EFFECTIVE RADIATED POWER (EIRP INCL. ALL CKT LOSSES)	13.0dbw	13.0dbw	30.7dbw	90.5dbw
TOTAL RECEIVED POWER: (INCL ALL CKT. LOSSES)				
85 FT. DISH (52.5 db)	-146.4dbw	-146.4dbw	-128.7dbw	—
210 FT. DISH (60.0 db)	—	—	-121.2dbw	—
LCRU L.G. (-7 db for ±60°)	—	—	—	-130.0dbw
LCRU H.G. (18.5 db for ±5°)	—	—	—	-104.3dBW
MARGINS (db):				
CARRIER	+16.0	+25.9	+9.0/+1.5	+25.2/-0.3
1.25 MHZ SUBCARRIER	+0.4	—	+2.5	—
124 KHZ SUBCARRIER	—	—	—	+37.3/+11.8
70 KHZ SUBCARRIER	—	—	—	+31.6
VOICE CHANNEL	+8.7	-0.2	+10.8	+51.3/+25.8
3.9 KHZ SUBCARRIER	+11.4	+0.9	+13.5	—
5.4 KHZ SUBCARRIER	+8.1	+0.4	+10.2	—
7.35 KHZ SUBCARRIER	+6.4	+1.2	+8.5	—
10.5 KHZ SUBCARRIER	+3.1	+1.1	+5.2	—
14.5 KHZ SUBCARRIER	+3.0	+0.1	+5.1	—
VIDEO CHANNEL	—	—	+1.0/-13.5	—

*PM/NB ALL MARGINS 1.0 db greater than PMI/NB

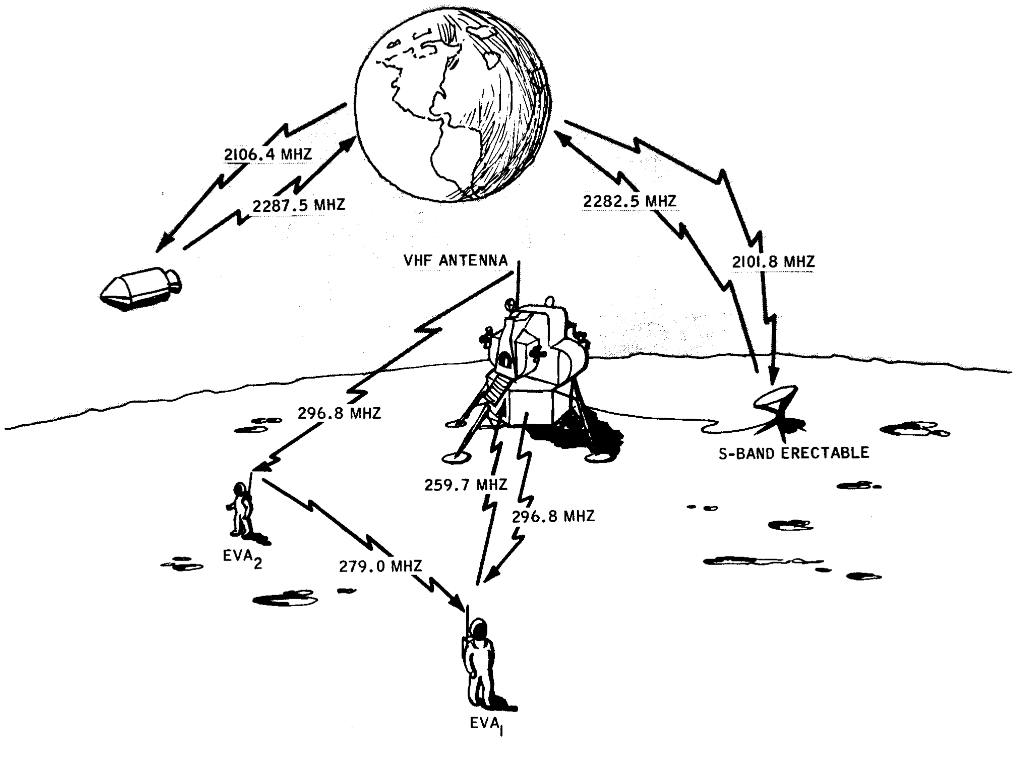

Figure 1. EVA.-to-MSFN Relay Communications System

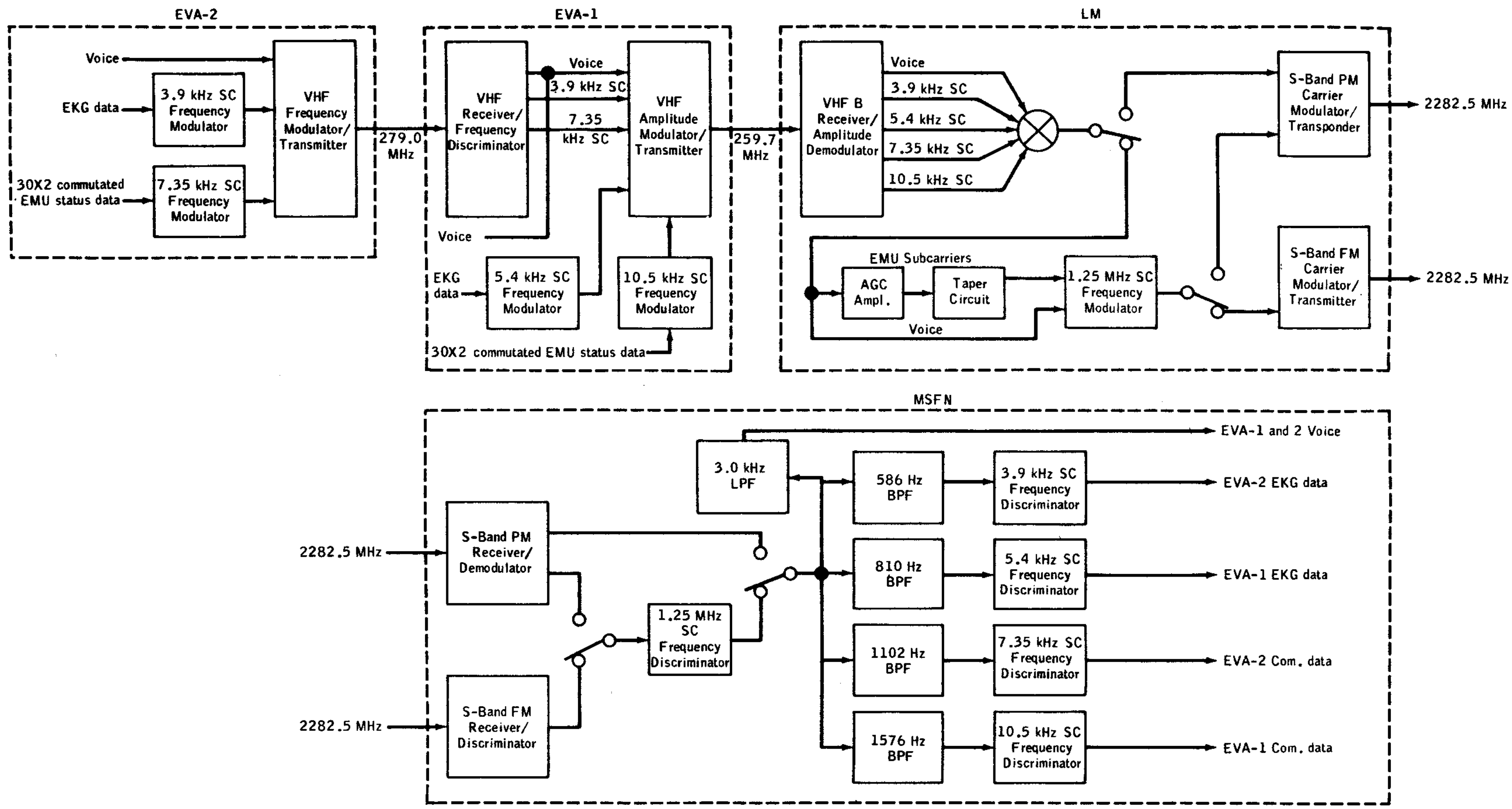

Figure 2. Down-link EVA-to-MSFN Communications System Configuration (Dual Mode)

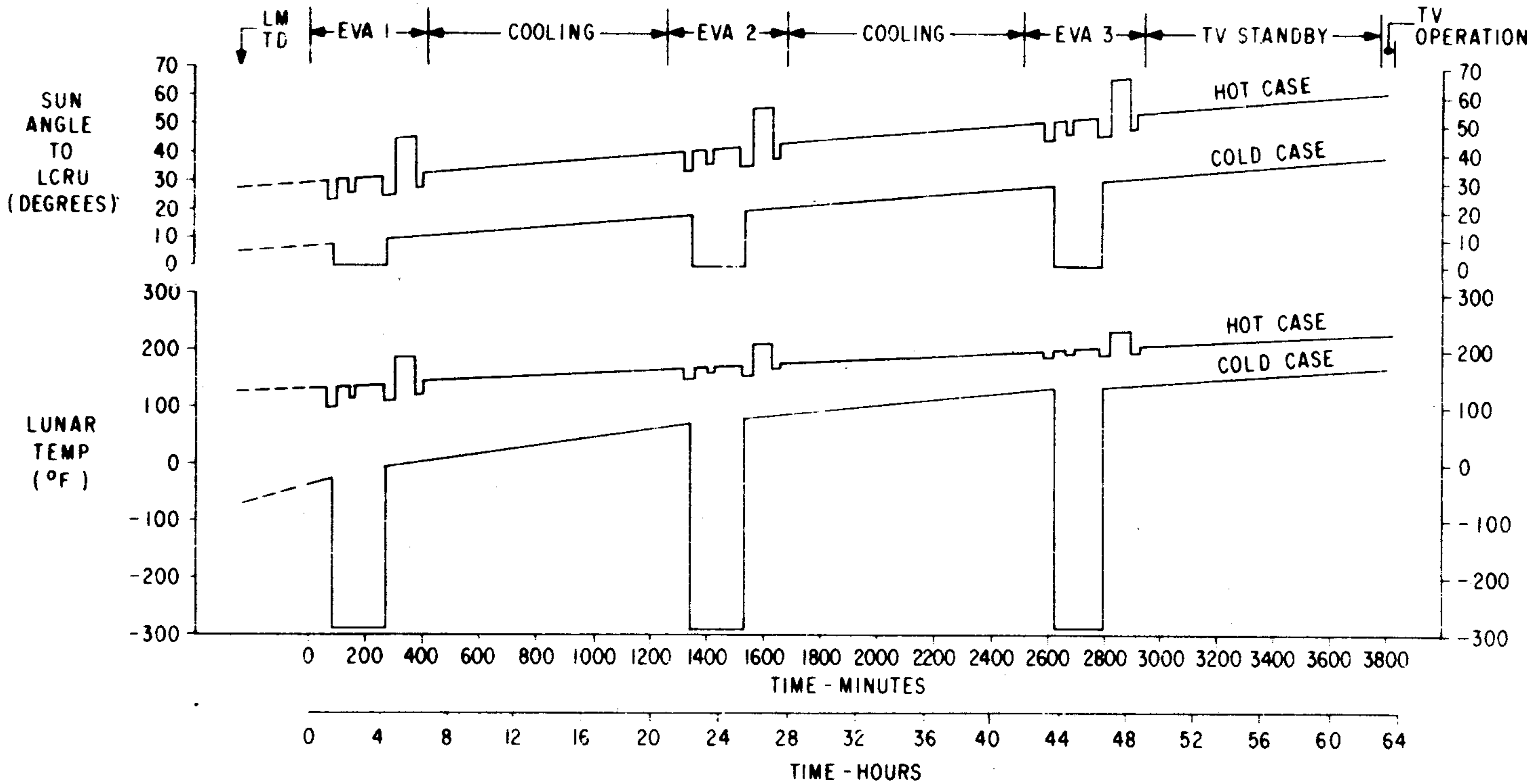

Figure 3. LCRU Timeline No. 1

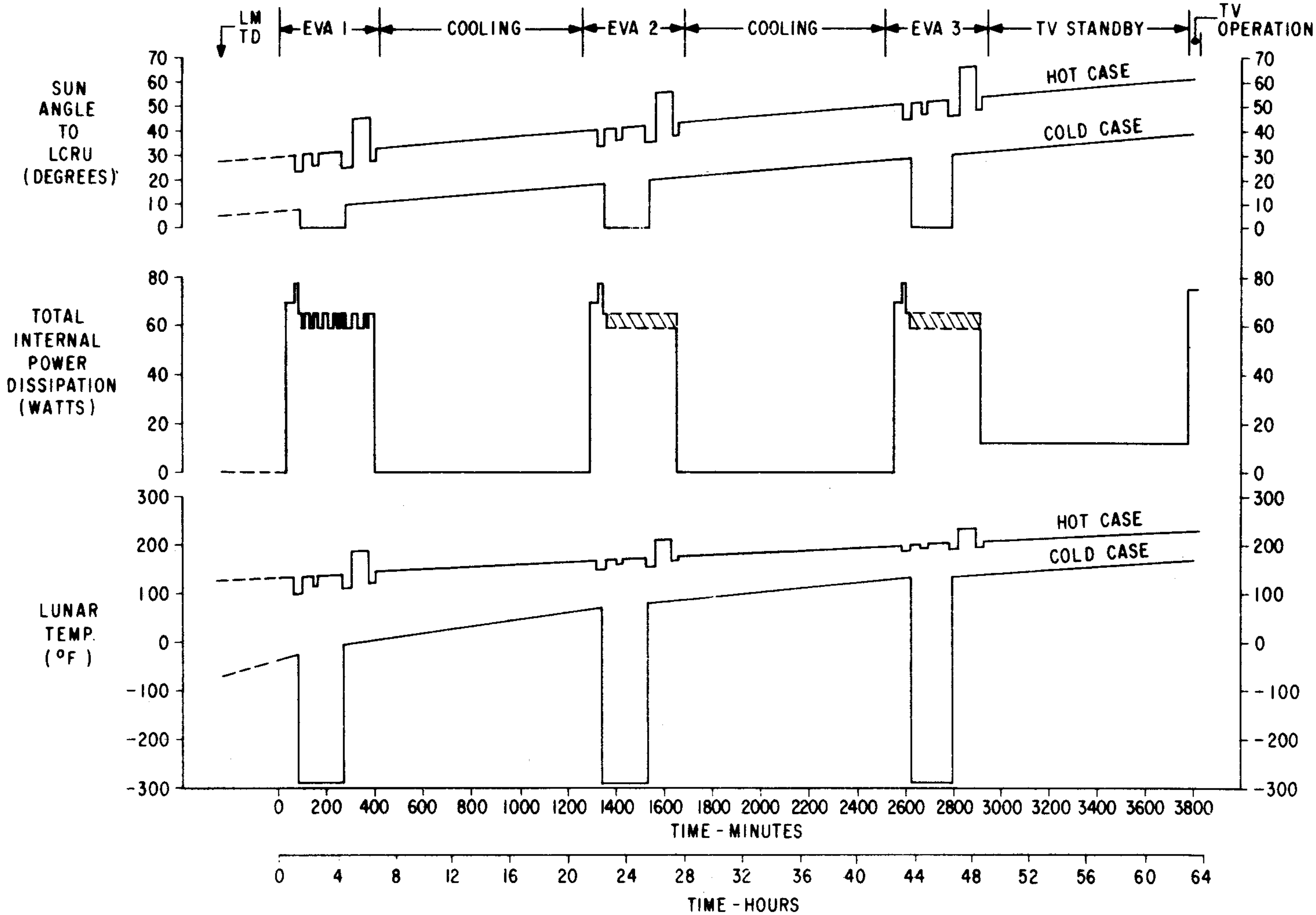

Figure 4. LCRU Timeline No. 1 (Including Dissipation)

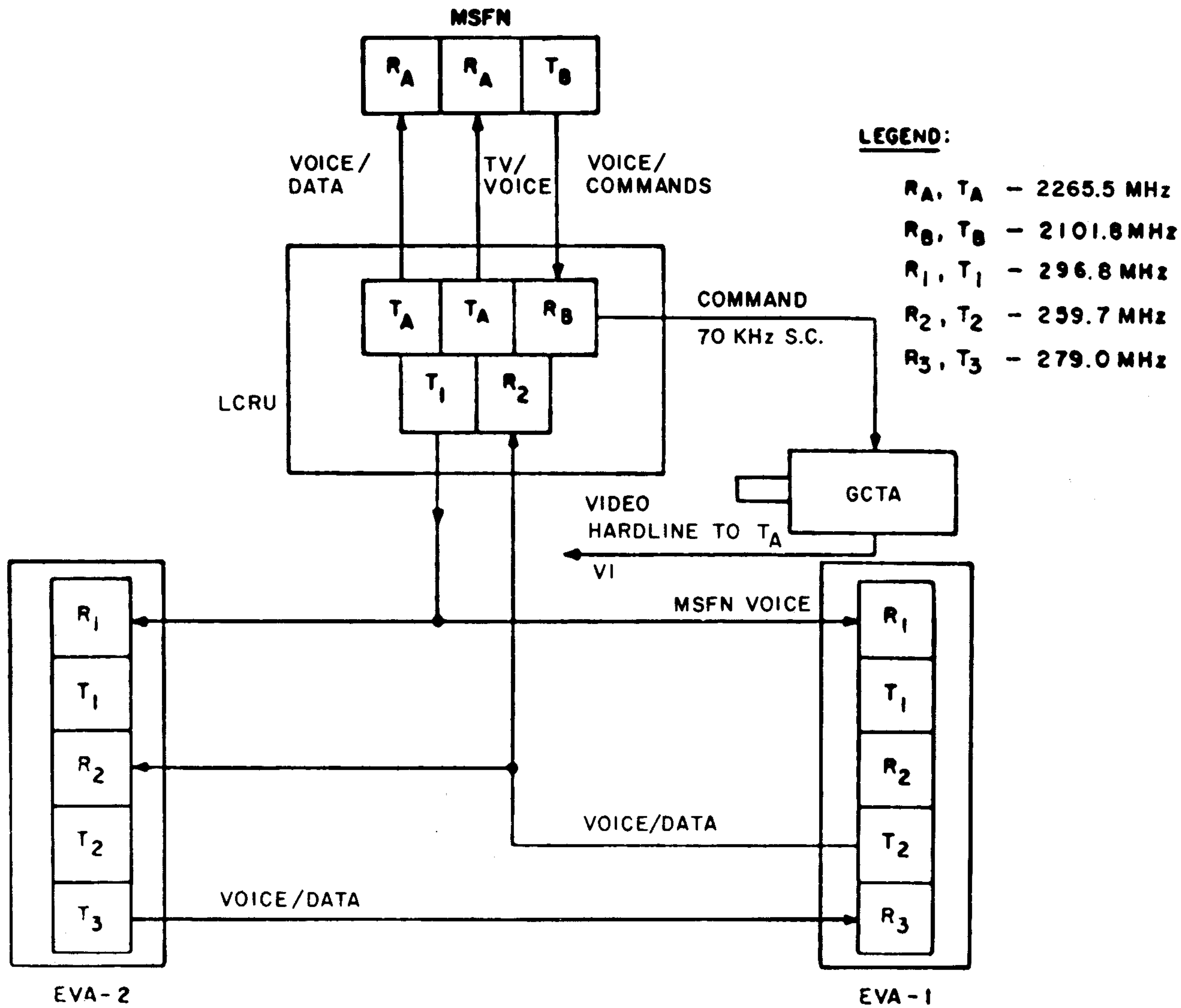

Figure 5. System Communications Links

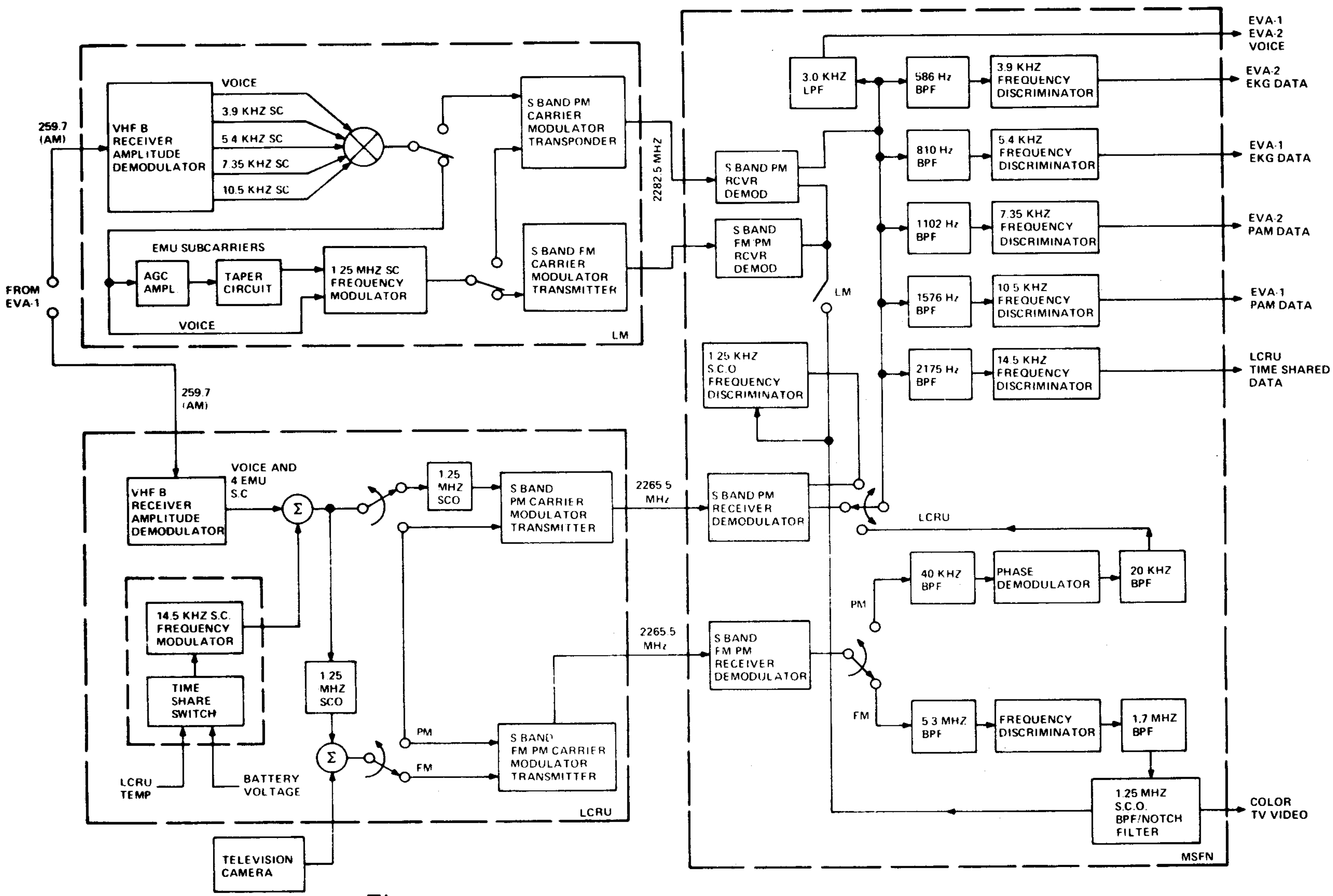

Figure 6. Down-link Communications system, EVCS/LCRU/MSFN and LM/LCRU/MSFN

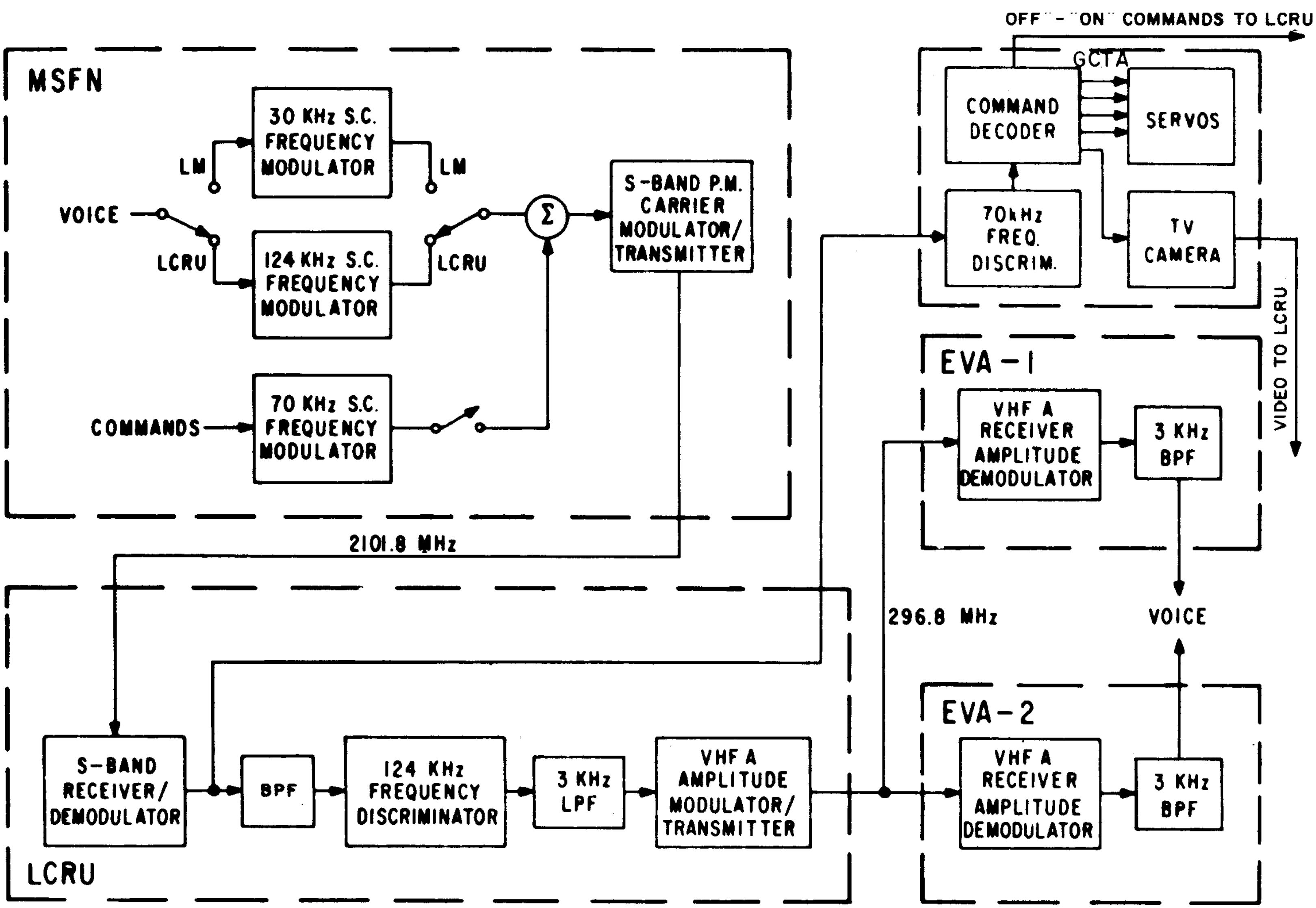

Figure 7. Up-link MSFN/LCRU/EVA.-l/EVA.-2 Communications System

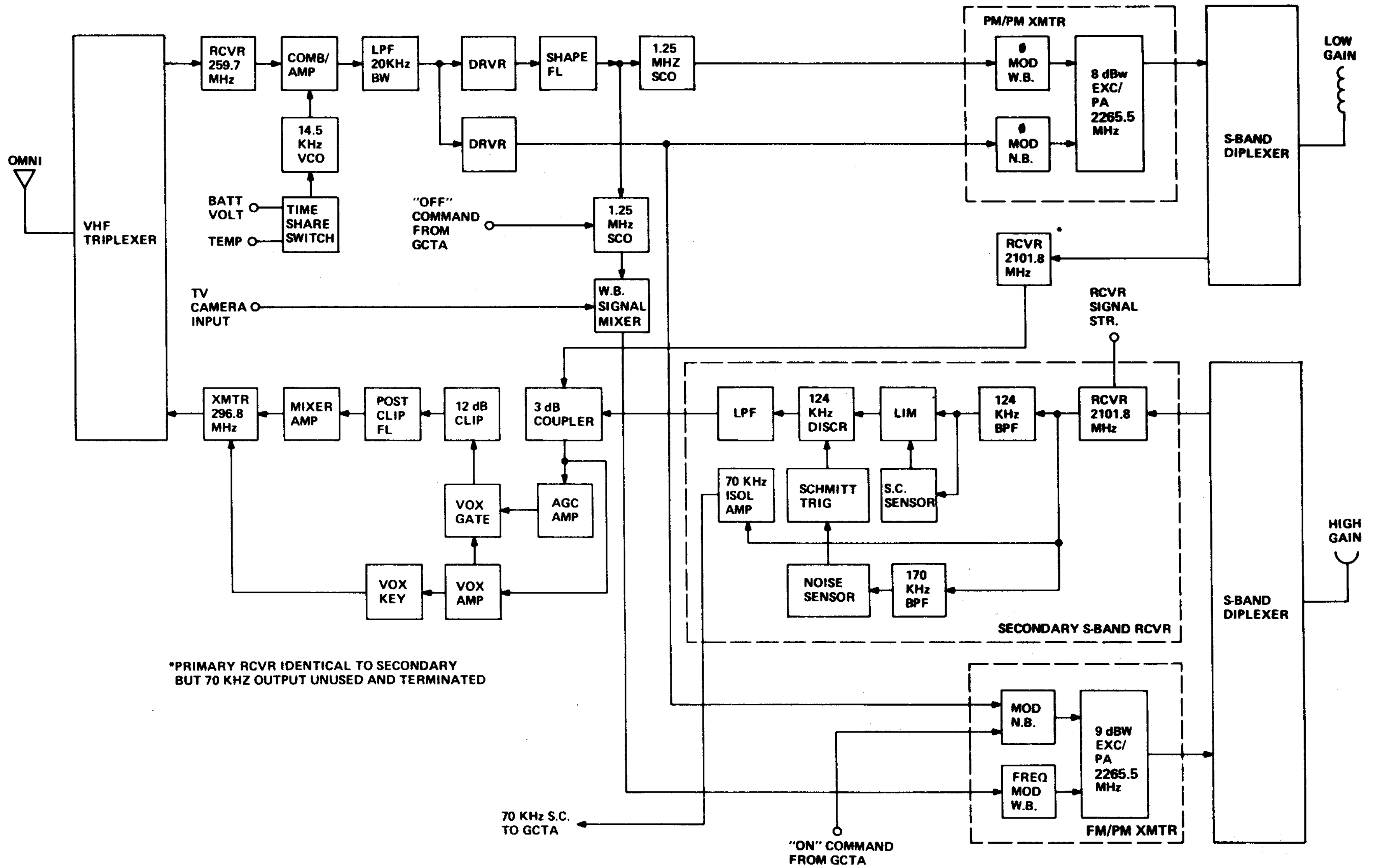

Figure 8. LCRU Subsystem Configuration

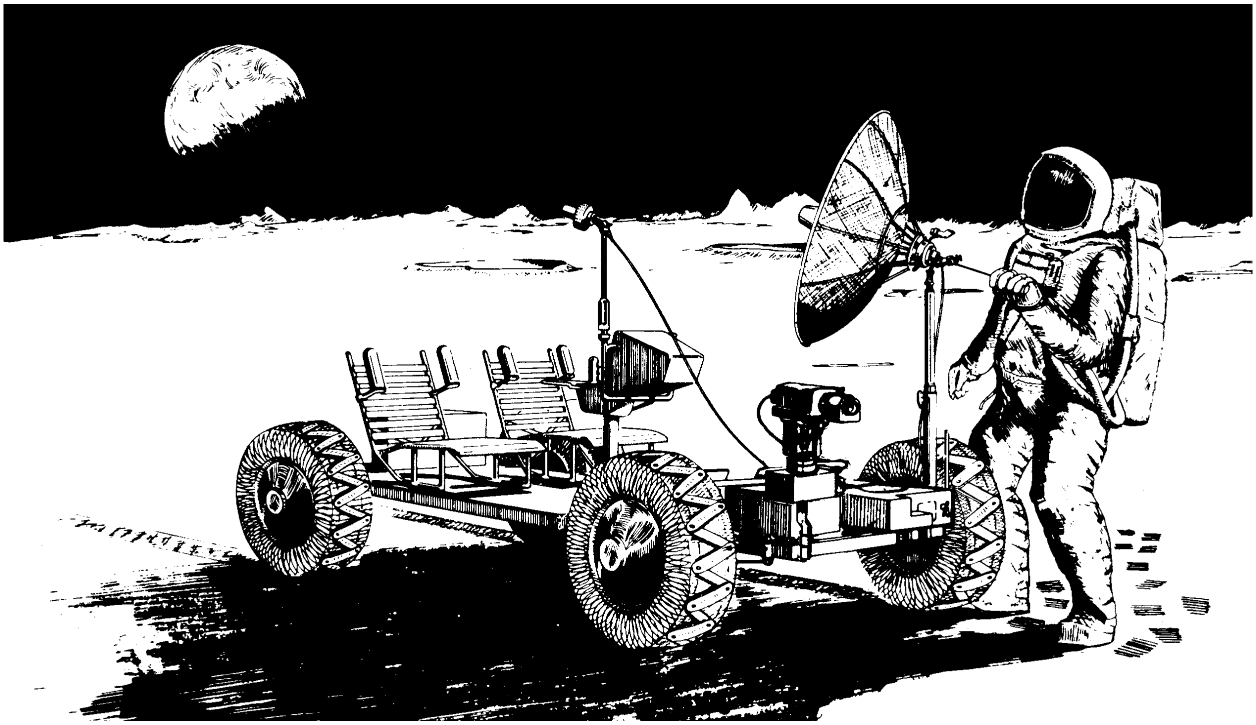

Figure 9. LCRU and Lunar Rover Vehicle

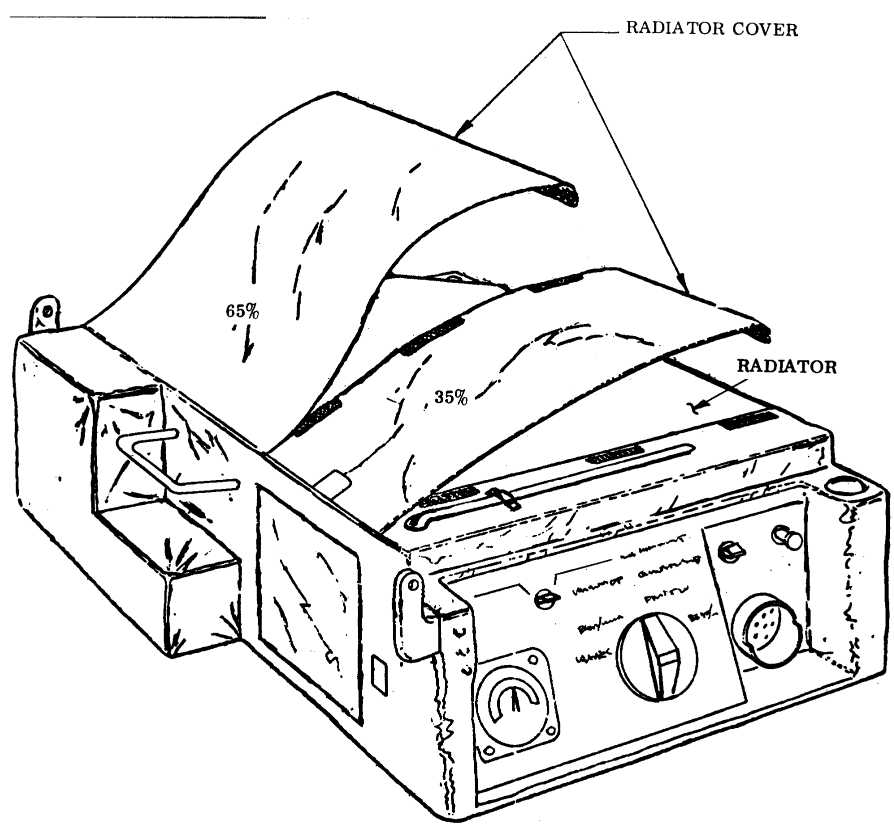

Figure 10. LCRU Thermal Blanket

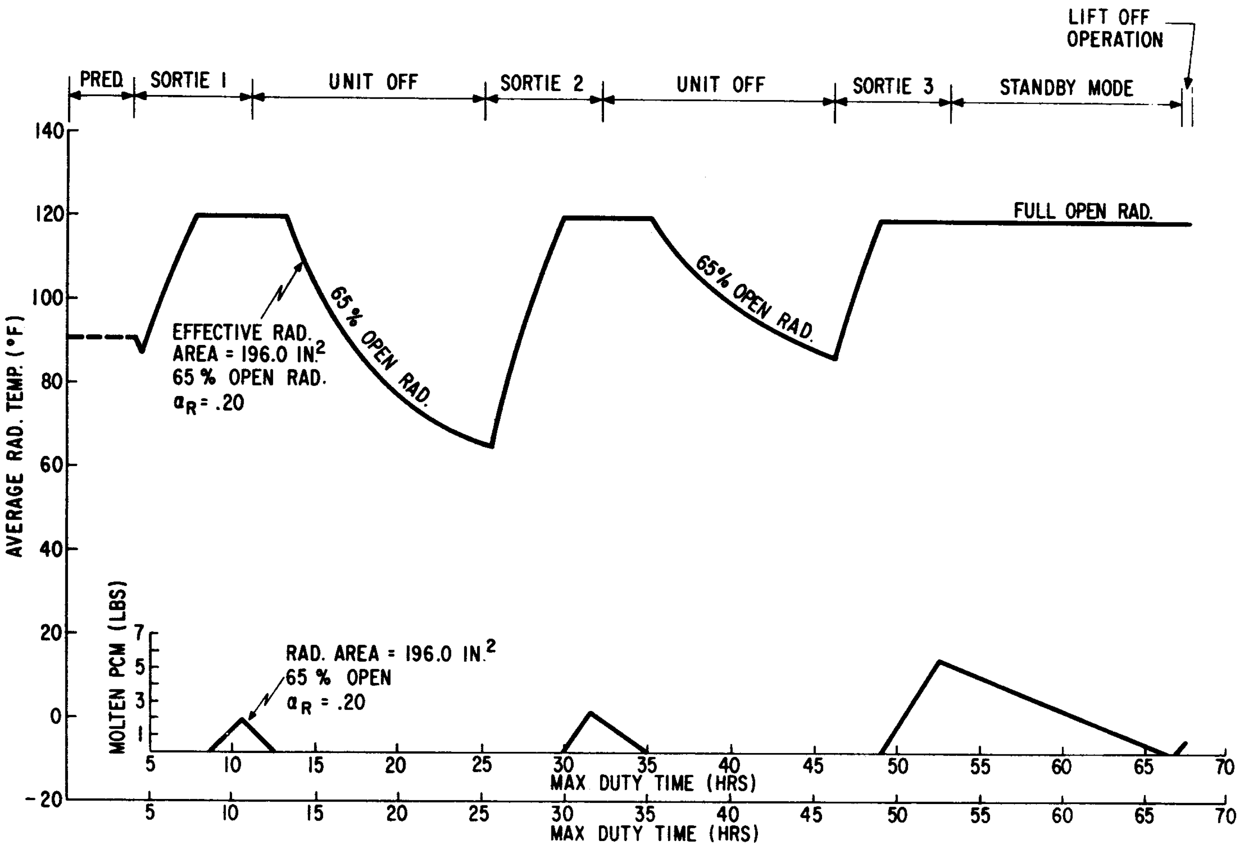

Figure 11. Average Radiator Temperature Vs Maximum Duty Time with a 20° Sun Angle Start and Hot Traverse