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Summary

This paper discusses the philosophy of communication systems design for space stations currently under study, such as MORL, LORL and other similar concepts. For the early stations, the communication systems will make use of off-the-shelf equipment. The communication requirements existing for the different station concepts is summarized. The most important factors for choosing the communication system meeting the requirements are discussed.

A communication system for an early two man laboratory is presented, and its primary features are discussed. Finally the problem of accommodating the different kinds of telemetry data in a composite spectrum is discussed.

Introduction

Several studies were recently conducted to determine the configuration of manned space stations. Among the most important of these are the MORL (Manned Orbiting Research Laboratory, NASA), the LORL (Large Orbiting Research Laboratory, NASA), the extended Apollo concept (NASA), the OSSS (Orbital Space Station Study, USAF), and the MOL (Manned Orbiting Laboratory, USAF). In addition, a number of separate studies were performed on space station related experiment programs, experiment integration, ground support systems, boosters, and logistics vehicles.

Communications between the astronauts, between the vehicle and ground stations, and between the ground stations and the mission control center are required for both operational and experimental program support. The communication system will provide for the required voice, telemetry, command, and picture transmission and for vehicle tracking.

Communication System Philosophy

A communication system for a manned space station must provide efficient communications between the orbiting station and the mission control center. In general, the constraints imposed on the system design are a minimum development risk, minimum cost, program schedules, and reliability requirements. These imply that (a) use be made of existing facilities and equipments, (b) the ground network be limited to few stations, in order to save on the cost of manning and operating ground stations. Consideration (a) above obliges the designer to consider strongly the possibility of using concepts and equipments developed for the Gemini and Apollo space vehicles and design the system for a manned laboratory accordingly. Of course modifications will be necessary to meet the individual requirements and attain the operating reliabilities necessary for a manned space laboratory.

The reliability requirements can be different for each equipment. The equipment may fall into different categories, such as survival critical, i. e., the crew life may be endangered if the equipment fails (for instance, voice transmission), mission critical, i. e., the mission must be aborted if the equipment fails (such as for instance telemetry), experiment critical, i. e., the experiment return is degraded when the equipment fails (such as for instance television), and noncritical, i. e., neither crew life nor mission nor the experimental return is endangered, but for instance, crew entertainment fails, or some flexibility is lost. Further the operating periods of the equipment may differ from application to application; one equipment may be on continuously, while some other operates intermittently. In order to attain the required reliabilities with state-of-the-art equipments having a mean time to failure (MTF) between 2,000 and 10,000 hours, the system will be equipped with redundant duplicates of many equipments. Further in orbit maintenance and equipment replenishment via logistics vehicles is planned. Trade-offs often exist, and it is for example in some cases more economical to provide two identical telemetry links rather than combine all messages into a common format. By having two identical links it may be possible to carry less spares aboard the laboratory, yet meet the reliability goals.

In the different design studies it was found that adequate communication systems can be patterned after the individual link system (as planned for Gemini) or the unified S-band system, as planned for Apollo. In some cases the system may look like a hybrid, using components of both systems. Time frame of operation and link requirements will determine which approach is to be chosen.

The general system design trend is to make use of existing and planned equipments and the system is configured according to the communication requirements. In the different studies, further individual design ground rules may be introduced. In one study, the major constraint was flying at the earliest possible date, in another study it was optimization of the systems and operating costs, and in another study choice of the technically optimal system. Each set of ground rules resulted in a different system.

Communication Requirements

There are requirements for transmission of many different kinds of messages between a space station and the mission control center. For each class of messages usually one or several separate links are provided between the station and the ground; for example data from housekeeping or resulting from experiments are transmitted by telemetry links, voice will be transmitted by voice links, and so on.

For each individual station configuration, one will find a different set of requirements, which depends on the crew size, the mission, and the amount of experimentation to be performed. Table 1 presents a summary of the communications requirements found in space station studies. The table summarizes the amount of messages to be transmitted during peak operationl and includes a quality criterion.

The voice requirement exists for each type of station. The number of real time voice links increases with the crew size. It is also important to include an emergency voice capability. The emergency voice link serves primarily the purpose of notifying the ground that an emergency condition has occurred and that certain actions have been taken, or help is required from the ground. For space station studies in which the author participated, this capability is provided by a VHF voice link with sufficient power in the vehicle to allow reception on the ground with an omnidirectional antenna. This permits communication with specially equipped ground stations which do not track the vehicle. In this fashion, 360 minutes of coverage per day can be attained for a laboratory in a 400 km orbit with 30^{o} inclination, if all MSFN sites are equipped for emergency transmissions and receiving; the maximum occultation period for emergency communications is in the order of two hours. The network for normal operations can then be limited to a small number of ground stations.

Telemetry links will also be required, regardless of the station mission and size. There will always be a need for telemetering housekeeping data and experiment results. The data volume will increase with the crew size but will not be proportional to the crew size, since with increased crew size onboard data editing is possible, which reduces the load on the communications links.

The capacity and number of command links will also be a function of station size. The smaller the size, the more commanding from the ground appears necessary. For example in the LORL with a crew of 24 the command link becomes a data up link, since the crew has enough time to "command" the station. A large station could be made completely autonomous and reduce the function of a data up link to a minimum.

Television links are deemed necessary for biomedical and behavioral experimentation. Further they can serve very effectively as a public relations medium. For most space stations under consideration a TV down link is being considered. A TV up link was considered only for LORL, where the crew size of 24 warrants the expense of onboard entertainment.

Choice of Communication System

The communication systems for the different laboratories depend strongly on two factors, namely, the orbital parameters and the time period at which the vehicle will fly. The earlier the flight date, the more the designer leans to using individual links and VHF equipment. For later flights S-band equipment and elements of a unified carrier system are chosen. The orbit determines the available readout time and thus the capacity required of the links. In most cases a low altitude orbit is planned, with inclinations from 30° to 90°. Extensions to larger altitudes are considered for some concepts. In almost all cases existing ground stations shall be used. Table 2 illustrates the solutions presently considered for four laboratory configurations, an early two man laboratory, the extended Apollo concept, the MORL and the LORL.* Systems for early planned laboratories use equipments which are already developed, while systems for later vehicles allow development of specialized equipments matched exactly to the mission requirements.

As an example we present the onboard communication system for an early two man laboratory. This laboratory is planned for short flights, in the order of one month. It carries limited experimentation. Orbital altitudes are in the order of 320 to 350 km. A limited ground network of 5 stations shall be used. The minimum readout time per day shall be assumed with 60 minutes. Daily telemetry data accumulation shall not exceed 4×10^8 bits; hence a telemetry transmission capability of 150 kbps will be ample and provide for some growth. Voice transmission, digital and analog telemetry, television, command, and tracking capabilities are required. For photography readout a broad band analog link is required.

The above requirements can be met by the system shown schematically in Fig. 1. Three multiple antenna systems are used to achieve a close to omnidirectional coverage over the frequency range from VHF to C-band. The antenna element providing the best signal is chosen by manual switching. The VHF system uses a multiplexer to couple the different equipments to the antennas for voice operations, telemetry transmission, and command reception. Similarly, the S-band system employs a duplexer for combining television and broad band analog data transmission.

The voice system contains two VHF transceivers, tape recorders, a voice control center and intercommunication master station, and

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* There were two independent LORL studies, one for a rotating station and one for a zero-G station. The features given here are for the zero-G station; the details of the system are described elsewhere.[1] The communication system for the rotating LORL concept is a hybrid system combining the unified S-band system and individual links, and using several ground stations.

intercommunication substation. The transceivers are basically the same type as used for the Gemini vehicle. Their performance will be well suited for a space station and no new equipment development is required. Standby units, not shown in the diagram, will be available to achieve the desired system reliability. For emergency communications one of the transceivers will be coupled into the antenna multiplexer through a power amplifier and a sensitive preamplifier, which are bypassed in normal operation. These additional units, which are available as off-the-shelf items allow to contact ground stations even if they do not track the orbiting vehicle.

The intercommunication system allows communications between the different compartments and areas aboard the orbiting laboratory and further permits access to the voice transmission-receiving system from different areas aboard the laboratory. The tape recorders permit the recording of descriptive experiment data and of verbal instructions for the experimentation. This adds flexibility to the system.

The telemetry system consists of two virtually identical units, one for housekeeping telemetry and one for experimentation. The transmitters are the same as developed for Gemini and were chosen primarily because of early availability. They operate in the VHF band. An acquisition beacon is also provided. This beacon is kept operating constantly, and is switched off only when one or both telemetry transmitters become operational.

The telemetry subsystem transmits digital and analog signals. It can also accommodate real time and stored telemetry. This part of the system is tailored to specific needs and will be described later.

The command link operates in the low UHF band and uses the same antenna system and multiplexer as the voice and telemetry links. It is the digital command system (DCS) developed for Gemini, and is used without modifications.

The TV system transmits pictures of approximately home TV quality. This is required for the evaluation of biomedical and behavioral experimentation. The frame rate is 15 per second at 525 lines and 500 resolution elements along a line. The video bandwidth is accordingly 2 Mc. This is transmitted in FM at 20 W and occupies a 10 Mc bandwidth at S-band frequencies. The equipment would be a modified unit such as the one used for broad band transmissions from present satellites.

Finally, the broad band system can operate at a 6 Mc video bandwidth. The S-band transmitter, transmitting 10 W at 30 Mc bandwidth is state-of-the-art satellite equipment.

Telemetry Signal Channelizing for the Discussed System

In this section we discuss one of the detailed problems associated with the systems conception of a communication system for manned spacecraft, the specific arrangement of telemetry channels. The arrangement discussed here is employed for the system presented in the last section. Each of the two identical telemetry signals shall transmit a 3.3 kbps real time data stream, further a 72.6 kbps data stream played back from the recorders, and three analog channels of 1, 2 and 3 kc bandwidth each. The channels are combined in the channelizer, shown in Fig. 2, and transmitted in frequency modulation over one single transmitter.

The basic digital rate is 3.3 kbps. This signal can be transmitted in real time when contact with a ground station is made; otherwise it is stored on tape recorder I and transmitted in non real time during each contact, speeded up 22:1. The analog channel can be transmitted in real time or can be recorded on recorder II and played back at a ratio of 1:1. The 36.3 kc PCM spectrum is placed into the baseband, while the other signals are placed on subcarriers of 72, 80, 92 and 112 kc. This fills a total bandwidth of 125 kc, which is well within the capabilities of the transmitter. The spectrum is shown schematically in Fig. 3. Before mixing the signals together they are filtered to decrease cross channel interference.

Different signal qualities will be required. While for the PCM signals 13 db signal to noise ratio will ensure an error rate of not more than $1:10^5$, the analog channels will require a signal to noise ratio of 30 db in order to be accurate better than 5%. The individual telemetry channels are therefore chosen such that the first modulation index (on the radio carrier) is 0.75, and the signal to noise ratio after the first demodulator is 13 db for all channels. For the analog FM/FM channels the additional improvement is realized in the second detection process, by choosing a modulation index of 3 on the subcarrier. Accordingly the bandwidth in the subchannels 3, 4 and 5 will be 8, 16, and 24 kc.

We can now determine the required power from the range equation

$$P_T = \frac{kT_E B(S/N)(4\pi)^2 R^2}{G_T G_R \lambda^2} \tag{1}$$

where k is the Boltzmann constant, T_E the operating temperature (700°K), B the respective channel bandwidth, (S/N) the required signal to noise ratio at the first demodulator output (13 db, no improvement assumed), R the maximum range (2.16×10^6m), G_T the vehicle antenna gain (0 db), G_R the ground antenna gain (18 db), and λ the wavelength (1.2 m). These calculations are summarized in Table 3.

We can also determine the available power in each channel for the 2.5 W transmitter. We approximate by concentrating the power of the baseband PCM in one spectral line, and the power of the other channels are also assumed to be concentrated in the subcarrier. For this approximation we obtain for the subcarrier power P_{sci} in the i-th subchannel:[2]

$$P_{sci} = 2P_{TOT}\left[J_1(m_i)\prod_{\substack{n=1\\n\neq i}}^{n=N} J_o(m_n)\right]^2 \qquad (2)$$

where P_{TOT} is the total transmitter power, $J_1(m_i)$ is the first order Bessel function of the modulation index m_i of the i-th channel on the radio carrier, and J_o the zero order Bessel function; the product of the J_o is taken over all subchannels with the exception of the channel i. Since we assume the modulation indices on the radio carrier for all channels to be 0.75, we obtain equal powers of 0.21 W for each channel.

In Table 3 we summarize now the data for all the telemetry subchannels. The bandwidth of each channel at the first IF provides for sufficient channel separation such that little interference is expected. The required power is always substantially below the available power and therefore the subchannels will have ample operating margins. Because of the approximative calculations employed, the margins vary widely. One could change the modulation indices and distribute the power more evenly as to obtain about equal margins. This is an iterative optimization procedures, which is cumbersome, and would be applied in the final system design.

Conclusions

This paper discusses the broad aspects of communication system designs for currently planned manned orbiting space stations, including the design philosophy. It also summarizes the communication requirements that have been discovered for manned orbiting laboratories. Then, in one example, a system is discussed, and a particular problem of this system, the telemetry link design, is presented.

References

1 E. I. Muehldorf, Communication System for a Manned Orbiting Station, Intl. Space Elecs. Symp., Oct 1964, Las Vegas, Nev.

2 B. D. Martin, The Pioneer IV Lunar Probe, A Minimum Power AM/PM System Design, JPL Tech Rept. 32-215, JPL, Pasadena, Calif. March 15, 1962.

TABLE I. GENERAL COMMUNICATION REQUIREMENTS FOR MANNED SPACE STATIONS

MESSAGE CLASS	TYPE OF MESSAGE AND PURPOSE	AMOUNT OF INFORMATION PER DAY	REMARKS	QUALITY
VOICE	TWO WAY COMMUNICATIONS WITH THE GROUND	5–50 KC–HOURS	REAL TIME	3 KC CHANNELS AT 10 DB S/N
	STORED COMMANDS TO STATION	3–9 KC–HOURS	ONBOARD STORAGE	
	STORED EXPERIMENT COMMENTS TO GROUND	3–9 KC–HOURS	ONBOARD STORAGE AND EDITING	
	TWO WAY STATION TO LOGISTICS VEHICLES	3–6 KC–HOURS DURING RENDEZVOUS	REAL TIME	
	EMERGENCY MESSAGES TO AND FROM GROUND	– – – – – – – –	TO NON-TRACKING STATIONS	
	BETWEEN SUITED ASTRONAUTS AND STATION	3–12 KC–HOURS DURING EXPERIMENTS	REAL TIME	
TELEMETRY	HOUSEKEEPING DATA	10^8–$3X10^8$ BITS	ONBOARD STORAGE AND REAL TIME, PCM	$1:10^5$ ERROR RATE
	EXPERIMENT DATA, DIGITAL	$2X10^8$–$4X10^8$ BITS	ONBOARD STORAGE AND EDITING, PCM	
	EXPERIMENT DATA, ANALOG	2–5 KC–HOURS	ONBOARD STORAGE AND EDITING	S/N 30 DB
	BIOMEDICAL DATA FROM SUITED ASTRONAUTS	0.5 KC–HOURS DURING OPERATION	ONBOARD STORAGE AND EDITING	
	SPACE TO SPACE—FOR EXAMPLE DE-ORBITING OF CARGO MODULE	10^5 BITS DURING OPERATION	REAL TIME, PCM	ERROR RATE $1:10^5$
COMMANDS	UP-DATA OR COMMANDS FROM GROUND TO STATION; COMPUTER UP-DATING	10^5–10^6 BITS	STORED, PCM	ERROR RATE $1:10^8$
	STATION TO LOGISTICS VEHICLES FOR RENDEZVOUS AND DE-ORBITING CARGO MODULES	10^4–10^5 BITS DURING OPERATIONS	REAL TIME, PCM	
TELEVISION	BIOMEDICAL AND OTHER EXPERIMENTATION, SPACE TO GROUND	1.4 MC–HOURS	REAL TIME AND STORED, ONBOARD EDITING, 2MC VIDEO	26 DB PEAK SIGNAL TO RMS NOISE
	CREW ENTERTAINMENT GROUND TO SPACE	2.3–4.5 MC HOURS	ONBOARD STORAGE, 4.5 MC VIDEO	
	WIDEBAND TRANSMISSION OF PHOTOGRAPHS RESULTING FROM EXPERIMENTS	3 MC–HOURS	STORED ON FILM, SENSED AND TRANSMITTED VIA A 6 MC LINK	
RADAR TRACKING	C-BAND TRANSPONDER	– – – – – – – –	TWO WAY TRACKING LINK COOPERATING WITH GROUND RADARS	– – – – – – – –
	S-BAND TRANSPONDER	– – – – – – – –		
	L-BAND TRANSPONDER	– – – – – – – –	TWO WAY TRACKING COOPERATING WITH LOGISTICS VEHICLE RADAR	

TABLE 2 - SYSTEMS CONSIDERED FOR ORBITING LABORATORIES

VEHICLE	EARLY TWO MAN LAB	EXTENDED APOLLO	MORL	LORL
FLIGHT TIME	POST 1966	POST 1968	POST 1969	POST 1970
ONBOARD SYSTEM FEATURES	INDIVIDUAL LINKS, VHF, USING COMPONENTS DEVELOPED FOR GEMINI	UNIFIED S-BAND AND INDIVIDUAL LINKS, USING ELEMENTS OF SYSTEM PLANNED FOR APOLLO	INDIVIDUAL LINKS USING VHF VOICE AND COMMAND AND USING S-BAND TELEMETRY AND TV	UNIFIED SYSTEM USING S-BAND CARRIER, VHF EMERGENCY VOICE.
GROUND STATION USAGE	A SET OF 5 STATIONS AROUND THE WORLD	A NUMBER OF MSFN STATIONS	TWO STATIONS IN THE CONTINENTAL U.S.	ONE STATION IN THE U.S.

TABLE 3 - TELEMETRY SUBCHANNEL SUMMARY

CHANNEL NO.	1	2	3	4	5
VIDEO SIGNAL	72.6 KB PCM	3.3 KB PCM	1 KC FM	2 KC FM	3 KC FM
VIDEO BANDWIDTH (KC)	36.2	1.66	1	2	3
BANDWIDTH AT FIRST IF (KC)	70	6.6	8	16	24
S/N OUT	13	13	30	30	30
S/N AT FIRST IF	13	13	13	13	13
MOD INDEX ON RADIO CARRIER	0.75	0.75	0.75	0.75	0.75
MOD INDEX ON SUBCARRIER	- -	0.75	3	3	3
POWER REQUIRED (W)	0.051	0.0094	0.011	0.022	0.033
POWER AVAILABLE (W)	0.21	0.21	0.21	0.21	0.21
OPERATING MARGIN (DB)	6.1	13.5	12.8	9.8	8
SUBCARRIER FREQUENCY (KC)	- - -	72	80	92	112

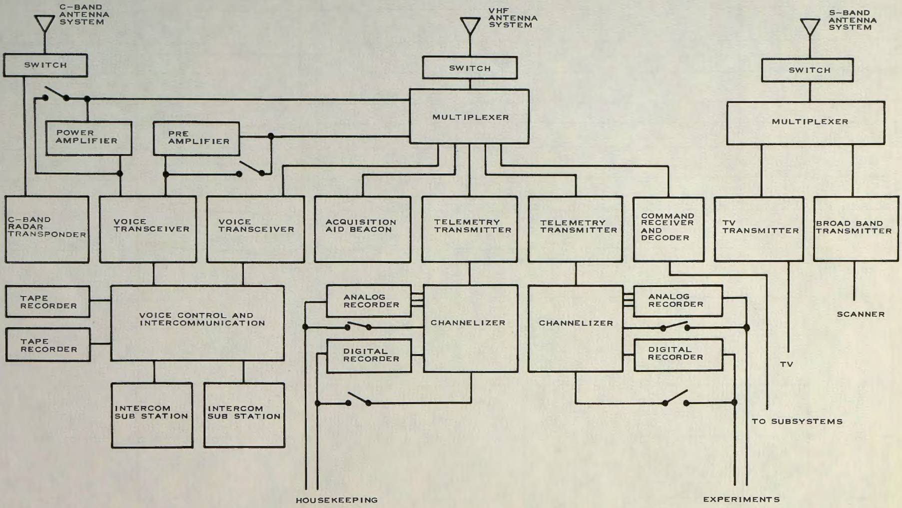

FIGURE I. COMMUNICATION SYSTEM FOR A TWO-MAN ORBITAL LABORATORY

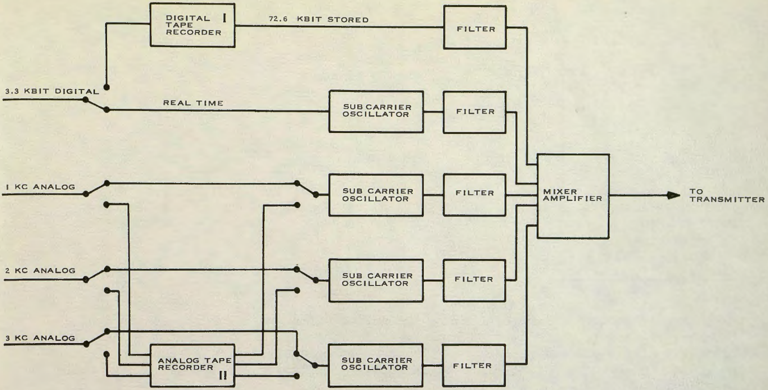

FIGURE 2. TELEMETRY CHANNELIZER

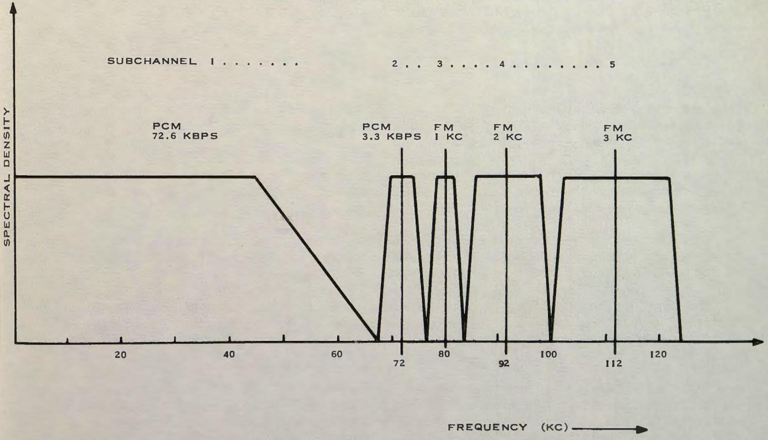

FIGURE 3. COMBINED TELEMETRY SPECTRUM