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## SPACE-SATELLITE COMMUNICATION IN THE 70s

by

Alan A. Paris

Space-satellite communications of the 60s will not suffice for the 70s. A refinement must occur. International emphasis for operational satellite systems demands more sophisticated systems and equipments to handle the large number of new applications arising. Payloads must include gear for weather observations, communications, navigation, reconnaissance, early warning, public health safe-guarding, and nuclear test monitoring. What direction should the communications industry take to accomplish these things? What technological support is needed?

Now is the time to take an overall view of the entire space-satellite field. Engineering during the 60s devoted attention to brute force communication technology necessary to prove feasibility and reliability. This paper examines the initial evaluation criteria and experimental results for the three categories of systems comprising this field: Satellite Communications, Space-vehicle Contained Communications, and Ground-based Tracking and Telemetry Communications. The feasibility requirements established early in the 60s form the framework from which today's technique and equipment trends have developed. See Figure 1. Studying these trends provides the clue to the special problems encountered in each of the above categories.

### SPACE SATELLITE COMMUNICATIONS

During the 1960-1967 period, NASA, DoD and industry engaged in satellite experiments on programs such as Courier, Score, Telstar, Echo, Needles, Relay, Early Bird, Syncom, ATS, LES, and IDSCP. Objectives set forth were technical, economic, and utilitarian. Early evaluations considered the length of orbital life, orbital types and shapes, and low to synchronous altitudes. Measurements included the percentage of time available, the number of user stations, and use of the available frequency spectra. Weight, Power, stabilization, and communications channel capacity presented the problems.

#### Power Output/Information Limiting

The ability to obtain a large quantity of highly intelligible information superseded the orbital problem in importance and the major information limiting factor was power output. Further complicating the problem was the need for good audio information and TV reception, and consideration had to be given to the subjective reactions due to time delays inherent in synchronous altitude systems and the less than standard TV signal-to-noise performance caused by power limitations in

today's satellites. RCA studied this problem for the Navy on a program entailing use of a communications satellite to broadcast TV signals from Ground Stations to an aircraft and then to home receiving sets. See Figure 2. A down-link analysis which shows the different satellites considered for use on this program is shown in Table I. The available frame rate for the video bandwidths used by earlier satellites such as Early Bird and Syncom, shows that much higher frame rates are needed in the future to provide conventional TV pictures. Real time transpacific TV via Satellite was demonstrated during the Tokyo Olympic games with good quality pictures. However, it took special receiving equipment and an 85 foot dish antenna to boost the low transmitter power and antenna gain of Syncom and make that feat possible. By using an aircraft for a relay, it was determined that the physical limitations would preclude an equivalent antenna gain even if very special receivers were used requiring 200°K of receiver noise temperature. Therefore, the basic problem boiled down to the difference between an 85 foot dish and a 40 inch dish - a significant 30 db difference in gain. Table 1 shows that improvements in satellite antenna gain, transmitter power, and receivers are necessary requirements for the additional bandwidth needed to provide conventional broadcast performance. Similar conclusions were obtained from studies of new systems such as the proposed Broadcast (Direct to Home) and Distribution type satellites.

#### Interference/Common Carrier Bands

Organizations involved in Air Traffic Control Communications have developed an interest for using the VHF frequency region because of the investment previously made in commercial aviation equipment. The problem of frequency utilization and planned sharing of common carrier bands by both ground and airborne facilities proved that additional propagation experimentation was needed to stay within the lower frequency region. The ATS-1 experiments showed that unwanted signals were picked-up from Japanese point-to-point communication ground stations operating at 149 megacycles and were rebroadcast. Also, the VHF experimentation indicated that certain antenna scalloping effects were encountered under certain conditions from aircraft flying at low altitudes and were probably due to the interference between direct and reflected signals bouncing off the wings. These plus fading problems caused by multipath signals reflected off the ocean, required additional technique developments in interference reduction.

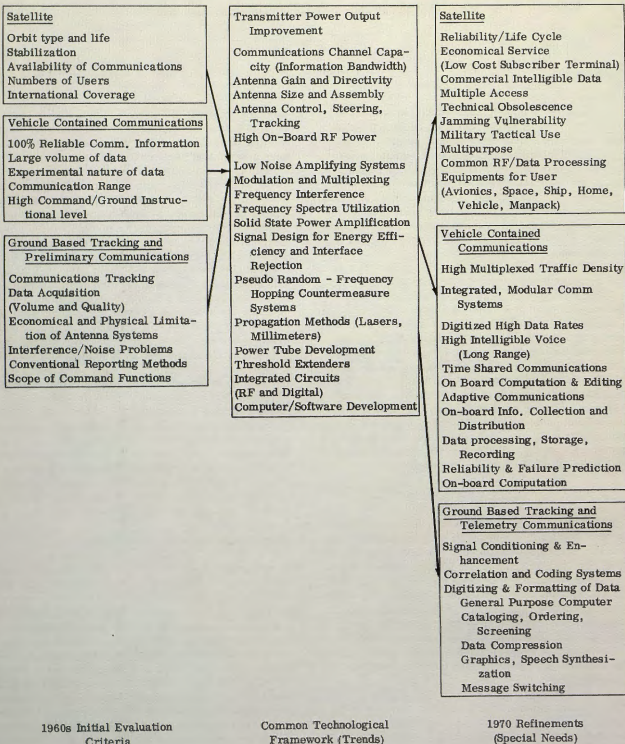


FIGURE 1.

TABLE I. GROUND TO SATELLITE TO AIRCRAFT STUDY

	DOWN LINK ANALYSIS				
	JDSCP	SYNCOM I & II	Early Bird	Advanced Technical Satellite	SYNCOM I & II
<u>Transmitter Power</u>	2.5W 4dbw	2.0W 3dbw	4.0W 6dbw	195W 23dbw	2.0W 3dbw
<u>Antenna Gain</u>	6.5db	6.0db	9.0db	36db	6db
<u>Frequency</u>	7270mc	1820mc	4170mc	800mc	1820mc
<u>Path Loss</u>	202db	190db	198db	183db	190db
<u>Misc. Losses</u>	3db	3db	3db	3db	3db
<u>Dish Diameter</u>	40"	40"	40"	40"	85"
<u>Antenna Gain</u>	35db	22db	30db	16db	52db
<u>Received Power</u>	-159.5dbw	-162dbw	-156dbw	-111dbw	-132dbw
<u>Receiver Temp.</u>	200°K	200°K	200°K	200°K	40°K
<u>BW for 10db C/N</u>	4kc	2kc	9.6kc	200mc	10mc
<u>Video BW*</u>	880cps	440cps	2.1kc	45mc	2.2mc
<u>Frame Rate for Video BW</u>	1 per minute	1/2 per minute	2 per minute	Conventional	Conventional
<u>Remarks</u>	Present Day Satellite		Future Satellites		Tokyo Olympics

\*m = 1.27

FM Gain = 10db

Economical User Stations

Congressional objectives -- stated when the new communications satellite legislation was proposed in 1962 -- required that any operational system provide global coverage as well as economical service. Rapid growth of technology, however, has created the problem of technical obsolescence of a Satellite and the user terminals. As the initial cost of placing these satellites in orbit is very high, industry must determine how far within certain time limits it can proceed technically to provide systems that require simplified, multipurpose low cost user terminals. An erroneous selection today of a satellite system and the resulting designs of the ground stations could cause a very expensive changeover seven or eight years from now.

Following is a brief commentary of the specific problems encountered. The need for more information - bandwidth coupled with multiple access, required development of new modulation and multiplexing schemes. Experiments with passive structures lessened with the confidence obtained from the reliability and power capability performance of the active repeaters. The need for improvements in primary power sources, and the efficiency of power amplifiers were identified. Additional engineering effort was also warranted by the improvement in reliability and life-time of the equipment in orbit.

Technical Trends (1960 - 1967)

Improvements in power output are being obtained through the attention given to antennas, power amplifiers,

and primary power sources on such programs as the ATS (Advanced Technical Satellite) and the Lincoln Experimental Satellite (LES). The outputs of these efforts will benefit all space vehicle programs. Multi-beam phased array antennas for C-, S-, and X-band as well as UHF and VHF antennas are being developed. Deployable large antennas capable of being electronically or mechanically despun, are being evaluated.

To work with these new antenna configurations to obtain maximum use of the frequency band and prevent interference among the multi-beams received, development of new antenna polarization and gain isolation techniques, new feed systems, filters, RF switches, and attitude sensors are required. Precise stabilization capabilities could set the limits for the antenna gain and directivity of new higher gain, narrow beam antennas thereby requiring advancements for electronically steering and controlling these arrays. Tube-type amplifiers using Klystrons and TWT's for FM application, as well as solid-state power amplifiers are being developed. Triodes for AM which can be used to provide UHF compatibility for broadcast satellites are also being considered to furnish the kilowatts of radiated power needed by low-cost terminals in a network of the future.

Problems associated with tube-life and cooling require industry to develop high power solid-state devices or lightweight combiners paralleling the solid-state transistors. Power amplifiers used with retrodirective phased-array antennas reduce the requirement for the maximum cooling and combiners and eliminate the need for phase-shifters and a computer. Paralleling and combining hundreds of these solid-state devices is possible because of the reduction in size of individual components and improvements in circuit technology due to the hybrid, MOS and large-scale integrated arrays. Development of smaller equipments, requiring less power because they include RF, IF and digital integrated circuits, and the concurrent development of more efficient, large, lightweight solar-arrays with capabilities up to 50 kilowatts, offer the greater opportunities for getting the power expansion needed in the transmission system of the satellite.

New modulation and multiplexing techniques being developed in industrial and government laboratories will help improve signal intelligibility in VHF, information bandwidth; and the multi-access capability of satellite systems. In the VHF region, employment of narrow-band FM as well as signal sideband is being tried to obtain 4-to-8 db improvement in signal margin at low level signals. This also will compensate for doppler shift. The Lincoln Experimental Satellite program is using various digital modulation and demodulation techniques, employs Vocoders and a 16-ARY system. Linear and microwave dual transponders, developed for use on the ATS experiments, will permit simultaneous access by several ground stations using Frequency Division Multiplex. Use of Time Division schemes such

as SAGE and NTDS employed in the early 1960's by Air Defense Systems, offer opportunities for many ground stations to time-share the use of satellites (multi-access).

Developments in new propagation mediums provide the means for solving special communication problems. DoD and NASA have sponsored many contracts for development of techniques and equipment for millimeter wave propagation that provides narrowbeam directivity with wide information-bandwidth capability. Pointing accuracy for satellite programs like OAO and the AOSO may be provided by laser communication techniques employing such new devices as the carbon-dioxide nitrogen laser found to have about 250 watts of CW power with a 13 per cent efficiency factor.

Another trend concerns application of techniques previously employed in military communication links to satellite systems. As an example, new tactical satellite programs such as DSCS require counter/countermeasures equipment to prevent jamming by an enemy or unintentional interference. The broadband frequency-hopping techniques and sequential coding used in early warning systems can provide this feature. In these systems, all communication signals with the voice/teletype data are converted to a series of pulses with the transmitter carrier frequency changed after each pulse. The choice of frequencies for each pulse is determined by a pseudo random sequence generator. Both ground terminals seeking to communicate with one another must have identical pseudo-random sequence generators at the receiving terminal and must be tuned to the same channel on which the other will transmit its next pulse. VHF repeater and calibration devices, and also stations still using systems originally developed for other systems, are being examined for application to satellite communication problems.

#### 1970 Refinements (Communication Industry Direction)

In the 70's and 80's these technology trends will make economic use of weather, navigation, broadcast, and distribution satellites possible. Satellites will be used for sea and air rescue systems, and for military communications systems (IDSCP and Tacsat). Multipurpose satellites providing five to six thousand two-way telephone channels, television, aircraft-to-aircraft communications and meteorological data will also be provided. Air traffic control satellites possibly employing VHF for ground-to-satellite-to-ground as well as satellite-to-aircraft-to-satellite transmissions will be in use. Satellites for use in surveillance of the ocean and for the benefit of public health programs in the United States such as air pollution will also apply. Lunar Satellites to provide relays for moon expeditionary activities and earth activities are also envisioned. In addition, studies are being conducted on orbiting data relays to link manned and unmanned spacecraft via satellite communications.

The supplier of communication equipment is now recognizing the tremendous need for new products required by the user of these satellite systems. Cognizance must be taken of the knowledge obtained in the 60's and of the portfolio of systems, techniques, and equipments developed so proper planning and direction of these resources into new products can be achieved. The experimental phase is coming to an end. Application will provide the media for the era of "Information Explosion". Figure 2 illustrates the new dimensions in communications available.

Only through the use of standardized modules capable of being oriented for a specific purpose of a multi-mode purpose radio can the industry hope to satisfy economically the demands of the user. The tremendous increase in tactical and support information available to the military user via satellites requires the development of multi-mode radios because of space limitation in vehicles such as tanks, jeeps, ships, and aircraft. Application of the techniques mentioned previously in the user equipments to provide wideband, time-shared communications is an approach to the multi-mode problem. The developer of new integrated-circuit, ultra-reliable voice radios for Navy and USAF aircraft applications in the UHF, HF, and VHF frequency regions is able today, because of the tremendous size reductions and the advent of digital synthesizer techniques, to modularize his equipment and, through logical design principles, not preclude its adaptation for satellite use. Starting at the beginning of the design cycle, even though the specification does not call for it, provisions must be provided, for this future demands.

As another example, the RTCA Committee SC 110/111, devoted to Universal Air-Ground Digital Communication System studies for commercial and military aircraft, when observing the rapid progress of VHF satellite repeater experimentation had the foresight to include standards for this mode of propagation. Builders of VHF/UHF commercial equipment should also consider the effects of these new developments. Suppliers of TV systems and components have to track carefully decisions made on satellite systems related to direct-to-home broadcasting or via network distribution. Home and studio equipments will certainly need adaptation. Ground equipment presently used for long haul point-to-point communications may have to be integrated with satellite receiving stations into multipurpose information distribution centers. Multiplexing different types of information in wideband, coaxial-cable networks is mandatory to cover the ground distribution problems. Obtaining data from and feeding data to these new space satellite systems will require many new data-processing computers and peripheral equipment to edit, time share, and distribute the data. To prevent saturation of the satellite communications channel capacity, the use of Frequency Division Multiplex (FDM) or Time Division Multiplex (TDM) will be required in operational systems.

## VEHICLE CONTAINED TELEMETRY AND SPACE COMMUNICATION SYSTEMS

The basic objectives behind the earlier experimental efforts in Vehicle Contained Communications was to provide 1) 100 per cent reliable communications information, 2) the largest quantity of returned data to the control centers, and 3) the receipt of the highest amount of ground instructional-level data. To perform these communication functions, telemetry systems were needed for conditioning, coding, multiplexing, and retransmission of data to ground stations, and Command systems are used for receipt of ground-derived information. The command system requires receivers, demodulators, and decoders. The vehicle also requires CW or pulse transponding systems and internal communications equipment, and voice communications equipment for both external vehicle-to-vehicle and ground stations transmissions.

### Data Rate/Communication Range

Depending upon whether the mission phase is an earth orbital, a lunar orbiter, a lunar lander, mars orbiter, or a space probe, requires differences in transmitter power, receiver sensitivity, and antenna gain. Variable communication ranges can occur from an earth orbital range of 22,000 nautical miles to the extremes of a 47-billion nautical mile range from Pluto. Tables II and III provide illustrative examples of studies made by NASA and RCA engineering activities on three different frequency ranges. Certain assumptions were made regarding the bandwidth requirements, signal-to-noise ratio and such other parameters as the vehicle antenna radiated power and the characteristics of the ground receiving system. In every case, these examples demonstrate the differences in requirements for each of the missions noted.

The extent of the coming communication range and data problem can be easily visualized in terms of TV picture transmission quality. A communications link to Mars, approximately one-thousand times the distance of the moon from the earth, because of the inverse square relationship, would have to have a million times the bit capacity to provide the same picture quality per given time frame. The Ranger 7 spacecraft when approaching the moon transmitted over 4,000 pictures in fifteen minutes, would be able to transmit only a fragment of one picture approaching Mars. MARINER 4 with the capacity of about 8 and 1/3 bits per second will need 8 and 1/2 hours to transmit one picture. To be successful, Voyager will need a capacity of at least a few thousand bits per second. A typical man-planetary mission may call for  $10^5$  bits per second duplicating the range of performance at Mars for some  $10^6$  to the  $10^7$  bps.

Data rates for telemetry systems vary anywhere from 1 to 16 bits per second for planetary missions to the near

TABLE II. ILLUSTRATIVE COMMUNICATION SYSTEMS

Parameter	Earth Satellite	Lunar Orbiter	Lunar Lander	Mars Orbiter	Space Probe
Range	$4 \times 10^3$	$4 \times 10^5$	$4 \times 10^5$	$4 \times 10^8$	$4 \times 10^{10}$
Earth Antenna Gain	$10^3$	$4 \times 10^4$	$4 \times 10^6$	$10^6$	$10^6$
Vehicle Antenna area (m <sup>2</sup> )	0.05	7	2.5	100	100
System Temperature (°K)	400	220	400	100	100
Vehicle Radiated Power (Watts)	200	50	10	150	150
Bandwidth (cps) for S/N = $10^3$ watts/watt	$4 \times 10^6$	$10^6$	$10^6$	$2.5 \times 10^3$	0.25

TABLE III. COMMUNICATION SYSTEM PARAMETER COMPARISON

Parameters	Aircraft	Manned Satellites	Unmanned Satellites	Lunar & Planetary Spacecraft
Ground to Air/Space	VHF/UHF Links	Command Link	Command Link	Command Link
Gnd. Tx Power	50-100 Watts	600 Watts	3 kw	10 kw
Gnd. Ant. Gain	0 db	18 db	14 db	46 db
Air Ant. Gain	-3 db	-6 db	-6 db	18 db
Air Rx Syst N. F. (db)	11 to 17 db	11 db	15 db	9 db
Min. Acceptable S/N	10 db	10 db	5 db	5 db
Air/Space to Ground	VHF/UHF Links	Telemetry Link	Telemetry Link	Telemetry Link
Air Tx Power	25 W	3 watts	0.2 to 2.0 W	3 Watts
Air Ant. Gain	-3 db	-6 db	-6 db	18 db
Gnd. Ant. Gain	0 db	18 db	19 db	46 db
Gnd. Rx Syst. N. F. (db)	13 to 15 db	4 db	3 db	2.6 db
Min. Acceptable S/N	10 db	10 db	5 db	0-3 db

## Assumptions:

Communications in VHF or UHF region.

Reliability of Communications Approximately Equal.

earth missions requiring 100 k bits per second. Command systems vary in data requirements from 1 bit per second for planetary systems to 1 kilobit per second for orbital and lunar systems. Data Communications between spacecraft separated by a 6,000 nautical mile range may require up to 16 kilobits per second. Presently we are obtaining 1.6 kilobits per second at ranges of 600 nautical miles. Good quality voice communications at the maximum possible ranges are needed for rendezvous between spacecraft for manned planetary missions and for vehicle-to-earth communications. Use of VHF in the 300 MHz<sub>2</sub> region attains a range coverage

of 600 nautical miles while future manned Planetary efforts will require increased ranges.

Discussions with experienced range-personnel has shown that a great portion of the data acquired in the earlier experimental efforts was found to be superfluous and burdensome and should be given to electronic editing functions aboard the spacecraft.

System Functional Complexity/Reliability

In previous systems separate individual subsystems for each of the functions were placed in the vehicle for

purposes of demonstrating reliability and the success of the experiment. Figure 5 shows that the space vehicle's functional complexity is increasing and is coupled with a need for a meantime-to-first failure in the order of magnitude of five years. As our space exploration objectives become more ambitious in terms of mission assignment, distance, payload, and manpower, there will be a continuous need for improvement in the communications systems capability.

#### Technological Trends (1960 - 1967)

The effort described previously related to improving the data-rate, power, and antenna gain and is similar to the work undertaken for technological improvement in the vehicle-contained communications field. This includes the work in millimeters, antennas, integrated circuits, power amplification, modulation techniques and low noise amplifying devices. The MARINER 4 experiments used a 10-watt tube while Watkins Johnson has recently developed a 20-watt tube for NASA which it is hoped can provide from the same restraints 20 bits per second instead of the 8 and 1/3 bits. It is also anticipated that power tube developments in the order of magnitude of 100 watts with larger improvements in a data-rate may be achievable. Large deployable antennas with extensions in sizes from 20-to-30 feet can possibly also provide data increases of 100.

S-Band communications in the ranges between 2100 to 2300 MGH<sub>z</sub> were resorted to because of the crowded VHF, UHF spectrum and required development of new equipments. NASA and DoD have embarked on programs such as the United S-Band system for MARINER and Pioneer and the SGLS and ASGLS Programs which are the space-ground link systems for both MOL and future military spacecraft systems. Though there are some basic differences, generally the attempt is to provide full duplex-link operation for the up and down links of the spacecraft with as much multiplexed information such as telemetry, voice and command data provided as possible.

Programs such as LEM and Apollo have added to the inventory of S-band equipments by developing steerable antennas, power amplifiers and transponders. Advanced VHF Transceivers have also been developed on these programs. New spacesuit communication equipment was recently contracted for by NASA. PCM telemetry systems capable of amplifying, digitizing, and multiplexing data into several PCM bit streams are finding practical use aboard spacecraft. Work in reliability improvement of equipments is concerned with studies in the basic physics of aging, deterioration of electronic parts and materials, and corona effects.

#### Refinements in 1970's (Industry Direction)

The vehicle-contained communications field requires the most dense, meaningful, and reliable data to be

transmitted and processed by the least and most versatile equipment. Individual subsystems were used in the early experiments because of the relative simplicity of the experiments and the need for reliability; however, the 70's can anticipate refinements in these subsystems. The development of concepts and equipment to obtain greater capability through efficient utilization and organization of spacecraft functions will lead to integrated TT&C (telemetry, tracking, and commands communication) systems.

With the advent of integrated circuits many DoD agencies and industrial firms have undertaken efforts to study time-sharing of communications functions by use of on-board computers. The Office of Naval Research embarked on a program with RCA called SCORSS to study the number of times certain individual elements of communications systems are used in aircraft missions. SCORSS used a computer to assemble those circuits and communications functions required when a specific independent operation is to take place. In the future we can see the use of computation, data processing, and storage combined with traffic analysis to use common transmitters and receivers for telemetry, command, tracking, and data exchange. Studying network coverage and space missions simultaneously, may allow storing of certain data when out of range and transmission of this data when coming into contact in another phase of the mission. Figure 6 illustrates the TT&C concept.

The new TT&C may require use of an on-board computer for editing to provide the most important data through redundant transmissions. Technology advances in integrated circuits allow the use of more sophisticated spacecraft systems. RCA has been investigating the application of its VIC (Variable Instruction Computer) for possible use in these systems. In addition, a great deal of work has been done by RCA to develop a program for the Navy called MINCOMS that provides TDM, FDM, and PCM multiplex equipment for reduction of the amount of cabling and redundant equipment in aircrafts, space vehicles, and ships. This technology can be very useful for improving the on-board information collection and distribution problem which presently exists when we try to signal one particular circuit for each data point. The sophisticated changes suggested for the vehicle will require similar applications to the surface equipment.

Use of on-board computers, minimization of equipment, and the advent of integrated functions made possible by integrated circuitry may also provide the equipment-redundancy techniques that are economical and capable of providing the high-reliability requirements of future spacecraft missions. Coupling the developments in understanding, the aging problems in electronic components, and the techniques reliability prediction with diagnostic test methods, will allow future manned-flight missions to predict the appearance of a failure long before it happens and take corrective action. This may be



in the form of on-board maintenance or the activation of a backup system. New automatic checkout systems have to be provided with self-checking, fault location, indicating, organizing, and adaptive features to provide the on-board maintenance and diagnoses.

Other technical developments at the finger tips of the industrial communications-system designer which will enhance the vehicle communications system are laser communications and recorders of the laser or magnetic variety. Considering the advancements the engineer has made in ultra-reliable radios, transponders, data processing, multiplexing, recording, and computation systems, he is in a good position to cover the new applications if he has kept ahead of the specific requirements and test results of the spacecraft-communications experiments.

#### GROUND BASED TRACKING AND TELEMETRY SYSTEMS

NASA and DOD Tracking and Data Acquisition networks can be placed in broad categories associated with the type of missions being supported. The three basic missions are 1) the unmanned earth satellite mission, 2) deep space mission, (lunar and planetary) and 3) the manned satellite mission. In the early 50s and 60s, the instrumentation facilities such as the Mini Track were used for the unmanned satellite missions and the Deep Space Instrumentation Facility (DSIF) for the NASA lunar and planetary programs, and special tracking ground-instrumentation stations were used for specific manned space flight missions like the Mercury. Ships of the DAMP type were used for tracking and data acquisition in the 60s. New aircraft to be used for the same purpose are contemplated for ARIA (Apollo Range Instrumentation Aircraft), SGLS (Space Ground Link System) and the advanced SGLS programs for satellite and MOL command and control were also established during the 60s.

The 70s may possibly see the advent of the ODRN (Orbiting Data Relay Network) in which NASA and DOD hope to replace some of the older ground and ship facilities. Communication functions included in this category are: RF Reception-Demodulation, RF Transmission-Modulation, Data Processing and Computation, and Recording and Interrogation. These systems process telemetered flight data into conventional and graphical reports and provide the command functions to the spacecraft or satellite vehicle.

#### Physical and Economic Limitations of Antennas

Early experimentation, especially in the DSIF, used 890 MHz for earth to spacecraft transmissions and 960 MHz from spacecraft to earth. These frequency ranges, however, caused problems because the designers reached the economical and physical limitations of ground station antennas. Extending dish sizes from 85 to 250 feet incurred prohibitive costs when related to

the relative increase in performance. Consideration was then given to building antennas to no greater accuracy than foreseeably required and using them in a gain limited manner; that is, operating as high in frequency as the antenna accuracy permitted. However, by going into the higher frequency regions above 890 to 960 megacycles, designers realized approximately twice the distance for the same transmitter power and antenna diameters. Therefore, stations were phased into higher UHF frequency ranges such as the 2290 to the 2300 megahertz range for transmission from spacecraft to earth and the 2110 to 2120 megahertz range for earth to spacecraft transmissions.

#### Scope of Command Functions

The simplified command systems, initially designed to process FM/PM modulation at 900 megahertz at transmission bandwidths of only  $3\frac{1}{2}$  KHZ, are insufficient for the higher frequency regions and for more complicated future space missions. A wider bandwidth detection capability is necessary and will have to be implemented in receivers used in the higher frequency regions. The command signals, provided initially by simple audio frequency tones, were also found incapable for handling the large scope of command functions needed. The system must be able to turn single functions on and off, address subsystem functions, select the time of execution, and regulate data insertion and extraction. Longer space mission will require more reporting to and from the man in the vehicle.

#### Interference/Noise Problems

Noise, which in the communication system sense is composed of randomly varying signals, is introduced in systems by the statistical nature of the universe. Noise signals in an information transfer system have two effects on the information both of which produce the same end result - inability to distinguish the information. Noise perturbs the information by adding and subtracting from its components until the information is no longer recognizable; and, second, it suppresses the information. This occurs because practical communication systems must be built with limited dynamic signal range.

When power plus noise exceeds the system dynamic capacity, both noise and the information power will be limited or suppressed. This effect is exceedingly common because many mechanizations of receivers deliberately use limited and suppressed noise in situations of high signal to noise energy. Since noise is never absent from any communication system, particularly an interplanetary communication systems where the receivable signal power is small, it effects the final limits of communication distance and the information bandwidth. The sources of noise in interplanetary communications systems are numerous, but the largest contributors may be classified as 1) man made interference, 2) galactic background and source,

3) atmospheric and earth noise and absorption, and 4) Antenna Johnson and receiver noise.

Many sources of noise are external to the antenna and impart noise into the system as receivable energy in both the bandwidth and the look-angle of the antenna. The natural radioactive noise sources may be examined separately if a reasonable isolation from man-made interferences is attempted. This was the primary reason why the deep space tracking stations were located at isolated and inaccessible sites, and in natural geographic depressed terrain. Tradeoffs had to be made between equipment sizes, antenna sizes, power, transmission distances, and optimization for certain specific noise conditions. Galactic noise is the sum of the background plus any of the discrete noise sources that may be included in the antenna field of view. It is, therefore, dependent upon the antenna beamwidth and becomes more granular as the receiving antenna beam is made smaller (antenna gain is increased).

Galactic noise is augmented by earth and atmospheric noise captured by the antenna. The warmth of the earth causes noise to be injected directly into the back lobes of the receiving antenna; and, by refraction from the ionosphere, directly into the side lobes and even the main beam when the antenna is depressed below critical angles. The amount of noise energy collected is a function of the depth of the atmosphere through which the received beam must transverse. Receiver noise (Shot Noise and Johnson effect) problems were encountered in the early systems because of the vacuum tube front ends. This noise is dependent upon the thermal temperature of the input elements in the receiver and their impedance. In the past, the ultimate distance to which satisfactory communications could be obtained rested largely upon the definition of how much degradation the user was willing to accept in the received intelligence before calling it a threshold. There was no discrete threshold on some of the simpler analog mechanizations of AM and FM Telemetry, and the data simply became more and more noisy until it became a matter of conjecture whether noise-like-data was being received or data-like-noise.

#### Volume of Data

The volume of data extracted from the early experimental satellites and spacecraft was voluminous; the quantity received being limited in scope only by the ingenuity and inventiveness of the experimenters. However, much of this data was useless and deteriorated the reliability of the overall system. Future techniques for data processing, signal conditioning, and enhancement were required to find meaningful data for the control networks. The same problems related to data-rate, information-bandwidth, and power - as discussed in the previous sections - were encountered in the Ground-Based Telemetry category.

#### Technological Trends (1960 - 1967)

Improvements previously discussed covered accomplishments in RF power received and transmitted and the antenna developments by Industry. Then digital techniques came into use. Need for improvement in the scope and nature of Command functions necessitated the move toward digital techniques in processing and operating systems. Signals of marginal SNR complicate the overall processing picture causing uncertainty of the data recorded. Multiple reprocessing of the same data with digital techniques insures reliable results.

Use of newly developed signal conditioning and enhancement techniques will improve the quality of data extracted from a space vehicle and help reduce the volume required. Digitizing and formatting the data plus use of general purpose computers for data shuffling and/or bit-fiddling, will reduce extraneous data permitting selection of the most useable portion for cataloging, screening and ordering. Early processing achieves better use of the greater portion of the processing capability.

Data compression is a related area of development. This concept might be called an extension of the rapid data screen to the satellite itself. The criteria is a function of the experiments and the environment. In this area, work is vitally concerned with the basic information content of the data and determination of the means for practically measuring and conveying that information in an adaptive manner.

Assuming that the distance is minimized by selection of a time of operation during planetary perigee, the most effective controlling parameters for noise problems were the antenna dish diameters and the frequency. Experimental tests have shown that the region of relative atmospheric noise-power minimum is in the range of frequencies from 1 KMHz to 10 KMHz with the lowest point at approximately 1.5 KMHz to 2.5 KMHz during zenith pointing depending upon the galactic sources included in the beam. Switching to higher frequencies improved the results.

Techniques have been and are continuing to be developed to provide the best relationship for combining the results of communications power transmission and the probable received noise-power. Developments in low noise temperature amplifiers such as the Mazer type have made receiver noise input contributions to the overall communication system that can be and usually are lower than galactic and atmospheric noise. Other techniques used incorporate the linear reactance, tunnel diode, semi-conductor diode, and quantum mechanic tunnelling amplifier systems. Improvement of these low-noise amplifying devices to operate between 1000° down to 100°K in noise temperature without

using cooling air is being accomplished. Additional work may lead in the future to 20K noise figure receivers with or without cooling air.

The advent of phase track filters and similar correlation devices removed the uncertainty of discrete thresholds. Correlation devices provide a method for averaging out the interfering noise in either the time domain or the frequency domain or both. Various coding methods developed provide an improvement in the theoretical probability of bit-error when comparing the ratio signal energy-per-bit to the noise energy per cycle of bandwidth. Some of these systems are the non-coherent fsk, the coherent psk, and the 15-bit-word orthogonal coding systems. The threshold S/N at which degradation begins becomes lower as the coding of information becomes increasingly redundant. RCA's Advanced Technology Laboratories, examining the most economical combinations of equipment, have developed a FMFB (Frequency Modulation Feedback) demodulator for threshold extension that provides added system capability at a small fraction of the cost. This is better than always resorting to greater transmitter power, larger antennas or a still lower noise figure.

#### Communication Direction for the 1970s

Many challenges lie ahead for the 1970s. Some will only require refinements; others, something new. All direct the way for the communications industry. As man's specific explorations and military operations extend deeper and deeper into space, greater demands will be placed upon tracking, communications, and computational systems. Satellite orbiting data-relays or moon-based, deep-space tracking stations may provide relief for noise problems inherent in the earth's atmosphere but inject new problems due to other high-energy-point sources in the field of view of the receiving antennas.

While no problem regarding weight and size of receiving equipment exists for earth stations, one does exist in the space environment. RCA's "Blue Chips" development

program is a move in this direction. An S-band parametric amplifying system for NASA, it uses an integrated circuit array for microwave RF circuits. As more selective processing and control of data communications become necessary to handle the remote areas, conventional data reporting will be replaced by new graphic communication systems. Integrated-circuit voice and digital message-switching systems developed for communication networks like VOCOM and AUTODIN, will handle the distribution of voice and digital information to the large ground-monitoring complexes. And, development of new TV display techniques and holograms plus speech synthesis and recognition will let us know whether the explorers we send aloft are still okay.

Although each of the sections of this paper was devoted to an examination of the most significant problem in each category without repeating the technical effort or prediction for the 1970s, the information in one equally applies to the other. As you analyze the future remember: The future is nearer than we think. What is your company doing about communications for the future? Are you already aboard? To be ready for the future, start planning today.

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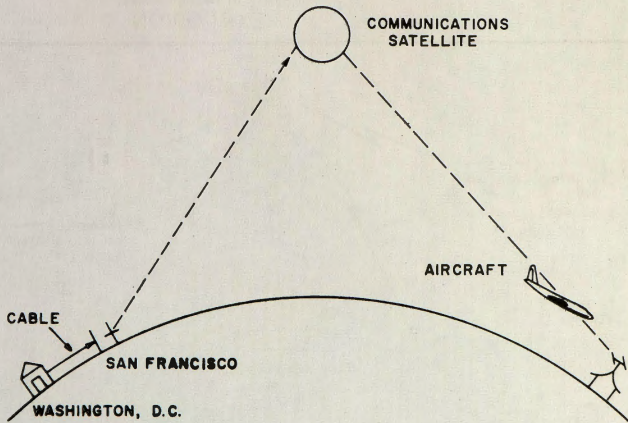


Figure 2. Example of Aircraft Relay System

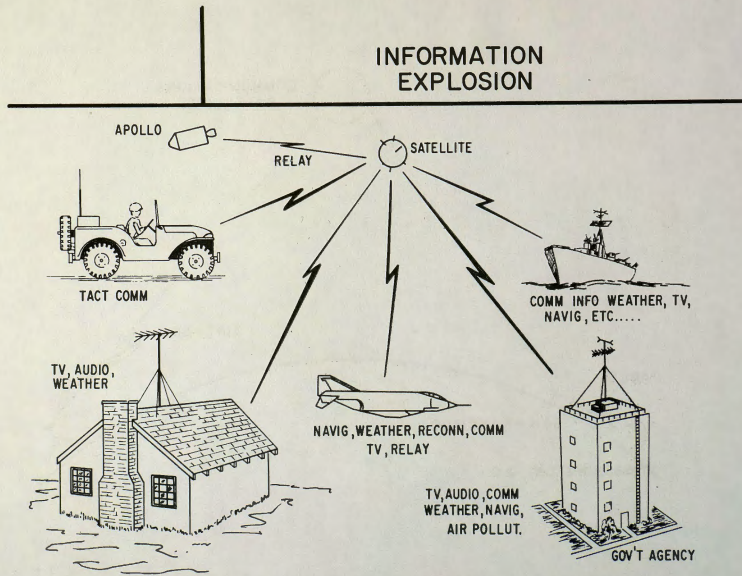


Figure 3. The Information Explosion

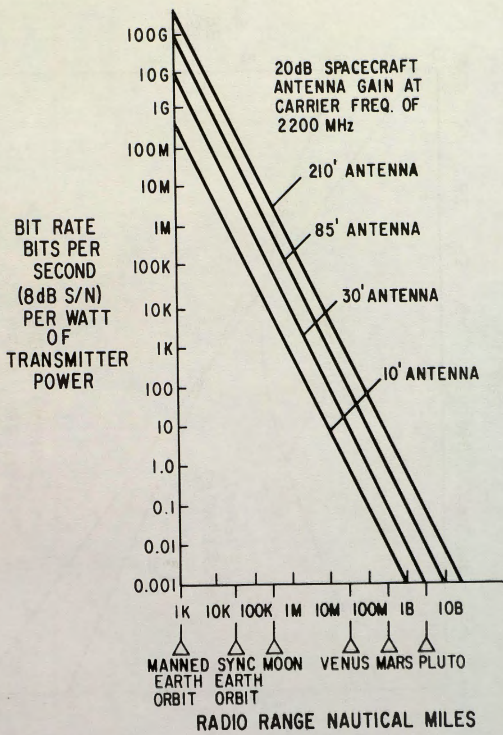


Figure 4. S-band Down-link Performance

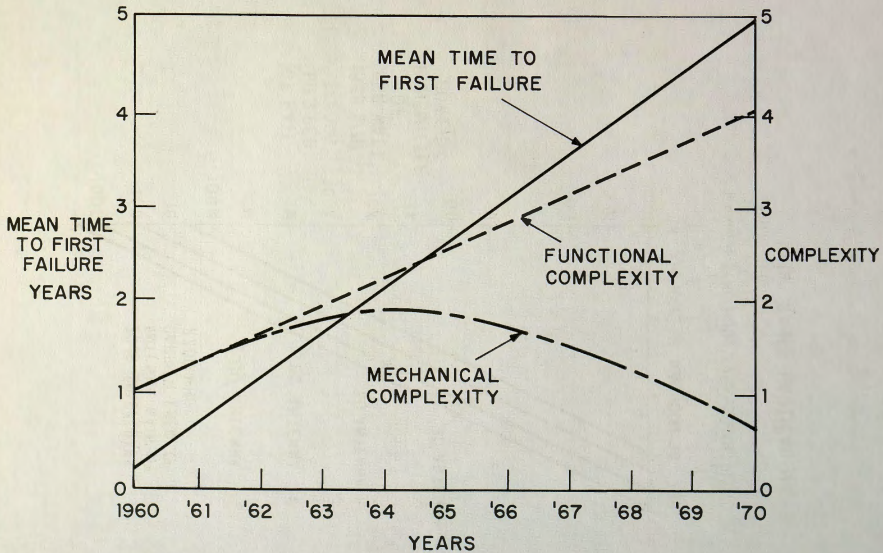


Figure 5. Reliability Trends for Vehicle-Contained Space Communication Equipment

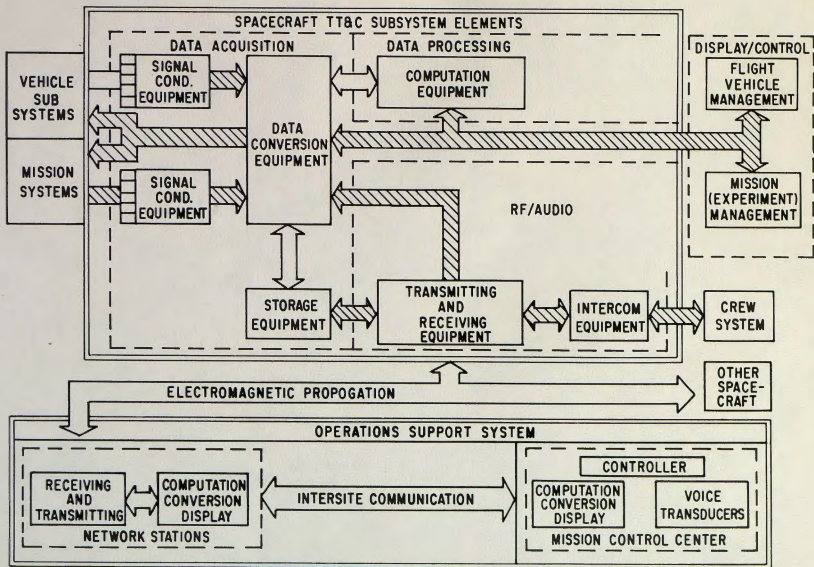


Figure 6. Elements of Space TT&C (telemetry, tracking, and commands communications)