APOLLO LUNAR COMMUNICATIONS

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Summary The Apollo unified S-band system was developed to handle ranging, telemetry, and voice data using one carrier. Television is transmitted in another mode with the same system. Frequent references are made to the unified S-band system in this report because other systems must work in conjunction with it; however, no description is provided because the S-band system is discussed thoroughly in numerous other reports.

The astronauts must coordinate their activities on the lunar surface, and communications are required between them as well as between them and Mission Control Center. A VHF system that has performed excellently in providing voice and telemetry information for lunar-surface use is described in this report.

Interest in television has progressed from casual to intense as the Apollo Program has matured; technology has evolved to provide color presentations using the same RF system that was once limited to black-and-white transmissions. The cameras that were developed for both black-and-white and color transmissions are described.

Future lunar-surface operations will require traverses too long to be accomplished easily on foot. A system that permits long-range communications from a motorized vehicle on the lunar surface is described.

Finally, brief descriptions of several communications-related lunar-environment experiments that have been proposed for the Apollo Program are discussed.

Introduction The design of the primary Apollo communications system - the unified S-band system - has been described in two separate reports at this conference. Thus, in this report, primary emphasis will be given to the relatively unpublicized aspects of the Apollo communications systems and components. Lunar-surface communications and TV hardware and techniques presently in use will be described, as well as a future lunar communications relay unit and several proposed communications experiments.

Lunar communications The communications RF links used in the Apollo Program relative to total lunar-surface operations are shown in figure 1. The significant lunar-surface elements depicted include two astronauts engaged in extravehicular activity (EVA), the lunar module (LM), the tripod-mounted TV camera, the deployed S-band erectable antenna, and the independently powered experiments package.

In the operational communications mode, duplex voice communications between the two astronauts and between the astronauts and Mission Control Center (MCC) are possible; in addition, telemetry data from both astronauts are relayed simultaneously to MCC via the ground stations in the Manned Space Flight Network (MSFN). As indicated, the lunar module pilot (LMP) communicates with the mission commander (CDR) via a VHF FM link. The CDR communicates with the LMP and MSFN via two VHF AM links, directly in the first instance and by relay through the LM and S-band erectable antenna in the second. In turn, MCC controllers communicate with both astronauts by relay through MSFN, the S-band erectable antenna, and the LM via VHF AM links.

The system allows the voice and data f rom the LMP to be received by the CDR, mixed with the CDR voice and data, and transmitted to MSFN via the LM and S-band erectable antenna. The LMP simultaneously receives only the CDR voice, thus completing the astronaut communications loop while effecting transmission to MSFN.

Transmissions from MSFN, relayed via the S-band erectable antenna and the LM, are received simultaneously by both astronauts, thus establishing the duplex communications required between the astronauts and MCC. Communications between the command module (CM) and the lunar-surface astronauts, if desired, are accomplished via relay through MSFN.

Extravehicular communications system The CDR and LMP each carry an independently operated backpack communications unit, called the extravehicular communications system (EVCS). In normal downlink operations, the LMP EVCS transmits a 2.3-kHz voice signal and two Inter- Rang Instrumentation Group (IRIG) subcarriers (3.9 and 7.35 kHz) via a 279.0-MHz VHF FM transmitter. This composite signal is received by the CDR EVCS, mixed with his 2.3-kHz voice signal and two IRIG subcarriers (5.4 and 10.5 kHz), and transmitted to the LM on the 259.7-MHz VHF AM link; the composite signal of voice and four subcarriers is relayed to MSFN via the S-band erectable antenna. The LMP EVCS receives the CDR EVCS signal (including his own EVCS transmission) on the 259.7-MHz VHF AM link, completing the duplex-voice link on the lunar surface.

In uplink operations, transmissions from MSFN are relayed via the S-band erectable antenna and LM to both astronauts simultaneously on the 296.8-MHz VHF AM link, which establishes duplex communications between MCC and the astronauts on the lunar surface.

The telemetry portion of each EVCS consists of an IRIG 30 x 1.5 PAM commutator and two standard IRIG subcarriers. The commutator output modulates the upper subcarrier, and the astronaut's electrocardiogram modulates the lower subcarrier. Signal-conditioning and failure-warning circuitry is incorporated as an integral part of the system.

Two backup modes in the EVCS can be actuated by controls located at the astronaut's chest. The first backup mode allows telemetry and duplex voice between either astronaut and MSFN, and between the astronauts on a time-shared basis. The second backup mode allows duplex voice-only communications between either astronaut and MSFN so that all communications are not lost.

High-density packaging techniques are used throughout the EVCS. The transmitters, receivers, telemeters, and other equipment all are modular. The resultant EVCS is 14.3 x 6.4 x 1.9 in and weighs 6.5 lb (all weights refer to weight on earth), Operating from a 16.8-v battery contained in the portable life-support system (PLSS), the EVCS transmits with a nominal output of 0.5 w.

In the present configuration, the EVCS can provide 26 data channels, four channels for synchronization and calibration, and one electrocardiographic channel. Only eight of the data channels were used on the Apollo 11 and 12 missions. A ninth channel (for carbon dioxide sensing) was added on Apollo 13 and will be used on future Apollo missions. The capability for additional data from the unassigned channels was incorporated in the design for future requirements on an as-needed basis.

Communications procedures At the time of descent to, and landing on, the lunar surface, the LM astronauts are hardlined into the spacecraft communications system and the S-band steerable antenna is used. During the preparation for EVA, the astronauts deploy, and switch to, the EVA antenna. Next, they disconnect from the LM system, connect to the EVCS, and, while still in the LM, establish RF links with each other and with MSFN. Just before opening the hatch, the astronauts close the TV circuit breaker, which energizes the TV camera. During the first EVA, the astronauts unstow and deploy the S-band erectable antenna and the experiments package, which have been stored in the LM descent stage. After they return to the LM following the first EVA, the astronauts switch to the S-band erectable antenna and power down the S-band steerable antenna to minimize energy consumption.

As previously mentioned, CM/LM/CM links are established via S-band links through MSFN. Although the VHF equipment could provide a direct LM/CM link, the requisite line-of-sight conditions for each CM pass are of extremely brief duration and thus impractical for operational use. However, the astronauts are given the line-of-sight time-interval information for each CM orbit for contingency use.

The communications systems discussed have been highly successful and virtually no problems have been experienced to date. Under current plans, the same hardware and procedures will be used through the Apollo 15 mission.

Experiments packages Other lunar-surface communications applications concern the self-contained experiments packages that were deployed on the first two lunar-landing missions. The Apollo 11 unit, called the early Apollo scientific experiments package (EASEP), was minimized to conserve weight on the first landing mission. The only equipment contained in the EASEP was a laser reflectometer, a lunar seismograph, communications units, and an array of solar cells.

A complete Apollo lunar-surface experiments package (ALSEP) was deployed on the Apollo 12 mission. The self-contained package, powered by a radioisotopic thermal generator, has a life expectancy of 2 yr.

As many as four separate ALSEP systems will be deployed and operated simultaneously during the Apollo Program. The downlink telemetry from the packages will operate on different frequencies (2276.5, 2278.5, 2279.5, and 2275.5 MHz in order of deployment). The uplink frequency for all four packages is 2119.0 MHz, but the command format will address each ALSEP separately to preclude inadvertent activation of the other three.

Television The lunar-surface TV configuration used in the Apollo Program to date is shown in figure 1. The TV camera is mounted to a deployable pallet on the LM descent stage during closeout operations at Kennedy Space Center. As the first astronaut descends the LM ladder to the lunar surface, he deploys the pallet by an activating lanyard, which enables the TV camera to view the astronaut as he first steps on the moon. Then, in the preliminary phases of the first EVA, he locates the camera for optimum viewing.

A black-and-white camera was the only TV used on the lunar surface during the Apollo 11 mission. Although an S-band erectable antenna was aboard the Apollo 11 LM, the antenna was not deployed. All TV transmissions were made via the S-band steerable antenna to the Jet Propulsion Laboratory (JPL) 210-ft-diameter antennas at Goldstone, Calif., and Parks, Australia.

The Apollo 11 camera used a slow scan rate of 10 frames/sec (320 scan lines). Initially, this rate was selected to confine the video bandwidth to 500 kHz, the bandwidth that was considered necessary at the time of the design freeze. Although this scan rate does provide a still picture with good resolution, some image smearing results during motion renditions. Because of the slow scan rate of the camera, the video waveform had to be scan converted at the receiving MSFN station to be compatible with the commercial system used to relay the signal to MCC.

The camera design provided for extremes in lunar lighting conditions (day and night) and for light levels ranging from 0.007 to 12 600 fc. Four different lenses were available to the astronauts for manual interchange as needed. On the Apollo 11 mission, the camera was deployed initially with the 80° (field of view) wide-angle lens. When the camera was relocated, the 35° lunar-day lens was attached and used for the remainder of the lunar stay. The 9° telephoto and 35° lunar-night lenses were not used.

Development of the Apollo 11 black-and-white camera was begun using state-of-the-art components and techniques and high-density packaging techniques. The camera was 11 x 6 x 3 in, weighed 7.5 lb, had a 7.5-w output, and used the spacecraft 28-v power source.

Although the black-and-white camera had been the only type intended for lunar-surface use, the success of the TV on the Apollo 11 mission raised the question as to whether the CM color camera could be modified for such use. When such an application was deemed possible, the immediate requirement existed to support the Apollo 12 and subsequent missions with color, rather than black-and-white, TV.

Unfortunately, the Apollo 12 TV camera vidicon tube was burned out as a result of being pointed directly at the sun. The S-band erectable antenna was deployed as planned and switchover was made after completion of the first EVA, so that, for the remainder of the Apollo 12 lunar stay, the voice and data were relayed via the erectable antenna. The astronauts switched back to the steerable antenna only when the erectable antenna, located 15 ft from the LM, was overturned by a jet firing that occurred during the pre-lift-off checkout of the reaction-control-system engines.

The major elements of the Apollo color TV camera are shown schematically in figure 2. Basically, the camera consists of a black-and-white camera with a color wheel rotating between the lens and the vidicon tube. This system provides the sequential color information that subsequently is converted to commercial video signals by MCC processing.

The line shown at the bottom of figure 2 shows the color sequencing of the color wheel, which has six sectors consisting of two sets of red, green, and blue filters. This configuration results from the motor speed and gear ratio used. The wheel rotates at 599. 4 rpm to yield six fields per revolution at the standard vertical color frequency of 59.94 Hz.

In operation, the image is focused by the lens through the color wheel onto the faceplate of the vidicon tube. As the wheel positions a color filter in the field, the vidicon tube stores the information and then reads it out. The information is processed by the camera electronics and sent to the transmitter. This process is repeated for the other colors. Because the color wheel rotates at the field rate, the color information is generated at a field-sequential rate.

The field-sequential color signals are processed at the MCC by a series of two tape recorders for the purposes of compensating for Doppler shift. The sequential color information then is routed to a scan converter that converts the sequential fields to the presentation of commercial TV format. As a new field is received into memory, the oldest field is erased, thus updating the information at the field rate.

In contrast to the black-and-white TV camera, the color camera uses a commercial scanning format (30 frame, 60 field, 2-to-l interlace, 525 lines) as defined by the National Television System Committee, with the exception of the 3.58-MHz color burst that is added to the TV signal later by the use of standard processing techniques. The standard scanning rate yields good motion rendition and precludes the need for scan conversion of the signal by MSFN.

As do commercial TV cameras, the Apollo camera outputs a video signal with a bandwidth as wide as 4 MHz. In the CM, the communications system restricts the transmitted bandwidth to approximately 2 MHz. The LM uses the same transmitted bandwidth, but the TV signal must share this bandwidth with biomedical and spacecraft telemetry data that interfere with the TV signal. This interference is eliminated by limiting the TV signal to 900 kHz. The result is a picture that has somewhat-degraded, but acceptable, resolution. The lighting-level capability of the camera is from 1 to 12 600 fc.

The camera (fig. 3) is 11.5 x 4.25 x 6.45 in, weighs 13.5 lb, uses a 28-v power system, and requires 14 w of power. A zoom lens eliminates the need for manually changing the lens as was necessary with the black-and-white camera. The field of view can be varied from 9° to 54° (zoom ratio of 6 to 1).

On the Apollo 14 mission, a lens cap will be used on the color camera to preclude damage to the vidicon tube while the astronauts relocate the camera. A bla6k-and-white camera may be carried as a backup unit.

New hardware After the successful conclusion of the Apollo 11 mission, detailed planning was begun for the Apollo 16 and subsequent lunar-landing missions. Studies indicated that the lunar-surface communications designed for the preliminary Apollo missions would constrain the more complex operations envisioned for these advanced Apollo missions.

Operational planning included lunar-surface traverses beyond the lunar horizon (with the resultant loss of signal at the LM) as well as explorations of lunar valleys and canyons. The present EVCS is limited to a nominal 2.7-km range for a two-man joint traverse or to a 3.8-km range if the EVA-relay technique is used. As a result, investigations into design and new hardware implementation were begun to satisfy the requirement for extended-range lunar-surface operations.

Various approaches to extend the range capability were investigated. These approaches included a 100-ft-high antenna on the LM, passive corner reflectors, active repeaters, and an EVCS relay system. All these concepts had undesirable aspects for the intended application, primarily because of complete dependence on the LM for relay purposes. Thus, from these initial investigations evolved a new, LM-independent approach to lunar-surface communications.

The proposed lunar-surface communications unit developed for the Apollo 16 and subsequent missions is shown deployed on the lunar roving vehicle (LRV) in figure 4. Called the lunar communications relay unit (LCRU), the device is a self-contained, independent, portable system that can provide the functions essential for direct voice, telemetry, and TV communications with MSFN.

Basically, the LCRU will contain a voice and data section consisting of a VHF AM transmitter and receiver for communications with the astronauts' VHF EVCS backpacks and an S-band transmitter and receiver for direct communications with MSFN. A wide-beamwidth (60°) S-band antenna will be used to minimize the requirement for manually pointing the antenna while the LRV is in motion. The TV section will consist of an FM transmitter that can provide color transmissions via a high-gain parabolic antenna.

The functional capabilities of the LCRU are as follows.

1) Provides voice-uplink relay from MSFN to astronauts
2) Provides voice/data-downlink relay via either high- or low-gain antenna
3) Provides color TV downlink using high-gain antenna
4) Provides command-uplink relay from MSFN to ground-commanded TV assembly (GCTA)
5) Operates on the LRV or modular equipment transporter
6) Operates in voice/data mode while hand-carried
7) Operates for 6-hr traverse on internal battery power (battery replaced between traverses)

8) Operates on LRV power in the event of battery depletion or failure These capabilities, of course, can be expanded or deleted as determined by program requirements.

Of the capabilities listed, it has been established that operation of the hand-carried LCRU (fig. 5) will be restricted to the voice and data mode; no TV operation will be required when the LCRU is hand-carried or when the LRV is in motion. The LCRU also offers an excellent potential for supporting selenographic surveys that may be performed on later Apollo missions.

Experiments Four prospective communications-related experiments intended primarily to determine the electrical properties of the moon are shown in figure 6.

VHF dielectric-constant experiment The VHF dielectric-constant experiment is being considered for the Apollo 16 and subsequent missions. Measurements are desired at each landing site. A 150-ft-long tape measure would be extended from the LM and the RF peaks and nulls would be measuredbyahandheldfield-strengthmeter. Investigationswouldbe made at 259.7 and 296.8 MHz, the frequencies presently used. These data would be of immediate value in determining the maximum range capability of existing hardware as well as in being design considerations for possible future equipment.

Bistatic-radar experiment The bistatic-radar experiment consists of transmitting signals to earth by two paths simultaneously from the command and service module (CSM) high-gain antenna. The wide-beam horn of the high-gain antenna would be used. As the CSM orbits the moon during the near -side pass, the antenna would be pointed at a specific lunar region. As the signal hit the moon and caromed off toward earth, the back orside lobe of the antenna would transmit directly to earth. The ground-station equipment that would be used to receive these signals is the 210-ft-diameter antenna at JPL. During the recording of the direct and reflected signals at JPL, only the S-band carrier would be transmitted.

The properties to be determined from this experiment are the Brewster angle (and hence the dielectric constant) and the surface roughness at S-band areas of the moon.

Also under consideration is using the CSM VHF signal as a bistaticradar experiment. In this instance, VHF signals would be transmitted via the CSM scimitar antennas and received at the Stanford University 150-ft VHF antenna array at Palo Alto, Calif. The addition of the VHF portion of the experiment would allow the acquisition of significant selenological information.

S-band transponder experiment The S-band transponder experiment consists of transmitting S-band signals from the CSM or the LM and receiving them at the MSFN stations. On the CSM, the high-gain antenna would be used; on the LM, the S-band steerable antenna would be used. The purpose of this ex eriment is to measure the Doppler shift resulting from lunar-gravitational-field effects on the spacecraft. No maneuvering or attitude controlling that would perturb the orbit would be performed during the experiment, so that all orbital perturbations could be correlated to gravitational-field effects. Also being considered is acquiring S-band data from the particles-and-fields subsatellite that would remain in the 111-km circular lunar orbit. The subsatellite, deployed f rom the CSM, would be a long-duration experiment with a life time of as long as 1 yr.

Surface electrical-properties experiment The surface electrical properties experiment (fig..7) is an RF interferometry experiment operating at eight selected frequencies of from 500 kHz to 32 MHz. The purpose of the experiment is to determine the subsurface characteristics of the moon, with the location of subsurface water being a prime objective. The experiment will be conducted b deploying a large dipole antenna and transmitter combination directly on the lunar surface; then the receiver portion of the experiment will be mounted on the LRV and field- strength data will be recorded on each of the eight transmitter frequencies as the astronauts conduct their scheduled explorations. These field-strength data will consist of both the direct ray and the reflected rays from the subsurface features of the moon. By the use of these data and range data obtained from a separate ranging system, the subsurface characteristics of the moon may be determined.

Concluding remarks The Apollo unified S-band system has performed in an excellent manner in the present configuration and no significant problems have been experienced to date. Current plans are to use the present hardware and procedures until new equipment is phased in on the Apollo 16 mission. Significant improvements have been made in the Apollo television system, primarily in that color, rather than black-andwhite, presentations were made possible at the same time that motion rendition was improved. Planning for the Apollo 16 and subsequent missions on which over-the-horizon traverses are envisioned revealed that a lunar communications relay unit would be required to free the astronauts from the line-of -sight communications restraint of dependence on the lunar module for relay. Four communications-related experiments have been proposed for implementation on the Apollo 16 and subsequent missions. In addition, a subsatellite with a 1-year life time has been suggested as another means of learning more about the physical properties of the moon. These experiments, in conjunction with continued improvement of lunar communications capabilities, will result in increased acquisition of scientific data from the Apollo Program.

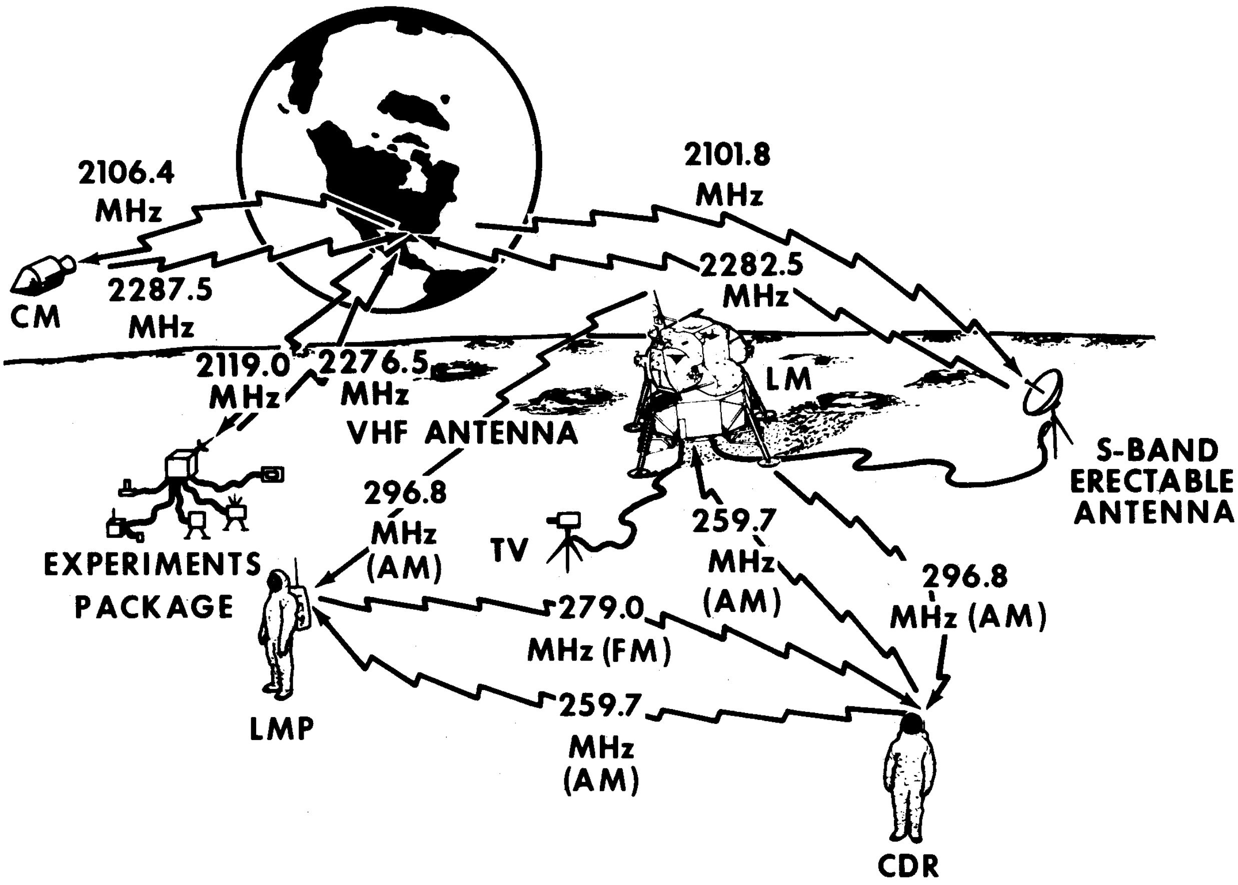

Fig. 1 - Apollo communications links.

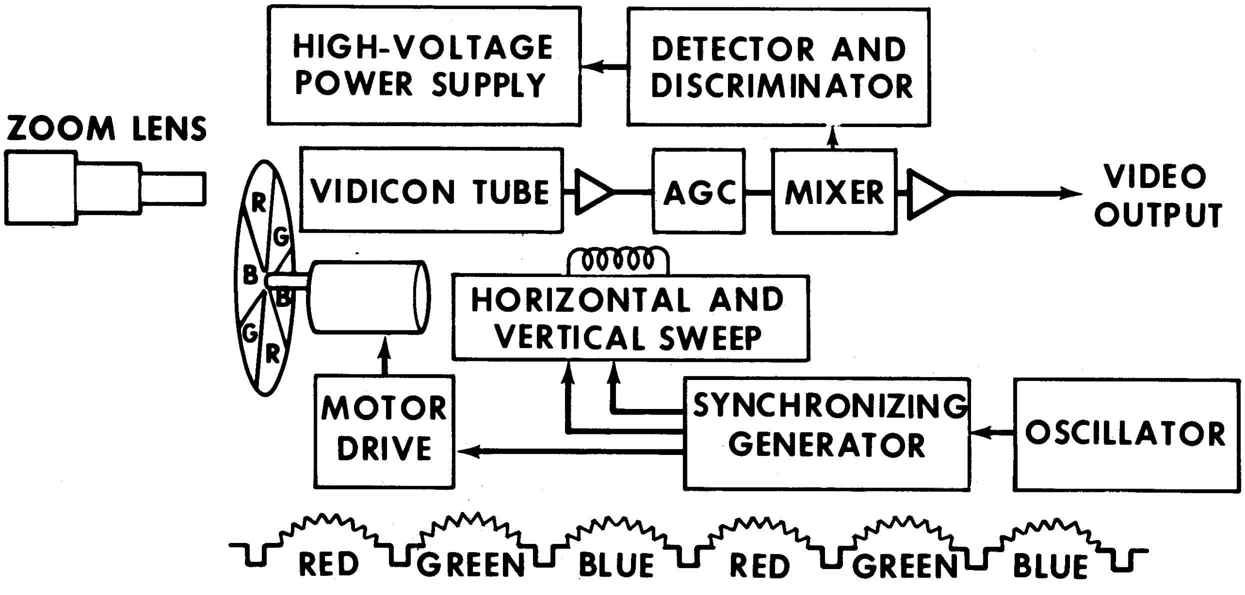

Fig. 2 - Schematic of Apollo color TV camera.

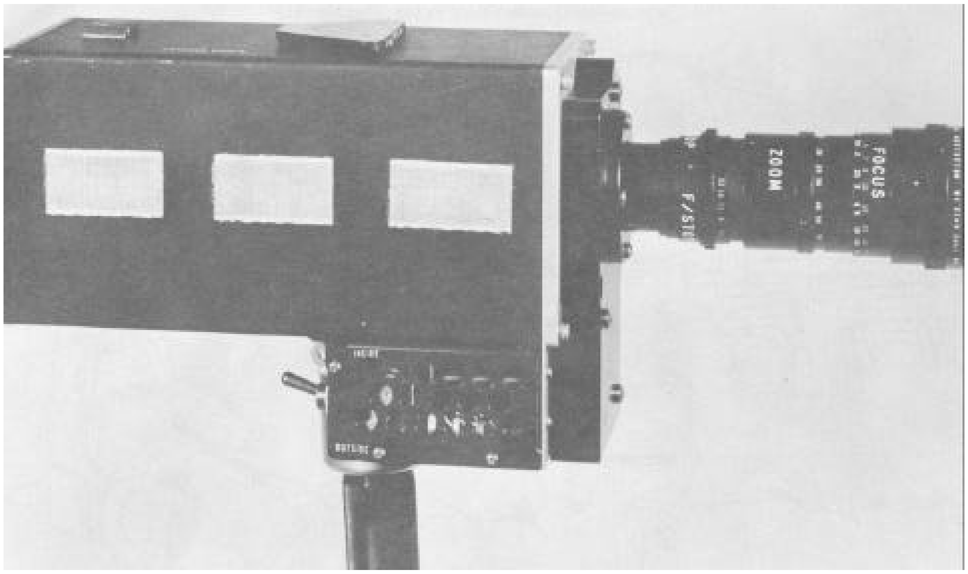

Fig. 3 - Apollo color TV camera.

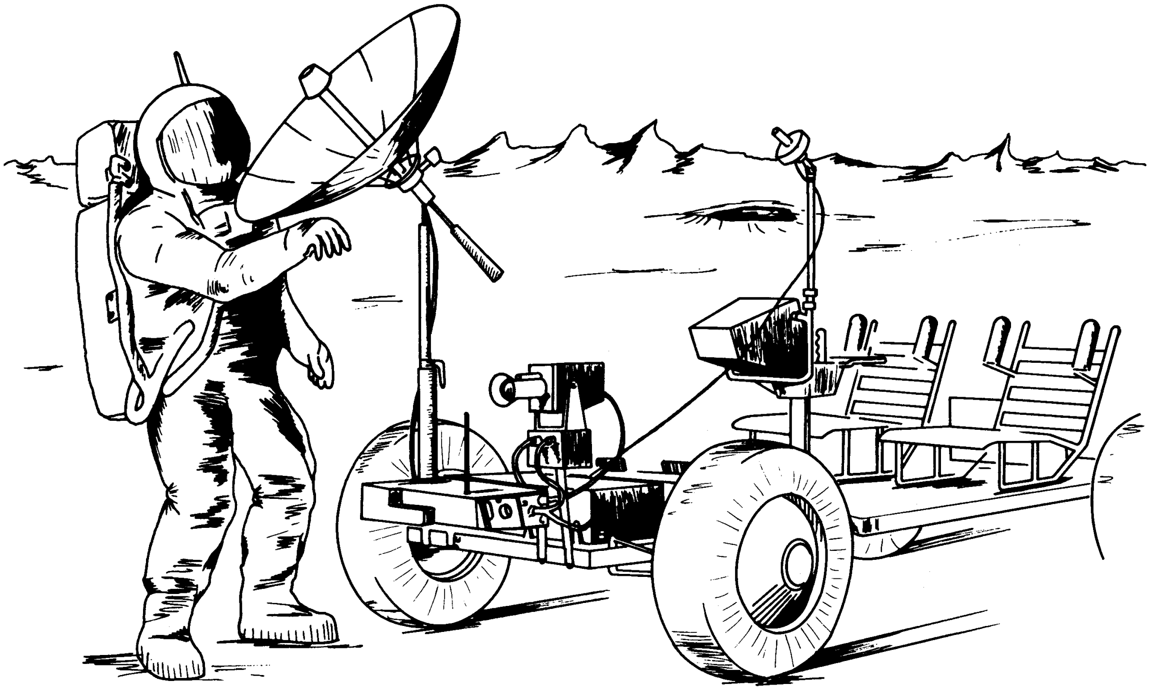

Fig - 4 - Deployed LCRU on lunar roving vehicle.

Fig. 5 - Hand-carried LCRU.

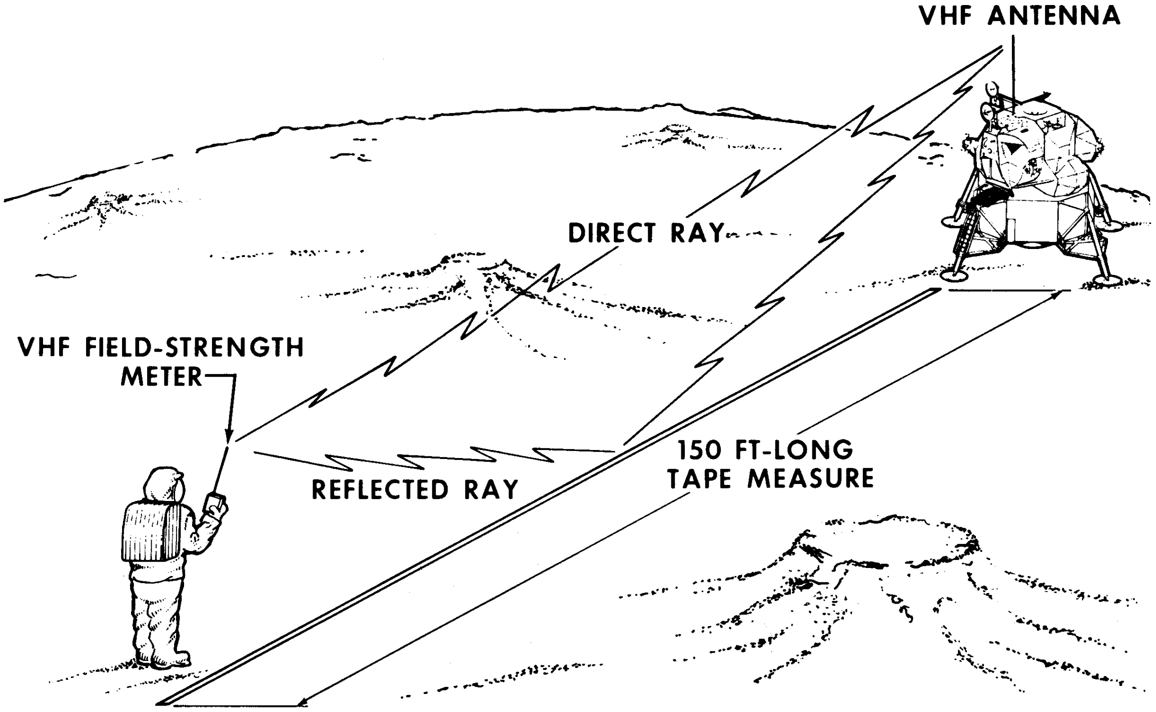

Fig. 6a - VHF dielectric-constant experiment.

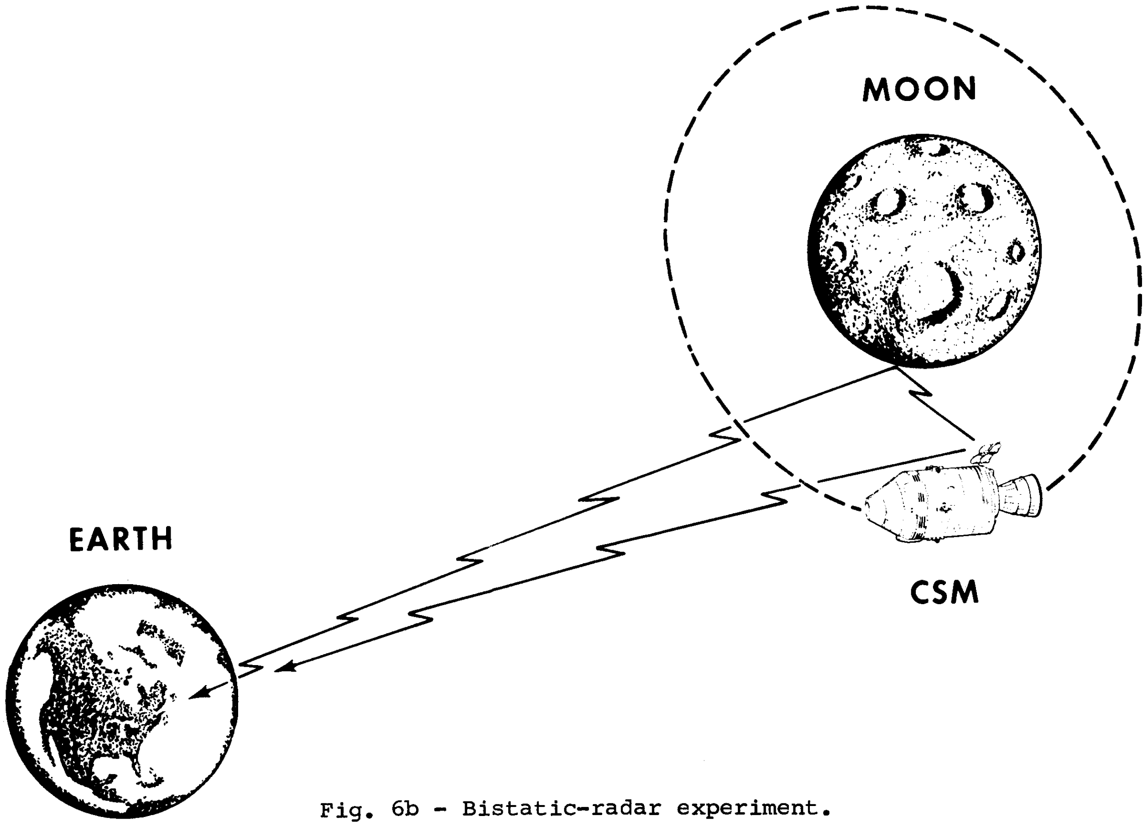

Fig. 6b - Bistatic-radar experiment.

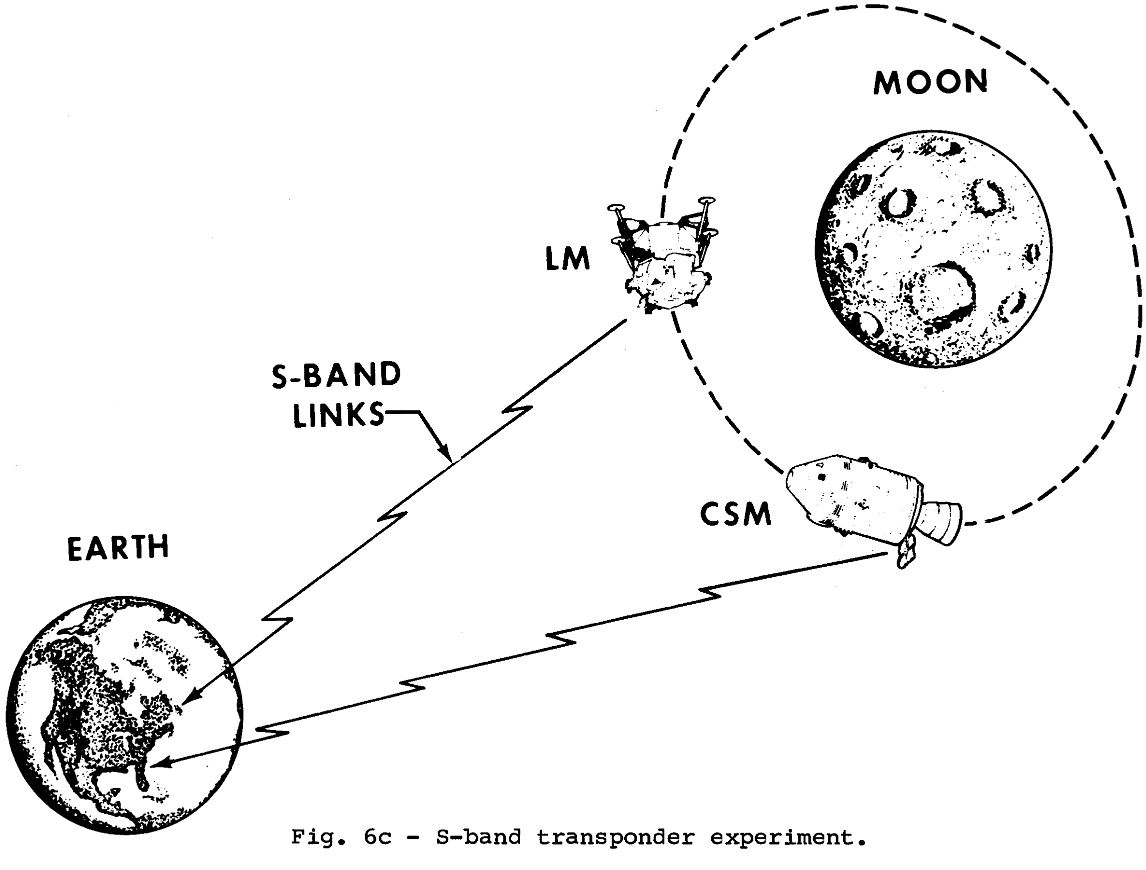

Fig. 6c - S-band transponder experiment.

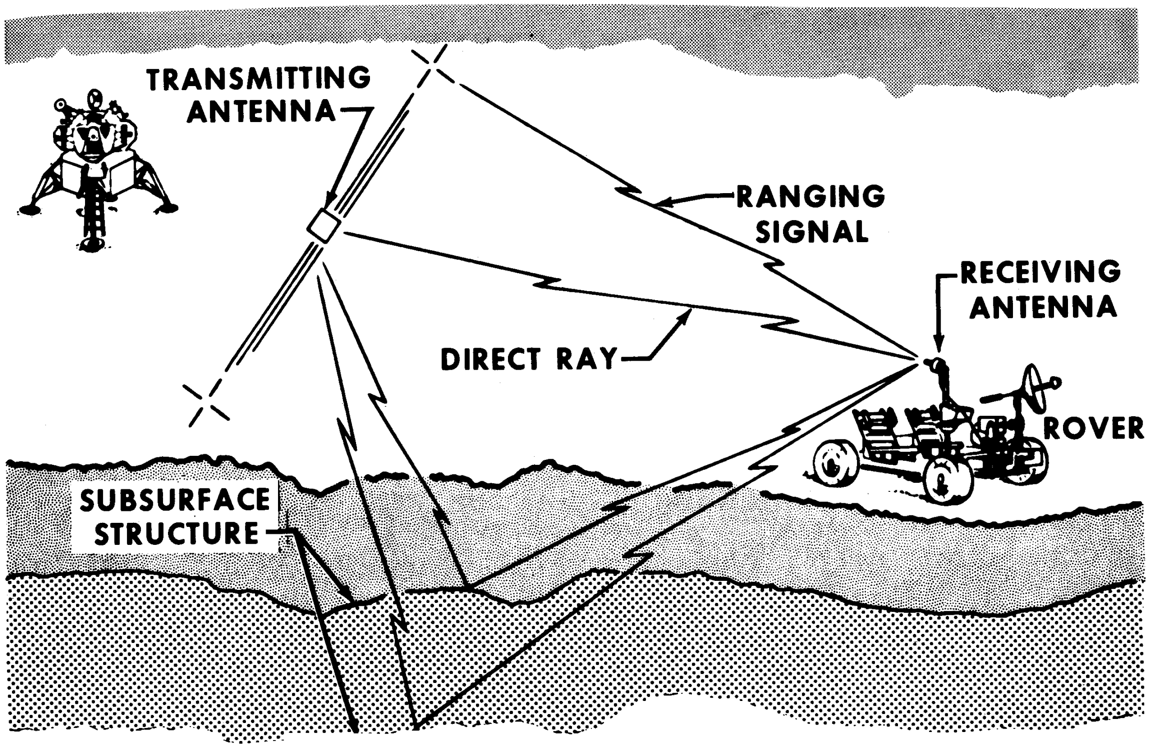

Fig. 7 - Surface electrical-properties experiment.