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# THE ATLAS - SCORE COMMUNICATION SYSTEM

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Project SCORE, or signal communication via orbital relay equipment, was an experiment to demonstrate conclusively that a radio relay system could be achieved utilizing a repeater installed in an orbiting space vehicle, and to define some of the problems which might require solution before a practical commercial or military system could be activated.

Many schemes have been proposed for the installation of microwave and very high frequency radio relay systems with distances between terminals or repeaters greater than line-of-sight. Some of these, such as airplanes or blimps circling fixed points at low speed, but high altitude and carrying self-directing antennas along with complete repeater facilities, have been calculated to be economically practical. However, the prospect of manning and maintaining such vehicles in isolated positions, for example over the Atlantic or Pacific Oceans, or over the Rocky Mountains in all kinds of weather, is formidable to say the least.

An orbiting satellite is plagued by neither of these problems at the present state of the art. Once in a proper orbit, it requires no additional external power to keep it there for its design life. It must, of necessity, be unattended, therefore, there is no problem of supply or maintenance. There is ample power for the operation of any installed electronic equipment available from the sun for the taking. The only problems remaining are the development of vehicles powerful enough to orbit a package of sufficient weight and capability to be commercially or militarily useful, the design and fabrication of suitable guidance and control equipment to correct perturbations in orbit, and the refinement of solar power conversion devices.

In Project SCORE, by taking advantage of the limitations of presently available vehicles, we could justifiably ignore some of these problems and design the communication equipment for a short life. Restrictions on the complexity of the system reduced the weight to a practical figure and yet left a sufficient margin of reliability. The detailed system and equipment design follows.

The vehicle provided for the communications package was an Air Force Atlas Missile 10B, lightened by removal of all but the most necessary guidance and safety equipment in order to carry additional fuel and the communication equipment. The communication equipment was mounted on rails which normally supported the guidance equipment under the fairing pods at the aft end of the missile.

Information made available to the USASRDL by the USAF indicated that the expected perigee would be approximately 100 miles and the apogee approximately 500 - 800 miles, and the life expectancy 2 - 3 weeks. The satellite would be launched from Cape Canaveral with a 30° inclination to the equator. This information was used to determine the ground station sites which were located at Fort MacArthur, California; Fort Huachuca, Arizona; Fort Sam Houston, Texas; and Fort Stewart, Georgia. An additional ground station was located at Cape Canaveral for use in final system tests.

A maximum communications range of 1000 miles was selected for system calculations based on the predicted apogee and perigee. The system calculations are summarized in Table 1.

| | SATELLITE | GROUND |
|---|---|---|
| TRANSMIT FREQUENCY | 132 MC | 150 MC |
| RECEIVE FREQUENCY | 150 MC | 132 MC |
| R.F. POWER OUTPUT | 8 WATTS | 1000 WATTS |
| NOISE FIGURE | 10 db | 6 db |
| I.F. BANDWIDTH | 40 KC | 40 KC |
| ANTENNA GAIN | -1 db | 16 db @ 150 MC |
| F.M. THRESHOLD | 10 db | 10 db |
| FADE MARGIN | 39 db | 19 db |
| AUDIO BANDWIDTH | 0.3-5.0 KC | 0.3-5.0 KC |

TABLE 1.
SYSTEM PARAMETERS

The satellite antenna pattern was essentially that of a multi-wavelength doublet. Therefore, nulls up to 15 db in depth were expected as the Atlas tumbled and rolled through space. This is the reason for the relatively large margin.

The selection of 40 kcs (± 20 kcs) IF bandwidth is based primarily on the following increments for the purpose stated:

Modulation (1st order side band) ± 5 kc
Frequency stability and drift (ground and satellite) ± 10 kc
Doppler shift ± 5 kcs

The satellite was conceived to perform a dual communications function. It was capable of serving as a "delayed repeater" or as a "real time" radio relay repeater. In delayed repeater mode, messages were sent from a ground station to the satellite system and stored until a command signal, originating from a different ground station, caused the satellite system to transmit this information back to the ground station originating the command. Since these stations could be separated by intercontinental distances, the amount of delay introduced is fixed by the orbital plane and period of the satellite and the location of the ground station involved. The amount of information is limited by the length of time the satellite is in view from each station, the transmission rate of the system and the maximum storage capacity contained in the satellite.

For real time repeater applications, the satellite served as an active radio relay repeating station with a capability of relaying for considerable distances by virtue of its extreme elevation. Again, the useful information rate is limited by the transmission rate of the system and the length of time that the satellite is in view from both stations simultaneously.

The location of stations on each coast provided the means for delayed repeater testing, while the location of the closer stations was based on obtaining test of the real time repeater within the capabilities of the system. These locations permitted time-in-view of the satellite of from three to ten minutes for a high percentage of the passes. This was primarily the basis for limiting the satellite recording time to four minutes.



HL SPACE (14)

A low level beacon was included in the airborne system to indicate the presence of the satellite and to permit tracking by the ground antennas. This beacon was at a nominal frequency of 108 mc and also served as a telemetry channel for temperature measurements within the satellite system.

To maintain proper control during the operational phase, a central control center was established at the Deal, New Jersey test site of USASRDL. Telephone and high frequency radio voice and teletype circuits were established among all stations of the system and the Deal control. Such an arrangement was found to be essential to the operational phase.

The satellite communications package which was conceived for Project SCORE was designed with four points in mind:

(1) It must be simple. Require no more than slight modifications of design of equipment already available, and require no special parts in order to fit in the overall time frame.

(2) It must be able to withstand the intense vibration expected during powered flight.

(3) It must provide its own temperature compensation since there is not an "ambient" temperature in space.

(4) Since the short time allotted for the project did not allow for thorough life testing of the equipment, the satellite package must consist of two identical communications systems utilizing slightly different r.f. frequencies, commanded from the ground, one intended for use if the other failed.

The components of the satellite are broken down as follows:

1. Antennas
2. Temperature control
3. Communications electronics
   a. Control Chassis
   b. Tracking Beacon
   c. Communications Transmitter
   d. Communications Receiver
   e. Recorder
   f. Power Sources

## Antenna System

The antenna system of the Atlas satellite was quite different from that of most previous satellites. There were no whips, instead slot antennas were used to excite the entire Atlas missile. (Figure 2 illustrates the type of antenna used.) The transmitters and beacons from each of the two systems were connected through "ring" isolaters and cavity isolating filters to two of the antennas which were located one in each pod. The receivers were likewise connected to two other antennas located in each pod. (Figure 3, illustrates the receiving antenna in place with the pod cover removed.)

## Temperature Compensation

The SCORE equipment was expected to function satisfactorily between the temperature of + 40°F and + 120 ° F, the high temperature limit being dictated by the transistors and battery and the low temperature by mechanical tolerances of the tape recorder and alternate type batteries. Most satellites are coated with a material with the correct a/e value to provide a temperature within specific boundaries. Here "a" is defined as the solar absorptivity of the material and "e" is its emissivity. The Atlas was too large to completely coat. Furthermore, the polished stainless steel located adjacent to the communications equipment was expected to attain a temperature of about 350°F after a short time in space. The compensation approach used was to apply an iridite finish to each pod cover and a high polish to the communication components. This was expected to produce a mean temperature of approximately 90°F within the communications package. The heat given off by the electronics due to their power dissipation was radiated to the pod cover and then reradiated into space.

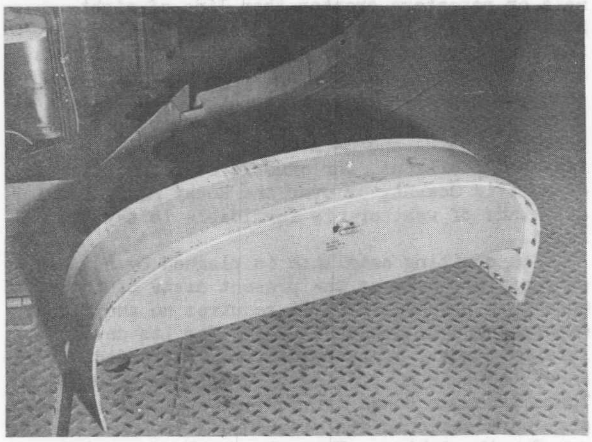

Figure 2. Slot Antenna Section for Satellite Communications Equipment

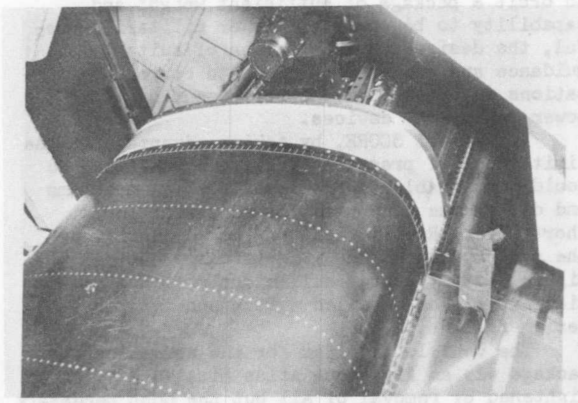

Figure 3. Receiver Section of Project SCORE Communications Antenna System Installed on AF Atlas Missile #10B

## Communications Equipment

The communications equipment was required to accomplish the following:

(1) Provide a tracking signal near 108 mc.

(2) Provide a delayed repeater or "courier" type of communications relay.

(3) Provide an instantaneous repeater for real time type of communications relay.

(4) Provide information of the temperature of various parts of the satellite.

(5) Be able to change mode of operation

Certain minimum requirements were specified for the ground stations. In addition to the usual facilities found in a transportable voice and teletype radio station, it was necessary to provide others for the control of the satellite's communications equipment. Monitoring of the tracking beacon transmitter was required with provision for extracting data therefrom. Recordings of signal levels, communications and other pertinent information were necessary so that a detailed performance evaluation could be made. The performance requirements were achieved in an assembly of equipments which made up a caravan of five motor vehicles and three power unit trailers. The basic block diagram of the ground station is shown in Figure 7.

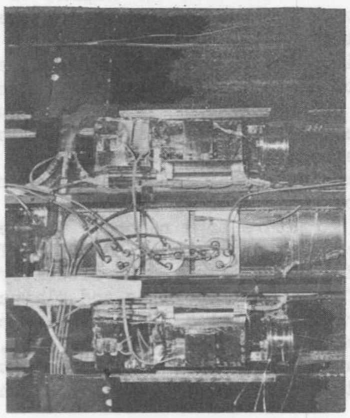

Figure 6. Communication Components Installed on Atlas Missile #10B, Pod Covers Removed

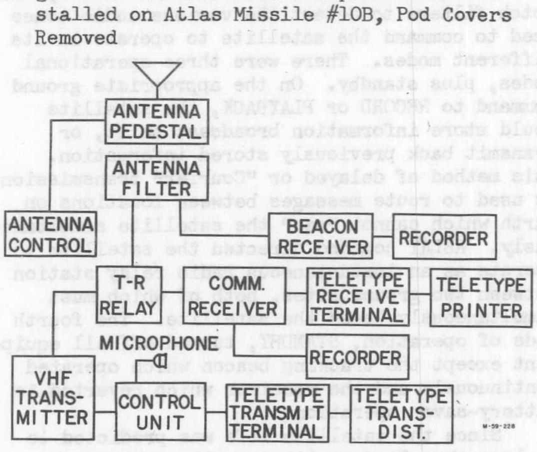


Figure 7. Block Diagram of Ground Station Portion of Project SCORE Communications System

The operating center with communication and tracking equipment is contained in a large van which is provided with both air conditioning and heating units. Other vehicles are used for maintenance purposes and transporting components of the antenna system and the power units. A typical site view of a ground station is shown in Figure 8.

The VHF communications receivers and transmitters in the ground station were commercial FM equipments adapted for use in the SCORE project. Fixed frequency receivers were used, modified to operate on about 132 megacycles. The receivers had a sensitivity of one-half microvolt for 20 db of noise quieting. Each of the receivers was capable of switching to either of the two satellite transmitting frequencies.

The transmitting equipment afforded a choice of either 250 watts or 1 kilowatt output power. These commercial FM transmitters were modified for operation on frequencies of about 150 megacycles and could operate on either of the two satellite receiving frequencies. The transmitters occupy the center of Figure 9 which is an interior view of the operations center.

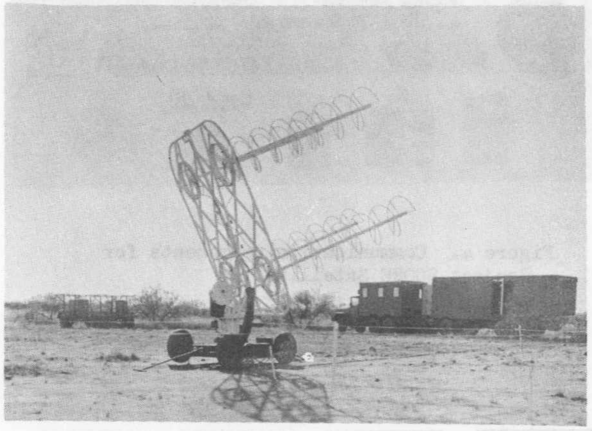

Figure 8. Typical Ground Station Site Showing Main Operations Van, Maintenance Truck, Power Units, and Remote Controlled Radi-Quad Antenna

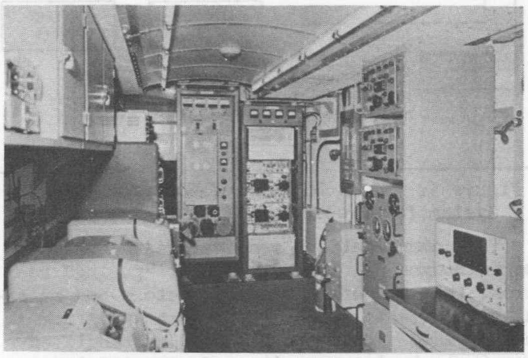

Figure 9. Interior View of Ground Station Operations Van

Two different types of teletype terminals were installed in the ground station, one for seven channel frequency division multiplex and the other a single channel equipment. The MUX terminal was a commercial item. Of the seven channels, the three of highest center frequency used a shift of 240 cycles, the remaining four, 85 cycles.

For single channel operation, Radioteletype Terminal Equipment AN/FGC-1 was used for receiving. For the transmitting terminal an 850 cycle audio frequency shift keyer was designed and built in the Signal Corps Laboratory.

upon command from the ground station.

(6) Operate for 21 days (the maximum expected life of the satellite.)

(Figures 4 and 5 show a picture of the communications system and a block diagram of the major operating components.)

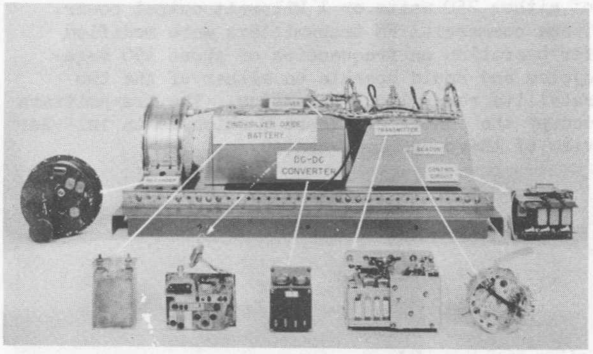


Figure 4. Communication Components for Project SCORE Satellite

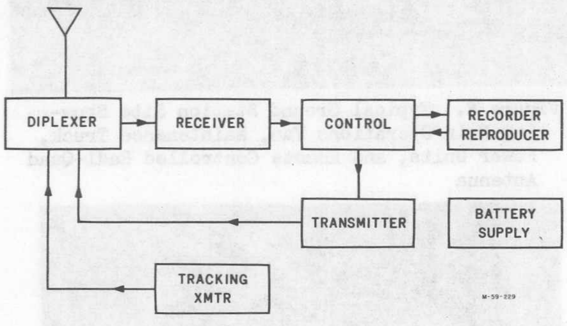


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Figure 5. Block Diagram of Communication System for Project SCORE Satellite

The communications receiver was a double superhetrodyne all transistor F.M. "paging" receiver; the type often used by doctors and salesmen to receive telephone calls when away from their office. A commercial model was modified extensively to increase its r.f. sensitivity, change its operating frequency, and insure proper operation throughout the expected temperature range. A battery-saver circuit consisting of a transistor multivibrator was incorporated. This circuit functioned to cyclically energize and de-energize the receiver at the rate of 1/4 second on and 2 1/2 seconds off. In the absence of a signal at the receiver frequency, the action of this multivibrator reduced the battery drain by a factor of 10. Upon application of a signal to the receiver input terminals, the multivibrator was stopped in the on condition, permitting the receiver to operate normally. In addition to its battery saving function, this circuit added a small measure of security against accidental operation since short pulses of noise or interference at the receiver frequency would not maintain the receiver in the "on" condition.

The transmitter was an existing vacuum tube "handie talkie" type, modified to deliver 8 watts output, frequency modulated at 132 megacycles. It was extensively modified to protect it against vibrations and to provide a means of dissipating the heat which it would generate. Its circuit was of a conventional type, crystal oscillator, indirect frequency modulator, frequency multipliers driving a power output tube.

The 30 milliwatt, 108 mc/s beacon was quite similar to the one used in Explorer I. It was transistorized and used one channel of FM-AM telemetry to transmit variations in the temperature of the electronics package or the missile (pod) skin. The circuit consisted of a crystal oscillator at 54 mcs followed by a frequency doubling output stage. The output stage was amplitude modulated by an audio oscillator whose frequency changed depending upon the temperature of a thermistor which was placed on the beacon chassis or on the pod skin.

The miniature tape recorder was designed and constructed entirely at USASRDL. The transistorized recorder electronic circuitry consisted of separate recording and playback amplifiers and an erase circuit. An "endless" or continuous loop of 1 mil mylar tape, 75 feet long with a speed of 3-3/4 inches per second, completed a record or playback cycle in 4 minutes.

The transistorized control unit used special notch filters to detect the various audio tones used to command the satellite to operate in its different modes. There were three operational modes, plus standby. On the appropriate ground command to RECORD or PLAYBACK, the satellite would store information broadcast to it, or transmit back previously stored information. This method of delayed or "Courier" transmission is used to route messages between locations on earth which cannot "see" the satellite simultaneously. RELAY command directed the satellite to operate as an instantaneous radio relay station between two ground sites, both of which must simultaneously "see" the satellite. The fourth mode of operation, STANDBY, turned off all equipment except the tracking beacon which operated continuously and the receiver which reverted to battery-saver operation.

Since the satellite life was predicted to be less than 21 days (it actually orbited for 35 days), a high-capacity chemical battery system was used rather than a costly and heavier solar converter supply with rechargeable nickel cadmium cells. Mercuric oxide batteries, although superior at higher temperatures, had a lower capacity (watt-hours per pound) than the zinc-silver oxide batteries. The latter type was therefore preferred although the former were purchased as a backup item.

(Figure 6 shows the flight packages installed in the Atlas 10B immediately prior to launch.)

Standard military teletype sets were used for receiving, transmitting and preparing messages on perforated tape.

A control unit was provided which originated the command tones sent to the satellite. The control unit also accomplished automatic switching of receivers, transmitters, teletype machines and other equipment in the proper sequence. A control panel at the operating position permitted the operator to choose any one of three operating sequences termed "Transmit," "Interrogate" and "Relay" by pressing an appropriate pushbotton. The tone frequency associated with the "Relay" function was a priority command which could take precedence over any function established by either of the other command tone frequencies, thus it could be used for instantly stopping any operating sequence in progress. Full remote control of the satellite's communication equipment was thereby achieved.

For monitoring the satellite's tracking beacons, receiving equipment was provided which enabled reception on both of the tracking frequencies near 108 megacycles. This equipment consisted of a VHF converter, a multicoupler and two R-390A/URR radio receivers. The receivers acted as tunable intermediate frequency amplifiers and were manually tuned to follow frequency changes due to doppler effects. The 4 db noise figure of this combination permitted successful tracking of the satellite when the signal level was only a few hundredths of a microvolt.

Other station equipment included magnetic tape and pen recorders as well as equipment for measuring radio and audio frequencies, teletype distortion and transmitter deviation, receiver performance, etc. The option of interconnecting any of the various equipments was afforded by means of a patch panel conveniently located at the operating position. The operating position is pictured in Figure 10.

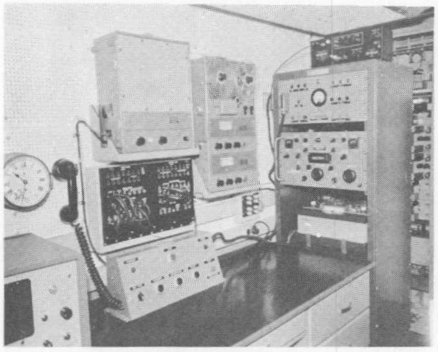

Figure 10. View of Operators Position of Ground Station Showing Control Panel, Communication Receivers, and Single Channel Teletype Modulator

The antenna system used by the ground station was directional type antenna consisting of four helcies on a thirteen foot square reflector. The gain of this array over an isotropic antenna is about 10 db at the tracking frequency and 14 db at the communication frequencies. This antenna was mounted on a modified searchlight pedestal so that it could be rotated 360° in azimuth and 90° in elevation. In all but the California station the antenna was positioned by reference to an indication from one of the tracking receivers. At the California station the azimuth control was slaved to the alidade of experimental direction finding equipment which resulted in a marked improvement in tracking accuracy.

After several postponements for various causes, on 18 December 1958 Air Force Missile 10B was launched into an orbit of approximately 118 miles perigee and 600 miles apogee, but otherwise was essentially as anticipated in the system design. Figure 11. It carried President Eisenhower's Christmas message to the world both in voice and teletype on each of the recorders of the communications package.

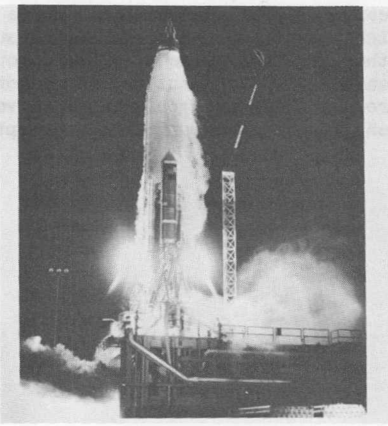

Figure 11. Launch of Atlas Missile #10B

On the first orbit, attempts were made by the California ground station to interrogate the communication package which was designated No. 1. An excellent carrier was received from the communication transmitter, but no modulation. Since no other orbit that day was close enough to the ground station, no further attempts were made to interrogate the communication equipment. On the following day, package No. 2 was interrogated by the installation team at Cape Canaveral. It responded and the ground crew received and recorded the President's message. It was then delivered by telephone to Washington.

On each of the subsequent days, each function for which the equipment was designed was tested and successfully demonstrated. For the period of operation of package No. 2, namely 18 Dec to 31 Dec 58, a maximum of 42 and a minimum of 30 orbits were tracked by each of the four stations. A maximum average of 12.6 minutes and a minimum 5.8 minutes tracking time per orbit was recorded by the four stations. During these times the communications package was interrogated 78 times, loaded with new material 28 times, and operated as a real time relay 11 times for a grand total of 117 deliberate operations. The total operation time for the life span of the battery was 7 hours and 47 minutes.

The failure of package No. 1 had been rather accurately determined to have been caused by a malfunction of the tape recorder which permitted the transmitter to remain on continuously. Under these conditions, its battery life would be about one hour. Sporadic transmissions from the beacon of this package on the second day duplicated those obtained on a laboratory system subjected to the assumed conditions.

Measurements obtained from the beacon of package No. 2 indicated that the temperature within the package remained around 140°F. This was beyond the upper edge of the design range and much higher than expected. Since the thermistor at this temperature was operating on the saturated portion of its characteristic, the actual temperature could have been much higher. No adverse affect could be directly traced to the elevated temperature.

This experiment has definitely demonstrated with a minimum of equipment that transcontinental and intercontinental communication systems can be established and that the operation of such a system either as a real time or delayed repeater type is feasible. Refinement and expansion within the foreseeable future could easily revolutionize all long distance communication concepts.