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STADAN-NASCOM SUPPORT FOR THE SERT II MISSION

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16. Abstract
This report describes the command and telemetry links between the SERT II spacecraft and the tracking stations of the Space Tracking and Data Acquisition Network (STADAN). The data transmission via the NASA Communications Network (NASCOM) from the tracking stations to the Spacecraft Control Center at Lewis is also described. The criteria for selection of the tracking stations are given, along with a description of the sets of tests performed with the stations, and on the spacecraft. A brief summary of the on-orbit operations concludes the report.

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SUMMARY

The essentials of the command and telemetry links between the SERT II spacecraft and the remote tracking stations of the Space Tracking and Data Acquisition Network (STADAN) are described, as well as the data transmission via the NASA Communication Network (NASCOM) from the tracking stations to the Spacecraft Control Center at Lewis. The radiofrequency link calculations and data line response curves are shown, with a summary of the tests which were performed to prove compatibility with the STADAN-NASCOM system. Problems discovered during the compatibility tests and their resolution are discussed.

The transmission of two STADAN telemetry receiver automatic-gain-control (AGC) signals, multiplexed with data from spacecraft Inter-Range Instrumentation Group (IRIG) channels 2 and 7 necessitated the design by the Goddard Space Flight Center of a set of resistance-capacitance (R-C) filters. A description of the filters and the effects on the telemetry baseband signal is given. The testing performed between the remote stations and the spacecraft control center is described and the results are given. A brief summary of the on-orbit operations concludes the report.

INTRODUCTION

The SERT II mission is a 6-month endurance test of ion thrusters. The conduct of the mission requires that data from the thrusters and from other experiments, along with the spacecraft housekeeping information, be transmitted from the spacecraft to the ground stations and then, by means of data quality telephone lines, to Lewis. It is also necessary to operate equipment aboard the spacecraft, which requires that commands be transmitted to the spacecraft by the stations, under control of the Lewis Spacecraft Control Center (SCC).

The telemetry and command systems of the SERT II spacecraft were designed to be compatible with the ground stations in the Space Tracking and Data Acquisition Network

(STADAN), and with the NASA Communications Network (NASCOM). The functions which are being performed by the STADAN and NASCOM networks are diversity reception and phase demodulation of the telemetry signal, addition of the diversity receiver automatic-gain-control signals to the telemetry baseband signal, and transmission of the composite signal to Lewis. The STADAN stations also transmit multitone commands to the spacecraft by means of a punched-paper-tape reader and a command encoder which modulates an amplitude modulation (AM) transmitter and feeds a command antenna.

This report presents the reasons why four stations were selected for support of the mission and a description of the telemetry and command links, the use of NASCOM lines, and the testing performed with the network. The report is concluded by a summary of the operations with the network.

STATION SELECTION

The Space Tracking and Data Acquisition Network consists of 10 tracking stations. These stations are located in Fort Myers, Florida; Fairbanks, Alaska; Johannesburg, South Africa; Quito, Ecuador; Rosman, North Carolina; Santiago, Chile; Winkfield, England; Orroral Valley, Australia; Tananarive, Malagasy Republic; and Kauai, Hawii. Estimates of the coverage necessary to monitor and control the spacecraft and the experiments revealed that the coverage supplied by all the stations would be much greater than required. Four of these stations were selected as the prime stations for support of the SERT II project. The selection process was simplified by the project requirement for reliable voice and data communications. Some stations have only high-frequency radio links which are less reliable than cable and microwave links ("Implementation of a Worldwide High Speed Data Transmission System for NASA Mission Support, Goddard Space Flight Center (GSFC) document X-500-66-402). Eliminating the stations which had high-frequency links at the time of selection left the stations at Fort Myers, Fairbanks, Orroral, Winkfield, and Rosman. The difference in coverage between Rosman and Fort Myers was insignificant due to their geographic proximity, and the Rosman station was arbitrarily selected. The real-time coverage provided by these four stations, supplemented by the data recorded on the spacecraft tape recorders, gives complete coverage of any orbit.

Orbit calculations are performed by the Goddard Space Flight Center's Data Systems Division from data supplied by minitrack installations at most STADAN sites. Scheduling of stations is performed by the Goddard Space Flight Center's Network Control Group (NETCON). At the request of the project, every pass from the prime stations was fed to the Spacecraft Control Center from launch through the completion of thruster startup. When the thruster operation became routine, the coverage was reduced to one pass from one of the prime stations per orbit. Approximately 6 weeks after launch the coverage was further reduced to one pass every other orbit. During this phase it is necessary to take data from the other stations in the network because the spacecraft now has a lower scheduling priority than it did at launch.

TELEMETRY DOWNLINK

Each ground station is equipped with one or more flexible telemetry links. The various systems used are not constantly connected to a particular data acquisition configuration, but are capable of being switched into different arrangements of antenna, receivers, data handling equipment, and recorders as required. The arrangement of equipment to support SERT II telemetry is shown in figure 1. All the prime SERT II stations are equipped with Satellite Automatic Tracking Antennas (SATAN) which provide a 22-decibel gain at the SERT II telemetry frequencies in the 136-megahertz band. The SATAN antenna array consists of 16 individual eight-element Yagi antennas attached to a hydraulically driven X-Y mount. The nine-Yagi arrays at Winkfield and Orroral, and the 40-foot (12-m) parabolic reflectors located at some STADAN stations can be used for SERT II, but the signal margin is reduced by 3 decibels. The 85-foot (26-m) parabolic antenna at Rosman has been used, and it increases the margin by 4 decibels.

The spacecraft antenna system produces right circular polarization, but the polarization as seen by the tracking station may be elliptical due to propagation and relative orientation of the spacecraft and station antennas. To compensate for these effects, the output of each Yagi antenna in the SATAN array is fed to coupling networks which produce two orthogonally polarized signals for diversity reception and two signals for tracking. Each of the signals is amplified at the array before being fed to the transmission line.

The autotrack receivers utilize the carrier component of the phase modulated telemetry signal to provide control voltages to the antenna servosystem. An angular error between the antenna pointing direction and the spacecraft line of sight results in a phase difference in the radiofrequency signals received by the antennas of the array. This phase difference is converted to error voltages which control hydraulic servoactuators in the antenna X and Y axes.

The sum signal and its orthogonally polarized signal from the antenna system are fed to separate telemetry receiver channels. The receivers are crystal stabilized, double conversion superheterodynes. The output of each receiver channel is fed to demodulators and a diversity combiner. The automatic-gain-control (AGC) levels of each channel control the combiner to give a baseband signal which is a combination of the signals in each channel; or in case one channel loses lock, it gives the signal from the other channel.

The demodulator and diversity combiner also compare the converted carrier frequency with an internal voltage-controlled oscillator (VCO) and derive a voltage proportional to the error. This error voltage controls the VCO, which causes the receiver-demodulator to track the apparent spacecraft radiofrequency changes due to Doppler effect.

The AGC record module accepts the AGC signals from each receiver channel and each demodulator channel and combines them into two independent output signals which are linear and proportional to the received signal strengths from -80 to -145 dBm (decibels referenced to 1 milliwatt).

Table I shows the power budget for telemetry. The total transmitter power is 0.35 watt (25 dBm). The maximum antenna gain was determined by the spacecraft support unit contractor on a 1/10 scale model of the spacecraft at a frequency of 1420 megahertz. This frequency was determined by taking the average between the 136-megahertz telemetry band and the 148-megahertz command band, and multiplying the result by 10. The maximum range (2762 km) was calculated by the geometry of the orbit with respect to a 10° minimum tracking antenna elevation angle. This range yields 144 decibels loss at the telemetry frequency band. The 19-decibel gain for the receiving antenna is the measured gain of a 40-foot (12-m) parabolic antenna or a nine-Yagi array. The passive element losses are the losses in the hybrid junctions and couplers at the antenna. Summation at this point yields the total received signal power. The three spacecraft voltage-controlled oscillators were set for 1/2-power preemphasis to give equal signal-to-noise ratios in each of the subcarriers, and the modulation index was set to leave 34 percent of the total power in the carrier for tracking purposes. The power in the IRIG 7 sideband is then 10 decibels below total power. The antenna patterns produced on the 1/10 scale model showed that for 95 percent of coverage, the -12-decibel contour was the lowest to be expected. Summation of these values yields the expected minimum signal.

COMMAND UPLINK

Figure 2 shows the elements of the STADAN command system. All commands are punched on paper tape and all command tapes are checked by means of teletype with the SERT II Spacecraft Control Center prior to use. The command format complies with the Aerospace Data Systems Standards except that the format is modified to allow SCC operator verification of correct command storage on the spacecraft prior to executing the command. The execute function is performed by a second transmission of the command address tone on verbal request by SCC. Proper timing of the command burst sequence is controlled by the command encoder. The tone burst output of the command encoder amplitude modulates an AM transmitter. Detectors on the transmitter allow visual and aural monitoring and tape recording of a command transmission. The transmitter feeds a command antenna which is slaved to the receive antenna. Table II shows the command power budget for the minimum transmitter-antenna combination (200-W transmitter - 10-dB antenna) at a STADAN station. The propagation losses are 1 decibel greater in the command frequency band because the frequency is 13 megahertz higher than telemetry. Summation at this point yields the total received signal power. The expected null depth of 16 decibels is the contour which provides 99 percent coverage on the 1/10 scale model. Since the spacecraft is not capable of polarization diversity reception, a total of 3 decibels is allowed for these losses. The station transmitter modulation level is 80 percent±5 percent. At the lower limit of this specification, the command receiver sensitivity is 2 microvolts (-101 dBm) or better. Summation of these values yields a 6-decibel margin with minimum station command facilities. Use of the 5-kilowatt transmitter and the SATAN command antenna increases the total effective radiated power (ERP) to 86 dBm and the adjusted signal margin increases to 29 decibels for maximum range.

NASCOM LINES

Real-Time Line Usage

Figure 3 shows the NASA communications lines between each of the prime STADAN stations, the NASCOM switching center, and the SERT II Control Center. Each solid line is a voice-data alternate, full duplex, four-wire line which meets American Telephone & Telegraph 4B specification. One line is assigned for data transmission and the other for voice communication, although the functions are interchangeable. The Goddard Space Flight Center's Multisatellite Operations Control Center is conferenced (both voice and data) with the SCC on all passes to provide assistance to SCC in operations with the STADAN stations, and to provide on-line monitoring of the data being fed to SCC. The dashed lines show the teletype communications provided by NASCOM. The teletype is used to transmit pass schedules, command requests, and pass summaries.

Figure 4 shows the AT&T 4B specification limits, the measured response of the line between SCC and GSFC, and the IRIG bands occupied by the SERT composite signal. Since the two AGC signals are analog, the composite signal is treated as an analog signal even though the real-time data and the command verify signals are digital. Consequently, no data modems are required. The envelope delay characteristic of the lines is not important for SERT II use since the maximum delay (3 msec) is several orders of magnitude less than the required correlation (1 to 2 sec) between each of the IRIG channels.

In addition to the real-time data and the command verify signals, the STADAN station receiver AGC signals are required at the spacecraft control center in order to give project personnel an estimate of the signal level prior to transmission of a command by a STADAN station. In order to add the AGC signals to the telemetry baseband signal at the stations, the GSFC Network Assurance Section utilized existing station line drivers and designed R-C filters to remove the preemphasis from the telemetry baseband signal and to remove the unneeded signals produced by the station IRIG multiplexer. Figure 5 shows the components of the filters and the station equipment needed to generate the composite signal.

At the input to the single-section R-C filter, the spacecraft 1/2-power preemphasized baseband signal produces an IRIG 7 (2.3 kHz) subcarrier that is 6 decibels higher than the IRIG 2 (560 Hz) subcarrier. The single-section R-C filter has a corner frequency of 720 hertz and a slope of -6 decibels per octave which produces a net loss at IRIG 7 of 8 decibels with respect to IRIG 2. The resultant baseband IRIG 7 is 2 decibels below IRIG 2. Since the NASCOM lines have a tolerance of 4 decibels in this frequency range, the 2-decibel difference is not significant. It was determined experimentally that the 82-ohm load resistor on the output of the line driver feeding the filter allowed the two spacecraft subcarriers to be at a slightly higher level than the station-generated subcarriers in the composite signal.

The AGC signals from the AGC record module are fed to IRIG channels 1 and 3 in the station multiplexer. The other IRIG channels produced in the multiplexer have their inputs grounded to eliminate modulation of the voltage-controlled oscillators by noise. One grounded VCO is set for IRIG 7, and, therefore, produces a subcarrier in the spacecraft IRIG 7 band. It was not possible to have this VCO turned off during a SERT pass because this might compromise use of the VCO by a spacecraft which was scheduled to be tracked by the station immediately following a SERT pass. To solve this problem, the dual-section R-C filter was designed. The corner frequency of this filter is 200 hertz and the rolloff is -12 decibels per octave. At the unwanted IRIG 7 frequency, the filter produces 43 decibels attenuation. The output of each filter is buffered by a line driver and then the two signals are summed in the linear input to the final line driver.

The composite signal, when received at SCC, is recorded on magnetic tape and simultaneously fed to a set of discriminators. The output of the discriminators is fed to the data processing equipment, and at the same time a strip chart of the four IRIG channels is made. Figures 6 to 9 show the composite signal strip chart from a typical pass. At acquisition of signal (fig. 6) the IRIG 2 (verify) channel is showing band-edge to band-edge noise spikes. Some degradation of the pulse code modulation (PCM) data on IRIG 7 can be seen. Both AGC signals are near -130 dBm, and the AGC B contains noise signals of approximately 100 percent. During this period no commands are sent because the presence of spikes in the verify channel increases the possibility of a false verification, which would necessitate retransmission of the command.

The signal quality criteria to be met before a command is transmitted are that (1) the PCM decommutator must be locked; (2) the verify channel must be free of band-edge to band-edge noise spikes; and (3) both AGC signals must be above -115 dBm. Figure 7 shows that AGC A is at -104 dBm and AGC B is at -100 dBm. The PCM data appear clean and the decommutator indicators showed that the signal was locked. No band-edge to band-edge spikes exist, and the previously scheduled commands were sent. For this pass these commands were tape recorder number 2 record (command 216) and tape recorder number 1 playback (command 166).

Figure 8 is a portion of figure 7 which has been recorded at a chart speed that is 10 times faster than for figure 7. Figure 8 clearly shows the clean real-time PCM wave train and the command verify signal for command 166. The first pulse in the verify wave train is the synchronizing pulse, followed by two "zeros" in the binary 4 and binary 2 positions. A "one" in the binary 1 position yields the first digit of the command number. The second digit of the command number is obtained from the next two pulses by ones in the binary 4 and 2 positions and a zero in the binary 1 position. The third digit, also a 6, is obtained from the last two pulses in the binary 4 and 2 positions, with a zero in the binary 1 position. The verify signal is checked for even parity, which is the case for this command, and no parity pulse is required. Figure 9 shows the end of the pass. For this pass IRIG 3 AGC B shows the signal dropping below -120 dBm, and at the same time IRIG 1 AGC A is above -110 dBm. The diversity system prevents degradation of the real-time data in this period. The first noise spikes indicating imminent end of the pass appear on AGC B. No commands would be transmitted after this time due to the probability of an improper verify and consequent rejection of the command. The noise spikes become more frequent on AGC B as time progresses, and the other IRIG channels show increased degradation. IRIG 1 AGC A shows a period of slightly more than 1 second where the signal drops from -115 dBm to below -130 dBm. This reduction in signal level was caused by desensitization of the station receivers by an aircraft communications transmitter in the vicinity of the station. This desensitization occurs infrequently and only at the Winkfield station, which is located near an airport. Four seconds after this occurrence severe degradation occurs on all the channels, and the decommutator loses lock. This terminates the pass for the control center even though the station maintains lock on the carrier for the remaining 7 seconds.

Tape Recorder Playback

The spacecraft tape recorder operates at 1.46 inches (3.71 cm) per second and can record for up to 144 minutes. The playback speed is 16 times faster than the record speed so that all the data which have been recorded can be received by a tracking station during a pass. On playback the tape recorder modulates the IRIG 10 subcarrier at 560 bits per second. The subcarrier oscillator, when not modulated, remains at the IRIG 10 lower band edge. The response of the NASCOM line (fig. 4) will not allow direct transmission of the recorded data to the spacecraft control center. The data are recorded on the station's recorder, and normally this tape is mailed to the spacecraft control center. If the recorded data are needed immediately, the stations can play back the station recorder at one-half the record speed, which translates the IRIG 10 signal into the pass band of the data lines. The spacecraft recorder on playback runs in reverse; that is, the bit stream is reversed. When a station is requested to transmit the spacecraft recorder data to SCC, the reels are transposed at the station so that the bit stream is no longer reversed and the SCC can process the data directly. The telemetry baseband signal was assigned to track 4, the center track on a seven-track tape transport, so that it is not necessary to change patching setups when the reels are transposed. The operation of sending spacecraft tape recorder data to the control center by means of the data lines has been infrequently used because there have been few instances when the normal waiting period for tape recorded data is inadequate.

TESTING

Compatibility Testing

A compatibility test was performed on the spacecraft by GSFC to provide the GSFC Tracking and Data Systems Directorate experience with the spacecraft under controlled conditions. The tests were selected from a general set of compatibility tests to test the interface between the spacecraft and STADAN tracking, telemetry, and command capabilities and limitations. A second purpose was to provide project personnel with a degree of familiarity with STADAN equipment and operational procedures. The tests were performed in late January and early February 1969 by the GSFC Network Assurance Group, which provided a test van containing equipment similar to the equipment found in a STADAN station. The flight model spacecraft was located in a clean area in the Models Preparation Building at Lewis. The van was located outside the building and connections were made to the spacecraft antenna ports with coaxial cable. A total of 72 tests were performed on the spacecraft. Detailed descriptions of the test can be found in a Goddard internal report (Compatibility Test Report, SERT II, Flight Model, Feb. 1969). Two spacecraft anomalies were discovered as a result of the tests. One flight telemetry transmitter exhibited excessive phase instability, and another transmitter exhibited low output power and spurious emissions. The first problem was solved by replacing the transmitter with another unit. The second problem was solved by replacing the output cable with a new cable of the proper length to match the transmitter to the antenna system.

During the compatibility test, a magnetic tape recording of the telemetry baseband signal was made for use by the GSFC Network Test Facility in determining the station equipment configuration, for use by the stations in familiarizing their personnel with the SERT II signals, and for prepass checkout of the stations with SCC.

Station Threshold Tests

Each of the prime stations was required to use a duplicate of the tape made during the compatibility test in order to determine the threshold level of the SERT II signals. The tape was used to modulate a radiofrequency signal generator. The output of the generator was then attenuated and fed to one of the station receiving systems; and the threshold levels for phase lock, real-time data, and command verify were measured. The stations reported threshold levels which were better than the minimum expected ("SERT II Tape Exercise No. 816A," Final Report, NASA-GSFC Network Assurance Section Support Document, Jan. 20, 1970). The stations then repeated the radiofrequency setup and fed the composite signal to SCC via NASCOM. The results of these composite signal tests are shown in table III. The lowest predicted threshold level for IRIG 2 and IRIG 7 was -127 dBm, and the worst measured threshold in these channels was 1 decibel less than was predicted. The average IRIG 3 threshold was 4 decibels below the IRIG 2 and IRIG 7 thresholds due to the attenuation of the dual-section filter.

SUMMARY OF PERFORMANCE

Following each pass over a station, a pass summary is compiled by the station and transmitted by teletype to the Goddard Space Flight Center (GSFC) and to the Spacecraft Control Center (SCC) at Lewis. GSFC has compiled the results of these data which show that in the period from launch (February 4, 1970) through June 22, 1970, STADAN and NASCOM have supported 1568 SERT II passes. These passes have produced over 543 hours of data. During 1278 of these passes, 2873 commands were scheduled. On three of these commands, which were properly transmitted, verified and executed, the planned spacecraft function was not performed. No reason has been found for these failures, and the commands did function properly when they were retransmitted. Thirty-four commands had to be retransmitted due to improper verify signals at SCC. These improper signal verifications were due to auroral scintillation interference with the radiofrequency link, noisy high-frequency communication links, and SCC equipment failures. Of the 543 hours of data, less than 3 percent of the data has been unusable due to ground equipment malfunctions, prediction errors, and propagation problems.

Lewis Research Center,
National Aeronautics and Space Administration,
Cleveland, Ohio, September 29, 1970,
704-00.

TABLE I. - POWER BUDGET FOR TELEMETRY

Parameter	Value at maximum range
Total transmitter power, dBm	25
Maximum antenna gain, dB	6
Propagation losses, dB	-144
Receiving antenna gain, dB	19
Passive element losses, dB	-1
Total received signal power, dBm	-95
Power in IRIG 7 sideband, dB	-10
Antenna null, dB	-12
Expected minimum signal, dBm	-117

TABLE II. - POWER BUDGET FOR COMMAND

Parameter	Value at maximum range
Total effective radiated power (ERP), dBm	63
Propagation losses, dB	-145
Receiving antenna gain, dB	6
Total received signal power, dBm	-76
Expected null depth, dB	-16
Cross-polarization losses, dB	-3
Expected null level, dBm	-95
Command receiver threshold, dBm	-101
Signal margin, dB	6

TABLE III. - MEASURED THRESHOLD LEVELS

Station	IRIG channel			
	1	2	3	7
	Threshold level, dBm			
Rosman	-129	-128	-125	-128
Fairbanks	-128	-126	-120	-127
Winkfield	-125	-129	-125	-127
Orroral	-125	-128	-120	-126
Average	-127	-128	-123	-127

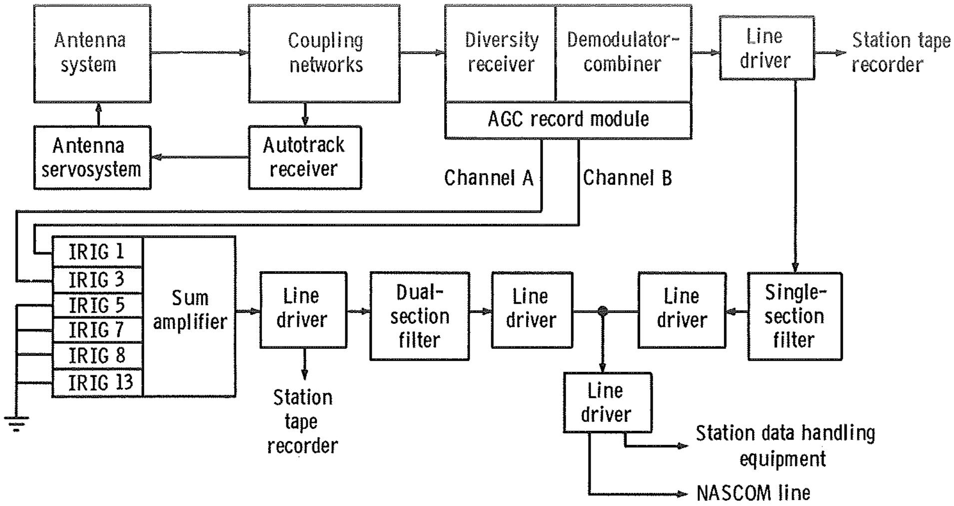

Figure 1. - Block diagram - STADAN telemetry equipment for SERT II.

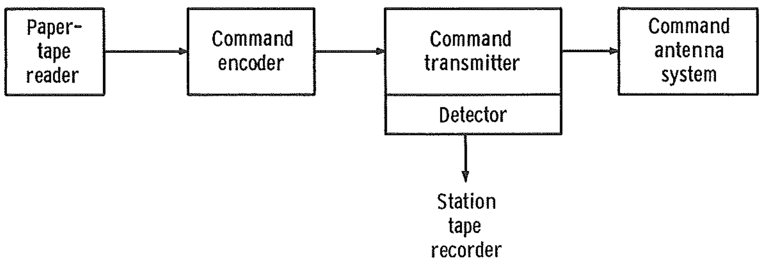

Figure 2. - Block diagram - STADAN command equipment for SERT II.

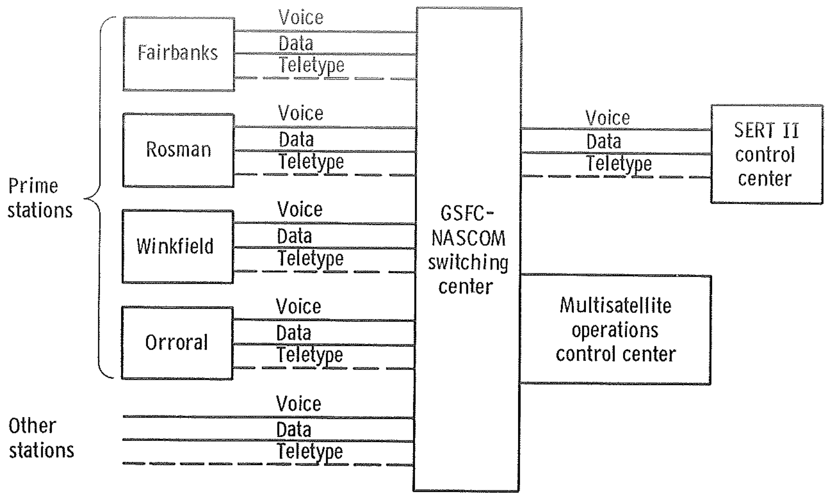

Figure 3. - Block diagram - SERT II-NASCOM lines.

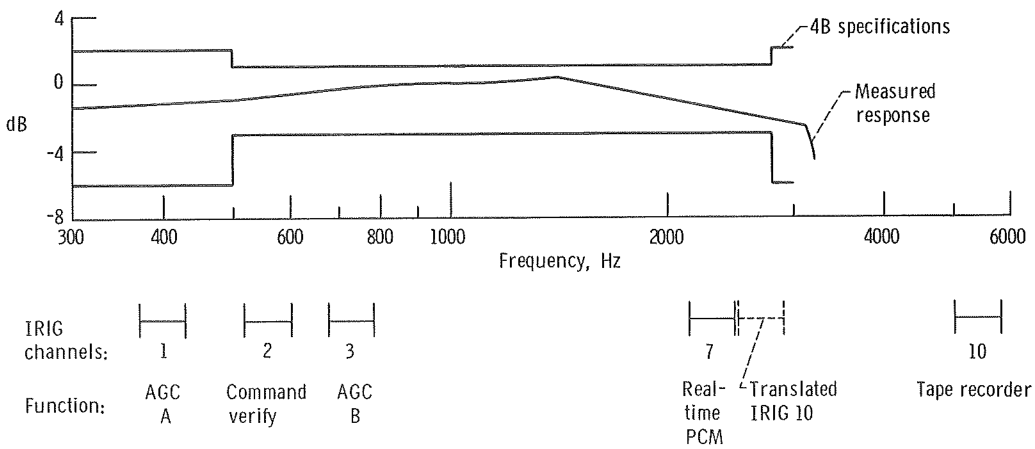

Figure 4. - Line response.

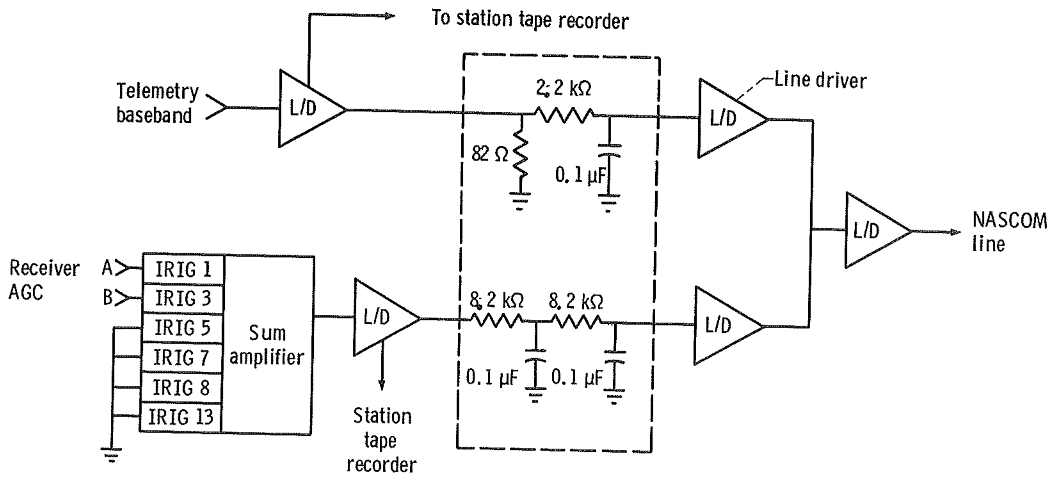

Figure 5. - Composite signal generation.

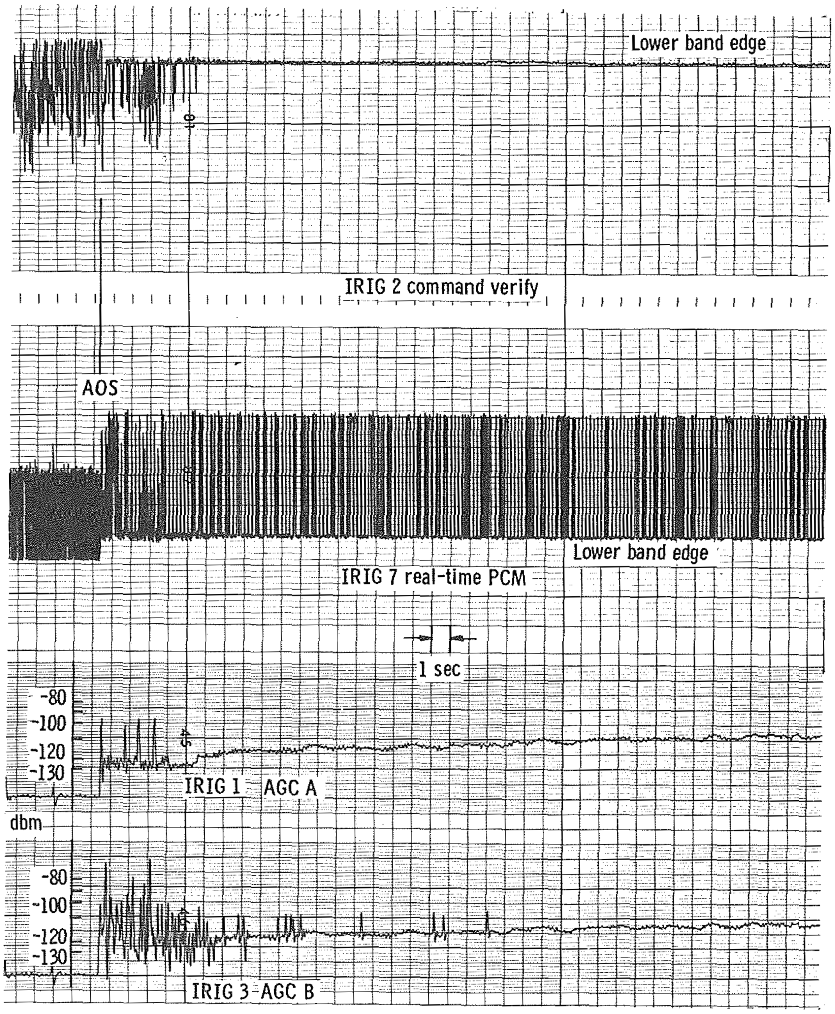

Figure 6. - Composite signal strip chart after acquisition of signal (AOS).

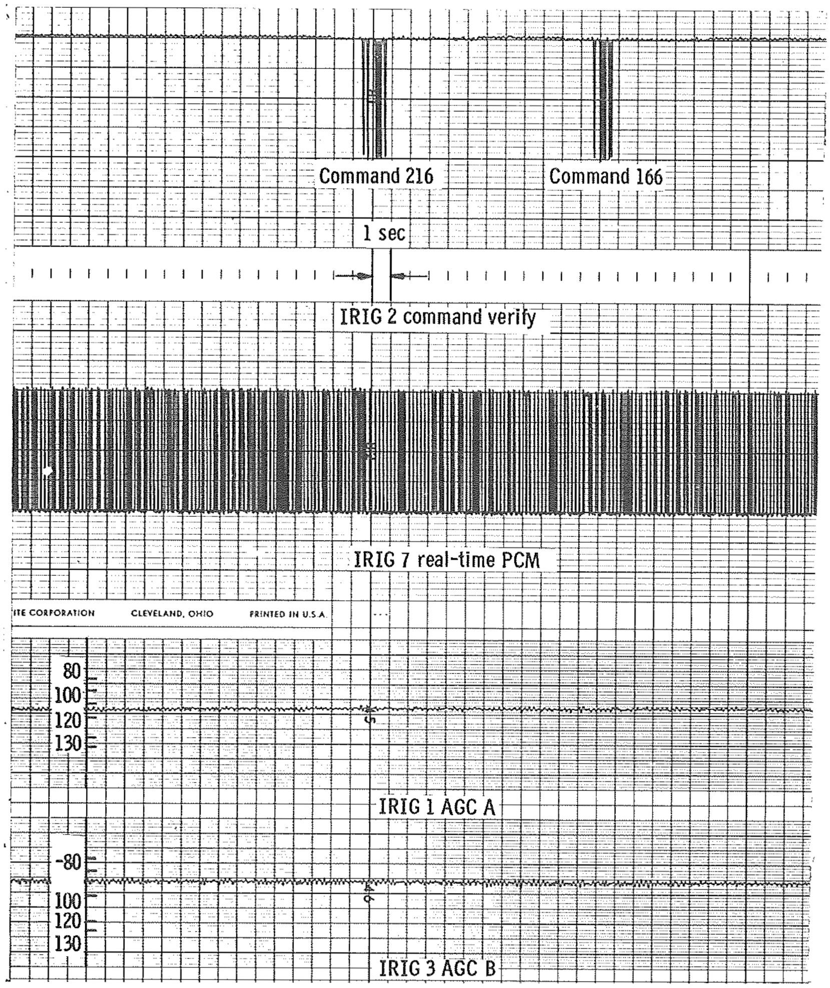

Figure 7. - Composite signal strip chart during command period.

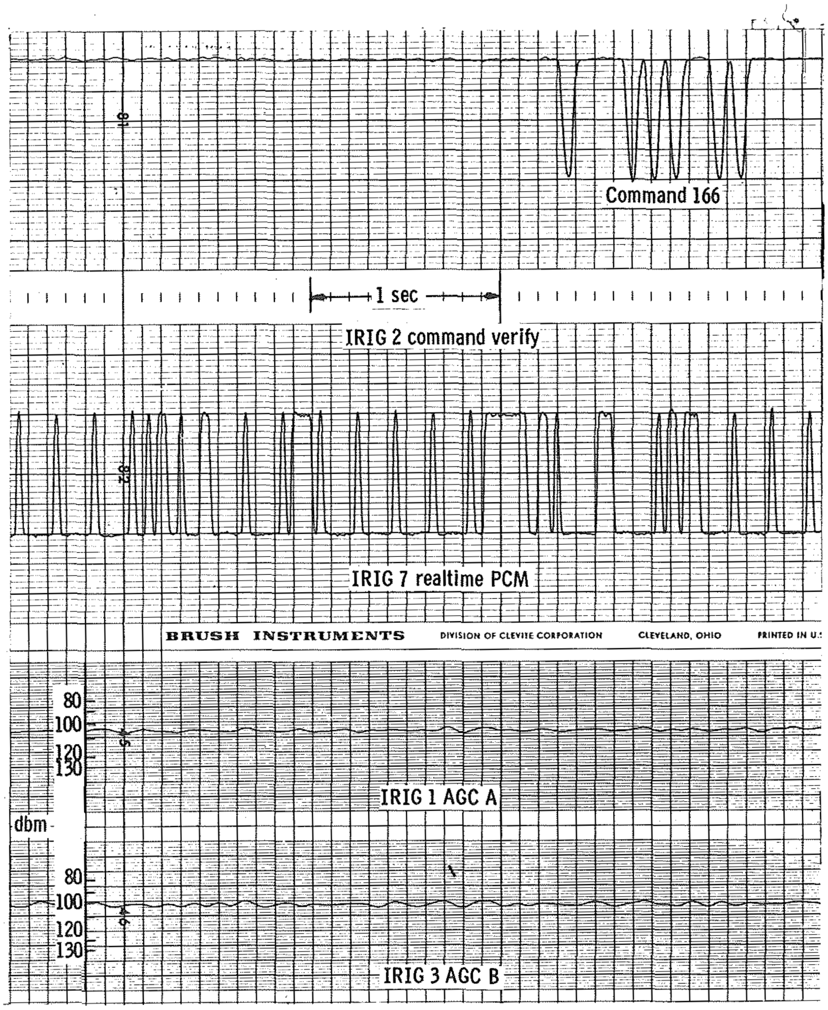

Figure 8. - High-speed composite signal strip chart.

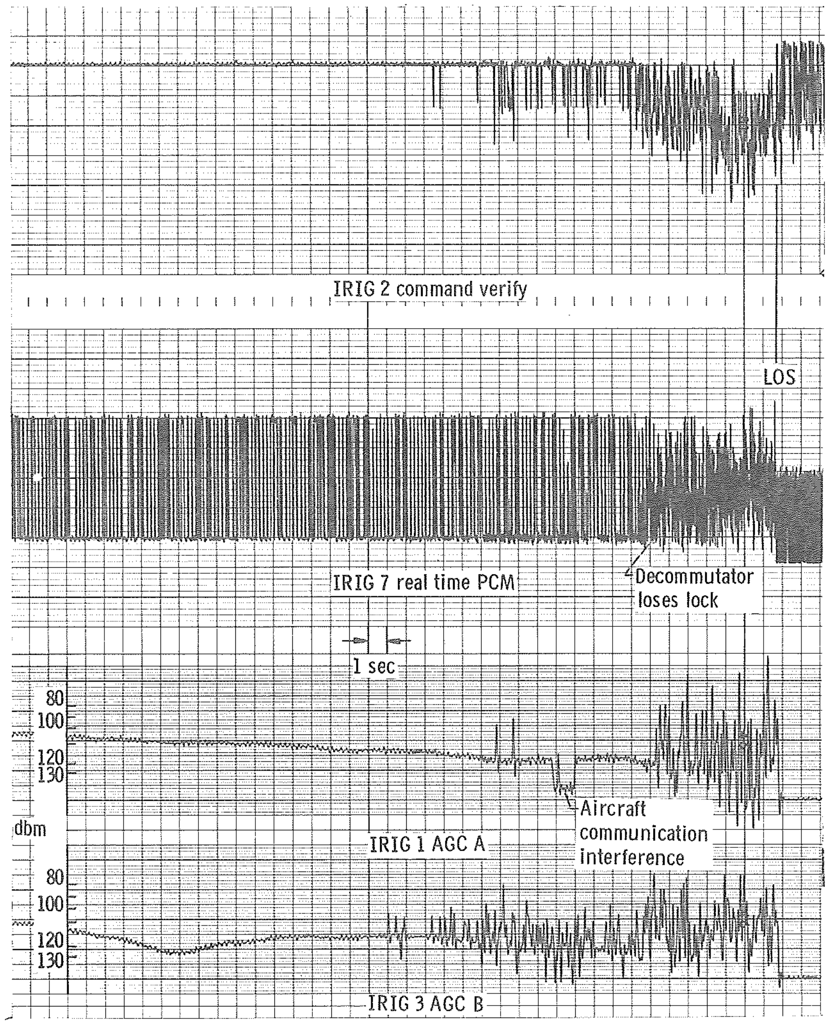

Figure 9. - Composite signal strip chart before loss of signal (LOS).

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— NATIONAL AERONAUTICS AND SPACE ACT OF 1958

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