Communication and Sciences Engineering

19p

RELAY I,

A COMMUNICATION SATELLITE

X64 10200

(NASA TMX-51052)

Code 2A

NASA. Goddard Space Flight Center, Greenbelt, Md.

double code

6021307

by:

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- Submitted for Publication

Note: Figure 7 is not available at this time.
RHPickard

Introduction

RELAY I was launched into a nearly nominal orbit at 2330 GMT, 13 December 1962. As of Orbit 1477 on 21 June 1963, 172 hours of communications have been accumulated. During this time 378 operations have been conducted. These were divided into 1245 experiments and demonstrations of engineering and public interest.

This paper provides a general description of the subsystems of the spacecraft and their performance.

Wideband Communication Equipment

The purpose of this system is to provide an experimental repeater suitable for transmission of one TV signal (plus its sound channel) or 600 one-way voice channels; or of high-speed data, facsimile, or teletype traffic with bandwidths of up to 4 megacycles. Two-way transmission tests through the repeater can be made, using 12 channels in each direction. (This number is determined by the available ground-station equipment, rather than a limitation of the satellite repeater, which can handle several times this number.)

Two completely independent wideband repeaters (except for the common antenna) are provided for increased reliability. Either one may be selected for operation by ground command.

The basic performance requirements of the satellite repeaters are similar to those used for conventional ground-based microwave links, so far as power output, bandwidth, gain, noise figure, and intermodulation are concerned. There are radical differences, however, in the size, weight, and power drain.

Biography

Robert H. Pickard

B.E.E.	George Washington University - 1954 Worked in Radar Techniques Group
1954-1956	Naval Research Laboratory, Washington, D. C.
1956-1959	Naval Research Laboratory and National Aeronautics and Space Administration, Head of Range Safety and Tracking Group, Project VANGUARD
1960-Present	Project RELAY Spacecraft Manager Goddard Space Flight Center

Sidney Metzger

B.S. in E.E.	New York University - 1937
M.E.E.	Polytechnic Institute of Brooklyn - 1950
1939-1945	Signal Corps Laboratories - Worked on Radio Communication Equipment
1945-1954	International Telephone & Telegraph Laboratories, Division Head in charge of military and commercial multiplex microwave links
1954-1963	Radio Corporation of America, Astro-Electronics Division - In charge of communications engineering; responsible for communications equipment for satellite projects SCORE, TIROS, and RELAY.
1963-Present	Manager of Components Development and Systems Research, Communications Satellite Corporation

Fellow I.E.E.E.; Associate Fellow A.I.A.A.; Chairman of Communications Committee - A.I.A.A.

LIST OF ILLUSTRATIONS

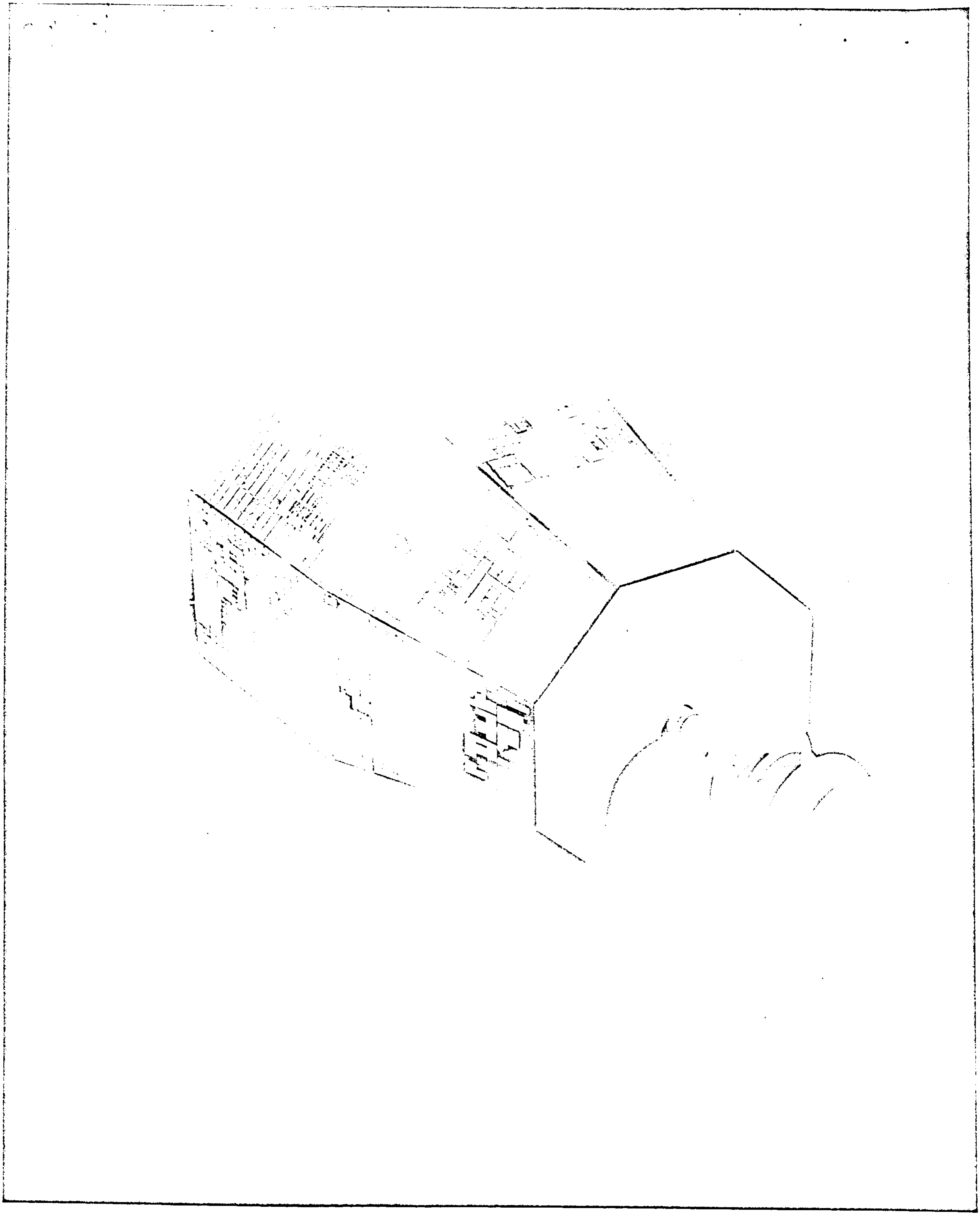

Figure 1 The RELAY Spacecraft

The system parameters were initially chosen to meet international (CCIR) standards (for a 2500-km reference circuit) between Europe and the Unites States. The sound channel is transmitted by frequency-modulating a 4.5-mc subcarrier which is then added to the video signal, and the combination used to frequency-modulate the ground transmitter. The 10 kw klystron to be used for the ground station transmitter has a bandwidth of only 10 megacycles, requiring a frequency multiplier in the satellite so that the satellite-to-ground path will have an adequate signal-to-noise ratio.

The satellite transmitter output power of 10 watts gives a margin of at least 6 db for TV transmission over ~~the~~ a maximum slant range of 5000 nautical miles.

The receiver is completely solid state using separate crystal-controlled transistor oscillators and varactor multipliers for both the input and output oscillator sources. Incorporated in the receiver housing is microwave beacon which is used for tracking by the ground communications stations. The beacon is a completely self-contained unit with a crystal-controlled transistor oscillator and varactor multipliers. The receiver and beacon outputs are combined and fed to a traveling wave tube for amplification to 10 watts power output. The microwave beacon signal at 4080 megacycles as amplified by the traveling wave tube has a radiated power out of the antenna of more than 100 milliwatts.

This traveling wave tube has been designed for long life, light weight, and high efficiency. A solid-state DC-DC converter is used to raise the 22.5 volts regulated input to the high voltages needed by the traveling wave tube.

The microwave antenna receives at 1725 Mc and transmits at 4170 Mc. It is contained in one mechanical assembly, consisting of a coaxial receiving antenna above a coaxial transmitting antenna. The whole assembly is located on top of the spacecraft, coincident with the spin axis. Both antennas are circularly polarized but of opposite sense. Vertical coverage extends from 40 to 115 degrees (-1 db points).

Telemetry Tracking and Command Equipment

The telemetry, tracking and command subsystem provides three basic functions in the spacecraft:

1. A VHF CW signal, from which the Minitrack stations provide orbital data,
2. Telemetry of performance data from the communication system and the radiation experiments, and
3. A command system, which receives the commands and converts them into a desired switching function.

The telemetry transmitters can be switched on and off by means of the command system. Operationally, one of the transmitters is on continuously to provide the tracking signal. The minitrack ground stations utilize this signal to track the satellite and provide orbital measurements.

The alternate transmitter is commanded ON when telemetry or horizon scanner data is desired. A modulation switch selects the transmitters to be modulated and the source of modulation (telemetry encoder or horizon scanner subcarrier oscillator). This switch is under the control of the command system.

The transmitters are crystal controlled, solid state, and are phase shift keyed by the modulating signals.

In the event of a failure of one transmitter the other would provide both tracking and telemetry signals.

The command system consists of a redundant set of command receivers, subcarrier demodulators and decoders. A pulse modulated subcarrier is transmitted via a VHF carrier to the command receivers which demodulate the carrier and send the subcarrier to the subcarrier demodulators where the pulse code is reconstituted. The code output is then fed to both decoders through a cross coupling network in such a fashion that either demodulator can activate either decoder. Thus, in the event of failure of receiver No. 1, subcarrier demodulator No. 1, and decoder No. 2 the command system will still function. The decoder uses a magnetic core shift register to transform the pulse code into a command signal. The command signals from the two decoders are "paralleled" so that either or both decoders can activate the control function.

The VHF antenna consists of four monopoles extending out from the separation ring face of the spacecraft. For command reception the antennas are fed in phase to produce dipole like pattern. For telemetry

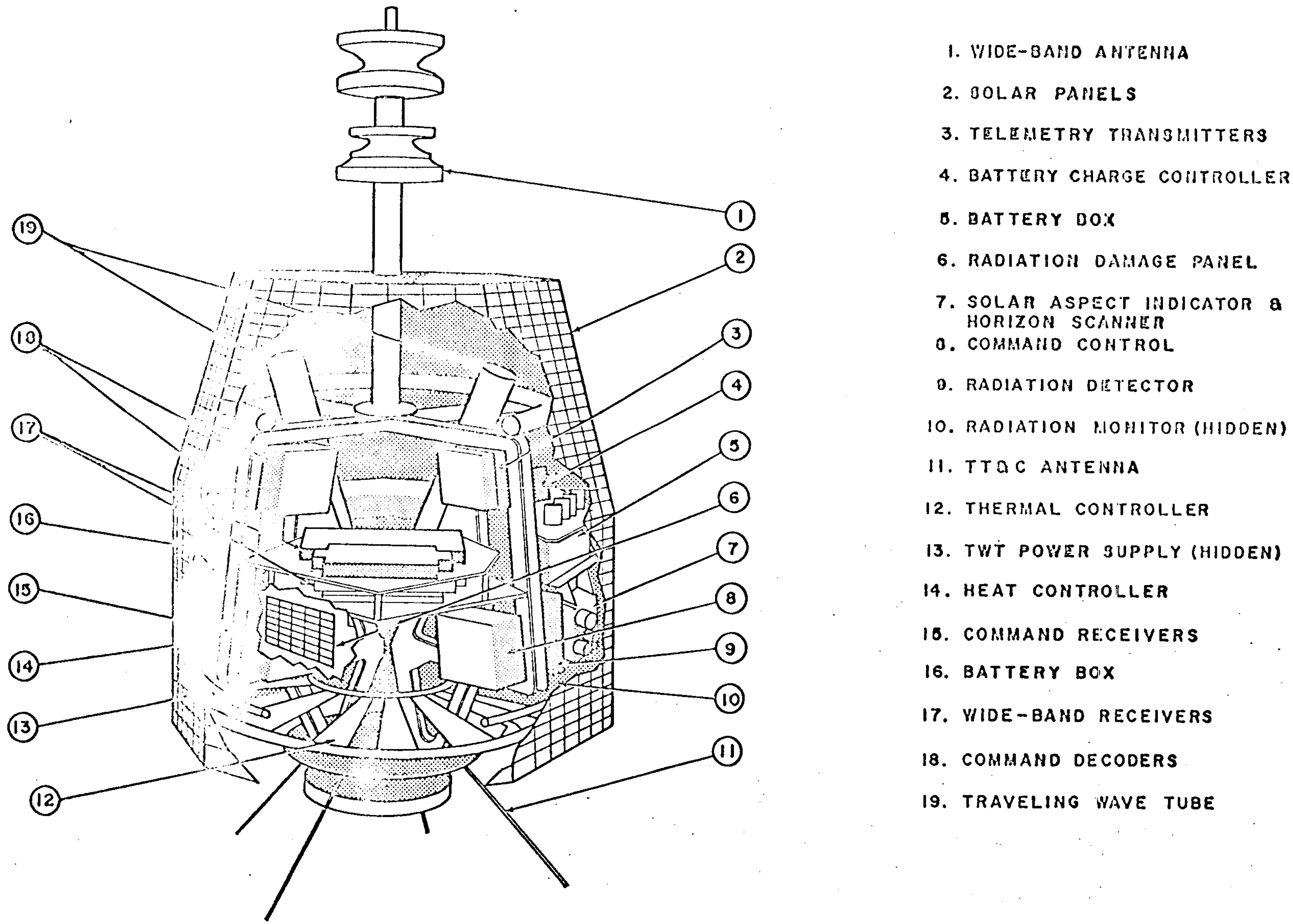

Figure 2 Cutaway Drawing of the RELAY Spacecraft

and tracking transmission the monopoles are fed in phase quadrature to produce a circularly polarized wave in the plane perpendicular to the spin axis. A diplexer harness is used to couple the two receivers and two transmitters to the antennas.

Power Supply Subsystem

The power supply consists of a solar cell array, hermetically sealed nickel cadmium storage batteries, and charge controlling electronics. The solar cells are boron-doped silicon cells, P on N, gridded and covered with 60 mil thick fused silica sheets. Under typical operating conditions the array is capable of generating an average power of 40 watts. Battery capacity is 9 ampere-hours.

Structure

The envelope of the spacecraft was dictated by the launch vehicle low drag fairing. This has resulted in an eight sided ~~cylinder~~ prism with a maximum diameter of 29 inches and a height of 19 inches, topped by an eight sided truncated pyramid 16 inches high. A cutaway drawing is shown in Figure 2. The structure is fabricated of riveted sections of light weight aluminum channels. ~~The total structure weight is 18.8 pounds.~~ The panels for support of the solar cells are epoxy-bonded, aluminum honeycomb construction.

Radiation Experiment

In addition to the communications repeaters, and other subsystems

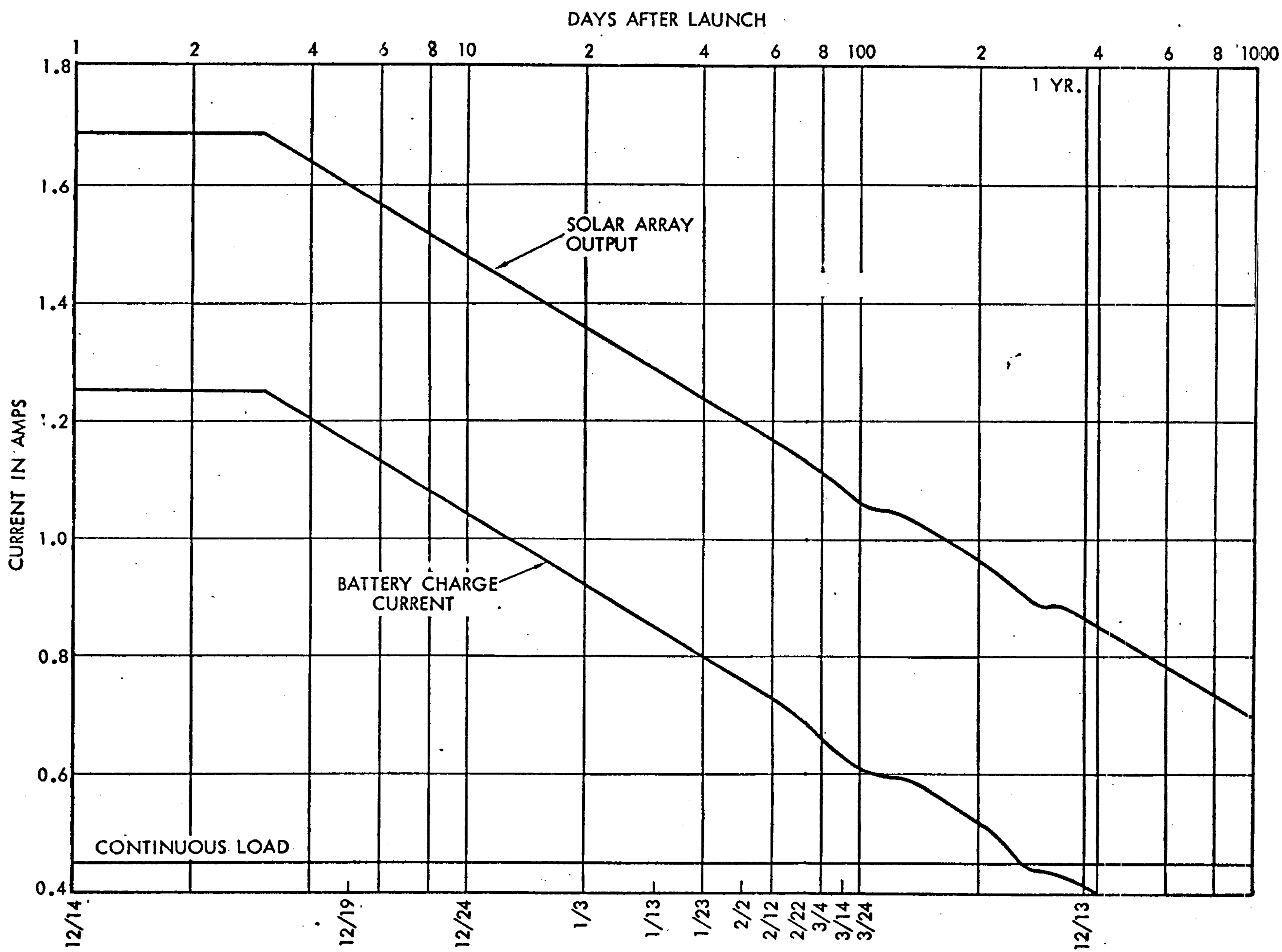

Figure 3 Solar Array Current vs. Time in Orbit

needed to support the principal mission of Relay, the spacecraft carries a group of components to obtain data on particle radiation in space. These ~~comprise~~ consist of six radiation detectors, and a collection of isolated solar cells and semiconductor diodes. The latter are accumulated on a "radiation damage effects" panel.

The radiation detectors are included to monitor the proton and electron spectra by measuring the flux density in various domains of intensity levels. Two of them are scintillation counters, four are PN junctions. One of the detectors is omnidirectional; the others are restricted to a small solid angle and are gated by an on-board magnetometer to measure only that flux normal to the earth's magnetic field. Accumulators in the telemetry encoder count and store the detectors' outputs. One hundred of the 128 telemetry channels are reserved for high-speed measurements of the outputs of the short-circuited cells. Thirty specially selected solar cells make up the radiation damage panel. The effects of radiation are observed by measuring short circuit current. The radiation damage panel contains in addition to the solar cells, six selected diodes, which are used to measure minority-carrier lifetime as affected by radiation.

Power Subsystem Performance

The variation of solar cell array current (and the corresponding battery charge current) vs. time in orbit is shown in Figure 3. It is seen that the output will be down to half its initial value about one year after launch. The 2 dips in the curves are due to passage of the satellite through eclipse. The effect of this decrease in output power of the solar cells due to radiation will be to decrease the permissable daily operating of the communication experiment. Figure 3 also shows that after one year of orbital lifetime, the solar array will be able to support some wideband operation. It is difficult to predict at this time what the duration of operation might be. Barring any major catastrophe, the functioning of the one year timer will in all probability terminate the life of the spacecraft.

Battery performance was normal until Orbit 548 at which time it was noted that one of the three batteries could not be charged. Subsequent failure analysis has indicated a malfunctioning charge controller. The spacecraft has been operating on two batteries since then. These two battery packs are capable of supplying power for up to 100 minutes of wideband operation per day. The specification for operation is 120 minutes with a full battery complement. It is evident that this failure has not seriously hampered experimental operations.

Spacecraft Temperature

The temperature of the spacecraft is a function of available sunlight and the degree of battery overcharge that is permitted. When the batteries are subjected to extended overcharge, the electrical energy supplied by the solar array will be dissipated as heat since chemical conversion is not possible once a fully charged state is reached.

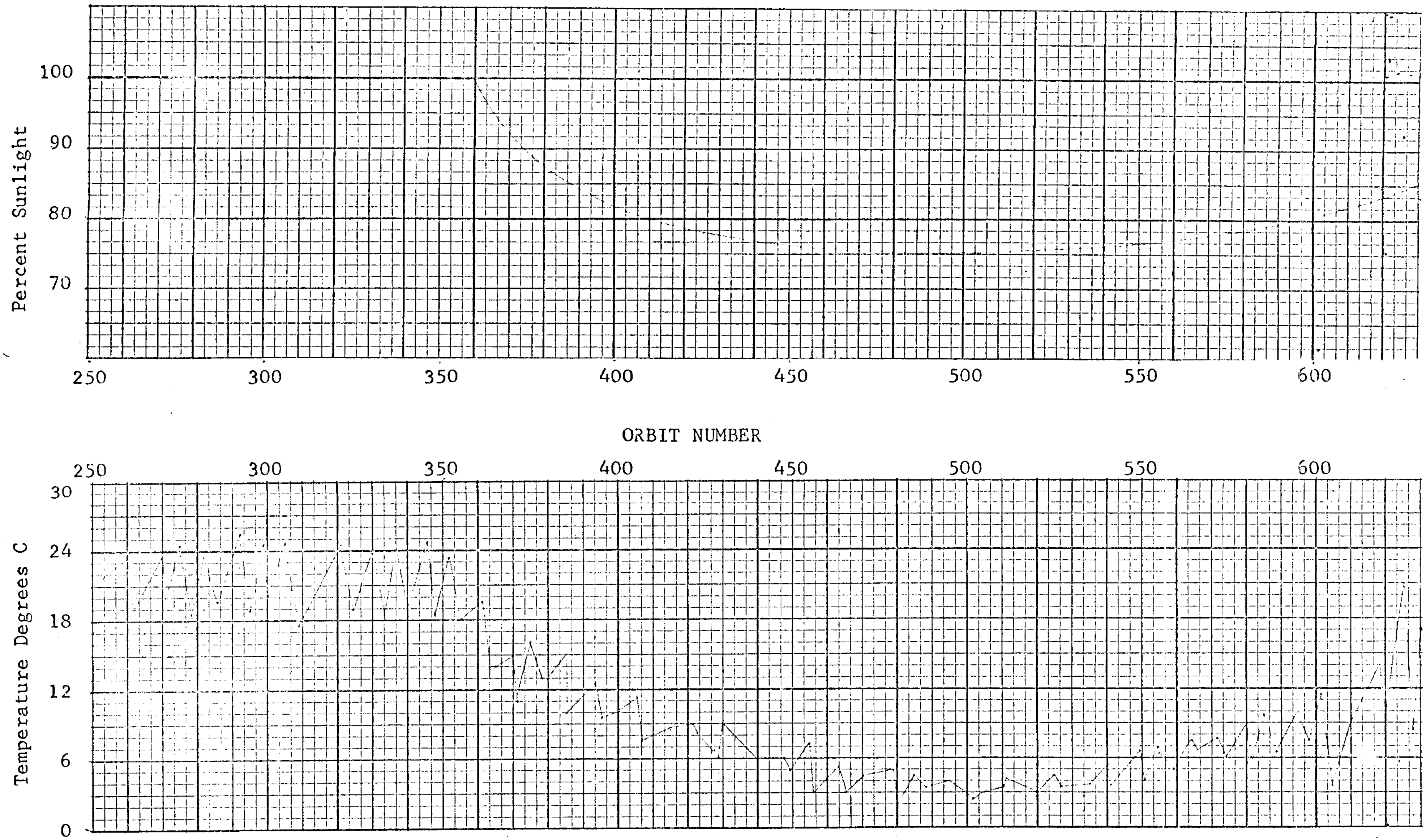

Figure 4 Temperature and Percent Sunlight vs. Orbit Number

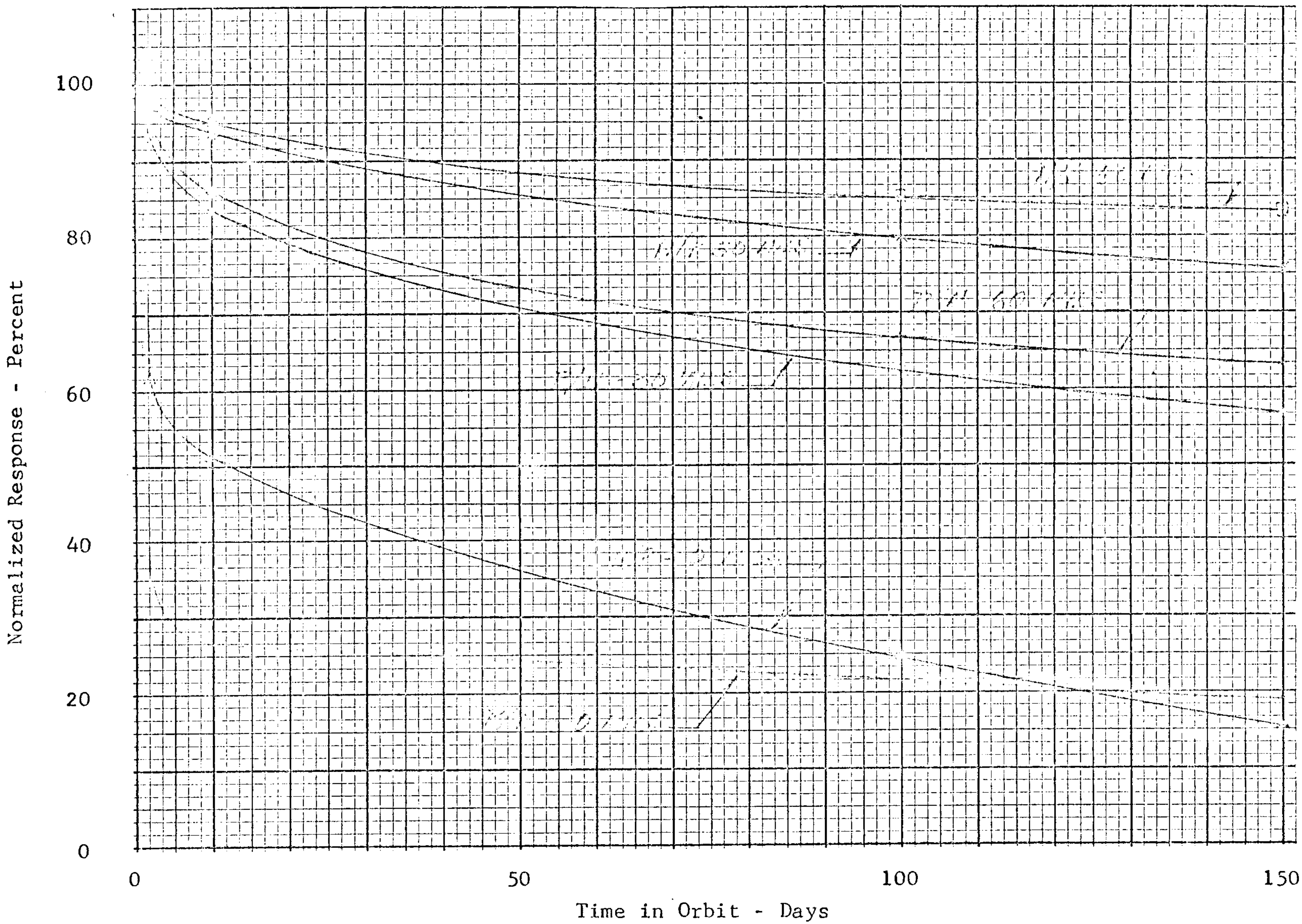

Figure 5 Results of Radiation Damage Experiment

(Courtesy of Dr. R. C. Waddel, GSFC)

Examination of Figure 4 reveals the dependence of the average temperature on total time in sunlight. The fine grain variations in temperature are due to variations in the charge state of the battery pack.

Radiation Experiment Results

Present data from the radiation damage experiment is consistent with a flux of about 5×10^{14} electrons/cm^2-day (1 MEV equivalent). Figure 5 summarizes the output of the solar cell experiment. The present output for these cells after 150 days in orbit are:

N-P 60 mil shield	83%
N-P 30 mil shield	76%
P-N 60 mil shield	64%
P-N 30 mil shield	57%
N-P 0 mil shield	15%
P-N 0 mil shield	19%

Transmission Tests

Various system performance experiments have been devised as objective tests to obtain quantitative and statistical data on the electrical parameters of the system by analyzing its response to carefully controlled excitations such as sine squared pulses and white noise. From the resulting data, it is possible to determine the performance degradation during the communications lifetime of the spacecraft with particular emphasis on applying failure mode information to future designs.

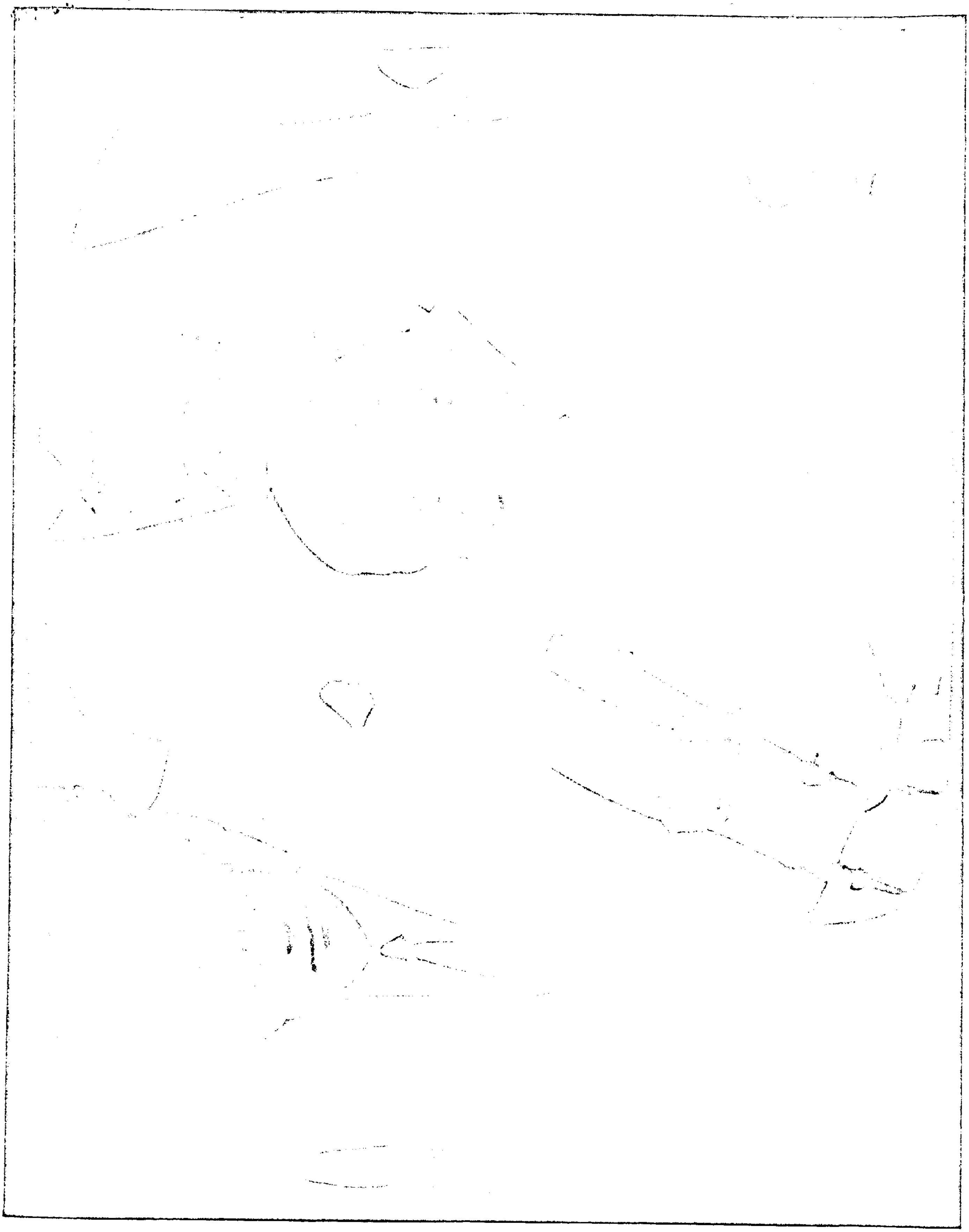

Figure 6 Monitor at Goonhilly Downs, England Transmission from Andover, Maine

System demonstration experiments emphasize quality television and telephony. They also include a variety of other data forms including high bit rate digital data, facsimile, telephoto, and multichannel teleprinter transmissions. The intent of these experiments is not only to demonstrate a system transmission capability for a variety of signals, but also to provide experimental data on the engineering aspects of these transmission forms.

A large number of television test patterns and picture material have been transmitted through the RELAY system. Multiburst signals, EIA test patterns, bar and window patterns, and typical picture material all show excellent quality. Figure 6 is a photograph of a monitor at Goonhilly Downs, England showing picture material transmitted from the United States via the Andover, Maine Ground Station.

A number of measurements of field, line and short time distortions at Nutley, New Jersey and Goonhilly, England have verified that the system objectives have been met. Line time photographs (Figure 7) show that over-shoot, ringing, and tilt are within system objectives. The ringing is at a rate determined by a sharp cutoff 3.2 mc low pass filter in the ground equipment which is used to remove the sound channel.

Multiple channel twoway telephone have been transmitted between U. S. and Brazil, U. S. and Europe and Europe and Brazil. In one experiment between U. S. and Europe, a two-way telephone call was looped back and forth between the two stations several times until a time delay was accumulated equal to that which would be present in a synchronous communication satellite.

Results of tracking the spacecraft with large diameter narrow beam-width antennas have been highly encouraging. The Goonhilly station reports that prediction data, provided at one week intervals by NASA, has been sufficiently accurate to permit programmed steering of the 85 foot diameter antenna.

The communication experience with RELAY to date, has generally been quite satisfactory. The capacity of experimental data forms has precluded a thorough evaluation of the system. However, data on linear and non-linear distortion indicates the system meets the objectives. Thermal noise is essentially as predicted except for ~~in~~ a few instances. Direct measurements of intermodulation noise are above objectives but the differential time delays are in compliance with the requirements. Television transmission between the better ground stations is of excellent quality.

Acknowledgement

The authors wish to acknowledge the cooperation of Dr. Raymond Waddel, Project Scientist for Radiation Experiment in supplying the test results presented herein.