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Cosmic-Ray Instrumentation in the First U. S. Earth Satellite*

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The first U. S. satellite, 1958 Alpha (Explorer I) carried instrumentation to measure cosmic-ray intensity, micro-meteorite impacts, and temperatures within the satellite. The instrumentation was designed with emphasis on conservation of electrical power, on stable and reliable operation, on operation over a wide range of temperatures, and on compactness and mechanical ruggedness.

The cosmic-ray instrumentation in 1958 Alpha operated according to expectations, providing several hundred recordings of data received during transits over ground stations. These data led to the discovery of a belt of high-intensity radiation around the earth.

1. INTRODUCTION

THIS paper describes the instrumentation carried by the first U. S. earth satellite, 1958 Alpha (popularly designated Explorer I), which was launched from the Cape Canaveral missile test center at 0348 U.T. on February 1, 1958.

It is believed that the instrumentation developed for this satellite for the purpose of measuring the total omnidirectional radiation flux^{1,2} was unique in several respects. It had exceptionally low power requirements in spite of the fact that its operation was stable over wide ranges of temperature and power supply voltage. In addition, it was physically compact and mechanically rugged.

2. DESCRIPTION OF COMPLETE SYSTEM

The 1958 Alpha instrumentation utilized two completely independent transmitters. The redundancy was intended to give the maximum possible assurance that the satellite could be acquired and tracked after its launching. Amplitude modulation was used on the higher powered transmitter while small deviation phase modulation was utilized on the lower powered transmitter, in order that compatibility with both the "minitrack" and "microlock" ground receiving and tracking systems would be assured.

* Assisted by U.S./I.G.Y. Project 32.1 of the National Academy of Sciences and the National Science Foundation.

¹ J. A. Van Allen, *Scientific Uses of Earth Satellites* (University of Michigan Press, Ann Arbor, 1956), Ch. 20, pp. 171-187.

² G. H. Ludwig and J. A. Van Allen, *J. Astronautics* 3, 59 (1956).

As can be seen in Fig. 1, the phase modulated transmitter radiated at a frequency of 108.000 Mc/sec, utilizing a linearly polarized asymmetrical dipole antenna. The cylindrical shell surrounding the instruments and the cone at the front of the payload were driven as the active elements of this antenna through a matching network in the insulating gap at their junction. The radiated power from this transmitter and antenna was approximately 10 mw with a design life expectancy of two to three months.

The amplitude modulated transmitter, radiating at a frequency of 108.030 Mc/sec, utilized a circularly polarized turnstile antenna. This antenna consisted of four flexible whips equally spaced about the circumference of the insulator located at the juncture of the instrumentation section and the fourth stage rocket casing, which was a permanent part of the satellite. This "high-power" transmitter operated with an output power of approximately 60 mw and contained batteries sufficient for a life of about two weeks.

Each of the transmitters was modulated by the summed outputs of sets of four audio-frequency subcarrier oscillators. These oscillators were, in turn, frequency modulated by their respective inputs over a range of plus and minus 7½% of the band center frequencies. Numbers two through five of the standard RDB telemetry channels were used in each set of oscillators.

Channels two (560-cps center frequency) for both systems telemetered the resistance of temperature sensing

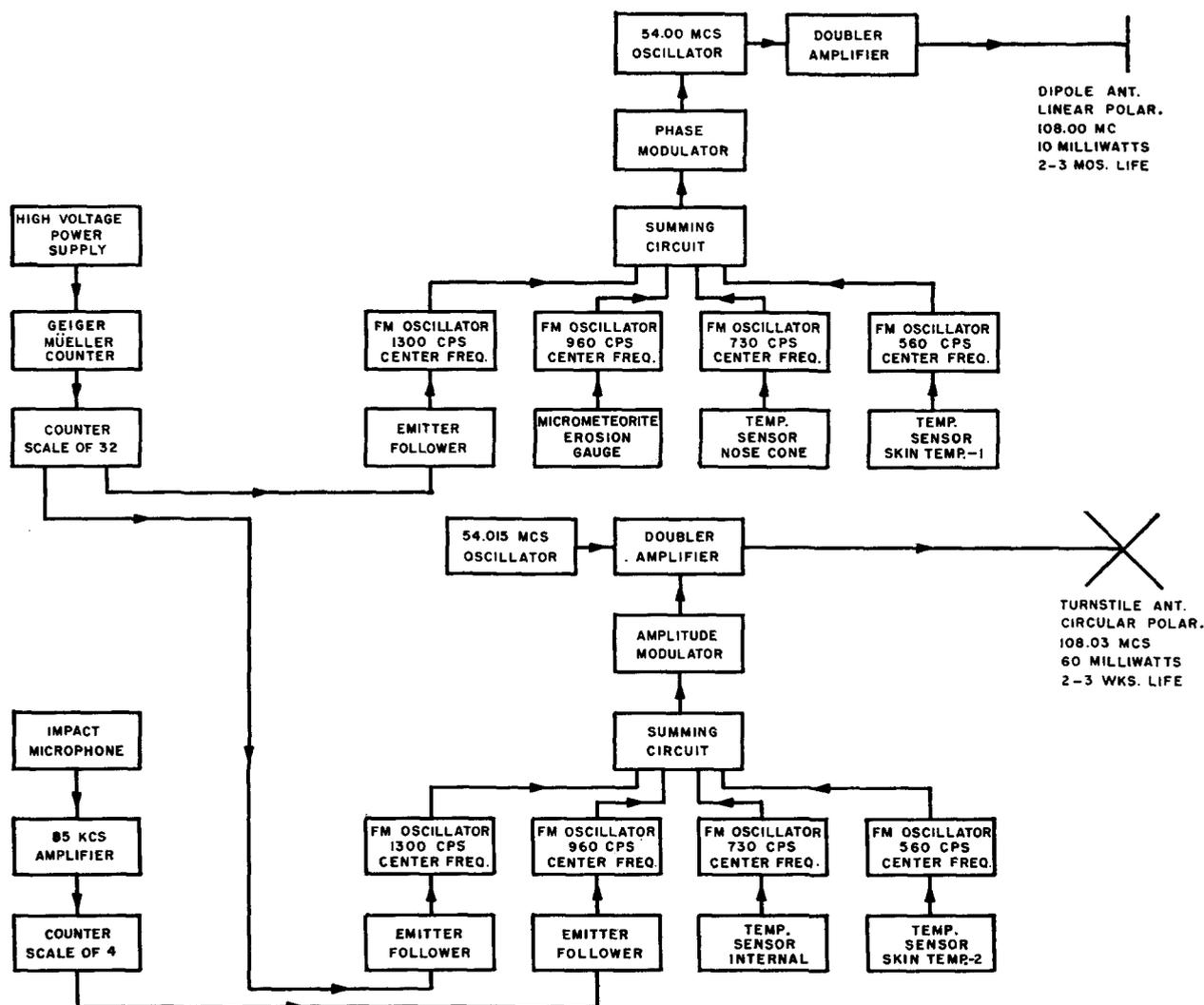


FIG. 1. Satellite 1958 Alpha block diagram.

thermistors located in thermal contact with the satellite shell. The thermistor which was a part of the low-power system was in contact with the aft end of the front cone, while thermistor number two on the high-power system telemetered the temperature of the aft end of the cylindrical shell surrounding the instruments. Channels three (730 cps center frequency) on both systems were also used in measuring temperatures, that of the stagnation point at the cone tip on the low-power system, and of the doubler-amplifier transistor heat sink of the high-power transmitter on the high-power system.

Micrometeorite experiments utilized the two number four channels (960-cps center frequency). The sensor on the low-power system consisted of a network of twelve grids of very fine wire. The wires were wound on flat bobbins so that they completely covered areas of about one square centimeter. When a micrometeorite of size 5μ or larger impinged on one of these twelve areas, the wire of this

grid was severed, causing a discontinuous change in the resistance of the network.

The other micrometeorite detector was a microphone placed in spring contact with the cylindrical shell, so that impacts of particles on the shell were registered. The output of the microphone was amplified by a tuned amplifier, and the individual impacts were counted by a binary scale of four. The state of the output stage of this scaler was telemetered over the high-power system.

The two number five channels (1300-cps center frequency) telemetered simultaneously the output of the scaler used to count the ionizing events in the Geiger-Müller counter of the cosmic-ray experiment.

Electrical power for all electronic circuits was obtained from batteries of Mallory type RM mercury cells.

Figure 2 is a line drawing of 1958 Alpha, showing the location of the various circuits and detectors. A photograph of the completed instrument package, with the fourth-stage

rocket casing detached, and with the shell and nose cone removed is included as Fig. 3. The ornate fretwork which supported the low-power transmitter section provided mechanical support during construction and assembly of the unit, but carried no physical load after the cylindrical shell was slipped over the assembly and secured in place.

Extensive environmental testing of the components, subassemblies, and complete payloads was performed to provide reasonable assurance of survival of the launching phase and proper operation in orbit. Included were vibration, spin, shock, axial acceleration, temperature, and vacuum tests over quite wide ranges of operating conditions.

3. COSMIC-RAY INSTRUMENTATION

The purpose of the cosmic-ray instrumentation was to measure the omnidirectional intensity of cosmic rays as a function of latitude, longitude, altitude, and time.¹ The

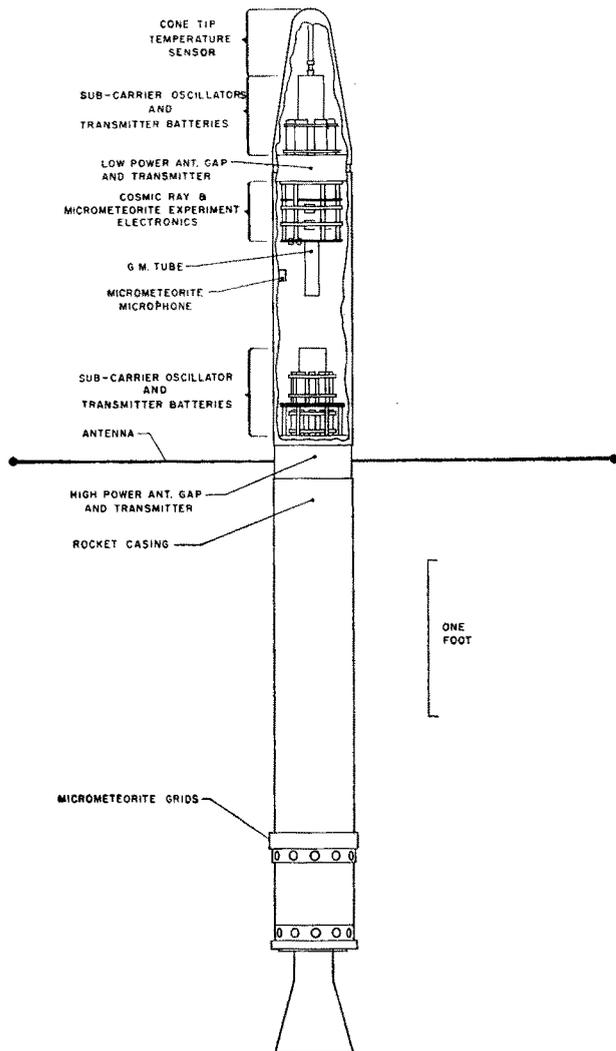


FIG. 2. Phantom drawing of 1958 Alpha.

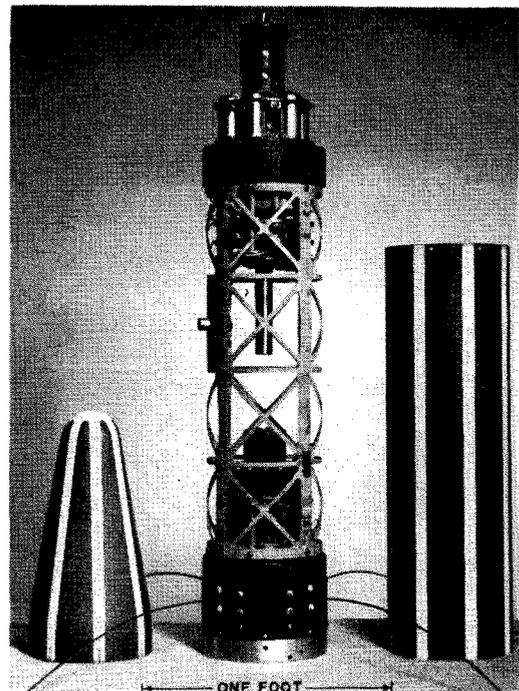


FIG. 3. Photograph of instrumentation section with shell and cone removed.

basic detector was a single Geiger-Müller tube whose counting rate was transmitted over the radio telemetering links to the ground receiving stations.

A commercially-available, thick-walled, halogen-quenched Geiger-Müller tube (Type 314 made by Anton Electronics Laboratories, Inc.) was selected because of its mechanical ruggedness, infinite life, and wide operating temperature range of -55 to 175°C . The tube operated at 700 v and had approximately 85% detection efficiency for cosmic rays.

Pulses from the G-M tube were scaled by a factor of thirty-two. The rectangular wave form appearing on the collector of one of the final scaler stage transistors frequency-modulated the two channel five subcarrier oscillators. Changes of state of this output scaler shifted the frequencies of the oscillators discontinuously between two chosen values.

A schematic diagram of the driver circuit, scalars, and output emitter followers is given in Fig. 4. Texas Instrument NPN type 2N335 silicon transistors were used in these circuits. The driver was a current amplifier stage in which the G-M tube ionizing current passed through the base-emitter junction, turning the transistor on for the duration of the pulse. Its output was a flat-bottomed negative pulse, having a rise time of less than one μsec , and an amplitude of about 2 v. This driver transistor was selected with sufficiently high forward current gain (beta) so that the input pulse caused collector saturation under all combinations of temperature and power supply voltage

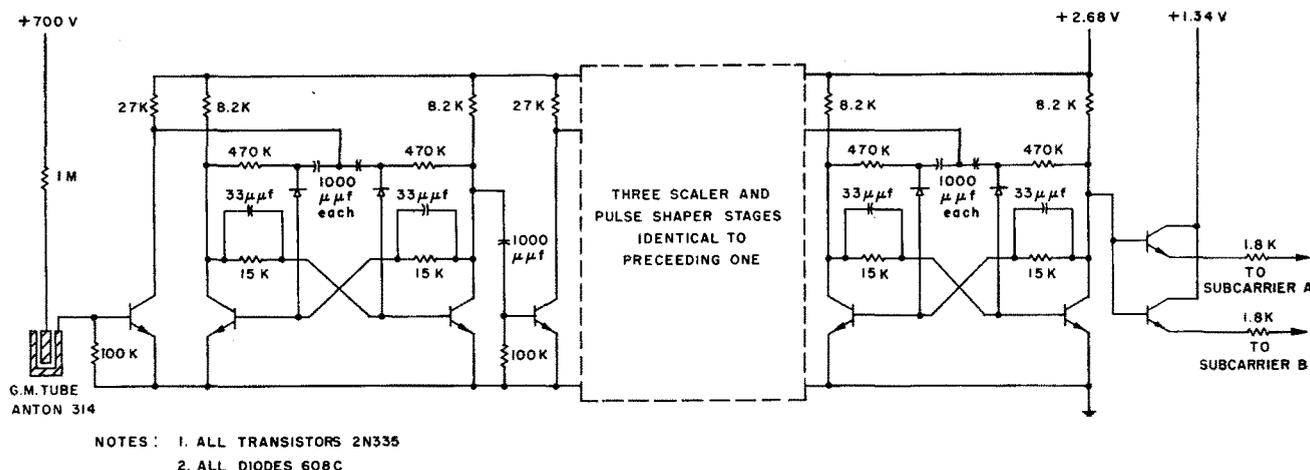


Fig. 4. Schematic diagram of pulse counting circuitry.

within the operating ranges. A beta of greater than fifty was required.

This driver pulse fed the first of the bi-stable multi-vibrator scaler stages. The scaler employed diode pulse steering and was base driven to provide high sensitivity to triggering pulses. Transistors with approximately equal beta were used in each stage. The customary base to ground resistors were omitted in order to reduce the power requirements and the number of components.

A pulse-shaping circuit was included between scaler stages, since the scaler input pulse requirements were rather critical. The rectangular collector wave form of the preceding scaler stage was differentiated and the resulting positive pulses were amplified to the point of collector saturation and inverted, providing flat bottomed negative driving pulses with short rise times for the succeeding

stage. As in the case of the driver transistor, it was sometimes necessary to select transistors (beta greater than 50) to produce saturating pulses in the low-temperature, low-power supply voltage operating condition.

The output of the final scaler stage was direct coupled to the inputs of the two channel five subcarrier oscillators by emitter-follower stages. The collector supply voltage for these stages was maintained at 1.34 v to provide regulation of the amplitude of the wave form driving the oscillators.

The specifications for the complete scale of thirty-two, including its driver stage, the pulse shaping circuits, and the output circuits were as follows:

Operating temperature	-50 to 100°C
Supply voltage	2.0 to 3.0 (2.68 nominal) v
Scaler power requirement, per stage	1.0 mw approx
Driver, shaper, and follower power requirements	essentially zero
Total power requirements	5.0 mw approx
Resolving time	250 μsec

A photograph of a circuit board containing these circuits is given in Fig. 5. This board was approximately 10 cm in diameter, 1.3 cm in thickness, and weighed 70 g.

The high-voltage power supply was developed by the Power Sources Division of the Signal Corps Engineering Laboratories, Fort Monmouth, New Jersey (SEL) to SUI specifications. It was a push-pull saturating reactor oscillator, with a transformer voltage step-up ratio of approximately 35 followed by a voltage quadrupler, and utilizing a corona discharge regulator tube for voltage regulation. Figure 6 is a schematic diagram of the supply.

Several special procedures and considerable selection of components were required to obtain high efficiency. The transistors, Raytheon silicon PNP type 2N790 (type 2N329 transistors were substituted in later supplies) were selected for low I_{co} . With the transistor in a grounded

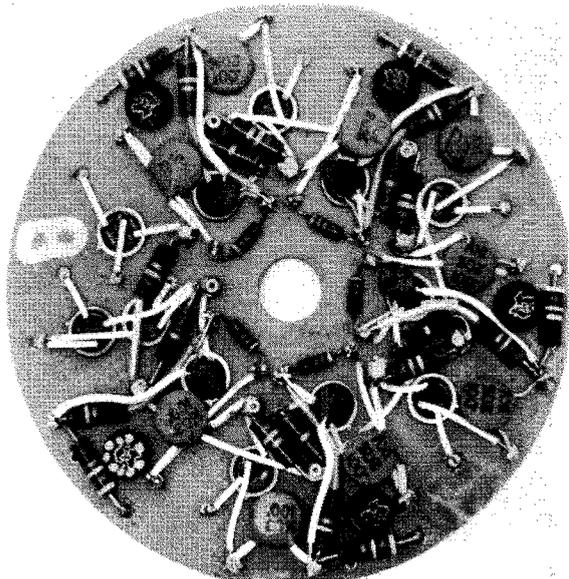


Fig. 5. Photograph of pulse counting deck.

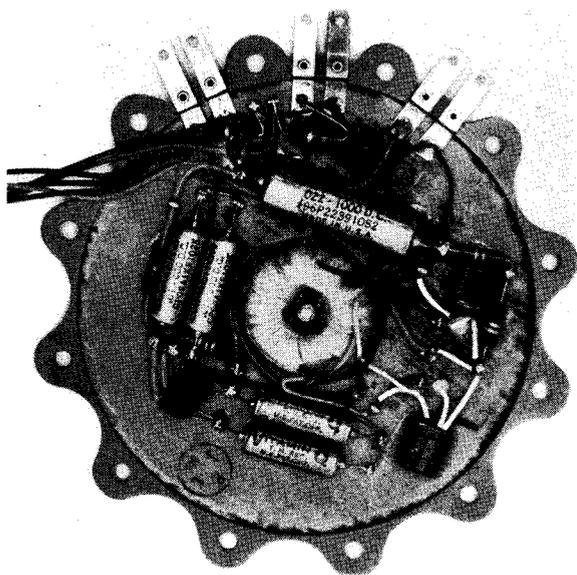


FIG. 7. Photograph of high-voltage power supply.

13 cm in diameter, was 1.6 cm in thickness, and weighed 85 g.

4. SUMMARY OF OPERATION IN ORBIT

The high-power transmitter operated satisfactorily for eleven days, until about 0000 u.t. on February 12, 1958. It subsequently returned to the air and operated sporadically until 1700 u.t. on February 26, 1958 at which time its signal disappeared completely. Excellent cosmic-ray data were obtained from this transmitter for the first eleven days. The low-power transmitter operated properly until May 9, 1958, on which date the modulation disappeared from the carrier. The carrier continued until May 14. From May 14 to June 16 the carrier reappeared sporadically. Medium quality cosmic-ray data were

TABLE I. Representative performance data for high-voltage power supply.

Temp (°C)	V_{in} (v)	I_{in} (ma)	I_{reg} (μ a)	I_{load} (μ a)	P_{in} (mw)	P_{out} (mw)	Eff. (%)
-15	4.5	1.35	0.1	1.1	6.1	0.8	13.8
	5.5	1.71	1.8	1.1	9.4	2.0	21.3
23	4.5	1.68	2.3	1.1	7.6	2.4	31.5
	5.5	2.15	4.7	1.1	11.8	4.1	34.8
65	4.5	1.97	2.9	1.1	8.9	2.8	31.4
	5.5	2.52	5.8	1.1	13.9	4.8	34.5

obtained from this transmitter from launching date until May 9 for close passes. More distant passes could not be used to obtain cosmic-ray data because of the low transmitted power. Temperature measurements were made even on distant passes, however, since extremely narrow pre- and post-detection band widths could be used to increase the signal-to-noise ratio to recover this very slowly varying information.

During the time the transmitters operated, approximately 1500 tape recordings were made of satellite passes by twenty stations. The stations were able to receive the rf carriers whenever the received signal levels were greater than about -155 dbm. Telemetry could be read from the carriers whenever the carrier levels exceeded -135 dbm. About 850 of the recorded passes contained readable cosmic-ray data.

Figure 8 is a photograph of a section of one of the charts produced in the reduction of the data. The transverse displacement of each of the four traces from their center positions is proportional to the change in frequency of the subcarrier oscillators. The top two traces indicate stationary temperatures, the third trace indicates that no outputs of the micrometeorite counter occurred in the depicted interval, and the fourth trace indicates a raw

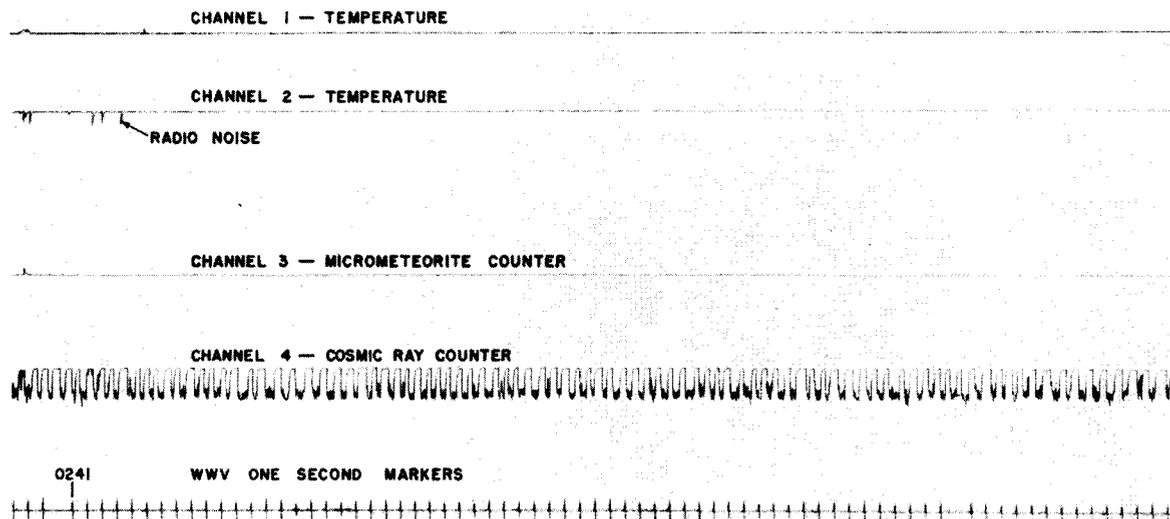


FIG. 8. Chart recording of a reduced tape recording of the high-power transmitter. Patrick Air Force Base, 0241 u. t., February 4, 1958, Satellite 1958 Alpha.

G-M tube counting rate of forty counts per second (the rate observed on the chart times thirty-two).

The cosmic-ray data from 1958 Alpha have been reduced in a preliminary manner, and led to the discovery of the high intensity radiation surrounding the earth at altitudes above 700 km.³⁻⁶ The detailed reduction of these data is continuing, and is expected to yield valuable information regarding spatial distribution and temporal variations of both the cosmic ray and the high-intensity radiation.

The micrometeorite and temperature data have been reduced by the Air Force Cambridge Research Center, Bedford, Massachusetts (AFCRC), and the Jet Propulsion Laboratory, Pasadena, California (JPL), respectively.⁷⁻⁹

³ Paper presented by J. A. Van Allen at joint meeting of National Academy of Sciences and American Physical Society on May 1, 1958.

⁴ Van Allen, Ludwig, Ray, and McIlwain "Observation of High Intensity Radiation by Satellites 1958 Alpha and Gamma," I.G.Y. Satellite Report Series No. 3: Some Preliminary Reports of Experiments in Satellites 1958 Alpha and Gamma, pp. 73-92 (National Academy of Sciences, Washington, D. C., 1958).

⁵ Also I. G. Y. Bulletin No. 13, Trans. Am. Geophys. Union **39**, 767 (1958).

⁶ Also Jet Propulsion **28**, 588 (1958).

⁷ E. Manring and M. Dubin, "Satellite micrometeorite measurements," I. G. Y. Satellite Report Series No. 3: Some Preliminary Reports of Experiments in Satellites 1958 Alpha and Gamma, pp. 25-29 (National Academy of Sciences, Washington, D. C., 1958).

⁸ E. P. Buwalda and A. R. Hibbs, "Satellite temperature measurements for 1958 Alpha-Explorer I," *Ibid.*, pp. 31-72.

⁹ Also I. G. Y. Bulletin No. 13, Trans. Am. Geophys. Union **39**, 770 (1958).

5. ACKNOWLEDGMENTS

The successful completion of a project as complex as the designing and building of an earth satellite is, of course, the result of close cooperation among the members of a large group of individuals and organizations. The payload system design was accomplished jointly by the State University of Iowa (SUI) and the Jet Propulsion Laboratory. The Air Force Cambridge Research Center designed and built the micrometeorite detectors, and the tuned microphone amplifier was furnished by Temple University in Philadelphia, Pennsylvania. The cosmic ray experiment and the micrometeorite impact scaler circuit were developed at SUI, while the temperature experiments were designed by JPL. The Signal Corps Engineering Laboratory developed the high-voltage power supply and provided the quartz crystals for the transmitters. JPL was responsible for the development of the subcarrier oscillators, transmitters and antennas, and for the assembly of the payloads.

The successful launching of the satellite was a result of the skill of the Army Ballistic Missile Agency (ABMA) at Huntsville, Alabama, and JPL, who provided the booster and high-speed stages, respectively, and conducted the launching operation.

The author is indebted to Professor J. A. Van Allen for his guidance in the accomplishment of this program.