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A Preliminary Directional Study of Cosmic Rays at High Altitude.*
I. Apparatus and Procedure

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To study the effects of secondary particles on the measurement of the primary directional intensity at high altitudes, a preliminary study has been carried out. Geiger counter telescopes at selected zenith angles from 0° to 90°, utilizing Pb filters up to 17 cm, have been sent up to 100,000 feet using constant-level Pliofilm balloons. Counting rates, temperature, pressure, and azimuthal orientation were radioed to the ground by means of a 15-channel f-m telemetering system. This paper describes in detail the electronic and mechanical features of the apparatus.

A description of the data and their interpretation are given in the following paper.

INTRODUCTION

IN view of the long-standing lack of information about the directional asymmetry of the primary cosmic radiation, and because of the importance of this information for an understanding of many cosmic-ray phenomena, a study of the directional distribution of primary rays and its dependence on latitude has been undertaken.

A large amount of data on the east-west and other asymmetries has been collected at sea level and at mountain elevation,[1] and a small effect is observed. The interpretation of these results is difficult, as most of the particles measured are secondaries produced in the atmosphere and no adequate information is available relating the direction of the secondary particles to that of the primaries.

Recent experiments[2–4] at intermediate altitudes (18 cm Hg pressure) with aircraft indicate a large east-west asymmetry of up to 35 percent, but there still remains the problem of relating these measurements to the primary particles because of the some 240 g/cm^2 of air above the equipment. If one assumes an absorption coefficient of 1/160 g^{-1} cm^2 in air for the primary particles, one would expect to observe not more than 20 percent of the incoming primaries in the vertical direction at this atmospheric depth, and even fewer at larger zenith angles. Cloud-chamber observations at similar altitudes show that fewer than 1/30 of the particles have energies greater than 2.0 Bev and support this conclusion.[5] Also, barometric and atmospheric temperature effects seem to be most troublesome at these intermediate altitudes.[6] The fact that the observed asymmetry is so large and increases for increasing hardness of radiation indicates that the high energy secondaries probably preserve the direction of the primaries to a large degree.

The only measurement of the E-W asymmetry at high altitudes[7] gives a seven percent effect at 100-g/cm^2 depth. This low value is in apparent contradiction with the above-mentioned results but may find an explanation in the accuracy with which the azimuthal direction of the recorded cosmic-ray particles was known. Also, the total intensity was measured in these experiments at an atmospheric depth where low energy secondary particles are most numerous and might cause a washing out of the primary asymmetry because of their angular divergence.

The recent development of constant-level high altitude balloons[8] provides the possibility of making

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* Assisted by the joint program of the AEC and the ONR.

[1] T. H. Johnson, Rev. Mod. Phys. **10**, 193 (1938); Vallarta, Perusquía, and de Oyarzábal, Phys. Rev. **71**, 393 (1947).

[2] Schein, Yngve, and Kraybill, Phys. Rev. **73**, 928 (1948).

[3] W. C. Barber, Phys. Rev. **75**, 590 (1949).

[4] Biehl, Neher, and Roesch, Phys. Rev. **75**, 688 (1949).

[5] Adams, Anderson, Lloyd, Rau, and Saxena, Rev. Mod. Phys. **20**, 334 (1948).

[6] Swann, Morris, and Seymour, Phys. Rev. **75**, 1317 (1949).

[7] T. H. Johnson and J. G. Barry, Phys. Rev. **56** 219 (1939).

[8] Spilhaus, Schneider, and Moore, J. Meteorology **5**, 130 (1948).

directional intensity studies at small atmospheric depths where most of the particles observed might be primary particles. Even at these maximum balloon altitudes, however, there are still about 13 g/cm^2 of air above a vertical counter telescope, which may reduce the primary intensity by as much as 10 percent. In addition, measurements of the primary directional distribution might be distorted by secondary particles moving upward through the atmosphere, by the multiplication of the primaries at large zenith angles where the air path is longer, and by charged secondary particles trapped in the earth's magnetic field above the atmosphere. Accordingly, an investigation of these effects has been made at one latitude (56°N geomagnetic), preliminary to the main asymmetry study planned for a series of geomagnetic latitudes.

The initial flights were made at Princeton in February of 1948 using the Dewey and Almy Type J-2000 Neoprene balloons, carrying from 30 to 40 pounds of equipment.[9] It became apparent that these balloons were inadequate for keeping the equipment within a few percent of the top of the atmosphere for extended periods of time. At this time the Office of Naval Research made available through Project Skyhook the large constant-level balloons developed by General Mills, Inc.,[10] which proved capable of carrying payloads of 90 pounds to altitudes approaching 100,000 feet and remaining at constant level for extended periods. Geiger counter telescopes were designed for measuring the directional distribution, and in June, 1948, a series of six flights was carried out at Camp Ripley, Minnesota (geomagnetic latitude of 56°N), using the Project Skyhook facilities there.

I. COUNTER GEOMETRY

The counter geometry used during the main part of this series is shown in Fig. 1. There were five threefold telescopes, their axes pointing to zenith angles of 0°, 22½°, 45°, 67½°, and 90°, respectively. Thus, counters 1, 0, and 1 made up the vertical telescope; 2, 0, and 2, the 22½° unit; and so on—counter 0 being common to all telescopes. The 1.9-cm and 7.6-cm Pb filters could be inserted in quadrants within this geometry, but as the dotted circles show, the first counter in each telescope had to be moved out to accommodate the 16.7-cm Pb filter. The method of connecting the counters to the coincidence circuit is shown in Fig. 2. The angles subtended were 21° perpendicular and 48° parallel to the plane of the counters' length for the 0, 1.9-cm, and 7.6-cm Pb filters, and 14° and 37°, respectively, for the 16.7-cm filter. Because of the decreased cross section presented by the telescope to particles off the axis, the effective angular aperatures are about half these values.

Showers

Counters of 6-in. length were provided in the geometries to detect air showers and possibly bursts and multiple events in the lead. Referring to Fig. 1, detection was provided in the following manner: considering the vertical threefold telescope, a coincidence between this telescope and counters 10 and/or 12 was considered a shower of two or more particles associated with the vertical direction. The few such showers detected all occurred in the lower atmosphere (below 15 cm Hg pressure), no events being observed at maximum altitude. This latter observation was a little disturbing

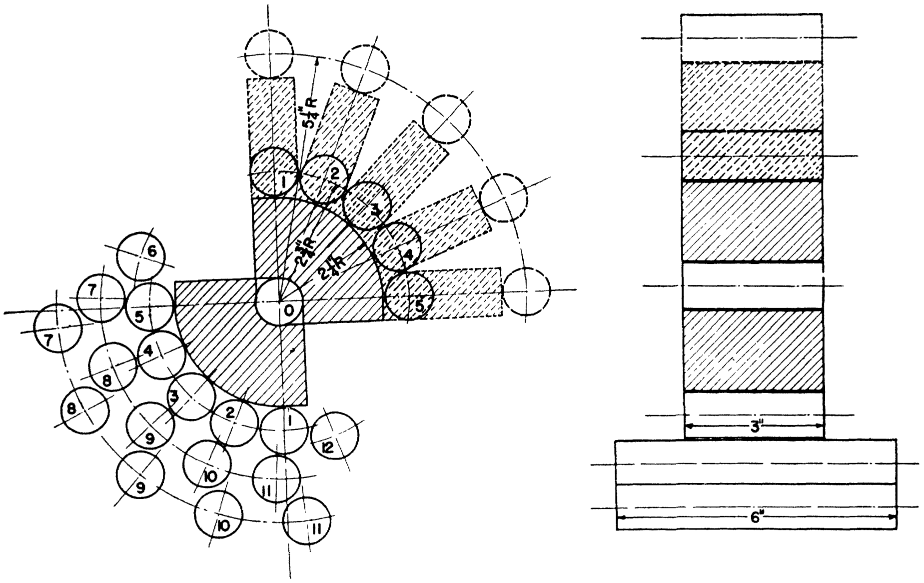

FIG. 1. Counter geometry.

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[9] J. R. Winckler, Phys. Rev. **74**, 1214 (1948).

[10] The inflation and launching techniques for this type of balloon are described in detail in reports on constant-level balloons of the Research Division, College of Engineering, New York University, A. F. Spilhaus, Director.

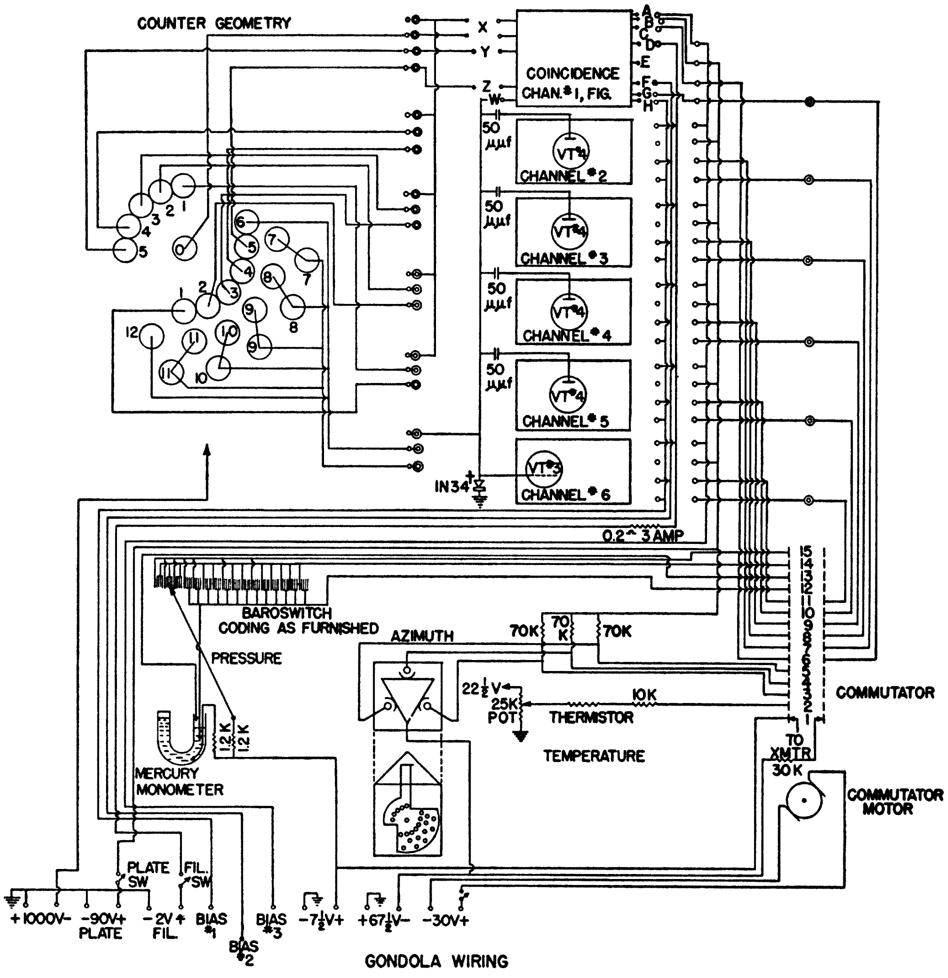

FIG. 2. Gondola wiring diagram.

since meson production events such as those observed by Schein and collaborators[11] might be expected. We have no explanation for this failure to observe such events other than that the shower channels did not work properly for some undetermined reason, or that the shower geometry was relatively inefficient for narrow bursts.

II. COUNTERS

A sketch of the Geiger-Müller counters used in the gondolas is shown in Fig. 3. A typical plateau is shown in Fig. 4. Although the geometric effective length was 3 inches, a measurement of the effective length similar to that used by Greisen and Nereson[12] gave a value of 2.75 inches.

III. DESCRIPTION OF GONDOLA AND COMPONENTS

The coincidence circuits (Fig. 5) were of the conventional threefold Rossi type, with a fourth tube forming a two-position stable flip-flop, regenerating through the screens of the first three tubes. The remaining four tubes on each channel were necessitated by the time-division properties of the telemetering

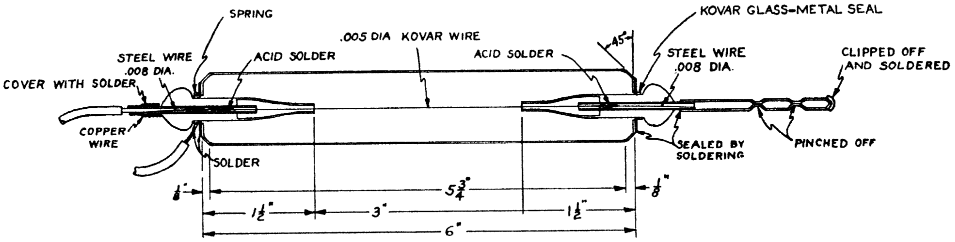

FIG. 3. Geiger-Müller counter construction.

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[11] Schein, Jesse, and Wollan, Phys. Rev. **60**, 615 (1941); Schein, Iona, and Tabin, Phys. Rev. **64**, 253 (1943).

[12] K. Greisen and N. Nereson, Phys. Rev. **62**, 316 (1942).

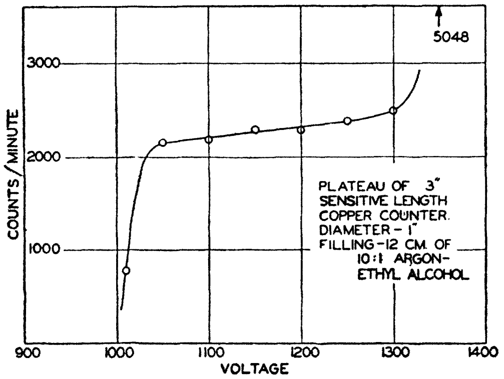

FIG. 4. Typical counter plateau.

scheme, and constituted a second coincidence between the stored Geiger-coincidence count and the arrival of the commutator on that channel. Thus, events which occurred on a particular channel after the start of sampling by the commutator were held over until the next cycle. "Partial" pulses which might be of doubtful interpretation on the record were thus avoided. One difficulty of the circuits was that each of the three bias voltages on each channel had to be selected with some care so that the circuit would work properly over a reasonable range of plate voltages. The resolving time of the coincidence circuit was better than 10 μsec., and tests with a Ra source nearby to give counting rates similar to those at maximum altitude showed that the effects of accidental coincidences and deadtime were negligible.

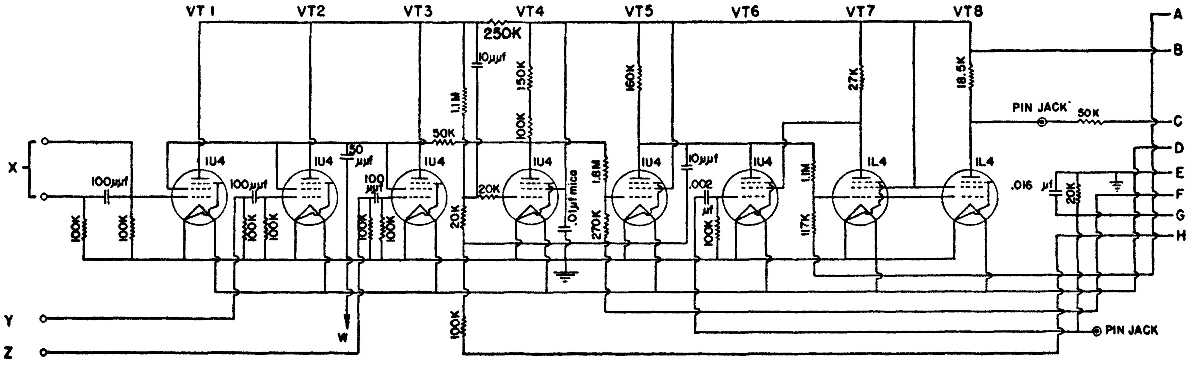

FIG. 5. Coincidence channel circuit diagram.

The pressure was measured by an aneroid baroswitch with coded contacts, supplemented by a small, non-spillable Hg manometer with contacts at about 1.0 and 1.5 cm. Temperatures were recorded by a resistive element (thermister). This "end" instrument, providing a continuously varying signal, could not be recorded on the flight film and had to be checked by occasionally measuring the pulse height on the temperature channel as shown on the monitoring oscillograph during flight. A pre-flight calibration of this pulse height made the measurement reliable to about ±5°C.

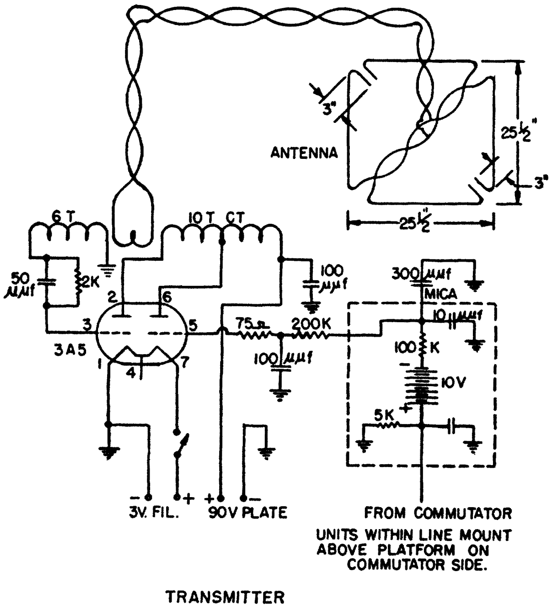

FIG. 6. 76-mc frequency-modulated transmitter.

The azimuthal orientation of the gondola was determined by means of three banks of photo-cells, each placed on a side of an equilateral triangle and viewing a 180° sector. Thus, by forming combinations of the three photo-channels, we were able to obtain six azimuthal bearings of the gondola. It was found necessary to calibrate the photo-cell array with relation to the time of day for each flight. The photo-cells were

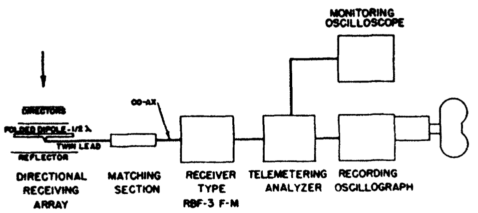

FIG. 7. Block diagram of ground receiving equipment.

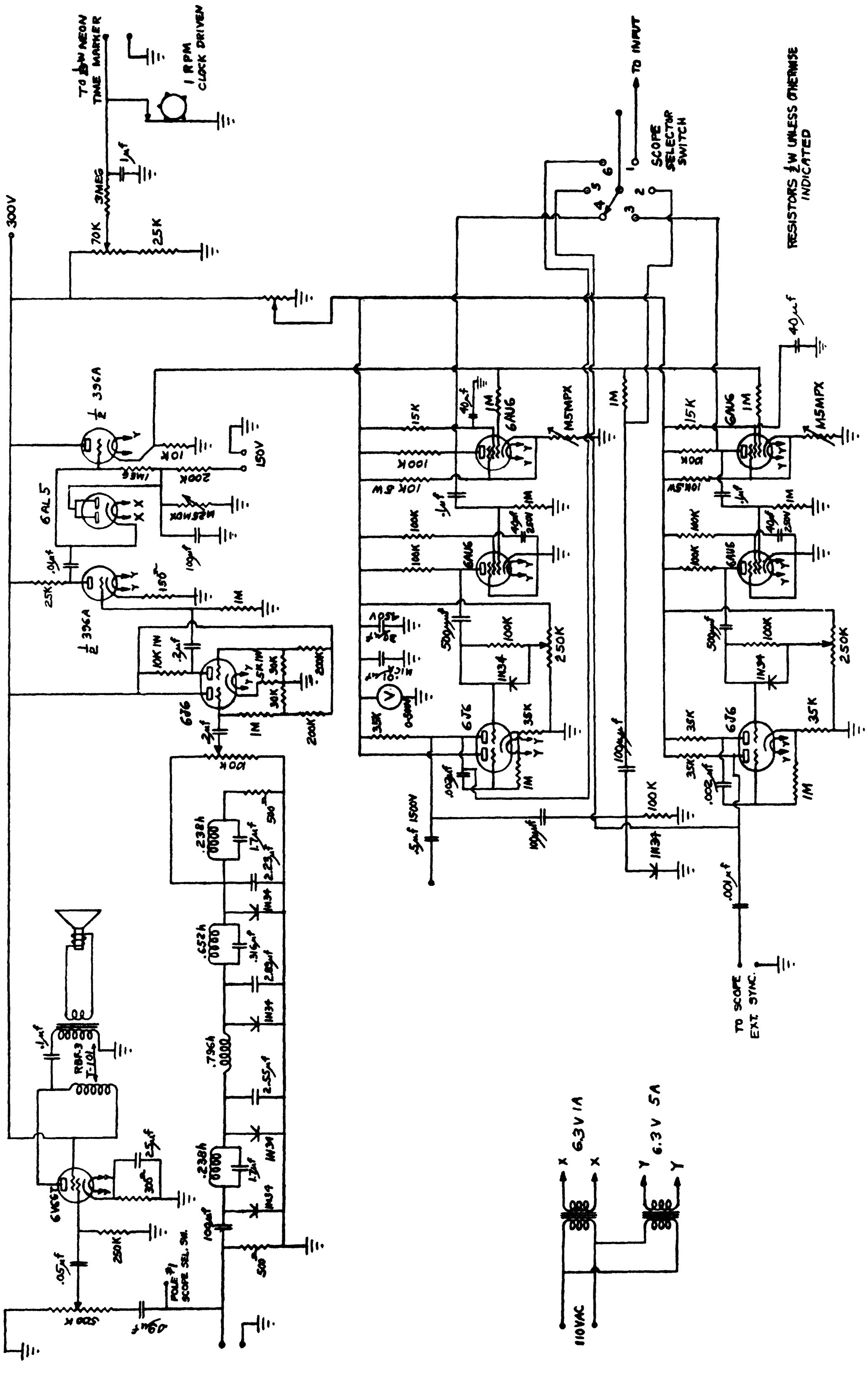

FIG. 8. Circuit diagram of telemetering analyzer.

shielded from reflected light from the balloon in order to obtain satisfactory azimuthal bearings. In flight the gondola rotated irregularly, often remaining at a fixed azimuthal position for a long period. Similar behavior was observed with clusters of Neoprene balloons in flights at Princeton. The addition of a jet-rotator with seven-foot arms operated by means of a cylinder of Freon refrigerant produced a uniform rotation of the gondola at high altitudes. Our experience indicates that without some such device to insure constant rotation the interpretation of the azimuthal data becomes very difficult.

All these end instruments, 15 channels in all, were fed into a time-division system of telemetering (Fig. 2). A small motor-driven wiper switch or commutator made contact successively to the 15 separate terminals at the rate of 10 complete samples per second. The information appearing on each terminal was either "on" or "off" and the frequency of a small reactance-tube modulated r-f oscillator (Fig. 6) was deviated accordingly by about 30 kc (carrier at approximately 76 mc). The r-f output of the transmitter was about 0.1 watt and was radiated by means of an Alford array, being concentrated in the horizontal plane. Even at this power output, little difficulty was experienced with signal strength, the signal still being well above the noise level when the equipment was 250 miles away at 40,000 feet. Apparently at 100,000-foot altitude, the signals would be satisfactory at 400 miles, the optical horizon.

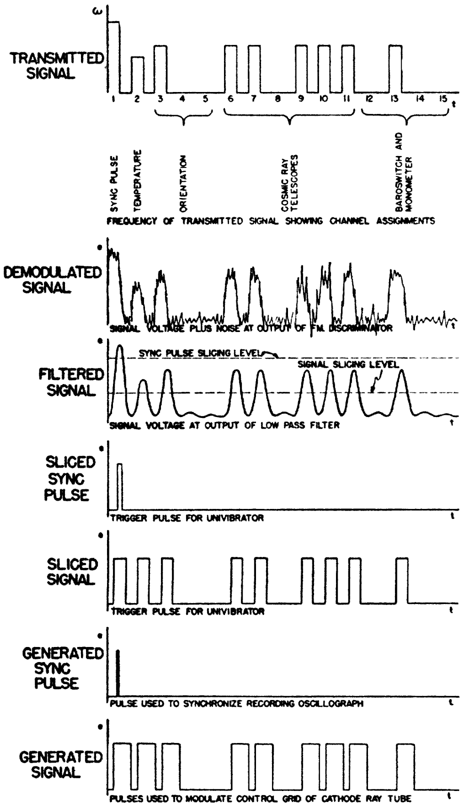

Fig. 9. Diagram of the telemetering process.

The gondola was constructed of Dow metal angles with aluminum sheet floor and ceiling; dimensions were 19 in.×19 in.×54 in. It contained, from top to bottom, photo-cells, counter array and temperature device, coincidence circuits, commutator and pressure instruments, batteries, transmitter, and antenna. The completed weight without lead but with enough battery power for about twelve hours of flight was 45 pounds. To keep the equipment at a reasonable temperature, 30° to 50°C, the gondola was completely covered with lightweight black paper, then one-third of the area covered with aluminum foil, and finally the whole gondola with two layers of Cellophane.

Receiving Scheme

A block diagram of the receiving and recording apparatus is shown in Fig. 7. The directional antenna fed through a $\lambda/4$ impedance matching section to the RBF-3 f-m receiver.[13] The output of the receiver was passed through a telemetering analyzer and into a recording oscillograph whose horizontal sweep (10 cycles/sec.) was synchronized with the commutator in the gondola by a master pulse transmitted once each cycle. The cathode-ray tube was photographed continuously by a 35-mm film moving at a rate of $\frac{1}{10}$ inch per second.

The functions of the telemetering analyzer (Fig. 8) were (1) to differentiate the signal from the noise, (2) to provide synchronizing pulses for the recording oscillograph, and (3) to modulate the control grid of the recording cathode-ray tube according to the intelligence of the received signal.

A diagram of the telemetering process is given in Fig. 9. All the graphs are plots of voltage *vs.* time with the exception of the topmost, which is frequency *vs.* time. The diagram is to a large degree self-explanatory; however, it should be noted that pulses applied to the cathode-ray tube modulated the Z-axis so that the camera saw the base line of the lowest graph at all times. A portion of a record is reproduced in Fig. 10. Note that each channel was blank unless "yes" information was given out by the end instrument, then the channel was filled in. Thus, a line appearing across any of the channels assigned to the cosmic-ray circuits was interpreted as a cosmic-ray count.

The system had the advantages of being able to transmit many pieces of information in a simple way, of having excellent discrimination against noise, of meeting the weight requirements of balloon equipment, and of giving a compact, easily readable record. However, it suffered the disadvantage of limiting the counting rate unless the commutating speed were

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[13] Loaned by the U. S. Navy Underwater Sound Laboratory, New London, Connecticut, through the kindness of Captain William L. Pryor, Jr., Commanding Officer.

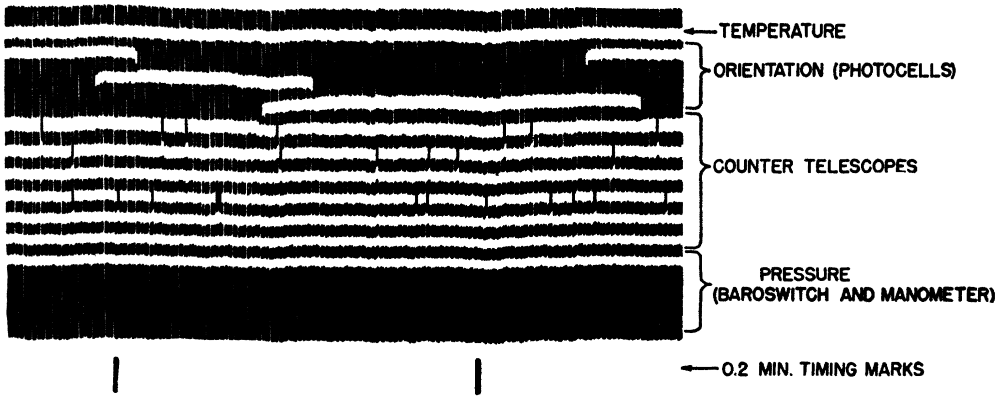

Fig. 10. Section of telemetering record.

increased,[14] and of requiring that random information be stored.

Calibration

The counter telescopes and coincidence circuits were calibrated by operating them at sea level over a long enough period to get 10,000 counts; i.e., about 1 percent statistics. Because of the long time required—the ground rate was about 1 count per minute without lead—two channels were run simultaneously by mounting the two adjacent telescopes so that each had a zenith angle of $11\frac{1}{4}°$. The counting rates thus obtained were corrected to the vertical rate without lead using the well-established $\cos^2\theta$ law. The results are given in Table I.

Table I. Calibration data summary.

Gondola No.	Amount of Pb cm	Vertical rate on ground without Pb—counts/min. (zenith angle during flight) 0°	22½°	45°	67½°	90°
V[a]	No Pb and 7.6	0.944±0.015	1.045±0.009	0.931±0.012	1.015±0.008	0.958±0.012
VI[b]	1.9	0.974±0.010	0.939±0.009	1.015±0.010	0.985±0.012	0.994±0.012
VII	7.6	0.932±0.009	0.955±0.008	1.031±0.010	1.017±0.008	1.000±0.011
VIII[c]	16.7	0.492±0.007	0.505±0.006	0.476±0.006	0.443±0.005	0.487±0.008
IX[d]	——	1.045±0.014	1.002±0.010	1.028±0.014		

[a] Two flights made with this gondola, one with no Pb, the other with 7.6 cm.
[b] Two flights made with this gondola with 1.9 cm Pb (one unsuccessful).
[c] At Princeton, modified to have 1.9 cm Pb in 0° and 22½° telescopes, no Pb in 45 telescope during flight.
[d] Gondola VIII had smaller solid angle to accommodate 16.7 cm of Pb (see Fig. 1). One flight.

Complete calibration data were taken at Minnesota ($\lambda = 56°$N, altitude 1100 feet). It is interesting to compare this to the Princeton data ($\lambda = 51°$N, 100 feet) by means of the ratio, average rate all telescopes at Minnesota/average rate all telescopes at Princeton, which equaled 1.059±0.004. This increased rate can be accounted for by the altitude difference, which was estimated to produce a 5 percent effect.[15]

Calibration data were taken after flights wherever possible and were in agreement with the pre-flight values.

ACKNOWLEDGMENT

We give our sincerest thanks to the many people who have contributed to this venture—in particular to Mr. D. B. Davis, head, and Messrs. E. G. Card and F. Schwarz of the shop staff for construction of gondolas and telemetering equipment; Miss H. Maginnis for construction of the counters; and Mr. E. L. Church for help in calibration of the units and analysis of data.

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[14] The average deadtime introduced by the commutator was 0.05 sec. so that the counting rate loss at the maximum observed rate of 0.5 counts/sec. was about 2.5 percent. Since the losses were even less at the highest altitudes, no corrections were made.

[15] B. Rossi, Rev. Mod. Phys. **20**, 540 (1948).

Fig. 10. Section of telemetering record.