RESULTS OF PIONEER I FLIGHT

by

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The launching of Pioneer I took place on a quiet geophysical day – 11 October, 1958. At Palo Alto, a proton magnetometer was operating and indicated that micropulsations in the magnetic field were down to about 1 microgauss.* One transient which occurred during the flight was a meteor radiant associated with Eta Aries; being a relatively unimportant event, it had no measurable effect upon the data which was obtained. In spite of the quiet nature of the day, a considerable amount of information was obtained, and is being studied. Some of it is complex, and the analysis is presently incomplete.

Although this discussion pertains primarily to Pioneer I, it should be pointed out that instrumentation changes were made in Pioneer II to accommodate broader scientific objectives.

Figure 1 shows the payload of Pioneer II, the outer configuration being similar to that of Pioneer I. One can note, near one leg of the dipole antenna, the micrometeorite diaphragm, approximately 60 square inches in area. The Doppler command receiver is a miniaturized version of a standard microlock receiver, a laboratory item normally housed in a large cabinet. Battery boxes are mounted around the edge. Next to these is shown the antenna multiplexer. The portion of the ring with large holes in it is the precessional damper. It is designed to remove those components of angular momentum associated with the transverse axes of the vehicle. The function of the retrorocket is to change the vehicle velocity to permit lunar capture.

In Figure 2 is shown a breakdown of the Pioneer I payload. Pioneer I carried a television system which was designed and installed by the Naval Ordnance Test Station. That system was mounted on the inside of the ring, utilizing the space around the Doppler receiver and the multiplexer. On Pioneer II, a television system

Figure 1. Pioneer II payload. Oblique view showing micrometeorite diaphragm and one leg of the dipole antenna

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*We are indebted to A. J. Dessler for this data.

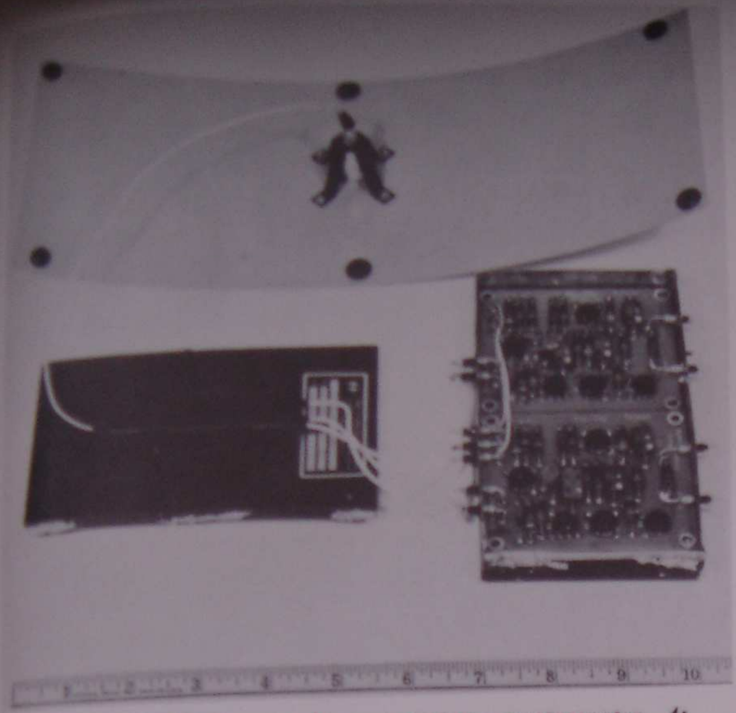

Figure 10. Micrometeorite momentum spectrometer. At top is the acoustical diaphragm and microphone. The wire leads to the 100-Kc amplifier; and to the right are the two multivibrator emitter-follower circuits

The simplest explanation for the 180-degree phase shift and zero in the data is that the magnetic intensity vector in space rotated through the spin axis of the vehicle. The spin coil, or search coil, measures only the component of the magnetic field (H) which is normal to the spin axis of the vehicle. The spin axis of the vehicle is invariant in space since the angular momentum is conserved. Amplitude fluctuations can be due to one of two causes or a combination, as follows: (1) the amplitude of the total magnetic intensity changed, or (2) the H vector rotated in a polar sense with respect to the spin axis, so that its component normal to the spin axis varied in size. Unless the H vector were very close to the spin axis, one would not expect dramatic changes in amplitude. In addition, a zero coupled with a 180-degree change in phase can most easily be explained as a sudden excursion of the H vector from one side of the vehicle, through the spin axis, to the other side.

The analysis being made by computer on magnetometer data will include phase differentiation between the RF and magnetometer signals, correlation, and statistical analysis of the amplitude fluctuations.

Figure 8 shows another characteristic type of signal of an almost periodic nature. One can note a progressive change in period and the data displays the appearance of a hydromagnetic fluctuation, perhaps of a compressional nature. The separation of transverse and compressional waves in the data is now being studied.

The magnetic measurements have indicated that the mean value of the field, in the region of 10 to 12 earth radii, is perhaps two or three times as large as is indicated from an eccentric dipole model. If this proves to be real, there are several processes to which this could be attributed: (1) a centrifugal instability resulting in general compressional effect; (2) a quiescent current ring; or (3) a winding around of the field lines, resulting in an isorotation of the outer atmosphere.

Figure 9 shows the television system developed at the Space Technology Laboratories, which was designed to operate over a 1-cycle passband to obtain a strip picture of the moon. This television system weighs approximately 2½ pounds. A Newtonian reflector is utilized for the telescope. This apparatus generates a line scan based upon the intrinsic vehicle spin. However, instead of developing an electrical signal corresponding to the light variations along a scan line, only one spot along such a line is sampled per vehicle revolution. Upon the next spin cycle, the spot is advanced by the width of one spot. A computation advances the sampled spot coherently with the vehicle spin. Thus a complete line is traced in a large number of spin cycles. In this manner, the over-all bandwidth requirement is reduced drastically.

The micrometeorite equipment shown in Figure 10 was supplied by Maurice Dubin of the Air Force Cambridge Research Center; the logic circuitry and the diaphragm were supplied by Space Technology Laboratory. The complete system (microphone, diaphragm, and amplifier) is designed to resonate at a 100-kilocycle rate. The signal is then detected and the envelope applied to a multivibrator, which varies the frequency of a subcarrier oscillator. There are two subcarrier oscillators, one for each momentum channel.

The counting rate for Pioneer I was spectacularly low. An average of approximately 10^{-2} counts per square meter per second was registered. This is on the order of one particle per cubic kilometer, if a mean value of about 10^4 meters per second is assumed for the velocity of these particles. On the high momentum channel, one count at 10^{-3} gram centimeters per second was registered over the complete flight.

The attempt has been made here to give a brief summary of the purposes, equipment, and results of the Air Force Pioneer I flight. The data which were obtained from this flight are still being analyzed, and so the results presented here are intended to be tentative.

J. Green: What do you think was the diameter of the smallest meteorite that was detected?

C. P. Sonett: That depends on the density and the velocity that you assume. I can't tell you very much about that since that was an experiment of the Cambridge Research Center. Clearly there is a spectrum of velocities and there may be a tremendous spectrum of densities – all the way from one-tenth or one-twentieth of a gram per cubic centimeter to perhaps 10 grams per cubic centimeter. It is very difficult to say what the diameter would be.

There is some variation in the sensitivity of the diaphragm. You can't very well test out this diaphragm with particles going at a velocity which was greater than the velocity of sound in the diaphragm. We used a dust accelerator, using particles of iron carbonyl, which produced velocities up to 3 or 4 kilometers per second. But I believe this still is below the velocity of sound in aluminum. One would have to look at this more carefully to see if the response was purely momentum-dependent.

of a different design, developed by Space Technology Laboratories, was utilized. The reduction in payload achieved by utilizing this system allowed the University of Chicago proportional-counter telescope to be carried within the weight limit and still utilize a television system. On the other side of the outer rim of the payload are the scientific instruments. The magnetometer search coil is just visible in the figure. The remainder of the equipment consists of electronics associated with the scientific apparatus.

The micrometeorite spectrometer sampled micrometeorites over two classes of momentum levels; the magnetometer had a range of 5 micro-oersteds to 12 milli-oersteds. The magnetometer search coil was fixed to the vehicle and, as a consequence, it generated an emf proportional to the spin rate of the vehicle,* yielding a 1.84-cps signal. This signal was telemetered so that both amplitude and phase information were available.

The temperature measurement displayed an exponential drop-off to a value of 34° F, which was somewhat lower than design value. This has been attributed to a lofting of the velocity vector of the booster stage at burnout. The internal temperature of the vehicle was sensitive to the angle between the spin axis and solar radiation. The top cone of the payload was at a high temperature, the bottom cone was facing away from the sun and was at low temperature, which resulted in a temperature gradient of perhaps 200 to 300° F across the inside of the vehicle. Radiative transfer was the primary means of attaining thermal equilibrium. As a consequence, each piece of equipment had a unique temperature, at variance with that measured by the thermometer, so that precise temperature measurements required close proximity to the sensor.

The vehicle velocity was measured by a coherent Doppler system. A command signal transmitted from the ground was received in the vehicle. The receiver locked onto the signal in a phase-coherent manner with a frequency offset, the return link being the 300-milliwatt transmitter. Depending upon command status, either velocity or telemetered data could be received. In addition to the Doppler function, the receiver also had various command functions; for instance, it received the signal to fire the retrorocket. Incidentally, rocket firing was designed to trigger the television system; since the retrorocket was not fired, the TV system was never put into operation.

Pioneer I had the disadvantage that the Doppler on-time at lift-off was 17 minutes, at the end of which time the vehicle was already at an altitude of 2,000 miles. On Pioneer II, this 17-minute gap was filled by an additional 100-milliwatt transmitter which served to back up the 300-milliwatt unit as well as permitting data to be obtained from lift-off.

In addition, a proportional-counter telescope, de-

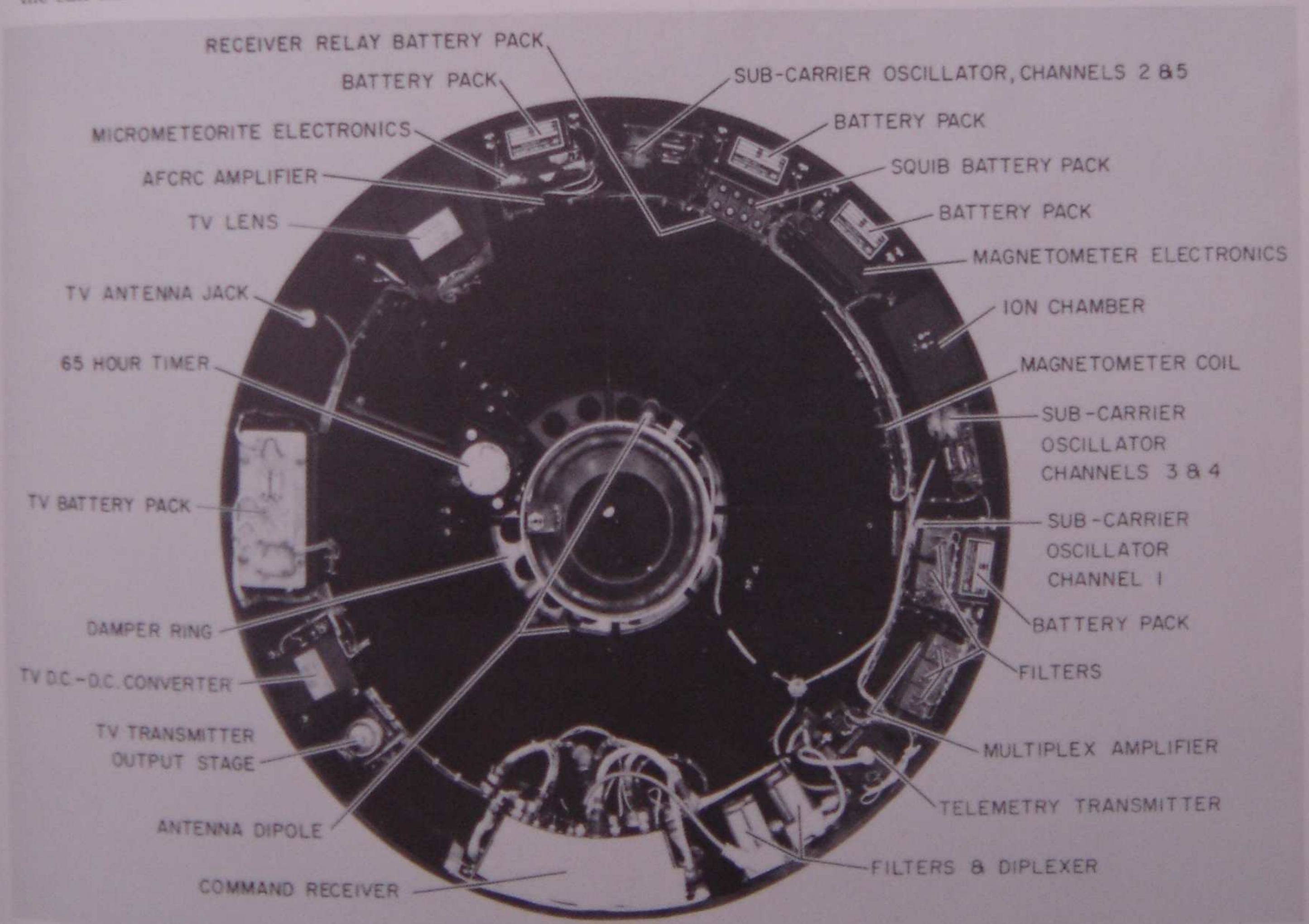

Figure 2. Pioneer II payload package

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*The phase and amplitude are coupled in a complex manner whenever $\dot{B} \neq 0$, where $\dot{B}$ is the time rate of change of B as measured from an inertial frame.

signed by the University of Chicago, with 5 grams per square centimeter shielding, was installed to count particles, either protons of energy greater than 40 to 60 mev, or electrons with a cutoff of 5 mev. This telescope was almost omnidirectional, one proportional counter being surrounded circumferentially by a set of six others.

Both Pioneer vehicles carried an ion chamber. The ion chamber was filled with argon at a pressure of 200 pounds per square inch. Its wall mass was 400 milligrams per square inch. Data transmission for this equipment occurred for 200 seconds, followed by a relay closure applying a fixed d-c potential across the d-c electrometer amplifier for calibration purposes. The telemeter displayed the calibration potential signal for 20 seconds, then the analog signal for 200 seconds.

Figure 3 is the ion chamber that was carried on both Pioneer I and Pioneer II. Shown is a subcarrier oscillator, which consists of an audio oscillator whose frequency functionally depends on the output voltage of the electrometer circuit. The multivibrator switched the calibration voltage on and off. The battery pack was designed to last for two days.

On Pioneer I the uncertainty of the chamber pressure and the non-linearity of the input-resistor network, which was the result of temperature variation, were considered in arriving at a satisfactory value of ionization. Figure 4 shows the results of Pioneer I measurements. The first point, at about 2000 miles above the earth's surface, indicates 3 roentgens per hour. At 6000 miles above the earth, a maximum of 10 roentgens per hour is reached. Then a slow and gradual drop-off takes place out to 24,000 miles. Some analysis remains to be done on these data. The above is a measure of mean specific ionization and will require comparison with the count rate from Pioneer II. It should be pointed out that the measured value and the true value of mean specific ionization differ in a manner dependent upon the differential spectra. The measured value is given by

Figure 3. Ion chamber and associated electronic circuitry. In the upper left-hand corner is the in-flight calibration multivibrator; just below is the electronic amplifier; at the bottom is the subcarrier oscillator; and to the right the battery pack

$$\bar{I}' = \frac{\int_{E_o}^{E_2} I_{sp}(E)\left(\frac{dn}{dE}\right)' dE}{\int_{E_1}^{E_2}\left(\frac{dn}{dE}\right) dE}$$

whereas the true mean specific ionization is represented by

$$\bar{I} = \frac{\int_{E_1}^{E_2} I_{sp}(E)\left(\frac{dn}{dE}\right) dE}{\int_{E_1}^{E_2}\left(\frac{dn}{dE}\right) dE}$$

where I_{sp} (E) is the specific ionization at energy E,

$\left(\frac{dn}{dE}\right)$ is the assumed differential spectra,

$$\text{and } \left(\frac{dn}{dE}\right)' = f(E - \triangle E) = f\left[E - \int_{E-\triangle E}^{E} f(E)\,dE\right]$$

The terms E_1 and E_2 represent the upper and lower energy cutoffs unmodified, $\triangle E$ the energy loss at energy E, and E_o the wall-modified lower energy bound, which may be assumed to be 0.1 mev.

Work is being carried on at the present time to obtain a qualitative idea of the differential spectrum shape from the evaluation of $\bar{I}$ utilizing $\bar{I}'$.

One of the most interesting experiments, and one that gives considerable scientific satisfaction, was that utilizing the magnetometer shown in Figure 5. But before I go into that, it is important to mention the characteristics of the amplifier because they pertain directly to the observations. The amplifier was tuned to the spin rate of 2 cps and had a passband of 2 cps. With the spin coil attached, the passband was modified by a dependence on angular velocity. The amplifier had gross automatic gain control in order to extend its range. Originally, the device was designed to test for the existence of a lunar field. Thus, the magnetometer was to be as sensitive as possible. As consideration of interplanetary fields developed, an extended upper limit was made for the magnetometer. The final upper limit chosen was 12 milli-oersteds, which was quite adequate for interplanetary purposes. Since the amplifier gain depended on the output voltage in a nonlinear manner, the raw data must be operated upon to arrive at the original field.

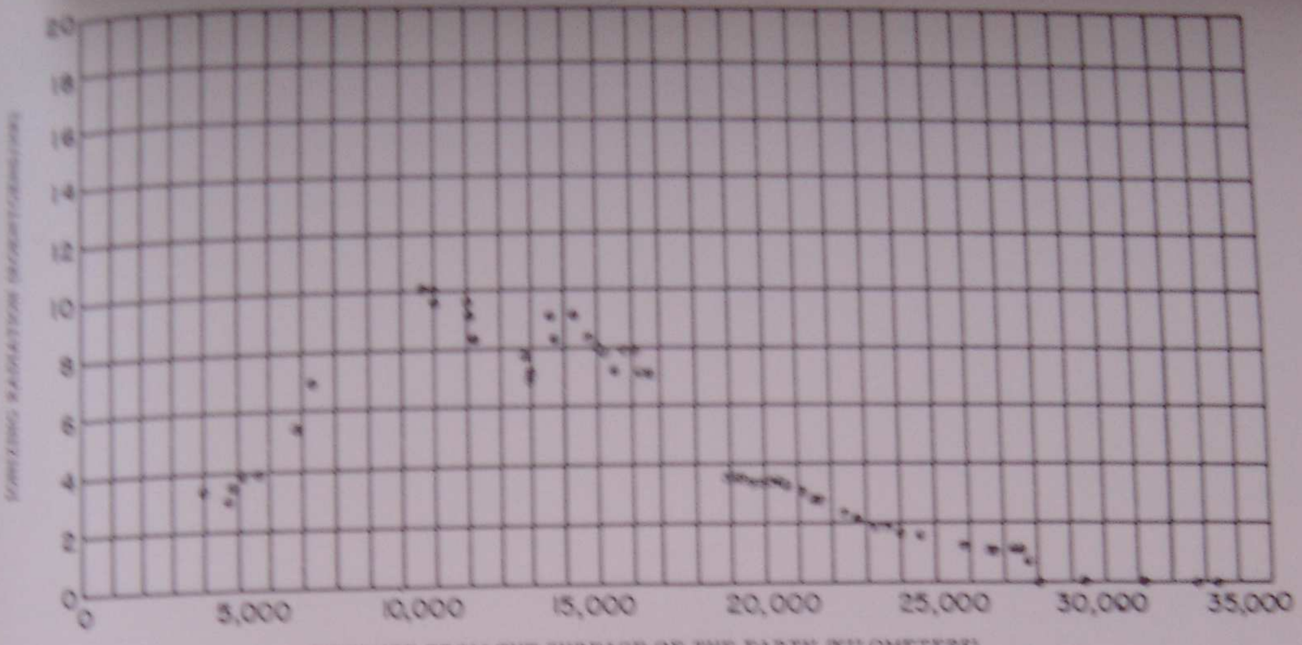

Figure 4. Pioneer I ionizing radiation versus distance from the surface of the earth. Breaks in data are due to loss of lock in the receiver phase loop

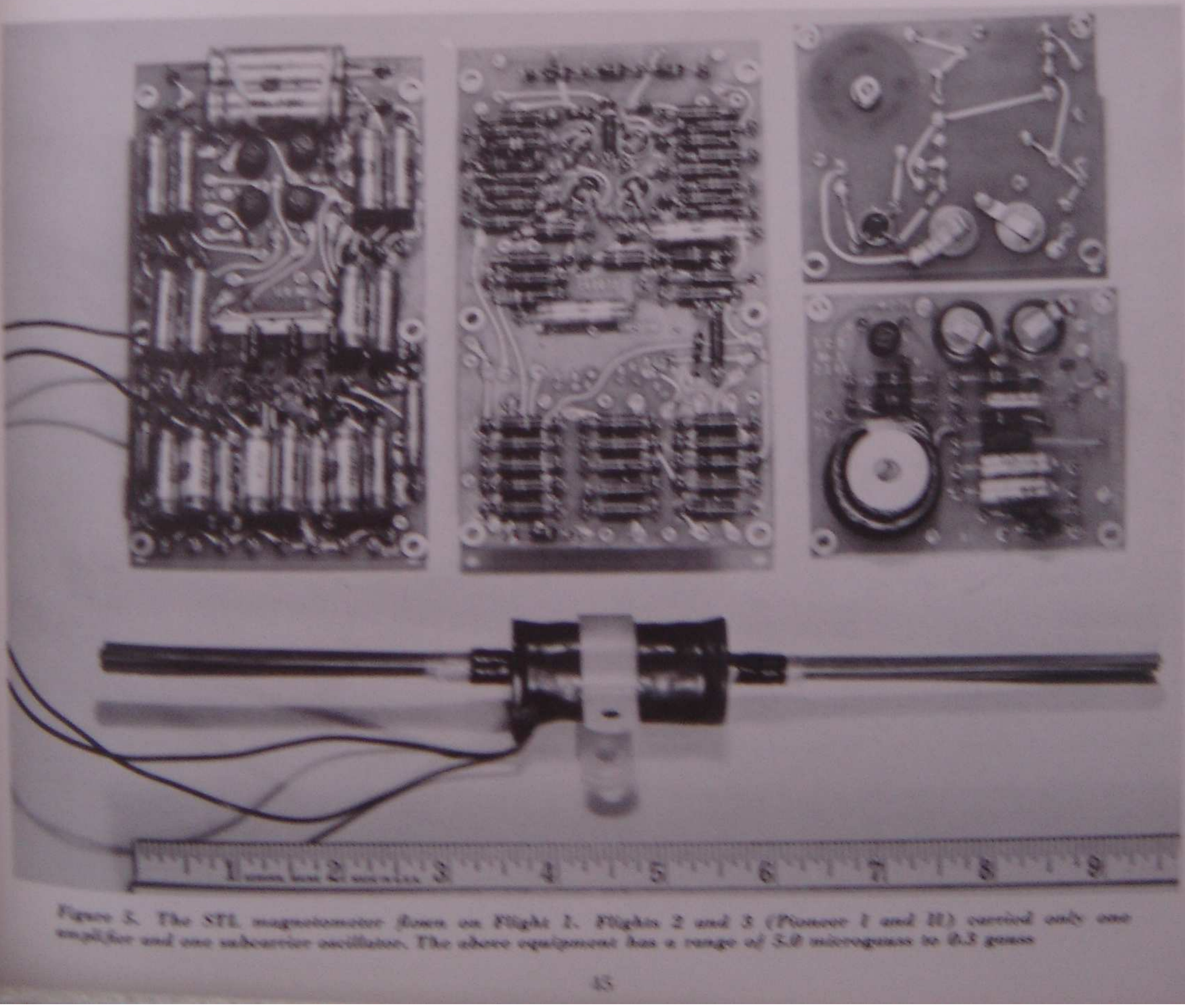

Figure 5. The STL magnetometer flown on Flight 1. Flights 2 and 3 (Pioneer I and II) carried only one amplifier and one subcarrier oscillator. The above equipment has a range of 5.0 microgauss to 0.3 gauss

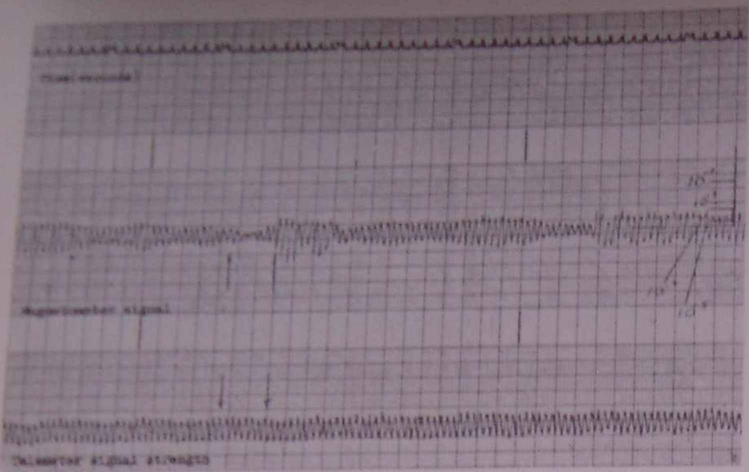

Figure 6. A typical magnetometer recording showing a signal zero associated with large phase change (between arrows), signal oscillations, and rapid changes in signal level. The magnetometer note shows a characteristic spin rate. Time is shown on the upper trace and the telemeter RF signal strength below to serve as a phase reference for the magnetometer. The scale for the magnetic field is indicated at the right-hand side, the units being oersted (emu). This record represents the signal at approximately 86,300 kilometers from the earth's surface

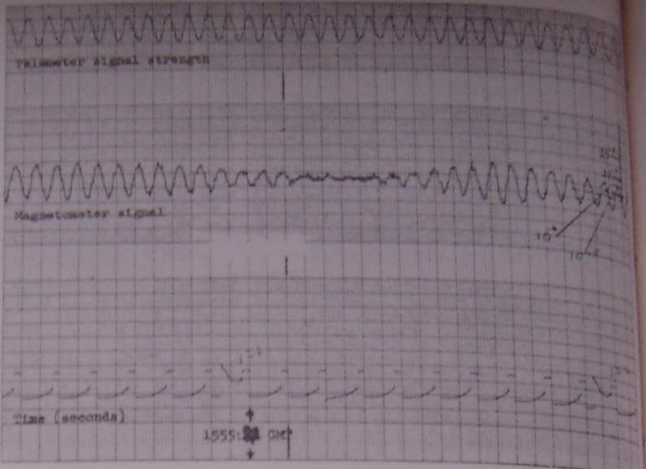

Figure 7. A time-expanded section of Figure 6 (the region about the indexing arrows) showing clearly the phase change of about π radians associated with the zero

Figure 8. Magnetometer signal showing almost periodic variations in the value of H

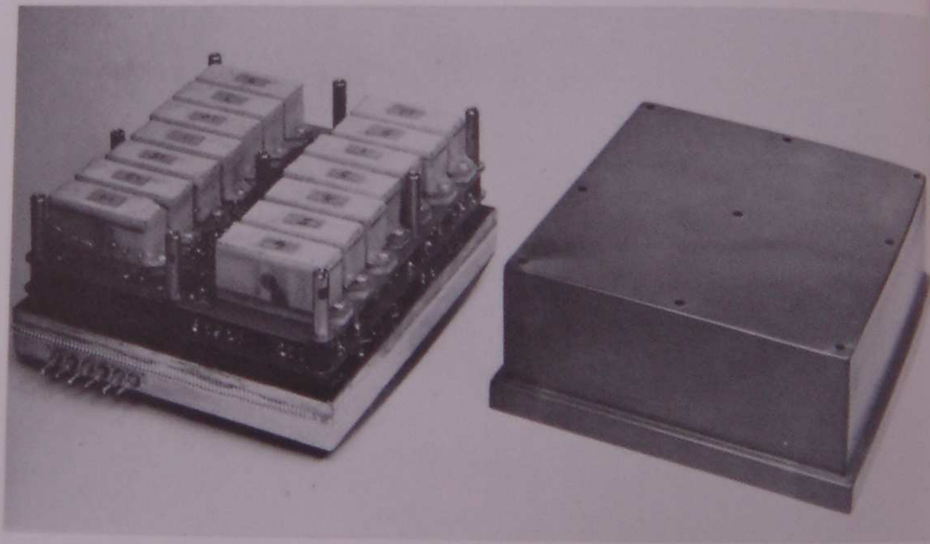

Figure 9. Space Technology Laboratories spot-scanning television system

Figures 6, 7, and 8 typify some of the magnetic field data. Phase shifts have been noticed which cannot be well assigned to the electronic equipment. Since the phase shifts are easy to substantiate, there is a good basis for the amplitude fluctuations which were observed. These fluctuations are of approximately two orders of magnitude. The fluctuations are modified by the characteristics of the amplifier, as previously mentioned, and so the peculiar type of sudden increase and slow decrease is partially a result of the amplifier gain characteristic. One notes a characteristic time of about 10 seconds in the data. Figure 6 shows data at about 10 earth radii. The region shown may be in the boundary of the coronal wind and geomagnetic field. Figure 7 is a time-expanded version of the same type of data. The amplitude variations are not as vividly displayed but phase changes can more easily be seen in such an expansion. A useful phase reference for the magnetometer signal is produced by recording the 2-cps spin rate, which was derived from the RF signal received on the ground. When passing through a zero such as the one indicated by the arrows in Figure 6, a 180-degree phase change takes place. Note that the field is of the order of 10^{-5} oersteds.