RESULTS FROM THE UK-2 SATELLITE

By C. C. Harvey

(Cavendish Laboratory, Cambridge, England)

Résumé. — *On décrit brièvement le satellite UK 2. Les données transmises présentent de l'intérêt pour les astronomes et les ionosphéristes ; principalement quand elles sont dépourvues de parasites, près de l'apogée du satellite. On présente des exemples des résultats obtenus, principalement ceux concernant les bandes de bruit ionosphérique et la propagation dans le mode Z. On décrit la méthode permettant de connaître l'orientation du satellite à un instant donné et l'on en déduit quelques résultats sur la polarisation des ondes dans le milieu.*

Abstract. — *The receiver in the satellite UK-2 is briefly described. Interference-free data received where the satellite is near the apogee of its orbit is of interest for astronomical and ionospheric work, and typical samples of such data are shown, the salient features being pointed out. Among the latter are the ionospheric noise bands, and the propagation of waves in the Z-mode. The method of determination of the orientation of the satellite at any given time is described, and the consequent conclusions about the polarisation of the signals are stated.*

Резюме. — Кратко описан спутник U.K. 2. Переданные данные представляют интерес для астрономов и специалистов ионосферы, главным образом когда они лишены помех, вблизи апогея спутника. Представлены примеры полученных результатов, главным образом относящихся к полосам ионосферного шума и распространению в моде Z. Описан метод позволяющий знать направленность спутника в данный момент, откуда выведены несколько результатов о поляризации волн в среде.

1. Introduction.

The satellite UK-2 (Ariel 2) was launched by N. A. S. A. from Wallops base, Virginia, on Good Friday, March 27th, 1964. The initial orbit was elliptical with an apogee of 1,360 kms and a perigee of 290 kms. The inclination of the orbit to the geographic equator was 51.67°, and the period was 101 m. In this paper the Cambridge experiment in the satellite is described and some preliminary results are given.

2. Description of the experiment.

The Cambridge experiment on board consists of a dipole antenna and a swept frequency receiver to measure the electric field strength in the upper ionosphere. The aerial has an overall length of 40 m ; it is kept taut by centrifugal force, and its deployment by electric motor from short boom on the satellite equator was an integral part of of the despin operation. The spin rate after deployment was 5.6 r.p.m. When the aerial is within the ionosphere its impedance varies with the electron density of the surrounding medium and with the orientation of the aerial. It was required to design an aerial which feeds to the receiver a signal which is independent of the surrounding medium and is proportional to the component of the electric intensity parallel to its length. To achieve this an input circuit was designed which presents to the aerial a high impedance, so that there is always a large impedance mis-match. The input circuit consists of a filter with a pass band of 0.5-3.5 MHz, followed by a broad band R. F. amplifier. The receiver is homodyne, that is to say, the received frequency is central on the local oscillator frequency ; the I. F. amplifier has a passband of approximately 0-10 kc/s, so that the overall bandwidth is 20 kc/s Except for a 3 second wait at 0.65 MHz, the oscillator frequency varies linearly with time over the frequency range 0.65-3.5 MHz, and this frequency sweep is triggered once every 28 seconds by a pulse from the telemetry encoder, thereby achieving synchronisation of the receiver frequency with the telemetry format. In order to make a frequency calibration of the receiver and to measure amplifier gain, a high stability oscillator was included in the receiver. This injects signals of 1 and 2 MHz and known amplitude into the input circuit of the receiver. So that there should still be some data even in the event of the aerial failing to deploy correctly, two ferrite loop aerials were mounted on the satellite equator and connected to the input circuit via a preamplifier working at 2.3 MHz.

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The I. F. amplifier drives two detectors, one for each of the telemetry data channels. Pulse coded frequency modulation telemetry is employed. The first detector has an integration time constant of 1 second, and the output is sampled every 0.87 seconds, which gives 28 samples per frequency sweep in the telemetered output. For 85 % of the orbit this output is recorded in analogue form on the satellite tape recorder, the other 15 % of the time being given to another experiment. On command from a telemetry station, the tape recorder reads out the information from a whole orbit in $2\frac{1}{4}$ minutes. This type of data is very useful for " quick-look " purposes. Far better frequency resolution is achieved with the second detector : this has a time constant of 25 ms and is sampled once every 72 ms, or 384 times per sweep, so that the receiver frequency changes by 10 KHz per sample. This output is continuously telemetered except for the same 15 % of the time, and when low speed data is being read out, but it can be received only when the satellite is within range of one of the 14 telemetry stations. At present both outputs are available in two forms, as pen recordings which can be made as the data is being converted from analogue to digital form, and as a list of printed numbers. Eventually, magnetic tape, the only practical way of dealing with large quantities of data, will be used to bring the information to Cambridge.

3. Bands of noise within the ionosphere.

Figure 1 shows pen recordings of eight successive sweeps of an early pass over Florida. The satellite was near apogee at a height of about 1,340 kms and had just passed into darkness. The following features are noticed.

1. Bands of noise at the low frequency end of the sweep.

2. The calibration frequencies at 1 and 2 MHz ; from these marks the frequency at any other point on the sweep can be found.

3. The noise at 2.3 MHz generated by the preamplifier associated with the ferrite loop aerial. As the R. F. amplifier is a broadband device, it follows that harmonics of the local oscillator can beat with the incoming signal, and, in particular, we see on these sweeps that there is a noise signal at 1.15 MHz, which is caused by the above 2.3 MHz noise together with the second harmonic of the local oscillator.

4. The input filter, which is responsible for the cut-off at 3.5 MHz in the figure, prevents radiation from higher frequencies being received using harmonics of the local oscillator. Nevertheless, some interfering signal of approximately

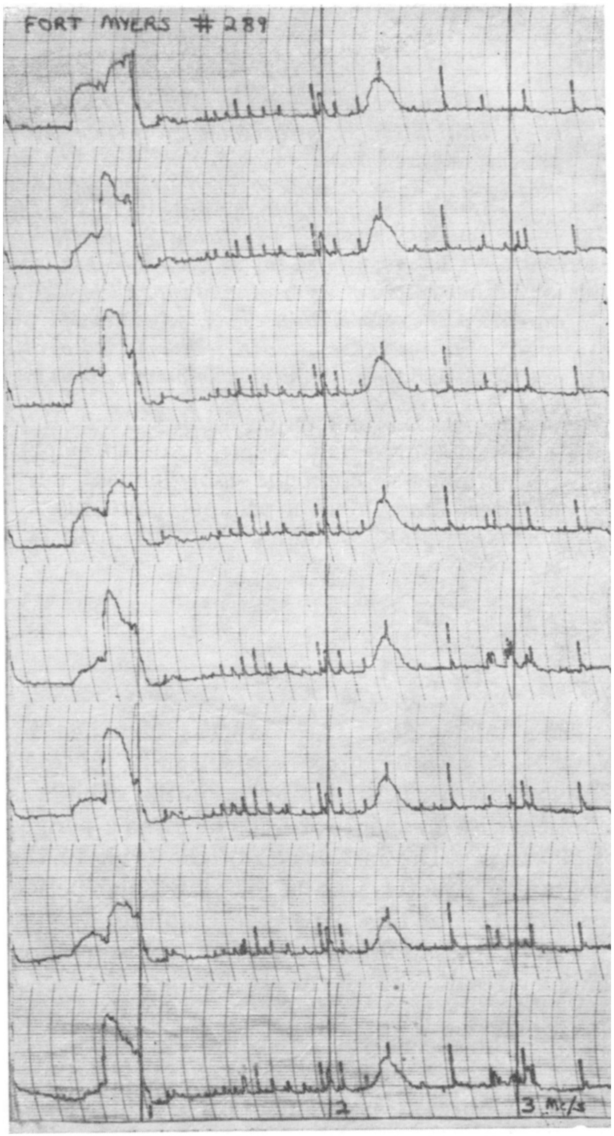

Fig. 1. — Pen recordings of eight successive sweeps, from the high speed telemetry output. The satellite was passing through apogee at 85° W, 10° N, just after sunset.

37.2 MHz, which appears to be generated within the satellite, can be seen interfering by beating with the eleventh and higher harmonics, forming the " spikes " which can be seen in harmonic progression on each sweep.

5. Apart from the above phenomena, at higher frequencies the noise level varies smoothly with frequency, rising to a maximum at about 3 MHz,

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Part of this is due to receiver frequency characteristics, and part is due to the spectrum of galactic radio emission ; Professor SMITH has already dealt with this aspect of the observations.

6. Given the plasma and cyclotron frequencies, which may be obtained in a way to be described, the frequency at which the extraordinary wave has a zero of refractive index, and is cut off, may be calculated. In this case it is about 1.2 MHz as can be seen there is a decrease in the noise level below this point, although the actual point of cut-off is hidden by the harmonic of the 2.3 MHz noise band.

There appear to be two bands of noise at the low frequency end of the sweep. From the satellite position, the cyclotron frequency f_H at the satellite can be calculated, and it has been found that if the lower edge of the upper noise band is assumed to be at a frequency $f = f_N$, the plasma frequency, then the upper edge coincides well with the frequency $f = (f_N^2 + f_H^2)^{1/2}$. That is, the noise band occupies the range $1 - Y^2 < X < 1$, where $X = (f_N/f)^2$ and $Y = f_H/f$ are the usual ionospheric parameters. It has also been found that the lower limit of the lower band corresponds to the frequency at which $X = 1 + Y$. This cut-off cannot usually be seen : indeed, it has disappeared in the last trace of figure 1. (As mentionned above, the receiver waits 3 seconds before starting to sweep) On this record, as on most $f_H > f_N$. What happens to the noise bands when $f_H > f_N$ is not yet clear, for although this condition frequently occurs, each time it has been observed so far ground breakthrough has spoiled the record.

The extraordinary mode which has a zero of refractive index when $X = 1 + Y$ is often referred to as the Z-mode. Figure 2 shows the familiar graph of the square of the refractive index plotted as a function of X for both the ordinary (O) and extraordinary (X) modes of propagation for the value $Y = \frac{1}{2}$, which is typical of values of $Y < 1$. In the calculation collisions have been neglected. The term Z-mode used by ionospheric physicists refers to propagation when the refractive index lies on that part of the extraordinary refractive index curve passing through R. As a ray enters the ionosphere it can be resolved into the O and X components, which, to a first approximation, can be thought of as propagating independently. The X component is reflected first at the level where X has risen to $X = 1 - Y$, and the O-component is reflected when $X = 1$. However, if the wave normals are close to the magnetic field direction, then the O curve and the Z-mode curve in figure 2 both pass near to P, close to which point both refractive indices change quickly

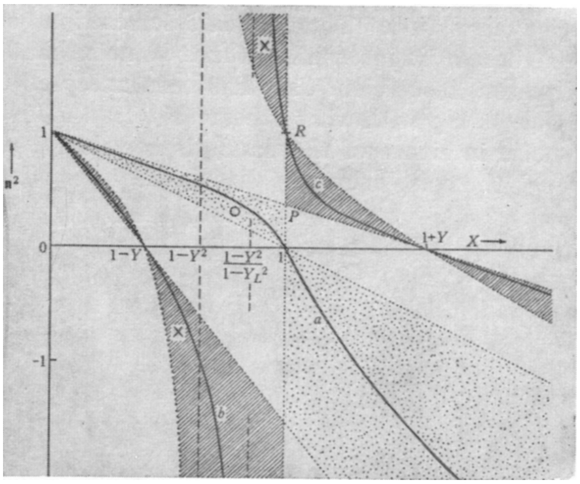

FIG. 2. — Variation of n² with X for intermediate inclination of the earth's magnetic field, when $Y < 1$. Electron collisions are neglected.

with associated rapid changes of polarisation. When collisions are taken into account, it is found that coupling occurs at this point, and energy is transferred from the O to the Z-mode. Since coupling can only take place when wave normals are close to the magnetic field directions, this is a possible focussing mechanism, and by studying the noise between $X = 1$ and $X = 1 + Y$ it may be possible to produce a relatively high resolution map of the sky at about $\frac{3}{4}$ MHz. But, in view of the amplitude of the signal, one may wonder whether the noise in the Z-mode is caused by some other mechanism.

It can be seen that the refractive index of the Z-mode reaches a very large value (infinite neglecting collisions) for a certain inclination of the wave normal to the magnetic field direction for all values of X between $X = 1$ and $X = 1 - Y^2$, the range of the upper noise band observed on the records.

Polarisation of the signals can be determined by a method to be explained below, and it is found that the electric vector of the signal between $X = 1$ and $X = 1 + Y$ is predominantly perpendicular to the magnetic field. It seems that energy is propagating in the Z-mode, and originated from coupling at the level where $X = 1$.

In the other noise band, at frequencies where X is slightly less than unity the electric field appears to be almost parallel to the magnetic field, and at the other end of the band, where X is slightly greater than $1 - Y^2$, there appears to be little polarisation. There is little correlation between the relative intensities of the two noise bands. At present insufficient data has been analysed to be able to say with what other variables the level of noise in either of the bands is correlated, although the noise below the plasma frequency does appear to be related to the geomagnetic latitude of the satellite and possibly the galactic coordinates of the magnetic field line direction, and the other noise band is generally rather less intense near Woomera than at any other station.

A further noise band has been observed on some passes. It is a low frequency band, and there is a cut-off at the upper end which can sometimes be seen at the lower end of the sweep, as in figure 3. It is often observed just as interference from the ground is being picked up at about 1 MHz. No expression for this cut-off in terms of the ionospheric parameters has yet been found, nor has the polarisation been determined. From the low-speed records it appears that this phenomenon is associated with sunrise and sunset : there are also abnormal amounts of interference at these times.

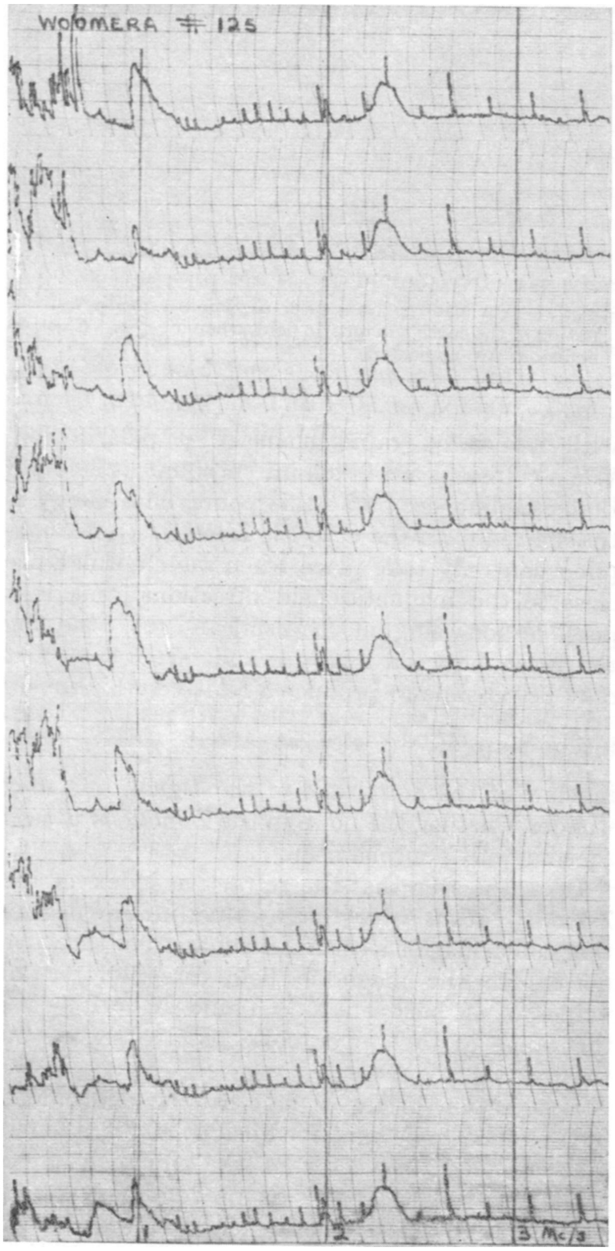

Fig. 3. — As in figure 1, the satellite approaching apogee ot 142° E, 19° S a little after sunset.

4. Determination of satellite spin axis direction.

The telemetry system operates at a frequency of 136.56 MHz. The satellite telemetry antenna has four elements arranged symmetrically about the spin axis and fed in quadrature, so that the signal is circularly polarised in the direction of

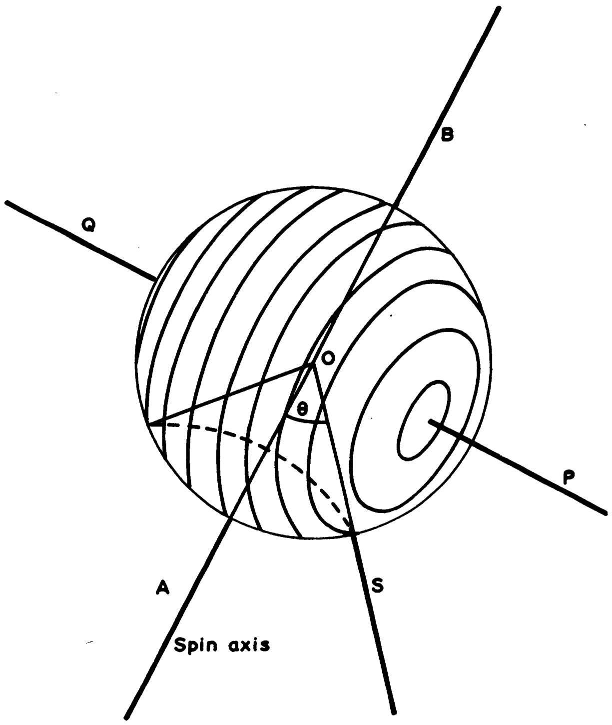

Fig. 4. — Schematic representation ot the polar diagram of the energy re-radiated from the long dipole antenna.

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this axis. The long dipole antenna of the Cambridge experiment intercepts and reradiates part of the telemetry signal to produce a radiation polar diagram as shown in figure 4.

The lines represent the directions of maximum fringe intensity. A-B is the spin axis direction, and the polar diagram has cylindrical symmetry about P-Q, the dipole aerial direction. It can be seen that, as the satellite rotates, the fringes cross the fixed line O-S representing the direction of the tracking station. The number of fringes seen per revolution depends upon the angle θ between the spin axis direction and the line of sight of the tracking station, and will vary sinusoidally between zero when $\theta = 0$ and a maximum of $L/\lambda = 18.2$ when $\theta = \frac{\pi}{2}$. The level of the telemetry signal received at the tracking station can be recorded, and figure 5 shows a recording of the A. G. C. voltages on the receivers. The top line shows the A. G. C. voltage of the amplifier, receiving right hand circularly polarised signals and the lower two lines show the voltage of the other amplifier on left hand polarisation. The modulation caused by the rotation of the satellite is very clear. The period A-B corresponds to one half revolution of the satellite. The variation of the fringe frequency as the satellite crosses the sky relative to the tracking station can be seen. The minimum fringe frequency occurs when θ is a minimum, and the condition for this is

$$s.z = 0 \quad \text{where } z = r \times (r \times v)$$

and s is the spin axis direction
r is the position of the satellite,
relative to the tracking station, v is the velocity of the satellite. From the time at which the minimum number, N_{min}, of fringes per revolution occurs the position and velocity of the satellite can be found, and the vector z calculated. If another linearly independent value of z is found from another recording, then the direction s may be calculated. In practice, to reduce the bulk of data, only two tracking stations are producing these A. G. C. records on selected passes, and on the records examined so far, the vectors z determined on successive passes have been almost parallel. However, by measurement of N_{min}, the angle θ may be estimated, and so, using z, the direction s may be calculated. Agreement between independent determinations indicates that errors are less than 5°. Figure 6 shows a map of the spin axis direction between the 24th and the 47th days after launch.

At the times A and B, and similar times, in figure 5, the satellite aerial is in the plane containing the s and r. Having determined the spin axis, the orientation can now be calculated as a

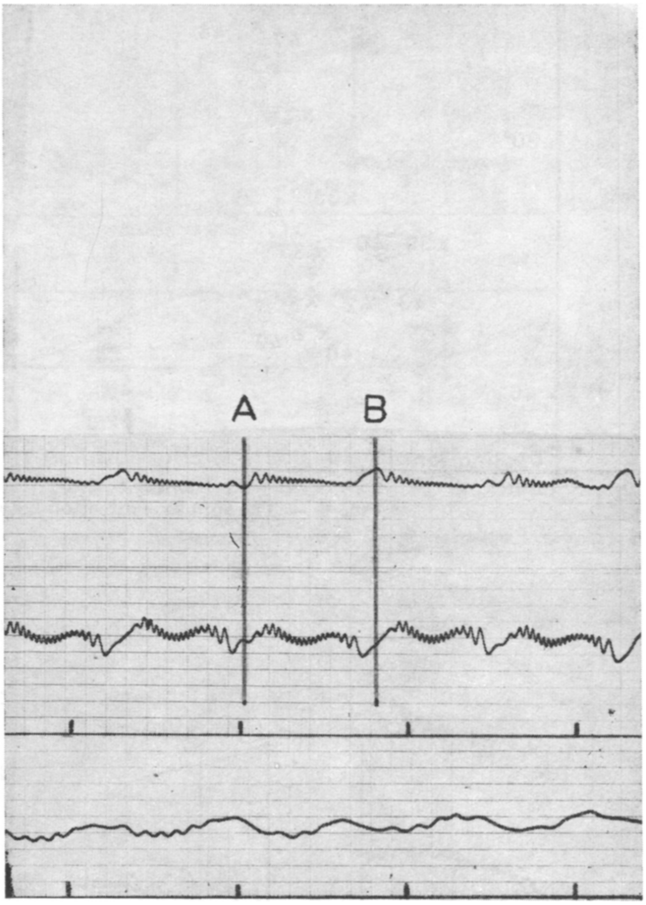

FIG. 5. — Recordings of the A. G. C. voltages on the telemetry receivers during part of a pass. The top and middle lines show the voltage on the receivers operating on right and left circular polarisation respectively, and the bottom line shows the left circular polarisation later during the pass. The modulation caused by the rotation of the satellite can be seen clearly.

function of time. Figure 7 shows a plot of the first parts of two successive sweeps on a pass occurring just after apogee. Also plotted is $\cos^2\alpha$, where α is the angle between the aerial direction and the computed magnetic field direction. There is good correlation, and when $\cos^2\alpha = 1$, so that the aerial is along the magnetic field line direction (at A), the signal is receiver noise only, indicating that the noise at frequencies below the plasma frequency is predominently polarised perpendicular to the magnetic field. The next figure is similar, four sweeps later. At

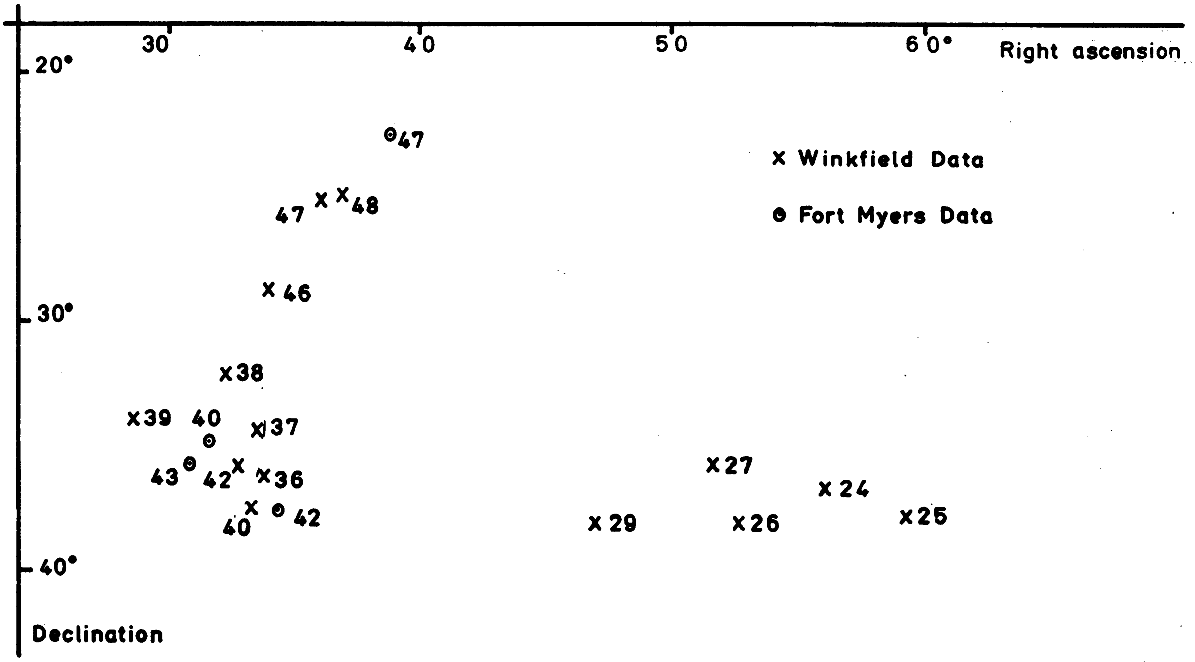

FIG. 6. — The spin axis direction between the 24th and 47th days after launch.

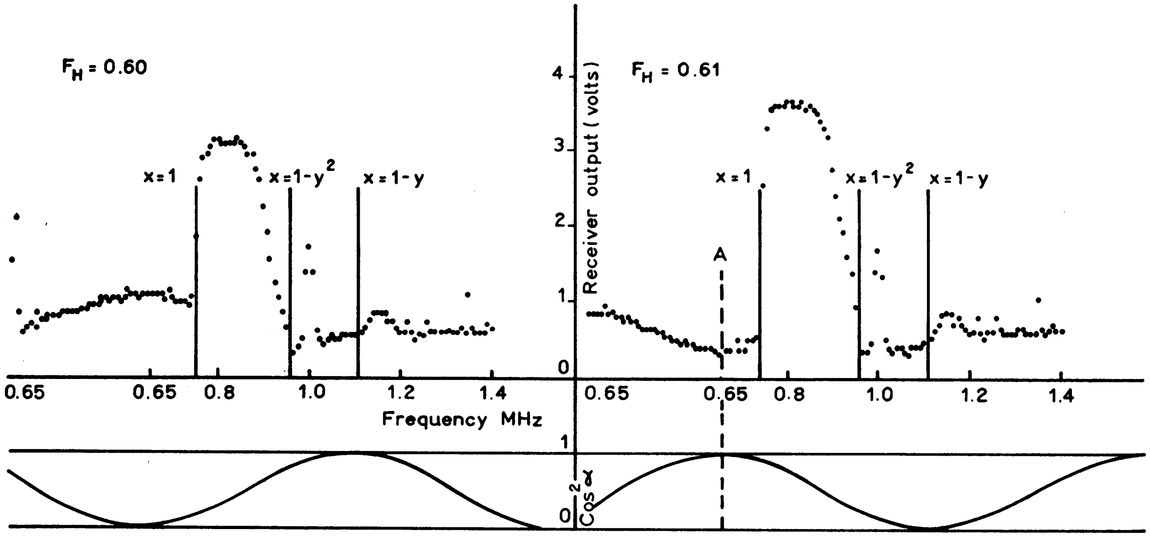

FIG. 7. — The output of the receiver plotted from the start of the sweep to 1.4 MHz for two successive passes. Also shown is the square of the cosine of the angle between the aerial and the magnetic field direction.

point where $X = 1$ the aerial is perpendicular to the magnetic field and the edge of the noise band $1 - Y^2 < X < 1$ is very much reduced in amplitude ; at this point the polarisation is mainly along the magnetic field direction. It will be possible to determine the polarisation of the other, lower frequency, noise band when a suitable pass such as was shown in figure 3 is found together with the data for determining the orientation during that pass.

From the A. G. C. records the spin rate of the satellite can be determined, although in sunlight this is better done using data from one of the other experiménts on board. The changes in spin rate are not understood. Initially the decay was much greater than expected, but there was a period of about three weeks in June during which the spin rate actually increased ; but then it continued to decrease and is now (August 10th) 1.8 r.p.m., and increasing again.

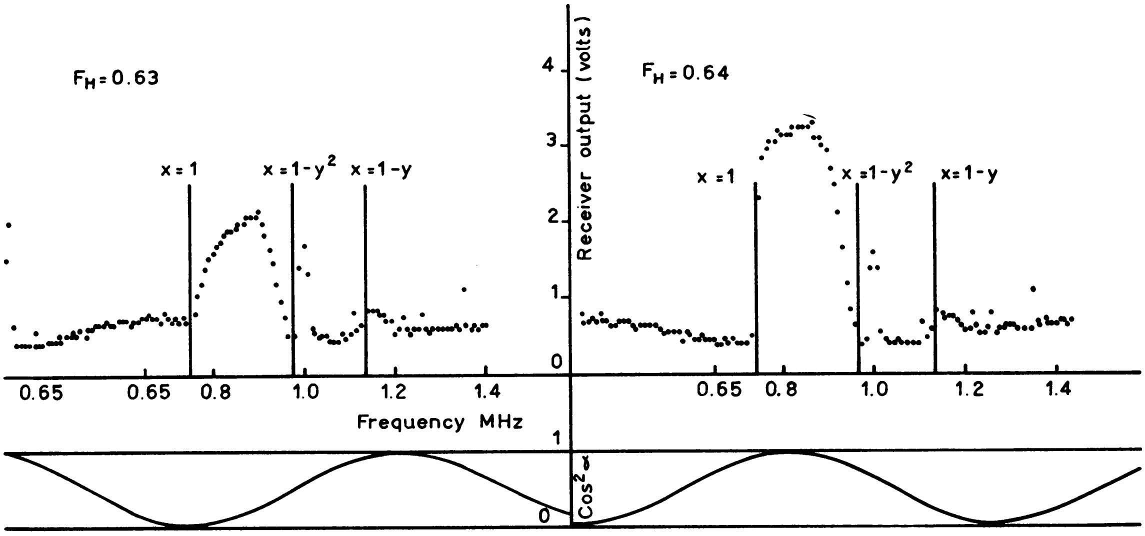

FIG. 8. — As in Figure 7, two minutes later.

Work at present continues on the many problems mentioned above. If Z-mode focussing looks promising for obtaining relatively high resolution observations of the sky, a full wave investigation of the problem will be undertaken.

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