NRL Report 6830

Electron-Content Variations and Change Rates Obtained During the Spring and Summer of 1967 by the Measurement of Faraday Rotation of 137-MHZ Radio Waves Transmitted from ATS-1

JOHN M. GOODMAN, MELVIN W. LEHMAN, AND EDWARD PIERNIK

Radar Geophysics Branch
Radar Division

March 17, 1969

NAVAL RESEARCH LABORATORY
Washington, D.C.

This document has been approved for public release and sale; its distribution is unlimited.

CONTENTS

Abstract	ii
Problem Status	ii
Authorization	ii
BACKGROUND AND JUSTIFICATION	1
SYSTEM DESCRIPTION AND MEASUREMENTS	1
DATA ANALYSIS	2
DISCUSSION	16
CONCLUSIONS	21
REFERENCES	22

ABSTRACT

Vhf radiowave transmissions (137.350 MHz) from the geostationary satellite ATS-1 (1966-110A) have been analyzed to determine the electron-content variations during the Spring and Summer of 1967. The regularities of the ionosphere during the observation period were found to be roughly the same as those which were observed during the Early Bird observation period of 1965. In particular it was found that there exist two extremal regions of the content-change rate function—one associated with sunrise and one associated with sunset.

Irregularities in the electron content were observed to occur during both magnetically quiet and disturbed days, although extremely dramatic enhancements were recorded following two magnetic storms.

Although a Chapman distribution is barely justifiable theoretically, it was found that the diurnal content excursion is roughly proportional to the diurnal excursion in the square of $f0F2$ as predicted by simple Chapman theory.

PROBLEM STATUS

This is an interim report on one phase of the problem.

AUTHORIZATION

NRL Problem R02-05
Project RF 05-151-402-400

Manuscript submitted October 22, 1968.

ELECTRON-CONTENT VARIATIONS AND CHANGE RATES OBTAINED DURING THE SPRING AND SUMMER OF 1967 BY THE MEASUREMENT OF FARADAY ROTATION OF 137-MHz RADIO WAVES TRANSMITTED FROM ATS-1

BACKGROUND AND JUSTIFICATION

The study of radiowave transmissions from the synchronous satellite Early Bird (1965-28A) yielded some interesting features of the ionosphere which have since been published (1,2). The magnitudes of both the Faraday rotation and the amplitude scintillation were determined, and the ionospheric electron content and the motion of irregularities were extracted from these data. The simplicity of these measurements was a result of several factors. First the satellite was geostationary, making it possible to receive transmissions with a high-gain narrow beamwidth antenna for long periods of time without modification. Therefore, from the analytical point of view, the magnetic field parameter $\overline{H \cos \theta \sec \chi}$ could be considered approximately independent of time. Also, the satellite transmitter power and polarization characteristics were approximately constant functions of time. These factors made it possible to associate changes in the electric vector orientation and electric field intensity with ionospheric characteristics.

ATS-1 is a synchronous satellite, which was launched on December 7, 1966. Its geostationary nature and antenna attitude made it possible to conduct measurements similar to those associated with the Early Bird. The nominal coordinates for ATS-1 during the experiment were such that the azimuth was 259.5 degrees, and the elevation was 4.75 degrees — as compared with the Early Bird azimuth and elevation of 119 and 24 degrees, respectively. The exceedingly low value of elevation during the present set of measurements was expected to make the study of true content variations more difficult, since ionospheric tilting and horizontal gradients present a potentially serious problem for highly oblique paths. Moreover, ionospheric refraction and path splitting are an order of magnitude more severe near the horizon than at high elevations. However, since the magnetic control over various ionospheric propagation effects which are readily detectable at low elevation might be equally as interesting as the unperturbed total content, a study of the ATS-1 transmissions was felt to be a worthwhile undertaking.

SYSTEM DESCRIPTION AND MEASUREMENTS

The Randle Cliff facility includes a 150-ft-diameter dish antenna (Fig. 1), which has a beamwidth of 3.6 degrees at 138.6 MHz — the vhf radar frequency which is typically employed during radar observations of missile payloads, meteors, satellites, and the radio aurora. The feed system associated with the antenna is shown in Fig. 2 and consists of four vertical dipoles and two horizontal dipoles. Figure 3 is a block diagram of the receiving system used during the ATS-1 experiment. In brief the system may be described as follows: Ahead of the dual-channel Remanco Model SR-108 receiver are two vhf preamplifiers (one for vertical and one for horizontal polarization) with a gain of 10 dB. The receiver has a sensitivity of 0.3 μV and a noise figure of 5.0 dB for a 50-Ω antenna input impedance. Its overall frequency stability is $\pm 0.005\%$, and the i-f bandwidth is 40 kHz at a frequency of 120 kHz. After frequency conversion to 120 kHz, the vertical and horizontal components of the satellite signal were fed into the amplifiers of an x-y oscilloscope to reproduce the polarization orientation visually. These x-y tracings were

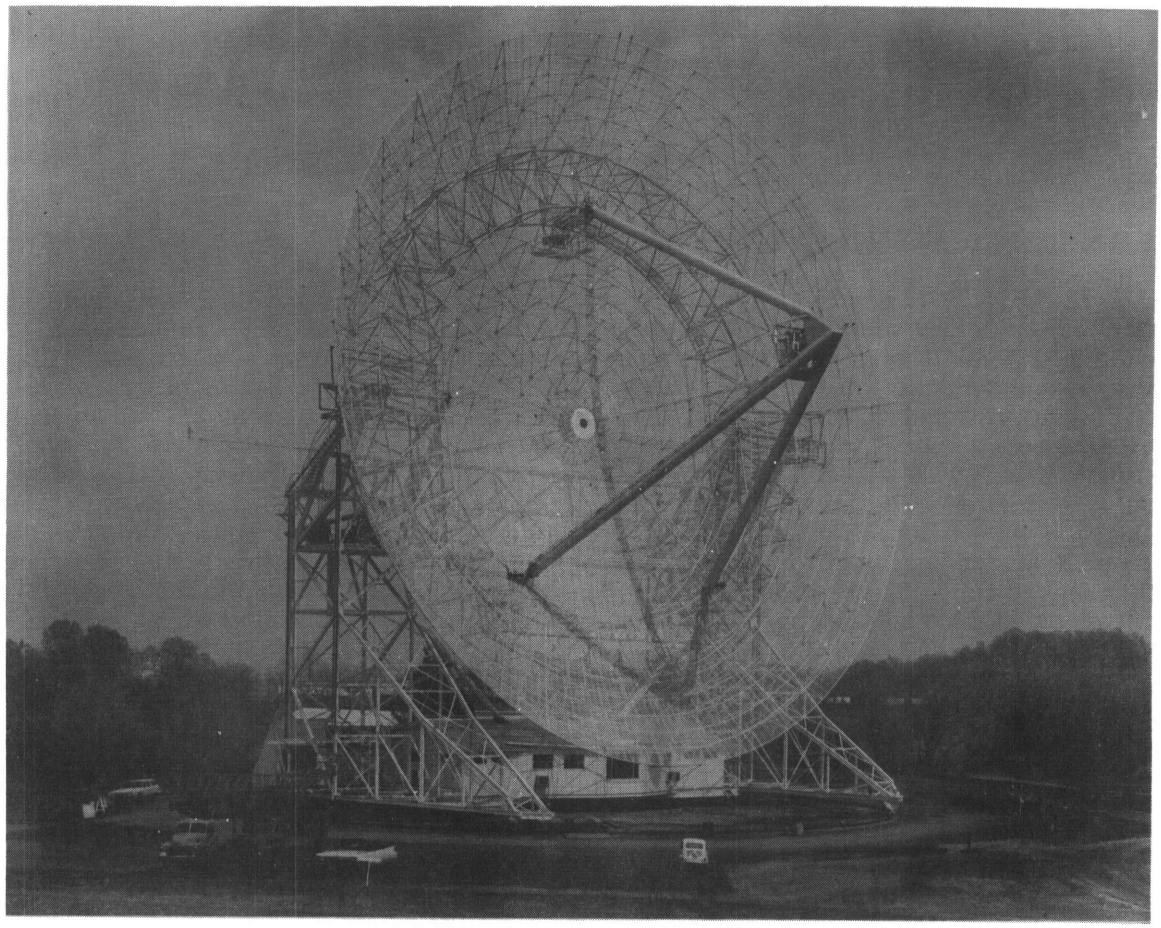


Fig. 1 - Randle Cliff 150-ft-diameter antenna

photographed at a frame rate of one per minute on 35-mm film. The output signals were also fed into a Sanborne recorder model 154-100B; pen recordings of the vertical and horizontal polarization signal amplitude were made.

Film data were analyzed manually to determine the ambiguous polarization orientation, and the pen recordings served as a back-up system. The polarization angle and angular rate data were put on punched cards, and a Hewlett-Packard data plotting system (model 2031E) was used to translate the digitized data into graphical form.

DATA ANALYSIS

Figure 4 illustrates the observation periods which are considered in this report. Uninterrupted recording periods for which polarization orientation information was effectively continuous are denoted by run numbers. A total of approximately 1900 data hours is included in this study (490 in April, 677 in May, 244 in June, 182 in July, and 307 in August). All data were considered in the analysis of the electron-content change

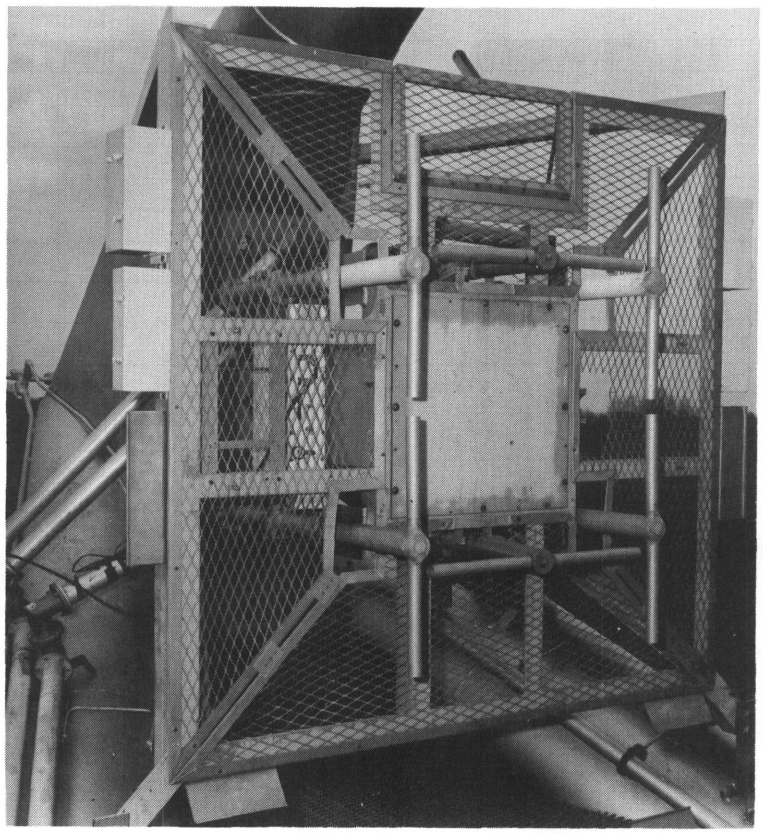


Fig. 2 - Vhf antenna feed assembly

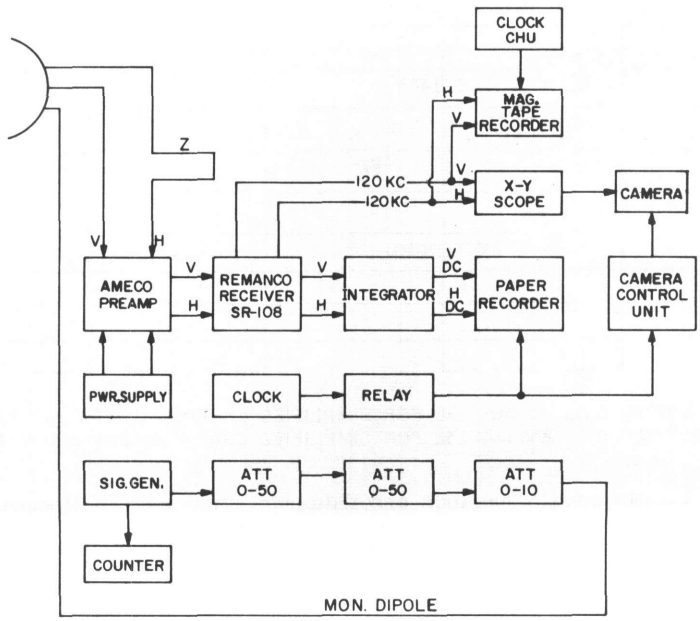
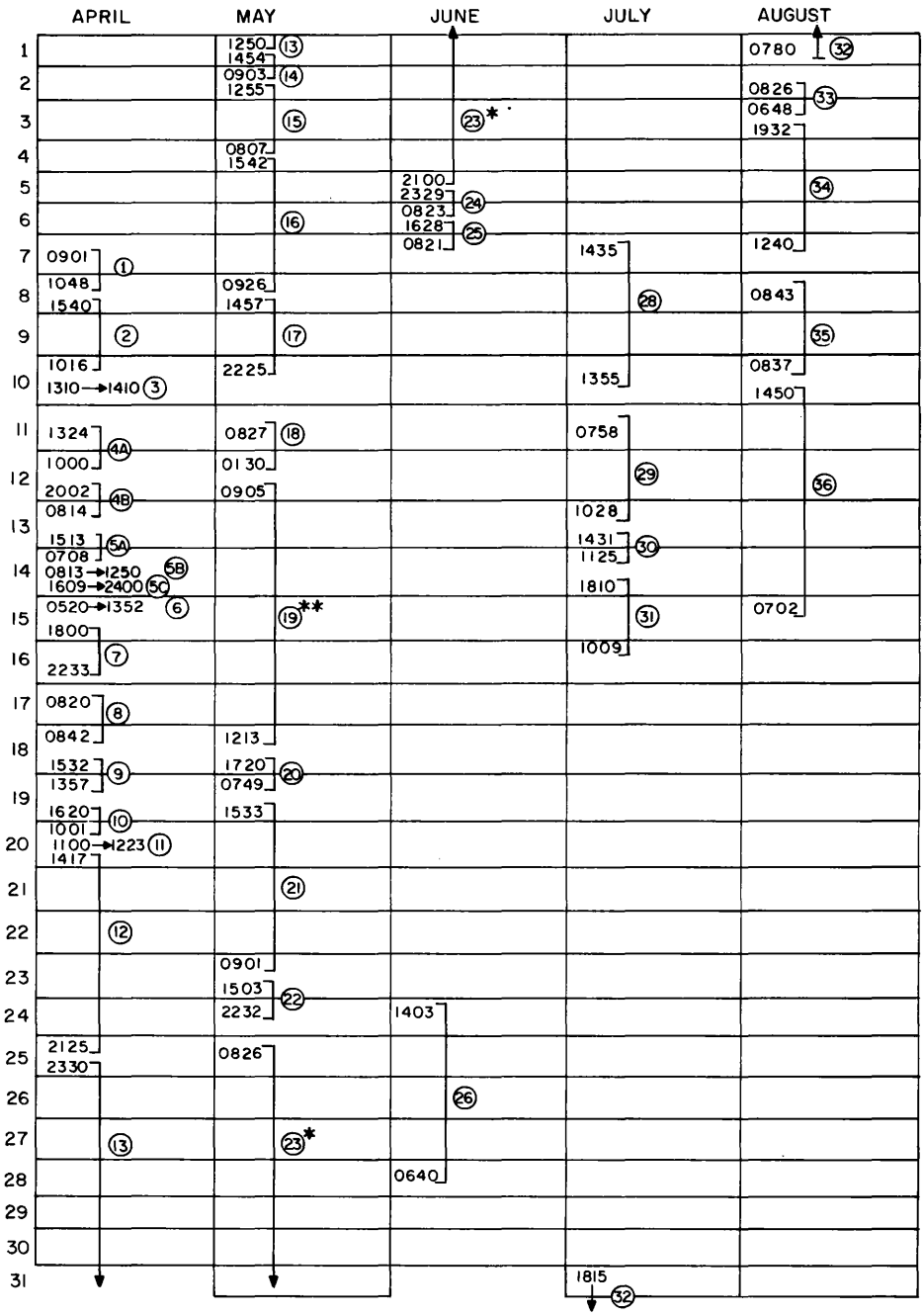


Fig. 3 - Receiving and data reduction system



** SEGMENTED AS 19A AND 19B FOR SIMPLIFIED GRAPHICAL REPRESENTATION
* SEGMENTED AS 23A AND 23B FOR SIMPLIFIED GRAPHICAL REPRESENTATION

Fig. 4 - Observation periods and data run numbers. The longest observation period corresponding to run 23 was from 0826 EST on May 25, 1967, to 2100 EST June 5, 1967.

rates, whereas only sufficiently long runs* were considered in the analysis of the long-term electron-content data. The significant continuous runs were 12, 13, 16, 17, 19, 21, 23, 26, 28, 34, 35, and 36; these runs comprised about 70% of the data recorded between April 7, 1967, and August 16, 1967.

Figures 5a through 5n display the diurnal variations of the ambiguous Faraday rotation angle Ω; Figs. 6a through 6e represent the Faraday rotation rates and the electron-content change rates dC/dt (in absolute value) for the months of April, May, June, July, and August, respectively.

The amount of Faraday rotation of the ATS-1 radiowave electric vector was generally ambiguous; hence, it was not possible to determine the absolute electron content. The chief justification for the experiment flows from the fact that true *variations* in content are measurable for the case of synchronous satellite transmissions. It is interesting to note, however, that it is possible under certain conditions to resolve the polarization ambiguity at a single frequency in the vhf domain, as indicated in the following procedure:

Suppose that the amount of Faraday rotation Ω is strictly defined by the relation

$$\Omega = \Gamma(f_0F2)^2, \tag{1}$$

where $(f_0F2)^2$ is the square of the $F2$ maximum critical frequency, and is itself proportional to the $F2$ maximum electron density, and Γ is a function which accounts for all other functional dependences of Ω. In particular, if we assume that the ionosphere is Chapman distributed,

$$\Gamma = \Gamma(\text{ray path geometry},\ f,\ H_s,\ hF2), \tag{2}$$

where f is the radio frequency, H_s is the neutral atmospheric scale height, and $hF2$ is the altitude of the $F2$ maximum. Furthermore, for single-frequency transmissions from a synchronous satellite, there is no necessity to consider the magnetic field variations due to ray path orientation changes; hence,

$$\Gamma = \Gamma(H_s,\ hF2). \tag{3}$$

Therefore, the rotation rate is

$$\frac{d\Omega}{dt} = \frac{d\Gamma}{dt}(f_0F2)^2 + \Gamma\frac{d}{dt}(f_0F2)^2. \tag{4}$$

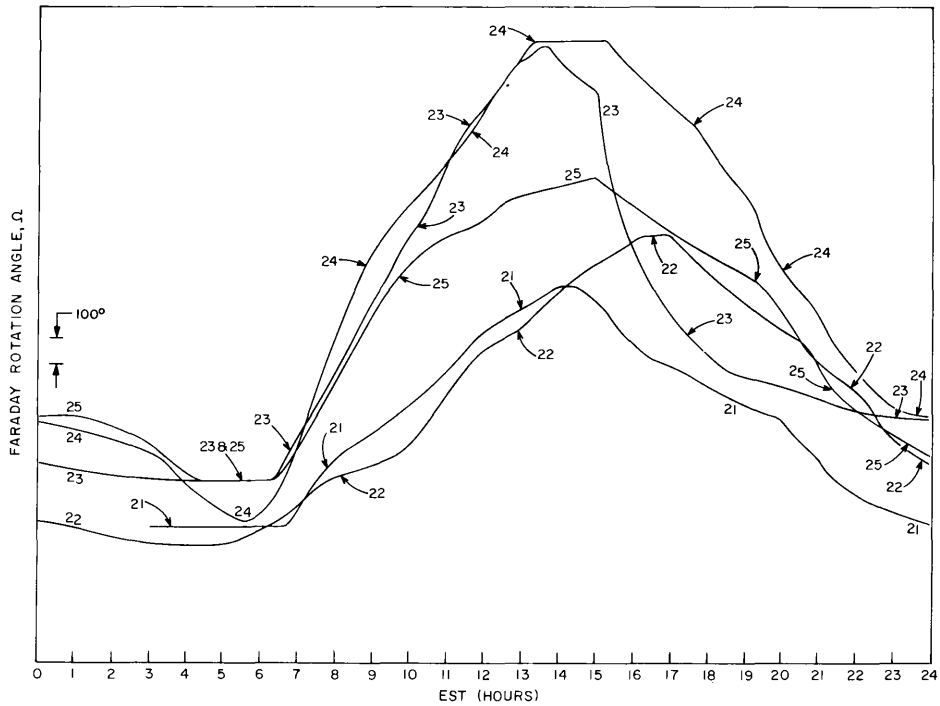
Hence,

$$\Gamma = \left[\frac{d\Omega}{dt} - \frac{d\Gamma}{dt}(f_0F2)^2\right]\Big/\left[2(f_0F2)\frac{d}{dt}(f_0F2)\right]. \tag{5}$$

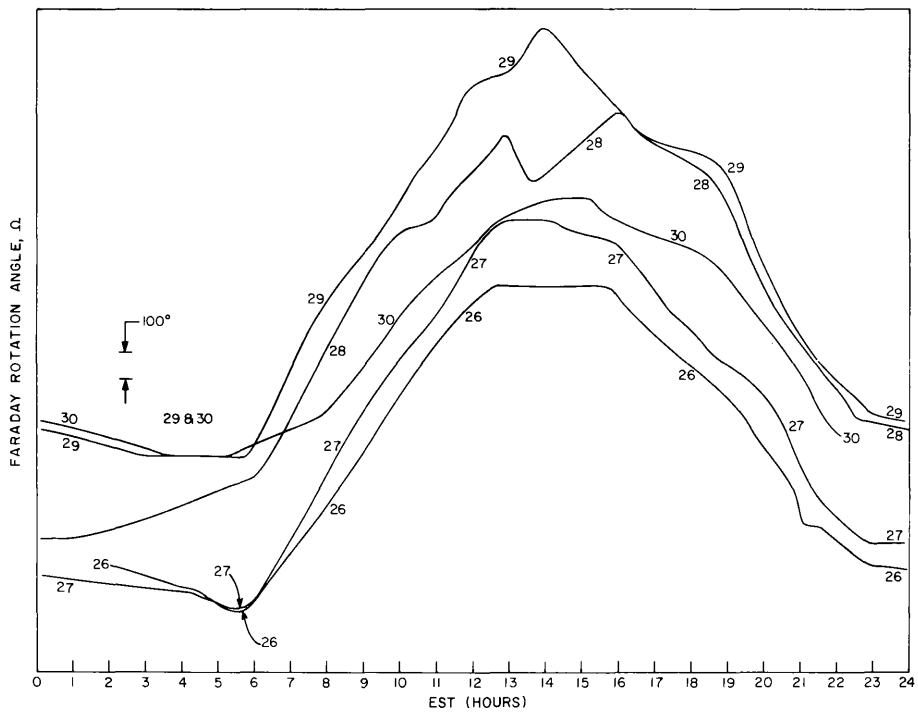
Substituting Eq. (5) into Eq. (1) we have

$$\Omega = (f_0F2)^2\left[\frac{d\Omega}{dt} - \frac{d\Gamma}{dt}(f_0F2)^2\right]\Big/\left[2(f_0F2)\frac{d}{dt}(f_0F2)\right]. \tag{6}$$

*A run was considered to be sufficiently long if it comprised a continuous record of polarization data which had a duration in excess of 48 hr. This was to allow some comparison of the daily behavior of the electron content.

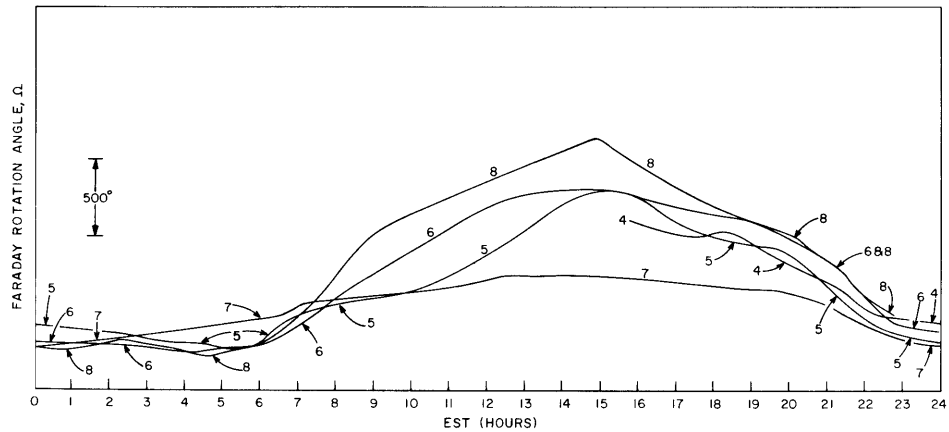


(a) April 21 and April 25, 1967

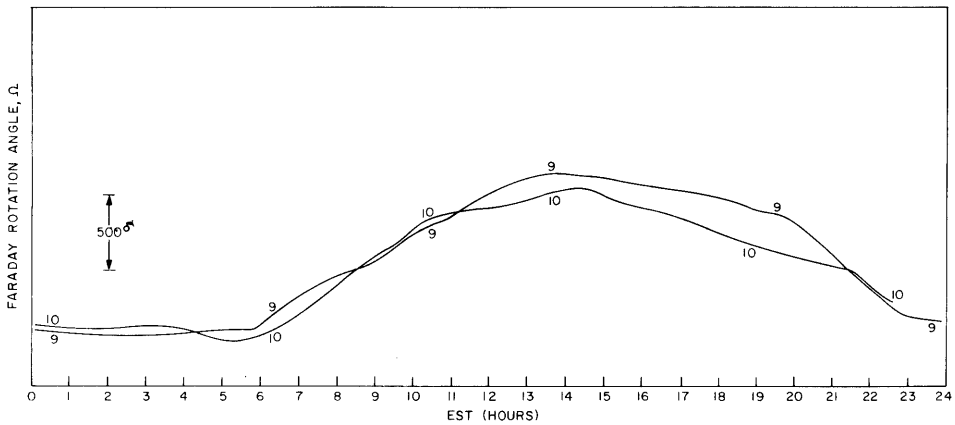


(b) April 26 and April 30, 1967

Fig. 5 - Diurnal variations of the ambiguous Faraday rotation angle between the periods denoted, inclusive. The baseline reference level is arbitrary.

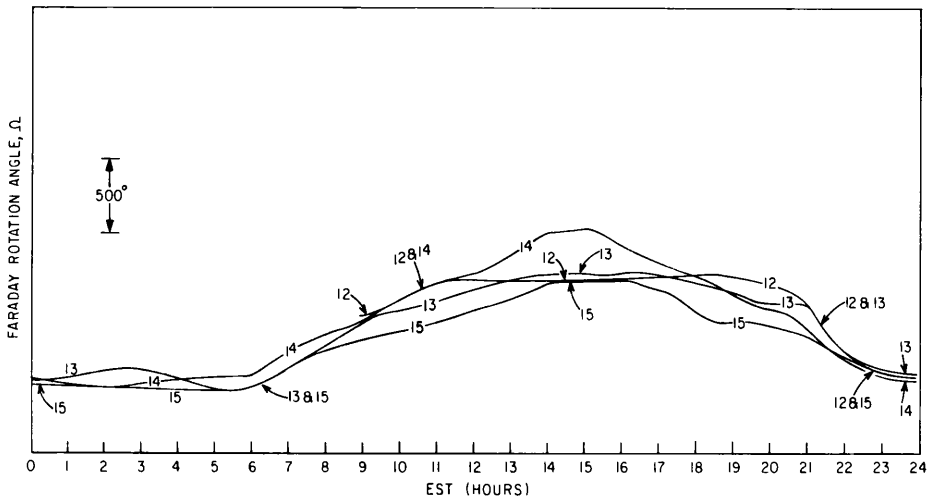


(c) May 4 and May 8, 1967

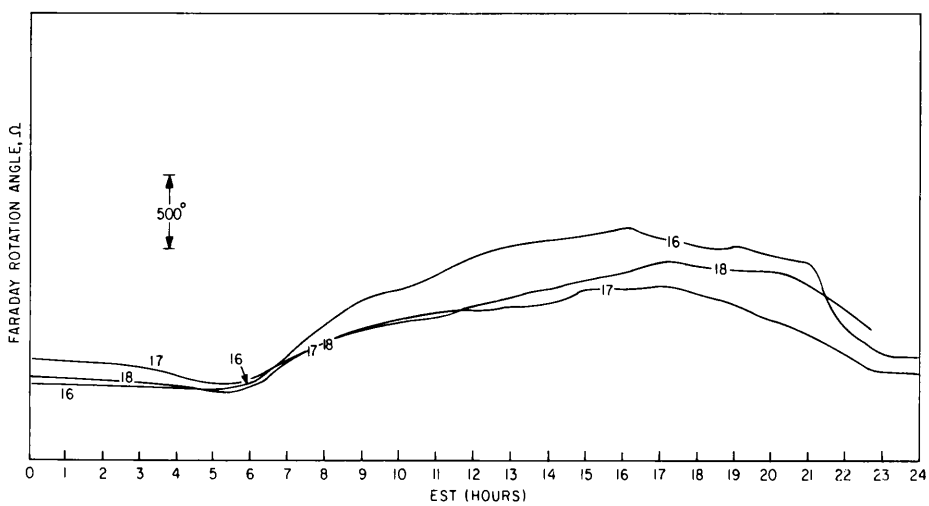


(d) May 9 and May 10, 1967

Fig. 5 - Diurnal variations of the ambiguous Faraday rotation angle between the periods denoted, inclusive. The baseline reference level is arbitrary (Continued).

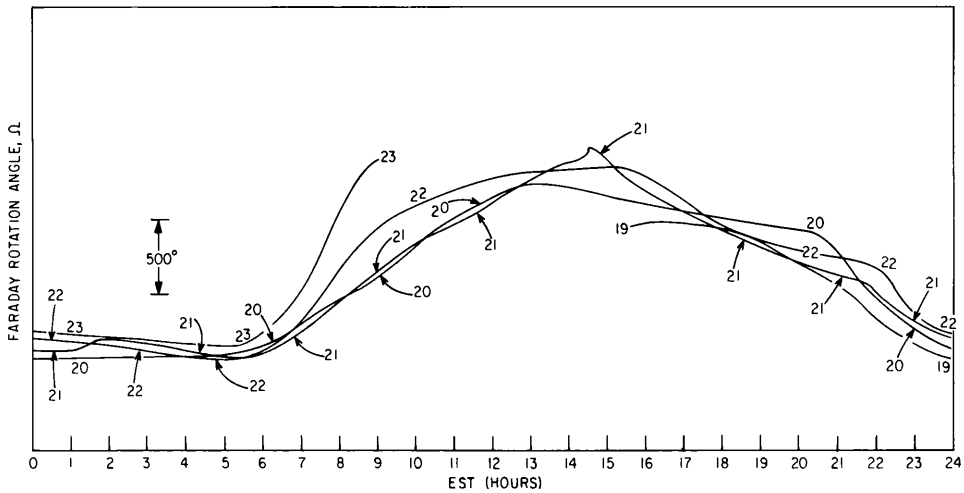


(e) May 12 and May 15, 1967

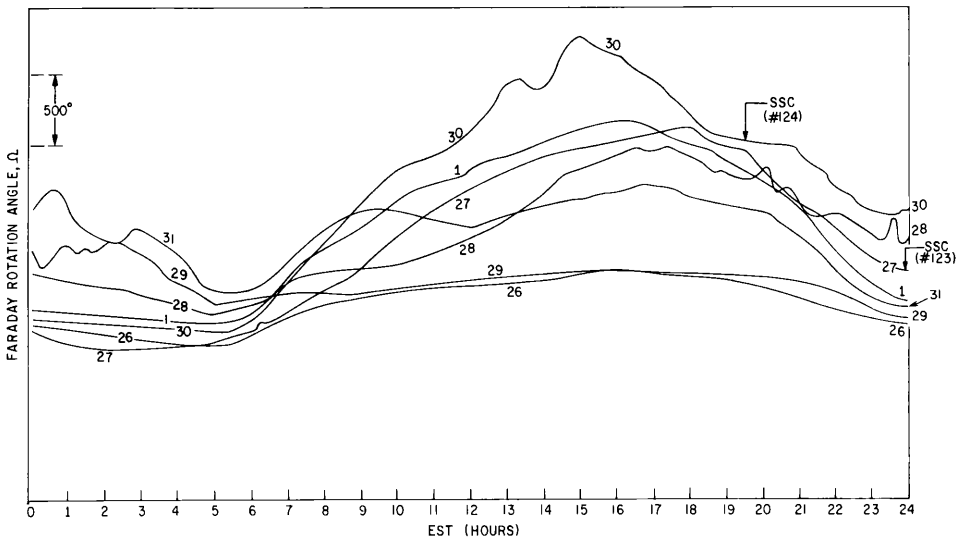


(f) May 16 and May 18, 1967

Fig. 5 - Diurnal variations of the ambiguous Faraday rotation angle between the periods denoted, inclusive. The baseline reference level is arbitrary (Continued).

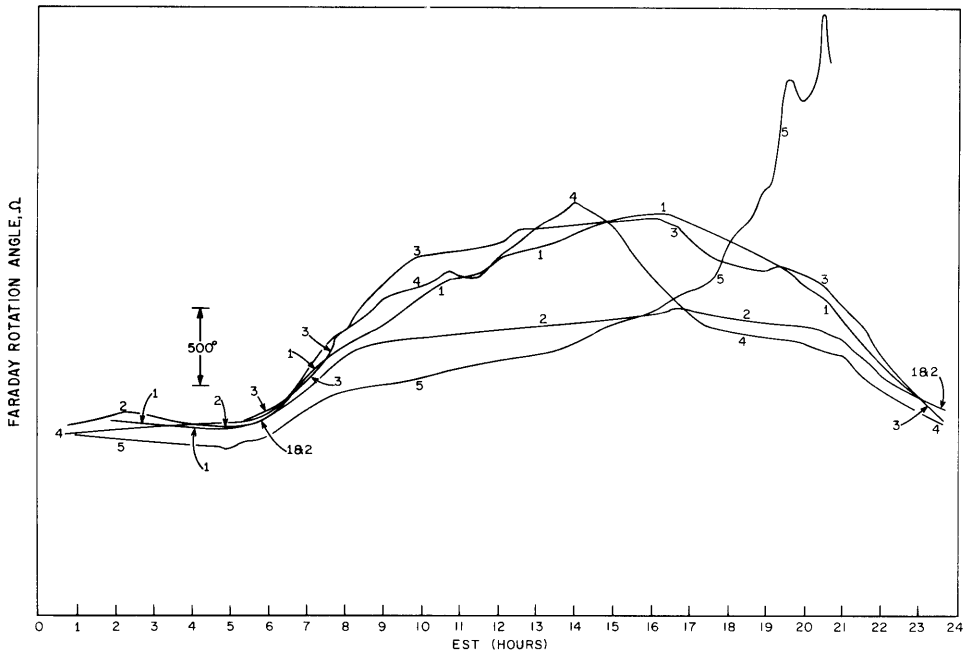


(g) May 19 and May 23, 1967

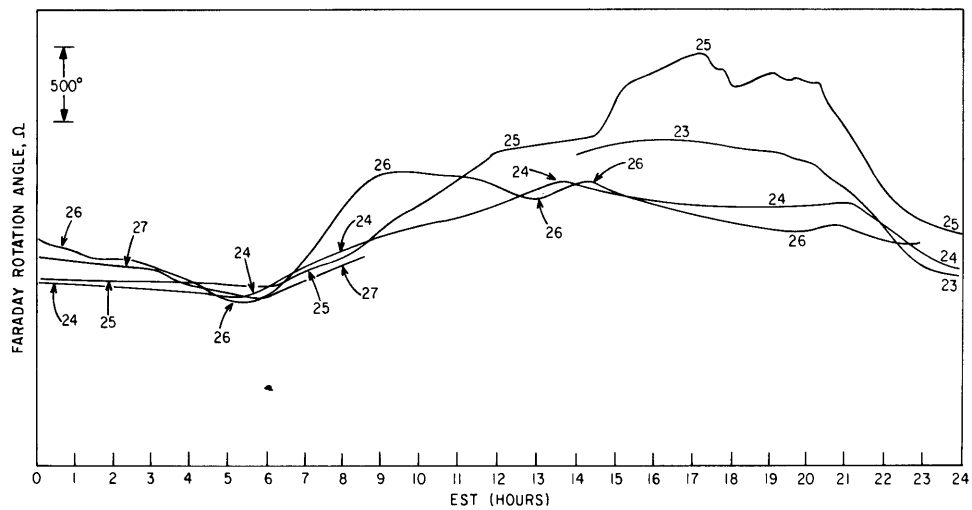


(h) May 26 through May 31 and June 1, 1967

Fig. 5 - Diurnal variations of the ambiguous Faraday rotation angle between the periods denoted, inclusive. The baseline reference level is arbitrary (Continued).

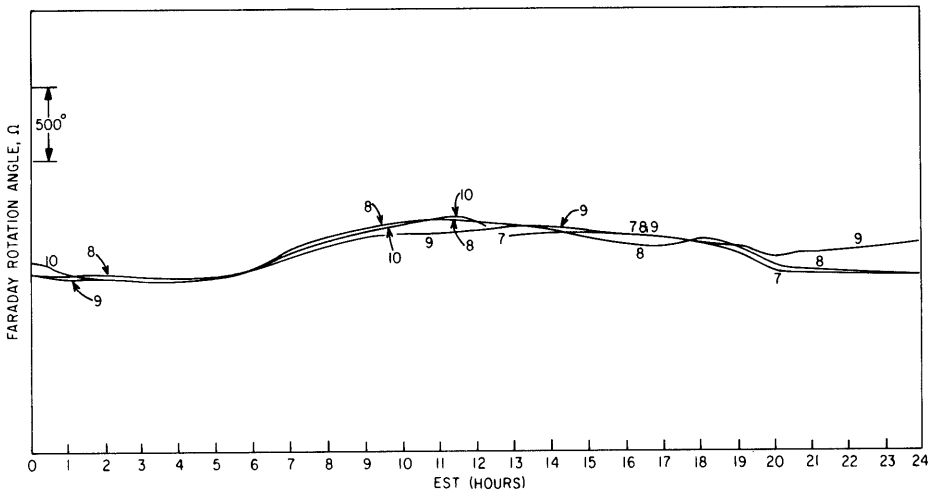


(i) June 1 and June 5, 1967

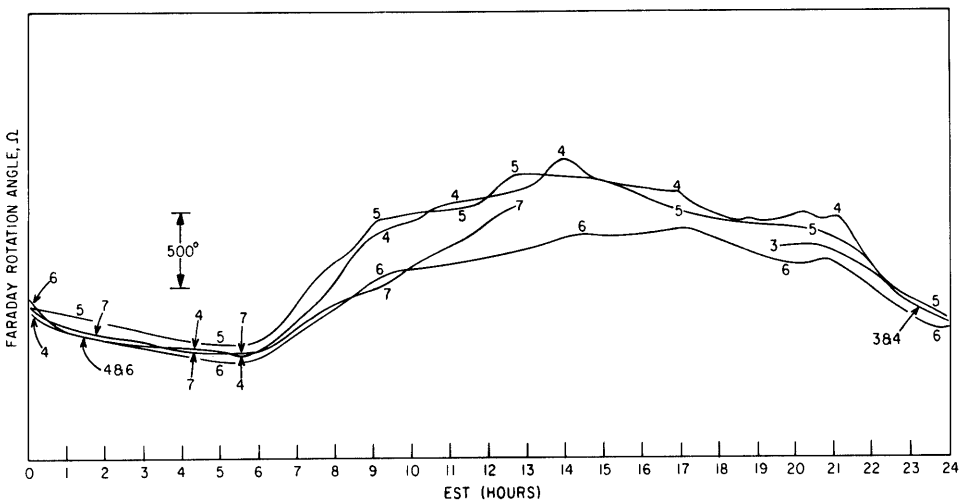


(j) June 23 and June 27, 1967

Fig. 5 - Diurnal variations of the ambiguous Faraday rotation angle between the periods denoted, inclusive. The baseline reference level is arbitrary (Continued).

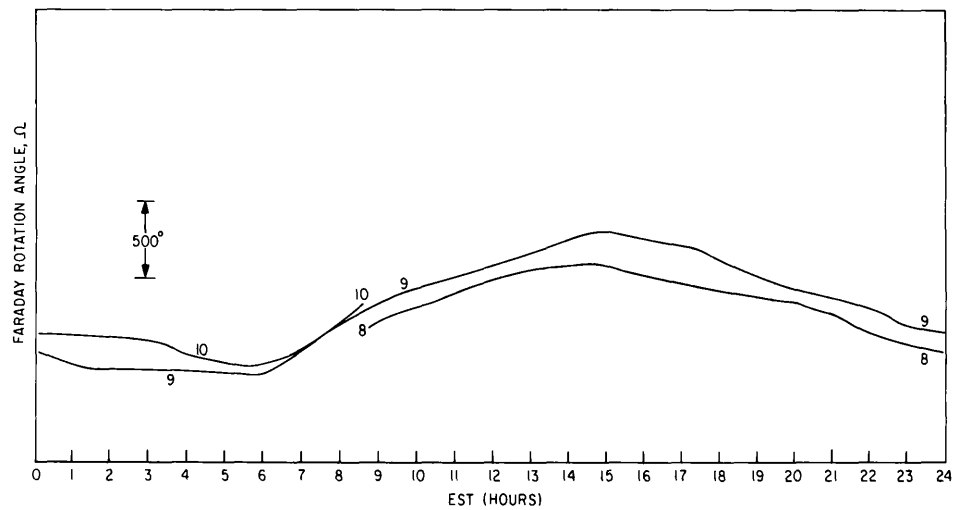


(k) July 7 and July 10, 1967

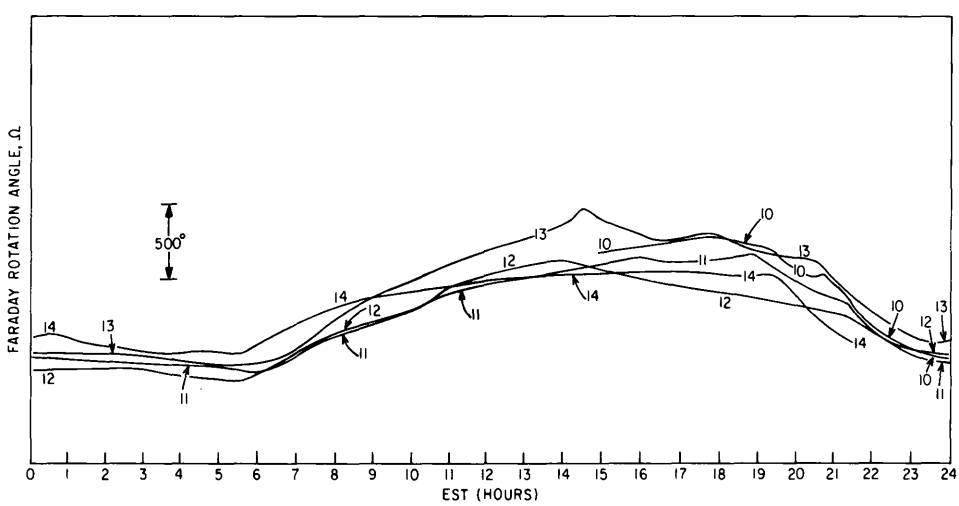


(l) August 3 and August 7, 1967

Fig. 5 - Diurnal variations of the ambiguous Faraday rotation angle between the periods denoted, inclusive. The baseline reference level is arbitrary (Continued).

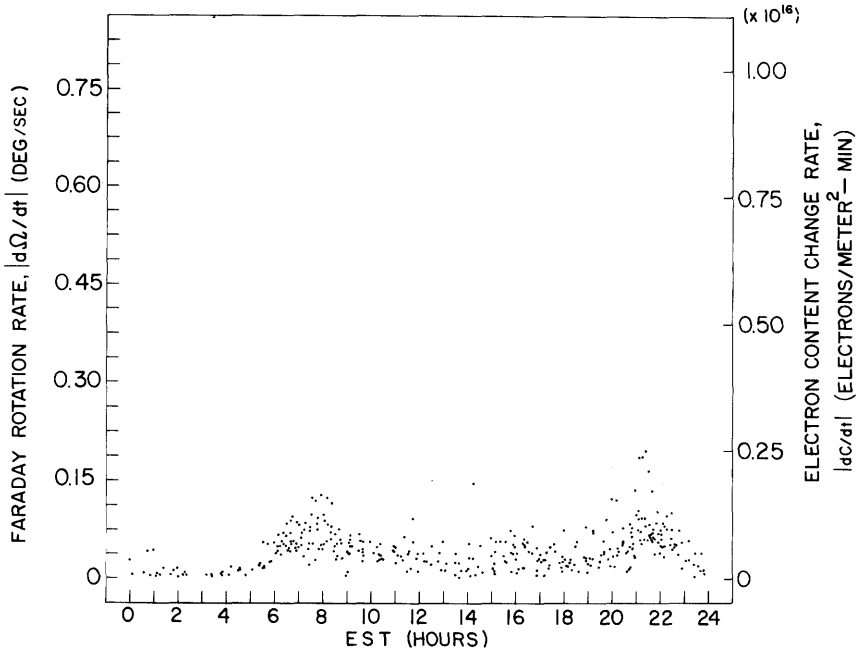


(m) August 8 and August 10, 1967

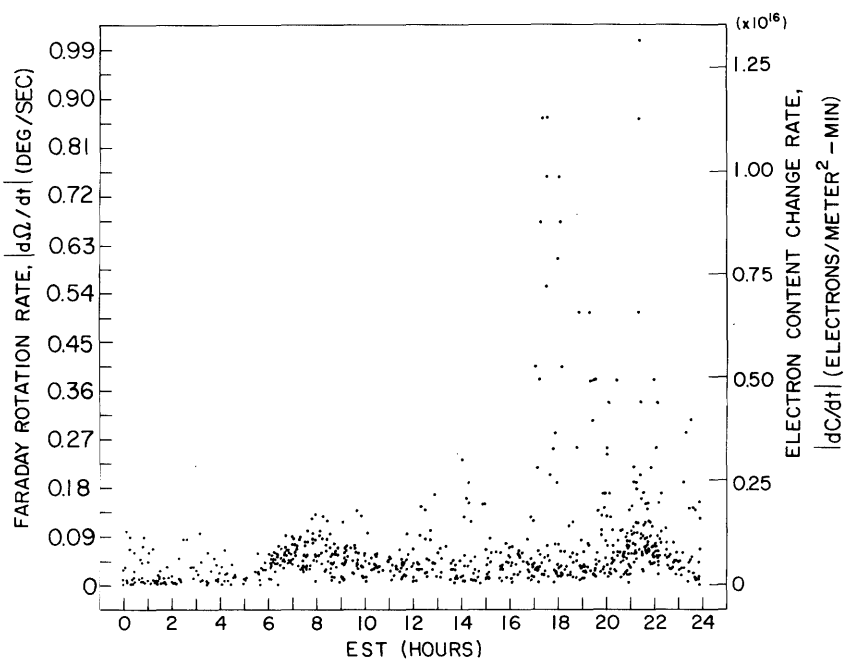


(n) August 10 and August 14, 1967

Fig. 5 - Diurnal variations of the ambiguous Faraday rotation angle between the periods denoted, inclusive. The baseline reference level is arbitrary (Continued).

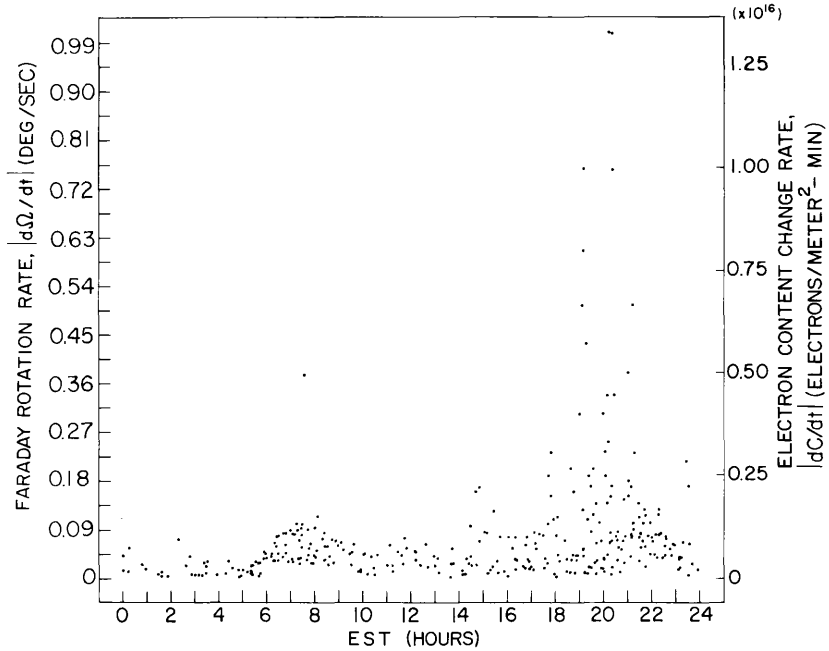


(a) April 1967

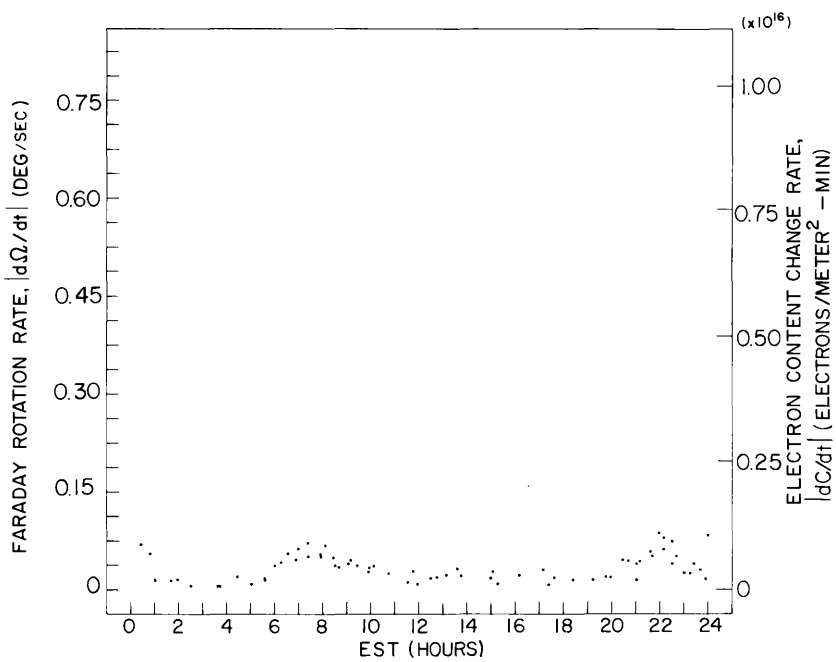


(b) May 1967. Note the large afternoon values due to magnetic storm 122 on May 25.

Fig. 6 - Absolute values of the Faraday rotation rate $|d\Omega/dt|$ in units of degrees/second for the indicated month. Also depicted are the electron-content change rates $|dC/dt|$ in units of electrons/meter^2-minute.

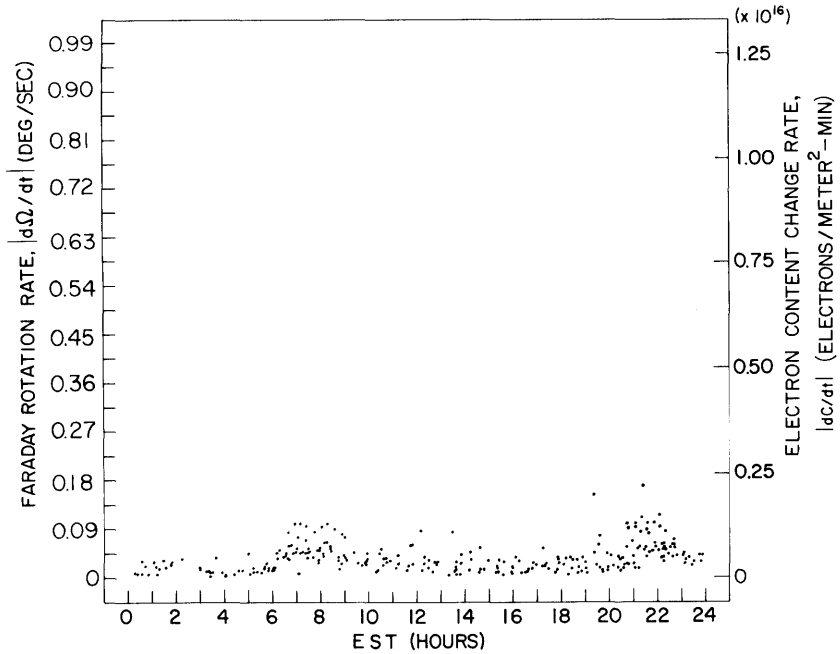


(c) June 1967. Note the large afternoon values due to magnetic storm 125 on June 5.



(d) July 1967

Fig. 6 - Absolute values of the Faraday rotation rate $|d\Omega/dt|$ in units of degrees/second for the indicated month. Also depicted are the electron-content change rates $|dC/dt|$ in units of electrons/meter^2-minute (Continued).



(e) August 1967

Fig. 6 - Absolute values of the Faraday rotation rate $|d\Omega/dt|$ in units of degrees/second for the indicated month. Also depicted are the electron-content change rates $|dC/dt|$ in units of electrons/meter^2-minute (Continued).

If $d\Gamma/dt = 0$, then

$$\Omega = \left[\frac{f_0F2}{2}\ \frac{d\Omega}{dt}\right] \Big/ \left[\frac{d}{dt}(f_0F2)\right], \tag{7}$$

which is a simple prescription for deducing Ω. It depends only on a knowledge of f_0F2, the rate of change of f_0F2, and the Faraday rotation rate. The functions f_0F2 and $d(f_0F2)/dt$ may be determined from vertical incidence ionosonde, and $d\Omega/dt$ is determined from the Faraday fading records. Unfortunately, however, the conditions under which Eq. (7) was derived do not hold in general. In practice overestimates of Ω are obtained during morning hours, and underestimates are obtained in the late afternoon. These incorrect estimates of Ω result from negating the term $d\Gamma/dt$, which is positive as the ionosphere is being "warmed" and is negative as the ionosphere is being "cooled."

A number of investigators have successfully resolved the polarization ambiguity of synchronous satellite transmissions by a variety of techniques. Klobuchar and Whitney (3) used a 220-MHz lunar radar technique, which was possible since the amount of polarization rotation was typically less than 180 degrees during nocturnal hours at that frequency. By deducing the electron content from S-66 and/or BE-C radiowave transmissions (at 40 and 41 MHz) when the satellites were in the viewing-aspect neighborhood of Early Bird, Checcacci (4) was able to resolve the ambiguity in rotation associated with Early Bird transmissions. Nakata (5) claims some success in resolving the ambiguity by a technique not too dissimilar than that outlined in the previous paragraph. A technique for converting rotation angle to electron content has also been described by Garriott, et al. (6).

Without resorting to the use of Eq. (7), no fruitful technique was open to us at the time of observation for resolving the polarization ambiguity. As a consequence, the results in this report are relative with regard to content. However, they are absolute with regard to the amount of buildup or decay which occurs (or the integrated production and loss rates which correspond to these build-up and decay processes).

DISCUSSION

The striking regularities of ionospheric behavior can be seen by examining Figs. 5. The daily behavior is in general characterized by a buildup in ionization after sunrise and a decay in ionization in the late afternoon. The region of most rapid buildup (on quiet days) occurs shortly after ground sunrise and has a duration of 2 to 3 hr, if one arbitrarily defines the "most rapid" region such that it is associated with an electron-content change rate which is at least twice that of the midnight and/or midday values. The region of most rapid decay occurs several hours after ground sunset being centered at approximately 2130 EST. It also has a duration of 2 or 3 hr on quiet days. Another quiet-day ionospheric regularity is the "nocturnal plateau" region between 2300 EST and ground sunrise. This is a period in which little or no ionization is being produced; evidently, dN/dt (the electron density time derivative) is controlled by loss mechanisms, such as electron-ion recombination. (In some instances photoelectrons from the conjugate sunrise region may enhance the local content prior to local sunrise.) Of course this situation should hold immediately after sunset. Why does the flat region occur much later? Well, the rate at which electrons recombine with positive ions is proportional to the product of the number of positive ions and the number of electrons which are present. Quite obviously this rate must decrease as the population of free electrons and positive ions is reduced by recombination. This is of course a simplified argument, since it neglects a competing loss process — attachment — which depends only on the number of electrons which are present. In the attachment case electrons "attach" themselves to neutral atoms. Since the reduction in the supply of neutral particles due to ionization is wholly negligible, we may compute the electron-loss rate due to this process by forming the product of the electron density and the attachment coefficient β, which represents the cross section for the process. Both of these competing processes predict a flattening of the electron-content curve following sunset as the ionosphere begins to deplete its copious supply of free electrons. The termination of the plateau is usually abrupt at sunrise as the photoionization process quickly overcomes electron loss as the dominant process.

It is rather interesting to note that the electron-content plateau level is evidently not closely tied to the peak value of content obtained on the preceding day. Look for example at Fig. 5a, which corresponds to Run 12. We see that the Faraday rotation difference corresponding to the April 22 and 23 plateau regions is about the same order as the difference in the peak values of rotation Ω on April 21 and 22 and in the proper direction. However, the plateau value on April 24, although not too well defined, was in general comparable with the plateau value on April 23, while the midday peak value of Ω was considerably larger on April 23 than on April 22. In a similar manner one may by inspection find examples which suggest a lack of close correlation between the plateau level difference and the peak value difference on following days.

Some other interesting features of the Faraday rotation curves — which are assumed to represent the total electron content of the ionosphere to within an additive content — are the distortions which occur. By far the most striking are the effects of magnetic storms. Figure 7 shows the rapid enhancement in Ω on May 25, 1967, which corresponds to the positive phase of a magnetic storm which commenced at 1735 EST. This storm effect is the subject of another report* and need not be discussed in detail here. However, possible explanations for the observed enhancement in Ω are

*NRL Memorandum Report 1858, March 1968.

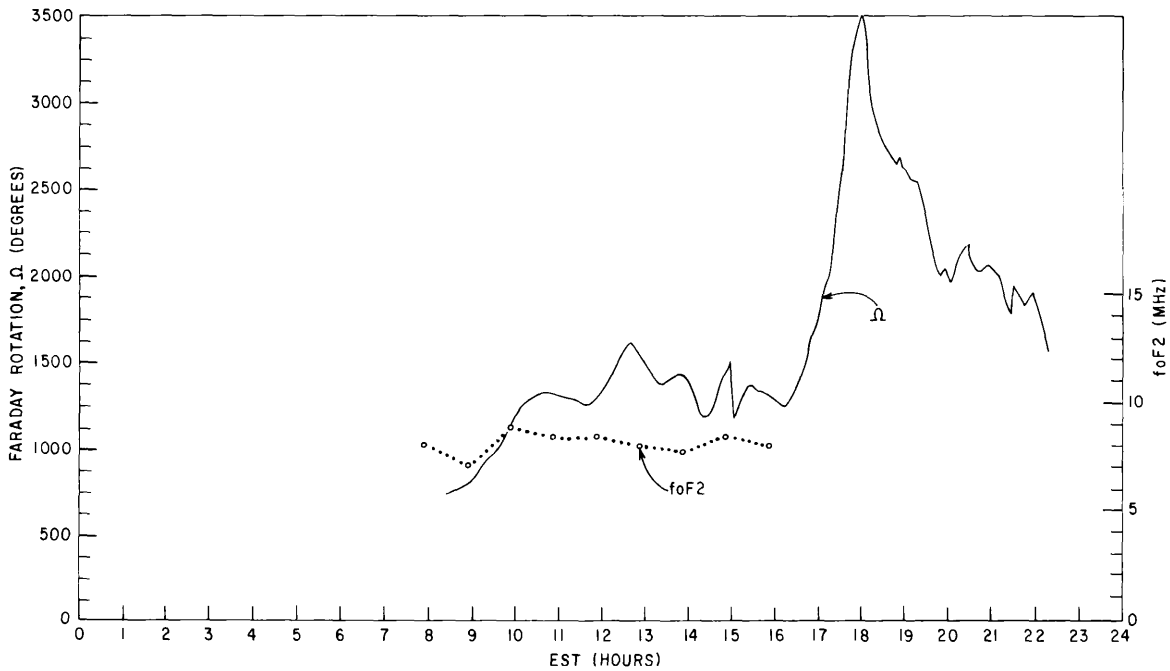


Fig. 7 - Ambiguous Faraday rotation and f_0F2 values (Ft. Belvoir) associated with magnetic storm 122 on May 25

1. Large east-west gradient in $hF2$,

2. Large increase in plasma scale height due to heating via MHD waves, thus producing a decrease in the electron loss rate,

3. Excess ionization production associated with the energetic storm particles through particulate collisions,

4. Down-drift of already existing ionization, or dumping from above, and

5. Electrodynamic raising of electrons to high altitudes where collisions are infrequent and losses are less severe.

Recent dispersive doppler measurements by Hibberd and Ross (7) show that large excursions in content do arise during the positive phase of magnetic storms. In fact they conclude that the content may become twice as large as that which exists prior to the onset of the storm.

Another example of a large-scale rotational enhancement occurred on June 5, 1967. The Ω curve is among those depicted in Fig. 5i and is redrawn in Fig. 8 along with the ionosonde values of f_0F2 obtained from Ft. Belvoir. This excursion in Ω coincided with the main phase of magnetic storm 125. With regard to the rotational excursion for this storm, we are in a more reasonable position to assess the probable causal mechanism since no sudden ionospheric disturbance was in evidence over Ft. Belvoir. We see from Fig. 8 that f_0F2 roughly corresponds to the shape of the Ω curve, which suggests that the ionosphere is exhibiting a real increase in the total population of electrons during the early evening hours. This is due either to a decrease in electron loss or an increase in electron production. There is certainly no need to invoke the possibility of gradient enhancement in this case, although it is admitted that this effect may be present to some extent. This feature of the June 5 data suggests that the May 25 excursion was likewise associated with a real total ionospheric buildup in electron population due to increased production or decreased loss. However, each storm must be considered individually.

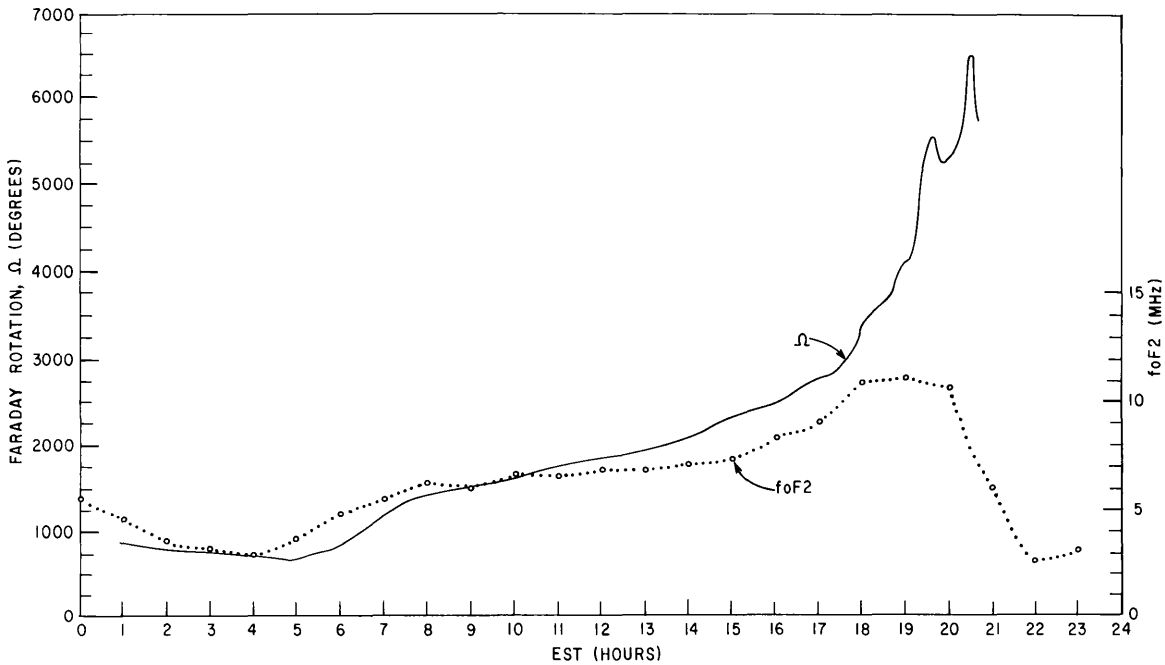


Fig. 8 - Ambiguous Faraday rotation and f_0F2 values (Ft. Belvoir) associated with magnetic storm 125 on June 5

The justification for considering the behavior of the ionosphere during storms on an individual basis may be found, as before, by resorting to examples. The storm corresponding to the Ω curve on Fig. 8 (which is also depicted on Fig. 5i) and called magnetic storm 125 possessed an A storm index* of 60. The storm associated with the Ω curve depicted in Fig. 7 is denoted magnetic storm 122 and possessed an A index of 240. Even though the storms were considerably different in terms of some sort of integrated magnitude, their Faraday rotational effects were nearly identical. On the other hand two other storms occurred between May 26 and June 4. Storm 123 commenced at approximately 2400 EST on May 27, and storm 124 commenced at approximately 1929 EST on May 30. Storm 123 had an A index of 53, and storm 124 had an A index of 59. As we can see from Fig. 5h no gross distortions in Ω occur at the onset of these storms.

The existence of large-scale quiet-day† perturbations may be seen on some of the days for which Faraday rotation information was obtained. These occur on April 28 (Fig. 5b), May 4 and May 8 (Fig. 5c), May 13 (Fig. 5e), May 21 (Fig. 5g), June 3 and June 4 (Fig. 5i), July 8 (Fig. 5k), and August 4, 5, and 6 (Fig. 5l).

Perturbations (of the undramatic variety) also occurred on disturbed days. In Fig. 5h we note that kinks appear on the Ω curves corresponding to May 28, 29, and 30. On these days the A_{FR} indices were 35, 35, and 37, respectively. Curves corresponding to June 25 and 26 on Fig. 5j for which the A_{FR} indices were 22 and 18, respectively, exhibit very marked perturbations. The May disturbances are associated with magnetic storm 123, and the June disturbances are probably related to magnetic storm 127. The A storm indices for storms 123 and 124 were — as indicated previously — 53 and 59, respectively, and the A storm index for storm 127 was about 27.

*The A storm index is an integrated index of magnetic activity which is more or less proportional to the total excess activity related to a particular storm. The A_{FR} index is the daily Fredericksburg magnetic activity index.

†Here quiet day implies that the A_{FR} index for the day was less than 15. Higher values of A_{FR} will imply disturbed days.

Perturbations of the variety pointed out in the two preceding paragraphs probably result from traveling ionospheric irregularities in the F region such as those detected by Thome (3). These have also been noticed by Titheridge (9). On inspection of Fig. 9, it is clear that traveling disturbances are also present in the 1965 Early Bird data (1).

Another interesting feature of the Ω curve is the diurnal excursion.* Figure 10 shows the diurnal rotational excursions $\Delta\Omega$, in addition to the content excursion ΔC, plotted as functions of the diurnal excursion in the quantity $(f_0F2)^2$. Note the rough correlation which indicates that the F-region electron density partially controls the total content. For convenience we may write

$$\Delta\Omega(\text{electrons}/m^2) = 1.24 \times 10^{10} \tau \Delta (f_0F2)^2, \tag{8}$$

where τ is the slab thickness in meters and f_0F2 is the $F2$ region maximum critical frequency in megahertz. Since $\Delta\Omega$ is very roughly a linear function of $\Delta(f_0F2)^2$, we may infer that

1. The ionosphere roughly approximates some sort of Chapman behavior and

2. The effect of temporal variations in τ is less than the effect of temporal variations in F-region electron density.

If τ were a constant, we would anticipate a perfectly straight line, if ΔC were strongly tied to $\Delta(f_0F2)^2$. However, if τ and f_0F2 were independent random variables, we would expect the data in Fig. 10 to be noisy. To some degree both linearity and noisiness are evidenced. Of course this argument is of necessity on shaky ground, since the justification for the use of Eq. (8) is questionable. In fact recently the interpretation of the slab thickness in terms of mean electron-ion temperature has suffered (10). Nevertheless, it is an interesting exercise to evaluate the mean slab thickness to which the data on Fig. 10 correspond. The median straight-line fit to the data is given by

$$\Delta\Omega(\text{degrees}) = 20 \Delta (f_0F2)^2.$$

Also

$$\Delta C(\text{electrons}/m^2) = 3.50 \times 10^5 \Delta NF2$$

implies that τ = 350 km since $\Delta NF2 = 1.24 \times 10^{10} \Delta(f_0F2)^2$ and $\tau = \Delta C/\Delta NF2$ on the basis of Eq. (8). This value for slab thickness is considerably smaller than earlier results obtained at Randle Cliff. In fact during the Summer of 1964 and 1965 a value of 442 km was obtained. However, the present value is in general agreement with a summer result of 327 km obtained by Bhonsle, et al. (11), during 1962. The Randle Cliff measurement was felt to exhibit at least a 25% overestimate due to the fact that a fade rate analysis was employed (12). This adjustment reduces the 1964-1965 NRL figure to approximately 332 km.

Figures 6 illustrate the diurnal behavior of the electron-content-change rate function dC/dt (in absolute value) for April, May, June, July, and August, respectively. Excluding May and June temporarily, we see that the time of maximum buildup occurs at about 0800 ± 1 hr EST, and the time for which the content decay process has its maximum is at about 2100 ± 1 hr EST. It is interesting that ionospheric sunrise precedes the morning extremum and that the evening extremum is preceded by sunset. Ignoring physics, symmetry would suggest that the evening extremum should occur at about 1600 ± 1 hr EST. This is not true since the morning extremum — being based on production primarily — is strongly tied to solar illumination, whereas the evening extremum — being based

*The diurnal excursion is defined to be the greatest maximum minus the smallest minimum which occurs during the day or, more precisely, the upper bound of all possible extremal differences.

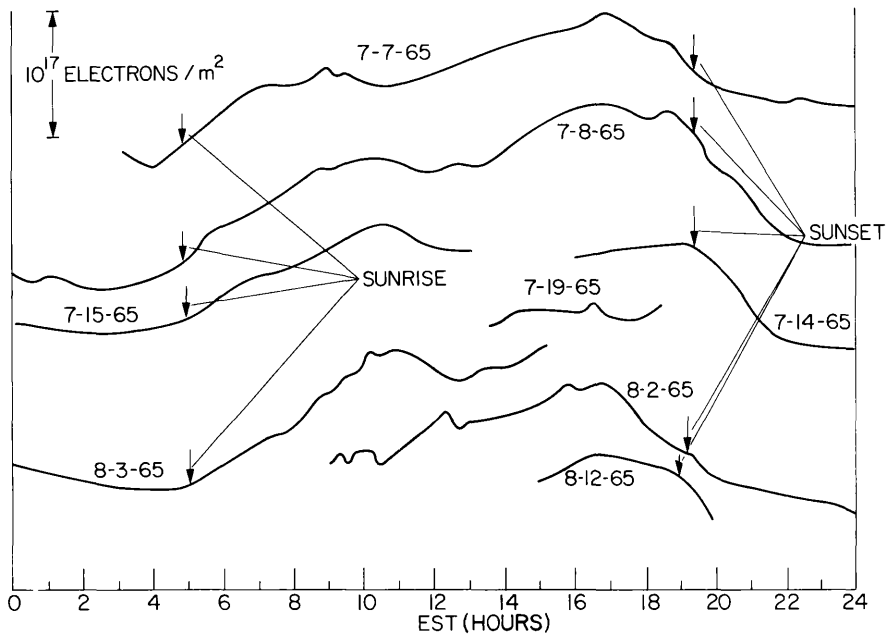


Fig. 9 - Faraday rotation data obtained during 1965 at Randle Cliff. The transmitting satellite was Early Bird (1965-28A).

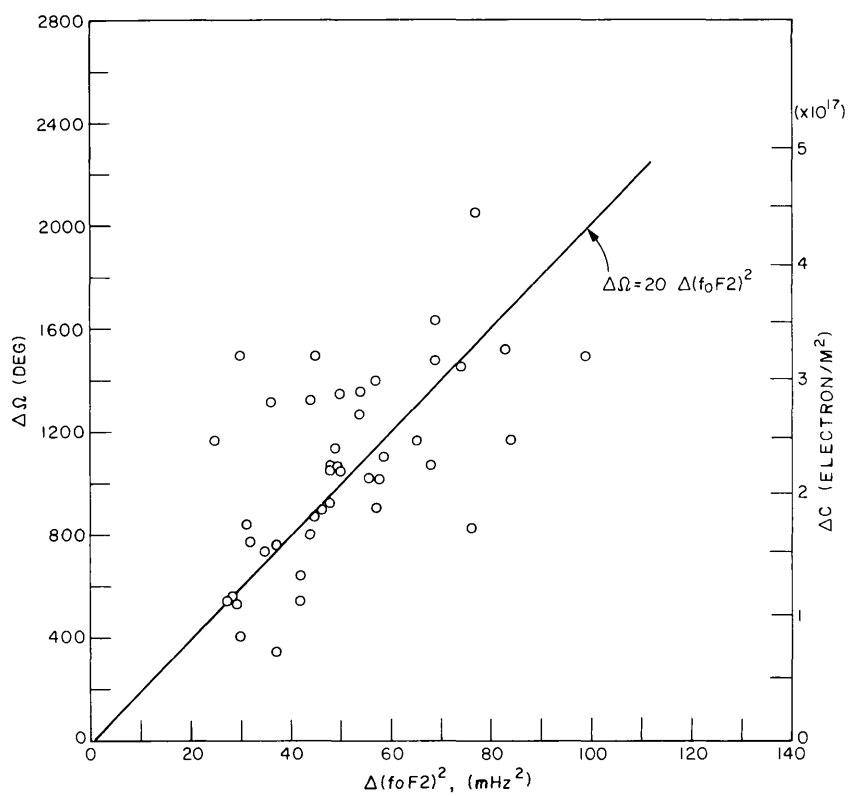


Fig. 10 - Diurnal excursion in Ω (also in the content C) versus the diurnal excursion in $(f0F2)^2$. The diurnal excursion is defined to be the maximum value minus the minimum value during the day.

on recombination primarily — is, roughly speaking, much less dependent on solar illumination. Decay depends on the number of electrons and ions which are present. Furthermore, since the cross section for radiative recombination is smaller than that for three-body recombination, the upper F region decays quite sluggishly since collisions of all types (and especially three-body collisions) are infrequent at high altitudes.

Examining Figs. 6b and 6c we see the manifestation of the magnetic storms which occurred on May 25, 1967, and June 5, 1967, respectively. Excursions in the build-up and decay rates were fully four or five times larger than the normal extrema of dC/dt.

One final observation is worth mentioning. The fact that the decay is most rapid at 2100 ± 1 hr EST rather than at sunset is a result to some extent of the peculiar geometry of the experiment. For example, the 1000-km sunset is approximately 4 hr later than ground sunset and at the $F2$-maximum altitude, sunset is delayed at least 2 hr. On the other hand as a first approximation the sunrise event occurs at all altitudes simultaneously. Clearly one would expect the morning extremum to be more closely tied to local sunrise than the afternoon extremum to local sunset; this was observed.

CONCLUSIONS

For over 1900 hr between April 7 and August 15, 1967, the electron-content variations of the ionosphere were monitored at the Randle Cliff receiving station. The regularities of the ionosphere during the observation period were found to be roughly the same as those which were observed during the Early Bird observation period of 1965. In particular it was found that there exist two extremal regions of the content-change rate function — one associated with sunrise and one associated with sunset. Due to the sluggishness of recombination the decay of electron content is gradual, and content remains at a fairly high level for several hours following ground sunset. Geometrical effects further delay the nocturnal extremum.

Irregularities in the electron content were observed to occur during both magnetically quiet and disturbed days, although extremely dramatic enhancements were recorded following two magnetic storms. On May 25 the electron content increased 5×10^{17} electrons/m^2 in the course of 90 min, and a similar occurrence was recorded on June 5, 1967. Several sources of the content enhancement are possible, but the leading candidates are increased electron production, electron downdrift or dumping, and decreased electron loss due to either heating of the plasma or electrodynamic lifting.

Although a Chapman distribution is barely justifiable theoretically, it was found that the diurnal content excursion is roughly proportional to the diurnal excursion in the square of $foF2$ as predicted by simple Chapman theory.

REFERENCES

1. Goodman, J.M., "Diurnal Dependence of Electron Content Variations," J. Geophys. Res. 71 (No. 3):985 (1966)

2. Goodman, J.M., "Some Evidence of E_s-Layer Effects upon 137-MHz Radio Waves," J. Atmospheric Terrest. Phys. 29:607 (1967)

3. Klobuchar, J.A., and Whitney, H.E., "Middle-Latitude Ionospheric Total Electron Content: Summer 1965," Radio Sci. 1:1149 (1966)

4. Checcacci, P.F., "Ionospheric Measurements by Means of the Early Bird Geostationary Satellite," Radio Sci. 1:1154 (1966)

5. Nakata, Y., "Variation in Ionospheric Electron Content Measured by Radio Waves from Syncom 3," Radio Sci. 1:1145 (1966)

6. Garriott, O.K., Smith, F.L., and Yuen, P.C., Planetary Space Sci. 13:829 (1965)

7. Hibberd, F.H., and Ross, W.J., J. Geophys. Res. 72:5331 (1967)

8. Thome, G.D., "Incoherent Scatter Observations of Traveling Ionospheric Disturbances," J. Geophys. Res. 69:4047 (1964)

9. Titheridge, J.E., "Continuous Records of the Total Electron Content of the Ionosphere," J. Atmospheric Terrest. Phys. 28:1135 (1966)

10. Evans, J.V., Planetary Space Sci. 15:1387 (1967)

11. Bhonsle, R.V., da Rosa, A.V., and Garriott, O.K., "Measurements of the Total Electron Content and Equivalent Slab Thickness of the Midlatitude Ionosphere," J. Res. Nat. Bur. Std. 69D:929 (1965)

12. Goodman, J.M., "Analysis of Electron Content Errors Introduced Through Use of a Simplified Faraday Rotation Technique," NRL Memorandum Report 1684, Feb. 1966

Security Classification

DOCUMENT CONTROL DATA - R & D

(Security classification of title, body of abstract and indexing annotation must be entered when the overall report is classified)

1. ORIGINATING ACTIVITY *(Corporate author)* Naval Research Laboratory Washington, D.C. 20390	2a. REPORT SECURITY CLASSIFICATION UNCLASSIFIED 2b. GROUP

3. REPORT TITLE

ELECTRON-CONTENT VARIATIONS AND CHANGE RATES OBTAINED DURING THE SPRING AND SUMMER OF 1967 BY THE MEASUREMENT OF FARADAY ROTATION OF 137-MHz RADIO WAVES TRANSMITTED FROM ATS-1

4. DESCRIPTIVE NOTES *(Type of report and inclusive dates)*

Interim report on one phase of the problem.

5. AUTHOR(S) *(First name, middle initial, last name)*

John M. Goodman, Melvin W. Lehman, and Edward Piernik

6. REPORT DATE March 17, 1969	7a. TOTAL NO. OF PAGES 26	7b. NO. OF REFS 12
8a. CONTRACT OR GRANT NO. NRL Problem R02-05 b. PROJECT NO. RF 05-151-402-400 c. d.	9a. ORIGINATOR'S REPORT NUMBER(S) NRL Report 6830 9b. OTHER REPORT NO(S) *(Any other numbers that may be assigned this report)*	

10. DISTRIBUTION STATEMENT

This document has been approved for public release and sale; its distribution is unlimited.

11. SUPPLEMENTARY NOTES	12. SPONSORING MILITARY ACTIVITY Department of the Navy (Office of Naval Research), Washington, D.C. 20360

13. ABSTRACT

Vhf radiowave transmissions (137.350 MHz) from the geostationary satellite ATS-1 (1966-110A) have been analyzed to determine the electron-content variations during the Spring and Summer of 1967. The regularities of the ionosphere during the observation period were found to be roughly the same as those which were observed during the Early Bird observation period of 1965. In particular it was found that there exist two extremal regions of the content-change rate function—one associated with sunrise and one associated with sunset.

Irregularities in the electron content were observed to occur during both magnetically quiet and disturbed days, although extremely dramatic enhancements were recorded following two magnetic storms.

Although a Chapman distribution is barely justifiable theoretically, it was found that the diurnal content excursion is roughly proportional to the diurnal excursion in the square of f_0F2 as predicted by simple Chapman theory.

DD FORM 1 NOV 65 1473 (PAGE 1)

S/N 0101-807-6801

Security Classification

Security Classification

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Electron content						
Change rates						
Faraday rotation						
Magnetic activity						
Slab thickness						
Synchronous satellite						

DD FORM 1 NOV 65 1473 (BACK)
(PAGE 2)

Security Classification