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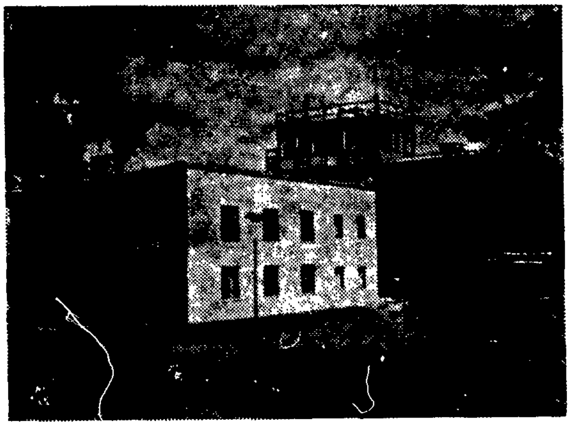

NORTHERN LATITUDE PROPAGATION

by

LUDWIK LISZKA
KIRUNA GEOPHYSICAL OBSERVATORY
Kiruna C, Sweden

Final Report
Contract No. AF 61(052)-601
23 March 1963

Monitoring Agency Document No.
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ABSTRACT

Satellite recordings made at Kiruna Geophysical Observatory at frequencies 20 and 54 Mc/s during the last three years are investigated with respect to the occurrence of scintillation with emphasis on the 54 Mc/s results. Studies of diurnal and seasonal variations of scintillation at 54 Mc/s show that the shape of the diurnal curve is dependent on magnetic activity and that seasonal variations are not important. The depth of scintillation at 54 Mc/s is better correlated with magnetic activity than at 20 Mc/s. There exists a difference between daytime and night-time scintillation. A statistical analysis of the diffraction pattern produced by radio waves from Transit IV A at 54 Mc/s is also presented. The most important result is the evidence that auroral zone scintillation may be produced at altitudes below F-maximum. Investigation of the shape of ionospheric irregularities have shown that if these are assumed to be two-axial ellipsoids orientated along the magnetic field lines, axis ratios of order of magnitude 10 will be obtained.

A. SATELLITE SCINTILLATION OBSERVED IN THE AURORAL ZONE

1. Introduction

The scintillation phenomenon has been investigated by a number of authors both for radio-stars and artificial satellites. In particular, the conditions for which the phenomenon occurs and its connection with other geophysical parameters, was studied.

The scintillation, which is dependent on the fluctuation of the refraction index, should decrease with frequency. The phenomenon is, however, not negligible at the higher frequencies and has been observed in radio-star recordings at frequencies of about 1000 Mc/s (Ko, 1960). Under certain conditions the opposite frequency dependence, that is, the increase of scintillation amplitude with frequency, has been observed (cf. Aarons, 1962).

Radio-star scintillation is observed most often during the night with the maximum generally occurring shortly after local midnight. A secondary maximum at midday has been observed in Australia and Canada, but not in England (Booker, 1958).

The results of 20 months data from 1957 $\alpha 2$ and 1958 $\delta 2$ transmissions, mainly on 20 Mc/s, recorded at Urbana, Illinois ($\varphi = 40^{\circ}$N), have been used for investigation of diurnal and seasonal variation of scintillation by Yeh and Swenson (1959). They have found that the night-time maximum occurs throughout the year. A daytime maximum has also been observed during summer and autumn months. An investigation of large number of records of 1958 $\delta 2$ at 20 Mc/s made at Kiruna, Sweden, ($\varphi = 67.8^{\circ}$N) (cf. Liszka and Hultqvist, 1961) has shown that the scintillation is a very common phenomenon in the auroral zone. No evident diurnal variation has been found, only a slightly lower occurrence of scintillation during the daytime.

A number of authors have found that in moderate geographic latitudes, the radio-star scintillation is correlated with the occurrence of ionospheric spread F (cf. e.g. Lawrence, Jespersen and Lamb, 1961). A similar correlation has been found for the satellite scintillation (Yeh and Swenson, 1959; de Mendonca, Villard and Garriott, 1960). In addition, correlation with sporadic E has been sought both for satellite and radio-star scintillation. In the case of satellite scintillation, no correlation was found in moderate latitudes (de Mendonca, Villard and Garriott, 1960). In the auroral zone, a weak correlation between the occurrence of scintillation at 20 Mc/s and E_s type a (auroral) has been found (Liszka and Hultqvist, 1961). Better correlation has been found at 54 Mc/s (Liszka, 1962b). Also conflicting results have been obtained for radio-star scintillation by different authors (cf. Bolton, Slee and Stanley, 1953; Hartz, 1958).

Measurements of the height at which the satellite scintillation is produced has given values mainly above 300 kilometers (cf. Frihagen and Tröim, 1961). All these results suggest that both satellite and radio-star scintillation, in moderate geographic latitudes, are produced in the F-region of the ionosphere. However, observations of auroral zone satellite scintillation, discussed below, have shown that a considerable proportion of them is associated with the occurrence of the auroral sporadic E layer.

The results obtained at frequencies 20 and 54 Mc/s, in particular from Transit IV A, where a rather uniform series of measurements has been collected, have been published as Scientific Report No. 5 of this contract and also in "Arkiv för Geofysik", Bd. 4, No. 8, p. 211-225, 1963. Here, only a brief summary of the research will be given.

2. Description of the instrumentation and of scaling techniques

The equipment used for amplitude measurements at 20 Mc/s has been described by Liszka and Hultqvist (1961). The equipment used for recordings at 54 Mc/s consisted of a horizontal dipole with one reflector element, a Hammarlund Model SP-600 receiver, a Keithley DCVTM Model 220 amplifier, an Esterline-Angus recorder and a programmed coupling clock. The audiosignals from the receiver, having a bandwidth of 8 kc/s, were detected and then amplified and recorded with a paper speed of 3 inches/minute. Time marks on the record were provided by a crystal clock at the Observatory. The amplitude recordings were completely automatic, and usually 4-5 recordings per day were made.

Two scaling techniques were used for obtaining a convenient parameter for characterizing the statistical properties of the signals. At 20 Mc/s where the scintillation was usually very deep and Faraday rotation uncommon, the scintillation index defined by Yeh and Swenson (1959) was used. To every amplitude record a scintillation index S was attributed according to the following rule:

$S = 0$, regular Faraday rotations;
$S = 1$, Faraday rotations with superimposed scintillation;
$S = 2$, Faraday rotations completely obscured by scintillation.

The intermediate values 0.5 and 1.5 were also used.

At 54 Mc/s, where Faraday rotation was a more frequent phenomenon and the period of Faraday rotation large enough to be easily distinguished from single scintillations, another scaling method was used. An amplitude scintillation index defined as the ratio of the mean deviation from the average amplitude level to the average amplitude ($\overline{\Delta A}/\overline{A}$) was employed. The average amplitude deviation ($\overline{\Delta A}$) was defined as half the difference between the average maximum ($\overline{A}_{max}$) and average minimum ($\overline{A}_{min}$) amplitude around the maximum of a Faraday rotation thus

$$\frac{\overline{\Delta A}}{\overline{A}} = \frac{\overline{A}_{max} - \overline{A}_{min}}{\overline{A}_{max} + \overline{A}_{min}}$$

As the values $\overline{A}_{max}$ and $\overline{A}_{min}$ were scaled by hand, a subjective error was introduced into the amplitude scintillation index. This subjective error is of importance when the Faraday rotation is completely obscured by very deep scintillation. Almost all scaling was, however, performed by one and the same person. The index obtained was used for a statistical investigation of the occurrence of scintillation. It provides a fairly good measure of the depth of scintillation. The index was calculated for every Faraday rotation and, in all, nearly 2000 amplitude records were reduced by the described procedure. About 700 records of the 54 Mc/s Transit IV A transmissions taken in the 8-month period March-October 1962 were reduced and used for a statistical investigation of the occurrence of scintillation.

3. Discussion of the occurrence of satellite scintillation

a) Diurnal variations

As mentioned in the introduction, it has been found from observations of radio-stars that scintillation is most frequent during the night-time. Observations of Cassiopeia in England by Dagg (1957) and Chivers (1960) have shown that scintillation has a maximum in amplitude and rate before local midnight but close to the local magnetic midnight. In College, Alaska, it has been found by Little and others (1962), that maximum scintillation occurs at about 0150 local standard time which is the time of local magnetic midnight. Little has therefore suggested that the mean diurnal time of maximum activity at any north-temperate or auroral zone latitude is that of local magnetic midnight. A secondary maximum at midday has been noted in Australia and Canada but not in England (Booker, 1958).

In a study of satellite scintillation made by Yeh and Swenson (1959) at Urbana, Illinois, it has been shown that the night-time maximum occurs around local midnight throughout the year. That is not in contradiction with results obtained for radio-star scintillation, because the time of magnetic midnight at Urbana is very close to the time of local midnight. A daytime maximum has also been observed during summer and autumn months. An investigation of the occurrence of satellite scintillation at 20 Mc/s in the auroral zone (cf. Liszka and Hultqvist, 1961) has shown no clear diurnal variation of scintillation index S; the average level of the scintillation index is very high at night and only slightly lower during the daytime. The results of the observations at 54 Mc/s made in Kiruna have shown that the maximum of scintillation occurs at about 2300 local time what well corresponds to the magnetic midnight. It is interesting that two secondary maxima seem to appear; one at about 0800 and the second at about 1700 local time. Similar maxima seem to occur on the diurnal curve for the scintillation of Cygnus A observed in Alaska (cf. Little and others, 1962, Fig. 11). Also diurnal curves for quiet and disturbed days were investigated. For both disturbed and quiet days the diurnal curve has again a maximum at midnight, but for disturbed days it has almost twice the amplitude of the quiet day maximum. The whole level of the diurnal curve for disturbed days is remarkably higher than for the quiet day curve.

b) Seasonal variations

It has been found both for 20 and 54 Mc/s results that seasonal variations of the scintillation index are not important. It has been observed, however, at 54 Mc/s, that the probability of occurrence of different intervals of the amplitude scintillation index changes from month to month. There would seem to be two sources for these differences;

a. analysed transits for each month correspond only to a part of the day which is different for different months, and

b. the average level of magnetic activity varies from month to month.

It has been found that the first of these is less important than the second.

c) Day-to-day variation

The same tendency for the scintillation at 54 Mc/s to depend on magnetic activity may be seen in the day-to-day variations of the 54 Mc/s scintillation index. It has been found that the curve of scintillation index generally follows the level of the magnetic activity. For some periods a lead-lag correlation was carried out between both parameters: scintillation index and magnetic Ap-index.
A positive correlation of 0.4-0.5 for zero time displacement has been found. This indicates a definite correlation between depth of scintillation and magnetic activity on a given day.

d) Frequency and latitude dependence of the scintillation

Even comparing results obtained in the auroral zone at 20 Mc/s (cf. Liszka and Hultqvist, 1961) with observations on 54 Mc/s a significant difference between the two frequencies is seen in the depth and occurrence frequency of scintillation.

At 20 Mc/s, both for Sputnik III and Discoverer 32, the frequency of occurrence of pure Faraday rotation was less than 10%. However, for Explorer VII, transmitting at the same frequency, the corresponding occurrence frequency was about 30%. This was probably due to the inclination of the orbit of the latter satellite. Points of penetration of Explorer VII signals through the ionosphere were located a few hundred kilometers to the south of Kiruna, i.e. south of the auroral zone. This fact seems to confirm the latitude dependence of the occurrence of scintillation observed by Kent (1959) and Frihagen and Tröim (1961).

4. Correlation between scintillation and other geophysical parameters

The various correlations between scintillation index at 54 Mc/s, and magnetic activity, ionospheric spread F, and sporadic E have been investigated. The results are discussed below.

a) Correlation with magnetic activity

The correlation between radio-star scintillation observed in the auroral zone at frequencies 223 Mc/s and 453 Mc/s, and magnetic activity has been investigated by Little and others (1962). Little has carried out a lead-lag correlation between these scintillation indices and the magnetic K-index at College, and found a positive correlation with a maximum generally for zero time displacement. The correlation between magnetic activity and satellite scintillation observed in the auroral zone at 20 Mc/s has been investigated by Liszka and Hultqvist (1961). Values of the relative scintillation index, S, were compared with simultaneous values of magnetic Q-index at Kiruna. No significant difference between the frequency distributions of the scintillation index for different values of Q was found.

Results obtained from observations at 54 Mc/s have shown that the scintillation index is correlated with the magnitude of magnetic disturbances. The correlation has also been investigated separately for day- and night-time observations. It has been found that the same depth of scintillation, between 25 and 75 % of amplitude, seems to be associated with larger magnetic disturbances during the day than during the night.

b) Correlation with ionospheric spread F

As mentioned in the introduction the correlation of both radio-star and satellite scintillation with the ionospheric spread F has been investigated, with positive results, by a number of authors. However, the results of observations at Kiruna at 20 Mc/s support the opposite conclusion, since no significant correlation between the occurrence of scintillation and of spread F has been found. Scintillation has occurred only slightly more often during periods with spread F than the reverse case.

At 54 Mc/s no correlation with spread F was found for daytime transits. The observations of night-time transits, however, do exhibit such a correlation. Care must be exercised in interpreting these results because of a selective process involved in the data recording, namely that during the periods with auroral E_s there is usually no information about the F-layer. It is seen that the number of observations containing no F-layer information increases rapidly with scintillation index, especially at night.

c) Correlation with E_s

This type of correlation has been sought both in radio-star and satellite scintillation. As mentioned above, conflicting results have been obtained by different authors. Observations at 20 Mc/s made at Kiruna (cf. Liszka and Hultqvist, 1961) have indicated that the occurrence of scintillation is more probable during periods of auroral sporadic E.

Results of observations at 54 Mc/s have shown a correlation between scintillation and the sporadic E of auroral type only during the night-time. Daytime auroral E_s, and other types of E_s, are not correlated with scintillation at 54 Mc/s. This observation seems to imply that the night-time scintillation phenomenon is associated with the lower ionosphere.

5. Conclusions

The results of this investigation may be summarized as follows:

1. The curve of diurnal variation of the scintillation index at 54 Mc/s is dependent on magnetic activity, the average level of the curve being higher for disturbed than for quiet days. Maximum scintillation is observed around midnight.
2. Seasonal variations of scintillation at 54 Mc/s are considerably smaller than the day-to-day variations associated with magnetic activity.
3. The depth, and the frequency of occurrence of scintillation, decreases with observing frequency. However, scintillation at 54 Mc/s seems to be better correlated with magnetic activity than that at 20 Mc/s.
4. Scintillation of the same depth is associated with smaller magnetic disturbances during the night than during the day.
5. Scintillation is correlated with the night-time auroral sporadic E. This fact together with the previous ones indicates that there exists

an important difference between daytime and night-time scintillation, which may be produced by two different mechanisms.

B. A STUDY OF IONOSPHERIC IRREGULARITIES USING SATELLITE TRANSMISSIONS AT 54 Mc/s

1. Introduction

It may be easily shown that the diffraction pattern produced on the ground by a satellite transmitter is especially suitable for measurements of its velocity and structure, as the direction of the velocity may be known from the knowledge of the orbit. Two antennas situated along the direction of pattern velocity will indicate the time delay between details of the pattern, which will be directly proportional to the pattern velocity. This method has been used by Frihagen and Tröim (1961). The measurements, carried out mostly in southern Norway have given results similar to those obtained from radio-star scintillation studies. Other investigations of satellite scintillation have involved measurement of the autocorrelation time of the amplitude fluctuations recorded at a fixed receiver. If the height of the scintillation-producing region is assumed, it is possible to calculate the scale size of the ionospheric irregularities. This method has been applied by Kent (1961), for the equatorial region, assuming the scintillation to be produced in the F-region, and by Liszka (1962a) in the auroral zone, with a satellite moving below the F-2 maximum, so that E-region heights could be assumed.

Since a large number of recordings made at Kiruna (geographic latitude 67.8°N) have indicated (cf. e.g. Liszka, 1962b) that an important part of auroral zone scintillation is related to E-region phenomena, a spaced receiver experiment has been carried out to investigate these low scintillations. The aim of the experiment was to measure the pattern velocity, the scale size and the amplitude distribution of the pattern as a function of time, which is necessary for determination of the height and sizes of the irregularities responsible for the scintillation phenomenon. Transmissions from 1961 Omicron 1 (Transit IV) at 54 Mc/s have been used.

The results of this experiment have been published as Scientific Report No. 6 of this Contract and also in "Arkiv för Geofysik", Bd. 4, No. 9, p. 227-246. Here only a short summary will be given.

2. The height of the scintillation-producing region

It may be shown that from measurements of the pattern velocity of a satellite of known orbit, the height at which the scintillation is produced, may be calculated.

If the satellite velocity is parallel to the base line of antennae, it may be determined simply by measuring time delays between similar amplitude fades, recorded at both antennae. When the pattern velocity differs from that of the base line and the pattern is anisometric, the velocity may still be obtained if the orientation of the major axis of the characteristic ellipse is known. This may be calculated if the assumption is made that the ionospheric irregularities have the shape of strongly elongated two-axial ellipsoids, oriented along the geomagnetic field lines, which is in agreement with existing experience (cf. e.g. Spencer, 1955).

In spite of this assumption, an equation may be obtained expressing the pattern velocity through: the time delay between similar fades, the length of the baseline and of orientations of the correlation ellipse and of the satellite velocity. Knowing the pattern velocity, the height of the scintillation-producing region may be easily calculated.

Calculations have been made for about 50 fast amplitude records of Transit IV at 54 Mc/s from October and November 1962. It has been found that daytime scintillation is usually produced at heights above F-maximum, but during the night-time, the height of the scintillation-producing region may be as low as 100 km.

3. Determination of the structure of the diffraction pattern on the ground and of the ionospheric irregularities

The structure of the diffraction pattern on the ground may be determined for any pattern by the statistical analysis of the amplitude at three points. However, for a satellite transmitter, it is possible to determine the axes of the correlation ellipse by employing the same assumption as in the previous section, i.e. that ionospheric irregularities producing the pattern have the shape of strongly elongated two-axial ellipsoids, oriented along the geomagnetic field lines and assuming that the irregularities are statistically similar during the entire passage. In this case, the direction of the major axis of the correlation ellipse may be calculated and only the axes of the ellipse have to be determined, which can be made with the use of only two spaced antennae. It may be done using the characteristic time of the autocorrelation function measured at one point. This will be related to the length of the axes of the ellipse, pattern velocity (assumed constant for the whole passage and determined using two spaced antennae) and to the angle between the direction of pattern velocity and one of axes of the ellipse.

In the case of a thin diffracting layer the autocorrelation ellipse will be a projection of an average ellipsoidal irregularity in the ionosphere, and thus the parameters of the average ionospheric irregularity may be calculated. Such analysis has been made for 6 passages of Transit IV A. The obtained results are given in the following table.

Table I

Rev. No.	m (km)	l (km)	R = l/m
6643	0.7	5.6	8
6657	0.6	11.0	18
6669	0.6	8.0	13
6670	0.7	7.5	11
6683	1.4	12.5	9
6684	0.6	12.5	21

Quantities m and l are respectively the minor and major semiaxes of the average ionospheric irregularity. Values obtained for R are in good agreement with those measured for radio-star scintillation by Spencer (1955).

4. Regular structures observed during periods of intense scintillation

Frihagen and Tröim (1961) have observed on fast amplitude records at 108 Mc/s a deep and nearly sinusoidal type of fading which only lasted over a few periods and which showed a time delay between records taken at two spaced antennae, indicating that it is introduced in the ionosphere. They have proposed that this phenomenon is caused by diffraction at a single "blob" in the ionosphere and that it similar to that observed for radio-star scintillation by Wild and Roberts (1956). Apparently the same kind of amplitude variation was observed on several occasions at Kiruna on records of Transit IV at

54 Mc/s showing intense scintillation. The phenomenon was usually more persistent than that observed by Frihagen and Tröim and lasted up to a hundred periods. The fading periods varied between 50 and 500 msec with predominance of 100 msec periods. Two main types of the phenomenon were observed:

(a) Oscillations with monotonically increasing (or decreasing) amplitude and period. They last usually for about 10 periods and are observed at large satellite elevations.

(b) Oscillations with fairly constant period, most often of about 100 msec and lasting up to 100 periods. This type of oscillation occurs mostly during a period of low signal level but may also be superimposed on slow amplitude scintillation. It occurs at both high and low satellite elevations. More observations are needed for explanation of this phenomenon.

5. Conclusions

The most important result of this work is the evidence that auroral zone scintillation may be produced at altitudes below F-maximum. This is in good agreement with previous results obtained in the auroral zone (cf. Liszka, 1963). Low altitudes, down to 100 km, of the scintillation-producing region occur more frequently during the night-time. During the forenoon hours, when some of the measurements were made, the scintillation is produced at or above F-maximum.

Determinations of the shape and dimensions of ionospheric irregularities have confirmed the results of Spencer (1955) from radio-star scintillation studies. Assuming that irregularities are two-axial ellipsoids orientated along the magnetic field lines, axis ratios between 8 and 21 were obtained.

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