GEOPHYSICAL INSTITUTE
of the
UNIVERSITY OF ALASKA

ESTIMATED ABSORPTION OF 136 MC/S SATELLITE RADIO SIGNALS

Interim Technical Report No. 1

prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

GODDARD SPACE FLIGHT CENTER

under

Contract No. NAS 5-1413

February 1962

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1. AURORAL ABSORPTION

by Roy Basler

According to the Appleton-Hartree magneto-ionic theory, the total non-deviative absorption of radio field strength is given by

$$\text{Absorption (db)} = \frac{8.69}{(\omega \pm \omega_L)^2} \frac{2\pi e^2}{mc} \int N\nu \, ds$$

where

N = electron density

ν = collision frequency

$\omega = 2\pi f$ = observing frequency (angular)

ω_L = longitudinal component of gyromagnetic frequency

ds = element of path length

For frequencies in the high HF and the VHF range, ω_L can be neglected, in which case

$$\text{Absorption} = 1.2 \times 10^{-9} \frac{N\nu}{f^2} \frac{\text{db}}{\text{km}}$$

where f is in mc/s, N in electrons/cm^3, and ν in sec^{-1}.

Absorption of 27.6 mc/s cosmic noise monitored with a broad beam antenna (3 element yagi) has been recorded for several years at College, Alaska. At this frequency the highest observed values of auroral absorption are in the range from 10-20 db. These high values of aurorally associated absorption occur mostly in the fall and winter months and are almost absent in the summer. The amount of auroral absorption at 27.6 mc/s as a function of frequency of occurrence for the month of February 1958 is shown in the following graph. The records were scaled every 15 minutes, so some of the peak absorption valuss may not be included if they occurred during the 15 min interval between scalings; however, the graph represents a fair sampling of the data. February 1958 was an extremely disturbed month, so this graph should be regarded not as a typical expectation curve but rather as an indication of what might be expected during periods of maximum auroral activity.

Auroral absorption is characteristically irregular, and it can change by as much as 2-3 db/min at 27.6 mc/s. Changes as fast as 4-5 db/min have been observed, but are rare.

Taking a maximum of 20 db at 27.6 mc/s (which is extreme), using the inverse frequency squared relation, and neglecting for the moment the fact that cosmic noise is a diffuse source and the satellite is a point source, the maximum absorption which would be expected at 136 mc/s is

$$\text{Abs (max)} = \left[\frac{27.6}{136}\right]^2 \times 20 = 0.8 \text{ db.}$$

At 136 mc/s the radio transmission is along the line-of-sight path from the satellite to the receiving antenna. By recording the radio signal strength as the satellite sweeps across the sky it is possible to detect the presence of any absorbing regions, even the very small ones. In order to sense the absorption structure as effectively as can be done with satellites, cosmic noise would have to be monitored with a pencil beam antenna. The sizes of the absorbing irregularities in the auroral zone are not known since almost all of the studies of auroral absorption have been made with broad beam antennas, but it is not unreasonable to expect some fine structure with angular dimensions of one or two degrees as seen from the ground. It is thus difficult to correct for the effect of antenna beam width for the commonly occurring auroral absorption events, but the maximum absorption to be expected at 136 mc/s can still be estimated at less than one db since the figure of 20 db used in the above calculation probably refers to an occasion when the entire antenna beam was very nearly filled with bright aurora, thus removing the effect of the antenna pattern.

As an alternative approach to the estimate of the maximum absorption, it is possible to use the spectroscopic information that the maximum electron density in a bright auroral display is of the order of 10^7 el./cm^3. Assuming the total absorption to occur in a layer 10 km thick with an average collision frequency of the order of 10^5 sec^{-1} (the approximate value at 100 km), the absorption at 136 mc/s is given by

$$\text{Absorption} = 1.2 \times 10^{-9} \frac{N\nu}{f^2} \frac{\text{db}}{\text{km}} \times 10 \text{ km}$$

$$= 1.2 \times 10^{-9} \frac{10^7 \times 10^5}{(136)^2} \times 10 \text{ db}$$

$$= 0.65 \text{ db.}$$

Thus the maximum expected aurorally associated absorption at vertical incidence is less than one decibel. For oblique incidence this figure must be multiplied by the secant of the angle of incidence.

The above estimate is based on the Appleton-Hartree magneto-ionic theory, which is not now considered strictly applicable*. However, it is easily accurate enough to use in such order of magnitude calculations as have been carried out above.

Absorption measurements have been made simultaneously over a north-south distance of over 1000 km, spanning the auroral zone, in both Alaska and Norway. These studies have shown that periods of disturbance generally coincide over a magnetic latitude range of 4 to 8 degrees, centered on the auroral zone. However, the detailed structure of absorption events may differ significantly over distances of less than 200 km, indicating that small scale structure of the absorption does exist. This result is itself consistent with the observation that absorption is closely correlated to the presence of visual aurora in the beam of the riometer antenna.

The Norwegian studies (Norwegian Defence Research Establishment Report No. 35, part I-III, April 1961) show that the detailed correlation between stations separated by 200-300 km tends to be better along a line of constant magnetic latitude than along a magnetic meridian. Some recent and very preliminary studies in Alaska suggest that a close degree of correlation exists over a magnetic east-west baseline as long as 700 km.

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*We cannot use the actual mean absorption frequency in the Appleton-Hartree formula. But as long as we adopt a suitable effective collision frequency, the calculations should be good first order estimates.

2. NON-AURORAL ABSORPTION AND OTHER CONSIDERATIONS

by Harold Leinbach

(i). Polar Cap Absorption

The above calculations have treated aurorally-associated absorption. A second class of events, important at high latitudes, is the polar cap absorption (PCA). This type of absorption results from bombardment of the polar cap ionosphere by solar cosmic rays ejected by certain large solar flares. These events are relatively rare compared with auroral absorption; some 10 PCA events may be recorded during a year of high sunspot activity. During the minimum years of the sunspot cycle, the frequency of PCA events may drop to zero per year.

PCA events are important, however, because of the large magnitude of absorption which may be attained, and because the high values of absorption may persist for several successive days. Polar cap absorption occurs in a uniform and thick horizontal layer, as has been demonstrated both experimentally and theoretically. Therefore extrapolation of the absorption observed at say 27.6 mc/s to the absorption expected at higher frequencies can be made with fair certainty. The assumption is that the inverse frequency dependence holds for the absorption at frequencies above 27 mc/s; this contention has been experimental verified in several events. A small correction should be made to the absorption measured with a wide vertical beam in order to estimate the absorption per unit vertical column. This correction does not change the order of magnitude estimate below.

We assume that the maximum probable value of absorption at 27.6 mc/s, using a wide vertical beam, is 30 db. Then the expected absorption per vertical column at 136 mc/s is approximately $(27.6/136)^2 \times 30$ db = 1.2 db. At moderate zenith angles, χ, the expected absorption is then 1.2 x sec χ db.

In a given year, at least 50% of the PCA events should have maximum absorption values far less than the extreme of 30 db used above.

(ii). Sudden Ionospheric Disturbances (SID's and SCNA's)

Sudden ionospheric disturbances (SID's), and the equivalent sudden cosmic noise absorption (SCNA) events result from ionization of the D-region by electromagnetic radiation from solar flares. Thus SID's and SCNA's are restricted to the sunlit hemisphere. At the latitude of College, SCNA's are seldom observed with a vertical 27.6 mc/s riometer; events with magnitudes greater than 1 or 2 db are very rare. One of the largest SCNA's ever observed occurred on July 29, 1958, when a maximum value of absorption of about 6 db was recorded at 27.6 mc/s. This value would be equivalent to about 0.25 db at 136 mc/s (vertical incidence), assuming a uniform absorbing layer, and an inverse frequency dependence of the absorption.

We conclude that SCNA's will not be important factors in the reception of 136 mc/s signals from satellites.

(iii). Validity of the Inverse Frequency Squared and Secant Laws

Two riometers, one at 27.6 mc/s and the other at 50 mc/s, were operated at College for two years. These riometers used scaled three-element, vertically-directed Yagi antennas, so that the absorption could be directly intercompared. Spot checks of the ratio of the absorption at the two frequencies were made for numerous auroral absorption events, with the conclusion that the ratio did not depart significantly from the inverse frequency squared law. More detailed checks of the ratio were made during the great polar cap absorption events of July 1959, with the same conclusion. In the later case, the only departures from the inverse frequency squared law were towards higher than predicted ratios, that is, towards smaller relative absorption at the higher frequency than expected. No explanation has yet been given for this result.

The secant law for the absorption at oblique angles has been verified, by comparison of absorption data obtained with a 27.6 mc/s riometer using a vertical three-element Yagi, and another 27.6 mc/s riometer using a north-pointing, horizontally-directed four-element Yagi, with a beam elevation angle of about 35 degrees. Polar cap absorption is always greater on the oblique antenna, with a ratio of absorption to that at vertical incidence equal to that given by the secant law. In most PCA events, no inherent latitude increase of absorption occurs over the distance covered by the two beams.

The secant law has also been sufficient to explain the ratio of absorption at vertical and oblique incidence, for those auroras which were uniform over the sky. Non-uniform auroras may, of course,give higher absorption in one beam than the other.

3. SUMMARY AND CONCLUSIONS

by Leif Owren

The maximum ionospheric absorption expected for a 136 mc/s satellite radio signal observed from a station in the auroral zone at the zenith angle X is:

Auroral absorption	0.8 sec X db
Polar cap absorption	1.2 sec X db
Sudden cosmic noise absorption	0.25 sec X db

These maximum values apply to periods of very high solar activity and will be attained only on rare occasions. More typical values at 136 mc/s might be:

Auroral absorption	0.3 sec X db
Polar cap absorption	0.5 sec X db
Sudden cosmic noise absorption	Negligible

For large zenith angles the secant factor may lead to an overestimate of the expected absorption, in particular for auroral absorption when looking across the auroral zone.

The auroral absorption zone typically extends over 7-8 degrees of geomagnetic latitude during moderately disturbed and disturbed magnetic conditions. In Alaska this zone appears to be centered approximately on the geomagnetic latitude of College, 64.5°N.

The auroral absorption may change at a rate of 0.1 db per minute at 136 mc/s. The duration of a typical event is of the order of 20-30 minutes but the disturbed period may last for a few to several hours. The frequency of occurrence may vary from ninety per cent of any given monthly period during very high solar activity to a few per cent during low solar activity.

Polar cap absorption extends in a fairly uniform layer over the arctic region down to about 62° geomagnetic latitude during the first 24 hours. With the onset of the associated magnetic storm it usually spreads to lower latitudes also. During the initial phase of a PCA event the absorption increases at a rate of up to 0.1 db per hour at 136 mc/s and reaches maximum after 6-12 hours. The duration of a moderate event is of the order of 1-2 days and the decay curve has the form of a damped oscillation with daytime peaks and nighttime troughs. The frequency of occurrence varies from about ten events per year during maximum solar activity to perhaps one or no events in a minimum year.

The estimated 136 mc/s absorption is based on extrapolation of 27.6 mc/s cosmic noise absorption measurements according to the inverse frequency squared law. The validity of this law for auroral and polar cap absorption has been established over the lower VHF range by simultaneous vertical beam observations of cosmic noise at 27.6 and 50 mc/s. The secant law for oblique incidence has been tested by simultaneous vertical and oblique beam observations on 27.6 mc/s. It is reliable for polar cap absorption, and may be used with some caution for auroral absorption.

The extrapolation of cosmic noise absorption results obtained with wide antenna beams to satellite radiations implies the assumption that the absorbing medium is fairly homogeneous and does not contain small, highly absorbing clouds. The assumption is well justified for polar cap and sudden cosmic noise absorption, and probably also holds for auroral absorption since the latter generally is associated with diffuse, post-breakup auroral forms.

During the early phase of auroral activity when auroral forms are sharply delimited, thick layers of small electron density irregularities may form which cause signal attenuation by multiple scattering. This attenuation could be more important than a possible, but so far experimentally unverified, true absorption in small, underlying clouds. A distinction between the two types of attenuation would be difficult for a satellite radio signal observed with a single antenna. The attenuation of 136 and 400 mc/s satellite radio signals by multiple scattering in the auroral ionosphere will be discussed and estimated in a separate report.