An Analysis of Multi-Station Ground Observations of VLF Hiss

Lalmani, Manoranjan RAO, V.V. SOMAYAJULU and B.A.P. TANTRY

*Electronics and Radio Physics Laboratory,
Department of Physics, Banaras Hindu University,
Varanasi, India*

(Received February 19, 1972)

(Revised April 24, 1972)

The possibility that VLF hiss observed at low latitudes is a consequence of waveguide mode propagation of energy from sources located in the auroral zone is examined in some detail. From the locii of the hypothetical point sources which would yield the observed power ratios for any given pair of stations, it is found that sources located in a region around the auroral zone can explain the observations at all stations. It is also shown that the accepted values of the dominant mode attenuation in the terrestrial waveguide can explain the observed hiss spectral densities at low latitudes only if we assume the presence of an extended source along the auroral zone.

Of the various types of VLF-emissions, hiss is perhaps the least known phenomenon. Its unstructured character resembling white noise makes its identification on a frequency-time spectrogram rather difficult. Hiss has been observed over a wide range of frequencies from approximately 1 kHz to 500 kHz, though its character may differ within this frequency range. Above 2 kHz the occurrence of hiss is maximum in the evening and night sectors (McINNES, 1961; JORGENSEN, 1966). JORGENSEN (1966) has summarized ground observations of VLF hiss from 13 stations in both hemispheres ranging in geomagnetic latitudes from 34° to 89° , and has shown that the maximum spectral densities in the frequency range 4-9 kHz vary from 10^{-19} to 10^{-14} watts/m²/Hz. He concludes that hiss comes down through the ionosphere over the auroral zone and then propagates through the earth ionosphere waveguide to lower latitudes. Similarly, ONDOH and ISOZAKI (1965) suggest that their simultaneous hiss observations at Moshiri (geomag. lat: 34° N) and Hiraiso (geomag. lat: 26.2° N) are consistent with the attenuation rates of the dominant mode in the earth ionosphere waveguide. Similar suggestions were made earlier by DOWDEN (1961) and ELLIS (1961).

Evidently, it is desirable to see whether ground based hiss observations at a number of stations covering a reasonably wide range of latitudes could be satisfactorily accounted for by the mode propagation and, if so, to enquire into the physical nature of the sources in the auroral zone. It is precisely with this view that the present investigation was undertaken. Firstly, we calculated the locus of point sources which would yield the observed power ratios for any given pair of stations using the method suggested by DOWDEN (1961). The ratio of powers observed at two distances d_1 and d_2 from the source can be written as:

$$\frac{P(d_1)}{P(d_2)} = \frac{d_2}{d_1} \cdot \exp[2\alpha(d_2 - d_1)] \quad (1)$$

where α is the attenuation factor.

If we know the ratio of power between two stations, we can draw from Eq. (1) a curve signifying the possible locations of the dipole sources ('point dipoles') provided α is known. This approach was adopted earlier by DOWDEN (1961) and ELLIS (1961). The entire process is repeated for all the stations under study. In Table 1, we show the maximum spectral densities measured at various stations. For convenience, the southern latitude stations are listed first. In a study of this kind, it would be evidently desirable to have simultaneous measurements at all the stations at the same frequency. A glance at the table shows that this is not the case. If,

Table 1. Observations of VLF Hiss*

Station	Geomag. lat.	Max. Spect. density W.m ⁻² (Hz) ⁻¹	Observation		Reference
			Period	Frequency	
Byrd	70.6° S	1 × 10 ⁻¹³	Jun.-Aug. 1962	1-20 kHz	HELMS and TURTLE (1964)
Macquarie Island	61.1° S	6.5 × 10 ⁻¹⁴	Dec. 1959- Mar. 1960	4 kHz	DOWDEN (1961)
Hobart	51.7° S	3 × 10 ⁻¹⁵	Dec. 1959- Mar. 1960	4 kHz	DOWDEN (1961)
Adelaide	45.0° S	1 × 10 ⁻¹⁶	Mar.-Aug. 1960	4-6 kHz	ELLIS (1961)
Camden	42.6° S	1 × 10 ⁻¹⁶	Mar.-Aug. 1960	4-6 kHz	ELLIS (1961)
Mundaring	43.0° S	1.0 × 10 ⁻¹⁶	Mar.-Aug. 1960	4-6 kHz	ELLIS (1961)
Nord	80.8° N	1 × 10 ⁻¹⁴	Nov.-Dec. 1964	8 kHz	JORGENSEN (1966)
Godhavn	79.9° N	1 × 10 ⁻¹⁴	Nov.-Dec. 1964	8 kHz	JORGENSEN (1966)
Narssarssuaq	71.2° N	1 × 10 ⁻¹⁴	Nov.-Dec. 1964	8 kHz	JORGENSEN (1966)
Tromso	67.1° N	1.5 × 10 ⁻¹⁵	Aug.-Dec. 1963	8 kHz	HARANG and LARSEN (1965)
Moshiri	34.3° N	5.4 × 10 ⁻¹⁸	Jan.-Nov. 1963	4-6 kHz	IWAI <i>et al.</i> (1964)
Hiraiso	26.2° N	4.4 × 10 ⁻¹⁹	Jun.-Dec. 1966	5 kHz	ONDOH and ISOZAKI (1968)

* After JORGENSEN (1966).

however, we confine our attention to only the stations in the southern hemisphere we find that all measurements except those at Byrd refer to frequencies between 4–6 kHz. Moreover, the periods of measurements at these stations are reasonably close. Thus we choose for our analysis the data recorded at the following stations: Macquarie Island, Hobart, Adelaide, Camden and Mundaring.

Besides being critically dependent on the electron density and collision frequency profiles in the lower ionosphere, the attenuation factor α is also a function of the azimuthal direction of propagation, the nature of the terrain, etc. It is, however, neither possible nor absolutely necessary for our present purpose to give detailed considerations to all these factors. From the theoretical and experimental studies of various authors (*e.g.*, WAIT, 1962; BARR, 1971; CHALLINOR, 1966; FIELD, 1969; CHAPMAN and MACARIO, 1956) we find that a value of 10 db/1000 km is reasonable for the attenuation of the 5 kHz wave. DOWDEN (1961), for example, uses a value of 10 db/1000 km for 4 kHz.

With the above value of attenuation we have drawn curves showing the possible locations of point sources from Eq. (1) for different combinations of stations. The results are shown in Fig. 1 from which we find that, in general, the curves extend over large distances. The source extent is relatively limited for the high power ratio between two close stations. This is evident from the curve drawn for Macquarie Island and Hobart

Fig. 1 Showing locations of stations selected for analysis. The coordinates are geomagnetic with SP indicating geomagnetic south pole. MI (Macquarie Island), H (Hobart), Ad (Adelaide), M (Mundaring) and C (Camden). Thick curves show possible locations of point sources calculated from Eq. (1). Each curve is calculated for a pair of stations and is labelled by combined symbols denoting the two stations.

denoted by MI-H. An interesting fact emerges from Fig. 1 if we divide the entire hemisphere into latitude zones each of, say, 10° wide. All the curves pass through the latitude zone between 60° and 70° . The parts of curves which lie in this latitude range are shown dotted for convenience. Thus it seems likely that hiss sources located in a narrow latitudinal range around the auroral zone can account for observations at all lower latitudes. This is consistent with the experimental observations that hiss zones are the same as the auroral zones of precipitation (JORGENSEN, 1966).

From the observed spectral densities at various stations, it is, in principle, possible to calculate back the attenuation coefficient and to compare the result with the value assumed for locating the point sources. To do this we have to assume the source location. If we assume the source is situated at, say, 65° latitude and if we measure the minimum distances to different stations from this latitude we find $\alpha = 10.5 \pm 1.4$ db/1000 km. This is in good agreement with the value of 10 db/1000 km assumed for drawing the curves for different combinations of the stations. It therefore follows that the observed variation of VLF hiss intensity is consistent with the dominant mode propagation in the earth ionosphere waveguide only if we assume the presence of a source extending all along a latitude close to the auroral zone. It is expected that a similar conclusion would be reached if the measurements in the northern hemisphere were analysed.

It should finally be pointed out that some low latitude observations (see for example, ONDOH and ISOZAKI, 1965) cannot be explained within the framework of the waveguide mode propagation. A detailed discussion of such observations is, however, beyond the scope of this brief communication.

The research reported here was supported by the National Oceanic and Atmospheric Administration of the United States, under the contract No. : E-33-70 (N).

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