LETTERS TO THE EDITOR

RADIOPHYSICS

Very-Low-Frequency Discrete Emissions received at Conjugate Points

In a recent article[1] describing a geomagnetic conjugate point experiment an accurately synchronized pair of spectrograms was shown. As shown in Fig. 1 of that article a sequence of six noise bursts in the 5–6 kc./s. frequency region was observed at both Knob Lake, Canada (68° N., geomagnetic), and at Byrd Station, Antarctica (70° S., geomagnetic); but the sequence began at Knob Lake 0·8 ± 0·1 sec. before it began at Byrd.

However, close inspection of Fig. 1 indicates that in each case the sequence is not six separate bursts but a pair of bursts seen three times. In support of this it will be noticed that the shapes and separation of the two bursts in each pair are similar and in each case the first burst occurs at a slightly higher frequency than the second. Furthermore, the time separation between successive pairs (using the time-scale provided) is 1·6 ± 0·1 sec., which is just twice the delay between Knob Lake and Byrd. Thus at intervals of 0·8 sec. this pair of bursts appeared alternately at Knob Lake and Byrd.

This phenomenon cannot be due to successive reflexions in opposite hemispheres of electromagnetic energy because the observed time delays are too short. Whistler observations in these latitudes show 5 kc./s. propagation times between 1·5 and 2·5 sec. for a single hemisphere to hemisphere trip[1]. Even then these times refer to lower latitudes because geomagnetic field lines terminating at latitudes greater than about 62° do not allow 5 kc./s. propagation of this type[2]. Thus if this phenomenon were due to whistler type echoes the delays would be several times longer.

However, such a sequence of alternate reception at conjugate points was predicted in a theory proposed by me[3] for the production of very-low-frequency discrete emissions. In fact such a conjugate point experiment was suggested as a test for the theory.

According to this theory Doppler-shifted cyclotron radiation is emitted by a small cloud or bunch of electrons spiralling along a field line. Only the downward-shifted frequency can propagate so that radiation is only emitted backwards. If the bunch should survive several trips along the field line from hemisphere to hemisphere, being reflected at the ends by magnetic mirror effect, then an observer at each end of the field line would receive an emission each time the bunch was travelling away from him. Thus for each observer the time between successive emissions would be the complete (there and back) oscillation period of the cloud and the delay between the sequences observed in opposite hemispheres would be half this period[3].

The complete oscillation period of 1·6 sec. from Fig. 1 (ref. 1) would correspond to 60 keV. electrons (for minimum helical pitch angles of 20°) if the guiding field line was that connecting the two observing stations or 15 keV. electrons if the guiding field line was typical of those (around 60°) producing nose whistlers observed at Byrd[2]. These electron energies deduced from the oscillation period (15–60 keV.) are close to those (5–25 keV.) required by my theory to produce the detailed frequency-time shape of observed discrete emissions[3].

I thank Prof. G. R. A. Ellis, of the Physics Department, University of Tasmania, for advice.

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[1] Lokken, J. E., Shand, J. A., Wright, Sir C. S., Martin, L. H., Brice, N. M., and Helliwell, R. A., *Nature*, **192**, 319 (1961).

[2] Smith, R. L., *The Use of Nose Whistlers in the Study of the Outer Ionosphere* (Stanford Electronics Laboratory, 1960).

[3] Dowden, R. L., *J. Geophys. Res.*, **67**, 1745 (1962).

Dowden suggests that the six bursts of noise shown in Fig. 1 of our article consist of a pair of bursts seen three times at each end of the path, and that this interpretation provides support for a new theory of very-low-frequency emissions which he has published elsewhere.

We agree that this interpretation is entirely consistent with the data reported in our article. As a matter of fact, further study of the original tape recordings has shown additional noise bursts which can be fitted into a repetitive or echo pattern, in which the phase is opposite at the two ends of the path. The echoing of noise bursts between stations in opposite hemispheres is a common occurrence, and is the subject of a detailed study now in progress at the Radioscience Laboratory, Stanford University. Results of this work will be reported in the near future.

Although we can support the 'echo' interpretation of Fig. 1, we question Dowden's conclusion that the phenomenon cannot be due to successive reflexions in opposite hemispheres of electro-magnetic energy travelling in the whistler mode. His argument is based on the fact that whistler observations at these latitudes show 5 kc./s. propagation times between 1·5 and 2·5 sec. for a single hemisphere-to-hemisphere trip (one-hop), while the observed one-hop delay of the noise bursts is only 0·8 sec. (one-half of observed period of 1·6 sec.). It is implied that both the path of propagation and the electron density in the magnetosphere are about the same in the two cases. Neither of these assumptions is justified, as we shall see.

Whistler-mode path latitude bears little relation to the latitude of the receiving station. For example, data analysed by Smith[1] show a variation in the nose frequency (closely related to path latitude) at Byrd from 4·5 kc./s. to 12 kc./s. For the model of electron density derived by Smith, the corresponding minimum gyro-frequencies at the top of the path are about 11·2 kc./s. and 30 kc./s., respectively. The corresponding effective geomagnetic latitudes are 61° and 55°, respectively. Other data show that even lower latitude paths are often observed at Byrd Station[2].

Another factor affecting propagation time is the electron density along the path of propagation. Carpenter has shown that electron densities are often markedly depressed during magnetic storms[2]. One-