EFFECT OF MAGNETIC ANOMALIES ON VERY LOW FREQUENCY DISCRETE EMISSIONS*

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The author has suggested (Dowden 1962) that the spectrogram (frequency *v.* time) shapes of V.L.F. discrete emissions can be explained as Doppler-shifted cyclotron radiation from electrons spiralling along a geomagnetic field line *away* from the observer. The emission frequency is given by Eidman (1958),

$$f = \gamma h[1+\beta n \cos\theta \cos\psi]^{-1},$$

where h is the gyro frequency, $\gamma^2 = 1-\beta^2$, β is the electron velocity in units of the velocity of light, n is the refractive index of the medium at the frequency f and direction θ, θ is the angle between the field and the direction of emission, and ψ is the pitch angle of the spiralling electrons.

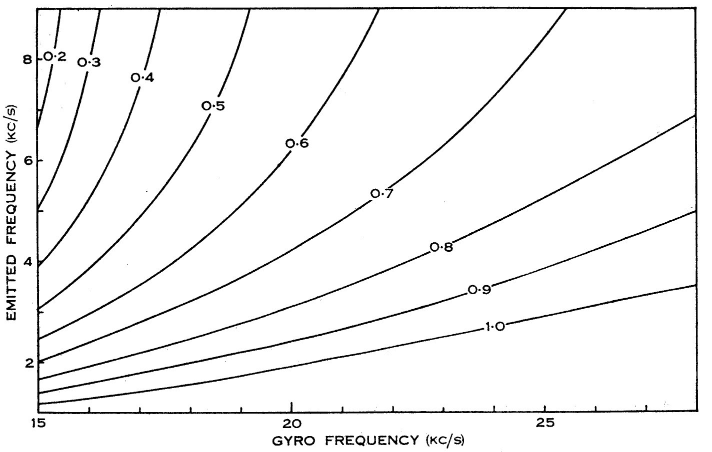

Fig. 1.—Doppler-shifted cyclotron frequency emitted by electrons of energy 75 keV in a medium of scale frequency $a = 500$ kc/s shown as a function of gyro frequency for several values of cos ψ_0.

It is reasonable to assume that γ and β are constant, that the electron density in the exosphere is everywhere proportional to the magnetic field, that θ is either constant or a function of h only, and that ψ is given by the invariance of magnetic moment:

$$\sin^2\psi/\sin^2\psi_0 = h/h_0,$$

where subscript zero can refer to any known point such as the equatorial plane or point of minimum magnetic field. In this case the variation of frequency emitted by an electron spiralling along a field line is produced entirely by the variation of

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magnetic field (or gyro frequency) along the path. This is shown in Figure 1 for small θ, for electrons of energy 75 keV, and for several values of cos ψ_0 defined at the arbitrary level $h_0 = 15$ kc/s.

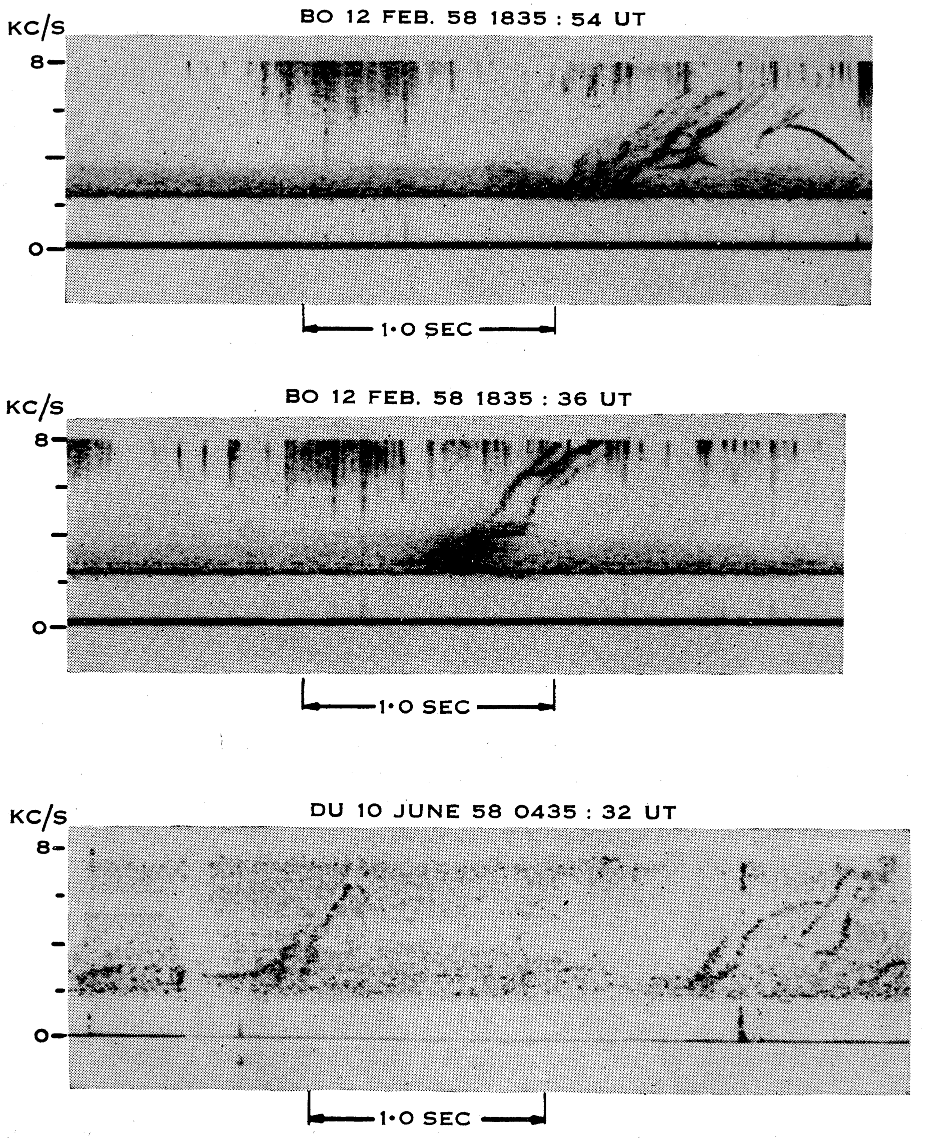

Fig. 2.—"Unusual events" recorded at Boulder and Dunedin (after Helliwell and Carpenter 1961).

For a dipole magnetic field, consideration of electron travel times and wave group propagation times gives the spectrogram shapes of "hooks" for hemisphere to hemisphere traverses and those of "falling tones", "risers", and "pseudo noses" for incomplete traverses (Dowden 1962). However, many discrete emissions have distorted spectrograms which cannot be explained by the theory, if a dipole field is assumed. Examples of these are shown in Figure 2.

The following points suggest that these distorted emissions are produced by magnetic anomalies in a predominantly dipole magnetic field. An atlas of spectrograms of V.L.F. emissions (Jones *et al.* 1963) observed at times of quiet conditions, moderate disturbance, and severe disturbance, indicates that the degree of distortion increases with the degree of disturbance. Reference to Figure 1 shows that the emitted frequency can be quite sensitive to small changes in magnetic field or gyro frequency, particularly for large pitch angles. Anomalies observed by satellites and space probes appear to have significant amplitudes. These are shown in Table 1 (the last two entries refer to hydromagnetic fluctuations).

TABLE 1

SATELLITE OBSERVATIONS OF MAGNETIC ANOMALIES

Region (Earth radii)	Amplitude (gammas)	Remarks	Reference
7	-50	(ring current?)	Smith *et al.* (1960)
$5\frac{1}{2}$	$+15$	quiet period	Heppner *et al.* (1963)
—	800	disturbance	Dolginov *et al.* (1960)
—	140	disturbance	Dolginov & Pushkov (1962)
7	10	H.M. (100–500 s)	Judge & Coleman (1962)
10	100	H.M. ($0\cdot3$ c.p.s.)	Sonett *et al.* (1960); Coleman *et al.* (1960)

It is not clear what anomalies should be taken as typical during disturbed periods in the region of interest ($L{\sim}4$ Earth radii or $h{\sim}15$ kc/s). However, to demonstrate the effect a number of hypothetical anomalies of 54 gamma ($\Delta h = 1\cdot5$ kc/s) were assumed. These models are shown in Figure 3 together with the resulting distorted hooks calculated from the integrals for electron travel times and wave group propagation times given previously (Dowden 1962). Field lines were chosen so that the minimum gyro frequency $h_0 = 15$ kc/s. The first model is a purely dipole field. In the remaining models the undisturbed dipole field is shown by the broken curve. Two hooks have been computed for each model corresponding to $\cos\psi_0 = 0\cdot5$ and $0\cdot4$ respectively. Both are produced by electrons of 150 keV moving in a medium of scale frequency 500 kc/s along a field line terminating at about 59° geomagnetic latitude.

In each case the total fields (dipole plus anomalies) are taken as symmetrical about the geomagnetic equatorial plane. This is not particularly likely (especially for cases 4, 5, and 6) but was chosen to show the different effects of the anomalies on the predominantly falling and rising parts of the hooks respectively. A more realistic approach would be to consider different models for opposite hemispheres. Since very little of the distortion arises from propagation effects (as discussed later), the resultant hooks from a combination of any two field models shown here can be synthesized by connecting (at the point of minimum emitted frequency f_0) the falling part of one hook with the rising part of another. It should also be remembered that, in the majority of cases, some or all of the falling branch will be missing, as discussed previously (Dowden 1962). Thus the observed events shown in Figure 2 appear to correspond to those shown for model 5 of Figure 3.

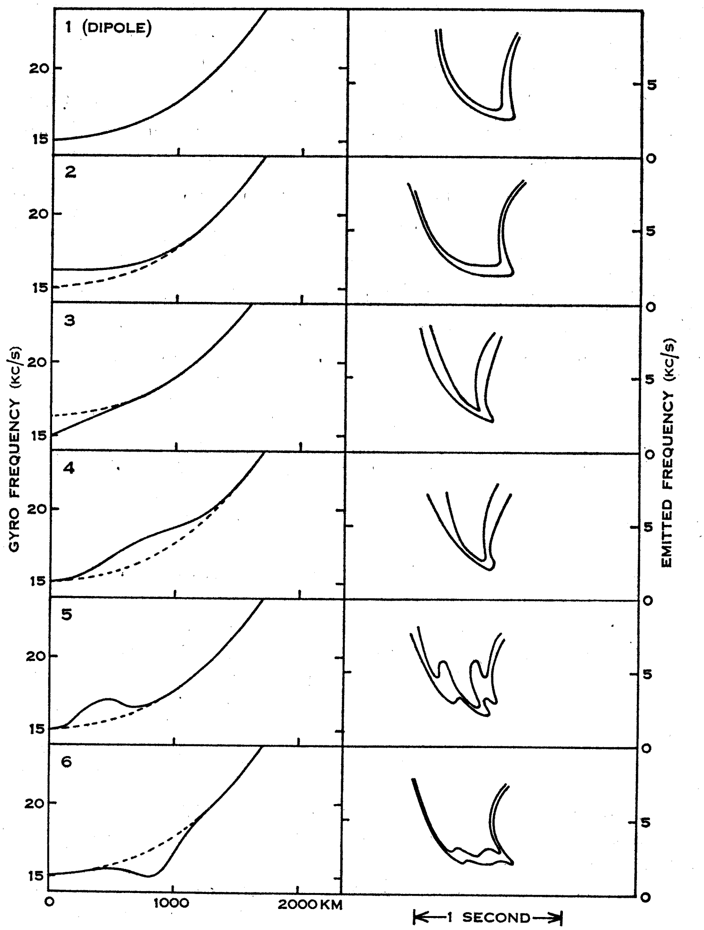

Fig. 3.—Hooks calculated for electron bunches of energy 150 keV, pitch cosines of 0·4 (inner) and 0·5 (outer) respectively, moving in a medium of $a = 500$ kc/s along the field line $\lambda = 59°$. The magnetic field models are shown on the left as gyro frequency versus distance along the field line measured from the equatorial plane.

An electron bunch emitting Doppler-shifted cyclotron radiation acts as a naturally occurring magnetometer in orbit in the exosphere. As in the case of a man-made orbiting magnetometer, unambiguous magnetic data can be deduced if the orbit parameters (energy, pitch, field line) are known. It may be possible to deduce both these and the magnetic anomalies from a single distorted hook. However, qualitative measurements are possible even without knowing these parameters. In Figure 3 we see that the distortions of the hooks relative to the undistorted or "dipole" hook are roughly similar to the distortions of the anomalous fields relative to the pure dipole field. Thus, for any emission which is recognizable as a distorted form of a standard or dipole hook, we can get some idea of the shape and the sign of the anomaly.

It has been shown above (see Figs. 1 and 3) that the frequency-time shape of some V.L.F. emissions is remarkably sensitive to small field anomalies: changes of a few percent over a few hundred kilometers would be detectable. Whistlers, on the other hand, are quite insensitive to anomalies along the propagation path. Indeed, in an investigation into the effects of much larger anomalies on whistlers, Spreiter and Briggs (1962) found that, although there might be an appreciable change in the nose frequency and nose time delay, there is very little change in shape; i.e. the frequency-time plot of a nose whistler produced in a highly anomalous field could be closely fitted to one produced in a dipole field by suitably changing the field line latitude and the scale frequency or electron density.

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