WIDE–BAND BURSTS OF V.L.F. RADIO NOISE (HISS) AT HOBART*

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Summary

Wide-band bursts of radio noise from the upper ionosphere or exosphere have been observed at frequencies from 100 c/s to 250 kc/s. The observed intensity [$Wm^{-2} (c/s)^{-1}$] ranges from nearly 10^{-9} at 100 c/s to 10^{-19} at 250 kc/s. However, the intensity at the source (above the ionosphere), deduced by subtracting the losses suffered in the ionosphere and below the ionosphere, shows a relatively flat spectrum at a level of the order of $10^{-10} Wm^{-2} (c/s)^{-1}$.

I. Introduction

V.L.F. noise, also known as " hiss " or geomagnetic noise, is audio-frequency radio noise originating in the upper ionosphere or exosphere which tends to occur at times of aurora and geomagnetic activity (Ellis 1959). It usually occurs in bursts of minutes or hours' duration. These bursts are usually narrow band (a few kilocycles bandwidth) centred at around 5 kc/s (Ellis 1959). Sometimes, particularly at times of strong geomagnetic disturbance, very wide-band bursts occur (Ellis 1959 ; Dowden 1960). Some very wide-band bursts have been observed covering a range of from less than 5 kc/s to more than 200 kc/s (Dowden 1960). Later observations (this paper) have followed these wide-band bursts down to less than 100 c/s so it seems likely that occasionally bursts spread over the range from 100 c/s or less to a few hundred kc/s—a frequency ratio of several thousand.

This paper examines the ground level intensities recorded at several spot frequencies (125, 240, 410, 760 c/s, 1·8, 4·3, 9·0, and 230 kc/s) during wide-band bursts observed at Hobart. The corresponding intensities at an arbitrary level above most of the ionosphere (550 km) are deduced from considerations of the losses affecting the wave from that level to the observing point.

II. Experimental

(a) Techniques

The receiving systems were broadly similar to those described elsewhere (Ellis 1959). A vertical loop antenna fed a wide-band amplifier followed by a narrow-band pass amplifier for each channel. Special techniques were used to avoid spurious effects of atmospherics and other impulsive noise.

In one recording system the detected outputs were applied to the vertical deflection plates of a C.R.O. During an impulse the C.R.O. spot would be deflected well off scale but between impulses the spot would be deflected only by

continuous signal.   When such a display is photographed by slowly moving film
the continuous level between impulses is readily apparent.

The second system was developed by Ellis (1959) for recording on a pen
recorder.   This also records only the continuous level between impulses.   In
this method the detected outputs were applied to a partially unidirectional
integrator.   This had a long time constant of many tens of seconds for increases
in signal but a very short time constant of some milliseconds for signal decreases.
The system is thus the reverse of a peak-reading voltmeter.

Both systems give strong discrimination (of about 40 dB) against atmos-
pherics even when the " mark-space " ratio of atmospherics is very high.   In
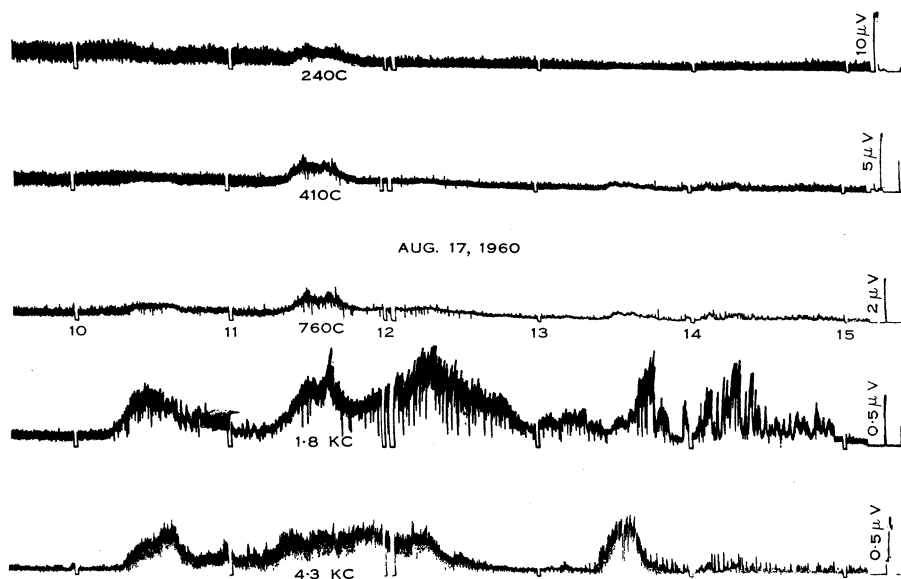some cases both recording systems were used on the one frequency channel.

Fig. 1.—Typical wide-band (c. 1130 L.T.) and narrow-band bursts.

Further discrimination from any spurious effects follows from the nature
of the phenomena studied.   That shown in Figure 1 is fairly typical.   The
smooth rise and fall of amplitude during bursts, the duration of bursts (order
of an hour), and the relative infrequency of bursts (around 10 per month), make
the phenomena readily distinguishable from steady background noise or man-
made bursts of interference.

Two basic methods of intensity calibration were used.   In the first the loop
antenna was replaced by a signal generator or noise generator of the same
impedance.   Burst intensities were then deduced from this receiver sensitivity
calibration and the effective height of the loop antenna calculated from measure-
ment of its physical dimensions.   The second method gave direct calibration
by generating a known field strength in the vicinity of the antenna from a remote
auxiliary loop.   Both methods gave consistent results.   The calibration and
reading accuracy (about 10%) was more than adequate for the argument pre-
sented in this paper.

Only six recording channels were available so that simultaneous recordings were not made at all eight frequencies mentioned above. However, there was sufficient frequency overlap to suggest that the wide-band bursts measured mainly at the higher frequencies were similar to those measured mainly at the lower frequencies.
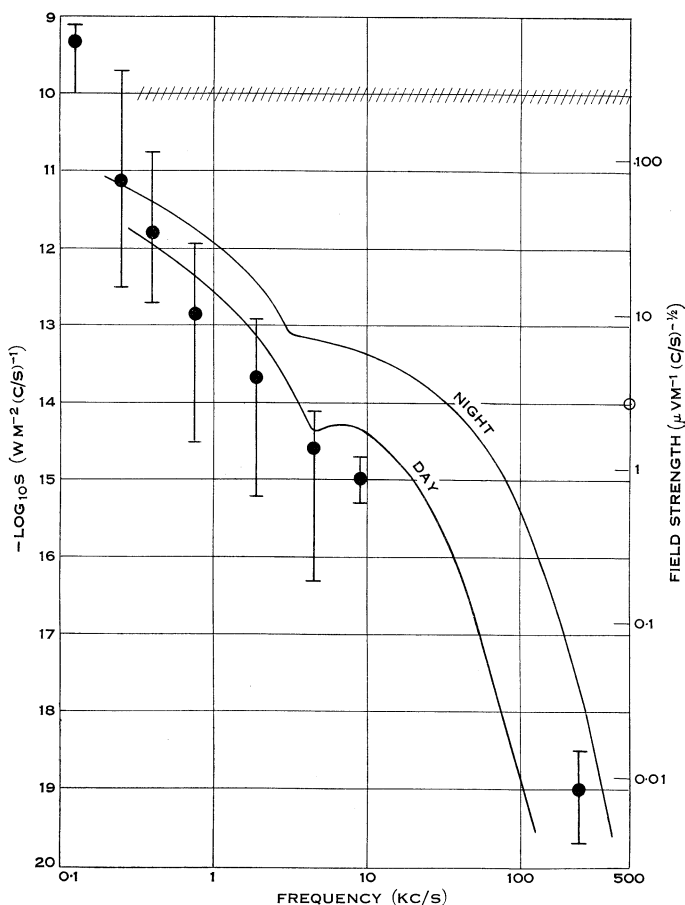

Fig. 2.—Medians and spread of peak intensities of observed wide-band bursts. Curves are expected ground intensities for a " white " source above the ionosphere at the hatched level $[10^{-10}\ \mathrm{Wm^{-2}\ (c/s)^{-1}}]$. The right-hand ordinate is field strength.

Two sweep-frequency analysers covering the ranges 40–500 c/s and 400 c/s to 6 kc/s, though of less sensitivity and of restricted use for intensity measurement, were used to check the interpretation of the fixed-frequency records.

(b) Observations

Twenty-five wide-band bursts recorded over a period of about 15 months are considered here. Figure 1 shows one of these recorded on the five frequencies operating at the time. Other narrow-band bursts at around 2 and 5 kc/s are

seen on the same record. The median intensities and the spread of intensities recorded is shown plotted in Figure 2. Medians for 125 c/s and for 9·0 and 230 kc/s may not be truly representative, as less than five values were obtained for each. The burst signal to background noise ratio was best around the middle of the band (20 dB at 5 kc/s) but worsened in both directions to about 5 dB at 100 c/s and 10 dB at 200 kc/s.

III. DISCUSSION

Although there is no strong evidence to indicate the level at which V.L.F. noise is produced, we will assume here that it is above most of the ionosphere, that is, above (say) 550 km. Directional and spaced observations (Ellis 1960; Dowden 1961) show that V.L.F. noise bursts often appear to be coming from virtual sources of quite small areas on the Earth's surface. Consequently we adopt the model that the burst is generated in a relatively narrow tube of force somewhere above the ionosphere, is then piped down through the ionosphere in the " whistler mode ", and radiated out under the ionosphere in the two-surface (Earth or ocean and ionosphere) waveguide to the observer. We require, then, the losses suffered in these two modes.

The Earth-ionosphere waveguide losses have been calculated by Watt and Maxwell (1957) for frequencies from 1 to 100 kc/s. Curves are given of field strength versus frequency for propagation over day-time and night-time sea-water paths of various distances for a unit " white " point source. In our case the distance between the virtual source and the observing point is not known for each burst but a typical median value can be estimated along the following lines.

Suppose all sources were point sources and that they were randomly distributed about Hobart. We consider an annular area centred on Hobart at distance r, width dr, and area dA. We define the probabilities: $p_s(r, dr)$ of a source occurring within this annular area; $p_0(r, dr)$ of it being observed at Hobart if it did occur; and $p_{0s}(r, dr)$ of an *observable* source occurring within this area (within r and $r+dr$). It follows:

$$p_s(r,dr) \propto dA \propto r.dr$$
$$p_0(r,dr) \propto \text{intensity on arrival at Hobart}$$
$$\propto e^{-\alpha r}/r$$

where α =attenuation coefficient for the Earth-ionosphere waveguide mode.

$$p_{0s}(r,dr) = p_s(r,dr) \cdot p_0(r,dr)$$
$$= e^{-\alpha r} \cdot dr.$$

We define a median range $\bar{r}$ such that

$$\int_0^{\bar{r}} p_{0s}(r,dr) = \int_{\bar{r}}^{\infty} p_{0s}(r,dr),$$

that is

$$\frac{1}{\alpha}[e^{-\alpha r}]_{\bar{r}}^0 = \frac{1}{\alpha}[e^{-\alpha r}]_{\infty}^{\bar{r}}.$$

Hence

$$e^{-\alpha \bar{r}} = \tfrac{1}{2}.$$

The attenuation coefficient, α, is strongly frequency dependent, but typical values are around 3 dB per 1000 km (Watt and Maxwell 1957) so that the typical range ($\bar{r}$) will be around 1000 km.

Suppose instead the sources were very large so that everywhere in the vicinity of Hobart was essentially uniformly illuminated by each burst. We consider the same annular area described above. The total power intercepted by this annulus is proportional to its area,

$$dP_s(r) \propto r.dr,$$

Transmission over distance r to Hobart would decrease this by a factor $e^{-\alpha r}/r$, so that the power observed at Hobart from this area (from ranges r to $r+dr$) is then

$$dP_{0s}(r) = K.e^{-\alpha r}.dr,$$

K being a constant of proportionality. We define the median range $\bar{r}$ as that range within which half of the observed power occurs. Then

$$K \int_0^{\bar{r}} e^{-\alpha r}.dr = K \int_{\bar{r}}^{\infty} e^{-\alpha r}.dr.$$

Hence the same argument as that above leads to $\bar{r} \approx 1000$ km.

Selection of the $\bar{r} = 1000$ km day and night curves of Watt and Maxwell gives us the below-ionosphere losses for the frequency range 1–100 kc/s. Those for frequencies outside this range are estimated by extrapolation.

The attenuations for whistler mode propagation through the ionosphere were obtained from curves by Helliwell (1958) using a model day-time ionosphere from 80 to 550 km given by Francis and Karplus (1960). Night-time attenuations were estimated from this model by disregarding the ionosphere below 100 km. The values found are roughly consistent with whistler mode echo observations (Dowden 1959) at 17 kc/s and observations of 512 kc/s signals from the ground made by a receiver carried in a rocket to a height of over 400 km (Mechtly and Bowhill 1960).

The losses for propagation through the ionosphere (whistler mode) and below the ionosphere (waveguide) are combined and plotted in Figure 2 for day and night conditions. We have assumed a " white noise " source of intensity 10^{-10} Wm^{-2} (c/s)$^{-1}$ at a level of 550 km. The curves thus represent the expected intensity at an observing station on the ground about 1000 km from the point immediately below the source. The accuracy of these curves deteriorates towards both ends of the frequency scale. The treatment used above breaks down at the low end because the distances involved approach a wavelength. At the high frequencies the attenuations are so large that small errors in the estimation of parameters become important. Both ends will suffer from the extrapolations.

It is seen from Figure 2 that the expected " ground level " spectrum resulting from this flat or " white " source spectrum fits the observed intensities to an order of magnitude or so, although an intensity proportional to wavelength

might give a better fit at the low frequency end.   The main point emerging from this study is that much of the very strong frequency dependence of observed intensities is accounted for by attenuation.

Intensities of over 10^{-14} Wm^{-2} (c/s)$^{-1}$ at 512 kc/s have been observed at a height of 400 km by Mechtly and Bowhill (1960).   This is a lower limit (receivers overloaded) and so consistent with our results.   On the other hand, at frequencies above 900 kc/s, at times when the ionosphere above Hobart is transparent, ground level intensities (due to cosmic noise) of only 2×10^{-19} Wm^{-2} (c/s)$^{-1}$ are observed (Ellis 1957).   This is some nine orders of magnitude less than our value. However, it must be remembered that very wide-band bursts are rare and occur only during very severe disturbances, whereas the ionosphere is transparent at low frequencies only during very quiet conditions.   Nevertheless, this does show that, at least at the higher frequencies, a continuous high background level does not exist.

IV. ACKNOWLEDGMENTS

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