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 $\mathrm{d}r$, and area $\mathrm{d}A$. We define the probabilities: $p_s(r, \mathrm{d}r)$ of a source occurring within this annular area; $p_0(r, \mathrm{d}r)$ of it being observed at Hobart if it did occur; and $p_{0s}(r, \mathrm{d}r)$ of an *observable* source occurring within this area (within r and $r+\mathrm{d}r$). It follows:

$$\begin{aligned} p_s(r,\mathrm{d}r) &\propto \mathrm{d}A \propto r.\mathrm{d}r \\ p_0(r,\mathrm{d}r) &\propto \text{intensity on arrival at Hobart} \\ &\propto \mathrm{e}^{-\alpha r}/r \end{aligned}$$

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

$$\begin{aligned} p_{0s}(r,\mathrm{d}r) &= p_s(r,\mathrm{d}r)\cdot p_0(r,\mathrm{d}r) \\ &= \mathrm{e}^{-\alpha r}\cdot \mathrm{d}r. \end{aligned}$$

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

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

that is

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

Hence

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

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,

$$\mathrm{d}P_s(r) \propto r.\mathrm{d}r,$$

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

$$\mathrm{d}P_{0s}(r) = K.\mathrm{e}^{-\alpha r}.\mathrm{d}r,$$

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

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

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} $(\mathrm{c/s})^{-1}$ 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.

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