4.2 The noise background: choice of operating frequencies

There is always a minimum incident field strength needed to give a detectable signal in a radio receiver. This minimum may be set either by the intrinsic noise generated within the receiver or by noise received by the antenna from external sources. Intrinsic receiver noise is usually the limiting factor at frequencies greater than 100 MHz, while noise from the galaxy, the ionosphere, or industrial equipment dominates the lower frequencies. Figure 18, which has been adapted from JASIK [1961], shows typical threshold levels as a function of frequency ν, for receivers with a 1 MHz bandwidth.

$V_{noise} \propto \delta f^{1/2}$
$V_{pulse} \propto \delta f$ $\Rightarrow$

$\Rightarrow$ Threshold levels scale down by a factor $\delta f^{1/2}$ when using another bandwidth.

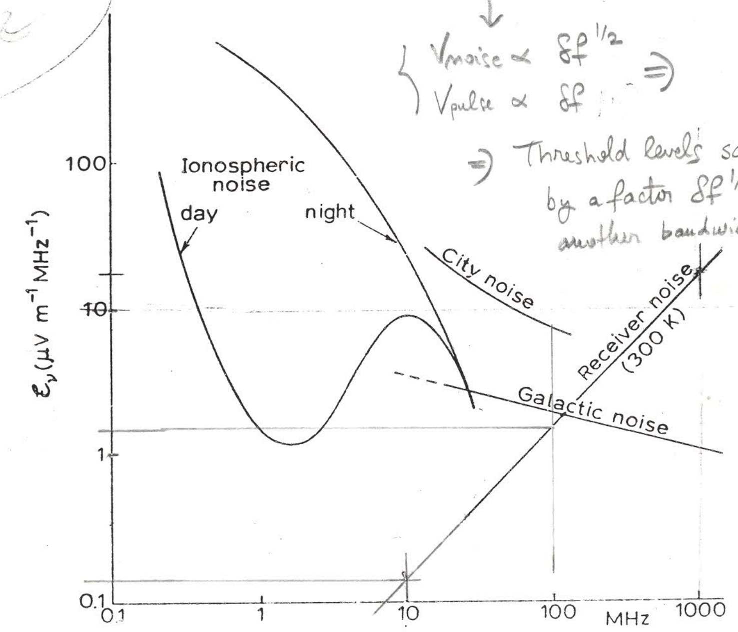

Fig. 18. Minimum detectable field strengths for a half-wave dipole antenna at different receiver frequencies, in a bandwidth of 1 MHz. around the selected ν.

The minimum possible receiver noise is set by the thermodynamic fluctuation noise (Johnson noise) which appears across the input terminals as a result of the resistance R between them. Practical receivers may have noise levels some two or three times greater than this. According to a well-known formula (see, for instance, BENNETT [1960]) the noise voltage v_n in a bandwidth $d\nu$ is given by:

$$\boxed{v_n^2 = 4R\,kT\,d\nu.} \tag{74}$$

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White noise ≡ independent of the frequency (no 'colour' as long as it is independent of frequency).

The noise voltage increases as the square root of the bandwidth. This is a characteristic feature of all noise, and contrasts with the pulse amplitude discussed in section 4.1 which varied directly with the bandwidth. A special feature of eq. (74) is that v_n is independent of the actual frequency ν. However our interest is not so much in v_n as in $\boxed{\mathcal{E}_\nu}$, the field strength in a given bandwidth at frequency ν needed to give a signal greater than v_n at the receiver terminals. It turns out that $\mathcal{E}_\nu$ increases in proportion to ν, as shown in fig. 18. We can see this by considering an example in which $\mathcal{E}_\nu$ is linked to v_n through a half-wave dipole. Whatever the frequency, ν, to which it is tuned, the dipole has a radiation resistance at that frequency of 70 Ω, and so is readily matched to a resistive receiver input impedance of 70 Ω. Assuming the effective temperature T to remain constant, the noise levels as given by eq. (74) will be the same for any dipole, independent of ν. To calculate the voltage at the receiver terminals due to a field strength $\mathcal{E}_\nu$ we multiply $\mathcal{E}_\nu$ by the distance over which it acts: for a half wave dipole this distance is approximately $\frac{1}{2}\lambda$. Thus to yield the constant noise level v_n of eq. (74) requires that $\mathcal{E}_\nu \times \lambda$ should be constant, or $\mathcal{E}_\nu \propto 1/\lambda \propto \nu$.

Half wave dipole

Summary: $\mathcal{E}_\nu \propto \nu\sqrt{\Delta\nu}$, $V_{noise} \propto (\Delta\nu)^{1/2}$

$\mathcal{E}_\nu \equiv \mathcal{E}_{min}$
$\mathcal{E}_{min} \times d = V_{noise}$
$\Rightarrow \mathcal{E}_{min} \propto \nu$

One way to improve the receiver sensitivity is to have an array of dipoles, whose voltages are added together through suitable matching networks. This increases the signal voltage without changing the noise. The price paid for the improvement is that the antenna system becomes markedly directional, the increase in gain on one direction being compensated for by a reduction in others. Another possibility is to reduce the effective temperature T of the receiver preamplifier stage. Whereas $T = 300$°K represents the normal conditions with conventional receivers, one may now use parametric amplifiers cooled in liquid air or liquid helium and approach noise temperatures of 30°K or even ~3°K. However, little use of such techniques has yet been made for detecting the air shower radio pulses.

At frequencies below 100 MHz, intrinsic receiver noise becomes less important than the noise received by the antenna from the galaxy. Galactic noise is the dominant natural background from 100 MHz down to about 30 MHz. The noise level is usually specified by the equivalent temperature which must be substituted in eq. (74) to give the observed noise (fig. 19). The noise temperature increases from about 500°K at 100 MHz to 50000°K at 20 MHz. However, the corresponding noise voltage v_n increases only by a factor 10, and $\mathcal{E}_\nu$ increases only by a factor 2. In fig. 18 the region 20 MHz–100 MHz is one in which the background field strength is roughly independent of frequency, and has a value ~1 µV m⁻¹ in a 1 MHz bandwidth. The value varies somewhat during the 24 hours, being a maximum when the Milky Way is overhead.

from $\sqrt{500}$ to $\sqrt{5\times10^4}$
$\sqrt{5}\times10$ to $\sqrt{5}\times100$

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