Sky Noise

Author's Foreword

I have spent countless hours under the tutelage of Gary Peach G7SLL in my quest to understand many of the fundamentals of noise and its impact on our abilities as hams to intelligently copy signals on the ham bands. This article provides a summary of my work.

I share this so that hams may have, at a minimum, an awareness of these concepts. For those of you who are ambitious, I commend this to your in depth study so that you may gain a degree of expertise.

I am very grateful and deeply indebted to Gary's boundless expertise and patient guidance in over two dozen emails on this topic.

Gary has had a fascinating career in the advanced sciences. I suggest you visit his QRZ.com web page for an overview.

Larry WB9KMW
FCARC Technical Director

Sky Noise & the Noise Power Formula

Sky noise arises from several sources, such as:

- Galactic radiation
- Earth heating
- The sun

In ham radio communications, antenna noise temperature (T) is the temperature of a hypothetical resistor at the input of an ideal noise-free receiver that would generate the same Noise Power per unit bandwidth as that at the antenna output at a specified frequency (*f*).

It is this noise temperature at a given frequency, eg, 14.0 MHz on the 20m ham band, which gives rise to sky noise.

The magintude of noise power in a receiver is further determined by the bandwidth (B) setting of the DSP filter, eg, 2,300 Hz for SSB.

$$\text{Noise Power is } \kappa \times T \times B$$

Where κ = Boltzman's constant = 1.38 $*10^{-23}$ Joules/second/degree Kelvin, or
Watts (W) per Hertz (Hz) per degree Kelvin (°K)
T = Temperature in degrees Kelvin, °K
B = Bandwidth in Hertz, Hz

Greek letter 'κ' kappa is used for the Boltzmann constant to distinguish it from 'K' for Kelvin.

For radio reception, noise power is also referred to as noise floor and Threshold (T/H).

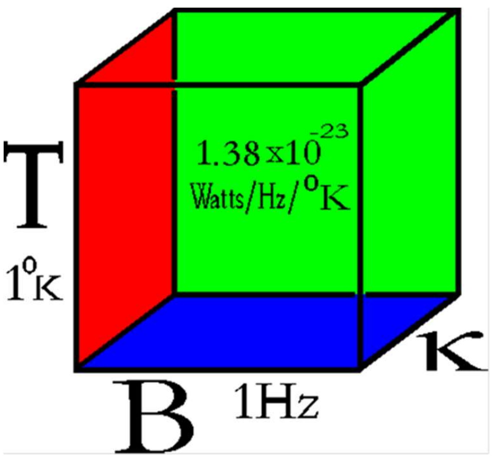
Boltzmann constant (K)

The Boltzmann constant, κ, is a fundamental constant of physics. The constant is named after Ludwig Boltzmann, a 19th-century Austrian physicist. The physical significance of κ is that it provides a measure of the amount of energy, i.e, heat, corresponding to the random thermal motions of the molecules of a substance.

This is the source of thermal or Johnson noise.

The Boltzmann constant has a value of $1.3806488 \times 10^{-23}$ Watts (W) per Hertz (Hz) per degree Kelvin (°K).

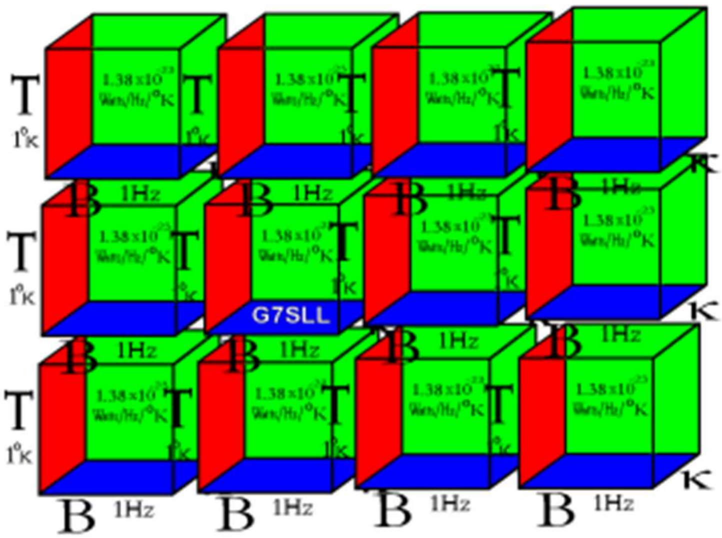
This can be viewed as the amount of energy inside this box, or K x °T x B, representing a 'brick of noise.'



The logarithmic equivalent of the Boltzmann constant, relative to one milliwatt, is

-198.6 dBm/°**K**/Hz

If temperature rises (or falls) and/or bandwidth increases (or decreases), the power proportionally changes, as represented, for example, by this multidimensional figure. The total noise is represented by this ‘noise wall.’



Temperature (T)

When we measure Temperature, T, we measure the state of turbulence of particles making up the environment of measurement. The greater the turmoil, the higher the numerical value representing Temperature. Temperature is the measure of thermal noise. The limiting factor of receiver sensitivity is noise.

Absolute zero is the point where Brownian motion ceases. With Brownian motion, any minute particle suspended in a liquid or gas moves chaotically under the action of collisions with surrounding molecules. As Temperature decreases, this chaotic motion subsides.

The Kelvin scale is used to scientifically measure Temperature.

<u>Absolute zero</u> 0 °K is defined as -273.16 °C

Based on measurements of cosmic microwave background radiation,

The average Temperature of the <u>universe</u> is approximately 2.73 °K = T_{CMB}

The average Temperature on the <u>earth’s surface</u> is approximately

288 °K, with a minimum of 184 °K and a maximum of 330 °K = T_o

Most of the noise on high frequency (HF) bands is due to <u>sky Temperature,</u> $T_{(SKY}$, which manifests itself as antenna noise Temperature. At 1 Hertz, the sky Temperature is approximately 4.7 x 10^{18} °K.

Noise Temperature is inversely proportional to the square of frequency, *f*.

The sky Temperature may be expressed in decibels by the formula:

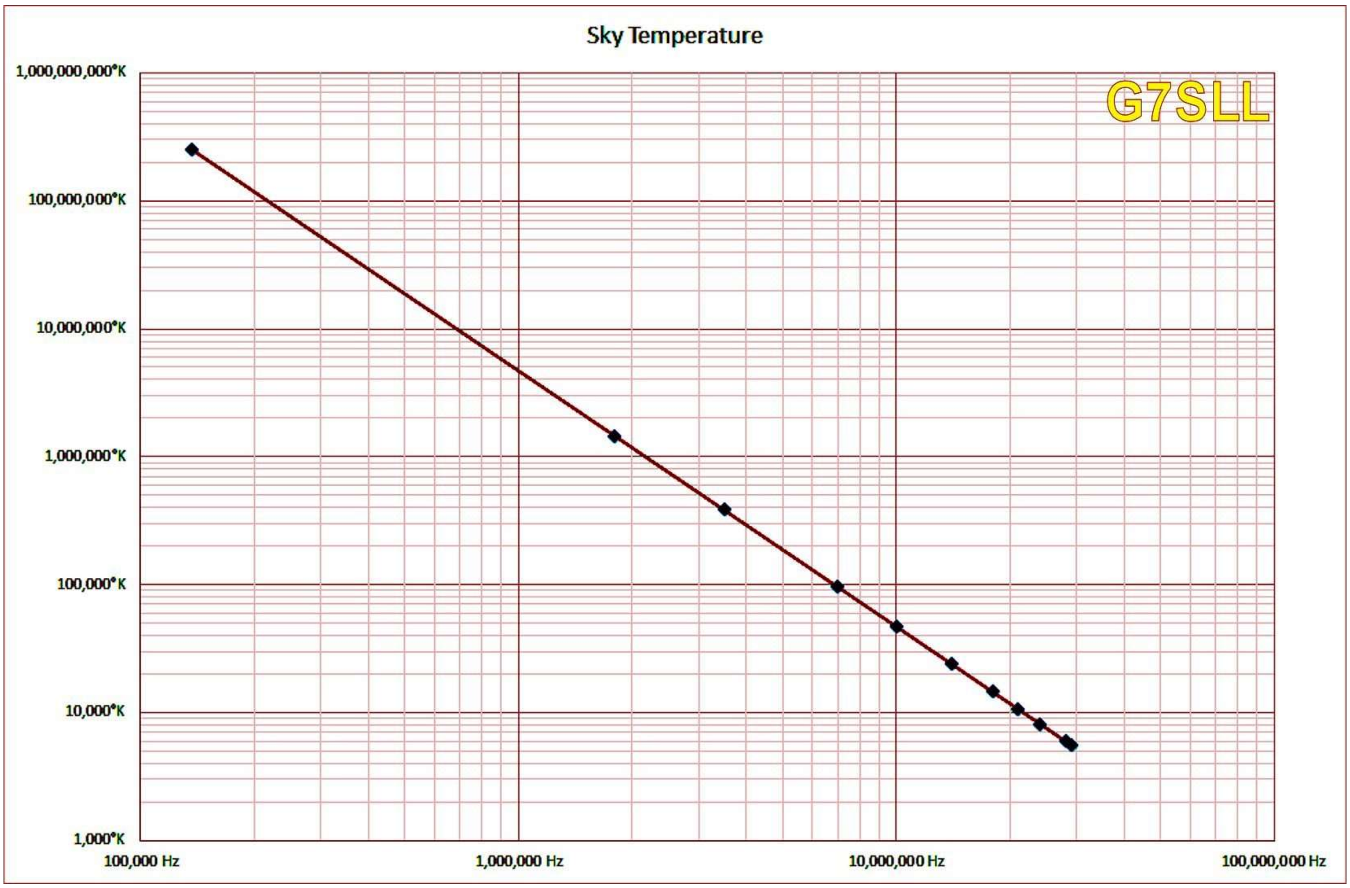
$$T_{(SKY)}\ \text{dB} = 186.7\ \text{dB} - 20 \log (f)$$

For example, at the edge of the 20 meter ham band, ie, 14.0 MHz, the sky Temperature in decibels is:

$186.7\ \text{dB} - 20 \log (14.0 \times 10^6) = 43.8\ \text{dB}$ or a Temperature of $10^{4.38}$ °K = 23,988 °K

(Note that we convert decibels to Bels before exponentiation, ie, 43.8 dB = 4.38 Bels.)

Below is a depiction of sky Temperature as frequency increases, based on this log-log graph. To further illustrate, the sky Temperature at the 10.0 MHz crossing point may be computed as 46,774 °K.



At 1 Hz, $T_{(SKY)}$ is simply 186.7 dB, since log(1) = 0.

186.7 dB may be expanded as 6.7 dB + 180 dB, and further expressed in logarithmic form as log (4.699×10^{18}). Note that $10^{0.672} = 4.699$. Gary G7SLL estimates $T_{(SKY)} = 4.699 \times 10^{18}$ or very specifically, 4,698,742,746,258,770,000 °K.

Bandwidth (B)

A number of factors can affect the signal-to-noise ratio, SNR. One factor is actual bandwidth of the receiver. As noise spreads out over all frequencies, it is found that the wider the bandwidth of the receiver, the greater the level of the noise. Hertz bandwidth does NOT refer to an actual frequency like 14.230 MHz but instead to a frequency difference between the highest and lowest reception frequencies.

$$\text{Bandwidth} = \Delta f = f_{(\text{high})} - f_{(\text{low})}$$

For example, in ham radio, for the SSTV mode, a bandwidth of 2,800 Hertz lets noise in from 14,230,000 Hz to 14,232,800 Hz. A logarithmic expression for this mode in decibels is:

$$10 \log (\Delta f \text{ Hz})$$

$$10 \log (2800 \text{ Hz}) = 34.47 \text{ dB}$$

Similar calculations may be made for the reception bandwidth of other transmission modes.

- PSK31: 31 Hz; 14.91 dB
- CW: 50 Hz; 16.99 dB
- RTTY: 150 Hz; 21.76 dB
- SSB: 2300 Hz; 33.62 dB
- SSTV: 2800 Hz; 34.47 dB

Putting It All Together

The Threshold (T/H) noise floor is expressed by the formula, ΚTB. We have demonstrated that this can be expressed as a logarithmic sum of these three factors:

$$-198.6 \text{ dBm} + [186.7 \text{ dB} - 20 \log (f)] + 10 \log (\text{Hz})$$

Let's determine the noise floor on 14.300 MHz for SSB reception of bandwidth 2,300 Hz.

The full expression is:

$$\underbrace{-198.6 \text{ dBm}}_{\text{Κ}} + \underbrace{[186.7 \text{ dB} - 20 \log (14.3 \times 10^6)]}_{\text{T}} + \underbrace{10 \log (2300)}_{\text{B}} =$$

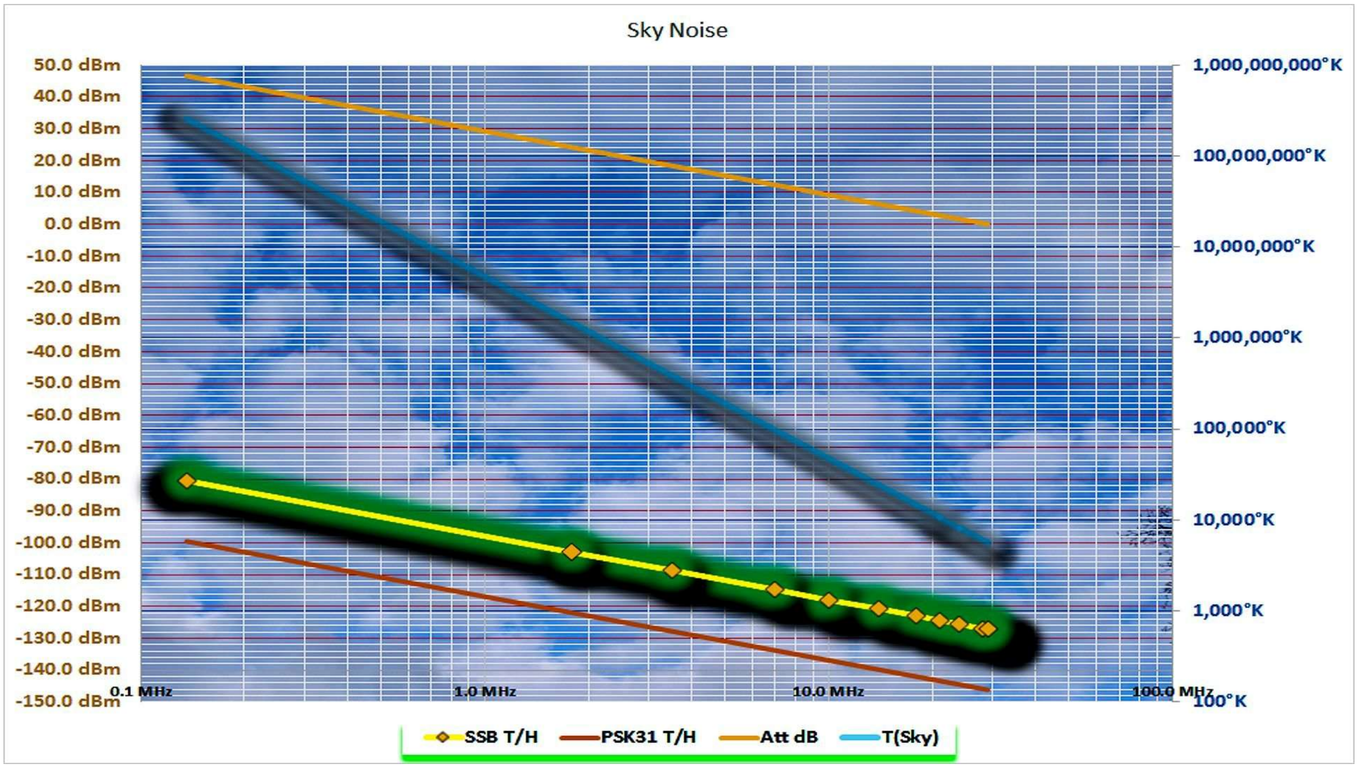
-198.6 dBm + 186.7 dB - 23.1 dB - 120 dB + 33.6 dB = **-121.4 dBm Threshold (T/H)**

In another example, the noise floor at 14.070 MHz for a PSK31 signal of bandwidth 31 Hz is:

$$-198.6 \text{ dBm} + 186.7 \text{ dB} - 20 \log (14.07 \times 10^6) + 10 \log (31) =$$

-198.6 dBm + 186.7 dB - 23.0 dB - 120 dB + 14.9 dB = **--140.0 dBm Threshold (T/H)**

The following chart helps illustrate this interplay of frequency and bandwidth for SSB and PSK31 modes.



It is instructive to observe how much attenuation in noise occurs at higher frequencies. For example, consider the noise floor difference between 7 MHz and 14 MHz, ie, the 40 and 20 meter ham bands, for a given mode.

Notice from the formula that all factors except frequency drop out of the equation. That is,

$$-198.6 \text{ dBm} + [186.7 \text{ dB} - 20 \log (7.0 \times 10^6)] + 10 \log (\text{Hz}) \text{ minus}$$

$$-198.6 \text{ dBm} + [186.7 \text{ dB} - 20 \log (14.0 \times 10^6)] + 10 \log (\text{Hz}) =$$

$$20 \log (14.0 \times 10^6) - 20 \log (7.0 \times 10^6) \text{ or even more simply,}$$

$20 \log (14.0) - 20 \log (7.0) = 22.9$ dB – 16.1 dB = **6 dB, or one theoretical S-unit of attenuation**

In general, the <u>attenuation in noise power between two frequencies</u> is:

$$20 \log (f_{(high)}/ f_{(low)})$$

Consider then the change in noise power between the highest and lowest HF ham bands is:

$$20 \log (30 \text{ MHz}/1.8 \text{ MHz}) = 24.44 \text{ dB, or four S-units}$$

The RSGB Radio Communications Handbook has published an empirical study of background noise, under the conditions listed in the following table.

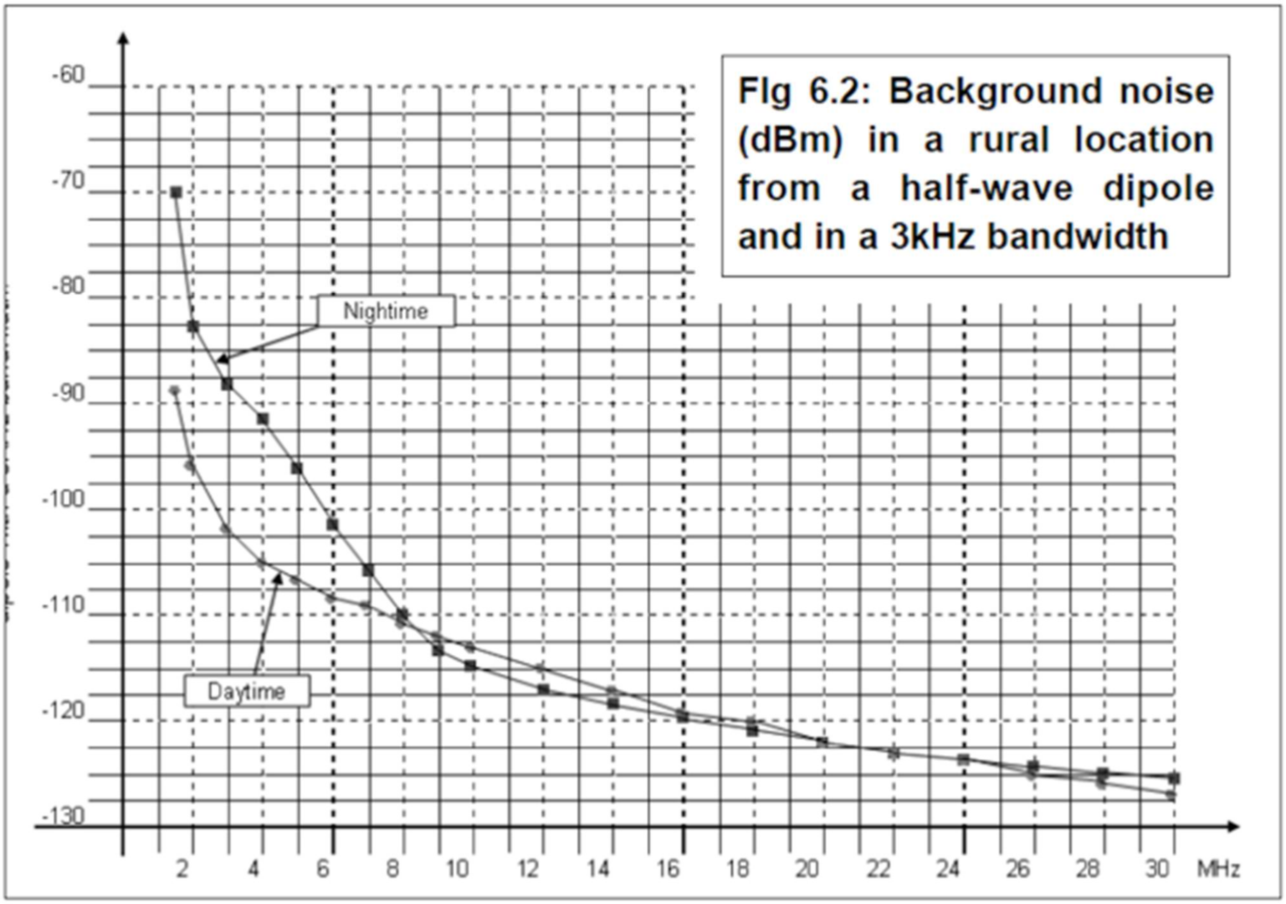


Fig 6.2: Background noise (dBm) in a rural location from a half-wave dipole and in a 3kHz bandwidth

Using the KTB formula, -198.6 dBm + [186.7 dB **–** 20 log (*f*)] + 10 log (3000), we can now compare this study with the theoretical noise Threshold (T/H) at selected frequencies.

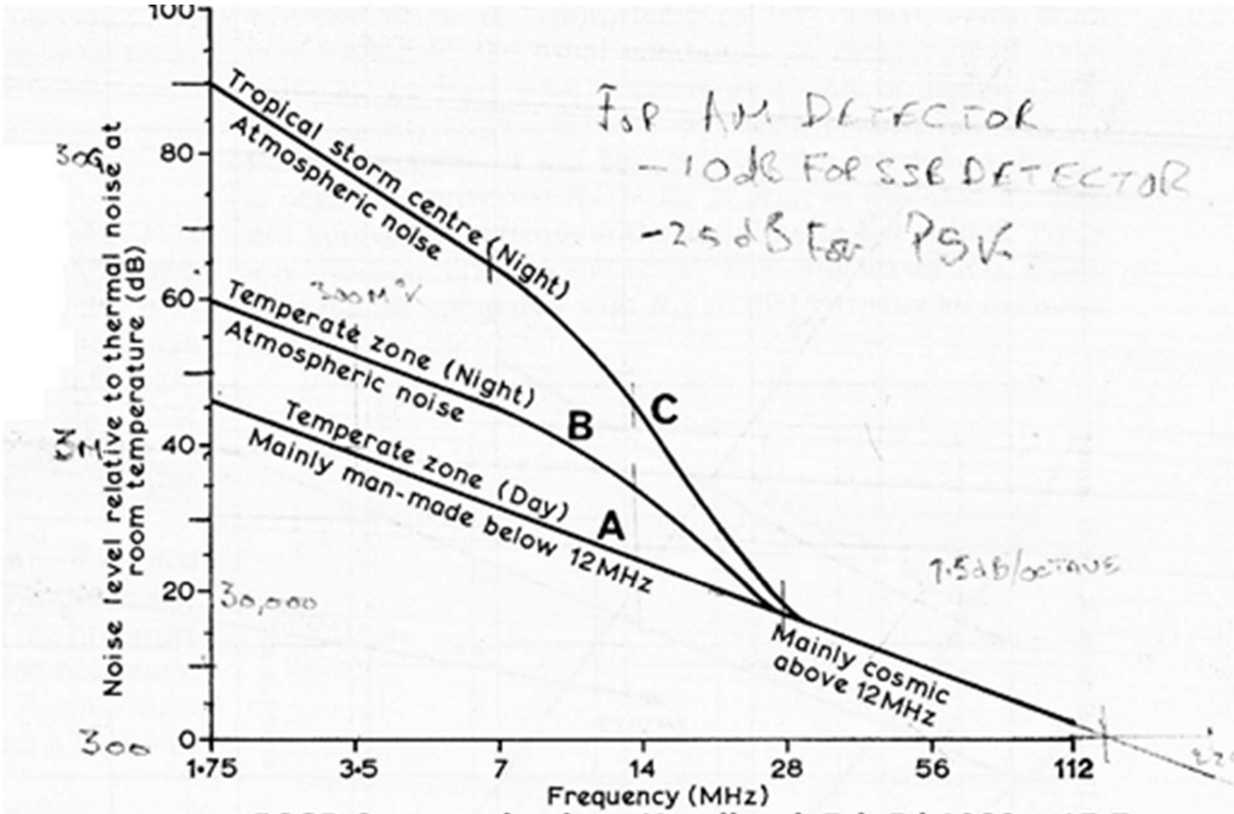
For example, 14.0 MHz, the chart displays almost -118 dBm at daytime, versus:

-198.6 dBm + [186.7 dB **–** 20 log (14.0 x 10^6)] + 10 log (3000) = **-120.0 dBm Threshold (T/H)**

At 28.0 MHz, the chart displays about -126 dBm at daytime, versus:

-198.6 dBm + [186.7 dB **–** 20 log (28.0 x 10^6)] + 10 log (3000) = **-126.0 dBm Threshold (T/H)**

An older RSBG Communications Handbook (1982 edition) estimated the thermal Temperature, $T_{(SKY)}$, in excess of ambient Temperature, T_o, for a range of frequencies.



RSGB Communications Handbook 5th Ed 1982 p 15.7

Let's examine this graph using the theoretical equation, $T_{(SKY)}$ dB = 186.7 dB – 20 log (f).

If we assume the room (ambient) Temperature is 300 °K, it can be represented as 24.8 dB. We will solve for f in MHz and observe if the theoretical sky Temperature coincides with the line crosssing the x-axis.

186.7 dB – 20 log (f x 10^6) = 24.8 dB = $T_{(SKY)}$ dB = T_o dB

f = 124.5 MHz which is a reasonable estimate.

Let's examine the y-axis crossing point of approximately 46 dB. Adding the relative 24.8 dB for comparative room Temperature, we have 70.8 dB. Applying the formula, we get:

186.7 dB – 20 log (1.75 x 10^6) = 61.8 dB = $T_{(SKY)}$ dB, so at this end of the scale the chart doesn't reconcile well with the theoretical calculation.