Temperature, Power, dBm, and dB

We often measure signal strength in radio astronomy in terms of antenna temperature. Using this measure, the galactic background temperature at 20 MHz is on the order of 50 thousand kelvins (50 kilo kelvin). A physical 50 ohm resistor at 50,000 kelvins connected to the antenna terminals of our receiver would generate the same noise power as the galactic background. (ok - this is a little impractical, but it illustrates the principle)

The simple relationship between power (P in watts) and temperature (T in Kelvins) is given by:

$$P = kTB \qquad (1)$$

where B is the bandwidth in hertz used to make the measurement. Boltzmann's constant (k) equals 1.38E-23 j/k.

Using this relationship, we can represent signal strength either in terms of temperature or power.

Decibels referenced to 1 milliwatt (dBm)

Power could be expressed in watts or milliwatts, but a more convenient way is to use a logarithmic representation. Decibels referenced to 1 milliwatt, known as (dBm), is a common method.

$$\textbf{Power in dBm} = 10*\text{LOG}(P/.001) \qquad (2)$$

where P is in watts and (P/.001) is the ratio of the power (P) to one milliwatt.

Let's use the example of calculating the power expressed in dBm in a 7 kilohertz bandwidth due to the 50 kK galactic background at 20 MHz.

Given that T = 5E4, and B = 7E3, and k = 1.38E-23 we solve P = kTB = 4.83E-15 watts.

Converting from watts to dBm: 10*Log(4.83E-15/.001) = -113.2 dBm.

If you want to work backward from dBm to power that is also easy:

10^(P in dBm/10) = 10^(-113.2/10) = 4.83E-12 milliwatts = 4.83E-15 watts

Decibels (dB), a unitless ratio.

Decibels are a unitless logarithmic measure of the ratio of two numbers. In the example above the denominator was chosen to be a 1 milliwatt reference level.

In a more general sense we may express a power ratio in dB as

$$\text{Ratio in dB} = 10 \text{ Log } (P1/P2) \qquad (3)$$

P1 and P2 could be the input power and the output power of an amplifier in which case we would be expressing the gain of the amplifier in dB.

Or P1 and P2 could be the input and output power in a lossy cable in which case we would be expressing the cable attenuation in dB.

Why use dB and dBm?

Let's use an example to see the difference between working in watts and working in dB and dBm.

Start out with 4.83E-15 watts at the antenna terminals and then go thru a lossy coax cable which attenuates the signal by a factor of 6.3. Next go thru an amplifier that boosts the signal by a factor of 20 and then another cable that attenuates by a factor of 4 before reaching the receiver. How many watts reach the receiver?

{[(4.83E-15)/6.3]*20}/4 = 3.83E-15 watts

We can restate the same problem using dB and dBm. The signal level at the antenna terminals is -113.2 dBm, followed by a cable with 8 dB of loss feeding an amplifier with 13 dB of gain followed by a cable with 6 dB of loss.

(-113.2 dBm – 8 dB +13 dB – 6 dB) = -114.2 dBm

10^(-114.2/10) = 3.8E-12 milliwatts = 3.8E-15 watts

The ability to simply add and subtract dB and dBm offers a clear advantage. Also, we can quickly see the signal level at each point along the signal path.

After using dB for a while you come to recognize a few numerical power ratios expressed in dB

Power Ratio	dB=10*Log(ratio)
.001	-30
.01	-20
0.1	-10
1	0
2	3
4	6
8	9
10	10
20	13
100	20

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