

# The Galactic Background in the Upper HF Band

Dave Typinski, January 2013

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This memo introduces the galactic background (GB) emission and discusses mathematical models of the GB brightness temperature in the direction of the galactic polar regions. A very simple model for antenna temperature due to the galactic background is derived.

## Introduction and Review

One of the easiest ways to find out whether a radio telescope is working is to disconnect the antenna and see if the strip chart or spectrogram bottoms out. We can perform this easy test because the galaxy is awash with non-thermal radio emission from a few tens of kHz through several GHz. This galactic background emission achieves maximum intensity near 3 MHz, although the ionosphere prevents observation of this peak from the ground.

In the HF band, the GB is mostly synchrotron radiation emitted by electrons in the interstellar medium as they interact with the galactic magnetic field. At 20 MHz, about sixteen percent of the observed GB toward the galactic poles is synchrotron emission from other galaxies (see Figure 1 below). The generic term “galactic background” usually refers to the sum of the galactic and extragalactic components.

The GB is a very important factor in determining what we can observe, for it is the noise through which we must make our observations. In the HF band, the limiting factor in detecting weak signals with a radio telescope is usually not the sensitivity of the receiver, loss in the feed line, or gain of the antenna—rather it is the relatively high brightness temperature of the galactic background. Thus, if we are to perform quantitative analysis of observations made with a radio telescope, we must quantify the galactic background.

Cane performed several measurements of the GB towards the galactic poles and compared his results with many previously published values.<sup>1</sup> Since he was using single dipole antennas with a very large beam widths—larger but similar to the beam formed by a Radio Jove dual dipole array—the galactic poles were chosen to reduce any variation caused by the hotter galactic plane. A mathematical model is provided; however, the user must fit their own curve to the data to obtain the values of several constants.

Dulk contributes the appropriate constants and uses the model to successfully calibrate long wavelength radio telescopes.<sup>2</sup> Ellingson presents a concise summary of the model and discusses a slightly adjusted model that could work better as an average GB given that a portion of the galactic plane is often in view of a wide beam antenna.<sup>3, 4, 5</sup>

## Observed Antenna Temperature

An antenna with a very wide beam—e.g., one dipole—will see almost an entire hemisphere of the sky. Since the inefficiencies in an antenna's elements are negligible, the noise temperature at the antenna terminals at the design frequency is very nearly equal to the spatial average of the visible sky's brightness temperature. The antenna temperature in kelvin is given by:<sup>6</sup>

$$T_{ANT} \approx T_{SKY} = \frac{1}{2k} I_f \frac{c^2}{f^2} \quad (\text{Eqn 1})$$

where

$I_f$  = Intensity of the galactic background as a function of frequency

$f$  = RF frequency in Hz

$k = 1.38 \times 10^{-23} \text{ J} \cdot \text{K}^{-1}$ , Boltzmann's constant

$c = 3.00 \times 10^8 \text{ m} \cdot \text{s}^{-1}$ , speed of light

The Intensity of the galactic background, with units of  $\text{W} \cdot \text{m}^{-2} \cdot \text{Hz}^{-1} \cdot \text{sr}^{-1}$ , as a function of frequency in MHz is given by:

$$I_f = I_g f_{\text{MHz}}^{-0.52} + I_{eg} f_{\text{MHz}}^{-0.80} \quad (\text{Eqn 2})$$

Putting equations 1 and 2 together, we have a mathematical model of antenna temperature due to the galactic background:

$$T_{ANT} = \frac{c^2}{2k f^2} \left( I_g f_{\text{MHz}}^{-0.52} + I_{eg} f_{\text{MHz}}^{-0.80} \right) \quad (\text{Eqn 3})$$

where the constants of proportionality for the galactic and extragalactic components are:<sup>3</sup>

$$I_g = 2.48 \times 10^{-20} \text{ (Galactic intensity constant, Cane/Ellingson)}$$

$$I_g = 3.2 \times 10^{-20} \text{ (Galactic intensity constant, Duric/Tokarev)}$$

$$I_{eg} = 1.06 \times 10^{-20} \text{ (Extragalactic intensity constant, Cane/Ellingson)}$$

Equation 3 is plotted in Figure 1. It should be noted that this is an average minimum temperature for an antenna having a beam looking at roughly the whole visible sky (one hemisphere). The GB at all points in the visible hemisphere is effectively averaged by the very wide antenna beam. Since this model is based on observations of the galactic polar regions, the observed temperature will be higher if any part of the galactic plane happens to be in view of the antenna.

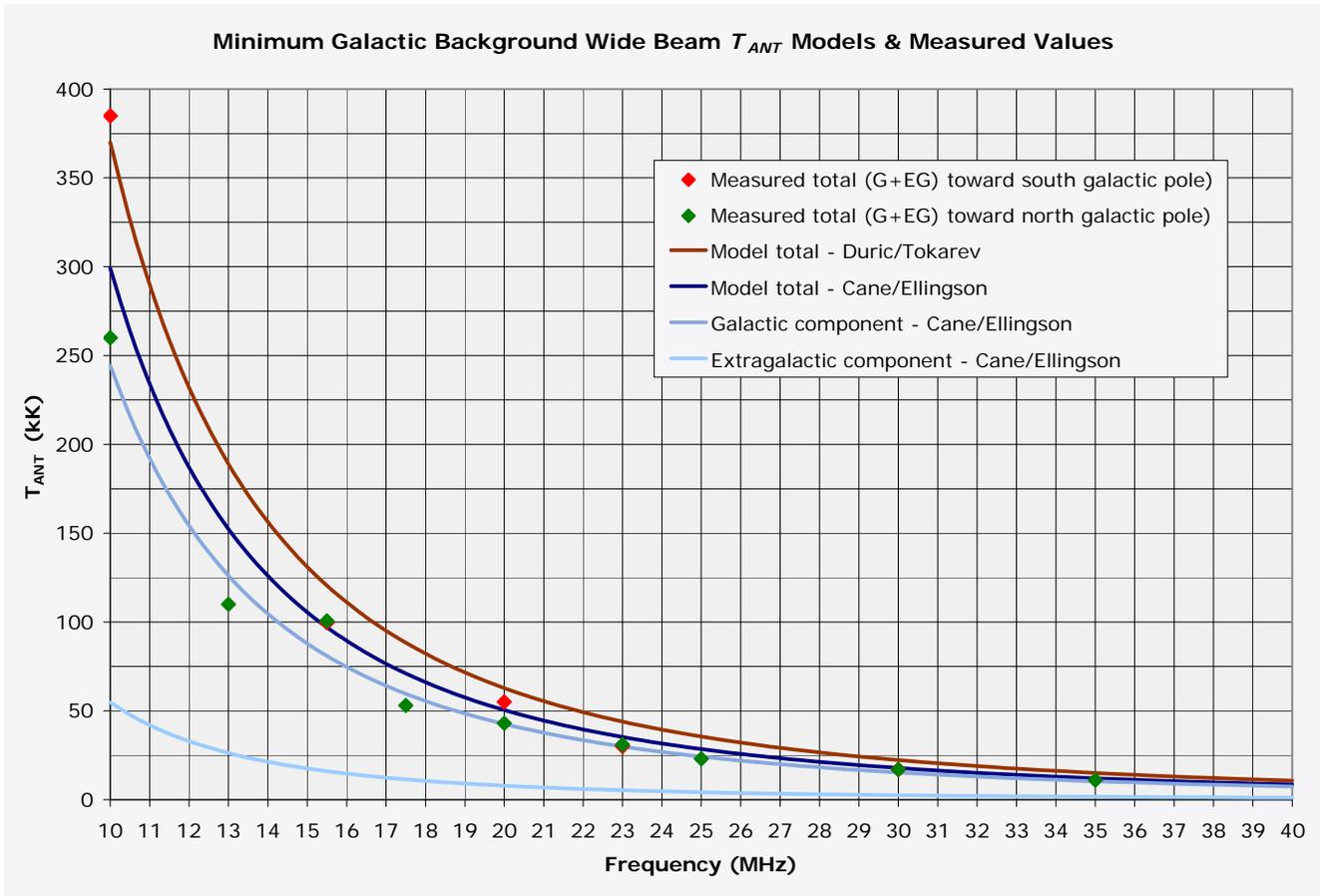


Figure 1 – The galactic background in the upper HF band with some measured data points. Measured data represents total observed galactic plus extragalactic emission. <sup>1</sup>

If we fit a power function of the form  $T = Af^b$  to either of the models' curves, we arrive at a very close approximation of Equation 3. We find the exponent  $b$  is equal to  $-2.56$ . This is the brightness temperature spectral index of the GB, which describes how fast the brightness temperature falls off with increasing frequency.

By setting  $T$  at 20 MHz to 50 kK, from the Cane/Ellingson model, we can find the constant of proportionality  $A$ . A simple galactic background temperature equation is thus created. This model differs from the Cane/Ellingson model by no more than 0.06 dB from 10 to 40 MHz:

$$T_{ANT} = \frac{50}{20^{-2.56}} f^{-2.56} = 1.07 \times 10^5 f^{-2.56} \quad (\text{Eqn 4})$$

where

$T_{ANT}$  = antenna temperature in kK  
 $f$  = frequency in MHz

A Radio Jove dual dipole array has roughly half the beam width of a single dipole. We would expect the minimum GB observed with the array to be somewhat less than that predicted by Equation 4 since the Jove array can more effectively point at the relatively cold galactic pole better than a single dipole can. Using an even higher gain antenna—and thus a narrower beam width—will produce still lower minimum observed temperatures for the same reason.

A 30 MHz map of the sky made with data from radio telescopes having antenna beams a few degrees wide shows that the coldest parts of the sky have a temperature of about 12 kK toward galactic coordinates  $l = 230^\circ$ ,  $b = \pm 40^\circ$ .<sup>7</sup> Using a spectral index of  $-2.56$  and calculating a new constant of proportionality  $A = 7.25 \times 10^4$  based on 12 kK at 30 MHz, we find that the narrow beam antenna temperature toward the coldest part of the sky at 20 MHz is about 34 kK.

## Conclusion

For many years, a figure of 50 kK has been used for the GB at 20 MHz. The data points in Figure 1 indicate a 20 MHz temperature  $\pm 5$  kK from the 50 kK nominal value depending on which galactic pole is under observation. An array of dipoles can lower the observed temperature by narrowing the beam width. However, any intrusion of the galactic plane into the antenna beam will increase the observed temperature—often greatly, depending on the proximity of the galactic core to the beam centerline. Considering these variables, there can be no universal GB value as a function of frequency alone. A minimum galactic background temperature of 50 kK near 20 MHz observed with a small array is a reasonable working figure for calculations concerning best case (lowest GB brightness temperature) scenarios.

For spectrographs and single channel receivers with a wide tuning range, it is useful to know how the GB changes in terms of dB across the observing bandwidth. This variation, along with Equation 4, is plotted in Figure 2.

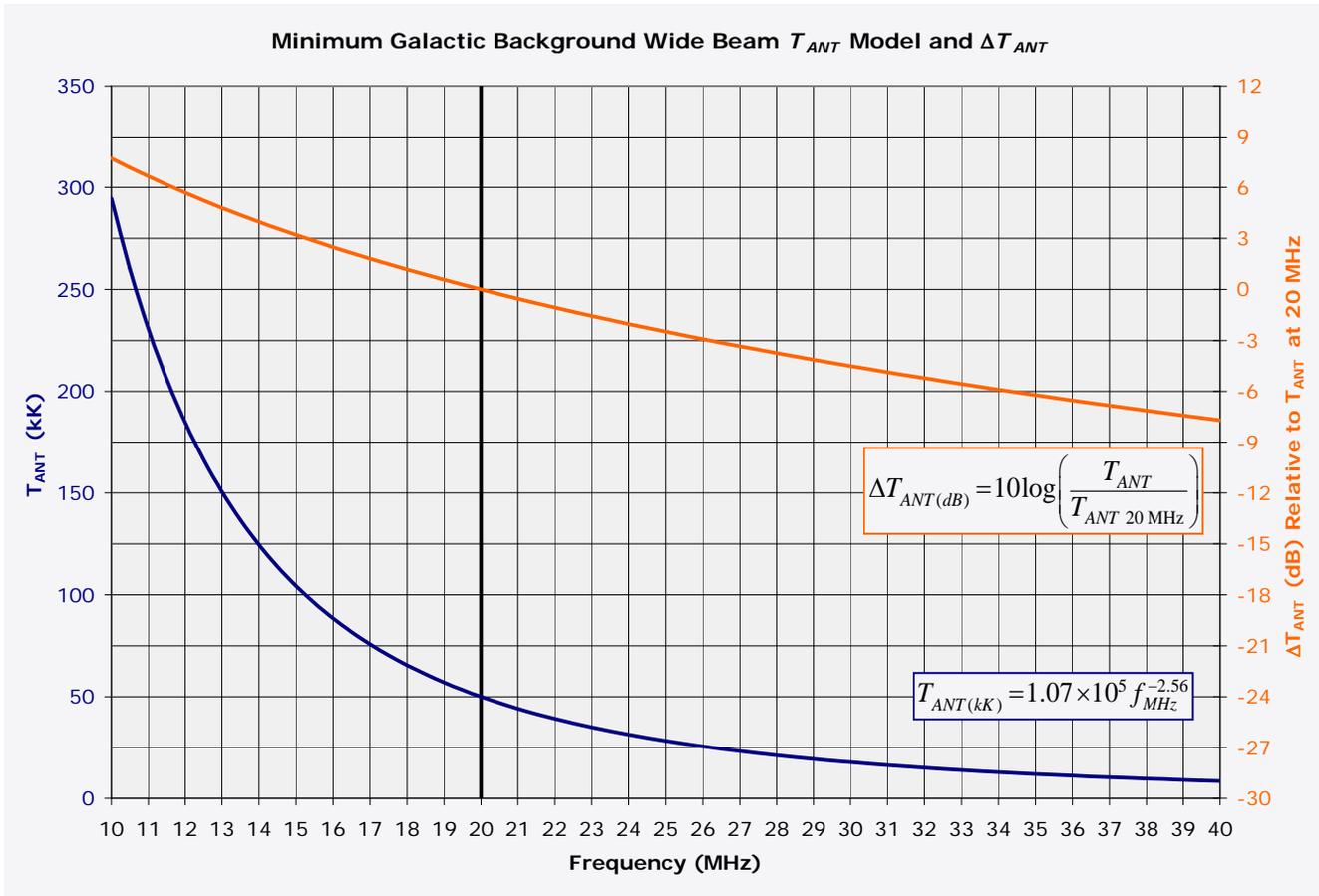


Figure 2 – Simple minimum galactic background wide beam antenna temperature model and variation with frequency in terms of dB relative to 20 MHz antenna temperature.

## References

- <sup>1</sup> Cane, H., *Spectra of the Non-Thermal Radio Radiation from the Galactic Polar Regions*, (1979).
- <sup>2</sup> Dulk, G., *Calibration of Low-Frequency Radio Telescopes Using the Galactic Background Radiation*, (2001).
- <sup>3</sup> Ellingson, S., *Antennas for the Next Generation of Low-Frequency Radio Telescopes*, (2005).
- <sup>4</sup> Duric, N., *RFI Report for the US South-West*, (2003).
- <sup>5</sup> Tokarev, Y., *Cosmic Background with Model of Cloudy Interstellar Medium*, (1999).
- <sup>6</sup> Ellingson, S., *Design and Evaluation of an Active Antenna for a 29-47 MHz Radio Telescope Array*, (2007).
- <sup>7</sup> Cane, H., *A 30 MHz Map of the Whole Sky*, (1978).