Spectral Detection of GPS and H-I Using a Single Omnidirectional Antenna

Steven W. Ellingson
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In the following analyses, it is assumed that the receiving antenna is "omnidirectional"; i.e., sensitive to the entire sky with gain approximately equal to 1. Thus, the noise power spectral density measured at the antenna terminals, in the absense of any other sources, is $kT_{amb} \approx -174$ dBm/Hz. We shall also assume that the receiver noise figure is 4 dB. All power levels cited below will be referenced to the antenna terminals.

I. Detecting GPS C/A Signals

The GPS system is designed such that the C/A (narrowband) signal from a single GPS satellite has a nominal signal-to-noise ratio (SNR) of -30 dB within it's occupied bandwidth B of 2 MHz, as measured at the terminals of an omnidirectial antenna. The unavoidable background noise in this same bandwidth, referenced to the antenna terminals, is $kT_{amb}B$ or -111 dBm. Therefore, a single GPS C/A signal is about -141 dBm at the antenna terminals. The measurement noise in this same bandwidth is $kT_{amb}B$ plus 4 dB, or -107 dBm. The resulting signal-to-noise ratio (SNR) is -34 dB or about 4×10^{-4}.

To achieve a 5σ detection of the GPS signal, we need $5L^{-1/2}$ =SNR, where L is the number of samples collected at the Nyquist rate of 2 MSPS, assuming complex samples. This gives $L = 1.6 \times 10^8$, or $\tau = 79$ s. However, note that there are typically at least 4 GPS satellites above the horizon at any given time; in this case, the SNR is actually -28 dB. This reduces τ for a 5σ detection to about 5 s.

Typically, a receiver generates samples at a rate much greater than Nyquist for the signals of interest. Does this affect τ or nature of the detection process? Not at all. For example, oversampling by a factor of 10 just means that 9 out of 10 samples are not helping. This is perhaps counterintuitive, but consider that it is really the same as saying that 9 out of 10 spectral bins are not contributing to the measurement (Remember Parseval's Theorem?), which is perhaps a bit more obvious. Actually, in this case, we are only wasting *8* out of 10 samples since another 2 MHz of spectrum is required to provide the GPS-free (noise only) measurement.

Finally, note that it was really not necessary to explicitly use the value of B in this computation. All that is needed to determine sensitivity is the SNR in whatever bandwidth is used. Once we know how many Nyquist-rate samples L are required, the only value in knowing B is to determine τ using the relationship $B\tau = L$.

II. Detecting Galactic H-I

The 1420 MHz emission of neutral galactic hydrogen is concentrated in the Galactic plane, which covers somewhere between 1% and 10% of the sky. At each point on the sky where significant H-I is present, it has a brightness temperture between 1°K and 100°K. Based on the above considerations, we can bound the antenna temperture due

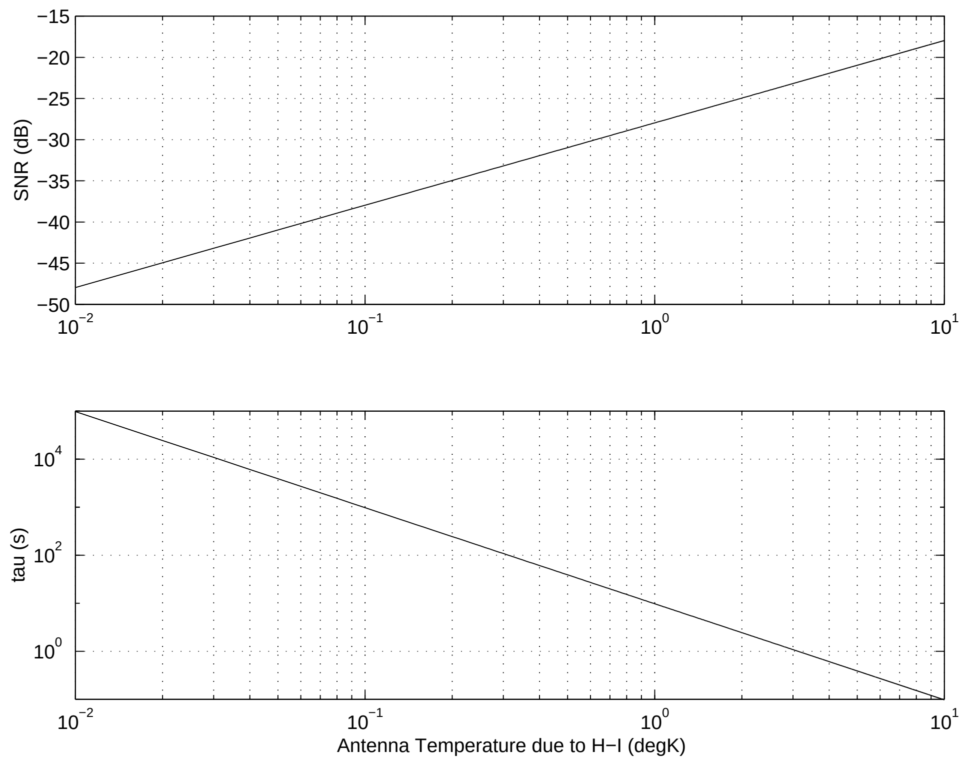

Fig. 1. SNR and required integration time for a 5σ detection (τ), as a function of source-induced antenna temperature.

to H-I alone to be between 0.01°K and 10°K; a range of three orders of magnitude. A reasonable and conservative guess 0.1°K. Using this value, the power due to H-I at the antenna terminals is estimated to be about −208 dBm/Hz. The measurement noise per unit bandwidth is kT_{amb} plus 4 dB, or −170 dBm/Hz. The resulting signal-to-noise ratio (SNR) is −38 dB, or 1.6×10^{-4}.

Assuming this estimated SNR, we need $L = 10^9$ Nyquist-rate samples for a 5σ detection. Due to Galactic rotation, the bandwidth of the H-I "line" is on the order of 1 MHz as observed by an omnidirectional antenna. Due to the Nyquist sampling rate of 1 MSPS, this gives $\tau \approx 16.3$ min.

Because there is so much uncertainty in the actual source-induced antenna temperature, it is worthwile to consider how SNR and τ vary for the full range of possibilities. This is shown in Figure 1.