RFI Radiation Limits in the Vicinity of the GBT

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1 Introduction

Control of RFI from our own equipment in the vicinity of the GBT separates into two problems: What radiation level is harmful, and how do we measure radiation from equipment with enough sensitivity to detect this radiation? The first question has many answers because they depend on the spectral and temporal properties of the RFI signal and on the radio astronomy measurement being conducted. At best, we can only choose a few typical cases to set general radiation limits. The answer to the second question requires that we use some of the same integration and signal analysis techniques that are used in the astronomical observations and that we compensate for the sensitivity of the cooled radio astronomy receivers with higher gain receiving antennas closer to the potential sources of interference. This document suggests radiation limit guidelines for measurement and shielding of equipment and recommends a few measurement procedures.

Harmful radiation limits for interference to all radio telescopes are set forth in the ITU Handbook on Radio Astronomy (chapter 4, formally included in Annex of Recommendation ITU-R RA.769) using bandwidths determined by allocation radio astronomy frequency bands and a standard integration time of 2000 seconds. The Handbook on Radio Astronomy lists harmful flux density limits for radio astronomy bands for continuum observations above 13 MHz and for spectral line observations above 327 MHz.

Here we deal specifically with expected GBT observations anywhere between 25 and 3000 MHz. Locally generated interference is most often strongest in this frequency range. To accurately reflect the specific interference susceptibility of the GBT we use typical receiver noise temperatures, bandwidths, and integration that are somewhat different from the standard values in the Handbook on Radio Astronomy. Different parameter values are chosen for continuum, spectral line, and pulsar observations. Interference to pulsar measurements was not mentioned in the Handbook on Radio Astronomy.

With the above exceptions, the method for computing harmful interference levels is the same as specified in the Handbook on Radio Astronomy. Interfering signals are assumed to arrive through the far sidelobes of the GBT with an effective gain of 0 dBi. Harmful interference is defined to be an unwanted signal with a strength equal to one tenth of the rms noise fluctuation in one spectral or continuum channel as computed with the radiometer equation

$$\Delta T = \frac{T_{sys}}{\sqrt{B\tau}}, \tag{1}$$

where T_{sys} is the system temperature in Kelvins, B is the bandwidth in Hz, and τ is the integration time in seconds. From the noise fluctuations, ΔT, in Kelvins the harmful flux density per unit bandwidth limit in $Wm^{-2}Hz^{-1}$ is

$$\Delta S = 0.1 \frac{k \Delta T}{\lambda^2 / 4\pi}, \tag{2}$$

where k is Boltzman's constant, 1.38×10^{-23} Joules/K, and λ is the wavelength in meters.

2 Observing Receiver Parameters and Flux Density Limits

From Equations 1 and 2 the important observing parameters for computing the harmful interference level at a given frequency are system temperature, T_{sys}, bandwidth, B, and integration time, τ. Bandwidth and integration time depend on the observing type, but the system temperature is the same for all types at each frequency. Below about 300 MHZ the system temperature is dominated by cosmic background radiation. The system temperature values assumed for the GBT at octave frequency intervals between 25 and 3200 MHz are given on the second line of Tables 1, 2, and 3 below.

The computed harmful limits turn out to be fairly close to the same for the three observing types. The wide bandwidths used in continuum and pulsar observations are offset by their short integration times compared to spectral line observations. See Figure 1.

2.1 Spectral line

Spectral line observations are most vulnerable to narrow band interference where the spectral characteristics of the interfering signal are roughly the same as those of the astronomy signal being measured. Typical spectral line widths of natural radiation are roughly 10^{-5} to 10^{-3} of the observing frequency, and spectrometer resolutions of 10^{-5} are typically employed. For a given interference signal strength the signal is most evident when its bandwidth is less than or equal to the spectrometer resolution. Chosen typical resolutions are shown on the third line of Table 1.

The integration time for a spectral line measurement can be many hours, but we'll take a more typical value of one hour ($\tau = 3600^s$). Lines 4, 5, and 6, respectively, of Table 1 show the computed values of ΔT_{rms}, ΔS in Janskys ($10^{-26} W m^{-2} Hz^{-1}$), and ΔS in dB($W m^{-2} Hz^{-1}$).

Table 1. Spectral line parameters and radiation limits

Frequency (MHz)	25	50	100	200	400	800	1600	3200
System Temp. (K)	35000	8000	1300	250	60	30	15	20
Bandwidth (kHz)	0.5	0.5	1	2	4	8	16	32
ΔT_{rms} (mK)	26100	5960	685	93.2	15.8	5.58	1.98	1.86
ΔS (Jy)	314	287	132	71.8	48.7	68.9	97.7	367
ΔS (db($W/m^2/Hz$))	-235.0	-235.4	-238.8	-241.4	-243.1	-241.6	-240.1	-234.4

2.2 Continuum

Continuum observations are sensitive to the total power in the passband of a relatively wide filter. Broadband interference sources, such as switching transients, power line noise, and florescent lights, are more harmful to continuum than to spectral line measurements because the total integrated power in a wide pass band can be relatively high. Narrowband interference does affect continuum observations, but the power per unit bandwidth within the signal's spectrum must be higher to match the same total power from a broadband interferer.

A filled aperture telescope like the GBT normally does not use long integrations for continuum observations at frequencies below a few GHz. The confusion of background radio sources sets a fundamental limit of detectability, and integration times of a few tens of seconds are typical. (The GBT will integrate for long periods of time when observing continuum sources as part of a VLBI, but these measurements are relatively insensitive to local interference at one antenna.) The bandwidth used in continuum observations is generally limited to the largest bands that are relatively free of narrowband interference. The adopted values for bandwidth and integration time at each frequency are shown in lines 3 and 4, respectively, of Table 2.

Table 2. Continuum parameters and radiation limits

Frequency (MHz)	25	50	100	200	400	800	1600	3200
System Temp. (K)	35000	8000	1300	250	60	30	15	20
Bandwidth (MHz)	0.2	0.5	1	3	5	20	40	100
Integ. time (sec)	10	10	10	10	20	40	40	40
ΔT_{rms} (mK)	24700	3580	411	45.6	6.0	1.06	0.38	0.32
ΔS (Jy)	297	172	79.2	35.1	18.5	13.1	18.7	63.1
ΔS (db($W/m^2/Hz$))	-235.3	-237.6	-241.0	-244.5	-247.3	-248.8	-247.2	-242.0

2.3 Pulsars

Pulsar observations are most vulnerable to wideband impulsive interference, particularly if the impulses are periodic. Bandwidths used are usually limited by the loss of time resolution due to pulse dispersion that can be tolerated. Dispersion is proportional to the observing frequency cubed, so bandwidths can be quite wide at high frequencies. Since pulsar observations use some type of spectrometer they are more tolerant of narrowband interference because a modest number of spectrometer channels can be discarded without must loss of information.

Integration times up to an hour or more are typical of pulsar measurements, but the effective integration time used in our sensitivity calculations is much less than this because the data is generally divided into many separate time bins over the pulse period. We shall assume that the interference is perfectly periodic and that the dispersion is small so that all interference is in the same time bin. This is too pessimistic for observations of a known pulsar since the interference is unlikely to have the same period as the pulsar, but pulsar searches look for all possible periods and dispersions. We shall choose a total observing time of 15 minutes (900 seconds), which is representative of a sensitive pulsar search and assume that the time resolution is 1% of the pulsar period; hence, the effective integration time is 9 seconds.

Note that the values for ΔT and ΔS in Table 3 are **peak** temperatures and flux densities, not time averaged values in the same sense as for continuum observations. This will require an additional RFI measurement to look for periodic impulsive noise from potential source of interference. Flux density limits are listed only for frequencies of 100 MHz and above in Table 3 because pulse dispersion is normally so severe at lower frequencies that it precludes useful observations.

Table 3. Pulsar parameters and radiation limits

Frequency (MHz)	100	200	400	800	1600	3200
System Temp. (K)	1300	250	60	30	15	20
Bandwidth (MHz)	0.3	2.5	20	100	300	800
ΔT_{rms} (mK)	792	52.8	4.48	1.02	0.28	0.24
ΔS (Jy)	153	40.6	13.8	12.4	13.8	47.2
ΔS (db($W/m^2/Hz$))	-238.2	-243.9	-248.6	-249.1	-248.6	-243.3

Figure 1 shows a graphical summary of the radiation limits for the three types of observing.

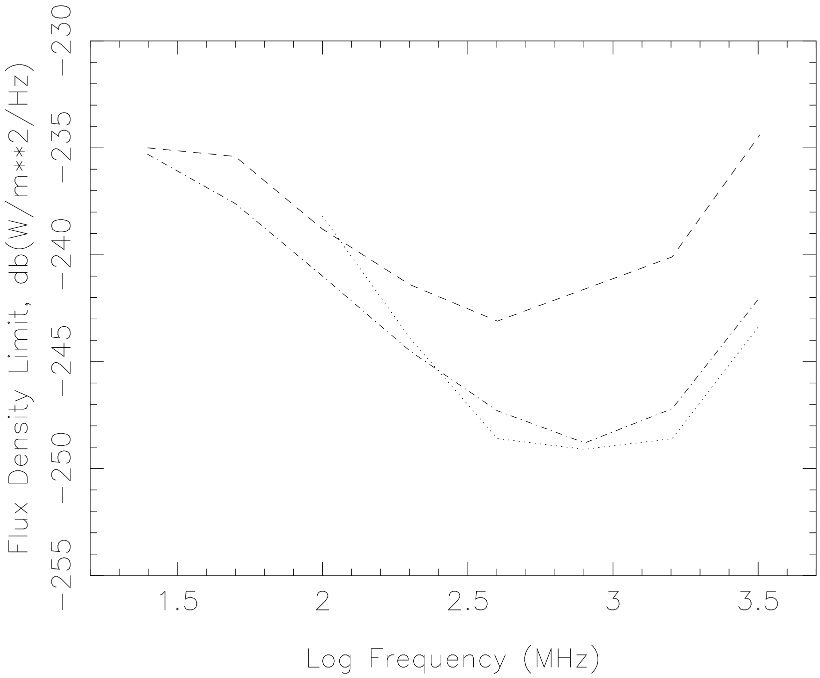

Figure 1: RFI radiation limits for three types of GBT observing: spectral line (dashed), continuum (dot-dashed), and pulsar (dotted).

3 RFI Measurement Procedures

We cannot match the low receiver noise temperatures on the GBT with our RFI measurement equipment, but we can compensate for this with some gain in the RFI measurement antenna and by putting our antenna closer to the RFI source than the source is from the the GBT feeds. To achieve the sensitivities of radio astronomy systems we also need to approximate the time-averaging and signal processing capabilities of the GBT backends with our RFI measurement setup. For example, a spectrum analyzer with a 1 kHz video bandwidth will, at best, have a 33 dB disadvantage to a GBT spectrometer integrating for an hour. By requiring that the interference be only 10% of the radio astronomy sensitivity we need an additional 10 dB of sensitivity. Hence, we need 43 dB more sensitivity than is provided by a typical spectrum analyzer measurement, less any advantage from the antenna gain and proximity.

Many RFI tests will be conducted in the anechoic chamber where the antenna to source distance is typically 7 meters. Column 3 of Table 4 shows the $1/r^2$ difference is space loss between 7 meters distance and the distance from the GBT prime focus for various sites around the telescope where RFI generators might be located. Values with an asterisk include an additional 10 dB for shielding from the primary GBT surface minus the GBT feed gain toward the center of the dish. Column 2 lists approximate distances from the GBT prime focus to the stated location. Where the distance depends on the position of the GBT, minimum distances are given.

In the anechoic chamber the system temperature will be roughly 600 K, 300 K each from the absorber walls and the first amplifiers. The ratio of this temperature to the GBT system temperatures ranges from -18 dB at 25 MHz to +16 dB at 1600 MHz. All but three of the locations in Table 4 have a relative space loss of 25 dB or higher so we can make up for the largest system temperature difference plus the 10 dB due to the requirement that interference be less than 10% of the sensitivity level. Table 5 shows the system temperature ratio plus 10 dB at each frequency.

For a given frequency and RFI source location the sensitivity advantage (disadvantage) of the anechoic chamber over the GBT is the relative space loss from Table 4 minus the system temperature ratio from Table 5 plus the gain of the RFI measurement antenna. For the three locations closest to the GBT prime focus we cannot achieve the necessary sensitivity in the anechoic chamber above about 100 MHz, but we can for all of the other RFI source locations and frequencies. We do need much of the integration and signal processing sensitivity of the GBT, however.

In general, we should make three types of measurements on potential sources of RFI: a broadband power measurement for maximum sensitivity to wideband noise, a spectrum measurement for narrowband signals, and a video statistical and spectrum analysis of the broadband detected power to look for impulsive noise. To the extent feasible, measurements should be made over the 25 to 3000 MHz frequency range. Achieving full sensitivity at a representative set of frequencies will be quite time consuming, so some judgements about the likelihood of a piece of equipment radiating a given type of interference will be needed. A fair bit of measurement automation is called for.

Table 4. Relative space loss to locations around GBT

Location	Approx. Distance (meters)	Attenuation (dB) Rel. to 7 meters
Top of Gregorian receiver room	11	4
Lasers on feed arm (closest)	12	5
Lasers on feed arm (closest)	52	17
Lasers on the ground	120	25
Equipment room lower alidade	80	31*
Active surface control room	55	28*
GBT control building	125	25
RSI building	120	25
Interferometer control building	550	38
Laser lab old 300-ft building	760	41
140-ft (center of base)	570	38
Machine shop	1530	47
Jansky lab (center of new wing)	1660	48
85-1 telescope	940	43
85-2 telescope	470	37
85-3 telescope	1660	48

Table 5. Anechoic chamber to GBT system temperature ratios plus 10 dB for interference margin, assuming $T_{anechoic} = 600$ K

Frequency (MHz)	25	50	100	200	400	800	1600	3200
GBT Sys. Temp. (K)	35000	8000	1300	250	60	30	15	20
Anechoic/GBT (dB) - 10	-7.7	-1.2	6.6	13.8	20.0	23.0	26.0	24.8

3.1 Broadband (continuum) measurement