EVLA Memo # 106
RFI Emission Limits For Equipment at the EVLA Site

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Abstract

Limits for emissions by electronic equipment located at the EVLA site are given. These are based on the ITU standards for harmful interference, and take account of the attenuation provided by fringe rotation. It is pointed out that in most practical circumstances, these emission levels are independent of integration time for imaging interferometers such as the EVLA. Bi-static radar experiments set an emissions level 22 dB more stringent than those established by ITU standards, but only within very narrow frequency ranges.

1 Introduction

The problem of man-made emissions interfering with the EVLA's astronomical observations has been addressed in a number of earlier memos. Memo #46 proposed emission limits appropriate for total-power radiometry, utilizing a velocity bandwidth (1 km/s) and time average (9 hours) considerably more stringent than the 3 km/s and 2000 seconds used by the ITU[1,2]. The attenuation of the RFI signal provided by differential phase winding was described in detail in Memo #49, where it was concluded that the stringent limits proposed in Memo #46 could be relaxed by at least $\sim$ 15 dB. More recently, Memo #104 established emissions limits for 'self-polluting' modules in the IF electronics, utilizing the ITU levels for bandwidth and time, for total power radiometry. This last memo included a review of the various protections that a phase-tracking interferometer has against RFI compared to a total-power system, and concluded by stating that the strict limits based on total power radiometry can probably be relaxed by 20 to 30 dB for the EVLA.

These various memos, and the different standards employed, have clearly created confusion on just what the limits on RFI emissions are. The purpose of this memo is to establish, for once and for all, just what these limits should be, based on a realistic assessment of their effects on the EVLA's ability to image emissions of astronomical origin.

2 The RFI Emission Limit Criterion

The limits on RFI emissions are based on a very simple criterion: The INR – the Interference to Noise Fluctuations Ratio – over an integration time and resolution bandwidth of astronomical interest must be less than 0.1:

$$INR < 0.1. \tag{1}$$

The application of this criterion is very straightforwards for total-power ('single-dish') radio astronomy. In this case, the rms fluctuations in the determination of the noise power for an observation of duration τ seconds, in bandwidth $\Delta\nu$ Hz, with a radio telescope with system temperature T_{sys} Kelvin, is

$$\sigma_P = \frac{kT_{sys}\Delta\nu}{\sqrt{\Delta\nu\tau}} = kT_{sys}\sqrt{\frac{\Delta\nu}{\tau}} \qquad \text{watts,} \tag{2}$$

where k is the Boltzman constant, 1.38×10^{-23} J K^{-1}, and the measures of system temperature and noise power are referred to the output of the antenna feed horn.

[1]Recommendation ITU-R RA.769-2, International Telecommunications Union, Radiocommunication Sector, May 2003
[2]Handbook, Radio Astronomy, 2nd edition, ITU Radiocommunication Sector, Geneva, 2003

The harmful RFI emission limit is met if the power in the RFI signal, P_h, satisfies $P_h < \sigma_P/10$, thus

$$P_h < \frac{kT_{sys}}{10}\sqrt{\frac{\Delta\nu}{\tau}} \qquad \text{watts.} \tag{3}$$

The widely used ITU limits on RFI emissions are based on an integration time of 2000 seconds, and a resolution bandwidth corresponding to a velocity resolution of 3 km/sec. The conversion of velocity width to frequency is given by $\Delta\nu = 10^4\nu_G$, where ν_G is the RF frequency in GHz. Hence, for the ITU requirements, $\Delta\nu/\tau = 5\nu_G$, and $P_h < 3.2 \times 10^{-24} T_{sys}\sqrt{\nu_G}$ watts, as measured at the output of the horn.

3 Additional Factors for Interferometers

Analysis of the harmful limit for interferometry is complicated by a number of additional factors:

Sensitivity The sensitivity of a two-element interferometer is $1/\sqrt{2} = 1.5$ dB better than each of its antennas. This is a small factor which we neglect.

RFI Coherency The interfering signals reaching the two antennas must be coherent to be detected by the correlator. We are presuming for this memo a single source of narrow-band emission coupled radiatively to two antennas, so this coherence criterion is established by definition.

Imaging Coherency An interfering signal generally enters the antenna through its sidelobes, which impresses upon the signal a very different phase than that imposed onto the astronomical signal entering through the main beam. In addition, the RFI signal will be subject to a very different propagation phase offset than the astronomical signal. The phase of the RFI signal, as measured by the correlator, is randomized compared to the desired astronomical signal, so the amplitude of the RFI in the image will be reduced by a factor of $\sim N_a$, where N_a is the number of antennas, independent of any phase winding arguments. For the EVLA, with $N_a = 27$, this incoherency provides an additional ~14 dB of isolation.

Fringe Phase Winding Phase-tracking interferometers must continuously slip the phase of antenna-based signals to maintain coherency for the broad-band signals from an astronomical source as it moves relative to the two antennas. The correlator output signal of a (stationary) source of RFI will show a phase rotation at the 'natural' rate of $\nu_f = \omega_e u \cos\delta$, which upon integration can greatly diminish the RFI amplitude. The attenuation can vary from near zero for short-baseline, low-frequency signals, to factors exceeding 50 dB for long-baseline, high-frequency signals.

These factors are discussed at length in EVLA Memo #49. Here we apply the results to establish practical limits for emissions at the EVLA site.

4 Emission Limits for Interferometers

EVLA Memo#49 gives a useful expression for the attenuation in an image of a stationary source of RFI provided by phase winding:

$$R = 12\sqrt{\tau\nu_G B_K \cos\delta}. \tag{4}$$

In this expression, B_K is the maximum baseline in the array in kilometers, τ is the integration time in seconds, ν_G is the RF frequency in GHz, and δ is the source declination. Note that we have inverted the definition from that given in Memo #49 (so that $R > 1$), and that the baseline distribution factor f has been set to a value $f = 4$, as suggested in Memo #49 for the EVLA. This expression is valid only for those circumstances where its value is greater than one.

To this attenuation can be added the factor N_a, describing the mutual phase incoherence of the RFI signal. The sum of these two effects describes the extra isolation that an imaging interferometer enjoys over a total power radiometer system, and hence also provides the factor by which limits on interfering emissions can be relaxed for an interferometer. We then get, for the harmful limit,

$$P_h < \frac{kT_{sys}}{10}\sqrt{\frac{\Delta\nu}{\tau}}\left(N_a + 12\sqrt{\tau\nu_G B_K \cos\delta}\right) \qquad \text{watts.} \tag{5}$$

Applying the ITU standard frequency width corresponding to a velocity resolution of 3 km/sec, and setting $N_a = 27$, the expression for the maximum tolerable power can be written

$$P_h < 100kT_{sys}\left(2.7\sqrt{\frac{\nu_G}{\tau}} + 1.2\nu_G\sqrt{B_K\cos\delta}\right) \qquad \text{watts} \tag{6}$$

5 Independence of the Emission Limit on Integration Time

The second term in Eq. 6, describing the attenuation due to fringe winding, is larger than the first if

$$\tau\nu_G B_K\cos\delta > 5, \tag{7}$$

a condition which is nearly always met. For example, at a frequency of 1 GHz ($\nu_G = 1$) in the D-configuration ($B_K = 1$), at a declination of $\delta = 0$ degrees, fringe-winding attenuation dominates for integrations longer than 5 seconds. The integration time needed lengthens for northern declinations, but even at $\delta = 85$ degrees, fringe winding dominates for observations exceeding 1 minute in length. For the ITU integration time of 2000 seconds, only for observations within 6 arcminutes of the NCP will the fringe winding not be sufficient to reduce the RFI effect more than the 14 dB provided by the incoherency of the signals for observations at 1 GHz in the D-configuration.

Examples such as this lead us to conclude that for the purpose of establishing a practical limit which applies for virtually all realistic observing scenarios, we can assume the fringe-winding term dominates. Specification of a northern declination limit is also required, as fringe-winding provides decreasing protection for northern sources, and none at all for emissions exactly coincident from the direction of the pole. We take $\delta = 85$ degrees for this limit, noting that only $\sim 0.25\%$ of the sky observable from the EVLA lies north of this limit.

With these assumptions, we find, for the D-configuration, the harmful power within the ITU-specified resolution bandwidth to be

$$P_h < 5\times10^{-22}\nu_G T_{sys} \qquad \text{watts.} \tag{8}$$

Because the protection afforded by fringe-winding has the same integration time dependency as the sensitivity of the array, the harmful power limit derived above is **independent of integration time**.

6 Conversion to Power Flux Density

The limit above applies to the power in the RFI, as measured within a bandwidth equivalent to 3 km/sec velocity resolution, which is provided by the antenna feed to the first stage of amplification. Conversion of this to the power emitted by a transmitter requires knowledge of three additional factors – the effective collecting area of the victim antenna in the direction of the source of emission, the effective shielding of the radiation source, and the distance between source and victim.

We make the standard assumption here that the victim antenna's effective cross-section area is that corresponding to an isotropic antenna:

$$A_e = \frac{\lambda^2}{4\pi}. \tag{9}$$

The power flux density, F_h at the antenna horn, is related to the power limit by $F_h = P_h/A_e$, so that the limit in the power flux density becomes

$$F_h < 7.0\times10^{-20}\nu_G^3 T_{sys} \qquad \text{watt/m}^2. \tag{10}$$

If the gain of the antenna in the direction of the interfering source is a factor G greater (or less) than isotropic, then the emission limit must be decreased (or increased) by this same factor. In general, the far-out sidelobes of large antennas have a gain near to, or less than isotropic, so the limits based on this assumption should be representative.

The resulting PFD harmful limits are given in the following table. The values of T_{sys} shown for the Cassegrain feed bands are those we expect to achieve, rather than the requirements given in the EVLA Project Book. At P-band, we have assumed a value of 50K, rather than the 150K currently achieved, reflecting our hope for a future improvement at this band. The right-hand column shows the equivalent broad-band spectral power flux density, expressed in astronomical units, which would provide the same power within the bandwidth listed.

Table 1: Harmful Threshold RFI Power Flux Densities for the EVLA

Band	ν_G GHz	$\Delta\nu$ kHz	T_{sys} K	F_h Wm^{-2}	F_h $\mathrm{dB(Wm^{-2})}$	S_h Jy
4	.075	0.75	1000	3.0×10^{-20}	-195	3.9×10^{3}
P	.325	3.25	50	1.2×10^{-19}	-189	3.7×10^{3}
L	1.5	15	25	5.9×10^{-18}	-172	3.9×10^{4}
S	3.0	30	25	4.7×10^{-17}	-163	1.6×10^{5}
C	6.0	60	25	3.8×10^{-16}	-154	6.3×10^{5}
X	10	100	30	2.1×10^{-15}	-147	2.1×10^{6}
U	15	150	35	8.3×10^{-15}	-141	5.5×10^{6}
K	23	230	40	3.4×10^{-14}	-135	1.5×10^{7}
A	34	340	45	1.1×10^{-13}	-129	3.4×10^{7}
Q	45	450	66	4.2×10^{-13}	-124	9.4×10^{7}

The equivalent isotropic power of the emitting source is then related to this limit by

$$EIRP < 4\pi r^2 S F_h / G \qquad \text{watts} \tag{11}$$

where S is the shielding factor for the emitter, in the direction of the victim antenna, and G is the gain of the victim antenna, relative to isotropic.

As an example, suppose $r = 300$ meters, the emitter lies within a 20 dB shield, and that the interference enters the victim antennas through a 0 dBi sidelobe. The limit on the EIRP for harmful interference at L-band is then found to be 7 nW. To meet the limit, there can be no emissions from this source above that level, as measured within a 15 kHz bandwidth over the frequency range of 1 to 2 GHz.

7 More Stringent Limits for Bi-Static Radar Experiments

The limits on RFI emissions are proportional to the square root of the resolution bandwidth. For nearly all astronomical observing, the 3 km/s limit utilized by the ITU will set the most stringent level likely to be necessary. However, bistatic radar experiments utilize very much narrower bandwidths, and will thus require a considerably more stringent level of protection. There are three bands which are, or will be, utilized for these experiments, and for which special RFI protection will be needed. The essential characteristics are shown in the following table. The center frequency is given in the first column, the highest frequency resolution in the second column, and the maximum bandwidth in the third.

Table 2: Characteristics of Bi-Static Radar Experiments

Frequency GHz	Resolution Hz	Bandwidth kHz
2.38	0.8	0.8
8.51	2.8	2.8
34.32	11.4	11.4

The resolution bandwidth for these experiments is set by the required velocity resolution of 0.1 m/s – a factor of 30,000 narrower than the ITU resolution bandwidth. This factor lowers the harmful power levels by 22 dB over the values given in Table 1, for all three bands. As shown in Table 2, the bandwidths over which this work will be done are very narrow, and fixed, so that in principle, the more stringent emissions standards are to be applied only within these narrow bands.

An open question is how these more stringent, but limited, standards can be applied effectively. Given that shielding is not likely to be made more effective by 22 dB within these narrow bandwidths at the three frequencies, it may not be cost-effective (especially given the rarity of these bistatic experiments) to require that the emissions standards be tightened by 22 dB over all bands. A more effective means may be to identify electronics which are known to exceed these standards at the bands identified, and to have these turned off during such experiments. Obviously, such equipment cannot be critical to the observing!