VLA/VLBA Interferference Memo #34
Notes on RFI Emissions Levels

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Abstract

This memo attempts to set practical, easy-to-apply limits to RFI emissions for the EVLA.

1 Introduction

A number of memos in the EVLA Memo Series have addressed aspects of the problem of setting practical limits on RFI emissions. However, the limits set differ between these memos, reflecting an evolving understanding of the practicalities involved, and they are expressed in units which are indirectly connected to those measured in the field. This memo summarizes my best understanding of the issues, and expresses the limits in units which are directly measured.

2 The RFI Emission Limit Criterion

The limits on RFI emissions are based on a very simple criterion: The Interference to Noise fluctuations Ratio, or INR, 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. The limit on the harmful interference power, P_h, which is delivered from the antenna horn to the first amplifier, is

$$P_h < \frac{kT_{sys}}{10}\sqrt{\frac{\Delta\nu}{\tau}} \qquad \text{watts,} \tag{2}$$

within a given bandwidth, $\Delta\nu$ Hz, and for an integration duration of τ seconds.

The harmful emission limit depends on bandwidth and integration time. We have adopted the widely accepted ITU standards – a bandwidth appropriate to a velocity resolution of 3 km/sec, and an integration time of 2000 seconds. The bandwidth is then given by $\Delta\nu = 10^4\nu_G$ Hz, where ν_G is the RF frequency in GHz.

As discussed in EVLA Memo#106, these limits can be relaxed for interferometers, primarily because the effect of fringe-winding is to reduce the effective power of the interference on the image, but also because the RFI is in general incoherent with respect to the astronomical signal of interest. EVLA Memo #49 discusses these points in detail. For most practical situations, the fringe winding is the dominant effect, and Memo #106 provides us with a practical limit to the RFI power, as seen at the input to the first-stage amplifier, within the bandwidth given in the preceding paragraph, for the 'D'-configuration:

$$P_h < 5 \times 10^{-22}\nu_G T_{sys} \qquad \text{watts.} \tag{3}$$

It is noted that this limit is independent of integration time – increased integration increases sensitivity, but it also decreases the effect of the RFI signal, with the same dependency. This limit is the EVLA's adopted standard, appropriate for 3 km/sec velocity resolution.

I note here that the harmful limit increases with increasing bandwidth and with increasing baseline length – both scaling as the square root. Hence, continuum observations, and high spatial resolution observations, are more tolerant to RFI. However, the limits we set must be based on reasonable 'worst-case' criteria – so a high spectral resolution observation, near the north celestial pole, made with low spatial resolution is the adopted standard.

3 The Coupling Equation

My prior treatments of the problem muddied the water by attempting a conversion to power flux density, or (even worse) spectral power flux density. These are unnecessary, as power is what is emitted, what is received, and what has to be limited. What we require is a general expression between the power received by a victim antenna, P_r (within the accepted 3 km/sec velocity bandwidth), and that which is emitted by some alien piece of equipment, P_e, in order to establish appropriate standards on the radiated power.

The appropriate expression ('coupling equation') is easy to derive. It is:

$$P_r = \left(\frac{\lambda}{4\pi r}\right)^2 \frac{G_r G_e}{S} P_e \qquad (4)$$

where:

- λ is the wavelength, and r is the distance between the transmitter and victim. These must be in the same units.
- G_r is the gain of the victim antenna in the direction of the transmitter, relative to isotropic.
- G_e is the gain of the transmitting antenna in the direction of the victim, relative to isotropic.
- P_e is the emitted power from the transmitting antenna, within a bandwidth corresponding to a velocity width of 3 km/sec.
- S is the existing shielding for the transmitting antenna.

To obtain the limit on the emitted power, we solve Eqn. 4 for P_e, and substitute the harmful limit, P_h for P_r, to obtain:

$$P_e < \left(\frac{4\pi r}{\lambda}\right)^2 \frac{S}{G_r G_e} P_h \qquad (5)$$

Substituting the adopted level (Eqn. 3) for P_h, using $\lambda_m = 0.3/\nu_G$, where λ_m is the wavelength in meters, we find

$$P_e < 8.77 \times 10^{-19} \frac{S}{G_e G_r} r_m^2 \nu_G^3 T_{sys} \qquad \text{watts} \qquad (6)$$

where r_m is the distance **in meters** between the transmitter and the victim, and P_e is the total power emitted by the transmitter, within any bandwidth corresponding to a velocity resolution of 3 km/sec.

I now switch to the useful engineering units. The limit on emitted power, in dB Watts, becomes:

$$P_{e,dBW} < -180.6 + 20 \log r_m + 30 \log \nu_G + 10 \log T_{sys} - G_{e,dBi} - G_{r,dBi} + S_{dB} \qquad (7)$$

where r_m is the distance in meters, the gain factors, $G_{e,dBi}$ and $G_{r.dBi}$ are expressed in dBi, and the shielding factor, S_{dB} is in dB.

To simplify notation, I will drop the dB and dBi subscripts in all the following discussion.

4 An Illustrative Example

Let us now assume the separation between emitter and victim is one meter, so $r_m = 1$, and that both the emitter and victim's gains are isotropic, so $G_e = G_r = 0$ dBi. The power emission limit for the radiating emitter is then

$$P_e < -180.6 + 30 \log \nu_G + 10 \log T_{sys} + S \qquad \text{dBW} \qquad (8)$$

Inserting approximate values of frequency and system temperature for each band, we derive the maximum allowed power (within the RBW listed), assuming there is no shielding (S = 0 dB), as shown in the following table.

This table is easily extended to other distances. For a distance of 10 meters, add 20 dB. For a distance of 100 meters, add 40 dB, and for a distance of 1 km, add 60 dB. If the victim and transmitting antennas both have estimated gains of, say, 5 dBi towards each other, than 10 dB is to be subtracted from the power limit. And if there is already 20 dB of shielding around the emitting antenna, than this is added to the power limit given above.

Table 1: Harmful Threshold RFI Power for the EVLA

For r=1 meter Isotropic emission and reception No shielding				
Band	ν_G	$\Delta\nu$	T_{sys}	P_e
	GHz	kHz	K	dBW
4	.075	0.75	1000	-185
P	.325	3.25	50	-178
L	1.5	15	25	-161
S	3.0	30	25	-152
C	6.0	60	25	-143
X	10	100	30	-136
U	15	150	35	-130
K	23	230	40	-123
A	34	340	45	-118
Q	45	450	66	-113

5 Computation of Additional Shielding

These results can be easily extended to compute how much additional shielding is required for equipment being located at the EVLA site.

Suppose the power radiated by the device in question – over 4π steradians, and within the 3 km/second bandwidth, is P_e dBW. Denote by P_h the harmful power in dBW, taken from the above table. The **additional** shielding needed, in dB, will be given by

$$S_{add} = P_e - P_h - R + G_e + G_r - S \tag{9}$$

where

- P_e is the measured radiated power, in dBW, within the 3 km/sec equivalent BW,
- P_h is the harmful power, in dBW, within that same BW, taken from Table 1, for the band of interest,
- $R = 20 \log r_m$ is a 'space factor', and r_m is the distance between radiator and victim, in meters,
- G_e is the gain, in dBi, of the emitting device towards the victim,
- G_r is the gain of the victim antenna, in dBi, towards the emitter, and
- S is the existing shielding, in dB, of the radiating system, due to racks, rooms, walls, etc.

6 Practical Issues Arising from Differing Measurement Bandwidths

Typically, the spectral scanning hardware used to measure the RFI emission from some piece of equipment will utilize a resolution bandwidth (RBW) larger – and sometimes significantly larger – than the astronomical standard of $\Delta\nu = 10\nu_G$ kHz. In this case, some care must be taken in interpreting the results. Some examples follow, to help clarify the issues. In all cases, I assume the 'natural' width of the RFI emission to be much narrower than the bandwidth utilized for the setting of the emission standard.

- If the emissions measured with the wide RBW system lies below the threshold for harmful interference, **and** the sensitivity of the measurement is also below the threshold (i.e., the noise power as measured by the equipment is less than the harmful limit), then no adjustements are needed, and the equipment passes the test.
- If, however, the RBW utilized causes system sensitivity to be worse than the limits we are trying to meet, a narrower measurement bandwidth is mandatory, in order to improve the measurement sensitivity.

- If an emission is found which lies above the maximum established, and the RBW is significantly greater than the 3 km/sec velocity equivalent, the emission standard has not necessarily been violated, as the emission may come from two lines which are in separate 3 km/sec velocity widths, but are unresolved in the RBW utilized. In this case, the frequency range spanned by the RBW must be re-measured with an RBW closer to that specified by the 3 km/sec standard, in order to determine whether the emission is within a single bandwidth-equivalent to 3 km/sec velocity width (in which case the equipment fails the test), or whether the emissions are at multiple frequencies, separated by more than the frequency equivalent to 3 km/sec, and each of which lies below the harmful threshold.
- If the emission is itself resolved over a frequency width greater than the equivalent to 3 km/sec, it will be necessary to measure it with an RBW as close to the 3 km/sec bandwidth equivalent, in order to determine if the emission exceeds the harmful threshold.

I sincerely hope this memo clarifies, for once and for all, what has become an unnecessarily confusing subject!