EVLA Memo # 104
RFI Emission Goals on Internally-Coupled Signals

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Abstract

Limits are given for internally-generated and coupled RFI for EVLA electronics.

1 Introduction

EVLA Memo #46 established goals for limiting internally-generated RFI emissions by EVLA electronics. However, these limits are based on a model where the emissions are electromagnetically coupled to the RF signal path through the antenna's horn. It has since been recognized that RFI generated within a module can be directly coupled into the signal path within that module. The purpose of this short memo is to reword the emission goals in a more general way for easier application.

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

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

where k is the Boltzman constant, 1.38×10^{-23} J K^{-1}. The RFI emission limit is met if the power in the RFI signal, P_r, satisfies

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

The widely used ITU limits on RFI emissions are based on an integration time of 2000 seconds, and a resolution bandwidth appropriate for 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 $P_r < 3.2 \times 10^{-24} T_{sys}\sqrt{\nu_G}$ watts, as measured at the output of the horn.

3 Application to Internally-Coupled Signals

Memo #46 applies the INR requirement to radiatively coupled signals and is not directly applicable to internally coupled signals. This case is simpler, for we need only consider the effect on the INR of a signal generated within some module, and are not concerned with factors such as shielding, antenna effective area, or space loss, which complicate the radiatively coupled scenario.

We imagine a measurement with an astronomical autocorrelator in which rather than observing cold sky, the noise power is provided by a matched load of 300K terminating the input of the module in question. The noise temperature normally seen at the input to this module is GT_{sys}, where G is the system gain between the front-end and the module. The INR requirement is thus modified to

$$INR < \frac{0.1GT_{sys}}{300}, \tag{4}$$

which in engineering units of dB, become

$$INR_{dB} < -35 + 10\log G + 10\log T_{sys}. \tag{5}$$

We have presumed at this point that the INR measurement is made with an astronomical correlator with the ITU values of 2000 seconds and 3 km/sec velocity bandwidth. This is not practical for a lab measurement, and because of the (generally) high gain preceding the modules in question, generally not necessary. Assume that the INR measurement is made with a spectrum analyzer with effective integration time of τ_m milliseconds, and resolution bandwidth, of B Hz. Reducing the resolution bandwidth from the very wide astronomical widths (typically a few kHz) to some tens or hundreds of Hertz improves the accuracy of the measurement (and shortens the time needed), and is a valid procedure providing the actual width of the RFI of concern is less than the RBW.

With this change in methodology, the INR requirement becomes

$$INR < \frac{0.1GT_{sys}}{300}\sqrt{\frac{10^{-3}\tau_m}{2000}\frac{10^4\nu_G}{B}} \tag{6}$$

which in engineering units becomes

$$INR_{dB} < -46.3 + 5\log\tau_m - 5\log B + 10\log G + 10\log T_{sys} + 5\log\nu_G \tag{7}$$

As an example, consider the EVLA's downconverter (T304) module, where the 2nd harmonic of the 4096 MHz LO has been found to be contaminating the X-band RF signal. For this module at X-band, $\nu_G = 8.2$, $G = 10^6$, (ignoring any losses), and $T_{sys} = 30K$. Inserting these values, we have

$$INR_{dB} < 33.0 + 5\log\tau_m - 5\log B \tag{8}$$

If the effective integration time is 100 msec, and the resolution bandwidth 100 Hz, then the RFI goal is met if the INR is less than 33 dB for this particular module.

4 Relaxation for Interferometers

The INR criterion established in the preceding section applies directly to a total-power radio astronomy system. In interferometry, the application is somewhat more complicated by a number of additional considerations, as described in EVLA Memo #49. I list these below:

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 can be neglected.

Baseline Coherency Internally-generated signals independently coupled into two antennas must be phase coherent for the preceding considerations to apply. In general, if there is much more than 1 radian of phase slip between the two independent signals over the image cell-crossing time (typically a few seconds), the signals can be considered incoherent. If ϕ is the typical phase rotation, in turns, in this time, the effect of the interfering signal on the output product is reduced by $\sim 1/\phi$.

Imaging Coherency Even if the two injected signals are coherent between two antennas as described above, the phases of the product will not in general be coherent in the imaging process, as the phase of the desired astronomical signal arrives by a very different process. For an array of 27 antennas, there are 351 independent pairs, and if the RFI signals are of random phase in each, the effect on an image is reduced by ~ -13 dB.

Fringe Phase Winding Imaging phase-tracking interferometers must continuously slip the phase of antenna-based signals to maintain coherency for signals from an astronomical source. If the internally coupled signal is subject to this differential phase slip, its effect on an image can be dramatically reduced. The attenuation is proportional to the length of the E-W component of the baseline, to the frequency, and to $\cos\delta$. For baselines of kilometers, frequencies above 10 GHz, and observations near the equator, the attenuation can be by 40 dB or more! However, as the EVLA is a reconfigurable array, with baselines as short as 30 meters, observing at frequencies as low at 73 MHz, and which will observe sources arbitrarily close to the north celestial pole, the fringe-winding factor cannot be assumed to have an appreciable effect, especially at the lower frequency bands.

Of the above factors, the only one which can be generally applied is the imaging coherency, providing about 13 dB reduction from the ITU 'single-dish' goals. However, when considering RFI module emissions at higher frequencies, where even in the 'D' configuration there will be significant phase winding loss, a further reduction in the ITU goals of 20 dB or more is possible for most practical scenarios. Equation 16 in EVLA Memo #49 suggests that the attenuation by fringe-winding in an image over a period of 2000 seconds for the 'D'-configuration will be approximately

$$R_{db} = -27 - 5\log(\nu_G) - 5\log(\cos\delta). \tag{9}$$

In summary, it is probably safe to relax the strict ITU emission goals for the EVLA by $\sim$ 20 dB for all but the lowest frequency (below 1 GHz) emissions. For high frequencies (say, above 10 GHz), a relaxation of 30 dB should be considered acceptable.