EVLA Memo #47
Estimated Shielding for the EVLA Ethernet Switches

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Abstract

As a part of the Monitor and Control Bus (MCB), each EVLA antenna will be equipped with Ethernet switches which are likely to cause internal interference. In order to ensure that these MCBs will not affect future astronomical observations at the EVLA, a test has been performed to estimate the amount of shielding required.

1 Harmful Threshold Levels

To be able to determine the required shielding of on-site equipment we need to define the maximum allowed power level of an interfering signal: the interference can be acceptable if its contribution to the output is small compared to the noise. A detailed description of how to estimate suitable maximum allowed emission levels (a.k.a. 'detrimental levels') for the VLA/EVLA has been given by Thompson, Moran & Swenson (1998) and Perley (2002). Therefore, in this memo we will not go into any details but just summarize the main concepts and assumptions following Perley (2002).

Firstly we consider the signal to be acceptable as long as the incoming signal does not contribute more than 10% to the total noise; SNR < 0.1. Further we use the detrimental levels calculated for a single dish telescope. For a synthesis array, effects such as fringe rate will reduce the harmful effect of the interfering signal (Thompson, Moran & Swenson 1998; Perley 2002); this will not be considered in this memo.

Now, assuming F_h [Wm^{-2}] is the power flux density of the interfering signal incident at the antenna, and F_N [Wm^{-2}] is the minimum detectable power flux density, the SNR can be written as

$$SNR = \frac{F_h}{F_N} = \frac{F_h \lambda^2 G \sqrt{t_{\text{int}}}}{4\pi k T_{\text{sys}} \sqrt{\Delta\nu}} \leq 0.1 \tag{1}$$

where k is Boltzmann's constant, T_{sys} is the system temperature, $\Delta\nu$ is the bandwidth, t_{int} is the integration time and G is the side lobe gain (we assume the interfering signal is most likely to be received in the far side lobes of the antenna, see Thompson, Moran & Swenson 1998).

To rewrite Eq. 1 into a formula with commonly used astronomical variables, we note that in spectral line observations a velocity resolution ΔV [m/s] is usually used ($\Delta\nu = \nu\Delta V/c$). In addition we will assume a 0dB gain ($G = 1$) and so we can rewrite Eq. 1 solving for the harmful threshold level F_h of the interfering signal

$$F_h \leq \frac{0.4\pi k T_{\text{sys}} \nu^{2.5} \sqrt{\Delta V}}{c^{2.5} \sqrt{t_{\text{int}}}} \tag{2}$$

Note that F_h is the allowed power flux density within the channel bandwidth $\Delta\nu$. Eq. 2 can be used for any observing frequency, integration time and velocity resolution. To quantify this equation, we estimate F_h considering a typical VLA observation using $\Delta V = 1$ km/s and $t_{\text{int}} = 8$ hours[1]. The results are listed in Table 1 in addition to the typical system temperatures and frequency ranges of the current VLA (taken from the VLA web page). To achieve the F_h values we used the listed typical T_{sys} and a frequency in the center of the band. Using the frequency resolution corresponding to 1 km/s we also calculate the corresponding spectral flux density S in units of Jy. We further list the corresponding ITU levels, which are 8dB higher than our more stringent limits. This table is also illustrated in Fig. 1 which plots the harmful threshold levels for the VLA. A simple two-point interpolation indicates typical values in the frequency ranges between the bands currently covered by the VLA.

We note that the detrimental levels listed in Perley (2002) are for the EVLA (using e.g. expected improved receiver temperatures), but agree with Table 1 within a few dB. Therefore, within a few dB our results derived in this report will be applicable also for the EVLA system.

[1] In the ITU levels a velocity resolution of 3km/s and 2000s integration is used, however a more conservative limit should be put on our internally generated RFI.

Table 1: Typical Harmful Threshold Levels for the VLA Bands.

Band	Frequency Range MHz	T_{sys} K	$\Delta\nu$ kHz	F_h Wm^{-2}	S Jy	F_h $dBWm^{-2}$	ITU F_h $dBWm^{-2}$
4	73-74.5	5000	0.25	4.9×10^{-22}	196	-213	-205
P	300-340	170	1.10	7.0×10^{-22}	64	-212	-203
L	1240-1700	35	4.70	5.5×10^{-21}	116	-203	-195
C	4500-5000	45	16.0	1.5×10^{-19}	938	-188	-180
X	8100-8800	35	28.4	4.8×10^{-19}	1690	-183	-175
U	14500-15300	120	49.7	6.8×10^{-18}	13682	-172	-163
K	22000-24000	60	76.7	1.0×10^{-17}	13038	-170	-162
Q	40000-50000	80	150.1	7.1×10^{-17}	47302	-161	-153

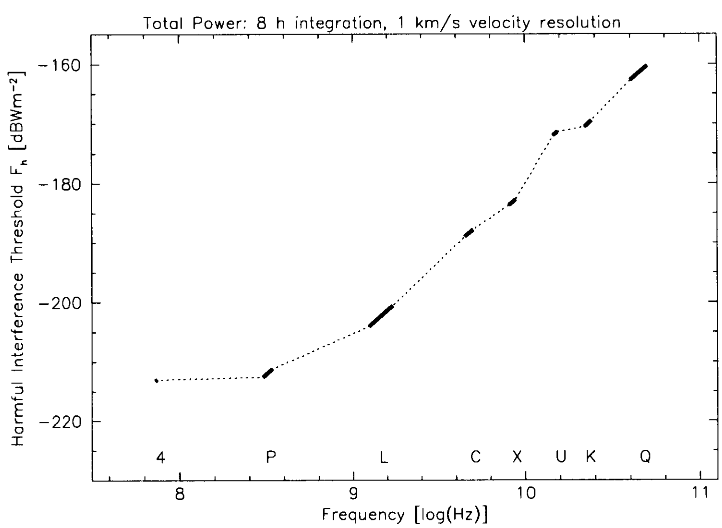

Figure 1: Calculated maximum acceptable power flux density (of an interfering signal) at different VLA bands, using typical observational values for the integration time (8 h) and the velocity resolution (1 km/s).

2 Test Setup & Results

To determine how the MCBs will affect an observation, the total emitted power from the MCB units could have been measured in a shielded chamber and directly compared to the suggested detrimental levels in Table 1. However, the absolute calibration of the VLA RFI shielded chamber is uncertain. Instead we looked at the relative levels between a test signal and the peak levels emitted by the MCBs:

1) The MCBs plus a test signal at 1440 MHz (ranging over a few different transmitted power levels between −40 and −70dBm) was used in the shielded chamber at the VLA site. This gives the relative strength between the noise peaks of the MCBs and the test signal. The spectra can be seen in Fig. 2, displaying a −50dBm test signal together with the MCB emission. We note that this −50dBm signal is 14dB higher than the peak levels at frequencies around 1440 MHz, but is close in level to the peak MCB emission at frequencies between 1.8 and 2.3 GHz.

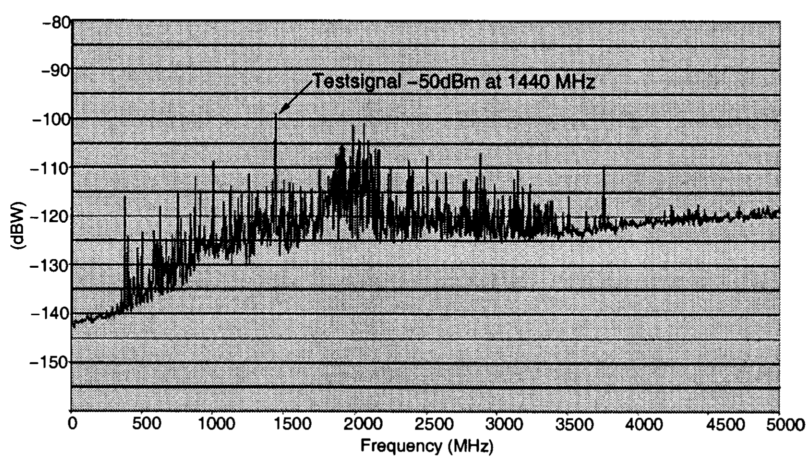

Figure 2: MCBs and a −50dBm test signal at 1440 MHz. Note that the y-axis scale is not calibrated and thus does not show absolute units.

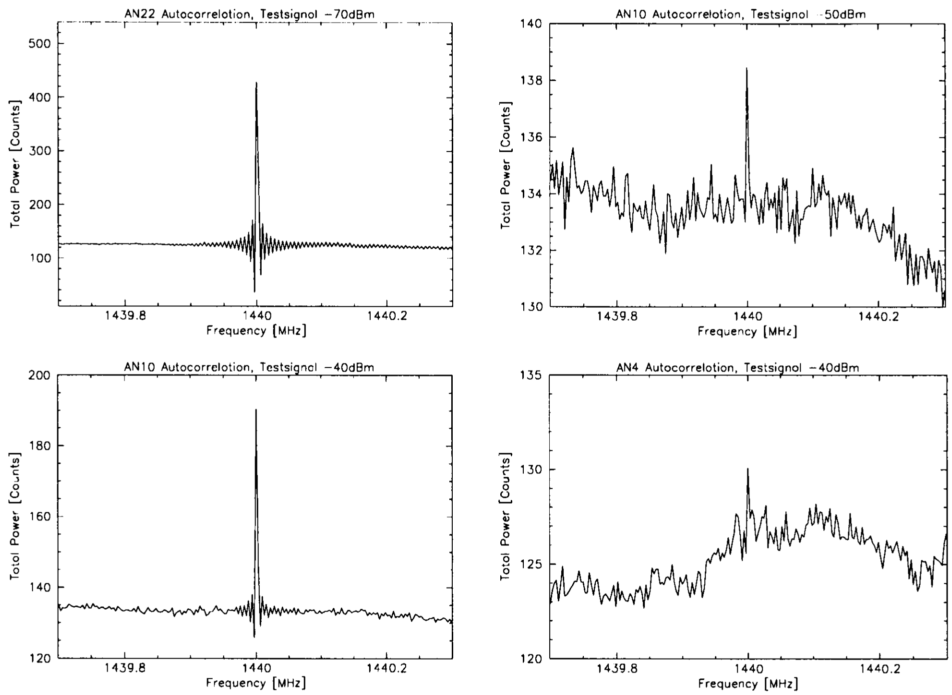

Figure 3: VLA autocorrelation spectra at a few antennas with different strengths on the input test signals. Spectral resolution is 3.05 kHz (corresponding to a velocity resolution of 0.63 km/s), and integration time 40 s.

2) The same test signals were transmitted inside the vertex room of AN22, and VLA data were recorded. The resulting autocorrelation spectra were used to derive the observed SNR. Since the autocorrelation spectra of the VLA correlator easily 'saturate'[2], we used a few different input signal strengths in steps of 10dB to make sure we had at least one autocorrelation spectrum of AN22 where the spectrum was not saturated. In addition, we also looked at the autocorrelation spectra of nearby antennas to compare the shielding needed at locations away from the source of interference.

Figure 3 shows four of the autocorrelation spectra, measured in the units of the VLA correlator. To convert to real units (e.g. Jy) an antenna based amplitude gain would need to be applied, and in addition we usually as-

[2]The signal does not saturate the electronics but the spectra appear saturated due to insufficient digitization.

Table 2: Estimated shielding required at 1440 MHz.

Signal	AN	Dist.	SNR	S[1]	Signal[2]	MCB lev[3]	35m[4]	8h[5]	S[6]
					corr	corr	corr	corr	res
dBm	No.	m		dB	dB	dB	dB	dB	dB
−70	22	1	907	40	20	−14	–	13	59
							−31	13	28
−50	10	225.8	15	22	0	−14	16	13	37
−40	10	225.8	72	29	−10	−14	16	13	44
−40	4	188.5	15	22	−10	−14	15	13	26

sume that for correlated data the signal has entered via the main beam with its corresponding effective area. An additional correction for the difference of the effective collecting areas between an isotropic radiator and the main beam would thus also be needed. However, we are simply interested in the SNR, and any such calibration factors will thus cancel out. We can therefore look directly at the SNR and derive the shielding needed to suppress the SNR to below 0.1.

Table 2 lists the results of the tests. The measured SNR is used to estimate the shielding S ($S = 10\log(\frac{\mathrm{SNR}}{0.1})$) required to suppress the SNR to 0.1. Correction factors are then applied, for instance correction for different levels of the input test signal strength. From this table we can conclude that the worst case requires around 59dB shielding at L-band frequencies. This is illustrated in Fig. 4, displaying our observed autocorrelation spectra converted to units of dBWm^{-2} using P= $kT_{sys}\Delta\nu$. Note that the signal is 6dB lower than the MCB peaks.

[1]The shielding needed for suppressing the SNR to 0.1.

[2]The test signal used in the antenna differs by this amount from the −50dBm test signal.

[3]The test signal used in the antenna is 14dB higher than the peak MCB levels at 1440 MHz.

[4]The decrease in space loss (increase in signal flux density) if the antenna would have been at a distance of 35m (corresponding to the closest distance between two antennas in D-array) from the interfering signal.

[5]The extra shielding needed recalculating the 40 s and 0.63 km/s resolution VLA observation into a 8 h 1 km/s observation = 13dB.

[6]Resultant total amount of shielding.

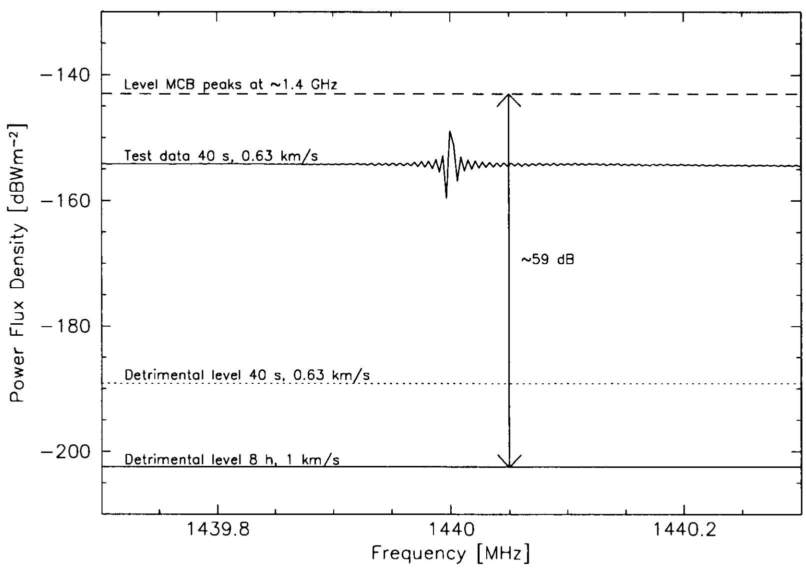

Figure 4: The −70dBm test signal seen at AN22 compared to detrimental levels. This signal is 6dB lower than the MCB peaks at corresponding frequencies.

3 Extrapolation to Other Frequency Bands

Our results can be extrapolated into other frequency bands. We here consider a few examples important for the EVLA, scaling the shielding needed in order for the MCBs not to be seen in the total power spectrum of the antenna where the MCB is located. Two corrections are applied; the first one is by comparing the harmful threshold levels of the 1440 MHz (L-band) with the band in question, using either Table 1 or Fig. 1. The second correction is derived from the difference between the power levels of the MCB between L-band and the band in question, using Fig. 2.

C band 4.5 GHz: The VLA detrimental level is 15dB higher at C-band than at L-band (Table 1), and the MCB emission levels are about 5dB lower at C-band (Fig. 2). This results in a 39dB shielding needed at 4.5 GHz.

S band 2 GHz: The peak levels of the MCBs occur at frequencies around 2 GHz (coinciding with the EVLA S-band), and are around 12dB higher than at 1440 MHz (Fig. 2). Including the effect of a 4dB higher detrimental level (Fig. 1) we find that an extra 8dB; thus 67dB shielding would be necessary at 2 GHz.

P band 0.3-0.5 GHz: The MCB peaks at 300-500 MHz might be as large as 4dB below the 1440 MHz peaks (Fig. 2), while the detrimental level has decreased with 9dBs (Table 1). As a result 64dB attenuation is necessary at P-band frequencies.

4 Conclusions

We have described and presented the results from an RFI test of the EVLA Ethernet switches performed at the VLA. The test results indicate that more attenuation is needed to shield the MCBs from affecting the measurements in the antenna where the MCB itself is located, than to the nearest antenna (at an assumed distance of 35m). Based on detrimental levels calculated for a single dish, this test further implies that a shielding of 59dB is necessary at 1.4 GHz. However, since the highest levels of the MCB emission occur at around 2 GHz, we scale the shielding required and suggest that around 67dB attenuation is appropriate at those frequencies in order not to affect future EVLA observations. For EVLA, the detrimental levels are expected to vary only a few dB (Perley 2002), and so 67dB will still be a valid number. Among the factors that we have not considered is that the EVLA vertex room might provide a better shielding than the current vertex room.

5 References

[1] Thompson, Moran & Swenson, 'Interferometry and Synthesis in Radio Astronomy', 1998, Krieger Publishing Company

[2] Perley, R., 2002, EVLA Memo 46, 'Minimum RFI Emission Goals for EVLA Electronics'