Collected LWA Engineering Memos
About Radio Frequency Interference and Siting (RFS)

2008 May 1 – 2010 August 12

Editor: Jayce Dowell (UNM)

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Engineering Memo

RFS0001 – IPRM2 System Documentation

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3/7/08 (updated 5/1/08)

1. System components and setup

The Iowa Portable Monitoring System (IPRM; LWA memo 76) has been upgraded to IPRM2 in order to accommodate observing at frequencies between 1-1000 MHz. This included installing a wider band LNA, and a new LP filter. Figure 1 displays the block diagram for the 1-100 MHz system, using the Big blade antenna. Figure 2 shows the block schedule for the 100-1000 MHz system using the Icom discone antenna. This system is the same as the lower frequency one, except for that the discone antenna does not use a balun and biasT. IPRM 2 will be used for initial, shorter (2 hours) surveys of strong RFI peaks at four of our main candidate sites.

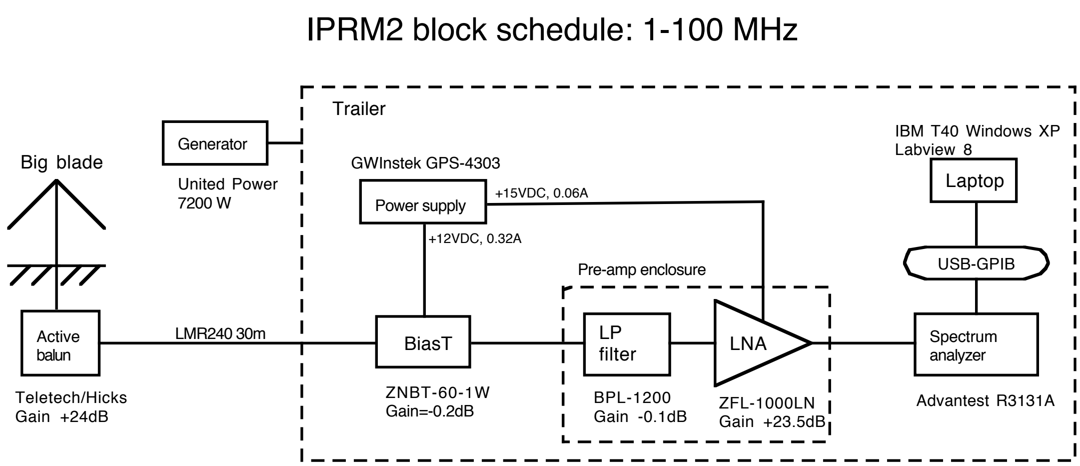


Figure 1: IPRM2 block schedule for 1-100 MHz observations using the Big blade antenna.

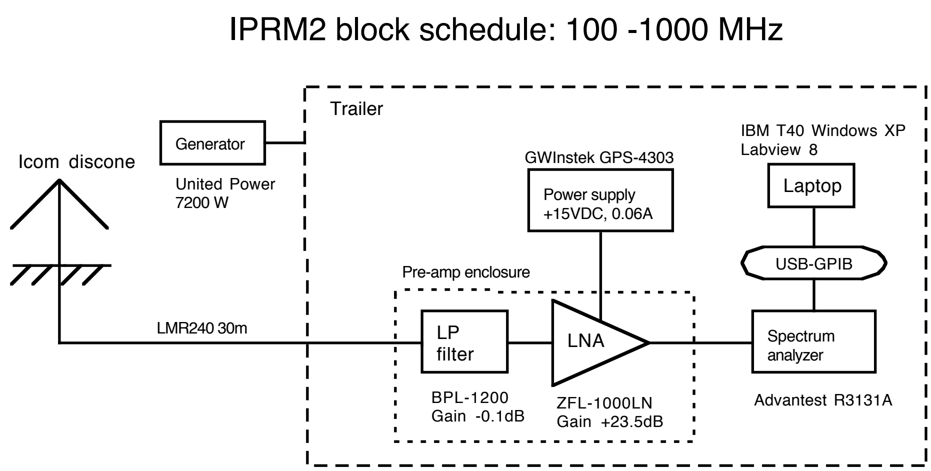


Figure 2: IPRM2 block schedule for 100-1000 MHz observations using the Icom discone antenna, which is not using the balun and biasT.

The system consists of the following components:

1. Antenna: Either the Big blade (for frequencies between 1-100 MHz), or the Icom discone (for frequencies between 100-1000 MHz). Figures 3 and 4 show the gain versus frequency for the two antennas respectively. We note that Fig. 4 is likely not valid (too large variations), and that we have no information on how the measurements were performed.
2. Active balun: LWDA Teletech/Hicks balun with G = +24 dB, NF = 2.7 dB and IIP3 = 7.5 dBm. Only used for the big blade.
3. Minicircuits BiasT (ZNBT-60-1W, using +12VDC, 0.32A), powering the balun. The insertion loss is on average 0.2 dB. Only used for the big blade antenna.
4. LP filter (BPL-1200) with a cutoff at 1200 MHz, and a typical loss of 0.1 dB.
5. LNA (ZFL-1000LN) with G = +23.5 dB, NF = 2.9 dB and IIP3 = -8 dBm when powered by +15VDC (max 0.06A).
6. Spectrum analyzer (Advantest R3131A).
7. USB-GPIB interface.
8. Laptop (IBMT40 running Windows XP) controlling the spectrum analyzer via a LabView 8 program.
9. Power supply for the biasT (Protek P1805).
10. Power supply for the LNA (BK Precision 1670 DC).
11. Portable generator (United Power 7200 W).

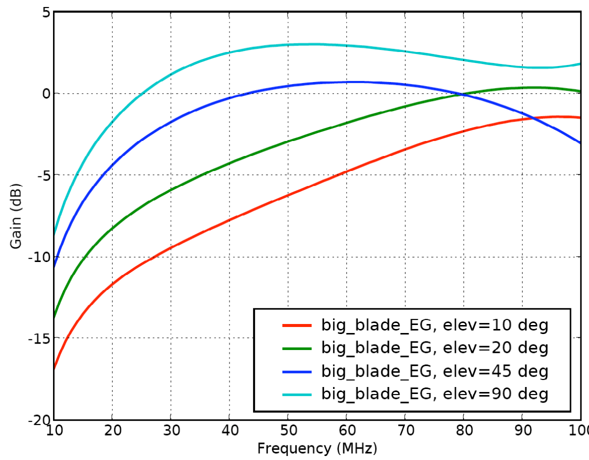


Figure 3: Simulated Big blade antenna gain versus frequency for four different elevations.

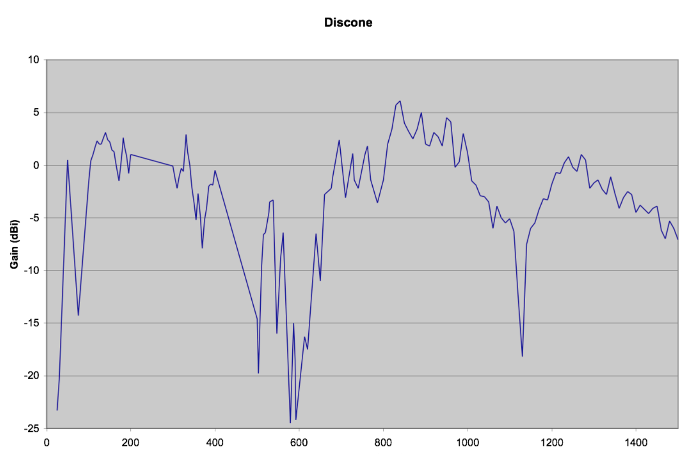


Figure 4: Measured Icom discone antenna gain versus frequency. It is not known how these measurements were performed, and it is likely that the antenna has a much more stable characteristics than what this plots indicates.

2. Observing parameters

The observing parameters for the two frequency ranges are the following:

a) 1-100 MHz:

START FREQ:	1 MHz	STOP FREQ:	100 MHz
RBW:	10 kHz	VBW:	10 kHz

SWEEP TIME: 0.5ms
Total integration time: 2 hours

b) 100-1000 MHz:

START FREQ:	100 MHz	STOP FREQ:	1000 MHz
RBW:	100 kHz	VBW:	100 kHz

SWEEP TIME: 0.5ms
Total integration time: 2 hours

3. Cascade analysis

Cascade analyses of the two setups were performed using Cascade v.1-4 (input and output files listed in appendix A). The main results are:

a) 1-100 MHz system: Total power gain 44.5 dB, IIP3 = -27 dBm, and NF = 2.7 dB.
b) 100-1000 MHz system: Total power gain 17.9 dB, IIP3 = -2.4 dBm, and NF = 6.6 dB.

APPENDIX A

Input file 1-100 MHz

```
# @ IPRM2 with Big blade
#  defaults
rin=50 rout=50  rho=1
# Teletech/Hicks balun
balun g=24 iip3=7.5 nf=2.7
# BiasT ZNBT-60-1W
biast gain=-0.2  nf=0.2
# LMR 240 cables, 24+6 m length
# www.timesmicrowave.com/cgi-bin/calculate.pl at 74 MHz
cableloss g=-2 nf=2
# filter: 1200 MHz LP filter Minicircuits BLP-1200
lpfilter g=-0.1  nf=0.1
# LNA ZFL-1000LN
lna g=23.5 iip3=-8.0 nf=2.9
# end of input file
```

Output file 0-100 MHz

```
**********************************************************
*                CASCADE ANALYSIS                        *
*                 Version   1.4                          *
*           (c) 1997-2001 Dan McMahill                   *
*              mcmahill@alum.mit.edu                     *
**********************************************************

Processing input file "iprm_BB.cas"

@ IPRM2 with Big blade
**********************************************************
*   Default Values Changed                               *
**********************************************************

   Input  Resistance for each Stage = 50 Ohms
   Output Resistance for each Stage = 50 Ohms
   Default Rho (for IIP3 calc.)     = 1

**********************************************************
*   Stage #1  "balun"                                    *
**********************************************************
   Power Gain= 24.00 dB, Voltage Gain= 24.00 dB
   NF=  2.70 dB
   Input Res. = 50 Ohms,  Output Res. = 50 Ohms
   IIP3=  7.50 dBm ( 54.49 dBmV), RHO=  1.00

   Total Power   Gain               =   24.00 dB
   Total Voltage Gain               =   24.00 dB
   Total Noise Figure               =    2.70 dB
   Noise Figure from this stage only =   2.70 dB

   IIP3                             =    7.50 dBm
   IIP3 from this stage only        =    7.50 dBm
```

```
*********************************************************
*   Stage #2  "cableloss"                               *
*********************************************************
    Power Gain= -2.00 dB, Voltage Gain= -2.00 dB
    NF=  2.00 dB
    Input Res. = 50 Ohms,  Output Res. = 50 Ohms
    No Distortion In this Stage

    Total Power   Gain               =  22.00 dB
    Total Voltage Gain               =  22.00 dB
    Total Noise Figure               =   2.71 dB
    Noise Figure from this stage only =  0.01 dB

    IIP3                             =   7.50 dBm

*********************************************************
*   Stage #3  "biast"                                   *
*********************************************************
    Power Gain= -0.20 dB, Voltage Gain= -0.20 dB
    NF=  0.20 dB
    Input Res. = 50 Ohms,  Output Res. = 50 Ohms
    No Distortion In this Stage

    Total Power   Gain               =  21.80 dB
    Total Voltage Gain               =  21.80 dB
    Total Noise Figure               =   2.71 dB
    Noise Figure from this stage only =  0.00 dB

    IIP3                             =   7.50 dBm

*********************************************************
*   Stage #4  "switch"                                  *
*********************************************************
    Power Gain= -0.70 dB, Voltage Gain= -0.70 dB
    NF=  0.70 dB
    Input Res. = 50 Ohms,  Output Res. = 50 Ohms
    IIP3= 55.00 dBm (101.99 dBmV), RHO=  1.00

    Total Power   Gain               =  21.10 dB
    Total Voltage Gain               =  21.10 dB
    Total Noise Figure               =   2.71 dB
    Noise Figure from this stage only =  0.01 dB

    IIP3                             =   7.49 dBm
    IIP3 from this stage only        =  33.20 dBm

*********************************************************
*   Stage #5  "lpfilter"                                *
*********************************************************
    Power Gain= -0.10 dB, Voltage Gain= -0.10 dB
    NF=  0.10 dB
    Input Res. = 50 Ohms,  Output Res. = 50 Ohms
    No Distortion In this Stage

    Total Power   Gain               =  21.00 dB
    Total Voltage Gain               =  21.00 dB
    Total Noise Figure               =   2.71 dB
    Noise Figure from this stage only =  0.00 dB

    IIP3                             =   7.49 dBm
```

```
**********************************************************
*   Stage #6  "lna"                                      *
**********************************************************
   Power Gain= 23.50 dB, Voltage Gain= 23.50 dB
   NF=  2.90 dB
   Input Res. = 50 Ohms,  Output Res. = 50 Ohms
   IIP3= -8.00 dBm ( 38.99 dBmV), RHO=  1.00

   Total Power   Gain                =  44.50 dB
   Total Voltage Gain                =  44.50 dB
   Total Noise Figure                =   2.73 dB
   Noise Figure from this stage only =   0.03 dB

   IIP3                              = -29.00 dBm
   IIP3 from this stage only         = -29.00 dBm


**********************************************************
*** ANALYSIS OF THE 6 ELEMENT CASCADE IS COMPLETE ****
**********************************************************

**********************************************************
*      Noise Figure Contribution Summary                 *
**********************************************************

Stage          Noise Figure    Possible Noise Figure
               in the system       Improvement
---------------  ----------------  ----------------------
balun            2.700 dB          2.677 dB
lna              0.033 dB          0.018 dB
cableloss        0.010 dB          0.005 dB
switch           0.005 dB          0.003 dB
biast            0.001 dB          0.001 dB
lpfilter         0.001 dB          0.000 dB

**********************************************************
*          IIP3 Contribution Summary                     *
**********************************************************

 Stage        IIP3 in the system
---------------  --------------------
lna             -29.000 dBm
balun             7.500 dBm
switch           33.200 dBm

**********************************************************
*          CASCADE ANALYSIS COMPLETE                     *
**********************************************************
```

Input file 100-1000 MHz

```
# @ IPRM2 with Icom discone
#  defaults
rin=50 rout=50 rho=1
# LMR 240 cables, 24+6 m length
# www.timesmicrowave.com/cgi-bin/calculate.pl at 500 MHz
cableloss g=-5.5
# filter: 1200 MHz LP filter Minicircuits BLP-1200
lpfilter g=-0.1  nf=0.1
# LNA ZFL-1000LN
lna g=23.5 iip3=-8.0 nf=2.9
# end of input file
```

Output file 100-1000 MHz

```
*********************************************************
*                CASCADE ANALYSIS                        *
*                 Version   1.4                          *
*           (c) 1997-2001 Dan McMahill                   *
*             mcmahill@alum.mit.edu                      *
*********************************************************

Processing input file "iprm_discone.cas"

@ Iprm2 with Icom discone
*********************************************************
*   Default Values Changed                               *
*********************************************************

    Input  Resistance for each Stage = 50 Ohms
    Output Resistance for each Stage = 50 Ohms
    Default Rho (for IIP3 calc.)     = 1

*********************************************************
*   Stage #1  "cableloss"                                *
*********************************************************
    Power Gain= -5.50 dB, Voltage Gain= -5.50 dB
    NF=  0.00 dB
    Input Res. = 50 Ohms,  Output Res. = 50 Ohms
    No Distortion In this Stage

    Total Power   Gain                = -5.50 dB
    Total Voltage Gain                = -5.50 dB
    Total Noise Figure                =  0.00 dB
    Noise Figure from this stage only =  0.00 dB

*********************************************************
*   Stage #2  "lpfilter"                                 *
*********************************************************
    Power Gain= -0.10 dB, Voltage Gain= -0.10 dB
    NF=  0.10 dB
    Input Res. = 50 Ohms,  Output Res. = 50 Ohms
    No Distortion In this Stage
```

```
    Total Power   Gain                       =  -5.60 dB
    Total Voltage Gain                       =  -5.60 dB
    Total Noise Figure                       =   0.34 dB
    Noise Figure from this stage only        =   0.34 dB

**********************************************************
*   Stage #3  "lna"                                      *
**********************************************************
    Power Gain= 23.50 dB, Voltage Gain= 23.50 dB
    NF=  2.90 dB
    Input Res. = 50 Ohms,  Output Res. = 50 Ohms
    IIP3= -8.00 dBm ( 38.99 dBmV), RHO=  1.00

    Total Power   Gain                       =  17.90 dB
    Total Voltage Gain                       =  17.90 dB
    Total Noise Figure                       =   6.56 dB
    Noise Figure from this stage only        =   6.48 dB

    IIP3                                     =  -2.40 dBm
    IIP3 from this stage only                =  -2.40 dBm


**********************************************************
*** ANALYSIS OF THE 3 ELEMENT CASCADE IS COMPLETE ****
**********************************************************

**********************************************************
*      Noise Figure Contribution Summary                 *
**********************************************************

  Stage        Noise Figure    Possible Noise Figure
               in the system       Improvement
---------------  ----------------  ----------------------
lna              6.482 dB          6.217 dB
lpfilter         0.345 dB          0.080 dB
cableloss        0.000 dB          0.000 dB

**********************************************************
*          IIP3 Contribution Summary                     *
**********************************************************

 Stage        IIP3 in the system
---------------  --------------------
lna               -2.400 dBm

**********************************************************
*          CASCADE ANALYSIS COMPLETE                     *
**********************************************************
```

IPRM2 Hardware Upgrade to IPRM3

LWA Engineering Memo RFS0008 Version 2
Joe Craig, Ylva Pihlström, Steve Tremblay & Frank Schinzel
10/12/08 (Version 1 5/1/08)

Summary

The Iowa Portable RFI Monitor (IPRM) system has been upgraded in hardware to accommodate for longer surveys and a frequency range up to 1 GHz, and is now labeled IPRM3. The upgrade includes the inclusion of an RF switch to enable remote switching between the two antennas used (an LWA prototype antenna for 1-100 MHz, and the Icom discone for 100-1000 MHz), and a few changes to filters and software. Here we report on the new hardware of the monitoring system. This version (Version 2) of the document includes additional upgrade of the calibration system.

System components

The system consists of the following main components (see Fig. 1 for a block schedule):

1. Antennas:
   - An LWA prototype antenna (1-100 MHz)
   - The Icom discone (100-1000 MHz)

2. Active balun:
   - For measurements with the Big Blade antenna, the signal passes through an LWA balun (G = +35 dB, IIP3 = -18.3 dBm, NF = 2.7 dB)

3. Bias-Tee:
   - The active balun is powered via a Bias-Tee (ZBNT-60-1W, using +15.5VDC and 0.23 mA, G= -0.2 dB, NF = 0.2)

4. 3 dB attenuator:
   - A 3dB attenuator pad is included to account for the loss through the hybrid used in the calibration

5. RF switch:
   - A highly isolated switch operating on a single supply voltage selects the channel input (ZX80-DR230+, G = -1 dB, IIP3 = +55 dBm)

6. LP filter:
   - BPL-1200 with a cutoff at 1200 MHz (Gain = -0.1 dB, NF = 0.1)

7. LNA:
   - ZFL-1000LN (G = +23.5 dB, IIP3 = -8 dBm, NF = 2.9)

8. Noise Source for system calibration:
   - Elecraft N-gen wideband noise generator (100kHz – 500 MHz, +/- 3dB)

9. Spectrum Analyzer:
   - Advantest R3131A

10. USB-GPIB interface

11. Laptop:
    - An IBMT40 running Windows XP is controlling the spectrum analyzer via a LabView 8 program.

12. Power supply for the LNA and the biasT:
    - GWInstek GPS-4303

13. Portable generator:
    - United Power 7200 W

14. Battery Backup
    - APC UPS XS Series (540W/900VA)

In addition to the components listed above we also have the possibility of including additional attenuators, which is needed for the lower frequency range that has an additional amplifier as compared to the higher frequency range. When used, these attenuators are inserted between the Big Blade antenna terminals and the active balun. The attenuators are SMA fixed coaxial types of +5, +10 and +20 dB respectively, 2 of each (Mini-circuits VAT-5+, VAT-10+ and VAT-20+).

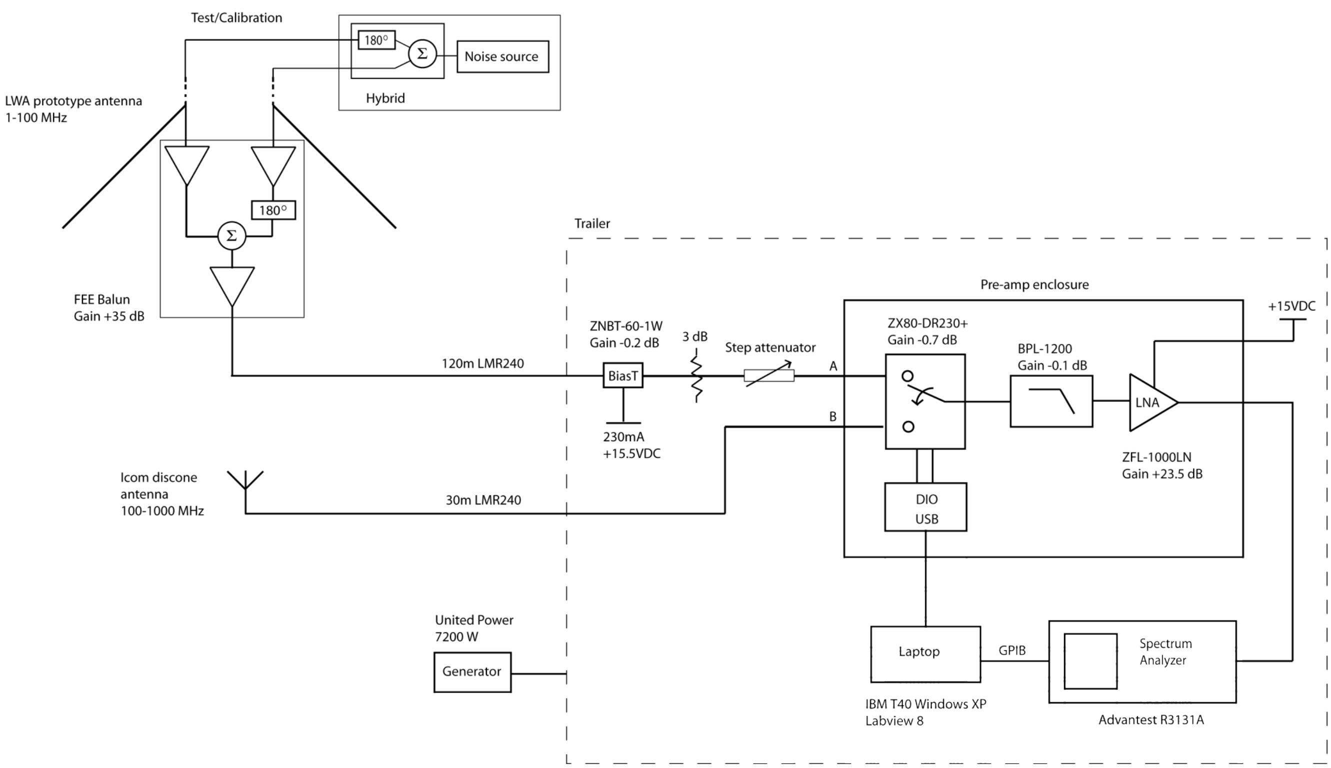


Figure 1: Block diagram of the upgraded IPRM (version 3). The system now can switch between taking data from an LWA prototype antenna and the discone antenna.

Characterization of the Iowa Portable RFI Monitor v3

LWA Engineering Memo RFS0010
Joe Craig, Ylva Pihlström
4/30/08

Summary

The Iowa Portable RFI Monitor (IPRM) system has been upgraded in hardware to accommodate for longer surveys and a frequency range up to 1 GHz, and is now labeled IPRM3. The upgrade includes the inclusion of an RF switch, to enable remote switching between the two antennas used (the Big Blade for 0-100 MHz, and a discone for 100-1000 MHz), and a few changes to filters and software. The full system documentation will be reported on in the EM for task RFS0008. Here we report on the result of a lab test of the system linearity. The measured values are P_{1dB} = -38.5 dBm, IIP3 = -27 dBm, and a total gain of 44.5 dB. These values for the total system agree well with a cascade analysis (Table 2; see also EM RFS0001).

Test setup

The system was setup according to a typical observation, using the same cables, balun, pre-amp enclosure and spectrum analyzer (Fig. 1). Two linearity measurements were performed: i) a measurement of the pre-amp enclosure only, to confirm parameters given in the data sheet, and ii) a measurement of the complete IPRM3 system.

For measurement i), the test signal was fed directly into the channel A pre-amp enclosure input, while for measurement ii) it was fed through the LWDA balun, via the 30m LMR240 cable, the BiasT and then into the channel A input of the pre-amp enclosure. The pre-amp enclosure contains an RF switch, controlled by a laptop via an USB port. The signal then passes through an LNA to finally be recorded in a spectrum analyzer. Channel B was terminated in both tests.

The 1dB compression point, P_{1dB}, was measured using a test signal of 50 MHz (Fig. 2), by varying the input power. Similarly, the 3rd order intercept point, IIP3, was measured using the intermodulation at 53 MHz produced by two test signals of 49 MHz and 51 MHz respectively (Fig. 3). The results are listed below in Tables 1 and 2, and shown graphically in Figures 4 and 5. The values measured for the total system are in good agreement with a cascade analysis done (Table 2; see also EM RFS0001).

Parameter	**Measured (pre-amp only)**
Total gain	24.4 dB
P_{1dB}	-17.5 dBm
IIP3	-8 dBm

Table 1: Measured linearity parameters for the pre-amp enclosure (IIP3 used in cascade analysis).

Parameter	**Measured**	**Cascade analysis**
Total gain	44.5 dB	44.5 dB
P_{1dB}	-38.5 dBm	
IIP3	-27 dBm	-29 dBm
Noise Figure		2.7 dB

Table 2: Measured linearity parameters versus calculated.

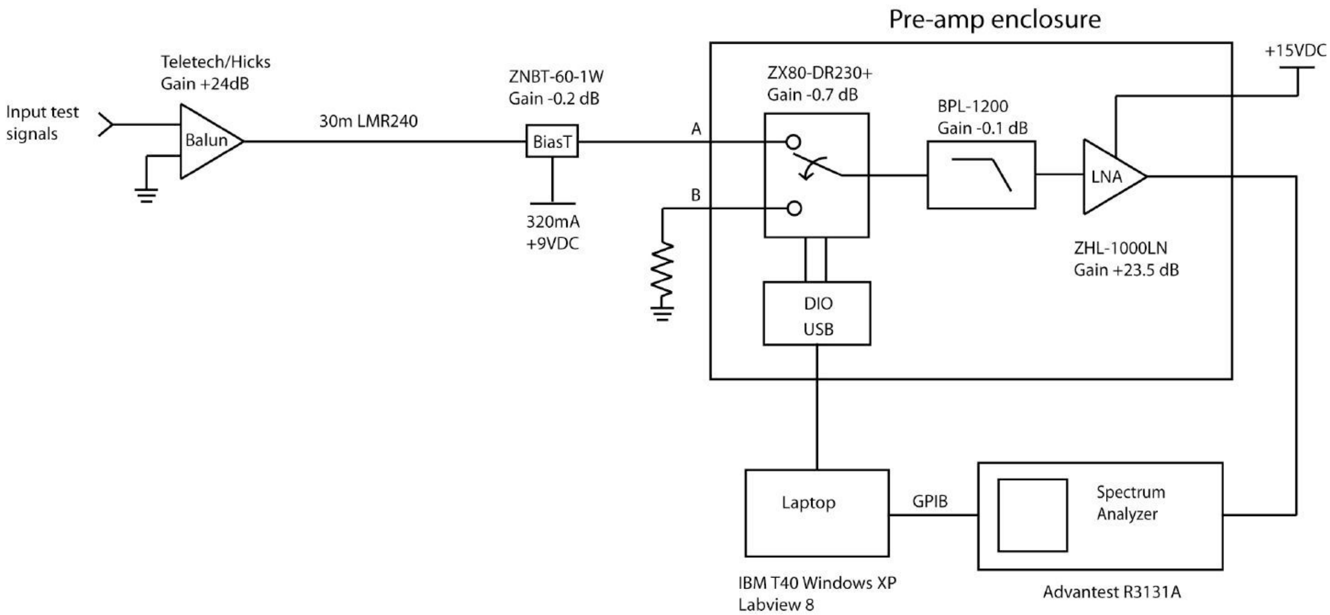


Figure 1: Block diagram of the test setup.

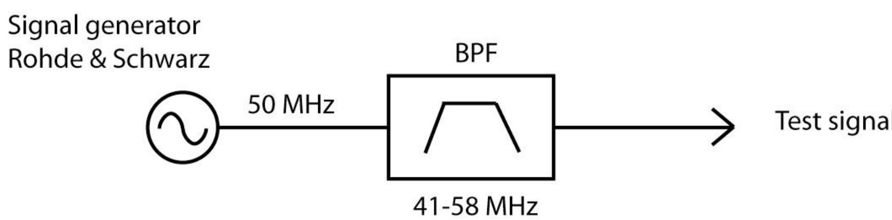


Figure 2: Generation of test signal for P_{1dB} measurement.

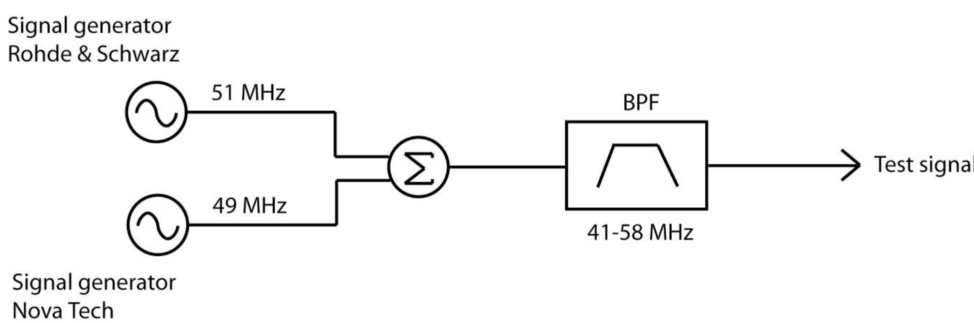


Figure 3: Generation of test signal for IIP3 measurement.

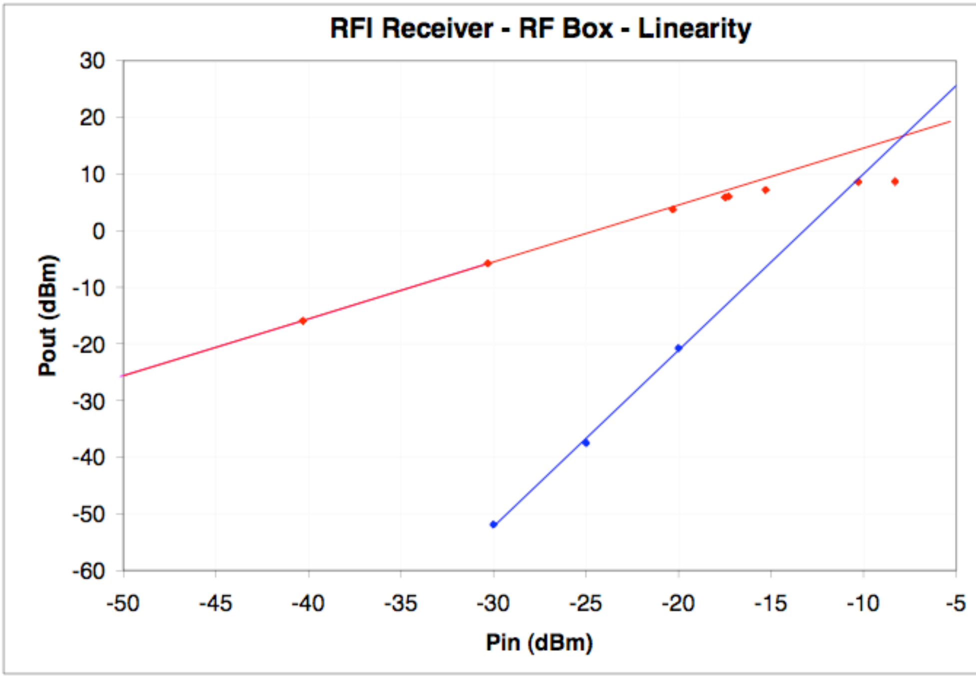


Figure 4: Results of pre-amp enclosure linearity test, yielding P_{1dB} = -17.5 dBm and IIP3 = -8 dBm.

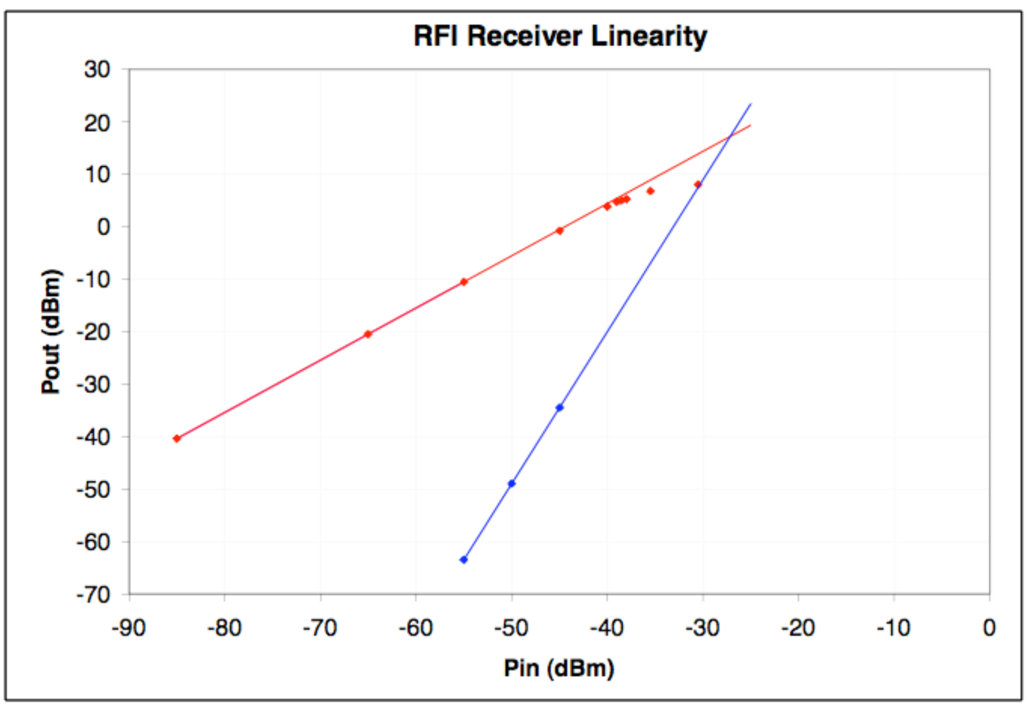


Figure 5: Results of receiver linearity test, yielding P_{1dB} = -38.5 dBm and IIP3 = -27 dBm.

Detrimental Interference Levels at Individual LWA Sites
LWA Engineering Memo RFS0012

Y. Pihlström, University of New Mexico

August 4, 2008

1 Introduction

The Long Wavelength Array (LWA) will optimally operate at frequencies between 10-88 MHz. With 53 planned stations spread across the state of New Mexico, the Radio Frequency Interference (RFI) environment will vary depending on factors such as direct line of sight to radio transmitting towers and the proximity to congested areas. Man made RF signals are potentially harmful to observations, both in blocking spectral areas as well as causing non-linear effects in the electronics of the LWA system.

In defining harmful interference levels, we separate between i) signals that affect the characteristics of the analog electronics, and ii) signals that will affect the sensitivity of astronomical observations. Harmful signal levels for case i) will be determined by linearity tests of the final electronics design. These signal levels may be much higher than those defined in ii), since the presence of a few strong, narrowbanded signals do not necessarily define a site as useless. If the electronics still operate in the linear regime and a large fraction of the LWA bandwidth is clear of RFI, a more or less full astronomical observing capacity can still be acheived. Case ii) concerns low-level RFI that is present over a larger fraction of the bandwidth, which will delimit the observing capabilities. In this memo we provide an estimate of the detrimental interference levels of weak RFI signals. These limits can be used to judge whether a candidate site is suitable as an LWA station, and will also define the allowed emissions levels of LWA electronics. The effects of strong RFI signals are not included in this memo.

We point out that the levels defined here should be used within the LWA project. Limits on external transmitters however, are only required to follow the limits specified in RA.769-2 within allocated radio astronomy bands (Sect. 6). These limits are somewhat less stringent than the ones presented in this memo, since they do not specifically consider typical LWA observing parameters.

2 Defining the harmful signal level

In radio astronomy it is standard practice to define an interfering signal to be harmful to observations if it exceeds the rms noise level by more than 10% (Thompson, Moran & Swenson 1998). In other words, a non-detrimental interfering signal must have a signal to noise ratio SNR ≤ 0.1. Here we outline how to estimate acceptable emission levels (for more details, see Perley 2002).

We assume that $F_{\rm RFI}(\nu)$ [Wm^{-2}] is the power flux density of the interfering signal incident at the antenna, and $F_{\rm N}(\nu)$ [Wm^{-2}] is the minimum detectable power flux density. Then, the SNR can be written as:

$$SNR = \frac{F_{\rm RFI}(\nu)}{F_{\rm N}(\nu)} = \frac{F_{\rm RFI}(\nu) G_{\rm r} c^2 \sqrt{\Delta t}}{4\pi k T_{\rm sys}(\nu) \nu^2 \sqrt{\Delta\nu}} \leq 0.1 \qquad (1)$$

where $T_{\rm sys}(\nu)$ is the system temperature in K, ν is the frequency in Hz, $\Delta\nu$ is the bandwidth in Hz, Δt is the integration time in s and $G_{\rm r}$ is the receiving antenna gain. $F_{\rm RFI}(\nu)$ is the allowed power flux density within the channel bandwidth $\Delta\nu$. For a noise limited system, Eq. 1 can be used for any observing frequency, integration time and frequency resolution.

3 LWA specific parameter values

The value of $F_{\rm RFI}(\nu)$ depends on the parameters $T_{\rm sys}(\nu)$, $G_{\rm r}$, $\Delta\nu$, and Δt (Eq. 1) . Here we discuss the LWA specific values of these parameters.

3.1 System temperature

The system temperature $\mathrm{T_{sys}}(\nu)$ is a combination of external noise (cosmic, atmospheric and earth-generated noise) and internal noise (noise generated in the active parts of the antenna, and in the receiver). Except for night time atmospheric noise at the lowest frequencies around $10-20$ MHz, and excluding man made interference signals, the system temperature between $10-88$ MHz is dominated by the cosmic noise. The most important contribution to the cosmic noise is the Galactic background radio emission. Cane (1979) measured this emission at frequencies between $5.2-23$ MHz and also combined these results with data for frequencies up to 100 MHz. From these measurements the following expression for the sky brightness can be derived (e.g. Cane 1979; Duric et al. 2003; Ellingson 2005):

$$I_\nu = I_{\rm g}\nu_{\rm M}^{-0.52}\frac{1-e^{-\tau_\nu}}{\tau(\nu_{\rm M})} + I_{\rm eg}\nu_{\rm M}^{-0.8}e^{-\tau_\nu} \qquad [\mathrm{Wm^{-2}Hz^{-1}sr^{-1}}] \tag{2}$$

where $\nu_{\rm M}$ is the frequency in MHz, $\tau(\nu_{\rm M}) = 5\nu_{\rm M}^{-2.1}$ is the optical depth, and $I_{\rm g} = 2.48\times10^{-20}$ and $I_{\rm eg} = 1.06\times10^{-20}$ belongs to the Galactic and extra-galactic contributions respectively. This is the sky brightness measeured in the direction of the Galactic poles, and at other positions on the sky there will be additional noise contributions from primarily the Galactic plane. With the large field-of-view of individual dipoles, these variations are however assumed to be small. In the Rayleigh-Jeans part of the spectrum, the sky temperature can then be derived from:

$$T_{\rm sky} = \frac{1}{2}I_\nu\frac{c^2}{k\nu^2} \qquad [\mathrm{K}] \tag{3}$$

As already mentioned, in the standard LWA observing band $10-88$ MHz the system temperature will be dominated by the sky temperature. However, the LWA electronics may be susceptible to signals outside the observing band, which could cause additional noise in the observing band via third order intermodulation products. In RFI site surveys we should therefore scan the spectrum at frequencies up to 1 GHz. At frequencies above 100 MHz the sky temperature falls off, and in estimating the system temperature we have to take into account the contributions from the antenna and first gain stage, $T_{\rm ant}$, the cable, $T_{\rm cable}$, and the analog receiver temperature $T_{\rm ARX}$. These values are calculated in LWA Engineering Memo ARX0003 (Craig 2008), and are listed in Table 3.1. Note that Craig (2008) gives $T_{\rm ARX}$ for two cases, one maximum and one minimum gain version respectively. Here we are using the values for the maximum gain. The total noise contribution from the cascaded system is calculated according to:

$$T_{\rm sys} = T_{\rm sky} + T_{\rm ant} + \frac{T_{\rm cable}}{G_{\rm ant}} + \frac{T_{\rm ARX}}{G_{\rm ant}G_{\rm cable}} \qquad [\mathrm{K}] \tag{4}$$

In Figure 1 we plot $T_{\rm sky}$ (dotted blue line), the noise temperature due to all system components excluding the sky (dashed red line), and the total $T_{\rm sys}$ for frequencies $1-1000$ MHz.

Component	Gain dB	Noise Figure dB	Noise temperature K
Antenna	35	2.7	$T_{\rm ant}$ = 250
Cable	−15	15.0	$T_{\rm cable}$ = 8881
ARX	62.4	3.8	$T_{\rm ARX}$= 406

Table 1: LWA analog signal chain component characteristics.

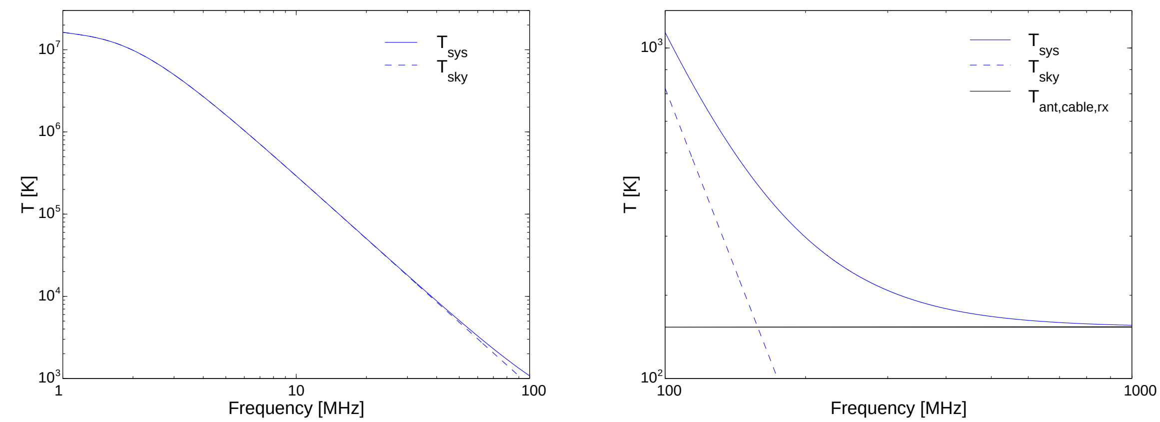


Figure 1: The LWA dipole system temperature brightness at frequencies $1-100$ MHz (left) and $100-1000$ MHz (right). The solid blue line is the total system temperature, the dashed blue line is the contribution from the sky ($T_{\rm sky}$) and the black solid line is the combined contribution from antenna, cable and receiver ($T_{\rm ant,cable,rx}$). At the lower frequencies the system is sky noise dominated.

3.2 Spectral resolution and integration time

The maximum allowed emissions levels depends on the bandwidth considered as well as the total integration time. The LWA spectral resolution is defined to be ≤ 100 Hz (Clarke, Kassim & Ellingson, 2007), required for Radio Recombination Line (RRL) work. 100 Hz corresponds to 0.37 and 1.5 km s^{-1} for 80 and 20 MHz respectively (typical velocity resolutions for spectral line observations are around 1 km s^{-1} or less). Thus, 100 Hz seems to be a good approximation and will therefore be used as the value for $\Delta\nu$ in the following calculations. A typical observation may go on for about 8 hours, defining the integration time Δt.

3.3 Antenna gain

We use a 0 dB gain ($G_r = 1$), assuming that the interfering signal will enter via a sidelobe rather than via the mainlobe. The true value of this gain factor is not known, and the level of the interfering signal is further likely to change when the signal moves around in the sidelobe patterns. Therefore, a 0 dB gain appears to be a reasonable, conservative estimate.

4 Detrimental interference levels at an LWA site: 1-100 MHz

An RFI signal incident on an array of dipoles located within a diameter of 100 m is likely to affect most dipoles similarly and we therefore define the harmful level threshold based on the effect on a single dipole. Equation 1 is used to calculate the maximum acceptable emissions levels F_{RFI}. Figure 2 shows the calculated power flux density F_{RFI} at any LWA station, using a bandwidth of 100 Hz and an integration time of 8 hours.

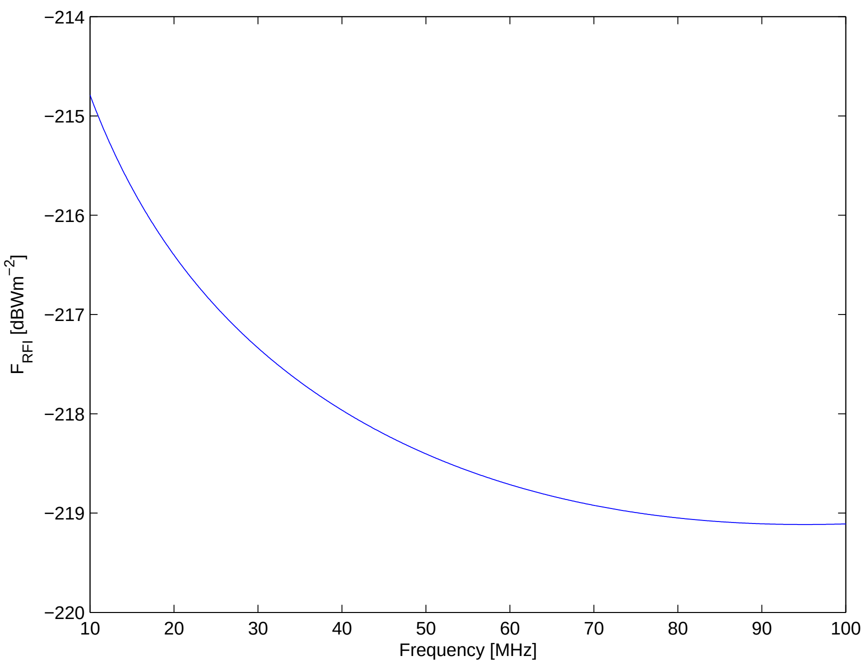


Figure 2: Detrimental interference levels at a single LWA site for frequencies up to 100 MHz in a 100 Hz bandwidth.

Note that these are the emission levels incident at the receiving antenna, thus space loss will be a helpful shielding factor. To calculate the total power that is acceptable[1] to be transmitted by a transmitter at a distance d (measured in km), correct for the space loss according to:

$$P_{\mathrm{RFI,dist}} = F_{\mathrm{RFI}} + 71 + 20\log\left(\frac{d}{1\ \mathrm{km}}\right) \quad [\mathrm{dBW}] \tag{5}$$

5 Possible effects from out-of-band signals

For completeness, we also discuss the possibility of out-of-band signals affecting the LWA station observing capabilities. Normally weak RFI that is harmful to astronomical observations arise in-band, however it can be of interest to consider the RFI environment also outside the observing band. In particular we are

[1] Acceptable by LWA standards, in practice external transmitters obly have to follow the limits stipulated in RA.769-2, see Sect. 6

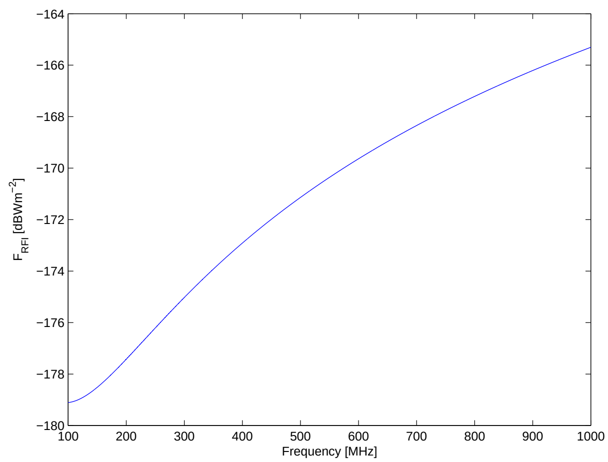


Figure 3: Lower limits to detrimental levels of out-of-band RFI signals at any individual LWA station in a 100 Hz bandwidth for frequencies 100-1000 MHz.

interested in scoping the presence of out-of-band signals causing third order intermodulation products (IMP) within the LWA band. The detrimental levels of out-of-band signals causing IMP will be higher than those calculated directly from Eq. 1, since the IMPs will have a lower amplitude in-band. The exact amplitude relation is hard to calculate and depends on the amplitude of the input signals, but we know that the LWA out-of-band rejection provided is >40 dB. Thus, to estimate a lower limit to out-of-band detrimental levels we add 40 dB to the levels calculated using 1. These levels are plotted in Fig. 3.

We point out that these limits only are applicable for signals that might cause in-band IMPs. The presence of most signals in the 100-1000 MHz band will most likely not affect the LWA observations. As an example, a 0.2 W cell phone signal at 850 MHz (30 kHz bandwidth) transmitted at a distance of 500 m would cause a signal level of -97dBWm^{-2} incident at the LWA station. Even though this signal is about 70 dB above the levels plotted in Fig. 3, the high frequency is unlikely to cause third order IMPs and will therefore not affect LWA observations.

6 ITU levels

The International Telecommunications Union (ITU) has determined harmful threshold limits for the spectral power flux density in the frequency bands allocated to radio astronomy, listed in Recommendation ITU-R RA.769-2. These levels would correspond to the start of data loss for radio astronomical observations, defined to when detrimental interference contributes 10% additional noise to the system. The ITU levels are thus globally adopted upper limits for protecting operations at current radio telescopes, but they are not tailored to specific routine observations at radio telescopes such as for instance the VLA or the LWA.

The ITU defined threshold levels for radio astronomy spectral line observations given in ITU-R RA.769-2 do not list frequencies below 327 MHz explicitly. However, using the system temperatures defined for continuum observations (Table 1, ITU-R RA.769-2) and the ITU defined spectral resolution of 3 km/s and an integration time of 2000 sec, the ITU threshold levels for three frequencies in the LWA band are listed in Table 6. These levels are slightly higher that the levels given in Fig. 2, due to the different bandwidth and integration time used.

Frequency MHz	T_{sys} K	Bandwidth kHz	Power flux density $dBWm^{-2}$
13.385	50,000	0.1	-212
25.610	15,000	0.25	-214
73.8	750	0.75	-213

Table 2: ITU defined threshold levels of interference detrimental to spectral line observations.

7 References

Cane, H.V., 1979, MNRAS, 189, 465

Duric, N., Theodorou, A., Smith, K., et al., 2003, *RFI Report for the US South-West*, LOFAR project report

Craig, J., LWA Engineering Memo ARX0003, 2008

Ellingson. S., 2005, IEEE Trans. Antennas and Propagation, Vol. 53, No. 8, 2480

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

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

High Sensitivity Measurement Protocol
LWA Engineering Memo RFS0015

Y. Pihlström, University of New Mexico

August 4, 2008

1 Background

To assess the suitability of a candidate site as an LWA station site, the low-level RFI environment needs to be surveyed. The harmful threshold levels for observations at individual LWA sites have been defined in LWA EM RFS0012, describing the maximum level of interference acceptable within a given observing bandwidth. In this engineering memo we define a measurement protocol for surveying candidate sites for such low-level RFI.

2 Required measurement sensitivity

The sensitivity of the measurements is given by the following expression:

$$S = \frac{4\pi}{G}\frac{\nu^2}{c^2}\frac{kT_{\rm sys}}{\sqrt{\Delta\nu\Delta t}} \qquad [\mathrm{Wm^{-2}Hz^{-1}}] \tag{1}$$

where G is the antenna gain in a given direction, ν is the observing frequency in Hz, $\Delta\nu$ is the bandwidth in Hz, and Δt is the integration time in s. At the low frequencies where LWA will operate, the system temperature $T_{\rm sys}$ is sky noise dominated and given in LWA EM RFS0012. To evaluate the low level RFI environment at an LWA site, we must achieve sensitivities as close as possible to the defined harmful interference levels. For an individual LWA site, the levels are defined for a bandwidth $\Delta\nu = 100$ Hz and an integration time Δt of 8 hours. At ν =50 MHz (mid LWA band) the system temperature is about 5,000 K, and the corresponding harmful level is -218.3 dBWm^{-2}. To reach these sensitivities using a 100 Hz bandwidth, a total integration time of more than 700 hours would be required. We adopt a more practical approach using a resolution bandwidth of 1 kHz, achieving sensitivities 2-3 times the defined harmful levels within a 10-12 hour integration time.

3 Measurement modes

For in-band frequencies, $\nu = 1-100$ MHz, measurements should be taken in both a high sensitivity mode and a transient mode:

High sensitivity mode To achieve sufficient sensitivity for detecting potential harmful in-band low-level RFI, this mode requires an integration time of 10 hours using a 1 kHz bandwidth resolution. Here we assume that the time series data is taken with a sampling board using 100 MHz bandwidth. These measurements should be done for each polarization. Including time for calibration, the total length of a run is about 24 hours.

Transient mode Shorter scans should be inserted every 30 minutes of the observations to survey the sky for transient signals. RFI signals may occur as short pulses, for example aeronautical marker beacons pulses with typical time delays of a few 100 μs. To detect such pulses the transient mode requires a time resolution of 1μs, and sampling of data over the 100 MHz range for 1 second using a bandwidth of 1 MHz.

While the in-band measurements are the highest priority during high sensitivity runs, the spectrum analyzer monitoring system can be used simultaneously to scan the frequency band $\nu = 100 - 1000$ MHz, using a 100 kHz resolution bandwidth.

4 Calibration

The sensitivity of the measurement system, $S_{\rm sys}$, should be estimated using a matched load, taking measurements in the high sensitivity mode for about 1 minute (to be scaled for reporting purposes), and for 1 second in the transient mode. This calibration should be done in the beginning of each experiment.

5 On-board data processing

The sampling board should handle a 100 MHz bandwidth, and being able to store 1 second of data to be processed real-time. The real-time processing should include an FFT producing 1 kHz channels, and the recording of rms power and maximum power for each 1 second chunk of data. These 1 second spectra should be averaged to 1 minute values for further off-board data processing and storage.

Measuring 12 hours per polarization (which includes calibration), a total measuring time of 24 hours is needed. The data volume will be the product of the number of polarizations (2), the number of 1 minute averaged data samples (12×60), the channel bandwidth (1 kHz) and the number of outputs (2; the rms power and maximum). This yields 2.88 Msamples per day.

6 Data reporting

The data output from the sampling board should be written into a format readable by a python script. The script should for each polarization produce the following plots:

- The spectral power flux density $S_{\rm SPFD}$ [dBWm^{-2}Hz^{-1}] for the maximum, mean and minimum rms statistics averaged over the 12 hour measurement period. In the same plot, the sensitivity $S_{\rm sys}$ [dBWm^{-2}Hz^{-1}], should be indicated, as well as the harmful threshold levels in units of dBWm^{-2}Hz^{-1}.
- A waterfall plot of the spectral power flux density $S_{\rm SPFD}$.
- An occupancy plot, with the frequency as the x-axis (in 1 kHz steps) and the occupancy as the y-axis. The occupancy is defined is the fraction of measurements where the power is 10 dB over the mean power.

For the transient mode data, only one plot is required displaying the spectral power flux density $S_{\rm SPFD}$ [dBWm^{-2}Hz^{-1}] for the maximum, mean and minimum rms statistics based on the 1μs samples. The instrument sensitivity S_{sys} [dBWm^{-2}Hz^{-1}] should be plotted.

Shielding Requirements LWA Electronics Racks

LWA Engineering Memo RFS0025

Ylva Pihlström

2/16/09

Summary

To properly shield the LWA antennas from internally generated emission, the electronics will be placed in enclosures in a shielded rack. The racks will be located inside a shielded shelter. Here we estimate an approximate level of shielding required by the racks to be about 60-80 dB. One shielded rack has already been ordered for the LWA mobile workstation.

1. Detrimental levels

LWA1 will be located at the LWDA site, next to the VLA core. Therefore, we must satisfy the shielding implied by the EVLA detrimental levels, as well as the LWA detrimental levels.

- EVLA: The latest estimates for the EVLA harmful levels are given in EVLA Memo #106 [1]. Here we give the levels at three different frequencies:
  - 75 MHz: -195 dBWm^{-2} (RBW 0.75 kHz)
  - 1.5 GHz: -172 dBWm^{-2} (RBW 15 kHz)
  - 6.0 GHz: -154 dBWm^{-2} (RBW 60 kHz)

- LWA: The estimates for a single LWA station harmful levels are given in LWA Engineering Memo RFS 0012 [2]:
  - 75 MHz: -219 dBWm^{-2} (RBW 0.1 kHz)

2. Electronics emission levels

Since there does not exist any complete, prototype electronics set, we make an estimate based on emissions from LWDA electronics presented in LWA Memo #44 [3]. Assuming there will be 256 such units, we multiply the emission by 256 to get a total estimate. Table 1 list the peak emissions measured for the LWDA receiver chain in three different frequency ranges (~75 MHz, 1.5 GHz and 6 GHz), and the resulting recalculation of the emission to be compared to the EVLA limit. Table 2 repeats this information, but for the LWA limits. Clearly the shielding problems will be worst at the lower frequencies, and shielding levels of the order of 100dB may be needed.

Freq. (MHz)	RBW (kHz)	Measured peak (dBm/RBW)	Level at 300m distance (dBWm^{-2}Hz^{-1})	EVLA limit RBW (kHz)	Level at 300m distance (dBWm^{-2} /RBW)	Level at 300m distance x256 (dBWm^{-2} /RBW)	EVLA limit (dBWm^{-2}/ RBW)	Total shielding (dB)
75	1	-43.0	-164	0.75	-135	-111	-195	84
1430	1	-76.3	-197	15	-155	-131	-172	41
5960	10	-67.7	-198	60	-150	-126	-154	28

Table 1: Estimated total shielding required for LWA1 equipment, to comply with EVLA detrimental levels.

Freq. (MHz)	RBW (kHz)	Measured peak (dBm/RBW)	Level at 10m distance ($dBWm^{-2}Hz^{-1}$)	LWA limit RBW (kHz)	Level at 10m distance ($dBWm^{-2}$ /RBW)	Level at 10m distance x256 ($dBWm^{-2}$ /RBW)	LWA limit ($dBWm^{-2}$ /RBW)	Total shielding (dB)
75	1	-43.0	-134	0.1	-114	-90	-219	129

Table 2: Estimated total shielding required for LWA1 equipment, to comply with LWA detrimental levels.

3. Shielding provided from shelter

The shelter will be modified to allow for RF shielding. The requirements specify the shelter to shield at a level of 60dB. This, however, is the requirement not taking into account the penetrations expected in the shelter entry panel. With all penetrations done the shielding must be less, but a rough estimate is that shielding levels of at least 40dB should still be achieved. This level should be safe to assume at all frequencies.

4. Shielding provided from enclosures

The LWDA electronics was contained within enclosures, with estimated shielding factors of 20-30dB at frequencies above 1 GHz. At lower frequencies, these enclosures provided more or less no shielding [3].

5. Required shielding by racks

Assuming ~100dB shielding is required at low frequencies, and that 40dB of these are provided by the shelter, another 60dB is needed from the racks. Equipto class R3 racks provide shielding levels of about 60-80dB at frequencies below 100 MHz, slowly declining at higher frequencies (Fig. 1). With the given emission estimates, this will just be sufficient to shield at lower frequencies.

At 1 GHz (EVLA L-band frequencies) the rack is claimed to shield about 70dB. Including 20dB from the enclosures, and 40dB from the shelter, there should be no problems fulfilling the shielding requirements at frequencies above 1 GHz.

6. Conclusive remarks

These estimates indicate that shielding levels of 80-130 dB are needed at frequencies below 100 MHz, and about 40 dB at 1 GHz. We note that these estimates are very uncertain, and that they are made in ‘good faith’. For example, the emissions levels measured in the VLA shielded chamber at frequencies below ~300 MHz are poorly calibrated, and we have no information about the emissions from the final equipment to be installed at any frequency.

The first LWA station will provide the final emission information, which will be used to make more proper shielding estimates for the following LWA stations. A first Equipto (R3 shielding level) rack has been ordered for the LWA mobile workstation. If possible, a shielding test will be performed on the rack once it has been modified for its purpose.

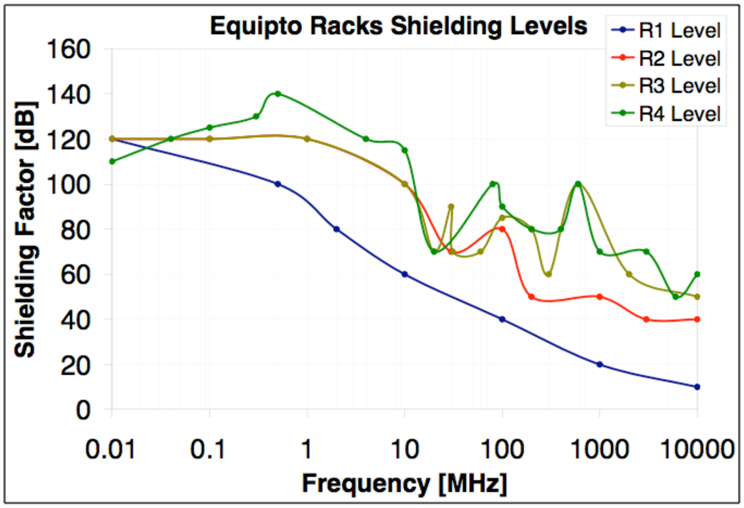


Figure 1: Shielding levels of Equipto racks, 4 different levels. Provided by Equipto.

References

[1] Perley, R., Brundage, B. & Mertely, D., EVLA Memo #106
[2] Pihlström, Y., LWA Engineering Memo RFS0012
[3] Kerkhoff, A., LWA Memo #44

Planned shelter modifications for RFI shielding

LWA Engineering Memo RFS0028

Ylva Pihlström

2/16/09

Summary

The LWA shelter housing electronics will consist of a modified shipping container. Since these containers are not RFI tight to start with, a few changes must be done considering shielding requirements. Here we describe these modifications, which are also listed in the LWA Shelter preliminary design review document.

1. Total shielding

The estimate of total shielding is presented in LWA Engineering Memo RFS0025 [1]. In this memo the required shielding levels of the racks was calculated using an estimated shielding level of the shelter of 60dB, and of the electronics racks to 60-80dB. The shelter shielding level is based on both an attempt to divide the amount of shielding between different components, but also on the availability of components for the shelter. For example, Honeycomb filters are available with typical shielding ~40-100 dB in the LWA frequency range. Furthermore, companies specializing in custom container modification appear to have good knowledge of this level of shielding, but less likely so for levels above 80dB (LWA Engineering Memo SHL0006, [2]). The modifications indicated in this memo assume a 60dB shielding.

2. Modifications to the shelter container

2.1 Floor and walls

The container should have a metal sheet covering the entire floor of the shelter, to be fully welded to the metal sides of the shelter. No additional cover floor on top of the metal floor will be needed. If the walls in the container initially have vents at the sides, these vents must be closed and sealed.

2.2 Entry door

The entry should be equipped with an RF tight door, rated for 60dB shielding. A second door should be installed outside the RF door, with the aim of protecting the entrance from weather and dust which otherwise significantly can decrease the shielding properties of the door over extended time scales.

2.3 Shelter entry panel

The Shelter Entry Panel (SEP) is a bulkhead providing access for power and RF cables into the shelter, located about 12 inches from the original end doors of the container (the exact positioning to be determined by container wall corrugation structure). This SEP must be constructed so that RF shielding is achieved. The frame should be welded to the shelter structure with no gaps. The SEP should have a connector panel, with 512 N-type female bulkhead connectors mounted, and special care taken to ensure proper RF shielding. Details of the structure of this entry panel will be worked out with the vendor.

2.4 HVAC filters

The combined shelter equipment is estimated to have a cooling need of 3.4 ton [3]. This will presumably be distributed over 2 HVAC units, mounted on the short side of the container. For RF shielding purposes, the HVAC units will need Honeycomb filters on all ducts and returns.

2.4 Power line filters

The LWA station power consumption is estimated to be 10-15 kW at 110 VAC. The power lines must be equipped with power line filters.

References

[1] Pihlström, Y., LWA Engineering Memo RFS0025
[2] Copeland, J., & Munton D., LWA Engineering Memo SHL0006
[3] Tremblay, S., LWA Engineering Memo SHL0030

Plan for LWA1 shelter and racks shielding test

LWA Engineering Memo RFS0031

Ylva Pihlström

10/22/09

Introduction

The LWA shelter housing electronics will consist of a modified shipping container. LWA Engineering Memo RFS0028 [1] describes the modifications done to the shelter to reduce leakage of signals from the shelter electronics to the LWA dipoles. The estimate is that the shelter should shield around 60dB, and the electronics racks 60-80dB to achieve sufficient levels of shielding. This document outlines the shielding tests planned to measure the resulting shielding after the shelter has been installed at the site. The test of the racks is planned for late October or early November, while the shelter will not be ready for testing until December 2009.

1. Shelter shielding test

Measurement of the shielding level of the shelter will be performed in the open-air. The shielding factor will be estimated from the difference in power (corrected for space and cable losses) between a reference signal transmitted inside the shelter, and the same signal measured at known positions outside. The transmitting antenna will be a wideband omni-directional antenna for frequencies below 1 GHz. Above 1 GHz we may use a dual arm, planar log spiral antenna. The receiving antenna will be a directional antenna, with an LNA, and the signal collected on a spectrum analyzer.

The synthesizer source can produce an output of +10 to +15 dBm, and we can therefore setup an approximate power budget:

Transmitted power (isotropic)	+10dBm
Space loss 10m distance (isotropic)	- 31dBm
Receiving antenna A_eff 6dBi at 90cm	- 6dB
Shelter shielding	- 60dB
---------------------------------------	--------------
Resulting received power	- 87 dBm

Using a narrow RBW in a spectrum analyzer, the noise floor is typically of the order of -120 dBm. Therefore, as long as the signal is transmitted outside the shielded racks a good SNR should be achieved.

2. Rack shielding test

Measurement of the shielding level of the rack will be performed in a similar way as for the shelter. The shelter will be placed inside the VLA shielded chamber. Again, a transmitting antenna will be placed inside the rack and the resulting signal will be measured outside the rack. The reference measurement will be with the rack door open. A similar power budget as in 1) will be expected. Otherwise standard procedures for testing inside the chamber (3 reference positions for receiving antenna) will be followed.

References

[1] Pihlström, Y., LWA Engineering Memo RFS0028

RF emissions from fluorescent lighting

Ylva Pihlström

11/10/09

The LWA shelter contains fluorescent lighting, which is a cost and maintenance efficient choice for a remote shelter. Installments of fluorescent light have been known to cause high interference levels in, for example, the AM bands, often disturbing AM radio transmissions. Here we briefly discuss the known, typical emissions levels of fluorescent lighting and whether EVLA or LWA1 observations might be affected.

Dan Mertely, NRAO, has performed various emissions tests at a sample of different compact fluorescent lamps (CFL) fixtures (private communication). The results thereof showed mixed results, with some CFLs having levels above the EVLA detrimental levels and others below. For all cases though, if the ballast failed to ignite the plasma, the CFLs flickered with significantly higher levels of emissions. We show two examples here; Figure 1 is for a non-flickering, low-level emission CFL, and Figure 2 is a flickering CFL normally at a level similar to the CFL in Fig.1. Both plots show power levels that have been adjusted for 150 m space loss. The CFLs in the LWA shelter are at about 300 m distance from the nearest EVLA antenna, adding another 6 dB space loss. The LWA shelter shielding factor has not yet been measured, but was in the design documents defined to 60 dB. Thus, for most cases including flickering CFLs, the LWA lights should not affect EVLA operations.

For the LWA frequencies, the problem is slightly worse as can be seen in the figures, since the emissions tend to increase at VHF frequencies. Of course, the tests in the VLA shielded chamber do not very accurately reflect the power levels since it is too small to allow sufficient number of modes to propagate. Nevertheless, these are the best estimates available, and will be used in the brief discussion here. At the LWA1 site we assume the nearest dipole is at a stand off distance of 20 m, reducing the space loss (as compared to the figures) with 17.5 dB. The LWA detrimental levels are estimated for a 100 Hz RBW, and is about -218 dBW/100 Hz in the LWA frequency band. With a correction of about 7 dB due to the narrower RBW, a power level as in Figure 1 of -125 dBW/10kHz would be reduced to -175 dBW/100 Hz including space loss and 60 dB shielding for the shelter. This is still about 40 dB above our detrimental level.

Although these indicative numbers imply that CFLs are potentially harmful for the LWA, we point out that the CFLs are not normally switched on during LWA1 operations, and if they are, presumably only during a minimal amount of time. If the lights are switched on during regular LWA operations, a note should be made in a log file to the observed, warning for possible RFI effects.

Acknowledgements

Dan Mertely, NRAO, has kindly provided the included figures and discussed the results of the tests.

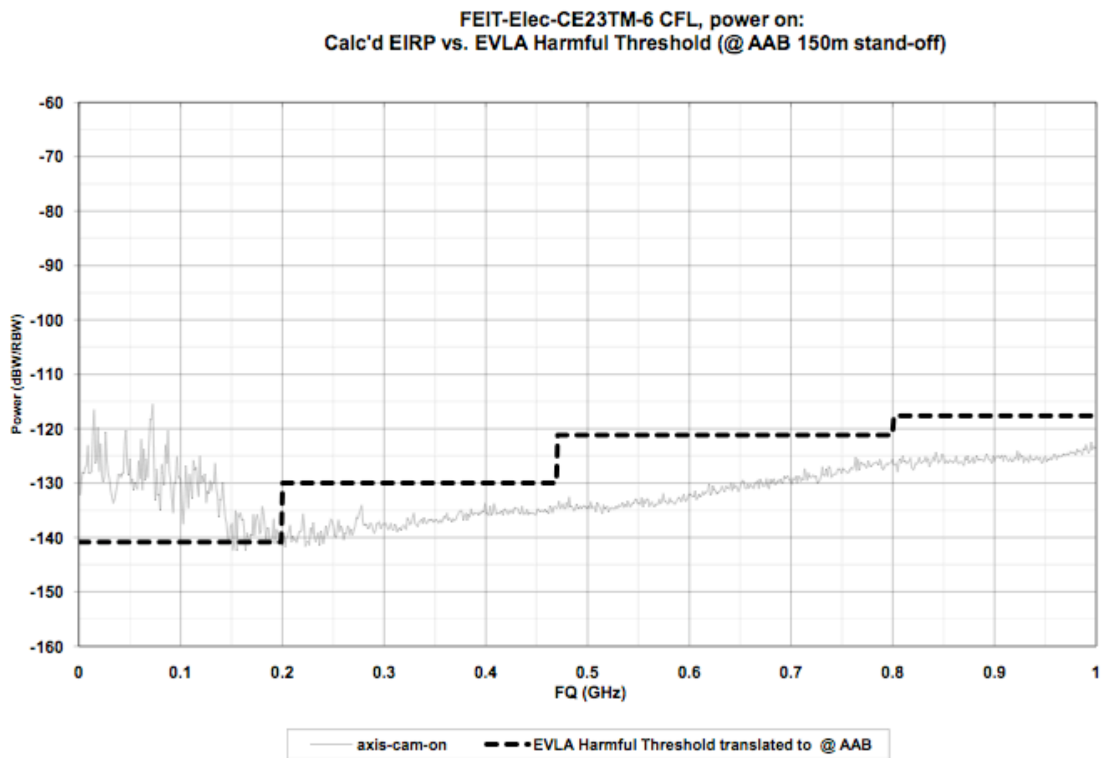


Figure 1: Solid curve shows emissions in a 3 kHz RBW channel, and dashed line corresponds to the EVLA detrimental levels.

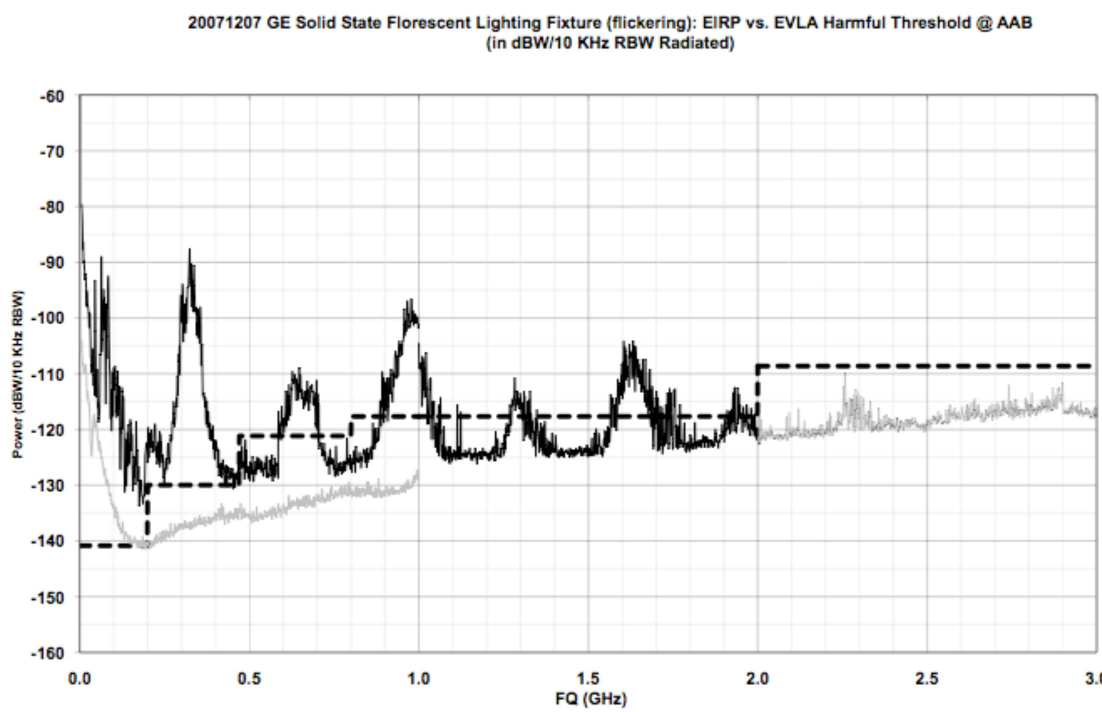


Figure 2: Solid curve shows emissions in a 10 kHz RBW channel, and dashed line corresponds to the EVLA detrimental levels. The high emission levels are caused during the CFL flickering.

Analog Receiver Rack Shielding Factor

LWA Engineering Memo RFS0033

Ylva Pihlström, Dan Mertely, Steve Tremblay & Joe Craig

1/10/10

Introduction

The LWA-1 shelter will contain electronics potentially harmful for LWA and the EVLA. To shield the analog receiver, a Premier RFI shielded rack was ordered. The manufacturer has measured the racks to supply a shielding level of about 40dB. With modifications to the rack, the rack was taken to the VLA reverberation chamber to measure the resulting shielding levels. These tests gave a shielding factor of about 25dB, which is 15 dB lower than expected. A sniffer device was applied and tracked down the leakage to door handles and along the door fittings. If these racks should be used in the future, a more stable design of the gaskets must be considered.

1. Test description

The rack was placed inside the shielded chamber with a transmitting antenna ('Ridgeway' discone antenna) suspended about 3ft above the rack floor using styrofoam. A receiving antenna (Pomeroy) was collecting the data fed into a spectrum analyzer, controlled by a PC. Each measurement set contains collecting data with the receiving antenna in three different positions to account for different mode propagation. The max level of the three measurements were used in the analysis of the data. Measurements were taken as follows:

1. Open reference: Both rack doors were fully opened.
2. Closed reference: Both doors fully closed.
3. Cable reference: Cable to transmitting antenna terminated with 50ohm.

Each measurement were taken with 801 points, and at two frequency regimes 0-1 GHz and 0-20 GHz. Below about 700 MHz the chamber is not well calibrated due to the lack of supported modes, and results may be invalid.

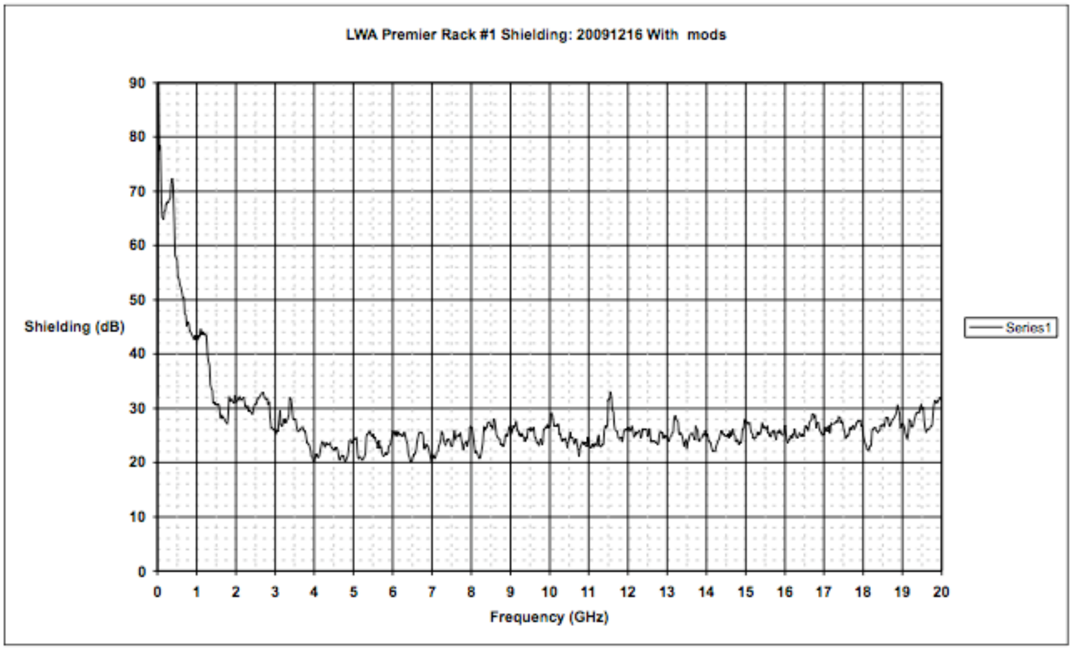
After an initial test run the shielding factor was measured to be about 25 dB. A sniffer device consisting of a handheld radio was used to track down the leakage points of the rack. It was found that leakage was worse at the door handles and around the door edges, as well as in the bottom part of the rack. The rack was examined, and it was found that the doors were not set to equally hard close the doors. Copper wool was applied around the door handles, and the door gasket was 'fluffed' by hand until the sniffer device no longer could detect emission around the doors. The above measurements were repeated, with a slight increase of about 5dB in the shielding factor. The shielding factor across the 0-20 GHz band are shown in Fig. 1 (although measurements below 700 MHz are uncertain). Little emission was found to leak from the side panels of the rack.

2. Conclusions

We found that the racks provide about 15 dB lower shielding than expected, even after substantial modifications including copper wool have been applied. The amount of shielding required for the digital receiver will depend on the shelter shielding factor and the emission levels from the digital receiver itself, none of which are measured yet. If more than 20-25 dB shielding is required by the electronics rack, we suggest the following options:

1. Work with Premier to improve the door gaskets, and the door fitting to improve the shielding levels. The door gaskets cannot be allowed to deteriorate with time or number of opening/closings of the rack doors.

2. Chose a different shielded rack provider to a higher cost, e.g. Equipto.



LWA Premier Rack #1 Shielding: 20091216 With mods
Shielding (dB)
Frequency (GHz)
Series1
0
10
20
30
40
50
60
70
80
90
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20

LWA1 shelter shielding factor

LWA Engineering Memo RFS0034

Ylva Pihlström[1], Steve Tremblay[1], Joe Craig[1], Dan Mertely[2] & Robert Elliott[2]

3/11/10

[1]University of New Mexico, [2]National Radio Astronomy Observatory, [3]Oklahoma State University

1. Motivation

The LWA shelter that houses electronics is an RFI modified shipping container. LWA Engineering Memo RFS0028 [1] describes the modifications done to reduce leakage of signals from the shelter electronics to the LWA dipoles as well as to the EVLA. According to the design requirements, the shelter should shield at least 60dB. Additional shielding required to prevent harmful RFI emission will be provided by racks and chassis inside the shelter. The shelter design includes modifications such as bulkhead panels for the cable entries and airconditioners, which may be weak spots in terms of RFI leakage. On March 10, 2010 we conducted measurements to confirm that the required 60dB shelter shielding factor was met.

2. Test setup and results

The measurements were performed in open-air. The shielding factor was estimated from the difference in power between a reference signal transmitted inside the shelter, and the same signal measured at known positions outside. The antennas were wideband (200MHz-1GHz) directional antennas, and the signals collected on a spectrum analyzer (noise floor approximately -120dBm). The signal was transmitted at +10dBm, and the antennas were for all measurements located approximately 9ft apart and directed toward each other. For all measurements the environmental door was open. The shielding factor was measured at two frequencies, 315 MHz and 1 GHz. Weather conditions at the site were very cold and windy, which prevented us from performing more extensive measurements.

For each position (in front of the door, at the bulkhead panel, and at the airconditioner side) a reference signal was first measured with the door open, and subsequent measurements taken with the door closed. The first measurement outside the door yielded a shielding factor of 54dB, slightly below our required 60dB level. The edges of the RFI tight door were cleaned with alcohol, but no improvement was seen. A handheld radio was therefore used as a sniffer device, and the leakage was located to the bulkhead panel on the short side of the shelter. An inspection revealed that some of the cables entering the shelter through the bulkhead were not tightened completely and all cables were checked and tightened. This improved the shielding factor by 20dB. Results from measurements at 315 MHz and 1 GHz are listed in Tables 1 and 2 respectively.

3. Emission levels at the EVLA

At this point, we do not have any measurements of the digital processing (DP) system. However, we expect one of the noisier components to be a LAN switch, and NRAO have previously made emission measurements of such devices. Using these as typical numbers, and assuming that the nearest EVLA antenna is at a distance of 325m from the electronics we estimate the effective power incident on the EVLA antenna. Fig. 1 shows the emission levels from the LAN switch at the antenna assuming 75dB shelter shielding only, and the incident emission including also 40dB additional shielding from racks and 10dB from the DP chassis to be placed inside the shelter.

Position	Comment	Signal strength (dBm)	Shielding (dB)
In front of door	Door open	-14	
In front of door	Door closed	-90	76
Bulkhead panel side	Door closed	-91	77
Airconditioner side	Door closed	-68	54

Table 1: Results from measurements at 315 MHz.

Position	Comment	Signal strength (dBm)	Shielding (dB)
In front of door	Door open	-19	
In front of door	Door closed	-93	74
Bulkhead panel side	Door closed	-101	82
Airconditioner side	Door closed	-61	42

Table 2: Results from measurements at 1 GHz.

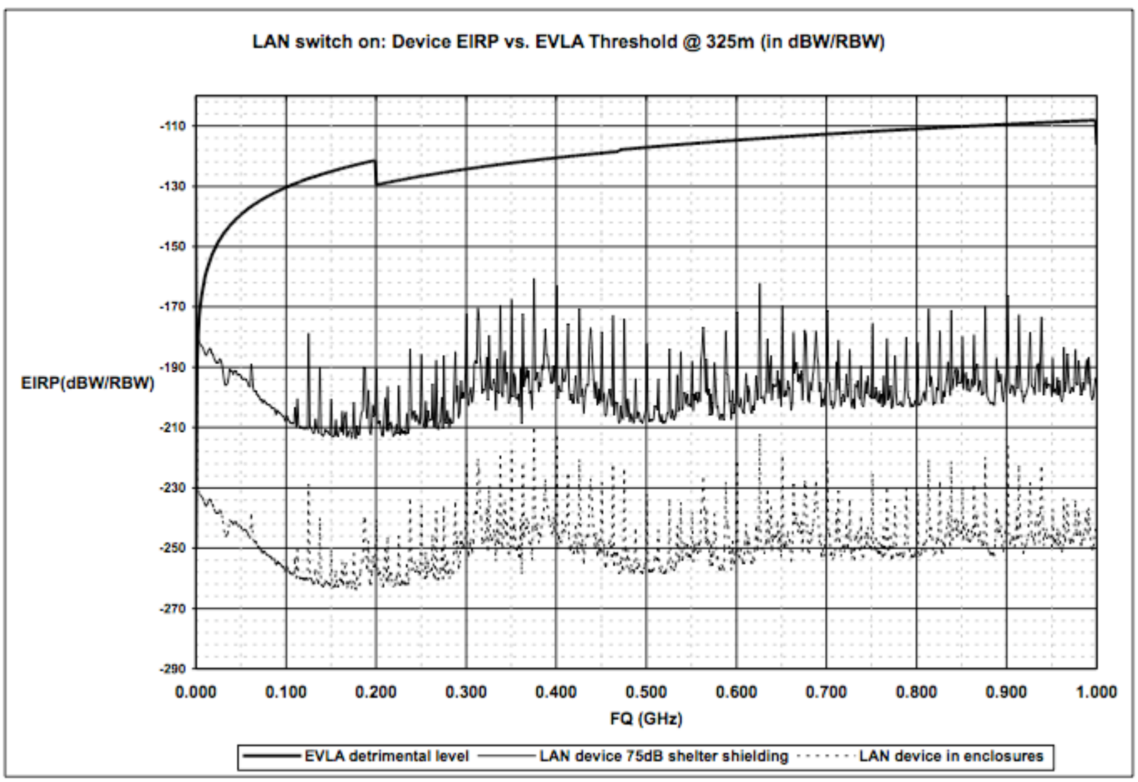


Figure 1: Solid, thin line displays LAN switch emission levels versus the EVLA detrimental levels at a distance of 325m (solid, thick line), assuming the LAN switch is inside the LWA1 shelter with a 75dB shielding. An additional 50dB of shielding is expected from the electronics racks and chassis inside the shelter, which would reduce the emission to the level displayed by the dotted line.

4. Emission levels at the LWA

The detrimental levels for the LWA are calculated for a much narrower resolution bandwidth (RBW) of 100 Hz [2] as compared to the EVLA [3]. The emissions measurements of the LAN device were done with a 10kHz RBW, and we therefore just adjust our detrimental level to this resolution. The resulting detrimental level is plotted in Fig. 2 in addition to the emission levels measured for the LAN device, assuming a distance of 10m to the nearest LWA antenna. As can be noted from the plot, it appears as if another 40dB shielding might be needed. However, the emission levels for frequencies below 200 MHz are poorly calibrated inside the shielded chamber. In addition the resolution bandwidth is not matched with our defined limits. When a sample DP system arrives we therefore recommend attempting a set of emission measurements in the shielded chamber at 100-1000 kHz resolution to investigate the typical RFI emissions bandwidth.

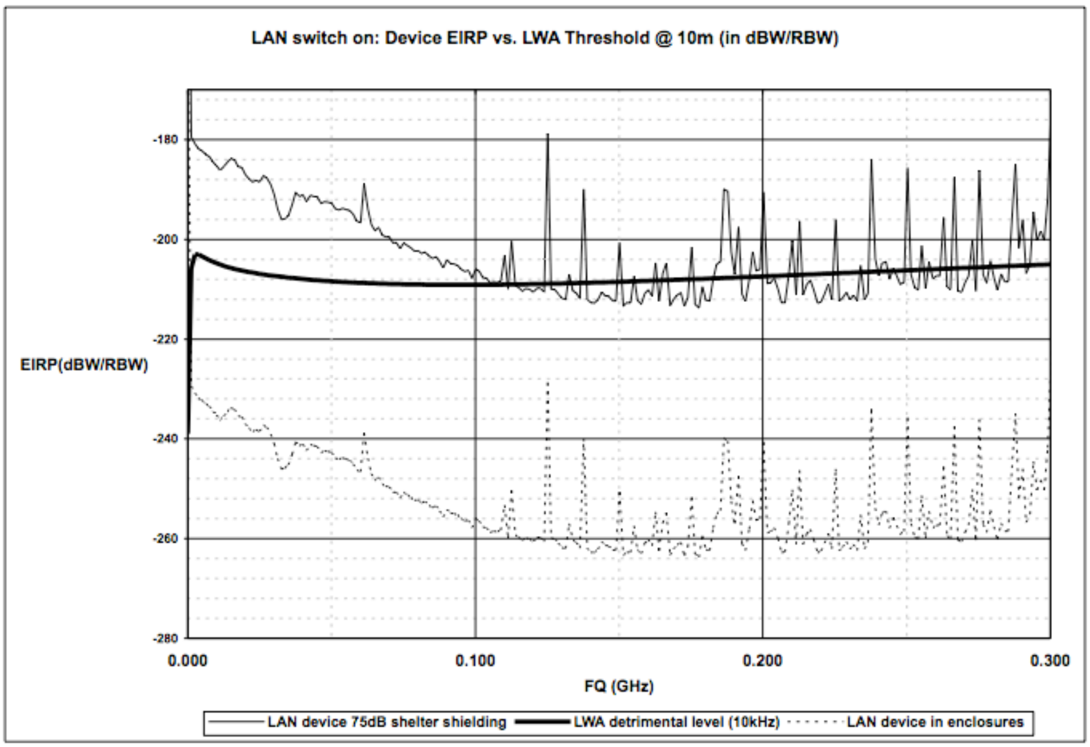


Figure 2: LAN switch emission levels (solid, thin line) versus the LWA detrimental levels (solid, thick line), assuming the LAN switch is inside the LWA1 shelter with a 75dB shielding. The levels estimated including an additional 50dB from the electronics racks and chassis inside the shelter are also shown (dotted line). Note that the resolution bandwidth of 10kHz is 100 times wider than the 100 Hz specified for the LWA detrimental levels.

4. Conclusions and recommendations

The shelter has an approximate shielding level of 75dB at both 315 MHz and 1 GHz. This meets our specifications with a margin. There is a problem with leakage of emission at the side of the shelter where the airconditioners are located. We believe that this is related to a set of cables to the temperature control that go straight through the honeycomb filter. This must be changed, and later this year we will redo measurement to confirm that the problem no longer exists. Typically, shielding measurements of, e.g., shielded racks (for example Equipto and Premier racks) do not display any significant decrease of the shielding factor as the frequency drops below 300 MHz, and we will adopt a shelter shielding factor of 75dB also at LWA frequencies.

For EVLA frequencies, we have demonstrated that assuming similar emission levels to a LAN switch, we are well within the detrimental levels. For LWA frequencies the results are less obvious and will depend on the internal shielding that can be provided. We recommend that once the full DP system is installed inside the shelter a survey of emissions outside the shelter for LWA frequencies should be performed. We anticipate that this can be done in the late summer or early fall of 2010, with the help of the RFI group at NRAO.

References

[1] Pihlström, Y., LWA Engineering Memo RFS0028
[2] Pihlström, Y., LWA Engineering Memo RFS0012
[3] Perley, R., VLA/VLBA Interference Memo #34

Digital Receiver Rack Shielding Factor

LWA Engineering Memo RFS0035
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8/12/10

Introduction

To shield the LWA-1 digital receiver and prevent emissions that may be harmful to LWA and EVLA, a Premier RFI shielded rack was ordered with modification to improve the shielding levels determined at a previous test (LWA Engineering Memo RFS0033). The modifications included a new door closing system to especially reduce leakage around door handles. The rack was taken to the VLA reverberation chamber to measure the resulting shielding levels. These tests resulted in shielding levels of 18-28dB, which are 12-22dB lower than expected. A sniffer device was applied and tracked down the main leakage points to the side panels, along all sides of the doors, and along the four panels on top of the rack.

1. Test description

The rack was placed inside the shielded chamber with a transmitting antenna ('Ridgeway' discone antenna) suspended about 2ft above the rack floor using styrofoam. A receiving antenna (Pomeroy) was collecting the data fed into a spectrum analyzer, controlled by a PC. A mode stirrer was used in the chamber to provide three different measurements for each data set, to account for different mode propagation. The average of the three measurements were used in the analysis of the data. Measurements were taken as follows:

1. Open reference: Both rack doors were fully opened.
2. Closed reference: Both doors fully closed.
3. Cable reference: Cable to transmitting antenna terminated with 50ohm.

Each measurement were taken with 801 points between 0-20 GHz. Below about 700 MHz the chamber is not well calibrated due to the lack of supported modes, and results may be invalid.

From these measurements the shielding factor was measured to be about 25-28 dB for frequencies 1-9 GHz, 20-25dB for 9-11 GHz, 18-20dB for 11-17 GHz and 20-24dB for 17-20 GHz (Fig. 1). Thus, from our previous test of the rack (LWA Engineering Memo RFS0033) the rack shielding improved by about 3dB for low frequencies, and deteriorated with up to 7dB for higher frequencies.

A sniffer device consisting of a handheld radio and a piece of carbon-loaded foam (to prevent signal reflection) was used to track down the leakage points of the rack. The main points of problems were:

- Along the side panels.
- Along the doors, especially along the top and bottom parts.
- Along the four panels mounted on top of the rack.

2. Recommended rack improvements

With the sniffer results we identified the main areas of leakage. There are several modifications that could be done that would help to improve the shielding:

1. Include gaskets along all panels, especially side panels. There were gaskets around these panels in the first version of the rack we tested, but this version lacked the gaskets[1].

[1] Premier was notified about the missing gaskets and are shipping those to the LWA Project Office.

2. The screw holes for the side panels were poorly fitted to the holes in the panels, making a good fit difficult. Better precision in making the panels and associated holes would help. The panels to be used will probably be fabricated at UNM, in which case the tolerances used by both Premier and UNM must be high.
3. For both the side panels, as well as for the panels at the top (which did have gaskets) the distances between screw positions are very large. To improve the RF shielding the distance between the screws should be a factor of 3 or 4 smaller.
4. The worst leakage points along the door were identified to areas where the gasket on the inside of the door was either not overlapping or poorly overlapped. Making sure that there are no holes in the gasket coverage would improve the shielding.
5. The doors still seem to leak along at random positions at all sides. Even though the new door locking system appears to be an improvement, a suggestion would be to place the clamps on the outside of the rack (unless that would be an issue with fitting the racks inside the shelter).

3. Conclusions

We found that the racks provide about 12-22dB lower shielding than the Premier specified 40dB. We recommend that the modifications suggested above should be done, and then the rack should be tested again.

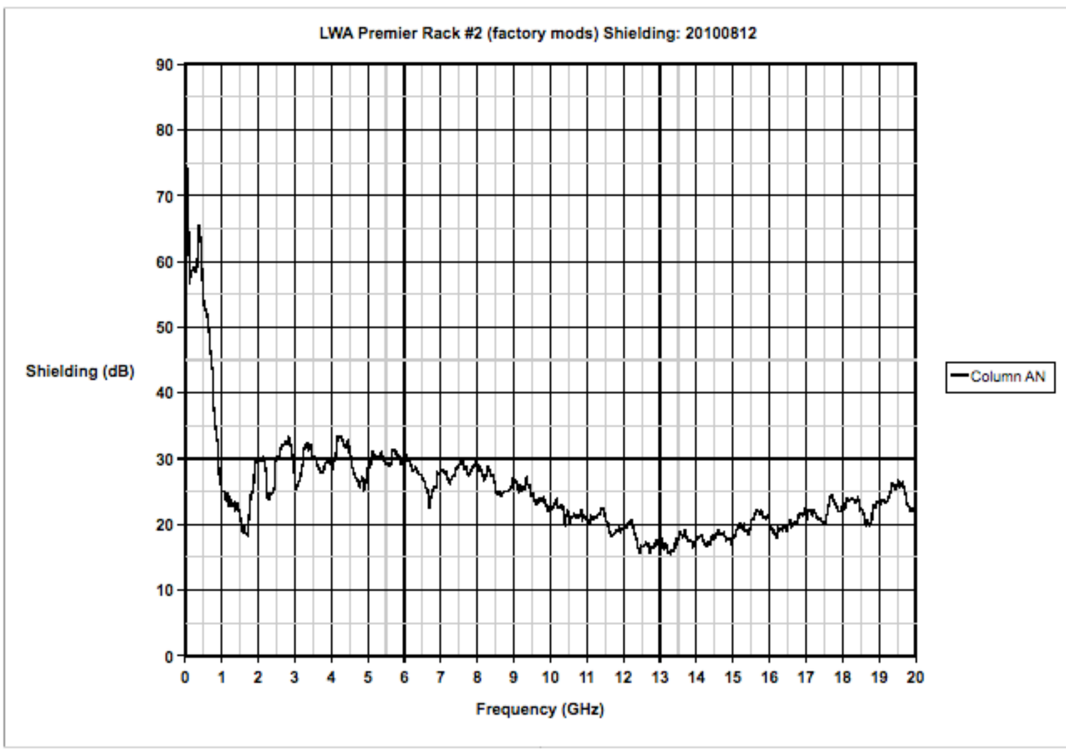

Fig. 1: Shielding as a function of frequency for the modified Premier rack. Rack specified level is at 40 dB.

References

Pihlström, Y., Merely, D., Tremblay, S., & Craig, J., LWA Engineering Memo RFS0033