VLA-VLBA Interference Protection Memo #36

EVLA Vertex Room Sourced RF Propagation Losses

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Abstract

Propagation losses from an EVLA antenna vertex room source to the input of 5 radio astronomy receivers are presented. The propagation losses are calculated from new empirical data collected during April and May 2008 on-antenna tests. The test and data calculation procedures are described. An example of how the results may be used in determining RFI emissions limits for vertex room based RF devices is summarized.

1 INTRODUCTION

In order to determine the detrimental effects on astronomical observing from an RF-generating device located in an EVLA vertex room, it is necessary to know the device-to-receiver propagation losses. Once the total propagation losses are known, the losses may be subtracted from the device effective isotropic radiated power (EIRP) to determine the power the RF device would present at the input of the first stage of amplification of the receiver (RX) front ends (FE). The resulting input power level may then be compared to the EVLA detrimental RFI levels, as documented by Perley[1], to determine the required shielding for the device.

This memo documents the results of a new, April and May, 2008, propagation tests performed in EVLA antenna 24. Previous tests performed by Ridgeway[2] showed unusual jumps in the propagation losses measured by different, but adjacent-band receivers. These new tests were designed to fully document the new test procedures and results, and verify or correct the previous results. The test procedures and results are discussed, and an example use of the data is presented.

2 PURPOSE

The purpose of this VLA Site Generated RFI Control Plan is to:

1) Review and partially document previous, undocumented vertex room propagation test results,
2) list and document the April/May 2008 test procedures and equipment used,
3) describe the data and data analysis technique,
4) present the new propagation test results, and
5) review a typical use of these data in determining required shielding for vertex room located devices.

3 2003 Propagation Test Overview

In Ridgeway's 2003 vertex room to VLA receiver propagation losses test, a synthesizer-generated CW tone was transmitted at 5 frequencies in each of 7 VLA RX bands[3] while the power levels at the output of the RX FE were measured and recorded. Transmit (TX) and receive (RX) cable losses, as well as RX FE

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[1] EVLA series memo #106, section 5, Equation 8. Perley et. al.
[2] Un-published 2005 memo, "Suppression of Self-Generated RFI Emissions for the EVLA, Vsn 6", Sec 2, R. Ridgeway et. al. Currently available at: \\Filehost\evla\techdocs\RFI\documents-reports\RR-rfi-suppression-report\evla-rfi-suppression-v6.doc.
[3] Private communication, R. Ridgeway to D. Mertely, 2006.

gain were compensated for in determining the propagation losses in each band[3]. The synthesizer, cabling, and antenna used are unknown. The 5 results for each VLA band were averaged[4]. A summary of the test results is presented in Table 1.

Notice the significant jump in the path losses calculated at P and L bands (330 vs. 1420 MHz), and again between Ku and K bands (14,950 vs. 22,480 MHz). These jumps are suspicious not only due to the magnitude of the change, but also due to the major differences in RX FE—the VLA P-band RX is a room temperature system mounted at the apex of the antenna, behind the subreflector, whereas the VLA L-band RX is located in the vertex room, bolted directly to the end of the massive, L-band feedhorn. A similar design difference exists between the old VLA Ku band RX front end and the new K-band RX front end—although both front ends are located in the vertex room, the VLA Ku band system, with it's notoriously high noise temperature, is connected to the remotely-mounted feedhorn through a fairly long length of lossy, room temperature waveguide, whereas the newer, VLA K-band RX, is directly bolted to the K-band feedhorn. It is believed that these differences in RX design and the differences in noise temperature characterization that result, may be responsible for the unusual jumps in calculated path loss seen between these receiving bands.

Table 1. VLA antenna vertex room to FE path loss, 2003 test results.

Frequency	Measured Vertex room Path Loss
330 MHz	-70 dB
1.42 GHz	-83 dB
4.75 GHz	-86 dB
8.4 GHz	-75 dB
14.95 GHz	-77 dB
22.48 GHz	-105 dB
40.0 GHz	-115 dB

4 April/May 2008 Test Procedures and equipment used

In these new, April/May 2008 propagation analysis tests, synthesized CW signals for 5 VLA/ELVA bands were transmitted through commercial antennas temporarily placed in the EVLA antenna 24 vertex room. The synthesizer was set to sweep a CW signal across the receiving range of each of the receiving bands while a spectrum analyzer (set to peak-detect and peak-hold) recorded the power level at the RCP output of the corresponding RX front end. (See table 2 for a detailing of the frequency ranges covered.) Although the transmit and receive systems were not frequency synchronized, the transmit sweep duration was set to much slower (20 seconds) than the spectrum analyzer RX sweep (typically under 1 second), in order to insure that the recorded power levels had time to stabilize at each frequency point. Due to the likelihood of uneven power density and emission patterns throughout the vertex room and in the immediate proximity of the RX feeds, the transmit sweep was performed twice—once with the TX antenna at a fixed location and pointing (generally toward the ceiling of the vertex room), and a second time with the TX antenna being moved to different pointings as the spectrum analyzer swept through its full frequency span. An initial file was recorded of the peak-detect, peak-hold RFI signal + noise power level of the RX with the synthesizer off. This power level vs. frequency data vector was used as a baseline for establishing the power setting of the synthesizer during subsequent tests in that receiving band.

[4] Ibid.: Ridgeway private communication.

The TX power output level was empirically set to produce at least a 10 dB signal to noise ratio (SNR) over the band pass noise level of each RX, while insuring that no RFI signal peak was above the test tone power level, as seen at the output of the radio astronomy RX FE. The power of the test tone was, however, kept low enough to avoid causing a RX output power level greater than approximately -20 dBm, in order to avoid the non-linear region of the NRAO front end low noise amplifiers (LNA)[5].

Appendix A of this report contains the detailed equipment list and set-up parameters used for each receiving band, as well as a record of test conditions and output data files.

5 April/May 2008 Test data and data analysis description

The frequency vs. peak-detect, peak-hold power data files were read in to Excel spreadsheets. The data file names, with their descriptions are may be found in Appendix A. The data files and data analysis spreadsheets are currently stored on a network disk at:

\\Filehost\evla\techdocs\RFI\prop-tests (PC addressing)
/home/evla/techdocs/RFI/prop-tests (UNIX addressing)

For each VLA frequency band, the following data analysis steps were performed in order to generate a plot of propagation loss vs. frequency from EVLA vertex room emitter to the input of each radio astronomy RX:

1. A three point averaging filter was applied to the linearlized received power data vectors in order to remove noise and smooth the received, power level data vectors.
2. Corrected, received power level data vectors were created by subtracting cable losses (FE to spectrum analyzer), antenna reflection losses, and front end RX gain data vectors from the smoothed, received-power data vector. For P-band, the FE gain factor used was a constant +38 dB, as determined from FE records for the SN11 F102 FE used in antenna 14. For C, X, and K bands, the FE gain factor was extracted from the FE noise temperature (NT) test set data. For the L-band receiver SN11, the gain data was extracted from the FE NT test set data, as corrected below 1200 MHz using a composite, axial ratio test file provided by Bob Hayward[6]. These data were used in-concert to overcome the low band edge gain deficiency of the NT test set.
3. Corrected, TX power level data vectors were created by adding cable losses (synthesizer to TX antenna), and antenna reflection losses, from synthesizer output power levels.
4. The corrected TX power level data vectors were subtracted from the corrected, RX power level data vectors to produce the propagation losses (vs. frequency) from the output of the transmitter antenna, to the input of the radio astronomy RX front end.

Plots of the propagation loss vs. frequency data vectors may be found in Appendix B of this report. Unreliable results outside of the standard VLA bands should be expected, and are due to poor receiver gain characterization outside current frequency operating limits.

A summary of the average, VLA-band propagation results may be found in Table 2, below. The rather low P-band propagation loss value was seen in both the 20080429 and 20080520 test data, and is believed

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[5] In an internal memo by J Effland (http://www.cv.nrao.edu/~jeffland/Compression.pdf), the 1 dB compression point for a number of un-cooled NRAO LNAs was found to be in the range of 0 dBm (output power). The 1% compression point of an amplifier is generally considered to be approximately 12 dB below the 1 dB compression point. Insuring that the output power of the FE was near or below -20 dBm kept the test signal well into the linear region of the amps.
[6] rhayward to dmertely email correspondence of 19 May, 2008. The data may be found at: \\Filehost\evla\techdocs\RFI\prop-tests\20080429\analysis \Gain-vs-Freq-for-Mert-Book1.xls.

to be real. The rapidly-decreasing propagation loss results seen in the L-band test data below 1200 MHz (after correction of receiver gain data) is one validation of the P-band results (See Appendix B).

Table 2. EVLA antenna vertex room to FE-input path loss, 2008 test results.

Frequency	Measured Vertex room Path Loss
306-340 MHz	-45 dB
1340-1730 GHz	-73 dB
4.5-5.0 GHz	-78 dB
8.0-8.8 GHz	-72 dB
14.4-15.4 GHz	N/A
22.48 GHz	-74 dB
40-50 GHz	N/A

6 Typical Shielding Requirements Calculation Procedure

In order to determine the amount of shielding required of a digital or RF module designed for EVLA vertex room use, it is necessary to know:

1. the effective Isotropic radiated power (EIRP) of the device,
2. the propagation losses from the vertex room to each of the EVLA RX FE, and
3. the detrimental threshold for each EVLA FE, expressed as power into the first stage of amplification.

The device EIRP may be calculated from emissions test data collected in the EVLA/ALMA reverberation chamber located at the VLA site. The units are typically expressed as dBW, and indicate the total power that would be emitted by the device if it were to radiate RF power uniformly (spherically, or isotropically, from a single point). Subtracting the vertex room to FE propagation losses for each frequency (as found in this report) from the EIRP power level produces the power in dBW at the input to the first stage of amplification of each RX FE. From EVLA series memo #106, section 5, Equation 8[1] ($P_h < 5 \times 10^{-22} \nu_G T_{sys}$ watts.), the detrimental threshold may be calculated as a function of frequency and system temperature. A simple subtraction of the projected EIRP power values on a frequency-by-frequency, or by-band basis from 10 x LOG10 of the calculated detrimental threshold values indicates the amount of shielding required to insure that the RF emissions from the device (if located in the same antenna vertex room) would fall below the detrimental threshold as expressed by an Interference to Noise Fluctuations Ratio (INR) of < 0.1[7]. For simplicity, the detrimental threshold vs. frequency curve and the RFI input power vs. frequency curve are typically plotted on the same graph, allowing a simple visual subtraction to be performed for any frequency of interest.

[7] EVLA series memo #106, section 2, Equation 1. Perley et. al.

APPENDIX A: April/May 2008 Test Procedures and equipment used

20080429 L, C, X, K, P band tests:

L-BAND:

TX:
Wiltron 68347B 20 GHz synthesizer to TM176-mm2000, SN0001 to AEL H5000R horn, at center of vertex room floor, facing up.
Sweep: 1-2 GHz, in 20 sec.
Power: -10 dBm out

RX:
L-band F103 FE SN28 card cage, SN11 dewar RCP out to TM176-mm1500, SN0001 RF cable to LOIF Agilent E4407B spectrum analyzer.
Sweep: 1-2 GHz
RBW=1 MHZ, RL = -10 dBm, pk hold typ 2 min, no averaging.

SNR ~ 20 - 30 dB, 1 MHz RBW NL ~ -68 dBm
Some misc. items were left in the vertex room, but the testers were outside the door for the TX test. The FRM was not explicitly set-up for L-band. We believe it was set to X-band (R Ferraro "corrtest" program was probably executing by then—It is mostly X-band)

1st file = LNOTX.csv: L-band, no TX test. ~ 3.5 min pk hold
2nd file = LTX.csv: L-band, TX in vertex room.
3rd file = LTXmove.csv: L-band, TX, horn moved--pointed to multiple positions, ~ 20 sec each position. (after lunch break). (Both testers remained in the vertex room.)

C-BAND:

TX:
Wiltron 68347B 20 GHz synthesizer to TM176-mm2000, SN0001 RF cable to AEL H5101 horn, at center of vertex room floor, facing up.
Sweep: 4-8 GHz, in 20 sec.
Power: -10 dBm out

RX:

C-band F304 FE XN-4 RCP out to TM176-mm1500, SN0001 to LOIF Agilent E4407B spectrum analyzer.
Sweep: 4-8 GHz
RBW=1 MHZ, RL= -10 dBm, peak hold typically 2 minutes, no averaging.

SNR ~ TBD dB.
Some misc., non-RF absorbing items were left in the vertex room, but the testers were outside the door for the TX test. The FRM was not explicitly set-up for C-band. We believe it was set to X-band (R Ferraro "corrtest" program was probably executing by then—It is mostly X-band)

1st file = CNOTX.csv: C-band, no TX test. ~ 2 min pk hold
2nd file = CTX.csv: C-band, TX in vertex room.

3rd file = CTXmove.csv: C-band, TX, horn moved—pointed to multiple positions, ~ 20 sec each pos. (after lunch break). (Both testers remained in the vertex room.)

X-BAND:

TX:
Wiltron 68347B 20 GHz syn to TM176-mm2000, SN0001 to ARA WH-8212 horn, at center of v-room floor, facing up.
sweep: 8-12 GHz, in 20 sec.
Power: 0 dBm out <========= Note change.

RX:
X-band F*** FE SN28 RCP out to
TM176-mm1500, SN0001 to
LOIF Agilent E4407B
Sweep: 8-12 GHz
RBW=1 MHZ, RL=-10 dBm, pk hold typ 2 min, no averaging

SNR ~ TBD dB, 1 MHz RBW
Some junk in V-room, but both testers were outside the door for the TX test.

1st file = XNOTX.csv X-band, no TX test. ~ 2 min pk hold
2nd file = XTX.csv: X-band, TX in vertex room.
3rd file = XTXmove.csv: X-band, TX, horn moved--pointed to multiple positions, ~ 20 sec each pos. (after lunch break). Both testers in V-room.

KBAND:

TX:
Wiltron 68347B 20 GHz syn to
TM176-mm2000, SN0001 to
Bonardi E520 horn, at center of v-room floor, on 3 ft tripod, facing up.
sweep: 18-20 GHz, in 20 sec.
Power: +10 dBm out <========= Note change.

RX:

K-band F109 FE SN29 RCP out to
TM176-mm1500, SN0001 to
LOIF Agilent E4407B
Sweep: 18-20 GHz
RBW=1 MHZ, RL=-10 dBm, pk hold typ 2 min, no averaging
LO-in @ 16.256 GHz, -1 dBm

SNR ~ TBD dB, 1 MHz RBW
Some junk in V-room, but Colin & I were outside the door
for the TX test. Running SYSTARTK (FRM was set-up).

1st file = KNOTX.csv X-band, no TX test. ~ 2 min pk hold
2nd file = KTX.csv: X-band, TX in vertex room.

3rd file = KTXmove.csv: X-band, TX, horn moved--pointed to multiple positions, ~ 20 sec each pos.
(after lunch break). Both testers in V-room.

PBAND:

TX:
Wiltron 68347B 20 GHz syn to
TM176-mm2000, SN0001 to
TBD 200 - 1300 MHz conical log spiral, at center of v-room floor, facing up.
sweep: 300-350 MHz, in 20 sec.
Power: -TBD dBm out <=========

RX:

P-band F102 FE SNTBD RCP out to
TM176-mm1500, SN0001 to
LOIF Agilent E4407B
sweep: 300-350 MHz
RBW=1 MHZ, RL=-10 dBm, pk hold typ 2 min, no averaging

SNR ~ TBD dB, 1 MHz RBW
Some junk in V-room, but Colin & I were outside the door
for the TX test. Running SYSTARTP (FRM was set-up).

1st file = PNOTX.csv X-band, no TX test. ~ 2 min pk hold
2nd file = PTX.csv: X-band, TX in vertex room.
3rd file = PTXmove.csv: X-band, TX, antenna moved--pointed to multiple positions, ~ 20 sec each pos.
(after lunch break). Both testers in V-room.

Re-test of vertex room P-band propagation 20080520.
(The P-band test of 20080429 was repeated on 20080520 because the transmitter synthesizer power level had not been recorded during the prior test.)

EVLA antenna 24.

PBAND:

TX:
Wiltron 68347B 20 GHz syn to
TM176-mm2000, SN0001 to
TBD 200 - 1300 MHz conical log spiral, at center of v-room floor, facing up.
sweep: 300-350 MHz, in 20 sec.
Power: -10 dBm out <=========

RX:

P-band F102 FE SNTBD RCP out to
TM176-mm1500, SN0001 to
LOIF Agilent E4407B
sweep: 300-350 MHz

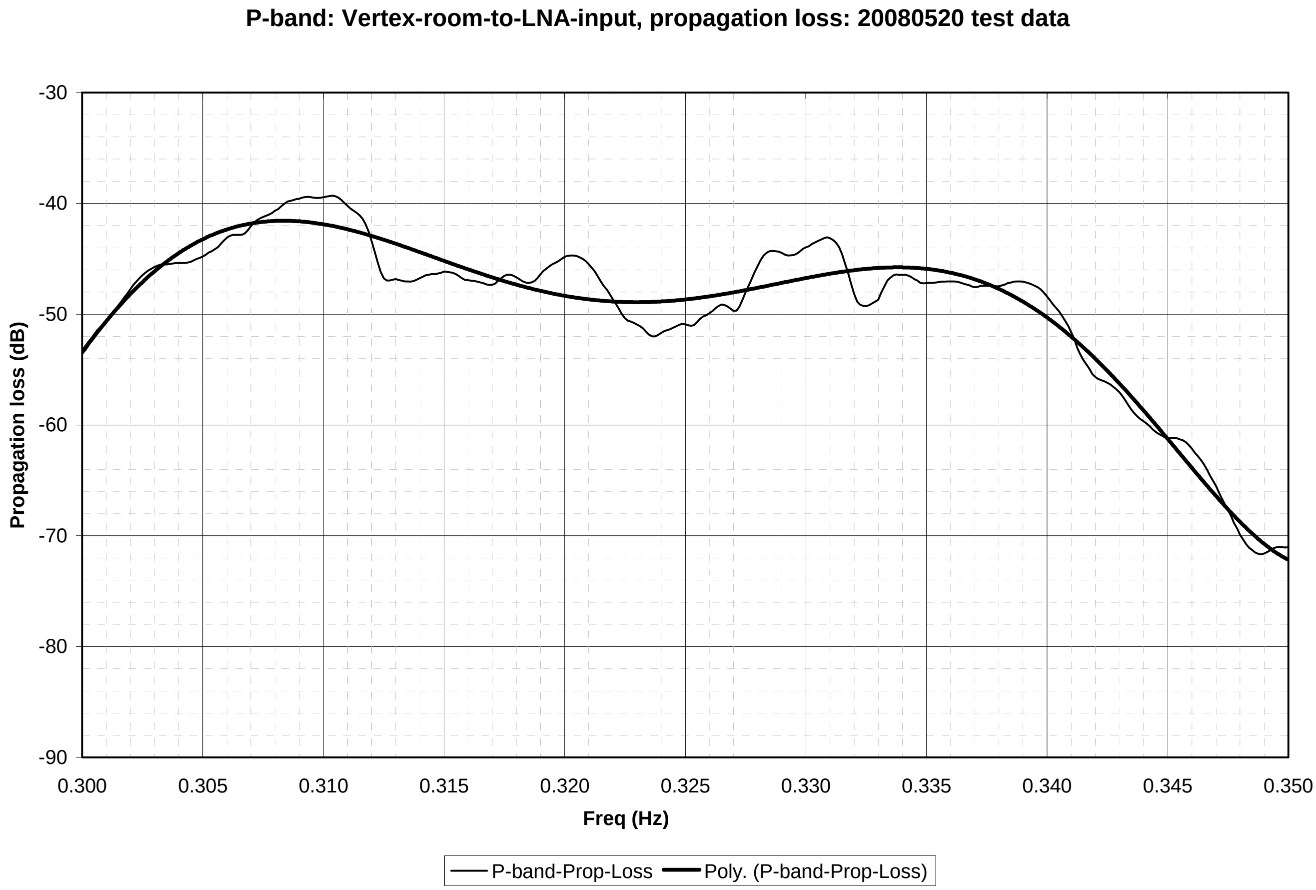
RBW=1 MHZ, RL=-10 dBm, pk hold typ 2 min, no averaging

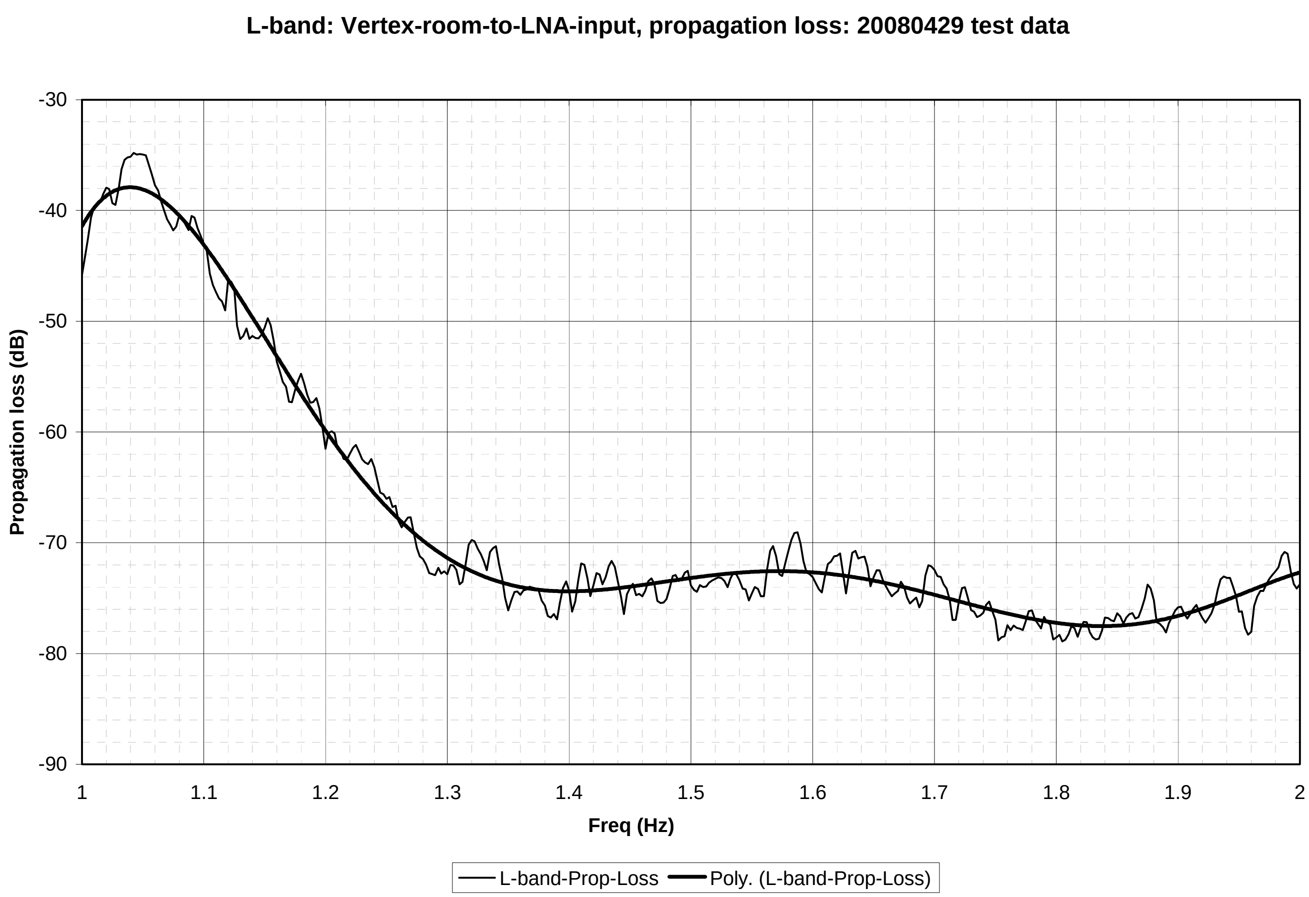
SNR ~ TBD dB, 1 MHz RBW
Some junk in V-room, but Colin & I were outside the door
for the TX test. Running SYSTARTP (FRM was set-up).

1st file = PNOTX.csv X-band, no TX test. ~ 2 min pk hold
2nd file = PTX.csv: X-band, TX in vertex room.
3rd file = PTXmov.csv: X-band, TX, antenna moved--pointed to multiple positions, ~ 20 sec each pos.
Both testers in V-room.

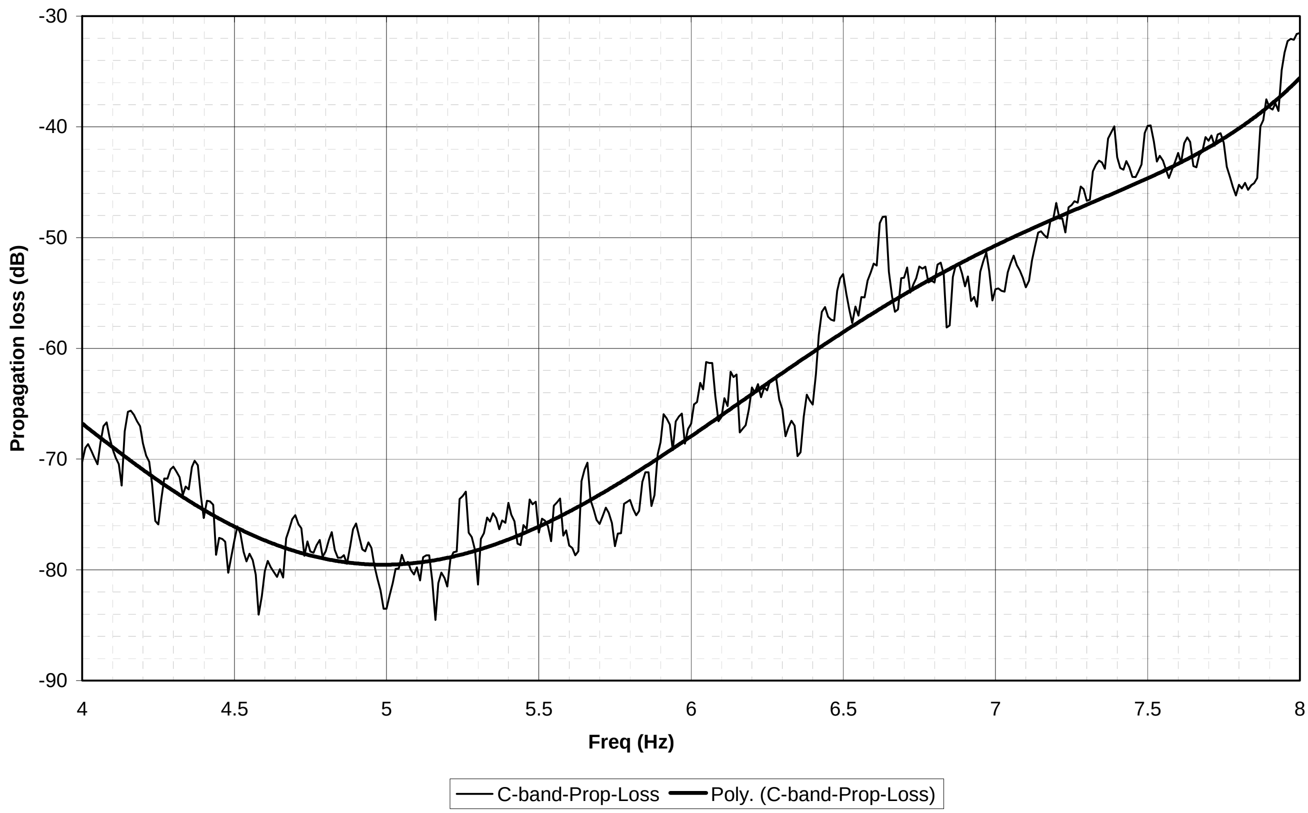
4th file = PNOTXTRM.CSV: P-band no TX, P-band bulkhead terminated @ outside vertex wall
5th file = PTXMVTRM.CSV: P-band TX, P-band bulkhead terminated @ outside vertex wall

APPENDIX B: EVLA antenna vertex room RFI to receiver FE propagation losses

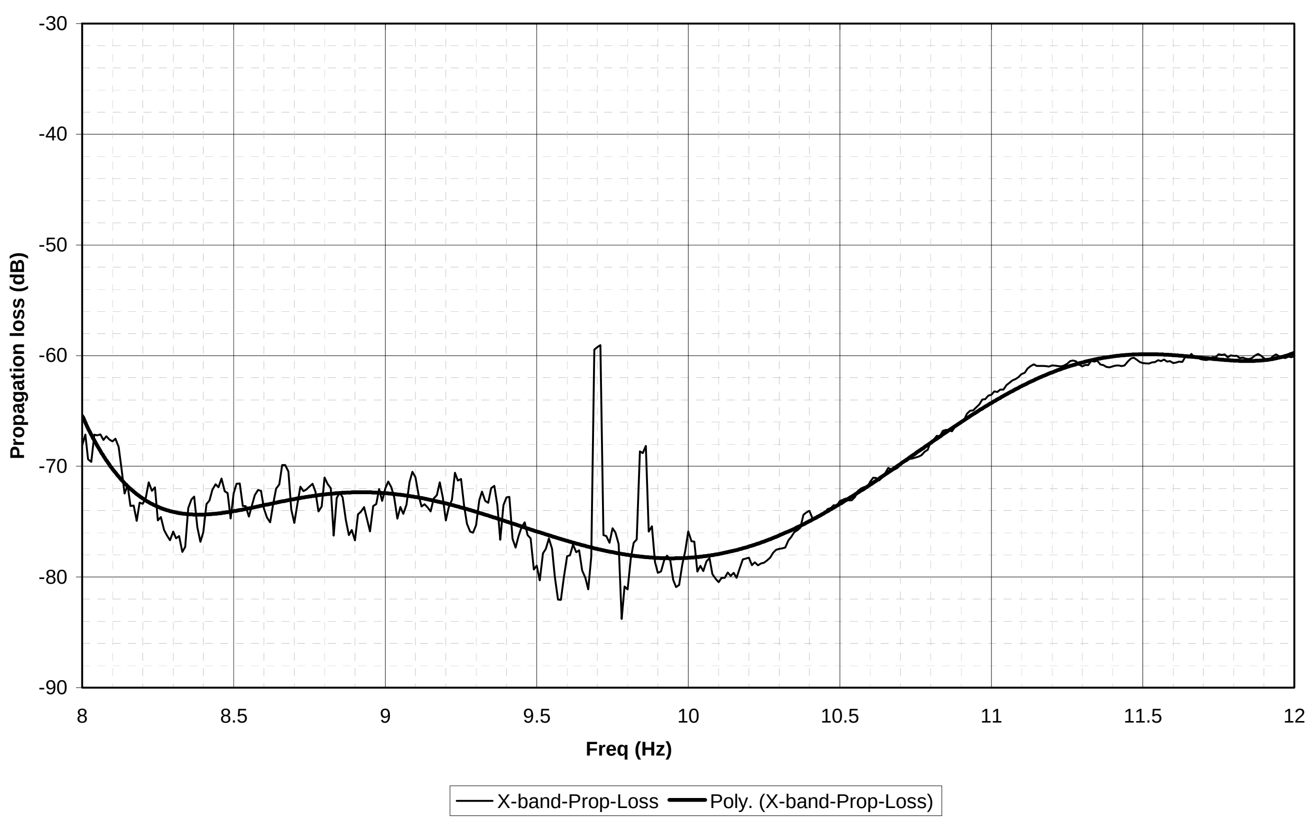


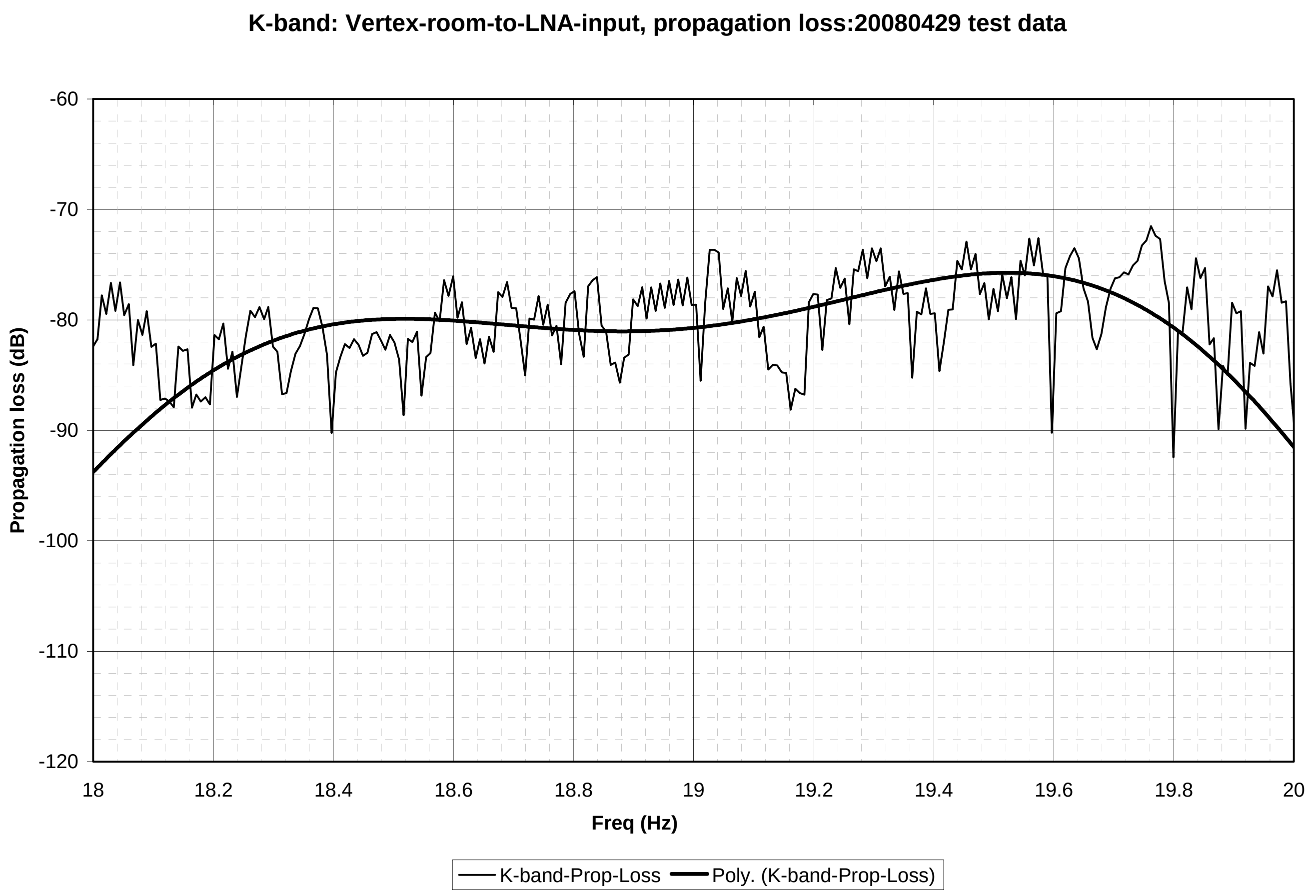


C-band: Vertex-room-to-LNA-input, propagation loss: 20080429 test data



X-band: Vertex-room-to-LNA-input, propagation loss: 20080429 test data




K-band: Vertex-room-to-LNA-input, propagation loss:20080429 test data
-60
-70
-80
-90
-100
-110
-120
Propagation loss (dB)
18
18.2
18.4
18.6
18.8
19
19.2
19.4
19.6
19.8
20
Freq (Hz)
K-band-Prop-Loss
Poly. (K-band-Prop-Loss)