National Radio Astronomy Observatory Student Cooperative Education Program

EVLA Shielded Chamber Characterization, Radiated Emissions Test Protocol, RF Shielding Characteristics of Buildings at the VLA Site, And Radiated Emissions Test of MCB Ethernet Switchgear

VLA/VLBA Interference Memo #32

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Co-op: August 12, 2002 through January 17, 2002

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Summary

This paper documents work done both during my co-op period at NRAO and my employment as a student prior to the co-op period. The total span covered by these assignments is early June of 2002 to mid January of 2003. The major projects completed during this period were the characterization of the EVLA shielded chamber for radiated emissions tests of new equipment, the characterization of the architectural RF shielding properties of the various buildings present at the VLA site, and emissions tests of two sets of proposed MCB Ethernet switches. The first two tasks were necessary to determine the effects of the introduction of new equipment at the site for the development of the EVLA and the last task is representative of tests to be conducted for every new component for the EVLA. I hope that this will serve as a starting point and a reference for future co-op students and other users of the EVLA shielded chamber at the VLA site.

Table of Contents

Introduction -- **1**

I. Characterization of the EVLA Shielded Chamber -------------------- **2**
1. ***General Description of the Chamber*** ------------------------- **2**
2. ***Shielding Effectiveness*** ------------------------------------- **3**
3. ***SWR Effects*** --- **4**
4. ***Power Level Offset from OATS*** -------------------------------- **6**
5. ***Error Introduced by the Chamber*** ---------------------------- **12**

II. Radiated Emissions Test Protocol ---------------------------------- **13**
1. ***Test Environment/Equipment*** -------------------------------- **13**
2. ***Test Setup/Procedure*** --------------------------------------- **14**

III. Characterization of RF Shielding Properties ---------------------- **20**
of Buildings at the VLA Site
1. ***Shielding*** -- **20**
2. ***Path Loss Estimation*** --------------------------------------- **28**

IV. Radiated Emissions Test of MCB Ethernet Switchgear --------------- **30**
1. ***Test Rationale, Setup, Procedure*** ---------------------------- **30**
2. ***Emissions of Cisco 3508 and***
   CentreCom 7216 Ethernet Switches ----------------------------- **31**
3. ***Emissions of Cisco 4506 Ethernet Switch*** --------------------- **34**
4. ***Harmful Level Comparison to Emissions*** ---------------------- **38**

Appendix A: Selected ITU Harmful Threshold Levels ------------------ **43**

Appendix B: EVLA Memo 47 --- **44**

Appendix C: References -- **52**

List of Figures

- •SWR Effects on a Single Position 5
- •SWR Effects on Multiple Positions 6
- •Chamber Offset Characterization from Single Data Set 1 9
- •Chamber Offset Characterization from Single Data Set 2 9
- •Chamber Offset Characterization from Single Data Set 3 10
- •Chamber Offset Characterization from Single Data Set 4 10
- •Chamber Offset Characterization from Single Data Set 5 11
- •Chamber Offset Characterization from Single Data Set 6 11
- •Test Setup Boundary Conditions 14
- •Correlator Room Shielding 23
- •SLOB Shielding 24
- •SLOB Shielding (2) 24
- •Pedestal/Vertex Room Shielding 25
- •EVLA Termination Room/CB 1st Floor Shielding 25
- •L-Band Shielding at VLA Site 29
- •Baseline Noise 31
- •Cisco 3508 and CentreCom 8216 Ethernet Switches 32
- •Cisco 4506 Ethernet Switch 32
- •Cisco 3508 100kHz Total Span 33
- •Chamber to OATS Comparison of Ethernet Switch Emissions 33
- •Baseline Noise 35
- •Cisco 4506 Ethernet Switch (0-10GHz Emissions) 35
- •Cisco 4506 Ethernet Switch (0-5GHz Emissions) 36
- •Cisco 4506 5-6GHz Emissions 36
- •Cisco 4506 2.9Ghz Detail During Startup 37
- •Cisco 4506 2.9Ghz Detail During Normal Operation 37
- •Cisco 4506 Ethernet Switch Vertex Room Installation w/ no additional shielding vs. ITU Harmful Levels 39
- • Cisco 3508 Ethernet Switch Vertex Room Installation w/ no additional shielding vs. ITU Harmful Levels 39
- • Cisco 4506 Ethernet Switch Correlator Room Installation vs. ITU Harmful Levels 40
- • Cisco 3508 Ethernet Switch Correlator Room Installation vs. ITU Harmful Levels 40
- • Cisco 4506 Ethernet Switch Vertex Room Installation w/ G-Rack vs. ITU Harmful Levels 41
- • Cisco 3508 Ethernet Switch Vertex Room Installation w/ G-Rack vs. ITU Harmful Levels 41

Abstract

The EVLA shielded chamber was purchased to provide a stable environment for radiated emissions tests for new equipment and for current equipment which was previously untested for radio frequency interference (RFI). However, the shielded chamber has no absorber or mode stirring fans. It was feared that without these measures reflections within the chamber, standing wave effects, and the possibility of inadequate shielding effectiveness would make accurate, repeatable measurements impossible. To calm these fears, a number of tests were developed and carried out to evaluate the chamber's performance in terms of shielding effectiveness, SWR effects, accuracy in measurement, and repeatability in measurement. The reasoning, methods, and results of these tests are given in this paper.

However, having an accurate environment for measurement is not enough to predict the effects of new equipment on VLA or EVLA observations. To do this, in addition to accurate emission levels of new equipment, the path loss from any location at the site to the nearest elements of the array must be known. Therefore, an established set of testing guidelines was developed to help ensure accurate, repeatable results in the chamber, and tests of the shielding characteristics of many possible locations for new equipment at the VLA site were tested. The results are chronicled in this document.

With these results and the emission levels of any piece of equipment tested in the shielded chamber, the necessary shielding requirement for that equipment may immediately be found. With this knowledge in hand, radiated emissions testing for the MCB Ethernet switches was performed, and the results listed in this paper. This type of test and analysis will be one of the most frequent and important tasks of the Interference Protection Office during the initial design and construction phases of the EVLA.

Introduction

The EVLA, when completed, will be the most sensitive radio telescope of its kind. The increase in sensitivity over the existing VLA will be achieved by slightly lower system temperatures and by a vast increase in instantaneous observing bandwidth. This increase in bandwidth, along with the introduction of large quantities of new high-speed digital electronics may however, cause a problem. In the design stages of the EVLA, it will be necessary to know what emissions will be caused by the new electronics of the array, and how these emissions will effect observations. To do this, a precise method of finding the emissions from new equipment must be available, as well as a method of predicting the effects of these emissions on observations.

The EVLA shielded chamber located in the NE corner of the warehouse at the VLA site was purchased to provide a stable, standard environment for RFI emissions testing. However, the shielding, standing wave ratio (SWR) effects, accuracy, and repeatability of measurements done in the chamber were all unknown at the time of purchase. Tests were carried out to evaluate each of these parameters, the results of which are presented in this paper.

To evaluate the effect of emissions, once measured and deemed accurate, the path loss between the proposed location of the equipment and the nearest array element (or the element with least path loss) must be known. Ignoring minor contributions of multi-path propagation, ground reflection, and other unknown contributors, the path loss becomes the product of the gains of the emitter and receiver, space (propagation) loss, and shielding. All of these quantities are discussed in this paper.

With all of the resources presented in this paper, it is possible to find the shielding required for any new proposed piece of equipment such that its emissions will not affect EVLA observations. One set of radiated emissions tests is also given in this paper for the MCB Ethernet switches for use in the master and control bus.

I. Characterization of the EVLA Shielded Chamber

To reliably use the EVLA shielded chamber, a number of quantities had to be tested. Every possible parameter contained in the chamber that could cause variation in radiated emissions measurements needs to be known to state that results found within the chamber are accurate to within some reasonable margin of error. Common methods of eliminating error include rf absorber, mode stirring, and position specific antenna correction factors (ACF). All of these methods present different problems, are prohibitive due to cost, and none give 100% accuracy or 0dB error. For the tests done for the EVLA, effective isotropic radiated power (EIRP) levels of approximately –140dBW are expected, while the harmful threshold at L-band (1420MHz) for a spectral line observation for total power measurements is –239dBW/m^{2}Hz (ITU, 21). Therefore, typically speaking, total path loss including shielding will need to be on the order of 100dB. With this in mind, error due to measurement of even 10dB would represent only a 10% error in terms of design requirements, which may be acceptable.

General Description of the Chamber

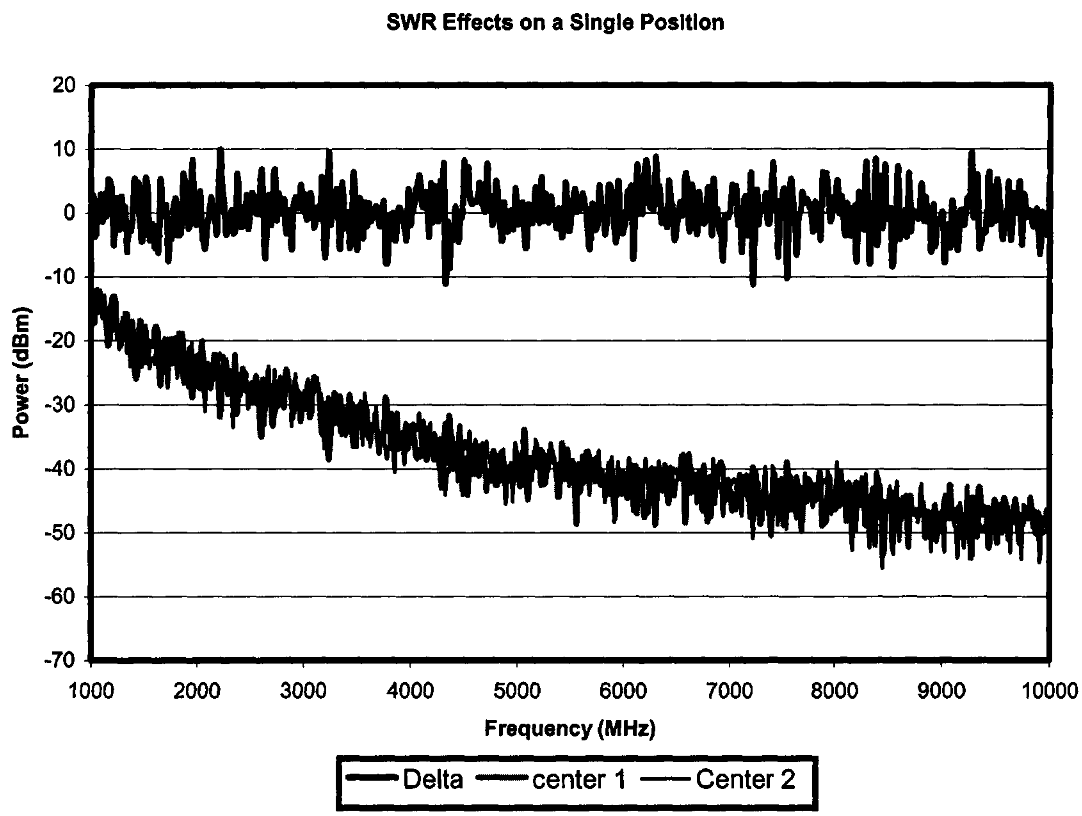
The EVLA shielded chamber is approximately 36'x 16'x 10'. It is a modular unit with removable and interchangeable panels. It has two, single door openings, approximately 7'x 3' in size. The doors utilize a captive-when-closed finger stock arrangement in which a single lip on the door fits between two pieces of high deflection finger stock set inside a cavity. The walls are composed of two layers of steel plate attached to either side of particleboard sheets. The walls are approximately ¾" thick. All power enters the room through a filtered power box. All other connections into the room are through special bulkhead penetration plates.

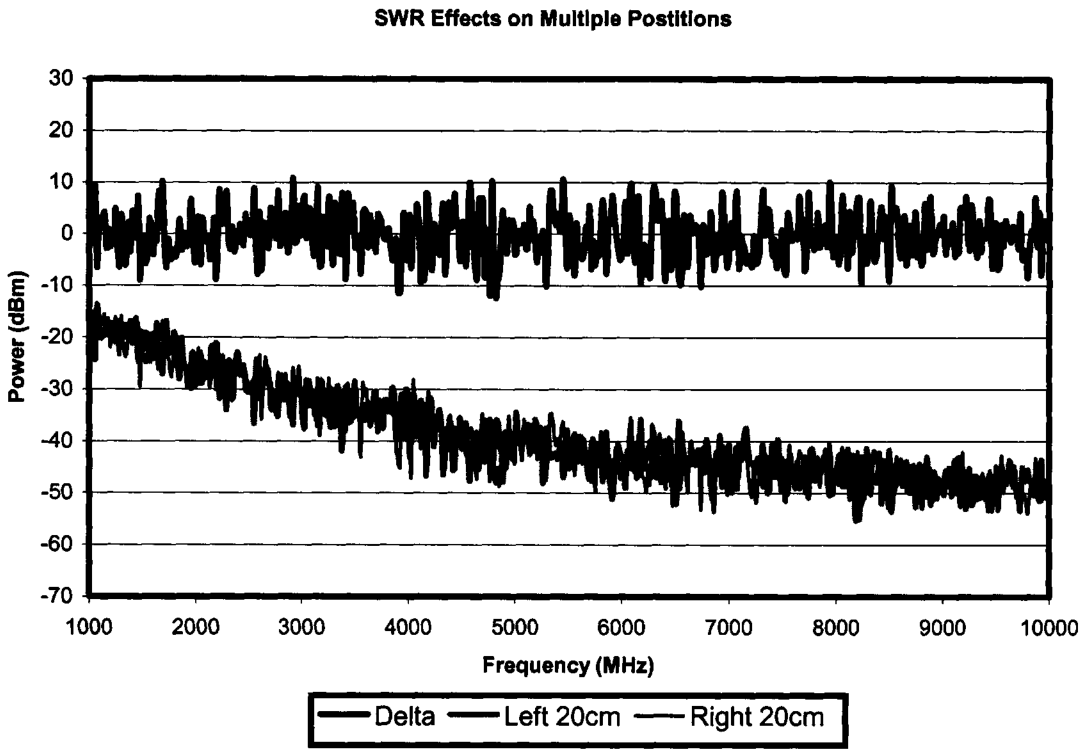
Shielding Effectiveness

The first tests done to evaluate the performance of the shielded chamber were shielding effectiveness tests. Tests for shielding effectiveness were performed using two separate methods, which arrived at reasonably agreeable results for the overall shielding characteristics of the chamber. The first method employed a 'shielded chamber effectiveness and leak detector system', acquired through military surplus and originally used by the U.S. Navy in similar characterizations. The second test used a calibrated source and detector. A Gigatronics 610 and an HP 8670 series signal generators with a Stoddard conical log spiral 1-10GHz left circular polarization, directional off-tip antenna fed through 8' of 3/8" heliax cable were used as sources. An HP 70000 series spectrum analyzer with a Tensor 1-10GHz double ridged guide horn through 3' of 3/8"coaxial cable was used to detect the signal. The signal levels of the source were first calibrated at a known distance and then placed in the chamber; the difference between the measurements inside and outside of the chamber give the effective shielding at a given frequency. Both methods have indicated the effective shielding of the chamber to be 55dB at 1GHz and 35dB at 10GHz. This is a fairly important indicator about the chamber's performance and usability. Due to the location of the chamber, within the bounds of the VLA site, emission of high-powered signals is unacceptable. If the chamber had been found to possess inadequate shielding, tests of equipment could not be conducted any day that observations are run. This would limit testing to one day per week, which would mean that testing could not be accomplished in a timely manner. However, because the chamber has 35-55dB of shielding, and is located inside a metal building with approximately 20dB of shielding and an additional 50dB of propagation loss to the nearest VLA antenna, testing of equipment with emission levels of up to about −115dBW at L-band during observations should not cause any problems.

SWR Effects

The effects of SWR in a standard reverberation chamber have traditionally been thought to be the main cause of error associated with measurements taken within them. SWR, along with multi-path propagation and phase differentials, can set up patterns of constructive and destructive interference within a chamber causing some error to always be associated with the chamber. Furthermore, moving the equipment under test (EUT) or the receiving antenna can change the SWR in the chamber and change the power levels recorded in the test. The military actually built in a method of using changes in SWR due to positional changes of the Rx antenna into their method of radiated emissions testing. An average of power levels taken during a lateral position and height search with the Rx antenna were supposed to eliminate error to some degree (Javor, 142). To test for SWR effects, a standard measurement setup was used (described later under *radiated emission test protocols)* and the position of the EUT and the Rx antenna was varied. As the position of each was varied, the power levels of the emissions were recorded. The maximum change in power levels seen was around 10dB from such tests. On average, the level change remained within +/- 3dB. Also, with the same typical setup and with no spatial change, two measurements were taken in succession. Due to phase variations, differences in multi-path reflections, and many other parameters, these two measurements actually showed the same type of variation as those with spatial changes. What this means is that an average may be taken for the emissions of equipment while the setup is left in exactly the same configuration, and the error in the measurement may be decreased by this averaging.





Power Level Offset from OATS

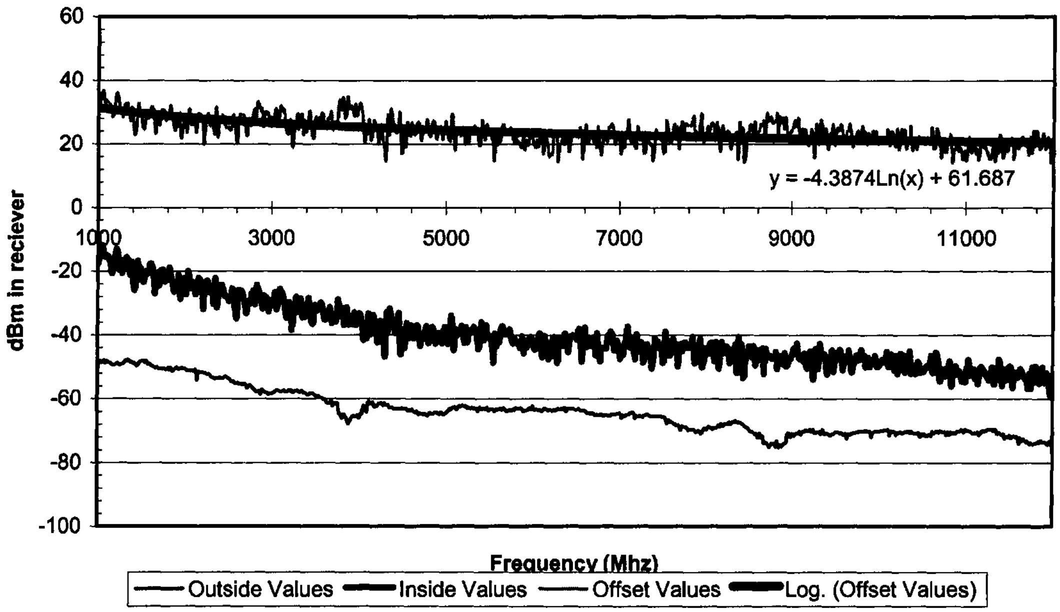
In Smith, a NIST standard spherical source is used to generate a very well known E-field to calculate a "position specific "antenna correction factor (ACF). This ACF has all of the effects of the chamber built into it (Smith, 353). After several tests performed both in the chamber and in an open-air test site (OATS), a regular frequency-dependant curve appeared to exist in all of the data from the chamber but not in the data from the OATS. When this trend was seen, a test was developed to find the exact form of this amplitude offset curve between the chamber and the OATS. In this test, a conical omni-directional antenna powered by a Gigatronics signal generator through ~35' of heliax cable was used as a source for both the inside and outside tests. An HP 70000 series spectrum analyzer with a Tensor 1-10GHz double ridged guide horn through ~10' of heliax cable was used as a receiver in both in the chamber and OATS tests. In both the outdoor and indoor tests, the position and height of the Tx antenna was varied. Plots were gathered using a laptop computer and a data capture program through a GPIB interface. The exact same equipment with the exact same settings was used both inside and outside. The data from these tests nearly speaks for itself. The offset between the chamber and the OATS is nearly constant. It is a function of frequency, and there appears to be some random fluctuations which will essentially be the error associated with the chamber. The best-fit curve

$$\text{offset}=61.687-4.3874\ln(f_{MHz})$$

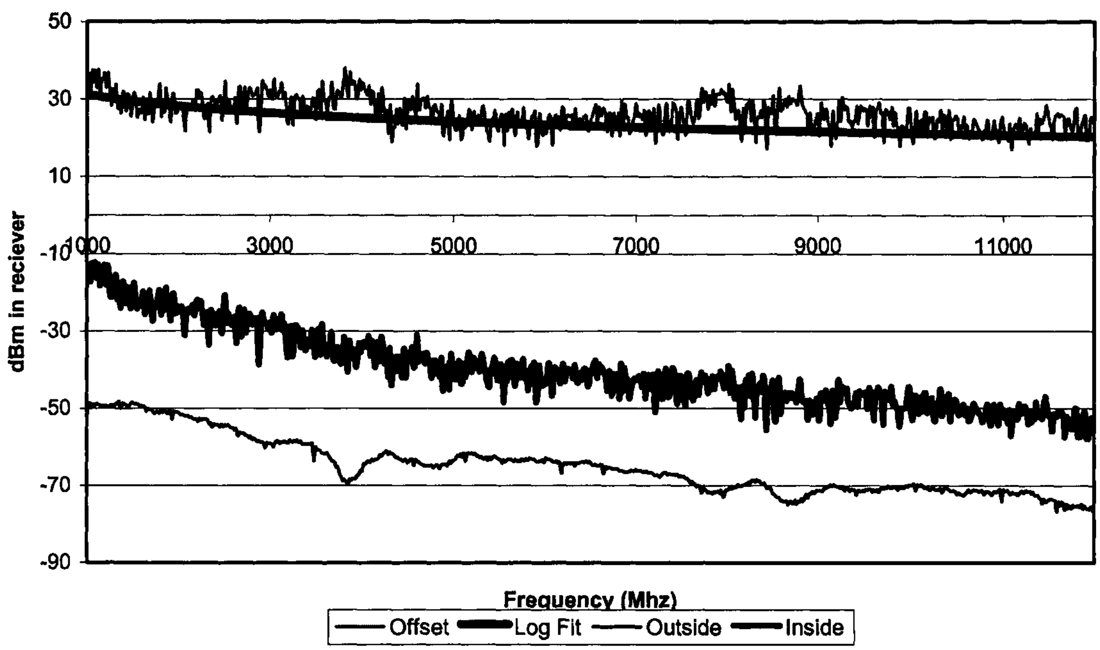
is kept constant in all of the plots. When this function is subtracted from measurements done inside of the chamber, the measurement itself is accurate to within the error of the offset. An interesting quality of the offset is that it is large and positive. This means that for any tests done in the chamber, roughly 20dB of sensitivity is added to the system due to the increase in power levels from outside to in the chamber. This offset may be due to many factors such as the 'microwave oven effect' (re-reflection of RF waves inside the chamber), wave-guide effects in which the apparent space loss is decreased because the environment is essentially a multi-mode wave-guide structure, apparent gain suppression of highly directional horns, apparent gain increase for omni-directional antennas, and many other factors. Reguardless of the causes of this function, it represents the correction factor associated with a specific antenna in a specific measurement scheme for measurements performed in a specific environment. In this particular case, the entire setup is one favorable for radiated emissions testing which is likely to be the most likely to be used in most testing in the EVLA shielded chamber. The setup consists of a Tensor

1-10GHz double-ridged guide antenna, the shielded chamber, and an omni-directional source (to simulate equipment testing). The standard setup with the Rx antenna 1m from the wall centered in the chamber with the EUT inside a standard setup boundary as shown in a later section of this paper is also embedded into this offset function. More or less, this offset and the methodology behind it represents an offshoot of the position specific antenna factors discussed in Smith (IEEE 1996 International Symposium on Electromagnetic Compatibility). The accuracies gained from the procedure are not as great as in those obtained with position specific antenna factors, however this method does allow for reasonable accuracy to be maintained within a completely unlined chamber without much in the way of very specialized and expensive equipment. Due to this increase in power levels and sensitivity to emissions it may even be favorable, if the error introduced is acceptable, to use unlined chambers for radiated emissions testing. However, this is only applicable if this offset curve may be well characterized, as in this case.

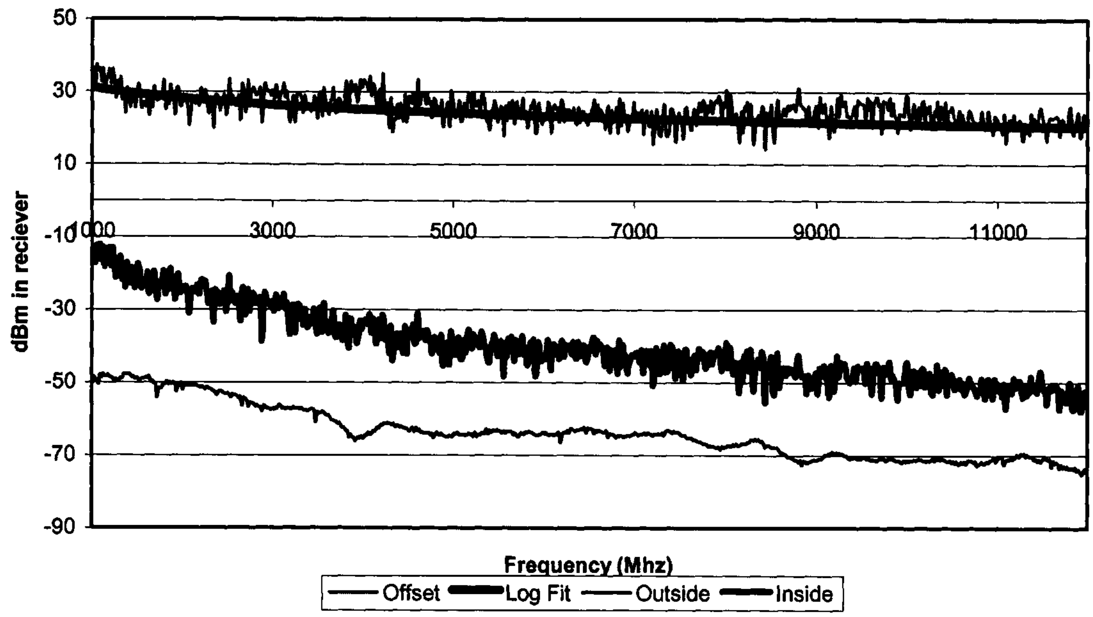
Chamber Offset Characterization Form Single Data Set 1



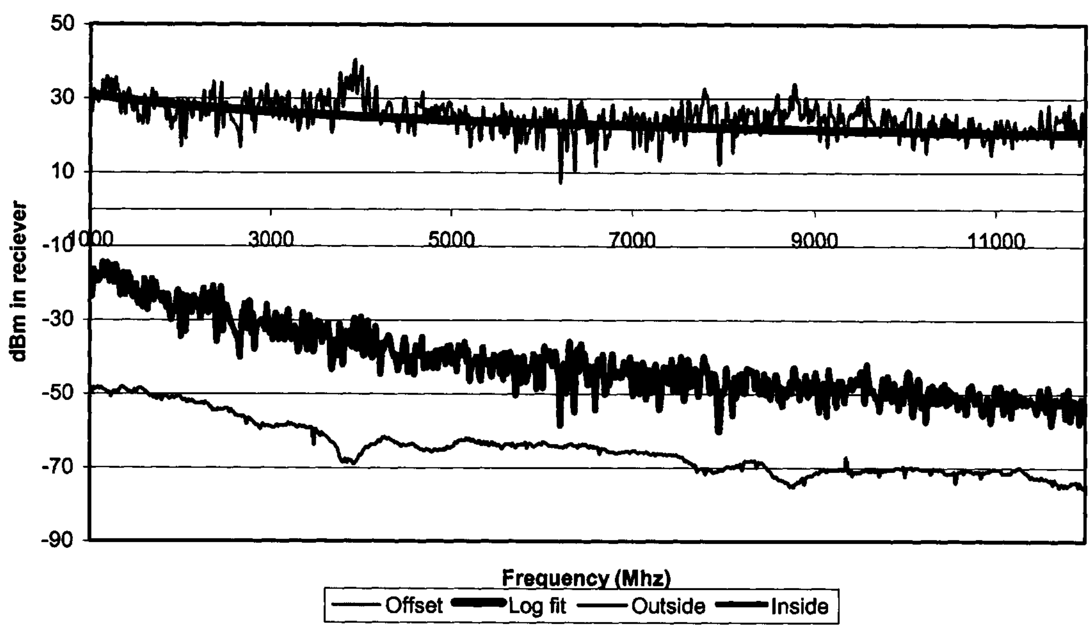
Chamber Offset Characterization Form Single Data Set 2



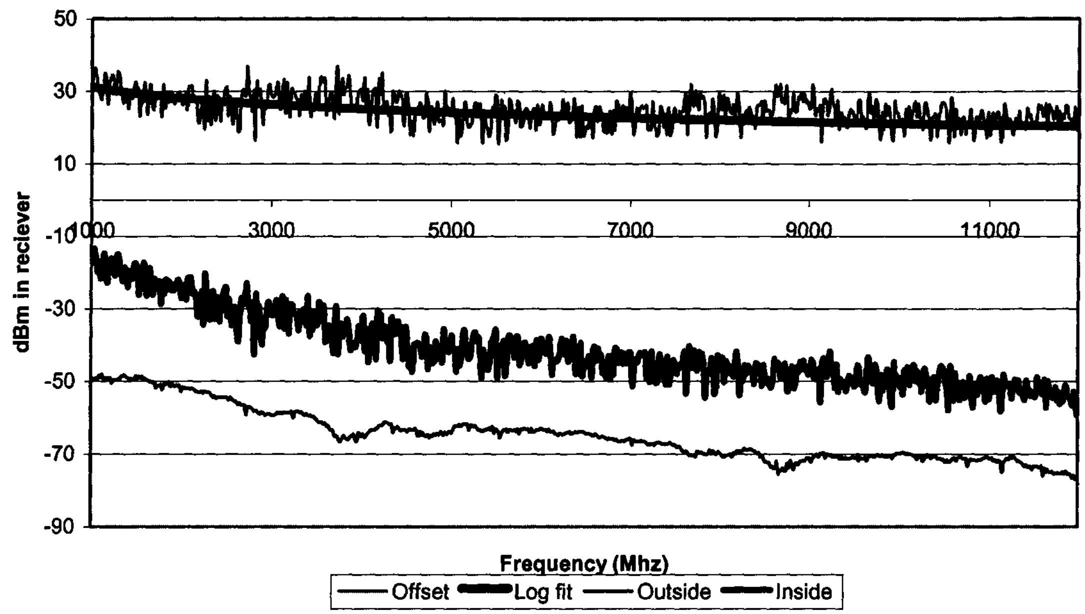
Chamber Offset Characterization Form Single Data Set 3



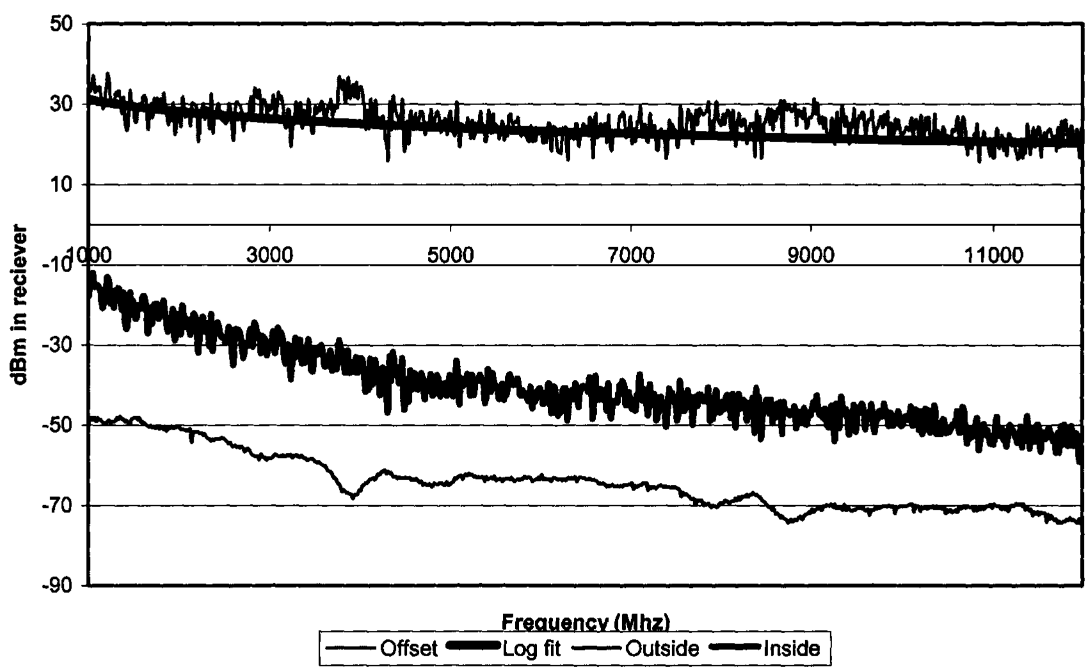
Chamber Offset Characterization Form Single Data Set 4



Chamber Offset Characterization Form Single Data Set 5



Chamber Offset Characterization Form Single Data Set 6



Error Introduced by the Chamber

The error introduced by the chamber may readily be seen in the plots for chamber vs. OATS offset. Almost all of the variation in the offset curve is caused by random fluctuations within the chamber. This is the error in measurement caused by the chamber. By taking the best fit curve shown in the plots for the offset to be the average value for the offset at any particular frequency, the standard deviation of the real data from this average may be calculated by $\sigma^2=\sqrt{}(x-x'/n-1)$. After computing σ^2 for several position comparisons, it was found that the average standard deviation was 3.813dB, the greatest was 4.403, and the smallest was 3.249, from several comparisons among single data sets. The error margin required by the FCC for commercial testing is only 4dB, the military allows only 3dB (Javor, 142). When looking at an average from all outside positions compared to an average from all inside positions, 10 samples for the indoor average and 6 samples for the outside average, the standard deviation dropped to about 2.2dB. The error in measurement may be even further reduced by performing multiple scans while the EUT and Rx antenna are left in a single position, and averaging the data retrieved. This may be easily achieved by setting the spectrum analyzer to video average mode and performing perhaps, 100 scans. The error would then be reduced by the large sample size, with SWR effects causing randomly distributed variations in the amplitude of the power received in each scan. The amount of this reduction is indeterminate, however it is estimated that data with errors of less than +/- 2dB could be attained by using this averaging method with large enough sample sizes.

II. Radiated Emissions Test Protocol

For the processes of characterizing the impact, in terms of RFI, that each new piece of equipment introduced into the VLA and EVLA will have, it is necessary to codify a standard test setup and procedure with common equipment to measure, calibrate, and report on the emissions from this new equipment. This paper will present the standards used for the EVLA shielded chamber test setup and procedure for radiated emissions testing. The test setup and procedure guidelines of MIL-STD-462 and IEEE radiated emissions test guidelines have been adopted and adapted where applicable to form those used for the tests done for the VLA and EVLA.

Test Environment/Equipment:

The minimum test frequency used in the chamber must be at least 126MHz. For frequencies lower than this, the chamber will exhibit less than ideal measurement characteristics due to a dramatic decrease in the number of possible propagation modes.

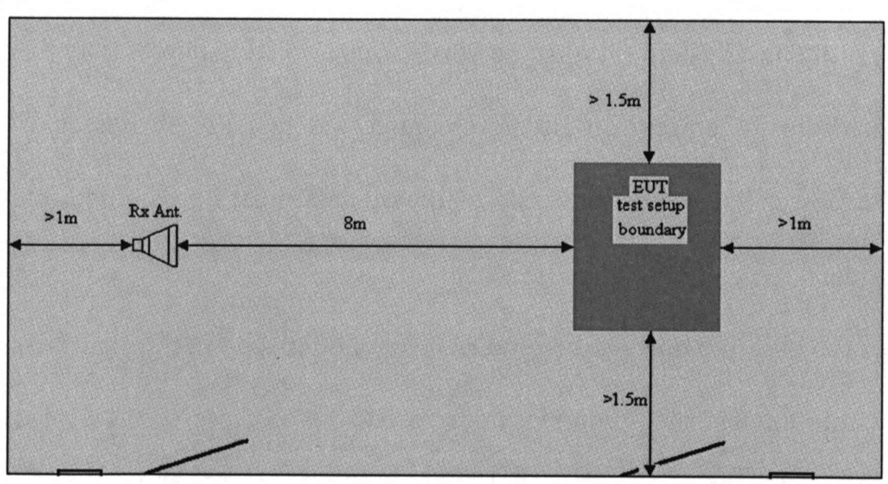
The recommended receiver for use in radiated emissions testing in the chamber is an HP 70000 series spectrum analyzer with a frequency range of 0.01-26.5GHz, 3MHz-10Hz RBW, calibrated noise floor ~ -120dBm with preamp off. The recommended Rx antenna for use in the chamber is a Tensor 1-10GHz double-ridged guide antenna. Other characterized antennas are available for 200MHz-1GHz and for higher frequencies, 12-26.5GHz. All antennas used for chamber measurements should be well characterized throughout their usable frequency range. All cabling used for measurements in the chamber should be well characterized and the loss of this cabling should be accounted for in calculation of EIRP or SPFD.

For calibration purposes, a standard test tone is emitted inside the chamber at a known level across all frequencies used in the test. To emit this tone, a standard, somewhat calibrated set of equipment must be used. Gigatronics 610 and HP 8672 synthesized signal generators have been used as reliable sources of test tones at frequencies from 1-10GHz. These generators feed an omni-directional cone antenna inside of the chamber. The cabling should be well characterized and the loss accounted for in the calibration test process.

Test Setup/Procedure

<u>Setup</u>

For every test performed in the shielded chamber, to maintain consistent results, the same setup must be used. The test setup boundary and Rx antenna placement should be kept as consistent as possible in every test. The figure below gives guidelines for equipment under test (EUT) placement and for Rx antenna placement. The test setup boundary is also currently well marked within the chamber. These guidelines should be followed as precisely as possible.



Test Setup Boundary Conditions

Also, the EUT and the Rx antenna should be placed 1-2m off of the ground at the same height during each test, as well as at least 1m from the ceiling of the chamber when possible. Two phenolic tripods are currently used to support the antennas at a height of up to 2.5m during calibration and testing.

Testing

Before each emissions test, a calibration signal should be applied using a characterized emitter at a known power. This signal should be swept from below the lowest frequency of the test to above the highest frequency of the test. The lowest frequency that should be used in the chamber is 126MHz. Below this frequency, the number of possible modes that can exist begins to fall below 100 in the chamber(MIL-STD-461E, 123). The highest frequency of use with current equipment is 22GHz. The signal should be with +/-4dB of the expected value in the receiver to be used for the test. Next, with the calibration antenna and all subsequent cabling removed, leaving just the Rx antenna and cabling in the chamber with the doors closed and lights off, a scan over the entire test frequency range must be performed to establish the baseline noise floor (sensitivity) of the test system. It must be verified that no RFI sources may be detected in the chamber, with no equipment in the chamber. If signals are detected in the test chamber, the power level and frequency of the signals must be recorded and presented with the test data.

After the baseline noise scans, the EUT may be placed in the chamber. The EUT should lie within the test setup boundary described above. Approximately 1m of cabling from the EUT should be run parallel to the front of the test setup boundary in front of (toward the Rx antenna) the EUT. With the EUT setup in a simulated operational state, (power on, EUT functioning normally, data on, Tx on, all cabling connected and active, etc.) the doors of the chamber should be closed with all personnel outside of the chamber and the lights turned off. The SA should be set such that the frequency span divided by the RBW is greater than 1022. The reference level must be set such that the lowest amplitude of noise fluctuation on the screen is not truncated by the bottom of the screen (when the SA is not on peak hold mode). With the SA in peak hold mode, perform the emission scan over the selected frequency range. When the scan is complete, a plotter or data acquisition program may be used to record the raw data. For a standard HP GPIB plotter, simply ensure that all settings for GPIB communications between the plotter and SA are correct, and then select DSP (display key) and then select plot on the right hand side menu bar. For the GPIB data acquisition program HP7Dump3, all settings for communications must be correct, in DOS mode on the computer to which the SA is connected (via the GPIB and Micro488 interface) typing QB at the DOS prompt when in the directory of QBasic and the data dump program will start the QBasic program in the proper directory. Once QBasic is started, opening HP7Dump3 (or the most current version), and running the program will begin data acquisition. Following the onscreen prompts and entering the correct information for the scan that is being performed is imperative. If data is entered incorrectly, the data dump program will record the wrong settings and will change the settings on the SA. Once the raw data is recorded, the SA may be turned off and all equipment removed from the chamber. It is important to keep the chamber clear of all unnecessary equipment and personnel during testing. The QBasic code for HP7Dump3 is included after this section.

With the data on a floppy disk, as the data dump program provides, it is possible to import the data into an excel file and perform calibration calculations on the data in the spreadsheet. A spreadsheet that takes raw dBm and calibrates it to EIRP at the EUT from the system described with the Tensor horn as an Rx antenna is shared on the NRAO network computer IPGCoop. With a plot of the emissions from a particular piece of equipment, manual calibration of several of the most powerful points of the emissions may be sufficient to draw conclusions about the impact of the device on the VLA/EVLA. To do this, the equation below takes dBm readings, with a known ACF and frequency, and converts these readings into EIRP(dBW/Hz).

$$\mathrm{EIRP}=10\mathrm{Log}\left[\frac{4\pi 10^{((P(\mathrm{dBm})-30)/10)}}{10^{((20\mathrm{Log}(F\,(\mathrm{MHz}))-29.8-\mathrm{ACF})/10)}}\right]-[10\mathrm{Log}(\mathrm{RBW}_{\mathrm{Hz}})]-[10\mathrm{Log}(1/4\pi r^2)]-[\mathrm{offset}]$$

Where the term '[offset]' is the chamber power level offset from OATS testing. Once the emission levels are calibrated in dBW/Hz, the total path loss to the nearest array element may be subtracted from the levels to find an SPFD at the feed of the nearest antenna at the VLA. This SPFD may be compared to the ITU harmful level criterion in the specific frequency range of interest (once the ITU levels are changed to a /Hz bandwidth). When compared to these levels, the emissions of every device at the VLA site after shielding and space loss must be lower than those that would be harmful to the EVLA. If the levels are higher than these levels after path loss, additional required minimum shielding should be reported for the installation of the EUT.

HP7Dump3

```
50 DECLARE SUB GETNPRINT ()
100 CLS
200 CLOSE
300 com$ = "com1:19200,n,8,1,bin,RB8192"
400 REM:
500 REM:
600 OPEN com$ FOR RANDOM AS #1
610 INPUT "INPUT CENTER FREQUENCY IN MHz:", CF$
620 INPUT "INPUT SPAN IN MHz:", SP$
630 INPUT "INPUT RBW IN KHz:", RBW$
640 INPUT "INPUT REFERENCE LEVEL IN dBm:", RL$
642 INPUT "PEAK HOLD ON? (Y/N):", PHO$
650 Q$ = ""
660 WHILE Q$ <> "Q"
682   INPUT "INPUT SEQUENTIAL FILE NUMBER FOR OUTPUT FILE NAME:",
OFN$
690   OPEN "A:\TDAT" + OFN$ + ".TXT" FOR OUTPUT AS #2 LEN = 400
700   T = TIMER
800   DO WHILE T + .2 > TIMER
900   LOOP
910   PRINT "Initializing the Micro488"
1000  FOR i = 1 TO 5
1100    PRINT #1, CHR$(13);
1200    T = TIMER
1300    DO WHILE T + .1 > TIMER
1400    LOOP
1500  NEXT i
1600  PRINT #1, "I": CALL GETNPRINT: REM- Init  u488
1700  PRINT #1, "EC;1": CALL GETNPRINT: REM- enable echo
1800  PRINT #1, "H;1": CALL GETNPRINT: REM- enable HW handshake
1900  PRINT #1, "X;0": CALL GETNPRINT: REM- disable XON/XOFF handsh
2000  PRINT #1, "TC;2": CALL GETNPRINT: REM- Set EOL term from SW=CR
2100  PRINT #1, "TB;4": CALL GETNPRINT: REM- Set EOL term from 488 bus=
2700  PRINT "initialization complete"
2720  PRINT #1, "A": CALL GETNPRINT: REM- Abort I/O-Reset 488 bus
2730  PRINT #1, "C": CALL GETNPRINT: REM- Clear all 488 devices-reset.
2740  REM
2742  PRINT #1, "OA;18;TRDEF TRA,1024;": CALL GETNPRINT
2743  REM- "TA"to HP SA = Set display data to 1024 values.
2744  PRINT #1, "OA;18;SP "; SP$; "MHZ;": CALL GETNPRINT
2745  REM- "TA"to HP SA = Set span
2746  PRINT #1, "OA;18;CF "; CF$; "MHZ;": CALL GETNPRINT
2747  REM- "TA"to HP SA = Set center frequency
2748  PRINT #1, "OA;18;RL "; RL$; "DBM;": CALL GETNPRINT
2749  REM- "TA"to HP SA = Set reference level
```

```
2750  PRINT #1, "OA;18;RB "; RBW$; "KHZ;": CALL GETNPRINT
2751  REM- "RB"to HP SA = Set resolution bandwidth
2752  IF PHO$ = "Y" THEN PRINT #1, "OA;18;MXMH TRA;": CALL GETNPRINT
2753  IF PHO$ = "N" THEN PRINT #1, "OA;18;CLRW TRA;": CALL GETNPRINT
2754  REM- set peak hold or not.
2755  REM-
2760  T = TIMER
2761  DO WHILE T + 2 > TIMER
2762  LOOP
2763  REM-
2766  PRINT #1, "OA;18;TRA?;": CALL GETNPRINT: REM-Output TA to dv18"
2768  REM- "TA"to HP SA = Output display data ascii string to 488
2270  PRINT #1, "EC;0": CALL GETNPRINT: REM- Disable echo.
2780  PRINT #1, "EN;18": REM- CMD u488 TO READ 488 BUS .
2790  P = 0
2800  DO WHILE (LOC(1) OR (P < 50000))
2810    P = P + 1
2900    D$ = D$ + INPUT$(LOC(1), 1)
3300  LOOP
3400  PRINT D$, "P="; P
3402  DCH$ = "": DNUM$ = "": DNUM = 0
3410  FOR PT = 0 TO LEN(D$)
3412    DCH$ = MID$(D$, PT + 1, 1)
3414    IF DCH$ <> "," THEN DNUM$ = DNUM$ + DCH$ ELSE PRINT #2,
STR$(DNUM); ","; DNUM$; CHR$(10); CHR$(13); : DNUM$ = "": DNUM = DNUM
+ 1
3430  NEXT PT
3500  PRINT #2, CF$
3510  PRINT #2, SP$
3520  PRINT #2, RBW$
3530  PRINT #2, RL$
3540  PRINT #2, PHO$
3600  PRINT #1, "C;18": CALL GETNPRINT: REM- Clear all 488 devices-reset.
3700  CLOSE #2
3710  INPUT "PUSH ENTER TO CONTINUE, Q TO QUIT: ", Q$
3800 WEND
3900 CLOSE
10000  END
20000 SUB GETNPRINT
20100 T = TIMER
20200 DO WHILE T + .1 > TIMER
20300 LOOP
20400 A$ = INPUT$(LOC(1), #1): PRINT A$
30000 END SUB
```

Program Written by Dan Mertely

III. Characterization of RF Shielding Properties of Buildings at the VLA Site

In order to determine the RF shielding requirements for any given piece of equipment at the VLA site, the total path loss from the place of installation to the nearest element of the array must be known. Most available numbers for this path loss at various positions at the site had previously been based on assumptions and speculation. A fairly thorough examination of total path loss from many points at the VLA site to the nearest array element in the worst case (i.e. least path loss) was performed. A mobile monitoring cart was assembled with an HP 70000 series spectrum analyzer and amplifiers covering 200MHz-10GHz with less than 4dB noise figures and roughly 30dB gain in each amplifier band with manually operated coaxial switches to switch bands. This cart was instrumental in making many of the shielding and path loss measurements presented in this section.

Shielding

The shielding provided by the architecture of buildings at the VLA site represents a significant portion of the overall path loss from a radiating source to the nearest array elements. Knowing this quantity is therefore helpful, if not necessary, in determining the required shielding for radiating sources within the site. To find the shielding of the buildings at the site, the shielding provided by a number of buildings at the site was directly measured using a straightforward approach. For those buildings not directly measured, similar buildings in construction may be used to approximate the attenuation due to architecture.

Test Setup/ Procedure

All of the structures tested for shielding mentioned in this paper, with the exception of the vertex room, used the same setup and procedural guidelines. A Gigatronics 610 signal generator with ~6' of heliax cable feeding a Tensor 1-10GHz double ridged guide horn was used as a source in the tests. An HP 70000 series spectrum analyzer fed by ~6' of coaxial cable from a Stoddard 1-10GHz directional off-tip LCP conical log spiral antenna was used as a detector in the tests. All of the equipment was set up previous to each of the tests in an open-air environment with minimal reflective surfaces in the vicinity to establish a baseline for received power at several frequencies for a calibration run. In this calibration, the same separation distance (roughly 10m), transmission power, Tx and Rx antennas, and SA settings were used as in the test. Then, the source was moved into the area of the under test, the separation distance of the calibration was maintained, and with the SA on peak hold, the signal generator was swept from 500MHz to 8GHz. The Rx and Tx antennas were carefully aligned in each setup because of the high directivity of both antennas. This alignment was performed by moving the antennas until the received signal power attained a peak value. After the tests were performed, the data could be analyzed in a very straightforward manner. It is known that

$$P_r=(\lambda/4\pi r)^2\, G_t G_r S P_t\,;$$

where P_t is power transmitted, G_t is the gain of the transmit antenna, $(\lambda/4\pi r)^2$ is free space attenuation, S is attenuation from shielding, P_r is the power received, and the gain of the receive antenna is G_r. (S) can then be found by the difference (in dB) between P_r in the calibration with no shielding and the test with all other terms kept constant. By the relation:

$$S=[P_r(4\pi r/\lambda)^2\ (1/G_tG_rP_t)]_{cal} + [P_r(4\pi r/\lambda)^2\ (1/G_tG_rP_t)]_{test}$$

in which all terms, when kept constant, cancel except P_r from the calibration and the test so that:

$$S(dB)=[P_r(dB)]_{cal}-[P_r(dB)]_{test}.$$

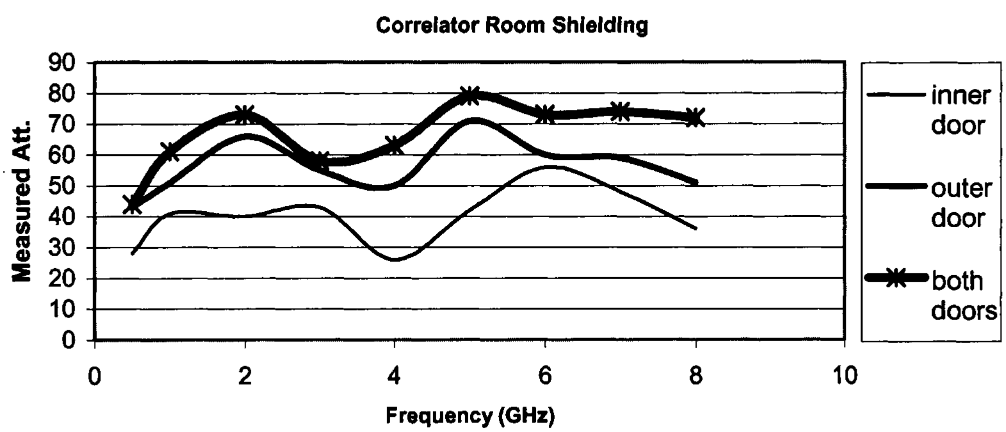
For the vertex room of the antennas, the tests were considerably more complicated. Due to the difficulty in repeating the shielding tests of other areas tested and keeping a 10m-separation distance from the vertex room, a different test method was developed. A signal source was put into the vertex room of antenna 22, which also houses the w8 monitor system in place to monitor RFI in P and L band. With the signal source generating an L-band signal (1440MHz), the W8 monitor was used to record the incident power into the L-band feed. Also, the VLA was used to measure the power generated by the signal source incident on other antennas. The power generated by the source was calculated and measured for confirmation in the EVLA shielded chamber. The difference between the produced power and the incident power at the L-band feed horn was taken as a measurement of the shielding of the vertex room. In addition to this, the fact that the vertex room is very similar in construction to the pedestal room is helpful to the extent that the measured, frequency dependent shielding for the pedestal room should be nearly identical for the vertex room.

Results

The plots below give the results of the shielding tests performed on structures at the VLA site. For those not measured directly, a similar structure may be used. A list of those structures not measured and the shielding that should be assumed for that structure is given after the plots. Some error may be present in the data from additional atmospheric attenuation (which may vary from day to day and with temperature), multi-path propagation, reflection, and absorption. Attempts were made to minimize each of these effects in the tests performed.

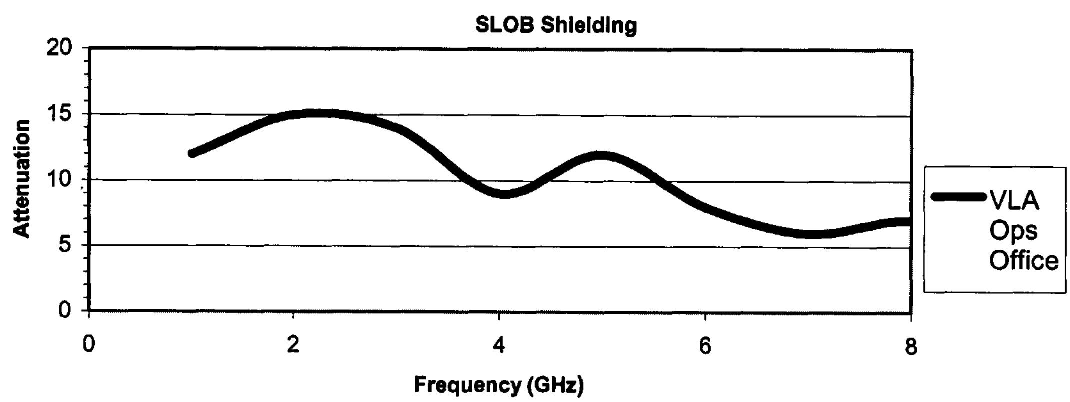
Correlator Room

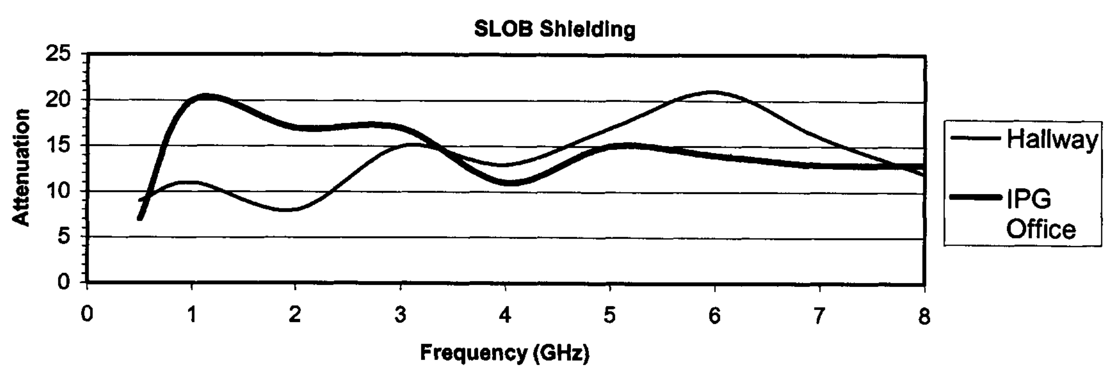
The Correlator room is a large shielded chamber that currently houses the VLA Correlator. It has a double door entryway to prevent disruption of observations due to emissions from the Correlator during normal maintenance. The Correlator is known to produce high-powered emissions at every 100MHz interval from 100MHz to as high as 22GHz. Also, during the EVLA transition phase, the MCB Ethernet switches are possibly to be housed in this room.



Science, Library, and Office Building (SLOB)

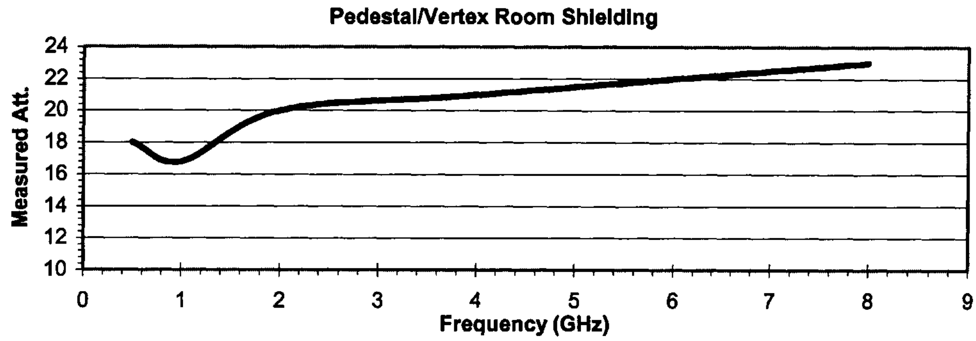
Two separate tests were performed on the SLOB. The first test done measured the apparent shielding from the IPG office in the SLOB and from the main hallway in the SLOB. These original tests turned up some very interesting results, which seemed impractical because the shielding was much higher than anticipated. In light of this surprise, the tests for these areas were repeated. The repeated tests for the hallway through the outside east-facing door and for the IPG storage room were nearly exactly what had been seen before. Upon inspection of the path, a few possibilities for increased path attenuation became apparent. The presence of a large bush outside of the IPG storage room, the presence of various metallic items inside the storage area, and the presence of a metal door (in the case of the hallway measurement) may have caused more apparent shielding than the architecture of the building itself. To minimize these types of error, the VLA ops room was chosen as an area for additional measurement. There was no greenery in the transmit-receive path from this room, and no metal objects stored in the room to affect the shielding measurements.





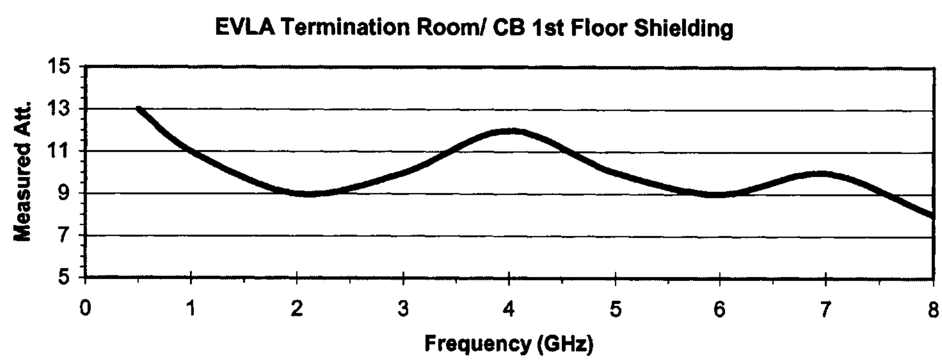
Vertex and Pedestal Room

The values presented here were directly measured for the pedestal room of the antennas. The only value actually measured for the vertex room was at a frequency of 1440MHz. The shielding at this frequency of the vertex room was calculated by Ylva Pihlström and I to be roughly 20dB.



EVLA Fiber Termination Room/ Control Building(CB) (1st floor):

Measurements made in the EVLA fiber termination room and in other positions for the CB 1st floor showed about the same results. For the most part, the only emissions from these areas will be from computers. The shielding of these areas was found to be approximately 5 to 10dB depending on proximity to windows and doors. When near doors and windows, the measured attenuation decreased.



Electronic Room (D-Racks Location):

The tests performed in this area showed no apparent attenuation at any frequency from 200MHz-8GHz. This may be due to the presence of very large, unscreened windows at the North end of the room. A plan to screen these windows to gain some shielding was proposed and rejected for aesthetic reasons.

L-Band Shielding Tests

The remaining measurements were performed only at L-band (from 1GHz-1.5GHz). This was done because the majority of anticipated emissions from these locations will be from computers and other equipment with most high-powered emissions in this band.

Tech Services Building:

The L-band shielding characteristics of the Tech Services Building have been carefully measured. From inside of the machine shop, approximately 15dB of shielding at was present. From in front of the offices to the North, approximately 25dB of shielding was seen, with nearly equivalent results from the vending area. The weakest point in terms of the shielding of this building were the double doors facing North with about 5dB shielding, and the windows with no apparent shielding. All equipment at normal locations (in an office or within the machine shop) within the building may be assumed to have 15dB of architectural shielding. Also, the same shielding may be assumed to exist in all buildings with similar construction at the site.

AAB Building:

With the large opening in the North face of the AAB, performing a shielding measurement for the AAB as a whole would be pointless. However, from within the offices at the AAB, approximately 20dB of shielding was found at L-band. This may seem a bit outrageous, but the small windows and metal shell of the building as well as screening of the windows may account for this large shielding effect.

Control Room (Op. Area):

Tests were performed to characterize the shielding at L-band of the operator's area in the control building. Shielding in this area tended to be about 15-20dB, with the weakest areas being around the doors. Improvements of up to 5dB were still seen by latching the doors instead of letting the doors rest on the doorframe. Many inexpensive improvements could potentially restore the shielding of this area to 30dB or more of shielding at L-band. Small wire mesh screening placed over the windows on the doors, bonded to the existing screen may help to improve shielding. Also, bulkhead plates bonded to the construction cloth with filtered connectors for all penetrations of the shielding may help. Other methods will be researched and reported on.

ALMA Engineering Trailer:

After an initial survey of this building determined that shielding (10dB) was insufficient to house a large number of high speed pc's, a number of improvements were implemented to increase the architectural shielding of the trailer. These changes and the before and after shielding results are given in VLA/VLBA Interference Memo 29. The results of the shielding test after the improvements showed that the trailer would attenuate L-band plane waves 30dB.

ALMA Contractor's Trailer:

Tests of the contractor's trailer at the ALMA test site showed attenuation of only about 3dB for L-band radiation. The trailer has all wood construction with screened windows, so these results were anticipated.

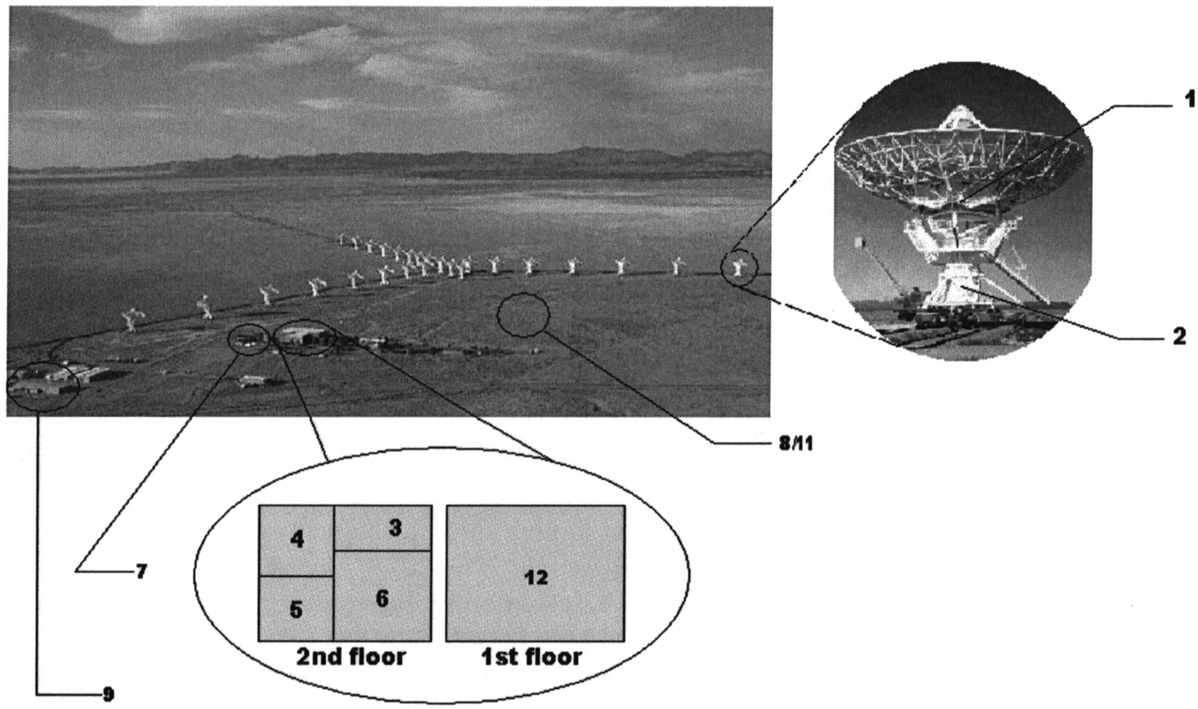
Hoffman Box (ALMA Tower):

After improvements described in VLA/VLBA Interference Memo 29, the shielding of the Hoffman Box at the base of the ALMA weather and web-cam tower was measured and found to be about 20dB.

Propagation Loss Estimation

When considering the overall path loss between many of the buildings at the VLA site to the nearest array element, the propagation loss that occurs with all spherically propagating waves is likely to constitute the bulk of the overall loss. However, in dB doubling the distance between the source and the receiver only results in 6dB of additional attenuation. Therefore, estimations of distances from any particular building at the site to the nearest array element are not accuracy critical. In fact, the attenuation due to spherical propagation is between 50dB and 60dB for most buildings at the VLA site while the difference in the separation from the building to the nearest antenna may vary as much as 200m. The single case that this is definitely not true for is the antennas themselves. The path loss from one antenna to the next or from the vertex or pedestal room of an antenna to itself, with shielding included, can be less than 60dB. This loss, in any case, may be calculated by the simple formula att.=$10\log(1/4\pi r^2)$. In addition to calculation of the loss, measurements were performed using a calibrated source with a calibrated receiver to find this propagation loss between several points of interest to the nearest array element. All of these measurements fell within 3dB of the calculated values based on rough estimates of the distance between the two points. Below is a table of approximate path losses from several buildings at the site for L-band only using the shielding data from the previous section of this paper.

L-Band Shielding at the VLA Site



#	Location	Shielding	*Space Loss to Nearest Antenna	**Total Path Loss
1	Vertex Room	20dB	30dB	50dB
2	Pedestal Room	20dB	30dB	50dB
3	Control Room	20dB	60dB	80dB
4	Electronics Area	0dB	60dB	60dB
5	Corr. Room	60dB	60dB	120dB
6	Other 2nd Floor CB	5dB	60dB	65dB
7	SLOB	20dB	50dB	70dB
8	ALMA Trailer	30dB	60dB	90dB
9	Engineering Services Bldg.	15dB	50dB	65dB
10	Antenna Barn Offices	20dB	50dB	70dB
11	ALMA Contractor's Trailer	0-3dB	60dB	60dB
12	1st Floor CB	5-10dB	60dB	65dB

* Indicates worst-case possibility (the shortest distance to the nearest antenna in any currently possible configuration). Rounded to the nearest 5dB boundary.
** Takes into account space loss, shielding, reflection, and absorption. Assumes isotropic radiators and 0dBi gain for VLA antennas.

IV. MCB Ethernet Switch Emissions Test

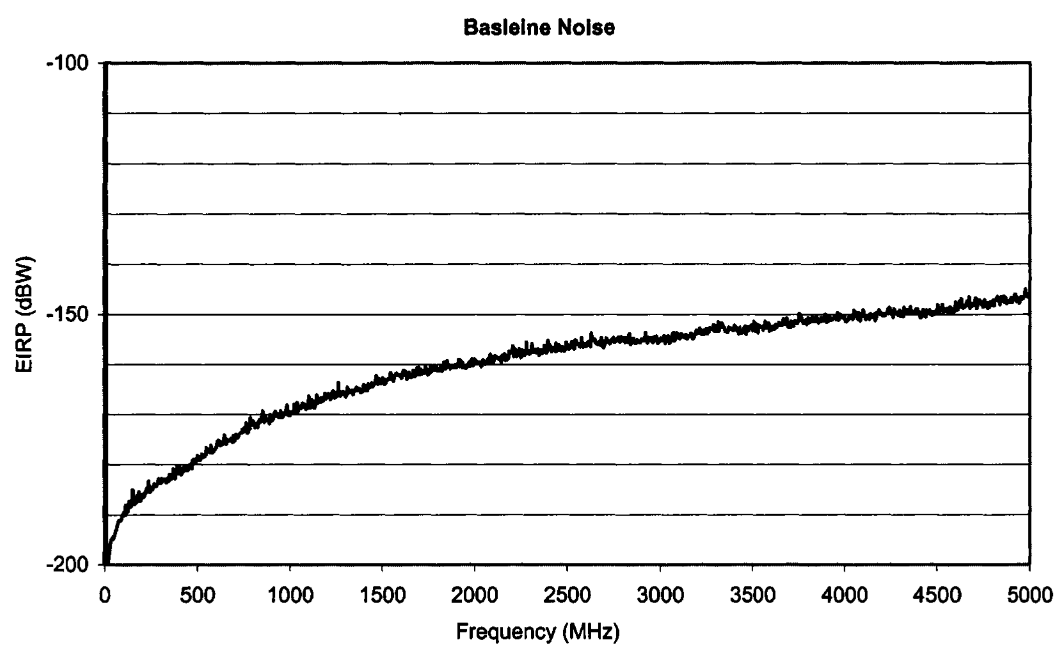
As part of the master and control bus (MCB), a set of Ethernet switching equipment will be installed in each antenna of the EVLA and a corresponding set will be installed within the control building. These switches will be responsible for transmitting all of the data gathered by the samplers from each receiver in the EVLA antennas, and therefore must be located in the vertex room (near the receivers). To allow for these pieces of digital equipment to be placed so near to the feeds of the antennae, the emission of the switches, after shielding and path loss from the vertex room must fall below the international telecommunications union (ITU) harmful thresholds for RFI. The scientific staff has recommended using the harmful levels listed for the total power incident on a single dish. Interferometers such as the VLA gain immunity to interference based on a number of factors as discussed in EVLA Memo 46. However, in the worst-case scenario with a very compact array, observing at low frequencies where the switches tend to radiate with more power, most of the immunity of an interferometer to RFI is lost.

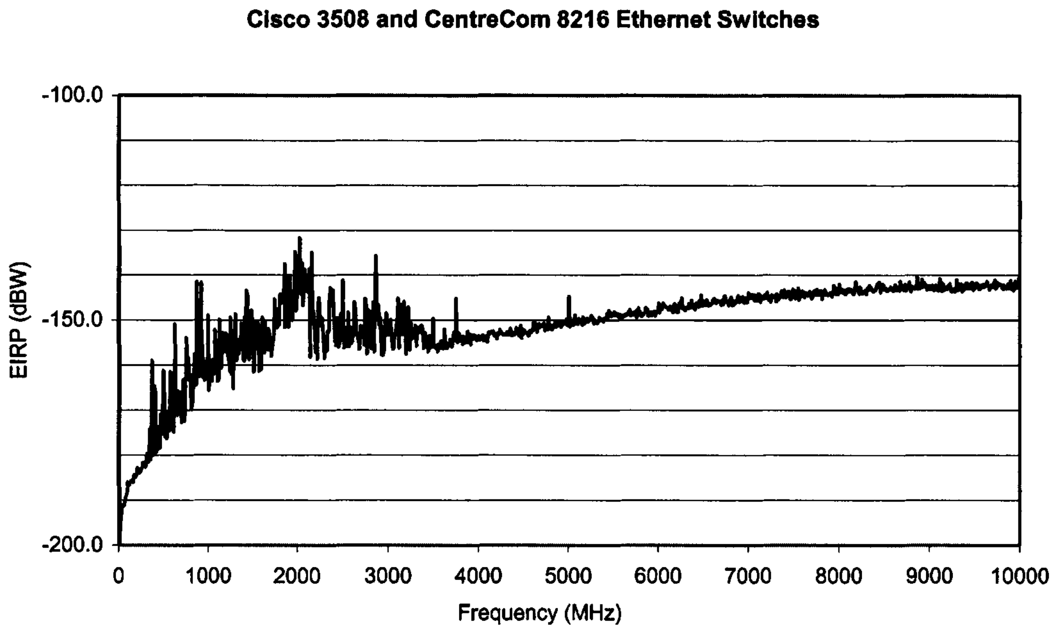
Test Rationale/Setup/Procedure

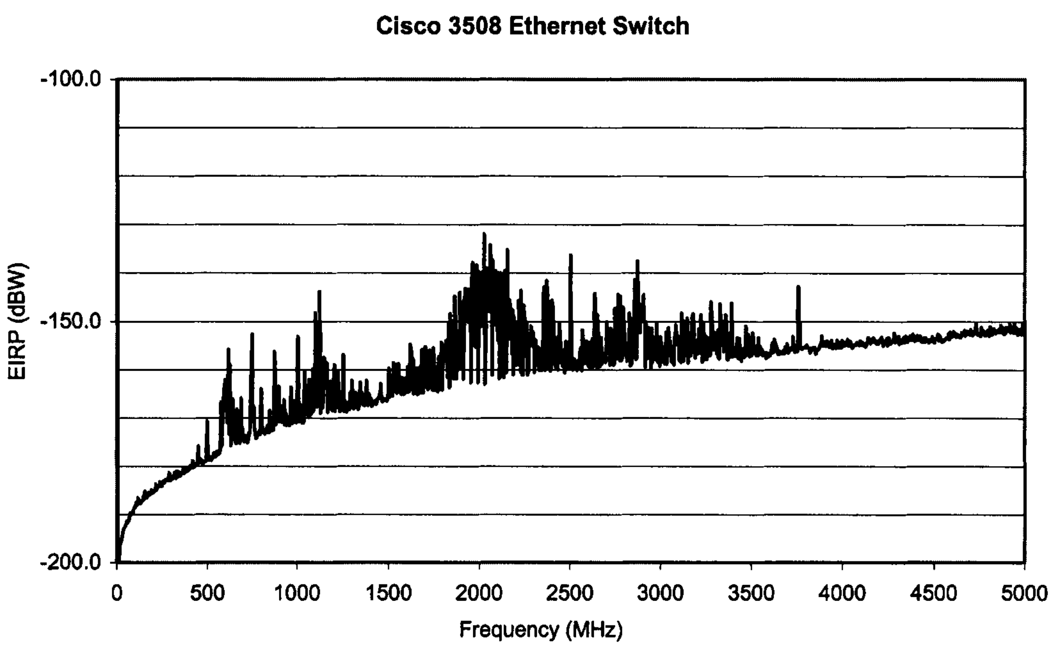
Two sets of Ethernet switchgear were proposed for use in the MCB. One of these sets consisted of a Cisco 3508 and a CentreCom 8216 FXL/SC Ethernet switch. The other was a single Cisco 4506 Ethernet switch. It was believed that changing the amount of data traffic on the switches would change the emissions. Therefore, after extensive setup, the first set of switches was tested with and without data traffic being sent through them. For the second set, the Cisco 4506 switch, the time needed for this additional setup was not available before testing, but it is assumed that the response to traffic would be similar. The test setup and procedure were kept consistent with the 'Radiated Emissions Test Protocol' mentioned above. There were no noted anomalies in the data collected, the calibrations were well within expected error, and no RFI was noted in the chamber before the tests with the equipment off.

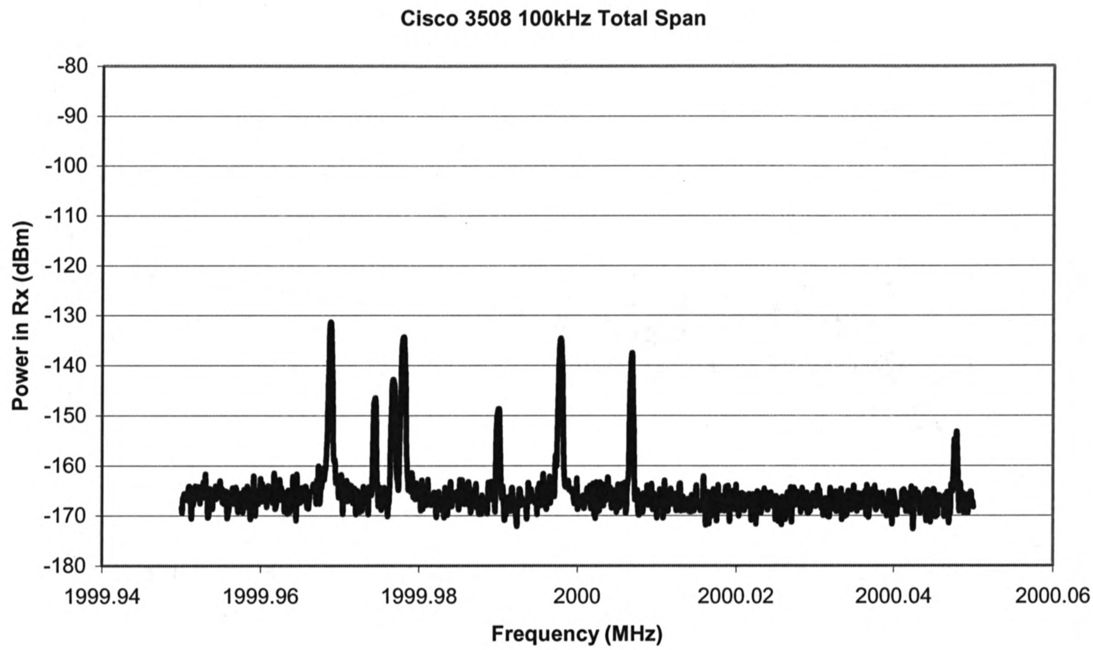
Emissions of Cisco 3508 and CentreCom 7216 Ethernet Switches

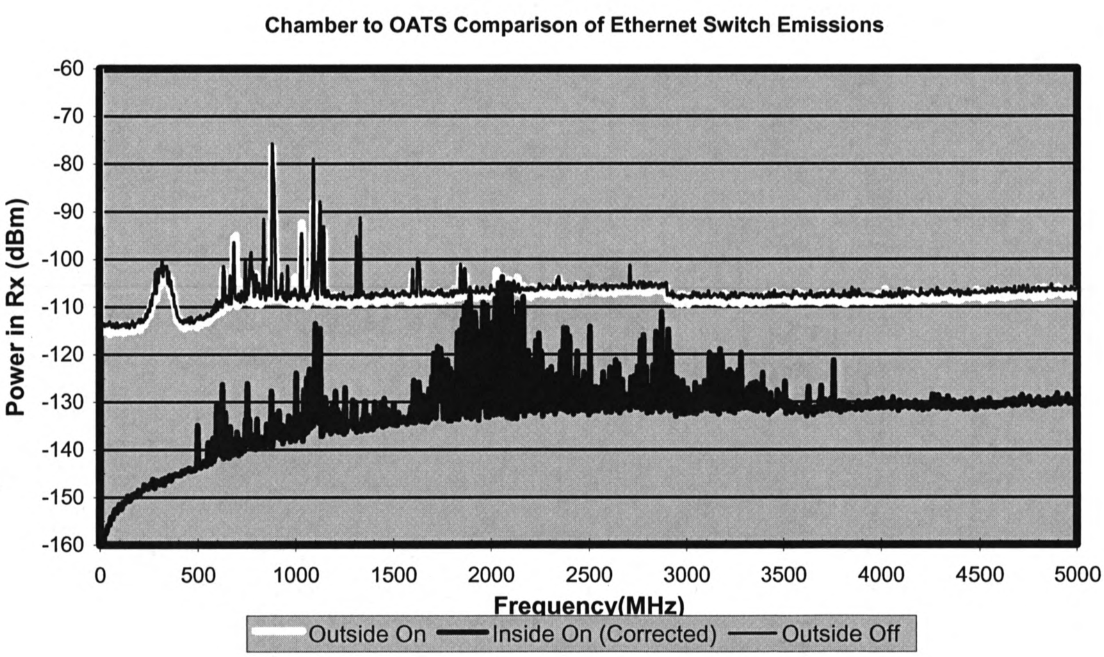
Below are the results of the emissions tests performed on the first set of MCB Ethernet switches. Plots of the baseline noise of the system and the emission spectra of the devices are shown. The resolution bandwidth for the Rx used to capture the data for the plots was 100kHz. The plots represent 1022 data bins gathered via computer. The data presented has an error associated with it due to the effects of the shielded chamber, these effects cause the data to have a standard deviation from average of ~4dB.




Cisco 3508 and CentreCom 8216 Ethernet Switches
-100.0
-150.0
-200.0
EIRP (dBW)
0
1000
2000
3000
4000
5000
6000
7000
8000
9000
10000
Frequency (MHz)


Cisco 3508 Ethernet Switch
-100.0
-150.0
-200.0
EIRP (dBW)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency (MHz)


Cisco 3508 100kHz Total Span
Power in Rx (dBm)
-80
-90
-100
-110
-120
-130
-140
-150
-160
-170
-180
1999.94
1999.96
1999.98
2000
2000.02
2000.04
2000.06
Frequency (MHz)

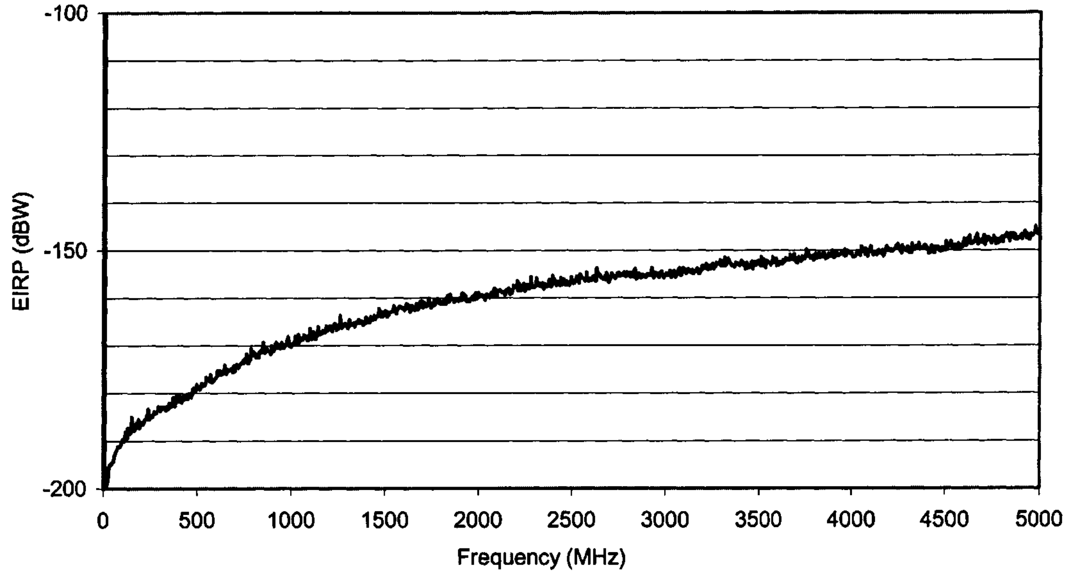

Chamber to OATS Comparison of Ethernet Switch Emissions
Power in Rx (dBm)
-60
-70
-80
-90
-100
-110
-120
-130
-140
-150
-160
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency(MHz)
Outside On
Inside On (Corrected)
Outside Off

All of the plots above have been fully calibrated, with the exception of the last two plots, and represent the effective isotropic radiated power of the equipment. From these plots it may be seen that the peak emissions from this equipment is near –130dBW at a frequency of 2GHz. Scans with lower noise floors (from reduced RBW) above 5GHz showed very minimal emissions, more than 30dB down from the peak at 2GHz. The last plot in the series shows the benefit of doing this particular measurement in the shielded chamber, without the effects of which, the emissions from the Ethernet switches would have been nearly undetectable. The 'Outside Off' line represents the ambient interference at the OATS. The only points of discrepancy between this line and the 'Outside On' line, when the switch was turned on, is at the 2GHz peak. The 'Inside On' line has been corrected for the chamber's effects and shows the same power levels as the outdoors test with the advantage of 20dB of sensitivity. The emissions from this equipment are comprised of very narrow discrete frequency spikes. Very many of these spikes closely spaced, give the illusion in the plots that the interference is 'broad band hash'.

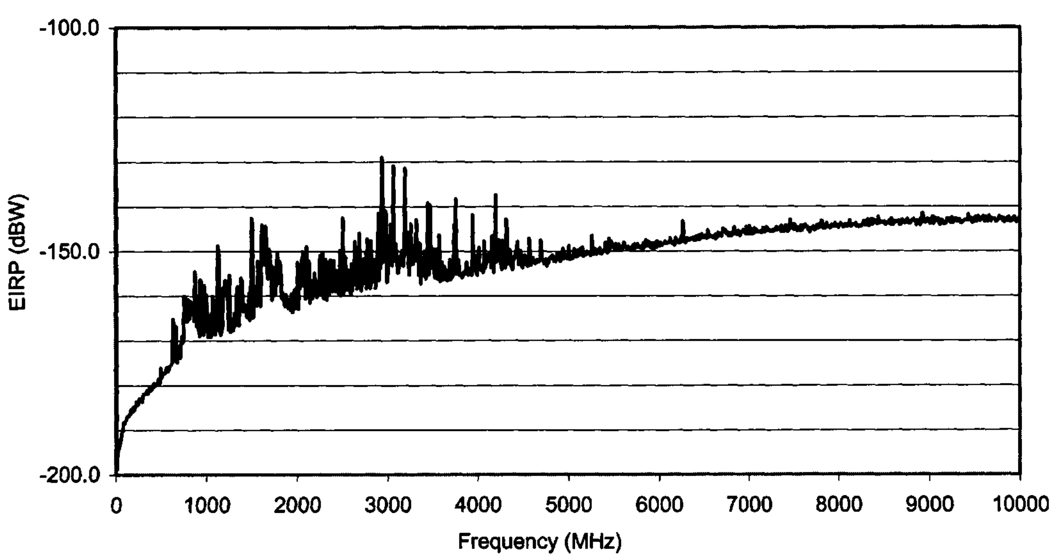
Emissions of Cisco 4506 Ethernet Switch

Below are the results of the emissions tests performed on the second set of MCB Ethernet switches. Plots of the baseline noise of the system and the emission spectra of the devices are shown. The resolution bandwidth for the Rx used to capture the data for the plots was 100kHz. The plots represent 1022 data bins gathered via computer. As with other data gathered in the chamber, the plots below represent data with a standard deviation of ~4dB from average.

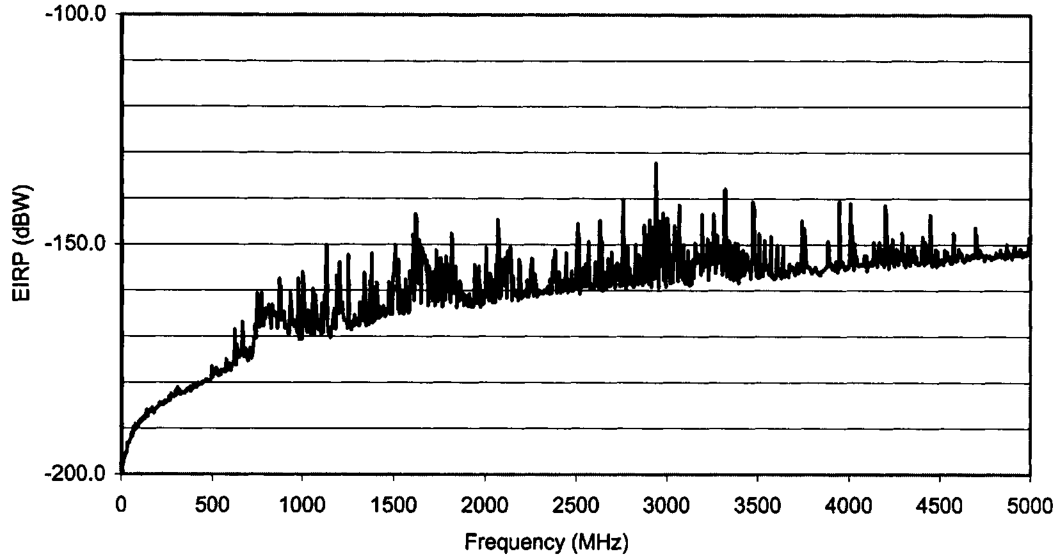
Basleine Noise



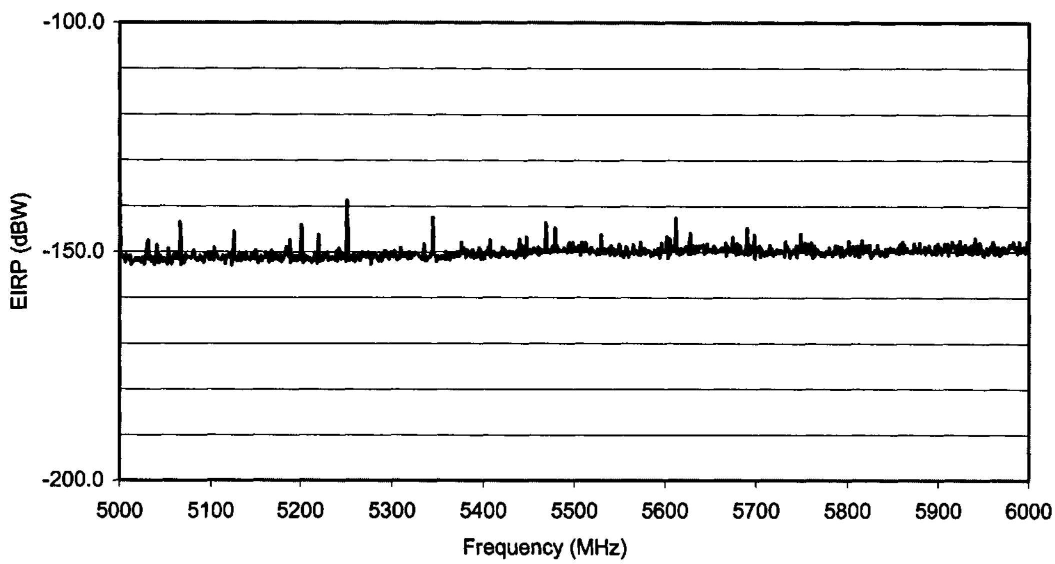
Cisco 4506 Ethernet Switch



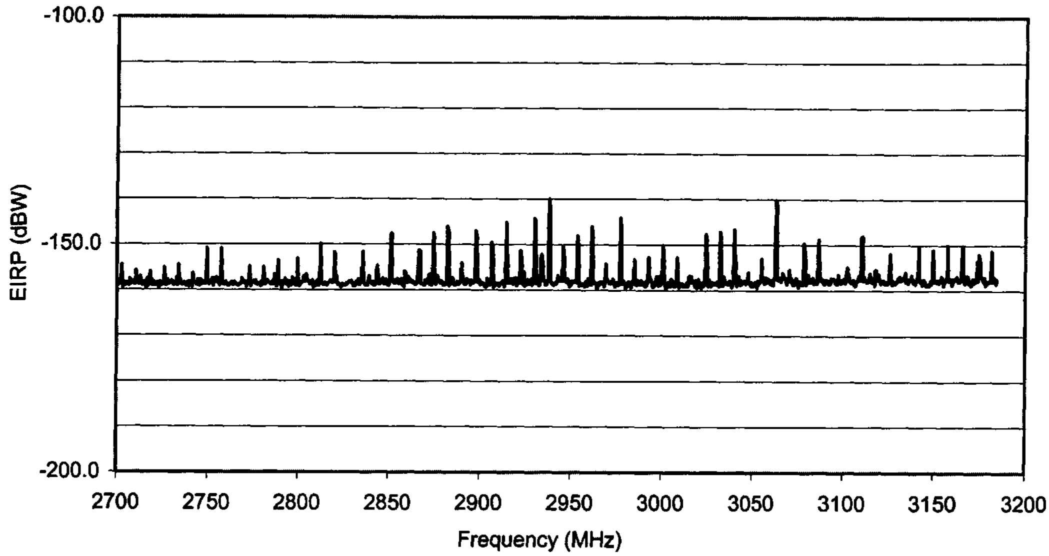
Cisco 4506 Ethernet Switch



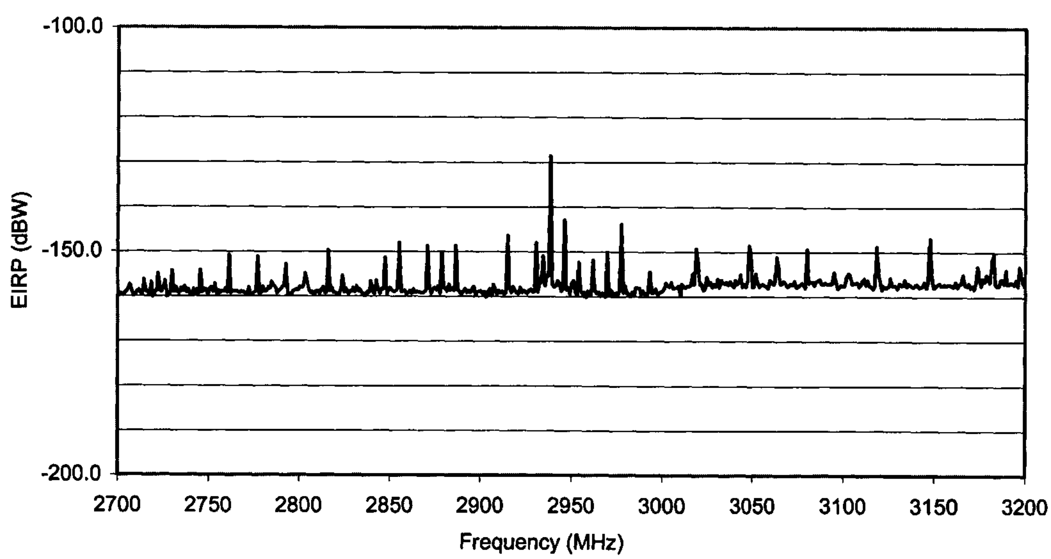
Cisco 4506 5-6GHz emissions



Cisco 4506 2.9 GHz detail during startup



Cisco 4506 2.9GHz detail during normal operation

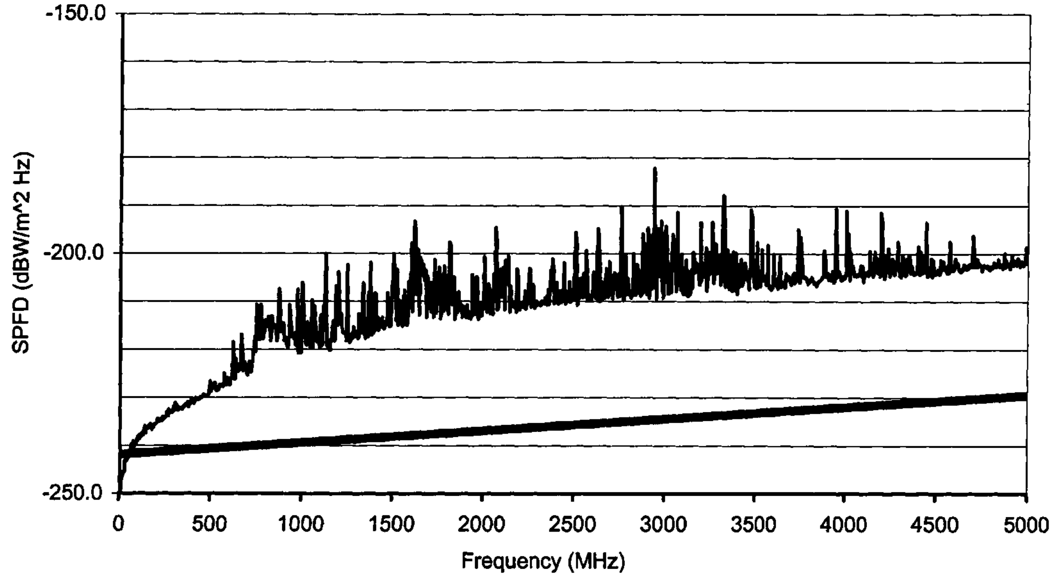


All of the plots in this series have been fully calibrated. From these calibrated plots it may be seen that the peak emissions from this equipment is about –130dBW at around 3GHz. Emissions from this device continue up beyond 6GHz to as high as 8GHz before the emissions are undetectable with current equipment. Also, the emissions from this device are comprised of very narrow discrete frequency spikes, not broadband noise. In addition to this, there is an apparent difference between the emissions of the equipment during the initial power-up of the switch. This operation tends to increase the number of spikes seen around 2.9 GHz. The peak power levels in general do not change (the plot is not indicative of this).

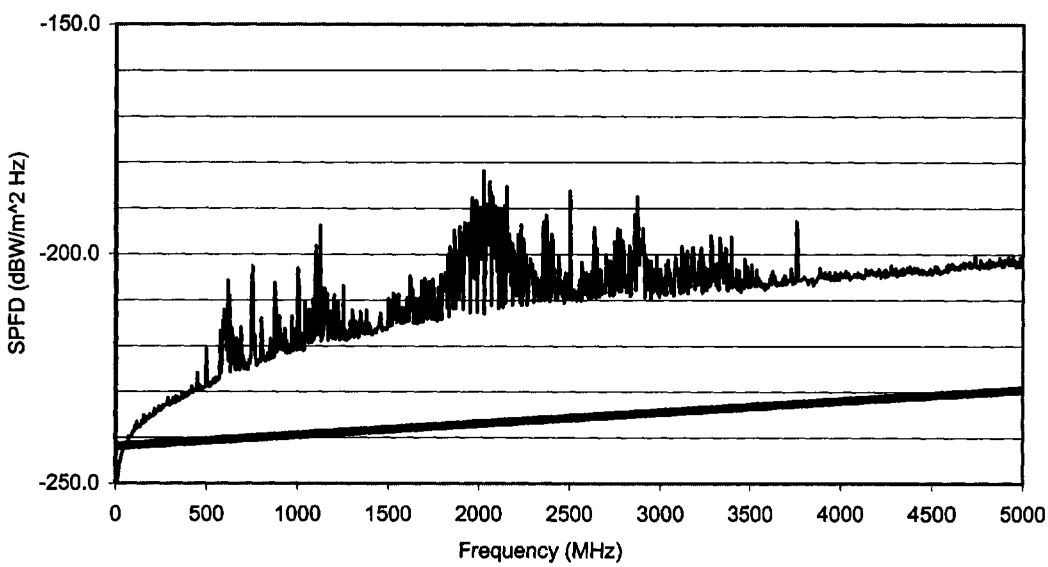
Harmful Level Comparison to Emissions

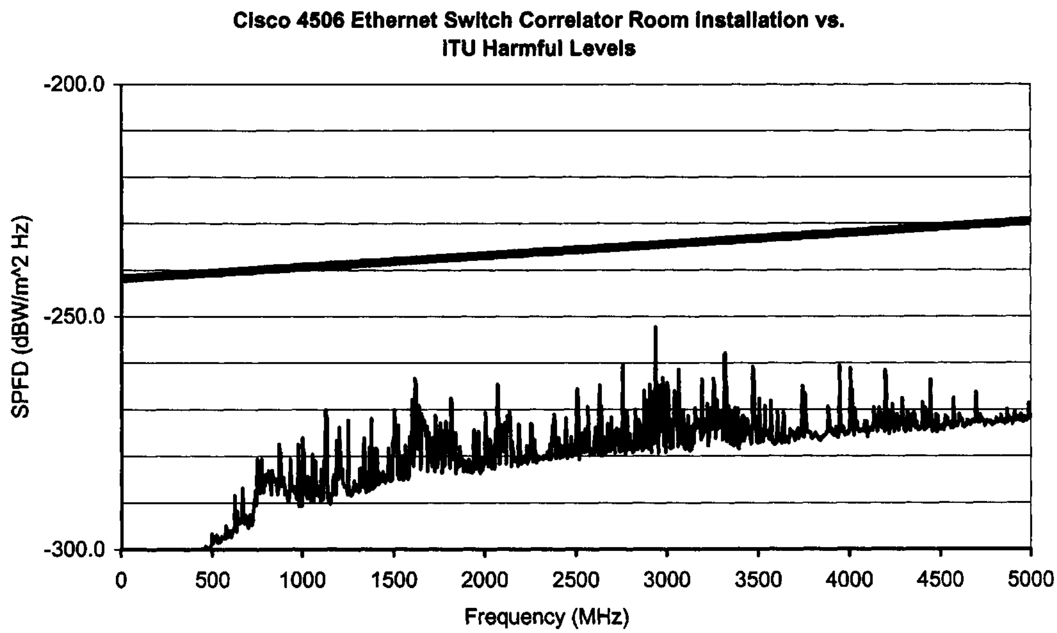
With the emissions levels given above and the path loss from the proposed locations of installation of the Ethernet switches, a determination of possible additional shielding required is possible. In this analysis, the ITU harmful threshold limits for single dish RFI will be used. These limits are changed to a per Hertz bandwidth and a least-squares regression of the harmful levels from 1-5GHz is used for comparison to the SPFD of the switches at the feed of the antennas in the worst case. The plots below give a good representation of this comparison. The first plots show the estimated worst-case SPFD at the feed of the antennas with the Ethernet switches installed in the vertex room with no additional shielding present. The second set of plots shows the estimated SPFD of the switches at the feed of the antennas with the switches installed in the Correlator room of the CB. The final set of plots shows the estimated SPFD of the switches at the feed when installed in the vertex room with an additional 60dB of shielding (this is the required shielding for the G-Rack).

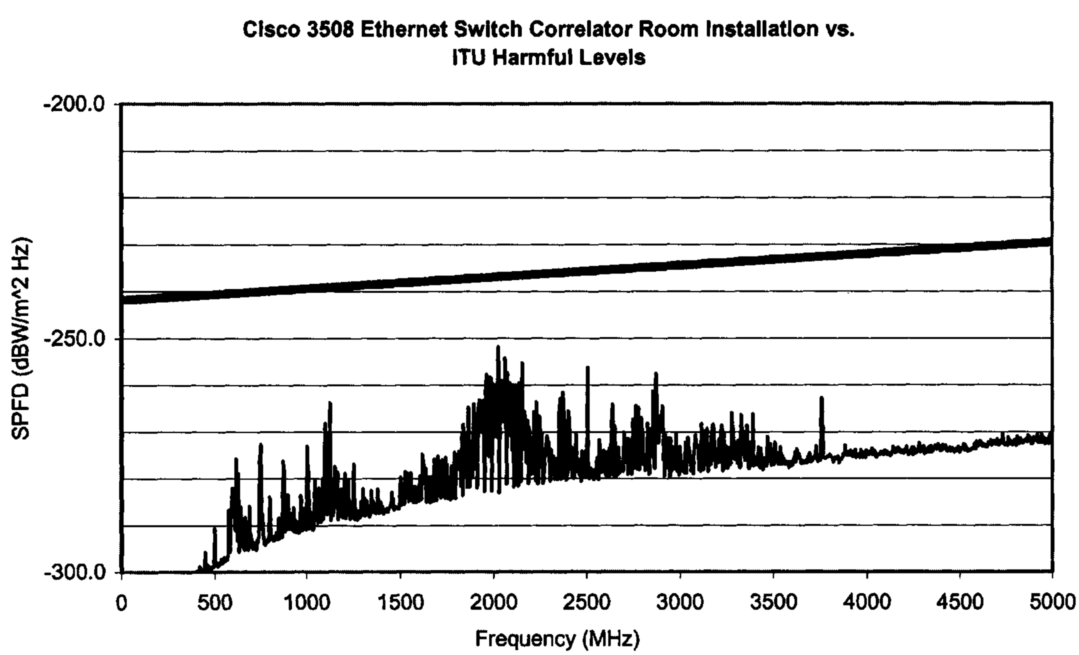
Cisco 4506 Ethernet Switch Vertex Room Installation w/ no additional shielding vs. ITU Harmful Levels



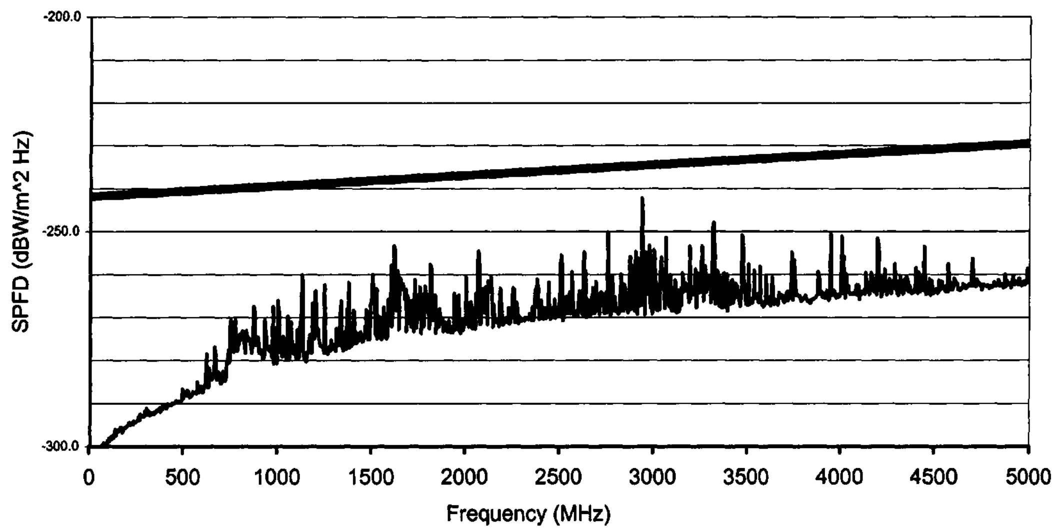
Cisco 3508 Ethernet Switch Vertex Room Installation w/ no additional shielding vs. ITU Harmful Levels



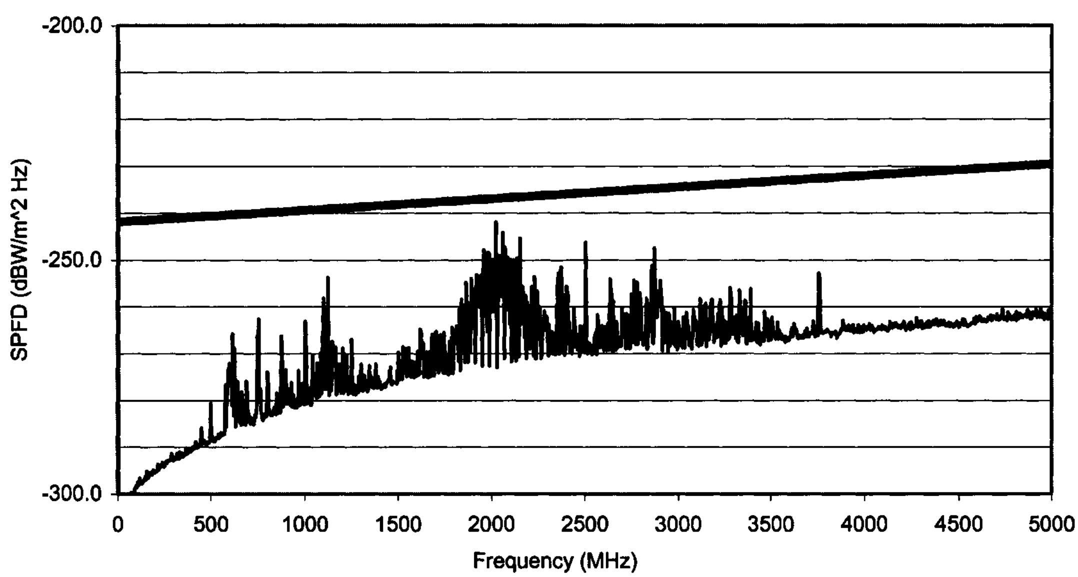

Cisco 4506 Ethernet Switch Correlator Room Installation vs.
ITU Harmful Levels
-200.0
-250.0
-300.0
SPFD (dBW/m^2 Hz)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency (MHz)


Cisco 3508 Ethernet Switch Correlator Room Installation vs.
ITU Harmful Levels
-200.0
-250.0
-300.0
SPFD (dBW/m^2 Hz)
0
500
1000
1500
2000
2500
3000
3500
4000
4500
5000
Frequency (MHz)

Cisco 4506 Ethernet Switch Vertex Room Installation w/ G-Rack vs. ITU Harmful Levels



Cisco 3508 Ethernet Switch Vertex Room Installation w/ G-Rack vs. ITU Harmful Levels



The plots above show that both switch systems would need additional shielding to be installed in the vertex room of every antenna (ie. with a shielded rack of some sort). In fact, they show that a very significant amount of shielding (~55 or 60dB) is needed for installation in the vertex room to prevent unwanted interference to observations. The plots also show that if the switches were installed in the Correlator room, with no shielding greater than what the room provides, the switches would not cause any interference to observations for the EVLA. The G-Rack, in which the switches are to be installed, showed only about 20-30dB of shielding in initial testing. Design changes and modifications with shielding as a top priority are underway. Limiting the maximum length of discontinuities at boundaries (such as wave-guide air filter attachments, bolt-on plates, etc.), designing better weld joints, and placing RF absorber lining for the inside of the box may help to make the rack attenuate emissions from inside the rack by as much as necessary.

Appendix A: Selected ITU Harmful Threshold Levels

The following table is taken from the ITU Handbook on Radio Astronomy.

Center Freq.	Spectral Line Channel BW	Min. Ant. Noise Temp.	Rx Noise Temp.	System Sensitivity (Noise Fluctuations)		Threshold Interference Levels		
				Temp.	Power Spectral Density	Input Power	PFD	SPFD
F (MHz)	Δf (kHz)	T_A (K)	T_R (K)	ΔT (mK)	ΔP_S (dB(W/Hz))	ΔP_H (dBW)	$S_H \Delta f$ (dB(W/m^2))	S_H dB(W/(m^{2}Hz)
327	10	40	60	22.3	-245	-215	-204	-244
1420	20	12	10	3.48	-253	-220	-196	-239
1612	20	12	10	3..35	-253	-220	-194	-238
1665	20	12	10	3.48	-253	-220	-194	-237
4830	50	12	10	2.20	-255	-218	-183	-230

From the numbers presented in this abbreviated table, a simple linear equation developed through a linear least squares regression line may be used to compare emission levels against graphically. The equation for the best fit of this data is:

$$0.002471(f_{(MHz)}) - 241.885$$

This gives a correlation coefficient of R^2=0.98 to the data given and is nearly a perfect fit. One discrepancy worth note is that at the low end of the spectrum ~300MHz, the line gives a 3dB less stringent level to adhere to. The full ITU harmful levels may be directly compared to emission levels after testing has been done, this formula for the harmful levels simply presents a simple, easy to understand method of comparison for 300MHz to 5GHz.

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

1

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

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

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

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 $t_{int} = 8$ 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

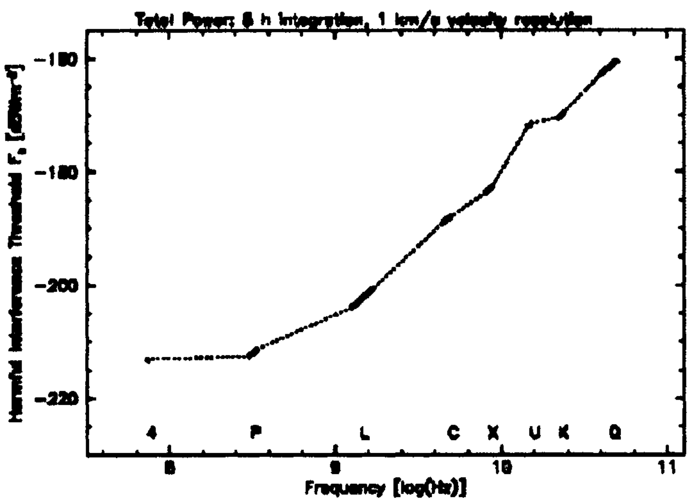

Figure 1: Calculated maximum acceptable power flux density (of an interfering signal) at different VLA bands, using typical observational values for the integration time (8 h) and the velocity resolution (1 km/s).

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.

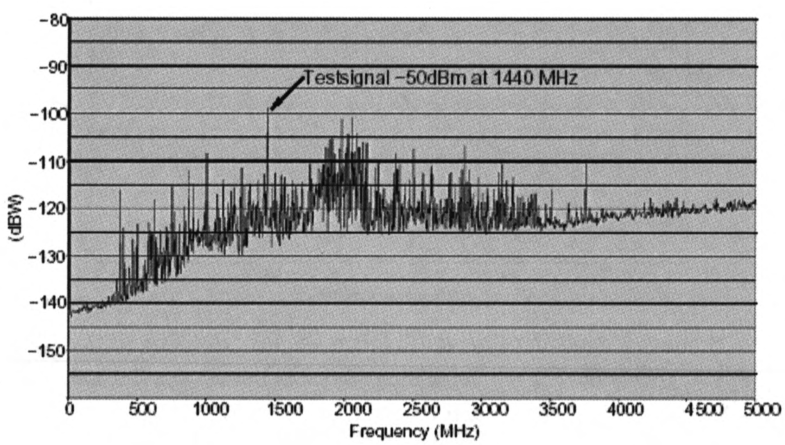

Figure 2: MCBs and a −50dBm test signal at 1440 MHz. Note that the y-axis scale is not calibrated and thus does not show absolute units.

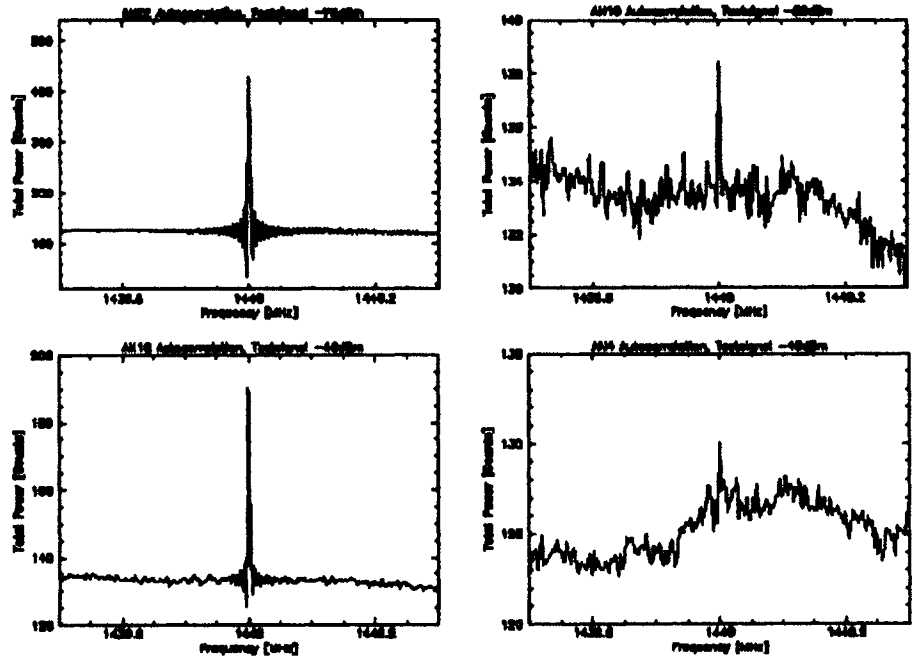

Figure 3: VLA autocorrelation spectra at a few antennas with different strengths on the input test signals. Spectral resolution is 3.05 kHz (corresponding to a velocity resolution of 0.63 km/s), and integration time 40 s.

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] corr	MCB lev[3] corr	35m[4] corr	8h[5] corr	S[6] 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.

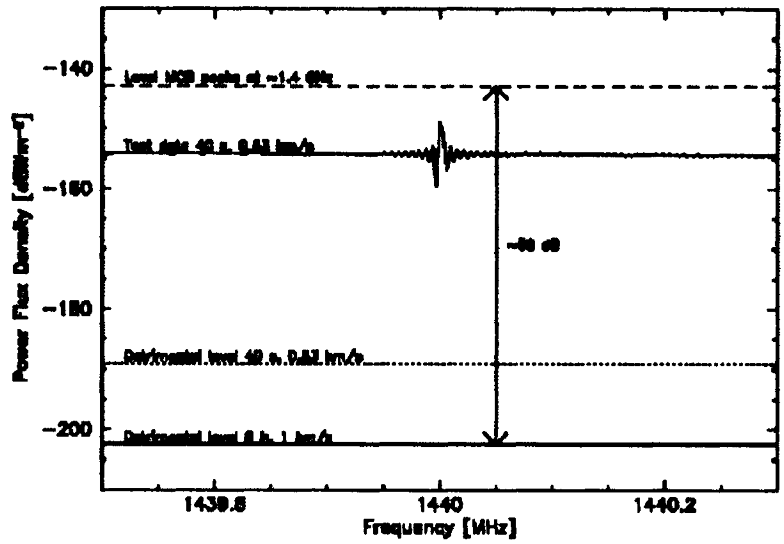

Figure 4: The -70dBm test signal seen at AN22 compared to detrimental levels. This signal is 6dB lower than the MCB peaks at corresponding frequencies.

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'

Appendix C: References

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