National Radio Astronomy Observatory
Socorro, New Mexico

VLA TEST MEMORANDUM NO. 188

A PROPOSAL TO CONTROL LOCAL INTERFERENCE AT THE VLA

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1 ABSTRACT

The VLA suffers serious interference (RFI) problems in the 72.9 - 74.7, 300 - 345, and 1200 - 1740 MHz observing bands. The VLBA has a much less serious problem, in general, than the VLA because of geographical separation of antennas and well shielded local electronics. For convenience we can catagorize interference as internal to the receiver system electronics, local to the NRAO site, or external to the site (distant). This memo examines the local RFI problem of the VLA in some detail. It discusses the harmful interference levels, establishes the harmful effective isotropic radiated power (HEIRP) as a function of location and frequency, and proposes methods to identify individual sources of harmful RFI. Finally it proposes methods to mitigate harmful RFI, primarily by shielding, and to control/prevent additional proliferation of local RFI. Unfortunately, the proposed methods require a large commitment of manpower and dollars. The dominant sources of RFI are digital devices of many kinds and leakage of local oscillator and reference frequencies.

2 HARMFUL LEVELS OF INTERFERENCE

The internationally recognized authority for regulating use of the radio spectrum is the International Telecommunications Union (ITU). An organ of the ITU, the International Radio Consultative Committeee (CCIR), serves as the recognized authority for technical and operating standards through the issuance of recommendations. Because the ITU Frequency Allocations have the force of international treaty law to the extent accepted by each nation, the ITU/CCIR Recommendations have an implied level of authority in most countries, including the United States.

Therefore, ITU/CCIR Recommendation 769 "Protection Criteria Used for Radioastronomical Measurements" (1992) (AOC Library TK5101.A1I49) is the US standard for protection of the radio astronomy frequency bands per the NTIA/FCC frequency allocation tables and footnotes. This is the ONLY leverage radio astronomy has on other users of the radio spectrum, and it ONLY applies in the allocated/footnoted radio astronomy bands, subject to the limits of frequency sharing with other radio services.

However, for our need to control our own locally generated RFI, the ITU/CCIR Rec. 769 harmful levels of interference certainly can be applied by us throughout the VLA tunable frequency ranges. Here we do so!

We assume the worst case VLA situation of spectral line mode, shortest baselines in D configuration (least reduction of RFI by fringe rotation), integration time of 2000 sec (medium sensitivity), and antennas nearest buildings pointing with 0 dBi sidelobes on the local RFI emitters. We also assume that most RFI sources have bandwidths approximately less than or equal to the spectral channel bandwidth. Then ITU/CCIR Rec 769 Table 2 harmful levels become for our case:

Freq	Ch BW	AntTmp	RcvTmp	DeltaT	HP	HPD
(MHz)	(kHz)	(K)	(K)	(mK)	(dBW)	(dB(W/m^2))
74	5	1000	100	290	-208	-207
327	10	40	100	22	-215	-204
611	10	15	100	18	-217	-200
1420	20	10	20	3.4	-220	-196
1665	20	10	20	3.4	-220	-194
2695	20	10	20	3.4	-220	-189
4830	50	10	20	2.1	-218	-183

where HP = Harmful Power level at receiver input (feed output)
HPD = Harmful Power Density into 0 dBi sidelobes

We include 611 and 2695 MHz as these bands may be added to the VLA in the future.

3 EMITTER HARMFUL EIRP

Now that we have harmful power density levels incident onto VLA antennas, we can look at the harmful emitted power by the source in effective isotropic radiated power (EIRP) for several VLA antenna pads and site buildings. An isotropic radiator of P watts produces a far field power density of PD watts per square meter at a distance of R meters according to PD = P/(4piR^2), or in dB(x) = 10log(x) units: EIRP(dBW) = PD(dB(W/m^2)) + 20log(R(m)) + 11.0 dB.

From VLA drawing B2190001 of the Site-Wye Layout, we see that antenna pads W8 (always occupied) and W9 are about 175m from the control building; pads W9, W10, and W12 are 225m or less from the servo, cryo, and machine shops; and pads W12 and W14 are less than 175m from the antenna/transporter barns. Because two adjacent antenna pads make a short baseline, the nominal distance of most local RFI sources is about 200 meters.

Given the harmful distance HR of 200m and the harmful power densities HPD above, we get harmful emission HEIRP for that and other distances:

Freq	HPD	HEIRP@200m	HEIRP@1km	HEIRP@100km
(MHz)	(dB(W/m^2))	(dB(W))	(dB(W))	(dB(W))
74	-207	-150	-136	-96
327	-204	-147	-133	-93
611	-200	-143	-129	-89
1420	-196	-139	-125	-85
1665	-194	-137	-123	-83
2695	-189	-132	-118	-78
4830	-183	-126	-112	-72

Figure 1 shows harmful EIRP (HEIRP) vs line-of-sight distance for VLA harmful power density (HPD) at these VLA frequency bands. Note that most terrestrial emitters beyond a few kilometers of distance will be attenuated by intervening terrain. Local emitters could be attenuated by intervening building walls, racks, etc.

4 KNOWN AND SUSPECTED EMITTERS

Digital Devices

In recent years, digital devices have proliferated at the VLA site. Besides the obvious computing devices (personnal computer, VME computer, workstation, mini-computer, programmable controller, terminal, FAX, modem, printer, etc.), many other common devices contain microprocessors or high speed digital circuitry which radiate radio frequencies above 70 MHz. Some of these devices, such as programmable controllers and digital monitor circuits, we recently added inside VLA antennas, without testing for radio emission levels! All but the cheapest uninterruptable power supply (UPS) contains a microprocessor and digital circuits. For example, the Socorro Electric Cooperative power-demand-meter and their remote generator startup controller radiate RF. The list goes on. See Table 1 for a list of some of the known and suspected emitters on the VLA site.

Digital circuits radiate an impulsive broad continuum of radio frequencies. The spectrum depends on the rise and fall times of a multitude of current transitions; and the radiated power depends on the magnitude of the current transistions and the filtering/shielding of the circuits. Usually the strongest emissions and the highest frequencies occur at the clock frequency and its harmonics. Personnal computer (PC), workstation, and VME computer clock frequencies now approach that of the VLA correlator in the shielded room -- 100 MHz.

The VLBI recording system (VLBA station VME computer, data acquisition rack (DAR), and recorder) appears to be the strongest emitter in the control building over the 70 to 350 MHz range. Figure 2 shows an example of the VLBI system emissions.

The correlator, a large and power hungry digital device, generates the most unintentional RF power at the VLA site. Fortunately, it is inside a very well shielded room. Unfortunately, a number of cables penetrate that shield, conduct RFI through the shield, and radiate it out into the control building and to the antennas.

LO Leakage

In the control building and in each antenna, virtually every local oscillator (LO) and reference frequency radiates out of modules and transmission lines at some level.

Antennas

Digital clock harmonics and LO leakage within an antenna radiate into the feeds of itself and into the feeds of adjacent antennas. Some of the frequencies may radiate or conduct directly into some parts of the front end or receiver circuits. The B-rack in every antenna radiates so much LO and digital circuit RF in the 74, 327, and 1400 MHz bands, that we have spent and still are spending many dollars and person months to suppress it with shielding and optical fibers.

Radios and Scanners

FM/AM radios and scanners on site radiate LO and harmonic frequencis directly out of the cabinets and out of their antennas. Some also radiate digital hash. Several radiate RFI known to interfere with 327 MHz observations.

2-Way Radios

The site 2-way radios, used every working day by many staff and after hours by janitor/guards, produce a very strong second harmonic at 324.05 MHz, in the middle of the VLA P-band. Interference occurs when transmitting, but in addition it is possible that the receiver LO could radiate at a significant level while the unit has power on. Presently we have 47 radio units on site.

Vehicle Emissions

Many of the older site vehicles generate very strong broad band RFI impulses from electric arcs in the engine ignition and generator/regulator. These impulses have a steep spectrum; generally very strong at 74 MHz and significantly weaker at L-band. New vehicles contain digital computing devices. When these vehicles drive by or work near one or more antennas, especially in the C and D configurations, these RFI impulses can produce high peak power levels into L-band. Figure 3 shows one such site vehicle's peak spectrum from 1 - 2 GHz when passing about 10 meters from an isotropic monitoring antenna. The vertical scale on the right side gives the power out of the antenna in dB(W). The sloping line represents an incident power density of -100 dB(W/m^2), which corresponds to vehicle EIRP of -69 dB(W) at a distance of 10 meters. The peak vehicle emission at 1360 MHz is about -78 dB(W) out of the antenna, -54 dB(W/m^2) power density incident onto the antenna, and -23 dB(W) EIRP emitted from the vehicle.

5 FCC PART 15 EMISSION LIMITS FOR DIGITAL DEVICES

The Federal Communications Commission (FCC) regulates incidental radio emission from devices marketed within the US. The FCC specifies the regulation in its Rules Part 15, which defines two classes of digital devices. Class A digital devices are marketed for use in a commercial, industrial or business environment. Class B digital devices are marketed for use in a residential environment. Class B device emission limits are about 10 dB lower than Class A devices, but NRAO rarely purchases Class B (home entertainment) devices.

From FCC Part 15.109 (Oct 91), Radiated emission limits, we derive these relevant parameters for Class A devices:

Freq (MHz)	74	327	611	1400	2695
FCC Max Field(uV/m)	90	210	210	300	300
@ FCC Distance (m)	10	10	10	10	10
@ FCC Bandwidth(MHz)	0.1	0.1	0.1	1	1
MaxPD@FCCdist(pW/m2)	21.5	117	117	239	239
Max EIRP (nW)	27	147	147	300	300
Max EIRP (dB(W))	-76	-68	-68	-65	-65
HEIRP@200m (dB(W))	-150	-147	-143	-139	-132
HPD (dB(W/m2))	-207	-204	-200	-196	-189
Distance@HPD (km)	1000	1780	1120	1000	450

Therefore digital devices radiating at FCC Class A limits at the VLA site and directly to VLA antennas exceed the harmful levels by 70 to 80 dB. To be below the harmful levels, a Class A device would have to be beyond a line-of-sight distance of 1780 km. That's medium-earth-orbit!

We assume the worst case, which often is the actual case at our frequencies, that the device radiates discrete frequencies of bandwidth less than 10 kHz, such as harmonics of a clock frequency.

6 PEELING THE RFI ONION

First the Worst Offenders

We will never find and eliminate or mitigate all emitters down to the harmful levels given above. There simply is not sufficient antenna/subarray time, people time, equipment sensitivity, and funds to do a complete job. However, given a reasonable commitment of people, time, and equipment, we can start by identifying the worst offenders down to some practical limit. Then we can mitigate the worst down to the limit of funds, people, impact on site maintenance, and impact on observing.

Directional Antenna & Spectrum Analyzer Outside Buildings

A rotatable directional antenna, low noise amplifier, and swept frequency spectrum analyzer would pick out strong emitters in and about site buildings. The antennas could be a log periodic for the bands below 1 GHz, and ridged horns with low back lobes for the bands above 1 GHz. The spectrum analyzer must be able to measure RFI frequencies with error down to 10 kHz. The antenna/analyzer system must be portable, possibly using the environmental RFI monitor trailer and rotatable mast.

Frequencies & Levels - VLA Antenna @ W8 & Spectrum Analyzer

Sweeping a VLA antenna beam in azimuth at low elevation (8 to 10 degrees) past site buildings would pick out local emitters. Triangulating with two antennas could reject distant over-the-horizon emitters in line with site buildings. A swept frequency spectrum analyzer tapped into a D-rack IF could detect the worst (strongest) offenders with frequency error down to 10 kHz. Pad W8 always has an antenna and is the closest to the control building.

Frequencies & Levels - Subarray in Spectral Line

Lower level RFI could be identified in frequency and level by using a subarray of 3 antennas closest to site buildings and by using the correlator in spectral line mode. The subarray would point at the north celestial pole to minimize RFI rejection by fringe rotation. Spectral snapshots of 12.5 MHz bandwidth would step through a frequency band (similar to SYSLQUIK RFI snapshots). Correlator and fluke set constraints might limit compatibility with observing. Inverse-square-of-distance effects on RFI amplitudes on the 3 baselines could help separate local signals from distant ones. This is costly in array and people time.

7 LOCATING EMITTERS: FINDING NEEDLES IN THE HAYSTACK

Spectral Signatures

Locating emitters requires knowing spectral signatures measured by peeling the onion methods described above. The spectral signature includes the frequency +/- 10 kHz for discrete frequencies, and bandwidth/amplitude modulation for broad emitters. Very broad continuum emitters will be very difficult to locate. Intermittant emitters will also be very difficult.

Standing Wave Problem

Locating local emitters becomes difficult in the common site environment where reflections from building walls and racks set up standing waves throughout a room or even an entire building. The RFI signal seems to be everywhere and seems to come out of everything. An antenna/probe walkabout through the standing waves to find the area(s) of highest level provides the most efficient technique. This is time consuming, 30 to 60 minutes per emitter. Multiple emitters at the same frequency (eg. LO leakage) consume even more time.

Receiver Walkabout, Freq < 1300 MHz

Experience shows that, given a frequncy +/- 10 kHz, a walkabout using a handheld receiver with rubber-duckie antenna and variable attenuator can be very effective for frequencies < 1300 MHz. We have used an Icom IC-R1 receiver plus a small variable attenuator between antenna and receiver.

Small Antenna Walkabout & Spectrum Analyzer, Freq > 1300 MHz

For frequencies > 1300 MHz, a walkabout with a small directional antenna can be effective. The low noise amplifier and spectrum analyzer should be quasi mobile on a cart. It requires two people, one to walk the antenna and one to watch the analyzer for signal maxima.

Near-field Probe

Locating one emitter among several at the same frequency may require a near-field probe as a substitute antenna connected to the hand held receiver or to the analyzer. The probe can be a commercial unit or a small wire loop on the end of a bulkhead coaxial connector.

Power On/Off

Ultimate verification that a specific device is the emitter may require turning off its power (completely). Beware that some commercial devices' power-off switch may leave some internal circuits powered and active. Some emitters are essential to array operation so that power off means loss of observing data for some period of time unless done during array maintenance.

8 MITIGATING EXISTING EMITTERS

Shielding/Filtering Devices

Shielding and filtering individual commercial devices generally is impractical. Shielding usually interferes with the user by covering keys/buttons/switches and obscuring visual indicators and monitor screens. All cables penetrating a shield must be filtered without degrading the performance of the device. All this requires costly hardware and many expert person hours per device. The VLA site has many emitting devices.

A filter or isolating amplifier on the antenna port may effectively reduce LO leakage to a radio/scanner antenna. A low pass filter will reduce harmonic levels of 2-way radio transmissions radiated from antennas, but will not reduce emissions radiating directly from the case or power wiring. Low pass filters for 47 site radios would cost over 5 k$, depending on limitations of connectors and space, plus many person hours to research, order, and install.

Shielding/Filtering Modules

Shielding and filtering VLA electronics modules which emit harmful RFI is not practical. The module housing would have to be rebuilt or replaced. The AMP push-on connector blocks have no equivalent with RFI filtered pins, even if digital driver/receiver circuits could function with the filter capacitance (a vexing problem with the B-rack shields). The push-on coaxial connectors generally leak RF worse than BNC connectors.

Shielding/Filtering Racks

Shielding and filtering electronic system racks in the control building, most of which probably emit harmful RFI, is not practical. The shielding cost and effort would be several times that of the B-rack shields in the VLA antenna vertex rooms. Numerous coaxial and digital cables enter each rack through the floor. Most or all digital cables would need to be replaced with optical fiber and transmit/receive interfaces (very expensive).

Shielding/Filtering Cables

Any shield around a device is effective only to the extent EVERY wire penetrating the shield is filtered, at the point of penetration, to attenuate the passage of RFI. As mentioned above, the capacitance of LC filters can interfere with the functioning of digital circuits. Ferrite chokes around wires and cables have limited attenuation. Sometimes filtering can be avoided if the wires can be shielded continuously from one shielding cage to another. Generally this is difficult to achieve, especially eliminating leaky gaps at junctions and connectors.

Shielding Coax

Throughout the VLA electronics system, we have used much flexible coaxial cable to carry LO reference and other signals at frequencies within our observing bands. Some of this coax has only a single layer of braided shield, which leaks significantly at higher frequencies. Such coax found leaking harmful RFI could be replaced with double-layer braided coax, which has 20 to 30 dB less leakage. In extreme cases, semi-rigid solid-shield coax may be necessary.

Using the Correlator Shielded Room

A limited amount of VLA equipment which emits high above the harmful levels could be relocated inside the correlator shielded room. To avoid an inordinate amount of cable penetrating the room shield, the most amenable equipment most effectively silenced would be the VLBI racks (amoung the worst emitters in the control building at P-band). However, there may be a catch-22 situation, as the VLBI DAR-rack contains 500 - 1000 MHz IF amplifiers and baseband converters which may be susceptible to penetration by the high ambient RFI inside the correlator room.

When the pulsar processor gets a VME-based system, it may also have to go into the correlator room or into its own shielded cage. However, the pulsar baseband processor (old MKIII VLBI terminal) may also lack adequate immunity from the ambient RFI.

This is a classical electromagnetic compatibility (EMC) problem, where environmental immunity of equipment plays a critical role!

Shielding/Filtering Buildings

An alternative to shielding/filtering many existing (and future) devices, racks and cables, could be shielding entire buildings. In recent years, architectural shielding has developed rapidly in shielding effectiveness and cost effectiveness. It is most cost effective when designed into construction of the building, but significantly more expensive when retrofitted into an existing building. Most difficult is shield continuity across windows, doors, ceiling/floor/wall junctions, and filtering at shield penetrations. Our AOC library has an excellent reference book by L. Hemming, "Architectural Electromagnetic Shielding Handbook", 1991, TK454.4.M33A77.

Estimated cost of materials and labor: TBD (maybe several hundred k$ M&S + 6 person months design + 20 person months installing).

9 PREVENTION; a.k.a. CONTROL

Futility of Purchasing RFI Specifications

Recent attempts to purchase personal computers and peripherals, and uninterruptable power supplies meeting FCC Part 15 Class B emission limits failed because neither we nor the vendors understood that Class B devices are only made for consumer sales, where we need commercial (Class A) devices. Furthermore, Class B emission limits being only about 10 dB lower than Class A, still emit 70 dB above our needs! Puchasing to military emission specs is 10 to 100 times more costly, and rarely available.

Require Testing and Shielding

We could require testing the emission levels of every digital device and adding necessary filtering and shielding before allowing use at the VLA. But this consumes several person hours per test plus unestimable hours and dollars shielding and filtering to reduce emissions by the typical 70 - 80 dB. The dedicated test equipment and shielded room would also be costly.

It simply is not practical to shield/filter each device to below the harmful level, so we could just ban it from the site and force the user to find or build a substitute compliant at some compromise level.

Essential Emitters: Power Off

Since there are so many harmful emitters which are essential to the operation or maintenance of the VLA, the only alternative is to turn off all power to each during non-work hours or during affected observing. We must accept RFI or specially shield/filter those emitters which are essential for observing, eg. online system, master LO, D-racks, etc. Power off requires the cooperation and vigilance of all site staff, which depends on understanding the RFI problem. Of course, all harmful emitters amenable to power off must be identified. Periodic RFI surveillance would be necessary.

10 WHERE TO START & WHERE TO STOP

Start by identifying and mitigating the strongest emitters in the 327 MHz band as suggested in sections 6, 7, and 8 above. When experience with person hours, dollar costs, and inconvenience to site staff indicate, stop, evaluate the RFI level achieved relative to the harmful level, and evaluate alternative mitigation and control measures.

We have started some procedures.

1. The EMC engineer extracts P-band (300-345 MHz) observing from the VLA schedule each month and generates two documents; one for the array operators which shows when the VLBI system will be powered off and when it will be on, and one for posting in site buildings showing when suspect emitters (PCs, scanners, and certain test equipment) should be powered off. From the posted schedule, the site guard keeps a log showing times of mobile radio transmissions during the P-band observing. The ADC recorder group restores the VLBI system to operational status after the shut-down period.

2. The EMC engineer plans and conducts tests to identify emitters, especially prior to observing runs at P-band and 4-band. He has set up and continues to improve a basic environmental spectrum monitor which reveals some local emissions as well as the many external emissions.

3. During and following observing programs susceptible to local and external RFI, the EMC engineer communicates with array operators and the principal observer to identify RFI, frequencies, and emitters.

4. Array spectral snapshots of the full tunable band 1220 - 1750 MHz, SYSLQUIK, will be extended to P-band, and later to other bands. Such snapshots, taken with the array pointing at the noth celestial pole to remove RFI rejection by fringe rotation, reveal strong internal, local, and external RFI.

TABLE 1: SOME KNOWN & SUSPECTED RFI EMITTERS

EMITTER	LOCATION	Fo(MHz)	Harm#	Fn(MHz)
Digital Data Switch	Control Bldg (CB)			
Modems	Control Bldg (CB)			73-345
Modems	Ant Assm Bldg (AAB)			73-345
Computer terminals	Site			73-345
Sun Workstation	CB			
4820 parallel link	CB comp--correl			
Pulsar video conv	CB elex room	100-200	3	300-600
Pulsar computer	CB elex room			
Pulsar equipment	CB elex room			
VLBI data acq	CB elex room			320-325
VLBI VME computer	CB elex room	16,20,25	4-21	73-345
VLBI bar code rdr	CB elex room			322.735
ModComp computers	CB comp rm			320.0
UPS IPM	CB	15.00	20-23	300-345
UPS Best	CB & Tech Serv	7.3728	10-46	73-345
UPS Best	CB	11.0592	28-31	300-345
UPS Best	CB	14.7456	5-23	73-345
UPS Best	CB	14.7756	5-23	73-345
UPS Best	CB	17.754	17-19	300-345
Telephone Co PBX	CB	8.192	9-42	73-345
Personnal Computers	CB, Tech Serv, ..			73-345
PC printers	CB, Tech Serv, ..			73.770
PC printers	CB, Tech Serv, ..			73.755
Ant Control Unit	Each antenna	12.800	23-30	300-345
Data Set M1	Each antenna	10.000	30-34	300-345
Wye Comm	Each antenna	11.0592	27-31	300-345
Radios, 2-way	Site	162.025	2	324.00
PLC	Ant transporter	11.000	27-31	300-345
PLC	Generator bldg	11.000	27-31	300-345
Fuel pump card/ctrl	TechServ			73-345
Thermostats/cntctrs	TechServ, AAB			73-345
NumrCtrl machine shp	TechServ			73-345
Vehicles	Site			73-1700
Vending machines	Site			73-345
Radio scanners	Site			73-345
VCR's	VSQ, Visitor Ctr			73-345
Master Local Osc	CB elex rm			73-1700
D-racks	CB elex rm			73-1700
Copiers	CB, TechServices			
Ctrl Bldg HVAC	CB			
FAX	CB			
SEC power demand mtr	Generator bldg			
Maser dissociator	CB			

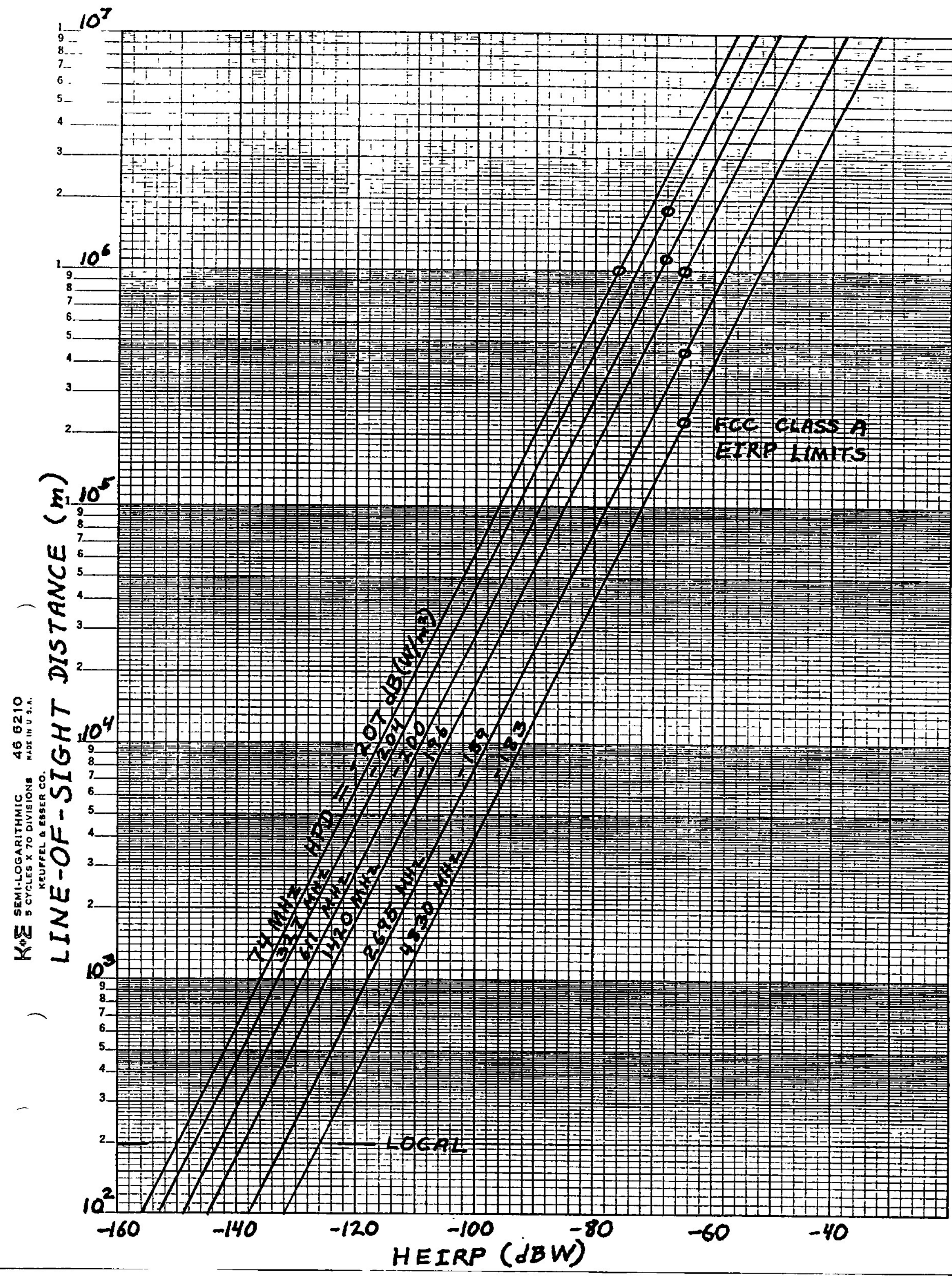
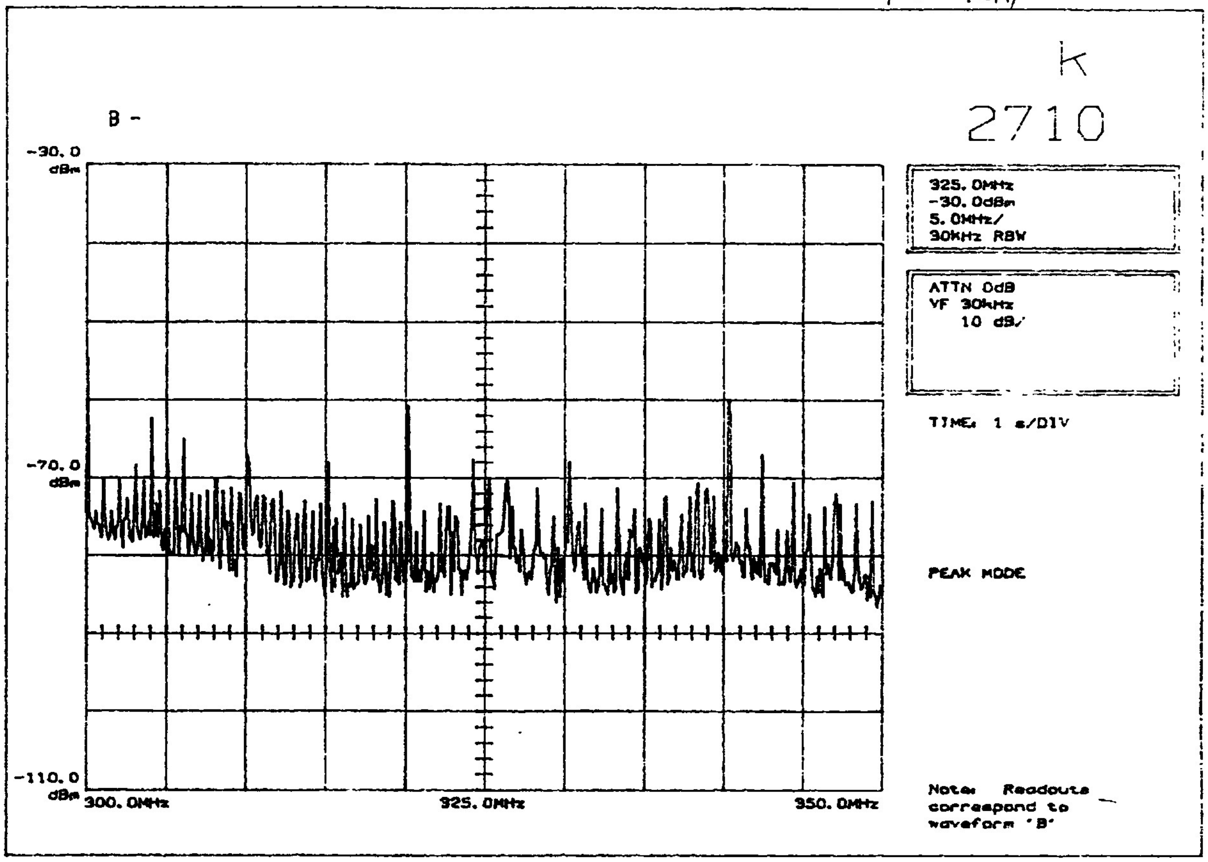


FIGURE 1: Emitter Harmful EIRP vs Line-of-Sight Distance at Several VLA Frequency Bands.

DISCONE ANT
WJ6201-49 AMP
VLA ALL ON EXCEPT VERO
PEAK MODE 4:10 PM
WB/CJ 2/16/94



DISCONE ANT
WJ6201-49 AMP
VLA/VLBI OFF/PULSAR OFF EXCEPT INTEL/$
WB/CJ Feb 16, 94

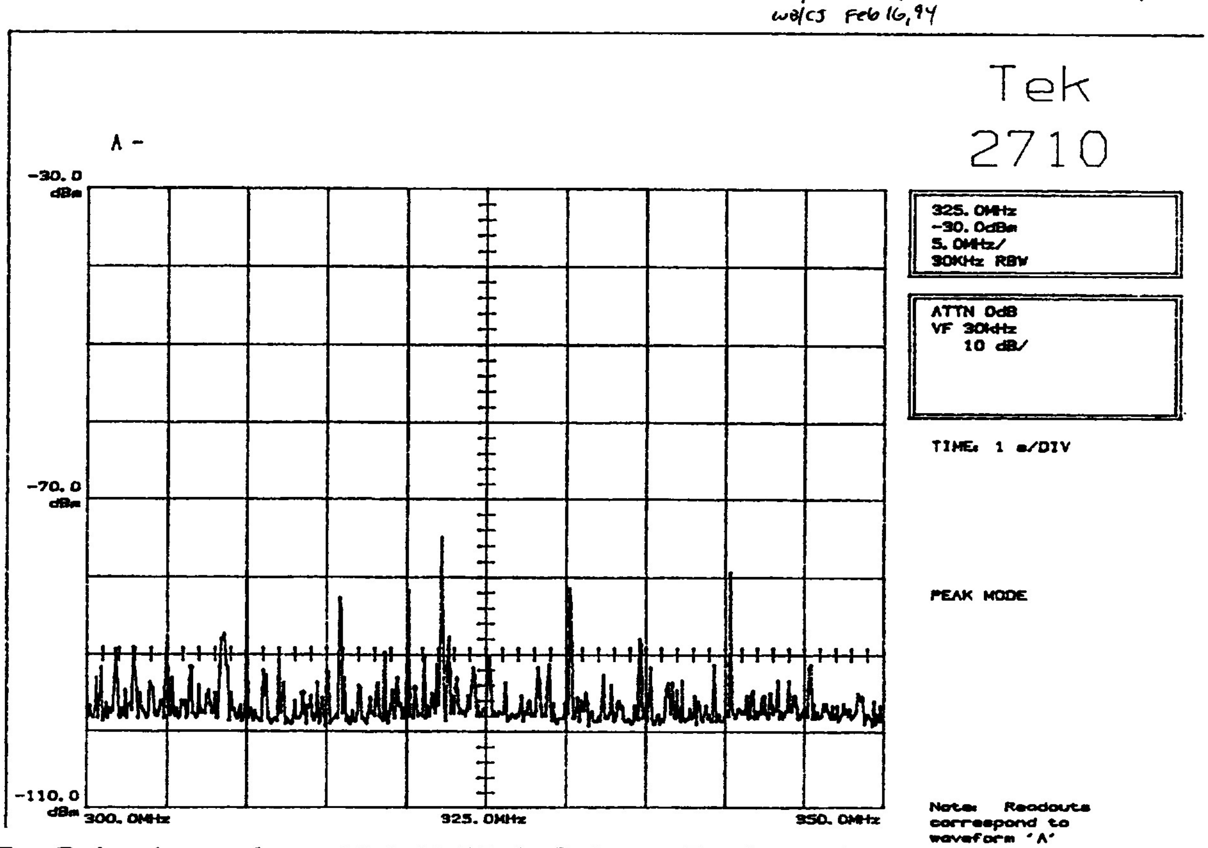


FIGURE 2: TOP: Emissions from VLA VLBI & Pulsar Equipment.
BOTTOM: Background Emissions from Other Equip.

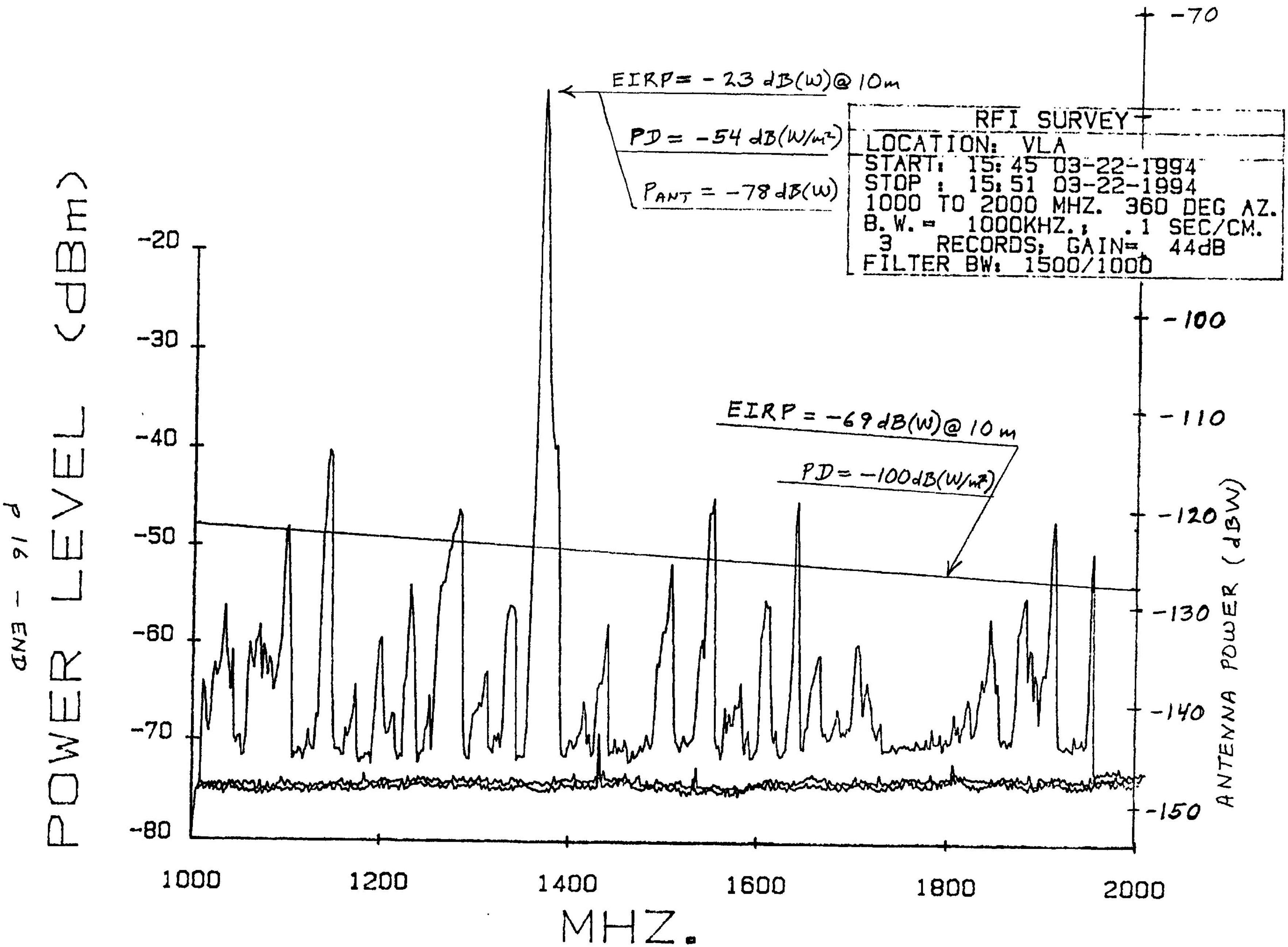


FIGURE 3: Peak Spectrum of a Site Vehicle at L-band.