VLB ARRAY MEMO No. 383

NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

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To: VLBA Configuration/Site and Electronics Groups

From: W. D. Brundage

Subj: RFI at the Haystack Site

HARMFUL INTERFERENCE LEVELS

An important criterion in VLBA site selection is the present and anticipated radio frequency interference (RFI) environment.

The 1982 VLBA Red Book [NRAO 82] established harmful interference levels (HIL) for each tuning range. HIL's for signals coherent with VLBA frequencies could be much lower. This memo considers only external RFI, not self-RFI. The Red Book HIL's are listed in $dBWm^{-2}$ units of flux density incident on a VLBA antenna sidelobe gain of +10 dBi. This memo uses HIL's in dBWi units of power relative to one watt out of an isotropic receiving antenna. Units of dBWi are directly related to power levels measured by spectrum monitoring systems and to power levels coupled from the VLBA antenna into the receiver system. Harmfulness is intrinsically determined by the signal power entering the receiver input (feed port). The Red Book says, "The harmful limit for (external) interference ... is estimated to be approximately 20 dB below the system noise power in a receiving channel."; i.e., HIL = $k\ T_s\ B/100$. That power is coupled to the incident flux density by the antenna gain which can range from +83 dB to -30 dB. Therefore, if we know the dBWi of an incident signal, we add the dBi gain of the antenna in matched polarization toward the signal to obtain the dBW power into the receiver. See CCIR Report 675, CCIR Rec. 509, CCIR Report 224-5, Section 4, and CCIR Report 696-1.

The VLBA tuning ranges from VLBA Memo 354, the system temperatures T_s, the bandwidth B, and the HIL in $dBWm^{-2}$ for +10 dB sidelobe gain, and the HIL in dBWi are listed in Table I.

TABLE I

Estimated Harmful Interference Levels (HIL)
within the VLBA Tuning Ranges

HIL $\approx$ K T_s B/100

Band Name (cm)	Specified Tuning Range (GHz)	Accessible Range (GHz)	T_s System Noise Temperature (K)	B Bandwidth (MHz)	HIL Flux Density In + 10 dB Sidelobe ($dBWm^{-2}$)	HIL Power Out Isotropic Antenna (dBWi)
90	.312- .342	Same	120	6.6	-158	-160
50	.580- .640	Same	100	6.0	-154	-161
20	1.35 - 1.75	1.30- 1.80	30	[27]	-145	-160
13	2.15- 2.35	2.10- 2.60	30	10	-145	-164
6	4.60- 5.10	Same	32	10	-138	-164
(5)	(5.90- 6.40)	Same	35	[10]	-136	-163
3.6	8.0 - 8.8	7.9 - 8.9	37	50	-126	-156
(2.8)	(10.2 -11.2)	Same	45	100	-127	-152
2	14.4 -15.4	Same	65	50	-118	-153
1.3	21.7 -24.1	20.0-26.3	45	100	-113	-152
0.7	42.3 -43.5	Same	60	100	-107	-151
( )	Are optional					

Note: T_s is from VLBA Electronics Group Front-End Summary, February 1984.

Estimates of harmful interference levels for signals outside the VLBA tuning ranges are very difficult to quantify now because the passband, filter, intermodulation, and gain compression characteristics of the VLBA receivers are unspecified and mostly unknown. Filter out-of-band rejection characteristics will be limited by the phase slope (group delay) and phase stability specifications. See VLBA Memo 295, CCIR Rec. 517-1, CCIR Report 697-1, and CCIR Report 854. Image rejection will be limited in the 50 cm and 2 cm bands. For some sort of reference level, I assume here that harmful effects will occur for RFI signals above a level 20 dB below the first GaAsFET amplifier input power level for 1 dB gain compression, which I estimate is -75 dBW. Therefore, the estimated HIL_O for frequencies significantly outside the VLBA tuning range for the bands 90 cm to 2 cm is -95 dBWi or less.

Estimates of existing RFI levels are made from several sources:

1. Calculated signal levels from transmitters listed in the data bases of the National Telecommunications and Information Agency (NTIA).

2. Knowledge of local transmitters and other emitters.

3. On-site spectrum monitoring.

Estimates of future RFI levels are made from "educated guesses" of future development in the surrounding area.

NTIA DATABASE

By way of the National Science Foundation, NTIA provided NRAO lists of fixed location transmitter frequencies and estimated signal levels for each VLBA site in each VLBA tuning range. No mobile, airborne or space transmitters were included. The data from the NTIA Government Master File (GMF) is reasonably complete and fairly correct for Federal Government transmitters authorized prior to about December 1983. The data from the FCC Non-Government Master File (NGMF) is significantly incomplete and notoriously incorrect for locations and powers. Therefore, most of the signals from the NTIA database exist at some received level but many existing signals do not appear in the lists.

NTIA estimated signal levels at the VLBA sites by a simplistic propagation model in their Geographic Display Model (GDM) printouts. The model assumes that transmitter antenna and the VLBA antenna are 100 feet above smoothly curved earth. This over-estimates signal levels for VLBA sites at low spots in irregular terrain, but underestimates levels for high sites, such as Kitt Peak, where the transmitter may be line-of-sight. Furthermore, the model assumes the transmitter power datum is effective isotropic radiated power (EIRP) directed toward the VLBA receiver. The actual EIRP toward the VLBA receiver may be +12 dB to -20 dB relative to the assumed power for frequencies $\lesssim$ 1400 MHz and +30 dB to -60dB for frequencies $\gtrsim$ 1400 MHz.

Therefore, evaluating the NTIA lists is difficult. However, they are useful in flaging very high level signals.

LOCAL TRANSMITTERS AND OTHER EMITTERS

The most obvious and most serious RFI sources at the Haystack site are the three local radar systems. These radars are the Westford Atmospheric Science Radar at 440 MHz, the Millstone Hill Satellite Tracking Radar at 1295 MHz, and the Haystack Satellite Long Range Imaging Radar. R. Ingalls of the Haystack Observatory provided the radar characteristics listed in Table II. Note the average powers, modulations, and current operating times.

Other local emitters mentioned by Ingalls at the Green Bank Interference Identification and Excision Workshop are high speed digital logic and arcing 23 KV power lines.

Residential development approaching the Haystack/MIT land brings with it the usual urban intentional and incidental emitters, including TV booster amplifiers oscillating in the 312-342 MHz range and microwave oven emissions in the 13 cm and 6 cm bands.

SPECTRUM MONITORING BY HAYSTACK

Staff of the Haystack Observatory did spectrum monitoring of the VLBA bands at 320 MHz, 610 MHz, 1.3 GHz, 2.2 GHz, and 10 GHz, with emphasis on the three radars at 440 MHz, 1295 MHz and 10 GHz, and UHF TV Channel 38. They made spectrum analyzer measurements at the Haystack antenna site, Farmhouse site #1, and Conscience Hill site #2 in October and November 1983 and in April and May 1984.

A MIT Haystack Observatory report by R. P. Ingalls, dated 1 June 1984, gives the methods, results and conclusions. A copy is on file in the VLBA Project Office (C. Williams). NRAO staff R. Thompson, J. Campbell, J. Oty, K. Kellermann, B. Peery and W. Brundage also have copies.

Their measured peak signal levels are listed in Table III.

TABLE II

Characteristics of Radars at/near Haystack Observatory

Characteristic	Westford Atmospheric Science Radar	Millstone Hill Satellite Tracking Radar	Haystack Satellite Imaging Radar
Frequency	440.0 and 440.2 MHz	1295.0 MHz	10.0 GHz
-3 dB Bandwidth	100 kHz	1 MHz Pulse 10 MHz Ramp	100 kHz Pulse 10 MHz Narrow Band Ramp 1000 MHz Wide Band Ramp
-40 dB Bandwidth	$\sim$ 20 MHz now > 20 MHz future		
Power: Peak/Average	2.5 MW/125 kW	2.5 MW/125 kW	300 kW/150 kW
Modulation	Pulse width 2 ms to 10 µs Rise time $\sim$ 0.5 µs to < 0.5 µs Phase reversal > 10 µs	Pulse Phase reversal Linear FM ramp	Pulse width 1 ms to 250 µs Narrow band FM ramp Wideband FM ramp
Power Tube	Klystron	Klystron	Traveling wave tubes
Filter	Third harmonic filter	?	?
Antenna	150-ft AZ-EL 220 ft zenith	84 ft AZ-EL	120 ft AZ-EL
Operating Time	Intermittent 2 days/week at 24 hours/day	30 to 50% of year	Regularly $\sim$ 1 week out of every 6 weeks

TABLE III

Peak Signal Levels near Haystack Observatory
measured October 1983-May 1984 by Haystack Staff
(Spectrum Analyzer in Maximum Hold Mode)

Signal	Location	Peak Level (dBWi)	Peak/HIL (dB)	Peak/HIL_0 (dB)
1295 MHz Radar	Sites #1 and #2	-57	103	>38
1295 MHz Radar	Haystack	-52	108	>38
440 MHz Radar	Site #1	-73	-	22
440 MHz Radar	Site #2	-64	-	31
10 GHz Radar, Pulsed	Site #2	-94	58	-
10 GHz Radar, FM	Site #2	-124	28	-
UHF TV Channel 38	Site #2	-97	64	-
UHF TV Channel 38	Haystack	-74	87	-

Notes: HIL = Harmful Interference Level within and close to VLBA tuning range.

HIL_0 = Harmful Interference Level outside VLBA tuning range.

SPECTRUM MONITORING BY NRAO

NRAO-VLA staff J. Oty and J. Campbell have assembled a camping trailer with an automated spectrum monitoring system for the VLBA bands 90 cm-2 cm. Monitoring started at the Pie Town, NM site in July 1984 and will end in late August. A report on Pie Town RFI will be made.

Current plans have the system scheduled for monitoring in Massachusetts in late 1984 or early 1985.

ESTIMATED RFI LEVELS IN VLBA BANDS

90 cm, 0.312-0.342 GHz

General: Military band is 225-328.6 MHz and 335.4-399.9 MHz with many airborne emitters, some > 1 KW EIRP. Many air bases are in MA and CT. Instrument Landing System (ILS) transmitters, fixed only, exist at nearly all airfields, military, public, and private, at 328.6-335.4 MHz. HIL = -160 dBWi.

Fixed Transmitters:

f (GHz)	No. of Signals	with	Pi/HIL (dB)	Source
0.312 -0.3286	14		72 to 84	NTIA
0.3286-0.3354	79 within 200 mile radius			NTIA
0.3354-0.342	3		45 to 77	NTIA

Conclusions: Many very strong land and airborne emitters are in this band. Emissions are generally intermittent with short duration. ILS band emitters are fixed on land, less than 30 W EIRP, and usually emit continuously.

Operation in this band will be difficult with frequent RFI effects in the data, but perhaps little worse than high altitude sites such as Kitt Peak.

50 cm, 0.580-0.642 GHz

General: This is the UHF TV band with Channel 37, 608-614 MHz reserved for radio astronomy. The strongest TV signal in this band at Haystack is the adjacent Channel 38, with Channel 36 also present. Almost every TV channel in this band has a signal level which exceeds the HIL. HIL = -161 dBWi.

Fixed Transmitters:

f (GHz)	Pi/HIL (dB	Source
0.584-0.590 Ch 33	32	NTIA
0.602-0.608 Ch 36	41/48	Haystack at Site #2/NTIA
0.608-0.614 Ch 37	<0	Haystack/NTIA
0.614-0.620 Ch 38	64/79	Haystack at Site #2/NTIA
0.626-0.632 Ch 40	29	Haystack
0.632-0.638 Ch 41	29/45	Haystack/NTIA
0.650-0.656 Ch 44	64	Haystack

Conclusions: Observing in this band at any site around Haystack will be impossible with the present receiver design. This band has straight amplification back to the video converters which have limited dynamic range and limited image rejection < 30 dB.

20 cm, 1.35-1.75 GHz

General: This band is adjacent to the Millstone Hill Satellite Tracking Radar at 1295 MHz. When it emits, all other RFI sources are insignificant. HIL = -160 dBWi.

Fixed Transmitters:

f (GHz)	Pi/HIL (dB)	Source
1.295	103	Haystack at Site #1 and 2
1.30 -1.35	98, 56, 35	NTIA; FAA and AF radars
1.68 -1.72	79, 70, 59, 48, 47	NTIA; Government links, radiosonds
1.72	~ 30	Haystack
1.72 -1.75	55, 54, 52	NTIA; Government links

Conclusions: Observing in this band with the current VLBA receiver design will be impossible while the 1295 MHz radar is emitting, which is 30 to 50% of each year. Other radars 1.30-1.35 GHz could cause problems at times. The 1.72 GHz signal could eliminate some OH observing.

13 cm, 2.15-2.35 GHz

General: This band contains allocations for fixed point-to-point, telemetry, deep space, mobile, radiolocation and amateur. Microwave ovens at 2450 MHz are adjacent. Brief monitoring by Haystack detected few signals. HIL = -164 dBWi.

Fixed Transmitters:

f (GHz)	Pi/HIL (dB)	Source
2.13-2.20	69, 51, 39, 36	NTIA; point-to-point
2.20-2.25	13 Tx at 67 to 51 dB	NTIA; point-to-point
2.25-2.30	67, 60	NTIA; point-to-point
2.30-2.35	60, 54	NTIA; point-to-point

Conclusions: This band probably would have few RFI problems. The Haystack monitoring implies few of the point-to-point paths pass close to Haystck. Nearby "dirty" microwave ovens could be an occasional problem.

6 cm, 4.60-5.10 GHz

General: This band contains the new 4.50-4.80 GHz allocation for fixed satellite space-to-earth emitters which could become a future problem. Fixed and mobile allocations are 4.50-4.99 GHz. Aeronautical radiolocation allocations are 5.00-5.25 GHz. The exclusive radio astronomy band is 4.99-5.00 GHz. HIL = -164 dBWi.

Fixed Transmitters:

(GHz)	(dB)	Source
4.60-4.80	54, 54	NTIA
4.80-4.99	56, 54, 53	NTIA

Conclusion: If no point-to-point paths are close to Haystack, this band would have few RFI problems. Future satellites could cause RFI problems.

5 cm, 5.90-6.40 GHz (optional)

General: This band contains allocations for radiolocation and amateur 5.85-5.925 GHz, fixed-satellite earth-to-space 5.925-6.875 GHz and fixed point-to-point 5.925-6.425 GHz. HIL = -163 dBWi.

Fixed Transmitters: The NTIA database indicates a large number of point-to-point transmitters. Estimated signal levels are nearly worthless because highly directive antennas are used.

Conclusions: RFI problems could exist now and in the future if point-to-point paths pass near Haystack. Only spectrum monitoring would indicate existing RFI potential.

3.6 cm, 8.0-8.8 GHz

General: This band contains allocations for fixed and satellite space-to-earth 8.025-8.50 GHz and radiolocation 8.50-9.0 GHz. Satellite radar is allocated 8.55-8.65 GHz and airborne doppler radar 8.775-8.825 GHz.

Fixed Transmitters: The NTIA database indicates a large number of point-to-point transmitters. Estimated signal levels are nearly worthless because highly directive antennas are used.

Conclusions: RFI problems could exist now and in the future if point-to-point paths pass near Haystack. Only spectrum monitoring would indicate existing RFI potential.

2.8 cm, 10.2-11.2 GHz (optional)

General: This band is adjacent to the Haystack Satellite Imaging Radar at 10.0 GHz. The band contains allocations for radiolocation (radar) 10.0-10.55 GHz, fixed 10.55-10.68 GHz and 10.70-11.70 GHz, satellite space-to-earth 10.7-11.7 GHz and radio astronomy (passive) 10.68-10.70 GHz.

Fixed Transmitters: The NTIA database indicates a large number of point-to-point transmitters. Estimated signal levels are nearly worthless because highly directive antennas are used.

Conclusions: Observations from any site near Haystack probably would be useless during Haystack radar emission (1 out of 6 weeks) with present VLBA receiver design. Other RFI problems could exist now and in the future if point-to-point paths pass near Haystack. Only spectrum monitoring would indicate existing RFI potential.

2 cm, 1.3 cm, and 0.7 cm

General: The NTIA database indicates several point-to-point transmitters in the 2 cm and 1.3 cm bands. Estimated signal levels are nearly worthless because highly directive antennas are used.

Conclusions: RFI problems at 2 cm and 1.3 cm could exist now and in the future if point-to-point paths pass near Haystack. Only spectrum monitoring would indicate existing RFI potential.

CONCLUSIONS BY R. INGALLS, HAYSTACK

The main conclusions in Ingalls' report are reproduced here.

"The levels measured under several representative conditions are listed in Table III for max hold measurements. Two of the three radars are five percent duty high peak power radars and the average power would be correspondingly less. The problem with the radars as I see it is that they will potentially cause intermodulation distortion if the receiver bandpasses are not properly controlled and the peak value is most relevant here. With the exception of the 10 GHz LRIR in 'wideband mode', none of the radar frequencies fall in the VLBA bands. The 4th harmonic of 440 MHz is at 2200 and the 8th harmonic of 1295 at 10360. Out-of-band skirt rejection is the most important factor for signals entering the receiver front ends.

"The UHF TV band is a problem. The Radio Astronomy Channel 37 is neatly bracketed by two local stations on 36 and 38 and another local channel, 44, is close by. Fortunately, the locations at Conscience Hill and the Farmhouse gave 20 dB lower levels than on the top of the hill, although the measurements apply to ground level.

"My conclusions on the siting possibilities at either the Farmhouse (#1) or Conscience Hill (#2) are that they are suitable for a VLBA antenna if suitable RFI precautions are taken right from the beginning in the construction of the station.

"1. The radar interference levels measured from the radars at UHF and L-band are substantially lower at the two field sites than at Haystack. No problem has been experienced at Millstone from the X-band radar. We have successfully lived with these radars for many years after making a number of quite reasonable precautions and corrections such as listed below.

"2. The RF amplifiers of the VLBA receivers should be band disciplined following the low noise amplifier to eliminate out-of-band radar signal intermodulation distortion. For higher frequencies, high pass filtering may suffice (that is waveguide for transmission line) but bandpass filters should be used at the lower frequencies.

"3. IF and baseband amplifiers and components that cover any radar frequency, particularly 440 MHz (and the UHF TV band to boot!) should be 'waterproofed' against these signals.

"4. Local Oscillator, Bias, Leveler and other control circuits that can rectify sneak RF signals and produce unwanted "modulation" effects should be well shielded and bypassed. This may require construction practice that is more MIL spec. than is conventional with Radio Astronomy equipment.

"5. There are locally available gating signals from the several radars that could be used for a last resort method of excising radar interference. This may be quite practical since the UHF and L band radars which are the more difficult problem have only 5 percent maximum duty cycle transmitters. This represents only .22 percent integration time loss.

"6. While the UHF TV band problem may be particularly obnoxious here, it is ubiquitous.

"7. To us, the many advantages of these sites close to Haystack would seem to outweigh the strong precautions necessary against RFI from the radars."

CONCLUSIONS BY AUTHOR

The Haystack Observatory area should <u>not</u> be a VLBA antenna site. The reasons are:

1. The 50 cm 0.58-0.64 GHz band will not be usable with the current VLBA receiver design because of the very high level UHF TV signals.

2. The 20 cm 1.35-1.75 GHz band will not be usable with the current VLBA receiver design whenever the Millstone Hill Satellite Tracking Radar at 1295 MHz is operating. Presently it operates 30 to 50% of each year. The future could have more frequent operation.

3. The optional 2.8 cm 10.2-11.2 GHz band will not be usable with the current VLBA receiver design whenever the Haystack Satellite Imaging Radar is operating. Presently it operates about one week out of every six, about 17% of the year.

4. Changing the receiver design for operation near Haystack in subparts of the 50 cm, 20 cm and 2.8 cm bands could be possible in principle, but is not recommended. CCIR Report 697-1 indicates some fundamental limitations. We do not want even one unique receiver in the VLBA system of remote antennas. This antenna would then be eliminated from the array for some observing programs.

5. Extraordinary measures in RFI proofing the receiver cabling, IF and control/monitor systems could be necessary to prevent problems from the Westford Atmospheric Science Radar at 440 MHz.

6. If NRAO locates a VLBA antenna near Haystack and three high-power radars, then in principle a VLBA antenna could be located at electronic sites such as Heleakala and Mount Lemon.

7. CCIR Report 696-1, Section 8.6, says:

   "To improve the chances of successful frequency sharing, radio-astronomy observatories should be sited as far as possible from urban areas and transmitters with interfering potential, and should be shielded to the greatest extent possible by surrounding terrain. These precautionsd are, however, likely to affect only the sharing possibilities discussed above. At frequencies above 10 GHz and particularly above 20 GHz, the need to site observatories at high altitudes to minimize atmospheric absorption may limit the extent to which site-shielding is practicable."

8. CCIR Recommendation 314-5:

   "... unanimously ..." recommends "... that radioastronomers should be encouraged to choose sites as free as possible from interference."

REFERENCES

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CCIR Report 224-5: "Interference Protection Criteria for the Radio Astronomy Service," ITU/CCIR, Vol. II, p. 497, Geneva, 1982.

CCIR Report 675: "Radiation Diagrams of Antennae at Space Research Earth Stations for Use in Interference Studies," ITU/CCIR, Vol. II, p. 37, Geneva, 1982.

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