VLA SCIENTIFIC MEMORANDUM NO. 101

VLA PERFORMANCE

The purpose of this report is to succinctly describe the VLA performance as presently designed and to estimate the change of performance with a change of design. The "nominal" VLA will have the following characteristics: 27 antennas, four "wye" configurations, 35 MHz bandpass, system noise temperature of 50° at several frequencies, dual polarization.

I. General Characteristics

1. Sensitivity

The sensitivity of the VLA as presently designed is given by

$$\Delta S = 1.65 \times 10^{-4} \ \frac{27}{N} \ (35/B)^{1/2} \ (T/50) \tag{1}$$

ΔS = 5 x rms noise = detection level in flux units
N = number of elements
B = bandwidth in MHz
T = receiver noise temperature
Assuming: 12 hour integration
All pairs correlated
Dual polarization
50% dish efficiency
71% array efficiency.

The minimum detectable point source (5 rms) using the above system is 0.2 milliflux units and the dependence with N (number of telescopes), B (bandwidth) and T (system temperature) is obvious from equation (1). Using a bandwidth of 500 MHz and a system temperature of 20°K, both of which are reachable, the detection limit would be 1.7×10^{-5} f.u. Whether this level is in fact reachable will be discussed later.

2. Sidelobe Level

The sidelobe levels and falloff of the nominal VLA at $\delta = 30°$ are summarized in Table Ia. These values are approximate and have been taken from Vol. III, Chapter 3 of the VLA proposal. The dependence of the levels with N (number of telescopes) and B (the bandwidth) are shown in the last column. The effect of atmospheric turbulence (from Hinder and Ryle) are given in Table Ib.

Table Ia

Sidelobe Characteristics of the Nominal VLA

	PEAK		MEAN		
	Inner*	Falloff*	Inner*	Falloff*	Dependence
Inside field of view	-18 dB	0.5 dB	-25 dB	1.0 dB	N^{-1}
Outside field of view	-22 dB	3.0 dB	-29 dB	3.0 dB	$N^{-1}\ B^{-1}$

* Sidelobe level immediately outside HPBW (zone 1)

* Falloff is the decrease in sidelobe level with a doubling of the distance. (Zones)

Table Ib

Atmospheric Sidelobe Level*

Wavelength (cm)	Configuration			
	21 Km	7 Km	2.1 Km	0.78 Km
1	-25 dB	-26	-28	-29
3	-28	-28	-30	-31
6	-33	-33	-33	-35
21	-30	-34	-35	-35
75	-25	-30	-34	-35

* From Hinder and Ryle Fig. 2.
Corrected for 351 interferometers, 1 dB better stability in N. Mexico.

3. Confusion

For an evaluation of the VLA the effect of confusion must be considered. Using a recent compilation of Kellermann we will use

$$N = N_o S^{-1.5} \qquad S > S_o$$

$$N = N_1 S^{-1.0} \qquad S < S_o$$

where

Wavelength	N_o	S_o	N_1
75	800	.350	1352
21	150	.130	416
6	60	.065	235

with N in number of sources per steradian with a flux density greater than S.

The source density below 10^{-3} f.u. is currently not available and we will assume that the slope -1.0 persists. Actually the data suggest a slope of -0.8 below 10^{-2} f.u., but one should be conservative in this calculation, especially since at very weak levels the slope may again become more negative. We shall assume that all of the sources are unresolved.

II. Comments

1. How Deep Can the VLA Really Go?

Probably the most important aspect of the VLA is its sensitivity. Although the nominal system is designed to reach 10^{-4} f.u., a sensitivity limit of 10^{-5} f.u. is likely at some future time. Changes in the design which might make the VLA incapable of reaching 10^{-5} f.u. should be avoided.

There are at least five limitations to the ultimate VLA sensitivity.

i. ΔS = receiver noise

ii. ΔS_C = confusion in the synth. beam

iii. ΔS_P = rejection of a strong source in the primary beam

iv. ΔS_F = rejection of a strong source in the field of view

v. ΔS_A = atmospheric sidelobes.

The results of a calculation to determine the flux density level expected for each of the above limitations is given in Table II. Three wavelengths have been considered: 75 cm, the longest wavelength which may be used, 21 cm and 6 cm. At shorter wavelengths the source density is small and the major limitation will be the system noise. The dependence of the various values on bandwidth B, number of antennas N, and system temperature T, all relative to the nominal VLA, are given in the last column. A more detailed description of the calculations leading to Table II is given in the appendix. The derived values in the appendix are rms values.

It was unclear what specific values to list in Table II. The rms values (or 5 x rms values) are not directly comparable among the various terms. A proper criterion really depends on the nature of the experiment being performed. It was decided to use a 1% significance level; that is, given 100 synthesized areas, what is the maximum flux density expected. In these terms

$$\begin{aligned}
\Delta S\,(1\%) &= 2.5\ \Delta S(\mathrm{rms}) \\
\Delta S_C(1\%) &= 100\ \Delta S_C(\mathrm{rms}) \quad \text{if } N \sim S^{-1.0} \\
\Delta S_P(1\%) &= \sim 5\ \Delta S_P(\mathrm{rms}) \\
\Delta S_F(1\%) &= \sim 5\ \Delta S_F(\mathrm{rms})
\end{aligned}$$

The values of 5 for ΔS_P and ΔS_F are guesses. We have also not included "beam cleaning" techniques and strong source subtraction which could remove the largest sidelobes. For the atmospheric sidelobes we took 5 times the sidelobe level (in Table Ib) times the strongest source in the field of view.

Table II

Sensitivity Limits of VLA

		Configuration				
		I 21 Km	II 7 Km	III 2.1 KM	IV 0.78 Km	Dependence
	ΔS	8.3 -5	8.3 -5	8.3 -5	8.3 -5	$B^{-0.5}$ N^{-1} T
75 cm	ΔS_C	1.9 -4	1.7 -3	1.5 -2	1.4 -1	
	ΔS_P	1.0 -3	3.3 -3	1.0 -2	2.1 -2	$B^{-1.0}$ N^{-1}
	ΔS_F	3.3 -6	3.0 -5	2.6 -4	2.4 -3	$B^{-1.7}$ N^{-1}
	ΔS_A	5.0 -6	1.5 -5	5.0 -5	3.4 -4	N^{-1}
21 cm	ΔS_C	4.0 -6	3.6 -5	3.2 -4	2.9 -3	
	ΔS_P	1.3 -4	4.1 -4	6.5 -4	(8.0 -4)	$B^{-1.0}$ N^{-1}
	ΔS_F	6.5 -7	6.0 -6	5.0 -5	---	$B^{-1.7}$ N^{-1}
	ΔS_A	5.0 -7	1.8 -6	1.3 -5	9.5 -5	N^{-1}
6 cm	ΔS_C	2.3 -7	2.1 -6	1.9 -5	1.7 -4	
	ΔS_P	4.6 -6	7.5 -6	(9.0 -6)	(9.0 -6)	$B^{-1.0}$ N^{-1}
	ΔS_F	2.3 -7	2.0 -6	---	---	$B^{-1.7}$ N^{-1}
	ΔS_A	1.5 -7	1.3 -6	6.0 -6	3.6 -6	N^{-1}

Values in (   ) indicated the field of view is equal to the primary beam in which case S_F = S_P and are unaffected by B.

ΔS = noise sensitivity

ΔS_C = confusion in synthes. beams by weak sources

ΔS_P = confusion by strong sources in the primary beam

ΔS_F = confusion by strong sources in the field of view

ΔS_A = atmospheric fluctuations

B,N,T with respect to nominal VLA

Comments concerning the detection of weak sources:

1) The VLA, even with super receivers, will be sensitivity limited at wavelengths shorter than ∿ 9 cm for the larger configurations. This is due to the low density of sources and the small area of sky observed. At 6 cm there are only 200 sources in the primary beam above 10^{-5} f.u.

2) At 21 and 11 cm there is significant confusion from strong sources in the primary beam. In order to reach 10^{-5} f.u. the bandwidth must be increased to ∿ 400 MHz to decrease ΔS_P. Then with 20° receivers, 10^{-5} is obtainable. However, the field of view is then only 8". Many fields of view are desirable.

3) At 75 cm the instrument is confusion limited again by strong sources in the primary beam. Short of increasing the bandwidth (which is difficult at 75 cm), the sensitivity limit is 1×10^{-3} and there is no need to have a system temperature better than 500°. Alternatively with a bandpass of 1 MHz and 300° receivers nearly the entire primary beam can be synthesized in configuration I with a sensitivity of $\sim 5 \times 10^{-3}$.

4) A change in the number of telescopes N has little effect on the performance. All of the limiting flux densities (except confusion ΔS_C which is unimportant at configuration I) vary as N^{-1}. However, if increased sensitivity is desired, it is best to decrease T and increase B for wavelengths longer than 11 cm in order to decrease the sidelobe levels.

5) For detection work the optimization of the transfer function is not critical. The term ΔS_F due to sidelobe response of sources in the field of view is smaller than ΔS_P for nearly all wavelengths and configurations. Optimization of the rejection outside of the field of view might be more profitable (if it is at all possible). What about synthetic large bandwidths? Needless to say, a larger diameter telescope would produce the rejection.

2. Observations of Bright Sources

The mapping of strong sources are not affected by confusion. The performance for this type of observation is measured by Table 1a and b. Assuming that some sort of beam cleaning is used, sidelobe levels of -20 to -23 db within the field of view should be obtainable at all configurations. Except at 1 cm, atmospheric sidelobes are a factor 3 to 20 times smaller.

The sidelobe level depends on N^{-1}. However, even for a decrease of 5 telescopes, the sidelobe level in the field of view should increase by less than 1 db.

3. Spectral Line Observations

With the use of narrow bandwidths, the minimum noise sensitivity ΔS is a factor $\sim$ 25 less. Extragalactic confusion is not a problem because of the lack of frequency structure. The performance of the VLA, as for bright sources, is measured by Table 1a and b. One uncertainty is the performance of the array at the 7 or 21 Km configuration where there are 300 x 300 or 1000 x 1000 synthesized beams in the primary beam. Could the VLA successfully map a large galactic source which filled the beam and contained a complex distribution of line radiation?

Ed Fomalont - June 28, 1972

APPENDIX

I. The dependence of various terms on B (Bandwidth), N (Number of telescopes) and T (System Temperature).

A. ΔS (system noise) $\sim N^{-1} B^{-1/2} T$ (see eqn. 1)

B. Sidelobes inside field of view.

The sidelobe level is roughly given by the contribution of all correlators adding randomly at any point outside the main beam. Since the number of correlators $\sim N^2$, the sidelobe level varies as $(N^2)^{-1/2} \sim N^{-1}$. This dependence is suggested by Fig. 3-3 in Vol. III.

C. Sidelobes outside the field of view.

A similar argument holds for the N^{-1} dependence. Given a strong source of flux density S outside the field of view, the bandwidth B smears the source radially with respect to the beam center in proportion to B. Hence the peak intensity goes as B^{-1}. However, I am not sure this is correct. In Fig. 3-12 Vol. III, the dependence on B is only $B^{-1/2}$.

II. Calculation of various VLA parameters and definition of the more obscure terms.

N_S = number of sources in field of view.

S_P = strongest source expected in primary beam.

S_F = strongest source expected in field of view. Varies as B^{-2}.

ΔS_C = rms confusion in synthesized beam.

ΔS_P = rms sidelobes from S_P. The sidelobe level in dB is shown in parenthesis.

ΔS_F = rms sidelobes from S_F. The sidelobe level in dB is shown in parenthesis.

ΔS = rms noise using nominal VLA.

ΔS_A = atmospheric rms sidelobe.

TA[redacted]E [redacted]

VLA PARAMETERS

CONFIGURATION

		I	II	III	IV	DEPENDENCE
	ARRAY LENGTH	21 Km	7 Km	2.1 Km	0.78 Km	
	FIELD OF VIEW	1′.6	4′.8	14′.2	42′.4	B^{-1}
	ΔS		3.3×10^{-5}			$B^{-0.5} N^{-1} T$
75cm	PRIM. BEAM	127′	127′	127′	127′	
	SYN. BEAM	6″.8	20″.4	61″.1	183″	
	S_P	3.3	3.3	3.3	3.3	
	S_F	3.3 -4	3.0 -3	2.6 -2	2.4 -1	B^{-2}
	ΔS_c	1.9 -6	1.7 -5	1.5 -4	1.4 -3	
	ΔS_P	2.1 -4 (42)	6.6 -4 (37)	2.1 -3 (32)	4.2 -3 (29)	$B^{-1} N^{-1}$
	ΔS_F	6.6 -7 (27)	6.0 -6 (27)	5.2 -5 (27)	4.8 -4 (27)	$B^{-1.7} N^{-1}$
	ΔS_A	1.0 -6	3.0 -6	1.0 -5	7.6 -5	N^{-1}
	N_s	2.9	26.1	235	2114	$B^{-1.5} N T^{-1}$
21cm	PRIM. BEAM	36′	36′	36′	36′	
	SYN. BEAM	1″.9	5″.7	17″.1	51″.1	
	S_P	1.3 -1	1.3 -1	1.3 -1	1.3 -1	
	S_F	1.0 -4	9.2 -4	8.3 -3	6.0 -2	B^{-2}
	ΔS_c	4.0 -8	3.6 -7	3.2 -6	2.9 -5	
	ΔS_P	2.6 -5 (37)	8.2 -5 (32)	1.3 -4 (30)	1.6 -4 (29)	$B^{-1} N^{-1}$
	ΔS_F	1.3 -7 (29)	1.2 -6 (29)	1.0 -5 (29)	–	$B^{-1.7} N^{-1}$
	ΔS_A	1.0 -7	3.6 -7	2.6 -6	1.9 -5	N^{-1}
	N_s	0.9	8.0	72	456	$B^{-1.5} N T^{-1}$
6cm	PRIM. BEAM	10′.2	10′.2	10′.2	10′.2	
	SYN. BEAM	0″.6	1″.7	5″.1	15″.0	
	S_P	2.3 -3	2.3 -3	2.3 -3	2.3 -3	
	S_F	5.8 -5	5.2 -4	2.3 -3	2.3 -3	B^{-2}
	ΔS_c	2.3 -9	2.1 -8	1.9 -7	1.7 -6	
	ΔS_P	9.2 -7 (34)	1.5 -6 (32)	1.8 -6 (31)	1.8 -6 (31)	$B^{-1} N^{-1}$
	ΔS_F	4.6 -8 (31)	4.1 -7 (31)	–	–	$B^{-1.7} N^{-1}$
	ΔS_A	2.9 -8	2.6 -7	1.2 -6	7.3 -7	N^{-1}
	N_s	0.5	4.5	20	20	$B^{-1.5} N T^{-1}$