National Radio Astronomy Observatory
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The Spectral Line Correlator for the VLA

VLA Electronics Memorandum #104

by

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Spectral line observations will be an important part of the radio astronomy programs done with the VLA. The electronics for the VLA are compatible with spectral line work and the operating frequencies are chosen to correspond with the most important atomic and molecular lines (H, OH, H_2CO, H_2O, and NH_3). The main additional equipment needed are a line receiver or cross correlator and a computer for data reduction and display. The spectral line computer has been described by B. G. Clark in VLA Memorandum #13. This memo will discuss the VLA correlator, estimated costs and some of the options available.

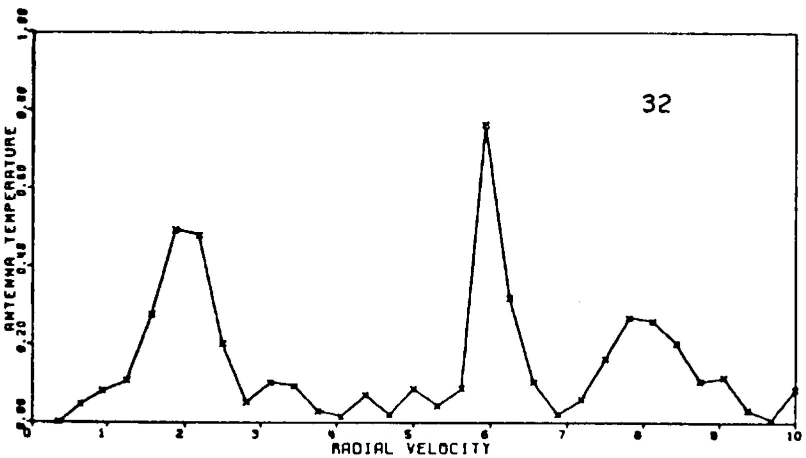
The VLA will have 27 antennas which will mean 351 independent pairs of antennas to be correlated. In order to obtain both amplitude and phase information two correlators are needed for each frequency channel. The number of frequency channels will most likely be either 64 or 128. This will mean 44928 or 89856 total correlators. The number of IF processors needed will be 27 or 54 if two receivers on each antenna are to be used simultaneously. The maximum total bandwidth depends on the speed of the switching logic used in the correlator and can be as much as 20 MHz, but at considerable cost increase. The number of bandwidths which can be selected is open and will be about 8 settings with a bandwidth change of a factor of 2 for each setting.

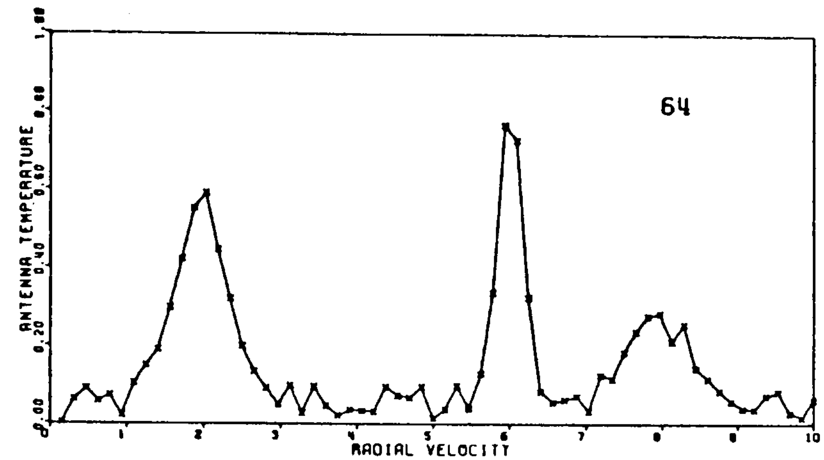
The two principle options available are the number of channels (64 or 128) and the maximum bandwidth (5, 10 or 20 MHz). The table gives some bandwidth and resolution figures for the main spectral lines.

		Resolution						Total Velocity Range		
	No. of Channels	64			128					
	Bandwidth (MHz)	5	10	20	5	10	20	5	10	20
	Δf for 1 Kms^{-1} (kHz/Kms^{-1})	(Kms^{-1})			(Kms^{-1})			(Kms^{-1})		
H/OH	5	16	31	63	8	16	31	1000	2000	4000
H_2CO	16	5	10	20	2	5	10	310	620	1240
H_2O/NH_3	74	1	2	4	1/2	1	2	68	135	270

The resolution indicated is at the maximum bandwidth and better resolution can be obtained by switching to a smaller bandwidth.

The effect of different resolutions on a simulated line spectrum is illustrated in the figure for 32, 64, 128 and 256 frequency channels. The noise has been kept constant so each factor of 2 improvement in resolution requires a $\sqrt{2}$ increase in integration time. One useful mode of observing which is being considered is to correlate 702 pairs of receivers rather than 351. This would allow two receivers at each telescope to be used. Simultaneous polarization measurements can be made in this parallel mode or the correlator outputs can be combined to give a $\sqrt{2}$ improvement in the noise. The latter would represent a factor of 2 loss in resolution in return for a factor of 2 improvement in signal to noise in the spectrum. This results from maintaining the total bandwidth constant with only 1/2


32
ANTENNA TEMPERATURE
RADIAL VELOCITY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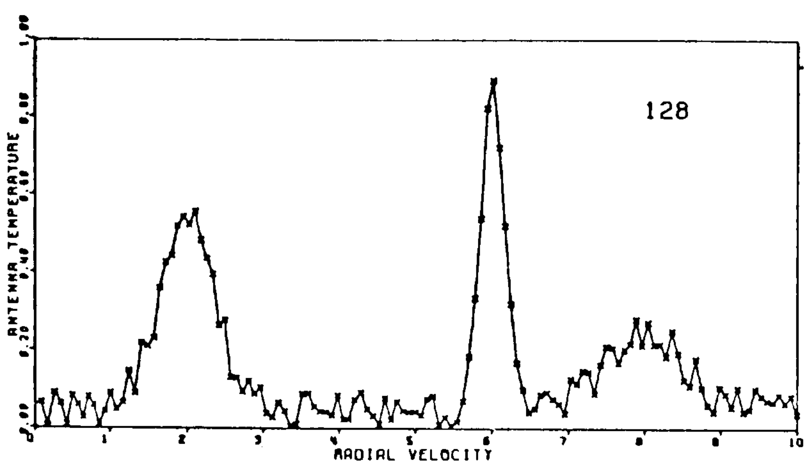
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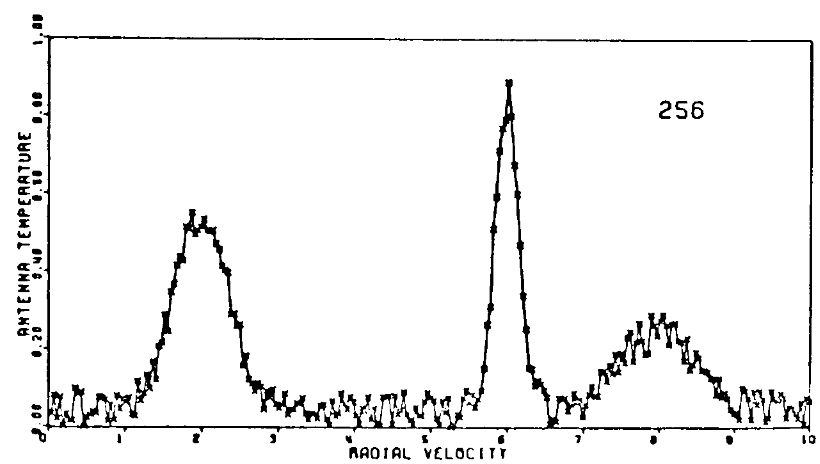
RADIAL VELOCITY


256
ANTENNA TEMPERATURE
RADIAL VELOCITY

the number of frequency channels available, and averaging the spectra from the two independent receivers.

The resolution vs bandwidth graph is an attempt to show the number of channels required for various spectral lines. In certain cases, such as the H_2O line, it will not be necessary to look at all the spectral features simultaneously. The ability to split the correlator into a parallel mode discussed above could provide two independent spectral windows for observing velocity separated features in a source. This also makes it possible to place the two bands side by side, thus doubling the bandwidth of the correlator (i.e., 5 MHz → 10 MHz, 10 MHz → 20 MHz). The computer will probably not be able to handle more than 256 channels. The other limits will be imposed by the cost of the correlator which will be discussed next.

A conservative cost estimate of several correlator options is given in the table.

DIGITAL CORRELATOR:

Bandwidth	Number of Frequency Channels	Approximate Cost
4 - 5 MHz	64	$ 1200 K
	128	1800 K
	256	3000 K
7 - 8	64	1600 K
	128	2400 K
10	64	2000 K
	128	3000 K

IF PROCESSOR:

	Number of Frequency Channels	Approximate Cost
	27	270 K
	54	540 K

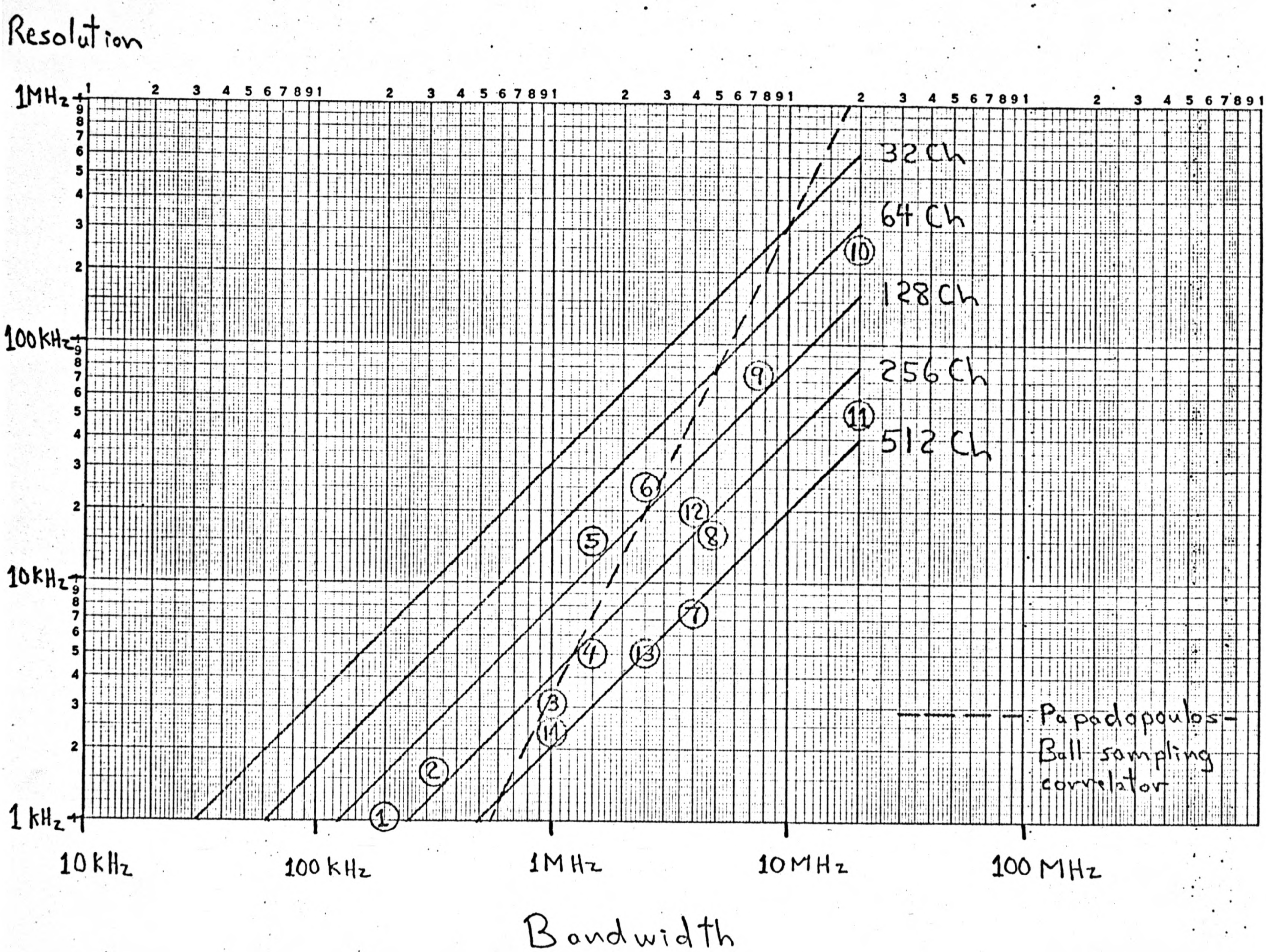
The bandwidth is the intrinsic bandwidth of the correlator and can be doubled by using the parallel mode discussed above. The number of correlators needed is 702 times the number of frequency channels. The cost of the IF processor must be added to the cost of the digital correlator (the cost may be reduced to $150K/300K if a single sideband IF processor can be used). The cost of a factor of 2 in number of channels is about the same as the cost of a factor of 2 in bandwidth. Hence the question is which is more important, number of channels or bandwidth?

The least expensive spectrometer is a 64 channel 5 MHz correlator with 27 IF channels costing 1200K + 270K = $1470K. The bandwidth can be doubled to 10 MHz by increasing the number of IF processors to 54 making the cost $1740K (the alternative of going to a 10 MHz digital correlator will cost $2270K). It can be seen from the bandwidth-resolution graph that all the experiments are starved for channels with a 64 channel correlator. The direction to go is toward more channels with a 128 channel 5 MHz correlator costing $2070K. An increase to 54 IF channels will provide 10 MHz bandwidth, 2 separate velocity windows or a factor of 2 decrease in noise using both receivers at a cost of $2340K. This last configuration would seem to have the most advantages for the spectral line experiments envisaged. The number of channels is the critical factor and a 128 channel correlator is essential. Building 64 channels and adding 64 later is a very difficult and costly way to construct the VLA correlator. In any event, the correlator should be designed for parallel operation even if there are only 27 IF processor channels available initially.

Notes On the Bandwidth-Resolution Graph

		Resolution	Bandwidth
1.	H cold galactic clouds	0.2 Km/s	40 Km/s
	OH narrow emission lines	0.2	40
2.	H_2CO dust cloud absorption	0.1	20
3.	H_2CO Cas A absorption	0.2	60
4.	H high velocity clouds	1	300
	H galactic structure	1	300
	OH galactic center absorption	1	300
5.	H_2O emission lines	0.2	20
6.	H other galaxies	5	500
7.	H_2O W49-Orion multiple lines	0.1	60
8.	H_2CO galactic center absorption	1	300
9.	NH_3 galactic center emission	1	100
10.	H extragalactic search	50	4000
11.	H/He/C recombination lines (1.3 cm)	50 kHz	20 MHz
	(10 & 11 will use whatever bandwidth is available)		
12.	H/He/C recombination lines (6 cm)	20 kHz	4 MHz
13.	H galactic center	1 Km/s	500 Km/s
14.	OH galactic clouds	0.5	200

In the graph a circle represents the required bandwidth and resolution for each experiment listed above. The bandwidth and resolution available for a 32 through 512 channel correlator is shown by the 45° solid lines. The dotted line indicates a possible Papadopoulos-Ball sampling correlator. Any given correlator will cover all those experiments above and to the left of the line. Experiments below the line can be done, but with less than optimum bandwidth or resolution.



Resolution
1 MHz
100 KHz
10 KHz
1 kHz
32 Ch
64 Ch
128 Ch
256 Ch
512 Ch
Papadopoulos-Ball sampling correlator
10 KHz
100 KHz
1 MHz
10 MHz
100 MHz
Bandwidth