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LBA -- A discussion document

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Also. AT. 44.5/025

1. Scope

This document is intended as a supplement and continuation of the "LBA Review Report" (AT/44.5/023) and should be used in conjunction with it. The discussion here aims to address the key issues pertinent to making a decision on the choice of a VLBI system for the LBA.

2. Finances

As always, the final system is going to be ultimately determined by the money available. The LBA funding situation is as follows:
a) Current AT finance is ~A$1M for the total project, about $700K for recorder/playback units.
b) CRC finance was not made available in the 1st round. Next round is at the end of June. Amount budgeted for equipment was ~$5M, based on VLBA equipment for 7 stations.

3. Scientific specifications

The ultimate choice of VLBI equipment should be governed by the science that it aims to explore. Three areas provide constrains:

a) Spectral line:
A spectral resolution of 1 KHz has been suggested (Ray Norris), although 0.5 KHz has also been mentioned (Jessica Chapman). This impacts the BW for each channel at record (filters) and the number of spectral points available in the correlator. Note that 1 KHz is also the specification for RadioAstron and the Canadian correlator. Polarization also appears important so at least 2 IF channels are needed. Imaging capability is needed i.e. >4 telescopes should be available.

b) Continuum imaging:
Continuum observers would like the widest possible bandwidths and the maximum number of stations. More than 4 stations should be provided for imaging studies and at least 2 IFs for polarization/multifrequency observations (4 IFs would be better).
Bandwidths of up to 64 MHz total have been suggested to fit in with most available VLBI systems.

c) Astrometry/Geodesy:
Maximum spanned Bandwidth is the main requirement. This implies that channelization is important with at least 2 channels/IF and at least 2 IFs.

Suggested signal specification:

2 IFs - either 2 frequencies or 2 polarisations
2 channels/IF - total number of channels 4
Max. BW/channel - 16 MHz (as per VLBA)
Total BW = 64 MHz in 4 x 16MHz channels.
Filtering to match correlator channels to give 1 KHz spectral resolution.
Sampling - 1 or 2 bit (to fit with available hardware)

This matches the specification of the available Hardware systems (VLBA and Radioastron) and the possible correlators.

4. Recorders and Playbacks

In the previous report it was concluded that with current finance it would be impossible to equip a multi-station (>4) VLBI system with VLBA or K4 recording/playback equipment. The only possible affordable choice is the Canadian S-2 system. Even then it may be necessary to acquire only S-2 systems with half their planned capacity. Such reduced-capacity systems are only available for the S-2 due to its very modular construction.

Suggested choice

Canadian S-2 recorders and playbacks. Negotiate with S-2 team for better interfacing with our systems.

5. Data Acquisition System

This system accepts the IF signals and produces the required channels of sampled and digitised data. All channelization, band conversion and filtering is done here. Formatting is also done by the VLBA system although this is not necessary for the S-2 which does user-transparent internal formatting and deformatting. Possible systems are:

a) VLBA DAS
This has all the capabilities necessary and it is commercially available at US$200K price! With the Canadian S-2 recorders the formatter part of the VLBA DAS is not necessary, saving ~$40K. However, the timing and control/communications is done via the VME computer in the formatter unit, so some of the formatter unit will have to be provided. Also, the input is at 0.5-1GHz and some up-conversion of the AT bands may be necessary.

b) AT narrow-band back-end.
This was always planned to be the DAS for the original LBA proposal. It fits much better with the AT IF system BUT it's still in the design/prototype stage. Channelization and filtering to be determined by the choice of correlator to provide the 1 KHz spectral resolution. This can be achieved with a 2 MHz filter for the AT correlator design given below.

The narrow-band backend original design also included array-tieing and circular polarisation electronics. If operation was restricted to using a single-dish only at the CA and a hybrid was used at the antenna (already done for Mk2 VLBI) to get circular polarisation, the required narrow-band system for the LBA will be considerably simplified. The necessary operations will now be band-conversion, channelization, filtering and sampling/digitisation.

Suggested DAS

Redesign the AT narrow-band back-end to provide 2 channels/IF, 2-IFs, suitably filtered and digitised. Cost is uncertain but guesstimates in the past ranged about $50K/system.
The BWs that need to be provided are 2MHz -- 16 MHz with AT correlator or 0.25 MHz -- 16 MHz with LBA correlator.

6. Correlators

The original LBA proposal called for fringe-rotation at the antenna (FRA). However, VLBI correlators have traditionally been built with fringe-rotation at the correlator (FRC) which allows much greater flexibility. Although fringe rotators could be built for our antennas, this method becomes difficult for outside antennas and probably impossible for intercontinental baselines.
Current opinion seems to be overwhelmingly in favour of FRC and only systems with fringe rotation at the correlator will be investigated here.

a) AT correlator
The size of such a correlator is limited by the number of AT-correlator chips and blocks set aside for the LBA (6 blocks).
With the currently available chips we can build:
6-station COMPLEX correlator

- 4 IF input channels at 16 MHz each
- 4 products/baseline (All Stokes parameters)
- 1 KHz spectral resolution at 2MHz bandwidth (2048 channels), achieved with recirculation.

Additional hardware that needs to be built is:
- Fringe-rotators for each baseline as in traditional complex correlators. Main effort in construction since these are well understood.
- Switching matrix for the correlator to be designed and built.
- Interfacing for recorders.
- SOFTWARE

A possible drawback of the AT design is the difficulty of acquiring more AT-correlator chips for future expansion.

b) VLBA correlator
The costs of building a copy of the VLBA correlator, as obtained from NRAO, are so low that make this proposition very attractive. The costs are US$105k for 6-stations or US$123k for 8-stations! These are for boards already built outside and system integration done in house. Cost may go up by ~25% for smaller quantities.
Software can also be obtained free of charge for NRAO.

Problems arise for the AT since we propose to not use VLBA recorder and playback units. Thus the software/hardware will need to be changed to accommodate the Canadian S-2 recording system. Perhaps the easiest but least elegant approach is to reformat the S-2 output to VLBA format, as already done for MkIII VLBI. This could be done in the playback unit.

The other area of impact on the AT design is in the filtering. The VLBA correlator has a maximum 1024 spectral points which gives only 256 spectral points for full polarisation (4 products). Thus, filters down to at least 0.250 MHz must be provided. This leads to the full VLBA DAS set of filters i.e. 125 KHz to 16 MHz in steps of x2.

c) Canadian Radioastron correlator
This is still in the definition stage and first units will not be available until end 1994. It meets the 1KHz spectral resolution with 2MHz coverage, which may be reduced if polarisation is required. Maximum channel bandwidth is 8MHz as per Radioastron specs.

The advantage of this design is that it will use the S-2 playbacks. - Even if a different correlator is built for the LBA there may still be areas of common interest in the playback interface design.

Suggested correlator choice

AT design of 6-station COMPLEX correlator with:
- 4 IF input channels at 16 MHz each
- 4 products/baseline (All Stokes parameters)
- 1 KHz spectral resolution at 2MHz bandwidth (2048 channels), achieved with recirculation.

7. Summary of suggested system for the LBA

Data Acquisition system (DAS)

- Redesigned AT narrow-band backend
- 2 input IFs, 64MHz maximum BW
- 4 baseband channels (2 per IF) of 16 MHz max. BW
- 1 or 2 bit sampling
- Bandwidth range: (1MHz), 2, 4, 8, 16 MHz

Record and Playback units

Canadian S-2 units.

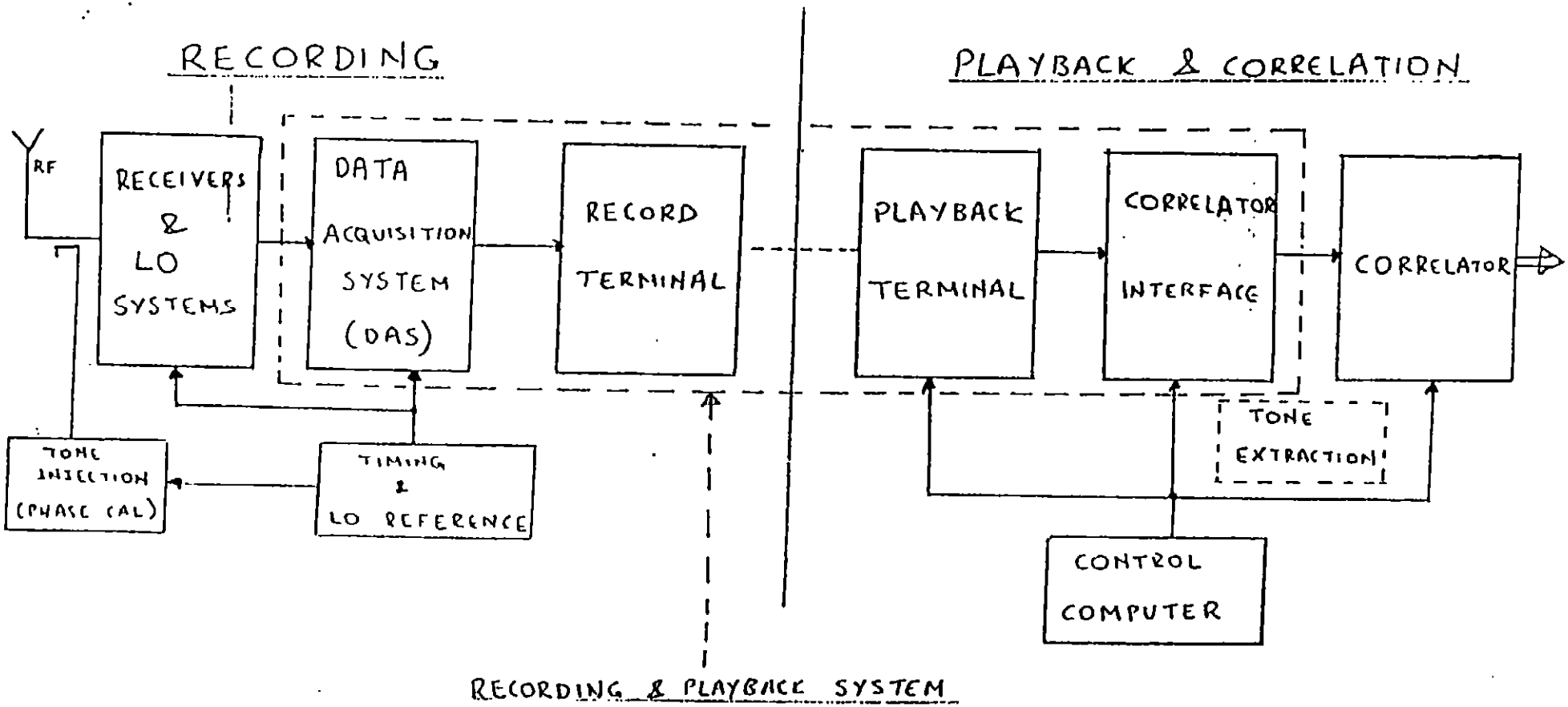
Correlator

AT 6-station COMPLEX correlator with:
- 4 IF input channels at 16 MHz each
- 4 products/baseline (All Stokes parameters)
- 1 KHz spectral resolution at 2MHz bandwidth (2048 channels), achieved with recirculation.
- All fringe rotation at the correlator.

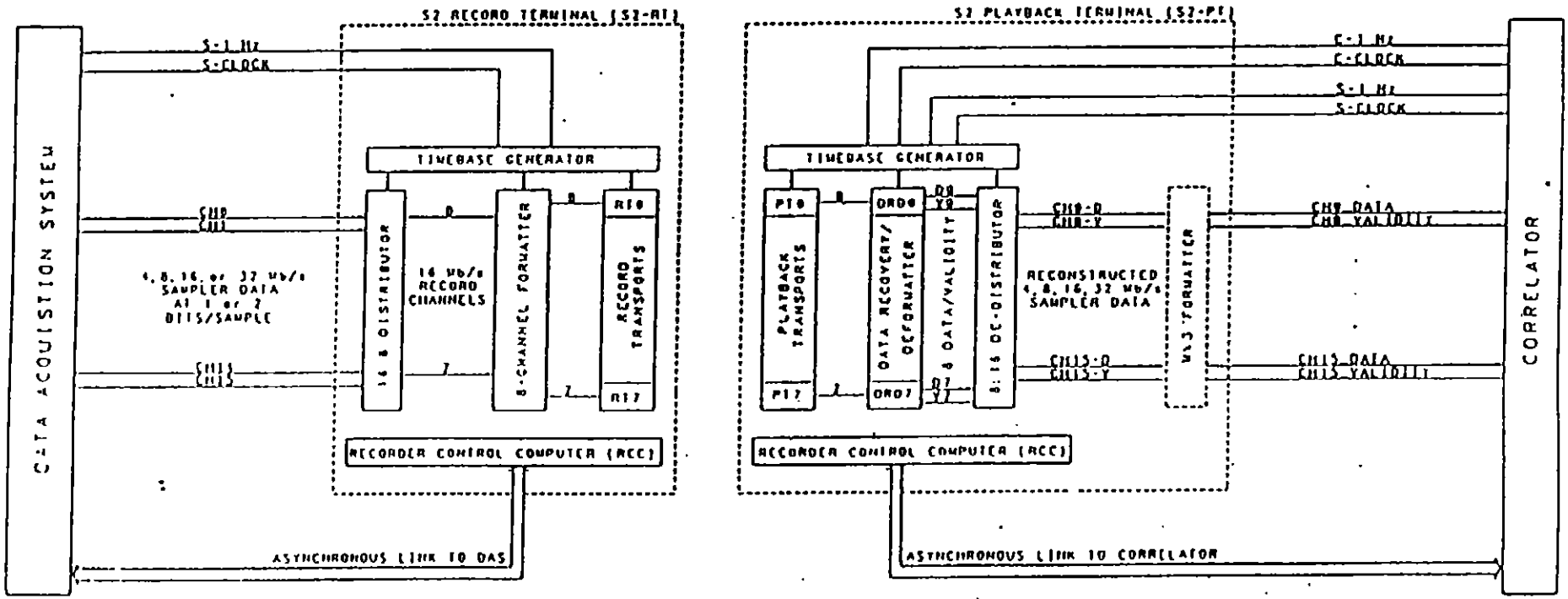
ATTACHMENTS

LBA Overview Schematic
Canadian S-2 Schematic
VLBA signals specification summary
VLBA DAS Schematic
VLBA Correlator specification summary
VLBA correlator cost estimates.

LBA OVERVIEW



CANADIAN S-2 VLBI SYSTEM FOR RADIOASTRON.



VLBA Specification Summary
1989 January 1

SIGNALS

IF Processing --	
Number of IFs	4
IF Frequency Range	500 - 1000 MHz
Baseband Conversion --	
Number of Converters	8 (expandable to 16)
Number of Channels	16 -- USB and LSB from each converter
Bandwidths	16, 8, 4, 2, 1, .5, .25, .125, .0625 MHz
LO Quantization	10 kHz
Aggregate Bandwidth	256 MHz
Sampling --	
Number of Samplers	16
Sample Rates	32, 16, 8, 4, 2, 1, 0.5 Msmp/s
Level Quantization	2 or 4 levels
Aggregate Data Rates	512 Msmp/s, 1024 Mbit/s *1*
Formatting --	
Number of Bitstreams	32
Multiplexing	4:1, 2:1, 1:1, 1:2, 1:4 bitstream:track
Format	Programmable, including Mark 3
Framing	Transparent or data-replacement
Aggregate Bit Rate	512 Mbit/s (expandable to 1024 Mbit/s)
Recording --	
Number of Data Tracks	64 (expandable to 128) -- on 2 recorders
Record Rate per Track	8, 4, 2 Mbit/s (plus 9/8 parity) *2*
Duration per Pass	1 hour *2*
Passes per Tape	16
Duration per Tape	16 hours *2*
Capacity per Tape	7.37 Tbit
Aggregate Bit Rates	128 Mbit/s sustainable *2*
	512 Mbit/s peak

Notes: *1* Maximum aggregate bandwidth/sampling capacity cannot be formatted or recorded without expansion.

2 Durations refer to "sustainable" 4 Mbit/s track record rate which allows unattended operation for 24-hour period.

CHANGE LETTER	DWN BY	CHK'D BY	APP'D BY	DATE	D C N & DESCRIPTION

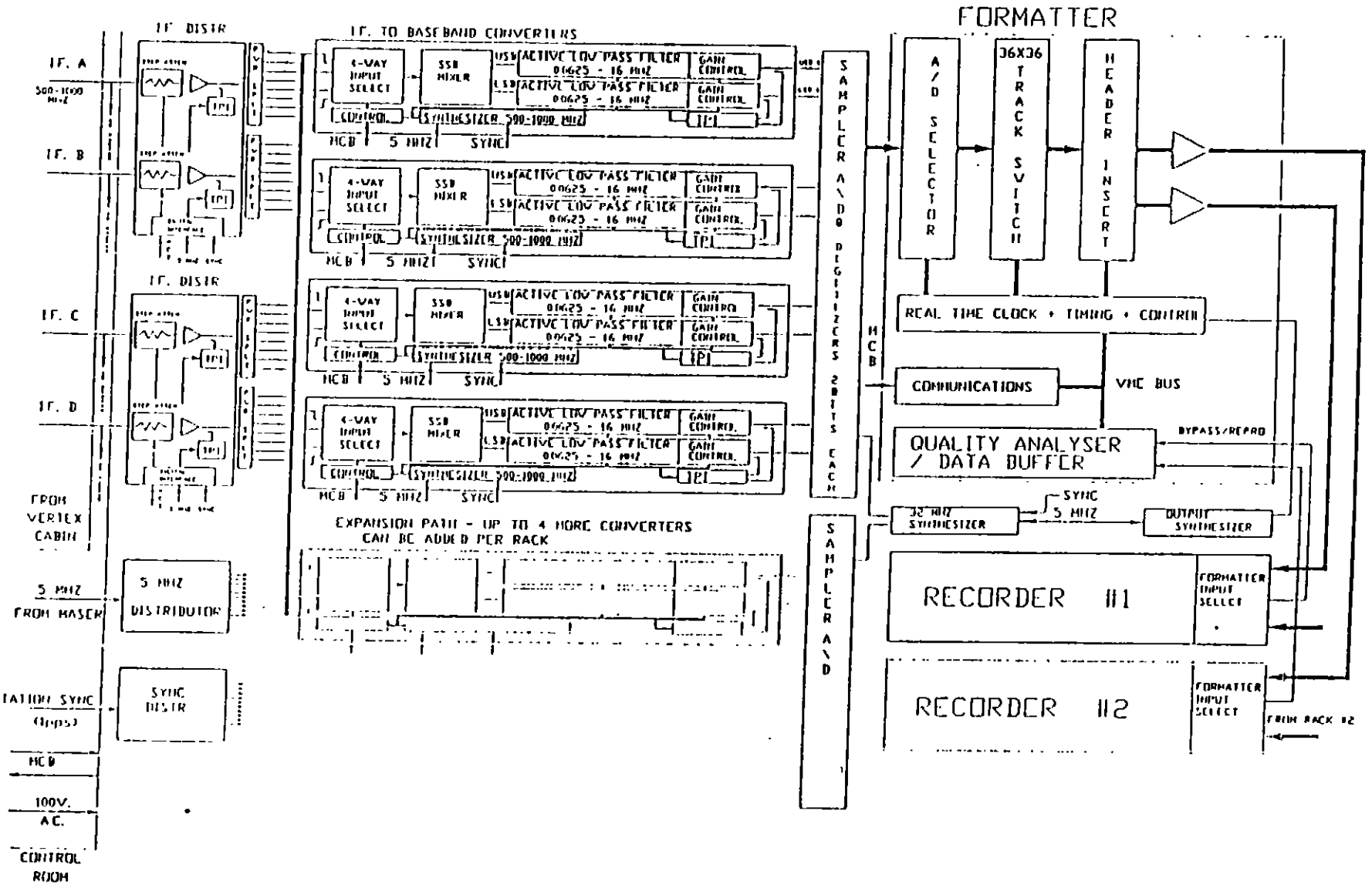


Figure 7.1

NOTES: HCB = MONITOR AND CONTROL BUS.
SYNC = STATION SYNC (1pps)

IN FULL VLBA SYSTEM THERE ARE 2 RACKS, AND 2 RECORDERS PER STATION.
EACH RACK HAS 4 CONVERTERS AND 1 FORMATTER.
IN THIS CONFIGURATION
MAX # IF CHANNELS = 4(EACH 500-1000MHz)
MAX # BASEBAND CHANNELS = 16(0 USB + 0 USB)
MAX DATA OUTPUT RATE = 512MB/S

ELECTRONIC NOTES: UNLESS OTHERWISE NOTED. RESISTORS: CAPACITORS: INDUCTORS.	USED ON	DRAWN FOR: A.E.ROGERS	DATE: 7-07	NORTHEAST RADIO OBSERVATORY CORPORATION HAYSTACK OBSERVATORY WESTFORD, MASSACHUSETTS	
		DRAWN BY: A.E.ROGERS	7-07		
		CHECKED BY:		VLBA DATA ACQUISITION SYSTEM	
	SCALE NONE	PROJECT			
	CLASSIFICATION	ENGINEER:		AER\ACORACK	C 54100S007

C-54100S007

CORRELATOR

Basic Dimensions --		
Stations	s = (10), (15), 20	*1* *2*
Channels	c = 1, 2, 4, 8	
Spectral Points	l = 32, 64, 128, 256, 512, 1024	*3*
Other Capabilities --		
Oversampled Input Data	f = 1, 2, 4, ...	
Interleaving	n = 1, 2 (n <= f)	
Overlapping	v = 1, 2, 4, ...	
Interpolation	z = 1, 2	
Polarization	p = 1 (Normal), 2 (Polarized)	*3*
Polarized Resol'n Factor	y = 1, EXCEPT p=2 & l=256 ==> y = 2	
Mode Limits --		
"F" (FFT section)	s c n v z y / f <= 160	*1*
"X" (XMult/Acc section)	s (s+1) c p l /2 <= 262,144	*2*
Timing --		
Sample Rate	32, 16, 8, 4, 2 Msmp/s	
Speedup Factor	1, 2, 4 -- constant, full-speed playback	
Integration Time Quantum	131.072 ms	
Integration Time, max.	134 s	
Archive Data Rate	0.5 Mbyte/s, maximum	
Tracking --		
Delay Range	Unlimited, via playback offset	
Delay Switching Range	6000 samples	
Coarse Delay Rate Range	+/- 50 sample/s	
Fine Delay Range	+/- 1/2 sample	
Fine Delay Accuracy	0.001 sample	
Phase Accuracy	0.002 turn	
Fringe Rate Range	Unlimited (+/- full bandwidth)	
Fringe Acceleration Range	+/- 10.4 Hz/s	
Pulsar Gate --		
Gate Profile	Arbitrary	
Pulse Phase Resolution	1024 points/period	
Pulse Timing Resolution	Equal to FFT length	
Simultaneous Correlation --		
Sub-Arrays	10	
Switched Models	> 8	
Switching Interval Quantum	100 ms	

Notes: *1* For "F" mode limits, s = 10, 20 only.
2 For "X" mode limits, s = 15, 20 only.
3 l <= 256 for polarized correlation (p = 2).

COST ESTIMATE for "MINI VLBA CORRELATOR"

Based on VLBA Correlator Cost Projection of 90/10/4

STATIONS		4		6		8		10	
Playbacks		4		6		8		10	
Modules	Unit Cost	#	Cost	#	Cost	#	Cost	#	Cost
Track Recovery	1,072	8	8,573	12	12,859	16	17,145	20	21,432
Deformatter	967	4	3,866	6	5,799	8	7,732	10	9,665
FFT	2,889	8	23,115	12	34,673	16	46,231	20	57,788
XMA (full)	3,148	0	0	4	12,592	4	12,592	12	37,775
XMA (partial)	2,136	4	8,544	8	17,088	8	17,088	12	25,632
Master Control	3,036	1	3,036	1	3,036	1	3,036	2	6,071
FFT Control	3,616	1	3,616	2	7,233	2	7,233	2	7,233
Integrator	5,000	1	5,000	1	5,000	1	5,000	1	5,000
Bins	1,016	3	3,048	4	4,064	5	5,080	6	6,096
Racks	1,022	1	1,022	2	2,044	2	2,044	2	2,044
TOTAL COST			59,820		104,387		123,180		178,735
Power [kW]			1.38		2.49		2.99		4.40

NOTES:

1. This estimate is based on detailed module itemizations from a recent cost analysis for the VLBA Correlator. Procurements for smaller versions of the same design would incur significantly higer unit prices

2. Division of modules among bins follows accurately the approach used in the VLBA correlator. This may be inefficient for the smaller systems shown (although the costs involved are not large in any case.)

3. The following are *not* included --
   a) PLAYBACK DRIVES. These are part of the VLBA's data recording subsystem.
   b) COMPUTER EQUIPMENT. The VLBA correlator includes about $225,000 in computer hard- and software.
   c) POWER SUPPLIES. The total power requirement is shown, however. This is supplied primarily at +5 VDC, although a small fraction is at -5.2 and +15 VDC.
   d) SPARES.

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