NATIONAL RADIO ASTRONOMY OBSERVATORY

Green Bank, West Virginia

MEMORANDUM

To: Scientific Staff

From: S. Weinreb

Subject: This memo discusses a number of technical decisions which must be made concerning the autocorrelation hydrogen line radiometer for the 300-foot telescope. These decisions are: The number of receivers, the number of channels, and the bandwidths to be provided. A block diagram and cost estimate of the complete system are given. Finally, a plea is made that we try to obtain a low noise front-end for hydrogen line work at the 300-foot telescope.

Number of Receivers

The sensitivity of a radiometer can be increased by $\sqrt{2}$ by using 2 receivers and observing 2 independent polarizations. If the radiometer is of the switched comparison type, an additional factor of $\sqrt{2}$ can be gained by using 4 receivers so that each polarization is monitored all of the time.

For a one-bit autocorrelation system, the rms deviation, ΔT, of a spectral measurement, is given by,

$$\Delta T = \alpha \frac{T}{\sqrt{\tau \cdot \Delta f}}$$

where T is the noise temperature at the receiver input, τ is the observation time, Δf is the half power bandwidth, and α is given by the following table:

TABLE I

	Total Power Mode	Switched Mode	Relative Cost
1 Receiver System ------------	1.05	2.1	.80
2 Receiver System ------------	.74	1.48	1.
4 Receiver System ------------	.74	1.05	1.40

The relative cost of the autocorrelation system is not proportional to the number of receivers because a large portion of the system can be time shared.

Two more factors should be considered in this decision: (1) A 100 channel, 2 receiver correlator, can be used as a 50 channel, 4 receiver, correlator but the converse is not true. (2) In the NRAO developed correlator channel the maximum bandwidth which can be analyzed is 6 mc for 1 receiver, 4 mc for 2 receivers, and 2 mc for 4 receivers.

My recommendation is the 2-receiver system.

Number of Channels

By the number of channels, N, it is meant the number of points which are determined on the autocorrelation function. In terms of the spectrum, N is proportional to the ratio of the bandwidth analyzed, B_1, to the half-power bandwidth, Δf, of an equivalent spectral scanning filter. The constant of proportionality depends on the maximum spurious response in the scanning function. If this be -7 db, $B_1/\Delta f = .67N$; -16 db, $B_1/\Delta f = .4N$; and -29 db, $B_1/\Delta f = .33N$. Values of B_1 and Δf for N = 100 are given in Table II.

It is of interest to compare N with N', the number of filters in a multichannel filter receiver where the filters are spaced so that half power points of adjacent filters coincide. If we set the half-power bandwidth of the filter equal to Δf, the half-power width of the scanning function, and assume the same total band is to be covered we find N = 2.5N' for the case of -16 db spurious lobes. From this we might conclude that it takes 2.5 points on the autocorrelation to give the same information as one point on the spectrum.

This does not sound correct because it seems to say that the operation on the autocorrelation function to give the spectrum loses information while the inverse operation gains information; this is foolish because the same operation is involved, the Fourier transform. This argument would say N = N'. The N = 2.5N' argument is incorrect because the autocorrelation method gives the spectrum continuously for every f, while the filter system gives the spectrum only for values of f at Δf intervals. For example, at a frequency where the filter half-power points coincide the filter system with N = 2.5N' does not gives as good a spectral representation as the autocorrelation system.

The N' for an N cannot be generally stated. Only for a particular spectral shape and a particular error criterion (such as equal mean square error from the true spectrum) can an equivalent N be stated.

Choice of B_1 and Δf

The ratio of the bandwidth analyzed, B_1, to the frequency resolution, Δf, is fixed by N and the spurious frequency rejection. B_1 and Δf can be varied by changing the master clock frequency in the correlator and changing one filter in each receiver. For a two receiver system each value of B_1 and Δf will cost approximately $3,000. The maximum value of B_1 is limited to about 4 mc. Values of Δf below 3 Kc do not appear useful for hydrogen line observations. A possible set of values for B_1 and Δf, assuming N = 100, is given in Table II.

TABLE II

B_1	Δf -16 db Spurious	Δf -7 db Spurious	Δf -29 db Spurious
4 mc ------	100 Kc	60 Kc	130 Kc
1.2 mc ------	30 Kc	18 Kc	60 Kc
400 Kc ------	10 Kc	6 Kc	30 Kc
150 Kc ------	3 Kc	1.8 Kc	6 Kc

Block Diagram and Cost

A possible block diagram for the system is given in Figures I, II, and III. Cost estimates and sources of each item on the block diagram are given in Table III.

Two of each of items (1) through (16) are needed for a two receiver system. The estimated cost of two sets of items (1) through (16) is $24,000. The price given for the remaining items totals $60,000 and is for a two receiver system. The total price is thus $84,000 for a 100 channel, two receiver system having 4 bandwidths.

This price assumes that NRAO performs the engineering and testing of the correlator using printed circuit boards fabricated by an outside vendor. If the complete correlator is built by Control Equipment Corporation, $30,000 should be added. An additional 100 channels would cost $50,000 if built by NRAO and $70,000 if built by CEC.

TABLE III -- COST ESTIMATES

Item	Description	Source	Est. Cost
(1)*	Precision Attenuator	AIL	$ 250
(2)*	Frequency Converter $B_1 = 4$ mc		1,500
(3)*	Frequency Converter $B_1 = 1.5$ mc		1,500
(4)*	Frequency Converter $B_1 = .4$ mc		1,500
(5)*	Frequency Converter $B_1 = .15$ mc		1,500
(6)*	Video Amplifier	John Fluke	550
(7)*	DC Amplifier	Philbrick	200
(8)*	RC Integrator	NRAO	100
(9)*	Clipper	S. Weinreb	800
(10)*	Alarm Circuits	S. Weinreb	200
(11)*	Voltage to Frequency Converter	Dymec	1,200
(12)*	Digital Synchronous Detector	S. Weinreb - Ransom	200
(13)*	Signal Counter	"	900
(14)*	Comparison Counter	"	900
(15)*	Sampler	S. Weinreb	500
(16)*	Digital Synchronous Detector	NRAO	200
(17)	Control Circuitry	NRAO	1,500
(18)	Reference Generator Divider	NRAO	1,000
(19)	Master Clock	NRAO	2,000
(20)	Drivers	NRAO	900
(21)	Drivers	NRAO	1,600
(22)	100 Channels	NRAO	45,000
(23)	Output Coupler	S. Weinreb - Ransom	2,000
(24)	Power Supplies		6,000
		Total --------------	$84,000

* Two needed for two receiver system.

Low Noise 1420 mc Amplifier

The rms fluctuation, ΔT, will be of the order of 5° for hydrogen line measurements on the 300-foot telescope assuming a bandwidth of 10 Kc, observation time of 10 seconds, and 2000° single channel noise temperature of a crystal mixer. Thus, although a multi-channel receiver and a very large reflector are used, the sensitivity is poor because only 10 seconds a day can be used on each source.

I believe that a strong effort should be made to obtain a factor of 3 or more reduction in receiver noise and thus increase the sensitivity per unit observation time by a factor of 10. This might be achieved by copying the Harvard or Cal Tech hydrogen line masers, by a tunnel diode amplifier, or, as discussed below, with a parametric amplifier.

From NRAO's previous experience with 3 (unsuccessful) parametric amplifiers and my own experience, I would say that a parametric amplifier can be successfully used with the 300-foot antenna and the autocorrelation system (which is relatively insensitive to gain changes) if the following steps are taken:

1. The pump source is to be frequency and amplitude stabilized. Not doing this is analogous (only worse) to operating an IF amplifier off of an unregulated unstable DC power supply. A proper pump source can be assembled for $10,000.
2. An up-converter type parametric amplifier is to be preferred if a system noise temperature under 300° can be obtained. If not, a negative-resistance type may be used if a circulator and temperature control is incorporated.
3. Wide tuning range and mechanical stability may be incompatable. Since most hydrogen line measurements are made within a few megacycles of 1420 mc it may be advantageous to obtain a simple, fixed tuned amplifier at this frequency.
4. The switch, circulator, amplifier, crystal mixer, and 30 mc preamp should be rigidly connected and tested as a unit to be mounted at the feed. A TWT pump amplifier and amplitude control should be mounted at or near the feed. The power supplies and remaining components of the pump would be in the control room.

I would estimate the cost of two of these amplifiers including a stabilized pump at $35,000. This should be compared with the cost of the total system and the factor of 10 improvement in utilization of observing time.

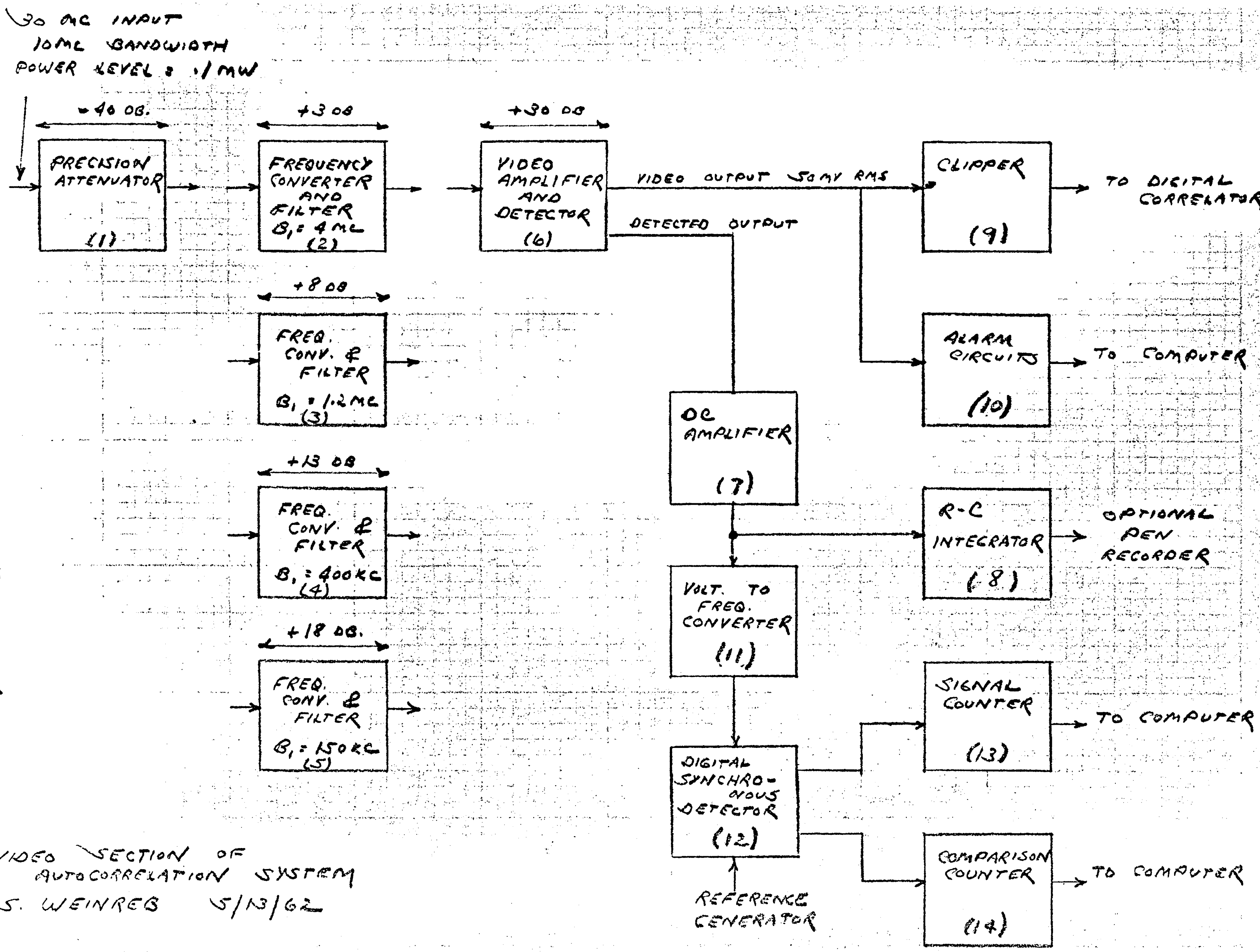

FIGURE 2

VIDEO SECTION OF AUTOCORRELATION SYSTEM

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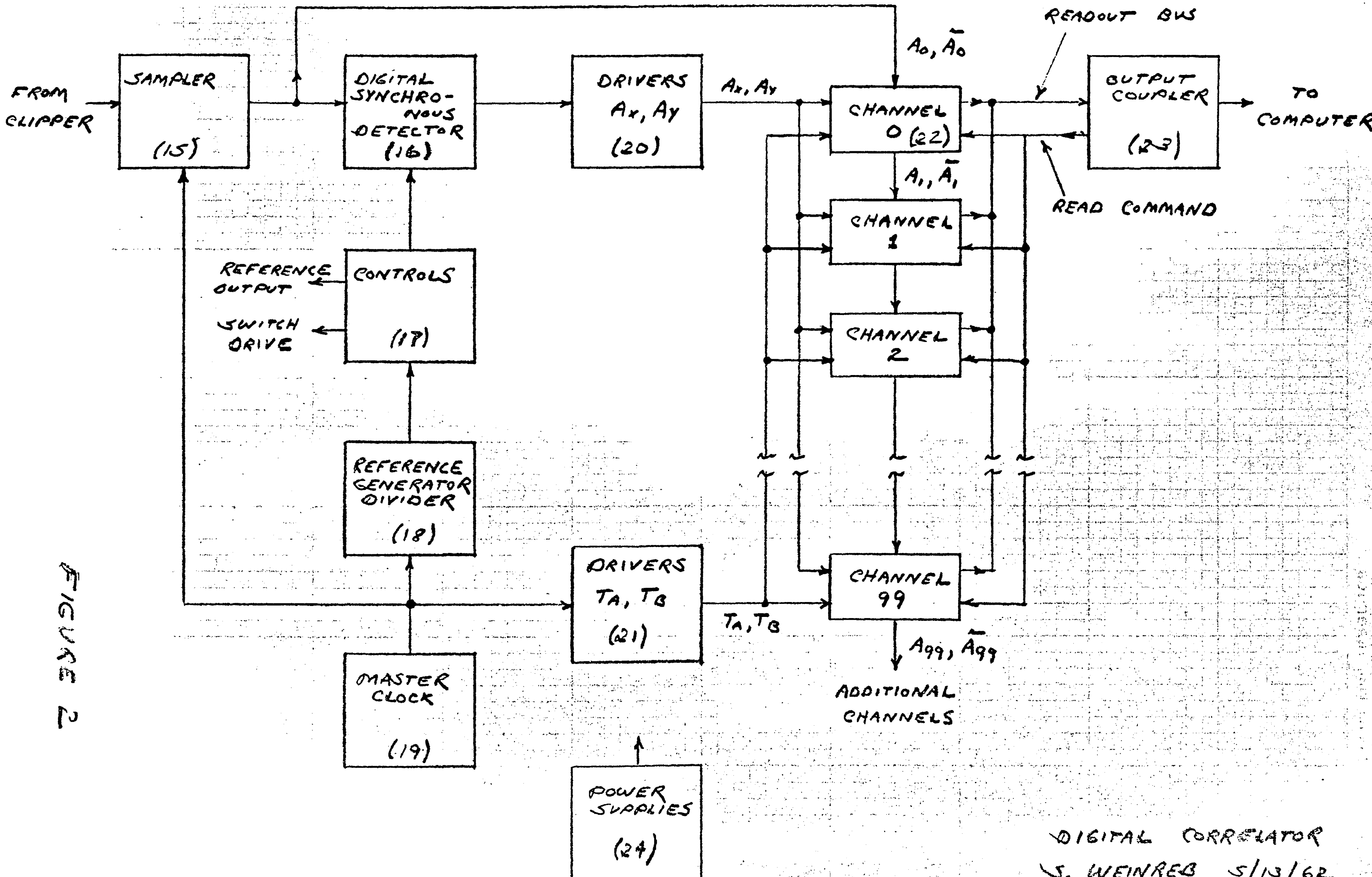
FROM CLIPPER
SAMPLER (15)
DIGITAL SYNCHRO-NOUS DETECTOR (16)
DRIVERS Ax, Ay (20)
Ax, Ay
A0, Ā0
CHANNEL 0 (22)
READOUT BUS
OUTPUT COUPLER (23)
TO COMPUTER
A1, Ā1
READ COMMAND
CHANNEL 1
CHANNEL 2
REFERENCE OUTPUT
SWITCH DRIVE
CONTROLS (17)
REFERENCE GENERATOR DIVIDER (18)
DRIVERS TA, TB (21)
TA, TB
CHANNEL 99
A99, Ā99
ADDITIONAL CHANNELS
MASTER CLOCK (19)
POWER SUPPLIES (24)
DIGITAL CORRELATOR
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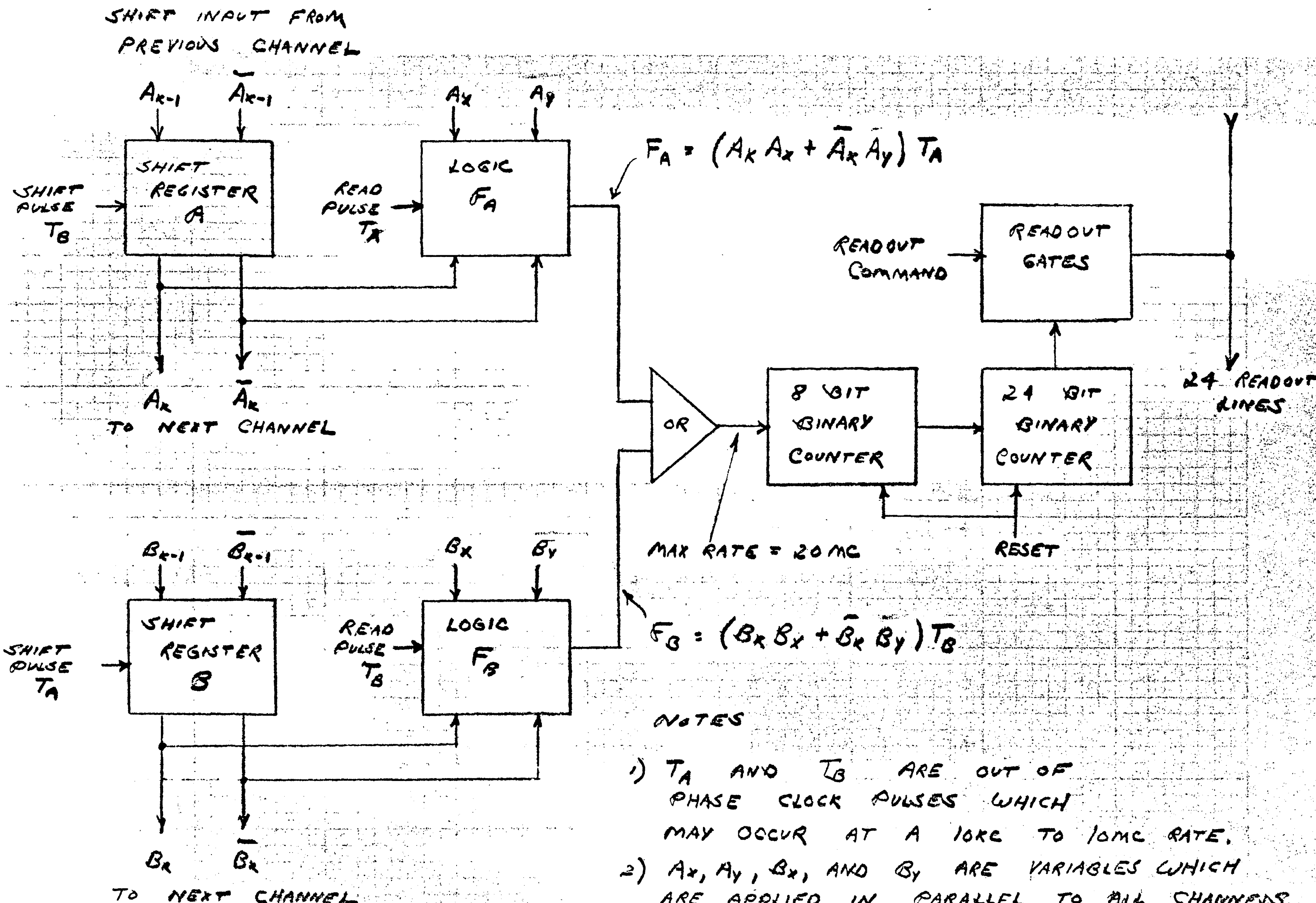
FIGURE 2



NOTES

1) T_A AND T_B ARE OUT OF PHASE CLOCK PULSES WHICH MAY OCCUR AT A 1 KC TO 10 MC RATE.

2) A_x, A_y, B_x, AND B_y ARE VARIABLES WHICH ARE APPLIED IN PARALLEL TO ALL CHANNELS. A_x AND A_y CHANGE AT TIME T_B, B_x AND B_y AT TIME T_A.

CORRELATOR CHANNEL
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FIGURE 6