NATIONAL RADIO ASTRONOMY OBSERVATORY

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SPECTRAL PROCESSOR MEMO NO. 22

MEMORANDUM June 25, 1984

To: 300-ft Project Group

From: R. Fisher

Subj: Spectral Processor Design

This note is a collection of thoughts which have come from an attempt to synthesize the spectral processor specifications in Memos 18 and 20 and to define in more detail a few areas which have been lightly treated so far.

General design.

Figure 1 shows the four spectrometer configurations which satisfy the pulsar and spectral line requirements. At the maximum bandwidth stated at the left of each diagram the output data rates are the same for all four configurations. In Figures 1b and 1c the input switches indicate the biplex time sharing of the FFT hardware between two input channels. Biplexing is also used in Figure 1a to obtain the 40 MHz bandwidth. In Figure 1d one of the FFT blocks could handle both IF channels, and in a couple of the succeeding figures this is shown. The outputs of Figure 1d are intermediate quantities to be combined in computing Stokes parameters. These quantities may be time-averaged before computing the Stokes parameters if there is an advantage to doing so.

Figures 2-4 show the configurations of the decimation-in-frequency pipeline FFT hardware for the 1024, 512 and 256 channels per IF setups. Each stage has 512 butterflies which are serviced in rotation by only one multiplier set. The input and output of each butterfly is two complex numbers each of which contain two real samples. Hence, each stage can handle as many as 2048 real samples at a time. The FFT stages are shown divided according to the combinational dependence of their input data, e.g., in stage 2 and beyond the top half of the data is never combined with the bottom half. Also, the first stage contains the finest vector rotation increments, so half of stages 2 and beyond looks exactly like an FFT device with half as many points and the sine and cosine coefficients remain the same.

Since real data instead of complex data are put into the FFT the output for each frequency channel is split between two complex output data points. These two points must be combined with a vector rotation similar to a butterfly operation, and this is the job of the "real data unscrambler". Again, only one multiplier set services this entire function stage with the only difference between the three configurations being the data and coefficient addressing sequence. Note that the configuration in Figure 4 is of no value to spectral line work, but it is required by the pulsar observers to achieve 12.8 us time resolution. In this case the multiplier set in each stage skips half of the butterflies.

Figure 5 is an overview of the spectral processor hardware. It shows the polarimeter sections from Memo 18 in more detail than diagrams from previous memos and incorporates the fast adder concept from Tim Hankins. Not shown here is Rich Lacasse's split stream idea to handle 40 MHz bandwidth data (80 MBytes/sec) which required another stage similar to the real unscrambler stage. I think that this high data rate can be more cheaply handled in the input buffer memory, but Ron Weimer and I are discussing the point. Notice that in the polarization mode one of the two FFT blocks is sitting idle and half of the butterflies in the active block are being skipped to achieve the 12.8 us data resolution.

At narrower bandwidths one could handle more than 256 channels, but there was no strong need for this expressed by the people at the meeting which generated Memo 18. There will have to be a lot of high speed memory buffering of data in the polarizer and fast adder stages, so increasing the number of channels in the pulsar modes would add considerably to the cost of the spectrometer. Not shown in Figure 5 are the RFI excision functions. These involve only detectors ahead of the A/D converters and the fast adder block as will be explained later.

<u>Polarimeter</u>.

Figure 6 shows the intermediate products on the way to the Stokes parameters and the calculations involved in correction for Faraday rotation. The quantity g is the relative gain of the two receivers connected to orthogonal linear polarizations. The 8-point accumulators are suggested under the assumption that the accumulator would be cheaper than more than one multiplier in each of the two succeeding stages that would be necessary at the higher data rate. If Faraday correction is not required the Stokes generator and Faraday rotator would be turned off and the gain correction applied to the integrated intermediate values (W,X,Y,Z) in the spectral processor or data reduction computer.

<u>Dedispersion</u>.

Figure 7 shows how dedispersion is implemented in the fast adder-memory. With the 20 MHz bandwidth the FFT presents 256 data points for each IF or each Stokes parameter every 12.8 us. Each data point is a spectrometer frequency channel, sixteen of which are represented on the vertical axis of Figure 7. On the lower horizontal axis is an accumulator memory which contains a dedispersed time sequence of amplitude samples. The bin on the left is the newest sample, and the memory is addressed in a way which simulates the data being shifted to the right once per output sample interval.

Because of dispersion pulsar radiation arrives later at lower frequencies so the lower frequency channel outputs must be added to the time stream further to the right. The two curves show two possible memory mapping functions representing two different dispersions. With no dispersion all of the channels would accumulate in the same memory cell, and with very high dispersion many cells may be skipped in mapping frequency into time. In principle one does not gain much time resolution by having memory time cells smaller than the dispersion sweep time across one channel, but Tim Hankins and Val Boriakoff say that say that some "over-sampling" is useful. Tim suggests a factor of 16. This seems high and is worth a bit of discussion. The sky frequency may increase or decrease with increasing channel number so the dedispersor must be capable of dealing with "negative" dispersions as shown by the dashed curve.

Other data averaging.

The fast adder/memory is useful for all other forms of data averaging, each implemented with different addressing schemes. Figure 8 is a rough schematic sketch of all of the averaging modes that seem to be required. The solid blocks represent one or two dimensional memory blocks required for data accumulation. The dashed boxes represent auxiliary memory used to keep track of excised RFI contaminated data as will be discussed later.

Mode 1 is the same as Figure 7. Modes 4 and 6 imply no averaging at all. Mode 2 might be useful for pulsars where the period is known but the dispersion is not. The aspect ratio of the box drawn implies about 1000 samples per period which would involve an impractical amount of memory (1/4 megaword), but 8 or 16 samples per period would still be useful. Mode 3 is the same as 1 except that further time averaging synchronous with the pulse period is performed. This reduces the data rate to the computer even further.

Mode 5 simulates a spectrometer with fewer channels and slower time resolution for use in pulsar searches as better search processors become available. One might imagine a 1 MByte computer transfer rate allowing 2 x 32 channels with 200 us time resolution. The MASSCOMP could do no more than store a few seconds of data at this rate.

Mode 7 is the garden variety total power integration. Long integrations would imply large word sizes so we will probably want to dump to the computer something like every 500 ms. With 2048 channels this would imply a 4 kiloword data rate which would allow 250 us per channel of processing time. Dumps as short as 2 ms should be allowed.

Modes 6 and 8 assume that the FFT has been bypassed with mode 6 operating only on voltage samples which cannot be averaged and mode 8 on power samples which can. Mode 6 and a very fast mode 8 would have to operate in burst mode--fill the hardware memory then dump to the computer. Mode 9 is a variation on modes 2 and 7 with only three (up to 8 might be useful) spectral accumulators with different time duty cycles. This would be used for frequency switching and pulse on/pulse off integration.

RFI excision.

Two kinds of RFI excision are required, narrowband and wideband. The former can be dealt with at a relatively slow rate (10 ms or slower), but it should be possible to detect and remove the latter at the highest time resolution of the spectrometer (12.8 us). For all of the pulsar types of observing narrowband interference will be excluded by manually turning off some of the spectrometer channels before inclusion in any averages. Dynamic narrowband excision seems unnecessary and unduly complicated. However, a good display for interference monitoring will be required so the observer can quickly decide which channels to delete. Some interference logging would also be extremely helpful even if it could be done only between scans.

In spectral line observing some form of dynamic narrowband excision will be done in the spectral processor computer on the 50 to 500 ms time scale. This will probably be done by differentiating each spectrum dump looking for and dropping channels which cause excursions beyond a selected level. Deleted data will be kept track of and compensated for in the longer average.

Wideband impulsive interference will be excised in the time domain by deleting entire spectra from any averages. For simple spectrum averaging this requires only that we keep tack of the number of deleted spectra in a counter and correct the average amplitude in the processor computer. However, with dedispersion or any other form of time sequenced data output each time datum will need a bad data counter associated with it which is incremented each time a data value is deleted from the accumulator. This might best be done with parallel memory and a memory value incrementer which is triggered by the bad data flag at accumulation time. The bad data counter word would not have to be as wide as the data word itself, and memory addressing could be common to both. Again, data compensation would be performed in the processor computer. The relative size of the parallel memory is shown schematically with the dashed boxes in Figure 8.

Detection of wideband impulsive interference is best done at the baseband output of the IF processor. A possible circuit is shown in Figure 9. This circuit responds to pulses with small duty cycles by comparing the outputs of a slow and a fast integrator whose time constants can be set to match the pulse speed. The slow integrator is prevented from long responses to very large pulses with a clipper whose level can be set by the observer through the computer. A quick zeroing switch under computer control is included for times when a new input level is expected. The size of the difference in integrator outputs which causes a bad data signal is controlled with the DAC on the negative input to the comparator.

JRF/cjd

Attachments
- Figure 1 - 4 FFT Configurations
- Figure 2 - 1024 Channel FFT
- Figure 3 - 2 x 512 Channel FFT
- Figure 4 - 2 x 256 Channel FFT
- Figure 5 - Spectral Processor Hardware
- Figure 6 - Stokes Parameter Generator and Faraday Rotator
- Figure 7 - Dedispersion Mapping
- Figure 8 - Parallel Memory for Interference (2 pages)
- Figure 9 - Wideband Interference Detector

4 FFT configurations

FIGURE 1

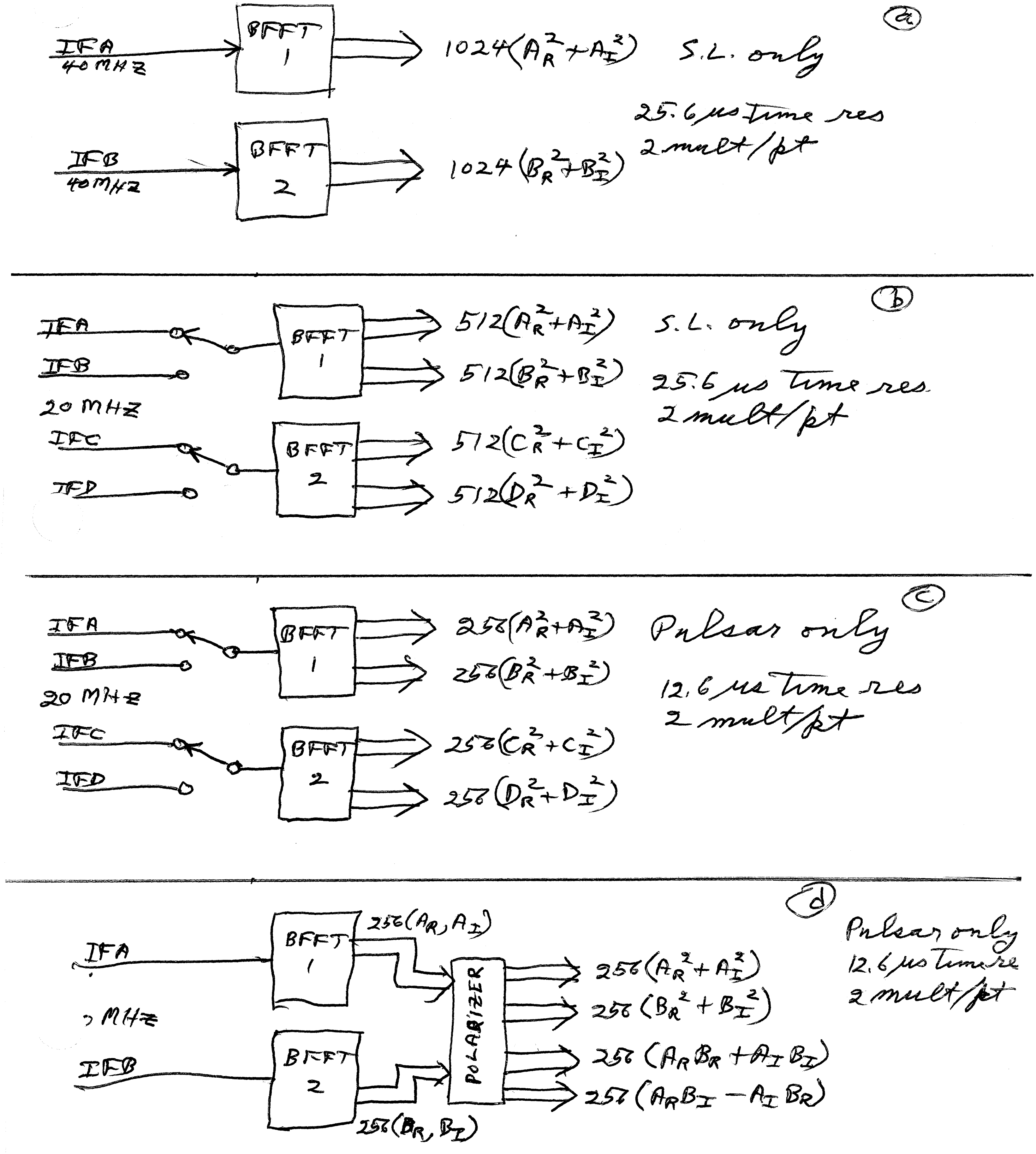


FIGURE 2

1024 Channel FFT

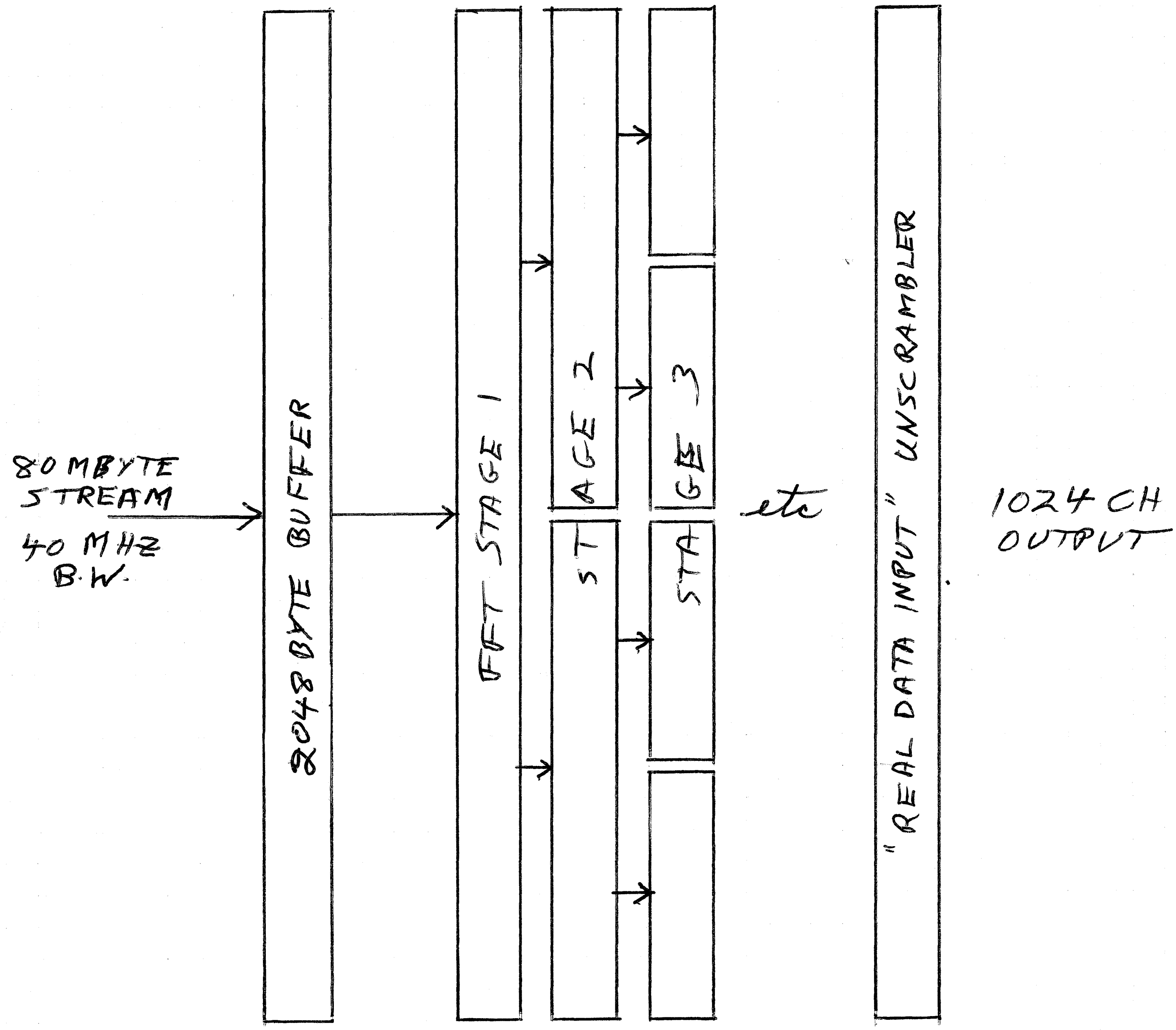


FIGURE 3

2X512 Channel FFT

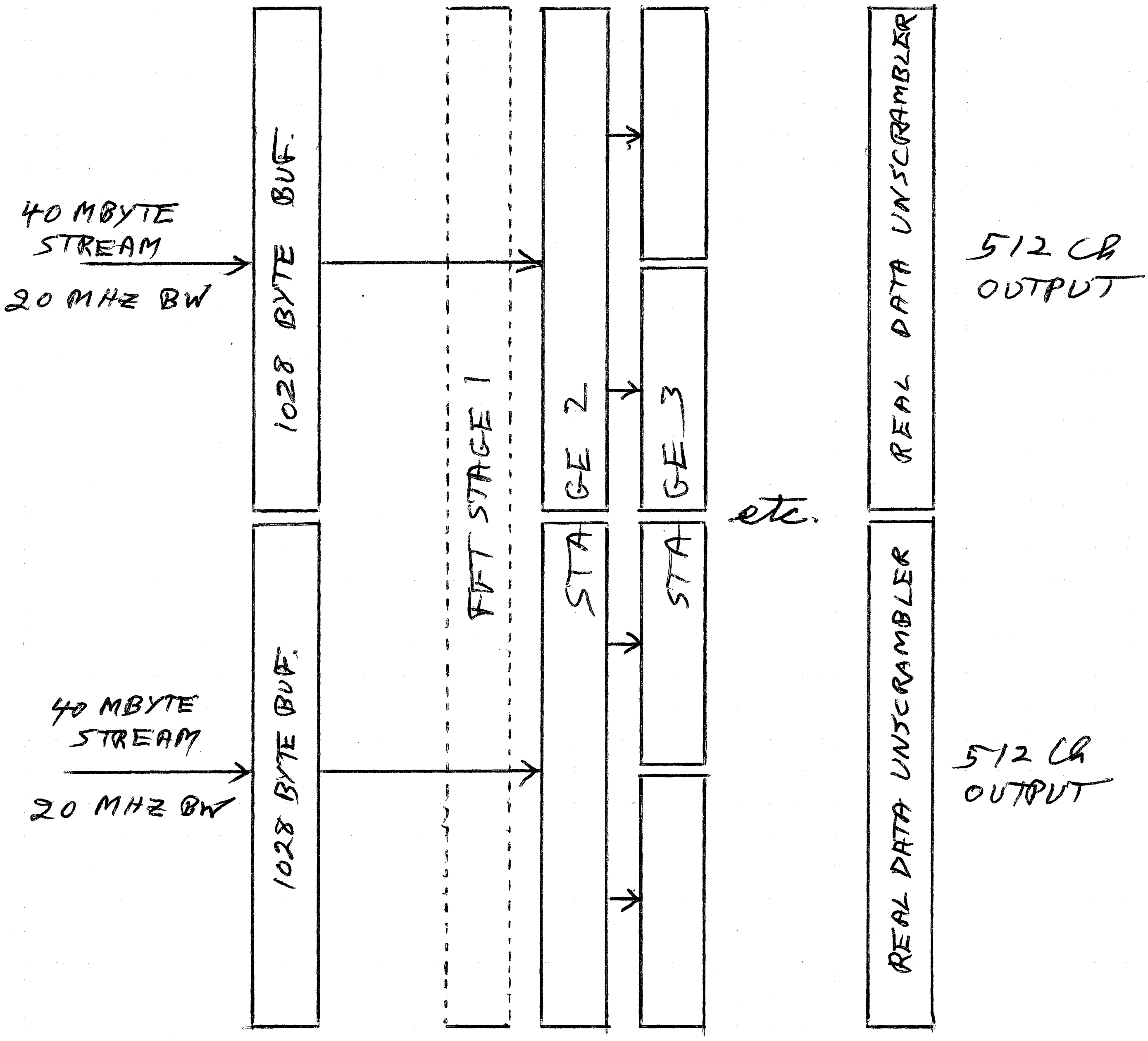
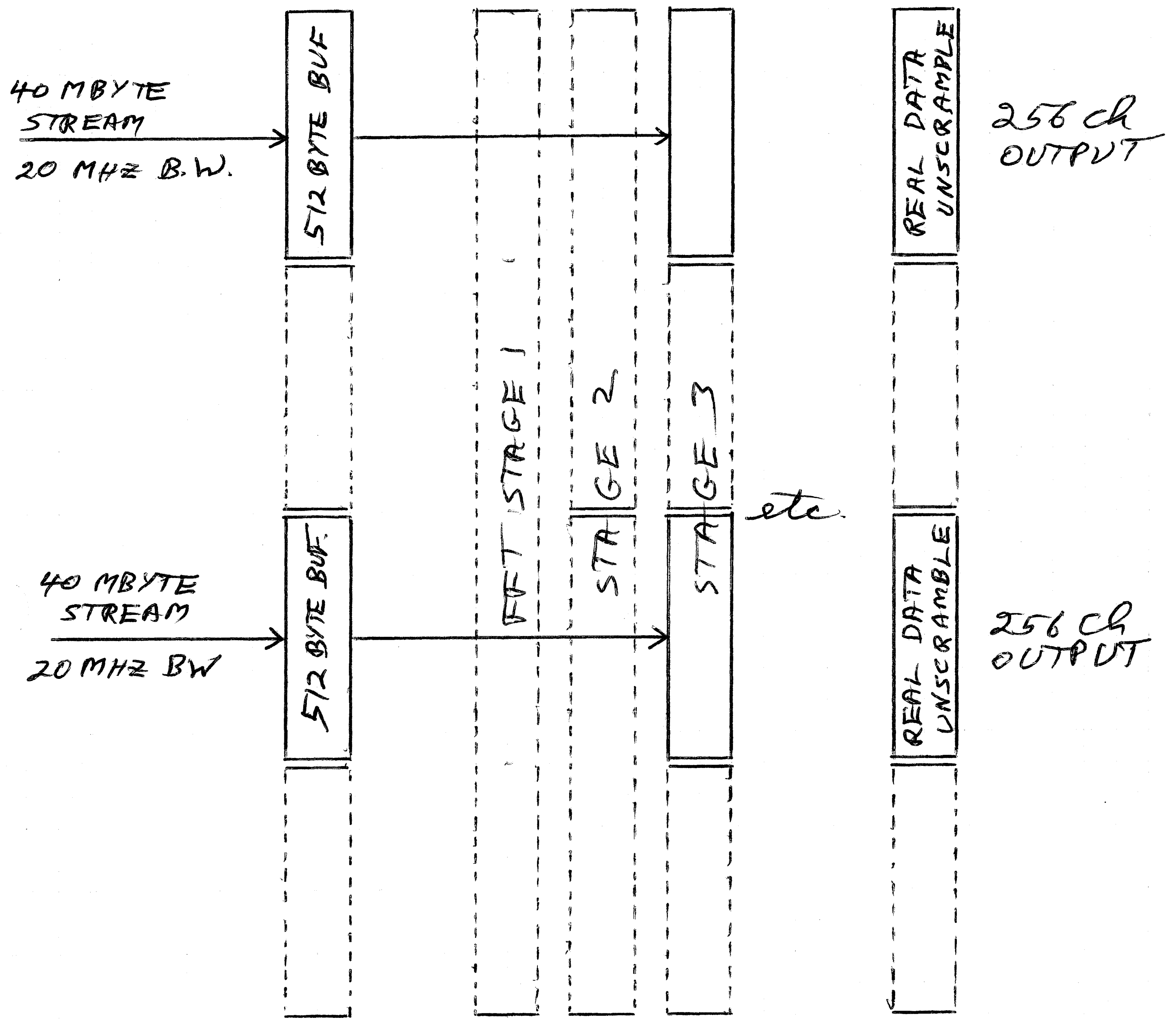


FIGURE 4

2 X 256 Channel FFT
2 X time resolution



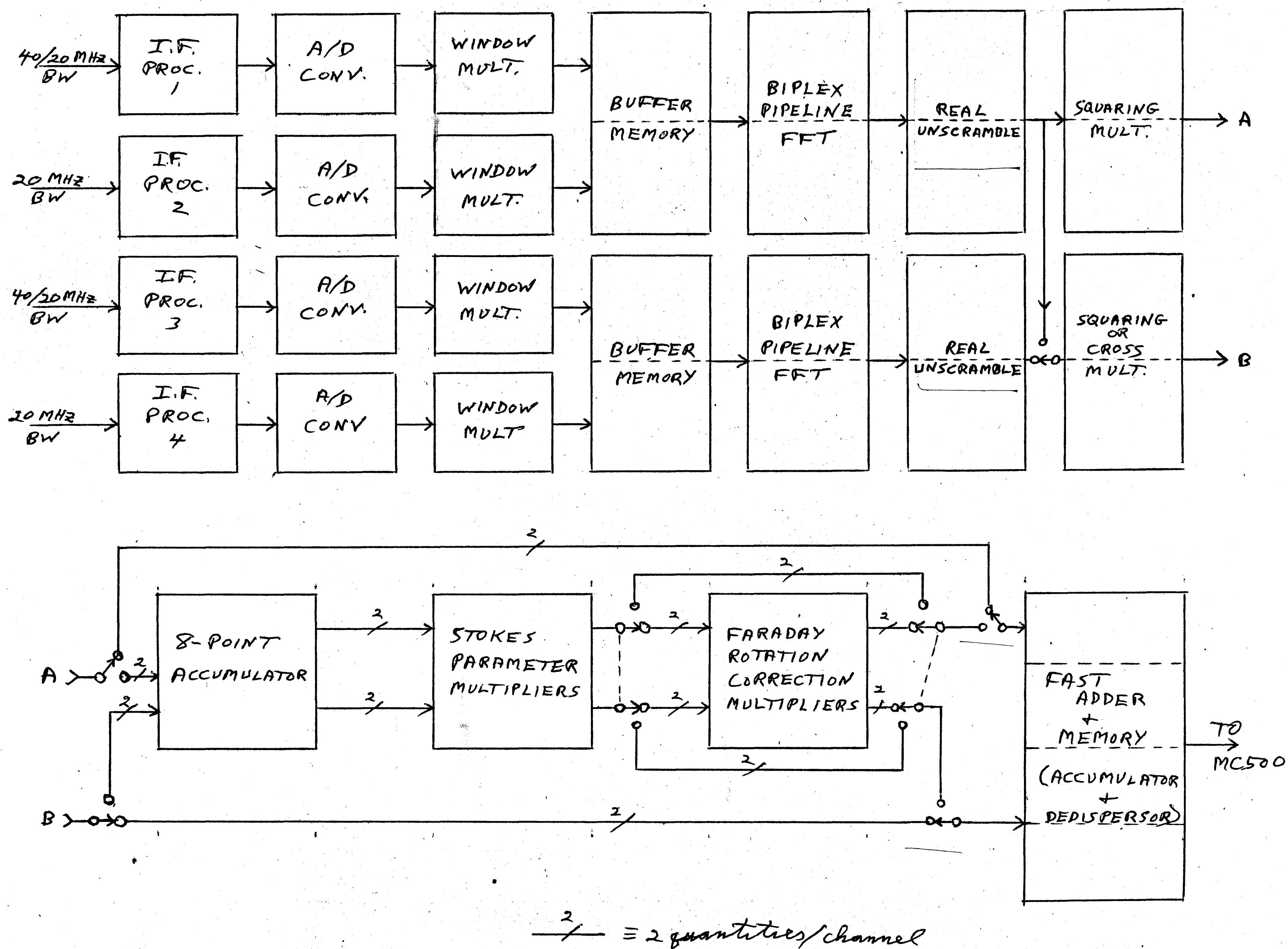

40/20 MHz BW
20 MHz BW
40/20 MHz BW
20 MHz BW
I.F. PROC. 1
I.F. PROC. 2
I.F. PROC. 3
I.F. PROC. 4
A/D CONV.
A/D CONV.
A/D CONV.
A/D CONV
WINDOW MULT.
WINDOW MULT.
WINDOW MULT.
WINDOW MULT
BUFFER MEMORY
BUFFER MEMORY
BIPLEX PIPELINE FFT
BIPLEX PIPELINE FFT
REAL UNSCRAMBLE
REAL UNSCRAMBLE
SQUARING MULT.
SQUARING OR CROSS MULT.
A
B
A
B
8-POINT ACCUMULATOR
STOKES PARAMETER MULTIPLIERS
FARADAY ROTATION CORRECTION MULTIPLIERS
FAST ADDER + MEMORY (ACCUMULATOR + DEDISPERSOR)
TO MC500
2
≡ 2 quantities/channel

FIGURE 5

Stokes parameter generator
and
Faraday rotator

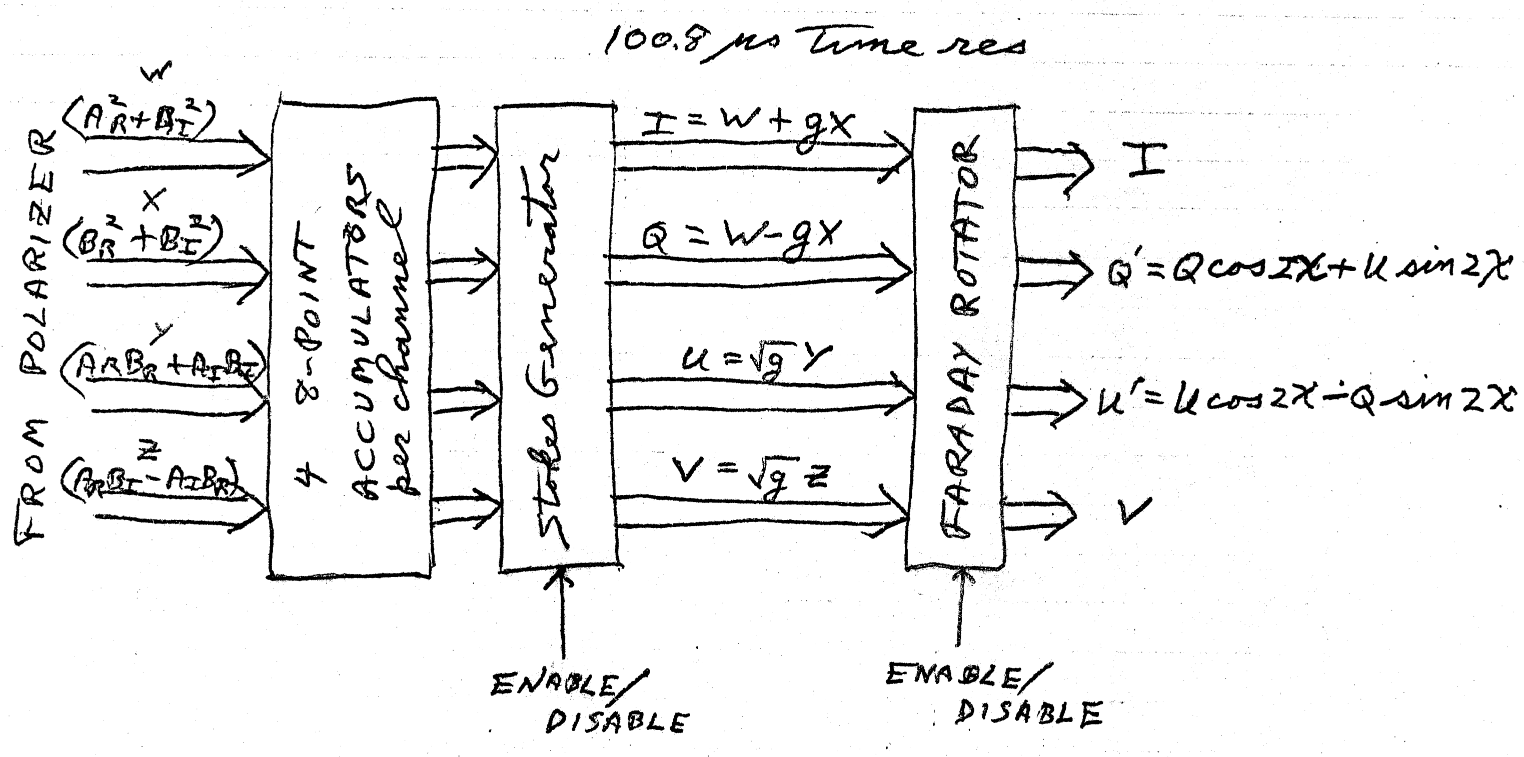


FIGURE 6

FIGURE 7

DEDISPERSION MAPPING

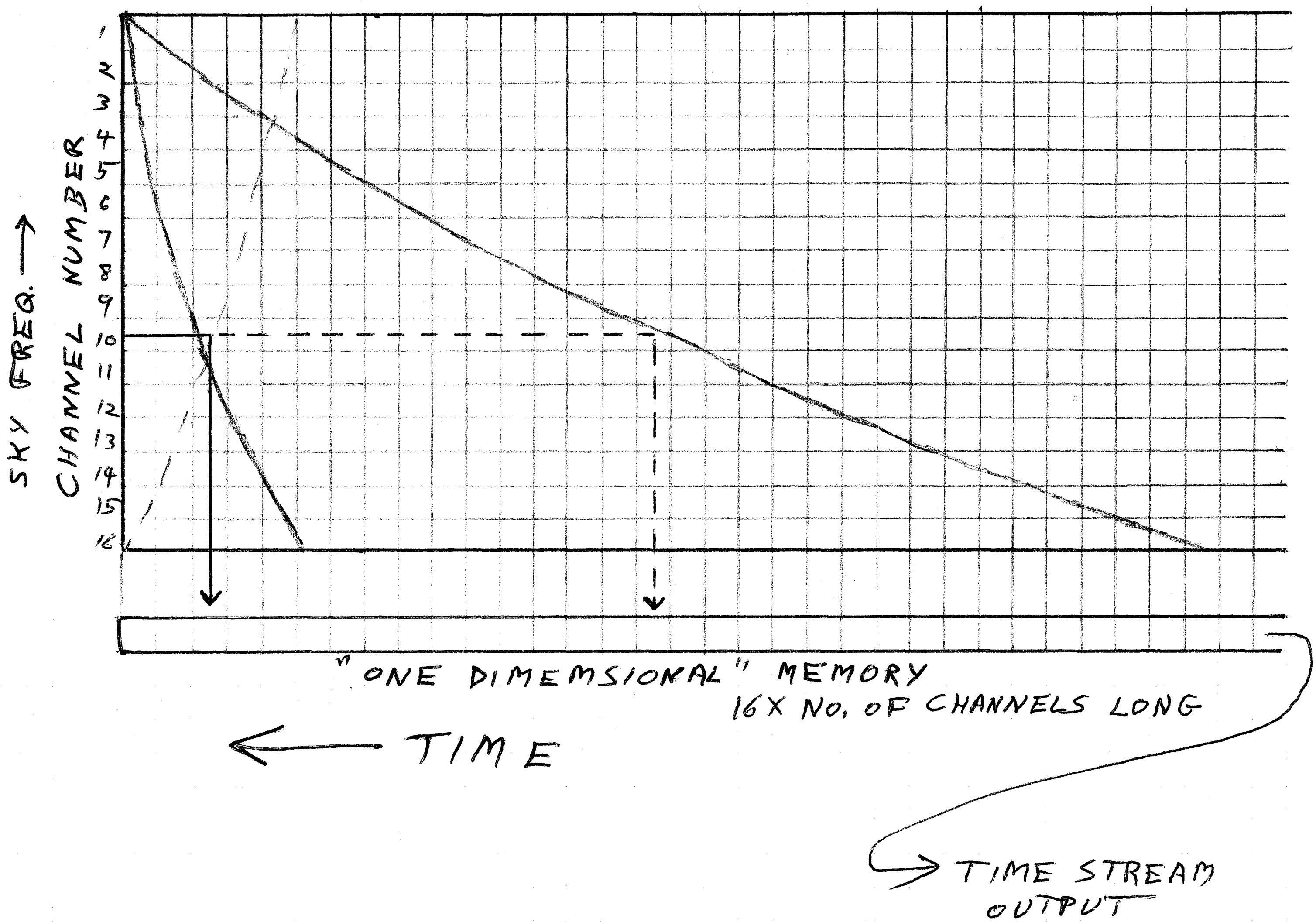
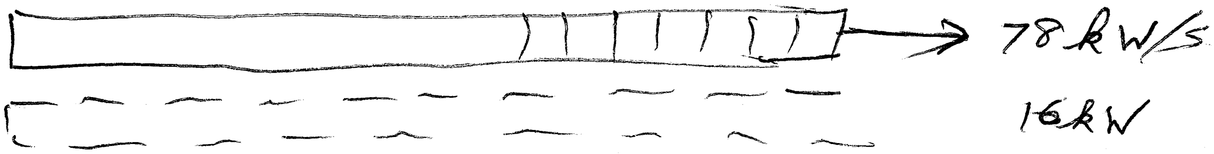


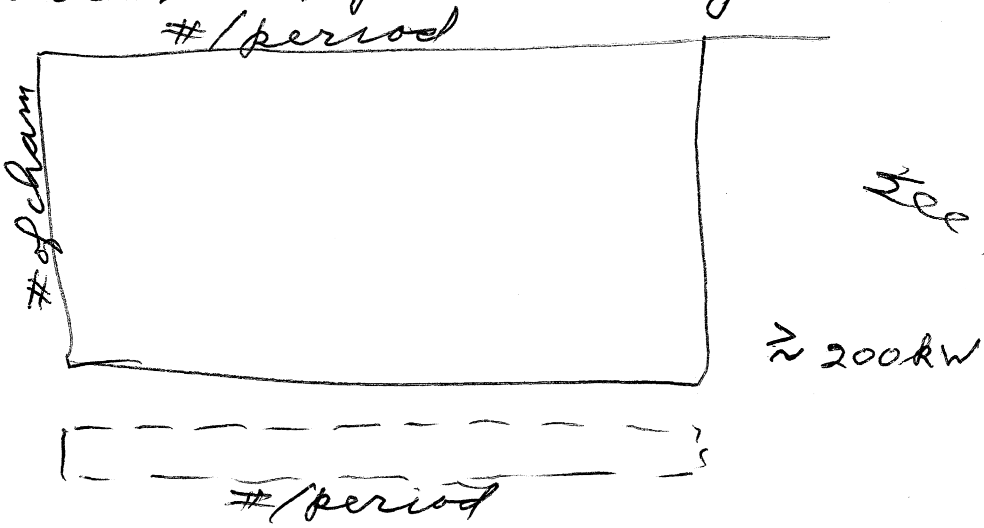
FIGURE 8

Parallel memory for interference

Dedispersed freq. avg

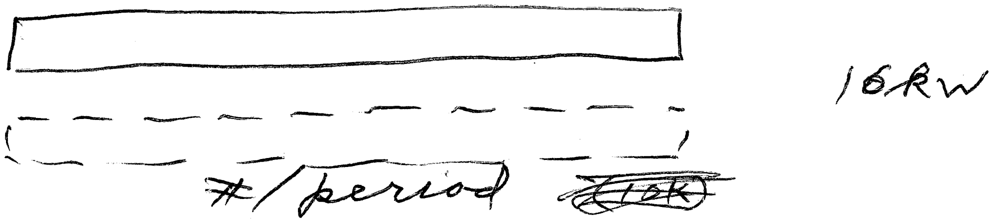


2. Synchronous spectrum avg



See 9 instead

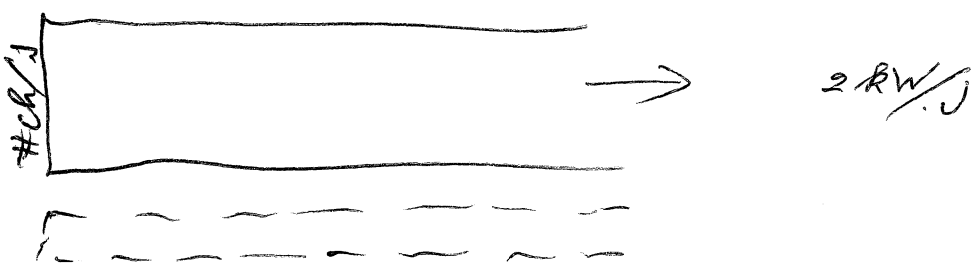
3. Synchronous dedispersed average



4. No freq or time avg

NO EXCISION

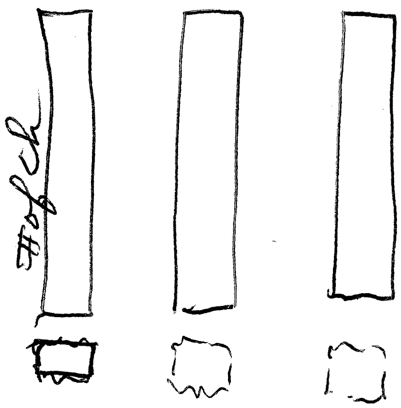
5. Partial freq. and time avg



6. Untransformed time samples

NO EXCISION

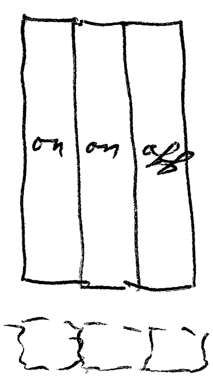
7. Fixed integration time spectrum average



2 kw

8. Untransformed but squared and averaged time samples.

9. 2 Pulse on — Pulse off spectrum averaging



8 kw

FIGURE 9

WIDEBAND INTERFERENCE DETECTOR