NATIONAL RADIO ASTRONOMY OBSERVATORY
Charlottesville, Virginia 22901

Electronics Division Internal Report No. 125

CORRELATION RECEIVER MODEL III: OPERATIONAL DESCRIPTION

A. M. Shalloway, R. Mauzy, J. Greenhalgh

NOVEMBER 1972

NUMBER OF COPIES: 200

CORRELATION RECEIVER MODEL III: OPERATIONAL DESCRIPTION

A. M. Shalloway, R. Mauzy,
J. Greenhalgh

I. SYSTEM DESCRIPTION

The receiving system described here is the equivalent of a multi-channel spectrum analyzer, and measures the power spectrum over a selected bandwidth and center frequency. It does this indirectly by first producing a one bit correlation function of the selected signal. The correlation function is Fourier transformed by an on-line computer to produce the power spectrum. The theory of digital auto-correlation receivers and a description of an early receiver are available in the literature [1], [2]. Figure 1 illustrates a typical complete system as used in radio astronomy.

The front-end receives, amplifies and mixes the signal to an IF of 30 or 150 MHz and applies this signal to the input of the receiver. In some cases there will be an IF Processor Rack between the front-end and the correlation receiver.

The IF-Filter System filters out a selected bandpass and heterodynes it to the video frequency range, such that one side of the bandpass is at zero frequency. This signal is clipped to provide a rectangular waveshape of fixed amplitude. The only correspondence between the clipped and unclipped signal is their zero crossing point.

The clipped signal is then fed into the digital system where it is sampled at a frequency equal to twice the bandwidth. The output of the sampler is called a "one bit" sample. It indicates only whether the signal is positive (+1) or negative (-1). The digital system is a high speed special purpose computer which uses the sampled data to produce 384 point, 192 point or 96 point one bit auto-correlation or cross-correlation functions.

These functions are formed from the discrete one bit samples as opposed to the normal autocorrelation or cross-correlation function considered as a result of continuous (analog) comparisons, e.g.:

$$\text{Analog autocorrelation function} = R_x(\tau) = \lim_{T\to\infty} \frac{1}{2T} \int_{-T}^{+T} x(t)x(t+\tau)dt \tag{1}$$

$$\left.\begin{array}{l}\text{Many bit digital}\\ \text{autocorrelation}\\ \text{function}\end{array}\right) = \rho''_x(\tau_n) = \frac{1}{K} \sum_{k=1}^{K} x(t_k)\; x\,(t_k + \tau_n) \tag{2}$$

where:

$t_k = k\Delta t \quad k = 1,2,3\ldots K \quad$ [K = (sample rate) (integration time)]

$t_n = n\Delta t \quad n = 0,1,2\ldots N-1$ (N = number of channels)

Δt = time between samples

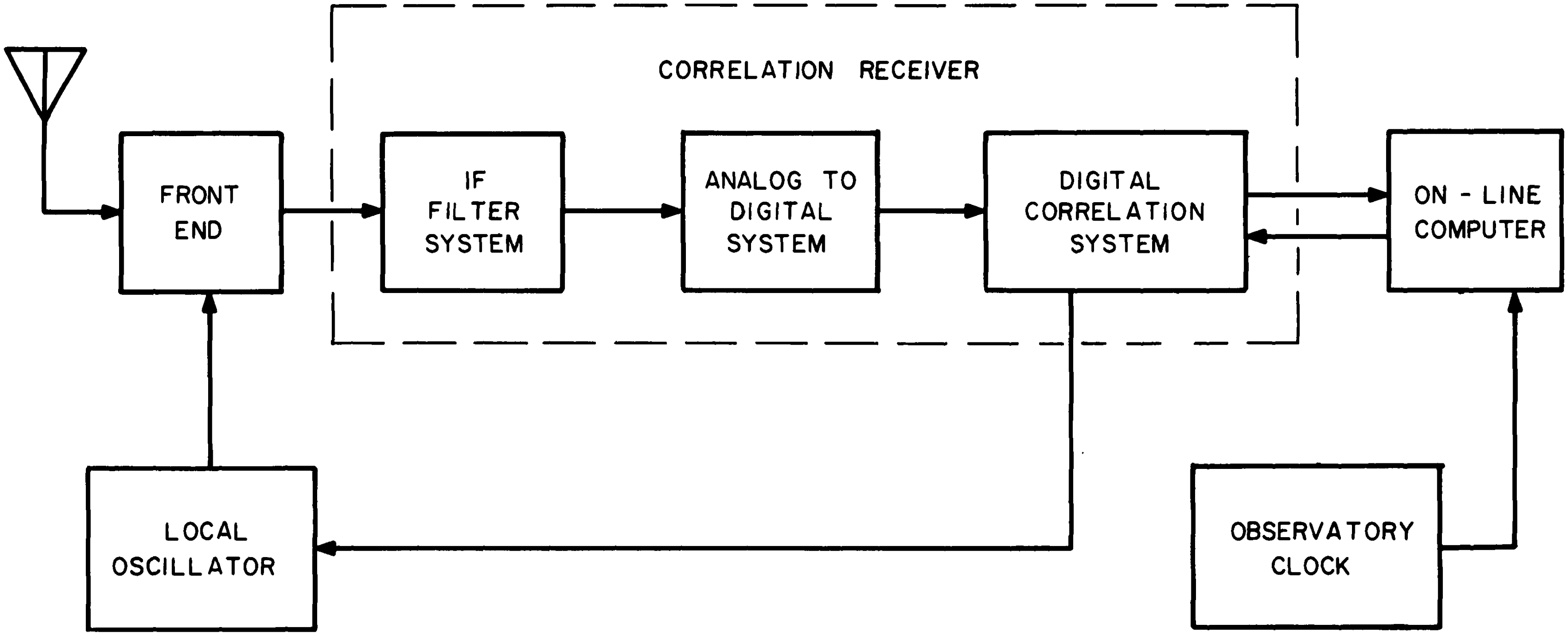
$$\left.\begin{array}{l}\text{Digital one bit}\\ \text{autocorrelation}\\ \text{function}\end{array}\right) = \rho'_y(\tau_n) = \frac{1}{K} \sum_{k=1}^{K} y(t_k)\; y\,(t_k + \tau_n) \tag{3}$$

where:

$y(t_k) = +1$ if $x(t_k) > 0$

$y(t_k) = -1$ if $x(t_k) < 0$

The functions described here are obtained, for each point, by summing the results of a comparator whose inputs are the "present" sample and a previous sample taken $n\Delta t$ seconds prior to the "present" sample. n = channel number. To eliminate the requirements for high speed reversible counters to do the summing, the +1 and -1 are replaced with 1 and 0 respectively. Unidirectional counters sum the 1's and 0's, and the on-line computer program applies a correction factor to compensate for the change to 1 and 0. The physical process is described in a later portion of this report.



RADIO ASTRONOMY RECEIVING SYSTEM

FIG. 1

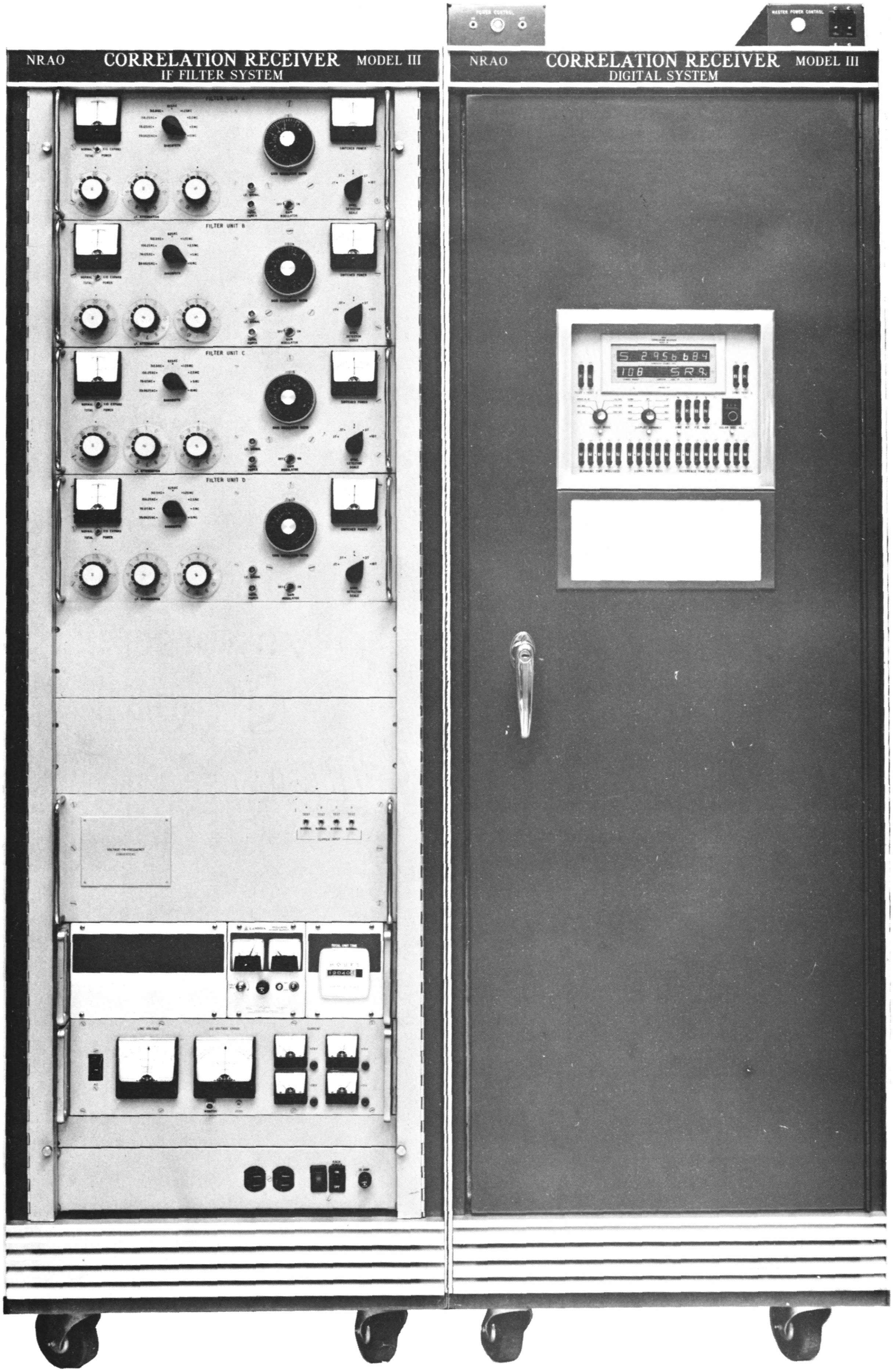


Figure 2

Correlation Receiver Racks

This correlation function is the result of an integration for a selected period of time (normally 10 seconds), as chosen by the observer. The integrated function is stored in a core memory until called for by a general purpose on-line computer, and the correlator starts another integration process for the next period of time.

In the process of clipping, amplitude information is lost. To recover the amplitude information, the unclipped bandpass signal is square-law detected, smoothed, and converted to a train of pulses by a voltage to frequency converter. Counters connected to the frequency converter outputs produce a count which is proportional to total power in the received signal. This data is also sent to the on-line computer.

The on-line computer applies a clipping correction and performs an inverse Fourier transform to generate a power spectrum. The computer data is available as an on-line graph by means of a storage oscilloscope and an X-Y recorder, as a printed tabular output, and as an output on magnetic tape which can be further processed by an off-line computer.

The operation of this system as a radio astronomy receiver can be similar to that of a continuum Dicke receiver. The receiver is continually switched between the signal to be observed and a reference signal. In the case of the correlation receiver, the two sets of data obtained are handled separately until it reaches the computer, at which point the reference is subtracted from the signal (a portion of which is approximately equal to the reference and the remainder is the spectral line to be observed). The difference result from this subtraction is the spectral line.

II. FUNCTIONAL SPECIFICATIONS OF RECEIVER

Number of Channels: 385

In autocorrelation, Channel 0 is the result of correlating the "present" (latest) sample with itself. Thus as an autocorrelator Channel 0 indicates the number of samples taken. Channel 384 is a counter which indicates the number of samples taken whether the instrument is used as an autocorrelator or as a cross-correlator.

Number of Receivers: 4 designated as A, B, C and D.

Modes:

Autocorrelation	Cross-Correlation
1. 1 ea. 384 channels	5. 1 ea. 384 channels
2. 2 ea. 192 "	6. 2 ea. 192 "
3. 2 ea. 96 " and 1 ea. 192 "	7. 3 ea. 96 " and 1 ea. 96 " autocorrelation
4. 4 ea. 96 "	

8. 1 ea. 192 ch. A/C - double frequency (20 MHz BW max.). Mode 8 is incorporated in the digital unit but as of this writing, the necessary filters, mixers, etc. have not been designed into the IF-Filter unit.

Bandwidths:

1. 10 MHz	6. 312.5 kHz
2. 5 MHz	7. 156.25 kHz
3. 2.5 MHz	8. 78.125 kHz
4. 1.25 MHz	9. 39.0625 kHz
5. 625 kHz	

Any receiver may have any bandwidth, independent of the other three receivers.

Switching Rates:

Three standard rates are available:

1. 1 Hz switching frequency, 50%/50% duty cycle
   10 sec. dump time, 10 ms blanking time
2. Same as #1 but 30 ms blanking time
3. 1 Hz switching frequency, 90%/10% duty cycle,
   10 sec. dump time, 10 ms blanking time.

Other than the above, any switching cycle can be obtained within the following limitations:

The values of blanking, signal and reference time within one switching cycle can have values:

Blanking Time	- 1.700 to 99.999 ms	These may be solar
Signal Time	- 0.0000 to 9.9999 sec.	or sidereal as selected
Reference Time	- 0.0000 to 9.9999 sec.	by the sync control.

NOTE: If Reference Time = 0 and Signal Time ≠ 0 the control words are not determined by the present setting of the switches, etc. They were determined by some previous setting. Therefore, if it is desired to operate the correlators in non-switching mode, the settings should be: Signal Time = 0 Reference Time ≠ 0 and use the Reference Data out of the correlator as Signal Data.

The number of these switching cycles per dump can have the values:

001 to 999

However, between dumps into the computer, the maximum integrated signal or reference time should not exceed 26.843 solar seconds. See additional description of "100 ms blanking time" in Section V.A.

Switching Modes:

1. Load switching
2. Frequency switching
3. Continuum observation

These may be accompanied by a continuous running calibration or a separate calibration. There may also be gain modulator switching and for an analog continuum recording - synchronous detector switching.

III. BANDWIDTH, RESOLUTION AND SENSITIVITY

The output spectrum produced by the on-line computer consists of computed points spaced δf apart over a total bandwidth, B. Each point represents the power within a filter having approximately a sin x/x shape with a half-power width, $\Delta f = 1.21\ \delta f$, and a spacing between nulls of $2\delta f$. The bandwidth, B, can be selected by front-panel switches. The relation between bandwidth, resolution, spacing, and receiver rms fluctuation, ΔT, is as follows:

$$\delta f = \frac{B}{N} \qquad \Delta f = \frac{1.21B}{N}$$

50%/50% Duty Cycle $\Delta T = \frac{3.06T}{\sqrt{\tau \Delta f}}$

90%/10% Duty Cycle $\Delta T = \frac{1.63T}{\sqrt{\tau \Delta f}}$

Total Power $\Delta T = 1.53T \sqrt{\frac{1}{\tau_{ON} \Delta f} + \frac{1}{\tau_{OFF} \Delta f}}$

where N is the number of channels (i.e., 384, 192, or 96), T is the system noise temperature and τ is the integration time.

The selected values of B and the resulting values of Δf, δf, and ΔT are tabulated in Table 1. The values of ΔT in the table are for a system noise temperature of 100°, an integration time of 10 seconds and a duty cycle of 50%/50%. For an actual noise temperature, T, and integration time, τ, the ΔT value should be multiplied by T/100 and divided by $\sqrt{\tau/10}$. When examining a spectrum, 5.6% of the points should fall outside of a $4\Delta T$ interval, 1.2% outside of a $5\Delta T$ interval, and 0.2% outside of a $6\Delta T$ range.

At the edges of a measured spectrum the RMS fluctuation increases due to the attenuation at the edges of the band restriction filter in the correlator IF section. At the 6 dB attenuation point the RMS fluctuation doubles and data points beyond the 6 dB level should be ignored. The spectrum channel numbers within the 6 dB points of the receiver bandpass are given in Table 1.

IV. IF FILTER SYSTEM

General Description

The If Filter System may receive from one to four IF signals from the front-end box, provide filtering to establish the desired bandwidth, convert them to a lower frequency and clip the signals in preparation for digital processing. Other functions such as level control, gain modulation, total power detection, synchronous detection and voltage-to-frequency conversion are also included.

Most of the IF processing is performed in four similar drawers designated as Filter Units A, B, C and D. Each unit provides a selection of nine

TABLE 1

BANDWIDTH, RESOLUTION AND SENSITIVITY

BANDWIDTH B	RESOLUTION Δf kHz	CHANNEL SPACING δf kHz	RMS FLUCTUATION for T=100°, τ=10 sec ΔT	USABLE CHANNELS* RECEIVER			
				A	B	C	D
384 CHANNELS							
10 MHz	31.5	26.0417	0.55°	24-367			
5 MHz	15.8	13.0208	0.77°	29-372			
2.5 MHz	7.9	6.5104	1.09°	21-370			
1.25 MHz	3.94	3.2552	1.54°	19-364			
625 kHz	1.97	1.6276	2.18°	18-359			
312.5 kHz	0.985	0.8138	3.08°	18-370			
156.25 kHz	0.492	0.4069	4.36°	22-377			
78.125 kHz	0.246	0.20345	6.17°	22-374			
39.0625 kHz	0.123	0.10173	8.73°	22-372			
192 CHANNELS							
10 MHz	63.0	52.0833	0.39°	12-184		14-180	
5 MHz	31.5	26.0417	0.55°	15-186		13-183	
2.5 MHz	15.8	13.0208	0.77°	11-185		13-185	
1.25 MHz	7.88	6.5104	1.09°	10-182		11-183	
625 kHz	3.94	3.2552	1.54°	9-180		4-178	
312.5 kHz	1.97	1.6276	2.18°	9-185		8-182	
156.25 kHz	0.985	0.8138	3.08°	11-189		10-184	
78.125 kHz	0.492	0.40690	4.36°	11-187		11-181	
39.0625 kHz	0.246	0.20345	6.17°	11-186		10-184	
96 CHANNELS							
10 MHz	126.0	104.1667	0.27°	6-92	6-92	7-90	7-90
5 MHz	63.0	52.0833	0.39°	7-93	8-93	7-92	7-90
2.5 MHz	31.5	26.0417	0.55°	6-93	7-92	7-93	6-93
1.25 MHz	15.8	13.0208	0.77°	5-91	6-93	6-92	5-92
625 kHz	7.88	6.5104	1.09°	5-90	5-91	3-90	3-90
312.5 kHz	3.94	3.2552	1.54°	5-93	5-92	4-91	5-93
156.25 kHz	1.97	1.6276	2.18°	6-94	7-94	5-92	5-93
78.125 kHz	0.985	0.81380	3.08°	6-94	6-91	6-91	7-93
39.0625 kHz	0.492	0.40690	4.36°	6-93	6-93	5-92	7-93

* Numbered from 1 to 38, 19 or 9

bandwidths from 39.0625 kHz to 10 MHz in octave steps. A block diagram of the filter chain is shown in Figure 3. The input signal is filtered at 30 MHz and then converted to a lower frequency for the output of the next filter. The reason for the successive lowering of the frequency is to permit the final bandwidth determining filter to operate at a center frequency where its design will produce maximum cut-off slope. Low gain amplifiers are used between mixers and filters to correct for filter insertion losses, power loss due to bandwidth reduction and to provide an accurate source and load impedance for the filters. Diode switches are used for selecting filters and other signal paths because of their small size and low power drain.

The main signal output is a spectrum located between zero and a frequency equal to the bandwidth selected. This signal is fed to a clipper in a fifth drawer and then to the digital rack for sampling and correlating. A parallel signal path through a square law detector and voltage-to-frequency converter provides an output frequency proportional to total power for counting and calibration in the digital system. The digital system furnishes switching signals to the filter system to operate the gain modulators, synchronous detectors, and test signals to the clippers.

The fifth drawer contains the oscillators, clippers, voltage-to-frequency converters and a noise generator. There are eleven crystal oscillators in temperature stable ovens with output frequencies from 120 MHz to 175 kHz. Each oscillator from 40 MHz down drives four transistor-diode switches that are controlled by the bandwidth switches in the filter drawers. Each switch output is fed to a mixer in one of the filter chains. Use of common oscillators for all filter units permits phase coherence of identical signals fed through two or more drawers as required for cross correlating.

The clippers receive a video signal and provide over 50 dB of limiting. The output signals go to the digital rack to be sampled. The voltage-to-frequency converters are commercial plug-in units made by Anadex. A broadband noise generator is included for checking band shapes and levels at either 30 or 150 MHz.

Operational Description

The level of the IF inputs must be greater than -50 dBm for 10 MHz bandwidth. This level is for the most sensitive arrangement in the input circuits of the filter units and provides an input signal-to-internal noise ratio of about 26 dB. The signal levels are controlled by step attenuators at the input (see Figure 3). Adjustments are made to set the total power meter reading to approximately 100 (mid-scale) giving one volt on the X1 output for recording. This setting places the level at optimum for the square law detector though offsets up to ± 2 dB should give negligible error.

The input center frequency is normally 30 MHz. A mixer can be added by internal cabling changes to permit operation at 150 MHz. The oscillator for this mixer is at 120 MHz so that the spectrum is not reversed as a result of changing IF frequency. The gain modulator consists of two variable attenuators of the same model and two coax switches. The attenuator exposed on the front panel is switched in the circuit when the front-end switch is in the reference position. Adjustment of the attenuator will remove differences in level between signal and reference. A synchronous detector has been provided primarily for use in adjusting the gain modulators. Its sensitivity is adjustable relative to system temperature. Outputs are provided at the top of the rack for recorders. The bandwidth switch and other controls on each filter unit operate independently, making it unnecessary to adjust filter units not being used.

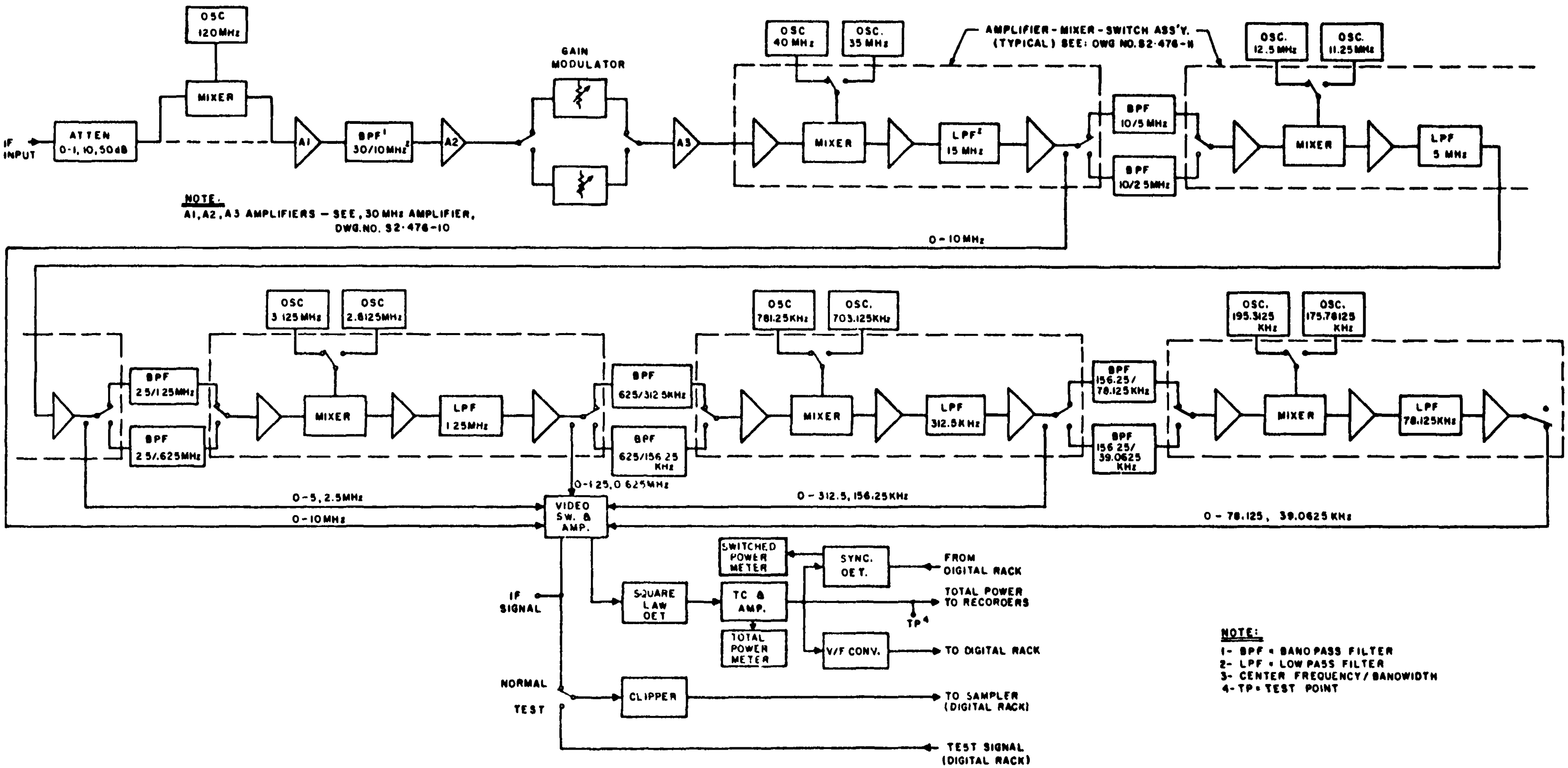
The particular filter units being used are determined by the mode switch on the front of the digital system. Reference should be made to the description of the digital control panel for information on the different modes of operation.

The oscillators are oven controlled with a stability better than one part in 10^7 per day for frequencies of 2.8 MHz and above, one part in 10^6 for the 781 and 703 kHz, and 5 parts in 10^6 for the 195 and 175 kHz oscillators. The frequency offsets due to drifts in all of these oscillators will usually be less than 100 cps and the drift will be less than 15 cps per day.

The oscillator frequencies have been chosen so that a signal appearing at 30 MHz or 150 MHz at the IF input will appear in the center of the spectrum produced by the computer. The channel numbering and location of the center for each mode is given under the Data Processing section. The frequency spacing, δf, between spectral points and usable channels is given in Table 1.

The spectrum is inverted by each mixer in the IF Unit after the 30 MHz input so that bandwidths of 10, 1.25, 0.625, 0.078, and 0.039 MHz have inverted spectra when correlated. However, the DDP-116 computer corrects the inversion so that all spectra are recorded with increasing <u>IF</u> frequency corresponding to increasing point number or left-to-right on the CRT display. The correspondence to <u>RF</u> frequency will depend on whether the first LO is above or below the line frequency.

The square law detector output is amplified to a one volt nominal level and provided on the front panel and at the top of the rack for monitoring or recording total power. A ten times output with offset is also available for recording. Synchronous detector outputs of $\pm$ 10 V full scale are provided. The IF signal jacks on the front panels may be useful when strong interference is suspected. The spectrum at this jack is located at "video" frequency.



CORRELATION RECEIVER MODEL III
IF. FILTER SYSTEM

Figure 3

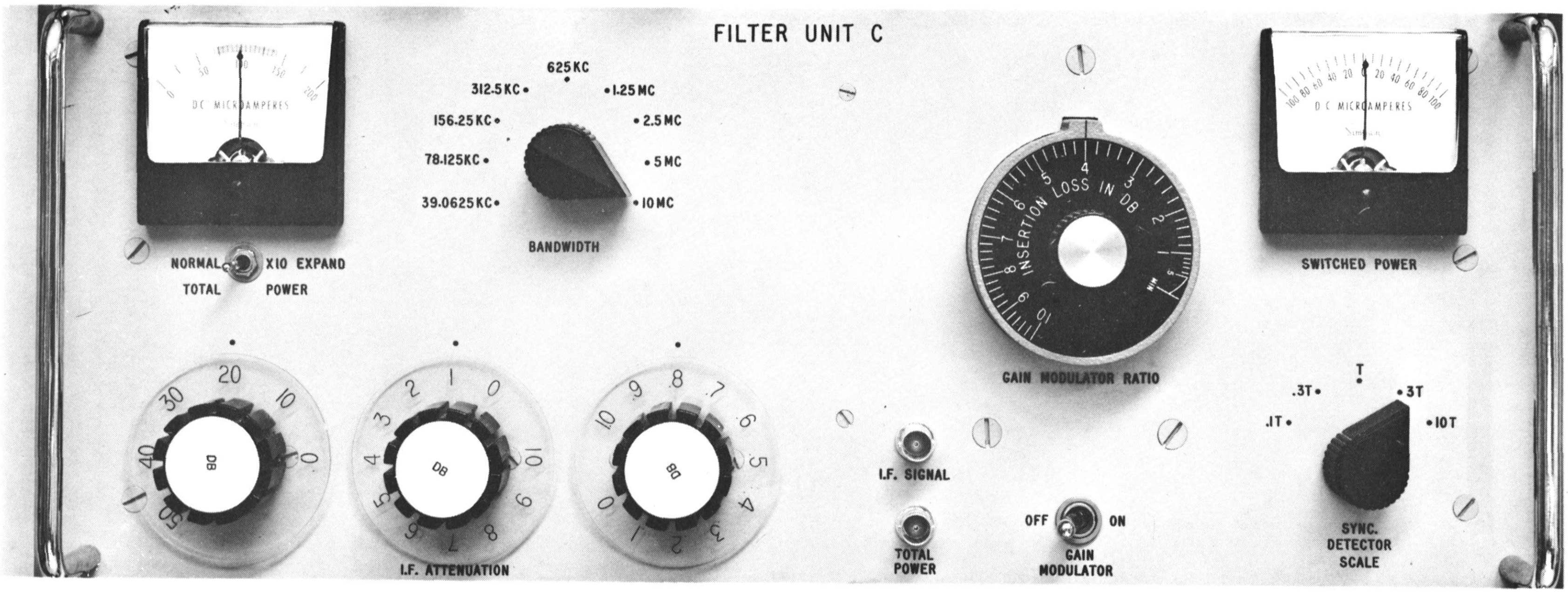


Figure 4

IF Filter System Controls

Clipper test switches permit feeding test frequencies through the clippers to the digital rack for troubleshooting. The frequency selection of the test signal is made in the digital rack.

Input and Output Connections

IF Inputs A, B, C and D

Feed Filter Units A, B, C and D.

Center frequency - 30 or 150 MHz (internal changes required when changing center frequency).

Level - Minus 50 dBm or greater per 10 MHz bandwidth.

Total Power X1 A, B, C and D

Level - 1 V open circuit.

Source impedance - 2000 ohms.

Operating range - 0.5 to 2 V for square law detector error less than 3%.

Total Power X10 A, B, C and D

Level - Zero volts nominal for a total power X1 level of one volt.

Source impedance - 2000 ohms.

Operating range - Plus and minus 10 V maximum for +2 and 0 V, respectively, on total power X1.

Synchronous Detector A, B, C and D

Level - Zero volts nominal for a balanced receiver.

Source impedance - 2000 ohms.

Operating range - $\pm$ 10 V maximum.

Noise Generator

Level - Approximately -28 dBm in a 10 MHz band.

Operating range - 10 to 170 MHz.

V. DIGITAL UNIT

A. Block Diagram Description:

Refer to the block diagram of Figure 5. The clipper output, which has been previously described as a rectangular waveshape containing the frequency information of the original received signal, is sampled at a rate equal to twice the filter bandwidth. The sampler provides a compatible digital output which is synchronized to the digital system logic clock.

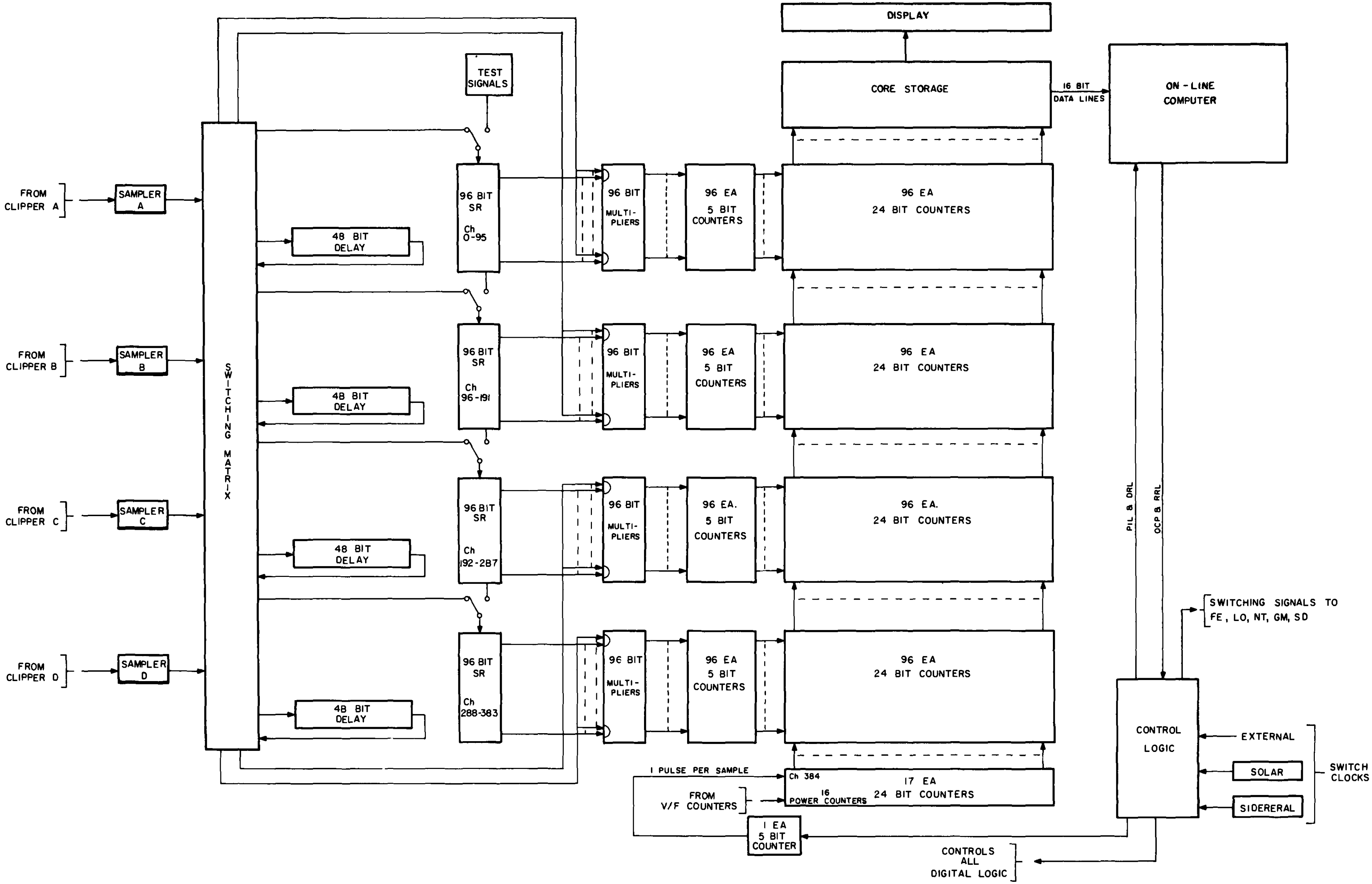
The sampled data is continuously stored in a 96, 192 or 384 bit shift register which is updated at every clock (sample) pulse. Each shift register stage feeds a one bit multiplier. The other input to the multiplier is, in the case of autocorrelation, the "present" ("latest" data output of the sampler). In cross-correlation the other input to the multiplier is the "present" sample delayed by an amount equal to one-half the shift register storage length, i.e., 48, 96 or 192 sample periods. This provides a correlation comparison between the present sample and the previous 95, 191, or 383 samples, each spaced τ seconds behind the adjacent sample; where τ is the sampling period.

Each time a multiplier indicates a correlation (i.e., 00 or 11) a pulse is sent to the corresponding counter. The counters thus count the number of times a particular delay correlates with the "present" sample. In autocorrelation, the first channel always correlates, as it multiplies the present sample times itself, thus it generates a record of how many samples are taken during one integration period. For cross-correlation an additional 385th channel, numbered ch. 384, has been added. Channel 384 counts the number of samples taken during an integration period; therefore, during autocorrelation channels 0 and 384 contain the same number.

As the bandwidth and sampling rate are changed, the clock into the shift register also changes to correspond to the sampling rate. The clock to the multipliers always operates at 20 MHz. For example, the shift register may be shifting at a 5 MHz rate and the multipliers, multiplying at a 20 MHz rate. Thus for each sample, each channel counter would receive the results of four multiplications. This causes the final integrated counter numbers to always vary around the same value.

At the end of a signal or reference period a blanking period occurs and the data in the 24 most significant bits of the counters is transferred to a section of the core memory. At this time all counters are reset and a new integration is started at the end of the blanking period. Each full counter consists of 29 binary bits of data. The first five - least significant bits - are integrated circuit flip-flops and the data contained in them is discarded as it is a small portion of the rms deviation. The next 16 bits are integrated circuit flip-flops whose data must be transferred to core at the end of signal or reference time. Because of the counter design, these 16 bits of data must be transferred to core at approximately the end of every 100 ms during signal or reference time. This transfer causes an automatic 1.7 ms blanking time. Thus, as an example; when switching at 1 Hz, 50/50% duty cycle, with a 10 ms blanking time - the correlator will integrate signal for 490 ms. During the 490 ms, four automatic 100 ms blanking times will occur. The actual integration time will then be 490-(4) (1.7) = 483.2 ms. To simplify the calculation of the actual integration time for any value of signal or reference settings, follow these rules:

a. Never use a total integration time of less than 5 ms.
   The number of bits of data discarded (5 bits) is based
   on the fixed rate of operation of the multipliers (20 MHz)



CORRELATION RECEIVER DIGITAL SYSTEM BLOCK DIAGRAM

FIG. 5

a. (cont.)

and a minimum integration period of 5 ms. The use of less than 5 ms will result in some of the data beyond the RMS deviation being discarded and a possible error in the resulting spectrum.

b. In the equations that follow, let:

TS = Time setting in milleseconds of signal or reference switches.

$n = \left[\frac{TS}{100}\right]$ i.e. n = the greatest integer in $\frac{TS}{100}$

$m = \frac{TS}{100} - n$ milliseconds

IT = total integration time in ms for any value of TS.

c.1. If $m > 1.8$ ms $IT = 100 + (n-1)\ 98.3 + (m-1.7)$

2. If $m < 1.9$ ms $IT = 100 + (n-1)\ 98.3 + m$

d. It should be kept in mind that, in equation 1, if $(m-1.7) < 5$ ms the last integration in signal or reference before each dump time will consist of an integration period less than 5 ms and result in a small amount of data being thrown away. This will result in a decrease in signal to noise ratio but it will probably be insignificant. Each user must determine this for himself.

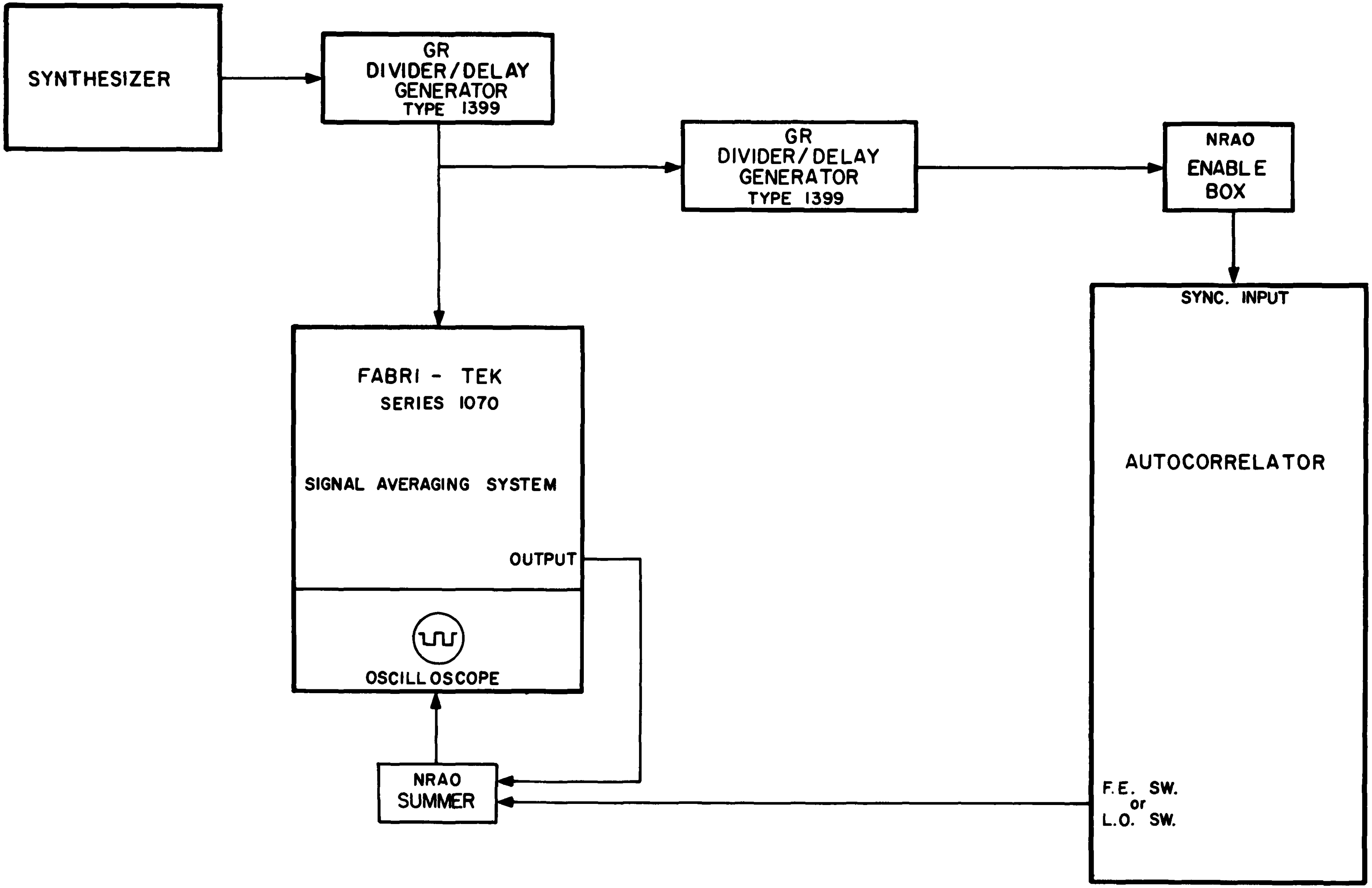
The core memory contains the following data: signal correlation function, reference correlation function, power counters, control words (control knob position information, LO offset frequencies, sense bits, etc.). At dump time an interrupt (PIL) is sent to the computer and the computer can begin removing one word at a time as required. The computer is allowed the entire time until the next dump time in which to remove the data.

At the beginning of an observation the correlator can be synchronized to the computer or to a pulsar by sending a pulse (-6 volts to ground - minimum length 100 ns; or switch closure - no bounce allowed - to ground) into the Sync

Input. The correlator will reset itself, start a blanking time and send a PIL to the computer. It will then begin a new switching cycle. The computer can then remove the data from the correlator and check the control words to see if all knobs are correctly set. However, the computer should not try to use the autocorrelation function or power counters as a result of the first PIL. The blanking time associated with this first PIL will begin between 50 ns and BT + 500 μsec. (BT = blanking time) after the Sync Pulse goes to ground. The exact time depends on when during the switching cycle the Sync Pulse occurs. If it occurs during Signal or Reference Time, the delay after the Sync Pulse will be 50 n sec. to 100 μsec. and this is perfectly good for pulsars. If the Sync Pulse occurs just before or during Blanking Time, the delay after the Sync Pulse will be 100 μsec. to BT + 500 μsec. This is perfectly good for normal line observations at all Green Bank telescopes.

Pulsar Observations:

Figure 6 illustrates the setup for pulsar observations. The synthesizer and one of the GR divider/delay units generates the basic frequency for operation of the Fabri-Tek Series 1070 Signal Averaging System. This same basic frequency is passed through another GR Delay unit and Enable Box into the Sync Input of the Correlator. One of the unused switching outputs (front-end sw. or LO sw.) is fed into the summer along with the output of the Fabri-Tek. This allows the observer to determine the phasing between the correlator switching and the pulsar. An appropriate delay is then entered into the second GR Delay unit and the button on the Enable Box depressed and released. The Enable Box sends a shaped pulse into the correlator each time the GR Delay generates a pulse. The last pulse prior to the release of the button synchronizes the correlator.



BLOCK DIAGRAM FOR PULSAR OBSERVATIONS

FIGURE 6

As described in a previous paragraph, if the sync pulse occurs during signal or reference time, the maximum reset time for the correlator is 100 μsec which is negligible. However, if the pulse occurs just prior to or during blanking time, the delay will be between 100 μsec and BT + 500 μsec. This may not be negligible, in which case the Enable Box button should be depressed again for a new sync after resetting the GR Delay Unit to a new value.

In this setup, the computer will be started and stopped from the control panel, but the computer will have no control over synchronization of the correlator.

The digital rack, including all controls, displays, and input-output, is RFI shielded to prevent transmission of the many signals generated by the digital logic. Except for servicing, the doors should not and need not ever be opened.

The following section describes the controls and display in detail and thus contains much information required by the observer.

B. Controls and Displays

Figure 7 illustrates the front panel controls.

In the following discussion, reference will be made to the format of the data transmitted from the correlator to the computer. This is contained in Appendix I. Each title below is a control switch or display.

Test 1

Test 1 sets a square wave generator to one of nine frequencies as listed in format word 1582 A. If one of the four test switches on the IF rack is in the test position, the square wave is sent to the input of the clipper associated with the test switch and the normal video noise signal is disconnected from the clipper input. A square wave input to a correlator produces

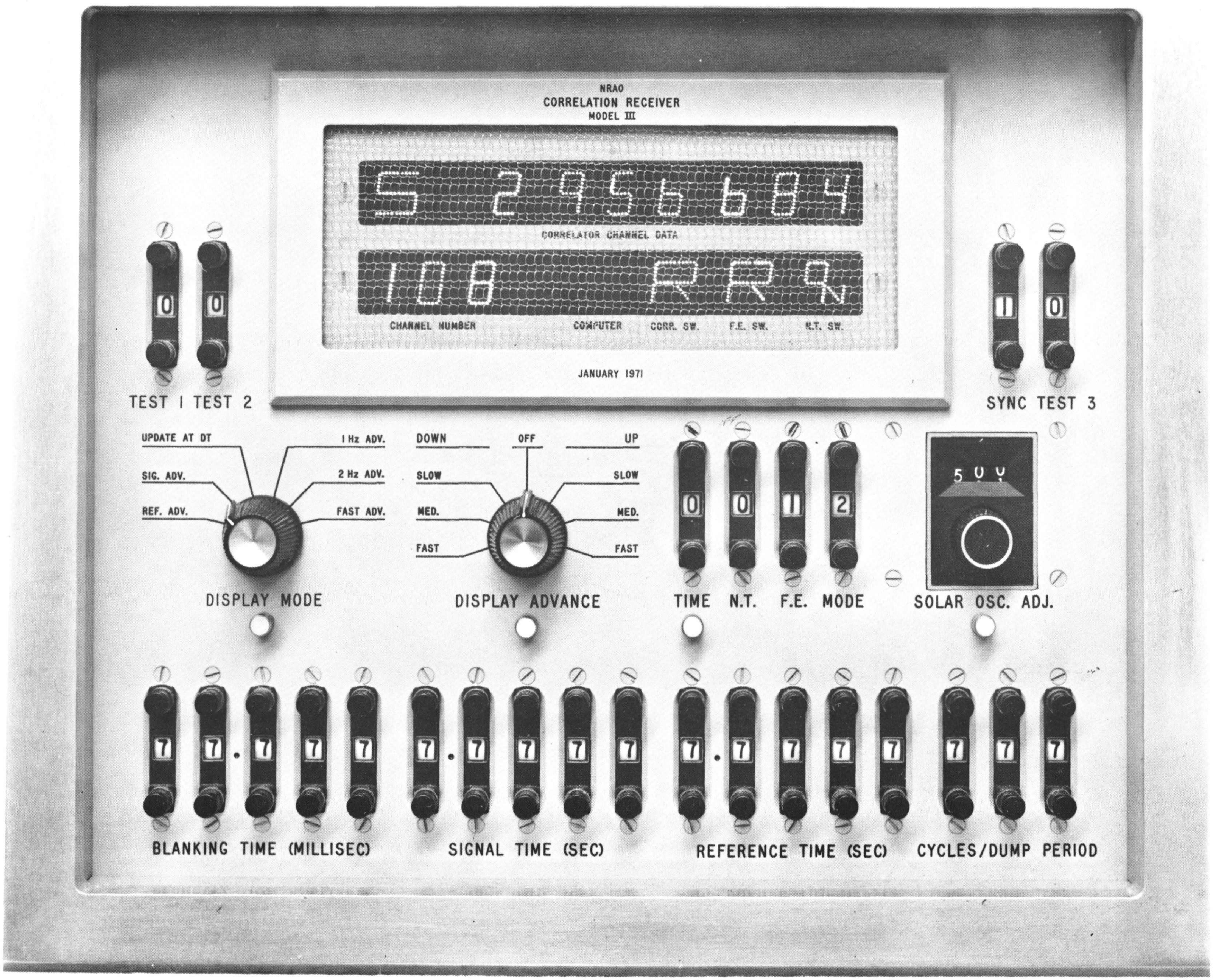


Figure 7

Digital System Front Panel Controls

a triangular correlation function. For the above test to work, Test 2 must be on 0.

Test 2

If Test 2 = 0 and all four IF test switches are off, the correlator is in normal operating condition. Positions 1 through 4 feed 1's and 0's directly to the correlator as per format word 1582B. Positions 5 and 6 feed the square wave, as set on Test 1, directly into the correlator with both inputs in (5) or out (6) of phase. Position 9 causes all numerical displays to display a figure 8.

Alphanumeric Display (left to right)

Top Row:

Element #1 - Alphabetical-displays R or S to indicate whether correlation data displayed is reference or signal.

Element #2 thru 9 - Numerical-represents the correlation value of one channel as integrated between the last two dump times.

Bottom Row:

Elements #1 thru 3 - Numerical-represents number of channel (0 thru 384) or power counter (385 thru 392) being displayed on top row. The power counter numbers correspond to computer words, as listed in the format, which follows:

Displayed Channel Number	Data	Computer Words Signal		Computer Words Reference
385	REC.A NT OFF	770-771	or	1556-1557
386	REC.B NT OFF	772-773	or	1558-1559
387	REC.C NT OFF	774-775	or	1560-1561
388	REC.D NT OFF	776-777	or	1562-1563
389	REC.A NT ON	778-779	or	1564-1565
390	REC.B NT ON	780-781	or	1566-1567
391	REC.C NT ON	782-783	or	1568-1569
392	REC.D NT ON	784-785	or	1570-1571

Element #4 - Alphabetical-when dump time occurs, a letter C is displayed for 30 to 40 ms. Whenever the computer accepts a word from the correlator the letter C is displayed for 30 to 40 ms. If the computer accepts words at a rate whose period is less than 30 to 40 ms, the display remains on until 30 or 40 ms after the last word is accepted.

Element #5 - Alphabetical-an R or an S is displayed to indicate the internal logic switching of the correlator.

Element #6 - Alphabetical-an R or an S is displayed to indicate the state of the logic signal being sent from the correlator to the front end switch driver.

Element #7 - Alphabetical-indicates the state of the logic signal being sent from the correlator to the noise tube driver. If the symbol $^{\text{O}}$N is displayed, the noise should be on. If nothing is displayed the noise tube should be off.

Elements #4 thru 7 - Alphabetical-if any of the test switches on the IF rack are on, or if Test 2 switch is not in Position 0, the display on these four units will go out and the word TEST will be displayed. This indicates to the operator or observer that antenna data is not being sent into the digital correlator.

Sync

Selects which oscillator will control the switching cycles of the correlator:

0 = External 10 kHz source. (Logic level swing 0 to -6 volts.)
For example - 10 kHz signal from timing generator (sidereal).

1 = Internal sidereal oscillator.
For specifications of oscillator see Appendix 3.

2 = Internal solar oscillator.
For specifications of oscillator see Appendix 4.

Test 3

This is a spare switch with no function at present.

Display Mode

REF ADV - activates Display Advance Control on reference channels.

SIG ADV - activates Display Advance Control on signal channels.

UPDATE AT DT - Channel Number display remains stationary. Correlator Channel Data is updated after each dump time.

1 Hz ADV - advances Channel Number at 1 Hz rate and displays latest Correlator Channel Data as it advances. When it reaches channel number 392 it then returns to channel number 0 and switches from signal to reference or vice versa.

2 Hz ADV - same as 1 Hz ADV but at 2 Hz.

FAST ADV - same as 1 Hz but at 64 Hz. This is a spring return position. When the knob is released it returns to 2 Hz ADV.

Display Advance

When activated by the Display Mode this control advances the Channel Number in an upward or downward direction, as indicated, and new Correlator Channel Data is displayed for each channel even at fast advance.

This is a spring return switch and returns to the OFF position when released.

Time

0 = Allows complete control of the switching cycle by means of the Blanking Time, Signal Time, Reference Time and Cycles/Dump Period switches. When using this position, it is up to the observer to insure that the switch positions are compatible with the operation of the correlator.

1, 2 and 3 = Provide three standard switching cycles as indicated in format word 1603.

See Figure 8 for an illustration of standard cycle 1 and 2.

N. T.

Controls switching cycle of noise tube logic output from correlator as indicated in format word 1577.

Figure 8 illustrates position 2 = 1/2 switch frequency which is the standard cycle used. Notice that the switching cycle is symmetrical between the dump times. This requires an even number of signal-reference cycles between dump times.

If N. T. switch position 2 is used and a switched frequency system is employed with a center signal frequency and a lower and higher reference frequency, care must be taken in handling the data. Notice that the noise tube will be on only one of the reference frequencies - i.e., either high or low depending on how the switching of the L.O. happens to start. Thus if the noise tube is on for reference high frequency, it will always be off for reference low frequency and vice versa.

F. E.

Controls switching cycle of front-end logic output from correlator as indicated in format word 1577.

Mode

Eight modes are available as indicated in format word 1576.

Solar Osc. Adj.

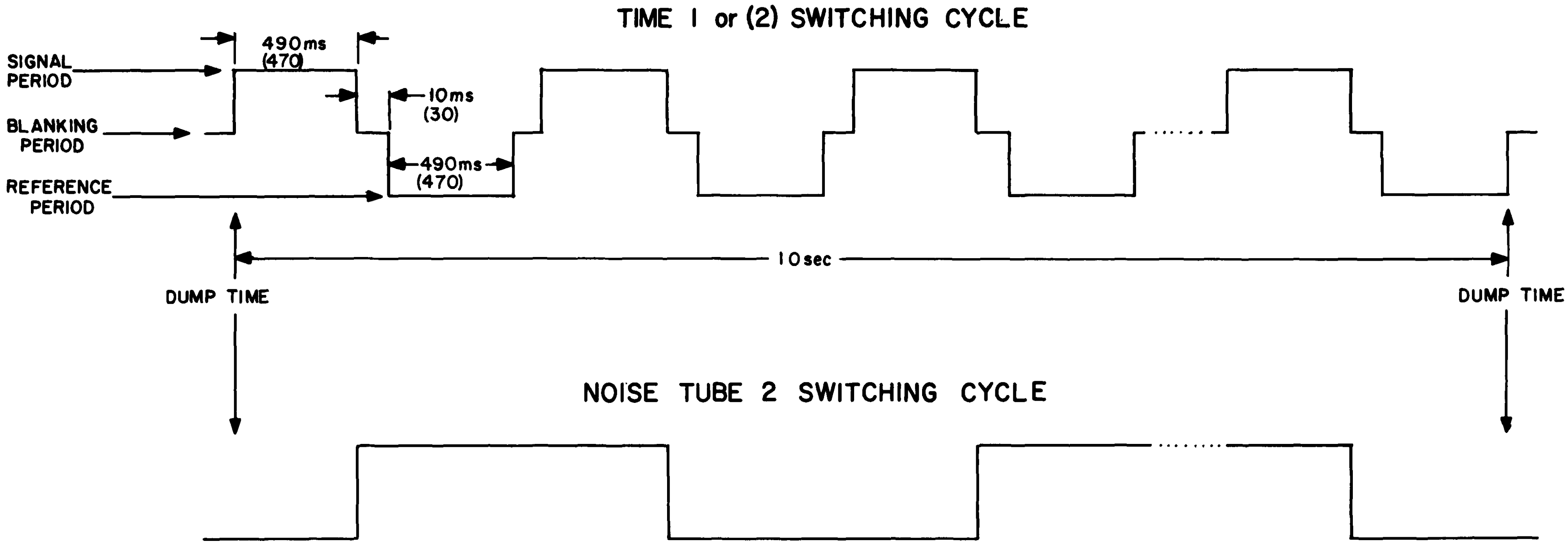
This is a ten turn potentiometer which varies the Solar Oscillator approximately ± 50 Hz from 1 MHz. The variation is linear within ± 10%. A calibration chart can be made for this control and it will repeat the calibrated positions to better than ± 1%.

Pilot Lights

These four small white lights - all in one horizontal row - indicate when the switch, under which each light is located, is operative. Examples: Display Advance Light indicates that the Display Mode switch is in one of its first two positions and the Display Advance switch will perform its function. Time light indicates that the time switch is on one of its three standard positions (1, 2 or 3). When the Time light is off, the Time switch is in position 0 and the Blanking Time, Signal Time, Reference Time and Cycles/Dump Period switches are operative.

Blanking Time
Signal Time
Reference Time
Cycles/Dump Period

These four sets of switches provide the observer with complete control over the correlator switching cycle with the limits described in Section II. These switches and the Solar Oscillator potentiometer are mainly provided for pulsar observation requirements.



SIGNAL-REFERENCE & NOISE TUBE SWITCHING CYCLES

FIGURE 8

VI. COMPUTER PROCESSING FOR AUTOCORRELATION

The autocorrelation receiver is designed to interface with the Honeywell DDP-116 computers at the NRAO 140-foot and the 300-foot telescopes. The computer can also be used for tasks associated with antenna pointing simultaneously with the autocorrelation processing; an executive program exists in the computer for this time sharing operation.

Correlator-Computer Data Transfers

The transfer of data from the correlator to the computer is initiated by an interrupt (a break in the normal computer program sequence). The computer responds to the interrupt by transferring the data for the previous correlator dump period into the computer memory. A special multiplexer address is maintained for transfer of data from the correlator. This allows the computer to respond to other input devices and return to the same point. The input transfer requires between about 35 and 175 ms, depending on the number of other tasks to which the computer responds.

Since the correlator employs two banks of memory - one for the current dump period and one for the previous dump period - the computer need not respond immediately to an interrupt. Operating with a 10 sec dump time, the computer may take as long as 10 sec to complete the input after the interrupt. This provides for a convenient information buffer in case of special extraordinary conditions - a long queuing line of tasks to be performed by the computer or a tape re-write condition.

The interrupt marks the end of the correlator integration period. The first interrupt is usually synchronized with the start time for the observation. The first data input is used only to check receiver controls. Subsequent interrupts occur after each dump time period is complete.

Data Processing

The autocorrelation data is broken into groups according to the receiver configuration. Signal and reference data within a given receiver are handled separately. Four major steps occur in processing the output of each receiver. The process is repeated for each receiver according to the mode.

1. Normalization - Each receiver has, as its first counter output, a count of the number of attempts at correlation. A series of calculations is carried out which is equivalent to the following: Half the value of the first counter is subtracted from and divided into the counter value for each channel. This expresses the number of correlations for each channel as a fraction of the number of attempts. These numbers can range -1 to +1 although for most spectra they are less than .1 in magnitude.

2. Clipping Correction - The normalized readout, ρ_{yi}, of the i^{th} channel is used to calculate ρ_{xi}, the autocorrelation function of the i^{th} channel:

$$\rho_{xi} = \sin \left(\rho_{yi} \frac{\Pi}{2}\right)$$

3. Fourier Transform - Each receiver has N channels for signal and N channels for reference (N = 96, 192, or 384) with normalized, corrected readouts ρ_{xi}, i = 0, ..., N - 1. N spectral estimates, P_j, j = 1, ..., N are computed:

$$P_j = \rho_{xo} + 2 \sum_{i=1}^{N-1} \rho_{xi} \cos \left[\frac{i(j-1)\pi}{N} \right]$$

This form of the Fourier transform gives the center of the band at a channel value of $j = N/2 + 1$. Thus the spectral estimate corresponding to the center of the IF pass-band occurs as in Table IV.

TABLE IV

Center Channels (Autocorrelation)

Mode	Center Channels
1	193
2	97,289
3	49, 145, 289
4	49, 145, 241, 337
8	97, 289

4. Re-Inversion - Those bandwidths for which inversion occurs in the IF signal processing (see page 13) are re-inverted. Further inversions may occur according to the program and local oscillator set-up so as to produce increasing velocity with increasing channel numbers.

Inversion is accomplished by swapping channel pairs (e.g., 2-96, 3-95, ..., 48-59) and leaving the center channel unmoved. Channel 1 is also left in place.

On-Line Outputs

Spectra can be displayed and printed. They are normalized spectra (the average value is 1) and can be used to monitor the system.

The normal output display is the "quotient" spectrum which is computed from the signal transform, S_j, and reference transform, R_j, as follows:

$$Q_j = \frac{S_j - R_j}{R_j} \qquad j = 1, \ldots, N$$

In case of total power observations, the signal and reference transforms are replaced by on-source and off-source transforms respectively.

The quotient spectrum is the normal switched output of a spectral-line radiometer corrected for gain variation (by division by R_j). It is proportional to the line temperature and may be converted to temperature units by multiplying by the system temperature. The appropriate system temperature is the sum of receiver noise temperature, antenna signal temperature, and 1/2 the calibration noise temperature, all averaged over the receiver bandwidth. This quantity can be computed from the total power (continuum) counters with calibration noise on and off.

Observing Techniques

Three different observing techniques are commonly used. The processing program in the on-line computer provides displays and data recording facilities that depend on the observing technique. Three observing techniques for which programs have been written are: Total power (integration), switched power (integration), and mapping.

Total Power

Total power observations require the measurement of on-source and off-source spectra. The off-source measurement is used to determine the reference and to calibrate the gain variation across the band. It should match the on-source measurement as to mode and receiver bandwidths and should use a flat spectrum for RF input.

This method can offer advantage over switched power observing since the same off-source measurement can be used for several on-source measurements. It is also sometimes possible to invest integration time in the off-source measurement during time when sources are inaccessbile. Both these factors improve the signal-to-noise ratio. However, total power observations require very high receiver stability during the time interval between on-source and off-source measurements; the required stability may or may not be achieved with a particular front-end.

Data is integrated in the correlator for the dump period (10 seconds). These outputs are integrated in the computer (typically 60 seconds). The integrated spectra is then recorded on tape. Further computer integrations are recorded and also added with the first to produce an average spectra for that observation.

The observation - average is used only for on-line displays and does not affect that which is recorded on tape. If the observation is an off-source measurement, it can be stored so as to allow computation of quotients during subsequent on-source observations.

TABLE I

Total Power On-Line Outputs

Description	CRT	Plotter	Printer
current spectra (transforms of the most recent dump period)	√	√	
current quotient (quotient of current spectra and stored off-source spectra)	√	√	
cumulative spectra (average of spectra since the start of the observation)	√	√	√
cumulative quotients (quotient of cumulative spectra and stored off-source spectra)	√	√	√
stored off-source spectra	√	√	√
cumulative quotients minus a linear baseline	√	√	√

Switched Power

Switched power observations involve measurement of a signal and a reference measurement at the same sky position. The spectra are derived by one of the switching techniques: frequency, beam, load, and time switching have all been used according to the experiment and equipment. The spectral source switching (e.g., switching of the L.O.) is synchronized to the switching of the correlator between its signal and reference data, (typically 1 Hz). The data is integrated in the correlator for one dump period (typically 10 seconds). Further integration is performed in the computer (typically 60 seconds). These integrated signal and reference spectra are recorded on tape and are used to compute quotients. Subsequent computer integrations are also recorded and added together with the first to produce the average for the entire observation.

TABLE II

Switched Power On-Line Outputs

Description	CRT	Plotter	Printer
cumulative signal (average of signal spectra since the start of the observation)	√	√	√
cumulative reference (average of reference spectra since the start of the observation)	√	√	√
cumulative quotients (quotient of cumulative signal and cumulative reference)	√	√	√
cumulative quotients minus a linear baseline	√	√	
correlator counter data			√
power counter data			√
correlator control words			√

Mapping

Mapping observations require that power spectra be recorded at the most frequent possible interval. Both signal and reference spectra are recorded every 10 seconds. Frequency swithcing is usually employed in this type of observation. The eventual off-line output is usually a contour map with the contours representing temperature as a function of velocity and sky position.

Data may be recorded with either a 50/50 or a 90/10 duty cycle (see page 8). For a 90/10 duty cycle, the off-line processing programs average the reference spectra across the entire observation. Thus a reference measurement of very low noise is combined with a signal measurement with nearly twice as much integration as with 50/50.

TABLE III

Mapping On-Line Displays

Description	CRT	Plotter	Printer
current signal (most recent spectra)	√	√	√
current reference (most recent spectra)	√	√	√
current quotient (quotient of most recent spectra)	√	√	
cumulative quotient (average of quotients since start of observation)	√	√	√
cumulative quotients minus a linear baseline	√	√	
correlator counter data			√
correlator control words			√

REFERENCES

1. S. Weinreb, "A Digital Spectral Analysis Technique and Its Application to Radio Astronomy", Technical Report 412, M.I.T. Research Laboratory of Electronics, Cambridge, Massachusetts, August 30, 1963 - Available as AD418-413 from U. S. Clearinghouse for Federal Scientific and Technical Information, Springfield, Virginia 22151, $3.00.

2. A. M. Shalloway, (1964) - IEEE NEREM Record 6, 98-9.

APPENDIX I

DETAILED DESCRIPTION OF DATA TRANSFERRED FROM CORRELATOR TO COMPUTER

Computer Words		Description	Format - DDP-116 Word Bits Note: All even numbered words have a "1" in word bit 1. All odd words have a "0" in word bit 1.																
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
0 thru 769	385 Channels of Signal Correlation	Each channel is represented by a 24-bit word which is taken into the computer as two words. Channel 384 is a total count channel for use in cross correlation.	1st word	1	2^{14}	2^{13}	2^{12}	2^{11}	2^{10}	2^{9}	2^{8}	2^{7}	2^{6}	2^{5}	2^{4}	2^{3}	2^{2}	2^{1}	2^{0}
			2nd word	0	0	0	0	0	0	0	2^{23}	2^{22}	2^{21}	2^{20}	2^{19}	2^{18}	2^{17}	2^{16}	2^{15}
770 771	Receiver A - Signal Power Counter Noise Tube Off	Each counter is represented by a 24-bit word which is taken into the computer as two words.	Same format as words 0 - 769																
772 773	Receiver B - Signal Power Counter Noise Tube Off																		
774 775	Receiver C - Signal Power Counter Noise Tube Off																		
776 777	Receiver D - Signal Power Counter Noise Tube Off																		
778 779	Receiver A - Signal Power Counter Noise Tube On																		
780 781	Receiver B - Signal Power Counter Noise Tube On																		
782 783	Receiver C - Signal Power Counter Noise Tube On																		
784 785	Receiver D - Signal Power Counter Noise Tube On																		
786 thru 1555	385 Channels of Reference Correlation	Each channel is represented by a 24 bit word which is taken into the computer as two words. Channel 384 is a total count channel for use in cross correlation.	Same format as words 0 - 769																
1556 1557	Receiver A - Reference Power Counter Noise Tube Off	Each counter is represented by a 24-bit word which is taken into the computer as two words.	Same format as words 0 - 769																
1558 1559	Receiver B - Reference Power Counter Noise Tube Off																		
1560 1561	Receiver C - Reference Power Counter Noise Tube Off																		

(continued)

Computer Words		Description	Format - DDP-116 Word Bits															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1562 1563	Receiver D - Reference Power Counter Noise Tube Off	Each counter is represented by a 24-bit word which is taken into the computer as two words.	Same format as words 0 - 769															
1564 1565	Receiver A - Reference Power Counter Noise Tube On																	
1566 1567	Receiver B - Reference Power Counter Noise Tube On																	
1568 1569	Receiver C - Reference Power Counter Noise Tube On																	
1570 1571	Receiver D - Reference Power Counter Noise Tube On																	
1572	Receiver A - Bandwidth	4-bit word: 0 = reserved 1 = 10 MHz 2 = 5 MHz 3 = 2.5 MHz 4 = 1.25 MHz 5 = 625 kHz 6 = 312.5 kHz 7 = 156.25 kHz 8 = 78.125 kHz 9 = 39.0625 kHz	1	0	0	0	0	0	0	0	0	0	0	0	2^3	2^2	2^1	2^0
1573	Receiver B - Bandwidth	Same as word 1572	Same as word 1572															
1574	Receiver C - Bandwidth	Same as word 1572	Same as word 1572															
1575	Receiver D - Bandwidth	Same as word 1572	Same as word 1572															

Computer Words	Description: Mode	Receiver	Channel Numbers	Format DDP-116 Word Bits (1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16)
1576 Mode of Operation	1. 1 ea. 384 ch. A/C	A	0-383	1 0 0 0 0 0 0 0 0 0 0 0 2^3 2^2 2^1 2^0
	2. 2 ea. 192 ch. A/C	A	0-191	
		C	192-383	
	3. 2 ea. 96 ch. & 1 ea. 192 ch. A/C	A	0-95	
		B	96-191	
		C	192-383	
	4. 4 ea. 96 ch. A/C	A	0-95	
		B	96-191	
		C	192-287	
		D	288-383	
	5. 1 ea. 384 ch. C/C	A	stored data - 0-383	
		B	delayed data -0-383	
	6. 2 ea. 192 ch. C/C	A	stored data - 0-191	
		B	delayed data - 0-191	
		C	stored data - 192-383	
		D	delayed data - 192-383	
	7. 3 ea. 96 ch. C/C & 1 ea. 96 ch. A/C	A	stored data - 0-95	
		C	delayed data 0-95	
		B	stored data - 96-191	
		A	delayed data - 96-191	
		C	stored data - 192-287	
		B	delayed data - 192-287	
		D	288-383	
	8. 1 ea. 192 ch. A/C-double frequency	A		
	[Sampler B contains A delayed by	Sampler A	stored data 0-95	
	τ nanoseconds. Sampler B_1 contains	Sampler B	non-stored data 0-95	
	A advanced by τ nanoseconds.	Sampler B	stored data 96-191	
	$\tau = 0.5 \times 10^9 \div$ maximum sampling rate	Sampler B	non-stored data 96-191	
	available in cps.]	Sampler A	stored data 192-287	
		Sampler A	non-stored data 192-287	
		Sampler B_1	stored data 288-383	
		Sampler A	non-stored data 288-383	

Computer Words		Description	Format - DDP-116 Word Bits															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1577	Front-End Switch	2-bit word: 0 = Signal 1 = Reference 2 = Modulate	0	0	0	0	0	0	0	0	0	0	0	0	2^1	2^0	2^1	2^0
															N.T. SW.		F.E. SW.	
	Noise Tube Switch	2-bit word: 0 = On 1 = Off 2 = 1/2 Switch Frequency 3 = Switch Frequency (NT On Signal)																
1578	Receiver A,B,C,&D Gain Modulator	1-bit word per receiver: 0 = On 1 = Off	1	0	0	0	0	0	0	0	0	0	0	0	2^0	2^0	2^0	2^0
															D	C	B	A
1579	Sense Switches	8 ea. 1-bit words: Each bit can be a one or a zero to indicate the condition of a sense switch.	0	0	0	0	0	0	0	0	2^0	2^0	2^0	2^0	2^0	2^0	2^0	2^0
												Word						
											H	G	F	E	D	C	B	A
1580	Switching Sync. Control	2-bit word: 0 = Sidereal Osc. - (Ext. 10 kHz) 1 = Sidereal Osc. - (Int. 10 kHz) 2 = Solar Osc. - (Int. 1 MHz)	1	0	0	0	0	0	0	0	0	0	0	0	0	0	2^1	2^0

Computer Words		Description	Format - DDP-116 Word Bits 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1581	Clipper Test Signals	4 ea. 1-bit words: Word A: 0 = Normal } Receiver A - Clipper 1 = Test } Word B: 0 = Normal } Receiver B - Clipper 1 = Test } Word C: 0 = Normal } Receiver C - Clipper 1 = Test } Word D: 0 = Normal } Receiver D - Clipper 1 = Test }	0	0	0	0	0	0	0	0	0	0	0	0	2^0 D	2^0 C	2^0 B	2^0 A
1582	Digital Test Signals	Word A applies only when word 1581 is not all zeros <u>and</u> Word B is zero. 2 ea. 4-bit words: Word A: 0 = reserved 1 = 10 MHz 2 = 5 MHz 3 = 2.5 MHz 4 = 1.25 MHz 5 = 625 kHz 6 = 312.5 kHz 7 = 156.25 kHz 8 = 78.125 kHz 9 = 39.0625 kHz Word B: 0 = 1 = A=1 B=0 2 = A=1 B=1 3 = A=0 B=1 4 = A=0 B=0 5 = $A=\bar{B}=$Word A 6 = A=B=Word A 7 = 8 = 9 = Lamp Test NOTE: The blank positions may be assigned a meaning in the future, at which time they can be filled in.	1	0	0	0	0	0	0	0	2^3 (B)	2^2 (B)	2^1 (B)	2^0 (B)	2^3 (A)	2^2 (A)	2^1 (A)	2^0 (A)

Computer Words		Description	Format - DDP-116 Word Bits																
				1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1583	Spare Word	8 ea. spare bits for future use		0	0	0	0	0	0	0	0	S	S	S	S	S	S	S	S
1584 1585 1586 1587	Frequency-Local Oscillator A	1-Correlator word, 8=BCD digits, split into two BCD digits per computer word: BCD digits: 0 = Tens of Hz 1 = Hundreds of Hz 2 = Units of kHz 3 = Tens of kHz 4 = Hundreds of kHz 5 = Units of MHz 6 = Tens of MHz 7 = Hundreds of MHz	1st word	1	0	0	0	0	0	0	0	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0
												10^1				10^0			
			2nd word	0	0	0	0	0	0	0	0	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0
												10^3				10^2			
			3rd word	1	0	0	0	0	0	0	0	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0
												10^5				10^4			
			4th word	0	0	0	0	0	0	0	0	2^3	2^2	2^1	2^0	2^3	2^2	2^1	2^0
												10^7				10^6			
1588 1589 1590 1591	Frequency - Local Oscillator B	Same as words 1584 thru 1587	Same as words 1584 thru 1587																
1592 1593 1594 1595	Frequency - Local Oscillator C	Same as words 1584 thru 1587	Same as words 1584 thru 1587																

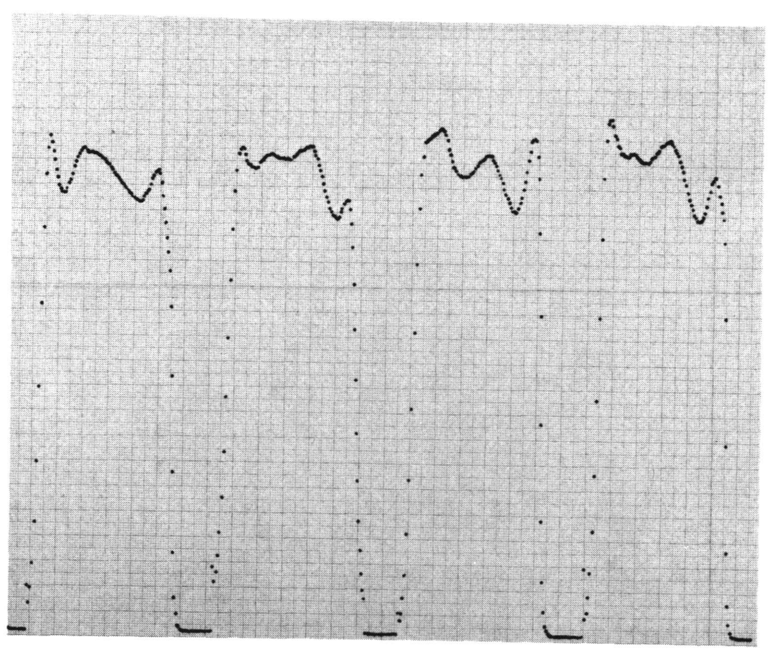
Computer Words		Description	Format - DDP-116 Word Bits
			1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
1596 1597	**Blanking Time**	1-Correlator word, 5-BCD digits. The first three digits are in the first computer word, the next two digits are in the second computer word: BCD digits: 0 = Units of microseconds 1 = Tens of microseconds 2 = Hundreds of microseconds 3 = Units of milliseconds 4 = Tens of milliseconds NOTE: When word 1580 is 0 or 1, BCD bits 0 & 1 will always be zero.	1st word: 1 0 0 0 $\underbrace{2^3\ 2^2\ 2^1\ 2^0}_{10^2}$ $\underbrace{2^3\ 2^2\ 2^1\ 2^0}_{10^1}$ $\underbrace{2^3\ 2^2\ 2^1\ 2^0}_{10^0}$ 2nd word: 0 0 0 0 0 0 0 0 $\underbrace{2^3\ 2^2\ 2^1\ 2^0}_{10^4}$ $\underbrace{2^2\ 2^2\ 2^1\ 2^0}_{10^3}$
1598 1599	**Signal Time**	Same preliminary description as words 1596 & 1597: BCD digits: 0 = Hundreds of microseconds 1 = Units of milliseconds 2 = Tens of milliseconds 3 = Hundreds of milliseconds 4 = Units of seconds	Same as words 1596 & 1597
1600 1601	Reference Time	Same as words 1598 & 1599	Same as words 1596 &1597
1602	**Cycles per Dump Period**	1-Correlator word, 3-BCD digits: BCD digits: 0 = Units of switching cycles 1 = Tens of switching cycles 2 = Hundreds of switching cycles	Same as word 1596

Computer Words		Description	Format - DDP-116 Word Bits															
			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
1603	Standard Time Modes	1-Correlator word, 4-BCD digits: BCD digits: 0 = Front panel switches control words 1596 thru 1602 The following modes automatically determine the value of words 1596 thru 1602 as indicated: word→ 1596-7 (BT), 1598-9 (ST), 1600-1 (RT), 1602 (C/D) 1 = 10000, 0490^0, 0490^0, 010 2 = 30000, 0470^0, 0470^0, 010 3 = 10000, 0890^0, 0090^0, 010 These modes produce the following conditions: DT, BT, SW RATE, DUTY 1. 10 sec., 10 ms., 1 cps., 50%/50% 2. 10 sec., 30 ms., 1 cps., 50%/50% 3. 10 sec., 10 ms., 1 cps., 90%/10%	0	0	0	0	0	0	0	0	0	0	0	0	2^3	2^2	2^1	2^0

APPENDIX II

SPECTRAL OUTPUT WITH IF NOISE GENERATOR INPUT

The following plots show the bandpass spectra measured with the internal IF noise generator connected to the inputs of receivers A, B, C, and D. The same results should be obtained if an unswitched front-end with flat bandpass is connected to the receiver inputs.

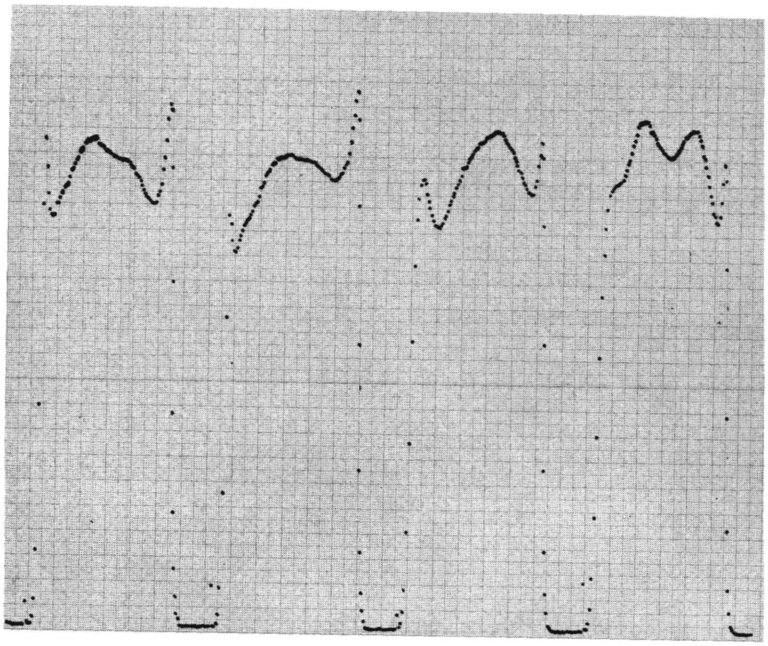


A B C D

Receivers

10 MHz Bandwidths

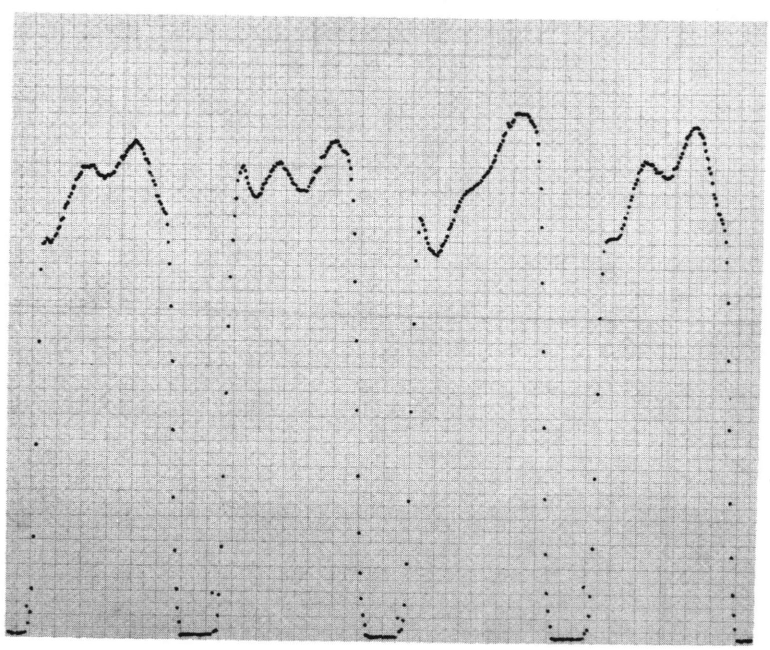
Bandpass Spectra



A B C D

Receivers

5 MHz Bandwidths

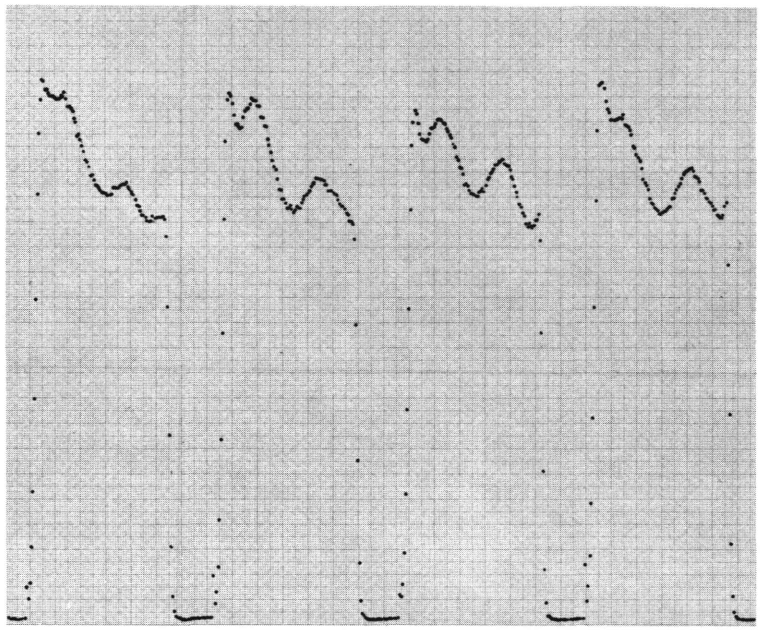


A B C D

Receivers

2. 5 MHz Bandwidths

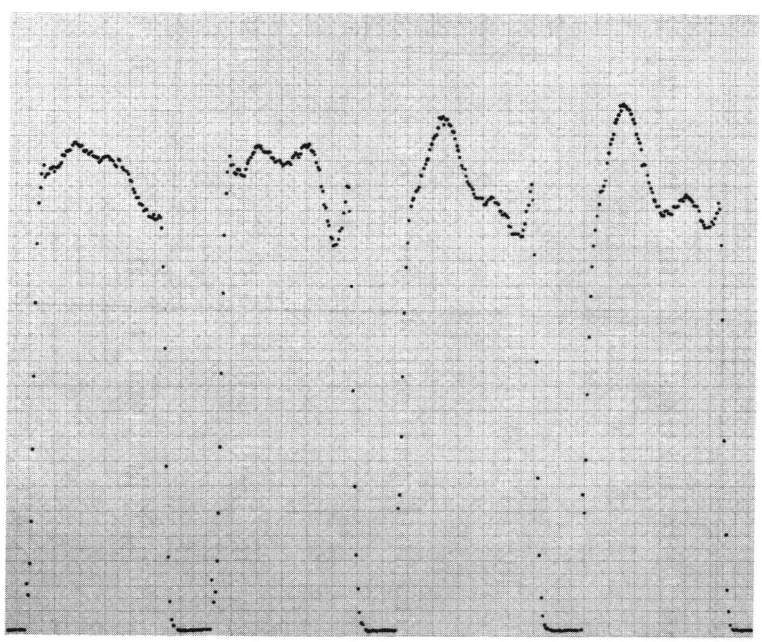
Bandpass Spectra



A B C D

Receivers

1.25 MHz Bandwidths

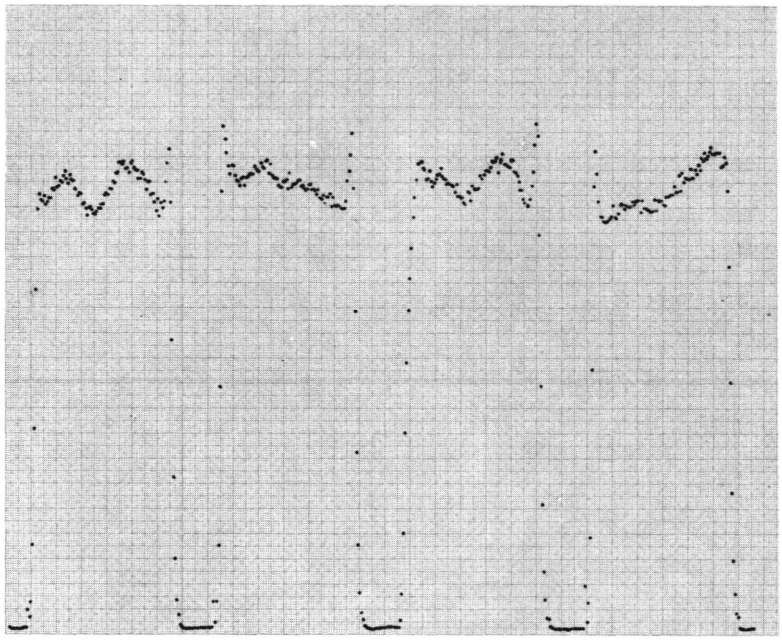


A B C D

Receivers

625 kHz Bandwidths

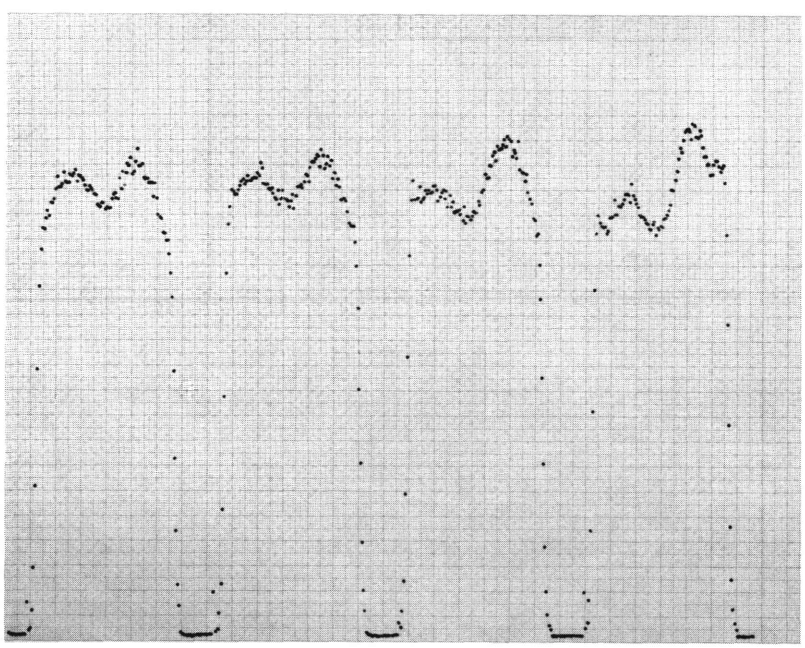
Bandpass Spectra



A B C D

Receivers

312 kHz Bandwidths

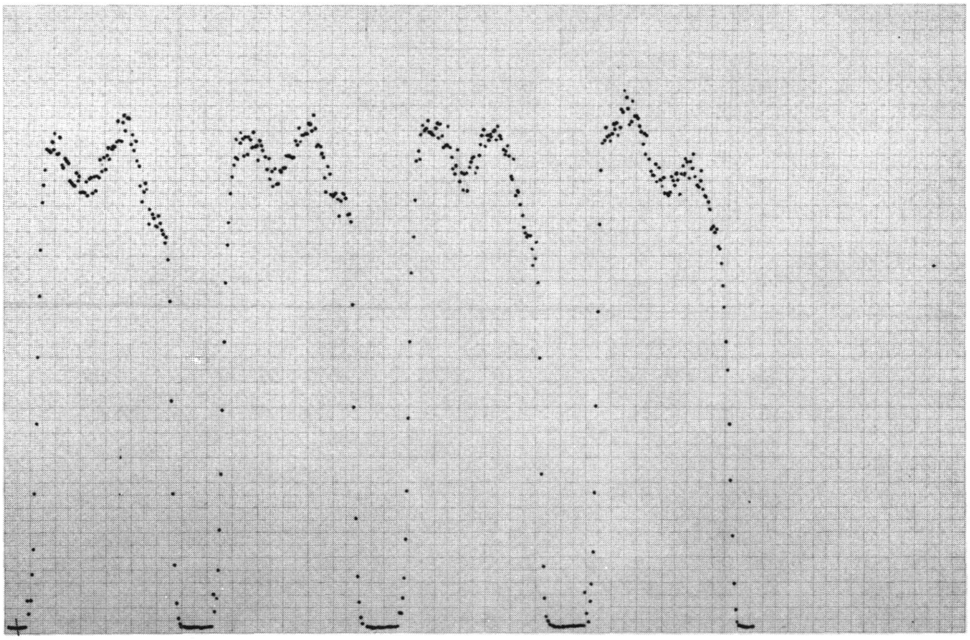


A B C D

Receivers

156 kHz Bandwidths

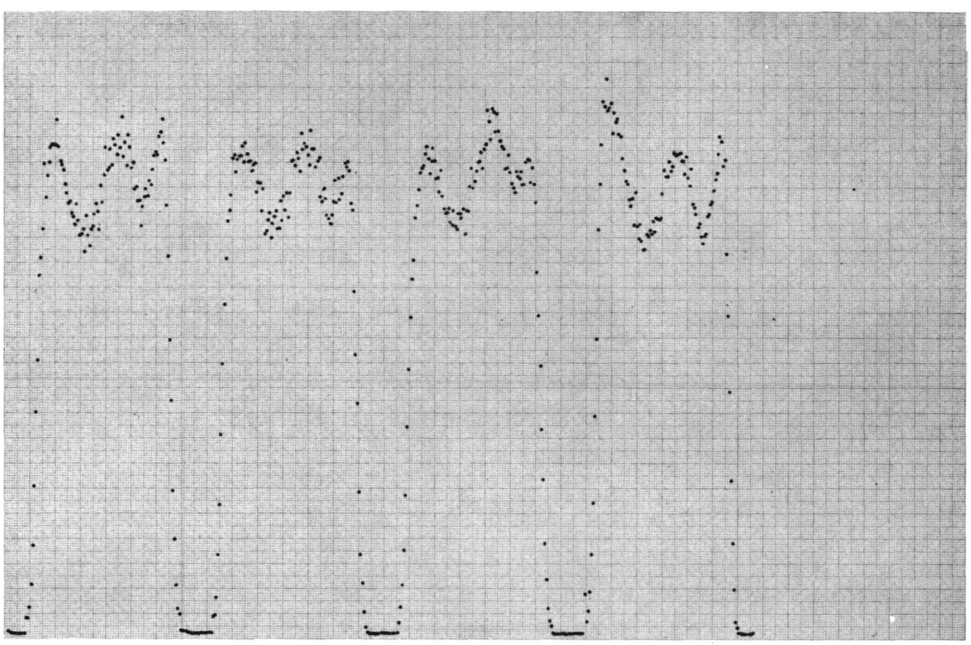
Bandpass Spectra



A B C D

Receivers

78 kHz Bandwidths



A B C D

Receivers

39 kHz Bandwidths

APPENDIX III

Specification of Sidereal Switching Oscillator.

Type: TCXO - temperature compensated crystal oscillator

Frequency: 4.01095164 MHz

Frequency Stability: $\pm$ 1 pp 10^6 over temperature range of -40°C to + 75°C

Aging Rate: 1 pp 10^8 per week.

APPENDIX IV

Specifications of Solar Switching Oscillator

Type: VCXO - voltage controlled crystal oscillator

Frequency: 1.000000 MHz

Frequency Deviation: ± 50 Hz

Frequency Stability: (over ambient temperature of +20°C to +50°C)

1 part in 10^6 (0.0001%) per month

1 part in 10^7 (0.00001%) per hour

1 part in 10^8 (0.000001%) per 0.1 sec (averaged over 0.1 sec)

Linearity: within ± 10% (10 Hz) of best straight line

Corrected Linearity (calibrated by NRAO): within ± 1% (± 1 Hz) of best straight line (i.e., the linearity is sufficiently repeatable to allow the calculation of a calibration curve, which can be used to eliminate some - 1% - of the linearity error). This assumes no error, variation, or ripple in the modulation voltage or the equipment used to measure it.

Maximum Deviation Rate: 100 Hz

Modulation Voltage: ± 4.5 volts centered at +4.5 volts.

Stability Measurements: Counter should be triggered near the +1.5 volt level of the falling edge of the oscillator output.

Modulation Voltage Generation:

Power Supply: Voltage +15 volts

Line Regulation 0.01% +1 mv

Load Regulation 0.02% +2 mv

Ripple and Noise 1/2 mv RMS; 1 1/2 mv pk-pk.

Temperature Coefficient 0.01%/°C

Series Resistor: 301 Ω ±1% TC ≦ 50 ppm/°C

Zener Diode: IN2624B TC = 0.0005%/°C

Potentiometer: 10 turn 1K Ω ±3%

linearity = ±0.25%; TC = ±20 ppm/°C

Circuit