NATIONAL RADIO ASTRONOMY OBSERVATORY

MEMORANDUM

February 24, 1967
IG No. 0267

To: IG File

From: J. Coe

Subject: 3-Element Interferometer Receiver Backend

The purpose of this memo is to provide sufficient information for initial operation of the 3-element interferometer receiver backend. A more detailed report containing schematics, functional details, and test data is being prepared.

1.0 Basic Design Requirements

The 3-element interferometer receiver backend was designed to operate with the three 85-foot antennas on a 2700 meter baseline. The backend processes the IF signals received from the three antennas and produces outputs proportional to the correlated component of noise received by each pair of antennas. The processing of the IF signals primarily consists of delaying and correlating these signals.

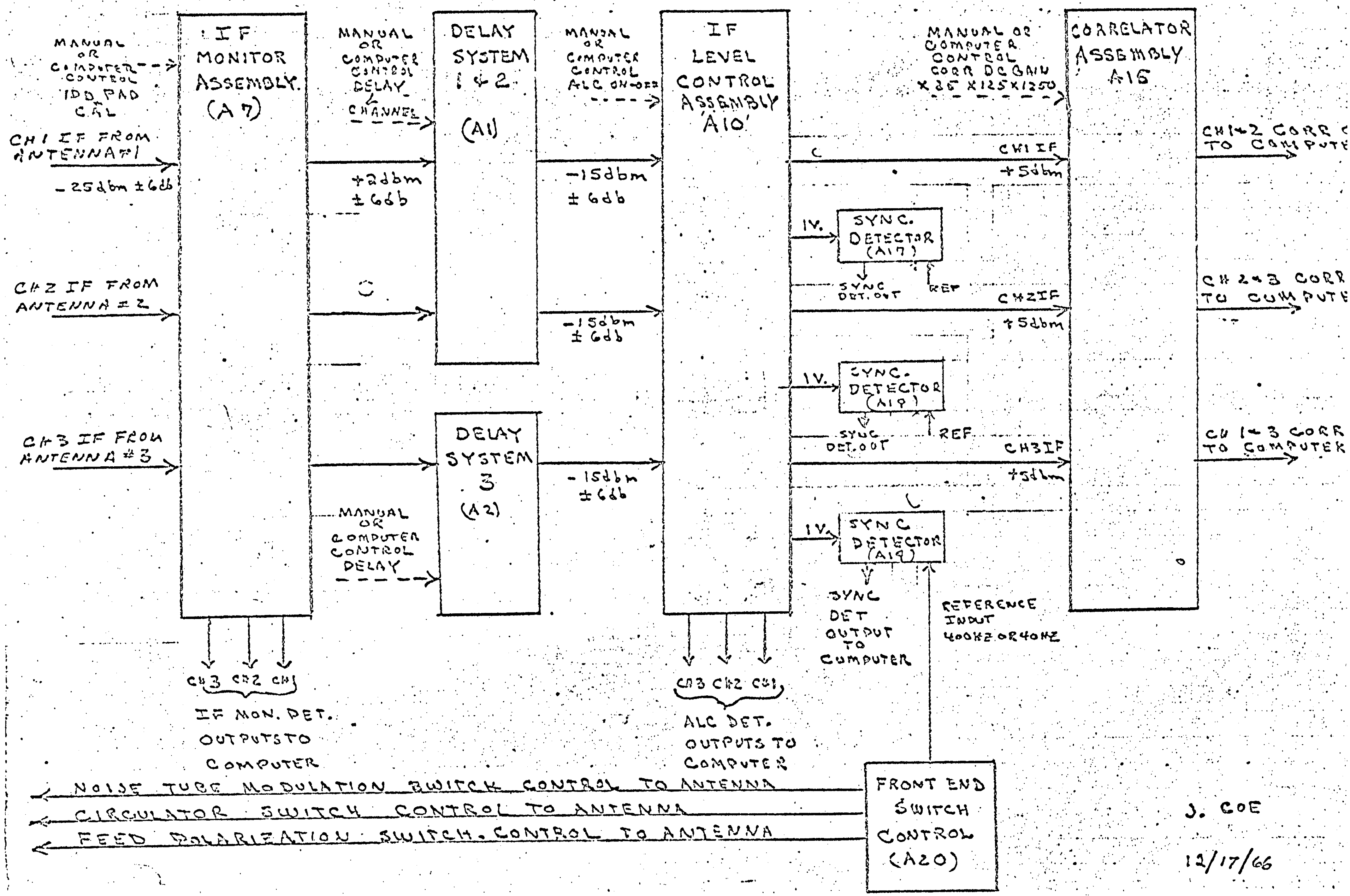
The backend will be controlled and monitored by the interferometer computer. All of the control functions can be either manually operated or computer controlled. The outputs from the backend are at the levels required by the computer.

The present backend is designed to operate with single frequency frontend receivers. Adequate space and power has been provided to expand the backend to operate in a dual frequency three-element interferometer system.

1.1 IF Signal Processing

The 3-element interferometer receiver backend operates with a 2 to 12 MHz bandwidth signal at levels of -25 dBm ± 6 dB. The block diagram of the backend is shown in Figure 1. The IF signals are first filtered and amplified in the IF monitor assembly. A DC output to the computer and a meter are provided in this system to monitor the IF level in each of the three channels. The IF output from the IF monitor system is at +2 dBm ± 6 dB.

FIG. 1 3-ELEMENT INTERFEROMETER RECEIVER BACKEND BLOCK DIAGRAM



J. COE

12/17/66

As shown on the block diagram, delay system 1 and 2 provides the required delay for the IF signals from antennas 1 and 2. These two antennas must be the pair with the greatest baseline separation. Delay system 3 provides the delay for signals from the center antenna. Each of the delay systems provide from 0 to 8997.8 nanoseconds of delay. This delay time is sufficient to compensate for the differences in delay of the RF signals between the source and the antennas when the maximum baseline length is 2700 meters. Differences in IF cable lengths between the antennas and the interferometer control building will be equalized by utilizing the spare buried IF baseline cable and an IF cable compensation system. The output levels from the delay systems and the inputs to the IF level control assembly must be -15 dBm ± 6 dB. The IF level control assembly is designed to compensate for level changes of ± 6 dB from the nominal -15 dBm input level. The IF inputs to the correlator assembly are held constant at +5 dBm by the IF level control. The IF level control assembly also provides outputs proportional to the leveled IF signals to the computer and the synchronous detector.

The corrector assembly provides an output nearly proportional to geometric mean of the correlated power in each pair of IF signals. With the input level at +5 dBm and with the ratio of correlated to uncorrelated noise power equal to one; the peak output from the correlator will be approximately ± 9 V. The correlator DC gain can be set at 25, 125, or 1250, providing approximately ± 9 V peak outputs for ratios of correlated to uncorrelated noise power of 1, .1, and .01. The IF level control reduces the stronger correlated signals so the peak output voltage is not directly proportional to the correlated noise power but is given by the following equation:

(1) $$V_{\text{peak corr. out}} = 2\,G_c K_D \frac{P_c}{P_n + P_c}$$

where G_c = DC gain of correlator = 25, 125, or 1250.

K_D = Correlator detector constant = .35 at +2 dBm level.

P_c = Correlated noise power.

P_n = Uncorrelated noise power.

Equation (1) applies only when the ratio of correlated noise power to uncorrelated noise power is identical in both antenna systems.

1.2 Noise Modulation and Switched Receiver Systems

The synchronous detectors and the frontend switch control system are used with a noise tube and several switches in the interferometer receiver frontend to provide:

1) A switched receiver system for use in obtaining antenna pointing correction data, or
2) A noise modulation system to detect system gain and noise temperature changes.

The switched receiver system utilizes the switchable circulator ahead of the first paramp in the frontend as an RF switch. The switching rate is 40 Hz and the synchronous detectors will be used to obtain an output independent of gain changes for position work.

The noise modulation system will inject a known amount of noise (5 °K) into the RF signal path in front of the first paramp at a 400 Hz rate. The synchronous detector will be balanced, using the post-detection gain modulator to give 0 V out with a 5 °K noise injection. Any change in system noise temperature will give an output as shown in equation (2).

$$(2) \qquad V_{SD} = \frac{9.7\,\Delta T}{82.5 + \Delta T} \text{ volts}$$

where ΔT is the change in noise temperature, the original system temperature was 80 °K, and the synchronous detector gain was set for 5 °K full scale.

In addition to controlling the frontend switches used in the switched receiver system and the noise tube modulation systems, the frontend switch control provides for either manual or computer control of the feed polarization switches. These switches and the dual polarization feed permit selecting either right or left polarization from each antenna.

1.3 Computer Control of Backend Functions

The 3-element interferometer receiver backend function can be operated manually or by the computer relay contact outputs. A bus system is utilized where either the computer relay bus or the manual bus is energized. Blocking diodes are used to isolate the computer and manual buses. The backend system utilizes eight separate computer or manual control buses. These buses are CH 1, CH 2, CH 3 receiver control CH 1 and 2 delay, CH 3 delay and CH 1 and 2, CH 2 and 3, CH 3 and 1 correlator control. Selection of manual or computer control is accomplished utilizing the switches on the power control panel in the backend.

The backend functions which are computer controlled are listed below under the control bus with which they are associated.

1.3.1 CH 1, CH 2, or CH 3 Receiver Control Bus Functions

CAL ON — This control switches out a 3 dB attenuator in the noise tube modulation signal path in the receiver frontend which increases the noise signal from 2.5 °K to 5 °K.

SWEEP ON — Operation of this control turns on the tunnel diode sweeper in the frontend box which injects a swept RF signal into the first paramp. In addition, the SWEEP ON control locks the noise tube modulation switches in the noise position, turns off the noise tube, and switches a 20 dB pad into the IF signal path to prevent amplifier saturation. This sweep system allows the bandpass of the entire system to be checked.

FEED POLARIZATION SWITCH RIGHT POSITION — This control function switches the right polarized feed signal into the RF amplifier. When this control function is off the left polarized feed signal is fed into the RF amplifier. A contact closure is fed into the computer from the antenna when the feed polarization switch is in the right position.

ALC OFF/ALC ON — This function switches the IF level control system off and on. Normal operation of the interferometer system will be with the IF level control system ON.

1 DB PAD OUT/IN -- This control function switches a 1 dB attenuator out or in ahead of the IF monitor detector. This attenuator and switch is used as a calibration of the IF monitor detector which monitors the IF signal level prior to the delay and level control systems.

1.3.2 CH 1 and 2 Delay Control Bus Functions

DELAY IN CHAN 2/DELAY IN CHAN 1 — This function selects the channel that the delays may be switched into.

DELAY NO. 12 IN/DELAY NO. 12 OUT — This control switches the delays into or out of the channel which the delay system is in. Delay No. 12 increases the time delay of the selected channel by 4,500 nanoseconds.

Delay No. 11 IN	—	Adds	2,250 nanoseconds
Delay No. 10 IN	—	Adds	1,125 nanoseconds
Delay No. 9 IN	—	Adds	562.5 nanoseconds
Delay No. 8 IN	—	Adds	281.3 nanoseconds
Delay No. 7 IN	—	Adds	140.6 nanoseconds
Delay No. 6 IN	—	Adds	70.3 nanoseconds
Delay No. 5 IN	—	Adds	35.2 nanoseconds
Delay No. 4 IN	—	Adds	17.6 nanoseconds
Delay No. 3 IN	—	Adds	8.8 nanoseconds
Delay No. 2 IN	—	Adds	4.4 nanoseconds
Delay No. 1 IN	—	Adds	2.2 nanoseconds

1.3.3 CH 3 Delay Control Bus Functions

This group of functions under this control bus are identical to those given for the CH 1 and 2 delay control bus functions with the one exception that the delays are always in CH 3.

1.3.4. CH 1 and 2, CH 2 and 3, CH 1 and 3, Correlator Control Buses

The functions under these control buses are CORR GAIN 1250, CORR GAIN 125, and CORR GAIN 25. These functions control the DC gain of the correlator. CORR GAIN 1250 provides a fullscale output for source temperatures of 1 °K, CORR GAIN 125 provides fullscale output for source temperature of 10 °K, and CORR GAIN 25 provides fullscale output for source temperatures of 100 °K.

1.4. Backend Analog Outputs to the Computer

The 3-element interferometer receiver backend provides 12 analog outputs to the computer. These analog outputs are routed through the backend monitor unit and the analog input buffer unit. The backend monitor unit provides a patch panel, 8 recorder channels, a two-channel oscilloscope, and 3 audio amplifiers with which any of the analog signals may be displayed and monitored. The analog input buffer unit provides a high impedance differential input amplifier for each of the analog inputs. The outputs from these amplifiers are connected to the computer analog-to-digital converter.

1.4.1. The CH 1, CH2, and CH 3 IF Monitor Detector Outputs

The CH 1, CH 2, and CH 3 IF monitor detector outputs are entered into the computer on A-D converter channels 6, 7, and 8. The following table lists the computer readout for various input signal levels to the backend. These readouts were utilizing Dr. Clark's ADCT computer program where 1.0 corresponds to a 10 V full-scale A-D converter reading. The IF signals were simulated by using cascaded IF amplifiers providing 70 to 80 dB of gain.

1.4.2. The CH 1, CH 2, and CH 3 ALC Detector Outputs

The CH 1, CH 2, and CH 3 ALC detector outputs are fed into the computer on A-D converter channels 25, 26, and 27. Table 2 lists the computer readouts over a range of input levels with ALC OFF.

TABLE 1

COMPUTER READOUT OF IF MONITOR DETECTOR OUTPUTS

Detector Input Level	CH 1 IF Det. Out. A-D Conv. CH 6 Computer Readout	CH 2 IF Det. Out. A-D Conv. CH 7 Computer Readout	CH 3 IF Det. Out. A-D Conv. CH 8 Computer Readout
+8 dBm	-.673	-.654	-.659
+7 dBm	-.587	-.571	-.575
+6 dBm	-.504	-.491	-.495
+5 dBm	-.428	-.417	-.419
+4 dBm	-.359	-.348	-.352
+3 dBm	-.295	-.286	-.292
+2 dBm	-.239	-.233	-.237
+1 dBm	-.192	-.185	-.188
0 dBm	-.149	-.145	-.147
-1 dBm	-.114	-.110	-.114
-2 dBm	-.082	-.081	-.084
-3 dBm	-.057	-.057	-.059
-4 dBm	-.038	-.037	-.039

TABLE 2

COMPUTER READOUT OF ALC DETECTOR OUTPUTS WITH ALC OFF

Detector Input Level	CH 1 ALC Detector Output A-D Conv. CH 25	CH 2 ALC Detector Output A-D Conv. CH 26	CH 3 ALC Detector Output A-D Conv. CH 27
+6 dBm	-.329	-.339	-.358
+5 dBm	-.211	-.219	-.229
+4 dBm	-.099	-.108	-.116
+3 dBm	-.005	-.004	-.009
+2 dBm	+.051	+.072	+.072
+1 dBm	+.133	+.130	+.144
+0 dBm	+.180	+.210	+.210
-1 dBm	+.229	+.259	+.259
-2 dBm	+.272	+.292	+.304
-3 dBm	+.310	+.327	+.337
-4 dBm	+.341	+.359	+.366

1.4.3. The CH 1, CH 2, and CH 3 Sync Detector Outputs

The CH 1, CH 2, and CH 3 sync detector outputs enter the computer on A-D converter channels 10, 11, and 12. No test data is available at the present time but the computer readouts can be computed utilizing equation (2). The polarity of the voltage is reversed in the analog buffer unit.

TABLE 3

CALCULATED COMPUTER READOUT OF SYNC DETECTOR OUTPUTS

System Temperature	Calculated Computer Readout of Sync Detector Outputs
80 °K	- 0
90 °K	-.104
100 °K	-.188
110 °K	-.256
120 °K	-.313
130 °K	-.360
140 °K	-.402
150 °K	-.437
160 °K	-.470

These values were calculated assuming the noise injected is 50 °K, the sync detector was balanced with a system temperature of 80 °K, the synchronous detector gain is set for 5 °K fullscale and the ALC system is ON.

1.4.4. The CH 1 and CH 2, CH 2 and CH 3, and CH 3 and CH 1 Correlator Outputs

The CH 1 and CH 2, CH 2 and CH 3, and CH 3 and CH 1 correlator outputs are entered into the computer on A-D converter channels 0, 1, and 2. Table 4 gives the computer outputs for various ratios of correlated to uncorrelated noise. At 0 dB the ratio of correlated to uncorrelated noise in each channel is 1 and at -3 dB the ratio is .5.

TABLE 4

COMPUTER READOUT OF CORRELATOR OUTPUTS

Ratio Correlated to Uncorrelated Noise in dB	Computer CH 0 CH 1 and 2 Correlator Readout DC Gain - 25	Computer CH 1 CH 2 and 3 Correlator Readout DC Gain 25	Computer CH 2 CH 3 and 1 Correlator Readout DC Gain 25
0 ± .05 dB	-.858 ± .002	-.887 ± .002	-.903 ± .002
-1 "	-.760	-.794	-.799
-2 "	-.672	-.692	-.700
-3 "	-.603	-.614	-.602
-4 "	-.514	-.516	-.519
-5 "	-.441	-.446	-.463
-6 "	-.373	-.366	-.377
-7 "	-.327	-.321	-.447
-8 "	-.259	-.260	-.252
-9 "	-.209	-.205	-.205
-10 "	-.166	-.169	-.165
DC Gain = 125			
-10 "	-.77 ± .01	-.79	-.80
-11 "	-.64	-.64	-.65
-12 "	-.51	-.52	-.53
-13 "	-.43	-.42	-.44
-14 "	-.35	-.34	-.37
-15 "	-.28	-.28	-.29
-16 "	-.22	-.23	-.24
-17 "	-.19	-.19	-.19
-18 "	-.13	-.13	-.14
-19 "	-.11	-.11	-.11
-20 "	-.09	-.09	-.09
DC Gain = 1250			
-20 "	-.83 ± 0.1	-.75	-.88
-21 "	-.65	-.73	-.71
-22 "	-.53	-.61	-.58
-23 "	-.43	-.46	-.50
-24 "	-.36	-.38	-.39
-25 "	-.30	-.34	-.29
-26 "	-.25	-.28	-.27
-27 "	-.23	-.22	-.23
-28 "	-.15	-.20	-.16
-29 "	-.11	-.16	-.11
-30 "	-.07	-.11	-.09

The time constants of the correlator systems have been measured at the output of the analog buffer. These values are:

CH 1 and 2	Correlator System Time Constant	30 millisec.
CH 2 and 3	Correlator System Time Constant	32 millisec.
CH 3 and 1	Correlator System Time Constant	32 millisec.

The values listed in Table 4 were taken with an analog buffer time constant of 1 second.

2.0. Operating Procedure

2.1. Modes of Operations

The 3-element interfereometer receiver backend is required to operate in two modes. In the primary mode the system will be used as an interferometer with the correlator outputs of primary interest. The second mode of operation will be operation as a switched receiver with the synchronous detector outputs conveying the desired information.

2.2. Application of Power

The backend requires 120 V AC and 24 V DC power. This power is applied by actuating the 120 V AC and 24 V DC switches on the POWER CONTROL panel.

2.3. Interferometer Mode

During operation in the interferometer mode the computer will control the backend functions. To place all of the backend systems under computer control the eight COMPUTER/MANUAL switches on the POWER CONTROL panel are placed in the COMPUTER position. Operation with only two antennas in the interferometer mode requires that the COMPUTER/MANUAL switches associated with these two antennas be placed in the computer position.

2.3.1. Interferometer Mode Adjustments

Initially and after system component changes, the following adjustments may be required:

1. Adjust IF signal level into the backend to produce a reading of 15-20 microamps on the CH 1, 2, and 3 LEVEL meters located on the IF MONITOR panel. Adjustment is made using the ATTENUATOR control on this panel.

2. Balance out the correlator offset by adjusting the control below the CH 1 and 2, CH 2 and 3, and CH 3 and 1 CORR OUT meters to give a meter reading of 0 ± 5 microamps with the DC GAIN set at 1250. This adjustment is made with the antennas off source so no correlated noise is present.

3. Adjust the synchronous detectors gains to give 5 °K fullscale deflection. These adjustments must be made with the antennas off source and with ALC ON. Initial switch settings are listed below.

a. Switch the GAIN MODULATOR RANGE OFF.

b. Set FUNCTION switch to SYNC DET > 10 Ω since switching rate is 400 Hz.

c. Set FULL SCALE TEMPERATURE to 10.

d. Set METER MONITOR to ANALOG.

e. Set ANALOG OUTPUT SCALE EXPAND X 1.

f. Set TIME CONSTANT to 10 sec.

g. Switch OFFSET RANGE to OFF.

h. Now on the FRONT END SWITCH CONTROL panel depress the SWITCHED MODE and LOAD POSITION RELEASE switch for all three channels. Verify that the CH 1, CH 2, and CH 3 NOISE MOD./SWITCHED MODE switch indicator is in the NOISE MOD. position. This means the noise tube modulation switches in the front end are being driven at a 400 Hz rate.

i. On the IF MONITOR panel switch the CH 1, CH 2, and CH 3 CAL switch-indicators ON. This control switches the noise level injected to 5 °K when it is ON.

j. Adjust the INPUT LEVEL controls on all three synchronous detectors to give a fullscale meter reading of +100 microamps. This sets the gain of the synchronous detector to the required level to produce a fullscale output for a 5 °K signal.

k. Switch the GAIN MODULATOR RANGE to the .7 to 1.2 position and adjust gain modulator ratio to balance out the 5 °K signal and produce a 0 reading on the meter. This completes the adjustment of the synchronous detector system.

2.3.2. Interferometer Mode Operational Checks

During operation in the interferometer mode the backend is controlled by the computer. Sufficient data is also available to the computer to determine if a malfunction has occurred providing the computer is programmed to analyze these inputs. As a backup to this computer analysis of malfunctions critical functions are displayed on the backend. The normal meter readings are listed below. Anything outside of these ranges indicates a malfunction or improper computer control and corrective action is required.

Meter Readings

IF MONITOR panel CH 1, CH 2 and CH 3 LEVEL meters. — Any reading within the range of 2.5 to 47.5 microamps indicating input IF levels of -31 dBm to -19 dBm is acceptable to the backend. Readings outside this range require corrective action such ad adjusting the ATTENUATOR control on the IF MONITOR panel to bring the reading within range.

IF LEVEL CONTROL CH 1, CH 2, and CH 3 METERS. — With the METER FUNCTION switch in the IF LEVEL position and with ALC ON, these meter readings should be 27.5 ± .5 microamps at all times. With the IF MONITOR meters reading within the correct range, any deviation from this reading indicates the automatic level control system is not functioning properly or a malfunction has occurred in the delay systems.

Meter Readings

CH 1 and 2, CH 2 and 3, CH 3 and 1 CORR OUT meters. — These meters should have a maximum swing of ± 50 microamps at all times. If the meters indicate levels above the ± 50 microamp values (off scale) either the computer selected correlator gain is wrong for the source being observed, the correlator offset controls have been improperly set, or a malfunction has occurred in the correlator system. In all three cases corrective action is required, as readings of ± 50 microamps correspond to ± 10 V into the computer's A-D converter which is the maximum limit of signal levels that can be read.

SYNCHRONOUS DETECTOR METER READINGS with the synchronous detector and frontend switch controls set as detailed in paragraph 2.3.1.3 — the synchronous detector meter should always read between 0 and + 100 microamps. These meter readings provide an indication of the change in system noise temperature where the more positive readings mean higher temperatures.

Switch Positions

In the interferometer mode of operation the computer will be controlling switch positions. The following switch positions are mandatory for normal operation.

IF MONITOR panel — CH 1, CH 2 and CH 3 SWEEP control switches must be off.

IF LEVEL CONTROL panel — CH 1, CH 2 and CH 3 ALC switches must be ON.

FRONT END SWITCH CONTROL panel — CH 1, CH 2 and CH 3 SIGNAL POSITION/LOAD POSITION switches must be in the SIGNAL POSITION. CH 1, CH 2 and CH 3 NOISE MODULATION/SWITCHED MODE switch must be in the NOISE MODULATION position. CH 1, CH 2 and CH 3 NOISE POSITION/LOAD POSITION switches — Both positions of these switches must be lighted indicating that the noise modulation switches are being driven at the 400 Hz rate switching between the NOISE and LOAD positions. If any of these switches are locked in the LOAD POSITION, they may be released by depressing the SWITCHED MODE and LOAD POSITION RELEASE switch associated with that channel.

2.4. Switched Receiver Mode

Any one or all of the three channels of the system may be operated in a switched receiver mode. The switched receiver mode will be used to provide a gain stable receiver for position observations to develop antenna pointing correction curves.

2.4.1. Switched Receiver Mode Adjustments

The following adjustments and switch settings are required for the particular channel which is being used in the switched mode.

1. POWER CONTROL panel switched receiver mode adjustments — The RECEIVER CONTROL switch for the channel used in the switched mode must be in the MANUAL position. When this switch is in the COMPUTER position the NOISE MOD/SWITCHED MODE SWITCH will not lock in the switched mode position.

2. IF LEVEL MONITOR panel switched receiver mode adjustments -- Adjust the IF signal level into the backend to produce a reading of 15-20 microamps on the LEVEL meters on the IF MONITOR panel. Adjustment should be made with the ATTENUATOR control on this panel when the antenna is off of the source.

   The CAL and SWEEP switches should be OFF during operation as a switched receiver.

3. IF LEVEL CONTROL panel switched receiver mode adjustments —
   The ALC ON/OFF switch should be in the ON position.
   The IF LEVEL CONTROL adjustment should be used to set the METER to 27.5 ± .5 microamps with METER FUNCTION switch in the IF LEVEL position.
   FRONT END SWITCH CONTROL switched receiver mode switch positions — Depress the SWITCHED MODE and LOAD POSITION RELEASE switch to unlock the RF SWITCH from the LOAD position. Then place the NOISE MOD/SWITCHED MODE switch in the switched mode position.

4. SYNCHRONOUS DETECTOR switched receiver mode adjustments — In the switched receiver mode of operation the synchronous detector output contains the desired information. The RF switch in the receiver frontend is switched by a 40 Hz square wave between the LOAD POSITION (a load at 300 °K) and the SIGNAL POSITION (feed). The gain modulator in the synchronous detector will be used to balance out the difference between the signal from the 300 °K load and the signal from the feed with the antenna off of the source. The GAIN MODULATOR switch should be at the 0-2.0 position and the GAIN RATIO control adjusted to zero the ANALOG function on the meter.

Then the output from the synchronous detector should change only if the signal from the feed changes. The full scale temperature switch position on the synchronous detector is determined by the temperature of the source being scanned. Because of the adjustments made to input level controls in paragraph 2.3.1., the markings on the switch position should be divided by two to obtain actual full scale source temperatures. The time constant switch setting is determined by the rate of scanning the source and should probably be 1 second or 3 seconds.

A summary of the synchronous detector switch positions for the switched mode of operation is given below.

Switch	Position
GAIN MODULATOR RANGE	0-2.0
FUNCTION switch	SYNC DET > 10 Ω
FULL SCALE TEMPERATURE	As required.
METER MONITOR	ANALOG OUT
ANALOG OUTPUT SCALE EXPAND	X 1
TIME CONSTANT	1 SEC
OFFSET RANGE	OFF

The synchronous detector outputs are available to the computer through the A-D converter channels 10, 11, and 12. These outputs may also be displayed on a recorder in the backend monitor unit.