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TECHNICAL REPORT

A FULL-AUTOMATIC SYSTEM FOR THE OBSERVATIONS OF INTERPLANETARY SCINTILLATION

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1. Introduction

The observations of interplanetary scintillation (IPS) of radio sources at 69 MHz have been continued at three separate stations (Toyokawa, Fujigane and Sugadaira) since 1971. Observations were limited within about ten minutes near the culmination of each radio source, and therefore it was very difficult to observe transient phenomena such as interplanetary shock waves. Antenna multi-beams which are produced by a phasing matrix in declination have recently become steerable in the east-west direction, and we can observe each radio source for about ninety minutes. Antenna beams, receiver gain and data acquisition are controlled full-automatically. As it is financially and geographically impossible to use exclusive telephone lines or radio links for the system control and the data transmission in a real time, the observations and data recording are controlled independently at each station. In the IPS observations time coincidence among separate stations must be accurate within a few milli-seconds. This time coincidence is also assured automatically.

This report gives technical descriptions about the IPS observation system.

2. Overall view of IPS observation system

Geometrical arrangement of the three stations is shown in Figure 1. A block diagram of the observation system is shown in Figure 2. Observations at every station are controlled by a program-timer, and the time coincidence among the stations is assured by the time standard clock which is synchronized with radio time signal. Data acquisition is controlled by a minicomputer. Data stored on a digital tape at each station are transmitted to a host computer at Toyokawa via public telephone lines. In the following sections detailed description of each block are given.

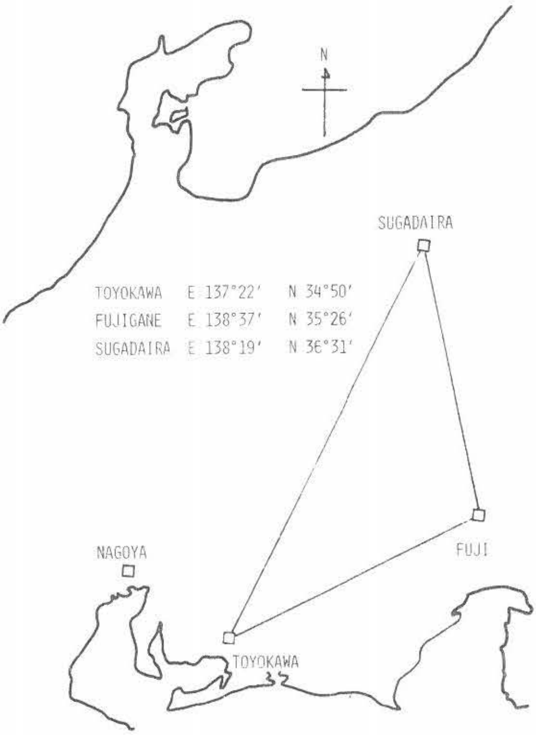

Figure 1. Geometrical arrangement of three stations.

3. Antenna

The antenna is a two-dimensional array of half wave dipoles placed a quater wave-length over a reflecting plane. The antenna at Toyokawa consists of 16 x 32 dipole elements, and those at Fujigane and Sugadaira have 16 x 16 elements. The spacing between dipole elements is 0.6 wave-length. The dipole element has an impedance of 100 ohms.

Sixteen multi-beams are formed in the north-south direction with a Butler matrix (Figure 3). Beam separation in the north-south direction is equal to the half power beam width of about 6 degrees. This gap of the multi-beams is covered with a NS-3° phase shifter which can change the direction of beams by 3 degrees in the north-south direction.

In the east-west direction, the antenna beam can be pointed at

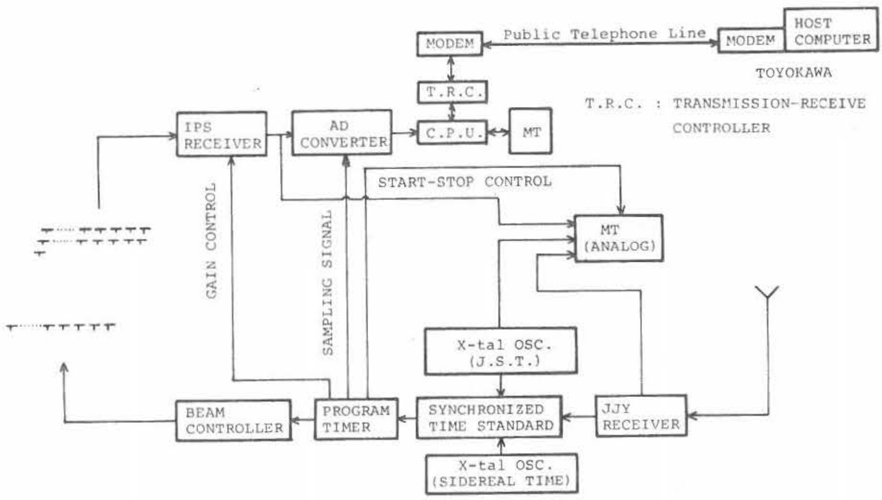

Figure 2. IPS observation system

three directions with EW-15° phase shifter: the meridian direction and the directions tilted by -15° and +15° from the meridian plane. In each of the three direction the beam is finely tilted in 2.5° step with EW-2.5° phase shifters.

3.1. Feed system

The feed system in the case of 256 dipole elements is shown in Figure 3. The antenna array is divided into two parts in the east-west direction. The feed system of each part is a branch feed system (a Christmas-tree feed system). The parallel lines with 200 ohms impedance are used as transmission lines from dipole elements to the junction of eight elements. The antenna impedance of 100 ohms is matched to that of the parallel line with a matching stub, and every dipole is followed by an EW-15° phase shifter. The impedance matching at every T-junction is made with a stub. Eight dipoles in the east-west direction are collected and then the parallel transmission lines are changed to 8D2V coaxial cable (50 ohms) with an U-balun. Sixteen coaxial cables are connected to the Butler matrix through the NS-3° phase shifter. One of the sixteen outputs of the matrix is selected and amplified. Signals from the east and west parts of the antenna

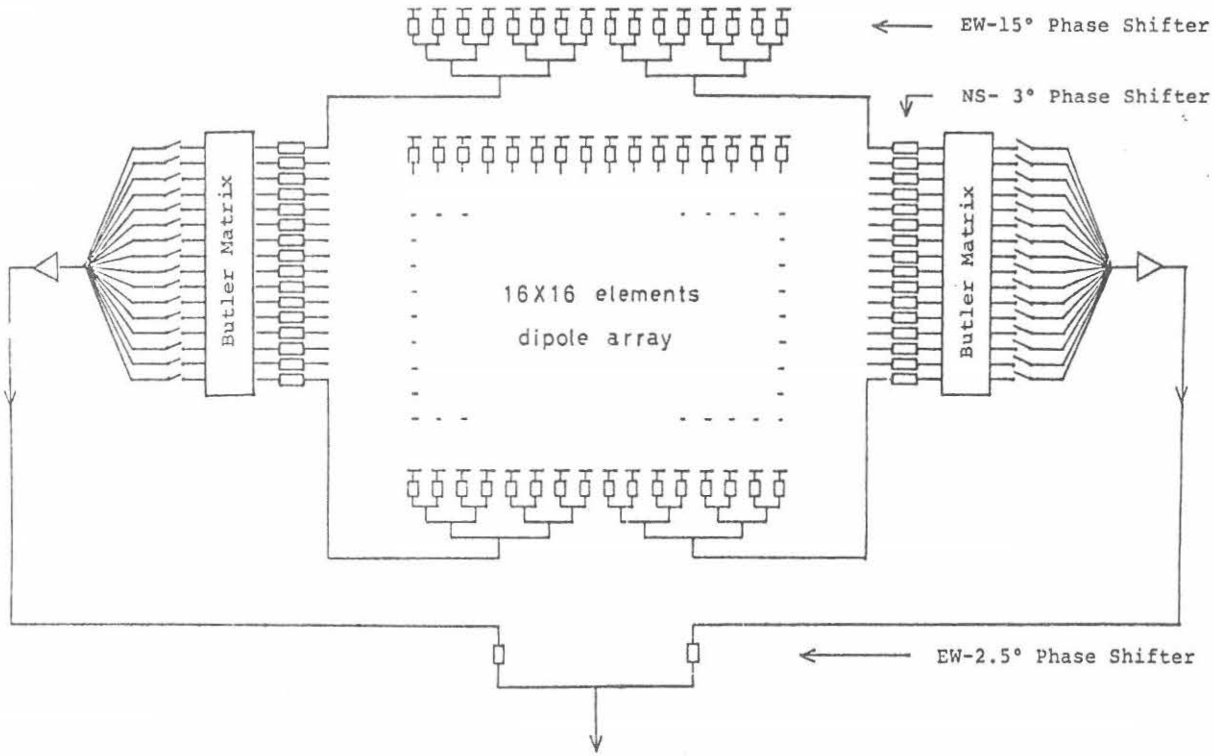

Figure 3. Antenna system.

are added through the EW-2.5° phase shifters. As the 2.5° phase shifters are used to change the antenna beam direction in a small angle, they are put at the points where the signals from eight dipoles are combined.

3.2. EW-15° phase shifter (Parallel line type)

The phase of signal is shifted by changing length of the parallel transmission lines with reed-relay switches as shown in Figure 4. The relays are tiny ones with twin contacts. A pair of phase shifters is put in one plastic case. A short-circuited stub at an input compensates the reactance which is caused by two relays without working which are equivalent to two open-circuited brance lines. The same kind of reactance at an output is also compensated at the following matching section. The average loss of the phase shifters is 0.48 db and the rms phase error is less than 5.5 degrees.

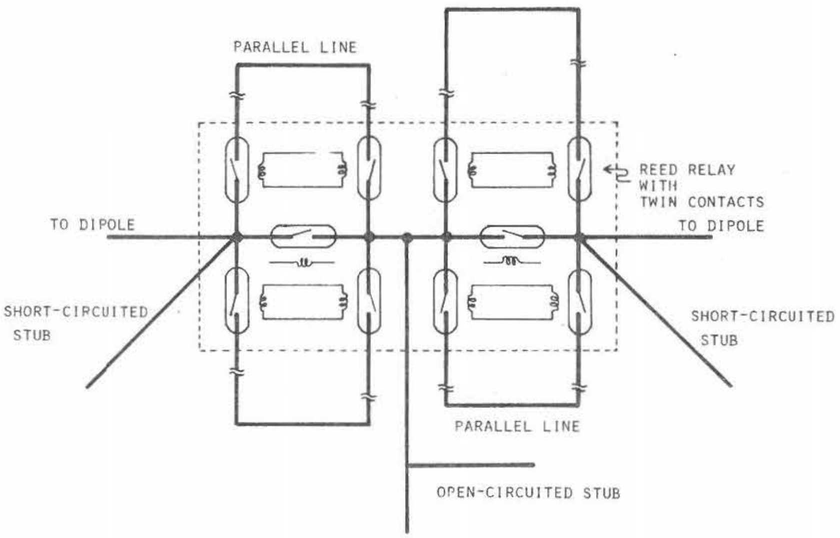

Figure 4. EW-15° phase shifter (parallel line type).

3.3. EW-15° and EW-2.5° phase shifter (Coaxial cable type)

The phase shifter of the coaxial type is shown in Figure 5. Switches driven by solenoids change the cable length to shift the phase. Four phase shifters (two EW-15° phase shifters and two EW-2.5°

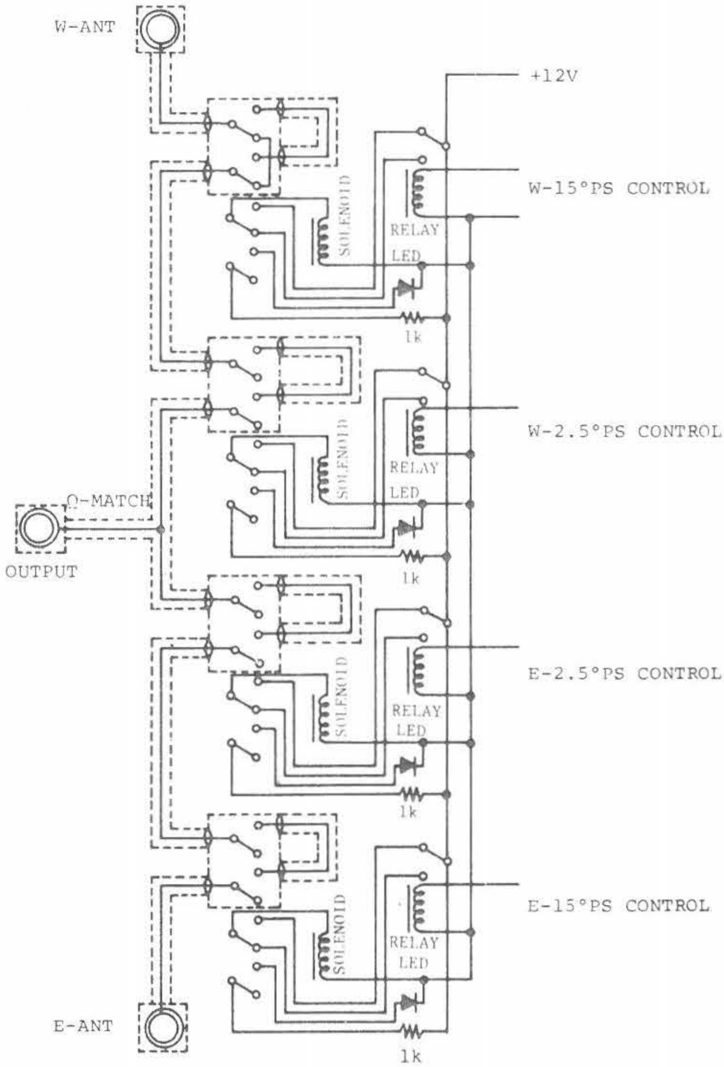

Figure 5. EW-15° and EW-2.5° phase shifter (coaxial cable type).

phase shifters), a T-junction for signals from the east and west parts of the antenna and Q-match circuit are mounted in one case. The insertion loss of this circuit is less than 0.3 db and the VSWR is less than 1.2. The phase error is less than 1 degree.

3.4. Butler Matrix

The Butler matrix of Figure 6 has sixteen inputs and outputs. This matrix consists of 32 rat-race circuits and 48 phase-cables The rat-race is indicated by a simbol ⊗, and the numbers noted on the phase-cables show the cable length in unit of $\lambda/16$. When the phase gradient of input signals from No.1 to No.16 is $\pm n\lambda/16$, the signals appears at the output numbered $\pm n$. We measured signal levels and phases at the inputs from No.1 to No.16 with a signal generator connected to the output terminal of No.0. And we obtained the average distribution loss of 12.33 db and the average phase error of

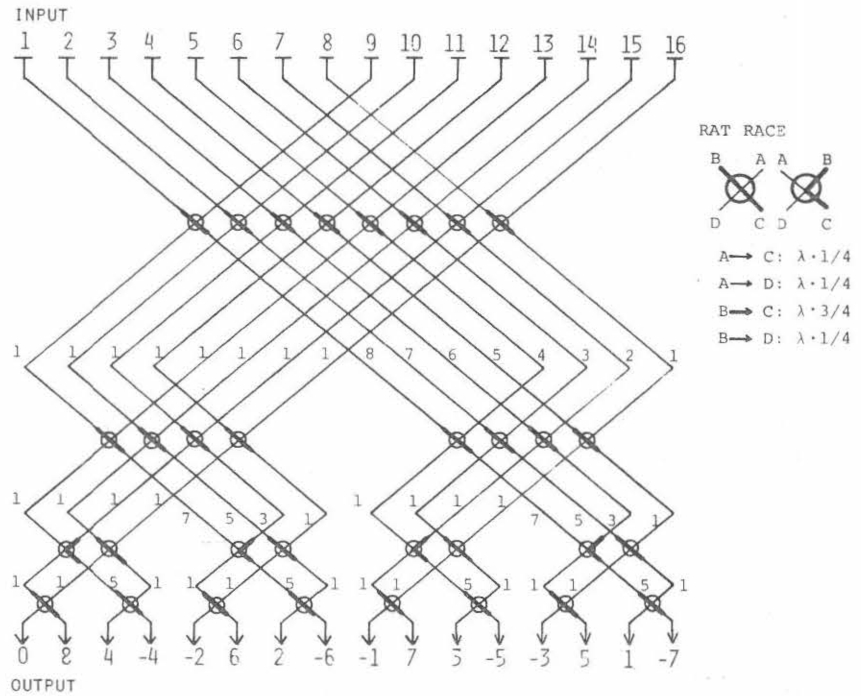

Figure 6. Butler matrix.

1.34 degrees. If we take into consideration that the pure distribution loss due to four cascaded rat-races which are ideally lossless is 12.04 db, the loss of the matrix is estimated to be 0.29 db.

4. Receiver

The block diagram of the receiver system is shown in Figure 7. The Dicke receiver is used and the Dicke switch is placed before the preamplifier. This Dicke receiver can be easily switched to the phase-switched interferometer. A terminal resistance of 50 ohms at a room temperature is used as the reference of the Dicke switch. The switching frequency is 200 Hz. A phase-locked-loop (PLL) frequency synthesizer is used as a local oscillator, whose frequency can be quickly changed when interferences affect observations. The RF frequency of the receiver was 69.3 MHz when we began the IPS observations, but, recently, we have been forced to shift the frequency down to 68.8 MHz due to interferences. A low pass filter (f_c = 10 Hz) is used to restrict aliasing in A/D conversion. As the Dicke receiver cannot eliminate large DC bias due to the extended galactic background radiation, this DC component is eliminated with a high pass filter (f_c = 0.1 Hz). The output of the high pass filter is digitized and recorded on a digital magnetic tape. On the other hand, the same output is frequency-modulated for an analog recorder.

4.1. Gain levels through the receiving system

A system temperature is mainly determined by the strong background radiation. The transmission line loss from a dipole to an input of a preamplifier is estimated to be 3.8 db and the noise figure of the preamplifier is 2.3 db; thus, the noise temperature at the input of the preamplifier is estimated to be 1200°K including the background radiation of 2000°K. This noise temperature is equal to 1.7×10^{-14} watts (=108 dbm) for a band width of 1 MHz. The gain diagram is shown in Figure 8.

The signal level at the preamplifier of the radio source 3C144, which is one of the IPS sources with high mean intensity, is estimated to be 1×10^{-14} watts with the following parameters: flux density at 70 MHz is 1700×10^{-26} watts $m^{-2}Hz^{-1}$, antenna area is 2500 m^2 and the transmission line loss is 3.8 db. As the noise temperature is equal to

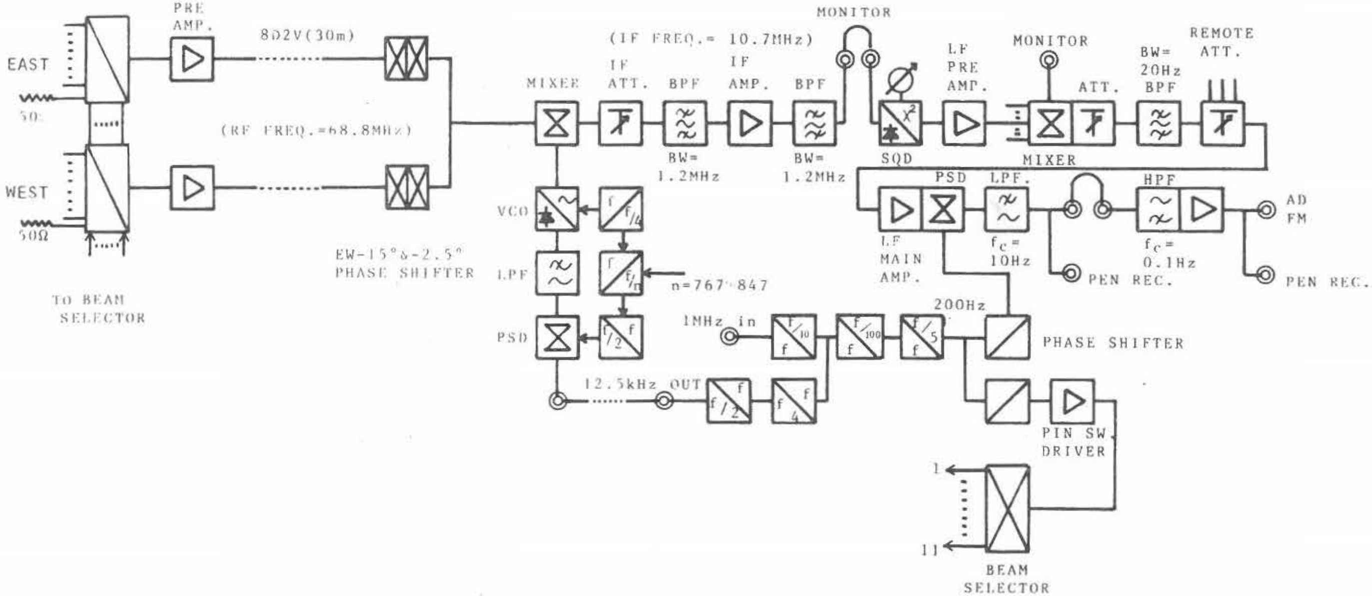

Figure 7. Block diagram of receiver system.

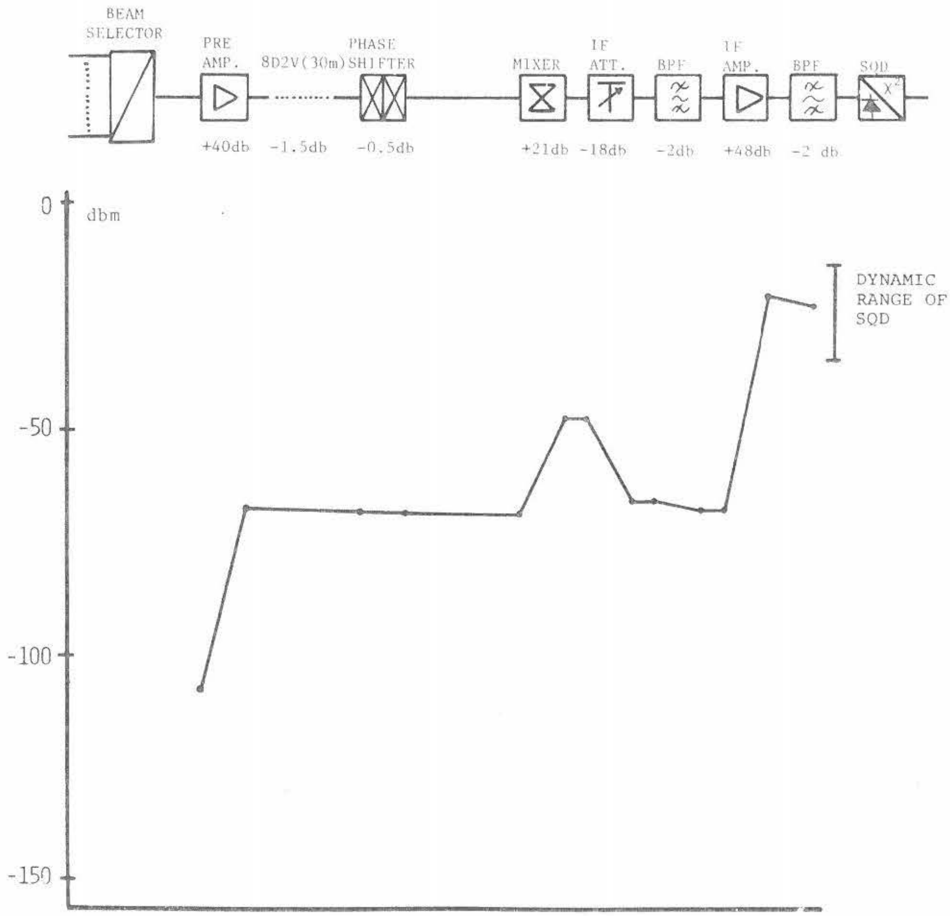

Figure 8. Gain diagram.

or higher than the input power of IPS radio sources, it is not necessary to adjust the system gain of the RF section according to the mean intensity of radio sources. But the attenuator at the low frequency section after the square low detector is controlled to the optimum level for recording according to the intensity of the scintillation.

4.2. Beam selector

The multi-beam selector consists of twelve PIN diode switches as shown in Figure 9. The eleven switches are connected to the Butler matrix and the other one is connected to the terminal resistance of 50 ohms which is used as a reference of Dicke system. By driving the latter switch and one of the former eleven switches alternately, this selector functions as the Dicke switch.

4.3. RF and IF amplifiers

Preamplifiers consists of 2-stage FET amplifiers which are a cascade amplifier and an output buffer (Figure 10). The band width is 3 MHz and the gain is 40 db. The noise figure is 2.3 db.

The IF amplifier is put between two band pass filters which are designed to reduce interferences. Each filter consists of 4-stage Butterworth filters coupled with capacitors. The center frequency is 10.7 MHz and the band width is 1.2 MHz.

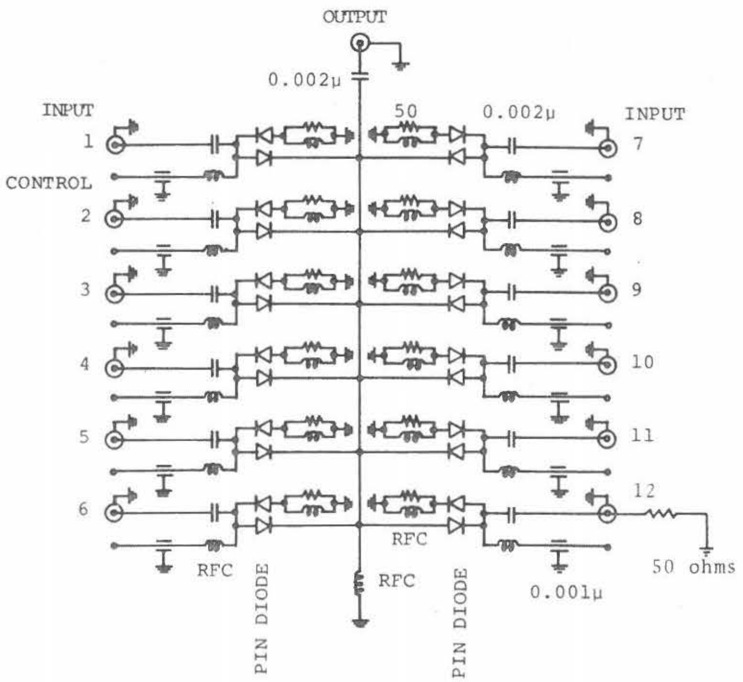

Figure 9. Beam selector.

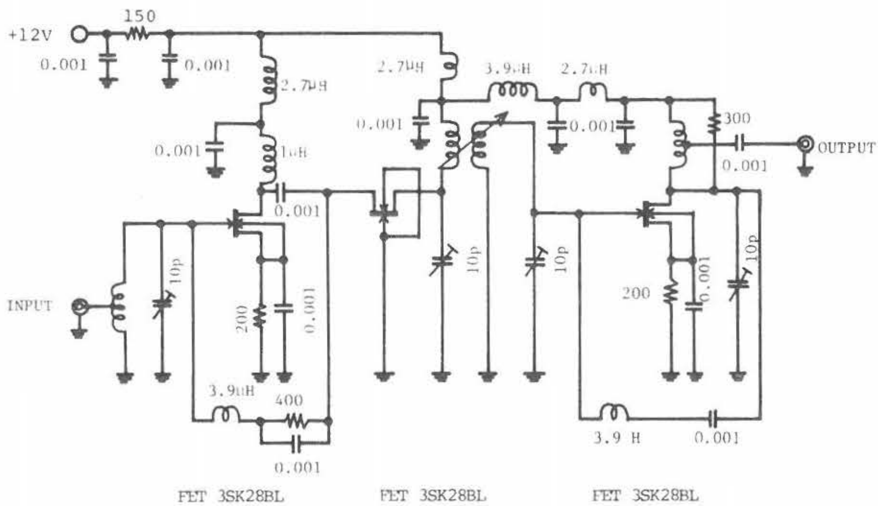

Figure 10. Preamplifier.

4.4. Mixer and square law detector

The double-balanced modulator MC1496G is used as a mixer or a square law detector. The mixer made of this modulator, shown in Figure 11, has a characteristic of high carrier suppression of 40 db. The gain of this mixer is 24 db and the band width is 2 MHz.

This modulator can be used as a square law detector by connecting signal to both signal and carrier input ports (Figure 12). The dynamic range is 20 db for the input signal level from -34 dbm to -14 dbm. Output voltage of 400 mV is obtained from the input level of -20 dbm.

4.5. RF-local oscillator

The local oscillator consists of the PLL frequency synthesizer as shown in Figure 13. The voltage controlled oscillator (VCO) circuit is Hartley type. The high speed scaling circuit is used as a programable counter. Frequency is variable from 76.7 to 84.7 MHz in 0.1 MHz step. A phase sensitive detector consists of a digital circuit. The phase difference between the VCO and the reference signal is converted into DC-voltage with a charge-pump circuit and an active low pass filter.

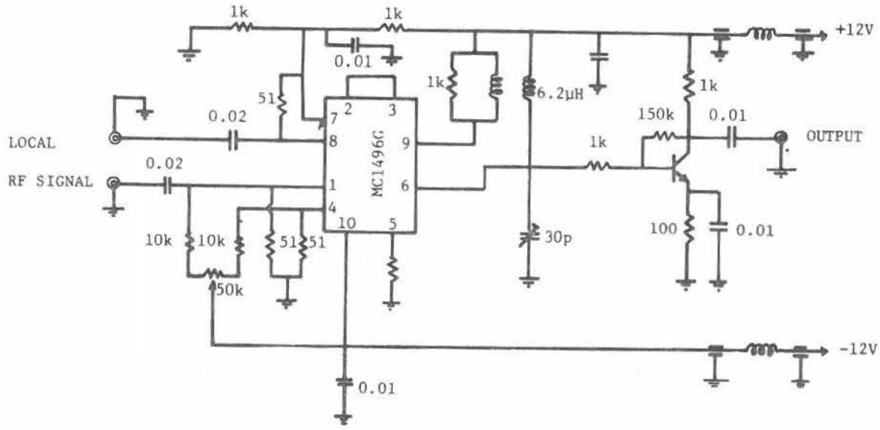

Figure 11. RF-mixer.

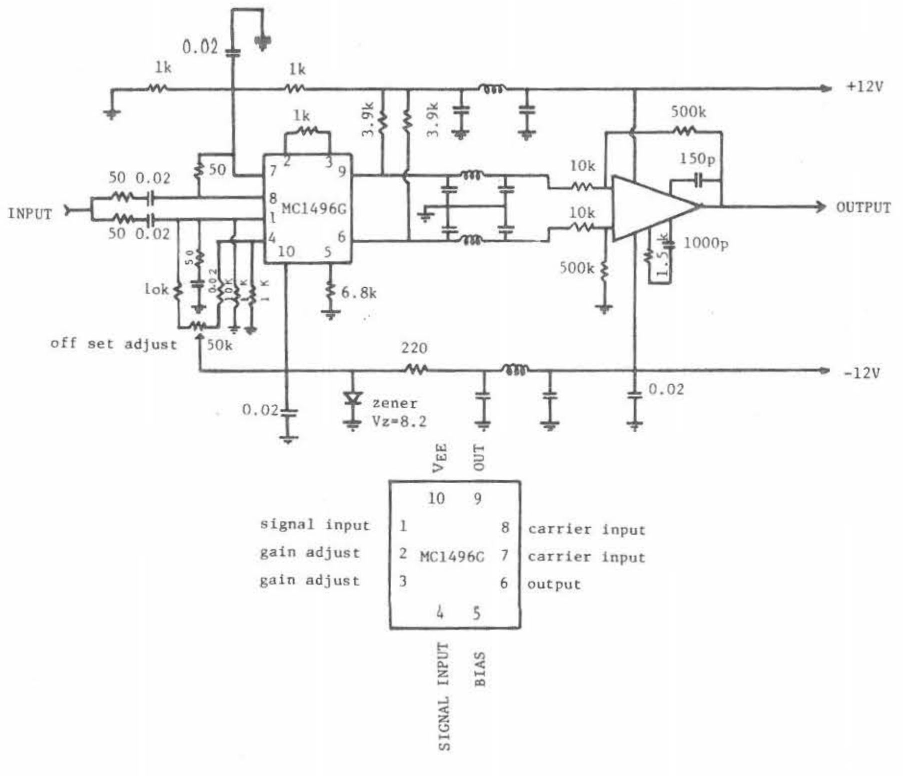

Figure 12. Square law detector.

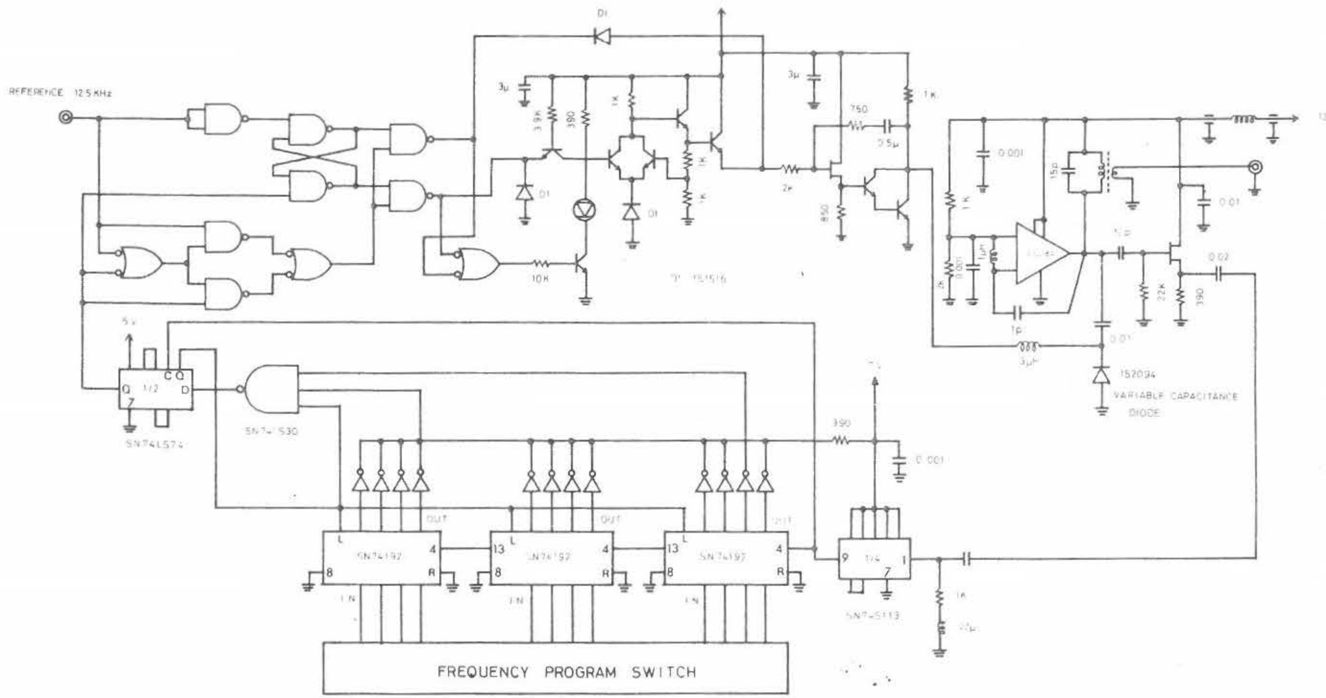

Figure 13. RF-local oscillator

A FET is used in the low pass filter to improve a carrier-to-noise ratio. This oscillator is carefully designed to depress the effects of noises from power lines. The second harmonic level is less than -16 db against the fundamental, and the output level is -5 dbm.

4.6. LF phase sensitive detector

A sample-and-hold circuit with a FET is used as a phase sensitive detector (Figure 14). To depress a ripple component of the output signal, MOS CA31030 is used as an output buffer amplifier. This sample-and-hold circuit reduces the ripple component to considerably low level without using a low pass filter which is apt to have effects on the phase and amplitude characteristics of the IPS signal.

In the IPS observations it is important to check the phase and amplitude characteristics of the receiver in a frequency range from DC to ∿10Hz. So it is very important to set the high pass filters (fc = 0.1 Hz) at three stations with identical characteristics. We measured these characteristics of the three receivers. The phase difference (converted to time lag) is as small as less than 3 msec at a frequency of 0.1 Hz; furthermore, effects on the phase and amplitude

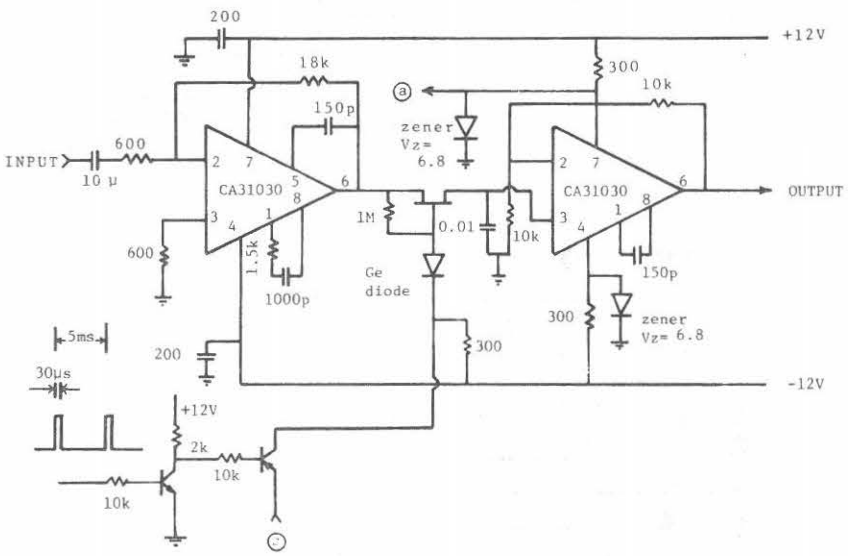

Figure 14. LF phase sensitive detector

by the high pass filters is corrected through the process of the computer analysis of the spectrum.

5. Controller

Observations and data recording are controlled independently at each station with the following equipments: (1) the time-standard which assures time coincidence among the distant stations, (2) the program-timer which memorizes the sequence of observations and controls the observation system according to the memory.

5.1. Time-standard

The time-standard system has two clocks: the Japan standard time (JST) clock made with a highly stabilized X-tal oscillator (5×10^{-8}/

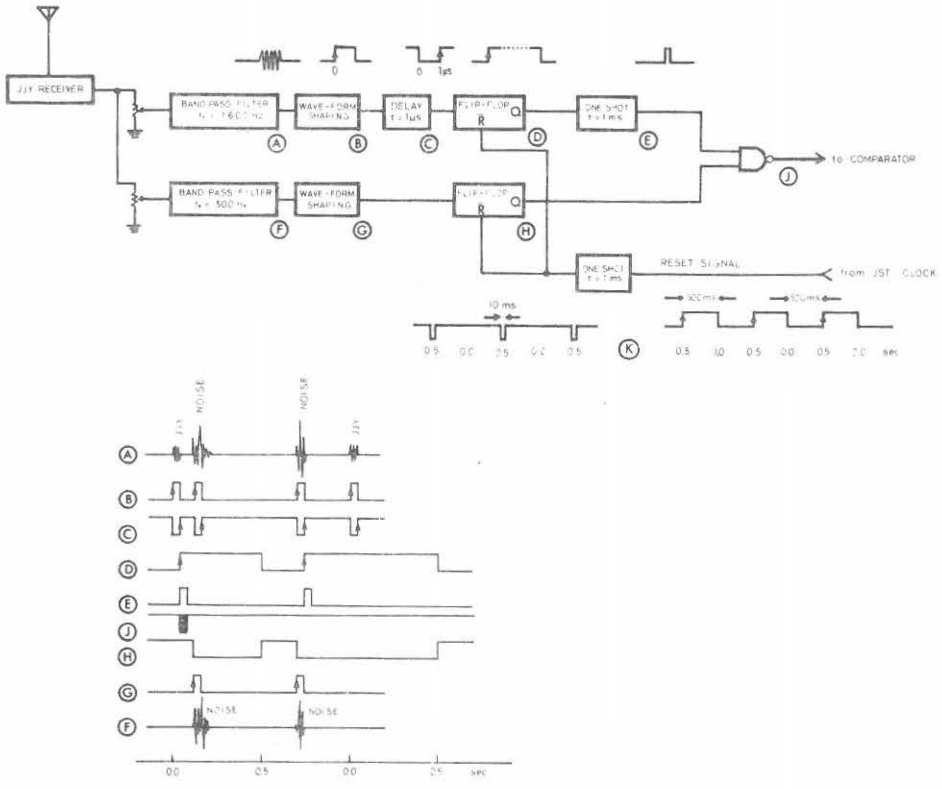

Figure 15a. Signal selector.

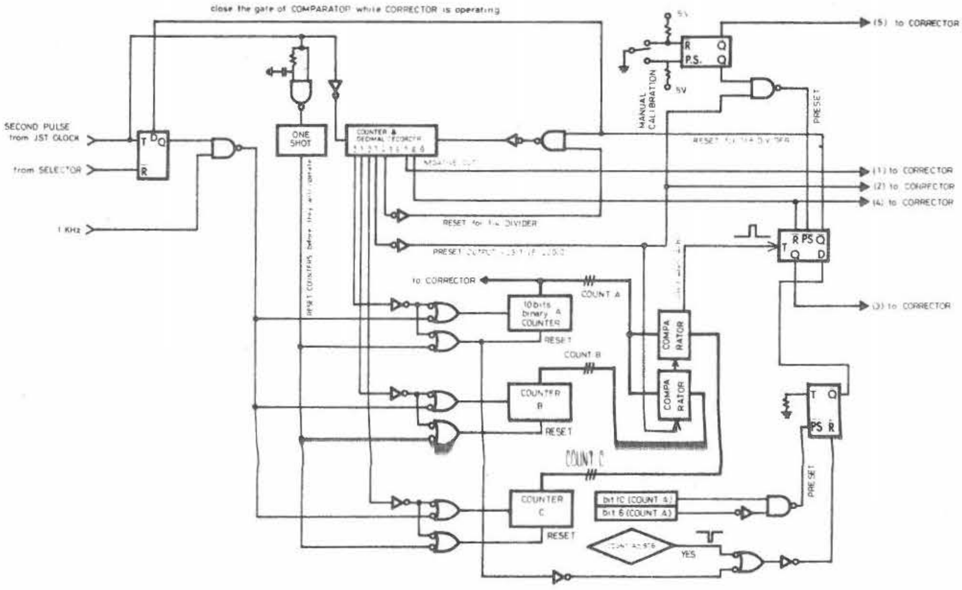

Figure 15b. Time-difference comparator

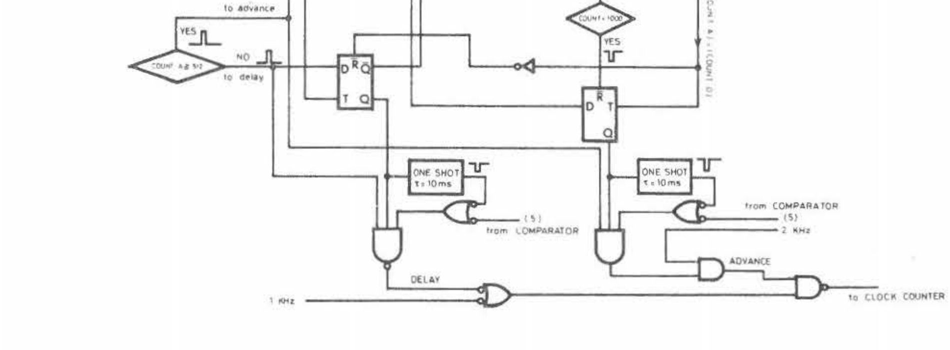

Figure 15c. Time-difference corrector

a day) and the sidereal time (S.T.) clock. The S.T. clock is used to decide a time to start or stop observations, and the start time of data sampling with an A/D converter is determined by the JST clock which is synchronized among three stations.

Time coincidence among the stations, which is most important for the measurements of the solar wind velocity, is obtained by synchronizing the clock with the JJY signal which is the radio service of the time standard in Japan. The key point of this system is how to discriminate between the JJY signals and the interference noises automatically.

The JST clock system is divided into four blocks which are a JJY signal selector, a time-difference comparator, a time-difference corrector and a clock counter.

(1) signal selector (Figure 15a)

The signal selector discriminates between the JJY signals and noises with filters. The time-difference comparator discriminates between these signals logically. Narrow band noises are rejected with a JJY band pass filter (f_0 = 1600 Hz). Wide band noises can be distinguished from the JJY signals because the wide band noises pass through both the JJY filter and the other filter (f_0 = 500 Hz) and are removed by taking coincidence between the outputs of the two filters. To assure the timing of coincidence, signals from the JJY filter are delayed by 1 μsec. The flip-flops have a function of gates to reduce noises which pass through the signal selector. Gates are closed by signals out of the filters and opened by the internal clock pulse whose timing is shown by ⓚ in Figure 15a. By limitting the duration when the gate is opened to pass the signal from the filter, the chance to detect noises is reduced.

(2) time-difference comparator (Figure 15b)

Noises which survive through the selector is removed by this comparator logically. Noises are classified into two groups: one is the noise with random time interval and the other is the noise like a pulse train with a short pulse intervals.

Time difference between the output pulse from the selector and the internal clock pulse is measured three times sequentially with the three counters (A, B and C). If the counter A does not agree with those of B and C, measurements are repeated until the three counts agree. Thus noises with random time intervals are removed; furthermore, when the time difference is more than 20 msec, measurements are done over again, because the drift of the internal clock made with the qualtz oscillator is less than 20 msec a day; therefore, a large time difference is considered to be caused by noises.

Noises like a pulse train are detected by the selector just after the gate is opened, and three counters give the same count. However, this count is as large as close to 500 msec, because the gate is opened by the pulse delayed by 500 msec against the second pulse of the internal clock. Because of the large count, this kind of noise can be removed.

(3) time-difference corrector (Figure 15c)

To delay the clock, the gate of 1 kHz signal from the X-tal oscillator to a clock counter is closed, and, to advance, the 1 kHz signal is replaced with the 2 kHz signal. For providing against measurement errors which will occur by any chance, correction for delay or advance is limitted within 10 msec at a time.

5.2. Program-timer

The program-timer has 4-kbits dynamic shift register driven with a control signal of 150 kHz (Figure 16a). One data consists of 40 bits as shown in Figure 16b. Data can be written in and read out of the register from the address set by the address switches. The sixteen bits from bit 0 to bit 15 show the sidereal time when an observation starts or stops. The other bits from bit 16 to bit 39 are the data to control the system. When this time-data coincide with the time of the S.T. clock, an observation starts and the controller (Figure 17) operates: a desired beam is selected, an analog tape-recorder and a pen recorder are switched on and the receiver gain is controlled according to the control-data. An A/D converter starts sampling of data by the minute signal of the JST clock just after the observation starts at the sidereal time.

6. Data acquisition system

IPS signals out of the high pass filter are digitized at a sampling frequency of 20 Hz and the dynamic range of the A/D converter is 10 bits. Data are stored on a digital magnetic tape by the central processor unit (C.P.U.). The C.P.U. is a minicomputer with

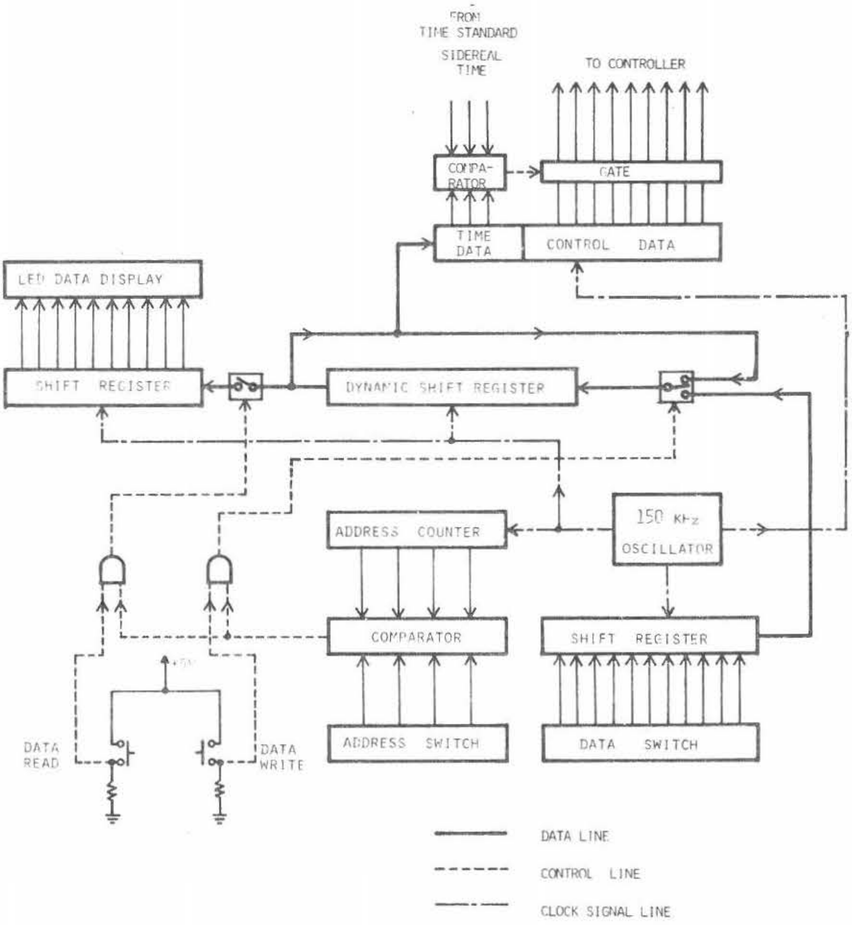

Figure 16a. Program-timer

0 – 15		16	17 – 25		26 – 28	29 – 39
TIME		ON,OFF	BEAM SELECT		GAIN	(SPARE)
HOUR	MINUTE		EW	NS		

Bit 0 - 15 : Sidereal time when an observation will start or stop.

Bit 16 : Start or stop of the observation.

Bit 17 - 25 : Beam control : bit 17 to 20 control the beam in hour angle and bit 21 to 25 control in declination.

Bit 26 - 28 : Receiver gain.

Bit 29 - 39 : (Spare)

Figure 16b. Bit construction of register.

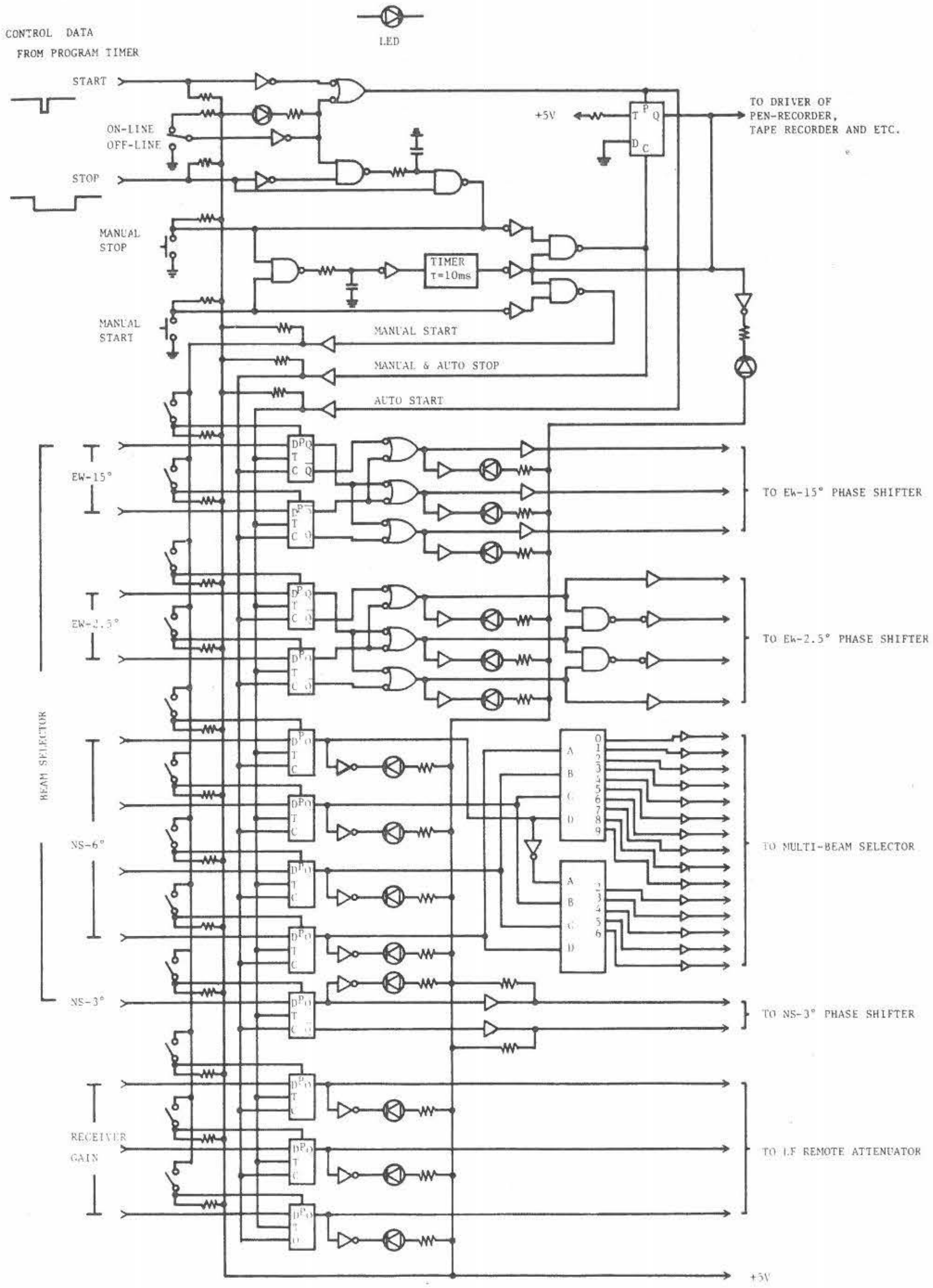

Figure 17. Controller

4-kwords memory. Collected data on a tape are transmitted to the host computer at Toyokawa during off-observing time. Data transmission is started by commands from the host computer. Data transfer rate is 1200 baud, which is limitted by the quality of the transmission line.

An analog recording system supports the digital recording system in the case of computer troubles. An analog tape-recorder records the 1 kHz signal, JJY radio signals and the frequency-modulated IPS signal.