NATIONAL RADIO ASTRONOMY OBSERVATORY
Green Bank, West Virginia

Electronics Division Internal Report No. 20

THE 20-CHANNEL EXTRA-GALACTIC HYDROGEN LINE RECEIVER

Bertil Hoglund

SEPTEMBER 1963

NUMBER OF COPIES: 100

THE 20-CHANNEL EXTRA-GALACTIC HYDROGEN LINE RECEIVER

by

Bertil Höglund

Introduction

The design of the extra-galactic multichannel receiver to be described here started in the middle of 1961. It was planned to use the receiver with the 300-foot telescope, so the special requirements introduced by that telescope had to be included in the design of the receiver. The main receiver parameters were determined from the following facts [1]:

1. The signals expected are very small, even with a 300' telescope. Except for a few nearby galaxies, the maximum signals will be only a few degrees Kelvin.
2. The 300' telescope is a transit instrument and it takes 40 seconds for a point on the celestial equator to pass the 10' antenna beam. The receiver integration time should be considerably less than 40 seconds. (A moving feed arrangement was not considered.)
3. The system noise temperature was assumed to be 200 - 300 °K (at the time an Adler tube front-end was contemplated).

After consideration of the three points above it was decided to make a system consisting of 20 channels, each with a bandwidth of 95 kc, separated by 100 kc/s and having an integration time of 10 seconds. This was thought to be a reasonable compromise between the requirements for both frequency resolution and sensitivity. For a frequency switched receiver with image suppression (by the RF preamplifier), and assuming a 200 °K system noise temperature, this gives output noise fluctuations of about 0.3 °K.

Receiver Circuit

The receiver is of the frequency switched type. It is switched between a 2 Mc/s wide band centered at 1425 Mc/s (comparison band) and another 2 Mc/s wide band, pretuned to any frequency between 1425 and 1390 Mc/s (signal band). The switch rate is 400 c/s. Each of the 20 channels, together covering the 2 Mc/s band, records the difference in noise power between the signal and the comparison bands. This difference is a measure of the neutral hydrogen radiation received.

Figure 1 shows the block diagram of the receiver.

The signals picked up by the antenna are amplified in a low noise RF pre-amplifier (parametric amplifier followed by a tunnel diode amplifier). They are then mixed alternately with two LO frequencies, one fixed at 1395 Mc/s, and one that can be chosen at will between 1390 and 1360 Mc/s depending on the expected frequency of the signals to be received.

The resulting 30 Mc/s IF is further amplified, passed through a gain modulator and finally converted to a 5 Mc/s signal through mixing with a 25 Mc/s oscillator. After further amplification at 5 Mc/s the signal is distributed to the various channels by a low output impedance channel driver.

Each channel is preceded by a second (individual) gain modulator, the use of which will be described later. In the channels amplification takes place at the proper channel frequency. The bandwidth is restricted to 95 kc/s by a crystal filter. The RF is finally detected in a germanium diode, leaving only a 400 c/s square wave after filtering out the RF and DC components (in the presence of a signal).

The square wave, which contains the signal information, is passed through a narrow band selective amplifier centered at 400 c/s which passes the fundamental frequency only. A synchronous detector (solid state chopper) converts the 400 c/s signal to a slowly varying DC voltage that is passed through a low pass network with a time constant of 10 seconds.

The outputs of the 20 channels are sampled at 10-second intervals by a stepping switch and fed to the digital output system which converts the instantaneous voltage from each channel to digital form. The data is punched out and printed on tape. The channel outputs are also displayed sequentially on a recorder started simultaneously with the stepping switch.

Four monitor channels are recorded continuously on a separate recorder. One is an ordinary 95 kc/s wide channel centered at 5 Mc/s. Two frequency switched channels have a bandwidth of 400 kc/s and are centered at 4.9 and 5.1 Mc/s, respectively. The fourth is a total power channel, 2 Mc/s wide, centered at 5 Mc/s, giving a check of the gain stability of the receiver. A more detailed description of the various parts of the receiver will now be given.

Antenna Feed and Calibration

The feed is a horn made by Jasik Laboratories. It is modified by the addition of three tuning slugs in order to provide broad band matching. The VSWR is 1.02 - 1.04 over the frequency range 1350-1430 Mc/s.

In the bottom of the horn are two neon bulbs (NE 51) barely projecting into the waveguide. The bulbs can be fed with a square wave of 400 c/s to give a modulated calibration signal. About 70 V are needed to light the bulbs. Tests have shown that the noise output from this type of lamp is dependent on the current through it. Over a range of currents from 1.5 mA to 2.5 mA the noise is relatively constant, though. The supply to the bulbs is 18 V p-p taken from the square wave generator and fed to the primary side of a transformer where a 10 V Zener diode keeps the voltage constant. On the secondary side the voltage is about 150 V p-p. A diode removes the negative part of the cycle and so the lamps are fed with a 400 c/s pulsating DC voltage with an amplitude of 75 V.

The bulbs are situated symmetrically about the center of the bottom face of the horn, 2" apart. A bulb placed in the center of the bottom would give a stronger coupling to the horn probe. The equivalent antenna temperatures of the bulbs were calibrated with the system shown in figure 2. The dummy load was held either in melting ice or in water of 3-6 °C. The two bulb signals were determined to be 1.7 °K and 3.5 °K, respectively. With both bulbs on, the noise temperature should be the sum, i.e., 5.2 °K, and this also proved to be the case. The losses in the two sides of the switch plus the cables were measured later. The load side proved to have 0.2 db more loss than the signal side and thus the fixed calibration values should be increased to 1.8 °K, 3.7 °K and 5.5 °K, respectively.

The change in VSWR for the horn due to the presence of the lamps was found negligible.

During focusing of the feed on the 300' telescope it turned out that also a high intensity calibration signal would have been desirable. This could easily have been obtained with a third bulb in the center of the bottom face projecting wholly into the waveguide. Calibration signals close to 100 °K can be reached in this way.

Parametric Amplifier

A parametric amplifier designed by Microwave Physics Corporation is used as the input amplifier. It is a non-degenerate type employing a pump frequency of 14.1 Gc/s. The 3 db bandwidth is 38 Mc/s and the gain is 15 db. Self-bias is used.

The original rack mount was changed to a base plate mount at NRAO and at the same time some superfluous hardware (used for pump power measurement) was removed.

The noise temperature of the parametric amplifier itself (including circulator) is about 110 °K. Input cable loss contributed about 10 °K.

As the second stage a tunnel diode amplifier made by Micro State Electronics is used. It is quite broad, 70 Mc/s, between 1 db points, and has a noise temperature of about 450 °K and a gain of 15 db. With a parametric gain of 15 db the tunnel diode adds about 15 °K to the system temperature.

The overall front-end temperature as measured with an argon noise tube and an AIL test receiver is 135-140 °K. On the antenna 50-100 °K will be added to this figure.

Mixer and Local Oscillator

The two LO frequencies supplied to the first mixer are obtained in the following way. The outputs of a fixed oscillator (comparison oscillator, f = 13.95 Mc/s), and a variable oscillator (signal oscillator, f = 13.9-13.6 Mc/s) are fed to a diode switch operated by a 400 c/s square wave generator. For optimum switching the two signals should be of equal magnitude. The output of the variable oscillator, which is larger than that of the fixed, is therefore attenuated by a proper amount. The input level at the switch is about 1 mW. After the switch, which introduces a loss of about 6 db, the two frequencies are amplified in a transistor amplifier to give adequate drive power for the frequency multiplier which follows next. 20-25 mW is necessary to drive this unit.

The variable oscillator is a commercial unit (Manson Labs, Model N317A) covering the frequency range 2-34 Mc/s in four bands. The accuracy quoted by the manufacturer is 10^{-8} per day. When the oscillator frequency is checked with a Hewlett-Packard counter a discrepancy of 10-20 c/s is found. The stability is very good, however, and the difference is of no importance with the present receiver parameters. Of the four bands available on the Manson oscillator, only a small part of one is actually used. The other bands, however, proved to be very valuable during alignment and checking of the various receiver parts.

The frequency can be changed in steps of 500 c/s on the band used, and this corresponds to 50 kc/s after the frequency multiplier. A continuous frequency change is provided by an auxiliary unit, a pullable 1 Mc/s oscillator, which goes with the main oscillator.

At present two comparison LO frequencies are available. One is 13.95 Mc/s, mentioned above, and is obtained from a crystal oscillator made by James Knight Company. It is transistorized and completely enclosed in a constant temperature oven.

The second comparison oscillator was built in order to reduce the baseline drift (as a function of frequency, for the channels taken together at any particular time) when the receiver is tuned to signals more than 6 Mc/s below the orginal comparison frequency. It was made at NRAO and has a frequency of 13.895 Mc/s. This unit is also transistorized and is (with the crystal) enclosed in an oven.

The frequency multiplier is built by Micromega, Inc. It consists of a transistor driver amplifier followed by two quintuplers and two doublers, all employing varactor diodes. The total multiplication factor is 100. The input range covered is 13.95 - 13.60 Mc/s. The output level at 1390 Mc/s is measured to be 275 mW, as against 320 according to the manufacturer's specifications, but the power is still adequate for driving the mixer. The loss in the 300' of cable between pillbox and receiver at the 300' telescope is about 10 db and the mixer end of the cable is padded by another 10 db for matching reasons.

The purity of the multiplier output has been checked with a spectrum analyzer. It turns out that the drive level is quite critical. Too little drive gives no output, whereas too much gives strong spurious side frequencies. With the correct drive level the spurious frequencies are more than 25 db down. The permissible drive range is wide enough to ensure perfect stability in this respect.

The mixer is the first part of an LEL mixer-preamplifier (type LAC-3) and is of the balanced type employing two 1N21E crystals. It needs about 1 mW LO power.

IF Amplifiers

The 30 Mc/s IF is amplified first in the mixer-preamplifier unit just mentioned, which is situated in the pillbox at the focus of the telescope together with the RF amplifiers. A second 30 Mc/s amplifier is contained in the back-end of the receiver. In a tube mixer the 30 Mc/s IF is converted to 5 Mc/s by mixing with a 25 Mc/s LO.

The LO is a transistorized crystal unit made by Bliley Electric Company and enclosed in an oven. The output is about 1 mW across 50 ohm. This output is not enough to drive the mixer tube and therefore an amplifier is provided before the mixer tube.

At 5 Mc/s the signal is amplified in an LEL amplifier (a 10 Mc/s unit converted to 5 Mc/s) and then fed into the channel driver.

The channel driver is a RC-coupled transistor amplifier with a low-impedance emitter follower output stage (about 2 ohm). Its prime function is to provide an impedance match to the input of the channels seen in parallel.

Channels

Each of the 20 channels consists of an IF section, detector, 400 c/s tuned amplifier, a phase detector and a time constant network. See Figure 3. The RF section is straightforward. Four transistor amplifier stages are provided; the filter is placed between the first and the second. The maximum RF level before the detector is a little over 1 V; at higher levels distortion occurs.

The filters, which cover the frequency range 4.050-5.950 Mc/s, are made by McCoy Electronics Company. During alignment of the RF sections and the filters it proved necessary in some cases to add a small capacitance in parallel with the filter output or input (or both) in order to obtain a good bandpass curve. Figure 4 shows some of the filter responses.

The 400 c/s amplifier contains four transistor stages. After a first conventional stage follows the selective part, a commercial unit (White Instrument Labs, type 252, containing a twin-T feedback network) which passes only the fundamental of the square wave. The center frequencies of the White amplifiers have been checked. They all agree within 1 c/s. At the center frequency the phase shift through the White units is zero.

After the White amplifier follows a phase splitting stage driving a push-pull amplifier. The secondary of the output transformer is capable of giving 80 V p-p undistorted sine wave. A phase shift of 15-25° takes place in the stages succeeding the White amplifier. The output transformer contribution seems negligible.

The phase detector is a chopper unit made by Solid State Electronics Company (Model 50). It consists of two matched transistors coupled emitter-to-emitter. The reference voltage is applied between the bases and the signal voltage between the collectors. From the common emitters a full wave phase detected output is obtained. The maximum peak rectified output is 4 V.

The reference voltage is coupled via a transformer. On the secondary side a Zener diode ensures a constant reference amplitude.

There are two provisions for controlling the RF output level before the detector. A potentiometer is used to change the supply voltage to the collectors in the RF section and gives a change of a few db. A potentiometer at the input of each channel controls the input RF level. The audio amplifier gain can be adjusted by a potentiometer after the White amplifier.

During testing it turned out that a fairly strong 400 c/s signal leaked into the audio section. It finally proved to be pick-up on the -12 V supply from the reference square wave voltage. An RC filter reduced the pick-up to an unimportant level.

Gain Modulators

The operation of the gain modulator is described in detail in [2].

When the antenna is pointed in a direction where there is no hydrogen line radiation, or tuned outside the hydrogen line band, ideally there should be no output of the phase detector (except noise). In the present case the frequency switching causes the channels to see a different part of the parametric amplifier bandpass in the two switched positions. The gains are not equal in the two positions and this results in a 400 c/s modulation of the receiver noise. The main gain modulator can be adjusted so that its gain is lower during that time of the switching cycle when the high gain portion of the parametric bandpass curve is seen. By proper balancing, the phase detector output can thus be adjusted to zero, but in general only for one channel. The reason is that the gain difference is not the same over the 2 Mc/s covered by the channels due to the curvature of the bandpass curve.

In order to be able to balance all channels in the absence of a hydrogen line signal, individual gain modulators precede each channel. They are mounted on a separate chassis and are all transistorized. With the main gain modulator the center channel of the 2 Mc/s band is balanced first and then the individual gain modulators are adjusted.

Square Wave Generator

The 400 c/s square wave drives the frequency switch, the neon calibration bulbs, the gain modulators, and provides the reference voltage for the phase detectors. The total current drain on the unit is about 350 mA.

A tuning fork sine wave oscillator (Delta-f, Inc., Model DFO-80B) is used as the stable frequency source. Its output (which is clipped) is fed to a transistor switch circuit which alternately connects two DC power supplies to the square wave output.

Filtering

During the tests of the receiver it appeared that spurious frequencies entered the channels. The fourth harmonic of the comparison oscillator (13.95 x 4 = 55.8 Mc/s) combined with the second harmonic of the 25 Mc/s second LO to give

5.8 Mc/s, which enters channels 18 and 19. Further, the second harmonic of the comparison LO combined with the 25 Mc/s LO to give 2.9 Mc/s, which is not a channel frequency, but threatened to overdrive the 5 Mc/s LEL amplifier because of its relatively high level.

In order to overcome these problems all oscillators are well screened, and extra filtering is used. At the outputs of the comparison LO and the second LO low-pass filters (f_o = 15.0 and 27.0 Mc/s, respectively) are placed to prevent harmonics to leak through. Before the 5 Mc/s amplifier a highpass filter (f_o = 3.8 Mc/s) rejects the 2.9 Mc/s signal. After this modification, the spurious responses do not cause trouble.

Digital Output System

The digital output system will be described in a separate report (John Parker). Briefly, it functions as follows.

The output voltage from the twenty channels is fed to a stepping switch which is sampled every 10 seconds. The output from the switch is fed to the high input impedance (100 M) converter unit where it is converted to a number of pulses, the number being proportional to the voltage. The pulses are counted and the number is punched on tape for each channel in succession. A bias voltage gives a minimum count of pulses of 100 in the absence of an input signal. The sensitivity is 1 mV/pulse.

From the cathode of the input tube the voltage from the channels is also fed to a recorder for visual monitoring.

Operational Remarks

The detector current in any channel should not exceed 8μA. Above this level over-driving may occur. The detector currents should be approximately equal in each channel. This is not entirely necessary, but it is easier to keep the currents within the allowed range if they are all equal.

Since the calibrations are weak, they are not suitable for checking the channel overall gains. A convenient way of doing this is first to lock the frequency switch in either signal or comparison position, and balance the channels. An artificial calibration signal is then created simply by offsetting the main gain modulator course control one or two steps (in the correct direction). The audio gain controls are used to set the gains equal in all channels.

The system noise temperature was checked by observing the radio sources Hercules A and 3C 353, assuming their flux to be known. After proper correction for the detector law both sources gave the same result, $T_{syst} = 250\ °K$.

The total power stability is fairly good, considering the fact that it is not a switched total power system. The short-time stability (over 1/2 hour) is of the order of 0.05 db.

Figure 5 shows some sample records.

References

[1] Orhaug, Torleiv, "Consideration of a Hydrogen Line Multichannel Receiver," NRAO memo, July 1961.

[2] Orhaug, Torleiv and Waltman, William, "A Switched Load Radiometer," Publ. N.R.A.O., Vol. 1, No. 12, February 1962.

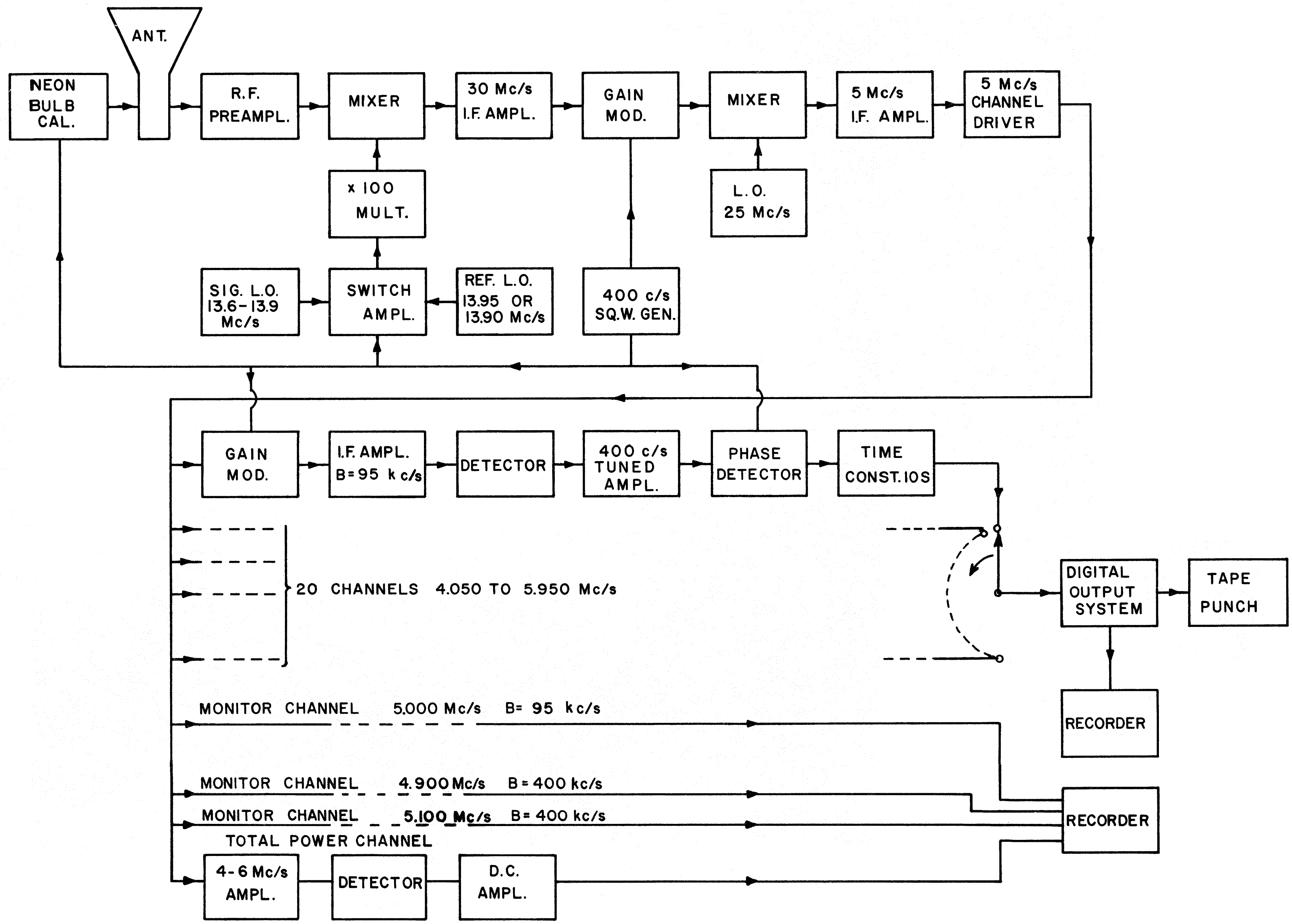


Fig. 1. Block diagram of receiver.

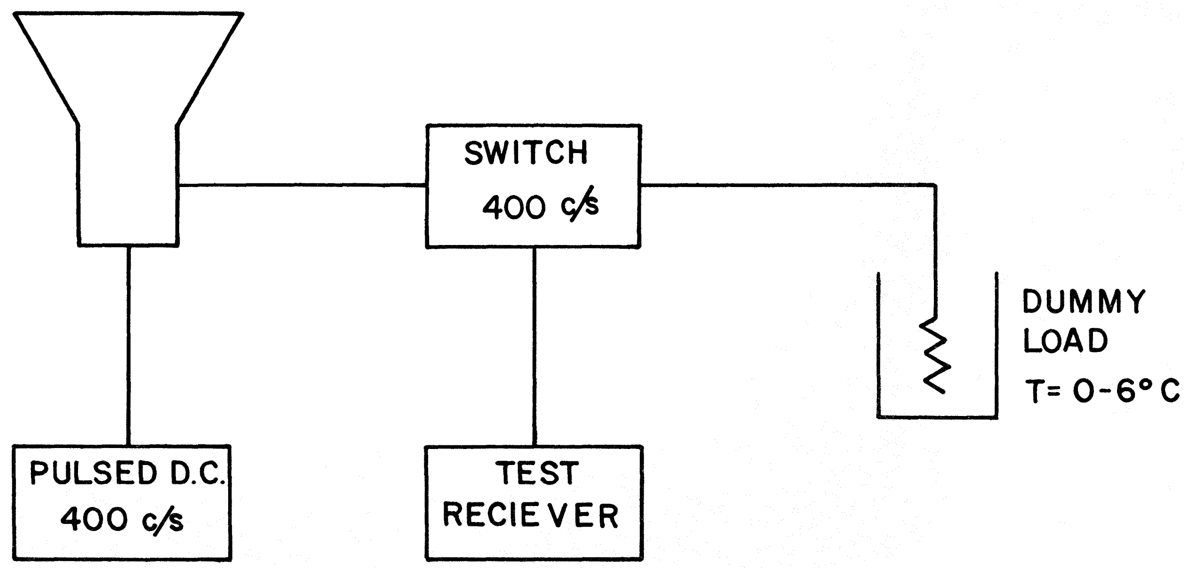
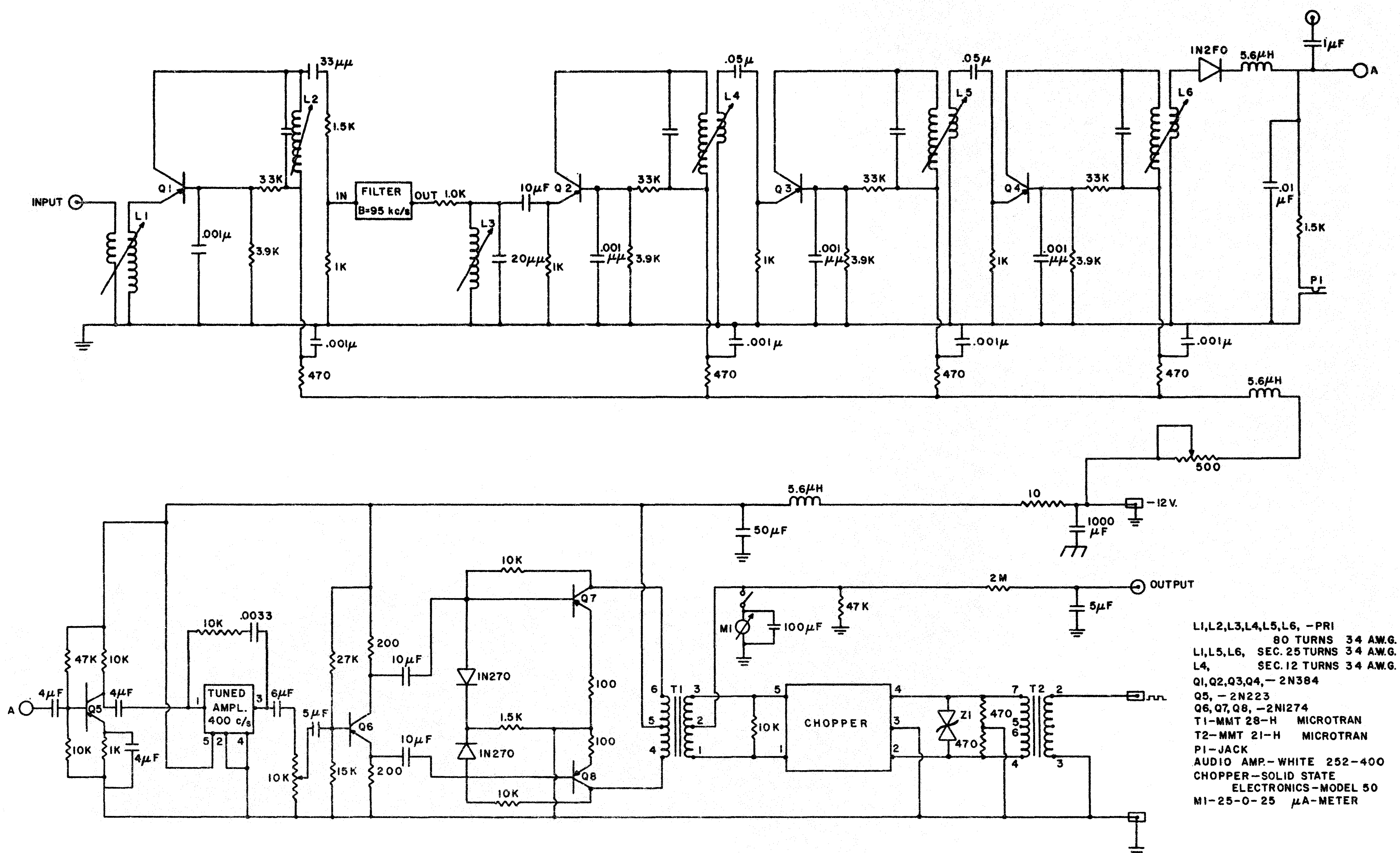


Fig. 2. Neon bulb calibration arrangement.



L1,L2,L3,L4,L5,L6, —PRI 80 TURNS 34 A.W.G.
L1,L5,L6, SEC. 25 TURNS 34 A.W.G.
L4, SEC. 12 TURNS 34 A.W.G.
Q1,Q2,Q3,Q4, — 2N384
Q5, — 2N223
Q6,Q7,Q8, — 2N1274
T1 — MMT 28-H MICROTRAN
T2 — MMT 21-H MICROTRAN
P1 — JACK
AUDIO AMP. — WHITE 252-400
CHOPPER — SOLID STATE ELECTRONICS — MODEL 50
M1 — 25-0-25 μA-METER

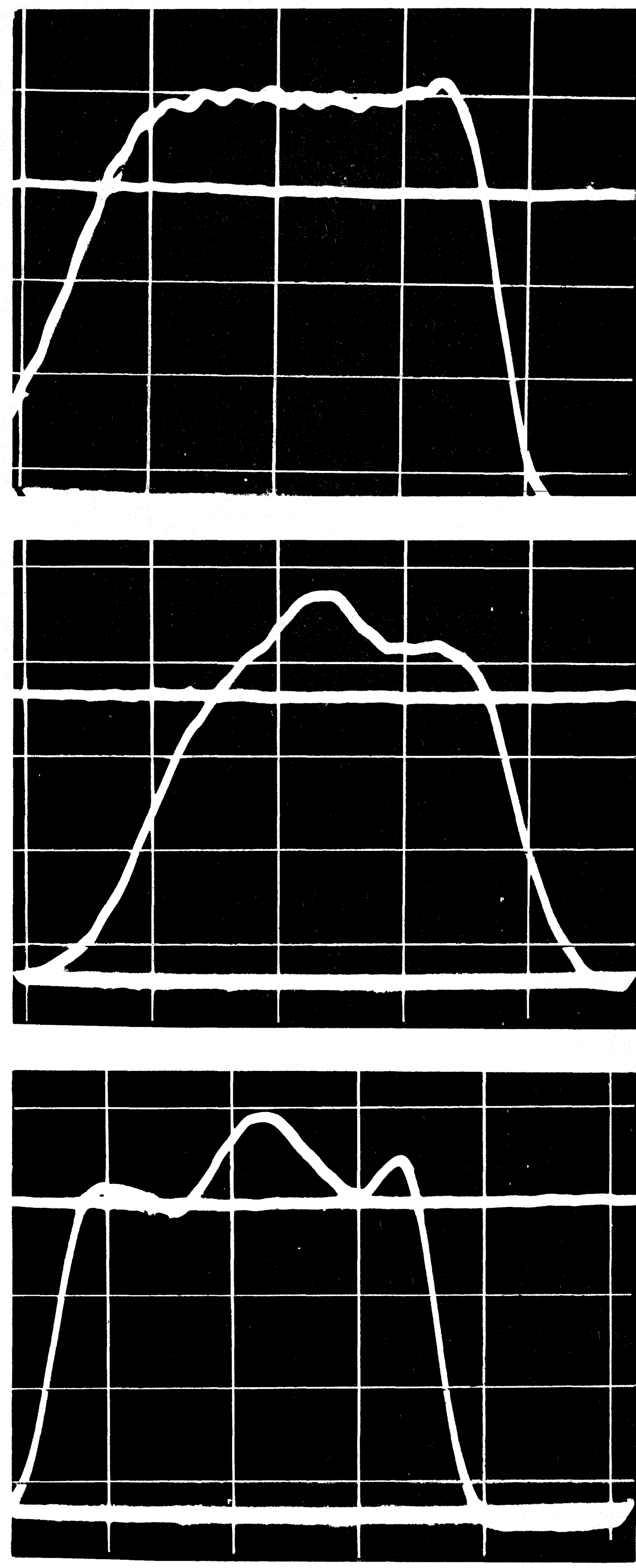


Fig. 4. Band shape of three channels. Top: The best channel (16). Middle: The worst channel (9). Bottom: A typical channel (6). The bandwidths are 98.8, 96.3 and 92.0 kc/s, respectively. The horizontal line indicates the -1 db level.

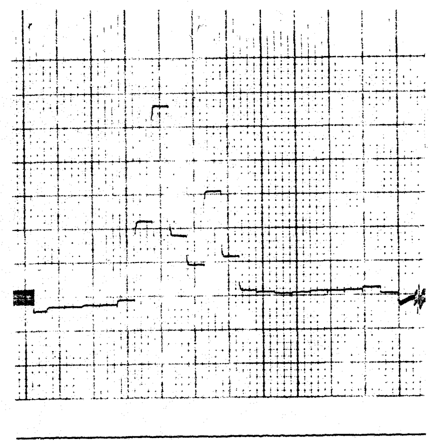


Fig. 5a. Record of Galactic hydrogen at $l \approx 71°$, $b \approx +1°$.

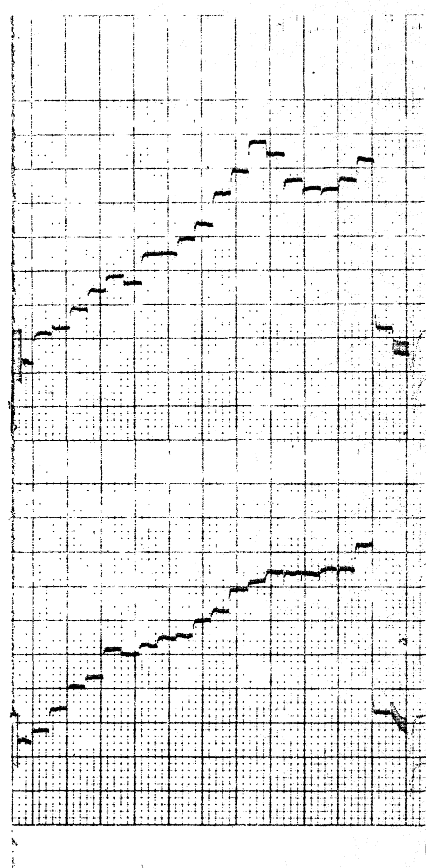


Fig. 5b. Record of M 101. The bottom curve representing the baseline is obtained 1° east of the galaxy, the top one is taken at transit.

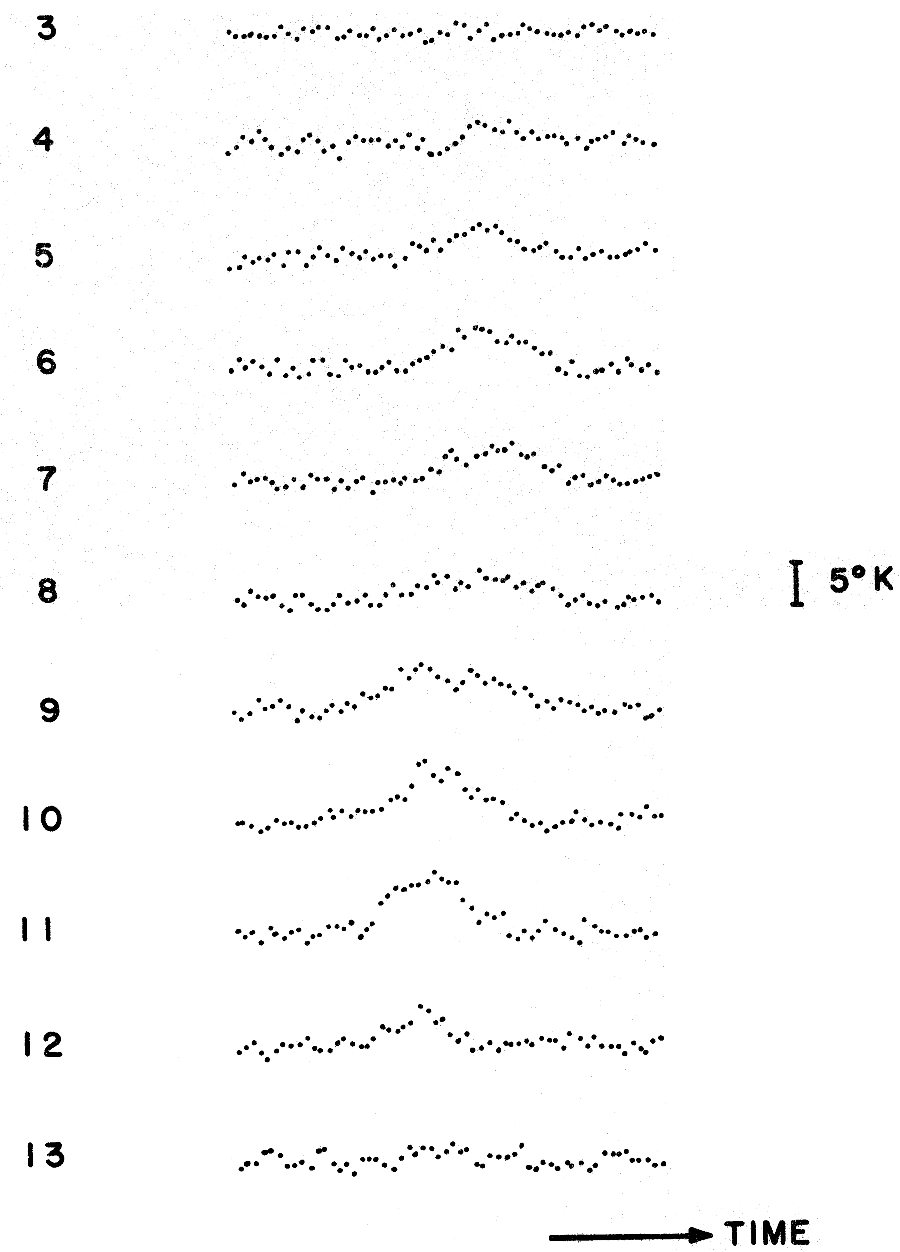


Fig. 5c. Transit of M 101 Sept. 8, 1963 in channels 3 through 13. Local oscillator frequency 1389.51 Mc/s. Interval between points 10 sec.

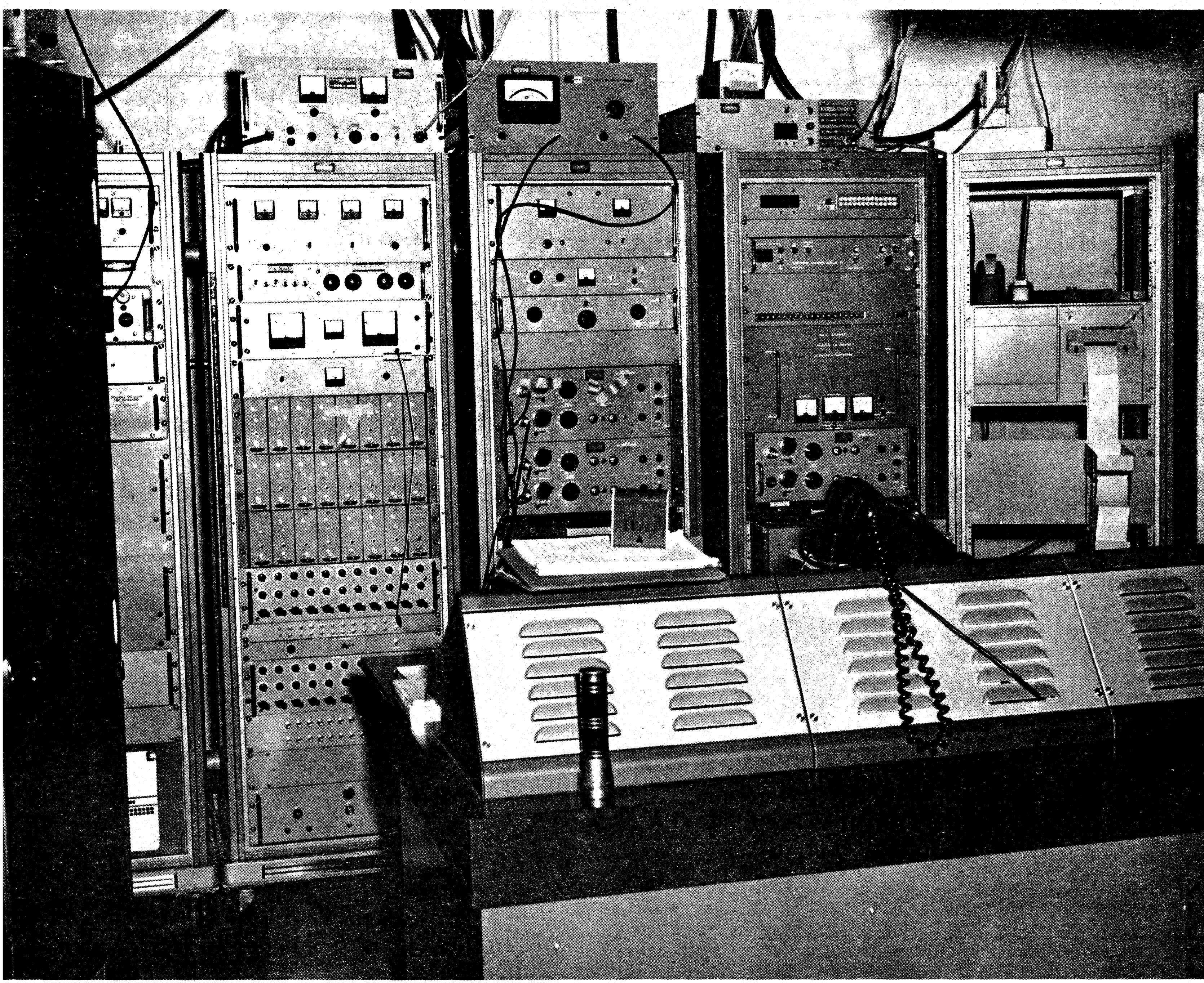


Fig. 6. Photo of multichannel receiver in 300-foot telescope control building.