MICROWAVE SOLAR RADIOMETER AT 2800 MHz

By K. Narayanan and R. V. Bhonsle

(*Physical Research Laboratory, Ahmedabad-9*)

Received May 18, 1971

(Communicated by Dr. K. R. Ramanathan, F.A.SC.)

Abstract

A Dicke-type microwave radiometer has been developed for daily measurement of solar flux at 2800 MHz. The antenna system, consists of a 5 foot parabolic dish with horn feed, is equatorially mounted and is capable of tracking the sun for about 8 hours each day. The dynamic range of the radiometer is such that even strong solar bursts (flux $= 10{,}000 \times 10^{-22}$ Watts m^{-2} Hz^{-1}) can be recorded by using the receiver in the AGC mode.

The calibration procedure and the errors involved in the measurement of the solar flux are briefly discussed. Some sample records of solar bursts made by means of this equipment are presented.

Introduction

It is well known that microwave radiation emitted by the sun in the centimeter wavelength region is usually classified into three categories: (1) the quiet sun component which is observed in the absence of sunspots, (2) the slowly varying component which is associated with sunspots and (3) the transient or burst component associated with solar flares (Kundu, 1965). At the time of solar flares electromagnetic radiation including X-rays and corpuscular radiation are also emitted. The flare-time X-radiation produces extra ionization in the lower ionosphere and causes fade-out in the long distance shortwave radio communication. The solar corpuscular radiation is responsible for the polar-cap blackouts and geomagnetic storms. Thus, the measurements of flare-time electromagnetic and corpuscular radiations are important for the study of solar-terrestrial relationships. So far as solar X-rays are concerned, they are absorbed in the earth's atmosphere and hence it is impossible to study them directly with ground-based techniques. But it has been shown from rocket and satellite measurements of solar X-rays and simultaneous ground-based microwave solar flux measurements, that there is often a close relationship between the microwave bursts at 10·7 cm waves and X-rays that are emitted at the time of solar flares; sometimes there is agreement even in fine structure details of their time profiles (Kundu, 1965). In order to study the physics of solar flares, sudden ionospheric disturbances, and their relationships, a Dicke-type microwave radiometer at 2800 MHz similar to the one being used in Canada (Medd and Covington, 1958) has been set up recently at the Physical Research Laboratory, Ahmedabad. The present paper describes the experimental set up and discusses sample recordings made with this radiometer. The calibration procedure and errors involved in the measurements of solar flux are also explained.

PRINCIPLE OF OPERATION

Figure 1 shows the block diagram of the Microwave Radiometer at 2800 MHz. If changes of the order of 10% in the solar flux are to be measured, the sensitivity $\triangle T$ of the system should at least be 20° K. To achieve this, a Dicke-type switching system was incorporated in the receiver. Here, the receiver input is continuously switched between the antenna and a noise source at a rate of one KHz. This way the antenna noise temperature is

SOLAR MICROWAVE RADIOMETER AT 2800 MHz (AHMEDABAD)

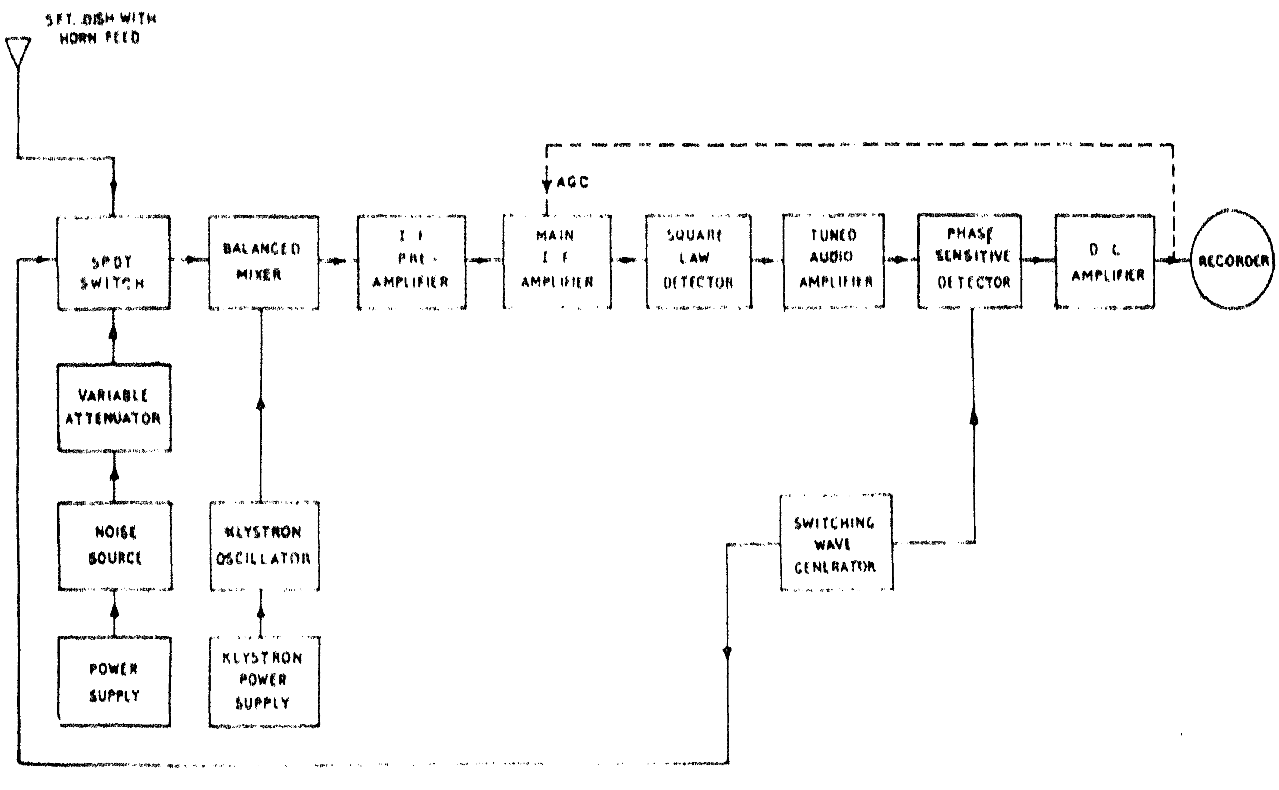

FIG. 1. Block schematic of the microwave radiometer at 2800 MHz.

compared with the temperature of the noise source several times a second. The switching frequency is high enough so that the gain has no time to change during one cycle. At the detector the difference between the antenna noise temperature and the temperature of the comparison noise source appears as a square wave at the switching frequency. It can be shown (Kraus, 1966) that the fluctuations at the output, $\triangle T_G$, due to a variation in receiver gain of $\triangle G$, is given by

$$\triangle T_G = \frac{\triangle G}{G_{HF}} (T_A - T_C) \tag{1}$$

where,

T_A is the antenna noise temperature

T_C is the temperature of the comparison noise source

and

G_{HF} is the high frequency power gain of the receiver.

Thus, if $T_A = T_C$, the gain variation will have no effect on the receiver sensitivity.

The antenna is connected to one side of the Dicke-switch, the other side being connected to a dummy load. The common point of the switch is connected to the mixer input terminal. A square-law detector follows the I.F. amplifier. Thus the output voltage is proportional to the receiver input power and hence the antenna noise temperature. The modulation component at the switching frequency of the detected output is fed into an audio amplifier tuned to the switching frequency. The audio amplifier output is then synchronously detected by a phase-sensitive rectifier (PSR). The D.C. output of the PSR is further amplified by a D.C. amplifier which drives a milliammeter type chart recorder. The variations in the gain of the receiver after detection will not affect the sensitivity of the system but only its calibration.

Parameters of the Ahmedabad microwave radiometer at 2800 *MHz*

Operating frequency	..	2800 MHz
I.F. frequency	..	30 MHz
Image frequency	..	2740 MHz
I.F. Bandwidth	..	4 MHz

Effective noise band-width of the receiver	.. 8 MHZ (since image rejection has not been attempted)
I.F. Noise Figure	... 1·8 db
Total noise Figure	.. 9 db (source impedance 50 ohm)
Detector	.. Square-law type
Post-detector time constant	.. 1 Sec.
Dynamic range of the receiver	.. 40 db.

EQUIPMENT

(*a*) *Antenna and Feed.*—The antenna used is a parabolic reflector with horn feed. It is equatorially mounted and its declination can be adjusted mechanically. It is driven in hour angle by a motor so as to track the sun for eight hours in a day. The output of the horn is taken to the mixer by a flexible co-axial line. The antenna beam width has been measured by allowing the sun to drift through the antenna beam as shown in Fig. 2. By rotating the horn feed in the mount by 45°, 90° and 180° and taking the transits, the circular symmetry of the antenna beam has been verified

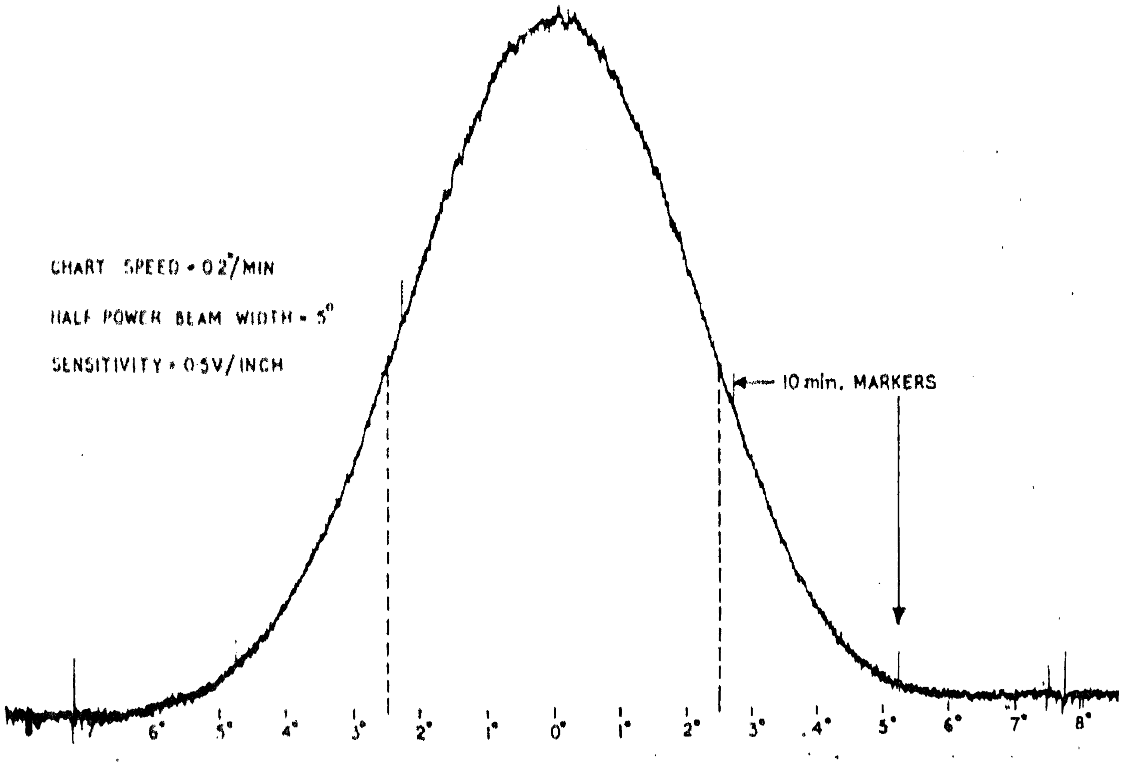

FIG. 2. Transit of the sun through the antenna beam.

The gain of the antenna was measured by comparing it with a standard gain horn. The antenna system parameters are summarized below:

Dish diameter	.. 5 feet (1·53 meters)
F/D	.. 0·43
Surface deviation	.. Less than ± 2·5 mm
Feed	.. Prime focus horn feed with co-axial output
Mounting	.. Equatorial
VSWR	.. 1·3
Feed taper	.. 10 db
Efficiency (measured)	.. 61·5%
Capture area	.. 1·125 m^2
Beam width (measured)	.. 5°
Circular symmetry	.. Within ± 10 min. of arc
First side-lobe level	.. — 25 db
Gain	.. 30·9 db

(*b*) *The Receiver.*—To minimize cable losses, the Dicke-switch, the mixer and I.F. pre-amplifiers are located at the antenna pedestal, and the I.F. output is taken to the receiving hut by a 50 ohm cable for further amplification in the main amplifier. The local oscillator power is fed to the mixer through a long co-axial cable. The Dicke-switches are two-PIN diode-SPST switches (H.P. Model 3505) connected to form a SPDT. They are driven in push-pull at a rate of one KHz by voltages derived from the switching wave generator. Switching at a rate of one KHz is made possible by the use of these solid-state switches. The fluctuations in the gain of the system decrease as the frequency of switching increases. Hence the high switching-frequency rate helps in reducing the gain fluctuations by comparing the antenna noise temperature to the temperature of the noise source more often in a second. Use of higher switching frequency also helps in simplifying the post-detection audio circuitry and eleminates power line interference more efficiently.

The mixer is a double balanced mixer (Sage Model 2533). The I.F. pre-amplifier is shown in Fig. 3 *a*. The main I.F. amplifier, the low-frequency circuits and their stabilized power supplies are all kept in the air-

onditioned receiving hut. One stage of the seven stage main I.F. ampli-
er is shown in Fig. 3 *b*.

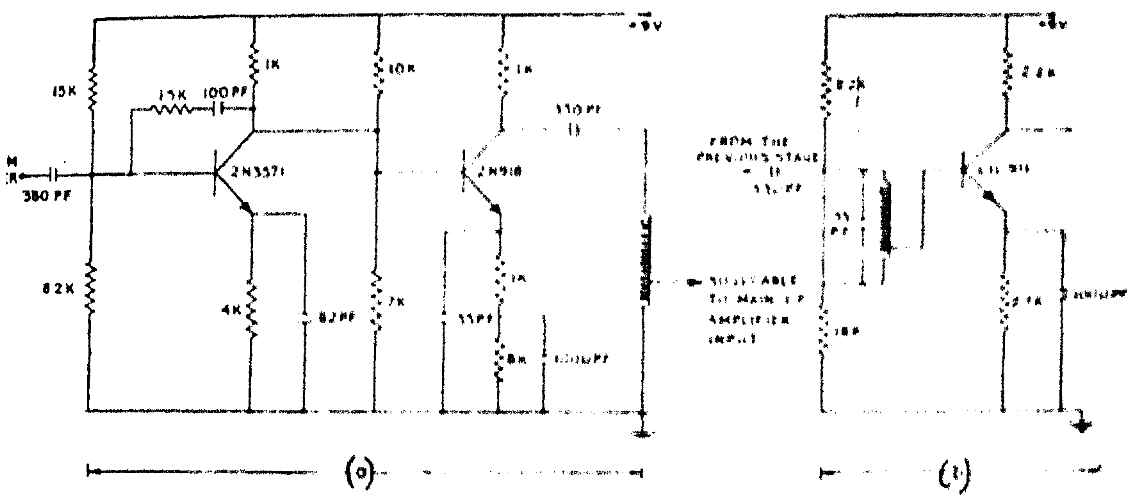

FIG. 3. (*a*) I.F. Pre-amplifier, (*b*) One stage of the main I.F. amplifier

To accommodate the peak intensities of strong solar bursts within the dth of the chart, a new I.F. amplifier, whose gain can be varied to a large tent by a control voltage was developed. One of the stages is shown in g. 4 as an insert. By forming a feed-back loop as shown by the dotted e in Fig. 1 and recording the AGC voltage, we were able to get an input wer compression *i.e.*, the dynamic range of 40 db for a full scale deflection the chart. Figure 4 also shows the output voltage as a function of input wer for receiver operation with and without AGC loop. This will enable to record solar radio outbursts which may be even 100 times stronger in the quiet-sun flux level. The main I.F. amplifier is used as a linear iplifier for the quiet-sun flux measurement and is converted into a quasi-;arithmic amplifier, by the introduction of AGC, while recording bursts.

The circuit details of the tuned audio amplifier, phase sensitive rectifier, C. amplifier and the switching frequency generator are described elsewhere ıonsle *et al.*, 1971).

The local oscillator uses a 726 C Klystron mounted in a co-axial mount, d gives an output of 120 mW. The cable carrying this power to the mixer the antenna pedestal also attenuates it to the required level of 1·5 mW.

CALIBRATION PROCEDURE

The radiometer is calibrated by using HP model 349A, coaxial noise source ich consists of an argon gas filled discharge tube coupled to a transmission line in the form of a helix. The noise source gives an excess noise of 15·7 ± 0·5 db or 10,500° K in the frequency range of 1000–4000 MHz. A known amount of noise power is injected into the receiver by using a calibrated variable attenuator between the noise source and receiver, and the deflection due to this is noted. By measuring the change in the deflections on the chart corresponding to the two antenna positions *i.e.*, on the sun and off the sun (into the cold sky), and comparing this with the calibration point of the noise source, the antenna noise temperature due to the sun is calculated. Proper allowance has to be made for various cable losses and mismatch losses.

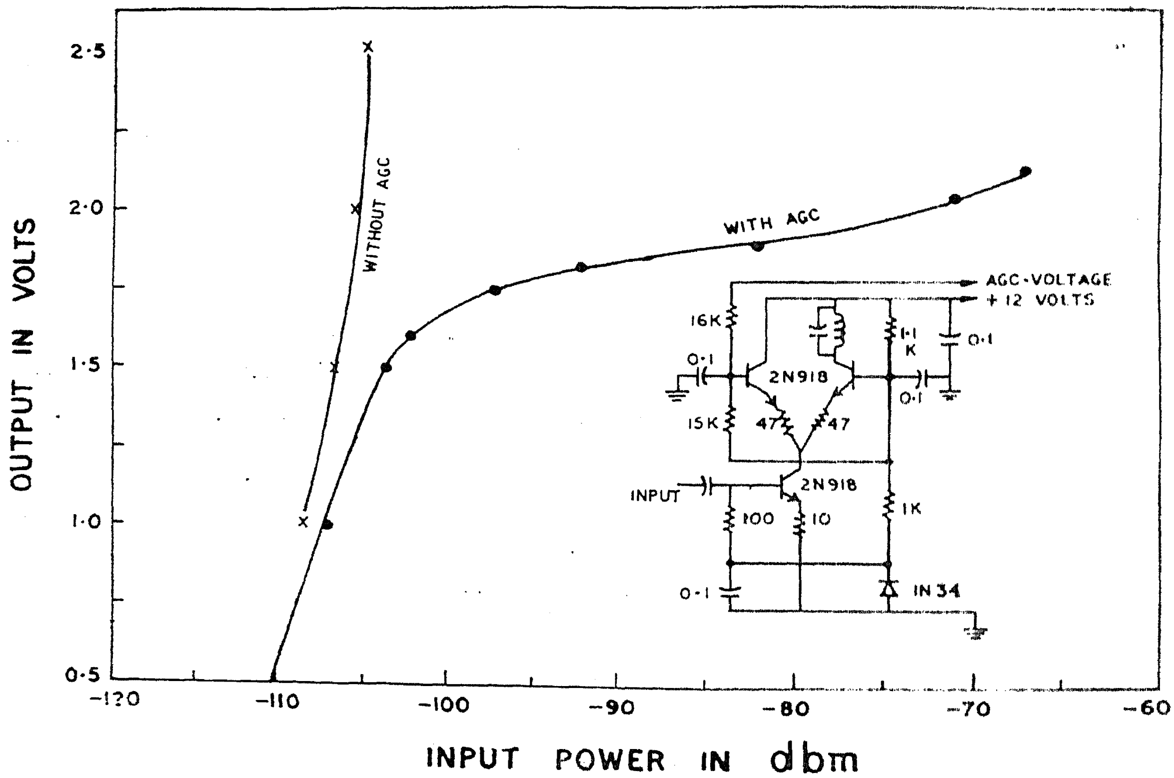

FIG. 4. Input *vs*. Output curves for receiver operation with and without AGC. The insert shows one stage of the AGC amplifier.

The source flux density (S) is related to the measured antenna temperature by the relation

$$T_A = \frac{SA}{2gk} \qquad (2)$$

where,

A is the effective aperture of the antenna, m^2

k is the Boltzmann's constant,

The coefficient 'g' takes into account the difference in angular dependence of the source and the antenna's directional pattern. The factor 2 in the denominator accounts for the fact that the antenna sees only one polarization. It can be shown that the coefficient 'g' can be approximated to unity, considering the relative angular widths of the source and antenna beam (Kuz'min and Salomonovich, 1966).

Hence the sun can be considered as a point source, relative to the antenna beam width with very little error. Using the relation (2), the solar flux can be calculated.

The above procedure is useful for calibration of the slowly varying component and bursts of moderate intensity when the receiver is operated in the linear mode. However, for strong bursts, the receiver has to be operated in the AGC mode, and hence a recource to Fig. 4 has to be taken. For input power calibration upto an input noise-temperature of about 10,000° K, the argon gas discharge noise source can be utilized. For calibration at higher intensities, however, a signal generator has to be used. One can calculate the noise temperature from the formula.

$$P_{in} = kT_A B \tag{3}$$

where,

P_{in} is the input power, watts

T_A is the antenna noise temperature, deg. Kelvin

k is Boltzmann's constants ($1 \cdot 38 \times 10^{-23}$ Joules per deg. Kelvin)

and

B is the noise bandwidth of the receiver, Hz.

Sources of Error

There are both systematic and random errors in the measurement procedure.

1. The argon gas discharge noise source has not been calibrated against any primary standrad noise source.

2. The antenna efficiency has been measured using a standard gain horn. But the attenuator used in the measurement has a ± 1 db accuracy

line in the form of a helix. The noise source gives an excess noise of 15·7 ± 0·5 db or 10,500° K in the frequency range of 1000–4000 MHz. A known amount of noise power is injected into the receiver by using a calibrated variable attenuator between the noise source and receiver, and the deflection due to this is noted. By measuring the change in the deflections on the chart corresponding to the two antenna positions *i.e.*, on the sun and off the sun (into the cold sky), and comparing this with the calibration point of the noise source, the antenna noise temperature due to the sun is calculated. Proper allowance has to be made for various cable losses and mismatch losses.

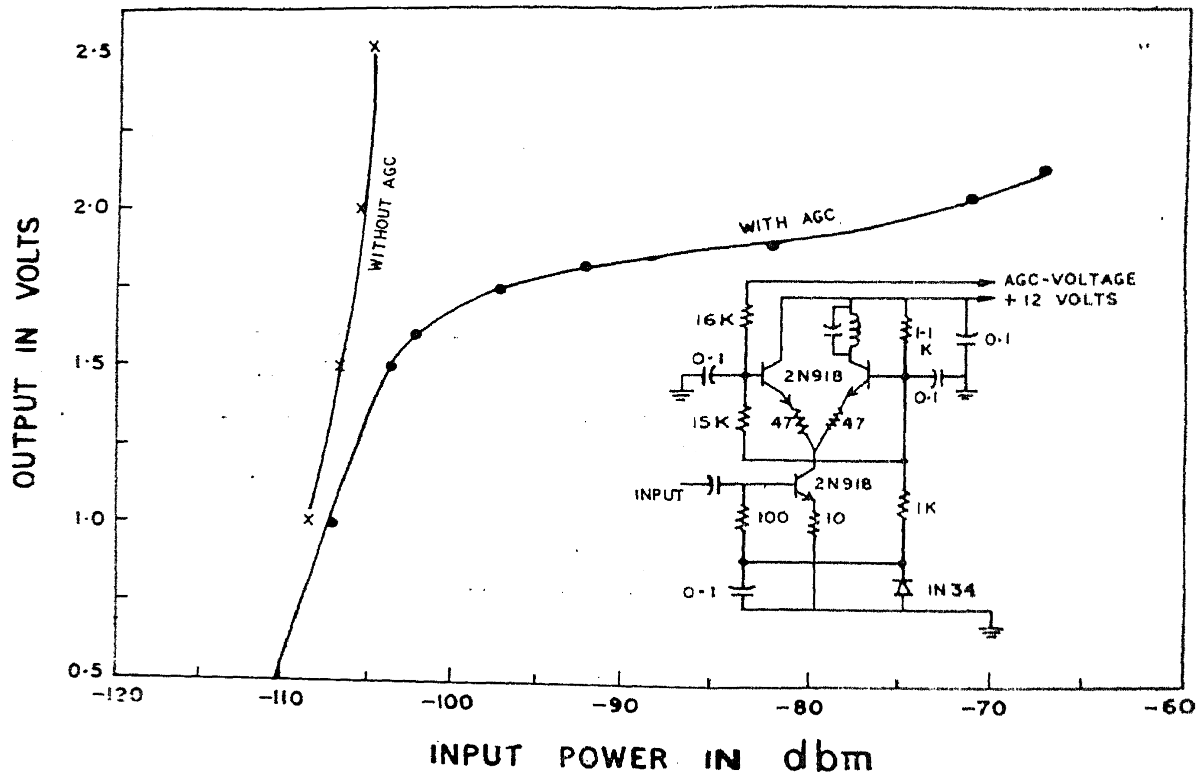

FIG. 4. Input *vs.* Output curves for receiver operation with and without AGC. The insert shows one stage of the AGC amplifier.

The source flux density (S) is related to the measured antenna temperature by the relation

$$T_A = \frac{SA}{2gk} \qquad (2)$$

where,

A is the effective aperture of the antenna, m^2

k is the Boltzmann's constant,

The coefficient 'g' takes into account the difference in angular dependence of the source and the antenna's directional pattern. The factor 2 in the denominator accounts for the fact that the antenna sees only one polarization. It can be shown that the coefficient 'g' can be approximated to unity, considering the relative angular widths of the source and antenna beam (Kuz'min and Salomonovich, 1966).

Hence the sun can be considered as a point source, relative to the antenna beam width with very little error. Using the relation (2), the solar flux can be calculated.

The above procedure is useful for calibration of the slowly varying component and bursts of moderate intensity when the receiver is operated in the linear mode. However, for strong bursts, the receiver has to be operated in the AGC mode, and hence a recource to Fig. 4 has to be taken. For input power calibration upto an input noise-temperature of about 10,000° K, the argon gas discharge noise source can be utilized. For calibration at higher intensities, however, a signal generator has to be used. One can calculate the noise temperature from the formula.

$$P_{in} = kT_A B \tag{3}$$

where,

P_{in} is the input power, watts

T_A is the antenna noise temperature, deg. Kelvin

k is Boltzmann's constants ($1 \cdot 38 \times 10^{-23}$ Joules per deg. Kelvin)

and

B is the noise bandwidth of the receiver, Hz.

SOURCES OF ERROR

There are both systematic and random errors in the measurement procedure.

1. The argon gas discharge noise source has not been calibrated against any primary standrad noise source.

2. The antenna efficiency has been measured using a standard gain horn. But the attenuator used in the measurement has a ± 1 db accuracy

only and this contributes to a ± 2% error in the gain measurement of the antenna.

3. The attenuation of the cable between the noise source and the receiver input has been measured with an accuracy of only ± 1 db.

4. The variable attenuator can be set only with an accuracy ± 1 db.

5. The excess noise-temperature of the noise source can vary by ± 0·5 db.

Items 2, 3, 4 and 5 constitute the random errors. However, the flux values as measured by our equipment agree within a few per cent with those published by ESSA, Boulder. Measurement accuracy can be considerably improved if the various losses in the system are determined by means of a precision variable attenuator (accuracy ± 0·1 db) which is being acquired.

Discussion of Records

Figure 5 *a* shows a record of solar flux level with the antenna tracking the sun. The flux due to the quiet sun and slowly varying component as measured by our instrument was 160 flux units (one flux unit = 10^{-22} Watts

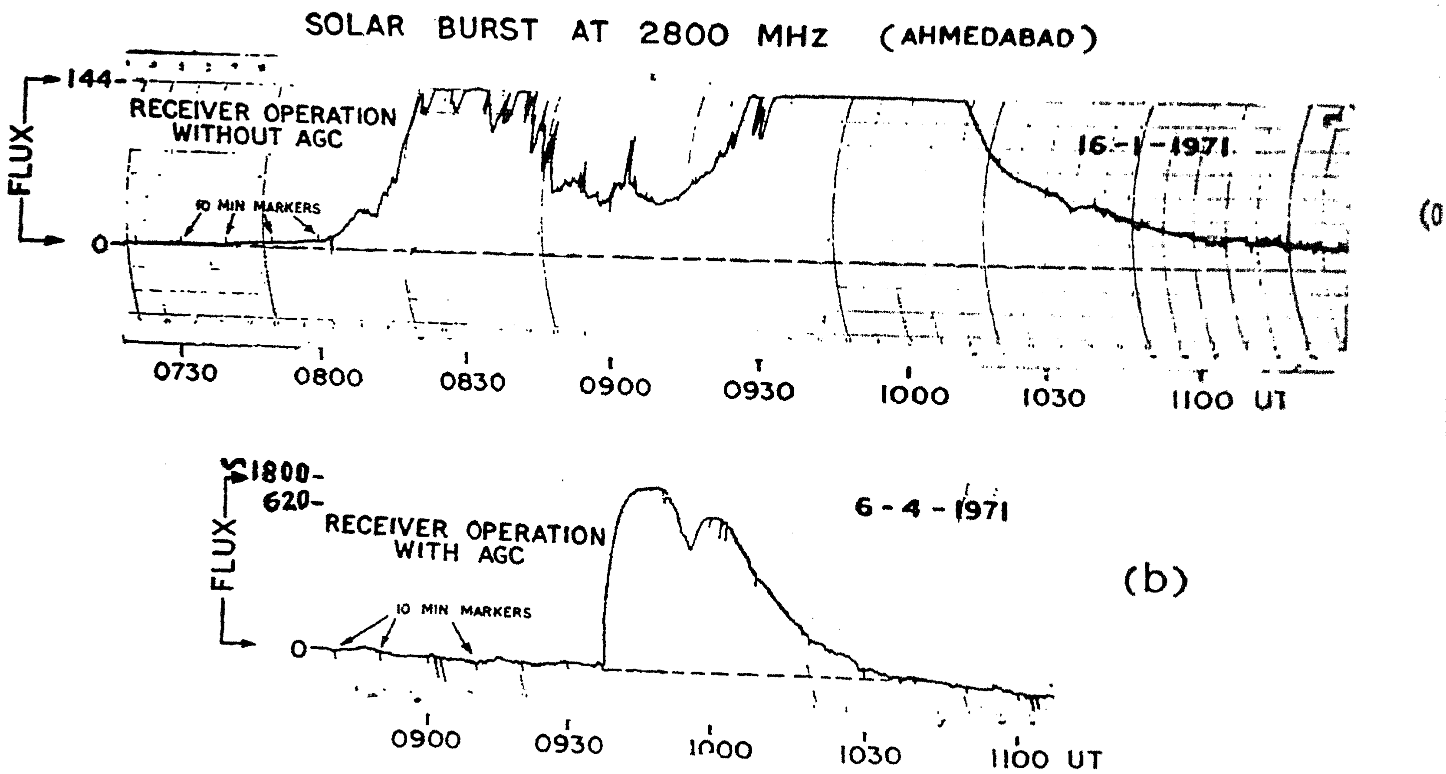

FIG. 5. Sample recordings of the microwave radiometer at 2800 MHz.