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ELECTRONIC DEVICES FOR INFRARED ASTRONOMICAL OBSERVATIONS

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ABSTRACT

A circuit system of electronics is presented along with its characteristics which has been designed and used for the purpose of the infrared photometry. The system consists of a low noise preamplifier for infrared detectors, a phase shifter to adjust the phase of the reference signal and a synchronous rectifier having an arbitrary time constant. These units are described in detail on their resulting properties such as the noise figure, the linearity or the frequency response etc.

1. Introduction

An electronic system for the infrared measurement in astronomy is essentially a low noise amplifier whose circuit constitution is the same as that of a 'lock-in amplifier', where an electric signal of alternating current, which corresponds to the intensity of the incident infrared radiation, is rectified by means of a reference signal synchronized to the modulation frequency. This low level signal from the detector even buried under the apparent noise level can be picked up by selecting an appropriate time constant of the rectification, i. e. a sufficiently narrow band width of amplification.

In this paper we describe an electronic system outline and its characteristics of the device which has been designed and constructed for the purpose of infrared observations in Okayama Astronomical Observatory. We have carried out observations several times since December 1968 in the place, and celestial objects such as Moon[1], planets, some infrared stars and many variable stars have been investigated by the photometric and polarimetric measurements. In these observations our electronic system have shown a rather satisfactory performance in reliability and stability.

2. Circuit Compositions—Synchronous Rectification and Phase Shifter

An impedance of PbS detector is typically less than 1 MΩ at the room temperature, but it exceeds 10 MΩ when cooled to the temperature of liquid nitrogen. So one must use the preamplifier of a very high input impedance and of a lower noise level compared to that of PbS detector itself. In our system

1) Matsumoto et al., 1969 COSPAR report, to be published.
S. Hayakawa et al., 1970 Space Research, 10, 1007.

112 A type pre-amplifier of P. A. R. Co. has been in use (Zin=100 MΩ, gain Av =100. and noise figure N. F. ≤1 dB under the actual condition), which can satisfy severe conditons sufficiently.

After the pre-amplifier A. C. main amplifier of about 20 dB is connected and then the A. C. signal modulated by the mechanical chopper is again rectified by means of the synchronized reference signal and is converted to D. C. voltage. The obtained D. C. signal is recorded on the chart or tape recorder etc. after being amplified by a D. C. amplifier. The whole scheme of our electronic circuit is shown by a block diagram of Fig. 1.

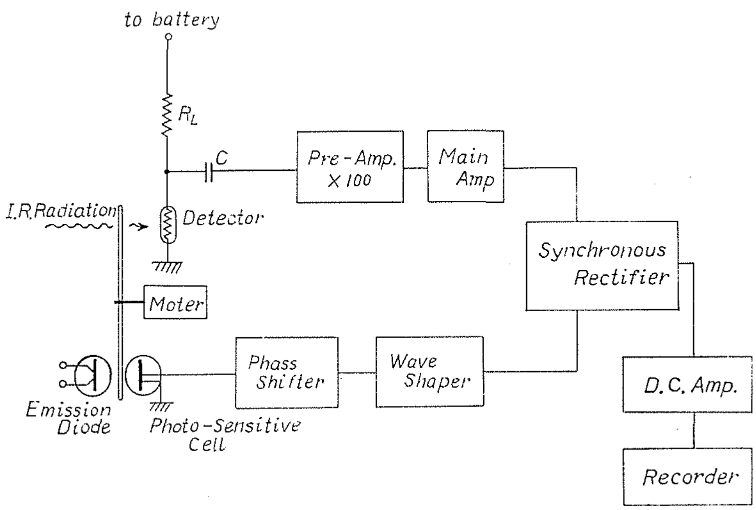

Fig. 1. The block diagram of the electronic system for the infrared astronomical measurement.

(1) *Reference signal generator*

There may be many ways to get the reference signal; for example from a special switching part which is sensitive to metalic pieces of the chopper plate, or from an A. C. generator coupled to the axis of the motor, and so on. However we use a pairing set of a Ga-As emission diode[1] and a silicon photo-sensitive cell in order to obtain the reference signal in such way as they are confronted each other in both sides of the rotating chopper plate. So the light emitted by the Ga-As diode is received by the photo-sensitive cell, generating the corresponding reference signal[2].

(2) *Synchronous recetification*

An elementary circuit of the transistor synchronous rectifier is shown in Fig. 2. This is the same pattern as the phase detector[3] which can yield the output voltage proportional to the cosine of the phase difference between two input signals. The germanium alloyed transistor can be used for these purpose

1) Ga-As emission diode: Hayakawa Electric Co. (Type GLE-502)
2) The emission spectrum of Ga-As diode is very narrow banded (9300 Å±200 Å, at 25°C), so its scattered light dose not interfere the infrared radiance.
3) Kawakami, M. ,Denshi Kairo V' 215.

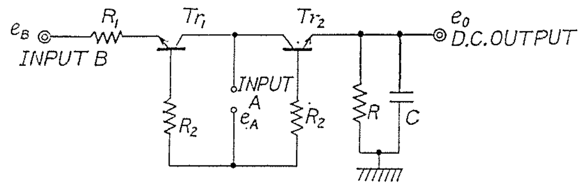

Fig. 2. The elementary circuit of the synchronous rectification.

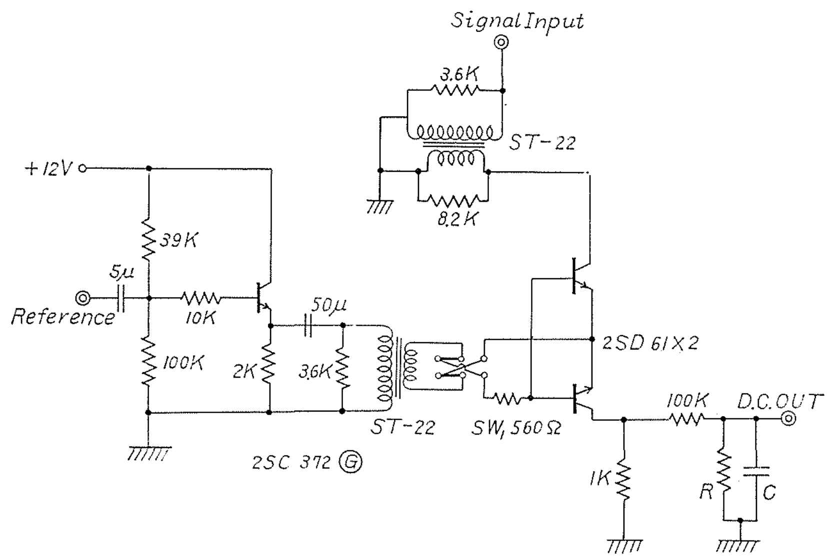

Fig. 3. The synchronous rectifier. The impedance of reference signal is reduced by an emitter follower. Two input transformers (ST-22) are used for impedance matching. The time constant $\tau = RC$ is decided by a resistor R and a capacitor C in the output terminal side.

because it operates well with the exchange of its collector and emitter, so the A. C. signal is rectified by the alternating biasing of the square waved reference signal. The practical circuit in use is shown in Fig. 3. The linear response to the input signal is also verified (see the next section). But the existence of transformers for the impedence conversion make the frequency response worse, especially in lower frequencies ($\leq$50 Hz), although it is not necessary in such low frequency region because of the higher optimum frequency of our detector.

(3) *Phase shifter*

The rectification efficiency of the synchronous rectification is proportional to the product integration of the two input waves; the reference and the intrinsic signal. So one must adjust their phase angle of waves to either zero phase difference or 180° phase difference. It the phase adjustment is carried out to zero phase difference, the D. C. output has positive sign, and in the opposite case, it becomes to have negative sign.

As these two signals are generated independently, the phase difference may be fixed arbitrarily. However it is possible in our system to adjust wave phases each other by shifting the phase angle by an electronic circuit as in the next

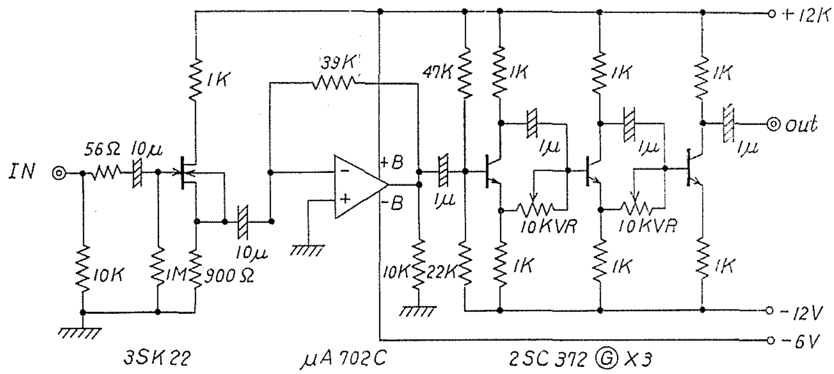

Fig. 4. The phase shifter of the reference signal.

figure, in spite of moving the position of the reference signal generator.

The phase at the collector in the usual transistor circuit of the emitter-grounded type is inverted to the input wave phase. On the other hand the wave at the emitter is not inverted in phase as in the emitter follower type. So one can obtain the signal of arbitrary phase lag to the input wave by superposing the waves from the collector and the emitter.

3. Resulting Characteristics

The PbS detector using for the test of the electronic set explained above is a high sensitive cell cooled by liquid nitrogen, whose sensitive proper area is 1×1 mm. The radiation to be detected is collected by a Fabri lens of 1 cmϕ, so the effective area S_1 of the detector is about 3/4 cm^2. Some characteristics of the electronic system are shown as follows in the use of this PbS cell.

(1) Noise Level

The input noise level of the PbS detector which can be expressed by a concept of noise equivalent power (N. E. P.) is shown in Table 1, comparing the noise of the preamplifier itself. The noise of the detector is supposed to come

Table 1. Noise level of the detector (PbS) under the conditions as the chopping frequency f_0 equals 200 Hz and the band width $\Delta\nu$ is 1 Hz (the left column). The right column shows the noise of the pre-amplifier when a 10 MΩ resistor is connected at the input.

	PbS detector	(without PbS) $R=10$ MΩ
Noise (μV)	1.80	1.15
N. E. P. (W)	2.2×10^{-12}	——
Bias	$V_B=22.5$ V $R_B=10$ MΩ	

from many typer of complicated noise sources (Johnson noise, flicker noise, current noise, radiation noise and so on), but in the low frequency region it is expressed in the $1/f$ law as a general feature. On the other hand the cooled

PbS detector has a rather slow response time of the order of 10 msed, so one must find out the optimum operating condition experimentally about the bias voltage, temperature or modulation frequency, etc. The detailed report on the optimum condition of the liquid nitrogen PbS detector is seen in some reference (see for example Potter and Eisenman, 1962 Appl. Optics, 1, 567).

(2) Linearity Check

It is important to check the linear response of the electric signal against the incident infrared radiance. The test is easily carried out by changing the diaphragm radius of the infrared radiator. In Fig. 5 it can be seen that the linearity of the system in the range from 10^{-8} W to 10^{-11} W is realized exactly. Above the incident radiance of 10^{-8} W the curve bends down because of the satulation effect of the main amplifier. However this satulation effect may be avoidable by an attenuator before the main amplifier.

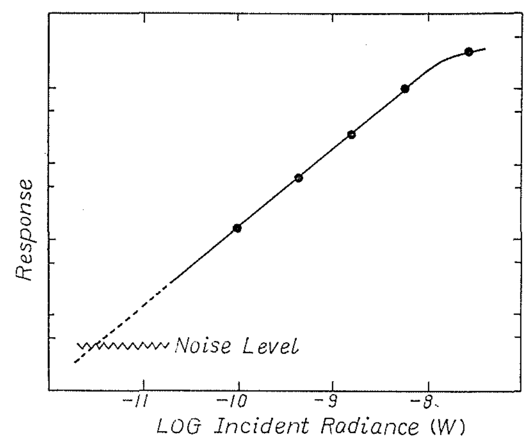

Fig. 5. Linearity test of the electric signal against to the infrared radiance from the radiator. The test condition is as follows; the black body temperature is 1000°K; the modulation frequency equals to 200 Hz; the effective wavelength is 2.2 μ.

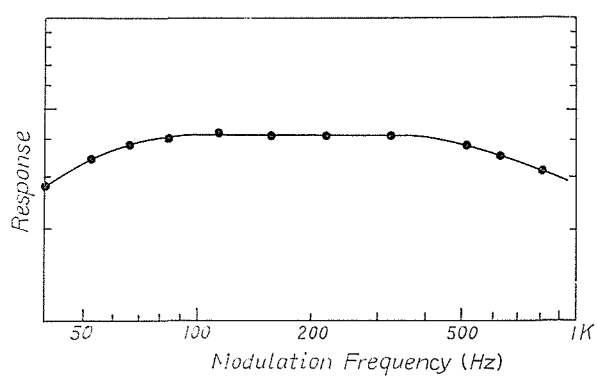

Fig. 6. The frequency response of the circuit system, measured by the PbS detector in the room temperature.

(3) Frequency response and other characteristics

As is described before, the liquid nitrogen cooled PbS cell has a very slow time constant of the order of 10 msec. So it must be necressary to use the PbS cell in the room temperature, where the time constant is less than one millisecond, in order to test the frequency response of the circuit system.

The lower limit of the frequency response is restricted by transformers used in the synchronous rectifier in the Fig. 3. The transformers are necessary for the impedance matching in the transister circuit. (The another type of synchronous rectification by the use of field-effect transistors will be developed which can be served in direct coupling because of their high imput impedance.) But in the usual case of PbS detector or other photo-conductive detectors, such as Hg-doped Germanium detector, the practical frequency of the optimum condition is in the range from 100 Hz to 1 kHz.