ON THE IMPROVEMENT OF ACCURACY IN MEASURING WEAK NOISE SIGNALS AT MICROWAVE FREQUENCIES

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Summary—To improve stability of a radiometer, we must first design the equipment so as to reduce the influence of variations in modulation frequency as well as in local frequency. All power supplies should then be kept constant within 0.1%.

Substitution error is apt to be the main cause of incorrect calibration, which can be reduced remarkably by applying a new simple method of extending the *h-f* circuit.

Two applications of Faraday rotation are suggested in reducing substitution error and in the static modulation. A high modulation frequency which may be obtained from the latter application will reduce fluctuations on the record.

In completing calibration curves, it is preferable to use magic tees as the attenuator.

I. Introduction

None will have serious objection, at present, to use Dicke's method[1] or something of the kind in measuring weak noise signals at microwave frequencies. So we deal only with the case where it is used.

Of course, there are many troublesome problems in measuring weak signals, which are to be compared with thermal noise from resistive termination, with constant accuracy of about 1%. But these problems may be summarized into three subjects, *i.e.*, the improvement of stability, the improvement of the accuracy of calibration and the reduction of fluctuations on the recorder.

We have studied on these subjects about the equipment for the observation of solar noise, and we relate here some results and opinions, though they are not yet fully investigated.

II. The Improvement of Stability

If we pay regular attention to the deterioration of tubes and preheat the equipment sufficiently, we may attribute the cause of instability to the variation of line voltage, line frequency and weather conditions. Now we must first design the equipment such as to reduce the influence of these variations and then stabilize these variations themselves as much as possible.

1. h-f part

Here, we must consider the variation of frequency and output power at the local oscillator, the latter being of less importance. As the frequency variation, on the other hand, is apt to exert an influence directly upon the accuracy of calibration (see III, 1), *h-f* circuits should have a good match around the frequency used and, in addition, it is desirable to stabilize the frequency itself to a certain extent.[2] The use of single-resonant cavity in the *h-f* circuit is generally undesirable.

2. i-f part

Owing to a high gain and a wide bandwidth, the number of *i-f* tubes generally exceeds 10. Accordingly, the gain of the amplifier is largely dependent on supply voltages. However, only slight and gradual change is left when both heater and high voltage supplies are kept constant within the order of 0.1%.

A considerable change of gain may arise when a tube is substituted. In this case, the calibration will change due to the nonlinearity of diode detector unless the gain is adjusted to the previous value. To avoid this trouble, it is most preferable to use square-law detector as is mentioned later, but the automatic gain control system may also be available.

3. l-f part

We have already described that it is undesirable to use selective circuits in the *l-f* amplifier,[3] as the gain is apt to change with the change of modulation frequency (line frequency) and atmospheric temperature. The *l-f* amplifier has become very stable after we adopted the system of lacking these circuits and applied negative feed back to each stage.[2]

4. Power supplies

It is hard to keep the sensitivity constant within the order of 1% unless we stabilize all supply voltages within 0.1%. This stability can be obtained with circuits as described on other pages.[2]

5. Weather conditions

It is difficult in general to keep the room at constant temperature and low humidity, as it is very expensive. But the gain has little connection with temperature, though we must adjust zero point frequently at the corresponding position on the recorder paper. If the humidity, on the other hand, increases up to near 100%, accuracy decreases to a certain extent, but it may be tolerable as these cases are very few.

III. The Improvement of the Accuracy of Calibration

To perform the accurate calibration, we must first reduce the substitution error, prepare the proper noise standard and then complete the calibration curves.

1. The reduction of substitution error

Substitution error is one of the main causes of deteriorating the accuracy of calibration, which is apt to be overlooked. It is caused when the output impedance of a standard noise circuit is unequal to that of the signal circuit to be calibrated. Generally, even a mismatch of 1.1 in v.s.w.r. may cause some error, unless the crystal converter is carefully adjusted (see the foot note on the next page). When the input circuit has a sharp resonance around the frequency concerned, calibration may also change with the drifting of local frequency.

The cause of this error can be considered as follows. The *i-f* impedance and the conversion loss of the crystal converter is largely dependent on the *h-f* impedance looked from the converter, and so the output noise changes with *h-f* impedance. Consequently, when the modulator is matched and the input circuit is mismatched, for instance, it seems as if there were some noise source (positive or negative) at the input, which is equal to the substitution error.

Two methods are presented as follows, which are considered to be effective for the reduction of substitution error.

A. Long line method. Now, when we connect a resistive load having some reflection at the in put and change its position gradually, the deflection on the recorder will change as shown in Fig. 1, *i.e.*, it will change sinusoidally around the mean deviation. Though we can not reject this mean deviation, it is generally easy to make it negligible for the reflection of less than 1.2 in v.s.w.r. The sinusoidal component, on the other hand, is generally large and it is troublesome to make this variation less than 100° K *p-p* when a shorting plunger is moved slowly in the input waveguide.* However, the substitution error can markedly be reduced without fine adjustments.

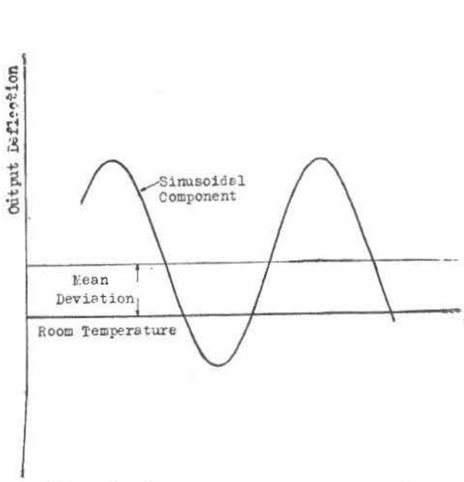

FIG. 1. Output variation due to the impedance change in *h-f* circuit.

Suppose now that the variation is sinusoidal as to the single frequency f_1 in the pass-band of the receiver. If another frequency f_2 exists in such a manner as to cause variation of opposite phase and eqnal amplitude, these variations will be cancelled each other. The variation will also disappear in the actual case if such relations exist among the whole frequencies in the pass-band.

These circumstances can be realized by extending the transmission line in the *h-f* circuit to an adequate length. For example, to remove the variation caused by moving the position of a shorting plunger, the length of the transmission circuit should be so chosen that the reactance at the *h-f* side of the converter covers from $-\infty$ to $+\infty$ for all frequencies in the receiving band. This length l can be represented as follows,

$$l = \frac{\lambda_1 \lambda_2}{2(\lambda_1 - \lambda_2)}$$

where, λ_1, λ_2 are the wavelengths at the upper and lower limit of the pass-band. For instance, l is about 19 metre for the center frequency of 4,000 MC and band width of 6 MC when the waveguide of 58×29 centimetre is used. Practically, however, a half of this length will be sufficient for the present purpose, as the reflection is small.

It is most desirable to prolong the length between the converter and the modulator, but tolerable success can be expected by increasing the distance between the modulator and the input terminal. In the latter case, however, the line near the modulator and the modulator itself should have little reflection, otherwise calibration will change with the frequency drifting.

Fortunately, we could make an experiment easily using a part of the feeder in

* It can be reduced to less than 20° K by the following method: (1) is the use of hybrid junction at the *i-f* input, (2) is to adjust *experimentally* the path-difference between two side arms of the magic *T* at the balanced converter and (3) to adjust *experimentally* the length between the magic *T* and the image rejection filter.

the interferometer.[2] The result was very satisfactory. We could perceive no error for the impedance variation within 1.2 in v.s.w.r. of the load 13 metre apart from the modulator. The only defect in this method is that the noise figure increases a little, but it is rather of little consequence.

FIG. 2. The desirable arragement in measuring solar radio noise.

The desirable arrangement in measuring solar radio noise is illustrated in Fig. 2.

B. Non-reciprocal method. This method has not yet been ascertained by experiment.

The substitution error may also be eliminated by inserting a non-reciprocal circuit between the converter and the modulator. Uuder these circumstances, the *h-f* impedance looked from the converter will be constant, having no connection with the input circuit.

The non-reciprocal circuit may be obtained only by utilizing Faraday rotation as shown in Fig. 3, though the frequency range in which the insertion loss might be neglected is now not so wide enough.

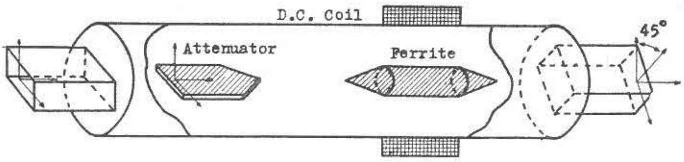

FIG. 3. A non-reciprocal circuit using Faraday rotation.

2. Noise standard

As the noise standard at microwave frequencies, we can only use thermal radiation emitted from the resistive load at known temperature. Though a resistive load at room temperature is the one that we can readily available, we must prepare another standard which is called 'hot load'.

The hot load which we use at present is shown in Fig. 4. The temperature of the resistor can be kept constant within $\pm 0.5°$ C around 300° C. The heating power is so adjusted as to minimize the change of indication when the thermometer in the waveguide is moved slowly as shown in the figure.

The sky temperature[4] may be used as a sub-standard, which is convenient to watch the receiver gain. The noise of a fluorescent lamp, on the other hand, is largely dependent on the surrounding temperature,[5] and it should rather be considered as a noise source which must be calibrated by the hot load.

3. The completion of calibration curves

To complete calibration curves, it is necessary to use proper noise sources and accurate attenuators. However, the accurate calibration of the attenuator is generally difficult.

We have considered that the most accurate calibration can be performed if magic tees and noise sources are combined as shown in Fig. 5.

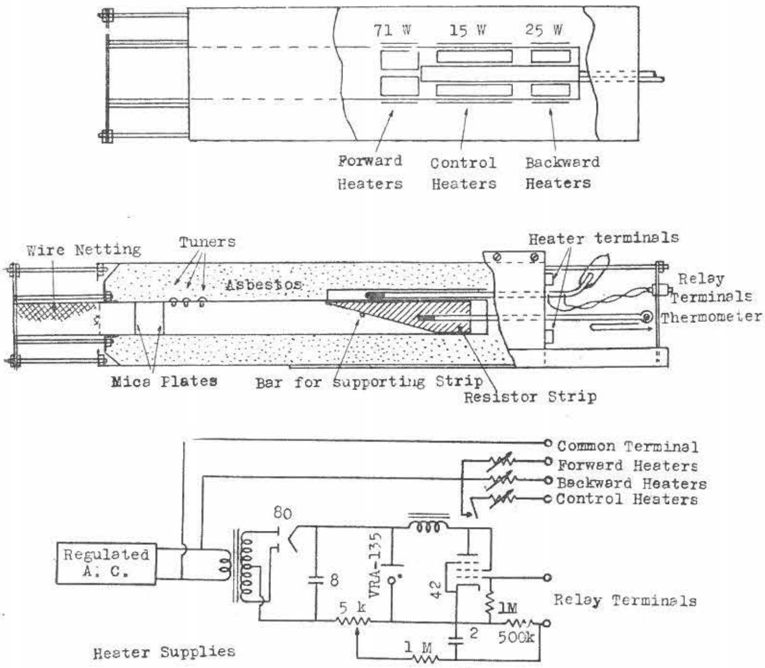

FIG. 4. The hot load used in our laboratory.

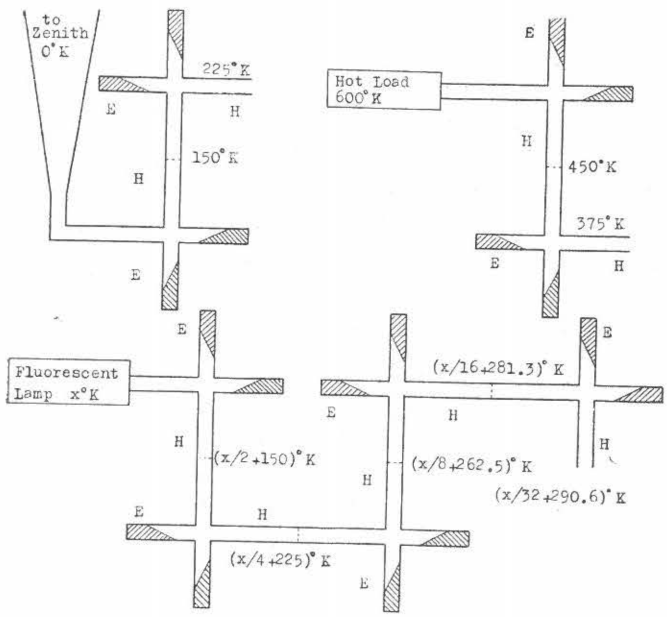

FIG. 5. Standard noise signals for the calibration.

If the square-law detector is employed and that all other circuits are linear, the calibration will become very simple. In this case, two standard points are sufficient to calibrate the whole range and, in addition, the amount of attenuation in the *i-f* amplifier is the same as in the complete equipment. Now, a square-law detector of stable characterisitic is rather hard to obtain. But the crystal rectifier may be available if the low output level is allowed. In this case, however, a higher modulation frequency will be required if no selective circuit is inserted in the *l-f* amplifier.

IV. The Reduction of Output Fluctuations

The output fluctuations[2] are inversely proportional to $F/\sqrt{B\tau}$, where F is the noise figure, B is the receiving bandwidth and τ is the overall time constant. In observing solar radio noise, τ must be less than about 1 second.

To reduce output fluctuations it is preferable to choose wider band width and, in addition, to receive two bands on both sides of local frequency. However, it may not be allowed when the signal or the aerial system is sensitive to frequency.

As has been pointed out by Dicke and Steinberg, the choice of a higher modulation frequency may be effective to improve noise figure of the receiver, though it may not be so fruitful as in metre waves. It is, however, difficult to realize more than scores of cycles mechanically. Only a static modulation will be able to satisfy this requirement.

At the frequency where Faraday rotation can be used, the static modulation can be realized by an instrument as shown in Fig. 6. The intermittent current of high frequency flows in the coil, so that the *h-f* circuit is terminated in the input and resistor alternatively.

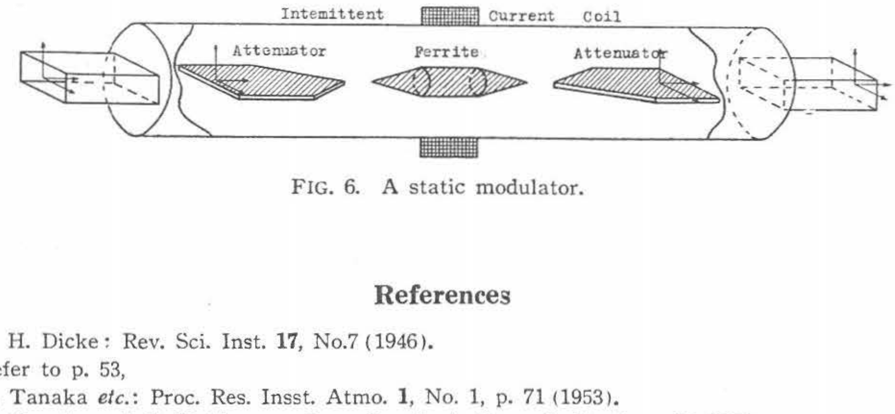

FIG. 6. A static modulator.

References

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2) Refer to p. 53,
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