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Fluctuation sensitivity models of microwave radiometers

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***Abstract*— This paper offers a comparative analysis of the fluctuation sensitivity of radiometers of different types. We have considered mathematical models of fluctuation sensitivity , taking into account the destabilizing factors. Practical recommendations on the approaches to increasing the fluctuation sensitivity have been provided. We have covered the results of the calculation of fluctuation sensitivity on a standard radiometry receiver that operated in different modes.**

Keywords*— *Fluctuation sensitivity, anomalous fluctuations of the receiver, temporary instability, radio physical research, scientific instrumentation.

I. Introduction

Fluctuation sensitivity is one of the basic characteristics of radiometers. It determines the level of device fitness for sensing natural processes with minimum changes in the brightness temperature. In this paper, we have included a comparative analysis of the fluctuation sensitivity of radiometers of different types as well as the ways of increasing the sensitivity.

II. Radiometer models

Full-power radiometers are one of the most widespread radiometer types and they have potentially highest sensitivity [1]. However, due to the influence of anomalous fluctuations of receiver parameters, practical implementations of full-power radiometers cannot achieve the theoretical (potential) sensitivity. Fig. 1 shows a generalized structural scheme of a full-power radiometer.

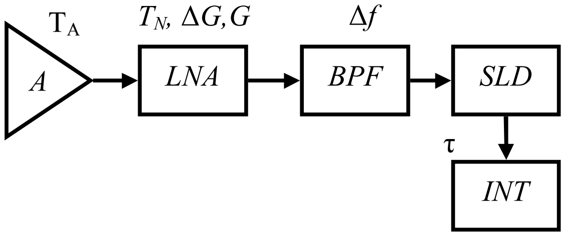

Fig. 1. Generalized structural scheme of a full-power radiometer

The structural scheme comprises antenna A, low-noise amplifier (LNA), bandpass filter (BPF), square-law detector (SLD) and integrator (INT). The sensitivity of the full-power radiometer ΔT_A, is determined via [5]:

$$\Delta T_A = \left(T_N + T_A\right) \times \sqrt{\frac{1}{\Delta f \times \tau} + \left(\frac{\Delta G}{G}\right)^2}\,, \tag{1}$$

where T_A is the noise temperature of the LNA, Δf is the bandwidth of the BPF, t is the time constant of the integrator, T_A is the noise temperature of the antenna, the relation of ΔG to G is the amount of normalized fluctuations of the receiver's transmission coefficient. By analyzing formula (1) we can conclude that the sensitivity of the full-power radiometer is reduced as the noise temperature of the antenna increases. Here, the sensitivity is determined by the technological parameters of the receiver. These parameters (apart from the parameters pre-defined during hardware design, Δf, τ) influence anomalous fluctuations.

Fig. 2 shows the structural scheme of a Dicke's radiometer.

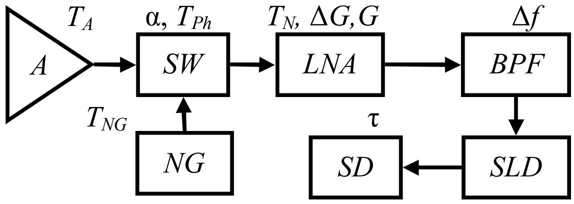

Fig. 2. Structural scheme of a Dicke's radiometer

As compared to the full-power radiometer, the structural scheme of a Dicke's radiometer (see Fig. 2) is fitted with an additional switch (SW), noise generator (NG) and synchronous detector (SD) [2]. If we take into account the parameters of the switch, then sensitivity ΔT_A, of the Dicke's radiometer is determined via the following formula:

$$\Delta T_A = \sqrt{2 \cdot \frac{\left(T_A + T_N + \left(T_{Ph} \cdot (1-\alpha)\right)\right)}{\Delta f \times \tau} + 2 \cdot \frac{\left(T_{NG} + T_N + \left(T_{Ph} \cdot (1-\alpha)\right)\right)}{\Delta f \times \tau} + \left(T_A - T_{NG}\right) \cdot \left(\frac{\Delta G}{G}\right)^2}\,, \tag{2}$$

where T_{Ph} – physical temperature of the input switch, α – losses of the input switch, T_{NG} – noise temperature of the noise generator.

By analyzing formula (2) we can conclude that the sensitivity of Dicke's radiometers is reduced, which is caused by: 1) the losses in the input switch (SW); 2) the reduction of the equivalent time of signal accumulation by 2 times (as compared to full-power radiometers); 3) the influence of anomalous fluctuations and an equivalent increase in the noise power at the input due to the input of noise generator signal into the measurement path.

Improved sensitivity in Dicke's radiometers is possible through technological facilitation: reduced losses in the *SW*, reduced anomalous fluctuations in the receiver, reduced physical temperature of the *SW*, receiver, etc.

A special case in radiophysical sensing implements the null method of measurement where the last summon of formula (2) is reduced to zero (applicable to (2) where $T_A = T_{NG}$) thus making high stability radiometers based on this method possible [3]. Fig. 3 shows a generalized structural scheme of high stability radiometers.

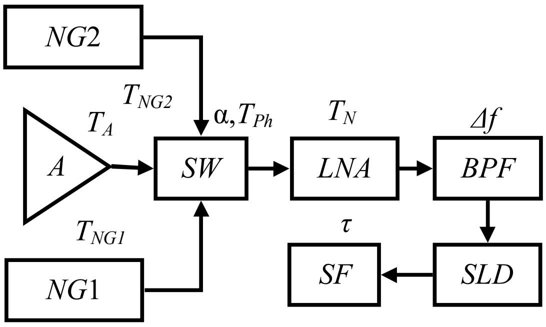

Fig. 3. Generalized structural scheme of high stability radiometers

As compared to Dicke's radiometers, the structural scheme (see Fig. 3) is fitted with reference generator (*NG*2), and synchronous filter (*SF*) performs the synchronous filtration of the signals from the antenna and the noise generators [4, 5]. The sensitivity of a high stability radiometer is described via the following formula:

$$\Delta T_A = \sqrt{\frac{T_{NG1}\cdot\left(T_{NG1}+T_{NG2}\right)}{\Delta f\cdot\tau} + \frac{T_{NG1}\cdot 4\cdot\left(T_N+T_{Ph}\cdot(1-\alpha)\right)}{\Delta f\cdot\tau} + \frac{2\left(T_N+T_{Ph}\cdot(1-\alpha)\right)^2}{\Delta f\cdot\tau} - \frac{T_A\left(T_A+T_{NG2}+2T_{NG1}\right)}{\Delta f\cdot\tau}}, \quad (3)$$

where T_{NG1} and T_{NG2} are the noise temperatures of the first and second noise generators, respectively.

If we analyze expression (3), we can conclude that in high stability radiometers, there is no influence of anomalous fluctuations of transmission coefficient, and the fluctuation sensitivity is reduced as the noise temperatures of reference noise generators increases.

In papers [6-8], a new method of increasing fluctuation sensitivity was described. It is based on the multi-receiver design principle used together with the null method of measurement. Here, increased fluctuation sensitivity is implemented based on the following:

1) the physical effects that emerge when the measured noise signal is compared to reference noise sources that have low dispersion;

2) the continuous measurement of the signal from the antenna implemented by dividing it across different receivers in time.

Fig. 4 shows a generalized structural scheme of a high stable multi-receiver radiometer.

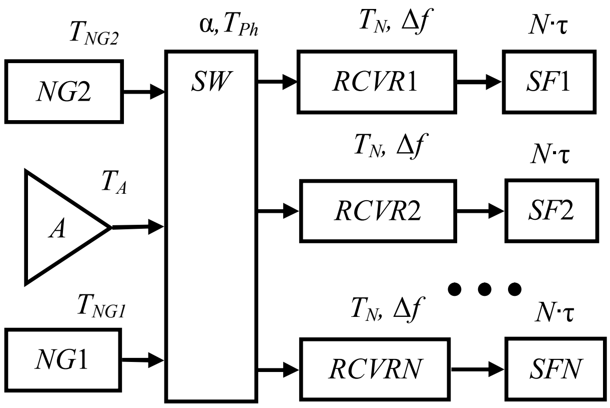

Fig. 4. Structural scheme of a high stable multi-receiver radiometer

The fluctuation sensitivity of a multi-receiver radiometer is described by the following expression:

$$\Delta T_A = \sqrt{\frac{2(T_{NG1}+T_N+T_{Ph}\times(1-\alpha))^2+\frac{T_{NG2}^2}{4}}{N\times\Delta f\times\tau}}, \quad (4)$$

where N is the number of receivers. If we analyze formula (4), we can conclude that the fluctuation sensitivity in multi-receiver radiometers is increasing proportionally to the square root from the number of receiver channels relative to the sensitivity of a single receiver channel, without increasing the duration of measurements. This is in accordance with the theoretical [8] and experimental [9] research. Increased sensitivity is achieved by increasing the time constant of the synchronous filter. Here, the properties of the measurements have dynamics on par with high stability radiometers with one receiver. This is possible due to the separation of antenna's signal in time across the receiver channels.

To perform a comparative evaluation of the mathematical models in question we have calculated the fluctuation sensitivity of radiometers of different types. The results of the calculations are given in Fig. 4.

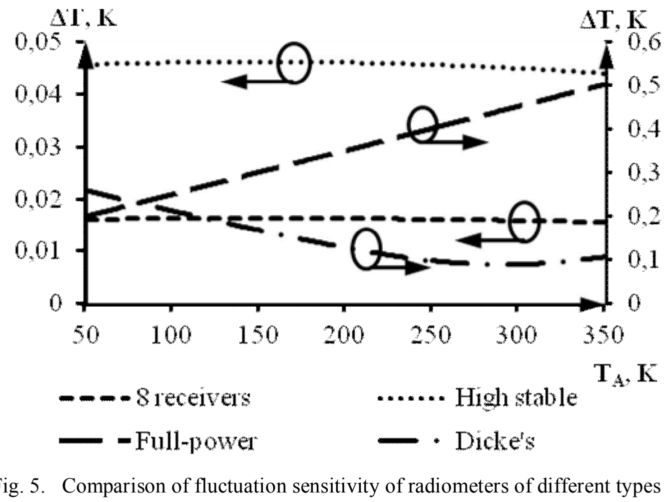

Fig. 5. Comparison of fluctuation sensitivity of radiometers of different types

We evaluated the mathematical models in the dynamic range between 0 and 350 K. We took the parameters of the receiver based on the typical values for microwave radiometry systems [10] operating in the frequency range between 1...40 GHz. Namely, the noise temperature of the receiver is T_N=150 K, the normalized fluctuations of the receiver's transmission coefficient are $\Delta G/G = 10^{-3}$ and the noise temperatures of reference noise generators are $T_{NG1}=T_{NG2}$=300 K. As the rule of thumb, 8 receivers are sufficient for evaluating the sensitivity of a high stability multi-receiver radiometer.

III. Conclusion

Having analyzed the results of the comparative evaluation of the mathematical models, we conclude the following. If we consider the practical applications where high fluctuation sensitivity is required, then it makes sense to use high stability microwave radiometers. The sensitivity can be increased extensively (without technology improvements) by utilizing multiple receivers. In all types of microwave radiometers, the fluctuation sensitivity depends on the values of the noises measured. This peculiarity makes full-power radiometers the preferred choice over Dicke's radiometers for noise signals that are close to absolute zero (in the example considered in Fig. 5, those have temperatures up to 80 K). For high stability radiometers, the creation of new principles for the measurement process workflow is a pressing objective, as they should provide for reduced power of reference noise generators in order to increase the fluctuation sensitivity. Increased sensitivity in high stability radiometers can be achieved by removing the switch from the input microwave part. Evidently, this is the objective for future research in this promising area.

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