UDC 621.396.628:523.164

CENTIMETER BAND RADIOMETER ELIMINATING THE EFFECT OF SPURIOUS SIGNALS BY MEANS OF AUTOMATIC HETERODYNE FREQUENCY CONTROL

L. I. Gershtein

Izvestiya VUZ. Radiofizika, Vol. 8, No. 4, pp. 771-774, 1965

A description is given of the operating principle and circuit of a centimeter band radiometer in which an automatic heterodyne frequency control system is employed to eliminate the effect of spurious signals on measurement results. The system is controlled by the mixer current component with the modulation frequency. The method employed enables rectifiers and double bridges to be omitted in radiometer construction. Results of tests with the experimental model are given.

In radio astronomy measurements comparing different sources, the radiometer input is permanently connected to an antenna. When making such measurements it does not matter if a spurious signal is present so long as its magnitude does not change during the measurements.

Present radiometer constructions enable spurious signals to be eliminated by the use of rectifiers and double bridges. However these elements narrow the radiometer band. Moreover, rectifiers introduce appreciable losses in certain sections of the spectrum, and double bridges complicate the construction of the apparatus. It is therefore of some interest to eliminate the effect of a spurious signal on the results of measurements without using the elements mentioned.

The spurious signal arising in a radiometer of the unbalanced (single crystal) type with a directional coupler in the heterodyne circuit is made up of two components.

Component 1 is associated with the unequal reflection from input and modulator of the noise power radiated by the mixer at the receiving channel frequencies which are again incident on the mixer. This component is considered in [1]. Applying similar calculations to a radiometer with a waveguide line and two receiving channels one can obtain an expression for component 1 of the spurious signal at the radiometer output (with a square-law second detector):

$$V_{\mathrm{I}} = 2\rho\varkappa T\left[(p_2^2 - p_e^2)(f_1 - f_2) + \int\limits_{f_h - f_1}^{f_h - f_2} Q(f)\, df + \int\limits_{f_h + f_2}^{f_h + f_1} Q(f)\, df\right] G. \tag{1}$$

Here V_1 is the voltage of component 1 at the output, ρ is the characteristic impedance of the guide, $\varkappa$ is Boltzmann's constant, T is the equivalent temperature of the mixer, p_2 is the reflection coefficient of the radiometer input, p_e is the modulator reflection coefficient, f_1 and f_2 are the upper and lower limits respectively of the IF amplifier pass band (the form of the frequency characteristic is taken to be rectangular), G is the radiometer gain*, f_h is the heterodyne frequency, and

$$Q(f) = p_e \cos\frac{4\pi l_m\sqrt{f^2 - f_c^2}}{c} - p_2\cos\frac{4\pi l_a\sqrt{f^2 - f_c^2}}{c}$$

(l_m and l_a are the distances from the modulator and antenna input to the mixer respectively, c is the velocity of light, f is the frequency, and f_c is the critical frequency of the waveguide).

Component 2 is caused by the unequal reflection of heterodyne power from the input and modulator, which leads to the modulation of the heterodyne signal arriving at the mixer, and, correspondingly. of the mixer noise at the intermediate frequency. Taking into account that the propagation paths of the powers reflected from the input and modulator are identical for both component 1 and component 2, the following approximate expression for component 2 can be obtained

$$V_{\mathrm{II}} = nP_h Q(f_h)\, G, \tag{2}$$

*The radiometer gain consists of two factors: $G = G_0 u$, where G_0 is the power gain from the radiometer input to the second detector, and u is the voltage gain from the output of the second detector to the radiometer output.

where V_2 is the voltage of component 2 at the radiometer output, P_h is the heterodyne power, n is a numerical coefficient which is determined by the dependence of the mixer noise at the intermediate frequency on heterodyne power; the remaining quantities in expression (2) are the same as in expression (1).

It is clear from the definition of component 2 that the voltage V_2 at the output is caused by the presence in the mixer current of a component with the radiometer modulation frequency; component 2 of the spurious signal will be absent if there is no component with the modulation frequency in the mixer current.

If the constant voltage component, proportional to the magnitude of the mixer current component with the modulation frequency, is separated out by means of a selective amplifier with a phase-sensitive detector connected to the mixer, we are able to observe the sign and relative magnitude associated with component 2 of the spurious signal.

The dependence of expression (2) on the heterodyne frequency is determined by the quantity $Q(f_h)$; it in its turn is an alternating quasiperiodic function of frequency, passing through zero for a series of values of f_h. To a good approximation the frequency intervals between these values (roots of the expression $Q(f) = 0$) are inversely proportional to the length of the waveguide line (from mixer to antenna).

By automatic control of the heterodyne frequency, using the absence of a crystal current component with the modulation frequency as an indication, it is possible to hold the value of $Q(f_h)$ close to zero, and so also the value of V_2 at the radiometer output. Automatic frequency control is possible at any of the frequencies which are roots of the equation $Q(f) = 0$. Since these frequencies are fairly close together (in the experimental model they are spaced $(2\text{-}5)\cdot 10^{-3} f_h$ from each other), automatic frequency control is possible in practice at any of the previously given frequencies. Thus component 2 of the spurious signal is eliminated by automatic control of the heterodyne frequency.

In addition to this, by automatic control of f_h, the quantities appearing in expression (1) for component 1 of the spurious signal do not change their values (except T and G) during measurements on any of the chosen frequencies; T and G may change their magnitudes slowly and insignificantly. Thus automatic frequency control also leads to the stabilization of component 1 of the spurious signal.

The expression $Q(f)$ is close to an odd function of frequency relative to those frequency values which are roots of $Q(f) = 0$. Thus the two integrals appearing in expression (1) whose integrands are $Q(f)$, and whose limits are symmetrically placed on either side of the f_h values, will have roughly equal values but opposite signs; since their sum appears in expression (1) the magnitude of component 1 will be very much reduced.

What has been said about the decrease in component 1 is naturally of a qualitative nature. It is difficult to determine the quantitative relationships in their general form. Expression (1) was calculated on a computer for a number of concrete cases; as a result of these calculations we may conclude that when the automatic frequency control system operates the size of component 1 is reduced roughly by an order of magnitude on the average. Calculation and experiment show that the remaining value of component 1 of the spurious signal depends on the automatic control point which is chosen, and can vary by a factor of several times (from one point to another).

One might ask whether the required signal itself on entering the radiometer will not bring the frequency control system into action and thus lower the sensitivity of the radiometer. Calculation of the size of this effect has shown that in the worst possible case the reduction in sensitivity is negligibly small (less than 0.1%).

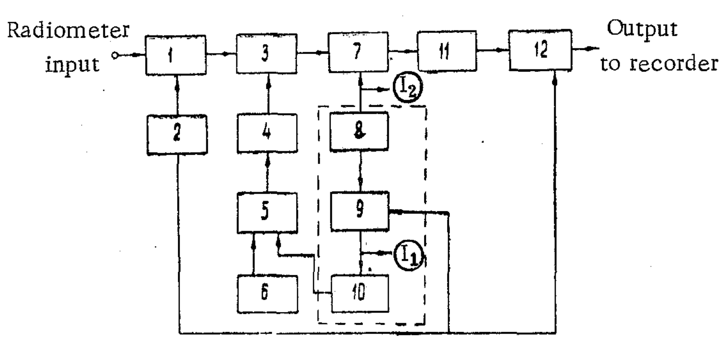

Fig. 1. Block diagram of the radiometer: 1) mechanical waveguide modulator; 2) modulation frequency generator F_m = 182 cps; 3) directional coupler; 4) heterodyne of band (1.7 ÷ 2.7 cm); 5) controlled heterodyne feed source; 6) device for manual control of feed source; 7) single crystal mixer; 8) F_m frequency amplifier; 9) phase-sensitive detector; 10) automatic frequency control circuit filter; 11) IFA (f_{int} = 100 Mc; Δf = 27 Mc, noise factor 2.5); 12) radiometer low-frequency unit. I_1 mixer current indicator, I_2 control system indicator. Units surrounded by the broken line refer to the automatic frequency control system only.

Fig. 1 gives a block diagram of the experimental apparatus. As is clear from the block diagram the radiometer employs a single crystal circuit with a directional coupler. The receiver band (λ = 1.7-2.7 cm) is basically determined by the mixer cavity construction 7. The mechanical disc modulator 1 and directional coupler 4 operate satisfactorily over the whole working range of the waveguide employed. The intermediate frequency f_{int} = 100 Mc. For such a choice of f_{int} the heterodyne noise will be small, which makes it unnecessary to use bridge circuits to reduce this noise level. A selective amplifier 8 tuned to the modulation frequency $F_m \doteq 182$ cps is connected to the indicator of the mixer crystal current I_1. The automatic frequency control signal passes from the output of amplifier 8 to the phase-sensitive detector 9, and then through filter 10 to the controlled feed source 5 of heterodyne 4. Thus the control circuit is closed. For control and preliminary setting of the selected operating point of the circuit, indicator I_2 and the manual tuning control 6 of the feed source (and so of the heterodyne frequency) are provided.

The test model which was set up had the following data:

1) Tuning range 11.1-17.5 Gc,

2) recorder line drift corresponds to 1-10 deg per hour.

3) sensitivity (for a 1 sec time constant) from 2° to 4° over the whole band.

To sum up one can say that by using this system of heterodyne frequency control regulated by the absence of the mixer current component with modulation frequency, component 2 of the spurious signal is eliminated, and component 1 (which in this case determines the whole spurious signal at the radiometer output) is greatly decreased in magnitude and remains stable over the time in which measurements are made comparing different sources.

The method we have described of suppressing the spurious signal is very simple to construct. All that is necessary is an additional selective amplifier with a phase-sensitive detector (at the modulation frequency of the given radiometer). The input of this amplifier is connected to the mixer, and the output of the phase-sensitive detector is connected in series with a reference voltage to the supply stabilizer of the circuit on which the heterodyne frequency depends. Thus the supply stabilizer not only serves as such, but also as a power amplifier in the frequency control circuit.

The use of this method of suppressing the spurious signal enables the rectifiers (in the input) and balanced mixers to be dispensed with; such a simplification of the microwave channel enables large (of the order of an octave) radiometer tuning limits to be obtained, while the operating frequency is changed simply by varying the heterodyne frequency.

REFERENCES

1. V. S. Troitskii, ZhTF, 25, 1426, 1955.

7 December 1964

Scientific Research Radiophysical Institute,
Gor'kii University