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RATIO-TYPE DIGITAL RADIOMETER

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The paper continues studying the new type of a modulation radiometer, providing the unbiased estimation of power (or its associated features) of radiometric signals at the receiver with an instable predetection section. The receiver block diagram has been developed. The radiometer analog and digital parts are concretized. The basic operations of processing signals that underwent analogue processing (transfer to the intermediate frequency, amplification and envelope detection of the noise radio signal modulated by a square wave) can be realized on an EPLD.

Keywords: radiometry, uncertainty function, super broadband radiometry complex.

INTRODUCTION

Microwave radiometers [1] are an integral part of modern information-measuring devices, systems and complexes, which are used while solving problems in various branches of science (Earth remote sensing, astronomy, meteorology, etc.) and national economy (study of vegetation at different stages of the growing season, soil moisture analysis and waters of the seas and rivers). They estimate the power or its associated parameters of object radio emission signal. The accuracy of initial estimation greatly influences on the second estimation qualitative indicators, respectively, on the quality of problem solutions. This accuracy depends on the experimental conditions and the type of used receiver. It is known [2, 3] that modern radiometric receivers (full power, modulation, etc.) require relatively frequent calibration because their gain is unstable (the gain changes by unknown way in time). This instability shifts radiometric signal parameters estimation at the receiver output. The existing instability eliminating methods require cumbersome technical solutions (the receiver tract input thermostabilization [4]) or complicate signal processing algorithms, except in some cases the ability of operative capture rapidly changing processes.

In the article, It is continuing to study the new type of modulation radiometer [5-8], providing unbiased estimation of radiometric signals power at the receiver with unstable predetection section. The receiver block diagram is developing. Its analog and digital part are concretized. Digital part implements in FPGA the basic operations of the signal processing, which is digitized after preliminary analog processing (transfer to the intermediate-frequency amplifier and envelope detector of the noise radio-signal modulated square wave). The veracity of the developed scheme is confirmed by simulation.

PROBLEM STATEMENT

It is necessary to develop the structural scheme of digital radiometer, which excludes predetection section instability influence on measurement results by the mean of signal energies ratio calculation. It is also necessary to approve the veracity of developed scheme by modeling.

Initial data. Let us assume the synthesized [6] as an original signal processing algorithm by maximum Likelihood method:

$$\Delta T_A^\circ = \left(T_{ng}^\circ + T_n^\circ\right)\left\{\frac{\int_{-\infty}^{\infty} m(t)u_d^2(t)\,dt}{\int_{-\infty}^{\infty}\left[1-m(t)\right]u_d^2(t)\,dt} - 1\right\}, \quad (1)$$

or

$$T_A^\circ = \left(T_{ng}^\circ + T_n^\circ\right)\frac{\int_{-\infty}^{\infty} m(t)u_d^2(t)\,dt}{\int_{-\infty}^{\infty}\left[1-m(t)\right]u_d^2(t)\,dt} - T_n^\circ, \quad (2)$$

where $\Delta T_A^\circ = T_A^\circ - T_{ng}^\circ$ is the fluctuation of antenna temperature, T_A° is the antenna temperature, T_{ng}° is the noise generator temperature, T_n° is the internal noise temperature, $m(t)$ is modulation function, $u_d(t)$ is the observation, after decorrelation filter and is followed from the next observation equation:

$$u(t) = s_h(t) + n_h(t) + n_r(t) \quad (3)$$

where $n_r(t)$ is the regularizing additive noise (Gaussian noise),

$s_h(t) = \int_{-\infty}^{\infty}\left[s(\tau)m(\tau) + s_{ng}(\tau)\left(1-m(\tau)\right)\right]h(t-\tau)\left[1+\xi(t-\tau)\right]d\tau$

is the signal at the predetection section output ($s(t)$, $s_{ng}(t)$ are the signals at the output of antenna and noise generator),

$$n_h(t) = \int_{-\infty}^{\infty} n(\tau)\, h(t-\tau)\left[1+\xi(t-\tau)\right]d\tau \quad (4)$$

is internal noise $n(t)$ at the predetection section output, $\xi(t)$ is the instability function.

The fulfillment of the following conditions was assumed While synthesizing of algorithm (2):

− predetection section of the receiver contains an antenna (A), switch (modulator) (M), noise generator (with known parameters and characteristics) (NG). This predetection section is characterized by impulse characteristic $h(t)\left[1+\xi(t)\right]$, which may be performed using a mixer, amplifier, various filter in a real device (factor $1+\xi(t)$ represents the impulse characteristic stability by time and function $\xi(t)$ is unknown but not random);

– radiometric noise signal from the object is observed on the intrinsic noise background of receiver and can not be separated from it by statistical grounds;

– modulation function $m(t)$ has square wave type with period T_m and its amplitude is set to 0 or 1;

– the observation is $t\in\left[0,T\right]$.

Structural scheme of digital radiometer development. Let us transform the algorithm (1) to the form, convenient to its digital realization. To do this, it is necessary to exclude the observation decorrelation operations ($u_d(t)$ substitute to $u(t)$), replace it to the intermediate frequency ($u(t)$ substitute to $U(t)$) and digitalize this observation ($U(t)$ substitute to $U_q(k\Delta t)$) after the passing of envelope detector. (square detector and integrator with a little integration time). Taking in attention the signal noise nature and the possibility of the noise power to be small the quantization levels is chosen as 16 bits. Let us place the gain, which provides the signal voltage according to ADC requirements before the analog-digital convertor. Modulation signal (square wave) is digitalizing with information signal. Then (1) can be written in the following form:

$$T_A^{\circ}=\left(T_{ng}^{\circ}+T_n^{\circ}\right)\frac{\sum_{k=0}^{K}M_q\left(k\Delta t\right)U_q^2\left(k\Delta t\right)}{\sum_{k=0}^{K}\left(1-M_q\left(k\Delta t\right)\right)U_q^2\left(k\Delta t\right)}-T_n^{\circ}. \quad (5)$$

The algorithm (5) corresponds to the structural scheme, shown on the Fig. 1.

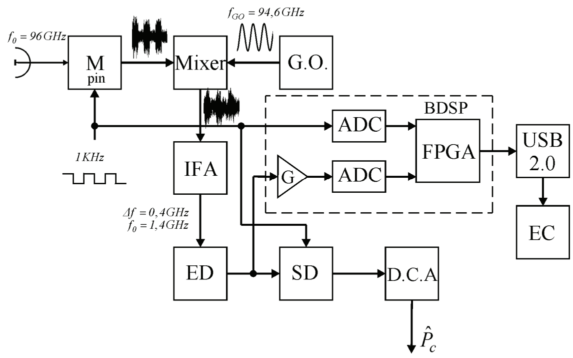

Fig. 1. Block diagram of the synthesized radiometer in digital analysis

The simulation of radio-type digital radiometer is shown in Fig. 2

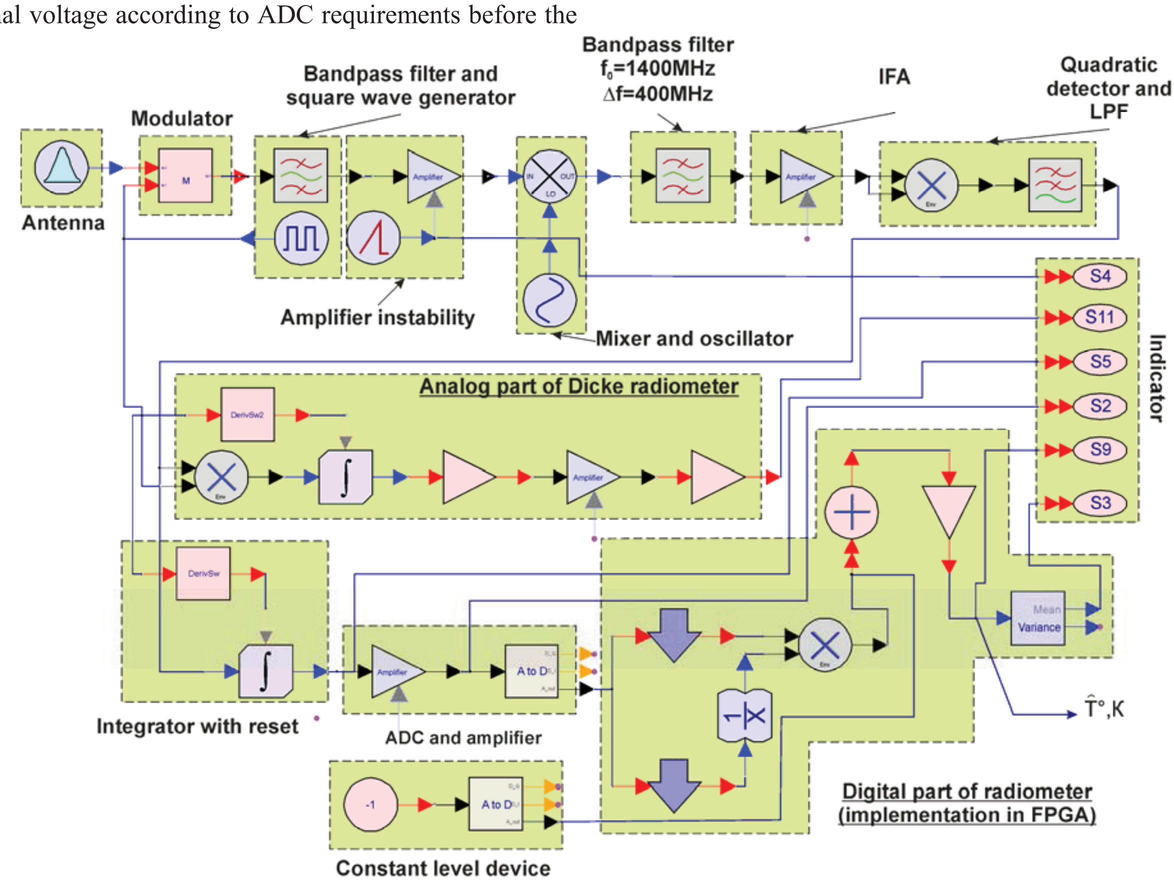

Fig. 2. Simulation of radio-type digital radiometer in Systemvue

Let us divide block diagram into main parts: the analog and digital part.

The analog part of the scheme operates as follows:

– Signal from antenna output is coming through modulator (M) with pin-diodes (input signal range is limited to 90-100 GHz) to receiver input. Modulator periodically connects to the receiver antenna output or blocks it, depending on the control voltage at pin-diodes, which can be described as "square wave" function with frequency 1 KHz;

– Modulated signal will be coming to the mixer, to the second input of which will come the signal from the oscillator (Gunn diode oscillator – $G.O.$) with frequency 94,6 GHz;

– An intermediate frequency signal (1,2-1,6 GHz) is coming to the intermediate-frequency amplifier (IFA) with the amplifier's gain 60 dB;

– After amplification, the signal will be coming to the envelope detector (ED) (quadratic detector and integrator with small integration time relatively modulation period);

– The signal is amplified to the required level for the correct operation of analog-to-digital converter (ADC);

– Subsequent processing will be performed in the digital part.

The digital part:

– In ADC analog signal is digitized (ADC requirements: 16 bits quantization and sampling step in time order is not more than 0,3 ns);

– Digital signal will be coming to the field-programmable gate array ($FPGA$), where the digital signal (square wave is regulated by modulator) also will be coming to;

– The algorithm (5) is implemented in FPGA;

– The signal power estimation (from antenna output) or useful signal power fluctuation (relatively noises power of modulator) will be supplied to the terminal device from FPGA output (USB 2.0, electronic computer – EC).

Graphs, which explain the scheme work principles are shown in the Fig. 3 and 4. The following data was used while the modelling:

− the predetection section gain coefficient changes by 20% for the observation time (The acting graph of predetection section gain coefficient is shown in the Fig. 3);

− equivalent receivers noise temperature $T_n^\circ \approx 290^\circ$ K;

− equivalent generators noise temperature $T_{ng}^\circ \approx 0^\circ$ K;

− several values of equivalent antenna noise temperature was investigated as $T_A^\circ \approx [290^\circ, 580^\circ, 870^\circ]$ K (graphs of antenna effective temperature estimation $\hat{T}_A^\circ$ are shown in Fig. 4);

− the fixed realizations of random processes are used while simulating that provide possibility of results comparison.

From the analysis of Fig. 4 it follows that temperature fluctuation is measured correctly in average. In practise the fluctuation estimation of antenna noise temperature with respect to noise generator temperature needs to be measured more exactly. It is obviously that measurements errors decrease with increasing of independent samples number in the integration time interval. This is achieved by integration time increase or operating frequency bandwidth widening (It can be chosen firstly the operating frequency bandwidths or used the decorrelation filters, which adaptively widen the real bandwidths, that means proportionally to singal/noise ratio.

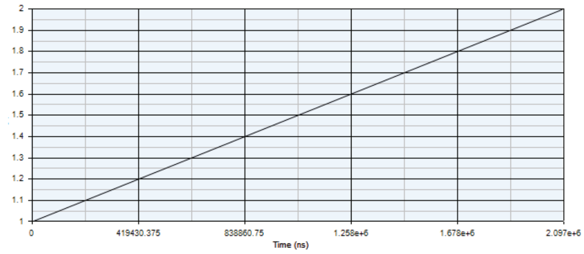

Fig. 3.The normalized amplification factor of receiver predetection section as a time observation function.

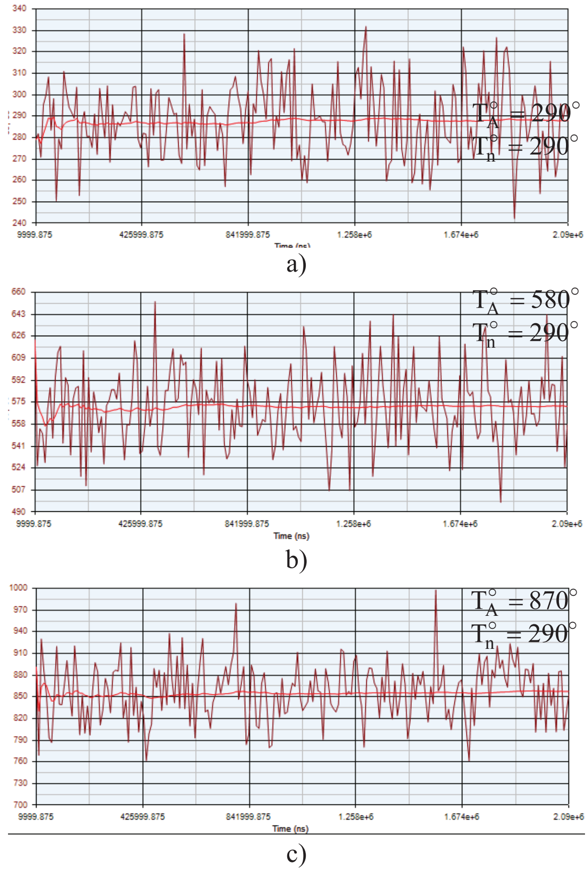

Fig. 4. The change of antenna effective noise temperature T_A° with fixed T_{ng}° so as fixed T_n°

For comparison, the antenna effective noise temperature estimation graph on the output of the classical modulation radiometer [1, 2] is shown on Fig. 5.

From analysis of Fig. 5 it follows that value estimation at the output of classical modulation radiometer is shifted because of the receivers predetection section gain coefficient change.

Additional temperature estimation averaging (or its shifting) in current case possible only at the output of

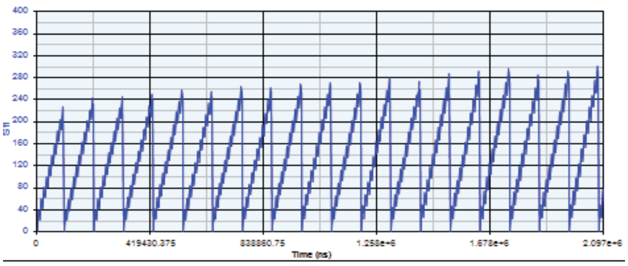

Fig. 5. The change of temperature fluctuation $\hat{T}_A^{\circ}$ at the output of classical modulation radiometer

new proposed radiometer and has no sence at the output of classical modulational radiometer.

Limiting error estimation of one parameter can be found in following form:

$$\sigma_{\lambda}^2 = 4\frac{\left(T_A^{\circ}(\lambda) + T_n^{\circ}\right)^2 N}{T\sum_{n=0}^{N-1}\Delta F_n}, \qquad (6)$$

where ΔF_n is the operating frequency bandwidth after decorrelation filter [3], $N^{-1}\sum_{n=0}^{N-1}\Delta F_n$ is the average bandwidth corresponding to some average value of function in observation interval. N − periods quantity T_m for the observation time T.

The potential fluctuation sensetivity [5], found in the next form:

$$\Delta T_{min}^{\circ} = 2\sqrt{2}\frac{T_A^{\circ}(\lambda) + T_n^{\circ}}{\left(T_m\sum_{n=0}^{N-1}\Delta F_n\right)^{-0,5}}. \qquad (7)$$

CONCLUSIONS

The algorithm of radio-type digital radiometer is considered and its digital form is developed. The digital block diagram according to the digital algorithm has been constructed. The obtained results of radio-type digital radiometer and the evaluation results are verified by simulations. Analytical expression of antenna effective temperature evaluation limiting error and potential fluctuation sensitivity are obtained.

GRATITUDE

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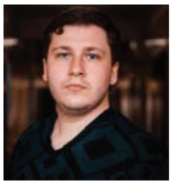

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Цифровой радиометр с вычислением отношения мощностей сигналов / В.В. Павликов, А.В. Одокиенко, Нгуен Ван Кием, Е.А. Продан, В.В. Манивчук // Прикладная радиоэлектроника: науч.-техн. журнал. – 2016. – Том 15, № 4. – С. 370 – 374.

Продолжены исследования нового типа модуляционного радиометра, осуществляющего несмещенное оценивание мощности (или связанных с ней параметров) радиометрических сигналов в приемнике с нестабильной додетекторной частью. Разработана структурная схема приемника. Конкретизированы аналоговая и цифровая части радиометра. Основные операции обработки сигналов, прошедших аналоговую обработку (перенос на промежуточную частоту, усиление и детектирование огибающей шумового радиосигнала, промодулированного меандром), могут быть реализованы на ПЛИС.

Ключевые слова: радиометрия, функция неопределенности, сверхширокополосный радиометрический комплекс.

Ил.: 05. Библиогр.: 08 назв.

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Цифровий радіометр з обчисленням відношення потужностей сигналів / В.В. Павліков, А.В. Одокієнко, Нгуєн Ван Кієм, Е.О. Продан, В.В. Манівчук // Прикладна радіоелектроніка: наук.-техн. журнал. – 2016. – Том 15, № 4. – С. 370 – 374.

Продовжено дослідження нового типу модуляційного радіометра, який виконує незміщене оцінювання потужності (чи пов’язаних з нею параметрів) радіометричних сигналів у приймачі з нестабільною додетекторною частиною. Розроблено структурну схему приймача. Конкретизовано аналогову та цифрову частини радіометра. Основні операції обробки сигналів, які пройшли аналогову обробку (перенесення на проміжну частоту, підсилення і дефектування згинаючої шумового радіосигналу, який промодульовано меандром), можуть бути реалізовані на ПЛІС.

Ключові слова: радіометрія, цифрова обробка сигналів, вимірювання ефективної шумової температури.

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