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OPTIMIZATION OF THE NUMBER OF CHANNELS OF A MULTICHANNEL RADIOMETRIC RECEIVER

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Background: Improving the positioning accuracy of passive radiometric correlation-extreme navigation systems (RM CENS) of aircraft (AC) by landmarks depends on the ability of information RM sensors of systems to form two-dimensional images of ground objects in real time. The use of matrix RM sensors, which are based on multichannel RM receivers of the millimeter wave range (MMW), makes it possible to realize the required speed of the CENS

Objectives: The aim of the work is to optimize the number of multiplexed channels per one amplifying-converting path of a multi-channel RM receiver with linear multiplexing and separation of channels according to the form of signals.

Materials and methods: As an optimization criterion in this work, it is proposed to use the gain in sensitivity obtained as a result of the use of a multichannel RM receiver with linear multiplexing and signal waveform separation in comparison with the sensitivity of a RM receiver with time division multiplexing.

Results: As a result of the analysis of the process of functioning of a multichannel RM receiver with time division multiplexing in this work a relation was obtained for the sensitivity of an individual channel of a RM receiver with time division multiplexing.

Conclusions: It can be concluded that it is optimal to create a matrix RM receiver based on combining 16 RM channels of the superheterodyne type into one amplifier-conversion path. In this case, the total number of amplifying-converting paths is equal to four. The sensitivity of each channel remains high enough.

KEY WORDS: millimeter-wave radiometric receiver.

ОПТИМІЗАЦІЯ КІЛЬКОСТІ КАНАЛІВ БАГАТОКАНАЛЬНОГО РАДІОМЕТРИЧНОГО ПРИЙМАЧА

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Актуальність: Підвищення точності визначення місцезнаходження пасивних радіометричних кореляційно-екстремальних систем навігації (РМ КЕСН) літальних апаратів (ЛА) по наземних орієнтирах залежить від здатності інформаційних РМ датчиків систем формувати двовимірні зображення наземних об'єктів в реальному масштабі часу. Застосування матричних РМ датчиків, основою яких є багатоканальні РМ приймачі міліметрового діапазону хвиль (ММД), дозволяє реалізувати необхідну швидкодію КЕСН [1,2].

Мета роботи: Метою роботи є оптимізація кількості каналів, що ущільняються на один підсилювально-перетворювальні тракт багатоканального РМ приймача ММД з лінійним ущільненням і розділенням каналів за формою сигналів.

Матеріали та методи: В якості критерію оптимізації в даній роботі пропонується використовувати виграш в чутливості, що отримується в результаті застосування багатоканального РМ приймача з лінійним ущільненням і розділенням каналів за формою сигналів в порівнянні з чутливістю РМ приймача з тимчасовим ущільненням каналів.

Результати: В результаті аналізу процесу функціонування багатоканального РМ приймача з тимчасовим ущільненням каналів в даній роботі отримано співвідношення для чутливості окремого каналу РМ приймача з тимчасовим ущільненням каналів.

Висновки: Можна зробити висновок про те, що оптимальним є створення матричного РМ приймача на основі об'єднання 16 РМ каналів супергетеродинного типу на один підсилювально-перетворювальні тракт. При цьому загальна кількість підсилювально-перетворювальних трактів дорівнює чотирьом. Чутливість кожного каналу залишається досить високою.

КЛЮЧОВІ СЛОВА: радіометричний приймач міліметрового діапазону хвиль.

ОПТИМИЗАЦИЯ КОЛИЧЕСТВА КАНАЛОВ МНОГОКАНАЛЬНОГО РАДИОМЕТРИЧЕСКОГО ПРИЕМНИКА

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Актуальность: Повышение точности местоопределения пассивных радиометрических корреляционно-экстремальных систем навигации (РМ КЭСН) летательных аппаратов (ЛА) по наземным ориентирам зависит от способности информационных РМ датчиков систем формировать двумерные изображения наземных объектов в реальном масштабе времени. Применение матричных РМ датчиков, основой которых являются многоканальные РМ приемники миллиметрового диапазона волн (ММД), позволяет реализовать требуемое быстродействие КЭСН.

Цель работы: Целью работы является оптимизация количества уплотняемых каналов на один усилительно-преобразовательный тракт многоканального РМ приемника ММД с линейным уплотнением и разделением каналов по форме сигналов.

Материалы и методы: В качестве критерия оптимизации в данной работе предлагается использовать выигрыш в чувствительности, получаемый в результате применения многоканального РМ приемника с линейным уплотнением и разделением каналов по форме сигналов по сравнению с чувствительностью РМ приемника с временным уплотнением каналов.

Результаты: В результате анализа процесса функционирования многоканального РМ приемника с временным уплотнением каналов в данной работе получено соотношение для чувствительности отдельного канала РМ приемника с временным уплотнением каналов.

Выводы: Можно сделать вывод о том, что оптимальным является создание матричного РМ приемника на основе объединения 16 РМ каналов супергетеродинного типа на один усилительно-преобразовательный тракт. При этом общее количество усилительно-преобразовательных трактов равно четырем. Чувствительность каждого канала остается достаточно высокой $\delta T \cong 1K$.

КЛЮЧЕВЫЕ СЛОВА: радиометрический приемник миллиметрового диапазона волн.

PROBLEM STATEMENT

Formulation of the problem. Improving the positioning accuracy of passive radiometric (RM) correlation-extreme navigation systems of aircraft on landmarks depends on the ability of information RM sensors systems to form two-dimensional images of ground objects in real time. The use of matrix RM sensors, which are based on multichannel RM receivers of the millimeter wavelength band (MMWB), makes it possible to realize the required speed of the correlation-extreme navigation systems [1 – 3].

Analysis of the literature. Multichannel RM receiver MMWB can be made either in the form of a set of receiving channels (matrix of receivers), or according to the scheme of multiplexing channel signals to a common amplifier-converting path [2, 3].

In [2, 3], a functional diagram (Fig. 1) is shown that implements the method of linear multiplexing with channel separation according to the waveform, as well as the method of time multiplexing of channels. In [3], as a result of analyzing the passage of signals from a large number of channels through a common amplifier-conversion path, relations were obtained for the sensitivity and signal-to-noise ratio at the output of each individual channel of a multichannel RM receiver.

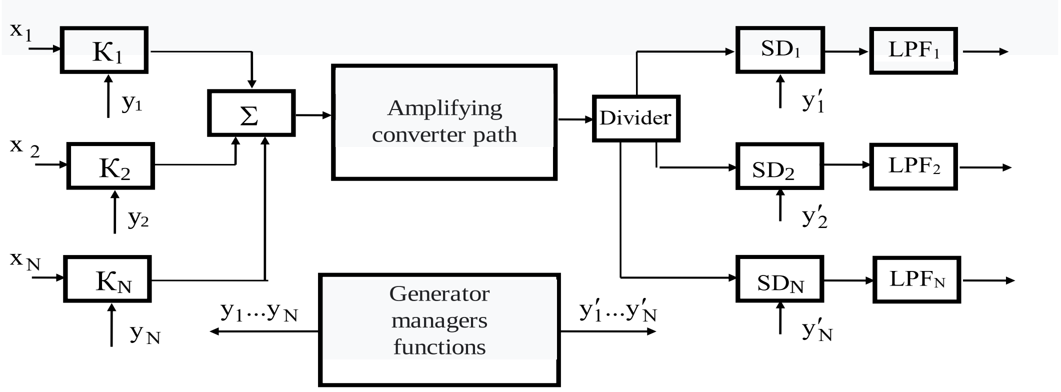

Fig. 1. Functional diagram of a multichannel RM receiver with linear multiplexing and channel separation according to the waveform

Multichannel RM MMB receiver with linear signal waveform multiplexing functions as follows. The useful signal is a narrow-band normally distributed noise with a spectrum width and Δf a radio brightness temperature T_{ci} proportional to the radiation intensity of the sighted area of the surface or an object at the input of the **i**-th channel.

With the help N of switches (K_i), signals (x_i) are modulated in each channel by orthogonal digital functions from the family, which is built on the basis of the ensemble of Walsh functions (y_i) [4, 5]. Further, the signals of all channels are fed to the input of the adder and to the common amplifier-conversion path, where the noise of the RM receiver with power is added to the signal T_N .

If the receiver is made according to a super heterodyne circuit, the amplifying-converting path contains a frequency converter (mixer and local oscillator), an intermediate frequency amplifier and a square-law detector. In the case of constructing a receiver according to a direct amplification scheme, this path contains several stages of low-noise high-frequency amplifiers and a square-law detector.

Further, the mixture of signal and noise, passing through the square-law detector, is divided by power N into channels and fed to synchronous detectors (SD_i), to the second inputs of which demodulating functions from the family of inverted Walsh functions arrive (y^I_i). The low-pass filter (LPF) integrates the signal with the noise structure over time τ.

Taking into account the orthonormality of the Walsh functions, the signal at the output of each channel is proportional to the intensity (power) of the signal at the input of this channel (x_i).

In the case of time-division multiplexing of channels, the functional diagram of the multichannel RM [3] does not change. The difference is that the switches are connected in series to the adder.

For the case when the brightness temperatures of signals at all inputs are equal to the maximum value $T_{ci} = T_c$, $i \in \overline{1,N}$, the ratio for the sensitivity of an individual channel of a multichannel RM receiver can be represented as [3]:

$$\delta T = \frac{2T_N}{\sqrt{\Delta f \tau}} \sqrt{1 + Nq + \frac{N(N+1)}{4} q^2}\ , \tag{1}$$

where $q = \frac{T_s}{T_N}$ – is the signal-to-noise ratio at the input of each RM channel.

An analysis of the results of calculations by formula (1) shows that combining, for example, 64 channels per one amplifier-conversion path leads to an increase in inter-channel interference and, as a consequence, to a deterioration in the sensitivity of each channel.

For a super heterodyne RM receiver, the degradation in sensitivity compared to a single-channel modulation RM is ~ 6 times. The sensitivity of direct amplification RM (at $N = 64$) deteriorates by a factor of 12 in comparison with a single-channel modulation RM (at $\tau = 0{,}1\,s$). It seems expedient to limit the number of channels (channel signals) multiplexed into one amplifying-converting path of a multichannel RM receiver.

Purpose of work. The aim of the work is to optimize the number of multiplexed channels per one amplifying-converting path of a multi-channel RM receiver MMB with linear multiplexing and separation of channels according to the form of signals.

RESEARCH MATERIALS

As an optimization criterion in this work, it is proposed to use the gain in sensitivity obtained as a result of the use of a multichannel RM receiver with linear multiplexing and waveform separation of channels in comparison with the sensitivity of a RM receiver with time division multiplexing.

As a result of the analysis of the process of functioning of a multichannel RM receiver with time division multiplexing, the diagram of which is given in [4], in this work a relation was obtained for the sensitivity of an individual channel of a RM receiver with time division multiplexing of channels:

$$\delta T' = \frac{2\sqrt{N}\, T_N}{\sqrt{\Delta f\, \tau}}\ . \tag{2}$$

In the case of time multiplexing (2) at the same exposure time (signal accumulation time τ) of one element (pixel) of the image, the sensitivity deteriorates in times $\sqrt{N}$.

The result of dividing the right-hand side of expressions (2) and (1) characterizes the gain in the sensitivity of a separate channel for different compaction methods at the same parameter values $\Delta f, \tau$:

$$\delta_T = \frac{\delta T'}{\delta T} = \frac{1}{\sqrt{\frac{1}{N} + q + \frac{N+1}{4} q^2}}\ . \tag{3}$$

Figure 2 shows the dependencies $\delta_T(N)$. The calculations were carried out for two values of the input signal. The value $T_C = 300\,K$ corresponds to the maximum input signal of the RM channel. In this case, the signal-to-noise ratio for a super heterodyne RM receiver $q = 0{,}1$ $(T_ш = 3000\,K)$, for a direct amplification receiver $q = 0{,}6$ $(T_ш = 500\,K)$ (curves 1, 2 in Fig. 2).

The value $T_c = 5\,K$ corresponds to the real case of receiving a low-intensity input signal of the RM of the MMB receiver. In this case, the signal-to-noise ratio for the super heterodyne RM receiver $q = 0{,}0016$, for the RM receiver of direct amplification $q = 0{,}01$ $\left(T_ш = 500\,K\right)$ (curves 3, 4, Fig. 2).

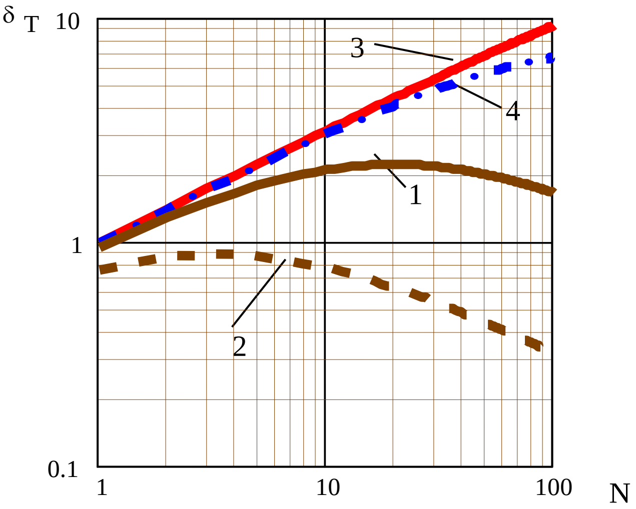

Fig. 2. Dependency graph $\delta_T = N$

The range of values $\delta_T \geq 1$ corresponds to the gain in the sensitivity of a multichannel RM with multiplexing of the channels in the form of signals.

For super heterodyne RM receivers, this region exists over the entire range of values under consideration N (curve 1 in Fig. 2).

The maximum gain is observed with the number of compressed channels $N = 16 - 20$.

In the case of the RM receiver of direct amplification, due to the significant influence of the signals of adjacent channels on the quality of the formed image, the gain in sensitivity compared to the sensitivity of the RM receiver with time division multiplexing is not observed (curve 2).

The maximum approximation of the sensitivity of the multichannel RM with linear waveform division to the sensitivity of the RM with time division is observed for $N = 3 \ldots 6$ the channel values.

If a multichannel RM receiver receives a small input signal $\left(T_c = 5\,K\right)$, due to a weak interfering effect of input signals on the output signal-to-noise ratio, there is a significant gain in sensitivity for a multichannel RM receiver with linear channel multiplexing in signal shape, both for a super heterodyne receiver and for a RM receiver direct amplification.

CONCLUSIONS

Thus, we can conclude that it is optimal to create a matrix RM receiver based on combining 16 RM channels of the super heterodyne type into one amplifier-conversion path. In this case, the total number of amplifying-converting paths is equal to four. The sensitivity of each channel remains high enough $\delta T \cong 1K$.

Combining 16 channels of direct amplification RM receivers into one amplifier-conversion path is also possible. Although the sensitivity in this case deteriorates in comparison with the single-channel modulation RM by a factor of 5 ... 6, the absolute value of the sensitivity ($\delta T = 0{,}04 \ldots 0{,}2\,K$ at $\tau = 0{,}1\,s$) remains quite acceptable for the stable operation of the RM correlation-extreme navigation systems MMB.

The advantage of the applied method of linear compaction in comparison with time compaction is an increase in the exposure time of each individual element of the frame by $\sqrt{N}$ times, with a significant reduction in the cost of the design of a multichannel RM receiver (16 times, respectively), and as a consequence, a decrease in the cost of the entire matrix RM sensor (taking into account the cost of a multi-beam antennas and processing systems).

КОНФЛІКТ ІНТЕРЕСІВ

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