METHOD FOR IMPROVING SELECTIVITY OF SIGNALS IN RADIO COMMUNICATION

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ABSTRACT

Taking into account the characteristics of railway radio communication a precision wideband phase shifter to 90˚ for an intermediate frequency signal is offered. A phase preselector of a receiver, combined with its frequency converter, is developed, allowing to further increase selectivity of adjacent and image channels, as well as sensitivity of a receiver while simplifying its structure. The results of calculations of structural elements and transmission of signals in the range of radio frequencies used are shown.

Keywords: railway, radio communication, receiver, selectivity, sensitivity, image channel, adjacent channel, wideband phase shifter to 90˚, frequency response, phase response, phase preselector, stability gain.

Background. *In railway radio receivers of meter wave band (frequency f = 151–156 MHz) two frequency conversions are used, generating two image channels, separated from the main channel into two intermediate frequencies. In the previous generation radio stations (e.g. in Russia ZhR-U) intermediate frequencies f_{int1} = 24 MHz and f_{int2} = 1,596 MHz are fixed, and of the latest generation «Transport», RS-46 MC – f_{int1} = 10,7 MHz and f_{int2} = 456 kHz.*

The latter f_{int} are more than by 2 times lower than the former, which significantly complicates the frequency preselectors, which are the input device ID and radio frequency amplifier (RFA) for suppression of the first image channel and the first intermediate frequency amplifier (IFA 1) – for the second image channel. It is advisable to look for a way to simplify and reduce the cost of the receiver, including to move from two to one frequency conversion and in low meter range f_{int} = 456 kHz. Such a problem cannot be solved only by means of a frequency preselector.

Objective. *The objective of the authors is to consider a method, which can be applied for improving selectivity of signals in radio communication systems.*

Methods. *The authors use general scientific and radio engineering methods, mathematical apparatus, graph construction, evaluation approach, comparative analysis.*

Results.

1. Setting a task

It is known that in a super-oscillator receiver frequency ω_s of the main signal and mirror ω_i channels are arranged symmetrically (in inversed manner) with respect to oscillator frequency ω_h on ω_{int}. There are two symmetrical sidebands of balance-modulated (BM) signal in relation to its carrier frequency, moreover, they often contain a variety of information. To separate them a phase detection method is used [1]. Problematic unit of this division is a wideband phase shifter (WPS) to 90°, it is usually made on two crossed four-pole devices, the amplitude-frequency characteristics (AFC) of which should be identical, and phase-frequency characteristic (PFC) should differ by an angle ϕ = 90°.

Usually, these conditions are met with a relatively large error. In PFC error $\Delta\phi$ = 2–3°, in which the degree of suppression of the second sideband for coherent detection of the signal BM is 20–25 dB, instead of the required 60 dB, which requires $\Delta\phi$ = 0,1° provided identity of AFC of four-pole devices of WPS. Therefore, the phase coherent detection method is almost not used.

The idea of phase separation of sidebands of BM signal can be realized to further suppress the image channel in the receiver provided that it will be managed to develop WPS to 90° with $\Delta\phi \le 0,1°$ in the frequency band 18,8 kHz instead of 3,1 kHz for a voice signal (VS). Of course, the problem is much more complicated, and the following should be taken into account:

– in a phase detector narrowband SSB AM signal with a variable amplitude is converted to a VS of tonal range (with zero carrier) being a wideband with a variable amplitude, which can be rotated by 90° with the error $\Delta\phi$ = 2–3°, which is unacceptable;

– the input of frequency converter receives two two-band signals with a constant amplitude (FM or PM), which are transferred to a lower (intermediate) frequency, remaining narrowband with constant amplitude. The latter enables to have at the output of WPS different signal amplitudes, because they can be equalized with limiters; amplitude difference is small, and a phase shift of 90° can be made easier and more accurate.

2. Development of a precision wideband phase shifter to 90˚ for an intermediate frequency signal

As a phase shifter of this class it is proposed [2] to use two identical consecutive elementary RC-circuits connected in parallel to each other and in reverse order, as shown in Pic. 1.

In each circuit, the voltage on the resistor U_R is shifted in phase at 90° with respect to the voltage on the capacitor U_C, as evidenced by the j icon in its resistance $X_C = 1/j\omega C$ [3]. Geometric sum of these voltages is equal to the voltage U at the circuits' input that can be represented by a right triangle, the right angle of which is located on the circle, and the hypotenuse of U coincides with its diameter (Pic. 2). The second circuit allows to remove voltage $U_{R2} = U_{R1}$ relative to the ground.

With change of frequency ω a right angle does not change in size, but only slides along the circle by vertex. The amplitude of voltages on R and C varies both on the divider according to resistance change X_C. Quantitatively voltage modules are as follows:

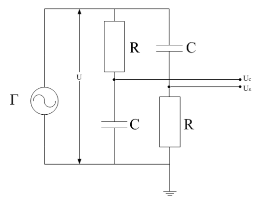
$$U_c = U\frac{\frac{1}{\omega C}}{\sqrt{R^2+(\frac{1}{\omega C})^2}}, \text{ or } K_c = \frac{U_c}{U} = \frac{1}{\sqrt{1+(\omega RC)^2}},$$

$$U_R = U\frac{R}{\sqrt{R^2+(\frac{1}{\omega C})^2}}, \text{ or } K_R = \frac{U_R}{U} = \frac{1}{\sqrt{1+(\frac{1}{\omega RC})^2}},$$

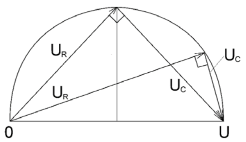
where K is a coefficient of voltage transmission of the divider.

From the standpoint of achieving minimum difference of voltages U_C and U_R it is necessary to

Pic. 1.



Pic. 2.



select at the intermediate frequency resistances of a resistor a and of a capacitor, equal in module, i.e. $R=|X_C|$, when $K_R=K_C=1/\sqrt{2}=0,707$.

Table 1 shows the results of calculations of K_R and K_C for the worst case when f_{int} = 456 kHz, and a maximum bandwidth is 18,8 kHz [4]. The difference $|K_C–K_R|=0,014$=max is both at the bottom of the band and at the top that is much smaller than the permissible value of 0,1 [5]. AFC and PFC are shown in Pic. 3. The phase frequency was controlled visually on a computer on a model for the phase shifter in the program Multisim, and its accuracy was measured on the produced layout of the phase shifter using F2–34 device. The error $\Delta\phi$ = 0,1° occurs in the frequency band of 25 kHz and in the vicinity of the intermediate frequency it is $\Delta\phi$ = 0,2°.

Note that, as similar to WPPS to 90° one sequential RL-circuit can be used, because the resistance of inductance $X_L=1/j\omega L$. In this embodiment, R is grounded, from which voltage U_R is removed and from the secondary coil of inductance L U_L is removed. But the transformer is structurally inconvenient, it has a relatively high resistance. Therefore, preference is given to two identical RC-circuits, on the basis of which a phase preselector of a receiver is created.

3. Elements of a phase preselector

Pic. 4 is a block diagram of a super-oscillator receiver where the dotted line shows blocks of a developed [2] phase preselector. It consists of two converters CV of input signal frequency, an oscillator O with a phase shifter PS to 90°, two successive RC-circuits, the summator Σ with connections indicated there. In this case, two RC-circuits are not connected in parallel with each other, as discussed above, and each is connected to the output of one converter. But their inputs receive the same signal, but shifted in phase by 90°. These circuits eliminate a phase shift.

The operation of a phase preselector is as follows.

The information inputs of converters receive the sum of signals of one main $u_s(t)$ and an image $u_i(t)$ channels:

$u_{in}(t)=u_s(t)+u_i(t)=U_s\sin[\omega_s t+\Theta_s(\text{в}_s, t)+U_i\sin[\omega_i t+\Theta_i\sin[\omega_i t+\Theta_i(\text{в}_i, t)]$,

where $\Theta(\text{в}, t)$ is a function of a component phase of a signal, carrying information.

The second input CV1 receives fluctuation of the oscillator $u_o(t)=U_o\sin\omega_o t$ directly, and the second input CV P2 – through a phase shifter PS to 90°, i.e. $u_p(t)=U_o\sin\omega_o t$. Since the frequencies $\omega_s=\omega_o+\omega_{int}$ and $\omega_i=\omega_o-\omega_{int}$ where ω_{int} is, then

$U_{in}(t)=U_s\sin[(\omega_o+\omega_{int})t+\Theta_s(\text{в}_s, t)]+U_i\sin[(\omega_o-\omega_{int})\cdot t-\Theta_i(\text{в}_i, t)]$.

Frequency converter CV consists of a multiplier of signals with the load (LFF). Fluctuations at the output of multipliers:

$u_{int1}(t)=u_{in}(t)\,u_o(t)=0,5U_sU_o\cos[\omega_{int}t+\Theta_s(\text{в}_s, t)]+0,5U_iU_o\cos[\omega_{int}t+\Theta_i(\text{в}_i, t)]+HF$,

$u_{int2}(t)=u_{in}(t)\,\hat{u}_o(t)=0,5U_sU_o\sin[\omega_{int}t+\Theta_s(\text{в}_s, t)]-0,5U_iU_o\sin[\omega_{int}t+\Theta_i(\text{в}_i, t)]+LF$,

where HF components are removed at loads CV and FSS.

It can be seen that at the output of CV2 terms are shifted in phase to 90° in relation to the signal CV1 and the image channel signal has a minus sign (–). With RC-circuits phase shift is eliminated, which allows in the summator Σ to eliminate an image channel signal. With this in mind, the sum of signals $u_{int1}(t)$ and $u_{int2}(t)$ gives at the output of the summator Σ fluctuation $U_\Sigma(t)=U_sU_o\cos[\omega_{int}t+\Theta_s(\text{в}_s, t)]$, i.e., the main signal without image channel fluctuations.

The summation of signals in the block Σ is because of $\omega_s<\omega_o$. If this inequality is reversed, it should not be summation, but subtraction. Then it will be necessary to the second input of the summator to supply a signal not from the input, but from the output of phase inverter PI (Pic. 4).

From the output of FSS signal CV2 enters IFA, and then through the nonlinear element NE to the input of the frequency detector FD. As known, on the non-linear element there is an effect of suppression of a weak signal by a strong one – remaining elements of the image channel are suppressed.

The degree of suppression of the image channel signal $u_i(t)$ by a phase preselector $a_p=-20\lg[\sin(0,5\Delta f)]$. If $\Delta\phi$ = 0,1° the value a_p = –60dB. This value increases due to suppression of the image channel by the frequency preselector of the receiver comprised of series-connected circuits of the input device (ID) and RFA, and also due to the nonlinear element NE (Pic. 4).

Since the degree of suppression of the image channel signal by the phase preselector is sufficient, it is possible to reduce the intermediate frequency from 10,7 MHz to f_{int} = 456 kHz, when FM signal still

Pic. 3.

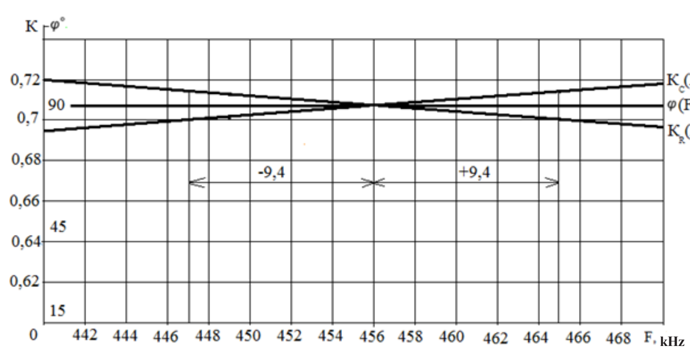
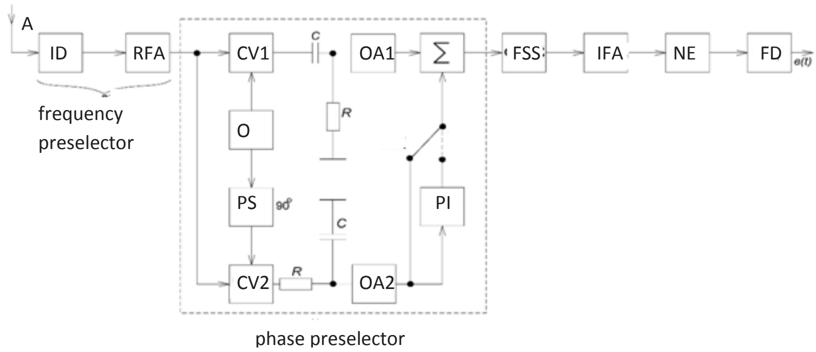


Table 1

f, kHz	f_{int}=456 kHz	f_{int}+9,4 kHz	f_{int}–9,4 kHz
K_C	1/√2=0,707	0,7	0,714
K_R	1/√2=0,707	0,714	0,7
ΔK_{max}	0	0,014	0,014



Pic. 4.

remains narrowband (Δf_p=18,8 kHz<<Δf_s=456 kHz). In this case, RFA can be performed on a single circuit instead of four coupled circuits and FSS of the intermediate frequency path – on six LC-circuits instead of quartz filters. FM signal detector, should also be made not on quartz, but on LC-circuit. This will largely simplify and reduce the cost of the receiver with the improvement of its main indicators.

Conclusions.

1. A wideband phase shifter (WPS) to 90° for the intermediate frequency signal on two successive RC-circuits, connected in parallel and in reverse order, is developed. WPS error is $\Delta\phi$<0,2° in the frequency range of 50 kHz.

2. On the basis of WPS a phase preselector is created suppressing in addition the image channel by 60 dB and allowing to reduce the intermediate frequency of a radio receiver of railway communications as well as to increase its selectivity for adjacent channel and sustainable rate gain in the intermediate frequency tract, which greatly reduces the cost of the receiver, improves its quality and electromagnetic compatibility of radio devices.

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