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Phase Preselector Intended to Suppress Image Frequency in the Radio Receiver

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ABSTRACT

Until now, to suppress the image channel, radio receivers use a frequency preselector consisting of oscillatory circuits of the input device and a radio frequency amplifier. But the frequency preselector does not suppress strongly enough the image frequency. Therefore, two frequency conversions are often used in railway radio communication systems. For example, for station radio communications at frequencies f = 151–156 MHz, two frequency converters with f_{pr1} = 24 MHz and f_{pr2} =1,596 MHz are used, which greatly complicates the design of the receiver.

The article proposes to use a phase preselector, which is the second parallel quadrature frequency converter, the signal of which, after passing additional elements, is summed with the signal of the first frequency converter with high suppression of the image frequency. With this method of organising communication, the bandpass phase shifter will be a problematic block in the phase preselector, since it must have a small error Δφ.

A bandpass phase shifter made on RC circuits with a minimum phase shift error Δφ = 0,1˚ within a frequency band of 25 kHz is described. In case of increasing the frequency band, the phase shift error remains minimal, but it is necessary to use limiting amplifiers to equalise the amplitudes of the signals at its output.

The use of a phase preselector instead of a frequency preselector will help to reduce the intermediate frequency, which will lead to high selectivity, both in the adjacent and image channels with single-sideband modulation, and will also simplify and reduce the cost of the signal receiver.

Keywords: *transport, communication, phase and frequency preselectors, image and adjacent channel selectivity, 90° bandpass phase shifter, phase inverter, RC circuits, signal multipliers, amplitude limiting amplifiers.*

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INTRODUCTION

Radio communication plays an important role in ensuring continuity and safety of transportation by all modes of transport, including railway.

The most important problem is to ensure reliability of communication and signal transmission without significant distortion. At the same time, until now, to suppress the image channel, radio receivers use a frequency preselector consisting of oscillatory circuits of the input device and a radio frequency amplifier that does not suppress strongly enough the image frequency. Therefore, two frequency conversions are often used in railway radio communication systems.

The article suggests using a phase preselector, which is the second parallel quadrature frequency converter, the signal of which, after passing additional elements, is summed with the signal of the first frequency converter with high suppression of the image frequency.

The phase preselector suppresses the image frequency in the radio receiver more effectively than the known frequency preselector, and they are used together in the receiver [1–4]. This makes it possible to have high selectivity in the image channel and select only a single low intermediate frequency f_{pr} = 465 kHz, at which selectivity in the adjacent channel is also high. The principle of operation of the phase preselector is based on double single-sideband modulation (SSB AM), when each of the two sidebands of an amplitude-modulated (AM) oscillation without a carrier wave carries different information, i.e., there are two channels. In a radio receiver, these channels are separated according to the circuit proposed by the Soviet scientist E. G. Momot whose inventions on this topic were described in his monograph «Design and Technology of Synchronous Radio Reception» [5], originally published in Leningrad in 1941. But in 1941, the Great Patriotic war began, and during the enemy air strike on the besieged Leningrad, the printing house where the entire print run of the monograph by Eugeny Momot was stocked, burned down. And only after Great Patriotic war it was accidentally possible to find an approval copy of this monograph and publish it for the second time in 1961, i.e. exactly 20 years later. This history preceding the second edition was told in the preface written by the famous scientist, corresponding member of the USSR Academy of Sciences V. I. Siforov V. I. [5].

The *objective* of the article is to substantiate the use and technical solution regarding a bandpass phase shifter made on RC circuits with a minimum phase shift error $\Delta\varphi$ = 0,1˚ within a frequency band of 25 kHz.

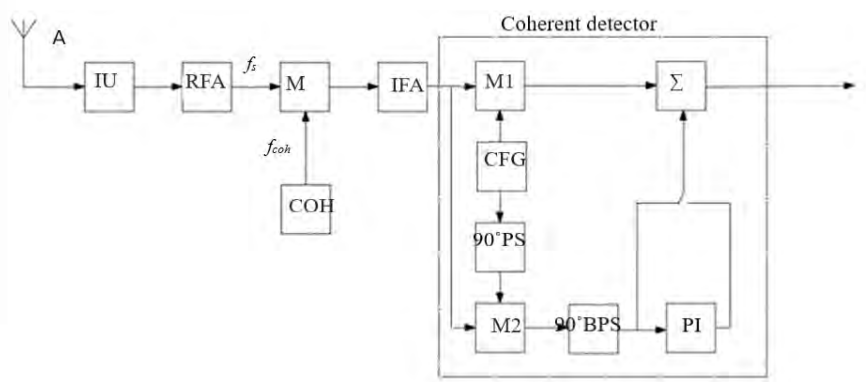
RESULTS

1. Twofold Single Sideband Amplitude Modulation with One Sideband

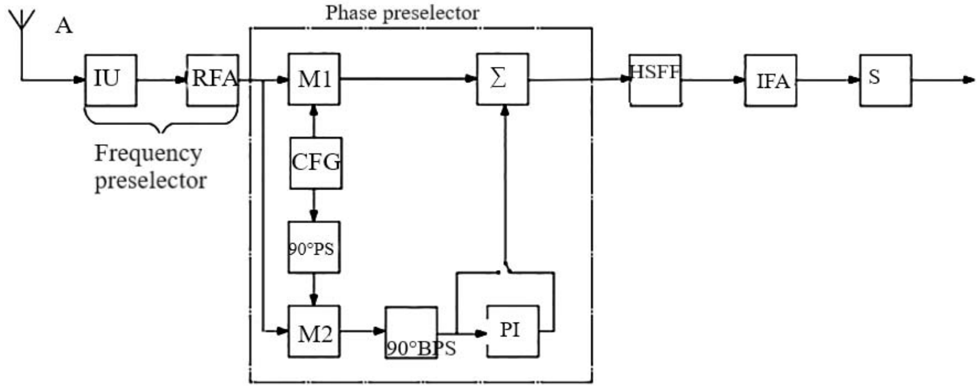
Since the signals of the two channels are transmitted simultaneously on two sidebands of the same amplitude modulated (AM) waveform without a carrier wave, they must be separated during coherent detection in the radio receiver.

The circuit intended for such separation [5] of two channels is shown in Pic. 1. The coherent detector is outlined with a dotted line [5].

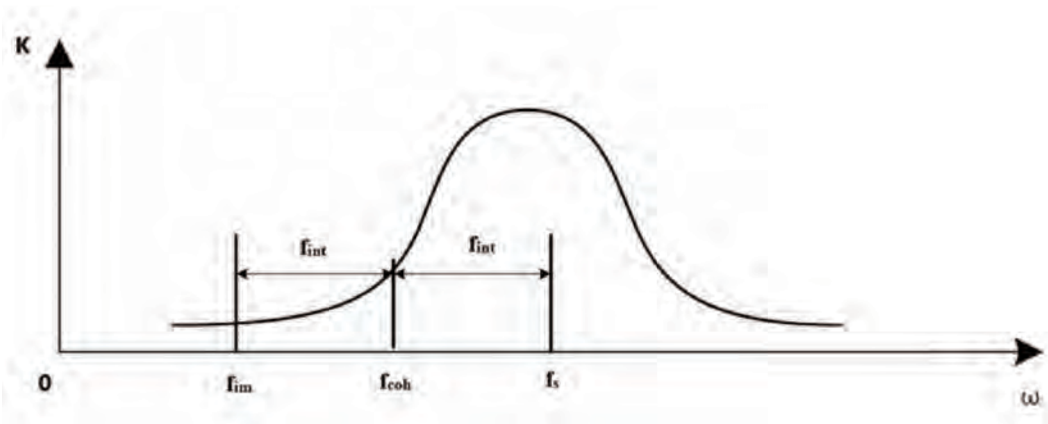
The operation of the coherent detector circuit is as follows. The input voltage from the frequency



Pic. 1. Scheme of channel separation in a coherent detector [5].
The following abbreviations are used in Pic. 1 and in further Pics.: A – antenna, IU – input unit, M – multiplier, COH – coherent oscillator, RFA – radio frequency amplifier, IFA – intermediate frequency amplifier, f_s – frequency of the information signal, f_{coh} – oscillator frequency, f_{int} – intermediate frequency, f_{im} – image frequency, CFG – carrier frequency generator, PS – phase shifter, BPS – bandpass phase shifter, PI – phase inverter, ∑ – adder, HSFF – highly selective frequency filter, S – speaker, AL – amplitude limiter, FD – frequency detector, AFA – audio frequency amplifier.



Pic. 2a. Block diagram of a radio receiver with a phase preselector [compiled by the authors].



Pic. 2b. Operation of a frequency preselector [compiled by the authors].

converter after amplification in the intermediate frequency amplifier IFA is fed to the first inputs M1 and M2 of the coherent detector
$u_w(t) = U_c \sin(\omega - \Omega_1)t + U_c \sin(\omega + \Omega_2)t$.

The «carrier» frequency is supplied to the second input M1 from the carrier frequency generator $u_{cfg}(t) = U \sin\omega t$ [6] directly, and the same voltage is supplied to the second input of the second multiplier through the phase shifter [7].

At the output of units M1 and M2, signals are obtained [8]:

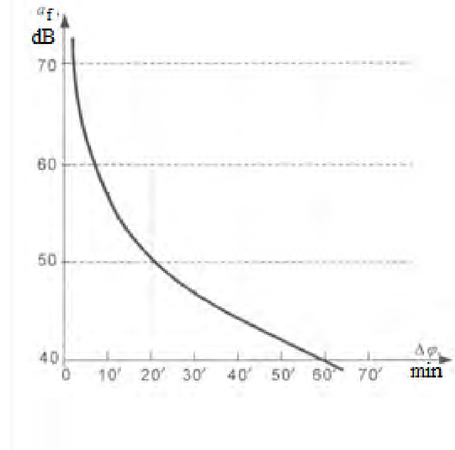
$$u_{m1}(t) = u_{fc}(t)u_{coh}(t) = 0{,}5U_{coh}U_c \cos(\Omega_1 t) + $$
$$+ 0{,}5U_{coh}U_c \cos(\Omega_2 t) + HF;$$

$$u_{m2}(t) = u_{fc}(t)' u_{coh}(t) = 0{,}5U_{coh}U_c \cos(\Omega_1 t + 90^\circ) + $$
$$+ 0{,}5U_{coh}U_c \cos(\Omega_2 t - 90^\circ) + HF =$$
$$= -0{,}5U_{coh}U_c \sin(\Omega_1 t) + 0{,}5U_{coh}U_c \sin(\Omega_2 t) + HF.$$

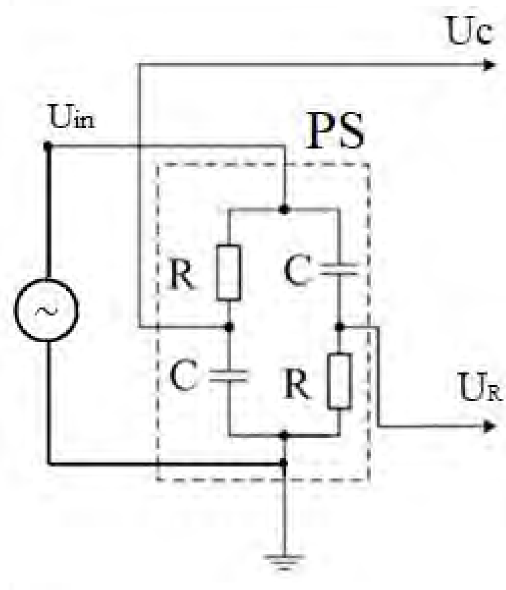
Thus, the signals of both channels are separated, which requires two adders $\sum$: the adder $\sum_1$ is fed from the input of the phase inverter PI, and to $\sum_2$ – from the output of PI.

2. Phase Preselector

The phase preselector, like the frequency preselector, suppresses the image frequency in the radio receiver. The image frequency is separated from the local oscillator frequency in the frequency converter by an intermediate frequency f_{int}, but on the other side of the main signal frequency, as two sidebands of the AM waveform are separated from its carrier frequency. Therefore, the «image channel» during frequency conversion should occupy the same frequency band [10–18] as the main channel does. This disrupts radio communication. However, the image frequency can be suppressed according to the «quadrature SSB AM» model, since according to it the coherent detector consists of a frequency multiplier with a low-pass filter at its output [19], and the frequency converter also consists of a signal multiplier with an intermediate frequency bandpass filter. To suppress the image frequency in a standard receiver, it is necessary to connect in parallel to the main frequency converter, the second same converter and all other blocks of the «quadrature SSB AM».



Pic. 3. Calculated values of the degree of suppression of the mirror channel [compiled by the authors].



Pic. 4a. Scheme of 90° BPS on RC-circuits [compiled by the authors], where PS – bandpass phase shifter, RC – RC circuits, Uin – input voltage, R – resistor, C – capacitor, Uc and UR – voltages at the outputs of the BPS.

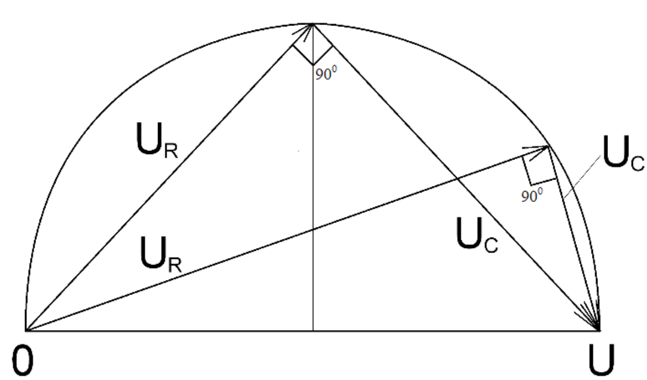
Pic. 2a shows a block diagram of a radio receiver with a phase preselector, where the signal from antenna A is fed to the frequency preselector. Pic. 2b shows graphically its operation [7]. The radio frequency amplifier's output is connected to the first inputs of the multipliers M1 and M2 of both frequency converters. The local oscillator COH is connected directly to the second input M1, and the same oscillator is also connected to the second input M2, but through a 90° phase shifter PS. The frequency of the local oscillator u_{coh} can be greater than the frequency of the main signal u_s, but less than the frequency of the image frequency: $\omega_{im} > \omega_{coh} > \omega_s$ or vice versa.

The output of M1 is connected directly to the first input of the adder ∑, to the second input of which the output M2 is connected through the 90° bandpass phase shifter (BPS) and a phase inverter PI, which shifts the phase of the input signal by 180°, connected in series. The output of the adder is connected to the speaker S through highly selective frequency filters (HSFF) and intermediate frequency amplifier (IFA) connected in series. It can be seen that the coherent detector of the «quadrature OSSB AM» is switched to the frequency converter of the receiver according to Pic. 2a.

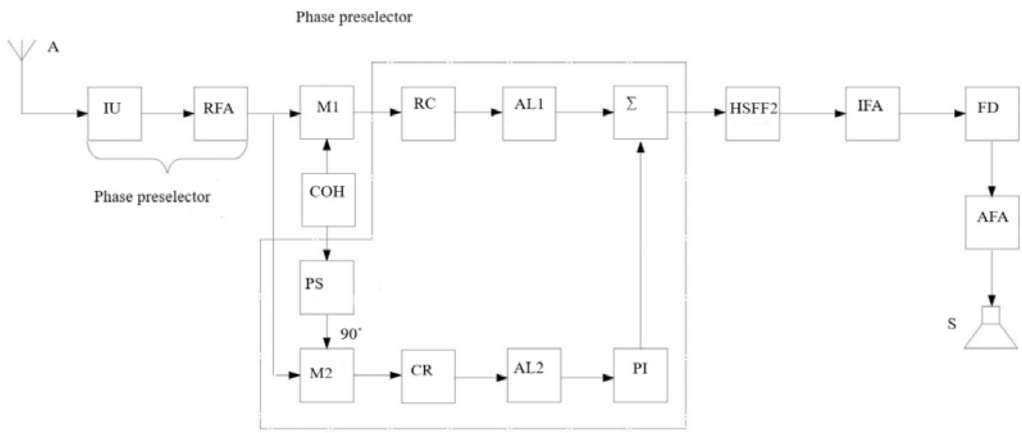
High-frequency (HF) components are filtered out in the HSFF, which performs selectivity in the adjacent channel. The image frequency is suppressed as a result of phase compensation according to the formula for suppressing the single sideband modulation with one side band with supressed carrier waveform in the coherent detector according to «quadrature SSB AM» model [20].

$$a_f = 20\lg\left|\frac{1+\alpha}{\sqrt{\alpha^2 - 2\alpha\cos\Delta\varphi + 1}}\right|, \text{ dB},$$

where α is the ratio of the amplitudes of conventional SSB AM, and Δφ – phase error, more precisely, the phase difference of SSB AM.



Pic. 4b. Vector diagram of BPS [compiled by the authors].



Pic. 5. Structure diagram of the receiver with the upgraded BPS [compiled by the authors].

If $a = \frac{a_2}{a_1} = 1$, then α_f is transformed to the form:

$$a_f = 20\lg\left|\frac{2}{2(1-\cos\Delta\varphi)}\right| =$$

$$= 20\lg\left|\frac{2}{\sqrt{2^2\sin^2\left(\frac{\Delta\varphi}{2}\right)}}\right| = 20\lg\left|\frac{1}{\sin(0,5\Delta\varphi)}\right|, \ |\text{dB}|.$$

Pic. 3 shows the dependence built according to the formula presented above, from which it follows that at $\Delta\varphi = 2'$ the value of $\alpha_f = 80$ dB. However, in [21, P. 48], it is said that the real 90˚ BPSs provide $\Delta\varphi = (2–3)^\circ$, which corresponds to $\alpha_f = 30$ dB, which is not enough.

To increase α_f, it is necessary to improve 90° BPSs.

3. Modernisation of 90˚BPSs

An expedient increase in α_f is possible when 90˚BPSs are made using RC circuits [9], according to Pic. 4a. Their operation is presented graphically in Pic. 4b with changing frequencies.

The experiment showed that the phase shift between U_R and U_c by 90˚ is preserved in the frequency band of 25 kHz with an error of $\Delta\varphi = 0,1^\circ$, since the capacitance resistance $X_c = \frac{1}{j\omega C}$, and multiplication by the sign of j means a phase shift by 90˚, according to [10, p. 46]. However, the amplitudes of U_R and U_c signals differ greatly from each other in the frequency band of more than 25 kHz, so it is necessary to use limiting amplifiers to equalise them.

The structure diagram of the receiver with RC circuits and limiting amplifiers [9] is shown in Pic. 5.

The operation of the circuit in Pic. 5 is self-explanatory as it is discussed in detail in Pic. 2 and Pic. 4.

CONCLUSION

1. It is proposed to use the principle of coherent detection of signals of two channels presented simultaneously on two sidebands of one amplitude-modulated (AM) oscillation without a carrier frequency when converting the frequency in the receiver to suppress the image frequency.

2. The simplest and most accurate phase shifter using two RC circuits connected in parallel and in reverse order [9; 11] with signal amplitude limiting amplifiers, which suppress the image frequency much more effectively than the known frequency preselector has been developed [24; 25].

3. The developed phase preselector provides not only high selectivity for the image channel, but also allows having a single low intermediate frequency, at which selectivity is also high for the adjacent channel.

4. The formula for suppressing the mirror frequencey has been refined as:

$$a_f = 20\lg\left|\frac{1}{\sin(0,5\Delta\varphi)}\right|, \ |\text{dB}|.$$

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