## MODEM OPTIONS FOR DIGITAL RADIO COMMUNICATION SYSTEMS

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## ABSTRACT

New versions of the modulator and demodulator (modem) for the digital railway radio communication system GSM-R have been developed, which increase the noise immunity twofold. To realize «cos» and «sin» blocks, a phase modulator is used, two coherent quadrature demodulators are connected to its output in parallel. It is shown that «cos» block generates the signal cos [msinϕ(t)], which is transferred to the operating frequency of the transmitter by means of subsequent blocks representing the structure of the one-side amplitude modulation driver, forming the final phase-modulated signal. It is proposed to detect an FM signal not from the modulation envelope, as it is done customary, but coherently, which excludes the quadrature component of the interference.

*Keywords:* *railway, radio communication, digital signal, Gaussian filter, modulation, coherent FM signal detector, noise immunity, frequency efficiency.*

**Background.** *The digital radio communication system GSM-R is widely used not only in Russia, since it has high frequency and power efficiency, uses separate coding of the source of the RS and the channel. Its transmitter (TRT) includes [1, 2]:*

*1) analog-to-digital converter (ADC);*

*2) minimizer of the frequency band of the digital signal (DS);*

*3) modulator with amplifiers.*

**Objective.** *The objective of the authors is to consider modem options for digital radio communication systems.*

**Methods.** *The authors use general scientific and engineering methods, comparative analysis, mathematical apparatus.*

**Results.** *Minimization of the frequency band is achieved by doubling the elementary sending (1 or 0) of the digital signal after dividing its discharges into even and odd components and using continuous phase shift of the DS, and linearly within one elementary parcel up to ± 90º, respectively. If you change the parcel from 1 to 0 or vice versa, the phase characteristic of the DS suffers an acute break, causing the frequency band to expand. To eliminate the shortcoming, the fracture is rounded using a Gaussian filter [1, 2]. It is with this filter that the second stage of modulation in the TRT begins, the structural diagram of which is shown in Pic. 1.*

*The amplitude-frequency response (AFR) of the Gaussian filter is determined by the formula* $G(f)=\exp[-\left(\frac{f}{B}\right)^2 ln\sqrt{2}]$, *where B is the bandwidth of the filter at –3 dB, which is analogous to AFR of a parallel oscillatory contour. In GSM cellular communication systems, the value of* $BT_c = 0,3$, *where* $T_c$ *is the duration of an elementary impulse. In the scheme of Pic. 1, indirect frequency modulation takes place, i.e. phase modulation (PM), a time-integrated via a modulating signal, as indicated by I block, as well as a phase-modulated signal [1, 2].*

$$u_{pm}(t) = \sin[\omega t + m\sin\phi(t)] = U_m\{\sin\omega t\cos[m\sin\phi(t)] + \cos\omega t\sin[m\sin\phi(t)]\}, \quad (1)$$

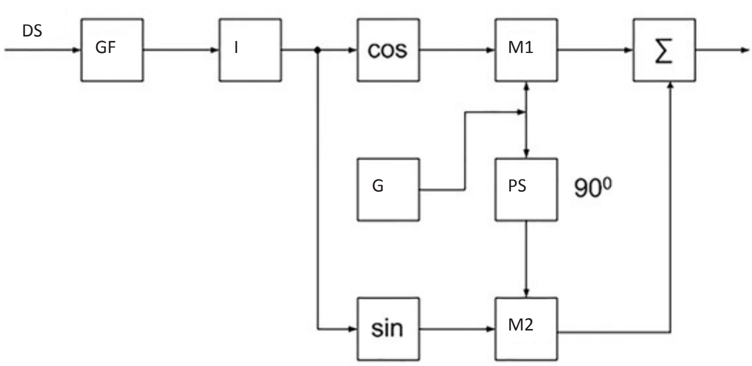
*We see that (1) corresponds to the structure of the scheme after block I. Here* $m\sin\phi(t)$ *is the signal from the output of the integrator I.*

*Note that the indirect FM is much narrower than the direct FM. For example, in train radio communication (TRC), carried out at a frequency of 2,13 MHz, frequency deviation of 12 kHz (two doublers and one trebler) was used to obtain a deviation of 2,5 kHz with indirect FM in the ZhR-U system, and for a straight line FM in the latest generation of «Transport» frequency multiplier is absent.*

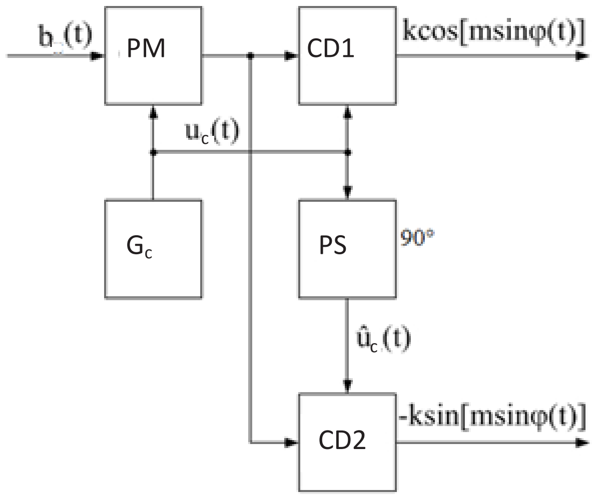
*Gaussian filter, having a bell-like AFR, selects from the input digital signal the component of the resonant frequency to which it is tuned, and several nearby frequency components weakened by the slopes of its AFR. This means that the GF converts the input digital signal into a practically analog signal b(t), which can be represented in quasi-harmonic form as the projection of an analytical (complex) signal onto the real axis:*

$b(t) = U(t)\cos\phi(t)$,

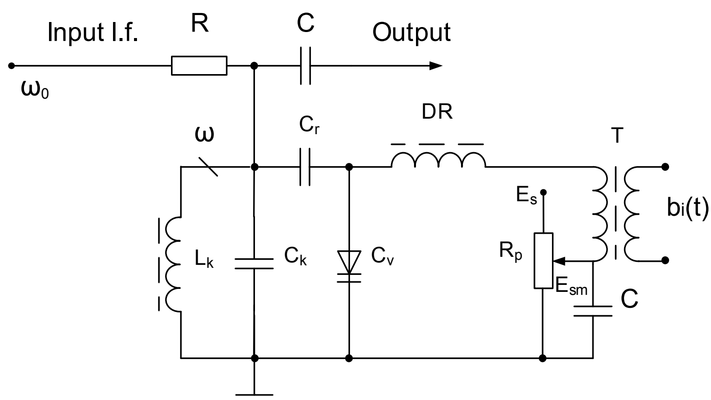
*where U(t) – modulation envelope,* $\phi(t)$ *– phase of a signal.*




***Pic. 1. Block diagram of the second stage of GSM-R system modulation.***
***Pic. 1 denotes: GF – Gaussian filter; I – integrator; «cos», «sin» – blocks that convert the input signal into the corresponding argument of its function; G – oscillator of carrier frequency; M – multipliers of signals; PS – phase shifter at 90º; Σ – adder.***




***Pic. 2. Expanded structural diagram of «cos» and «sin» blocks of the GSMK manipulator.***
***Pic. 2 denotes: PM – phase modulator; $G_c$ – oscillator of the auxiliary carrier frequency; CD –coherent phase detector consisting of a series-connected multiplier of signals and a low-pass filter (LPF); PS – phase shifter by 90˚.***




***Pic. 3. Schematic diagram of PM on a single circuit.***

*In the block I this signal is integrated over time: ∫kb(t)dt = ∫kU(t)cosϕ(t)dt, where κ – proportionality coefficient, and then goes to the input of «cos» and «sin» blocks. At the output of the blocks, respectively, there are oscillations cos∫kU(t)cosϕ(t)dt and sin∫kU(t) cosϕ(t)dt respectively. To calculate these integrals, the authors proposed to multiply and divide the integrands by* $\frac{d\varphi(t)}{dt}=\Omega(t)$ *– circular frequency of the modulating signal, then the signal at the output of the integrator I:*

$$b_I(t)=\int\frac{kU(t)}{\Omega}\cos\varphi(t)\frac{d\varphi}{dt}dt=m\sin\varphi(t),$$

*and at the output of «cos» and «sin» blocks, respectively:*

$$cos\int\frac{kU(t)}{\Omega(t)}cos\varphi(t)d\varphi(t)=cos[msin\varphi(t)]; \qquad (2)$$

$$sin\int\frac{kU(t)}{\Omega(t)}cos\varphi(t)d\varphi(t)=sin[msin\varphi(t)], \qquad (3)$$

*where* $m=\frac{kU(t)_{max}}{\Omega(t)_{max}}$ *– FM index at* $kU(t)_{max}=\Delta\omega_d$ *– frequency deviation.*

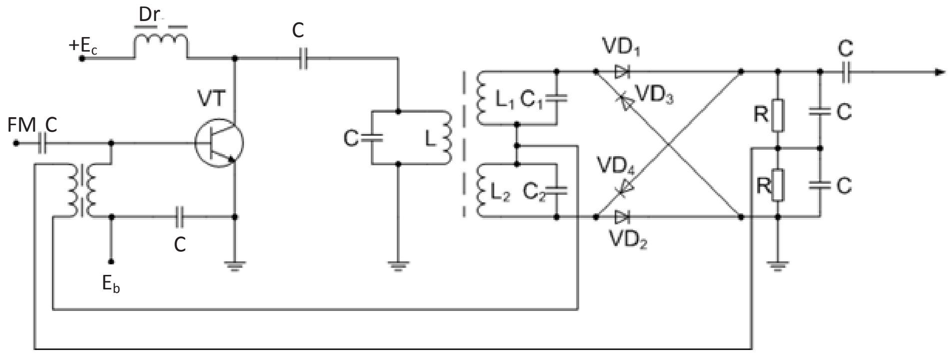
*In turn [1]:*

$$\cos[msin\varphi(t)]=J_0(m)+2\sum_{n=1}^{\infty}J_{2n}(m)cos2n\varphi(t); \qquad (4)$$

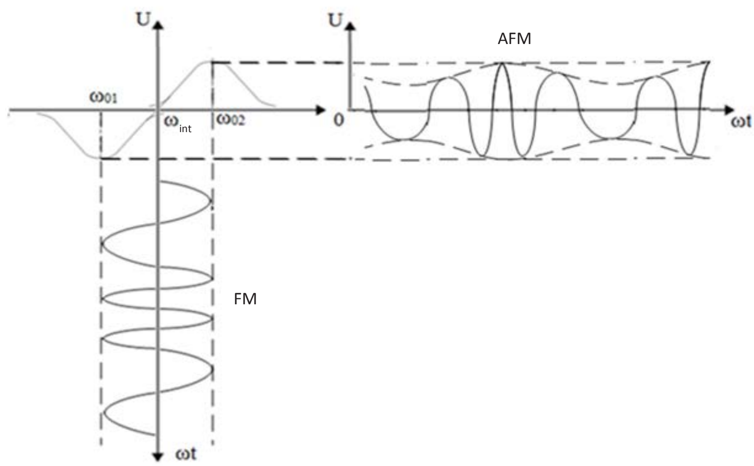
$$\sin[msin\varphi(t)]=2\sum_{n=1}^{\infty}J_{2n-1}(m)\sin(2n-1)\varphi(t), \qquad (5)$$

*where $J_n(m)$ – Bessel function of the first kind of order n from the argument m. It is seen that the first expression consists of a constant component and an infinite sum of even harmonics, and the second – only from an infinite sum of odd harmonics. Further, the signal cos[msinϕ(t)] goes to one input of the multiplier M1, and the signal sin[msin ϕ(t)] – to one input of the multiplier M2. The oscillation of the carrier frequency of the transmitter $u_c(t) = U_c\sin\omega_0 t$ from the generator G goes directly to the second input M1 and to the second input M2 – through the phase shifter PS by 90˚ in the form* $'u_c(t)=U_c cos\omega_0 t$ *. At the output of these multipliers there are oscillations:*

$$u_{m1}(t) = u_s(t)\,u_c(t) = cos[msin\phi(t)]U_c sin\omega_0 t = 0,5U_c\{sin[\omega_0 t + msin\phi(t)] + 0,5U_c sin[\omega_0 t - msin\phi(t)]\}; \qquad (6)$$




*Pic. 4a. Schematic diagram of the demodulator on two detuned circuits.*




*Pic. 4b. A graph of the FM conversion in the AFM for a demodulator on two detuned circuits.*

$u_{m2}(t) = u_s(t)\,{}'u_c(t) =$

$= \sin[m\sin\phi(t)]U_c\cos\omega_0 t =$
$= 0{,}5U_c\{\sin[\omega_0 t + m\sin\phi(t)]–$
$– 0{,}5U_c\sin[\omega_0 t - m\sin\phi(t)]\}$. (7)

*From the output of the multiplier M1, the signal goes to one input of the adder $\Sigma$, and from the output of the multiplier M2 – to its other input. At the output of the adder oscillation*

$u_\Sigma(t) = u_{m1}(t) + u_{m2}(t) = U_c\sin[\omega t + m\sin\phi(t)]$, (8),
*which coincides with (1).*

*In the known sources of GSM, «cos» and «sin» blocks are not disclosed, but are represented by squares, so we realize their structure. Taking into account formula (1), it is possible to propose the implementation of these units in the form of a single phase modulator operating at a subcarrier frequency, to the output of which two parallel coherent quadrature detectors are connected in parallel, as shown in Pic. 2.*

*The circuit works as follows.*

*The signal input of the PM is fed from the integrator $b_i(t) = m\sin\phi(t)$ to the information input of the FM, and to the second input there is a carrier frequency oscillation $u_c(t) = U_m\sin\omega t$ from the generator $G_c$. At the output of PM, a signal $u_{pm}(t) = U_m\sin[\omega t + m\sin\phi(t)]$, is obtained, which is fed to the information inputs CD1 and CD2. From the output of the generator $G_c$, an oscillation $u_c(t) = U_m\sin\omega t$ enters the second input of CD1 directly, and the second input CD2 – through the phase shifter PS by 90˚, i.e.* ${}'u_c(t) = U_m\cos\omega t$. *At the output of these multipliers, oscillations are obtained:*

$u_{m1}(t) = u_{pm}(t)\,u_c(t) = U_m\sin[\omega t + m\sin\phi(t)]\,U_m\sin\omega t = 0{,}5U_m^2\cos[m\sin\phi(t)] + h.f.;$

$$u_{m2}(t) = u_{pm}(t)\cdot{}'u_c(t) =$$
$$= U_m\sin\left[\omega t + m\sin\varphi(t)\right]U_m\cos\omega t =$$
$$= 0{,}5U_m 2\sin[m\sin\varphi(t)] + \text{h.f.}$$

*LPF of both CD eliminate high-frequency (h.f.) components, so that at the output of CD, the signals coincide with the output signals of «cos» and «sin» blocks in Pic. 1. Therefore, at the output of the remaining blocks, the signals remain unchanged.*

*In Pic. 3 there is a schematic diagram of the phase modulator.*

*The circuit is a voltage divider consisting of a resistor R and an LC oscillating circuit tunable in frequency and phase by a modulating signal $b_i(t)$ by means of the varicape capacitor $C_v$. The working point of the varicape is given by the potentiometer $R_p$ from the shift source $E_s$. The linear section of PFC of a single circuit is small, up to ±30˚. To increase it, it is possible to use connected contours, for which, as shown in [1], the maximum linear portion is $\Delta\varphi_{mlp} = \pm\frac{\pi(n-1)}{2}$ rad, where $n \geq 2$ is the number of connected loops. The* *implementation of coherent detectors is simple and requires no explanation.*

*It follows from the foregoing that «cos» block in Pic. 1 generates a signal cos[msinϕ(t)], which carries out single sideband amplitude modulation (SSB AM) by the phase method in subsequent blocks, in structure coinciding with SSB AM generator, for transferring it to the working frequency* $\omega_0$ *of the transmitter. But according to the formula (1), instead of all blocks after the integrator, one phase modulator can be used at the transmitter carrier frequency* $f=\frac{\omega_0}{2\pi}=900$ *MHz, since such modulators are known [5].*

*The transmitted FM signal on the receiving side is detected [1] in two steps:*

*1) coversion of FM into amplitude-frequency-modulated (AFM) signal;*

*2) detection of AFM signal over the modulation envelope.*

*To increase the noise immunity, it is proposed [6] to detect the AFM signal not in the modulation envelope, but coherently, because the FM signal is for the AFM carrier frequency oscillation. With coherent detection, the quadrature component of the interference is eliminated, which reduces the interference power by an average of two times. In Pic. 4a, a schematic diagram of a coherent detector of FM signals on a detuned contour developed in [6] is presented, and in Pic. 4b – time diagrams explaining its operation.*

*In Pic. 4a, the output circuit of the last IF amplifier on the transistor is tuned in resonance to the intermediate frequency, and the detector circuits are detuned symmetrically with respect to the intermediate frequency* $\omega_{int}$*, as shown in Pic. 4b (*$\omega_{01}, \omega_{02}$*). The multiplier is made on a circular diode balance modulator, which has minimal nonlinear distortion. At the output of the multiplier we get the signal:*

$$u_M(t) = U_{AFM}(t)U_{FM}(t) \cong U_m[1 + M\sin\Omega t]\cos^2[\omega_{int}t + m\sin\Omega t] = U_m[1 + M\sin\Omega t]0.5(1 + \cos 2(\omega_{int}(t) + m\sin\Omega t) = 0.5U_m M\sin\Omega t + H.F. + const,$$

*where M – depth of AFM, m – FM index, and* $\Omega t$ *is used instead of* $\phi(t)$*.*

*The LPF (RC-chains of the multiplier) passes only the first term to its output, i.e. the transmitted speech signal is* $u_{lpf}(t) = 0.5U_m\sin\Omega t = KU(t)\sin\Omega t$*, where K = 0.5Um – constant; U (t) = M. The second is that the high-frequency (h.f.) term is filtered out, and the constant component is eliminated by the separation capacitor-C at the output.*

**Conclusions.**

*1. The implementation of «cos» and «sin» blocks in the GSM-R system based on the phase modulator is proposed, to the output of which two quadrature coherent detectors are connected.*

*2. It is shown that «cos» block generates the signal cos[msinϕ(t)], which is transferred to the working frequency of the transmitter with the blocks whose structure coincides with the structure of the one-side amplitude modulation (SSB AMP) driver, as a result, we have a phase-modulated signal.*

*3. It is proposed to form a vibration with PM at a carrier frequency of* $f_c$ *= 900 MHz without a coherent detector, since such modulators are known [5] and this simplifies the transmitter scheme.*

*4. It is proposed to demodulate the FM signal by coherent detection of the AFM signal, and not over the modulation envelope as usual. This increases the noise immunity of receiving signals in half.*

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