Feature Article

Method of Diversed Transmission with Digital Signals Inversion

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Task assignment. Digital signals become increasingly used in modern information transmission systems. To improve noise immunity space diversion method is applied in some systems, when several identical signal copies are being transmitted and received by remotely located antennas. The distance between diversed antennas is selected in such a way that fading of signals amplitude received by different channels becomes uncorrelated. This may help to decrease negative influence of signals fading. Moreover, the approach is advantageous in signal-to-noise relation.

However, the obtained improved quality of communication is often no enough. Apart from that, in the media of multichannel transmission the transmitted bit sequenced frequently become corrupted by intersymbol interference (ISI), when each received bit is formed as a sum of transmitted bit and several preceding ones. This decreases noise immunity considerably.

At the same time there is a possibility to significantly decrease negative influence of intersymbol interference and increase signal-to-noise relation using already available system resources. Such possibility is available in two-way communication systems and diversed transmission used both on reception and transmission, and some types of phase-shift keying. The article described this approach.

Approach entity description. We are going to study the algorithms of signals processing in accordance with the proposed approach with use of binary phase phase-shift keying of digital signals (BPSK).

Assume that ratio of space diversion on transmitting side equals N_T, and on receiving side equals N_R. These ratios may be equal, or differ. The signals from each of N_T transmitting antennas are being received by each of N_R receiving antennas, forming the sum of signals in them. Assume that transmission ratios from transmitting antennas to receiving antennas are described by matrixes $\mathbf{K}_C$ and $\mathbf{K}_S$ (fig. 1). During transmission we see phase shift of receiving compounds with respect to the signal in transmitting antennas. For convenience of further study, matrix K_C shall describe transmission of sin-phase components, and matrix K_S shall describe orthogonal components of the signals. Orders of each matrix are equal $N_T \times N_R$.

At the influence of ISI after corresponding correlative processing the sum of reply is formed for current transmitted bit and several preceding bits. In [1-3] it is shown that the preceding bits shall be summed up with the current bit with various phase shifts. Assume that the number of preceding bits of noticeable level equals m. Then their levels after correlation processing on the receiving side may as well be described with the pairs of matrixes $\mathbf{R}_{Ck}$ and $\mathbf{R}_{Sk}$ (indexes «C» and «S» also belong to transmission of in-phase and orthogonal components; $k=1 \div m$).

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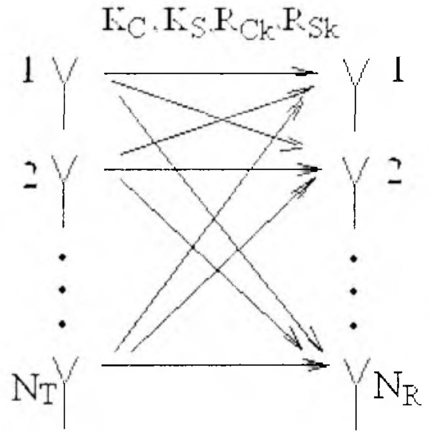

Fig. 1.

Information of orders of components of all matrixes may be received either with the help of regularly transmitted test signals (which as a rule are used against intersymbol interference), or with the help of special markers, assigned to each transmitted signals. This gives opportunity to measure the amount of these markers in each received signal. Part from decrease of intersymbol interference, the described approach improves signal-to noise relation.

Let us first study the case of absence of intersymbol interference, and then consider its influence. In this case receiver get combination of signals equal to $S_j(t)$, where $j=1 \div N_R$. The signals than are phased and combined with some weight factors a_j. Let us consider that the most noise-eliminating optimal combination is realized. That said, weight factors shall be proportional with amplitudes of combined signals and reciprocally proportional noise powers in diversed receivers. However, noise characteristics of receivers are usually equal, and if it is not true, the differences of noise characteristics are easily leveled by corresponding transmission factors, i.e. assume that a_j, are proportional to amplitudes of signals.

The signals are being demodulated then, however, unlike processing analog signals, digital signals have some peculiarities. Let us show that described classic combination of remote signals is similar to slightly different processing. Assume that $S_j(t)=U_j\cos[\omega t+\varphi_j+\psi(t)]$, where U_j is signal amplitude of j branch; ω is carrier frequency; φ_j is signal phase shift of j branch; $\psi(t)$ is phase change bearing the transmitted information. After phasing the sifts disappear, each signal is multiplied by value U_j and correlation device is fed with voltage equal to:

$$S_\Sigma(t) = \cos[\omega t + \psi(t)\}]\sum_{j=1}^{N_R} U_j^2 = U_\Sigma \cos[\omega t + \psi(t)\}]$$

The device multiplies the voltage by signal $S_c(t)=S_0\cos\omega t$ and integrates at the interval of bit length. Let us assume that the level of S_0 is so, that at the correlating device output we obtain voltage $\pm U_\Sigma$, the sign depending on transmitted information symbol.

Let us now study another option of combining of diversed signals. Preliminary phasing is not fulfilled, and correlators are installed into each transmission channel, each channel using two correlators, one for separation of in-phase component, and the other orthogonal component. The obtained voltages are added to each other and to all the voltages from outputs of other correlating devices with weight factors, proportional to their value (as in the previous situation, without respect to their signs). Using as well two comparison signals $S_0\cos\omega t$ and $S_0\sin\omega t$, one for extraction of inphase component, the other for extraction of orthogonal component.

In this case adopted signals at the output of correlators form voltages $\pm U_j\cos\varphi_j=\pm U_{cj}$ и $\pm U_j\sin\varphi_j=\pm U_{sj}$, in both options desired signals have equal level after combining.

Study one of receivers and case of double transmission at signal emission, $N_T=2$. The signal at its input equals the sum of signals from each of transmitters. Initial phases of those two components are mutually independent random values, altering at velocity of fast fading, and conditioned by transmission channel properties. Mutual phase shift of components is also a random value, evenly distributed in the space between 0 and 2π. So, statistical properties of fading of received signal are totally independent from mutual phase shift of signals in transmitting antennas. Fading statistics shall be the same for emitting inphase and antiphase signals, what is used in described approach.

Naturally, to change the phase of emitted signal in an antenna in case of BPSK, it is enough to invert logical values of transmitted signal. Signal fading at input of transmitter may occur in two situations. One of them arises when fluctuating factors of transmission from both transmitters are currently small in value. The other occurs when both transmission factors have considerable value, but opposed phases, and both signals are mutually deducted and die. Whilst the first situation is not considerably affected by inversion of one of transmitted signals, in other situation the summed signal shall be considerably increased instead of become weaker. Since the transmission system has information on current values of all transmission factors, it may immediately switch signals transmitted from different antennas from direct to inverse to get advantage. No considerable structural changes are required for that, since inversion may be fulfilled in low-powered blocks of logic processing.

We calculate the value of advantage, gained when we use such diversed transmission with initial inversion firstly with lack of intersymbol interference.. Assume that inverting is done in some of N_T transmitters. If the combination of signals in receivers is described by column vector $\mathbf{S(t)}$, containing N_R elements, it may be seen as, $\mathbf{S}(t) = \mathbf{K}_C^T \mathbf{h}_q S_0(t) + \mathbf{K}_S^T \mathbf{h}_q \widetilde{S}_0(t)$

where $\mathbf{h}_q$ is column vector, describing q option of inversion; $S_0(t)$ and $\widetilde{S}_0(t)$ are initial emitted signal and its option shifted by 90°. Vector $\mathbf{h}_q$ contains N_T elements, equal either +1, or -1.

Signals are not mutually correlated; assume their powerequal to 1. Weight factors for optimal combination are conditioned by vectors $\mathbf{A}=\mathbf{K}_C^T\mathbf{h}_q$ and $\mathbf{B}=\mathbf{K}_S^T\mathbf{h}_q$. Value of desired signal after summing is equal to:

$$U_\Sigma = \mathbf{h}_q^T \mathbf{K}_C \mathbf{K}_c^T \mathbf{h}_q + \mathbf{h}_q^T \mathbf{K}_S \mathbf{K}_S^T \mathbf{h}_q = \mathbf{h}_q^T \mathbf{G}_0 \mathbf{h}_q$$

where matrix $\mathbf{G}_0 = \mathbf{K}_C \mathbf{K}_c^T + \mathbf{K}_S \mathbf{K}_S^T$.

We write the aggregate of noise processes a^2. It can be shown as a sum of two orthogonal compounds n(t), $\mathbf{n}_{ci}(t)$ and $\mathbf{n}_{si}(t)$ as a column vector, respectively, $\mathbf{n}$, $\mathbf{n}_c$ and $\mathbf{n}_s$. Then the power of noise compound after optimal combination is equal to:

$$P_n = \overline{(\mathbf{A}^T \mathbf{n}_c + \mathbf{B}^T \mathbf{n}_s)^2} = \sigma_n^2 (\mathbf{A}^T \mathbf{A} + \mathbf{B}^T \mathbf{B})/2 = \sigma_n^2 \mathbf{h}_q^T \mathbf{G}_0 \mathbf{h}_q / 2$$

where the top line means time averaging. Relation of desired signal level to mean square root of noise at q option of inverting shall be equal to . The system chooses an option of vector $\mathbf{h}_q$, which provides maximum noise immunity. Thus using the described approach relation of desired and interfering components shall be equal to:

$$\rho_2 = \max_q \{\rho_q\} = \sigma\left(\sqrt{\max_q \{\mathbf{h}_q^T \mathbf{G}_0 \mathbf{h}_q\}}\right)/2 \qquad (1)$$

Implementation of remote transmission approach with inverting. The described method may be implemented with the help of the following aggregate schemes of transmitting part (fig. 2) and receiving part (fig. 3). In transmitting part input informational bits current S_{IN} is being coded in coder (C), or may be directly transmitted to BPSK modulator (M). High-frequency signal from the generator (G) is transmitted to the modulator as well, with initial phase altered depending on values of modulating logic variable. After that the signal is modulated in the invertor (180°) and transmitted to multiplexer (MUX).

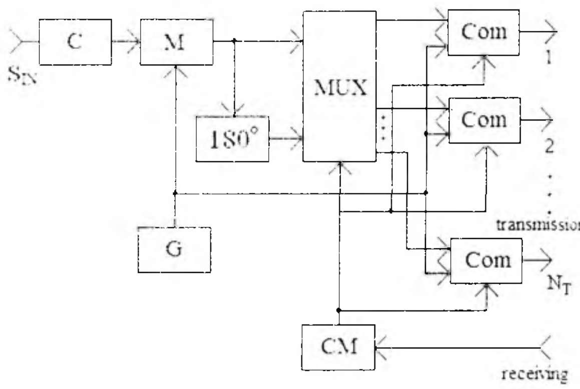

Fig. 2.

Each output of MUX is connected only with one of its two output signals (either direct one, or inverted). Selection is done by the control module (CM). After that, if successive channels test is applied, all signals are transmitted to channel multiplexors (Com.). They are used for switch either into operational mode of information transmission, or into test mode. In information transmission mode all of them are getting input signals from MUX. In test mode each of them connects the signal from the generator output for the period of pulse duration.

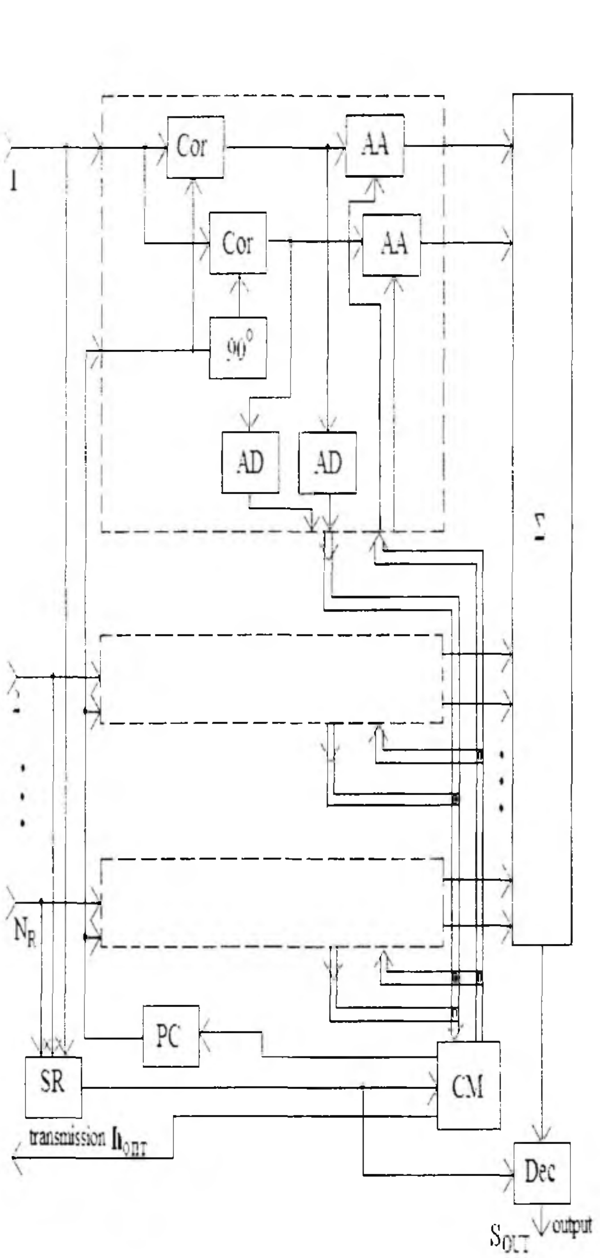

Fig. 3.

Therefore, not only one single test signal is formed, but test complex. Test signals are remote in time for the duration of m symbols. In intervals between them the signals are not emitted. Test signal, emitted individually by each transmitted, is received by all the remotely located receivers and used for identification of values of matrixes elements K_C and K_S, as well as all the matrixes R_{Ck} and R_{Sk}.

Receiving side processes the signals in each diversed branch by uniform block, which contains correlators (Cor), analog-to-digital converters (AD), phase changer (90°), adjustable amplifiers (AA) and digitally controlled phase changer (PC). During transmission of test complex (which is picked up by test synchronization receiver (SR) with the help of blocks Cor and AD all elements of matrixes K_C, K_S, R_{Ck} and R_{Sk} are changed and picked up in control module (CM).

Correlation processing is fulfilled with the help of digitally controlled reference generator, which have its frequency tuned according to bearing frequency with the help of orthogonal compounds in each transmission channel. Weight factors in summator (Σ), required for optimal combining, are conditioned by adjustable amplifiers (AA), which are also controlled with the help of CM. Result of combination is transmitted to decoder (Dec) and then to output (S_{OUT}). For the period of test signals receiving, decoder is blocked with the help of SR. CM also forms the vector $\mathbf{h}_{opt}$ for translation to transmitting side and control over inverting process.

Conclusions

Use of the described inverting approach during diversed transmission provides possibility of considerable improvement of noise immunity and decrease negative effects of intersymbol interference and depth of fading. The improvement increases in good pace as diversity order increases, however at greater diversities the positive effect become slower. From the point of approach efficiency rate at transmission is equal to rate at reception.

Reference

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