Feature Article

# Increase of noise immunity of signal's transmission on channel with diversity

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*Abstract*

Many data transmission systems have an internal resource which can be used to enhance noise immunity of transmission. In this article opportunities of increase of immunity to interference and frequency-selective fadings, consisting in redundancy of frequency resource in the form of frequency diversity will be examined ([1-3]).

If the transmission is realized under conditions of multipathing, then the choice of way of using the redundancy is depended on the bandwidth of the signal. By transmitting broadband signals it is necessary to take into account the phenomenon of multipathing, which occurs when a great number of overreflectors of signal is present. By tropospheric or ionospheric wave propagation there is inhomogeneity of electrophysical properties of the medium. In urban conditions multipathing appears due to the variety of urban relief with lots of metal fragments.

Due to the multipathing total signal at the receiving point is a superposition of a great number of individual signals which come in different rays. In the frequency region mutual amplitude-phase relations in a superposition of different signals are different at different frequencies. It leads to the important non-uniformity of the frequency response of the channel and the appearance of fall - through in some of its areas (the appearance of frequency-selective fadings - FSF). FSF parameters are determined by the frequency correlation radius $R_F$.

If the bandwidth of the signal is less than $R_F$, then the use of frequency diversity allows you to get the win with an appropriate combination of received signals. Fading in the various branches of the diversity occur independently, as a result of it a depth of the fading of total signal after combining is reduced. Also there is a definite advantage for the signal to noise ratio. However, the frequency resource, which consists of diversity, may be more effectively. There are different situations. There is the feedback channel in the transmission system (eg., service channel) or it is absent.

### Feedback channel is absent

In this case, along the branches of diversity not the same copies of signal are transmitted (as in the "classical" diversity), and various signals, which are additionally connected by means of coding. Consider the example of the double-diversity ([4]). By using some kind of block code with **k** information and **b** check symbols the presence of double-diversity should be considered as a general expanded field with size **n = k + b** for placing both the information and the check symbols of one block, with that **b = k**. After the forming

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of such an extended block it is transmitted not entirely on a concrete diversity channel, but its fragments are transmitted in different channels of diversity. By double diversity in one channel of diversity information part of block is transmitted and in the other channel of diversity at the same time or with a fixed time shift is transmitted the check part of the block.

If, because of the fading signal was lost in one branch of diversity, it means that in the appropriate code block have been erased **n / 2 = b** symbols. With the use of correcting properties of the code, these symbols can be restored. The stability to impulse noise is increased. Earlier encoding (if it was applied) could eliminate just short-term noise, because usually is **b << k**, but now would be eliminated the interference of much larger total duration, which is equal to half the length of information part of the block. The use of convolutional coding will give an additional advantage. In this case, you can use the algorithms of "soft" Viterbi decoding and take into account current levels of signals in the branches of diversity.

In the case of broadband signals with a bandwidth much wider then $R_F$, the work of "classical" system with diversity is complicated significantly. By frequency-selective fadings in the band of working frequencies not only deviation the form of amplitude-frequency characteristics from uniform, but the deflection from linear phase-frequency characteristics occurs. In various branches of the diversity these phase-frequency characteristics are different. By general adjustment of phase of diversity signals this phase difference in different parts of the band spectrum of diversity signals can't be removed. As a result, by addition of diversity signals different parts of the signal are added together with a different phase shift, that in different parts of the spectrum of signal leads to a strengthening and weakening of the spectral components, and the non-uniformity of amplitude - frequency response is not reduced. At the same time intersymbol interference (ISI) is not eliminated, i. e. use of diversity as a method makes no sense.

Under these conditions, it is offered to modify the method of OFDM (Orthogonal Frequency Division Multiplex) ([5, 6]). Also, as with OFDM, in the signal band are used few subcarriers. The original stream of symbols is divided into several sub-streams according to the number of subcarriers forming M private channels. Symbol rate for all private channels is the same and less than the rate of the original stream of symbols in M time. As a result, the duration of each symbol can be also increased in M times, and ISI will less influence on it. However, if by using OFDM the influence of ISI eliminates, the negative FSF manifistation remains. In the bands of the spectrum, where we have FSF, is broken the transmission of appropriate sub-stream of information symbols, which are lost forever.

The offered modification of the frequency diversity method is that the frequency range of all channels of diversity is also divided into sub-ranges. In contrast to OFDM, the width of the sub-ranges is determined not by duration of information symbols, but the requirement that the bandwidth of the spectrum of each sub-band must be no more than $R_F$. The initial signal is also divided into sub-flows transmitted each in its own sub-band. Let the total bandwidth of the signal $P_0 = MR_F$ be, i. e, in one channel of diversity there are $M$ sub-channels for transmission of the original information signal. But due to redundancy in the system there is still $M (N-1)$ of the same sub-channels, where $N$ - the multiplicity of diversity.

In the modified method, the stream of information symbols is encoded with code rate equal to 1 / $N$. The stream of symbols increases in $N$ times, and for transmission uses all $MN$ sub-channels. In this situation the advantage, obviously, have convolutional codes. In the received signal the level of the symbols of different sub-channels differs significantly due to FSF, that shows on the desirability of using "soft" decoding. Effective "soft" decoding of block codes is attended by significant mathematical and technical difficulties, whereas "soft" Viterbi algorithm for decoding convolutional codes is simple enough.

At the transmitting side totality of output signals is divided into two groups just because two different transmitters at different frequency ranges are used. If the frequency ranges of both diversity channels are located together in order to be covered by the same transmitter, the division into two groups, is not necessary. Therefore, the method can be used not only when the frequency redundancy present in the form of width of band margin, multiple of the band of one diversity channel (in this case - double – fold margin), but in any case of the width, i. e multiplicity is not required.

If the frequency redundancy is small, the number of new symbols added by the coding is also small. With a large margin we can choose the encoding rate large enough and provide greater noise immunity and transmission of information. As the algorithm is not changed of the ratio of the value of the frequency margin and the band of one channel, it does not conform to the notion of the multiplicity of diversity in the usual understanding. In this generalized case, we can speak about fractional multiplicity of diversity.

Consider the probability that a result of FSF loss of information happens at least in one of the sub-channels. If you are using a method similar to OFDM, the probability $P_2$ of this event is

$$P_2 = 1 - (1 - P_1)^M$$

where $P_1$ - the probability of losing one of the sub-channels due to the influence of FSF. In the case of using of the offered method the probability of losing one of the sub-channels is equal to:

$$P_3 = \sum_{i=Q+1}^{M+Q} \frac{(M+Q)!}{i!(M+Q-1)} P_1^i \left(1 - P_1\right)^{M+Q-i}$$

where $Q$ - the number of additional sub-channels, organized by frequency redundancy. The value of $P_3$ is much lower than $P_2$ and decreases rapidly with increasing $M$ and $Q$. Estimation of $P_3$ is shown for the case of a hard block decoding. If a soft convolutional decoding is used, then the win will be greater.

**Feedback channel is present**

In this case, information about the parameters of the received signals can be sent to the transmitting side. Transmission quality of each subchannel is estimated and encoding is made in each of them independently, depending on the state of the channel ([6]).

The foregoing is illustrated by block coding. Suppose that in each sub-channel (numbered $j$, $j = 1 \div M + Q$) is used block code with block size in $nj$ symbols, where $kj$ symbols are information, the remaining bj symbols are check, $nj = kj + bj$. Then, if for some period of time in the system without redundancy can be passed $L_1$ = nM symbols, in this method over the same period of time can be passed $L_2 = n\ (M + Q) = L_1 + \Delta L$ symbols.

The value of "addition" ΔL is divided between sub-channels so as to compensate the worsening of transmission quality in each of them. For this, the conditions are kept:

$$\mathrm{nM} = \sum_{j=1}^{M+Q} K_j, \quad \mathrm{nQ} = \sum_{j=1}^{M+Q} b_j$$

In the "bad" sub-channels the number of information symbols is decreased, and is added the number of check symbols to compensate the worsening of transmission quality. In the "good" sub-channels, on the contrary, the number of check symbols is decreased because the transmission quality is good, and the number of information symbols is added to compensate a decrease of the transmission rate in bad sub-channels. This changes the data transmission rate in each sub-channel and the value of error of symbols remains roughly the same in all sub-channels. There is the exchange of resource of transmission quality between sub-channels with the maintaining the overall information transmission rate constant. By a sufficiently large total number of sub-channels $M + Q$, with the same statistical properties of fading in each sub-channel considering the statistical properties of the set of channels constant, we can conclude that by the working number both "bad" and "good" and "secondary" sub-channel is approximately constant. At a constant rate will be observed an approximately constant probability of symbol error.

However, in the case of a small number of sub-channels, if the rate of information transmission maintains constant, the probability of a simultaneous worsening of the transmission in a large number of channels at once becomes visible and, therefore, is visible the possibility of temporary significant worsening of information transmission. In this case, if some delay in the transmission of information is allowed, we can organize exchange of redundancy resource not only between the channels, but also in the time field. This is achieved by adjusting not only the transmission rate in the individual sub-channels, but the overall rate of information transmission in system as a whole.

For this stream of information symbols intended for transmission, is written down in accumulating memory at a constant rate, and read at a variable rate. Reading rate depends on the total quality of all sub-channels. At time intervals of general worsening of the quality of transmission in all sub-channels the information parts of the *kj* blocks are reduced and the overall rate of transmission is reduced. Transmission lag is compensated by the fact that in other periods of time she is at higher rate.

Enlarged structural schemes for realization of this method is shown in Figures 1 and 2. On the transmitting side (Fig. 1), the stream of information symbols $S_{INF}$ is received and written down in the accumulating memory (AM) at a constant rate and is read at a rate that depends on the general state of the sub-channels of transmission. Then Switch (Comm) distributes a stream of symbols to sub-channels in accordance with their quality. In each sub-channels ki symbols are written down to memory blocks (MB). Then, in the encoder (E) an appropriate number of check symbols is added to them, there is modulation in modulators (M), the group signal is formed in the adder, and with the help of transmitter (TR) it is transmitted. Work of blocks is controlled by a control block (CB1).

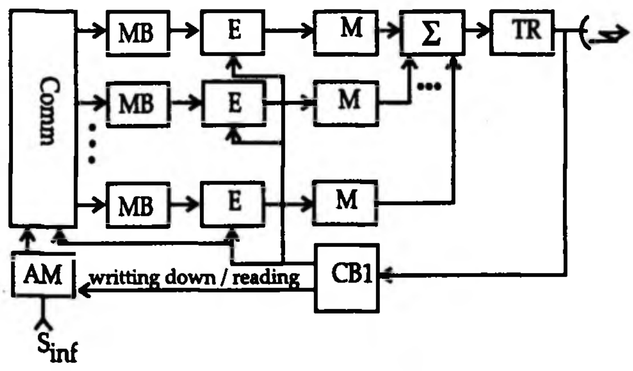


Fig. 1

On the receiving side (Fig. 2) sub-streams are separated by filters (F), then with the help of demodulators (DM) and decoders (DC) the informational parts are chosen of them. With the help of switch (Comm) a continuous stream of transmitted information symbols SINF is grouped. The analyzer of levels (AL) is continuously determined the quality of signals in all sub-channels. On its basis control block (CB2) fixes the size of information and check parts of blocks for all sub-channels. This service information is sent to the transmitting side and manages the work of CB2.

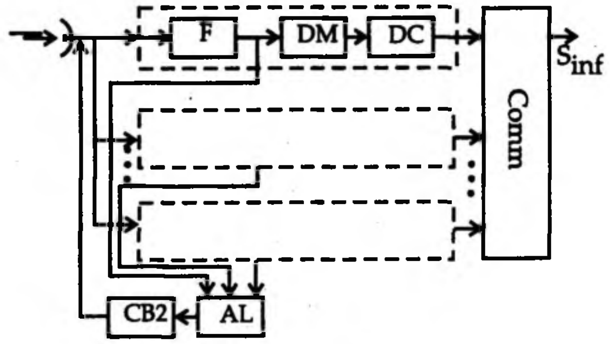


Fig. 2

To read with non-uniform rate for uniform writing of incoming symbols is required accumulating memory of appointed volume. Important is the choice of the ratio between the rate of entry of symbols and a middle rate of their reading. If they are equal may appear situations as a memory overflow, and its devastation. The first situation corresponds to long-term general worsening of the quality of sub-channels. In the second situation, when the overall quality of sub-channels is high, the value of the symbol error becomes significantly less than the required standards. The greater is the probability of one situation, the less is the probability of another. Changing the ratio between the rate of making of symbols and medium rate of transmission we can remove the balance of probabilities in one direction or another. With increase of volume of accumulating memory the probability of both situations at the same time decreases, but increases the delay in the transmission of information.

By the absence of feedback all the subchannels priori considered equal in quality, and on the receiving side the signal quality in them is different, and by decoding of a sequence of symbols it is better to use "soft" decoding. By using block codes "soft" decoding is difficult, while by using of convolutional codes "soft" decoding is easy to realize in practice. In the case of feedback all the received symbols come roughly the same quality and the use of "soft-coding is not obligatory, it is enough effectively" hard "decoding, which is easily realized by block codes.

Permanency of quality of all symbols is achieved on the transmitting side by the changing of coding parameters. By analogy, this situation is logically designated as "soft" coding. Such "soft" coding is probably easier realised with the help of block codes. The ratio between the size of the information and check parts in block codes can be changed exactly without difficulty with small discrete, especially when the length of block is large. In convolutional codes, coding rate is adjustable, for example, by perforation (puncturing), it is significantly coarser.

**Conclusions**

The redundancy of the frequency resource of transmission system can be used more efficiently, using a fractional diversity, when all the available frequency resource is used. Thus, the influence of intersymbol interference and frequency selective fading on the transmitted signals eliminates.

In the absence of a feedback channel convolutional codes with soft decoding at the receiver should be used. In the presence of a feedback channel it is effectively to use "soft" block coding of transmitted signals with the "hard" decoding at the receiving.

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