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On improving OFDM systems performance *

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Abstract

Modifications of the OFDM* multiple access technique improving parameters of the mobile communication, are proposed. They aim to neutralize three main drawbacks of the OFDM technique:

- Difficulties in achieving good parameters in the mobile communication using OFDMA system due to multipath propagation and the Doppler shift influence.
- Difficulty or impossibility to make soft handover.
- Big value of the peak-factor.

This task can be achieved with the help of FBS and MT-FBS methods.

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1 Introduction

Nowadays we use three multiple access techniques in modern communication systems: TDMA, FDMA (including OFDM [1,2]), and CDMA. All methods have their advantages and disadvantages. Orthogonal multiplexing technique (OFDM) allows one to achieve high frequency efficiency and avoid reflection signals influence if the reflection situation does not change during a cycle.

*The list of abbreviations can be found at the end of the paper.

The main disadvantages of OFDM systems include the Doppler shift influence on frequency difference between two adjacent signals in wireless systems, problems with multiplexing of signals from different locations in systems like TDMA, and a large value of the peak-factor (maximal to average power ratio).

The new method of diversity and multiplexing named Frequency Bank System (FBS) [3,4] is to some extent a combination of OFDM and CDMA. The goal of FBS is to decrease disadvantages of both methods and use their advantages. In other words, FBS preserves frequency efficiency of OFDM and also allows transmitting several signals in the same frequency band without multiplexing like in CDMA, but prevents a usefull signal from affecting by other signals and reflection.

2 FBS essence

Let M signals be transmitted with PSK modulation. Each symbol i of each signal corresponds to its phase φ_i.

For simplicity of explanation let M = 4. In the case of FBS method, each symbol of each signal is transmitted four times in four carriers. The sign of phase φ_i (+ or -) corresponds to the Walsh function (see Fig. 1).

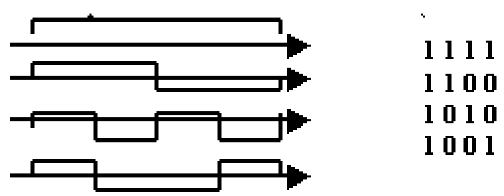

Figure 1: The example of Walsh function for M = 4.

All four signals are transmitted in the same sub-carriers with respect to orthogonality condition (see the transmitter part of Fig. 2).

Each symbol of one signal is transmitted four times but the frequency band is expanded only twofold due to orthogonality. Four signals are transmitted in the same frequency band 2ΔF. It can be shown that any signal can be received without influencing other signals. For example, consider the signal S_2. In the receiver after FFT, the phase sign of frequencies f_2 and f_4 is changed to the opposite: instead of ϕ^0 it becomes $-\phi^0$ or instead of -ϕ^0 it becomes ϕ^0 (see the receiver part of Fig. 2). After the phase change, the sum of phases at all four frequencies does not depend on the phases of signals S_1, S_3, and S_4.

The block diagram of FBS system for M = 4 is shown in Fig. 3. Transmitters in the system shown in Fig. 3 need both carrier phase synchronization and symbol (timing) synchronization at the input of the receiver like in all OFDMA systems.

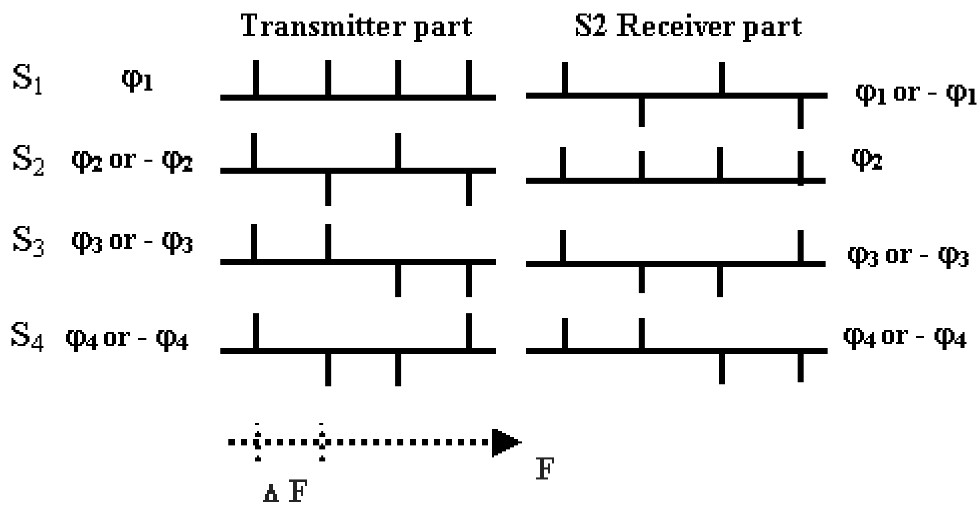

Figure 2: FBS constellation for N = 4.

In a similar way 8 signals can be transmitted at the same 8 frequencies (M = 8). So M can be any power of 2. This phase compensation process is reminisced of color signal phase changes compensation in PAL system [5]. Like in the PAL system, phase changing in modulator and phase reconstruction in demodulator allow one to remove the phase changing in channel. The following observations can be made:

A- FBS is not OFDM (or COFDM [2]) because in OFDM each frequency contains different information (various phases) while in FBS each frequency contains the same information (plus or minus sign of same phases).

B- In FBS with MPSK modulation, Walsh signals are implemented not like in CDMA, because in CDMA Walsh signal pulse polarity (amplitude sign) of information signal (before modulator) is changed, which is equivalent to the phase change from φ to $\varphi + \pi$ while in FBS method the phase of signal after modulator is changed from φ to -φ. In other words, the difference between CDMA (or MC CDMA) and FBS is that in CDMA spreading preceeds modulation, while in FBS spreading follows modulation. The next difference is even more important: in CDMA useful signal recovery takes place after decoder, contrary to FBS where it is before decoder. Decoder is a nonlinear unit; therefore in CDMA we have problems with another signal and reflections influence.

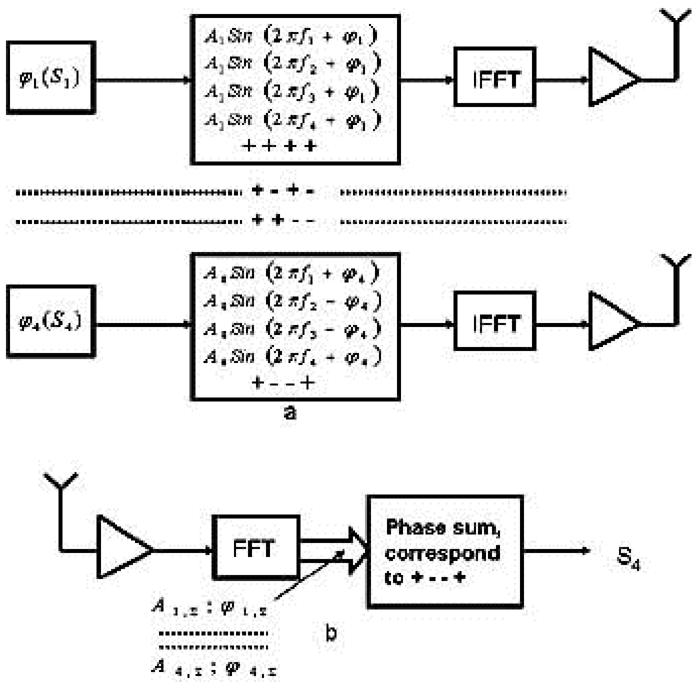

Figure 3: FBS-4 block diagram, a - transmitter, b - S_4 receiver.

3 Mathematical description of FBS

According to the FBS principle, one symbol of l^{st} (one of M) signal can be described as:

$$s_{(i,l),FBS} = E_l \sum_{k=0}^{k_{max}-1} e^{j\left[2\pi f_k t + (-1)^{W_{kl}}(\theta+\beta_i)\right]} \tag{1}$$

where

$0 \leq t < T$,

E_l is the magnitude of a component,

θ is a certain arbitrary phase, chosen for a certain system,

β_i is the information symbol of a l FBS signal (BPSK or QPSK representation), i.e. $\beta \in \{+1, -1\}$ for BPSK or $\beta \in \{+1+j, -1+j, 1-j, -1-j\}$ for QPSK,

$f_k = f_0 + k\Delta f$ are FBS carrier frequencies, $k = 0, \ldots, k_{max}$=*M-1,* where $\Delta f = |f_k - f_{k+1}| = 1/T$,

$\varphi_{i,k}$ is the sequence of phases of a l FBS carrier pattern.

This symbol duration T corresponds to the orthogonality rule. In transmitting signal symbol duration is T + Δ (Δ is the guard interval duration) [5]. Demodulation will be processed with the symbol duration T. The term (-1)^{Wkl}defines the phase sign. The magnitude of W_{kl} can be obtained from the data file, which depends on the order. For the 8^{th} order (M = 8), where $k_{max} = l_{max}$ = M = 8 , one possible data file is shown in Table 1 (different lines order is also possible).

l k	0	1	2	3	4	5	6	7
0	2	2	2	2	2	2	2	2
1	2	2	2	2	1	1	1	1
2	2	2	1	1	2	2	1	1
3	2	2	1	1	1	1	2	2
4	2	1	2	1	2	1	2	1
5	2	1	2	1	1	2	1	2
6	2	1	1	2	2	1	1	2
7	2	1	1	2	1	2	2	1

Table 1. W_{kl} values example for the Walsh function with M = 8.

For a signal $S_{(k4)}$ k is 0 through 7 and W_{kl} is taken from the line corresponding to l= 4. Total at the same 8 frequencies 8 signals can be transmitted with l from 0 till 7. The receiver cuts the guard interval, performs FFT and changes the phases corresponding to useful l, or multiply by $(-1)^{W_{kl}}$

The complex l^{st} FBS signal defined by (1) is obtained as inverse fast Fourier transform, or

$$s_{i,l(t)} = \Im^{-1}\left(s_{i(kl)FBS}\right) \qquad (2)$$

In the general case, each transmitter in neighboring cells can transmit several signals with l from l_P till l_Q, so that each symbol of FBS signal can be described as

$$s_{i,(P \div Q)FBS}\left(t\right) = \sum_{l=l_P}^{l=l_Q} \Im^{-1}\left(s_{i,k,(P \div Q)FBS}\right) \qquad (3)$$

In the same frequency band the receiver can receive some signal groups (3), which differ in the values of l, magnitude, and delay. For example, one transmitter transmits among eight possible FBS-8 signals only signals numbered 0,1,2,3, and 4, that is P = 0 and Q = 4. In addition, it receives reflection signals and noise. A neighboring transmitter can transmit the remaining three signals.

4 Phase shift influence in FBS

Reflections, Doppler shift and other reasons cause the phase shift proportional to frequency. The difference between frequencies in FBS signal is constant and equals to 1/T. The phase change (ωt) for each component will be different and proportional to the frequency difference change. In Fig. 4 there is an example of phase changes for the case of FBS-8 with the central frequency f$_c$. FBS-M signals can be divided into two groups: M/2 signals with a symmetrical phase distribution (left part) and M/2 signals with a non-symmetrical phase distribution (See Fig. 4, right part).

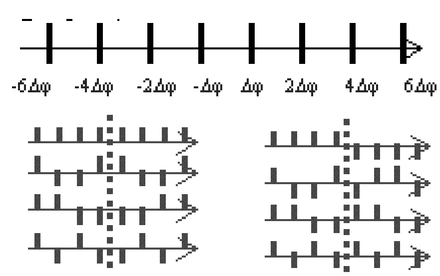

Figure 4: Phase changes due to delay, Doppler shift, and another reasons in FBS-8 signal.

For a symmetrical phase distribution, the phase shifts sum before and after phase changing in receiver is zero (see Fig. 5).

After phase changing in receiver for a non-symmetrical phase distribution (see Fig. 6), the sum of phase shifts is not zero but constant. That is why it does not depend on information phases.

At usual, useful signal receiver can "know" delay and Doppler shifts of all signals received together with the useful signal. Thus the summary phase shift (φ_Σ) can be compensated.

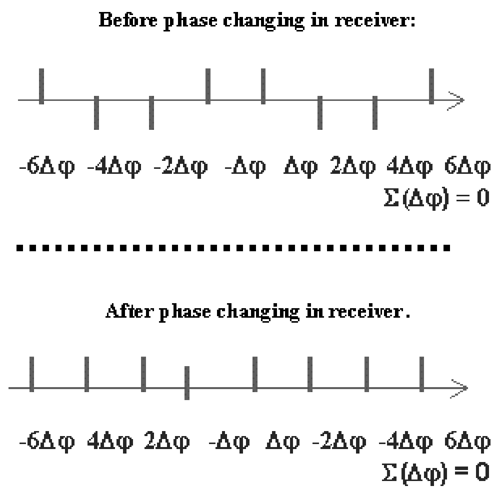

Figure 5: Symmetrical summary phases shifts.

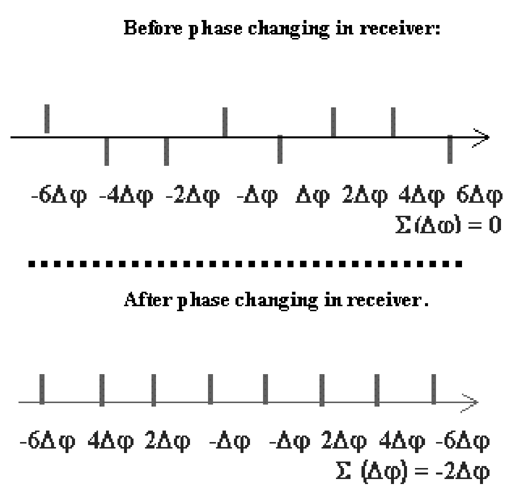

Figure 6: Summary phases shift in non-symmetrical phase distribution.

5 Examples of FBS implementation modes in cellular systems

FBS system can be implemented in all wireless communications including broadcasting systems, personal telephone systems, military systems, and so on. Let us illustrate this by an example of one of the third generation cellular telephone systems, namely, UTRA TDD [6]. In this method, the signal after multiplexer is spread 16 times with the help of a Pseudorandom Sequence (PRS) and input to modulator QPSK (See Fig. 7.)

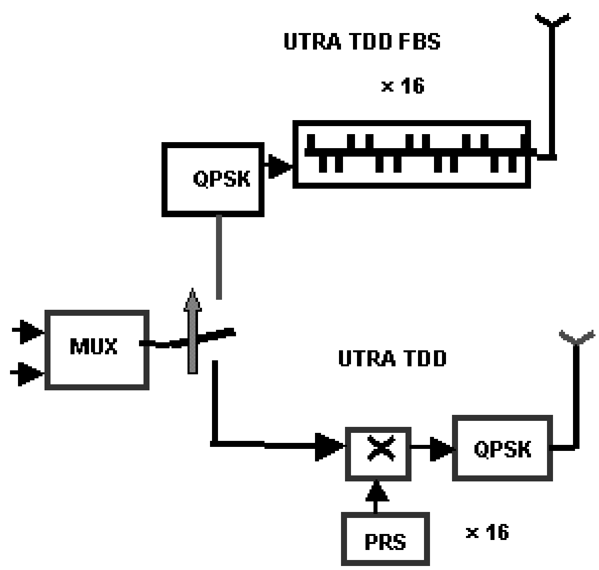

Figure 7: Changeover possibility from 3G UTRA TDD to UTRA TDD FBS.

In the case of UTRA TDD, the FBS signal after multiplexer is input to modulator QPSK and after this it is spread 16 times with the help of Walsh functions for M = 16. The changeover from UTRA TDD to UTRA TDD FBS gives an opportunity getting either frequency band twice narrower, or user number twice larger. As in the case of usual CDMA system, we can distribute users from one UTRA TDD FBS group between several neighboring cells. Similarly to the CDMA system, there is a possibility of soft handover in the FBS method.

The FBS method takes into account only the influence of signals at the same frequency and with the same phase shaping (similar signals) in other cells. The example below shows that in a typical case it creates no problems. Let us calculate this influence in the case shown in Fig. 8.

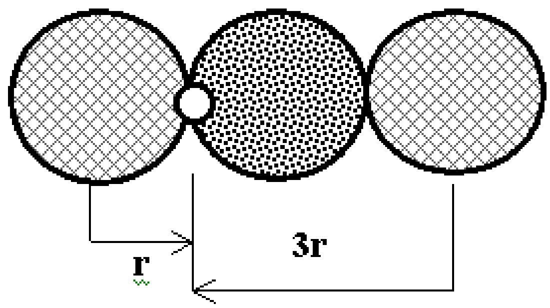

Figure 8: Arrangements of similar signals.

Calculations were performed in accordance with Recommendation ITU-R P.370-7 for the following set of parameters: frequency - 900 MHz, transmitting antenna height - 8.6m, radio horizon - 12km, and r = 10km. Under these conditions, the field density at the distance of 3r is 20 dB less than that at the distance r. The value 20 dB is completely sufficient not to disturb receiving.

The important FBS advantage (especially for cellular or WLAN systems) is its more preferable power distribution. In the case of FBS-M, M signals are transmitted instead of one signal in OFDM. It is possible to show that the output power does not increase but even decreases. Consider a usual QPSK channel with the frequency band ΔF, the signal voltage $V_S$in the input decoder and the noise voltage V_N. We have

$$S/N = V_S/V_n \tag{4}$$

Since in the case of FBS-M all useful signal information results are summed up arithmetically, the input signal voltage is MV_S, the frequency band equals to M/2*ΔF, and the noise level is

$$V_{N,FBS} = \sqrt{\frac{M}{2}}\, V_N \tag{5}$$

As a result, the signal to noise ratio in the FBS-M case is

$$S/_N FBS = \sqrt{2M}\, S/_N \tag{6}$$

The output signal in transmitter in this case is a mean-square sum of signals, since the signals have different frequencies. That is:

$$V_{out,FBS} = \sqrt{M}\ V_{out} \tag{7}$$

Let FBS transmitter output power be the same as an usual system signal power. In this case the signal to noise ratio in the FBS method is

$$S/_N FBS = \sqrt{2}\, S/_N \tag{8}$$

In other words, for the same signal to noise ratio, FBS requires 3dB less power than an ordinary QPSK signal. In comparison with a OFDMA signal, we get the same power. But in the case of OFDMA, we have M signals with one spectral component with the amplitude equal V. In the case of FBS, we have M signals, each of them includes M spectral components with the amplitude V_{FBS}, where:

$$V_{FBS} = \frac{V}{\sqrt{M}} \tag{9}$$

In spite of the fact that the OFDMA signal with the amplitude V and the FBS signal with M components with the amplitudes V_{FBS} have the same power (see Fig. 9), the first signal is more dangerous

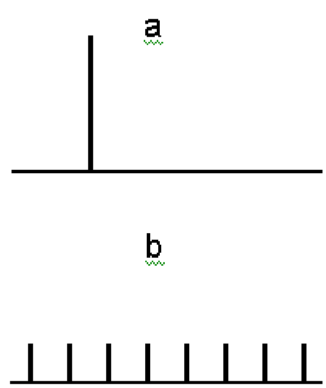

Figure 9: One OFDMA signal spectrum (a) and M components of one FBS signal (b) with the same power.

6 Signal structure, algorithm decoding and simulations

Similarly to other communication systems, FBS signal can be transmitted by cycles. Each cycle begins with a special training signal used for synchronization and compensation of delay, reflections, and Doppler shift. The training signals of all M signals in the same frequency band include only one individual component. So, the receiver "knows' amplitude, additional phase shift, delay, and the presence of all signals reflections. This "knowledge" can be used for testing needed for a useful signal phase calculation. The direct phase calculation of a large number of sinusoidal signals with different amplitudes is a difficult, though solvable, mathematical problem. At the first research stage, other algorithms were investigated. Their detailed description will be the topic of a separate article, but in any case all algorithms include the following compulsory stages:

- synchronization with respect to the useful signal,
- guard interval removal,
- FFT calculation,
- phase turning with respect to the useful signal Walsh function,
- useful signal phase calculation.

The main FBS advantage is its smaller influence on the structure changes of neighboring signals transmitted together with the useful one. In the case of orthogonal signals transmission, the most dangerous changes are caused by orthogonality destruction due to the Doppler shift. For comparison of the Doppler shift influence, the following simulation was performed. One signal (the fourth one) was transmitted in both systems, carrying information which corresponds to the signal phase. This phase was changed randomly and each time the fourth signal phase difference $|\Delta\varphi|$ between transmitting and receiving values was calculated. Obviously, the bigger $|\Delta\varphi|$ corresponds to the bigger BER. The result of this simulation ($|\Delta\varphi|$ standard deviation) is shown in Fig 10. As in the case of standard deviation, the mean value of phase changing in FBS is noticeably less than in OFDMA.

In Fig. 11 one can see Doppler shift influence on the useful signal. Eight signals were transmitted in both systems (OFDM-8 and FBS-8) with information again corresponding to the signal phase. The useful signal is the fourth one. The receiver made synchronization with this signal, so that it had no Doppler shift. All remaining signals did have the Doppler shift. To imitate this Doppler shift, the signal phases were changed by 180^0 after (1 – p) % of useful signal symbol duration $\left|\Delta\varphi^0\right|$.

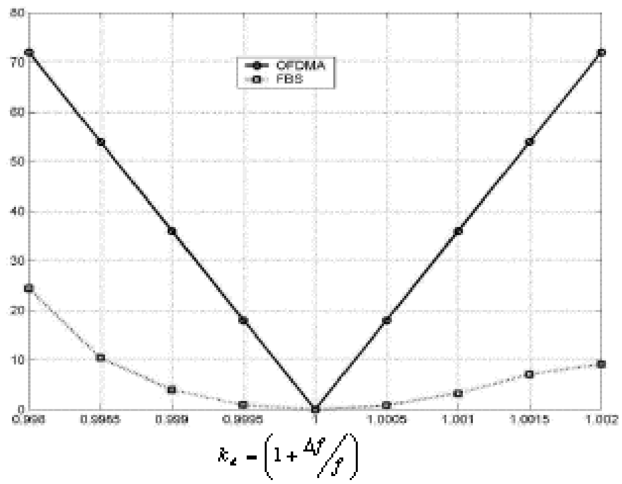

Figure 10: Doppler shift (frequency changing) influence on its signal phase.

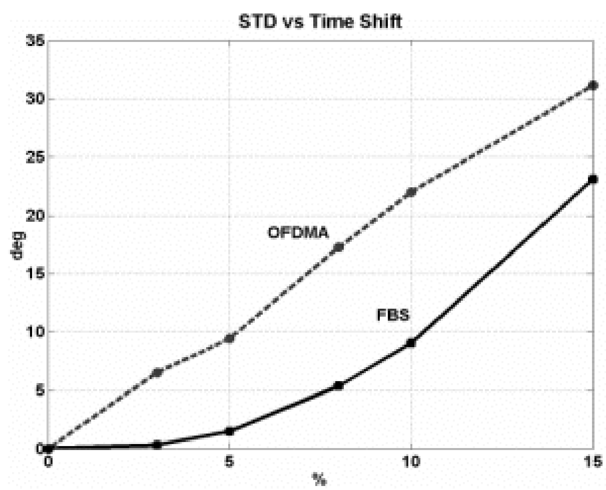

Figure 11: Neighboring signals Doppler shift influence (symbol duration changing) on the useful signal phase.

In this case, FBS had as well an important advantage in comparison with OFDMA.

It is well known that the Doppler shift destructs the orthogonality in OFDMA signal. Let us notice that in the case of OFDM systems it is possible to implement pilot signals at some additional carriers like in DVB-T system. But this option does not work in the case of OFDMA systems where various sources can work at various carriers.

In the case of FBS this destruction is noticeably smaller.

7 Peak-factor decreasing

Another disadvantage of OFDM and OFDMA signals is their large value of the peak-factor (maximum to average power ratio). Apart from the low frequency efficiency problem, there is a strong influence on other signal receivers. Even in the case of low power signal, there are moments with a strong signal. We suggest a possible solution of this problem [7].

The OFDM and up-link FBS signals may be classified as results of a single-side band modulation and may be represented as:

$$x_1(t) = A\sum_{k=1}^{k=M-1}\cos\left[2\pi\left(f+\frac{k}{T}\right)t+\varphi_k\right] \tag{10}$$

where A is the carrier coefficient, k is the carrier number, M is the carrier quantity, f is the carrier frequency, ϕ_k is the k-carrier phase, and T is the symbol duration excluding the guard interval.

However, these signals may also be classified as a spectral modulation method, because the output signal is formed as a sum of spectral components.

In addition to these kinds of signal, a double-side band OFDM or FBS signal may be formed represented as shown in Fig. 12.

The double FBS signal (MT-FBS) may be represented in the following form:

$$\begin{aligned} x_2(t) = A_0\cos(2\pi f_0 t) + A\sum_{k=1}^{k=M-1}\cos\left[2\pi\left(f+\tfrac{k}{T}\right)t+\left(\tfrac{\pi}{2}-\varphi_k\right)\right] + \\ + A\sum_{k=1}^{k=M-1}\cos\left[2\pi\left(f-\tfrac{k}{T}\right)t+\left(\tfrac{\pi}{2}+\varphi_k\right)\right] \end{aligned} \tag{11}$$

where A_0 is the carrier coefficient.

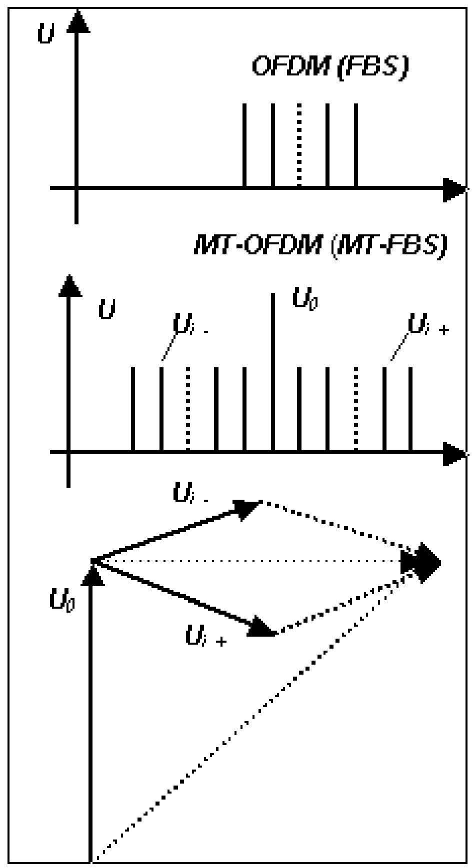

Figure 12: Spectrum and two components vector diagram of MT-OFDM or MT-FBS signal .

The symmetrical spectral components phase relations are similar to the phase relations for FM signal components with a small modulation index (see Fig. 12). Such a signal may be amplified by a limiter-amplifier with a maximal possible efficiency.

A double-side band signal without carrier may also be obtained [7]. These signals are refereed as mirror twinned OFDM or FBS (MT-OFDM or MT-FBS). They may be obtained and amplified using limiter-amplifiers as shown in [7].

The spectral feature of the method is a doubling the carriers' number, which doubles the width of the transmission frequency band. However, concerning the full transmission-reception system of the modified system, error protection increases and transmission and reception are simplified, so that the total frequency range of the whole system is increased by only 20%. This is due to the fact that the modified system requires less error protection because of the doubling of information in two bands, such that each of them carries the full information. More detailed description of this method and first results of simulation can be found in [7].

8 Conclusion

The new diversity method (FBS) is proposed, which combines advantages of well-known CDMA and OFDM methods and, at the same time, is free of some of their negative features.

The conclusions:

- In the case of FBS multipath propagation, the Doppler shift and other phase changes are essentially compensated.
- It is possible to increase frequency efficiency in the case of wireless mobile system.
- The FBS system enables to determine and compensate the influence of neighboring signals.
- In the case of FBS, the energy of spectral components is decreased essentially.
- It is possible to decrease peak-factor under the same bit error rate conditions.

Foregoing abbreviations

OFDM – Orthogonal Frequency Division Multiplex,

COFDM – Code Orthogonal Frequency Division Multiplex,

OFDMA - Orthogonal Frequency Division Multiplex Access,

MT-OFDM – Mirror Twin Orthogonal Frequency Division Multiplex,

FBS - Frequency Bank System,

MT – FBS - Mirror Twin - Frequency Bank System,

CDMA – Code Division Multiplex Access,

MC CDMA – Multi-Carrier Code Division Multiplex Access,

UTRA TDD – Universal Terrestrial Radio Access - Time Division Duplex

QPSK – Quadrature Phase-Shift Keying,

DVB-T – Digital Video Broadcasting – Terrestrial

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