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A Comparison of Characteristics of 4D 2FSK-MPSK and 2D MPSK Signals

N. Ugrelidze[1], S. Shavgulidze[2], D. Akobia[2]
[1] *Caucasus University, Tbilisi, Georgia*
[2] *Georgian Technical University, Tbilisi, Georgia*

ABSTRACT: *The paper compares four-dimensional 2FSK-MPSK signal systems and two-dimensional MPSK signals according to spectral performances, distance characteristics and receiver complexity. Spectral performance is represented by power spectral density, the values of signal out of band power and normalized bandwidth. The distance characteristics of the signals are represented by the minimum squared value of their Euclidean distance, while the receiver complexity is estimated by the complexity of the signal detector. Computational analytical expressions of power spectral density and out of band power are given and corresponding graphical curves for a wide range of 2FSK-MPSK signals are presented. The normalized bandwidth values are given in tabular form. Under conditions of the same complexity of the receivers and at practically the same bandwidth, the advantage of four-dimensional 2FSK-MPSK signals over MPSK signals in terms of distance characteristics is obvious.*

KEYWORDS: *Signal, Power spectral density, Bandwidth, Out of band power, Euclidean distance.*

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I. Introduction

The construction of efficient digitaly modulated signals and the study of their characteristics is one of the central and traditional tasks of the theory and practice of communication [1,2]. With regard to the widespread adoption of multi-antenna systems today, this issue has become more active, as indicated in recent articles [3-9], which focuses on various spatial modulation schemes based on two- or multidimensional signals.

In turn, such signals are characterized by structures that are a hybrid L-ary frequency shift keying (LFSK) and M-ary phase shift keying (MPSK). These are the so-called signal constellations of the LFSK-MPSK type [10-18]. It is known that such signals have better distance characteristics compared to conventional two-dimensional (2D) signals [10,12-17]. However, the question naturally arises - what are the spectral characteristics of such signals compared to traditional 2D MPSK signals? For four-dimensional (4D) signals ($L = 2$, 2FSK-MPSK constellations) such estimates are made for certain classes of them [10,13,14], which we present in this article in a new, convenient analytical form for further calculations. We will also touch on comparisons in terms of receiver's complexities.

Below, the signal spectral performances will be represented by their power spectral density (PSD), normalized double sided bandwidth (B_N), and signal out of band power (Pob). The distance characteristics of the signals will be represented by the minimum value of their squared Euclidean distance ($d^2_{\min}$). The complexity of the signal receivers will be assessed according to the complexity of their demodulator and the detector included in it.

II. The Performances of Signals

The determination of spectral performance is based on the calculation of the PSD of signals, which can be realized based on the Welch algorithm [19-21], the distinctive advantage of which is the good smoothing of the signals, and the disadvantage, the losses during sharp peaks, which is less characteristic of the signals we have discussed.

On the other hand, PSD can also be defined analytically by calculating the autocorrelation function and taking its Fourier transform and presented in the same way as the expressions in the literature [10,13,14], but in a modified form that fits our calculations below. For example, for 2FSK-MPSK signals we can write:

$$G(f)/Ts = (\mathrm{sinc}[2\pi(F + h/2)])^2 + (-\mathrm{sinc}[\pi(F + h/2)])^2 + (\mathrm{sinc}[2\pi(F - h/2)])^2 + (-\mathrm{sinc}[\pi(F - h/2)])^2 , \qquad (1)$$

in which $\mathrm{sinc}[x] = \sin [x] / x$; $F = fTs$ is the normalized frequency, where f is the frequency offset from the carrier; Ts is the duration of the corresponding signal (elemental signal) of one transmitted M-ary symbol; h is a modulation index whose value $h = 0$ corresponds to the case of MPSK. In the calculations it is always assumed that the signal energy $Es = 1$.

An important characteristic parameter of the signal spectrum is also its fractional out of band power [22,23], which can be calculated with the following formula:

$$\mathrm{Pob}(B) = 1 - \int_0^{\mathrm{B}} [G(f)/Ts]df , \qquad (2)$$

where B is the normalized value of double sided bandwidth (b) and $B = bTs$.

For some 2FSK-MPSK signals the PSD curves, constructed according to formula (1), are shown in Figures 1 and 2.

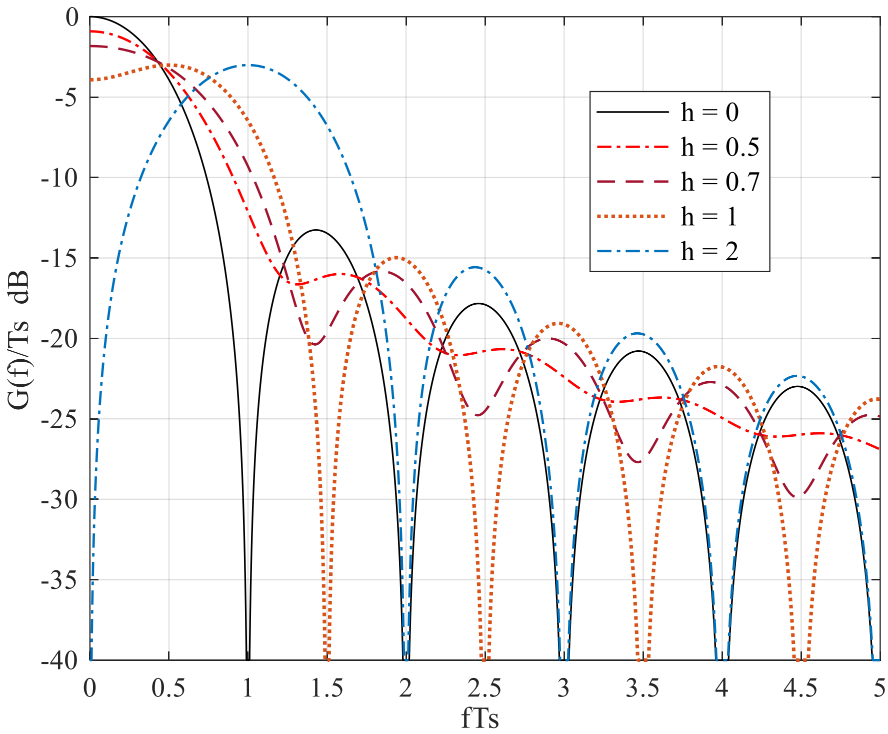

Fig. 1. Power spectral density *G(f)/Ts* versus *fTs* for low values of modulation indexes

It can be seen from the above figures that with increasing h, the main part of the signal power is shifted and concentrated in the direction of the high-frequency spectrum, and, therefore, the signal bandwidth expands. An increase in h also worsens the characteristic of the fractional out-of-band power, which is clearly seen from the results constructed with the help of (2) and presented in Figures 3 and 4.

There are several options for determining signal bandwidth [23,24]. In this case it will be implemented according to the frequency band in which a certain percentage of the total signal strength is accumulated, namely 99%, 95%, 90% and ≈ 50%(3 dB). We use its normalized value $B_N = B / B_{\mathrm{MPSK}}$, where B is the double sided normalized bandwidth of the 2FSK-MPSK signal, and B_{MPSK} is the normalized bandwidth of the MPSK signal ($B_{\mathrm{MPSK}}(99\%) = 10.2858$; $B_{\mathrm{MPSK}}(95\%) = 2.0729$; $B_{\mathrm{MPSK}}(90\%) = 0.8485$; $B_{\mathrm{MPSK}}(3\text{ dB}) = 0.2713$). The results are shown in Table 1, which shows that the 2FSK-MPSK and MPSK signals have almost identical signal bandwidth values, which is particularly noticeable for relatively small h.

It should be noted that the use of the Welch algorithm gives us practically identical results to the above.

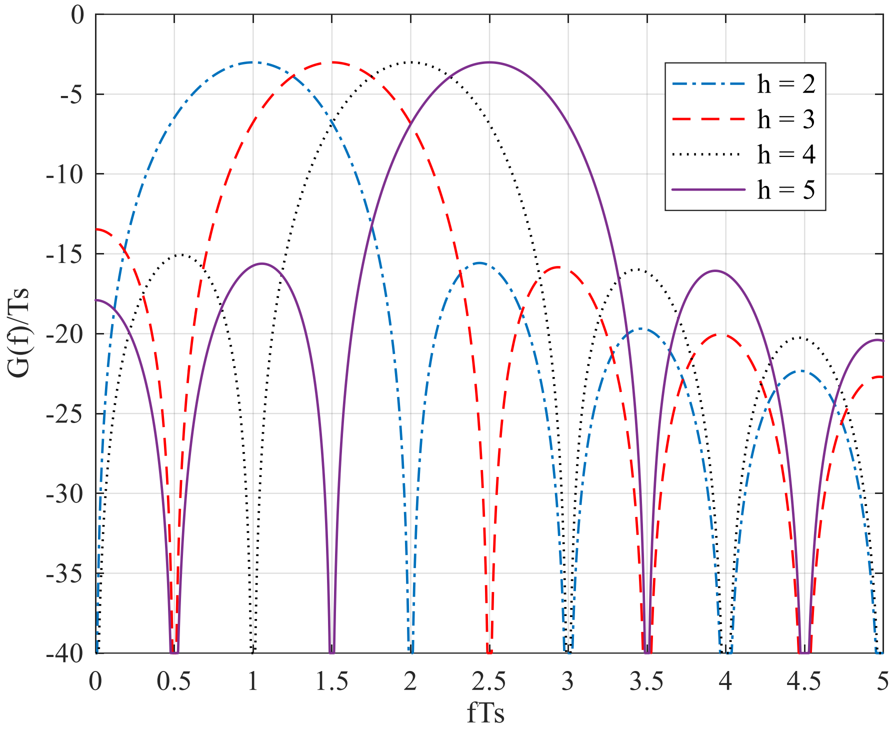

Fig. 2. Power spectral density *G(f)/Ts* versus *fTs* for high values of modulation indexes

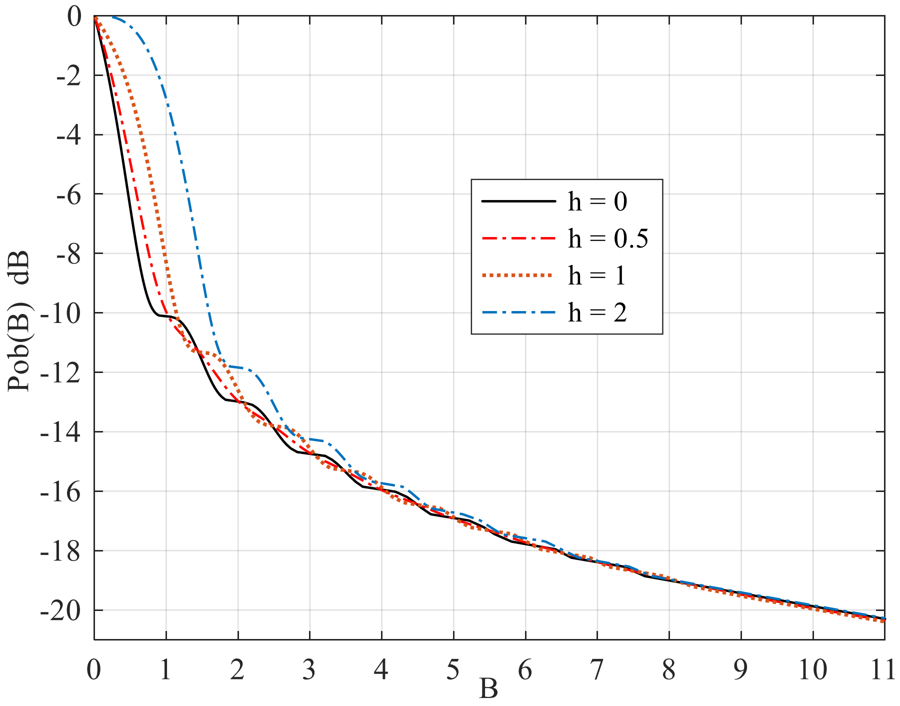

Fig. 3. Fractional out of band power for low values of modulation indexes

The distance parameters of the signals are represented by the minimum squared Euclidean distance ($d^2_{\min}$) and the corresponding results are given in [17], when $h = 0.1, 0.2, \dots, 1$. It should be noted that as shown in [17], for the given fixed values of M ($M = 5, 6, \dots, 16$), for 2FSK-MPSK signals the value of $d^2_{\min}$ increases with increasing modulation index h and for certain h ($h \leq 1$) it reaches the saturated value - the upper

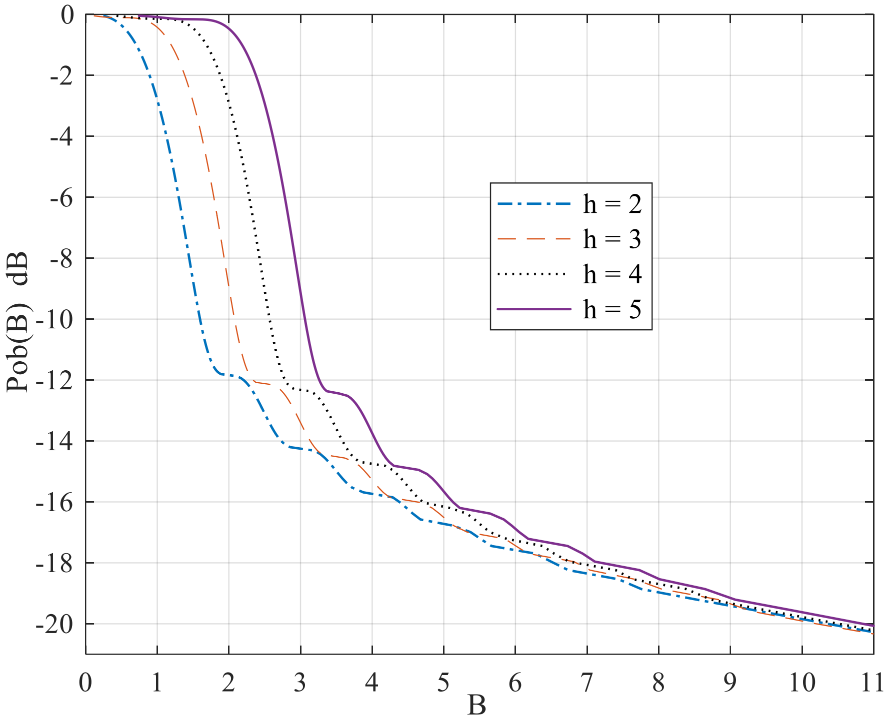

Fig. 4. Fractional out of band power for high values of modulation indexes

Table 1. Bandwidth characteristics of 2FSK-MPSK signals

Mod. Index h	Bandwidth, B_N			
	99%	95%	90%	3 dB
0.1	0.9994	0.9853	1.0210	1.0087
0.2	0.9975	0.9721	1.0744	1.0352
0.3	0.9940	0.9704	1.1256	1.0809
0.4	0.9894	0.9715	1.1603	1.1478
0.5	0.9851	0.9740	1.1871	1.2385
0.6	0.9824	0.9777	1.2125	1.3553
0.7	0.9809	0.9825	1.2394	1.4983
0.8	0.9801	0.9886	1.2697	1.6636
0.9	0.9799	0.9964	1.3045	1.8431
1	0.9802	1.0061	1.3449	2.0271
1.5	0.9913	1.0991	1.6169	2.8910
2	1.0068	1.1969	1.8825	3.7833
3	0.9915	1.4074	2.4498	5.5962
4	1.0217	1.6272	3.0272	7.4241
5	1.0546	1.8525	3.6089	9.2581

limit of $d^2_{\min}$. It should be noted, however, that this saturated value is achieved more rapidly with increasing M. For example, if $M = 5$, then it is equal to 2.0000 and is reached for $h = 1$, if $M = 9$, then it is equal to 1.3820 and is reached for $h = 0.7$, and if $M = 15$, then it is equal to 0.5858 and is reached for $h = 0.4$. However, 2FSK-MPSK always has a better value of $d^2_{\min}$ than MPSK. Also noteworthy is the fact that with increasing M, the advantage of 2FSK-MPSK over the MPSK increases with respect to the corresponding values of $d^2_{\min}$, while the spectral characteristics of these signals do not depend on M.

Receiver complexity can be estimated by the complexity of the maximum likelihood detector, the approach presented in [4], where each addition-subtraction, multiplication-division, sorting-root extraction, rounding, and so on, is considered as one floating-point operation (Flop). It is easy to see that in this case the

2FSK-MPSK and MPSK signal detectors will have the same realization complexity. Only, in case of coherent reception of 2FSK-MPSK signals, it is necessary to have two reference signals with different frequencies.

III. Conclusions

A comparison is made between 4D 2FSK-MPSK signals and 2D MPSK signals according to their power spectrum and distance characteristics. Numerical data have shown that these signal classes have the same receiver complexity and the same bandwidth, while 4D signals have better distance characteristics than 2D MPSK signals [17].

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