EFFICIENT USE OF MOBILE RADIO CHANNELS

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Abstract

This paper deals with GMSK and 4-Level FSK modulation schemes which are adopted in the land mobile services. The analysis of group delay interaction has been carried out by approximative mathematical reflections. Better spectral efficiency, achieved together with keeping up good energetic efficiency, can be the result of the above analysis. Many current and proposed mobile data transfer applications would provide a better service, and be more spectrally efficient, if the data rates could be increased.

Keywords

group delay, phase characteristic, channel capacity, channel spacing, adjacent channel selectivity, modulation speed, BER (Bit Error Rate), linearity, spectral efficiency, root-raised-cosine, GMSK (Gaussian minimum shift keying), FSK (frequency shift keying).

1. Introduction

Digital signals are being increasingly used to improve communication efficiency in the land mobile service. Efficient use of limited spectral resources remains one of the key goals of the communication industry. With regard to the very limited number of land mobile radio channels, the mo-demodulation scheme has to be carefully chosen if spectral and energy efficiencies and also robustness against signal distortions and interferences should be considered. In particular, spectral efficiency is required, because the available bandwidth is fixed and the less the spectral allocation for each signal, the greater the number of users who can be served. Energetic efficiency is also necessary in order to minimize the portable radiomodem size and weight, which are directly related to the emitted power.

2. The Relationship between Channel Capacity, Bandwidth and Signal-to-Noise Ratio

The most important question associated with a communication channel is the maximum rate at which it can transfer information. The theoretical maximum to the rate at which information passes error free over the channel, the Hartley-Shannon law, states that the channel capacity C_k is given by:

$$C_k = B\log_2(1+\frac{S}{N}) \tag{1}$$

where C_k is channel capacity
B is bandwidth
S is signal power
N is noise power

The general goal of this paper is to achieve an understanding of fundamental limits of radio channel capacity in presence of group delay without any compensation.

In this phase of the project's being worked upon, certain simplifications are assumed. An indoor radio channel is demonstrated.

3. Characterization of Data Transceiver

The communication system under consideration [8] processes modulation techniques: root-raised-cosine filtered four-level frequency shift keying, or Gaussian minimum shift keying described in 3.2. The receiver part uses double conversion. Two high selective filters are used to achieve good adjacent channel selectivity of 70 dB to be compatible with ETS300113 [4]. The receiver demodulator is dc coupled to the modem part. The ac coupling from the modem's trasmit output to the frequency modulator is applied to utilize PLL techniques. The 3dB cut-off frequency of the ac coupling network used here does not surpass 5Hz. Having a good signal-to-noise performance in the built-in baseband signal processor, the modem needs 14dB signal-to-noise ratio to achieve a bit error rate value of 10^{-4} without forward error correction mode [6].

4. Initial Prerequisites of a Model

The dominant factor in channel spacing is adjacent channel selectivity performance and effectuated modulation speed. The currently implemented modulation speed is 21.68 kBd in channel spacing 25kHz. The bit error rate value of 10^{-4} without forward error correction mode is required. A consideration of this value is not, however, subject of the present paper.

4.1 Land Mobile Radio Channel

The paper refers to constant envelope angle modulation systems for use in the land mobile service, using the available bandwidth, operating on radio frequencies between 30MHz and 1GHz, with channel separations of 12.5kHz, 20kHz and 25kHz intended for data transmissions [4]. The channel mask used for the initial consideration of channel capacity is shown in Fig.1.

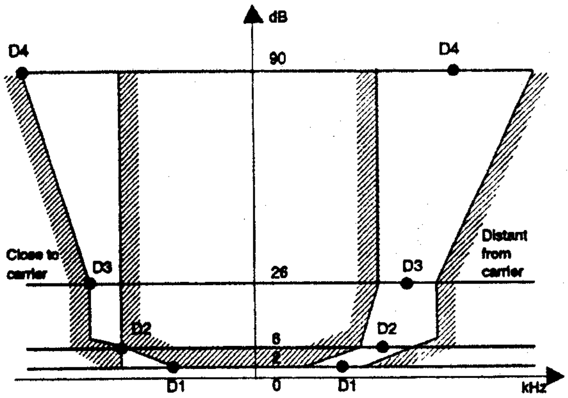

Fig. 1. Channel limits of the selectivity characteristic

Depending on the channel separation, the selectivity characteristic shall keep the frequency separations from the nominal centre frequency of the adjacent channel as stated in Table 1.

Table 1. Selectivity characteristics

Channel separation[kHz]	Frequency separation of filter curve from nominal centre frequency of adjacent channel [kHz]			
	D1	D2	D3	D4
12.5	3.00	4.25	5.50	9.50
20	4.00	7.00	8.25	12.25
25	5.00	8.00	9.25	13.25

4.2 Determination of Available Channel Capacity

The question whether the group delay of a communication channel is the significant degradation factor or not, may give rise to a long discussion. One aspect, however, is clear: attention must be paid to its linearity, frequency and phase response (group delay).

First, we examine the channel capacities for various relative bandwidths which reveal their theoretical limits. The modified Shannon-Hartley formula is used to create the plot in Fig. 2.

Using eqn. (1), we express S and input

$$N = N_0 B \qquad (2)$$

where N_0 is normalized noise power

$$N_0 = kT \qquad (3)$$

where k is Boltzmann constant $1{,}38.10^{-23}$ J/K
T is absolute temperature

and relative bandwidth

$$B_r = \frac{B}{C_k} \qquad (4)$$

and we get

$$S[dBm] = 10\log\left[1000\,kTB_r C_k\left(2^{\frac{1}{B_r}} - 1\right)\right] \qquad (5)$$

and

$$N[dBm] = 10\log(1000\,kTB_r C_k) \qquad (6)$$

where dBm is decibel milliwatt

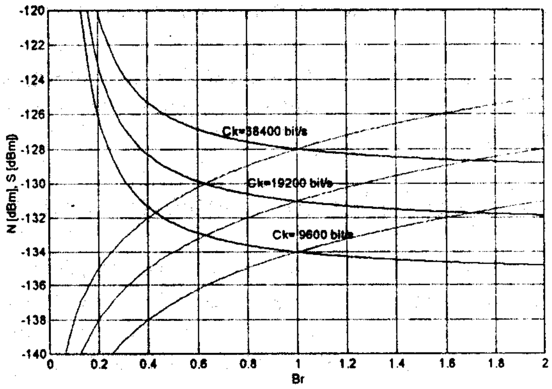

Fig. 2. Signal and noise power levels against relative bandwidth

Note that in applying eqn. (1) and Fig. 1 the theoretical limit of radio channel capacity in channel spacing 25kHz is approximately 70kBd. The traditional approach is to consider the real situation where all transmissions are corrupted by additive degradation parameters. This paper is focused on the group delay interaction.

4.3 Techniques of Efficient Narrow-Band Modulation

Gaussian filtered minimum shift keying (GMSK) and root-raised-cosine filtered four-level frequency shift keying are suitable for high speed, as they produce a nearly constant envelope and sufficiently compact frequency spectrum when combined with the low-pass filtering normally present in land mobile trasceivers. In general, the narrower the bandwidth of the pre-modulation filter, the more compact is the RF signal spectrum. Fig. 2. [6] shows the spectrum of baseband modulation signal for random data input

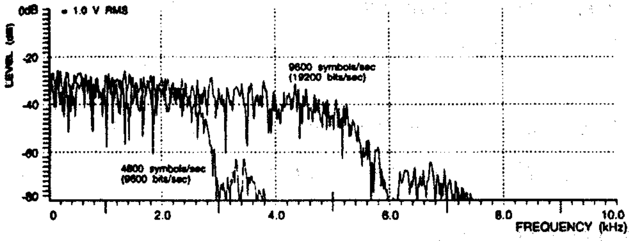

Fig. 2. 4-level baseband modulation signal spectrum, random data

while Fig. 3. shows its theoretical RF spectrum

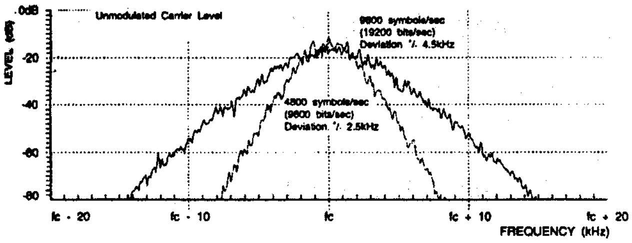

Fig. 3. Theoretical RF spectrum plot for random data input

Generally, orthogonal coherent detection is employed to detect GMSK and 4-level FSK signals due to its good static BER performance.

4.4 Group Delay and Selective Filters

The group delay of a highly selective filter varies considerably within the passband. This introduces a distortion into modulated signal and then into digital data. For a very low distortion, filters with a linear phase response in the pass-band are required, which, however, possess rather low selectivity. Because of fundamental laws, very high selectivity and linear phase - i.e. constant group delay - cannot be realized at the same time.
The group delay definition is [5]

$$\tau_g = \frac{d\varphi}{d\omega} \tag{7}$$

where τ_g is group delay
φ is phase angle value
ω is angle velocity

4.5 BER Degradation due to Phase Error

Fig. 4 shows computer simulation result of BER performance against signal level with signal-to-noise ratios as an independent variable for binary phase shift keying modulation with phase error occuring when correlator is used to demodulate data signal [7]. The same mathematical formula can be applied to GMSK correlation demodulator and the same operational tendency of BER degradation occurs in 4-level FSK demodulation scheme.

$$P_e(\gamma) = \frac{1}{2}\operatorname{erfc}(\sqrt{\gamma}\,\cos(\Delta\varphi)) \tag{8}$$

where $\gamma = \frac{S}{N}$ signal-to-noise ratio
$P_e(\gamma)$ is bit error rate
$\Delta\varphi$ is phase error

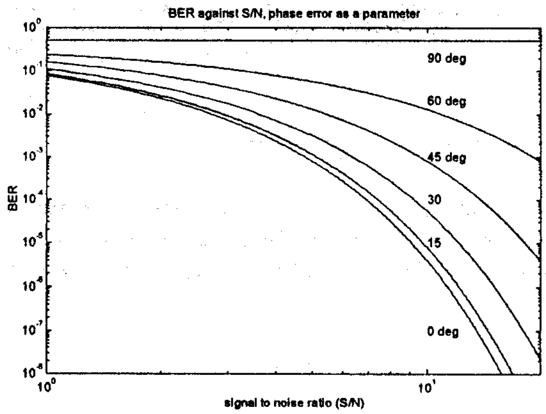

Fig. 4. BER against S/N, phase error as a parameter

4.6 BER Degradation against Modulation Speed

The behaviour of data trasmission over radio channel with non constant group delay characteristic (i.e. non-linear phase characteristic) is investigated. By passing data signals over radio channels and then by demodulating them, a BER degradation increases. Approximate computer simulation results are used to show the above communication system, when phase non-linearities abases data transfer. The BER degradation being investigated in this paper is elucidated in Fig. 5. Even if the consideration be simplified (the BER variations due to the constant bandwidth, while modulation speed varies, are not implied), the basic limits for the selection of modulation techniques and speeds are indicated.

$$P_e(\Delta\varphi) = \frac{1}{2}\operatorname{erfc}(\sqrt{\gamma}\ \cos(\Delta\varphi)) \qquad (9)$$

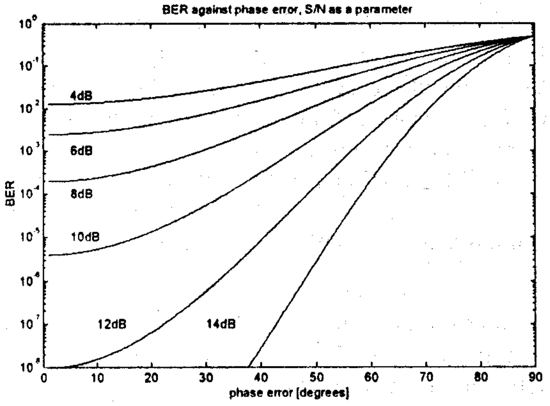

Fig. 5. BER against phase error, S/N as a parameter

In case of signal-to-noise ratio of 14 dB, simple mathematics shows that a phase shift of 60 degrees (Fig. 5, $P_e(\Delta\varphi)$ of approx. 10^{-4} is required) represents the acceptable time delay of $4.7\,\mu s$, when 2-level FSK (GMSK) modulation scheme and modulation speed of 70 kBd is under consideration.

$$t_d = \frac{2\,\varphi}{360\,f_b} \qquad (9)$$

where t_d is time delay
φ is phase value
f_b is bit rate

Thus, the value of t_d is the initial limit of the group delay variation within the passband of the bandwidth-optimized filtered indoor radio channel for theoretical modulation speed of 70 kBd being implemented. The system under consideration contains IF highly selective filters with a group delay variation of approximately $9\,\mu s$. With regard to GMSK modulation technique the theoretical Shannon-Hartley channel capacity limit tends to get decreased due to the channel group delay characteritic.

5. Conclusions

First, approximative simulation results show that the theoretical Shannon-Hartley channel capacity limit of the investigated communication system tends to get degraded by the indoor radio channel group delay.

Second, a modulation speed up to 19.2 kBd is, in the conceipt promulgated above, achievable with an undubitable certainty.

Hence, any data trasmissions using lower modulation speeds should not be preferred for data transmission in the land mobile service to maintain good spectral efficiency.

To say that the communication system is only as effective as the linearity of its communication channel reaches, is not an exaggeration.

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Karel DANĚK was born in Nové Mìsto na Moravì, Czech republic, in 1961. He received the Ing (MSc) Degree from the Technical university of Brno, Dept. of Telecommunication in 1984. His present interests are in the land mobile radio communications and rf circuit design.