Optimal Receiver Filter Design for Spreading Gains in Split Channel BFSK Environment

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Article Info
Page Number: 559 – 566
Publication Issue:
Vol. 71 No. 3s (2022)

Article History
Article Received: 22 April 2022
Revised: 10 May 2022
Accepted: 15 June 2022
Publication: 19 July 2022

Abstract

In this paper, we design optimal receiving filters for spreading gains (SG) in Split Channel Binary Frequency Shift Keying (SC-BFSK) systems. For the filter design, the data transmission speed is 1 Mbps, the two tones spacing is 4 MHz, and the channel is an additive white Gaussian noise (AWGN). By changing filter passband bandwidth and transition band, the bit error ratio (BER) performance is observed. Among many combinations of passband and transition band, we select the filter that provides the best BER performance. According to the results, the filter specification is a function of spreading gain. According to the results of the simulation, the optimal receiver filter for SG = 1 is the one with a passband bandwidth of 600 kHz and a transition band of 500 kHz. The optimal receiver filter for SG = 4 is the filter with a passband bandwidth of 200 kHz and a transition band of 200 kHz. The optimal receiver filter for SG = 16 is the filter with a passband bandwidth of 100 kHz and a transition band of 100 kHz. Those results confirm the optimal receiver filter is a function of the SGs, and as the SG is larger, the passband bandwidth and the transition band become smaller.

Keywords: Split channel binary frequency shift keying, spreading gain, pseudo random noise sequence, Finite impulse response filter, Bit error ratio, Filter design.

1. Introduction

Frequency selective fading occurs when the coherent bandwidth is narrower than the transmission signal bandwidth. This is associated with multipath channel responses and happens when the multipath delay spread is bigger than the transmission symbol period. Frequency selective fading causes performance degradation in broadband mobile communication systems and needs equalizer to compensate for the distortion (Gui, X. et al., 1999, Liu, Z. et al., 2002). However, split channel binary frequency shift keying (SC-BFSK) uses more frequency resource than conventional BFSKs, but it enjoys the frequency diversity due to the largely separated two tones. SC-BFSK is a method of transmitting binary data by using separated two tones (Kim, K.M. et al., 2021, Lee, G.H. et al., 2020, Ryu, H.G. et al., 2003). In a SC-BFSK receiver, proper filter design is important to avoid the signal to noise ratio (SNR) losses and ensure good bit error ratio (BER) performance. Since improper filter design may cause significant SNR losses and BER degradation, careful filter design is important (Lee, D.W., 2019).

In this paper, we consider optimum receiver filter design for the SC-BFSK. First, the transmit signal's spectrum is observed for various spreading gains (SGs). Then, by changing the receiver filter specifications, the BER performance is examined. The optimum filter is the one shows the lowest BER. Alternatively, if a certain filter requires the smallest required SNR to ensure the BER of 1E-4, that filter can be considered as the optimum receiver filter. In this paper, the latter method is used to find the optimum filter. The receiver filter is designed in a form of a finite impulse response (FIR) filter. For the spreading codes, the pseudo noise (PN) codes are used. The PN code preferably uses a long PN sequence. (Chugg, K.M. et al., 2005). For the filter design, the system environments are as follows. The transmission rate is 1 Mbps, the interval between the two tones is 4 MHz, and the channel is assumed to be an additive white Gaussian noise (AWGN) channel. If SG is 4 and 16, the spreading codes are all 1. When the SG is 64 or higher, the PN code is used for the spreading code. Therefore, it is possible to use the same filter for both SG 1 and SG 64 or higher SGs. When designing the filter, the filter length is an important parameter. If the transition band is too narrow, sufficient filter length can avoid the insertion loss of the filter. In this paper, when the transition band bandwidth is 100 kHz and the pass band bandwidth is 100 kHz, the sufficient filter length is found to avoid the insertion loss. The proper filter length is turned out to be 551 taps. By fixing the filter length as 551 taps, the filter design is carried out using the MATLAB's filter design toolbox. The optimal receiver filter is the filter requires the smallest SNR (Signal to noise ratio) for the BER (Bit Error Ratio) of 10^{-4}. According to the results of filter design, the optimal receiver filter for SG = 1 is the one with a pass band bandwidth of 600 kHz and a transition band of 500 kHz. The required SNR is 8.15 dB. The optimal receiver filter for SG = 4 is the filter with passband bandwidth of 200 kHz and transition band of 200 kHz, where the required SNR is 2.55 dB. The optimal receiver filter for SG = 16 is the one with a passband bandwidth of 100 kHz and a transition band of 100 kHz, where the required SNR is -1.32 dB.

2. System Model

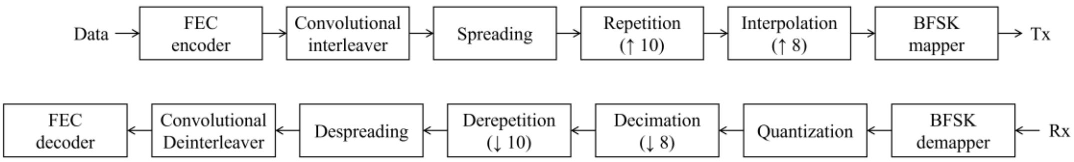


Fig. 1; Block Diagram of System Model

Figure 1 is a block diagram of the system model of SC-BFSK. The message data are encoded by forward error correction code (FEC) by convolutional encoder. Then, convolutional interleaving is performed. Convolutional interleaving is used to improve the decoder's performance by reducing the probability that a burst error occurs in a group of data (Shiyamala, S. et al., 2010). Thereafter, direct sequence spread spectrum (DSSS) is performed. The DSSS is an effective countermeasure against electric attacks (Kang, T. et al., 2013). The DSSS signal is then 10 times repeated and 8 times interpolated. This procedure is for modeling the analog part. Finally, the signal is modulated on two tones by SC-BFSK. In this paper, the interval between the two tones is 4 MHz. At the receiver, after quantizing the received signal, the resulting signal is 8 times decimated to lower the sampling clock and combined for 10 times repeated signals. After that, dispreading, de-interleaving, and FED decoding recover the transmitted message. The BER is examined by comparing the transmitted and the received data.

3. Spectrum for Spreading Gain

By using the computer simulation, we observe the transmit spectrum for the SGs and spread codes. The SGs are 4, 16, 64, and 128. The spreading code is the PN code. The baseline spectrum is the one with SG = 1. All the spectrums are compared with this.

The simulation is conducted using two random PN codes, each PN code is referred to as PN1 and PN2. Figure 2 shows the spectrum. The x-axis is the frequency, and the y-axis is the power spectral density (PSD). The PSD shows the strength of energy across the frequency.

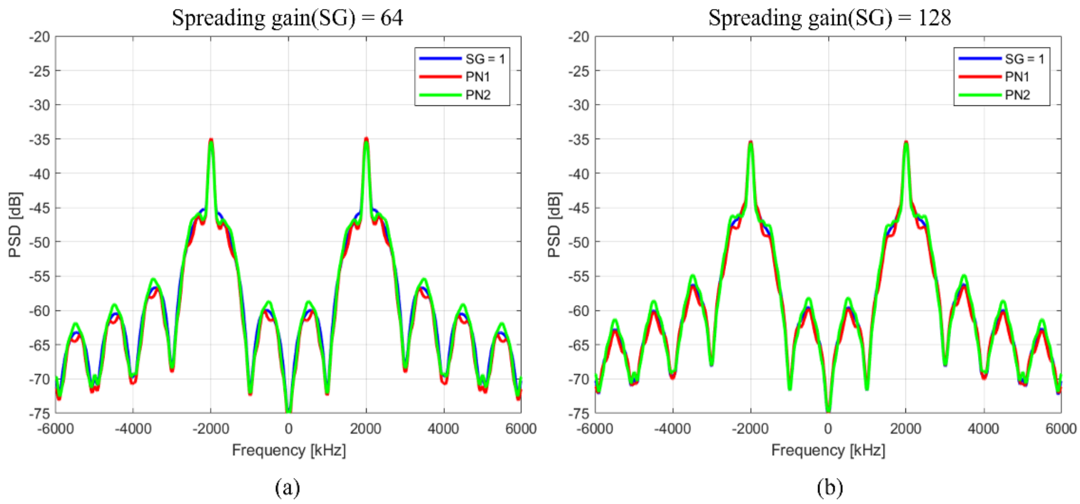


Fig. 2; Spectrums for (a) SG = 64 and (b) SG = 128

Figure 2(a) and 2(b) show the spectrums with SG = 64 and SG = 128, respectively. Three spectrums are compared for SG = 1, PN1, and PN2. As shown in the figures, all the spectrums shows a similar shape. The spectrum is not much dependent on the spreading codes.

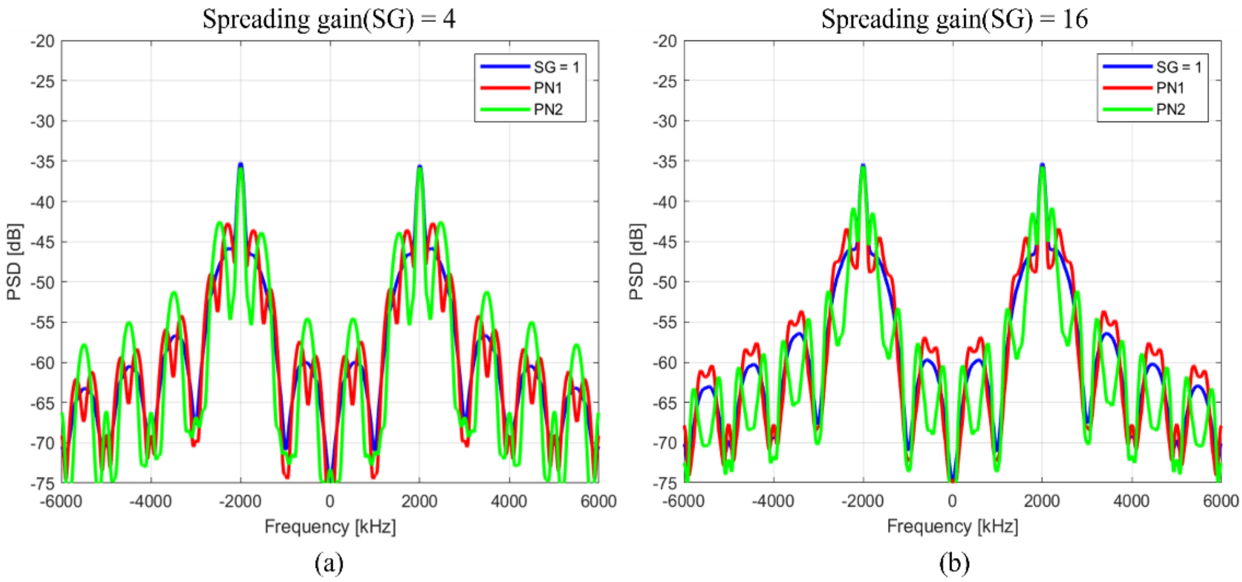


Fig. 3; Spectrums for (a) SG = 4 and (b) SG = 16

Figure 3 shows the spectrums when SGs are 4 and 16. In SG 4 and 16, the spectrum using the PN code shows an irregular shape of spectrum, unlike the spectrum when SG is 1. This is because when SG is small, randomness of the PN code violated. If the PN code is not random and has regularity, the spectrum is distorted. Accordingly, in the simulation, when the SG is less than 64, the spreading code is not a PN code but a code of all 1, and this is called ALL 1. For SG 64 or higher, filter design is carried out by using the PN code as the spreading code.

4. Receiver Filter Design

According to the spectrum comparison for the SGs and the spread codes, when SG is 4 and 16, the receiver filter should be designed using the spreading code of ALL 1. When SG = 64 or higher, the filter should be designed under PN code.

4.1. Filter Length

When designing a filter, the length of the filter is an important parameter. Short-length filters have advantages over long filters in terms of computational complexity. However, a filter of too short length causes a large passband ripple or insufficient stop-band attenuation. Accordingly, the filter design problem may be regarded as an optimization problem for finding a filter that satisfies a given specification with a minimum filter length (Ichige, K. et al., 2000).

The optimal filter length is designed through simulation. Assume that the SG is 16, the data transmission speed is 1 Mbps, and the bandwidth of both the pass band and the transition band is 100 kHz. Since the spectrum is the sharpest in SG 16 among the SGs of interest in this paper, we decide the filter length first in SG 16. If the transition band is sharp and the filter length is not sufficient, the inband loss may happen. This loss result in the insertion loss of the filter and should be avoided. To determine the filter length, the length varies from 101 to 551 in 50 steps, and the passband is carefully observed.

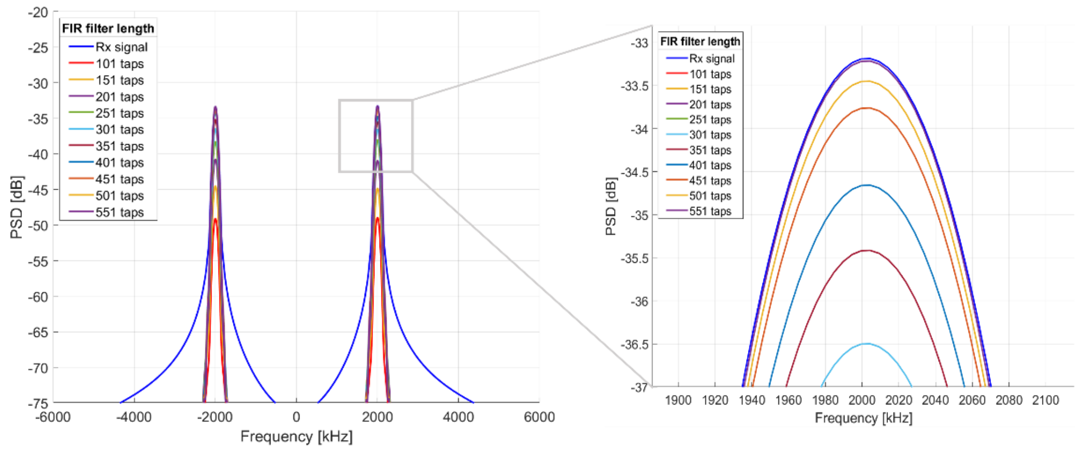


Fig. 4; Receive Spectrum by Filter Length

Figure 4 shows the spectrum of the signal after passing through the filters. At the center of one of the two tones, it is confirmed how much the power of the signal decreases due to the filter. According to the resuls, the length of the filter with the smallest decrease in intensity of the received signal after passing through the filter is 551 tabs. Therefore, we set the filter length as 551.

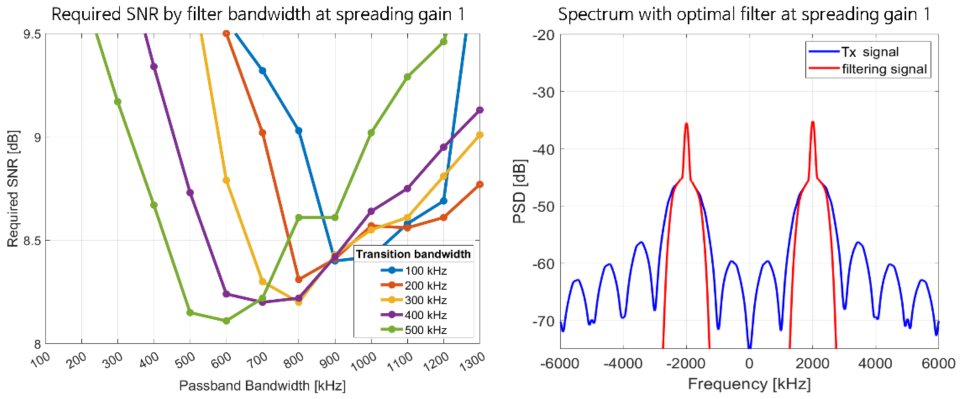
5. Receiver Filter Design Simulation

In the SC-BFSK systems, the optimal receiver filter design is performed using MATLAB. The receiver filter is designed as an FIR filter. It is assumed that the optimal receiver filter is the filter with the smallest required SNR for a BER of 10^{-4}. The receiver filter design simulation is performed in SG 1, 4, and 16.

Table 1. Receiver Filter Design Parameters

Receiver FIR filter design parameters	
Data Rate	1 Mbps
Interval between Two Tones	4 MHz
Filter length	551 taps
Transition band	100 ~ 500 kHz
Pass band	100 ~ 1,300 kHz

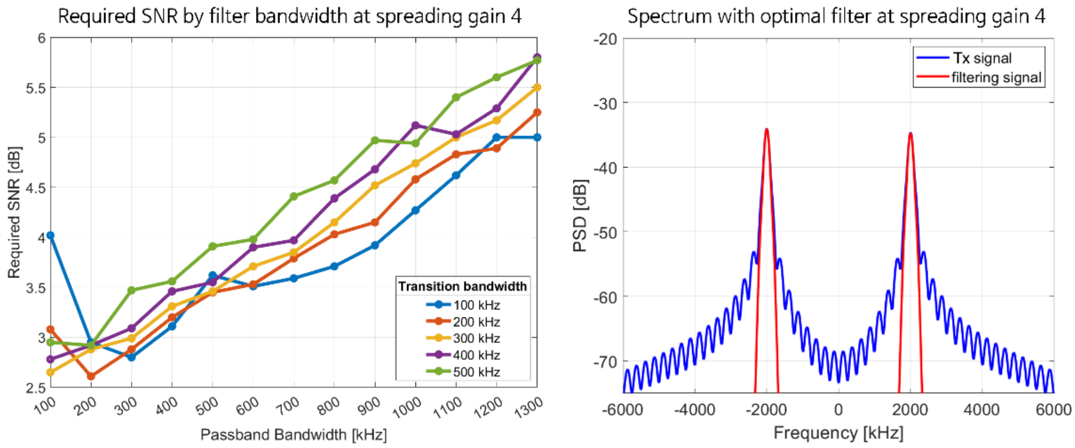
Table 1 shows the receiver filter design parameters. The data transmission rate is 1 Mbps, the interval between two tones is 4 MHz, and the filter length is 551. The transition band is varied from 100 kHz to 500 kHz with 100 kHz step. The passband bandwidth varied from 100 kHz to 1,300 kHz with 100 kHz step. When the bandwidth of the filter is smaller than 100 kHz, the length of the filter should be longer to prevent loss of signal strength by the filter.



(a) (b)

Fig. 5; Required SNR by Filter Bandwidth on Spreading Gain 1

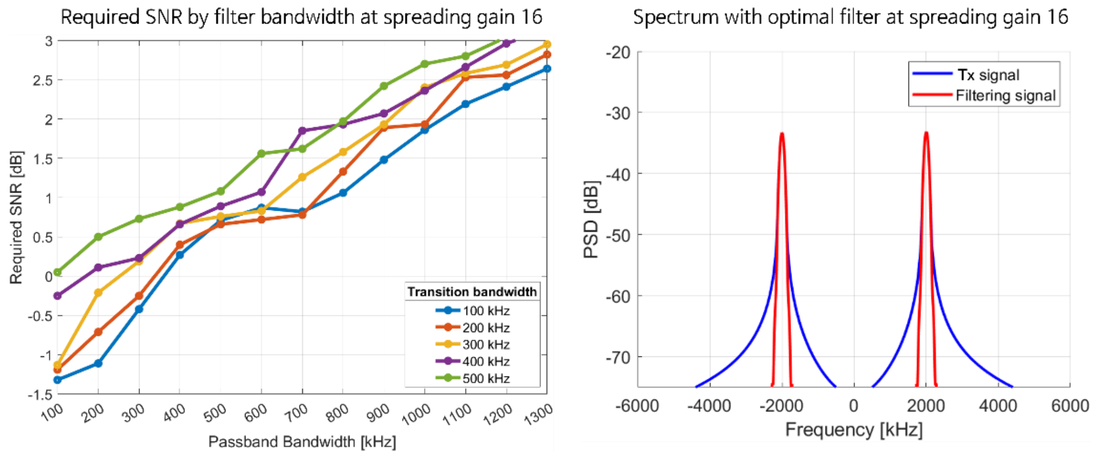
Figure 5-(a) shows the required SNR for BER of 10-4 for SG = 1, and figure 5-(b) is the filter output spectrum when the optimal filter is applied. According to the results, the optimal filter when SG = 1 is a filter with the lowest required SNR of 8.11 dB. The transition band bandwidth is 500 kHz, and a passband bandwidth is 600 kHz. In figure 5-(b), the blue spectrum is a transmitted signal, and the red spectrum is the filter output spectrum. It is observed that the remaining signals except for the main tone are removed by the filter, and the power of the main signal is not reduced.



(a) (b)

Fig. 6; Required SNR by Filter Bandwidth on Spreading Gain 4

Figure 6-(a) is the required SNR with BER of 10-4 for SG = 4, and figure 6-(b) is the spectrum when the optimal filter is applied. According to the simulation results, the optimal filter is the one with the lowest required SNR of 2.55 dB, a transition bandwidth of 200 kHz, and a passband bandwidth of 200 kHz. In figure 6-(b), the blue spectrum is a transmitted signal, and the red spectrum is the filter output spectrum. It is observed that the remaining signals except for the main tone are removed clearly, and the power of the main signal is not altered.



(a) (b)

Fig. 7; Required SNR by Filter Bandwidth on Spreading Gain 16

Figure 7-(a) is the required SNR with BER of 10^{-4} for SG = 16, and Figure 7-(b) is the spectrum when the optimal filter is applied. According to the simulation results, the optimal filter is the one with the lowest required SNR of -1.13 dB, a transition bandwidth of 100 kHz, and a passband bandwidth of 100 kHz. In figure 7-(b), the blue spectrum is a transmitted signal, and the red spectrum is the filter output spectrum. It is observed that the remaining signals except for the main tone are removed clearly, and the power of the main signal is not altered.

6. Conclusion

In this paper, the optimal receiver filter with the best performance for each SG in the SC-BFSK systems is designed. Prior to filter design, spectrums are observed when PN codes are used as spreading codes for SGs 1, 4, 16, 64, and 128. It was confirmed that the spectrum changed irregularly according to the spreading code at SG 4 and 16. Therefore, in the case of SG 4 and 16, the filter is designed using ALL 1 as the spreading code. The optimal receiver filter is the one with the smallest required SNR for a BER of 10-4. The final results of the optimum receiver filters are as follows. When SG = 1, the transition band is 500 kHz, and the passband is 600 kHz. When SG = 4, the transition band is 200 kHz, and the passband is 200 kHz. When SG = 16, the transition band is 100 kHz, and the passband is 100 kHz. Those results indicate that if the proposed filter is used for the receiver filter of SC-BFSK, the optimum BER performance can be expected.

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