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Ph.D. DISSERTATION

Design of Mobile Receiver for Wireless Communication Systems in High Adjacent Channel Interference

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BY

KANG HOON

FEBURARY 2019

DEPARTMENT OF ELECTRICAL AND
COMPUTER ENGINEERING
COLLEGE OF ENGINEERING
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Abstract

Since the wireless communication system transmits information through air without an electrical connection, interference due to the problem of frequency allocation may occur. In the existing wireless communication system, adjacent channel interference (ACI) occurs due to a problem of network cell design. Therefore, this dissertation proposes a receiver design technique that can improve the demodulation performance in the environment with high ACI. In order to improve the demodulation performance of the receiver in this environment, a new design of a low-pass lter (LPF) and a new automatic gain control (AGC) algorithm are proposed.

First, a square-root-raised-cosine (SRRC) lter of the receiver is considered by overriding the matched lter constraint. The proposed design algorithm uses a recursive steepest descent algorithm when the lter coef cients of the transmitter are xed, and the proposed receiver lter can be designed differently according to the desired design factors as follows. First, when the inter-symbol interference (ISI) criterion is relaxed in the receiver while maintaining the stopband attenuation, the proposed receiver lter can be designed to have fewer lter taps than the conventional ones without degrading bit error rate (BER) performance. In this case, the proposed receiver lter design with a reduced number of lter taps reduces the computational complexity, that is, power consumption, and detection delay of the receiver. Next, using the proposed receiver lter design algorithm, it is possible to improve the stopband attenuation performance while maintaining the ISI with the same number of taps as in the conventional case. In this case, a LPF robust to ACI can be obtained as a result.

Second, a new AGC algorithm using ACI will be described. The proposed AGC algorithm adjusts the digital gain based on the estimated ACI power to prevent performance degradation in an environment with high ACI. In estimating the ACI power, the power ratio of the input and output signals of the LPF is used for a single carrier

systems and the power ratio of the input and output signals of the fast Fourier transform (FFT) is used for the orthogonal frequency division multiplexing (OFDM). The additional quantization noise and the clipping noise are prevented by controlling the level of the signal input to the analog-to-digital converter (ADC) while maintaining the level of the signal input to the demodulator through the digital gain control. From the numerical analysis, the proposed AGC algorithm has better BER performance than the conventional AGC algorithm in the environment with high ACI.

keywords: Adjacent channel interference (ACI), Automatic gain control (AGC), Orthogonal frequency division multiplexing (OFDM), Single carrier communication system, Square-root-raised-cosine (SRRC) lter, Wireless mobile communication systems

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Chapter 1

INTRODUCTION

1.1 Introduction

The wireless communication refers to the transmission and reception of information between terminals that are not through wires, cables, or any other type of electrical connection. There is an advantage that a user can move a terminal freely, and therefore, a lot of standards and products for applying a wireless communication system, such as mobile communication systems, wireless delity (WiFi), satellite communication, broadcast radio, and bluetooth technology are released.

However, due to the expansion of wireless communication systems, there is a growing problem of frequency allocation. In the case of existing wireless communication systems, mutual interference occurs between adjacent channels due to problems in network cell design, and this is called adjacent channel interference (ACI). In modern wireless communications, the use of unlicensed band is increasing rapidly, especially due to the rise of internet of things (IoT). This implies that the network without consideration of the adjacent channel is formed, and the possibility that the wireless terminal is placed in a high ACI environment is increased. Therefore, this dissertation deals with the design of receivers that can enhance the receiver performance in a high ACI environment.

There are two parts that can enhance the performance of the wireless terminal under high ACI. The rst is a low-pass lter (LPF) design that can overcome ACI. The second is to reduce the in uence of ACI through an automatic gain control (AGC) algorithm.

First, for the study of LPF, this dissertation uses the square-root-raised-cosine (SRRC) lter which is widely applied in the existing single carrier wireless communication systems. The research on the conventional SRRC design technique is focused on making the spectrum characteristic to the desired form while minimizing the inter-symbol interference (ISI). Most SRRC lter have been designed by optimizing both the transmitter and the receiver simultaneously under the matched lter constraint. However, if the communication standard is determined, there is a disadvantage in that the receiver lter cannot be changed. Recently, a receiver lter design technique overriding the matched lter constraint is emerging. In this dissertation, SRRC lter design technique is proposed by overriding the matched lter constraint. Through the proposed lter design algorithm, the proposed receiver lter design can be changed according to the proposed lter speci cation. That is, it is possible to reduce the number of taps of the lter while showing the same performance as the existing one, and it may show better performance than the conventional lter while maintaining the number of taps of the receiver lter.

Second, the main purpose of the AGC is to keep the power of the received signal constant. The received signal power is highly uctuated by distance between transmitter and receiver and by mobility of the receiver even though the transmitted signal has constant power. When the receiver demodulates the received signal without power gain controlling, bit error rate (BER) will be increased due to the unwanted quantization noise and clipping noise in analog-to-digital converter (ADC). AGC of the receiver minimizes the distortions from quantization and clipping in the ADC [32]. The conventional AGC algorithms do not consider ACI and thus it cannot guarantee that the signal applied to ADC in the receiver is kept at the desired level when ACI is high.

This causes additional quantization noise or clipping in the ADC, which eventually degrades the demodulation performance of the receiver. In this dissertation, performance degradation caused by ACI is discussed in single carrier (SC) wireless communication system and orthogonal frequency division multiplexing (OFDM) wireless communication system. Next, a new AGC algorithm is proposed that adjusts the input signal power of the ADC while keeping the power of the signal input to the demodulator constant by using digital gain method.

1.2 Overview of Dissertation

The rest of the dissertation is organized as follows.

Chapter 2 introduces the wireless mobile communication systems, the interference, and the conventional algorithms. First, single carrier wireless mobile communication systems and OFDM wireless mobile communication systems are brie y reviewed. Second, ACI is brie y reviewed. Finally, the conventional SRRC lter design algorithm and the conventional AGC algorithms are introduced. Next, two AGC algorithms are introduced for single carrier wireless mobile communication systems and OFDM wireless mobile communication systems, respectively and their performance degradation due to high ACI.

In Chapter 3, a new SRRC receiver lter design algorithm is proposed. First, ISI and stopband attenuation are brie y reviewed as the lter design criteria and these are derived in the matrix form for the proposed SRRC lter design algorithm. Second, a new SRRC receiver lter design algorithm based on the steepest descent method is proposed. Finally, performance assessment of the proposed SRRC lter in various environments is provided through a numerical analysis.

In Chapter 4, a new AGC algorithm using digital gain method is proposed and a performance of the proposed AGC algorithm in various environments is provided through a numerical analysis. As in Chapter 2, a new AGC algorithm is introduced

for single carrier wireless mobile communication systems and OFDM wireless mobile communication systems, respectively. First, the optimum digital gain for each modulation scheme is found through BER performance analysis according to various digital gains. Second, ACI estimation method is described. Finally, performance assessment of the proposed AGC algorithm in various environments is provided through a numerical analysis.

In Chapter 5, conclusions from researches of the dissertation are given.

Chapter 2

PRELIMINARIES

In this chapter, several de nitions and fundamentals are presented to explain the proposed receiver design algorithm. First, wireless mobile communication systems such as overall structure of single carrier communication systems and OFDM systems are brie y reviewed. Second, ACI is brie y reviewed. Third, the conventional algorithms for SRRC receiver lter and AGC are reviewed.

2.1 Wireless Mobile Communication Systems

2.1.1 Single Carrier Systems

A system model of single carrier wireless mobile communication systems is illustrated in Figure 2.1. Modulated data passes through the pulse shaping lter (PSF) and digital-to-analog converter (DAC) to make a band-limited analog signal. The converted analog signal is transmitted through the narrowband channel, which is typically a multi-path fading channel in wireless mobile communication systems. Even though the multi-path fading and ACI are the most important channel distortions in the wireless communication systems, the design of the SRRC receiver lter will focus on ISI and ACI in the additive white Gaussian noise (AWGN) channel. In the receiver side, ACI and AWGN are added to the received signal. After gain controlling by variable gain am-

pli er (VGA), the received signal is converted to a digital signal by ADC. After converting the received analog signal to a digital signal by an ADC, the digitized received signal is ltered by LPF and demodulated. In the 3rd generation (3G) mobile communication systems such as wideband code division multiple access (WCDMA) and high speed downlink packet access (HSDPA), the transmitter uses SRRC lter with roll-off factor 0.22 as PSF and the receiver uses the same lter as LPF [1].

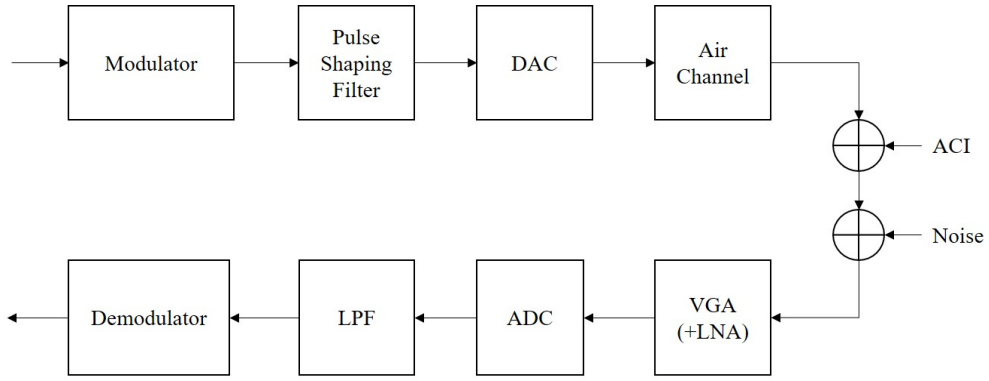

Figure 2.1: System model of single carrier wireless mobile communication system.

2.1.2 OFDM Systems

A system model of OFDM wireless mobile communication systems is illustrated in Figure 2.2. Modulated data is mapped to subcarrier and passes through inverse fast Fourier transform (IFFT) and DAC. On the receiver side, ACI and AWGN are added to the received signal. After gain controlling by VGA, the received signal is converted to a digital signal by ADC. The digitized received signal is transformed to modulated data by fast Fourier transform (FFT) and subcarrier de-mapper.

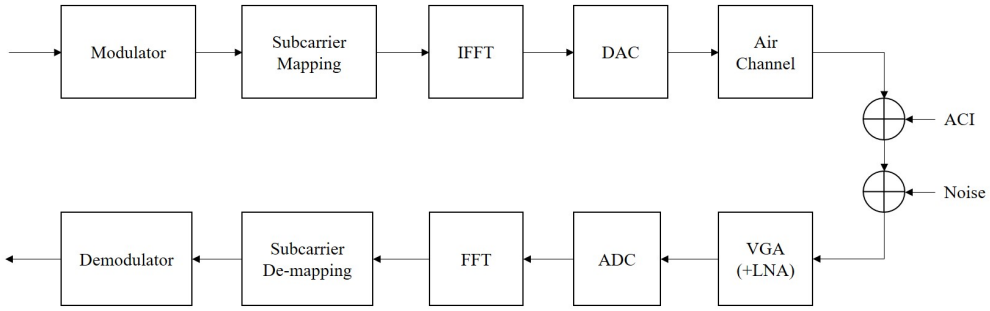

Figure 2.2: System model of OFDM wireless mobile communication system.

2.2 Adjacent Channel Interference

In wireless mobile communication systems, the mobile receiver may receive the signal containing ACI which comes from channels that are adjacent in frequency as illustrated in Figure 2.3. The ACI may be larger when the neighboring cell is transmitting signals through the adjacent frequency that the receiver is receiving at the cell boundary. If the receiver does not perform any processing for ACI, the demodulation performance may be signi cantly degraded.

In the case of a single carrier wireless mobile communication systems, the LPF and the AGC algorithm of receiver can reduce the in uence of the ACI. In the case of OFDM wireless communication systems, the in uence of ACI can be reduced by improving the AGC algorithm. First, considering the LPF, the effect of the ACI can be reduced by improving the stop-band attenuation capability of the lter. However, an appropriate lter design algorithm is required, because the number of taps of the lter is greatly increased when simply improving the stop-band attenuation capability of the lter. Second, considering the AGC, additional quantization noise and clipping noise may be increased in the ADC when the AGC is operated without considering the power of the ACI. In this case, the received signal cannot achieve the required signal-to-noise ratio environment, and demodulation performance may be degraded. Therefore, AGC algorithm is needed to adjust the power of the input signal so that no

additional noise is generated in ADC under a high ACI.

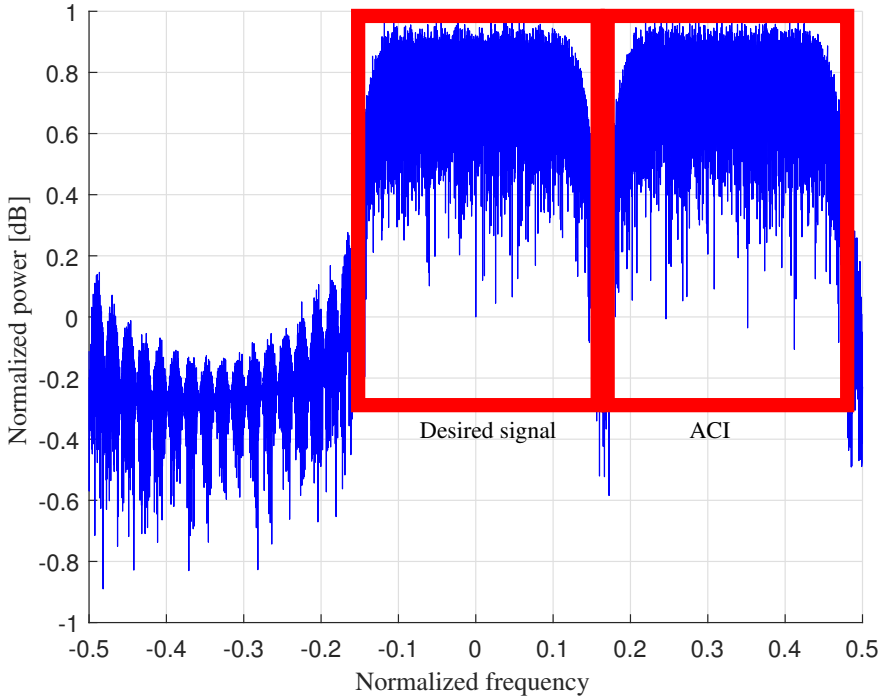

Figure 2.3: Received signal with ACI.

2.3 SRRC Filter

In wireless communication systems, the received signal is often distorted by the ISI due to the narrow-band band-pass signaling. In order to realize an ISI-free system, the receiver must have a SRRC lter identical to that of the transmitter known as the matched lter design [1]. In wireless communication systems, it is also important to ensure that the magnitude response of the SRRC receiver lter is desirable in the frequency domain because one of the main purposes of the SRRC lter in the receiver

is to remove ACI. That is, most of receiver lter design algorithms attempt to minimize the ISI and meet the target magnitude response under the matched- lter constraint. There are three different design methods for the SRRC lters as follows:

i) Optimize the magnitude response of the SRRC lter with zero ISI [2] [8].

ii) Optimize the magnitude response of the SRRC lter with minimum ISI [9] [14].

iii) Optimize the SRRC lter through a joint cost function of the ISI and the magnitude response [15] [19].

In fact, when the communication speci cation is xed by a standard, there is no way to modify the receiver lter in the conventional systems because the matched- lter constraint should also be satis ed by the receiver. However, several studies modi ed the receiver lter by relaxing the matched- lter constraint with no degradation of the ISI, which shows high potential for new receiver lter designs [20] [22]. In the wireless communication systems, the speci cation of the SRRC transmitter lter is given as a standard [1]. And in the receiver side, it makes a matched lter, which is known to have the best BER performance. This is the most popular design rule for the SRRC lters of the receivers in the wireless communication systems.

The conventional design method for the SRRC transmitter lter is to generate its lter coef cients by the inverse discrete Fourier transform (IDFT) of the following frequency response

$$H_t(f) = \begin{cases} 1; & |f| < \frac{1}{2V} \\ \sqrt{\frac{1+\cos\left\{\frac{V}{\alpha}\left(|f| - \frac{1}{2V}\right)\right\}}{2}}; & \frac{1}{2V}\alpha \le |f| \le \frac{1+\alpha}{2V} \\ 0; & \frac{1+\alpha}{2V} < |f| < \frac{1}{V}: \end{cases} \tag{2.1}$$

The time domain response of the SRRC lter is given as

$$h_t(t) = \frac{\sin\left\{\frac{t}{V}(1-\alpha)\right\} + 4\alpha\frac{t}{V}\cos\left\{\frac{t}{V}(1+\alpha)\right\}}{\frac{t}{V}\left[1 - \left(4\alpha\frac{t}{V}\right)^2\right]}; \tag{2.2}$$

which is also used as the receiver lter response as noted earlier [23].

2.4 Automatic Gain Control

In wireless communication systems, the received signal power uctuates greatly due to the distance between the transmitter and the receiver and the mobility of the receiver, even when the transmitted signal has constant power. When the receiver demodulates the received signal without controlling the power gain, the high ACI increases the BER due to unwanted quantization noise and clipping noise in ADCs. Thus, AGC in the receiver is necessary to minimize the signal distortion due to quantization and clipping. That is, the goal of AGC is to hold the input signal of the demodulator constant by controlling a VGA [32]. If the receiver is in a high ACI environment, such as those of cellular communication systems, the received signal quality will be distorted by clipping or quantization in ADC when the AGC has no protection scheme for high ACI.

As will be described later, in most of OFDM systems, AGC will make power of the FFT output signal constant, where demodulation is performed using this signal. In this case, the AGC is operated using the FFT output signal as shown in Figure 2.4.

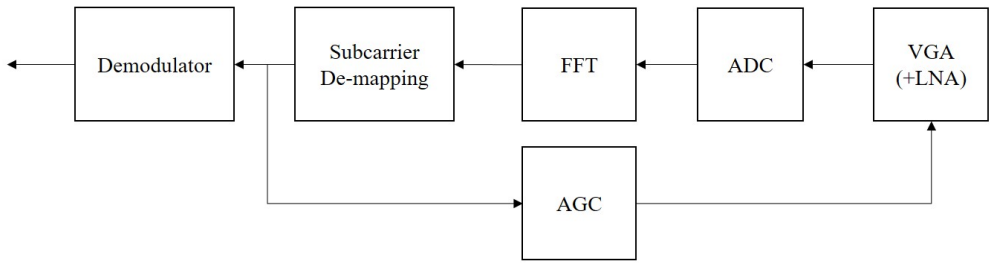

Figure 2.4: AGC algorithm using the FFT output signal in OFDM.

To analyze the performance of the AGC, the 12 bit ADC with ideal quantization and clipping is assumed. This means that additional distortion, such as differential nonlinearity, offset, gain error, or voltage noise, does not occur.