A Joint Scheme of AGC and Gain/Phase Mismatch Compensation for QPSK DCR

Yun-Jeong Song, Ho-Jin Lee, Sung-Woong Ra, and Young-Wan Kim

ABSTRACT— This paper presents a simple gain/phase blind compensation algorithm with an automatic gain control (AGC) function for the adoption of the AGC function and compensation for gain/phase imbalances in quadrature phase shift keying (QPSK) direct conversion receivers (DCRs). The AGC function is interactively operated with the compensation algorithm for gain/phase imbalances. By detecting the gain sum and difference values between the I-channel and Q-channel, the combined AGC and gain imbalance compensation algorithm provides a simpler DCR architecture.

Keywords—Automatic gain control (AGC), gain mismatch, quadrature phase shift keying (QPSK), direct conversion receivers (DCR).

I. Introduction

The demands for a simple design architecture that provides small size, low cost, and a low power receiver are ever increasing in current wireless communication. An alternative receiver technique for a compact portable terminal may have a direct conversion architecture. In general, a direct conversion receiver (DCR) has an impairment factor due to a gain/phase imbalance, which is a major source of performance degradation in a DCR architecture. Compensation algorithms for gain/phase imbalance have been presented in the literature [1]-[3]. In the presence of a gain/phase imbalance, the automatic gain control (AGC) operation which is based on a complex domain gain detector prior to the compensation of gain imbalance, can change the gain/phase imbalance values. In this paper, we propose a new inter-operational gain/phase imbalance compensation architecture with AGC for quadrature phase shift keying (QPSK) DCRs. Since the gain imbalance is related to the gain status of the I-channel and Q-channel, the AGC function is set to operate relatively with the compensation scheme for gain imbalance. The AGC and the compensation for gain imbalance are interactively operated by detecting the gain difference and sum values between the I-channel and Q-channel to achieve a simple architecture and improve performance. The proposed joint scheme is simpler than the conventional AGC and compensation for the gain imbalance algorithm for the DCR design architecture. The joint scheme for a combined gain/phase imbalance compensation with AGC operation can be an efficient solution for the needs of wireless communication receivers.

Manuscript received Nov. 25, 2003; revised Aug. 17, 2004.

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II. Compensation of I/Q Imbalance and AGC for a QPSK DCR

The imbalance situation can be considered as an auto- and cross-correlation problem [3]. In general, the scheme of AGC and gain imbalance compensation is implemented separately. However, it is possible to operate a gain imbalance compensation and gain control interactively. Figure 1 presents the proposed I/Q mismatch compensation and AGC scheme, in which the input signal with the gain/phase imbalance may be expressed by

$$r(k) = A(I(k) + w_I(k) + j(\gamma I(k)\sin\phi + \gamma Q(k)\cos\phi + w_Q(k))), \quad (1)$$

where $w_I(k)$ and $w_Q(k)$ are the I-channel and Q-channel noise functions, γ is the gain imbalance factor, ϕ is the phase imbalance factor, and A is the amplitude of the received signal.

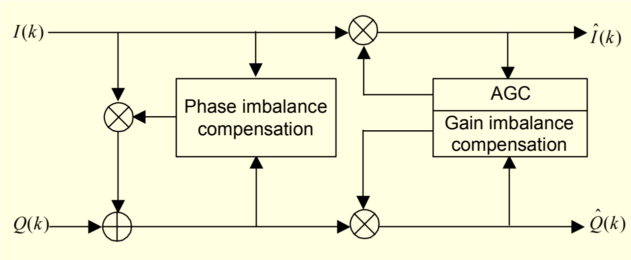

Fig. 1. Gain/phase imbalance compensation and AGC block diagram.

The relative imbalance factors are considered in the Q-channel.

1. Compensation of Phase Imbalance

The adaptive loops can be applied for compensation of the phase imbalance between the I- and Q-channels. The used adaptive loops are given in Fig. 2. The error value, *e(k),* is the multiplication value between the I-channel and Q-channel. The loop gain is β, which is a control measure of the acquisition speed. For loop stability, the gain is usually given by a small value. The received signal is re-written by (2) with no noise notation:

$$r(k) = A\big(I(k) + j(\gamma\, I(k)\sin\phi + \gamma\, Q(k)\cos\phi)\big). \tag{2}$$

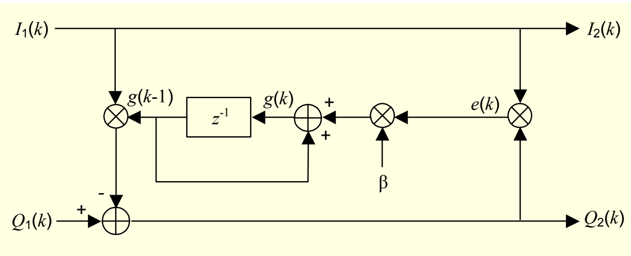

Fig. 2. Compensation structure for a phase imbalance.

It is assumed that the relative imbalance factors are only considered in the Q-channel relative to the I-channel. Therefore, $Q_2(k)$ is given by

$$Q_2(k) = Q_1(k) - g(k-1)I_1(k)\,, \tag{3}$$

where $Q_1(k)$ and $I_1(k)$ are the Q-channel and I-channel signals which include imbalance factors. The error value is given by

$$\begin{aligned} e(k) &= I_2(k)Q_2(k) \\ &= A^2 I_1(k)(\gamma Q(k)\cos\phi + \gamma I(k)\sin\phi - g(k-1)I(k)). \end{aligned} \tag{4}$$

The register of intergrater *g(k)* is represented as

$$\begin{aligned} g(k) &= g(k-1) + \beta e(k) \\ &= (1-\beta A^2 I^2(k))g(k-1) \\ &\quad + \beta A^2 I(k)(\gamma Q(k)\cos\phi + \gamma I(k)\sin\phi). \end{aligned} \tag{5}$$

After solving the difference equation for (5), the register in the integrator for a steady state is

$$g(k) = \gamma \sin\phi\,. \tag{6}$$

Finally, the compensated Q-channel output, $Q_2(k)$, is given by

$$Q_2(k) = A\gamma Q(k)\cos\phi\,. \tag{7}$$

2. Joint Algorithm of AGC and Gain Imbalance Compensation

We propose a method to compensate gain imbalance by detecting the gain difference between the I-channel and Q-channel and control the gain by detecting the gain sum of the I-channel and Q-channel. After AGC is operated for the I-channel, the compensation for the gain imbalance is performed for the Q-channel. The AGC concept is based on the coherent AGC in [4]. Gain control and gain compensateion loops for the QPSK receiver are shown in Fig. 3. The coherent AGC concept is that the gain is controlled for the I-channel by using the absolute values of *I(k)* and *Q(k)*. The gain detector for QPSK, *b(k)*, is given by

$$b(k) = |AI(k)| + |A\gamma Q(k)\cos\phi|. \tag{8}$$

Since the target gain, χ_{tgt} , of the loop is equal to the desired value in a steady state, it has

$$\begin{aligned} \chi_{tgt} &= \big(|AI(k)| + |A\gamma\, Q(k)\cos\phi|\big)(Q_{reg} + \lambda_{ref}), \\ Q_{reg} &= \frac{\chi_{tgt}}{|AI(k)| + |A\gamma Q(k)\cos\phi|} - \lambda_{ref}, \end{aligned} \tag{9}$$

where Q_{reg} represents the value of the register in the integrator for a steady state. The reference value, λ_{ref} , prevents the output of the multiplier from null status by setting a constant value. To find the gain control loop chracteristic, the register of intergrater, *y(k)*, is represented as

$$\begin{aligned} y(k) &= y(k-1) + \alpha p(k) \\ &= (1-\alpha(|AI(k)|) + |A\gamma Q(k)\cos\phi|))y(k-1) \\ &\quad + \alpha(\chi_{tgt} - (|AI(k)|) + |A\gamma Q(k)\cos\phi|\lambda_{ref}), \end{aligned} \tag{10}$$

where α is utilized to control the acquisition time and noise bandwidth of the AGC loop. In a steady state, the register in the integrator becomes

$$y(k) = \frac{\chi_{tgt}}{|AI(k)| + |A\gamma Q(k)\cos\phi|} - \lambda_{ref}. \tag{11}$$

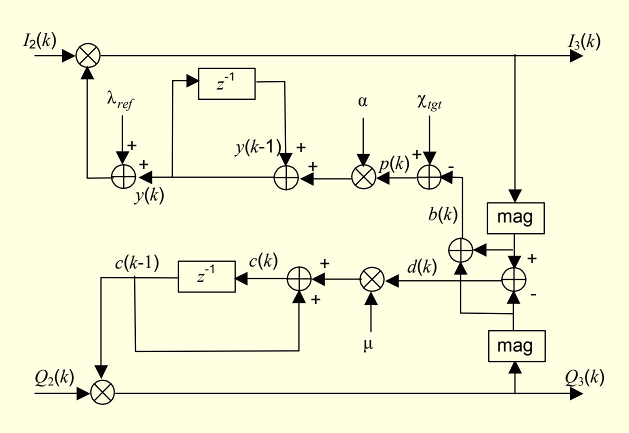

Fig. 3. AGC and gain compensation structure.

In the final stage, the I-channel signal is given by

$$I_3(k)=|AI(k)|\times\left(\frac{\chi_{tgt}}{|AI(k)|+|A\gamma Q(k)\cos\phi|}-\lambda_{ref}\right). \quad (12)$$

The gain imbalance compensation loop is required to compensate for the gain difference between the I-channel and Q-channel. $Q_3(k)$ is given by

$$Q_3(k)=Q_2(k)c(k). \quad (13)$$

The difference signal, $d(k)$, is represented as

$$d(k)=\left||AI(k)|\times\left(\frac{\chi_{tgt}}{|AI(k)|+|A\gamma Q(k)\cos\phi|}-\lambda_{ref}\right)\right|-|Q_2(k)|. \quad (14)$$

The loop output, $c(k)$, is given by

$$\begin{aligned}c(k)&=c(k-1)+\mu d(k)\\&=(1-\mu|\gamma AQ(k)\cos\phi|)c(k-1)\\&\quad+\mu\left(\left||AI(k)|\times\left(\frac{\chi_{tgt}}{|AI(k)|+|\gamma AQ(k)\cos\phi|}-\lambda_{ref}\right)\right|\right). \quad (15)\end{aligned}$$

In a steady state, the register in the integrator is

$$c(k)=\frac{\chi_{tgt}}{(|AI(k)|+|AQ(k)\gamma\cos\phi|)\gamma\cos\phi}-\frac{\lambda_{ref}}{\gamma\cos\phi}. \quad (16)$$

The compensated and controlled Q-channel signal is given by

$$\begin{aligned}Q_3(k)&=Q_2(k)c(k)\\&=|AQ(K)|\left(\frac{\chi_{tgt}}{(|AI(k)|+|AQ(k)\gamma\cos\phi|)}-\lambda_{ref}\right). \quad (17)\end{aligned}$$

III. Simulation and Results

To verify the performance of the derived algorithm in section II, the proposed joint scheme is implemented for a QPSK DCR communications system. In simulation, the initial values of gain and phase imbalances are 20% and 15°, respectively. The symbol timing is optimized for a simple simulation. From Fig. 4, it is shown that the AGC function and the compensation for

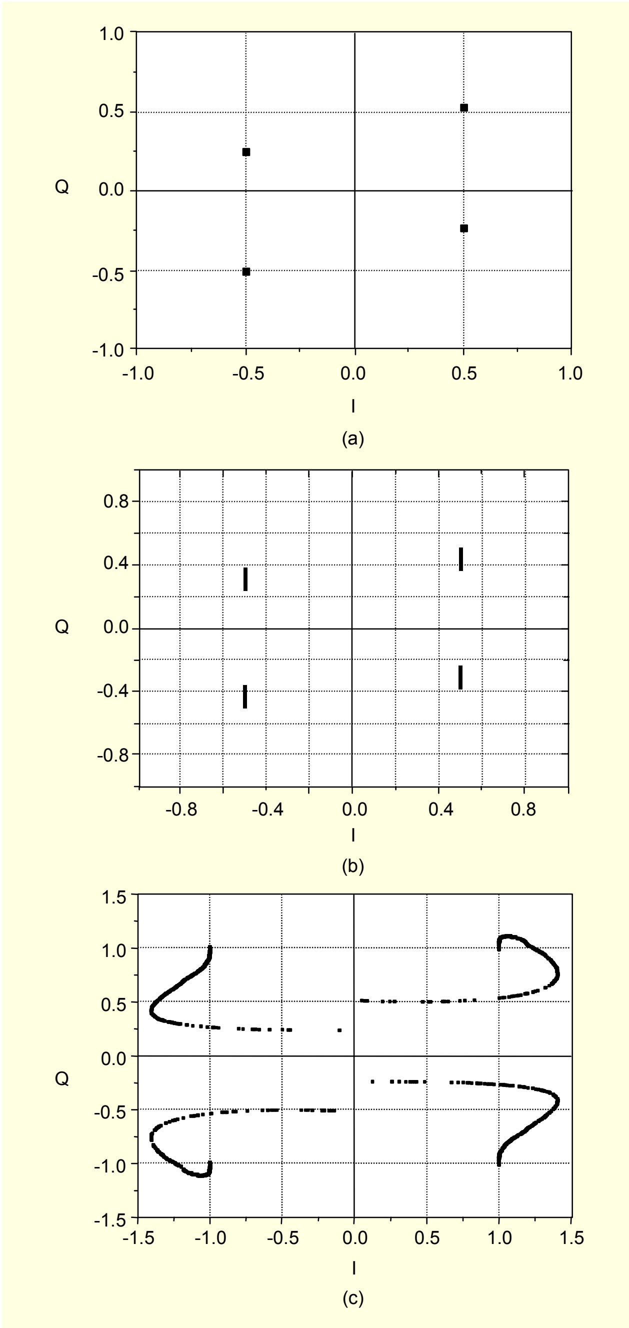

Fig. 4. Constellation of (a) a distorted signal, (b) phase compensated signal, and (c) gain compensated signal with an AGC operation (acquisition and tracking performance).

gain imbalance are operated simultaneously, and the proposed algorithm compensates efficiently for the gain imbalance by the interactive AGC operation, as shown in Fig. 4(c). The state of the register in the AGC loop is shown in Fig. 5. Since the AGC scheme is coherent, the output of the integrator varies according to the phase of the signal. The parameters are set as follows: $\alpha = 0.003, \quad \beta = 0.0005, \quad \mu = 0.001$.

IV. Conclusion

We presented a new signal processing method for a joint operation AGC and the compensation of I-and Q-channel imbalances for a QPSK DCR. The algorithm employs only three adaptive loops to implement the gain and phase imbalance compensation and AGC function. AGC is interactively operated with the compensation algorithm for gain/phase imbalances. The joint scheme can reduce complexity compared to the separation algorithm for I/Q imbalance compensation and AGC. It provides a simple DCR design architecture and improved performance.

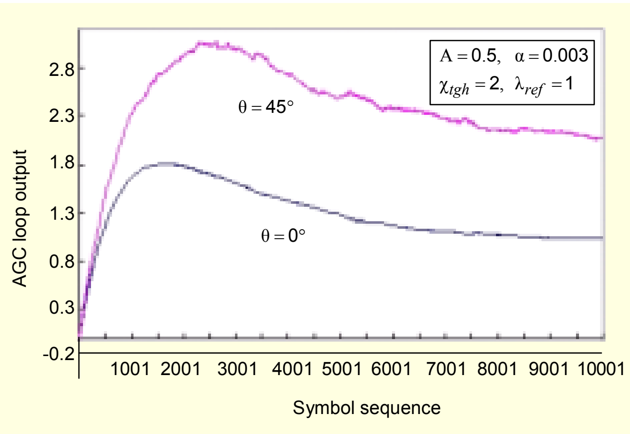

Fig. 5. Transition characteristics of the coherent AGC loop.

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