

Wireless Repeater with Equalization of Feedback Channel and Phase noise for LTE-Advanced Uplink

Heung-Gyoon Ryu, Haeseong Jeong

Department of Electronic Engineering, Chungbuk National University, Korea

ecomm@cbu.ac.kr, haeseongz@gmail.com

Abstract— When the gain of a wireless repeater is larger than the isolation between transmit and receive antennas of the repeater, the feedback signal that comes into the receive antenna from the transmit antenna of the repeater causes the repeater to go into feedback oscillation regardless of the input signal. In this paper, we propose adaptive equalizer and phase noise compensator in order to effectively cancel feedback channel and phase noise in wireless repeater system based on LTE-Advanced uplink system. In a repeater system, the performance has got worse caused by feedback channel and phase noise. Thus, the interference cancellation system requires to removing the interference signal in wireless repeater. In this paper, in order to cancel feedback channel, we use adaptive equalizer such as NLMS and RLS. And, in LTE-Advanced uplink standard, block type pilot is a common pilot pattern in wireless communication systems. So the phase noise compensator exploits block type pilot. Instead of estimating phase noise in other algorithms, which are pretty difficult and complex to get accurate estimation results, the proposed method directly estimates the interference components caused by phase noise and improves estimation accuracy. After that, we reconstruct the interference matrix and suppress the interferences by the inverse matrix method. BER performance of proposed method is satisfied 12.5dB at 10^{-4} .

Keywords—Phase noise, Feedback channel, Equalizer, Repeater, LTE-Advanced.

I. INTRODUCTION

In order to meet ever increasing requirements on higher wireless access data rate and better quality of service (QoS), the Third Generation Partnership Project (3GPP) initiated its Long Term Evolution (LTE) standardization work at the end of 2004 and successfully completed this task at the end of 2007. Immediately after that, 3GPP started its LTE-Advanced standardization process to address the requirements and challenges of IMT-Advanced systems by considering a series of new transmission technologies [1]. It is anticipated that 3GPP will submit this newly developed LTE-Advanced standard as a candidate technical proposal for IMT Advanced mobile systems.

When the gain of a wireless repeater is larger than the isolation between transmit and receive antennas of the repeater, the feedback signal that comes into the receive

antenna from the transmit antenna of the repeater causes the repeater to go into feedback oscillation regardless of the input signal [2]-[6]. In a repeater system, the performance has get worse caused by various effects such as phase noise, feedback signal, IQ imbalance, carrier frequency offset, symbol timing offset and more. But, in this paper, we just consider feedback signal and phase noise. In the receiver side of wireless repeater, it will receive reference signal from base station which is ideal input of wireless repeater and the other is feedback signal from transmitter side of repeater which is amplified. Also, this feedback signal may have a multipath signal. Therefore, wireless repeater will continuously receive the interference from transmitter side of repeater. In this case, repeater system may unstable due to feedback. Also, in wireless repeater system, the phase noise effect can exist at up and down converter of wireless repeater. In wireless repeater system, if there are phase noise effects, the performance of system will get worse. Thus, the interference cancellation system is required in order to cancel the interference signal in wireless repeater. In this paper, we consider a multipath channel exists in feedback channel and identify the unknown multipath channel by adaptive equalizer such as NLMS (Normalized least mean square) and RLS (Recursive least square). Also, we consider phase noise at wireless repeater system.

Therefore, we propose adaptive equalizer and phase noise compensator based on LTE-Advanced uplink system in order to effectively cancel multipath feedback channel and phase noise. The purpose is to effectively cancel feedback channel and phase noise in wireless repeater by using adaptive equalizer and phase noise compensator. Then, we analyze and evaluate the performance of wireless repeater based on LTE-Advanced uplink system. In order to cancel feedback channel, we use adaptive equalizer such as NLMS and RLS. And, in LTE-Advanced uplink standard, block type pilot is a common pilot pattern in wireless communication systems. So the phase noise compensator exploits block type pilot. Instead of estimating phase noise in other algorithms, which are pretty difficult and complex to get accurate estimation results, the proposed method directly estimates the interference components caused by phase noise and improves estimation

accuracy. After that, we reconstruct the interference matrix and suppress the interferences by the inverse matrix method.

II. SYSTEM MODEL

Figure 1 is the frame structure of LTE-Advanced uplink system.

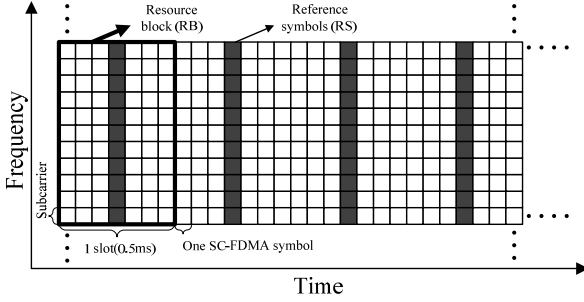


Figure 1. The LTE-Advanced uplink frame structure.

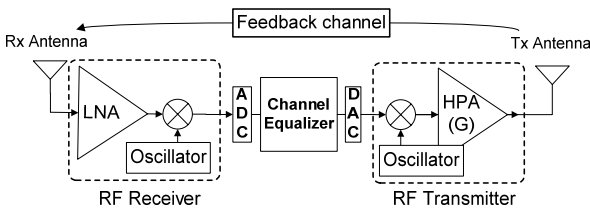


Figure 2. Structure of wireless repeater.

In order to estimate channel and compensate phase noise, we use reference symbol such as block type pilot. Figure 2 is structure for wireless repeater. In this paper, we propose wireless repeater based on LTE-Advanced uplink system. In order to cancel interference, we adapt adaptive equalizer. At wireless repeater system, if the phase noise exist, the performance of this system will get worse. Figure 3 is block diagram of wireless repeater system. The phase noise is existed at RF transmitter and RF receiver among base station, mobile station and wireless repeater respectively. In this paper, we just consider feedback signal and phase noise at wireless repeater. Therefore, we estimate unknown channel and evaluate the performance of wireless repeater based on LTE-Advanced uplink system. Figure 3 is feedback channel model for wireless repeater. Equation (1) shows the ideal case of repeater system and figure 3 and equation (2), (3) shows the feedback channel model for wireless repeater which is actual case.

In this paper, the feedback channel considers feedback gain and delay. In time domain, the input signal with feedback signal is expressed as follows.

$$x(n) = G \cdot u(n), \quad (1)$$

which G is a constant amplifier.

$$y_F(n) = h(n) * x(n) + n(n), \quad (2)$$

which $h(n) = \sum_i \alpha_i \cdot \delta(n - \tau_i)$.

Through figure 4 we have $x(n) = \frac{G}{1 - GH} \cdot u(n)$, especially when $|H| = \frac{1}{G}$ exists, system becomes internally unstable.

$$y_C(n) = u(n) + \sum_i \alpha_i u(n - \tau_i) + n(n), \quad (3)$$

where α is feedback gain, τ is delay $n(n)$ is AWGN. Since the input signal is very small than feedback signal, $\alpha > 1$. Figure 5 is signal compositions in time domain.

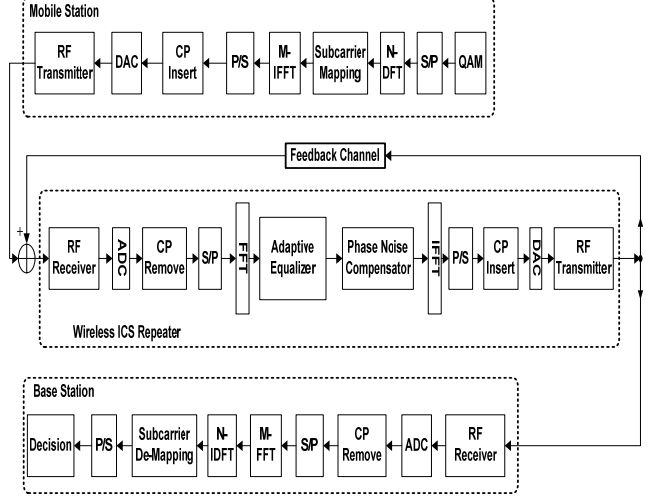


Figure 3. Block diagram of wireless repeater system.

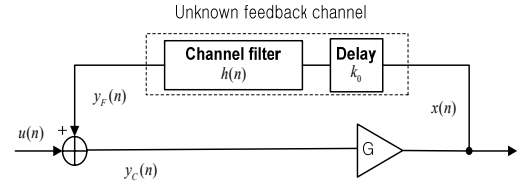


Figure 4. Feedback channel model for wireless repeater.

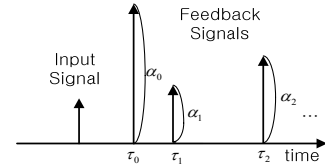


Figure 5. Signal compositions in time domain.

III. ADAPTIVE EQUALIZER IN REPEATER SYSTEM

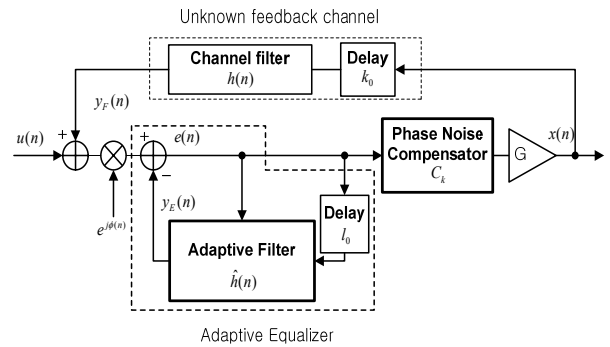


Figure 6. Block diagram of adaptive equalizer and phase noise compensator for wireless repeater.

As we discussed previously, the interference effects of feedback signal may cause the distortion in repeater system due to existence of multipath feedback channel. Therefore, in this

paper interference cancellation system is implemented by adaptive equalizer. There are many schemes and algorithms for adaptive equalizer. But in this paper, we consider the channel identifier algorithm in order to realize the unknown channel inside repeater and by identifying the unknown channel we can produce the feedback signal. The error of estimated signal is as follows.

$$\begin{aligned} e(n) &= i(n) \cdot e^{j\phi(n)} + y_F(n) \cdot e^{j\phi(n)} - y_E(n) \\ &= i(n) \cdot e^{j\phi(n)} + h(n) * x(n-k_0) \cdot e^{j\phi(n)} - w(n) * e(n-k_0). \end{aligned} \quad (4)$$

Consequently, by producing the feedback signal we can eliminate the interference effects in receiver sides of repeater. Following figures 6 shows the channel identifier and adaptive equalizer and phase noise compensator for wireless repeater system. From figure 6 we have

$$x(n) = \left\{ \left(\frac{1}{1+G\hat{H}} \cdot G \right) / \left(1 - \frac{H}{1+G\hat{H}} \cdot G \right) \right\} \cdot u(n).$$

Finally by simplifying, it will be as following equation (5).

$$x(n) = \frac{G}{1 + (\hat{H} - H) \cdot G} \cdot u(n), \quad (5)$$

which H is unknown multipath channel and $\hat{H}$ is FIR adaptive equalizer which can be expressed in frequency domain as follows:

$$\text{Unknown multipath feedback channel: } H = \sum_i \alpha_i \cdot z^{-\hat{\tau}_i}.$$

$$\text{Adaptive FIR equalizer: } \hat{H} = \sum_i \hat{\alpha}_i \cdot z^{-\hat{\tau}_i}.$$

A. NLMS Adaptive Filter

An adaptive algorithm is a set of recursive equations used to adjust the weight vector $\hat{h}(n)$ automatically to minimize the error signal $e(n)$ such that the weight vector converges iteratively to the optimum solution that corresponds to the bottom of the performance surface, i.e. the minimum of MSE. The least-mean-square (LMS) algorithm is the most widely used among various adaptive algorithms because of its using the negative gradient of the instantaneous squared error. According to figure 6, the LMS algorithm updates the weight vector as follows.

$$\begin{aligned} \hat{h}_l(n+1) &= \hat{h}_l(n) - \mu \nabla e^2(n) \\ &= \hat{h}_l(n) - \mu \frac{\partial e^2(n)}{\partial \hat{h}} = \hat{h}_l(n) - 2\mu e(n)x(n-l) \end{aligned}, \quad (6)$$

where μ is the step size or convergence factor that determines the stability and the convergence rate of the algorithm. In the case of Normalized LMS, the LMS algorithm normalizes the step size with respect to the input signal power.

$$\hat{h}_l(n+1) = \hat{h}_l(n) - \frac{2\mu e(n)x(n-l)}{N\sigma_x^2}, \quad (7)$$

where $\sigma_x = \frac{1}{N} \sum_{l=0}^{N-1} x^2(n-l)$ and N is tap number.

Step size is now bounded in the range of 0 to 2. It makes the convergence rate independent of signal power by normalizing the input vector with the energy of the input signal in the adaptive equalizer.

B. RLS Adaptive Filter

Unlike the NLMS algorithm that is derived from the minimization of the expectation of squared error, the recursive least-square (RLS) algorithm is derived from the minimization of the sum of weighted least-square error which is expressed as follows:

$$J_{LS}(n) = \sum_{l=1}^n \lambda^{n-l} e^2(n), \quad (8)$$

where λ^{-1} is the forgetting factor and has a value less than and close to 1. The forgetting factor weights the current error heavier than the past error values to support filter operation in nonstationary environments. Therefore, in the least-square method, the weight vector is optimized based on the observation starting from the first to the current time. Therefore, RLS algorithm can be expressed as following equation.

$$\hat{h}_l(n+1) = \hat{h}_l(n) + g(n)e(n), \quad (9)$$

where the updating vector is defined as

$$g(n) = \frac{r(n)}{1 + x^T(n)r(n)}, \quad (10)$$

and

$$r(n) = \lambda^{-1}P(n-1)x(n), \quad (11)$$

where $P(n)$ is the inverse correlation matrix of input data.

$$P(n) \equiv R^{-1}(n) = \left(\sum_{l=1}^n \lambda^{n-l} x(l)x^T(l) \right)^{-1},$$

can be computed recursively as

$$P(n) = \lambda^{-1}P(n-1) - g(n)r^T(n). \quad (12)$$

IV. PHASE NOISE COMPENSATOR

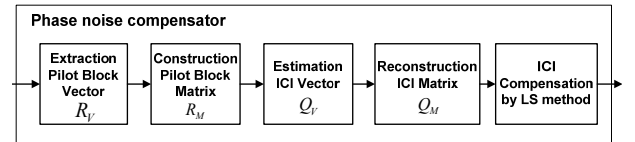


Figure 7. Block diagram of phase noise compensator.

In this section, we propose a phase noise compensator, which is based on block type pilot. The ICI components are caused by phase noise. Instead of estimating phase noise, which is fairly difficult to get accurate estimation results, we estimate the ICI components directly from the received pilot block. Then by reconstructing the ICI matrix, we can make suppression to the interferences by inverse matrix method and finally improve system performance. Figure 7 is block diagram of phase noise compensator. We extract pilot block vector, and construct pilot block matrix by using pilot block vector. And then, we estimate ICI vector caused by phase noise by using pilot block matrix. And we reconstruct ICI matrix, and finally, we compensate ICI effects by LS method. At the receiver, after removing the cyclic prefix and N -DFT, we obtain the matrix expressed frequency domain signal vector as

$$\mathbf{Y} = \mathbf{Q}_M \cdot \mathbf{R}_V + \mathbf{N}, \quad (13)$$

where $\mathbf{R}_V = [R_0, R_1, \dots, R_{N-1}]^T$,

$$R_{\tilde{i}} = \begin{cases} \sum_{r=1}^2 \alpha_r \cdot (X_i \cdot H_{\tilde{i}}^{1,r} + (-1)^{i+1} X_i^* \cdot H_{\tilde{i}}^{2,r}), & \tilde{i} \in S_c \\ 0, & \tilde{i} \notin S_c \end{cases} \quad \text{is the frequency}$$

domain received signal distorted by channel characteristic, and

$$\mathbf{Q}_M = \begin{bmatrix} Q_0 & Q_1 & Q_2 & \dots & Q_{N-1} \\ Q_{-1} & Q_0 & Q_1 & \dots & Q_{N-2} \\ Q_{-2} & Q_{-1} & Q_0 & \dots & Q_{N-3} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ Q_{-(N-1)} & Q_{-(N-2)} & Q_{-(N-3)} & \dots & Q_0 \end{bmatrix}. \quad (14)$$

is the ICI matrix.

From the expression of Q_L , we can see that

$$Q_{-k} = \frac{1}{N} \sum_{n=0}^{N-1} e^{j[2\pi(-k+\varepsilon)n/N + \phi(n)]} = \frac{1}{N} \sum_{n=0}^{N-1} e^{j[2\pi(-k+\varepsilon)n/N + \phi(n) + 2\pi n]} = \frac{1}{N} \sum_{n=0}^{N-1} e^{j[2\pi((N-k)+\varepsilon)n/N + \phi(n)]} = Q_{N-k} \quad (15)$$

Then, the ICI matrix $\mathbf{Q}_M$ can be rewritten as

$$\mathbf{Q}_M = \begin{bmatrix} Q_0 & Q_1 & Q_2 & \dots & Q_{N-1} \\ Q_{N-1} & Q_0 & Q_1 & \dots & Q_{N-2} \\ Q_{N-2} & Q_{N-1} & Q_0 & \dots & Q_{N-3} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ Q_1 & Q_2 & Q_3 & \dots & Q_0 \end{bmatrix}. \quad (16)$$

We can see that the ICI matrix is a circulant matrix with only N different components. Then Eq. (12) can be written as

$$\mathbf{Y} = \mathbf{Q}_M \cdot \mathbf{R}_V + \mathbf{N} = \begin{bmatrix} Q_0 & Q_1 & Q_2 & \dots & Q_{N-1} \\ Q_{N-1} & Q_0 & Q_1 & \dots & Q_{N-2} \\ Q_{N-2} & Q_{N-1} & Q_0 & \dots & Q_{N-3} \\ \vdots & \vdots & \vdots & \dots & \vdots \\ Q_1 & Q_2 & Q_3 & \dots & Q_0 \end{bmatrix} \begin{bmatrix} R_0 \\ R_1 \\ R_2 \\ \vdots \\ R_{N-1} \end{bmatrix} + \mathbf{N}. \quad (17)$$

We can treat Eq. (16) as an equations set and the N components in $\mathbf{Q}_M$ as the unknown values. If we can estimate these N values by solving this equations set, the $\mathbf{Q}_M$ matrix can be reconstructed and the interferences of phase noise can be suppressed by multiply the inverse $\mathbf{Q}_M$ matrix with the received signal.

Rewrite Eq. (16) as

$$\mathbf{Y} = \mathbf{Q}_M \cdot \mathbf{R}_V + \mathbf{N} = \mathbf{R}_M \cdot \mathbf{Q}_V + \mathbf{N} \quad (18)$$

$$= \begin{bmatrix} R_0 & R_1 & R_2 & \dots & R_{N-1} \\ R_1 & R_2 & R_3 & \dots & R_0 \\ R_2 & R_3 & R_4 & \dots & R_1 \\ \vdots & \vdots & \vdots & \dots & \vdots \\ R_{N-1} & R_0 & R_1 & \dots & R_{N-2} \end{bmatrix} \begin{bmatrix} Q_0 \\ Q_1 \\ Q_2 \\ \vdots \\ Q_{N-1} \end{bmatrix} + \mathbf{N}$$

The ICI vector $\mathbf{Q}_V$, which contains the N components in $\mathbf{Q}_M$, can be easily estimated from the received signal, since $\mathbf{R}_M$ is consisted of pilots, which are already known to the receiver. Assuming the channel characteristic has already been estimated, we can calculate all components in matrix $\mathbf{R}_M$ and obtain the inverse data matrix $\mathbf{R}_M^{-1}$. Thus, the ICI vector $\mathbf{Q}_V$ can be obtained by least square (LS) method.

$$\mathbf{Q}_V = (\mathbf{R}_M^H \cdot \mathbf{R}_M)^{-1} \cdot \mathbf{R}_M^H \cdot \mathbf{Y}. \quad (19)$$

After that, the ICI matrix $\mathbf{Q}_M$ can be reconstructed from the estimated $\mathbf{Q}_V$ by very simple mapping process.

We assume that the phase noise is highly correlated during the pilot block and the following data blocks. Since in wireless communications, symbol period and frame size are usually

very short, this assumption is feasible. Therefore, the influence of phase noise on the data block can be easily suppressed by least square method.

$$\mathbf{Y}_{\text{suppressed}} = (\mathbf{Q}_M^H \cdot \mathbf{Q}_M)^{-1} \cdot \mathbf{Q}_M^H \cdot \mathbf{Y} = \mathbf{R}_V + (\mathbf{Q}_M^H \cdot \mathbf{Q}_M)^{-1} \cdot \mathbf{Q}_M^H \cdot \mathbf{N}. \quad (20)$$

V. SIMULATION RESULTS

TABLE 1. SIMULATION PARAMETERS.

FFT size	128
Cyclic Prefix	32
Number of Subcarriers	128
Modulation	16QAM
Channel	AWGN + Feedback channel
Phase noise variance	0.005, 0.01, 0.05

The table 1 is the simulation parameters for wireless repeater. In this paper, we consider LTE-Advanced uplink system. In order to evaluate the two different algorithms, we have simulated for multipath feedback channel which is shown as follows.

Case of feedback channel: $h_1 = 1.8\delta(n-10) + 1.2\delta(n-15)$.

Figure 8 shows signal compositions of input signal and feedback signal in time domain.

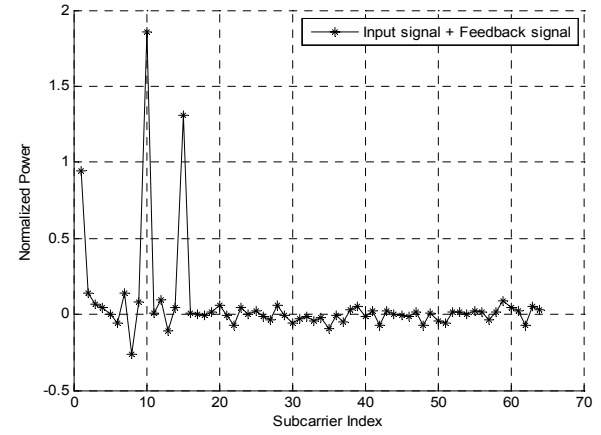


Figure 8. Signal compositions of input signal and feedback signal in time domain.

For evaluation we used Normalized MSE method which is :

$$MSE = 10 \log_{10} \frac{\sum_{l=1}^n (y_F(l) - y_E(l))^2}{\sum_{l=1}^n y_F(l)^2}$$

As it is clear from simulation results the convergence speed of RLS is faster than NLMS for both channels. This mean that RLS adaptive equalizer is able to eliminate the interference which is amplified transmitted multipath feedback signal. As results, we can obtain more good performance compare to NLMS algorithm. However, in actual case the multipath feedback channel is more complicated and randomly created and it may contain with nonlinearly change interval delay, especially when user is in motion. Therefore, our future work is to devise a faster algorithm in order to identify the random multipath feedback channel. Figure 10 is BER performance of adaptive equalizer and phase noise compensator in case of 16QAM. In figure 10, an AE means the adaptive equalizer, and a PNC means the phase noise compensator. The dot line is

case of without cancellation of feedback channel and phase noise. And the 3 dash lines are after feedback channel cancellation by using adaptive equalizer such as RLS. In this result, the phase noise effects remain. The solid line of pentagram marker is after compensation between feedback channel and phase noise by adaptive equalizer and phase noise compensator.

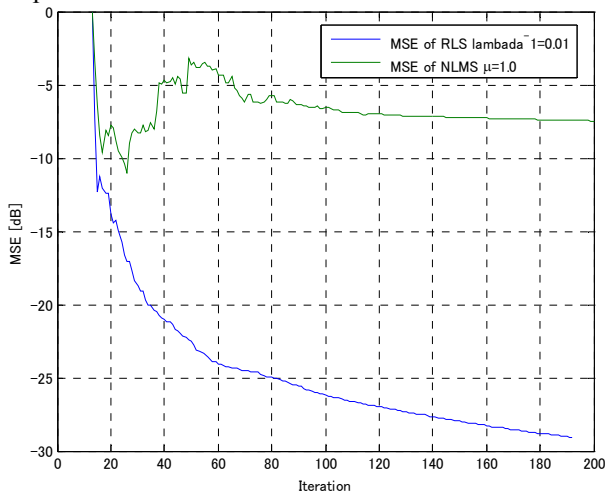


Figure 9. Comparison of NLMS and RLS.

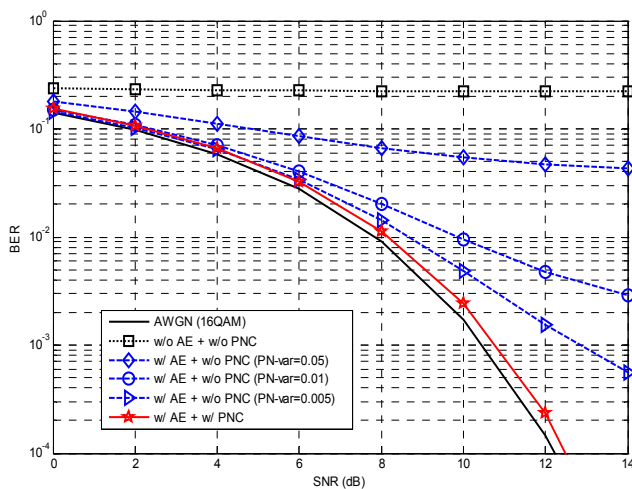


Figure 10. BER performance of adaptive equalizer and phase noise compensator (16QAM).

ACKNOWLEDGMENT

This research was supported by Basic Science Research Program through the National Research Foundation of Korea(NRF) funded by the Ministry of Education, Science and Technology(No. 2010-0007567)

REFERENCES

- [1] 3GPP TR 36.814 V1.2.1, "Further Advancements for EUTRA: Physical Layer Aspects," *Tech. Spec.n Group Radio Access Network Rel. 9*, June 2009.
- [2] S. J. Kim, J. Y. Lee, J. C. Lee, J. H. Kim, B. Lee, and N. Y. Kim, "Adaptive feedback interference cancellation system (AF-ICS)," *IEEE Microwave Symposium (MTT-S) Digest*, pp.627-630, 2003.

- [3] J. Lee, S. Park, H. Choi, Y. Jeong and J. Yun, "A design of co-channel feedback interference cancellation system using analog control," *Microwave Conf., 36th European*, Sept. 2006.
- [4] W. Moon, S. Im, and C. Kim, "Adaptive feedback interference cancellation using correlation for WCDMA wireless repeaters," *The Institute of Electronics Engineers of Korea, Journal*, vol. 44, issue 7, July, 2007.
- [5] T. Yoo, D. Woo, J. Kim, S. Ha, J. Van, and J. Lee, "Wireless repeating interference cancellation using signed-DLMS adaptive algorithm," *The Institute of Electronics Engineers of Korea, Conference & Workshop*, vol. 30, issue 1, July, 2007.
- [6] D. Choi and H. Yun, "Interference cancellation repeater," *PCT Patent WO 2007/078032 A1*, July 12, 2007.
- [7] Haeseong Jeong and Heung-Gyoon Ryu "Phase Analysis and Performance Evaluation of Wireless ICS Repeater based on OFDM System" *Proceeding of the 11th International Conference on Computer, Communication Systems(ICCCS 2010)*, Nov, 2010.
- [8] Donald Duttweiler, "Proportionate Normalized Least-Mean-Square Adaptive Echo Canceller" *IEEE Transaction on Speech and Audio Processing*, Vol. 8, No. 5, September 2000.
- [9] Akihiko Sugiyama, Hiroshi Sato, Akihiro Hirano and Shigeji Ikeda "A Fast Algorithm for Adaptive FIR Under Computational Constraint for Adaptive Tap-Position Control" *IEEE Transaction on Circuits and System, Analog and Digital Signal Processing*, Vol. 43, No. 9, September 1996.