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파이롯 신호가 있는 Balanced QPSK DS-SS 통신의 자동 주파수 제어

(Automatic Frequency Control For Balanced QPSK DS-SS communication With Pilot Signal)

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요 약

레일리 페이딩 환경 하에서 주파수 천이로 생겨나는 balanced QPSK DS-SS통신의 왜곡을 보상하기위해서 효율적인 위상 추정 방법을 고안하는 것이 필요하다. 이 논문에서는 파이롯 신호를 이용한 세 가지 종래의 방법 및 복소수 기법이 제시되고 비교되었다. 성능 비교 결과 복합적인 복소수 기법이 몇 가지 제약 사항을 가지고 있는 종래의 다른 방법보다 더 나음을 알 수 있었다.

Abstract

In order to compensate for the degradation caused by the frequency shift under the Rayleigh fading with the balanced QPSK DS-SS communication, it is necessary to devise an efficient phase estimation method. In this paper, using the pilot signal, three conventional methods and a complex number method are presented and compared. The performance comparison results show that the combination complex number method is better than the other conventional methods, which have some limiting conditions.

Keywords : Rayleigh fading, CDMA, Automatic frequency control, balanced QPSK DS-SS

Ⅰ. INTRODUCTION

Under the Rayleigh fading environment and the mobility of the vehicle, there is the fast phase variation of the receiver, which causes the receiver performance to degrade.

Therefore it is necessary to estimate the phase variation and compensate for it continuously. In the CDMA system with the pilot signal, it is possible to estimate the phase variation using the pilot signal after getting the initial PN code acquisition.

After modeling the baseband equivalent phase estimation model of balanced QPSK DS-SS, some methods are presented for the phase estimation.

In addition, by considering the realistic Doppler frequency shift variation under fading environment, the combination complex number method has the best performance for SNR equals 10 dB and 20 dB comparing it to other old combination methods.

Ⅱ. SYSTEM MODEL

In this section we consider a model in figure 1. for the phase estimation under the fading. Figure 2 shows the equivalent baseband model presented in

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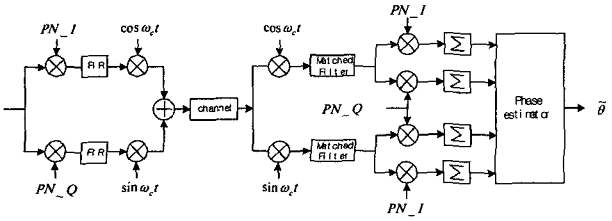

그림 1. balanced QPSK DS-SS 통신의 위상 추정 모델
Fig. 1. The phase estimation model of balanced QPSK DS-SS communication.

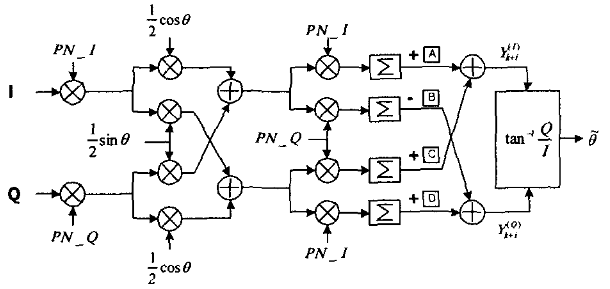

그림 2. 그림 1.과 등가의 기저대역 시스템 블럭
Fig. 2. Equivalent Baseband system block presented in Fig. 1.

Figure 1. Each transmitter has been assigned two independent spreading sequences. At the receiver, we assume that the demodulation is in the synchroniza-tion state and the power gain has been normalized. Ignoring the effect of the FIR spectral shaping filters, the received signal can be described as follows:[1],[2]

$$r(t) = \sqrt{I^2(t) + Q^2(t)} \cdot \{\cos[\omega_0 t - \phi(t) + \theta]\} \tag{1}$$

$$\phi(t) = \tan^{-1}[\frac{Q(t)}{I(t)}] \tag{2}$$

where

I(t) is the I channel signal which includes the pilot and PN code I, Q(t) is the Q channel signal which includes pilot and PN code Q. θ is the phase shift which has uniform distribution. In Figure 2. :

àA + àC : $Y_{k+i}^{(I)} = D_{k+i} \cdot \cos\theta_{k+i} + A_{k+i}^{(I)}$ (3)

àD - àB : $Y_{k+i}^{(Q)} = D_{k+i} \cdot \sin\theta_{k+i} + A_{k+i}^{(Q)}$ (4)

where

D_{k+i} : Pilot signal

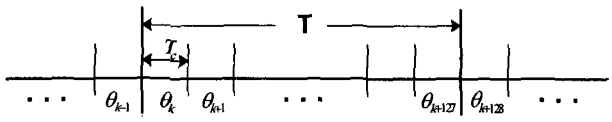

그림 3. 위상 천이 구조
Fig. 3. Phase Shift Structure.

$A_{k+i}^{(I)}$, $A_{k+i}^{(Q)}$: Additive white Gaussian noise

III. Methods for phase control

In this section, we will describe some methods for phase control and describe their limited conditions.

At first, let's assume that the phase shifts are distributed as follows.

Those following methods explain the relationship between two neighboring phase shifts for the different kind of methods used for different situations.

3.1 Idea 1 : Simple arc tangent Method

Condition : AWGN is too small to affect the transmitted signals.

This is a direct method as it simply uses an arc tangent to get the phase shift at every PN chip.

$$\tilde{\theta}_{k+i} = \tan^{-1}\frac{Y_{k+i}^{(Q)}}{Y_{k+i}^{(I)}} = \tan^{-1}\frac{D_{k+i}\sin\theta_{k+i}}{D_{k+i}\cos\theta_{k+i}} = \theta_{k+i}$$

i=integer (5)

In this case, if AWGN is too small to affect the transmitted signals, it is the best way to recover the phase shift because it estimates the phase one by one. It means we can neglect the relationship between two adjacent phase shifts.

3.2 Idea 2 : Summation method

Condition : The phase shift is constant during a signal period.

Since the condition of the idea 1 is too limited, we consider using summation to get rid of the noise with the characteristic of AWGN [3]. During a signal period $(T=128T_c)$:

$$\tilde{\theta}_m=\tan^{-1}\frac{\sum_{i=128n}^{128n+127}Y^{(Q)}_{k+i}}{\sum_{i=128n}^{128n+127}Y^{(I)}_{k+i}}=\tan^{-1}\frac{\sum_{i=128n}^{128n+127}\alpha_m D_{k+i}\sin\theta_{k+i}+A^{(I)}_{k+i}}{\sum_{i=128n}^{128n+127}\alpha_m D_{k+i}\cos\theta_{k+i}+A^{(Q)}_{k+i}} \quad (6)$$

n = integer

where

$$E[A^{(I)}_{k+i}]=0\ ,\quad E[A^{(Q)}_{k+i}]=0 \quad (7)$$

α_m : Rayleigh fading coefficient (flat fading)

$A^{(I)}_{k+i}$, $A^{(Q)}_{k+i}$: Additive white Gaussian noise

If the phase shift is constant during a signal period, we can get :

$$\tilde{\theta}_m=\tan^{-1}\frac{128\cdot\alpha_m D_{k+i}\sin\theta_m}{128\cdot\alpha_m D_{k+i}\cos\theta_m}=\theta_m \quad (8)$$

3.3 Idea 3 : Moving window Method

Condition : the phase shift is changing slowly and the initial phase at every signal period should be known.

It is the extended idea for summation method.

$$\theta_{k+i+1}-\theta_{k+i}=\Delta\theta \ \text{(constant)} \quad (9)$$

The phase sequence can be written as follows:

$$\theta_{k+1}=\theta_k+\Delta\theta$$

M

$$\theta_{k+i}=\theta_k+i\cdot\Delta\theta \quad (10)$$

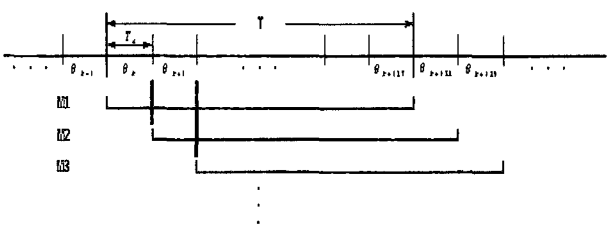

그림 4. 이동 창 방법도

Fig. 4. Moving Window Method Diagram.

During T, the number of the phase is $2^7=128$, after using the combination of two adjacent phases for 7 times, we can get only one item for the denominator and numerator, respectively.

$$M_1=\tan^{-1}\frac{[\sin\theta_k+\sin(\theta_k+\Delta\theta)+\cdots+\sin(\theta_k+127\Delta\theta)]}{[\cos\theta_k+\cos(\theta_k+\Delta\theta)+\cdots+\cos(\theta_k+127\Delta\theta)]}$$

$$=\tan^{-1}\frac{[2\sin(\frac{\theta_k+\Delta\theta+\theta_k+2\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}+2\sin(\frac{\theta_k+3\Delta\theta+\theta_k+4\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}\cdots+2\sin(\frac{\theta_k+(n-1)\Delta\theta+\theta_k+n\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}]}{[2\cos(\frac{\theta_k+\Delta\theta+\theta_k+2\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}+2\cos(\frac{\theta_k+3\Delta\theta+\theta_k+4\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}\cdots+2\cos(\frac{\theta_k+(n-1)\Delta\theta+\theta_k+n\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}]}$$

$$=\tan^{-1}\frac{\sin[\theta_k+\frac{1}{n}(1+2+\ldots+n)\cdot\Delta\theta]}{\cos[\theta_k+\frac{1}{n}(1+2+\ldots+n)\cdot\Delta\theta]}$$

$$=\theta_k+\frac{1}{n}(1+2+\ldots+n)\cdot\Delta\theta \quad (11)$$

$$M_2=\theta_k+\frac{1}{n}[2+3+\cdots+(n+1)]\cdot\Delta\theta \quad (12)$$

$$M_2-M_1=\frac{1}{n}\cdot(n)\cdot\Delta\theta=\Delta\theta \quad (13)$$

As shown above, this method includes summation and the random noise can be omitted after phase detection.

3.4 Idea 4 : Complex number method

Condition : The phase shift is changing slowly and the initial phase at every signal period should be known.

If we know the difference between two neigh-boring phase shifts, we may calculate the phase shifts one by one. In order to avoid the effects of

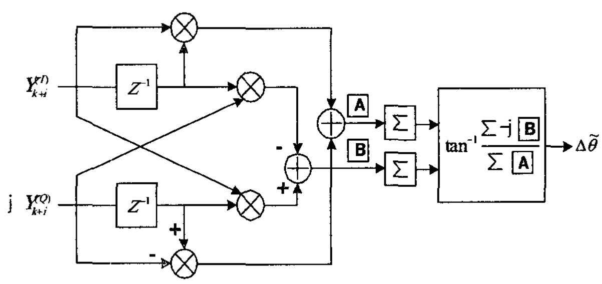

그림 5. 복소수 기법의 블록도

Fig. 5. Complex Number Method Block Diagram.

noise, summation and moving window are used.

This method is the best way to get the phase increment or decrement.

$$\text{àA}: \quad Y_{k+i}^{(I)} \cdot Y_{k+i+1}^{(I)} - j \cdot Y_{k+i}^{(Q)} \cdot j \cdot Y_{k+i+1}^{(Q)}$$
$$= D_{k+i} \cdot D_{k+i+1} \cdot \cos\theta_{k+i} \cdot \cos\theta_{k+i+1} + D_{k+i} \cdot D_{k+i+1} \cdot \sin\theta_{k+i} \cdot \sin\theta_{k+i+1}$$
$$= D_{k+i} \cdot D_{k+i+1} \cdot [\cos(\theta_{k+i+1} - \theta_{k+i})] \quad (14)$$

$$\text{àB}: \quad j \cdot Y_{k+i}^{(I)} \cdot Y_{k+i+1}^{(Q)} - j \cdot Y_{k+i+1}^{(I)} \cdot Y_{k+i}^{(Q)}$$
$$= j \cdot D_{k+i} \cdot D_{k+i+1} \cdot \sin\theta_{k+i+1} \cdot \cos\theta_{k+i} - j \cdot D_{k+i} \cdot D_{k+i+1} \cdot \sin\theta_{k+i} \cdot \cos\theta_{k+i+1}$$
$$= j \cdot D_{k+i} \cdot D_{k+i+1} \cdot [\sin(\theta_{k+i+1} - \theta_{k+i})] \quad (15)$$

If the difference between two neighboring phase shifts are constant, we will add all values of $Y_{k+i}^{(I)}$ and $Y_{k+i}^{(Q)}$, respectively.

$$\sum A = D_{k+i} \cdot D_{k+i+1} \cdot [\cos(\theta_{k+i+1} - \theta_{k+i})] + \cdots D_{k+i+126} D_{k+i+127} [\cos(\theta_{k+i+127} - \theta_{k+i+126})]$$
$$= 127 \cdot D^2 \cdot \cos(\Delta\theta) \quad (16)$$

$$\sum B = D_{k+i} \cdot D_{k+i+1} \cdot [\sin(\theta_{k+i+1} - \theta_{k+i})] + \cdots D_{k+i+126} D_{k+i+127} [\sin(\theta_{k+i+127} - \theta_{k+i+126})]$$
$$= 127 \cdot D^2 \cdot \sin(\Delta\theta) \quad (17)$$

$$\Delta\tilde{\theta} = \tan^{-1} \frac{\sum B}{\sum A} = \Delta\theta \quad (18)$$

and now we use a moving window to get Δθ at every PN chip.

If we consider the process of this method carefully, we will discover that the moving window is used twice for the complex number method and it indicates that it may be better than the moving window method.

Ⅳ. A Combination method for real situation

What is the real situation? If we know how the phase shift (especially for phase increment or decrement) changes, we can look for and select the best method, which is used under different situations. As we all know that the variation of the received carrier frequency depends on the vehicle velocity and moving direction[1],[2] :

$$f_d = \frac{v}{\lambda} \cdot \cos\theta \quad (19)$$

f_d : Doppler frequency

v : car speed

λ : wavelength

θ : the angle between the direction of arrival of the signal and the direction that the vehicle is traveling

If we consider the Doppler frequency with a macro-graphic view, we'll see the random phase shift. As a matter of fact, the time unit of phase shift and the time unit of car moving are not at the same order of magnitude, just as the difference between the alternation of a nations economy and a private wealth.

Consider the time unit of phase shift as Tc (1/1228800) .The phase shifts change slowly in spite of the random car moving route.

Let's build a model shown in Figure 6: a car is moving on a road which is 500 m away from the base station. Assume two cases:

1) Constant speed is $v = 60 km/hour$

2) Constant acceleration is $1.85 m/s^2$ (it means the speed changes from 0 km/hour to 100 km/hour in 15 seconds) with the initial speed as zero.

We can see the doppler frequency, phase shift and

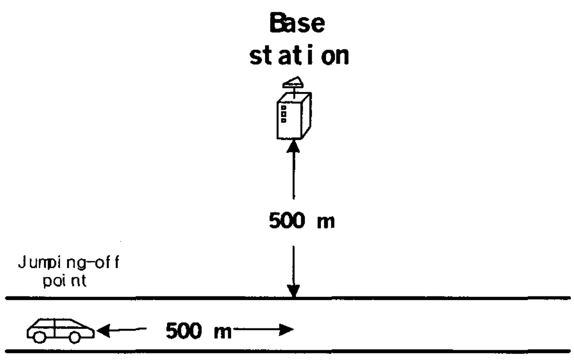

그림 6. 주행 중인 차 환경 모델
Fig. 6. Moving car environment model.

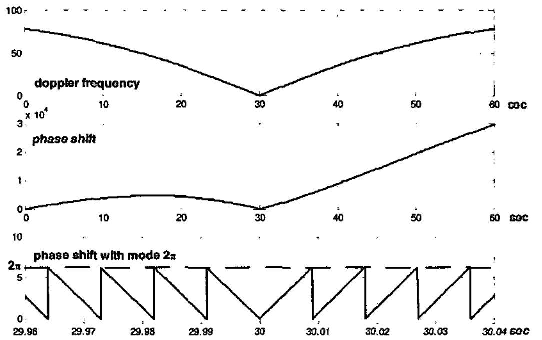

그림 7. 주행 차 모델에서 도플러 주파수와 위상 추정 시뮬레이션(등속도)

Fig. 7. Doppler frequency and phase shift simulation of the moving car model (constant speed).

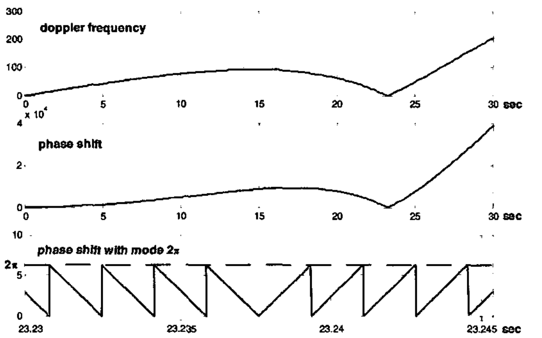

그림 8. 주행 차 모델에서 도플러 주파수와 위상 추정 시뮬레이션(등가속도)

Fig. 8. Doppler frequency and phase shift simulation of the moving car model (constant acceleration).

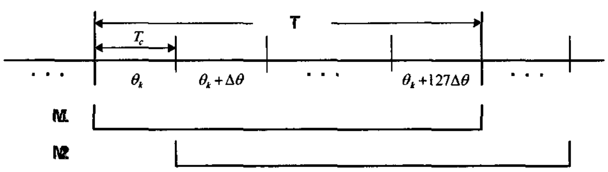

그림 9. 위상 천이 모델

Fig. 9. Phase Shift Model.

the phase shift (mode 2π) shown in Figures 7 and 8. Comparing a signal period 128Tc (128/1228800= 1.0417e-004), the phase shift and the phase shift (mode 2π) are changing slowly and the increase or the decrease can be considered constant.

Let's review the methods. Which is better for the hypothetical phase shift case. Apparently, we choose the summation method, moving window method and the complex number method. Unfortunately, they cannot be used solely because the summation requires the constant phase shift and both the moving window method and the complex number method need to know the initial phase at every signal period. How about combing them?

Let's rebuild the phase shift model :

After using summation method, we may derive :

$$M_1 = \tan^{-1}\frac{[\sin\theta_k + \sin(\theta_k+\Delta\theta)+\cdots+\sin(\theta_k+127\Delta\theta)]}{[\cos\theta_k + \cos(\theta_k+\Delta\theta)+\cdots+\cos(\theta_k+127\Delta\theta)]}$$

$$= \tan^{-1}\frac{[2\sin(\frac{\theta_k+0+\theta_k+\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}+2\sin(\frac{\theta_k+2\Delta\theta+\theta_k+3\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}\cdots+2\sin(\frac{\theta_k+126\Delta\theta+\theta_k+127\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}]}{[2\cos(\frac{\theta_k+0+\theta_k+\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}+2\cos(\frac{\theta_k+2\Delta\theta+\theta_k+3\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}\cdots+2\cos(\frac{\theta_k+126\Delta\theta+\theta_k+127\Delta\theta}{2})\cdot\cos\frac{\theta_k}{2}]}$$

$$= \tan^{-1}\frac{\sin[\theta_k+\frac{1}{128}(0+1+2+\ldots+127)\cdot\Delta\theta]}{\cos[\theta_k+\frac{1}{128}(0+1+2+\ldots+127)\cdot\Delta\theta]}$$

$$= \theta_k + 63.5\times\Delta\theta \quad (20)$$

After using moving window method, we may derive :

$$M_1 = \tan^{-1}\frac{[\sin\theta_k + \sin(\theta_k+\Delta\theta)+\cdots+\sin(\theta_k+127\Delta\theta)]}{[\cos\theta_k + \cos(\theta_k+\Delta\theta)+\cdots+\cos(\theta_k+127\Delta\theta)]}$$

$$= \tan^{-1}\frac{\sin[\theta_k+\frac{1}{128}(0+1+2+\ldots+127)\cdot\Delta\theta]}{\cos[\theta_k+\frac{1}{128}(0+1+2+\ldots+127)\cdot\Delta\theta]}$$

$$= \theta_k + 63.5\times\Delta\theta \quad (21)$$

$$M_2 = \tan^{-1}\frac{[\sin(\theta_k+\Delta\theta)+\sin(\theta_k+2\Delta\theta)+\cdots+\sin(\theta_k+128\Delta\theta)]}{[\cos(\theta_k+\Delta\theta)+\cos(\theta_k+2\Delta\theta)+\cdots+\cos(\theta_k+128\Delta\theta)]}$$

$$= \tan^{-1}\frac{\sin[\theta_k+\frac{1}{128}(1+2+\ldots+128)\cdot\Delta\theta]}{\cos[\theta_k+\frac{1}{128}(1+2+\ldots+128)\cdot\Delta\theta]}$$

$$= \theta_k + 64.5\times\Delta\theta \quad (22)$$

and

$$\theta_k = M_1 - 63.5\times\Delta\theta$$

$$= M_1 - 63.5\times(M_2 - M_1)$$

$$= 64.5\times M_1 - 63.5\times M_2 \quad (23)$$

Let's call this method the combination moving window method.

If we combine the Eqs. (16), (17), (18), and (20), we may also get the phase shift as follows :

$$\theta_k = M_1 - 63.5 \times \Delta\theta = M_1 - 63.5 \times \tan^{-1}\frac{\sum B}{\sum A} \qquad (24)$$

and let's call it the combination complex number method.

We use the summation method to get the esti-mated phase which includes θ_k and $\Delta\theta$, and use the moving window method or complex number method to get $\Delta\theta$.

V. COMPARISON UNDER SIMULATION

Let's use the model shown in sector IV as the simulation model. During a signal period in the process, we'll see the phase control results by using the summation method, the combination moving window method and the combination complex number method, respectively. They are shown as follows :

SNR = 10 dB

As shown in Figure 10, the combination complex number method is the best because it uses moving window double the times than the combination moving window method uses, and the summation method is the worst for its estimated phase is the summation of θ_k and $63.5 \times \Delta\theta$.

The combination moving window method and the combination complex number method depend on the summation method. The difference between them is the estimated $\Delta\theta$, so the $\Delta\theta$ is same with the constant difference phase at every PN chip during a signal period.

When the SNR increases, the simulation lines of combination moving window method and the combination complex number method are closed to each other and combine to one line at last. The following figure shows us the simulation results with SNR=20dB.

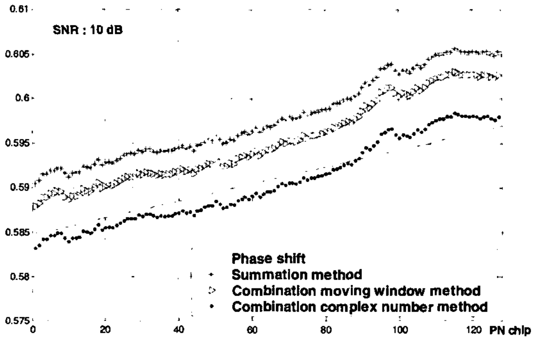

그림 10. 10dB에서 주행 중인 차 모델의 위상 천이 제어 시뮬레이션

Fig. 10. Phase shift control simulation of the moving car model at 10 dB.

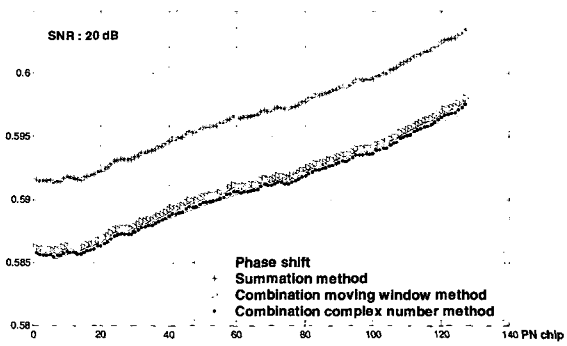

그림 11. 20dB에서 주행 중인 차 모델의 위상 천이 제어 시뮬레이션

Fig. 11. Phase shift control simulation of the moving car model at 20 dB.

VI. CONCLUSIONS

The four methods are reviewed as the phase estimation method under the fading environment with the mobility of a vehicle.

Considering the realistic Doppler frequency shift under the fading environment, the combination complex number method is the best choice because the moving window method can only be used with a large SNR. When the SNR decreases, the performance gets worse. If we want to get high performance under very bad circumstances, we have to design another better method that is better than the combination complex number method.

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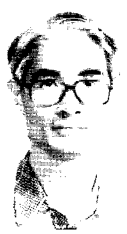

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