Adaptive Channel Estimation in WCDMA STTD Systems

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Abstract - **The receiver performance with the use of a space time transmit diversity (STTD) scheme is more susceptible to the accuracy of channel estimate than that without the use of the STTD scheme since the despreading signals suffer from the effect of crosstalk and the transmit power is equally divided into multiple transmit antennas. As a result, the efficiency of channel estimation in the WCDMA STTD system becomes an important issue more than that in the non-STTD system. In this paper, an adaptive channel estimator (ACE) is designed to mitigate the performance degradation due to inaccurate channel estimation. Numerical results show that the performance improvement significantly increases with the use of the proposed ACE, particularly when the channel condition becomes worse.**

I. INTRODUCTION

There have been proposed a number of diversity schemes for DS-CDMA systems [1]. Time diversity can be achieved with the use of interleaving and channel coding. The rake receiver can obtain the diversity effect by combining each multipath signal component. The space diversity can be realized with the use of multiple antennas at the transmitter and/or the receiver. Since it may not be practical to employ multiple antennas in the mobile handset, the transmit antenna diversity is widely employed in the downlink of the WCDMA system [2]. The transmit antenna diversity scheme can be realized using an open-loop or closed-loop scheme. The information on the channel is not used to transmit the signal in the open-loop diversity scheme, while it is obtained from the receiver to control the transmit gain of each antenna in the closed-loop diversity scheme [2].

The use of a space time transmit diversity (STTD) scheme has been applied to the data channel in the WCDMA system as an open-loop transmit diversity scheme [2]. It was shown that the performance can significantly be improved with the use of an STTD scheme [3]. The STTD scheme employs multiple transmit antennas to provide both the time and space diversity particularly when the Doppler frequency is low or the channel has a small number of multipaths. It was reported that the receiver performance of the STTD scheme is more susceptible to channel estimate error than that of a non-STTD scheme since the error can cause the crosstalk between the adjacent symbols [4]. Moreover, the channel estimate may become more erroneous in the STTD scheme since the total transmit power is split into multiple transmit antennas, decreasing the SIR of the despread pilot signal. As a result, it is required to use an efficient channel estimator to fully obtain the effect of transmit diversity.

Unlike in the non-STTD scheme, however, there have not been much studies on channel estimation in the STTD scheme. The receiver performance of the STTD rake receiver was evaluated when a brick-wall type lowpass filter is used as the channel estimation filter (CEF) [4]. A few channel estimation schemes were proposed for the STTD transceiver using the orthogonal property of the pilot signal transmitted from each transmit antenna [5,6]. The receiver performance of the STTD scheme in the WCDMA system is compared with that of the non-STTD scheme when a moving average (MA) FIR filter is used as the CEF [7]. It was shown that the receiver performance is significantly changed depending upon the tap size of the MA CEF and the maximum Doppler frequency. However, there have been few studies on adaptive channel estimation schemes. In this paper, we proposed an adaptive channel estimator (ACE) for the WCDMA STTD system by modifying the ACE for non-STTD DS-CDMA system [8]. The receiver performance with the use of the proposed ACE is evaluated in the STTD and non-STTD scheme.

Section Ⅱ describes the structure of the WCDMA STTD downlink system. The proposed ACE is described in Section Ⅲ. The performance of the proposed scheme is evaluated in terms of the BER performance in Section Ⅳ. Finally, conclusions are summarized in Section V.

II. WCDMA STTD DOWNLINK SYSTEM

Fig. 1 depicts the structure of the WCDMA STTD transmitter for the dedicated physical channel (DPCH) [2]. The STTD encoded DPCH data $x_i(t)$ at antenna-*i*, *i* = 1 and 2, can be represented as

$$x_1(t) = \begin{cases} s_1[k],\ t = 2kT \\ s_2[k],\ t = (2k+1)T \end{cases}$$
$$x_2(t) = \begin{cases} -s_2^*[k],\ t = 2kT \\ s_1^*[k],\ t = (2k+1)T \end{cases} \tag{1}$$

where T is the symbol time duration. In parallel with the DPCH transmission, the orthogonal pilot symbol sets [*A*, *A*] and [*A*, -*A*] (or [-*A*, *A*]) are transmitted through a common pilot channel (CPICH) of each antenna during two-symbol time interval. The channel

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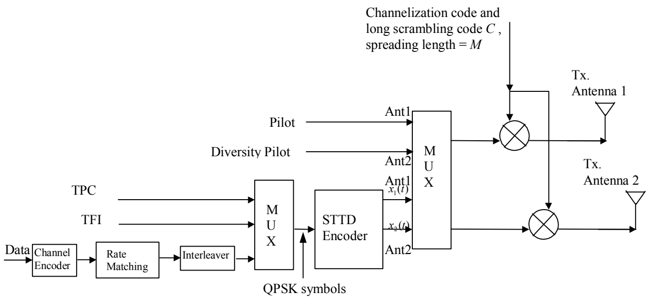


Fig. 1. Structure of the WCDMA STTD transmitter for DPCH transmission.

coding, rate matching and interleaving are done as in the non-diversity mode. It can be assumed that the channel between each transmit antenna and the mobile receiver suffers from independent fading if the transmit antennas are spaced sufficiently.

We consider a WCDMA STTD rake receiver with L multipath branches. For ease of description, denote $r_{1,l}[k]$ and $r_{2,l}[k]$ by the value of the l-th path received signal $r_l(t)$ despread at $t = 2kT$ and $t = (2k+1)T$, respectively, as

$$\begin{aligned} r_{1,l}[k] &= r_l(2kT) = h_l^1[k]s_1[k] - h_l^2[k]s_2^*[k] + n_{1,l}[k] \\ r_{2,l}[k] &= r_l((2k+1)T) = h_l^1[k]s_2[k] + h_l^2[k]s_1^*[k] + n_{2,l}[k] \end{aligned} \tag{2}$$

where $h_l^i[k]$ is the channel gain of the l-th path between the transmit antenna i and the receiver and $n_{j,l}[k]$ is the noise in the l-th path at time $t = (2k\text{-}1+j)T$, j=1 and 2. Here, we assume that the channel gain is not changed during two-symbol time interval.

After multiplying the despread DPCH symbol by the estimated channel gain, the desired symbol is obtained by combining the despread symbols. The channel gain for each antenna is obtained by despreading the orthogonal CPICH symbols. The despread CPICH symbol $p_{1,l}[k]$ and $p_{2,l}[k]$ of the l-th path at $t = 2kT$ and $t = (2k+1)T$ are respectively given by

$$\begin{aligned} p_{1,l}[k] &= p_l(2kT) = \beta h_l^1[k]A + \beta h_l^2[k]A + n_{1,l}'[k], \\ p_{2,l}[k] &= p_l((2k+1)T) = \beta h_l^1[k]A - \beta h_l^2[k]A + n_{2,l}'[k] \end{aligned} \tag{3}$$

where β^2 is the power ratio of the CPICH to DPCH signal, i.e., $\beta = h_l^{CP}[k]/h_l[k]$. The instantaneous channel gain $\tilde{h}_l^{CPi}[k]$ of antenna-i , i = 1 and 2, can be obtained by correlating the despread CPICH symbol with the orthogonal pilot symbol over two-symbol time duration

$$\begin{aligned} \tilde{h}_l^{CP1}[k] &= \left(p_{1,l}[k]A^* + p_{2,l}[k]A^*\right)/2 \\ h_l^{CP2}[k] &= \left(p_{1,l}[k]A^* - p_{2,l}[k]A^*\right)/2\,. \end{aligned} \tag{4}$$

The channel estimate $\hat{h}_l^{CPi}[k]$ can be obtained by averaging the instantaneous channel gain $\tilde{h}_l^{CPi}[k]$ over N_l symbols,

$$\hat{h}_l^{CPi}[k] = \frac{1}{N_l}\sum_{j=-N_l/2}^{N_l/2} \tilde{h}_l^{CPi}[k+j],\ i = 1 \text{ and } 2. \tag{5}$$

The desired symbol can be obtained by

$$\begin{aligned} \hat{s}_1[k] &= \sum_{l=0}^{L-1}\left(\hat{h}_l^{CP1*}[k]r_{1,l}[k] + \hat{h}_l^{CP2}[k]r_{2,l}^*[k]\right) \\ \hat{s}_2[k] &= \sum_{l=0}^{L-1}\left(-\hat{h}_l^{CP2}[k]r_{1,l}^*[k] + \hat{h}_l^{CP1*}[k]r_{2,l}[k]\right). \end{aligned} \tag{6}$$

Assuming ideal channel estimation, the received signal can be represented as [4]

$$\begin{aligned} \hat{s}_1[k] &= \beta\sum_{l=0}^{L-1}\left\{(|h_l^1[k]|^2 + |h_l^2[k]|^2)s_1[k] + h_l^{1*}[k]n_{1,l}[k] + h_l^2[k]n_{2,l}^*[k]\right\} \\ \hat{s}_2[k] &= \beta\sum_{l=0}^{L-1}\left\{(|h_l^1[k]|^2 + |h_l^2[k]|^2)s_2[k] - h_l^2[k]n_{1,l}^*[k] + h_l^{1*}[k]n_{2,l}[k]\right\}. \end{aligned} \tag{7}$$

If a channel estimation error occurs, (6) can be represented as [4]

$$\begin{aligned} \hat{s}_1[k] = \beta\sum_{l=0}^{L-1}\Big\{&(|h_l^1[k]|^2\,\varepsilon_l^{1*}[k] + |h_l^2[k]|^2\,\varepsilon_l^2[k])s_1[k] + h_l^{1*}[k]n_{1,l}[k] \\ &+ h_l^2[k]n_{2,l}^*[k] + s_2^*[k]\,|h_l^1[k]|\,|h_l^2[k]|\,e^{-j\theta_l^{12}[k]}(\varepsilon_l^2[k] - \varepsilon_1^{1*}[k])\Big\} \\ \hat{s}_2[k] = \beta\sum_{l=0}^{L-1}\Big\{&(|h_l^1[k]|^2\,\varepsilon_l^{1*}[k] + |h_l^2[k]|^2\,\varepsilon_l^2[k])s_2[k] - h_l^2[k]n_{1,l}^*[k] \\ &+ h_l^{1*}[k]n_{2,l}[k] + s_1^*[k]\,|h_l^1[k]|\,|h_l^2[k]|\,e^{-j\theta_l^{12}[k]}(\varepsilon_l^{1*}[k] - \varepsilon_l^2[k])\Big\} \end{aligned} \tag{8}$$

where $h_l^i[k] = \left|h_l^i[k]\right|e^{-j\theta_l^i[k]}$, $\hat{h}_l^i[k] = \left|\hat{h}_l^i[k]\right|e^{-j\hat{\theta}_l^i[k]}$, $\hat{h}_l^i[k] = h_l^i[k]\varepsilon_l^i[k]$, for i = 1 and 2, and $\theta_l^{12}[k] = \theta_l^2[k] - \theta_l^1[k]$. It can be seen that the channel estimate error can cause the crosstalk between $\hat{s}_1[k]$ and $\hat{s}_2[k]$. Moreover, since the channel estimation should be done for each transmit antenna, the SIR of the CPICH pilot signal is decreased by one half, degrading the accuracy of channel estimate. The accuracy of the channel estimator affects the receiver performance in the STTD scheme much more than that in the non-STTD scheme.

III. ADAPTIVE CHANNEL ESTIMATOR

We consider the use of an adaptive MA filter as the CEF since the use of general FIR filters does not provide any significant improvement over the use of an MA FIR filter [8]. When a non-STTD scheme is employed, we correlate the received pilot symbol for a given correlator's interval m_l as

$$w_l(m_l) = \sum_J \mathrm{Re}\left\{\bar{h}_l^*[k]\bar{h}_l[k-m_l]\right\}\Big/\sum_J\left|\bar{h}_l[k]\right|^2 \tag{9}$$

where $\bar{h}_l[k]$ is pre-filtered output of $\hat{h}_l[k]$ to suppress the noise components larger than the maximum allowable Doppler frequency. With a given threshold η for all integer values of m_l , m_l^{NST} satisfying $w_l(m_l^{NST}) = \eta$, can be found in an experiencing channel [8]. The optimum tap size of the MA CEF can be represented as a function of m_l^{NST} as [8]

$$\hat{N}_{l,NST} = \left(\frac{2^4 m_{l,NST}^4 A_l(\upsilon + I_{oc}/I_{or})}{\zeta_c\gamma_c\varsigma_l^{\,4}}\cdot\frac{1+K_l}{K_l\cos^4\theta_l/9 + 1/\chi_l}\right)^{1/5} \tag{10}$$

where A_l is the ratio of the total signal to the l-th path signal power, υ is the orthogonality factor, I_{or} and I_{oc} respectively denote the power spectral density of the received signal from the desired base station and from other base stations, ζ_c is the spreading factor of the CPICH, γ_c denotes the CPICH E_c/I_{or}, ς_l is the normalized maximum Doppler frequency equal to $2\pi f_d m_l^{NST} T$, K_l and θ_l respectively are the Ricean factor and the incident angle of the l-th path signal, and χ_l is equal to 24 and 45 in the case of the classic and flat spectrum, respectively. Note that the quantity $2\pi f_d m_l^{NST} T$ can be calculated for a given channel condition. Since the optimum tap size can be represented as a function of the symbol interval of the correlator in (10), we can design an ACE using a small number of correlators as shown in Fig. 2, where the ACE of the l-th finger is depicted. The ACE consists of the channel parameter estimator (CPE) and channel estimation controller (CEC). The CPE classifies one of the predetermined channel conditions based on the output of the correlators. Each correlator in the CPE generates $w_l(m_{l,j}^{NST})$ for $m_{l,1}^{NST} < m_{l,2}^{NST} < \cdots < m_{l,G_l}^{NST}$. Using the property that $w_l(m_l^{NST})$ fast decreases as m_l^{NST} increases, the channel environment can be classified by comparing $w_l(m_{l,j}^{NST})$ with a threshold η. If the j-th correlator output of the l-th finger becomes less than η for the first time, i.e.,

$$w_l(m_{l,j}^{NST}) < \eta \text{ and } w_l(m_{l,i}^{NST}) \geq \eta,\ i = 1,2,...,j-1,\ j=1,2,\ldots,G_l \quad (11)$$

the CPE infers that the channel environment belongs to the channel condition-j. In this case, the tap size of the corresponding MA filter is set to $N_{l,j}$, $1 \leq j \leq G_l$. Note that N_{l,G_l+1} corresponds to the case when no correlator output is smaller than the threshold. This happens when the channel response too slowly varies. The parameters of the CPE as $\boldsymbol{m}_l$ and $\boldsymbol{N}_l$ are determined in the CEC considering possible values of the Ricean factor, path power, CPICH Ec/Ior and Ior/Ioc [8]. Thus, the channel condition can be estimated in real time without exact a priori information on the operating condition.

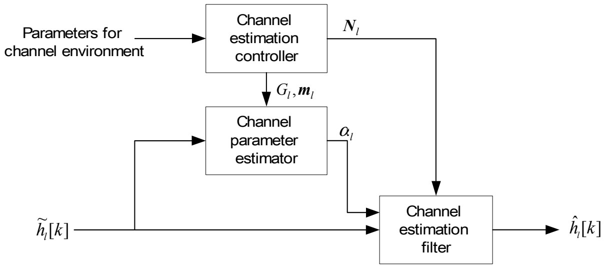
The SIR of the despread pilot symbol is reduced to one half compared to that of the non-STTD scheme since the transmit power is equally split into the two transmit antennas. However, the SIR of the pilot symbol becomes the same as that of the non-STTD scheme after (4) due to the two-symbol averaging effect. Thus, the ACE proposed for non-STTD scheme can be applied to the STTD scheme without much modification when $\tilde{h}_l^{CPi}[k]$ is employed as the input of the ACE. Instead, since it requires two symbols for (4), the tap size of the MA CEF and the correlator's interval of the CPE need to be decreased by one half. For example, assume that $m_{l,NST} = 40$ and $\hat{N}_{l,NST} = 20$ for the ACE in the non-STTD scheme. These values should be changed to $m_{l,ST} = 20$ and $\hat{N}_{l,ST} = 10$ in the STTD scheme. Considering the change of the relationship between $m_{l,ST}$ and $\hat{N}_{l,ST}$, the optimum tap size of the MA CEF in the STTD scheme is determined by

$$\hat{N}_{l,ST} = \left(\frac{2^3 m_{l,ST}^4 A_l(\upsilon + I_{oc}/I_{or})}{\zeta_c \gamma_c \varsigma_l^4} \cdot \frac{1+K_l}{K_l \cos^4\theta_l/9 + 1/\chi_l} \right)^{1/5}. \quad (12)$$

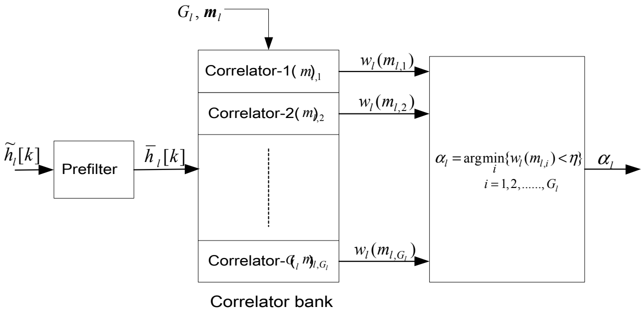
Note that the optimum tap size is decreased by a factor of $2^{1/5}$ when the STTD scheme is employed. Other procedures for the ACE design are the same as those in the non-STTD case [8].

IV. PERFORMANCE EVALUATION

In order to investigate the effect of channel estimation on the receiver performance in the STTD scheme, the receiver performance is evaluated when the proposed ACE is employed. The simulation condition is summarized in Table 1 and 2. Considering the margin for cell/multipath search, γ_c is usually set to -10 dB [9], but the case of γ_c = -13dB is also considered for performance comparison. Note that Ior/Ioc=9dB and Ior/Ioc=-3dB represent the case when the mobile is near the base station and near the cell boundary, respectively. We consider the use of a CEF with one slot averaging time interval in the fixed channel estimator (FCE) for performance comparison. The proposed ACE employs four correlators and five CEFs, i.e., the CEC determines such that $\boldsymbol{m}_l$ = {6, 13, 29, 63} and $\boldsymbol{N}_l$={3, 5, 10, 19, 29} when $0 \leq K_l < \propto$, $-90° \leq \theta_l \leq 90°$, $\gamma_c = -10\text{dB}$, $-5\text{dB} \leq I_{or}/I_{oc} \leq 10\text{dB}$, $1 \leq A_l \leq 10$ and $24 \leq \chi_l \leq 45$.



(a) Structure of the ACE for the *l*-th finger



(b) Structure of the channel parameter estimator

Fig. 2. Proposed ACE.

Table 1. Simulation condition.

	Parameter	Value
DPCH		144 Kbps
CPICH	Ec/Ior	-13dB, -10dB
Channel	Rayleigh	3GPP model (Case-1, Case-3)
Power control		Step size: 1dB, Control period: 1 slot (0.667ms)

Table 2. Propagation channel condition.

3GPP Case-1		3GPP Case-3	
Relative Delay [ns]	Average Power [dB]	Relative Delay [ns]	Average Power [dB]
0	0	0	0
976	-10	260	-3
		521	-6
		781	-9

Fig. 3, 4, 5 and 6 depict the receiver performance in terms of the required DPCH Ec/Ior for a BER of 10^{-3} when the proposed ACE is employed for channel estimation in both the STTD and non-STTD systems. Note that the required DPCH Ec/Ior for a BLER of 10^{-2} approximately results in a BER of 10^{-3}. It can be seen that the use of the proposed ACE can provide significant performance improvement over the use of the FCE in the STTD scheme compared to that in the non-STTD scheme. The ACE in the STTD scheme can provide performance improvement of up to 0.6 dB over the use of the FCE even when the CPICH power is relatively high (e.g., γ_c=-10dB). The performance improvement increases as the CPICH power decreases or the mobile moves toward the cell boundary. Since the MA CEF of the FCE is optimum at high Doppler frequency (i.e., about f_d = 250Hz), the DPCH Ec/Ior gain with the use of the ACE increases as f_d decreases.

Table 3 summarizes the Ec/Ior gain with the use of the proposed ACE over the FCE at f_d = 6Hz. Since the transmit power is equally divided into the two transmit antennas in the STTD scheme, the accuracy of channel estimation deteriorates. Thus, when γ_c is -10dB in the STTD scheme, the SIR of the CPICH is approximately the same as that when γ_c is -13dB in the non-STTD scheme. The receiver performance of the STTD scheme depends on the accuracy of the channel estimate much more than that of the non-STTD scheme due to the effect of crosstalk. As a result, it can be seen from Table 3 that the DPCH Ec/Ior gain in the STTD scheme with γ_c=-10dB is larger than that in the non-STTD scheme with γ_c=-13dB under the most of channel conditions.

Note that the transmit power of the CPICH is not controlled in response to the channel condition unlike the transmit power of the DPCH. The performance difference due to the use of the ACE and FCE in the non-STTD scheme is maximized when the channel has a small number of multipaths and low Ior/Ioc as in Fig. 4 since the accuracy of the channel estimate significantly affects the receiver performance. In this case, a large number of bit errors can occur when the signal suffers from deep fading since the instantaneous SIR of the CPICH pilot symbol is significantly decreased. This performance degradation decreases as the number of multipaths increases or Ior/Ioc increases because the multipath diversity effect is obtained or a sudden SIR fall-off occurs less frequently, respectively.

When an STTD scheme is employed, there exists at least two multipaths even when the channel has a single path between each transmit and receive antenna, making the receiver never experience flat fading in the STTD scheme. As a result, the effect of no power control of the CPICH in the STTD scheme is less important than that in the non-STTD scheme. In this case, the receiver performance becomes less affected by the accuracy of channel estimate compared to that in the non-STTD scheme. As a result, when the channel has a small number of multipaths and low Ior/Ioc, the use of the ACE in the STTD scheme does not provide significant gain over the non-STTD scheme as shown in Fig. 4.

V. CONCLUSIONS

In this paper, an ACE has been proposed for the WCDMA STTD system. The proposed ACE can significantly improve the receiver performance compared the fixed channel estimator. The performance improvement increases as the transmit power of the CPICH decreases or the mobile moves toward the cell boundary. In addition to performance improvement, the proposed ACE can also be used for other purposes since it can provide the information on the speed of channel variation. In the next generation mobile systems, it is likely to employ multiple antennas at the transmitter and/or the receiver. In this case, the accuracy of channel estimation becomes much important due to the effect of crosstalk and split transmit power, requiring the use of an efficient channel estimator to fully obtain the advantage of the use of multiple antennas.

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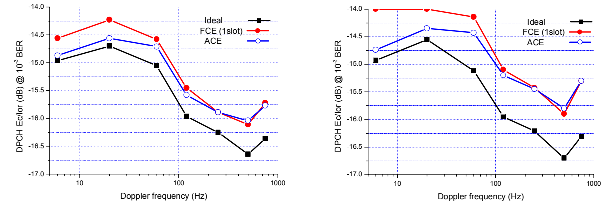
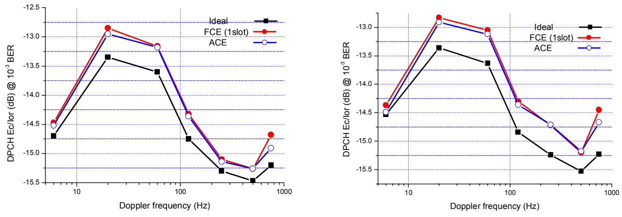
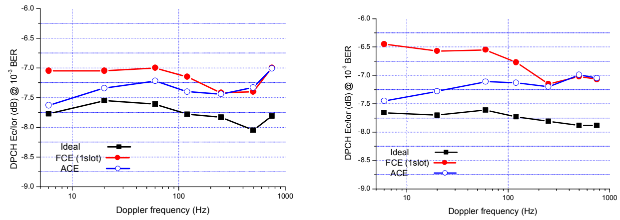


(a) STTD, γ_c =-10dB **(b) STTD, γ_c =-13dB**

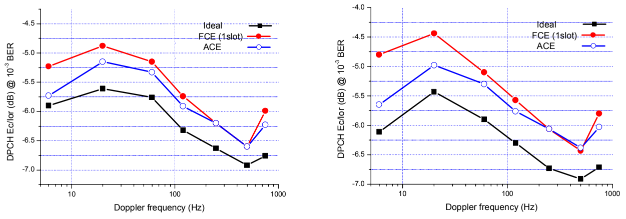


(c) Non-STTD, γ_c =-10dB **(d) Non-STTD, γ_c =-13dB**

Fig. 3. Required Ec/Ior (Case-1 and Ior/Ioc=9dB).

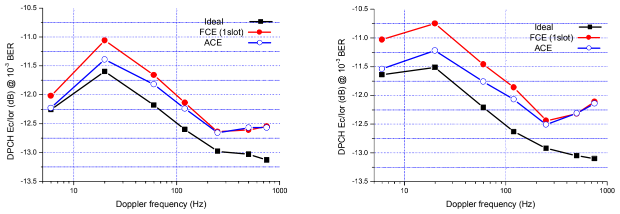


(a) STTD, γ_c =-10dB **(b) STTD, γ_c =-13dB**

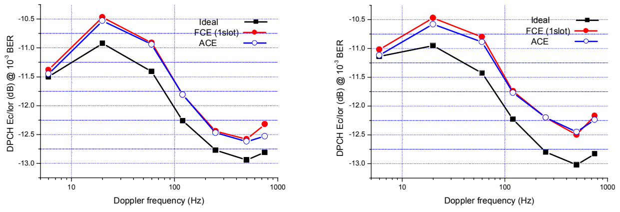


(c) Non-STTD, γ_c =-10dB **(d) Non-STTD, γ_c =-13dB**

Fig. 4. Required Ec/Ior (Case-1 and Ior/Ioc=-3dB).

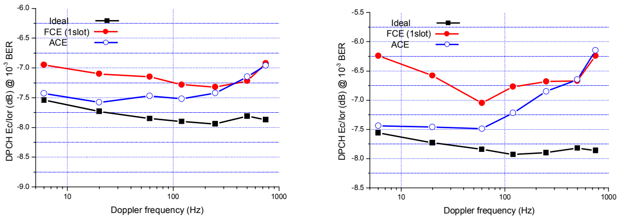


(a) STTD, γ_c =-10dB **(b) STTD, γ_c =-13dB**

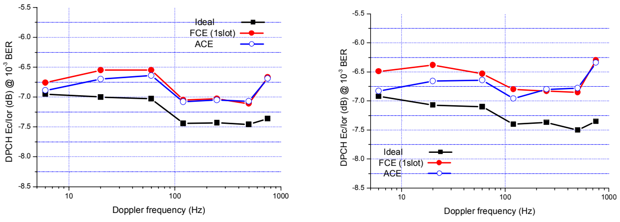


(c) Non-STTD, γ_c =-10dB **(d) Non-STTD, γ_c =-13dB**

Fig. 5. Required Ec/Ior (Case-3 and Ior/Ioc=9dB).



(a) STTD, γ_c =-10dB **(b) STTD, γ_c =-13dB**



(c) Non-STTD, γ_c =-10dB **(d) Non-STTD, γ_c =-13dB**

Fig. 6. Required Ec/Ior (Case-3 and Ior/Ioc=-3dB).

Table 3. Ec/Ior gain with the use of the ACE over the FCE at f_d = 6Hz.

		Ior/Ioc=9dB		Ior/Ioc=-3dB	
Channel	γ_c (dB)	No STTD (dB)	STTD (dB)	No STTD (dB)	STTD (dB)
Case-1	-10	< 0.1	0.2~0.3	0.5	0.6
	-13	0.1	0.6	0.8	1.0
Case-3	-10	< 0.1	0.2~0.3	0.2	0.5
	-13	0.2	0.5	0.3~0.4	1.2