# Transmission Characteristics of the 1.6Mbps / 4Mcps diffCDMA with Continuous Chip Shaping over 4 MHz Bandwidth Channel Occupation

# 占有帯域幅 4MHz チャネル上における連続チップ波形整形技術を適用した 1.6Mbps/4Mcps 差分 CDMA の伝送特性

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***Abstract:*** *From the frequency usage efficiency points of view, the novel diffCDMA with continuous chip shaping is proposed in this paper to achieve such high reliability as shown in free space propagation. Continuous chip shaping is facilitated by substituting smoothing function over adjacent chip fringes, in which the function touches current and next chips with 0th order contact and varies with the steepest gradient just at the center.*

*The diffCDMA is verified through simulations over such urban multi-ray Rayleigh fading environment as poor and narrow 4MHz bandwidth radio channel for 1.6Mbps transmission via 4Mcps to be error free by employing both continuous chip shaping in direct spectrum scrambling and BCH(63, 51) double error correction code.*

## 1. INTRODUCTION

It is important to improve high capacity and high-speed transmission of such CDMA featured with low power transmission, high reliability, and system flexibility. This CDMA is strongly eager to be developed as the third or so-called the forth generation CDMA in serving high speed links more than meg-bps among high speed running land vehicle through urban multi-ray propagation environment. As CDMA being well known as given by the direct product of primary modulating PSK and spread spectrum code, the CDMA transmission capacity is nominally defined by the PSK capacity multiplied by the spreading spectrum code number. And the frequency bandwidth of the CDMA is, therefore, defined by the convolution of the PSK and the spread spectrum code bandwidth.

Because of the Walsh function being adopted to span the code space in addition to the primary PSK modulation, the CDMA is seemed to be inherited robustness from both Walsh code and PSK genius during fading propagation.

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BER vs. CNR is shown in fig.1 for CDMA of employing QPSK as the primary modulation measured after propagation through such two-ray Rayleigh fading environment as 10 dB DUR with 0.5 micro-sec delay spread. As clearly shown in fig.1, the transmission quality is catastrophically degraded if bandwidth being restricted beyond the Nyquist chip limit, i.e. 1 Hz/chip, where it becomes to be remarkable in fading degradation through multi-ray propagation environment. On the other hand, the multi-ray fading robustness is also catastrophically improved in BER meanings by expanding frequency occupancy from the limit to doubled 2 Hz/chip and quadrupled 4Hz/chip. After expanding the CDMA transmission bandwidth beyond the doubled 2Hz/chip, BER is saturated to the characteristics for the doubled bandwidth.

Being depended on symbol speed, CDMA bandwidth is especially extended beyond the Nyquist limit by switching its chip value at every chip fringe. In fact, even if it reduces transmission capacity to the unique single PSK, the secondary modulation vanishes itself bandwidth to zero to match the PSK bandwidth in the case of every spectrum spreading code being set to be unique in every chip.

However, it is possible to reduce CDMA bandwidth close to the Nyquist chip limit with decreasing varying gradient by continuous shaping at every chip fringe.

If the continuous chip shaping spreading code is employed in the secondary modulation of CDMA over a given limited frequency bandwidth, this CDMA is expected to transmit high capacity in Fig.1 BER vs. Eb/No of CDMA, limited within Nyquist chip limit, doubled, or quardrupled bandwidth, through two ray Rayleigh fading environment of DUR=10 dB with 0.5 micro second delay spread

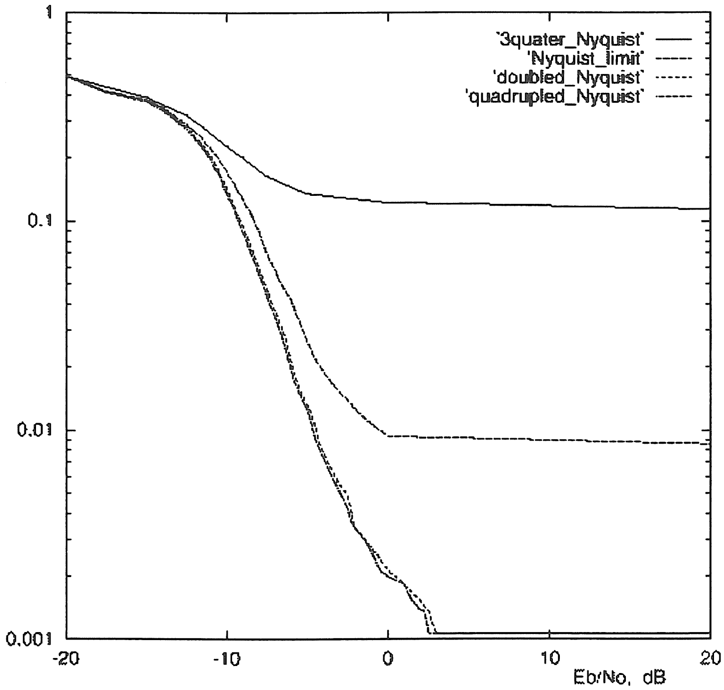


Fig.1 BER vs. Eb/No of CDMA, limited within Nyquist chip limit, doubled, or quardrupled bandwidth, through two ray Rayleigh fading environment of DUR=10 dB with 0.5 micro second delay spread

formation in such high reliability shown in fig.1 as the case of doubled bandwidth.

From the frequency usage efficiency points of view, the novel CDMA with continuous chip shaping is proposed in this paper to achieve such high reliability as shown in free space propagation.

## 2. CONTINUOUS CHIP SHAPING

### 2.1 Concept of Continuos Chip Shaping

Reducing CDMA bandwidth is not only effective for finite frequency resources but also promising solution for realizing such high reliability in given bandwidth as free space with base of prevention both from fading bandwidth expansion and spectrum distortion through multi-ray propagation. CDMA being defined by convolution of the primary PSK modulation and spreading code spectrum, reduction of the secondary modulation bandwidth is also discussed here as the important problem in addition to phase continuous PSK previously reported in VTC'98.

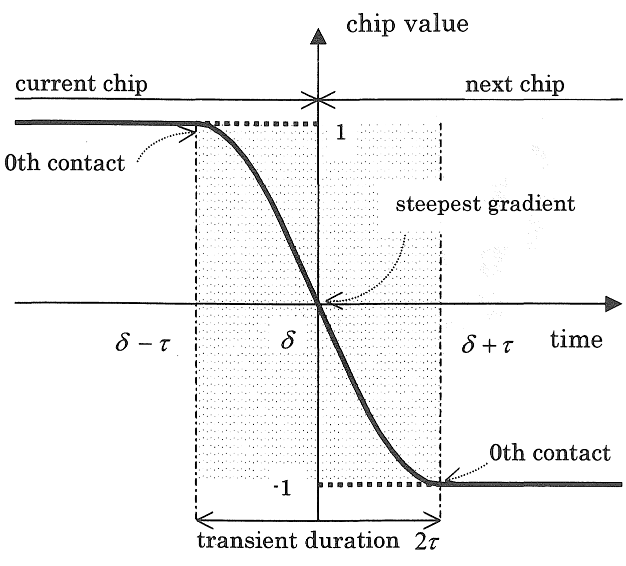


Fig.2 Illustrative time response of continuous chip

Typical code waves are illustrated in fig.2. As shown by dotted lines, the existing code wave is given by square topped signal to maintain a unique value within the whole duration of every chip to cause a jump at every fringe in proportion to the chip value difference between adjacent chips. If there exist no jumps around all chip fringes, CDMA modulated signal is obviously reduced frequency occupied bandwidth to arbitrary single PSK with victim of losing code space spanning ability.

It is, however, necessary to maintain individual code value at every chip center, but is sufficient to keep the same value in neighbors at the center in order to spread the spectrum of the primary modulating PSK along its individual code axis. It becomes to be possible to reduce the occupied bandwidth where the rapid variation is suppressed to yield smooth chip wave in the secondary modulation.

Continuous chip shaping is facilitated as shown in fig.2 as solid curve by substituting smoothing function over newly introducing transient duration spanning over adjacent chip fringes. The former is the current and the later is the next chip. The smoothing

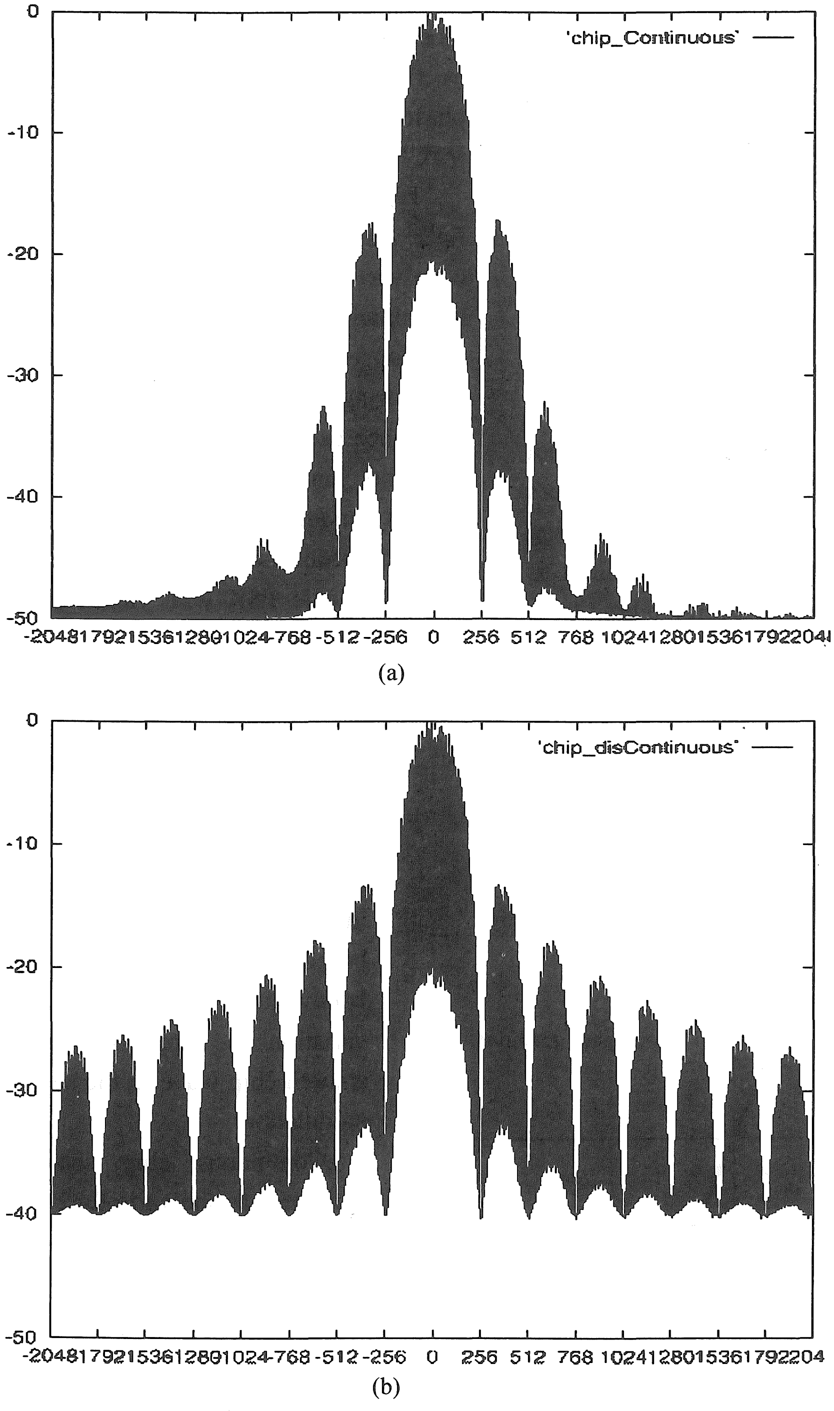


Fig.3 Frequency response comparison between continuous chip shaping (a) and discontinuous chip wave power spectrum (b)

function touches current and next chips at the front and tail ends with 0th order contact, respectively, and varies with the steepest gradient just at the center of the transient duration, i.e. at every fringe. For example, $w(t)$ given by following eq.1 is matched to the above chip smoothing function.

*here,*

$$w(t) = w_c + \Delta_w S(t) \quad (1)$$

*$w_c$ is the current chip value,*

$\Delta_w = w_c - w_n$,

*$w_n$ is the next chip*

*value,*

*S(t) is such a function given by*

$$S(t)=\begin{cases}\frac{1}{2}\left(1+\sin\frac{\pi t_m}{\tau}\right), & if\left|t_m\right|<\tau \\ 0, & else\end{cases} \qquad (2)$$

*where,*

$$t_m = t\big|_{\mathrm{mod}\delta},\ \delta \text{ is chip duration} \qquad (3)$$

## 2.2 Bandwidth Reduction Effect of Continuous Chip Shaping

Both lower and upper eight side lobes are shown in fig.3 as averaged instantaneous spectrum at plural symbols fringes. Figs.3a and 3b show the ensemble averaged spectrum of continuous chip shaping and chip discontinuous existing CDMA, respectively. If the transient duration, r, is set to be same to the chip duration, $\delta$, the side lobes are efficiently reduced by 3.69, 13.75, and 24.59 dB at the second, third, and forth harmonics. The side lobe reduction effect is observed by more than 30 dB at eighth harmonics.

It is adequate to the assumption to define all the spectrum except main lobe are interference rather than unnecessary component in communication system, because of the alias being leaked into inside from the outside and of remarkable distortion being occurred at band edges IF frequency bandwidth being limited. It requires so widely expanded bandwidth up to doubled bandwidth as shown in fig.3 in order to suppress the interference energy of the chip discontinuous CDMA to the equal level of the continuos chip shaping.

In paradoxically speaking for the existing CDMA which employs the chip discontinuous in the secondary modulation, the newly proposing continuous chip shaping CDMA is able to reduce the bandwidth to improve fading or frequency selective fading robustness by this frequency reduction effect in the multi-ray propagation environment.

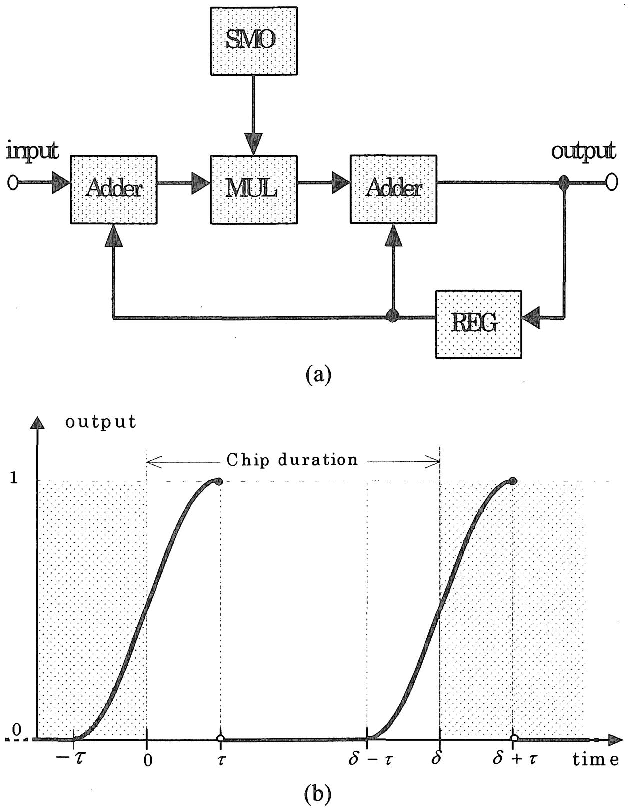


Fig.4 Block diagram of the continuous chip shaping circuit CS (a), and illustrative example of the smoothing function SMO (b)

### 2.3 Circuitry Configuration of Continuous Chip Shaping

The continuous chip shaping is realized by merely prefixing the chip continuity circuit shown in fig.4a to the secondary modulator of existing CDMA. In this figure, the smoothing function of eq.2 is stored in a ROM, which is marked with SMO, to read out by modulus $\delta$ time base as shown fig.4b. The register REG latches the output at the tail-end of the transient duration and keeps the holding value within the following chip duration, and the mark MUL or Adder means a multiplier or an adder, respectively.

## 3. CDMA WITH CONTINUOUS CHIP SHAPING

### 3.1 System Configuration

The system configuration of the CDMA with continuous chip shaping is illustrated in fig. 5 as significant functional block diagrams. As shown in fig. 5a for the continuous chip shaping CDMA transmission module, the circuitry skeleton is almost the same to the existing CDMA transmission module with exception of the continuous chip shaping CS and error correction coding circuits ECC.

The CS is interpolated between spectrum

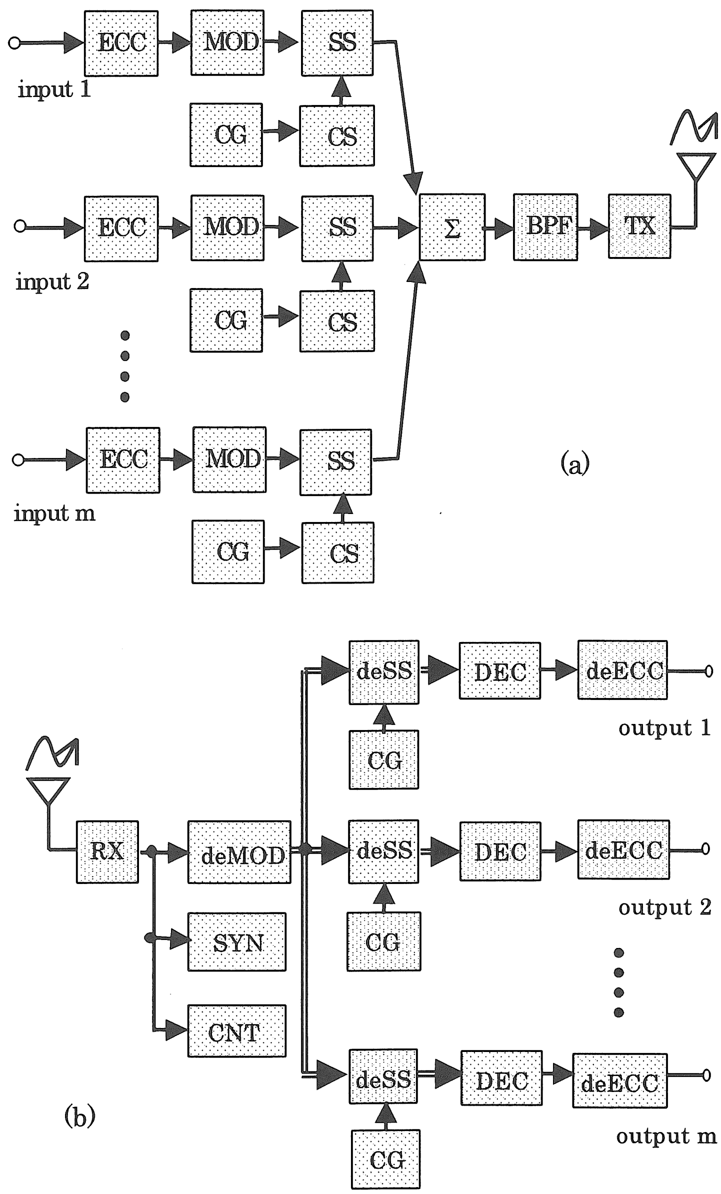


Fig.5 Block diagram of continuous chip shaping CDMA, m speech channel transmission module (a), and m' speech channel receiving module (b)

spreading code generator CG and the secondary modulator SS for every transmission channel. The ECC is pre-fixed to the primary modulator to yield double error correction BCH (63,51) code along to individual bit string, if bit grouping scheme S of fig.6 being adopted. That is, two ECC will be employed for each spectrum spreading code if the primary modulation is performed as QPSK. Here, mark MOD, $\Sigma$, or BPF means the primary PSK modulator, adder or band-pass filter, respectively. And, the total number of transmission channels is m.

Circuit topology of the receiving module of the continuous chip shaping CDMA is almost the same as shown in fig. 5b to the existing CDMA receiving module. Mark RX, SYN, CNT, deSS, CG, or DEC means the receiving unit, synchronization detector, control signal recovery circuit, the primary demodulator, de-spread spectrum circuit, spectrum de-spreading code generator, or decision circuit, respectively. The deECC is attached to the tail end of the decision circuit DEC to correct the double errors within 63 bits block along the individual bit string. Here, the total receiving speech channel is m'.

In general speaking, the transmission channel number m is required to be larger than receiving speech channel m', even if the maximum transmission capacity is achieved in the case of m being equal to m'. In fact, control and synchronization carry through these redundant m-m' channels both in cdmaOne and WcdmaOne, or carry by redundant time slot shared by time

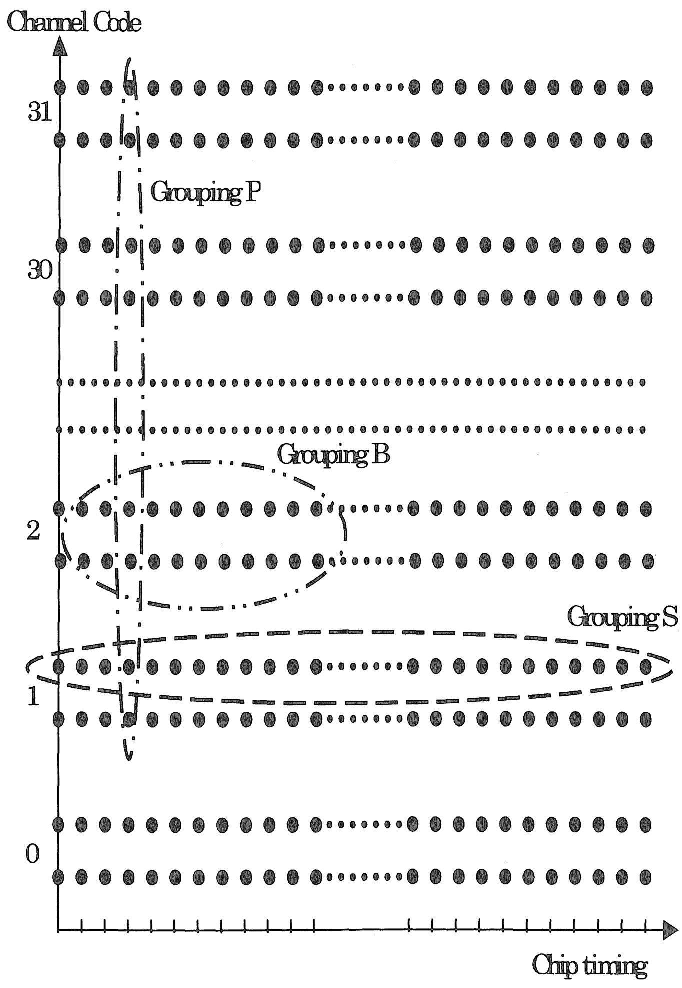


Fig.6 ECC bit map comparison among typical grouping schemes on the plane spanned by time and code

compression to yield equivalent redundancy both on time and frequency space in Wide CDMA, in which m is at a glance nearly equal to m'.

Fortunately, a novel CDMA system, named by diffCDMA, has been already reported in previous VTC98 to perfectly exclude redundancy of the channel or time slot. This diffCDMA is categorized into an enhanced system of WcdmaOne from transmission and signaling points of views, and is also characterized on such technologies as differential coding and post de-spreading spectrum analytic receiving to be verified by 2Mbps transmission ability within 5MHz bandwidth even through multi-ray fading environment.

### 3.2 Signal Scheme

The maximum transmission capacity of diffCDMA with ECC is achieved by simultaneously employing all of the 32 speech channels of 32 kHz symbol rate QPSK as the primary modulation. So long as the diffCDMA being facilitated in CDMA with phase continuous QPSK to exclude any redundancy, the spread spectrum code length is enough to be 32, because of transmission m being equal to receiving channel number m', and of receiving channel number m' being sufficiently 32.

Figure 6 shows 3 kind bit mapping schemes where ECC being employed. Grouping S means the case of 12 redundant bits of BCH ECC being interpolated after every 51 information bits. Individual two BCH (63,51) block codes are simultaneously adopted into every spectrum spreading code along time bases. Grouping B is rather simple to adopt BCH with somewhat loss in transmission efficient, where 12 redundant bits are interpolated after every 50 information bits. Every shortened BCH (62,50) is employed for every DS/SS code along to time axis. The resulting grouping P is performed along to DS/SS code axis. That is, shortened BCH (62,50) is also convenient to introduce into diffCDMA, because one of 32 code channels being devoted to so-called controlling signal.

The maximal transmission capacity is

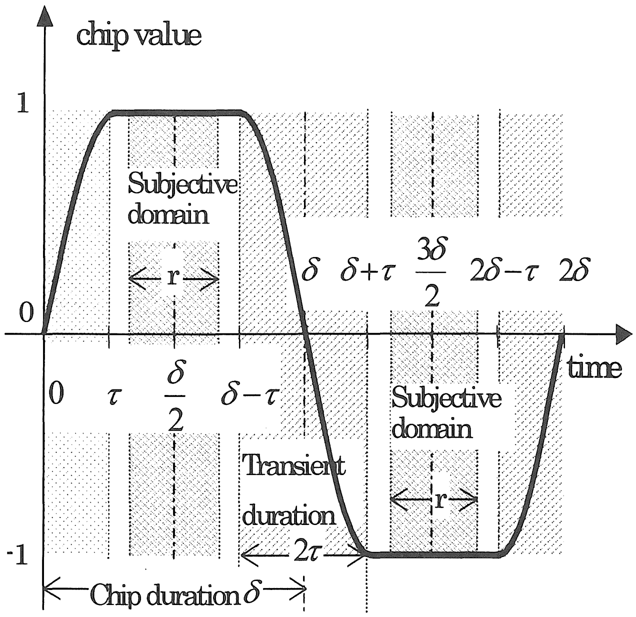


Fig.7 Relationship between subjective time domain, r, and transient duration, $2\tau$, in the continuous chip shaped waves

given by 1.66Mbps where grouping S being adopt in the prosing diffCDMA as discussed in the followings. Where the bandwidth is restricted within 4 MHz over transmission channel, and chip rate is 4Mcps if 4 fundamental segments being employed in every symbol.

## 4. SIMULATION RESULTS

### 4.1 Continuous Chip Shaping Effect

Excessive bandwidth expansion is caused in the secondary modulation of DS/SS from the chip discontinuity at every chip fringe. The continuos chip shaping is able to reduce this excessive frequency expansion as discussed in the above with the victim of increasing the transient time domain for varying the chip value. The subjective domain for detecting chip value is consequently reduced as shown in fig.7. That is, the longer the transient duration being set to decrease the frequency bandwidth, the shorter the subjective domain being restricted.

Figure 8 shows the relation between BER vs. subjective domain at receiving level of CNR=-5dB, in which the horizontal axis means subjective domain ratio, r/$\delta$. Here, $\delta$ is chip length, and r is half of the transient duration at tail and front chip ends.

While the subjective domain ratio changes from zero to unity, the BER shows a trade off as showing continuous chip shaping effect at around r=3/8 like a priori expectation. If the transient duration is expanded to whole chip duration, the subjective domain is vanished. On the other hand, if no subjective domain is employed, the BER is degraded from the excessive frequency expansion during the secondary modulation.

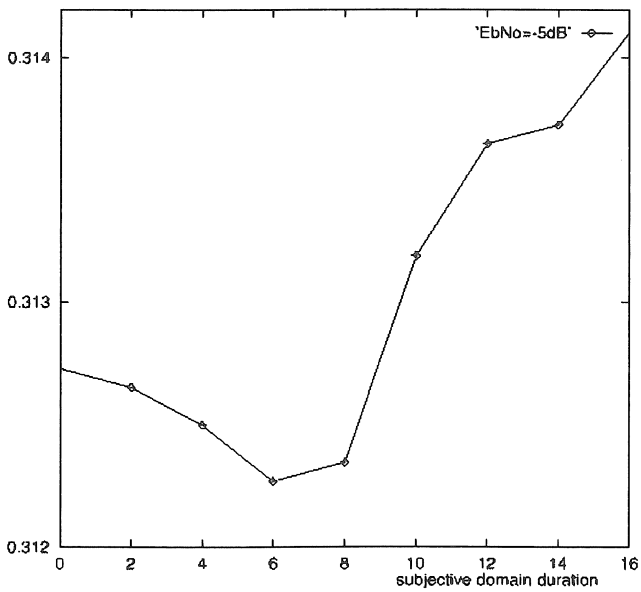


Fig.8 ECC bit map comparison among typical grouping schemes on the plane spanned by time and code

### 4.2 BER Improvement Effect

The BER improvement effect of continuous chip shaping diffCDMA is verified as shown in fig.9 through computer simulation. Simulations are performed under following conditions. All 1.66 Mbps signals are carried by 4.096Mcps on 4.096MHz frequency bandwidth at the 2GHz domain from 300km/h bullet trains passing through such urban environment as two-ray Rayleigh fading of DUR= 10dB with 0.5 micro second delay spread. The all codes of 32length Walsh sequence are employed to span 32 code space. The BCH (63,51) ECC is employed to correct double errors within 63bit block as grouping S along individual bit string of 32k symbol/second. The transient duration ratio, r/$\delta$ is set to be a quarter.

Therefore, $f_dT$ and Doppler shift are set to be 0.015 and 0.3 ppm in the all simulations, respectively. Such compensations as RAKE receiving and power control are easily facilitated in the diffCDMA, which are excluded from simulations to make the continuous chip shaping effect clear. CNR are measured on the maximum transmission capacity of 1.66Mbps when all the 32 code being employed.

Simulation results are shown in fig.9 to improve two-ray Rayleigh fading robustness by vanishing any bit errors via employing continuous chip shaping, phase continuous QPSK, and BCH (63, 51) ECC at CNR=10.0dB if communications being carried from 10 km/h walking pedestrians. BER is null at CNR=15.2dB if from 100 km/h running vehicles, or at CNR=17.5 dB if from 1,000 km/h flying aircraft through the urban environment mentioned in the above. In discussing diffCDMA, 64 bits are simultaneously carried through 32 code channels, BER is observed to be zero in Eb/No meanings at -8.0dB for pedestrian, at 2.8dB for vehicles, or 0.5dB for aircraft after compensation by 10log64, respectively.

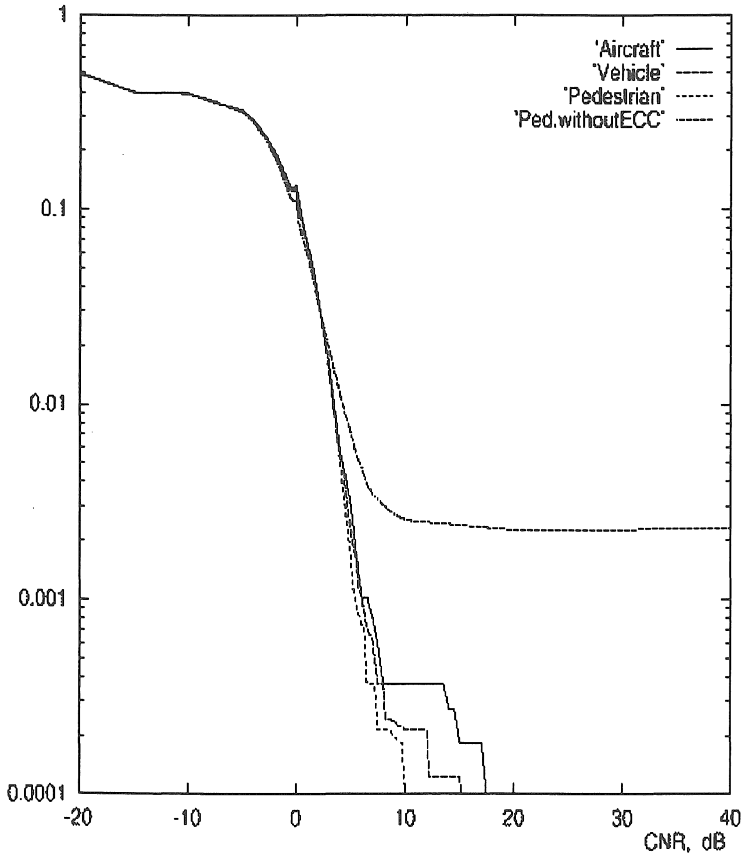


Fig.9 BER vs. CNR response comparison among aircraft, vehicle, and pedestrian communication of double error correction 1.6Mbps/ 4.096MHz diffCDMA through two ray Rayleigh environment with 0.5 micro second delay spread

## CONCLUSION

The newly proposing diffCDMA with continuous chip shaping has been successfully discussed in this paper with emphasis both on realizing bullet train and aircraft 1.6 Mbps CDMA communication system. The diffCDMA is able to put high capacity and high speed CDMA communication on the developing stages with employing such novel techniques as continuous chip shaping, phase continuous primary modulations, and BCH double error correction.

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（受付 平成12年3月18日）