

# Optimum Detection of CDMA

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## ABSTRACT

Here we describe methods of detection of Code Division Multiple Access signal against Gaussian noise. We transmit differentially encoded signal and in the receiver, we do signal processing to reduce noise injected by the mixer or RF front end. Similar noise reduction method is also proposed for carrier recovery and hence the demodulator works. The detector is followed by BCH decoding which is syndrome based.

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## 1.0 INTRODUCTION

Direct sequence code division multiple access is currently used in data communication IEEE standard 802.11 and for voice band by Qualcomm. It has several advantages like lower noise than FSK, higher cell capacity and soft hand off. Qualcomm uses orthogonal code to spread the data sequence at the transmitter and despread it at the receiver. The optimum detection of synchronous and asynchronous CDMA with PRN sequence was first proposed in reference [1]. Here we optimize the signal to noise ratio in analog domain. The decoding of BCH code which is used to protect against fading is different. Also we do not use any analog to digital conversion or any sampling of signal avoiding injection of noise. There is no exponential increase in calculation like in maximum likelihood method [2].

There was a lot of research activity to use MUD detector in digital domain to reduce the crosscorrelation from different users [3]. A method is used here which could be inspired by the reference [4]. Near-far problem, once was the focus of research activity, is resolved here using separate demodulator for each user in asynchronous transmission of uplink. Adaptive detector is avoided here as its power consumption is high. The demodulator described here is most suitable for low power application. The detector was proposed in reference [5][6] for GPS receiver and radar detector, except we propose a coding by BCH code against noise and fading [7]. Section I introduces the subject and section II describes the basic principle followed in this paper to achieve lowest noise possible. Section III explains the requirement of carrier and data clock recovery. The next section explains the signal path in the demodulator. This is followed by the section on Asynchronous CDMA. We conclude the paper in the following section.

## 2.0 PRINCIPLE OF OPTIMUM DETECTION

Here we propose few demodulators for synchronous and asynchronous CDMA with Walsh-Hadamard Code or Pseudo random sequence as the spreading code. We use same open loop gain for carrier recovery and the demodulator in analog domain, so that the performance is balanced. Moreover, we do not use sampling and use comparator as detector followed by a syndrome decoder for BCH code in digital domain. As we avoid using analog to digital conversion or MUD detector we reduce noise injection and power consumption. We have found that an integrator for a high pass filtered signal reduces the noise variance [5]. To get that in synchronous CDMA, we transmit  $\sum_{n=1}^N (C_{n,i+1} - C_{n,i})$ , where  $C_{n,i}$  is the chip sequence coded with data bit for  $n^{\text{th}}$  user and  $i^{\text{th}}$  time. As it is synchronized in chip as well as in data bit, it is linear and we decode it by individual chip sequence at the hand set as it is downlink. When we correlate by the chip sequence, we do not use integrate and dump circuit, but a simple integrator. Thus we get double integration. The variance will be

$$\sigma^2 = R(0) = 2 \int_0^{\infty} 1/w^4 dw$$

assuming a White (AWGN) noise spectrum which is flat. If we block the dc, then we get reduced noise variance. Similarly, we can use the method of triple integration, which uses double difference  $[C_{i+2} - 2C_{i+1} + C_i]$ . This may produce a transmission which is 4 times than normal amplitude. Here, we should get the increased power of transmission for noise reduction in integration. Hence we do not consider this case any further. We use Manchester coded data, which when integrated comes to zero all the time. We compare it with zero voltage and latch it at a delay flip flop at the data clock, avoiding a AtoD. Then in digital domain we do decoding of BCH code.

### 3.0 CARRIER AND DATA CLOCK RECOVERY

The carrier recovery PLL has a mathematical form  $(s+a)/[(s+b)s+k]$  which is stable with second order response to a step jump in phase. The root locus could be found in [8], from which we can find the maximum gain  $K$  for optimum second order response. The carrier recovery and data clock recovery block diagram is shown in Figure 1 [9].

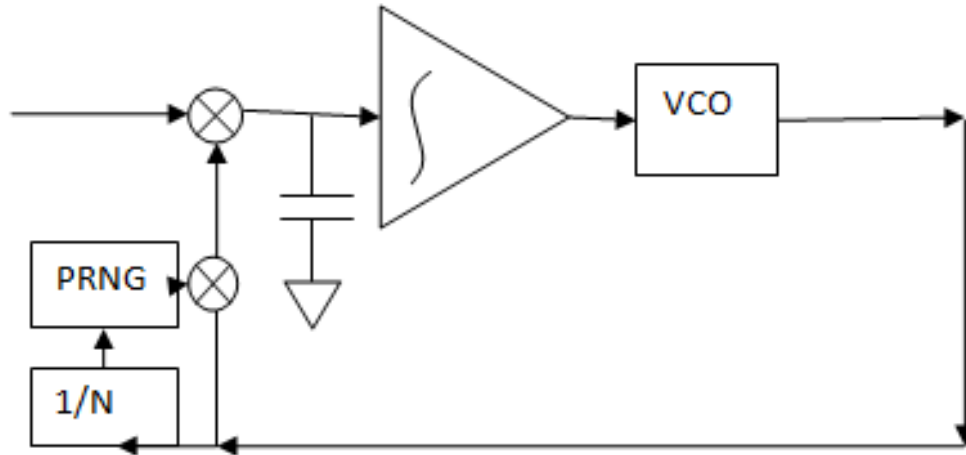


Figure 1. Carrier recovery and demodulation of synchronous CDMA

The phase locked loop can be explained as: the mixer has one input  $A(t)\cos(\omega_c t) + \text{noise}$  like data, where  $A(t)$  could be sinusoidal waveform. The voltage controlled oscillator generates  $\sin(\omega_c t)$  term which is used to frequency divide to generate  $A(t)$  and they are mixed. This signal is used in the main mixer. So the output of the mixer is  $\sin(\omega_c t) \cdot \cos(\omega_c t) + \text{noise} \cdot \sin(\omega_c t)$  which is double integrated to VCO input.

### 4.0 DEMODULATOR

Now we find the signal after integration and energy associated with it. The transmitted signal is PAM or  $\sum_{n=1}^N (C_{n,i+1} - C_{n,i})$  i.e. summation of differential PAM modulated by carrier plus a tone for data clock and carrier recovery. If for an user the data to be transmitted is  $\{1, -1, -1, 1, 1, -1\}$ , then after encoding it will be  $\{1, -1, -1, 1, -1, 1, 1, -1, 1, 1, -1, -1, -1, 1, 1, -1, 1, -1, -1, 1, -1, -1, 1, 1, 1, -1, -1, 1, -1, 1, 1, -1, 1, 1, -1, 1, -1, -1, -1, \dots\}$  and  $\{1, -2, 0, 2, -2, 2, 0, -2, 2, 0, -2, 2, -2, 0, 2, 0, 0, 2, 0, -2, 2, -2, 0, 2, -2, 0, 2, -2, 2, 0, -2, 2, 0, -2, 2, -2, 0, \dots\}$ . If we integrate it, we do not get the sequence coded with PRN sequence but a triangular shaped signal which we correlate with the PRN  $\{1, -1, -1, 1, -1, 1, 1\}$ .

We can have the optimum detection as explained in reference [6]. We will have maximum capacity of  $N$ , where  $N$  is the length of chip sequence. It has subtractor to nullify the crosscorrelation term. This increases the noise. This is shown in Figure 2. If  $X_i$ s are the correlators' output then that should be multiplied by a matrix to get the exact output which is fed to the detector. For chip length of 7 and correlator noise  $N$  the output can be given as,

$$Y = \begin{bmatrix} 1 & -1/7 & \dots & -1/7 \\ -1/7 & 1 & \dots & -1/7 \\ \dots & \dots & \dots & \dots \\ -1/7 & -1/7 & \dots & 1 \end{bmatrix}^{-1} [X + N]$$

We can have a design with a code  $[C_1 - C_1(t-T_c)]$  with no cross correlation which lowers noise variance.

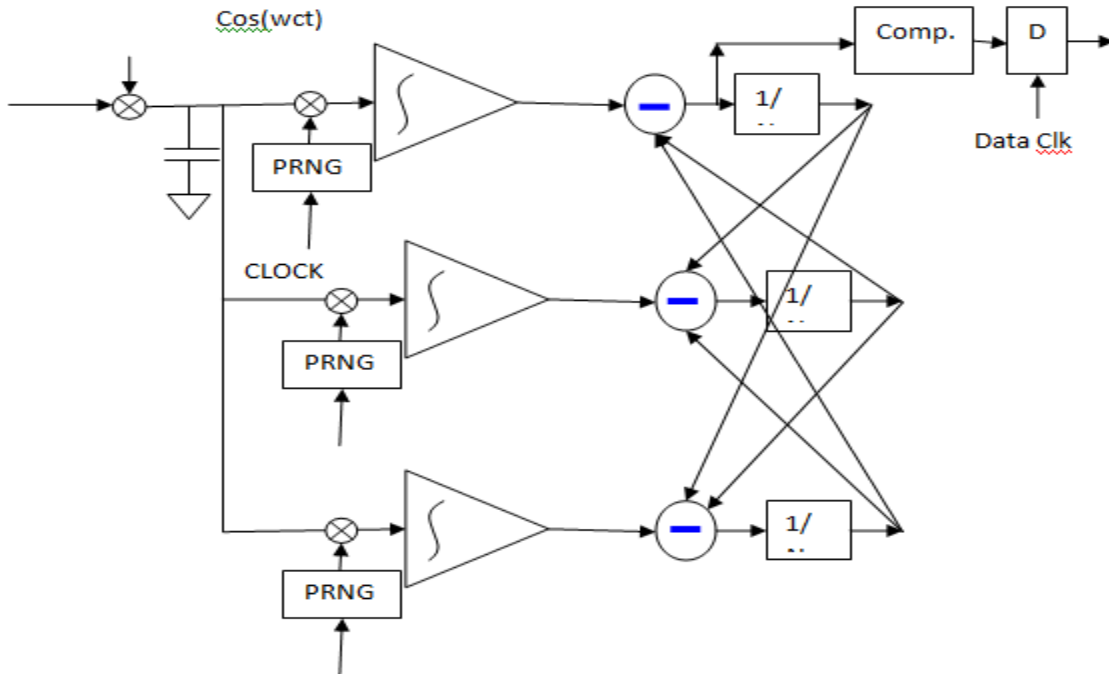


Figure 2. Detection of DS-CDMA with analog DFC

### 5.0 ASYNCHRONOUS CDMA

Like synchronous CDMA, we transmit the CDMA signal along with a tone. The zero cross over signifies the beginning of data. The tone frequency is  $f_0/n$  for different users modulated by  $f_c$ . We recover the tone signal using PLL and get the carrier as well. At the base station we calculate the time delay and put equal time in synchronous transmission. In the hand set we correct the delay in a closed loop i.e. delay locked loop.

The delay of the user to the data clock tone is converted into a voltage and integrated to use as the control voltage. The control voltage delays or take ahead the outgoing asynchronous uplink bit in delay locked loop. When the voltage is zero, it signifies that synchronization has occurred. The integrator maintains the voltage required for lock. The schematic diagram is shown in Figure 3.

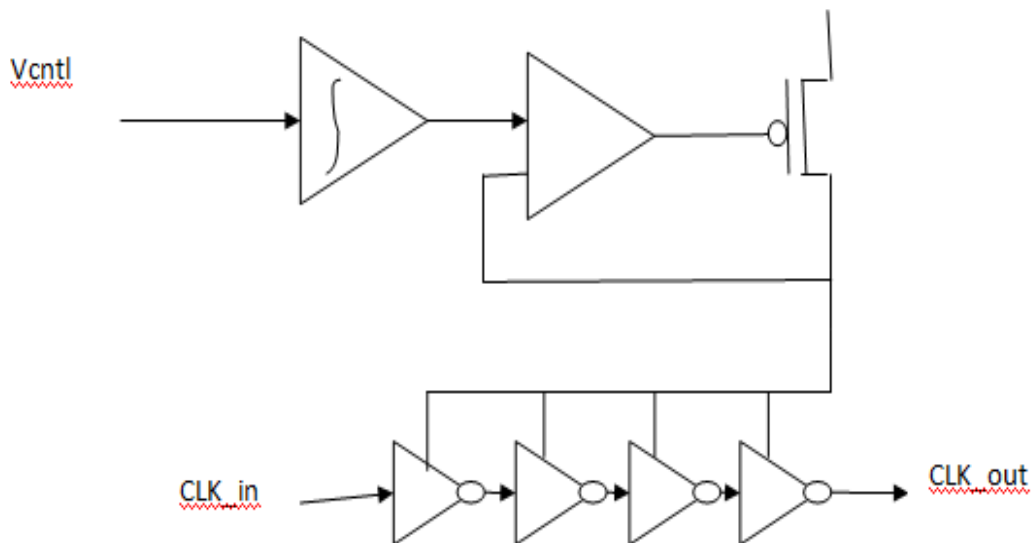


Figure 3. Variable delay in clock

The mathematical formulation is done in Figure 4 where we find a loop with a delay and loop filter. The transfer function is multiplication of two transfer function of PLL loop. The transfer function is given by  $(s+a)/(s^2+bs+c)$  for single PLL. Hence the closed loop with delay in transmission will be of 4<sup>th</sup> order. The root locus for stability can be found in reference [8,9]. The problem is to find the maximum delay possible for which the closed loop is stable. The actual implementation is shown in Figure 5, for which a PLL is used to find the delay. This is used during synchronization for stationary handset.

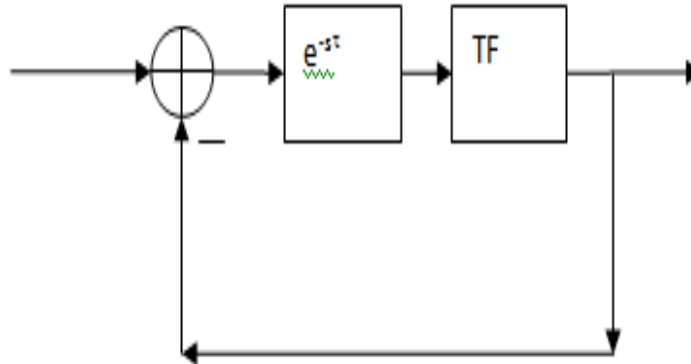


Figure 4. Stability analysis to get maximum allowable time delay between mobile and basestation

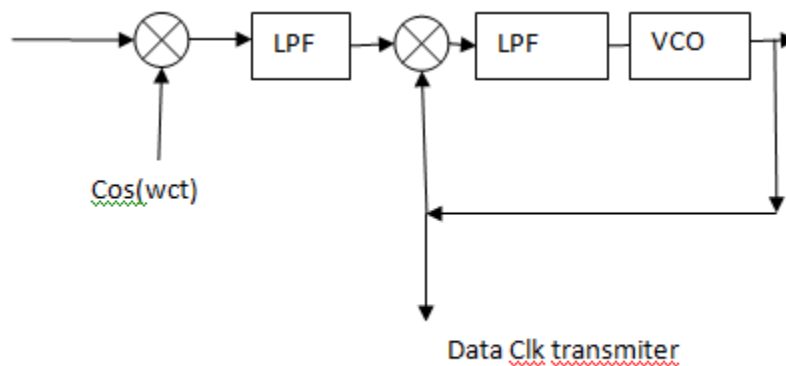


Figure 5. Data clock generation for the asynchronous data to be synchronized at base station.

The demodulator is similar to synchronous CDMA. Here, there is a loop for synchronization which is required as we are transmitting the same PRN code for all N user with a rotation and in differential mode. Where more capacity is required we use analog DFC [10] to cancel the crosscorrelation. Otherwise we use the differential code i.e.  $[C_1 - C_1(t - T_c)]$ . As it has no subtraction it has less noise and no cross correlation from other user.

We can also use Walsh-Hadamard code, which has no crosscorrelation when it is synchronized, except, PRN codes are better to get and track the distance of handset.

### CONCLUSION

It is necessary to understand that detection will depend on the presence of noise at the detector (here it is a comparator). We use analog technique to reduce the noise and to enhance that effect we differentially code the Manchester coded data. Further enhancement is done by changing the code making analog circuit as simple as possible. The uplink transmission is synchronized at base station and the mathematics is discussed here. A probable solution is also given here. This allows higher capacity for uplink CDMA transmission.

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