REPORT ON

Design, Model Implementation, and Evaluations of the cdma2000 Reverse-link

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Abstract

cdma2000 service is the evolutionary enhancement of the IS-95A, and IS-95B standards to support 3G services defined by the International Telecommunications Union (ITU). cdma2000 comes in two phases. The first is cdma2000 1XRTT that operates within a 1.25 MHz bandwidth and thus, can be used in existing CDMA channels as it uses the same bandwidth. The second phase is 3XRTT, which requires a 5MHz spectrum commitment for both the forward and reverse links. The 1X and 3X refer to the number of 1.25 MHz wide radio carrier channels used, and RTT refers to radio-transmission technology.

This report presents a design and implementation procedure for a simulation model of the cdma2000 reverse link. The reverse link has been implemented at the National Institute of Standards and Technology (NIST), using Signal Processing WorkSystem (SPW) software simulation tools developed by Cadence Design System Inc. The model has been developed in a generic manner that includes all the reverse link six radio configurations and their corresponding data rates according to the IS-2000 specifications. For performance evaluations and measurements, a sophisticated link budget has also been implemented in accordance with IS-2000 specifications. The report, after providing a tutorial review of the reverse link characteristics and its SPW implementation, presents the results of our measurement and performance evaluations when transmitted over imt2000 fading channels.

1. Introduction

The reverse link model was implemented using a simulation tool called the SPW (Signal Processing Worksystem[1]). The report describes the requirements and SPW implementations for the mobile station CDMA (Code Division Multiple Access) operation on the reverse link of a cdma2000 system [2]. The cdma2000 requirements, specified in [1,2], define the data rates, channel structures, channel encoding, spreading algorithms, baseband filtering, modulation parameters, transmission modeling, and channel decoding. To perform measurements for

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[1] Signal Processing Work System and SPW are registered trademarks of Cadence Design Systems, Inc. The SPW is identified in this report to foster understanding. Such identification does not imply recommendation or endorsement by the National Institute of Standards and Technology, nor does it imply that this product is necessarily the best available for the purpose.

[2] The cdma2000 system is based on the Telecommunications Industry Association (TIA) standard which is also known as IS2000.

evaluating the performance of the cdma2000 reverse link, a link budget with the TIA/EIA IS-2000 [2] specifications has been developed. The link budget emphasizes the calculation of output power for the reverse channels using open loop power estimation. Finally, the report discusses the measurement criteria in which the results, in terms of Frame Error Rate (FER) and Bit Error Rate (BER), are obtained.

2. Reverse CDMA Channel Signals

The reverse link of the cdma2000 system is the link from the mobile station to the base station. The channels transmitted on the reverse link are as follows:

> Access Channel
> Enhanced Access Channel
> Reverse Common Control Channel
> Reverse Pilot Channel (*R-PCH*)
> Reverse Dedicated Control Channel (*R-DCCH*)
> Reverse Fundamental Channel (*R-FCH*)
> Reverse Supplemental Channels (*R-SCH*)
> Reverse Supplemental Code Channels (*R-SCCH*)

The first three channels are common channels used for the communication of ISO Layer 3 and MAC (Medium Access Control) messages from the mobile station to the base station [4]. The focus in this report is on the remaining five channel types, which are allocated on a per user basis. These five channels i.e. *R-PCH, R-DCCH, R-FCH, R-SCH* and *R-SCCH* are the signals transmitted on the Reverse Traffic Channel.

Signals transmitted on the Reverse Traffic Channel are specified by six different Radio Configurations [1]. For the reverse traffic operation in Radio Configurations 1 and 2, a single *R-FCH* and up to seven *R-SCCH*'s are utilized. These two Radio Configurations are designed for backward compatibility with the existing IS-95 CDMA system. As our main concern is the cdma2000 system, Radio Configurations 1 and 2 will not be discussed in our evaluations.

For the reverse traffic operation in Radio Configurations 3 through 6, an *R-PCH* is required together with up to one *R-DCCH*, up to one *R-FCH*, and up to two *R-SCH*'s. The following sections describe the channel structures, modulation parameters and other characteristics of these four Reverse Traffic Channels.

2.1 Reverse Fundamental and Supplemental Channels

User voice and data traffic are transported across the reverse link on the *R-FCH* and *R-SCH*'s. As the basic structures of *R-FCH* and *R-SCH*'s are similar, they are discussed together and differences are noted. A single *R-FCH* per mobile is permitted, providing variable data rates up to 9.6 kbps in Radio Configurations 3 and 5, or 14.4 kbps in Radio Configurations 4 and 6. The use of *R-SCH*'s offers two additional higher rate channels with fixed rate transmissions.

Table 2.1 lists the spreading rates, ratesets, and possible data rates for different Radio Configurations. The two spreading rates 1 and 3 correspond to chip rates of 1.2288 and 3.6864 Mcps respectively. Rateset defines a particular set of data rates. The data rates in Radio Configurations 3 and 5 are included in rateset 1, while the data rates in Radio Configurations 4 and 6 are in included in rateset 2. The lowest four data rates (e.g. 1500, 2700, 4800, 9600 bps for rateset 1) in each Radio Configuration are the permitted rates for the *R-FCH*, while all of the rates are available for the *R-SCH*'s.

Table 2.1: Radio Configuration characteristics for the Reverse Fundamental and Supplemental Channels

Radio Configuration	Associated Spreading Rate	Rateset	Data rates (in bps)
3	1	1	1500, 2700, 4800, 9600, 19200, 38400, 76800, 153600 & 307200
4	1	2	1800, 3600, 7200, 14400, 28800, 57600, 115200 & 230400
5	3	1	1500, 2700, 4800, 9600, 19200, 38400, 76800, 153600, 307200 & 614400
6	3	2	1800, 3600, 7200, 14400, 28800, 57600, 115200, 230400, 460800 & 1036800

2.1.1 Framing and Encoding

Data is processed in 5 or 20 ms frames. The 5ms-frame option will not be discussed in this report. The data rate on the *R-FCH* can be fixed or variable during transmission. The variable rates are changed on a frame by frame basis. For the *R-SCH*'s, the data rate remains constant during transmission. Figure 2.1 shows the framing and encoding procedures for the Reverse Fundamental and Supplemental Channels. The details of each block will be discussed in subsequent sections.

Information Bits → Add Reserved/Erasure Bit → Add Frame Quality Indicator → Add Encoder Tail Bits → Convolutional Encoder → Symbol Repetition → Symbol Puncture → Block Interleaver → **Modulation symbols**

Figure 2.1: Reverse Fundamental and Supplemental Channel Structure
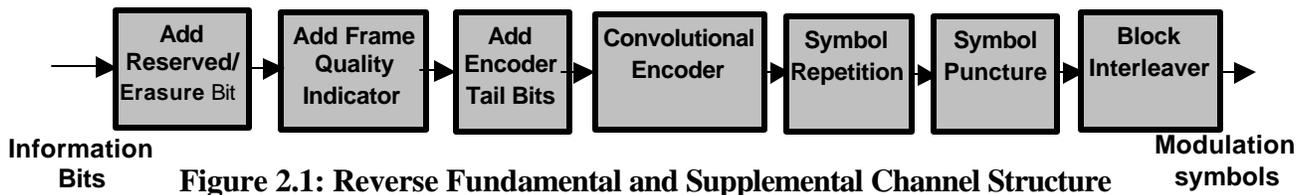
The first three blocks append bits to a frame of information bits. A single reserved or erasure indicator bit may be placed prior to the information bits. The information bits are followed by the frame quality indicator (CRC bits) and eight encoder tail bits. The CRC (Cyclic Redundancy Code) bits are used as an error detection mechanism at the receiver. Encoder tail bits are used to

terminate the convolutional code. Figures 2.2 and 2.3 illustrate the order of the bits which form the 20ms frame structure for the *R-FCH* and the *R-SCH,* respectively. The bit allocations for the reserved bit, information bits, CRC, and encoder tail bits are summarized in Tables 2.2 and 2.3 for the *R-FCH* and the *R-SCH,* respectively. Data rates are calculated by the total number of bits in a 20ms frame.

R/E	Information Bits	F	T

R/E – Reserved/Erasure Indicator Bit

F – Frame Quality Indicator (CRC)

T– Encoder Tail Bits

Figure 2.2: Reverse Fundamental Channel frame structure

R	Information Bits	F	R/T
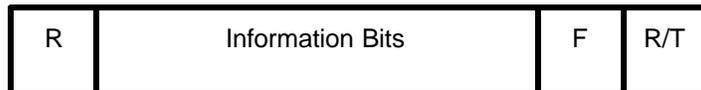
R – Reserved Bit

F – Frame Quality Indicator (CRC)

R/T– Reserved/Encoder Tail Bits

Figure 2.3: Reverse Supplemental Channel frame structure

After the framing procedures, the convolutional or turbo encoder encodes its input at a higher rate for error protection purposes. Symbol repetition and symbol puncturing further adjust the transmitted bit rate to the desired chip rate (1.2288 or 3.6484 Mcps) specified by the Radio Configurations. The symbols are then scrambled in the block interleaver for protection against bursty errors. The output symbols from the block interleaver are used for the modulation process. The parameters associated with each of the blocks in Figure 2.1 for Radio Configurations 3 through 6 are given in Figures 2.4 through 2.7 respectively.

Table 2.2: Reverse Fundamental Channel frame summary

Radio Config.	Data Rate(bps)	Number of Bits per Frame				
		Total	Reserved	Information	CRC	Tail Bits
1	9600	192	0	172	12	8
	4800	96	0	80	8	8
	2400	48	0	40	0	8
	1200	24	0	16	0	8
2	14400	288	1	267	12	8
	7200	144	1	125	10	8
	3600	72	1	55	8	8
	1800	36	1	21	6	8
3 and 5	9600	192	0	172	12	8
	4800	96	0	80	8	8
	2700	54	0	40	6	8
	1500	30	0	16	6	8
4 and 6	14400	288	1	267	12	8
	7200	144	1	125	10	8
	3600	72	1	55	8	8
	1800	36	1	21	6	8

Table 2.3: Reverse Supplemental Channel frame summary

Radio Config.	Transmission Rate (bps)	Number of Bits per Frame				
		Total	Reserved/ Flag	Information	CRC	Reserved/ Tail Bits
3 and 5	614400[3]	12288	0	12264	16	8
	307200	6144	0	6120	16	8
	153600	3072	0	3048	16	8
	76800	1536	0	1512	16	8
	38400	768	0	744	16	8
	19200	384	0	360	16	8
	9600	192	0	172	12	8
	4800	96	0	80	8	8
	2700	54	0	40	6	8
	1500	30	0	16	6	8
4 and 6	1036800[4]	20736	0	20712	16	8
	460800[5]	9216	0	9192	16	8
	230400	4608	0	4584	16	8
	115200	2304	0	2280	16	8
	57600	1152	0	1128	16	8
	28800	576	0	552	16	8
	14400	288	1	267	12	8
	7200	144	1	125	10	8
	3600	72	1	55	8	8
	1800	36	1	21	6	8

2.1.2 Reserved and Erasure Indicator Bits

The reserved/erasure indicator bit is used to indicate a bad frame on the forward channel or to re-enable its transmitter after tuning to another frequency. On the *R-FCH*, a reserve/erasure bit indicator is included in the channel structure for Radio Configurations 4 and 6. For more details please see Figures 2.4 through 2.7 which include only the lowest four data rates. On the *R-SCH*'s, a reserved bit is included when one of the data rates: 1800, 3600, 7200, or 14400 bps is used in Radio Configurations 4 and 6.

2.1.3 Frame Quality Indicator

The frame quality indicator is a cyclic redundancy code, which is a number of bits generated from, and appended to, the end of the data in a frame to provide error detection. The data includes all the bits within the frame, except the frame quality indicator itself and the encoder tail

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[3] 614400 bps rate only for Radio Configuration 5.

[4] 1036800 bps rate only for Radio Configuration 6.

[4] 460800 bps rate only for Radio Configurations 6.

bits. Frame quality indicator is used at the receiver to determine if the frame is in error. The number of bits (6 to 16) for the frame quality indicator at each data rate in Radio Configurations 3 through 6 is also shown in Figures 2.4 through 2.7. The generator polynomials for the CRC calculation of the frame quality indicator:

16-bit frame quality indicator: $x^{16} + x^{15} + x^{14} + x^{11} + x^6 + x^5 + x^2 + x + 1$
12-bit frame quality indicator: $x^{12} + x^{11} + x^{10} + x^9 + x^8 + x^4 + x + 1$
10-bit frame quality indicator: $x^{10} + x^{19} + x^8 + x^7 + x^6 + x^4 + x^3 + 1$
8-bit frame quality indicator: $x^8 + x^7 + x^4 + x^3 + x + 1$
6-bit frame quality indicator: $x^6 + x^5 + x^2 + x + 1$

2.1.4 Encoder Tail Bits

All Reverse Fundamental and Supplemental Channels use 8 tail bits for code termination of the forward error protection (FEC). The eight tail bits are added to the end of the frame before FEC. These tail bits are set differently for the two types of FEC i.e. convolutional codes and turbo codes.

2.1.5 Convolutional Encoder

Once the frame, shown in Figures 2.2 and 2.3, is formed, it is encoded using either convolutional or turbo coding (turbo coding will not be discussed in this report). This encoding serves to recover the corrupted received input data. The encoding rate (1/2, 1/3, or 1/4) assigned to every data rate for Radio Configurations 3 through 6 is given in Figures 2.4 through 2.7. All convolutional coders used in the system have a constraint length of 9 (i.e., k = 9). The encoder for each encoding rate is discussed in Appendix A.

2.1.6 Symbol Repetition

Code symbol outputs from the convolutional coder are repeated, based on the repetition factor specified in Figures 2.4 through 2.7. The repetition factor represents the number of times a symbol appears. For instance, a repetition factor 1 means no repetition; a factor of 2 means a symbol is repeated once.

Symbol repetition plays a role in adjusting the transmission rate to the desired chip rate (1.2288 or 3.6484 Mcps). For Radio Configurations 3 through 6, the repetition factors are specified as follows: 16 for 1500 or 1800 bps; 8 for 2700 or 3600 bps; 4 for 4800 or 7200 bps; 2 for 9600 or 14400 bps; and 1 for the remaining data rates.

2.1.7 Symbol Puncture

Following symbol repetition, some symbols are punctured (or deleted) as required to provide a correct rate for the modulation process. The puncturing patterns used with convolutional codes are defined in Table 2.4. Each puncturing pattern is associated with its puncturing ratio. This ratio is also specified in Figures 2.4 through 2.7 for every data rate in Radio Configurations 3 through 6.

A '0' in a puncturing pattern means that a symbol is deleted and '1' means that a symbol is passed. The MSB in the pattern corresponds to the first symbol in the symbol group corresponding to the length of the puncturing pattern. The pattern is repeated for all remaining symbols in the frame. For example, the 5-symbol puncturing pattern for Radio Configuration 3 is '11110', which means the first, second, third, and fourth symbols are passed, while the fifth symbol of each consecutive group of five symbols is removed.

Table 2.4: Punctured Codes Used with Convolutional Codes

Radio Configuration	Data Rates (bps)	Basic Code Rate	Puncturing Ratio	Puncturing Pattern
3 and 5	1500	1/4	1 of 5	'11110'
3 and 5	2700	1/4	1 of 9	'111111110'
4 and 6	1800, 3600, 7200, 14400	1/4	8 of 24	'111010111011 101011101010'
4	28800, 57600, 115200, 230400	1/4	4 of 12	'110110011011'
6	1036800	1/2	2 of 18	'111011111 111111110'

2.1.8 Block Interleaver

After puncturing, the symbol ordering is rearranged in the block interleaver. This is to protect groups of data from being corrupted at the same time by any deep fade or noise burst. For the *R-FCH* and the *R-SCH* with Radio Configurations 3 through 6, the symbols input to the block interleaver are written sequentially at addresses 0 to (N-1), where N is the interleaver size. The interleaved symbols are read out in a permuted order from address A_i, as follows:

$A_i = 2^m \ (i \ mod \ J) + BRO_m \left(\lfloor i / J \rfloor \right)$
where   i = 0 to N-1;
$\lfloor x \rfloor$ indicates the largest integer less than or equal to x;
$BRO_m(y)$ indicates the bit-reversed m-bit value of y (i.e. $BRO_3 \ (6) = 3$);
Parameter m and J are specified in Table 2.5.

Table 2.5: Interleaver parameters

Interleaver size, N	m	J
384	6	6
768	6	12
1536	6	24
3072	6	48
6144	7	48
12288	7	96
576	5	18
2304	6	36
4608	7	36
9216	7	72
18432	8	72
36864	8	144

2.1.9 Post-Interleaver Repetition

Following the block interleaver, symbols on the R-FCH, R-SCH1, and R-SCH2 may be repeated. For the case of R-FCH and R-SCCH with a spreading rate of 3, the repetition factor is 3. On the R-SCH, the repetition factor depends on the radio configuration, Walsh length, and data rate. Table 2.6 lists the possible repetition factors.

Bits/Frame	Bits	Bits (Data rate: kbps)	R	Factor	Deletion	Symbols	Rate(ksps)
16 Bits/20 ms	6	8 (1.5)	¼	16x	1 of 5	1,536	76.8
40 Bits/20 ms	6	8 (2.7)	¼	8x	1 of 9	1,536	76.8
80 Bits/20 ms	8	8 (4.8)	¼	4x	None	1,536	76.8
172 Bits/20 ms	12	8 (9.6)	¼	2x	None	1,536	76.8
360 Bits/20 ms	16	8 (19.2)	¼	1x	None	1,536	76.8
744 Bits/20 ms	16	8 (38.4)	¼	1x	None	3,072	153.6
1,512 Bits/20 ms	16	8 (76.8)	¼	1x	None	6,144	307.2
3,048 Bits/20 ms	16	8 (153.6)	¼	1x	None	12,288	614.4
6,120 Bits/20 ms	16	8 (307.2)	½	1x	None	12,288	614.4

Figure 2.4: Reverse Fundamental and Supplemental Channel Structure for Radio Configuration 3
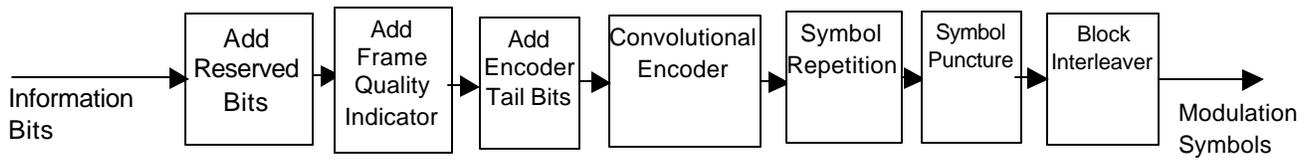
Bits/Frame	Bits	Bits	Bits (Data rate) (kbps)	R	Factor	Deletion	Symbols /Frame	Rate(ksps)
21 Bits/20 ms	1	6	8 (1.8)	¼	16x	8 of 24	1,536	76.8
55 Bits/20 ms	1	8	8 (3.6)	¼	8x	8 of 24	1,536	76.8
125 Bits/20 ms	1	10	8 (7.2)	¼	4x	8 of 24	1,536	76.8
267 Bits/20 ms	1	12	8 (14.4)	¼	2x	8 of 24	1,536	76.8
552 Bits/20 ms	0	16	8 (28.8)	¼	1x	4 of 12	1,536	76.8
1,128 Bits/20 ms	0	16	8 (57.6)	¼	1x	4 of 12	3,072	153.6
2,280 Bits/20 ms	0	16	8 (115.2)	¼	1x	4 of 12	6,144	307.2
4,584 Bits/20 ms	0	16	8 (230.4)	¼	1x	4 of 12	12,288	614.4

Figure 2.5: Reverse Fundamental and Supplemental Channel Structure for Radio Configuration 4

Bits/Frame	Bits	Bits (Data rate) (kbps)	R	Factor	Deletion	Symbols	Rate(ksps)
16 Bits/20 ms	6	8 (1.5)	¼	16x	1 of 5	1,536	76.8
40 Bits/20 ms	6	8 (2.7)	¼	8x	1 of 9	1,536	76.8
80 Bits/20 ms	8	8 (4.8)	¼	4x	None	1,536	76.8
172 Bits/20 ms	12	8 (9.6)	¼	2x	None	1,536	76.8
360 Bits/20 ms	16	8 (19.2)	¼	1x	None	1,536	76.8
744 Bits/20 ms	16	8 (38.4)	¼	1x	None	3,072	153.6
1,512 Bits/20 ms	16	8 (76.8)	¼	1x	None	6,144	307.2
3,048 Bits/20 ms	16	8 (153.6)	¼	1x	None	12,288	614.4
6,120 Bits/20 ms	16	8 (307.2)	1/3	1x	None	18,432	921.6
12,264 Bits/20 ms	16	8 (614.4)	1/3	1x	None	36,864	1,8432

Figure 2.6: Reverse Fundamental and Supplemental Channel Structure for Radio Configuration 5

Bits/Frame	Bits	Bits	Bits (Data rate) (kbps)	R	Factor	Deletion	Symbols	Rate(ksps)
21 Bits/20 ms	1	6	8 (1.8)	¼	16x	8 of 24	1,536	76.8
55 Bits/20 ms	1	8	8 (3.6)	¼	8x	8 of 24	1,536	76.8
125 Bits/20 ms	1	10	8 (7.2)	¼	4x	8 of 24	1,536	76.8
267 Bits/20 ms	1	12	8 (14.4)	¼	2x	8 of 24	1,536	76.8
552 Bits/20 ms	0	16	8 (28.8)	¼	1x	None	2,304	115.2
1,128 Bits/20 ms	0	16	8 (57.6)	¼	1x	None	4,608	230.4
2,280 Bits/20 ms	0	16	8 (115.2)	¼	1x	None	9,216	460.8
4,584 Bits/20 ms	0	16	8 (230.4)	¼	1x	None	18,432	921.6
9,192 Bits/20 ms	0	16	8 (460.8)	¼	1x	None	36,864	1,843.2
20,712 Bits/20 ms	0	16	8 (1,036.8)	½	1x	2 of 18	36,864	1,843.2

Figure 2.7: Reverse Fundamental and Supplemental Channel Structure for Radio Configuration 6

Table 2.6 Post-Interleaver Repetition for R-FCH, R-SCCH, and R-SCH

Channel Type	Radio Configurations	Repetition Factor
R-FCH	1, 2, 3, 4	1
	5, 6	3
R-SCCH	1, 2	1

2.2 Reverse Dedicated Control Channel

The R-DCCH is used for the transmission of higher level data and control information from a mobile station to a base station. This channel can be enabled or disabled on a frame by frame basis.

2.2.1 Framing and Encoding

The basic frame structure and encoding is illustrated in Figure 2.8. It is similar to that of the *R-FCH* and the *R-SCH*, described in the previous Section. The data rate for the *R-DCCH* is fixed at 9600 or 14400 bps for 20ms frames. Table 2.7 lists the framing and encoding parameters for different Radio Configurations. The *R-DCCH* frame structure, prior to convolutional coding, is shown in Figure 2.9.
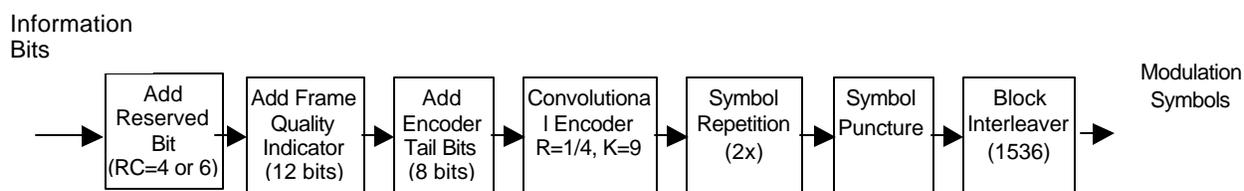
Figure 2.8: Reverse Dedicated Control Channel Structure

Table 2.7: Framing and encoding parameters for R-DCCH

Radio Configuration	Spreading Rate	Data Rate (bps)	Information Bits	Reserved Bit	Convolutional Code Rate	Puncturing
3	1	9600	172	0	¼	None
4	1	14400	267	1	¼	8 of 24
5	3	9600	172	0	¼	None
6	3	14400	267	1	¼	8 of 24

R – Reserved Bit
F – Frame Quality Indicator (CRC)
T– Encoder Tail Bits

Figure 2.9: Reverse Dedicated Control Channel Frame Structure

2.2.2 Reserved Bits

A reserved bit is included preceding the information bits in a 20 ms frame, as shown in Figure 2.9 (for Radio Configurations 4 and 6). As mentioned earlier, the reserved bit is used to denote a bad frame on the forward channel, or to re-enable its transmitter after tuning to another frequency.

2.2.3 Frame Quality Indicator

A cyclic redundancy check is conducted on all *R-DCCH* frames to detect if the frame has been corrupted by errors. The frame quality indicator (CRC) is calculated on all the bits within the frame, except the frame quality indicator itself and the encoder tail bits. The 20ms frame uses the 12-bit frame quality indicator with the following generator polynomial:

12-bit frame quality indicator: $\qquad x^{12} + x^{11} + x^{10} + x^9 + x^8 + x^4 + x + 1$

2.2.4 Encoder Tail Bits

All *R-DCCH* frames use eight tail bits for the code termination of convolutional coding. The eight tail bits are set to '0' and are added to the end of every frame prior to error correction encoding.

2.2.5 Convolutional Encoder

Once the frame shown in Figure 2.9 is formed, convolutional encoding is performed to protect the data in the frame from being corrupted during transmission. The encoding rate for all Radio Configurations is ¼, with a constraint length of 9. The encoder used for this rate is the same as that used for *R-FCH* or *R-SCH* (see Appendix A).

2.2.6 Symbol Repetition

After convolutional encoding, each coded symbol is repeated once (i.e., each symbols appears twice) for all Radio Configurations.

2.2.7 Symbol Puncture

Following symbol repetition, some symbols may be punctured (or deleted) as required to provide a correct rate for the modulation process. For Radio Configurations 3 and 5, symbol puncturing is not required. For Radio Configurations 4 and 6, symbols are deleted at the puncturing ratio 8 of 24, which means 8 symbols out of every group of 24 symbols are deleted. The puncturing pattern is the same as that given in Table 2.4.

2.2.8 Block Interleaver

After symbol puncturing, the symbol order is rearranged in the block interleaver. A single frame's worth of data is interleaved at a time. The interleaver size is equal to the total number of symbols before modulation. For the 20 ms frame option, the interleaver size is 1536 symbols.
As described in Section 2.1.4 the symbols input to the block interleaver are written sequentially at addresses 0 to (N-1), where N is the interleaver size. The interleaved symbols are read out in a permutated order from address A_i, as follows:

$$A_i = 2^m \ (i \ mod \ J) + BRO_m \ (\lfloor i \ / \ J \rfloor)$$

where   m = 6, J = 24 (obtained from Table 2.5);
         i = 0 to N-1;
         $\lfloor x \rfloor$ indicates the largest integer less than or equal to x;
         $BRO_m(y)$ indicates the bit-reversed m-bit value of y;

2.2.9 Post-interleaver Repetition

For spreading rate 3, symbols are repeated two additional times, resulting in three output symbols per interleaver symbol.

2.3 Reverse Pilot Channel

The Reverse Pilot Channel is an unmodulated spread spectrum signal used for initial acquisition, time tracking, rake receiver coherent reference recovery, and power control measurement. The *R-PCH* is transmitted with Radio Configurations 3 through 6. The mobile station inserts a Reverse Power Control Subchannel on the *R-PCH*. This subchannel carries the power control bit, which is sent to the base station for power control purposes.

Each 20 ms frame in the *R-PCH* is divided into 16 power control groups of 1.25 ms duration. For the spreading rate of 1 (1.2288 Mcps), there are 1536 x 1 = 1536 PN chips in a power control group. For the spreading rate of 3 (3.6864 Mcps), there are 1536 x 3 = 4608 PN chips in a power control group. In each power control group on the *R-PCH*, the pilot signal and the Reverse Power Control Subchannel are multiplexed such that the pilot signal is transmitted in the first 1152 x N chips, and the subchannel is transmitted in the following 384 x N PN chips. N is used to represent the spreading rate (1 or 3). Each of the 384 x N PN chips on the Reverse Power Control Subchannel is a repetition of the forward power control bit generated by the mobile station. This is illustrated in Figure 2.10.
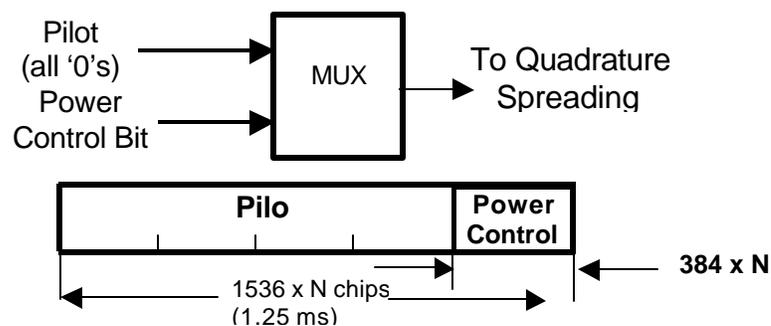
Figure 2.10: Reverse Power Control Subchannel Structure

3. Multiplexing and Transmission

This section first describes the manner in which the reverse channel signals are orthogonally spread and combined, followed by the arrangement of quadrature spreading and finally, the

transmission filter will be discussed. Figure 3.1 illustrates the modulation process for radio configurations 3 through 6. The long code generator, which will be discussed in section3.2, operates at 1.2288 Mcps for configurations 3 and 4, and 3.6864 Mcps for configurations 5 and 6. For radio configurations 1 and 2, the procedure is similar to that of IS-95 and is not described here. Figure 3.2 illustrates the process generating spreading codes. For Radio Configurations 3 and 4, the long code generator operates at the chip rate of 1.228 Mcps and for Radio Configurations 5 and 6 (spreading rate 3), it operates at the chip rate of 3.6864 Mcps.

3.1 Orthogonal Spreading

Orthogonal codes are used to multiplex the reverse channels i.e. *R-FCH, R-DCCH,* and *R-SCH's*. Each channel is spread by an orthogonal Walsh function. The orthogonal characteristics of the Walsh functions ensure that the channels do not interfere with each other. The generation of Walsh functions is discussed in Appendix B.

The specific Walsh functions used for different reverse channels are listed in Table 3.1. The Walsh function W_m^n indicates the m-th row of an n x n Hadamard matrix. For example, W_2^4 corresponds to the second row of a 4 x 4 Hadamard matrix, which is 0011. As shown in Figure 3.1, the Walsh functions are converted to symbols (-1, +1) and multiplied with the corresponding reverse channels. Tables 3.2, 3.3, 3.4, and 3.5 outline the Walsh code assignments for supplemental channels along with allowable data rates and corresponding post-interleaver repetition rates.

The spread reverse channels are scaled by relative gains and combined. Supplemental channel 2 (R-SCH2), reverse pilot channel (R-PCH), and the reverse dedicated control channel (R-DCCH) are combined through addition to make up the I-Channel. The Q-Channel consists of the reverse fundamental channel (R-FCH) and the reverse supplemental Channel 1 (R-SCH1). The spread reverse channels are then scaled by relative gains, which will be discussed in the section describing the Link Budget (section 6). After gain adjustment, the spread *R-SCH2, R-PCH*, and *R-DCCH* are combined to form the I-Channel. Meanwhile, spread *R-FCH* and *R-SCH1* are combined to form the Q-Channel. This complex signal (I and Q channels) is then spread by the quadrature spreading that will be discussed in the next section.

Table 3.1: Walsh functions for reverse CDMA channels

Channel Type	Walsh Function
Reverse Pilot Channel	W_0^{32}
Reverse Dedicated Control Channel	W_8^{16}
Reverse Fundamental Channel	W_4^{16}
Reverse Supplemental Channel 1	W_1^2 or W_2^4
Reverse Supplemental Channel 2	W_2^4 or W_6^8

Table 3.2: Reverse supplemental channel Walsh functions with spreading rate 1 when only one supplemental channel is operating

Reverse Supplemental Channel 1			Reverse Supplemental Channel 2		
Walsh Function	Data Rate (kbps)	Post-Interleaving Symbol Repetition	Walsh Function	Data Rate (kbps)	Post-Interleaving Symbol Repetition
W12 = (+-)	307.2 230.4 153.6 115.2 76.8 57.6 38.4 28.8 or Less	1 1 1 2 2 4 4 8	Not Supported		
W24 = (++--)	115.2 76.8 57.6 38.4 28.8 or Less	1 1 2 2 4	Not Supported		
Not Supported			W24 = (++--)	115.2 76.8 57.6 38.4 28.8 or Less	1 1 2 2 4
Not Supported			W68 = (++----++)	57.6 38.4 28.8 or Less	1 1 2

.

Table 3.3: Reverse supplemental channel Walsh functions with spreading rate 1 when two reverse supplemental channels are operating.

Reverse Supplemental Channel 1			Reverse Supplemental Channel 2		
Walsh Function	**Data Rate (kbps)**	**Post-Interleaving Symbol Repetition**	**Walsh Function**	**Data Rate (kbps)**	**Post-Interleaving Symbol Repetition**
W12 = (+-)	307.2 230.4 153.6 115.2 76.8 57.6 38.4 28.8 or Less	1 1 1 2 2 4 4 8	W24 = (++--)	115.2 76.8 57.6 38.4 28.8 or Less	1 1 2 2 4
W12 = (+-)	307.2 230.4 153.6 115.2 76.8 57.6 38.4 28.8 or Less	1 1 1 2 2 4 4 8	W68 = (++----++)	57.6 38.4 28.8 or Less	1 1 2
W24 = (++--)	57.6 38.4 28.8 or Less	2 2 4	W68 = (++----++)	57.6 38.4 28.8 or Less	1 1 2

Table 3.4: Reverse supplemental channel Walsh functions with Spreading Rate 3 when only one reverse supplemental channel is operating.

Reverse Supplemental Channel 1			Reverse Supplemental Channel 2		
Walsh Function	Data Rate (kbps)	Post-Interleaving Symbol Repetition	Walsh Function	Data Rate (kbps)	Post-Interleaving Symbol Repetition
W12 = (+-)	1,036.8 614.4 460.8 307.2 230.4 153.6 115.2 76.8 57.6 38.4 28.8 19.2 or Less	1 1 1 2 2 3 4 6 8 12 16 24	Not Supported		
W24 = (++--)	307.2 230.4 115.2 76.8 57.6 38.4 28.8 19.2 or Less	1 1 2 3 4 6 8 12	Not Supported		
Not Supported			W24 = (++--)	307.2 230.4 115.2 76.8 57.6 38.4 28.8 19.2 or Less	1 1 2 3 4 6 8 12
Not Supported			W68 = (++----++)	115.2 57.6 38.4 28.8 19.2 or Less	1 2 3 4 6

Table 3.5: Reverse supplemental channel Walsh functions with spreading rate 3 when two reverse supplemental channels are operating.

Reverse Supplemental Channel 1			Reverse Supplemental Channel 2		
Walsh Function	Data Rate (kbps)	Post-Interleaving Symbol Repetition	Walsh Function	Data Rate (kbps)	Post-Interleaving Symbol Repetition
W12 = (+-)	1,036.8	1	W24 = (++--)	307.2	1
	614.4	1		230.4	1
	460.8	1		115.2	2
	307.2	2		76.8	3
	230.4	2		57.6	4
	153.6	3		38.4	6
	115.2	4		28.8	8
	76.8	6		19.2 or Less	12
	57.6	8			
	38.4	12			
	28.8	16			
	19.2 or Less	24			
W12 = (+-)	1,036.8	1	W68 = (++----++)	115.2	1
	614.4	1		57.6	2
	460.8	1		38.4	3
	307.2	2		28.8	4
	230.4	2		19.2 or Less	6
	153.6	3			
	115.2	4			
	76.8	6			
	57.6	8			
	38.4	12			
	28.8	16			
	19.2 or Less	24			
W24 = (++--)	115.2	2	W68 = (++----++)	115.2	1
	57.6	4		57.6	2
	38.4	6		38.4	3
	28.8	8		28.8	4
	19.2 or Less	12		19.2 or Less	6
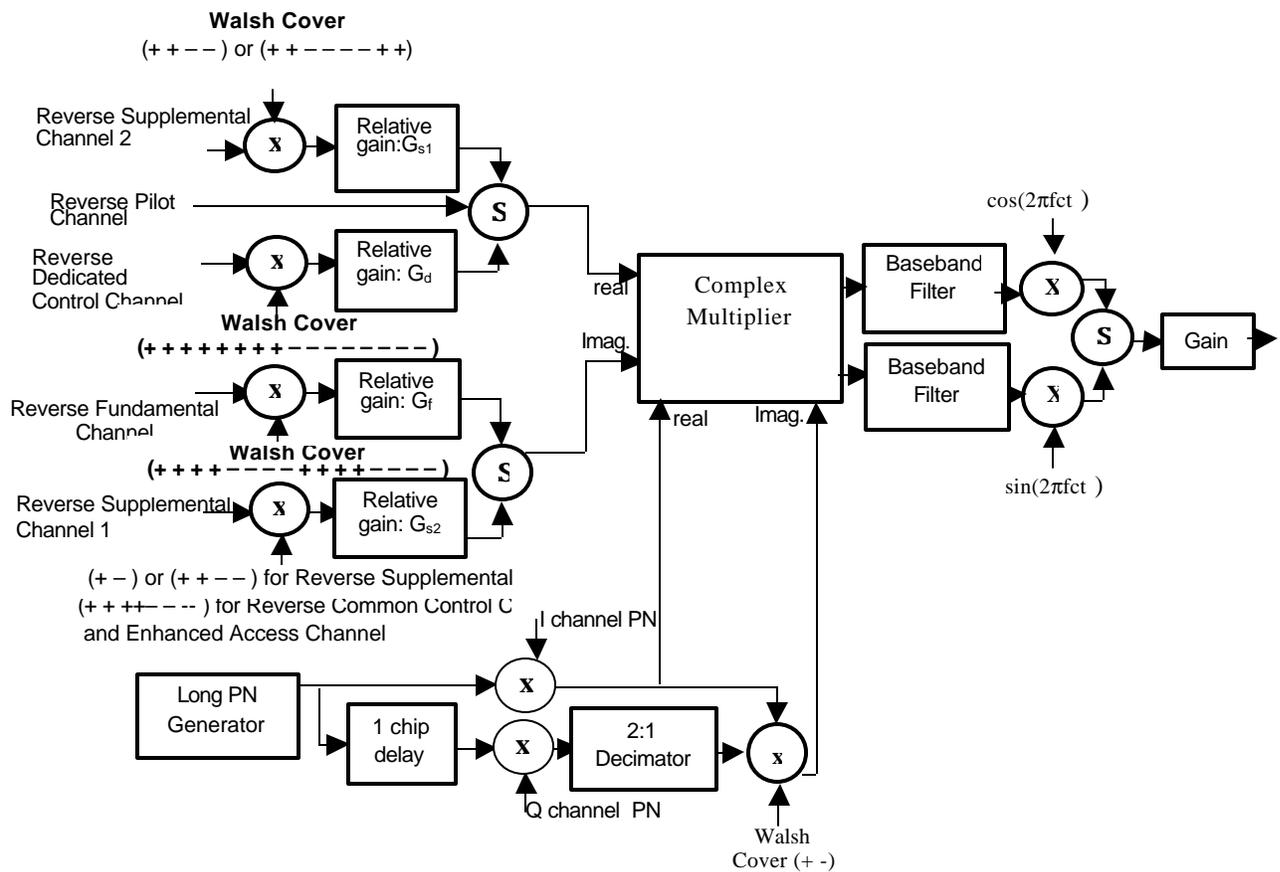
Figure 3.1: I and Q Mapping for Radio Configuration 5

3.2 Quadrature Spreading

The spreading sequence is arranged in a way that reduces the effect of the multipath fading channel and restores some of the orthogonality losses between users. The arrangement of the quadrature spreading is shown in Figure 3.2. The I-Channel and Q-Channel data is complex multiplied by a complex spreading sequence for radio configurations 3 through 6. The in-phase spreading sequence is formed by multiplication of the I-Channel PN sequence and the I long code sequence. The quadrature-phase spreading sequence is formed by the multiplication of three elements:

1) the in-phase spreading sequence;

2) a W_1^2 Walsh function;

3) the decimated by 2 output of the multiplication of the Q-Channel PN sequence and the Q long code sequence, where the Q long code sequence is the I long code sequence delayed by 1 chip.

The I long code sequence is generated with period of 2^{42}-1 chips by the following characteristic polynomial:

$$p(x) = x^{42} + x^{35} + x^{33} + x^{31} + x^{27} + x^{26} + x^{25} + x^{22} + x^{21} + x^{19} +$$
$$x^{18} + x^{17} + x^{16} + x^{10} + x^7 + x^6 + x^5 + x^3 + x^2 + x + 1$$

Each PN chip of the long code is formed by the modulo-2 inner product of a 42-bit mask and the 42-bit state vector of the sequence generator shown in Figure 3.4. The mask used for generating the I long code varies depending on the channel type on which the mobile station is transmitting. The masking procedure will not be discussed in this report. The long code generator is required to generate spreading sequence at a chip rate of 1.2288 Mcps for Radio Configurations 3 and 4 (spreading rate 1), and 3.6864 Mcps for Radio Configurations 5 and 6 (spreading rate 3).

The I-Channel and Q-Channel PN sequences are periodic with a period of 2^{15} chips for spreading rate 1 and 3 x 2^{15} chips for spreading rate 3. For spreading rate 1, the PN sequences are based on the following characteristic polynomials:

$$P_I (x) = x^{15} + x^{13} + x^9 + x^8 + x^7 + x^5 + 1 \qquad \text{(I-Channel)}$$
$$P_Q (x) = x^{15} + x^{12} + x^{11} + x^{10} + x^6 + x^5 + x^4 + x^3 + 1 \qquad \text{(Q-Channel)}$$

The maximum length PN sequence that can be obtained from these polynomials is 2^{15}-1. In order to obtain the I-Channel and Q-Channel PN sequence (of period 2^{15}), a '0' is inserted in each sequence after 14 consecutive '0' outputs (this occurs only once in each period). Therefore, the PN sequences have one run of 15 consecutive '0' outputs instead of 14. For spreading rate 3, the PN sequences are truncated sequences of a maximal length linear feedback shift register sequence based upon the following characteristic polynomial:

$$P (x) = x^{20} + x^9 + x^5 + x^3 + 1$$

The I-Channel and Q-Channel PN sequences are formed from this maximal length sequence of length 2^{20}-1 using different starting positions and truncating the sequences after 3 x 2^{15} chips. The starting position of the I-Channel PN sequence is such that the first chip is the '1' after the 19 consecutive '0's. The starting position of the Q-Channel sequence is the starting position of the I-Channel PN sequence delayed by 2^{19} chips.
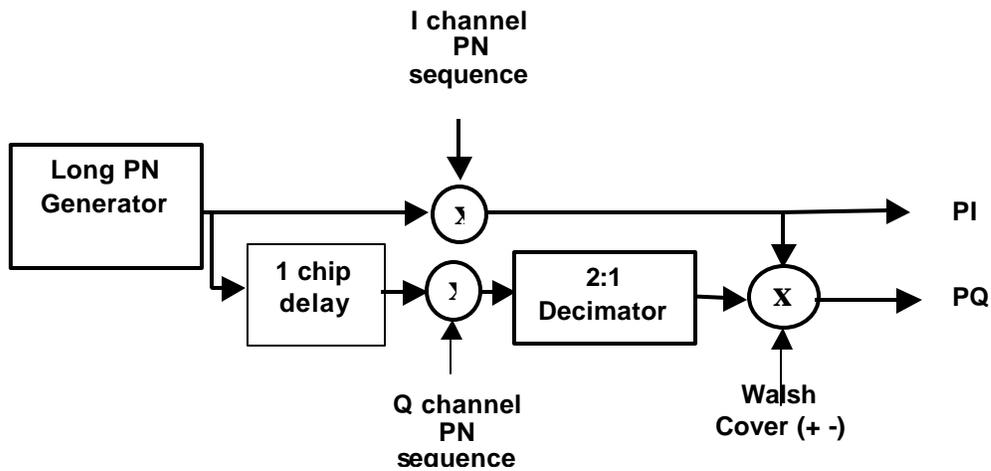
Figure 3.2: Generation of the reverse link quadrature spreading codes P$_I$ and P$_Q$

3.3 Baseband Filtering

Following complex spreading, the resulting I and Q impulses are passed through a transmission filter, which is a complex low-pass baseband filter. . The baseband filter has a frequency response S (f) that satisfies the limits given in Figure 3.3. The normalised frequency response is contained within the limits $\pm\delta_1$ in the passband $0 \le f \le f_P$, and is less than $-\delta_2$ in the stopband $f \ge f_S$. The numerical values for the parameters are $\delta_1 = 1.5$ dB, $\delta_2 = 40$ dB, $f_P = 590$ kHz, and $f_S = 740$ kHz.
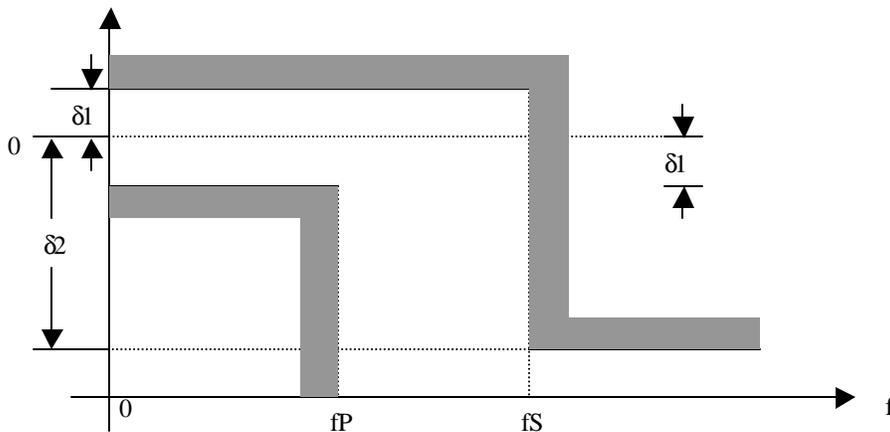
Figure 3.3: Baseband Filter Frequency Response Limits
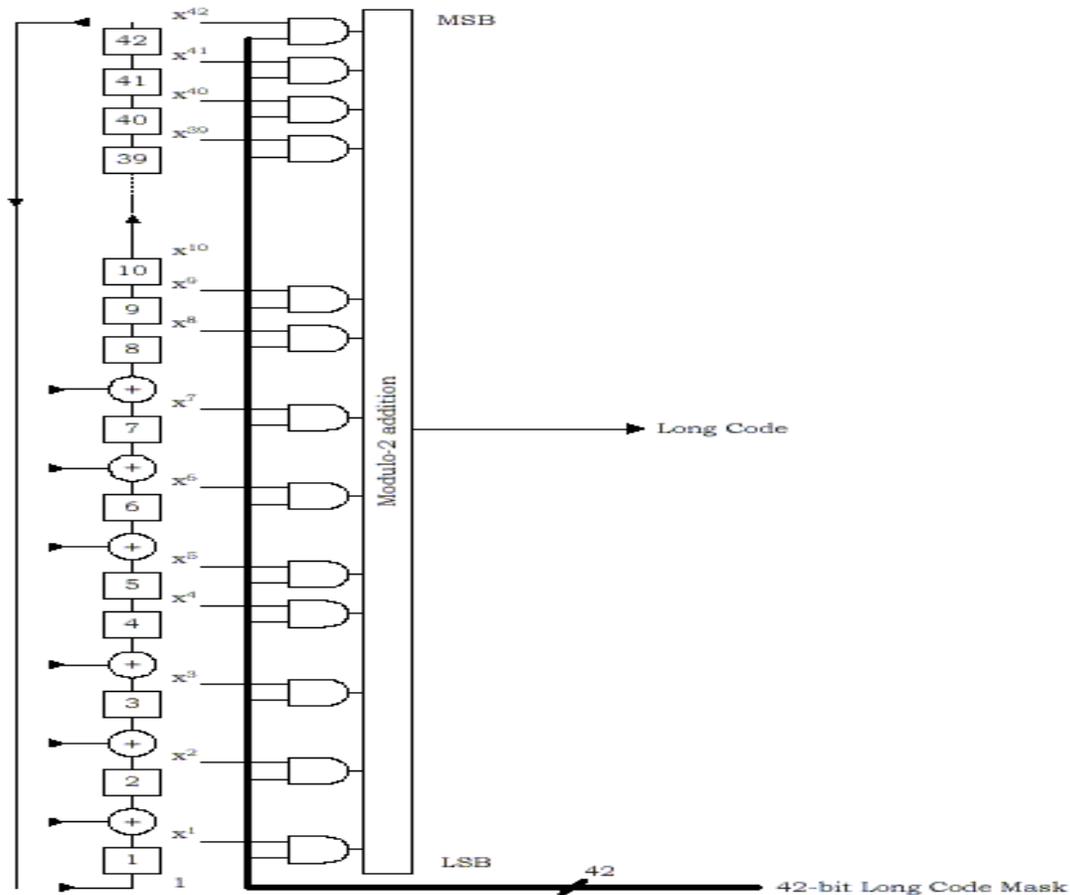
Figure 3.4 Long code generator

4. Channel Model

The channel model used in the reverse link systems is that specified by IMT2000 for Vehicular Model-A. This model takes into account both the slow and the frequency selective fast fading. The slow fading is modeled by lognormal shadow fading. The frequency selective fast fading is modeled by the superposition of multiple single flat faded paths with different arrival times and different average powers. The average power and arrival time are assumed to be fixed and are determined by the channel impulse response. Each path has a Rayleigh distribution, with the power spectrum suggested by Jakes [6]. Figure 4.1 shows a six-path frequency selective fading channel that has been used for the reverse link. Further details on the channel modeling can be found in [3]. This model, and all the other IMT2000 channel models, can be modeled using a generalized SPW block. The SPW block for the Vehicular Model-A, designed by Cadence and used for the reverse link, is shown in Figure 4.2.
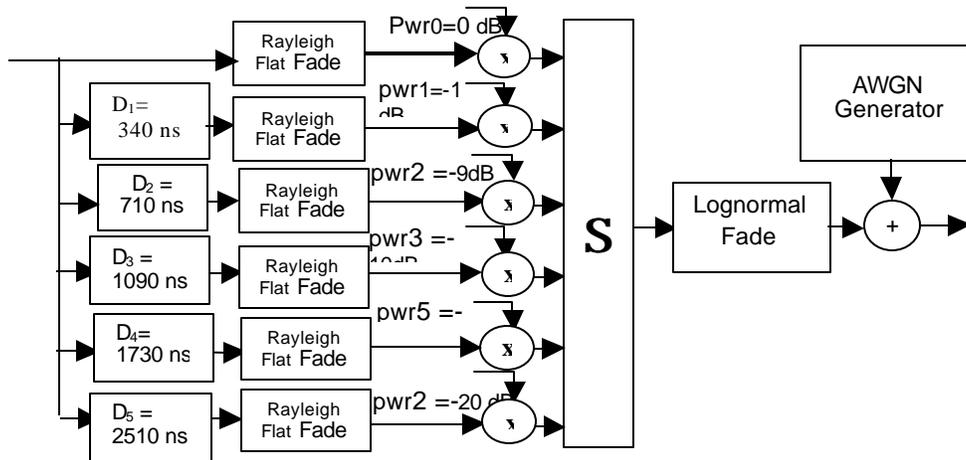
Figure 4.1: Frequency Selective Fading channel

FOUR/SIX PATH CHANNEL MODEL PARAMETERS			
Sampling frequency (Hz)	10.0e6		
Carrier frequency	1.0e9		
		Delay (nsecs)	Power (dB)
Minimum path loss (dB)	0.0		
Average path loss (dB)	49.0	Path 1	0.0	0.0
Path loss standard deviation (dB)	1.0	Path 2	200.0	-0.9
Decorrelation length (m)	20.0	Path 3	800.0	-4.9
Default Doppler frequency (Hz)	5.0	Path 4	1200.0	-8.0
Number of paths (4 or 6)	6	Path 5	2300.0	-7.8
		Path 6	3700.0	-23.9
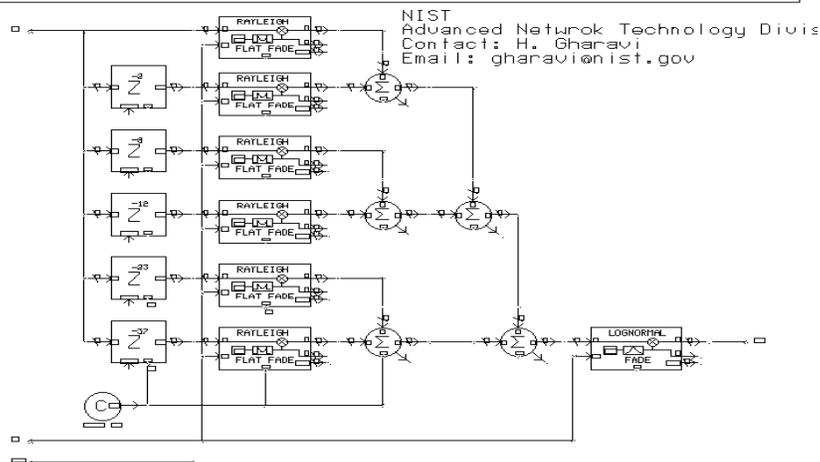
Figure 4.2: SPW Freque ncy Selective Fading channel block for the Vehicular Model-A

After the channel, as shown in Figure 4.1, white gaussian noise (WGN) is added to simulate the effect of overall interference in the system, including thermal noise and inter-cell interference. The dominating interference in CDMA systems tends to be inter-cell interference which is due to the possibility of the system having a unity reuse factor (if traffic is very heavy in adjoining

cells). The carrier-to-interference ratio (C/I) is often used to denote this inter-cell interference, and it can have values of 0dB or less. In other words, the aggregate energy of the interference from neighboring cells may be higher than the energy of the desired signal.

5. Receiver

The receiver for the reverse link model consists of a rake receiver followed by a channel despreader. The rake receiver is a coherent receiver that attempts to collect the signal energy from all received signal paths that carry the same information. The rake receiver therefore can significantly reduce the fading caused by these multiple paths. The channel despreader takes the outputs from the rake receiver and recovers the channel data, by despreading the outputs using the appropriate Walsh function or quasi-orthogonal function.

The first stage in the receiver model is the receiver filter. This is a filter which has identical parameters to the transmitter filter described earlier. The next stage is to bring all the rake fingers into time alignment for combining. The received signal at the receiver is a composite signal made up of the sum of multiple reflections of the transmitted signal. Each reflection has a different delay, amplitude and phase shift. The separation of the composite signal into individual time aligned signals occurs when the composite signal is delayed by a different delay for each path. Therefore, a single complex signal input becomes a complex vector output, with a vector length equal to the number of fingers in the rake receiver. Two types of rake receivers have been developed for the reverse link: 1) rake receiver with fade channel estimation and, 2) ideal rake receiver. The following provides details of the rake receiver design.

5.1 Rake Receiver Design

The number of fingers in the rake receiver depends on the bandwidth of the received signal. The number of fingers denotes the number of resolvable paths that are received – in other words, N fingers implies that N reflections of the transmitted signal arriving at the receiver with different delays may be detected and combined. In the reverse link model, a four or a six finger rake receiver is used depending on the transmitted chip rate. For the lower chip rate of 1.2288Mcps, the number of fingers in the rake receiver is four, whereas for the higher chip rate of 3.6864Mcps, the number of fingers is six.

The rake receiver in the reverse link model includes a timing feedback loop to adjust the delays applied to the composite received signal. At the start, assumptions made are that the receiver knows the multipath delays. This information is used to time align on the reflected paths is such a way that all the finger inputs are delay adjusted to the start of the second frame.

Within each rake finger of the receiver, the directly spread pilot symbols are used to estimate the channel as follows. It is assumed in the receiver that the short PN sequence starting position is know. The PN sequence (P_I and P_Q in figure 3.2), is locally generated, and delayed by one frame to match up with input data, which is subsequently removed from the data. The output data at this point includes the sum of all the spread data chips that is equivalent to the sum of all the spread channels. It is this stream that forms the *data_chip* output of the RAKE FINGER block. The output is then despreaded with respect to Walsh function w0. After down sampling, data

represents the estimated channel coefficients. The channel coefficient values are then complex conjugated, repeated (to chip rate) and multiplied.

The pilot symbols are also used to estimate the time correction for each finger. Within each finger there are three paths, an early path, an on-time path and a late path, which are taken from different samples in the down sampling of the signal to the chip rate. In each of these paths the complex PN sequence is removed and despread using the pilot Walsh sequence W0. The despread symbols represent the pilot symbols with the channel correction applied. The complex magnitudes of the symbols on each path are used to calculate a timing correction once per frame. The timing correction may be ± 1. It is formed as follows:

For each input magnitude:
$$Y_e(n+1) = (1-A) * Y_e(n) + in_e(n)$$
$$Y_o(n+1) = (1-A) * Y_o(n) + in_o(n)$$
$$Y_l(n+1) = (1-A) * Y_l(n) + in_l(n)$$

When n = size of frame:
$$\boldsymbol{l} = \frac{Y_l(n+1) - Y_e(n+1)}{Y_o(n+1) + 1}$$

if $|\boldsymbol{l}| > threshold$

        then   if $\boldsymbol{l} < 0$ $t = +1$
                 else $t = -1$.

else t = 0.

where $Y_e(n)$ is n^{th} early path filtered value; $Y_o(n)$ is n^{th} on-time path filtered value; $Y_l(n)$ is n^{th} late path filtered value; A is the specified filter coefficient; $in_e(n)$ is n^{th} input value of early path; $in_o(n)$ is n^{th} input value of on-time path; $in_l(n)$ is n^{th} input value of late path; t is timing correction value; and *threshold* is a predefined value which decides whether a timing correction is required.

The timing correction feedback loop means that the rake receiver does not deviate too far from the correct timing for time aligned fingers, and for correctly despread data.

5.2 SPW Implementation of Receiver

Clicking on the receiver block in the reverse link model reveals a block diagram similar to the one shown above. As can be seen, the receiver consists of a COMPLEX FILTER block, followed by a COMPLEX VARIABLE DELAY block whose function is to time align the reflected paths. The next block is the rake Receiver block, which has outputs for the data chips for all the fingers, and a timing correction vector. The running sum of the timing correction values and the original channel delays is fed back through a VECTOR REPEAT block (to match rate to sample rate). The fed back values are then added to the sample delay, which is equal to the sample delay for one frame minus the total filter delay minus the on-time sample delay (e.g., 3 sub-chips). The total delay vector is then used as the delay input for the COMPLEX VARIABLE DELAY block.

Figure 5.1: SPW block for the reverse link Receiver

The data-chip outputs from the rake receiver are fed into the channel despreader block, which separates the data into channels and removes the orthogonal spreading. The final blocks remove the modulation from the data, making it into a single data stream rather than two data streams (I & Q).

As mentioned earlier, it is assumed in the receiver that the short PN sequence starting position is known by the mobile, and is locally generated as shown in Figure 5.1 as the COMPLEX PN SEQUENCE block.

Clicking on the RAKE RECEIVER block in the RECEIVER block (Figure 5.1), reveals the block diagram shown in Figure 5.2. The first block in this Figure is the COMPLEX VECTOR TO SCALAR block, which splits the input vector into 4 or 6 parallel branches (number depends on number of possible resolvable paths). Each branch is fed into a RAKE FINGER block. The timing correction outputs from all the fingers are combined into a scalar vector of length 4 or 6 using the SCALR TO VECTOR block. This vector is the output of the RAKE RECEIVER block, along with the complex data chips from each of the fingers. The remaining blocks in the RAKE RECEIVER block are a scalar constant that generates a hold signal for fingers 5 & 6 if only 4 paths are present and a timing block, which generates a reset signal once every symbol. This rest signal is used in the RAKE FINGER blocks to reset the sum & dump blocks.

Clicking on any of the RAKE FINGER blocks in Figure 5.2, shows the block diagram displayed in Figure 5.3. In this Figure, the top path is the early path, which, in this case, is sample 0 when the signal is down sampled by 8. The middle path is the on-time path, which is sample 3 of the down sampling, and the bottom path is the late path, which is sample 6 in this case. The late path and the early path are identical, and are just used for the timing correction calculation. Their outputs from the COMPLEX DOWNSAMPLE block are each fed into a COMPLEX CORRELATE & DUMP block, to remove the short PN sequence from their data, and subsequently despreading them with Walsh function W0. The correlate & dump block is reset by the reset signal every symbol. The output is fed into a COMPLEX DOWNSAMPLE BLOCK which down samples the data by the Walsh length, taking the last chip of each symbol as the value. The magnitude of this complex number is then found, and fed into the appropriate input port on the RAKE TIMING block.
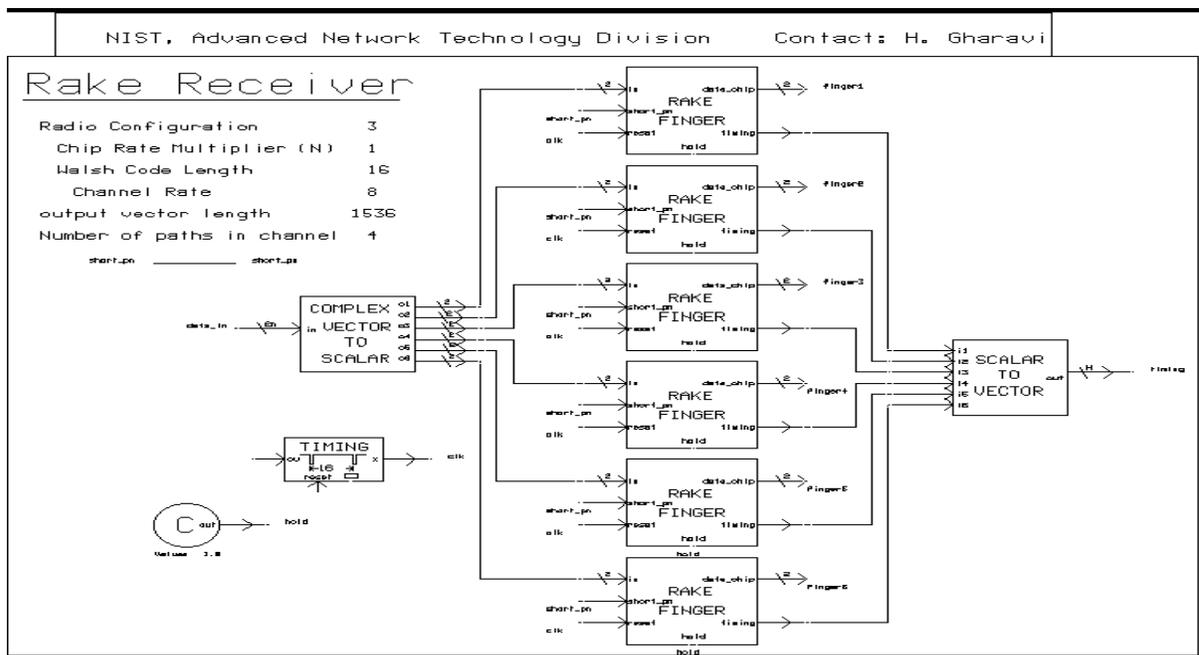
Figure 5.2: SPW block for cdma2000 rake receiver

The on-time path differs from the early & late paths in the fact that the correlate & dump function is split into two blocks. This is to allow the output of the data chips to be used to perform fade compensation. The first block is the COMPLEX DESPREAD, which removes the complex short PN sequence from the data. The data at this point is equivalent to the sum of all the spread channels multiplied by the fading channel. The second block is the COMPLEX SUM & DUMP block, which has the effect of despreading the data with respect to Walsh function W0. The data after this block is fed into two separate COMPLEX DOWN SAMPLE blocks. They both take the last chip of the symbol, which is equivalent to the channel coefficient estimate. The on-time path (center of above diagram) then has a block to find the magnitude of the complex signal, which is fed into to the on-time input of the RAKE TIMING block. The RAKE TIMING block estimates the timing correction once per frame as defined earlier. The output of the block is delayed by a unit delay, which allows for stable feedback, and then sent out through the *timing* output port of the RAKE FINGER block.

The output from the second COMPLEX DOWN SAMPLE block is the estimated channel coefficient values. The estimated coefficients are complex conjugated, repeated (to chip rate) and multiplied with the data chips to give a data stream that is equivalent to the sum of all the spread channels. It is this stream that forms the *data_chip* output of the RAKE FINGER block.

Figure 5.3: SPW block for cdma2000 rake finger

5.3 Ideal Receiver

In the ideal receiver, perfect channel estimation is assumed. This is accomplished by storing the entire flat fading channel coefficients as a complex vector. The vector dimension is equal to the number of frequency selective fading paths. This vector is then fed from the channel directly to the ideal receiver. At the receiver, the coefficients for each path are first separated and then applied to each rake finger after being time aligned in accordance with the delay in each reflected path.

The SPW ideal receiver block is shown in Figure 5.4. As can be seen, in the ideal case the receiver consists of two COMPLEX VARIABLE DELAY blocks. The first block time aligns the reflected paths for the signal which is equal to the sample delay for one frame minus the total filter delay. The second COMPLEX VARIABLE DELAY blocks time aligns the reflected paths for the fading coefficients which, for this case, is equal to the sample delay for one frame minus half the total filter delay.

The next block is the Ideal rake Receiver block which is shown in Figure 5.5. The Ideal rake Receiver block has a similar structure as the non-ideal block except for an additional VECTOR

TO SCALAR block containing fading channel coefficients. Clicking on a RAKE FINGER in this Figure, shows the block diagram displayed in Figure 5.6.

Figure 5.4: SPW block for the ideal receiver

Figure 5.5: SPW block for the ideal rake receiver

Figure 5.6: SPW block for ideal receiver rake finger

As shown in this figure, the channel coefficient values are complex conjugated, and multiplied with the data chips to perform fade compensation. The output signal is then passed through the COMPLEX DOWNSAMPLE block. The output of this block is subsequently fed into a COMPLEX DESPREAD block, which removes the PN sequence from the data, and then despreads it with the Walsh function W0. It is this stream that forms the *data_chip* output of the RAKE FINGER block.

5.4 Channel Despread

Following the RAKE RECEIVER block is the CHANNEL DESPREAD block. This block takes the data chips output by each finger of the rake and separates them into the individual channels using the channel Walsh functions.

Clicking on the CHANNEL DESPREAD block in the receiver block displays its contents as in Figure 5.7. As can be seen, this Figure shows a series of WALSH DESPREAD blocks – one for each code channel in the reverse link model, and a set of blocks to locally generate the Walsh functions. For the non-traffic channels, a Walsh function is generated by an IS95 WALSH SEQUENCE block, followed by a bulk delay block, with the delay equal to one frame in chips. There is also an additional block that splits the complex data from the rake fingers into real and imaginary parts.

Clicking on a WALSH DESPREAD block, reveals a set of six smaller WALSH DESPREAD blocks (one for each rake finger) which despread the data on each finger individually using the same Walsh function. The despread data for each finger is then combined into a vector scalar.

The components of the vector are then summed (real and imaginary parts summed separately) to give the despread scalar value[6]
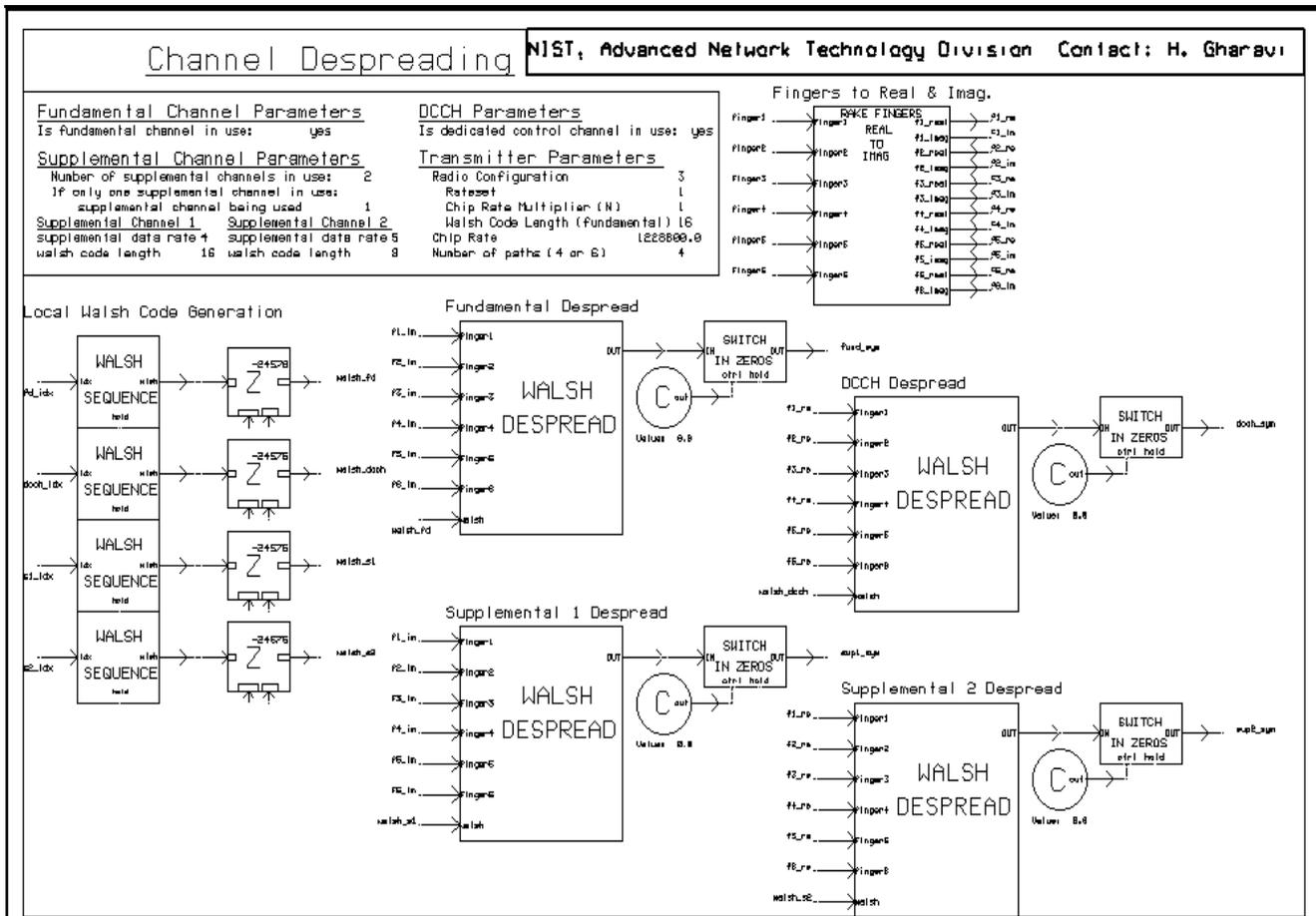
Figure 5.7: SPW block for channel despreading

The Walsh despreading is implemented as follows. First, if the data is traffic data then any rotation to give a QOF is removed. The complex data chips are then split into real and imaginary streams. Each stream is fed into a SIMPLE CORRELATE AND DUMP block, correlating the data with the walsh function. These blocks are reset every symbol period (Walsh length). The outputs of the SIMPLE CORRELATE AND DUMP block is then down sampled by the Walsh length, taking the last sample in every symbol period. This value represents the despread modulation symbol output. It should be noted that as the input data chips are scalar there is only a SIMPLE CORRELATE AND DUMP block followed by a DOWN SAMPLE block used for the reverse link. In addition, since the outputs of the CHANNEL DESPREAD block are scalar, there would be no need for de-modulation.

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[6] Please note that in this implementation "Maximal Ratio Combining" has not been considered.

6. Base Station Decoding

The reverse link decoder shown in Figure 6.1 consists of three major blocks-Fundamental decoder, Supplemental decoder, and dedicated control channel (DCCH) decoder. The supplemental channel block consists of supplemental-1 channel (R-SCH1) decoder and supplemental-2 channel (R-SCH2) decoder. The decoders for all the channels are the reverse of the encoders, with the exception of the fundamental channel.

The fundamental channel uses blind rate detection to determine the data rate. The fundamental decoder first removes the long code (using inverse of long code and a SIMPLE DESPREAD block). The data is then formed into frames using the SCALAR TO VECTOR block. Each frame is de-interleaved, and the output from the de-interleaver is fed into one of four decoding paths.

Each path consists of a DEPUNCTURE block which inserts zeros into the data stream, where encoded data was punctured. Then, with the exception of the full rate path in the forward link, the data is averaged over the repetition length (opposite of symbol repetition in encoding).

Following the removal of any symbol repetition, the error-correcting code is removed using a VITERBI DECODER block. The CRC is then checked and removed together with the reserved bit.

The CRC check and the Viterbi metric are used in the blind rate detection, as will be described in the following section. The output of the DATA RATE DECISION block (right side of block diagram) is used to select the output data frame. Further details of blind rate detection and SPW implementation are described in the following section.

6.1 Blind Rate Detection

Traffic data rates on fundamental channels are variable, with the ability to change on a frame by frame basis. Since the rate information is not explicitly transmitted, a decision must be made at the receiver based on the incoming frame. The rate decision determines which of the four frame formats is assumed for the given radio configuration.

Please note that no particular rate decision algorithm has been described in the cdma2000 specification. In the following section, the rate decision mechanism implemented for SPW modeling is discussed together with some general information on rate decision. Bear in mind that rate decisions are not necessary for supplemental channels since the rates are fixed.
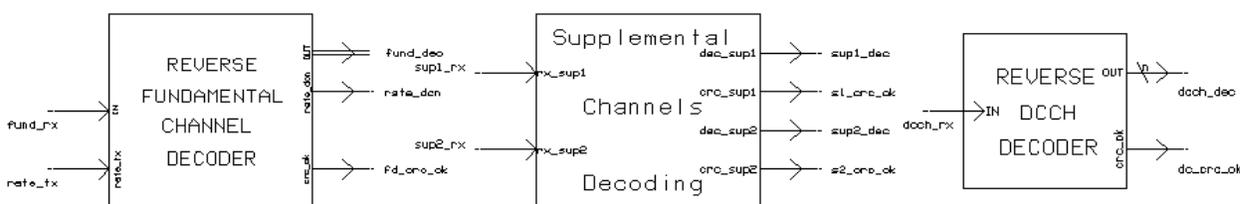
Figure 6.1: SPW block for base station decoding

6.2 SPW Implementation

Following the deinterleaving process at the receiver, the fundamental traffic data is decoded in four parallel paths – one for each of the possible rates. As shown in Figure 6.2, the output of these paths is the decoded data assuming a specific rate. The rate decision block simply chooses one out of the four possible outputs to be passed on as the decoded data.

The rate decision is selected based on the CRCs and Viterbi metrics computed in each of the paths. In the event of a single CRC success, the rate that triggers the success is chosen. It is necessary to have another decision measure, both as a backup and to handle the lower rates of radio configuration 1, which does not include CRCs. For cases of zero or multiple successes, the Viterbi metric is the determining factor. This measure represents the accumulated metric associated with the winning path of the Viterbi decoder. The Viterbi metrics are first scaled to account for the difference in encoded bit stream length that the metrics are computed over. The rate associated with the maximum (correlation) metric is selected in this case.

It should be noted that in the reverse link model an option of selecting an ideal blind rate detection has also been included. This is performed by directly feeding the rate information from the fundamental encoder block to the fundamental channel decoder block.
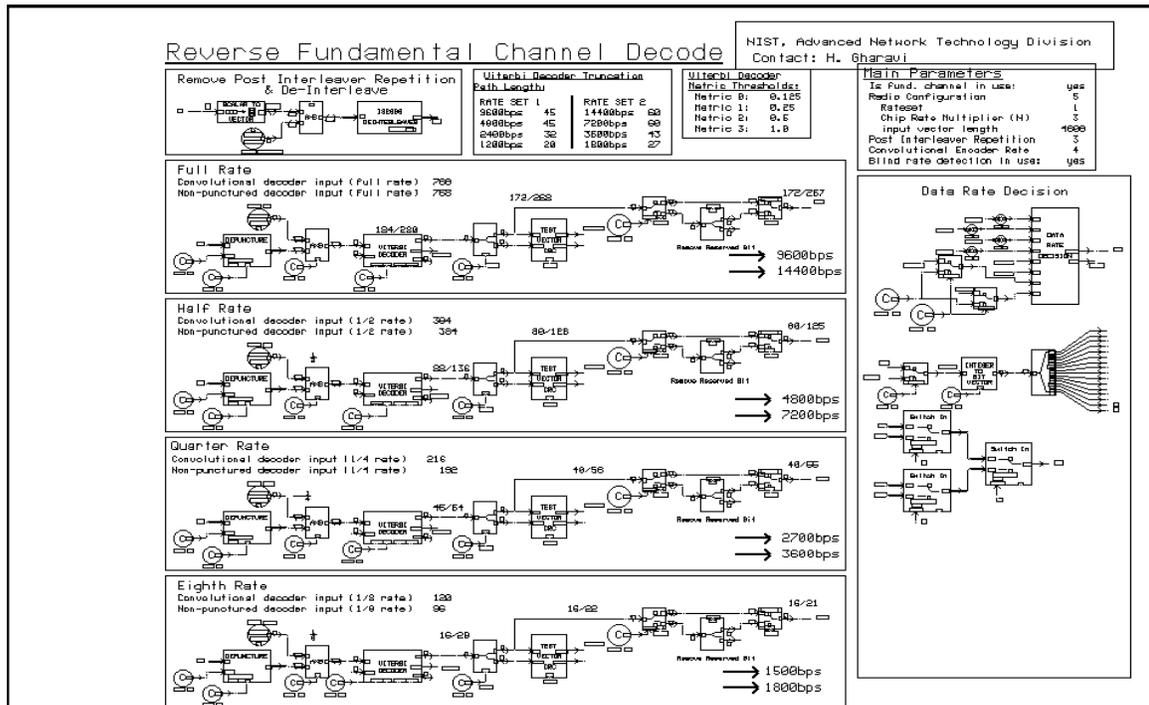
Figure 6.2: SPW block for fundamental channel decoding and blin rate dection

7. FER & BER Count

Once the data has been decoded, it is compared with the transmitted data and bit-error and frame-error ratios are calculated. The FER is calculated for both supplemental channels and the fundamental channel. In particular, for the fundamental channel, it is important to know if the blind rate detection is working or not. BERs are calculated for all channels. The final BERs and FERs at the end of a simulation can be found in the error log file for that simulation.

The FER & BER COUNT block contains FER/BER blocks for all the channels. Within each FER/BER block a filename can be defined to record the FER/BER every frame (parameter: *Filename for Error Ratios)*. Another filename (or two for the fundamental channel) can be set to record the BER/FER at the end of each simulation run – parameter above WRITE AT END (file) block. Within this block, a parameter can be set so that it either overwrites or appends the error ratio to the given file. Default value is 'w' (overwrite).

8. Link Budget

The reverse link power budget is based on the equations specified in the cdma2000 Physical Layer Proposal [3]. In the equations, mean power is referenced to the nominal CDMA Channel bandwidth of 1.23 MHz for spreading rate 1 (*N=1*) and 3.69 MHz for spreading rate 3 (*N=3*).

For simplicity, Code Channel is used to represent the Reverse Fundamental Channel (*R-FCH*), the Reverse Supplemental Channel 1 (*R-SCH1*), the Reverse Supplemental Channel 2 (*R-SCH2*), or the Reverse Dedicated Control Channel (*R-DCCH*).

The output power of each Code Channel is set by the mobile station relative to the output power of the Reverse Pilot Channel (*R-PCH*). Therefore, the first task is to determine the output power of the *R-PCH*, P_{pilot} using open loop power estimation. Then, the output power of every Code Channel, P_{code} can be calculated, based on P_{pilot} and the stored parameters in the mobile station. The calculated P_{code} is then applied to the Relative Gain block shown in Figure 3.1 so that every Code Channel can be adjusted to its desired output power for transmission.

8.1 Pilot Output Power Calculation

The equation for calculating the mean pilot channel output power when transmitting on the Reverse Traffic Channel[5] with Radio Configurations (*RC*) 3 through 6 is as follows:

P_{pilot} *(dBm) =*

– Mean input power (dBm)
+ Offset power
+ NOM_PWRS – (16 x NOM_PWR_EXTS)
+ INIT_PWRS
+ RL_GAIN_ADJS   *Equation 1*

where P_{pilot} is the mean pilot channel output power. *Mean input power* is the received power at the mobile station's antenna connector (Iorx) from the base station. O*ffset power* is summarized in Table 8.1 for different Radio Configurations.

Table 8.1: Open loop power offsets for Reverse Traffic Channel

Spreading Rate	Radio Configuration	Offset Power[7]
1	3 or 4	-84.5
3	5 or 6	-79.5

---

[7] For simplicity, the Offset Power constants are expressed without units. For example, -73 is equal to $10 \times \log 10(10^{-7.3}$ mW$^2)$.

NOM_PWR$_S$ is the nominal transmit power adjustment. *NOM_PWR_EXT$_S$* is the extended nominal transmit power offset. These two parameters are correction factors to be used by the mobile station in the open loop power estimate, initially applied on the Access Channel[8].

INIT_PWR$_S$ is the adjustment that is made to the first Access Channel probe so that it can be received somewhat below the level required for it to be detected by the base station. This conservatism partially compensates for occasional, partially decorrelated path losses between the Forward CDMA Channel and the Reverse CDMA channel.

The purpose of having both an *INIT_PWR$_S$* and a *NOM_PWR_EXT$_S$* is to distinguish between their uses. If *INIT_PWR$_S$* were 0, then *NOM_PWR$_S$ – (16 x NOM_PWR_EXT$_S$)* would be the correction that should provide the correct received power at the base station. The *NOM_PWR$_S$ – (16 x NOM_PWR_EXT$_S$)* correction allows the open loop estimation process to be adjusted for different operating environments. The total range of the *NOM_PWR$_S$ – (16 x NOM_PWR_ EXT$_S$)* correction is –24 to +7 dB. The range of the *INIT_PWR$_S$* is –16 to +15 dB, with a nominal value of 0 dB.

RL_GAIN_ADJ$_S$ is the gain adjustment of the channel relative to the last channel used (i.e. the Access Channel, the Enhanced Access Channel[9], or the Reverse Common Control Channel[10]) before the Reverse Traffic Channel is operating. As a whole, it can be seen that P_{pilot} will be adjusted to a higher value as soon as the *Mean input power* drops or vice versa, provided the stored parameters mentioned above are kept constant.

8.2 SPW Implementation

The mean pilot channel output power, *Ppilot* is calculated in the SPW reverse link model from the following parameters, based on Equation 1 (see Figure 8.1):

> Received power at the mobile station's antenna connector (*Iorx*) – set by user.
> Offset power – defined in Table 8.1.
> NOM_PWRS, NOM_PWR_EXTS, and INIT_PWRS – set by user.

The total range of the *NOM_PWRS – (16 x NOM_PWR_EXTS)* correction is –24 to +7dB.
The range of *INIT_PWRS* is –16 to +15dB.

> *RL_GAIN_ADJS* – set by user.

---

[8] Access Channel is used by the mobile station for controlling and sending short messages such as call origination, page response, and registration.

[9] Enhanced Access Channel is used by the mobile station to initiate communication with the base station or to respond to a mobile station directed message.

[10] Reverse Common Control Channel is used for the transmission of user and signaling information to the base station when Reverse Traffic Channel is not in use.

<u>Link Budget Parameters</u>

```
Received Power at Mobile Station   -75.0 dBm/1.23MHz   3.16227766e-11 W/1.23MHz  N=1
       Antenna connector (Iorx)           dBm/3.69MHz                   W/3.69MHz  N=3

Open loop power offset             -84.5
```

<u>Mobile Station Stored Parameters</u>

```
NOM_PWRs                    0.0    RLGAIN_TRAFFIC_PILOTs          0.0
NON_PWR_EXTs                0.0    RLGAIN_SCH_PILOT[1]s           0.0
INIT_PWRs                   0.0    RLGAIN_SCH_PILOT[2]s           0.0
RL_GAIN_ADJ                 0.0


Calculated Pilot Power      -9.5 dBm      0.0001122018454 W
```

Figure 8.1: Pilot channel output calculation in SPW

With Radio Configuration 3 (*RC=3*), the *Offset power* is equal to –84.5 (see Table 8.1). As shown in Figure 8.1, each of the stored parameters *NOM_PWR$_S$, NOM_PWR_EXT$_S$, INIT_PWR$_S$, and RL_GAIN_ADJ$_S$* is set to zero. Using Equation 1,

$$\boldsymbol{P_{pilot}} = -(-75) + (-84.5) + 0 - (16 \times 0) + 0 + 0 = -9.5 \text{ dBm.}$$

This value in dBm is converted into W, which equals to $10^{\frac{-9.5-30}{10}} = 0.112$ mW, and applied to the Relative Gain block of the Reverse Pilot Channel.

8.2 Code Channel Output Power Calculation

Based on the output power of the Reverse Pilot Channel, P_{pilot} calculated in Equation 1, the mobile station sets the output power of each of the Code Channels (*R-FCH, R-SCH1, R-SCH2 or R-DCCH*), P_{code} as follows[11]:

P_{code} *(dBm) =*
> P_{pilot} *(dBm)*
> *+ 0.125 x (Nominal_Attribute_Gain*
>   *– Multiple_Channel_Adjustment_Gain)*
> *+ RLGAIN_TRAFFIC_PILOTS*
> *+ RLGAIN_SCH_PILOT [i]S)*   Equation 2

In Equation 2, *Nominal_Attribute_Gain* represents the nominal *R-FCH, R-SCH1, R-SCH2, or R-DCCH* power relative to the Reverse Pilot Channel power. This parameter is defined in Table 8.2

---

[11] The values of Nominal_Attribute_Gain, Multiple_Channel_Adjustment_Gain, RLGAIN_TRAFFIC _PILOT$_S$, and RLGAIN_SCH_PILOT$_S$ are integers, specified in units of 0.125 dB

for each data rate in rateset 1 and rateset 2 supported by the mobile station[12]. The integer value under the *Input Data Rate* column is used as an index to specify the data rate (in kbps) in rateset 1 and rateset 2.

Each Code Channel is assigned a *Nominal_Attribute_Gain* depending on the data rate operated on that Code Channel. For example, if the *R-SCH1* is transmitting at data rate 4 (19.2 kbps) with Radio Configuration 5 (corresponds to rateset 1), the *Nominal_Attribute_Gain* would be 50. It can be seen in Table 8.2 that the *Nominal_Attribute_Gain* increases with the data rate in kbps.

Similarly, *Pilot_Reference_Level* is also specified in Table 8.2. Each Code Channel is associated with its *Pilot_Reference_Level* depending on the data rate operated on that Code Channel. *Pilot_Reference_Level* is used to determine the *Multiple_Channel_Adjustment_Gain* of the channel.

Table 8.2: Nominal_Attribute_Gain and Pilot_Reference_Level Table

Input Data Rate	Data Rate (in kbps)		Nominal_Attribute_Gain		Pilot_Reference_Level	
	rateset 1	rateset 2	rateset 1	rateset 2	rateset 1	rateset 2
0	9.6	14.4	30	44	0	3
1	4.8	7.2	-2	15	0	3
2	2.7	3.6	-22	-13	0	3
3	1.5	1.8	-47	-42	0	3
4	19.2	28.8	50	56	1	7
5	38.4	57.6	60	72	11	14
6	76.8	115.2	72	80	21	28
7	153.6	230.4	84	88	36	43
8	307.2	460.8	96	104	54	61
9	614.4	1036.8	112	128	68	83

If the mobile station is transmitting on only one Code Channel in addition to the Reverse Pilot Channel, then the *Multiple_Channel_Adjustment_Gain* shall be set to zero. If the mobile station is transmitting on two or more Code Channels in addition to the Reverse Pilot Channel, then the *Multiple_Channel_Adjustment_Gain* is calculated as follows:

---

[12] The data rates in Radio Configurations 3 and 5 are included in rateset 1, while the data rates in Radio Configuration 4 and 6 are in included in rateset 2.

1) Select the Code Channel having the highest *Pilot_Reference_Level* among all the Code Channels as *Max_Channel.*

2) Set *Multiple_Channel_Adjustment_Gain* of the Max_Channel to 0.

For all other Code Channels,

Multiple_Channel_Adjustment_Gain =
> *Pilot_Reference_Level* of the Max_Channel
> − *Pilot_Reference_Level* of that particular Code Channel

Equation 3

As an example, the mobile station is transmitting with Radio Configuration 5 (rateset 1) on the *R-FCH* at data rate 0, *R_DCCH* at data rate 0, *R-SCH1* at data rate 4, and *R-SCH2* at data rate 5. The calculation of *Multiple_Channel_Adjustment_Gain* for every Code Channel based on its associated *Pilot_Reference_Level* is shown in Table 8.3.

In this example, *R-SCH2* is the *Max_Channel,* which has the highest *Pilot_Reference_Level* of 11 among all the Code Channels. However, the *Multiple_Channel_Adjustment_Gain* of the *R-SCH2* equals to 0, which is the lowest among all the Code Channels.

Table 8.3: Example of Multiple_Channel_Adjustment_Gain calculation

Code Channel	Input Data rate	*Pilot_Reference_Level*	*Multiple_Channel_ Adjustment_Gain*
R-FCH	0	0	11 − 0 = 11
R-DCCH	0	0	11 − 0 = 11
R-SCH1	4	1	11 − 1 = 10
R-SCH2	5	11	0

P_{code} is further adjusted by *RLGAIN_TRAFFIC_PILOTS*, which is the gain adjustment of the Reverse Traffic Channel relative to the Reverse Pilot Channel. Similarly, *RLGAIN_SCH_PILOT [i]S* is the gain adjustment of the Reverse Supplemental Channel i relative to the Reverse Pilot Channel.

The adjustment *RLGAIN_SCH_PILOT[i]S* is valid for Reverse Supplemental Channels only. Both *RLGAIN_TRAFFIC_PILOTS* and *RLGAIN_SCH_PILOTS* are the mobile stations stored parameters.

8.3 SPW Implementation

Based on Equation 2, the output power for each of the *R-FCH*, *R-SCH1*, *R-SCH2*, or *R-DCCH* is calculated in the SPW reverse link model from the following parameters:

P_{pilot} – calculated from Equation 1.

Nominal_Attribute_Gain – defined in Table 8.2.

Multiple_Channel_Adjustment_Gain – calculated from Pilot_Reference_Level, which is also defined in Table 8.2.

RLGAIN_TRAFFIC_PILOTS – set by user.

RLGAIN_SCH_PILOT [i]S – set by user.

An example of calculating the output power for every Code Channel is shown in Figure 8.2. The mobile station is configured to transmit with Radio Configuration 5 (rateset 1) on the *R-FCH* at data rate 0, *R-DCCH* at data rate 0, *R-SCH1* at data rate 4, and *R-SCH2* at data rate 5.

First, the pilot channel output power, P_{pilot} is calculated using Equation 1. For Radio Configuration 5, the *Offset power* is equal to –79.5 (see Table 8.1). By having the following parameters set by the user in Figure 8.2:

Mean input power (Iorx) = −89.5 dBm,
NOM_PWRS = 0,
NOM_PWR_EXTS = 0,
INIT_PWRS = 0,
RL_GAIN_ADJS = 0,

P_{pilot} is equal to −(−89.5) + (−79.5) + 0 – (16 x 0) + 0 + 0 = 10 dBm.

Table 8.4: Parameter calculation on every Code Channel

Code Channel	Input Data rate	*Nominal_ Attribute_Gain*	*Pilot_Reference_ Level*	*Multiple_Channel_ Adjustment_Gain*
R-FCH	0 (9.6 kbps)	30	0	11 − 0 = 11
R-DCCH	0 (9.6 kbps)	30	0	11 − 0 = 11
R-SCH1	4 (19.2 kbps)	50	1	11 − 1 = 10
R-SCH2	5 (38.4 kbps)	60	11	0

Second, the *Nominal_Attribute_Gain* and *Pilot_Reference_Level* for every Code Channel are determined from Table 8.2, depending on the data rate operated on the channel. As discussed in the previous section, the *Multiple_Channel_Adjustment_Gain* is calculated from the *Pilot_ Reference_Level*. The result is summarised in Table 8.4.

```
Link Budget Parameters
Received PSD at Mobile Station    -89.5 dbm/1.23MHz 1.122018454e-12W/1.23MHz  N=1
    Antenna connector (Iorx)            dBm/3.69MHz                W/3.69MHz   N=3
open loop power offset            -79.5 dB
Mobile Station Stored Parameters
NOM_PWRs                0.0         RLGAIN_TRAFFIC_PILOTs    0.0
NON_PWR_EXTs            0.0         RLGAIN_SCH_PILOT[1]s     0.0
INIT_PWRs              0.0         RLGAIN_SCH_PILOT[2]s     0.0
RL_GAIN_ADJ            0.0

Calculated Pilot Power          10.0  dBm   0.01            W
Highest Pilot_Reference_Level     11

Fundamental Channel Power
Nominal_Attribute_Gain 30
Pilot_Reference Level    0
Fundamental power      12.375    dBm 0.01727825981   W

DCCH Power
Nominal_Attribute_Gain   30
Pilot_Reference_Level     0
DCCH power              12.375  dBm 0.01727825981   W

Supplemental Channel 1 Power
Nominal_Attribute_Gain   50
Pilot_Reference_Level     1
Supplemental 1 power    15.0    dBm   0.0316227766    W

Supplemental Channel 2 Power
Nominal_Attribute_Gain   60
Pilot_Reference_Level    11
Supplemental 2 power    17.5     dBm  0.05623413252 W
```

Figure 8.2: Code Channel Power Calculation in SPW

Third, *RLGAIN_TRAFFIC_PILOT$_S$*, *RLGAIN_SCH_PILOT [1]$_S$*, and *RLGAIN_SCH_PILOT[2]$_S$* are set to 0 by user as shown in Figure 8.2.

Eventually, the output power of every Code Channel is calculated as follows:

1) *R-FCH* output power = 10 + 0.125 (30 – 11 + 0) = 12.375 dBm;
2) *R-DCCH* output power = 10 + 0.125 (30 – 11 + 0) = 12.375 dBm;
3) *R-SCH1* output power = 10 + 0.125 (50 – 10 + 0 + 0) = 15.0 dBm;
4) *R-SCH2* output power = 10 + 0.125 (60 – 0 + 0 + 0) = 17.5 dBm.

Please note that *RLGAIN_SCH_PILOT [i]$_S$* is not applied to the *R-FCH* and the *R-DCCH*. For every Code Channel, the calculated power in dBm is converted into W and applied to the corresponding Relative Gain block shown in Figure 3.1.

From *Equation 2:*

P_{code} *(dBm) =*
   P_{pilot} *(dBm)*
      -0.125 x (Nominal_Attribute_Gain
      - Multiple_Channel_Adjustment_Gain
      + RLGAIN_TRAFFIC_PILOT$_S$
      + RLGAIN_SCH_PILOT [i]$_S$)

9. System Parameters & Performance Evaluations

In the previous section it was shown how the transmit power for each coded channel is calculated relative to the pilot channel . In the reverse link, the signal-to-noise plus interference ratio for a given user for each coded channel consisting of a R-FCH, R-DCCH, SCH1, and SCH2 are calculated. In this measurement, it is assumed that these channels are transmitted via a wideband fading channel with 6 paths, in accordance with the IMT2000 specifications (the parameters of the channel will be discussed later). Figure 3.1, in Section 5 shows the 6 path fading channel that has been used for transmitting the reverse link traffic channel. The noise and interference have been modeled as Additive White Gauassian Noise (AWGN).

The spreading factor for each code channel was set according to the RC and the selected data rate. The reverse pilot channel power is calculated according to the link budget discussed earlier. The pilot channel is an unmodulated spread spectrum signal. The pilot bits are placed at the beginning of each slot. The instantaneous pilot power was set at 3 dB above the data. The chips are oversampled by a factor of 8. The SRRC filter with a roll-off factor of 0.22 was implemented with a complex Finite Impulse Response (FIR) filter.

In our simulations, we assume that each finger in the receiver has perfect synchronization with the corresponding path in the channel with perfect sub-chip synchronization (ideal phase locked loop).

9.1 Signal-to-Noise-Ratio

In the previous section, a description of how the average transmit powers for Reverse Pilot channel (R-PCH), Reverse Fundamental channel (R-FCH), Reverse Supplemental channel 1 (RSCH1), Reverse Supplemental Channel 2 (R-SCH2), and Reverse Dedicated Control Channel (R-DCCH) are calculated. The next step is to calculate Eb/Nt, which is defined as the ratio of the combined received energy per bit to the effective noise power spectral density for R-PICH, R-FCH, R-SCH1, R-SCH2, or R-DCCH [5] at the receiver base station antenna connector.

The Eb/Nt on the Traffic Channel is calculated from the sum of all the individual $[T\_Eb(i)]_{CH}/Nt(i)$ ratios for each of the R-FCH, R-SCH1, and R-SCH2. For example, for R_FCH,

$$\{E_b / N_T\}_{R-FCH} = \sum_{i=0}^{N-1} [T\_E_b(i)]_{R-FCH} / Nt(i)$$

Where N is the number of reflected paths in the transmission channel and the calculation of T_Eb's and Nts are given below:

$$\{T\_EB(i)\}_{R-FCH} = \frac{(path\_loss) \cdot (pwr\_fch) \cdot (pwr(i))}{bitr\_ate}$$

where pwr_fch is the fundamental power calculated from the link budget and pwr (i) is the power of the ith path. For instance, as shown in Figure 4.1, for the six paths IMT-2000 vehicular Model A these powers are defined as: pwr(0) = 0 dB, pwr(1) = - 1 dB, pwr (2) = -9 dB, pwr (3) = -10 dB, pwr (4) = -15, and pwr (5) = -20 dB.

Similarly the total effective noise Nt (i) is obtained as:

$$Nt(i) = I_o * \{\sum_{j=0}^{N-1} pwr(j)\} + Nt \quad j \ne i$$

Where I_0 is defined as the total power spectral density of a single user in the cell and is calculated from the following equation:

$$I_o = \frac{(total\_power \cdot (path\_loss))}{chip\_rate}$$

Nt is the interference power in (W/Hz) which is applied to obtain the variance of the Additive white Gaussian noise (AWGN) and is calculated using the following relationship:

Variance for AWGN generator (in W) = *(channel_os) . (chip_rate) .(Nt)*
Where *channel_os is the channel over sampling and its value is 8.*

9.2 Dependent Parameters for Measurement

9.2.1 Transmitter Parameters

Radio Configuration

This parameter defines the radio configuration in use and sets the values of several other top level parameters. It can take values of 3, 4, 5 or 6.

Rateset

This parameter gives the IS95 rateset of data rates in use. Rateset 1 is based on a full fundamental rate of 9600 bps & rateset 2 is based on a full fundamental rate of 14400 bps.

Spreading Rate

This gives the spreading rate in use – either 1 or 3.

Chip Rate

This parameter is derived from the spreading rate and the mode of transmission. It gives the chip rate of the data that is sent on the RF carrier (1.2288 Mcps for spreading rate 1 and 3.6864 Mcps for spreading rate 3)

Fundamental Walsh Length

This parameter gives the Walsh length of the function used to spread the fundamental data, and is always set to 16.

Channel Rate

This defines the sampling rate for the transmission filter (e.g., 8).

Transmission Filter File/Receiver Filter File

These parameters define the files that contain the filter coefficients for the transmitter & receiver filters.

9.2.2 Fundamental Channel Parameters

Is fundamental channel in use?

This has an value of yes or no and defines whether the fundamental channel is being used or not.

output vector length

This is the frame length after the data has been encoded, interleaved including any post interleaver repetition applied.

post interleaver repetition

This is the value of the post interleaver repetition which rate matches the interleaved symbol rate to the modulation symbol rate. It is 1 for spreading rate 1, and 3 for spreading rate 3.

Walsh index
> This defines index of Walsh function that is the spreading function for data on the fundamental channel.

Is input data rate fixed?
> This has a value of yes or no. If value is yes, then the data rate of the fundamental channel is fixed to one value, otherwise it is random and can change from frame to frame within the simulation.

Input data rate
> This defines the fixed frame rate – takes values of 0, 1, 2 or 3, where 0 = full fundamental data rate (9.6/14.4 kbps), 1 = half rate (4.8/7.2 kbps), 2 = quarter rate (2.7(2.4)/3.6 kbps) and 3 = eighth rate (1.5(1.2)/1.8 kbps).

9.2.3 DCCH Parameters

Is dedicated control channel in use?
> This has an value of yes or no and defines if R-DCCH is being used or not.

Walsh index
> This defines index of Walsh function that is the spreading function for data on the R-DCCH.

9.2.4 Supplemental Channel Parameters

Number of supplemental channels
> This parameter defines the number of supplemental channels that are being simulated. It can take values of 0, 1 or 2.

Supplemental channel being used
> This parameter defines which supplemental channel (1 or 2) is being used if only one channel is in use.

Following the above parameters, are two sets of identical parameters, one set for each supplemental channel.

Supplemental used
> This parameter defines supplemental channel in question is being used or not. It is set from the above 2 parameters, and can take values of yes or no.

Supplemental data rate
> This parameter defines data rate on the channel. It can take values of 0 – 9 where 0 = 9.6/14.4 kbps, 1 = 4.8/7.2 kbps, 2 = 2.7/3.6 kbps, 3 = 1.5/1.8 kbps, 4 = 19.2/28.8 kbps, 5 = 38.4/57.6 kbps, 6 = 76.8/115.2 kbps, 7 = 153.6/230.4 kbps, 8 = 307.2/460.8 kbps and 9 = 614.4/1036.8 kbps (first value rateset 1, second value rateset 2).

Walsh index
> This defines the index of the Walsh function used to spread the channel. It is set, as there are only a limited number of indexes that can be used.

Walsh length
> This defines the length of the Walsh function used to spread the supplemental channel data. It is derived from the fundamental Walsh length & N.

The parameters detailed above are all editable in the models. However, as described, many of them are set by other parameters, so there are only a certain number that should be set by the user. These are:

Transmission Parameters
> Radio configuration (3 - 6)
> Channel rate
> Transmission filter file

Fundamental Channel Parameters
> Is fundamental channel in use?
> Is input data rate fixed?
> Fixed frame rate (0 – 4)

DCCH parameters
> Is dedicated control channel in use?

Supplemental Channel Parameters
> Number of supplemental channels (0 – 2)
> supplemental channel being used (1 or 2)
> data rate (supplemental) (0 – 9)

9.2.5 Link Budget Parameters

Received Power (Iorx) in dBm/1.23MHz or dBm/3.69MHz

Mobile Station Stored Parameters
> *NOM_PWRs*
> *NOM_PWR_EXTs*
> *INIT_PWRs*
> *RLGAIN_TRAFFIC_PILOTs*
> *RLGAIN_SCH_PILOT[1]s*
> *RLGAIN_SCH_PILOT[2]s*
> *Relative channel correction*

9.2.6 Channel Simulator Parameters

Vehicle speed
carrier frequency
path delays (in nsec) and path powers in dB
> This list is comprehensive. The user should not change any parameters not detailed here, as the remaining parameters are calculated from the listed parameters.

9.3 Permitted Parameter Settings

In the reverse link, it is in the supplemental data rates that some non-permitted values can cause problems. Unlike the forward link, the Walsh indexes are specified, and therefore are not set by the user but by SPW. The maximum allowable data rate on the supplemental channels depends on which supplemental channel it is, and the radio configuration. R-SCH2 has less allowable data rates, because the walsh function for this channel is either W_2^4 or W_6^8, whereas for R-SCH1 the Walsh function is either W_1^2 or W_2^4. Table 9.1 defines the radio configurations in which each supplemental data rate is allowed.

Table 9.1: Permitted reverse supplemental data rates versus radio configurations

Supplemental 1 Data Rate (*parameter value*)	Radio Configurations where data rate allowed	Supplemental 2 Data Rate (*parameter value*)	Radio Configurations where data rate allowed
1.5 or 1.8 kbps (*3*)	3, 4, 5 & 6	1.5 or 1.8 kbps (*3*)	3, 4, 5 & 6
2.7 or 3.6 kbps (*2*)	3, 4, 5 & 6	2.7 or 3.6 kbps (*2*)	3, 4, 5 & 6
4.8 or 7.2 kbps (*1*)	3, 4, 5 & 6	4.8 or 7.2 kbps (*1*)	3, 4, 5 & 6
9.6 or 14.4 kbps (*0*)	3, 4, 5 & 6	9.6 or 14.4 kbps (*0*)	3, 4, 5 & 6
19.2 or 28.8 kbps (*4*)	3, 4, 5 & 6	19.2 or 28.8 kbps (*4*)	3, 4, 5 & 6
38.4 or 57.6 kbps (*5*)	3, 4, 5 & 6	38.4 or 57.6 kbps (*5*)	3, 4, 5 & 6
76.8 or 115.2 kbps (*6*)	3, 4, 5 & 6	76.8 or 115.2 kbps (*6*)	3, 4, 5 & 6
153.6 or 230.4 kbps (*7*)	3, 4, 5 & 6	153.6 or 230.4 kbps (*7*)	6 (230.4)
307.2 or 460.8 kbps (*8*)	3, 5 & 6	307.2 or 460.8 kbps (*8*)	5 (307.2)
614.4 or 1036.8 kbps (*9*)	5 & 6	614.4 or 1036.8 kbps (*9*)	None

The supplemental Walsh function is set according to the following rule:

Walsh function W_2^4 is always preferred for supplemental 1
> This means that when possible W_6^8 is used for supplemental channel 2, when both channels are present. This occurs when the supplemental 2 data rate is 57.6 kbps or less, or 115.2 kbps for spreading rate 3. If W_6^8 is used for R-SCH2, and the R-SCH1 data rate is 57.6 kbps or less, or, 115.2 kbps when spreading rate is 3, then W_2^4 is used to spread R-SCH2. Otherwise W_1^2 is used. Here the post interleaver repetition rate matched the interleaved data rate to the required modulation symbol rate.

The choice of Walsh function is made by the SPW model, and should not be altered by the user.

9.4 Channel Simulator Parameters

Noise Power Spectral Density
> PSD of white gaussian noise (thermal and interference) (in dBm/ (CDMA bandwidth)MHz

Path Loss (in dB)
> Average path loss between mobile and base station.

Vehicle speed
> Channel model used is vehicular A, and the parameters define the speed at which the moving vehicle is travelling in kilometers per hour.

Carrier Frequency
> This defines the frequency of the carrier in GHz.

Number of paths
> Either 4 for chip rate 1.2288 Mcps or 6 for chip rate 3.6864 Mcps.

10. Test & Evaluation

Up to five different channel types can be transmitted on the reverse link of the cdma2000 system. The simulation parameters and calculations of the signal-to-noise ration were described in the previous section. These parameters can be set by the user to perform tests under various transmission conditions. The results presented in this report are based on a single user transmission and concentrate mainly on Radio Configuration 5 and 6 of the cdma2000 reverse link. The carrier frequency was set at 1.9 GHz. For every set of experiments the mean output channel powers were calculated by the reverse link model in accordance with the link budget (see section 8). All the initial values and relative gain adjustments in the link budget were set to zero. As discussed earlier, the mean pilot channel power was first calculated by the SPW model's link budget by specifying the Received Power Spectral Density (PSD) at the mobile station's antenna connector.

The results are presented in terms of E_b/Nt versus Bit Error Rate (BER) and Frame–Error Rate (FER). For each test, the necessary parameters are first tabulated and the results are subsequently presented. For each point in the BER/FER graph, E_b/Nt is calculated by changing the value of I_{oc}. In addition, for each set of results the amount of path-loss associated with Lognormal fading has been indicated.

10.1 Measurement 1 (RC = 5)

Table 10.1 Test Parameters and mean power values for measurement 1

Channel	Transmitted channel	Information Rate (kbit/s)	Receiver type	Path_loss (dB)	Vehicular Speed (Km/hr)	P_{code} (dBm)	Received PSD (dBm)
R-PICH	yes	Unmodulated	Non-Ideal	100	100	-3.0	-76.5
R-FCH	yes	9.6 Fixed	"	"	"	-.625	"
R-SCH1	yes	38.4	"	"	"	4.5	"
R-SCH2	yes	38.4	"	"	"	4.5	"
R-DCCH	yes	9.6	"	"	"	-0.625	"
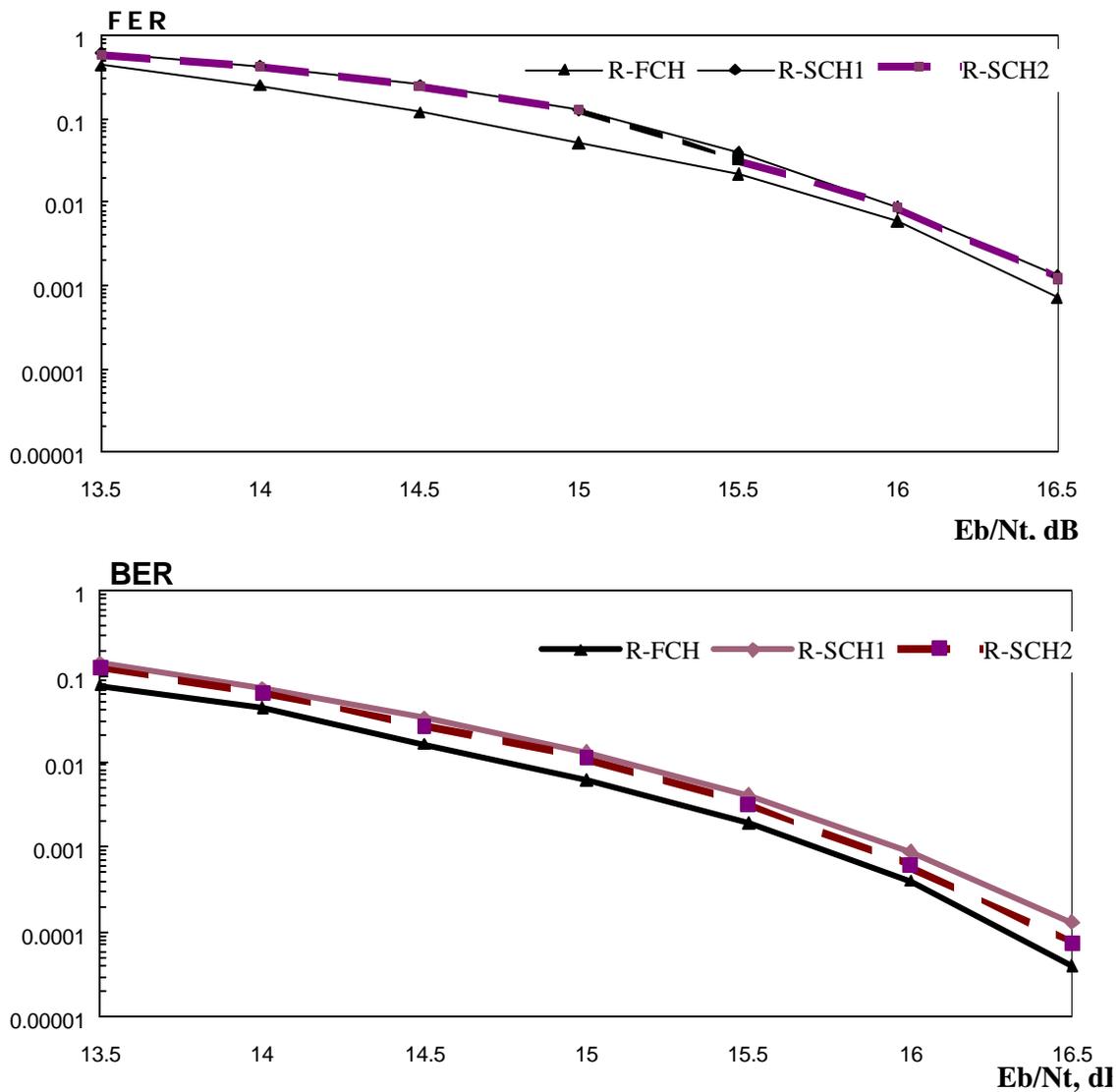
Figure 10.1 FER/BER versus Eb/Nt for R-FCH, R-SCH1, and R-SCH2 using "non-ideal rake-receiver"

10.2 Measurement 2 (Radio Configuration 5)

Table 10.2: Test Parameters and mean power values for measurement 2

Channel	Transmitted channel	Information Rate (kbit/s)	Receiver	Path_loss (dB)	Vehicular Speed (Km/hr)	P_{code} (dBm)	Received PSD (dBm)
R-PICH	yes	Un-modulated	Non-Ideal	100	100	-3	-76.5
R-FCH	yes	9.6	Non-Ideal	100	100	0.625	-76.5
R-SCH1	yes	19.2	Non-Ideal	100	100	3.25	-76.5
R-SCH2	no	19.2	Non-Ideal	100	-	3.25	-
R-DCCH	yes	9.6	Non-Ideal	100	100	0.625	-76.5
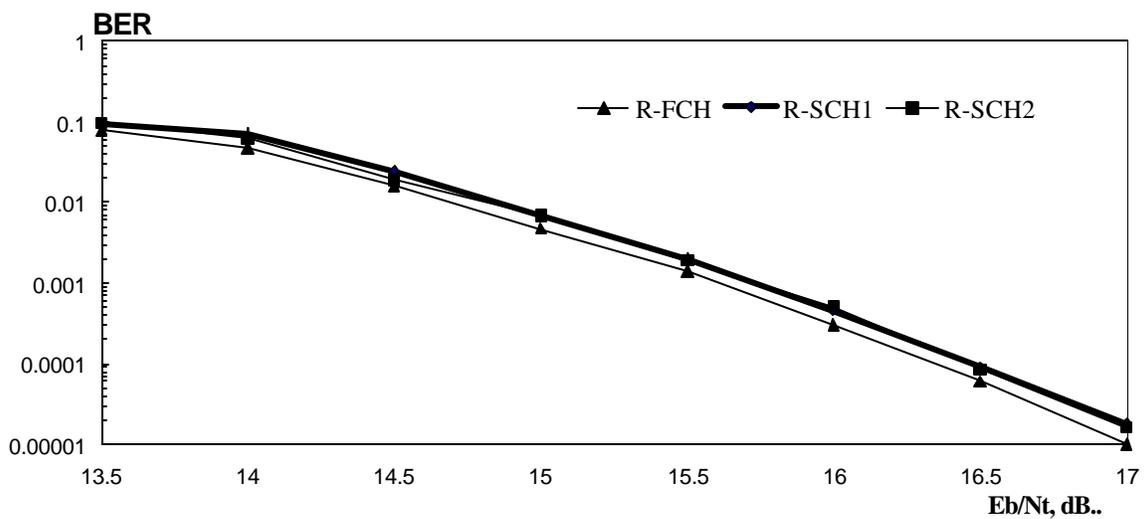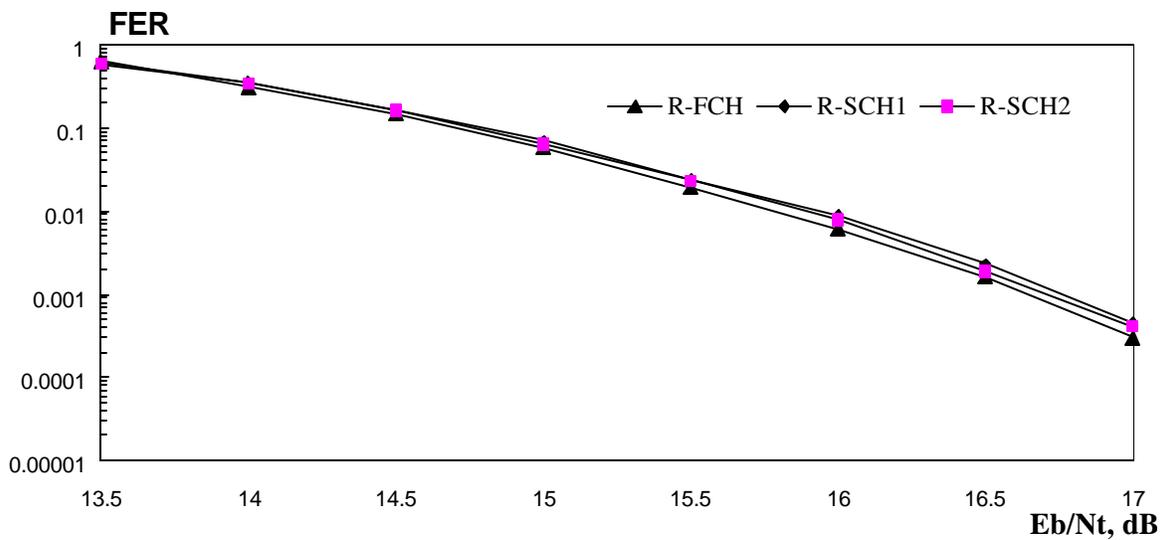
Figure 10.2: FER/BER versus Eb/Nt for R-FCH, R-SCH1, and R-SCH2 using "non-ideal rake-receiver"

10.3 Measurement 3 (Radio Configuration 6)

Table 10.3: Test Parameters and mean power values for measurement 3

Channel	Transmitted Channel	Information Rate (kbit/s)	Receiver	Path_loss (dB)	Vehicular Speed (Km/hour)	P_{code} (dBm)	Received PSD at MS (dBm)
R-PICH	yes	un-modulated	Non-Ideal	100	100	-3	-76.5
R-FCH	yes	14.4	Non-Ideal	100	100	2	-76.5
R-SCH1	yes	28.8	Non-Ideal	100	100	4	-76.5
R-SCH2	yes	28.8	Non-Ideal	100	100	4	-76.5
R-DCCH	yes	14.4	Non-Ideal	100	100	2	-76.5
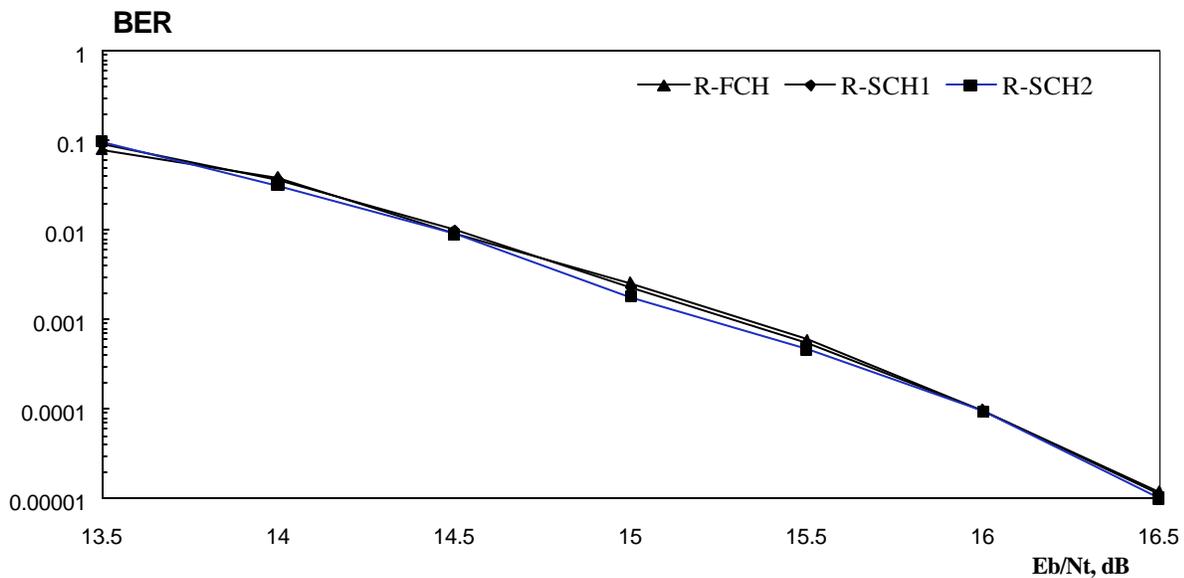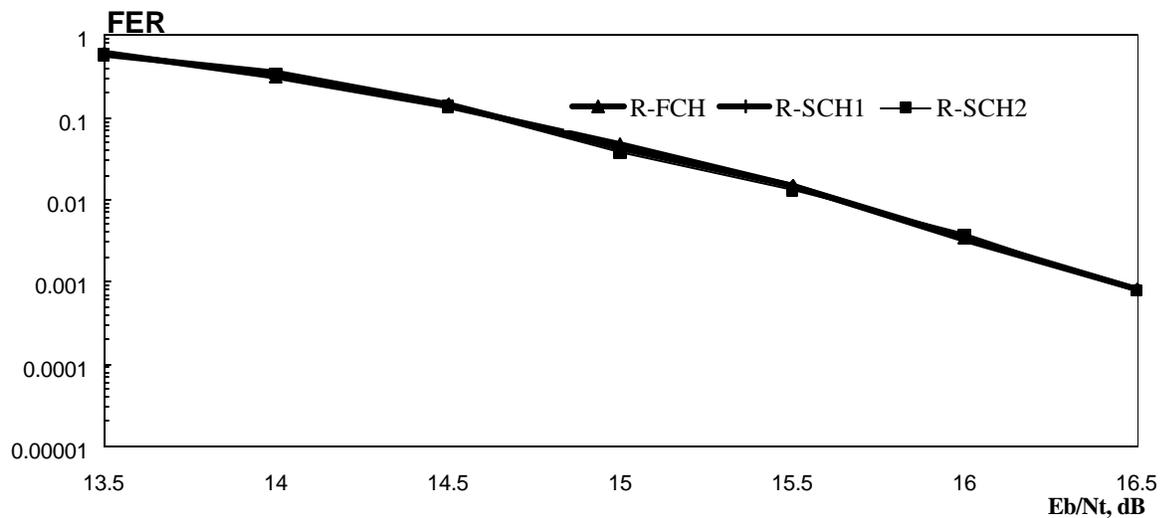
Figure 10.3 FER/BER versus Eb/Nt for R-FCH, R-SCH1, and R-SCH2 using "non-ideal rake receiver"

10.4 Measurement 4 (RC = 5)

Table 10.4: Test Parameters and mean power values for measurement 4

Channel	Transmitted channel	Information Rate (kbit/s)	Receiver	Path_loss (dB)	Vehicular Speed (Km/hr)	P_{code} (dBm)	Received PSD (dBm)
R-PICH	yes	Unmodulated	Ideal	100	100	-3.0	-76.5
R-FCH	yes	9.6 Fixed	"	"	"	-.625	"
R-SCH1	yes	19.2	"	"	"	-3.25	"
R-SCH2	yes	19.2	"	"	"	-3.25	"
R-DCCH	yes	9.6	"	"	"	-0.625	"
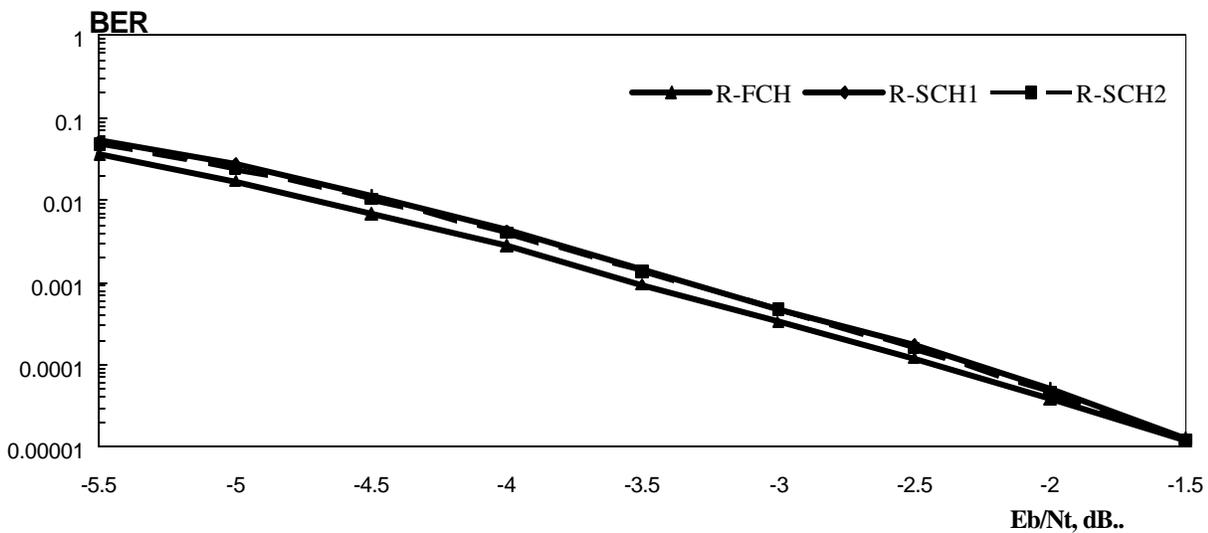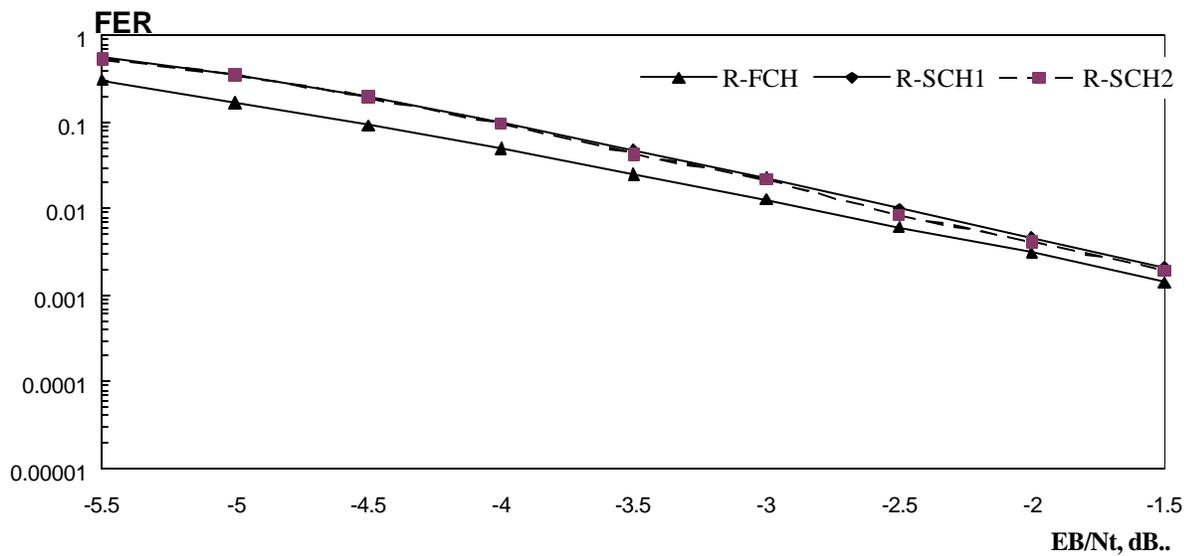
Figure 10.4 FER/BER versus Eb/Nt for R-FCH, R-SCH1, R-SCH2, using "ideal rake receiver"

10.5 Measurement 5 (RC = 6)

Table 10.5 Test Parameters and mean power values for measurement 5

Channel	Transmitted channel	Information Rate (kbit/s)	Receiver	Path_loss (dB)	Vehicular Speed (Km/hr)	P_{code} (dBm)	Received PSD (dBm)
R-PICH	yes	Unmodulated	Ideal	100	100	-3.0	-76.5
R-FCH	yes	14.4 Fixed	"	"	"	2.0	"
R-SCH1	yes	28.8	"	"	"	4.0	"
R-SCH2	yes	28.8	"	"	"	4.0	"
R-DCCH	yes	14.4	"	"	"	2.0	"
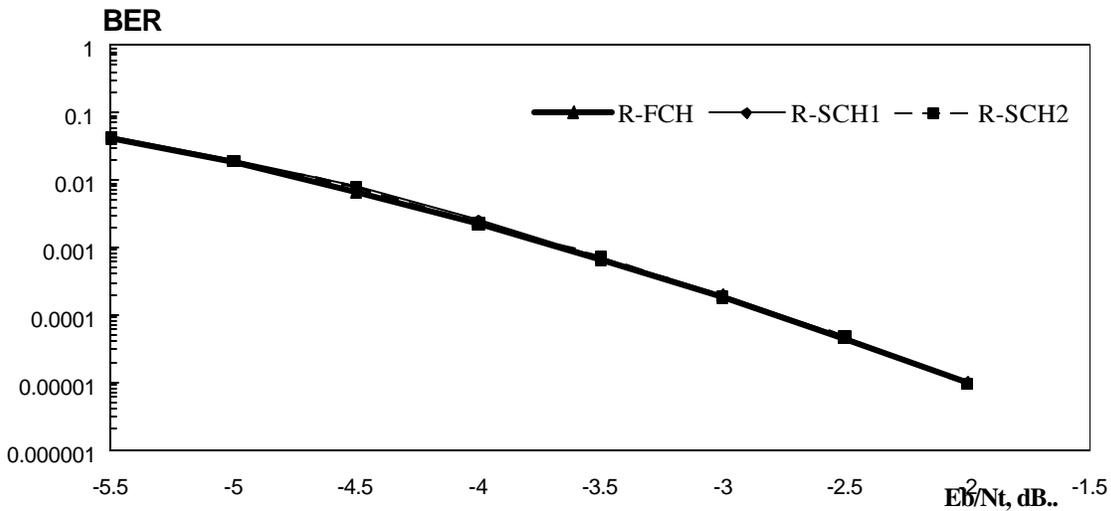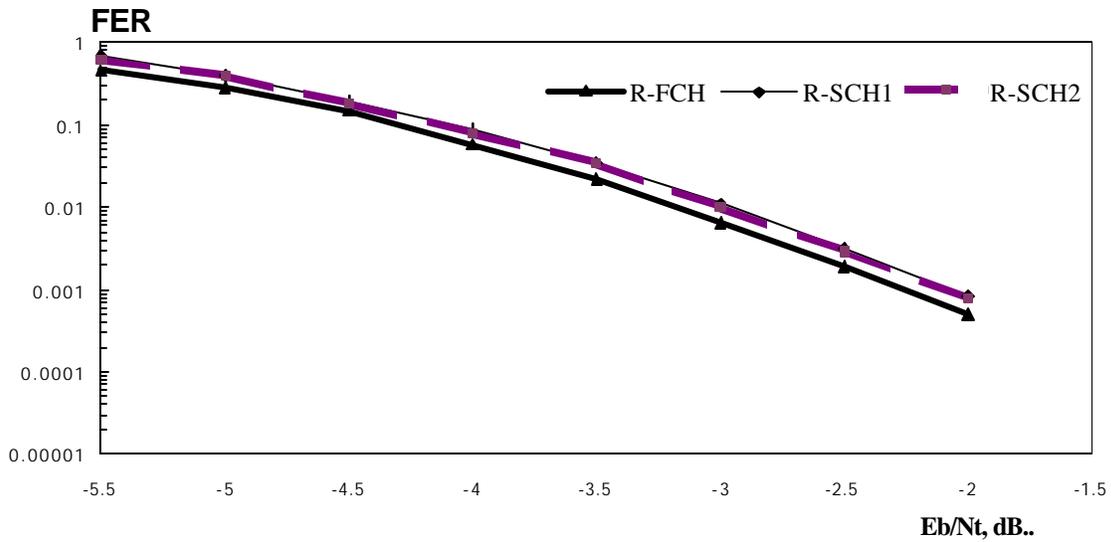
Figure 10.5: FER/BER versus Eb/Nt for R-FCH, R-SCH1, R-SCH2, using "ideal rake receiver"

10.6 Comparisons between Ideal and Non-Ideal Receiver

Comparing the results between the ideal and non-ideal rake receivers indicates a significant performance difference between the two. For instance; for radio configuration 6 (Figures 10.3 and 10.5) the difference in terms of Eb/Nt is nearly 18 dB. One important factor, which may explain such a relatively poor performance, is the fact that, in this model, the channel is estimated without taking into account the neighboring pilot symbols. More importantly, in the despreaded symbols, all the rake fingers are summed together unweighted. Indeed, by applying an appropriate combining method such as "Maximal Ratio Combining,' the performance can be
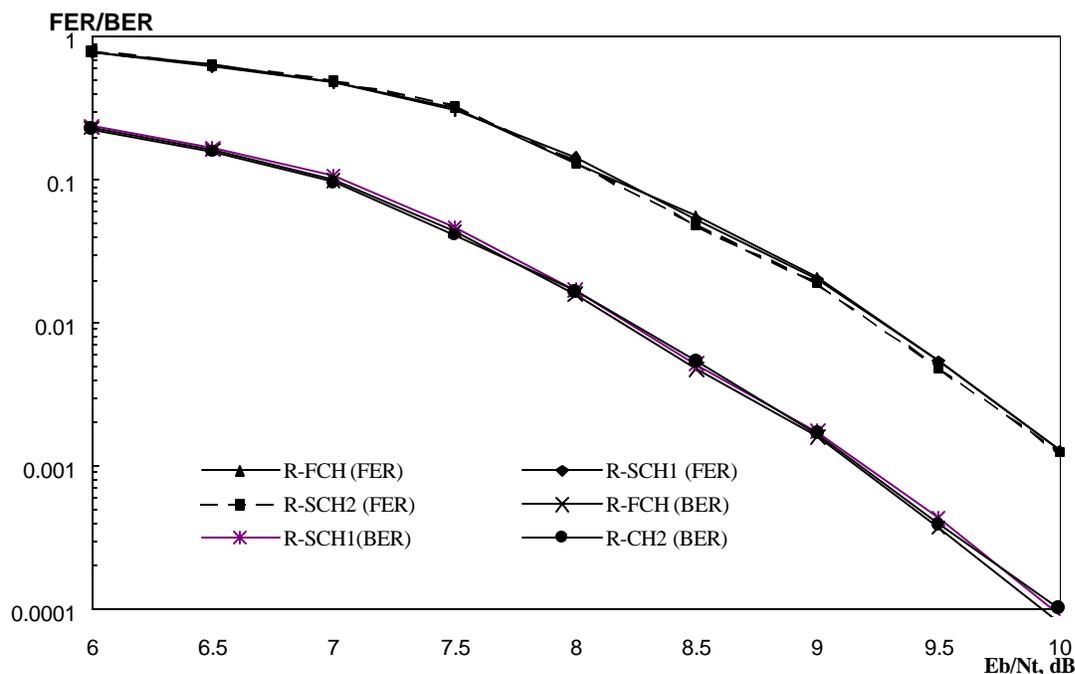
improved considerably. This has been verified in our recent experiments where such a method was incorporated in the rake receiver model. Although further details of the model design are beyond the scope of this report, Figure 10.6 shows the FER/PER performance when Maximal Ratio Combing is applied.

Figure 10.6   FER/BER of the non-ideal rake with "maximal Ratio Combining" receivers for R-FCH, R-SCH1, and R-SCH2.

11. Conclusion

Having previously developed the cdma2000 forward link and the Multicarrier models, the next challenge was to develop the cdma2000 reverse link. CDMA systems rely heavily on strict power control to effectively manage the channel capacity of the system. Each mobile has its own power control to handle the path loss and the aggregate interference. In the cdma2000 reverse link a tight budget link has been specified to handle the power allocation on every transmitted channel. Thus, one of our most important objectives in developing the reverse link has been the implementation and inclusion of the link budget in our model. The link budget has been a crucial factor in performing our measurements according to the test environment and the link parameters specified by the standard.

In addition, as the standard policy is not to recommend any specific design for the receiver, our next challenge was to develop a suitable receiver for our model. Bear in mind that the efficiency of a receiver can have a significant effect on the overall performance of a CDMA system. We have therefore implemented two types of receivers: 1) non-ideal (with the assumption that the receiver knows the multipath delays), and 2) ideal receiver. In our experiments the performance of both receivers has been evaluated and compared. Furthermore, it was suggested that with an additional Maximal Ratio Combining scheme, the rake receiver performance can be enhanced considerably.

Finally, the viability of the cdma2000 reverse link has undergone extensive testing to revalidate the model. However, considering the complexity, the share size of the model, and the limited manpower, there is no way that we can guarantee the full accuracy of the model. Nevertheless, we plan to continue our efforts to further test and revalidate the model and perform further research and investigations to extend the model in conjunction with recent TIA/EIA IS2000 revisions.

12. Reference

[1] TR45.5's RTT candidate submission. *"The cdma2000 ITU-R RTT Candidate Submission (0.18)"* July 27, 1998.

[2] TIA/EIA Interim Standard, "Physical Layer Standard for cdma2000 Spread Spectrum Systems", March 2000 (revision of TIA/EIA/IS-2000.2).

[3] Murali Krishnan, John Lundell and Siavash M. Alamouti *"An SPW Implementation of Wideband DS-CDMA Forward Link Physical Layer"* February 15, 1999.

[4] TIA/EIA/IS-2000.3-A, "Medium Access Control (MAC) Standard for cdma2000 Standards for Spread Spectrum Systems", March 2000.

[5] Standards Proposal No. 3385 (J-STD-018). *"Recommended Minimum Performance Requirements for 1.8 to 2.0 GHZ Code Division Multiple Access (CDMA) Personal Stations"* September 27, 1995.

[6] W. C. Jakes, microwave mobile communications. John Wiley and Sons, INC, , New York (1974).

Acknowledgement:

Appendix A

Convolutional Coding

The generator function for each encoding rate (1/4, 1/3, or ½ is listed in Table A. For the rate 1/3, the generator function g3 is not applicable. For the rate ½ g2 and g3 are not applicable. The code symbols are sent out such that the code symbol (c_0) encoded with generator function g_0 goes out first, the code symbol (c_1) encoded with generator function g_1 is output second, and so forth if necessary.

The state of the convolutional encoder, upon initialization, is the all-zero state. The first code symbol that is output after initialization is a code symbol encoded with generator function g0. The encoders for the three different rates are illustrated in Figure A-1, Figure A-2, and Figure A-3. The constraint length is 9 for every encoder.

Encoding Rate	g0 (octal)	g1 (octal)	g2 (octal)	g3 (octal)
¼	765	671	513	473
1/3	557	663	711	N/A
½	753	561	N/A	N/A

Table A: Generator functions for different encoding rates
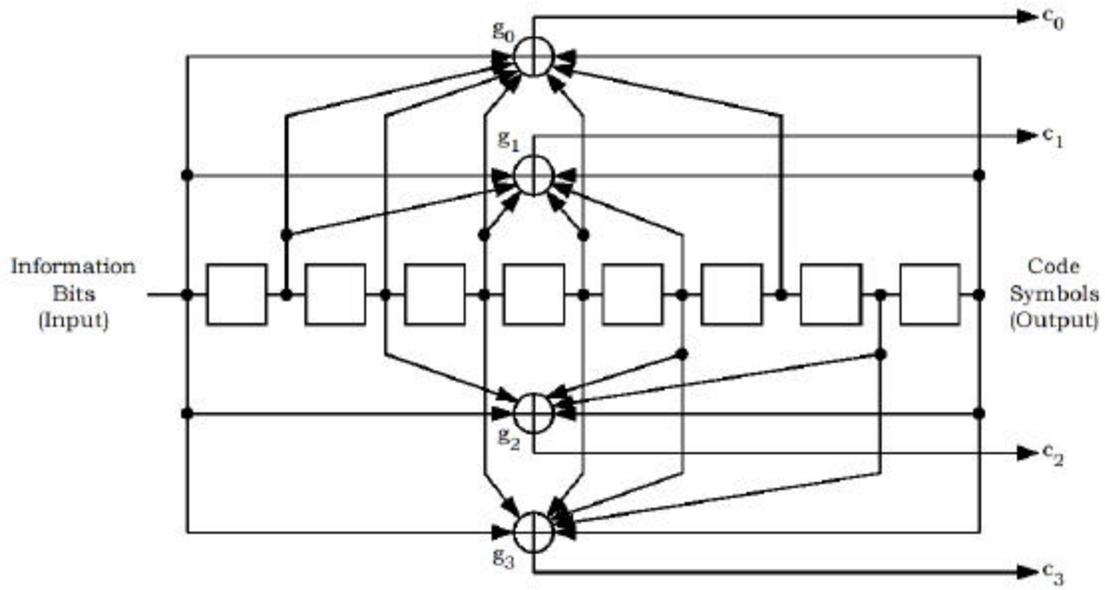
Figure A-1: K = 9, Rate = 1/4 Convolutional Encoder
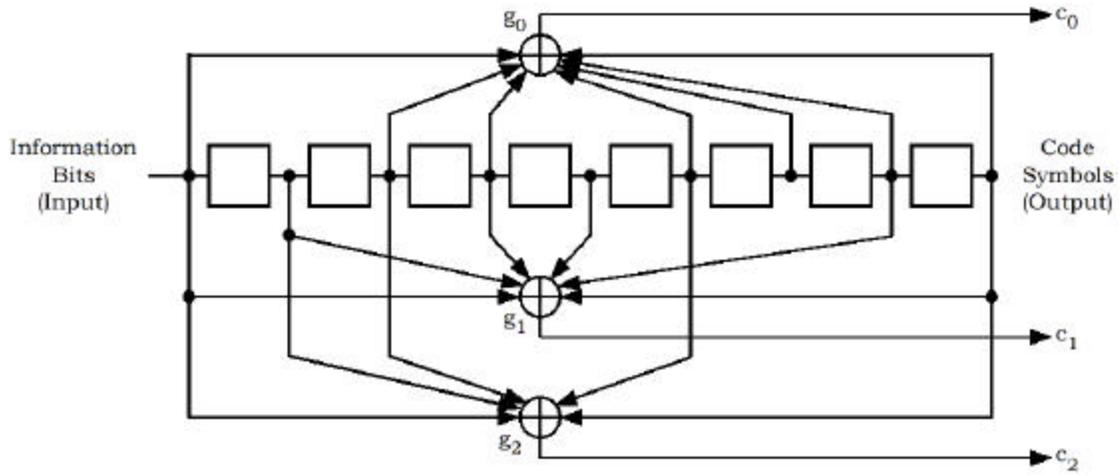
Figure A-2: K = 9, Rate = 1/3 Convolutional Encoder
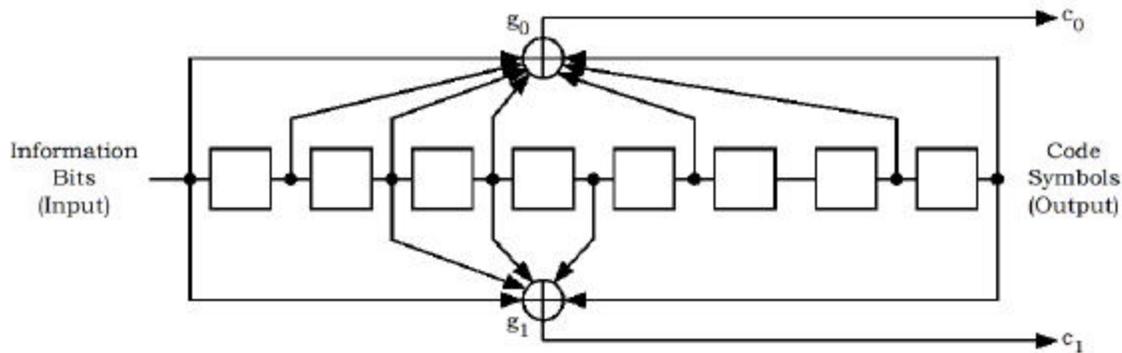
Figure A-3: K = 9, Rate = 1/2 Convolutional Encoder

Appendix B

Walsh Function Generation

The Walsh functions are generated from Hadamard matrices. A Walsh function Wn^N represents a Walsh function of length N that is serially constructed from the n-th row of an N x N Hadamard matrix. The zero-th row being Walsh function 0, the first row being Walsh function 1, etc. Within function n, Walsh chips are transmitted serially from the n-th row from left to right. Hadamard matrices are formed using the following recursion process:

$$\mathbf{H_1} = 0, \quad \mathbf{H_2} = \begin{matrix} 0 & 0 \\ 0 & 1 \end{matrix}, \quad \mathbf{H_4} = \begin{matrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 1 \\ 0 & 0 & 1 & 1 \\ 0 & 1 & 1 & 0 \end{matrix}, \quad \mathbf{H_{2N}} = \begin{matrix} \mathbf{H_N} & \mathbf{H_N} \\ \mathbf{H_N} & \overline{\mathbf{H_N}} \end{matrix}$$

where N is a power of 2 and $\overline{\mathbf{H_N}}$ denotes the binary complement of **HN**.