Forward Traffic Channels

- **Forward Traffic Channels**

- At the end of this section, the following objectives will have been accomplished:
    - Understand what Forward Traffic Channels are used for, how they are generated and which are the main modulation parameters associated with them.
    - Introduce the concept of “Service Options”.
    - Understand the process of analog-to-digital signal conversion
    - Understand the role of the vocoders, the type of vocoders used in CDMA, and where they are physically located.
    - Understand the Forward Traffic Channel frame structure for both the 8 kb and the 13 kb vocoder and the purpose of the “tail bits”.
    - Understand the purpose of the Symbol Puncturing step applied to the modulation symbols when the 13 kb vocoder is used.
    - Introduce the concept of Power Control Subchannel and identify its effect on the Forward Traffic Channel bit stream.
    - Demonstrate how spreading and despreading work in a composite signal made of three different bit streams.
    - Understand the concept of “Composite I” and “Composite Q”
    - Understand the concept of QPSK, “I” and “Q” mapping, signal constellations, and phase transitions
    - Understand how the CDMA Forward Channels are demodulated and the concepts of “correlator”, “search correlator”, “finger” and “rake receiver”.
    - Understand the concept of Traffic Frame Staggering
    - Summarize the messages transmitted on the CDMA Forward Channels

CDMA Forward Traffic Channels



Forward Traffic Channel

Σ

CDMA Cell Site

Pilot

Forward Traffic Channel

Sync

Forward Traffic Channel

Paging

Forward Traffic Channel

- Used for the transmission of user and signaling information to a specific mobile station during a call
- Maximum number of traffic channels: 64 minus one Pilot channel, one Sync channel, and 1 through 7 Paging channels
  - This leaves each CDMA frequency with at least 55 traffic channels
  - Unused paging channels can provide up to 6 additional channels
  - Realistic loading will typically be about 17 subscribers when using the 13 kb vocoder (22 when using the 8 kb vocoder)

Service Options



Service Options

- 8 kb vocoder
- 13 kb vocoder
- mobile station loopbacks
- facsimile
- circuit switched data
- packet switched data
- etc.. . . . . .

Σ

CDMA Cell Site

Forward Traffic Channel

Other Channels

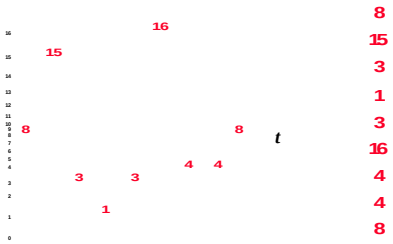
- How *traffic bits* are processed is determined by implementing defined Service Options
- Service Options can be requested as follows:
  - by the mobile station upon call origination and during traffic channel operation
  - by the system when paging the mobile station and during traffic channel operation
  - Service Option type can be changed while a call is in progress
- Mobile station and base station may negotiate the service option to be provided

Digital Stream 0 (DS0)

Analog Voice Signal

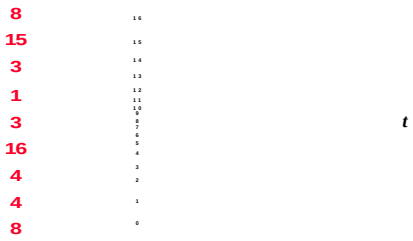
Sampling

Quantizing



64 kbs

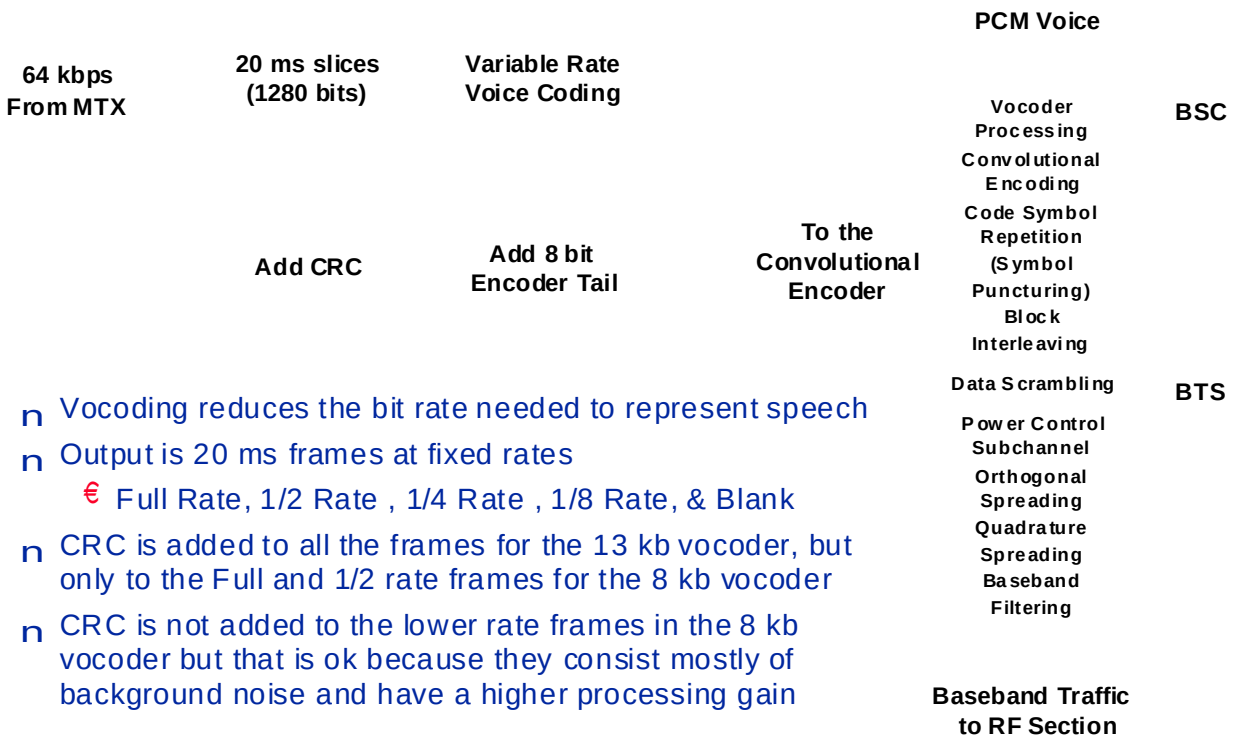
Signal Regeneration



Analog to Digital Conversion

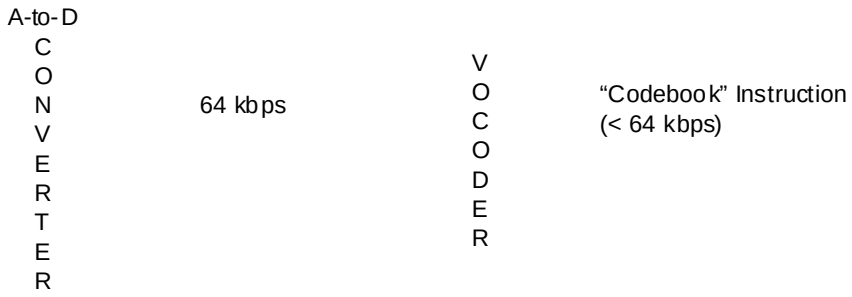
- A-law, devised by CCITT
- MU-Law, devised by BELL

Traffic Channel Vocoding



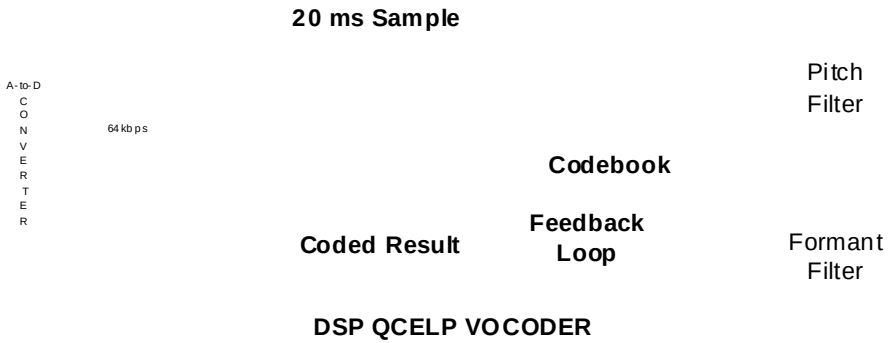
- Vocoding reduces the bit rate needed to represent speech
- Output is 20 ms frames at fixed rates
  - Full Rate, 1/2 Rate , 1/4 Rate , 1/8 Rate, & Blank
- CRC is added to all the frames for the 13 kb vocoder, but only to the Full and 1/2 rate frames for the 8 kb vocoder
- CRC is not added to the lower rate frames in the 8 kb vocoder but that is ok because they consist mostly of background noise and have a higher processing gain

Variable Rate Vocoding



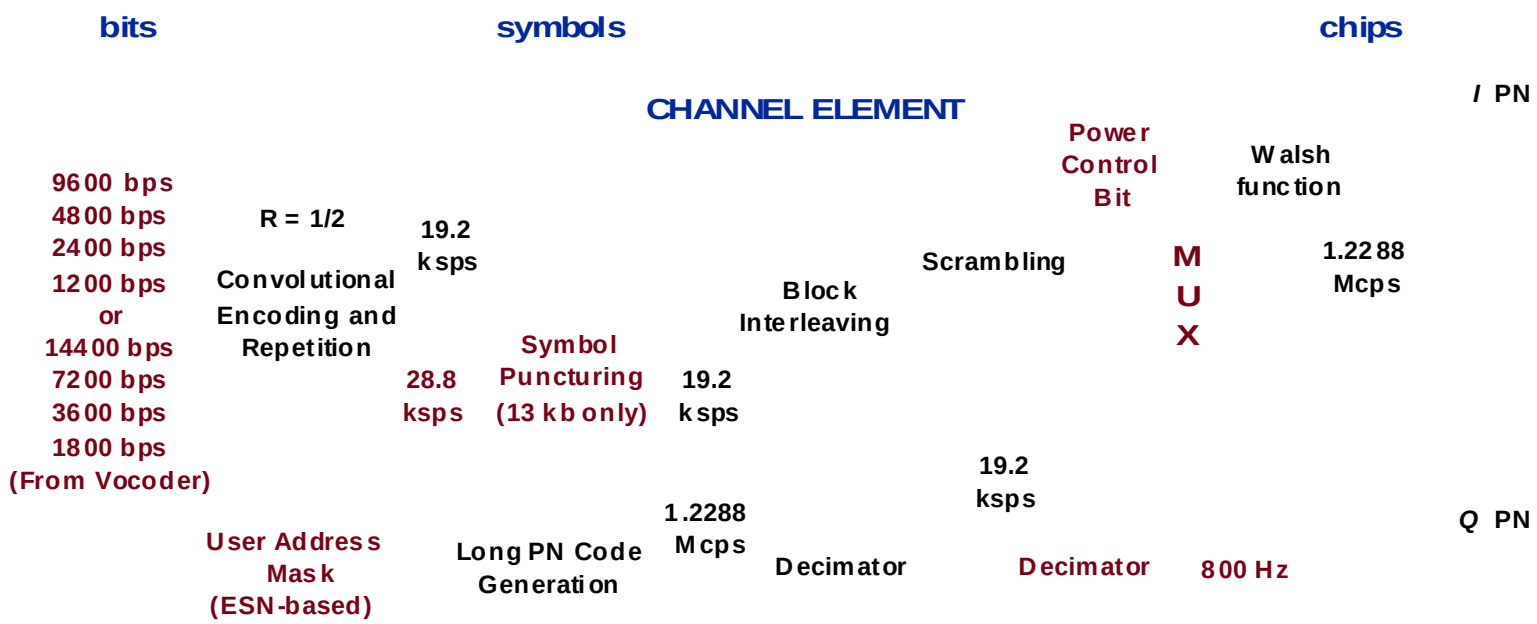
- Speech coding algorithms (digital compression) are necessary to increase cellular system capacity
- Coding must also ensure reasonable fidelity, i.e., a minimum level of quality as perceived by the user
- Coding can be performed in a variety of ways (ex. waveform, time or frequency domain)
- Vocoders transmit parameters which control “reproduction” of voice instead of the explicit, point-by-point waveform description

Variable Rate Vocoding



- Performed by Digital Speech Processors (DSPs)
- TDMA uses VSELP encoding - fixed at 8 kbps rate
- CDMA uses QCELP - encoding a variable rate (adaptive threshold)
  - Ranges from 13 kbps to 1 kbps (averaging 4 kbps)
  - Takes advantages of natural pauses in speech
- Both VSELP & QCELP are *Hybrid* Coders which combine waveform matching & speech signal parameters

Forward Traffic Channel Generation



Forward Traffic Channel Modulation Parameters

Data Rate (8 kb vocoder) (13 kb vocoder)	9600 14400	4800 7200	2400 3600	1200 1800	Bits Per Second
PN Chip Rate	1.2288	1.2288	1.2288	1.2288	Mega Chips Per Second
Code Rate	1 / 2	1 / 2	1 / 2	1 / 2	Bits Per Code Symbol
Code Symbol Rate (8 kb) (13 kb)	19200 28800	9600 14400	4800 7200	2400 3600	Code Symbols Per Second
Code Repetition	1	2	4	8	Mod. Symbols* Per Code Symbol
Mod. Symbol Rate (8 kb) (13 kb)	19200 28800	19200 28800	19200 28800	19200 28800	Mod. Symbols Per Second
Puncturing Rate (13 kb)	2/3	2/3	2/3	2/3	—
Mod. Symbol Rate Going Into Block Interleaver	19200	19200	19200	19200	Mod. Symbols Per Second
PN Chips / Mod. Symbol	64	64	64	64	PN Chips / Mod. Symbol
PN Chips / Bit	128	256	512	1024	PN Chips / Bit
E_s	$E_b/2$	$E_b/4$	$E_b/8$	$E_b/16$	Energy per Mod. Symbol

* each repetition of a “code symbol” is called a “modulation symbol”

Forward Traffic Channel Frame structure

Rate Set	Transmission Rate	Number of Bits per Frame				
		Total	Reserved	**Information**	CRC	**Tail Bits**
1	9600	192	—	**172**	12	**8**
	4800	96	—	**80**	8	**8**
	2400	48	—	**40**	—	**8**
	1200	24	—	**16**	—	**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**

Tail Bits (step 1)

$b_3\ b_2\ b_1$ 0 0 0

$C_{0,1}$

$b_3\ b_2$ **b_1** **0** **0** **0**

$C_{1,1}$

$b_3\ b_2$ b_1 0 0 0

Tail Bits (steps 2 & 3)

b_3 b_2 b_1 0 0

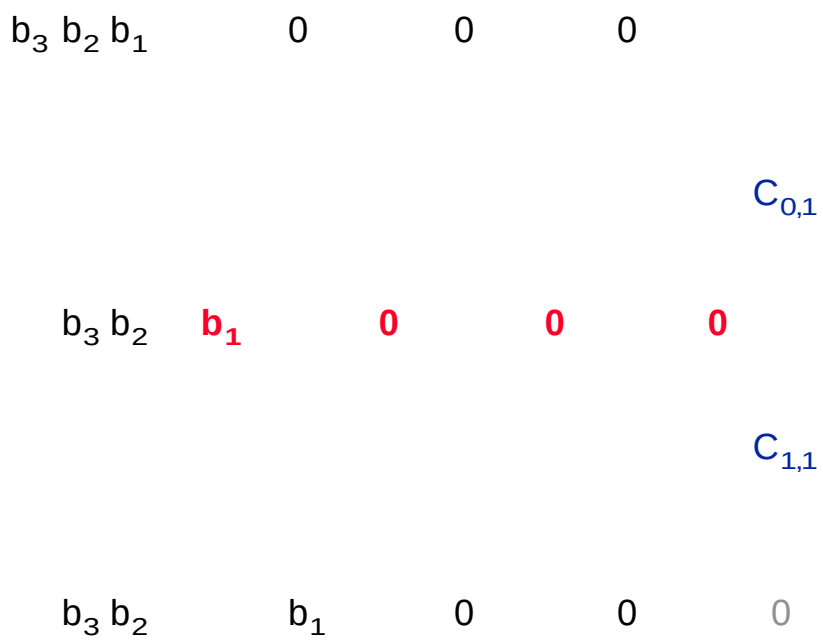
$C_{0,3}$ $C_{0,2}$ $C_{0,1}$

b_3 **b_2** **b_1** **0**

$C_{1,3}$ $C_{1,2}$ $C_{1,1}$

b_3 b_2 b_1 0

Tail Bits (steps 2 & 3) – cont.



Tail Bits (step 4)

0 0 0 b_3 b_2 b_1 0

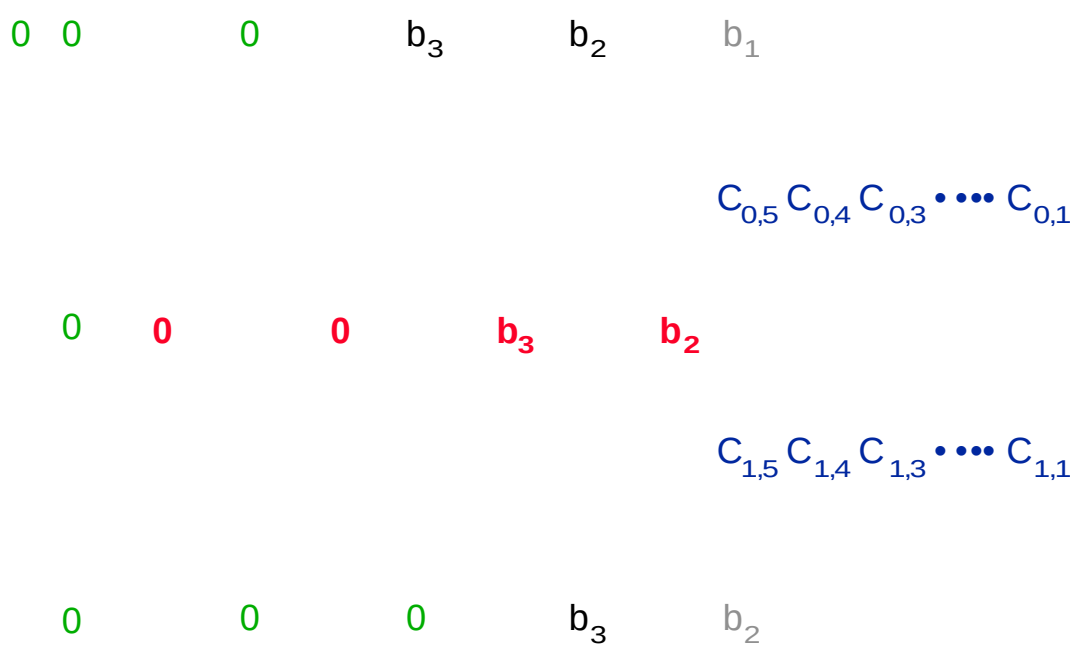
$C_{0,4}$ $C_{0,3}$ $C_{0,2}$ $C_{0,1}$

0 0 **0** **b_3** **b_2** **b_1**

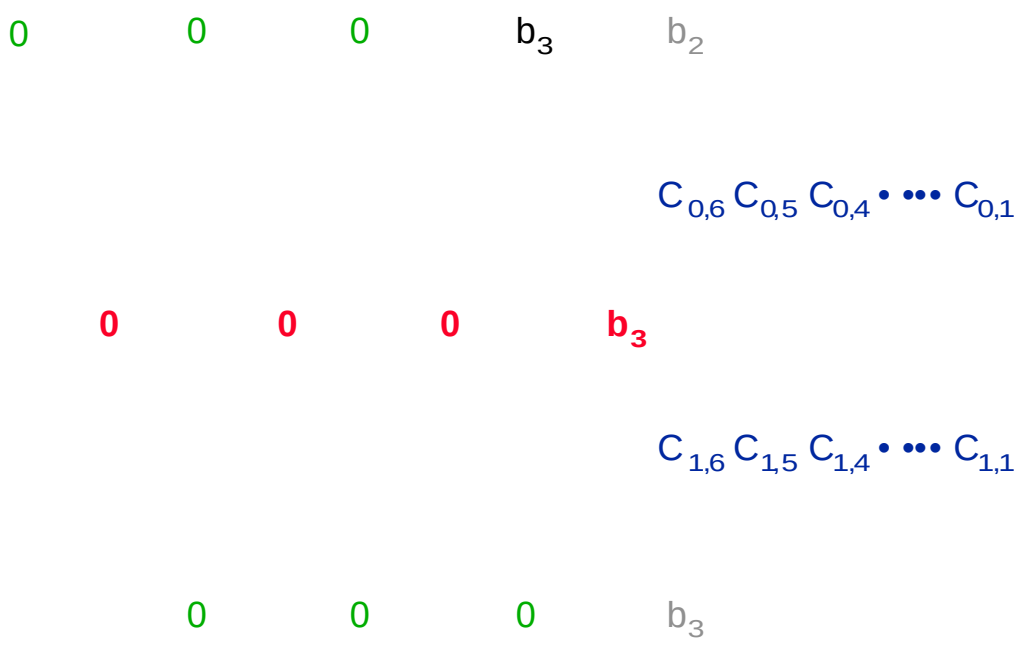
$C_{1,4}$ $C_{1,3}$ $C_{1,2}$ $C_{1,1}$

0 0 0 b_3 b_2 b_1

Tail Bits (steps 5 & 6)



Tail Bits (steps 5 & 6) – cont.



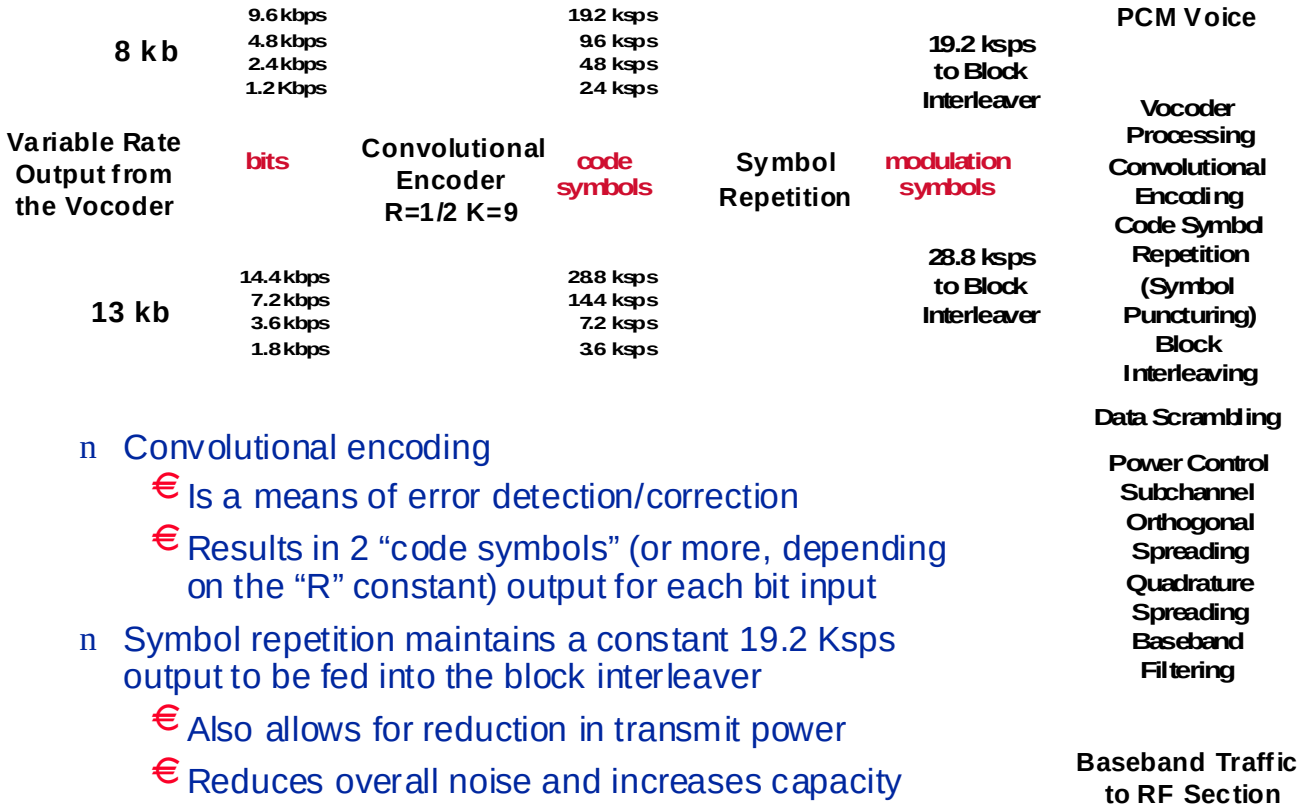
Forward Traffic Channel Frame Information Bits for Multiplex Option

Transmit Rate	Mixed Mode (MM)	Traffic Type (TT)	Traffic Mode (TM)	Traffic (bits per frame)		
				Primary	Signaling	[Secondary]
9600	‘0’	—	—	171	—	—
	‘1’	‘0’	‘00’	80	88	—
			‘01’	40	128	—
			‘10’	16	152	—
			‘11’	—	168	—
		‘1’ (optional)	‘00’	80	—	88
			‘01’	40	—	128
			‘10’	16	—	152
			‘11’	—	—	168
4800	—	—	—	80	—	—
2400	—	—	—	40	—	—
1200	—	—	—	16	—	—

Forward Traffic Channel Frame Information Bits for Multiplex Option 2

Transmit Rate	Mixed Mode (MM)	Frame Mode (FM)	Traffic (bits per frame)		
			Primary	Signaling	[Secondary]
14400	'0'	—	266	—	—
	'1'	'0000'	124	138	—
		'0001'	54	208	—
		'0010'	20	242	—
		'0011'	—	262	—
		'0100'	124	—	138
		'0101'	54	—	208
		'0110'	20	—	242
		'0111'	—	—	262
		'1000'	20	222	20
7200	'0'	—	124	—	—
	'1'	'000'	54	67	—
		'001'	20	101	—
		'010'	—	121	—
		'011'	124	—	67
		'100'	54	—	101
		'101'	20	—	121
		'110'	20	81	20
3600	'0'	—	54	—	—
	'1'	'00'	20	32	—
		'01'	—	52	—
		'10'	20	—	32
		'11'	—	—	52
1800	'0'	—	20	—	—
	'1'	—	—	—	20

Convolutional Encoding and Symbol Repetition



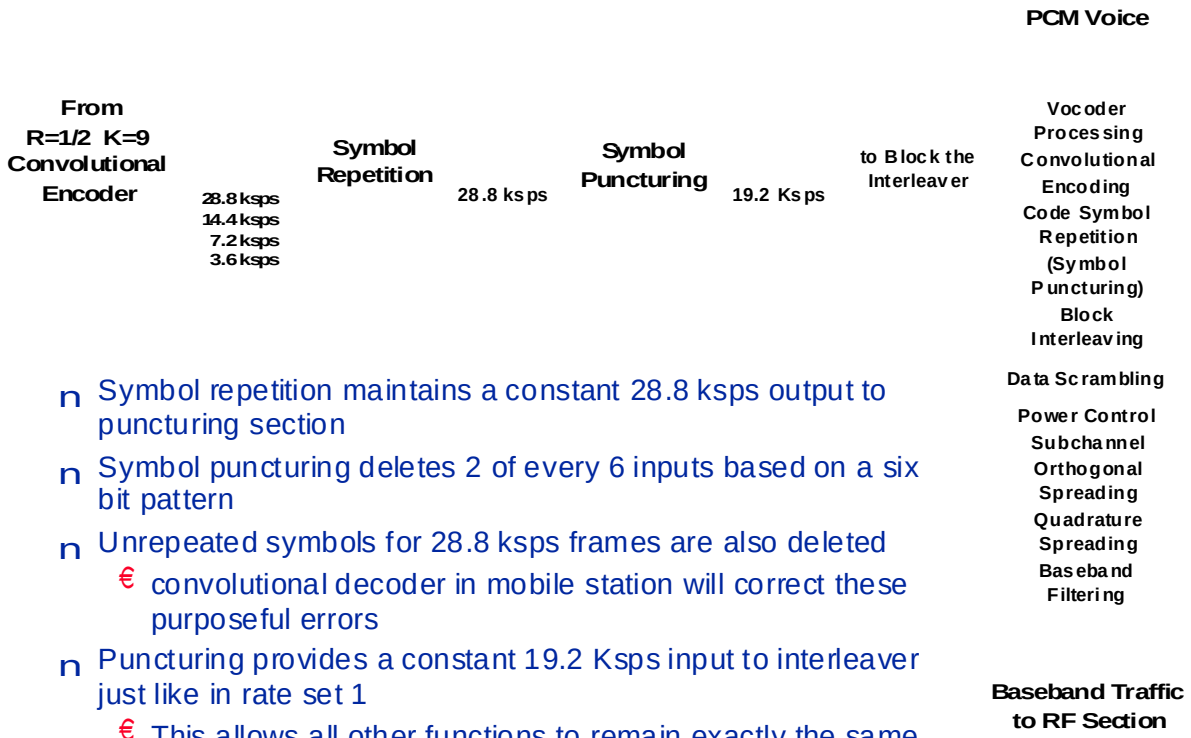
- Convolutional encoding
  - Is a means of error detection/correction
  - Results in 2 “code symbols” (or more, depending on the “R” constant) output for each bit input
- Symbol repetition maintains a constant 19.2 Ksps output to be fed into the block interleaver
  - Also allows for reduction in transmit power
  - Reduces overall noise and increases capacity

Symbol Repetition and Power Reduction

Data Rate (bps)	Energy per Modulation Symbol	Full Energy		
9600	$E_S=E_b/2$			
4800	$E_S=E_b/4$	1/2 Energy		
2400	$E_S=E_b/8$		1/4 Energy	
1200	$E_S=E_b/16$			1/8 Energy

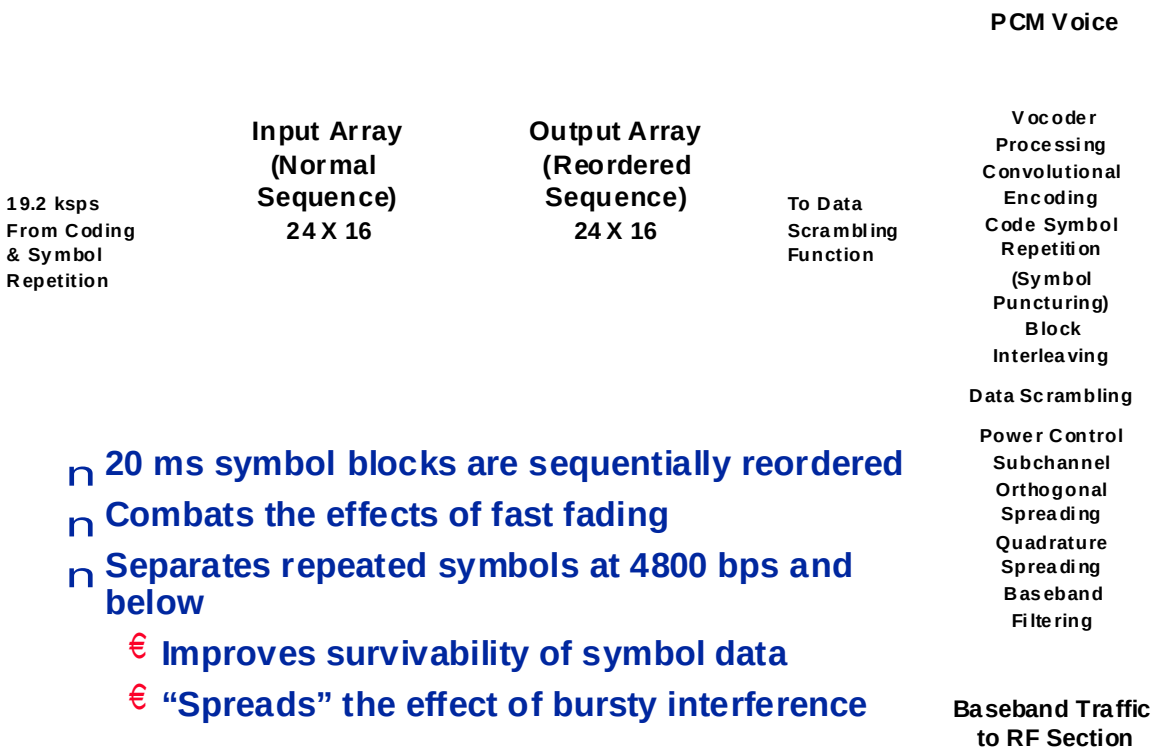
- Symbol repetition provides a constant rate to the block interleaver
- Lower rates symbols are sent at reduced power levels
- The energy per bit across all rates is identical when integrated
- Overall signal power requirement (thus noise) is reduced

Symbol Puncturing
Rate Set 2 (13 kb Vocoder)



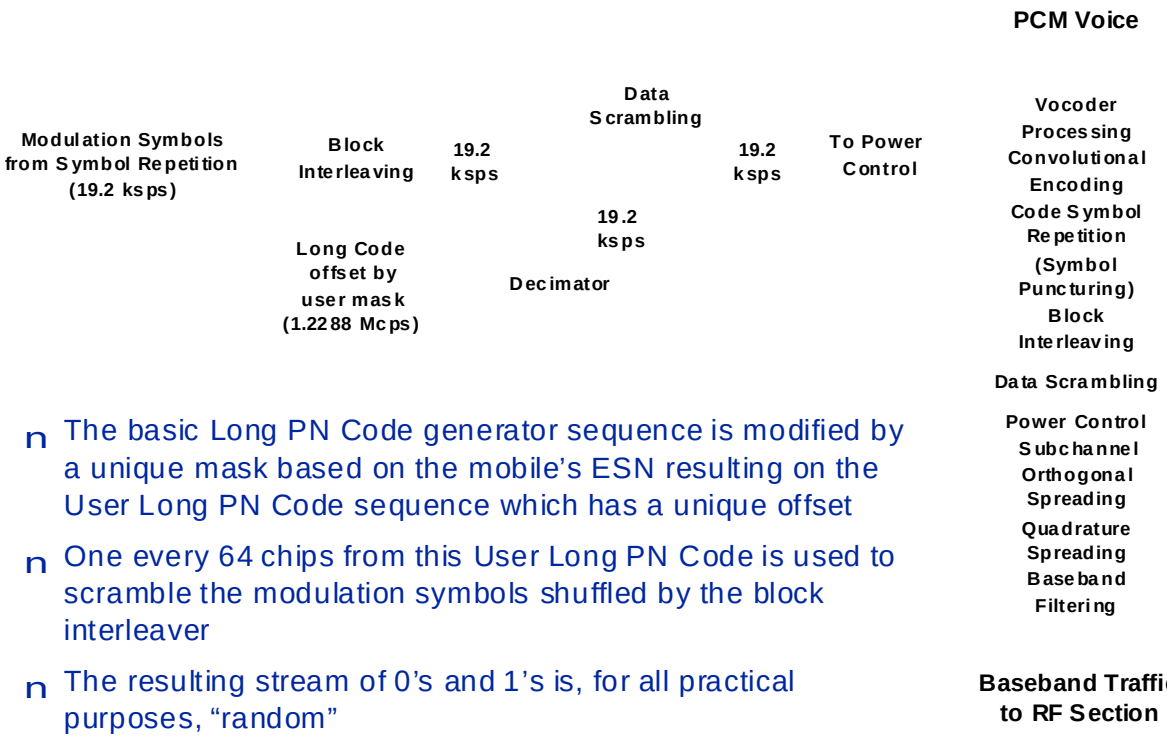
- Symbol repetition maintains a constant 28.8 ksps output to puncturing section
- Symbol puncturing deletes 2 of every 6 inputs based on a six bit pattern
- Unrepeated symbols for 28.8 ksps frames are also deleted
  - convolutional decoder in mobile station will correct these purposeful errors
- Puncturing provides a constant 19.2 Ksps input to interleaver just like in rate set 1
  - This allows all other functions to remain exactly the same

Block Interleaving



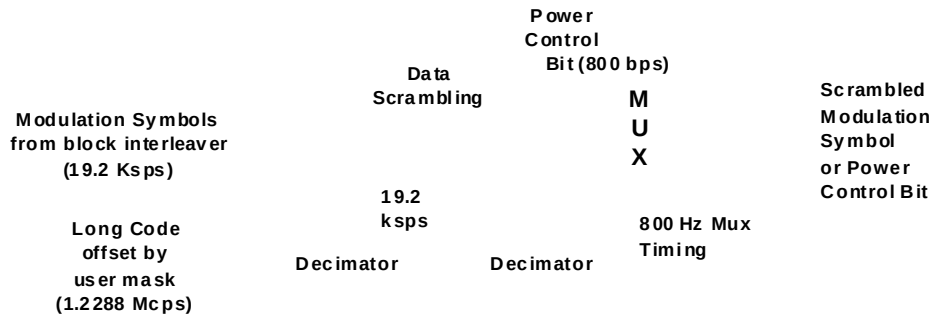
- 20 ms symbol blocks are sequentially reordered
- Combats the effects of fast fading
- Separates repeated symbols at 4800 bps and below
  - Improves survivability of symbol data
  - “Spreads” the effect of bursty interference

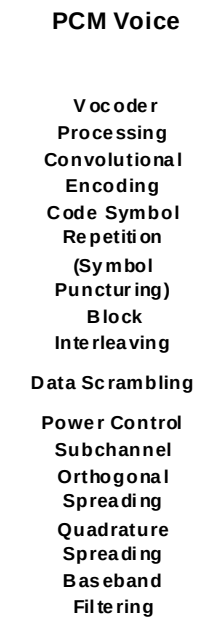
Data Scrambling



- The basic Long PN Code generator sequence is modified by a unique mask based on the mobile's ESN resulting on the User Long PN Code sequence which has a unique offset
- One every 64 chips from this User Long PN Code is used to scramble the modulation symbols shuffled by the block interleaver
- The resulting stream of 0's and 1's is, for all practical purposes, "random"

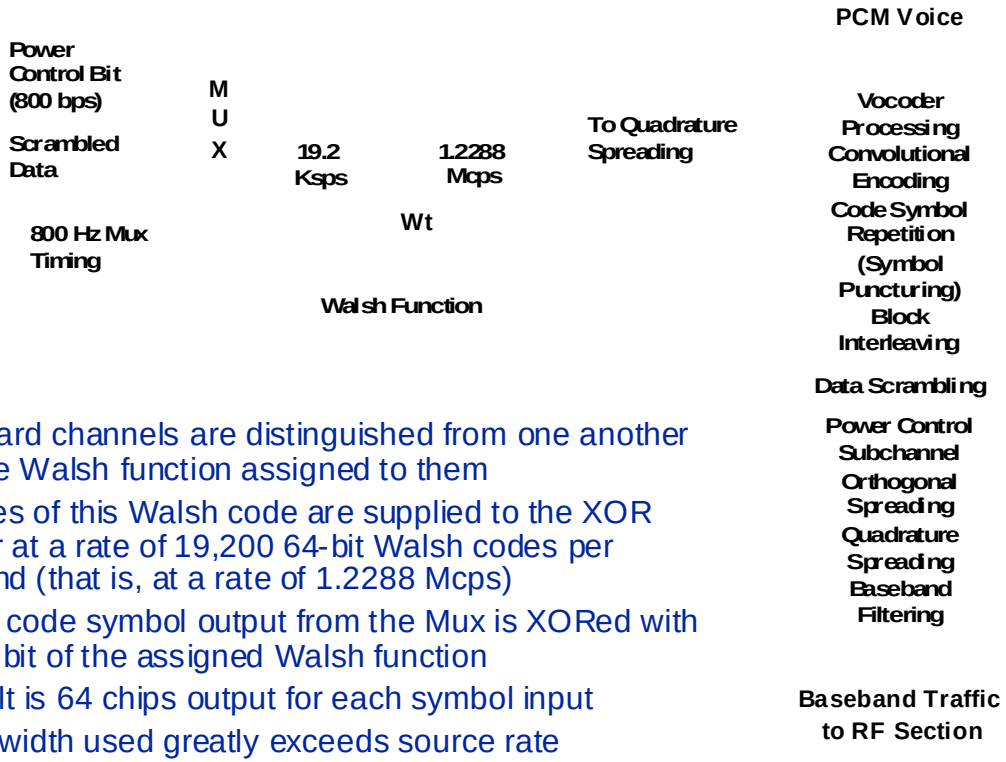
Power Control Sub Channel





- Every 1.25 ms (800 times per second) the base station estimates the received signal strength on the Reverse Traffic Channel of a particular mobile station
- Based on this estimation, the base station determines whether that mobile station should increase or decrease its transmission power
- A “power up” (0) or “power down” (1) one-bit command is sent by the base station to that mobile station 800 times a second on the corresponding forward traffic channel. This constitutes the “Power Control Subchannel” for that mobile station
- At the rates of Set 1, these “Power Control Bits” overwrite (puncture) TWO out of every 24 modulation symbols. At the rates of Set 2, these “Power Control Bits” overwrite (puncture) ONE out of every 24 modulation symbols
- The Power Control Bits are sent in the forward traffic channel at *full power* and *uncoded.*

Orthogonal Spreading



- Forward channels are distinguished from one another by the Walsh function assigned to them
- Copies of this Walsh code are supplied to the XOR mixer at a rate of 19,200 64-bit Walsh codes per second (that is, at a rate of 1.2288 Mcps)
- Each code symbol output from the Mux is XORed with each bit of the assigned Walsh function
- Result is 64 chips output for each symbol input
- Bandwidth used greatly exceeds source rate

Direct and Inverse Walsh Code

- **RULE:** ***"XOR the symbol with the Walsh Code, then send the result"***
  - **If the symbol is "0", each bit in the Walsh Code remains unchanged**
  - **If the symbol is "1", each bit in the Walsh Code is flipped**

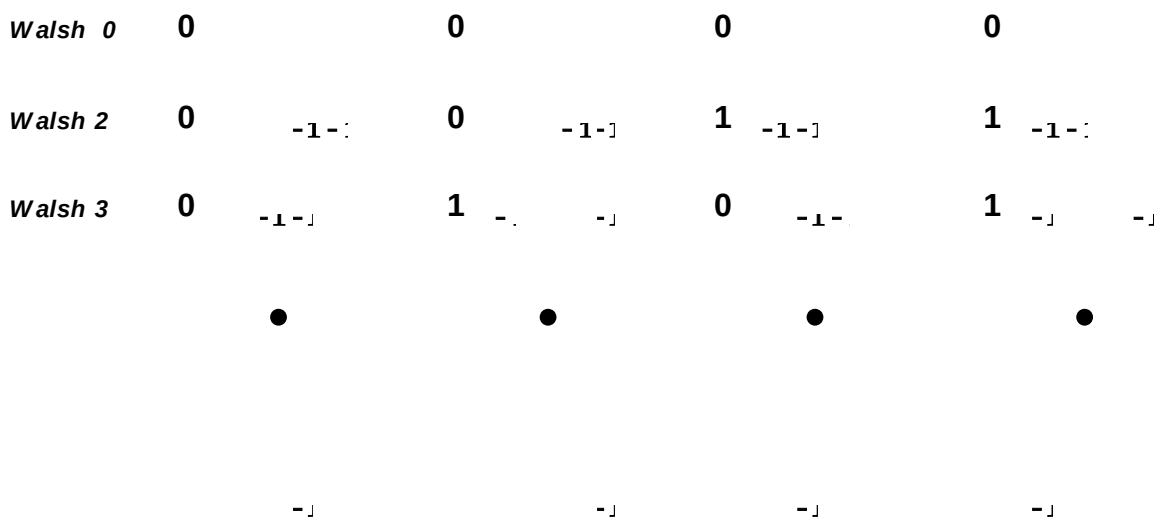
ZEROes are represented by +1 pulses, and ONEs by -1 pulses

Direct Walsh Codes **Used to represent "0" modulation symbols**		**Negated Walsh Codes** **Used to represent "1" modulation symbols**	
			-1 -1 -1 -1
0 0 0 0		**1 1 1 1**	
0 1 0 1	**-1 -1**	**1 0 1 0**	**-1 -1**
0 0 1 1		**1 1 0 0**	
0 1 1 0		**1 0 0 1**	
	-1 -1		**-1 -1**
	-1 -1		**-1 -1**

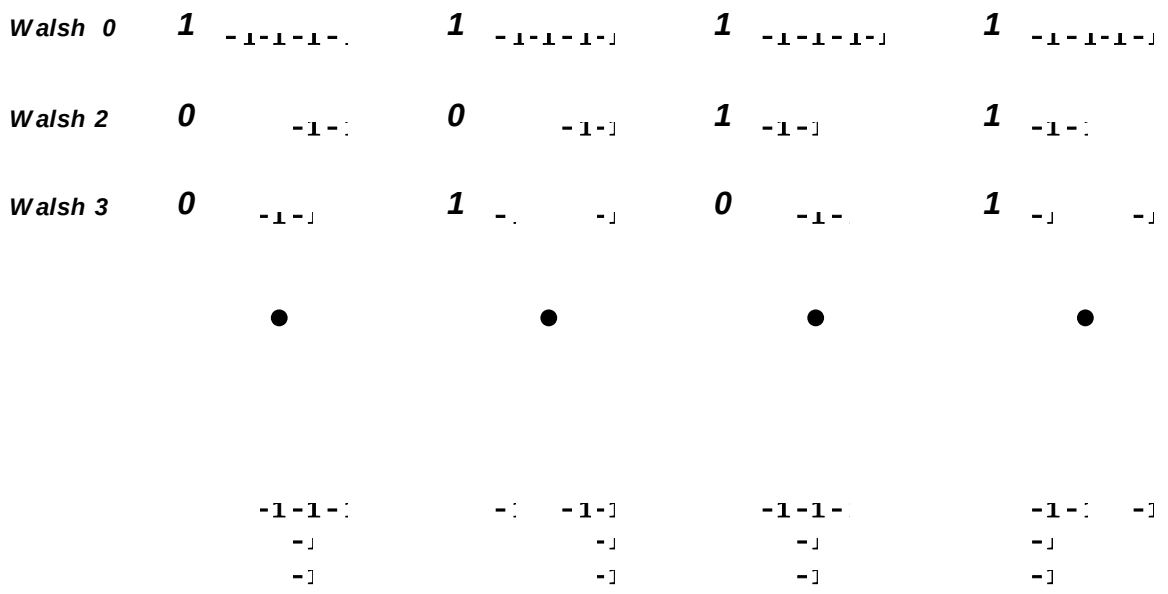
Creating a Composite Signal

			Modulation Symbols	Chips	
User A	uses Walsh code 0	to send	0		(the direct code is sent)
User B	uses Walsh code 2	to send	1	-1 -1	(the inverse code is sent)
User C	uses Walsh code 3	to send	0	-1 -1	(the direct code is sent)
				•	
				-1	(the electrical signals are added, chip by chip)

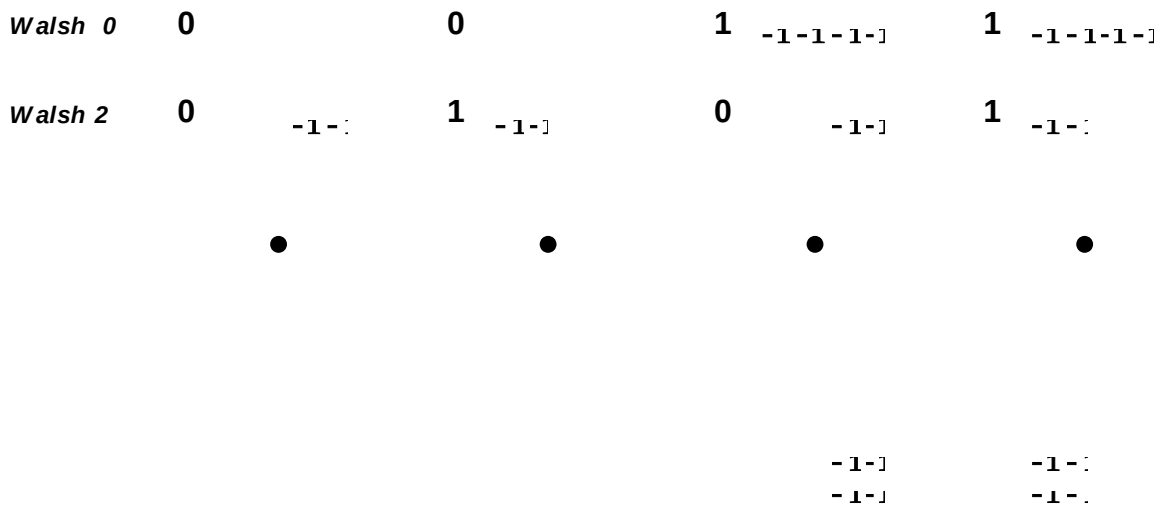
Example Building Blocks



Example Building Block cont.



Example – Building Blocks (Walsh 0 and 2)

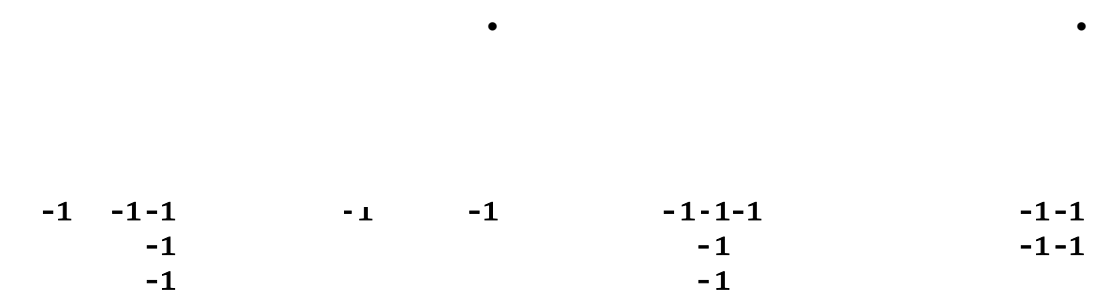


Example: Spreading three Sequences

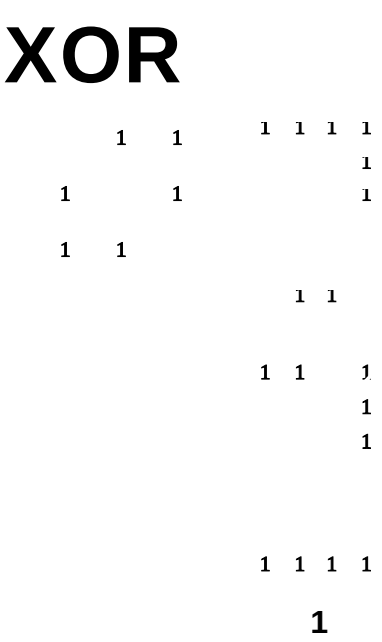
A ***Walsh 0*** ***1 0 0 1 0 1***

B ***Walsh 2*** ***0 0 1 0 0 1***

C ***Walsh 3*** ***1 1 0 0***



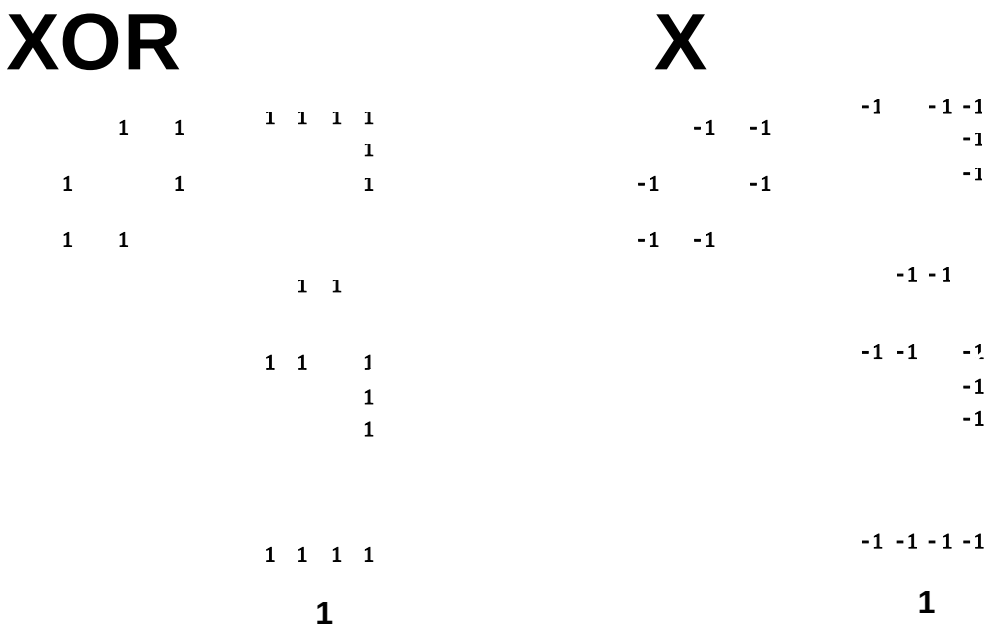
Extracting a code channel from the composite signal



- To extract a Forward CDMA Code Channel from the composite signal do the following:
  - “XOR”, chip-by-chip, the composite signal with the Walsh code that was used to encode the information for that channel
  - Integrate (add up) the resulting 0’s and 1’s
  - If the result is close to N times 1, conclude that a **1** was sent
  - If the result is close to N times 1, conclude that a **0** was sent
  - If the result is close to N/2 times 0 and N/2 times 1, conclude that **no signal** was sent

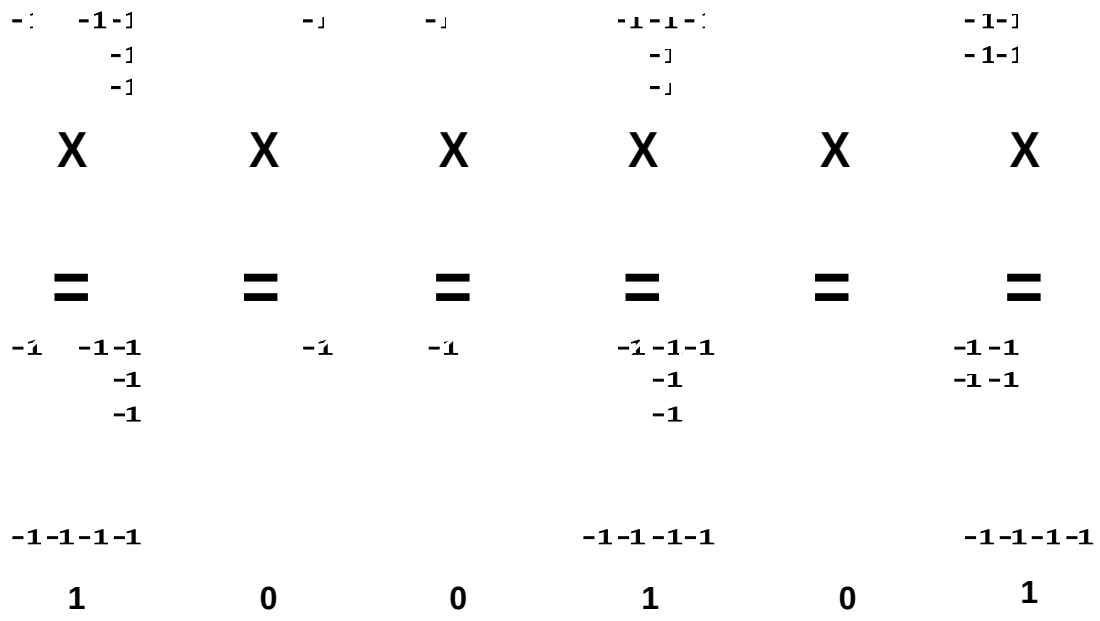
An Equivalent Procedure

Represent 0's by +1's and 1's by -1's,
then multiply by (instead of XORing with) the Walsh code



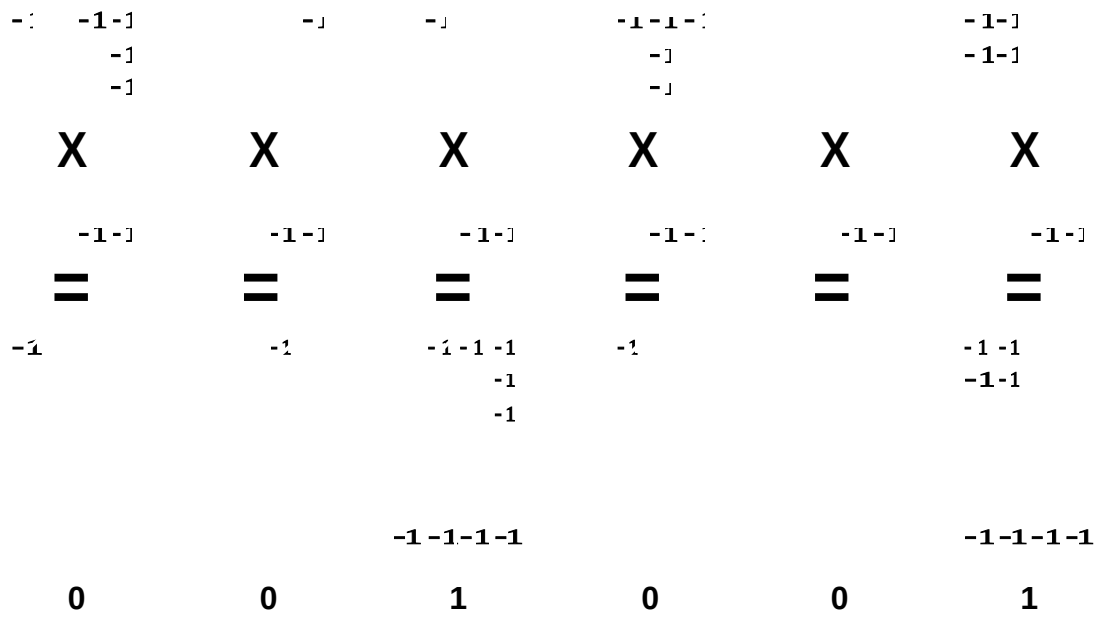
Example – Despreading with Walsh Code 0 (User “A”)

Sent by “A”: **1 0 0 1 0 1**



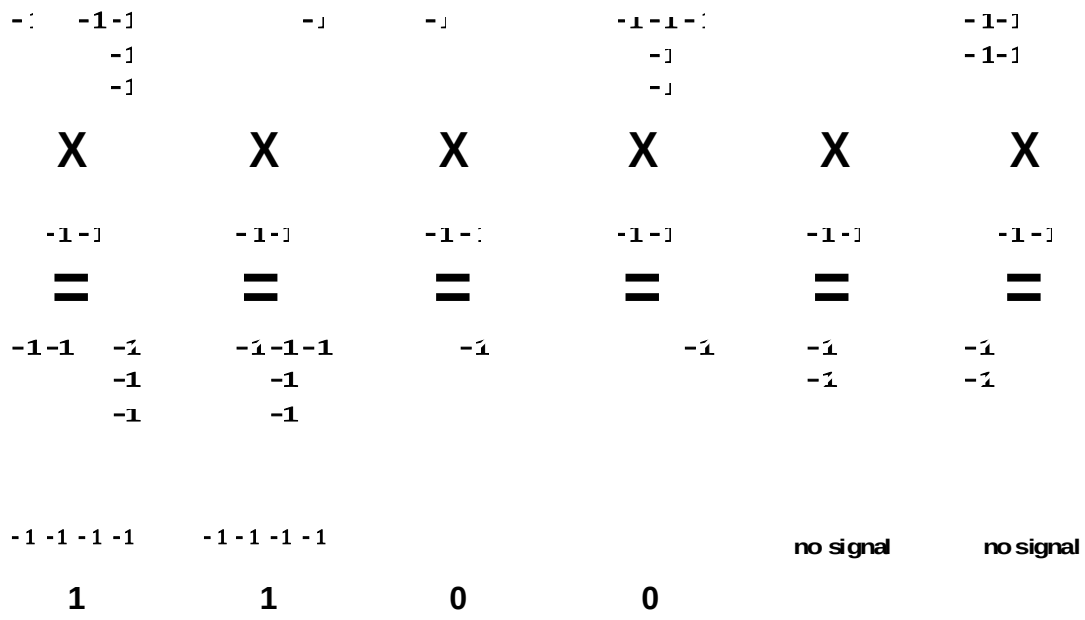
Example – Despreading with Walsh Code 2 (User “B”)

Sent by “B”: **0 0 1 0 0 1**



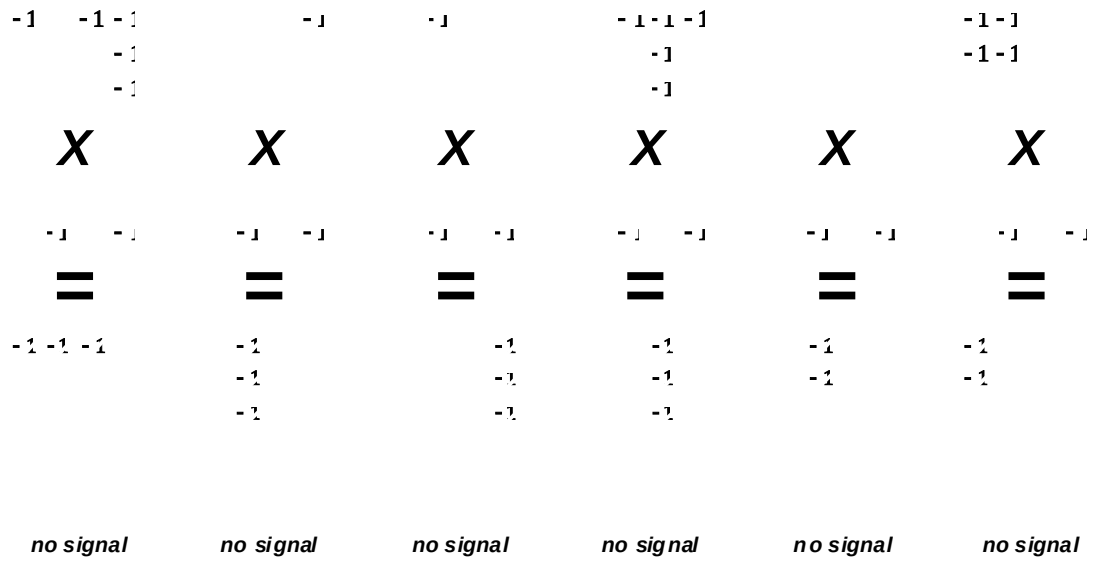
Example – Despreading with Walsh Code 3 (User “C”)

Sent by “C”:1 1 0 0

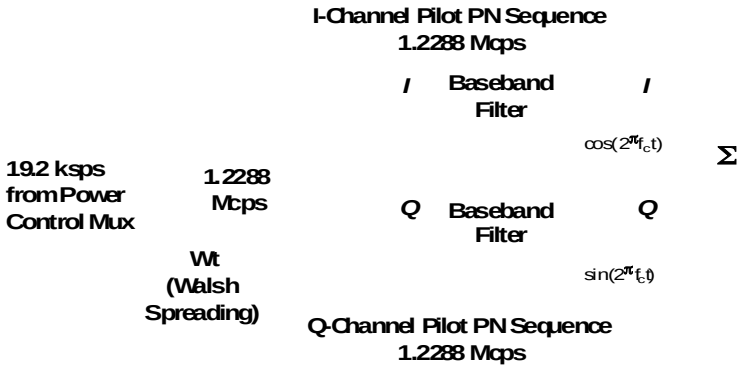


Example – Despreading with Walsh Code 1 (No User)

"nothing was sent with this code"



Quadrature Spreading & Baseband Filtering



- The forward traffic channel is combined with two different PN sequences: “I” and “Q”
- Baseband filtering ensures the waveforms are contained within the 1.25 MHz frequency range
- The final step is to convert the two baseband signals to radio frequency (RF) in the 800 MHz or 1900 MHz range

PCM Voice

Vocoder Processing

Convolutional Encoding

Code Symbol Repetition (Symbol Puncturing)

Block Interleaving

Data Scrambling

Power Control Subchannel

Orthogonal Spreading

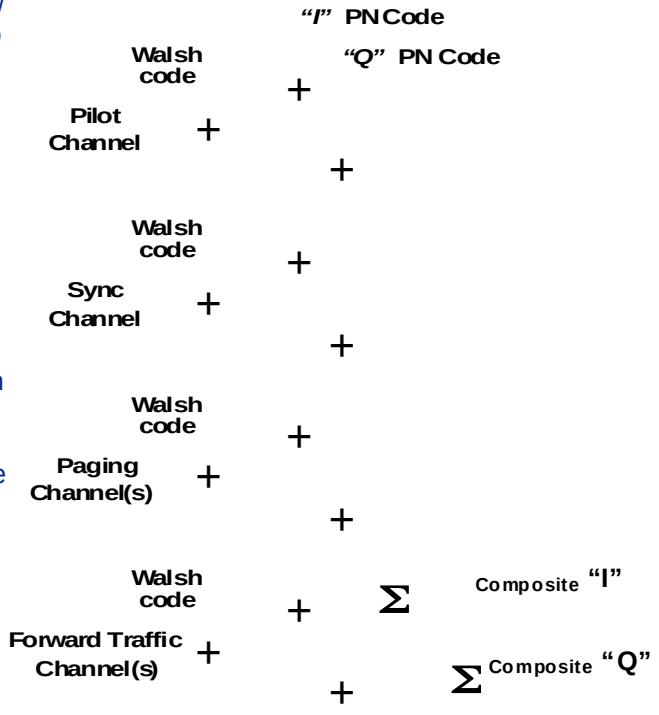
Quadrature Spreading

Baseband Filtering

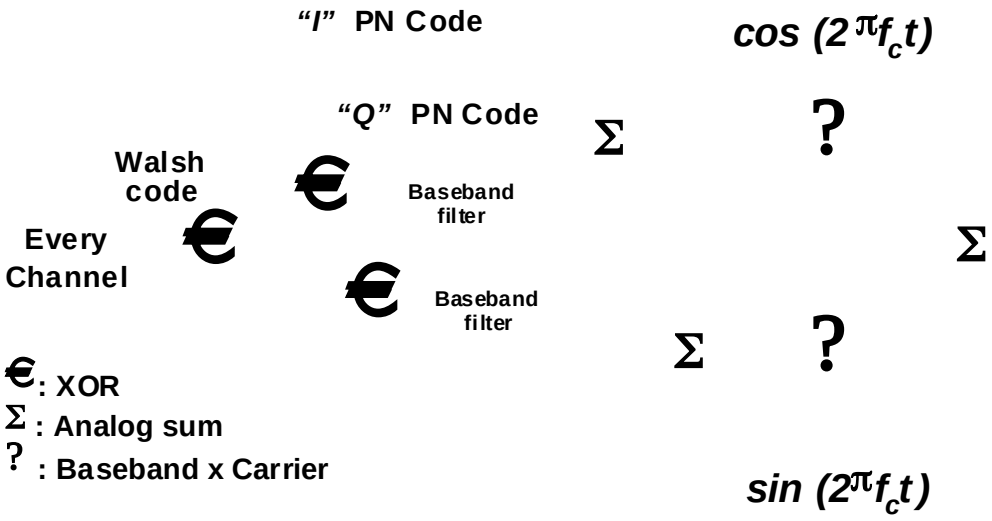
Baseband Traffic to RF Section

Composite “I” and “Q”

- All forward channels in a partition (Sector/ Cell) are combined with the same I and Q sequences
- These sequences have a particular offset that sets this partition apart from up to 511 neighboring partitions
  - This ensures that a mobile station does not mistakenly decode the signal from a channel with the same Walsh code from the wrong base station
- The I and Q signals for all 64 channels on each sector of a cell are added together in the analog card producing a composite I and a composite Q for each sector in the cell
- The contribution of the overhead channels (Pilot, Sync, and Paging) to the composite signal is fixed. The contribution of each Forward Traffic Channel depends on the distance of the mobile station relative to the base station



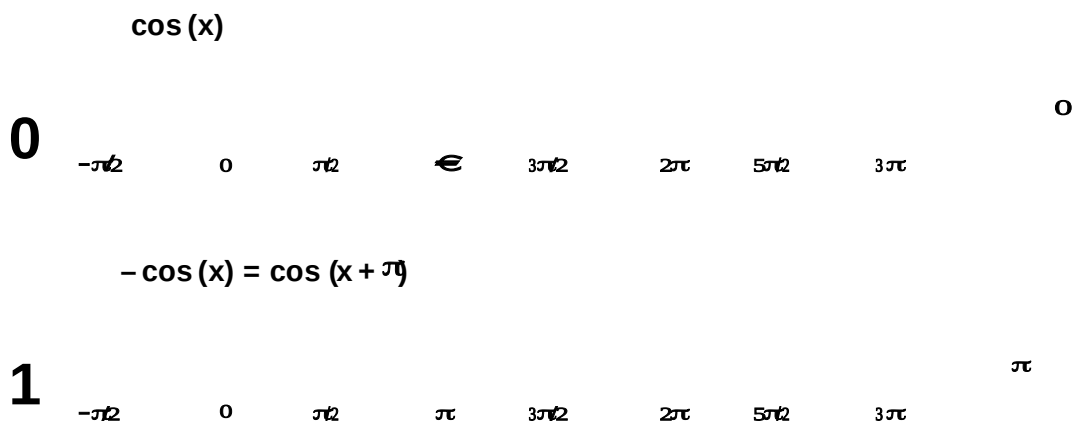
Quadrature Phase Shift Key (QPSK) Modulation



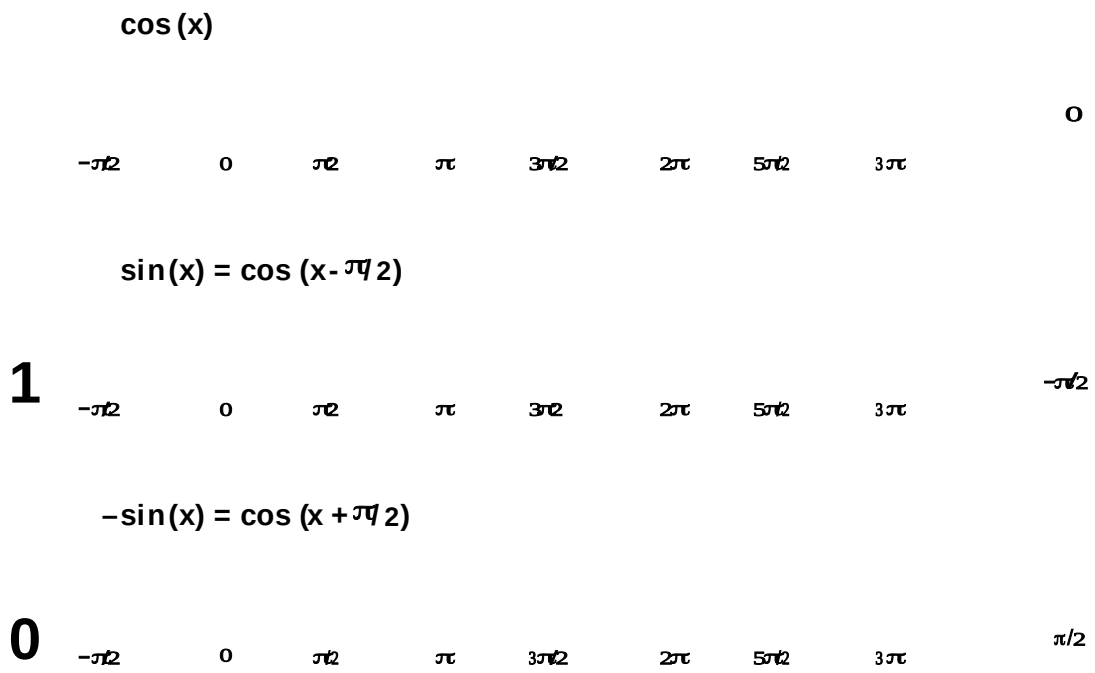
$$I_1 \cos(2\pi f_c t) + I_2 \cos(2\pi f_c t) = (I_1 + I_2) \cos(2\pi f_c t)$$

$$Q_1 \sin(2\pi f_c t) + Q_2 \sin(2\pi f_c t) = (Q_1 + Q_2) \sin(2\pi f_c t)$$

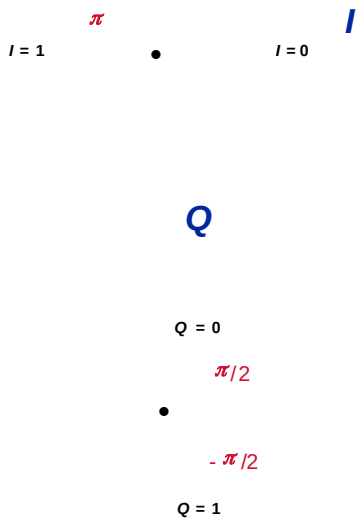
QPSK Modulation



QPSK Modulation cont.

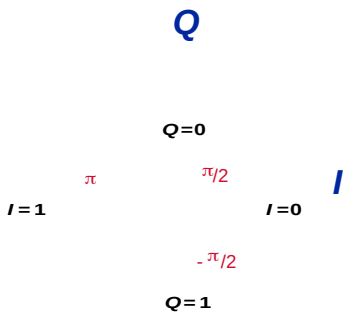


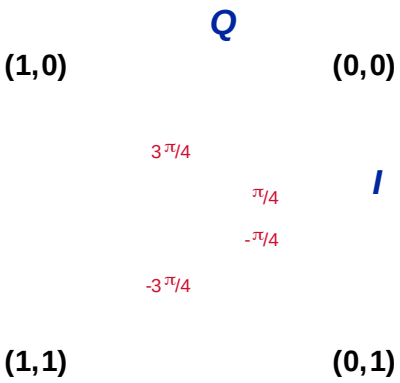
I & Q Mapping (“I”, “Q”, or Both?)



- We could use the ***cos*** and ***–cos*** functions to represent the two states of the “I” signal (0 and 1). This is equivalent to using the ***cos*** function with phases ***0*** and ***π*** respectively
- Or we could use the ***-sin*** and ***sin*** functions to represent the two states of the “Q” signal (0 and 1). This is equivalent to using the ***cos*** function with phases ***π/2*** and ***- π/2*** respectively
- What would happen if we add the signal representing “I” to the signal representing “Q” in order to obtain a signal representing both “I” and “Q” simultaneously?
  - Hint: add the vectors for I=0, Q=0, then for I=0, Q=1, etc.

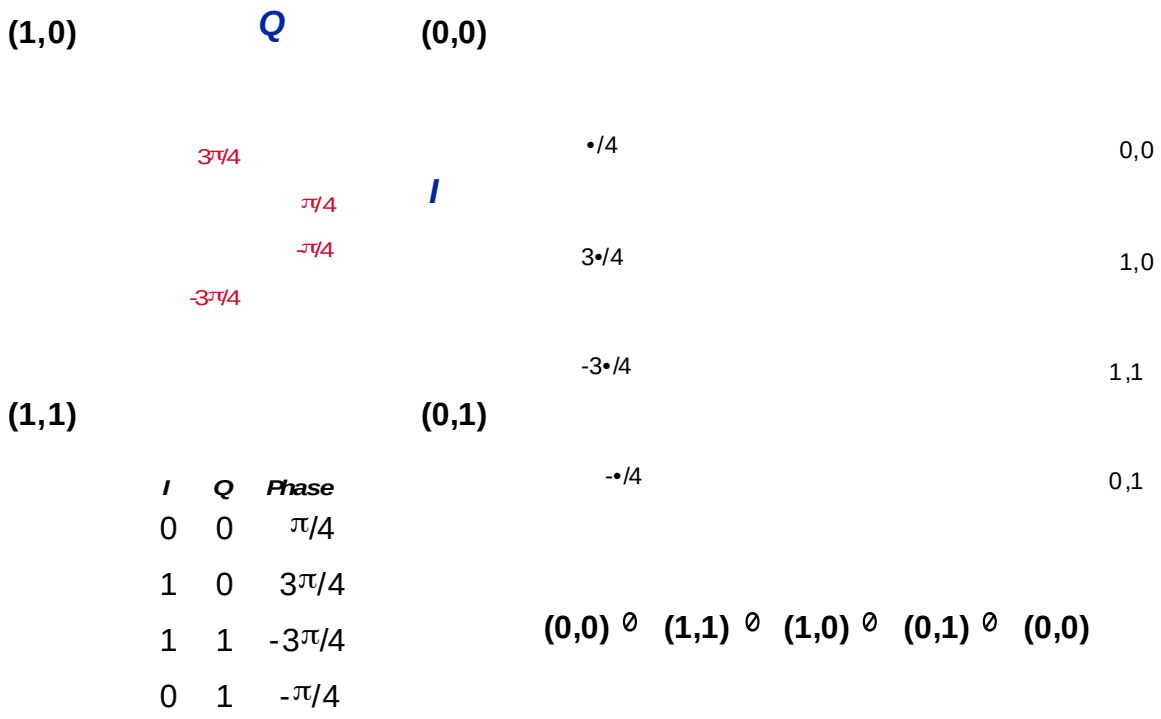
I & Q Mapping (Signal Constellation)





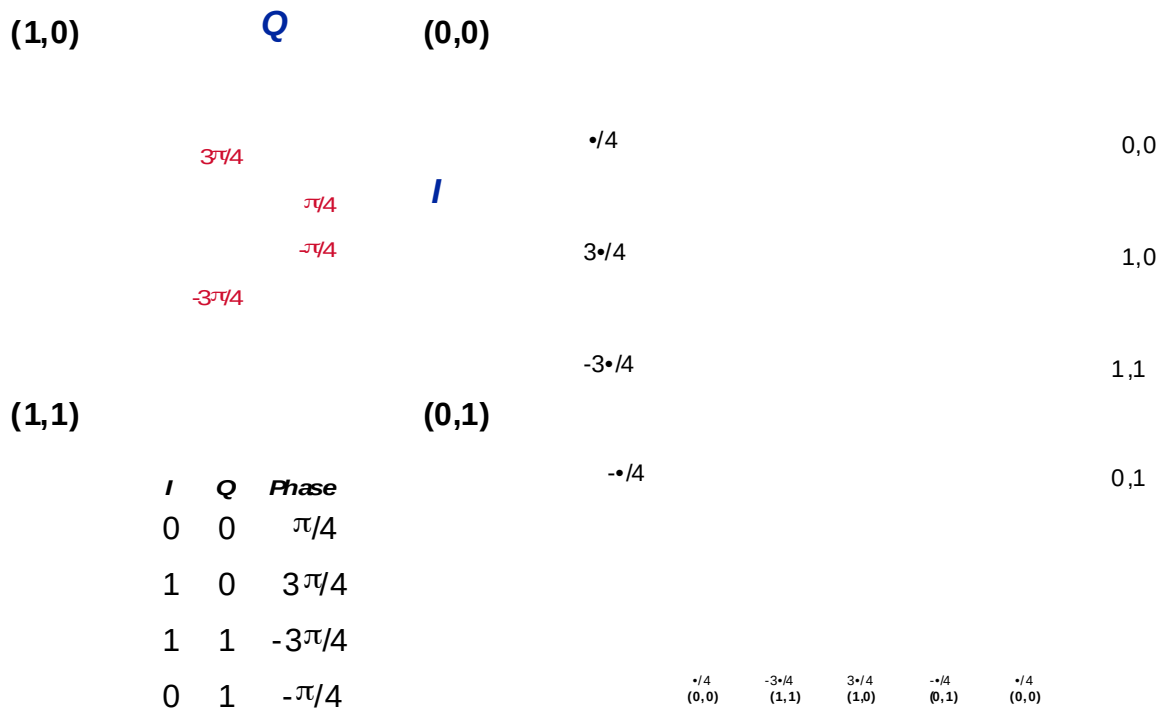
- We have four possible cases:
  - when I=0 & Q=0, the state corresponds to a ***cos*** function with phase ***π/4***
  - when I=1 & Q=0, the state corresponds to a ***cos*** function with phase ***3π/4***
  - when I=1 & Q=1, the state corresponds to a ***cos*** function with phase ***-3π/4***
  - when I=0 & Q=1, the state corresponds to a ***cos*** function with phase ***-π/4***

I & Q Mapping (Phase Transitions)



I	Q	Phase
0	0	π/4
1	0	3π/4
1	1	-3π/4
0	1	-π/4

I & Q Mapping (States Transitions)



Traffic Channel Frame Staggering

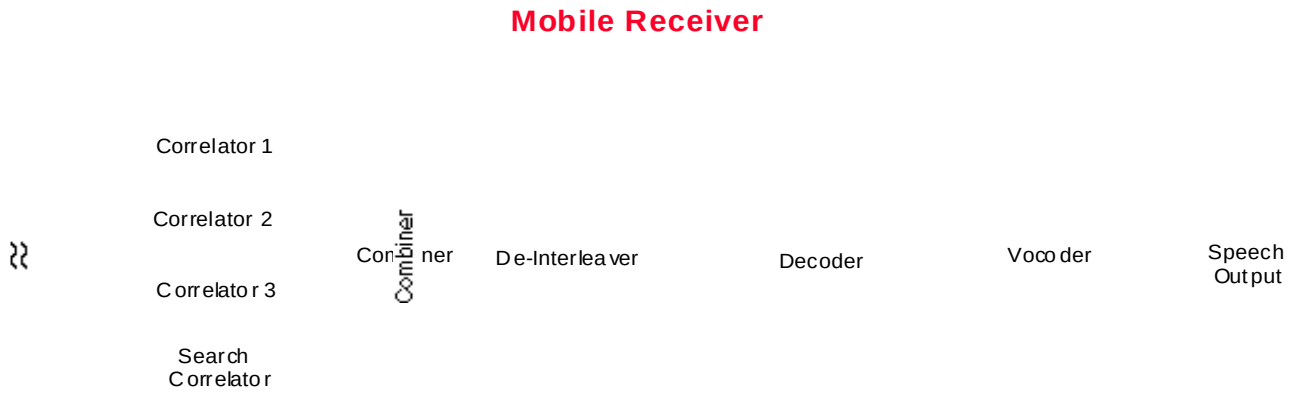


430 / 2 chips = 32.6 miles = 0.175 ms each way



- Frames received from all mobile stations serviced by a base station arrive to that base station with delays that depend on the distance between each mobile station and the base station
- If the base station has the maximum allowed coverage radius of about 32.6 miles, the delay between the earliest and the latest frame received is not greater than 0.35 ms (0.175 ms maximum offset of the mobile timing relative to system timing plus up to 0.175 ms for the frame to arrive to the base station).
- Frame staggering spreads the demand on system processing resources and/or system interconnect links by offsetting the traffic frame transmission for different mobile stations (in the forward and reverse directions) in 1.25 ms increments relative to the system time
- The amount of frame offset for a particular mobile is indicated in a *Channel Assignment Message* or an *Extended Handoff Direction Message*
- Support is required by the mobile station, but optional by the base station
- Currently, frame staggering is not implemented (not needed)
- May degrade soft handoffs into hard CDMA-to-CDMA hard handoffs.

Forward Channel Demodulation



- IS-95A/J-STD-008 requires a minimum of four processing elements that can be independently directed
  - Three elements must be capable of demodulating multipath components
  - One must be a “searcher” that scans and estimates signal strength at each pilot PN sequence offset

End of section