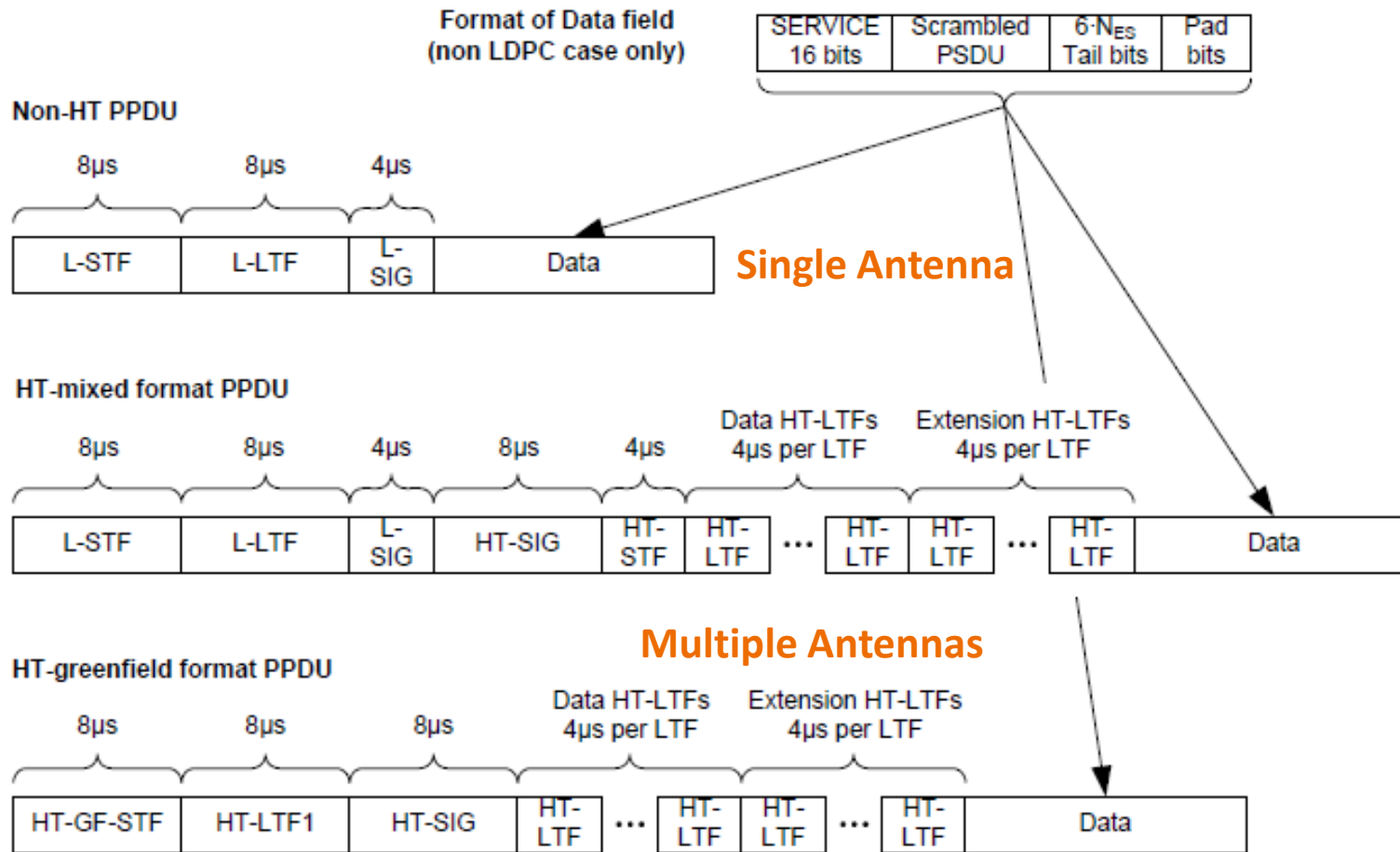


MIMO Transmitter in IEEE802.11

Lecturer: Dr. Rui Wang

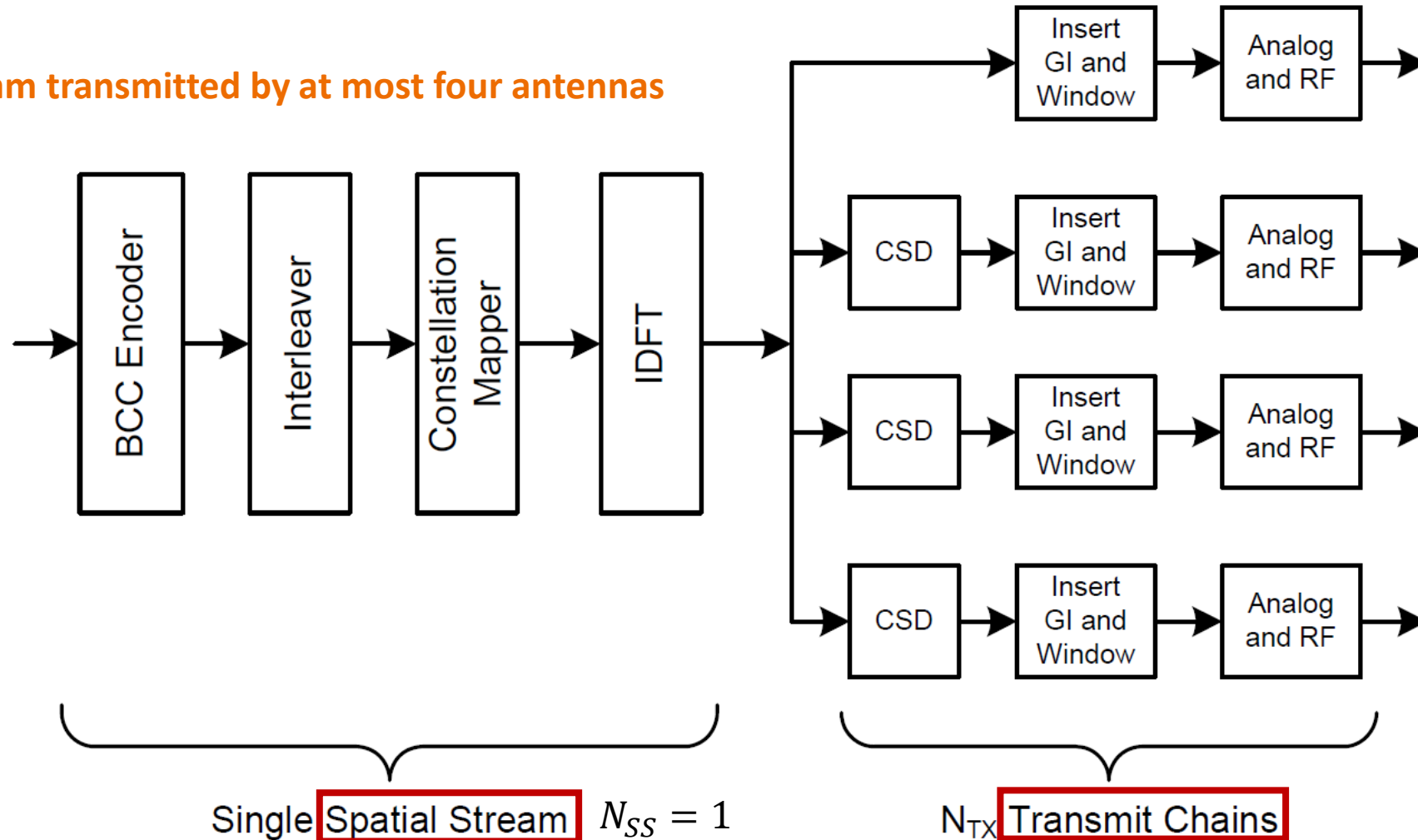
Recap: Three PPDU Formats



- **Non-HT**: either the AP or the STA does not support HT
- **HT-mixed**: AP and STA support HT, however, other STAs may not support HT
- **HT-greenfield**: all the STAs support HT
- L-STF, L-LTF, HT-STF, HT-LTF are known to the Rx
- L-SIG, HT-SIG: basic information about the PPDU

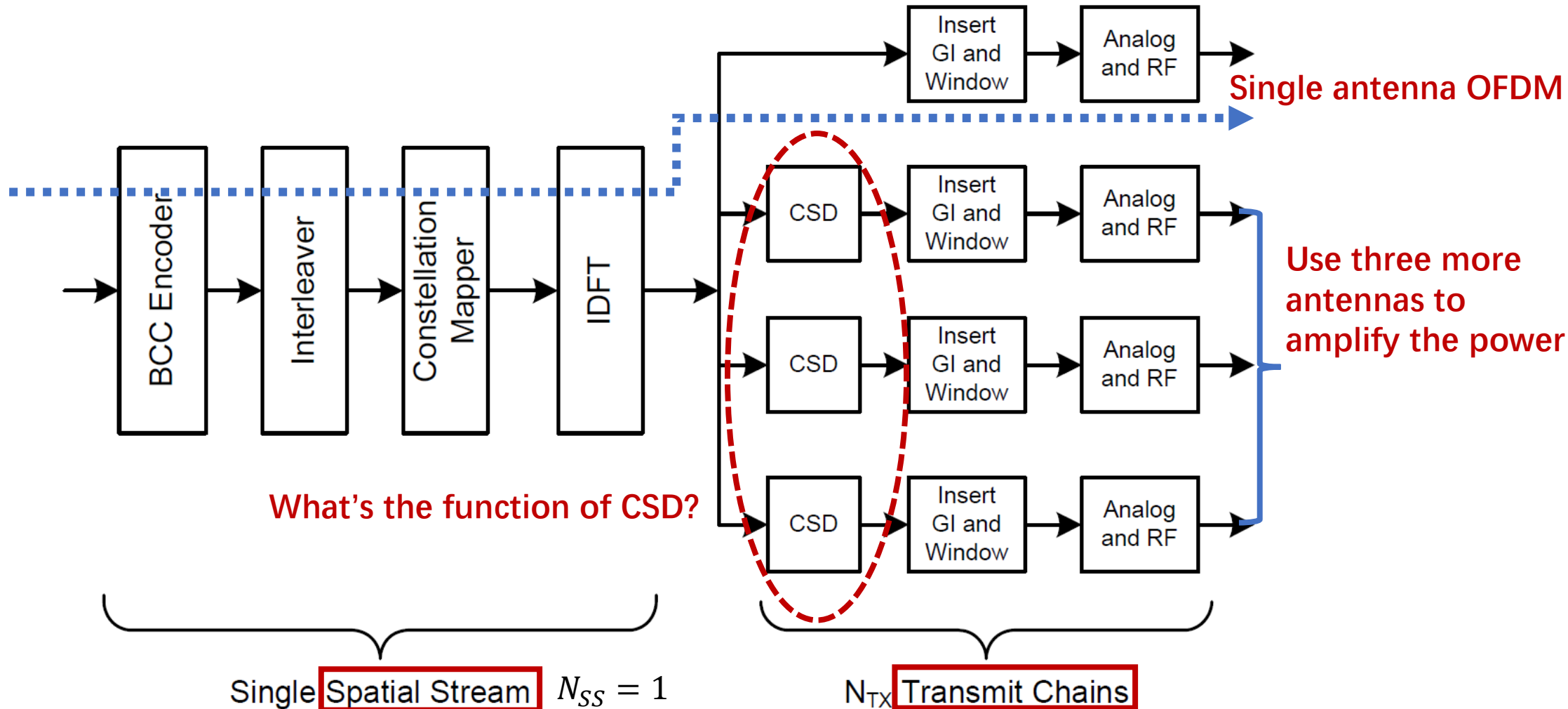
Single Spatial Stream (19.3.3)

One data stream transmitted by at most four antennas



“... generate the HT-SIG of the HT-mixed format PPDU. These transmitter blocks are also used to generate the non-HT portion of the HT-mixed format PPDU, except that the BCC encoder and interleaver are not used when generating the L-STF and L-LTFs.”

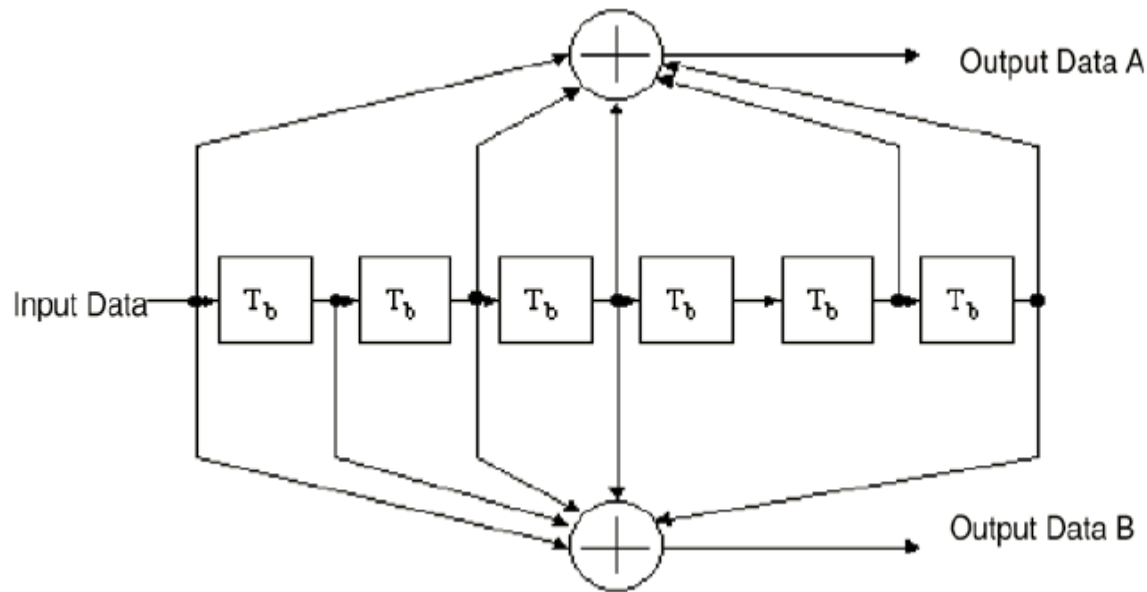
Single Spatial Stream (19.3.3)



“... generate the HT-SIG of the HT-mixed format PPDU. These transmitter blocks are also used to generate the non-HT portion of the HT-mixed format PPDU, except that the BCC encoder and interleaver are not used when generating the L-STF and L-LTFs.”

Channel Coding

- **Binary convolutional code (BCC) – 17.3.5.6**



Punctured Coding ($r = 3/4$)

Source Data

X_0	X_1	X_2	X_3	X_4	X_5	X_6	X_7	X_8
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Encoded Data

A_0	A_1	A_2	A_3	A_4	A_5	A_6	A_7	A_8
B_0	B_1	B_2	B_3	B_4	B_5	B_6	B_7	B_8



Stolen Bit



Bit Stolen Data
(sent/received data)

A_0	B_0	A_1	B_1	A_2	B_2	A_3	B_3	A_4	B_4	A_5	B_5	A_6	B_6	A_7	B_7	A_8	B_8
-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------	-------

- **Data interleaving – 17.3.5.7**

Interleaves the bits of each spatial stream (changes order of bits) to prevent long sequences of adjacent noisy bits.

Modulation and Coding Scheme (MCS, 19.5)

Table 19-27—MCS parameters for mandatory 20 MHz, $N_{SS} = 1$, $N_{ES} = 1$

MCS Index	Modulation	R	$N_{BPSCS}(i_{SS})$	N_{SD}	N_{SP}	N_{CBPS}	N_{DBPS}	Data rate (Mb/s)	
								800 ns GI	400 ns GI (see NOTE)
0	BPSK	1/2	1	52	4	52	26	6.5	7.2
1	QPSK	1/2	2	52	4	104	52	13.0	14.4
2	QPSK	3/4	2	52	4	104	78	19.5	21.7
3	16-QAM	1/2	4	52	4	208	104	26.0	28.9
4	16-QAM	3/4	4	52	4	208	156	39.0	43.3
5	64-QAM	2/3	6	52	4	312	208	52.0	57.8
6	64-QAM	3/4	6	52	4	312	234	58.5	65.0
7	64-QAM	5/6	6	52	4	312	260	65.0	72.2
NOTE—Support of 400 ns GI is optional on transmit and receive.									

NBPSCS: Number of coded bits per subcarrier

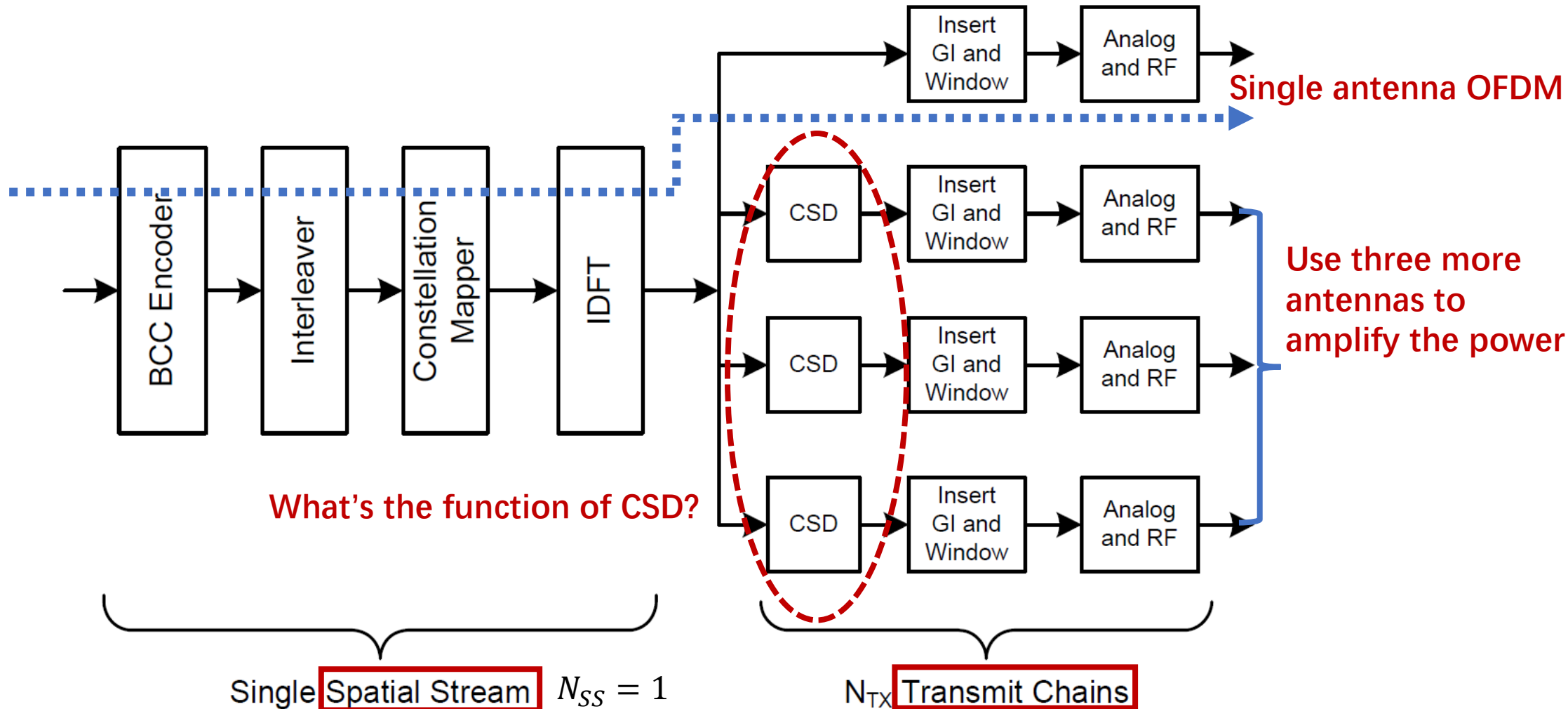
N_{SD}: Number of data subcarriers

N_{SP}: Number of pilot subcarriers

NCBPS: Number of coded bits per symbol

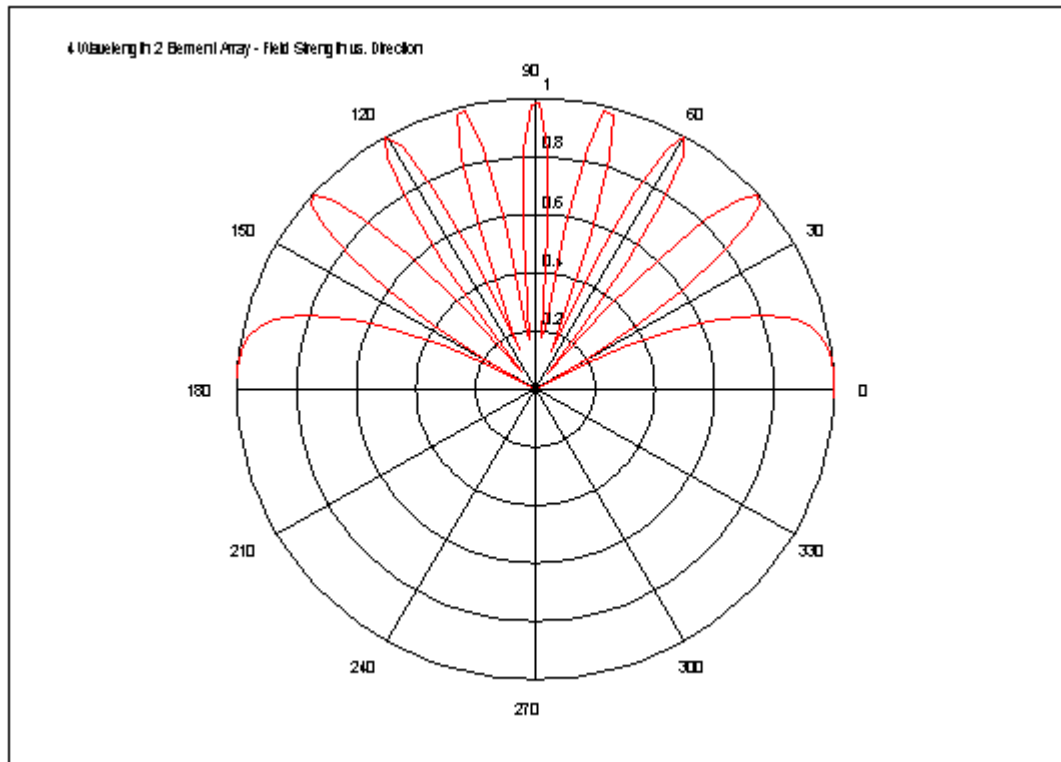
N_{DBPS}: Number of data bits per symbol

Recap: Single Spatial Stream (19.3.3)



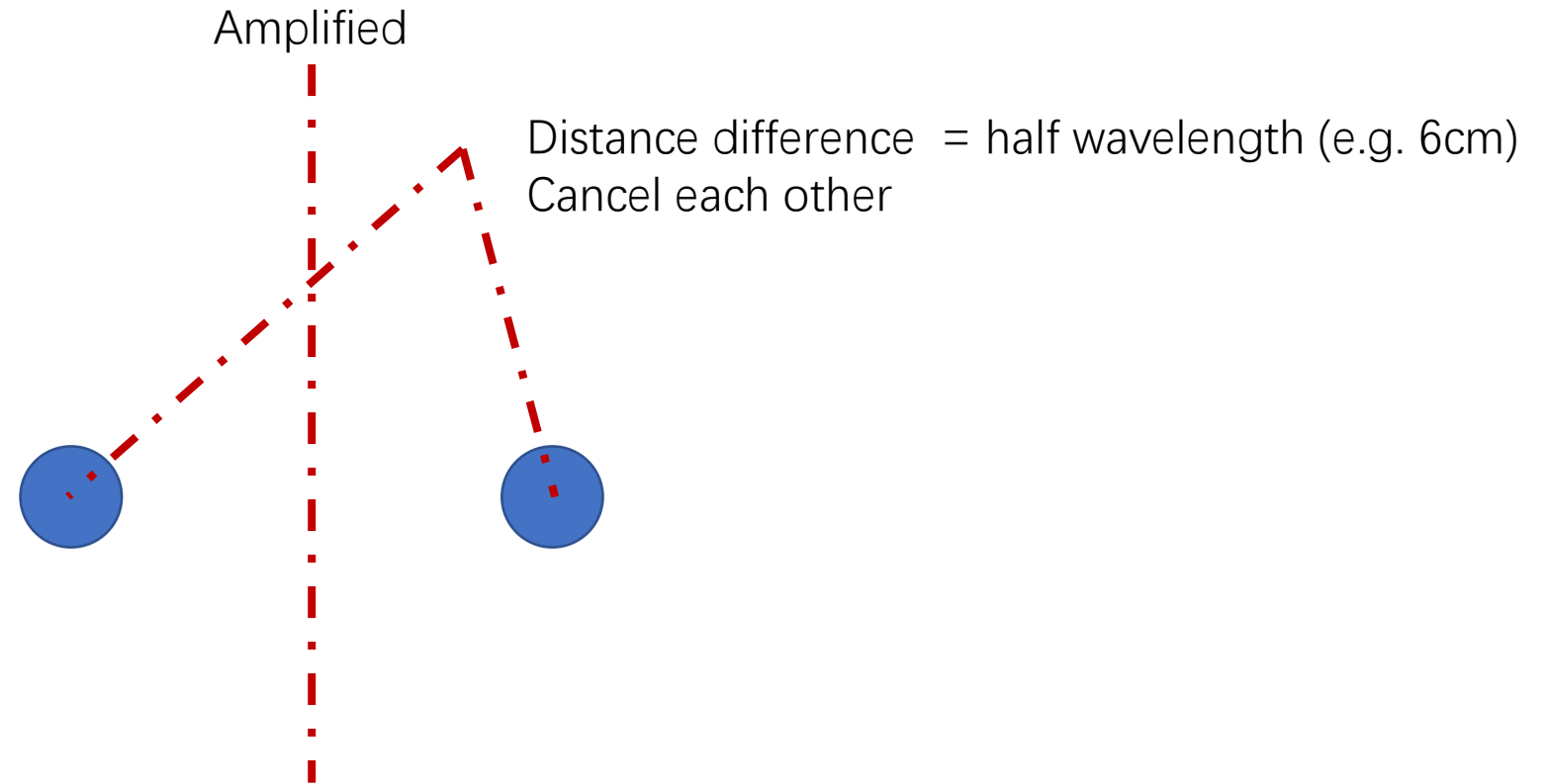
“... generate the HT-SIG of the HT-mixed format PPDU. These transmitter blocks are also used to generate the non-HT portion of the HT-mixed format PPDU, except that the BCC encoder and interleaver are not used when generating the L-STF and L-LTFs.”

Array Pattern



- Why antenna specific delay (cyclic shift)?
- If two antenna ports transmit the same signal at the same time, there might be effect of beamforming
- Not desired at the phase of packet synchronization
- Cyclic shift is applied to avoid the beamforming effect

Array Pattern



Cyclic Shift (19.3.9.3.2)

Table 19-9—Cyclic shift for non-HT portion of packet

$T_{CS}^{i_{TX}}$ values for non-HT portion of packet				
Number of transmit chains	Cyclic shift for transmit chain 1 (ns)	Cyclic shift for transmit chain 2 (ns)	Cyclic shift for transmit chain 3 (ns)	Cyclic shift for transmit chain 4 (ns)
1	0	—	—	—
2	0	-200	—	—
3	0	-100	-200	—
4	0	-50	-100	-150

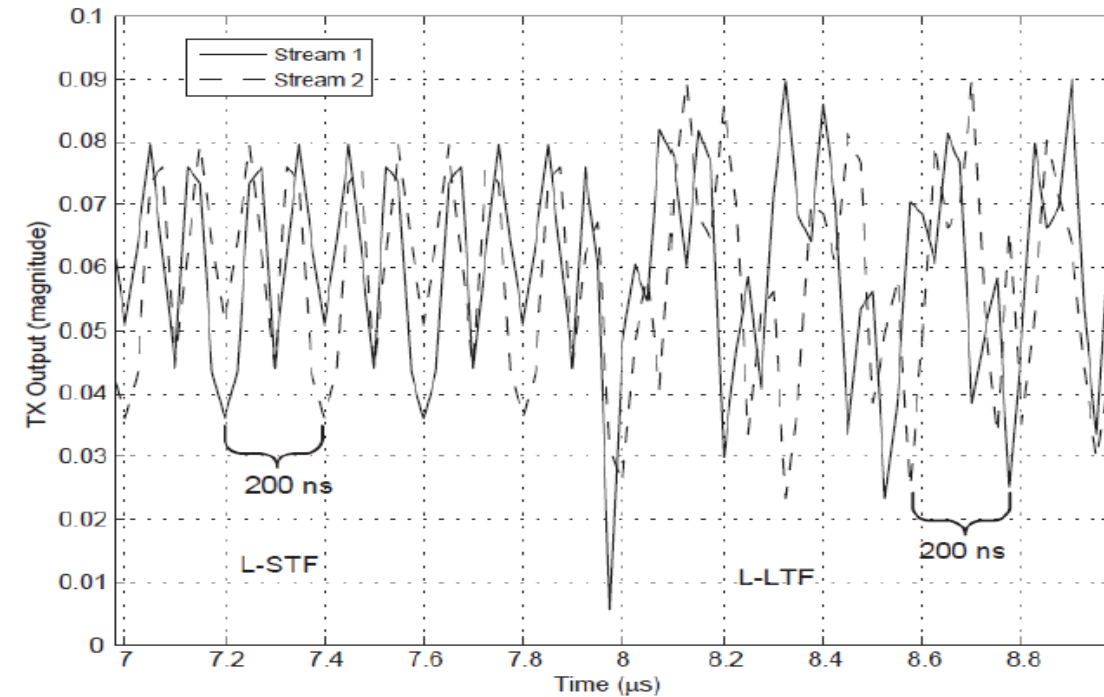
50ns is the duration of one sample

Let $s(t)$ be the signal without cyclic shift, TCS is the cyclic shift value, then the cyclic shift is as follows.

$$s_{CS}(t; T_{CS})|_{T_{CS} < 0} = \begin{cases} s(t - T_{CS}) & 0 \leq t < T + T_{CS} \\ s(t - T_{CS} - T) & T + T_{CS} \leq t \leq T \end{cases}$$

“Cyclic shifts are used to prevent **unintentional beamforming** when the same signal or scalar multiples of one signal are transmitted through different spatial streams or transmit chains.”

Cyclic Shift is different from the Cyclic Prefix of OFDM, which is referred to Guard Interval (GI) in standard



Cyclic Shift - Example

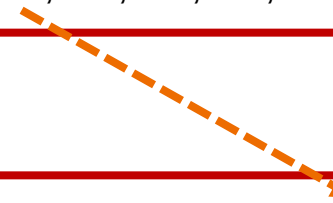
- Suppose non-HT mode, two antennas transmit the same signal, CSD happens after IFFT
- Suppose cyclic shift is 200ns, which include 4 samples

Tx Antenna 1:

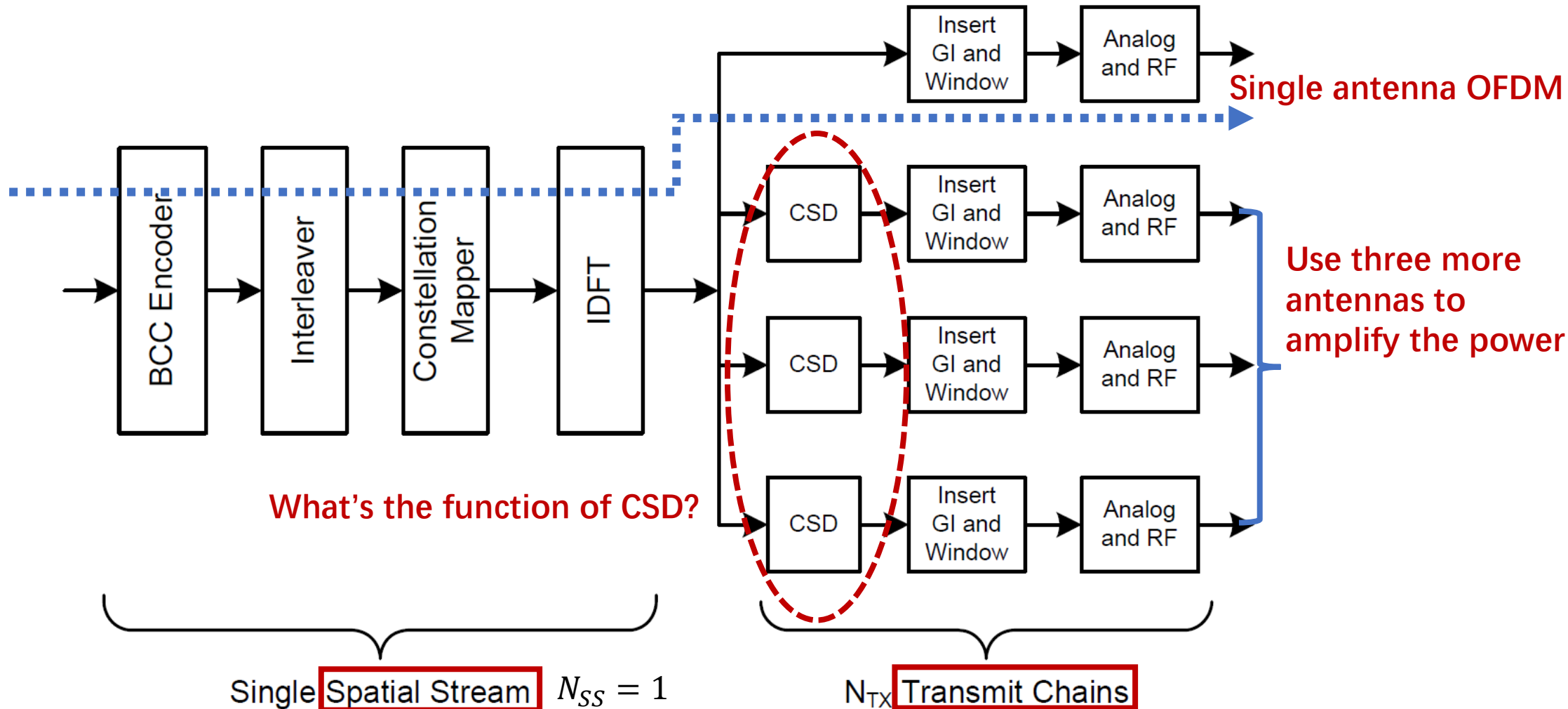
S1, S2, S3, S4, S5, ..., S64

Tx Antenna 2:

S61, S62, S63, S64, S1, ..., S60



Recap: Single Spatial Stream (19.3.3)



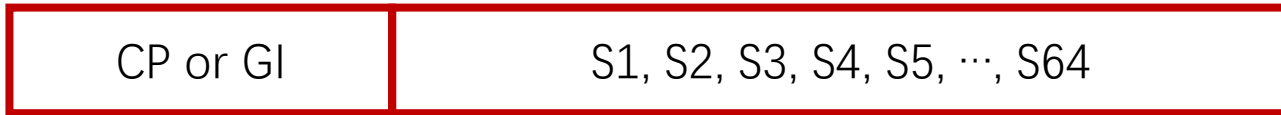
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Cyclic Shift - Example

- Suppose non-HT mode, two antennas transmit the same signal, CSD happens after IFFT
- Suppose cyclic shift is 200ns, which include 4 samples



Analysis of Cyclic Shift



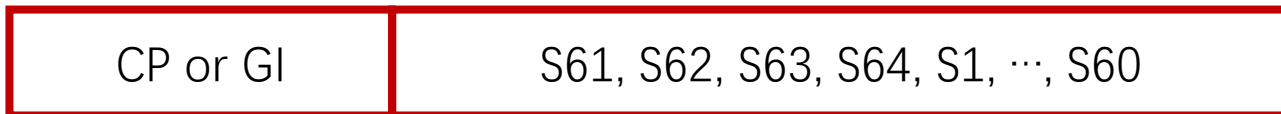
Tx Antenna 1

Impulse response $h_1 \Rightarrow$ after DFT $\{H_1^1, H_1^2, \dots, H_1^{64}\}$

Rx Antenna 1

Tx Antenna 2

Impulse response $h_2 \Rightarrow$ after DFT $\{H_2^1, H_2^2, \dots, H_2^{64}\}$



Analysis of Cyclic Shift

$$\begin{bmatrix} D_1 \\ D_2 \\ \dots \\ D_{64} \end{bmatrix} \text{IDFT} \Rightarrow \begin{bmatrix} S_1 \\ S_2 \\ \dots \\ S_{64} \end{bmatrix} \quad \text{Add CP} \Rightarrow \text{Convolution with } I_1 \Rightarrow \text{Remove CP} \Rightarrow \text{DFT} \Rightarrow \begin{bmatrix} H_1^1 D_1 \\ H_1^2 D_2 \\ \dots \\ H_1^{64} D_{64} \end{bmatrix}$$

Tx Antenna 1

Impulse response $I_1 \Rightarrow$ after DFT $\{H_1^1, H_1^2, \dots, H_1^{64}\}$

Rx Antenna 1

Tx Antenna 2

Impulse response $I_2 \Rightarrow$ after DFT $\{H_2^1, H_2^2, \dots, H_2^{64}\}$

$$[?] \text{IDFT} \Rightarrow \begin{bmatrix} S_{61} \\ S_{62} \\ \dots \\ S_{60} \end{bmatrix}$$

Analysis of Cyclic Shift

Tx Antenna 1

$$D_k = \sum_{n=1}^{64} S_n e^{-\frac{2\pi j}{64}kn} = S_1 e^{-\frac{2\pi j}{64}k} + S_2 e^{-\frac{2\pi j}{64}2k} + \dots + S_{64} e^{-\frac{2\pi j}{64}64k}$$

Tx Antenna 2

$$\begin{aligned} & S_{61} e^{-\frac{2\pi j}{64}k} + S_{62} e^{-\frac{2\pi j}{64}2k} + \dots + S_{60} e^{-\frac{2\pi j}{64}64k} \\ &= \left[S_1 e^{-\frac{2\pi j}{64}k} + S_2 e^{-\frac{2\pi j}{64}2k} + \dots + S_{64} e^{-\frac{2\pi j}{64}64k} \right] e^{-\frac{2\pi j}{64}4k} \\ &= D_k e^{-\frac{2\pi j}{64}4k} \end{aligned}$$

Analysis of Cyclic Shift

$$\begin{bmatrix} D_1 \\ D_2 \\ \dots \\ D_{64} \end{bmatrix} \text{IDFT} \Rightarrow \begin{bmatrix} S_1 \\ S_2 \\ \dots \\ S_{64} \end{bmatrix} \quad \text{Add CP} \Rightarrow \text{Convolution with } I_1 \Rightarrow \text{Remove CP} \Rightarrow \text{DFT} \Rightarrow \begin{bmatrix} H_1^1 D_1 \\ H_1^2 D_2 \\ \dots \\ H_1^{64} D_{64} \end{bmatrix}$$

Tx Antenna 1

Impulse response $I_1 \Rightarrow$ after DFT $\{H_1^1, H_1^2, \dots, H_1^{64}\}$

Rx Antenna 1

Tx Antenna 2

Impulse response $I_2 \Rightarrow$ after DFT $\{H_2^1, H_2^2, \dots, H_2^{64}\}$

$$\begin{bmatrix} D_1 e^{-\frac{2\pi j}{64} 4} \\ D_2 e^{-\frac{2\pi j}{64} 4 \times 2} \\ \dots \\ D_{64} e^{-\frac{2\pi j}{64} 4 \times 64} \end{bmatrix} \text{IDFT} \Rightarrow \begin{bmatrix} S_{61} \\ S_{62} \\ \dots \\ S_{60} \end{bmatrix} \quad \text{Add CP} \Rightarrow \text{Convolution with } I_1 \Rightarrow \text{Remove CP} \Rightarrow \text{DFT} \Rightarrow \begin{bmatrix} H_2^1 e^{-\frac{2\pi j}{64} 4} D_1 \\ H_2^2 e^{-\frac{2\pi j}{64} 4 \times 2} D_2 \\ \dots \\ H_2^{64} e^{-\frac{2\pi j}{64} 4 \times 64} D_{64} \end{bmatrix}$$

Analysis of Cyclic Shift

$$\begin{bmatrix} D_1 \\ D_2 \\ \dots \\ D_{64} \end{bmatrix} \text{IDFT} \Rightarrow \begin{bmatrix} S_1 \\ S_2 \\ \dots \\ S_{64} \end{bmatrix}$$

Tx Antenna 1

Impulse response $I_1 \Rightarrow$ after DFT $\{H_1^1, H_1^2, \dots, H_1^{64}\}$

$$\begin{bmatrix} (H_1^1 + H_2^1 e^{-\frac{2\pi j}{64}4})D_1 \\ (H_1^2 + H_2^2 e^{-\frac{2\pi j}{64}4 \times 2})D_2 \\ \dots \\ (H_1^{64} + H_2^{64} e^{-\frac{2\pi j}{64}4 \times 64})D_{64} \end{bmatrix}$$

Rx Antenna 1

Tx Antenna 2

Impulse response $I_2 \Rightarrow$ after DFT $\{H_2^1, H_2^2, \dots, H_2^{64}\}$

$$\begin{bmatrix} D_1 e^{-\frac{2\pi j}{64}4} \\ D_2 e^{-\frac{2\pi j}{64}4 \times 2} \\ \dots \\ D_{64} e^{-\frac{2\pi j}{64}4 \times 64} \end{bmatrix} \text{IDFT} \Rightarrow \begin{bmatrix} S_{61} \\ S_{62} \\ \dots \\ S_{60} \end{bmatrix}$$