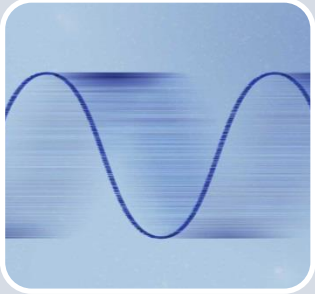
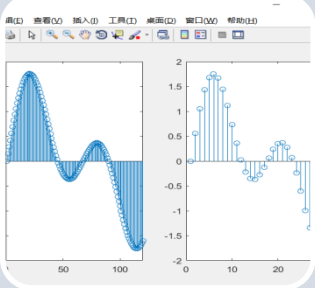


System Requirements and Configurations



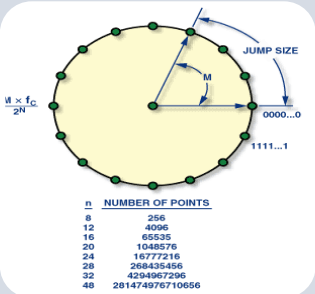
ADC Configuration

- RF SoC supports F_s in range of 1024 MHz - 4096 MHz.
- Our LTE Cell search IP needs F_s of 1.92MHz.
- ADC F_s is configured to 3932.16MHz as it is a multiple of 30.72MHz (LTE Rate). Reference ADC clock needed 491.52MHz.



Decimation

- Our System needs decimation of 2048.
- 8x decimation in RF Soc. From 3932.16MHz to 491.52MHz.
- 256x decimation in our custom IP to achieve F_s of 1.92MHz at LTE Cell search IP.

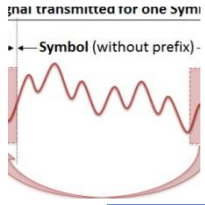


NCO (Numerically Controlled Oscillator)

- NCO configured to down convert carrier frequency to DC.
- 48-bit NCO per RF-ADC.
- Mixer is programmed to fine mode.

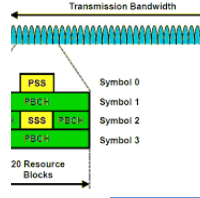
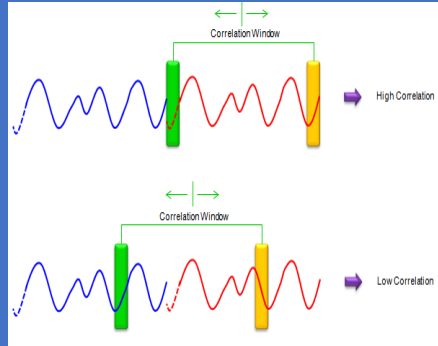


Main LTE Blocks – For Cell Search



CP Correlation

- Cyclic Prefix is an exact copy of the last part of OFDM symbol



PSS

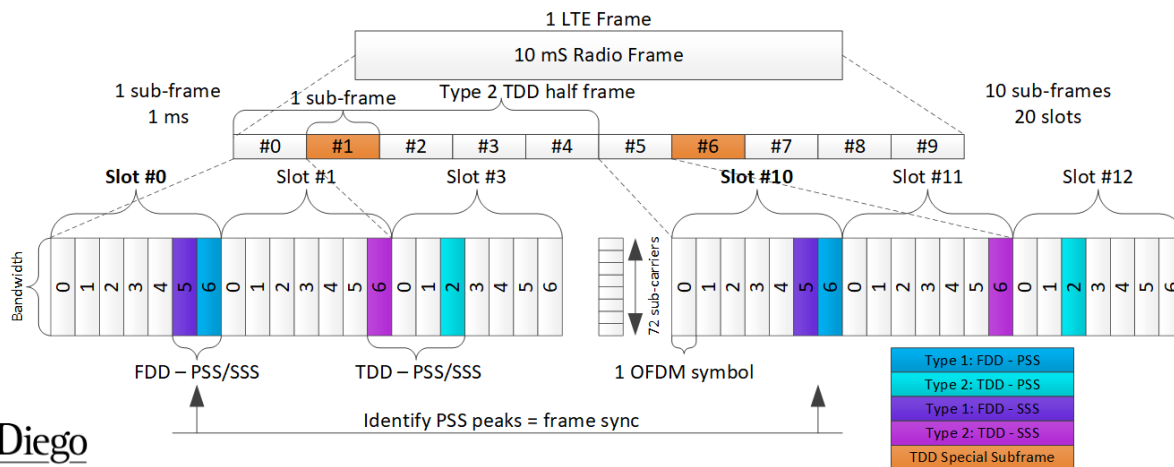
- 3 Zadoff-Chu root sequences defined in Frequency domain.
- IFFT to get time domain sequences which reduces HW complexity.
- Correlate Rx signal with 3 known time domain PSS sequences.

$$= 3N_{ID}^{(1)} + N_{ID}^{(2)}$$

$N_{ID}^{(1)} \in \{0, 1, \dots, 335\}$

SSS

- 1 of 168 known sequences.
- Polynomial based 3 binary sequences on Galois field.
- Correlation in frequency domain by taking 128-point FFT on Rx Symbol.



The physical cell identity, N_{ID}^{cell} , is defined by the equation:

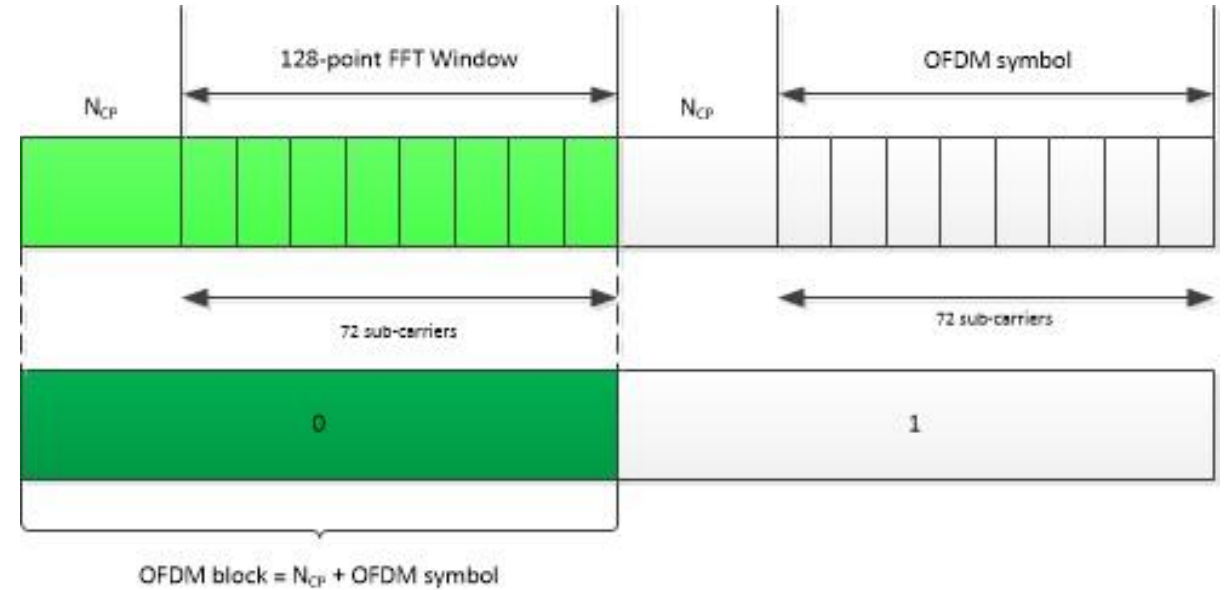
$$N_{ID}^{CELL} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$$

- $N_{ID}^{(1)}$ is the physical layer cell identity group (0 to 167).
- $N_{ID}^{(2)}$ is the identity within the group (0 to 2).

Frequency Estimation

Test Bench: Verified HLS code with Matlab Simulated results

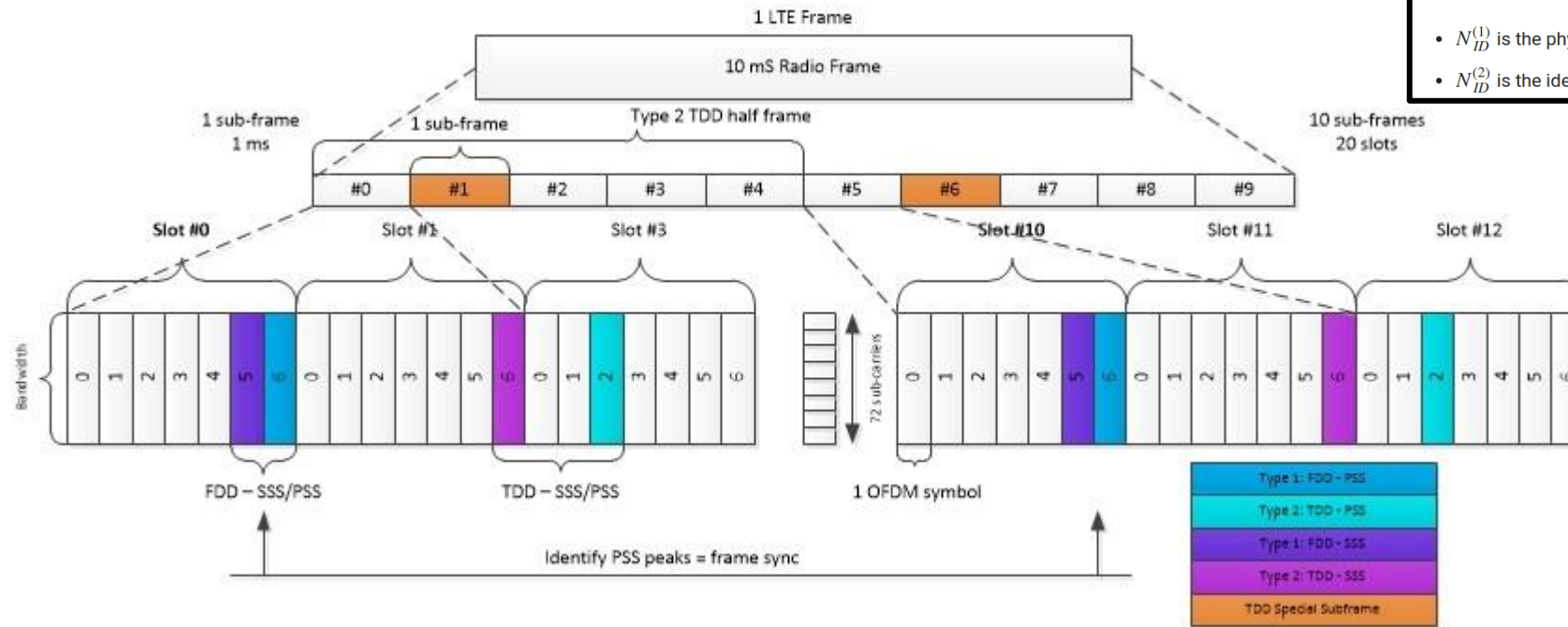
```
cp_corr_csim.log x
96 555.542602539062500 555.533203125000000
97 572.667480468750000 572.657836914062500
98 575.054260253906250 575.044494628906250
99 576.773376464843750 576.763488769531250
100 574.544860839843750 574.534851074218750
101 566.088073730468750 566.077758789062500
102 580.017028808593750 580.006408691406250
103 587.009460449218750 586.998352050781250
104 590.618041992187500 590.606750488281250
105 612.359985351562500 612.349243164062500
106 -----
107 RMSE(R)
108 0.005147035699338
109 -----
110 *****
111 PASS: The output matches the golden output!
112 *****
113 The maximum depth reached by any of the 3 hls::stream() instances in the design is 96000
114 INFO: [SIM 1] CSim done with 0 errors.
115 INFO: [SIM 3] ***** CSIM finish *****
116
```



Identify data to recover

- $f_s = 1.92\text{MHz}$, OFDM symbol = 128 samples
- $N_{CP} > L$, Channel impulse response
- CP = Cyclic Prefix, reduce likelihood of Inter-symbol Interference (ISI)

Synchronization



The physical cell identity, N_{ID}^{cell} , is defined by the equation:

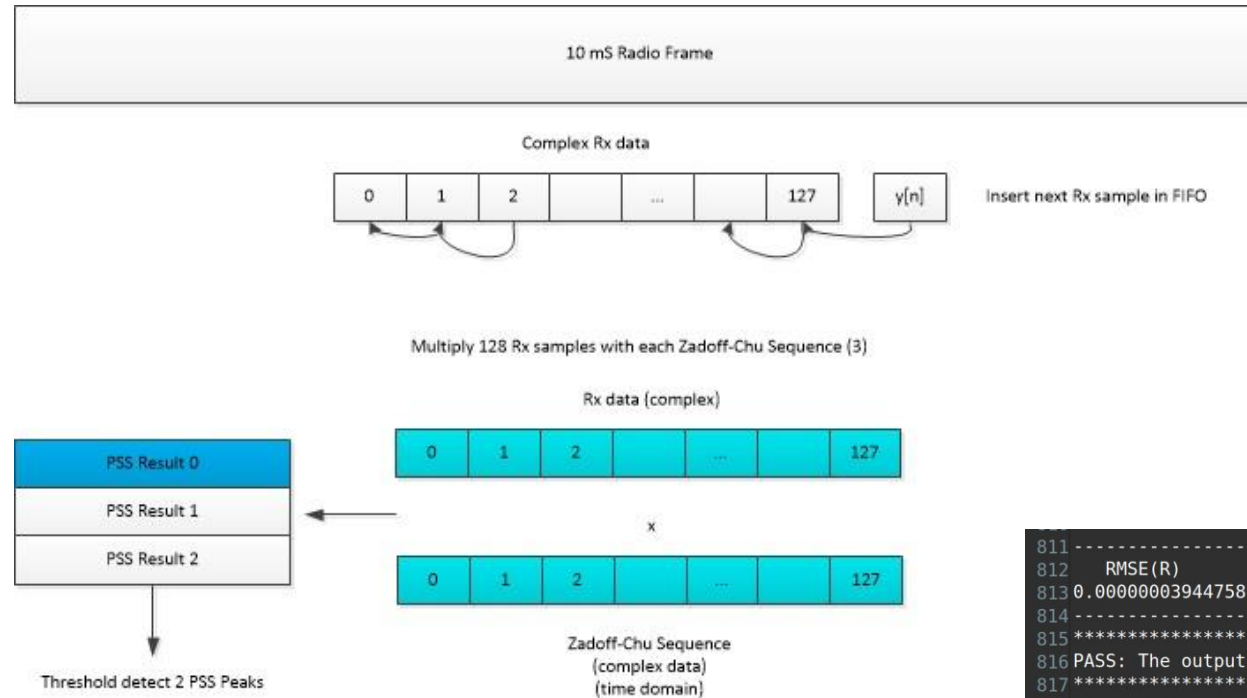
$$N_{ID}^{CELL} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$$

- $N_{ID}^{(1)}$ is the physical layer cell identity group (0 to 167).
- $N_{ID}^{(2)}$ is the identity within the group (0 to 2).

Structure of LTE frame

- Identify 2 peaks over 10 slots (1 frame)
- Keep searching for pair of peaks to maintain sync using threshold detect - maintain sync
- Identify PSS / SSS to decode the Cell ID

Synchronization - PSS



The physical cell identity, N_{ID}^{cell} , is defined by the equation:

$$N_{ID}^{CELL} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$$

- $N_{ID}^{(1)}$ is the physical layer cell identity group (0 to 167).
- $N_{ID}^{(2)}$ is the identity within the group (0 to 2).

Test Bench: Verified HLS code with Matlab Simulated results

```
cp_corr_pss_sss_csim.log x
1 INFO: [SIM 2] ***** CSIM start *****
2 INFO: [SIM 4] CSIM will launch GCC as the compiler.
3 Compiling ../../../../cp_corr_pss_sss_test.cpp in debug mode
4 Compiling ../../../../cp_corr_pss_sss.cpp in debug mode
5 Compiling ../../../../matmul_partition.cpp in debug mode
6 Generating csim.exe
7
8 n=0
9
10 Index Description Calculated Gold
11 000 pss_rslts_0 0.011211848817766 0.011211834847927
12 000 pss_rslts_1 0.007450049743056 0.007450057193637
13 000 pss_rslts_2 0.008478664793074 0.008478645235300
14
15 001 pss_rslts_0 0.002562189241871 0.002562147332355
16 001 pss_rslts_1 0.005705999676138 0.005705954041332
17 001 pss_rslts_2 0.007109185680747 0.007109189871699
18
19 RMSE (R)
20 0.000000039447585
21
22 *****
23 PASS: The output matches the golden output!
24 *****
25 The maximum depth reached by any of the 1188 hls::stream() instances in the des
26 INFO: [SIM 1] CSim done with 0 errors.
27 INFO: [SIM 3] ***** CSIM finish *****
```

Identity within the group (0 to 2)

- Identify known sequence in Rx data
 - 1 of 3 possible Zadoff-Chu sequences
- Part 1 of getting Physical Cell ID (504 Unique IDs)
- Complex multiply: Rx data and Zadoff-Chu sequences (converted to time domain)
- Threshold detection to determine correlation peaks

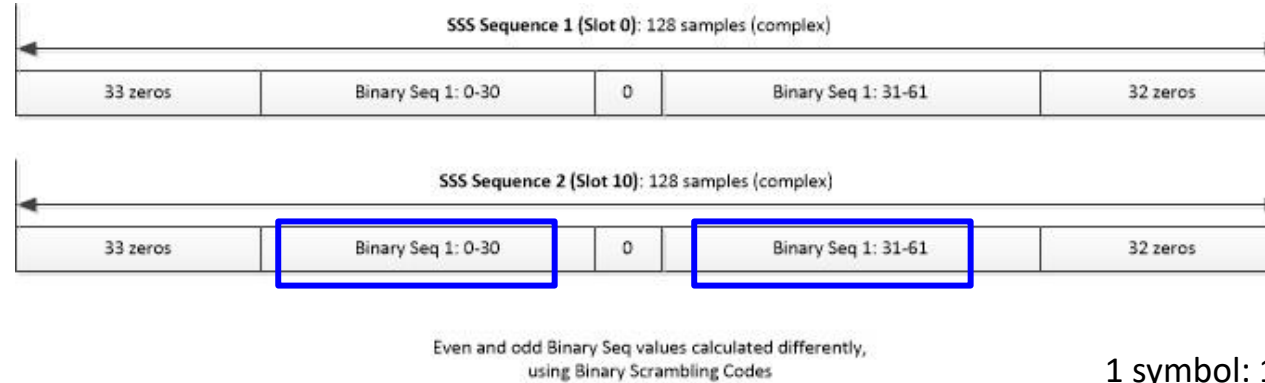
Synchronization - SSS

Test Bench: Verified HLS code with Matlab Simulated results

```

cp_corr_pss_sss_csime.log x
1 INFO: [SIM 2] ***** CSIM start *****
2 INFO: [SIM 4] CSIM will launch GCC as the compiler.
3 Compiling ../../../../cp_corr_pss_sss_test.cpp in debug mode
4 Compiling ../../../../cp_corr_pss_sss.cpp in debug mode
5 Compiling ../../../../matmul_partition.cpp in debug mode
6 Generating csim.exe
7 Start Read
8 Calling sss_sync
9
10 n=0
11
12 Index Description Calculated Gold
13 0 Out_11r -0.247550204396248 -0.247584104537964
14 0 Out_11i 0.003370870836079 0.003370859427378
15 0 Out_12r -0.250740051269531 -0.251053690910339
16 0 Out_12i 0.000468272890430 0.002253722399473
17 0 Out_21r 0.749129891395569 0.749139189720154
18 0 Out_21i -0.001893163658679 -0.001893070875667
19 0 Out_22r 0.749780058860779 0.749722421169281
20 0 Out_22i -0.000135826820042 -0.000306707486743
...
1516 167 Out_11r -0.258170008659363 -0.258163273334503
1517 167 Out_11i 0.003966394811869 0.003966243937612
1518 167 Out_12r 0.750460088253021 0.748103439807892
1519 167 Out_12i 0.000252946862020 -0.000963220431004
1520 167 Out_21r -0.252290070056915 -0.252318084239960
1521 167 Out_21i 0.001886585028842 0.001886588521302
1522 167 Out_22r 0.749579966068268 0.749049842357635
1523 167 Out_22i 0.000177846755832 0.000045595592383
1524
1525 -----
1526 RMSE(R)
1527 0.001652569510043
1528 -----
1529 *****
1530 PASS: The output matches the golden output!
1531 *****
1532 The maximum depth reached by any of the 1188 hls::stream() insta
1533 INFO: [SIM 1] CSim done with 0 errors.
1534 INFO: [SIM 3] ***** CSIM finish *****
1535

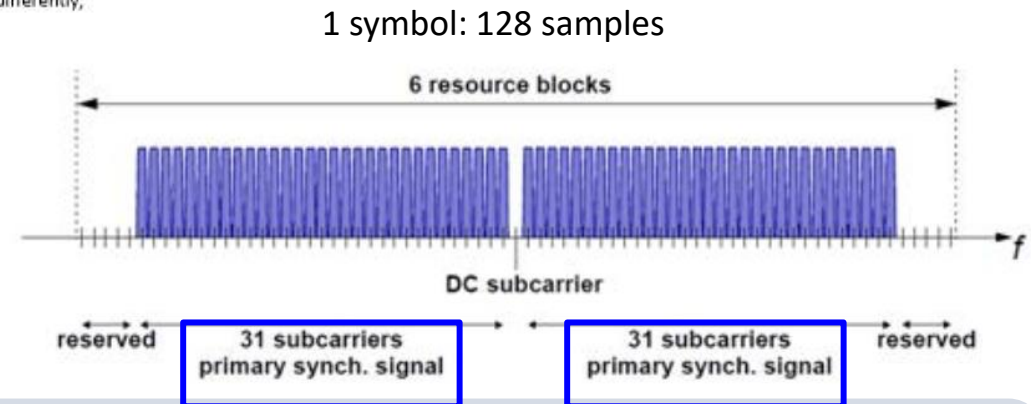
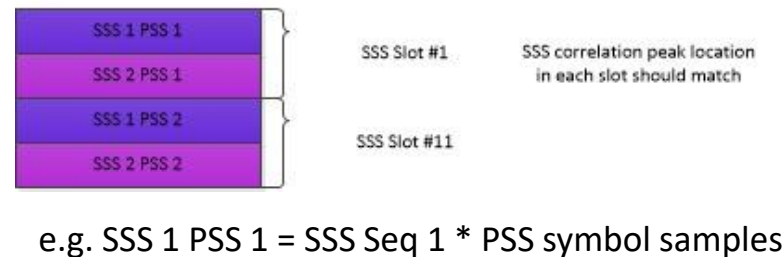
```



The physical cell identity, N_{ID}^{cell} , is defined by the equation:

$$N_{ID}^{CELL} = 3N_{ID}^{(1)} + N_{ID}^{(2)}$$

- $N_{ID}^{(1)}$ is the physical layer cell identity group (0 to 167).
- $N_{ID}^{(2)}$ is the identity within the group (0 to 2).



Physical layer cell identity group (0 to 167)

- FFT to demodulate OFDM data
- SSS Correlation: Multiply and accumulate 2 SSS Sequences (binary scrambling codes)
 - Demodulated Rx data
- Threshold detection to determine correlation peaks
- Peak location range [0 167] = physical layer identity group