# FREQUENCY INTERLEAVER PERFORMANCE IN LTE INTERFERENCE

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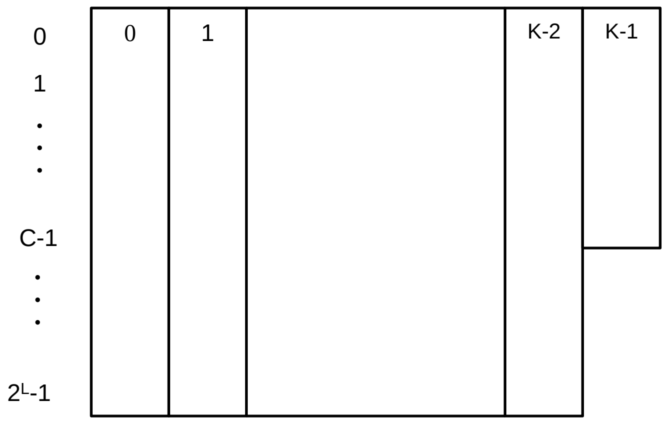
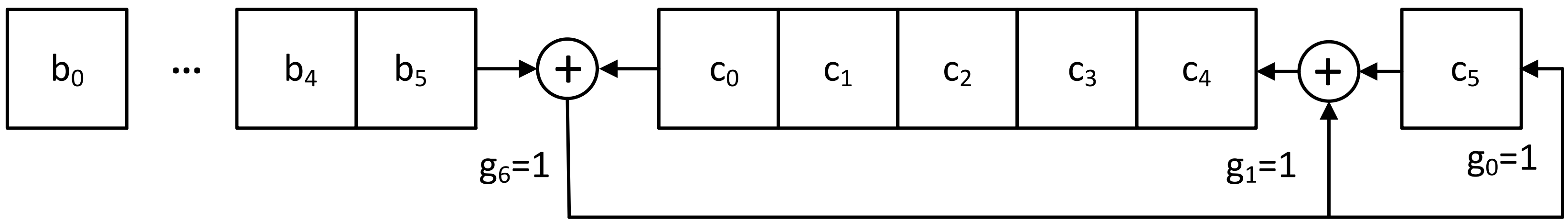
# EPoC Downstream Frequency Interleaver

# TWO-DIMENSIONAL STORE BLOCK STRUCTURE

- **2-D store**
- **$2^L$ rows and *K* columns**
- **L and K are chosen depending on FFT size**
- **$N_I$ data subcarriers and scattered pilots**
- $K = ceil(\frac{N_I}{2^L})$
- $C = N_I - 2^L(K-1)$ **subcarriers in the last column**



# CRC ADDRESS GENERATOR




- **6-stage linear feedback shift register (LFSR) for calculating the CRC of each row address**
- **Defined using a primitive generator polynomial of degree 6:**

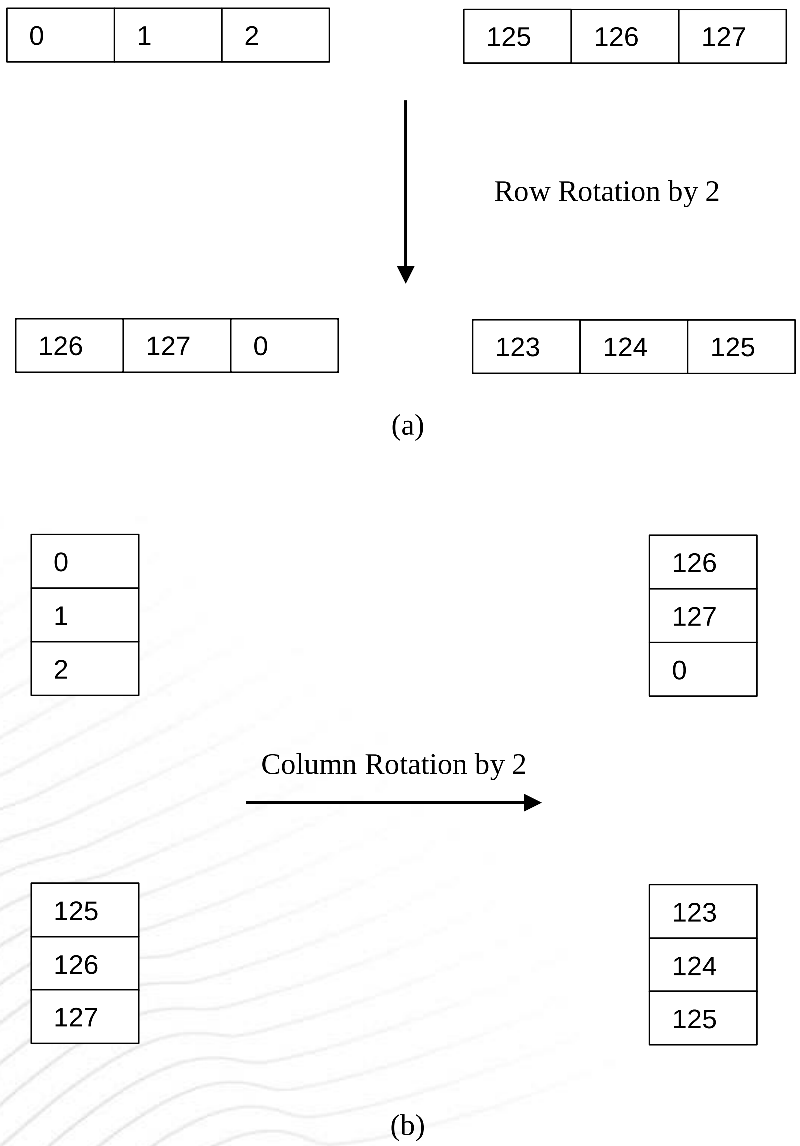
$$G(X) = X^6 + X^1 + 1$$

- **Input sequential row address $b_5, b_4, b_3, b_2, b_1, b_0$**
- **Output permuted row address = CRC value $c_5, c_4, c_3, c_2, c_1, c_0$**

# FREQUENCY INTERLEAVING PROCESS

- Write successive consecutive subcarriers into the 2-D store in the row given by the L bit CRC value of each L bit row address.
- Rotate the subcarriers in each row written by the same L bit CRC value of the row address modulo the number of columns in that row (either modulo K for a row below C or modulo K-1 for row C and higher) using a right circular shift.
- Rotate the subcarriers in each column by the L bit CRC value of [K-1 minus the column address] using a downward circular shift. Note that the last column K-1 with a CRC value of 0 in not rotated.
- Read the subcarriers out of the 2-D store column-wise from row 0, column 0 to row C-1, column K-1.

# ROW AND COLUMN ROTATION



# CALCULATION OF SUBCARRIER POSITIONS

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- **Permuted output subcarrier number in the 2-D store in row r, column c as sc(r,c) given by:**

$$sc(r,c) = sc_0\left[\left(r - CRC(K-1-c)\right) mod\ 2^L\right] + \left(c - \left(r - CRC(K-1-c)\right) mod\ 2^L\right) mod\ M,$$

$$where\ M = \begin{cases} K, for\ \left(r - CRC(K-1-c)\right) mod\ 2^L < C \\ K-1, otherwise \end{cases}$$

- **$sc_0[n]$ is an array of $2^L$ elements where each element contains the cumulative number of subcarriers previously written into the 2-D store**
  - Represents the starting (i.e. lowest) subcarrier number in a permuted row
- **Note that if the last column contains fewer subcarriers than $2^L$, the cumulative value in $sc_0[n]$ takes into account those previously written permuted output rows that were shorter by one subcarrier**
- ***Large 2-D store Lookup Table is not needed***
- ***Direct calculation without variable number of clock cycles***

# FREQUENCY DE-INTERLEAVING PROCESS

- Write the subcarriers into the 2-D store column-wise from column 0, row 0 to column K-1, row C-1.
- Rotate the subcarriers in each column by the L bit CRC value of [K-1 minus the column address] using an upward circular shift (reverse of interleaver). Note that the last column K-1 with a CRC value of 0 in not rotated.
- Rotate the subcarriers in each row written by the same L bit CRC value of the row address modulo the number of columns in that row (either modulo K for a row below C or modulo K-1 for row C and higher) using a left circular shift (reverse interleaver).
- Read the subcarriers out of the 2-D store row-wise in the row order given by the L bit CRC value of each L bit row address skipping the last column at or beyond row C.

# EPoC INTERLEAVER OUTPUT (PARTIAL)

| | |
|---|---|
| # Subcarriers | 3745 |
| # Rows | 64 |
| # Columns | 59 |
| Last Column | 33 |

| Read ROW | Column 0 Subcarrier | Write ROW | Column 0 Subcarrier | COLUMN: Rotation: | 0 44 | 1 4 | 2 52 | 3 22 | 4 38 | 5 14 | 6 62 | 7 26 | 8 42 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | 0 | 0 | 0 | 390 | 350 | 283 | 2944 | 3020 | 2821 | 2870 | 3186 | 3262 |
| 1 | 1930 | 48 | 59 | 48 | 2319 | 2162 | 2212 | 1130 | 1089 | 1007 | 939 | 1372 | 1331 |
| 2 | 2866 | 24 | 117 | 24 | 3254 | 3097 | 3147 | 3410 | 3486 | 3287 | 3336 | 201 | 160 |
| 3 | 936 | 40 | 176 | 40 | 1323 | 1283 | 1216 | 1596 | 1555 | 1473 | 1405 | 2013 | 2089 |
| 4 | 3334 | 12 | 234 | 12 | 152 | 1 | 3731 | 659 | 618 | 536 | 468 | 2948 | 3024 |
| 5 | 1404 | 60 | 293 | 1 | 2081 | 1930 | 1799 | 2471 | 2547 | 2348 | 2456 | 1134 | 1093 |
| 6 | 468 | 20 | 351 | 20 | 3016 | 2924 | 862 | 72 | 3658 | 3517 | 3625 | 3414 | 3490 |
| 7 | 2398 | 36 | 410 | 36 | 1085 | 993 | 2791 | 1884 | 1843 | 1703 | 1694 | 1600 | 1559 |
| 8 | 3568 | 6 | 468 | 6 | 3482 | 3390 | 392 | 2819 | 906 | 766 | 757 | 663 | 622 |
| 9 | 1638 | 54 | 527 | 54 | 1551 | 1459 | 2321 | 1005 | 2718 | 2578 | 2686 | 2475 | 2551 |
| 10 | 702 | 30 | 585 | 30 | 614 | 522 | 3256 | 3285 | 436 | 296 | 287 | 76 | 3662 |
| 11 | 2632 | 46 | 644 | 46 | 2543 | 2451 | 1325 | 1471 | 2248 | 2108 | 2216 | 1888 | 1847 |
| 12 | 234 | 10 | 702 | 10 | 3654 | 3620 | 154 | 534 | 3183 | 3043 | 3151 | 2823 | 910 |
| 13 | 2164 | 58 | 761 | 58 | 1839 | 1689 | 2083 | 2346 | 1369 | 1229 | 1220 | 1009 | 2722 |
| 14 | 3100 | 18 | 819 | 18 | 902 | 752 | 3018 | 3515 | 198 | 5 | 3735 | 3289 | 440 |
| 15 | 1170 | 34 | 878 | 34 | 2714 | 2681 | 1087 | 1701 | 2010 | 1934 | 1803 | 1475 | 2252 |

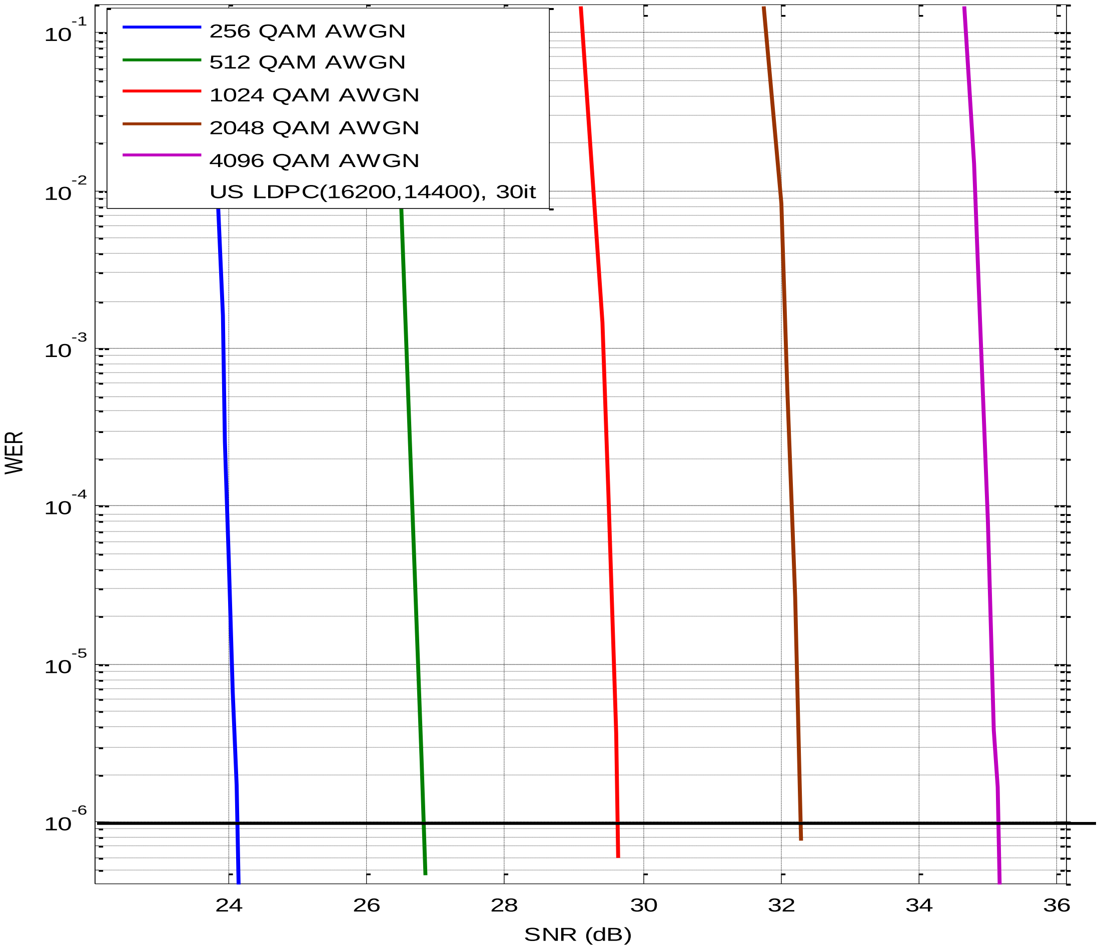
# *LTE Interference Model*

# LTE INTERFERENCE MODEL

- **10 MHz wide LTE interference placed in the center of the 190 MHz OFDM band**
  - LTE PSD -20 dB below the PSD of the OFDM signal (moderate)
  - LTE PSD -3 dB below the PSD of the OFDM signal (strong)
- **A 4K FFT with 50 kHz subcarrier spacing would affect 200 subcarriers out of 3800 subcarriers in 190 MHz**
- **Modulation orders of 4096-QAM, 1024-QAM, and 256-QAM**
- **Performance with and without frequency interleaving simulated**
- **The increased SNR threshold of the AWGN background under LTE interference with frequency interleaving shown**

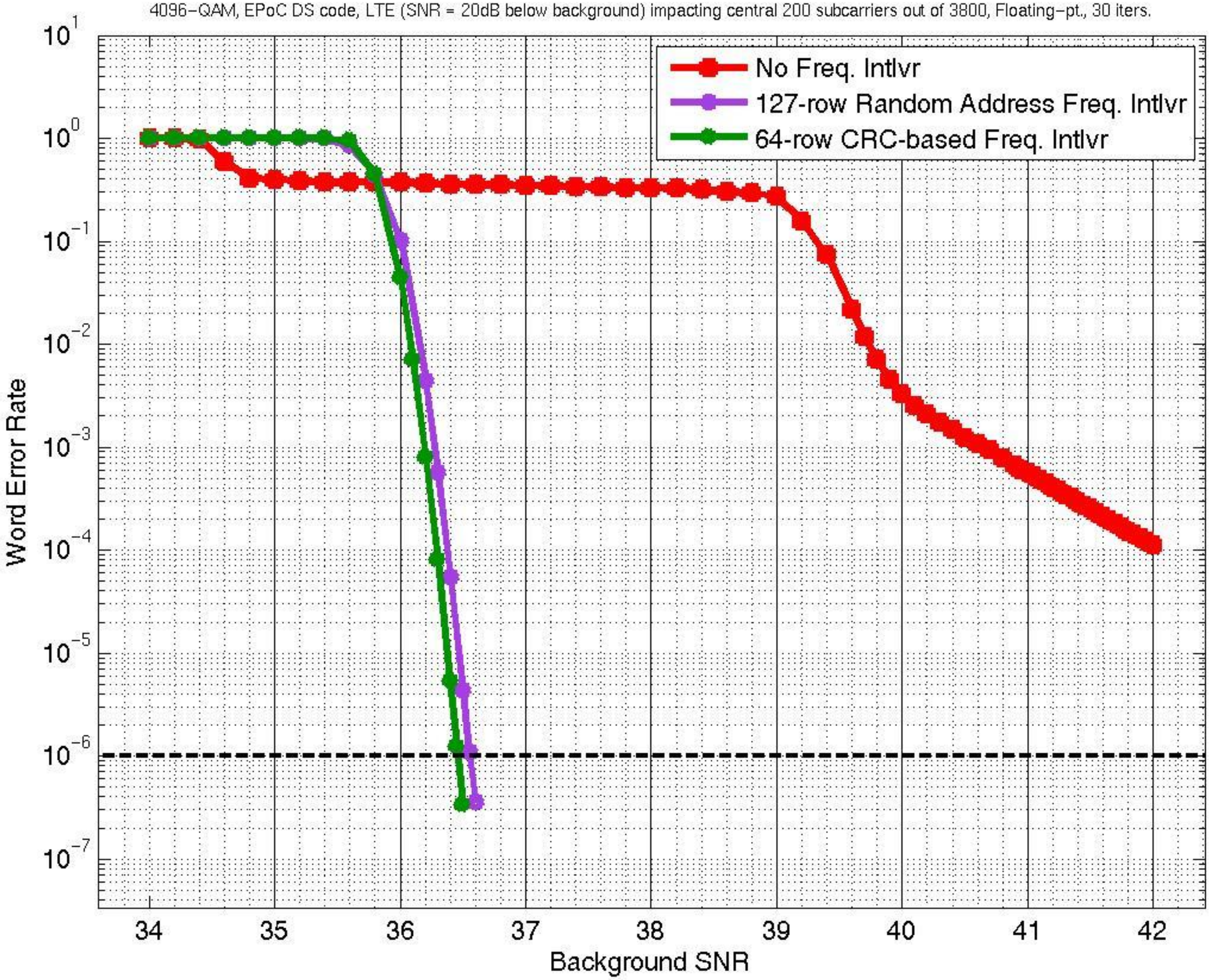
# *EPoC Frequency Interleaver Performance in LTE Interference*

# FEC PERFORMANCE IN AWGN CHANNEL

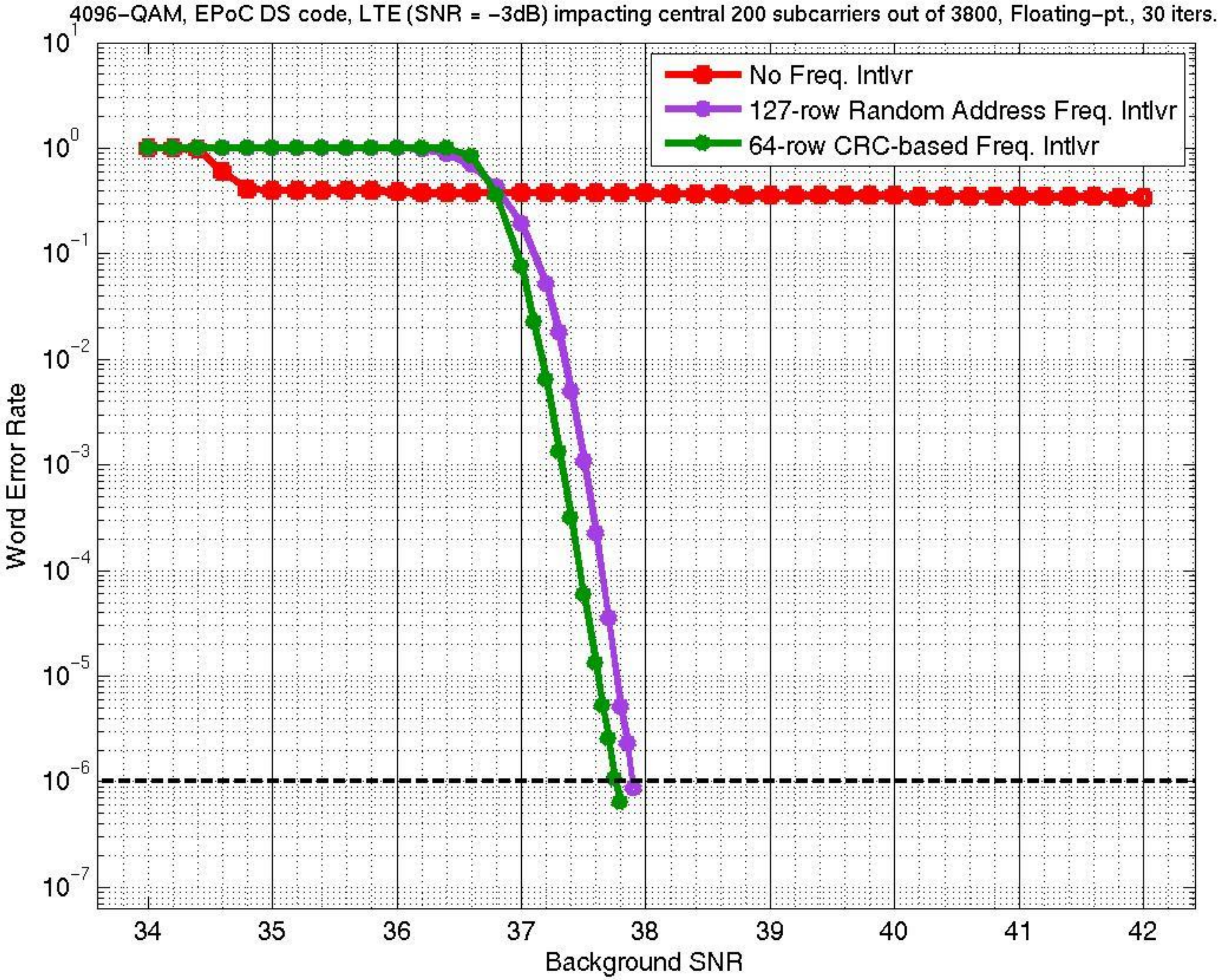



| Downstream (16200, 14400) code (30 iterations) | | 256QAM | 512QAM | 1024QAM | 2048QAM | 4096QAM |
|---|---|---|---|---|---|---|
| | SNR@WER=1e-6 | 24.11dB | 26.83dB | 29.64dB | 32.29dB | 35.16dB |
| | SNR@BER=1e-8 | 24.1dB | 26.82dB | 29.62dB | 32.28dB | 35.15dB |

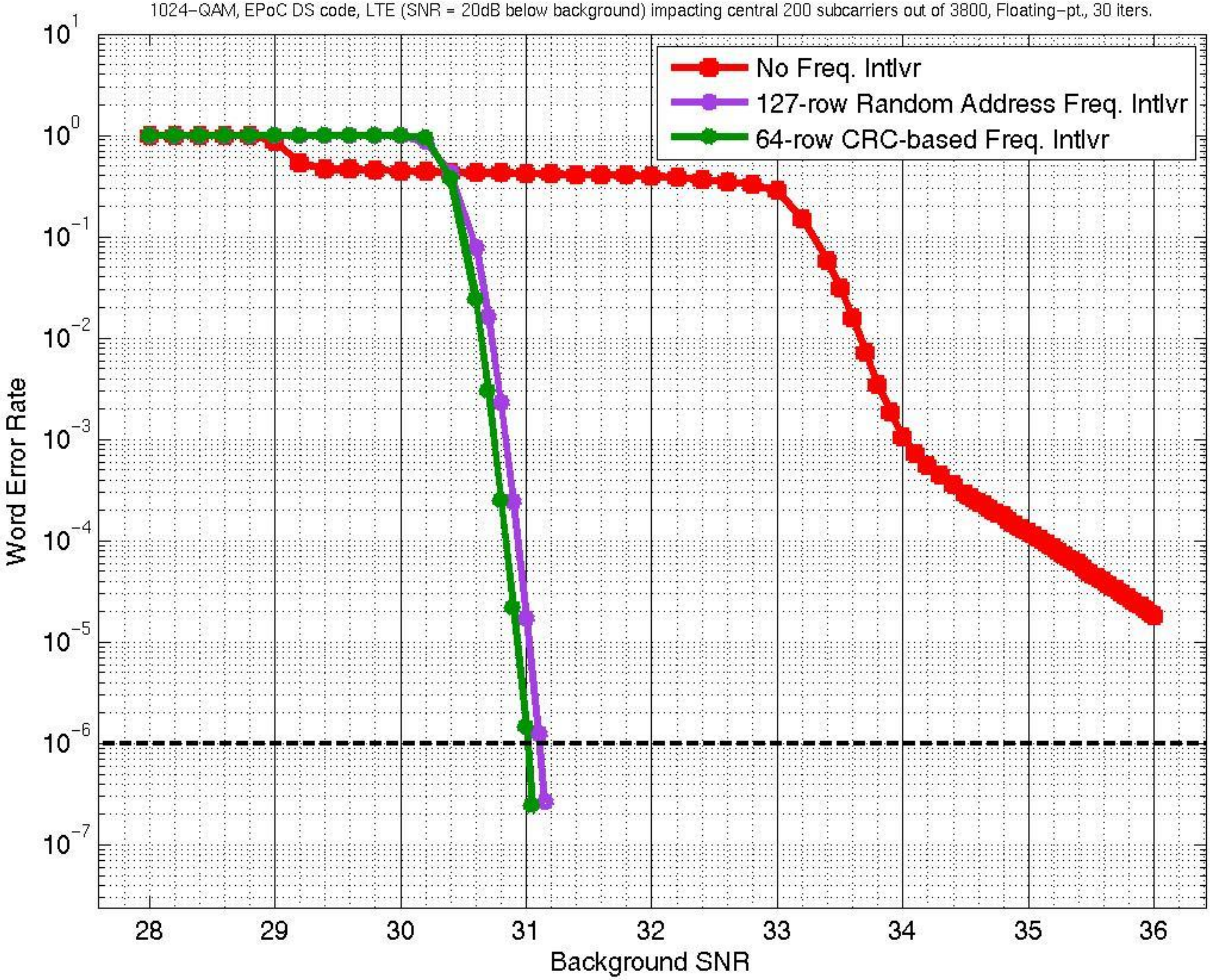
# 4096-QAM IN -20 dB 10 MHz LTE INTERFERENCE



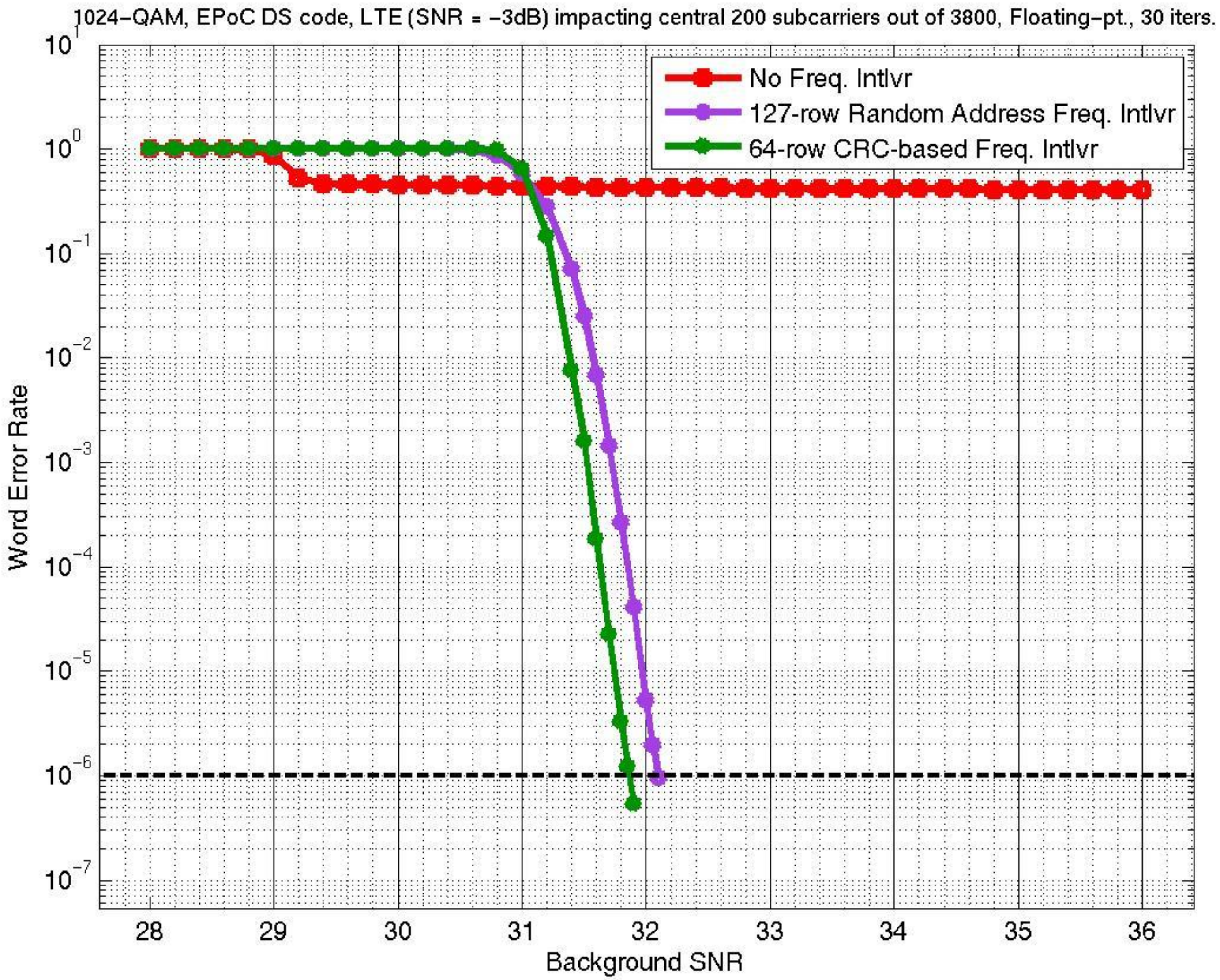
# 4096-QAM IN -3 dB 10 MHz LTE INTERFERENCE



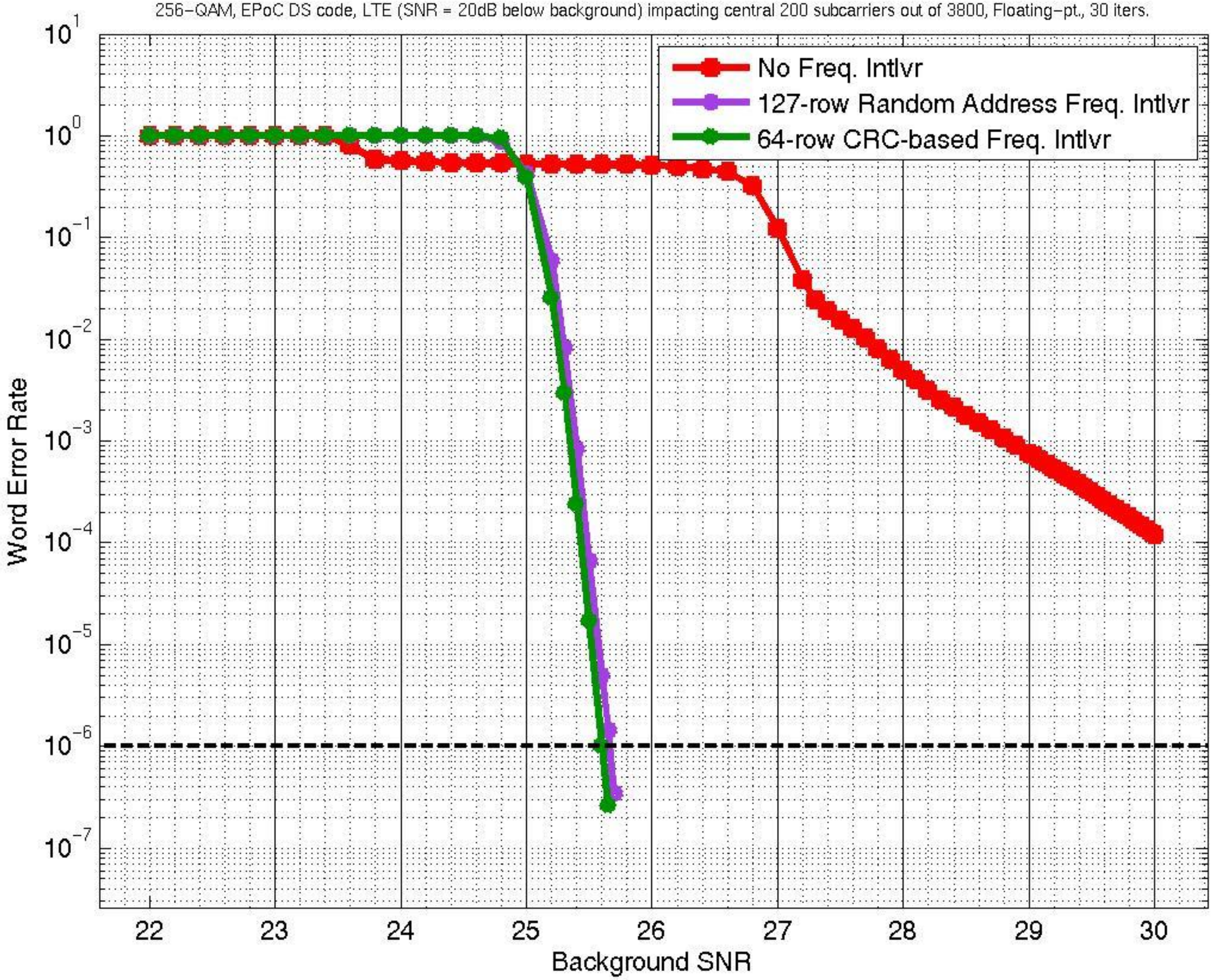
# 1024-QAM IN -20 dB 10 MHz LTE INTERFERENCE



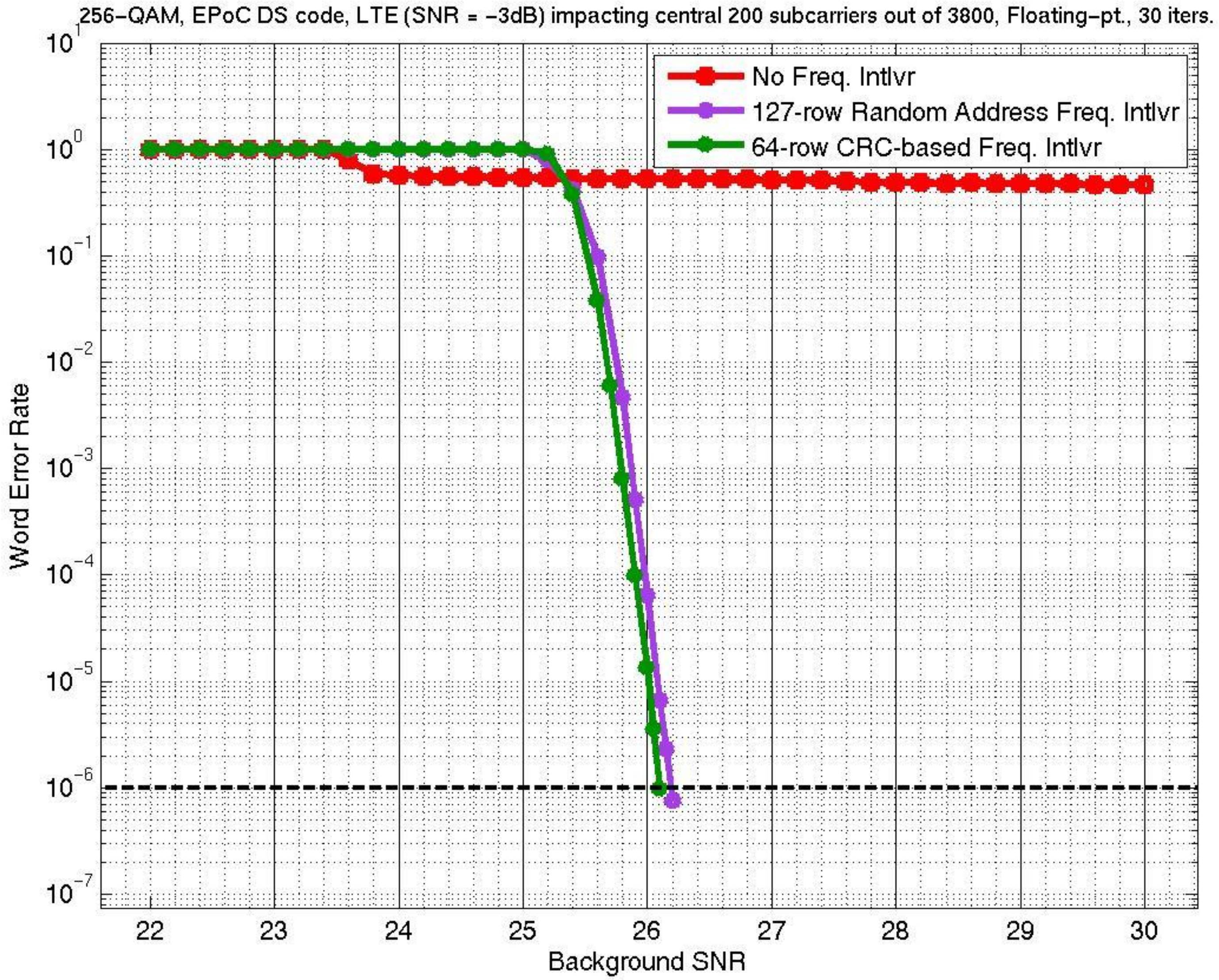
# 1024-QAM IN -3 dB 10 MHz LTE INTERFERENCE



# 256-QAM IN -20 dB 10 MHz LTE INTERFERENCE



# 256-QAM IN -3 dB 10 MHz LTE INTERFERENCE



# CONCLUSION

- **2-D Random (non-systematic) frequency interleaver described**
  - CRC encoded row write addressing at the input
  - CRC encoded rotation of both rows and columns to prevent periodicity
  - Sequential column read addressing at the output
  - Provides pseudo-random subcarrier frequency dispersion
  - Non-systematic random ordering of subcarriers across the entire spectrum
- **10 MHz wide LTE interferer in the center of a 190 MHz OFDM band at both moderate and strong interference levels simulated**
- **Modulation orders of 4096-QAM, 1024-QAM, and 256-QAM evaluated**
- **Frequency interleaver improved performance in LTE interference has been demonstrated**
- **Noise margin loss in AWGN with LTE interference determined**
  - Less than 1.5 dB better SNR needed with a moderate -20 dB LTE interferer
  - Less than 2.5 dB better SNR needed with a strong -3 dB LTE interferer

# *Thank You*