



Novel Interleaved Z_4 -Linear PRN Codes for NavIC L1-SPS

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- IRNSS known as Navigation with Indian Constellation (NavIC) is launching a new civilian signal in the L1 frequency band.
- This calls for the design, selection and performance optimization of primary and secondary PRN codes for the NavIC L1 signal.
- This design is presented here.

- Primary code period = 10230 (a challenge!)
- Symbol balance within each period
- Low values of even and odd correlation
- Data-Pilot code pair orthogonality
- Low values of cross-correlation with other L1-band GNSS signals
- Overlay code period-1800
- Low full and partial-period correlation values for overlay codes

- One approach to achieving period 10230 is to use an existing sequence design having period close to 10230
- Followed by padding or truncation to obtain period 10230
 - Eg. Short-cycling LFSR-based sequences to achieve period 10230.
- However, padding or truncation tends to degrade correlation properties
- Here , we adopt a different approach...

This work is the result of a joint, collaborative effort between:

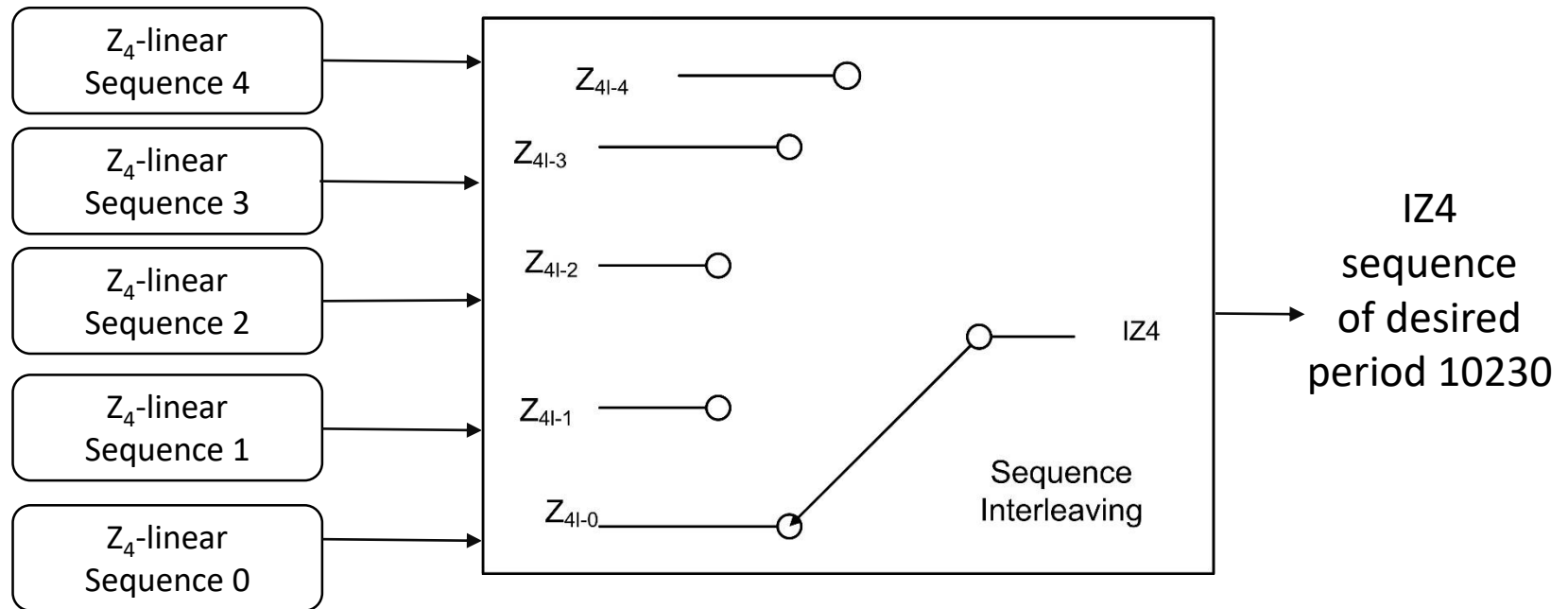
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- Our approach: use the factorization: $10230 = 5 \times 2046$
- Interleave 5 Z_4 -Linear sequences, each of period 2046 to achieve period 10230 without need for padding or truncation
- Z_4 denotes the set $\{0,1,2,3\}$ of integers modulo 4
- A Z_4 -Linear sequence is a binary sequence derived from a sequence over Z_4
- The resulting sequence family is termed as the family of Interleaved Z_4 -Linear (IZ4) spreading codes
- A family of 170, IZ4 sequences are available for the NavIC L1 Signal

Structure of the IZ4 Spreading Code



Each Z_4 -linear sequence has period 2046

IZ4 Sequence = Interleaved Z_4 -Linear Sequence

Achieving Various Performance Measures

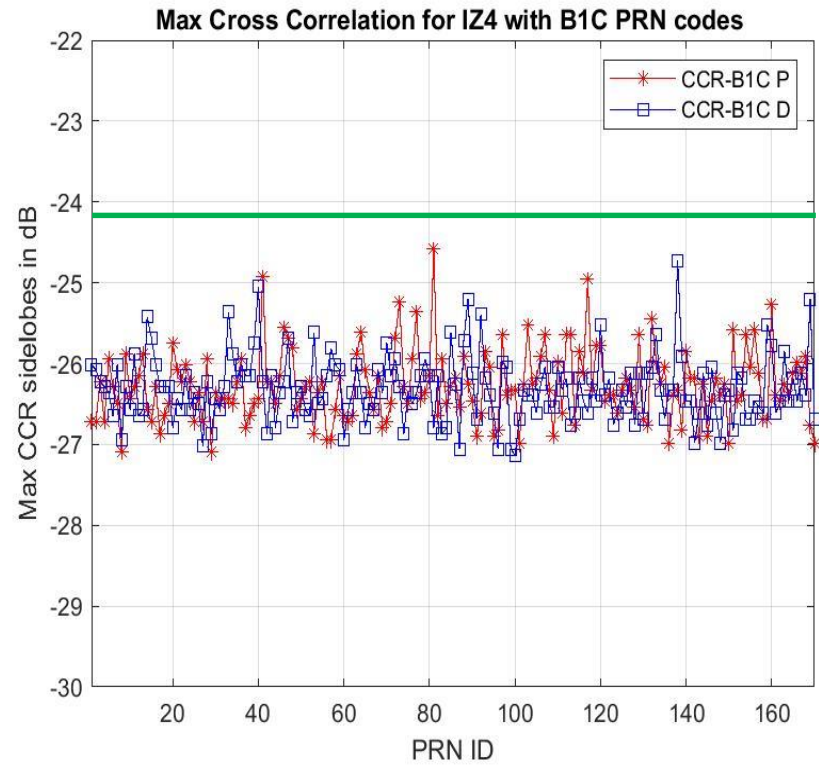
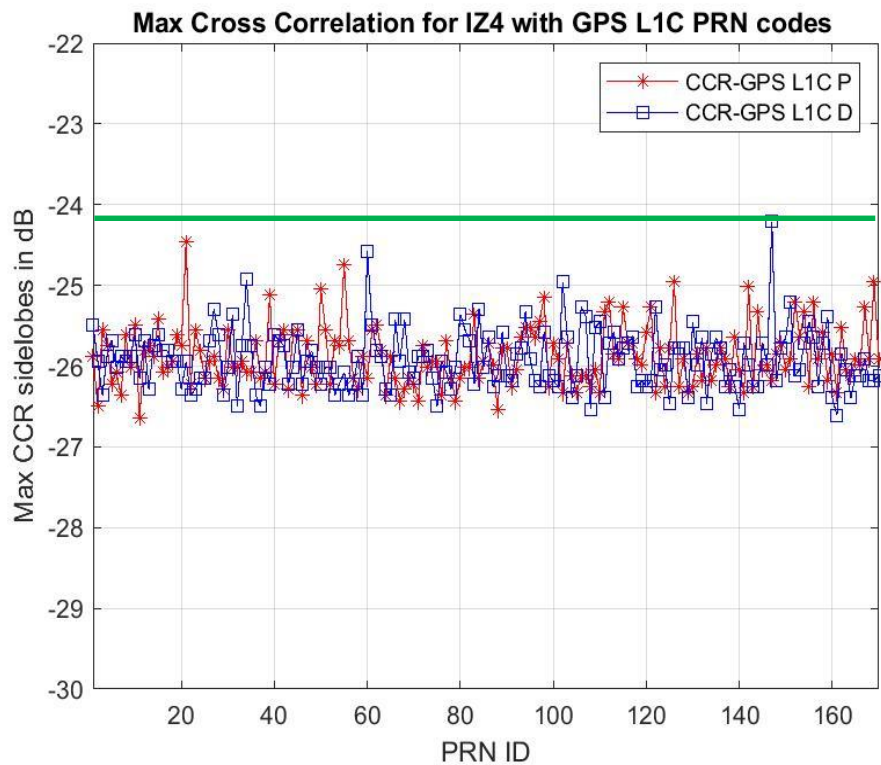
| Performance Measure | Achieved Through Mathematical Design | Achieved Through optimisation |
|--|--------------------------------------|-------------------------------|
| Low Even Autocorrelation | ✓ | |
| Low Even Cross-Correlation | ✓ | |
| Balance | ✓ | |
| Pilot-Data Orthogonality | ✓ | |
| Low Odd Autocorrelation | | ✓ |
| Low Odd Cross-Correlation | | ✓ |
| Low Correlation in presence of Doppler | | ✓ |
| Low Inter-System Interference | | ✓ |

| | |
|--------------------------------|-----------------------------------|
| Ease of Implementation: | Intelligent circuit design |
|--------------------------------|-----------------------------------|

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|----------------------|----------------------------------|
| Overlay Code: | Truncated Z4-linear codes |
|----------------------|----------------------------------|

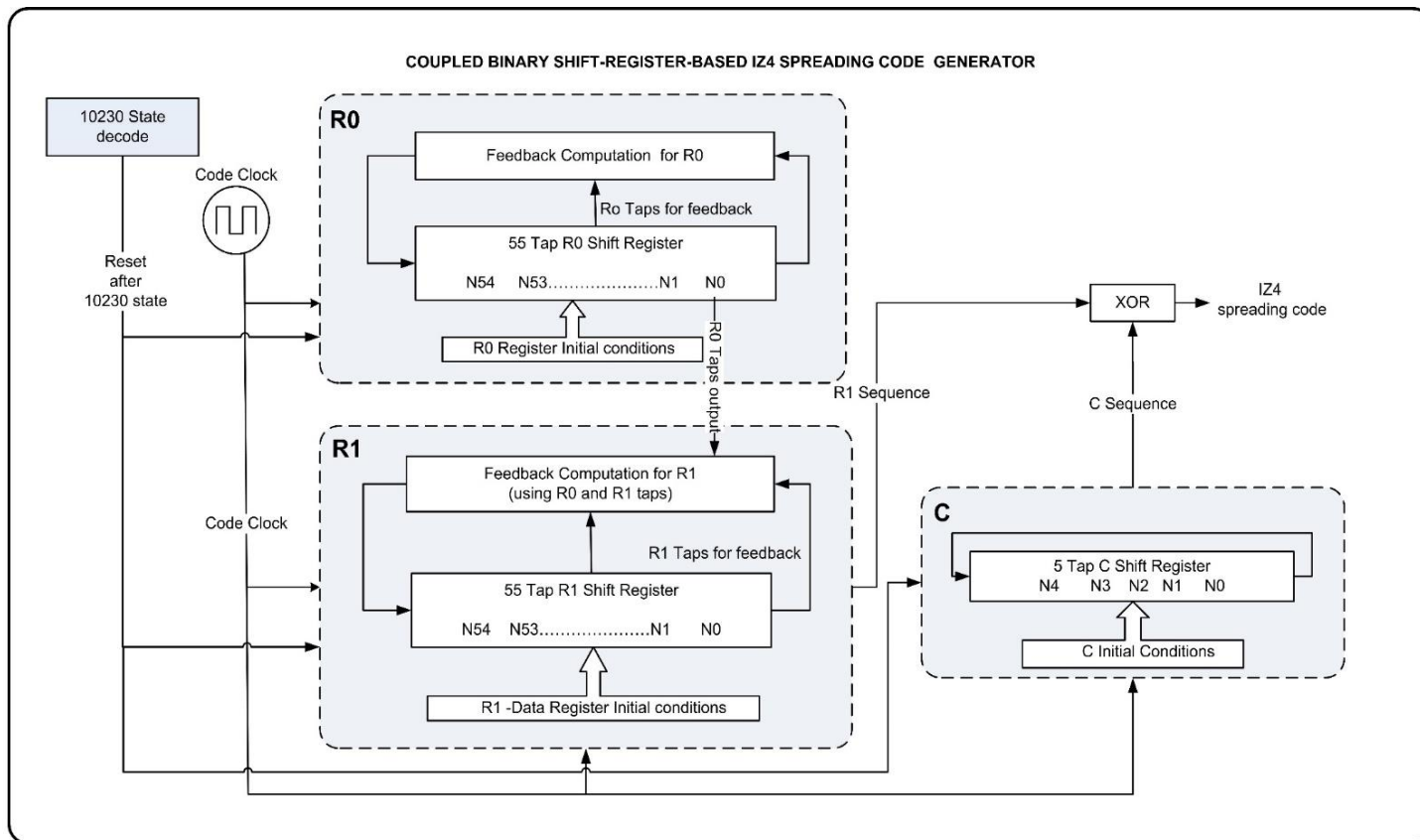
| Performance Parameters | IZ4 Codes | Weil Codes with Padding | Weil Codes with Truncation |
|---|-----------|-------------------------|----------------------------|
| Maximum Even Auto Correlation Side lobe | -31.7 dB | -31.2 dB | -31.19 dB |
| Maximum Even Cross-Correlation Side lobe | -31.7 dB | -27.21 dB | -27.29 dB |
| Maximum Odd Auto Correlation Side lobe | -29.83 dB | -28.03 dB | -31.19 dB |
| Maximum Odd Cross - Correlation Side lobe | -26.5 dB | -26.22 dB | -27.29 dB |
| Balance | 0 and 2 | 0 | 0 |
| Orthogonality | 0 | 2 | 2 |

Inter System Cross-Correlation Analysis Of NavIC L1 Primary IZ4 Codes



- Total PRN codes Analyzed = 170 IZ4 codes
- Correlated with 420 GPS L1C codes and 126 B1C codes
- Max Inter System Cross Correlation (dB) of -24.2 dB with GPS L1C and -25.57 dB with BDS B1C.
- **Max Inter System Cross Correlation of IZ4 does not degrade the Inter system cross-correlation performance of other GNSS signals**

Coupled-Shift-Register-Based Implementation



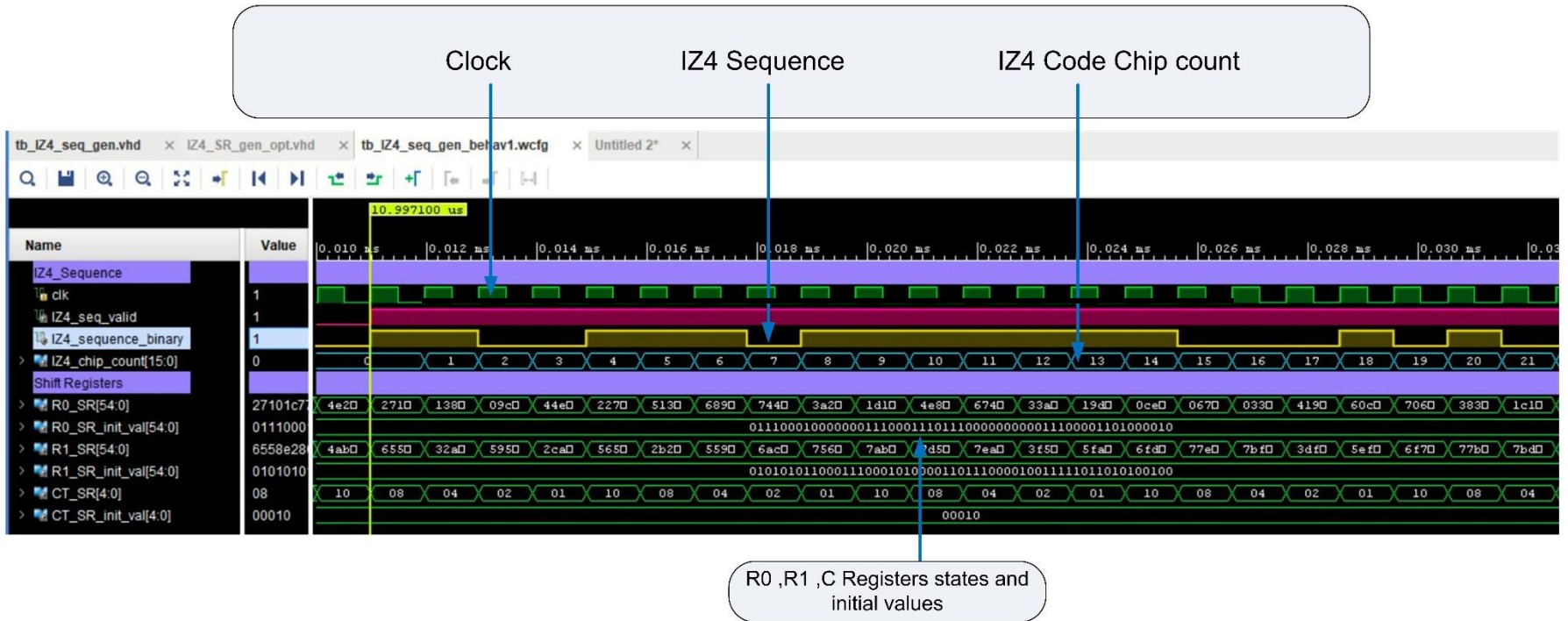
- IZ4 codes are implementation friendly as they use shift registers.
- Three shift registers (two 55-tap and one 5-tap) with feedback logic.
- Entire family of IZ4 codes can be generated, just by changing initial conditions.

Overlay Code (Truncated Z_4 -Linear Code) and its Performance

- Design is based on cyclic truncation of Z_4 -linear codes (Overlay Code period 1800 chips)
- NAVIC L1 Overlay Codes are Implementation friendly as they use shift registers.
- Implementation requires two 10-tap shift registers with feedback logic.
- All the NAVIC L1 Overlay Codes can be generated by changing initial conditions.

| Performance Parameters | Truncated Z_4 -Linear Sequences | LFSR-Based Overlay Codes | Weil-Based Overlay Codes |
|--|-----------------------------------|---|--------------------------|
| Maximum Even Auto Correlation Sidelobe | -24.44 dB | -22.69 dB (for t-Gold codes) -24.76 dB (for m codes) | -25.11 dB |
| Maximum Even Cross Correlation Sidelobe | -20.0 dB | -19.6 dB | -19.90 dB |
| Maximum Partial Cross Correlation (100 chips) Sidelobe | -7.13 | -7.13 | -5.68 |
| Balance | 0 | 0 | Up to 48 bits |

Hardware Simulation Waveforms for IZ4 Sequence



- Generator is implemented using a Xilinx FPGA.
- However, the design is shift register based and tool independent, hence can work on any FPGA.

- NavIC L1 SPS has adopted the IZ4 family of spreading codes as primary codes
- NavIC L1 overlay codes are cyclic truncation of Z_4 -linear codes.
- **The selected codes do not degrade the Inter system cross-correlation performance of other GNSS signals in the same band**
- IZ4 codes compare well in comparison with performance of other GNSS codes in the same L1 band.
- A Joint IISc-ISRO Patent on design of Interleaved Z_4 -Linear Sequences has been filed

