

Novel and Indigenous IZ4 Spreading Codes for the NavIC L1 SPS Signal

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NAVigation with Indian Constellation (NavIC) is an indigenous navigation satellite system for India and surrounding regions, developed by ISRO, that aids in terrestrial, aerial and marine navigation, vehicle tracking and fleet management as well as disaster management. A new standard positioning service (SPS), civilian signal is being introduced in the L1 frequency band, partly with a view towards providing increased availability of NavIC signals, to mobile-phone users. This called for the design of a family of spreading codes with desirable properties such as balance, even and odd auto and cross-correlation properties. A challenging aspect of the design was the requirement, arising from the presence of an on-board atomic clock having a frequency of 10.23 MHz, that the designed signals have period 10230, while most existing signal designs have period that is of the form p or $(p^n - 1)$ for p prime, or else, $2(2^n - 1)$. To overcome this hurdle, the designers of the Global Positioning System (GPS) and the Beidou Satellite System (BDS) started with a family of Weil sequences having period that is a prime p close to the desired period, $p = 10223$ and $p = 10243$ respectively, and then employing either padding or truncation, to achieve the desired period of 10230. However, either truncation or padding results in a degradation of correlation properties.



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An ISRO scientist, Dr. Dileep Dharmappa, brought this need for signal design to the notice of IISc faculty member Prof. P. Vijay Kumar, as the latter had extensive prior experience in the design of such codes. The two started working on the problem and were joined soon after, by a scientist from the Space Applications Centre (SAC) of ISRO, Ms Sugandh Mishra, introduced to them by SAC Director Mr Nilesh Desai. The team, led by Prof. P. Vijay Kumar, collabora-

tively came up with a design that enabled achieving the desired period of 10230, without need for either truncation or padding.

This was achieved by interleaving a set of five Z_4 -linear sequences, each of period 2046. Here, Z_4 denotes the set of integers modulo 4 and a Z_4 -linear sequence family is a nonlinear family of binary sequences that is interestingly, the projection of a sequence family that is linear in the Z_4 domain. The incorporation of additional innovative features into the design such as interleaving based on the Chinese Remainder Theorem, intelligent selection and sign-flipping of the five constituent sequences, as well as extensive further computer-based optimization, led to the Interleaved Z_4 -Linear (IZ4) spreading code family. IZ4 codes have even-correlation properties that improve significantly upon those of either GPS or Beidou signal sets, see Table I. In terms of balance and odd-correlation, all three signal sets are comparable. An added plus is that IZ4 sequences are simply generated using two 55-bit coupled shift registers along with some simple additional circuitry.

Performance Parameter	IZ4 Spreading codes	GPS (L1C) Spreading codes	BDS (B1C) Spreading codes
Even Autocorrelation	-31.7 dB	-31.2 dB	-31.19 dB
Even Crosscorrelation	-31.7 dB	-27.21 dB	-27.29 dB
Odd Autocorrelation	-29.83 dB	-28.03 dB	-31.19 dB
Odd Crosscorrelation	-26.5 dB	-26.22 dB	-27.29 dB
Symbol Imbalance	0 or 2	0	0
Pilot-Data Orthogonality	0	2	2

Table I: Comparing IZ4 code performance with codes employed by GPS and Beidou. Lower values of correlation, imbalance and orthogonality are more desirable. Note the large 4 dB improvement in even cross-correlation, shown in boldface.

Following rigorous evaluation by an independent ISRO team, the decision was made by ISRO to incorporate the IZ4 design into the L1 signal of NavIC. A high-level IISc-ISRO meeting, including the Chairman of ISRO and the Director of IISc was held on June 17, 2021, to commemorate the successful design [1,2]. The IZ4 design was presented at IEEE ISIT 2021 [3] as well as at the Fifteenth International Committee on Global Navigation Satellite Systems organized by the United Nations Office for Outer Space Affairs, Sep. 2021 [4]. A joint IISc-ISRO Indian patent on the IZ4 design has been granted [5]. A PCT application has been filed [6] that received a favorable written opinion and international search report.

In summary, the IZ4 code is a novel and indigenous joint IISc-ISRO signal design for the NavIC L1 signal that has improved even-correlation properties and is easy to implement. Quoting from the ISRO website: "This is a significant achievement in the navigation signal domain. This further strengthens the Government of India's initiative of Atmanirbhar Bharat."

This work could not have been accomplished without the strong encouragement and support contributed by senior administration and scientists within ISRO as well as senior administration and faculty within IISc and IISc's IPTeL.

REFERENCES

- 1) Link to report on ISRO website:
<https://www.isro.gov.in/update/25-jun-2021/navic-11-adopts-indigenous-digital-codes-designed-isro-and-iisc>
- 2) Link to report on IISc website:
<https://iisc.ac.in/designing-the-iz4-family-of-spreading-codes-for-the-navic-11-signal/>
- 3) P. Vijay Kumar, Dileep Dharmappa, Sugandh Mishra, "Interleaved Z4-Linear Sequences with Improved Correlation for Satellite Navigation", *Proc. IEEE International Symposium on Information Theory (ISIT 2021)*, Melbourne, July 12-20, 2021.
- 4) Sugandh Mishra, Dileep Dharmappa, "Novel Interleaved Z4-Linear PRN Codes for NavIC L1-SPS," presentation at the *International Committee on Global Navigation Satellite Systems (ICG-15)* organized by the United Nations Office for Outer Space Affairs, 29 Sep. 2021, Vienna, Austria (reporting on joint work with Prof. P. Vijay Kumar).
- 5) Indian Patent :
 - a) Title: Method and System for Generating Spreading Codes Based on Interleaved Z4-Linear Sequences for Navigation Systems
 - b) Applicants: Indian Institute of Science, and Indian Space Research Organization
 - c) Inventors: Panganamala Vijay Kumar, Dileep Dharmappa and Sugandh Mishra
 - d) Application No.: 202041006792
 - e) Date of Filing: Feb 17th, 2020
 - f) Patent No. 38332
 - g) Date Granted: Nov. 30, 2021.
- 6) International Patent Cooperation Treaty Application:
 - a) Title: Method and System for Generating Spreading Codes Based on Interleaved Z4-Linear Sequences for Navigation Systems
 - b) Applicants: Indian Institute of Science, and Indian Space Research Organization
 - c) Inventors: Panganamala Vijay Kumar, Dileep Dharmappa and Sugandh Mishra
 - d) Date of filing: Feb 16th, 2021
 - e) International Application No.: PCT/IN2021/050147.
 - f) A favorable international search report and written opinion were received on May 31, 2021.