New Preamble Proposal for 10BASE-T1S

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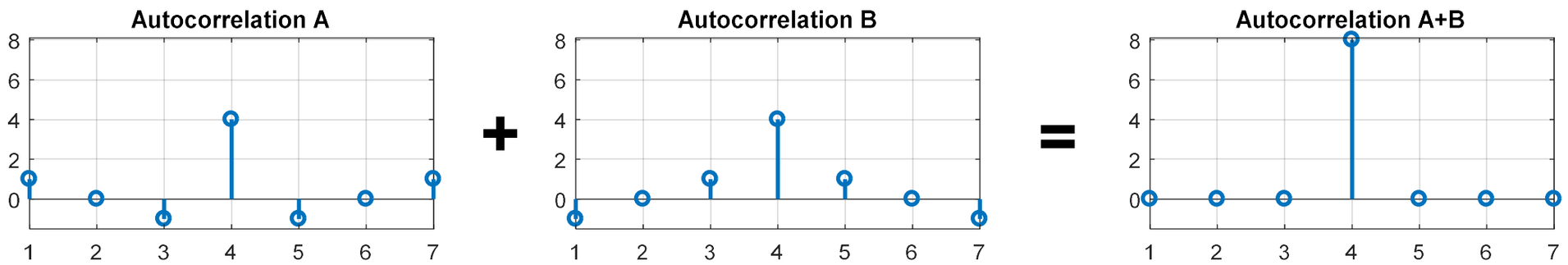
Problem Statement

- A matched filter (correlator-based receiver) maximizes the SNR at the receiver, which is important for optimum detection and synchronization of the preamble in noisy conditions.
- The aperiodic autocorrelation of existing Ethernet preamble and 802.3cg candidate preamble are suboptimum and can be improved.
- We propose a new preamble built from Golay complementary sequences which has superior aperiodic autocorrelation properties for reliable detection and synchronization at the start of a 10BASE-T1 frame in a noisy channel environment, and good merit factor for low emissions.
- The proposed sequences replace the preamble and SFD to allow detection without additional overhead and allow low complexity implementation at the receiver.

Complimentary Sequences

- Golay published an article in 1961 [1] which introduced complimentary sequences. They have a number of interesting properties.
  - The two sequences (complements) have aperiodic autocorrelation which sums to a Kronecker delta function (thumb tack)

e.g. for the simple sequences A=[1 1 -1 1] and B=[1 1 1 -1], autocorrelation gives:



  - Even without the complement, one set of a complimentary pair has good aperiodic autocorrelation
  - Have good "Golay Merit Factor" which means the sequence will have good peak to average power
  - Longer complimentary sequences can be concatenated from shorter sequences. For example, A_new=[A B];B_new=[A –B]

1. M. J. E. Golay, "Complementary Series", IRE Transactions on Information Theory, Vol 7, No. 2 (1961)

Aperiodic Autocorrelation Quality Metrics

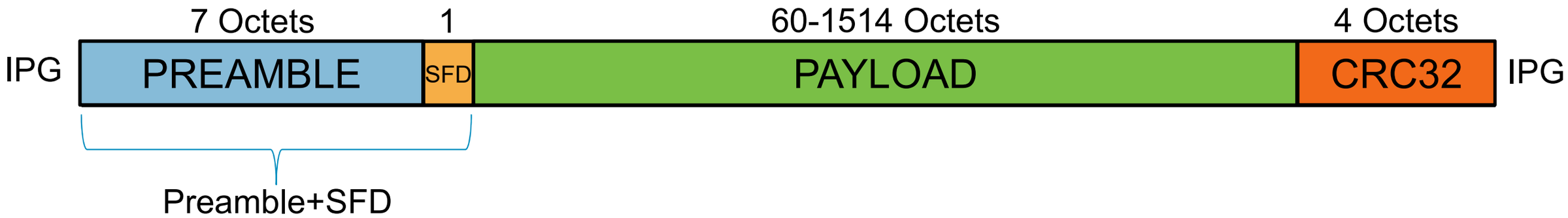
- Two measures of the goodness of autocorrelation of sequences and suitability for synchronization purposes are peak side lobe height and Golay Merit Factor which was defined by Golay [2]
- If one half of the autocorrelation side lobes of a sequence of length N are $c_k = \sum_{j=0}^{N-k-1} x_j x_{j+k} \quad k = 1, \ldots N-1$, the Golay Merit Factor (MF)$=\frac{N^2}{2\sum_{k=1}^{N-1} {c_k}^2}$ and is the ratio of the energy of the main lobe to the energy of the side lobes.
- The smaller the denominator, the lower peak to average ratio of the sequence
- For example: Golay Merit Factor of the sequence on previous page:

$$\frac{4^2}{2(1+0+1)}=4$$

2. M. J. E. Golay, “Sieves for Low Autocorrelation Binary Sequences”, IEEE Transactions on Information Theory, Vol 23, No. 1 (1977)

Ethernet Frame & Preamble

- An Ethernet frame consists of:
  - Preamble (7 octets) 0x55555555555555 [note: sent LSB first so 4'b1010 on wire]
  - SFD (1 Octet) 0xD5
  - Payload (60-1514 Octets)
  - Frame Check Sequence (CRC-32) (4 octets)
  - Inter-Packet Gap (12 octets minimum) between frames



- A DME encoded preamble+SFD would consist of 64 Unit Intervals (T2) or 128xT3s (T2 is the separation between clock transitions. T3 is the time from a clock transition to a data transition representing a one per 802.3 98.2.1.1.2 and 75.5.3)

Proposed Sequence for 10BASE-T1

- Golay pairs can be generated by concatenating shorter pair. A_new=[A B];B_new=[A –B]
- A 2^n Golay pair can be created by concatenation, starting from 2^0 ("δ") Can rearrange order of concatenation (delay vector D) and weighting (Wk) of B vector in an efficient structure. More details can be found in [3].
- D=[8 16 4 2 1] and Wk=[1 1 1 -1 1] create Golay pair with individual Golay merit factors of 4.57 (good) and the individual complements have a maximum side lobe height of 7
  - $\mathrm{Ga32} = [\,1\ \text{-}1\ \ 1\ 1\ \text{-}1\ 1\ 1\ \ 1\ \ 1\ \text{-}1\ \ \ 1\ \ 1\ \text{-}1\ 1\ \ 1\ \ 1\ \text{-}1\ \ 1\ \text{-}1\ \text{-}1\ \text{-}1\ 1\ \ 1\ \ 1\ \ 1\ \ \text{-}1\ \ 1\ \ 1\ \ 1\ \ \ \text{-}1\ \text{-}1\ \text{-}1]$
  - $\mathrm{Gb32} = [\text{-}1\ \text{-}1\ \text{-}1\ \ 1\ 1\ 1\ \text{-}1\ 1\ \text{-}1\ \text{-}1\ \text{-}1\ \ 1\ \ 1\ 1\ \text{-}1\ \ 1\ \ 1\ \ 1\ \ 1\ \text{-}1\ \ \ 1\ 1\ \text{-}1\ \ 1\ \text{-}1\ \text{-}1\ \text{-}1\ \ 1\ \text{-}1\ \ \text{-}1\ \ \ 1\ \text{-}1]$

- Ga32 and Gb32 each have maximum run lengths of 4

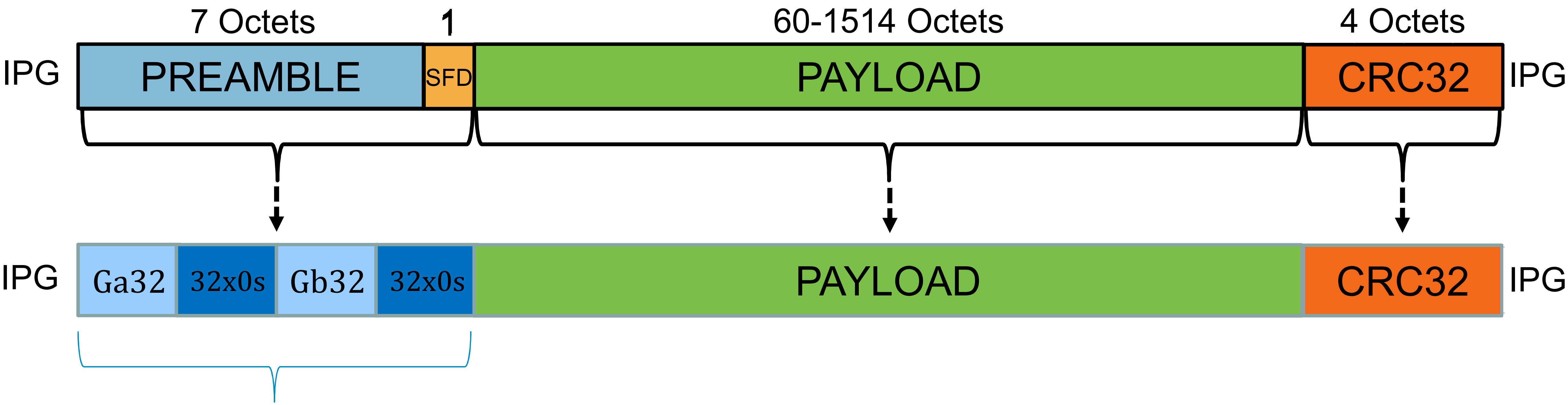
  We can use this Golay complementary pair as a building block for the proposed preamble:

$$\mathbf{preamble} = [\mathbf{Ga32}\quad \mathbf{zeros(1,32)}\quad \mathbf{Gb32}\quad \mathbf{zeros(1,32)}]$$

- Zeros in preamble provide spacing so the other pair of the sequence and the payload don't interfere with the sequences and the pair stays complementary.
- IPG of normal length before preamble and the payload of the packet afterwards is assumed.

3. S.Z. Budišin, "Efficient Pulse Compressor For Golay Complementary Sequences", Electronics Letters, Vol. 27 No. 3

Proposed 10BASE-T1 Preamble

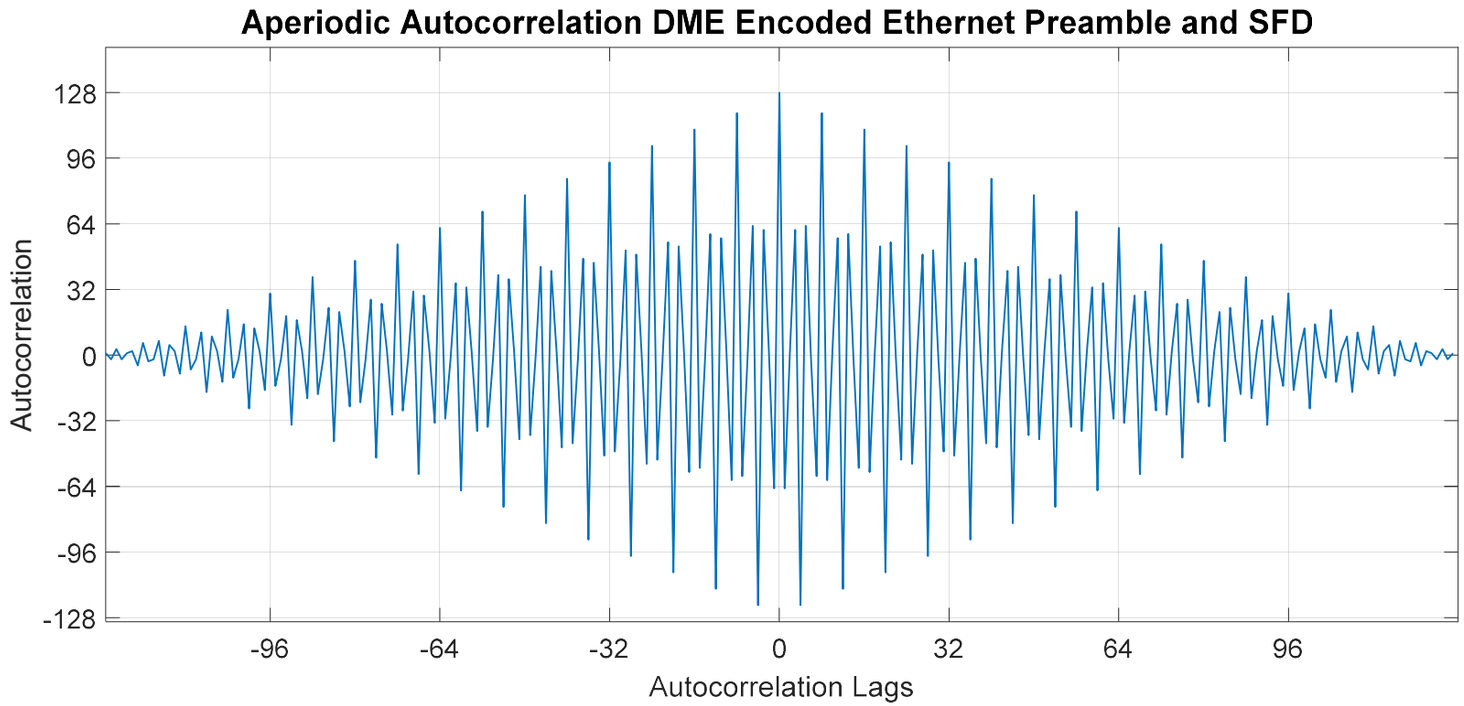


Proposed Preamble = [1 -1 1 1 -1 1 1 1 1 -1 1 1 -1 1 1 1 -1 1 -1 -1 -1 1 1 1 1 -1 1 1 1 -1 -1 -1 …
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 …
-1 -1 -1 1 1 1 -1 1 -1 -1 -1 1 1 1 -1 1 1 1 1 -1 1 1 -1 1 -1 -1 -1 1 -1 -1 1 -1 …
0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0]

- Proposed preamble is a Golay complementary sequence pair 2x32 bits long with 2x32 bits zero padding
- DME encoded preamble would be 64xT2 or 128xT3 long.
- Replace Preamble and SFD with Ga32 and Gb32 and padding with each bit of sequences one T3 long
- No added overhead over standard preamble.

Autocorrelation of Raw Ethernet Preamble and SFD

Preamble = 0x55555555555555D5 (LSB first, then DME Encoded)

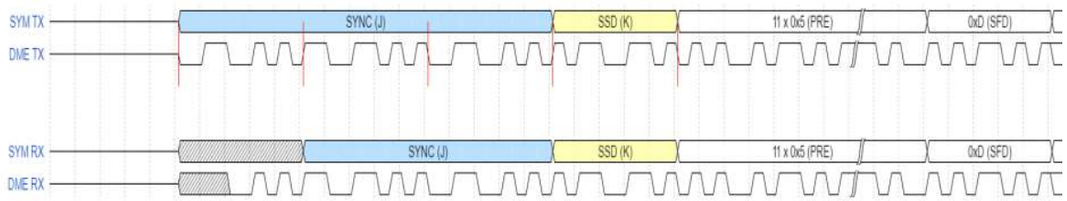


- Golay MF= 0.0332 and peak side lobe height is -122

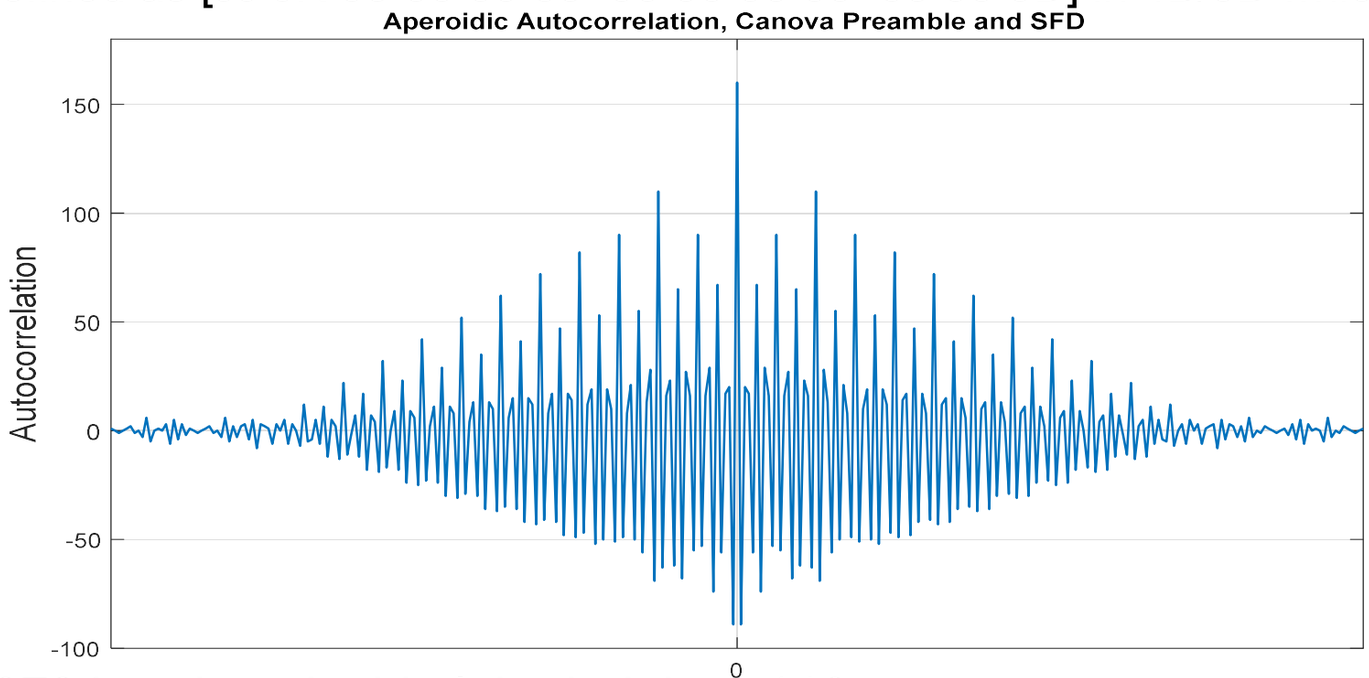
→A better sequence is needed for synchronization for 10BASE-T1

Autocorrelation of 10BASE-T1 Preamble and SFD (Canova proposal)

- In “8023cg_shot_reach_pcs_pma_plca.pdf” on 1 November 2017:

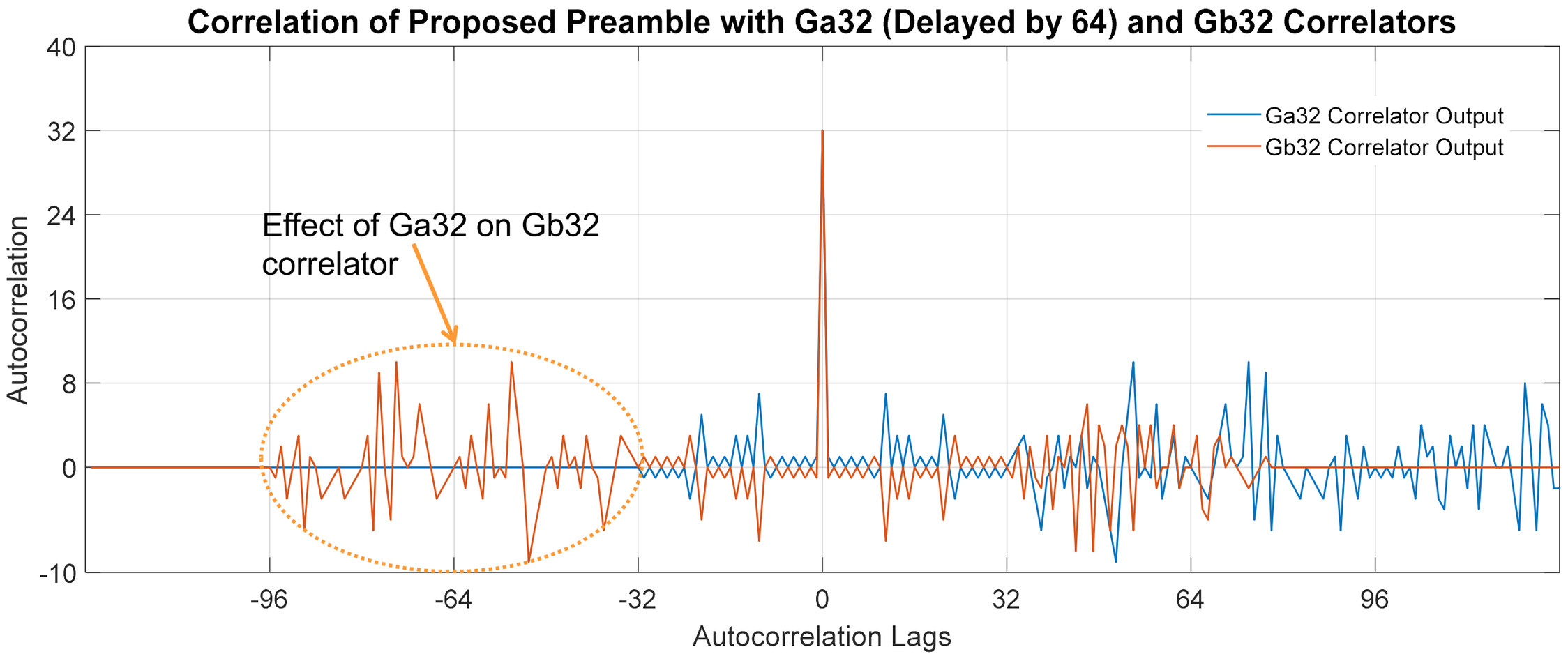


  - Preamble defined as [JJ JK 55 55 55 55 55 55 55 55 55 55 5D] in 4B/5B which is DME encoded



- Golay MF= 0.0784 and peak side lobe height = 110

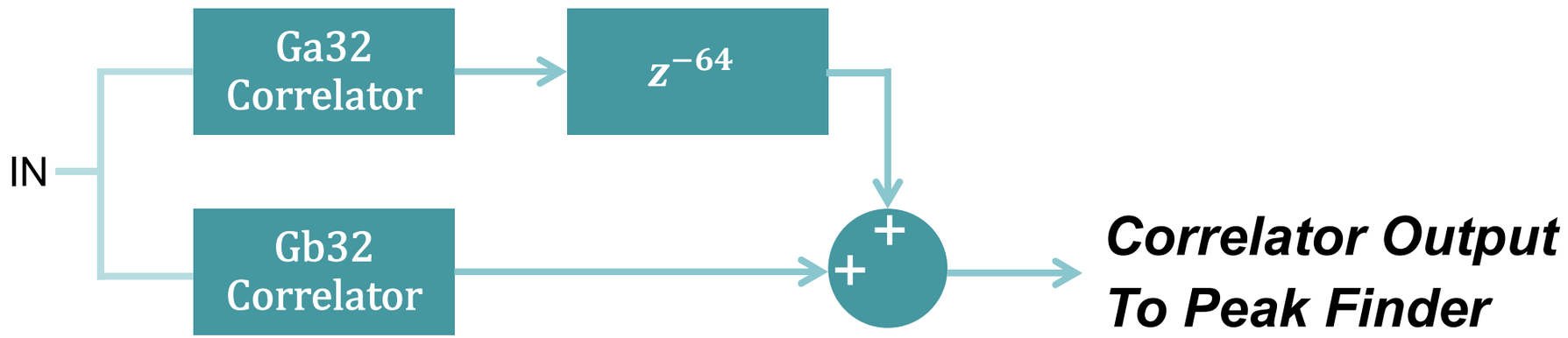
Correlation of Proposed Preamble Sequences



$$\mathbf{preamble} = [\mathbf{Ga32}\ \ \mathbf{zeros(1{:}32)}\ \ \mathbf{Gb32}\ \ \mathbf{zeros(1{:}32)}]$$

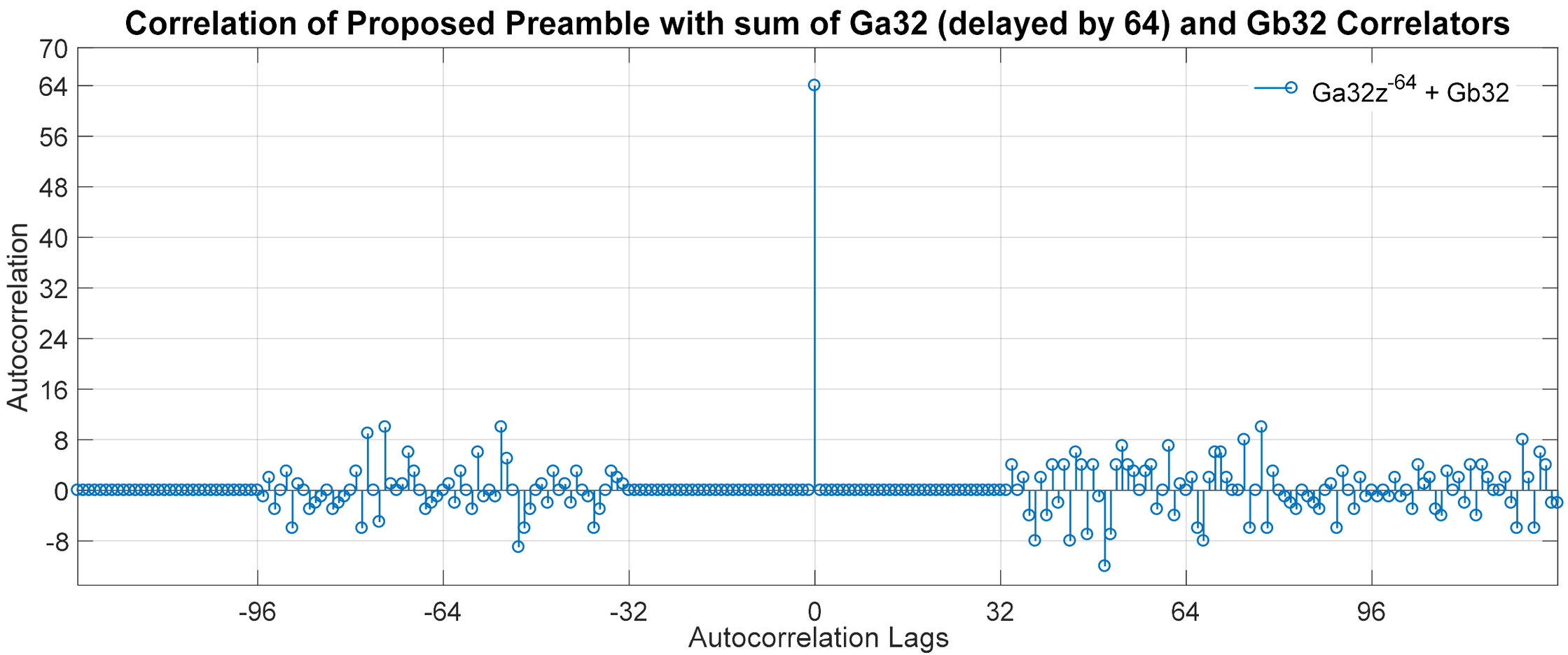
Individual Merit Factor 4.57, Max Side lobe height 7 (10, when combined as above)

Preamble Receiver Block Diagram



- This figure shows configuration used for the preamble receiver output shown on the next page.

Preamble Receiver Outputs for the Proposed Preamble



- Note zero correlation zones (ZCZ) before and after peak

MII Interface Compliance

- New preamble must allow 10BASE-T1 PHYs to interoperate with Clause 22 compatible MII MACs
- 22.2.2.3 -- Transmission of data from the MAC via the PHY
  - When TX_EN is asserted and the preamble is transmitted on TXD<3:0>, currently, the PHY Manchester encodes the preamble and SFD and transmits it on the MDI.
  - Instead, when Ethernet preamble and SFD defined in 22.2.3.2.1 are sent via MAC to PHY and TX_EN asserted, transmit new preamble sequence defined in this presentation on MDI followed by DME modulated packet data and CRC.
- 22.2.2.7 and 22.2.2.8 -- RX_DV and RXD during packet reception
  - A completely formed SFD is required to be sent from PHY to MAC via MII.
  - When new preamble detected at receiver, assert RXDV on MII synchronous with RX_CLK and transmit SFD on RXD<3:0> per table 22-4—Start of receive with no preamble preceding SFD

Conclusion

- The preamble based on complimentary sequences described in this presentation provides better correlation properties which would be used for robust synchronization
- The individual sequences have very good merit factor and low peak side lobe height and sum to the ideal correlation response
- The proposed preamble provides much better correlation properties and merit factor than the existing P802.3cg preamble
- Complementary sequences could also be used to establish time base for multiple access in a multi-point shared access application.
- Maintains MII compatibility with new preamble
- Replace preamble and SFD for 10BASE-T1 Ethernet frames with the 32-bit zero-padded Golay complementary sequence pair (128-bit total length) listed in this presentation.

Thank You!