LONG-REACH

MODIFIED mN/mN+1 ENCODING

CAPABLE TO PROCESS ON COUPLES OF CONTROL

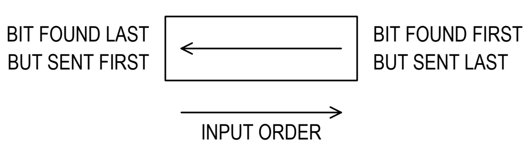
I. FOUNDATION

The encoding method described further in this memo is based on the 8N/8N+1 encoding introduced (invented?) by William Lo during the time of IEEE P802.3bp task force [1, 2], with the following modifications.

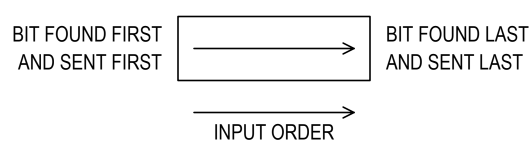
[1] https://www.ieee802.org/3/bp/public/mar14/Lo_3bp_02_0314.pdf (1000BASE-T1 PHY Encoder Proposal For Gigabit MAC Compatibility, March 2014)
[2] https://www.ieee802.org/3/bp/public/may14/Lo_3bp_01_0514.pdf (Correction to 1000BASE-T1 PHY 8N/8N+1 Encoder Equations, May 2014)

First, it treats on the input left to right, instead of right to left as in [1, 2], to decrease the transmit (encoding) delay, namely the argument accumulation delay.

ORIG. mN/mN+1 ENC.

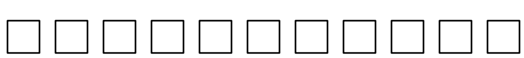


MOD. mN/mN+1 ENC.

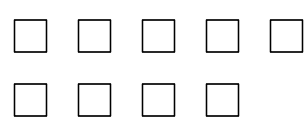


Second, it constructs the output in a tabular manner, with functionally natural rows of bits, instead in a bit stream manner as in [1, 2], that simplifies its description and reception.

ORIG. mN/mN+1 ENC.



MOD. mN/mN+1 ENC.



Third, it provides extra signaling options, obvious with its row-based definition but hardly seen with a bit stream-based definition as in [1, 2], in the form of forced output samples.

At the same time, like [1, 2], it treats on an input stream of independent transfer units, in singles if data, that is again like in [1, 2], but in couples if control, that is new to [1, 2].

For more information on formalization and generalization of the encoding approach which lies at the heart of the described method, see the author’s draft [3].

[3] https://arxiv.org/pdf/2302.13589, pp. 25-36

II. PRINCIPLES OF OPERATION — ENCODING PATTERNS, N=4

In the tables below, encoding input patterns for a span of N = 4 transfer units are listed. To fit into the output capacity, some patterns have aliases, therefore the output of such patterns can be unambiguously decoded only with the knowledge of its adjacent outputs, previous or next, in the stream. Here and further C and c mean the same (control).

TRANSFER SPAN PATTERNS

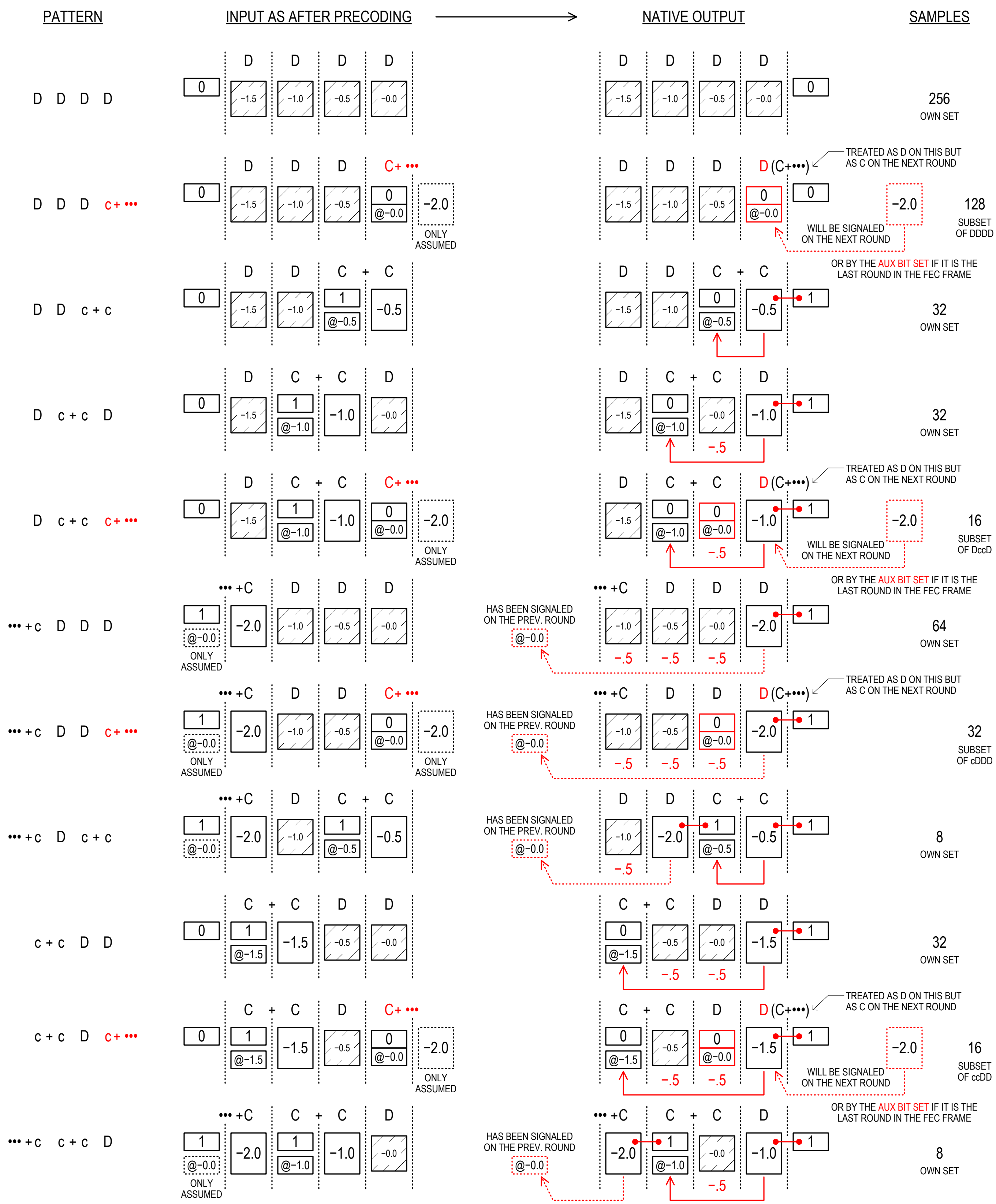
	PATTERN	ASSUMED AS	INVARIANT	STRICT EVEN	STRICT ODD	MIXED
(0)	D D D D	D D D D	D D D D	—	—	—
(1)	D D D c	D D D c+•••	—	—	D D D c+•••	—
(2)	D D c D	*MUST BE TREATED AS DDcc OR DccD DEPENDING ON THE CURRENT EVEN/ODD ORDER*				
(3)	D D c c	D D c+c	—	D D c+c	—	—
(4)	D c D D	*MUST BE TREATED AS DccD OR ccDD DEPENDING ON THE CURRENT EVEN/ODD ORDER*				
(5)	D c D c	*MAY BE TREATED AS cccc OR Dccc OR ccDc DEPENDING ON THE CURRENT ENCODING CONTEXT*				
(6)	D c c D	D c+c D	—	—	D c+c D	—
(7)	D c c c	D c+c c+•••	—	—	D c+c c+•••	—
(8)	c D D D	•••+c D D D	—	—	•••+c D D D	—
(9)	c D D c	•••+c D D c+•••	—	—	•••+c D D c+•••	—
(10)	c D c D	*MAY BE TREATED AS cccc OR cccD OR cDcc DEPENDING ON THE CURRENT ENCODING CONTEXT*				
(11)	c D c c	•••+c D c+c	—	—	—	•••+c D c+c
(12)	c c D D	c+c D D	—	c+c D D	—	—
(13)	c c D c	c+c D c+•••	—	—	—	c+c D c+•••
(14)	c c c D	•••+c c+c D	—	—	•••+c c+c D	—
(15e)	c c c c	c+c c+c	—	c+c c+c	—	—
(15o)		•••+c c+c c+•••	—		•••+c c+c c+•••	—
	16 TOTAL	11 + 1e + 1o	1 OUT OF 16	3 OUT OF 16	7 OUT OF 16	2 OUT OF 16

TREATABLE PATTERNS

	PATTERN	TREATED AS			ITS ALIAS	BECAUSE	TREATED AS
(0)	D D D D	D D D D	⟷	(1)	D D D c		D D D D(c+•••)
(3)	D D c c	D D c+c					
(6)	D c c D	D c+c D	⟷	(7)	D c c c		D c+c D(c+•••)
(8)	c D D D	•••+c D D D	⟷	(9)	c D D c		•••+c D D D(c+•••)
(11)	c D c c	•••+c D c+c					
(12)	c c D D	c+c D D	⟷	(13)	c c D c		c+c D D(c+•••)
(14)	c c c D	•••+c c+c D	⟷	(15o)	c c c c		•••+c c+c D(c+•••)
(15e)	c c c c	c+c c+c					
	(7 + 1e =) 8 OUT OF 17 (= 15 + 2)				(4 + 1o =) 5 OUT OF 17 (= 15 + 2)		

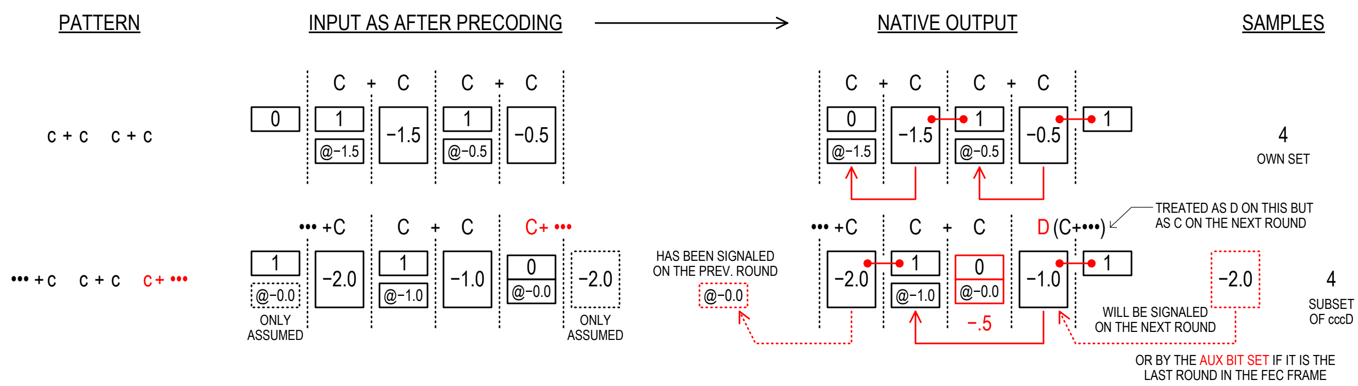
II. PRINCIPLES OF OPERATION — EXAMPLE COUPLED ENCODING, 8B/9B, UT=2BT, PART 1 OF 2

The following graphics illustrates the principles of operation of the coupled encoding on the example of a 2N / 2N+1 code with N = 4. Stream-like operation is assumed.



II. PRINCIPLES OF OPERATION — EXAMPLE COUPLED ENCODING, 8B/9B, UT=2BT, PART 2 OF 2

(Continued graphics from the previous page.)



LEGEND

0	BIT OF CONSTANT VALUE 0
1	BIT OF CONSTANT VALUE 1
-#.#	TWO BITS OF VARIABLE (PAYLOAD) DATA VALUE AT INPUT OFFSET −#.#, A CHOICE 1-OF-4
@-#.#	ONE BIT OF VARIABLE (PAYLOAD) CONTROL VALUE AT INPUT COUPLE (OFFSET, OFFSET+.5) , A CHOICE 1-OF-2
-#.#	TWO BITS OF CONTROL VALUE OFFSET, A CHOICE 1-OF-4, WITH −2.0 CODED SO ITS UPPER BIT IS 0 (E.G., 2b'00), AND −0.0 NOT PRESENT
-#.#	OFFSET ASSUMED FROM THE LATEST TRANSFER UNIT OF THE CURRENT INPUT, EXPRESSED IN HALVES OF COUPLE PERIODS
-.5	EXTRA DISPLACEMENT STRESSED DUE TO ENCODING
0 @-0.0	TWO BITS TREATED AS DATA ON THE CURRENT ENCODING ROUND, BUT AS OF CONTROL ON THE NEXT.
	DECODING PATH ELEMENTS (ARROWS) AND TIPS (LINKS)

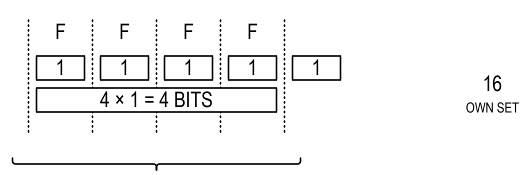
CONTROL DEFINITION EXAMPLE

$0 \le C_1, C_2 \le 1,\ C_1 \ne C_2$

ctrl@ $\begin{cases} C_1 & \text{DATA ERROR} \\ C_2 & \text{NORMAL IDLE} \end{cases}$

(USED 99.99% OF TIME)

FORCED OUTPUT



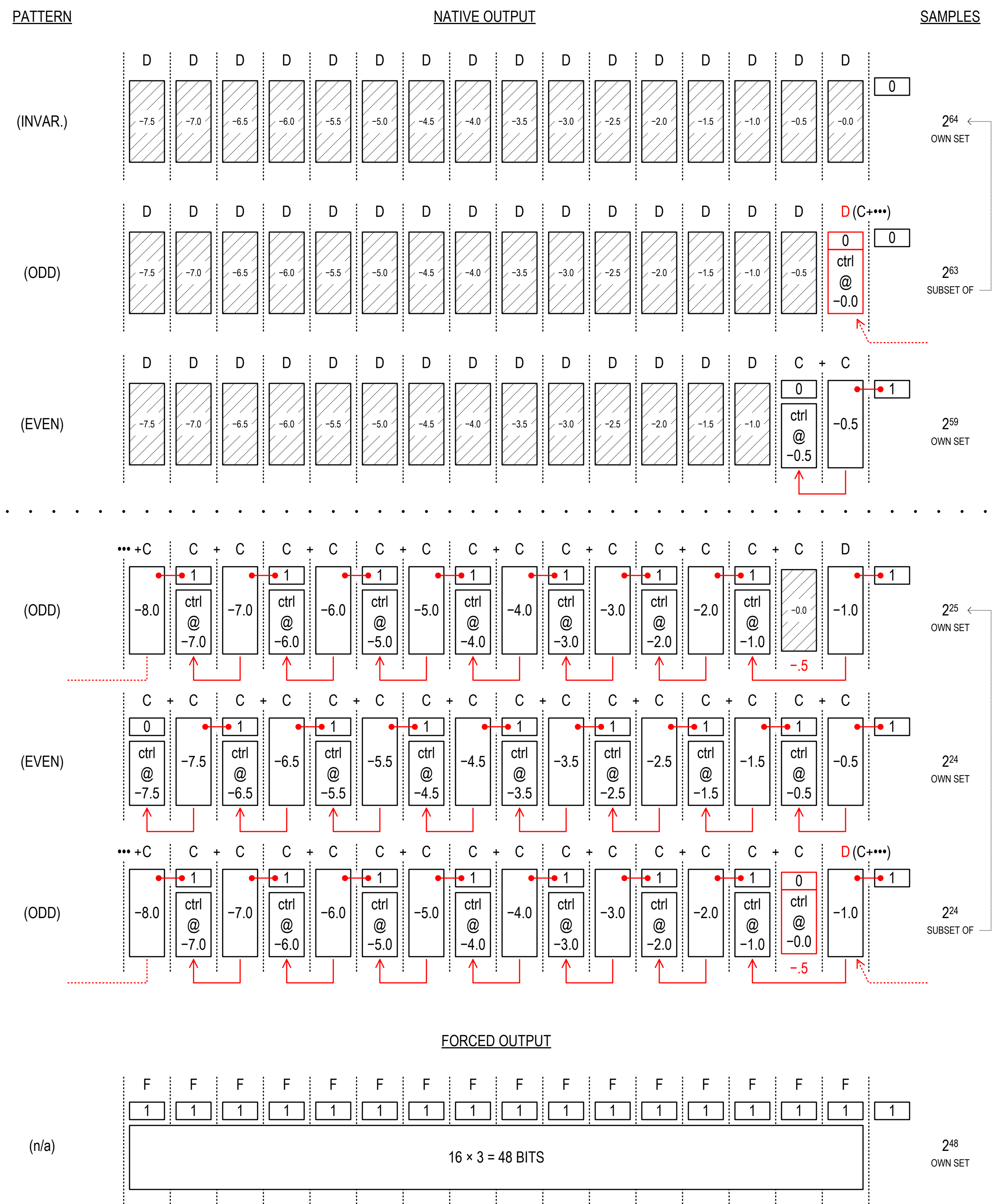
MAY BE USED FOR:

LPI
OAM
ORDERED SET
EVENTS, E.G., SYCHRONIZATION
EMERGENCY, E.G., BREAK
PREEMPTION
• • •
OTHER “RARE” CASES

Because the most observed extra displacement is .5, the argument accumulation delay (TX_ADD) is just twice the transfer unit time (UT), or equivalently four bit times (BT) here.

III. LONG-REACH COUPLED ENCODING, 64B/65B, UT=4BT — GENERAL DEFINITION

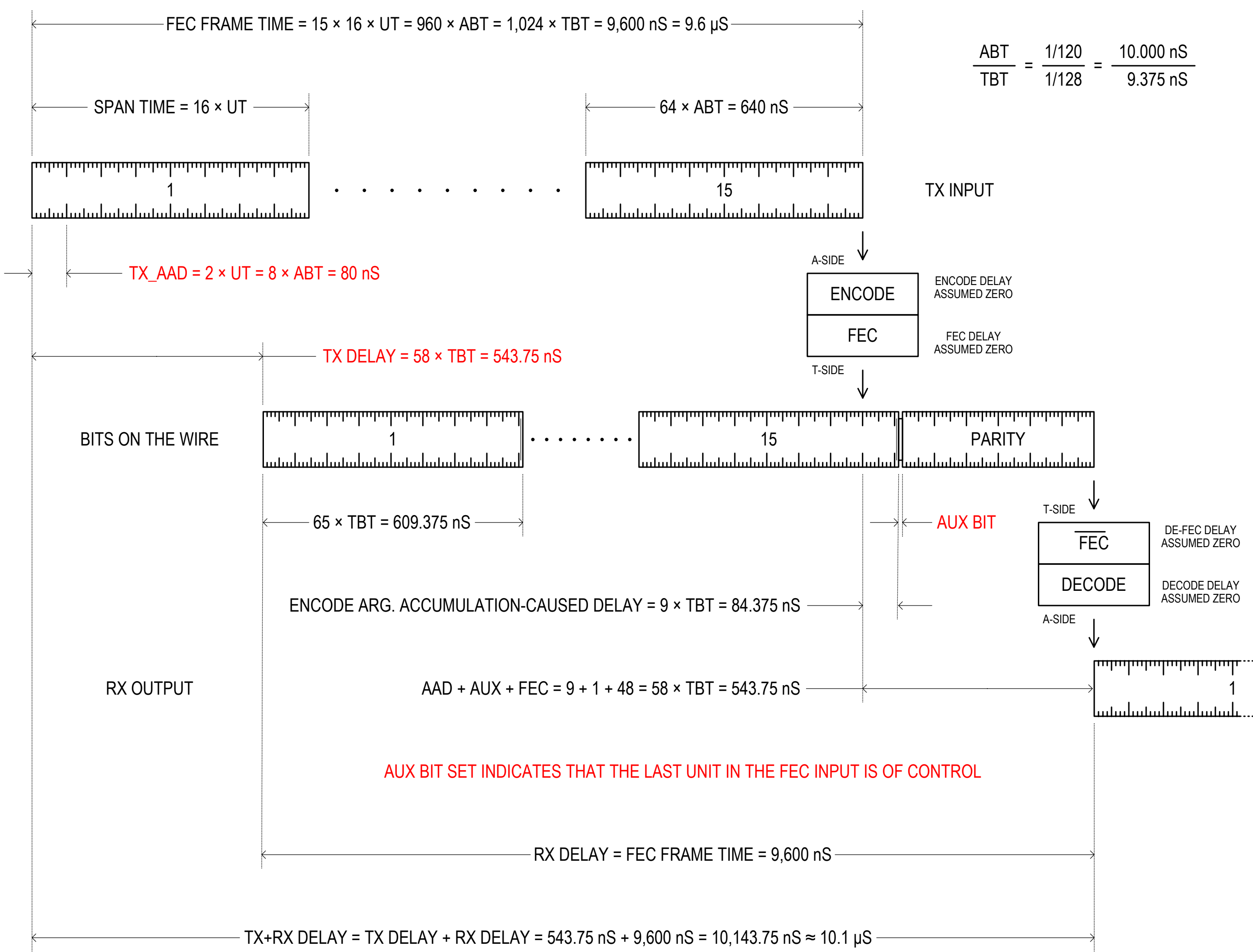
Below, all the cases of transfer units involved in the encoding are shown. A couple of two transfer units is capable to reflect 8 control symbols located with a single unit precision.



III. LONG-REACH COUPLED ENCODING, 64B/65B, UT=4BT — IDEAL-CASE CODING DELAYS

In a systematic FEC-based application, the ideal decoding delay is not a managed property because the respective FEC frame is decoded at once and as a whole. Therefore, the only managed property that we can optimize (minimize) here is the argument accumulation delay of the encoder at the transmitting side. At the same time, such optimization may affect back on the decoding delay: in our case, we almost neutralizes such by using the auxiliary bit to indicate on the pattern of the last encoding round in the FEC frame.

CODING DELAYS

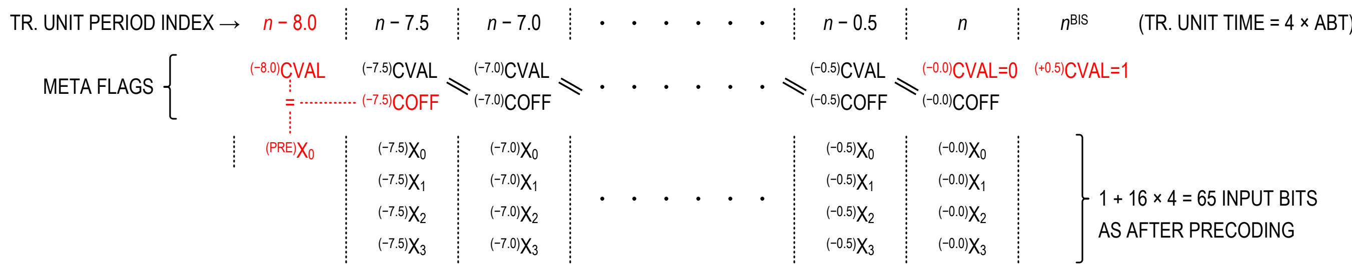


NOTE — ALL SHOWN DELAYS ARE CONSTANT AND FRAME CONTENT-INDEPENDENT.

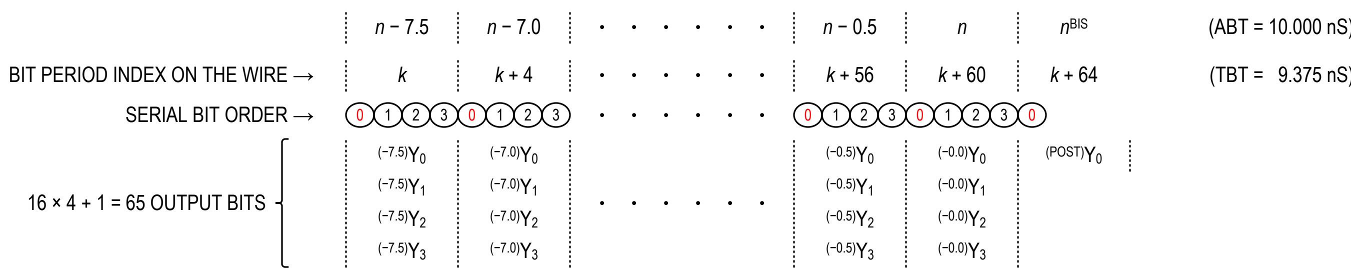
NOTE — TRANSFER UNIT TIME (UT) = NIBBLE TIME = FOUR BIT TIMES = 4 × ABT = 40 nS.

III. LONG-REACH COUPLED ENCODING, 64B/65B, UT=4BT — FORMAL DEFINITION, PART 1 OF 2

INPUT



OUTPUT



CONSTRAINTS

$^{(-0.0)}$CVAL = 0 AND $^{(+0.5)}$CVAL = 1 BY DEFINITION, n^{BIS} IS AN IMAGINARY PERIOD

$^{(-\#.\#)}$CVAL := 1 IF THE (−#.#)-TH UNIT PERIOD IS OF CONTROL VALUE, OTHERWISE 0

$^{(-\#.\#)}$COFF := 1 IF THE (−#.#)-TH UNIT PERIOD IS OF CONTROL OFFSET, OTHERWISE 0

$^{(-\#.\#)}$COFF = $^{(-\#.\#-.5)}$CVAL AND $^{(PRE)}X_0$ = $^{(-7.5)}$COFF = $^{(-8.0)}$CVAL BY DEFINITION

$^{(-\#.\#)}X_0$ OF THE OFFSET CODE INDICATING ON THE (−8.0)-TH PERIOD MUST BE 0

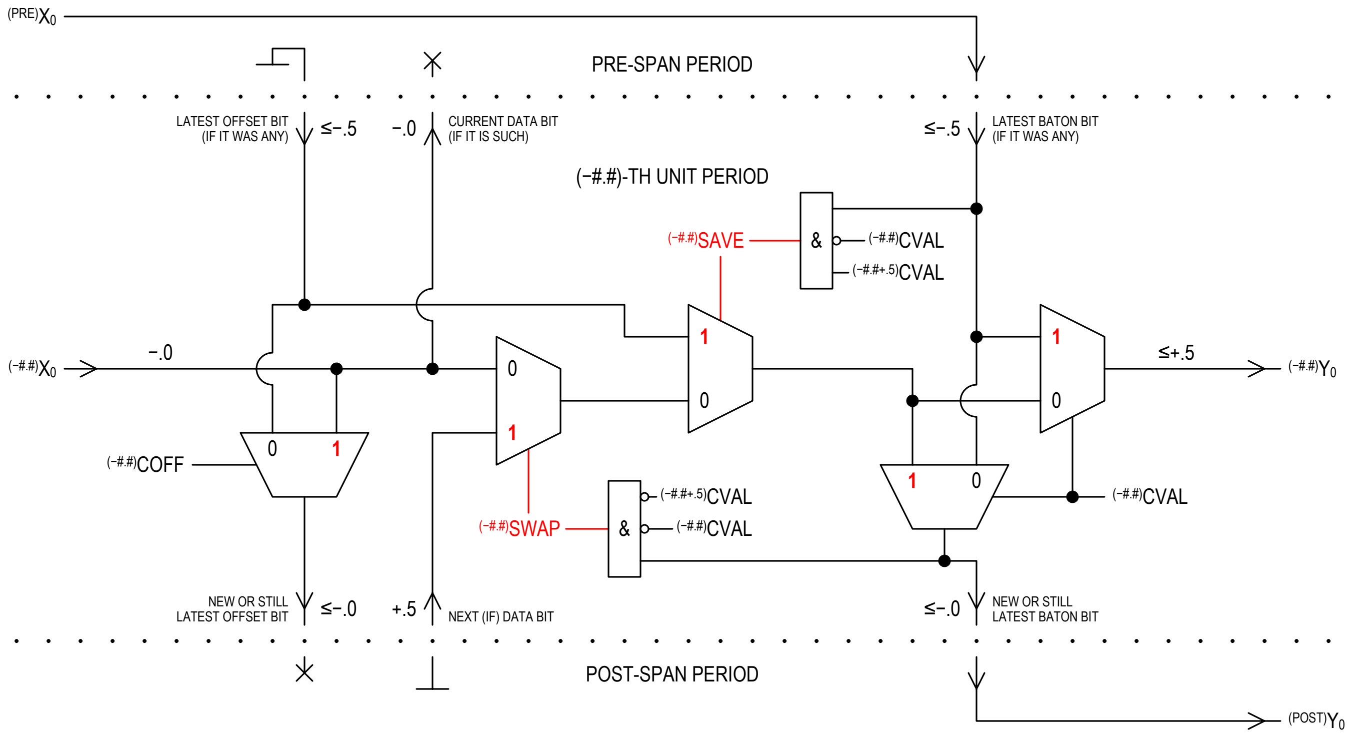
AUX := 1 IF THE LAST ROUND IN THE FEC FRAME IS OF ...c+•••, OTHERWISE 0

OFFSET CODES (RECOMMENDED)

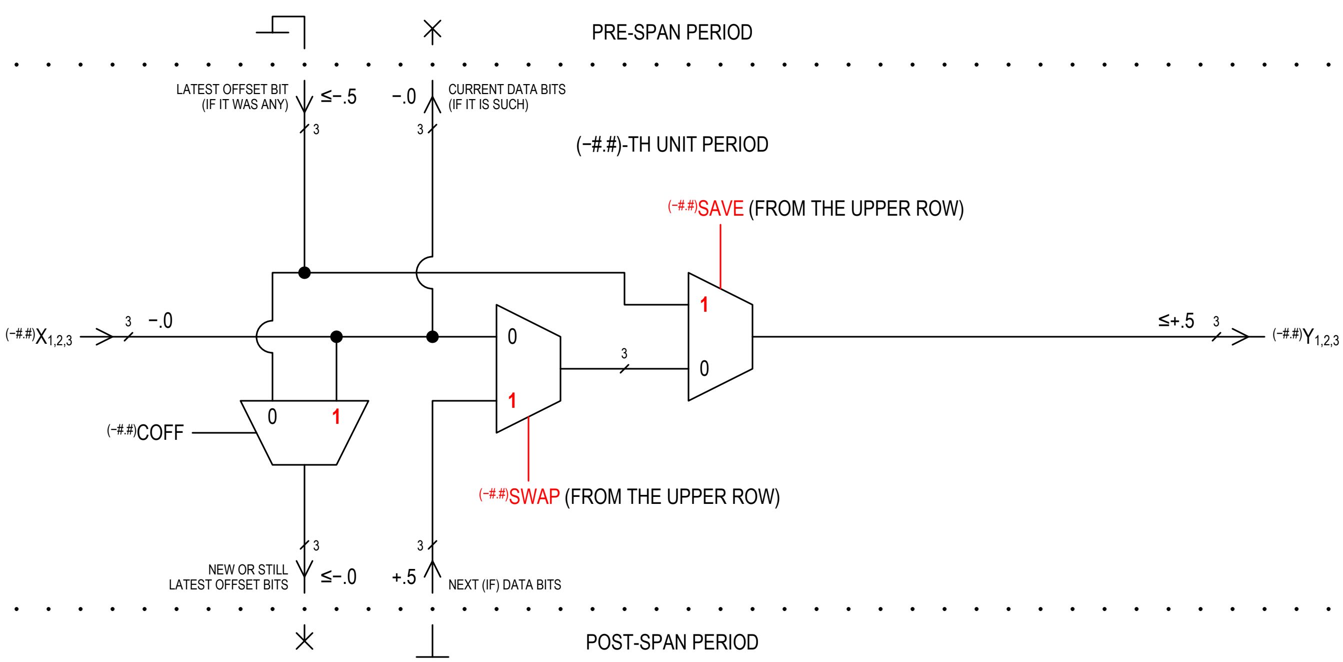
	−8.0	−7.5	−7.0	−6.5	−6.0	−5.5	−5.0	−4.5	−4.0	−3.5	−3.0	−2.5	−2.0	−1.5	−1.0	−0.5
	≡	≡	≡	≡	≡	≡	≡	≡	≡	≡	≡	≡	≡	≡	≡	≡
UPPER ROW	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1
REST ROWS	0	1	1	0	0	1	1	0	0	1	1	0	0	1	1	0
	0	1	1	1	1	0	0	0	0	1	1	1	1	0	0	0
	0	1	1	1	1	1	1	1	1	0	0	0	0	0	0	0

III. LONG-REACH COUPLED ENCODING, 64B/65B, UT=4BT — FORMAL DEFINITION, PART 2 OF 2

RELAYING OF BITS IN THE UPPER ROW



RELAYING OF BITS IN THE REST ROWS



III. LONG-REACH COUPLED ENCODING, 64B/65B, UT=4BT — PRECODER OPERATION (INFORMATIVE)

As shown below, the precoder works like a pipeline and treats on every MII input cycle to form the input bits, X's, and meta flags, CVAL and COFF, to the coupled encoder at the respective transfer unit period, *n*. Because the result depends on the preceding, current, and following MII input cycles only, combining the precoder and encoder into an integral function does not lengthen the argument accumulation delay over that of the encoder itself, i.e., two transfer unit times.

PER-UNIT PRECODING FUNCTION