APPENDIX R

Low-Density Parity Check Codes for Telemetry Systems

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Acronyms

AMT	aeronautical mobile telemetry
ASM	attached synchronization marker
CCSDS	Consultative Committee for Space Data Systems
FEC	forward error correction
FQPSK	Feher's quadrature phase shift keying
LDPC	low-density parity check
Mbps	megabits per second
SOQPSK-TG	shaped offset quadrature phase shift keying

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APPENDIX R

Low Density Parity Check Codes for Telemetry Systems

1.0   Background

This appendix provides the definition for the low-density parity check (LDPC) codes in Chapter 2 for aeronautical telemetry applications. The LDPC codes presented are intended to decrease error probabilities in a primarily noisy transmission channel for use in the aeronautical mobile telemetry (AMT) test environment.

The LDPC code is a linear block code. This type of code maps a block of k information bits together with a codeword (or codeblock) of n bits. Think of a linear block code as a chunk of input bits mapped to a longer chunk of output bits through a coder. This is sometimes called an n-k code. When k bits are mapped to a length n codeblock there are 2^k codewords; however, there are 2^n possible codewords composed of n bits. The idea with error correction codes is to pick the 2^k codewords of the 2^n total possible codewords that are far enough apart (in terms of Hamming distance) to guarantee you are able to correct a certain number of errors.

This particular version of LDPC code is systematic, meaning the transmitted codeblock contains duplications of the bits of the original information. It is also a quasi-cyclic linear block code, meaning the construction of these codes involves juxtaposing smaller cyclic submatrices (circulants) to form a larger parity matrix, all through linear operations.

This code, like all other forward error correction (FEC) schemes, requires an encoder on the transmission side and a decoder on the receiving side of the telemetry link. The codes offer much higher decoding speeds via highly parallelized decoder structures. This FEC code can only be coupled with SOQPSK-TG/FQPSK-B/FQPSK-JR modulation. The LDPC code itself does not guarantee sufficient bit transitions to keep receiver symbol synchronizers in lock so a randomizer, defined in this appendix, is required when implementing this FEC code.

Since LDPC is a block code, the start of a codeblock(s) must be identified in order for the decoder to function properly. This identifier, known as the attached synchronization marker (ASM), provides this marker and also aids in detection at very low values of E_b/N_0. Differential encoding/decoding normally associated with SOQPSK-TG/FQPSK-B/FQPSK-JR modulation is NOT required and should be disabled. Phase ambiguities will have to be resolved using the ASM.

2.0   Code Description

The LDPC code is a linear block code with options for $\{n,k\}$, where n is the length of the code block and k is the length of the information block. An LDPC code can be entirely defined by its parity check matrix, **H**. The k X n generator matrix that is used to encode a linear block code can be derived from the parity check matrix through linear operations.

Code rates, r, chosen for this AMT application are 1/2, 2/3, and 4/5. Information block sizes (k) are 1024 and 4096 bits. Given the code rate and information block sizes, codeword block sizes are calculated using $n = k/r$. See Table R-1.

Table R-1.	Codeblock Length per Information Block Size		
Information Block Length, *k*	Codeblock Length, *n*		
	Rate 1/2	Rate 2/3	Rate 4/5
1024	2048	1536	1280
4096	8192	6144	5120

The *k* X *n* generator matrix **G** shall be used to encode a linear block code. The matrix **G** can be derived from the parity check matrix **H**.

For each {*n,k*} in Table R-1 a parity check matrix **H** is constructed from size *M* x *M* submatrices per Table R-2.

Table R-2.	Submatrix Size per Information Block Size		
Information Block Length, *k*	Submatrix size *M*		
	Rate 1/2	Rate 2/3	Rate 4/5
1024	512	256	128
4096	2048	1024	512

3.0   Parity Check Matrices

Given the {*n,k*} in Table R-1, there are six parity check matrices that need to be constructed. Section 3.3 in Consultative Committee for Space Data Systems (CCSDS) standard 131.1-0-2[1] describes how each parity check matrix is constructed and is repeated here for clarity.

The **H** matrices for each code rate are specified below. $\mathbf{I}_M$ is the *M* x *M* identity matrix (main diagonal is 1's, all other entries are 0) and $\mathbf{0}_M$ is the zero matrix.

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[1] Consultative Committee for Space Data Systems. Low Density Parity Check Codes for use in Near-Earth and Deep Space Applications. CCSDS 131.1-0-2-S. September 2007. Rescinded. Retrieved 30 June 2015. Available at http://public.ccsds.org/publications/archive/131x1o2e2s.pdf.

Parity Check Matrices

$$H_{1/2} = \begin{bmatrix} 0_M & 0_M & I_M & 0_M & I_M \oplus \Pi_1 \\ I_M & I_M & 0_M & I_M & \Pi_2 \oplus \Pi_3 \oplus \Pi_4 \\ I_M & \Pi_5 \oplus \Pi_6 & 0_M & \Pi_7 \oplus \Pi_8 & I_M \end{bmatrix}$$

$$H_{2/3} = \begin{bmatrix} 0_M & 0_M & 0_M & 0_M & I_M & 0_M & I_M \oplus \Pi_1 \\ \Pi_9 \oplus \Pi_{10} \oplus \Pi_{11} & I_M & I_M & I_M & 0_M & I_M & \Pi_2 \oplus \Pi_3 \oplus \Pi_4 \\ I_M & \Pi_{12} \oplus \Pi_{13} \oplus \Pi_{14} & I_M & \Pi_5 \oplus \Pi_6 & 0_M & \Pi_7 \oplus \Pi_8 & I_M \end{bmatrix}$$

$$H_{4/5} = \begin{bmatrix} 0_M & 0_M & 0_M & 0_M & 0_M & 0_M & \\ \Pi_{21} \oplus \Pi_{22} \oplus \Pi_{23} & I_M & \Pi_{15} \oplus \Pi_{16} \oplus \Pi_{17} & I_M & \Pi_9 \oplus \Pi_{10} \oplus \Pi_{11} & I_M & H_{1/2} \\ I_M & \Pi_{24} \oplus \Pi_{25} \oplus \Pi_{26} & I_M & \Pi_{18} \oplus \Pi_{19} \oplus \Pi_{20} & I_M & \Pi_{12} \oplus \Pi_{13} \oplus \Pi_{14} & \end{bmatrix}$$

Permutation matrix Π_k has non-zero entries in row i and column entries are defined by $\pi_k(i)$ for $i \in \{0, \dots, M-1\}$

$$\pi_k(i) = \frac{M}{4}\left((\theta_k + \lfloor 4i/M \rfloor) \bmod 4\right) + \left(\phi_k(\lfloor 4i/M \rfloor) + i\right) \bmod \frac{M}{4}$$

where θ_k and $\phi_k(j)$ are defined in the following tables for the submatrix sizes defined in Table R-2 above for each code rate and information block size.

Code Rate =1/2, Information Block Size = 1024, M = 512

k	Θ_k	$\phi_k(0,M)$	$\phi_k(1,M)$	$\phi_k(2,M)$	$\phi_k(3,M)$
1	3	16	0	0	0
2	0	103	53	8	35
3	1	105	74	119	97
4	2	0	45	89	112
5	2	50	47	31	64
6	3	29	0	122	93
7	0	115	59	1	99
8	1	30	102	69	94

Figure R-1.   Parity Check Matrix **H** for (n=2048, k=1024) Rate 1/2

Code Rate =1/2, Information Block Size = 4096, M = 2048

k	Θ_k	$\phi_k(0,M)$	$\phi_k(1,M)$	$\phi_k(2,M)$	$\phi_k(3,M)$
1	3	108	0	0	0
2	0	126	375	219	312
3	1	238	436	16	503
4	2	481	350	263	388
5	2	96	260	415	48
6	3	28	84	403	7
7	0	59	318	184	185
8	1	225	382	279	328
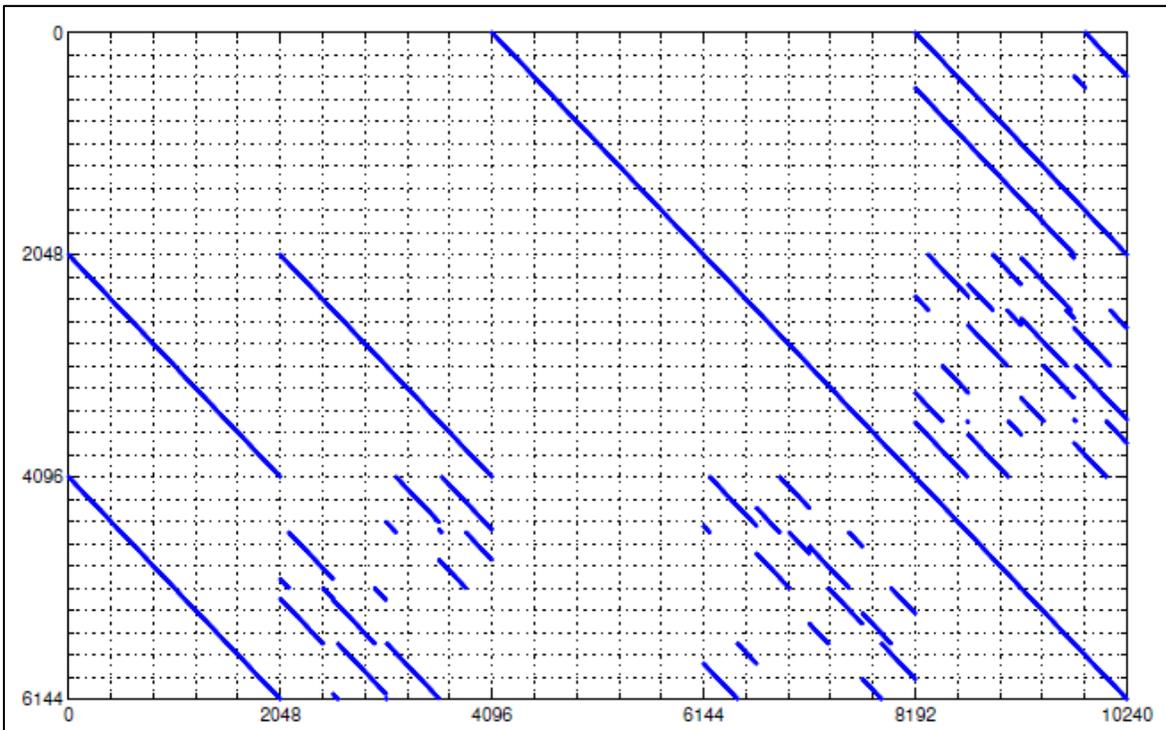
Figure R-2.   Parity Check Matrix **H** for (n=8192, k=4096) Rate 1/2

Code Rate =2/3, Information Block Size = 1024, M = 256

k	Θ_k	$\phi_k(0,M)$	$\phi_k(1,M)$	$\phi_k(2,M)$	$\phi_k(3,M)$
1	3	59	0	0	0
2	0	18	32	46	44
3	1	52	21	45	51
4	2	23	36	27	12
5	2	11	30	48	15
6	3	7	29	37	12
7	0	22	44	41	4
8	1	25	29	13	7
9	0	27	39	9	2
10	1	30	14	49	30
11	2	43	22	36	53
12	0	14	15	10	23
13	2	46	48	11	29
14	3	62	55	18	37
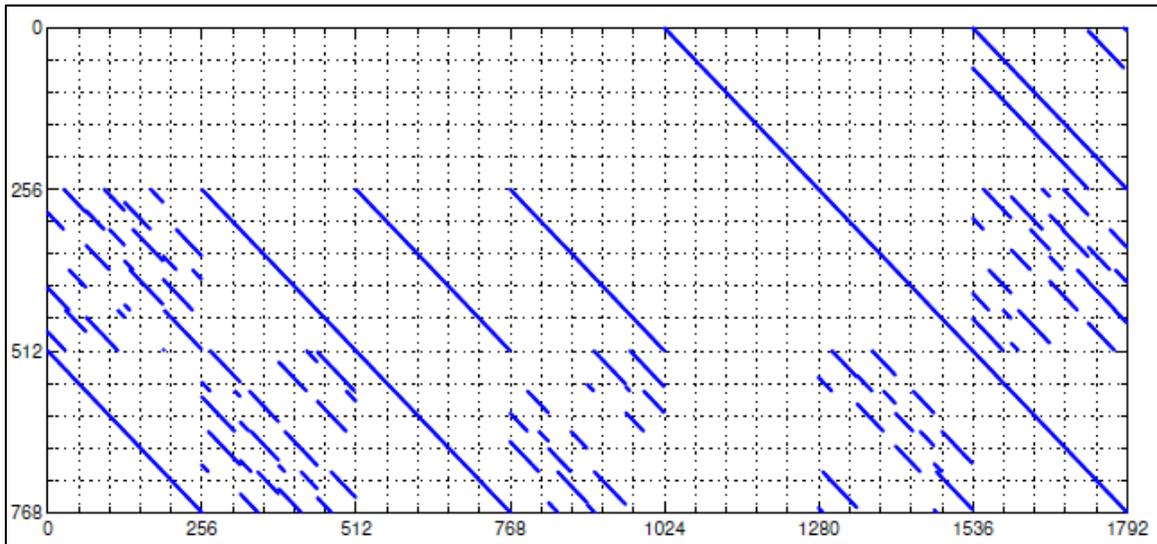
Figure R-3.   Parity Check Matrix **H** for (n=1536, k=1024) Rate 2/3

Code Rate =2/3, Information Block Size = 4096, M = 1024

k	Θ_k	$\phi_k(0,M)$	$\phi_k(1,M)$	$\phi_k(2,M)$	$\phi_k(3,M)$
1	3	160	0	0	0
2	0	241	182	35	162
3	1	185	249	167	7
4	2	251	65	214	31
5	2	209	70	84	164
6	3	103	141	206	11
7	0	90	237	122	237
8	1	184	77	67	125
9	0	248	55	147	133
10	1	12	12	54	99
11	2	111	227	23	105
12	0	66	42	93	17
13	2	173	52	20	97
14	3	42	243	197	91
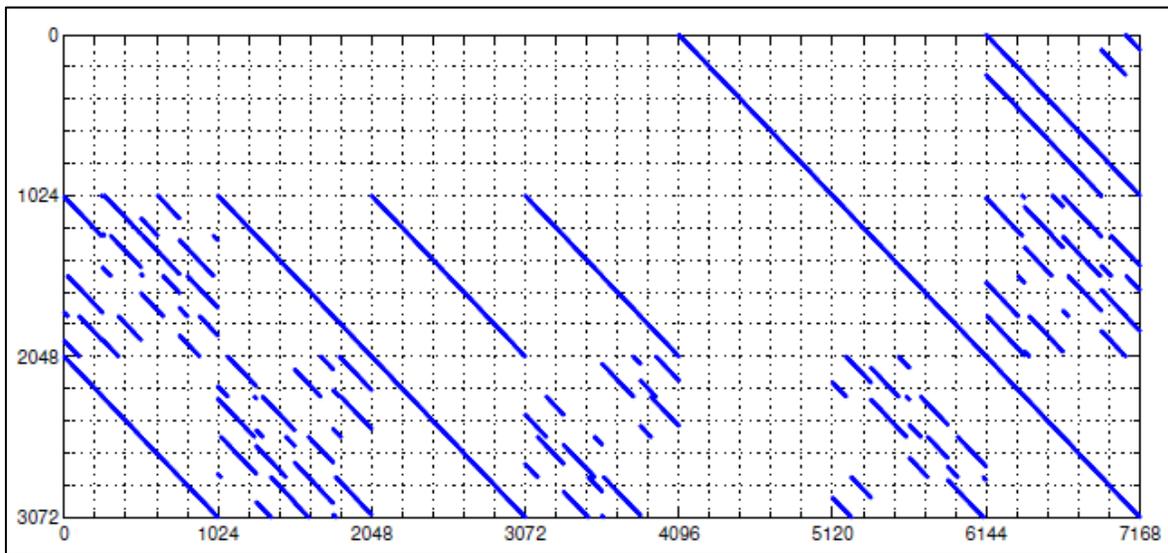
Figure R-4.   Parity Check Matrix **H** for (n=6144, k=4096) Rate 2/3

Code Rate =4/5, Information Block Size = 1024, M = 128

k	Θ_k	$\phi_k(0,M)$	$\phi_k(1,M)$	$\phi_k(2,M)$	$\phi_k(3,M)$
1	3	1	0	0	0
2	0	22	27	12	13
3	1	0	30	30	19
4	2	26	28	18	14
5	2	0	7	10	15
6	3	10	1	16	20
7	0	5	8	13	17
8	1	18	20	9	4
9	0	3	26	7	4
10	1	22	24	15	11
11	2	3	4	16	17
12	0	8	12	18	20
13	2	25	23	4	8
14	3	25	15	23	22
15	0	2	15	5	19
16	1	27	22	3	15
17	2	7	31	29	5
18	0	7	3	11	21
19	1	15	29	4	17
20	2	10	21	8	9
21	0	4	2	2	20
22	1	19	5	11	18
23	2	7	11	11	31
24	1	9	26	3	13
25	2	26	9	15	2
26	3	17	17	13	18
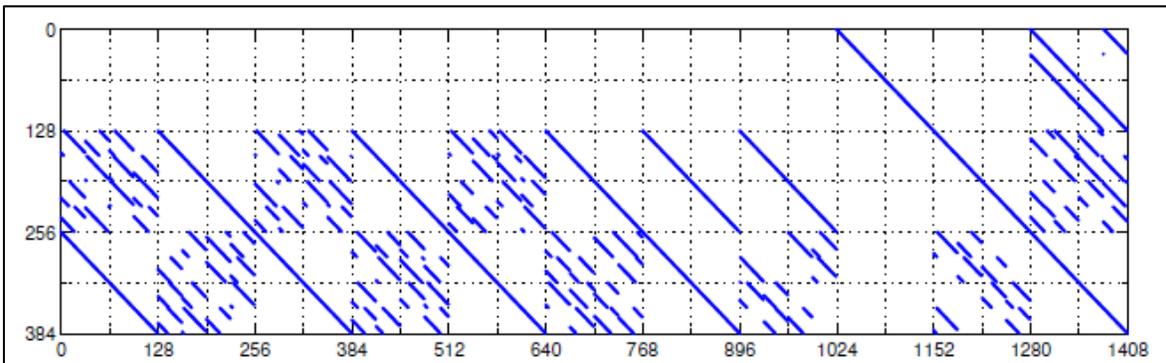
Figure R-5.   Parity Check Matrix **H** for (n=1280, k=1024) Rate 4/5

Code Rate =4/5, Information Block Size = 4096, M = 512

k	Θ_k	$\phi_k(0,M)$	$\phi_k(1,M)$	$\phi_k(2,M)$	$\phi_k(3,M)$
1	3	16	0	0	0
2	0	103	53	8	35
3	1	105	74	119	97
4	2	0	45	89	112
5	2	50	47	31	64
6	3	29	0	122	93
7	0	115	59	1	99
8	1	30	102	69	94
9	0	92	25	92	103
10	1	78	3	47	91
11	2	70	88	11	3
12	0	66	65	31	6
13	2	39	62	19	39
14	3	84	68	66	113
15	0	79	91	49	92
16	1	70	70	81	119
17	2	29	115	96	74
18	0	32	31	38	73
19	1	45	121	83	116
20	2	113	45	42	31
21	0	86	56	58	127
22	1	1	54	24	98
23	2	42	108	25	23
24	1	118	14	92	38
25	2	33	30	38	18
26	3	126	116	120	62
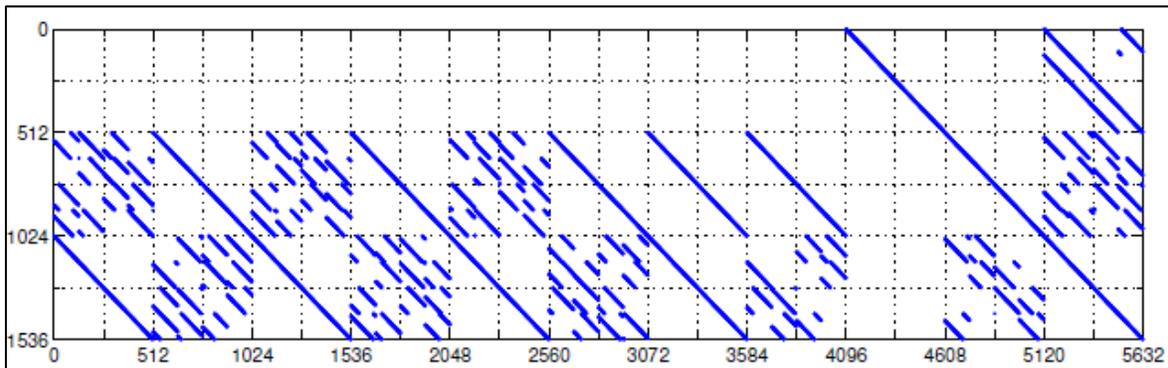
Figure R-6.   Parity Check Matrix **H** for (n=5120, k=4096) Rate 4/5

4.0   Encoding

The recommended method for producing codeblocks consistent with the parity check matrices is to perform matrix multiplication (modulo-2) by block-circulant generator matrices. This family of codes supports rates $K/(K+2)$, where $K=2$ for a rate 1/2 code, $K=4$ for rate 2/3, and $K=8$ for rate 4/5. Generator matrices, $\mathbf{G}$, have size $MK \times M(K + 3)$ if punctured columns are described in the encoding. (Note: If punctured columns are omitted, as in this case, $\mathbf{G}$ will have a size equal to $MK \times M(K + 2)$). Table R-3 lists the size of $\mathbf{G}$ for each information block size and code rate.

| Table R-3.	Generator Matrix Sizes		
Information Block Length, k	Generator Matrix ($\mathbf{G}$) Size		
	Rate 1/2	Rate 2/3	Rate 4/5
1024	1024×2048	1024×1536	1024×1280
4096	4096×8192	4096×6144	4096×5120

These generator matrices may be constructed as follows.

1. Let P be the $3M \times 3M$ submatrix of $\mathbf{H}$ consisting of the last $3M$ columns. Let Q be the $3M \times MK$ submatrix of $\mathbf{H}$ consisting of the first MK columns.
2. Compute $W=(P^{-1}Q)^T$, where the arithmetic is performed modulo-2.
3. Construct the generator matrix $\mathbf{G}=[I_{MK}\ \ W]$ where I_{MK} is the $MK \times MK$ identity matrix, and W is a dense matrix of circulants of size $MK \times M(N-K)$. The dimension of W is $MK \times 2M$.

Because the LDPC code is systematic and the generator matrix $\mathbf{G}$ is block-circulant, an efficient bit-serial encoder can be implemented as shown in Figure R-7. Initially, the binary pattern for the first row of circulants is placed in the shift registers, and the accumulator is set to the length $2M$ zero vector. The contents of the shift registers are added (modulo-2) to the accumulator if the first message bit is a 1, and the shift registers are cyclically shifted right one place. This is repeated for each subsequent message bit until $m=M/4$ cyclic shifts have been performed. The shift registers are then loaded with binary patterns for the next row of circulants, and the process continues in this manner until all message bits have been encoded.
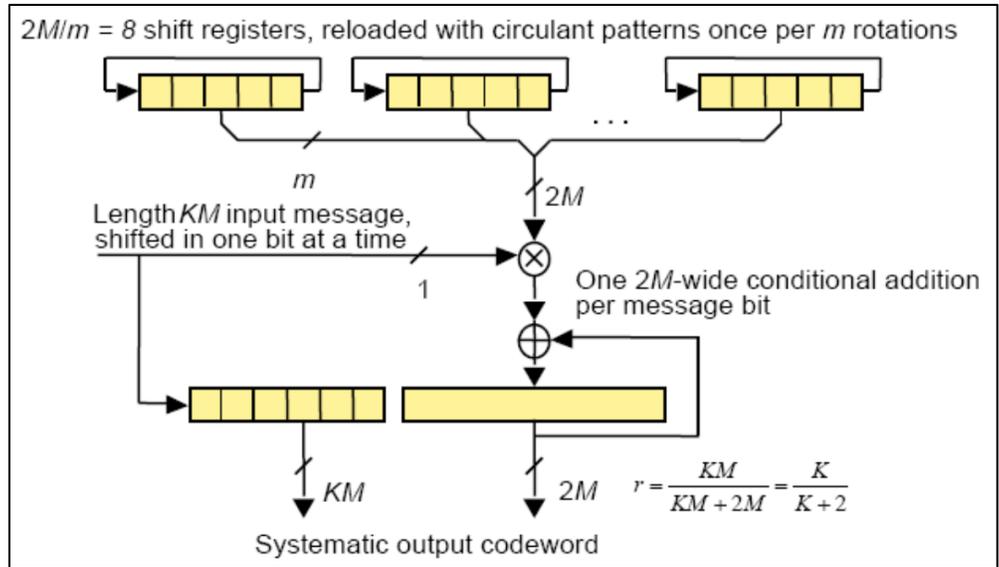
Figure R-7.   Quasi-Cyclic Encoder Using Feedback Shift Register

Computing the generator matrix **G** involves inverting a large binary matrix, a computationally demanding task. For convenience, **G** for each information bock size and code rate is tabulated here in a compact form.

4.1   Code Rate =1/2, Information Block Size = 1024, $M = 512$

The first 1024 columns of **G** form a 1024×1024 identity matrix and the remaining 1024 columns of **G** form a block matrix composed of 16 rows and 8 columns of circulant matrices, each of size 128×128. The first row of each circulant is given in hexadecimal format in Table R-4 according to its location in **G**. Subsequent rows of each circulant can be computed by applying the corresponding number of right circular shifts to the first row.

Table R-4. First Rows of Circulants in Generator Matrix, r=1/2, k=1024	
Row 1	
Columns 1025-1152	CFA794F49FA5A0D88BB31D8FCA7EA8BB
Columns 1153-1280	A7AE7EE8A68580E3E922F9E13359B284
Columns 1281-1408	91F72AE8F2D6BF7830A1F83B3CDBD463
Columns 1409-1536	CE95C0EC1F609370D7E791C870229C1E
Columns 1537-1664	71EF3FDF60E2878478934DB285DEC9DC
Columns 1665-1792	0E95C103008B6BCDD2DAF85CAE732210
Columns 1793-1920	8326EE83C1FBA56FDD15B2DDB31FE7F2
Columns 1921-2048	3BA0BB43F83C67BDA1F6AEE46AEF4E62
Row 129	
Columns 1025-1152	565083780CA89ACAA70CCFB4A888AE35
Columns 1153-1280	1210FAD0EC9602CC8C96B0A86D3996A3
Columns 1281-1408	C0B07FDDA73454C25295F72BD5004E80
Columns 1409-1536	ACCF973FC30261C990525AA0CBA006BD

Columns 1537-1664	9F079F09A405F7F87AD98429096F2A7E
Columns 1665-1792	EB8C9B13B84C06E42843A47689A9C528
Columns 1793-1920	DAAA1A175F598DCFDBAD426CA43AD479
Columns 1921-2048	1BA78326E75F38EB6ED09A45303A6425
Row 257	
Columns 1025-1152	48F42033B7B9A05149DC839C90291E98
Columns 1153-1280	9B2CEBE50A7C2C264FC6E7D674063589
Columns 1281-1408	F5B6DEAEBF72106BA9E6676564C17134
Columns 1409-1536	6D5954558D23519150AAF88D7008E634
Columns 1537-1664	1FA962FBAB864A5F867C9D6CF4E087AA
Columns 1665-1792	5D7AA674BA4B1D8CD7AE9186F1D3B23B
Columns 1793-1920	047F112791EE97B63FB7B58FF3B94E95
Columns 1921-2048	93BE39A6365C66B877AD316965A72F5B
Row 385	
Columns 1025-1152	1B58F88E49C00DC6B35855BFF228A088
Columns 1153-1280	5C8ED47B61EEC66B5004FB6E65CBECF3
Columns 1281-1408	77789998FE80925E0237F570E04C5F5B
Columns 1409-1536	ED677661EB7FC3825AB5D5D968C0808C
Columns 1537-1664	2BDB828B19593F41671B8D0D41DF136C
Columns 1665-1792	CB47553C9B3F0EA016CC1554C35E6A7D
Columns 1793-1920	97587FEA91D2098E126EA73CC78658A6
Columns 1921-2048	ADE19711208186CA95C7417A15690C45
Row 513	
Columns 1025-1152	BE9C169D889339D9654C976A85CFD9F7
Columns 1153-1280	47C4148E3B4712DAA3BAD1AD71873D3A
Columns 1281-1408	1CD630C342C5EBB9183ADE9BEF294E8E
Columns 1409-1536	7014C077A5F96F75BE566C866964D01C
Columns 1537-1664	E72AC43A35AD216672EBB3259B77F9BB
Columns 1665-1792	18DA8B09194FA1F0E876A080C9D6A39F
Columns 1793-1920	809B168A3D88E8E93D995CE5232C2DC2
Columns 1921-2048	C7CFA44A363F628A668D46C398CAF96F
Row 641	
Columns 1025-1152	D57DBB24AE27ACA1716F8EA1B8AA1086
Columns 1153-1280	7B7796F4A86F1FD54C7576AD01C68953
Columns 1281-1408	E75BE799024482368F069658F7AAAFB0
Columns 1409-1536	975F3AF795E78D255871C71B4F4B77F6
Columns 1537-1664	65CD9C359BB2A82D5353E007166BDD41
Columns 1665-1792	2C5447314DB027B10B130071AD0398D1
Columns 1793-1920	DE19BC7A6BBCF6A0FF021AABF12920A5
Columns 1921-2048	58BAED484AF89E29D4DBC170CEF1D369
Row 769	
Columns 1025-1152	4C330B2D11E15B5CB3815E09605338A6
Columns 1153-1280	75E3D1A3541E0E284F6556D68D3C8A9E
Columns 1281-1408	E5BB3B297DB62CD2907F09996967A0F4

Columns 1409-1536	FF33AEEE2C8A4A52FCCF5C39D355C39C
Columns 1537-1664	5FE5F09ABA6BCCE02A73401E5F87EAC2
Columns 1665-1792	D75702F4F57670DFA70B1C002F523EEA
Columns 1793-1920	6CE1CE2E05D420CB867EC0166B8E53A9
Columns 1921-2048	9DF9801A1C33058DD116A0AE7278BBB9
Row 897	
Columns 1025-1152	4CF0B0C792DD8FDB3ECEAE6F2B7F663D
Columns 1153-1280	106A1C296E47C14C1498B045D57DEFB5
Columns 1281-1408	968F6D8C790263C353CF307EF90C1F21
Columns 1409-1536	66E6B632F6614E58267EF096C37718A3
Columns 1537-1664	3D46E5D10E993EB6DF81518F885EDA1B
Columns 1665-1792	6FF518FD48BB8E9DDBED4AC0F4F5EB89
Columns 1793-1920	BCC64D21A65DB379ABE2E4DC21F109FF
Columns 1921-2048	2EC0CE7B5D40973D13ECF713B01C6F10

4.2   Code Rate =1/2, Information Block Size = 4096, *M* = 2048

The first 4096 columns of **G** form a 4096 × 4096 identity matrix and the remaining 8192 columns of **G** form a block matrix composed of 16 rows and 8 columns of circulant matrices, each of size 512 × 512. The first row of each circulant is given in hexadecimal format in Table R-5 according to its location in **G**. Subsequent rows of each circulant can be computed by applying the corresponding number of right circular shifts to the first row.

Table R-5. First Rows of Circulants in Generator Matrix, r=1/2, k=4096	
Row 1	
Columns 4097-4608	616DB583006DB99954780CD6DFC9908772D8260D390B1D462A8F62DE8809216194BE0531EE408AEAF27F50F3AD71865AC7910EEF8824A858CA7B13FC843DAFB1
Columns 4609-5120	BA3E0B010860D09066A8632E2B273DABDF90C26FCDD989C2831874EA7FBA23D940A294111C1B0C1CF62F56A376B94CF64FA594B987B19226E525704D7F2BC66E
Columns 5121-5632	226C671C22A59AC062490596EB1536C9F66AE799C2489FAD2C131E29ED64A25CB0ADC88D04C5EC8FECD7F78B3825E626858CFAA0DE77772CE8822C7AA39628A0
Columns 5633-6144	123B1C426E2A93366D067D26DE51362EA0BA916EBD1229521B1B044459B325785F3F3E24199B2460151E4CAA9FD26A5DC46BE0D6DA907EFAF38F413642F702F5
Columns 6145-6656	324AFD5D62F4CC251FF5C0FD95DE0FAB061F0C92CA5BC97F976118AD84E0663A3BF1B4F07D1CCCC2DF9E09D506B073DED87CC0653C944FC7D438223C0DF3EB67
Columns 6657-7168	E62AE13F8D4000D616E814045495F6E969C473B059386F5DDBCC25F4002EB132D73A98414D85346F55DEBFF875F7CB9D2466A412D180E0A1ADA18D281376A671

Columns 7169-7680	8EB0FB6BB7B9AD2A2132010511077F6BD424B6F5B578C11D0076B781930F755EBB72C41ED17519476C257C31C3159BF31FADA2755F1B8A23B22D6A428AA290E2
Columns 7681-8192	54CC73C7599AB67C6807C4286BECF8423F3216EF04E1B6DE61349DDB23E3A0EB0EF70C5BE1AD91D31B0BB532C1098DC619BF80F3853EEA357091C05D95170A7E
Row 513	
Columns 4097-4608	5E6381A718C0A817F8101ECDCDBF825E732E4356CEC42C222DBC476BD704837C382B7FBF282B739EDC22B5EEA2909F0EB3ACB9E41FE2AC791130A36A9CBFC1D9
Columns 4609-5120	D4F8DE28FA77F37E4A6B5A82A58CE917CA74C8397E9DB8EDCB2BF65DB91954457707FE876DFF812D4B99466DF479A00114F27E702249DB3E9311301E9CE98703
Columns 5121-5632	74FEAD0013FD861D67D7CE69D3635ECC6266E862D08B63077B45D3098306EA74159DAEA2263E58705EA5ABE58B7FD41862B9EC1D0F1BD47CD6CB42739C24F7FE
Columns 5633-6144	7ACFF6D64C8E8F94BEABE280CFDCFCFB26AC7330073C25E0313DCB75E6C5261F15D82AFA665F73A4B4DA4E5D1648EAB051EDEB9857C13C2F019FCBBA4F9DF2E1
Columns 6145-6656	9CEFF1147D792C14AA2E211C3B9B94B2C9F24F49B0B1ED6E200C88D743F5AC1EE283C3A0AC79B9F1F496BDE74A2AA591ACF2F526FB24413A58B495F91905F596
Columns 6657-7168	D8F1469BCA9CC5041C50F1FB479CF2680503AD85BA2C0C6D01D2D739F3129315E49A9F57236D9585CC0B8A9B4BFE9ADCD97BED9006C33976ACC00468693D56FA
Columns 7169-7680	1EE66371B0EA6C4E1E172C2C5D76806CB7376B8CDEAD96B14A1EC2B656298B9425EA2F0671082D70AA23C267D1F215C59239AEB40186DF0AB284625DC6BAF45E
Columns 7681-8192	FBFBE26BED98BB3B697764A6F82C94039CBF14CB538A7D87801ACBD3A444A858BB74F0A4707592EE6B7DC6D21B8F6B4A184B567C8AA4CD825EBF7F1EDCE015A5
Row 1025	
Columns 4097-4608	25453670647D23C5E445A705953F3BF4A5AF02E7BC46C969C8141D8782F171C9CFF7EBB20945DE5D363AD36D3BD5A0BA081C079CDD04B6E5968187C8A665344A
Columns 4609-5120	23E9B1897A6FDF427B5E910AA8D71F9CC6351474BC4563C20FD38953295D3BA15E7D1010503B7BA1C148251DB8A88AC64E6AF8C1CC056E4EEF1C927FEC40C35D
Columns 5121-5632	57140969483D9E33429FAFD177D031A43B727CF832C8DFFE8D8960CB55BE4BE27B69CC26F2FB731B53250D6F8EE7DFDA98812B9AAE9C02AE2FEDEA598D6B6E2F
Columns 5633-6144	22B6CCA50541BD9F5D48565E551B310E10A0DFCB8035A5EC86EB9CD8C811CDCBCCCEC3732EF93EE8C9418E25CA5744E07C45F9B161E277BCECE388B9B84AAEC4

Columns 6145-6656	DA37FE277C72CB5CB1BE92AD373867403E46B3535159687ADC79C39DEF7005C1F11F1CBD5F8877DA66AAC156EF27BB893F5F1132336D52E8AEB60EACF9BEB3CF
Columns 6657-7168	D204D92DFA496DAF564272E3FEC51CE53C8F2DF6ACB191E60E14CDEA28FD5ED0EBE09672ED11A3F6466FE3A967A4EC8390303059AE00DD83102A9F33B2943E4E
Columns 7169-7680	6E56928E7FEE3333A36FF3EE7598744CF7C298FEF3EACC7CCC0F36DCBA6D87BDD441081163A65E27C958AF79C33A98B81814015E77F82EF5120FBDAB540893B4
Columns 7681-8192	7BEB68CC37F23835C91F5D36D6BA6F0A5E68FEBB6E6A2F247EB5CF57684D0770249460788DFDC4A1218652BF881B4BB06308EF86484E7070AACC72D3977CF5D0
Row 1537	
Columns 4097-4608	6230DEF1ACD4425F7B155A2A285CB2A32CB9D46DA09B28167826E77AEBD85F0C416595E136184841451F5B3E1F17D02C3DB32C2AF50091D6376406D8CB78A9E3
Columns 4609-5120	D3B19911ACC450679EAE25B0F290FF372300F1A4BC91A43CB79DB270133D41DC4970F1420E71C0F816EF938C3C17F0FCBB6E920ED853EAF6D2DC6792BF87098A
Columns 5121-5632	B94C2E5DDE78C974AD6F423CD5ACA01EC9420AAF3FE83BEC31D47AACD3D62FA2476C38595BD66639368181E75B44BAA7ADBC2B42E1D82D7A59312BB9A16F7D35
Columns 5633-6144	0B13B44D828071E69DD90DCD9B713A05FD8C21AA5E6E6D8DA49A5C3B34F98A4E5E822513F0DA200235C65BFCA1DC2CE4AB21D146B778F6806680B8AC75285760
Columns 6145-6656	FEF66B861AA67C768A76D585DFADC8EB6556AD841DEA9F44ACB42B6016142B6B69F1833474FADEB0400CE4D9F3BD62AD96E57F3E93DD229180F2D4B5E77D098F
Columns 6657-7168	EEBE2DFA4D4D86ECB07EEE9565FB589855E1F53BA1B9784A8D195A0E3721551270089C535216636FBEB4D9E50A9EAC3DCB27891A7005A2AD87427E6B8326F6B3
Columns 7169-7680	CA225C7B2A9EABFFDDDBC130B5342917848B029917BA98FFD6EF2389006A6B417F678C61458EF625C96C0D3D07945ABB9836CF80823EB6244D86D114CC5DC2B1
Columns 7681-8192	94F5D55C398B16A71497C4CF102C2F1035C19D5DFC8A301B8DE33D41D909C15A3093B09E7489CE6AA14B331B70E76637FE6DDFFFA6DC4C510371CB0D2A6EA3DA
Row 2049	
Columns 4097-4608	AC5F866DD75CD4C2D5959AC37DE4E1E870313A5B2902F234CD939FE39F31FEBF8B46DAC906E3EBA9C3A74DE46E7A9140D3716667BB1EC22A87D5F8D048BDC5BA
Columns 4609-5120	57B6024327CDDFF3296BE6508C48045B71FA519156F8C125F4E3B7356576F32C63BC588908C4E8B3F9F2D12A9E8F35B6FCF296C17FD8E8D076406FA11D16175F

Columns 5121-5632	CC45AE82D672979E8A0A359B2328C79AE61F87EBE04DAC93430305486597 32000CE627417B3F8CFD4A992E7F2B680216AF773385B9337E1743D43FD96 5282CF5
Columns 5633-6144	AE71B0CAFEB4DA3E0B95F1341667C519FB9F89D7CEC711E57485F04A965 CDC832CBEC0BE1B2A3E23B5EAF4C5DAD8767E054B2225A60B88BE1DB6 A35E0BAEB237
Columns 6145-6656	A206BC721B252D52EA1F8E311203DFF0AE8D65BD1986055701A3C7FEB2D DEDD2D57C3BBA6A2BC56A9157677D7B48AD2907927176F6B22E8A92F6E 9863C9E16D9
Columns 6657-7168	11B6209E06EFE6ACBBBA2214EF5AEAB9D76645476B2C16B8D14E1AE3F3 A85188835922B914D3F32FE05B7987A2516B3D3C8983AE176DFD04349A45 359B422E1E
Columns 7169-7680	01CC2266F2B68A4323F8931D7AA37B1CBD70DC2FEE91592327207AA6121 795150A0DC918704A1A293778FE75A99FDCE77E820D0905EF7AC72A682F2 487A6E0FE
Columns 7681-8192	03F42D94FDE1C13F958DF61112DB4A27A8A8EF35087FD089729F0864C270 6CCB2B6CBD91A9A7B7B31E08EA3570A6E1BED495FC84FACD829F3234B 1D1DC574B67
Row 2561	
Columns 4097-4608	900AA496432959141795C615CBAEA98002440A0D447EF990435E452CC6902 03BDEBCBA3EEFC7A7CE71EB54B1728AEA9EDE70A7E6A1A8AE8616870 9A899738CCB
Columns 4609-5120	C5B7A094AEBEA8EC95A414A8DE5D3DBE6745CB0D330B78435AC2BB666 6BB2D43A19EAD3B3D9536D0BB92DB949570981C22805E7DEA452FA649C 84EDC4324A7FB
Columns 5121-5632	E6A9CAF4EE48400720B8F84CAC3A42483B7E571846E2A5F77A983EE31117 9CEC2D99878FF5AA06ACA0CBBA63B36985E0970761E7F837650BC46C9A 2EB1AEFA95
Columns 5633-6144	AC4D8AA5C970BB55FDF3408356C9EB2683B6FEE593736B66B49C055BD65 03EEF3C7CADD15C9B86DCA626E1ABF4B971D04C0A9A5AEF8305C3D0E4 CC02C32FA91E
Columns 6145-6656	D8949EF8FEADF7DA39D395B52D2779A0B305C4FD10C33A434878967D932 1B4835C035CA5802C37F6DC1E39AC30337253114176BBB26576317C72E954 8F179A5A
Columns 6657-7168	A200FC35B6A0934D57543A60F6114B7B0D78D8DD8932538E545D806A1D9 E47390F092501F4A470CF7B1F9144D0A8F1B0C3D607930A75E5A150233DC EEDB4C10B
Columns 7169-7680	217C8EB38D4D2A0EF12557321D504ECA670B41E496441FDE341F0232101D 4E3F4158FF6F4EAECC073AA811DD450F528BC6095868B7BF953926056BD4 09E5FE36
Columns 7681-8192	B82831B150B80A736D6CF7B16660ADCD5E1F4DB96E36E33DCC2F1506C7 B8B0F2A4EC362FB0CF7B8B3B08D6CD1AF7440729D4C3C02627AD8733A0 C94B2EBAF526

Row 3073	
Columns 4097-4608	FDB4463E6F8FBAF565B1C3320F5704A87309E529842378ECB733784F1CBD85F4F87FB0525C7C4D307061F74DE2FB3BDFBC77E04EAB75A64FFE51203AB925E807
Columns 4609-5120	1D1101A16A2C41DBDCA94C128560BEFDA4ECA6F22B44C6E5085A23F84106E4FD870FAA789E03FC37086E67B69FC8EB6421AA57FBA27866DFF712D5FEDA21FC51
Columns 5121-5632	76EE3CB2C4A8629C20FC646A7ADF2A4BE73DCEF53FC926067EB9964996BCEE403C5642CD2F8084E0C14D3627FAD9F0180DADF07331246C007F3AF95CC9B451CC
Columns 5633-6144	3638887EB493F5EE3361F07E00F115BC04AF404BE6BA3467322B37A8E6ABF47710D56C3BC751892CFD12F29CC4319D0562005562D05261D39FDF528A11E65BBE
Columns 6145-6656	A0BF07C52E9A9ED7AC3F0FB9196A450E162009509F20BEE74FCC6316BC4824D93CBAC25E470A7468A629EB520E980DE31F8C8873F4ED21B57AAEBF43A5754359
Columns 6657-7168	CD089ABE548975678C2123223CF3F345AE0CECF0A3726BFBB130E34169A874B6C4CDEFC0A05D7DA1EE475E5407F1535399086700874C13000E2EE21DF3EEFB65
Columns 7169-7680	4BEF6F2B4137DC6EF197D514E904B8F31BAD6C846D6BD7D7480F4818C3C57B4C7F53F168E48020273702071EE48EC53422C71C90AA0262982B82BB6FF3100D8A
Columns 7681-8192	EB3E8F033DA73FA82B3B93E50C60E5936A07D3218946588D0EFB39E1A55C0FB9DBA87DA50C4697EE2ED72B004301019E595B92A2F55F7F1B37C2030B79057F52
Row 3585	
Columns 4097-4608	59CA13359E16B10A7F8778BBAF5D45E32C643B524022FE777A8F557C14141D638E84BC4DBB1CE5866CD0B89C1CC5C6F7BF7E25D2B4FC28A16E67CF8BFAC4F4BD
Columns 4609-5120	A612F30067700487B6584B1AD578659FC2B7443228B2B7B443882DABBF55739CB9660F530631A2CFDCBE94D21692CAC01DA9EB5048FFF17BC4FB5957E8C9DF1F
Columns 5121-5632	29E0573D85359FB7924AABBDDDCD26F5740FFA6824FCFCBD53BF1DFB587E0667641DD3F82962F5E6EA26461279B0F69479645462983DBBBCC544DA90255121EA
Columns 5633-6144	A97C7B71923F0382DF60C9E34D84CAC289B578899EBCF924F4304B80581C9887B1198F074143DCC4324D7DF301466AC97903E688DD2E9186EDD2D90C34202AA3
Columns 6145-6656	90815D489B715FF604788F335322DF5C8856FD85F753785A96F4B2561990F458C69D3F99A8ED1BE99C3F5A14B19B37AC729B3F35ABF52006E814B597145FA3FD
Columns 6657-7168	86A5A2038BB67CF8225BCCF7A587E0D09B47D26BC4DB017F6A77B6DEC5AF5B117E399D8A336358D4AABE9C8E7EAAF6447638F2DC66EF65C100D06EE202013042

Columns 7169-7680	AD845A43D23E66FBA72D9D56457D66C7E44D98ED1E5F1D063A5D010439 30E9C2EDED8BA9DEE5F9DFF91CD887F097B9A2DF0099E278C253E0A549 C7A2D81078C6
Columns 7681-8192	680566EA7A1E724A99B5D7099AED278A3065BBC64BED441154DCD346D3 8C9771648D55656B16CF012D0C6EC8F616D3B758089A8147D731AE077D55 7204256F93

4.3   Code Rate =2/3, Information Block Size = 1024, *M* = 256

The first 1024 columns of **G** form a 1024 × 1024 identity matrix and the remaining 512 columns of **G** form a block matrix composed of 16 rows and 8 columns of circulant matrices, each of size 64 × 64. The first row of each circulant is given in hexadecimal format in Table R-6 according to its location in **G**. Subsequent rows of each circulant can be computed by applying the corresponding number of right circular shifts to the first row.

Table R-6. First Rows of Circulants in Generator Matrix, r=2/3, k=1024	
Row 1	
Columns 1025-1088	51236781781D416A
Columns 1089-1152	B0C8419FA21559A8
Columns 1153-1216	5F14E1E4D88726F1
Columns 1217-1280	762F6ED6CF32F06D
Columns 1281-1344	8ABFD971E17A0BE9
Columns 1345-1408	A5D147741B698D14
Columns 1409-1472	2A58AB30E2BC32D3
Columns 1473-1536	9F251FBC5DB8C768
Row 65	
Columns 1025-1088	D73C205BBEB231CB
Columns 1089-1152	CAB5EFF5B2C76C71
Columns 1153-1216	FA70FAD48828355F
Columns 1217-1280	68C6138FA5524A61
Columns 1281-1344	BB20031D7AA8FE69
Columns 1345-1408	432ADE446F49CE27
Columns 1409-1472	5E5DB9CCCEBD1326
Columns 1473-1536	E8782B1B01F2ABA2
Row 129	
Columns 1025-1088	4748E9513B41147A
Columns 1089-1152	17B1FBB78B4F914C
Columns 1153-1216	281F5680BA56DE50
Columns 1217-1280	74B0FB0817E33E2B
Columns 1281-1344	DD166CFB774B5959
Columns 1345-1408	AC7FDCEA4FECB5BE
Columns 1409-1472	ED747C81B540D66A
Columns 1473-1536	B2A6A2039A87967F

Row 193	
Columns 1025-1088	4780DCB2DC5CBFAE
Columns 1089-1152	55BC8FF84EC89440
Columns 1153-1216	E5D411223F09979F
Columns 1217-1280	DDDE9D940A15A801
Columns 1281-1344	194064639D254969
Columns 1345-1408	1BE32DDC829B0032
Columns 1409-1472	1326515A22EE88A2
Columns 1473-1536	0EC664DD2D701891
Row 257	
Columns 1025-1088	69748DFE6372F2EF
Columns 1089-1152	15F3B0D400ACD68A
Columns 1153-1216	CF4144CE1FE2581C
Columns 1217-1280	79B1A55BA59E54AE
Columns 1281-1344	65A2B47EEBAB0CF3
Columns 1345-1408	24DD87572CB0F71D
Columns 1409-1472	F24ABF15590F4DA6
Columns 1473-1536	9C3BAE51969C6502
Row 321	
Columns 1025-1088	D3A714B60B22789B
Columns 1089-1152	3DF5504D80F54C5A
Columns 1153-1216	9D75CF1465031211
Columns 1217-1280	09834A0C9F659C99
Columns 1281-1344	B9241BDF76EB3788
Columns 1345-1408	6F927251C86DECF1
Columns 1409-1472	390BE9F5BBB93D05
Columns 1473-1536	C6F435BFA1FF96B6
Row 385	
Columns 1025-1088	222461B658DC3E91
Columns 1089-1152	B01DF2A2EAD2DAA6
Columns 1153-1216	5572EE6278F6F63A
Columns 1217-1280	17B63CB2FDA3B97F
Columns 1281-1344	B233BB259F3D83F7
Columns 1345-1408	F64760C774989384
Columns 1409-1472	46F57E03F55B1C0B
Columns 1473-1536	5AC8A6CEA05466C1
Row 449	
Columns 1025-1088	AE8825521F85CA31
Columns 1089-1152	37BEED74B5303407
Columns 1153-1216	751FC9A15FCEE486
Columns 1217-1280	93F0F69BD04E72A4
Columns 1281-1344	C0EBFA3F49DF4DBB
Columns 1345-1408	03E52D815DC99A1D
Columns 1409-1472	98FE8BF01BB2CD6D

Columns 1473-1536	009C5290D81A18F6
Row 513	
Columns 1025-1088	4FFBAD88545CAA95
Columns 1089-1152	0C74659FA4828CA3
Columns 1153-1216	60CE56E32DA28B2E
Columns 1217-1280	299D4BF82FE54B81
Columns 1281-1344	51047BE3B3AE4F4B
Columns 1345-1408	F3AC9578B9477A4C
Columns 1409-1472	3730F81F92767E11
Columns 1473-1536	04E84EC3A3AD1F19
Row 577	
Columns 1025-1088	2D0E0CAB8EDD2185
Columns 1089-1152	CEFBE8F2F538522A
Columns 1153-1216	92DAEDC22C441893
Columns 1217-1280	BCB999157B35619D
Columns 1281-1344	069951BFB90A08E1
Columns 1345-1408	54C7E270CBA1656E
Columns 1409-1472	7FBBB806B6A06FB3
Columns 1473-1536	7224943B1C3A5723
Row 641	
Columns 1025-1088	1BAA14752EFCEBC0
Columns 1089-1152	CFF0894975557623
Columns 1153-1216	FA95908DC3F34D48
Columns 1217-1280	FECA650999A26E91
Columns 1281-1344	245433EBBE9CDA13
Columns 1345-1408	5771EAFF9B02D8FC
Columns 1409-1472	BCEBCA573D3775C8
Columns 1473-1536	1E46F2B951D0EAAB
Row 705	
Columns 1025-1088	32942F7F4743DDF4
Columns 1089-1152	8FA2F60AD62095EF
Columns 1153-1216	80E4A736B5E1A3A3
Columns 1217-1280	0119062872DAEDF4
Columns 1281-1344	E78006958CD99F95
Columns 1345-1408	D20625057C99C7A3
Columns 1409-1472	B569736DE2167610
Columns 1473-1536	0E1C6183ADF09FD0
Row 769	
Columns 1025-1088	E5C492DBB48B319A
Columns 1089-1152	E2D83ADEFEBBDEFE
Columns 1153-1216	AA944EEA53C77DB3
Columns 1217-1280	0FAA85D9C13B1F73
Columns 1281-1344	8ACED57F3BE4E807
Columns 1345-1408	33CB72627624F426

Columns 1409-1472	A0C6E669B5C74980
Columns 1473-1536	ABBAEFEA2D3B69AA
Row 833	
Columns 1025-1088	F8366DDAE56A6DDC
Columns 1089-1152	FDED5582F4EA6525
Columns 1153-1216	4C9628278ED17036
Columns 1217-1280	6E711B6D20A67966
Columns 1281-1344	3B28BDF004C21B93
Columns 1345-1408	1BC37B730FFC1786
Columns 1409-1472	5D20C81D345FE4B9
Columns 1473-1536	1D14A5663D369A93
Row 897	
Columns 1025-1088	5EBD4BD39B2217D0
Columns 1089-1152	56833BE1CDDBA6BC
Columns 1153-1216	B288169B4E3BB726
Columns 1217-1280	C2ED28FBFC395D1F
Columns 1281-1344	035B30C68F9A6B6F
Columns 1345-1408	539836A6E56A7B16
Columns 1409-1472	CEB1525C6ADB65A5
Columns 1473-1536	5F71754AA458B11A
Row 961	
Columns 1025-1088	0DB9D180B21C0B13
Columns 1089-1152	417D86C59DF33E49
Columns 1153-1216	183A8F6C44DAFA24
Columns 1217-1280	4E224C180C1F0B45
Columns 1281-1344	C93CD9CA23658555
Columns 1345-1408	7DDEC5E9451AD519
Columns 1409-1472	B122C72A6177EE99
Columns 1473-1536	1290B4C6B007D973

4.4   Code Rate =2/3, Information Block Size = 4096, M = 1024

The first 4096 columns of **G** form a 4096 × 4096 identity matrix and the remaining 2048 columns of **G** form a block matrix composed of 16 rows and 8 columns of circulant matrices, each of size 256 × 256. The first row of each circulant is given in hexadecimal format in Table R-7 according to its location in **G**. Subsequent rows of each circulant can be computed by applying the corresponding number of right circular shifts to the first row.

Table R-7. First Rows of Circulants in Generator Matrix, r=2/3, k=4096	
Row 1	
Columns 4097-4352	80924F648C014F2C73889C8B87D0491FA9FA060D2902D7ACC8B679CF61EEB5D9
Columns 4353-4608	6BB9E90F5C157AA1BF03EF756245D9179063F2CD999EF1E7F7925B3FB7AC7B2D

Columns 4609-4864	6CD39516B201F491E2BDCA4E34542B5AF3703B3C8EE753FBE998E87323F0B228
Columns 4865-5120	D1F551B2D7E7822F201E24066584D63CAA00E8DB909EB41C4157EBA0F5C76A50
Columns 5121-5376	F7C5731746C6DAC260A345189009C0B23372F1E9E0C5A079D00B09158E164B22
Columns 5377-5632	33D5F8A268041CAB66317898CD0024E3106EED5C2171B3F6276B8EA59AA981E0
Columns 5633-5888	010BFF3F52A49ED9A6FA7F151FCC72B2AF3BD932065043F7447B4D0FC4A2B93B
Columns 5889-6144	F8D345E6D2B0008D1B363BFE296B55AF38E3E16EC5856A122E4931CB3F2424B1
Row 257	
Columns 4097-4352	A099B776C642FF1D84B0DB797098E17E75FE9BB5CF7FA8739711A89660DAF24D
Columns 4353-4608	3CA8DE5500F68DB449BFF74251B24E4691EAF386C81014C91AC700298E095F0B
Columns 4609-4864	12CEE8B5F6B93C11AD628CB6CB81F76BE095C2C994A8BDDB4E2C48C942B4D481
Columns 4865-5120:	1F7E191B30E8FFD6D4A7E9BEF81BBB0AE6608F647B1AED9CCA7FEC5498C03F0F
Columns 5121-5376:	1132E816BDFA0C3450C3993911E10EB1097CD7A1F32C54C8B009654E56B25A2D
Columns 5377-5632:	5FD58EEAED460CEFC18E2FBAD2954467E32118F01D05456DEA2926A1E761DF76
Columns 5633-5888:	4C6C7BF3A2245C1B4630775DC59EA74A14EBCD8B5D72E343BC6F7FEA452F2CC2
Columns 5889-6144:	C09CE802B35EBF46D1F3069957DF1D152377F45ADF614CC0F5DAB8FCF394CCD0
Row 513	
Columns 4097-4352	FEFBA8CE169FD3775B2280EF3BD870FDDF7CB95F2943D0EEA84529FF0D1B1C19
Columns 4353-4608	0CA5DB06A87541C81BEF913D5145F20EFAD861F673B32028B4713377C056CE97
Columns 4609-4864	CA3F213365EE380F7E90466945BDE9F44087C8C73A7CC5F9DE71B7683D018D86
Columns 4865-5120	A6CDFD8D8117748A4B41C3F5A66765495711EDC02F9581F3E7C2E0FD9004B03B
Columns 5121-5376	77D0EF5DE2ACACA2A4371A5B111B877D0EDDF83C3341A5AA51261FA4B5A0D7EA
Columns 5377-5632	7C563512A6B73B3B43F8D1D113D751D6B2CABBC350FF0F8C29361DCE5EB87C8F
Columns 5633-5888	F6DFA5C672C2517931371ACB6462A596D41419CD4F0F84EFF98DCBBE610AE03E

Columns 5889-6144	05FF840FB320DD5C3FB4FE4A5858510914A5161B2AD3C3E7FD02358505190F0F
Row 769	
Columns 4097-4352	5B6D534EDE13068A2459CB07007121B0F07B08B8227047C1A629DCA5A4E30D28
Columns 4353-4608	5D00E72E5B6AD57A9F0F9E0608702BDE8BDBFA371C06D96BFE0E603775A875CB
Columns 4609-4864	692EB7DA76BD0D4AFE92FCB5B5184BAA3EEE37900144CA03B7A22EADE2F061FF
Columns 4865-5120	B3CDE2464AF1212979A99380340974A9F85478E5A2E8B907E74EEFA4CB7625E5
Columns 5121-5376	41AF736E0AA1416EA676E43CF5DFF372CFFC30D6C0A58A333268136A3020033F
Columns 5377-5632	F50111382FEBA594C255896AB59C06638406956F19B67F80A3A7276060D4E7F6
Columns 5633-5888	DCB75287BE9A2620A1F594570B269097A51A32548BAA6DD9B429B8AAF992C8C0
Columns 5889-6144	6210A36B63DE9C732339DC1AFA94CAB475574A6D1C4D0C17F148B8AD12816B47
Row 1025	
Columns 4097-4352	E24D7C17BCC46297EDC41AA9B5C9D93689843027C6A78449F8D151E1F42BE98F
Columns 4353-4608	4544BD9E6975DDD4BC9B3EFAD50AFC582CAE269677B130FED2C39D5EBDEE56B8
Columns 4609-4864	6A13BB53C03B0C8A4E0D1697322A1A3055054229A69B6CCB7E1FB0B885B90CD2
Columns 4865-5120	BE5C66B252E5C51D7D9E9E25922566C18F0234F2A330041AEC6A4F2729A2A30B
Columns 5121-5376	1E04A65CF0BA05C62B15FEF9967ECD975EC43C035DE4EE6422237F56834AC746
Columns 5377-5632	4FD0C1AF8A61F56686326F93EF63E2C114D55726A5F74BFD99AE7713DF2DE6CF
Columns 5633-5888	A9CC4B50995A682C6F6F12C80929FF208C72007D6A253FD36DE363E8EBF2B614
Columns 5889-6144	95F6F59DA4CE4BA4D6D4D371A2484F16EFA33CD34F71B81702F0E99C031B089D
Row 1281	
Columns 4097-4352	E16A7B75AB838252D1840EF2935AA1CCA5C8470F98202BABA93EEACE43EE56E1
Columns 4353-4608	B2D767F35B0F34FCE855B53B6B8DB8DD08BCF47684E904FA47965D72107897D1
Columns 4609-4864	3D38403A0D2696A767679C6F9CC37537A93A125CE7041EC4F39AD7452597ED13
Columns 4865-5120	A0CCD841B7CA93DB6F7039B929A820F55A95AA3786C96E0434DA46A084653B1A

Columns 5121-5376	08A907831A27892D0DD5B6C9FCB5229C0C03663794A4E94E3FB22E4068ED0EE8
Columns 5377-5632	53BCBD15AA8DEC3451CEF53541B04056E4DCA0393836E9B6DFCF9B01E901D933
Columns 5633-5888	BD160166307B70BE5618C6E0B4ADEBA46F65C69080D4C3FAADF1AA22911C2C69
Columns 5889-6144	42FB1575074655ABD1EFF5784CBE7FA0B110981C8A0BDF01C650189C2DC9FC74
Row 1537	
Columns 4097-4352	B403563011DDE16F92630CF312B3F7F495E74B3B582DFB9401F509A35BD2528C
Columns 4353-4608	A81600F6437FBD00FCF0E4AD41DE3598434EE3903CD1A17CF618E8E2A47EBC4C
Columns 4609-4864	A1D7816AE33BA46E3A9D5B3CBDACF93D538802ED0FCCEFF193DB9D6B79C7E508
Columns 4865-5120	54B42DDFAA7DE9B5299F4C1B5DA05487562D20349282F7061E3159E4EAB09D03
Columns 5121-5376	E15D45F2D1694FF3FF1AA1FC1E58E3FBD6875B71B982AD57AC96CD3B7BE8ACC6
Columns 5377-5632	90CADDAD41374E4BCA29AAB22CAD61989158C474E0725B4C4C5442D6A12D94D8
Columns 5633-5888	2827752CE49CB9C385AD35C1291109892EF85A7A6C043BD8E3BA4AC3D5146FB7
Columns 5889-6144	87002794AC4020B7D229EAE70E01E72F1772B0DA401ABE2C2D487EF60724DC83
Row 1793	
Columns 4097-4352	413A0F58974C76AB4C17AB24F37CB1055FC1827A1DDB0456CCAA7F9477CA64FC
Columns 4353-4608	904E1D9338D0795C6844F79ED8B26A9D306F66975CE704A925E72EC95509188B
Columns 4609-4864	2B5EC3212ADF35954F1CDA9CB6CCC28E422F23AF81659F6E4AFDD03EFB8AD730
Columns 4865-5120	84D1CCA3B5036F031EEDE0F1121E6F62D232DFB74A0582EB3303D1E98810A6C9
Columns 5121-5376	221F0EFCA2C81259B57F8E6943D0CD36088A64DA7FE2E6E7E0F63EAF873B8A79
Columns 5377-5632	57E9B39245C6173088B024F34ED7B64F8784413FF95E476474FECDAE7BD62E5A
Columns 5633-5888	807A807832F6AC83BC7CA7F754BBC7DE72CCC85425068F50ED52419643561832
Columns 5889-6144	1B9CF54C055FB01B40740A0D469855292AE8A0C58756BDD3C6DABE268551FD5F
Row 2049	
Columns 4097-4352	DD8CE660B7403DC8672EA620E65301B0865A23FE568C173669EE1D7F7A1BD748

Columns 4353-4608	3CCFAC84AB188D906D70525D092C3E2B46C6675C1CF4B30AB346022E43DA20B8
Columns 4609-4864	A01DC1159652EA260B411971B0E3D0393C1E75AB0EA462E1D07D0847EFA9CFBA
Columns 4865-5120	4153E6B4F4687D434414BAA200FA38CE46B28D3B4055C633AAD0ED2FACD6B415
Columns 5121-5376	5234FA7B72F478A193EC14698C611F3CB70BF72C15E0DCE9CC048A526AC1F46A
Columns 5377-5632	969C10820390DF8D90AD0138202A32182398B70405520538D08C1F799FBC0755
Columns 5633-5888	53D8304A8B5213FF88DD1620B1A5125AF1CC9A07F95C61C5C6C625F64FFCDBE6
Columns 5889-6144	ED1E06EC959FF323FD3E8AF3553D90BD529D699B08B873F164F59B1CD522AC0F
Row 2305	
Columns 4097-4352	A5C8A02849509DECECFADD4C89C03A78E1564A548D89DECD90DDBCAC7964E9F0
Columns 4353-4608	545B207877BBAFB5DED6AEAD3967CA72272E128C97B06868FD3BB85996640432
Columns 4609-4864	2995ED49B525D47CE868EFD6FDBB0BB6975DC82C8580D00ABCB9FFC6F532A0CB
Columns 4865-5120	9F0B1EC3BC16C2E7C94F5149D03677AD039452180B24DA434F5BBAA0BCEE64ED
Columns 5121-5376	910009CE6C11178F5BC794754EBA72003E9A53CDA988B33CE2D0A0965DAACA23
Columns 5377-5632	BF8A7AE5330F4813AE7F8E4F25666EAB3F0351BD34ABBFA8874D88D5FC4E9385
Columns 5633-5888	45A0C20F7DFD392872ABDCB19E4F6F097044266B9EA6F0B318A5011D0E51E735
Columns 5889-6144	EE58F5FC44AE859564B64F3D173C58FAE938AFB934CBB97245F7B1A1DDD4C559
Row 2561	
Columns 4097-4352	C7DF1E821B249BE35E6CAB842F3DFCD0141E428141C28BDCF54B0985329F6E2A
Columns 4353-4608	D8C083075232BDEADEA797B6C9E15606A72B8B48502B1C044BA89A8DBC54EB6E
Columns 4609-4864	718EF66E726EA72E631B9B22E193F012F3FB2D112468B0DB89F0C3C8A143E9B1
Columns 4865-5120	7D6BE8EA6A522A10F46EC5A56E3F572586884547536AFFAD0C82A42D88AAA64B
Columns 5121-5376	0B740E17EEF10A800DE1916C291C1535845114313E908D313B58018EB77DED61
Columns 5377-5632	9A5F7429731308EFAB68D1725D8F9501234F9035869415A62262095D77A9613A

Columns 5633-5888	9BDCBC26ABDE4672BE5F130E1089BE8BF5CA0ED3FCD9F28B75CC07E9822AA2EF
Columns 5889-6144	6AC735D6621C86CEA203E9E1FC993207EDC164396C7C8FF227F92979A313914D
Row 2817	
Columns 4097-4352	8E1D4E308C03F66D73D76A715F859BEDBC8D709D4BEFC1558D74B49860A90ABA
Columns 4353-4608	B67C75041BFB3A61BBBB73DE2B3D7BB5CB254F10257495E3185C71C3559D9CD0
Columns 4609-4864	ACB7A163EB1E088624F946909B29B2C7373C5CF4F6B1F3A75DC49B1574B3AAB8
Columns 4865-5120	327C55142CE3D1382EA917A7C6730E01BA6BA43767D53E84FFB7D61D6EAD24AD
Columns 5121-5376	CFAAC26024A1D642C795400B8646533A435A4FE899704FAFAE2BF452BD9AF093
Columns 5377-5632	53759538B5F4A8614F1AB4840CFC1EFD8CAFCB067C991FDF2658ABA23F8B0B93
Columns 5633-5888	6B3A35CDECD26C58B9F1318AF46F13767758FC0F74B7DD050A9B1A1C7F98B930
Columns 5889-6144	4B4C20D040F3A8C746453ECE10C0A1F4F74BDDB1A8FCFE1DE2C19148A5E88F1C
Row 3073	
Columns 4097-4352	A98B4DE68DDB2434893BEF8F2CF8DB584CEE8F0E39D30CD4C87017E7EE6886F8
Columns 4353-4608	23024E83F777D7DF0D7E46A8B5F9B1331D0BC2F79BF5559C3241D5BDC7E7A665
Columns 4609-4864	9E1DD50373C16CC97A5E390921B471EF5B39731CCC2CBDD08876080680F9D974
Columns 4865-5120	9DF22EE3AB758F85FD490012FCFF20B3329A5648D25859036C0586C65F46236C
Columns 5121-5376	B009BA2650ABAFC45653D61D2BFA255DE767D0B25AC7736E8E5200D21EE3E28F
Columns 5377-5632	FD96F63D0A22CD574ED61899ECDEB4BEB333F994AC7791FF89EC600B857D4DDD
Columns 5633-5888	C2773C7DCE36709F70180CFFAE22AD44A4A20211224F8ECFB336A54A681A1F59
Columns 5889-6144	5C00C419C78A79ADA49562EFB784ECE44BAF45C1E75BD84DE7C1C69100F8B93A
Row 3329	
Columns 4097-4352	DAB0C7C65F0D096351BF8A0EE9CEF5F7756A9A47B4EE80420DEFA16B0E74CF18
Columns 4353-4608	0FAB86E762595261852E38F9D797D4F796DA18169AFAC99E8235D4DD6C2BB887
Columns 4609-4864	15D0F65E9ADB2C67A887E5D8EF4E1080AC968F4C0D673CA7A74759A7F1B4E383

Columns 4865-5120	1B5641CE5FADE005EB947BE5E20E7DDAF6372655825B3516F2EC5B36D687895F
Columns 5121-5376	2C0BB35E3C3EDA32C19BFF6F3A2397A8E25C646059359D90A1372FCAEE250A43
Columns 5377-5632	8AABBF162C4499F2FECFA27F8D7582FB607B88D04F4A6100A3D2F8A88A2E5E80
Columns 5633-5888	D9C26C2A023943BC62F3C18658A0F5C64130BFF0D74BBB85EBFFFE197C94C6EC
Columns 5889-6144	0AED385393F69FA9F7E69DDC061B85E4E77D0BE2013061E94A0DB8AC2995096F
Row 3585	
Columns 4097-4352	775369B59AA940DA96B47429C339536B51ECC59C60BAD762FA275A6A8F90885A
Columns 4353-4608	922A84AE2B06B4003C0A7BE22FB211365376C3FBFC03EB0DEA264F6769B57EE2
Columns 4609-4864	E518ED3DD8553DC8815E57F23DADC1A3E99030AA02A3529604EE4BD66D770F8E
Columns 4865-5120	8AB3C94077F85772647897A76CFE4EC56FCAA7A28968065CC73BDD88ADA4D60C
Columns 5121-5376	9430F05CFEF8ACBBA73038463A9AD3BDE5BA4E94FDA81C6C51AB3C69201906E1
Columns 5377-5632	2613EFCF235670383ED865C6161C8A8958DC09289EA03658376277BE6E4E62AA
Columns 5633-5888	3C90B273B9870A069FE0F5164AA8F837B9905EEE7D3AEB794BA2F4CAA4F1EB01
Columns 5889-6144	01C2973BD37D564B7D21243A206BD8A7B435428BA8DD3DB7045541BCCE000F5F
Row 3841	
Columns 4097-4352	CEA89305914BEB1BE84B59A4A18CC1AEB5CC96326ADC69F3B4957198C60BB6E7
Columns 4353-4608	DB38C42E2947EFC39D2BBFA07C18C320A22C7B9C6CBFB72E6909BDC131B2E15E
Columns 4609-4864	ABECA69DD1395554C852ED7EE6817A6152B39B42F6D7D56B781D1803B8307C79
Columns 4865-5120	386FFC16B79E309255E7D5933870D116DE3828C68348493D8E288C8A3FBF741F
Columns 5121-5376	0936252D32CDEC49ACFE91F2BA885044E0A9ADFEA526F53641F97B86668C5972
Columns 5377-5632	F9D8560A97AFA4282DBCC4250B75A871276434FFA80959F04D3400D81937617D
Columns 5633-5888	799C3EDF3F1345908B306D8372A740E96707761FCCA9B861402134AE9488387F
Columns 5889-6144	F2DA86FE2BAA7E675DFDED45499AF1B40AE292B1DE6B7A7D4799C3B88177704D

4.5   Code Rate =4/5, Information Block Size = 1024, *M* = 128

The first 1024 columns of **G** form a 1024×1024 identity matrix and the remaining 256 columns of **G** form a block matrix composed of 32 rows and 8 columns of circulant matrices, each of size 32×32. The first row of each circulant is given in hexadecimal format in Table R-8 according to its location in **G**. Subsequent rows of each circulant can be computed by applying the corresponding number of right circular shifts to the first row.

Table R-8. First Rows of Circulants in Generator Matrix, r=4/5, k=1024	
Row 1	
Columns 1025-1056	678ECB51
Columns 1057-1088	FE821D5C
Columns 1089-1120	FA5F424B
Columns 1121-1152	F55927AA
Columns 1153-1184	3E826913
Columns 1185-1216	32E04B0C
Columns 1217-1248	4F88862B
Columns 1249-1280	803432EF
Row 33	
Columns 1025-1056	42B27625
Columns 1057-1088	9F8DA1E1
Columns 1089-1120	F8472D1B
Columns 1121-1152	D943D394
Columns 1153-1184	29261575
Columns 1185-1216	BA434C68
Columns 1217-1248	18EF349A
Columns 1249-1280	27CA1CC4
Row 65	
Columns 1025-1056	EC900397
Columns 1057-1088	64A4A063
Columns 1089-1120	9BCEC4A6
Columns 1121-1152	D05BA70F
Columns 1153-1184	E7155BE1
Columns 1185-1216	7FF09CC1
Columns 1217-1248	6E2E2059
Columns 1249-1280	7F1567E5
Row 97	
Columns 1025-1056	5616101C
Columns 1057-1088	EA060E2B
Columns 1089-1120	B673068B
Columns 1121-1152	923BDF8B
Columns 1153-1184	B9B9343D
Columns 1185-1216	049C63A8

Columns 1217-1248	333E9CFE
Columns 1249-1280	809B362D
Row 129	
Columns 1025-1056	9D41634C
Columns 1057-1088	404E17DA
Columns 1089-1120	3B4161F2
Columns 1121-1152	5235992E
Columns 1153-1184	EA4B4B8B
Columns 1185-1216	4690BCE1
Columns 1217-1248	F9DA36A1
Columns 1249-1280	16439BB1
Row 161	
Columns 1025-1056	5D7254B5
Columns 1057-1088	15B4978B
Columns 1089-1120	00D05224
Columns 1121-1152	107BD904
Columns 1153-1184	C85D7E58
Columns 1185-1216	0451F1A5
Columns 1217-1248	EE9D1897
Columns 1249-1280	913DA6F9
Row 193	
Columns 1025-1056	42819F61
Columns 1057-1088	343773CA
Columns 1089-1120	11A6492A
Columns 1121-1152	4832F43F
Columns 1153-1184	849C11ED
Columns 1185-1216	F0FE864F
Columns 1217-1248	CC270400
Columns 1249-1280	9726D66E
Row 225	
Columns 1025-1056	89EE2A44
Columns 1057-1088	685C1F67
Columns 1089-1120	1DF6E416
Columns 1121-1152	507BF2EF
Columns 1153-1184	8759C2FB
Columns 1185-1216	52162ABF
Columns 1217-1248	2B61D3FB
Columns 1249-1280	988708C4
Row 257	
Columns 1025-1056	4A8FEA09
Columns 1057-1088	53452354
Columns 1089-1120	A33E2E73
Columns 1121-1152	271E8211
Columns 1153-1184	16DF62E5

Columns 1185-1216	03DF81F4
Columns 1217-1248	8848BD0F
Columns 1249-1280	F95DF357
Row 289	
Columns 1025-1056	9BE0A7B3
Columns 1057-1088	617256EB
Columns 1089-1120	9A4D0BB4
Columns 1121-1152	FE3A3A19
Columns 1153-1184	FAA63D9E
Columns 1185-1216	65328918
Columns 1217-1248	D699BA35
Columns 1249-1280	4CDE6FE0
Row 321	
Columns 1025-1056	848B1FE5
Columns 1057-1088	0AB58A6F
Columns 1089-1120	341707F1
Columns 1121-1152	EF36474B
Columns 1153-1184	F623A7A5
Columns 1185-1216	A35EC9BA
Columns 1217-1248	24909B6E
Columns 1249-1280	64A7A898
Row 353	
Columns 1025-1056	BDDF3BAE
Columns 1057-1088	7202FA26
Columns 1089-1120	86F90C57
Columns 1121-1152	A0399F20
Columns 1153-1184	972B9A31
Columns 1185-1216	87B245AE
Columns 1217-1248	E0C5A338
Columns 1249-1280	4959AAD9
Row 385	
Columns 1025-1056	CF726C27
Columns 1057-1088	7B38429A
Columns 1089-1120	BA37C244
Columns 1121-1152	EE7717DB
Columns 1153-1184	E45C99CA
Columns 1185-1216	7E3E013B
Columns 1217-1248	7B800CA4
Columns 1249-1280	6527F2E7
Row 417	
Columns 1025-1056	75C63782
Columns 1057-1088	1CC40137
Columns 1089-1120	51E69F16
Columns 1121-1152	414B155F

Columns 1153-1184	DF1964DE
Columns 1185-1216	F13C71F7
Columns 1217-1248	6E9E8044
Columns 1249-1280	6C5CEC86
Row 449	
Columns 1025-1056	6F2A6DF8
Columns 1057-1088	9FF2BF82
Columns 1089-1120	D3625355
Columns 1121-1152	24466981
Columns 1153-1184	D5F14AC1
Columns 1185-1216	E1C24AEA
Columns 1217-1248	A8850D83
Columns 1249-1280	7A3C5120
Row 481	
Columns 1025-1056	BAABADC3
Columns 1057-1088	1ECF066D
Columns 1089-1120	76538348
Columns 1121-1152	FC5D4D54
Columns 1153-1184	43AD46CF
Columns 1185-1216	3342012C
Columns 1217-1248	63EBE2DC
Columns 1249-1280	D832EF8E
Row 513	
Columns 1025-1056	E6EC82F1
Columns 1057-1088	4AAFE782
Columns 1089-1120	14D89E38
Columns 1121-1152	23C83402
Columns 1153-1184	8B48D6BF
Columns 1185-1216	C823B89A
Columns 1217-1248	68A35626
Columns 1249-1280	E89FE121
Row 545	
Columns 1025-1056	4BBAA331
Columns 1057-1088	20EC16C9
Columns 1089-1120	6ADABE06
Columns 1121-1152	D803DA6D
Columns 1153-1184	FCC89D41
Columns 1185-1216	E57B10E8
Columns 1217-1248	CC3FF014
Columns 1249-1280	4DB74206
Row 577	
Columns 1025-1056	503FD586
Columns 1057-1088	52F68B91
Columns 1089-1120	97D69DF3

Columns 1121-1152	129C764E
Columns 1153-1184	8B2143F7
Columns 1185-1216	A36EF3BA
Columns 1217-1248	7C27896C
Columns 1249-1280	560F67B5
Row 609	
Columns 1025-1056	D70390E6
Columns 1057-1088	98B337EA
Columns 1089-1120	89568363
Columns 1121-1152	2A1681DF
Columns 1153-1184	4B4E928C
Columns 1185-1216	41EC3D9C
Columns 1217-1248	DFD92EB2
Columns 1249-1280	A5D5C85C
Row 641	
Columns 1025-1056	2A5088BD
Columns 1057-1088	76CB6810
Columns 1089-1120	CB693D21
Columns 1121-1152	C0E9EFD5
Columns 1153-1184	F992506E
Columns 1185-1216	299CE082
Columns 1217-1248	901155A6
Columns 1249-1280	0B93AA16
Row 673	
Columns 1025-1056	18FEFECE
Columns 1057-1088	B0063536
Columns 1089-1120	95487089
Columns 1121-1152	4BB31BB9
Columns 1153-1184	66F3FD97
Columns 1185-1216	E32B58A0
Columns 1217-1248	2A39427A
Columns 1249-1280	5CD8DE9F
Row 705	
Columns 1025-1056	1A8F8616
Columns 1057-1088	C5F7D2B2
Columns 1089-1120	5AD2BC4E
Columns 1121-1152	BF1E86DB
Columns 1153-1184	ACF7BFFA
Columns 1185-1216	F3589597
Columns 1217-1248	A777654C
Columns 1249-1280	12DD1364
Row 737	
Columns 1025-1056	FFC03A59
Columns 1057-1088	DC450527

Columns 1089-1120	33B4C871
Columns 1121-1152	BAA2EA33
Columns 1153-1184	93A751A6
Columns 1185-1216	F9D72E4D
Columns 1217-1248	69B50C7F
Columns 1249-1280	F74151F9
Row 769	
Columns 1025-1056	7BE8519D
Columns 1057-1088	AF6FFAFA
Columns 1089-1120	268DBA73
Columns 1121-1152	A356128C
Columns 1153-1184	0418BE2C
Columns 1185-1216	1A43465A
Columns 1217-1248	60C6DF65
Columns 1249-1280	0E2438A0
Row 801	
Columns 1025-1056	EC25DC05
Columns 1057-1088	66AEE4A8
Columns 1089-1120	A72A030A
Columns 1121-1152	B11FB610
Columns 1153-1184	DD74DAF7
Columns 1185-1216	62F6D565
Columns 1217-1248	554EAEB7
Columns 1249-1280	15F7AE6C
Row 833	
Columns 1025-1056	5147F90A
Columns 1057-1088	FF0EEC01
Columns 1089-1120	12A9966C
Columns 1121-1152	871705B1
Columns 1153-1184	E935FF30
Columns 1185-1216	46E32957
Columns 1217-1248	546D69FC
Columns 1249-1280	B8A1BD06
Row 865	
Columns 1025-1056	6A80EA6F
Columns 1057-1088	71A29506
Columns 1089-1120	EF78AACF
Columns 1121-1152	8D52B5ED
Columns 1153-1184	9F0A4966
Columns 1185-1216	61B3B68E
Columns 1217-1248	4B17AF96
Columns 1249-1280	5B282C2E
Row 897	
Columns 1025-1056	75582272

Columns 1057-1088	16E54299
Columns 1089-1120	7D070B9C
Columns 1121-1152	AB130157
Columns 1153-1184	76C619D2
Columns 1185-1216	5500E2D5
Columns 1217-1248	1F980459
Columns 1249-1280	5D9C7F83
Row 929	
Columns 1025-1056	6A0DDA1D
Columns 1057-1088	F6E8B610
Columns 1089-1120	25D0E0A1
Columns 1121-1152	242749E0
Columns 1153-1184	FEDA4A06
Columns 1185-1216	072D69D6
Columns 1217-1248	03C7DA79
Columns 1249-1280	51AA3355
Row 961	
Columns 1025-1056	6E9FEFF0
Columns 1057-1088	0797CBF1
Columns 1089-1120	E936C824
Columns 1121-1152	C9C1EAF5
Columns 1153-1184	D4607E46
Columns 1185-1216	88ED7B0E
Columns 1217-1248	92E160AD
Columns 1249-1280	731140AD
Row 993	
Columns 1025-1056	32FEFCAF
Columns 1057-1088	70863B75
Columns 1089-1120	3846F110
Columns 1121-1152	C4E23DFF
Columns 1153-1184	79D3F753
Columns 1185-1216	064648FA
Columns 1217-1248	830452F5
Columns 1249-1280	B9ED8445

4.6   Code Rate =4/5, Information Block Size = 4096, $M = 512$

The first 4096 columns of **G** form a 4096 $\times$ 4096 identity matrix and the remaining 1024 columns of **G** form a block matrix composed of 32 rows and 8 columns of circulant matrices, each of size 128 $\times$ 128. The first row of each circulant is given in hexadecimal format in Table R-9 according to its location in **G**. Subsequent rows of each circulant can be computed by applying the corresponding number of right circular shifts to the first row.

Table R-9.	First Rows of Circulants in Generator Matrix, r=4/5, k=4096
Row 1	
Columns 4097-4224	473BC533A12C3596F642673D0DBF1142
Columns 4225-4352	079A3868E1A6F556F0DF3DCA4493AE54
Columns 4353-4480	AE4C50F12AEF6EEDEA9BB30605F4A24C
Columns 4481-4608	B0B2B4B9035331ABF53DE4752E7EDABF
Columns 4609-4736	E7E08EF3E22EE7EFE645E9E59507A206
Columns 4737-4864	52E4A2C06270B2D1A418134BC0D58678
Columns 4865-4992	0A84E53303F4092DB47056AD3C0847AD
Columns 4993-5120	2DEF73813B17101E79A3A58A7E91C4E2
Row 129	
Columns 4097-4224	667AA815610234DBA0FFA951CABB8BA7
Columns 4225-4352	A3271642E4BCDD24F8D89BD783317ABB
Columns 4353-4480	CC64FA95F06AE45C7E38935D78BF5F80
Columns 4481-4608	510CE9ABC6156F008B317C79E0122B09
Columns 4609-4736	3CB09E20016A5F93E207C144E889F3B9
Columns 4737-4864	AE6185E4345C5971E03AD499EF850D33
Columns 4865-4992	FA8B392CE78B5712290CB2F518F3E0CC
Columns 4993-5120	429C39F0915EB60CA0545B6AB2967149
Row 257	
Columns 4097-4224	FE9FF6C26898CB926F9BCD129AA52083
Columns 4225-4352	3FC159DB58B64D39CB27847434F177E2
Columns 4353-4480	E040D71365D96A1D54FD20051D3A50E7
Columns 4481-4608	E8AC736B6D2BB5468FBF68DDF5789C2F
Columns 4609-4736	4954E4153CFF0F52F8F8F5B243A03E2B
Columns 4737-4864	99A1DDD23204D103E323158E0FEE7673
Columns 4865-4992	43C2A07046BA1B4307BA6CEC7D740CFE
Columns 4993-5120	CB4E113F94C6CAA4652EFD867B43D199
Row 385	
Columns 4097-4224	081E779BF01F34C97337A3ABC8698644
Columns 4225-4352	9C9E794155E27547283C1AB2706A388D
Columns 4353-4480	FB9DFD194731EC2AE99EA6B641B309A2
Columns 4481-4608	258D45A1BBEAFFC787E61289A54A2473
Columns 4609-4736	FDF3E96C7679E979911C4BE65A333250
Columns 4737-4864	178259F846AA95577C2EC448EE709423
Columns 4865-4992	A61BE7CCED0342965CA234AF02914916
Columns 4993-5120	E045B3C585714F272D40C8085AE5E8F4
Row 513	
Columns 4097-4224	7FB352B26E544BDC18D76B323C3CE1BB
Columns 4225-4352	8421967EE08A6F719B675F06F13FF05B
Columns 4353-4480	672C29DC5B80E18E2F4C42D0F6D5D6D4
Columns 4481-4608	7DE072F73A8015862A275B2CEA2FFC1C

Columns 4609-4736	284B87ABA22362D98952442BBDFBF4A3
Columns 4737-4864	2B798BCD5D8C0B02BBE5DE4A96569F99
Columns 4865-4992	409E72F4138595F8B3C14074BD8E33E0
Columns 4993-5120	3B07838358BBAE631C8258D6B07D2E1C
Row 641	
Columns 4097-4224	403149A1C88E4D4893FE719B2638B7FF
Columns 4225-4352	9886F3E90FC018699F3B39183F2219DC
Columns 4353-4480	F5B0D3AA451225867913FF8FF979BBE0
Columns 4481-4608	795DFCBCC98210C028FD21380EBDDABF
Columns 4609-4736	0BBE0D91FA504DC4DC8848AEA001577F
Columns 4737-4864	51653E755F6CB4F75ACE347EC899304D
Columns 4865-4992	1D0EE239D8A6C2E2EA13D4CFB3394FCA
Columns 4993-5120	BF707E3ACD882B91FDDD44A7EA0D1F3D
Row 769	
Columns 4097-4224	14EB386A5A4524983682993353F8D76E
Columns 4225-4352	F9850534D2FB4F19F787897435C5EB0F
Columns 4353-4480	B680840F8D34A0995BA0A94E309A9194
Columns 4481-4608	6C66CAA0567BFFD609B6484BCD477702
Columns 4609-4736	B62A4053A6916719693D50608EC1D717
Columns 4737-4864	23C38E6F64963EE836ADC6BBF39F4CD1
Columns 4865-4992	A40947C16AEAD43F621457BDB766A157
Columns 4993-5120	DD6118ACF503356D0B3479828C296016
Row 897	
Columns 4097-4224	AAB1061EC9FA6BA21E81D7E22D3A7ED2
Columns 4225-4352	F902B6C336258F5B6B54628AC96116DE
Columns 4353-4480	5968E3167BB1E221714B0F4B3B9D7E0A
Columns 4481-4608	F12374361559D0F0E0C7FCC959B1A9D8
Columns 4609-4736	C103B779B3A769AA8D955160E4B9F9B7
Columns 4737-4864	231B28E0B7490C8EB883F29AF6CC4F12
Columns 4865-4992	A7D1FA32F82AAF128FBC6AC53532AB89
Columns 4993-5120	17AC06392CDAC681817D2F5475016296
Row 1025	
Columns 4097-4224	434D8612F27169A49ED244393B87DB5E
Columns 4225-4352	B66D806A5A9ADF46D83C7DCFDB4B72CA
Columns 4353-4480	A78E0C64307885C6E67C870BD21EC431
Columns 4481-4608	11B79B0BB0B977D9792535C16AA7D982
Columns 4609-4736	B597FD60982B8C42D019390EFA14B3D5
Columns 4737-4864	C57FF5CFA1C438AC576782A5B48B78AA
Columns 4865-4992	AE278E95DA048F720B7DB5FB6488287B
Columns 4993-5120	893C7E7E8DCB6E5ED5DB819D8901B32C
Row 1153	
Columns 4097-4224	B7BA8906FC3AEADE22254872ECA99117
Columns 4225-4352	74F39404FA2779F4C55D649E5A6AA628
Columns 4353-4480	4A1F8910EBF76F2F4E3EF686266CEBB8

Columns 4481-4608	8363A57CF1377C68419BEFE6C848FEDA
Columns 4609-4736	8F141154BFA88D31446EF367ED965F98
Columns 4737-4864	1242B3F840426E98010B84A957090390
Columns 4865-4992	9CE9E0B619E61C4A481F1DD44360BCAC
Columns 4993-5120	0938AE511B2B47A42F5F59FBF547D991
Row 1281	
Columns 4097-4224	85B68FFC07A32A495D9A708FAECD2C41
Columns 4225-4352	69CFDFFD21D6B2CF3F91CF5820823B83
Columns 4353-4480	7D62406050908C82C21CF32B862166F2
Columns 4481-4608	82AF2DF8E6CADB5D043FBF863ACE6599
Columns 4609-4736	700097EE5FDDD825468C544985C983CE
Columns 4737-4864	69EE0178288A8E1A12009EBF2E4382DE
Columns 4865-4992	2B8D59DE631991AE1B67C70786B43BE2
Columns 4993-5120	860FC3354C9FE4253EBF307D1C643E22
Row 1409	
Columns 4097-4224	905330D76B16340120BB399A08061CBE
Columns 4225-4352	9D5765CE993D7092A8150DE46D6CA810
Columns 4353-4480	E03534D4DA2B66A0BF2AEF3B833E18DF
Columns 4481-4608	6C1C0D9EAB1E26FD2481F6BB6AB674C6
Columns 4609-4736	D98BD8D3FC0E0557352CF52EEA654A92
Columns 4737-4864	0DF8D4B0FD41AD3EE547119C2446F840
Columns 4865-4992	4C1F458D1E2F4B70D9023F0DFC06EFE9
Columns 4993-5120	24349C5D9DE2B048DC74D3E888043526
Row 1537	
Columns 4097-4224	E864E5EE002EB3B4C31A8D3B3E22D2C6
Columns 4225-4352	B3C4136542237F8E3C75AA228AB1B2F5
Columns 4353-4480	43DF20DF407EAC80CAF22FDDADD586C9
Columns 4481-4608	9414219FF80742652531AC5CC0E52866
Columns 4609-4736	1A68E6BC5CA7FCA386396D0F56A2E7A3
Columns 4737-4864	D9EC25B8DEA08EDB6A9E6CFFEC7B15C1
Columns 4865-4992	CD48176480B2E0FED349142BE9888043
Columns 4993-5120	9A70BAD89B53A4461301DF6C1763EB67
Row 1665	
Columns 4097-4224	5C9B0F852875D4B06EFA7FF418710592
Columns 4225-4352	6F7C0712083341F6A97F398A275243DC
Columns 4353-4480	3D046D9B0B0B6AB3FEB99F72A70BAF35
Columns 4481-4608	50F7B484C2530BEF63537B68EBDCF01C
Columns 4609-4736	672E8B1DD956431036302F8557CBB4E0
Columns 4737-4864	C9CAD206AB0AD88C655E0F52C70AEEA1
Columns 4865-4992	FF7EC97F9439C9D4CD71487F10065DE0
Columns 4993-5120	532339617D706AEFA50A23B90B57978C
Row 1793	
Columns 4097-4224	B7E0C9A5F3EF66B9ABA49150144FCBEF
Columns 4225-4352	2C9E63DC18BE8ADDA0FD7E7E8F7FC5FE

Columns 4353-4480	5C55C60E14C3D7AC4D00D9F6C827E1EC
Columns 4481-4608	4E40D57E1740089DB1248707D195C038
Columns 4609-4736	4500AD976DD321E6133113D244711330
Columns 4737-4864	0260379D0A20D10A899019157631007D
Columns 4865-4992	4DF741A808694A9956E493B4668B67FD
Columns 4993-5120	F89442CABAA2262C398171D62E938504
Row 1921	
Columns 4097-4224	CCF8A4E13D655D5591DC40D2C6607CEF
Columns 4225-4352	353E539A020B0C608F843A855BA9B7AE
Columns 4353-4480	CD31CCCB9388FECDEBEE1CCF42943E77
Columns 4481-4608	9CA39E64D8AC9E23F15A0CB4C73ACB80
Columns 4609-4736	3BF0F0DA9576923D95089979081ACA77
Columns 4737-4864	359B090725B62278F00D0222CAD4C0FF
Columns 4865-4992	4ABA29056D55C5AAD990AA10A9A1A9B2
Columns 4993-5120	27A09750826682C157BD7CD2178FDC96
Row 2049	
Columns 4097-4224	AFC3076AF8AFB82B45FE8F2628F489F1
Columns 4225-4352	2CFA95663A96A30FB3831F756D9E666A
Columns 4353-4480	011EE24F6C5EE283C3EE09A1D5FAF1B9
Columns 4481-4608	7B49CB7B94EDEB207221A9436E1FFDF5
Columns 4609-4736	5D36302EEBDD74AD27158F4D9DF0FA6E
Columns 4737-4864	497015959B333E79885FBE22B9B72707
Columns 4865-4992	E330EEAD520B31BAD1A5DC55EF54193A
Columns 4993-5120	D6C112F89677E27A26F1DC62E08DF49C
Row 2177	
Columns 4097-4224	2DF5B0291E619A18D802502086037C46
Columns 4225-4352	730D20AE9364A6AD090B789D8AA6C6CC
Columns 4353-4480	EA476A585503E90BCAAD943DD30E1BCC
Columns 4481-4608	1D5C236ED01E9E5C8E94E96FA7252ABF
Columns 4609-4736	3EB2DB84FB4837EA5153CA825D11F86B
Columns 4737-4864	574E63C92DD0E75AD8DDFF2B37CC97C9
Columns 4865-4992	5E83299E60C44293BF0824C62EB7980C
Columns 4993-5120	5678B852002834EB2D630EAC536FFB78
Row 2305	
Columns 4097-4224	9A41F048C1C68187734BFB916EC3BFAF
Columns 4225-4352	4B23BDA1162B30CB7AEA9F03BEBCF597
Columns 4353-4480	C65460BFAF9C8913608F9888E738F4A1
Columns 4481-4608	017AEE470FCA60F9711E9BE5EB98E7C9
Columns 4609-4736	4EE8869A59EDF8BDD52C5B5388B35249
Columns 4737-4864	8EB0D25B439273CA6545E82E69D8677C
Columns 4865-4992	5B23991A53041EA4B276405C156A9DE5
Columns 4993-5120	A90889BC74530A5F87CCF024E591E18F
Row 2433	
Columns 4097-4224	22735E1E720A8B3C29A80F3696D6F157

Columns 4225-4352	F68ED2F2389D5D2CDC59D706495D815F
Columns 4353-4480	D0EE25B73218D5717572387BFA03A7C2
Columns 4481-4608	A0717B27763FE223BDA3EB0DAFBEF276
Columns 4609-4736	9DBB8235D11298BEE28B39772ED91A35
Columns 4737-4864	92DE6FED2F6766E01DBA188153DEA205
Columns 4865-4992	48930E9A21873E62863CA15D6DB058D9
Columns 4993-5120	61A29088FE3983D0E1699EF0AAFA5FD1
Row 2561	
Columns 4097-4224	A730056900988893822528373E627D6FB
Columns 4225-4352	7862DE8A3D0F1A9387963F38A82E4703
Columns 4353-4480	78BAB9252EE72FB0C798C7C684B6E789
Columns 4481-4608	B7480D9712BFA72D122F243674AD887F
Columns 4609-4736	EC1851EB80A37133B68F0F709DB32E05
Columns 4737-4864	A809CB3638414FD6E156821BDAC256E0
Columns 4865-4992	B75342B6CFF7ED428521AB48A4C55D66
Columns 4993-5120	C9AB047D79A484289C820E8FADD87251
Row 2689	
Columns 4097-4224	A69C02525644F41D03197EF26112D606
Columns 4225-4352	3DF71AD0410035AE1AE7B0AB310B6967
Columns 4353-4480	C4F82E31B4D9B491EF8E4992FDBA61B0
Columns 4481-4608	B6B367CDE8DE0CAE22875F641288E733
Columns 4609-4736	5C142A9C7C2E259BD38D66117E9E861C
Columns 4737-4864	D27BF85E8EEE1920B57D0C62B512E2D6
Columns 4865-4992	68B4500340B7B92EDD05A44D36AC1651
Columns 4993-5120	4E77C4ABE92FE174B5D9F79070685288
Row 2817	
Columns 4097-4224	A22B2A6C9A75D7A6EEA5A0DF8A4950E2
Columns 4225-4352	24C4830123FAE1EB6EB0AC9C2D8C508E
Columns 4353-4480	1BB99D6785EBCCDD9CD6A50CF53CCA00
Columns 4481-4608	0624E36FD0817F2E198340098E60DFBF
Columns 4609-4736	A4EB92DD48085594C6F755C563F35020
Columns 4737-4864	04BDFF9A2309C6E673CE08D94A45BBC4
Columns 4865-4992	8B8EC43906C28869AD4E41FB147A7696
Columns 4993-5120	8AB66E9B68FA00BEF90D3E078D0C6FFC
Row 2945	
Columns 4097-4224	89A79E9CF0BE90A3D86305B6491A49B9
Columns 4225-4352	222A27A68236765AB32D41B1E0616C83
Columns 4353-4480	99931668E57EB6378C8F4ED1C27BEDD3
Columns 4481-4608	35166846D0C673B9A8D2184C1901433A
Columns 4609-4736	4D768A5E0109B5CBC198869334D81C43
Columns 4737-4864	2C6A48CC47FD21F9608107FF80FE37AA
Columns 4865-4992	4DD3A7395630BE4B64F776C5FC6B2C31
Columns 4993-5120	4DC16B1E2B2A7F6E0E9FDAE3B60F8FAA

Row 3073	
Columns 4097-4224	CFA794F49FA5A0D88BB31D8FCA7EA8BB
Columns 4225-4352	A7AE7EE8A68580E3E922F9E13359B284
Columns 4353-4480	91F72AE8F2D6BF7830A1F83B3CDBD463
Columns 4481-4608	CE95C0EC1F609370D7E791C870229C1E
Columns 4609-4736	71EF3FDF60E2878478934DB285DEC9DC
Columns 4737-4864	0E95C103008B6BCDD2DAF85CAE732210
Columns 4865-4992	8326EE83C1FBA56FDD15B2DDB31FE7F2
Columns 4993-5120	3BA0BB43F83C67BDA1F6AEE46AEF4E62
Row 3201	
Columns 4097-4224	565083780CA89ACAA70CCFB4A888AE35
Columns 4225-4352	1210FAD0EC9602CC8C96B0A86D3996A3
Columns 4353-4480	C0B07FDDA73454C25295F72BD5004E80
Columns 4481-4608	ACCF973FC30261C990525AA0CBA006BD
Columns 4609-4736	9F079F09A405F7F87AD98429096F2A7E
Columns 4737-4864	EB8C9B13B84C06E42843A47689A9C528
Columns 4865-4992	DAAA1A175F598DCFDBAD426CA43AD479
Columns 4993-5120	1BA78326E75F38EB6ED09A45303A6425
Row 3329	
Columns 4097-4224	48F42033B7B9A05149DC839C90291E98
Columns 4225-4352	9B2CEBE50A7C2C264FC6E7D674063589
Columns 4353-4480	F5B6DEAEBF72106BA9E6676564C17134
Columns 4481-4608	6D5954558D23519150AAF88D7008E634
Columns 4609-4736	1FA962FBAB864A5F867C9D6CF4E087AA
Columns 4737-4864	5D7AA674BA4B1D8CD7AE9186F1D3B23B
Columns 4865-4992	047F112791EE97B63FB7B58FF3B94E95
Columns 4993-5120	93BE39A6365C66B877AD316965A72F5B
Row 3457	
Columns 4097-4224	1B58F88E49C00DC6B35855BFF228A088
Columns 4225-4352	5C8ED47B61EEC66B5004FB6E65CBECF3
Columns 4353-4480	77789998FE80925E0237F570E04C5F5B
Columns 4481-4608	ED677661EB7FC3825AB5D5D968C0808C
Columns 4609-4736	2BDB828B19593F41671B8D0D41DF136C
Columns 4737-4864	CB47553C9B3F0EA016CC1554C35E6A7D
Columns 4865-4992	97587FEA91D2098E126EA73CC78658A6
Columns 4993-5120	ADE19711208186CA95C7417A15690C45
Row 3585	
Columns 4097-4224	BE9C169D889339D9654C976A85CFD9F7
Columns 4225-4352	47C4148E3B4712DAA3BAD1AD71873D3A
Columns 4353-4480	1CD630C342C5EBB9183ADE9BEF294E8E
Columns 4481-4608	7014C077A5F96F75BE566C866964D01C
Columns 4609-4736	E72AC43A35AD216672EBB3259B77F9BB
Columns 4737-4864	18DA8B09194FA1F0E876A080C9D6A39F
Columns 4865-4992	809B168A3D88E8E93D995CE5232C2DC2

Columns 4993-5120	C7CFA44A363F628A668D46C398CAF96F
Row 3713	
Columns 4097-4224	D57DBB24AE27ACA1716F8EA1B8AA1086
Columns 4225-4352	7B7796F4A86F1FD54C7576AD01C68953
Columns 4353-4480	E75BE799024482368F069658F7AAAFB0
Columns 4481-4608	975F3AF795E78D255871C71B4F4B77F6
Columns 4609-4736	65CD9C359BB2A82D5353E007166BDD41
Columns 4737-4864	2C5447314DB027B10B130071AD0398D1
Columns 4865-4992	DE19BC7A6BBCF6A0FF021AABF12920A5
Columns 4993-5120	58BAED484AF89E29D4DBC170CEF1D369
Row 3841	
Columns 4097-4224	4C330B2D11E15B5CB3815E09605338A6
Columns 4225-4352	75E3D1A3541E0E284F6556D68D3C8A9E
Columns 4353-4480	E5BB3B297DB62CD2907F09996967A0F4
Columns 4481-4608	FF33AEEE2C8A4A52FCCF5C39D355C39C
Columns 4609-4736	5FE5F09ABA6BCCE02A73401E5F87EAC2
Columns 4737-4864	D75702F4F57670DFA70B1C002F523EEA
Columns 4865-4992	6CE1CE2E05D420CB867EC0166B8E53A9
Columns 4993-5120	9DF9801A1C33058DD116A0AE7278BBB9
Row 3969	
Columns 4097-4224	4CF0B0C792DD8FDB3ECEAE6F2B7F663D
Columns 4225-4352	106A1C296E47C14C1498B045D57DEFB5
Columns 4353-4480	968F6D8C790263C353CF307EF90C1F21
Columns 4481-4608	66E6B632F6614E58267EF096C37718A3
Columns 4609-4736	3D46E5D10E993EB6DF81518F885EDA1B
Columns 4737-4864	6FF518FD48BB8E9DDBED4AC0F4F5EB89
Columns 4865-4992	BCC64D21A65DB379ABE2E4DC21F109FF
Columns 4993-5120	2EC0CE7B5D40973D13ECF713B01C6F10

5.0   Synchronization

Current receiver/demodulator designs can perform either coherent or non-coherent detection and demodulation. To accomplish symbol/bit synchronization, the transmitted synchronization sequence must contain sufficient transitions to ensure symbol/bit acquisition and tracking. At the same time, the symbol/bit synchronizer loop bandwidth should be designed for optimal phase-noise filtering and symbol tracking performance. Since the use of LDPC code does not guarantee sufficient bit/symbol transitions to acquire or maintain synchronization, it is highly recommended that a pseudo-randomizer be used after LDPC encoding in accordance with Section 6.0.

The ASM, depicted in Figure R-8 and Table R-10, is not randomized. Randomization ensures that coded symbols are spectrally near-white, thus allowing each ASM to provide synchronization for a set of randomized codeblocks in a codeblock frame.
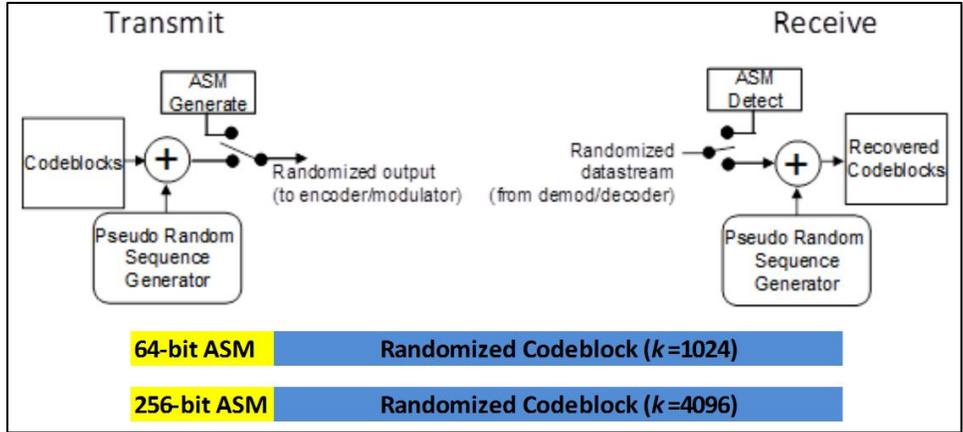
Figure R-8.   ASM/Codeblock Structure

Table R-10. ASM Definition	
64-bit Sequence	Definition (hex)
A	FCB88938D8D76A4F
$\bar{A}$	034776C7272895B0

At the transmitter side, the ASM is prepended to each set of randomized codeblocks as the synchronization header. At the receiver side, the ASM is detected and located in the received data stream. Refer to Figure R-8.

Length of the ASM is determined by the information block length (k). For k=1024 the ASM length will be 64 bits. For k=4096 the ASM will be 256 bits. The ASM is constructed with 64-bit sequences. The 64-bit ASM requires one 64-bit sequence; the 256-bit ASM sequence requires four 64-bit sequences. Let A be one 64-bit sequence and $\bar{A}$ is the inverse of A. The structure of the 64-bit sequence is A; the structure of the 256-bit ASM is $AA\bar{A}A$. Table R-10 defines the two 64-bit sequences.

The resulting randomized codeblock plus ASM is transmitted leftmost bits first, making the first series of bits to be transmitted as FCB8……… or 1111110010111000……… This is true for both 64-bit and 256-bit ASMs.

With the addition of the ASM prepended to the codeblock, over-the-air channel rate is no longer the inverse of the code rate r. Table R-11 shows the exact bandwidth expansion factor for each choice of code rate and information block length.

| Table R-11. Bandwidth Expansion Factor			
Information Block Length, k	Bandwidth Expansion Factor		
	Rate 1/2	Rate 2/3	Rate 4/5
1024	33/16	25/16	21/16
4096	33/16	25/16	21/16

As an example, assume an incoming baseband data rate of 5 megabits per second (Mbps). If an information block length of 1024 bits and rate 1/2 are chosen, the new over-the-air channel rate will be:

$$(5 \text{ Mbps})*(33/16) = 10.3125 \text{ Mbps}$$

6.0   Randomization

At the transmitter/encoder, a set of codeblock(s) in a codeblock frame shall be randomized by exclusive-ORing the first bit of the first codeblock with the first bit of the pseudo-random sequence until the end of the codeblock. The pseudo-randomizer resets to the initial state of "all ones" at the start of each codeblock frame for each ASM period.

The pseudo-random sequence is generated using the following polynomial: $h(x) = x8 + x7 + x5 + x3 + 1$. It has a maximal length of 255 bits with the first 40 bits of the pseudo-random sequence from the generator as 1111 1111 0100 1000 0000 1110 1100 0000 1001 1010….. The sequence begins at the first bit of a first codeblock in a codeblock frame and repeats after 255 bits, continuing repeatedly until the end of the last codeblock in a codeblock frame. The leftmost bit of the pseudo-random sequence is the first bit to be exclusive-ORed with the first bit of the codeblock. **Error! Reference source not found.** illustrates the pseudo-randomizer block iagram.
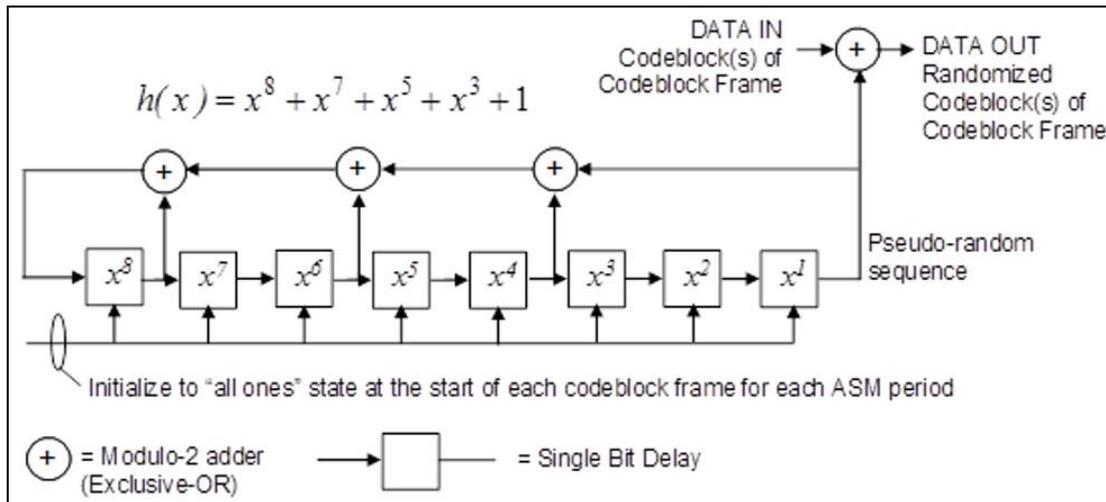
At the receiver, each original codeblock(s) of a codeblock frame is reconstructed using the same pseudo-random sequence. After locating the ASM, the pseudo-random sequence is exclusive-ORed with the received data bits immediately following the ASM. The pseudo-randomizer resets to the initial state of "all ones" at the start of each received codeblock frame for each ASM period.

7.0   Performance

The trade that must be made when choosing the information block size and coding rate is one between required coding gain, bandwidth expansion, and fading channel characteristics. Detection performance of the code is tightly coupled to the type of SOQPSK-TG/FQPSK-B/FQPSK-JR demodulator used. Plots of simulated performance for all six combinations of information block size and code rates with two different types of SOQPSK-TG/FQPSK-

B/FQPSK-JR demodulators on are shown in Figure R-9 and Figure R-10. Other demodulator configurations are considered in Perrins.[2]
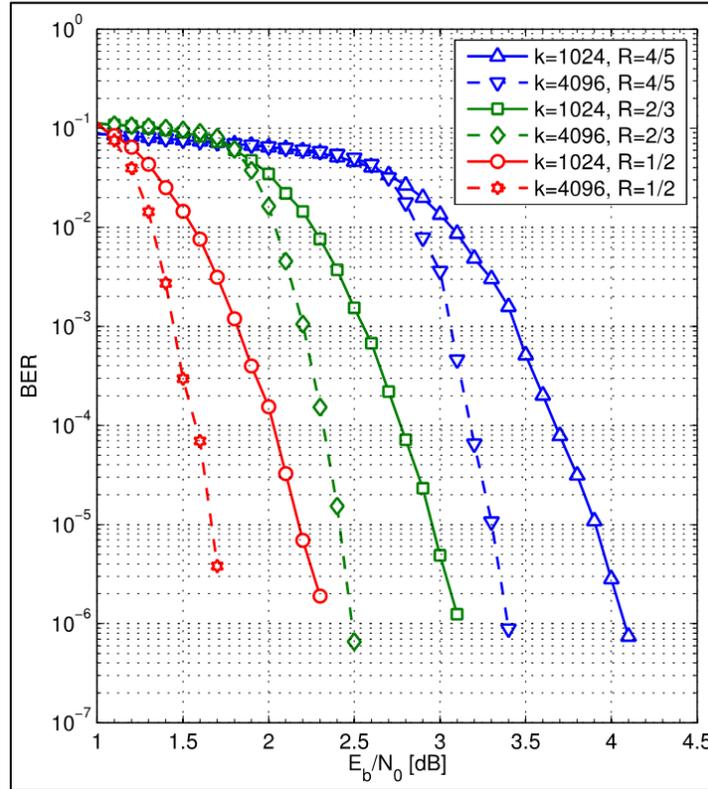

Figure R-9.   LDPC Detection Performance with 4-state Trellis Demodulator

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[2] E. Perrins, "FEC Systems for Aeronautical Telemetry", IEEE Transactions on Aerospace and Electronic Systems, vol. 49, no. 4, pp. 2340-2352, October 2013.
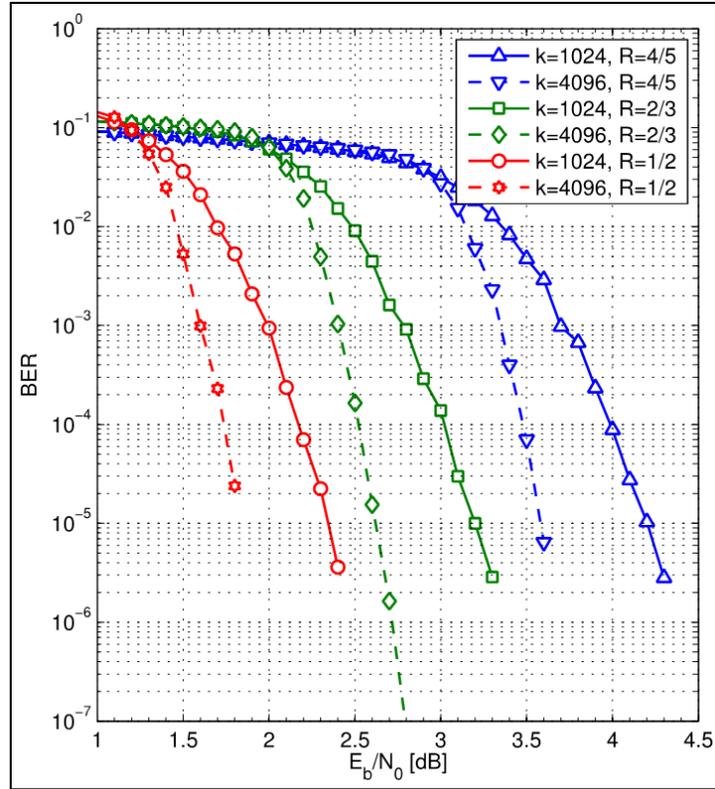
Figure R-10.   LDPC Detection Performance with Symbol-by-Symbol Demodulator

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E. Perrins, "FEC Systems for Aeronautical Telemetry", IEEE Transactions on Aerospace and Electronic Systems, vol. 49, no. 4, pp. 2340-2352, October 2013.

*** END OF APPENDIX R ***

*** END OF APPENDIX R ***