

(12) **United States Patent**
Fan et al.

(10) **Patent No.:** **US 11,750,223 B2**
(45) **Date of Patent:** **Sep. 5, 2023**

(54) **LOW-POWER BLOCK CODE FORWARD ERROR CORRECTION DECODER**

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(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 20 days.

(21) Appl. No.: **16/367,538**

(22) Filed: **Mar. 28, 2019**

(65) **Prior Publication Data**

US 2019/0305800 A1 Oct. 3, 2019

Related U.S. Application Data

(60) Provisional application No. 62/648,965, filed on Mar. 28, 2018.

(51) **Int. Cl.**
H03M 13/15 (2006.01)
H03M 13/00 (2006.01)
H03M 13/11 (2006.01)

(52) **U.S. Cl.**
CPC ... **H03M 13/1545** (2013.01); **H03M 13/1105** (2013.01); **H03M 13/157** (2013.01); **H03M 13/6561** (2013.01)

(58) **Field of Classification Search**
CPC H03M 13/1545; H03M 13/1515–1555; H03M 13/1105; H03M 13/157; H03M 13/6561; H03M 13/1525; H03M 13/1585; H03M 13/159

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

5,901,158 A * 5/1999 Weng G06F 11/1008 341/94
5,936,972 A * 8/1999 Meidan H04L 1/20 370/333

(Continued)

OTHER PUBLICATIONS

Hsie-Chia Chang, Chien-Ching Lin and Chen-Yi Lee, "A low-power Reed-Solomon decoder for STM-16 optical communications," Proceedings. IEEE Asia-Pacific Conference on ASIC., Taipei, Taiwan, 2002.*

(Continued)

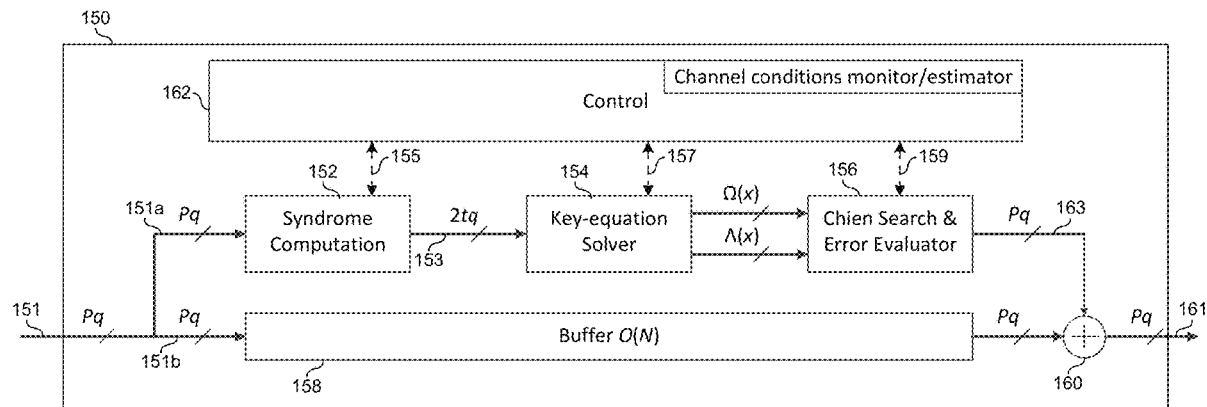
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(57) **ABSTRACT**

A system comprises a forward error correction decoder comprising syndrome computation circuitry, key-equation solver circuitry, and search and evaluator circuitry. The syndrome computation circuitry may comprise a plurality of syndrome compute units connected in parallel. The syndrome computation circuitry may be dynamically configurable to vary a quantity of the syndrome compute units used for processing of a codeword based on conditions of a channel over which the codeword was received. The syndrome computation circuitry may be operable to use a first quantity of the syndrome compute units for processing of a first codeword received over the channel when the channel is characterized by a first bit error rate and a second quantity of the syndrome compute units for processing of a second codeword received over the channel when the channel is characterized by a second bit error rate.

18 Claims, 8 Drawing Sheets



(56)

References Cited

U.S. PATENT DOCUMENTS

6,061,768 A * 5/2000 Kuo G06F 13/387
709/250
6,470,471 B1 * 10/2002 Noguchi H03M 13/1515
714/782
8,301,987 B2 * 10/2012 Dror H03M 13/153
714/785
8,327,242 B1 * 12/2012 Anholt H03M 13/1525
714/785
9,166,623 B1 * 10/2015 Bates H03M 13/45
2003/0101406 A1 * 5/2003 Song H03M 13/6561
714/774
2003/0229842 A1 * 12/2003 Lee H03M 13/151
714/785
2004/0177312 A1 * 9/2004 Xin H03M 13/15
714/782
2014/0108883 A1 * 4/2014 Tehrani H03M 13/1108
714/E11.031
2014/0136931 A1 * 5/2014 Nakamura H03M 13/05
714/785
2018/0034481 A1 * 2/2018 Garani H03M 13/617
2018/0157551 A1 * 6/2018 Ryabinin G06F 1/04

OTHER PUBLICATIONS

B. R. Surabhi, S. N. Nampoothiri and P. Jayakrishnan, "Design of area efficient and low power reed solomon decoder,"2016 Interna-

tional Conference on Control, Instrumentation, Communication and Computational Technologies (ICCICCT), Kumaracoil, 2016.*

J. Kessels, "VLSI programming of a low-power asynchronous Reed-Solomon decoder for the DCC player," Proceedings Second Working Conference on Asynchronous Design Methodologies, London, UK, 1995.*

R. Huynh, N. Ge and H. Yang, "A low power error detection in the syndrome calculator block for reed-solomon codes: RS(204,188)," in Tsinghua Science and Technology, vol. 14, No. 4, pp. 474-477, Aug. 2009.*

X. Zhang, I. Dror and S. Alterman, "Low-power partial-parallel Chien search architecture with polynomial degree reduction," 2016 IEEE International Symposium on Circuits and Systems (ISCAS), Montreal, QC, 2016.*

Ying Cui, Xiao Peng, Yu Jin, Peilin Liu, S. Kimura and S. Goto, "High-parallel LDPC decoder with power gating design," 2011 9th IEEE International Conference on ASIC, 2011.*

Sarwate, Dilip V. et al., High-Speed Architectures for Reed-Solomon Decoders, IEEE Transactions on Very Large Scale integration (VLSI) Systems, vol. 9, No. 5, Oct. 2001, pp. 641-655.

Park, J.I. et al.,Area-efficient truncated Berlekamp-Massey Architecture for Reed-Solomon Decoder, Electronics Letters Feb. 17, 2011 vol. 47 No 4.

Reed, I.S. et al., VLSI Design of Inverse-Free Berlekamp-Massey Algorithm, IEE Pproceedings-E, vol. 138, No. 5, Sep. 1991 pp. 295-298.

* cited by examiner

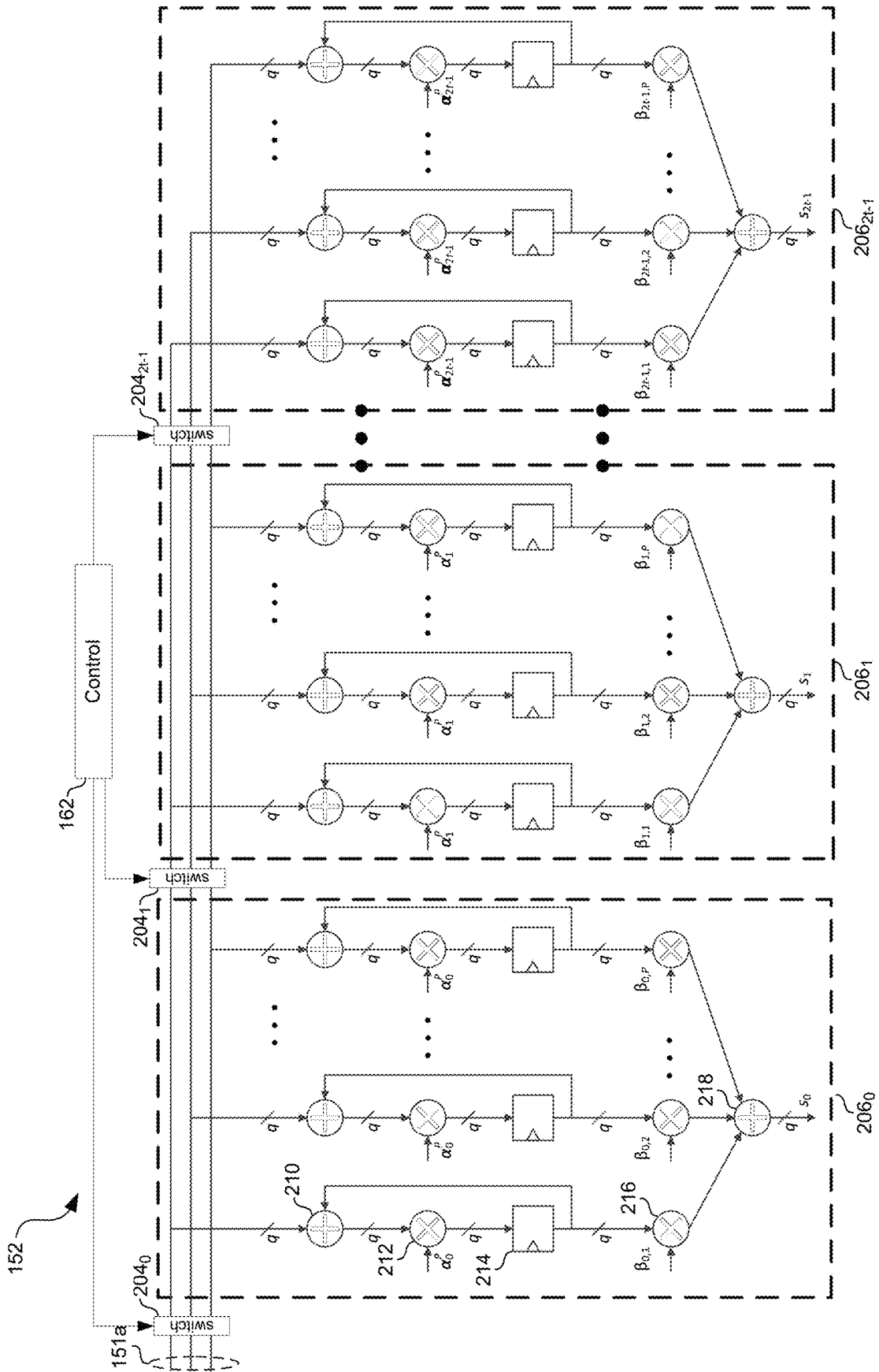


FIG. 2

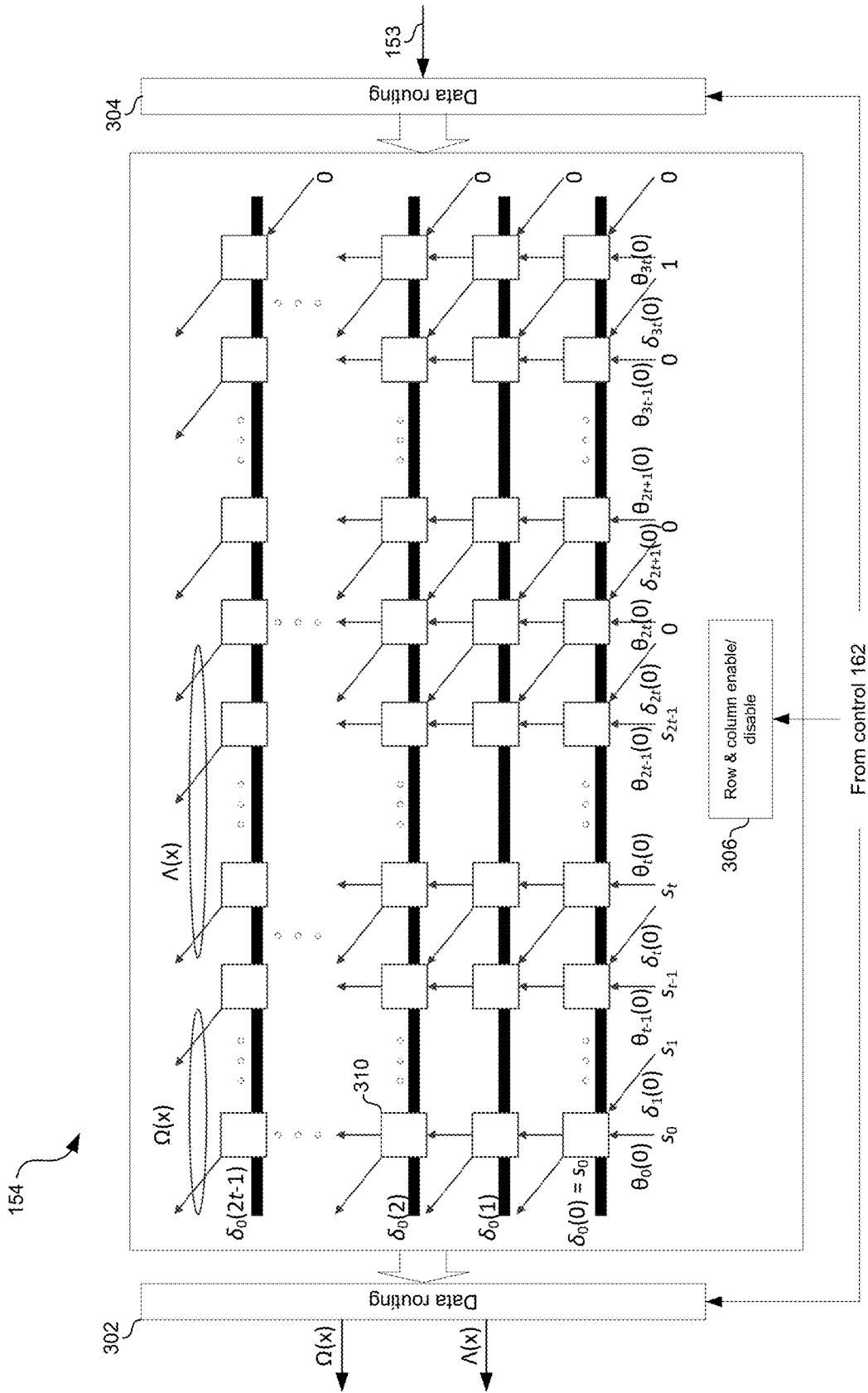


FIG. 3A

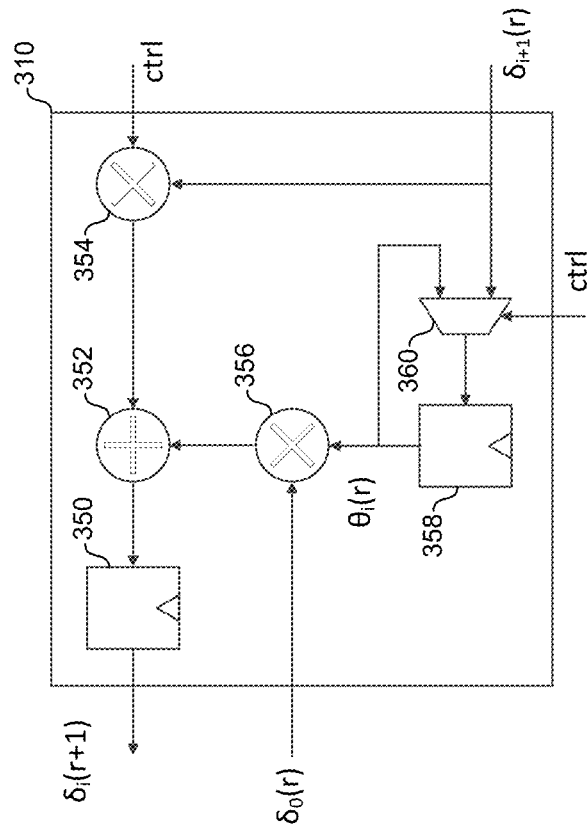


FIG. 3C

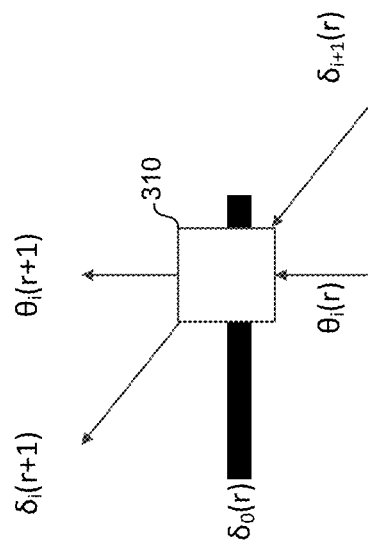
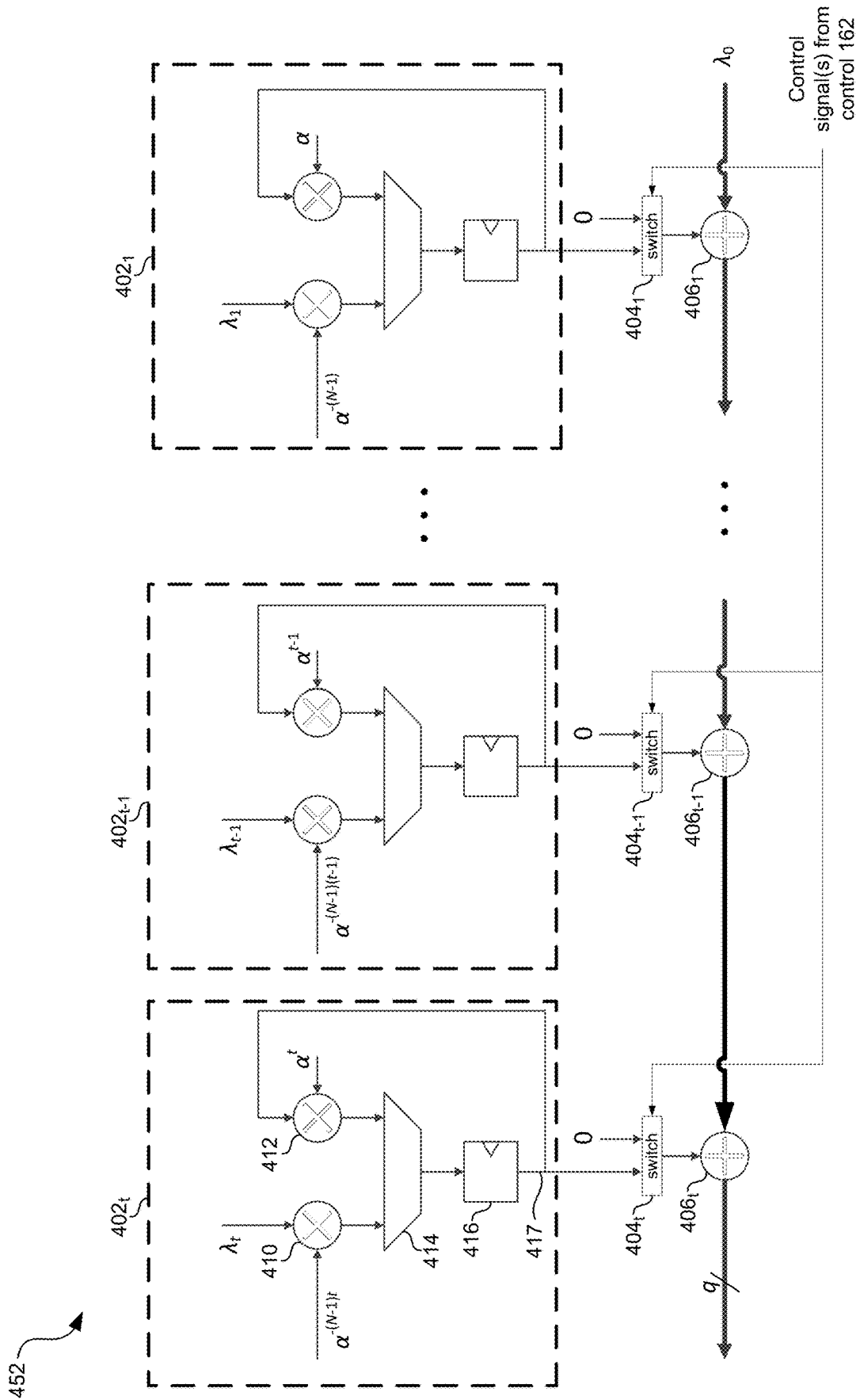


FIG. 3B



- To achieve target BLER
 - $t = 10$ for BER $\sim 1e-5$
 - $t = 7$ for BER $\sim 1e-6$
 - $t = 5$ for BER $\sim 1e-7$

BLER@BER =
 $7.5e-5$ & $t = 15$

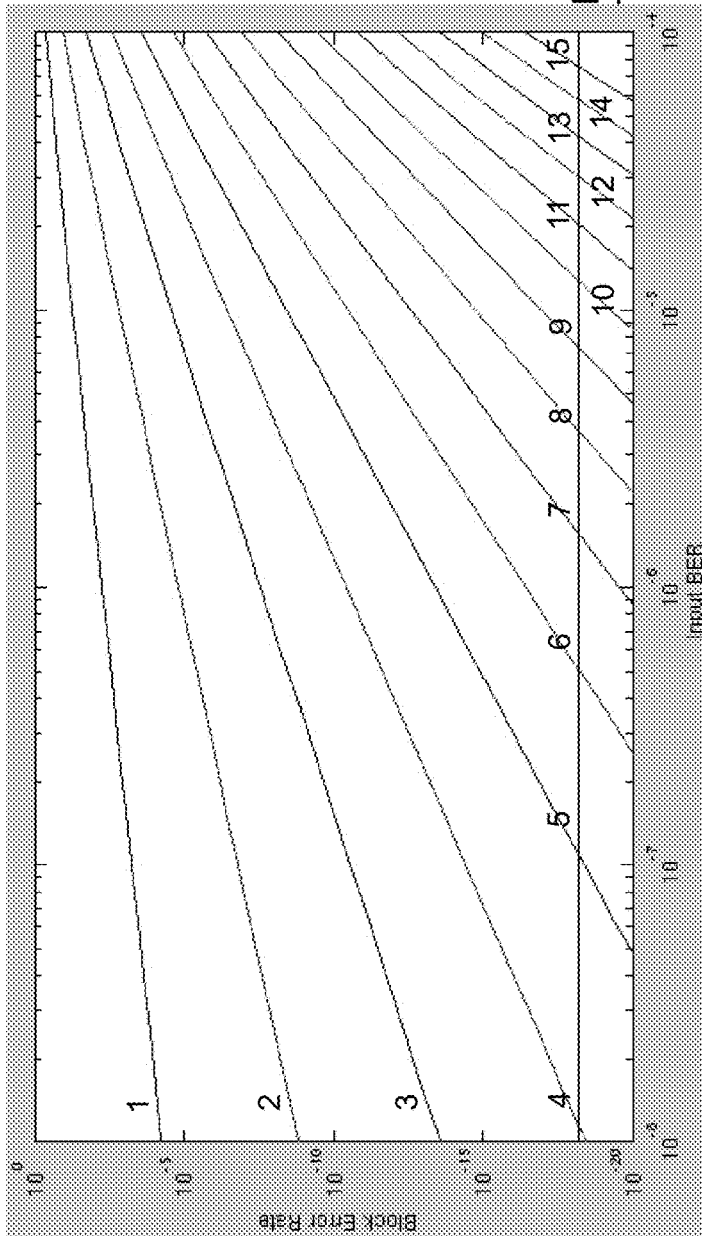


FIG. 5

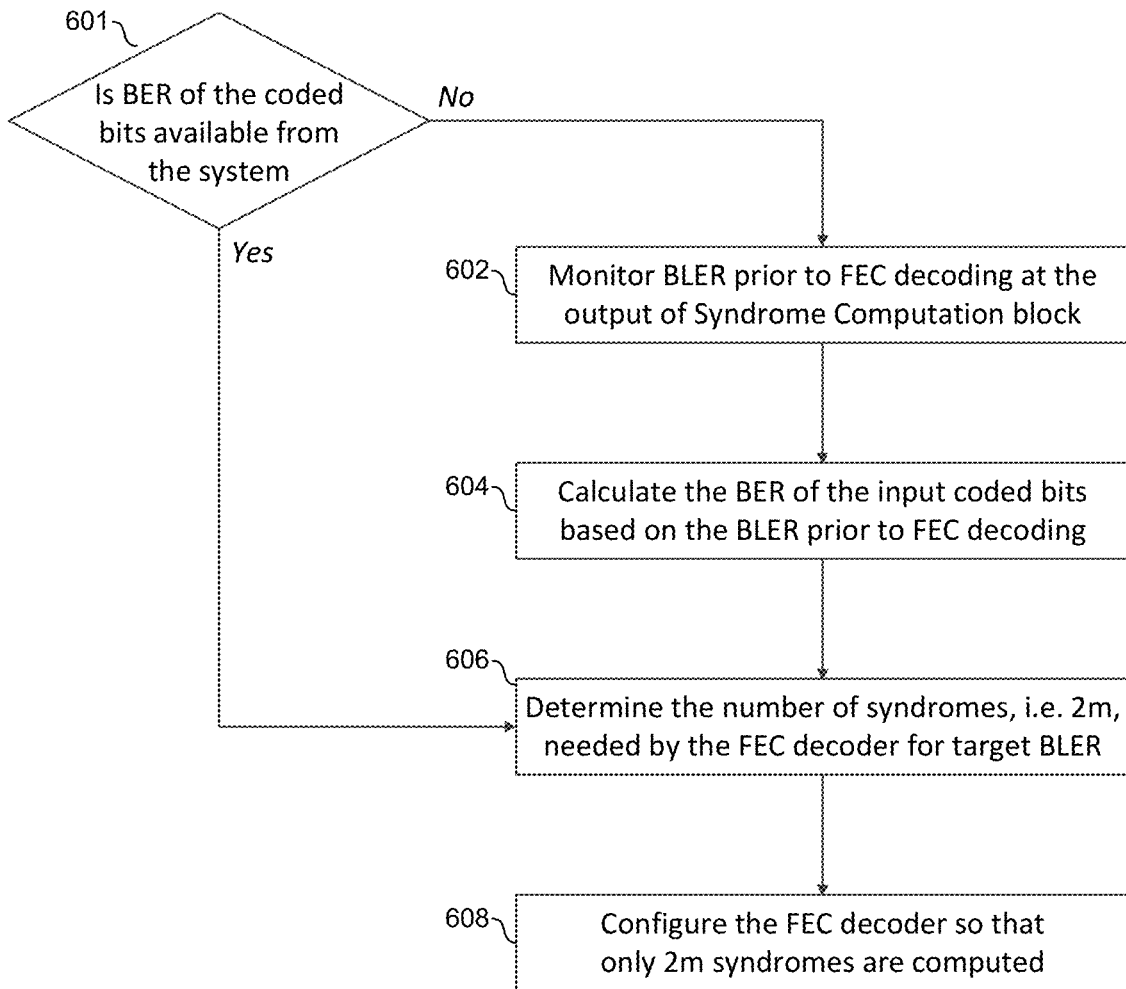


FIG. 6

LOW-POWER BLOCK CODE FORWARD ERROR CORRECTION DECODER

PRIORITY CLAIM

This application claims priority to U.S. Provisional application 62/648,965 titled “Low-Power Block Code Forward Error Correction Decoder” filed on Mar. 28, 2018, the entirety of which is hereby incorporated herein by reference.

BACKGROUND

Conventional systems and methods for forward error correction decoding can be overly power hungry, slow, expensive, and inflexible. Further limitations and disadvantages of conventional and traditional approaches will become apparent to one of skill in the art, through comparison of such systems with some aspects of the present invention as set forth in the remainder of the present application with reference to the drawings.

BRIEF SUMMARY

Provided are systems and methods for low-power block code forward error correction decoder, substantially as shown in and/or described in connection with at least one of the figures, as set forth more completely in the claims.

Advantages, aspects and novel features of the present disclosure, as well as details of various implementations thereof, will be more fully understood from the following description and drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A shows an example structure of a forward error correction (FEC) codeword which a low-power FEC decoder in accordance with an example implementation of this disclosure is operable to decode.

FIG. 1B shows the architecture of a low-power FEC decoder in accordance with an example implementation of this disclosure.

FIG. 2 shows an example implementation of the syndrome computation circuitry of FIG. 1B.

FIG. 3A shows an example implementation of key-equation solver circuitry of FIG. 1B.

FIG. 3B shows a zoomed-in view of one of the processing elements of the key-equation solver of FIG. 3A.

FIG. 3C shows an example implementation of the processing elements of the key-equation solver of FIG. 3A.

FIG. 4A shows an example implementation of the Chien search and error evaluator circuitry of FIG. 1B.

FIG. 4B shows an example implementation of the polynomial evaluation circuitry of FIG. 4A.

FIG. 5 illustrates that the number of syndromes needed to achieve a target block error rate (BLER) decreases when the bit error rate (BER) on the coded bits decreases.

FIG. 6 is a flowchart showing an example process for adapting a low-power FEC decoder in accordance with an example implementation of this disclosure.

DETAILED DESCRIPTION OF THE INVENTION

FIG. 1A shows an example structure of a forward error correction (FEC) codeword which a low-power FEC decoder in accordance with an example implementation of this disclosure is operable to decode. Each codeword com-

prises N (an integer) symbols, C_0 - C_{N-1} , each of which has q (an integer) bits. K of the symbols are message symbols and N-K (N minus K) of the symbols are parity symbols. The shown codeword structure supports correction of up to $t=(N-K)/2$ symbols. Example block codes include Reed-Solomon codes, BCH codes, Reed-Muller codes, etc.

FIG. 1B shows the architecture of a low-power FEC decoder 150 in accordance with an example implementation of this disclosure. The received codewords 151 are fed into two parallel paths 151a and 151b, each of the 151a and 151b being Pq (P “times” q) bits wide (P an integer). The first path comprises syndrome computation circuitry 152, key-equation solver circuitry 154, and Chien Search and Error Evaluator circuitry 156. The second path comprises a buffer 158 that introduces a delay equal to the delay of the first path. The outputs of the two paths are then combined in combiner 160 to result in an error corrected signal 161.

The control circuitry 162 is operable to manage operations of the other circuits of the FEC decoder 150 as described below in this disclosure. The control circuitry 162 may, for example, comprise logic that operates according to software and/or firmware loaded into memory of the control circuitry 162.

An example implementation of the syndrome computation circuit 152 is described below with reference to FIG. 2. An example implementation of the key-equation solver circuitry 154 is described below with reference to FIGS. 3A-3C. An example implementation of the Chien search and error evaluator 156 is described below with reference to FIGS. 4A and 4B. The buffer 158 may comprise any suitable volatile and/or nonvolatile memory elements.

FIG. 2 shows an example implementation of the syndrome computation circuitry of FIG. 1B. The example syndrome computation circuitry 152 comprises control circuitry 162, switches 204₀-204_{2t-1}, and a plurality of syndrome compute units 206₀-206_{2t-1}.

The control circuitry 162 may be operable to detect channel conditions present on a channel over which the codewords are received, and control the switches based on the detected channel conditions, as further described below. The control circuitry 162 in FIG. 1B is also operable to measure a block error rate at the output of the Syndrome Computation 152, based on which a bit error rate of the coded bits input to the low-power FEC decoder 150 is calculated. Control information is exchanged between the control circuitry 162 and the circuits 152, 154, and 156 via signals 155, 157, and 159.

The switches 204₀-204_{2t-1} may comprise transmission gates or any other suitable circuit operable to connect and disconnect (or enable and disable) a downstream one or more of circuits 206₀-206_{2t-1} from the signal path 151a.

Each of the syndrome compute units 206_T (T between 0 and 2t-1) comprises P processing chains, each comprising an adder 210, a first multiplier 212, a memory element 214, and a second multiplier 216. The outputs of the processing chains are then summed in adder 218 to generate syndromes ST according to equation 1 below.

The syndrome computation circuitry 152 is operable to calculate 2t syndromes S_0 - S_{2t-1} for each codeword, according to the following equation 1:

$$\begin{bmatrix} s_0 \\ s_1 \\ \vdots \\ s_{2t-1} \end{bmatrix} = \begin{bmatrix} \alpha_0^{N-1} & \alpha_0^{N-2} & \dots & 1 \\ \alpha_1^{N-1} & \alpha_1^{N-2} & \dots & 1 \\ \vdots & \vdots & \vdots & \vdots \\ \alpha_{2t-1}^{N-1} & \alpha_{2t-1}^{N-2} & \dots & 1 \end{bmatrix} \begin{bmatrix} c_{N-1} \\ c_{N-2} \\ \vdots \\ c_0 \end{bmatrix}$$

60

65

where $\alpha_0 = \alpha^w$, $\alpha_1 = \alpha^{w+1}$, \dots , $\alpha_{2t-1} = \alpha^{w+2t-1}$ are the powers of a primitive root α , and w is a given integer. If all syndromes are 0, then the codeword is error free, otherwise the codeword has one or more error symbols. The value of t is typically determined at the encoder based on the worst-case channel conditions for which the FEC decoder **150** is expected to reliably decode codewords. Thus, in a conventional FEC decoder, a fixed number of $2t$ syndromes are computed. Power consumption, however, increases with increasing values of t . Thus, when channel conditions are better than the worst-case and the FEC decoder is able to reliably decode codewords with a smaller number of syndromes, computing $2t$ syndromes burns unnecessary power. It is therefore desirable from a power consumption perspective to compute the minimum number of syndromes necessary for the current channel conditions. Because the syndrome computation is independent for each syndrome (that is, each of circuits **206**₀-**206**_{2t-1} can independently compute its respective one of the syndromes), the FEC decoder **150** may use only a subset of circuits **206**₀-**206**_{2t-1} to compute syndromes for any given codeword. That is, for a codeword received over channel conditions which only require computation of $2m$ syndromes (where m is an integer less than or equal to t), control circuitry **162** may open switches **204**_{2m}-**204**_{2t-1} to disconnect or disable the unneeded circuits **206**_{2m}-**206**_{2t-1} such that circuits **206**_{2m}-**206**_{2t-1} do not compute syndromes for that codeword—and thus burn less power.

FIG. 3A shows an overview of key-equation solver circuitry of FIG. 1B. In the example implementation shown, the key-equation solver circuitry **154** is implemented as a systolic array of processing elements **310** (of which only one is called out in FIG. 3A) arranged in $2t$ rows and $3t+1$ columns. The data in the systolic array flows row by row from the bottom to the top. At row r (r between 0 and $2t-1$), $3t+1$ elements of $\delta_i(r+1)$ and $\theta_i(r+1)$ are generated from $\delta_i(r)$, $\theta_i(r)$ and $\delta_0(r)$ at the previous row, where i between 0 and $3t$ is the column index of the array from the left to the right. As a result, at the last row, the systolic array finds out the error locator polynomial $\Lambda(x) = \lambda_t x^t + \lambda_{t-1} x^{t-1} + \dots + \lambda_0$ and the error evaluator polynomial $\Omega(x) = \omega_{t-1} x^{t-1} + \omega_{t-2} x^{t-2} + \dots + \omega_0$ by having $\lambda_i = \delta_{i+1}(2r)$ for i between 0 and t and $\omega_i = \delta_i(2r)$ for i between 0 and $t-1$. The error locator polynomial is used to find the locations of error symbols, and the error evaluator polynomial is used to calculate the value of the error symbol. In an example implementation, the processing elements in the systolic array may be implemented on hardware that is time-shared, thus reducing the amount of hardware needed to realize the key-equation solver circuitry **154**. In addition to the processing elements **310**, the key-equation solver circuitry **154** comprises data routing circuitry **302** and **304**, and row and column enable/disable circuitry **306**.

Which portion of the processing elements **310** in the array are enabled for any particular codeword is controlled by control circuitry **162** via row and column enable/disable circuitry **306**. For a codeword received over a channel requiring computation of m syndromes, $2m$ rows and $3m+1$ columns of the key-equation solver are enabled to generate an error locator polynomial $\Lambda(x)$ of degree m , and an error evaluator polynomial $\Omega(x)$ of degree $m-1$. Thus, where m is less than t , one or more processing elements **310** remain in an inactive or low power state and power consumption of the key-equation solver circuitry **154** is reduced as compared to calculating an error locator polynomial of degree t and an error evaluator polynomial of degree $t-1$.

The data routing circuitry **304** is operable to route syndromes S_0 - S_{2m-1} from bus **153** to inputs of processing elements **310** in columns 0 through $2m-1$ of the array, so that $\delta_i(0) = \theta_i(0) = S_i$ for i between 0 and $2t-1$.

The data routing circuitry **302** is operable to route: (1) signal $\Omega(x)$ from columns 0 through $m-1$ of row $2m$; and (2) $\Lambda(x)$ from columns m through $2m$ of the row $2m$ to the Chien search and evaluator circuitry **156**.

FIG. 3B shows a zoomed-in view of one of the processing elements of the key-equation solver of FIG. 3A with the input and output signals detailed.

FIG. 3C shows an example implementation of the processing elements of the key-equation solver of FIG. 3A.

FIG. 4A shows an example implementation of the Chien search and error evaluator circuitry of FIG. 1B. The Chien search circuitry **450** evaluates the error locator polynomial $\Lambda(x)$ at $x = \alpha^{-i}$ for i between $N-1$ and 0. If $\Lambda(\alpha^{-i}) = 0$, C_i is a symbol with error. The error value is given by $x^{2t}\Omega(x)/\Lambda'(x)$ for $x = \alpha^{-i}$, which is calculated by the error evaluator circuitry **470**. Each polynomial evaluation circuit **452** (of which only 2 are called out in the figure) processes a symbol of q bits each time. To detect and correct Pq bits each time in the low-power FEC decoder, P data paths are instantiated in each of the Chien search circuitry **450** and the error evaluator circuitry **470**.

Now referring to FIG. 4B, each polynomial evaluation circuit **452** comprises processing units **402**₁-**402** _{p} , switches **404**₁-**404** _{p} , and adders **406**₁-**406** _{p} .

Each of the processing units **402**₁-**402** _{p} comprises multipliers **410** and **412**, multiplexer **414**, and memory element **416** for generating a signal **417** which is output to a respective one of switches **404**₁-**404** _{p} .

The switches **404**₁-**404** _{p} are operable to switch the input of a respective one of the adders **406**₁-**406** _{p} between the output of a corresponding one of circuits **402**₁-**402** _{p} , and a digital '0' value. When a digital '0' is bypassed, it is equivalent that the corresponding term $\lambda_r x^r$ is removed from the polynomial $\Lambda(x)$.

The equation for calculating $\Lambda(x)$ can be written as $\lambda_t x^t + \lambda_{t-1} x^{t-1} + \dots + \lambda_1 x + \lambda_0$. Thus, computation for each degree term is independent and a polynomial evaluator architecture such as shown in FIG. 4B can be used. Where m (the number of syndromes) is less than t , the control circuitry **162** may disconnect or disable circuits **402** _{$m+1$} -**402** _{t} via switches **404** _{$m+1$} -**404** _{p} , resulting in reduced power consumption (the circuits **402** _{$m+1$} -**402** _{t} may be placed in a low-power state to further reduce power consumption). Given that the similar polynomial evaluator architecture shown in FIG. 4B can be used in each data path of polynomial evaluation for error evaluator circuitry **470**, where m (the number of syndromes) is less than t , the control circuitry **162** may disconnect or disable the similar circuits **402** _{$m+1$} -**402** _{t} in error evaluator circuitry for reduced power consumption.

FIG. 5 shows the relationship between the block error rate (BLER) of the codeword after the FEC decoding and the bit error rate (BER) of the coded bits input to the decoder when different number of syndromes $2m$ are computed for decoding, for an example Reed-Solomon code with $N=544$, $K=514$ and $q=10$. From the figure, it can be seen that when the BER of coded bits decreases, fewer syndromes need to be computed in the FEC decoder to achieve a same target block error rate (BLER). For example, the worst-case channel in this experiment has a coded BER of $7.5e-5$ and $t=15$ has been designed at the encoder to achieve the target BLER. When the input BER is better than the worst-case for which the FEC is designed, however, m can be set to a value less

than 15 to save power and still achieve the desired BLER (e.g., $m=10$ for $BER \sim 1e-5$, $m=7$ for $BER \sim 1e-6$, and $m=5$ for $BER \sim 1e-7$).

FIG. 6 is a flowchart showing an example process for adapting a low-power FEC decoder in accordance with an example implementation of this disclosure. The process begins with block 601. If the BER of the input coded bits is not available from the system outside the FEC decoder, it is estimated in blocks 602 and 604. If the BER is available from outside the FEC decoder, then the process advances to block 606.

In block 602, the block error rate (BLER) of the codeword prior to the error correction is monitored at the output of the syndrome computation circuitry 152. A codeword is error free if and only if all the syndromes are zero. This may comprise, for example, measuring the BLER over multiple codewords and then taking an average of the measured BLER values.

In block 604, the BER of the input coded bits is calculated (e.g., by control circuitry 162) from the block error rate determined in block 602, based upon the FEC parameters, e.g. N and q .

In block 606, with the BER of the input coded bits provided by the system outside FEC decoder or estimated inside FEC decoder, the value of m required to meet the target BLER is calculated. For example, the control circuitry 162 may calculate the value of m using a lookup table holding the data similar to that plotted in FIG. 5.

In block 608, the FEC decoder 150 is configured based on the value of m calculated in block 606. For example, the control circuitry 162 may: open one or more of the switches 204₀-204_{2t-1} to disconnect or disable one or more of the compute units 206₀-206_{2t-1} from the path 151a, close one or more of the switches 204₀-204_{2t-1} to connect or enable one or more of the compute units 206₀-206_{2t-1} to the path 151a; disable, via circuit 306, one or more rows and columns of processing elements 310 in the key-equation solver circuitry 154; enable, via circuit 306, one or more rows and columns of processing elements 310 in the key-equation solver circuitry 154; configure one or more of the switches 404₁-404_t to connect or enable a respective one or more of the adder 406₁-406_t to an output of a respective one or more of the circuits 402₁-402_t; and/or configure one or more of the switches 404₁-404_t to connect a respective one or more of the adder 406₁-406_t to digital '0' value and disconnect or disable a respective one or more of the processing units 402₁-402_t.

In accordance with an example implementation of this disclosure, a system comprises a forward error correction decoder (e.g., 150) comprising syndrome computation circuitry (e.g., 152), key-equation solver circuitry (e.g., 154), and search and evaluator circuitry (e.g., 156). The syndrome computation circuitry may comprise a plurality of syndrome compute units (e.g., 206₀-206_{2t-1}) connected in parallel. The syndrome computation circuitry may be dynamically configurable to vary a quantity of the syndrome compute units used for processing of a codeword based on conditions of a channel over which the codeword was received. Each of the syndrome compute units may comprise a plurality of adders (e.g., 210 and 218), a plurality of multipliers (e.g., 212 and 216), and a plurality of memory elements (e.g., 214). The syndrome computation circuitry may be operable to use a first quantity of the syndrome compute units (e.g., $2t$) for processing of a first codeword received over the channel when the channel is characterized by a first bit error rate and a second quantity of the syndrome compute units (e.g., $2m$) for processing of a second codeword received over the

channel when the channel is characterized by a second bit error rate, where the first quantity of syndrome compute units is greater than the second quantity of syndrome compute units and the first bit error rate is greater than the second bit error rate. The key-equation solver circuitry may comprise an array of processing elements (e.g., 310). The key-equation solver circuitry may be dynamically configurable to vary a quantity of the processing elements of the key-equation solver circuitry used for processing of a codeword based on conditions of a channel over which the codeword was received. Each of the processing elements of the key-equation solver circuitry may comprise a plurality of multipliers (e.g., 354 and 356), one or more adder (e.g., 352), a plurality of memory elements (e.g., 350 and 358), and one or more multiplexers (e.g., 360). The key-equation solver circuitry may be operable to use a first quantity (e.g., $2t*(3t+1)$) of the processing elements for processing of a first codeword received over the channel when the channel is characterized by a first bit error rate and a second quantity (e.g., $2m*(3m+1)$) of the processing elements for processing of a second codeword received over the channel when the channel is characterized by a second bit error rate, the first quantity of the processing elements of the key-equation solver circuitry may be greater than the second quantity of the processing elements of the key-equation solver circuitry, and the first bit error rate may be greater than the second bit error rate. The search and evaluator circuitry may comprise a plurality of processing units (e.g., 402) connected in parallel. The search and evaluator circuitry may be dynamically configurable to vary a quantity of the processing units of the search and evaluator circuitry used for processing of a codeword based on conditions of a channel over which the codeword was received. Each of the processing units of the search and evaluator circuitry may comprise a plurality of multipliers (e.g., 410 and 412), one or more multiplexer (e.g., 414), and one or more memory element (e.g., 416). The search and evaluator circuitry is operable to use a first quantity (e.g., t) of the processing units for processing of a first codeword received over the channel when the channel is characterized by a first bit error rate and a second quantity of the processing units (e.g., m) for processing of a second codeword received over the channel when the channel is characterized by a second bit error rate, the first quantity of the processing units of the search and evaluator circuitry is greater than the second quantity of the processing units of the search and evaluator circuitry, and the first bit error rate is greater than the second bit error rate.

As utilized herein the terms "circuits" and "circuitry" refer to physical electronic components (i.e. hardware) and any software and/or firmware ("code") which may configure the hardware, be executed by the hardware, and or otherwise be associated with the hardware. As used herein, for example, a particular processor and memory may comprise a first "circuit" when executing a first one or more lines of code and may comprise a second "circuit" when executing a second one or more lines of code. As utilized herein, "and/or" means any one or more of the items in the list joined by "and/or". As an example, "x and/or y" means any element of the three-element set $\{(x), (y), (x, y)\}$. As another example, "x, y, and/or z" means any element of the seven-element set $\{(x), (y), (z), (x, y), (x, z), (y, z), (x, y, z)\}$. As utilized herein, the term "exemplary" means serving as a non-limiting example, instance, or illustration. As utilized herein, the terms "e.g.," and "for example" set off lists of one or more non-limiting examples, instances, or illustrations. As utilized herein, circuitry is "operable" to perform a function whenever the circuitry comprises the necessary

hardware and code (if any is necessary) to perform the function, regardless of whether performance of the function is disabled, or not enabled, by some user-configurable setting.

Other embodiments of the invention may provide a non-transitory computer readable medium and/or storage medium, and/or a non-transitory machine readable medium and/or storage medium, having stored thereon, a machine code and/or a computer program having at least one code section executable by a machine and/or a computer, thereby causing the machine and/or computer to perform the methods described herein.

Accordingly, the present invention may be realized in hardware, software, or a combination of hardware and software. The present invention may be realized in a centralized fashion in at least one computing system, or in a distributed fashion where different elements are spread across several interconnected computing systems. Any kind of computing system or other apparatus adapted for carrying out the methods described herein is suited. A typical combination of hardware and software may be a general-purpose computing system with a program or other code that, when being loaded and executed, controls the computing system such that it carries out the methods described herein. Another typical implementation may comprise an application specific integrated circuit or chip.

The present invention may also be embedded in a computer program product, which comprises all the features enabling the implementation of the methods described herein, and which when loaded in a computer system is able to carry out these methods. Computer program in the present context means any expression, in any language, code or notation, of a set of instructions intended to cause a system having an information processing capability to perform a particular function either directly or after either or both of the following: a) conversion to another language, code or notation; b) reproduction in a different material form.

While the present invention has been described with reference to certain embodiments, it will be understood by those skilled in the art that various changes may be made and equivalents may be substituted without departing from the scope of the present invention. In addition, many modifications may be made to adapt a particular situation or material to the teachings of the present invention without departing from its scope. Therefore, it is intended that the present invention not be limited to the particular embodiment disclosed, but that the present invention will include all embodiments falling within the scope of the appended claims.

What is claimed is:

1. A system comprising:

a forward error correction decoder comprising syndrome computation circuitry, key-equation solver circuitry, and search and evaluator circuitry, wherein:

the syndrome computation circuitry comprises a plurality of syndrome compute units connected in parallel; and the syndrome computation circuitry is dynamically configurable to vary a quantity of the syndrome compute units used for processing of input coded bits based on conditions of a channel over which the input coded bits were received, the syndrome computation circuitry having a block error rate at an output of the syndrome computation circuitry, the block error rate being used to calculate a bit error rate of the input coded bits, the quantity of the syndrome compute units being varied in view of the bit error rate, the quantity of syndrome compute units being decreased in view of a decrease in

the bit error rate, the decrease in quantity of syndrome compute units being performed to achieve a target block error rate.

2. The system of claim 1, wherein each of the syndrome compute units comprises a plurality of adders, a plurality of multipliers, and a plurality of memory elements.

3. The system of claim 1, wherein:

the syndrome computation circuitry is operable to use a first quantity of the syndrome compute units for processing of a first codeword received over the channel when the channel is characterized by a first bit error rate and a second quantity of the syndrome compute units for processing of a second codeword received over the channel when the channel is characterized by a second bit error rate; and

the first quantity of syndrome compute units is greater than the second quantity of syndrome compute units and the first bit error rate is greater than the second bit error rate.

4. The system of claim 1, wherein:

the key-equation solver circuitry comprises an array of processing elements; and

the key-equation solver circuitry is dynamically configurable to vary a quantity of the processing elements of the key-equation solver circuitry used for processing of a codeword based on conditions of a channel over which the codeword was received.

5. The system of claim 4, wherein each of the processing elements of the key-equation solver circuitry comprises a plurality of multipliers, one or more adder, one or more memory elements, and one or more multiplexers.

6. The system of claim 4, wherein:

the key-equation solver circuitry is operable to use a first quantity of the processing elements for processing of a first codeword received over the channel when the channel is characterized by a first bit error rate and a second quantity of the processing elements for processing of a second codeword received over the channel when the channel is characterized by a second bit error rate; and

the first quantity of the processing elements of the key-equation solver circuitry is greater than the second quantity of the processing elements of the key-equation solver circuitry and the first bit error rate is greater than the second bit error rate.

7. The system of claim 1, wherein:

the search and evaluator circuitry comprises a plurality of processing units connected in parallel; and

the search and evaluator circuitry is dynamically configurable to vary a quantity of the processing units of the search and evaluator circuitry used for processing of a codeword based on conditions of a channel over which the codeword was received.

8. The system of claim 7, wherein each of the processing units of the search and evaluator circuitry comprises a plurality of multipliers, one or more multiplexer, and one or more memory element.

9. The system of claim 7, wherein:

the search and evaluator circuitry is operable to use a first quantity of the processing units for processing of a first codeword received over the channel when the channel is characterized by a first bit error rate and a second quantity of the processing units for processing of a second codeword received over the channel when the channel is characterized by a second bit error rate; and the first quantity of the processing units of the search and evaluator circuitry is greater than the second quantity of

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the processing units of the search and evaluator circuitry and the first bit error rate is greater than the second bit error rate.

10. A method comprising:

in a forward error correction decoder comprising syndrome computation circuitry, key-equation solver circuitry, and search and evaluator circuitry, wherein the syndrome computation circuitry comprises a plurality of syndrome compute units connected in parallel:

dynamically determining a quantity of the syndrome compute units to use for decoding input coded bits, wherein the determining is based on conditions of a channel over which the input coded bits were received, the syndrome computation circuitry having a bit block error rate at an output of the syndrome computation circuitry, the block error rate being used to calculate a bit error rate of the input coded bits, the quantity of the syndrome compute units being varied in view of the bit error rate, the quantity of syndrome compute units being decreased in view of a decrease in the bit error rate to achieve a target block error rate; and

decoding the codeword using the determined quantity of syndrome compute units.

11. The method of claim 10, wherein each of the syndrome compute units comprises a plurality of adders, a plurality of multipliers, and a plurality of memory elements.

12. The method of claim 10, wherein:

the codeword is received over the channel when the channel is characterized by a first bit error rate; the decoding uses a first quantity of syndrome compute units;

a second codeword is received over the channel when the channel is characterized by a second bit error rate;

the method comprises dynamically determining to use a second quantity of syndrome compute units for decoding the second codeword;

the first bit error rate is greater than the second bit error rate;

the first quantity of syndrome compute units is greater than the second quantity of syndrome compute units; and

the method comprises decoding the second codeword using the second quantity of syndrome compute units.

13. The method of claim 10, wherein the key-equation solver circuitry comprises an array of processing elements, and the method comprises:

dynamically determining a quantity of the processing elements of the key-equation solver circuitry to use for processing of a codeword, wherein the determining is based on conditions of a channel over which the codeword was received; and

decoding the codeword using the determined quantity of processing elements of the key-equation solver circuitry.

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14. The method of claim 13, wherein each of the processing elements of the key-equation solver circuitry comprises a plurality of multipliers, one or more adder, one or more memory element, and one or more multiplexer.

15. The method of claim 13, wherein:

the codeword is received over the channel when the channel is characterized by a first bit error rate; the decoding uses a first quantity of processing elements of the key-equation solver circuitry;

a second codeword is received over the channel when the channel is characterized by a second bit error rate;

the method comprises dynamically determining to use a second quantity of processing elements of the key-equation solver circuitry for decoding the second codeword;

the first bit error rate is greater than the second bit error rate;

the first quantity of processing elements of the key-equation solver circuitry is greater than the second quantity of processing elements of the key-equation solver circuitry; and

the method comprises decoding the second codeword using the second quantity of processing elements of the key-equation solver circuitry.

16. The method of claim 10, wherein:

the search and evaluator circuitry comprises a plurality of processing units connected in parallel; and

the search and evaluator circuitry is dynamically configurable to vary how many of the processing units are used for processing of a codeword based on conditions of a channel over which the codeword was received.

17. The method of claim 16, wherein each of the processing units of the search and evaluator circuitry comprises a plurality of multipliers, one or more multiplexer, and one or more memory element.

18. The method of claim 16, wherein:

the codeword is received over the channel when the channel is characterized by a first bit error rate;

the decoding uses a first quantity of processing units of the search and evaluator circuitry;

a second codeword is received over the channel when the channel is characterized by a second bit error rate;

the method comprises dynamically determining to use a second quantity of processing units of the search and evaluator circuitry for decoding the second codeword;

the first bit error rate is greater than the second bit error rate;

the first quantity of processing units of the search and evaluator circuitry is greater than the second quantity of processing elements of the search and evaluator solver circuitry; and

the method comprises decoding the second codeword using the second quantity of processing elements of the search and evaluator circuitry.

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