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Dabiri

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- (54) **HIGH SPEED TRANSCEIVER BASED ON EMBEDDED LEECH LATTICE CONSTELLATION**
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- (51) **Int. Cl.**
H04L 27/34 (2006.01)
H04L 7/04 (2006.01)
- (52) **U.S. Cl.**
CPC **H04L 27/3483** (2013.01); **H04L 7/042** (2013.01)

- (58) **Field of Classification Search**
CPC H03M 13/1505; H03M 13/25; H03M 13/251; H03M 13/256; H03M 13/3916; H03M 13/3944; H04L 1/0057; H04L 1/006; H04L 27/3477; H04L 27/3483
See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

- 4,933,956 A * 6/1990 Forney, Jr. 375/341
- 2012/0263454 A1* 10/2012 Koike-Akino et al. 398/25
- * cited by examiner

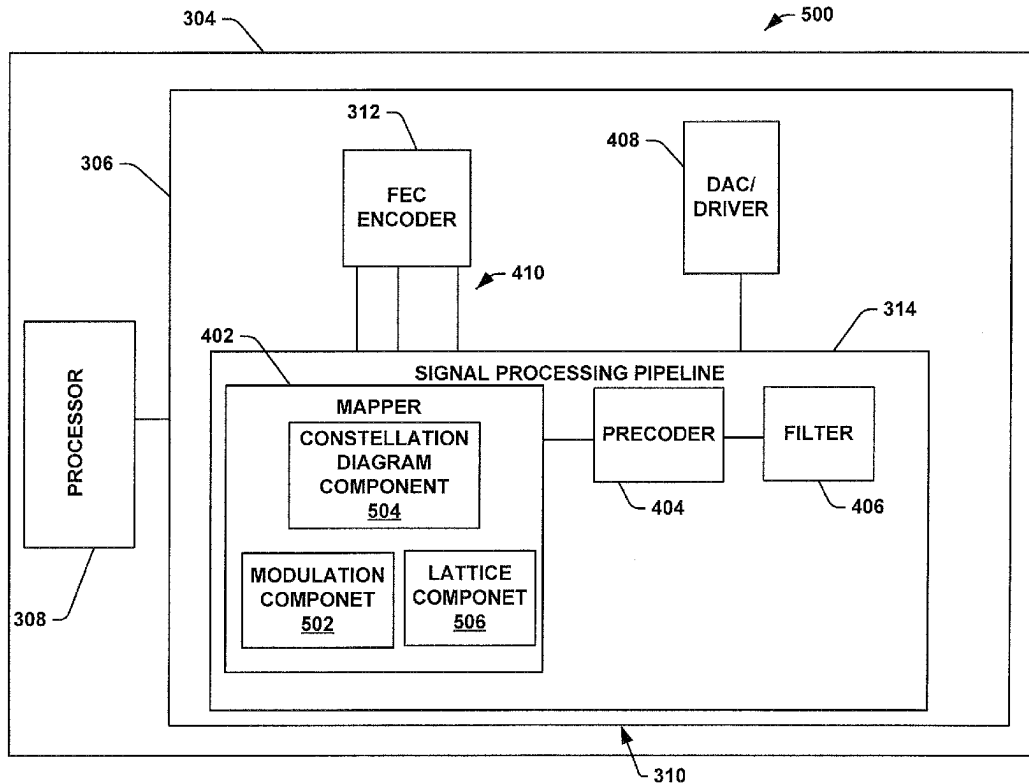
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(57) **ABSTRACT**

A transceiver architectures can comprises an encoder and a decoder for communicating high speed transmissions. The encoder can modulate signal data for being mapped in a constellation that is generated based on a leech lattice. The data can be transmitted at a high speed according to the constellation with an embedded leech lattice configuration in order to generate a coding gain. A decoder operates to decode the received input signal data with a decreased latency or a minimal latency with a high spectral efficiency.

20 Claims, 11 Drawing Sheets



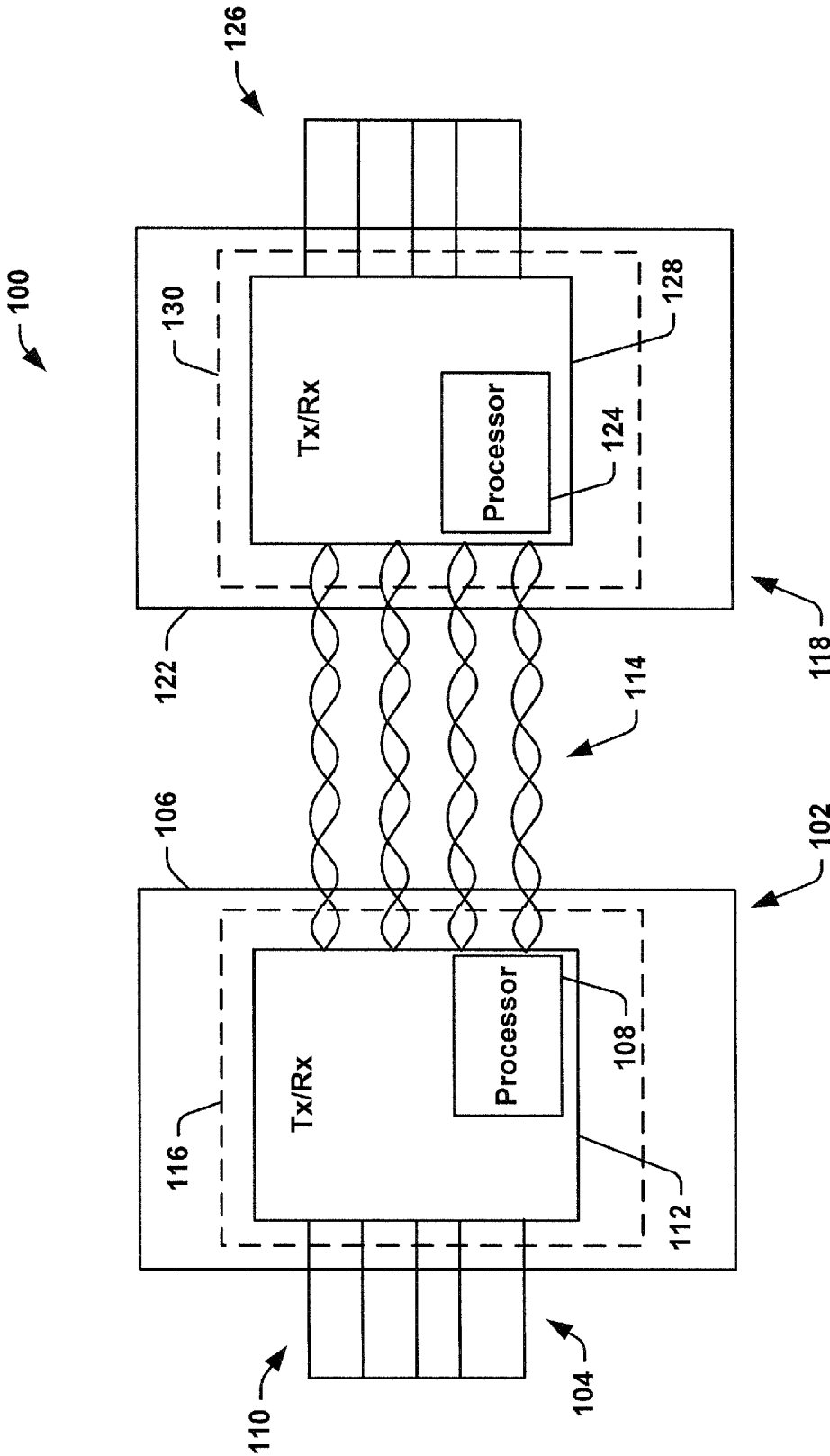


FIG. 1

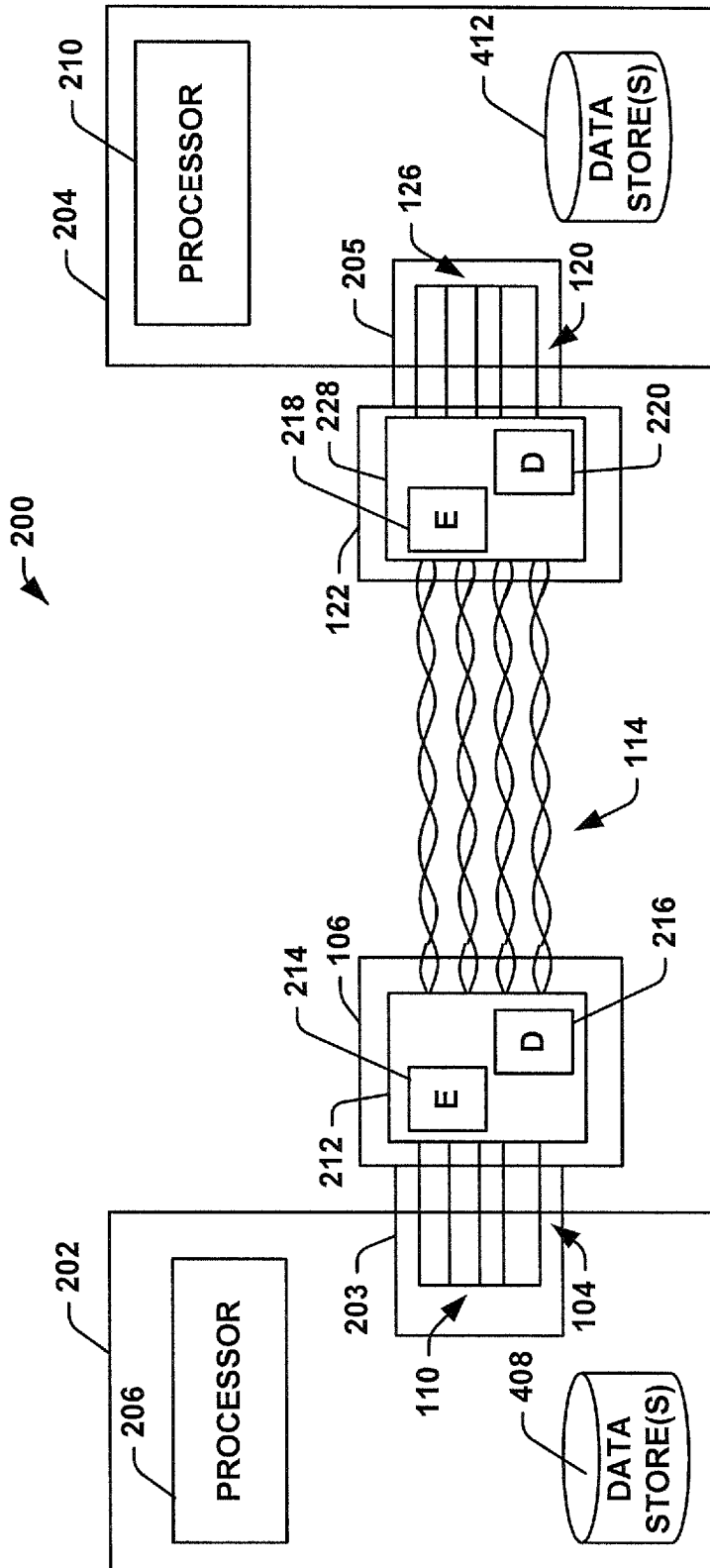


FIG. 2

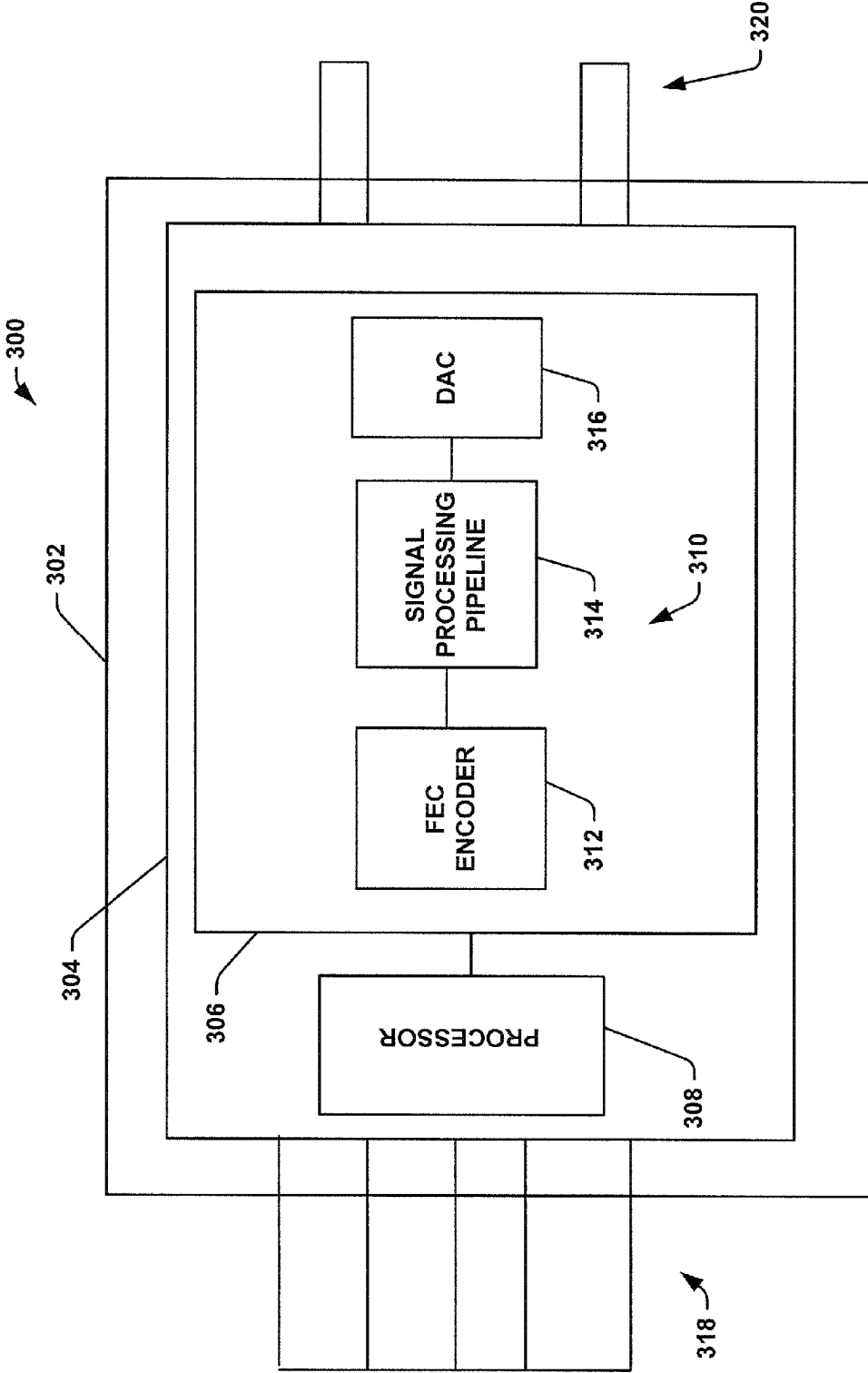


FIG. 3

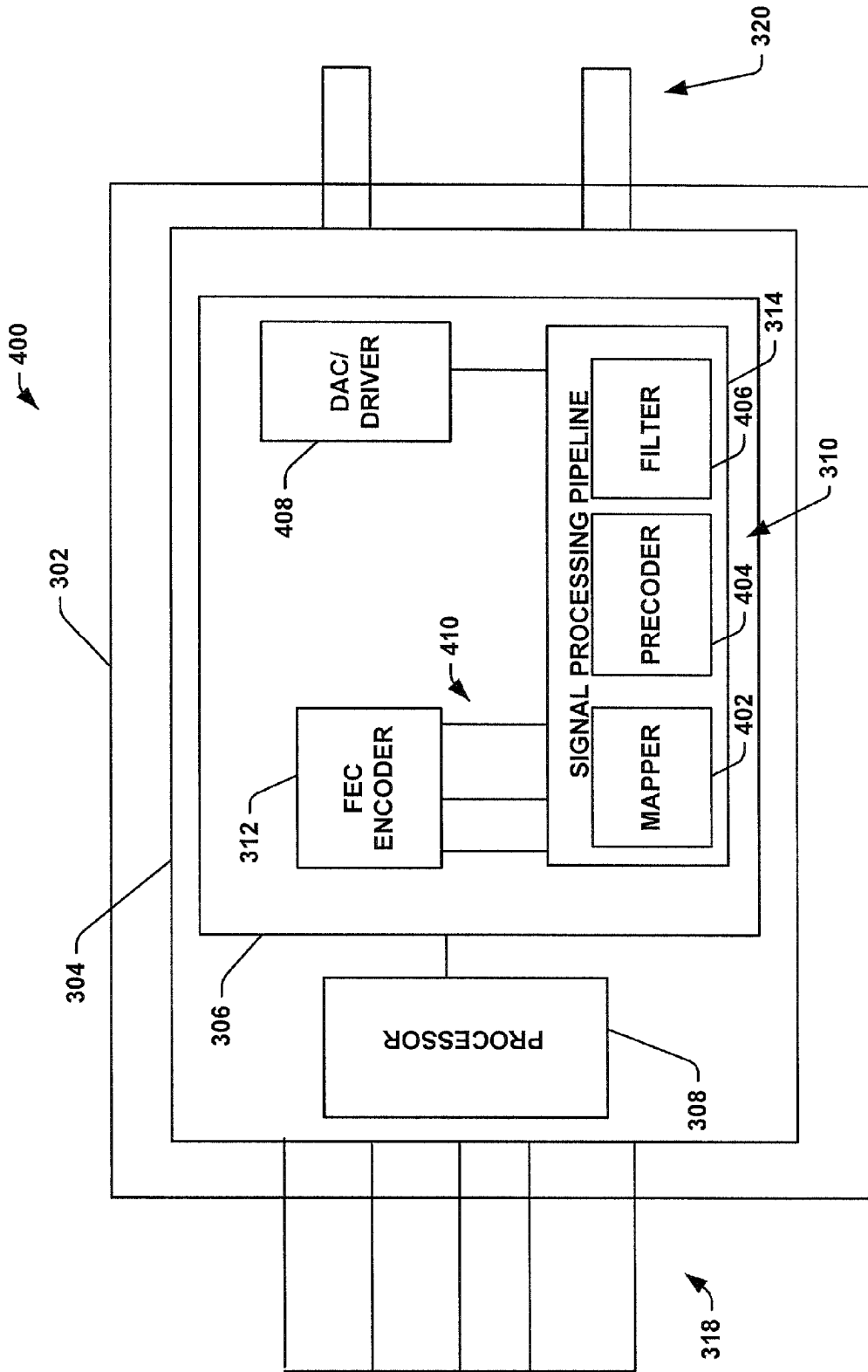


FIG. 4

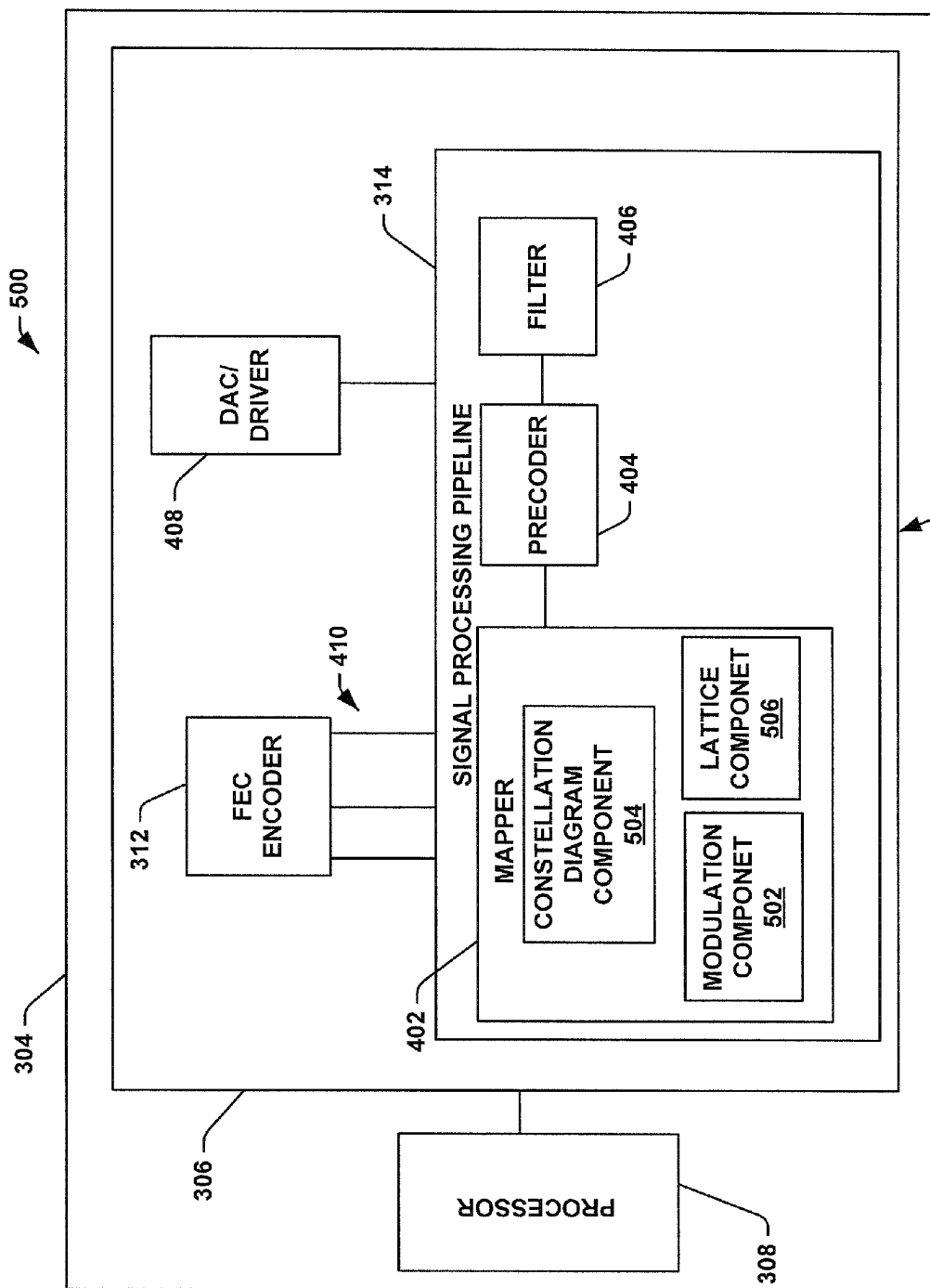


FIG. 5

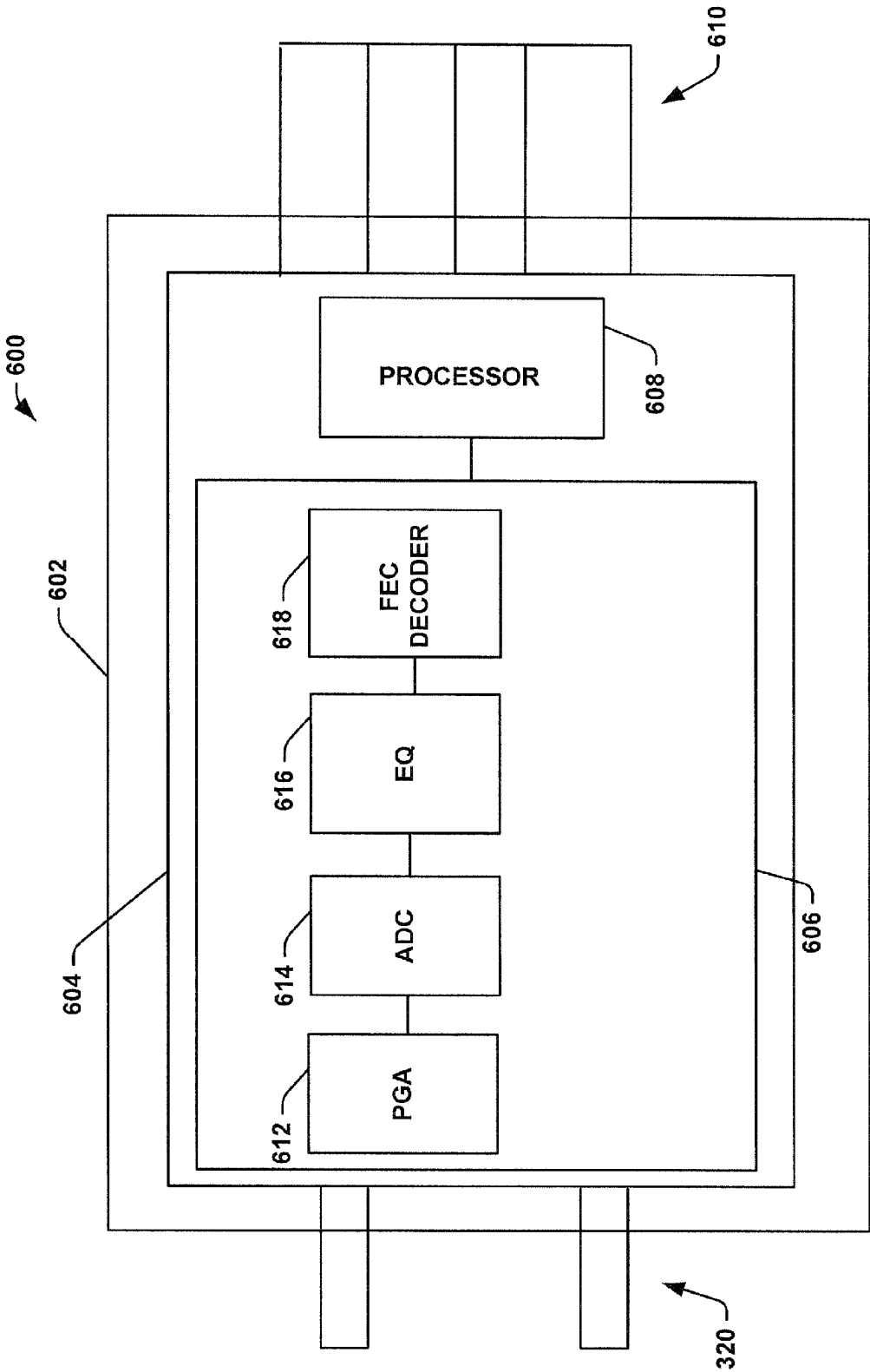


FIG. 6

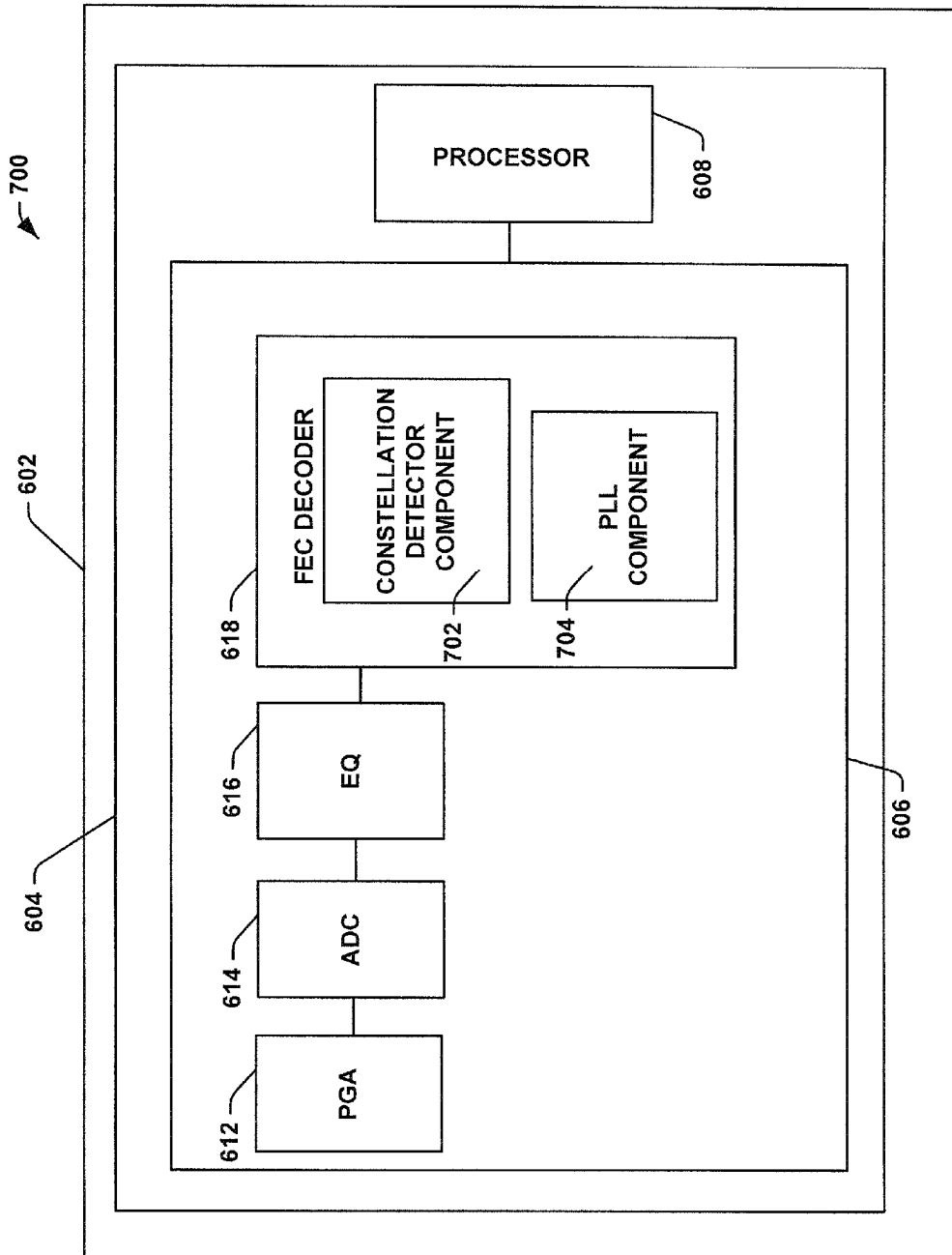


FIG. 7

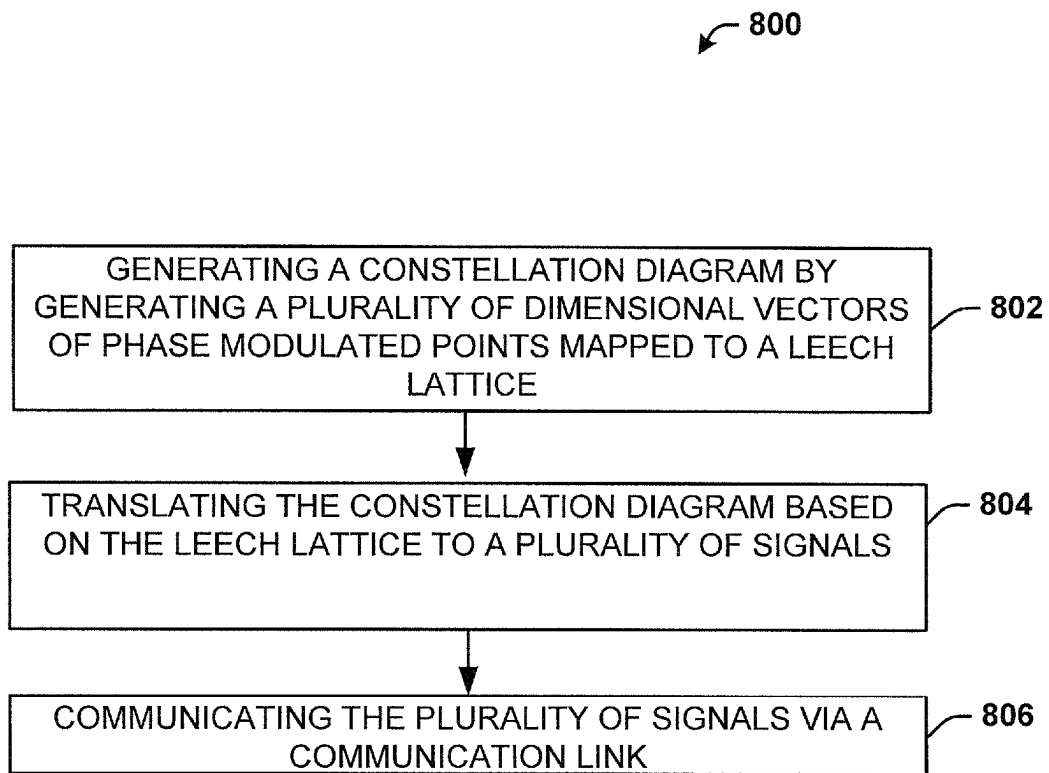


FIG. 8

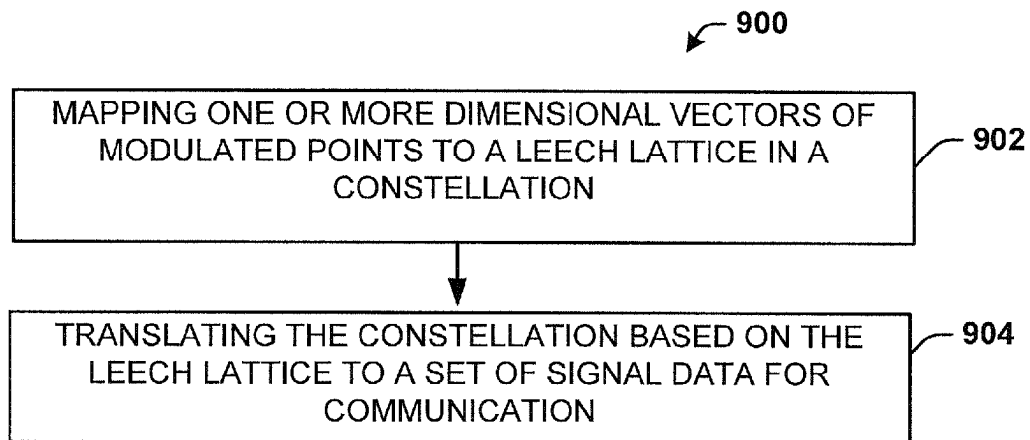


FIG. 9

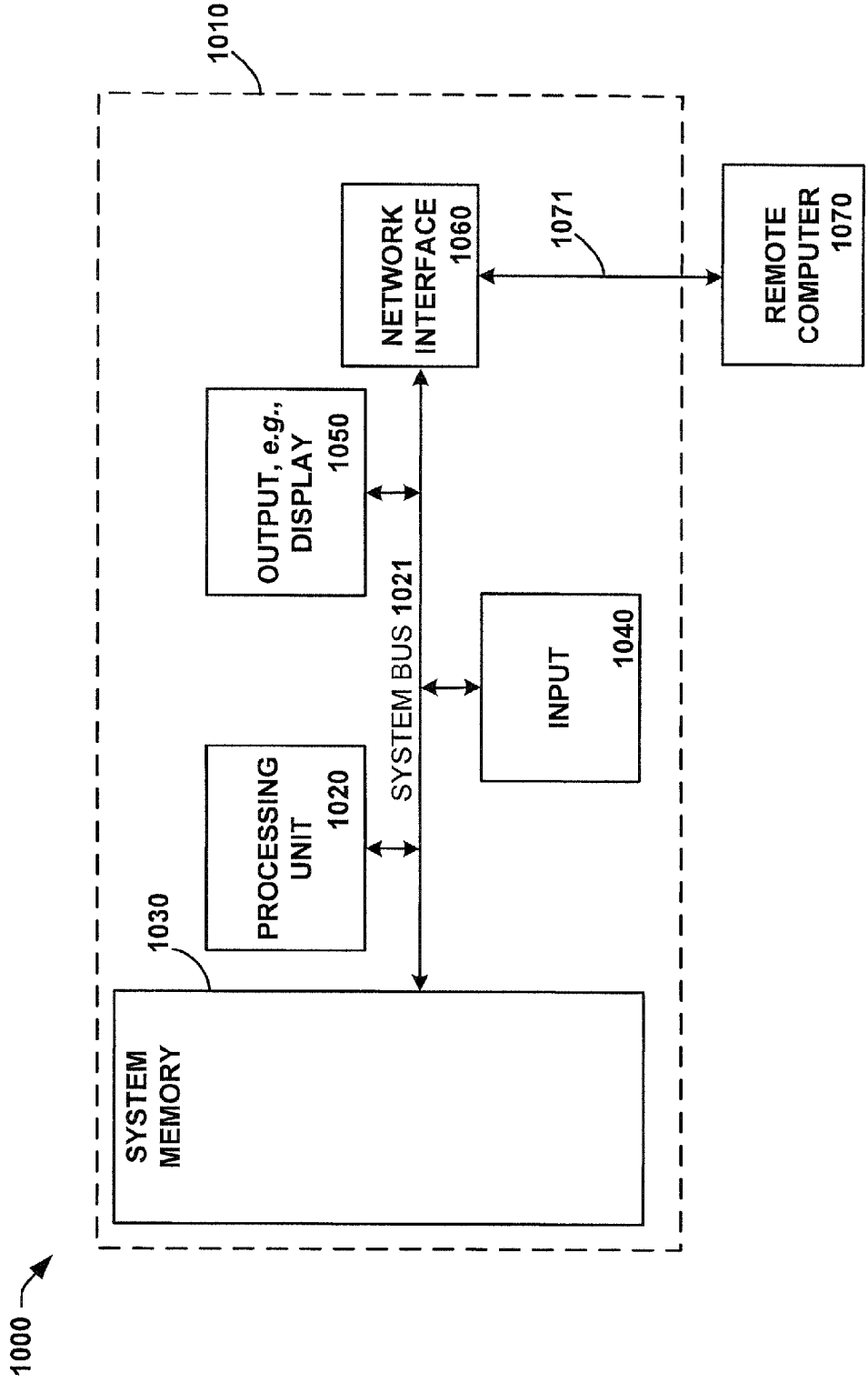


FIG. 10

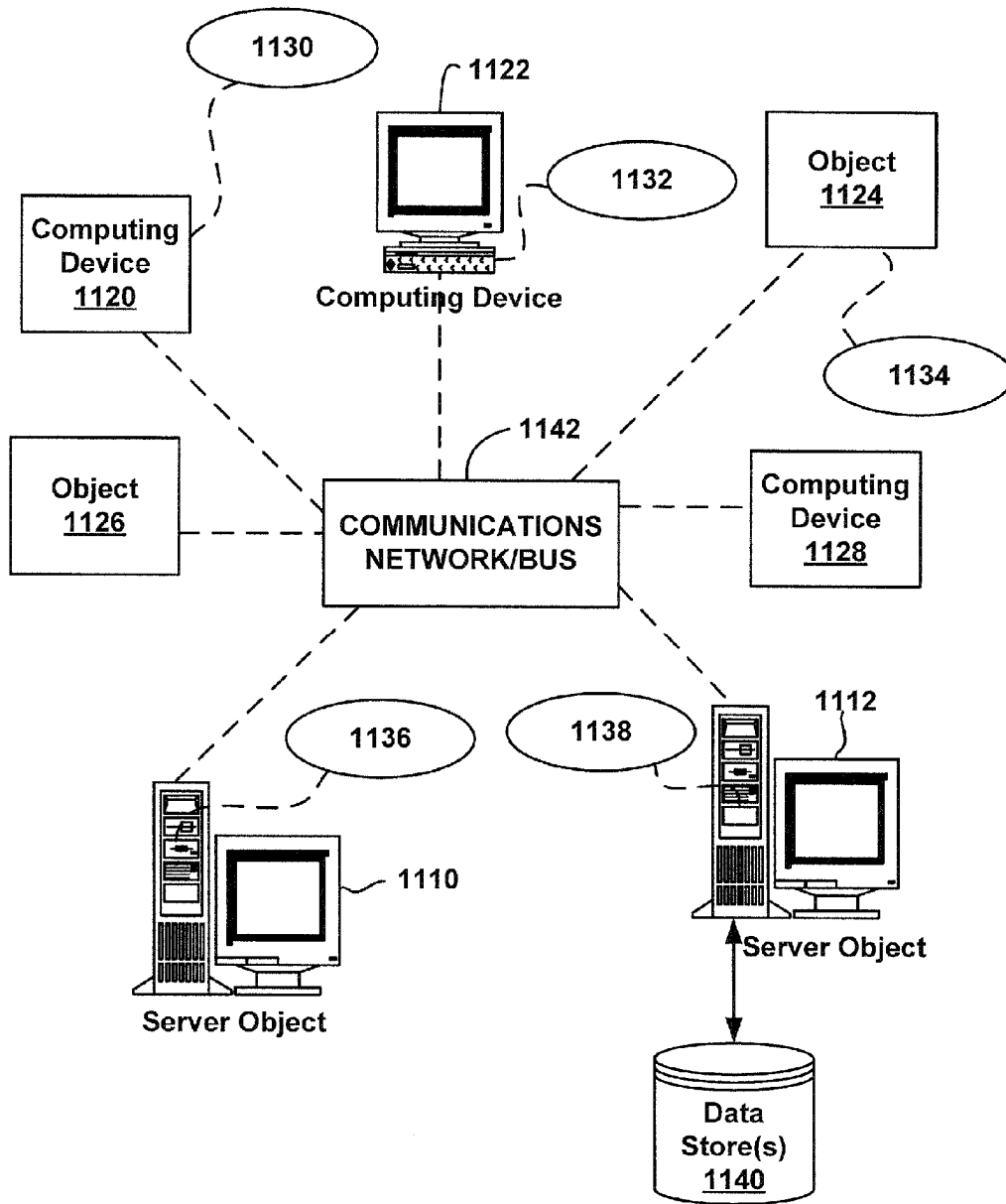


FIG. 11

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HIGH SPEED TRANSCIVER BASED ON EMBEDDED LEECH LATTICE CONSTELLATION

CROSS-REFERENCE TO RELATED APPLICATION(S)

The subject application for patent claims priority to U.S. Provisional Patent Application No. 61/869,395 entitled "TRANSMISSION OVER REDUCED PAIRS OF TWINAX CABLES AND COMMUNICATION CODING" filed Aug. 23, 2013, which is incorporated by reference herein in its entirety and for all purposes.

TECHNICAL FIELD

The subject disclosure relates generally to transceiver communications and more particularly to communications at a high speed based on embedded leech lattice constellations.

BACKGROUND

Cables are often utilized as physical media to connect devices that may be networked. Signals can be sent over a physical layer of wires, for example, in which signal coding can be used for enhancing the transmission. The cable can include a data link layer for messages sent between a controller (master) and a slave device. The messages could have a set of normal bits for bit synchronization, followed by a frame sync pattern, for example. The frame sync pattern, for example, can be followed by data bit frames, in which each frame could include a start bit, a bit data field, a parity bit and/or a set of fill bits of zero.

For applications requiring a high data rate with low latency performance, such as in Storage Area Networks and High Performance Computing, the interconnect media selected should have a very high bandwidth capacity, such as with twin axial (twinax) cable, to support the un-modulated baseband signal. To obtain low latency while having low power dissipation, baseband digital communication is typically used instead of a complex modulation scheme requiring sophisticated coding techniques. A drawback is media analog bandwidth. For example, in order to support 10 Gbps (Gigabit/sec) data communication, the media support a certain frequency Hertz of analog bandwidth. In order to achieve these bandwidths, the cable design and coding is refined to address performance parameters in this frequency range.

The above-described description is merely intended to provide a contextual overview of current cable interconnects and is not intended to be exhaustive. Other problems with conventional systems and corresponding benefits of the various non-limiting embodiments described herein may become further apparent upon review of the following description.

SUMMARY

The following presents a simplified summary in order to provide a basic understanding of some aspects described herein. This summary is not an extensive overview of the disclosed subject matter. It is intended to neither identify key nor critical elements of the disclosure nor delineate the scope thereof. Its sole purpose is to present some concepts in a simplified form as a prelude to the more detailed description that is presented later.

Various embodiments for transmission coding with a transceiver device are disclosed herein. An exemplary cable assembly comprises a transceiver device configured for com-

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municating a plurality of signals via a communication link, a memory storing executable instructions, and a processor, communicatively coupled to the memory, that facilitates execution of the executable instructions to perform operations. The operations can include, for example constructing a constellation diagram by generating a dimensional vector of phase amplitude modulated points mapped to a leech lattice. The operations can also include translating the constellation diagram based on the leech lattice to the set of signals.

In another embodiment, a transceiver device comprises a memory to store computer-executable instructions, and a processor, coupled to the memory, that facilitates execution of the computer-executable instructions to perform operations. The operations can include mapping one or more dimensional vectors of one or more phase amplitude modulated points to a leech lattice in a constellation diagram. The operations can also include translating the constellation diagram based on the leech lattice to a set of signals for a communication via a communication link.

In another embodiment, a constellation translation method comprises constructing, by a device with a processor, a constellation diagram by generating a plurality of dimensional vectors of phase modulated points mapped to a leech lattice. The constellation diagram is translated based on the leech lattice to a plurality of signals. The set of signals is communicated via a communication link.

The following description and the annexed drawings set forth in detail certain illustrative aspects of the subject disclosure. These aspects are indicative, however, of but a few of the various ways in which the principles of various disclosed aspects can be employed and the disclosure is intended to include all such aspects and their equivalents. Other advantages and novel features will become apparent from the following detailed description when considered in conjunction with the drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

Non-limiting and non-exhaustive embodiments of the subject disclosure are described with reference to the following figures, wherein like reference numerals refer to like parts throughout the various views unless otherwise specified.

FIG. 1 is a block diagram illustrating an example, non-limiting embodiment of a cable assembly system in accordance with various aspects described herein.

FIG. 2 is a block diagram illustrating another example, non-limiting embodiment of a cable assembly system with transceiver architecture in accordance with various aspects described herein.

FIG. 3 is a block diagram illustrating another example, non-limiting embodiment of cable assembly system with a transmit path of transceiver architecture in accordance with various aspects described herein.

FIG. 4 is a block diagram illustrating another example, non-limiting embodiment of cable assembly system with a transmit path of transceiver architecture in accordance with various aspects described herein.

FIG. 5 is a block diagram illustrating an example, non-limiting embodiment of a cable assembly system with transmit path of transceiver architecture in accordance with various aspects described herein.

FIG. 6 is a block diagram illustrating another example, non-limiting embodiment of a receive path of transceiver architecture in accordance with various aspects described herein.

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FIG. 7 is a block diagram illustrating another example, non-limiting embodiment of a receive path of transceiver architecture in accordance with various aspects described herein.

FIG. 8 is a flow diagram of a non-limiting embodiment for a receive path of transceiver architecture in accordance with various aspects described herein.

FIG. 9 illustrates a flow diagram of another non-limiting embodiment for a cable assembly system in accordance with various aspects described herein.

FIG. 10 illustrates a block diagram of an example electronic computing environment that can be implemented in conjunction with one or more aspects described herein.

FIG. 11 illustrates a block diagram of an example data communication network that can be operable in conjunction with various aspects described herein.

DETAILED DESCRIPTION

The disclosure herein is described with reference to the drawings, wherein like reference numerals are used to refer to like elements throughout. In the following description, for purposes of explanation, numerous specific details are set forth in order to provide a thorough understanding of the subject innovation. It may be evident, however, that various disclosed aspects can be practiced without these specific details. In other instances, well-known structures and devices are shown in block diagram form in order to facilitate describing the subject innovation.

In consideration of the above-described trends or deficiencies among other things, various embodiments are provided for transceiver architectures that employ constellation designs based on a leech lattice for coded communications where significant coding gain can be achieved with a low latency decoder and a high spectral efficiency. For example, by encoding with leech lattices, high speed transmission rates can be achieved with no increases in latency or a lower latency, such as with 100 Gbps transmission rates or greater for full-duplex communications over one or more communication links, such as optical communication links or a reduced number of twinaxial (twinax) pairs. For example, a cable assembly can include a set of twinaxial (or “twinax”) cables that can each comprise a full-duplex twinax pair of conductors or a half-duplex twinax pair of conductors, optical communication links, and/or fiber optic links. The cable assembly can be configured for communicating one or more signals in two directions simultaneously at transmission speeds of 100 Gigabytes per second or greater by utilizing coded lattices for modulation over communication links, such as processing or transmitting communications at speeds greater than 150 Gigabytes per second or greater than 200 Gigabytes per second.

Coded lattice modulation processes described herein can be based on leech lattices, for example. A lattice can comprise a set of points in an n-dimensional real space, in which the coordinates of each point can be derived by one or more linear combinations of a predefined set of vectors. The coefficients of the one or more linear combinations can comprise integer numbers. Leech lattices can be an even unimodular lattice Λ_{24} in 24-dimensional Euclidean space E^{24} . A leech lattice can comprise various characteristics and properties. For example, a leech lattice can be unimodular, and thus, can be generated by the columns of a certain 24×24 matrix with a determinant of one. The leech lattice can be even, or, in other words, the square of the length of any vector in Λ_{24} can be an even integer. In addition, the length of any non-zero vector in Λ_{24} is at least 2.

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The last condition is equivalent to the condition that unit balls centered at the points of Λ_{24} do not overlap. Each is tangent to 196,560 neighbors, and this is the largest number of non-overlapping 24-dimensional unit balls that can simultaneously touch a single unit ball. This arrangement of 196560 unit balls centered about another unit ball is so efficient that there is no room to move any of the balls; this configuration, together with its mirror-image, is the only 24-dimensional arrangement where 196560 unit balls simultaneously touch another. This property is also true in 1, 2 and 8 dimensions, with 2, 6 and 240 unit balls, respectively, based on the integer lattice, hexagonal tiling and E8 lattices, respectively.

The leech lattice does not comprise a root system and in fact is the first unimodular lattice with no roots (vectors of norm less than 4), and therefore has a center density of 1. By multiplying this value by the volume of a unit ball in 24 dimensions,

$$\frac{\pi^{12}}{12!},$$

one can derive the absolute density.

The constellation designs that are described can comprise translations or constructions of a basic constellations based on Leech lattices. This construction can comprise multiple steps. In one embodiment, a 24 dimensional array of PAM4 symbols can be considered in an analysis. A restriction can be applied to the 24 dimensional vector(s) of PAM4 points to lie or overlay on a Leech lattice. Based on the properties of the Leech lattice, a communication device can transmit 1 bit/dim using this basic constellation. In order to transmit more bits, the base constellation points can be translated by vectors of multiples of $4m$, where m is an integer. Therefore in order to transmit 2 bit/dim, the based constellation can be augmented in the communication by a translation vector whose elements comprise integers of the form $(4m)$, where $m=0, 1$. Furthermore, the 3 bit/dim can be derived by translation vectors, $(4m)$, where $m=0, 1, 2, 3$.

Referring now to FIG. 1, illustrated is an embodiment of a cable assembly **100** that can embody one or more coding modulation schemes based on leech lattice designs described herein. The cable assembly can comprise, for example, a first end device **106** and a second end device **122** for an interconnection of one or more devices (not shown), such as a computer device, mobile processing device, display device personal digital assistant, etc. The cable assembly **100** can operate as an active twinax cable device for high speed, full-duplex transmissions among devices or device processors with a reduced set of twinax conductor pairs for modulating communications based on constellation designs for an increase in coding gain and high spectral efficiency. Additionally, the cable assembly **100** can operate to simultaneously transmit and receive data at a transmission speed of 100 Gbps or greater for one or more different communication protocols via a communication link such as via wired and/or optical link communications to maintain or decrease latency in encoding and decoding processes.

For example, the cable assembly **100** can comprise an interface **110** and an interface **126** at each end that can include a set of interconnects **104, 120** (e.g., copper interconnects or optical links) that can operate to interface with a receiving port or a plug such as a Quad Small Form-factor Pluggable (QSFP), a Small Form-factor Pluggable, or other pluggable connector. The interface **110** and **126** can be operatively connected to a circuit board **116** and **130** or a surface mount or

processor package mount (e.g., a ball grid array or the like) having a processor **108** and **124**. The interface **110** and **126** can also include a plug portion (not shown) of the cable assembly **100**, which operates as a mate for connection to a plug or port of a device or processing device for communication between one or more other devices. The cable assembly **100** can be operable as an active cable device that draws or consumes power at one or more ends of the assembly **100**, and further processes, encodes and decodes transmissions of one or more communication protocols with low bit error rates and high efficiency.

The cable assembly **100** can comprise a plug assembly **102** and **118** at an end of the cable assembly **100** that comprises the plug portion or the interface **110** that operates as the mate for connection to a plug or port of a device. The plug assembly **102** or **118** can comprise a processor **108** or **124** operatively connected to the circuit board **116**, **130** or a surface mount respectively. The processor **108** or **124** can operate with a transceiver **112**, **128** to encode, decode, partition, or process error correction code (ECC) such as Forward Error Correction Code (FEC) according to one or more algorithms that can enable high speed, full-duplex transmissions of data at 100 Gbps or greater Gbps via the twinax pairs **114** based on leech lattice constellations.

In one embodiment, the processors **108** or **124** can operate to draw or consume power from an independent power source (not shown) located internally, which can be coupled to the circuit board or processor package **116**, **130**. In addition or alternatively, the signals being transmitted can be used to power the cable. For example, a power signal transmission can be utilized to power the processors for transmission, such as by an electromagnetic coupling or other remote power signals. A power source from the device coupled to the cable assembly can also be utilized to power the processors **108**, **124**, such as from an external power source located on the device. Alternatively, the cable assembly **100** can operate as a passive device without a power source or drawing power from one or more connected devices.

The processors **108** and **24** can be further integrated as transceiver processors that operate to communicate (transmit and/or receive) signals for full-duplex transmissions along the twinax pairs. In addition or alternatively, the processors **108** and **124** can be coupled to a transmitter, receiver, or transceiver **112**, **128** located within the plug assembly **102**, **118**. For example, a transceiver **112**, or **128** can be coupled to the processors on the circuit board **116** or **130** via routed traces or a processor package having connect pads, ball grid array, or other like interconnects mounted on the circuit board **116**, **130** (e.g., a printed circuit board) of the cable assembly **100**.

In one embodiment, high-speed transmission architecture of the cable assembly **100** can be based on an embedded leech lattice constellation that increases a coding gain in the transmission, in which an increase is obtained in a difference between a ratio (e.g., a signal to noise ratio) level of an uncoded transmission and a coded transmission for producing the same bit error rate levels as with an error correcting code. For example, a transceiver architecture having the transceiver **112** and/or **128** can employ a constellation design where significant coding gain is achieved with low latency decoding processes and high spectral efficiency, such as in transmissions where coding gain is desired for high speed applications, in which any bandwidth limitations can be mitigated by high spectral efficiency. Additionally, the latency of the decoding processes can be minimized by providing a coding gain in the coding processes of the encoded transmission and minimizing the latency of the decoder. The high

spectral efficiency increases the number of bits per bandwidth while maintaining requirements for a set of links, channels or twinax pairs **114**, for example.

A lattice, for example, can comprise a set of the points in an n-dimensional real space, where the coordinates of each point can be derived by one or more linear combinations of a predefined set of vectors where all the coefficients of the linear combination comprise integer numbers. A leech lattice can operate to achieve a maximum spatial density in 24 dimensions. The current methods that rely on simple constellations such as PAM-n, do not achieve coding gain from the constellation. Rather, coding gain is achieved by using long algebraic codes such as Reed-Solomon (RS) codes. These long algebraic codes suffer from a long latency. In addition, trellis coded modulation codes or TOM codes are not always suitable for high speed implementations, since reducing the latency for such decoders can result in a rapid increase in their complexity.

In an aspect, the transceiver system architecture of the cable assembly **100** can comprise transceivers **112**, **128** that are configured to generate coding modulations with a constellation design having translations of a constellation or a constellation diagram that is based on one or more leech lattices. Constructing the constellation can comprise multiple steps. For example, a twenty-four dimensional array of PAM-4 symbols can be analyzed within those steps for encoding/decoding communication signals over the pairs or the optical communication links **114**. The constellation diagram can comprise pulse-amplitude modulation (PAM) points or symbols where communicated data, a set of signals, or, in other words, message information is encoded in the amplitude of a series of signal pulses. In an analog pulse modulation processes or scheme the amplitudes of a train of carrier pulses can be varied according to the sample value of the message signal.

For example, the transceiver **112**, **128** can include a two-bit modulator (PAM-4) (not shown) that can operate to process two bits at a time and map the signal amplitude to one of four possible levels, for example -3 volts, -1 volt, 1 volt, and 3 volts. Demodulation can be performed by detecting the amplitude level of the carrier at every symbol period, for example. The transceiver **112**, **128** can operate to generate a twenty-four dimensional array of PAM-4 symbols, which can then be analyzed for further coding.

In another aspect, the transceiver **112** or **128** can operate to provide a restriction of the twenty-four dimensional vectors of PAM points (e.g., PAM-4 points) with a leech lattice, in which the twenty-four dimensional vectors of PAM points is applied to, mapped or overlaid on a Leech lattice. Based on the properties of the leech lattice, the transceiver **112** or **128** can transmit 1 bit/dim using this basic constellation. In order to transmit more bits, a translation is performed where the base constellation points by vectors of multiples of $4m$, where m is an integer. Therefore in order to transmit 2 bit/dim, an augmentation is made to the based constellation by a translation vector whose elements consists of integers of the form $(4m)$, where $m=0, 1$. Furthermore, the 3 bit/dim is derived by translation vectors, $(4m)$, where $m=0, 1, 2, 3$.

Referring now to FIG. 2, illustrated is an example of a cable assembly **200** that operates at high speed transmission for transmitting and receiving data back and forth from one or more devices by utilizing embedded leech lattice constellations. The cable assembly **200** comprises similar components as discussed above and further includes encoding components and decoding components mounted on a surface mount or circuit board **106** and **122** within plug assemblies, which

can encode and decode communication data or signals that are encoded based on a leech lattice constellation.

The cable assembly **200** can be operatively coupled to a first device **202** and a second device **204** via a plug **203** and a plug **205**, which can comprise a receiving port, for example, which can be a Quad Small Form-factor Huggable (QSFP), a Small Form-Factor Pluggable (SFP) port, a Small Form Factor SFF casing, or other receiving port configured for wired and/or optical links. The first device **202** or the second device **204** can respectively comprise a processor **206**, **210** and one or more data stores **208** and **212**. The first device **202** or the second device **204** can comprise a processing device such as a personal computer device, a mobile device, an input/output device, a display, a personal digital assistant, or other similar device operable for communicating via the plug **203** or **205**.

A surface mount or electronic board **106** and **122** of plug assemblies at opposite ends of the twinax pairs **214** can comprise transmitters **212** and **228**, which can include encoders **214** and **218** and decoders **216** and **220** respectively that are operatively coupled to a processor and/or transceiver architectures on circuit boards or respective mounting assemblies. The encoders **214** and **218**, for example, can operate to encode at least a part of information of signals from one format, code or communication protocol to another via one or more algorithms based on a leech lattice constellation. The decoder **216** or **220** can operate to reverse the operation of the encoder in order to convert the information from one format or protocol into another format or protocol. For example, the decoder **216** or **220** can operate to convert binary information from a number of lines to a unique output lines. For example, in cases where one or more encoders encode data from the first device **202** into one format for high speed transmission, the decoder **220** can operate to decode and/or re-code the data based on the second device **204** being a different device operating in a different communication protocol.

Another embodiment of the transceiver architectures **212** and **228** can employ constellation processes as described above. The encoder **214** or **218** can operate to map a constellation diagram as representation of a signal modulated by a digital modulation scheme such as a pulse amplitude modulation, quadrature amplitude modulation or phase-shift keying, for example. The constellation diagram can be a diagram or other representation of a set of signals to be transmitted as a dimensional scatter diagram in the complex plane at symbol sampling instants. For example, a twenty four dimension vector of pulse amplitude modulation points can be mapped to lie on a leech lattice. In a more abstract sense, the constellation diagram can represent the possible symbols that may be selected by a given modulation scheme as points in a complex plane. Further, the encoders **214** and **218** can be utilized to determine measurements of constellation diagrams to recognize the type of interference and distortion in a signal by the transmitters **212** and **228**. By representing a transmitted symbol as a complex number and modulating a cosine and sine carrier signal with the real and imaginary parts (respectively), the symbol can be sent with two carriers on the same frequency, for example, such as quadrature carriers. The use of two independently modulated carriers is the basis of quadrature modulation. In addition, phase modulation can be utilized where the phase of the modulating symbol is the phase of the carrier itself, as well as pulse amplitude modulation where the signals are encoded in the amplitude of a series of signal pulses.

As the symbols are represented as complex numbers, they can be visualized as points on the complex plane. The real and imaginary axes are often called the in phase, or I-axis, and the quadrature, or Q-axis, respectively. Plotting or mapping sev-

eral symbols in a scatter diagram produces the constellation diagram. The points on a constellation diagram are called constellation points. They are a set of modulation symbols which comprise the modulation alphabet.

The encoders **214** and **218** can operate to map constellations based on leech lattices with a twenty four dimensional array of symbols (e.g., PAM-4 symbols), and further operate to pre-code the symbols such as by Tomlinson-Harashima pre-coding, such as to pre-cancel known interference without a power penalty, for example. The encoders **214** and **218** can operate to linearly filter the pre-coded signals by processing the signals as time-varying input signals to produce output signals subject to a constraint of linearity. The linearly filtered signals could then be used for purposes of channel equalization as well as other optimization techniques, for example. In addition, the output of the linear filtering can be used to drive a digital to analog conversion process or line driver operations.

The decoders **216** and **220** can operate to receive the encoded signal on an analog front end and process the signals with a programmable gain and an analog to digital conversion process. The receive pathway of the decoders **216** and **220** can include a phase locked loop that generates an output whose phase is related to the phase of the input signal or for the purposes of a clock recovery process. The receive pathway of the decoders **216** and **220** can be a digital receive path that provides linear equalization processes and detector algorithms to reduce the bit error rate in detecting the constellation points based on the leech lattice transmitted. The decoders **216** and **220** can operate to provide a phase detection of the transmitted signals for detecting timing differentials between a received signal and a detected signal to drive a clock recovery loop. The output can then be applied to forward error correction decoding processes for controlling errors in data transmission.

Referring now to FIG. 3, illustrated is a cable assembly **300** having a transceiver architecture for transmission of encoded data at high transmission speeds (e.g., 80 Gbps or 100 Gbps and greater) along a transmit path. The cable assembly **300** can comprise a plug assembly **302** with a surface mount, circuit board, or signal processing device **304** that includes a transceiver device **306** for encoding and decoding communications based on constellations mapped according to leech lattices. The processing device **304** comprises a processor **308** that can have one or more internal memories for communication modulation and processing. The transceiver device **306** comprises a transmit path **310** that operates to transmit signals via one or more twinax or optic fibers **320** at speeds of at least 100 Gbps based on constellations generated with a leech lattice that achieves a density of twenty four dimensions.

The transmit path **310** of the transceiver device **306** can comprise an FEC encoder **312**, a transmit signal processing pipeline **314** and a digital-to-analog converter (DAC) **316**. The transceiver device **306** can receive one or more signals for modulation and transmission via an interconnect **318** that can comprise copper, optical and/or wireless interconnections for receiving signals from another device. On the transmit path **310**, the cable assembly **300** can include the FEC encoder **312** that can operate to encode data received and to transmit most significant bits (msbs) to the transmit signal processing pipeline **314**, which can include one or more processing components for processing signals concurrently or at the same time. The FEC encoder **312** or the signal processing pipeline **314**, for example, can receive signals over a set of bit stream pathways (e.g., three connections) and encode or assimilate the signals via mapping operations to output a set of symbols

for transmission across the channel (e.g., the twinax pairs 320). The DAC 316 can operate to convert the digital signal to an analog signal for transmission.

The signal processing pipeline 314 can operate to filter the output of the FEC encoder 312 with a linear constraint and perform channel equalization as well as other optimization operations. The output of the linear filtering processes can further drive the DAC 316 or a line driver (not shown), for example.

In an embodiment, the encoder 312 can operate with the signal processing pipeline 314 to generate a coding gain by embedding a leech lattice within a constellation or constellation diagram used for encoding and processing in the transmission signal processing pipeline 314. The transmit path 310 generates the constellation design with translations of constellations based on leech lattices. For example, the FEC encoder 312 can encode forward error correction code and signal points with a twenty four dimensional array of PAM-4 symbols. The encoder 312 can generate and apply a restriction of twenty four dimensional vectors on the PAM-4 points to lie or overlay on a Leech lattice, and thus, generate constellations with a leech lattice embedded within the encoded signals that comprise a leech lattice embedded therein.

In another aspect, based on the properties of the Leech lattice, the cable assemblies or transceiver architecture system 300 can transmit 1 bit/dim using this basic constellation. In order to transmit more bits, a translation can be performed where the base constellation points by vectors of multiples of $4m$, where m is an integer. Therefore in order to transmit 2 bit/dim, an augmentation can be made by the encoder 312 to the constellation or constellation diagram with an embedded leech lattice by a translation vector whose elements consists of integers of the form $(4m)$, where $m=0, 1$. Furthermore, the 3 bit/dim is derived by translation vectors, $(4m)$, where $m=0, 1, 2, 3$. Thus, the encoder 312 communicatively coupled to the signal processing pipeline 314 can operate can enable a coding gain based on encoding with constellations having or based on a leech lattice.

Referring to FIG. 4, illustrated is an embodiment of a cable assembly 400 comprising a transceiver architecture of a transceiver device for encoding and communicating signals based on embedded leech lattice constellations. On the transmit path 310 of the transceiver device 306 at the cable assembly 400, for example, the FEC encoder 312 can operate to generate FEC codes and encoding signal points, such as pulse amplitude modulated points of signals, in a constellations according to a Leech lattice. The transmit path 310 can operate multiple steps to define the points selected, which define a partition of the points in a 24 dimensional space. Alternatively, the space can be a twelve two-dimensional space, for example.

The transmit path 310, for example, can comprise the FEC encoder 312, and the transmit signal processing pipeline 314 that comprises a mapper component 402, a precoder component 404, and a filter component 406. The mapper component 402 can receive encoded signals, sampled points, or FEC of communication signals from the FEC encoder 312 via transmission paths 410 with one or more most significant bits (msbs) and/or other modulation signal data (such as FEC and other sampled data points). The mapper component 402 can process the received data into a constellation diagram having twenty four dimensional arrays of symbols (e.g., PAM4 symbols) and encode the data points according to a leech lattice so that the constellations generated are based on or generated according to a leech lattice constellation. The mapper component 402 thus maps the coded signals based on constellations with embedded leech lattice architectures. The coded

lattice modulation processes of the transmit path 310 can be based on leech lattices, for example, which can comprise a set of points in an n -dimensional real space, in which the coordinates of each point can be derived by one or more linear combinations of a predefined set of vectors. The coefficients of the one or more linear combinations can comprise integer numbers. Leech lattices can be an even unimodular lattice Λ_{24} in 24-dimensional Euclidean space E^{24} , for example. A leech lattice can be unimodular, and thus, can be generated by the columns of a certain 24×24 matrix with a determinant of one. The leech lattice can be even, or, in other words, the square of the length of any vector in Λ_{24} can be an even integer. In addition, the length of any non-zero vector in Λ_{24} is at least 2.

The precoder 404 can operate within the signaling pathway and can be in the form of a Tomlinson-Harashima pre-coder, for example. The precoder 404 can operate to perform transmit diversity and optimize the precoder with a receiver decoder at another transceiver device (not shown), which can be coupled to the communication links 320. Although the transceiver device 306 is illustrated with an encoding device, the transceiver can also include a decoder (not shown) also.

The signal processing pipeline 314 can further comprise the filter 406 for providing a linear constraint on the communications. The filter 406 can operate to perform channel equalization by minimizing errors or noise within the communication as well as other optimization processes for signal transmission at high speeds of 100 Gbps or greater. The output of the linear filter 406 can further be utilized to drive a DAC 408 for signal conversion and/or a line-driver 408 for signal amplification, for example.

Referring now to FIG. 5, illustrated is an embodiment for processing high speed signals based on embedded leech lattice constellations to enable a coding gain. The transceiver 306 comprises similar elements and components as discussed above. The mapper component 402 further comprises a modulation component 502, a constellation diagram component 504, and a lattice component 506 that operate to transmit communications based on constellations with an embedded leech lattice for enabling a coding gain, which is a measure in the difference between the signal-to-noise ratio (SNR) levels between the uncoded system and coded system desired to reach the same bit error rate (BER) levels when used with the error correcting code (ECC), such as a forward error correcting code (FEC, for example).

The modulation component 502 can be configured for generating phase amplitude modulated points with a number of bits at a time and mapping signal amplitudes to one or more amplitude levels. For example, the modulation component 502 can comprise a two bit modulator device that generates phase amplitude modulated points with two bits at a time and maps signal amplitudes to one of four amplitude levels, (e.g., -3 volts, -1 volt, 1 volt, and 3 volts, or other similar levels). Demodulation can thus be performed by detecting the amplitude levels of the carrier signal at each symbol period, for example.

The constellation diagram component 504 is configured for constructing a constellation diagram by generating a dimensional vector of phase amplitude modulated points mapped to a leech lattice. The constellation diagram component 504, for example, can receive an output from the modulation component 502 and generate a constellation of points to generate the constellation diagram. For example, the constellation diagram can be a representation of modulated signals by a modulation scheme, and delineate a signal in a complex plant at symbol sampling instants. The constellation diagram can diagram possible symbols that can be selected by a modulation scheme as a point in the complex plant, and used

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to recognize types of interference and distortion in a set of signals (a set being one or more), for example.

Upon reception of the signal, a decoder or demodulator (further described infra) either at a receiving transceiver device and/or at the transceiver device **306** can examine the received symbol, which may have been corrupted by the channel or the receiver (e.g. additive white Gaussian noise, distortion, phase noise or interference). The demodulator can operate to select, as its estimate of what was actually transmitted, that point on the constellation diagram which is closest (in a Euclidean distance sense, for example) to that of the received symbol. Thus, the demodulator could potentially demodulate incorrectly if the corruption has caused the received symbol to move closer to another constellation point than the one transmitted. The constellation or constellation diagram can allow for a straightforward visualization or analysis of this process, in which the received symbol can be an arbitrary point in the I-Q plane and then a transmitted symbol can be selected that is whichever constellation point is closest to it. For the purpose of analyzing a received signal quality, some types of corruption can be evident in the constellation/constellation diagram. For example, Gaussian noise can show as fuzzy constellation points. Non-coherent single frequency interference can show as circular constellation points. As another example, phase noise shows as rotationally spreading constellation points. Further, attenuation can cause the corner points to move towards the center. A constellation or a constellation diagram can visualize phenomena similar to those an eye pattern does for one-dimensional signals. The eye pattern or processing analysis can be used, for example, to examine timing jitter in one dimension of modulation.

The lattice component **506** can operate to embed points within the constellation according to a leech lattice by operating concurrently or in conjunction with the constellation diagram component **504**. The lattice component **506** can translate the constellation diagram based on a leech lattice to the set of signals, which are encoded communication data for transmission. The lattice component **506** can provide a restriction that the 24 dimensional vector(s) of modulated points (e.g., PAM4 points) lie or conform to a leech lattice. Based on the properties of the Leech lattice (discussed above), the transceiver device **306** can transmit 1 bit/dim using this constellation. In order to transmit more bits, the transceiver device **306** can operate to communicate at speeds of 100 Gbps or greater and translate the base constellation points by vectors of multiples of $4m$, where m is an integer. Therefore in order to transmit 2 bit/dim, the transceiver device **306** can augment the constellation based on a leech lattice by one or more translation vectors whose elements consists of integers of the form $(4m)$, where $m=0, 1$. Further, 3 bit/dim or more can be derived by translation vectors, $(4m)$; where $m=0, 1, 2, 3$.

Referring now to FIG. 6, illustrated is an embodiment for processing high speed signals based on embedded leech lattice constellations to enable a coding gain at a decoding stage. A cable assembly **600** comprises a plug assembly **302** having a mount, board, wafer package or processing device **604** that includes a transceiver device **606** and a processor **608**. The plug assembly includes one or more interconnects **610** for coupling to another device for communications, such as a display, personal digital device, computing device or the like. The transceiver device **606** is illustrated with an architecture that can comprise elements and components of the transceiver **306**, and the transceiver **306** can likewise further comprises the elements and components of the transceiver device **606**. For example, the transceiver device **606** can comprise a pro-

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grammable gain amplifier (PGA) **612**, an analog-to-digital converter (ADC) **614**, an equalizer component **616**, and an FEC Decoder **618**. The twinax pairs **320** communicate (transmit and receive) in a full-duplex mode of transmission as a communication link, for example, to and from the transceiver component **306**. The signal can be amplified by the PGA **612**, converted from analog to digital by the ADC **614**, equalized by the equalizer **616** and further decoded by the FEC decoder **618** for 80 Gbps or 100 Gbps and greater transmissions based on leech lattice constellations or constellations having embedded leech lattice configurations.

Upon reception of the signal, the FEC decoder **618** can examine the received symbol, which may have been corrupted by the channel or the receiver (e.g. additive white Gaussian noise, distortion, phase noise or interference). The decoder can operate to decode forward error correction code and select, as its estimate of what was actually transmitted, that point on the constellation diagram which is closest (in a Euclidean distance sense, for example) to that of the received symbol. The decoder **618** could potentially demodulate incorrectly if the corruption has caused the received symbol to move closer to another constellation point than the one transmitted. The decoder can thus utilize the constellation diagram to enable for a straightforward visualization or analysis of the constellation of points in an embedded leech lattice configuration to achieve a maximum density of this process, in which the received symbol can be an arbitrary point in the I-Q plane and then a transmitted symbol can be selected that is at least one constellation point is closest to it, for example, with a maximum density and least amount of latency and highest spectral efficiency.

Referring now to FIG. 7, illustrated is a transceiver architecture for increasing coding gain based on decoding with constellations constructed with a leech lattice. The cable assembly **700** comprises similar components as discussed above with regard to FIG. 6.

On the receive pathway of the cable assembly **700**, an input signal is received by an analog front end that comprises the programmable gain amplifier **612** and an analog to digital converter (ADC) **614**. The receive path can further comprise a digital receive path that comprises a linear equalizer **604** followed by the FEC decoder **618**. The FEC decoder **618** can comprise a constellation detection component **702** where detector algorithms can be processed to reduce the error rate in detecting the transmitted constellation points based on leech lattice constellations. Additionally or alternatively, a phase locked loop component (PLL) **704** can be configured for the purpose of generating the clock recovery from a clock component (not shown). The PLL component **704** can be configured to operate phase detection for detecting the timing differential between the receive signal and the detected signal, which can be utilized to drive a clock recovery loop, for example. In addition or alternatively, the PLL component **702** can utilize the signals derived from the constellation detector component **702** to detect a timing differential with the receive signal, or alternatively, by slicing the output of the linear equalizer **604** and utilizing the output signal as the detected signal. The output of the constellation detector **702** can then be applied to the decoder **618** for further controlling errors in data transmission and maintaining a low latency with high spectral efficiency in the communications received and transmitted.

Example Methods of Full Duplex Transmission Over Reduced Pairs of TWINAX Cables

While the methods or process flows described within this disclosure are illustrated in and described herein as a series of acts or events, it will be appreciated that the illustrated order-

ing of such acts or events are not to be interpreted in a limiting sense. For example, some acts may occur in different orders and/or concurrently with other acts or events apart from those illustrated and/or described herein. In addition, not all illustrated acts may be required to implement one or more aspects or embodiments of the description herein. Further, one or more of the acts depicted herein may be carried out in one or more separate acts and/or phases.

An example method **800** for a cable assembly to transmit and receive communication data at high speed transmissions based on a constellation leech lattice configuration is illustrated in FIG. **8**. At **802**, the method **800** initiates with constructing, by a device comprising a processor, a constellation diagram by generating a plurality of dimensional vectors of modulated points mapped to a leech lattice. The constellation diagram can be generated with a set of points, for example, that are generated according to a modulation scheme, such as a set of phase amplitude modulation or the like. For example, a set of PAM4 symbols or coefficients can be processed into a constellation configuration or diagram.

At **804**, the constellation diagram is translated or constructed based on the leech lattice to a plurality of signals for increasing a coding gain. At **806**, the set of signals are communicated via a communication link, such as via a high speed communication of 100 Gbps or greater.

In an aspect, a set of translation vectors can be generated by the constellation based on the leech lattice. The translation vectors can be a set of free vectors, displacement vectors, or vectors having a set of directed line segments (e.g., parallel line segments). The set of signals can thus be encoded or communicated according to the translation vectors. For example, the communicating can comprise transmitting more than one bit at a time based on a translation of points of the constellation diagram to translation vectors of multiples of $4m$, where m is an integer. Transmitting more than one bit at a time can comprise augmenting the constellation diagram based on the leech lattice with a translation vector comprising a number of vector elements with integers in a form of $4m$, where m equals an integer, and the number of elements corresponds to a number of bits being transmitted at a time. The vector elements can be any parameter (e.g., mapped signal points, coefficient data, directional or mathematical plane data, etc.) associated with vectors incorporated with signal data based on the leech lattice constellation.

At the decoding side, the method can further include decoding the set of signals received with a decrease in latency via optimization techniques based on the leech lattice constellation for minimizing and/or maintaining a low latency at a decoder. A time differential, for example, can further be determined between the received communication comprising the set of signals encoded and a detected signal. The detected signal, for example, can be from a splitting of an output from an equalizer or from an FEC decoder that detects and interprets the leech lattice constellation configuration of the encoded data. Additionally, a clock recovery loop can be driven by utilizing the time differential.

Referring now to FIG. **9**, illustrated is a method **900** for a cable assembly operable to communicate data at high speeds with high spectral efficiency. At **902**, a constellation diagram component configured for mapping one or more dimensional vectors of one or more phase amplitude modulated points to a leech lattice in a constellation diagram. At **904**, a lattice component configured for translating the constellation diagram based on the leech lattice to a set of signals for a communication via a communication link. The constellation diagram can be translated, for example, based on the leech lattice by analyzing a twenty-four dimensional array of

PAM-4 symbols and encoding the set of signals to be communicated via the communication link.

Example Computing Environment

As mentioned, advantageously, the techniques described herein can be applied to any device and/or network where power management is desirable in a multiprocessor system. It is to be understood, therefore, that handheld, portable and other computing devices and computing objects of all kinds are contemplated for use in connection with the various non-limiting embodiments, i.e., anywhere that a device may wish to implement power management for a multiprocessor system. Accordingly, the below general purpose remote computer described below in FIG. **10** is but one example, and the disclosed subject matter can be implemented with any client having network/bus interoperability and interaction. Thus, the disclosed subject matter can be implemented in an environment of networked hosted services in which very little or minimal client resources are implicated, e.g., a networked environment in which the client device serves merely as an interface to the network/bus, such as an object placed in an appliance.

Although not required, some aspects of the disclosed subject matter can partly be implemented via an operating system, for use by a developer of services for a device or object, and/or included within application software that operates in connection with the component(s) of the disclosed subject matter. Software may be described in the general context of computer executable instructions, such as program modules or components, being executed by one or more computer(s), such as projection display devices, viewing devices, or other devices. Those skilled in the art will appreciate that the disclosed subject matter may be practiced with other computer system configurations and protocols.

FIG. **10** thus illustrates an example of a suitable computing system environment **1000** in which some aspects of the disclosed subject matter can be implemented, although as made clear above, the computing system environment **1000** is only one example of a suitable computing environment for a device and is not intended to suggest any limitation as to the scope of use or functionality of the disclosed subject matter. Neither should the computing environment **1000** be interpreted as having any dependency or requirement relating to any one or combination of components illustrated in the exemplary operating environment **1300**.

With reference to FIG. **10**, an exemplary device for implementing the disclosed subject matter includes a general-purpose computing device in the form of a computer **1010**. Components of computer **1010** may include, but are not limited to, a processing unit **1020**, a system memory **1030**, and a system bus **1021** that couples various system components including the system memory to the processing unit **1020**. The system bus **1021** may be any of several types of bus structures including a memory bus or memory controller, a peripheral bus, and a local bus using any of a variety of bus architectures.

Computer **1010** typically includes a variety of computer readable media. Computer readable media can be any available media that can be accessed by computer **1010**. By way of example, and not limitation, computer readable media can comprise computer storage media and communication media. Computer storage media includes volatile and non-volatile, removable and non-removable media implemented in any method or technology for storage of information such as computer readable instructions, data structures, program modules or other data. Computer storage media includes, but is not limited to, RAM, ROM, EEPROM, flash memory or other memory technology, CDROM, digital versatile disks (DVD) or other optical disk storage, magnetic cassettes, mag-

netic tape, magnetic disk storage or other magnetic storage devices, or any other medium which can be used to store the desired information and which can be accessed by computer 1010. Communication media typically embodies computer readable instructions, data structures, program modules, or other data in a modulated data signal such as a carrier wave or other transport mechanism and includes any information delivery media.

The system memory 1030 may include computer storage media in the form of volatile and/or nonvolatile memory such as read only memory (ROM) and/or random access memory (RAM). A basic input/output system (BIOS), containing the basic routines that help to transfer information between elements within computer 1010, such as during start-up, may be stored in memory 1030. Memory 1030 typically also contains data and/or program modules that are immediately accessible to and/or presently being operated on by processing unit 1020. By way of example, and not limitation, memory 1030 may also include an operating system, application programs, other program modules, and program data.

The computer 1010 may also include other removable/non-removable, volatile/nonvolatile computer storage media. For example, computer 1010 could include a hard disk drive that reads from or writes to non-removable, nonvolatile magnetic media, a magnetic disk drive that reads from or writes to a removable, nonvolatile magnetic disk, and/or an optical disk drive that reads from or writes to a removable, nonvolatile optical disk, such as a CD-ROM or other optical media. Other removable/non-removable, volatile/nonvolatile computer storage media that can be used in the exemplary operating environment include, but are not limited to, magnetic tape cassettes, flash memory cards, digital versatile disks, digital video tape, solid state RAM, solid state ROM, and the like. A hard disk drive is typically connected to the system bus 1021 through a non-removable memory interface such as an interface, and a magnetic disk drive or optical disk drive is typically connected to the system bus 1021 by a removable memory interface, such as an interface.

A user can enter commands and information into the computer 1010 through input devices such as a keyboard and pointing device, commonly referred to as a mouse, trackball, or touch pad. Other input devices can include a microphone, joystick, game pad, satellite dish, scanner, wireless device keypad, voice commands, or the like. These and other input devices are often connected to the processing unit 1020 through user input 1040 and associated interface(s) that are coupled to the system bus 1021, but may be connected by other interface and bus structures, such as a parallel port, game port, or a universal serial bus (USB). A graphics subsystem can also be connected to the system bus 1021. A projection unit in a projection display device, or a HUD in a viewing device or other type of display device can also be connected to the system bus 1021 via an interface, such as output interface 1050, which may in turn communicate with video memory. In addition to a monitor, computers can also include other peripheral output devices such as speakers which can be connected through output interface 1050.

The computer 1010 can operate in a networked or distributed environment using logical connections to one or more other remote computer(s), such as remote computer 1070, which can in turn have media capabilities different from device 1010. The remote computer 1070 can be a personal computer, a server, a router, a network PC, a peer device, personal digital assistant (PDA), cell phone, handheld computing device, a projection display device, a viewing device, or other common network node, or any other remote media consumption or transmission device, and may include any or

all of the elements described above relative to the computer 1010. The logical connections depicted in FIG. 10 include a network 1071, such local area network (LAN) or a wide area network (WAN), but can also include other networks/buses, either wired or wireless. Such networking environments are commonplace in homes, offices, enterprise-wide computer networks, intranets and the Internet.

When used in a LAN networking environment, the computer 1010 can be connected to the LAN 1071 through a network interface or adapter. When used in a WAN networking environment, the computer 1010 can typically include a communications component, such as a modem, or other means for establishing communications over the WAN, such as the Internet. A communications component, such as wireless communications component, a modem and so on, which can be internal or external, can be connected to the system bus 1021 via the user input interface of input 1040, or other appropriate mechanism. In a networked environment, program modules depicted relative to the computer 1010, or portions thereof, can be stored in a remote memory storage device. It will be appreciated that the network connections shown and described are exemplary and other means of establishing a communications link between the computers can be used.

Example Networking Environment

FIG. 11 provides a schematic diagram of an exemplary networked or distributed computing environment. The distributed computing environment comprises computing objects 1110, 1112, etc. and computing objects or devices 1120, 1122, 1124, 1126, 1128, etc., which may include programs, methods, data stores, programmable logic, etc., as represented by applications 1130, 1132, 1134, 1136, 1138 and data store(s) 1140. It can be appreciated that computing objects 1110, 1112, etc. and computing objects or devices 1120, 1122, 1124, 1126, 1128, etc. may comprise different devices, including a multimedia display device or similar devices depicted within the illustrations, or other devices such as a mobile phone, personal digital assistant (PDA), audio/video device, MP3 players, personal computer, laptop, etc. It should be further appreciated that data store(s) 1140 can include one or more cache memories, one or more registers, or other similar data stores disclosed herein.

Each computing object 1110, 1112, etc. and computing objects or devices 1120, 1122, 1124, 1126, 1128, etc. can communicate with one or more other computing objects 1110, 1112, etc. and computing objects or devices 1120, 1122, 1124, 1126, 1128, etc. by way of the communications network 1142, either directly or indirectly. Even though illustrated as a single element in FIG. 11, communications network 1142 may comprise other computing objects and computing devices that provide services to the system of FIG. 11, and/or may represent multiple interconnected networks, which are not shown. Each computing object 1110, 1112, etc. or computing object or devices 1120, 1122, 1124, 1126, 1128, etc. can also contain an application, such as applications 1130, 1132, 1134, 1136, 1138, that might make use of an API, or other object, software, firmware and/or hardware, suitable for communication with or implementation of the techniques and disclosure described herein.

There are a variety of systems, components, and network configurations that support distributed computing environments. For example, computing systems can be connected together by wired or wireless systems, by local networks or widely distributed networks. Currently, many networks are coupled to the Internet, which provides an infrastructure for widely distributed computing and encompasses many different networks, though any network infrastructure can be used

for exemplary communications made incident to the systems automatic diagnostic data collection as described in various embodiments herein.

Thus, a host of network topologies and network infrastructures, such as client/server, peer-to-peer, or hybrid architectures, can be utilized. The “client” is a member of a class or group that uses the services of another class or group to which it is not related. A client can be a process, i.e., roughly a set of instructions or tasks, that requests a service provided by another program or process. The client process utilizes the requested service, in some cases without having to “know” any working details about the other program or the service itself.

In a client/server architecture, particularly a networked system, a client is usually a computer that accesses shared network resources provided by another computer, e.g., a server. In the illustration of FIG. 11, as a non-limiting example, computing objects or devices 1120, 1122, 1124, 1126, 1128, etc. can be thought of as clients and computing objects 1110, 1112, etc. can be thought of as servers where computing objects 1110, 1112, etc., acting as servers provide data services, such as receiving data from client computing objects or devices 1120, 1122, 1124, 1126, 1128, etc., storing of data, processing of data, transmitting data to client computing objects or devices 1120, 1122, 1124, 1126, 1128, etc., although any computer can be considered a client, a server, or both, depending on the circumstances.

A server is typically a remote computer system accessible over a remote or local network, such as the Internet or wireless network infrastructures. The client process may be active in a first computer system, and the server process may be active in a second computer system, communicating with one another over a communications medium, thus providing distributed functionality and allowing multiple clients to take advantage of the information-gathering capabilities of the server. Any software objects utilized pursuant to the techniques described herein can be provided standalone, or distributed across multiple computing devices or objects.

In a network environment in which the communications network 1142 or bus is the Internet, for example, the computing objects 1110, 1112, etc. can be Web servers with which other computing objects or devices 1120, 1122, 1124, 1126, 1128, etc. communicate via any of a number of known protocols, such as the hypertext transfer protocol (HTTP). Computing objects 1110, 1112, etc. acting as servers may also serve as clients, e.g., computing objects or devices 1120, 1122, 1124, 1126, 1128, etc., as may be characteristic of a distributed computing environment.

Reference throughout this specification to “one embodiment,” “an embodiment,” “an example,” “a disclosed aspect,” or “an aspect” means that a particular feature, structure, or characteristic described in connection with the embodiment or aspect is included in at least one embodiment or aspect of the present disclosure. Thus, the appearances of the phrase “in one embodiment,” “in one example,” “in one aspect,” or “in an embodiment,” in various places throughout this specification are not necessarily all referring to the same embodiment. Furthermore, the particular features, structures, or characteristics may be combined in any suitable manner in various disclosed embodiments.

As utilized herein, terms “component,” “system,” “architecture,” “engine” and the like are intended to refer to a computer or electronic-related entity, either hardware, a combination of hardware and software, software (e.g., in execution), or firmware. For example, a component can be one or more transistors, a memory cell, an arrangement of transistors or memory cells, a gate array, a programmable gate array, an

application specific integrated circuit, a controller, a processor, a process running on the processor, an object, executable, program or application accessing or interfacing with semiconductor memory, a computer, or the like, or a suitable combination thereof. The component can include erasable programming (e.g., process instructions at least in part stored in erasable memory) or hard programming (e.g., process instructions burned into non-erasable memory at manufacture).

By way of illustration, both a process executed from memory and the processor can be a component. As another example, an architecture can include an arrangement of electronic hardware (e.g., parallel or serial transistors), processing instructions and a processor, which implement the processing instructions in a manner suitable to the arrangement of electronic hardware. In addition, an architecture can include a single component (e.g., a transistor, a gate array, . . .) or an arrangement of components (e.g., a series or parallel arrangement of transistors, a gate array connected with program circuitry, power leads, electrical ground, input signal lines and output signal lines, and so on). A system can include one or more components as well as one or more architectures. One example system can include a switching block architecture comprising crossed input/output lines and pass gate transistors, as well as power source(s), signal generator(s), communication bus(es), controllers, I/O interface, address registers, and so on. It is to be appreciated that some overlap in definitions is anticipated, and an architecture or a system can be a stand-alone component, or a component of another architecture, system, etc.

In addition to the foregoing, the disclosed subject matter can be implemented as a method, apparatus, or article of manufacture using typical manufacturing, programming or engineering techniques to produce hardware, firmware, software, or any suitable combination thereof to control an electronic device to implement the disclosed subject matter. The terms “apparatus” and “article of manufacture” where used herein are intended to encompass an electronic device, a semiconductor device, a computer, or a computer program accessible from any computer-readable device, carrier, or media. Computer-readable media can include hardware media, or software media. In addition, the media can include non-transitory media, or transport media. In one example, non-transitory media can include computer readable hardware media. Specific examples of computer readable hardware media can include but are not limited to magnetic storage devices (e.g., hard disk, floppy disk, magnetic strips . . .), optical disks (e.g., compact disk (CD), digital versatile disk (DVD) . . .), smart cards, and flash memory devices (e.g., card, stick, key drive . . .). Computer-readable transport media can include carrier waves, or the like. Of course, those skilled in the art will recognize many modifications can be made to this configuration without departing from the scope or spirit of the disclosed subject matter.

What has been described above includes examples of the subject innovation. It is, of course, not possible to describe every conceivable combination of components or methodologies for purposes of describing the subject innovation, but one of ordinary skill in the art can recognize that many further combinations and permutations of the subject innovation are possible. Accordingly, the disclosed subject matter is intended to embrace all such alterations, modifications and variations that fall within the spirit and scope of the disclosure. Furthermore, to the extent that a term “includes,” “including,” “has” or “having” and variants thereof is used in either the detailed description or the claims, such term is intended to be inclusive in a manner similar to the term

“comprising” as “comprising” is interpreted when employed as a transitional word in a claim.

Moreover, the word “exemplary” is used herein to mean serving as an example, instance, or illustration. Any aspect or design described herein as “exemplary” is not necessarily to be construed as preferred or advantageous over other aspects or designs. Rather, use of the word exemplary is intended to present concepts in a concrete fashion. As used in this application, the term “or” is intended to mean an inclusive “or” rather than an exclusive “or”. That is, unless specified otherwise, or clear from context, “X employs A or B” is intended to mean any of the natural inclusive permutations. That is, if X employs A; X employs B; or X employs both A and B, then “X employs A or B” is satisfied under any of the foregoing instances. In addition, the articles “a” and “an” as used in this application and the appended claims should generally be construed to mean “one or more” unless specified otherwise or clear from context to be directed to a singular form.

Additionally, some portions of the detailed description have been presented in terms of algorithms or process operations on data bits within electronic memory. These process descriptions or representations are mechanisms employed by those cognizant in the art to effectively convey the substance of their work to others equally skilled. A process is here, generally, conceived to be a self-consistent sequence of acts leading to a desired result. The acts are those requiring physical manipulations of physical quantities. Typically, though not necessarily, these quantities take the form of electrical and/or magnetic signals capable of being stored, transferred, combined, compared, and/or otherwise manipulated.

It has proven convenient, principally for reasons of common usage, to refer to these signals as bits, values, elements, symbols, characters, terms, numbers, or the like. It should be borne in mind, however, that all of these and similar terms are to be associated with the appropriate physical quantities and are merely convenient labels applied to these quantities. Unless specifically stated otherwise or apparent from the foregoing discussion, it is appreciated that throughout the disclosed subject matter, discussions utilizing terms such as processing, computing, calculating, determining, or displaying, and the like, refer to the action and processes of processing systems, and/or similar consumer or industrial electronic devices or machines, that manipulate or transform data represented as physical (electrical and/or electronic) quantities within the registers or memories of the electronic device(s), into other data similarly represented as physical quantities within the machine and/or computer system memories or registers or other such information storage, transmission and/or display devices.

Unless otherwise indicated, all numbers, values and/or expressions referring to characteristics (e.g. speed) used in the specification and claims are to be understood as modified in all instances by the term “about.”

In regard to the various functions performed by the above described components, architectures, circuits, processes and the like, the terms (including a reference to a “means”) used to describe such components are intended to correspond, unless otherwise indicated, to any component which performs the specified function of the described component (e.g., a functional equivalent), even though not structurally equivalent to the disclosed structure, which performs the function in the herein illustrated exemplary aspects of the embodiments. In addition, while a particular feature may have been disclosed with respect to only one of several implementations, such feature may be combined with one or more other features of the other implementations as may be desired and advantageous for any given or particular application. It will

also be recognized that the embodiments include a system as well as a computer-readable medium having computer-executable instructions for performing the acts and/or events of the various processes.

What is claimed is:

1. A cable assembly, comprising:
 - a transceiver device configured for communicating a plurality of signals via a communication link, and comprising a memory storing executable instructions; and
 - a processor, communicatively coupled to the memory, that facilitates execution of the executable instructions to perform operations, comprising:
 - constructing a constellation diagram by generating a dimensional vector of phase amplitude modulated points mapped to a leech lattice, wherein the phase amplitude modulated points are generated with two bits at a time and signal amplitudes are mapped to one of four amplitude levels; and
 - translating the constellation diagram based on the leech lattice to the plurality of signals.
2. The cable assembly of claim 1, wherein the dimensional vector is a twenty-four dimensional vector.
3. The cable assembly of claim 1, wherein the transceiver device is further configured for transmitting one bit per dimension based on points of the constellation diagram.
4. The cable assembly of claim 1, wherein the transceiver device is further configured for transmitting more than one bit at a time based on a translation of points of the constellation diagram to translation vectors of multiples of $4m$, where m is an integer.
5. The cable assembly of claim 1, wherein the transceiver device is further configured for communicating the plurality of signals via the communication link comprising an optical link at a speed of 100 Gbps or greater.
6. The cable assembly of claim 1, further comprising a decoder configured for decoding the plurality of signals received via the communication link based on the leech lattice and increases a coding gain of the communication link.
7. The cable assembly of claim 1, wherein the transceiver device is further configured for transmitting more than one bit at a time by augmenting the constellation diagram based on the leech lattice with a translation vector comprising a number of vector elements with integers in a form of $4m$, where m equals an integer, and the number of elements corresponds to a number of bits being transmitted at the time.
8. The cable assembly of claim 1, wherein the leech lattice is embedded.
9. The cable assembly of claim 1, wherein the transceiver device is passively powered and draws power from the plurality of signals.
10. The cable assembly of claim 1, wherein the transceiver device is actively powered and draws power from a power source coupled to the cable assembly.
11. A transceiver device comprising:
 - a memory to store computer-executable instructions; and
 - a processor, coupled to the memory, that facilitates execution of the computer-executable instructions to perform operations, comprising:
 - mapping one or more dimensional vectors of one or more phase amplitude modulated points to a leech lattice in a constellation diagram;
 - translating the constellation diagram based on the leech lattice to a plurality of signals for a communication via a communication link; and
 - encoding the plurality of signals for the communication based on translation vectors generated via the translating.

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12. The transceiver device of claim 11, wherein the operations further comprise:

translating the constellation diagram based on the leech lattice by analyzing a twenty-four dimensional array of PAM-4 symbols and encoding the plurality of signals to be communicated via the communication link.

13. The transceiver device of claim 11, wherein the operations further comprise:

detecting a timing differential between a received communication comprising the plurality of signals encoded and a detected signal.

14. The transceiver device of claim 11, wherein the operations further comprise:

reducing an error rate in detecting a transmitted constellation point of the plurality of signals.

15. The transceiver device of claim 14, wherein the operations further comprise:

receiving a detection signal and detecting a time differential between a received signal and the detection signal.

16. A constellation translation method, comprising:

constructing, by a device with a processor, a constellation diagram by generating a plurality of dimensional vectors of phase modulated points mapped to a leech lattice; translating the constellation diagram based on the leech lattice to a plurality of signals;

communicating the plurality of signals via a communication link;

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generating a plurality of translation vectors according to the constellation diagram; and

encoding the plurality of signals for the communicating based on the plurality of translation vectors.

17. The constellation translation method of claim 16, further comprising:

transmitting more than one bit at a time based on a translation of points of the constellation diagram to translation vectors of multiples of $4m$, where m is an integer.

18. The constellation translation method of claim 16, further comprising:

transmitting more than one bit at a time by augmenting the constellation diagram based on the leech lattice with a translation vector comprising a number of vector elements with integers in a form of $4m$, where m equals an integer, and the number of elements corresponds to a number of bits being transmitted at the time.

19. The constellation translation method of claim 16, further comprising:

detecting a timing differential between a received communication comprising the plurality of signals encoded and a detected signal.

20. The constellation translation method of claim 19, further comprising:

driving a clock recover loop by utilizing the timing differential detected.

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