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TRANSMITTING DEVICE, TRANSMITTING AND RECEIVING SYSTEM USING THE TRANSMITTING DEVICE, AND TRANSMITTING AND RECEIVING METHOD

Abstract

A transmitting device is configured to generate a first encoded symbol and a second encoded symbol by encoding a first burst and a second burst, respectively. The transmitting device is configured to generate a first transmitting symbol and a second transmitting symbol by selectively inverting the first and second encoded symbols on the basis of a logic level of a bit with a specific sequence number of each of a previously generated transmitting symbol and the first burst.

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Background/Summary

CROSS-REFERENCES TO RELATED APPLICATION [0001] The present application is a continuation application of U.S. patent application Ser. No. 18/085,026, filed on Dec. 20, 2022, which claims priority under 35 U.S.C. § 119 (a) to Korean application number 10-2022-0077009, filed on Jun. 23, 2022, in the Korean Intellectual Property Office, which applications are incorporated herein by reference in their entirety.

BACKGROUND

1. Technical Field

[0002] The present disclosure relates to an integrated circuit technology, and more particularly, to a transmitting device, a transmitting and receiving system using the transmitting device, and a transmitting and receiving method.

2. Related Art

[0003] An electronic device includes many electronic components, and among them, a computer system may include many semiconductor devices each made of semiconductors. The semiconductor devices constituting the computer system may communicate with each other by transmitting and receiving clock signals and data. The semiconductor devices may be connected to other semiconductor devices through a signal bus such as a data bus, and may transmit a signal having information corresponding to data through the signal bus. The semiconductor devices may each include a signal transmitting circuit in order to transmit the signal through the signal bus, and the signal transmitting circuit may transmit the signal by transmitting an analog voltage through the signal bus. In general, the signal transmitting circuit may transmit an analog voltage corresponding to a high logic level and an analog voltage corresponding to a low logic level. However, in order to transmit more information through one-time signal transmission, a multi-level signal transmission method using pulse amplitude modulation (PAM) is used. In the multi-level signal transmission method, two or more bits of digital information may be transmitted as one analog signal by subdividing the level of the analog voltage transmitted through the signal bus.

SUMMARY

[0004] A transmitting device according to an embodiment of the present disclosure may include an inversion determination circuit, an encoding block, and an inversion block. The inversion determination circuit may be configured to generate a first inversion signal and a second inversion signal on the basis of a logic level of a bit with a specific sequence number of each of a previously generated transmitting symbol and a first burst. The encoding block may be configured to generate a first encoded symbol and a second encoded symbol by encoding the first burst and a second burst. The inversion block may be configured to generate a first transmitting symbol by selectively inverting the first encoded symbol on the basis of the first inversion signal, and to generate a second transmitting symbol by selectively inverting the second encoded symbol on the basis of the second inversion signal.

[0005] A transmitting and receiving method according to an embodiment of the present disclosure may include dividing output data into a plurality of bursts. The method may include determining whether a bit with a specific sequence number of each of a previously generated transmitting symbol and a bit with a specific sequence number of each of the plurality of bursts each have a first

logic level. The method may include generating a plurality of encoded symbols by encoding the plurality of bursts so that a maximum transition is avoided. The method may include generating a plurality of transmitting symbols by selectively inverting the plurality of encoded symbols on the basis of a result of the determination. The method may include transmitting a PAM-4 signal on the basis of the plurality of transmitting symbols.

[0006] A transmitting and receiving system according to an embodiment of the present disclosure may include a transmitting device configured to transmit a PAM-4 signal and a receiving device configured to receive the PAM-4 signal. The transmitting device may include a symbol encoding circuit and a transmitting circuit. The symbol encoding circuit may be configured to divide output data into a first burst and a second burst, to generate a first encoded symbol and a second encoded symbol by encoding the first burst and the second burst, to generate a first transmitting symbol by selectively inverting the first encoded symbol on the basis of a logic level of a bit with a specific sequence number of a previously generated transmitting symbol, and to generate a second transmitting symbol by selectively inverting the second encoded symbol on the basis of a logic level of a bit with a specific sequence number of the first burst. The transmitting circuit may be configured to transmit the PAM-4 signal on the basis of the first and second transmitting symbols.

Description

BRIEF DESCRIPTION OF THE DRAWINGS

[0007] FIG. 1 is a diagram illustrating a configuration of a semiconductor system in accordance with an embodiment of the present disclosure and a voltage level of a transmitted signal transmitted through a transmission signal bus.

[0008] FIG. 2 is a diagram illustrating a configuration of a transmitting and receiving system in accordance with an embodiment of the present disclosure.

[0009] FIG. 3 is a flowchart illustrating an operation of a transmitting device in accordance with an embodiment of the present disclosure.

[0010] FIG. 4 is a flowchart illustrating an operation of a receiving device in accordance with an embodiment of the present disclosure.

[0011] FIG. 5 is a diagram illustrating a configuration of a symbol encoding circuit illustrated in FIG. 2.

[0012] FIG. 6 is a diagram illustrating an example of a 7:8 codebook in accordance with an embodiment of the present disclosure.

[0013] FIG. 7 is a diagram illustrating a configuration of a transmitting circuit illustrated in FIG. 2.

[0014] FIG. 8 is a diagram illustrating a configuration of a receiving circuit illustrated in FIG. 2.

[0015] FIG. 9 is a diagram illustrating a configuration of a symbol decoding circuit illustrated in FIG. 2.

DETAILED DESCRIPTION

[0016] FIG. 1 is a diagram illustrating a configuration of a semiconductor system **1** in accordance with an embodiment of the present disclosure and a voltage level of a transmitted signal PS transmitted through a transmission signal bus **101**. In FIG. 1, the semiconductor system **1** may include a first semiconductor device **110** and a second semiconductor device **120**. The first semiconductor device **110** may provide various control signals necessary for an operation of the second semiconductor device **120**. The first semiconductor device **110** may include various types of host devices. For example, the first semiconductor device **110** may include at least one of a central processing unit (CPU), a graphics processing unit (GPU), a multi-media processor (MMP), a digital signal processor, an application processor (AP), and a memory controller. The second semiconductor device **120** may be, for example, a memory device, and examples of the memory device may include a volatile memory and a nonvolatile memory. Examples of the volatile memory

may include a static RAM (SRAM), a dynamic RAM (DRAM), and a synchronous DRAM (SDRAM), and examples of the nonvolatile memory may include a read only memory (ROM), a programmable ROM (PROM), and an electrically erasable and programmable memory (EEPROM), an electrically programmable ROM (EPROM), a flash memory, a phase change RAM (PRAM), a magnetic RAM (MRAM), a resistive RAM (RRAM), a ferroelectric RAM (FRAM), and the like.

[0017] The second semiconductor device **120** may be connected to the first semiconductor device **110** through a plurality of buses. The plurality of buses may be signal transmission lines, links, or channels for transmitting signals. Although not illustrated in the drawing, for example, the plurality of buses may include a clock bus, a command address bus, a data bus, or the like. The clock bus and the command address bus may be unidirectional buses, and the data bus may be a bidirectional bus. The second semiconductor device **120** may be connected to the first semiconductor device **110** through the transmission signal bus **101**. The transmission signal bus **101** may include any type of bus for transmitting a signal synchronized with a clock signal. For example, the transmission signal bus **101** may be a bidirectional bus such as the data bus. In an embodiment, the transmission signal bus **101** may be a unidirectional bus, and even when the transmission signal bus **101** is a unidirectional bus, the technical spirit of the present disclosure may be similarly applied. The transmitted signal PS transmitted through the transmission signal bus **101** may be a multi-level signal. For example, the transmitted signal PS may be a 4-level pulse amplitude modulation (PAM-4) signal that may have at least four different voltage levels. The transmitted signal PS may have one of the four different voltage levels according to a value of a symbol. The symbol may include at least two binary bits. The symbol may have at least a first state, a second state, a third state, and a fourth state. The first state may correspond to a logic value of 0, 0, the second state may correspond to a logic value of 0, 1, the third state may correspond to a logic value of 1, 0, and the fourth state may correspond to a logic value of 1, 1. The transmitted signal PS may have a first voltage level **V1**, a second voltage level **V2**, a third voltage level **V3**, and a fourth voltage level **V4**.

[0018] The graph illustrated in FIG. **1** is a diagram illustrating the voltage level of the transmitted signal PS transmitted through the transmission signal bus **101**. In the graph, an x-axis may denote time and a y-axis may denote voltage. In order to transmit a symbol in the first state, the transmitted signal PS may have the first voltage level **V1**. In order to transmit a symbol in the second state, the transmitted signal PS may have the second voltage level **V2**. In order to transmit a symbol in the third state, the transmitted signal PS may have the third voltage level **V3**. In order to transmit a symbol in the fourth state, the transmitted signal PS may have the fourth voltage level **V4**. The second voltage level **V2** may be higher than the first voltage level **V1**, the third voltage level **V3** may be higher than the second voltage level **V2**, and the fourth voltage level **V4** may be higher than the third voltage level **V3**. The transmitted signal PS may substantially maintain a current voltage level or the voltage level thereof may be changed to three other voltage levels depending on whether the state of the symbol transitions. For example, when the symbol transitions from the second state to the third state, the voltage level of the transmitted signal PS may be changed from the second voltage level **V2** to the third voltage level **V3**.

[0019] The first semiconductor device **110** may include a transmitting device **111** and a receiving device **112**. The transmitting device **111** and the receiving device **112** may be connected to the transmission signal bus **101** through a pad **113**. The transmitting device **111** may receive an internal signal **IS1** of the first semiconductor device **110** and transmit a transmitted signal PS generated on the basis of the internal signal **IS1** to the second semiconductor device **120** through the pad **113** and the transmission signal bus **101**. The receiving device **112** may receive the transmitted signal PS transmitted through the transmission signal bus **101** and the pad **113**, and generate the internal signal **IS1** on the basis of the transmitted signal PS. For example, the transmitting device **111** may generate the transmitted signal PS having one of the first to fourth voltage levels **V1** to **V4** according to a state of a symbol generated on the basis of a bit stream of the internal signal **IS1**.

The transmitting device **111** may include a digital to analog converter (DAC) that converts the bit stream of the internal signal **IS1**, which is a digital signal, into the transmitted signal **PS** which is an analog voltage. The receiving device **112** may detect a voltage level of the transmitted signal **PS** and restore the bit stream from the transmitted signal **PS**. The receiving device **112** may restore the symbol from the transmitted signal **PS** and generate the bit stream of the internal signal **IS1** on the basis of the symbol. The receiving device **112** may include an analog to digital converter (ADC) that converts the transmitted signal **PS**, which is an analog voltage, into the bit stream which is a digital signal.

[0020] The second semiconductor device **120** may include a transmitting device **121** and a receiving device **122**. The transmitting device **121** and the receiving device **122** may be connected to the transmission signal bus **101** through a pad **123**. The transmitting device **121** may receive an internal signal **IS2** of the second semiconductor device **120** and transmit a transmitted signal **PS** generated on the basis of the internal signal **IS2** to the first semiconductor device **110** through the pad **123** and the transmission signal bus **101**. The receiving device **122** may receive the transmitted signal **PS** transmitted through the transmission signal bus **101** and the pad **123**, and generate the internal signal **IS2** on the basis of the transmitted signal **PS**. For example, the transmitting device **121** may generate the transmitted signal **PS** having one of the first to fourth voltage levels **V1** to **V4** according to a state of a symbol generated on the basis of a bit stream of the internal signal **IS2**. The transmitting device **121** may include a digital to analog converter (DAC) that converts the bit stream of the internal signal **IS2**, which is a digital signal, into the transmitted signal **PS** which is an analog voltage. The receiving device **122** may detect a voltage level of the transmitted signal **PS** and restore the bit stream from the transmitted signal **PS**. The receiving device **122** may restore the symbol from the transmitted signal **PS** and generate the bit stream of the internal signal **IS2** on the basis of the symbol. The receiving device **122** may include an analog to digital converter (ADC) that converts the transmitted signal **PS**, which is an analog voltage, into the bit stream which is a digital signal.

[0021] FIG. **2** is a diagram illustrating a configuration of a transmitting and receiving system **200** according to an embodiment of the present disclosure. Referring to FIG. **2**, the transmitting and receiving system **200** may include a transmitting device **210** and a receiving device **220**. The transmitting device **210** may transmit a PAM-4 signal **PSM** to the receiving device **220**, and the receiving device **220** may receive the PAM-4 signal **PSM** transmitted from the transmitting device **210**. The transmitting device **210** and the receiving device **220** may be provided in different semiconductor devices. The transmitting device **210** may be applied as each of the transmitting devices **111** and **121** illustrated in FIG. **1**, and the receiving device **220** may be applied as each of the receiving devices **112** and **122** illustrated in FIG. **1**. In an embodiment, the transmitting device **210** may also be provided in the same semiconductor device as the receiving device **220**.

[0022] The transmitting device **210** may divide a full burst **DO<0:31>** corresponding to output data into a plurality of bursts, and generate a plurality of symbols on the basis of each burst. The full burst may include at least 16 bits, and may be divided into at least two bursts. In FIG. **2**, the full burst **DO<0:31>** of the output data may be 32 bits, and the full burst may be divided by 8 bits. The output data may be divided into a first burst **DO<0:7>**, a second burst **DO<8:15>**, a third burst **DO<16:23>** and a fourth burst **DO<24:31>**. However, such division of the output data does not intend to limit the number of bits and the number of bursts in the full burst, and the number of bits and the number of bursts in the full burst may be variously changed. The transmitting device **210** may generate the PAM-4 signal **PSM** on the basis of the plurality of symbols and transmit the PAM-4 signal **PSM** to the receiving device **220** through a first transmission signal bus **201**. The PAM-4 signal **PSM** may be a multi-level signal having a plurality of voltage levels as illustrated in FIG. **1**. The first transmission signal bus **201** may be a bidirectional bus and a data bus. The receiving device **220** may receive the PAM-4 signal **PSM** through the first transmission signal bus **201** and restore the plurality of symbols from the PAM-4 signal **PSM**. The receiving device **220**

may generate a full burst $DI<0:31>$ corresponding to input data on the basis of the restored symbols. The input data may have a value corresponding to the output data.

[0023] The transmitting device **210** may include a symbol encoding circuit **211** and a transmitting circuit **212**. The symbol encoding circuit **211** may receive the full burst $DO<0:31>$ of the output data. The full burst $DO<0:31>$ of the output data may be 32 bits, and may be divided into the first burst $DO<0:7>$, the second burst $DO<8:15>$, the third burst $DO<16:23>$, and the fourth burst $DO<24:31>$ each including 8 bits. The symbol encoding circuit **211** may generate first to fourth encoded symbols by encoding the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$. The symbol encoding circuit **211** may encode the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$ into the first to fourth encoded symbols on the basis of a code book. The code book may map the burst to a symbol capable of avoiding a maximum transition. The maximum transition may mean that a voltage level change occurring between consecutively transmitted PAM-4 signals is maximum. For example, when a previously transmitted PAM-4 signal has the first voltage level $V1$ or the fourth voltage level $V4$ illustrated in FIG. 1 and a currently transmitted PAM-4 signal has the fourth voltage level $V4$ or the first voltage level $V1$, the maximum transition may occur. The maximum transition may reduce an effective duration of the PAM-4 signal and increase consumption of power required for transmitting the PAM-4 signal. Accordingly, in an embodiment, the symbol encoding circuit **211** may convert the burst into a symbol capable of avoiding the maximum transition according to the code book, thereby reducing power used for transmitting the PAM-4 signal and extending the effective duration of the PAM-4 signal.

[0024] When a plurality of encoded symbols corresponding to a plurality of bursts are transmitted as the PAM-4 signal, the symbol encoding circuit **211** may selectively invert the plurality of encoded symbols to avoid a maximum transition between the plurality of encoded symbols. The symbol encoding circuit **211** may invert the most significant bits of the plurality of encoded symbols. For example, when a PAM-4 signal corresponding to the last symbol of the first encoded symbol is transmitted and then a PAM-4 signal corresponding to a first symbol of the second encoded symbol is transmitted, the symbol encoding circuit **211** may determine whether a maximum transition occurs between the two PAM-4 signals and invert the most significant bits of the second encoded symbol, on the basis the determination result. The symbol encoding circuit **211** may generate a plurality of transmitting symbols $TS<0:31>$ by selectively inverting the plurality of encoded symbols. The symbol encoding circuit **211** may generate a first transmitting symbol $TS<0:7>$ by selectively inverting the first encoded symbol, and generate a second transmitting symbol $TS<8:15>$ by selectively inverting the second encoded symbol. The symbol encoding circuit **211** may generate a third transmitting symbol $TS<16:23>$ by selectively inverting the third encoded symbol, and generate a fourth transmitting symbol $TS<24:31>$ by selectively inverting the fourth encoded symbol.

[0025] The symbol encoding circuit **211** may determine whether to invert the first encoded symbol on the basis of the logic level of a bit with a specific sequence number of a previously generated transmitting symbol. The symbol encoding circuit **211** may determine whether to invert the second encoded symbol on the basis of a logic level of a bit with a specific sequence number of the first burst $DO<0:7>$. The symbol encoding circuit **211** may determine whether to invert the third encoded symbol on the basis of a logic level of a bit with a specific sequence number of the second burst $DO<8:15>$. The symbol encoding circuit **211** may determine whether to invert the fourth encoded symbol on the basis of a logic level of a bit with a specific sequence number of the third burst $DO<16:23>$. The bit with the specific sequence number may be the last most significant bit of each of the transmitting symbol and the burst. The symbol encoding circuit **211** may invert each of the plurality of encoded symbols when the last most significant bits of the transmitting symbol and the burst each have a first logic level, and might not invert each of the plurality of encoded symbols when the last most significant bits each have a second logic level. The first logic level may be a

high logic level and the second logic level may be a low logic level. In an embodiment, the first logic level may be a low logic level and the second logic level may be a high logic level. Since the symbol encoding circuit **211** uses a previously generated transmitting symbol in order to determine whether to invert the first encoded symbol, and uses the first to third bursts DO<0:7>, DO<8:15>, and DO<16:31> instead of the previously generated transmitting symbol in order to determine whether to invert the second to fourth encoded symbols, time for converting the burst into the transmitting symbol in order to avoid the maximum transition may be shortened and the number of required logic stages and a delay time may be reduced. Accordingly, a high-speed operation of the transmitting and receiving system **200** may be implemented. In an embodiment, the symbol encoding circuit **211** may be modified to invert each of the plurality of encoded symbols when the last most significant bit has a second logic level and not to invert each of the plurality of encoded symbols when the last most significant bit has a first logic level.

[0026] The symbol encoding circuit **211** may extract at least one bit of each of the first to fourth bursts DO<0:7>, DO<8:15>, DO<16:23>, and DO<24:31>, and generate an interleaved symbol IS<0:3> on the basis of the extracted bits. The symbol encoding circuit **211** may generate the encoded symbol by encoding the remaining bits of the burst except for the bits extracted in order to generate the interleaved symbol IS<0:3>. The present disclosure is not limited thereto, and the at least one bit may be the first bit DO<0> of the first burst DO<0:7>, the first bit DO<8> of the second burst DO<8:15>, the first bit DO<16> of the third burst DO<16:23>, and the first bit DO<24> of the fourth burst DO<24:31>.

[0027] The transmitting circuit **212** may be connected to the symbol encoding circuit **211** and may receive the plurality of transmitting symbols TS<0:31> from the symbol encoding circuit **211**. The transmitting circuit **212** may generate the PAM-signal PSM on the basis of the plurality of transmitting symbols TS<0:31>. The transmitting circuit **212** may transmit the PAM-4 signal PSM to the receiving device **220** by driving the first transmission signal bus **201** on the basis of the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:23>, and TS<24:31>. The transmitting circuit **212** may serialize the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:23>, and TS<24:31>, and sequentially transmit the PAM-4 signal PSM corresponding to the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:23>, and TS<24:31>.

[0028] The transmitting circuit **212** may further receive the interleaved symbol IS<0:3> from the symbol encoding circuit **211**. The transmitting circuit **212** may transmit a PAM-4 signal PSI on the basis of the interleaved symbol IS<0:3>. The transmitting circuit **212** may transmit the PAM-4 signal PSI through a second transmission signal bus **202** different from the first transmission signal bus **201**. The second transmission signal bus **202** may be a data bus or any bidirectional bus. In an embodiment, the transmitting circuit **212** may transmit the PAM-4 signal PSM corresponding to the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:23>, and TS<24:31> and then transmit the PAM-4 signal PSI corresponding to the interleaved symbol IS<0:3> through the first transmission signal bus **201**. The transmitting circuit **212** may transmit the PAM-4 signal PSI generated on the basis of the interleaved symbol IS<0:3> at the same time or after the PAM-4 signal PSM generated on the basis of the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:23>, and TS<24:31> is transmitted.

[0029] The receiving device **220** may include a receiving circuit **221** and a symbol decoding circuit **222**. The receiving circuit **221** may be connected to the first transmission signal bus **201** and may receive the PAM-4 signal PSM transmitted from the transmitting device **210** through the first transmission signal bus **201**. The receiving circuit **221** may generate a plurality of received symbols RS<0:31> on the basis of the PAM-4 signal PSM. The receiving circuit **221** may receive a first received symbol RS<0:7>, a second received symbol RS<8:15>, a third received symbol RS<16:23>, and a fourth received symbol RS<24:31> from the PAM-4 signal PSM sequentially transmitted. The first received symbol RS<0:7> may have substantially the same logic value as the first transmitting symbol TS<0:7>, and the second received symbol RS<8:15> may have

substantially the same logic value as the second transmitting symbol TS<8:15>. The third received symbol RS<16:23> may have substantially the same logic value as the third transmitting symbol TS<16:23>, and the fourth received symbol RS<24:31> may have substantially the same logic value as the fourth transmitting symbol TS<24:31>. The receiving circuit **221** may be further connected to the second transmission signal bus **202**. The receiving circuit **221** may receive the PAM-4 signal PSI through the first transmission signal bus **201** or the second transmission signal bus **202**. The receiving circuit **221** may generate the interleaved symbol IS<0:3> on the basis of the PAM-4 signal PSI.

[0030] The symbol decoding circuit **222** may be connected to the receiving circuit **221** and may receive the plurality of received symbols RS<0:31> from the receiving circuit **221**. The symbol decoding circuit **222** may generate a plurality of decoded symbols by selectively inverting the plurality of received symbols RS<0:31>. The symbol decoding circuit **222** may determine whether a symbol has been inverted by the symbol encoding circuit **221** and selectively invert the plurality of received symbols RS<0:31> according to the determination result. The symbol decoding circuit **222** may generate a first decoded symbol by selectively inverting the first received symbol RS<0:7>, and generate a second decoded symbol by selectively inverting the second received symbol RS<8:15>. The symbol decoding circuit **222** may generate a third decoded symbol by selectively inverting the third received symbol RS<16:23>, and generate a fourth decoded symbol by selectively inverting the fourth received symbol RS<24:31>. The symbol decoding circuit **222** may invert the most significant bits of the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31>.

[0031] The symbol decoding circuit **222** may determine whether to invert the plurality of received symbols RS<0:31> on the basis of a previously generated received symbol and a previously received symbol. The symbol decoding circuit **222** may determine whether to invert the plurality of received symbols RS<0:31> on the basis of the logic level of a bit with a specific sequence number of each of the previously generated received symbol and the previously received symbol. The symbol decoding circuit **222** may determine whether to invert the first received symbol RS<0:7> on the basis of the logic level of a bit with a specific sequence number of a received symbol generated before the plurality of received symbols are generated. The symbol decoding circuit **222** may determine whether to invert the second received symbol RS<8:15> on the basis of the logic level of a bit with a specific sequence number of the first received symbol RS<0:7>. The symbol decoding circuit **222** may determine whether to invert the third received symbol RS<16:23> on the basis of the logic level of a bit with a specific sequence number of the second received symbol RS<8:15>. The symbol decoding circuit **222** may determine whether to invert the fourth received symbol RS<24:31> on the basis of the logic level of a bit with a specific sequence number of the third received symbol RS<16:23>. The bit with the specific sequence number may be the last most significant bit of the received symbol. The symbol decoding circuit **222** may invert the most significant bits of the plurality of received symbols when the last most significant bit of each received symbol has a first logic level, and might not invert the most significant bits of the plurality of received symbols when the last most significant bit has a second logic level. In an embodiment, the symbol decoding circuit **222** may be modified to invert the most significant bits of the plurality of received symbols when the last most significant bit of each received symbol has a second logic level, and not to invert the last most significant bits of the plurality of received symbols when the last most significant bit has a first logic level. When the symbol encoding circuit **211** detects whether the last most significant bits of a transmitting symbol and a burst each have a first logic level and inverts an encoded symbol, the symbol decoding circuit **222** may detect whether the last most significant bit of a previously received symbol has a first logic level and invert the received symbol. On the other hand, when the symbol encoding circuit **211** detects whether the last most significant bits of a transmitting symbol and a burst each have a second logic level and inverts an encoded symbol, the symbol decoding circuit **222** may detect whether the last most significant bit

of a previously received symbol has a second logic level and invert the received symbol.

[0032] The symbol decoding circuit **222** may generate a plurality of decoded bursts by decoding the plurality of decoded symbols, and generate input data on the basis of the plurality of decoded bursts. The symbol decoding circuit **222** may further receive the interleaved symbol $IS<0:3>$. The symbol decoding circuit **222** may generate the full burst $DI<0:31>$ of the input data by combining the plurality of decoded bursts with the interleaved symbol $IS<0:3>$. The full burst $DI<0:31>$ of the input data may have substantially the same logic value as the full burst $DO<0:31>$ of the output data of the transmitting device **210**.

[0033] FIG. **3** is a flowchart illustrating the operation of the transmitting device **210** illustrated in FIG. **2**. Referring to FIG. **2** and FIG. **3**, the transmitting device **210** according to an embodiment of the present disclosure may operate as follows. In an embodiment, the transmitting device **210** may encode symbols for generating the PAM-4 signal PSM in order to avoid the occurrence of a maximum transition in the PAM-4 signal PSM transmitted through the first transmission signal bus **201**. In step **S31**, the symbol encoding circuit **211** may receive the full burst $DO<0:31>$ of the output data. In step **S32**, the full burst $DO<0:31>$ of the output data provided to the symbol encoding circuit **211** may be divided into a plurality of bursts. For example, the symbol encoding circuit **211** may divide 32-bit output data into the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$ each including 8 bits. In step **S33**, the symbol encoding circuit **211** may extract at least one bit of each of the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$ in order to generate the interleaved symbol $IS<0:3>$. The extracted bits may be used to generate the interleaved symbol $IS<0:3>$. In step **S34**, it may be determined whether a bit with a specific sequence number of a previously generated transmitting symbol and a bit with a specific sequence number of each burst are each 1. Whether to invert the encoded symbol may be determined according to whether the bit with the specific sequence number of the previously generated transmitting symbol and the bit with the specific sequence number of each burst are each 1.

[0034] Step **S35** may be performed in parallel with step **S34**. In step **S35**, each burst may be encoded and generated as a plurality of encoded symbols. The symbol encoding circuit **211** may generate the first to fourth encoded symbols by performing 7:8 encoding on the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$. When the result of step **S34** is “No”, the plurality of encoded symbols might not be inverted and may be provided as the plurality of transmitting symbols $TS<0:31>$ in step **S36**. When the result of step **S34** is “YES”, the plurality of encoded symbols may be inverted and the plurality of inverted encoded symbols may be provided as the plurality of transmitting symbols $TS<0:31>$ in step **S37**. The symbol encoding circuit **211** may generate the plurality of transmitting symbols $TS<0:31>$ by inverting the most significant bits of the plurality of encoded symbols. In step **S38**, the PAM-4 signal may be transmitted on the basis of the transmitting symbol. The transmitting circuit **212** may receive the plurality of transmitting symbols $TS<0:31>$ output from the symbol encoding circuit **211**. The transmitting circuit **212** may transmit the PAM-4 signal PSM by driving the first transmission signal bus **201** on the basis of the plurality of transmitting symbols $TS<0:31>$. In step **S39**, the interleaved symbol $IS<0:3>$ may be transmitted. Step **S39** may be performed in parallel with step **S38**, or may be performed after step **S38** is performed. The transmitting circuit **212** may receive the interleaved symbol $IS<0:3>$ from the symbol encoding circuit **211**, and transmit the PAM-4 signal PSM on the basis of the interleaved symbol $IS<0:3>$. The transmitting circuit **212** may transmit the PAM-4 signal PSI by driving the first transmission signal bus **201** or the second transmission signal bus **202** on the basis of the interleaved symbol $IS<0:3>$.

[0035] FIG. **4** is a flowchart illustrating the operation of the receiving device **220** illustrated in FIG. **2**. The operation of the receiving device **220** according to an embodiment of the present disclosure will be described as follows with reference to FIG. **2** to FIG. **4**. At **S41**, the receiving device **220** may receive the PAM-4 signal PSM transmitted through the first transmission signal bus **201**. At

S42, the plurality of received symbols $RS<0:31>$ may be generated on the basis of the PAM-4 signal PSM. The receiving circuit **221** may convert the PAM-4 signal PSM into a digital signal and generate the plurality of received symbols $RS<0:31>$ on the basis of the digital signal. The plurality of received symbols $RS<0:31>$ may have substantially the same logic value as the plurality of transmitting symbols $TS<0:31>$ generated by the symbol encoding circuit **211**. At **S43**, it may be determined whether a bit with a specific sequence number of a previously generated received symbol is 1. The symbol decoding circuit **222** may receive the plurality of received symbols $RS<0:31>$. The symbol decoding circuit **222** may determine whether to invert the plurality of received symbols $RS<0:31>$ according to whether the bit with the specific sequence number of the previously generated received symbol is 1. When the result of **S43** is “No”, at **S44**, the plurality of received symbols $RS<0:31>$ might not be inverted and may be provided as the plurality of decoded symbols. When the result of **S43** is “YES”, at **S45**, the plurality of received symbols $RS<0:31>$ may be inverted and the plurality of inverted received symbols may be provided as the plurality of decoded symbols. The symbol decoding circuit **222** may generate the plurality of decoded symbols by inverting the most significant bits of the plurality of received symbols $RS<0:31>$. The plurality of decoded symbols may have substantially the same logic level as the plurality of encoded symbols generated by the symbol encoding circuit **211**. At **S46**, 8:7 decoding may be performed on the plurality of decoded symbols and the plurality of decoded bursts may be generated. The symbol decoding circuit **222** may generate the plurality of decoded bursts by decoding the plurality of decoded symbols.

[0036] In step **S47**, the interleaved symbol $IS<0:3>$ may be received. The receiving circuit **221** may receive the PAM-4 signal PSI from the first transmission signal bus **201** or the second transmission signal bus **202**, and restore the interleaved symbol $IS<0:3>$ on the basis of the PAM-4 signal PSI. The receiving circuit **221** may provide the interleaved symbol $IS<0:3>$ to the symbol decoding circuit **222**. In step **S48**, the decoded burst and the interleaved symbol $IS<0:3>$ may be combined. The symbol decoding circuit **222** may generate a plurality of bursts by combining the interleaved symbol $IS<0:3>$ and the plurality of decoded bursts, and the plurality of bursts may be provided as the full burst $DI<0:31>$ of the input data.

[0037] FIG. 5 is a diagram illustrating the configuration of the symbol encoding circuit **211** illustrated in FIG. 2. Referring to FIG. 5, the symbol encoding circuit **211** may include an encoding block **510**, an inversion determination circuit **520**, a symbol interleaving circuit **530**, and an inversion block **540**. The encoding block **510** may receive the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$ of the output data and generate first to fourth encoded symbols $ES<0:7>$, $ES<8:15>$, $ES<16:23>$, and $ES<24:31>$ by encoding the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$. At least one bit of each of the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$ may be provided to the symbol interleaving circuit **530**, and the encoding block **510** may generate the first to fourth encoded symbols $ES<0:7>$, $ES<8:15>$, $ES<16:23>$, and $ES<24:31>$ by encoding the remaining bits of each of the first to fourth bursts $DO<0:7>$, $DO<8:15>$, $DO<16:23>$, and $DO<24:31>$. In an embodiment, remaining bits of a burst may be all of the bits of the burst except at least one bit from the burst that is provided to the symbol interleaving circuit **530**. The encoding block **510** may include first to fourth encoders **511** to **514**. The first to fourth encoders **511** to **514** may each be a 7:8 encoder. The first encoder **511** may generate the first encoded symbol $ES<0:7>$ having 8 bits by encoding 7 bits of the first burst $DO<0:7>$. The second encoder **512** may generate the second encoded symbol $ES<8:15>$ having 8 bits by encoding 7 bits of the second burst $DO<8:15>$. The third encoder **513** may generate the third encoded symbol $ES<16:23>$ having 8 bits by encoding 7 bits of the third burst $DO<16:23>$. The fourth encoder **514** may generate the fourth encoded symbol $ES<24:31>$ having 8 bits by encoding 7 bits of the fourth burst $DO<24:31>$. The first to fourth encoders **511** to **514** may each map the 7-bit burst to an 8-bit encoded symbol on the basis of the code book. The first to fourth encoders **511** to **514** may each match the logic level of a bit with a specific sequence

number of the burst with the logic level of a bit with a specific sequence number of the encoded symbol. For example, the first encoder **511** may perform encoding so that the logic level of the last most significant bit DO<6> of the first burst and the logic level of the last most significant bit ES<6> of the first encoded symbol are substantially the same as each other. The second encoder **512** may perform encoding so that the logic level of the last most significant bit DO<14> of the second burst and the logic level of the last most significant bit ES<14> of the second encoded symbol are substantially the same as each other. The third encoder **513** may perform encoding so that the logic level of the last most significant bit DO<22> of the third burst and the logic level of the last most significant bit ES<22> of the third encoded symbol are substantially the same as each other. The fourth encoder **514** may perform encoding so that the logic level of the last most significant bit DO<30> of the fourth burst and the logic level of the last most significant bit ES<30> of the fourth encoded symbol are substantially the same as each other.

[0038] FIG. **6** is a diagram illustrating an example of a 7:8 code book according to an embodiment of the present disclosure. Referring to FIG. **6**, the burst may be mapped to the encoded symbol according to the code book. The encoded symbol may have a logic value capable of avoiding a maximum transition. In the code book, the seventh bit DO<6> of the burst and the seventh bit ES<6> of the encoded symbol may substantially maintain the same logic level. The first bit DO<0> of the burst may be provided to the symbol interleaving circuit **530** for interleaving. With reference to the code book, the encoded symbol ES<0:7> having 8 bits may be selected according to logic values of the second to eighth bits DO<1:7> of the burst.

[0039] Referring back to FIG. **5**, the inversion determination circuit **520** may receive a bit with a specific sequence number of each of the first to third bursts DO<0:7>, DO<8:15>, and DO<16:23>. For example, the inversion determination circuit **520** may receive a bit with a specific sequence number of each of the burst and the encoded symbol, the bits maintaining substantially the same logic value. For example, in an embodiment, the specific sequence number may be 7 and thus, the inversion determination circuit **520** may receive the seventh bit DO<6> of the first burst, the seventh bit DO<14> of the second burst, and the seventh bit DO<22> of the third burst. The inversion determination circuit **520** may generate a second inversion signal IF2 on the basis of the logic level of the seventh bit DO<6> of the first burst. The inversion determination circuit **520** may enable the second inversion signal IF2 when the logic level of the seventh bit DO<6> of the first burst is 1, and disable the second inversion signal IF2 when the logic level of the seventh bit DO<6> of the first burst is 0. The inversion determination circuit **520** may generate a third inversion signal IF3 on the basis of the logic level of the seventh bit DO<14> of the second burst. The inversion determination circuit **520** may enable the third inversion signal IF3 when the logic level of the seventh bit DO<14> of the second burst is 1, and disable the third inversion signal IF3 when the logic level of the seventh bit DO<14> of the second burst is 0. The inversion determination circuit **520** may generate a fourth inversion signal IF4 on the basis of the logic level of the seventh bit DO<22> of the third burst. The inversion determination circuit **520** may enable the fourth inversion signal IF4 when the logic level of the seventh bit DO<22> of the third burst is 1, and disable the fourth inversion signal IF4 when the logic level of the seventh bit DO<22> of the third burst is 0. The inversion determination circuit **520** may generate a first inversion signal IF1 on the basis of a transmitting symbol to be described below.

[0040] The inversion block **540** may receive the first to fourth encoded symbols ES<0:7>, ES<8:15>, ES<16:23>, and ES<24:31> from the encoding block **510**. The inversion block **540** may selectively invert the first to fourth encoded symbols ES<0:7>, ES<8:15>, ES<16:23>, and ES<24:31> on the basis of the first to fourth inversion signals IF1 to IF4, thereby generating the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:23>, and TS<24:31>. The inversion block **540** may include a first inverting circuit **541**, a second inverting circuit **542**, a third inverting circuit **543**, and a fourth inverting circuit **544**. The first inverting circuit **541** may receive the first encoded symbol ES<0:7> and the first inversion signal IF1 and selectively invert the first

encoded symbol ES<0:7> on the basis of the first inversion signal IF1, thereby generating the first transmitting symbol TS<0:7>. When the first inversion signal IF1 is enabled, the first inverting circuit **541** may generate the first transmitting symbol TS<0:7> by inverting the most significant bits ES<0>, ES<2>, ES<4>, and ES<6> of the first encoded symbol ES<0:7>. When the first inversion signal IF1 is disabled, the first inverting circuit **541** may provide the first encoded symbol ES<0:7> as is as the first transmitting symbol TS<0:7> without inverting the first encoded symbol ES<0:7>. The second inverting circuit **542** may receive the second encoded symbol ES<8:15> and the second inversion signal IF2 and selectively invert the second encoded symbol ES<8:15> on the basis of the second inversion signal IF2, thereby generating the second transmitting symbol TS<8:15>. When the second inversion signal IF2 is enabled, the second inverting circuit **542** may generate the second transmitting symbol TS<8:15> by inverting the most significant bits ES<8>, ES<10>, ES<12>, and ES<14> of the second encoded symbol ES<8:15>. When the second inversion signal IF2 is disabled, the second inverting circuit **542** may provide the second encoded symbol ES<8:15> as is as the second transmitting symbol TS<8:15> without inverting the second encoded symbol ES<8:15>. The third inverting circuit **543** may receive the third encoded symbol ES<16:23> and the third inversion signal IF3 and selectively invert the third encoded symbol ES<16:23> on the basis of the third inversion signal IF3, thereby generating the third transmitting symbol TS<16:23>. When the third inversion signal IF3 is enabled, the third inverting circuit **543** may generate the third transmitting symbol TS<16:23> by inverting the most significant bits ES<16>, ES<18>, ES<20>, and ES<22> of the third encoded symbol ES<16:23>. When the third inversion signal IF3 is disabled, the third inverting circuit **543** may provide the third encoded symbol ES<16:23> as is as the third transmitting symbol TS<16:23> without inverting the third encoded symbol ES<16:23>. The fourth inverting circuit **544** may receive the fourth encoded symbol ES<24:31> and the fourth inversion signal IF4 and selectively invert the fourth encoded symbol ES<24:31> on the basis of the fourth inversion signal IF4, thereby generating the fourth transmitting symbol TS<24:31>. When the fourth inversion signal IF4 is enabled, the fourth inverting circuit **544** may generate the fourth transmitting symbol TS<24:31> by inverting the most significant bits ES<24>, ES<26>, ES<28>, and ES<30> of the fourth encoded symbol ES<24:31>. When the fourth inversion signal IF4 is disabled, the fourth inverting circuit **544** may provide the fourth encoded symbol ES<24:31> as is as the fourth transmitting symbol TS<24:31> without inverting the fourth encoded symbol ES<24:31>.

[0041] The inversion determination circuit **520** may receive a transmitting symbol generated before the first transmitting symbol TS<0:7> is generated, and generate the first inversion signal IF1 on the basis of the previously generated transmitting symbol. The inversion determination circuit **520** may receive the fourth transmitting symbol TS<24:31>. The inversion determination circuit **520** may store the seventh bit TS<30> of the fourth transmitting symbol, and generate the first inversion signal IF1 on the basis of the logic level of the seventh bit TS<30> of the fourth transmitting symbol. When the first to fourth bursts DO<0:7>, DO<8:15>, DO<16:23>, and DO<24:31> are transmitted, the inversion decision circuit **520** may be in a state of storing the seventh bit TS<30> of the previously generated fourth transmitting symbol. The inversion determination circuit **520** may enable the first inversion signal IF1 when the seventh bit TS<30> of the previously generated fourth transmitting symbol is 1, and disable the first inversion signal IF1 when the seventh bit TS<30> of the previously generated fourth transmitting symbol is 0.

[0042] The symbol interleaving circuit **530** may receive at least one bit of each of the first to fourth bursts DO<0:7>, DO<8:15>, DO<16:23>, and DO<24:31>. The symbol interleaving circuit **530** may receive the first bits DO<0>, DO<8>, DO<16>, and DO<24> of the first to fourth bursts. The symbol interleaving circuit **530** may generate the interleaved symbol IS<0:3> on the basis of the first bits DO<0>, DO<8>, DO<16>, and DO<24> of the first to fourth bursts. For example, the symbol interleaving circuit **530** may sequentially provide the first bits DO<0>, DO<8>, DO<16>, and DO<24> of the first to fourth bursts as the first to fourth bits of the interleaved symbol

IS<0:3>.

[0043] FIG. 7 is a diagram illustrating the configuration of the transmitting circuit **212** illustrated in FIG. 2. Referring to FIG. 7, the transmitting circuit **212** may include a serializer **710** and a first transmission driver **720**. The serializer **710** may receive the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:24>, and TS<25:31> from the symbol encoding circuit **211**. The serializer **710** may sequentially output the first to fourth transmitting symbols TS<0:7>, TS<8:15>, TS<16:24>, and TS<25:31> in synchronization with a clock signal CLK. The serializer **710** may sequentially output the most significant bit MSB and the least significant bit LSB of one unit symbol in synchronization with the clock signal CLK. For example, the serializer **710** may sequentially output the four symbols TS<0:1>, TS<2:3>, TS<4:5>, and TS<6:7> of the first transmitting symbol, the four symbols TS<8:9>, TS<10:11>, TS<12:13>, and TS<14:15> of the second transmitting symbol, the four symbols TS<16:17>, TS<18:19>, TS<20:21>, and TS<22:23> of the third transmitting symbol, and the four symbols TS<24:25>, TS<26:27>, TS<28:29>, and TS<30:31> of the fourth transmitting symbol.

[0044] The first transmission driver **720** may receive the most significant bits MSB and the least significant bits LSB of the symbols from the serializer **710**. The first transmission driver **720** may be connected to the first transmission signal bus **201**, and transmit the PAM-4 signal PSM by driving the first transmission signal bus **201** on the basis of the most significant bit MSB and least significant bit LSB of the symbol output from the serializer **710**. The first transmission driver **720** may drive the first transmission signal bus **201** to one of the four different voltage levels V1 to V4 illustrated in FIG. 1, on the basis of the symbol.

[0045] The transmitting circuit **212** may further include a second transmission driver **730**. The second transmission driver **730** may receive the interleaved symbol IS<0:3> from the symbol interleaving circuit **530** of the symbol encoding circuit **211**. The second transmission driver **730** may be connected to the second transmission signal bus **202**, and may transmit the PAM-4 signal PSI by driving the second transmission signal bus **202** on the basis of the interleaved symbol IS<0:3>.

[0046] FIG. 8 is a diagram illustrating the configuration of the receiving circuit **221** illustrated in FIG. 2. Referring to FIG. 8, the receiving circuit **221** may include a first received symbol generation circuit **810** and a parallelizer **820**. The first received symbol generation circuit **810** may be connected to the first transmission signal bus **201** and may receive the PAM-4 signal PSM transmitted through the first transmission signal bus **201**. The first received symbol generation circuit **810** may receive first to third reference voltages VRL, VRC, and VRH in order to determine the logic level of the PAM-4 signal PSM. The first to third reference voltages VRL, VRC, and VRH may have different voltage levels so that the voltage level of the PAM-4 signal PSM may be determined. Referring to FIG. 1 together, the first reference voltage VRL may have a voltage level between the first voltage level V1 and the second voltage level V2. The second reference voltage VRC may have a voltage level between the second voltage level V2 and the third voltage level V3. The third reference voltage VRH may have a voltage level between the third voltage level V3 and the fourth voltage level V4. The first received symbol generation circuit **810** may generate a plurality of symbols corresponding to the PAM-4 signal PSM. The symbol may include a most significant bit MSB and a least significant bit LSB. When the voltage level of the PAM-4 signal PSM is lower than the first reference voltage VRL, the first received symbol generation circuit **810** may output a symbol having a logic level of 0, 0, and when the voltage level of the PAM-4 signal PSM is between the first and second reference voltages VRL and VRC, the first received symbol generation circuit **810** may output a symbol having a logic level of 0, 1. When the voltage level of the PAM-4 signal PSM is between the second and third reference voltages VRC and VRH, the first received symbol generation circuit **810** may output a symbol having a logic level of 1, 0, and when the voltage level of the PAM-4 signal PSM is higher than the third reference voltage VRH, the first received symbol generation circuit **810** may output a symbol having a logic level of 1, 1.

[0047] The parallelizer **820** may be connected to the first received symbol generation circuit **810** and may receive the most significant bit MSB and the least significant bit LSB of the symbol generated by the first received symbol generation circuit **810**. The parallelizer **820** may receive a plurality of symbols from the first received symbol generation circuit **810** and generate the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31>. The parallelizer **820** may sequentially store the plurality of symbols in synchronization with the clock signal CLK, and output the plurality of stored symbols as the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31>. The first received symbol RS<0:7> may have substantially the same logic value as the first transmitting symbol TS<0:7>, and the second received symbol RS<8:15> may have substantially the same logic value as the second transmitting symbol TS<8:15>. The third received symbol RS<16:23> may have substantially the same logic value as the third transmitting symbol TS<16:23>, and the fourth received symbol RS<24:31> may have substantially the same logic value as the fourth transmitting symbol TS<24:31>.

[0048] The receiving circuit **221** may further include a second received symbol generation circuit **830**. The second received symbol generation circuit **830** may be connected to the second transmission signal bus **202** and may receive the PAM-4 signal PSI transmitted through the second transmission signal bus **202**. The second received symbol generation circuit **830** may receive the first to third reference voltages VRL, VRC, and VRH in order to determine the logic level of the PAM-4 signal PSI. The second received symbol generation circuit **830** may determine the voltage level of the PAM-4 signal PSI on the basis of the first to third reference voltages VRL, VRC, and VRH, and restore the interleaved symbol IS<0:3>.

[0049] FIG. **9** is a diagram showing the configuration of the symbol decoding circuit **222** illustrated in FIG. **2**. Referring to FIG. **9**, the symbol decoding circuit **222** may include an inversion determination circuit **910**, an inversion block **920**, a decoding block **930**, and a data interleaving circuit **940**. The inversion determination circuit **910** may receive a bit with a specific sequence number of each of the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31>. The inversion determination circuit **910** may generate first to fourth inversion signals IF**11** to IF**14** on the basis of the bit with the specific sequence number of each of the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31>. The inversion determination circuit **910** may receive the seventh bit RS<6> of the first received symbol, the seventh bit RS<14> of the second received symbol, the seventh bit RS<22> of the third received symbol, and the seventh bit RS<30> of the fourth received symbol. The inversion determination circuit **910** may generate the second inversion signal IF**12** on the basis of the seventh bit RS<6> of the first received symbol. The inversion determination circuit **910** may enable the second inversion signal IF**12** when the seventh bit RS<6> of the first received symbol is 1, and disable the second inversion signal IF**12** when the seventh bit RS<6> of the first received symbol is 0. The inversion determination circuit **910** may generate the third inversion signal IF**13** on the basis of the seventh bit RS<14> of the second received symbol. The inversion determination circuit **910** may enable the third inversion signal IF**13** when the seventh bit RS<14> of the second received symbol is 1, and disable the third inversion signal IF**13** when the seventh bit RS<14> of the second received symbol is 0. The inversion determination circuit **910** may generate the fourth inversion signal IF**14** on the basis of the seventh bit RS<22> of the third received symbol. The inversion determination circuit **910** may enable the fourth inversion signal IF**14** when the seventh bit RS<22> of the third received symbol is 1, and disable the fourth inversion signal IF**14** when the seventh bit RS<22> of the third received symbol is 0. The inversion determination circuit **910** may generate the first inversion signal IF**11** on the basis of the seventh bit RS<30> of a previously generated fourth received symbol. Before the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31> are inputted, the inversion determination circuit **910** may be in a state of storing the seventh bit RS<30> of the previously generated fourth received symbol. The inversion determination

circuit **910** may enable the first inversion signal IF**11** when the seventh bit RS<30> of the previously generated fourth received symbol is 1, and disable the first inversion signal IF**11** when the seventh bit RS<30> of the previously generated fourth received symbol is 0.

[0050] The inversion block **920** may receive the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31>, and receive the first to fourth inversion signals IF**11** to IF**14** from the inversion determination circuit **910**. The inversion block **920** may generate the first to fourth decoded symbols DS<0:7>, DS<8:15>, DS<16:23>, and DS<24:31> by selectively inverting the first to fourth received symbols RS<0:7>, RS<8:15>, RS<16:23>, and RS<24:31> on the basis of the first to fourth inversion signals IF**11** to IF**14**. Referring to FIG. 5 together, the first decoded symbol DS<0:7> may have substantially the same logic value as the first encoded symbol ES<0:7>, and the second decoded symbol DS<8:15> may have substantially the same logic value as the second encoded symbol ES<8:15>. The third decoded symbol DS<16:23> may have substantially the same logic value as the third encoded symbol ES<16:23>, and the fourth decoded symbol DS<24:31> may have substantially the same logic value as the fourth encoded symbol ES<24:31>.

[0051] The inversion block **920** may include a first inverting circuit **921**, a second inverting circuit **922**, a third inverting circuit **923**, and a fourth inverting circuit **924**. The first inverting circuit **921** may receive the first received symbol RS<0:7> and the first inversion signal IF**11**, and generate the first decoded symbol DS<0:7> by selectively inverting the first received symbol RS<0:7> on the basis of the first inversion signal IF**11**. When the first inversion signal IF**11** is enabled, the first inverting circuit **921** may generate the first decoded symbol DS<0:7> by inverting the most significant bits RS<0>, RS<2>, RS<4>, and RS<6> of the first received symbol RS<0:7>. When the first inversion signal IF**11** is disabled, the first inverting circuit **921** may provide the first received symbol RS<0:7> as is as the first decoded symbol DS<0:7> without inverting the first received symbol RS<0:7>. The second inverting circuit **922** may receive the second received symbol RS<8:15> and the second inversion signal IF**12**, and generate the second decoded symbol DS<8:15> by selectively inverting the second received symbol RS<8:15> on the basis of the second inversion signal IF**12**. When the second inversion signal IF**12** is enabled, the second inverting circuit **922** may generate the second decoded symbol DS<8:15> by inverting the most significant bits RS<8>, RS<10>, RS<12>, and RS<14> of the second received symbol RS<8:15>. When the second inversion signal IF**12** is disabled, the second inverting circuit **922** may provide the second received symbol RS<8:15> as is as the second decoded symbol DS<8:15> without inverting the second received symbol RS<8:15>. The third inverting circuit **923** may receive the third received symbol RS<16:23> and the third inversion signal IF**13**, and generate the third decoded symbol DS<16:23> by selectively inverting the third received symbol RS<16:23> on the basis of the third inversion signal IF**13**. When the third inversion signal IF**13** is enabled, the third inverting circuit **923** may generate the third decoded symbol DS<16:23> by inverting the most significant bits RS<16>, RS<18>, RS<20>, and RS<22> of the third received symbol RS<16:23>. When the third inversion signal IF**13** is disabled, the third inverting circuit **923** may provide the third received symbol RS<16:23> as is as the third decoded symbol DS<16:23> without inverting the third received symbol RS<16:23>. The fourth inverting circuit **924** may receive the fourth received symbol RS<24:31> and the fourth inversion signal IF**14**, and generate the fourth decoded symbol DS<24:31> by selectively inverting the fourth received symbol RS<24:31> on the basis of the fourth inversion signal IF**14**. When the fourth inversion signal IF**14** is enabled, the fourth inverting circuit **924** may generate the fourth decoded symbol DS<24:31> by inverting the most significant bits RS<24>, RS<26>, RS<28>, and RS<30> of the fourth received symbol RS<24:31>. When the fourth inversion signal IF**14** is disabled, the fourth inverting circuit **924** may provide the fourth received symbol RS<24:31> as is as the fourth decoded symbol DS<24:31> without inverting the fourth received symbol RS<24:31>.

[0052] The decoding block **930** may receive the first to fourth decoded symbols DS<0:7>,

DS<8:15>, DS<16:23>, and DS<24:31> from the inversion block **920**. The decoding block **930** may generate first to fourth decoded bursts DB<1:7>, DB<9:15>, DB<17:23>, and DB<25:31> by decoding the first to fourth decoded symbols DS<0:7>, DS<8:15>, DS<16:23>, and DS<24:31>. The decoding block **930** may include first to fourth decoders **931** to **934**. In an embodiment, the first to fourth decoders **931** to **934** may each be a 8:7 decoder. The first decoder **931** may generate the first decoded burst DB<1:7> having 7 bits by decoding 8 bits of the first decoded symbol DS<0:7>. The second decoder **932** may generate the second decoded burst DB<9:15> having 7 bits by decoding 8 bits of the second decoded symbol DS<8:15>. The third encoder **933** may generate the third decoded burst DB<17:23> having 7 bits by decoding 8 bits of the third decoded symbol DS<16:23>. The fourth decoder **934** may generate the fourth decoded burst DB<25:31> having 7 bits by decoding 8 bits of the fourth decoded symbol DS<24:31>. The first to fourth decoders **931** to **934** may map the 8-bit decoded symbol to a 7-bit decoded burst on the basis of the code book illustrated in FIG. 6.

[0053] The data interleaving circuit **940** may receive the first to fourth decoded bursts DB<1:7>, DB<9:15>, DB<17:23>, and DB<25:31> from the decoding block **930**, and receive the interleaved symbol IS<0:3>. The data interleaving circuit **940** may generate the first to fourth bursts DI<0:7>, DI<8:15> DI<16:23>, and DI<24:31> of the input data by combining the first to fourth decoded bursts DB<1:7>, DB<9:15>, DB<17:23>, and DB<25:31> with bits of the interleaved symbol IS<0:3>. The data interleaving circuit **940** may generate the first burst DI<0:7> of the input data by combining 7 bits of the first decoded burst DB<0:7> and 1 bit (IS<0>) of the interleaved symbol. The data interleaving circuit **940** may generate the second burst DI<8:15> of the input data by combining 7 bits of the second decoded burst DB<9:15> and 1 bit (IS<1>) of the interleaved symbol. The data interleaving circuit **940** may generate the third burst DI<16:23> of the input data by combining 7 bits of the third decoded burst DB<17:23> and 1 bit (IS<2>) of the interleaved symbol. The data interleaving circuit **940** may generate the fourth burst DI<24:31> of the input data by combining 7 bits of the fourth decoded burst DB<25:31> and 1 bit (IS<3>) of the interleaved symbol.

[0054] A person skilled in the art to which the present disclosure pertains can understand that the present disclosure may be carried out in other specific forms without changing its technical spirit or essential features. Therefore, it should be understood that the embodiments described above are illustrative in all aspects, not limitative. The scope of the present disclosure is defined by the claims to be described below rather than the detailed description, and it should be construed that all changes or modified forms derived from the meaning and scope of the claims and the equivalent concept thereof are included in the scope of the present disclosure.

Claims

1. A transmitting device comprising: an encoding block configured to encode a first burst, a second burst, a third burst, and a fourth burst to generate a first encoded symbol, a second encoded symbol, a third encoded symbol, and a fourth encoded symbol, respectively; an inversion determination circuit configured to generate a first inversion signal based on a fourth transmitting symbol, to generate a second inversion signal based on the first burst, to generate a third inversion signal based on the second burst, and to generate a fourth inversion signal based on the third burst; and an inversion block configured to generate a first transmitting symbol based on the first encoded symbol and the first inversion signal, to generate a second transmitting symbol based on the second encoded symbol and the second inversion signal, to generate a third transmitting symbol based on the third encoded symbol and the third inversion signal, and to generate the fourth transmitting symbol based on the fourth encoded symbol and the fourth inversion signal.

2. The transmitting device according to claim 1, wherein the inversion determination circuit is configured: to generate the second inversion signal based on a logic level of a bit with a specific

sequence number of the first burst; to generate the third inversion signal based on a logic level of a bit with the specific sequence number of the second burst; to generate the fourth inversion signal based on a logic level of a bit with the specific sequence number of the third burst; and to generate the first inversion signal based on a logic level of a bit with the specific sequence number of the fourth transmitting symbol.

3. The transmitting device according to claim 2, wherein the bit with the specific sequence number is a last most significant bit of each of the first burst, the second burst, the third burst, and the fourth transmitting symbol.

4. The transmitting device according to claim 1, wherein the encoding block is configured to generate the first to fourth encoded symbols by encoding the first to fourth bursts so that a maximum transition is avoided, and to substantially maintain a logic level of a bit with a specific sequence number of each of the first to fourth encoded symbols to be substantially identical to a logic level of a bit with the specific sequence number of each of the first to fourth bursts.

5. The transmitting device according to claim 1, further comprising: a symbol interleaving circuit configured to generate an interleaved symbol based on at least one bit of each of the first to fourth bursts, wherein the encoding block is configured to generate the first to fourth encoded symbols by encoding remaining bits of the first to fourth bursts, respectively.

6. The transmitting device according to claim 1, further comprising: a transmitting circuit configured to transmit a 4-level pulse amplitude modulation (PAM-4) signal through a transmission signal bus based on the first to fourth transmitting symbols.

7. The transmitting device according to claim 6, further comprising: a serializer configured to generate a plurality of unit symbols each including one most significant bit and one least significant bit by serializing the first and second transmitting symbols; and a transmission driver configured to drive a transmission signal bus by a PAM-4 signal on the basis of the plurality of unit symbols.

8. A transmitting and receiving method comprising: dividing output data into a first burst, a second burst, a third burst, and a fourth burst; determining whether a bit with a specific number of each of a fourth transmitting symbol, the first burst, the second burst, and the third burst is a first logic level; encoding the first burst, the second burst, the third burst, and the fourth burst to generate a first encoded symbol, a second encoded symbol, a third encoded symbol, and the fourth encoded symbol, respectively; selectively inverting the first encoded symbol, the second encoded symbol, the third encoded symbol, and the fourth encoded symbol based on a result of the determination to generate a first transmitting symbol, a second transmitting symbol, a third transmitting symbol, and the fourth transmitting symbol, respectively; and transmitting a 4-level pulse amplitude modulation (PAM-4) signal based on the first transmitting symbol, the second transmitting symbol, the third transmitting symbol, and the fourth transmitting symbol.

9. The transmitting and receiving method according to claim 8, wherein a logic level of the bit with the specific sequence number of each of the first to fourth bursts matches a logic level of a bit with the specific sequence number of each of the first to fourth of encoded symbols.

10. The transmitting and receiving method according to claim 8, further comprising: before the generating the first to fourth encoded symbols, providing at least one bit of the plurality of bursts as an interleaved symbol, wherein, in the generating the first to fourth encoded symbols, the first to fourth encoded symbols are generated by encoding remaining bits of the first to fourth bursts, respectively.

11. The transmitting and receiving method according to claim 10, further comprising: transmitting a PAM-4 signal based on the interleaved symbol at the same time or after the transmitting the PAM-4 signal.

12. The transmitting and receiving method according to claim 8, further comprising: receiving the PAM-4 signal and generating a first received symbol, a second received symbol, a third received symbol, and a fourth received symbol; determining whether a bit with the specific sequence number of each of the first to fourth received symbols has the first logic level and generating a first

decoded symbol, a second decoded symbol, a third decoded symbol, and a fourth decoded symbol by selectively inverting the first to fourth received symbols according to a result of the determination; and generating a first decoded burst, a second decoded burst, a third decoded burst, and a fourth decoded burst by decoding the first to fourth decoded symbols, respectively.

13. The transmitting and receiving method according to claim 12, further comprising: receiving an interleaved symbol at the same time or after the generating the first to fourth received symbols; and generating input data by combining the first to fourth decoded bursts and the interleaved symbol.

14. A transmitting and receiving system comprising: a transmitting device configured to transmit a 4-level pulse amplitude modulation (PAM-4) signal; and a receiving device configured to receive the PAM-4 signal, wherein the transmitting device comprises: a symbol encoding circuit configured: to divide output data into a first burst, a second burst, a third burst, and a fourth burst; to generate a first encoded symbol, a second encoded symbol, a third encoded symbol, and a fourth encoded symbol by encoding the first to fourth bursts, respectively; to generate a first transmitting symbol by selectively inverting the first encoded symbol based on a fourth transmitting symbol; to generate a second transmitting symbol by selectively inverting the second encoded symbol based on the first burst; to generate a third transmitting symbol by selectively inverting the third encoded symbol based on the second burst; and to generate a fourth transmitting symbol by selectively inverting the fourth encoded symbols based on the third burst, and a transmitting circuit configured to transmit the PAM-4 signal based on the first to fourth transmitting symbols.

15. The transmitting and receiving system according to claim 14, wherein the symbol encoding circuit is configured: to cause a logic level of a bit with a specific sequence number of the first encoded symbol to match a logic level of a bit with the specific sequence number of the first burst; to cause a logic level of a bit with the specific sequence number of the second encoded symbol to match a logic level of a bit with the specific sequence number of the second burst; to cause a logic level of a bit with the specific sequence number of the third encoded symbol to match a logic level of a bit with the specific sequence number of the third burst; and to cause a logic level of a bit with the specific sequence number of the fourth encoded symbol to match a logic level of a bit with the specific sequence number of the fourth burst.

16. The transmitting and receiving system according to claim 15, wherein the bit with the specific sequence number is a last most significant bit of each of the first to third bursts and the fourth transmitting symbol.

17. The transmitting and receiving system according to claim 14, wherein the symbol encoding circuit comprises: an inversion determination circuit configured to generate a first inversion signal based on the fourth transmitting symbol, to generate a second inversion signal based on the first burst, to generate a third inversion signal based on the second burst, and to generate a fourth inversion signal based on the third burst; a first encoder configured to generate the first encoded symbol by encoding the first burst; a second encoder configured to generate the second encoded symbol by encoding the second burst; a third encoder configured to generate the third encoded symbol by encoding the third burst; a fourth encoder configured to generate the fourth encoded symbol by encoding the fourth burst; a first inverting circuit configured to generate the first transmitting symbol by selectively inverting the first encoded symbol based on the first inversion signal; a second inverting circuit configured to generate the second transmitting symbol by selectively inverting the second encoded symbol based on the second inversion signal; a third inverting circuit configured to generate the third transmitting symbol by selectively inverting the third encoded symbol based on the third inversion signal; and a fourth inverting circuit configured to generate the fourth transmitting symbol by selectively inverting the fourth encoded symbol based on the fourth inversion signal.

18. The transmitting and receiving system according to claim 17, further comprising: a symbol interleaving circuit configured to extract at least one bit of each of the first to second bursts, and to generate an interleaved symbol based on the extracted bits, wherein the first encoder is configured

to generate the first encoded symbol by encoding remaining bits of the first burst, the second encoder is configured to generate the second encoded symbol by encoding remaining bits of the second burst, the third encoder is configured to generate the third encoded symbol by encoding remaining bits of the third burst, and the fourth encoder is configured to generate the fourth encoded symbol by encoding remaining bits of the fourth burst.

19. The transmitting and receiving system according to claim 14, wherein the transmitting circuit comprises: a serializer configured to generate a plurality of unit symbols each including one most significant bit and one least significant bit by serializing the first to fourth transmitting symbols; and a transmission driver configured to drive a transmission signal bus by a PAM-4 signal on the basis of the plurality of unit symbols.

20. The transmitting and receiving system according to claim 14, further comprising: a receiving circuit configured to receive the PAM-4 signal and generate a first received symbol, a second received symbol, a third received symbol, and a fourth received symbol; and a symbol decoding circuit configured to generate a first decoded symbol by selectively inverting the first received symbol based on the fourth received symbol, to generate a second decoded symbol by selectively inverting the second received symbol based on the first received symbol, to generate a third decoded symbol by selectively inverting the third received symbol based on the second received symbol, to generate a fourth decoded symbol by selectively inverting the fourth received symbol based on the third received symbol, and to generate a first decoded burst, a second decoded burst, a third decoded burst, and a fourth decoded burst by decoding the first to fourth decoded symbols, respectively.

21. The transmitting and receiving system according to claim 20, wherein the symbol decoding circuit comprises: a first inverting circuit configured to generate the first decoded symbol by selectively inverting the first received symbol based on a logic level of a bit with a specific sequence number of the fourth received symbol; a second inverting circuit configured to generate the second decoded symbol by selectively inverting the second received symbol based on a logic level of a bit with the specific sequence number of the first received symbol; a third inverting circuit configured to generate the third decoded symbol by selectively inverting the third received symbol based on a logic level of a bit with a specific sequence number of the second received symbol; a fourth inverting circuit configured to generate the fourth decoded symbol by selectively inverting the fourth received symbol based on a logic level of a bit with the specific sequence number of the third received symbol; a first decoder configured to generate the first decoded burst by decoding the first decoded symbol; a second decoder configured to generate the second decoded burst by decoding the second decoded symbol; a third decoder configured to generate the third decoded burst by decoding the third decoded symbol; and a fourth decoder configured to generate the fourth decoded burst by decoding the fourth decoded symbol.

22. The transmitting and receiving system according to claim 21, further comprising: a data interleaving circuit configured to further receive an interleaved symbol and to generate input data based on the first decoded burst, the second decoded burst, the third decoded burst, the fourth decoded burst, and the interleaved symbol.
