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(54) **QUADRATURE MODULATOR WITH
FEEDBACK CONTROL AND OPTICAL
COMMUNICATIONS SYSTEM USING THE
SAME**

a continuation-in-part of application No. 10/669,130,
filed on Sep. 22, 2003, now Pat. No. 7,327,913.

Publication Classification(51) **Int. Cl.****H04L 27/20** (2006.01)**H04L 27/18** (2006.01)**H04B 10/04** (2006.01)(52) **U.S. Cl.** **375/279; 375/308**(57) **ABSTRACT**

The method and system are disclosed for automatic feedback control of integrated optical quadrature modulator for generation of optical quaternary phase-shift-keyed signal in coherent optical communications. The method comprises the steps of detecting at least a part of an output optical signal from the QPSK modulator, extracting of a particular portion of the output signal in frequency domain, and processing the signal in frequency domain to optimize the transmission of an optical link. The system and method of optical communications in fiber or free space are disclosed that implement the quadrature data modulator with automatic feedback control.

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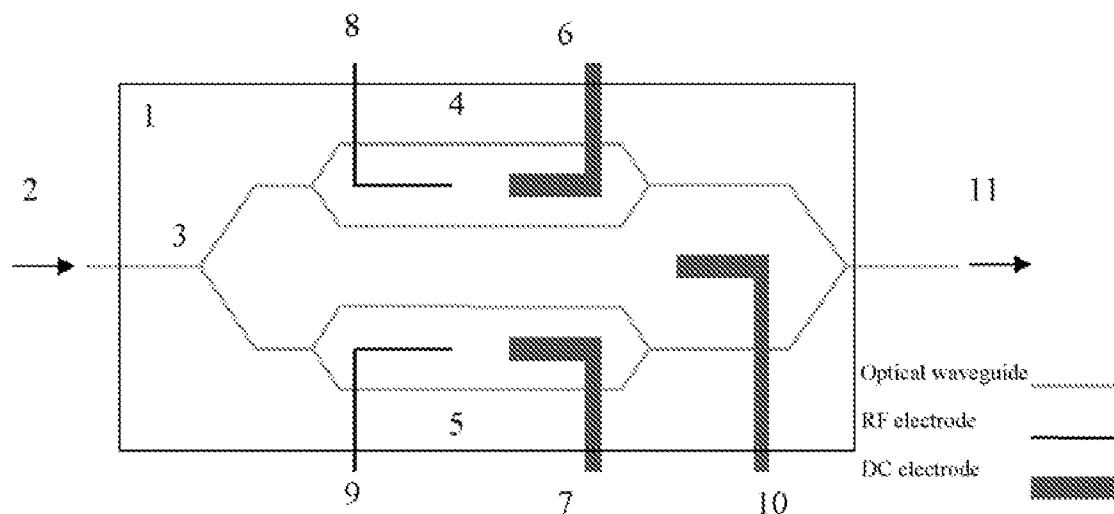
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(63) Continuation of application No. 11/679,376, filed on Feb. 27, 2007, now Pat. No. 8,050,351, which is a continuation-in-part of application No. 10/613,772, filed on Jul. 2, 2003, now Pat. No. 7,272,271, which is



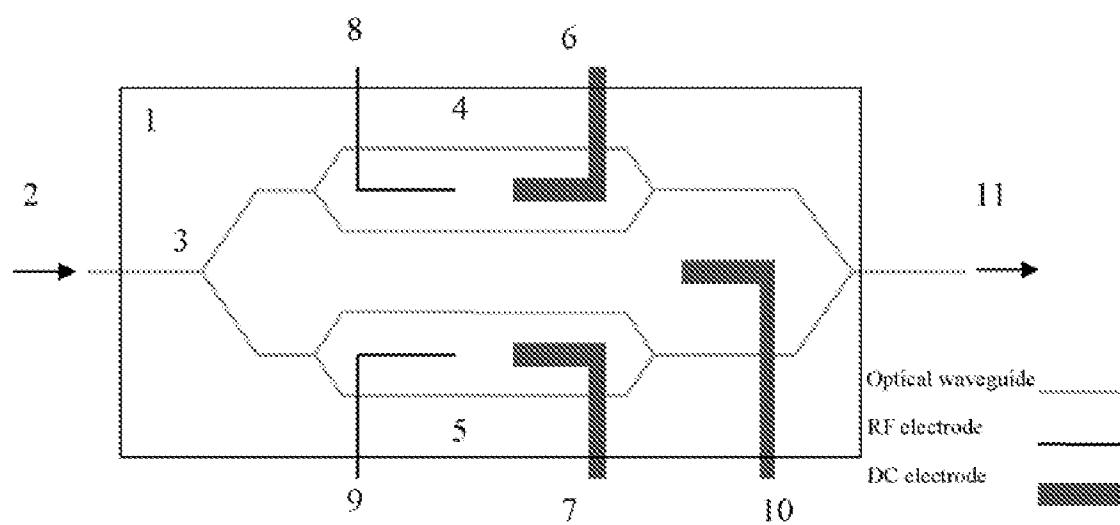


FIG. 1

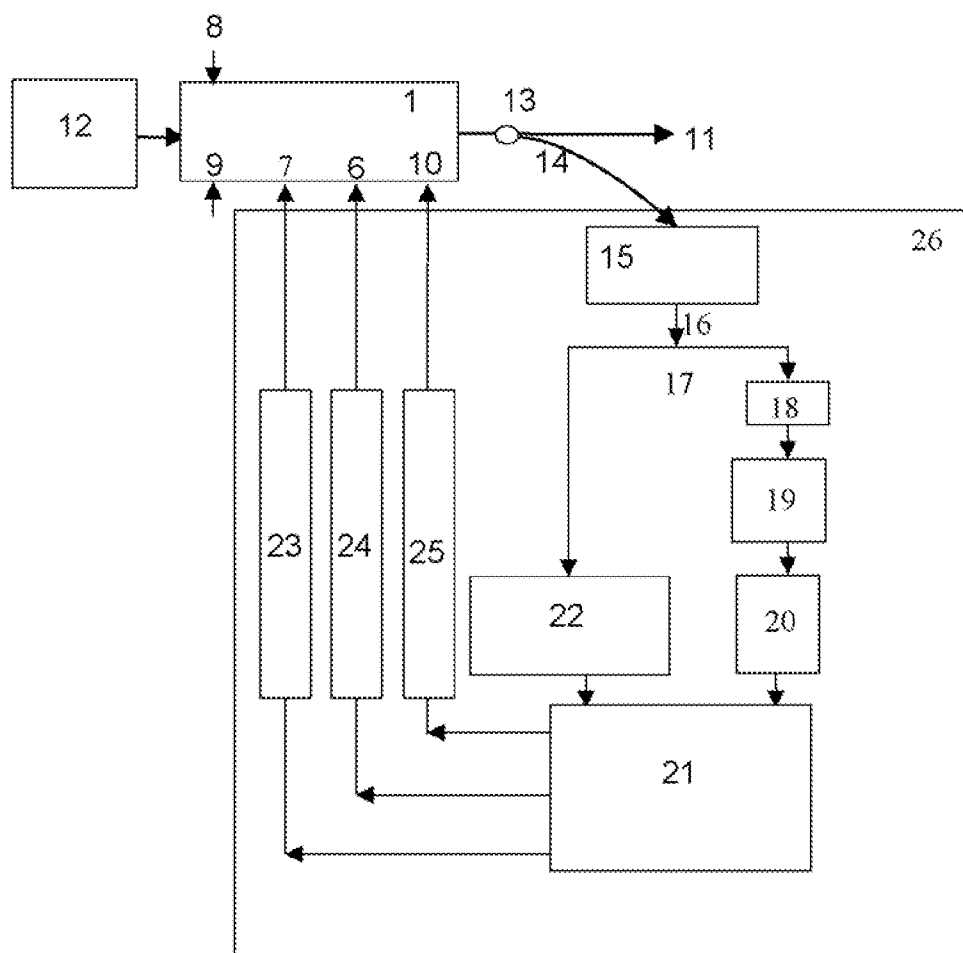


FIG. 2

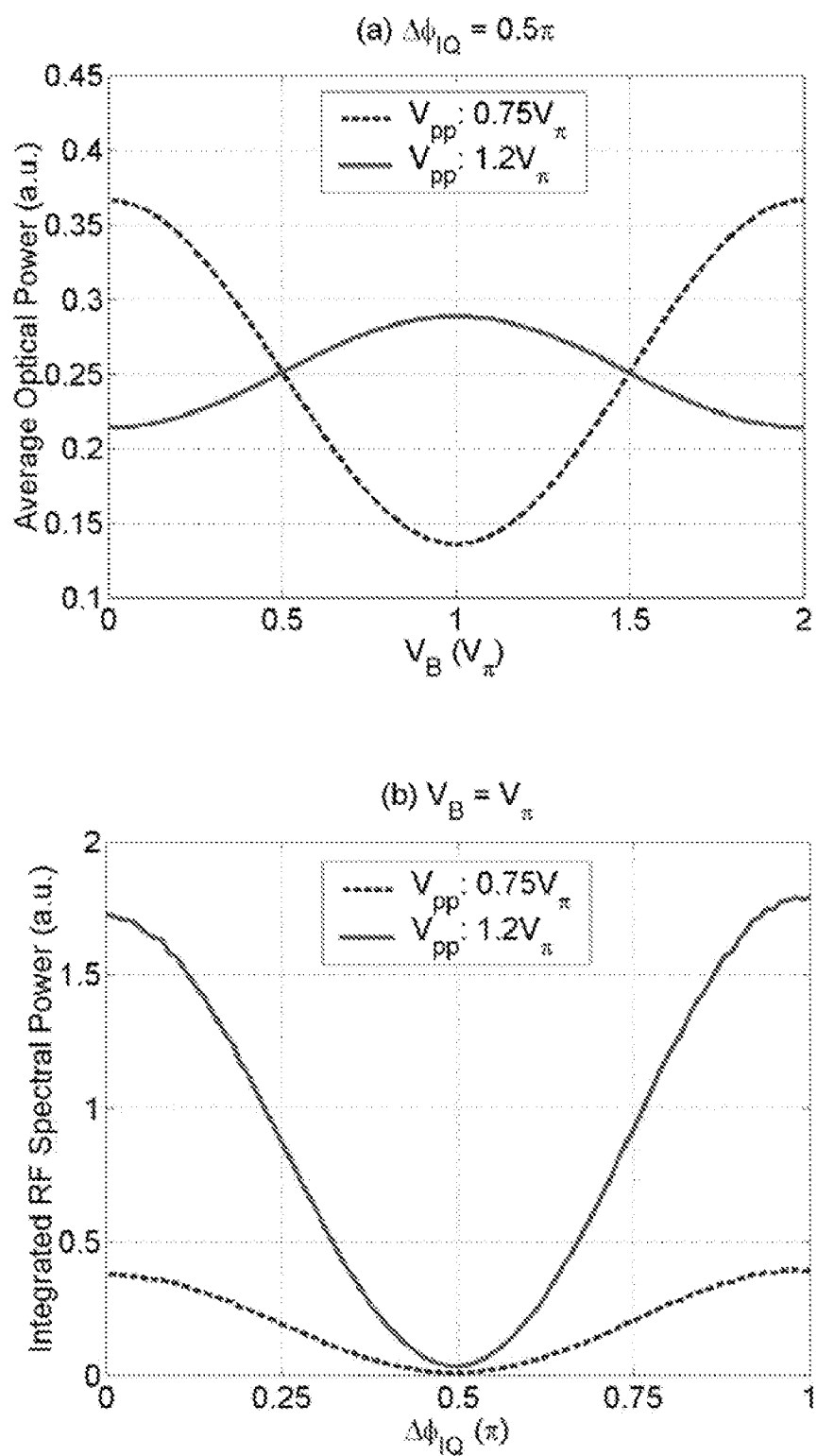


FIG. 3

(a) Initial Constellation

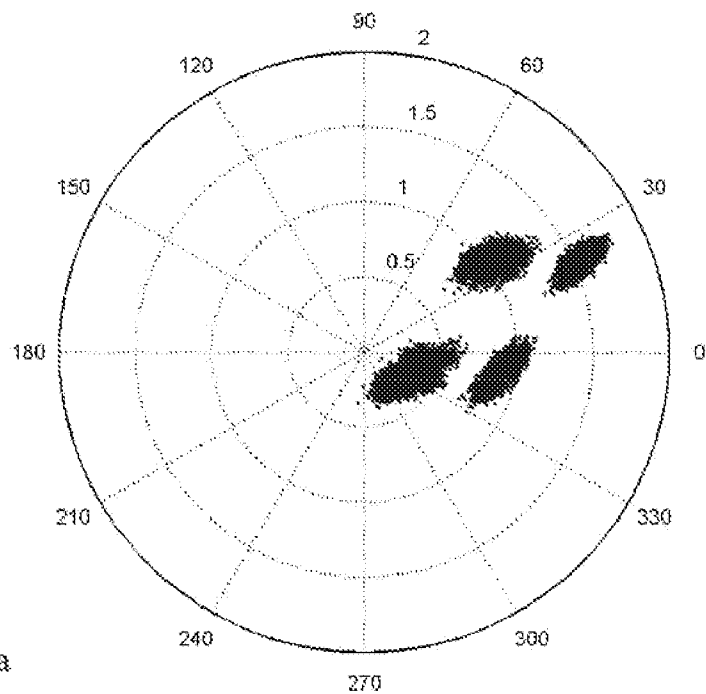


FIG. 4 a

(b) After 50 iterations

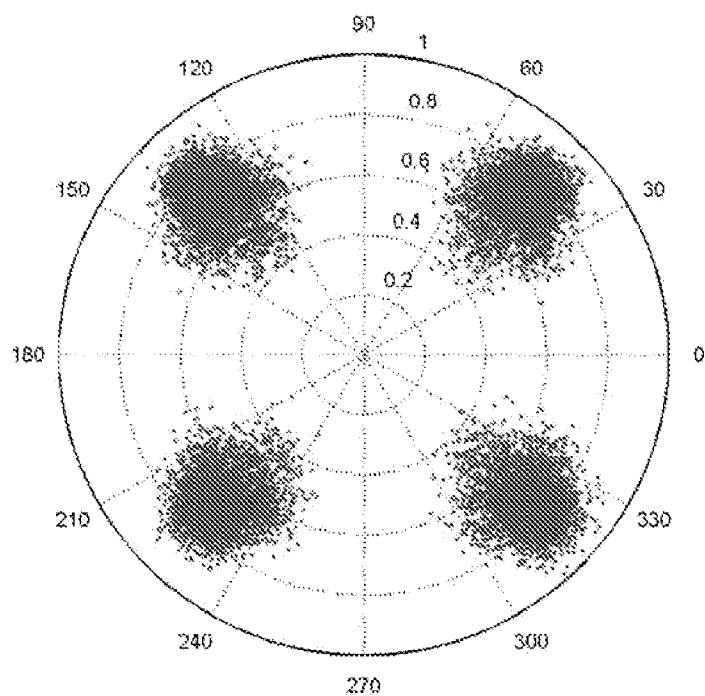


FIG. 4 b

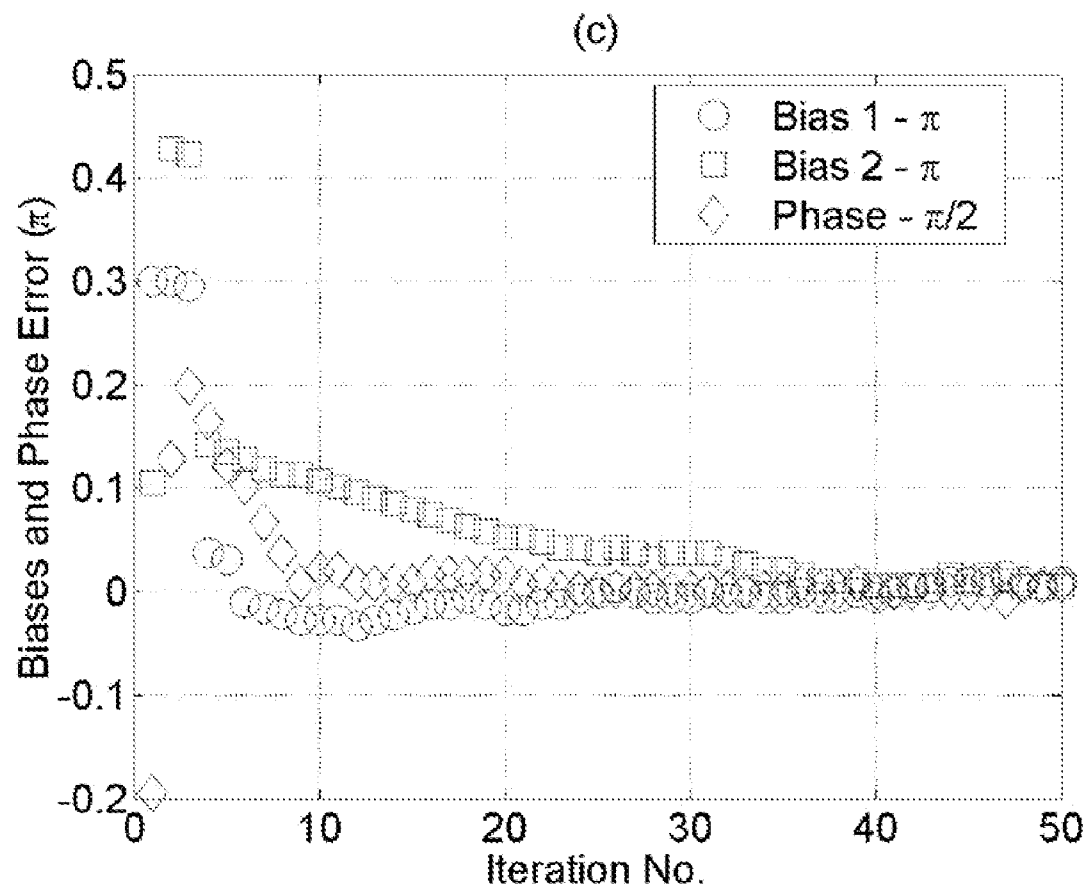


FIG. 4 c

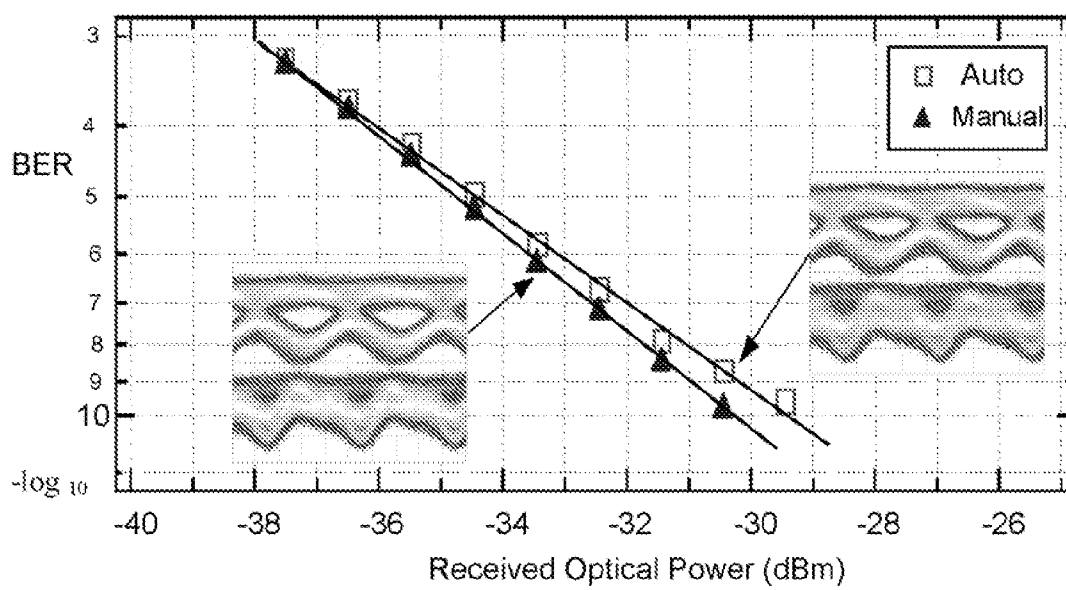


FIG. 5

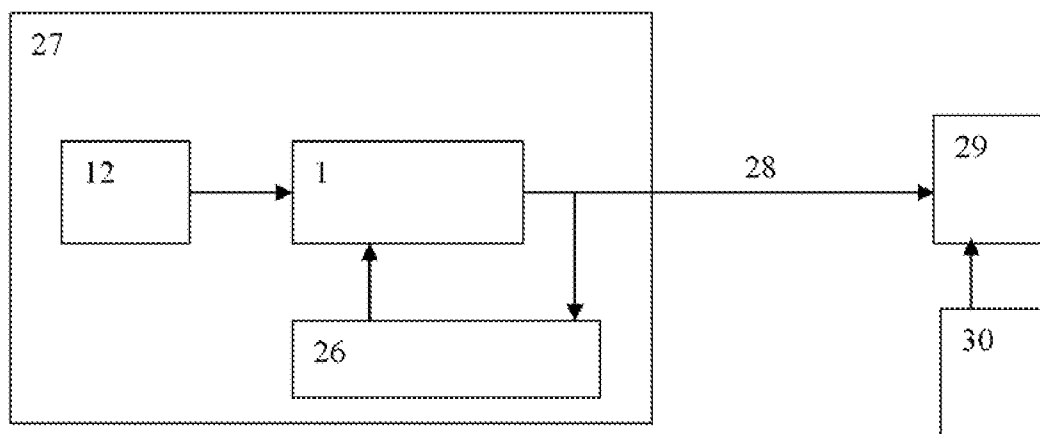


FIG. 6

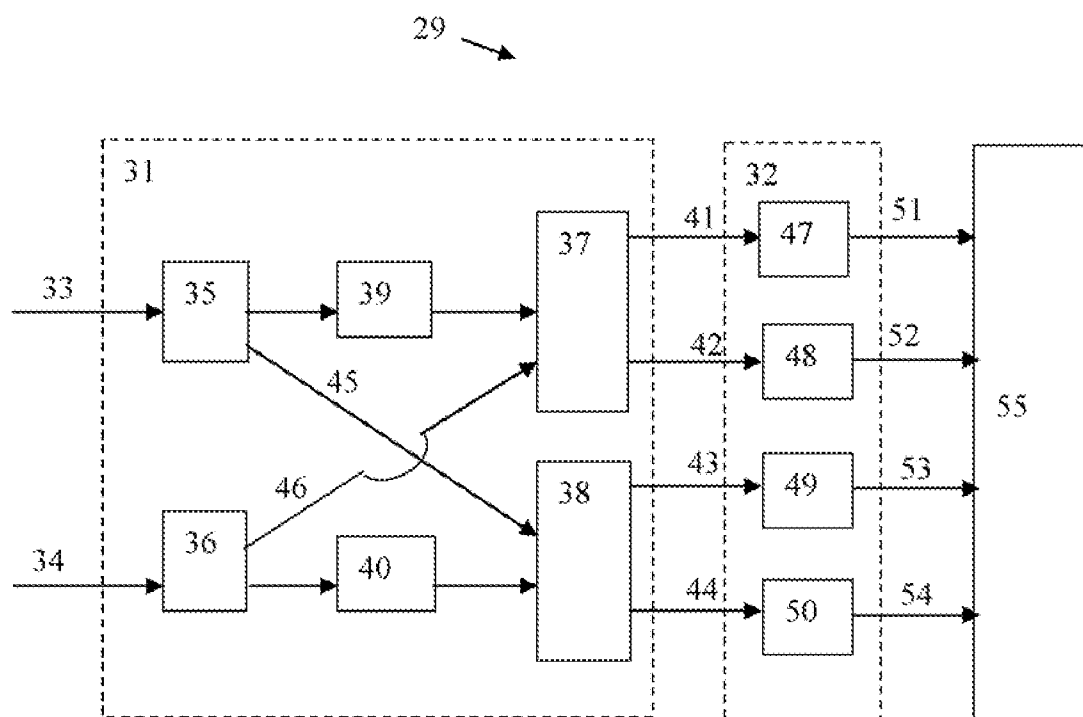


FIG. 7

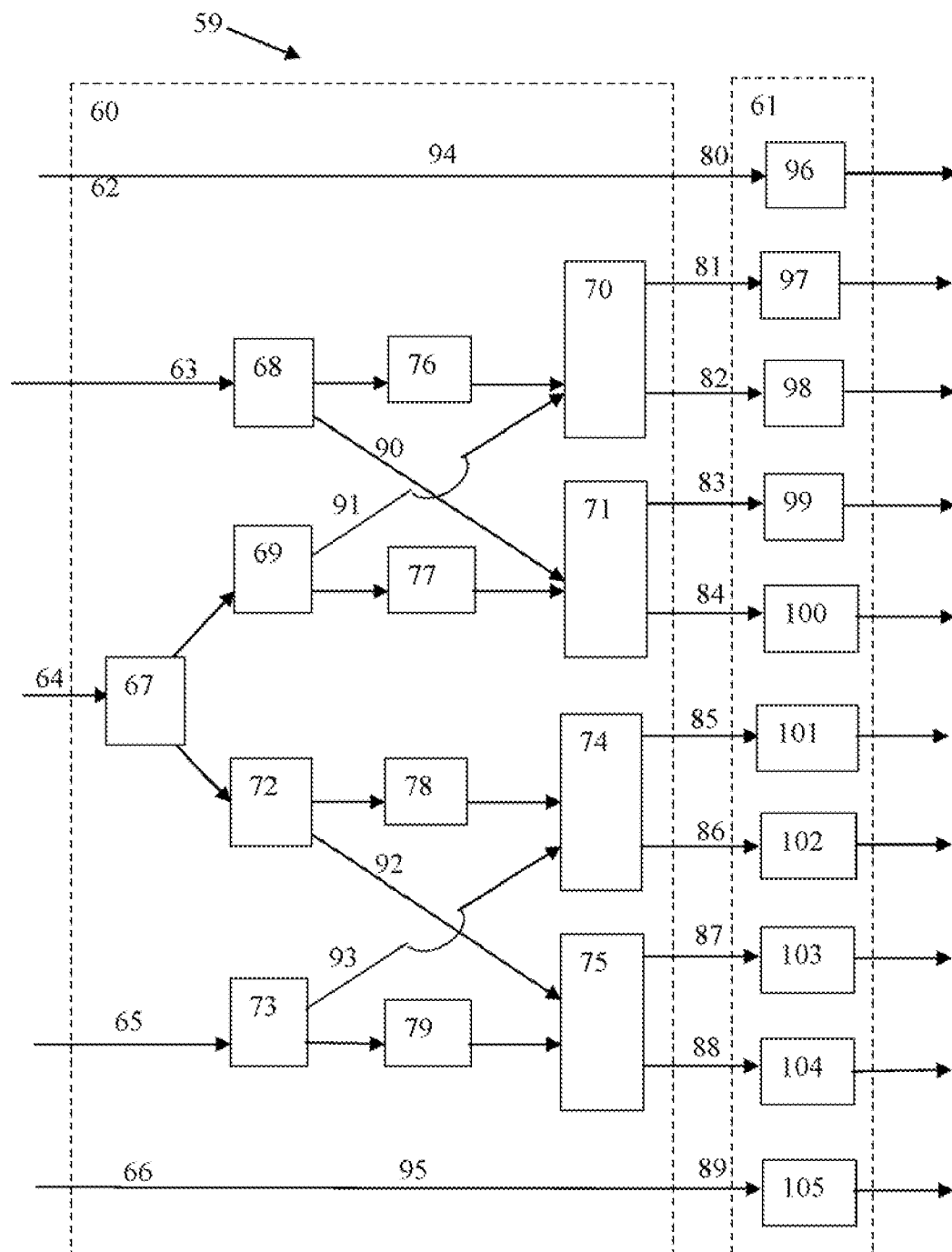


FIG. 8

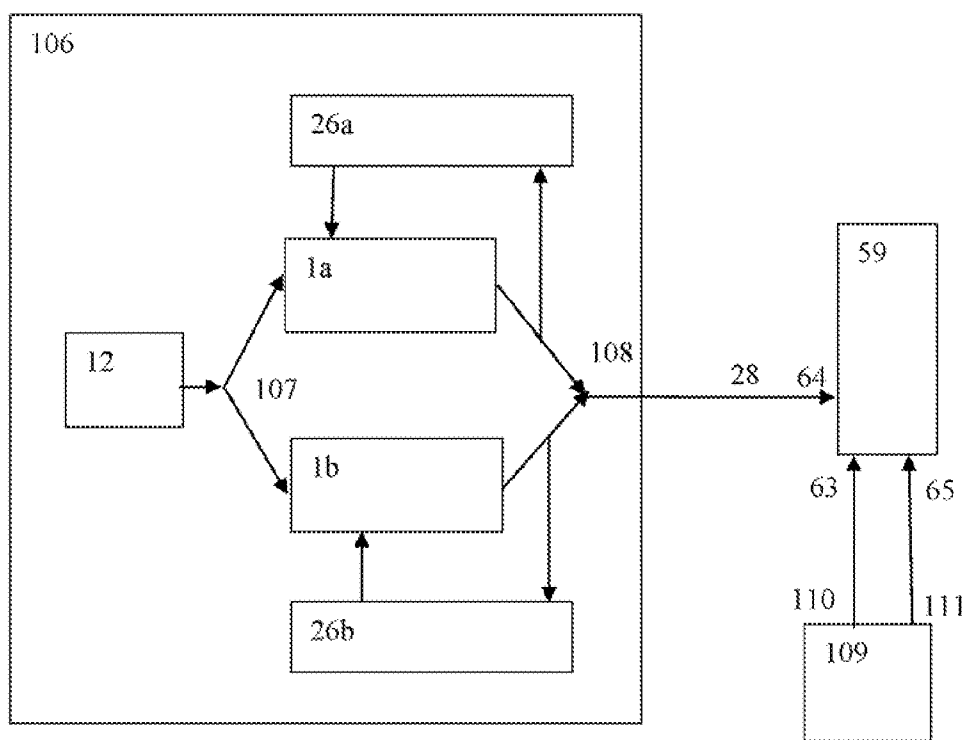


FIG. 9

QUADRATURE MODULATOR WITH FEEDBACK CONTROL AND OPTICAL COMMUNICATIONS SYSTEM USING THE SAME

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present invention claims a continuation of U.S. Ser. No. 11/679,376 filed Feb. 27, 2007, which is a continuation-in-part of U.S. Ser. No. 10/613,772 filed Jul. 2, 2003 and also a continuation-in-part of U.S. patent applications Ser. No. 10/669,130 filed on Sep. 22, 2003 and Ser. No. 10/672,372 filed on Feb. 7, 200, all of them incorporated herein by reference.

FIELD OF INVENTION

[0002] This invention relates generally to optical communications especially coherent communication with quaternary phase shift keying (QPSK) modulation format. Quadrature modulators are used in these systems for QPSK data encoding. The present invention relates to methods and systems of control for integrated quadrature modulators.

BACKGROUND OF THE INVENTION

[0003] Multi-level phase-shift-keying (PSK) offers high spectral efficiency transmission in coherent optical communication systems. Quaternary PSK (QPSK) format, in particular, has recently received much attention. An optical QPSK signal can be generated, e.g., by an integrated LiNbO₃ quadrature modulator (QM) with two parallel Mach-Zehnder modulators (MZMs) nested in a MZ interferometer. Each MZM is driven to produce a binary PSK (BPSK) signal. An optical QPSK signal is produced when two MZMs are biased at their null transmission points and the MZ interferometer is biased at the quadrature phase ($\pi/2$). FIG. 1 shows a schematic of a quadrature modulator 1 known in the prior art. The principle of its operation is as follows. Input optical beam 2 is splitted into two arms of the MZ interferometer by a splitter 3. Two Mach-Zehnder modulators 4 and 5 are placed in parallel; each MZM being located in each arm of the MZ interferometer. The biases of the MZMs are controlled by control signals 7 and 8 and driven by RF data signals 8 and 9. The Phase port of the QM 10 controls relative phase shift between the arms of the MZ interferometer.

[0004] In modern communication systems operating at a speed exceeding 10 Gbits/s, a precise stabilization of QPSK modulators is required. There is a need for an automatic feedback control loop that searches for these biases and phase operating points of the QM at initial startup and maintains them during operation.

SUMMARY OF THE INVENTION

[0005] The method and system are disclosed for an automatic feedback control of integrated quadrature modulator for generation of optical quaternary phase-shift-keyed signal in coherent optical communications.

[0006] The method comprises the steps of detecting at least a part of output signal from the modulator; extracting of a particular portion of the output signal in RF frequency domain; and minimizing the output signal in RF frequency domain by dithering a voltage applied to a phase shifter of the QPSK modulator. Additionally the method includes detecting

the output signal power and minimizing this output signal power by dithering a voltage applied to a first and a second bias of the QPSK modulator.

[0007] Alternative method includes detecting the output signal power and maximizing this output signal power by dithering a voltage applied to a first and a second bias of the QPSK modulator.

[0008] The control loop algorithm uses a steepest decent algorithm to search for optimal operating points of the quadrature modulator via dithering of its biases and phase. The criteria, for the dithering are based on minimization of the RF signal voltage and maximization or minimization of the optical average power of the output signal.

[0009] An optical communications system is proposed that incorporates QPSK modulator for data encoding with the feedback loop control of the modulator to improve transmission performance. In the preferred embodiment the communication system includes an integrated coherent receiver based on 90-degrees optical hybrid

[0010] Yet another object of the present invention is an optical communications system operating in two polarization states of light. The system incorporates two QPSK modulators each having its feedback loop control.

BRIEF DESCRIPTION OF THE DRAWINGS

[0011] FIG. 1 shows a schematic of a quadrature modulator with two parallel MZMs nested in a MZ interferometer with a phase bias (Prior Art).

[0012] FIG. 2 shows a schematic diagram of control unit for quadrature modulator in optical communications.

[0013] FIG. 3 shows simulation results for (a) average power versus bias voltage of MZM and (b) integrated RF spectral power versus $\Delta\phi_{IQ}$ for NRZ drive signal swing of 0.75 and 1.2V _{π} .

[0014] FIG. 4 shows constellation plots of the QM optical output at startup (a) and after 50 iterations of the control loop (b). Plot of deviations of the two biases and phase from then optimal points (π and $\pi/2$) versus iteration number are shown in (c).

[0015] FIG. 5 shows BER versus received optical power of the differentially detected QPSK signal with automatic control loop or with manual adjustment of the QM. Inset shows eye diagram (top) of the differentially detected 12.5 GSmp/s QPSK signal and the directly detected output from the QM (bottom), Horizontal scale: 20 ps/div.

[0016] FIG. 6 shows block diagram of an optical communication system that includes quadrature modulator having a control unit according to FIG. 2.

[0017] FIG. 7 shows a block diagram of a coherent optical receiver for the optical communications system of FIG. 6.

[0018] FIG. 8 shows a block diagram of a coherent optical receiver operating in two polarization states of light.

[0019] FIG. 9 shows block diagram of an optical communication system operating in two polarization states of light.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

[0020] A schematic diagram for a feedback control loop for the quadrature modulator is shown in FIG. 2. A light source 12 is launched into a quadrature modulator 1. In the preferred embodiment the light source is a CW or pulsed laser. The quadrature modulator is driven by two high-speed (>10 Gbits/s) non-return-to-zero (NRZ) binary data streams through RF

ports **8** and **9**. The optical output of the quadrature modulator is divided into two paths using a tap **13**. The optical beam **14** from the tapped output is impinged to a low-speed (e.g., 750 MHz) photodetector **15**. In the preferred embodiment the photodetector **15** is a single photon absorption photodetector. The electrical signal **16** from the photodetector **15** is divided into two by splitter **17** with one path connected to a DC block **18** to reject dc components of the electrical signal. This is followed by a RF spectral power detector (e.g., Schottky diode) **19** to extract the low-frequency RF spectral power (V_{RF}). The signal is then digitized using an analog-to-digital converter (ADC) **20** connected to a digital signal processing (DSP) unit **21**. The DSP unit contains a code that executes the control loop algorithm. The second path from the photodetector output is directly connected to another ADC **22** that provides monitoring of the optical average power. Outputs of the DSP unit are converted in analog signals by digital-to-analog converters **23**, **24**, **25** and directed to the two bias ports **6** and **7** and the phase port **10** of the quadrature modulator **1**.

[0021] The principle of feedback loop operation becomes clear from the following detailed description of its operation. FIG. 1 shows a schematic of a QM with two push-pull type MZMs with RF and DC bias electrodes nested in a MZ interferometer with a phase electrode for quadrature bias. Consider a single MZM, the directly detected optical output power is $P_o(t) = (kP_i/2) \{1 + \cos[\pi(V_s(t) + V_B)/V_\pi]\}$, where $V_s(t)$ is the NRZ drive signal with a peak-to-peak voltage swing V_{pp} , V_B is the bias voltage, V_π is the half-wave voltage, P_i is the input optical power, and k accounts for the insertion loss of the MZM. To generate optical BPSK signal, the MZM bias is set to the null transmission with $V_B = \pm V_\pi, \pm 3V_\pi, \dots$, and V_s varies between $\pm V_\pi$. The output average power over a period of time T is

$$\langle P_o(t) \rangle = \frac{kP_i}{2} \left(1 + \frac{1}{T} \int_0^T \cos \left[\frac{\pi}{V_\pi} (V_s(t) + V_B) \right] dt \right).$$

[0022] Taking the derivative of the above with respect to V_B and equating to zero gives

$$\begin{aligned} \frac{\partial \langle P_o(t) \rangle}{\partial V_B} &= -\frac{kP_i}{2} \frac{\pi}{V_\pi} \frac{1}{T} \int_0^T \sin \left[\frac{\pi}{V_\pi} (V_s(t) + V_B) \right] dt \\ &= 0 \Rightarrow \sin \left[\frac{\pi}{V_\pi} (V_s(t) + V_B) \right] \\ &= 0. \end{aligned}$$

[0023] The above is satisfied if $T_s = mV_\pi$ and $V_B = nV_\pi$ ($m, n = 0, \pm 1, \pm 2, \dots$). Taking the second derivative of $\langle P_o(t) \rangle$ with respect to V_B gives

$$\frac{\partial^2 \langle P_o(t) \rangle}{\partial V_B^2} = -\frac{kP_i}{2} \left(\frac{\pi}{V_\pi} \right)^2 \frac{1}{T} \int_0^T \cos \left[\frac{\pi}{V_\pi} (V_s(t) + V_B) \right] dt.$$

[0024] Therefore, the conditions for extrema of the average optical power are

$$\begin{aligned} \langle P_o(t) \rangle_{\max} &\Rightarrow \frac{\partial^2 \langle P_o(t) \rangle}{\partial V_B^2} < 0 \Rightarrow \cos \left[\frac{\pi}{V_\pi} (V_s(t) + V_B) \right] > 0, \\ \langle P_o(t) \rangle_{\min} &\Rightarrow \frac{\partial^2 \langle P_o(t) \rangle}{\partial V_B^2} > 0 \Rightarrow \cos \left[\frac{\pi}{V_\pi} (V_s(t) + V_B) \right] < 0. \end{aligned}$$

[0025] For null transmission of the MZM, $V_B = \pm V_\pi, \pm 3V_\pi, \dots$, so that the above can be written as follows

$$\begin{aligned} \langle P_o(t) \rangle_{\max} &\Rightarrow \frac{\partial^2 \langle P_o(t) \rangle}{\partial V_B^2} < 0 \Rightarrow \cos \left[\frac{\pi}{V_\pi} V_s(t) \right] < 0 \Rightarrow V_\pi < V_{pp} \leq 2V_\pi, \\ \langle P_o(t) \rangle_{\min} &\Rightarrow \frac{\partial^2 \langle P_o(t) \rangle}{\partial V_B^2} > 0 \Rightarrow \cos \left[\frac{\pi}{V_\pi} V_s(t) \right] > 0 \Rightarrow 0 < V_{pp} < V_\pi. \end{aligned}$$

[0026] Therefore, in order to maintain null transmission of the MZM for BPSK operation the average power of the MZM output should be maximized for $V_\pi < V_{pp} \leq 2V_\pi$ or minimized for $0 < V_{pp} < V_\pi$.

[0027] FIG. 3a shows a simulated output optical average power of the QM versus V_B for V_{pp} of 0.75 and $1.2V_\pi$. The simulation uses a 12.5 Gb/s NRZ pseudo-random binary sequence (PRBS) with a word length of $2^{11}-1$ with realistic waveforms (finite rise and fall times and ringings) driving the two MZMs of the QM biased to quadrature phase. The two NRZ signals are complementary with a 2-symbol relative time delay. Gaussian noise was added to the chive signal and to the input optical field to check the robustness of the response. As can be seen, the simulation result is consistent with the dependence of the average power on the MZM bias analyzed above.

[0028] Consider now the phase bias of the MZ interferometer of the QM where the phase shift between the two BPSK signals (I and Q) is $\Delta\phi_{IQ}$. It can be shown that the directly detected output power of the QM is given by

$$P_{QM} = (kP_i/4) \{ [1 - \cos(\pi V_I/V_\pi)]/2 - \cos(\pi V_Q/V_\pi)/2 + 2 \sin[\pi V_I/(2V_\pi)] \sin[\pi V_Q/(2V_\pi)] \cos(\Delta\phi_{IQ}) \},$$

where V_I and V_Q are the NRZ binary data signals applied to the two Minis biased at their null transmission points ($V_B = V_\pi$). Assuming V_I and V_Q varies between $\pm V_\pi$, the detected output can thus be simplified as follows

$$P_{QM} = \begin{cases} kP_i [1 + \cos(\Delta\phi_{IQ})]/2, & \text{for } V_I = V_Q = \pm V_\pi, \\ kP_i [1 - \cos(\Delta\phi_{IQ})]/2, & \text{for } V_I = \pm V_\pi \text{ and } V_Q = \mp V_\pi. \end{cases}$$

[0029] It is clear that data-like binary pattern will appear at the output of the QM if the MZ interferometer is not in quadrature ($\Delta\phi_{IQ} \neq \pi/2$). The RF spectrum of P_{QM} contains low-frequency components due to this data pattern. Therefore, a minimum integrated RF spectral power of P_{QM} should be an indication that $\Delta\phi_{IQ}$ is close to $\pi/2$. FIG. 3b shows the simulated integrated RF spectral power of $P_{QM}(V_{RF})$ for V_{pp} of 0.75 and $1.2V_\pi$ versus $\Delta\phi_{IQ}$ using similar NRZ drive signals with Gaussian noise as in FIG. 3a. The results are in agreement with the analysis. Note that the dependence of V_{RF} on $\Delta\phi_{IQ}$ is not affected by V_{pp} . Based on the analysis and results shown in FIG. 3, a QM control loop algorithm and model was developed.

[0030] The control loop uses a steepest decent algorithm to search for optimal operating points of the QM via dithering of its biases and phase. The dithering is performed continuously while monitoring the two feedback signals: V_{RF} and the average optical power. The criteria for the dithering is based on minimization of the signal V_{RF} and maximizes or minimizes the optical average power if the peak-to-peak NRZ drive signal is above or below the half-wave voltage (V_{π}) of the quadrature modulator as described earlier.

[0031] FIG. 4 shows typical simulation results of the control loop with Gaussian noise added to the drive signals and to the input optical field as before. One can see that the control loop is quite robust even in the presence of significant amount of amplitude and phase noise. Convergence to optimal operating points was observed for many random initial biases and phases of the QM tested.

EXAMPLE 1

QM Control Loop Experiment

[0032] An experiment on closed-loop control of the QM was conducted to investigate its performance for generation of a 12.5-GSym/s optical QPSK signal. A packaged LiNbO₃ QM was driven by two 12.5 Gb/s NRZ PRBS (word length: $2^{15}-1$) signals. The two NRZ signals are complementary with a 2-symbol relative time delay. The NRZ drive voltage swing applied to the QM was $V_{PP} \sim 1.2V_{\pi}$. The output of the QM was tapped off and directed to a 750-MHz photodetector where its output was divided into two with one path connected to a Schottky diode detector to extract the low-frequency RF spectral power (V_{RF}). The signal was amplified and directed to a commercial off-the-shelf (COTS) analog-to-digital converter (ADC) connected to a desktop computer (PC) running a code based on the control loop algorithm described earlier. The second path was amplified and directly connected to the ADC that provides monitoring of the optical average power. Outputs of a COTS digital-to-analog converter connected to the PC are directed to the two MZM bias ports and the phase port of the QM. This completes the QM feedback control loop.

[0033] The 12.5 GSym/s optical QPSK signal was directed to a receiver with an optical pre-amp and a band-pass filter. Differential detection of the 12.5 GSym/s QPSK signal was employed using a fiber-based asymmetric Mach-Zehnder (AMZ) interferometer with a one-symbol differential delay (80 ps). The two outputs of the AMZ demodulator were directed to a 15-GHz balanced photoreceiver. The differential phase shift of the AMZ was adjusted to approximately $\pm\pi/4$ to obtain maximum eye opening. FIG. 5 shows BER measurements of the differentially detected QPSK signal using the automatic control loop. Measurements using manual adjustment of the DC biases and phase of the QM by minimizing the BER are also shown. A power penalty of about 1 dB at 10^{-9} BER was observed for the control loop. This is attributed to the dithering and the relatively flat responses of V_{RF} and the average power near their optimal points as can be seen in FIG. 2. Nevertheless, the control loop concept was demonstrated and validated using COTS components. The QM control loop was operated continuously for about 20 hours with no degradation in performance. The control loop is expected to work for higher symbol rates since no high-speed components are required in the loop. The control loop also works for RZ format of the QPSK signal. Generation and detection of 12.5

GSym/s RZ-DQPSK has using the QM control loop was conducted and its performance was verified.

[0034] Coherent communications system with quadrature modulator having a control unit is another object of the present invention.

[0035] The block diagram of a coherent communications system according to the present invention is shown in FIG. 6. Optical transmitter comprises a light source 12 and a quadrature modulator 1 with a control unit 26 that allows optimizing the data transmission performance. Encoded optical signal is transmitted over the transmission link 28 to the coherent optical receiver 29 where the data is decoded by mixing the transmitted optical signal with a signal from a local oscillator 30.

[0036] In the preferred embodiment the coherent optical receiver is an integrated receiver based on 90-degrees optical hybrid as disclosed in co-pending U.S. patent applications Ser. No. 10/669,130 filed on Sep. 22, 2003 and Ser. No. 10/672,372 filed on Feb. 7, 2007 by the same inventors, incorporated herein by references.

[0037] FIG. 7 illustrates a coherent receiver 29 of the preferred embodiment. It includes an optical interface 31 and a receiving unit 32. The interface includes a first device input 33 and a second device input 34; first 35, second 36, third 37 and fourth 38 couplers (mixers); a first phase shifter 39 and a second phase shifter 40, and first 41, second 42, third 43, and fourth 44 outputs. The optical interface further includes two crossing waveguides 45 and 46, which cross each other. The receiving unit 32 includes four photodetectors 47, 48, 49, and 50 having outputs 51, 52, 53, and 54 respectively. The receiver further includes data digital signal processing unit 55.

[0038] The first 33 and the second 34 device inputs both are connected, respectively, to the first coupler 35 and the second coupler 36. One output of the first coupler 35 is connected to one input, of the third coupler 37 while another output of the first coupler 35 is connected to the one input of the fourth coupler 38 by a first crossing waveguide 45. An output of the second coupler 36 is connected to another input of the fourth coupler 38 while another output of the second coupler 36 is connected to another input of the third coupler 37 by a second crossing waveguide 46. The optical interface also includes at least one phase shifter positioned between two locations. The first location is one of the outputs of the first or second coupler. The other location is one of the inputs of the third or fourth couplers, which corresponds (connected by a crossing waveguide) to the first location. The first and second outputs of the third coupler 37 produce the first 41 and the second 42 device outputs, respectively. The first and second outputs of the fourth coupler 38 produce the third 43 and the fourth 44 device outputs, respectively.

[0039] Signals coming out of the outputs 41, 42, 43, and 44 impinge photodetectors 47, 48, 49, and 50, respectively. It is preferred that the photodetectors are PIN photodiodes. The photodiodes are located at equal distance apart. The distance between the neighbor photodiodes can be from 0.01 to 1 mm. In the preferred embodiment the distance is from 0.1 to 0.2 mm. The array of the photodiodes is fabricated on top of a single substrate. InGaAs photodiodes produced by OSI Optoelectronics, Inc. (Hawthorne, Calif.) are examples of such photodiodes. In the preferred embodiment the substrate is made of alumina.

[0040] In another embodiment an optical signal in two polarization states is transmitted over the communications

link and by a two polarization coherent detector. One embodiment of a coherent optical receiver **59** operating in two polarizations is shown in FIG. **8**. It includes an optical interface **60** and a set of photodiodes **61**. The interface includes a first device input **62**, a second device input **63**, a third device input **64**, a fourth device input **65**, a fifth device input **66**; a polarization beam splitter **67**, first **68**, second **69**, third **70**, fourth **71**, fifth **72**, sixth **73**, seventh **74**, and eighth **75** couplers (mixers); a first phase shifter **76**, a second phase shifter **77**, a third phase shifter **78**, and a fourth phase shifter **79**, first **80**, second **81**, third **82**, fourth **83**, fifth **84**, sixth **85**, seventh **86**, eighth **87**, ninth **88**, and tenth **89** device outputs. The device further includes two sets of crossing waveguides (**90** and **91**) and (**92** and **93**). The receiver may optionally include two alignment waveguides **94** and **95** are located on opposite sides of the optical interface **60**.

[0041] Signals coming out of the ten outputs **80**, **81**, **82**, **83**, **84**, **85**, **86**, **87**, **88**, **89** impinge photodetectors **96**, **97**, **98**, **99**, **100**, **101**, **102**, **103**, **104**, **105**, respectively. It is preferred that the photodetectors are PIN photodiodes. Similarly to the device in FIG. **7**, the photodiodes are located at equal distance apart. The distance between the neighbor photodiodes can be from 0.01 to 1 mm. In the preferred embodiment the distance is from 0.1 to 0.2 mm. During the fabrication the optical interface **60** alignment relatively the photodetector unit **61** is performed by light passing through waveguides **94** and **95** and positioning the unit **61** to maximize the current from photodiodes **96** and **105**. The accuracy of alignment is at least 1 micron. In the preferred embodiment the accuracy is about 0.1 micron.

[0042] An optical communication link shown in FIG. **9** illustrates light transmission in two polarizations according to the present invention. Two-polarization transmitter **106** includes the light source **12** and two (PSK modulators **1a** and **1b**, each being controlled by its control unit **26a** and **26b** respectively. Output beam from the light source **12** is split into two beams by polarization beam splitter **107**. Each of modulators **1a** and **1b** operates with the light of one polarization state. Output beam from the modulators **1a** and **1b** being combined by a polarization beam combiner **108** is transmitted over the communications link **28** towards the coherent optical receiver **59** operating in two light polarization states. The transmitted signal impinges the input **64** of the receiver **59**. In the receiver **59** the transmitted signal is mixed with two signals from a local oscillator **109** operating in two light polarization states. Local oscillator beams **110** and **111** have orthogonal polarization states and impinge the receiver **59** via the inputs **63** and **65** shown in FIG. **8**.

[0043] The elements in the optical receivers **31** and **60** can each be formed as part of a single planar chip made of an electro-optical material. In various embodiments, the chip is a monolithic piece of a wafer that can be made of semiconductor or ferroelectric materials including but not limited to LiNbO₃, and the like. In various embodiments, different effects relative to the output of the chip of the present invention are possible, including but not limited to, (i) thermo-optical, (ii) electro-optical, (iii) electro-absorption, and the like. The electro-optical material, which can be LiNbO₃, can be cut at X, Y, or Z planes. The device of the present invention can utilize a variety of different processes in its creation, including but not limited to, metal in-diffusion and/or (annealed) protonic-exchange technology, wet etching, reactive ion (beam) etching, plasma etching, and the like.

[0044] Integration of components in a single chip, such as LiNbO₃ and the like, can, among other things, reduce cost, improve performance, and provide better stability and control. The optical interfaces **31** and **60** of the present invention, when integrated on a single chip and/or in single package, can be used for various applications, including those that require simultaneous measurement of phase and amplitude of the optical field. In the preferred embodiment the receiving units **32** and **61** include the balanced receivers and optionally Trans-Impedance Amplifiers (TIAs), all formed as a part of a single integrated package.

[0045] Alternatively the integrated device chip can be made of the semiconductor material selected from Si and InP.

[0046] The description of the invention has been presented for purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise forms disclosed. Obviously, many modifications and variations will be apparent to practitioners skilled in this art. The application of the disclosed quadrature modulator is not limited to optical communications either free-space, fiber or waveguide. The present invention is related to any other possible applications of QPSK modulation technique.

What is claimed is:

1. The method for automatic feedback control of an integrated optical quadrature modulator comprising the steps of: data encoding of an input optical signal in the quadrature modulator, detecting at least a first part of an output optical signal from the quadrature modulator, extracting of a particular portion of the output signal in RF frequency domain and minimizing the portion of the output signal in RF frequency domain by tuning a voltage applied to a phase shifter connected to I and Q components of the quadrature modulator, the phase shifter providing a 90 degrees phase shift between I and Q components of the optical signal; achieving convergence to an optimal operating point of the quadrature modulator by the voltage tuning; and outputting a second part of the output optical signal with 90-degrees phase shift between I and Q signal components, wherein the second part of the output optical signal is PSK modulated.
2. The method of claim 1, wherein the tuning consists of dithering a control voltage applied to the phase shifter.
3. The method of claim 1, wherein the tuning is performed using a steepest descent algorithm.
4. The method of claim 1, wherein the tuning is performed continuously during the quadrature modulator operation.
5. The method of claim 1, further comprising discontinuing tuning when the optimal operating point is achieved.
6. The method of claim 1, wherein I component of the output signal is produced a first Mach-Zehnder (MZM) modulator and Q component of the output signal is produced a second Mach-Zehnder modulator, two MZMs forming a MZ interferometer, which serves as the quadrature modulator; and wherein each MZM is driven to produce binary PSK.
7. The method of claim 6, wherein the optimal operating point corresponds to each of the MZMs is biased at their null transmission point and the MZ interferometer is biased at the quadrature phase.
8. The method of claim 1, wherein the second output optical signal is QPSK modulated.

9. The method of claim 1, wherein the input signal to the quadrature modulator is pulsed signal.

10. The method of claim 1, further comprising:
detecting a power of the output optical signal,
tuning a first voltage applied to a first bias of the quadrature modulator and a second voltage applied to a second bias,
and

minimizing the power of the output optical signal.

11. The method of claim 1, further comprising:
detecting a power of the output optical signal,
tuning a first voltage applied to a first bias of the quadrature modulator and a second voltage applied to a second bias,
and

maximizing the power of the output optical signal.

12. A quadrature modulator, comprising:

a first modulator producing I component of an optical beam;

a second modulator producing Q component of the optical beam; the second modulator positioned in parallel to the first modulator forming a MZ interferometer;

a phase shifter introducing a 90-degrees phase shift between I and Q components of the optical beam;

a combiner combining I and Q components of the optical beam and outputting a quadrature modulated optical signal; and

a feedback loop connected to the combiner and the phase shifter; the feedback loop optimizing operation of the phase shifter to achieve the modulator operation at an optimal operating point.

13. The modulator of claim 12, wherein the first and the second modulators are Mach-Zehnder modulators.

14. The modulator of claim 13, wherein the feedback loop further includes branches providing optimization of MZMs operation.

15. The modulator of claim 13, wherein the optimal operation point corresponds to each of the MZMs is biased at their null transmission point and the MZ interferometer is biased at a $\pi/2$ phase.

16. The modulator of claim 12, wherein the feedback loop comprises a waveguide connected to the quadrature modulator output, extracting of a particular portion of the output signal, converting in RF frequency domain and minimizing the portion of the output signal in RF frequency domain by tuning a voltage applied to a phase shifter of the MZ interferometer.

17. The modulator of claim 16, further comprising a DSP unit controlling the feedback loop.

18. An optical communications system, comprising:

a transmitter for creating and sending a quadrature modulated signal, the transmitter including a quadrature modulator producing QPSK data modulation of an optical signal; the quadrature modulator comprising a first feedback loop connected to an output of the quadrature modulator and controlling a phase shifter of the quadrature modulator to achieve its operation at 90 degrees point;

a receiver, receiving the quadrature modulated signal and recovering QPSK modulated data.

19. The system of claim 18, wherein the first feedback loop provides an improved system performance allowing to achieve higher BER than without the feedback loop.

20. The system of claim 18, further comprising a second and a thirds feedback loop connected to an output of the quadrature modulator and controlling a first and a second Mach-Zehnder modulators, which produce I and Q components of the QPSK signal, respectively; and all three feedback loops improving performance of the system allowing to achieve higher BER than without the feedback loops.

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