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An adaptive optical circuit with self-organizing link

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Abstract —We have realized optical self-organizing nodes in which nonlinear weighting is enabled by an opt-electronic hybrid circuit based on optical bistability attained simply by coupling a light emitting diode (LED) and a photo diode (PD), which have their own nonlinearity. By connecting each nodes, we have demonstrated a self-organizing link which can build up a signal propagation path autonomously by itself, applying our newly considered adaptive algorithm. This algorithm is based on the fact that the nonlinearity attained by our coupled LED and PD devices can be regarded to be available for a well established nonlinear function which appears in typical adaptive control theory. We have also demonstrated our first fabrication of self-organizing optical network system with seven adaptive nodes. In this scheme, we have intentionally generated a disconnection or a breaking of wire link between certain nodes in the network, and then we have also confirmed that the optimum alternative route can be made autonomously and the transmission recovered. As a consequence, the present optical self-organizing network system can be a step toward a new method for peer-to-peer communications in optical transmission network.

1. INRODUCTION

In recent years, there have been developed information routing systems among personal communication terminals, e.g. cell phones. Such a kind of peer-to-peer communication is now being widely and actively studied. Self-organizing network which can select a partner by a terminal itself is suited for such communications. A number of network architectures based on adaptive algorithm have been proposed[1,2].

In the future development of such communication network, optical devices including optical fiber will have still more significance for the global communication infrastructures. Therefore, advantages of optical link circuit systems with adaptive algorithm should be noted.

We have demonstrated an adaptive optical circuit with self-organizing link in which nonlinear weighting is enabled by an opt-electronic hybrid circuit based on optical bistability attained simply by coupling a light emitting diode (LED) and a photo diode (PD), which have their own nonlinearity. We have also demonstrated both experimentally and numerically the self-organizing optical network system with seven adaptive nodes.

2. NETWORK MODEL

2.1 Nonlinear network with adaptive nodes

We noted the nonlinear characteristics of birefrengent optical crystal of which the refracitive indices change nonlinearly with incident light power. In a certain condition, incident light rays from both sides of this crystal are to be refracted individually with increase of each optical power, and finally link their optical paths with each other autonomously. Thus we intended to apply such autonomous processes of the natural phenomena to an artificial optical devices of more than one input-output. We call such a set of input-output function as a port. When such a port receives the signal from outside with multiple directions, it sends back the signals to each direction proportional to each signal strength. We call an optical device which has such a port (input-output) function as a node. Connecting these nodes, we can make up a self-organizing network provided the network as a whole, behaves as an individual node, i.e. send back signals toward the directions in proportion with received signal strength. In other words, when one send two types of signals from any two separated nodes of the network, these signals are to be adaptively selected while passing each node, and finally one optimum routing of the minimum transmission loss between original two sources should be achieved.

2.2 Node model

As an simple model of adaptive node, node with three bidirectional ports shown in Fig.2.1 is proposed. fundamental model. The names of its ports are labeled as port#0, port#1, and port#2 as shown in the figure.

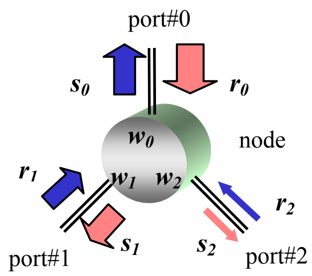

Fig.2.1. Schematic diagram of a node.

Also in this figure, s_0, s_1, and s_2 are signals sent out from each port. r_0, r_1, and r_2 are signals received from each port. Signal transmission will be done only between port#0 and 1 and port#0 and 2. Signals will be weighted by port weight w_0, w_1, and w_2 when the signals sent out from each port.

The port weights are described as follows,

$$w_0 = 1 \tag{2.1}$$

$$w_1 = \frac{\varepsilon + r_1}{2\varepsilon + r_1 + r_2} \tag{2.2}$$

$$w_2 = \frac{\varepsilon + r_2}{2\varepsilon + r_1 + r_2} \tag{2.3}$$

$$w_1 + w_2 = 1 \tag{2.4}$$

These port weights are going to be multiplied by r_0, r_1, and r_2 before they are send out. This can be expressed as below.

$$s_0 = r_1 + r_2 \tag{2.5}$$

$$s_1 = r_0 \times w_1 \tag{2.6}$$

$$s_2 = r_0 \times w_2 \tag{2.7}$$

The characteristics of the port weight w_1, for example, is shown in Fig.2.2. The key to realize this model as a hardware is a method how to reproduce these characteristics with opt-electronic circuit.

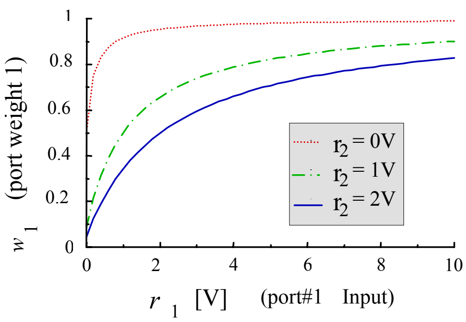

Fig.2.2. Port weight w_1 vs. input r_1 characteristics of port#1 with different r_2.

3. NUMERICAL SIMULATIONS

We examined if the network composed with the fundamental model really functions by numerical simulations. In this simulation, we composed lattice network connecting the node like shown in Fig.3.1, defined the initial value of w_1 and w_2 as 0.5, and the value of epsilon appeared in port weight as 1.0E-6.

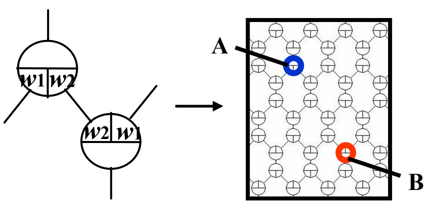

Fig.3.1. Connection of the node.

Fig3.2 shows the process of self-routing and self-optimization. First, both signals start to spread out in the network, but from when they encountered each other at one node, signal propagation path starts to converge into one particular path of which the transmission loss is minimum. In this case, minimum length. That is because encounter of two signals means that each signal acts as receiving signal for each other at that node. Result of this simulation shows that this network has both self-constructing function and self-optimizing function.

Next, by intention, we generated a disconnection between the node which is on signal propagation path that is already built up. See Fig.3.3. At (a), we put the obstacle between the nodes and cut off the signal propagation path. Receiving signals at port#0 or either port#1 and port#2 of nodes above and below the obstacle disappear. So, the signals start to spread again, and they start to converge from when they encountered once again. For the result, we confirmed that this network has a self-recovering function which can make an optimum alternative route when disconnection failure has occurred.

Current algorithm has a fault that when one put in the signal newly for example, from spot C in Fig.3.4, while one signal propagation path is already built up, signal propagation path between A and C also builds up (see Fig.3.4. (c')). In this case, receiving signal at A become an addition of signal from B and C. Thus, it is unable to receive correct signal from B at A. Also, strength of signal from A receiving at B becomes half a strength compared to the default situation, because other half of the signal goes to C. This means that the third person can intercept a signal from optional signal propagation path.

To prevent this, we considered to add a mechanism that cuts off an input from the port which is not used to signal transmission after the signal propagation path was built up. When the maximum voltage limit of the signal is x[V], signal strength of x[V] will be transmitted through one side of either port#1 or port#2 of the nodes while the propagation path was built up. If the signal was put in newly from C, its strength should be smaller than x[V] when it reached to the nodes which are being used for the transmission built up. Therefore, it is able to give self-protecting function to the network without disturbing the self-constructing, self-optimizing, and self-recovering functions which are provided by adaptive algorithm. Process of simulation of network having self-protecting function is shown in Fig.3.4 in order of (a), (b), and then (c). Signal from B is giving no affection to transmission of A and B, and the signal is just spreading out in the network.

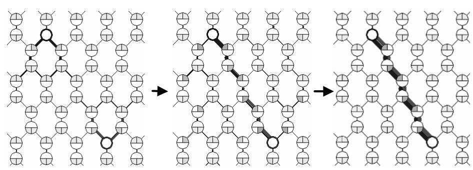

Fig.3.2. Process of self-construction and self-optimization.

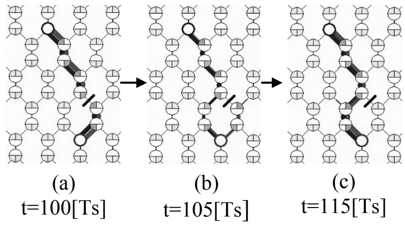

Fig.3.3. Process of self-recovery.

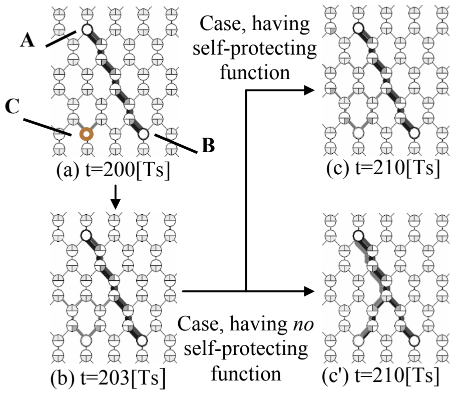

Fig.3.4. Process of self- protection.

4. OPTICAL NETWORK FABRICATION

4.1 Bistable optical device

As mentioned before, the key to realize the adaptive node as a hardware is a reproduction of nonlinear characteristic of port weighing. Since we are premising to realize optical peer-to-peer communication, we considered to use device which can control with light in analog and has positive feedback mechanism to cause nonlinear function.

There is bistable optical device as such device. In this study, we used bistable optical device which is hybrid type that is using light and electricity (see Fig.4.1). Light emitting diode (LED) emits light when bias current I_B flows through. Photo diode (PD) receives some part of light and feedbacks to LED in a form of current which is expressed as I_{FB} in Fig.4.1. While feedback current flows through LED, it also flows through feedback amount adjuster which is part expressed with u in the figure. Feedback amount adjuster is able to adjust the amount of feedback current, and by this, input-output characteristic of bistable optical device shows various nonlinear behavior. Fig.4.2 is a input-output characteristics of bistable optical device we made. Using this characteristic effectively, we considered to substitute nonlinear function appears in adaptive algorithm.

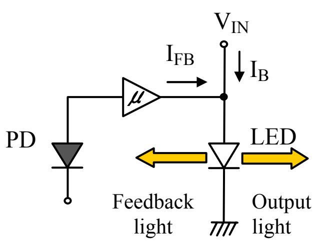

Fig.4.1. Schematic diagram of bistable optical device.

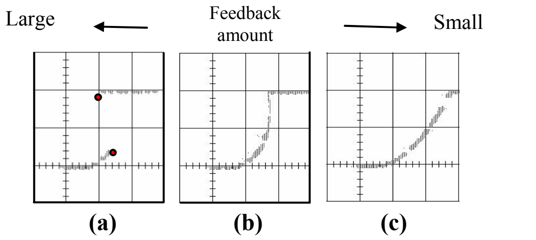

Fig.4.2. Input-output characteristics of bistable optical device, Horizontal axis : input voltage 200mV/div and Vertical axis : Output voltage 5V/div.

4.2 Adaptive optical circuit

Adaptive optical circuit is consisted of bistable optical device and voltage controlled amplifier (VCA) which multiplies the port weight to the signals. Fig.4.3 is a schematic diagram of the adaptive optical circuit. Since we built in VCA into the optical bistable devices to miniaturize the circuit, bistable optical device and VCA put together shall be called a bistable optical device anew. To avoid complication, mechanism of self-protection is not shown in the figure, but the comparators are set at each port#1 an port#2 to realize the action we mentioned at section 3.

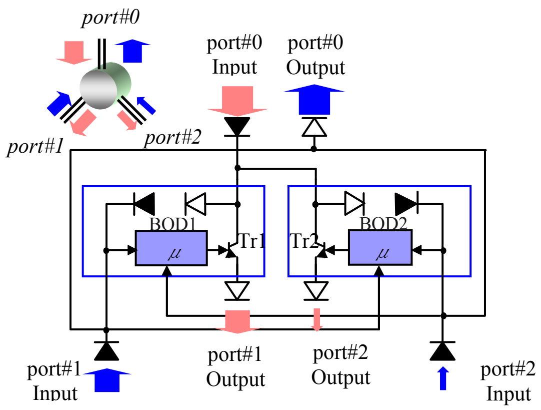

Fig.4.3. Schematic diagram of the optical link circuit.

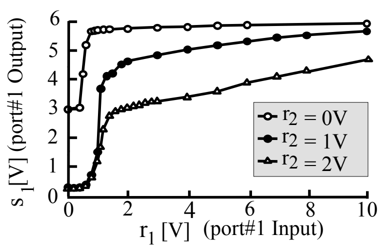

Fig.4.4. Input-output characteristics of optical link circuit.

We now explain about the operation of the circuit. Input signal from port#1 activates bistable optical device (BOD) 1 and input signal from port#2 activates BOD2. In the other hand, input from port#1 decreases the feedback amount of BOD2, while input from port#2 decreases the feedback amount of BOD1 according to their signal strength. Port weights adjusted by the operation above will be multiplied to the input signal from port#0. Thus, signals having strengths according to the input signal from port#1 and port#2 will be sent out from each output of the ports. Fig4.4 is a input-output characteristics of our optical link circuit when self-protecting function is off. Next, we will explain about the action when self-protecting function is on. This time we set the maximum DC voltage of the signal to 6.0V. When r_1 exceeds 6.0V, s_1 will immediately become 6.0V no matter how much the value of r_2 is. This can be said to other side of the port too.

4.3 Experiments on 7-node model

We composed 7-node model self-organizing network with our optical link circuit and considered about the possibility of the network. All the experiment was done with 1kHz 2.0Vpp sine wave with bias of DC 6.0V.

Fig.4.5 shows the condition of self-routing and self-optimization. Since the signals from reverse direction are sent mutually from two points, signal propagation path has formed. Graphs show how the signal sent from LED_1 is being transmitted to the receiver at LED_2. Each waveform is an output signal from each node in direction of LED_1 to LED_2. We do not show the graph of signals transmitted from LED_2 to LED_1 by matter of space, but almost the same waveforms were observed.

In this case of transmission, there is a question why did the network chose the path (a)-(c)-(e)-(f) instead of (a)-(b)-(d)-(f). We considered that self-optimizing function has worked and chose a path with less transmission loss by detecting the difference of the loss caused by connection of the circuits and from individual specificity of the circuits.

Next, we intentionally generated a disconnection between node (c) and (e) at the condition of Fig.4.5 to check the self-recovering function of the network. When we put the obstacle between (c) and (e), optimum alternative route was made autonomously and the transmission recovered immediately (see Fig.4.6).

Lastly, we checked its self-protecting function. See Fig.4.6. At this condition, if node (a) received a signal from node (c), self-protecting function should work and keep the transmission between (a) and (f) stable. This situation can be simplified as Fig.4.7. Graph located at upper right is a waveform of output light from upper port of node(a), and graph located at the left is a waveform of input light from LED_2. Then graph located at downer right is a waveform of input light from LED_3. While the propagation path is being formed between person at LED_1 and person at LED_2, third person inputs a signal at time t=a[s]. From the graphs, we can say that intercepting signal from third person would not give any affection to the transmission already built up.

4.4 Consideration

Since the scattering of the signal has directivity (ref. Fig.3.2 (a)), propagation path would not be formed in case the distance of A and B are too much separated horizontally compared to the vertical distance. One idea to raise a limit width is to connect the left end and right end of the lattice network and form a tubular equivalent type network. This network has an another merit of forming a alternative path in different to the path already exists using the self-protecting function. We will propose tubular equivalent type network with lows and sequence of (4n+2):(n+3). Network with this architecture will realize two pairs of people to do time sharing transmission from any two pairs of nodes located in first and last low. More further idea will be published elsewhere.

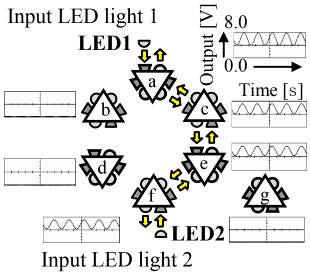

Fig.4.5. Results of the experiment on self-routing and self- optimization.

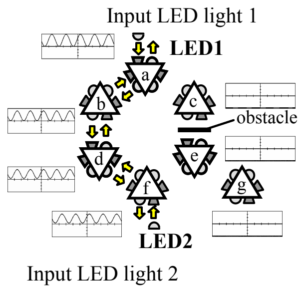

Fig.4.6. Results of the experiment on self-recovery.

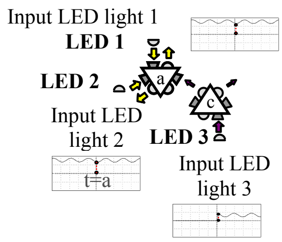

Fig.4.7. Results of the experiment on self-protection.

5. CONCLUSION

In this study, we have demonstrated the possibility of the optical self-organizing network in which adaptive algorithm is applied by numerical simulation and by experiment. In simulation, we confirmed all the self-organizing functions by our network. We have incorporated bistable optical devices into opt-electronic circuit and have achieved adaptive optical network. We confirmed that this network works effectively in 7-node configuration in experiments as well as simulations.

As a consequence, the present optical self-organizing network system can be a step toward a new method for peer-to-peer communications in optical transmission network.

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