(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
1 November 2001 (01.11.2001)

PCT

(10) International Publication Number
WO 01/82516 A1

(51) International Patent Classification[7]: H04J 14/02

(21) International Application Number: PCT/US01/13121

(22) International Filing Date: 24 April 2001 (24.04.2001)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
60/199,145 24 April 2000 (24.04.2000) US

(71) Applicant *(for all designated States except US)*: **LUCENT TECHNOLOGIES INC.** [US/US]; 600 Mountain Avenue, Murray Hill, NJ 07974-0636 (US).

(72) Inventors; and
(75) Inventors/Applicants *(for US only)*: **OLIER, Albert** [IL/IL]; Barzily Street 2/7, 75206 Rishon Le-Zion (IL). **INBAR, Hanni** [IL/IL]; Eilat Street 32/36, 58361 Holon (IL). **ABRAHAM, David** [IL/IL]; Skoklov Street 44, 62284 Tel-Aviv (IL). **MOR, Oded** [IL/IL]; Hasela 9c/3, 73142 Shoam (IL).

(74) Agent: **CONARD, Richard, D.**; Barnes & Thornburg, 11 South Meridian Street, Indianapolis, IN 46204 (US).

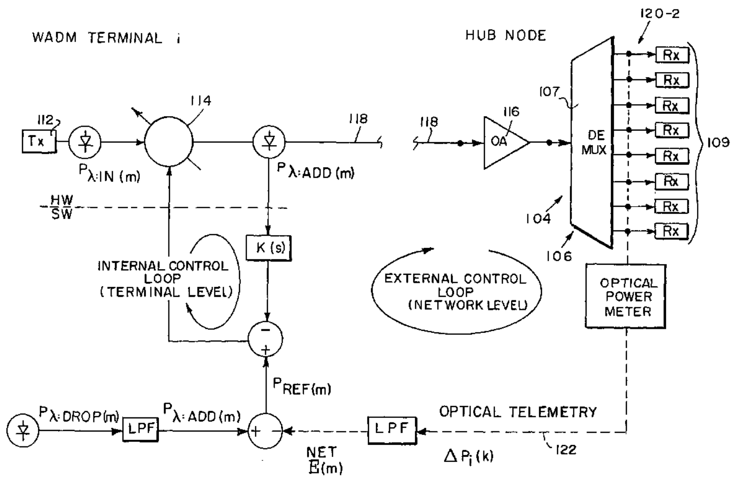
(81) Designated States *(national)*: AE, AG, AL, AM, AT, AU, AZ, BA, BB, BG, BR, BY, BZ, CA, CH, CN, CO, CR, CU, CZ, DE, DK, DM, DZ, EE, ES, FI, GB, GD, GE, GH, GM, HR, HU, ID, IL, IN, IS, JP, KE, KG, KP, KR, KZ, LC, LK, LR, LS, LT, LU, LV, MA, MD, MG, MK, MN, MW, MX, MZ, NO, NZ, PL, PT, RO, RU, SD, SE, SG, SI, SK, SL, TJ, TM, TR, TT, TZ, UA, UG, US, UZ, VN, YU, ZA, ZW.

(84) Designated States *(regional)*: ARIPO patent (GH, GM, KE, LS, MW, MZ, SD, SL, SZ, TZ, UG, ZW), Eurasian patent (AM, AZ, BY, KG, KZ, MD, RU, TJ, TM), European patent (AT, BE, CH, CY, DE, DK, ES, FI, FR, GB, GR, IE, IT, LU, MC, NL, PT, SE, TR), OAPI patent (BF, BJ, CF, CG, CI, CM, GA, GN, GW, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report*

For two-letter codes and other abbreviations, refer to the "Guidance Notes on Codes and Abbreviations" appearing at the beginning of each regular issue of the PCT Gazette.

(54) Title: GAIN EQUALIZATION IN DWDM NETWORKS



(57) Abstract: A method of controlling a network (115) through which information is transmitted in channels ($\lambda_1, \lambda_2, ...\lambda_n$) among nodes includes: (a) providing at a node a device (108) for removing from the network (115) and replacing on the network (115) a selected one (λ_i) of the channels, the device (108) including a first input port from the network (115) to the node and a first output port from the node to the network (115); (b) taking a measure of the strength ($P_{\lambda iDROP}$) of the received channel (λ_{iDROP}); (c) regenerating the channel (λ_{iIN}); (d) adjusting (114) the strength ($P_{\lambda iADD}$) of the regenerated channel (λ_{iIN}) to approximate the strengths of the remaining channels (($\lambda_1, \lambda_2, ...\lambda_n$)-$\lambda_i$); and (e) combining the regenerated and strength-adjusted channel (λ_{iADD}) with the remaining channels (($\lambda_1, \lambda_2, ...\lambda_n$)-$\lambda_i$) at the output port. The method further or alternatively includes (f) calculating an average signal strength ($P_{AVERAGE}$) for each active channel; (g) establishing a target signal strength ($P_{iTARGET}$) for each channel; (h) determining a required change (ΔP_i) in signal strength; and, (i) sending the node a message to adjust the strength of a signal coupled to the first output port.

WO 01/82516 A1

GAIN EQUALIZATION IN DWDM NETWORKS

Field of the Invention

This invention relates to networks. It is disclosed in the context of Dense Wavelength-Division Multiplexed (DWDM) networks, but is believed to be useful in other applications as well.

Cross-Reference to Related Applications

This application claims priority to U. S. S. N. 60/199,145, filed April 24, 2000, the disclosure of which is hereby incorporated herein by reference.

Background of the Invention

DWDM networks carry diverse types of traffic such as, for example, SONET, ATM, IP, and so on. These networks are capable of mixing different types of traffic in the same physical medium. A typical DWDM network includes an arbitrary number of nodes interconnected in a ring topology by a pair of optical fibers. Some of these nodes are regenerating interfaces, where the optical transmissions are converted to electrical signals, information from them is processed, the electrical signals are reconverted to optical signals, and the optical signals placed on the optical fibers again for circulation to other nodes.

The optical portion of a transmission network coupling two regenerating interfaces is known as the optical layer segment. A general overall description of a typical optical layer segment follows. The description is applicable for a variety of DWDM network topologies including: point-to-point DWDM networks with Wavelength Add/Drop Multiplexers (WADMs) along the optical path; single-hub, ring-based DWDM networks; and, multiple-hub, ring-based DWDM networks. In the case of single-hub, ring-based DWDM networks, the originating hub is also the terminating hub. In this case, the ring includes only one folded segment. In the case of multiple-hub, ring-based DWDM networks, "regeneration nodes" are dispersed along the ring. In this case, the ring is a concatenated series of two or more optical segments.

Disclosure of the Invention

According to one aspect of the invention, a method is provided for controlling a network through which information is transmitted in channels among nodes. The method includes: (a) providing at a node a device for removing from the network and replacing on the network a selected one or more of the channels, the device including a first input port from the network to the node and a first output port from the node to the network; (b) taking a measure of the strength of the received channel; (c) regenerating the channel; (d) measuring the strength of the regenerated channel; (e) adjusting the strength of the regenerated channel to approximate the strengths of the remaining channels; and (f) combining the regenerated and strength-adjusted channel with the remaining channels at the output port.

Illustratively according to this aspect of the invention, providing the device includes providing a device whose effects on the strengths of the removed channel, the regenerated and strength-adjusted channel and the remaining channels approximate known values.

Further illustratively according to this aspect of the invention, providing the device includes providing on the device a second output port at which the removed channel is recovered and a second input port at which the regenerated and strength-adjusted channel is recombined with the remaining channels.

Additionally illustratively according to this aspect of the invention, adjusting the strength of the regenerated channel to approximate the strengths of the remaining channels includes coupling the regenerated channel to an input port of an attenuator including a third input port, a control port and a third output port, coupling the third output port to the second input port, and providing at the control port a signal based, at least in part, upon the measured strength of the regenerated channel.

According to another aspect of the invention, or additionally according to this aspect of the invention, the method further includes: (g) calculating an average signal strength for each active channel; (h) establishing a target signal strength for each channel; determining a required change in signal strength; and, sending the node a message to adjust the strength of a signal coupled to the first output port.

Illustratively according to this aspect of the invention, taking a measure of the strength of the received channel includes taking a measure of the received power.

Further illustratively according to this aspect of the invention, establishing a target signal strength for each channel includes establishing a target power for each channel.

Additionally illustratively according to this aspect of the invention, establishing a target power for each channel includes establishing a target power $P_{iTARGET} = P_i + \gamma (P_{AVERAGE} - P_i)$, $0.25 \leq \gamma \leq 0.75$.

Illustratively according to this aspect of the invention, determining a required change in signal strength includes determining a required change in signal power.

Further illustratively according to this aspect of the invention, sending a node a message to adjust its power level includes sending the node a message to adjust its signal power.

Additionally illustratively according to this aspect of the invention, determining a required change in signal power includes determining the required signal change in decibels.

Illustratively according to this aspect of the invention, sending a node a message to adjust its power level includes sending the node a message to adjust its optical signal power.

Further illustratively according to this aspect of the invention, determining a required change in signal strength includes determining a required change in optical signal power.

Illustratively according to this aspect of the invention, the method further including removing a channel from the determinations of elements (b), (g) and (h) and sending a node a message not to adjust its power level if the channel is not being received at a node.

Additionally illustratively according to this aspect of the invention, elements (b) - (e) are performed in a first time, and elements (g) - (j) are performed in a second time, the second time being longer than the first time.

According to another aspect of the invention, apparatus is provided for controlling a network through which information is transmitted in channels among nodes. The apparatus includes a first device for (a) removing from the network and replacing on the network a selected one of the channels, (b) taking a measure of the strength of the received channel, (c) regenerating the channel, (d) adjusting the strength of the regenerated channel to approximate the strengths of the remaining channels, and (e) combining the regenerated and strength-adjusted channel with the remaining channels at the output port. The first device is coupled to an input port from the network to the node and to an output port from the node to the network.

Illustratively according to this aspect of the invention, the first device includes a first device whose effects on the strengths of the removed channel, the regenerated and strength-adjusted channel and the remaining channels approximate known values.

Further illustratively according to this aspect of the invention, the first device includes a first device having a second output port at which the removed channel is recovered and a second input port at which the regenerated and strength-adjusted channel is recombined with the remaining channels.

Additionally illustratively according to this aspect of the invention, he apparatus includes an attenuator having a third input port, a control port and a third output port. The the regenerated channel is coupled to the third input port, the third output port is coupled to the second input port, and the control port is provided with a signal based upon the measured strength of the regenerated channel.

According to another aspect of the invention, or additionally according to this aspect of the invention, the apparatus further includes a second device for (f) calculating an average signal strength for each active channel, (g) establishing a target signal strength for each channel, (h) determining a required change in signal strength, and, (i) sending the node a message to adjust the strength of a signal coupled to the first output port.

Illustratively according to this aspect of the invention, the first device takes a measure of the received power.

Further illustratively according to this aspect of the invention, the second device establishes a target power for each channel.

Additionally illustratively according to this aspect of the invention, the second device establishes a target power $P_{iTARGET} = P_i + \gamma (P_{AVERAGE} - P_i)$, $0.25 \leq \gamma \leq 0.75$.

Illustratively according to this aspect of the invention, the second device determines a required change in signal power.

Further illustratively according to this aspect of the invention, the second device sends the node a message to adjust its signal power.

Additionally illustratively according to this aspect of the invention, the second device determines the required signal change in decibels.

Illustratively according to this aspect of the invention, the second device sends the node a message to adjust its optical signal power.

Further illustratively according to this aspect of the invention, the second device determines a required change in optical signal power.

Additionally illustratively according to this aspect of the invention, the second device removes a channel from the determinations of elements (b), (f) and (g) and sends a node a message not to adjust its power level if the channel is not being received by the second device.

Illustratively according to this aspect of the invention, the first device performs elements (b) - (d) in a first time, and the second device performs elements (f) - (i) in a second time longer than the first time.

Brief Description of the Drawings

The invention may best be understood by referring to the following detailed description and accompanying drawings. In the drawings:

Fig. 1 illustrates a block diagram of an end-to-end optical layer segment incorporating the present invention;

Fig. 2. illustrates an enlarged block diagram of a detail of the segment illustrated in Fig. 1; and,

Fig. 3 illustrates an enlarged block diagram of a detail of the segment illustrated in Fig. 1.

Detailed Descriptions of Illustrative Embodiments

Referring now generally to Fig. 1, an optical layer segment 115 includes the following six Optical Network Elements (ONEs): an optical channel multiplexer 100 at the transmitting termination 102 of the segment 115; an optical channel demultiplexer 104 at the receiving termination 106 of the segment 115; a WADM 108; an equalization protocol; (an) optical amplifier(s) 116; and, an optical fiber 118.

The first ONE is the optical channel multiplexer 100 at the transmitting termination 102 of the segment 115. The optical channel multiplexer 100 may or may not be used in conjunction with a post amplifier 116 to amplify its output signal. The optical channel multiplexer 100 includes optical transmitters103, which generate the optical channels λ_1, λ_2, . . . λ_n, and a multiplexer 105, which aggregates channels λ_1, λ_2, . . . λ_n onto optical fiber 118. The optical transmitters 103 each include a power level control mechanism, for example, an optical attenuator.

The second ONE is the optical channel demultiplexer 104 at the receiving termination 106 of the segment 115, with or without a preamplifier 116. The optical channel demultiplexer 104 includes a demultiplexer 107 which separates the optical channels λ_1, λ_2, . . . λ_n, and optical receivers 109, which terminate the optical channels λ_1, λ_2, . . . λ_n.

The third ONE is the WADM 108. One or more WADMs 108 may be placed along the optical network 115 between regenerating interfaces100, 104. A WADM 108 isolates transmissions of a designated wavelength λ_i to be dropped from the multiplexed transmission λ_1, λ_2, . . . λ_n, but permits transmissions at other wavelengths (λ_1, λ_2, . . . λ_n) - λ_i to pass through, attenuated, but otherwise unaffected. The dropped transmissions λ_{iDROP} on wavelength λ_i are routed to an optical receiver 110, where they are detected and decoded. The WADM 108 also adds back to the through transmission (λ_1, λ_2, . . . λ_n) - λ_i whatever information is to proceed through the fiber away from the node 108 on the dropped, and now readded, wavelength λ_{iADD}. An optical transmitter 112, configured to transmit on the wavelength λ_i that was dropped, illustratively provides the signal λ_{iADD} to be added to an optical attenuator 114. λ_{iADD} is multiplexed in WADM 108 with the through transmissions (λ_1, λ_2, . . . λ_n) - λ_i. The attenuator 114 is configured so that its output power level $P_{\lambda iADD}$ (the power level of the added transmission) is equal to the power levels ($P_{\lambda 1}$, $P_{\lambda 2}$, . . . $P_{\lambda n}$) - $P_{\lambda iADD}$ of the through transmissions (λ_1 , λ_2 , . . . λ_n) - λ_i which, it must be remembered, were attenuated simply by passing through the WADM 108.

The fourth ONE is the equalization protocol, the algorithm by which performance of the network 115 is optimized. The equalization protocol optimizes signal power levels, or Optical Signal-to-Noise Ratio (OSNR) for each node 108. It also optimizes the performance of the entire network 115.

The fifth ONE is the optical amplifier 116. A plurality of optical amplifiers 116 typically are located along the network 115. Amplifiers 116 maintain the power budget along the network 115. Other ONEs may include optical pre-amplifiers 116 (see, for example, optical channel demultiplexer 104), optical post-amplifiers 116 (see, for example, optical channel multiplexer 100), or some combination of the two, all as previously noted. An optical amplifier 116 may also exist as a stand-alone element along the optical path. In practice, optical amplifiers 116 are deployed at designated locations along the network 115 according to the network 115 power budget.

The sixth ONE is the fiber 118 itself. The fiber 118 is the transmission medium between any other two ONEs. Because of the gain equalization mechanism discussed above, a fiber 118 may be of any suitable type(s), such as SMF, DSF, NZ-DSF, and so on.

Nodes which contain either optical multiplexers 100 or optical demultiplexers 104 are sometimes referred to as hub nodes 120. Specifically, a hub node containing an optical multiplexer 100 is referred to as a generating hub 120-1 and a hub node containing an optical demultiplexer 104 is referred to as a terminating hub 120-2.

A problem in optically amplified DWDM networks 115 is optimizing gain equalization for network 115 performance. Owing at least in part to the non-uniform spectral response of Erbium-Doped Fiber Amplifiers (EDFAs) 116, each optical channel λ_1 , λ_2 , . . . λ_n experiences a different optical gain. However, the distributed nature of DWDM networks 115, where WADMs 108 are distributed along the network 115, exacerbates the problem. In long-distance amplified systems, this can result in high Bit Error Rates (BERs) for some of the optical channels λ_1 , λ_2 , . . . λ_n. There are at least two reasons for this. The first is the OSNR that arises from crosstalk between stronger and weaker channels λ_1 , λ_2 , . . . λ_n. The second is an increase in the noise level due to Amplified Spontaneous Emissions (ASEs). It is therefore desirable to control and equalize either the optical powers or the OSNRs of the DWDM channels λ_1 , λ_2 , . . . λ_n in order to meet BER requirements. It is further desirable for this control and equalization to take place on a network 115 scale, for example, at detection planes.

The telemetry system of the present invention can perform at least the following three functions. First, the system can provide gain equalization of a channel λ_{iADD} added by a WADM 108. Second, the system can adjust the gains of all optical amplifiers 116 in the system to an optimal level. Third, the system can transfers nodal messages between network 115 nodes. Each of these functions is described in detail below.

The method of the invention can be implemented as follows. Several laser transmitter 103 power control schemes could be exploited for the optical channel λ_1 , λ_2 , . . . λ_n power level control without any impact on the upper layer of the equalization protocol. Such schemes include direct control of laser driving current and wavelength stabilization, use of an optical attenuator, for example, using step-motor technology or the like, integrated devices with Mach-Zender interferometer-based attenuators for power control, and other technologies suitable for optical power level control. The only qualification on the transmitter 103 power control mechanism is that it be transparent to the gain equalization mechanism.

The power level control loop is based on the corrective message from the hub node 120-2 that a particular WADM 108 terminal i needs to set the power level of its added optical channel λ_{iADD} appropriately. Detailed implementation is subject to the laser power level control technique that is used, and the desired performance. Automatic control can be implemented with hardware, for example, electronic circuitry, or by a software-based control loop, in order to obtain the desired performance. Again, implementation of the control strategy should be transparent to the equalization protocol.

The optical amplifier 116 AGC is based on a manual setting or a network 115 management system (NMS) automatic command. Optical amplifiers 116 along the network 115 should set and maintain an appropriate gain level of the optical signal, regardless of its power level, that is, regardless of the number of active channels λ_1 , λ_2 , . . . λ_n , the locations of the optical amplifiers 116 along the optical path, and so on.

The telemetry channel 122 provides network 115-level communication between the hub node 120 and the WADM 108 terminals along the network 115. The telemetry channel 122, or layer, thus permits transmission of any required measurements, reports, controls and commands necessary to support the gain equalization protocol. Implementation is a function of network 115 architecture and the types of communications transmitted. Options include an Optical Supervisory Channel (OSC) for inter-nodal communication. The format of the communication is a function of, among other things: the wavelength being used, for example, 1310nm, 1510nm, and so on; line rate, for example, 2Megabits per second (Mb/s), 10Mb/s, 155Mb/s, and so on; and, higher layer protocols, such as, for example, ATM, TCP/IP, and the like. The telemetry channel 122 could also be carried over any virtual supervisory channels between the hub node 120-2 and the various WADM 108 terminals. These could be, for example, ATM VPI/VCI connections, SONET/SDH message-based data communication channels, TCP/IP messages, and so on, again, based upon the network 115 configuration. Whatever the network 115 configuration and protocols that are being used, for the gain equalization protocol, only parameters such as bandwidth, message delay, and the like, are of consequence in order for the telemetry communications channel 122 to meet its performance requirements.

The general configuration of an illustrative gain equalization control loop at the network 115 level is illustrated in Fig. 2. The general configuration of an illustrative gain equalization control loop at the module 108 level is illustrated in Fig. 3. At the network 115 level, or external loop control level, the function of the hub node 120-2 is to measure the power level or OSNR of each received channel λ_1 , λ_2 , . . . λ_n. Once the hub node 120-2 receives these measurements, it generates corrective messages and transmits these corrective messages to each terminal 108 in order to effect in that terminal 108 to which each specific corrective message is addressed an adjustment of that terminal 108's specific wavelength λ_i power level with respect to the average power level within the network 115. It should be recognized that this control is not restricted to power level control alone, or to an implementation in hardware or software only.

The function of the telemetry system is to perform the optical measurement of the received power level or OSNR within the hub node 120-2 in order to monitor, indirectly, the received channel λ_i quality. The hub node 120 performs the optical power or OSNR measurement on each DWDM channel λ_1, λ_2, . . . λ_n, and compares that measurement to a defined target level. The result of each comparison is the generation of a correction message to the respective WADM 108 terminal. Each WADM 108 terminal receives its designated messages and adjusts the power level of the wavelength λ_i that it drops and adds using an Automatic Power Control (APC) loop to control its optical attenuator 114.

The control scheme maintains average optical power in order to equalize received power levels. Importantly, the scheme permits other predefined target power levels to be set, manually or automatically, based on (an)other weighting function(s). The hub node 120-2's tasks within the scheme are to: measure received optical power P_i, at an input port of each applicable DWDM receiver 109; calculate average optical power per channel,

$$P_{AVERAGE} = (1/N)\ \Sigma\ P_i,\ 1 \le i \le n,$$

over all active channels, that is, excluding inactive channels and those that have failed for whatever reason; set a new target power level for each channel,

$$P_{iTARGET} = P_i + \gamma\ (P_{AVERAGE} - P_i),$$

wherein γ is a convergence parameter having a value, for example, $0.25 \le \gamma \le 0.75$; calculate the change ΔP_i in optical power required,

$$\Delta P_i = 10 \times \log (P_{iTARGET}/P_i),\ \text{in dB};$$

and, send each terminal 108 a message to adjust its power level by ΔP_i dB. As noted, in case of a failure, for example, an optical fiber cut, transmitter failure or the like, where there is no power on a specified channel λ_i, that channel will not be considered in the calculation and its ΔP_i message will be set to zero dB in order to maintain it at its level prior to its becoming inactive.

The WADM 108 terminal, illustrated schematically in Fig. 3, drops and adds a single channel, or wavelength, λ_i. WADM 108 terminal includes a passive optical element 124 and an optical attenuator 114. The optically dropped channel λ_{iDROP} is terminated by an optical receiver 110, while the added channel λ_{iADD} is regenerated by an optical transmitter 112. Although other schemes are equally workable, in the illustrative embodiment, the optical attenuator 114 is used to adjust the added channel λ_i's power level $P_{\lambda iADD}$ to equalize it with the power levels of the passed-through channels $(\lambda_1, \lambda_2, \ldots \lambda_n) - \lambda_i$. During normal operation, equalization is performed independently at the module 108 level and at the network 115 level. Each module 108 activates an attenuator 114 control loop in an APC mode. Ignoring for purposes of explanation network 115 level control, the power level $P_{\lambda iADD}$ of the added channel λ_{iADD} should be adjusted to the power level $P_{\lambda iDROP}$ of the dropped channel λ_{iDROP} after digital low-pass filtering. That is:

$$\hat{P}_{\lambda iDROP}(m) = \alpha \times \hat{P}_{\lambda i\,DROP}(m-1) + (1-\alpha) \times P_{\lambda iDROP}(m);\ 0<\alpha<1$$

$$\hat{P}_{\lambda iADD}(m) = \hat{P}_{\lambda iDROP}(m) + IL_{\lambda iDROP} + IL_{\lambda iADD} - IL_{((\lambda 1, \lambda 2, \ldots \lambda n) - \lambda i)THROUGH}$$

where all channel $\lambda_1, \lambda_2, \ldots \lambda_n$ power levels are in dB, and where α is a tracking parameter that determines certain properties of the algorithm. As will be appreciated, this algorithm implements a unity gain low pass filter in the Z-plane. Thus, the reference output power of the APC loop should be $\hat{P}_{\lambda iADD}$. However, in order to take into account network 115 level control, the output reference power from the optical attenuator 114 should be:

$$P_{\lambda iREF} = \hat{P}_{\lambda iADD} + \varepsilon_{NET}(k) \text{ in dB}$$

where ε_{NET} is a network 115 level gain equalization control message that is sent via the optical telemetry channel 122 after processing of WADM 108 terminal i, and k is the number of the corrective message being sent. ε_{NET} is initially set to zero. Then, whenever a corrective message is received by the telemetry system, ε_{NET} is updated as follows:

$$\varepsilon_{NET}(0) = (0);$$

$$\varepsilon_{NET}(k) = \beta \times \varepsilon_{NET}(k-1) + (1-\beta) \times \Delta P_i(k),\ 0 \leq \beta \leq 1$$

where β is a tracking parameter that helps establish network 115 level convergence properties of the algorithm. Thus, this algorithm also implements a unity gain low pass filter in the Z-plane.

Abnormal operations that might occur and affect the gain equalization process include loss of $P_{\lambda iDROP}$ due, for example, to fiber cuts, remote transmitter failure and the like. In such cases, the algorithm will stop updating $P_{\lambda iDROP}$, since $P_{\lambda iDROP}$ is no longer valid. The algorithm will continue channel i attenuator 114 control and use the last valid value for $\hat{P}_{\lambda iADD}$ when calculating $P_{\lambda iREF}$. Control based upon $P_{\lambda iDROP}$ will resume when λ_{iDROP} is again available. An initial value for $\hat{P}_{\lambda iADD}$ should be defined, in case there is no dropped channel during power up.

Abnormal operations that might occur and affect the gain equalization process also include loss of $P_{\lambda iIN}$, due, for example, to local transmitter 112 failure or the like. In such cases, the algorithm continues to update $\hat{P}_{\lambda iADD}$ and $P_{\lambda iREF}$, but ignores further telemetry messages and stops adjusting the attenuator 114. Again, control resumes when λ_{iIN} is again available.

Abnormal operations that might occur and affect the gain equalization process also include loss of $P_{\lambda iADD}$, due, for example, to attenuator 114 failure, monitor failure, or the like. In such cases, the algorithm continues to update the above equations, but ignores further telemetry messages. Again, the algorithm stops adjusting the attenuator 114. Control resumes when λ_{iADD} is again available.

What is claimed is:

1. A method of controlling a network through which information is transmitted in n channels among nodes, the method including (a) providing at a node a device for removing from the network and replacing on the network a selected one of the channels, the device coupled to an input port from the network to the node and to an output port from the node to the network, (b) taking a measure of the strength of the received channel, (c) determining an average signal strength for each active channel, (d) establishing a target signal strength for each channel, (e) determining a required change in signal strength, and, (f) sending the node a message to adjust the strength of a signal coupled to the output port.

2. The method of claim 1 wherein taking a measure of the strength of the received channel includes taking a measure of the received power.

3. The method of claim 2 wherein establishing a target signal strength for each channel includes establishing a target power for each channel.

4. The method of claim 3 wherein establishing a target power for each channel includes establishing a target power $P_{iTARGET} = P_i + \gamma (P_{AVERAGE} - P_i)$, $0.25 \leq \gamma \leq 0.75$.

5. The method of claim 4 wherein calculating a required change in signal strength includes calculating a required change in signal power.

6. The method of claim 5 wherein sending a node a message to adjust its power level includes sending the node a message to adjust its signal power.

7. The method of claim 5 wherein calculating a required change in signal power includes calculating the required signal change in decibels.

8. The method of claim 7 wherein sending the node a message to adjust its power level includes sending the node a message to adjust its optical signal power.

9. The method of claim 1 wherein calculating a required change in signal strength includes calculating a required change in optical signal power.

10. The method of claim 1 further including removing a channel from the calculations of elements (b) – (d) and sending a node a message not to adjust its power level if the channel is not being received at a node.

11. A method of controlling a network through which information is transmitted in n channels among nodes, the method including (a) providing at a node a device for removing from the network and replacing on the network a selected one of the channels, the device including a first input port from the network to the node and a first output port from the node to the network, (b) taking a measure of the strength of the received channel, (c) regenerating the channel, (d) adjusting the strength of the regenerated channel to approximate the strengths of the remaining channels, and (e) combining the regenerated and strength-adjusted channel with the remaining channels at the output port.

12. The method of claim 11 wherein providing the device includes providing a device whose effects on the strengths of the removed channel, the regenerated and strength-adjusted channel and the remaining channels approximate known values.

13. The method of claim 12 wherein providing the device includes providing on the device a second output port at which the removed channel is recovered and a second input port at which the regenerated and strength-adjusted channel is recombined with the remaining channels.

14. The method of claim 13 wherein adjusting the strength of the regenerated channel to approximate the strengths of the remaining channels includes coupling the regenerated channel to an input port of an attenuator including a third input port, a control port and a third output port, coupling the third output port to the second input port, and providing at the control port a signal based upon the measured strength of the regenerated channel.

15. The method of claim 11 further including (f) calculating an average signal strength for each active channel, (g) establishing a target signal strength for each channel, (h) determining a required change in signal strength, and, (i) sending the node a message to adjust the strength of a signal coupled to the first output port.

16. The method of claim 15 wherein taking a measure of the strength of the received channel includes taking a measure of the received power.

17. The method of claim 16 wherein establishing a target signal strength for each channel includes establishing a target power for each channel.

18. The method of claim 17 wherein establishing a target power for each channel includes establishing a target power $P_{iTARGET} = P_i + \gamma (P_{AVERAGE} - P_i)$, $0.25 \leq \gamma \leq 0.75$.

19. The method of claim 18 wherein determining a required change in signal strength includes determining a required change in signal power.

20. The method of claim 19 wherein sending a node a message to adjust its power level includes sending the node a message to adjust its signal power.

21. The method of claim 19 wherein determining a required change in signal power includes determining the required signal change in decibels.

22. The method of claim 21 wherein sending a node a message to adjust its power level includes sending the node a message to adjust its optical signal power.

23. The method of claim 15 wherein determining a required change in signal strength includes determining a required change in optical signal power.

24. The method of claim 15 further including removing a channel from the determinations of elements (b), (f) and (g) and sending a node a message not to adjust its power level if the channel is not being received at a node.

25. The method of claim 15 wherein elements (b) - (d) are performed in a first time, and elements (f) - (i) are performed in a second time, the second time being longer than the first time.

26. Apparatus for controlling a network through which information is transmitted in n channels among nodes, the apparatus including a device at a node for (a) removing from the network and replacing on the network a selected one of the channels, the device coupled to an input port from the network to the node and to an output port from the node to the network, the device (b) taking a measure of the strength of the received channel, (c) determining an average signal strength for each active channel, (d) establishing a target signal strength for each channel, (e) determining a required change in signal strength, and, (f) sending the node a message to adjust the strength of a signal coupled to the output port.

27. The apparatus of claim 26 wherein the device for taking a measure of the strength of the received channel includes a device for taking a measure of the received power.

28. The apparatus of claim 27 wherein the device for establishing a target signal strength for each channel includes a device for establishing a target power for each channel.

29. The apparatus of claim 28 wherein the device for establishing a target power for each channel includes a device for establishing a target power $P_{iTARGET} = P_i + \gamma (P_{AVERAGE} - P_i)$, $0.25 \leq \gamma \leq 0.75$.

30. The apparatus of claim 29 wherein the device for calculating a required change in signal strength includes a device for calculating a required change in signal power.

31. The apparatus of claim 30 wherein the device for sending a node a message to adjust its power level includes a device for sending the node a message to adjust its signal power.

32. The apparatus of claim 30 wherein the device for calculating a required change in signal power includes a device for calculating the required signal change in decibels.

33. The apparatus of claim 32 wherein the device for sending the node a message to adjust its power level includes a device for sending the node a message to adjust its optical signal power.

34. The apparatus of claim 26 wherein the device for calculating a required change in signal strength includes a device for calculating a required change in optical signal power.

35. The apparatus of claim 26 wherein the device further includes a device for removing a channel from the calculations (b) – (d) and sending a node a message not to adjust its power level if the channel is not being received at a node.

36. Apparatus for controlling a network through which information is transmitted in channels among nodes, the apparatus including a first device for (a) removing from the network and replacing on the network a selected one of the channels, (b) taking a measure of the strength of the received channel, (c) regenerating

the channel, (d) adjusting the strength of the regenerated channel to approximate the strengths of the remaining channels, and (e) combining the regenerated and strength-adjusted channel with the remaining channels at the output port, the first device coupled to an input port from the network to the node and to an output port from the node to the network.

37. The apparatus of claim 36 wherein the first device includes a first device whose effects on the strengths of the removed channel, the regenerated and strength-adjusted channel and the remaining channels approximate known values.

38. The apparatus of claim 37 wherein the first device includes a first device having a second output port at which the removed channel is recovered and a second input port at which the regenerated and strength-adjusted channel is recombined with the remaining channels.

39. The apparatus of claim 38 further including an attenuator having a third input port, a control port and a third output port, and wherein the first device for adjusting the strength of the regenerated channel to approximate the strengths of the remaining channels includes a first device for coupling the regenerated channel to the third input port, the third output port coupled to the second input port, and the control port being provided with a signal based upon the measured strength of the regenerated channel.

40. The apparatus of claim 36 further including a second device for (f) calculating an average signal strength for each active channel, (g) establishing a target signal strength for each channel, (h) determining a required change in signal strength, and, (i) sending the node a message to adjust the strength of a signal coupled to the first output port.

41. The apparatus of claim 40 wherein the first device for taking a measure of the strength of the received channel includes a first device for taking a measure of the received power.

42. The apparatus of claim 41 wherein the second device for establishing a target signal strength for each channel includes a second device for establishing a target power for each channel.

43. The apparatus of claim 42 wherein the second device for establishing a target power for each channel includes a second device for establishing a target power $P_{iTARGET} = P_i + \gamma (P_{AVERAGE} - P_i)$, $0.25 \leq \gamma \leq 0.75$.

44. The apparatus of claim 43 wherein the second device for determining a required change in signal strength includes a second device for determining a required change in signal power.

45. The apparatus of claim 44 wherein the second device for sending a node a message to adjust its power level includes a second device for sending the node a message to adjust its signal power.

46. The apparatus of claim 44 wherein the second device for determining a required change in signal power includes a second device for determining the required signal change in decibels.

47. The apparatus of claim 46 wherein the second device for sending a node a message to adjust its power level includes a second device for sending the node a message to adjust its optical signal power.

48. The apparatus of claim 40 wherein the second device for determining a required change in signal strength includes a second device for determining a required change in optical signal power.

49. The apparatus of claim 40 wherein the second device further includes a second device for removing a channel from the determinations of elements (b), (f) and (g) and sending a node a message not to adjust its power level if the channel is not being received by the second device.

50. The apparatus of claim 40 wherein the first device includes a first device for performing elements (b) - (d) in a first time, and the second device includes a second device for performing elements (f) - (i) in a second time longer than the first time.

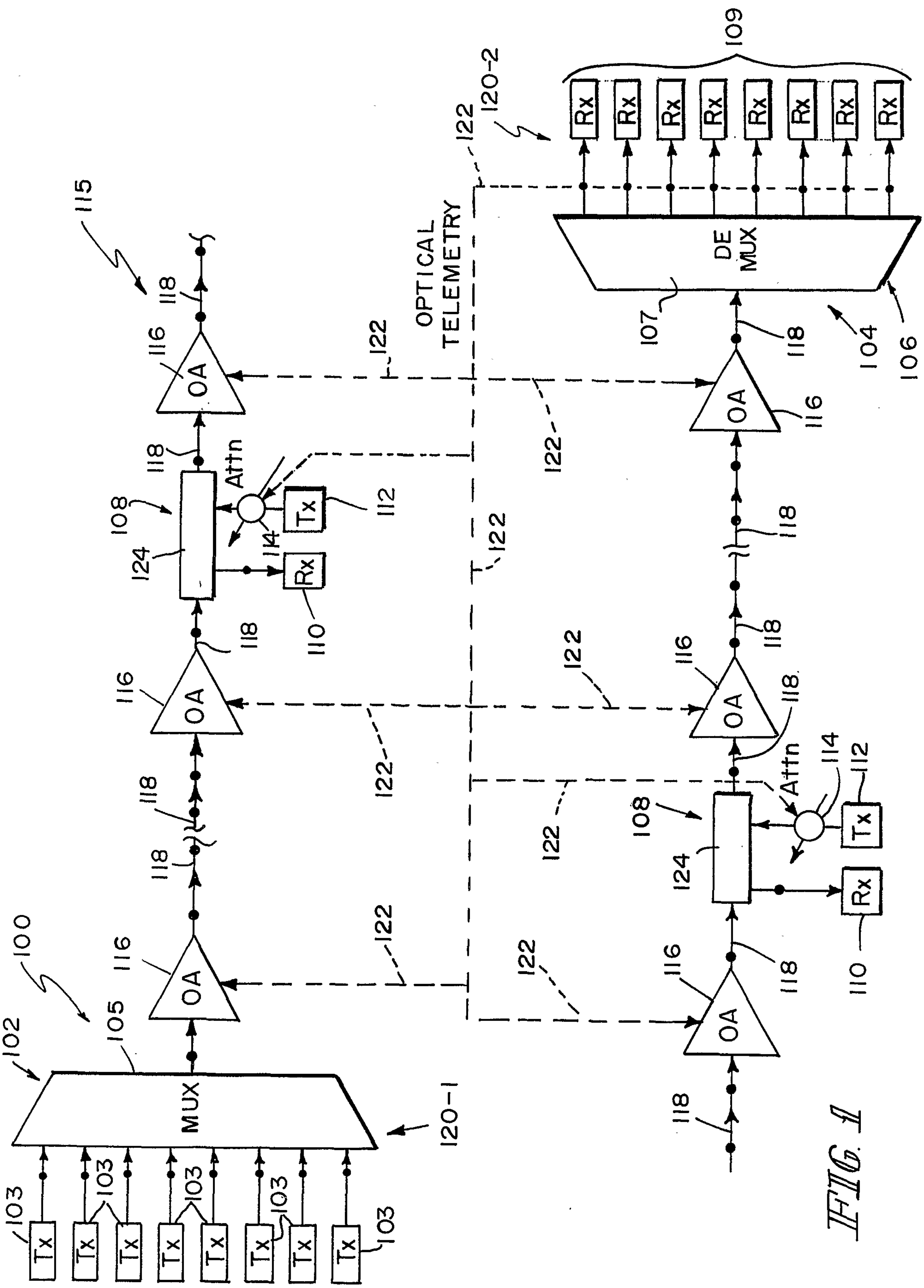

OPTICAL TELEMETRY
MUX
DE MUX
OA
Tx
Rx
Attn
100
102
103
104
105
106
107
108
109
110
112
114
115
116
118
120-1
120-2
122
124

FIG. 1

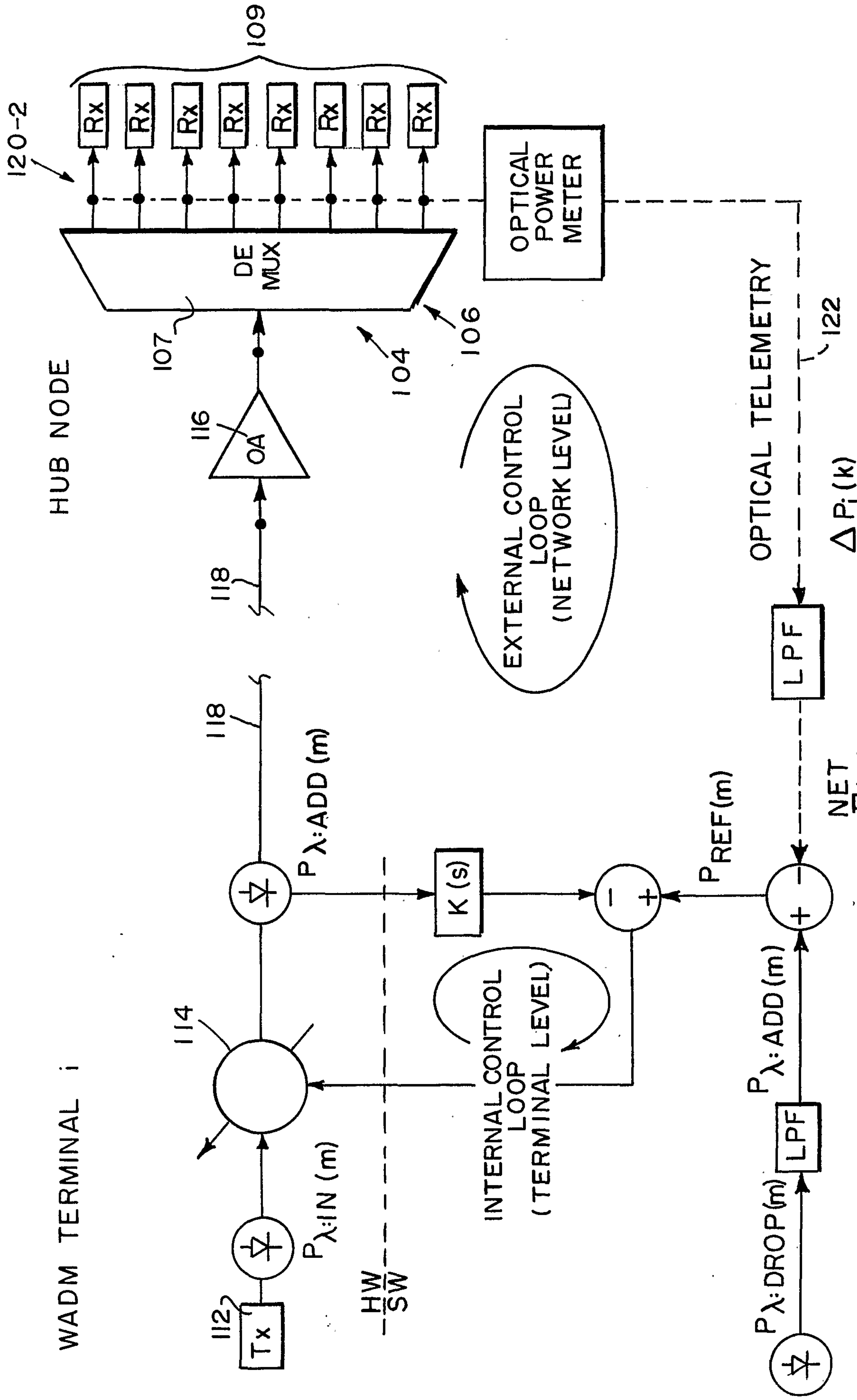

HUB NODE
WADM TERMINAL i
109
120-2
Rx
Rx
Rx
Rx
Rx
Rx
Rx
Rx
DE MUX
107
104
106
OPTICAL POWER METER
OPTICAL TELEMETRY
122
Δ P_i (k)
LPF
NET E(m)
116
OA
118
118
EXTERNAL CONTROL LOOP (NETWORK LEVEL)
P λ:ADD (m)
K (s)
P REF (m)
114
INTERNAL CONTROL LOOP (TERMINAL LEVEL)
P λ:ADD (m)
LPF
P λ:DROP (m)
P λ:IN (m)
112
Tx
HW
SW

FIG. 2

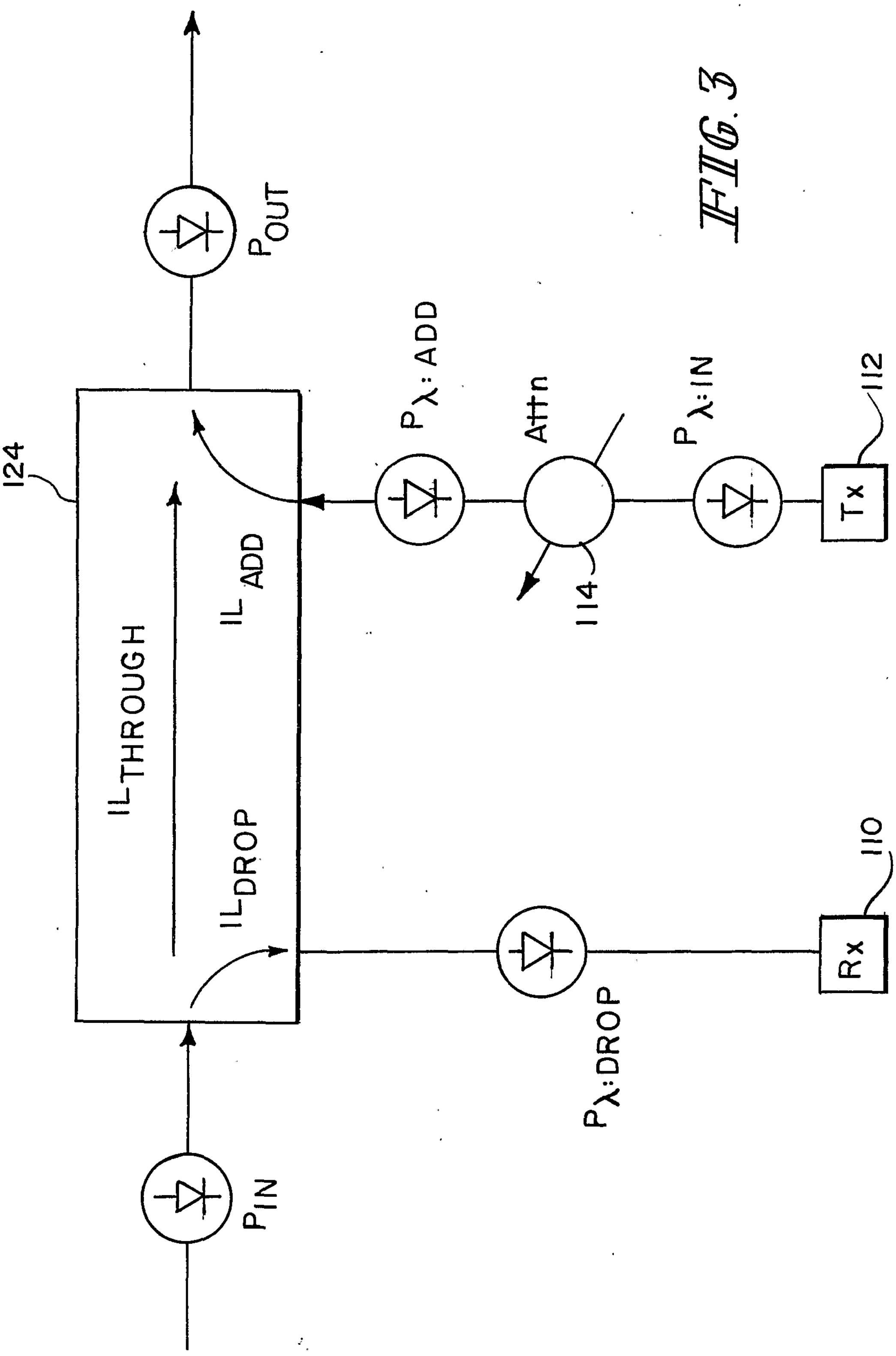

124
IL THROUGH
IL DROP
IL ADD
P OUT
P IN
Pλ: ADD
Attn
Pλ:IN
114
112
Tx
110
Rx
Pλ:DROP

FIG. 3

INTERNATIONAL SEARCH REPORT

International application No.
PCT/US01/13121

A. CLASSIFICATION OF SUBJECT MATTER
IPC(7) : H04J 14/02
US CL : 359/124, 110
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
U.S. : 359/124, 110, 127, 177, 187

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
Y, P	US 6,236,499 B1 (BERG et al.) 22 May 2001 (22.05.2001), entire document.	1-50
Y, E	US 6,219,162 B1 (BARNARD et al.) 17 April 2001 (17.04.2001), entire document.	1-50
Y, P	US 6,163,399 A (BERG) 19 December 2000 (19.12.2000), entire document.	1-50
Y, P	US 6,134,036 A (ANDREOZZI et al.) 17 October 2000 (17.10.2000), entire document.	1-50
Y, P	US 6,115,157 A (BARNARD et al.) 05 September 2000 (05.09.2000), entire document.	1-50
Y	US 6,040,933 A (KHALEGHI et al.) 21 March 2000 (21.03.2000), entire document.	1-50
Y	US 5,986,782 A (ALEXANDER et al.) 16 November 1999 (16.11.1999), entire document.	1-50
Y	JP 41-51918 A (NISHIMURA) 25 May 1992 (25.05.1992), abstract.	1-50
Y	JP 40-56431 A (TANAKA et al.) 24 February 1992 (24.02.1992), abstract.	1-50
Y	US 5,675,432 A (KOSAKA) 07 October 1997 (07.10.1997), entire document.	1-50
Y	US 5,225,922 A (CHRAPLYVY et al.) 06 July 1993 (06.07.1993), entire document.	1-50

☐ Further documents are listed in the continuation of Box C. ☐ See patent family annex.

* Special categories of cited documents:

"A" document defining the general state of the art which is not considered to be of particular relevance

"E" earlier application or patent published on or after the international filing date

"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)

"O" document referring to an oral disclosure, use, exhibition or other means

"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

"X" document of particular relevance; the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone

"Y" document of particular relevance; the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art

"&" document member of the same patent family

Date of the actual completion of the international search 01 June 2001 (01.06.2001)	Date of mailing of the international search report 27 JUN 2001
Name and mailing address of the ISA/US Commissioner of Patents and Trademarks Box PCT Washington, D.C. 20231 Facsimile No. (703)305-3230	Authorized officer Jason Chan Telephone No. 703-305-4700