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(71) Demandeur/Applicant:
HITACHI CABLE, LTD., JP

(72) Inventeurs/Inventors:
HISATO, UETSUKA, JP;
TAKAFUMI, CHIBA, JP;
HIDEAKI, ARAI, JP

(74) Agent: SMART & BIGGAR

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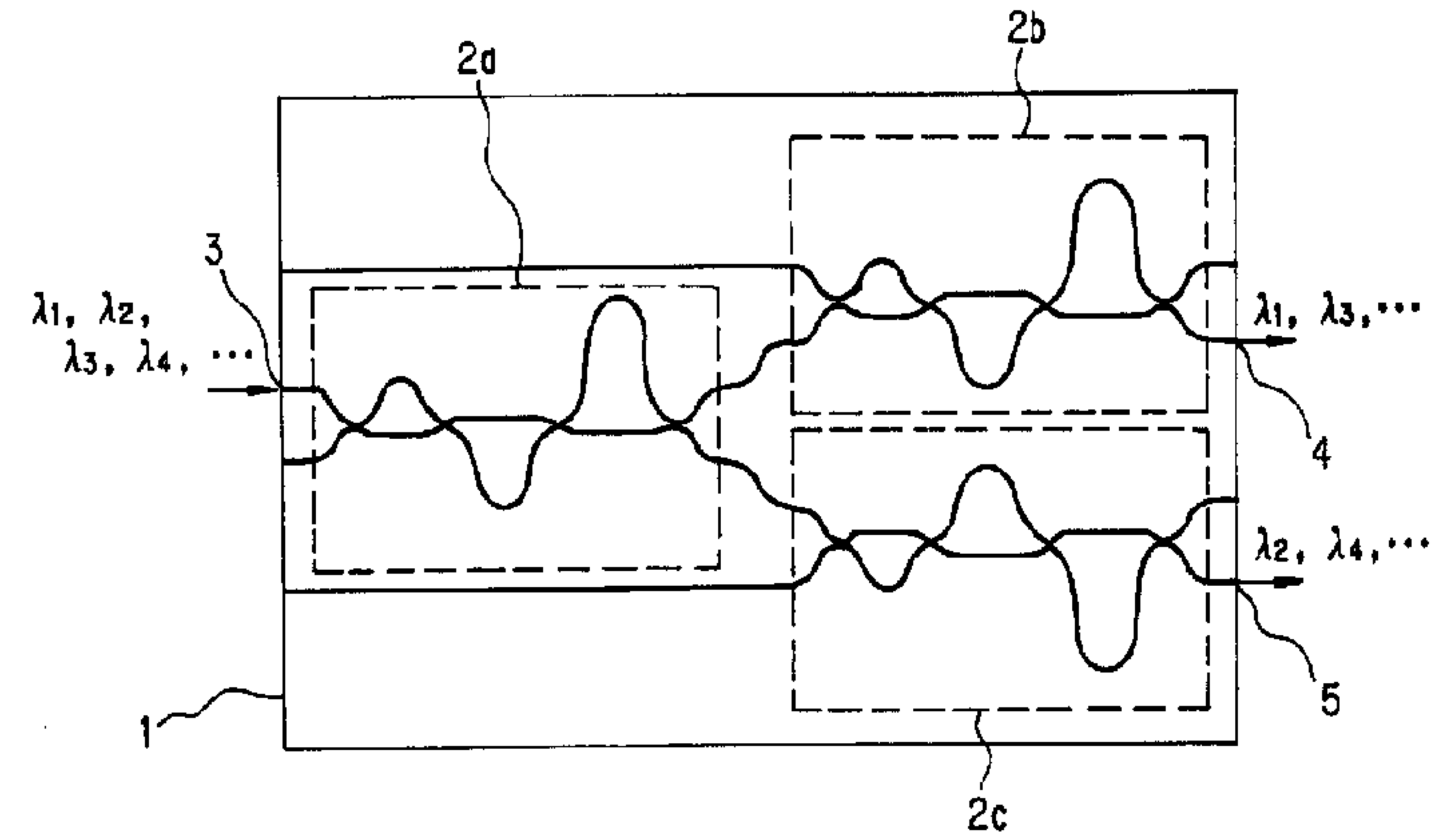


1 : QUARTZ SUBSTRATE
2a : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2b : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2c : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
3 : INPUT PORT
4 : OUTPUT PORT
5 : OUTPUT PORT
λ : OPTICAL SIGNAL

(57) Abrégé/Abstract:
In an optical multiplexer/demultiplexer comprising optical multiplexer/demultiplexer circuits connected in multistage, the optical multiplexer/demultiplexer circuits each have two input ports and two output ports, an optical path, through which input optical signals with predetermined wavelengths are output after multiplexing and demultiplexing, varies depending upon the input port; the optical paths in each of the optical multiplexer/demultiplexer circuits have mutually opposite wavelength dispersion characteristics, and one of the optical paths in a first optical multiplexer/demultiplexer circuit is connected to one of the optical paths, in a second optical multiplexer/demultiplexer circuit, having wavelength dispersion characteristics opposite to the optical path in the first optical multiplexer/demultiplexer circuit. By virtue of this construction, an optical multiplexer/demultiplexer can be realized which causes no significant wavelength dispersion and, at the same time, has excellent wavelength flatness characteristics in passband.

ABSTRACT OF THE DISCLOSURE

In an optical multiplexer/demultiplexer comprising optical multiplexer/demultiplexer circuits connected in multistage, the optical multiplexer/demultiplexer circuits each have two input ports and two output ports, an optical path, through which input optical signals with predetermined wavelengths are output after multiplexing and demultiplexing, varies depending upon the input port; the optical paths in each of the optical multiplexer/demultiplexer circuits have mutually opposite wavelength dispersion characteristics, and one of the optical paths in a first optical multiplexer/demultiplexer circuit is connected to one of the optical paths, in a second optical multiplexer/demultiplexer circuit, having wavelength dispersion characteristics opposite to the optical path in the first optical multiplexer/demultiplexer circuit. By virtue of this construction, an optical multiplexer/demultiplexer can be realized which causes no significant wavelength dispersion and, at the same time, has excellent wavelength flatness characteristics in passband.

OPTICAL MULTIPLEXER/DEMULTIPLEXER

FIELD OF THE INVENTION

The invention relates to an optical multiplexer/demultiplexer, and particularly to an optical multiplexer/demultiplexer which can significantly reduce the wavelength dispersion.

BACKGROUND OF THE INVENTION

An interleave system, which is one form of advanced wavelength multiplexing communications, requires an optical multiplexer/demultiplexer having a function such that a signal with certain channel wavelength spacings is demultiplexed to two signals with doubled channel wavelength spacings, or conversely, two signals are multiplexed to one signal.

Fig. 12 is an explanatory view showing one example of a prior art technique for coping with this demand. Since a broad and flat wavelength passband is required of the optical multiplexer/demultiplexer used in the interleave, as shown in Fig. 12, the prior art technique has adopted a multistage-connected construction of Mach-Zehnder interference circuits which each comprise four optical couplers (directional couplers) 24, 25, 26, 27 and waveguide pairs each comprising two waveguides with different lengths (28, 29), (30, 31), (32, 33), for connecting the optical couplers to each other (see, for example, U.S. Patent No. 5,852,505).

Fig. 13 shows a spectral response for an input/output port 22 in the case where a white light source is input through an input/output port 21, and Fig. 14 a spectral response for an input/output port 23. When signals λ_1, λ_2, λ_3, λ_4 with channel spacings of about 0.4 nm (frequency 50 GHz) are input through the port 21, λ_1 and λ_3 are output through the port 22 while λ_2 and λ_4 are output through the port 23. In this case, the output signals have channel wavelength spacings of about 0.8 nm (frequency 100 GHz). The multistage construction of Mach-Zehnder interference circuits shown in Fig. 12 has an advantage that, as shown in wavelength loss characteristics in Figs. 13 and 14, a broad and flat passband can be provided.

The optical multiplexer/demultiplexer shown in Fig. 12, however, suffers from a problem that the realization of good loss wavelength flatness disadvantageously leads to wavelength dispersion.

Fig. 15 shows wavelength dispersion characteristics for a path wherein optical signals are input through the port 21 and output through the port 22, and Fig. 16 wavelength dispersion characteristics for a path wherein optical signals are input through the port 21 and output through the port 23. For both the drawings, in the abscissa, frequency is used instead of the wavelength, while the ordinate represents only dispersion around passbands (around λ_1 passband and around λ_2 passband). As is apparent from the drawings, the dispersion around the passbands is about 30 ps/nm. This value, of course, varies depending upon parameters. In theory, however, it is unavoidable that improving the loss wavelength flatness leads to dispersion. This wavelength dispersion is significantly disadvantageous in terms of transmission speed of the system and relay distance.

SUMMARY OF THE INVENTION

Accordingly, it is an object of the invention to solve the above problem of the prior art and to provide an optical multiplexer/demultiplexer which causes no significant wavelength dispersion (theoretically has no wavelength dispersion) and, at the same time, has excellent wavelength flatness characteristics in passband.

According to the first feature of the invention, an optical multiplexer/demultiplexer comprises optical multiplexer/demultiplexer circuits connected in multistage, wherein:

the optical multiplexer/demultiplexer circuits each have two input ports and two output ports;

an optical path, through which input optical signals with predetermined wavelengths are output after multiplexing and demultiplexing, varies depending upon the input port;

the optical paths in each of the optical multiplexer/demultiplexer circuits have mutually opposite wavelength dispersion characteristics; and

one of the optical paths in a first optical multiplexer/demultiplexer circuit is connected to one of the optical paths, in a second optical multiplexer/demultiplexer circuit, having wavelength dispersion characteristics opposite to the optical path in the first optical multiplexer/demultiplexer circuit.

This optical multiplexer/demultiplexer may comprise two optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port; and

the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the second port in the second optical multiplexer/demultiplexer circuit while the fourth port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

Further, the optical multiplexer/demultiplexer may comprise two optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port; and

the fourth port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the second port in the second optical multiplexer/demultiplexer circuit while the third port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

Furthermore, the optical multiplexer/demultiplexer may comprise three optical multiplexer/demultiplexer circuits integrated with each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals;

said optical multiplexer/demultiplexer circuits have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port;

for other optical signals with predetermined wavelengths, the optical multiplexing/demultiplexing characteristics are such that the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port;

the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the second port in the second optical multiplexer/demultiplexer circuit, and the fourth port in the first optical multiplexer/demultiplexer circuit is connected to the second port in the third optical multiplexer/demultiplexer circuit; and

the fourth port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths while the third port in the third optical multiplexer/demultiplexer circuit is used as an output port for other optical signals with predetermined wavelengths.

Furthermore, the optical multiplexer/demultiplexer may comprise two optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port; and

the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the fourth port in the second optical multiplexer/demultiplexer circuit while the second port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

Furthermore, the optical multiplexer/demultiplexer may comprise two optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port; and

the fourth port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the third port in the second optical multiplexer/demultiplexer circuit while the second port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

Furthermore, the optical multiplexer/demultiplexer may comprise three optical multiplexer/demultiplexer circuits integrated with each other, wherein:

said optical multiplexer/demultiplexer circuits each comprise a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals;

said optical multiplexer/demultiplexer circuits have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port;

for other optical signals with predetermined wavelengths, the optical multiplexing/demultiplexing characteristics are such that the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port;

the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the fourth port in the second optical multiplexer/demultiplexer circuit, and the fourth port in the first optical multiplexer/demultiplexer circuit is connected to the third port in the third optical multiplexer/demultiplexer circuit; and

the second port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths while the second port in the third optical multiplexer/demultiplexer circuit is used as an output port for other optical signals with predetermined wavelengths.

The optical multiplexer/demultiplexer circuits are preferably constructed so that Mach-Zehnder interference circuits each comprising a plurality of optical couplers, including directional couplers, and two waveguides, with different lengths, connecting the optical couplers to each other are connected in multistage.

Further, the Mach-Zehnder interference circuits each preferably comprise a quartz-based plane optical waveguide substrate. In this case, since three Mach-Zehnder interference circuits can be integrated on a single substrate, the size of the optical multiplexer/demultiplexer can be reduced as compared with the case where three Mach-Zehnder interference circuits are connected through an optical fiber.

BRIEF DESCRIPTION OF THE DRAWINGS

The invention will be explained in more detail in conjunction with the appended drawings, wherein:

Fig. 1 is an explanatory view showing a preferred embodiment of the invention;

Fig. 2 is an explanatory view showing another preferred embodiment of the invention;

Fig. 3 is an explanatory view showing a Mach-Zehnder interference circuit as a constituent unit of the optical multiplexer/demultiplexer according to the invention;

Fig. 4 is an explanatory view showing wavelength loss characteristics in an output port 4 of an optical multiplexer/demultiplexer according to the invention;

Fig. 5 is an explanatory view showing wavelength loss characteristics in an output port 5 of an optical multiplexer/demultiplexer according to the invention;

Fig. 6 is an explanatory view showing wavelength loss characteristics in an output port 4 of an optical multiplexer/demultiplexer according to the invention;

Fig. 7 is an explanatory view showing wavelength loss characteristics in an output port 5 of an optical multiplexer/demultiplexer according to the invention;

Fig. 8 is an explanatory view showing a difference in wavelength dispersion characteristics according to one combination of input and output ports in the Mach-Zehnder interference circuit and the wavelength flatness of loss for this combination;

Fig. 9 is an explanatory view showing a difference in wavelength dispersion characteristics according to another combination of input and output ports in the Mach-Zehnder interference circuit and the wavelength flatness of loss for this combination;

Fig. 10 is an explanatory view showing a difference in wavelength dispersion characteristics according to still another combination of input and output ports in the Mach-Zehnder interference circuit and the wavelength flatness of loss for this combination;

Fig. 11 is an explanatory view showing a difference in wavelength dispersion characteristics according to a further combination of input and output ports in the Mach-Zehnder interference circuit and the wavelength flatness of loss for this combination;

Fig. 12 is an explanatory view showing a prior art technique;

Fig. 13 is an explanatory view showing the wavelength loss characteristics of a prior art technique;

Fig. 14 is an explanatory view showing the wavelength loss characteristics of a prior art technique;

Fig. 15 is an explanatory view showing the wavelength dispersion characteristics and wavelength loss characteristics in a passband of a prior art technique; and

Fig. 16 is an explanatory view showing the wavelength dispersion characteristics and wavelength loss characteristics in a passband of a prior art technique.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Preferred embodiments of the invention will be explained in conjunction with the accompanying drawings.

Fig. 1 shows a preferred embodiment of the waveguide-type optical multiplexer/demultiplexer according to the invention.

Fig. 2 shows another preferred embodiment of the waveguide-type optical multiplexer/demultiplexer according to the invention.

Both the preferred embodiments have an integrated structure of three Mach-Zehnder interference circuits 2a, 2b, 2c. These three Mach-Zehnder interference circuits 2a, 2b, 2c as constituent units of the waveguide-type optical multiplexer/demultiplexer have the same structure, except that, in Fig. 1, the Mach-Zehnder interference circuit 2c is vertically symmetrical with the Mach-Zehnder interference circuit 2b, while, in Fig. 2, the Mach-Zehnder interference circuit 2a is laterally symmetrical with the Mach-Zehnder interference circuits 2b and 2c.

As shown in Fig. 3, each of the Mach-Zehnder interference circuits 2a, 2b, 2c comprises four directional coupler-type optical couplers 10, 11, 12, 13 and a pair of waveguides (14, 15) which have different lengths and connect the coupler 10 to the coupler 11, a pair of waveguides (16, 17) which have different lengths and connect the coupler 11 to the coupler 12, and a pair of waveguides (18, 19) which have different lengths and connect the coupler 12 to the coupler 13. For the optical couplers 10, 11, the designed value of coupling is about 50%. The optical couplers 10, 11 may be replaced with MMI couplers.

For the optical couplers 12, 13, the designed value of coupling is about 2%. Assuming that the difference in length between the waveguides 14 and 15 is ΔL, the equivalent refractive index of the waveguide is Neff, and the center wavelength of a waveband used in this optical multiplexer/demultiplexer is λc, the difference in length between the waveguides 16 and 17 is $2\Delta L$ while the difference in length between the waveguides 18 and 19 is $4\Delta L - \lambda/\text{Neff}$. In this preferred embodiment, ΔL = 2,033 μm, Neff = 1.44, and λ = 1.55 μm. As shown in the drawing, the longer connecting waveguide 15 in the first stage is on the same side as the longer connecting waveguide 19 in the third stage, and the longer waveguide 17 in the second stage is connected on the side opposite to the waveguides 15 and 19. For convenience, numeral 6 designates a first port, numeral 7 a second port, numeral 8 a third port, and numeral 9 a fourth port.

Figs. 8 to 11 show the wavelength dispersion characteristics of the Mach-Zehnder interference circuit shown in Fig. 3. Fig. 8 shows the wavelength dispersion characteristics and wavelength loss characteristics of a path (an optical path) wherein, in the circuit shown in Fig. 8, optical signals are input through the upper input port (first port) and output through the upper output port (third port), and Fig. 9 shows the wavelength dispersion characteristics and wavelength loss characteristics of a path (an optical path) wherein, in the circuit shown in Fig. 9, optical signals are input through the lower input port (second port) and are output through the lower output port (fourth port). As is apparent from Figs. 8 and 9, these two paths are identical to each other in loss wavelength characteristics and are opposite to each other in wavelength dispersion characteristics. These paths may be connected to each other to mutually cancel the dispersion by taking advantage of this relationship. Although the passband is somewhat narrowed, the blocking characteristics are improved because filtering is performed twice. Therefore, the isolation is doubled. Similarly, a circuit shown in Fig. 10 wherein optical signals are input through the upper input port (first port) and are output through the lower output port (fourth port), and a circuit shown in Fig. 11 wherein optical signals are input through the lower input port (second port) and are output through the upper output port (third port), are identical to each other in wavelength loss characteristics and are opposite to each other in wavelength dispersion characteristics. Two-stage connection of the three multistage Mach-Zehnder interference circuits so as to cancel the dispersion by taking advantage of this relationship can realize an optical multiplexer/demultiplexer wherein the dispersion is theoretically zero.

In the preferred embodiment shown in Fig. 1, the first port in the Mach-Zehnder interference circuit 2a is an input port 3, and the third and fourth ports in the Mach-Zehnder interference circuit 2a are connected to the second port in the Mach-Zehnder interference circuit 2b and the second port in the Mach-Zehnder interference circuit 2c, respectively. Light input through the input port 3 is output through the output port 4 (the fourth port in the Mach-Zehnder interference circuit 2b) or the output port 5 (the third port in the Mach-Zehnder interference circuit 2c) according to wavelengths of the light.

On the other hand, in another preferred embodiment shown in Fig. 2, the first port in the Mach-Zehnder interference circuit 2a is an input port 3, and the third and fourth ports in the Mach-Zehnder interference circuit 2a are connected to the fourth port in the Mach-Zehnder interference circuit 2b and the third port in the Mach-Zehnder interference circuit 2c, respectively. Light input through the input port 3 is output through the output port 4 (the second port in the Mach-Zehnder interference circuit 2b) or the output port 5 (the second port in the Mach-Zehnder interference circuit 2c) according to wavelengths of the light.

For both the preferred embodiments, for example, when optical signals λ_1, λ_2, λ_3, λ_4 with wavelength intervals of 0.4 nm are input through the input port 3, the optical signals λ_1, λ_3 are output from the output port 4 while the optical signals λ_2, λ_4 are output from the output port 5. In this connection, the Mach-Zehnder interference circuits are connected to each other so that the wavelength dispersion caused in the Mach-Zehnder interference circuit 2a is cancelled by the Mach-Zehnder interference circuit 2c.

Figs. 4 to 7 show the optical characteristics of this preferred embodiment shown in Fig. 1. Fig. 4 shows the wavelength loss characteristics of an output port 4 in the case where optical signals are input through an input port 3, Fig. 5 the wavelength loss characteristics of an output port 5, and

Fig. 6 the wavelength loss characteristics and wavelength dispersion characteristics of the passband in the output port 4. As can be seen from the drawing, wavelength flatness is achieved for the loss in the passband, and, at the same time, the dispersion is substantially zero over the whole passband. Similarly, Fig. 7 shows the wavelength loss characteristics and wavelength dispersion characteristics for the passband in the output port 5. As can be seen from Fig. 7, the dispersion is substantially zero while maintaining the wavelength flatness of loss.

The optical circuit according to this preferred embodiment is a quartz-based plane optical wave circuit provided on a quartz substrate 1. This circuit is prepared as follows. A core glass layer is formed by sputtering and then patterned by photolithography and etching. A cladding is then formed thereon by plasma CVD. The core is formed of GeO_2- or TiO_2-doped SiO_2, the cladding is formed of SiO_2, and the substrate is also formed of SiO_2. After the preparation of the device, a CO_2 laser is preferably applied to correct an error involved in the preparation. The device preparation process, however, is not limited to this only, and any waveguide preparation process commonly used in the art is applicable.

Although the preferred embodiments have been described by taking a waveguide type as an example, the construction can be realized, for example, by using an optical fiber-type coupler.

As is apparent from the foregoing description, the present invention has the following effects.

(1) An optical multiplexer/demultiplexer can be provided

which does not cause any wavelength dispersion and, at the same time, has excellent wavelength flatness in the passband.

(2) The optical multiplexer/demultiplexer is connected in two stages. Therefore, filtering is performed twice, leading to improved isolation characteristics.

(3) Optical signals can be multiplexed and demultiplexed without increasing wavelength dispersion. This can realize an increased transmission speed and an increased relay distance in a wavelength multiplexing communication system.

The invention has been described in detail with particular reference to preferred embodiments, but it will be understood that variations and modifications can be effected within the scope of the invention as set forth in the appended claims.

WHAT IS CLAIMED IS:

1. An optical multiplexer/demultiplexer comprising optical multiplexer/demultiplexer circuits connected in multistage, wherein:

the optical multiplexer/demultiplexer circuits each have two input ports and two output ports;

an optical path, through which input optical signals with predetermined wavelengths are output after multiplexing and demultiplexing, varies depending upon the input port;

the optical paths in each of the optical multiplexer/demultiplexer circuits have mutually opposite wavelength dispersion characteristics; and

one of the optical paths in a first optical multiplexer/demultiplexer circuit is connected to one of the optical paths, in a second optical multiplexer/demultiplexer circuit, having wavelength dispersion characteristics opposite to the optical path in the first optical multiplexer/demultiplexer circuit.

2. An optical multiplexer/demultiplexer comprising two optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port; and

the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the second port in the second optical multiplexer/demultiplexer circuit while the fourth port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

3. An optical multiplexer/demultiplexer comprising two optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port; and

the fourth port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the second port in the second optical multiplexer/demultiplexer circuit while the third port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

4. An optical multiplexer/demultiplexer comprising three optical multiplexer/demultiplexer circuits integrated with each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals;

said optical multiplexer/demultiplexer circuits have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port;

for other optical signals with predetermined wavelengths, the optical multiplexing/demultiplexing characteristics are such that the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port;

the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the second port in the second optical multiplexer/demultiplexer circuit, and the fourth port in the first optical multiplexer/demultiplexer circuit is connected to the second port in the third optical multiplexer/demultiplexer circuit; and

the fourth port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths while the third port in the third optical multiplexer/demultiplexer circuit is used as an output port for other optical signals with predetermined wavelengths.

5. An optical multiplexer/demultiplexer comprising two

optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port; and

the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the fourth port in the second optical multiplexer/demultiplexer circuit while the second port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

6. An optical multiplexer/demultiplexer comprising two optical multiplexer/demultiplexer circuits connected to each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals, and have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port;

the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port; and

the fourth port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the third port in the second optical multiplexer/demultiplexer circuit while the second port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths.

7. An optical multiplexer/demultiplexer comprising three optical multiplexer/demultiplexer circuits integrated with each other, wherein:

said optical multiplexer/demultiplexer circuits each have a waveguide with first and third ports as terminals and a waveguide with second and fourth ports as terminals;

said optical multiplexer/demultiplexer circuits have optical multiplexing/demultiplexing characteristics such that, for optical signals with predetermined wavelengths, the optical signals input through the first port are output through the third port while optical signals input through the second port are output through the fourth port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the third port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the fourth port;

for other optical signals with predetermined wavelengths, the optical multiplexing/demultiplexing characteristics are such that the optical signals input through the first port are output through the fourth port while optical signals input through the second port are output through the third port, and the wavelength dispersion characteristics, in the case where the optical signals are input through the first port and output through the fourth port, are opposite to the wavelength dispersion characteristics in the case where the optical signals are input through the second port and output through the third port;

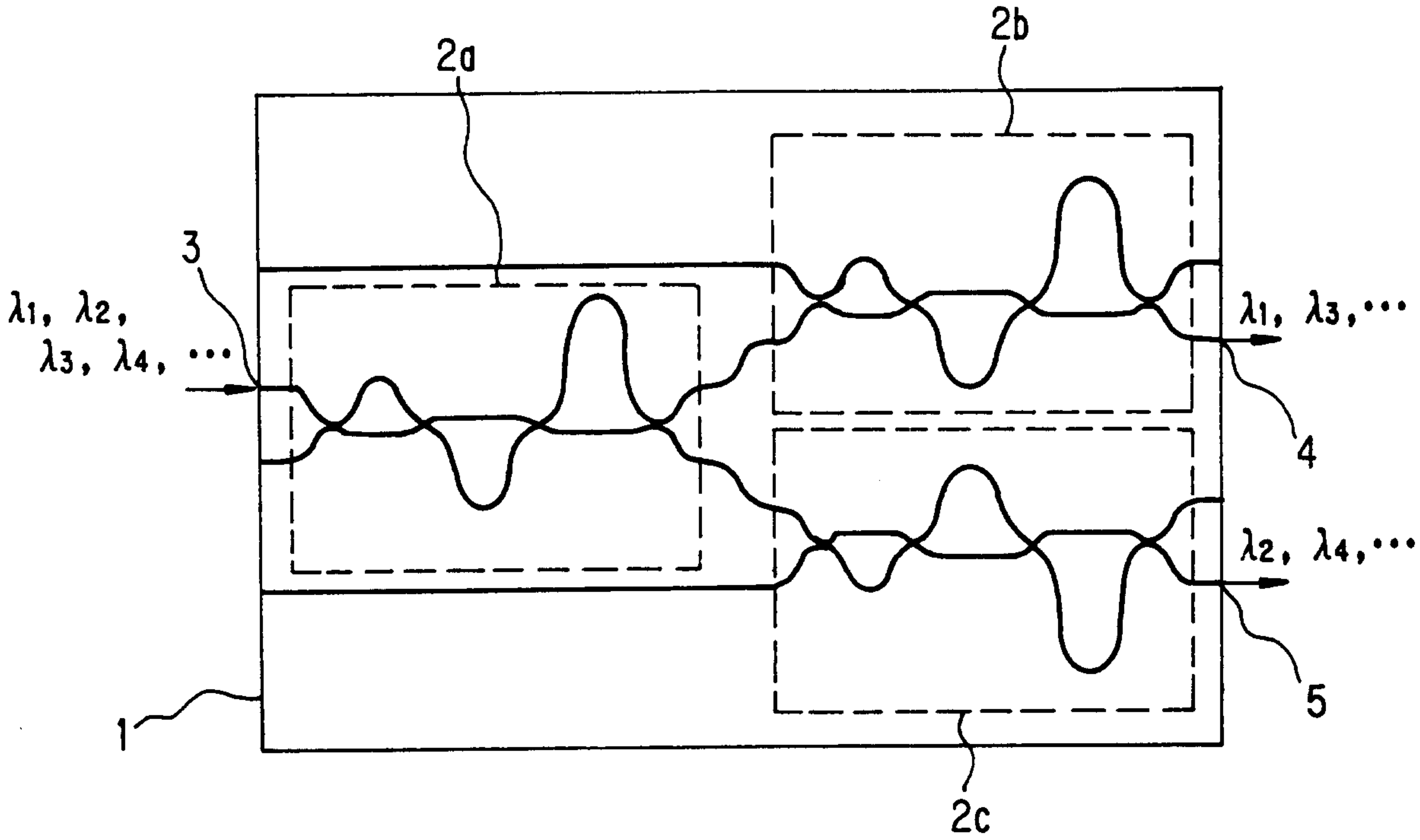
the third port in the first optical multiplexer/demultiplexer circuit, when the first port in the first optical multiplexer/demultiplexer circuit is used as an input port, is connected to the fourth port in the second optical multiplexer/demultiplexer circuit, and the fourth port in the first optical multiplexer/demultiplexer circuit is connected to the third port in the third optical multiplexer/demultiplexer circuit; and

the second port in the second optical multiplexer/demultiplexer circuit is used as an output port for optical signals with predetermined wavelengths while the second port in the third optical multiplexer/demultiplexer circuit is used as an output port for other optical signals with predetermined wavelengths.

8. The optical multiplexer/demultiplexer according to any one of claims 2 to 7, wherein the optical multiplexer/demultiplexer circuits are constructed so that Mach-Zehnder interference circuits each comprising a plurality of optical couplers, including directional couplers, and two waveguides, with different lengths, connecting the optical couplers to each other are connected in multistage.

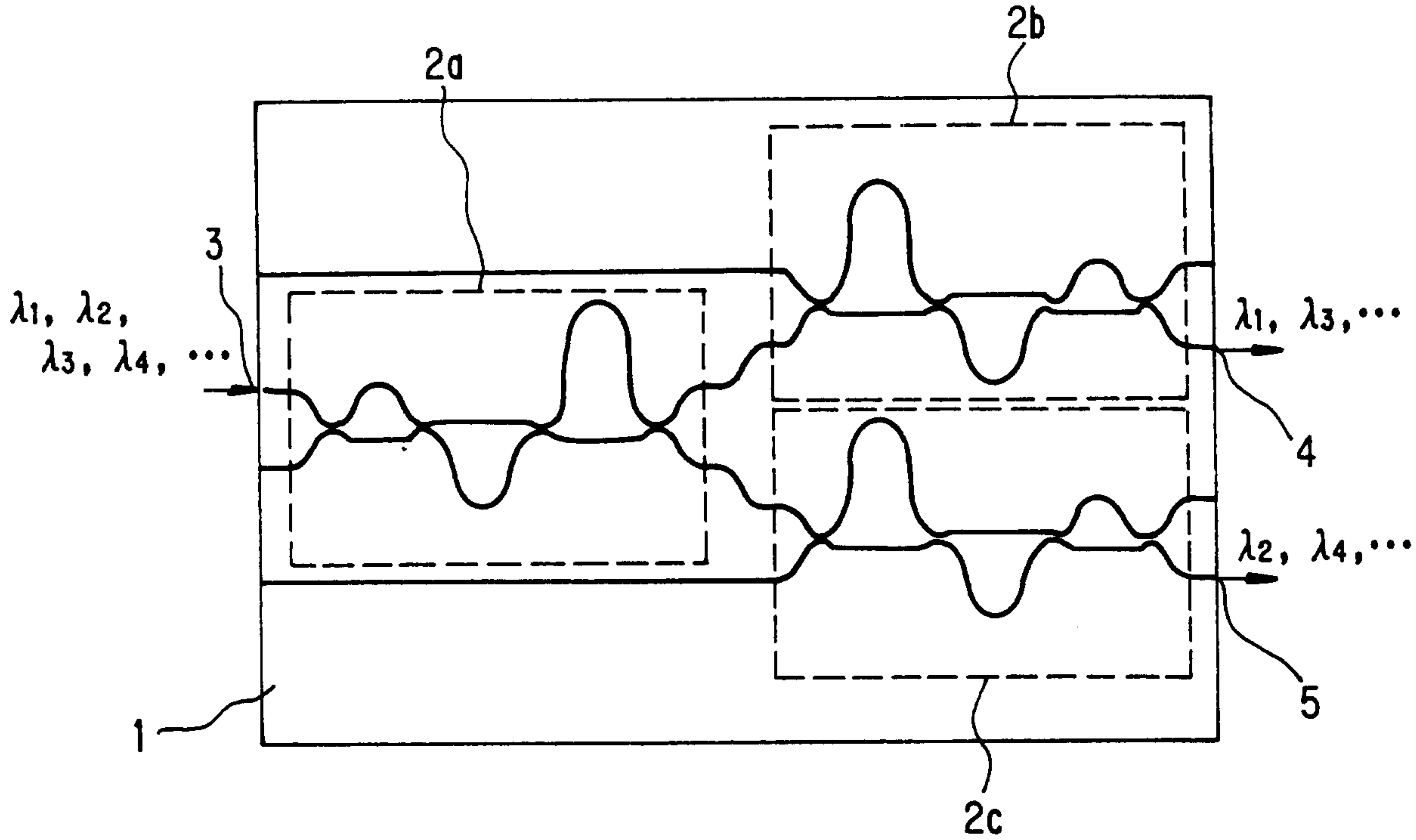
9. The optical multiplexer/demultiplexer according to claim 8, wherein the Mach-Zehnder interference circuits each comprise a quartz-based plane optical waveguide substrate.

FIG. 1



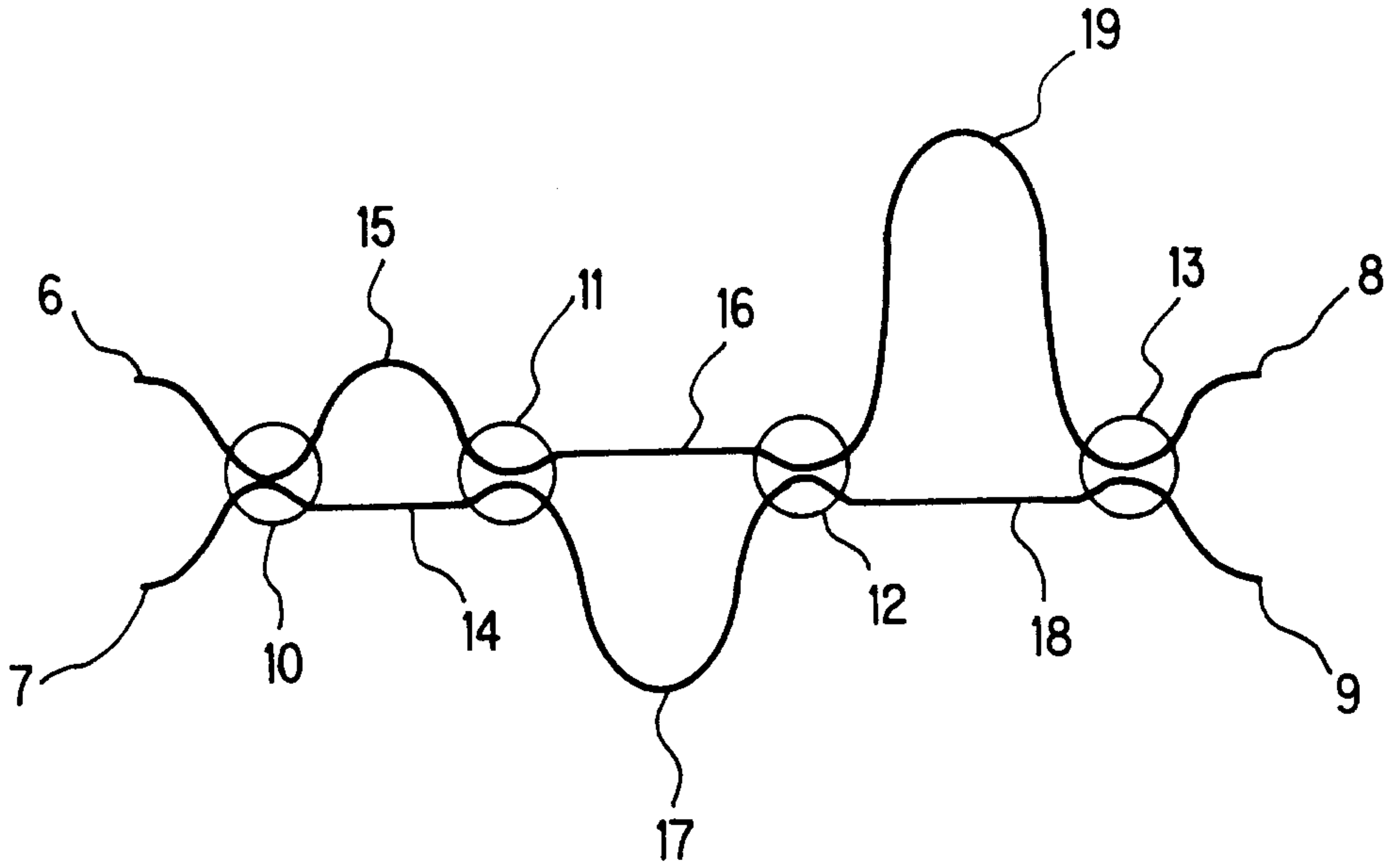
1 : QUARTZ SUBSTRATE
2a : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2b : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2c : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
3 : INPUT PORT
4 : OUTPUT PORT
5 : OUTPUT PORT
λ : OPTICAL SIGNAL

FIG. 2



1: QUARTZ SUBSTRATE
2a : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2b : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2c : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
3 : INPUT PORT
4 : OUTPUT PORT
5 : OUTPUT PORT
λ : OPTICAL SIGNAL

FIG. 3



6 : INPUT/OUTPUT PORT
7 : INPUT/OUTPUT PORT
8 : INPUT/OUTPUT PORT
9 : INPUT/OUTPUT PORT
10 : DIRECTIONAL COUPLER
11 : DIRECTIONAL COUPLER
12 : DIRECTIONAL COUPLER
13 : DIRECTIONAL COUPLER
14 : WAVEGUIDE
15 : WAVEGUIDE
16 : WAVEGUIDE
17 : WAVEGUIDE
18 : WAVEGUIDE
19 : WAVEGUIDE

FIG.4

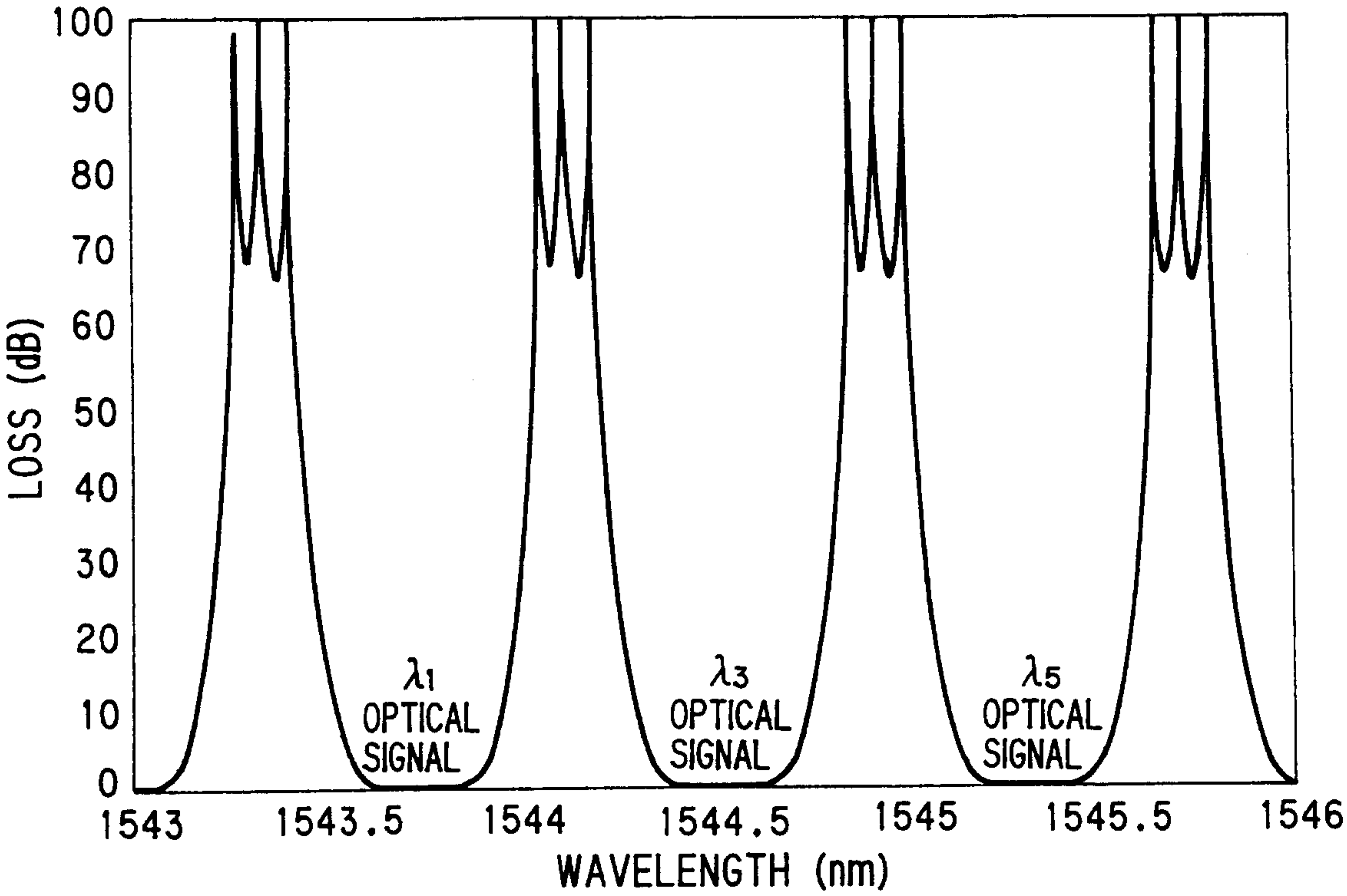

100
90
80
70
60
50
40
30
20
10
0
LOSS (dB)
λ1
OPTICAL
SIGNAL
λ3
OPTICAL
SIGNAL
λ5
OPTICAL
SIGNAL
1543
1543.5
1544
1544.5
1545
1545.5
1546
WAVELENGTH (nm)

FIG.5

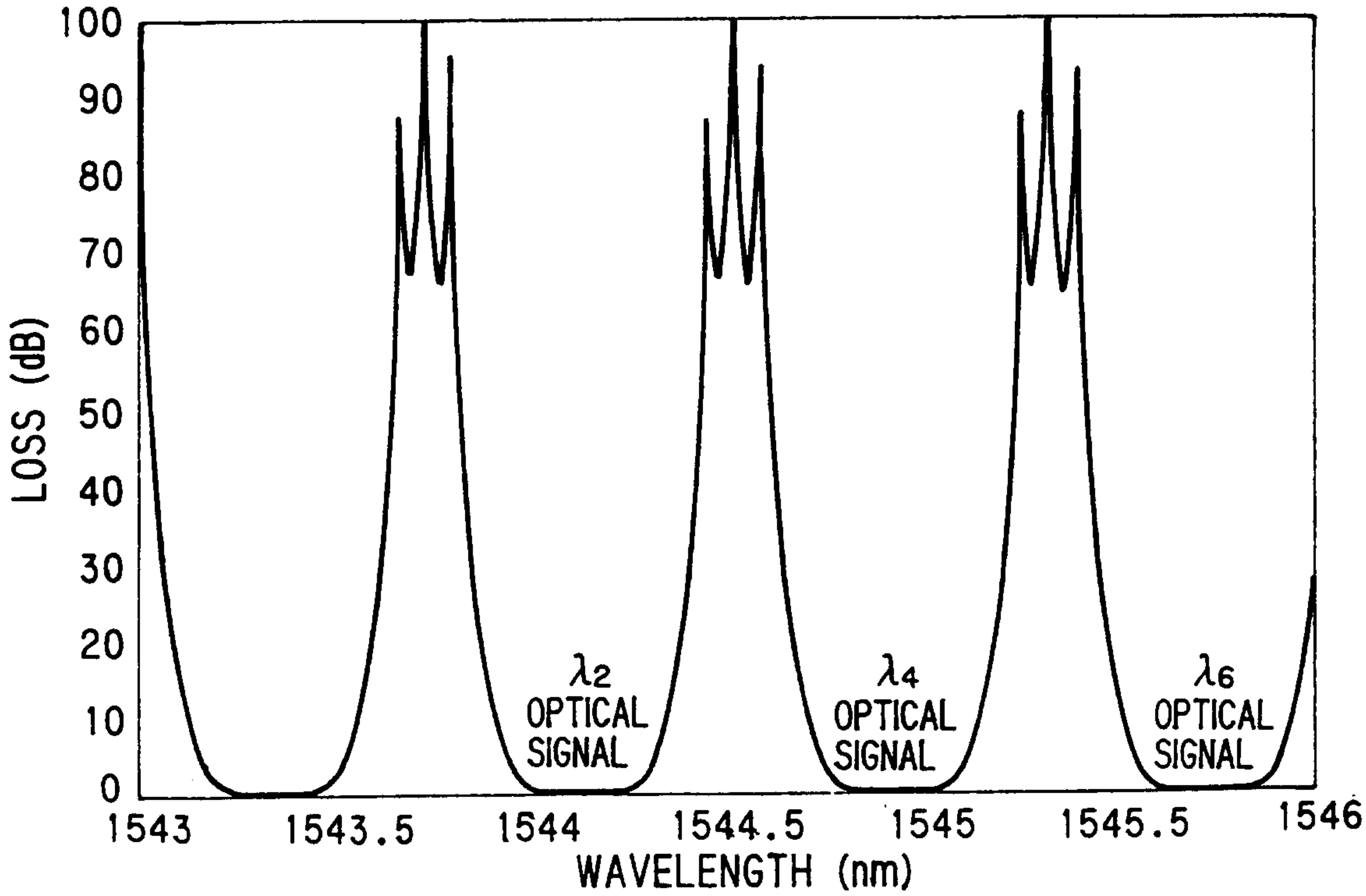

100
90
80
70
60
50
40
30
20
10
0
LOSS (dB)
λ2
OPTICAL
SIGNAL
λ4
OPTICAL
SIGNAL
λ6
OPTICAL
SIGNAL
1543
1543.5
1544
1544.5
1545
1545.5
1546
WAVELENGTH (nm)

FIG. 6

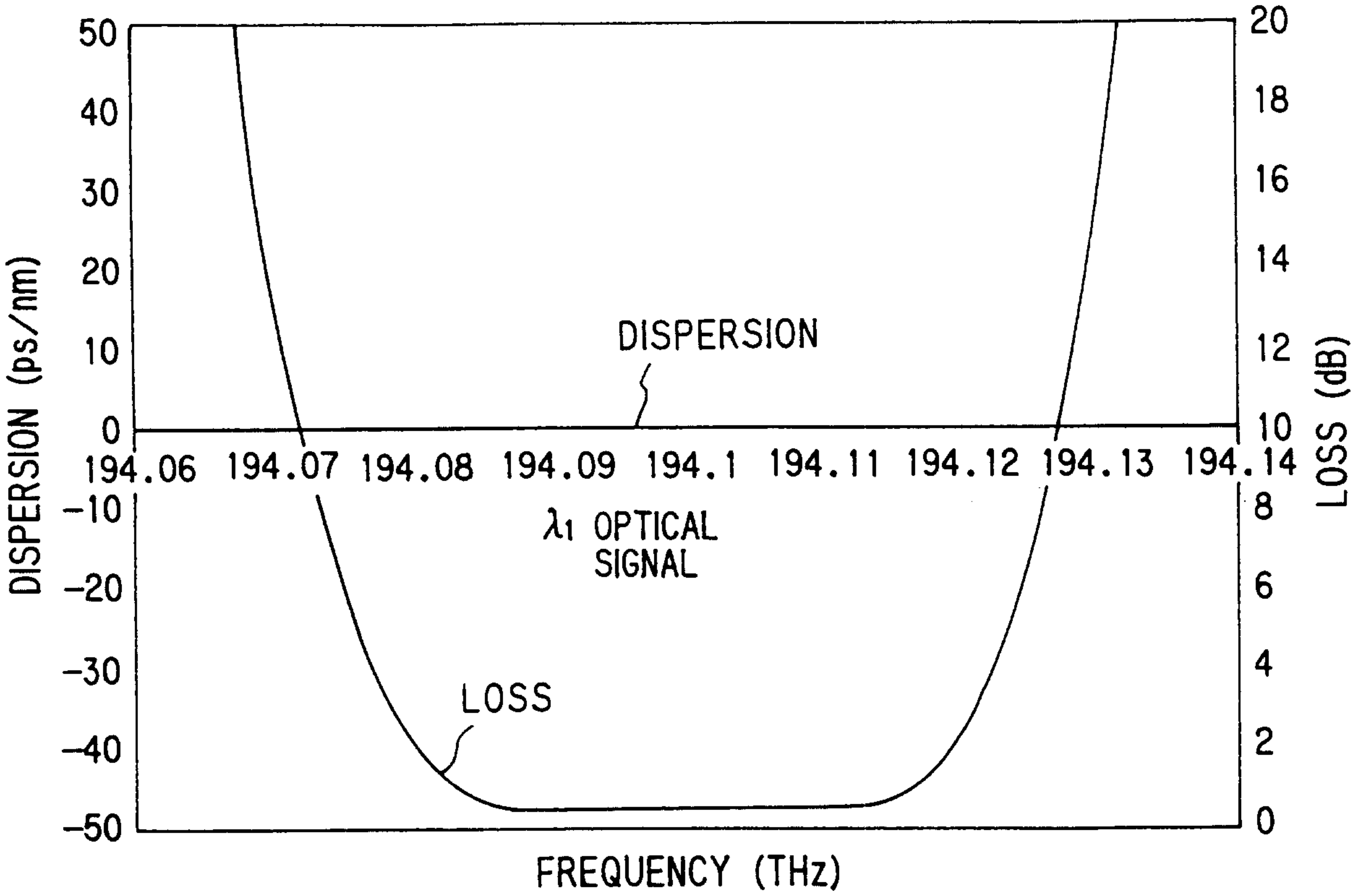

50
40
30
20
10
0
-10
-20
-30
-40
-50
DISPERSION (ps/nm)
20
18
16
14
12
10
8
6
4
2
0
LOSS (dB)
194.06
194.07
194.08
194.09
194.1
194.11
194.12
194.13
194.14
DISPERSION
λ1 OPTICAL SIGNAL
LOSS
FREQUENCY (THz)

FIG. 7

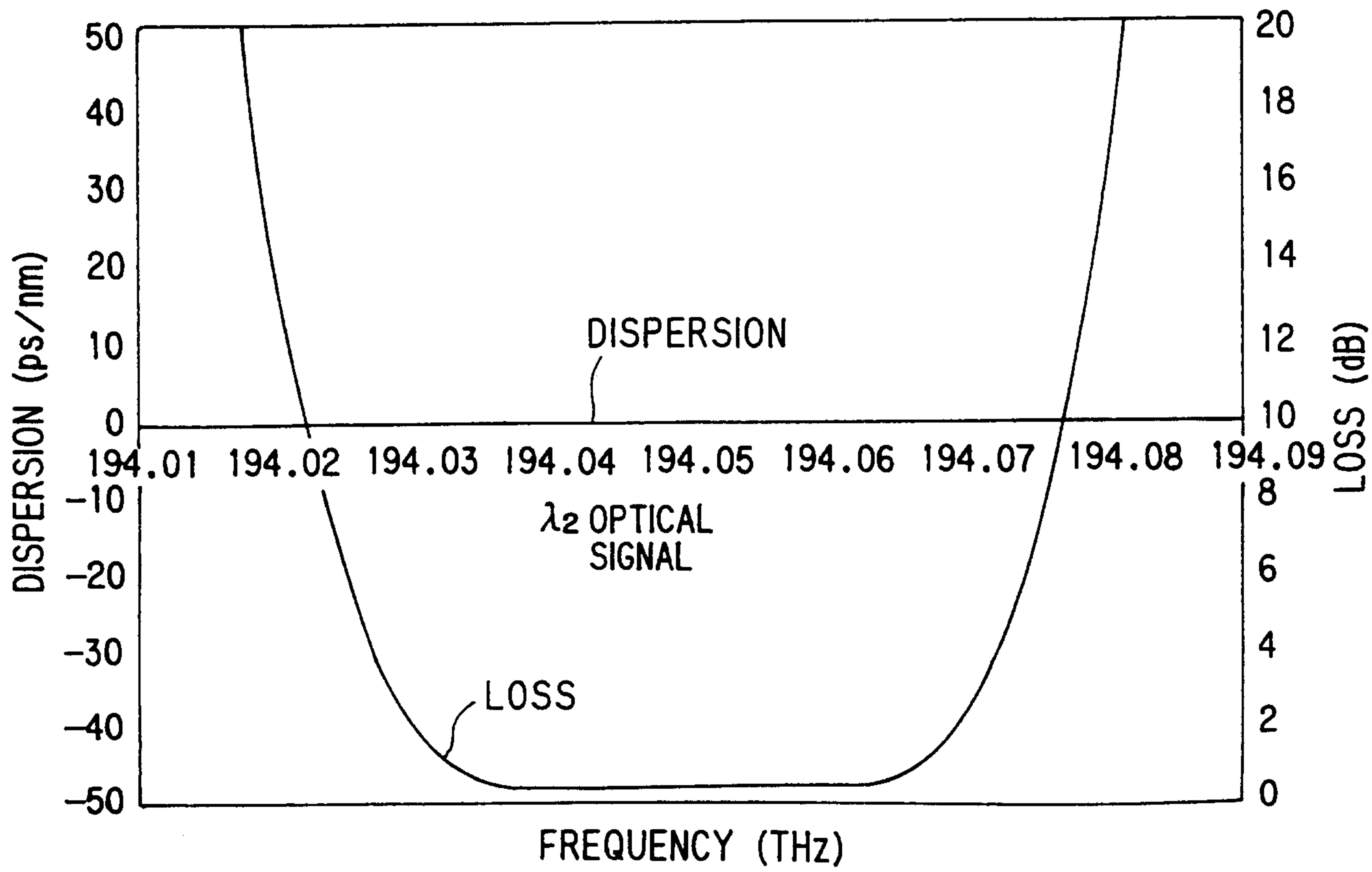

50
40
30
20
10
0
-10
-20
-30
-40
-50
DISPERSION (ps/nm)
20
18
16
14
12
10
8
6
4
2
0
LOSS (dB)
194.01
194.02
194.03
194.04
194.05
194.06
194.07
194.08
194.09
DISPERSION
λ2 OPTICAL SIGNAL
LOSS
FREQUENCY (THz)

FIG.8

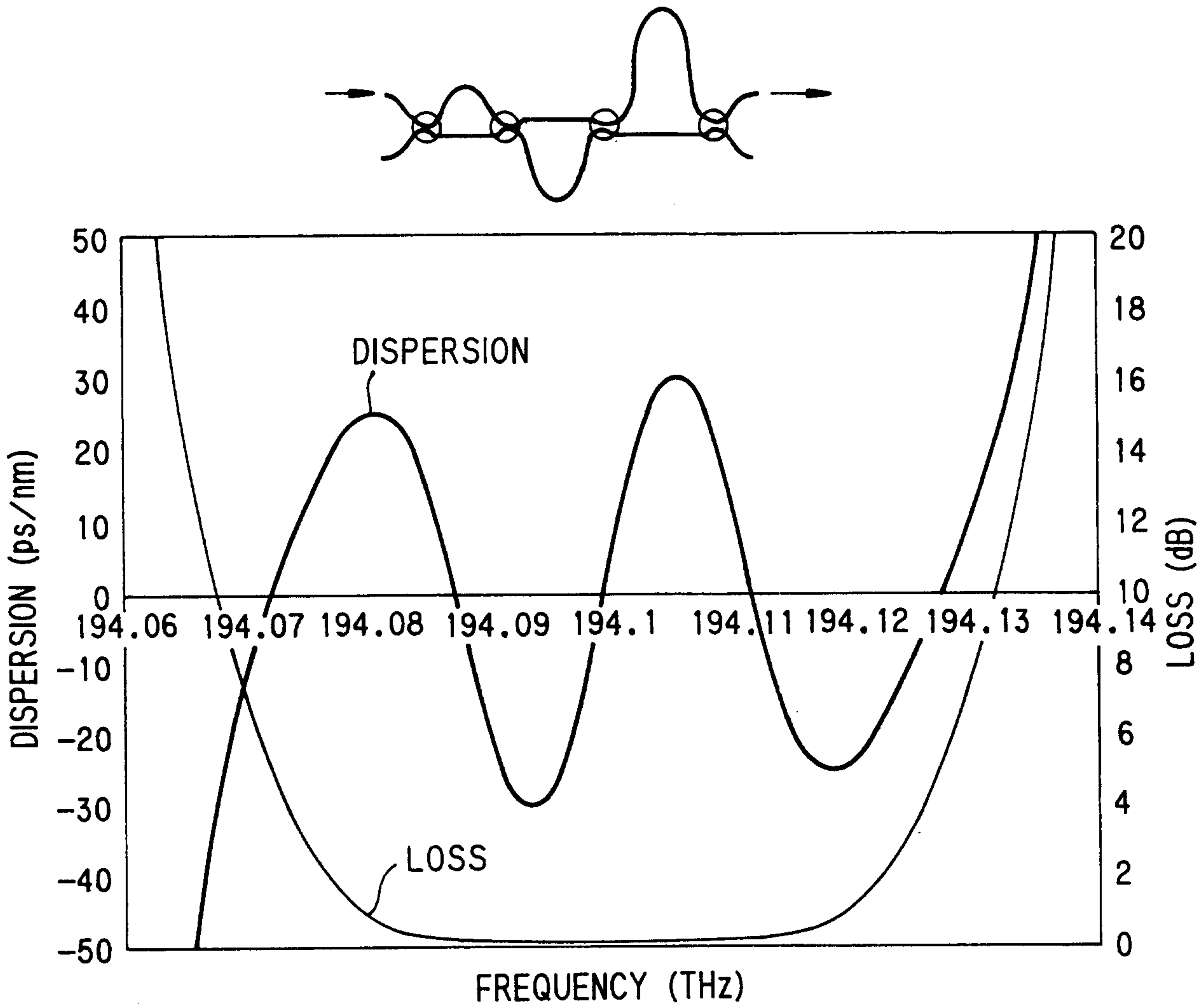

DISPERSION
LOSS
DISPERSION (ps/nm)
LOSS (dB)
FREQUENCY (THz)
50
40
30
20
10
0
-10
-20
-30
-40
-50
20
18
16
14
12
10
8
6
4
2
0
194.06
194.07
194.08
194.09
194.1
194.11
194.12
194.13
194.14

FIG.9

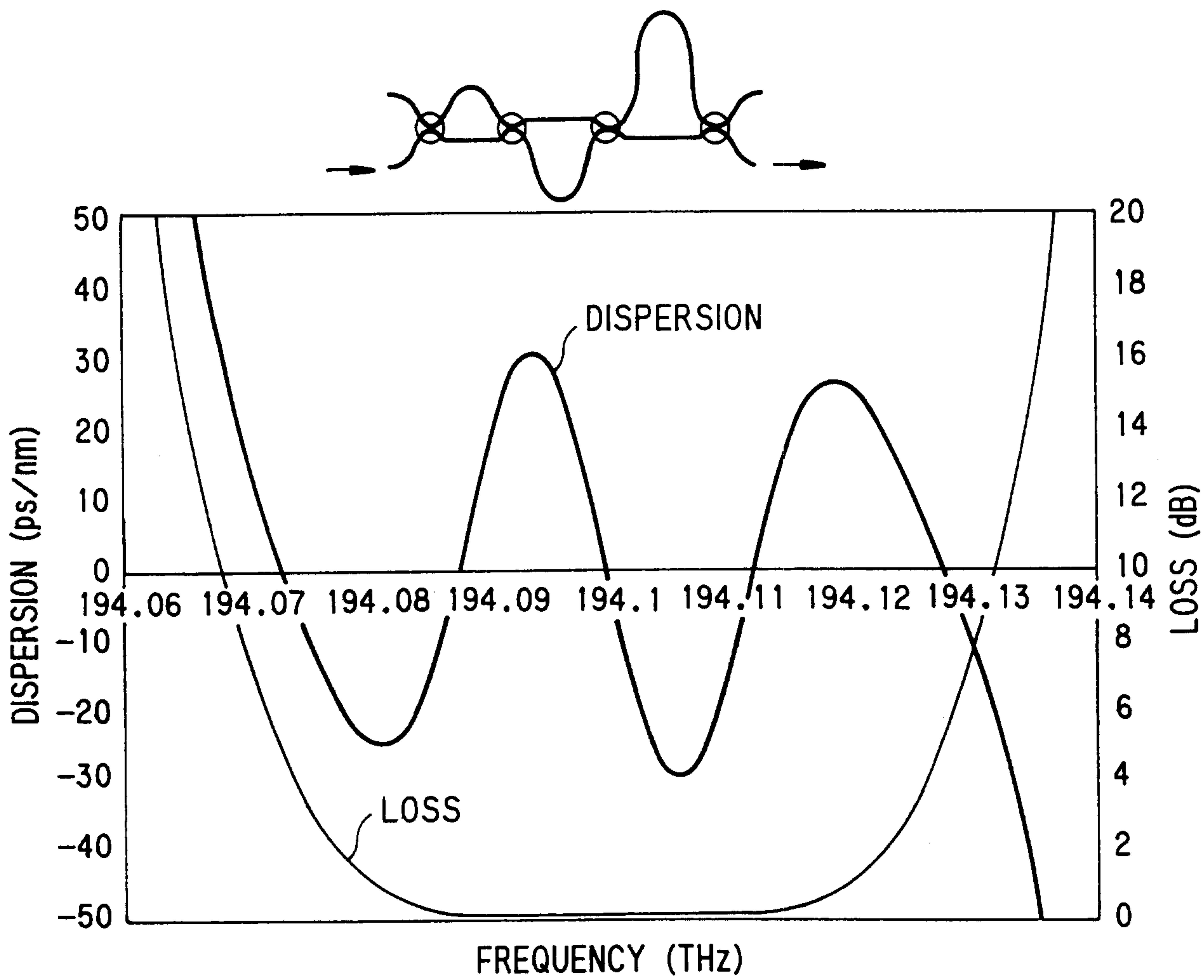

DISPERSION
LOSS
50
40
30
20
10
0
-10
-20
-30
-40
-50
20
18
16
14
12
10
8
6
4
2
0
194.06
194.07
194.08
194.09
194.1
194.11
194.12
194.13
194.14
DISPERSION (ps/nm)
LOSS (dB)
FREQUENCY (THz)

FIG. 10

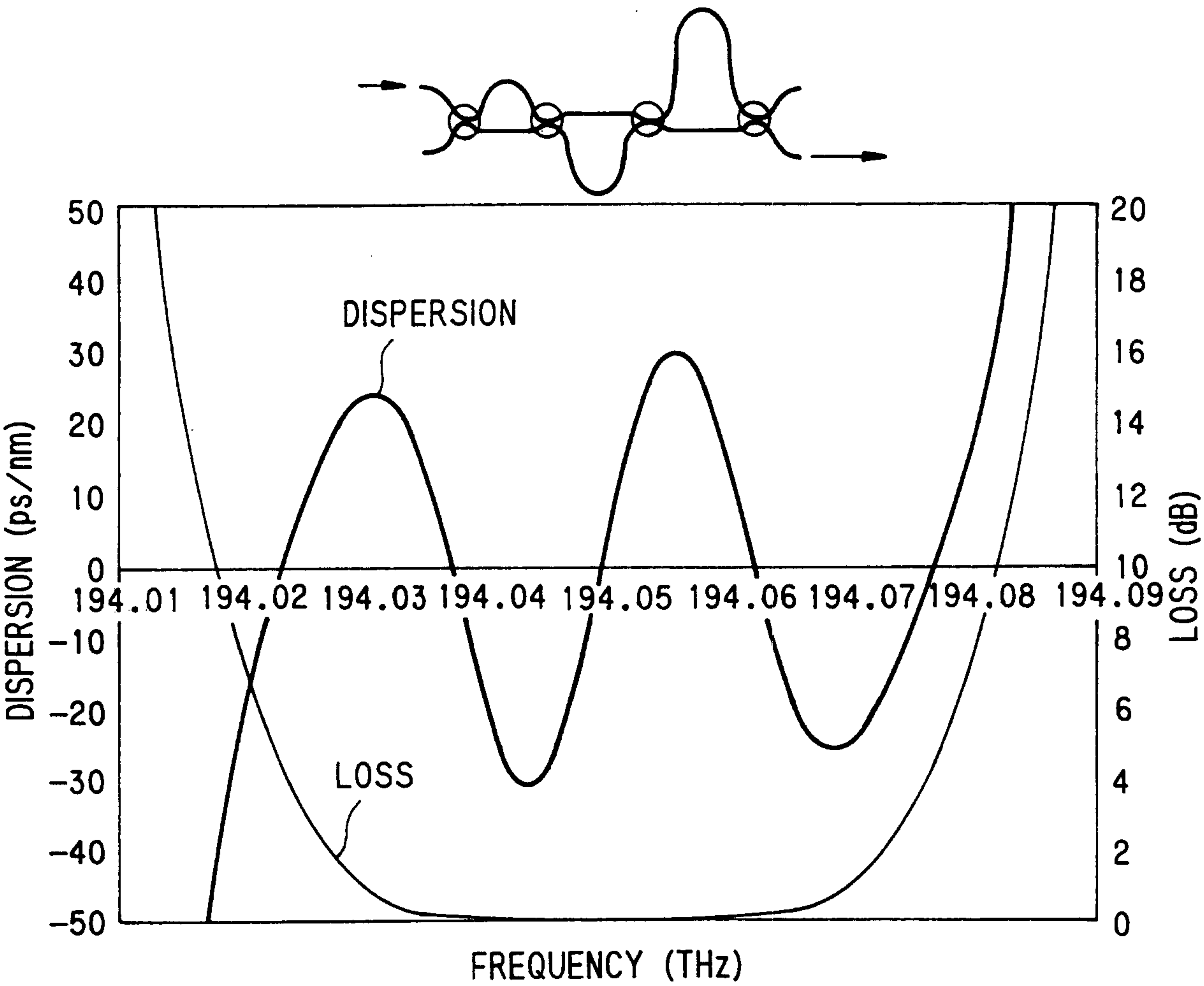

DISPERSION
LOSS
50
40
30
20
10
0
-10
-20
-30
-40
-50
DISPERSION (ps/nm)
20
18
16
14
12
10
8
6
4
2
0
LOSS (dB)
194.01 194.02 194.03 194.04 194.05 194.06 194.07 194.08 194.09
FREQUENCY (THz)

FIG. 11

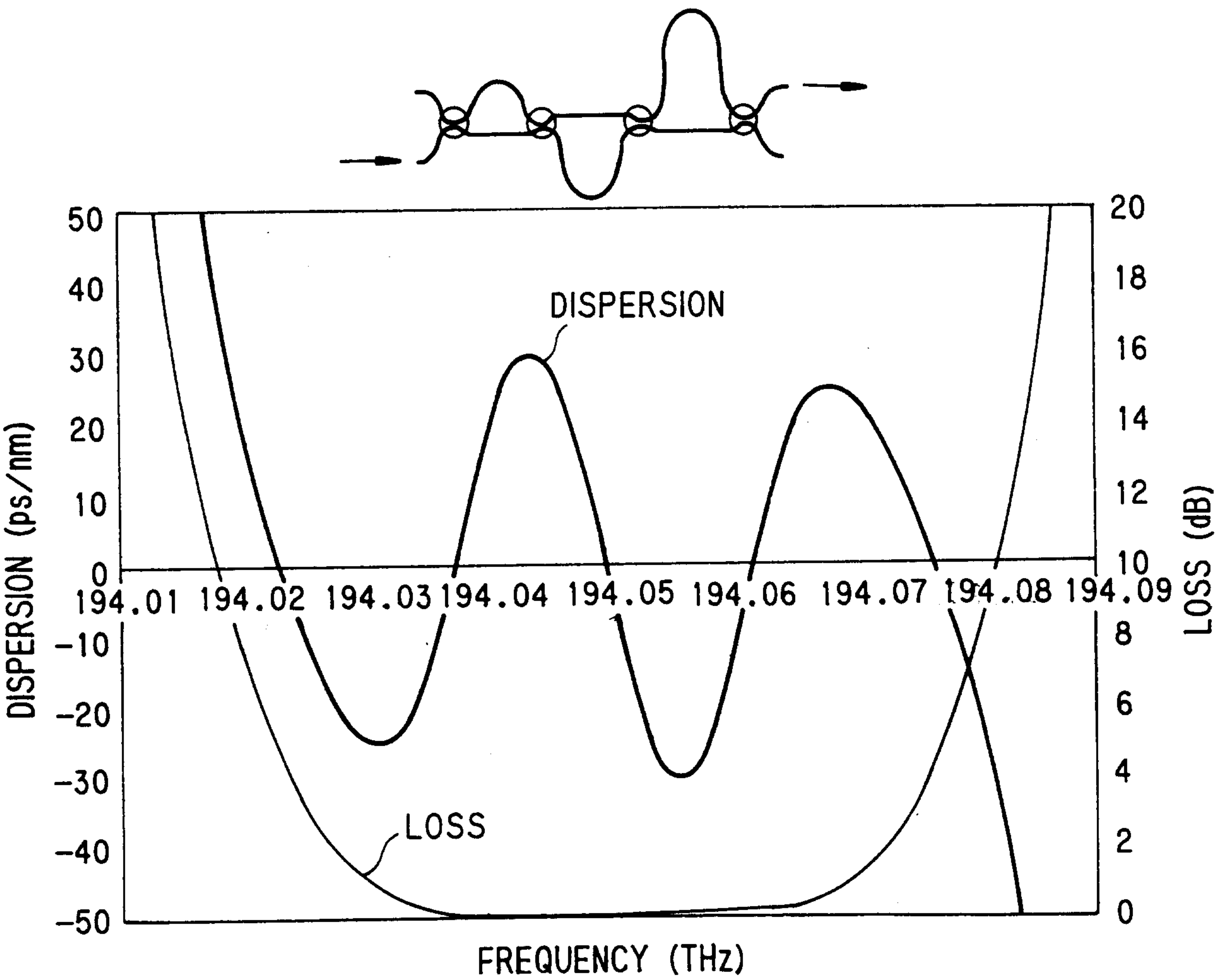
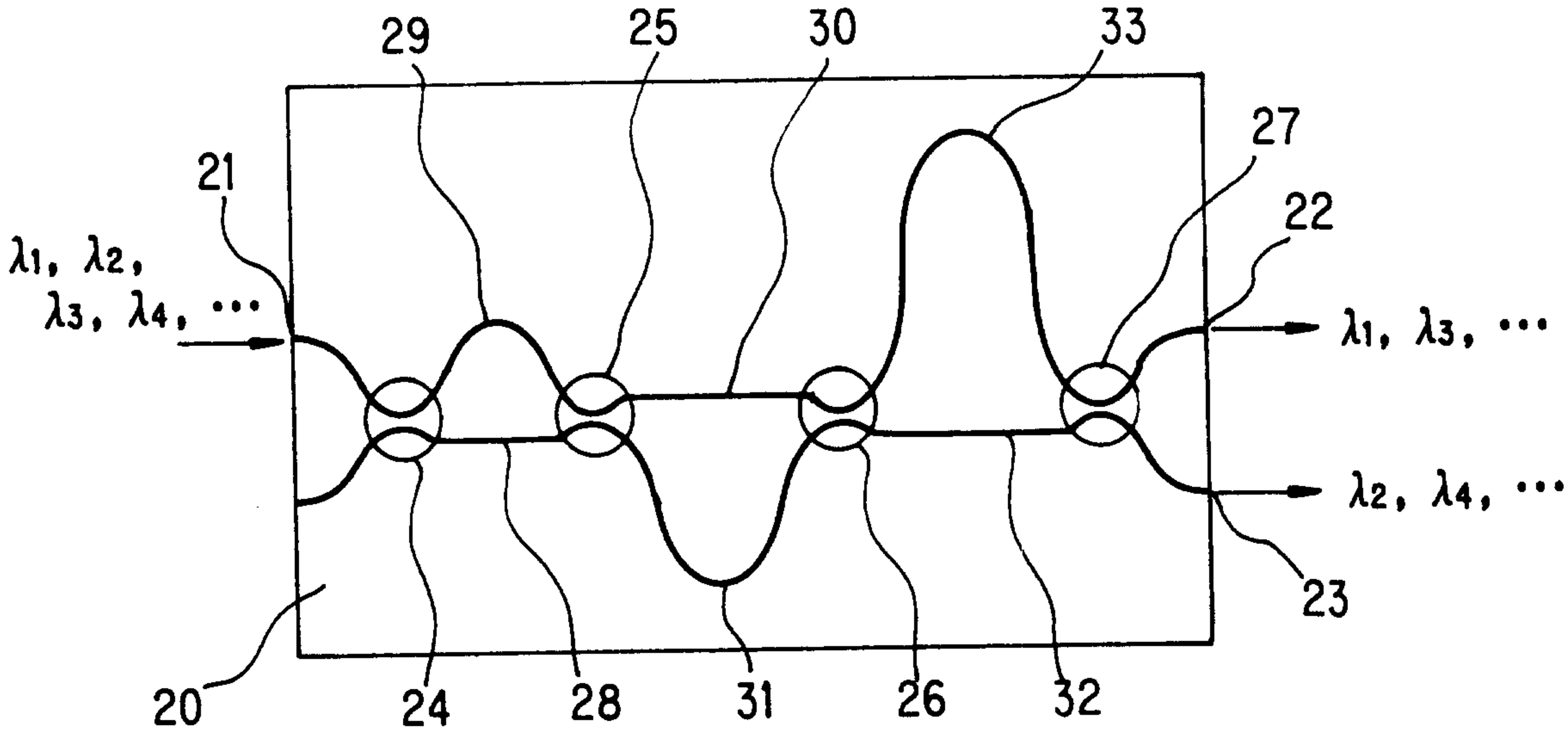

DISPERSION
LOSS
50
40
30
20
10
0
-10
-20
-30
-40
-50
20
18
16
14
12
10
8
6
4
2
0
194.01
194.02
194.03
194.04
194.05
194.06
194.07
194.08
194.09
DISPERSION (ps/nm)
LOSS (dB)
FREQUENCY (THz)

FIG. 12



20: QUARTZ SUBSTRATE
21: INPUT/OUTPUT PORT
22: INPUT/OUTPUT PORT
23: INPUT/OUTPUT PORT
24: DIRECTIONAL COUPLER
25: DIRECTIONAL COUPLER
26: DIRECTIONAL COUPLER
27: DIRECTIONAL COUPLER
28: WAVEGUIDE PAIR
29: WAVEGUIDE PAIR
30: WAVEGUIDE PAIR
31: WAVEGUIDE PAIR
32: WAVEGUIDE PAIR
33: WAVEGUIDE PAIR
λ: OPTICAL SIGNAL

FIG. 13

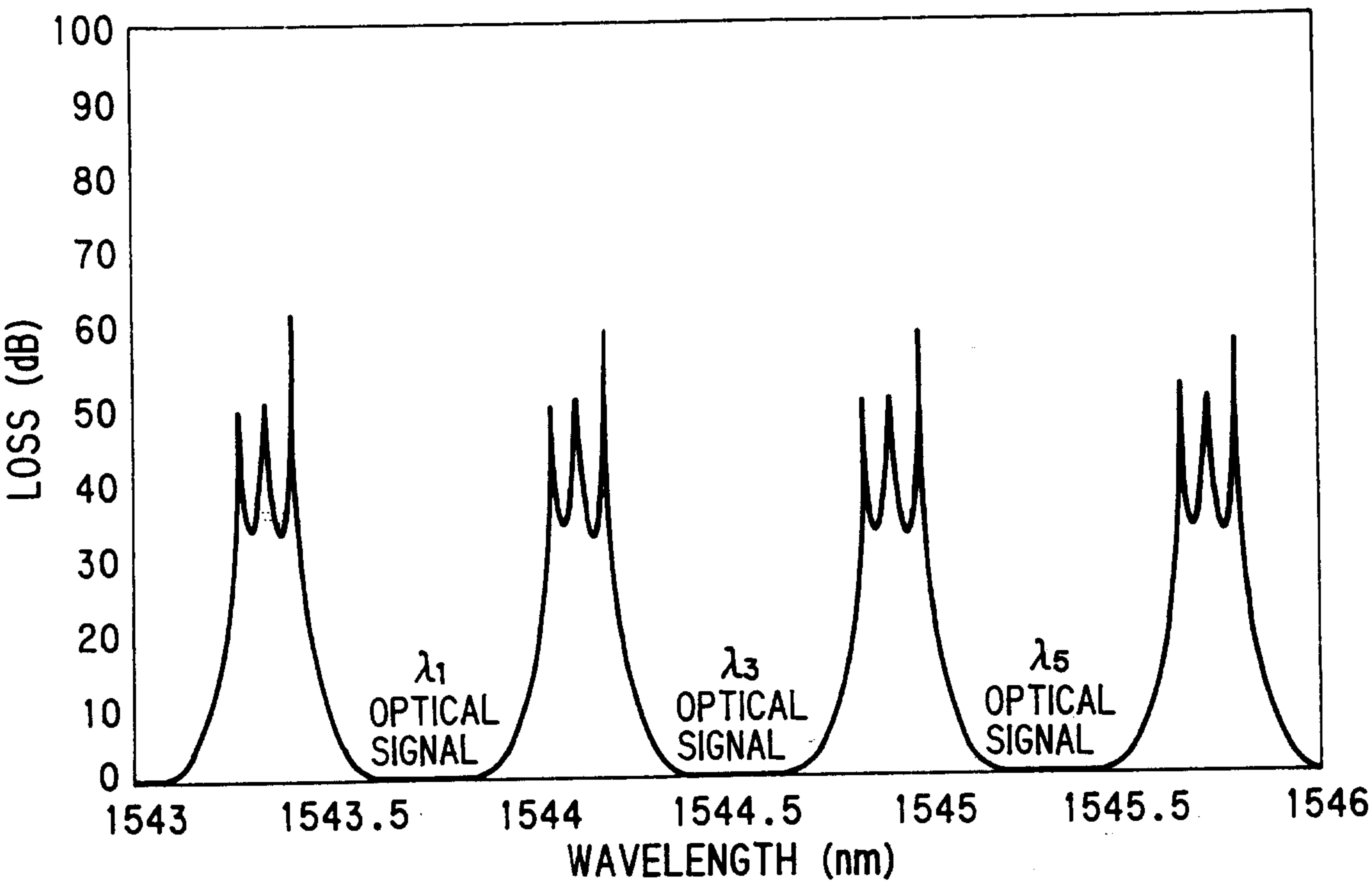

100
90
80
70
60
50
40
30
20
10
0
LOSS (dB)
λ1
OPTICAL
SIGNAL
λ3
OPTICAL
SIGNAL
λ5
OPTICAL
SIGNAL
1543
1543.5
1544
1544.5
1545
1545.5
1546
WAVELENGTH (nm)

FIG. 14

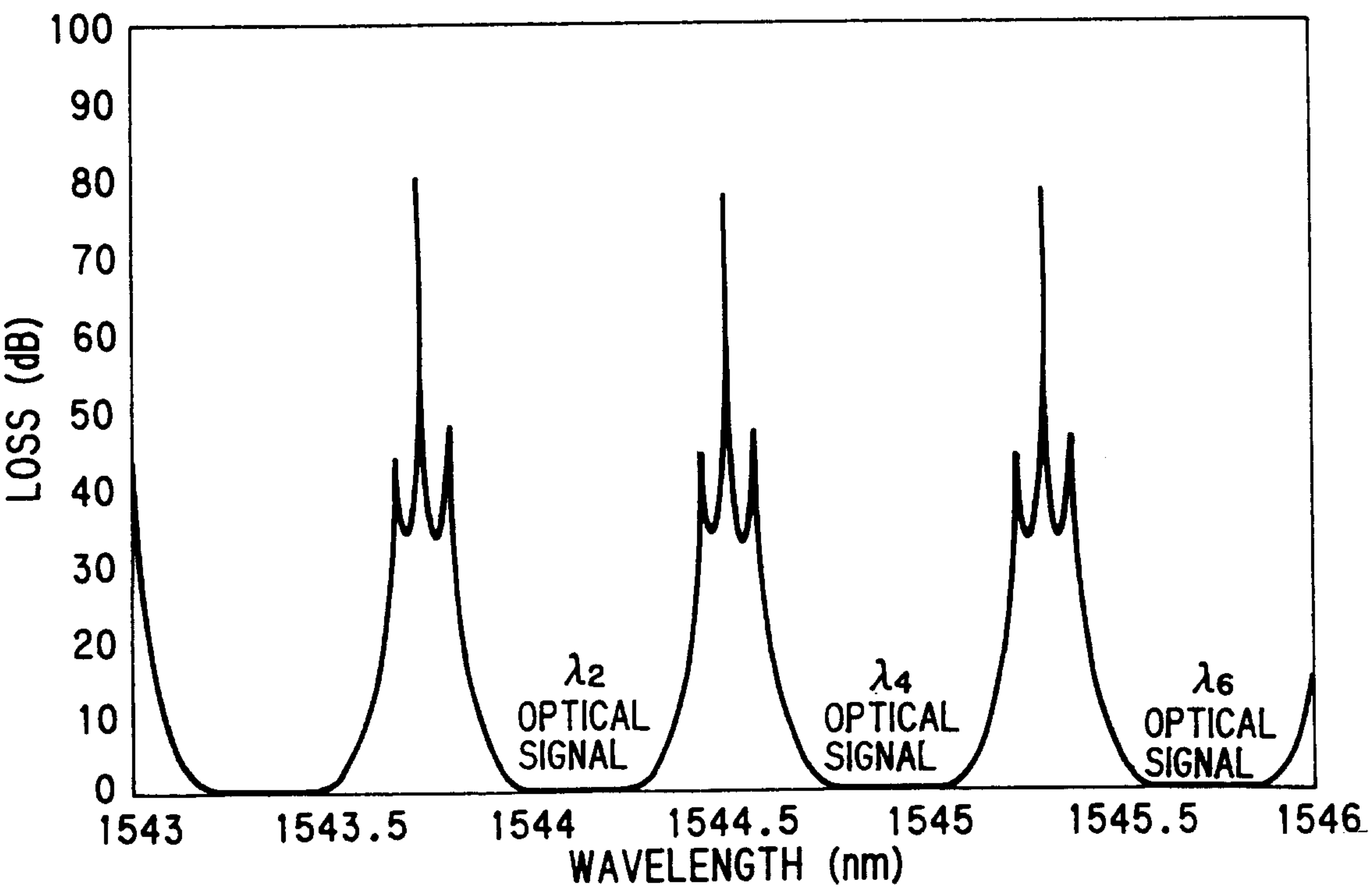

100
90
80
70
60
50
40
30
20
10
0
LOSS (dB)
λ2
OPTICAL
SIGNAL
λ4
OPTICAL
SIGNAL
λ6
OPTICAL
SIGNAL
1543
1543.5
1544
1544.5
1545
1545.5
1546
WAVELENGTH (nm)

FIG. 15

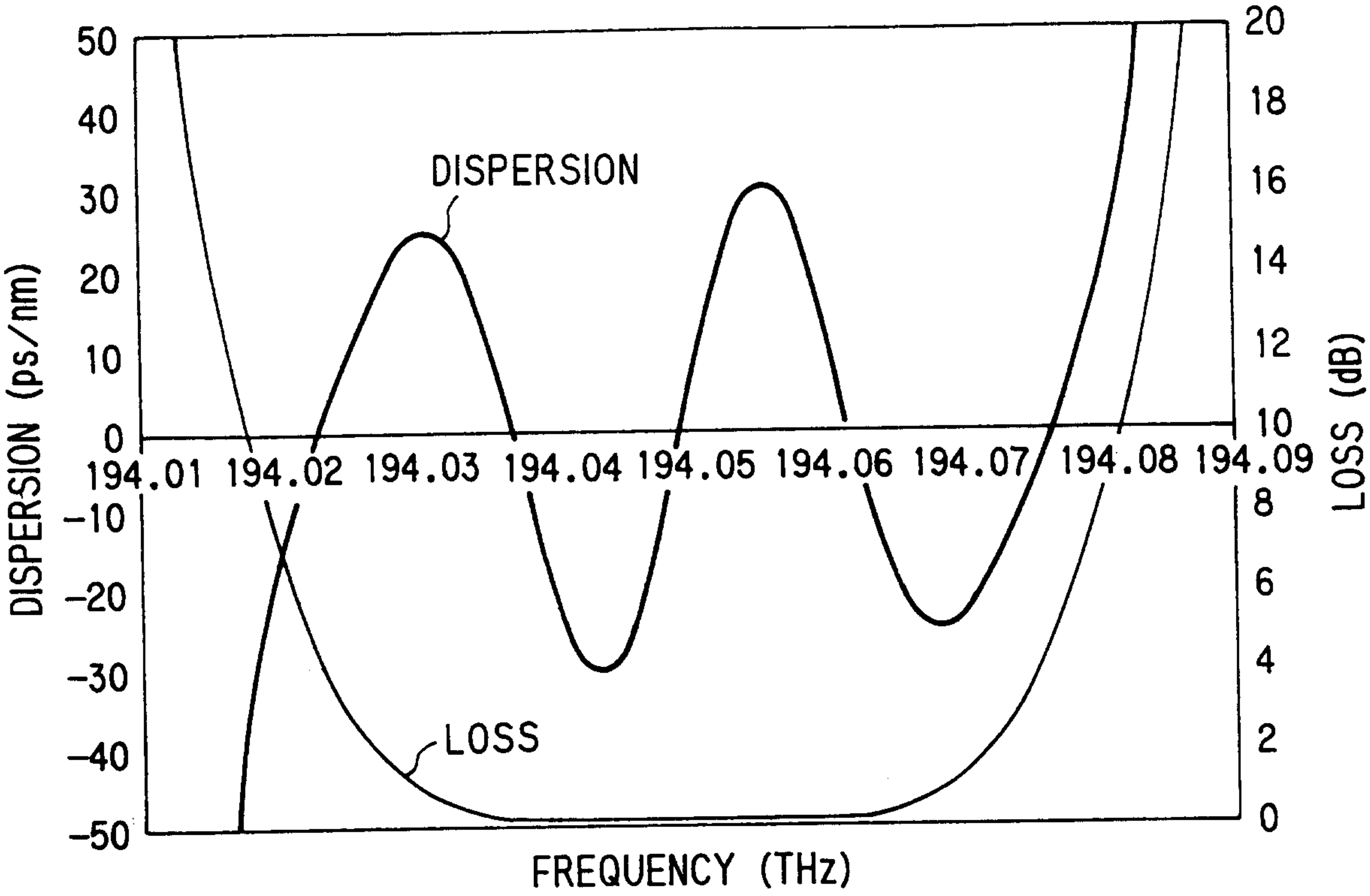
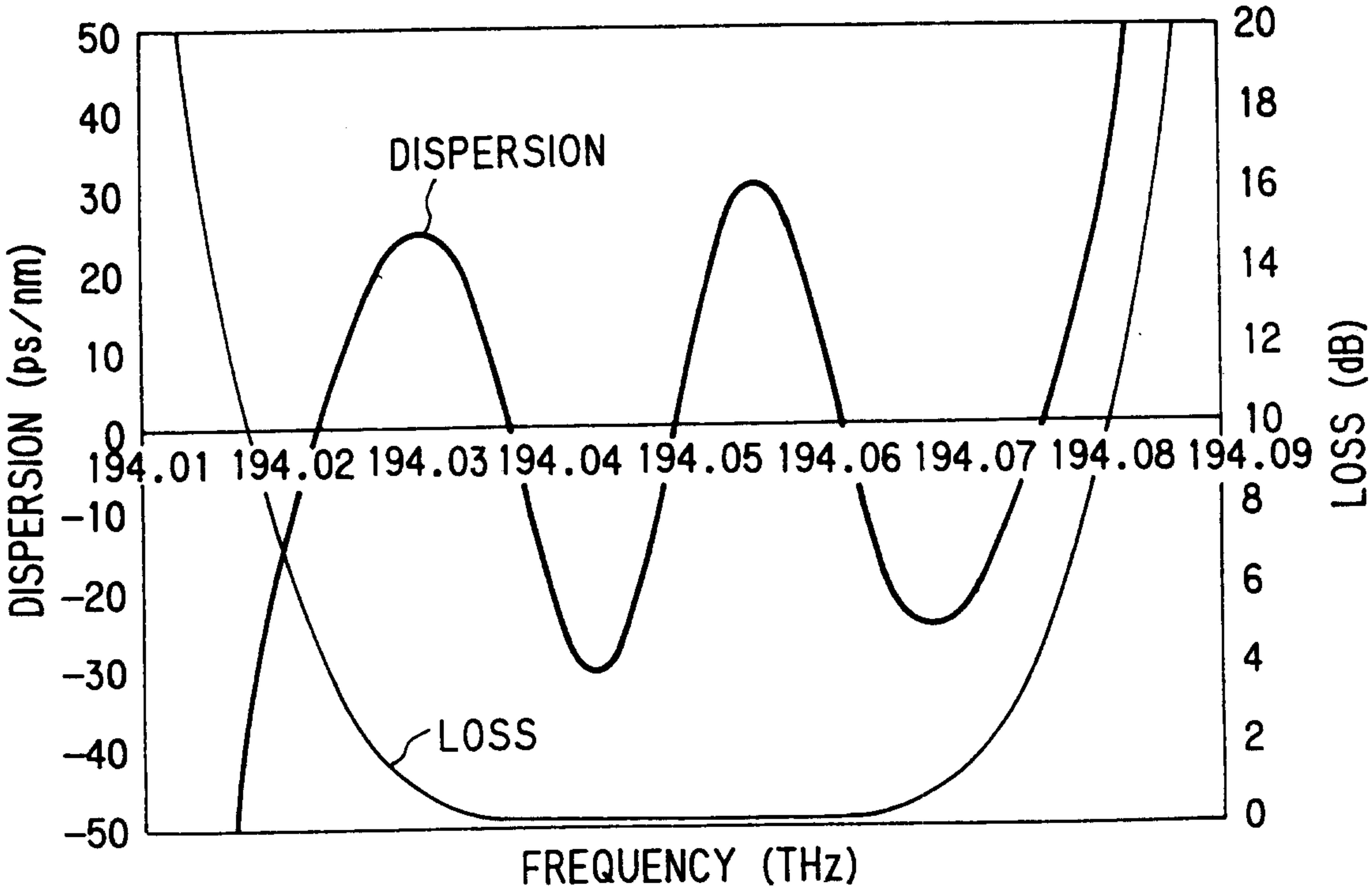
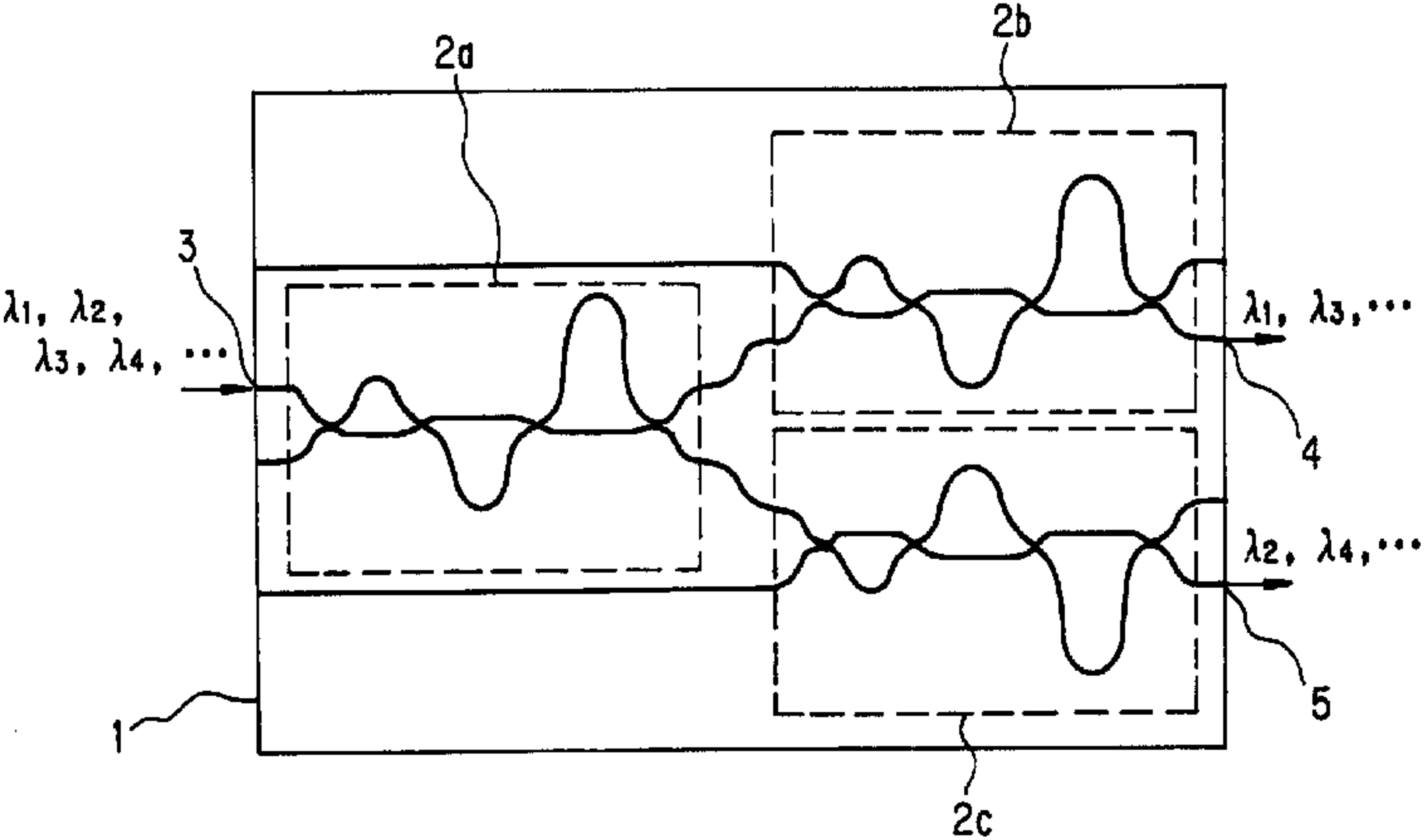

50
40
30
20
10
0
-10
-20
-30
-40
-50
DISPERSION (ps/nm)
DISPERSION
LOSS
194.01 194.02 194.03 194.04 194.05 194.06 194.07 194.08 194.09
FREQUENCY (THz)
20
18
16
14
12
10
8
6
4
2
0
LOSS (dB)

FIG. 16


50
40
30
20
10
0
-10
-20
-30
-40
-50
DISPERSION (ps/nm)
DISPERSION
LOSS
194.01 194.02 194.03 194.04 194.05 194.06 194.07 194.08 194.09
FREQUENCY (THz)
20
18
16
14
12
10
8
6
4
2
0
LOSS (dB)



1 : QUARTZ SUBSTRATE
2a : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2b : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
2c : MULTI-STAGE MACH-ZEHNDER INTERFERENCE CIRCUIT
3 : INPUT PORT
4 : OUTPUT PORT
5 : OUTPUT PORT
λ : OPTICAL SIGNAL