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Amplifier incorporating amplifying optical fibre

The present invention relates to an amplifier incorporating an optical fibre that amplifies, e.g. because of erbium doping. Such an amplifier is particularly suitable for application in optical fibre undersea transmission systems.

Erbium-doped optical fibre amplifiers are known, e.g. from document FR 2 638 854, as are associated undersea transmission systems. Such amplifiers enable high gains to be obtained merely by passing the signal along an optical fibre, in the range of wavelengths from 1.5 μm to 1.6 μm . However, it is known (see J.F. MARCEROU et al., Proceedings SPIE 1373, pp. 168-186, 1991), that full use of an erbium-doped optical fibre amplifier is limited by the optical noise it generates, known as "amplified spontaneous emission" (ASE). Amplified spontaneous emission is responsible in part for saturating the laser medium, to the detriment of amplifying the signal(s) present in the optical fibre. For this very reason, ASE is used for making excellent wideband superfluorescent sources.

Several solutions to this problem have already been proposed. To reduce the noise factor, it is possible to use short fibres, but this penalises gain. It is also possible to use fibres that are not optimised, but this requires pumping powers that are too high.

Proposals have also been made to limit the effect of amplified spontaneous emission in amplifiers by inserting an optical filter in the length of erbium-doped fibre. The optical filter blocks a noise component in both directions. However, this method suffers from the drawback of limiting the passband of the amplifier and is risky when amplifiers are used in cascade due to the fact that the frequencies differ slightly from one filter to another.

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In order to mitigate these drawbacks, the present invention proposes inserting one or more isolators into the amplifying optical fibre. This reduces the deleterious effects of optical noise.

5 The present invention thus provides an amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fibre,
10 characterised in that said means comprise an optical isolator.

In an undersea transmission system, the amplifying fibre is advantageously of the erbium-doped optical fibre type.

15 The invention will be better understood and its other advantages and features will emerge on reading the following description given by way of example with reference to the accompanying drawings, in which:

20 - figure 1 shows an amplifier of the invention having an amplifying optical fibre,

- figure 2 is a comparative diagram giving the gain of the figure 1 amplifier as a function of the length of its amplifying optical fibre,

25 - figure 3 is a comparative diagram giving the noise factor of the same amplifier as a function of the length of its amplifying optical fibre.

30 Surprisingly, the gain limitation introduced by the presence of amplified spontaneous emission is essentially due to noise propagating in the opposite direction to the optical pumping direction. According to the invention, this effect can be very considerably reduced by inserting an isolator in the doped fibre to limit saturation due to the optical noise propagating in the opposite direction to the signal.

35 Referring to figure 1, the amplifier 1 comprises in



series between an input terminal 2 for the optical signal to be amplified and an output terminal 3 for the optical signal: a wavelength multiplexer 4, a first length L of doped optical fibre, an isolator 5, and a second length L' of doped optical fibre. The various components constituting the amplifier are welded together. The multiplexer 4 provides coupling between the optical signal S to be amplified of wavelength λ_s and the pumping signal P of wavelength λ_p . The two signals S and P are applied to the input of the amplifying optical fibre.

In this embodiment, the amplifying optical fibre comprises a glass matrix having a core based on silica having oxides of the Al_2O_3 and GeO_2 type added thereto. It is doped with erbium to a concentration of 100 ppm. The index difference Δn between the core of the fibre and its cladding is $32 \cdot 10^{-3}$.

The amplifier also includes a device 6 for generating the pumping signal. This device comprises, for example, a laser diode delivering a pumping signal having a wavelength of $1.475 \mu m$ and a power of 35 mW.

The diagrams of figures 2 and 3 were obtained using an optical signal to be amplified having a wavelength of $1.55 \mu m$ and a power of -30 dBm. The diagram of figure 2 has the gain G of the amplifier expressed in decibels plotted as a function of the length l in metres of the amplifying fibre. Curve 10 was plotted for measurements using the amplifier of figure 1 without the isolator. Curve 11 was plotted using measurements using the same amplifier but fitted with the isolator 5.

The diagram of figure 3 plots the noise factor NF of the amplifier (in decibels) as a function of the length l . Curve 12 was plotted for measurements using the amplifier of figure 1 without the isolator. Curve 13 was plotted for measurements using the same amplifier but fitted with the isolator 5.



The optical isolator transmits a signal from a source while greatly attenuating the return energy. A single isolator may be based on a beam-splitting and polarising cube and a quarterwave plate. The incident light is polarised by the cube and is then circularly polarised by the quarterwave plate. The return beam is circularly polarised in the opposite direction. On passing through the quarterwave plate it is linearly polarised and it is blocked by the polarising cube.

Optical isolators are available off the shelf. In the present case, it must be transparent at two wavelengths (that of the signal to be amplified and that of the pumping signal) and the attenuation of the return beam must be greater than 25 dB. If necessary, a plurality of isolators can be used.

It can clearly be seen from the diagrams of figures 2 and 3 that without an isolator the amplifier cannot deliver a gain comparable to that obtained with an isolator, under operating conditions that are otherwise identical.

Under such conditions, the maximum gain appears around 60 metres (see the diagram of Figure 2). The isolator is therefore placed 25 m from the beginning of the doped fibre ($L = 25$ m), which is about halfway along the optimum length of 60 m. In curve 11, there is a small offset representative of the loss specific to the isolator (about 1.5 dB). This offset is nevertheless more than compensated, since for fibre lengths in the range 50 m to 60 m the gain of the amplifier with an isolator is more than 6 dB greater than the gain of the amplifier without an isolator.

As can be seen in the diagram of figure 3, the noise factor can be improved by more than 1.5 dB for the amplifier with an isolator (curve 13) compared to the amplifier without an isolator (curve 12). This

5 difference in terms of noise factor can be highly significant if the amplifier is used as a receiver preamplifier or as a line amplifier in a cascade configuration comprising a plurality of amplifier modules, in which case the problem raised by accumulating amplified spontaneous emission along the cascade is critical.

10 The amplifier of the invention makes it possible to include an optical filter in the fibre isolator, and where appropriate the optical filter can filter out a portion of the co-propagating noise.

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CLAIMS

1. Amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said
5 means being inserted in the length of the amplifying optical fibre, characterised in that said means comprise an optical isolator (5).

2. Amplifier according to claim 1 characterised in that the amplifying optical fibre is an erbium-doped
10 optical fibre.

3. Amplifier according to claim 1 or claim 2 characterised in that there is one isolator or a plurality of isolators.

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ABSTRACT

Amplifier incorporating amplifying optical fibre

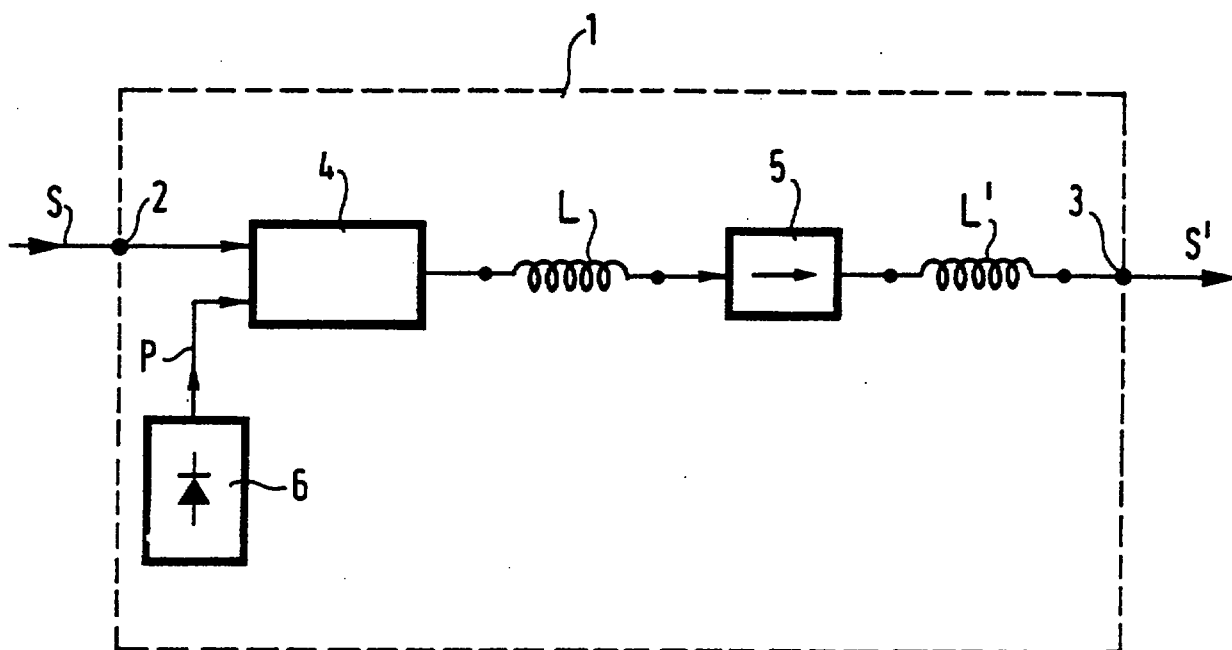
The invention concerns an amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fibre, characterised in that said means comprise an optical isolator (5).

FIGURE TO PUBLISH : FIG. 1

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FIG. 1



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FIG. 2

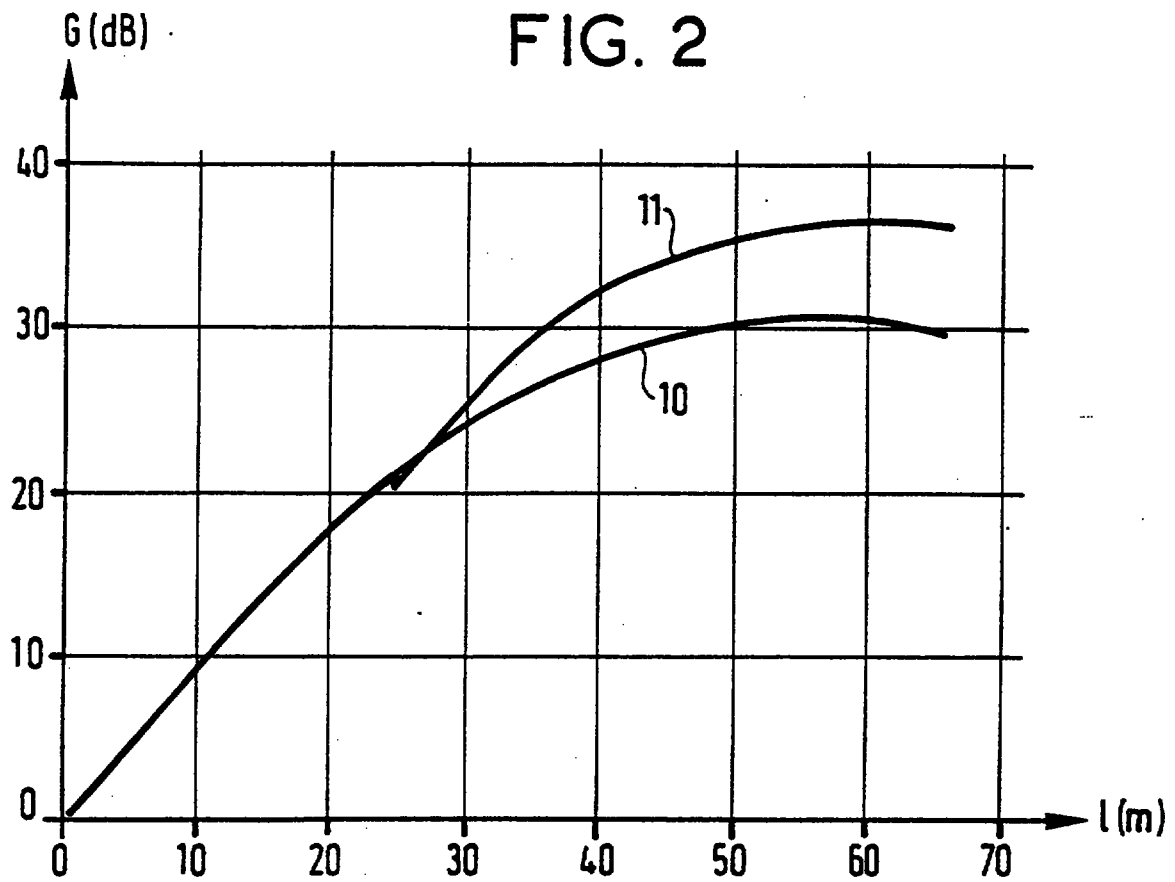
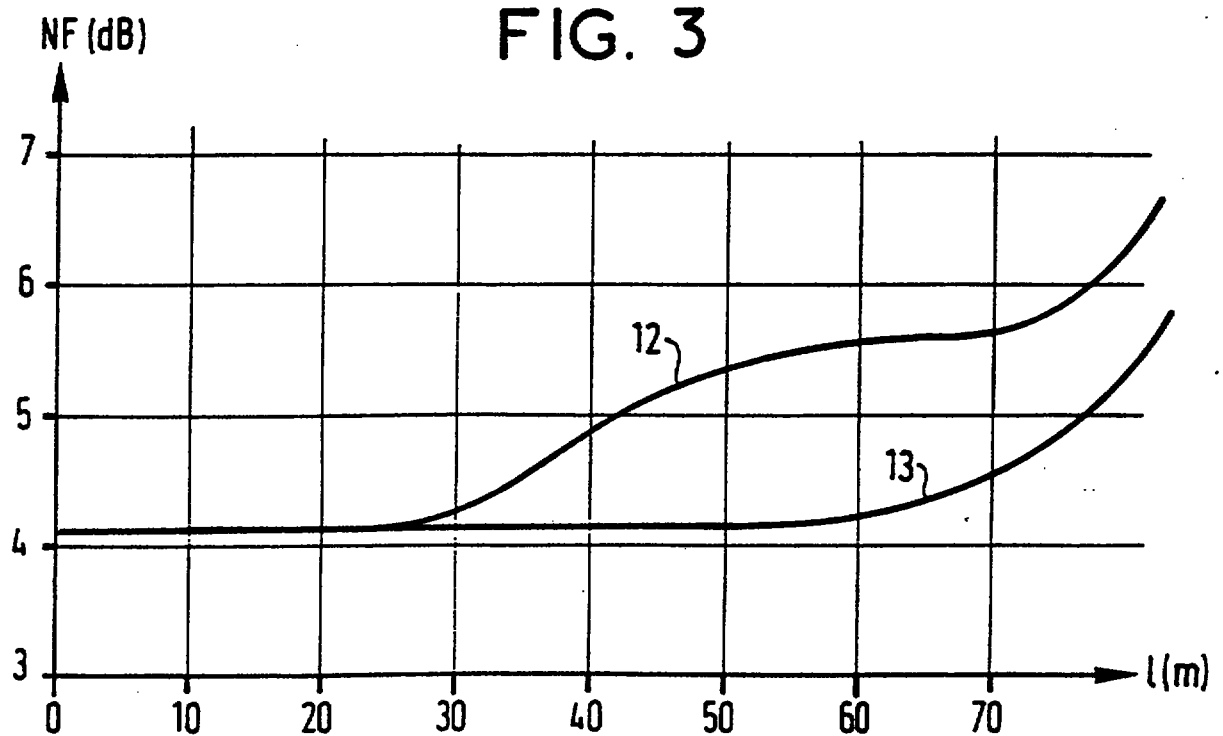


FIG. 3



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Amplifier incorporating amplifying optical fibre

The present invention relates to an amplifier incorporating an optical fibre that amplifies, e.g. because of erbium doping. Such an amplifier is particularly suitable for application in optical fibre undersea transmission systems.

Erbium-doped optical fibre amplifiers are known, e.g. from document FR 2 638 854, as are associated undersea transmission systems. Such amplifiers enable high gains to be obtained merely by passing the signal along an optical fibre, in the range of wavelengths from 1.5 μm to 1.6 μm . However, it is known (see J.F. MARCEROU et al., Proceedings SPIE 1373, pp. 168-186, 1991), that full use of an erbium-doped optical fibre amplifier is limited by the optical noise it generates, known as "amplified spontaneous emission" (ASE). Amplified spontaneous emission is responsible in part for saturating the laser medium, to the detriment of amplifying the signal(s) present in the optical fibre. For this very reason, ASE is used for making excellent wideband superfluorescent sources.

Several solutions to this problem have already been proposed. To reduce the noise factor, it is possible to use short fibres, but this penalises gain. It is also possible to use fibres that are not optimised, but this requires pumping powers that are too high.

Proposals have also been made to limit the effect of amplified spontaneous emission in amplifiers by inserting an optical filter in the length of erbium-doped fibre. The optical filter blocks a noise component in both directions. However, this method suffers from the drawback of limiting the passband of the amplifier and is risky when amplifiers are used in cascade due to the fact that the frequencies differ slightly from one filter to another.

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In order to mitigate these drawbacks, the present invention proposes inserting one or more isolators into the amplifying optical fibre. This reduces the deleterious effects of optical noise.

The present invention thus provides an amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fibre, characterised in that said means comprise an optical isolator.

In an undersea transmission system, the amplifying fibre is advantageously of the erbium-doped optical fibre type.

The invention will be better understood and its other advantages and features will emerge on reading the following description given by way of example with reference to the accompanying drawings, in which:

- figure 1 shows an amplifier of the invention having an amplifying optical fibre,

- figure 2 is a comparative diagram giving the gain of the figure 1 amplifier as a function of the length of its amplifying optical fibre,

- figure 3 is a comparative diagram giving the noise factor of the same amplifier as a function of the length of its amplifying optical fibre.

Surprisingly, the gain limitation introduced by the presence of amplified spontaneous emission is essentially due to noise propagating in the opposite direction to the optical pumping direction. According to the invention, this effect can be very considerably reduced by inserting an isolator in the doped fibre to limit saturation due to the optical noise propagating in the opposite direction to the signal.

Referring to figure 1, the amplifier 1 comprises in



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series between an input terminal 2 for the optical signal to be amplified and an output terminal 3 for the optical signal: a wavelength multiplexer 4, a first length L of doped optical fibre, an isolator 5, and a second length L' of doped optical fibre. The various components constituting the amplifier are welded together. The multiplexer 4 provides coupling between the optical signal S to be amplified of wavelength λ_s and the pumping signal P of wavelength λ_p . The two signals S and P are applied to the input of the amplifying optical fibre.

In this embodiment, the amplifying optical fibre comprises a glass matrix having a core based on silica having oxides of the Al_2O_3 and GeO_2 type added thereto. It is doped with erbium to a concentration of 100 ppm. The index difference Δn between the core of the fibre and its cladding is $32 \cdot 10^{-3}$.

The amplifier also includes a device 6 for generating the pumping signal. This device comprises, for example, a laser diode delivering a pumping signal having a wavelength of $1.475 \mu m$ and a power of 35 mW.

The diagrams of figures 2 and 3 were obtained using an optical signal to be amplified having a wavelength of $1.55 \mu m$ and a power of -30 dBm. The diagram of figure 2 has the gain G of the amplifier expressed in decibels plotted as a function of the length l in metres of the amplifying fibre. Curve 10 was plotted for measurements using the amplifier of figure 1 without the isolator. Curve 11 was plotted using measurements using the same amplifier but fitted with the isolator 5.

The diagram of figure 3 plots the noise factor NF of the amplifier (in decibels) as a function of the length l . Curve 12 was plotted for measurements using the amplifier of figure 1 without the isolator. Curve 13 was plotted for measurements using the same amplifier but fitted with the isolator 5.

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The optical isolator transmits a signal from a source while greatly attenuating the return energy. A single isolator may be based on a beam-splitting and polarising cube and a quarterwave plate. The incident light is polarised by the cube and is then circularly polarised by the quarterwave plate. The return beam is circularly polarised in the opposite direction. On passing through the quarterwave plate it is linearly polarised and it is blocked by the polarising cube.

Optical isolators are available off the shelf. In the present case, it must be transparent at two wavelengths (that of the signal to be amplified and that of the pumping signal) and the attenuation of the return beam must be greater than 25 dB. If necessary, a plurality of isolators can be used.

It can clearly be seen from the diagrams of figures 2 and 3 that without an isolator the amplifier cannot deliver a gain comparable to that obtained with an isolator, under operating conditions that are otherwise identical.

Under such conditions, the maximum gain appears around 60 metres (see the diagram of Figure 2). The isolator is therefore placed 25 m from the beginning of the doped fibre ($L = 25$ m), which is about halfway along the optimum length of 60 m. In curve 11, there is a small offset representative of the loss specific to the isolator (about 1.5 dB). This offset is nevertheless more than compensated, since for fibre lengths in the range 50 m to 60 m the gain of the amplifier with an isolator is more than 6 dB greater than the gain of the amplifier without an isolator.

As can be seen in the diagram of figure 3, the noise factor can be improved by more than 1.5 dB for the amplifier with an isolator (curve 13) compared to the amplifier without an isolator (curve 12). This

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difference in terms of noise factor can be highly significant if the amplifier is used as a receiver preamplifier or as a line amplifier in a cascade configuration comprising a plurality of amplifier modules, in which case the problem raised by accumulating amplified spontaneous emission along the cascade is critical.

The amplifier of the invention makes it possible to include an optical filter in the fibre isolator, and where appropriate the optical filter can filter out a portion of the co-propagating noise.

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CLAIMS

1. Amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fibre, characterised in that said means comprise an optical isolator (5).

2. Amplifier according to claim 1 characterised in that the amplifying optical fibre is an erbium-doped optical fibre.

3. Amplifier according to claim 1 or claim 2 characterised in that there is one isolator or a plurality of isolators.

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ABSTRACT

Amplifier incorporating amplifying optical fibre

The invention concerns an amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fibre, characterised in that said means comprise an optical isolator (5).

FIGURE TO PUBLISH : FIG. 1

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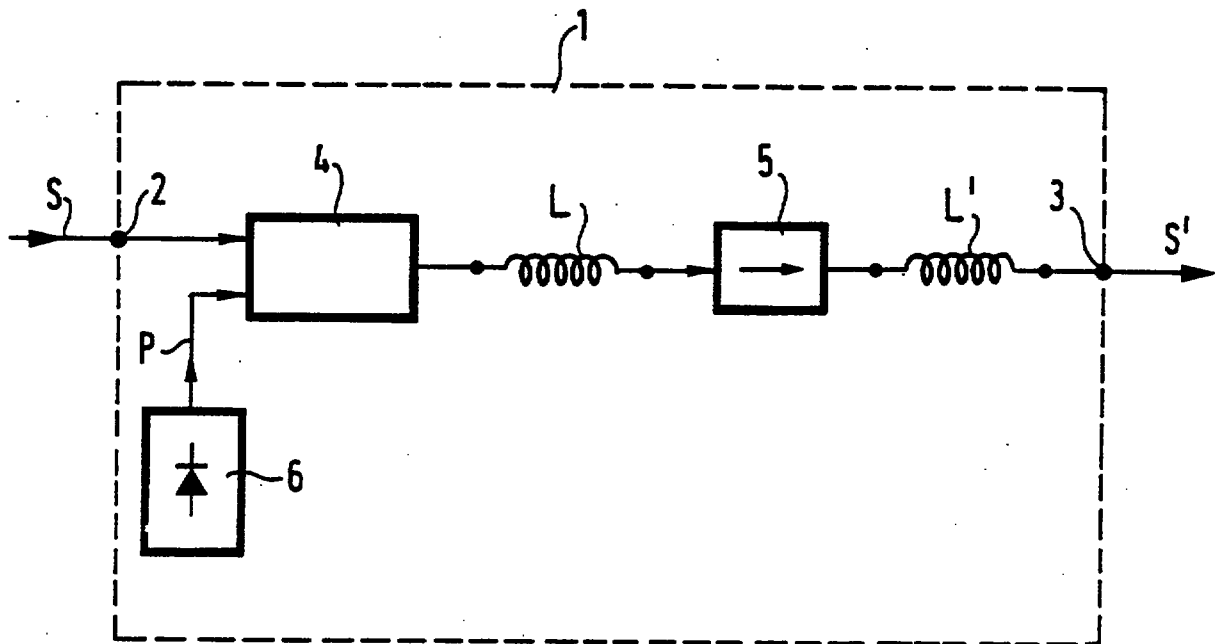
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FIG. 1



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FIG. 2

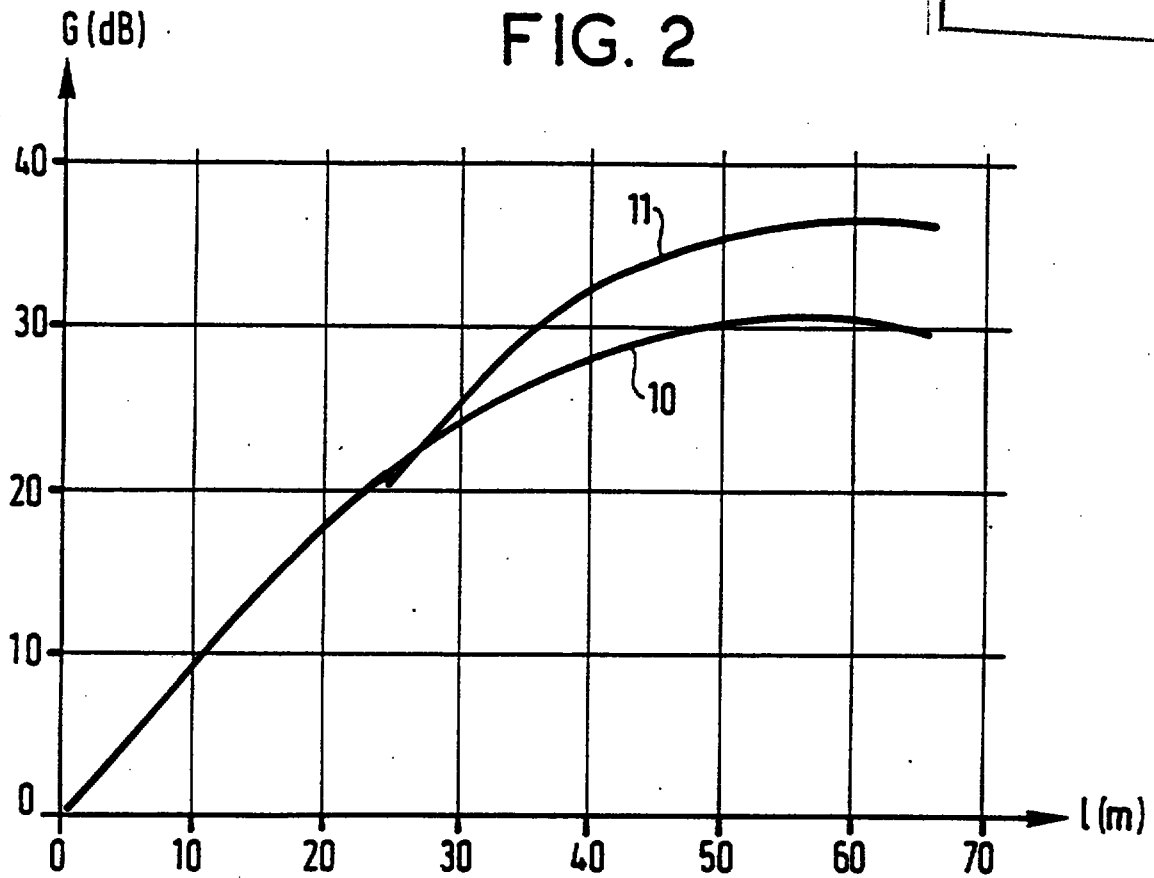
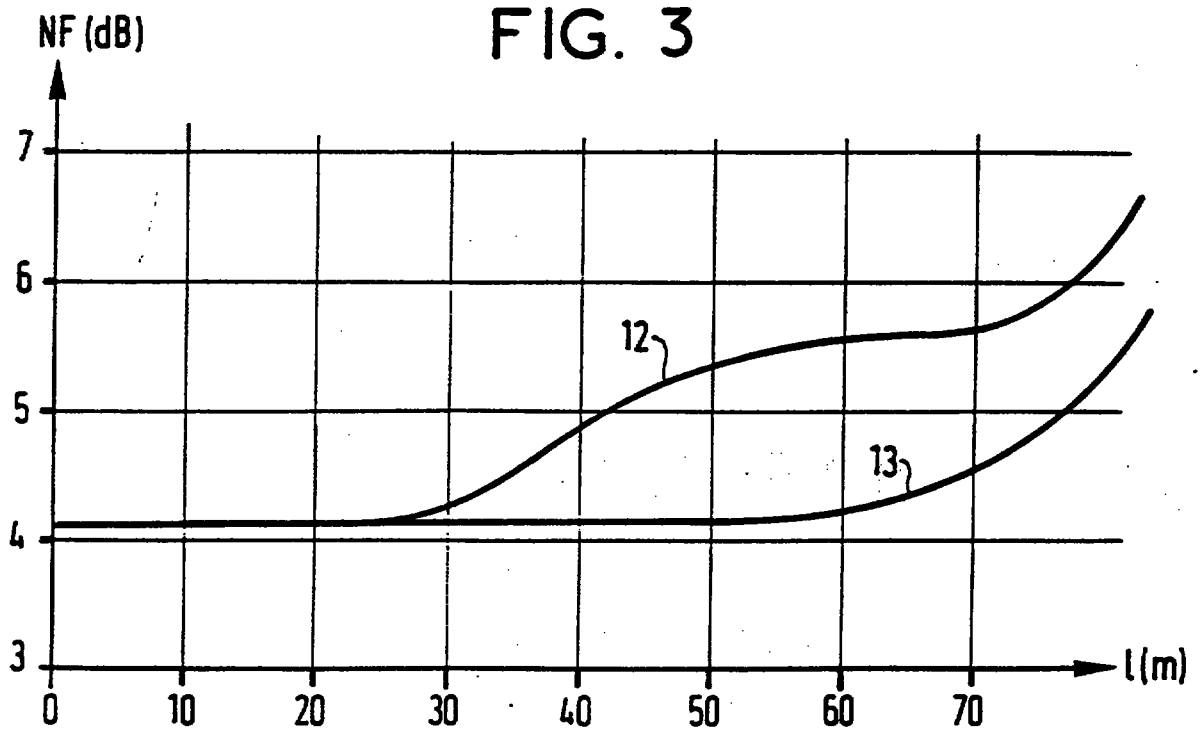


FIG. 3



Amplifier incorporating amplifying optical fibre

The present invention relates to an amplifier having an optical fibre that amplifies, e.g. because of erbium doping. Such an amplifier is particularly suitable for application in optical fibre undersea transmission systems.

Erbium-doped optical fibre amplifiers are known, e.g. from document FR 2 638 854, as are associated undersea transmission systems. Such amplifiers enable high gains to be obtained merely by passing the signal along an optical fibre, and this applies in the spectrum range 1.5 μm to 1.6 μm . However, it is known (see J.F. MARCEROU et al., Proceedings SPIE 1373, pp. 168-186, 1991), that when it is desired to make full use of an erbium-doped optical fibre amplifier, it is limited by the optical noise it generates, known as "amplified spontaneous emission" (ASE). Amplified spontaneous emission is then responsible in part for saturating the laser medium, which happens to the detriment of amplifying the signal(s) present in the optical fibre. Indeed, that is why ASE is used for making excellent wideband superfluorescent sources.

Several solutions ~~to this problem~~ have already been proposed for solving this problem. To reduce the noise factor, it is possible to use short fibres, but this penalises gain. It is also possible to use fibres that are not optimised, but that requires pumping powers that are too high.

Proposals have also been made to limit the effect of amplified spontaneous emission in amplifiers by inserting an optical filter in the length of erbium-doped fibre. The optical filter blocks a spectral component of the noise in both directions. However, that method suffers from the drawback of limiting the passband of the amplifier and is risky when amplifiers are used in cascade due to the fact that the frequencies differ a little from one filter to another. IEEE Photonics Technology Letters, vol. 2, no. 12, December 1990, pages 866-868 describes a

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two-stage amplifying fibre with an optical isolator disposed between the two stages for the purpose of eliminating noise induced by reflection.

In order to mitigate these drawbacks and as defined in claim 1, the present invention proposes using an isolator (one or more) and inserting it into the amplifying optical fibre. This serves to reduce into deleterious effects of optical noise.

~~The present invention thus provides an amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fibre, characterised in that said means comprise an optical isolator.~~

In an undersea transmission system, the amplifying fibre is advantageously of the erbium-doped optical fibre type.

The invention will be better understood and its other advantages and features will appear on reading the following description given by way of non-limiting example and accompanied by the accompanying drawings, in which:

- figure 1 shows an amplifier ~~of the invention~~ having an amplifying optical fibre, according to an embodiment of the invention;

- figure 2 is a comparative diagram giving the gain of the figure 1 amplifier as a function of the length of its amplifying optical fibre; and

- figure 3 is a comparative diagram giving the noise factor of the same amplifier as a function of the length of its amplifying optical fibre.

Surprisingly, the gain limitation introduced by the presence of amplified spontaneous emission is essentially due to noise propagating in the opposite direction to the optical pumping direction. According to the invention, this effect can be very considerably reduced by inserting

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an isolator within the doped fibre to limit gain saturation due to the optical noise propagating in the opposite direction to the signal.

With reference to figure 1, the amplifier 1 comprises in series between an inlet terminal 2 for the optical signal to be amplified and an outlet terminal 3 for the optical signal: a wavelength multiplexer 4, a first length L of doped optical fibre, an isolator 5, and a second length L' of doped optical fibre. The various components constituting the amplifier are connected together by welding. The multiplexer 4 provides coupling between the optical signal S to be amplified of wavelength λ_s and the pumping signal P of wavelength λ_p . The two signals S and P are applied to the inlet of the amplifying optical fibre.

In this embodiment, the amplifying optical fibre comprises a vitreous glass matrix having a core based on silica having oxides of the Al_2O_3 and GeO_2 type added thereto. It is doped with erbium to a concentration of 100 ppm. The index difference Δn between the core of the fibre and its cladding is 32.10^{-3} .

The amplifier also includes a device 6 for generating the pumping signal. This device comprises, for example, a laser diode delivering a pumping signal having a wavelength of $1.475 \mu m$ and a power of 35 mW.

The diagrams of figures 2 and 3 were obtained using an optical signal to be amplified having a wavelength of $1.55 \mu m$ and a power of -30 dBm. The diagram of figure 2 has the gain G of the amplifier expressed in decibels plotted up the ordinate as a function of the length l in metres of the amplifying fibre. Curve 10 was plotted for measurements using the amplifier of figure 1 without the isolator. Curve 11 was plotted using measurements performed using the same amplifier but fitted with the isolator 5.

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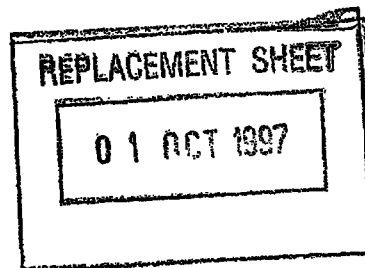
The diagram of figure 3 plots the noise factor NF of the amplifier (in decibels) as a function of the length l . Curve 12 was plotted for measurements performed using the amplifier of figure 1 without the isolator. Curve 13 was plotted for measurements taken using the same amplifier but fitted with the isolation 5.

The optical isolator serves to transmit a signal from a source while greatly attenuating the return energy. A single isolator may be constructed on the basis of a beam-splitting and polarising cube and a quarterwave plate. The incident light is polarised by the cube and is then circularly polarised by the quarterwave plate. The return beam is circularly polarised in the opposite direction. On passing through the quarterwave plate it is linearly polarised and it is blocked by the polarising cube.

Optical isolators components that are commercially available ~~off the shelf~~. In the present case, it must be transparent at two wavelengths (that of the signal to be amplified and that of the pumping signal) and the attenuation of the return beam must be greater than 25 dB. If necessary, it is possible to use a plurality of isolators. ~~can be used~~.

It can clearly be seen from the diagrams of figures 2 and 3 that without an isolator the amplifier cannot deliver a gain comparable to that obtained with an isolator, under operating conditions that are otherwise identical.

Under such conditions, the maximum gain appears around 60 metres (see the diagram of Figure 2). That is why the isolator is ~~therefore~~ placed 25 m from the beginning of the doped fibre ($L = 25$ m), which is about halfway along the optimum length of 60 m. In curve 11, there can be seen a small offset representative of the loss specific to the isolator (about 1.5 dB). This offset is nevertheless more than compensated, since for



fibre lengths in the range 50 m to 60 m the gain of the amplifier with an isolator is more than 6 dB greater than the gain of the amplifier without an isolator.

As can be seen in the diagram of figure 3, the noise factor can be improved by more than 1.5 dB for the amplifier with an isolator (curve 13) compared to the amplifier without an isolator (curve 12). This difference in terms of noise factor can be highly significant if the amplifier is being as a receiver preamplifier or as a line amplifier in ~~a~~ cascades configuration comprising a plurality of amplifier modules in which ~~case~~ the problem raised by accumulating amplified spontaneous emission along the cascade is critical.

It may be observed that the amplifier of the invention makes it possible to include an optical filter in the fibre isolator, and where appropriate the optical filter can serve to filter out a portion of the co-propagating noise.

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CLAIMS

1. An amplifier having an amplifying optical fiber (L, L'), the amplifier being one of the type pumped in co-propagation with the optical signal to be amplified (S) and propagating along said amplifying optical fiber, the amplifier (1) including optical noise reduction means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fiber (L, L'), characterized in that the optical noise reduction means comprise an optical isolator (5) whose position within said amplifying optical fiber is such that said isolator makes it possible to limit gain saturation due to the noise propagating in the opposite direction to the optical signal to be amplified (S).
2. An amplifier according to claim 1, characterized in that said isolator (5) is inserted about halfway along said amplifying fiber (L, L').
3. An amplifier according to claims 1 or 2, characterized in that said amplifying optical fiber (L, L') is 60 meters long and in that said isolator (5) is inserted in said amplifying optical fiber about 25 meters from the beginning of said amplifying optical fiber.
4. An amplifier according to any one of claims 1 to 3, characterized in that the optimum length of said amplifying optical fiber (L, L') corresponds to the gain maximum of said amplifier.
5. An amplifier according to any one of claims 1 to 4, characterized in that said amplifying optical fiber (L, L') is an erbium-doped optical fiber.
6. An amplifier according to any one of claims 1 to 5, characterized in that said optical isolator is single or multiple.



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ABSTRACT

Amplifier incorporating amplifying optical fibre

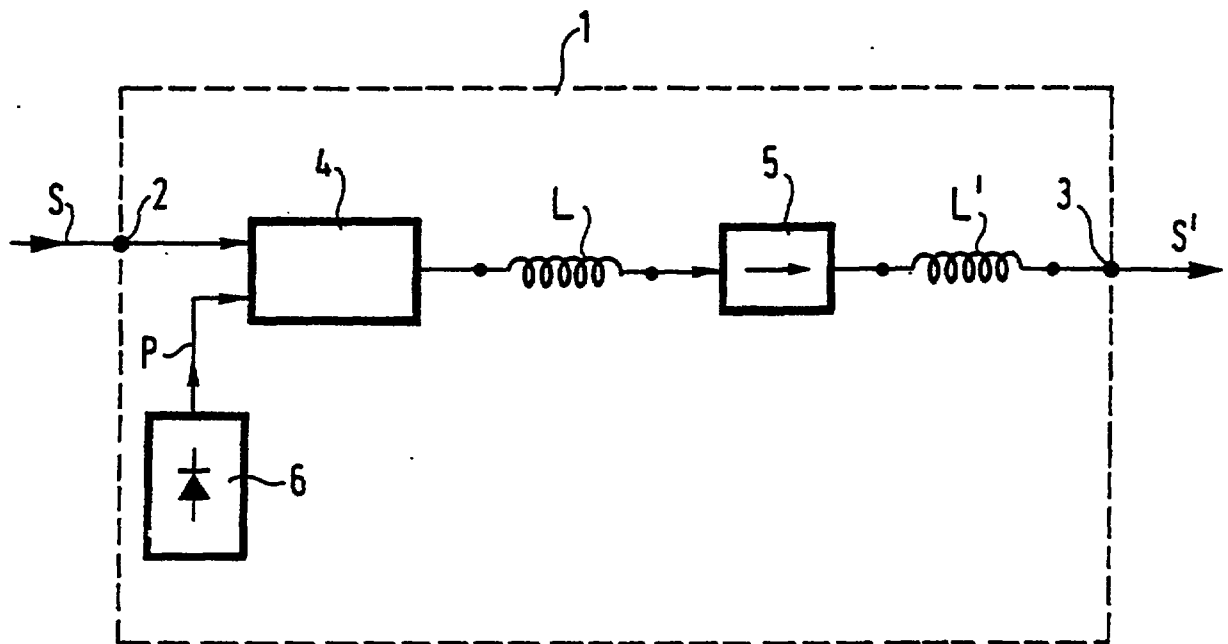
The invention concerns an amplifier incorporating an amplifying optical fibre, the amplifier including means for reducing the optical noise due to amplified spontaneous emission, said means being inserted in the length of the amplifying optical fibre, characterised in that said means comprise an optical isolator (5).

FIGURE TO PUBLISH : FIG. 1

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FIG. 1



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FIG. 2

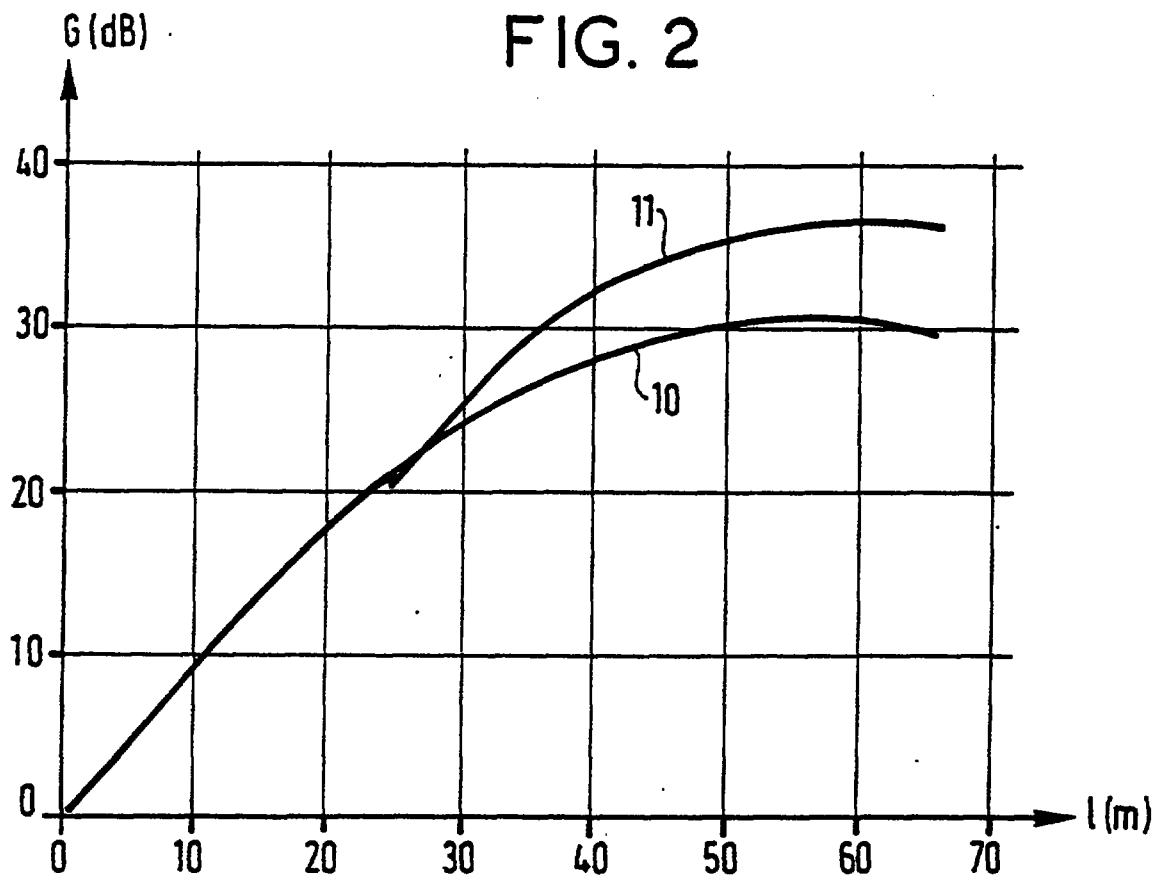


FIG. 3

