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8 AND 16 CHANNEL ALL-FIBRE DFB LASER WDM TRANSMITTERS WITH INTEGRATED PUMP REDUNDANCY

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Abstract - All-fibre DFB laser based 8 channel 100 GHz and 16 channel 50 GHz WDM transmitter arrays with integrated pump redundancy are demonstrated for the first time. Each fibre laser WDM channel in the modules remain in operation despite the drop out of several of the pump-diodes and the maximum penalty to an 8x8 channel 100 GHz system for the drop of 7 out of 8 pump diodes is just 14 dB.

Index Terms - WDM, Fibre grating lasers, Bragg gratings, Pump redundancy

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I. Introduction

Wavelength division multiplexing (WDM) is the preferred technique when upgrading system capacity [1], and it is standard to operate a series of laser or diode sources to transmit a desired ensemble of WDM channels. Current WDM transmission system designs are based on semiconductor DFB laser technology and consist of direct one-to-one connection of transmitter lasers to WDM channels. Such systems are inherently vulnerable to failure or deterioration to the output of the driving source. Transmitter failure results in the complete drop of the transmitted channel which in turn results in loss of data transmitted on that line.

DFB fibre lasers [2] exhibit ideal source characteristic for high bit-rate systems and, being based on and around a fibre Bragg grating, output power and wavelength stability, accuracy and fibre compatibility therefore are inherent to the lasers. The fact that they can also be designed to lase in a single polarisation with a high power (20 mW) single-sided CW output and high SNR [3] to avoid cross talk between adjacent channels, makes them ideal source candidates and strong rivals to their semiconductor counterparts. We have recently demonstrated that DFB fibre lasers are capable of this task, in a 4x10 Gbit/s WDM transmission experiment [4].

In this paper we demonstrate for the first time 8 and 16 channel 100 GHz and 50 GHz all-fibre laser based WDM transmitter modules with integrated pump redundancy. Such a scheme safeguards against the failure of one or more pump diodes. We demonstrate that with such a scheme the penalty to each of 8 WDM channels in a 8x8 channel system from the failure of the 1 out of 8 pumps is just 2 dB and that all WDM channels remain in operation despite the drop of 7 out of 8 pump-diodes.

II. Device description

In Fig. 1 is shown a schematic of the 8 channel transmitter module. This module consists of 8 pump diodes, a pump redundancy unit and 8 asymmetric all-fibre DFB lasers of length 5 cm with isolators on the output end [3]. The principle of the pump redundancy module is to split the powers from the pumps equally between the DFB-fibre lasers, such that each laser still will receive the pump power corresponding to that provided by one pump diode. The particular module is made up of 2x2 3dB couplers at 980 nm and equal splitting of 8 inputs to 8 outputs is obtained with 12 couplers. The total insertion loss for each pump input channel in this 8 channel module is ~1dB. A single 8x8 splitter would provide the same splitting principle.

Eight DFB fibre lasers separated in frequency by 100 GHz were made using a continuous grating writing technique [5] with CW 244 nm UV light and a phase-mask assembly. The lasers all operate in a single polarisation mode with a purity of >40 dB and with a single-sided output power ratio of ~50:1 [2]. The slope efficiency of the lasers is ~25% and using the pump redundancy scheme with ~50 mW (17 dBm) power from each pump diodes, results in CW output powers of ~5 dBm ± 0.25 dBm, from all the lasers. The outputs of the 8 lasers are combined in an all-fibre multiplexer consisting of seven 1550 nm 3-dB splitters with a total insertion loss of ~10 dB. Noise measurements of the lasers show RIN <-160 dB/Hz (f>10 Mhz) with RIN < -170 dB/Hz for frequencies larger than 20 MHz, indicating very quiet sources with performance well suited for high speed communication systems.

III. Results and discussion

Fig. 2a shows the multiplexed 8 channel 100 GHz system running with all 8 pump-diodes operating (0.02 nm res.). It shows that the SNR between the channels is in excess of 50 dB and that the channel powers are equal to within 2.0 dB. The reason for the slight increase in channel power inequality is due to a small difference in the splitting of the 1550 nm 3dB couplers in the all-fibre multiplexer. The power stability of the lasers is ~ 0.05 dBm and the wavelength stability is stable to within 0.1 pm measured with a wavemeter (0.1 pm res.). To demonstrate the benefit of the redundancy scheme and to test the effect on the output stability and power of the eight DFB fibre lasers, the pump diodes are one-by-one (Fig. 2b-2f) turned off. The power is obviously seen to drop, but the channels all remain lasing despite the dropping of 7 of the 8 pumps (Fig. 2f). The power penalty to each of the channels associated with the loss of 7 pumps is ~14dB, but more importantly the individual channel separations and the relative differences in channel powers remain constant. It should be noticed that the SNR is also unaffected by the pump failures. Due to the reduced pump power the lasing wavelength of the DFB fibre lasers does shift down, this shift is a result of the Er/Yb fibre used and is ~500 MHz/pump-drop. This particular fibre has a strong pump absorption (~250 dB/m) [6], to ensure an efficient conversion of the pump to the signal. The strong pump absorption results in heating [7] of the fibre, an effect however that easily can be minimised by the design of a proper heat dissipation scheme.

The use of a pump redundancy scheme is seen not only to allow for the failure of one or more pump-diodes, but also to provide the extra bonus of averaging any fluctuations in diode power. The extension of this scheme to provide 16 DFB fibre lasers with only 8 pumps can be realised by splitting the 8 outputs from the previous 8-channel scheme with an additional set of 3-dB couplers. This configuration is shown in Fig. 3 with a demonstration of how such a system would look with a modulator attached to each WDM channel output. To demonstrate such a system, 16 DFB fibre lasers now separated in frequency by 50 GHz were employed. The output spectrum of this module operated with 4 and 8 pumps is (without the modulators) shown in Fig. 4 and it can be seen that despite the reduced spacing to 50 GHz, the high SNR between adjacent channels is maintained. A splitting of the pump lasers to an extra 8 fibre lasers reduces the output power from each of the transmitter lasers but produces a module with the same redundancy of 1/8. Additionally the increased pump splitting has the advantage of reducing the price of the transmitter module because more channels are available from the same number of pumps.

If a redundancy scheme based on 3-dB couplers is considered, the total number of couplers N, required to make a nxk channel system ($n \le k$) with subsequent redundancy of $1/n$ is

$$N = 2^{m} \cdot (m + \sum_{i=0}^{h} 2^{i}) \qquad (1)$$

where $n=2^{m+1}$ is the number of pumps and $k=2^{h+m+1}$ is the number of supported WDM channels.

Depending on what pump redundancy and net output power from the sources is required, even a system consisting of the splitting of just 4 pumps to 16 lasers is from (1) seen to be possible with 16 3-dB couplers. Such a system will only have a redundancy of 1/4 though but will provide a SNR between 50 GHz channels which is in excess of 50 dB with an output power of -20 dBm from each transmitter laser. This output level is possible to increase by employing more powerful pump sources and a multiplexer with less insertion loss than the one demonstrated here. This type of multiplexer is used in this case to demonstrate that all-fibre transmitter sources are possible to manufacture.

IV. Conclusions

We have for the first time shown all-fibre laser based WDM transmitters employing a pump redundancy scheme. The demonstrated 8 and 16 channel (100 GHz and 50 GHz respectively) modules employ all-fibre DFB lasers and remains in operation on all channels despite the failure of several pump diodes. The proposed WDM transmitter units therefore can remain in operation without loss of transmitted data whilst failing pumps are being either replaced or serviced. Because of the high SNR of > 50 dB provided by the fibre-lasers, dense WDM grid spacings down to 25 GHz are readily applicable. We believe that these experiments demonstrate that the benefits of fibre grating lasers in conjunction with a pump redundancy scheme can provide a very attractive and highly reliable WDM transmitter unit.

Acknowledgements

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Figure captions:

Fig. 1. 8 channel 100 GHz DFB fibre laser WDM transmitter module with 8 x 8 pump redundancy scheme.

Fig. 2. Operation of the 100 GHz WDM transmitter unit with

a) all pumps,

b) - c) 7 - 6 pumps,

d) - e) 4 – 3 pumps,

f) 1 pump.

Fig. 3. 8 channel pumped 16 channel fibre laser based WDM transmitter module with 8 x 16 pump redundancy scheme.

Fig. 4. Operation of 16 channel 50 GHz WDM transmitter module with

a) all pumps,

b) 4 pumps.

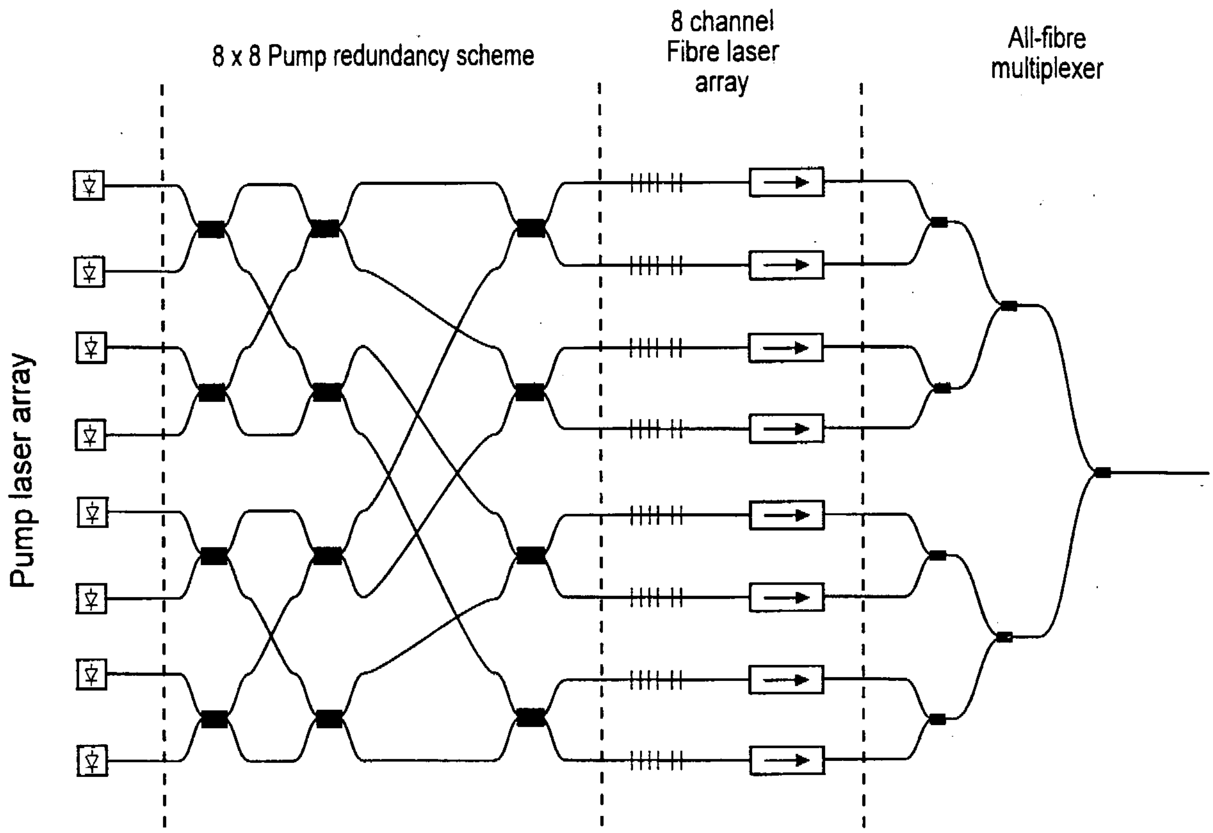
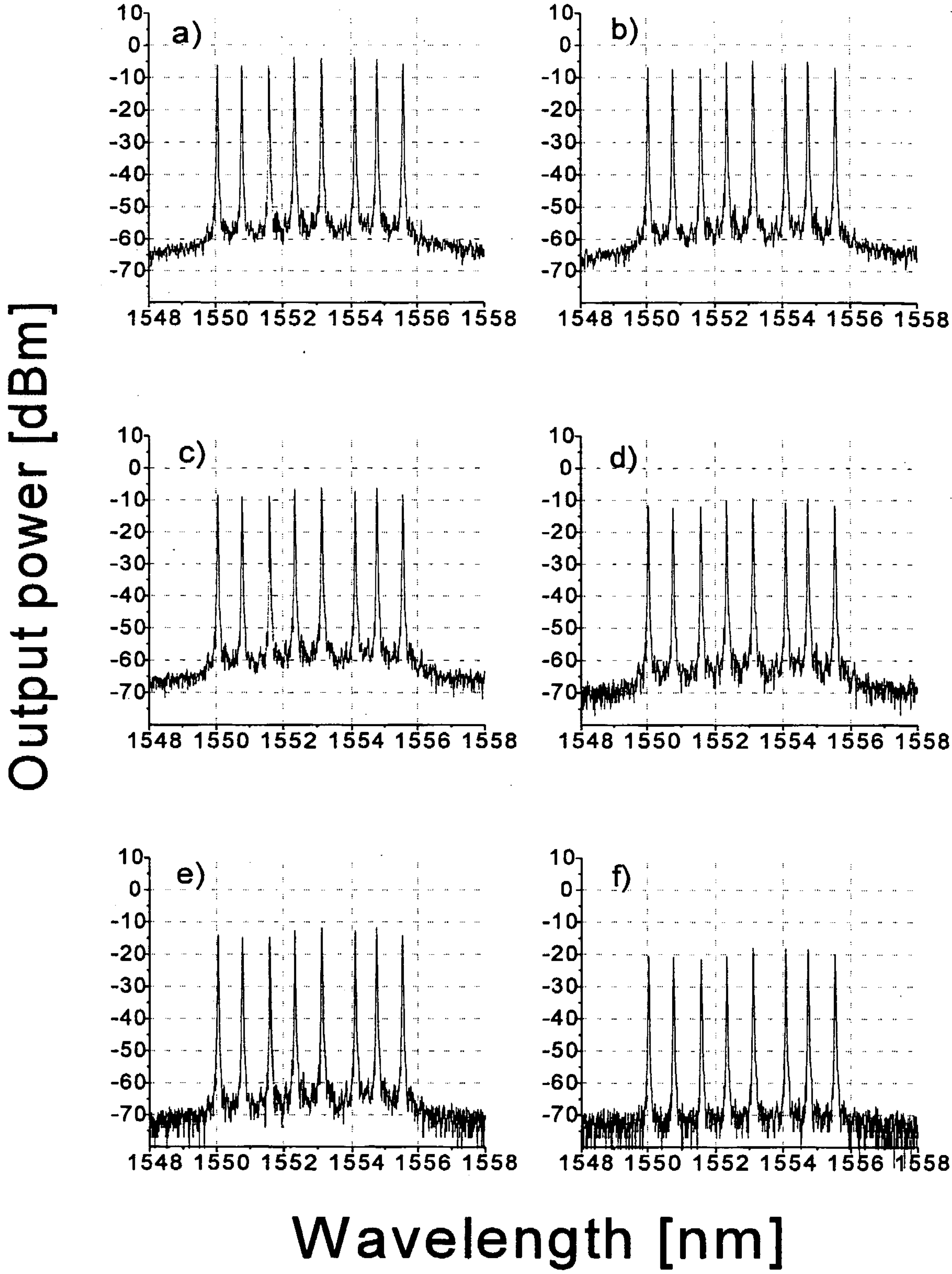

8 x 8 Pump redundancy scheme
8 channel
Fibre laser
array
All-fibre
multiplexer
Pump laser array

Fig. 1



a)
b)
c)
d)
e)
f)
10
0
-10
-20
-30
-40
-50
-60
-70
1548 1550 1552 1554 1556 1558
Output power [dBm]
Wavelength [nm]

Fig. 2

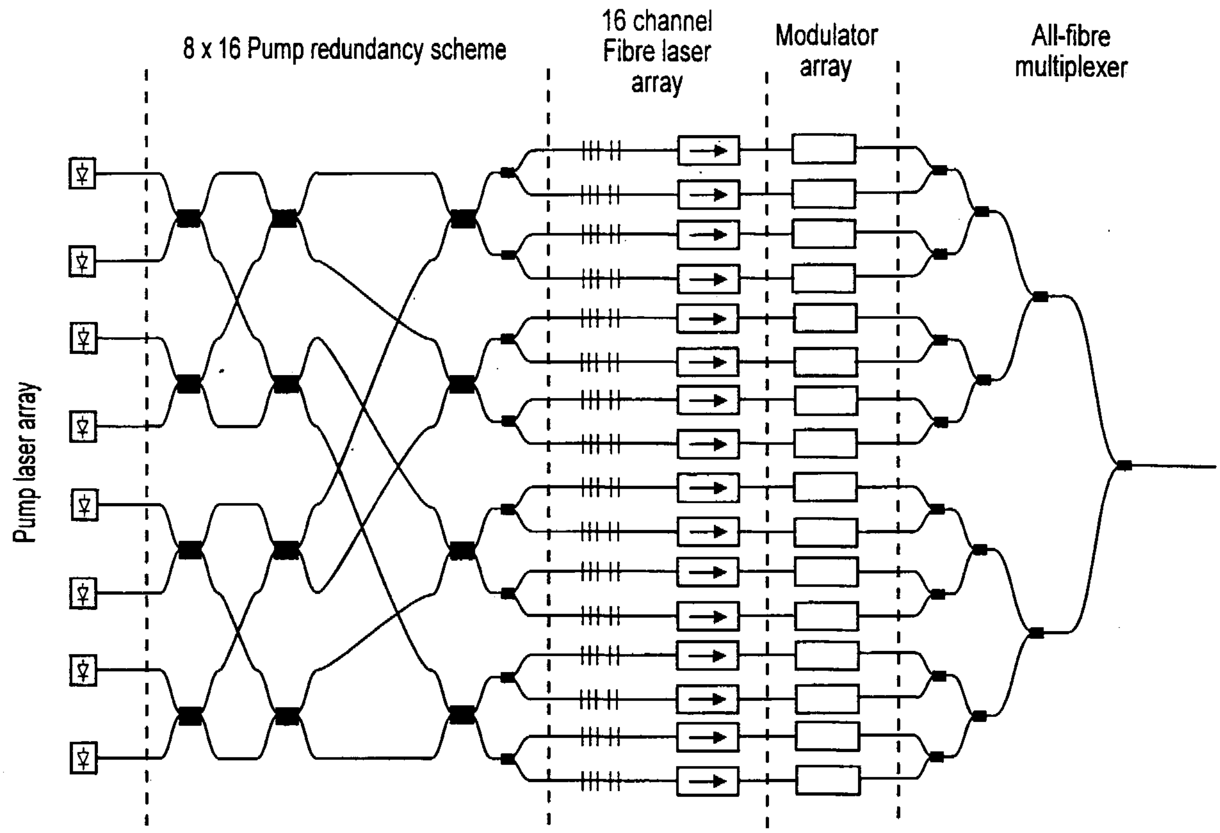

8 x 16 Pump redundancy scheme
16 channel Fibre laser array
Modulator array
All-fibre multiplexer
Pump laser array

Fig. 3

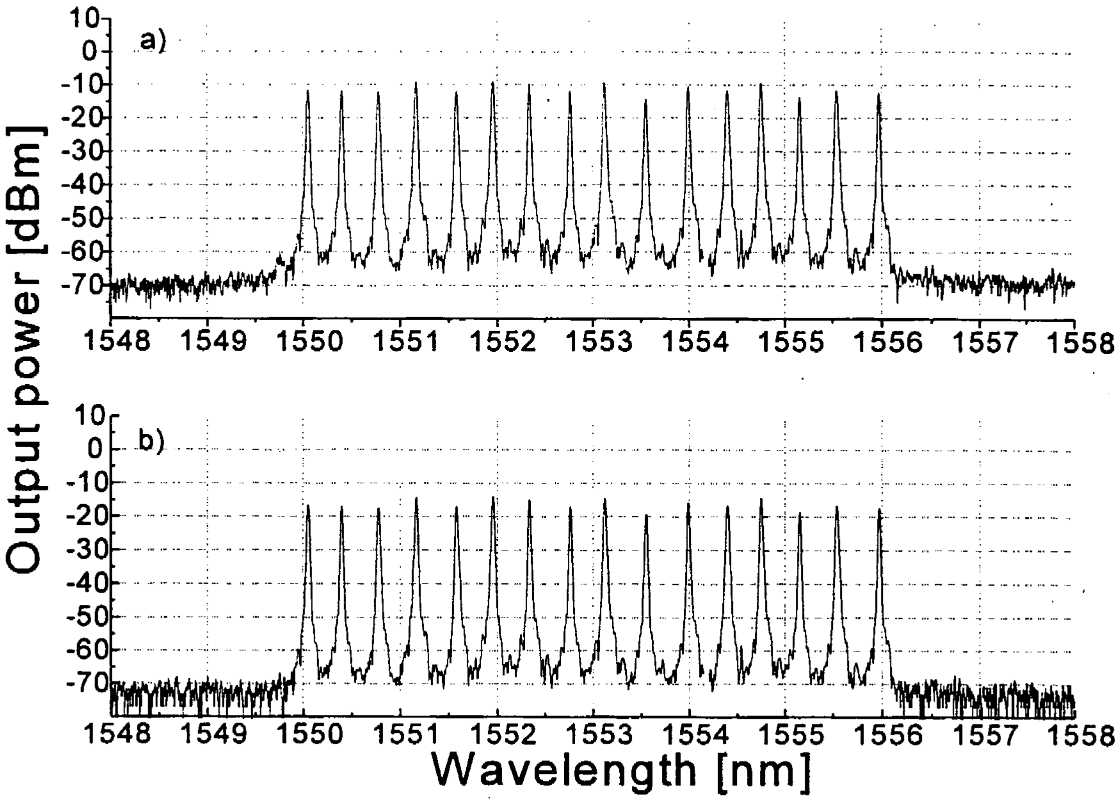

a)
b)
10
0
-10
-20
-30
-40
-50
-60
-70
Output power [dBm]
1548 1549 1550 1551 1552 1553 1554 1555 1556 1557 1558
Wavelength [nm]

Fig. 4