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TRADE-OFF BETWEEN GAIN EFFICIENCY AND NOISE FIGURE IN AN OPTIMISED FIBRE AMPLIFIER

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The trade-off between gain efficiency and noise figure is evaluated for an optimised EDFA pumped at 980nm. Operating at maximum gain efficiency results in an increased noise figure of ~4dB. Quadrupling the pump power can reduce the noise figure to 3.2 - 3.5dB.

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Erbium-Doped Fiber Amplifiers (EDFAs) operating at 1.53μm are proving to be indispensable components in the field of optical fiber communications. This is due to their compatibility with the fiber network, high gain performance and low pump threshold which results in a noise figure close to the quantum limit.

In a practical system, high gain efficiency and low noise figure are simultaneously required. Thus, a thorough investigation of the conditions under which optimum EDFA performance is achieved is worthwhile. In this communication, the optimum gain efficiency and the corresponding noise figure are calculated theoretically by varying the fiber design using parameters of cut-off wavelength (λ_c), numerical aperture (NA), and Er^{3+} doping confinement (R_e = ratio doping/core radius). We show that gain efficiency and noise figure are interdependent and slavish striving for maximum gain efficiency <u>always</u> compromises the noise performance.

For a 980nm pump co-propagating with the signal, a three-level model was employed which utilizes the effective overlap integral approximation[1]. The forward and backward ASE were evaluated for an equivalent bandwidth Δv=600GHz (4.5nm). The noise figure was then calculated by using the relation $NF=((P_{ASE(+)}/h\nu\Delta\nu)+1)/G$, where $P_{ASE(+)}$ is the forward ASE for two polarizations and G is the gain[2]. Additional parameters refer to germano-silicate fiber and were determined experimentally[3].

The results are summarized in Figs. 1 and 2 where the optimum gain efficiency and the corresponding noise figures are plotted against the numerical aperture of the fiber for various degrees of Er^{3+} doping confinement. In each case the optimum combination of fiber length, cut-off wavelength and pump power was determined so as to obtain the maximum gain efficiency. In Fig. 1 the results agree well with the best gain efficiency reported[4] to date (10.2dB/mW). Also shown are points taken from ref. 5 which lie close to the calculated curve. Note that for practically-attainable NA's of around 0.4, a gain efficiency as high as 22dB/mW may be possible.

The optimum gain efficiency is seen to increase quasi-quadratically with the numerical aperture, but is always accompanied by an increase in NF. Confining the dopant increases the optimum gain efficiency still further and improves the noise figure. From Fig. 2 it is also clear that for geometries fully optimised for gain efficiency alone, the corresponding noise figure departs considerably from the 3-dB quantum limit, being 4dB or more. This is due to the fact that under optimized conditions the ratio of the backward ASE to the pump power is also maximised. This strong backward ASE reduces the population inversion at the EDFA input and results in an increased noise figure.

Tolerances on the EDFA noise figure are stringent for pre- and line- amplifiers and can only be minimized by accepting a lower (i.e. sub-optimal) gain efficiency. For example, the noise figure of an EDFA for a given pump power can be reduced by decreasing the fiber length below the optimum, thus compromising the gain efficiency. The effect is shown in Figs. 3

and 4, where the maximum gain attainable for a given pump power is plotted with the constraint of achieving a given noise figure. It is clear that considerably greater pump power is required for a given gain as the constraints on noise figure are tightened. For example, for an amplifier having 30dB gain, reducing the noise from the figure of 4dB (which results from the maximum gain-efficient case) to 3.2dB requires the pump to be approximately quadrupled.

In conclusion, the optimised gain efficiency and the corresponding noise figure of an EDFA pumped at 980 nm have been calculated theoretically for a range of NAs and dopant confinements. In all cases, the noise figure departs considerably from the 3-dB quantum limit. Additionally, the pump power required to achieve a certain gain level with a predetermined noise figure was calculated. It is shown that to achieve figures close (e.g. 3.2dB) to the theoretical minimum of 3dB requires a substantial increase in pump power. Thus, contrary to expectations, highly gain-efficient designs are not necessarily ideal for use in optical pre-amplifiers. Note, however, that it may be possible to eliminate the effect of backward-travelling ASE on the noise figure by including an isolator within the amplifier length.

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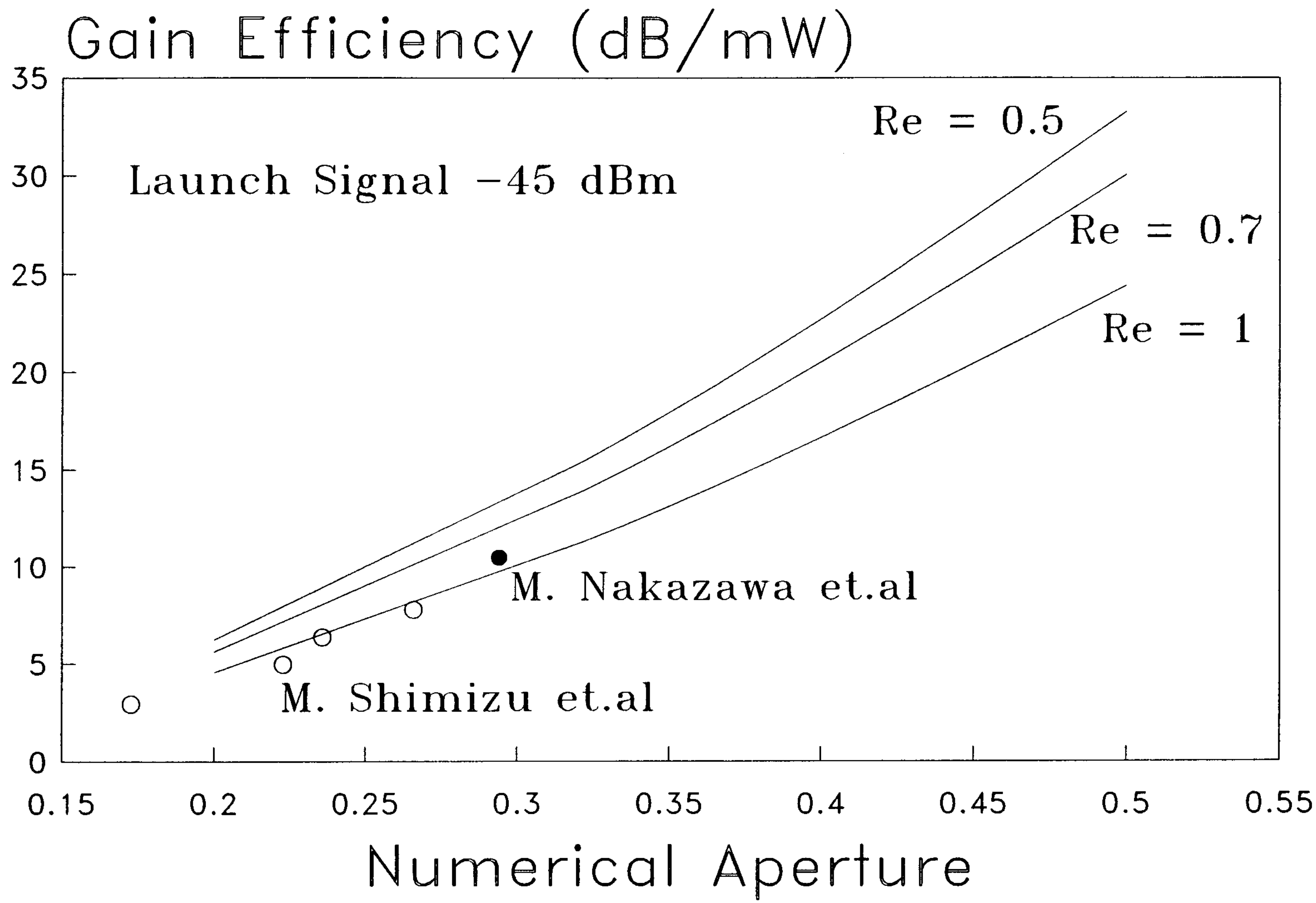
Figure Captions

Figure 1 Gain efficiency versus numerical aperture with dopant confinement as a parameter in an EDFA optimised for length and cutoff wavelengths.

Figure 2 Noise figure versus numerical aperture, optimised as in Figure 1.

Figure 3 Maximum gain achievable with a given pump power for the noise figures shown in a fibre optimised for length and cutoff wavelength. Launch signal = -45dBm, R_c = 0.7, NA = 0.2

Figure 4 Maximum gain achievable with a given pump power for the noise figures shown in a fibre optimised for length and cutoff wavelength. Launch signal = -45dBm, R_c = 0.7, NA = 0.3.


Gain Efficiency (dB/mW)
Launch Signal −45 dBm
Re = 0.5
Re = 0.7
Re = 1
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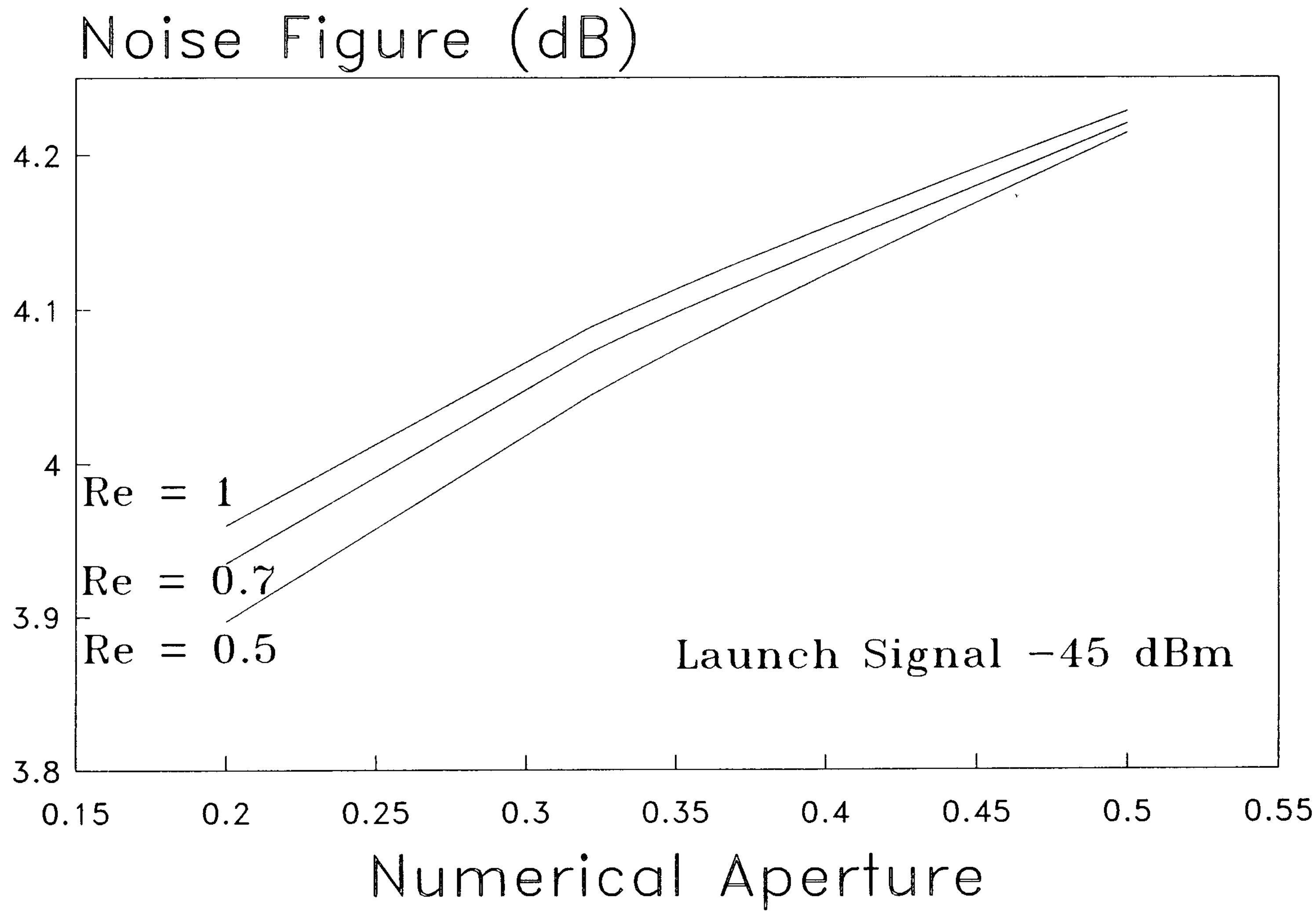
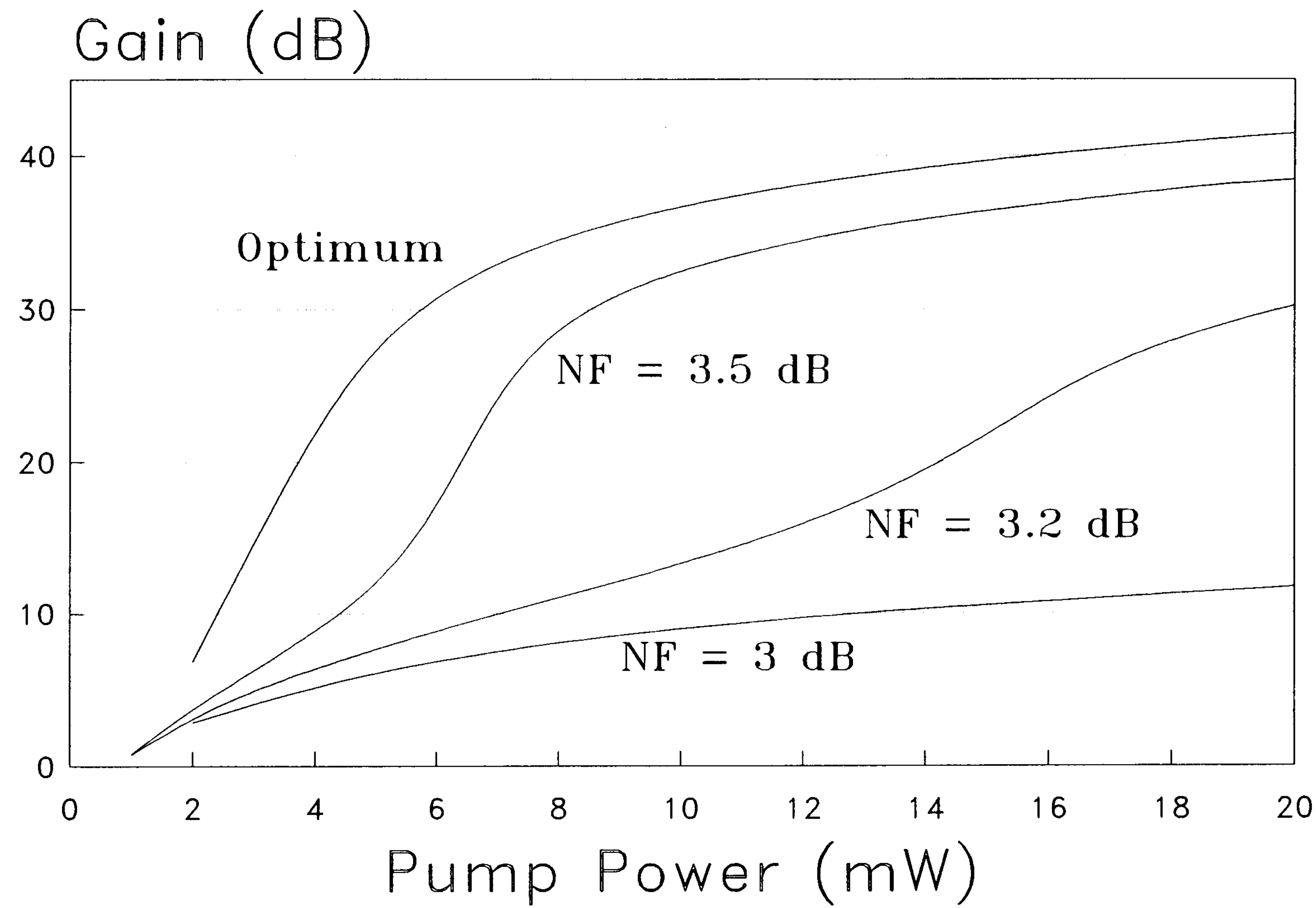
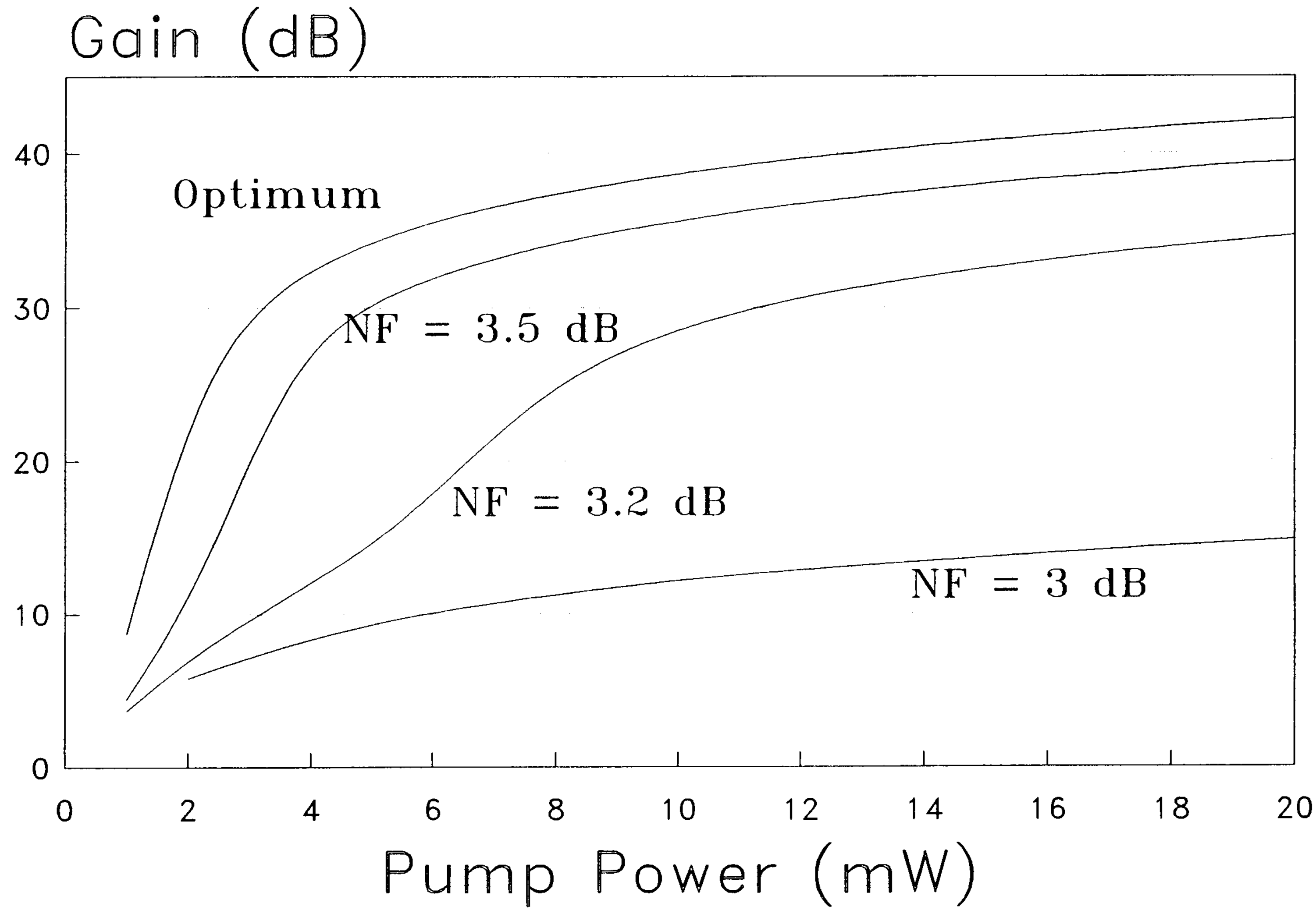
0
5
10
15
20
25
30
35
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
Numerical Aperture


Noise Figure (dB)
4.2
4.1
4
3.9
3.8
Re = 1
Re = 0.7
Re = 0.5
Launch Signal −45 dBm
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
Numerical Aperture


Gain (dB)
40
30
20
10
0
Optimum
NF = 3.5 dB
NF = 3.2 dB
NF = 3 dB
0
2
4
6
8
10
12
14
16
18
20
Pump Power (mW)


Gain (dB)
Optimum
NF = 3.5 dB
NF = 3.2 dB
NF = 3 dB
0
10
20
30
40
0
2
4
6
8
10
12
14
16
18
20
Pump Power (mW)