6.0 General conclusion.

The advent of active transmission lines is probably the most exciting event in the history of optical fibre communication which is revolutionising and setting a precedent to modern twenty first century technology. The trend today is moving towards active fibre transmission lines i.e. the transmission medium used to carry signals is also actively involved in amplifying signals that passes through it. Various fibre amplifiers had proliferated in recent years due to the intense research on this new technology which has drawn the interest of many prolific researchers. There are many deciding factors for choosing one optical fibre amplifier over the other, however factors like the gain of the signal per input pump power and the simplicity of designing and maintaining these optical fibre amplifiers would most probably take precedence over the other factors like low cost, immunity to environmental conditions, etc.

6.1 Advantages of a Raman fibre amplifier.

The simplicity of designing and maintaining a Raman fibre amplifier makes it a strong contender to rare earth doped fibre amplifier. In a Raman fibre amplifier, the amplifying fibre used can be of various types e.g. silica dioxide, rare earth doped, ZBLAN [8], depending on the need of the designer. In the case where a normal silica fibre is used, the Raman fibre amplifier would behave like a normal transmission fibre when the pump is absent and as an optical amplifier when the pump is present. In other words the Raman fibre amplifier would not attenuate the signal as it would with rare earth doped fibre amplifiers, when the pump is absent, attenuation in this case would exist in the form of normal fibre attenuation which exist in all fibres. Any signal can be amplified in a Raman fibre amplifier provided a suitable pump source can be found which is Raman shifted away. The greatest flexibility offered by a Raman fibre amplifier is that we can have the option of combining various pump and fibre material to achieve amplification of the desired signal. Table 3.1 shows the various fibre material and the Raman shift of these materials, hence by having a common pump source pumping different fibre materials, various signals can be amplified. This can be summarised in table 6.1

Pump (nm)	Fibre material	First Raman shift (cm^{-1})	Signal to be amplified 1^0 / 2^0
	SiO_2	450	545 / 559
532	ZBLAN	595	549 / 568
	$SiO_2 + P_2O_5$	1320	572 / 619
	SiO_2	450	1116 / 1176
1064	ZBLAN	595	1136 / 1218
	$SiO_2 + P_2O_5$	1320	1238 / 1479

Table 6.1 **Shows the various signals that can be amplified by choosing the relevant combination of fibre material and pump source.**

The fourth column of table 6.1 shows the amplification of the desired signal, by the first order stimulated Raman (denoted by 1^0), using various combination pump source and fibre material. Amplification is also possible using higher order stimulated Raman scattering, where amplification using the fourth order stimulated Raman was reported by Nakazawa M. et. al. 1984, [25]. Table 6.1 also shows the second order Raman (denoted as 2^0) for the various pump and fibre material combination where amplification of these signals is also possible. The second order stimulated Raman has a frequency shift which is two times that of the first order stimulated Raman.

6.2 Disadvantages of a Raman fibre amplifier.

Figure 4.4 and figure 4.8 shows the threshold of the first and second stimulated Raman in an optical fibre at various fibre length. Table 6.2 shows a summary of the threshold vs fibre lengths.

Fibre length (m)	1st order SRS (Watts)	2nd order SRS (Watts)
2.2	107	202
10.0	19	30

Table 6.2 **Shows the input power threshold needed to generate the first and second order stimulated Raman scattering at various fibre length.**

The disadvantage of a Raman fibre amplifier is the relatively high input power needed to achieve stimulated Raman scattering in an optical fibre, this in turn would lead to low signal gain per input pump power. Table 6.2 shows that in both cases we see that the threshold power needed to achieve stimulated Raman scattering is in the order of Watts (peak input power). This requirement is not a favourable factor since current laser diodes cannot achieve such high peak power requirement. However research is constantly being carried out on laser diodes pumped Raman fibre amplifiers with promising results, [9] and with better technology higher power laser diodes would make Raman fibre amplifiers feasible.

In order to increase the gain of the Raman fibre amplifier further, it is possible to specially fabricate a fibre to have special characteristics. Recalling equation 5.1:

$$P_s (L) = P_s (0) \exp \frac{gL_e P}{bA_e} \qquad (5.1)$$

We see that the amplification of the signal in a Raman fibre amplifier can be increased further if the denominator of the exponential term in equation 5.1 is made smaller and similarly the numerator of the exponential term in equation 5.1 made bigger. By fabricating a fibre with a smaller effective area A_e and making the fibre polarisation preserving, we can increase the amplification of the Raman fibre amplifier, similarly by fabricating a fibre with a higher Raman gain, and using a longer length of fibre we can increase the amplification of the signal. By increasing the germania doping level of an optical fibre, both the Raman gain can be increased and the effective core diameter can be decreased respectively, hence this increases the amplification of the Raman fibre amplifier, Spirit D.M.1991, [34] but these promising factors have drawbacks though, which leads to higher attenuation of the signal in the absence of the pump.

6.3 Suggestion for further work.

Optical fibre communication is constantly progressing towards higher and higher transmission rates. The whole idea is to have more bits transmitted per second, via a reduction in the pulse width. This is an interesting area which is worth looking into; the capability of the Raman fibre amplifier amplifying signals with high transmission rates, pulses in the femto second region. The peak power achievable from a femto second pulsed laser beam is in the order of Giga to Tera Watts, which is above the stimulated Raman scattering threshold power in silica fibres, hence even a femto second signal which is transmitted through the fibre has the capability of generating stimulated Raman scattering and this in turn has the capability to amplify signals which are Raman shifted away. Areas for further work can cover Raman induced cross talk and noise created from a Raman fibre amplifier in the femto second region. Work can also cover ways of making the Raman fibre amplifier constantly active and noise free, by varying the frequency or even the duty cycle of the femto second pump laser to match the stimulated Raman scattering lifetime.