Appendix A. Error calculations.

A 1.0 Introduction.

Error exist in all basic physical quantity that needs measurements like length, time, weight, etc. and when these basic quantities are measured, the percentage of errors contributed by the measurements of these basic quantity would add up and effect the final results i.e. derived quantity (velocity, pressure, dB gain, ...). The error in the final results can be substantial if care to reduce the errors created when measurements are made on these basic quantity are not taken care of initially.

Basically errors can be divided into two main groups, first is systematic errors e.g. errors created from measurement from tools and the error is inherit of that tool. Examples of systematic errors are like errors observed from measuring equipment e.g.. rulers and weighing machines - accuracy of the equipment used in the measurement. The second is accidental or random errors which implies reproducibility of the results of successive individual measurements. Random errors happens in an event e.g.. measuring the power of an amplified signal from the Raman fibre amplifier, pulse width measurement. The measurement varies from one successive measurement to the other i.e. like in a shooting target practice. If the sample size of the power measurement is large, we would see that the distribution of the power measurement behaving like that of a normal distribution, hence the experimental error of this distribution is given as the standard deviation (in short sigma, σ) Mark 1966, [24].

As per Using SPC to the best 1989, [44] the standard deviation is a standardised way of quantifying how the values in a distribution deviate from the average value of the distribution and is given by the following formula:

$$\sigma = \sqrt{\frac{\sum(X - X_{Avg})^2}{(n-1)}} \qquad (A.1)$$

Where X_{Avg} - is the average of all the readings in the sample size.

X - is the individual readings.

n - is the sample size / number of readings taken.

The standard deviation is a powerful statistical tool and it allows predictions to be made on the whole process variation based on a small sample size collected. We would naturally find values taken from the sample lying outside the sigma value, but 68.26% of the data would fall between +/- sigma from the average. If a process is in control, all the readings taken would be within +/- 3 sigma from the average or in other words, 99.73 % of the values taken from the sample would fall within this +/- 3 sigma limit.

A 1.1 Error in laser power measurement

The laser power output was measured using a OPHIR power meter. The output of the laser power was plotted in figure A1 and it shows the characteristics of a normal distribution. The average value had been calculated to be 49.824 μW and the standard deviation had been calculated to be 7.798 μW, this represents a variation of 15.051 % from the average value. Comparatively to a CW laser source, this is a high fluctuation of laser output. Further measurements were carried out to determine the standard deviation of the following parameters, as per given in table A.1:

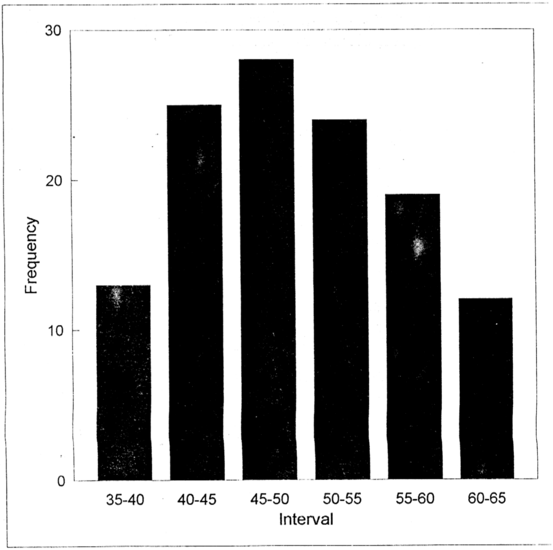

Figure A1 **Shows the power output from the laser, measured using an OPHIR power meter. The measurement shows a normal distribution.**

	Average, X_{avg}	Sigma, σ	% error
Pump power	49.82 μW	7.79 μW	15.05
Amplified Signal, (Intensity)	18.48	3.97	21.49
Signal (Intensity)	2.44	0.52	21.27
Pulse width, FWHM	15.24 ns	2.56 ns	16.84
Coupling efficiency, %	19.59	2.48	12.67

Table A.1 **Shows the average value and the standard deviation of various parameters.**

By studying the extend of error contributed by individual parameters, care can be taken to reduce these error contribution e.g. the pump had to be operated above the stimulated Raman scattering threshold by at least 15 % , below which, the stimulated Raman effect will be intermittently observed - hence amplification of the signal would also be intermittent. The error of the gain can be calculated by taking the partial differential equation of the gain, the gain is given as equation A2.

$$\text{Gain} = \frac{\text{Amplified signal (AS)- Signal}}{\text{Signal}} \tag{A2}$$

by taking the partial differential equation of equation A2 we get

$$\Delta\text{Gain} = \left(\frac{\partial G}{\partial AS}\right)_{Sig} \Delta AS + \left(\frac{\partial G}{\partial S}\right)_{AS} \Delta Sig \tag{A3}$$

simplifying equation A3 by keeping the signal constant in the former and the amplification constant in the latter, equation A3 can be written as follows: .

$$\Delta\text{Gain} = \left(\frac{1}{Sig}\right) \Delta AS + \left(\frac{AS}{Sig^2}\right) \Delta Sig \tag{A4}$$

by solving equation A4, the error for the gain can be estimated. Similarly the error for ln(gain) can be written as

$$\Delta(\ln(\text{Gain})) = \left(\frac{1}{\text{gain}}\right) \Delta\text{Gain} \qquad \text{(A5)}$$

from equation A5, ln (gain) in inversely proportional to the gain, hence by confining our measurement to the high gain area, we can reduce the error contribution. This is shows in figure 5.5 and figure 5.10, we see that the percentage of error in the high gain region is lower than that of the low gain region.

Appendix B. Fibre parameters

B 1.0 Definition of fibre parameters

The fibre used in this experiment is supplied by Newport model F-SV-20. The fibre parameters given by Newport are summarised in table B1.

Fiber	NA	Diameter µm	Lambda nm	V
Silica	0.1	4	1,064	1.18
	0.1	4	532	2.36

Table B1 Fibre parameters as per given by Newport.

Also given in table B1 is the V number of the fibre at 1064 nm and 532 nm pump. The V can be calculated from the fibre parameters, the V number is given [26], in equation B1.

$$V = \frac{2\pi}{\lambda} a\,(NA) \qquad (B1)$$

Where a - fibre core radius.

NA - fibre numerical aperture.

λ - operating wavelength.

From equation B1, we see that the V number combines two very important parameters of a fibre, namely the core radius and the NA of the fibre. The operating wavelength also needs to be taken into consideration, hence the V number would vary from different operating wavelengths. Another interesting point that can be noted is the cut-off V value, V_c which had been determined to be 2.405 by Gloge D.1971, [12]. For fibres with V smaller than that of V_c, only LP_{01} modes would be transmitted through this fibres, hence by calculating the V number of a fibre, we can determine whether the fibre is single mode or multi mode. From table B1, we find that the V number for the Newport fibre used in this Raman amplifier is single mode when operated at 1064 nm and just about single mode when operated at frequency doubled 532 nm.

Appendix C.

C.1 Publications in local and foreign journals.

C1	Authors :	F.J.Perera and H.B.Ahmad.
	Journal :	Jurnal Fizik Malaysia. (accepted).
	Title :	Raman Scattering in single mode optical fibre.
C2	Authors :	F.J.Perera and H.B.Ahmad.
	Journal :	Jurnal Fizik Malaysia. (submitted).
	Title :	Forward Raman fibre amplifier.
C3	Authors :	F.J.Perera and H.B.Ahmad.
	Journal :	Jurnal Fizik Malaysia. (submitted).
	Title :	Backward Raman fibre amplifier.
C4	Authors :	F.J.Perera and H.B.Ahmad.
	Journal :	Jurnal Fizik Malaysia. (submitted).
	Title :	Comparative study on forward and backward Raman fibre amplifier.
C5	Authors :	F.J.Perera, H.B.Ahmad and S. Radhakrishna.
	Journal :	Journal of Material Science, UK. (accepted).
	Title :	Stimulated Raman scattering in pure and doped silica fibre.
C6	Authors :	F.J.Perera and H.B.Ahmad.
	Journal :	Optics and Laser Technology, UK. (submitted).
	Title :	Raman amplification in few mode optical fibre.