DPSS Laser Beam Quality Optimization through Pump Current Tuning

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ABSTRACT

The goal of this study is to demonstrate how a DPSS laser beam's quality parameters can be simultaneously optimized through pump current tuning. Two DPSS lasers of the same make and model were used where the laser diode pump current was first varied to ascertain the lowest RMS noise region. The lowest noise was found to be 0.13% in this region and the best M^2 value of 1.0 and highest laser output power were simultaneously attained at the same current point. The laser manufacturer reported a M^2 value of 1.3 and RMS noise value of .14% for these lasers. This study therefore demonstrates that pump current tuning a DPSS laser can simultaneously optimize RMS Noise, Power and M^2 values. Future studies will strive to broaden the scope of the beam quality parameters impacted by current tuning.

Keywords: Current Tuning, M^2, RMS Noise, Power, Simultaneous Optimization

1. INTRODUCTION

An ideal laser beam has perfect beam qualities and in Table 1 we have a list of typical laser beam performance parameters that are generally of interest to laser users for their applications. Performance specifications 1 to 12 concern continuous wave (cw) lasers while 14 to 18 involve pulsed lasers. This list is by no means comprehensive

However, when a laser is in operation not all of the beam performance parameters are able to perform at their best. For example, one laser may have the highest Peak Power and worst Duty Cycle for an application. In another laser, attempts to improve the M^2 value of the beam by introducing apertures in the beam path may result in reduction of the Power. It therefore takes judicious considerations to ensure that laser beam parameters needed for a specific application are all at their best when the laser is in operation. This study strives to demonstrate that Root-mean-square (RMS) Noise, Power and M^2 can be simultaneously optimized in a Diode-pumped Solid State, DPSS, laser through pump current tuning.

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Table 1. Laser Beam Performance Specifications

1. Power	10. Polarization Power Ratio and Extinction Angle
2. Power Stability	11. Peak-to-peak Noise
3. Wavelength	12. RMS Noise
4. Beam	13. Energy per pulse
5. Ellipticity/Roundedness/Circularity	14. Pulse Duration
6. Beam Divergence	15. Duty Cycle
7. M^2	16. Peak Power
8. Gaussian Fit	17. Average Power
9. Beam Pointing Stability	18. Pulse Repetition Rate

2. EXPERIMENTAL SET-UP AND METHODS

In this study, we sequentially used two 532 nm Diode Pumped Solid State (DPSS) G-series lasers manufactured by JDSU. The layout of the laser is shown in figure 1. The lasers use 808 nm laser diodes/diode lasers to end-pump a Neodymium doped Yttrium Vanadate crystal (ND:YVO_4) laser.

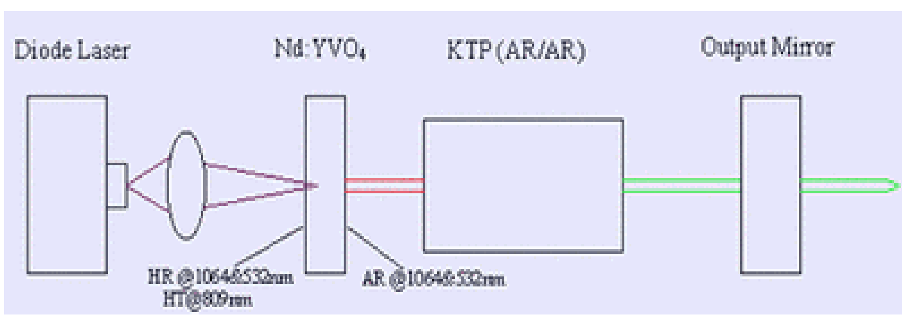

Figure 1. The layout for a continuous wave, cw, DPSS Laser with 532nm output. Image by "Vermin" from cr4.globalspec.com "The Engineer's Place for News and Discussion"

The Nd:YVO_4 crystal emits a polarized NIR laser beam at 1064nm. This beam immediately goes into a Potassium Titanyl Phosphate ($KTiOPO_4$) crystal for a frequency doubling; which converts the 1064 nm beam into a 532nm beam. The pump laser diodes are electrically pumped and we were able vary the pump current using the manufacturers interface software while analyzing the 532 nm output beam.

We measured laser beam RMS voltage data using an oscilloscope, and used two methods to ascertain the RMS Noise. Ideally we would have wanted to use a RMS Voltmeter to collect our noise data but none was available to us at the time of the experiment. Our set-up for RMS Noise data acquisition is shown in figure 2 where we used a UDT photodiode detector to sample the laser beam and a Tektronix TDS 210 Oscilloscope to collect the noise data. The sampled laser beam was also partitioned, as shown figure 3, to an Ophir Nova II Laser Power Meter using a Fused Silica 20/80 beam splitter cube for simultaneous data acquisition. An Ophir thermopile detector was used to intercept the laser beam signal that was routed into the Nova Power Meter.

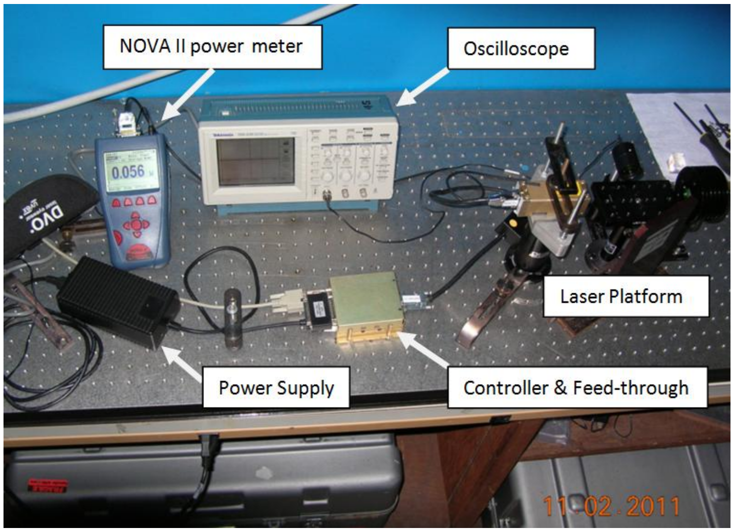

Figure 2. RMS Noise experiment setup.

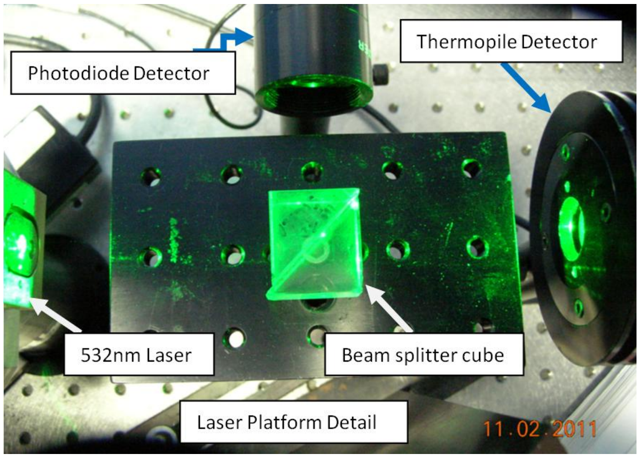

Figure 3. Laser beam partitioning scheme between the Ophir Nova II Laser Power Meter and Tektronix TDS 210 Oscilloscope using Fused Silica 20/80 beam splitting cube

In order to collect M^2 data we removed the beam splitter cube and routed the laser beam through an aperture, off to two beam steering mirrors, then through a focusing lens. The lens focused the beam into a Photon Inc. BeamScan Model 2597 beam profiler Scan Head detector on optical rail as shown in figure 4.

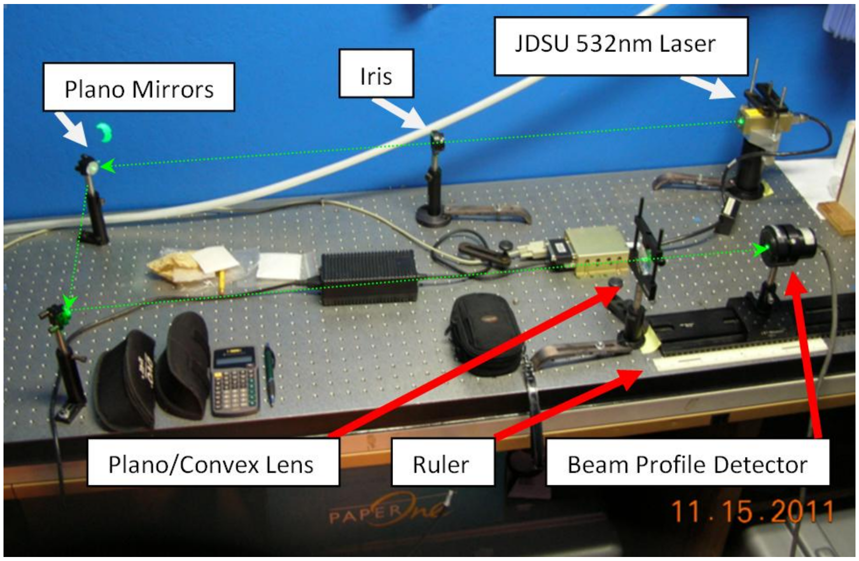

Figure 4. Experiment Setup for Measuring M^2.

The Rayleigh M^2 Method was used in which the beam waist size (D), Rayleigh Range ($2Z_R$) and laser beam wavelength (λ) data are used for the M^2 calculation[2]. We started measurements by first locating the waist of the beam between the lens and the profiler detector and recording its orthogonal diameters D_x and D_y. After that we determined the Rayleigh Range, $2Z_r$ of the beam. M^2 was determined at each current point where both power and RMS noise data were previously determined.

3. DATA, COMPUTATIONS AND RESULTS.

We shall designate the two lasers under study as Laser #1 and Laser #2. In this section we shall show data and associated graphical output for RMS Noise, Power and M^2, as a function of current.

In order to compute the RMS we first acquired the beams Direct Current (V_{DC}) and, the Alternating Current (AC) peak-to-peak voltages, Vpp, of the laser beams. The AC peak-to-peak voltage data was converted to its RMS equivalent value (V_{RMS}), assuming sinusoidal noise only, using this expression

$$V_{RMS} = Vpp \text{ x}.707 \qquad 1.$$

However, we do realize the scope and limitation of this assumption so we proceeded to verify the noise trend by also using the oscilloscope's own internally calculated cyclic RMS voltage to recalculate RMS Noise. In figure 6 we show that the resulting noise trends are qualitatively equivalent. In both cases the RMS Noise was computed as follows

$$\% \text{ RMS Noise}=V_{RMS}/V_{DC}\text{) x } 100 \qquad 2.$$

In Table 2 and 3 we show Laser #1's, and in Tables 4 we Laser # 2's RMS Noise data. The graphical output of Laser# 1 data is shown in 5, 6 and 7, while that of Laser# 2 is shown figures 8 and 9.

Table 2: Laser #1 RMS Noise% data, computation, and results by manual measurement.

DATA								COMPUTATION		RESULTS
	Current (A)	Power (mW)	Laser % Output GUI	AC: Vpp Range-Lo (mV)	AC: Vpp Range-Hi (mV)	AC: Vpp Range Avg (mV)	VDC (mV)	AC: Vp (Vpp/2) (mV)	AC: vRMS (Vp/√2) (mV)	RMS Noise % (vRMS/DC x100)
1	0.40	2	4	1.68	2.00	1.84	344	0.92	0.651	0.19
2	0.45	4	9	1.68	2.00	1.84	364	0.92	0.651	0.18
3	0.50	11	24	1.68	2.00	1.84	384	0.92	0.651	0.17
4	0.55	16	37	1.68	2.00	1.84	400	0.92	0.651	0.16
5	0.60	19	42	1.68	1.92	1.80	392	0.90	0.636	0.16
6	0.65	35	77	1.68	1.92	1.80	408	0.90	0.636	0.16
7	0.70	43	93	1.60	2.08	1.57	408	0.79	0.555	0.14
8	0.75	43	92	1.68	1.92	1.80	408	0.90	0.636	0.16

Table 3. Laser #1 RMS Noise% data, computation and results by oscilloscope RMS Cyc data.

DATA						COMPUTATION	RESULTS
	Current (A)	Cyc RMS Lo Range (uV)	Cyc RMS Hi Range (uV)	Cyc RMS Avg (mV)	VDC (mV) DC	Cyc Vac /Vdc	RMS Noise %
1	0.40	287	380	0.33	344	0.001	0.10
2	0.45	292	354	0.32	364	0.0009	0.09
3	0.50	299	389	0.34	384	0.0009	0.09
4	0.55	295	358	0.33	400	0.0008	0.08
5	0.60	287	356	0.32	392	0.0008	0.08
6	0.65	289	364	0.33	408	0.0008	0.08
7	0.70	294	388	0.34	408	0.0008	0.08
8	0.75	296	388	0.34	408	0.0008	0.08

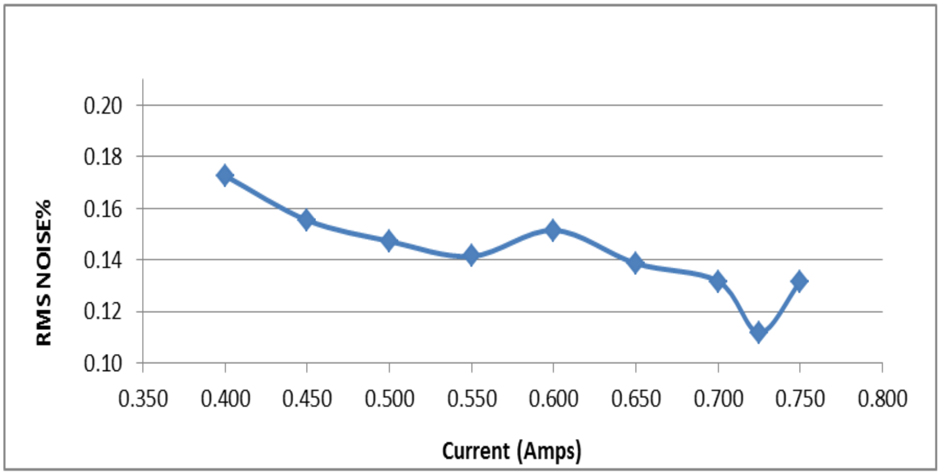

Figure 5. RMS Noise % as functions of current for Laser #1/Table 2.

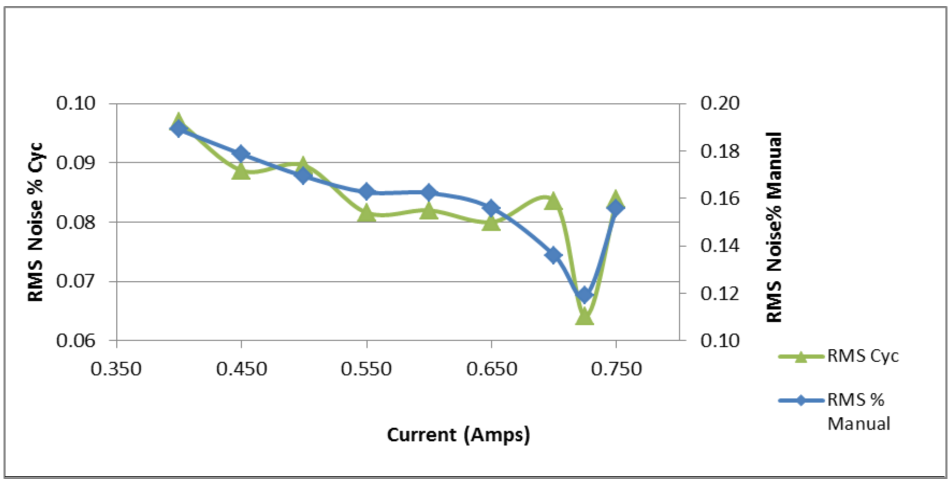

Figure 6. Comparison of RMS Noise % measurement methods.

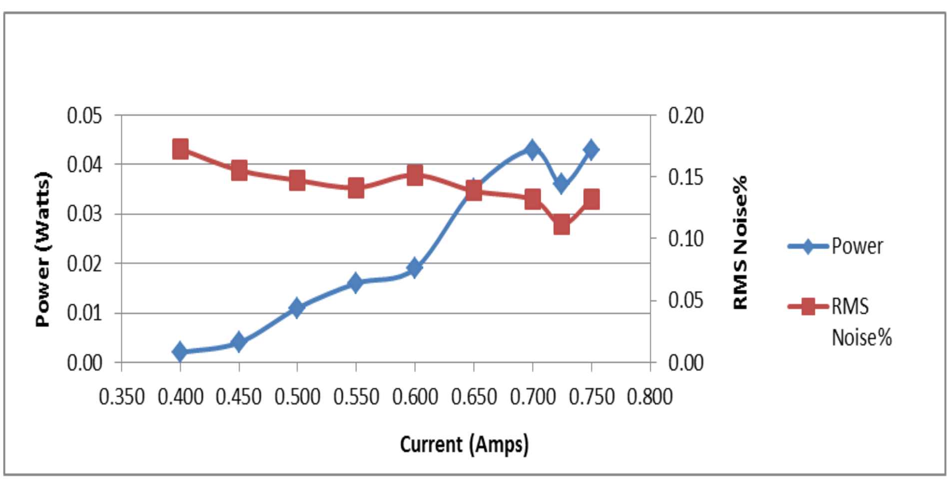

Figure 7. Power and RMS Noise % as functions Laser #1/Table 2.

Table 4. Laser #2 RMS Noise% data, computation, and results by manual measurement.

DATA								**COMPUTATION**		**RESULTS**
	Current (Amps)	Power (mW)	Laser % Output GUI	AC: Vpp Range-Lo (mV)	AC: Vpp Range-Hi (mV)	AC: Vpp Range Avg (mV)	VDC Cursor (mV)	AC: Vp (Vpp/2) (mV)	AC: vRMS (Vp/√2) (mV)	RMS Noise (vRMS/DC x100)
1	0.40	0	2	1.44	1.76	1.60	324	0.80	0.5657	0.17
2	0.45	6	18	1.52	1.68	1.60	384	0.80	0.5657	0.15
3	0.50	8	23	1.52	1.60	1.56	388	0.78	0.5515	0.14
4	0.55	22	58	1.52	1.68	1.60	408	0.80	0.5657	0.14
5	0.60	26	68	1.52	1.68	1.60	408	0.80	0.5657	0.14
6	0.65	27	71	1.52	1.68	1.60	408	0.80	0.5657	0.14
7	0.70	28	74	1.52	1.68	1.60	400	0.80	0.5657	0.14
8	0.75	51	100	1.44	1.68	1.56	416	0.78	0.5515	0.13

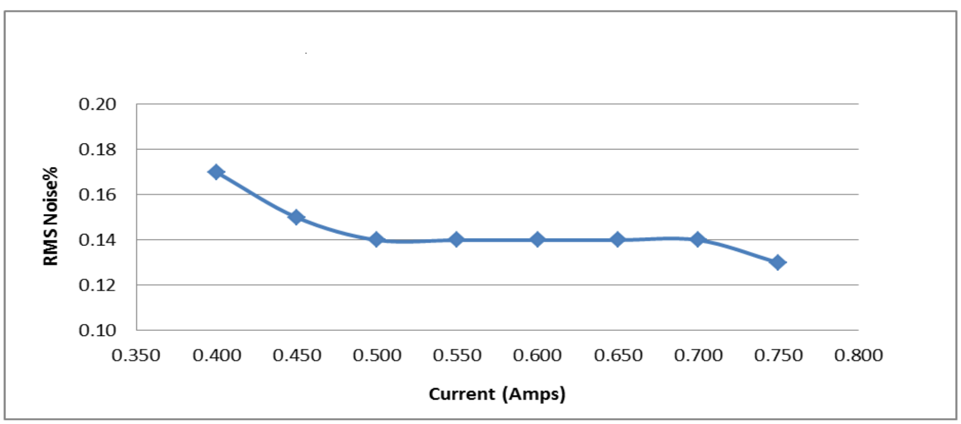

Figure 8. RMS Noise % as functions of current for Laser #2/Table 4.

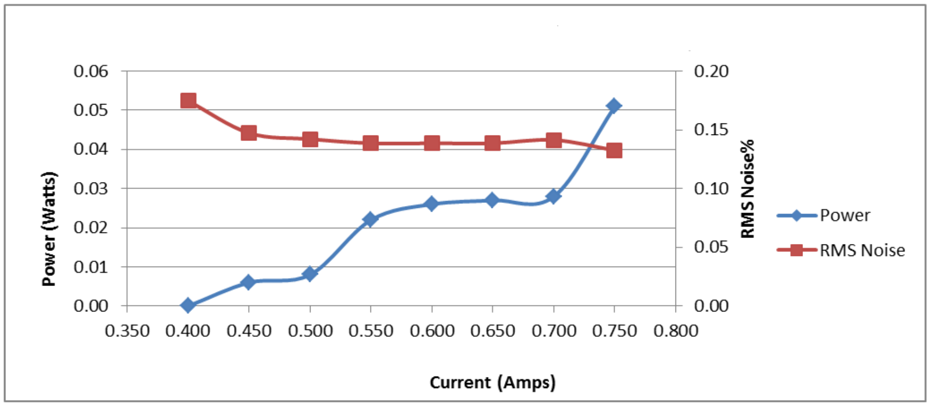

Figure 9. Power and RMS noise% as functions of current for Laser #2/Table 4.

In Table 5 and 6 we show data collected for the computation of the laser beam M^2 values. In this study we chose to calculate M^2_x only.

Table 5. Laser #1 M^2 Data, Computation and Results.

DATA									COMPUTATION	RESULTS
	Current (Amps)	Dx Waist Ø (µm)	Z_R target Ø (D_x* √2) (µm)	Dx Ø at Z_R upstream (µm)	Z_R location upstream fl (cm)	Dx Ø at Z_R downstream (µm)	Z_R location downstream fl (cm)	$2Z_R$ Rayleigh Range (mm)	M^2 values	Normalized M^2 values
1	0.40	52.0	73.54	73.6	21.1	73.4	21.9	8	1.00	1.11
2	0.45	51.2	72.41	72.2	21.1	72.4	21.9	8	0.97	1.08
3	0.50	50.8	71.84	71.9	21.1	71.9	21.9	8	0.95	1.06
4	0.55	50.5	71.42	71.3	21.1	71.4	21.9	8	0.94	1.05
5	0.60	50.0	70.71	70.8	21.1	70.8	21.9	8	0.92	1.03
6	0.65	50.0	70.71	70.5	21.1	70.7	21.9	8	0.92	1.03
7	0.70	49.2	69.58	69.6	21.1	69.4	21.9	8	0.89	1.00
8	0.75	48.6	68.73	68.6	21.2	68.6	21.9	7	1.00	1.26

Table 6. Laser #2 M^2 Data, Computation and Results

DATA									COMPUTATION	RESULTS
	Current (Amps)	Dx Waist Ø (µm)	Z_R target Ø (D_x* √2) (µm)	Dx Ø at Z_R upstream (µm)	Z_R location upstream fl (cm)	Dx Ø at Z_R downstream (µm)	Z_R location downstream fl (cm)	$2Z_R$ Rayleigh Range (mm)	M^2 values	Normalized M^2 values
1	0.40	54.5	77.1	77.0	21.1	77.2	21.9	8	1.10	1.17
2	0.45	53.0	75.0	74.9	21.1	74.9	21.9	8	1.04	1.11
3	0.50	52.8	74.7	74.4	21.1	74.6	21.9	8	1.03	1.10
4	0.55	52.0	73.5	73.6	21.1	73.4	21.9	8	1.00	1.07
5	0.60	51.8	73.3	73.3	21.1	73.0	21.9	8	0.99	1.06
6	0.65	51.6	73.0	72.9	21.1	73.1	21.9	8	0.98	1.05
7	0.70	51.0	72.1	72.1	21.1	72.2	21.9	8	0.96	1.03
8	0.75	50.2	71.0	70.9	21.1	70.8	21.9	8	0.93	1.00

M^2, at each current setting was calculated as follows

$$M^2 = \frac{\pi D^2}{4\lambda z_R} \qquad 3.$$

Where
D is the beam diameter at the its waist
$2Z_R$ is the Rayleigh Range, and
λ is the wavelength of the laser beam

Using this formula with data in Table 6, row 8 we obtained a M^2 value of value of .93 and this was best value. Since M^2 cannot be less than 1 we normalized the .93 to 1 and all our M_x^2 values accordingly. In figures 10 and 11 we show a graph of M^2 as a function of current for the two lasers. In both cases it is apparent that the M^2 values reduce to 1.0 or best value possible around .7 Amps.

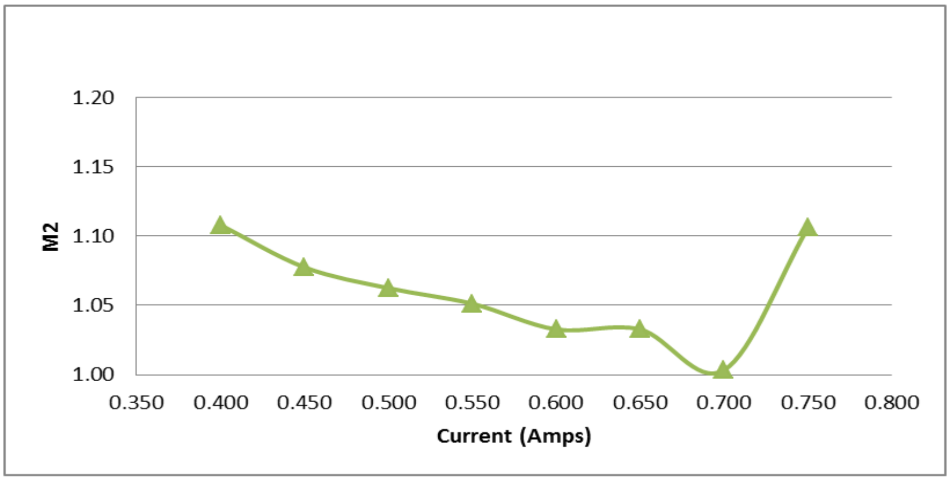

Figure 10. M^2 as function of current for Laser #1/Table 5.

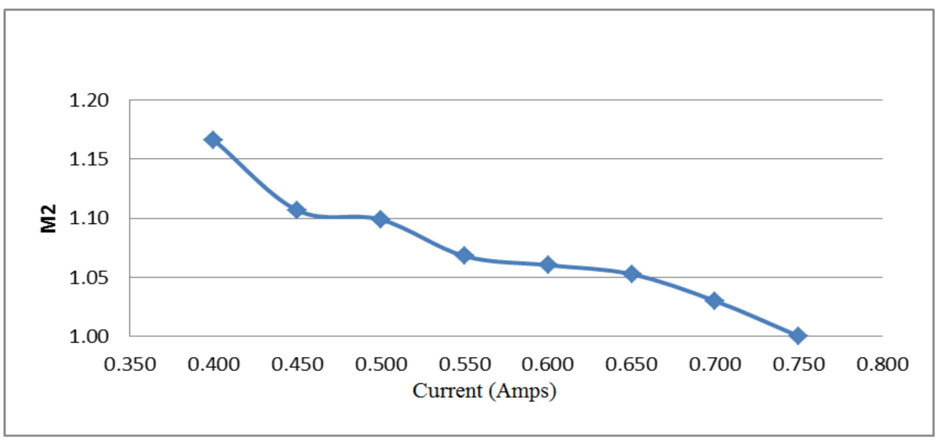

Figure 11. M^2 as function of current for Laser #2/Table 6**.**

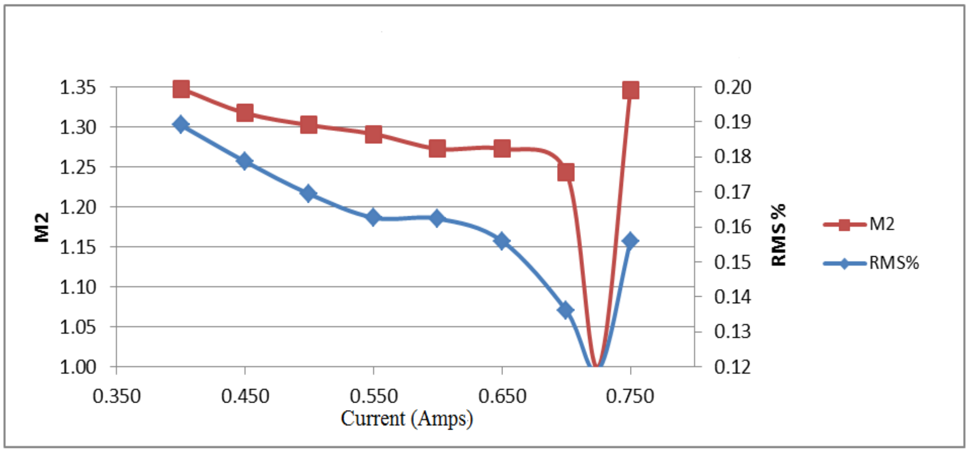

Figure 12. RMS and M^2 as function of current for Laser #1/Table 5.

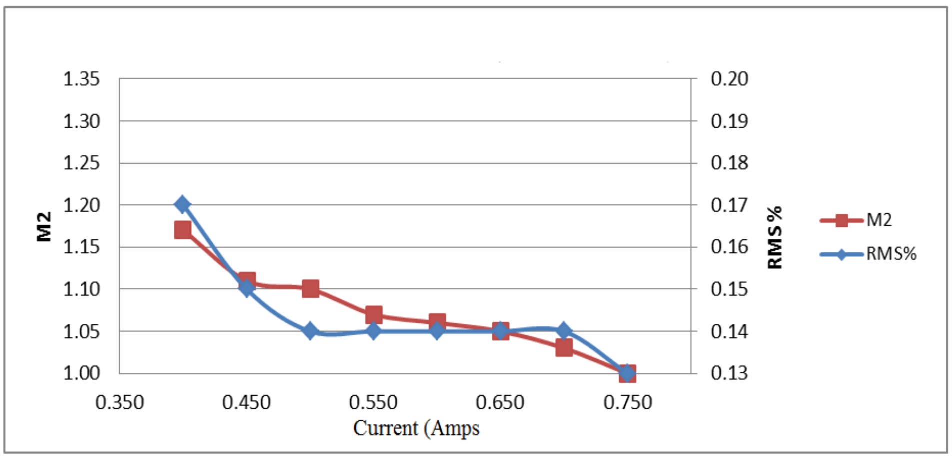

Figure 13. RMS and M^2 as function of current for Laser #2/Table 6.

4. DISCUSSION OF RESULTS

In this study we have shown that a DPSS laser beam's quality parameters can be optimized through pump current tuning. We have specifically shown how this can be done simultaneously for RMS Noise, Power and M^2. In figure 6 we demonstrated that even though we assumed only sinusoidal noise in our manual calculations the noise trend we established is similar to that attained using the oscilloscopes derived cyclical RMS Noise. Our graphical output in figures 5 and 8 clearly demonstrate that a lower RMS value is attainable by tuning the pump current. Moreover, we also show in figure 7 and 9 that the highest laser powers are achieved in this lowest RMS Noise region centered at .7A of pump current for both lasers under study.

Furthermore, we show in figure 10 and 11 that the M^2 value can be improved by simply tuning the current. Incidentally, the lowest M^2 value was achieved at the same current point as was the highest power levels, best M^2 value and lowest RMS Noise as shown in figures 12 and 13. Specifically, we have shown that for Laser#1, the best M^2 value and lowest RMS Noise % occurred at 0.725 Amps, and for Laser #2 the lowest RMS Noise% and M^2 values are in the same 0.7 to 0.75 Amp region. For comparison, in Table 7 below we show the manufacturer's specifications for the make and model of the two lasers used in this study.

Table 7. Laser Performance Specification reproduced from JDSU G-Series User Manual

Laser Parameter	**JDSU**	**SJCC Lab**
Power (mW)	20	50
M^2	<1.3	<1.3
RMS Noise (%)	<0.5 (20Hz - 1Mhz)	0.14

Our worst M^2 value for both lasers are within the manufacturer's specification of less than 1.3; however, by current tuning the lasers, we were able to improve the M^2 value to 1.0. We were also able to improve the RMS Noise % to 0.14 compared to the manufacturer's published value of .5.

There are many areas where the data we collected could have been compromised in this study and we plan to institute some improvements in future studies. First of all, we measured both the laser beam AC peak-to-peak and DC voltage values manually off the oscilloscope in order to calculate the RMS Noise %. Mindful of the possibility of errors, we validated this data by using the oscilloscope's own internally derived RMS Cyclical voltage and the trends established were similar.

Secondly, the Rayleigh Range for the M^2 calculation was measured with the ruler marking on the optical rails that carries the beam profiler scan head. These markings may not afford the best precision, so perhaps that's why some of our M^2 values fell below 1.0. Regardless, this does not change the trend established in this study that the best M^2 value can be achieved through current tuning and can also overlap with the highest power, and lowest RMS Noise of a laser beam.

The application and scope of the techniques examined in this study should go beyond the make and models of two lasers covered. In general, poor RMS Noise values in a laser are generally associated with power supplies so while troubleshooting most people swap them whenever they run into this issue. This study has shown that this poor RMS Noise values can be circumvented simply by current tuning, rather than changing power supplies.

This study has broken the general rule of thumb that the best M^2 value and highest cw powers are mutually exclusive. On one hand optimal laser power is needed for certain applications such as industrial, while on the other hand good M^2 values are also needed for fineness applications. A truly Transverse Electromagnetic $(TEM)_{00}$ should have a M^2 value of unity (M^2=1) and perfect Gaussian spatial profile, and such a laser beam exhibits the best beam qualities such as smallest beam waist/spot size and angle of divergence, and highest brightness compared to higher order modes[1]. However, in order to achieve a beam with a M^2 value close to one, the traditional approach includes insertion of apertures in the beam path to "clip-off" higher order TEM modes. Naturally, aperturing will also result in modest output powers. However, this study has shown that it is possible to have both the best M^2 value and highest power achievable in a DPSS laser if it can be current tuned or optimized. This study therefore opens the door for applications that require both the best M^2 values and high powers to be fully addressed.

This study has illustrated a method to locate a "synergetic pump current point/region" in a DPSS laser where at least some beam performance parameters can be simultaneously optimized. We have also shown that it is possible to have the best M^2 value and power in a laser, and the two do not have to be mutually exclusive. We are optimistic that this approach would be applicable to other laser types.

5. ACKNOWLEDGEMENTS

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