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Tests of Fiber Optic Cables at 300 and 4.2 K

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Abstract

Tests of Fiber Optic Cables at 300 and **4.2** K. Fawn Huisman (Reed College, Portland, OR **97202)** John Weisend (Stanford Linear Accelerator Center, Stanford, **CA** 94305)

Strange “cavity lights” have been observed **in** Superconducting Radio Frequency (SCRF) Cavities. In order to understand this phenomenon **a** spectral analysis of the light is necessary. However, the extreme conditions presented within the cavity require the equipment to function at cryogenic temperatures. Ocean optics P600 UV/VIS fiber optic cables were studied at 300 K and **4.2** K to determine whether **or** not they would be appropriate for cryogenic temperatures. At 300 K the performance of different lengths of cable, the effect of a lens and the effect of a junction were investigated by taking spectra of red, green, and yellow LEDs at a variety of distances from where the source and the cable/spectrometer were aligned. It was found that there was significant attenuation of the **signal** between the spectrometer alone and the spectrometer with any combination of cables. The lens reduced **the** number of locations where **a** readable signal was produced, but the intensity increased greatly when the lens was aligned with the light source. The junction did not seem to make a difference except when there was a large angle between the light source and the cable. At **4.2** K a **4** m cable and a lens were submerged in **liquid** Helium to test their capabilities at cryogenic temperatures. The fiber optic cable was found unsuitable for use as it did not function at **4.2** K, and the signal was essentially lost. However, the lens survived.

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Introduction

Particle physics has advanced greatly since World War II. This would not have been possible without particle accelerators providing the means to perform the high energy collisions that have resulted in the creation of the fundamental particles known today. However, higher energies are needed to continue this tradition, as the formation of the still "missing" particles requires very high energies. This need has lead to the development of a new generation of higher energy accelerators.

These accelerators are being created using a variety of technologies, including Superconducting Radio Frequency (SCRF) Cavities. Radio frequency cavities are microwave resonators that accelerate charged particle beams traversing their electric fields. Since the electric fields are oscillatory, a beam must be in the correct phase to ensure that it is always accelerated (Graber, J. 1993). SCRF cavities are distinctive and appear especially promising for use in the next generation of accelerators because the power losses drop dramatically when the temperature of a cavity is below the critical temperature. This means that there is less power loss during a cavity's operation, reducing power usage and allowing a higher power gradient (Wilson, C 2001). This higher gradient minimizes the length of accelerating sections, which along with the smooth shape and larger beam holes, allows for less disruption to the beam (Graber, J. 1993).

However, these cavities are not without problems, the greatest being the phenomenon known as field emission. Field emission occurs when the voltage reaches a high enough value that electrons are pulled from the cavity. Once emitted, the electrons interfere with the beam's acceleration, and thus lessen the energy of the beam. The electrons can also fall back onto the cavity surface, heating it and thus increasing the resistance (Graber, J. 1993).

Clearly, many aspects of field emission are understood, however, very little is known about what happens inside the cavity when it occurs. J.R. Delayen and J. Mammosser of Thomas Jefferson National Accelerator Facility lowered a CCD camera into a SCRF cavity in an attempt to answer that question. What they found was very unexpected. Glowing ovals of light were observed, mainly at the center of the beam axis (Figure 1). There is no satisfactory explanation for these "cavity lights", although it is believed that they may be due to field emission. Delayen and Mammosser proposed that the cavity lights "are due to charged particles generated by field emission and trapped in the RF fields. The particles could be heated on the cavity surface and projected toward its center where they are trapped by the RF fields. The glow could be due to light emission generated from the interaction with field emission, or by ionization of the residual helium gas" (Delayen and Mammosser, 1999). It should also be noted that in a recent paper by David Fryberger he eliminated most conventional explanations for the lights (Fryberger, 2001).

In order to better understand the cavity lights, it was decided that a spectral analysis of the light was necessary. In January 2002, Mammosser (Jlab), Anthony (SLAC), Fryberger (SLAC) and Weisend (SLAC) tested a plastic fiber optic cable at Jefferson lab, and determined it to be unsuitable. The cable had a strong absorption, and destroyed the signal.

The goal of this project was to ensure that a glass fiber optic cable would perform appropriately while submerged in liquid Helium. The effect that a junction has on fiber optic cables was also investigated, as well as the angle from source to receiver. This was done by performing experiments with the cables at 300 K and 4.2 K.

Materials and Methods

A spectral analysis was taken of red, green and yellow LED's at 300 K and 4.2 K. At 300 K each spectrum was gathered with the spectrometer alone, with a 2 m fiber optic cable, two 2 m fiber optic cables attached together, and a 4 m fiber optic cable. The green LED was also analyzed using the 2 m fiber optic cable with a lens attached at 300 K. At 4.2 K the 4 m cable and the lens were submerged in liquid helium. A spectral analysis was done on the yellow and green LED's with the 4 m cable at 4.2 K. The spectrometer used was an Ocean Optics USB2000 Miniature Fiber Optic Spectrometer. The fiber optic cables were Ocean Optics P600-2-UV/VIS. The two 2 m cables were joined using a small in-line adapter from Ocean Optics. A box was used to shield against background light. The data was collected using a LabVIEW program running on a Windows NT PC.

For the room temperature test the spectrometer and fiber optic cables were mounted on a stand that allowed them to be interchanged. The spectrometer was held in a support at the same height as the LED using plastic screws to hold it in place. The fiber optic cables used the same support, but with a faceplate. The plate had a hole with the same diameter as the tip of the cable drilled through it and aligned with the LED. The LED was placed 17.8 cm from the center of receiver, and fixed to a platform with the capability to move from left to right in the horizontal plane as shown in Figure 2.

Measurements were taken when the LED was aligned with the receiver (which shall be referred to as 0 cm from now on) and at 1.7 cm, 3.4 cm, 7 cm, -1.9 cm, -3.9 cm, and -7.8 cm. Positive measurements indicate that the LED was on the left side of the spectrometer, and negative measurements indicate the LED was on the right. All measurements were made from 0 to the negative side of the LED platform, as outlined in figure 3.

Measurements with the lens could not use the faceplate, so these measurements were done two ways. First the lens was aligned with the hole in the faceplate, so that it would have the same path to the LED, and then taped to the support. This was not stable enough to keep the alignment, so a second run was done, while the cable was hand held. The cable was centered on the LED by lining up the lens with the LED and adjusting the angle until the greatest signal was found. During the hand held test a notebook was used as a light shield, as this method rendered the box unusable.

For the 4.2 K test, a 4 m fiber optic cable and a lens were submerged in liquid helium and used to transmit the light from the LED to the spectrometer. The cable was put into the Dewar, looped at the bottom, tied in that loop with Kevlar and drawn back out where it was attached to the spectrometer (Figure 4). The lens was placed on the end of a 2 m fiber optic cable that was tied with Kevlar and placed in the Dewar. The spectrometer was fixed to the top plate beneath the LED support, which was also attached to the top plate, as shown in Figures 5 and 6. The top of the Dewar was wrapped in black cloth to eliminate background from the overhead lights. A reading was taken after the apparatus was lowered in to the Dewar to use as a control. The liquid Nitrogen jacket was filled, and another reading was taken to see if this had any effect. After the Dewar sat overnight, liquid Helium was pumped in, submerging between 2 and 2.5 m of the cable.

Results

Room Temperature Test (300 K)

Table 1 shows the peak intensity and corresponding wavelength, the half width and the base width of the signal for all the LED's and receivers at 300 K.

Figure 7 shows the intensity versus wavelength of the red LED at 3.4 cm for the 2 m cable, the 4 m cable, the spectrometer, and the 4 m cable with a junction. Figure 8 shows the same at –3.9 cm.

Figure 9 shows the intensity versus wavelength of the green LED at –1.9 cm for the 2 m cable, the 4 m cable, the spectrometer and the 4 m cable with a junction. Figure 10 shows the same at 1.7 cm.

Figure 11 shows the intensity versus wavelength of the green LED at 0 cm for the 2 m cable alone and with the lens attached. Figure 12 shows the same at 1.7 cm.

Figure 13 shows the intensity versus wavelength of the red LED at 0 cm for the spectrometer only. Figure 14 shows the same for the 2 m cable.

Cold Test (4.2 K)

Figure 15 shows the intensity versus wavelength of the yellow LED at 0 cm with 15.3 cm between it and the receiving 4 m cable while the cable is in the Dewar at room temperature and after the Dewar has been filled with liquid Helium.

Figure 16 shows the intensity versus wavelength of the green LED resting on top of the 4 m fiber optic cable with the cable submerged in liquid Helium.

Table 5 shows the peak intensity and corresponding wavelength, the half width and the base width of the signal for the yellow LED at 300 K and 4.2 K with the 4 m cable in the Dewar. Table 6 shows the same for the green LED when it was placed directly on top of the cable.

Discussion and Conclusions

Room Temperature Test (300 K)

A significant attenuation of the intensity signal was recorded for each LED, with the longer cables performing poorer than the spectrometer, as shown in Table 2 (note all percentages were rounded up to the nearest whole number). The green LED had the greatest overall attenuation, with a 27% loss of signal at 0 cm between the intensity high and low, a 69% loss at 1.7 cm, and a 63% loss at –1.9 cm. The yellow LED did slightly better overall with a 29% loss of signal between the intensity high and low at 0 cm, a 40% loss at 1.7 cm, and a 36% loss at –1.9 cm. The red LED had the least attenuation, with a 16% loss of signal between the intensity high and low at 0 cm, a 52% loss at 1.7 cm, and a 34% loss at –1.9 cm.

However, at 3.4 cm and –3.9 cm the longer cables picked up a signal, while the spectrometer and 2 m cable did not (Figures 7 and 8). For each LED at 3.4 cm, the 4 m cable and the 4 m cable with a junction picked up a signal, with the 4 m cable transmitting the greatest intensity, while the spectrometer and 2 m cable transmitted noise. At –3.9 the results were similar for the green and yellow LED, while the red LED's signal was picked up by the 2 m cable as well, however this intensity was the lowest transmitted. It appears that the longer cables, while having lower intensity overall, have a larger range making a longer cable a better choice when alignment is difficult.

Another significant discrepancy regarding intensity appeared at 1.7 cm and –1.9 cm (Figures 9 and 10, and Table 3). At 1.7 cm, for all the LED's, the spectrometer had the signal with the greatest intensity and the 2 m cable had a signal with an intensity that was significantly smaller (note all percentages rounded up to the nearest whole number). For the green LED the intensity of the 2 m cable was 70% smaller than the spectrometer's intensity, for the yellow LED it was 28 % smaller, and for red LED it was 45% smaller. When the LED was moved to –1.9 cm, the above relationship reverses. The 2 m cable has the greatest intensity, with the spectrometer producing a signal with a significantly smaller intensity. For the green LED, the spectrometer is 63% smaller than the 2 m cable, for the yellow LED, the spectrometer is 36% smaller, and for the red LED, the spectrometer is 22% smaller. It is possible this is due to the wavelength of the light, and how it reacts to the diffraction grating with different incidence angles producing variations in the intensity of the spectrum. Also, the LEDs may be brighter on one side.

When the lens was placed on the 2 m cable, the locations off center where a readable signal was produced were reduced, but the signal at 0 cm increased beyond the capabilities of the equipment (Figures 11 and 12). The greatest readable intensity was 4100 counts, and this was passed by the lens at 539 nm and 592 nm, resulting in a 53 nm gap in the data. At 0 cm, the other receivers had a width of 53 nm near their base, with, on average, 83% of the signal (2294 counts) found above that width. In addition, the slope of the signal produced by the lens is steeper than the slope of the other signals in the equivalent location. Thus, it appears likely that the lens has a maximum intensity well above 4100 counts, and would be useful in amplifying the intensity if the lens could be centered on the source. The lack of range may be due to the light needing to hit the lens relatively straight on, making it difficult for a source to register when most of its light is coming in at a significant angle.

The color of the LED did not seem to have a significant effect, however there were discrepancies between colors at 1.7 cm (Table 4). At 0 cm the 2 m cable produced the greatest intensity signal with the green LED, where yellow peaked with the spectrometer and red had a tie between the spectrometer and 2 m cable. However, if one examines the graph of the red LED at 0 cm closely (Figures 13 and 14), it seems that the slope of the signal with the 2 m cable is a bit shallower and will hit 0 before the spectrometer's signal. Therefore green is the only inconsistency, and the difference between the intensity from the 2 m cable and the spectrometer was 70 counts, which is only 2.2 % of the 2 m cable intensity, and 2.3 % of the spectrometer's intensity. This difference is so small, that it still fits the general pattern of the other readings.

At –1.9 cm the only inconsistency found was with the red LED. While the others had the 4 m cable in third and the spectrometer last, the red LED reversed those. The difference between the intensity of the 4 m cable and spectrometer for the red LED is 420 counts, which is 36.6 % of the intensity of the 4 m cable and 30.8% of the spectrometer's signal. At 3.4 cm, all the LED's had the greatest intensity reading with the 4 m cable, followed by the 4 m cable with a junction, and the rest only produced noise. At –3.9 cm it was the same as 3.4 cm, except for the red LED where the 2 m cable registered a small signal. At 1.7 cm the spectrometer alone yielded the largest intensity, however after that the order varied. Therefore, it seems that color makes little difference far from 0 cm and close to 0 cm, but in between it may have an effect. However, it is hard to tell given the small number of readings.

The junction did not seem to have an effect except at 3.4 and –3.9 cm (Figures 7 and 8). The other distances closer to center do not appear to have any noticeable pattern.

However, at 3.4 and –3.9 cm the 4 m cable had a greater intensity than the 4 m cable with a junction for every LED. The average change in intensity was 39 counts, which was 18.4 % of the 4 m cable's average intensity of 209 counts and 20.9 % of the joined cable's average intensity of 184 counts.

While the intensity of the signal varied significantly in a variety of ways, there was no shift in wavelength (Table 1). At 0 cm, 1.7 cm, and –1.9 cm for all the LED's the half-widths were the same for each receiver within 3 counts, and the base width was within 13 counts. At 1.7 cm and –1.9 cm the half width was within 6 counts and the base width was within 20 counts. However, this far from 0 cm the width of the signal line had increased greatly, making it difficult to determine where the end of the signal was. The peaks all occurred within 7 nm of one another for each LED. It is clear that there is no significant signal shift caused by changing receivers.

Conclusions

- At 0 cm, 1.7 cm, and –1.9 cm there was significant attenuation of the signal between receivers, with the longer cables producing a lower intensity signal.
- At 3.4 and –3.9 cm the 2 m and 4 m cables functioned best, picking up a signal when the others were transmitting only noise.
- There was a significant difference in performance of equipment when it was at 1.7 cm and when it was at –1.9 cm. The spectrometer performed best and the 2 m cable worse in the first case and the 2 m cable performed best and the spectrometer worse in the second case.

- The lens reduced the number of the locations off center where a readable signal was produced, but greatly amplified the signal when the lens and source were aligned.
- Color makes little difference far from 0 cm and close to 0 cm, but in between it may have an effect.
- The junction had little noticeable effect, except at the outer limits of 3.4 cm and -3.9 cm where the 4 m cable with the junction performed poorer than the 4 m cable without the junction.
- There was no shift in signal from receiver to receiver, as they all had consistent base and half widths, as well as peak locations.

Cold Test (4.2 K)

The fiber optic cable did not function at 4.2 K, and the signal was essentially lost (Figure 15). No reading was recorded when the yellow LED was 15.3 cm away vertically and at 0 cm horizontally. A signal with an intensity of 878 counts was produced when the green LED was set directly on top of the fiber optic cable (Figure 16). There did not seem to be any shift of the signal, as the signal from the green LED with 4 m cable at 4.2 K occurred from 500 to 647 nm with the peak at 556 nm, and the signal from the test at 300 K was from 509 to 645 nm with a peak at 558 nm (Table 5).

The lens survived and functioned as before after it warmed back up to 300 K.

Conclusions

- The fiber optic cable did not function at 4.2 K and is not suitable for the investigation of the cavity lights.
- The lens survived.

Acknowledgements

I would like to thank my mentor John Weisend for guidance, Perry Anthony for stepping in for John when necessary and for the LabVIEW expertise, Helen Quinn and Sekazi Mtingwa for running this program, the DOE for funding it, David Fryberger for all the help and information, Mike Racine and crew for putting all the things I needed together, and the EFD/CRYO office for making me feel welcome.

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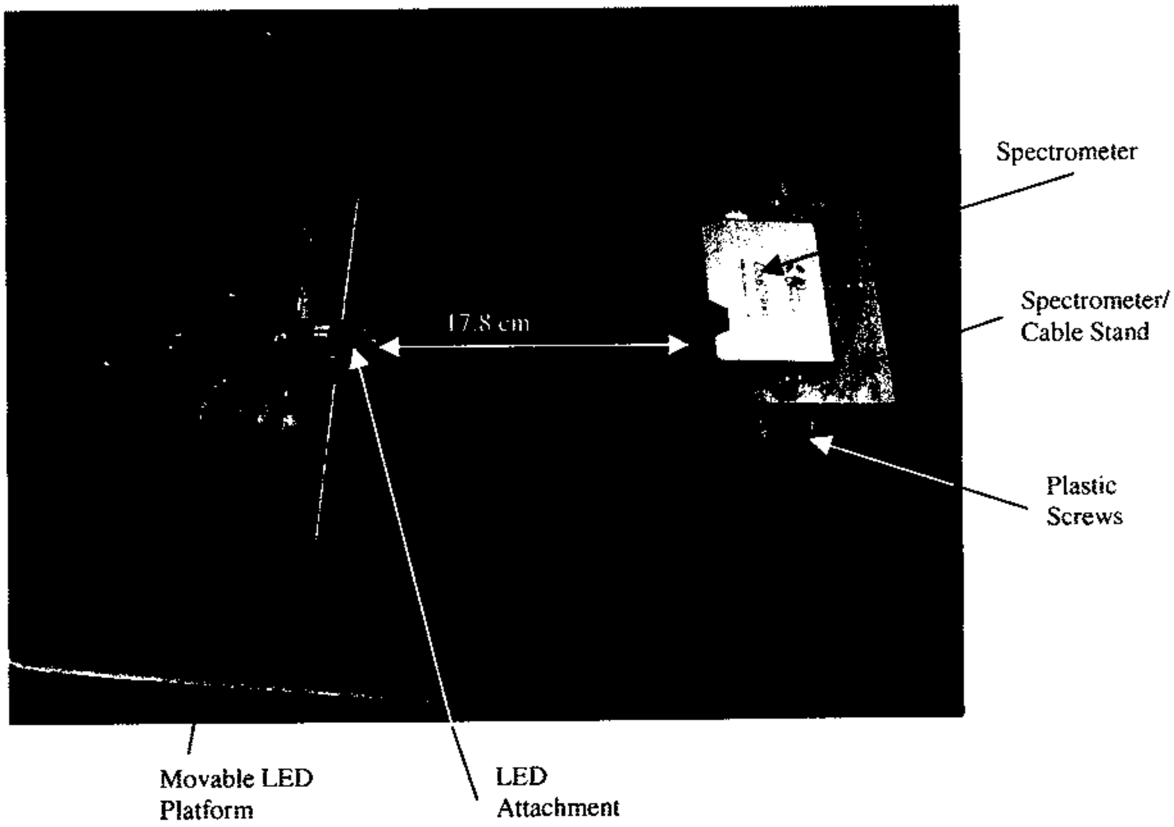
Fryberger, D (2001). "A Small Particle Model as a Possible Explanation of Recently Reported Cavity Lights." Nuclear Instruments and Methods in Physics Research pp 29-43

Graber, J. (1993). Superconducting RF Cavities: A Primer. Retrieved July 6, 2002, from Cornell University, Laboratory of Nuclear Studies (LNS), Superconducting Radio Frequency Group (SRF) Web site: http://www.lns.cornell.edu/public/CESR/SRF/BasicSRF/SRFBas1.html

Wilson, C (2001). "Design of a Superfluid Helium Test Dewar for Testing SQUIDs" Retrieved June 24, 2002, from DOE Office of Science Education Link Web site: http://educationlink.labworks.org/cgi-bin/edulink/pachelbel?ABSTRACTS_PAPERS

Figure 1: Photo of cavity lights, notice the oval in the upper left hand corner
(Courtesy of Delayen, J.R., Mammosser, J., 1999)

Figure 2: 300 K test platform with spectrometer only



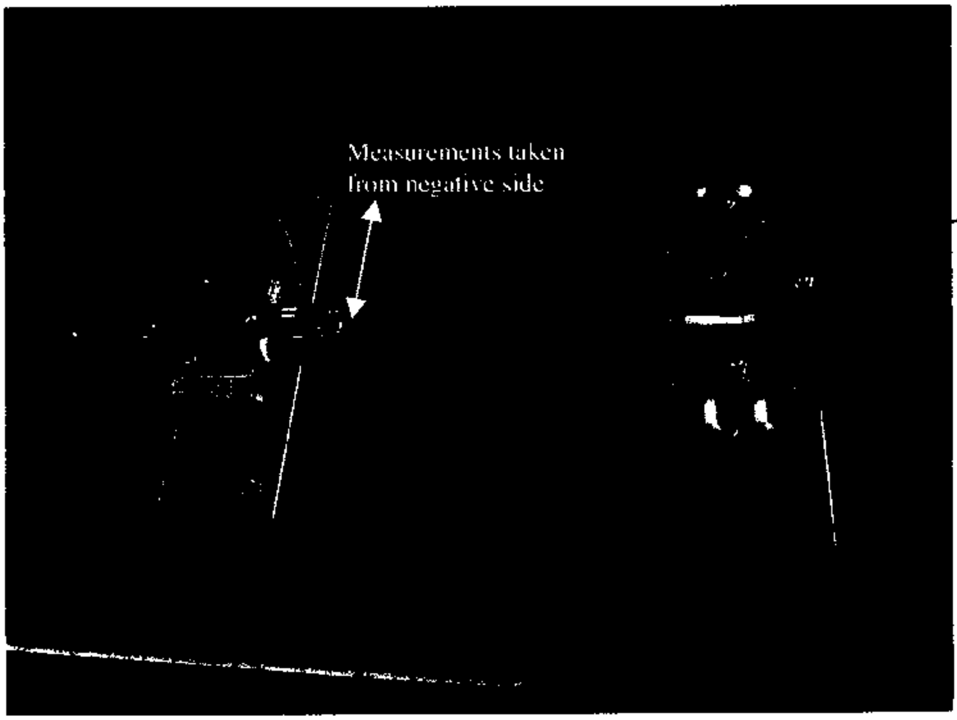


Figure 3: 300 K test platform with fiber optic cable

Face Plate

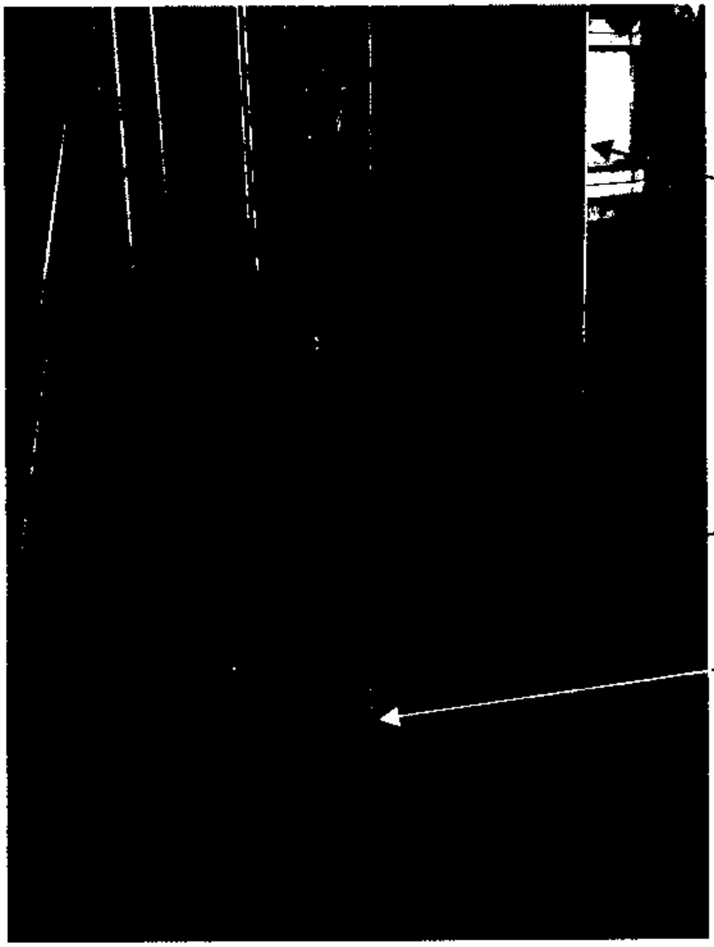


Fig 4: Securing of fiber optic cable for lowering into Dewar

Red White and Blue Dewar

Kevlar String

Lens attached to 2 m cable

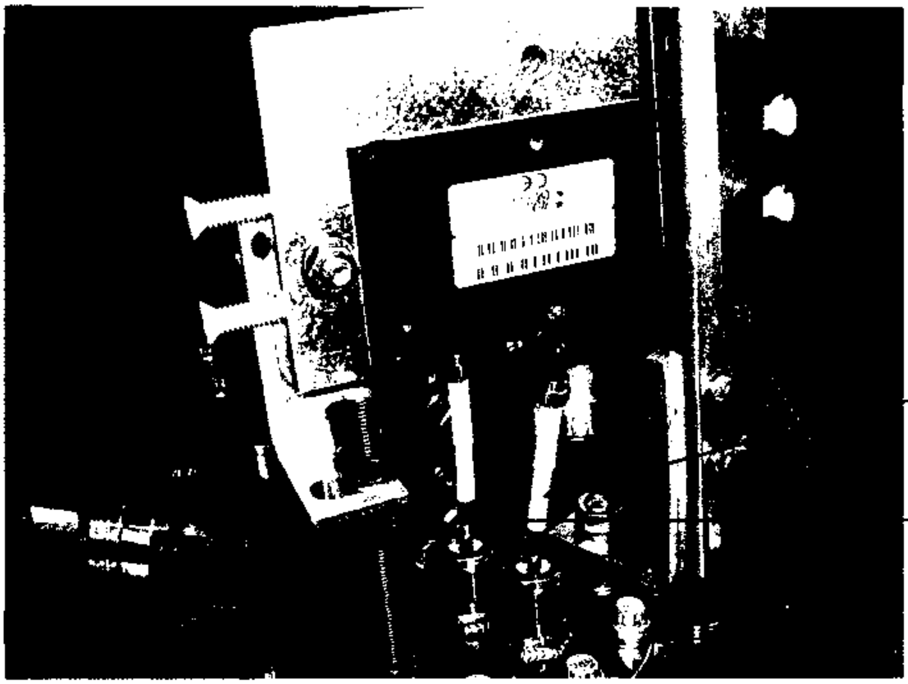


Figure 5: Spectrometer attached to top plate

Entry Point

Exit Point

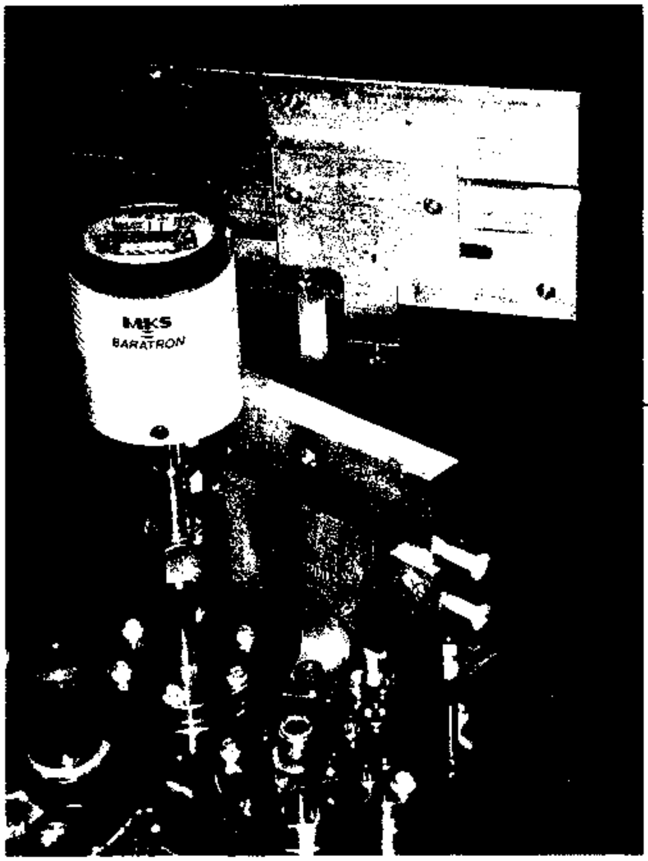


Fig 6: LED holder attached to top plate

LED Attachment

Figure 7: Red LED at 3.4 cm

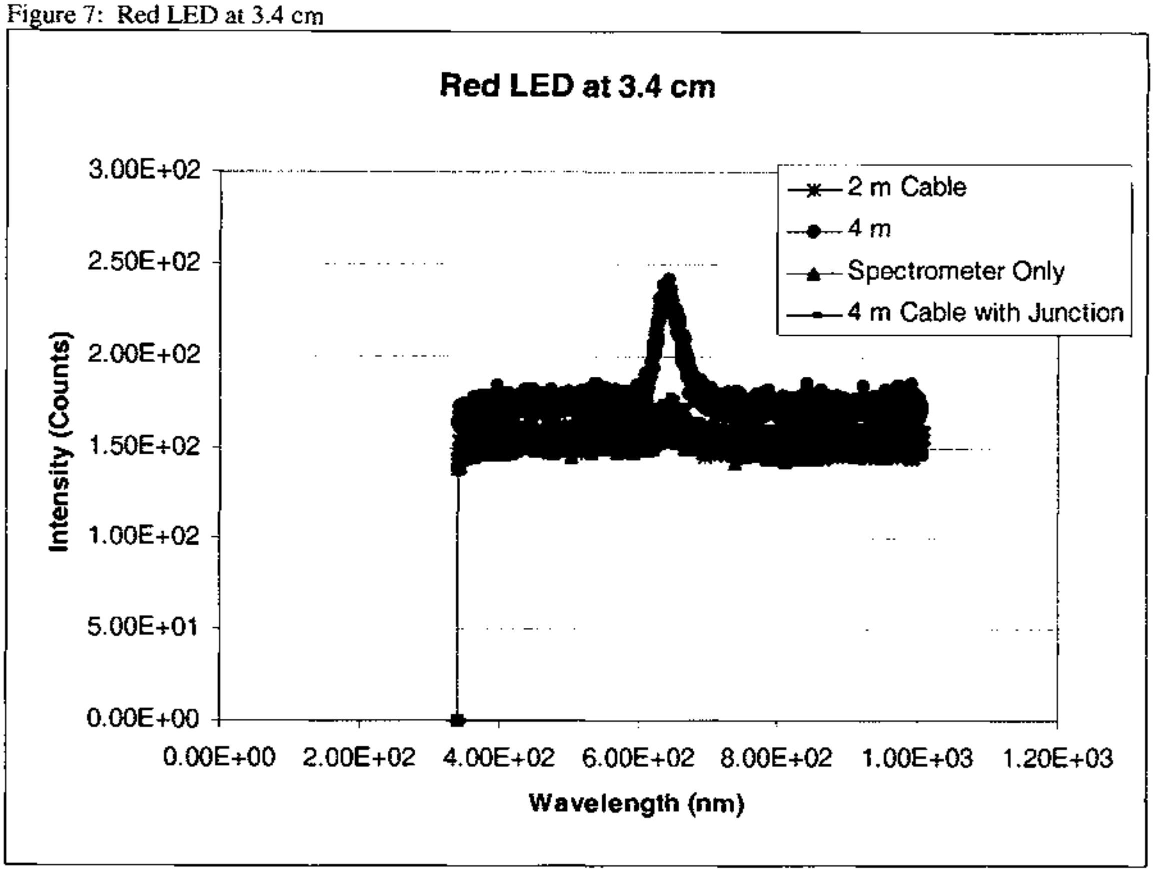


Figure 8: Red LED at –3.9 cm

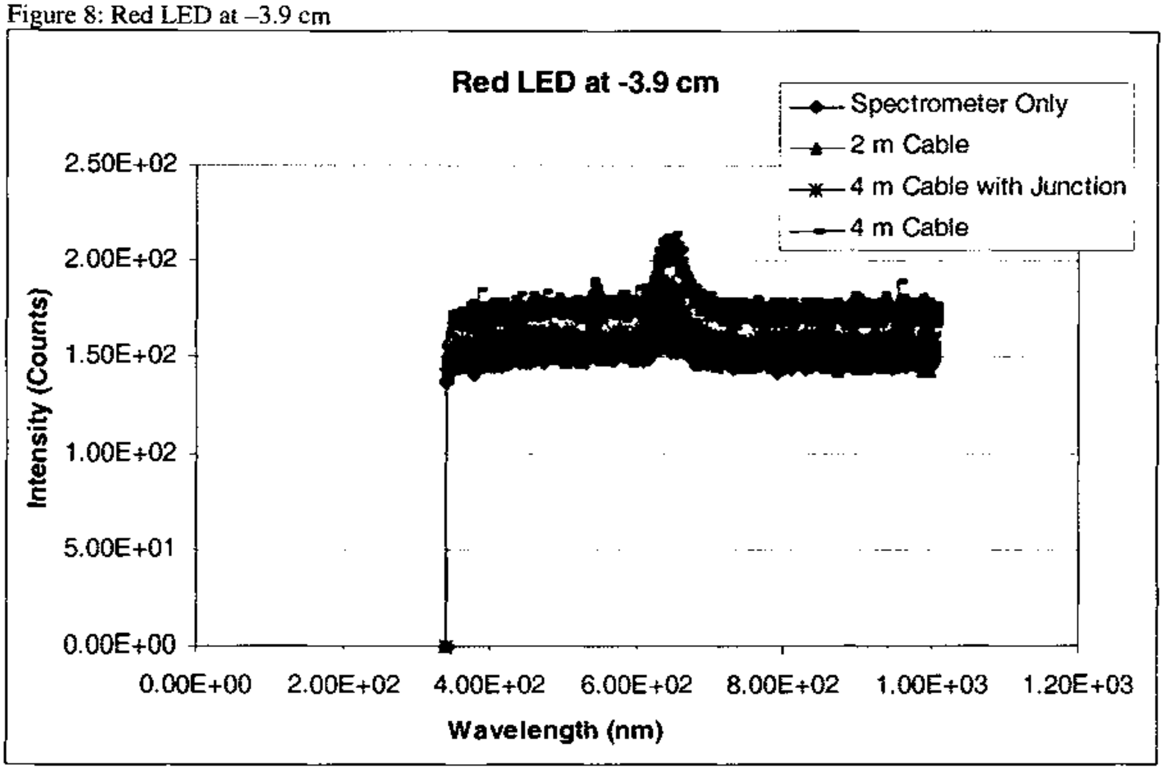


Figure 9: Green LED at -1.9 cm

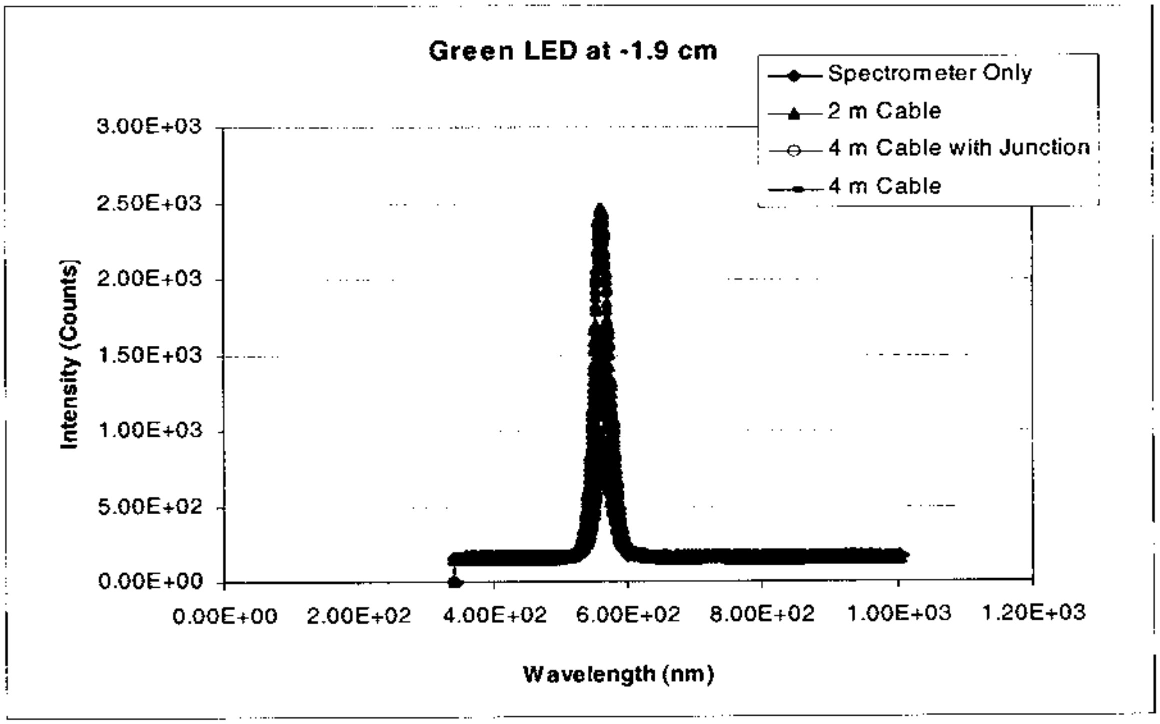


Figure 10: Green LED at 1.7 cm

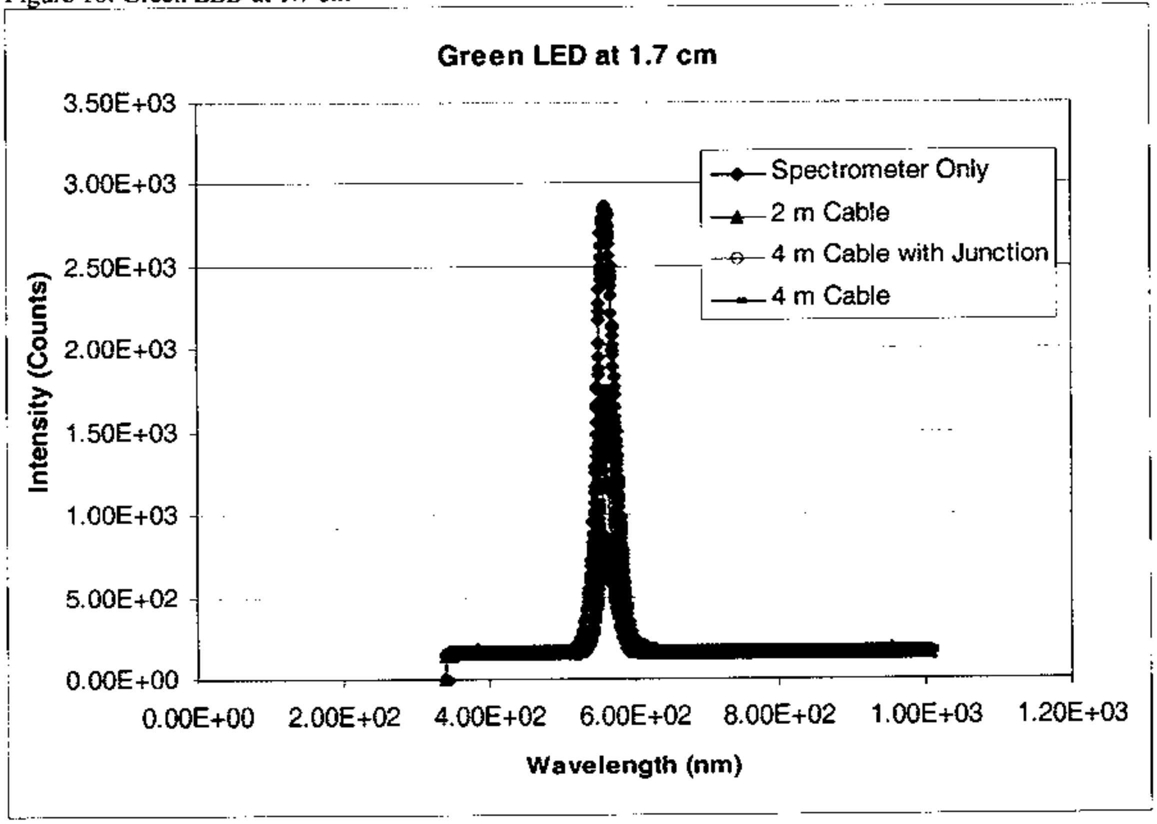


Figure 11: Green LED at 0 cm

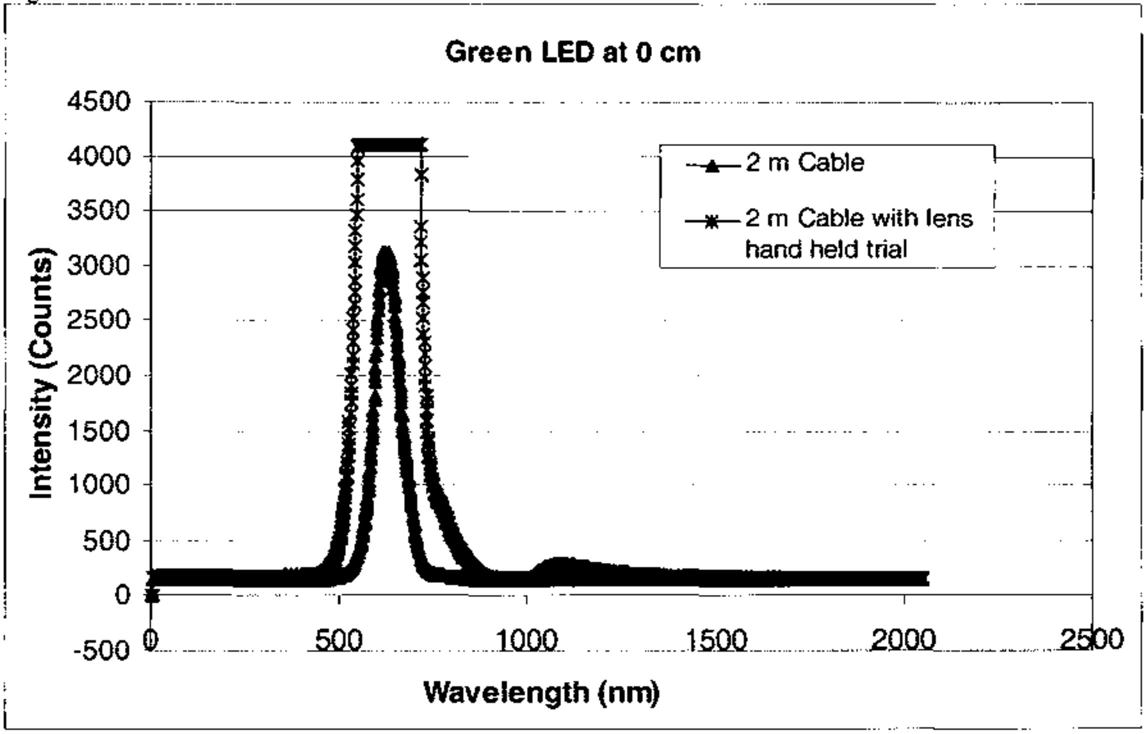


Figure 12: Green LED at 1.7 cm

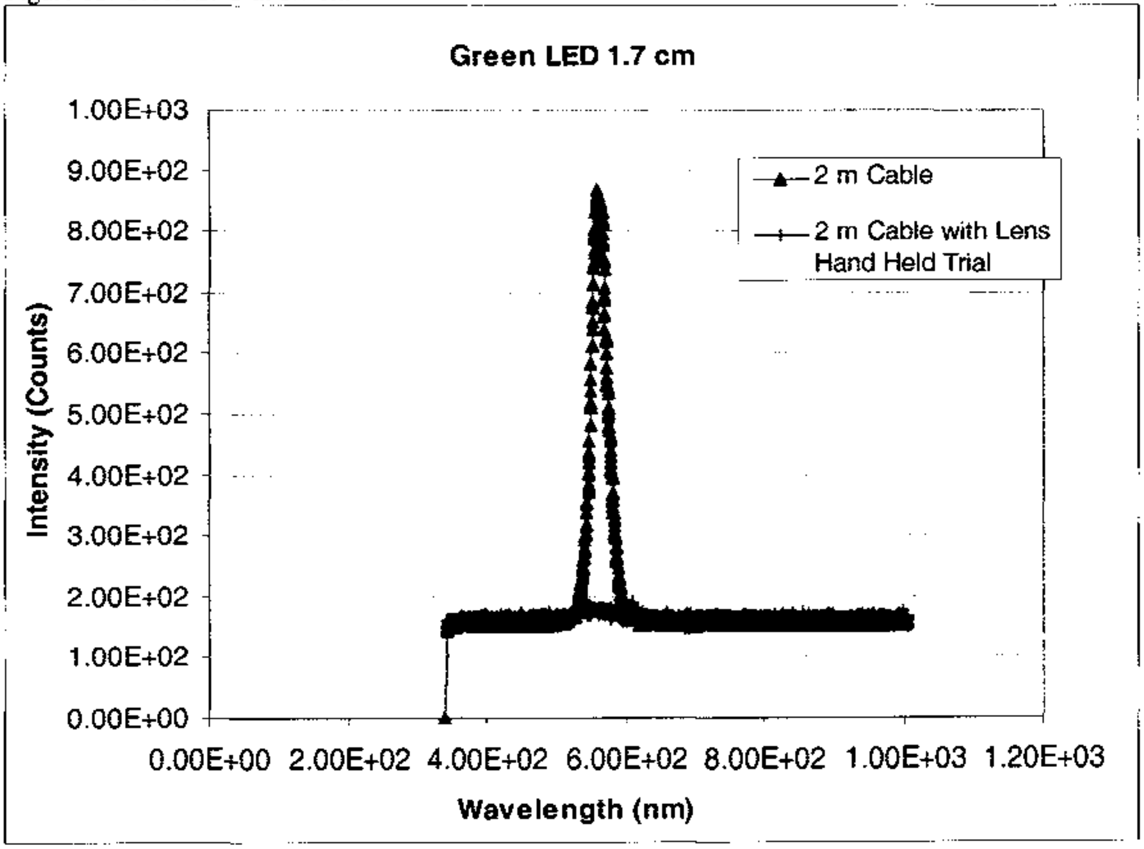


Figure 13: Red LED at 0 cm

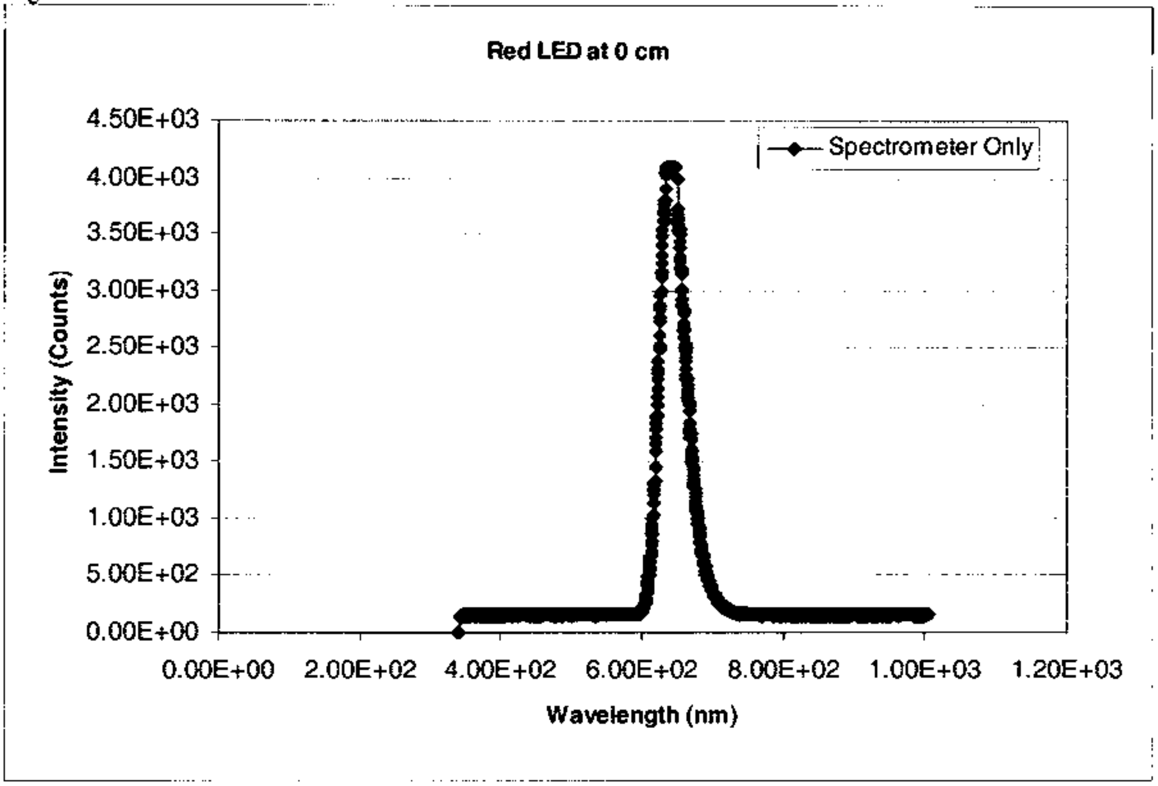


Figure 14: Red LED at 0 cm

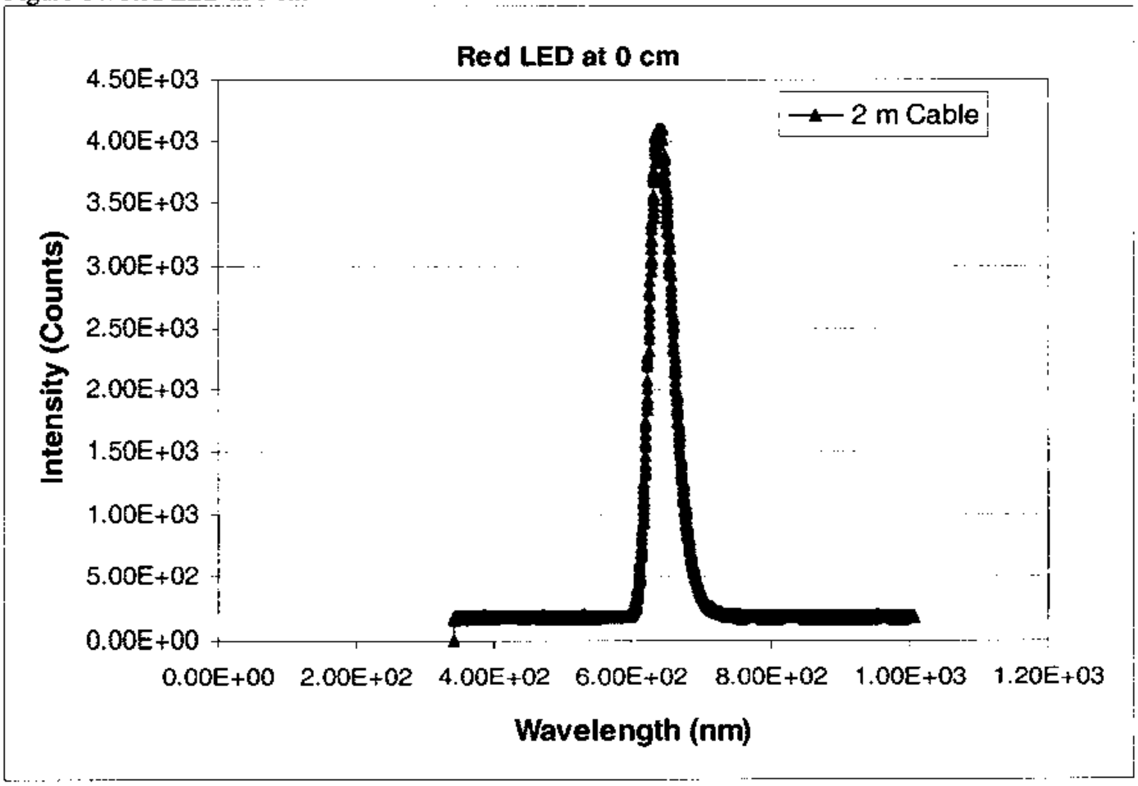


Figure 15: 4.2 K Test Yellow LED

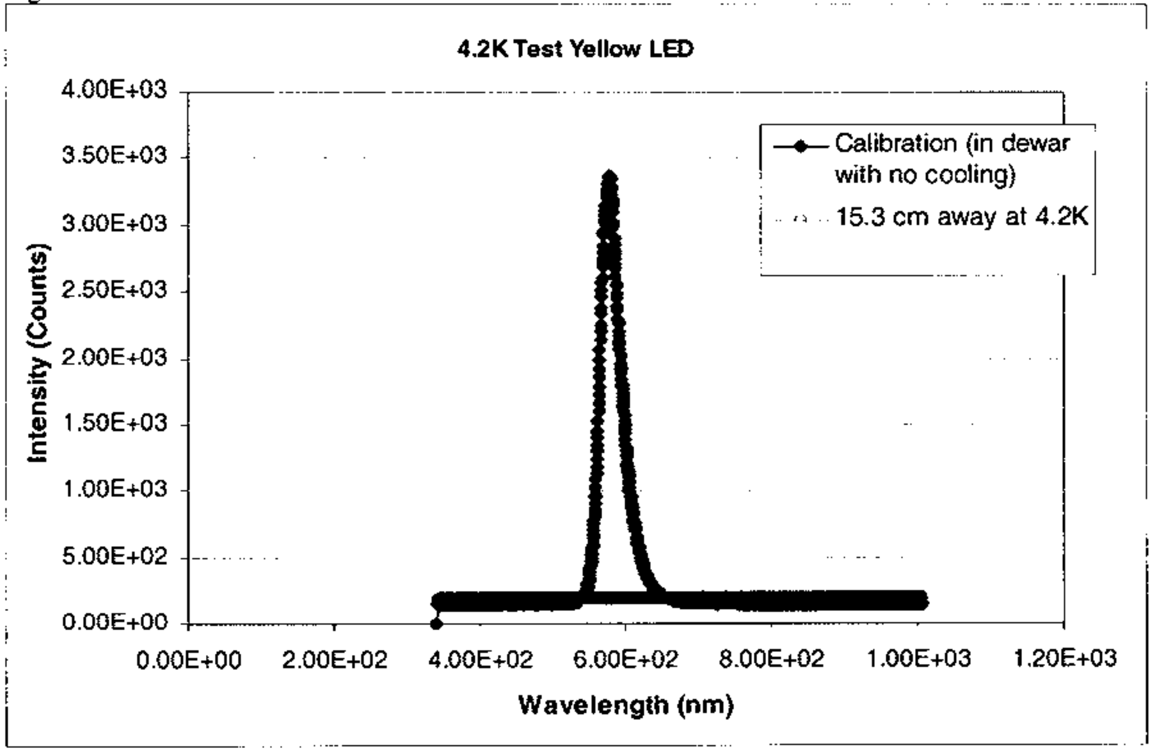


Figure 16: 4.2 K Test Green LED

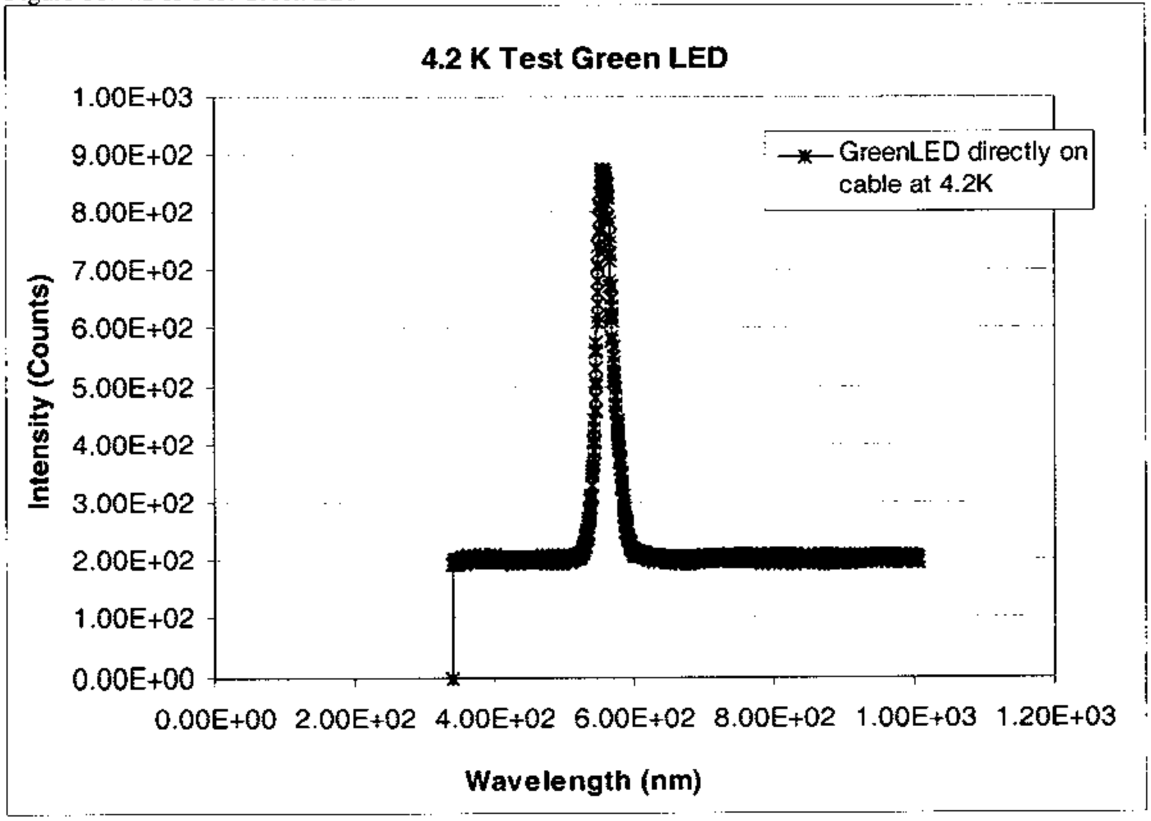


Table 1: Room Temperature Analysis

GREEN	Peak	Peak	1/2 Peak	1/2 Peak	1/2 Peak	1/2 Width	Start	End	Base Width
0 cm	Wave Length (nm)	Intensity (Counts)	Intensity (Counts)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)
Lens	537-592	4100	2050	529	595	66	507	647	140
Lens w/Tape	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
Spectrometer	564	3050	1525	548	576	28	506	646	140
2 m Cable	562	3120	1560	548	576	28	507	641	134
4 m with Junction	559	2270	1135	548	576	28	507	647	140
4 m Cable	563	2480	1240	548	575	27	507	647	140
1.7 cm									
Lens	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
Lens w/Tape	559	2220	1870	550	576	26	511	646	135
Spectrometer	561	2880	1522.5	549	576	27	511	647	136
2 m Cable	559	868	516.5	549	575	26	512	635	123
4 m with Junction	562	1740	952.5	549	575	26	511	643	132
4 m Cable	559	1540	852.5	548	574	26	511	647	136
3.4 cm									
Lens w/Tape	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable with Junction	564	182	168.5	545	598	53	507	593	86
4 m Cable	557	231	201.5	550	576	26	538	598	60
7 cm									
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 m Cable	None	None	None	None	None	None	None	None	None
4 m Cable with Junction	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
-1.9 cm									
Lens	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
Lens w/Tape	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
Spectrometer	562	900	532	551	577	26	514	645	131
2 m Cable	559	2470	1317	549	576	27	511	646	135
4 m with Junction	562	1640	902	549	575	26	511	645	134
4 m Cable	564	1320	742	548	575	27	510	647	137
Lens w/Tape	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise

2 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable with Junction	559	186	172.5	551	584	33	545	591	46
8ftCable	557	203	188.5	555	580	25	542	599	57
-7.8 cm									
Spec	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4ft Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 4ft joined	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
8ftCable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise

Red	Peak	Peak	1/2 Peak	1/2 Peak	1/2 Peak	1/2 Width	Start	End	Base Width
0 cm	Wave length (nm)	Intensity (Counts)	Intensity (Counts)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)
Spectrometer	639-649	4100	2126.5	623	665	42	565	741	176
2 m Cable	640-646	4100	2126.5	622	662	40	564	743	179
4 m Cable with Junction	641	3440	1796.5	624	663	39	564	737	173
4 m Cable	641	3990	2071.5	624	663	39	562	740	178
1.7 cm									
Spectrometer	641	3720	1936.5	624	663	39	564	742	178
2 m Cable	642	2040	1096.5	624	663	39	559	737	178
4 m Cable with Junction	641	1780	966.5	624	663	39	564	741	177
4 m Cable	641	2080	1116.5	624	663	39	562	742	180
3.4 cm									
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable with Junction	647	178	166.5	623	670	47	614	692	78
4 m Cable	643	242	208	626	667	41	613	693	80
7 cm									
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable with Junction	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
-1.9 cm									
Spectrometer	643	2570	1362	626	665	39	565	741	176
2 m Cable	640	3290	1722	624	663	39	564	739	175
4 m Cable with Junction	642	2810	1482	624	664	40	564	741	177
4 m Cable	641	2140	1147	624	663	39	562	742	180
- 3.9 cm									
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2m Cable	648	174	161.5	628	666	38	616	705	89
4 m Cable with Junction	641	190	169.5	624	667	43	603	702	99

4 m Cable	648	214	194	626	663	37	612	691	79
-7.8 cm									
4ft Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 4ft joined	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
8ft cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise

Yellow	Peak	Peak	1/2 Peak	1/2 Peak	1/2 Peak	1/2 Width	Start	End	Base Width
0 cm	Wave length (nm)	Intensity (Counts)	Intensity (Counts)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)	Wave length (nm)
Spectrometer	579	2760	1457	564	595	31	512	695	183
2 m Cable	580	2640	1397	564	596	32	511	694	183
4 m Cable with Junction	578	1960	1057	564	596	32	513	691	178
4 m Cable	578	2240	1197	564	596	32	511	695	184
1.7 cm									
Spectrometer	578	1940	1047	565	596	31	513	693	180
2 m Cable	580	1390	772	565	595	30	512	691	179
4 m Cable with Junction	578	1350	752	564	595	31	513	690	177
4 m Cable	580	1150	652	564	596	32	509	696	187
3.4 cm									
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable with Junction	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable	581	214	193	568	600	32	558	615	57
7 cm									
Spectrometer	579	1080	617	566	597	31	513	695	182
2 m Cable	578	1700	927	564	596	32	514	692	178
4 m Cable with Junction	579	1360	757	564	596	32	514	693	179
4 m Cable	580	1260	707	564	597	33	512	691	179
-1.9 cm									
Spectrometer	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
2 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable with Junction	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
4 m Cable	580	200	185	566	610	44	561	614	53
-3.9 cm									
4 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise
-7.8 cm									
4 m Cable	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise

Table 2: Percent of intensity lost between the highest intensity signal and lowest intensity signal

GREEN	Receiver	Greatest Intensity (Counts)	Receiver	Lowest Intensity (Counts)	Intensity lost (%)
0 cm	2 m cable	3120	4 m with Junction	1135	27
1.7 cm	Spectrometer	2880	2 m cable	868	69
-1.9 cm	2 m cable	2470	Spectrometer	900	63
RED					
0 cm	Spectrometer and 2 m Cable	4100	4 m with Junction	3440	16
1.7 cm	Spectrometer	3720	4 m with Junction	1780	52
-1.9 cm	2 m Cable	3290	4 m Cable	2140	34
Yellow					
0 cm	Spectrometer	2760	4 m with Junction	1960	29
1.7 cm	Spectrometer	1940	4 m Cable	1150	40
-1.9 cm	2 m Cable	1700	Spectrometer	1080	36

Table 3: Difference between the spectrometer and 2 m cable at 1.7 cm and –1.9 cm

GREEN	Spectrometer Intensity (Counts)	2 m cable Intensity (Counts)	%Difference
1.7 cm	2880	868	70
-1.9 cm	900	2470	63
YELLOW			
1.7 cm	1940	772	28
-1.9 cm	1080	1700	36
RED			
1.7 cm	3720	2040	45
-1.9 cm	2570	3290	22

Table 4: Receivers in order of intensity (Highest to Lowest)

0 cm	Highest Intensity	2nd Highest Intensity	3rd Highest Intensity	Lowest Intensity
GREEN	2 m	Spectrometer	4 m	4 m with Junction
RED	Spectrometer/2 m	None	4 m	4 m with Junction
YELLOW	Spectrometer	2 m	4 m	4 m with Junction
1.7 cm				
GREEN	Spectrometer	4m with Junction	4m	2 m
RED	Spectrometer	4 m	2 m	4 m with Junction
YELLOW	Spectrometer	2 m Cable	4m with Junction	4 m
-1.9 cm				
GREEN	2m	4m with Junction	4m	Spectrometer
RED	2m	4m with Junction	Spectrometer	4m
YELLOW	2m	4m with Junction	4m	Spectrometer
3.4 cm				
GREEN	4 m	4m with Junction	Others were noise	Others were noise
YELLOW	4 m	4m with Junction	Others were noise	Others were noise
RED	4 m	4m with Junction	Others were noise	Others were noise
-3.9 cm				
GREEN	4 m	4m with Junction	Others were noise	Others were noise
YELLOW	4 m	4m with Junction	Others were noise	Others were noise
RED	4 m	4m with Junction	2 m	Spectrometer

Table 5: Yellow LED calibration and 4.2 K readings with the 4 m cable in Dewar

Yellow	Peak	Peak	1/2Peak	1/2Peak	1/2Peak	1/2width	Start	End	Base Width
15.3 cm between source and receiver	Wave Length (nm)	Intensity (Counts)	Intensity (Counts)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)
300 K in Dewar	579	3370	1766	564	596	32	518	688	170
4.2 K in Dewar	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise	Noise

Table 6: Green LED directly on top of Cable

Green 4.2 K	Peak	Peak	1/2Peak	1/2Peak	1/2Peak	1/2 Width	Start	End	Base Width
On top Of Cable	Wave Length (nm)	Intensity (Counts)	Intensity (Counts)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)	Wave Length (nm)
	556	878	539	546	571	25	500	647	147