ADVANCED LED CURING SYSTEMS FOR THE OPTICAL FIBER MARKET

CRU World Optical Fiber & Cable Conference, 20 November 2019, D. Leonhardt

MOTIVATION - SAVINGS

Electric Rate ($/kWh)	# TOWERS	# Years
$ 0.10	1	1

System	Power Consumption at 100% (kW)* On each tower
F600 (6 lamps per tower @9.6kW)	57.6
PC6003 (5 lamps per tower @1.5kW)	7.5

*At 480V, 60Hz

$/year for specified # Towers to run 24/7/365	
F600 (6 lamps per tower @9.6kW)	$ 50,458
PC6003 (5 lamps per tower @1.5kW)	$ 6,570

Electrical Cost for Specified # of Towers and Years		
Time (years)	F600 (6 lamps per tower @9.6kW)	PC6003 (5 lamps
0	$ -	$ -
1	$ 50,457.60	$ 6,570.00
SAVINGS		$ 43,887.60
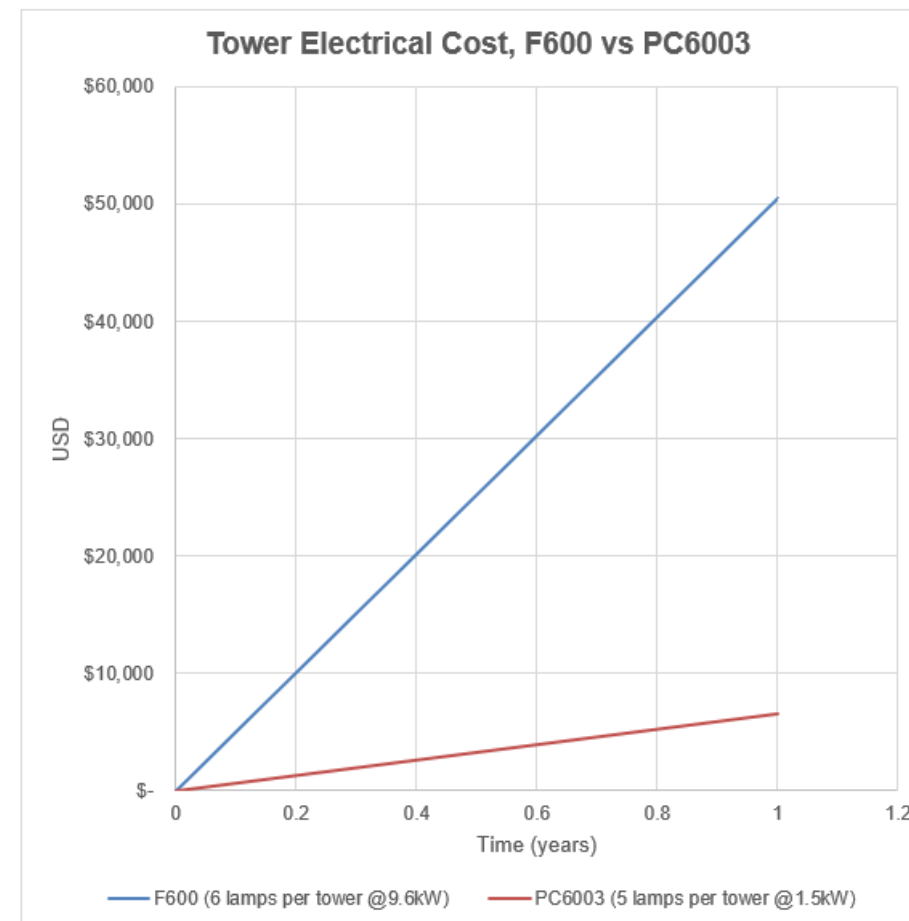
LED technology offers incredible electricity savings! But optical efficiency is just as important for overall efficiency and process performance.

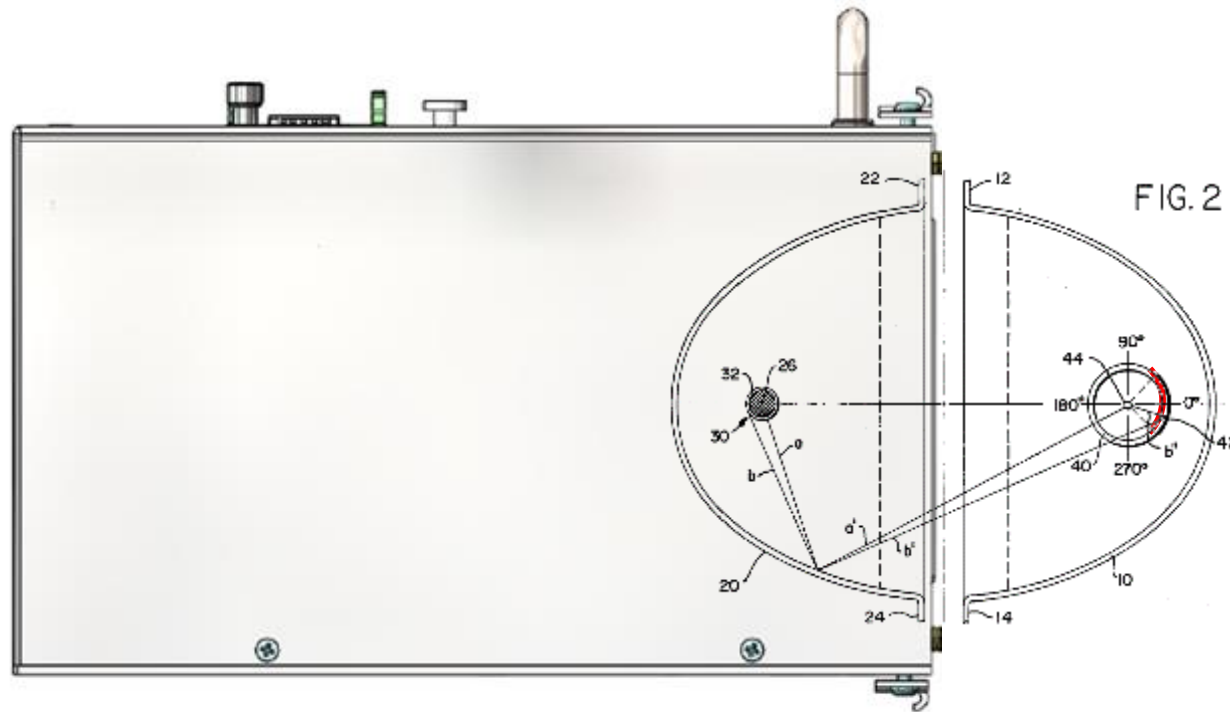Tower Electrical Cost, F600 vs PC6003

HISTORY

- US 4,710,638 (1987) – teaches most (below)
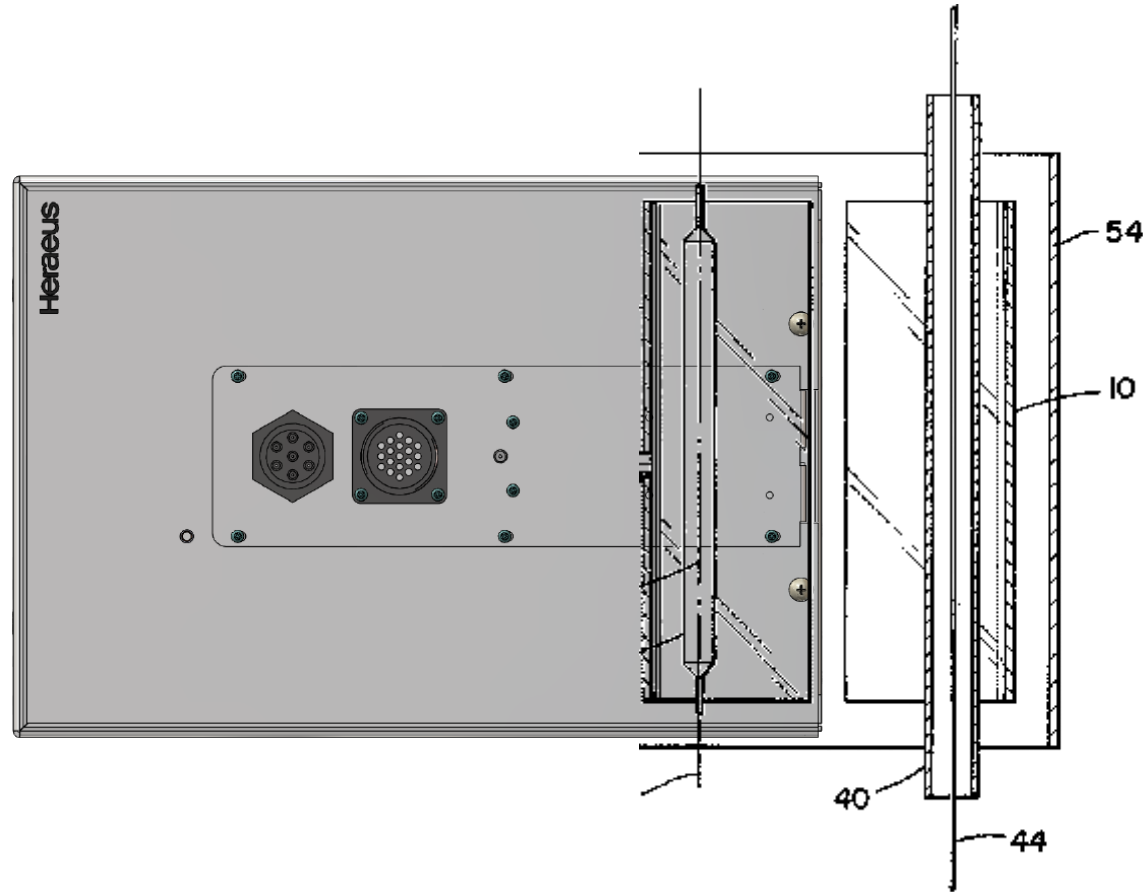
With the target placed in the focal plane of a mercury-based lamp, adding an external light shield was a fairly straightforward adaptation.
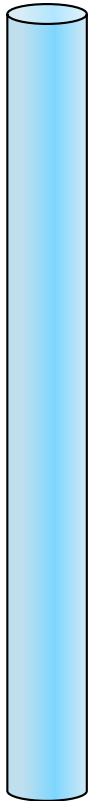
HISTORY

- US 4,710,638 (1987)
- US 6,419,749 B1 (2002)
- US 6,614,028 B1 (2003)
- US 9,132,448 B2 (2015)

FIG. 2

The external light shield completed the ellipse of the original optical design, allowing the UV light emitted from the bulb to be focused in the vicinity of the fiber for curing. While there have been some incremental changes to improve the focus on to the fiber, the design has been relatively unchanged from 1987.
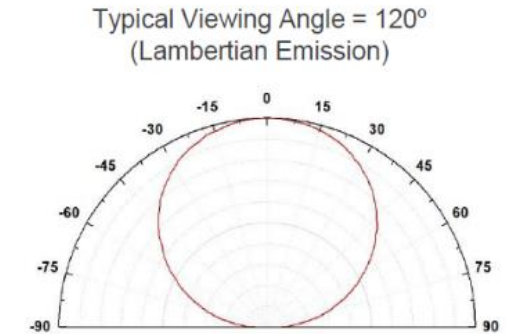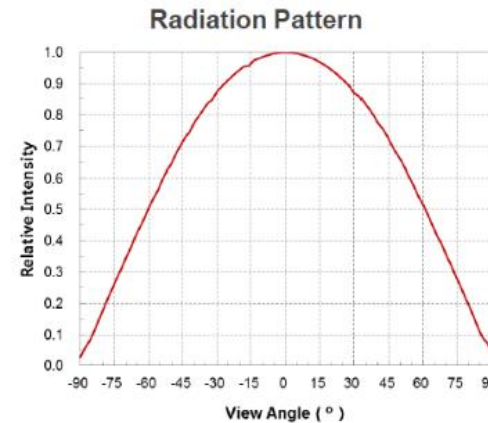
LEDS AS A LIGHT SOURCE

**Lambertian Light Sources (bulbs & LEDs)**

$A_{BULB} \cong 80 \text{ cm}^2$

$A_{LED} \cong 0.01 \text{ cm}^2$

vs

Radiation Pattern

Typical Viewing Angle = 120°
(Lambertian Emission)

Although mercury bulbs and LEDs are both Lambertian light sources, the form factors are wildly different, with LEDs enabling much more customization. Part of the customization should be greater efficiency in UV photon utilization, i.e. **photon management**.

LED OPTICAL SYSTEM DESIGNS -LARGE AREA VS LINE ARRAY

**Large Area Source
(7 X 10 LEDs)**

Line Source

TOP VIEW
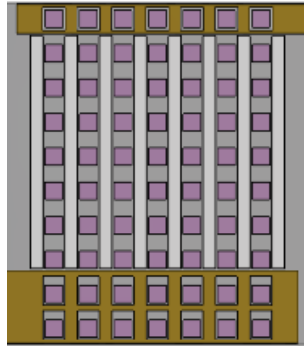
**Collection/
Focusing
Optic**
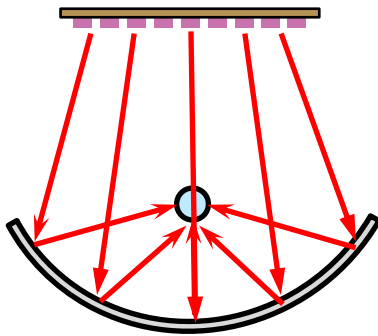
Allows higher optical energy input, but then relies on the back reflector for directing UV rays onto the fiber/curing area.

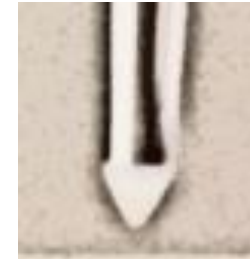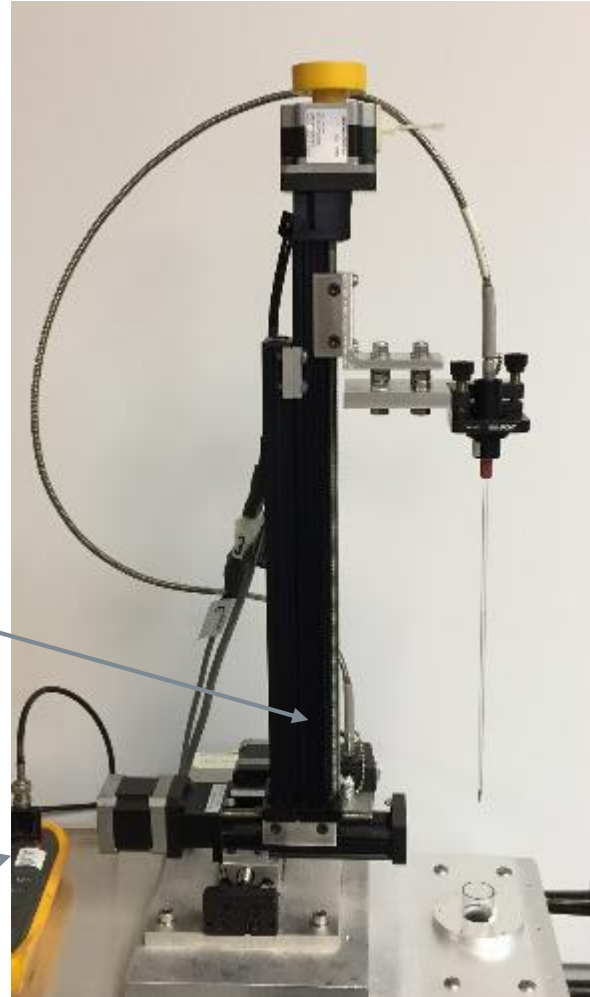Allows using significantly fewer LEDs while greatly increasing the peak intensity incident on the fiber.

METROLOGY – IRRADIANCE MAPPING WITHIN CURING TUBE

Intensity Measurements within Curing Tube

› "Probe" – collects diffuse radiation from all angles

› Detector

› Data Acquisition

› 3D Motion Stage

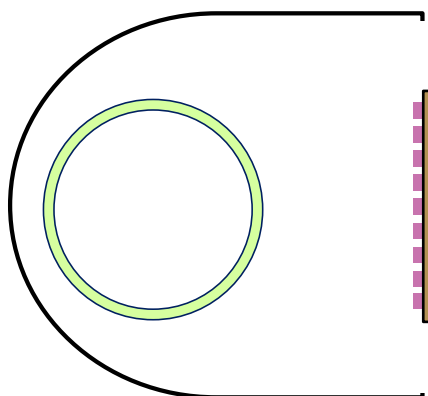3D Motion Stage

Data Acquisition

Probe

Enabled us to validate and compare relative intensities of various optical designs.
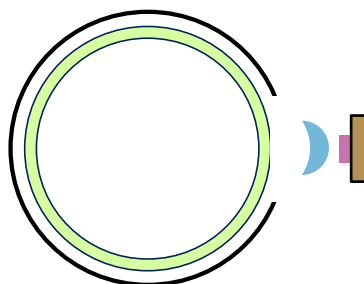
LED LAMP IRRADIANCE MEASUREMENT

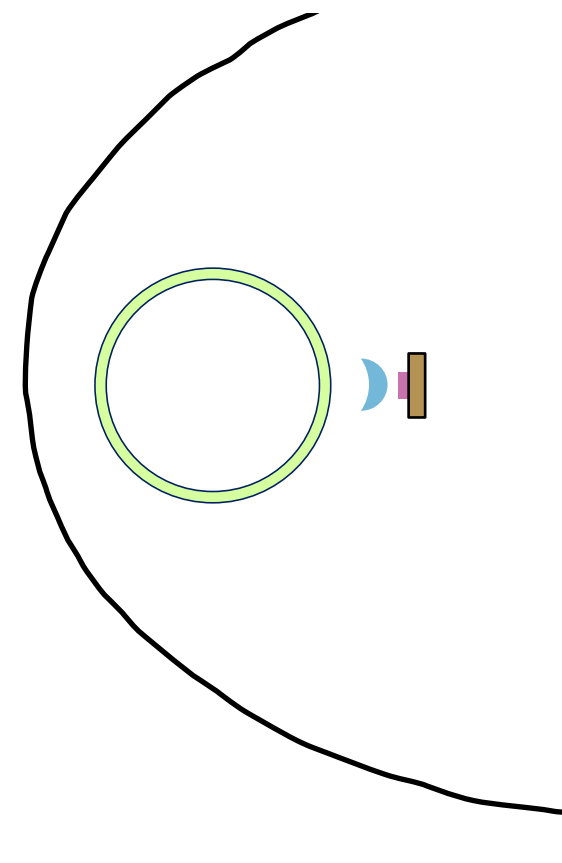**Measurements of 3 basic LED Systems with vendor-supplied reflector**

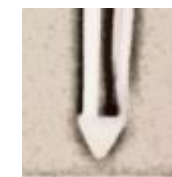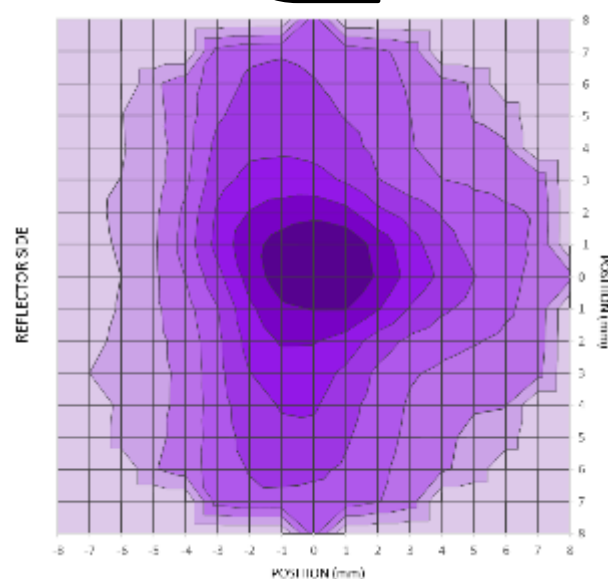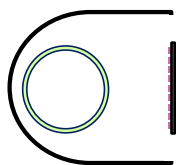PLANAR LED SYSTEM   LINEAR LED SYSTEM 1   LINEAR LED SYSTEM 2
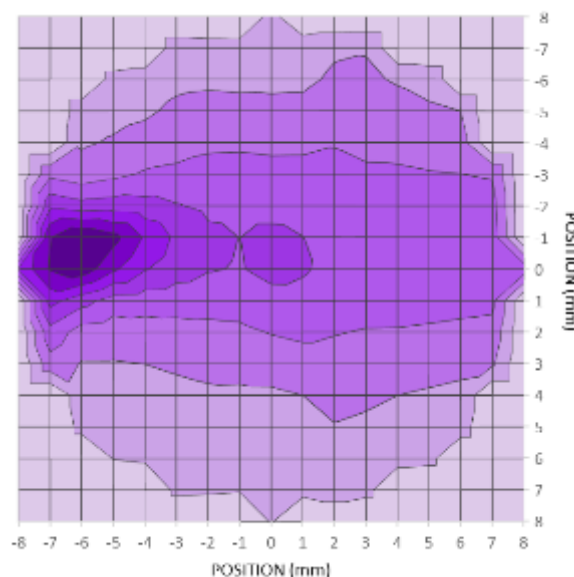
LED LAMP IRRADIANCE MEASUREMENT

Irradiance mapping showing normalized irradiance contours in the curing tube. Planar appears best, liner 2 worst. However, relative intensities show **average irradiance in the center of linear 2 is 3X higher than the planar!**
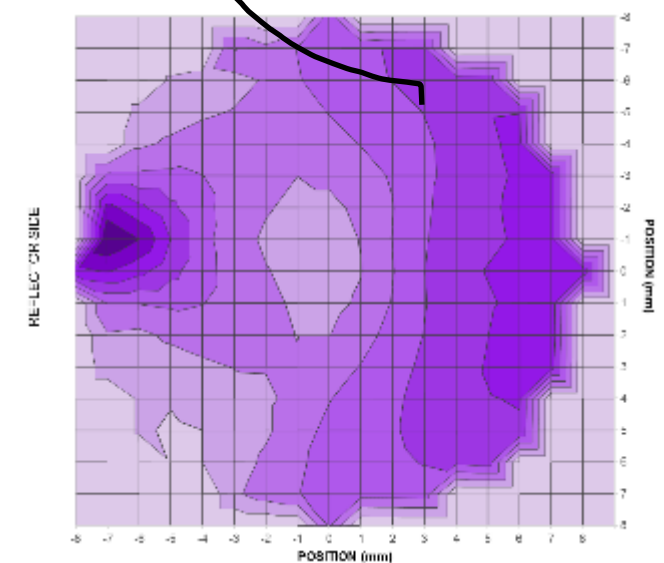
PLANAR LED SYSTEM

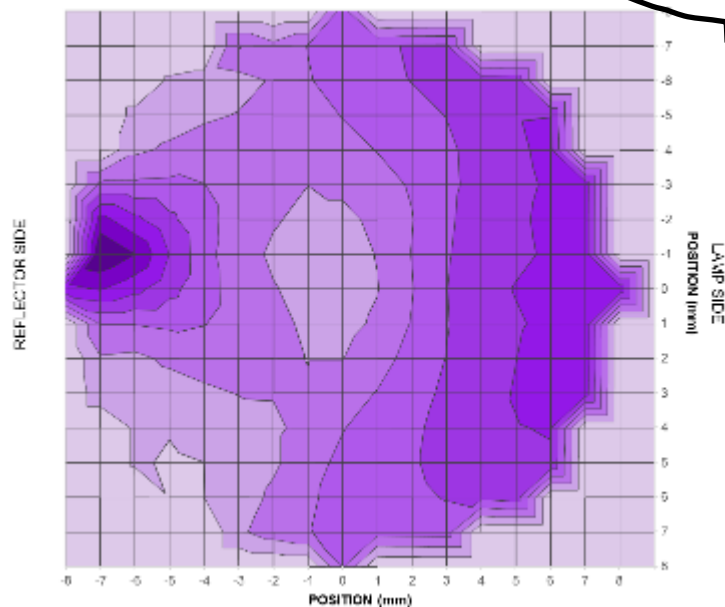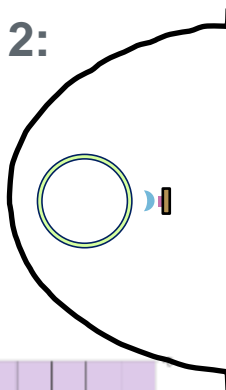LINEAR LED SYSTEM 1

LINEAR LED SYSTEM 2
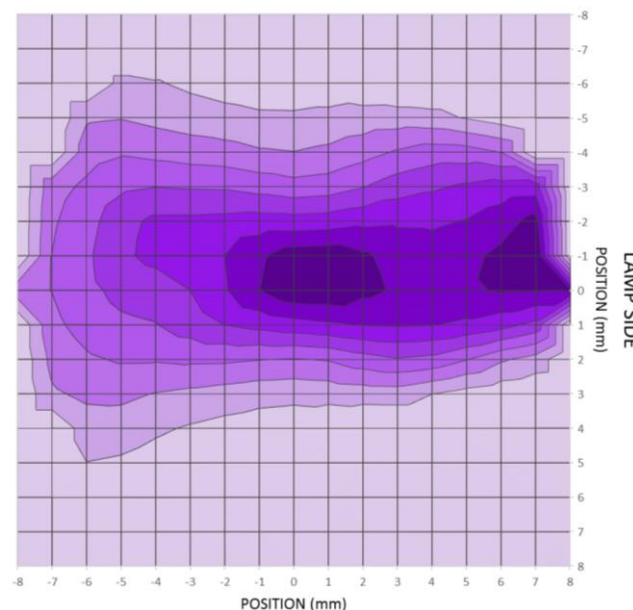
LED LAMP IRRADIANCE MEASUREMENT & CORRECTION

**LINEAR LED SYSTEM 2:**

STANDARD METAL-HALIDE
LAMP REFLECTOR

OPTIMIZED
REFLECTOR

By redesigning the back reflector of linear system 2 to optimize the central irradiance value, we can much more efficiently use the photons. With the optimized back reflector (right), the peak intensity is on center, **roughly 5X the intensity of the well targeted planar system** on the previous slide.

# LED LAMP IRRADIANCE MEASUREMENT & DESIGN OPTIMIZATION

Measurements of fully optimized LED System (primary optic as well as back reflector)
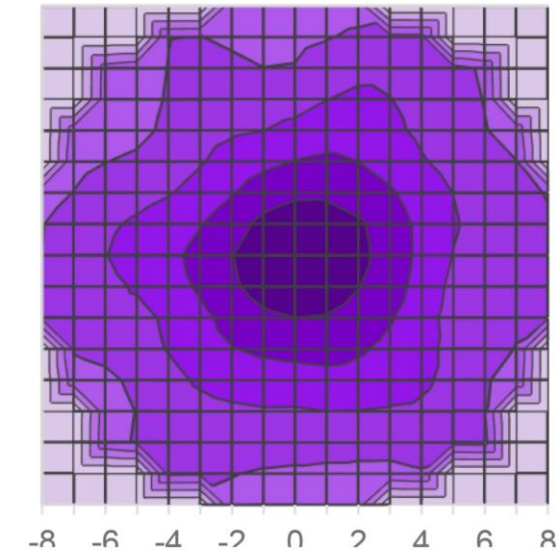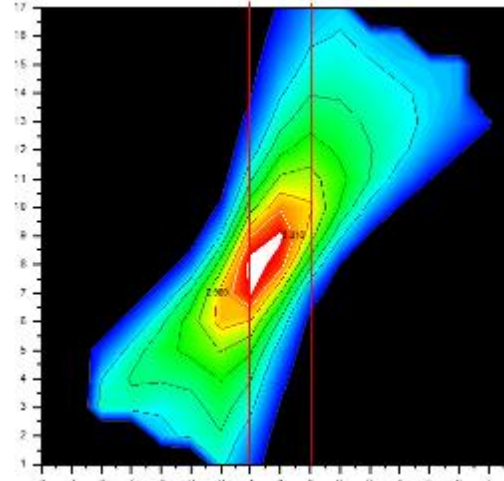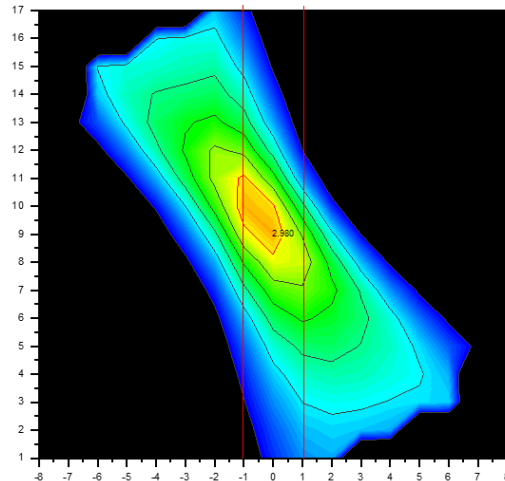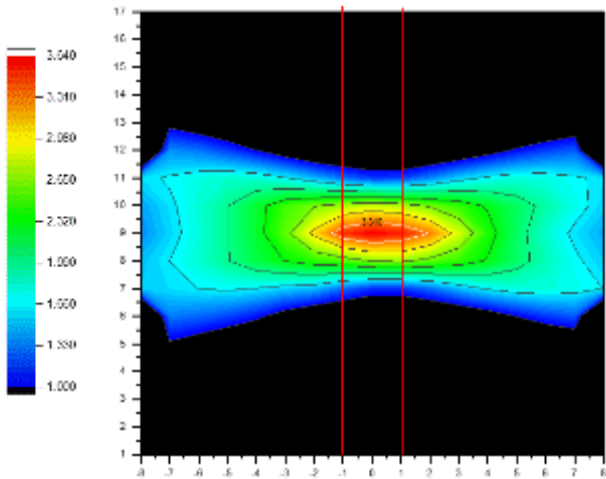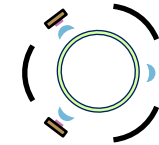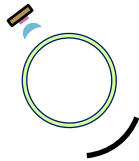
The design using a linear array (and focusing optic) along with a small back reflector. Due to the small form factor, we can position 3 arrays around the fiber to provide a very high irradiance on center with a fraction of the energy used in the planar array design.

METROLOGY - UNIFORMITY

Does uniformity matter?

TOP VIEW

REFLECTOR

CURING
TUBE

0°

180°

3mm ϕ
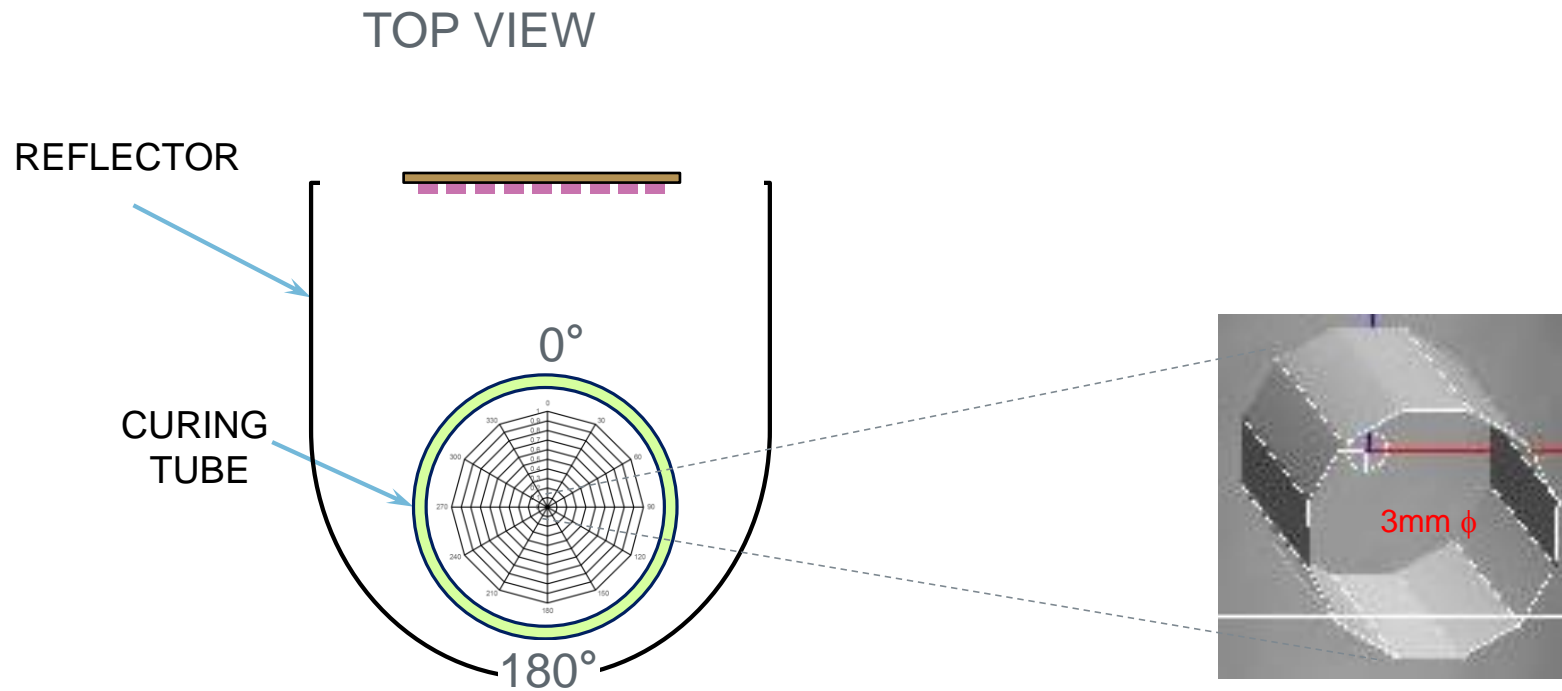
Uniformity of the irradiation around the target perimeter is critical for cable (wire) applications with the exception of small telecom fiber communication. By creating a small segmented cylinder around the center of the curing tube we can calculate and plot the intensity at each segment on a radar graph to illustrate the direction as well as magnitude of light striking the target.
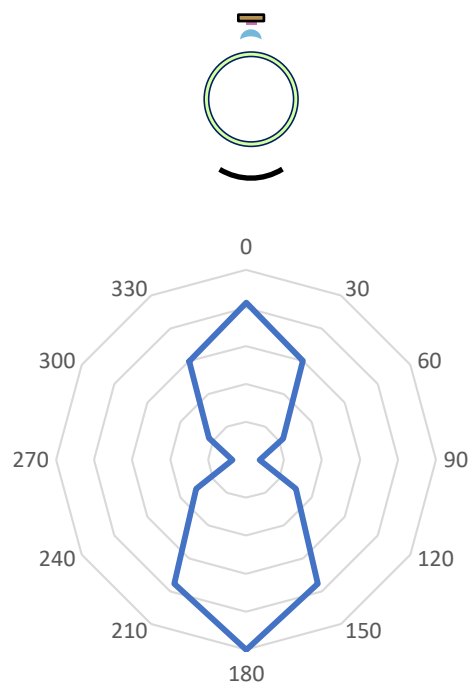
LED LAMP UNIFORMITY SIMULATIONS

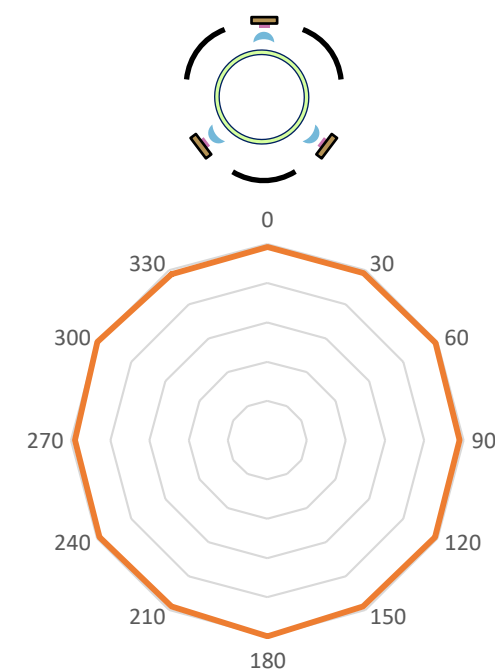**Uniformity issues arise very quickly...**

PLANAR SYSTEM

OPTIMIZED LINEAR SYSTEM

FULLY OPTIMIZED LINEAR SYSTEM
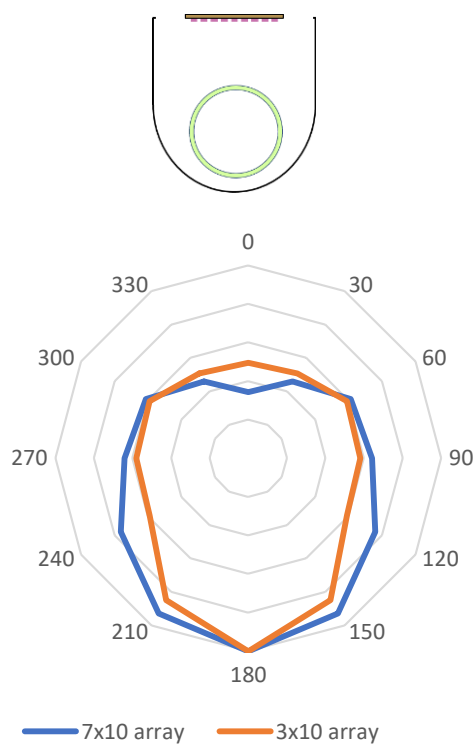
Deficiency of rays on the front of the fiber.

Very little rays on the sides of the fiber.

Uniformity of approximately 98%!

SUMMARY

- **Greater freedom in optical designs as LEDs are essentially point-of-use light sources**

- **Reflectors/lenses far easier to implement (pros and cons)**

- **Key design thinking is photon management**

  - Simulation & verification measurements

  - Process validation

  - Cure a line with a line…

- **When converting from mercury-based lamps to LED, the devil is in the details**

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THANK YOU!

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