Heraeus

A METHOD OF DRIVING MICROWAVE-DRIVEN LAMPS FOR IMPROVED PERFORMANCE

RadTech 2018 (Chicago, IL), 9 May 2018, D. Leonhardt

MOTIVATION

DC-driven lamps have be adopted for UV curing lamps for many years

- Improved equipment (higher efficiency, lighter weight, and more)
- More stable UV output for high-speed processes
- Slot arcing less of a problem
- Doesn't need multiple versions for 50Hz and 60Hz
- More precise power control

Continuous "DC" power causes 'color separation' when metal halides are present with vertical bulb

- Constant convection creates hot core and cooler surroundings (chimney effect)
- Metal halides recombine/dissociate in localized portion of bulb – making two different discharges in bulb
- Aka axial segregation, cataphoresis

Color separation leads to increased envelope temperatures and poor optical homogeneity

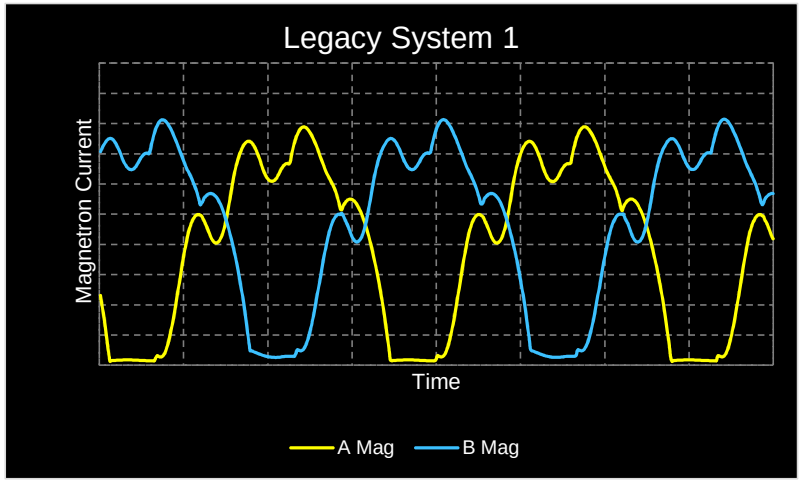
"DC-like" operation of the additive bulb that still maintains the benefits of the DC power supply and alleviates the inhomogeneity of the color separation

FERRORESONANT AND DC POWER SUPPLIES

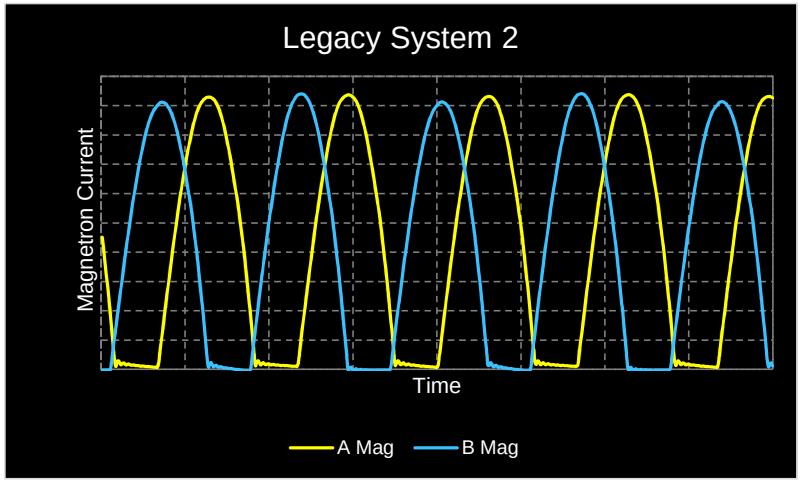
Ferroresonant designs

- Tried and true design; simple; moderately robust
- Heavy step-up transformers for HV
- HV is modulated at line frequency

180° out-of phase, phase-split



120° out-of phase, rectified by phase

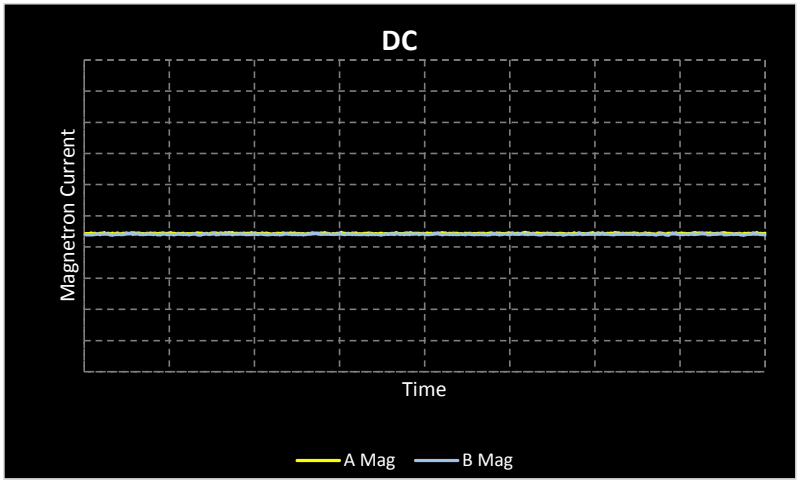


DC POWER SUPPLIES

DC designs

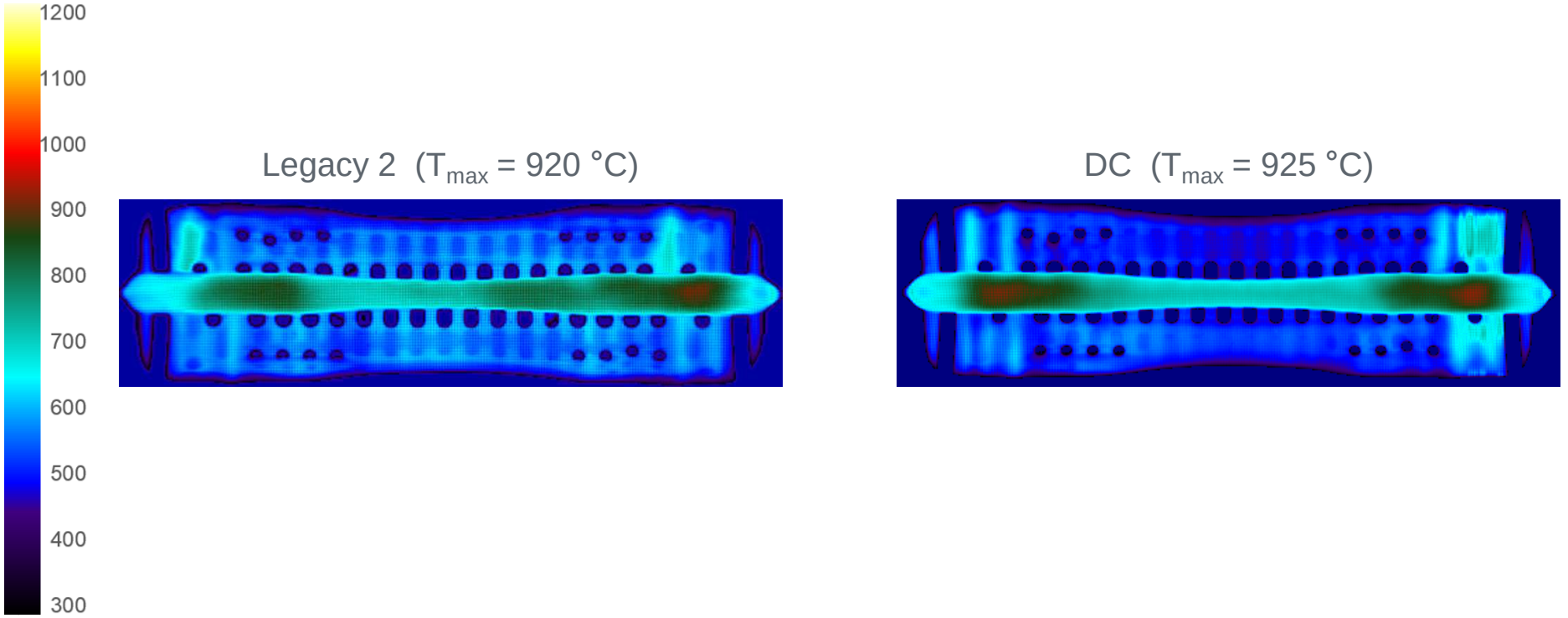
- Power factor correction built in – extremely high efficiency
- No heavy step-up transformers! Weight ~ 25% of ferroresonant design
- Can distribute load evenly to bulb

Constant current…



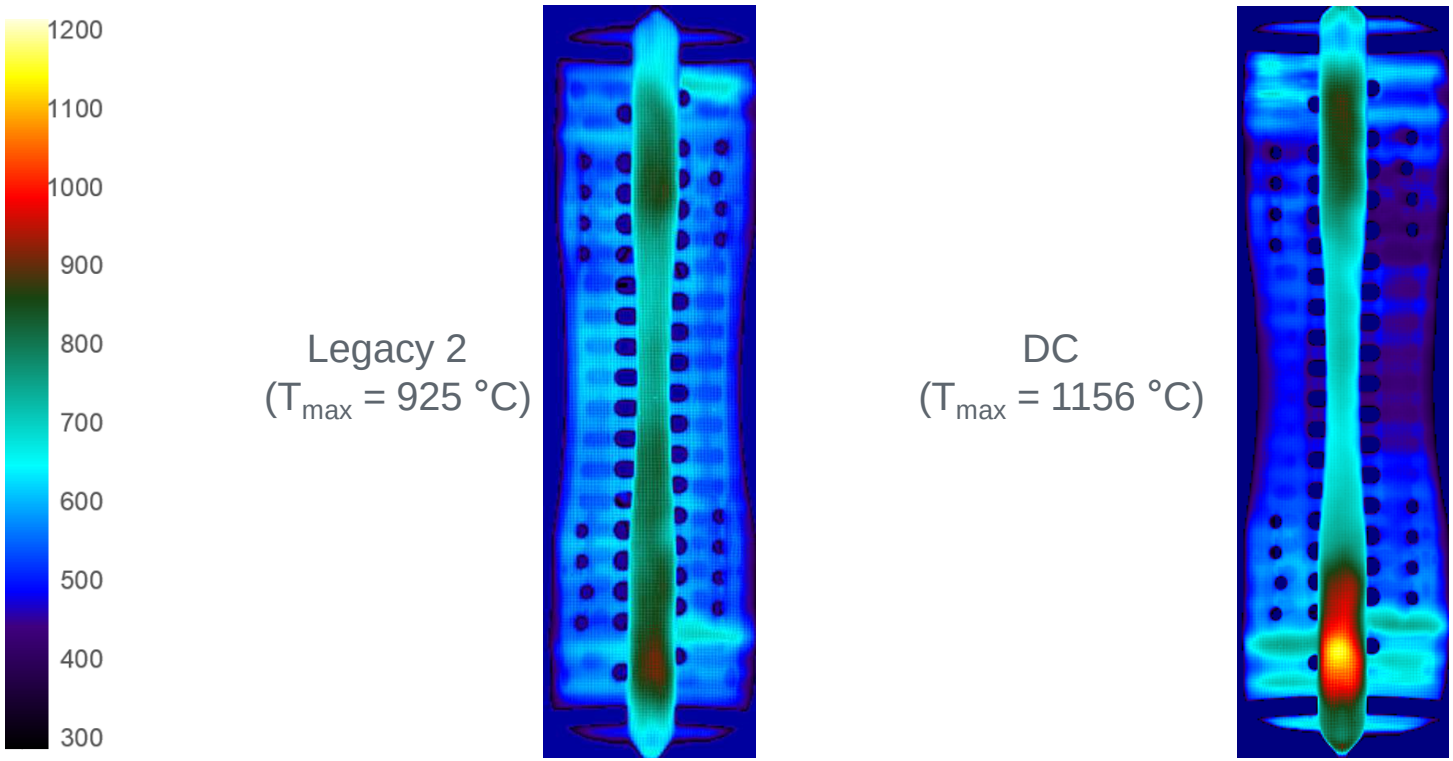
FERRORESONANT AND DC POWER BULB OPERATION

Temperature distribution of additive bulbs in horizontal orientation



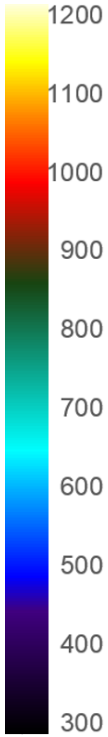
FERRORESONANT AND DC POWER BULB OPERATION

Temperature distribution of additive bulbs in vertical orientation

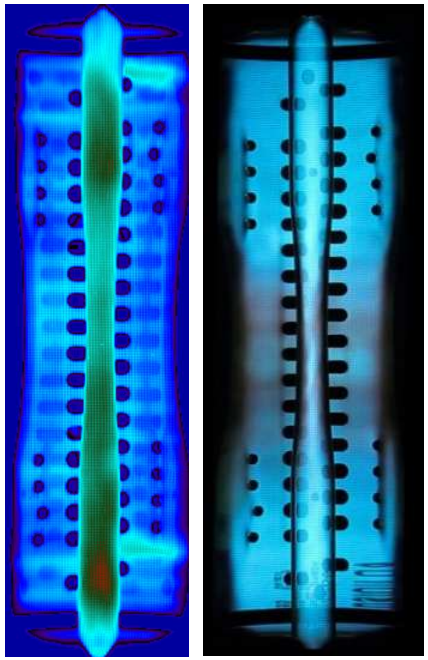


FERRORESONANT AND DC POWER BULB OPERATION

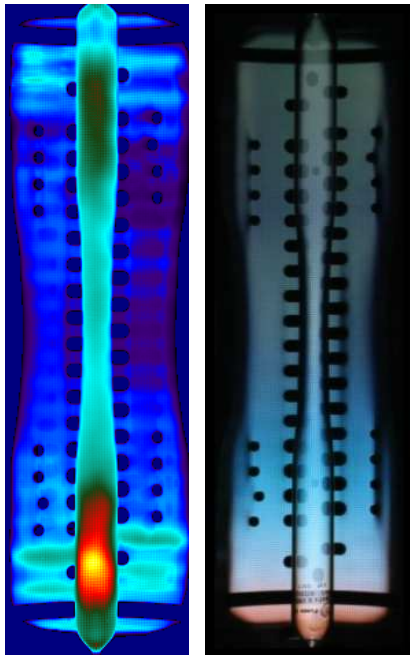
Temperature distribution and optical appearance of additive bulbs in vertical orientation



Legacy 2

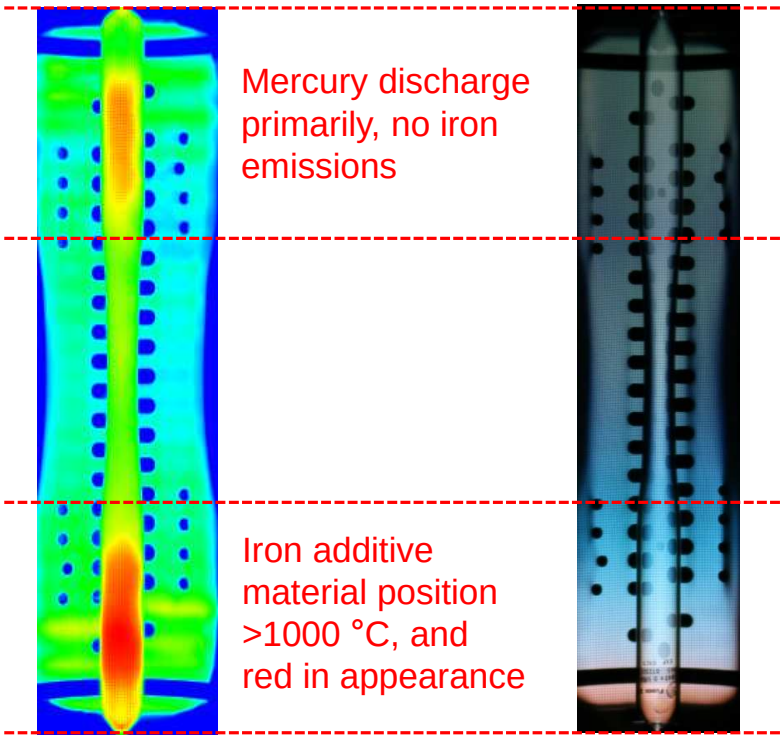


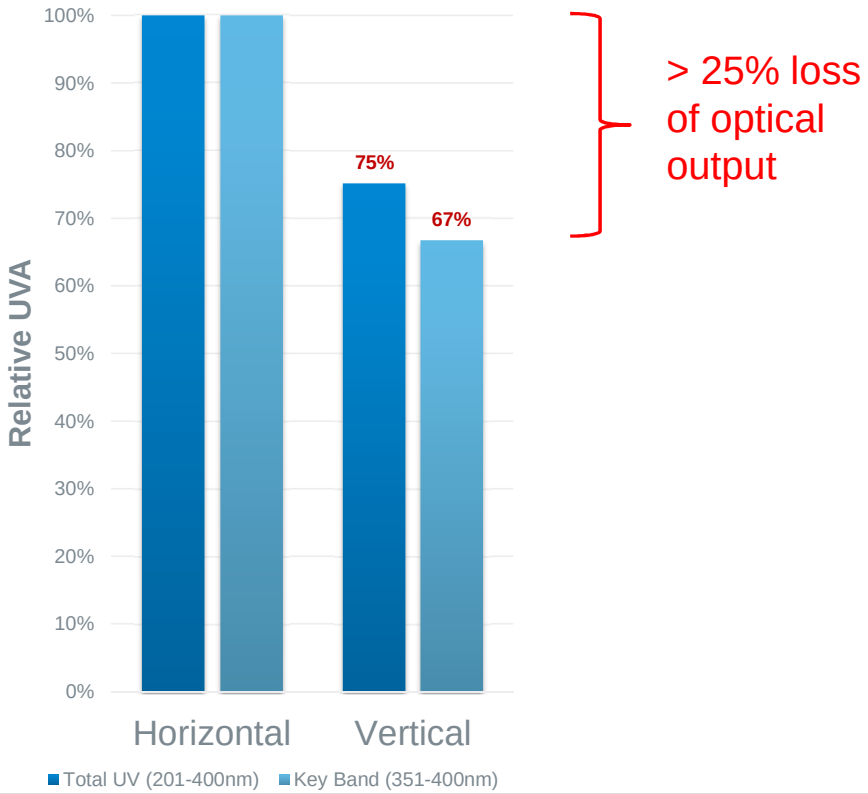
DC



DC OPERATION OF ADDITIVE BULB – BULB PERFORMANCE

Data from iron halide bulb operated by DC power, horizontal compared to vertical orientation



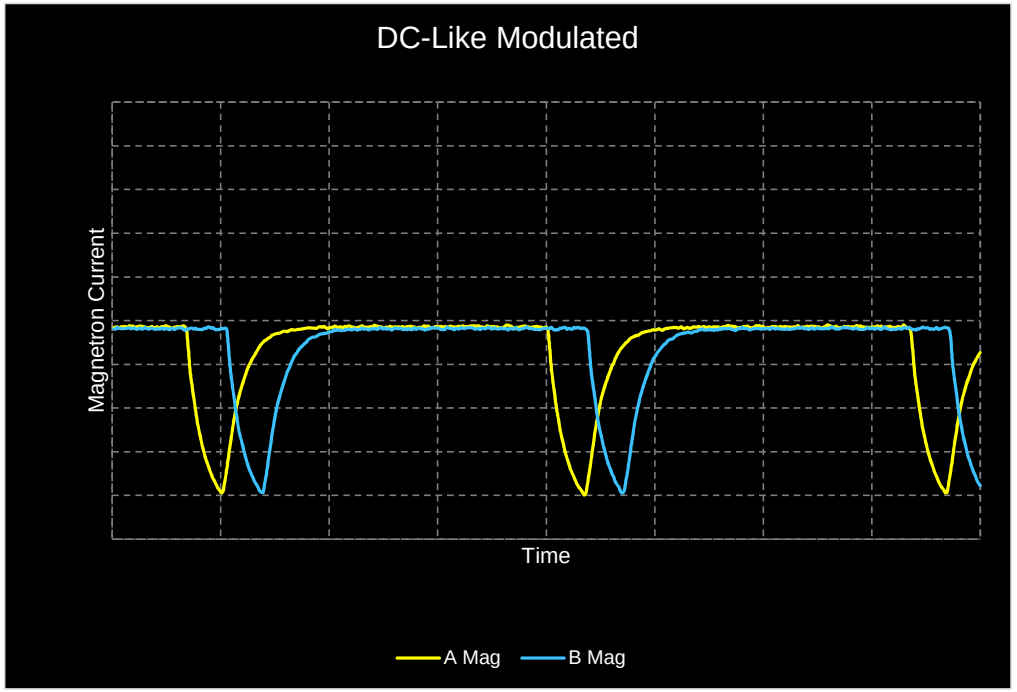


DC-LIKE OPERATION OF ADDITIVE BULB – MAGNETRON WAVEFORM

Briefly reduce power delivery to bulb to 'mix' additive but maintain DC operation character

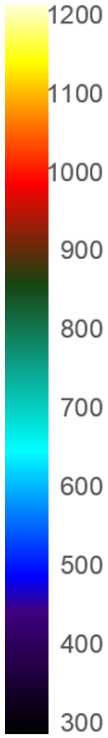
- Optimize duration, depth, waveform character and phase relationship
  - ~ 80% of modulation required
  - Magnetron currents ~ 40° out-of-phase
- Keep peak power low, to maximize component life
- Other critical parameters to optical output
  - Rise and fall of driving current waveform
  - Duty cycle
  - Phase angle
  - Frequency
  - Peak Current
  - Magnetron delay (A delayed or B delayed)

  - DC-like waveform is Patent Pending

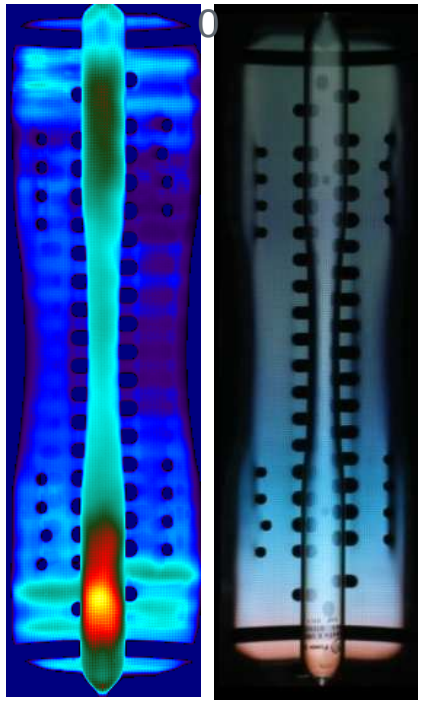


DC-LIKE OPERATION OF ADDITIVE BULB – BULB OPERATION

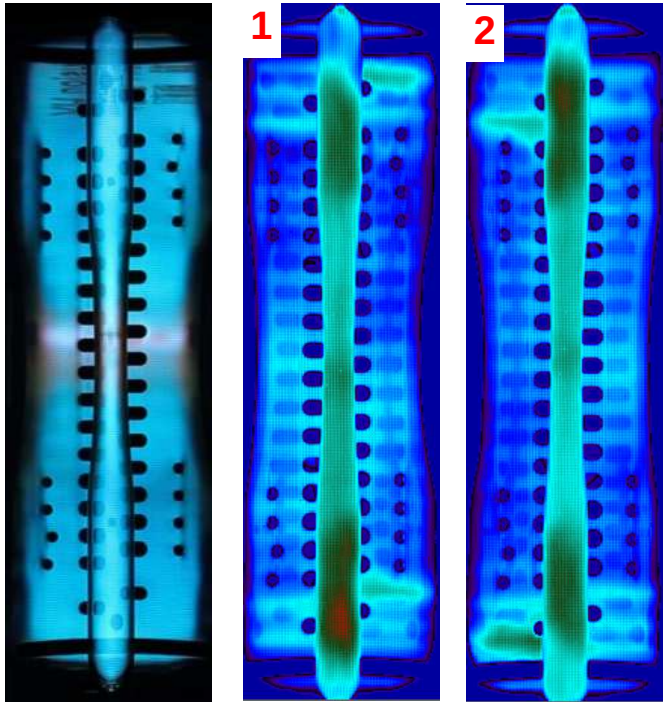
Temperature distribution of additive bulbs in vertical orientation



DC (as shown previously)



DC-like waveform

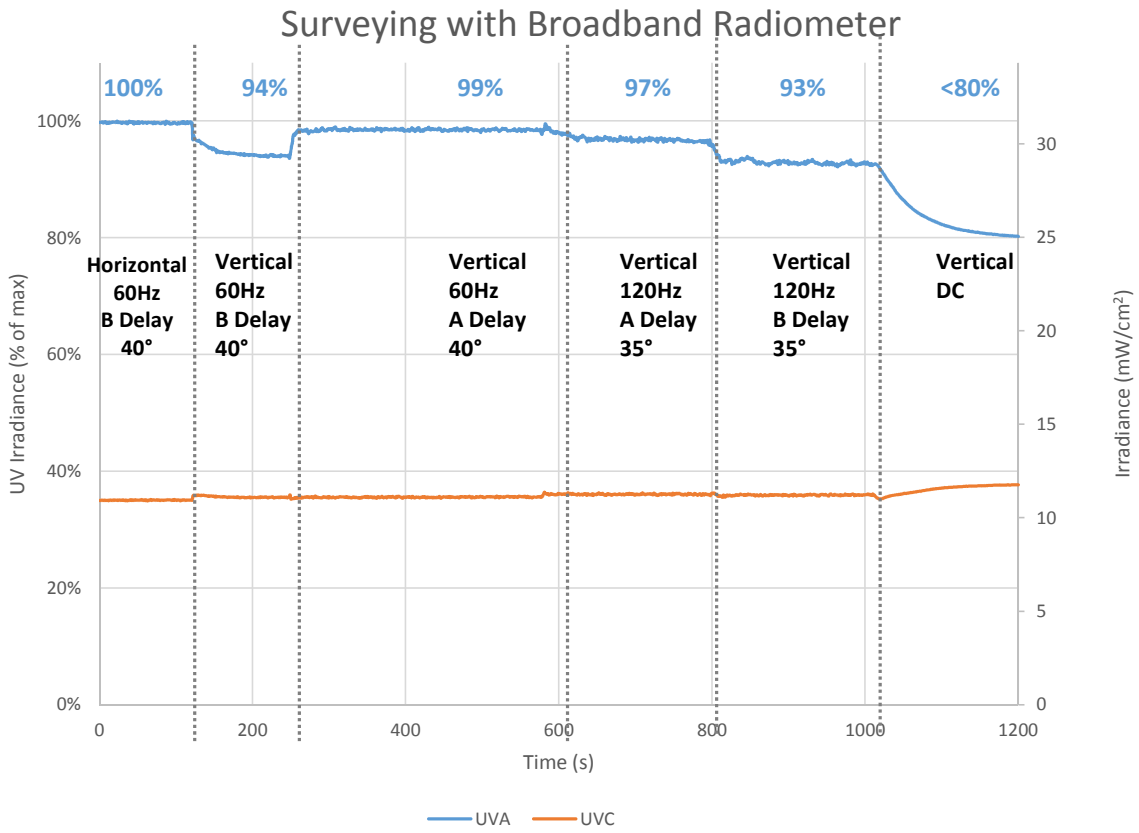


1: bottom magnetron delayed
T_{max} = 929 °C

2: top magnetron delayed

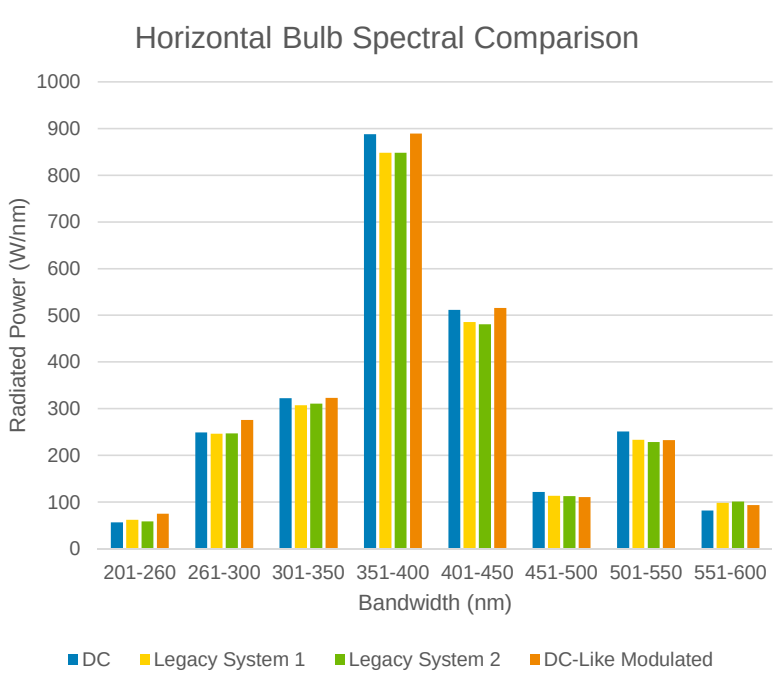
DC-LIKE OPERATION OF ADDITIVE BULB – LAMP PERFORMANCE

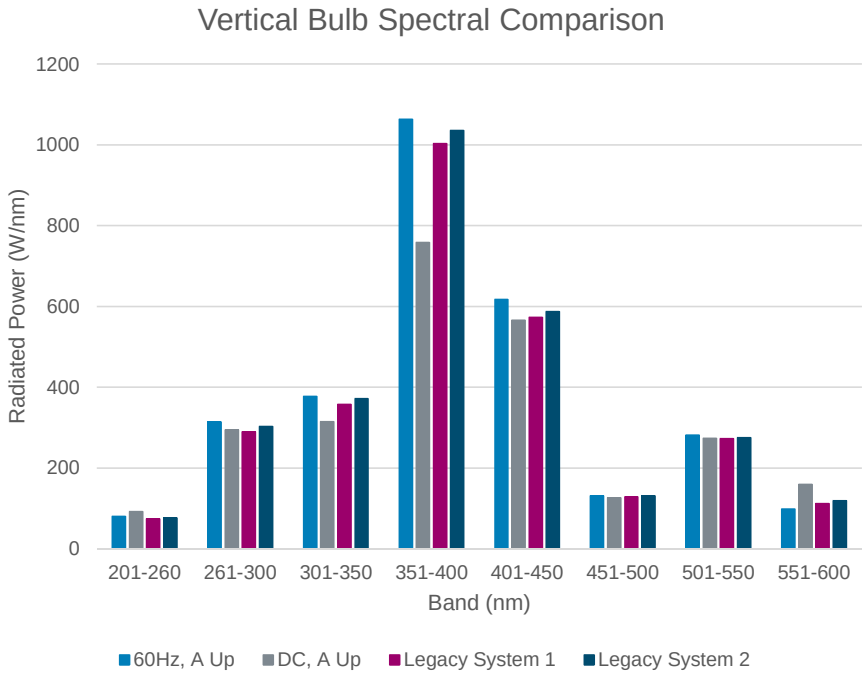
Orientation



DC-LIKE OPERATION OF ADDITIVE BULB – OPTICAL OUTPUT PERFORMANCE

Achieved improved performance for DC-like operation over legacy designs





SUMMARY

Achieved improved performance for DC-like operation over legacy designs

- Magnetron-driving waveform mostly “DC”
  - Minor fluctuations added to power delivered to bulb
  - Rise/Fall of waveform important for plasma stability
  - Also depends on additive composition (plasma reactions complex)
- Comparable or better bulb temperatures than when operated horizontally
  - No life time compromises
- Comparable or better bulb radiances
  - Horizontal: 4-6% higher than legacy power supplies, comparable to DC
  - Vertical: 6% higher than legacy power supplies, 15-25% higher than DC
- Comparable curing performance (still under study)

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THANK YOU FOR YOUR ATTENTION