The Dual Wavelength UV Transmitter Development for Space Based Ozone DIAL Measurements

Task Leader: Dr. Narasimha S. Prasad

Technical Interchange Meeting

8/28 and 8/29

NASA Langley Research Center

Hampton, VA 23681

UV Wavelength Conversion Task
Laser Risk Reduction Program

Technical Lead : Dr. Narasimha S. Prasad

Overall Objective:

To develop efficient 1-micron to UV wavelength conversion technology to generate tunable, single mode, pulsed UV wavelengths of 320 nm and 308 nm

Performance Goals

Solid-state, conductively cooled, single longitudinal mode, output energy ≥ 200 mJ, pulsewidth ~ 25 ns and pulse repetition frequency of 50 Hz

Merits

High pulse energy allows enhanced performance during strong daylight conditions

Technical Approach

- The 532 nm wavelength radiation is generated by a 1064 nm Nd:YAG laser through second harmonic generation. The 532 nm pumps an optical parametric oscillator (OPO) to generate 803 nm. The 320 nm is generated by sum-frequency generation (SFG) of 532 nm and 803 nm wavelengths
- The hardware consists of a conductively cooled, 1 J/pulse, single mode Nd:YAG pump laser coupled to an efficient RISTRA OPO and SFG assembly-Both intra and extra-cavity approaches are examined for efficiency

Potential Applications

Space-based lidar operation for future NASA missions including atmospheric ozone profiling using Differential Absorption Lidar (DIAL) technique

Partners

Sandia National labs,
POC: Dr. Darrell Armstrong
Fibertek, Inc.,
POC: Dr. Floyd Hovis

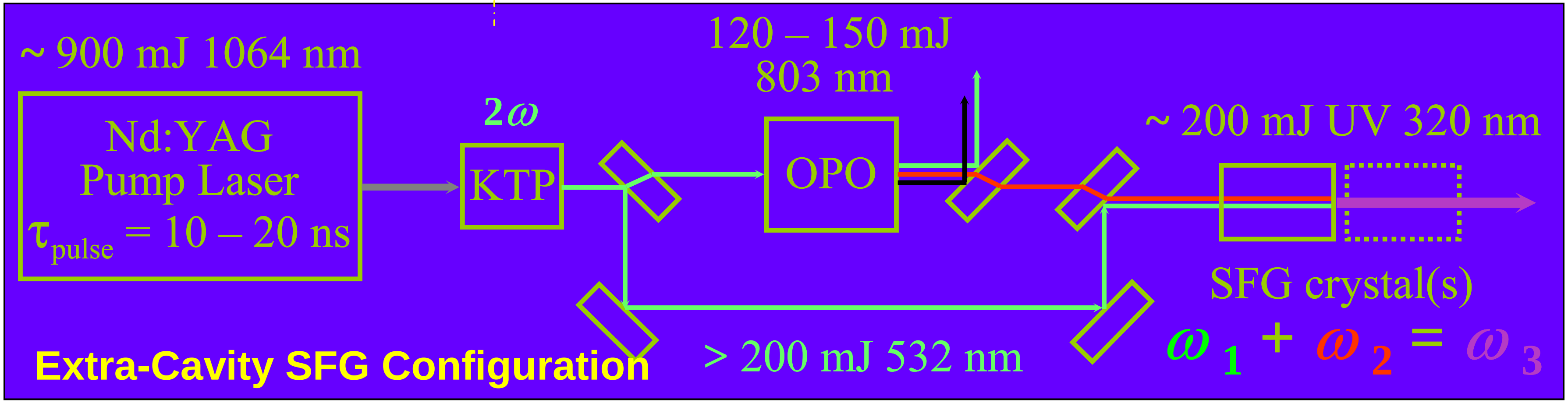
Accomplishments

- Efficient, state-of-the-art, tunable, single longitudinal mode UV conversion technology using 1 micron wavelength pump source and novel nonlinear optics based technology has been developed for remote sensing of ozone from space-based platforms
- The Nd:YAG pump laser unit that generates >1J/pulse, 50 Hz PRF and ~25 ns pulsewidth, with space qualifiable components and conforming to TRL 3 hardware has been built and tested
- Highly efficient nonlinear linear optics scheme to obtain UV wavelengths at >200 mJ/pulse output energies has been demonstrated
- The developed UV converter scheme is a highly stable and reliable technique suitable for space based lidar operations
- A technical path to develop highly compact (<2 Cu. ft), rugged, UV transmitter technology for space environments has been identified

High Energy UV Transmitter
Technical Approach

- **High energy low PRF is anticipated to provide high SNR under strong daylight conditions**

- **Basic Scheme comprises of a Nd:YAG laser pumped nonlinear optics based converter comprising of a second harmonic generation (SHG), optical parametric oscillator, (OPO) and sum frequency generation (SFG) processes**

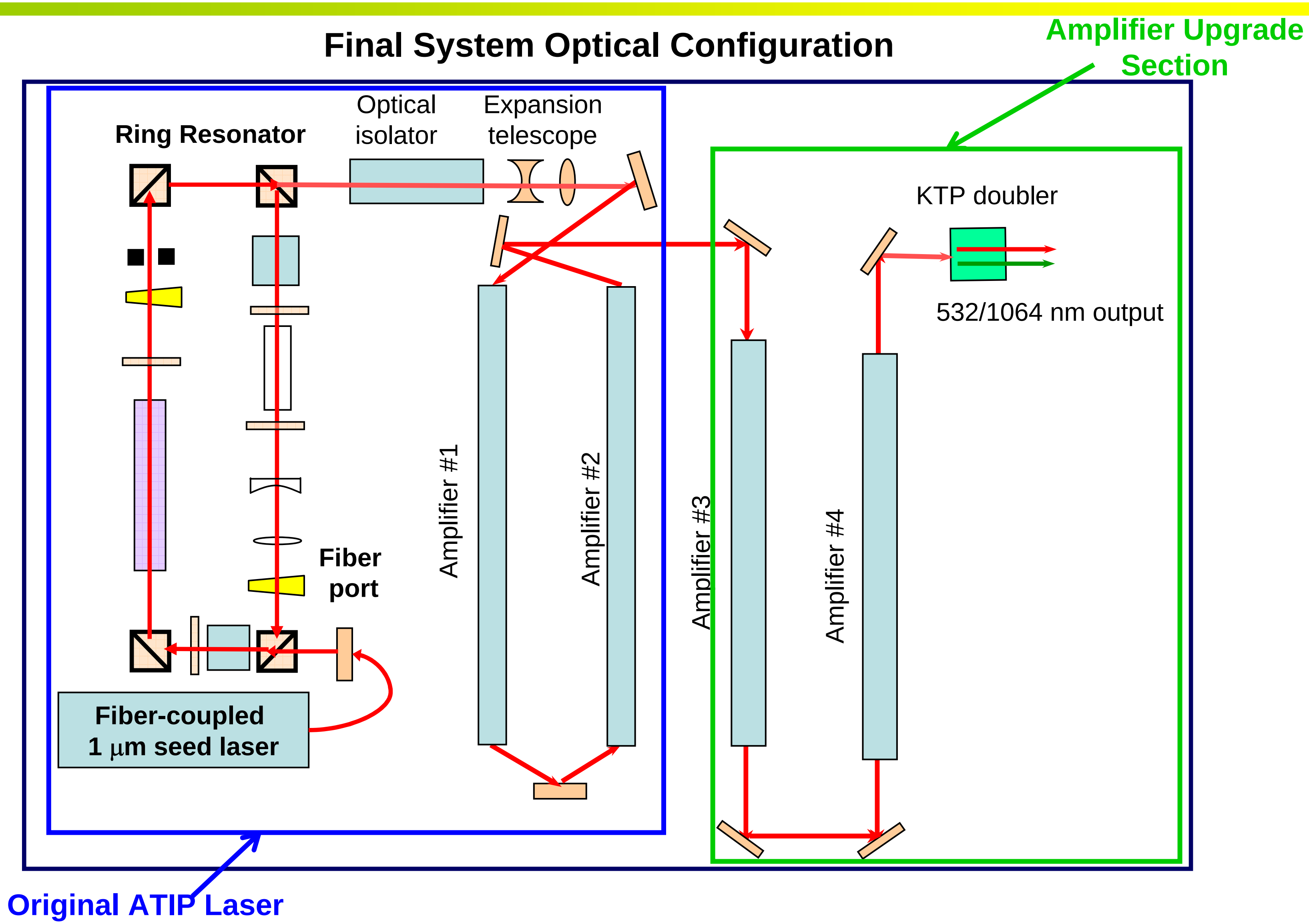


- **The pump Laser is an upgrade of a ~300 mJ/pulse system built under NASA's Advanced Technology Initiative Program (ATIP)**
- **The UV converter hardware TRL = 3**

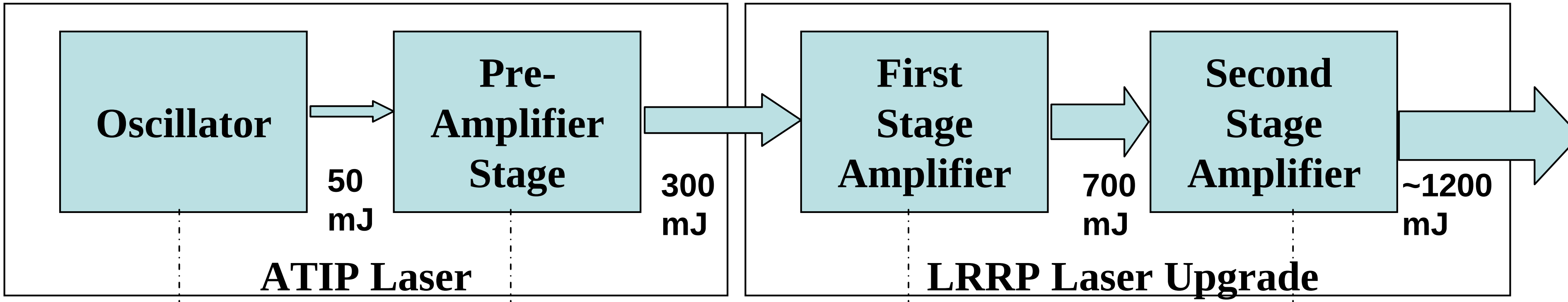
Nd:YAG Pump Laser

-Technical Scheme to achieve 1 J/Pulse-

Final System Optical Configuration



Pump Laser Performance



Oscillator Configuration
- 100 μs pump pulse
- 55 W/bar
- 100 bars

Oscillator Output
- 50 mJ/pulse
- PRF = 50 Hz
- 0.41 cm x 0.41 cm square beam
- $M^2 = 1.2$

Amplifier Configuration
- Vary pump pulse width
- 55 W/bar
- 112 bars/amp

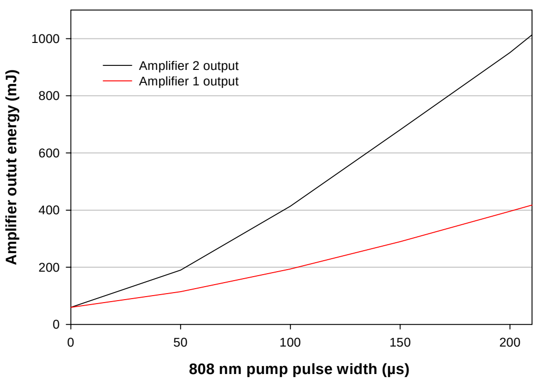
Peak Dual Amplifier Output
- 350 mJ/pulse
- $M^2 = 1.6$

Input	**= 280 mJ**
First Stage Output	**> 700 mJ**
PRF	**= 50 Hz**
Pulsewidth	**= ~16 ns**
Spatial Mode	**=Rect. Super Gaussian**
M2	**~ 2**
Optical Eff.	**>11%**
Wall Plug Eff.	**>7%**

Input	= 700 mJ
Second Stage O/P	> 1100 mJ
PRF	= 50 Hz
Pulsewidth	22 ns
Spatial Mode	SG
M2	2.5
Optical Eff.	11%
Wall Plug Eff.	7%

Amplifier
Modeling and Configuration

Modeling Results



Modeled output of dual 2-sided pumped and cooled amplifiers for 60 mJ input to first stage

Model is based on Franz-Nodvic result for a amplifying a square (in time) pulse

Model includes all key parameters explicitly

- Number of pump diodes (192)
- Peak diode power (75 W)
- Diode pulse width
- Input oscillator pulse energy (60 mJ)
- Input beam diameter
- Gain path length in amp
- Slab volume

Accounts for reduced gain for second pass

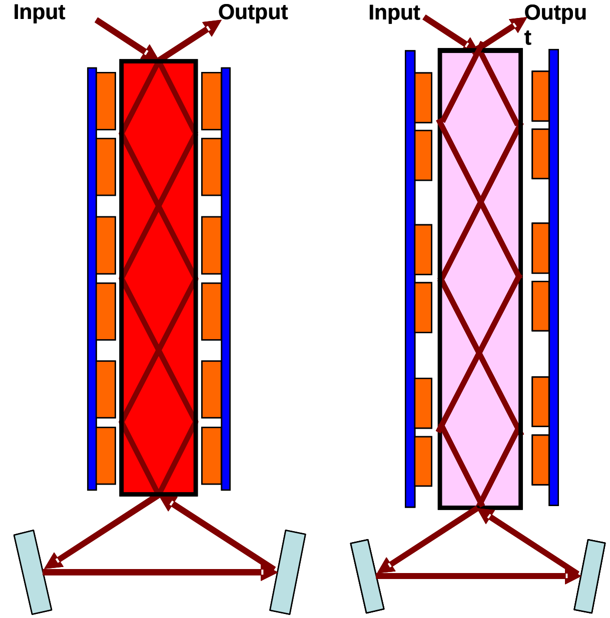
1 J per pulse output is predicted for 210 µs diode pump pulses

Amplifier modules

3 Bounces-Rectangular Shape-2 sided pumping in the TIR axis, 2 sided conduction cooling, Pump faces uncoated (~10%loss)

Dimensions	6.8 x 13.0 x 75.3 mm3
Incident Angle	Near Brewster (*57˚*)
Extraction	100% at full aperture
Aperture	11.5 x 6.8 mm2 (*internal*) 7.1 x 6.8 mm2 (*external*)
Doping Level	0.5 ± 0.1 % Nd3+
Pump Diodes	192 ea. 50 watt QCW bars (12 ea. 16 bar arrays)

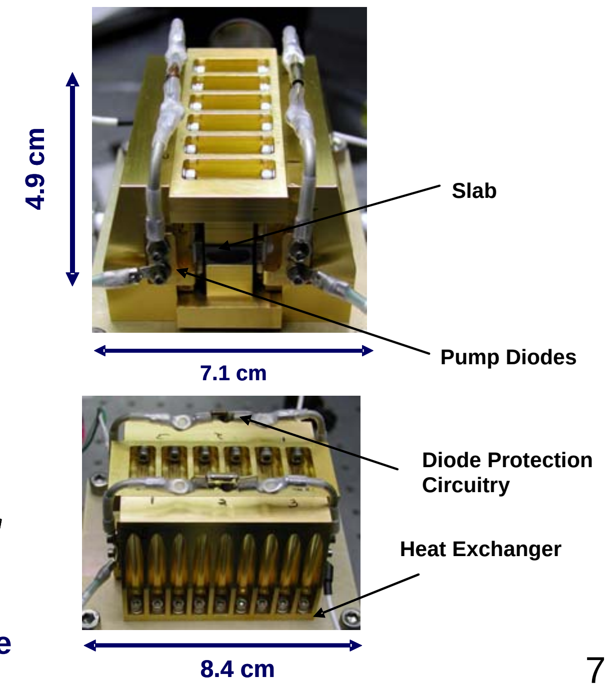
2-Sided Pumped & Cooled Amplifier



First Stage

Second Stage

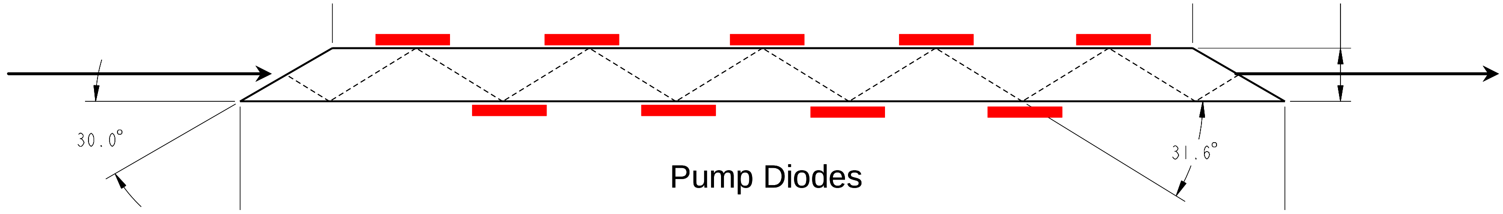
Prototype Two-Sided Pumped and Cooled Head Design



Second Stage Amplifier Design Configuration

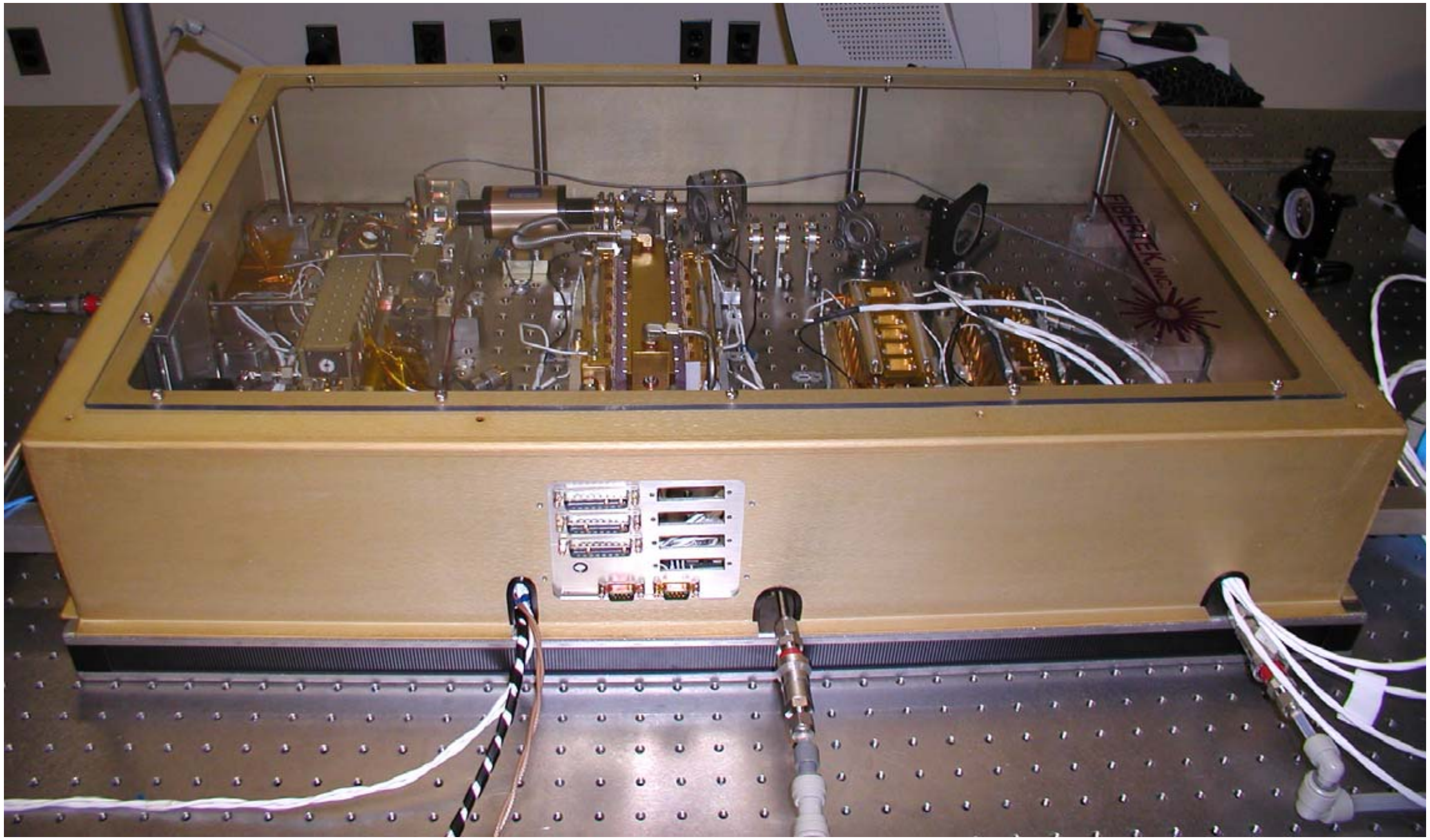
2-Sided Pumped Brewster Angle Slab Design Features

• Brewster angle design	Simplifies optical alignment, only single passed
• Mature technology	Reduces risk, based on synthesis of previously developed pump on bounce and Brewster angle designs
• Reduced tendency for parasitic oscillation	Parasitic control in Brewster slabs is well established
• Pump on bounce geometry	Allows good beam overlap with high gain regions with minimal diffraction effects



Design is a synthesis of Brewster angle and pump on bounce approaches

Full Nd:YAG Laser Unit



- The dimensions of this laser unit, including a SHG module, is 34” x 22” x 8”
- With latest diode bars and modified opto-mechanical components, the above package can be reduced to less than a quarter of its size

Final System
Control and Power Electronics

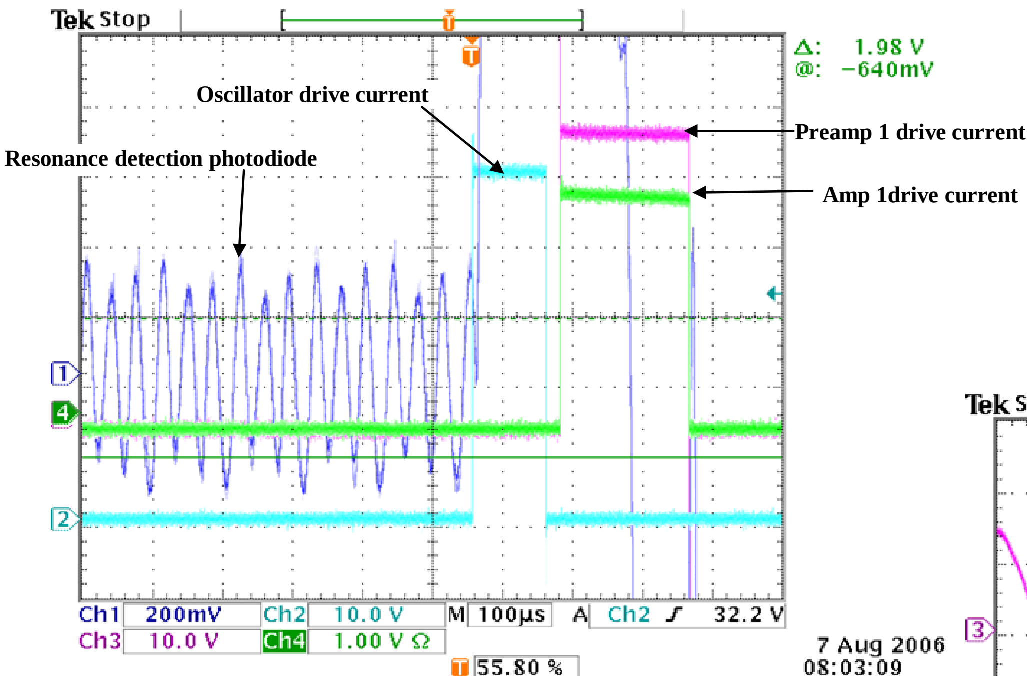
Custom power supplies and control electronics for the upgrade have been built

- **Control electronics consists of two 19"rack mountable boxes**
- **All power supplies are contained in two 19" rack mountable power supply modules**
- **Each amplifier can be individual set between high power and low power operation to allow the user to achieve a wide range of output powers at 50 Hz**

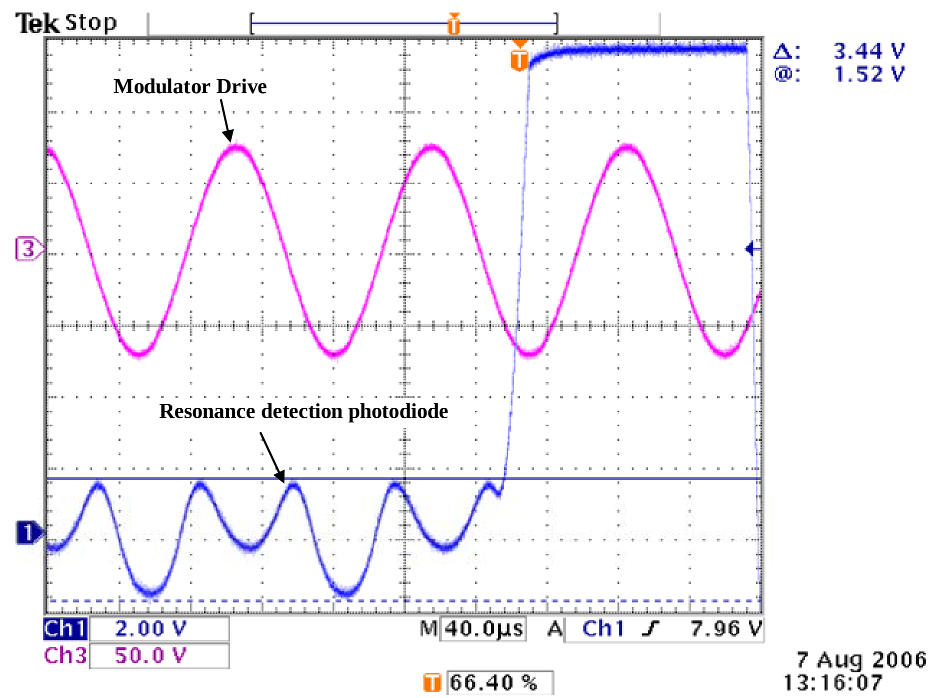
Single Power Supply Module

Control electronics

Diagnostic Waveforms

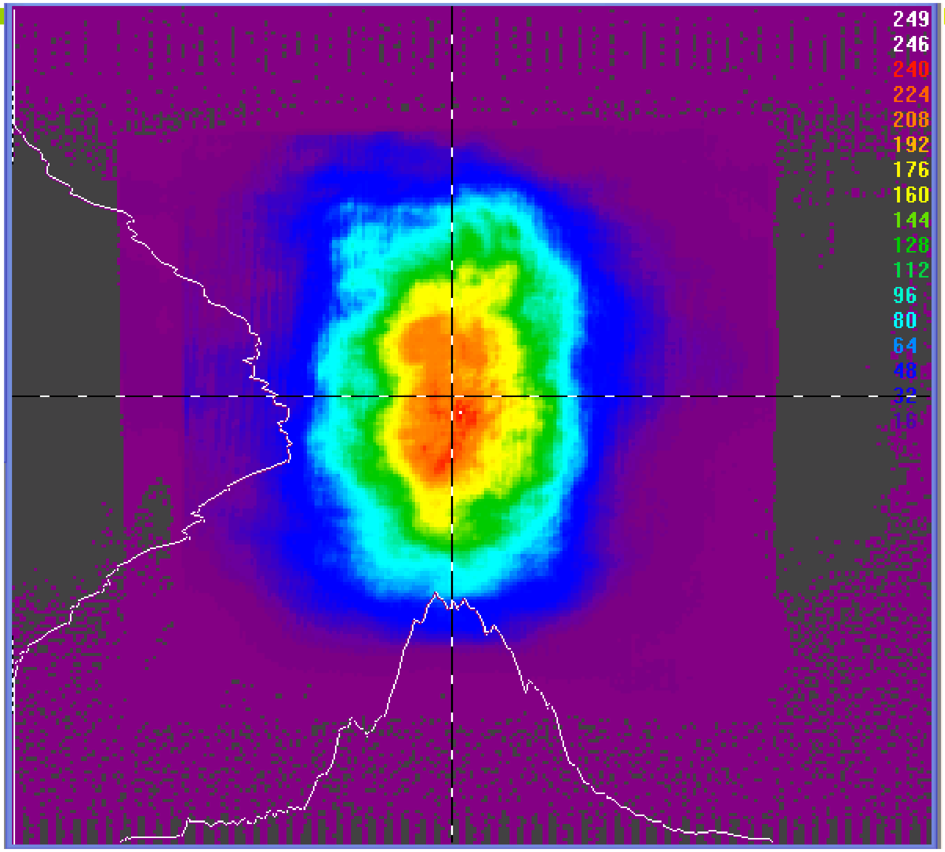


Resonance Detection Photodiode, Oscillator Current, Preamp 1 Current, and Amp 1 Current Temporal Profiles in Low Power Mode

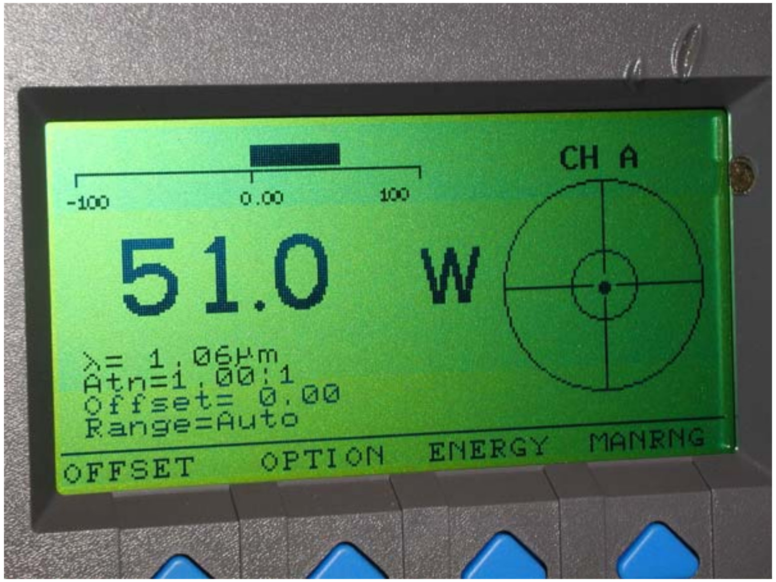


Resonance Detection Photodiode and RTP Modulator Drive Waveforms

Full System Results: Beam Profile & Typical Output Energy



Near field beam profile of final amplifier output



Average power at 50 Hz of 51.0 W (1020 mJ/pulse) for an input electrical power to all pump diodes of 724 W

1020 mJ/pulse and an electrical to optical efficiency >7% was achieved with only 58 W peak power per diode bar pumping the amplifiers.

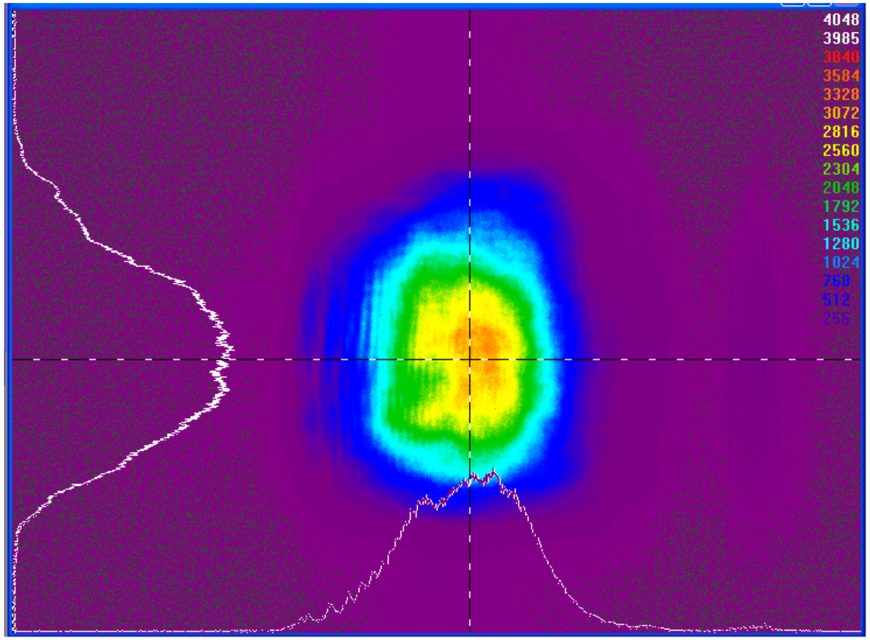
Output Spatial Performance

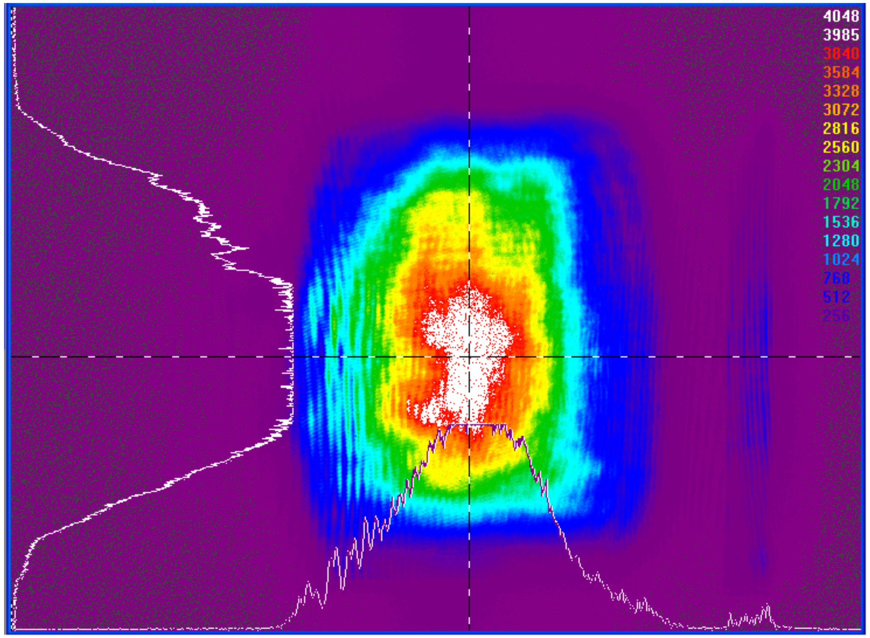
20 W output near field profile

- Amplifiers 1 & 2 low power, amplifiers 3 & 4 high power
- X diameter 4.4 mm, Y diameter 5.5 mm

52 W output near field profile

- All amplifiers high power
- X diameter 5.2 mm, Y diameter 7.2 mm



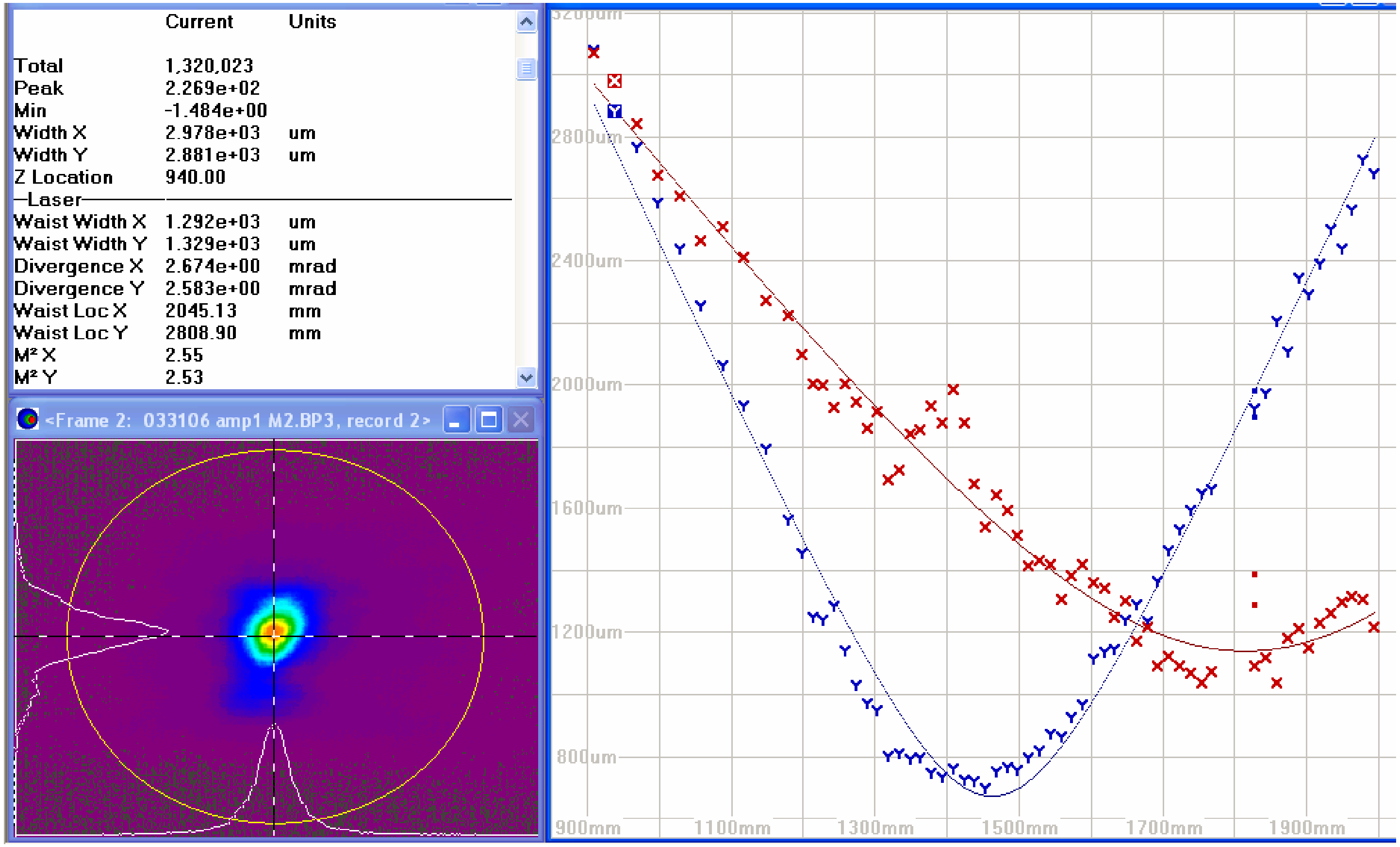


Flat spatial profiles are required for efficient harmonic conversions

Full System Beam Quality Measurements

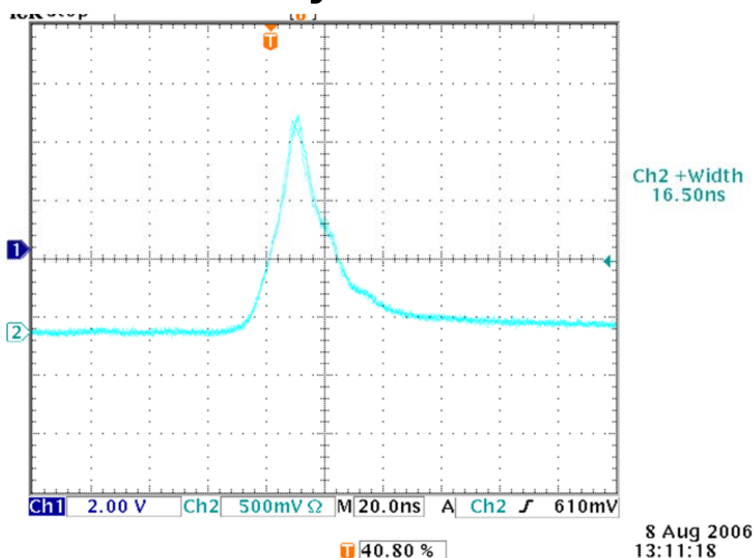
50 Hz, Full Power Beam Quality Measurements

$M_x^2 = 2.5$, $M_y^2 = 2.5$,

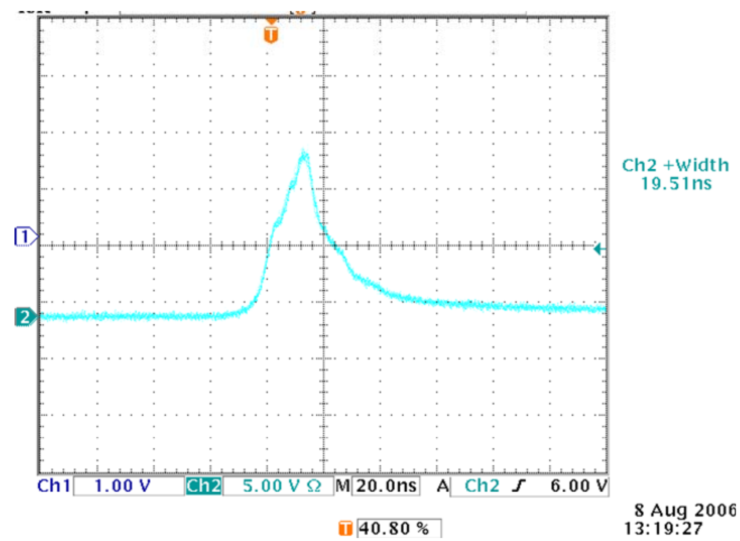


Temporal Characteristics

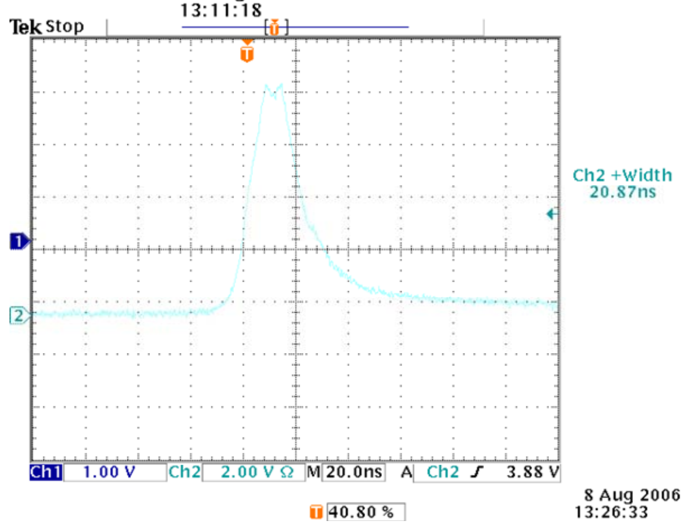
Oscillator Only: 16.5 ns



Oscillator + Preamp 1 + Preamp 2 : 19.5 ns



Oscillator + Amp 1 + Amp 2 : 20.9 ns



Full System:
Pulsewidth ~ 22 ns

Final Design and Performance Summary

Parameter	Specification	Goal	Final Design/Performance
Pulse Energy (mJ)	900	1200	1040
M^2	NA	2	2.5
Laser head package	Single breadboard	NA	Single breadboard in custom enclosure
Cooling	Conductive to diodes and slabs	NA	Conductive to diodes and slabs
Seeding	Ramp & fire	NA	Ramp & fire
Electronics	Separate custom module	NA	Separate custom module

UV Wavelength Conversion

- The nonlinear optics based technology to efficiently generate UV wavelengths has been established using a flash lamp pumped Nd:YAG laser
- Utilizes a novel (Rotated Image Singly Resonant Twisted RectAngle) RISTRA OPO to generate 803 and 731.5 nm wavelengths from 532 nm pump
  - Two RISTRA OPOs are used stable and single mode 803 nm:
    - A small or low energy RISTRA OPO that is locked by Pound-Drever-Hall (PDH) technique and seeded by New Focus tunable diode laser operating at 803 nm
    - The big or high energy RISTRA OPO that is pulse seeded from the small OPO and locked by energy stabilization technique

Conversion efficiencies

State-of-the-art conversion efficiencies have been demonstrated

RISTRA OPO Module

– At 320 nm, >200 mJ extra-cavity SFG with good beam Quality

►IR to UV efficiency > 21% (> 27% for 1 mJ seed)

– At 320 nm , up to 160 mJ intra-cavity SFG

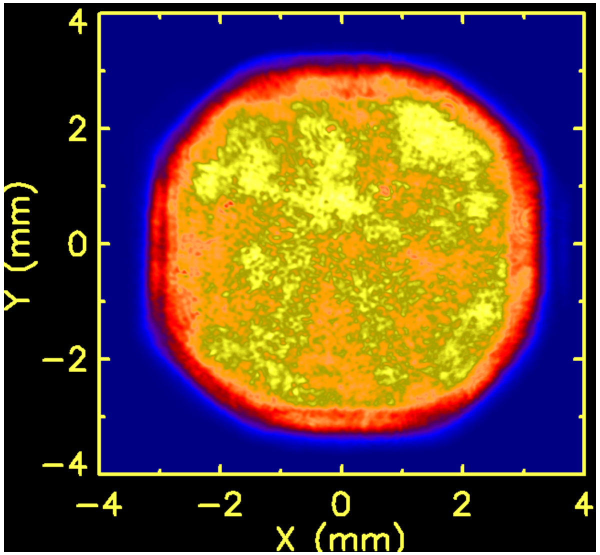
• ► IR to UV efficiency up to 24%

– Fluence ≤ 1 J/cm^2 for most beams

Image-rotating RISTRA Performance

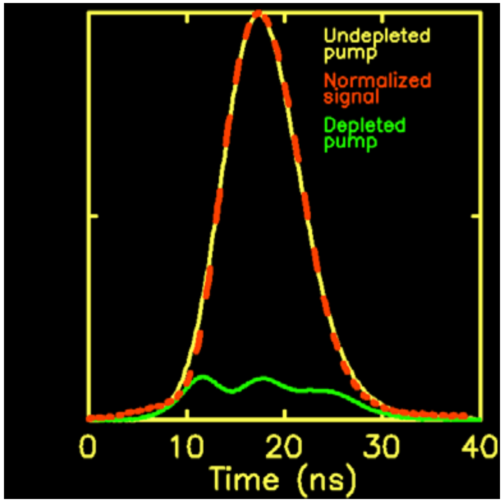
-Spatial fluence profiles and pump depletion-

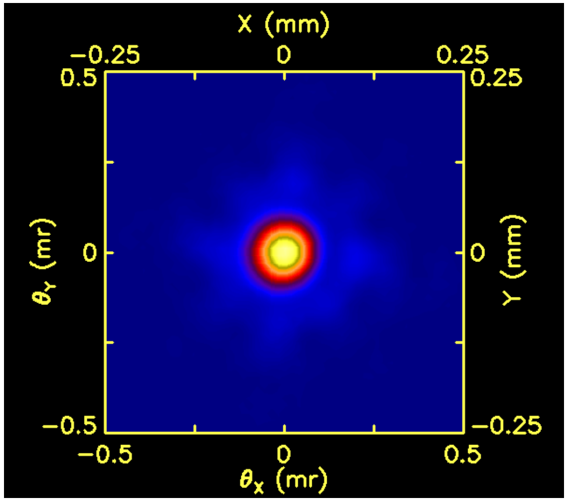
OPO signal near-field spatial fluence profile, Fresnel Number > 450



Flat pump profiles have facilitated high OPO conversion with good beam quality

Self-seeded oscillation in two-crystal RISTRA ~85% pump depletion



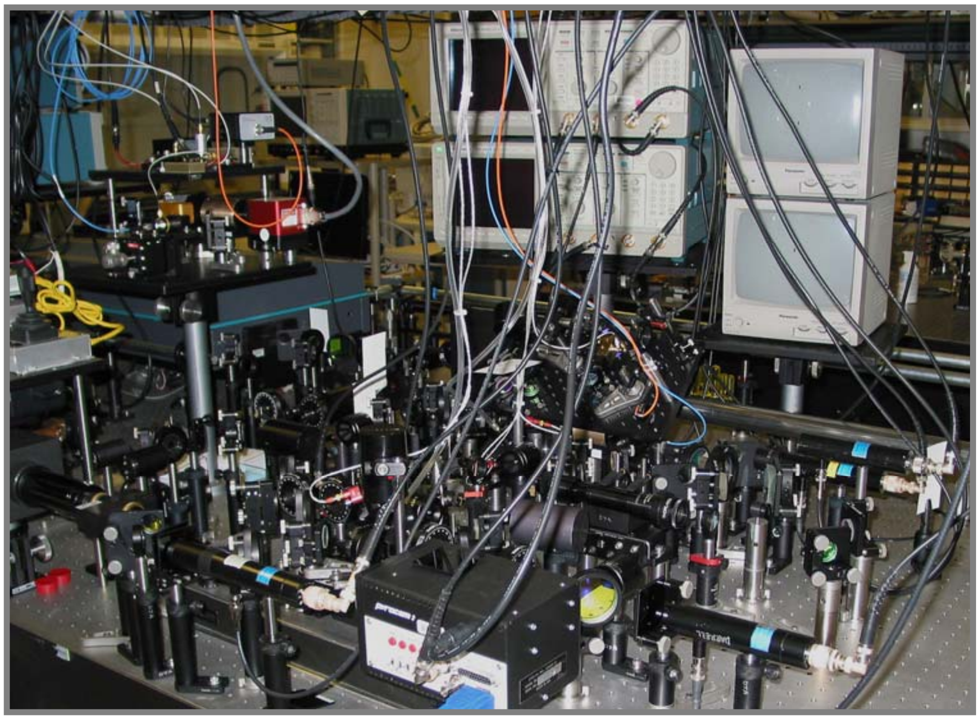


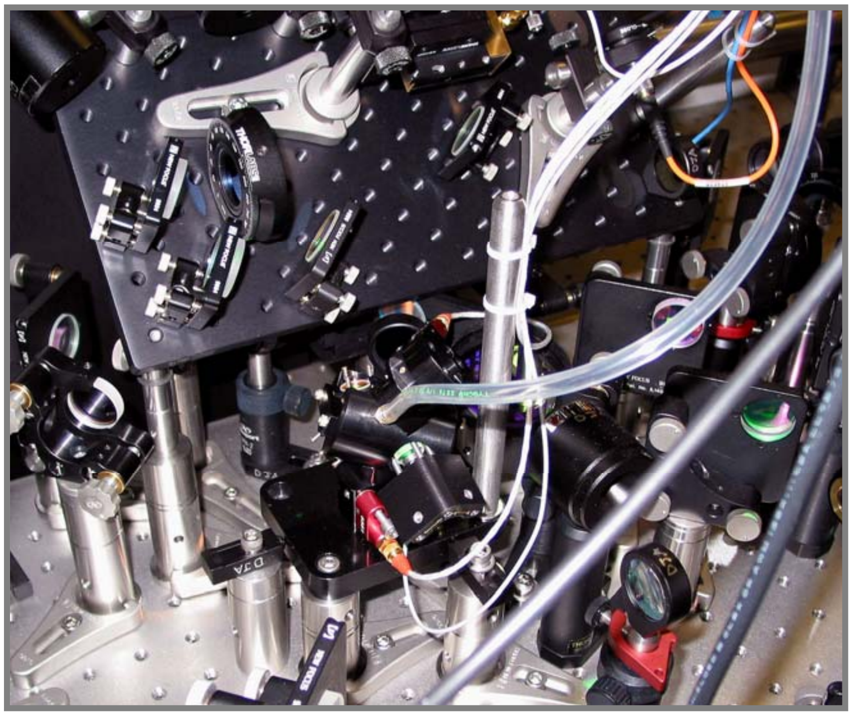
OPO signal far-field spatial fluence profiles, Fresnel Number > 450

Laboratory Setup

Breadboard with electronics and diagnostics used for technology demonstration

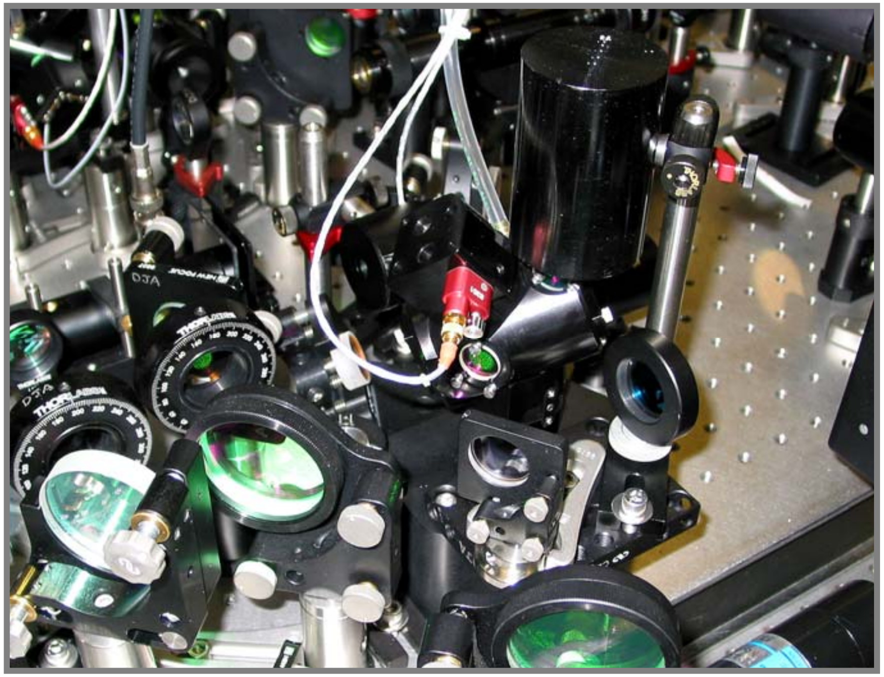
PDH stabilized injection-seeder OPO

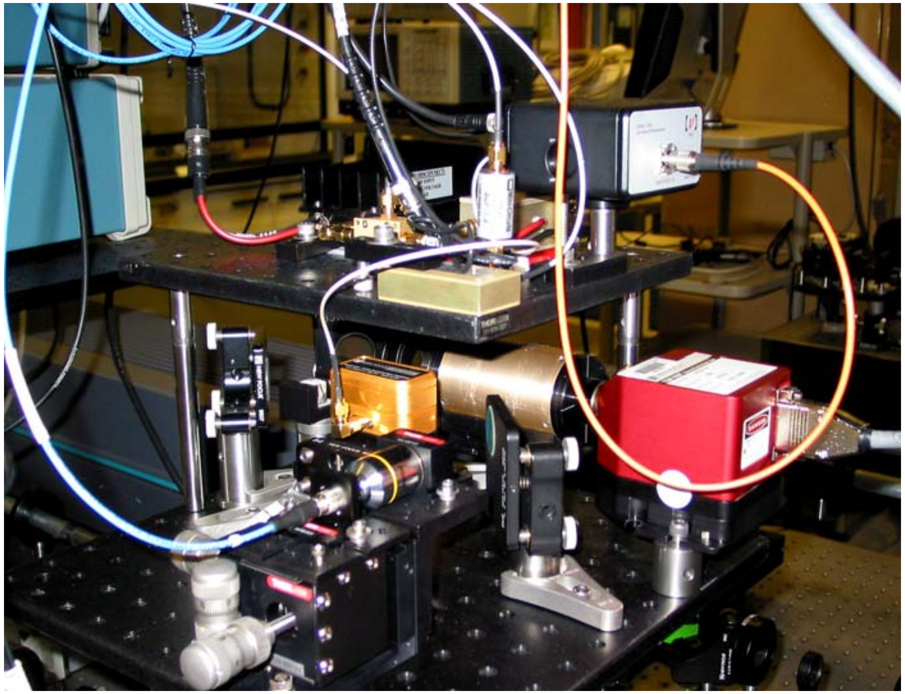




Extensive diagnostics are utilized for characterization of temporal and spatial profiles

Laboratory Set-up





Pulsed idler-seeded 803 nm OPO

Grating-tuned diode laser, phase modulation and RF electronics for PDH stabilization

Current Status

- Second harmonic generation efficiency (for pumping OPO and for SFG stage) exceeds 80%
- All components of 1576 nm pulsed idler-seeding system fully operational
  - Pound-Drever-Hall (PDH) stabilized RISTRA OPO
  - Sandia-built stabilization electronics
  - 1576 nm beam shaping optics and beam delivery optics
- 803 nm RISTRA OPO
  - Pulsed-idler seeded oscillation recently obtained
  - Frequency stabilization under construction
- Sum-frequency generation stage
  - All beam combining optics in place
  - LBO (12 mm x 12 mm x 40 mm) crystal for SFG stage to be delivered by 8/31

Current Status (Contd..)

- Method for pulsed injection seeding
  - Signal seed-pulse generated by backward pumping scheme replaced by idler pulse from separate small OPO
- Dimensions of 803 nm RISTRA OPO scaled up by factor of 1.5 to safely accommodate higher pulse energies
- To improve overall conversion efficiency
  - KTP crystals in OPO replaced by BBO in the big OPO
  - The small 803 nm diode seeded OPO is based on KTP
  - BBO crystal for SFG replaced by LBO for efficient conversion
- The UV converter scheme is being assembled on a 2’ x 2’ breadboard

Sub Tasks Nearing Completion

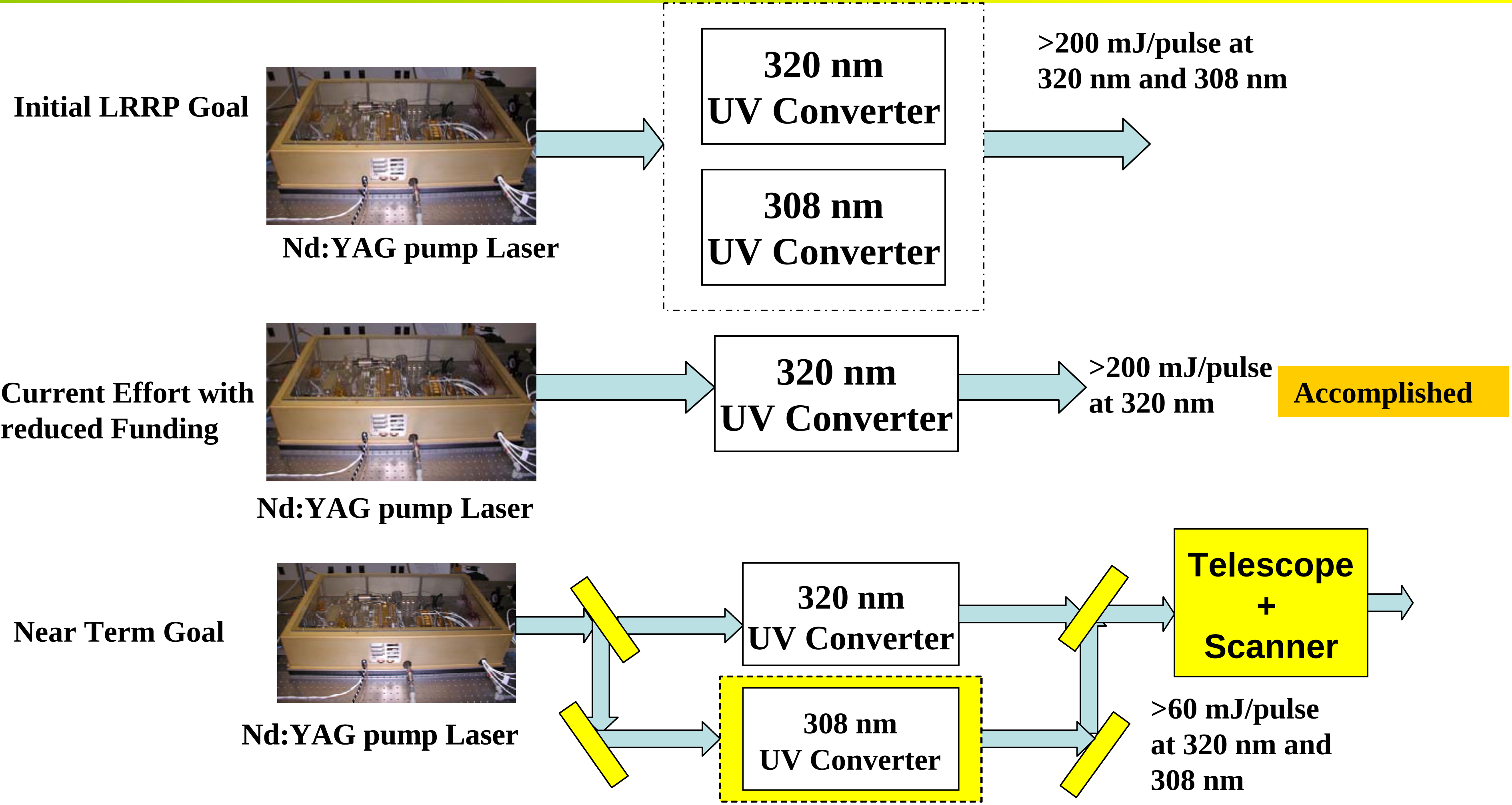
- Frequency stabilization of 803 nm OPO
  - Uses simple grazing incidence grating and split photodiode for feedback to control frequency of seeder OPO
- Sum-frequency generation stage
  - Requires delivery of LBO crystal
  - Final integration of all breadboard components
- Characterization of complete system on a 2' x 2' breadboard
  - Measure UV energy output and overall optical-to-optical conversion efficiency

Testing and Integration Efforts at NASA LaRC

- **Nd:YAG laser installation, testing and calibration complete**
  - **Flat pump profiles from Nd:YAG laser achieved**
- **SHG scheme to achieve 532 nm from 1064 nm established with >80% conversion efficiency**
- **Pump laser with UV converter setup integration**
  - Procurement of components for integration of the 1064 nm pump laser and UV converter complete
  - Small RISTRA OPO with a 803 nm diode assembled on a breadboard
  - Full integration will begin soon as soon as SFG module is ready

On Going and Future Work

Goal: To build fully Ozone functional DIAL System



Single pump laser based DIAL System: Components in yellow boxes will be built with additional resources

Summary and Conclusions

- All solid-state Nd:YAG pump laser development complete
  - The current laser design has been leveraged into other NASA and DOD programs
- Efficient high-pulse-energy UV generation technology has been demonstrated
  - **>200 mJ extra-cavity SFG; IR to UV efficiency > 21%**
  - **160 mJ intra-cavity SFG; IR to UV efficiency up to 24%**
- Custom designed opto-mechanical hardware for final prototype UV converter complete
- The system integration efforts at NASA LaRC is underway
- Current UV Transmitter effort is a technology demonstration with the hardware TRL = 3
  - Space qualifiable components have been used wherever possible
- The overall dimensions of the pump laser, associated electronics and UV converter setups can be reduced to less than 1/3rd their current sizes
- Solid-state UV Transmitter is amenable for space-worthy packaging