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# Multi-GHz Photoinjector Lasers for High Brightness X-ray Sources

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**Abstract:** We present a photogun laser (PGL) architecture that generates 11.424 GHz repetition rate, 2.0 ps FWHM, 249 nm pulses for injecting electron bunches into sequential RF buckets of a pulsed X-band linac. 

## 1. Introduction

Multi-GHz photogun lasers offer a path to high current, low emittance, and low energy spread electron beams from RF linacs. By distributing charge across a sequence of RF buckets (i.e. acceleration cycles) in each RF pulse, electron beam energy dispersion and emittance are reduced compared to when that charge is placed in a single RF bucket. Such beams enable high beam flux, quasi-mono-energetic X-rays and gamma-rays from laser Compton scattering devices [1]. They may also be used directly for FLASH radiotherapy, where ~10 nJ, ~100 MeV scale (< 1 µs) electron pulses may be used to minimize damage to healthy tissue. [2]

Here, we present an X-band, 11.424 GHz repetition rate photogun laser (PGL) that enables the generation of 11.424 GHz trains of electron bunches from a copper-based, high-gradient, X-band photogun. The PGL produces between 8.75 and 87.5 ns long bursts of pulses with between 100 and 1000 pulses (micropulses) per burst (macropulse). The presented laser architecture is easily adapted to RF linacs of any frequency.

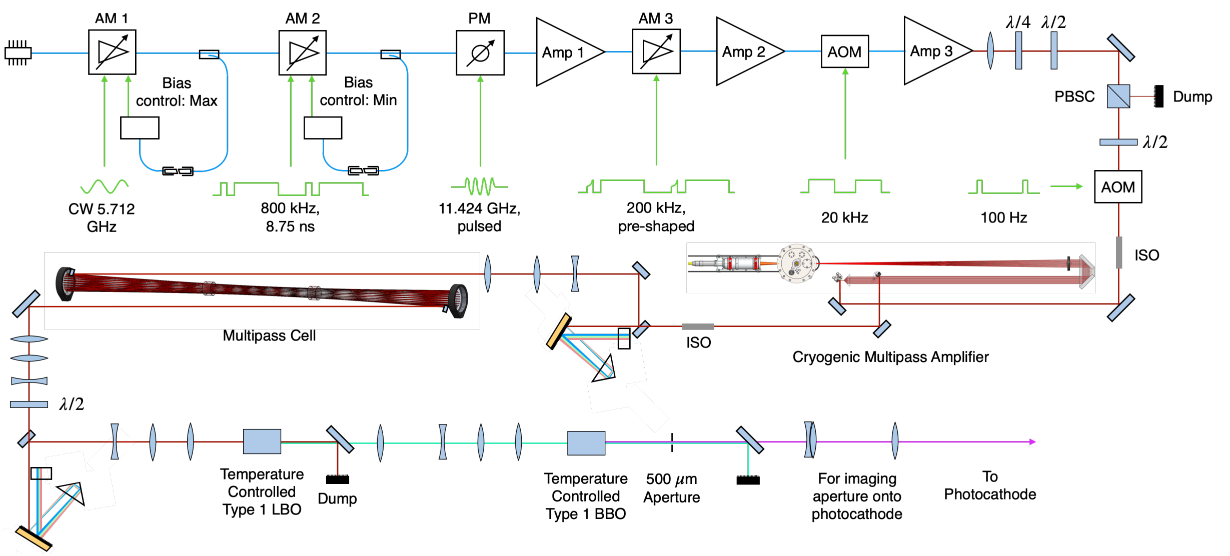


Fig. 1. X-band photogun laser architecture currently in operation at Lumitron Technologies, Inc.

## 2. Multi-GHz Pulse Synthesis

At the front end of the PGL is a fiber-based optical pulse synthesizer (OPS) similar to those described in [3,4]. Here, a narrowband, fiber-coupled DFB laser diode is temperature tuned to emit narrowband light at 995.2 nm, providing ideal overlap with the gain spectrum of the downstream Yb:YLF bulk amplifier (see section 3). The light then passes through fiber coupled Mach-Zehnder modulators AM 1 and AM 2. AM 1 modulates the signal into an 11.424 GHz train of ~50 ps pulses that are synchronized with the linac's master clock signal, and AM 2 carves the pulse train into a macropulse pattern. The pulses then each acquire a positive, pseudolinear chirp via 11.424 GHz modulation in a fiber-coupled electro-optic phase modulator, yielding 0.82 nm of compressible bandwidth.

## 3. Preshaping and Amplification

The output of the optical pulse synthesizer is amplified in three successive fiber amplifiers and a cryogenically cooled, Yb:YLF multi-pass amplifier. Gain in the fiber amplifiers is limited by Stimulated Brillioun Scattering induced damage. After the first fiber amplifier, macropulse pre-shaping via Mach Zehnder modulator AM 3 is employed to counteract the square-pulse macropulse distortion from the cumulative gain saturation in each of the amplification stages. The macropulses are downsampled after each fiber amplification stage until the signal passed to the Yb:YLF cryogenic amplifier is, in the case discussed here, a 100 Hz train of 8.75 ns macropulses. After all amplification stages, the macropulses are free of square pulse distortion. The output beam has an average power of 650 mW and, due to gain narrowing in the Yb:YLF cryogenic amplifier, a FWHM bandwidth of 0.12 nm. The beam then passes through a Treacy compressor with an 1850 l/mm reflective grating.

## 4. Nonlinear Pulse Compression and 4$^{th}$ Harmonic Generation

A bulk multi-pass cell (MPC) for spectral broadening [5] with two ~1 µm AR coated, 17.33 mm long H-ZF7LA glass cylinders is employed to compress the IR micropulses before conversion to UV. After 23 round trips in the cell, the IR bandwidth yields an FTL micropulse duration of 1.73 ps. After the MPC, the micropulses are first compressed in a Treacy compressor, and the now 195 mW of IR is converted to 17 mW of 249 nm UV through 4$^{th}$ harmonic generation. After passing through a 500 µm diameter aperture, the UV beam is 4 mW. The aperture, demagnified by 2x, is imaged onto the photocathode to induce a hard-edge beam profile. A Hamamatsu C10910 streak camera (~1 ps resolution in the 100 ps time window mode) reveals 2.0 ps FWHM UV PGL micropulses.

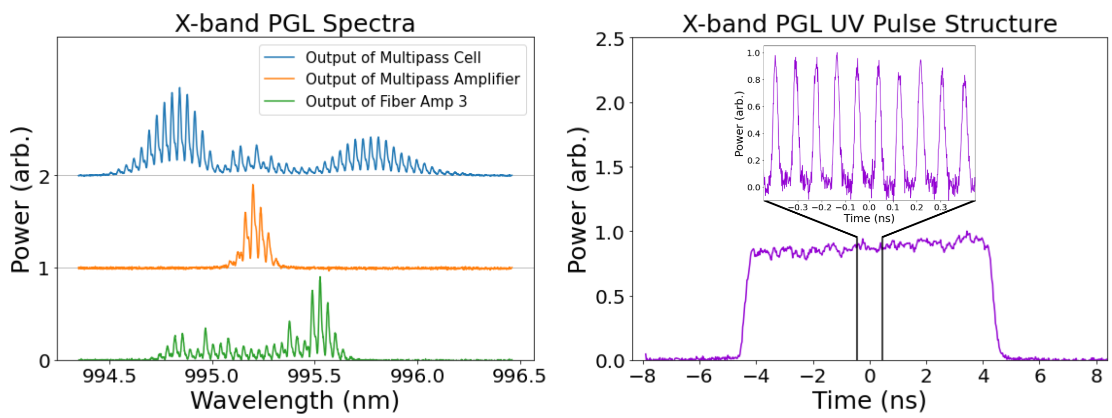


Fig. 2. a. IR spectra at key locations in the photogun laser beamline. The final IR spectrum after the multi-pass cell has a Fourier transform limit of 1.73 ps. b. UV macropulse and micropulses measured with a streak camera.

This X-band architecture can be easily adapted to linacs of other frequencies. Furthermore, it has been demonstrated that this same architecture can produce 87.5 ns, 1000 micropulse-long macropulses at X-band frequency with greater than 10 nC of charge per macropulse, making the system simultaneously capable of producing sufficient current for FLASH radiotherapy. In principle, bunch trains longer than 1000 micropulses may be generated with this architecture.

## 5. References

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