Very High Power* THz Radiation from Relativistic Electrons

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* = Megawatt peak, 20 watt average
Synchrotron Radiation Generation

Synchrotron Radiation Generation - so what's new here?
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Synchrotron Radiation Generation

THz

frequency (cm\(^{-1}\))

watts/cm\(^{-1}\)/mm\(^2\)/sr

∫Pdω=20Watts

- 2000K Black Body
- JLab FEL
- NSLS U4IR 800mA 90x90 mr
- JLab FEL Lasing
Synchrotron Radiation Source at JLab

FUTURE $\rightarrow$ electron storage ring $\rightarrow$ energy storage ring
Jefferson Lab Free-electron Laser Facility

“Energy Storage Ring”

**e-beam Specifications**
- sub-picosecond pulse length
- up to 75 MHz rep rate
- 40 MeV electron energy
Comparing Coherent THz Synchrotron and Conventional THz Sources

Larmor’s Formula: Power = \( \frac{3e^2a^2}{2c^3} \gamma^4 \) (cgs units)

**Auston switch**

\( \sim 100 \text{ V} \)

GaAs

\( E = \frac{100V}{10^{-4} \text{ m}} = 10^6 \text{ V/m} \)

\( a = \frac{F}{m} = \frac{10^6 \text{ V} \cdot e/m}{0.5 \text{ MeV} / c^2} = 10^6 \times \left( 3 \times 10^8 \right)^2 \frac{1}{0.5 \times 10^6} \)

\( \cong 10^{17} \text{ m/sec}^2 \)

**Synchrotron radiation**

\( e^- \rightarrow 40 \text{ MeV} \)

GaAs

\( a = \frac{c^2}{\rho} = \left( 3 \times 10^8 \right)^2 \frac{1}{0.5 \times 10^6} \cong 10^{17} \text{ m/sec}^2 \)

if \( \rho = 1 \text{ m} \)
Comparing Coherent THz Synchrotron and Conventional THz Sources

Larmor’s Formula: \( \text{Power} = \frac{3e^2a^2}{2c^3} \gamma^4 \) (cgs units)

\[ \text{Power} \propto \gamma^4 \]

Synchrotron

To compare radiation in the THz region, \(~40\) MeV electrons will get the critical energy into the IR. So,

\[ \gamma \approx 75 \]

\[ \gamma^4 \approx 10^7! \]

Relativistic electrons gain a huge factor in THz power.
Jefferson Lab Light Source Facility
Jefferson Lab FEL Superconducting Linac
Superconducting Radio-Freq. Linac
Jefferson Lab FEL Wiggler
Coherent THz measurement setup

We measured the bend-magnet synchrotron radiation right before the FEL, when the beam is maximally compressed.
Coherent THz measurement setup

- Crystal quartz window
- Collimating optic
- Nicolet Nexus 670 FTIR bench
- LHe cooled Si bolometer detector
Coherent THz compared to thermal source

![Graph showing measured intensity of coherent THz compared to a thermal source. The graph includes data from JLab scaled to 4.6 mA, JLab measured at 0.02 mA, and a 1400 K Thermal Source (Globar™).]
Quadratic Dependence of THz Emission on Current

Integrated THz Intensity (arb. units)

Current (µA)

Measured intensity

Fit to (Current)$^2$
Expected polarization ratio for 60 mrad port at 30 cm$^{-1}$ is 6:1.

We observed 5:1. Good agreement.
“Noise” vs. frequency

Bolometer detector output into a spectrum analyzer. FTIR scanning mirror turned off.

- JLab THz Beam
- Beam Blocked

Frequency (Hz) vs. dB V
Simultaneous production of THz, 3 µm, and 10 keV X-ray femtosecond pulses

- 800 fsec pulses at 37.4 MHz
- Synchronized to <<psec levels (same beam!)
- All three wavelengths at world class fluxes

THz pulses, ~20 W total power

3 micron lasing >1 kW

10 keV X-ray > 10^7 ph/sec/0.1% BW
The Future

- New accelerator with 10mA of average current
- Large THz extraction port (150 mr x 150 mr)
- Simultaneous IR light – electro-optic detection
- Dedicated laboratory
Jefferson Lab FEL Upgrade

Photo-cathode gun

3 s-c linacs

THz

Energy Recovery Loop
New THz facility in JLab FEL building
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