Very high Power THz radiation from Relativistic Electrons

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Abstract --**We report the production of high power (20 watts average, ~1 Megawatt peak) broadband THz light based on coherent emission from relativistic electrons. We describe the source, presenting theoretical calculations and their experimental verification. For clarity we compare this source with one based on ultrafast laser techniques.**

I. INTRODUCTION

We describe a program to develop and characterize broadband THz sources at the Free Electron Laser (FEL) facility at Jefferson Lab. This laboratory operates the first of a new generation of light sources based on a photo-injected Energy-Recovered, (superconducting) Linac (ERL)[1]. The machine for which we report the present data had the capabilities of generating a 48 MeV electron beam with sub-picosecond bunches at a repetition rate up to 75 MHz and at an average current of up to 5 mA. These electron bunches passed a chicane around the optical cavity, and therefore emitted synchrotron radiation.

In general, when an electron bunch length approaches that of the wavelength of the light being emitted, the entire bunch radiates coherently[2] generating a broadband spectrum as will be seen later.

For an accelerated electron the power produced is given by Larmor's formula[3] which in CGS units takes the form:

$$Power = \frac{2e^2a^2}{3c^3}\gamma^4 \quad (1)$$

where e is the charge, a is the acceleration, c the speed of light and γ is the ratio of the mass of the electron to its rest mass. For a conventional Austin switch THz emitter based on a laser pulse striking GaAs, the acceleration is identical to our emitter, but in our case γ is 75, yielding a considerable enhancement.

II. CALCULATIONS AND RESULTS

Details of the theory have been presented elsewhere[4], and further details will be presented in an upcoming paper, but in Fig. 1 we present calculations of the total power emitted by a 500 fsec fwhm electron bunch in units of (average) watts/cm^{-1} over the range 1-10,000 cm^{-1}, or 1 centimeter to 1 micrometer. We assumed the electron

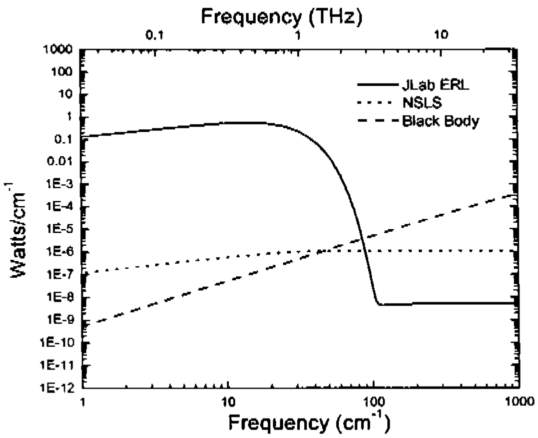
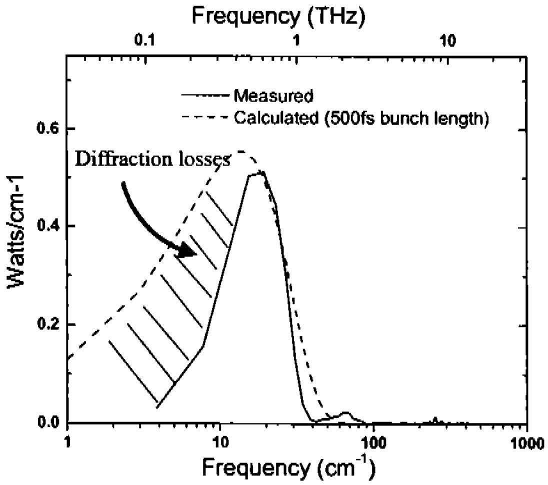


Figure 1

bunches had an energy of 40 MeV, carried a charge of 100 pC, and that they passed through a 1 m radius bend at a 37.4 MHz repetition rate. In the same figure we compare two other broadband sources, namely a 2000K thermal source, and the National Synchrotron Light Source U4IR facility[5] at Brookhaven National Laboratory. The superiority of the JLab ERL and the onset of the coherent emission are evident for frequencies < 100 cm^{-1}.

In Fig. 2, we present the results of our measurements and a comparison with our calculation. The spectral content of the emitted THz light was analyzed using a Nicolet 670 rapid-scan Michelson



interferometer and detected using a 4.2K Infrared Laboratories bolometer. Our collection angle was 60 × 60 milliradians and the extraction window was quartz. We were able to determine the absolute power in two ways, one using a calibrated pyro-electric detector, and one by comparing our spectra with that from a 1300K thermal source. The data has been scaled on the basis of these absolute power measurements.

III CONCLUSIONS

The spectral onset of the super-radiant enhancement of the THz light is clearly seen on the high frequency side. The onset shape is also seen to match closely the theoretical predictions. Note that there is a severe discrepancy on the lower frequency side due to diffraction effects. This can be understood in the following way. At 10cm^{-1} and with an f/17 beam, the diffraction-limited source size is 17 mm, almost the same as the extraction optics. At 1 cm^{-1}, the diffraction-limited source size would, at 170 mm, be more than 3 times larger than the vacuum chamber containing the electron beam!

We are now planning an upgrade to the facility at Jefferson Lab in which we will considerably upgrade the THz extraction aperture. The upgraded accelerator will also carry twice the average current and have the capability of stronger bunch compression which will lead to spectra extending to higher frequencies.

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