Coherent Transition and Smith Purcell Radiation Experiments

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Abstract. We review results from radiation experiments done at MIT on the Haimson Research Corporation (HRC) 17 GHz linear accelerator. Both Smith-Purcell radiation (SPR), and Coherent Transition radiation (CTR) were observed. To understand SPR, an Electric Field Integral Equation (EFIE) method was developed and confirmed with an experiment. Because our linac produces a train of bunches, radiation was only observed at integer multiples of the RF frequency. New measurements made on CTR show excellent agreement with EFIE expectations, on an absolute scale, and also provide a bunch length measurement. The possibility for an absolute scale bunch length measurement is confirmed with a proof of principle experiment. Future extension of the EFIE code and corollary experiments are discussed.

Keywords: transition radiation, Smith Purcell radiation, bunch length diagnostics
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INTRODUCTION

Experiments were conducted on the HRC 17 GHz linac at MIT. A single high power modulator [1] operates both the 17 GHz relativistic traveling wave klystron [2], and the DC linac gun. The DC linac beam is chopped and pre-bunched prior to injection into a dual feed 0.5 m traveling wave linac section [3]. The resulting beam is very high quality, with a measured emittance of 2.5 π mm-mrad, and a spot size of order 1 mm. This beam and RF source are used for a number of experiments, including the discussed diagnostic experiments using Smith-Purcell and Transition Radiation.

Transition radiation is produced when a charge passes through a thin metallic foil. SPR occurs when a charge passes above a periodic metallic structure, a grating. Though similar, they differ with respect to the frequency content of the radiation. TR is produced in a ~$1/\gamma$ cone with flat spectrum up to ~ω_p/γ [4]. SPR, on the other hand is produced at the fundamental harmonic according to the resonance condition:

$$\lambda = \ell\left(\frac{1}{\beta} - \cos\theta\right), \quad (1)$$

where the wavelength λ is related to the period ℓ of the grating, the relativistic factor β, and the observation angle θ [5].

SPR was used to measure the bunch length by measuring the radiation as a function of observation angle with a Helium cooled bolometer. These arbitrary unit

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measurements were compared with theory to determine the bunch length [6]. Detailed frequency measurements revealed that radiation was only produced at integer harmonics of the RF frequency, a form of frequency locking [7]. In the course of performing the experiments, a more accurate code was developed to analyze the SPR. An EFIE method was used to take into account the finite length of the grating [8-10]. In order to test this code, a grating was designed to emphasize the differences predicted by the code. Experiments were carried out with good agreement [11].

EXPERIMENTAL RESULTS

Experimental research was conducted to observe frequency locked CTR. A 5cm square titanium foil was placed at 45° to the beam. Radiation was extracted through a window, for which loss measurements were made in the frequency range of observation. A video diode detector was used with a matching horn antenna. This detector setup was scanned angularly across the window at a distance of 1 m from the foil center and beam.

CTR measurements were taken and results were found to agree quite well with EFIE code predictions as shown in Fig. 1. In Fig. 1, the theoretical power levels were calculated for radiation in the 110-170 GHz band, so that the comparison with experiment is on an absolute scale, not a relative scale.

TR has been used as a bunch length diagnostic due to the relatively flat frequency spectrum, which allows the coherent structure of CTR to be observed. Due to frequency locking, radiation from a train of bunches is produced at only integer harmonics of the RF frequency. These harmonics were observed with a double heterodyne system, after [6-7]. Results are shown in Fig. 2 for all peaks observed. Gaps occur because of the limited local oscillator frequency range. The linear fit to the data points returns a slope equal to the RF accelerator frequency of 17.14 GHz, as expected.

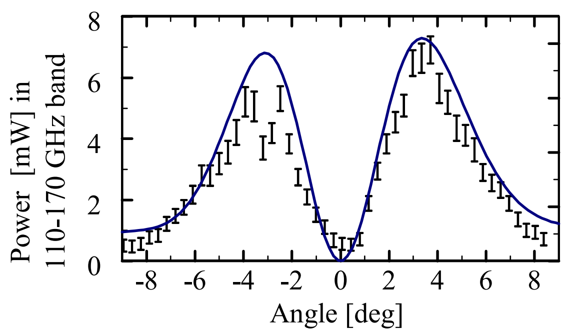

FIGURE 1. EFIE code shown by solid line with WR6 diode measurements shown by bars.

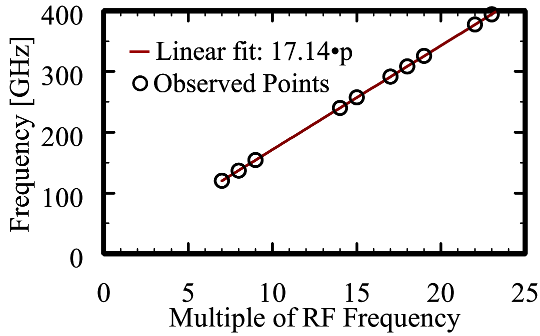

FIGURE 2. Frequencies observed with double heterodyne system shown with linear fit.

Frequency locking can be observed at power levels limited by the sensitivity of the detector, and that limit can be used to determine the bunch length, as shown in Fig. 3. The highest harmonic of radiation detected was 377.08 GHz, which corresponds to the 22nd harmonic of the RF frequency of 17.14 GHz. This gives an estimated bunch length of 1 +/- 0.2 ps.

FUTURE PLANS

The current version of the EFIE code calculates the radiation emitted when a charge passes above an arbitrary two dimensional surface, which is finite in height and length, but remains infinite in width. A natural extension of the EFIE code would be to calculate the radiation from a fully three dimensional surface. This extension may be quite computationally intensive though, and the added benefit may be slight. An experiment is planned to determine the effect of grating width on SPR.

The ultimate use of an accurate EFIE code is to use its predictive capability as a bunch length diagnostic. With this method, single bunch and single shot measurements would be possible. A proof of principle experiment was performed with the same grating used to confirm the EFIE code.

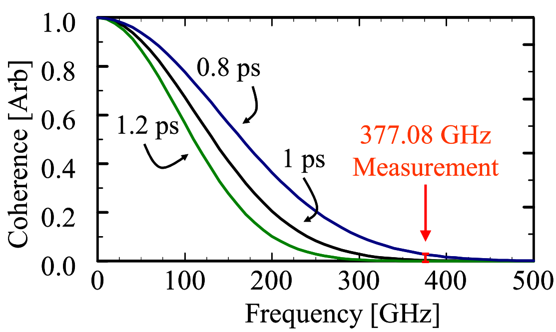

FIGURE 3. Bunch length measurement based on CTR heterodyne measurement sensitivity.

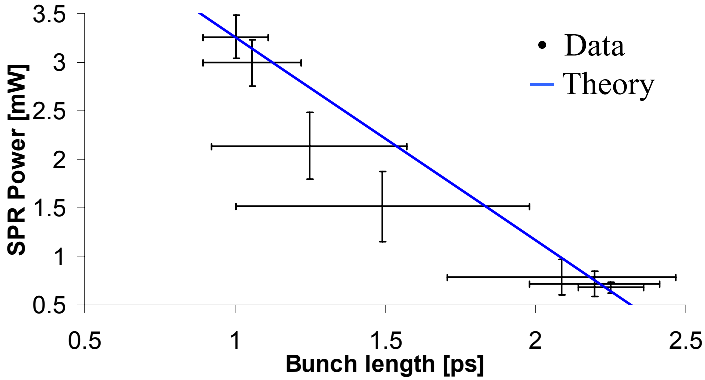

FIGURE 4. WR6 diode measurements for various bunch lengths, bars, compared with EFIE expectations, solid line.

Results are shown in Fig. 4 and are in good agreement with theoretical expectations. A new grating is currently being designed to measure sub-picosecond bunches. Theoretical expectations for one such grating are shown in Fig. 5. The large variation of power level with bunch length makes this method possibly quite sensitive.

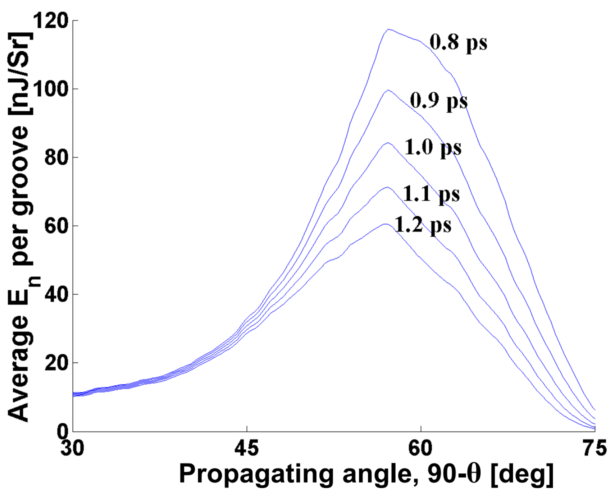

FIGURE 5. SPR power level predicted by EFIE code as a function of observation angle, for various bunch lengths.

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