TERAHERTZ DIAGNOSTIC FOR THE ADVANCED PHOTON SOURCE PARTICLE ACCUMULATOR RING

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ABSTRACT

- For the Advanced Photon Source Upgrade, we require accumulation of charge in a single bunch up to 20 nC [1].
- Electron beam microbunching instabilities can present operational limits on the practical operation of storage ring accelerators, and measurement and control may be important.
- In the present work, we outline components of a synchrotron radiation diagnostic beamline for the Advanced Photon Source Particle Accumulator Ring operating at frequencies up to approximately 1 THz.

MOTIVATION

- The intensity of coherent synchrotron radiation (CSR) is dependent on the longitudinal bunch profile.
- Observation of CSR can provide a sensitive diagnostic tool to detect instabilities.
- We propose an extension of the optical synchrotron radiation diagnostics port to support the detection of long wavelengths of incoherent synchrotron radiation (ISR) and CSR in the terahertz range, without installing a new beam port and without disturbing existing optical synchrotron radiation diagnostics.

THEORY

- Chosen spatial separation of the terahertz and optical frequencies because of the different opening angles of synchrotron radiation.
- Approximation to the vertical opening angle [2]:

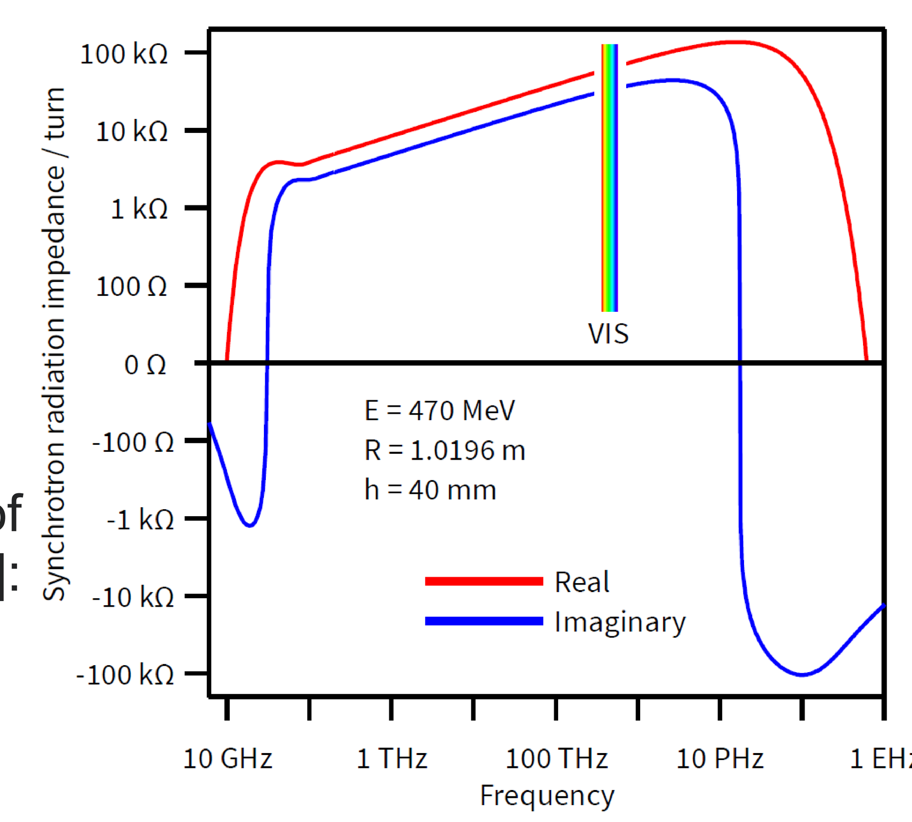
$$\Theta_{\text{vert}} = 1.66188 \times \left(\frac{c}{fR}\right)^{\left(\frac{1}{3}\right)} \text{[rad]}$$

- f is frequency, R is bending radius.
- Cutoff frequency f_{cutoff} incorporating the formation length of synchrotron radiation is given by [3]:

$$f_{\text{cutoff}} = \sqrt{\frac{\pi}{6}}\, c \sqrt{\frac{R}{h_c^3}}$$

- h_c is vacuum chamber height

Figure 1: Simulated longitudinal impedance due to synchrotron radiation for an electron between two infinite, conducting, parallel plates in a PAR dipole.



APPARATUS

- In-vacuum mirror assembly and transmission viewport to direct terahertz radiation to a suitable terahertz detector system.

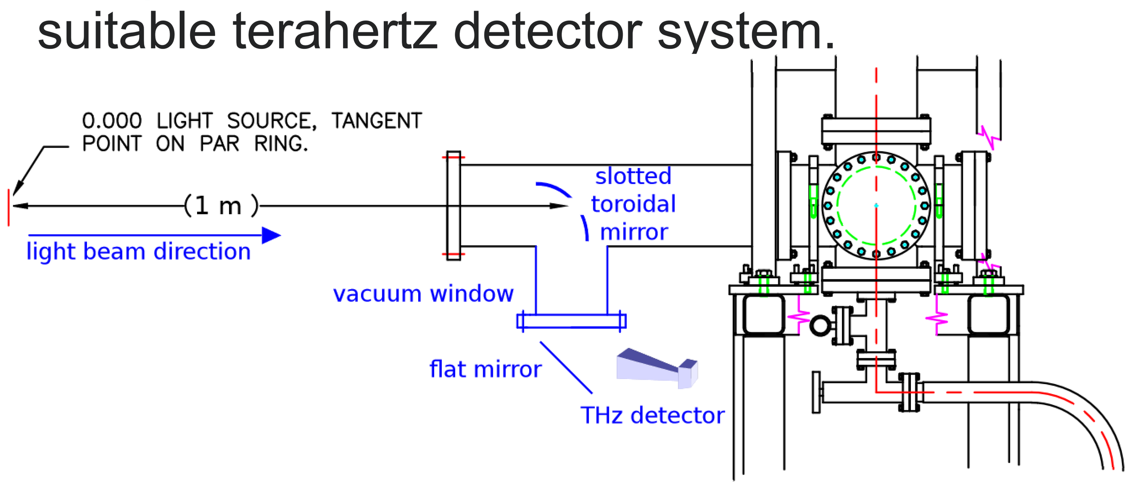


Figure 2: Schematic of terahertz diagnostic apparatus in the APS PAR. Implementation is limited to the replacement of a single spool piece that is part of the existing PAR photon monitor vacuum transport line.

- The proposed terahertz diagnostic mechanical assembly is illustrated in Fig. 3.

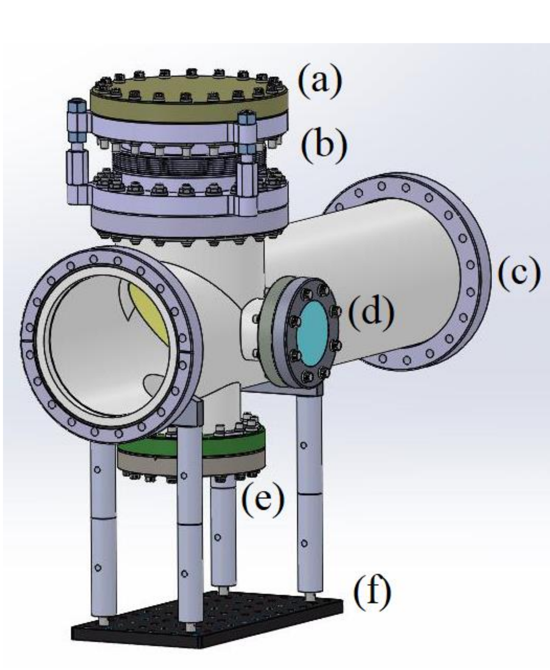


Figure 3: Overview of terahertz diagnostic principal components. The chamber replaces a spool piece on the optical photon monitor of the PAR. (a) Mirror assembly. A toroidal mirror is used to reflect terahertz radiation out of the quartz crystal mirror, where a detector is positioned. The fixed toroidal mirror has a clear aperture centered on the axis of the optical path to allow simultaneous transmission of the visible SR light through the chamber to the existing PAR photon monitor. (b) Bellows. (c) Stainless steel chamber weldment. (d) Optical viewport. (e) Quartz crystal window. (f) Al breadboard and optical posts.

FEATURES

- Focussing of Terahertz Radiation at Detector
  - A magnification of 0.3 leads to a focus point $0.3\ \text{m}$ after the mirror. This is achieved by a focal length of 231 mm. The focal length requires a horizontal radius $R_h = 653\ \text{mm}$ and vertical radius of $R_v = 326\ \text{mm}$.
- Optical Light Beamline Optical Stay Clear
  - Simulations in Synchrotron Radiation Workshop (SRW) [4].

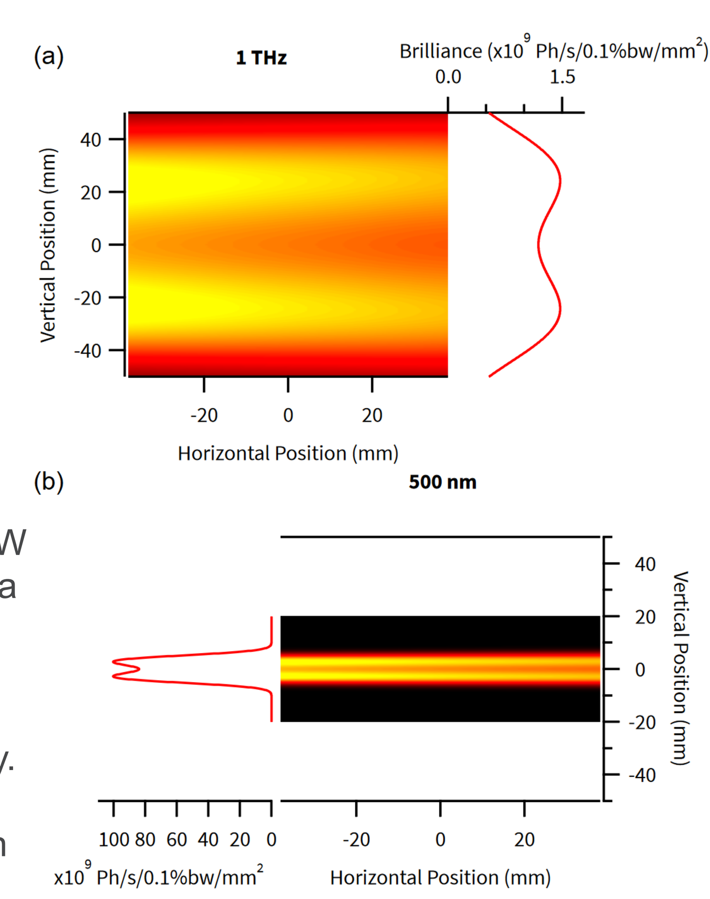


Figure 4: Simulations in SRW [4] of the beam profile from a single electron (point-like source). (a) Spatial distribution of synchrotron radiation at 1 THz frequency. (b) Spatial distribution of optical synchrotron radiation at 500 nm wavelength.

- Transparency of Terahertz Window
  - Frequency range of interest 50–2000 GHz.
  - Single crystal SiO_2 (quartz) window.
  - A z-cut orientation is specified to maintain the polarization of the beam in the presence of a birefringent quartz window.

DETECTOR

- Detector
  - At this initial proof-of-principle stage, the bandwidth of the detector system should be at the frequency where the highest flux is expected.
  - While the emitted power at the lower frequencies is expected to be higher, terahertz beam transport is more efficient for higher frequencies.
  - The detector architecture is summarised schematically in Fig. 5 below.

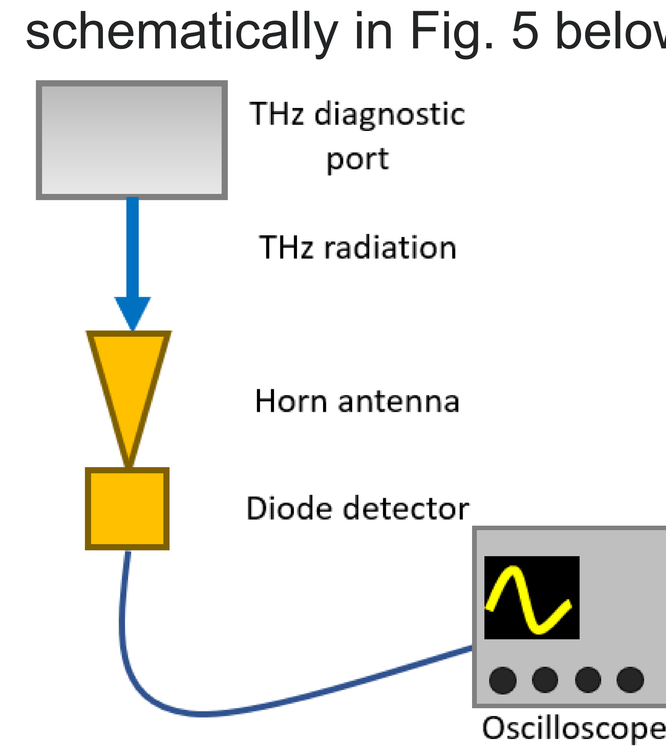


Figure 5: Schematic of detector arrangement for the PAR terahertz diagnostic during the initial phase.

- Detector Signal Amplification
  - The detector amplifier should not degrade the analog performance of the detector and should be sufficiently fast to observe the bunchlets from the linac.
  - Requires at minimum a frequency of $3\ \text{GHz}$.

SUMMARY

- A sub-terahertz beamline has been designed, and is in the process of fabrication and installation in the PAR ring at the APS. This beamline could be used as a diagnostic for beam instabilities in the PAR ring.
- Beyond the use of CSR for the detection of microbunching instabilities, CSR is also a useful source of infrared radiation.

ACKNOWLEDGEMENTS

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