ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-TUT01

SUPERRADIANT AND STIMULATED-SUPERRADIANT EMISSION OF BUNCHED ELECTRON BEAMS

A. Gover, Tel-Aviv University, Tel-Aviv, Israel
R. Ianconescu, Tel-Aviv University, Tel-Aviv and Shenkar College, Ramat-Gan, Israel
Friedman, Ariel University, Ariel, Israel
C. Emma, N. Sudar, P. Musumeci and C. Pellegrini, UCLA, Los Angeles, CA, USA

Abstract

We outline the fundamental processes of coherent radiation emission from a bunched charged particles beam [1]. In contrast to spontaneous emission of radiation from a random electron beam that is proportional to the number of particles N, a pre-bunched electron beam emits spontaneously coherent radiation proportional to N^2 through the process of (spontaneous) superradiance (SP-SR) (in the sense of Dicke's [2]). The SP-SR emission of a bunched electron beam can be even further enhanced by a process of stimulated-superradiance (ST-SR) in the presence of a seed injected radiation field. These coherent radiation emission processes are presented in term of a radiation mode expansion model, applied to general free electron radiation schemes: Optical-Klystron, HGHG, EEHG, and coherent THz sources based on synchrotron radiation, undulator radiation or Smith-Purcell radiation. The general model of coherent spontaneous emission is also extended to the nonlinear regime - Tapering Enhanced Stimulated Superradiance (TESSA) [3], and related to the tapered wiggler section of seed-injected FELs. In X-Ray FELs, these processes are convoluted with other effects, but they are guidelines for strategies of wiggler tapering efficiency enhancement.

MANUSCRIPTS

This tutorial lecture is based on a recently published review article [1] that details the physics and state of the art of research on the subject of superradiant emission of bunched electron beams, and particularly pre-bunched beam FEL. The readers are referred to this article for detailed presentation. Here is a short summary of the contents and conclusions of the tutorial lecture.

The fundamental coherent radiation emission processes from a bunched charged particles beam were outlined. In contrast to spontaneous emission of radiation from a random electron beam that is proportional to the number of particles, a prebunched electron beam can emit spontaneously coherent radiation proportional to the number of particles—squared, through the process of (spontaneous) superradiance (SP-SR) (in the sense of Dicke's [2]), as shown in Fig. 1.

In the presence of a seed-injected radiation field, the coherent SP-SR emission of a bunched electron beam can be even further enhanced by a process of stimulated superradiance – ST-SR.

In this review, these fundamental coherent radiation emission processes were considered for both single bunch and periodically bunched beams in a model of radiation mode expansion. The general model of coherent spontaneous emission was extended to the nonlinear regime, particularly for undulator (wiggler) interaction, where an exceedingly efficient radiative energy extraction process has been identified [3]: "Tapering-Enhanced Stimulated-Superradiant Amplification" (TESSA) (see Fig. 2).

Processes of SP-SR and TESSA take place also in tapered wiggler seed-injected free-electron lasers (FELs). In such FELs, operating in the x-ray regime, these processes are convoluted with other effects. However, these fundamental emission concepts are still useful guidelines for the strategy of wiggler tapering efficiency and power enhancement.

Based on this model, previous theories and experiments were reviewed on coherent radiation sources based on SP-SR (coherent undulator radiation, synchrotron radiation, Smith-Purcell radiation, transition radiation etc.) in the THz regime, and other on-going works on tapered wiggler efficiency-enhancement concepts in all optical frequency regimes up to UV and x rays.

Spontaneous Emission	Spontaneous Superradiance
(Shot-Noise Radiation)	P-SR

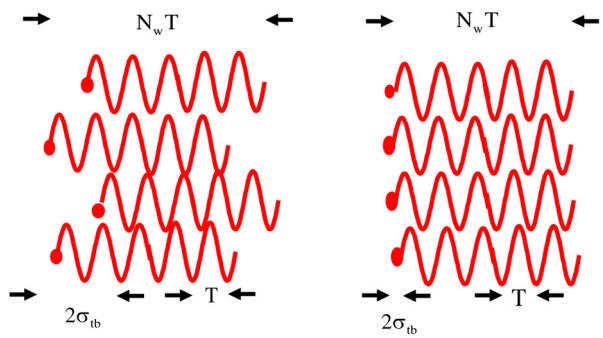

Figure 1: Coherent (right) vs. Random (left) superposition of radiation wavepackets.

ISBN: 978-3-95450-210-3 doi:10.18429/JACoW-FEL2019-TUT01

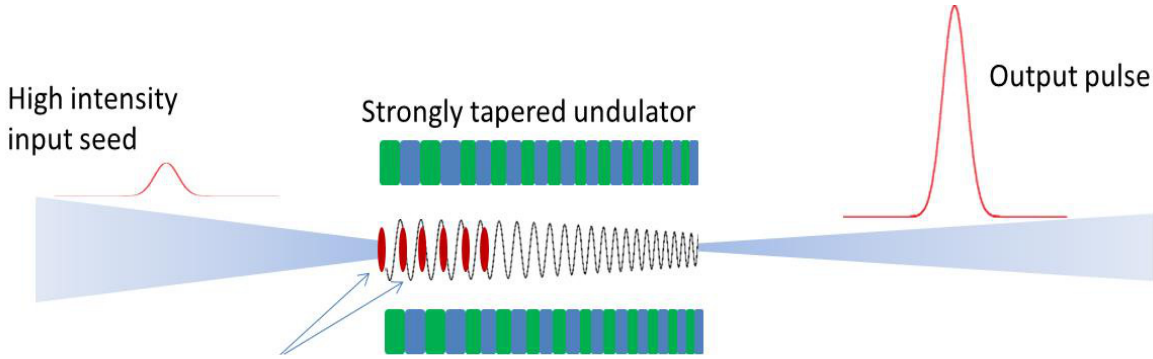

Figure 2: Tapering Enhanced Stimulated Superradiant Amplification - TESSA.

CONCLUSION

1. Fundamental radiation emission processes of bunched beam at zero order:

-Spontaneous Superradiance (SP-SR) $\propto n^2, z^2$

-Stimulated Superradiance (ST-SR) $\propto n, z, E(0)$

2. A. Model of periodical tightly bunched e-beam interaction with a single radiation mode in the nonlinear regime was used to describe:

   -SR and ST-SR in a uniform wiggler.
   -Tapering Enhanced Superradiance (TES),
   -Tapering Enhance Stimulated Superradiance Amplification (TESSA) and Oscillation (TESSO).
3. Presented self-interaction of a bunched beam in a uniform wiggler and seedless TESSA concepts.
4. Reviewed application of THz superradiant sources based on SR emission by sub-picosec bunches.
5. Reviewed applications of TESSA, TESSO in the THz to UV frequencies range.
6. Related to optimization of tapering strategy in the tapered wiggler section of X-Ray FELs.

ACKNOWLEDGEMENTS

This research was supported in part by a grant from the United State-Israel Binational Science Foundation (BSF), Jerusalem, Israel, the Israel Science Foundation (ISF), and the German-Israeli Project Cooperation (DIP)

REFERENCES

[1] A. Gover, R. Ianconescu, A. Friedman, C. Emma, N. Sudar, P. Musumeci and C. Pellegrini, "Superradiant and stimulated-superradiant emission of bunched electron beams ", *Review of Modern Physics*, vol. 91, no. 3, p. 035003, 2019. doi:1 0.1103/RevModPhys.91.035003

[2] R. H. Dicke, "Coherence in Spontaneous Radiation Processes", *Phys. Rev*., vol. 93, p. 99, 1954. doi: 10.1103/PhysRev.93.99

[3] N. Sudar *et al*., "High Efficiency Energy Extraction from a Relativistic Electron Beam in a Strongly Tapered Undulator", *Phys. Rev. Lett*., vol. 117, p. 174801, 2016. doi:10.1103/PhysRevLett.117.174801