# The Radiation of Two Dimension Dipole Oscillations in Subwavelength Hole Array

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**Abstract:** *Smith-Purcell radiation is a kind of moving dipole oscillation radiation. In the subwavelength hole array, there are two-dimension dipole oscillations to happen when the e-beam is moving through the holes in a beam channel. It leads to the Smith-Purcell radiation energy enhanced, compared to one dipole oscillation in electron beam moving above period occurred metal surface. In addition, the dipole oscillation radiation takes place inside the hole, so the hole also plays a role to resonant the radiation so that the Smith-Purcell radiation has a good direction. Therefore, the radiation of two-dimension dipole oscillations in subwavelength hole array form a kind of Smith-Purcell radiation with intensity enhanced and the radiation direction tuned. It has potential to develop the vacuum electrons device based on Smith-Purcell radiation, such as Orotron, on-table THz free electron laser.*

**Keywords:** subwavelength holes array; moving dipole oscillation; Smith-Purcell radiation

## Introduction

Subwavelength holes array (SHA) has the import applications in optics and bio-sensing, and it becomes an attractive structure in modern physics research. Compared to light excitation, the SHA excited by moving electron beam has unique character [1-5], for example, the two-sides diffraction radiations, and the two-sides surface plasmons coupling, which has been used for the THz radiation source.

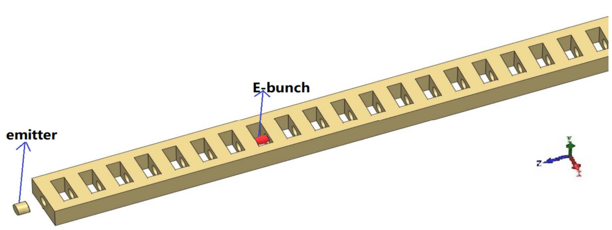


**Figure 1.** The schematic of moving electron beam passing through subwavelength holes array.

Before, the electron beams always passed above SHA, the unique two side diffraction is studied. However, the Smith-Purcell radiation is also from one-dimension dipole oscillation. Here, we drilled a hole through the holes of SHA in the Z direction as shown in Figure 1. Then we use an electron beam to pass through it. Two dimension dipole oscillations are excited.

The Smith-Purcell (SP) radiation from the moving two-dimension dipole oscillations has an intensity enhanced, and the radiation direction has also been controlled by the resonance character of the holes of SHA [6,7]. In order to study the SP radiation in THz, we use a SHA with the period L=200μm.

## Physical Mechanism

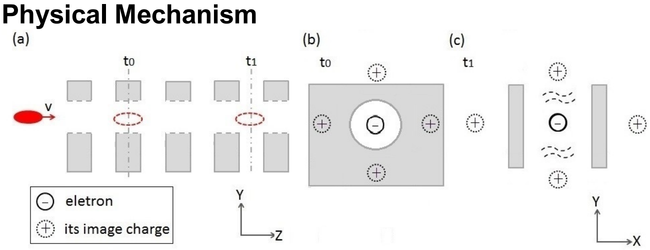


**Figure 2.** The radiation of two dimensions dipole oscillations in subwavelength hole array.

First, physical mechanism of two dimensions dipole oscillation has been studied. When electron pass through the holes, the four image charges will be introduced. When the electron moving through the holes periodically in z direction, the electron and the four image charges will form four moving dipole oscillations in two dimensions which are shown in Figure 2. It is the reason of SP radiation enhancement.

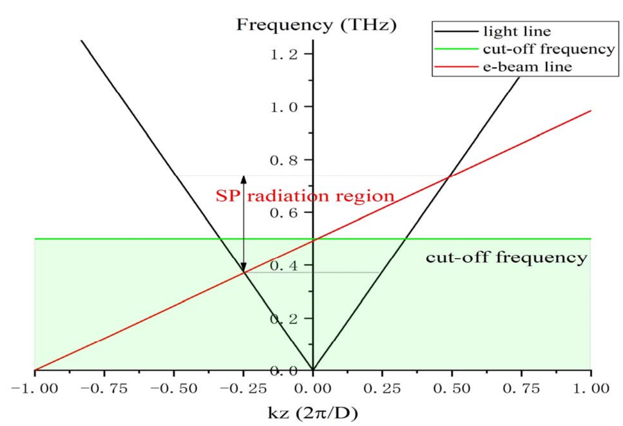


**Figure 3.** The Smith-Purcell radiation region (red line) and cut-off frequency (green line) are shown in the Brillouin diagram. The period is 200μm, and the hole length a is 300μm. The electron bunch energy is 30 keV.

The electron beam channel is inside the SHA, it means the radiation character is also effected by the hole size. One of the influences is the resonance, and the other is the extraordinary transmission. The mode inside the hole is mainly the fundamental mode TE10. The single hole size is a*b, and cut-off frequency of the hole is c/(2*a), c is the light velocity in vacuum. Changing the hole length, a, the cut-off frequency of the hole will be adjusted. In order to analysis the role of hole, in our structure the cut-off frequency is just in the SP radiation region by selecting electrons energy, as shown in Figure 3. It can be predicted that the cut-off frequency of the hole will affect the SP radiation.

## Simulation Study of Smith-Purcell Study

Using the CST Particle In Cell simulation, the role of the hole on the radiation has been revealed. A gaussian shape electron bunch is set with the bunch length and bunch charge *Q*=0.16fC.

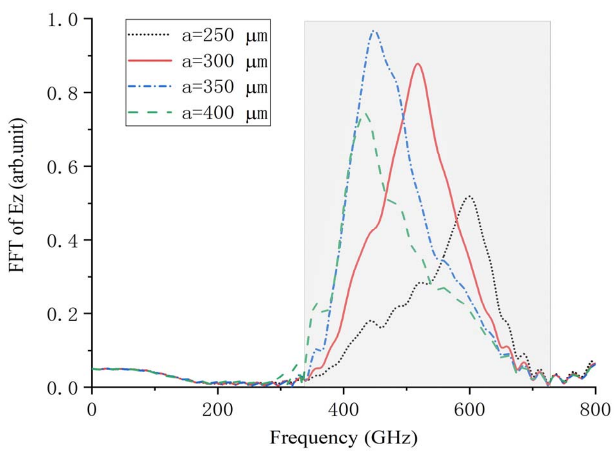


**Figure 4.** The spectrum of SP radiations for different hole lengths *a* excited by the same electron beam energy and SHA period *L*.

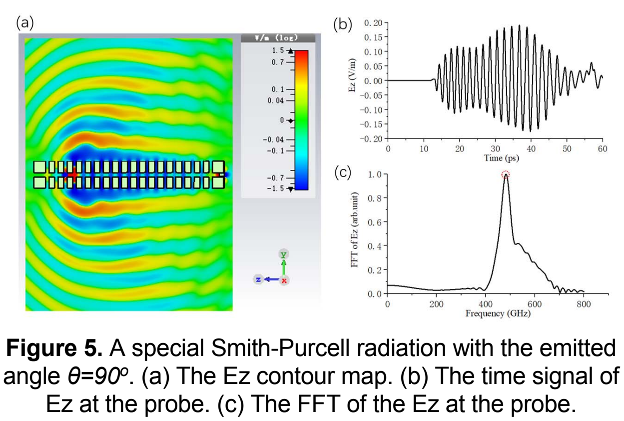


**Figure 5.** A special Smith-Purcell radiation with the emitted angle *θ=90º*. (a) The Ez contour map. (b) The time signal of Ez at the probe. (c) The FFT of the Ez at the probe.

We set a probe above the SHA to get the Ez component of radiation fields. The relation between the radiation fields and the hole length a is shown in Figure 4. The SP radiation band is almost the same, determined by the SHA period L and electron beam energy β, however, the radiation peak is obviously different. It shows that the peak of SP radiation will be decreased with the hole length *a* increasing, which agrees with that the cut-off frequency is decreased with the hole length *a* increasing.

For the vacuum electron device, The SP radiation which can focus the energy on 90º is very important. Here, we use the hole cut-off frequency to tune the SP radiation. When the hole length a is 320μm, the radiation angle is almost on 90º. The Ez contour map, time single and its FFT are given in Figure 5.

## Conclusion

Therefore, the radiation of two dimension dipole oscillations in subwavelength hole array form a special Smith-Purcell radiation, whose intensity is enhanced and radiation angle can be designed by the cut-off frequency of the hole. It is of significance to develop the vacuum electrons device based on Smith-Purcell radiation.

## Acknowledgements

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