“Shadowing” of the electromagnetic field of a relativistic electron

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About the shadow effect

E L Feinberg, SOV PHYS USPEKHI, 1979, 22 (6)

Fig. 2. Bremsstrahlung at a single and double scattering.


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… half-naked electron …
… in ionization loses …

B. M. Bolotovskil
Preprints of Lebedev Institute of Physics, Russian Academy of Sciences, Vol 140 p. 95

X. ARTRU. Interference and shadow effects in the production of light by charged particles in optical fibers.
The Coulomb field (C.F.) is considered as beam of quasi-real photons. The second target is in the shadow of the first one. The Coulomb field is « repaired » after a distance

\[ L \sim \gamma b \sim \gamma^2 \lambda \quad (\lambda \sim b/\gamma) \]
Particle passing through a narrow hole

\[ L = vt \]

\[ b = L/\gamma \]

\[ \lambda \sim b/\gamma \]

\sim\text{Figs.1.1,2.4 of } High\ Energy\ Electrodynamics\ in\ Matter,\ by\ Akhiezer\ and\ Shul’ga
Particle passing near a half-screen

Difference with the last figure:
only one side of the Coulomb field was removed.

THIS NEED TO BE TESTED EXPERIMENTALLY!
Another point of view of shadowing

The Coulomb field (C.F.) of the particle and the Forward diffracted radiation (FDR) interfere destructively.

→ Shadow effect is a rescattering effect (like the dynamical effect in PXR)
Shadow effect in Smith-Purcell radiation

*Example*: periodic set of foils.

Adding the single-foil Diffraction Radiation amplitudes (i.e., neglecting the shadow effect) leads to **over-estimate** the radiated energy.
Another example of light production:
Capture of virtual photons in an optical fiber
(X. A., C. Ray, RREPS’O7)
Regularly spaced balls:
→ *free* and *guided* Smith-Purcell radiations

Due to *shadowing*, the free and guided wave amplitudes are *less* than the *coherent addition* of single-ball amplitudes.
Possible « universal » bound for Smith-Purcell Radiation

Can one increase the total linear power \( \frac{dW}{dz} \) of a S.P. radiator?

- decrease the groove spacing?
- increase the groove depth?

In both cases shadowing will take place!
This suggests an universal upper bound for \( \frac{dW}{dz} \):

\[
\frac{dW}{dz} < C \frac{Z^2 \alpha}{b^2} \quad (\text{for } \gamma >> 1),
\]

where \( b \) is the impact parameter and \( C \) a numerical constant, independent from
the radiator material.

- this bound is independent on \( \gamma \).
- it applies to the total energy loss:

\[
W = \text{radiated energy} + \text{absorbed energy}.
\]
Rough derivation of the bound

- Total energy in *Diffraction Radiation* from a single foil:

\[ W = \frac{3}{8} \gamma Z^2 \alpha / b \quad (\hbar / 2\pi = c = 1 ; \alpha = 1/137) \]

- Necessary length to « repair » the Coulomb field:

\[ L_{\text{min}} \sim \gamma b \]

The maximum energy is obtained when the foils are spaced by \( L_{\text{min}} \),

\[ (dW/dz)_{\text{max}} = W / L_{\text{min}} \sim \frac{3}{8} Z^2 \alpha / b^2, \]

this gives \( C \sim 3/8 \)

Theoretical question:
- Can this bound be proven rigorously, and eventually improved?
Tomsk experiment: Shadowing effect observation using diffraction radiation
Use **bunch-coherent** radiation:
- to increases the signal by several (~8) orders of magnitude
- to make the incoherent backgrounds unimportant
**Tomsk microtron electron beam**

**Beam parameters**

- **Bunch**
  - \(N \approx 10^8\)
  - \(\sigma_l \approx 1.6 \text{ mm}\)
- \(\lambda > 9 \text{ mm}\)
- Coherent radiation

**Formation length**

\[
\frac{\gamma^2 \lambda}{4} \approx \frac{12^2 \cdot 11}{4} \text{ mm} = 0.4 \text{ m}
\]

**Electron field size**

\[
E_{\lambda} \approx 2\gamma\lambda
\]

\(\gamma\lambda \approx 12 \cdot 11 \text{ mm} = 130 \text{ mm}\)

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Experimental equipment and technique

**Beam parameters**

- **Electron energy**: 6.1 MeV
- **Macro-pulse duration**: 2~6 ms
- **Pulse repetition rate**: 1~8 Hz
- **Micro-pulse length**: ≈ 6 mm
- **Electrons number per micro-pulse**: ≈ $10^8$
- **Micro-pulses number per macro-pulse**: ≈ $10^4$
- **Beam size at the output**: 4×2 mm²
- **Emittance: horizontal**: $3 \cdot 10^{-2}$ mm × rad
- **Emittance: vertical**: $1.5 \cdot 10^{-2}$ mm × rad
**Detector**

Detector parameters:
- Wavelength range: $= 3 \sim 16$ mm,
- Sensitivity = 0.3 V/mWatt

The detector efficiency is declared by the manufacturer in the wavelength region $\lambda=3 \sim 16$ mm as a constant with accuracy ± 15%

$\gamma=12; \quad \lambda=9\sim 17$ mm

**Fig. 4** Dependence of the squared form-factor module on the radiation wavelength for the gaussian longitudinal distribution of electrons in a bunch.
Coherent radiation spectrum

BTR spectrum in wavelength region $\lambda=8\sim15$ mm, using the spectrometer of the grating type

Test of BTR, using the discrete wave filters, type of K. Hanke (CLIC note 298, 19. 04.1996) shows also, that the radiation is absent for $\lambda<9$ mm

So $\lambda>9$ mm
$\gamma=12$
$\gamma\lambda>110$ mm
$\gamma^2\lambda/4>300$ mm
Tests of absorber

• **Test on real photons**
  Test was performed using the 6 mm wavelength radiator

• **Test on pseudo-photons**
  Backward DR angular distribution

- No reflection registered

- Without absorber

- With absorber

No reflection registered
Method of angular distribution measurements

Parabolic telescope was used for angular distribution measurement to exclude the “pre-wave” zone effect contribution.

Experimental results

\( a \) opposite sides

\( b \) same side
BDR angular distribution

Scans on $L$ with step=20 mm (samples, with the same scale)

a) opposite sides

$L=20$ mm

$L=80$ mm

$L=160$ mm

$L=220$ mm

\sim No L dependance!
b) Same side

- **L=20 mm**
- **L=80 mm**
- **L=160 mm**
- **L=220 mm**

Complete shadowing

Partial shadowing
Total dependencies

a) 

b)
Theoretical treatment or FDR and BDR

\( (2 = \text{the mirror}) \)
Theoretical treatment.
FDR from absorber

\[ CF_1 = FDR_1 \cdot r(FDR_1) = FDR_1 \cdot t(FDR_1) \]
What we finally sum

$$t(FDR_1)$$

$$t(CF_2)$$
Résumé

1. The shadowing of an electron electromagnetic field in macroscopic mode was observed; the asymmetry of the shadow was checked.
2. Theoretical calculations of BDR from shadowed electron field have been undertaken (considering the interference of FDR from absorber with BDR from conductive target)
3. Wanted: a rigorous proof (or disprove) of an upper bound of the form $\frac{dW}{dz} < C \frac{Z^2 \alpha}{b^2}$ for the Smith-Purcell power.

Thanks to the organizing committee and to you for attention