Comment on "Measurement of Coherent Cherenkov Radiation from an Intense Beam of a Picosecond Electron Bunch"

In a recent Letter, Ohkuma, Okuda, and Tsumori [1] (OOT) report the observation of coherent Cherenkov radiation produced by a single bunch of 30-MeV electrons. Electrons passing through a Ti foil window traveled a path of 50 cm through air before striking a mirror placed to reflect the radiation to a detector. Broad peaks of radiation were observed at angles larger than the usual Cherenkov angle.

It is the purpose of this Comment to note that in our earlier work on coherent microwave Cherenkov radiation, we explained the angular distribution as a diffraction effect associated with the finite path [2,3]. A change in the index of refraction as assumed by OOT is not required. This diffraction is the result of a finite-length line source whose phase varies linearly along the length of the path, which is associated with the velocity of the electron bunch. In addition, the shape of the charge bunch contributes to the character of the radiation.

We have reported earlier measurements [4] in the S, X, and K microwave regions of the coherent Cherenkov radiation produced by the 100-MeV electron beam of the Naval Postgraduate School (NPS) S-band linac. All of the measurements showed radiation at an angle significantly greater than the Cherenkov angle given by $\theta_C = \cos^{-1}(1/n\beta)$. These measurements are in agreement with our calculations based on the diffraction [3–5] of the radiation.

We have attempted to reproduce the radiation distribution reported by OOT by integration of our single-bunch radiation pattern over their wavelength bands. We have assumed a symmetric trapezoidal charge bunch with an average length of 9 mm (30 ps) and a rise time of 1 mm, $n = 1.00027$, and $E = 30$ MeV. Our formulation for a single bunch gives the radiated energy per unit wavelength range

$$E(\lambda)d\lambda = Q(R/\lambda)^2 d\lambda\,, \tag{1}$$

where $Q = \mu c q^2/8\pi^2$, $R = 2\pi \sin\theta\, \text{sinc}(u) F(\mathbf{k})$, $u = \pi L \lambda^{-1} \times [1/(n\beta)^{-1} - \cos\theta]$, L is the path length, $\mathbf{k}$ is the wave vector, q is the charge in the bunch, and $F(\mathbf{k})$ is the form factor [5].

Figure 1 shows the result of the integration of $(R/\lambda)^2$ using the above parameters over the wavelength range $1.0 < \lambda < 1.4$ mm. The broad peak resulting from a finite-length path has a maximum at an angle of 46 mrad which compares well with the observed peak at 38 mrad. Calculations varying the above parameters show that the radiation pattern is quite stable, the maximum shifting only by a few mrad in each case. Calculations for the larger wavelength range of $0.4 < \lambda < 3.0$ mm give a similar, but more intense, peak with the maximum displaced to 56 mrad, showing the same trend as in Fig. 2 of OOT.

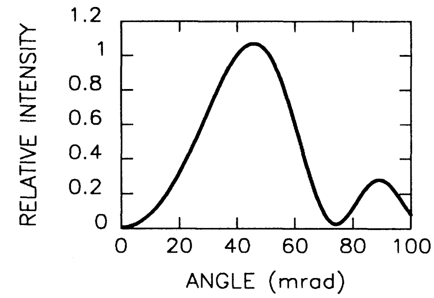

FIG. 1. Diffracted Cherenkov radiation pattern for 30-MeV electrons of average bunch length of 9 mm traveling a 50-cm path, calculated for the wavelength range $1.0 < \lambda < 1.4$ mm. The relative intensity is $(R/\lambda)^2$.

The peaks we calculate are in reasonable agreement with those observed by OOT. Full agreement between calculation and measurement requires knowledge of the beam bunch shape and inclusion of experimental effects such as the beam divergence and detector response. However, our basic point is that the large value for the angle of maximum emission may be explained by diffraction, analogous to single-slit diffraction in optics, and it is not necessary to modify the dielectric constant of air.

We note that for short paths, the phase-matching condition is relaxed, resulting in an increase of power. This may be seen in the expression for R where the sinc^2 function multiplies $\sin^2\theta$, and consequently the radiation diffracts to larger angles where more power appears. Also, in our formulation of diffracted Cherenkov radiation, peaks at larger angles than the main peak are present, as observed [4] at the NPS linac. It would be of interest to see if these smaller peaks could be observed by OOT in a further experiment.

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