

COMPUTER SIMULATION OF THE LASERTRON*

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The concept of the Lasertron can be most easily described by referring to the figures. A short bunch of electrons (short in time compared to the period of an rf cycle), is emitted from the cathode and accelerated by a dc potential toward the anode. An rf cavity, located just past the anode aperture, is the output cavity. The rf frequency is determined by the pulse rate of the electron bunches. Although other types of solid-state cathodes are possible, if a photocathode is used, then the light source will likely be a fast pulsing laser, hence the name "Lasertron." The device cannot be properly called a "Laser klystron" since that name implies the waves of rf current by which a dc beam is bunched. In the Lasertron, the electrons are emitted bunched and it is only necessary to accelerate them before space charge forces cause too much debunching.

The figures illustrate the numerical simulation of, in Case I, a pulsed photo diode with a simple drift tube and, in Case II, a photo diode with an output cavity, *i.e.*, a complete Lasertron. The simulations are made with the particle-in-cell plasma simulation program MASK¹ running on the SLAC IBM 3081.

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The calculable quantities that determine the quality of the device as a generator of rf power are (a) the spread in longitudinal momentum at the location of an output port and (b) the amplitude of the rf current for the fundamental frequency as found by a Fourier analyses of the bunched current. Figure 3 shows the calculated pulse length and momentum spread for the geometry shown in Case I (photo diode and drift tube). The data points shows include one case, for 1000 kV and 1000 A, that is similar to the one-dimensional calculation made by Zhao²; for this case, the 1-D data points are shown just above the plotted curves.

For the 1000 A, 1000 kV case, the 1-D calculation shows a pulse length of 85°, which is in reasonable agreement with the 80° found for the 2-D simulation. Both calculations start with a 60° pulse length although the MASK simulation includes some shaped rise and fall dependence so that the full-width, half-maximum is 60°. The Fourier analysis depends on pulse length; the optimum bunched beam for an rf source would be a delta-function of zero length and infinite current. One would expect the 1-D calculation to be conservative, *i.e.*, to show more debunching, as indeed it does. The longitudinal momentum spread found in the 1-D simulation (about 35% in this case) is much higher than found in the 2-D simulation (about 15%). The longitudinal momentum spread is important to a klystron, and to the Lasertron, because the efficiency of extracting rf energy from the beam depends on retarding the beam in the longitudinal direction without turning many particles back, or alternatively, letting many high momentum particles through to the collector.

The fact that the 2-D simulation shows a much lower momentum spread than does the 1-D case must be related to the 2-D effects and not just to the

more conservative nature of the 1-D calculation. The 2-D effect that appears to account for the difference is the induced retarding axial electric field caused by the generation of the azimuthal self-magnetic field by the relativistic pulse.

If the geometry used for the 2-D MASK simulation had not included the drift tube, but was instead a simple plane parallel-plate diode, then the comparison with Zhao's 1-D calculation would be for identical geometry except for 2-D effects. Then the 1-D calculation would be clearly conservative. The addition of a drift tube to the 2-D case makes the problem more realistic while, of course, allowing more time for the bunch to spread due to space damage. However, at least for the 1000 kV case, the beam is sufficiently relativistic so that this debunching in the drift tube is not very significant.

In Fig. 4, the ratio I_1/I_0 gives the Fourier amplitude of the fundamental frequency, normalized to the dc current. This value would be 2.0 for all harmonics for the optimum infinite delta function, and is 1.9 for the low current 60° bunch. It drops to a still very respectable 1.73 for the worst case; a 1050 A beam at only 500 kV. This result gives reason for optimism that the Lasertron could be a very efficient device.

Case II, a complete Lasertron rf source, is shown in Figs. 5 and 6. Here an rf field has been included at a port part-way down the drift tube. The rf voltage at the port was 450 kV and the phase was adjusted for maximum energy extraction from the electron beam. For this case, the MASK diagnostics show that 28% of the initial beam energy per pulse is finally absorbed on the walls of the drift tube. The remaining 72% is thus extracted as rf energy at the port. This was for a beam current of only 105 A peak, or an average beam power of only 8.75 MW. Even though the beam power in this case was low, the high output

efficiency confirms the arguments given above and is an encouraging sign that the Lasertron could be a very efficiency generator of rf power for future large accelerator projects.

As a final point; we have received a preprint from the INS in Tokyo³ of a preliminary experiment with their "Lasertron Mark I."

REFERENCES

1. A. Drobot, "MASK—A 2-D Particle-in-Cell Program for Electromagnetic Fields and Charged Particles," private communication.
2. Yang-Xiang Zhao, "A One-Dimensional Analyses of a Laser Photo-Electron Microwave Tube," unpublished note, January 1982.
3. Fukushima *et al.*, "Lasertron MARK I," INS-REP-490, March 1984.

FIGURE CAPTIONS

- Fig. 1. The top frame shows the layout of Case I, the photo-diode, to the same scale as the MASK output shown in the rest of the figures. The second frame shows the diode electric field; lines are in the direction of the local field and are proportional in length to local field intensity. The third frame shows a pulse moving from left-to-right.
- Fig. 2. Case I, the photo diode of Fig. 1, is shown in eight sequential views during one rf cycle.
- Fig. 3. Pulse length and momentum spread for the photo diode of Case I, 1050 A and 1000 kV. Points for the 1-D calculation of Ref. 2 are indicated.
- Fig. 4. The ratio I_1/I_0 for a Fourier analyses of the rf current from Case I measured at a "window" about midway in the drift tube.
- Fig. 5. The layout of Case II, a complete Lasertron, is shown in the top frame. The second frame shows the rf fields and the diode fields. The third frame shows a pulse of electrons moving from left to right. This pulse is 105 A peak current at 500 kV.
- Fig. 6. Case II, the Lasertron of Fig. 5, is shown in eight sequential views during one rf cycle.

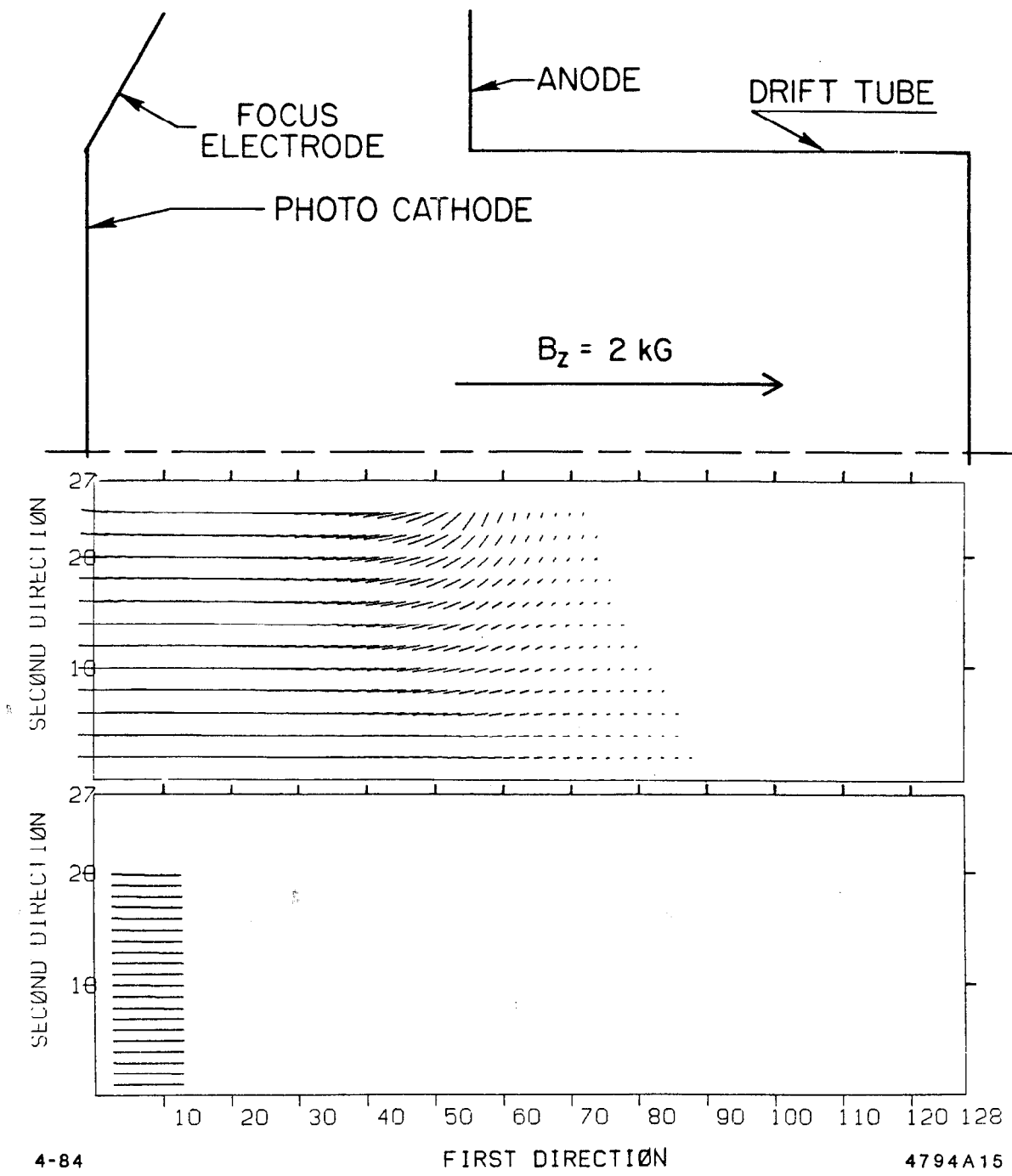


Fig. 1

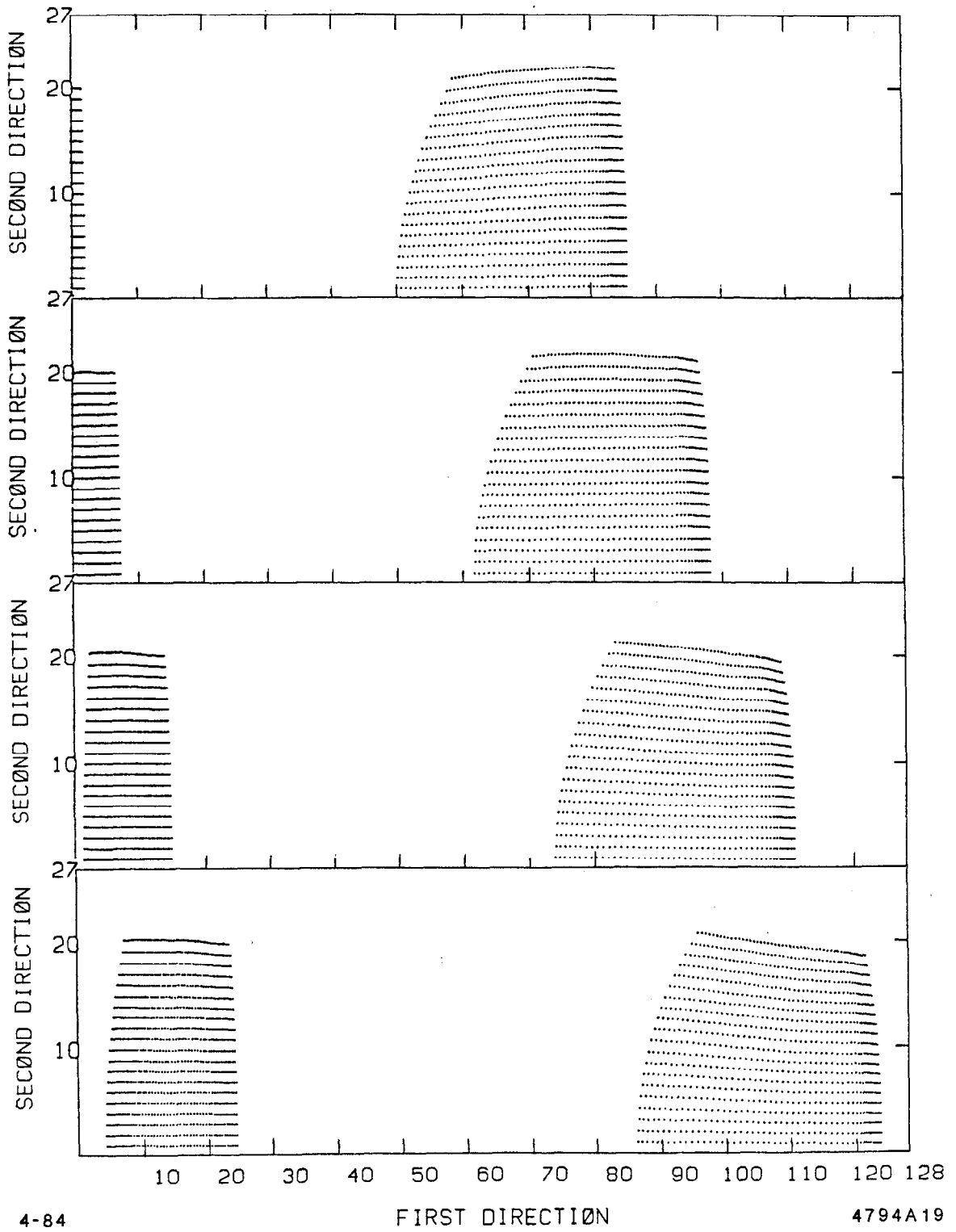


Fig. 2a

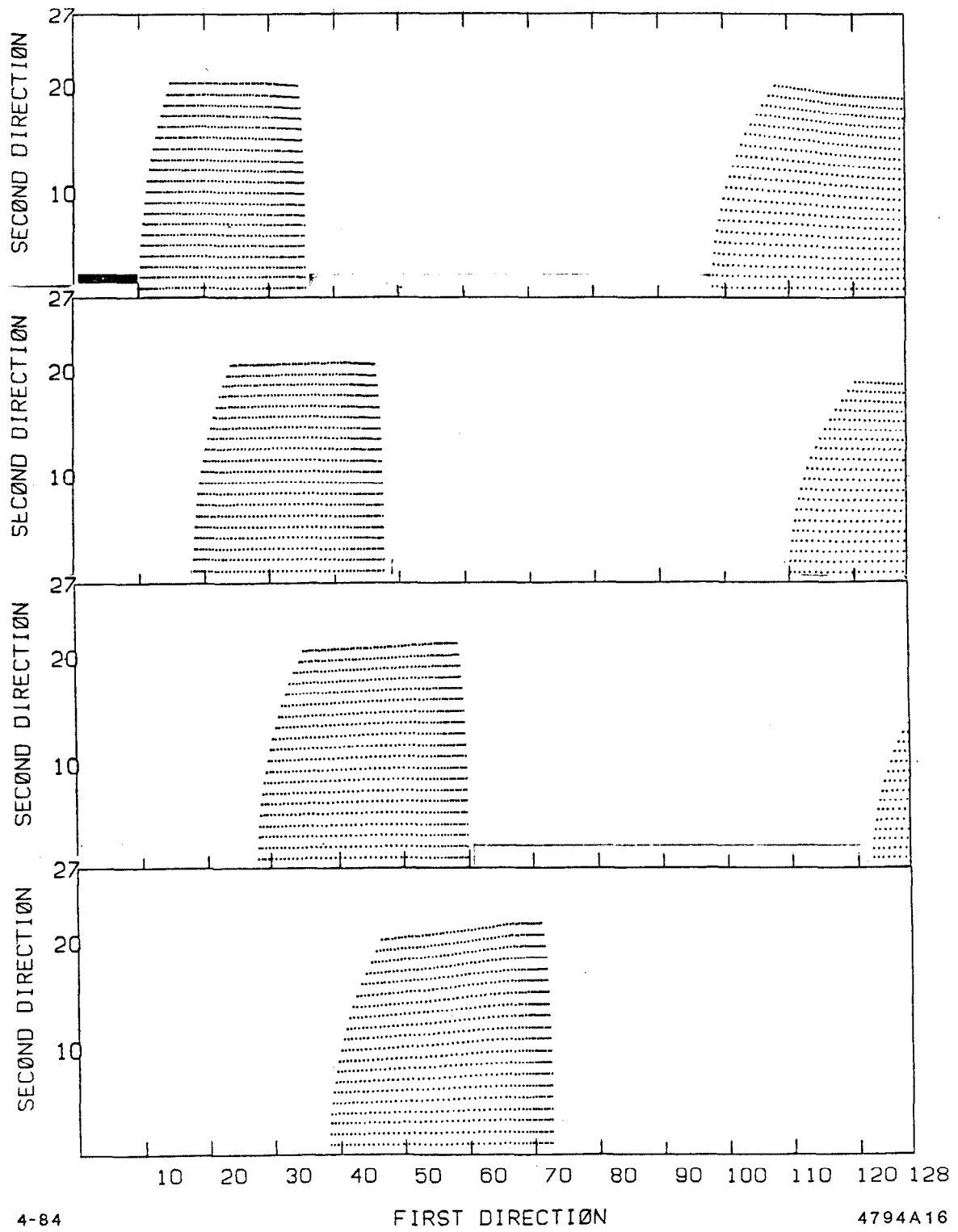


Fig. 2b

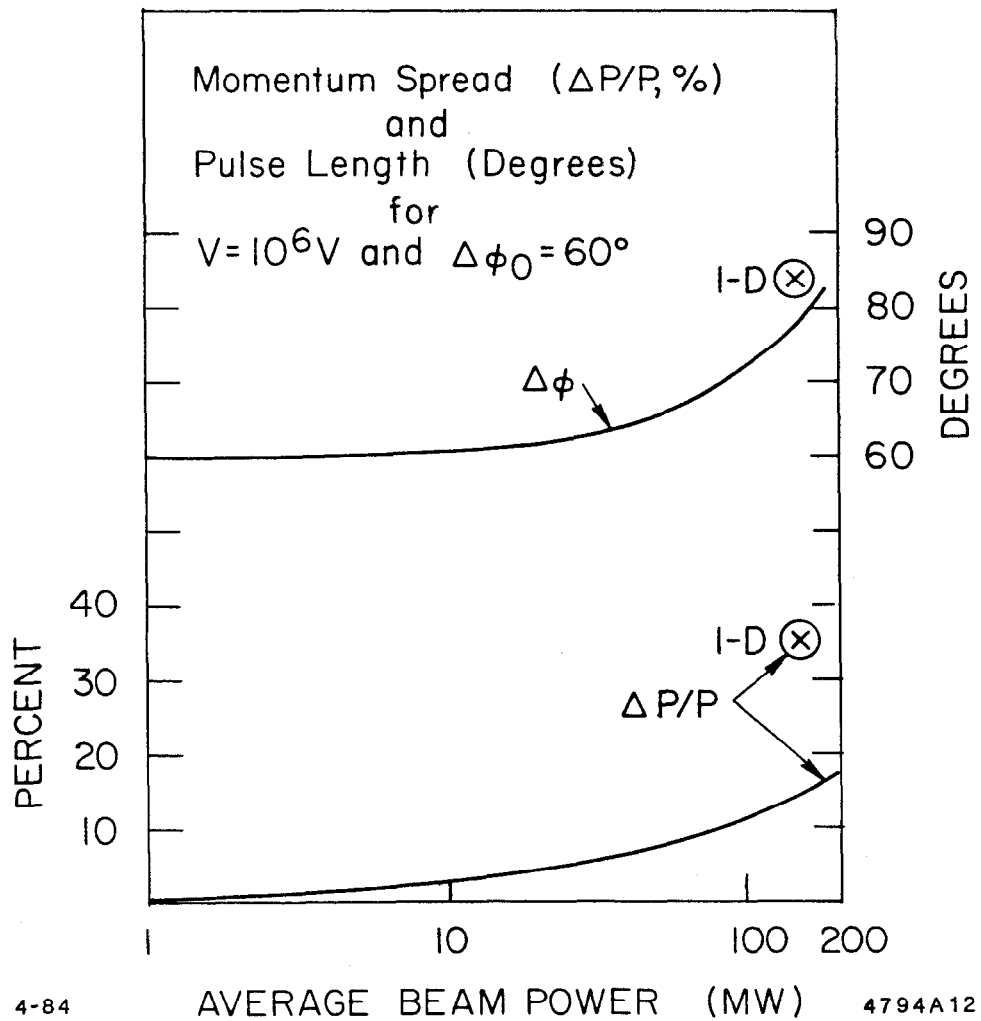
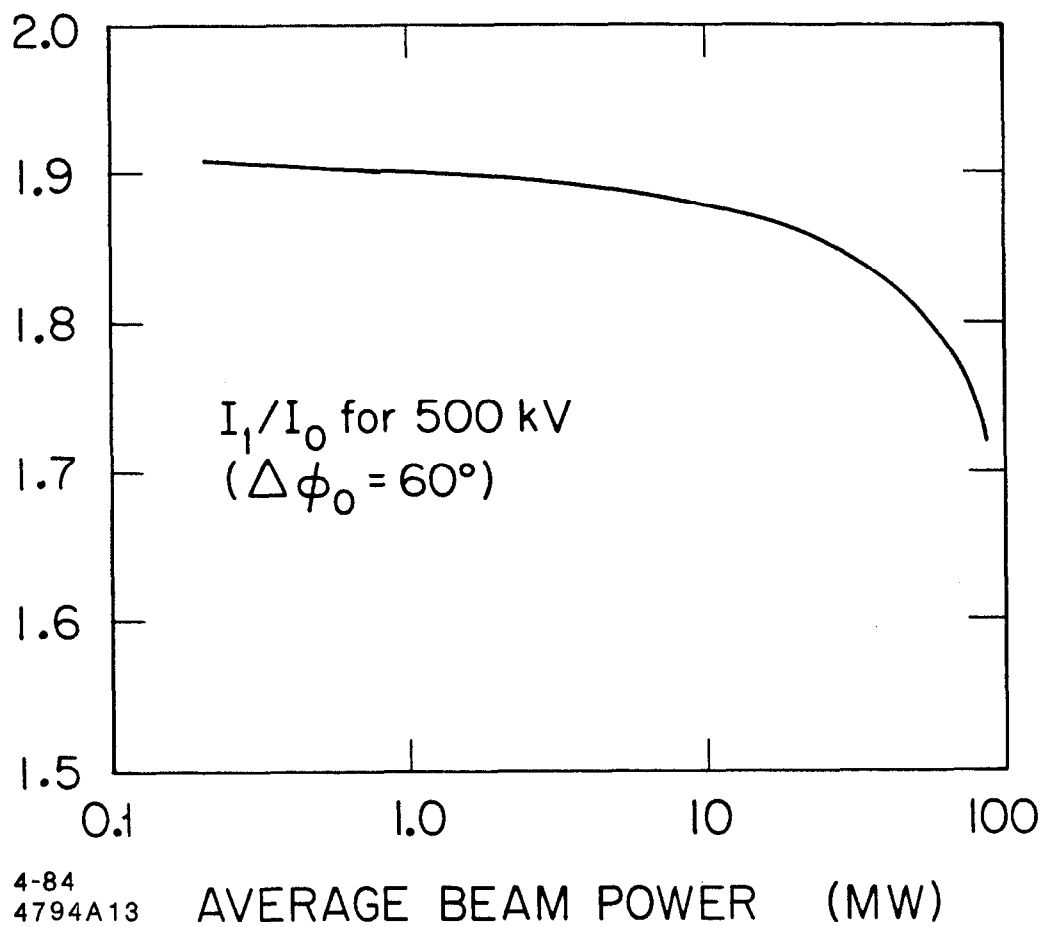


Fig. 3



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Fig. 4

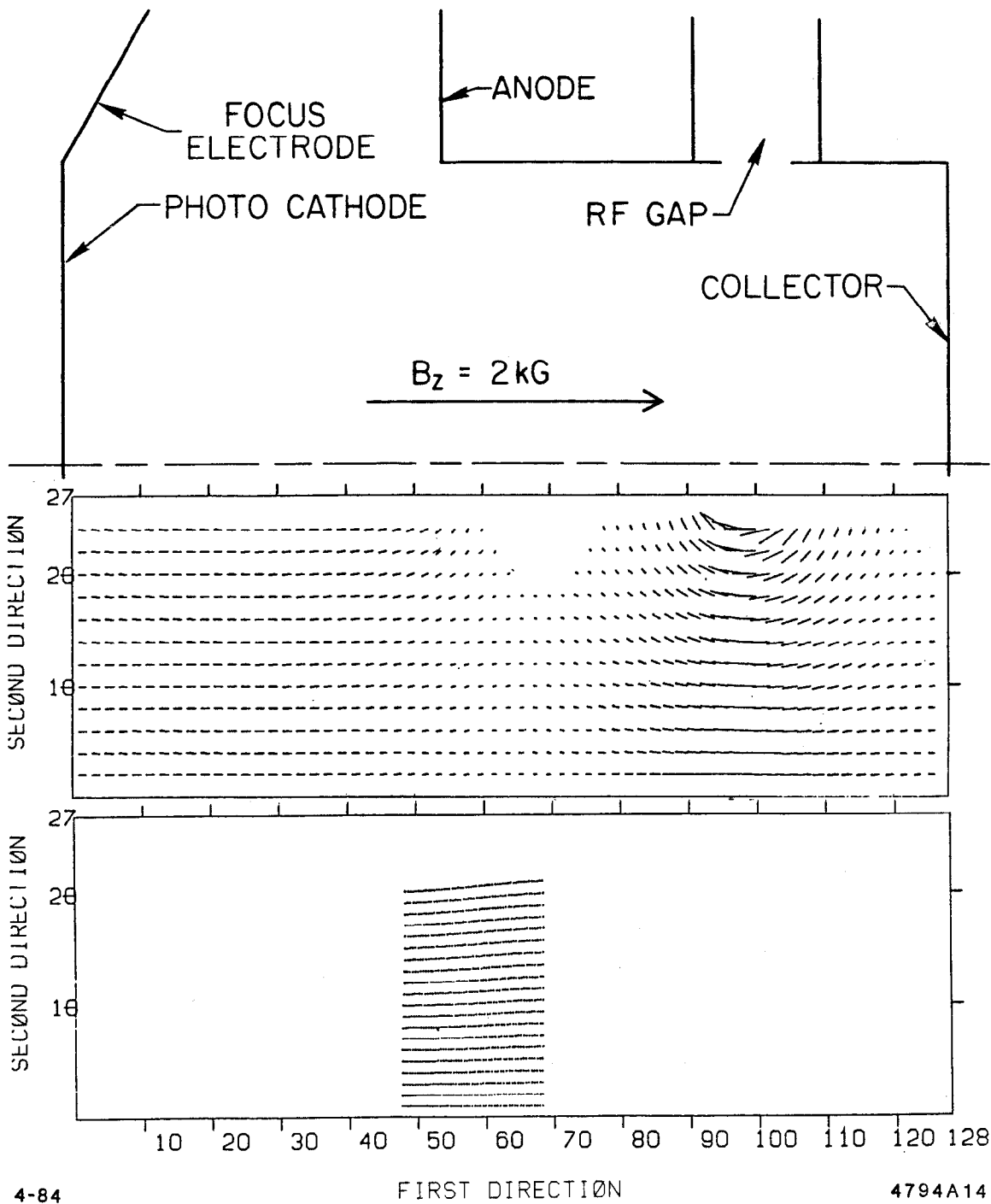
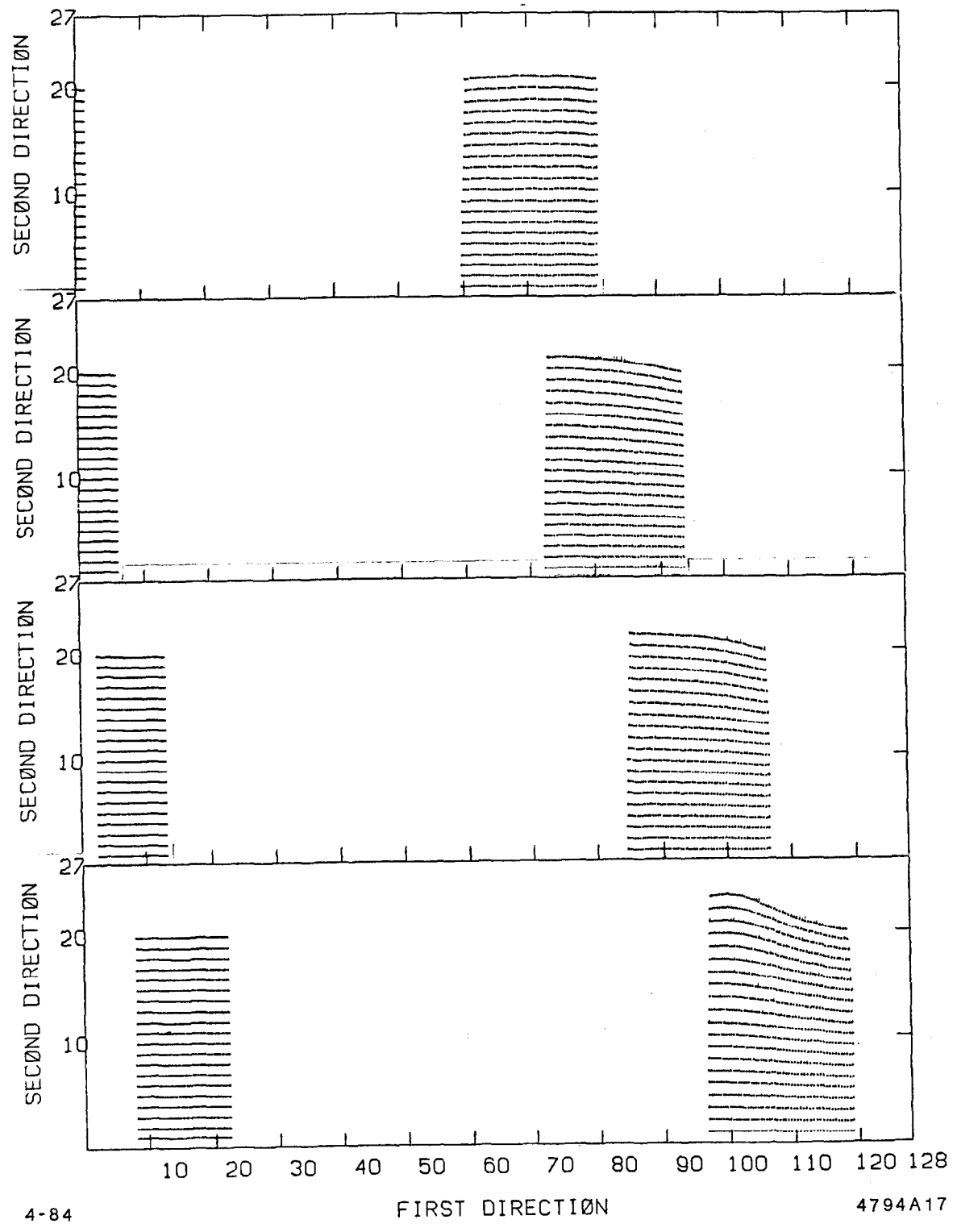


Fig. 5



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FIRST DIRECTION

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Fig. 6a

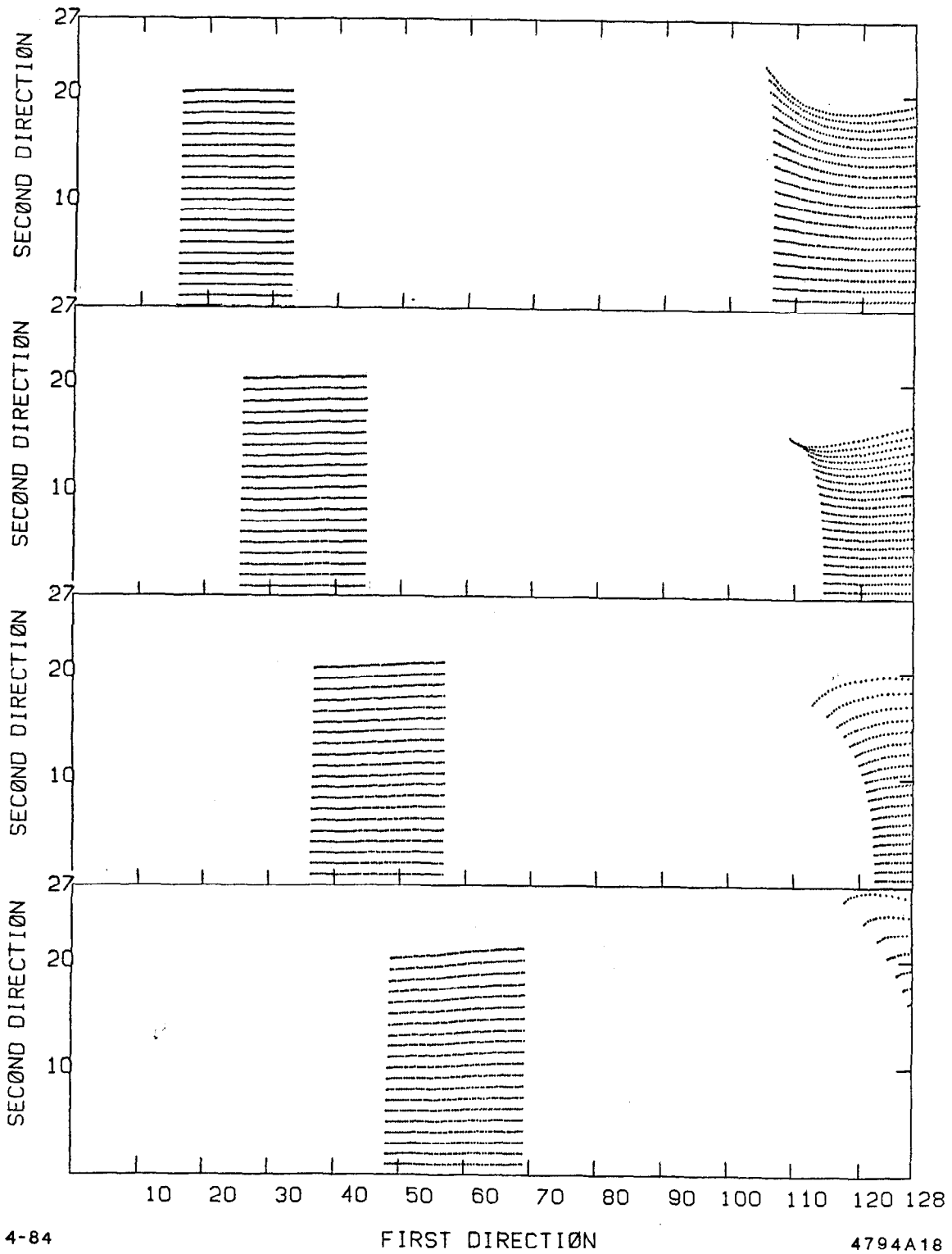


Fig. 6b