

Lawrence Berkeley National Laboratory

Recent Work

Title

ELIMINATION OF CURRENT TRANSIENTS IN A ONE-DIMENSIONAL HEAVY-ION DIODE

Permalink

<https://escholarship.org/uc/item/3s12t5ng>

Authors

Lampel, M.

Tiefenback, M.

Publication Date

1983



Lawrence Berkeley Laboratory

UNIVERSITY OF CALIFORNIA

RECEIVED
LAWRENCE
BERKELEY LABORATORY
APR 15 1983
LIBRARY AND
DOCUMENTS SECTION

Accelerator & Fusion Research Division

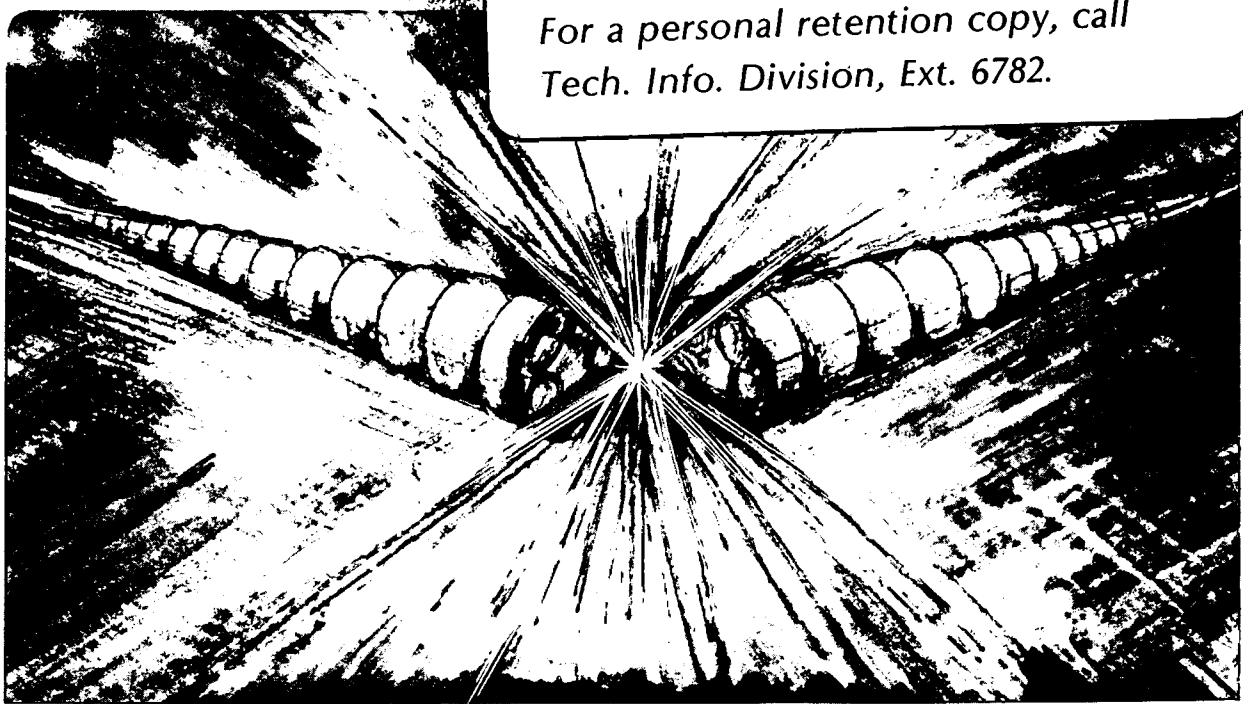
Submitted to Applied Physics Letters

ELIMINATION OF CURRENT TRANSIENTS IN A
ONE-DIMENSIONAL HEAVY-ION DIODE

Michael Lampel and Michael Tiefenback

January 1983

TWO-WEEK LOAN COPY
*This is a Library Circulating Copy
which may be borrowed for two weeks.
For a personal retention copy, call
Tech. Info. Division, Ext. 6782.*



LBL-14416
e

DISCLAIMER

This document was prepared as an account of work sponsored by the United States Government. While this document is believed to contain correct information, neither the United States Government nor any agency thereof, nor the Regents of the University of California, nor any of their employees, makes any warranty, express or implied, or assumes any legal responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by its trade name, trademark, manufacturer, or otherwise, does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof, or the Regents of the University of California. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof or the Regents of the University of California.

ELIMINATION OF CURRENT TRANSIENTS
IN A ONE-DIMENSIONAL HEAVY-ION DIODE*

Michael Lampel and Michael Tiefenback

Lawrence Berkeley Laboratory
University of California
Berkeley, California 94720

January 1983

*This work was supported by the Assistant Secretary for Defense Programs,
Office of Inertial Fusion, Laser Fusion Division, U.S. Department of Energy,
under Contract No. DE-AC03-76SF00098.

AN APPLIED VOLTAGE TO ELIMINATE CURRENT TRANSIENTS
IN A ONE-DIMENSIONAL DIODE*

Michael Lampel and Michael Tiefenback

Lawrence Berkeley Laboratory
University of California
Berkeley, California

Abstract

Development of sources for Heavy Ion Fusion motivates study of diode current transients. For the one-dimensional problem a unique applied voltage eliminates transients in the space charge dominated case:

$$V(t) = V \left[\frac{4}{3}(t/\tau) - \frac{1}{3}(t/\tau)^4 \right] \text{ for } t < \tau,$$
$$V(t) = V \text{ for } t \geq \tau$$

where L is diode length, V is steady state diode potential, q/m is charge to mass ratio, and $\tau = 3L\sqrt{m/2qV}$ is a particle transit time through the diode.

We derive this result and compare it to computer simulations and experimental results.

*This work was supported by the Assistant Secretary for Defense programs, Office of Inertial Fusion, Laser Fusion Division, U.S. Department of Energy, under Contract No. DE-AC03-76SF00098.

Research by the Heavy Ion Fusion (HIF) group at the Lawrence Berkeley Laboratory centers on the use of an induction linac to provide the multi-kiloampere bunched currents necessary to drive pellet fusion with particle beams [1]. An injection current of a few amperes at an energy of a few MeV is desirable for the operation of this device, and the HIF group has proceeded with the development of a Cs^+ model injector [2]. The front end of this injector is a space-charge limited diode, with a Pierce electrode for focusing and a hot anode to provide Cs^+ ions by contact ionization. In the steady-state, the diode obeys the Child-Langmuir law, $I \propto V^{3/2}$ [3]. If, however, the voltage is applied abruptly, transient current oscillations occur which decay away within a few multiples of the particle transit time across the diode. The HIF injector produces current pulses of a few microseconds duration, a length of time comparable to an ion transit time, so that transient effects can cause large current fluctuations throughout the pulse (Fig. 1). (By contrast, electron diodes typically have transit times of nanoseconds, usually much shorter than the electron pulse duration, so transient effects are normally unimportant.) Since the transverse beam dynamics in the injector is dominated by space charge, such fluctuations will lead to undesirable time-modulation of the focusing. Envelope variations can be reduced to acceptable levels if a current pulse uniform in time is provided.

An initial investigation of transient behavior was done with a computer code modelling a one-dimensional electrostatic diode. Setting the model diode length equal to the length of the HIF diode, 1/2 meter, and setting the model applied voltage risetime equal to the actual voltage risetime, ~ 150 nanoseconds, we obtain a result which shows qualitative agreement with the major features of the actual current pulse.

It is possible, however, to arrange for a voltage wave-form that will lead to a flat current pulse and eliminate transients; this can be seen from the following analytical argument, valid for any nonrelativistic species.

Consider a space-charge limited diode of length L filled with charge. Let us divide it into regions I and II on either side of the plane at x_0 (Fig. 2), and eliminate the charge in region II. We can keep conditions in region I unchanged by simultaneously altering the applied voltage to keep the electric field at x_0 unchanged, owing to our one-dimensional geometry. If, as the boundary between the regions travels from emitter to collector, the applied voltage is continually adjusted to satisfy the boundary condition $E(x_0(t)) = E_{CL}(x_0(t))$, then we obtain a current pulse that is a step-function in time. $E_{CL}(x)$ is the Child-Langmuir electric field solution as a function of position.

The potential across the diode is given by

$$\begin{aligned}\phi(L) - \phi(0) &= -\int_0^L dx' E(x') \\ &= -\int_0^{x_0} dx' E_I(x') - \int_{x_0}^L dx' E_{II}(x')\end{aligned}$$

where $E_{I(II)}(x)$ is the electric field in region I (II) of the diode. Let $\phi(0) = 0$. The electric field inside region I and on its boundaries is the same as if the diode were in the space-charge limited steady state, so

$$-\int_0^{x_0} dx' E_I(x') = \phi_{CL}(x_0) = V \left(\frac{x_0}{L} \right)^{4/3} \quad (2)$$

where V = final applied potential, L = diode length, and $\phi_{CL}(x) =$ Child-Langmuir potential as a function of x within the diode, $0 \leq x \leq L$.

Since region II is empty of space-charge, $E_{II}(x')$ is a constant, equal to $E_I(x_0)$ from continuity of the electric field across a boundary with no surface charge:

$$E_{II}(x') = E_I(x_0) = -4/3(V/L) x (x_0/L)^{1/3} .$$

Therefore,

$$-\int_{x_0}^L dx' E_{II}(x') = 4/3 (V/L) x (x_0/L)^{1/3} x (L - x_0) . \quad (3)$$

Combining the two integrals, and rearranging terms yield (for the time at which the leading particles in the diode are at x_0),

$$\phi(L) = V [4/3 (x_0/L)^{1/3} - 1/3 (x_0/L)^{4/3}] , \quad 0 \leq x_0 \leq L. \quad (4)$$

In order to express the applied voltage as a function of time, $V(t)$, we obtain the velocity of the boundary. Since every particle experiences only the Child-Langmuir electric field, this is found by equating the kinetic energy of a particle at x_0 and $\phi_{CL}(x_0)$, the potential drop between 0 and x_0 :

$$\frac{1}{2} m \dot{x}_0^2 = q\phi_{CL}(x_0) = qV x (x_0/L)^{4/3}$$

where \dot{x}_0 = particle (boundary) velocity, m = particle mass, q = particle charge, and ϕ_{CL} , x_0 , V , and L are as defined before. So

$$\dot{x}(x) = \sqrt{\frac{2qV}{m}} x \left(\frac{x}{L}\right)^{2/3} \quad (\text{dropping subscripts}).$$

Then

$$t(x) = \int_0^x \frac{dx'}{\dot{x}(x')} = 3 \sqrt{\frac{mL^{4/3}}{2qV}} x^{1/3} ;$$

$$\frac{t(x)}{\tau} = \left(\frac{x}{L} \right)^{1/3} \quad (5)$$

where $\tau = 3\sqrt{\frac{mL^2}{2qV}}$, a single particle transit time.

Using (5) to eliminate x in favor of t in (4):

$$V(t) = \begin{cases} V [4/3(t/\tau) - 1/3(t/\tau)^4], & 0 \leq t \leq \tau \\ V, & t > \tau \end{cases} \quad (6)$$

This result is reproduced numerically with our code. Based on this, the voltage applied to the HIF diode was modified by changing the risetime from .15 μsec to .6 μsec . The transit time for a Cs^+ ion across 1/2 m with 500 KV applied is 1.8 μsec and the closer match of voltage risetime to optimal rise produced significant improvement in the current pulse (Fig. 3). In particular the initial sharp peaks in current are eliminated, although the current risetime of $\sim 0.5 \mu\text{sec}$ is much less than the 1.8 μsec transit time. This shows a large reduction of unwanted transient fluctuations in a pulse of duration less than twice the length of the diode transit time.

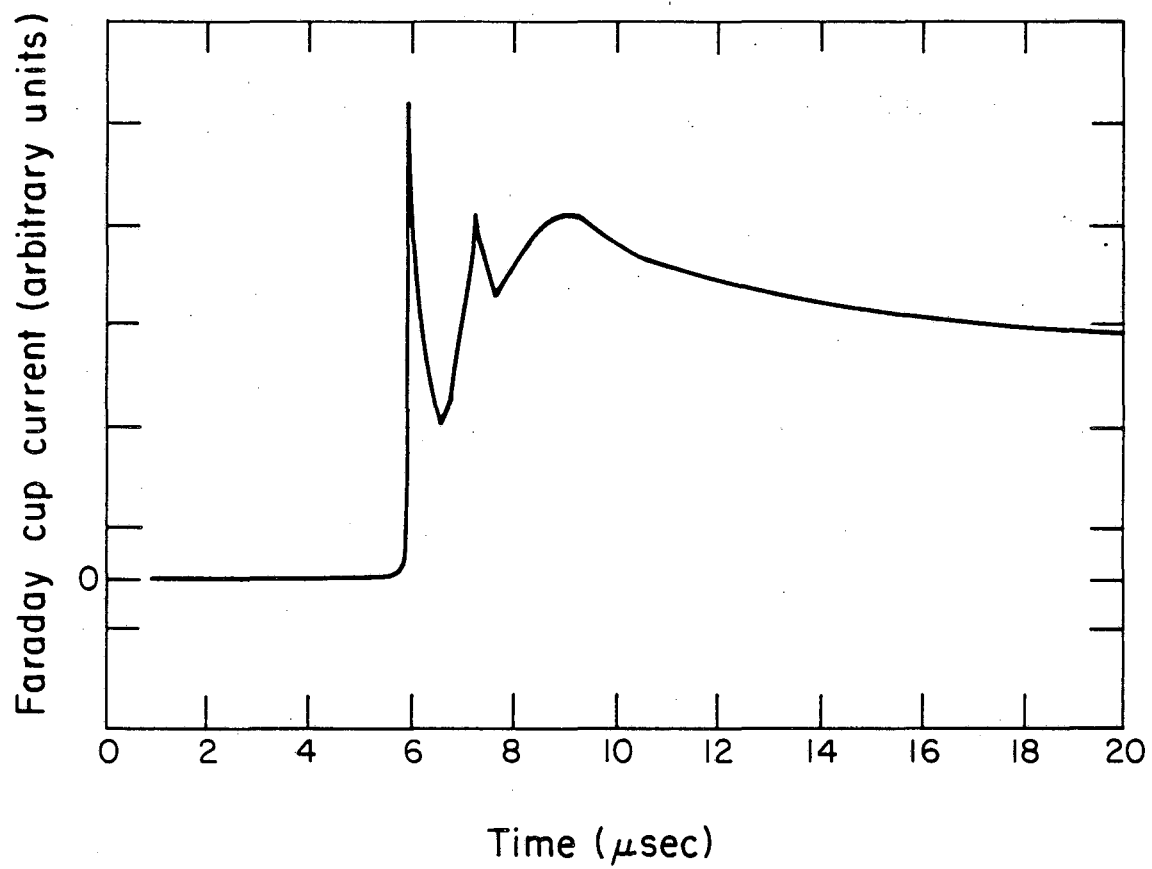
Our thanks to A. Faltens who first suggested an examination of the problem.

REFERENCES

1. D. Keefe, Linear Induction Accelerator for Heavy Ions, 1976 Proton Linear Accelerator Conference, Chalk River, Canada, Sept. 14-17, 1976 pp. 272-275.
2. S. Abbott, W. Chupp, D. Clark, A. Faltens, E. Hoyer, D. Keefe, C. Kim, R. Richter, S. Rosenblum, J. Shiloh, J. Staples, E. Zajec (Lawrence Berkeley Laboratory); W. Herrmannsfeldt (Stanford Linear Accelerator Center), Proc., Heavy Ion Fusion Workshop Held at Argonne National Laboratory, Argonne National Laboratory, Sept. 19-26, 1978 (ANL-79-41), pp. 50-55.
3. C. Child, Phys. Rev. 32, 492 (1911)
I. Langmuir, Phys. Rev. 2, 450 (1913)

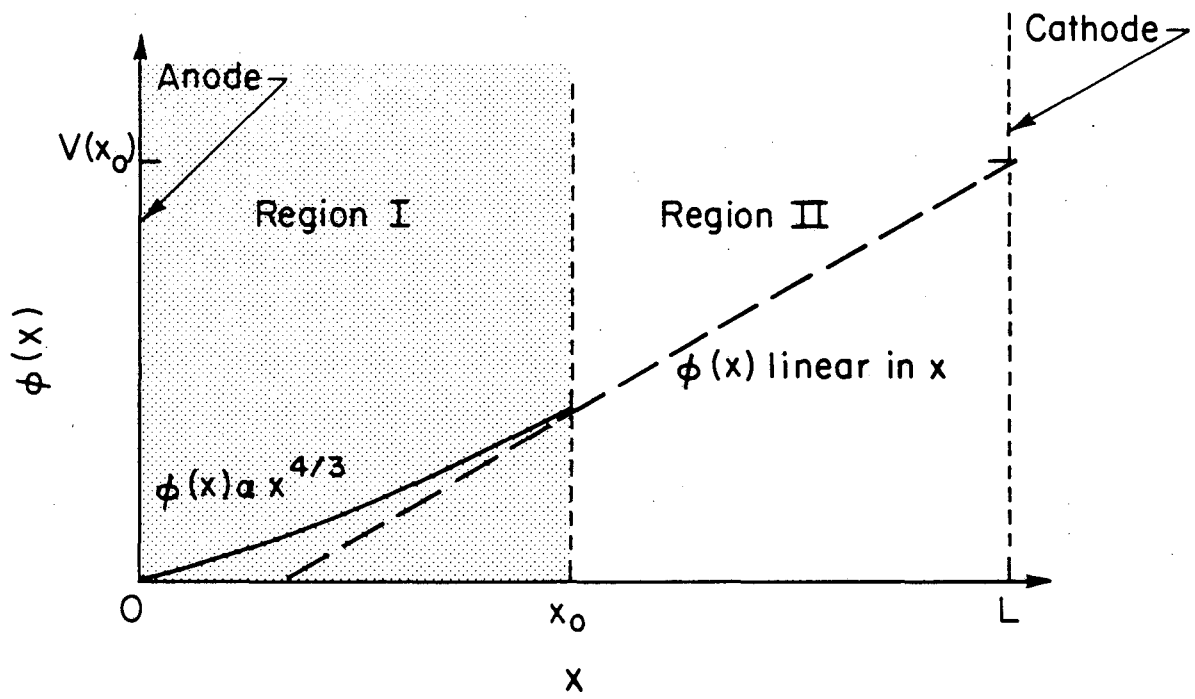
FIGURE CAPTIONS

- Fig. 1 Current pulse as seen on Faraday Cup at the end of the HIF diode for an abrupt voltage risetime (150 ns).
- Fig. 2 Uniform current flow out to a distance x_0 in a diode. Solid curve shows $\phi(x)$ for space charge limited flow, dashed curve shows $\phi(x)$ for free space. Key to time dependent flow is matching solutions at $x = x_0$.
- Fig. 3 Current pulse as seen on Faraday Cup after voltage risetime (to 500 ns) adjustment. Note elimination of sharp peaks at head of pulse. Current drops slowly due to voltage sag across the diode.



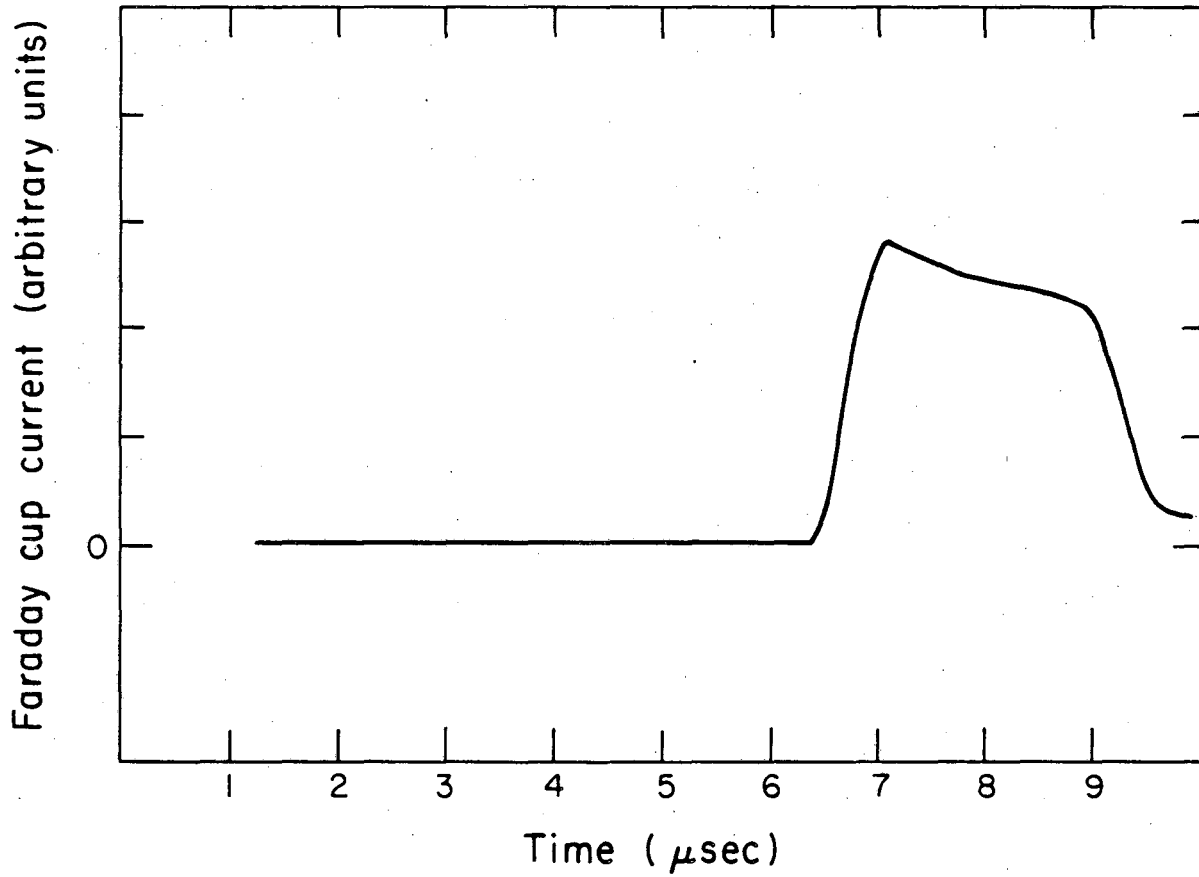
XBL 831 - 40

Fig. 1



XBL831 - 41

Fig. 2



XBL 831 - 39

Fig. 3

This report was done with support from the Department of Energy. Any conclusions or opinions expressed in this report represent solely those of the author(s) and not necessarily those of The Regents of the University of California, the Lawrence Berkeley Laboratory or the Department of Energy.

Reference to a company or product name does not imply approval or recommendation of the product by the University of California or the U.S. Department of Energy to the exclusion of others that may be suitable.

TECHNICAL INFORMATION DEPARTMENT
LAWRENCE BERKELEY LABORATORY
UNIVERSITY OF CALIFORNIA
BERKELEY, CALIFORNIA 94720