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Current characteristics of the present RAFAEL E-gun

In the space charge limited operating regime the electron gun maximal current is:

$$J_0 = 2.33 \cdot 10^{-6} \frac{V_0^{3/2}}{d^2} \left[A/m^2\right] \quad (1)$$

Where: V_0-Grid potential [volt]

d – distance from cathode to grid[m]

This equation is well-known Child-Langmuir law.

The cathode current:

$$I = \pi r^2 \cdot J_0[A] = 2.33 \cdot 10^{-6} \pi r^2 \frac{V_g^{3/2}}{d^2} [A] \quad (2)$$

Where: r – cathode radius

In the present gun: d=17mm – distance from cathode to grid

r=7.5mm

V_g= 6 - 20kVolt – grid potential

and therefore the current:

$$I = 1.421 \cdot 10^{-6} \cdot V_g^{3/2} [A] \quad (3)$$

Fig1. displays data characteristics of $I_c=I_c(V_g)$ obtained in three different ways:

1. The Child-Langmuir law (Eq.3).
2. "E-GUN" simulations carried out for different values of V_g for a fixed anode – cathode voltage V_{ac}=45 kV.
3. Experiments carried out by Yoram Lasser 31.10.02 (after the e-gun was cleaned and reassembled on the accelerator) the cathode. The cathode used was a new cathode model STD 600 M-type (0.6'' diameter). Experiment with different cathode temperatures and different V_{ac}=40,45,50 kV, are plotted. The gun was pulsed with the "Old Haim Pulser" which was operated with pulse duration t_p=13μs and blocking voltage V_g=-2kV. It is important to note that V_g is the "real value on the grid. It was obtained from the voltage read from the LABVIEW control program, by use of a "calibration cure", in order to take into consideration voltage drops on resistors and capacitors in the grid pulsing circuit.

Fig. 1
Cathode emision current

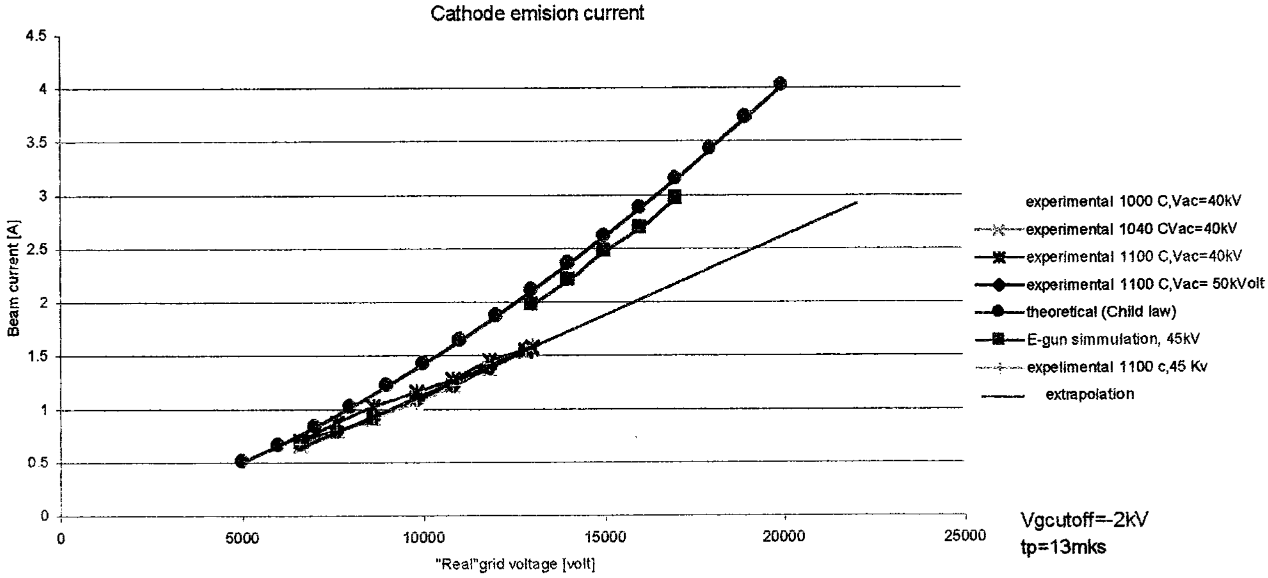
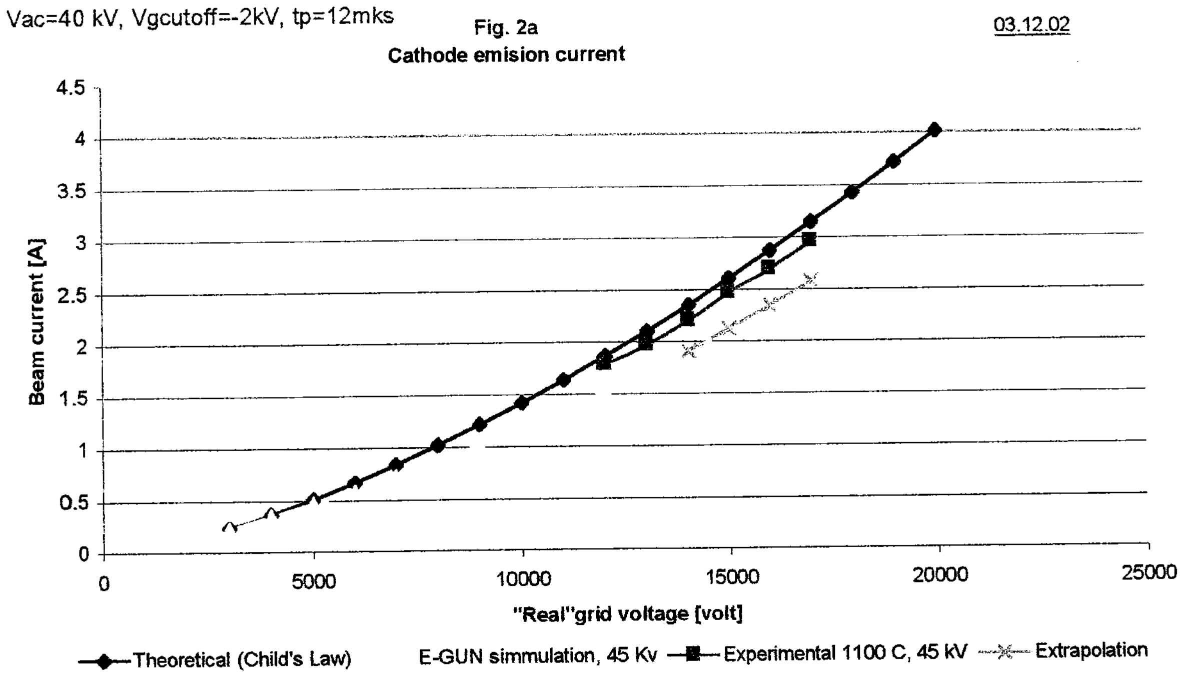


Fig. 2a,b. displays data characteristics of $I_c = I_c(V_g)$ obtained in the same three ways, with "New Haim Pulser"



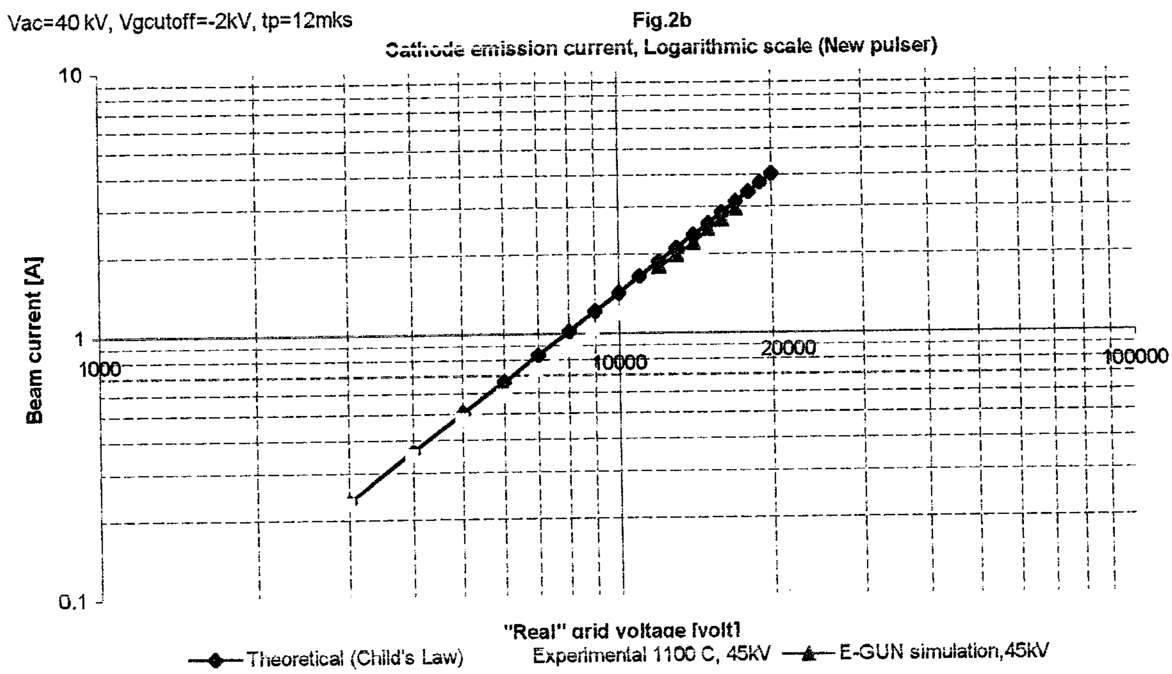
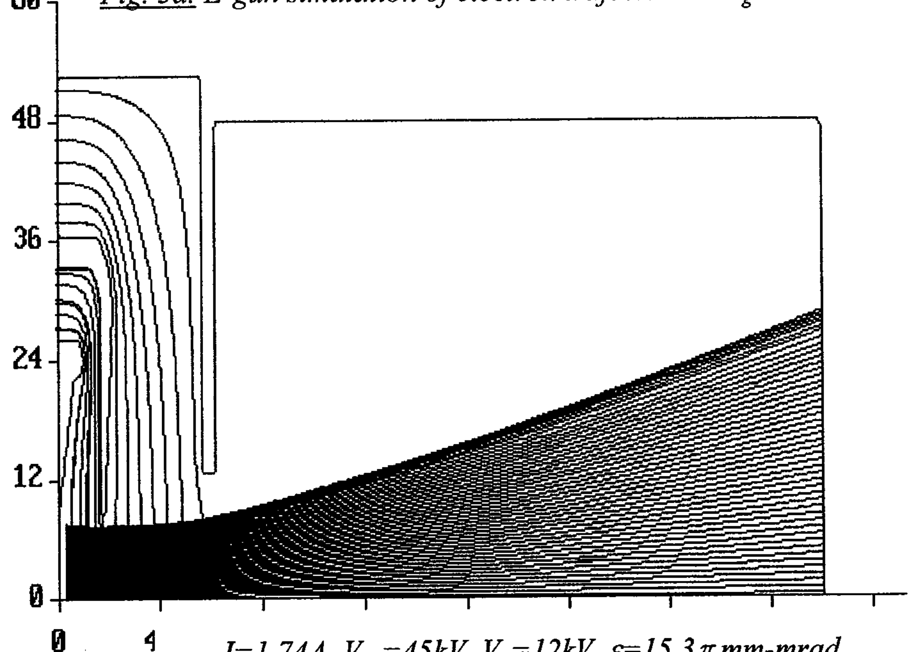


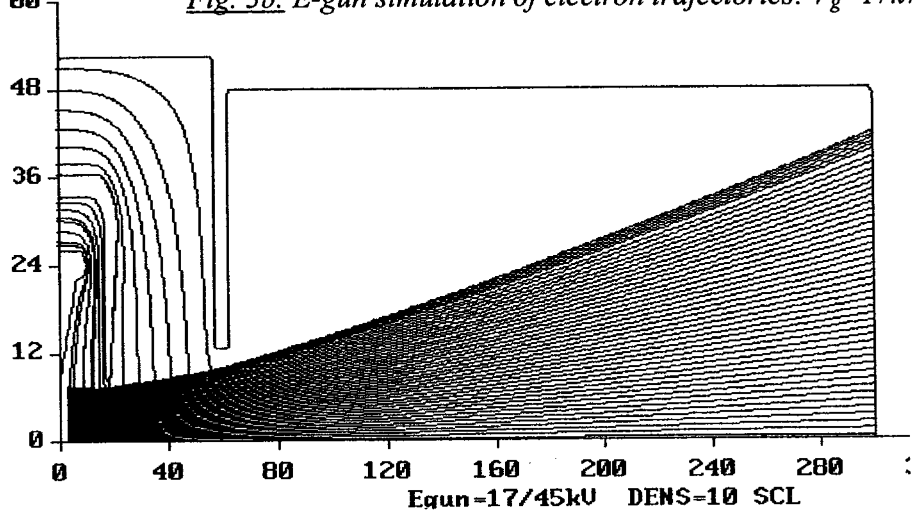
Fig.3 displays "E-gun" trajectories of the electron – gun in the "space charge limited regime" for V_{ac}=45kV and two values of V_g=12,17 kV.

Fig. 3a. E-gun simulation of electron trajectories: V_g=12kV



I=1.74A, V_{ac}=45kV, V_g=12kV, ε=15.3π mm-mrad, ε_n=6.579π mm-mrad

Fig. 3b. E-gun simulation of electron trajectories: V_g=17kV



I=2.88A, V_{ac}=45kV, V_g=127kV, ε=27.99π mm-mrad ε_n=11.97πmm-mrad

Fig.4 and Fig.5 display the current density distribution and the phase space distribution of the accelerated beam in these two cases of V_g= 12,17kV

Fig.6 shows the increase in emittance as a function of V_g for fixed V_{ac}=45kV.

Fig.4: The current distribution and phase – space distribution of the e – beam for V_g= 12kV, V_{ac}=45kV

Fig.4a

I = 1.746 AMPS, PERVEANCE = .1829 MICROPERVS
EMITTANCE =15.39 PI (MM-MR)
NORMALIZED EMITTANCE =6.579 PI (MM-MR)

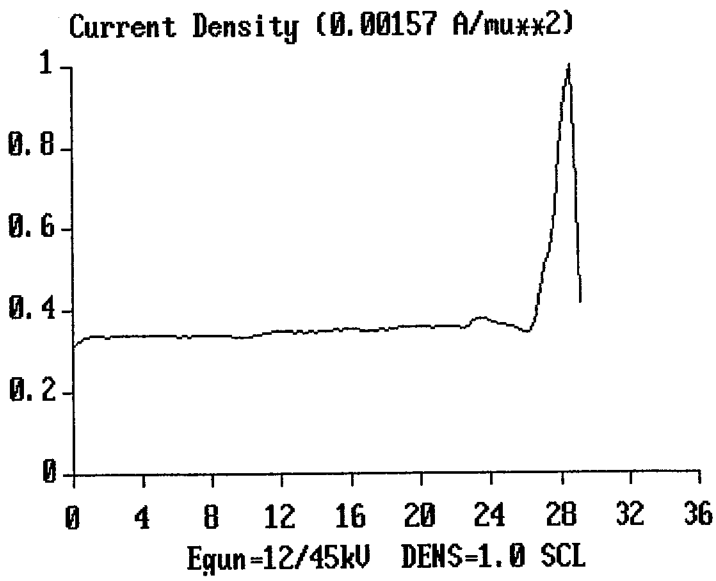


Fig.4b

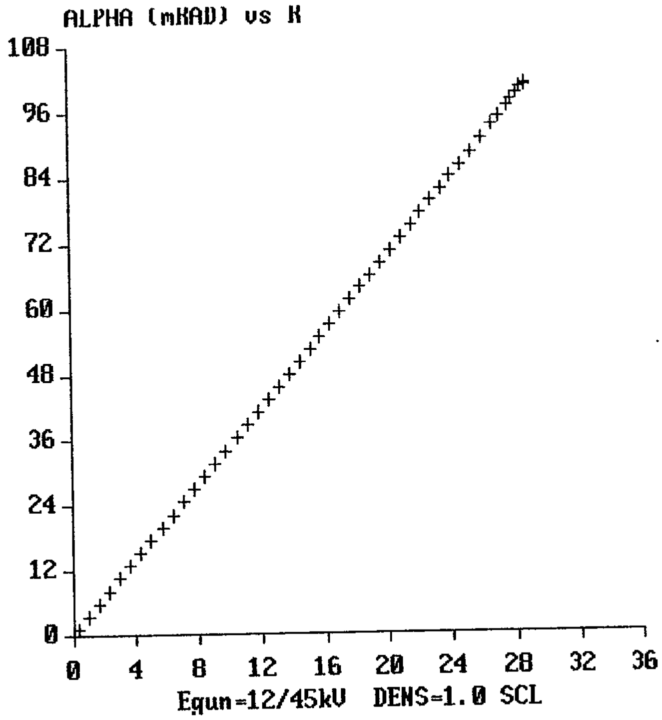


Fig. 5: The current distribution and phase – space distribution of the e– beam for V_g= 17kV, V_{ac}=45kV

Fig.5a

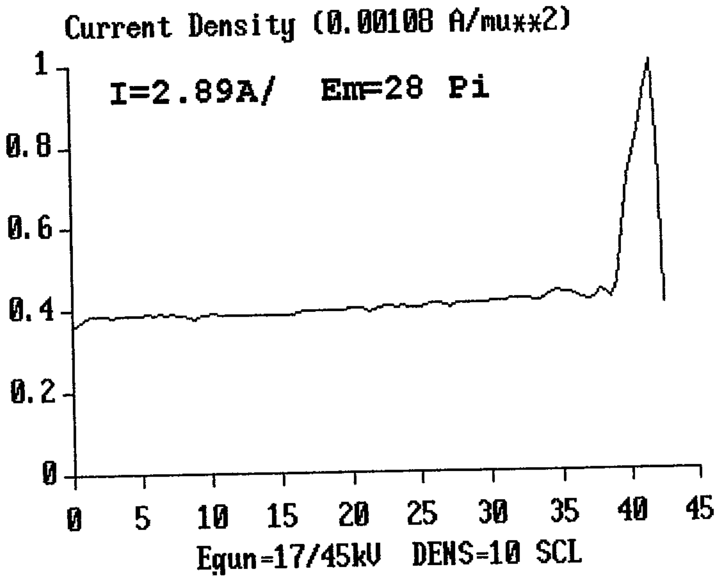


Fig.5b

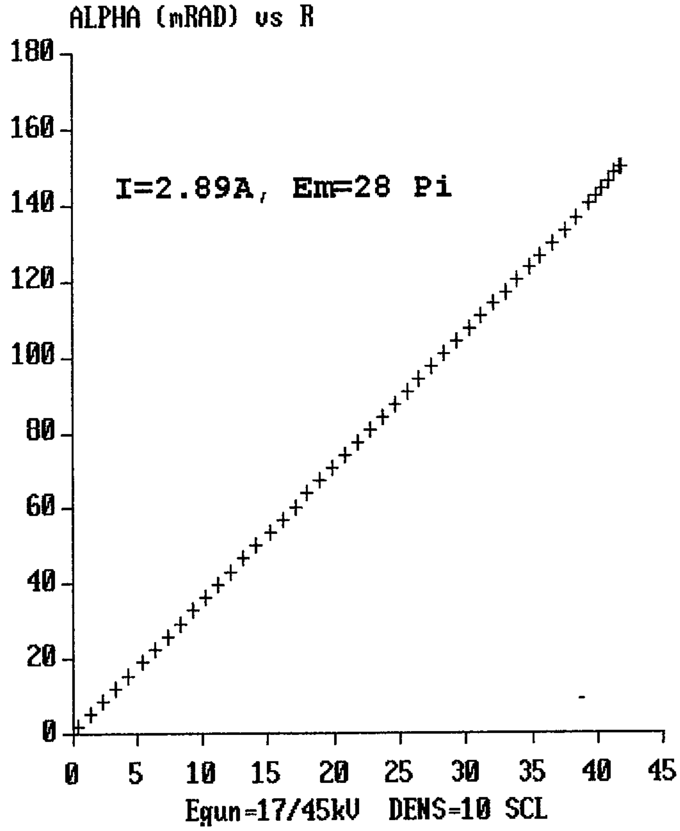
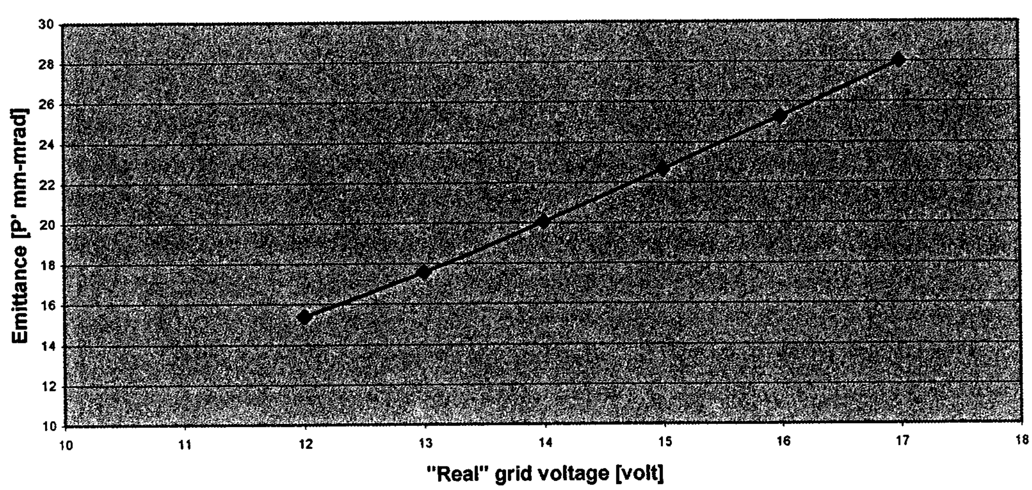


Fig. 6 Resutls of E-gun simulation



Observations

1. The E–GUN simulations of $I_c(V_g)$ (Fig.1,2) is a little lower but close to Child-Langmuir law (Eq.3). The experimental results are significantly lower than both predictions. A possible explanation: the grid–cathode spacing is in reality longer than 17mm (e.g.-because flanges were not tightened face to face – 22m!).

   An important observation is that the experimental curves for different V_{ac} are not really different, so that as far as the current parameter is concerted the grid operates well as a current control in the range 6 – 13kV (independent of V_{ac}).

   The weak dependence on cathode temperature indicates that the operation in all cases is in the space – charge regime.

2. While the grid operates well as a current control, it is known that when its voltage varies too much relative to a nominal voltage, it may cause defocusing effect and possibly emittance growth. Comparison of trajectories for V_g=12kV, 17kV (Fig. 3a,b) reveals bigger expansion in the latter case, but this can be attributed also to the space – charge effect at the larger current (I_c=2.69A increased of I_c=1.746A).

   Figs.4, 5 show, that the emittance in the case of V_g=17kV (ε=27.99π mm-mrad, ε_n=11.97π mm-mrad) is larger than the emittance of V_g=12kV (ε=15.39π mm-mrad, ε_n=6.579π mm-mrad) by a significant factor: $\times$1.82. This can be attributed also to the increase in current (according to Lawson – Penner law $\varepsilon \propto \sqrt{I_c}$,which would account for a factor of $\times$1.31)

Fig.6 indicates that the increase of emittance as a function of V_g is monotonic and nearly linear.

3. According to the C–L law (in 1D model!), in order to get transversely uniform potential in the grid region (to avoid focusing effect) one needs to satisfy:

$$\frac{V_g^{3/2}}{d_g^{\;2}} = \frac{V_{ac}^{3/2}}{d_a^2}$$

This ratio gives for V_{ac}=45kV d_g=17mm, d_a=57.5mm

$(V_g)_{opt}$=8.87kV

or alternatively, for Vg=12kV

$(V_a)_{opt}$=60.9kV

Because of these considerations we ran E – GUN also for Vac=60kV, V_g=12,17kV (Figs. 7, 8). Fig.6a shows nearly uniform flow from the cathode to the anode, however there is slight focusing effect, which should be attributed to the deviation from the 1D model of the C–L law. Fig.8a displays some expansion of the beam (under-focusing) between the cathode and anode, but the beam is still quite uniform.

Fig.7 E-GUN simulation for V_g=12kV, V_{ac}=60kV (optimal case): (a)trajectories,(b)current distribution, (c)phase space diagram.

I= 1.7840 A, PERVEANCE = .12139 MICROPERVS
EMITTANCE =11.37 PI(MM-MR) FROM 48 RAYS
NORMALIZED EMITTANCE =5.644PI(MM-MR)
*Average current density=0.00909 A/mm**2*

Fig.7a

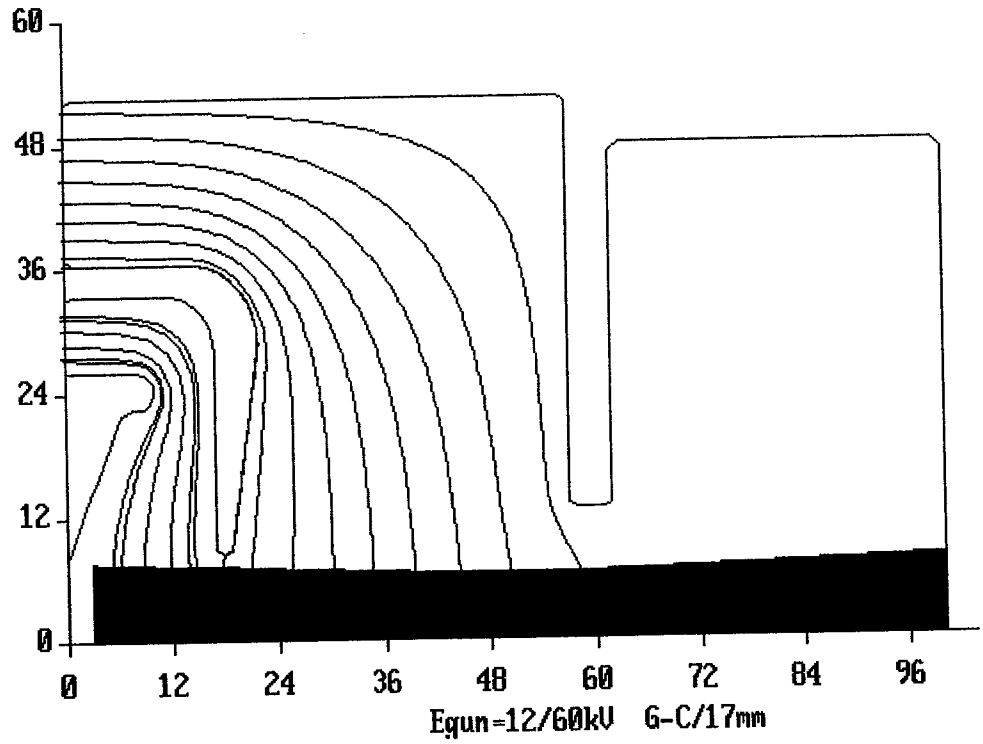


Fig.7b

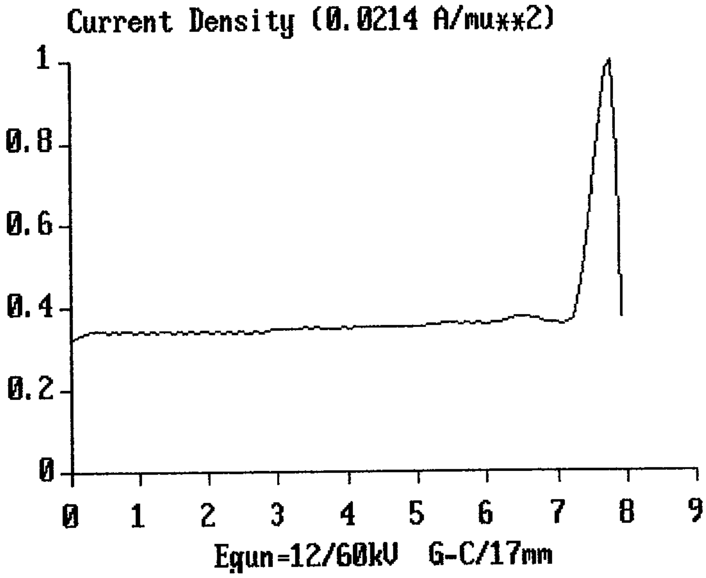

Current Density (0.0214 A/mu**2)
1
0.8
0.6
0.4
0.2
0
0 1 2 3 4 5 6 7 8 9
Equn=12/60kV G-C/17mm

Fig.7c

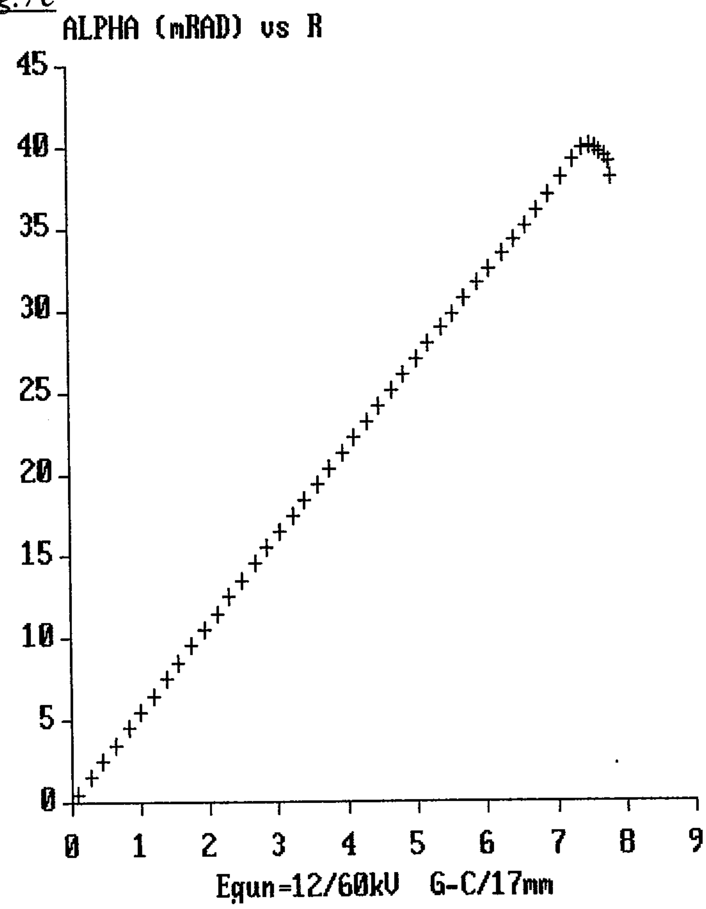

ALPHA (mRAD) vs R
45
40
35
30
25
20
15
10
5
0
0 1 2 3 4 5 6 7 8 9
Equn=12/60kV G-C/17mm

Fig.8 E-GUN simulation for V_g=17kV, V_{ac}=60kV (optimal case): (a)trajectories,(b)current distribution, (c)phase space diagram.

I= 2.9312 A, PERVEANCE = .19944 MICROPERVS
EMITTANCE =12.10 PI(MM-MR) FROM 48 RAYS
NORMALIZED EMITTANCE =5.997 PI(MM-MR)

Fig.8a

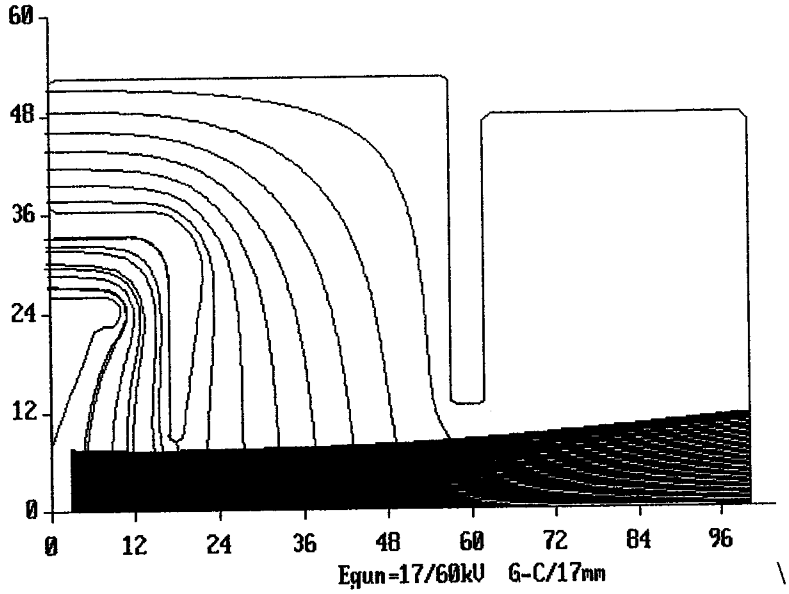


Fig.8b

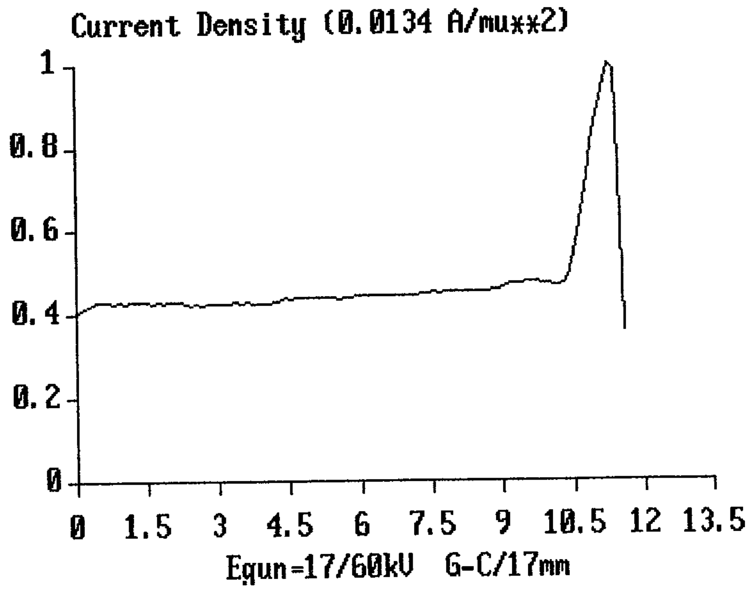
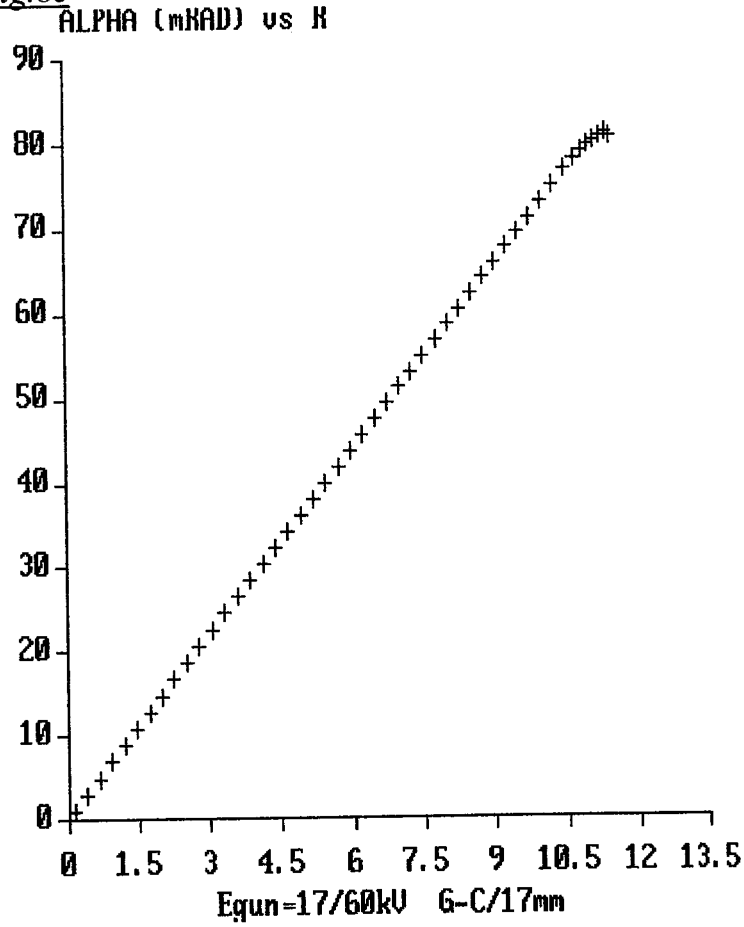


Fig.8c



The normalized emittance of (V_g=12kV, V_{ac}=60kV): ε_n=5.6π mm-mrad is better in this "optimal case than the normalized emittance of (V_g=12kV, V_{ac}=45kV): ε_n=6.58π mm-mrad (note that the currents are about the same I_c=1.75A). However in the case of V_{ac}=60 kV, even when we increase the grid voltage to V_g=17kV(fig7.), increasing the current significantly to I_c=2.93A, the normalized emittance only slightly increases (from ε_n=5.6π mm-mrad to ε_n=6π mm-mrad). This should be compared to the large increase in normalized emittance (factor of ×1.8) when we change V_g=12kV to 17kV for V_{ac}=45kV.