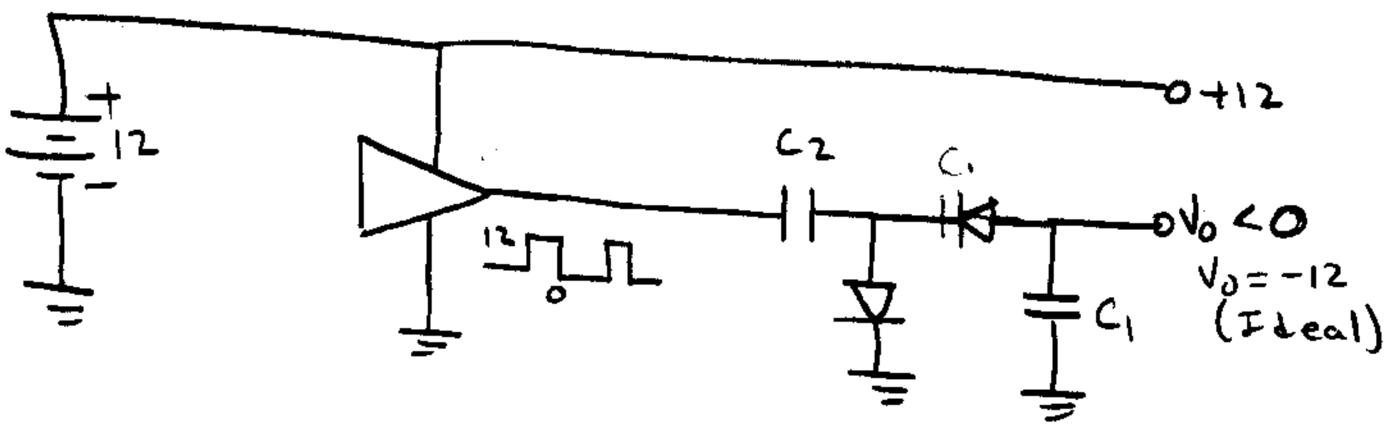
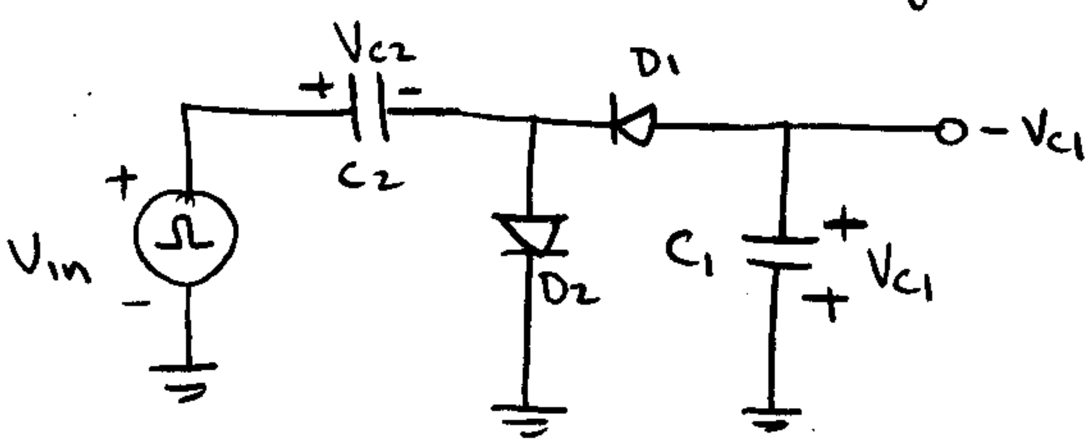
Charge Pumps

- Used as a Voltage doubler
  ⇒ 12V → 24V

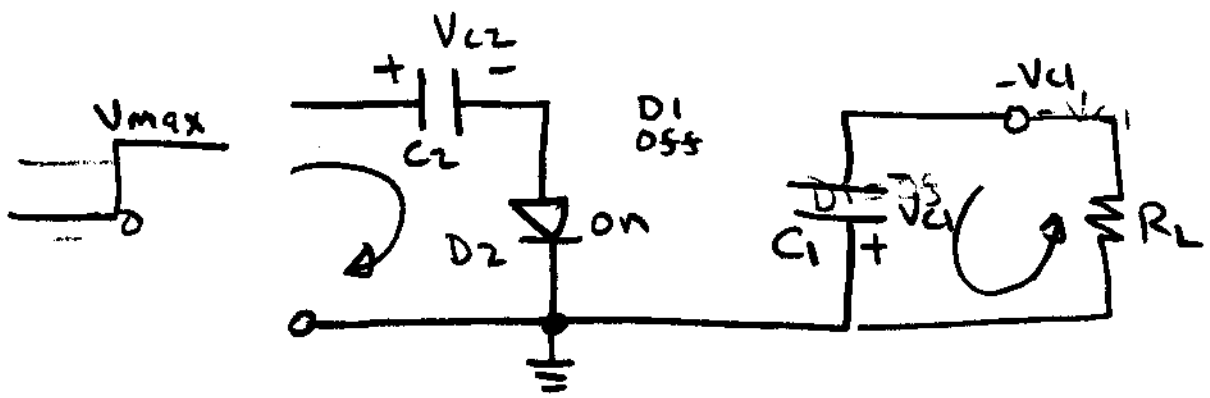
- Used to create a (−) supply from a Positive Supply



- Creates a Negative supply

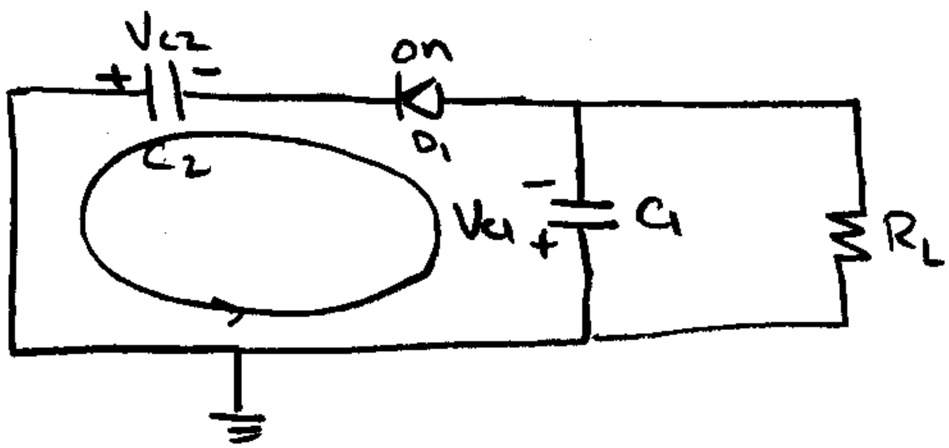


When V_{in} = Low → high



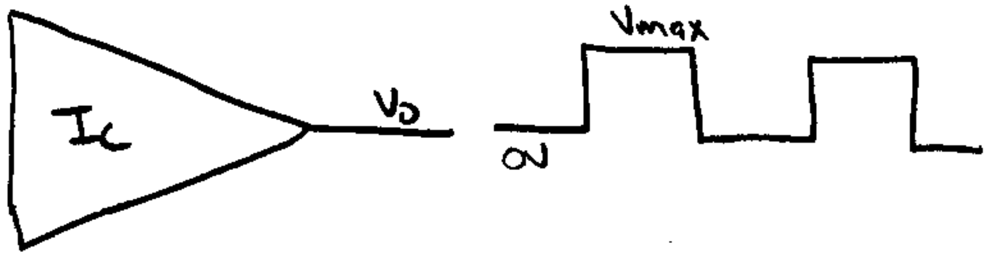
- C_2 Charges to Vmax through D_2
- C_1 Supplies power to R_L
  - Impulse of current through C_2 + D_2
  - Charge Transfer from Vin to C_2

When V_{in} ⇒ high → Low : D2 = off, D1 = on

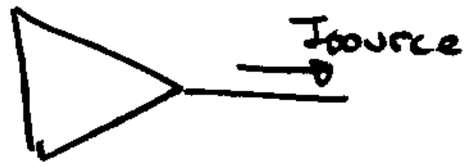


- Charge transfer from C_2 to C_1
- Impulse of current through C_2, D1, C_1

- Because of large impulse currents, V_{in} must be current Limited

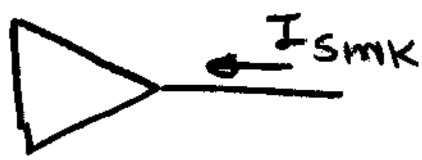


When $V_o = V_{max}$



$I_{source} = I_{max} \Rightarrow$ I.C. can source a Limited maximum current

When $V_o = 0$

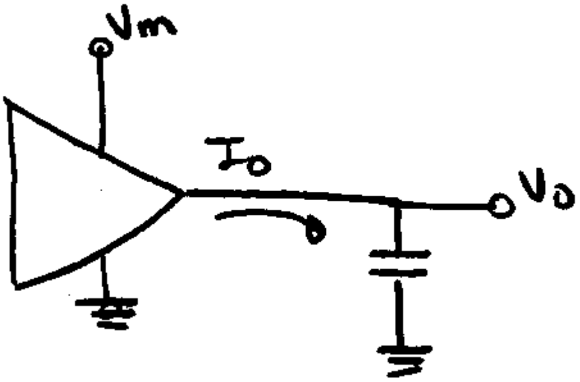


$I_{sink} = I_{max} \Rightarrow$ I.C. Can Sink a Limited amount of current.

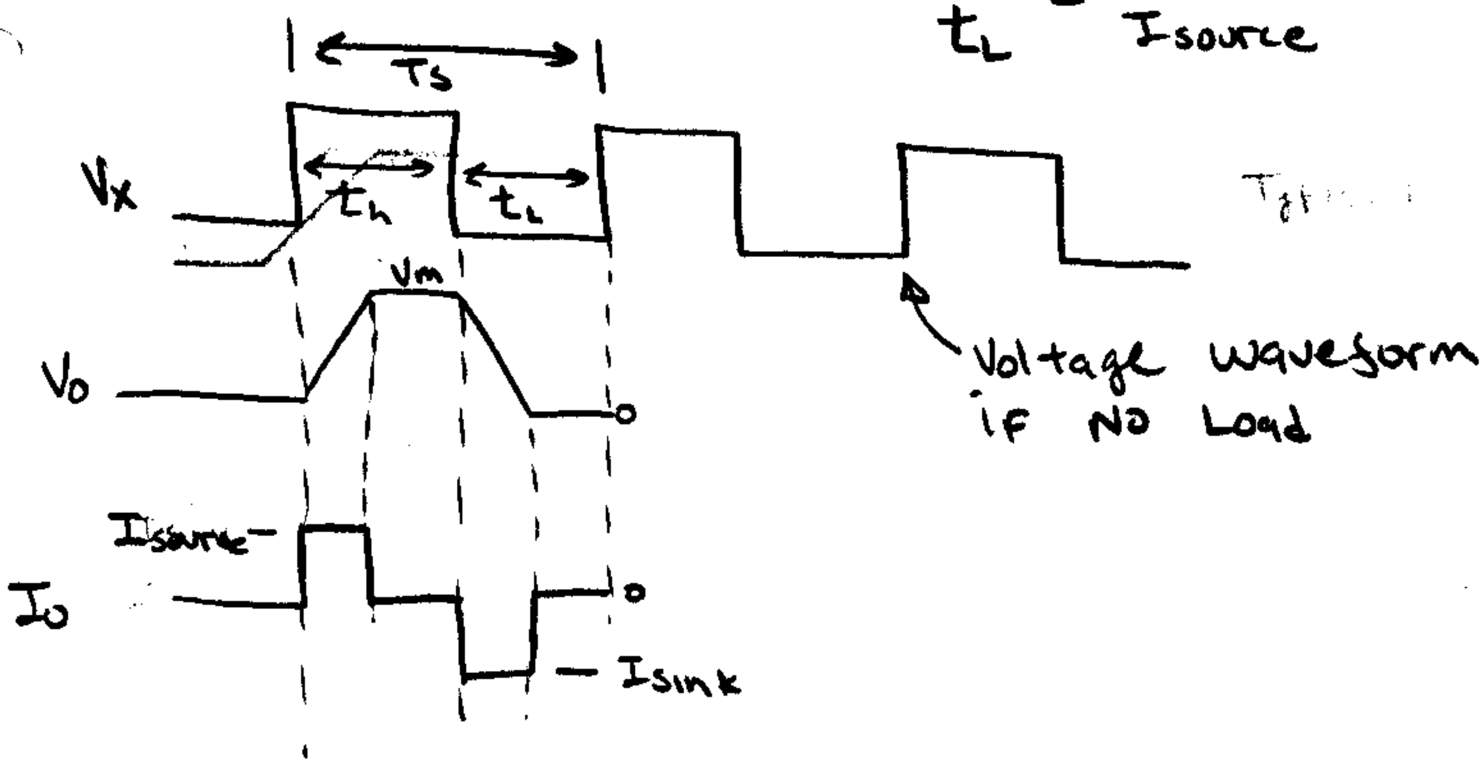
For a Typical Driver I.C.

$I_{source} \neq I_{sink}$

- Typical # for I.C. $\approx$ 200 mA

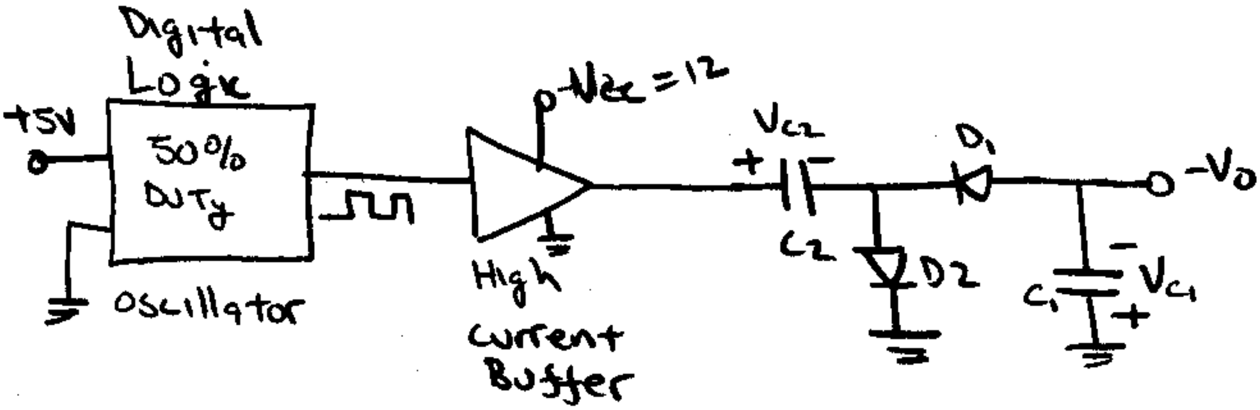


$$\frac{t_h}{t_L} = \frac{I_{sink}}{I_{source}}$$

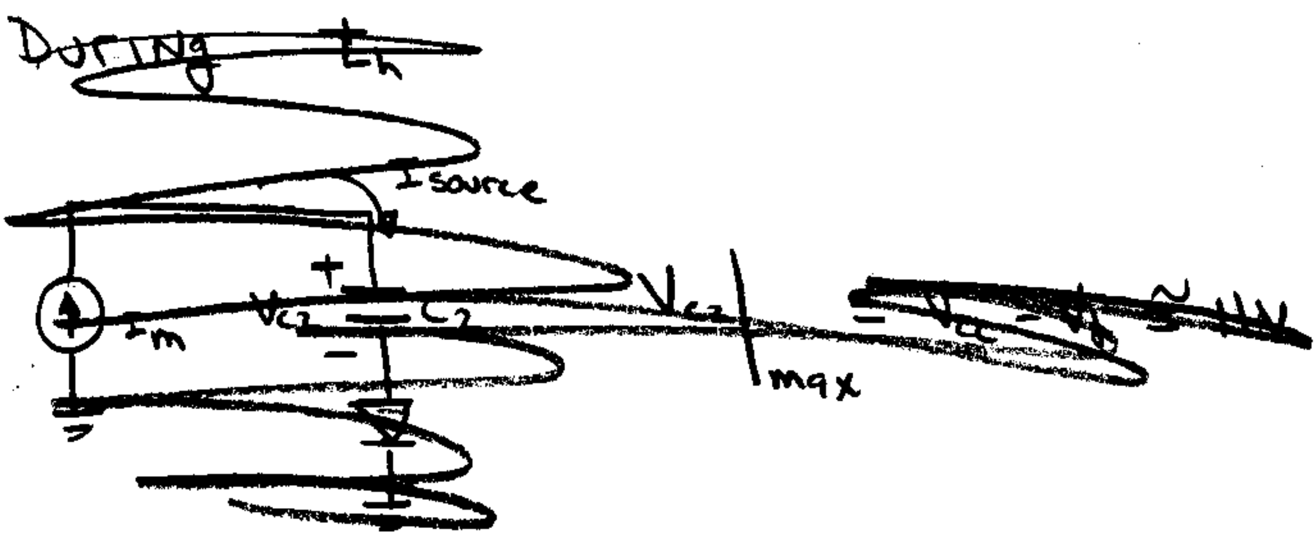


Assume $I_{source} = I_{sink} = I_m$

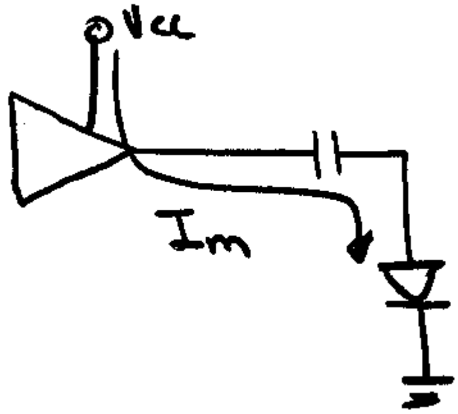
Design with 50% Duty Cycle



Note $|V_o| < V_{cc} - 2V_r$; use $V_r \cong 1V$

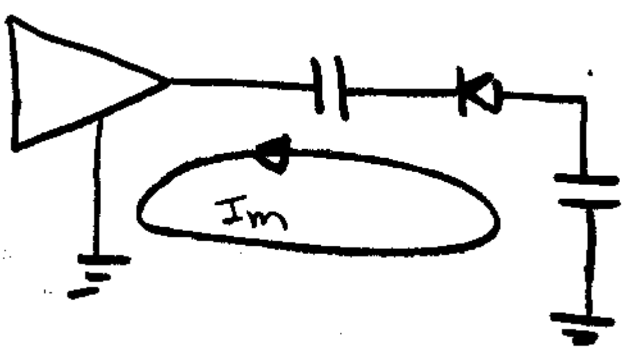


During t_h



Power into Circuit from Vcc

During t_L



- Charge sloshing around in circuit
- No Power from Vcc into circuit

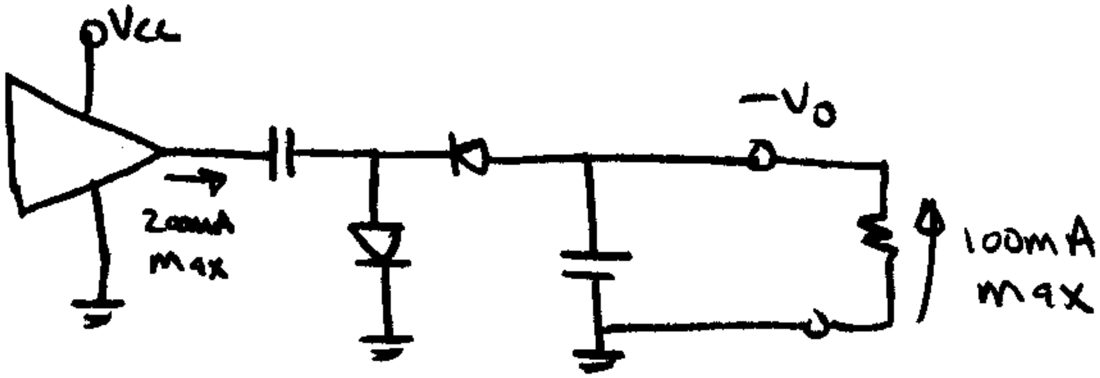
Over Both t_h & t_L, the Average current into the circuit is

$$I_{Avg} = I_m \left[\frac{t_h}{t_h + t_L}\right] = I_m \frac{t_h}{T_S} = I_m D$$

At Equilibrium, the max current out of this supply can provide is

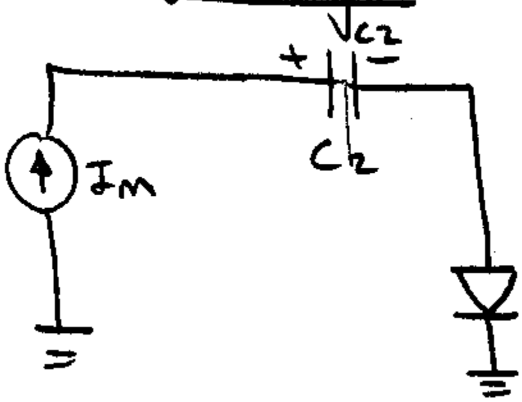
$$I_m\left[\frac{t_h}{T_s}\right]$$

⇒ if we have a driver that can source & sink 200 mA then the max current this charge pump voltage supply can provide is 100mA ⇒ 200mA $\frac{t_h}{T_s}$



Design Of Charge Pump

During t_h



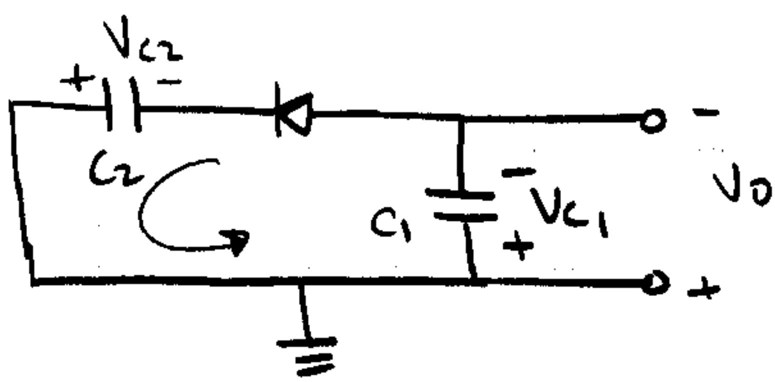
Charge Transferred from V_{cc} to C_2 is $I_m t_h$

Let $q_1 = I_m t_h$

Assume that V_{c2} charges to $V_{cc} - V_r$

⇒ Not always true – Desing always works

During t_L



Assume $C_1 = \text{Big} \Rightarrow V_0 = \text{Const}$

- Voltage on V_{c1} goes from $V_{cc} - V_r$ to $V_0 + V_r$

- C_2 transfers charge to C_1

- Before charge transfer

$$V_{c2}\Big|_i = V_{cc} - V_r$$

$$q_{c2}\Big|_i = C_2 V_{c2i} = C_2 (V_{cc} - V_r)$$

- After charge transfer

$$V_{c2}\Big|_f = V_0 + V_r$$

$$q_{c2}\Big|_f = C_2 V_{c2f} = C_2 (V_0 + V_r)$$

$$\Delta q_{c2} = \text{Charge transfer} = q_{c2}\Big|_i - q_{c2}\Big|_f$$

$$\Delta q_{C2} = C_2\left[V_{cc} - V_o - 2V_f\right]$$

and Δq_{C2} must equal q_1

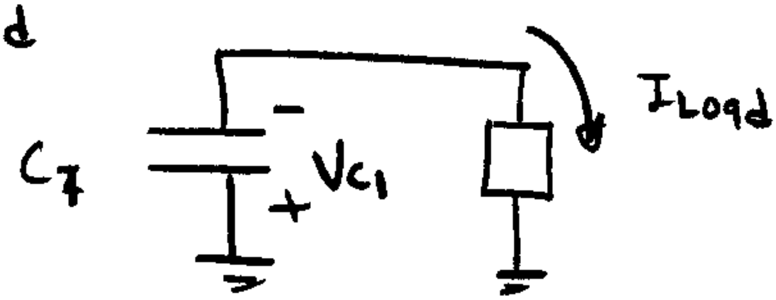
so

$$I_m t_n = C_2\left[V_{cc} - V_o - 2V_f\right]$$

Choose $C_2 \geq \left[\dfrac{I_m t_n}{V_{cc} - V_o - 2V_f}\right]$

Choosing C_1

During t_n, C_1 supplies current to Load



$$\Delta V_{C1} = \frac{I_{Load}\, t_h}{C_1}$$

Choose $C_1 > \frac{I_{Load}\, t_h}{\Delta V_{C1}}$

Where ΔV_{C1} = output Ripple

$$I_{Load} = I_{source} \frac{t_h}{T_s}$$

Design Summary

- Integrated Circuit Limitation
  I_{source}, I_{sink}
- $t_h + t_L = T_s$

ALSO
$|V_o| \le |V_{cc}| - 3$

$$I_o\Big|_{max} = I_{source} \frac{t_h}{T_s}\left[0.90\right]$$

can only get 90% of charge from C_2 to C_1

$$\frac{t_h}{t_L} = \frac{I_{sink}}{I_{source}}$$

Choose $C_2 \geq \left[\frac{I_{source} t_h}{V_{cc} - V_o - 2V_f} \right]$

Choose $C_1 \geq \frac{I_{omax} \, t_h}{\Delta V_{o1}}$

Design example

$V_{cc} = 12V$, $I_{sink} = I_{source} = 400 \text{ mA}$

Design a charge pump that can supply $V_o = -9V$ at 100 mA with less than 100 mV of Ripple

Soln:

Choose $F_s = 20 \text{ KHz}$

$\Rightarrow T_s = 50 \, \mu s$

Since $I_{sink} = I_{source}$

$$t_h = t_L = 25\,\mu s$$

$$C_2 > \frac{I_{source}\, t_h}{V_{cc} - V_0 - 2V_F}$$

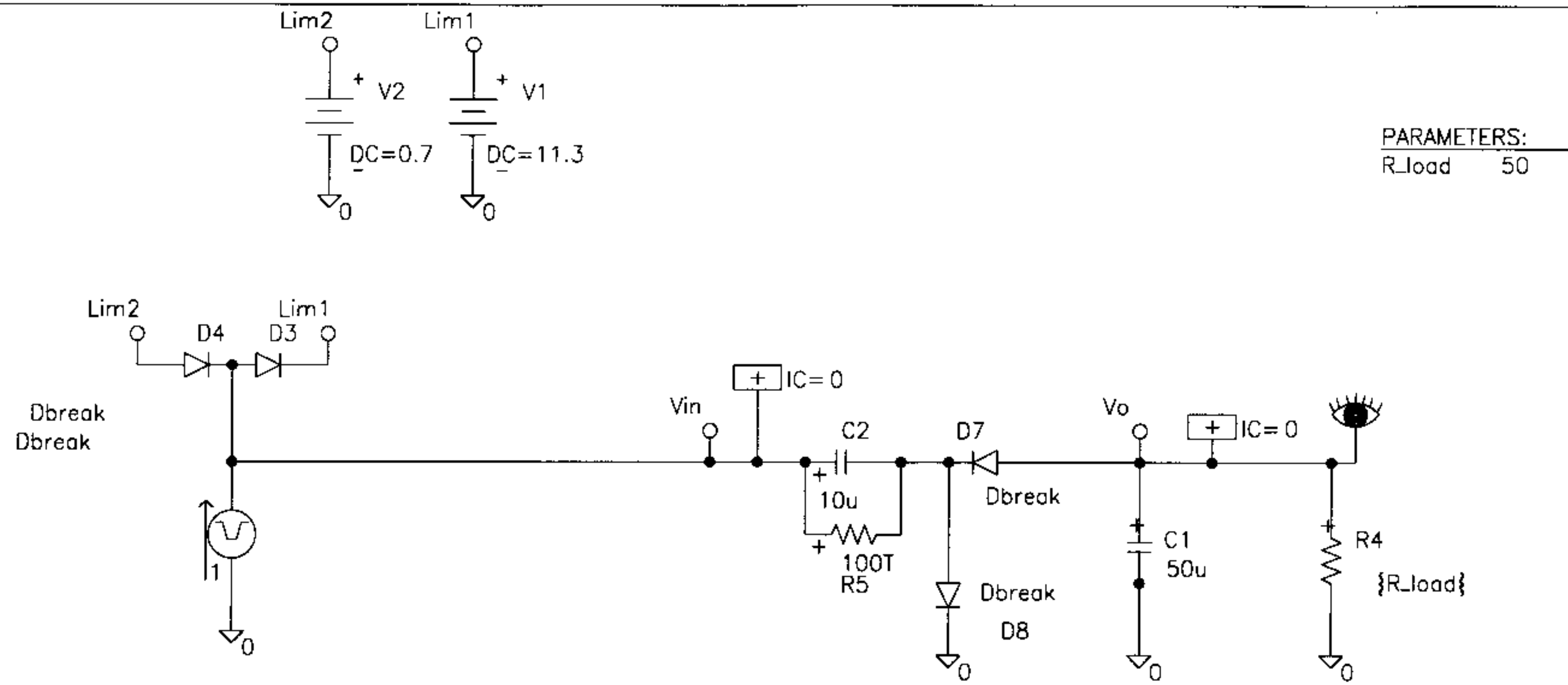
$$C_2 \geq \frac{(400\,mA)(25\,\mu s)}{12 - 9 - 2(1)} \geq 10\,\mu F$$

Choose $C_2 = 10\,\mu F$

choose $C_1 \geq \dfrac{I_{omax}\, t_h}{\Delta V_{o1}}$

$$\geq \frac{(90\,mA)(25\,\mu s)}{0.050\,V}$$

$$C_1 \geq 45\,\mu F$$

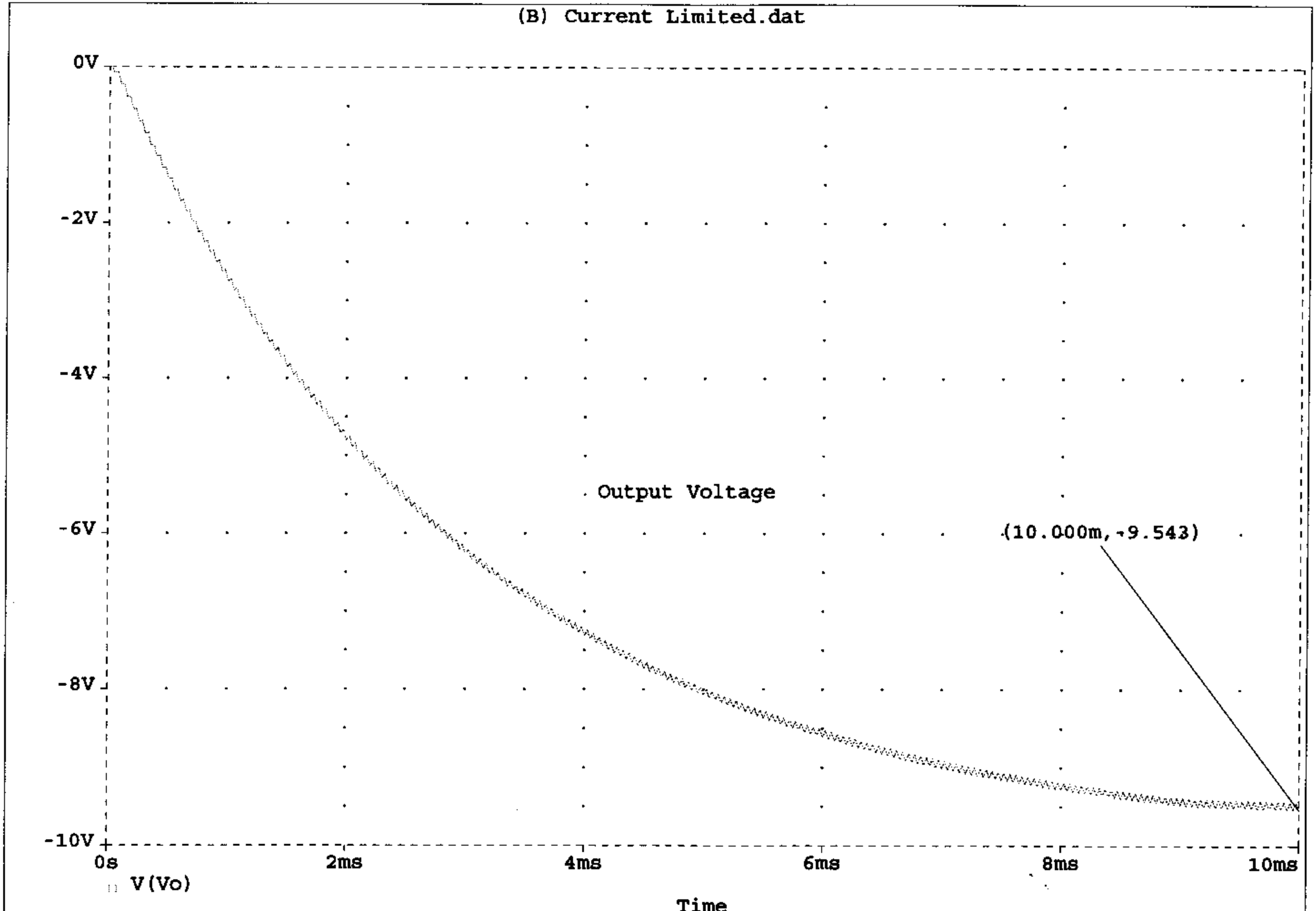


Lim2
V2
DC=0.7
0
Lim1
V1
DC=11.3
0
PARAMETERS:
R_load 50
Lim2
D4
D3
Lim1
Dbreak
Dbreak
1
0
Vin
IC=0
C2
10u
100T
R5
D7
Dbreak
Dbreak
D8
0
Vo
IC=0
C1
50u
0
R4
{R_load}
0

15

* D:\NAU\CLASS\Egr456\SPICE\Charge Pump\Current Limited.sch

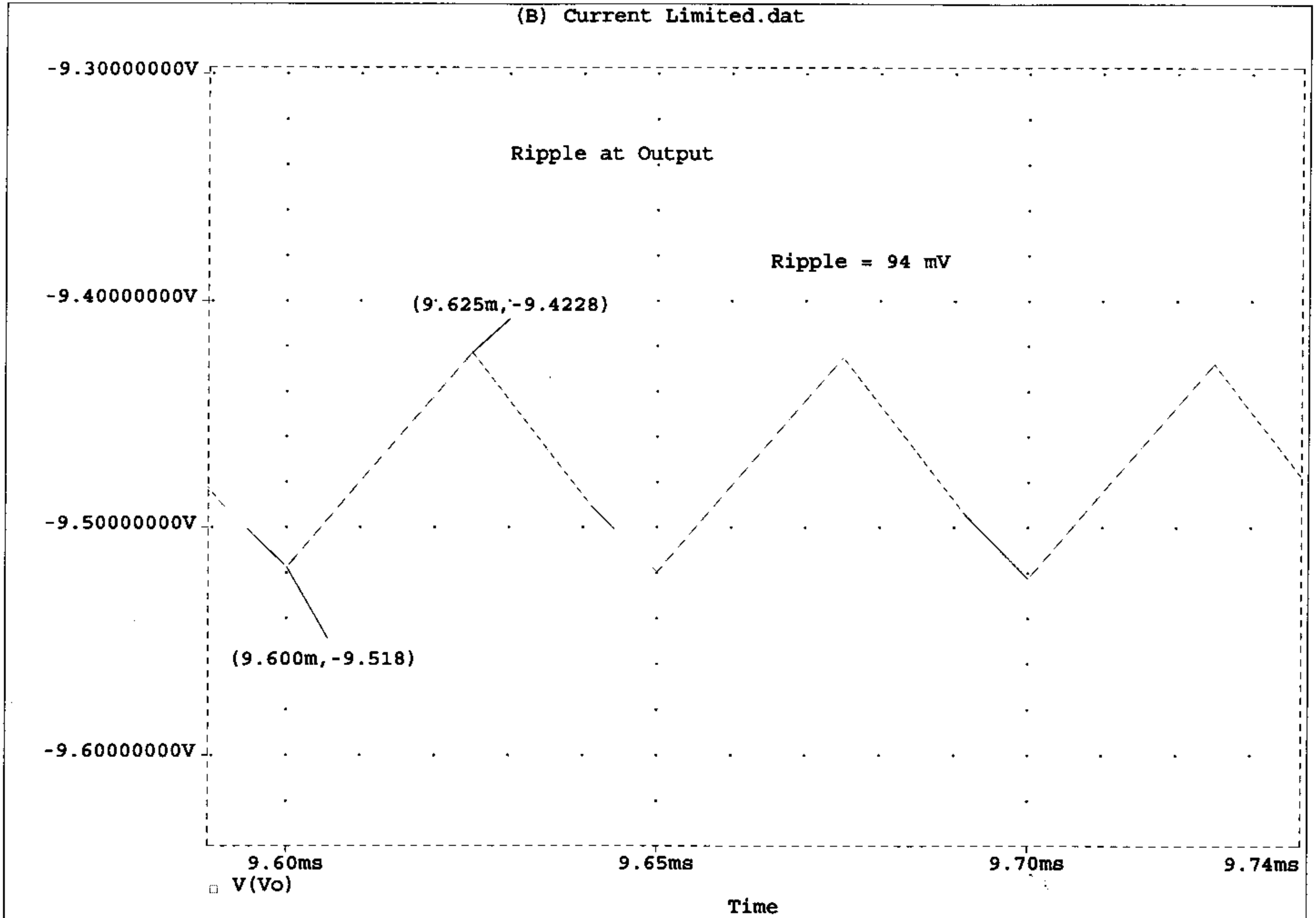
Date/Time run: 02/19/97 10:01:50 Temperature: 27.0



Date: February 19, 1997 Page 1 Time: 10:06:17

* D:\NAU\CLASS\Egr456\SPICE\Charge Pump\Current Limited.sch

Date/Time run: 02/19/97 10:01:50 Temperature: 27.0

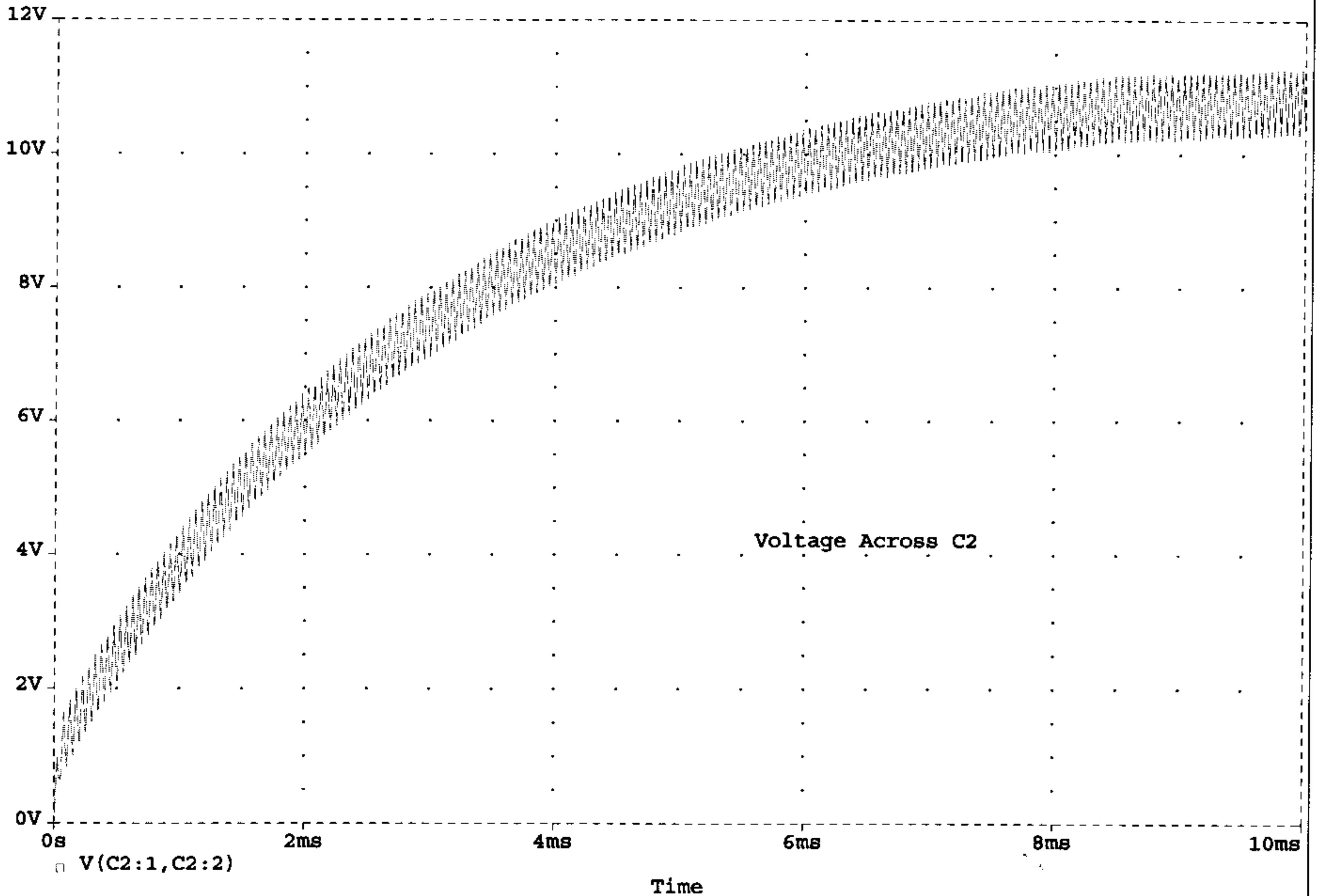


(17)

* D:\NAU\CLASS\Egr456\SPICE\Charge Pump\Current Limited.sch

Date/Time run: 02/19/97 10:01:50 Temperature: 27.0

(A) Current Limited.dat



Date: February 19, 1997 Page 1 Time: 10:04:07

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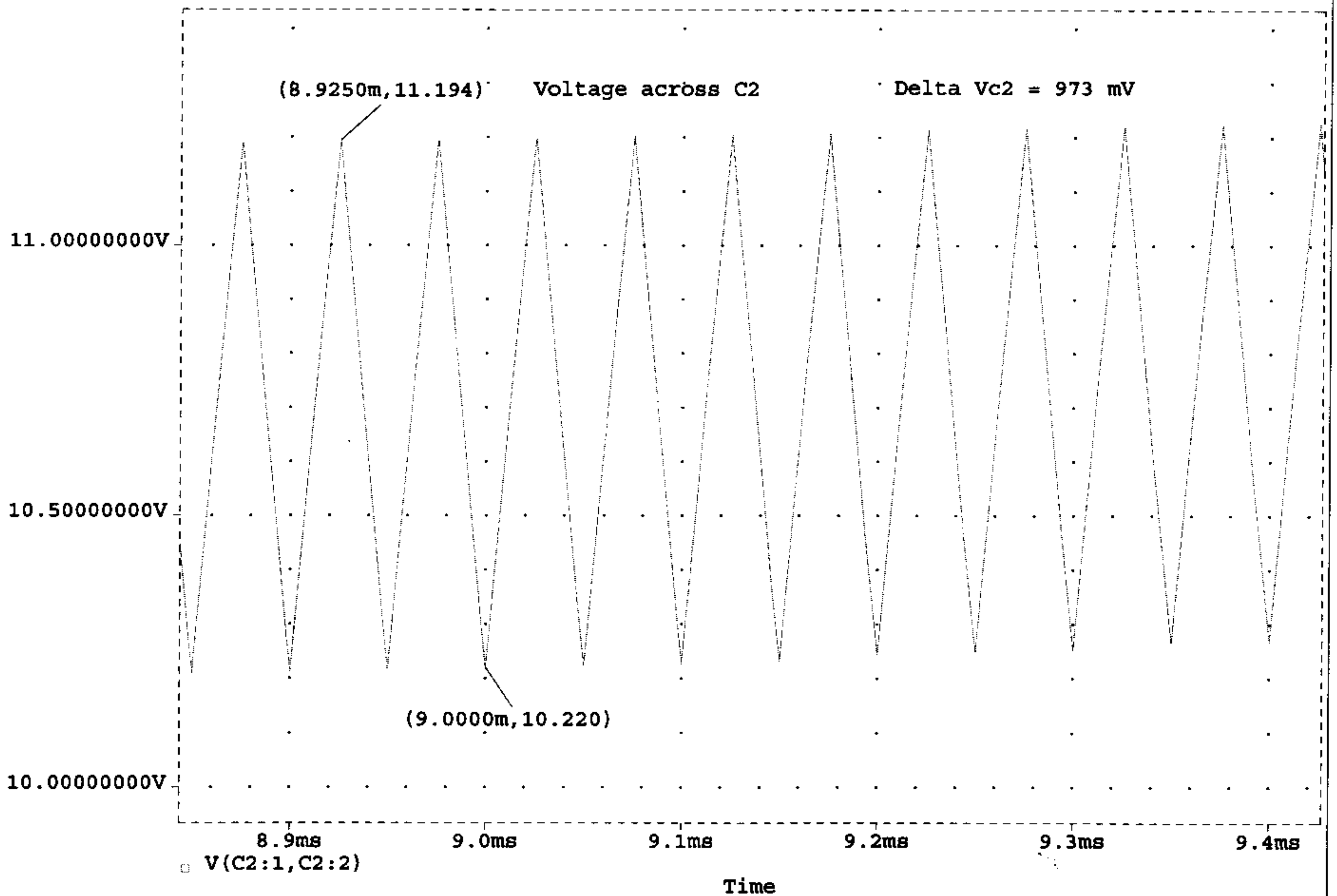
* D:\NAU\CLASS\Egr456\SPICE\Charge Pump\Current Limited.sch

Date/Time run: 02/19/97 10:01:50 Temperature: 27.0

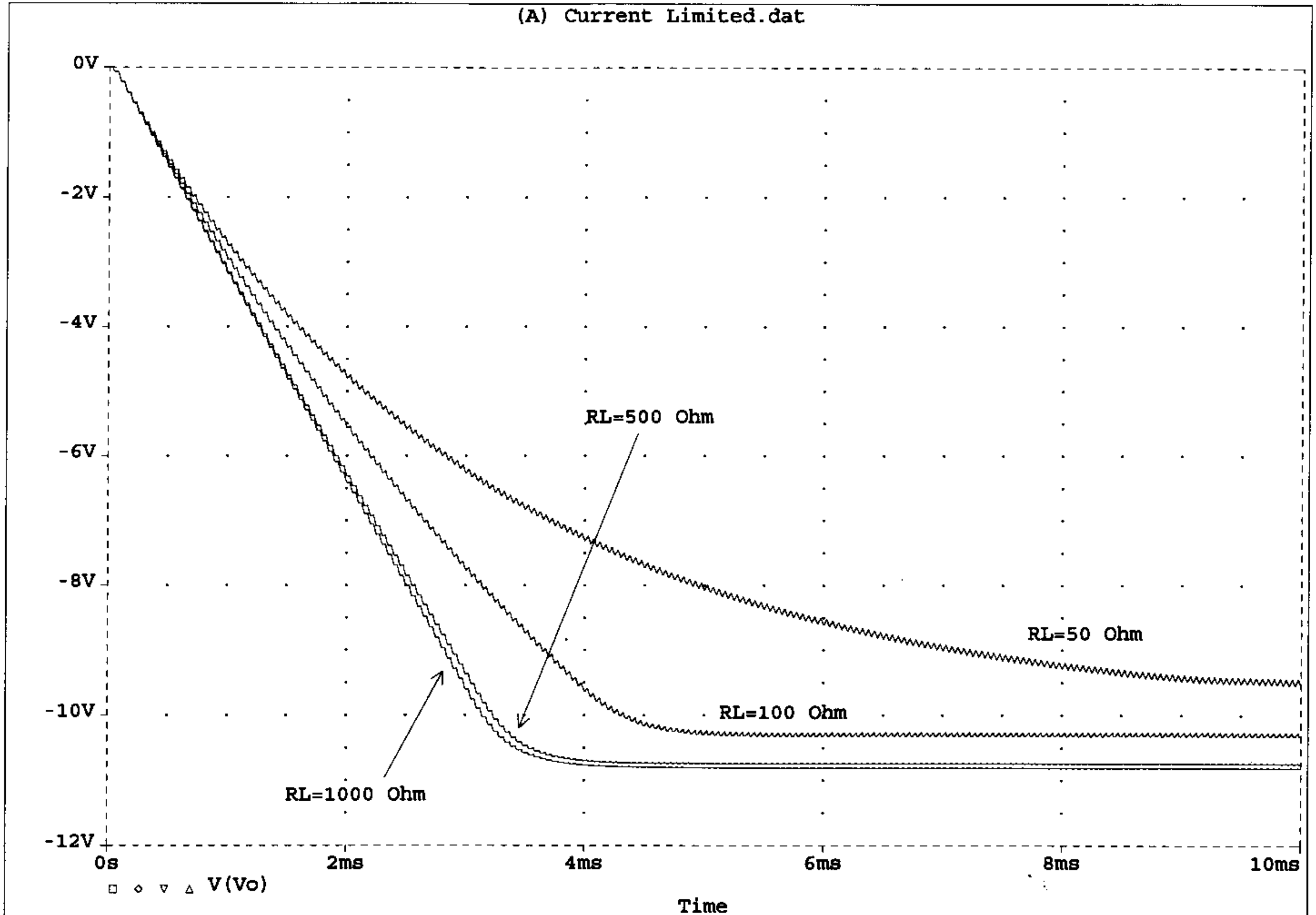
(A) Current Limited.dat



Date: February 19, 1997 Page 1 Time: 10:05:16

* D:\NAU\CLASS\Egr456\SPICE\Charge Pump\Current Limited.sch

Date/Time run: 02/19/97 10:08:50 Temperature: 27.0



Date: February 19, 1997 Page 1 Time: 10:13:44