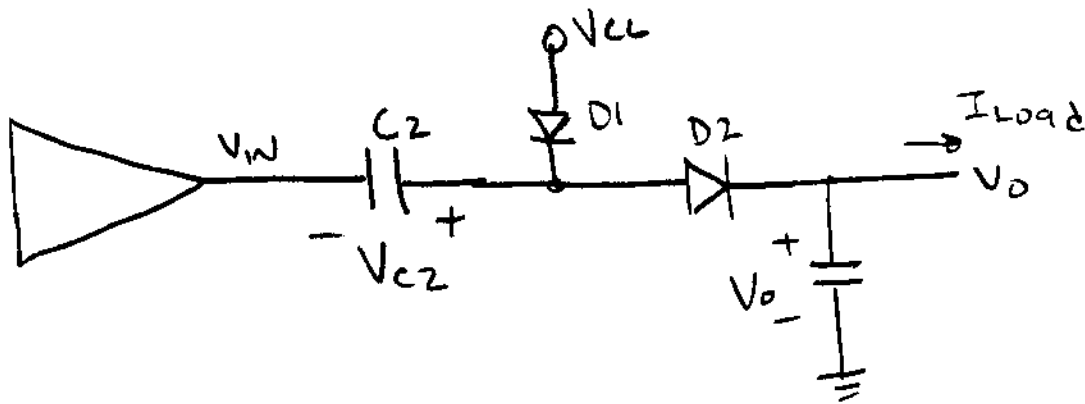
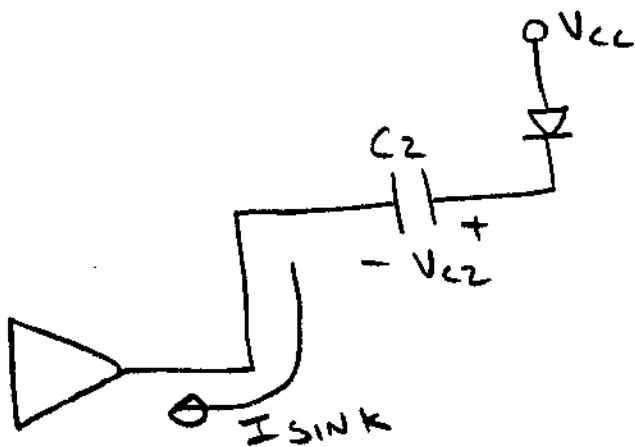


Voltage Doubling charge Pump

①



When V_{in} is Low, $D1 = \text{on}$, $D2 = \text{off}$



- V_{C2} charges to $V_{CC} - V_f$

- charge absorbed by C_2 is $(I_{\text{sink}}) t_L$

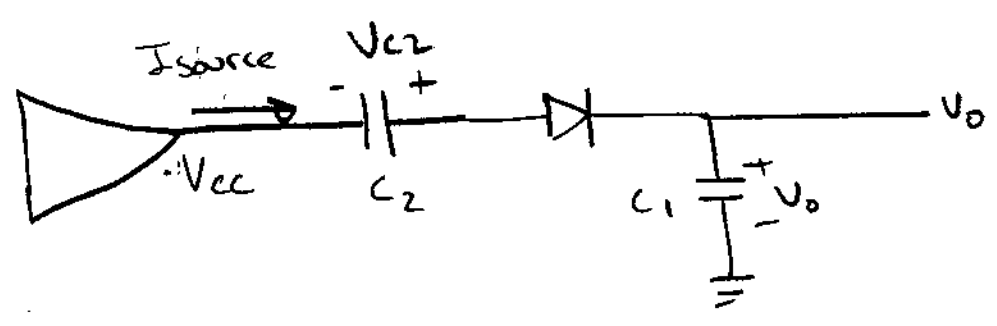
where t_L is the amount of time

V_{in} is zero.

Charge transferred to C_2 during t_L is

$$q_L = I_{sink} t_L$$

When V_{in} is at V_{CC} , D_1 is OFF and D_2 = ON



- charge transferred from C_2 to C_1

$$V_0 \text{ charges to } V_{CC} + V_{c2} - V_f = 2V_{CC} - 2V_f$$

- charge transferred from C_2 to C_1 is during t_H is

$$q_H = I_{source} t_H$$

During one cycle, The charge delivered to the Load is

$$Q_{Load} = (I_{Load})(t_H + t_L)$$

In steady state, it must be true that the charge transferred from V_{CC} to C_2 during t_L must be the same as the charge transferred from C_2 to C_1 during t_H which must be the same as the charge absorbed by the Load over one full cycle

$$\Rightarrow Q_H = Q_L \Rightarrow I_{source} t_H = I_{sink} t_L$$

$$\Rightarrow \frac{t_H}{t_L} = \frac{I_{sink}}{I_{source}} \quad (1)$$

also

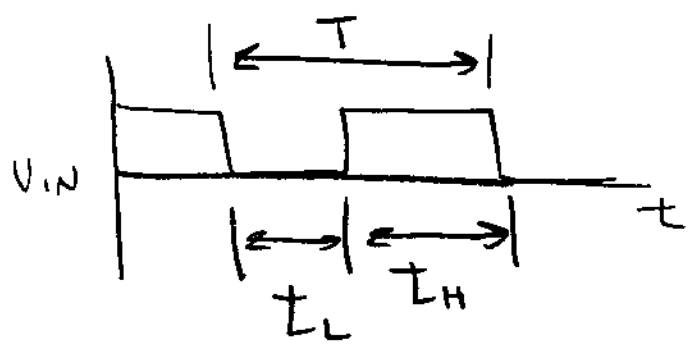
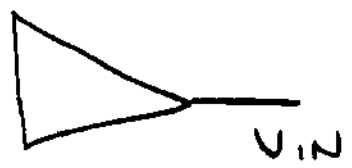
$$Q_L = Q_{Load} \text{ OR}$$

$$I_{Load} [t_H + t_L] = I_{sink} t_L$$

Since $t_H + t_L = T$ then

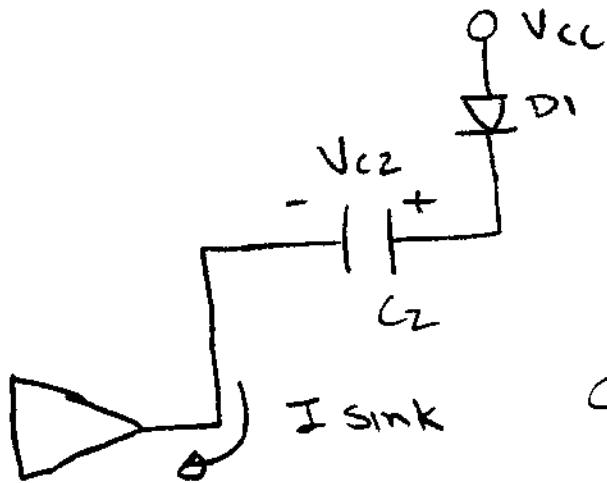
$$\textcircled{2} I_{Load} = I_{sink} \left[\frac{t_L}{T} \right] = I_{source} \left[\frac{t_H}{T} \right]$$

DRIVING INPUT WAVEFORM



Derivation of equation for C_2

During t_L , $D_1 = \text{on}$, $D_2 = \text{off}$ and C_2 is charged from V_{CC}



Charge transferred from V_{CC} to C_2

Amount of charge transferred is

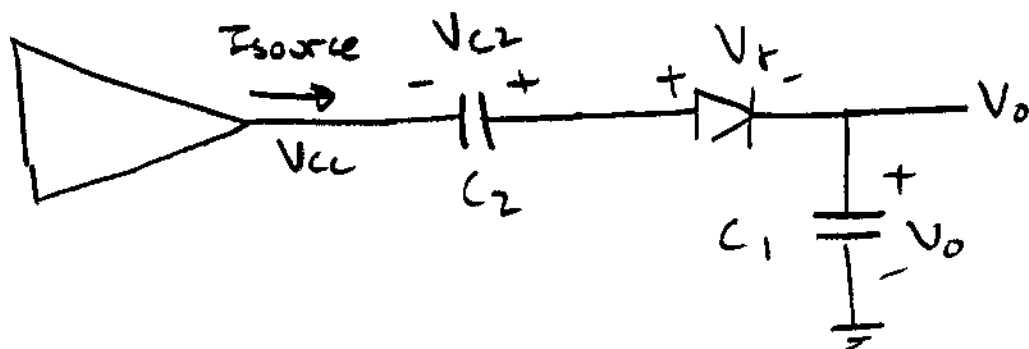
$$Q_L = I_{\text{sink}} t_L$$

During t_L assume that C_2 charges

up to $V_{CC} - V_D$

(6)

During t_H we have $D_1 = \text{off}$, $D_2 = \text{on}$



Assume C_1 is so big that $V_o = \text{const}$

- During t_H , C_2 will transfer charge to C_1

- at the end of t_H , the voltage on C_2 can be obtained from KVL

$$V_{CC} + V_{c2} - V_f - V_o = 0$$

$$\text{OR } V_{c2} = V_o + V_f - V_{CC}$$

Look at the charge transfer from C_2 to C_1

during t_H

(7)

at the end of t_L , the voltage on C_2 is $V_{CC} - V_{th}$

$$\Rightarrow V_{C2_i} = V_{CC} - V_{th}$$

$$Q_{L_i} = C_2 V_{C2_i} = C_2 (V_{CC} - V_{th})$$

at the end of t_H , the voltage on C_2 is $V_0 + V_{th} - V_{CC}$

$$V_{C2_f} = V_0 + V_{th} - V_{CC}$$

$$Q_{L_f} = C_2 (V_0 + V_{th} - V_{CC})$$

The charge transferred to C_1 is

$$\Delta Q = Q_{L_i} - Q_{L_f} = C_2 [2V_{CC} - V_0 - 2V_{th}]$$

Δq is the charge transferred from C_2 to C_1 during t_H . This charge must be the same as the charge transferred from V_{CC} to C_2 during t_L

$$\Rightarrow q_L = \Delta q$$

$$I_{SINK} t_L = C_2 [2V_{CC} - V_0 - 2V_T]$$

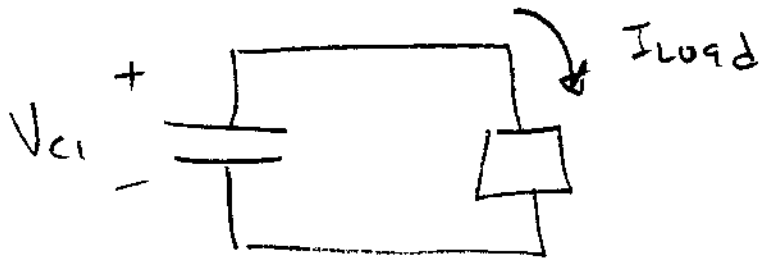
OR
$$C_2 = \frac{I_{SINK} t_L}{(2V_{CC} - V_0 - 2V_T)}$$

So choose

$$C_2 \geq \frac{I_{SINK} t_L}{2V_{CC} - V_0 - 2V_T} \quad (3)$$

Derrivation of equation for C_1

- During t_L C_1 sources current to the Load



$$\Delta V_{c1} = \frac{I_{Load} t_L}{C_1}$$

Choose

$$C_1 \geq \frac{I_{Load} t_L}{\Delta V_{c1}}$$

Where ΔV_{c1} is the ripple spec for the output voltage.

Voltage Doubler Summary

Integrated Circuit Limitation I_{source} , I_{sink}

$$t_H + t_L = T_s$$

$$I_{Load} \Big|_{max} = I_{sink} \left[\frac{t_L}{T_s} \right] = I_{source} \left[\frac{t_H}{T_s} \right]$$

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

$$C_2 \geq \frac{I_{sink} t_L}{2V_{CC} - V_o - 2V_\sigma}$$

$$C_1 \geq \frac{I_{Load} t_L}{AV_{C1}}$$

Example

(11)

Design a charge pump with

$$V_{CC} = 15$$

$$V_{Omin} = 24V @ 100mA$$

output current: 0 to 100mA

For the design assume $I_{sink} = I_{source}$

$$\Rightarrow t_H = t_L$$

choose a switching frequency of 20 KHz

$$\Rightarrow T_s = 50\mu s, \quad t_L = t_s = 25\mu s$$

$$\text{Choose } C_2 \geq \frac{(I_{sink}) t_L}{2V_{CC} - V_o - 2V_f}$$

$$\text{OR } C_2 \geq \frac{(200mA)(25\mu s)}{2(15V) - 24V - 2(0.7V)}$$

OR $C_2 \geq 0.87 \mu F$

choose $C_2 = 1 \mu F$

to choose C_1 , we need a ripple spec which was not specified.

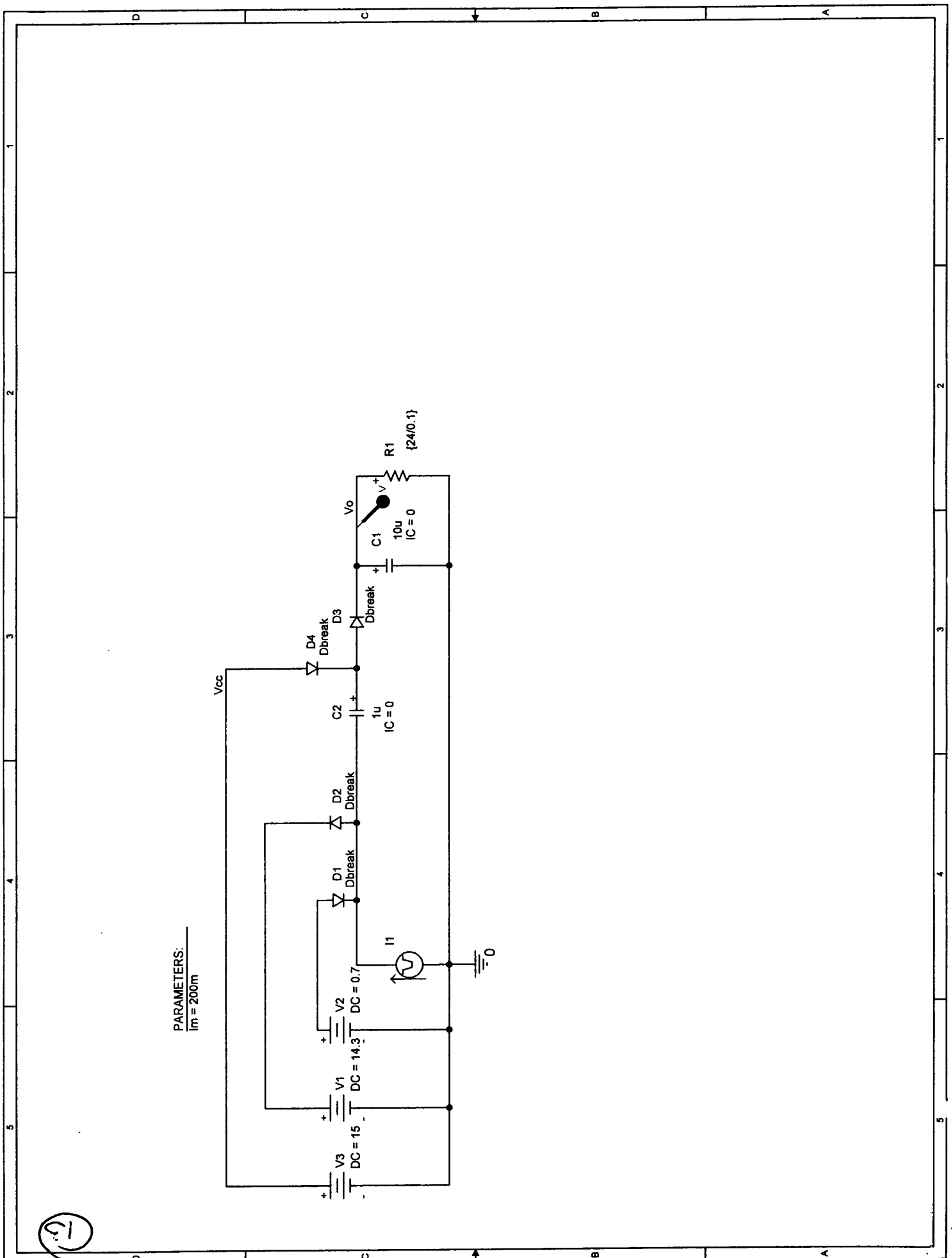
\Rightarrow design for ripple less than 1%

$\Rightarrow \Delta V_{C_1} = 0.24 V$

$\Rightarrow C_1 \geq \frac{(I_{load})(t_r)}{\Delta V_{C_1}}$

$C_1 \geq \frac{(100mA)(25\mu s)}{0.24V}$

$C_1 \geq 8.33 \mu F \Rightarrow$ choose $C_1 = 10 \mu F$

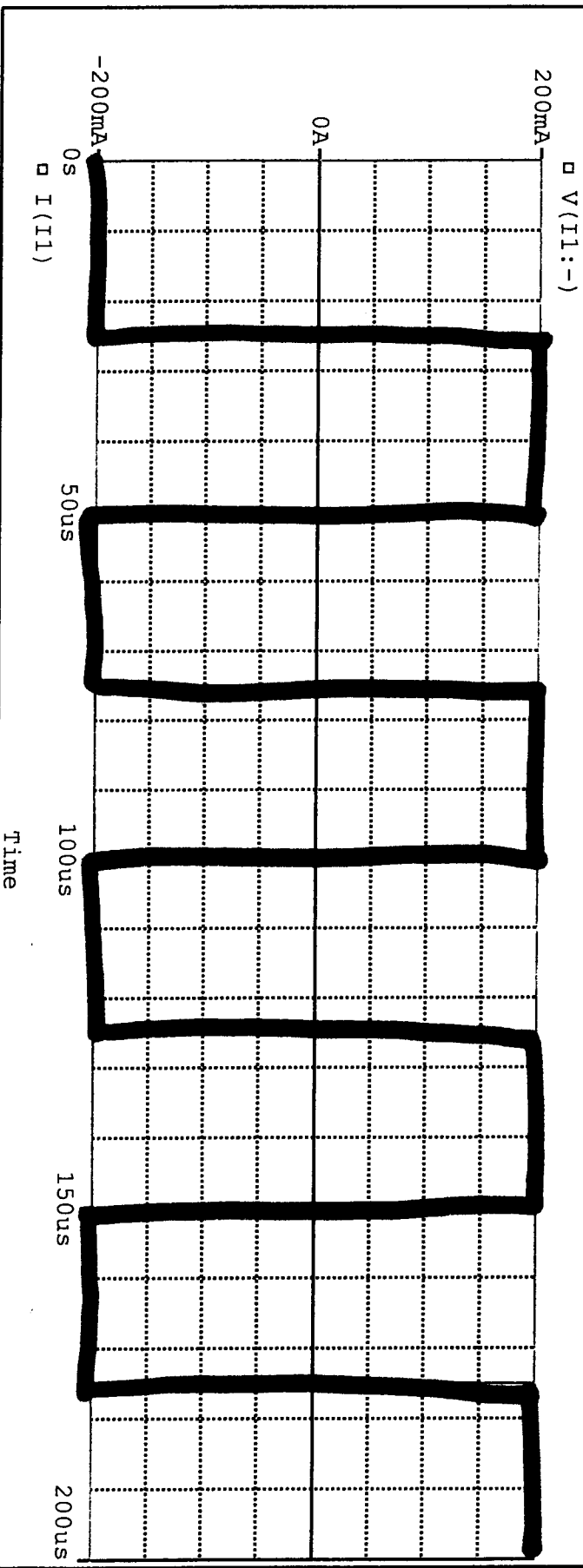
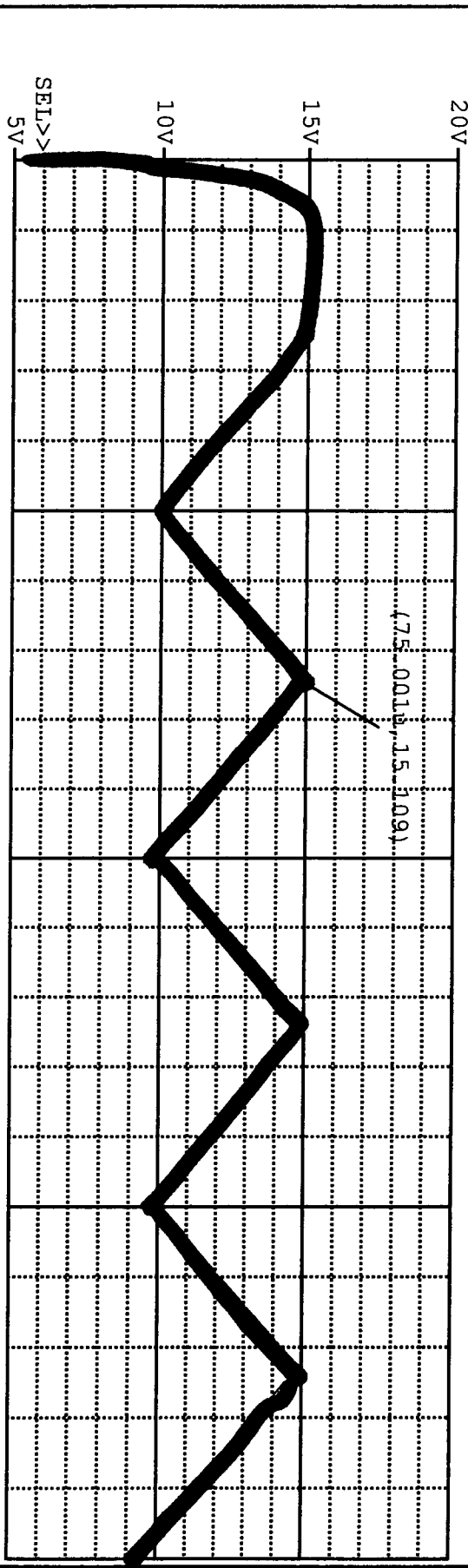


PARAMETERS:
Im = 200m

(1.9)

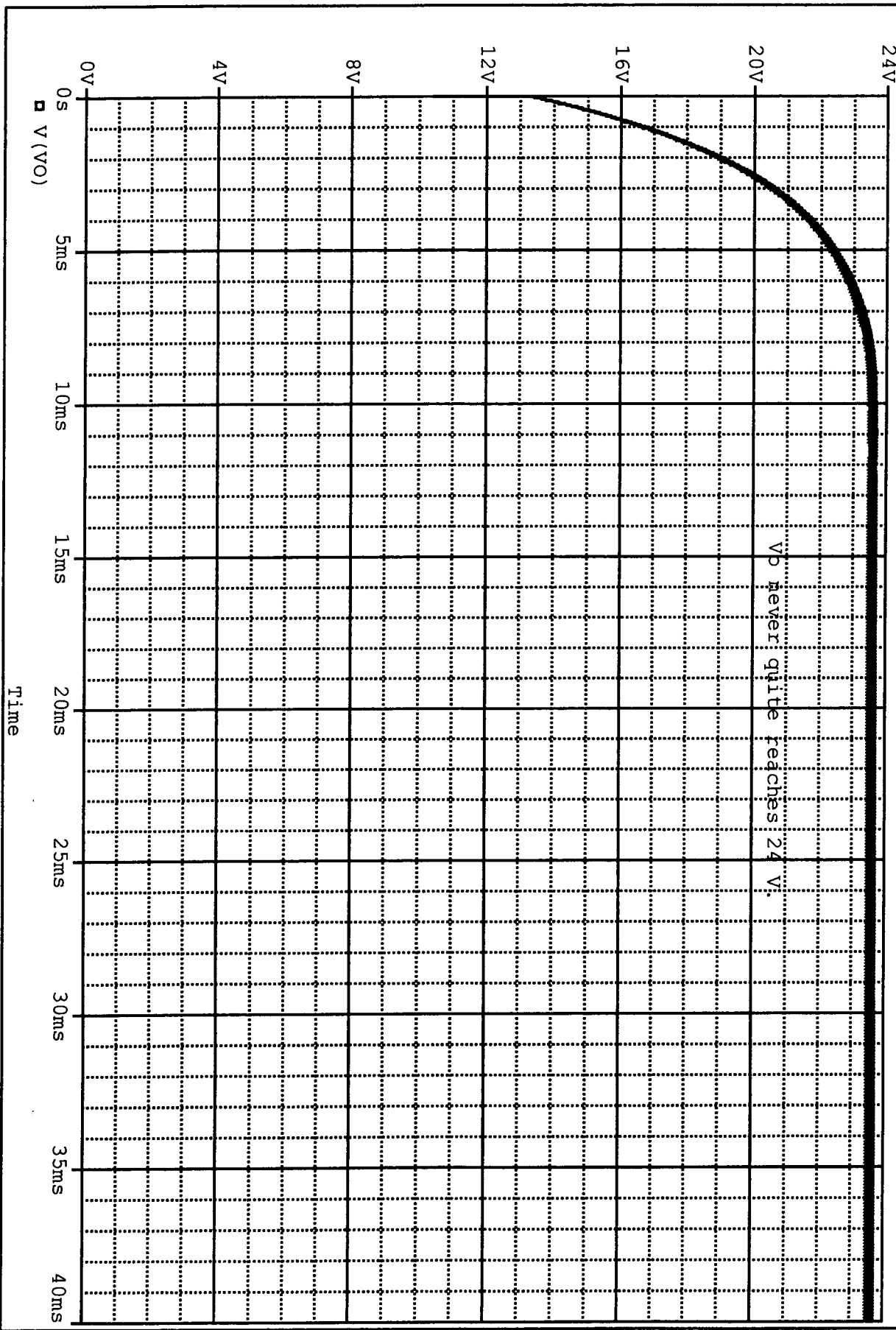
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Date/Time run: 11/07/00 10:58:43 Temperature: 27.0

(B) charge pump-SCHEMATIC1-Transient.dat (active)



5
** Profile: "SCHEMATIC1-Transient" [D:\NAU\CLASS\EGR456\Exams\charge pump-schematic1-transient.s...
Date/Time run: 11/07/00 11:16:42 Temperature: 27.0

(A) charge pump-SCHEMATIC1-Transient.dat (active)



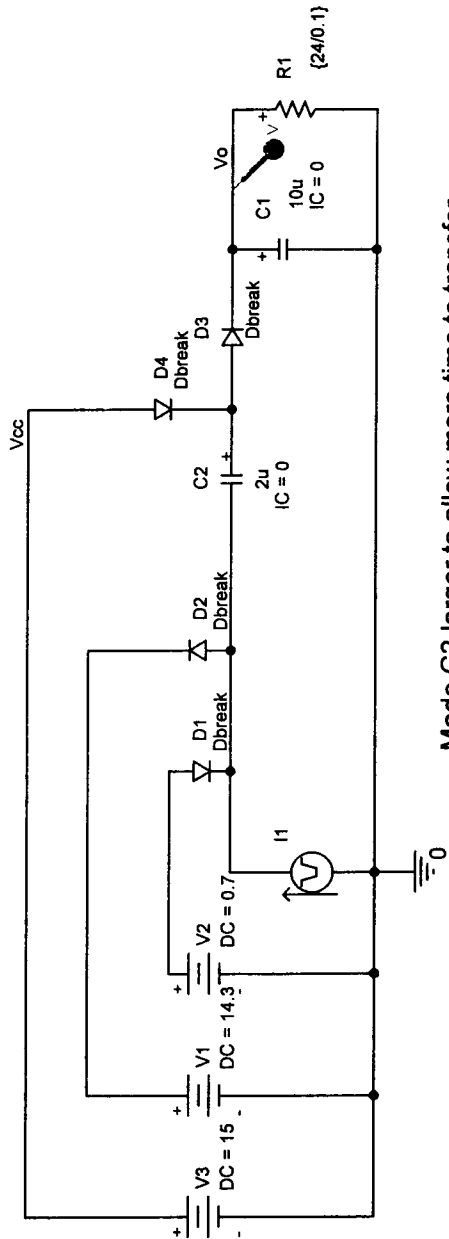
Date: November 07, 2000

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Time: 11:17:54

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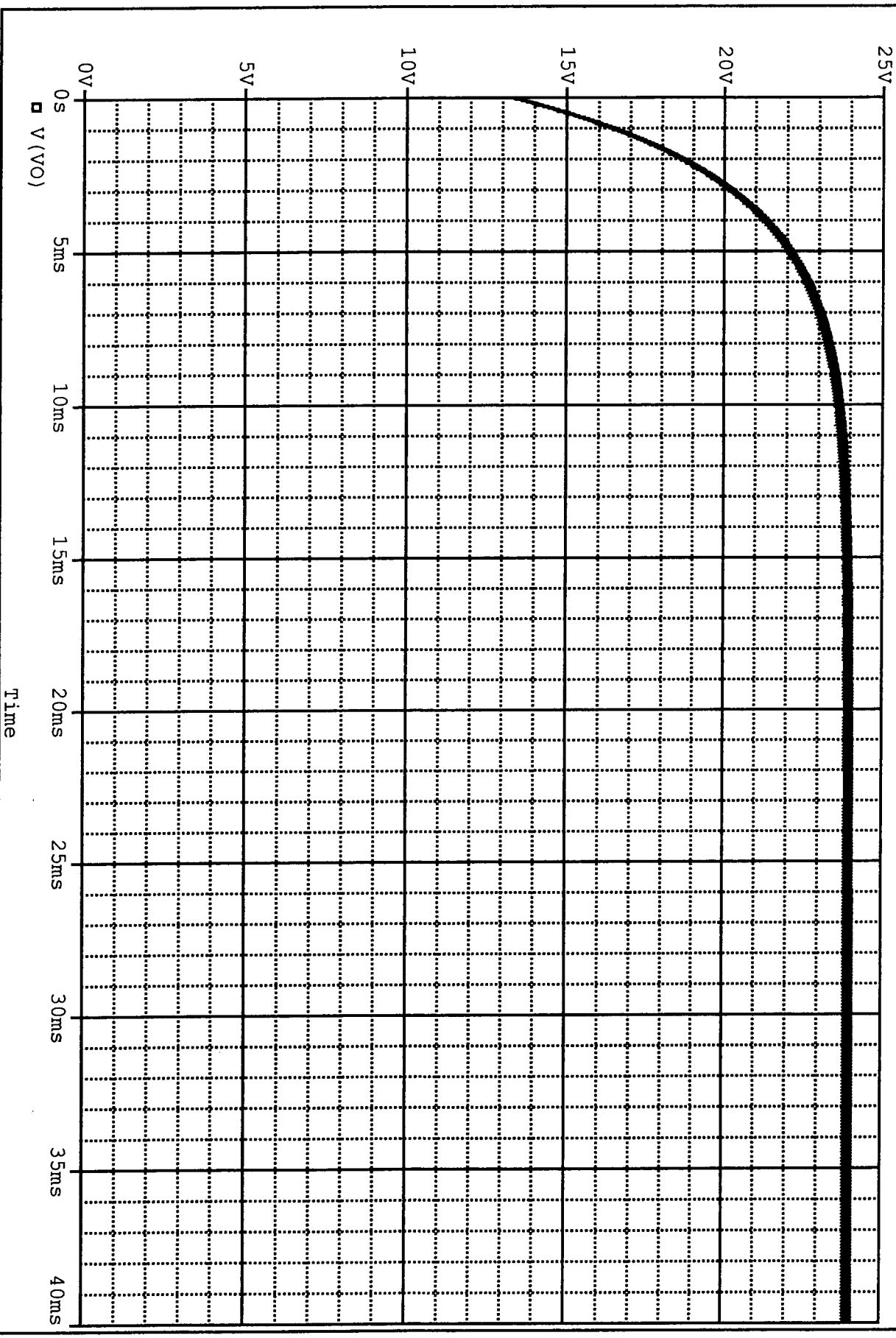
PARAMETERS:
 $i_m = 200m$



Made C2 larger to allow more time to transfer charge from Vcc to C2.

** Profile: "SCHEMATIC1-Transient" [D:\NAU\CLASS\EGR456\Exams\charge pump-schematic1-transient.s...
Date/Time run: 11/07/00 11:21:16 Temperature: 27.0

(A) charge pump-SCHEMATIC1-Transient.dat (active)

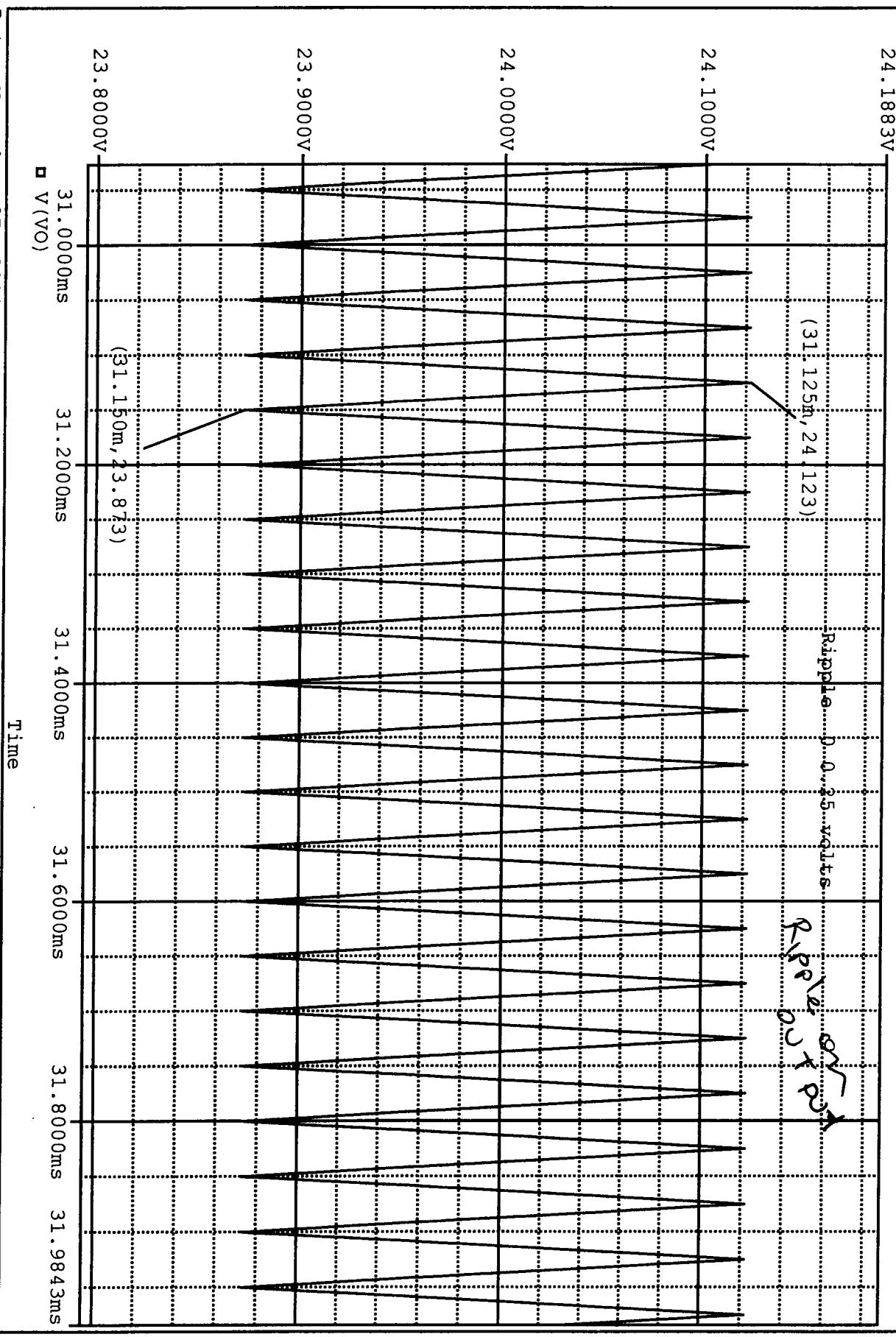


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Ripple on output = 0.25V

** Profile: "SCHEMATIC1-Transient" [D:\NAU\CLASS\EGR456\Exams\charge pump-schematic1-transient.s...
Date/Time run: 11/07/00 11:21:16 Temperature: 27.0

(A) charge pump-SCHEMATIC1-Transient.dat (active)



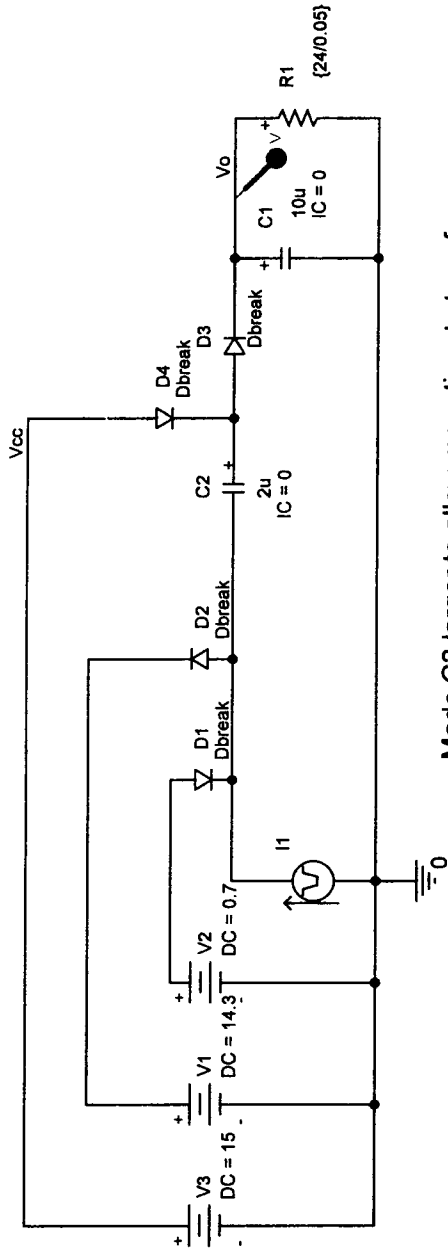
Date: November 07, 2000

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Time: 11:24:35

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PARAMETERS:
 $I_m = 200\text{m}$

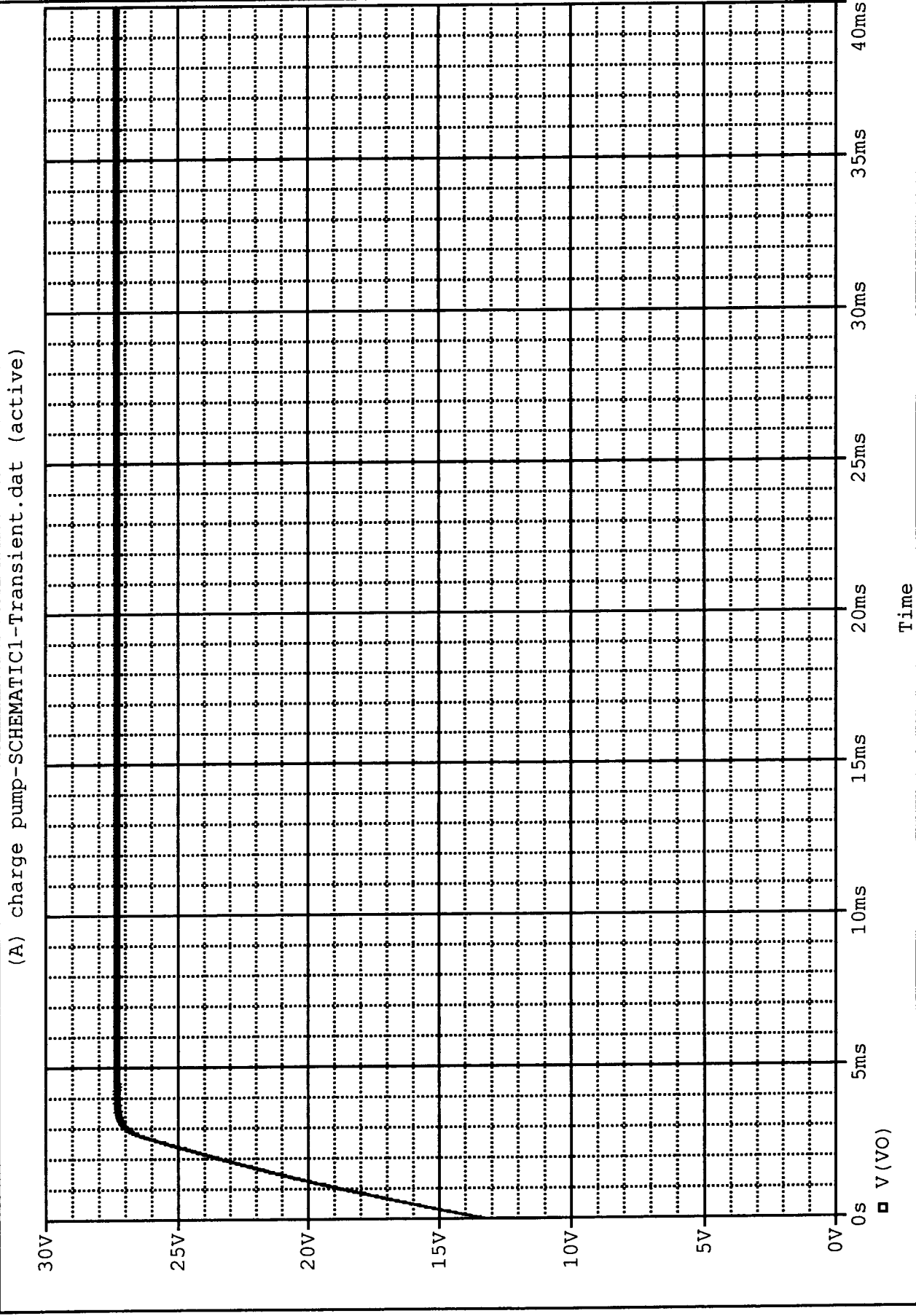


Made C2 larger to allow more time to transfer charge from Vcc to C2.

Test at 50 mA load

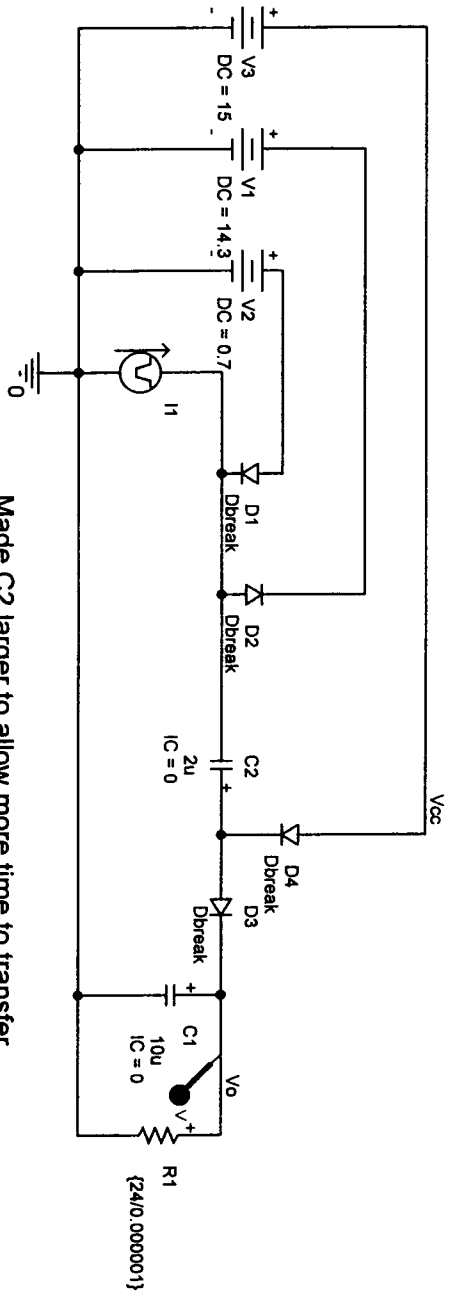
20

** Profile: "SCHEMATIC1-Transient" [D:\NAU\CLASS\EGR456\Exams\charge pump-schematic1-transient.s...
Date/Time run: 11/07/00 11:24:54 Temperature: 27.0



91

PARAMETERS:
Im = 200m



Made C2 larger to allow more time to transfer charge from Vcc to C2.

Test of NO load

5 4 3 2 1

** Profile: "SCHEMATIC1-Transient" [D:\NAU\CLASS\EGR456\Exams\charge pump-schematic1-transient.s...
Date/Time run: 11/07/00 11:26:06 Temperature: 27.0

