Name: ______________________________ (please print)

Signature: ___________________________

ECE 3455
Exam 2
April 19, 2008

Exam duration: 90 minutes

- You may have one 8 ½ x 11 in. "crib" sheet, written on both sides, during the quiz. You may have any calculator you choose, but no computers. No other notes or materials will be allowed.
- Show all work necessary to complete the problem on these pages. A solution without the work shown will receive no credit.
- Show units in intermediate and final results, and in figures.
- If your work is sloppy or difficult to follow, points will be subtracted.

This exam has 10 pages, including the cover sheet and a data sheet at the end. Raise your hand if you are missing a page.

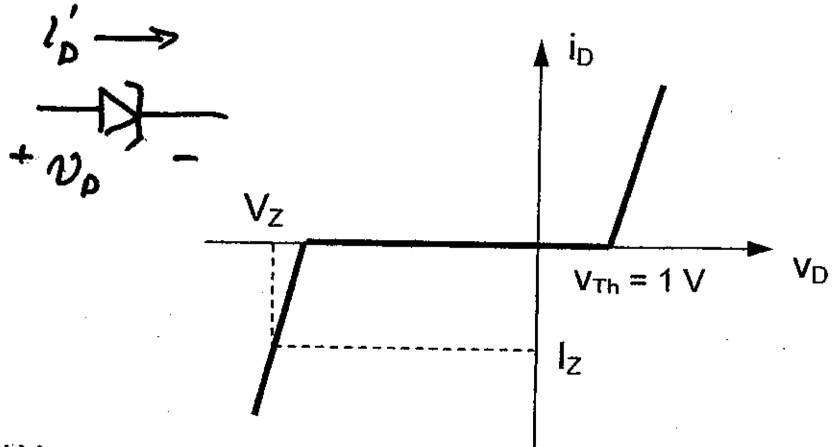
1 ________________/40

2 ________________/40

3 ________________/20

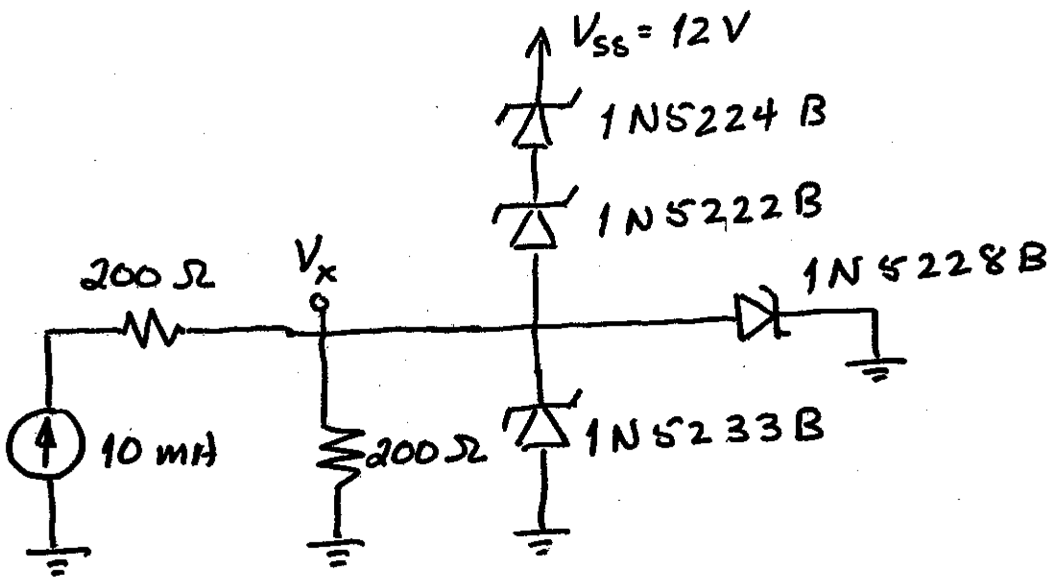
Total ________________/100

1. **(40 points)** The Zener diodes in the circuit below have the $I_D - V_D$ characteristics shown in the figure. In forward bias, they all have a turn-on voltage V_{TH} of 1 V and a series resistance of 50 Ω. The characteristics in reverse bias are different for each diode; this information is given in the data sheet attached to the back of this exam.



+35 i) Find V_x.

+5 ii) Draw an ac model for this circuit, and from it determine the variation in V_x given a variation in V_{ss} of +/- 1V.



The value of V_x will determine the state of the diodes. We will guess that it is sufficiently positive that 5233 is in breakdown, but not too large, so that 5224 and 5222 are in breakdown as well. Clearly then, 5228 is in forward bias.

So we have...

We need V_{ZO} :

Room for extra work

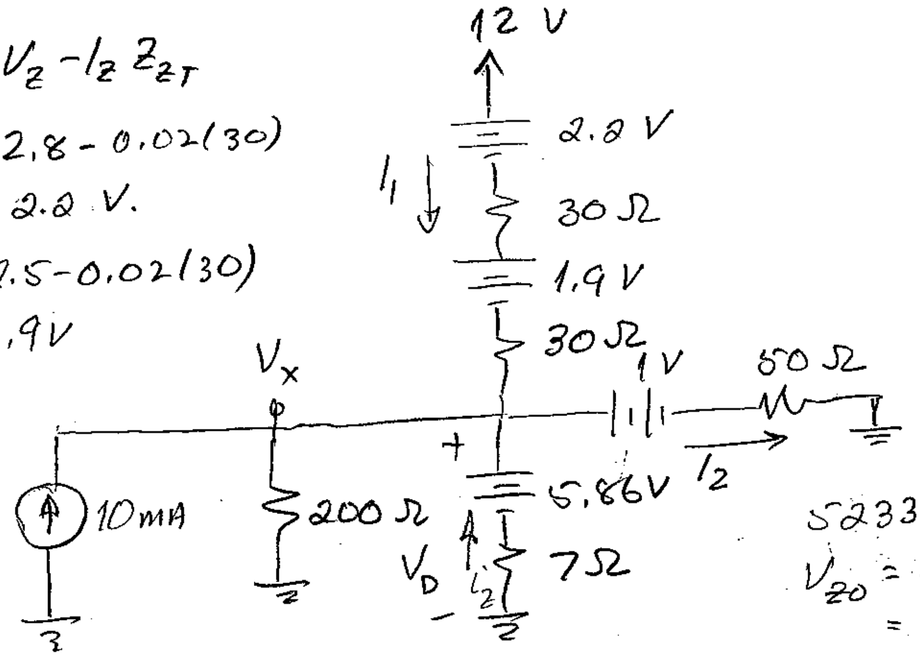
5224: $V_{Z0} = V_Z - I_Z Z_{ZT}$

$= 2.8 - 0.02(30)$

$= 2.2$ V.

5222: $V_{Z0} = 2.5 - 0.02(30)$

$= 1.9$V



5233:

$V_{Z0} = 6 - 0.02(7)$

$= 5.86$ V

Now $\frac{V_x}{200} + \frac{V_x - 12 + 2.2 + 1.9}{60} + \frac{V_x - 1}{50} + \frac{V_x - 5.86}{7} = 0.01$

$i_2' = \frac{0 - V_x + 5.86}{7}$

> 0 ✗

$\Rightarrow V_x = 5.413$ V ✗

This is ok except for 5233 since V_x is not sufficient to put it in breakdown. If we turn 5233 off ($i' = 0$) we have

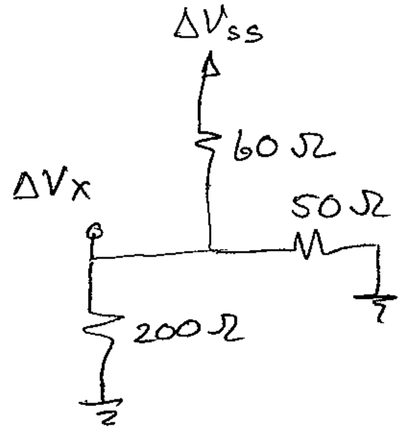
$$\frac{V_x}{200} + \frac{V_x - 12 + 2.2 + 1.9}{60} + \frac{V_x - 1}{50} = 0.01$$

$\Rightarrow V_x = 3.88$ V.

This is ok: $I_1 = \frac{12 - 3.88 - 2.2 - 1.9}{60} = 67.0$ mA ✓

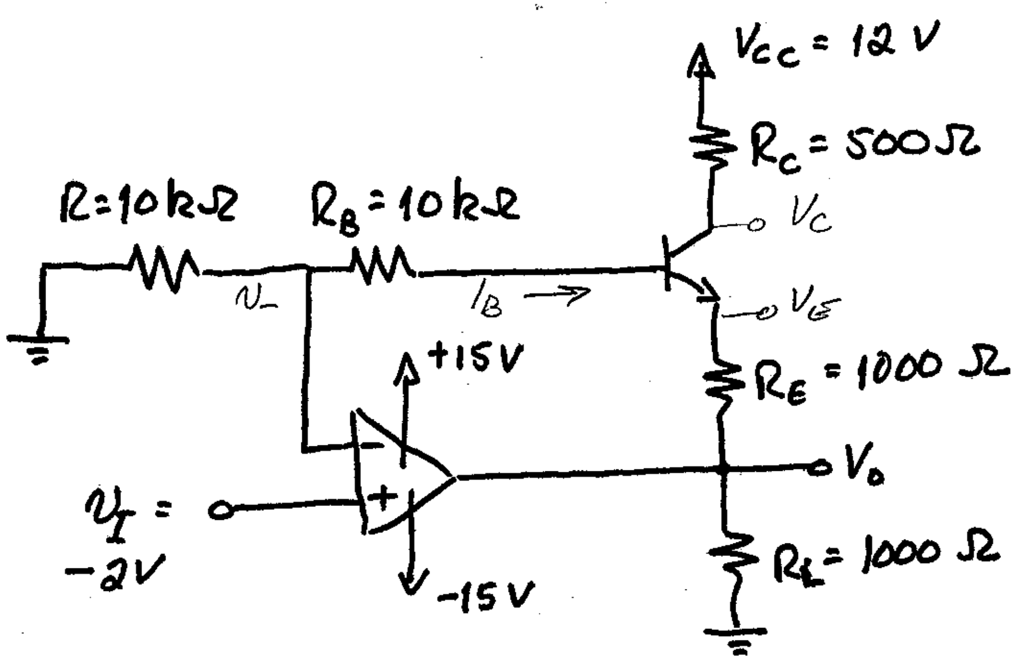
$I_2 = \frac{3.88 - 1}{50} = 57.6$ mA ✓ $V_D = -3.88$ V ✓

ii) The ac model is



$$\Rightarrow \Delta V_x = \Delta V_{ss} \cdot \frac{200 \| 50}{200 \| 50 + 60} = \underline{\underline{0.4\ V}}$$

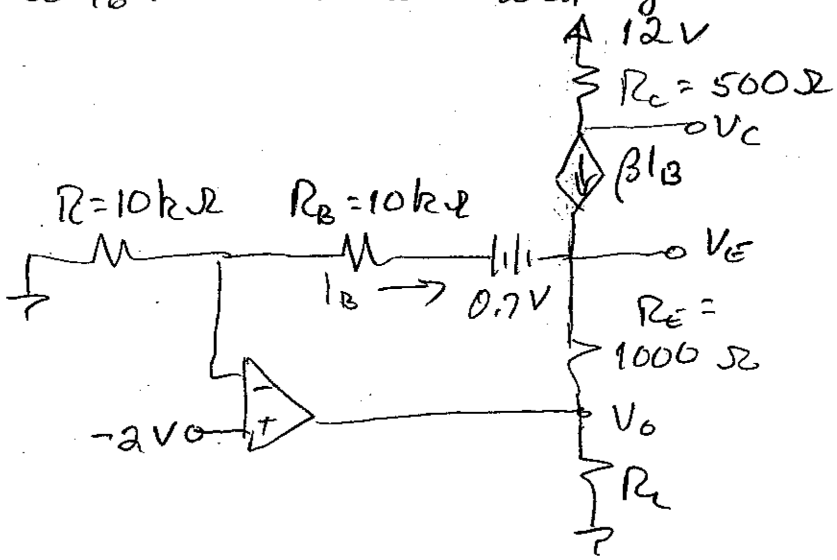
2. **(40 points)** In the circuit below, the op amp may be considered ideal; it has +/- 15 V power supplies, as shown. The BJT has $\beta = 80$ and $V_{CESAT} = 0.3$ V. Find the voltage V_O.



+4 $v_- = -2 \Rightarrow I_B = \frac{-(-2)}{10k} = 0.2\,mA$

So $I_B > 0$ and we will guess active mode:

+12



$V_C = 12 - \beta I_B \cdot 500$

$= 4\ V$

$V_E = -0.7 - I_B \cdot 20000$

$= -4.7\ V$

+9

$V_{CE} = +8.7\ V$ ✓

So active mode is OK. Now...

Room for extra work

$$V_o = V_E - I_E R_E = V_E - (\beta+1) I_B R_E$$

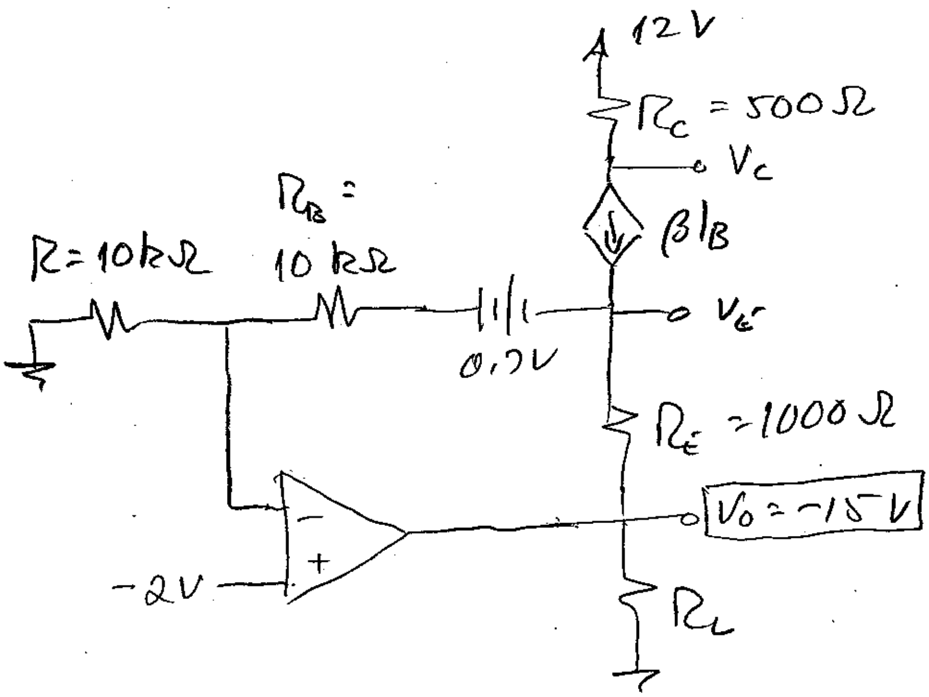
$$= -4.7 - 81 (0.2 mA) 1000$$

+5 $$= -20.9 \text{ V}$$

WHOA! This is greater than the power supply voltage (less negative) so the op amp will be saturated! +3

So we need to re-do this with $V_o = -15$ V. In that case we do not have negative feedback!

+7



$$20000\, I_B + 0.7 + (\beta+1) I_B\, 1000 - 15 = 0$$

$$I_B = \frac{14.3}{20000 + 81 \cdot 1000} = 0.1416 \text{ mA}$$

$$V_C = 12 - \beta I_B\, 500 = 6.34 \text{ V}$$

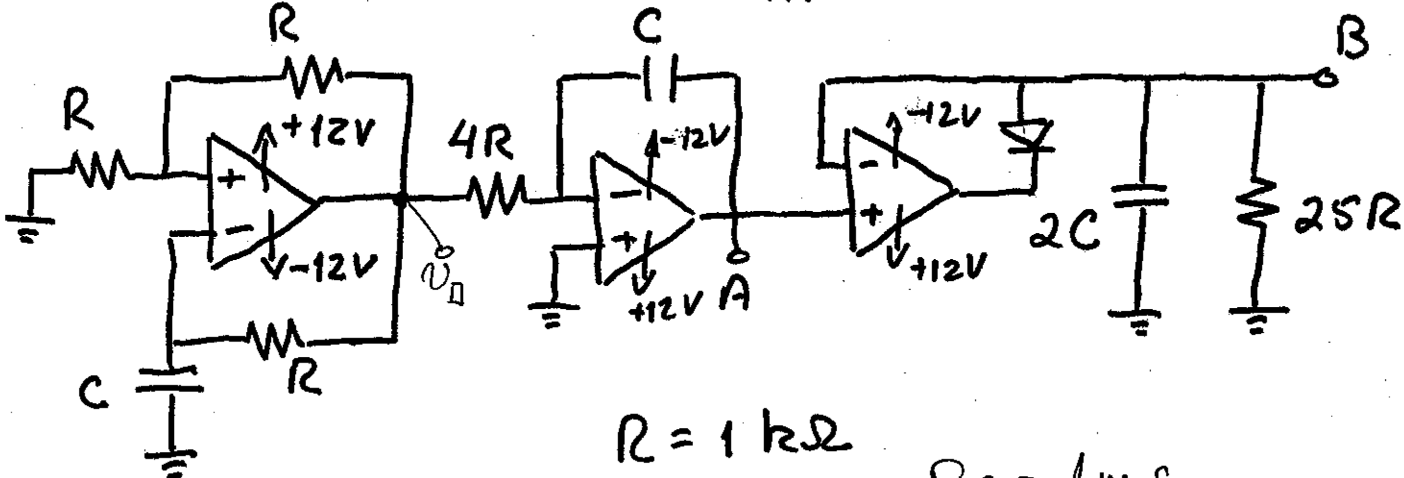
$$V_E = (\beta+1) I_B \cdot 1000 - 15 = -3.53 \text{ V}$$

$$\Rightarrow V_{CE} = 9.86 \text{ V}.$$ So we are still in active mode.

So we have $\boxed{V_6 = -15 \text{ V}}$.

3. (**20 points**) The diode in the circuit below is ideal. The op amps are also ideal, and have +/- 12 V power supplies, as shown. Provide clearly labeled plots showing ***voltage vs. time*** at the nodes labeled A and B. Use the grids provided on next page for your plots.

- Plot two cycles of the waveforms and ***clearly show amplitude and period*** in each case.
- You may wish to "round off" some of the results for ease in plotting, but stay within 10% of actual values.
- Points will be subtracted if the plots are sloppy or otherwise difficult to read.



$R = 1\ k\Omega$

$C = 1\ \mu F$

$RC = 1ms$

The first stage is an astable multivibrator with $L_+ = -L$ so we get a square wave with amplitude 12 V and

$$T = RC \cdot 2 \cdot \ln \frac{1+\beta}{1-\beta}$$

$$\beta = \frac{R}{R+R} = \frac{1}{2} \Rightarrow T = 2.197\ ms \simeq 2.2\ ms.$$

We now have an integrator:

$$v_A = \frac{-1}{4RC} \int_0^t v_\square\, dt.$$ So this gives a triangle wave with amplitude:

→ p.9

Room for extra work

$t = T/2 \Rightarrow v_A = \frac{1}{4ms} \cdot 12 \cdot \frac{T}{2} = 3.3$ V.

We integrated for one-half T to find the peak-peak amplitude. So the amplitude is $3.3/2 = 1.15$ V

Now we have a super diode but the diode turns on for $v_A < 0$. So we get a negative-going half-wave rectified signal at B which is filtered by 2C and 25·R. So this is essentially a power supply with ripple voltage

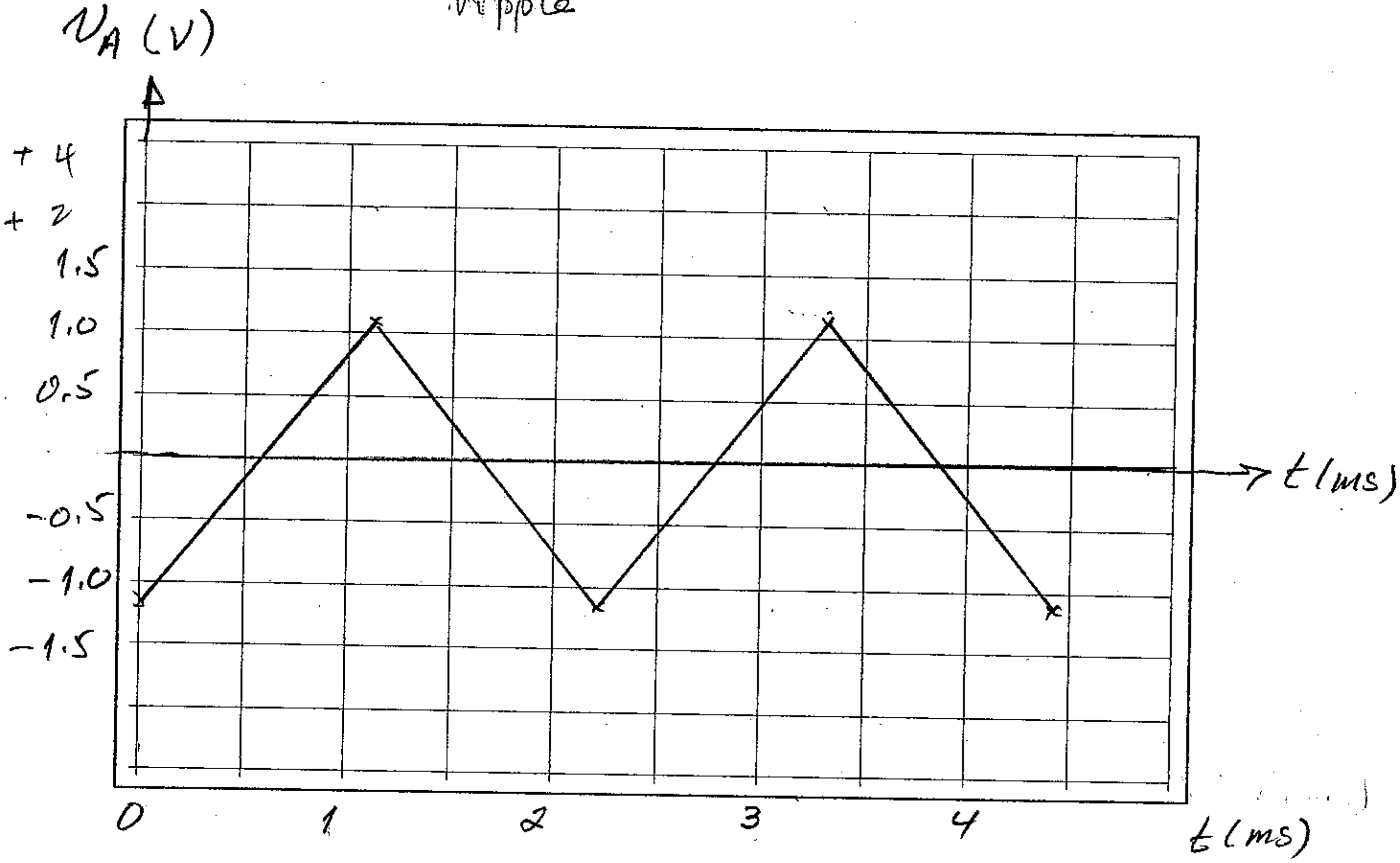
$$V_r = \frac{V_p T}{50RC} = \frac{1.15(2.2 \times 10^{-3})}{50 \times 10^{-3}}$$

$$V_r = 0.0506 \text{ V} \approx 50\text{mV}$$

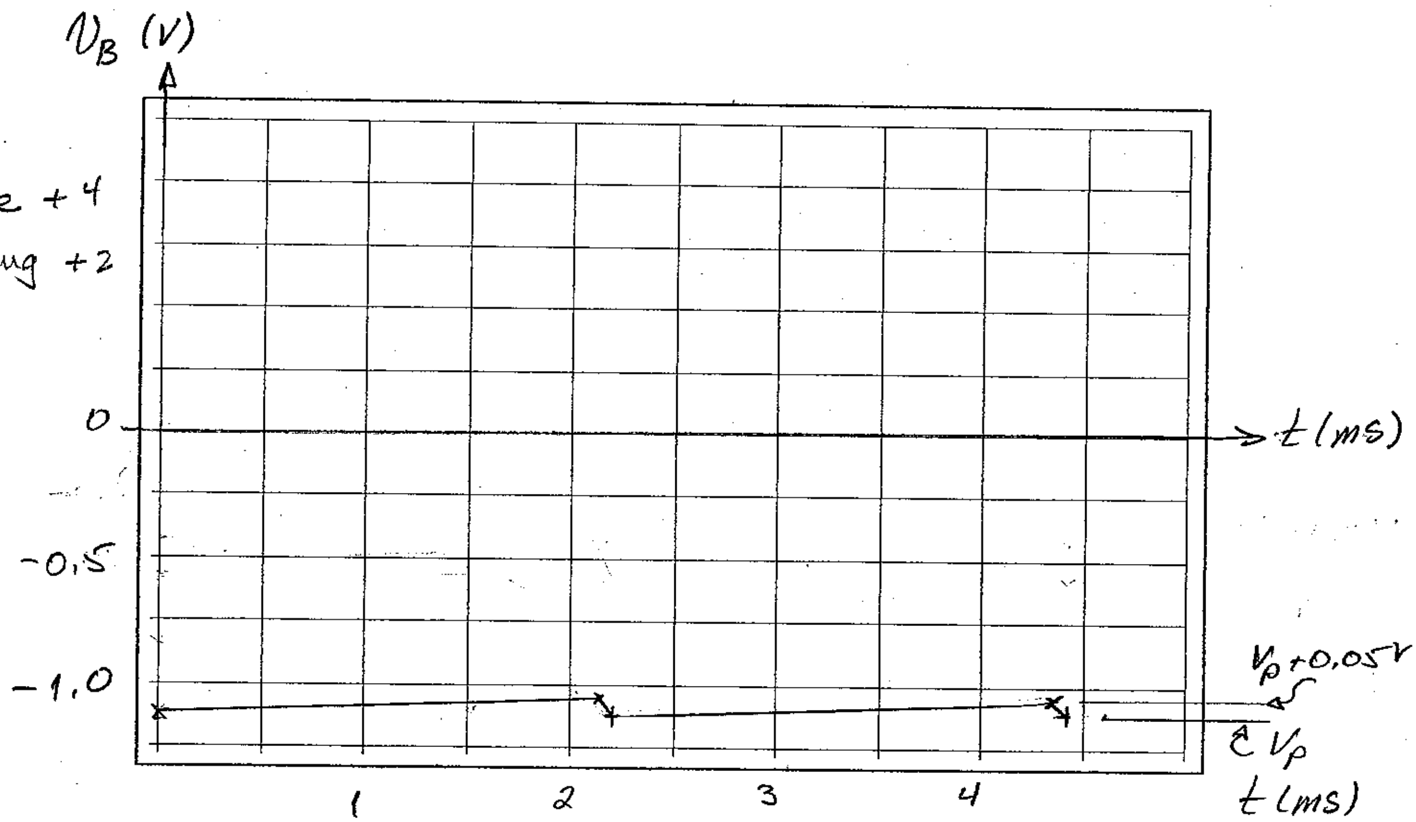
Assuming a linear variation, we have a straight line varying between V_p and $V_p + 0.05$ V as shown on the next page. We have indicated the charge-up portion as well.

period: +2 triangle ampl. +2
ripple +3 sign +1 } +8

shape + 4
graph + 2



shape + 4
graphing + 2



Electrical Characteristics @ T_A = 25°C unless otherwise specified

Table 1

Type Number	Zener Voltage Range (Note 3) V_Z @ I_{ZT}			Test Current I_{ZT}	Maximum Zener Impedance		Maximum Reverse Current		Maximum Temperature Coefficient @ I_{ZT}
	Nom (V)	Min (V)	Max (V)	mA	Z_{ZT} @ I_{ZT} (Ω)	Z_{ZK} @ I_{ZK} = 0.25mA (Ω)	I_R (µA)	@V_R (V)	%/°C
1N5221B	2.4	2.28	2.52	20	30	1200	100	1.0	-0.085
1N5222B	2.5	2.38	2.63	20	30	1250	100	1.0	-0.085
1N5223B	2.7	2.57	2.84	20	30	1300	75	1.0	-0.080
1N5224B	2.8	2.66	2.94	20	30	1400	75	1.0	-0.080
1N5225B	3.0	2.85	3.15	20	29	1600	50	1.0	-0.075
1N5226B	3.3	3.14	3.47	20	28	1600	25	1.0	-0.070
1N5227B	3.6	3.42	3.78	20	24	1700	15	1.0	-0.065
1N5228B	3.9	3.71	4.10	20	23	1900	10	1.0	-0.060
1N5229B	4.3	4.09	4.52	20	22	2000	5.0	1.0	+0.055
1N5230B	4.7	4.47	4.94	20	19	1900	5.0	2.0	+0.030
1N5231B	5.1	4.85	5.36	20	17	1600	5.0	2.0	+0.030
1N5232B	5.6	5.32	5.88	20	11	1600	5.0	3.0	+0.038
1N5233B	6.0	5.70	6.30	20	7.0	1600	5.0	3.5	+0.038
1N5234B	6.2	5.89	6.51	20	7.0	1000	5.0	4.0	+0.045
1N5235B	6.8	6.46	7.14	20	5.0	750	3.0	5.0	+0.050
1N5236B	7.5	7.13	7.88	20	6.0	500	3.0	6.0	+0.058
1N5237B	8.2	7.79	8.61	20	8.0	500	3.0	6.5	+0.062
1N5238B	8.7	8.27	9.14	20	8.0	600	3.0	6.5	+0.065
1N5239B	9.1	8.65	9.56	20	10	600	3.0	7.0	+0.068
1N5240B	10	9.50	10.50	20	17	600	3.0	8.0	+0.075
1N5241B	11	10.45	11.55	20	22	600	2.0	8.4	+0.076
1N5242B	12	11.40	12.60	20	30	600	1.0	9.1	+0.077
1N5243B	13	12.35	13.65	9.5	13	600	0.5	9.9	+0.079
1N5244B	14	13.30	14.70	9.0	15	600	0.1	10	+0.082
1N5245B	15	14.25	15.75	8.5	16	600	0.1	11	+0.082
1N5246B	16	15.20	16.80	7.8	17	600	0.1	12	+0.083
1N5247B	17	16.15	17.85	7.4	19	600	0.1	13	+0.084
1N5248B	18	17.10	18.90	7.0	21	600	0.1	14	+0.085
1N5249B	19	18.05	19.95	6.6	23	600	0.1	14	+0.086
1N5250B	20	19.00	21.00	6.2	25	600	0.1	15	+0.086
1N5251B	22	20.90	23.10	5.6	29	600	0.1	17	+0.087
1N5252B	24	22.80	25.20	5.2	33	600	0.1	18	+0.087
1N5253B	25	23.75	26.25	5.0	35	600	0.1	19	+0.089
1N5254B	27	25.65	28.35	4.6	41	600	0.1	21	+0.090
1N5255B	28	26.60	29.40	4.5	44	600	0.1	21	+0.091
1N5256B	30	28.50	31.50	4.2	49	600	0.1	23	+0.091
1N5257B	33	31.35	34.65	3.8	58	700	0.1	25	+0.092
1N5258B	36	34.20	37.80	3.4	70	700	0.1	27	+0.093
1N5259B	39	37.05	40.95	3.2	80	800	0.1	30	+0.094
1N5260B	43	40.85	45.15	3.0	93	900	0.1	33	+0.095
1N5261B	47	44.65	49.35	2.7	105	1000	0.1	36	+0.095
1N5262B	51	48.45	53.55	2.5	125	1100	0.1	39	+0.096
1N5263B	56	53.20	58.80	2.2	150	1300	0.1	43	+0.096
1N5264B	60	57.00	63.00	2.1	170	1400	0.1	46	+0.097
1N5265B	62	58.90	65.10	2.0	185	1400	0.1	47	+0.097
1N5266B	68	64.60	71.40	1.8	230	1600	0.1	52	+0.097
1N5267B	75	71.25	78.75	1.7	270	1700	0.1	56	+0.098

Notes: 3. Based on dc measurement at thermal equilibrium; lead length = 9.5mm (3/8"); thermal resistance of heat sink = 30°C/W.