AEC Assignment - 3

Q1) **Cut-in Voltage :**

- It is the minimum voltage at which a diode starts allowing current to flow through it.
- It is also known as threshold voltage
- It is generally around 0.6 - 0.7V

Knee - Voltage : Max reverse bias voltage for which diode does not break down.

- ~~It is generally the voltage after which the current through the diode rapidly increases~~
- It is called the reverse breakdown voltage
- It is around 0.7 to 0.8 V

Reverse Saturation Current :

- It is the current (I_s) that flows across a diode in the reverse bias direction when there is a reverse voltage.
- 'saturation' implies that this current reaches relatively constant levels in reverse bias.

Incremental - diode resistance :

- It is called as dynamic resistance.
- This resistance is used when we want to replace all the DC voltage sources in our circuit, to do small signal analysis
- $r_d = \frac{V_T}{I_D} = \left(\frac{1}{\frac{\partial I_D}{\partial V_D}}\right) = (\text{slope})^{-1}$

After placing the cursors in the appropriate plots, we get

Cut-in voltage $= 0.396\ V$

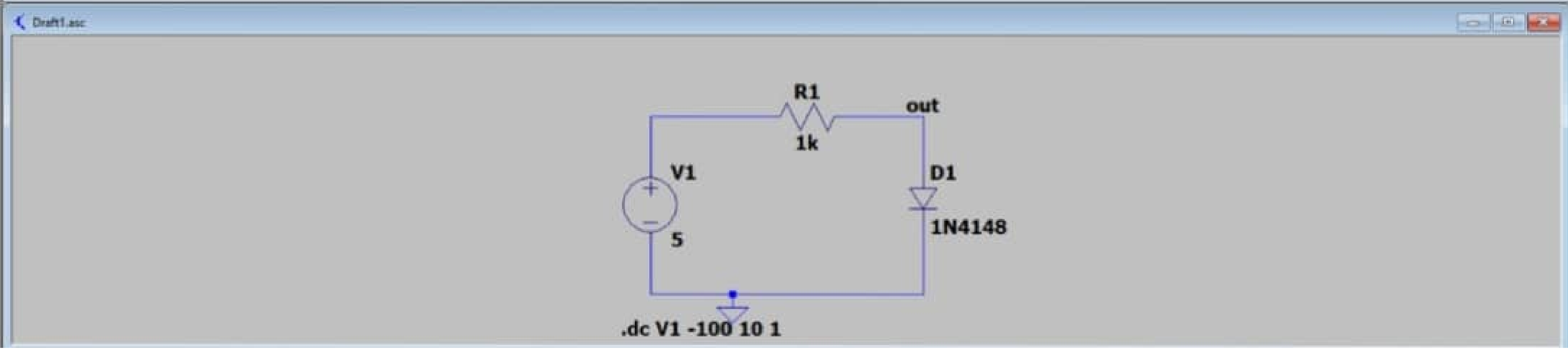
Knee Voltage $= 0.606\ V$

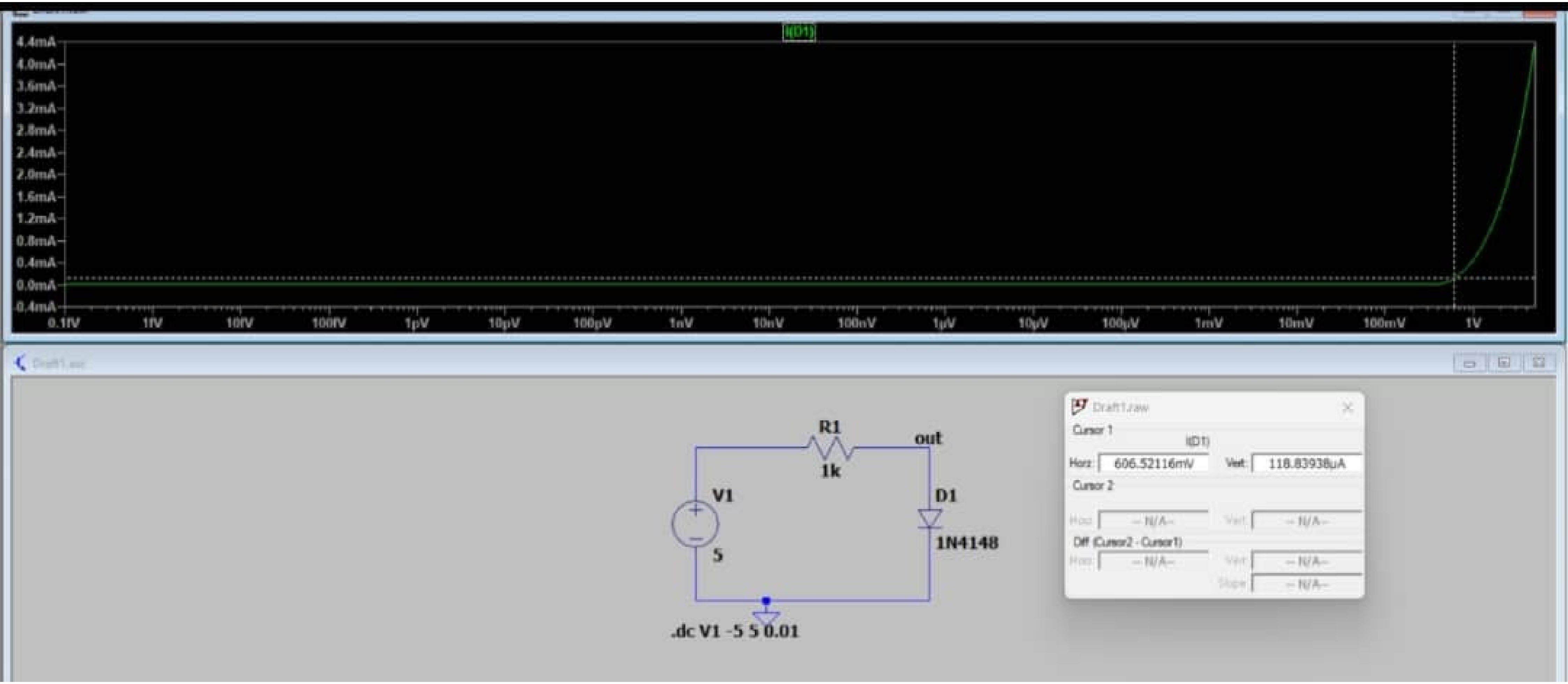
Reverse saturation current $= 2.5\ \mu A$

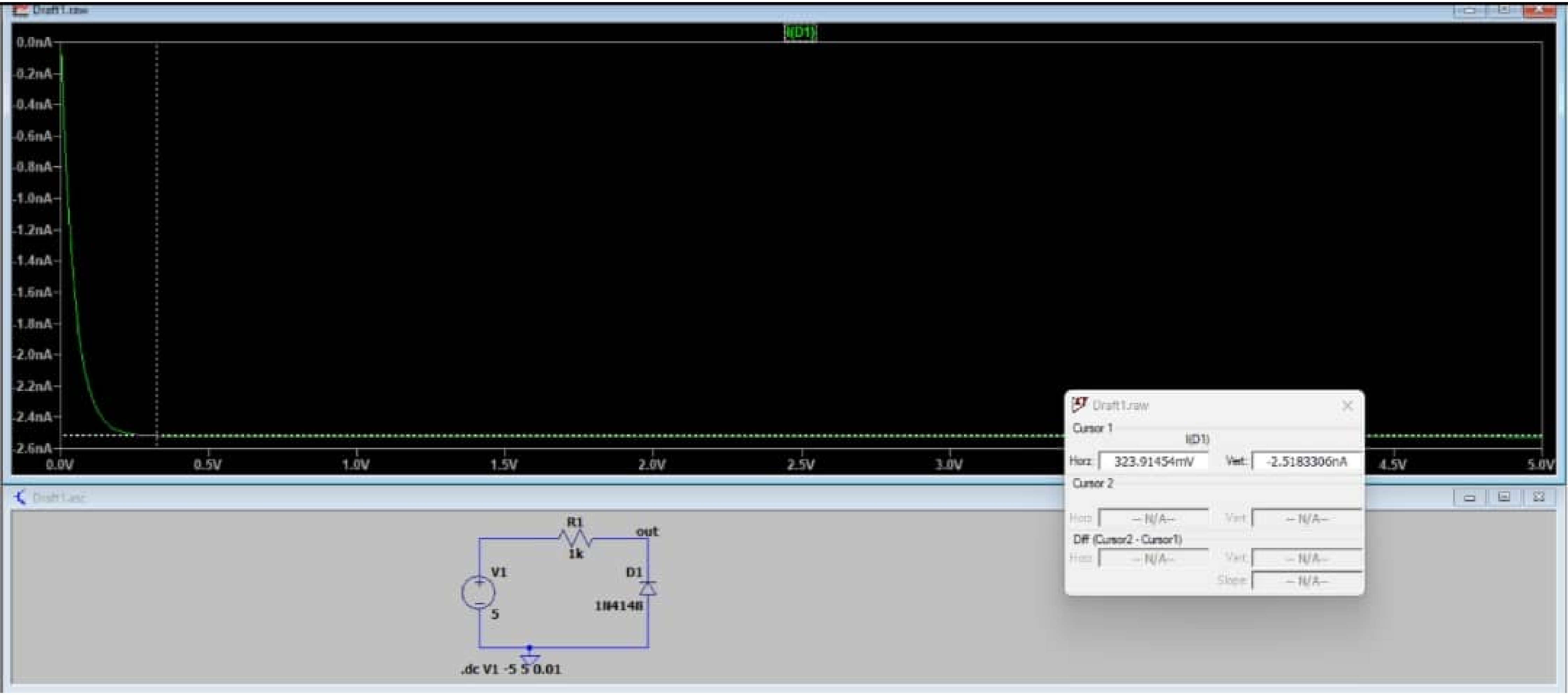
Incremental resistance $= \dfrac{1}{\frac{\partial I}{\partial V}}$

$= 10.98\ \Omega$

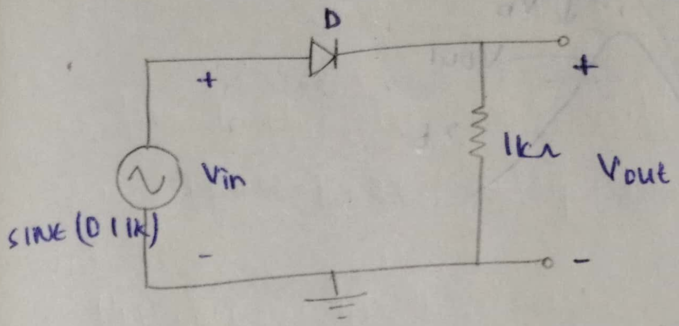

I(D1)
12mA
9mA
6mA
3mA
0mA
-3mA
-6mA
-9mA
-12mA
-15mA
-18mA
-21mA
-24mA
-27mA
-100V
-90V
-80V
-70V
-60V
-50V
-40V
-30V
-20V
-10V
0V
10V


Draft1.asc
R1
1k
out
V1
5
D1
1N4148
.dc V1 -100 10 1


I(D1)
4.4mA
4.0mA
3.6mA
3.2mA
2.8mA
2.4mA
2.0mA
1.6mA
1.2mA
0.8mA
0.4mA
0.0mA
-0.4mA
0.1fV
1fV
10fV
100fV
1pV
10pV
100pV
1nV
10nV
100nV
1µV
10µV
100µV
1mV
10mV
100mV
1V
R1
1k
out
V1
5
D1
1N4148
.dc V1 -5 5 0.01
Cursor 1
I(D1)
Horz: 606.52116mV
Vert: 118.83938µA
Cursor 2
Diff (Cursor2 - Cursor1)


Draft1.raw
I(D1)
0.0nA
-0.2nA
-0.4nA
-0.6nA
-0.8nA
-1.0nA
-1.2nA
-1.4nA
-1.6nA
-1.8nA
-2.0nA
-2.2nA
-2.4nA
-2.6nA
0.0V
0.5V
1.0V
1.5V
2.0V
2.5V
3.0V
4.5V
5.0V
Draft1.raw
Cursor 1
I(D1)
Horz: 323.91454mV
Vert: -2.5183306nA
Cursor 2
Horz: --N/A--
Vert: --N/A--
Diff (Cursor2 - Cursor1)
Horz: --N/A--
Vert: --N/A--
Slope: --N/A--
Draft1.asc
R1
1k
out
V1
5
D1
1N4148
.dc V1 -5 5 0.01

Q2) **Half Wave Rectifier :**



Here, the voltage input is a sinusoid signal

→ A half wave rectifier can ~~covert~~ convert an AC input voltage into DC voltage output.

→ However, it allows only half of the input signal to pass through it.

i.e

* During the positive half-cycles of input, the positive V_{in} will cause the current to flow into the diode in forward direction.

* During the negetive half-cycles of input, the diode will not allow any current to pass through it.

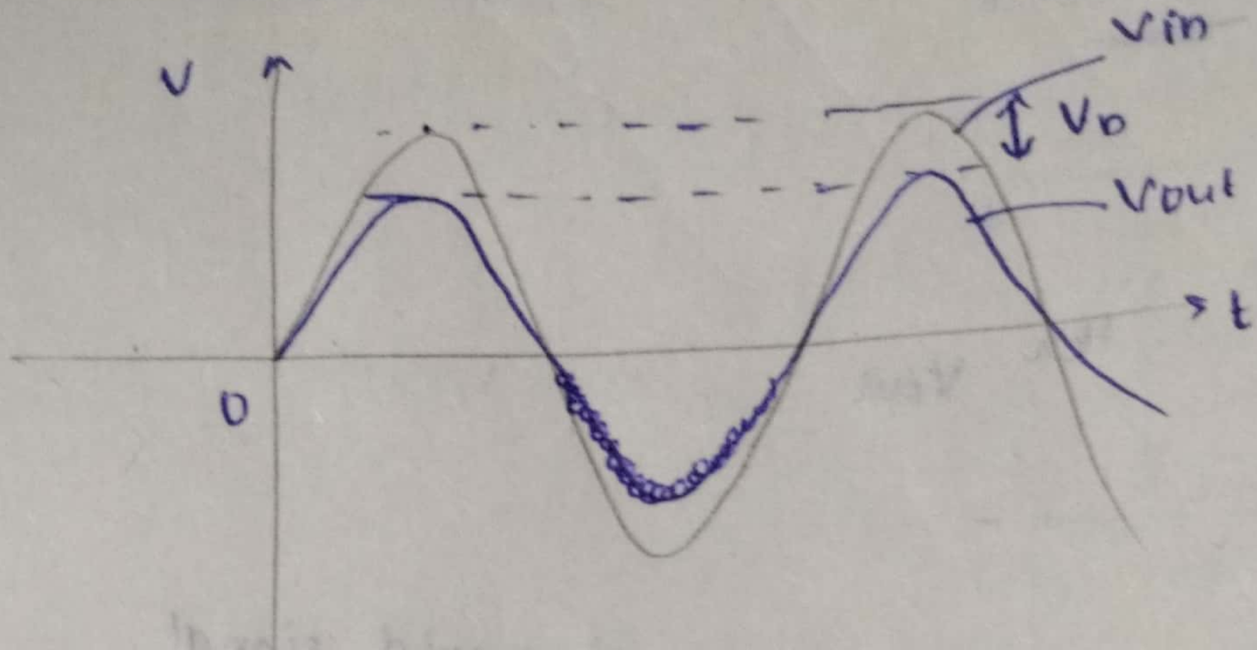
And thus, $V_{out} = 0$.

Here V_{out} is almost equal to V_{in} with small difference.

i.e
$$V_{out} = \begin{cases} 0 & V_{in} < V_D \\ V_{in} - V_D & V_{in} \geq V_D \end{cases}$$

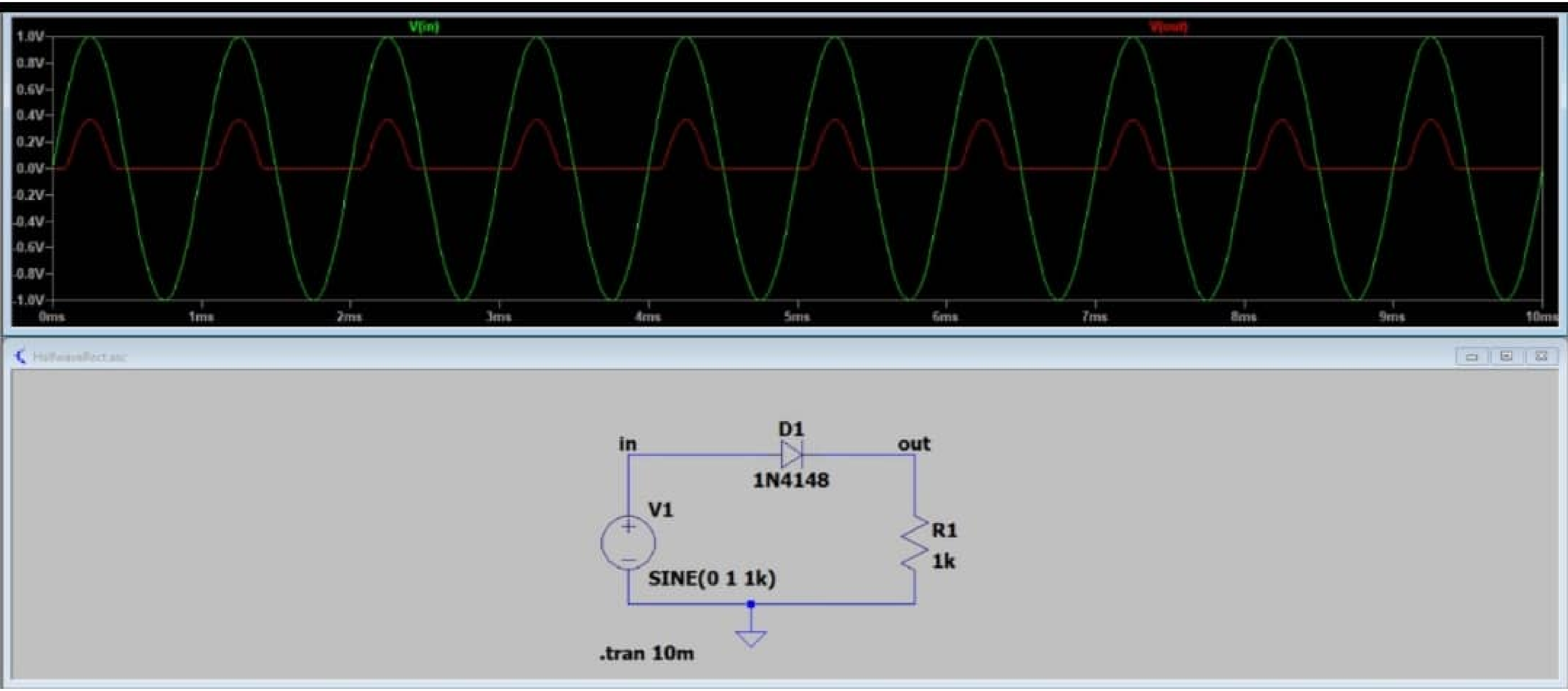
where $V_D = 0.7 / 0.8V$

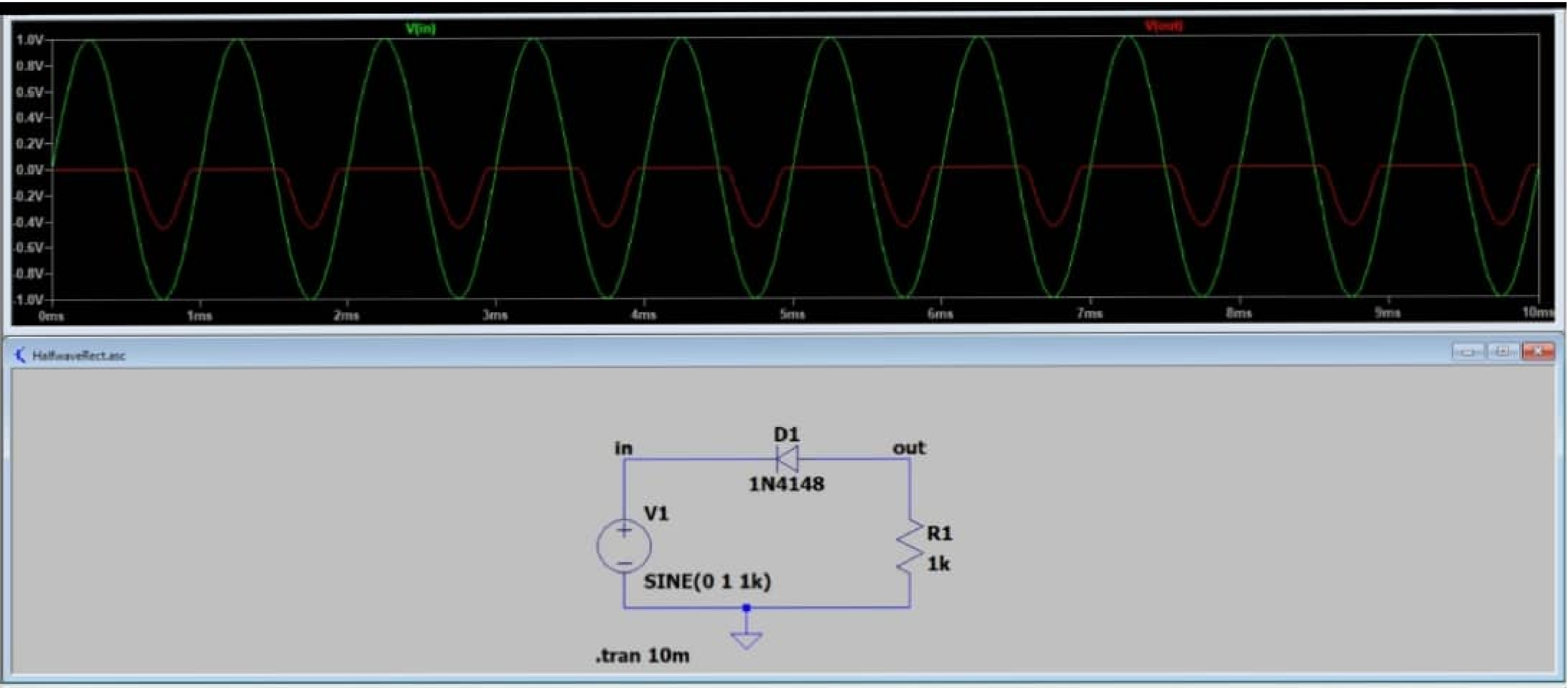
Input ~~signal~~ & output



Diode only work when $V_{in} > V_D$

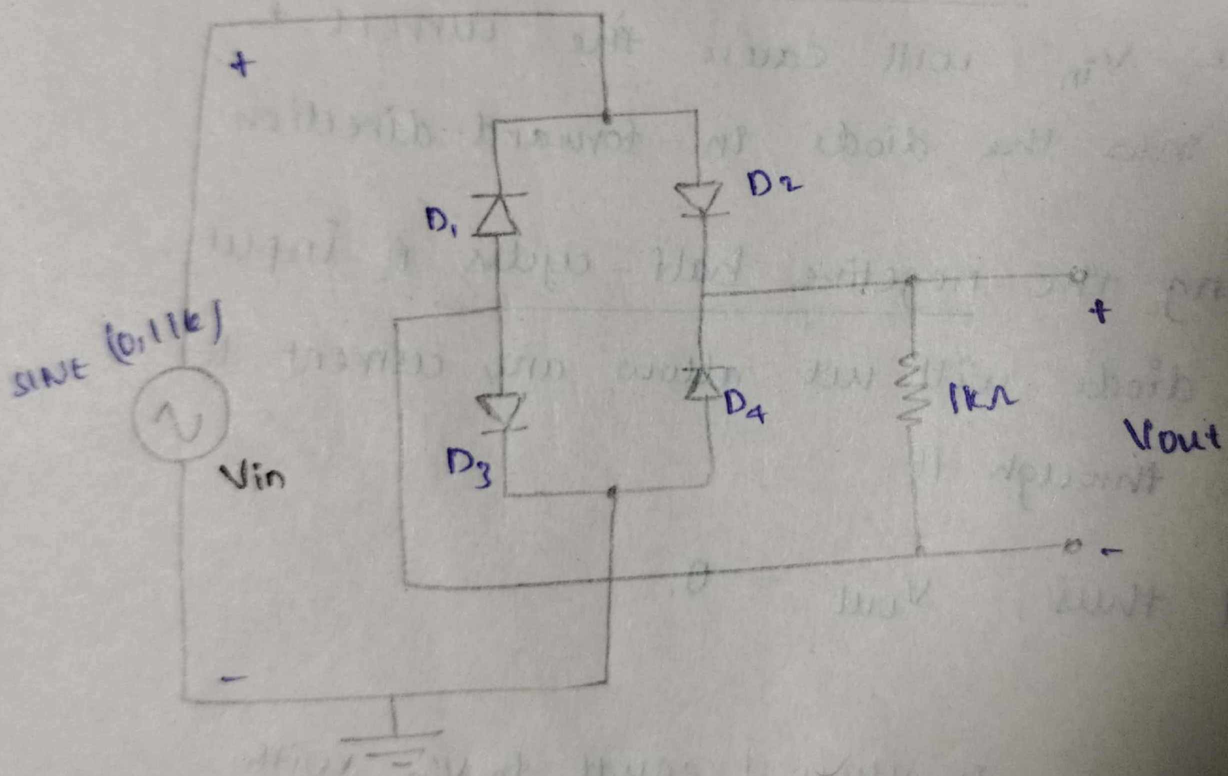
$V_D \longrightarrow$ Breakdown Voltage.


V(in)
V(out)
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
-0.8V
-1.0V
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
D1
in
out
1N4148
V1
R1
1k
SINE(0 1 1k)
.tran 10m



V(in)
V(out)
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
-0.8V
-1.0V
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
HalfwaveRect.asc
D1
in
out
1N4148
V1
R1
1k
SINE(0 1 1k)
.tran 10m

Q3) Full Wave Rectifier :



Even here, voltage input is given as a sinusoid.

→ A full wave rectifier converts the complete AC voltage ~~int~~ signal into a dc signal unlike in a half-wave rectifier.

* During positive half of cycle,

only diodes D_2 and D_3 are forward-biased, D_1 and D_4 are reverse-biased.

Hence, current only flows through D_2 and D_3 through the load resistance

(here V_{in} is +ve)

Diodes D_2 & D_3 offer some cutting voltage

hence,

$$V_{out} = V_{in} - V_{cut\,D_2} - V_{cut\,D_3}$$

and also similarly

if $V_{in} < 0.7V$
$< V_{cut\,D_2} + V_{cut\,D_3}$

then no current flows though circuit.

* During negetive half of cycle:

Now, D_1 and D_4 are forward-biased while D_2 and D_3 are reverse-biased.

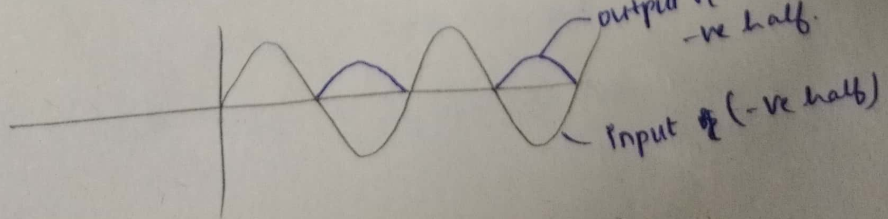
Now, current flows through D_1 and D_4 through load.

also,

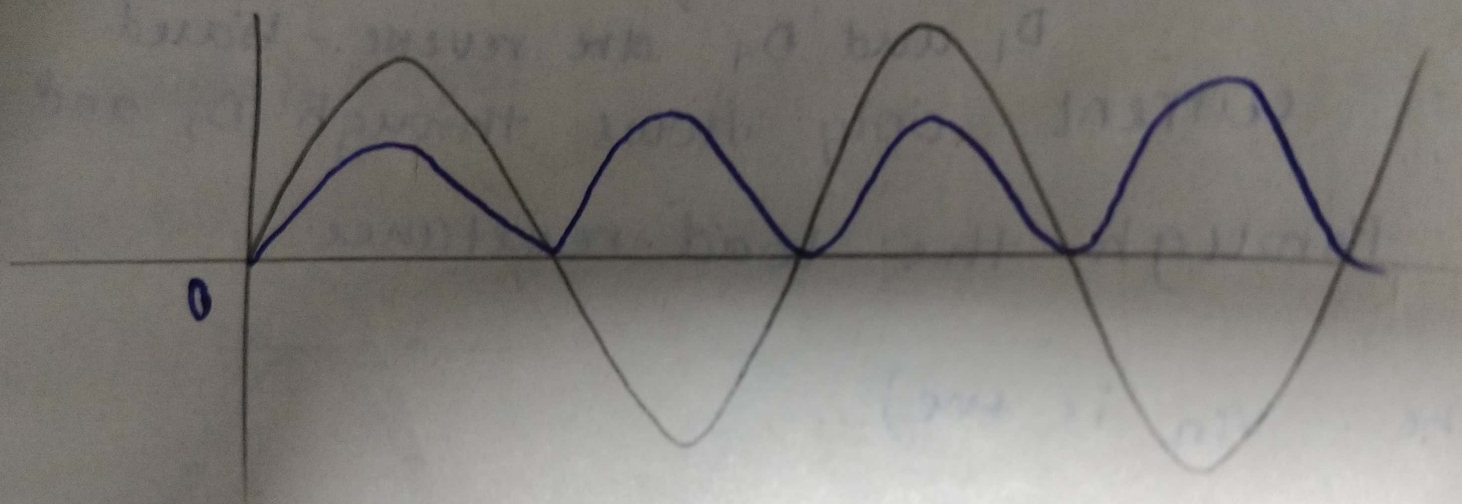
$$V_{out} = V_{in} - V_{cut\,D_1} - V_{cut\,D_4}$$

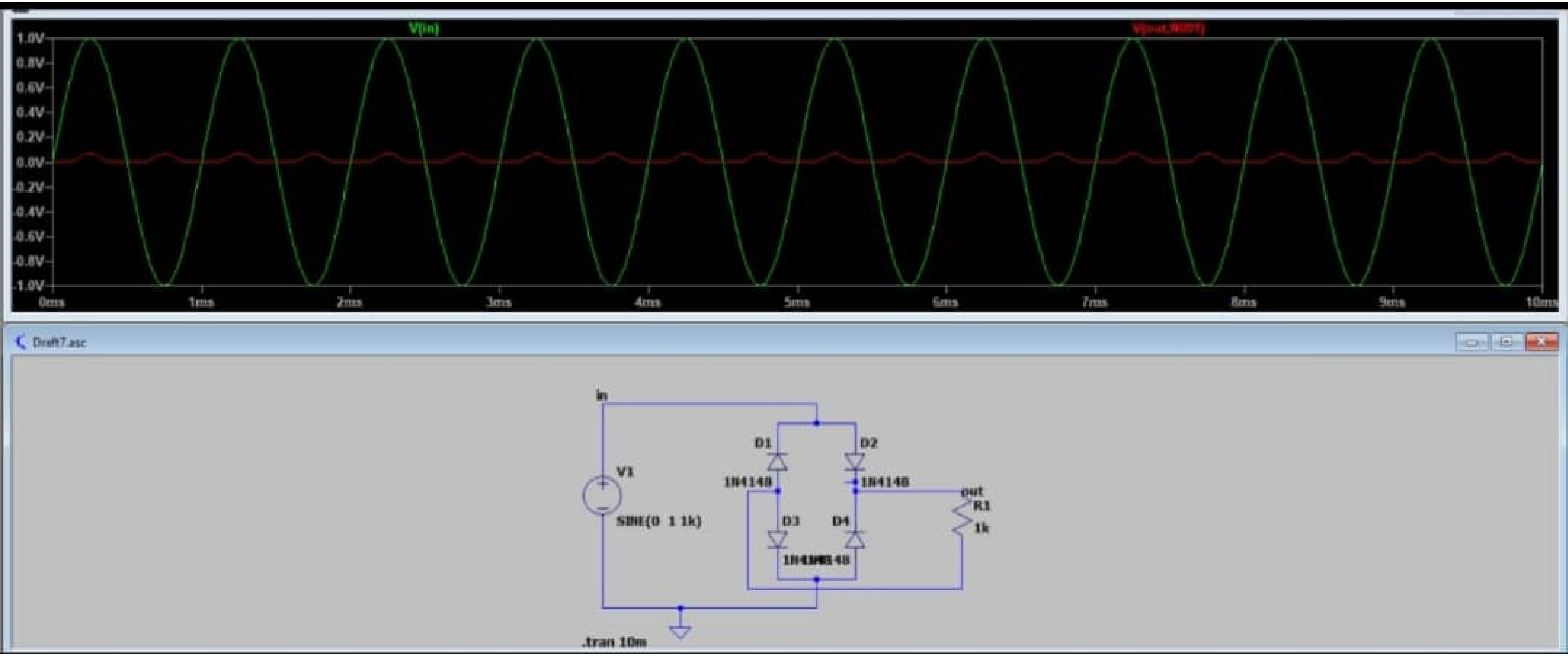
and if $V_{in} < 0.7V$
$< V_{cut\,D_1} + V_{cut\,D_4}$

then no current though circuit

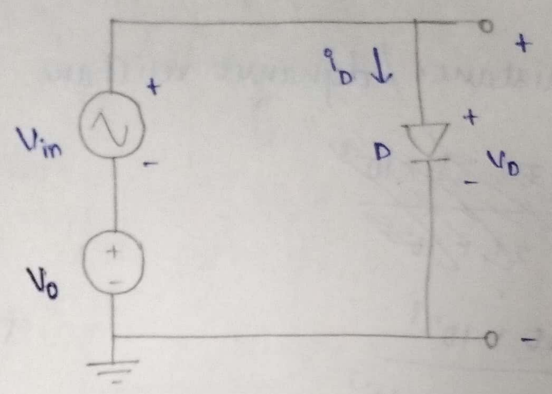


Input & Output:




V(in)
V(out,N001)
1.0V
0.8V
0.6V
0.4V
0.2V
0.0V
-0.2V
-0.4V
-0.6V
-0.8V
-1.0V
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
Draft7.asc
in
D1
D2
V1
1N4148
1N4148
out
R1
1k
SINE(0 1 1k)
D3
D4
.tran 10m

Q4)



Given, $V_0 = 1.2V$

$V_{in} = V_m \sin(\omega_0 t)$

(a)

We know that

dynamic conductance, $g = \dfrac{\partial I_D}{\partial V_D}$ ~~Large~~

$\Rightarrow \quad r_d = \dfrac{1}{g} = \dfrac{d V_D}{\partial I_D}$

also,

$$I_D = I_s\left[e^{+V_D/V_T} - 1\right] \approx \underline{I_s e^{V_D/V_T}}$$

$$\frac{d I_D}{d V_D} = I_s e^{V_D/V_T} \times \frac{1}{V_T}$$

$$= \frac{I_D}{V_T}$$

$\therefore$ $\cancel{\boxed{r_d = \frac{V_D}{V_T}}}$ $\boxed{r_d = \dfrac{V_T}{I_D}}$

From the lt spice simulation below, we can find I_D at $V = 1.2V$.

$I_D = 584.38$ mA

and $V_T = 26$ mV @ room temp

Thus,

incremental resistance / dynamic resistance

$$\cancel{r_d = \frac{578.33 \times 10^{-3}}{26 \times 10^{-3}}}$$

$$r_d = \frac{26 \times 10^{-3}}{589.78 \times 10^{-3}}$$

$$= 0.0441$$

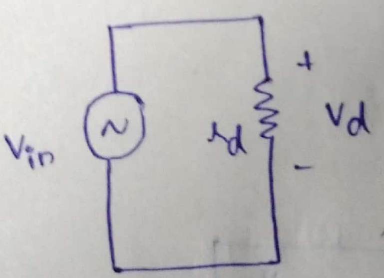
$$\cancel{\boxed{r_d = 43.2\ m\Omega}}$$

$$\boxed{r_d = 44.1\ m\Omega}$$

$\therefore$ Incremental resistance at $V = 1.2V$ is $44.1\ m\Omega$

Small signal model :

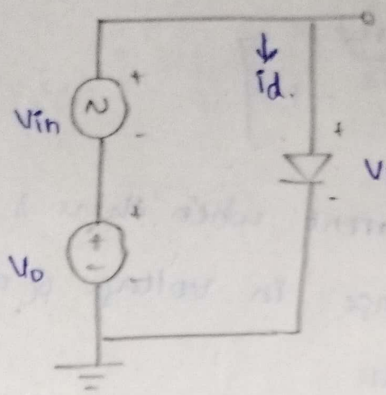
This is obtained by replacing the DC voltage sources with the incremental resistance r_d.

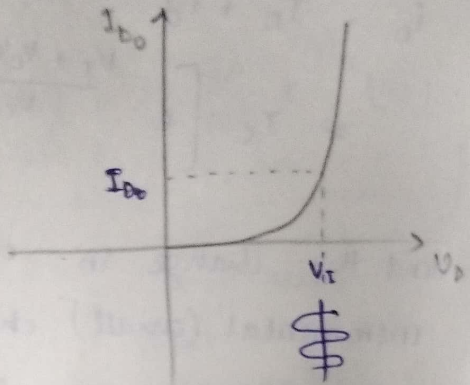


where

$r_d = 44.1\ m\Omega$

(b)





Note:

v_d / i_d — AC inputs

V_D / I_D — DC inputs

v_D / i_D — AC + DC inputs [through diode]

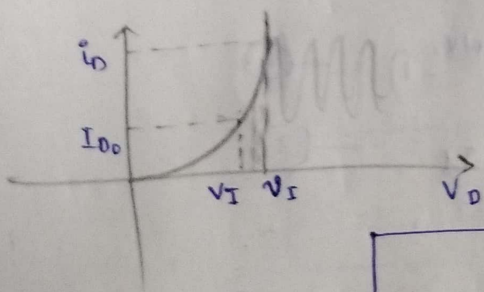
Voltage input through the diode

$$v_I = \underbrace{v_{in}}_{AC} + \underbrace{V_I}_{DC}$$

$$= V_0 \cos\omega t + V_I$$

When v_I reaches V_I, we send in a small sinusoidal signal v_i.

The current fluctuates as shown.



Here,
$$\boxed{i_D = I_s\left[e^{v_D/V_T} - 1\right]}$$

i_D, v_D ⟶ DC + AC

$$i_D = I_D + i_d$$

$$= I_s \left[e^{\frac{V_I + V_0 \cos \omega t}{V_T}} - 1 \right]$$

To find the change in current when there is an incremental (small) change in voltage of diode, use taylor's series expansion.

$$y = f(x) = f(x_0) + \left.\frac{\partial f}{\partial x}\right|_{x_0} (x - x_0) + \frac{1}{2!} \frac{\partial f}{\partial x} (x - x_0)^2$$

$$+ \cdots$$

say $V_I = V_{D_0}$

$$i_d + I_D = i_D = f(V_{D_0}) + \frac{\partial}{\partial V_D} \left(I_s \left(e^{V_D/V_T} - 1 \right) \right) (V_D - V_{D_0}) +$$

$$\frac{1}{2!} \frac{\partial^2 f}{\partial V_D^2} (V_D - V_{D_0})^2 + \cdots \quad \text{—} (4)$$

also,

$$v_D = v_d + V_{D_0}$$

~~$v_D - v_d$~~

$$v_d = v_D - V_{D_0} \quad \text{—} (1)$$

and

$$I_D = I_s \left(e^{V_D/V_T} - 1 \right) \quad \text{—} (2)$$

$$i_D = I_D + i_d \quad \text{—} (3)$$

Using all eqn's 1, 2, 3, 4

$$i_d = \frac{I_0}{V_T}\left(e^{V_D/V_T} \cdot V_d\right) + \frac{1}{2}\frac{I_0}{V_T^2} e^{V_D/V_T} (V_d)^2 + \underbrace{\left(\text{- - - - -} \right)}_{\text{These terms are -ve and negligible comparitively}}$$

$\Rightarrow$ i.e

$$\frac{\cancel{I_0}}{\cancel{V_T}}\left(\cancel{e^{V_D/V_T}}\right) \cdot V_d \gg \frac{1}{2}\frac{\cancel{I_0}}{V_T^{\cancel{2}}} \cancel{e^{V_D/V_T}} (V_d)^2$$

$$V_d \gg \frac{1}{2V_T}(V_d)^2 \quad \text{--- (5)}$$

$$\boxed{V_d \ll 2V_T} \quad \text{--- (6)}$$

$V_T \approx 26\text{ mV}$ @ 300k

$$\Rightarrow \boxed{V_d \ll 52\text{ mV}}$$

further, from 5, 6

$$i_d = \frac{I_0}{V_T} V_d$$

$$i_d = g\, V_d$$

$$\boxed{r_d = \frac{V_d}{i_d}} \rightarrow \text{Incremental / Dynamic resistance}$$

$\therefore$ $\boxed{V_d \ll 52\text{mV}}$ is the condition for validity of incremental model

(c)

V_{in}	ΔV_{out} $V_{max} - V_{min}$	ΔI_D $I_{max} - I_{min}$	Linearity
1mV	1.2 − 1.19 = 0.01 mV	577.8 − 575.6 = 2.2 mA	Linear
10mV	1.20 − 1.19 = 0.01 mV	591 − 562.4 = 28.6 mA	Linear
200mV	1.39 − 1.0 = 0.39 mV	892 − 282.9 = 609.1 mA	Non-linear

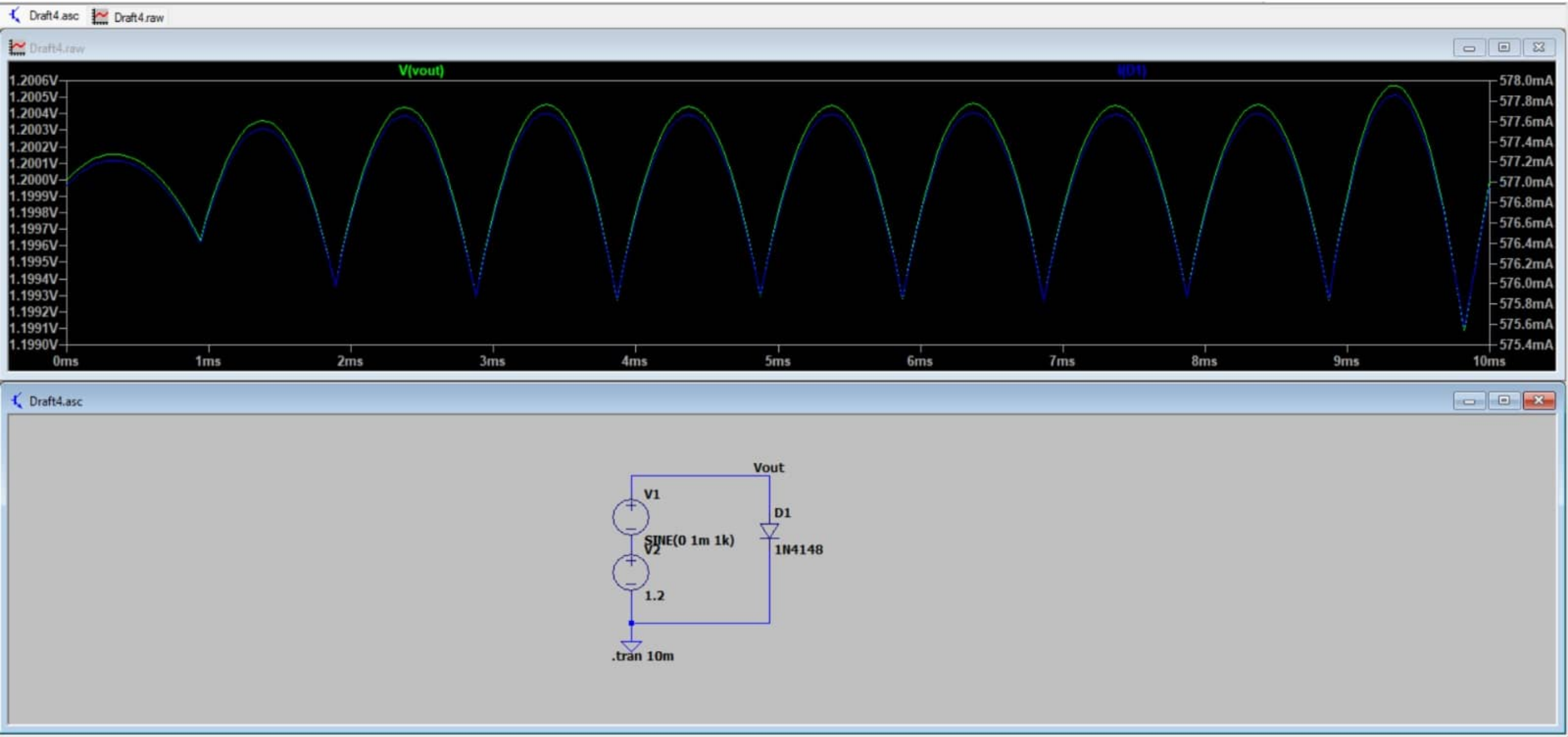
By observing the trends in the above table, there is a drastic change in ΔV_{out} and ΔI for 200 mV

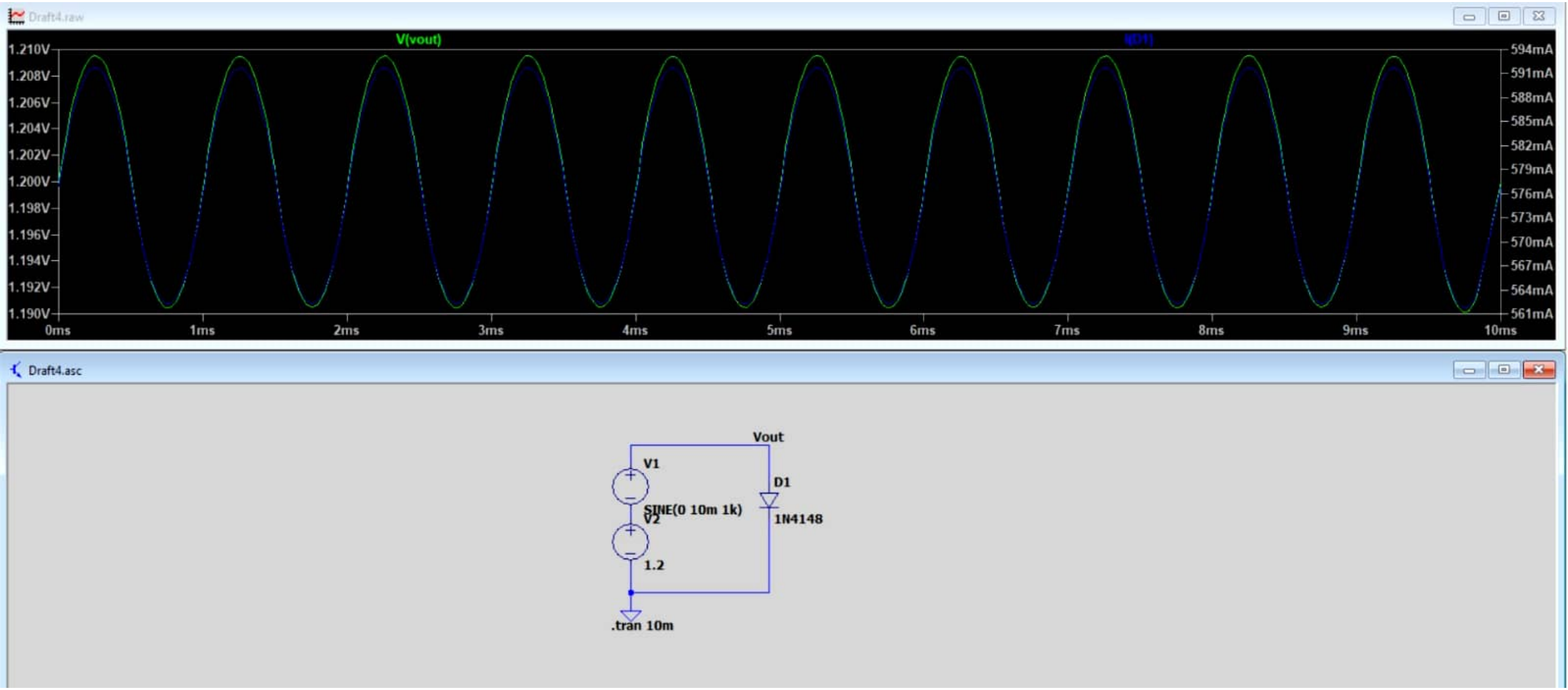
Thus, we can conclude

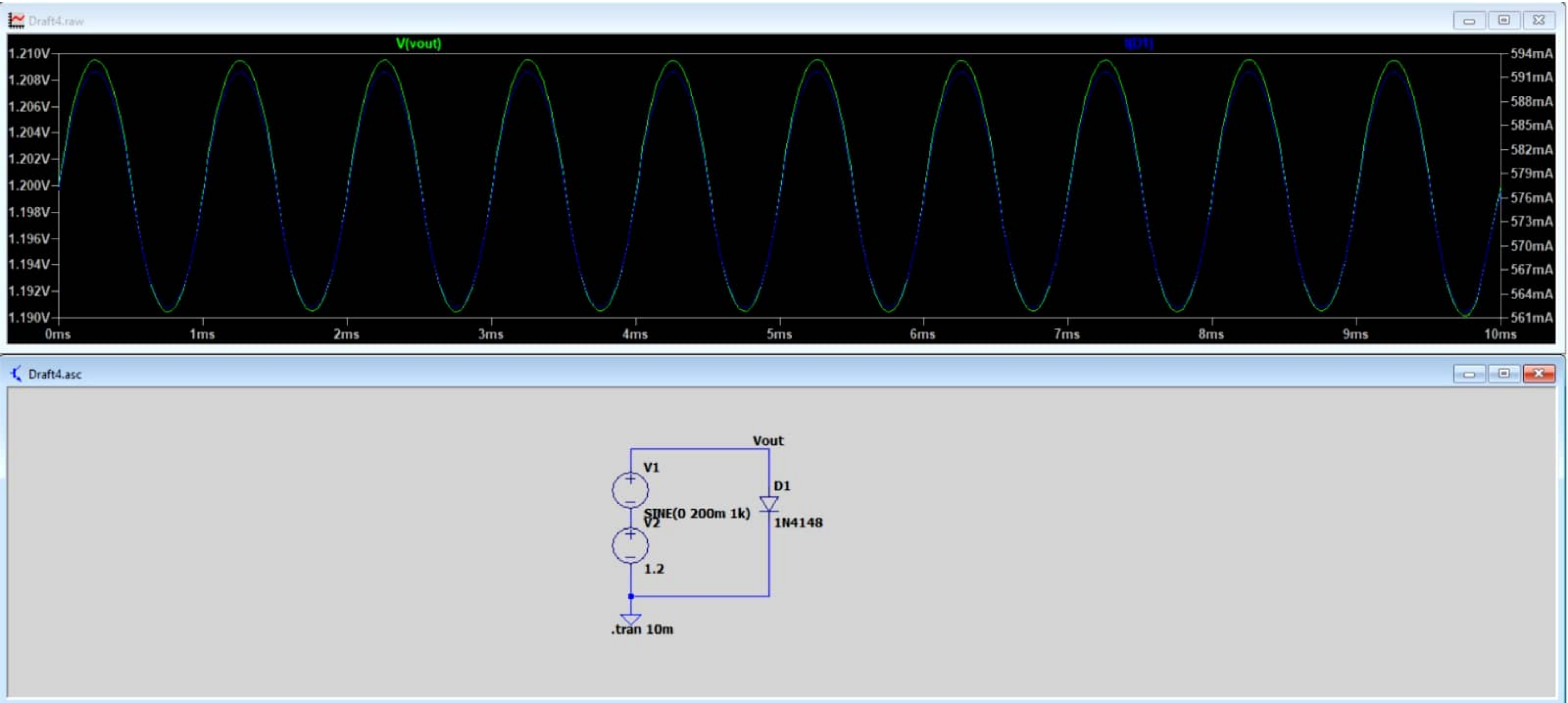
the small signal model can hold true to for inputs 1mV and 10mV and is in a linear mode.

And for input 200mV, the circuit can no longer behave like a small signal and is non-linear.

∴ 1mV, 10mV — Linear
200mV — Non-linear


Draft4.asc
Draft4.raw
V(vout)
1.2006V
1.2005V
1.2004V
1.2003V
1.2002V
1.2001V
1.2000V
1.1999V
1.1998V
1.1997V
1.1996V
1.1995V
1.1994V
1.1993V
1.1992V
1.1991V
1.1990V
578.0mA
577.8mA
577.6mA
577.4mA
577.2mA
577.0mA
576.8mA
576.6mA
576.4mA
576.2mA
576.0mA
575.8mA
575.6mA
575.4mA
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
Vout
V1
D1
SINE(0 1m 1k)
V2
1N4148
1.2
.tran 10m


Draft4.raw
V(vout)
I(D1)
1.210V
1.208V
1.206V
1.204V
1.202V
1.200V
1.198V
1.196V
1.194V
1.192V
1.190V
594mA
591mA
588mA
585mA
582mA
579mA
576mA
573mA
570mA
567mA
564mA
561mA
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
Draft4.asc
Vout
V1
D1
SINE(0 10m 1k)
V2
1N4148
1.2
.tran 10m


Draft4.raw
V(vout)
1.210V
1.208V
1.206V
1.204V
1.202V
1.200V
1.198V
1.196V
1.194V
1.192V
1.190V
594mA
591mA
588mA
585mA
582mA
579mA
576mA
573mA
570mA
567mA
564mA
561mA
0ms
1ms
2ms
3ms
4ms
5ms
6ms
7ms
8ms
9ms
10ms
Draft4.asc
Vout
V1
D1
SINE(0 200m 1k)
V2
1N4148
1.2
.tran 10m