In the ideal op amp circuit below,

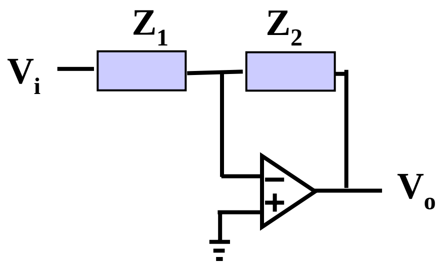
(a) find the complex transfer function G = Vo/Vi in terms of Z_1 and Z_2 .

(b) If the circuit is a high pass filter, find Z_1 and Z_2 in terms of R_1, R_2 and C and sketch the circuit. (8)

(c) Find the complex transfer function G = Vo/Vi in terms of R_1, R_2 , C and jω . (6)

(d) If for the high pass filter, cutoff frequency = 10kHz and |G| = 5 at cutoff. Find R_1 and C. Given R_2 = 1k Ω. (14)

(e) Sketch |G| (in dB) (= 20log |G|) versus angular frequency ω. Show clearly all intercepts in your sketch. (6)



(a) **Transfer function G**

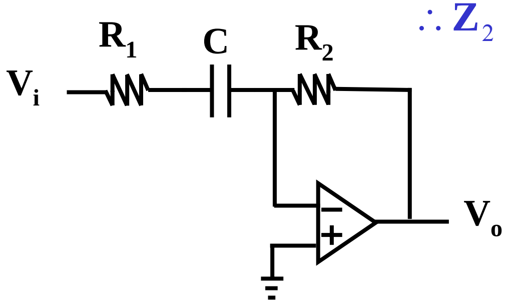
$$\therefore G = \frac{V_O}{V_i} = -\frac{Z_2}{Z_1}$$

If circuit is a high pass filter

$$\therefore Z_1 = R_1 + \frac{1}{j\omega C}$$

$$\therefore Z_2 = R_2$$

(b)



$$\therefore G = \frac{V_o}{V_i} = -\frac{Z_2}{Z_1} = -\frac{R_2}{R_1 + \dfrac{1}{j\omega C}} = -\frac{R_2}{R_1}\frac{1}{1 + j\dfrac{-1}{\omega C R_1}}$$

(c) **At cut-off**

$$\therefore G = -\frac{R_2}{R_1}\frac{1}{1-j}$$

(d) **If at cut-off, frequency is 10kHz and |Vo/Vi| =5**

$$\therefore \omega_{cutoff} = 2\pi(10\mathbf{k}) = \frac{1}{CR_1}$$

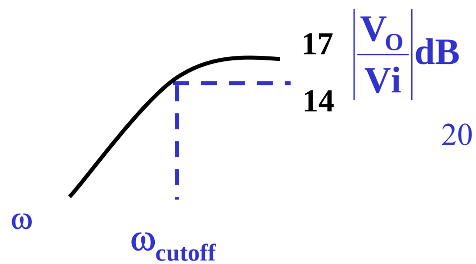
$$\therefore |G| = 5 = \frac{R_2}{R_1}\frac{1}{\sqrt{2}}$$

Given R_2 = 1k

$$\therefore R_1 = \frac{R_2}{|G|}\frac{1}{\sqrt{2}} = \frac{1\mathbf{k}\Omega}{5}\frac{1}{\sqrt{2}} = 141\Omega$$

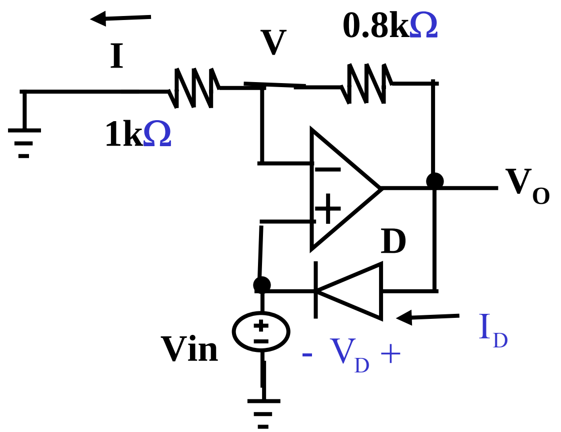
$$\therefore C = \frac{1}{\omega_{cutoff} R_1} = \frac{1}{2\pi(10\mathbf{k})141} \approx 1.13\mathrm{x}10^{-7}\mathbf{F} = 0.113\mu\mathbf{F}$$

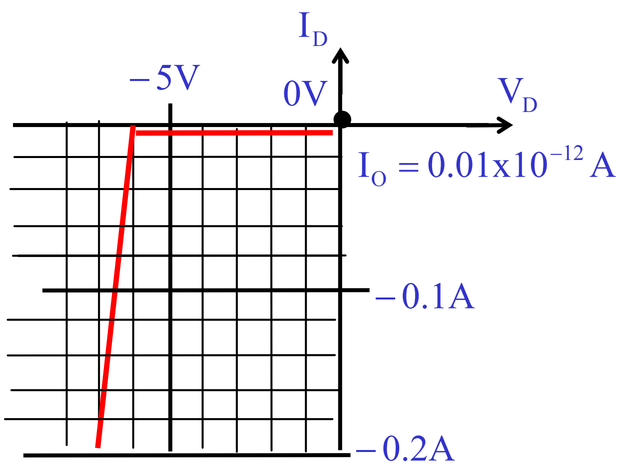
(e)



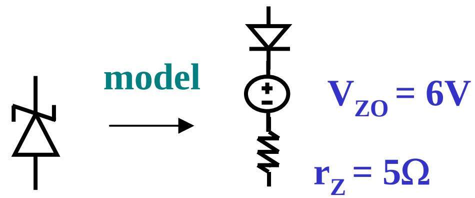
$$20\log\frac{R_2}{R_1} = 20\log\frac{1k}{141} = 17\mathbf{dB}$$

In the ideal op amp circuit, the diode has the reverse characteristics as shown. The diode equation is
I = Io exp [(V/25mV) – 1].
(a) Find the circuit model of the diode at breakdown.
(b) Find I_D if Vin = 1V.
(c) Find I_D if I = - 10mA. (30)





(a) **Model of diode at breakdown**



(b) **When Vin = 1V**

$$\text{Vin} = 1\text{V}, \therefore V = 1\text{V}$$

$$\therefore I = 1\text{mA}, \therefore V_O = 1.8\text{V}$$

$$\therefore I_D = I_O \left(e^{\frac{V_D}{25\text{mV}}} - 1\right)$$

$$= 0.01x10^{-12}\,\text{A}\left(e^{\frac{1.8-1}{25\text{mV}}} - 1\right) = 0.79\text{A}$$

(c) **When I = - 10mA**

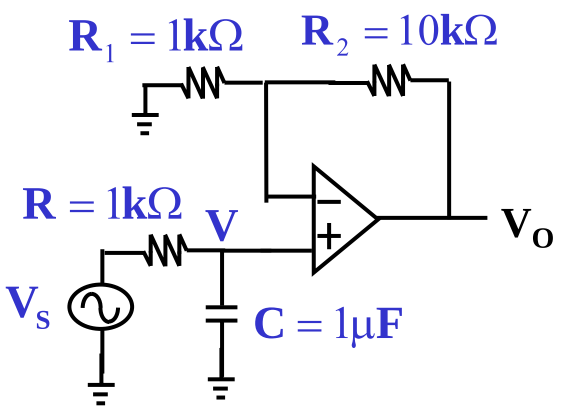
$$V_O = -18V$$

$$\text{Vin} = -10V$$

D is breakdown

$$I_D = -\frac{-10 - -18V - 6V}{5\Omega} = -0.4A$$

1. Given the ideal op amp filter circuit and $V_S = V_m \cos\omega t$ V
(a) Find V_O / V .
(b) Show that the complex transfer function G $(= V_O / V_S) =$.
(c) Find the cut-off frequency ω_O (in rad/s) . Find also the DC voltage gain (value of G when V_S is a DC voltage) .
(d) Find magnitude of G (= | G|) **in dB** when $\omega = 0$ and when $\omega = \omega_O$. Given **|G| in dB = 20 log$_{10}$ |G|** .
(e) Plot | G| versus ω . Show clearly the value of | G| when ω = 0 and $\omega = \omega_O$ in your plot. Is the op amp circuit a low pass filter?
(f) If $V_S = 1\cos 1kt$ V , find magnitude of V_O in V_{rms}.
(55)



1

a

apply KCL

$$\Rightarrow \frac{0V - V_-}{R_1} \cong \frac{V_- - V_O}{R_2}$$

$$V_- \cong V_+ = V$$

$$\therefore \frac{V_O}{V} \cong 1 + \frac{R_2}{R_1} = 1 + \frac{10k\Omega}{1k\Omega} = 11$$

---

b

$$V = V_S * \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\omega C}} = V_S * \frac{1}{1 + j\omega CR}$$

$$V_O = 11V = 11 * V_S \frac{1}{1 + j\omega CR}$$

$$= \frac{11 V_S}{1 + j\omega(1\mu F * 1k\Omega)}$$

$$G = \frac{V_O}{V_S} = \frac{11}{1 + j\omega * 1ms}$$

c ω_O = **cut-off frequency**

$$\omega_O = \frac{1}{1\mathbf{ms}} = 1\mathbf{krad/s}$$

when ω = 0

$$|\mathbf{G}| = 11$$

d

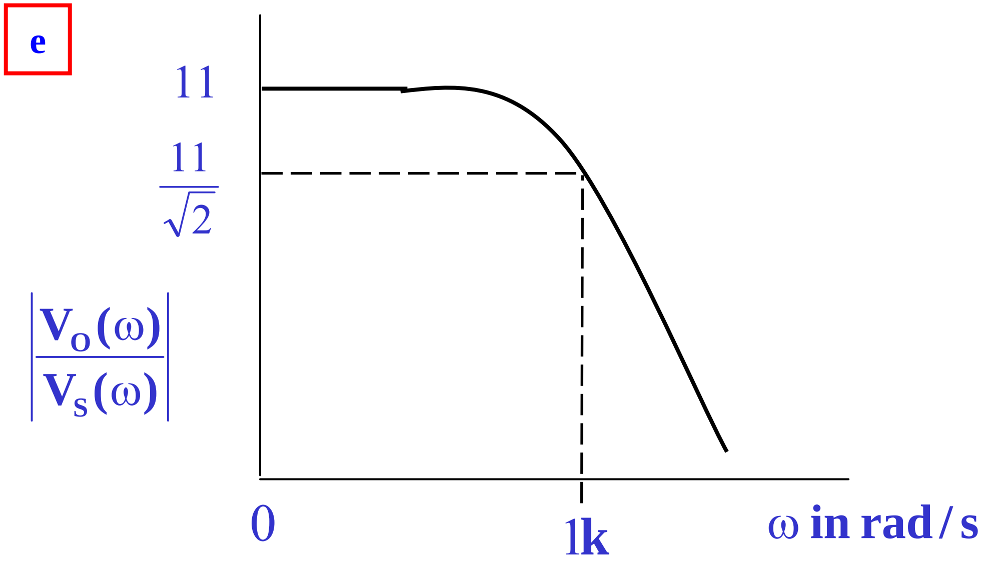
$$|\mathbf{G}| \text{ in dB} = 20\log_{10} 11 \cong 20.8 \text{ dB}$$

At cut-off frequency,

$$|\mathbf{G}| = \frac{11}{\sqrt{2}}$$

$$|\mathbf{G}| \text{ in dB} = 20\log_{10} \frac{11}{\sqrt{2}} \cong 17.8 \text{ dB}$$

e



Circuit is a low pass filter

f

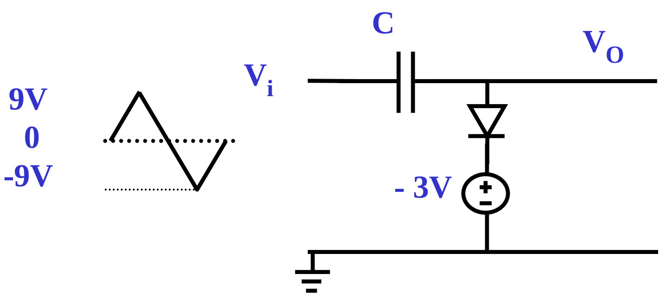
If Vi $= 1\cos(1kt)\,\mathbf{V}$

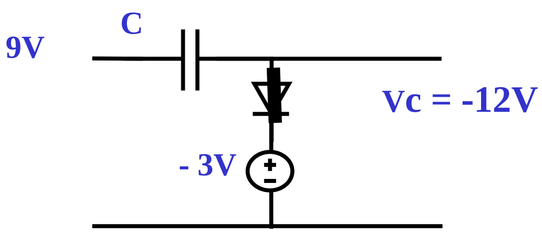
$$\mathbf{V_O} = \frac{11}{\sqrt{2}} * \frac{1}{\sqrt{2}} \mathbf{V_{rms}} = 5.5\mathbf{V_{rms}}$$

7 **(30)**

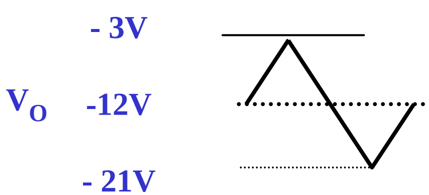
7. (a) In the ideal diode circuit, sketch Vo(t). Label clearly the voltages in your sketch. (12)
(b) In the ideal diode circuit, plot Vo versus Vi for 0V ≤ Vi ≤ 35V. Label clearly all voltages in your sketch. (18)

a

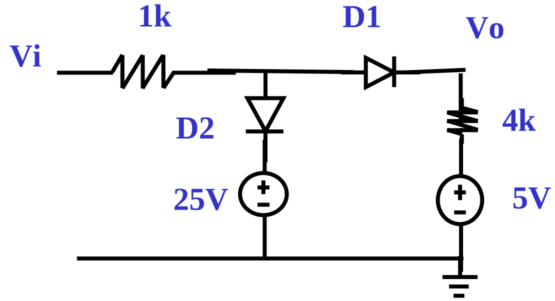


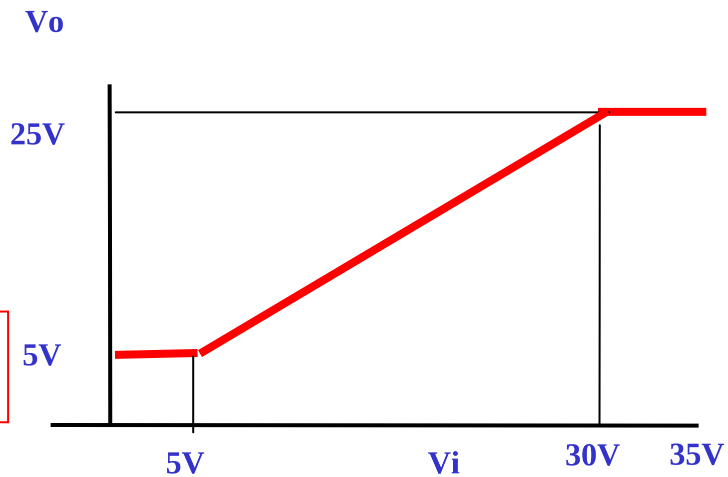


Vo = Vi + Vc = Vi - 12



b





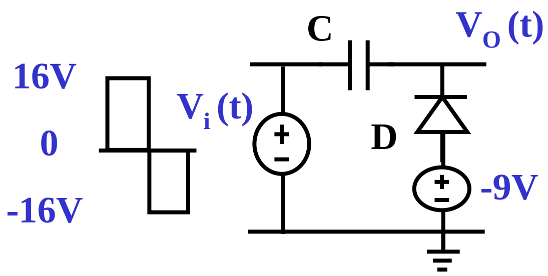
Vi < 5V, D1 and D2 OFF, Vo = 5V

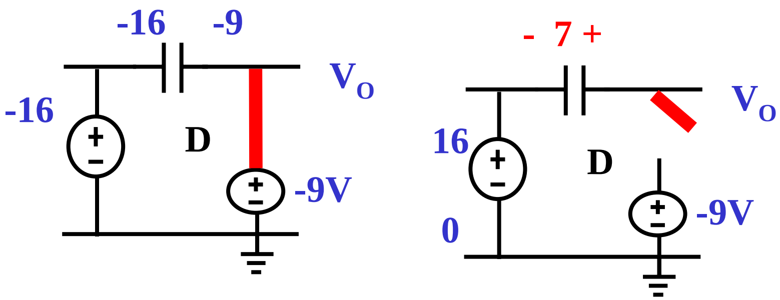
Vi > 5V, D1 ON,
Vo = 5 + I(4k)
= 5 + (Vi - 5)4k/(4k + 1k)
= 5 + (Vi - 5)4/5
Vi = 30, Vo = 5 + 25*4/5 = 25

Vi = 30V, Vo = 25, D2 ON, Vo is fixed at 25V

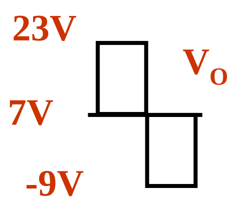
2

(a) In the ideal diode circuit, sketch Vo(t). Explain briefly the reasons for your answers. (12)

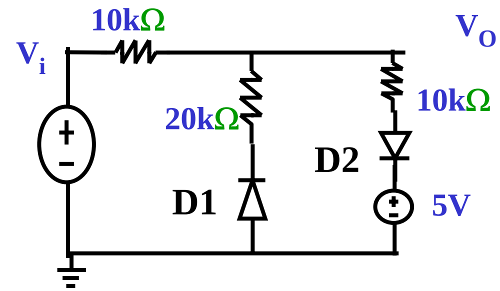


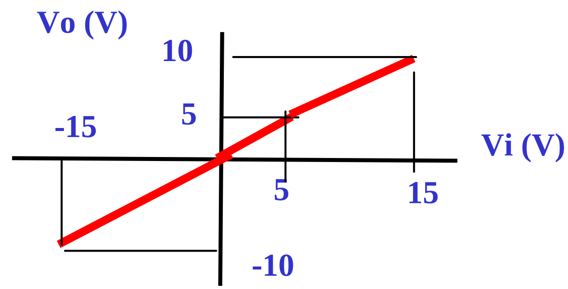


V_O = Vi + Vc = Vi + 7V



(b) In the ideal diode circuit below, plot Vo versus Vi for -15V ≤ Vi ≤ 15V. Label clearly all voltages in your sketch. Explain briefly the reasons for your answers. (15)





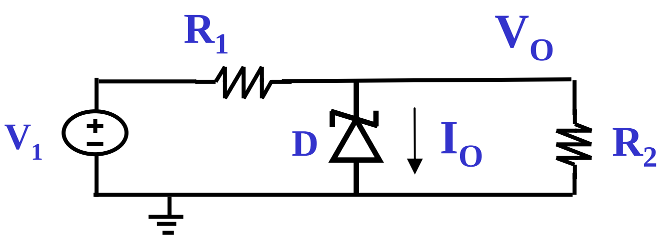
Vi = -15 to 0V, D1 ON, D2 OFF
Vo = Vi(2/3)

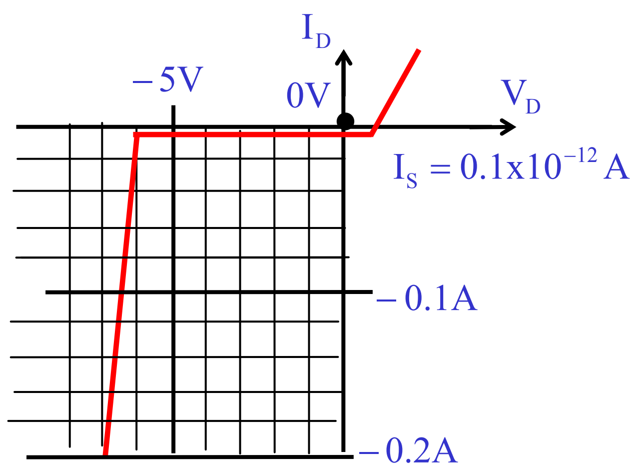
Vi = 0 to 5V, D1 OFF, D2 OFF
Vo = Vi

Vi = 5 to 15V, D1 OFF, D2 ON
Vo = 5 + (Vi – 5)/2

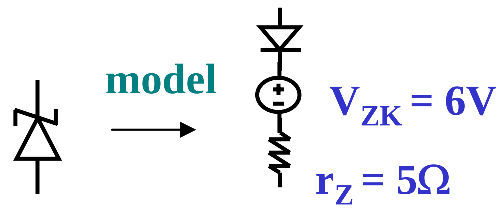
6

6. In the diode circuit, the diode has the reverse characteristics as shown. The diode equation is $\mathbf{I_D = I_S(e^{V_D/25mV} - 1)}$.
(a) Sketch the circuit model of the diode at breakdown.
(b) If $V_1 = 4V$, $R_1 = 1k\Omega$, $R_2 = 1k\ \Omega$, find I_O
(c) If $V_1 = -5.6V$, $R_1 = 0.7\Omega$, $R_2 = 0.1\ \Omega$, find I_O .
(d) If $V_1 = 16V$, $R_1 = 2k\Omega$, $R_2 = 2k\ \Omega$, find V_O .
Show clearly your reasons
(45)





a



b

$$V_O = \mathbf{V_1} * \frac{\mathbf{R_2}}{\mathbf{R_1 + R_2}} = 4V * \frac{1k\Omega}{1k\Omega + 1k\Omega} = 2V$$

diode is OFF

$$\therefore I_O = I_S = 0.1x10^{-12}\,A$$

c

$$V_O = \mathbf{V_1} * \frac{\mathbf{R_2}}{\mathbf{R_1} + \mathbf{R_2}} = -5.6V * \frac{0.1\Omega}{0.7\Omega + 0.1\Omega} = -0.7V$$

diode is ON

$$\therefore I_O = -I_S \left(e^{\frac{0.7V}{25mV}} - 1\right)$$

$$= -0.1x10^{-12} A \left(e^{\frac{700m}{25m}} - 1\right) \cong -0.145A$$

d

$$V_O = \mathbf{V_1} * \frac{\mathbf{R_2}}{\mathbf{R_1} + \mathbf{R_2}} = 16V * \frac{2k\Omega}{2k\Omega + 2k\Omega} = 8V$$

diode is BREAKDOWN

$$\frac{16\mathbf{V} - \mathbf{V_O}}{2\mathbf{k}\Omega} = \frac{\mathbf{V_O} - 6\mathbf{V}}{5\Omega} + \frac{\mathbf{V_O}}{2\mathbf{k}\Omega}$$

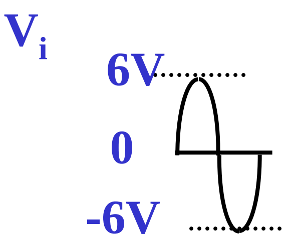
$$16\mathbf{V} - \mathbf{V_O} = 400(\mathbf{V_O} - 6\mathbf{V}) + \mathbf{V_O}$$

$$\mathbf{V_O} = \frac{2400\mathbf{V} + 16\mathbf{V}}{402} \cong 6.01\mathbf{V}$$

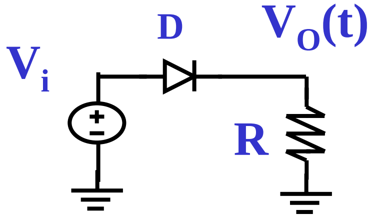
7

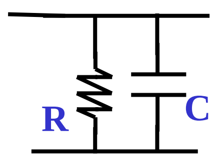
7. (a) Plot the waveform of $V_O(t)$. Show clearly the voltage and time in your plot.
(b) If a **capacitance C** is connected **in parallel** to R, sketch the waveform of V_O (t) . Show also that the ripple voltage Vr of $V_O(t)$ is about 0.18V.

Given that R = 3kΩ, C = 10 u F, diode is an **offset diode** and threshold voltage VF is 0.7V. (24)

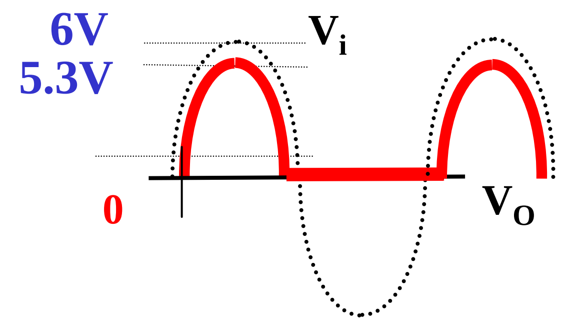


f = 1kHz



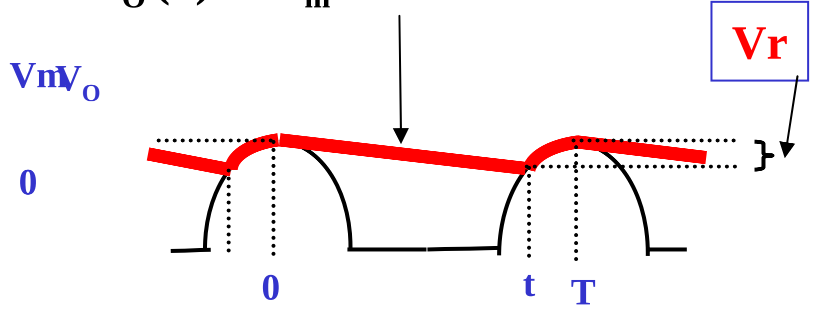


a



b

$$V_O(t) = V_m e^{-t/CR}$$



$$V_r = V_m(1 - e^{-t/RC}) \cong V_m(T/CR)$$

$$= (6V - 0.7V)(1ms/30ms) \cong 0.18V$$