EE101: Electrical Sciences

Tutorial-10, Nov. 10, 2017

Pre-Tutorial Problem

1. An ideal opamp with a diode in the feedback path is shown below. Assume $R_1 = 1\ k\Omega$ and $I_s = 10^{-13}$ A.

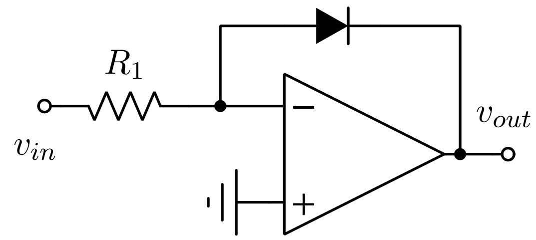


Figure 1: Opamp with a diode in the feedback

(i) If the diode is an ideal diode, what is the approximate output voltage for an input voltage $V_{in} = 2\sin\omega_0 t$.

(ii) If the diode is a Si PN-junction diode, what is the approximate output voltage for an input voltage $V_{in} = 2\sin\omega_0 t$.

(iii) If the diode is a Si PN-junction diode, what is the approximate output voltage for an input voltage $V_{in} = 0.75 + 0.05\sin\omega_0 t$.

Suggestion: You need to derive the output voltage expression for the third case.

Solution

(i) If the diode is an ideal diode, for positive current it acts as a short circuit.

$$V_{out} = \begin{cases} 0 & \text{for } V_{in} > 0 \\ +V_{DD} & \text{for } V_{in} < 0 \end{cases}$$

(ii) For Si PN-junction diode with large signal (amplitude much greater than 0.7 V),

$$V_{out} = \begin{cases} -0.7 & \text{for } V_{in} > 0.7 \\ \cancel{-V_{DD}} & \text{for } 0 < V_{in} < 0.7 \\ +V_{DD} & \text{for } V_{in} < 0 \end{cases}$$

$\rightarrow -0.7$ V

(iii) For small signals around 0.7 V, this circuit acts as a logarithmic amplifier. $V_{out} = 0.7 + V_T ln(\frac{v_{in}}{I_s R_1})$. In the given problem $v_{in} = 0.05$ V, $R_1 = 1\ k\Omega$ and $I_s = 10^{-13}$ A.

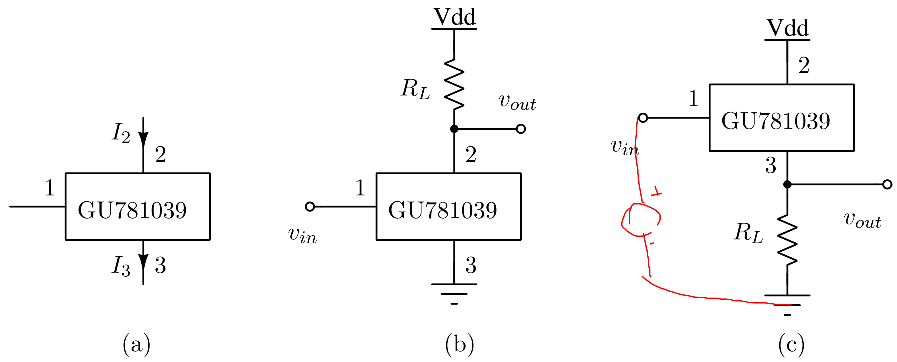


Figure 2: A transistor GU781039 and two circuits using this transistor.

Tutorial Problems

2. A 3-terminal transistor chip GU781039 is shown in Fig. 2(a). The transistor GU781039 has the following DC characteristics.

$$I_2 = I_3 = I_s ln(\frac{V_{13}}{V_T}),$$

where V_T is the thermal voltage. Impedance seen into the terminal 1 is infinity.

Derive the voltage gain expressions for the circuits in Fig. 2(b) and Fig. 2(c).

Solution

Small signal voltage gain $= G_m R_L = \frac{dI_{OUT}}{dV_{IN}} R_L$

For the circuit in (b), $V_{IN} = V_{13}$ and $I_{OUT} = -I_2$. $G_m R_L = \frac{-I_s}{V_{13}} R_L$

For the circuit in (c), $V_{IN} = V_1$ and $I_{OUT} = I_3$. Rewriting the current equation as $V_1 - I_3 R_L = V_T e^{I_3/I_s}$ and differentiating w.r.t. V_1 gives

$$1 - G_m R_L = \frac{V_T}{I_s} e^{I_3/I_s} G_m \Rightarrow G_m R_L = \frac{R_L}{R_L + \frac{V_T}{I_s} e^{I_3/I_s}}$$

3. A zener diode based shunt regulator is shown below. The zener diode has a reverse breakdown voltage $V_{Z0} = 3.5$ V and $r_z = 10\ \Omega$. What is the change in output voltage (across the 7 $k\Omega$ resistor) if the input voltage varies from 4.5 to 5.5 V.

Solution

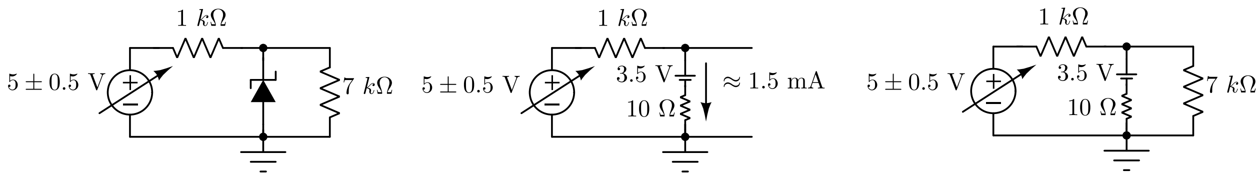


Figure 3: A zener diode based shunt regulator

Quick Check: Under no load, $I_Z = \frac{1.5}{1010}\ A \ \approx 1.5$ mA. The load current should not be more than 1.5 mA. In the current problem, load current is ≈ 0.5 mA.

KCL at the output node gives,

$$\frac{V_{OUT} - V_{IN}}{1000} + \frac{V_{OUT} - 3.5}{10} + \frac{V_{OUT}}{7000} = 0$$

From the above equation $\Delta V_{OUT} \approx \frac{\Delta V_{IN}}{101.14}$. If the input changes by ± 0.5 V, the output changes by $\approx \pm 5$ mV.

4. Let I_S=2cos 10t A in the circuit shown in Figure 4. Find the total energy stored at t = 0, if: (i) a-b is open circuited, (ii) a-b is short circuited.

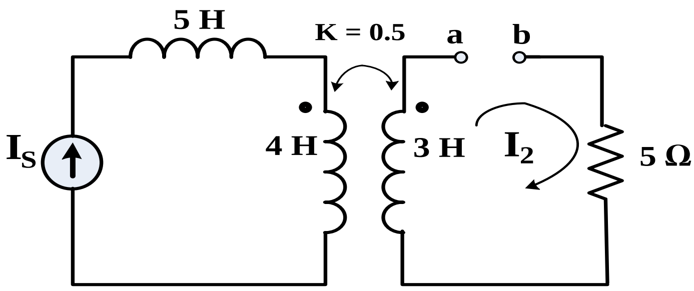


Figure 4

Solution:

$$\text{K} = 0.5 \;\rightarrow\; \frac{M}{\sqrt{L1L2}} = 0.5 \;\rightarrow M = \frac{\sqrt{12}}{2} = \sqrt{3}.$$

i) **<u>When a – b is open circuited:</u>**

Total energy stored = Energy stored in 5 H & 4 H inductor

$= \left(\frac{1}{2}\right) * 5 * I_S^2 + \left(\frac{1}{2}\right) * 4 * I_S^2$

At t = 0, Total energy stored, $W_{t=0} = \left(\frac{1}{2}\right) * 5 * 2^2 + \left(\frac{1}{2}\right) * 4 * 2^2 = \mathbf{18J}$

ii) **<u>When a - b is short circuited:</u>**

Let i_2 be the current in 2nd loop .

Applying KVL in 2nd loop: $-j\omega 3 I_2 - 5\, I_2 + j\, \omega\, \sqrt{3}\, I_s = 0\,,\quad \omega = 10$

$\downarrow$

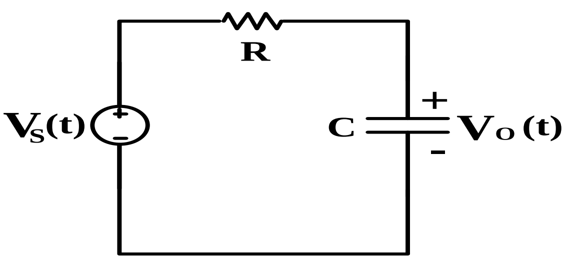
(Induced emf. In 3H coil due to current i_s in 4H coil .)

$$-j\,30\, I_2 - 5\, I_2 = -j\, 34.64 \;\Rightarrow\; I_2 = \frac{j34.64}{5 + j\,30} = -\frac{34.64}{5j - 30} = \frac{34.64}{30 - 5\,j} = 1.14\angle 9.46^0\text{A}$$

Total energy stored = $\left(\frac{1}{2}\right) * 5 * I_s^2 + \left(\frac{1}{2}\right) * 4 * I_s^2 + \frac{1}{2} * 3 * I_2^2 - M * I_s * I_2$ Joule.

$$W_{t=0} = 18 + \frac{1}{2} * 3 * \left((1.14\cos(10t + 9.46^0)\right)_{t=0})^2 - \sqrt{3} * 2 * \left((1.14\cos(10t + 9.46^0)\right)_{t=0}) = \mathbf{16\ J}$$

5. For the RC circuit given below, compute the frequency response. Draw the magnitude and the phase plot. (RC = 10 $^{-6}$ sec.)



Solution:

$$H(\omega) = \frac{V_0}{V_s} = \frac{1 / j\omega C}{R + 1 / j\omega C} = \frac{1}{1 + j\omega RC}$$

The magnitude and phase of $H(\omega)$ are obtained as:

$$H = \frac{1}{\sqrt{1 + (\omega / \omega_0)^2}}, \qquad \phi = -\tan^{-1}\frac{\omega}{\omega_0}$$,Where $\omega_0 = \frac{1}{RC}$.

Taking different values of ω, we calculate H and ϕ .

ω	H	ϕ **(degrees)**
0	0	0
ω_0	0.71	-45
$2\omega_0$	0.45	-63
$3\omega_0$	0.32	-72
$10\omega_0$	0.1	-84
$20\omega_0$	0.05	-87
$100\omega_0$	0.01	-89
∞	0	-90

The magnitude and phase plots are given below.

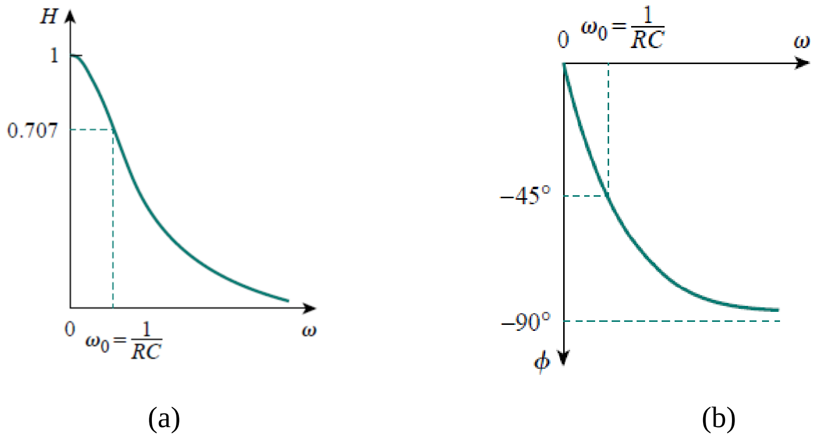


Figure 5: (a) Magnitude response, (b) Phase response