Name: Dr JBO

Student ID Number: Model Answer

Section:

Lecturer: Dr. Jamaludin Bin Omar

EEEB273 - Quiz 2 00

SEMESTER 1, ACADEMIC YEAR 2015/2016

Date: 25 June 2015 Time: 15 minutes

# **Question:**

A Widlar current source circuit to be designed has the configuration shown in Figure 1. The circuit parameters are:  $V^+ = +5.5 \text{ V}$  and  $V^- = -5.5 \text{ V}$ . The transistor parameters are:  $V_{BE1} = 0.6 \text{ V}$ ,  $V_A = 80 \text{ V}$ , and  $\beta = 120$  (Therefore, we can assume that  $I_C \approx I_E$ ).

(a) Design the Widlar current source circuit such that  $I_{REF} = 1$  mA and  $I_0 = 12$   $\mu$ A.

[4 marks]

 $i_C = I_S e^{v_{BE}/V_T}$ ; npn

 $i_C = I_S e^{v_{EB}/V_T}$ ; pnp

 $i_C = \alpha i_E = \beta i_B$ 

 $i_F = i_R + i_C$ 

(b) Find  $V_{BE2}$ . [2 marks]

(c) Calculate the output resistance  $(R_0)$  of the Widlar current source in Figure 1 using the following formula. Use parameters and results from part (a) above. [4 marks]

$$R_{O} = r_{o2} \left[ 1 + g_{m2} \left( R_{E} \| r_{\pi 2} \right) \right]$$

$$I_{REF} \bigvee_{Q_{1}}^{V^{+}} R_{1} \qquad R_{o} \bigvee_{Q_{2}}^{R_{O}} V_{C2}$$

$$I_{C1} \bigvee_{Q_{1}}^{V^{-}} V_{BE1} \qquad V_{BE2} \bigvee_{Q_{2}}^{R_{E}} R_{E}$$

$$R$$

Figure 1

### Answer:

(a)		
$R_1 = \frac{V^+ - V_{BE1} - V^-}{2} = \frac{V^+ - V_{BE1} - V^-}{2}$	$\frac{5.5 - 0.6 - (-5.5)}{10.4 \text{ k}\Omega} = 10.4 \text{ k}\Omega$	[2]
$I_{\it REF}$	lm	

$$R_E = \frac{V_T}{I_O} \ln \left( \frac{I_{REF}}{I_O} \right) = \frac{0.026}{12} \ln \left( \frac{1m}{12} \right) = 9.58 \text{k}\Omega$$
 [2]

(b) 
$$V_{BE2} = V_{BE1} - I_O R_E = 0.6 - (12)(9.58k) = 0.485V$$
 [2]

 $g_{m2} = \frac{I_O}{V_T} = \frac{12\mu}{0.026} = 0.462 \text{mA/V}$ [1]

$$r_{\pi 2} = \frac{\beta V_T}{I_O} = \frac{(120)(0.026)}{12\mu} = 260\text{k}\Omega$$
 [1]

$$r_{o2} = \frac{V_A}{I_O} = \frac{80}{12\mu} = 6.67 \text{M}\Omega$$
 [1]

$$R_O = r_{o2} \Big[ 1 + g_{m2} \Big( R_E \big\| r_{\pi 2} \Big) \Big]$$

 $R_O = (6.67 \text{M}) [1 + (0.462 \text{m}) (9.58 \text{k} || 260 \text{k})] = 35.1 \text{M}\Omega^{[1]}$ 

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# **Question:**

A Widlar current source circuit to be designed has the configuration shown in Figure 1. The circuit parameters are:  $V^+ = +5.0 \text{ V}$  and  $V^- = -5.0 \text{ V}$ . The transistor parameters are:  $V_{BE1} = 0.6 \text{ V}$ ,  $V_A = 80 \text{ V}$ , and  $\beta = 120$  (Therefore, we can assume that  $I_C \approx I_E$ ).

(a) Design the Widlar current source circuit such that  $I_{REF} = 1.2$  mA and  $I_0 = 12$   $\mu$ A.

[4 marks]

 $i_C = I_S e^{v_{BE}/V_T}$ ; npn

 $i_C = I_S e^{v_{EB}/V_T}$ ; pnp

(b) Find  $V_{BE2}$ . [2 marks]

(c) Calculate the output resistance  $(R_0)$  of the Widlar current source in Figure 1 using the following formula. Use parameters and results from part (a) above. [4 marks]

$$R_{O} = r_{o2} \left[ 1 + g_{m2} \left( R_{E} \| r_{\pi 2} \right) \right]$$

$$I_{REF} \bigvee_{Q_{1}}^{V^{+}} I_{C2} = I_{O}$$

$$V_{BE1} \bigvee_{V_{BE2}}^{R_{O}} \bigvee_{Q_{2}}^{V_{BE2}} R_{E}$$

$$R_{E} \bigvee_{Q_{1}}^{R_{1}} R_{E}$$

$$R_{E} \bigvee_{Q_{2}}^{R_{1}} R_{E}$$

Figure 1

Answer:

$$R_{E2} = \frac{V^{+} - V_{BE1} - V^{-}}{I_{REF}} = \frac{5 - 0.6 - (-5)}{1.2 \text{m}} = 7.83 \text{k}\Omega \qquad [2]$$

$$R_{E} = \frac{V_{T}}{I_{O}} \ln \left(\frac{I_{REF}}{I_{O}}\right) = \frac{0.026}{12} \ln \left(\frac{1.2 \text{m}}{12}\right) = 9.98 \text{k}\Omega \qquad [2]$$

$$R_E = \frac{V_T}{I_O} \ln \left( \frac{I_{REF}}{I_O} \right) = \frac{0.026}{12} \ln \left( \frac{1.2 \text{m}}{12} \right) = 9.98 \text{k}\Omega$$
 [2]

(b) 
$$V_{BE2} = V_{BE1} - I_{O}R_{E} = 0.6 - (12)(9.98 \text{k}) = 0.48 \text{V}$$
 [2]

$$I_{O} \qquad (I_{O}) \qquad 12 \qquad (12)$$
(b)
$$V_{BE2} = V_{BE1} - I_{O}R_{E} = 0.6 - (12)(9.98k) = 0.48V \qquad [2]$$
(c)
$$g_{m2} = \frac{I_{O}}{V_{T}} = \frac{12\mu}{0.026} = 0.462\text{mA/V} \qquad [1]$$

$$r_{\pi 2} = \frac{\beta V_{T}}{I_{O}} = \frac{(120)(0.026)}{12\mu} = 260k\Omega \qquad [1]$$

$$r_{\pi 2} = \frac{\beta V_T}{I_O} = \frac{(120)(0.026)}{12\mu} = 260\text{k}\Omega$$
 [1]

$$r_{o2} = \frac{V_A}{I_O} = \frac{80}{12\mu} = 6.67 \text{M}\Omega$$
 [1]

$$r_{o2} = \frac{V_A}{I_O} = \frac{80}{12\mu} = 6.67 \text{M}\Omega$$

$$R_O = r_{o2} \left[ 1 + g_{m2} \left( R_E || r_{\pi 2} \right) \right]$$

$$R_O = (6.67 \text{M}) \left[ 1 + (0.462 \text{m}) \left( 9.98 \text{k} || 260 \text{k} \right) \right] = 36.2 \text{M}\Omega$$
[1]

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## **Question:**

A Widlar current source circuit to be designed has the configuration shown in Figure 1. The circuit parameters are:  $V^+ = +5.0 \text{ V}$  and  $V^- = -5.0 \text{ V}$ . The transistor parameters are:  $V_{BE1} = 0.6 \text{ V}$ ,  $V_A = 100 \text{ V}$ , and  $\beta = 120$  (Therefore, we can assume that  $I_C \approx I_E$ ).

(a) Design the Widlar current source circuit such that  $I_{REF} = 1$  mA and  $I_0 = 10$   $\mu$ A.

[4 marks]

 $i_C = I_S e^{v_{BE}/V_T}$ ; npn

 $i_C = I_S e^{v_{EB}/V_T}$ ; pnp

 $i_C = \alpha i_E = \beta i_B$ 

 $i_E = i_R + i_C$ 

(b) Find  $V_{BE2}$ . [2 marks]

(c) Calculate the output resistance  $(R_0)$  of the Widlar current source in Figure 1 using the following formula. Use parameters and results from part (a) above. [4 marks]

$$R_{O} = r_{o2} \left[ 1 + g_{m2} \left( R_{E} \| r_{\pi 2} \right) \right]$$

$$I_{REF} \bigvee_{Q_{1}}^{V^{+}} R_{1} \qquad R_{o} \bigvee_{Q_{2}}^{R_{E}} R_{E}$$

$$I_{C1} \bigvee_{Q_{1}}^{V^{-}} V_{BE1} \qquad V_{BE2} \bigvee_{Q_{2}}^{R_{E}} R_{E}$$

$$R$$

Figure 1

#### Answer:

(a)		
$R_{\cdot} = \frac{V^{+} - V_{BE1} - V^{-}}{1 - V_{BE1}} = \frac{V^{-} - V_{BE1}}{1 -$	$=\frac{5-0.6-(-5)}{9.40k\Omega}$	[2]
$I_{REF}$	1m	[2]

$$R_E = \frac{V_T}{I_O} \ln \left( \frac{I_{REF}}{I_O} \right) = \frac{0.026}{10} \ln \left( \frac{1\text{m}}{10} \right) = 11.97 \text{k}\Omega$$
 [2]

(b) 
$$V_{BE2} = V_{BE1} - I_O R_E = 0.6 - (10)(11.97 \text{k}) = 0.48 \text{V}$$
 [2]

$$g_{m2} = \frac{I_O}{V_T} = \frac{10\mu}{0.026} = 0.385 \text{mA/V}$$
 [1]

$$r_{\pi^2} = \frac{\beta V_T}{I_O} = \frac{(120)(0.026)}{10\mu} = 312\text{k}\Omega$$
 [1]

$$r_{o2} = \frac{V_A}{I_O} = \frac{100}{10\mu} = 10.0 \text{M}\Omega$$
 [1]

$$R_O = r_{o2} \left[ 1 + g_{m2} \left( R_E || r_{\pi 2} \right) \right]$$
  

$$R_O = (10.0 \text{M}) \left[ 1 + (0.385 \text{m}) \left( 11.97 \text{k} || 312 \text{k} \right) \right] = 54.3 \text{M}\Omega^{[1]}$$

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# **Question:**

A Widlar current source circuit to be designed has the configuration shown in Figure 1. The circuit parameters are:  $V^+ = +5.5 \text{ V}$  and  $V^- = -5.5 \text{ V}$ . The transistor parameters are:  $V_{BE1} = 0.6 \text{ V}$ ,  $V_A = 100 \text{ V}$ , and  $\beta = 120$  (Therefore, we can assume that  $I_C \approx I_E$ ).

(a) **Design** the Widlar current source circuit such that  $I_{REF} = 1$  mA and  $I_0 = 10$   $\mu$ A.

[4 marks]

 $i_C = I_S e^{v_{BE}/V_T}$ ; npn

 $i_C = I_S e^{v_{EB}/V_T}$ ; pnp

 $i_C = \alpha i_E = \beta i_B$ 

 $i_F = i_R + i_C$ 

(b) Find  $V_{BE2}$ . [2 marks]

(c) Calculate the output resistance  $(R_0)$  of the Widlar current source in **Figure 1** using the following formula. Use parameters and results from **part (a)** above. [4 marks]

$$R_{O} = r_{o2} \left[ 1 + g_{m2} \left( R_{E} \| r_{\pi 2} \right) \right]$$

$$I_{REF} \downarrow V_{BE1} \qquad R_{O} \downarrow I_{C2} = I_{O}$$

$$V_{BE1} \qquad V_{BE2} \qquad R_{E} \qquad R_{I}$$

$$R_{E} \downarrow V_{BE2} \qquad R_{E} \qquad R_{E}$$

Figure 1

#### **Answer:**

ı	(a)		
	$R_{-} = \frac{V^{+} - V_{BE1} - V^{-}}{2}$	$=\frac{5.5-0.6-(-5.5)}{1.00}=10.4$ k $\Omega$	[2]
	$I_{REF}$	1m	[~]

$$R_E = \frac{V_T}{I_O} \ln \left( \frac{I_{REF}}{I_O} \right) = \frac{0.026}{10} \ln \left( \frac{1 \text{m}}{10} \right) = 11.97 \text{k}\Omega$$
 [2]

(b) 
$$V_{BE2} = V_{BE1} - I_O R_E = 0.6 - (10)(11.97 \text{k}) = 0.48 \text{V}$$
 [2]

 $g_{m2} = \frac{I_O}{V_T} = \frac{10\mu}{0.026} = 0.385 \text{mA/V}$  [1]

$$r_{\pi 2} = \frac{\beta V_T}{I_O} = \frac{(120)(0.026)}{10\mu} = 312\text{k}\Omega$$
 [1]

$$r_{o2} = \frac{V_A}{I_O} = \frac{100}{10\mu} = 10.0 \text{M}\Omega$$
 [1]

$$R_O = r_{o2} \left[ 1 + g_{m2} \left( R_E \| r_{\pi 2} \right) \right]$$
  

$$R_O = (10.0 \text{M}) \left[ 1 + (0.385 \text{m}) \left( 11.97 \text{k} \| 312 \text{k} \right) \right] = 54.3 \text{M}\Omega^{[1]}$$