(21) If a silicon diffusion is doped with boron at a concentration of $4.1\times10^{16}\ cm^3$, what is the concentration of electrons in this piece of silicon per cm^3? Assume $n_i = 1.5\times10^{10}\ cm^3$ at 300°k.

$$n = \frac{n_i^2}{P} = \frac{(1.5\times10^{10})^2}{4.1\times10^{16}} = \boxed{5487.8\ cm^3}$$

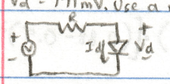
(22) If a PN junction is doped with boron at a concentration of $1.4\times10^{16}\ cm^3$ and phosphorus at a concentration of $7.5\times10^{17}\ cm^3$, then what is the built-in voltage in milivolts for this junction? Assume $n_i = 1.5\times10^{10}\ cm^3$ and $V_t = kt/q = 26mV$ at 300k.

$$\phi = 26\ln\left(\frac{1.4\times10^{16}\cdot 7.5\times10^{17}}{(1.5\times10^{10})^2}\right) = \boxed{818.33}$$

(23) If a PN junction is doped with boron at a concentration of $5.4\times10^{18}\ cm^3$ and phosphorus at a concentration of $1.9\times10^{17}\ cm^3$, then what is the built-in voltage in milivolts for this junction? Assume $n_i = 1.5\times10^{10}\ cm^3$ and $V_t = 26mV$ at 300°k.

$$\phi = 26\ln\left(\frac{5.4\times10^{18}\cdot 1.9\times10^{17}}{(1.5\times10^{10})^2}\right) = \boxed{937.46}$$

(24) If the input voltage to the diode circuit shown, V_i, changes by 1.8V then what will be the change in the diode voltage, V_d, in milivolts? To find the bias point needed for your small signal analysis use the constant voltage model for the diode with $V_d = 771mV$. Use a nominal value for $V_i = 12V$. Also use $R = 5.7k\Omega$ and $V_t = 26mV$.



$$I_d = \frac{V_i - V_d}{R} = \frac{12 - 0.771}{5700} = 0.00197A = 1.97mA$$

$$Z = \frac{V_T}{I_d} = \frac{0.026\ V}{0.00197A} = 13.198\Omega$$

$$V_d = \frac{13.198\Omega\cdot V_i}{13.198\Omega + 5700} = \frac{13.198V_i}{5713.198} = 0.00231V_i$$

$$V_d' = 0.771V + 0.0023V_i$$

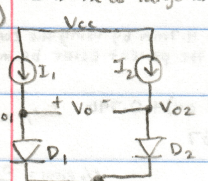
$$V_i = V_i' \pm 1.8V$$

$$V_d' = 0.771 + 0.00231(V_i \pm 1.8)$$

$$V_d' = 0.771 + 0.00231V_i \pm (0.00231\cdot 1.8)$$

$$V_d' = V_d \pm 0.004158 \rightarrow 4.158mV = \boxed{4.2mV}$$

(25) For the diode circuit shown, what is the output voltage, V_o, in milivolts? Assume that $I_1 = 10\times I_2$, and the junction area of D2 is 7x as large as the junction area for D1. Use $V_t = 26mV$.



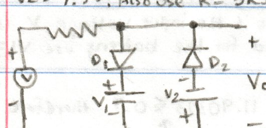
$$I_1 = I_{s1}\left(e^{\frac{V_{o1}}{nV_t}} - 1\right) \qquad I_1 \approx I_{s1}e^{\frac{V_{o1}}{nV_t}} \ (1) \qquad n=1$$

$$I_2 \approx I_{s2}e^{\frac{V_{o2}}{nV_t}} \ (2)$$

$$\frac{(2)}{(1)} = \frac{I_2}{I_1} = \frac{I_{s2}}{I_{s1}}e^{\frac{V_{o2}-V_{o1}}{V_t}} \rightarrow \frac{1}{10} = 7e^{\frac{-V_o}{26mV}} \rightarrow \frac{1}{20} = e^{\frac{-V_o}{26mV}} \rightarrow$$

$$-4.248 = \frac{-V_o}{0.026} \quad -0.11046 = -V_o \rightarrow 0.11046 = V_o \rightarrow \boxed{110.46mV}$$

* (26) For the diode circuit shown, what will the output voltage, V_o, be in volts if the input voltage, V_i, is equal to 5V? Assume that when a diode is turned on the voltage across it will be 0.7V, and for the batteries use $V_1 = 5.2V$ and $V_2 = 7.3V$. Also use $R = 5k\Omega$.



As the input is -5V

(27) A half-wave diode rectifier circuit driven by a 60Hz sine wave with a peak value of 14V. If the load resistance this circuit drives is 4.8kΩ and the ripple voltage at the output is 0.37 Vpp, then what is the average current in the diode in milliamps?

$F = 60Hz$ $\quad R_L: 4800\Omega$ $\quad I_L = \frac{V_p}{R_L} = \frac{14}{4800} = 0.0029A$

$V_p = 14V$ $\quad V_{pp}: 0.37$

$$I_{DAVG} = 0.0029A\left(1 + \pi\left(\sqrt{\frac{2(14V)}{0.37}}\right)\right) = 0.08215 = \boxed{82.15mA}$$

(28) If a MOSFET with $W = 5.6\mu m$ and $L = 1.5\mu m$ is biased in triode, what is the gate-to-drain capacitance, Cgd, in femtofarads? Assume the gate dielectric is silicon dioxide with $t_{ox} = 53.6$ angstroms.

$$C_{gd} = \frac{1}{2} \cdot C_{ox} \cdot W \cdot L \rightarrow \frac{1}{2} \cdot \frac{(3.9 \cdot 8.85 \cdot 10^{-12})}{(53.6 \times 10^{-10})} \cdot (5.6 \times 10^{-6}) \cdot (1.5 \times 10^{-6}) = 2.7045 \times 10^{-14} \rightarrow 27.045 \times 10^{-15} \rightarrow$$

$\boxed{27.1 \text{ femtofarads}}$

(29) If an NMOS FET with $W = 7.4\mu m$ and $L = 2.7\mu m$ is biased in triode with $V_{gs} = 1.2$ and $V_{ds} = 0V$, what is the on resistance of this MOS switch in Ohms? Use: $V_{TN} = 0.5V$ and $k'_n = 100\mu A/V^2$

$$R_{ON} = \frac{2V_{ds}}{2I_o} = \frac{1}{k'_n \cdot (W/L) \cdot (V_{gs} - V_{TN})} = \frac{1}{(100 \times 10^{-6})(7.4/2.7)(1.2 - 0.5)} = \boxed{5212.355\Omega}$$

(30) If a PMOS FET with $W/L = 22.7$ has $|V_{gs}| = 0.88$ and $|V_{ds}| = 1.32$, what is the magnitude of the drain current in microamps? Use: $V_{TP} = -0.5V$, $k'_p = 40\,\mu A/V^2$, $\lambda = 0$

$$I_d = \frac{1}{2} \cdot \frac{W}{L} \cdot k'_p \cdot \left[(|V_{gs}| - |V_{TP}|)^2 (1 + (\lambda \cdot |V_{DS}|))\right] \rightarrow I_d = \frac{1}{2} \cdot 22.7 \cdot (40 \times 10^{-6}) \cdot \left[(0.88 - 0.5)^2 (1 + (0 \cdot 1.32))\right] =$$

$I_d = 0.000065558 \rightarrow \boxed{65.558 mA}$

(31) A full-wave diode rectifier circuit is driven by a 60Hz sine wave with a peak value of 10V. If the load resistance this circuit drives is 9.6kΩ and the ripple voltage at the output is 0.5 Vpp, then what is the peak current in the diode in milliamps?

$V_p = 10V$ $\quad R = 9.6k\Omega$

$V_{pp} = 0.5pp$ $\quad I_D = 10/9600 = 0.0010416667A$

$$I_{peak} = I_D\left[1 + \pi\sqrt{\frac{2V_p}{V_{pp}}}\right] = 0.0010416667\left[1 + \pi\left[\sqrt{\frac{20}{0.5}}\right]\right] = 0.021738 \rightarrow$$

$\boxed{21.738 mA}$

(22) If the DC bias voltage, Vd, across a reverse biased PN step junction is equal to -2.8V then what is the capacitance of this junction in femtofarads? Assume that Cj0 for the junction is equal to 288.5 femtofarads. Also assume that the built-in voltage for this junction is equal to 899mV.

mt for step junction = 1/2

mt for linear junction = 1/3

$$C_j = \frac{C_{jo}}{(1 - V_d/V_o)^{mt}} \rightarrow \frac{288.5 \times 10^{-15}}{\left(1 - \left(\frac{-2.8V}{899 \times 10^{-3}}\right)\right)^{0.5}} = \boxed{142.23 \text{ femtofarads}}$$

* (23) If the DC bias current, Id, for a forward biased PN junction is equal to 0.1 mA then what is the voltage across this diode, Vd, in millivolts? Assume the saturation current for the diode, Is, is equal to 2fA. Also assume that the thermal voltage is equal to Vt = 26mV. Since the diode current is very sensitive to small changes in the diode voltage, be sure to give your answer to the nearest millivolt.

$I = 0.1mA = 0.0001A$ $\quad I_o = 2fA \rightarrow 2 \times 10^{-15}A$

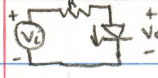
$V_d = ?$

$$I = I_o\left[e^{\frac{V_d}{V_t}} - 1\right]$$

$$0.0001 = (2 \times 10^{-15})\left[e^{V_d/(26 \times 10^{-3})} - 1\right] \rightarrow 5 \times 10^{10} = e^{\frac{V_d}{26 \times 10^{-3}}} - 1 \rightarrow \ln(5 \times 10^{10}) = \frac{V_d}{0.026} - 1 \rightarrow 24.635 = \frac{V_d}{0.026} - 1$$

$$25.635 = \frac{V_d}{0.026} \rightarrow V_d = 0.666651 = \boxed{666.5 mV}$$

(24) In the diode circuit shown the value for R was chosen to set the DC bias current, Id, equal to 4.7mA by using the constant voltage model for the diode with Vd = 700mV. If the actual voltage across the diode is 796mV, then what will be the percent error be in the actual DC bias current compared to the intended value? Use Vi = 11.2V



$V_i = I_d R + V_d$ $\quad R = 2234.04\Omega$ $\quad 11.2 = I_d(2234.04) + 0.796$

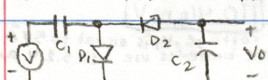
$11.2 = 0.0047(R) + 0.7$ $\quad I_d = 0.004657$

$$\%\,error = \left(\frac{actual - intended}{intended}\right)100$$

$$\%\,error = \frac{0.004657 - 0.0047}{0.0047} \cdot 100$$

$= \boxed{-0.91489\%}$

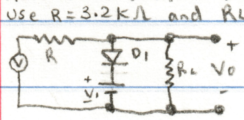
(25) For the diode circuit shown, what will the output voltage, Vo, be in volts if the input voltage, V, is a sine wave with an amplitude equal to 5.4V? Assume that when a diode is turned on the voltage across it will be 0.7V.



$2(V - V_d) = V_o$

$2(5.4 - 0.7) = 9.4 \rightarrow \boxed{-9.4V \text{ because of diode direction}}$

(26) For the diode circuit shown, what will be the output voltage, Vo, be in volts if the input voltage, V, is equal to 15V? Assume that when the diode is turned on the voltage across will be 0.7V, and for the battery use VI = 5.2V. Also, use R = 3.2kΩ and RL = 12.3kΩ.



$$V_o = V \cdot \frac{R_L}{(R + R_L)} = 15 \cdot \frac{12300}{3200 + 12300} = 11.90323 < 0.7 \quad \text{therefore} \quad V_o = V_1 + V_d$$

If true the value would be Vo.

$V_o = 5.2 + 0.7 = \boxed{5.9}$

(27) A full-wave diode rectifier circuit is driven by a 60Hz sine wave with a peak value of 20V. If the load resistance this circuit drives is 10kΩ and the maximum ripple voltage allowed at the output is 0.06 Vpp, then what must the minimum value be for the filter capacitor in microfarads?

$V_r = \frac{V_P}{2 f R_L V_{pp}} \rightarrow \frac{20V}{2 \cdot 60 \cdot 10000\Omega \cdot 0.06} = 2.7777777 \times 10^{-4} \rightarrow 0.000277777 \rightarrow \boxed{277.778 \mu F}$

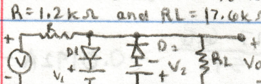
(31) A half-wave diode rectifier circuit is driven by a 60Hz sine wave with a peak value of 19V. If the load resistance this circuit drives is 9.0kΩ and the ripple voltage at the output is 0.22 Vpp, then what is the peak current in the diode in milliamps?

$i_{davg} = \frac{V}{R_L}\left(1 + 2\pi\sqrt{\frac{2V}{V_{pp}}}\right) \rightarrow \frac{19}{9000}\left(1 + 2\pi\left(\sqrt{\frac{2 \cdot 19}{0.22}}\right)\right) = 0.176441 \rightarrow \boxed{176.44 mA}$

(22) If the DC bias current, Id, for a forward biased PN junction is equal to 6.8mA then what is the capacitence of this junction in pF? Assume that the mean transit time for the junction is equal to 219 psec, and that the thermal voltage is equal to Vt = 26mV.

$\frac{26mV}{6.8mA} \rightarrow \frac{0.026V}{0.0068A} = 3.82353F \qquad \frac{219\ psec}{3.82353F} \rightarrow \frac{(219 \times 10^{-12})}{3.82353\ F} = 5.727 \times 10^{-11} \rightarrow \boxed{57.27 pF}$

(26) For the diode circuit shown, what will the output voltage, Vo, be in volts if the input voltage, V, is equal to -7V? Assume that when a diode is turned on the voltage across it will be 0.7V, and for the batteries use V1 = 7.3V and V2 = 8.4V. Also use R = 1.2kΩ and RL = 17.6kΩ



$V_o = \frac{V \cdot RL}{RL + R} = \frac{-7 \cdot 17600}{17600 + 1200} = \boxed{-6.55V}$

* (27) A full-wave diode rectifier circuit is driven by a 60Hz sine wave with a peak value of 19V. If the load resistance this circuit drives is 8.8kΩ and the ripple voltage at the output is 0.34Vpp, then during what percentage of each cycle does the diode conduct?

$\Delta t = T/4 - t_1$

$t_1: V\sin(2\pi f t_1) = V - V_{pp}$

$19\sin(2\pi 60 t_1) = 19 - 0.34$

$t_1 = \frac{1 \cdot \sin^{-1}(18.66/19)}{2 \times 60 \times 180} = 0.003666 = 3.66\,msec$

$\Delta t = \frac{t}{4} - t_1 \rightarrow \frac{1}{60 \cdot 4} - 0.00366 = 0.0041666667 - 0.00366 = 0.0005067$

$t = 2\Delta t = 2 \cdot 0.5067 = 1.0134\,ms \qquad \frac{1.0134}{(60)^{-1}} \times 100 = 6080.4$ Actual answer = 6.02

(28) If a MOSFET with W = 2.2μm and L = 1.5μm is biased in saturation, what is the gate-to-source capacitence, Cgs, in femtofarads? Assume the gate dielectric is silicon dioxide with tox = 56.7 angstroms.

$C_{ox} = \frac{3.9 \times 8.85 \cdot 10^{-12}}{56.7 \times 10^{-10}} = 0.006087 \qquad \frac{2}{3} \cdot 0.006087 \cdot (2.2 \times 10^{-6}) \cdot (1.5 \cdot 10^{-6}) = 1.339 \times 10^{-14} \rightarrow \boxed{13.39 \text{ femtofarads}}$

(29) If an PMOS FET with W = 52μm and L = 2.6μm is biased in triode with |Vgs| = 1 and Vds = 0V, what is the on-resistance of this MOS switch in Ohms? VTP = -0.5V, k'p = 40μA/V²

$\frac{1}{(40 \times 10^{-6})(52/2.6)(1 - 1 - 0.5|)} = \boxed{2500\Omega}$

(30) If a NMOS FET W/L = 73.5 has Vgs = 1.19 and Vds = 0.17, what is the drain current in microamps? Use VTN = 0.5V, k'n = 100μA/V², λ = 0.

$I_D = k'n\,(W/L)\left[(V_{gs} - V_{TN})V_{ds} - \frac{1}{2}V_{ds}^2\right] \qquad (100 \times 10^{-6})(73.5)\left[(1.19 - 0.5)0.17 - \frac{1}{2}(0.17)^2\right] = \boxed{755.9}$

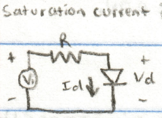
Compare $(1.19 - 0.5) = 0.69 > 0.17 \rightarrow$ triode formula

(31) A full-wave diode rectifier circuit is driven by a 60 Hz sine wave with a peak value of 18V. If the load resistance this circuit drives is 8.8kΩ and a 436μF filter capacitor is used, then what is the ripple voltage at the output in millivolts peak-to-peak?

$V_r = \frac{V_P}{2 f R_L V_{pp}} = \frac{18}{2(60)(8800)V_{pp}} = 436\mu F \rightarrow \frac{18}{0.000436} = 1056000\,V_{pp} \rightarrow \frac{41284.40367}{1056000} = V_{pp} \rightarrow$

$0.039095\,V \rightarrow \boxed{39.095 mV}$

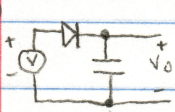
(24) If the DC bias current, Id, in the diode circuit shown is equal to 55.2mA then what is the voltage across the diode, Vd, in millivolts? Saturation current is 1femtoamp, Vt = 26mV.



$I_d = I_s\left[e^{Vd/Vt} - 1\right] \Rightarrow (1 \times 10^{-15})\left[e^{Vd/0.026} - 1\right] = 0.0552 \rightarrow$

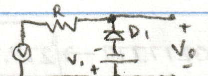
$\ln\left[e^{Vd/0.026} - 1\right] = (\ln(5.52 \times 10^{13})) \rightarrow \frac{Vd}{0.026} = 31.64198 \qquad Vd = 0.82269\,V \rightarrow \boxed{822.69 mV}$

(25) For the diode circuit shown, what will the output, Vo, be in volts if the input, V, is a sine wave with an amplitude equal to 6.1V? Assume that when the diode is turned on the voltage across it will be 0.7V.



$6.1V - 0.7V = \boxed{5.4V}$

(26) For the diode circuit shown, what will be the output voltage, V_o, be in volts if the input voltage, V, is equal to -2V? Assume that when the diode is turned on the voltage across it will be 0.7V, and for the battery use $V_1 = 8.4V$. Also use $R = 5.9k\Omega$.



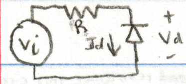
This circuit doesn't have a current going through the diode, so $\boxed{V_o = -2V.}$

(27) A half-wave diode rectifier circuit is driven by a 60Hz sine wave with a peak value of 14V. If the load resistance this circuit drives is $1.6k\Omega$ and $385\mu F$ filter capacitor is used, then what is the ripple voltage at the output in millivolts peak-to-peak?

$$\frac{14V}{0.000385} = (60 \cdot 1600 \cdot V_{pp}) \rightarrow \frac{36363.63636}{(60 \cdot 1600)} = V_{pp} \longrightarrow V_{pp} = 0.3787878V \rightarrow \boxed{378.78mV}$$

(31) A half-wave diode rectifier circuit is driven by a 60Hz sine wave with a peak value of 18V. If the load resistance this circuit drives is $4.2k\Omega$ and the ripple voltage at the output is 0.39 peak-to-peak, then during what percentage of each cycle does the diode conduct?

(24) The diode in the circuit shown has a reverse breakdown voltage of $V_Z = 6.6V$ at $I_Z = 8.8mA$ and an incremental resistance of $r_Z = 47\Omega$. If this circuit is used as a simple voltage regulator with Vd as the output voltage, then what will the Load Regulation be in mV/mA if a load resistor is attached? Use $V_i = 17V$ and $R = 543\Omega$.



Current through R: $I = \frac{(V_i - V_Z)}{R} \rightarrow I = \frac{17 - 6.6}{543} = 0.0192A \rightarrow 19.2mA$

$I_L = I - I_Z \rightarrow I_L = 19.2mA - 8.8mA = 10.4mA$

The minimum value of $R_L = \frac{V_Z}{I_L} = \frac{6.6}{10.4mA} =$

$R_L = 634.62\Omega$

Change in output $V_o = (R_Z)(-1mA) \rightarrow -47mV$ Load Regulation: $\frac{\Delta V_o}{\Delta I_L} = \frac{-47mV}{1mA} = \boxed{-47\, mV/mA}$

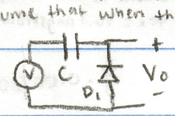
(28) If a MOSFET with $W = 11.2\mu m$ and $L = 1.2\mu m$ is biased in triode, what is the gate-to-source capacitance, Cgs, in femtofarads? Tox = 36.1 angstrom

$\frac{1}{2} \cdot C_{ox} \cdot W \cdot L$ $C_{ox} = \frac{3.9 \cdot 8.85 \cdot 10^{-12}}{36.1 \times 10^{-10}} = 0.00956$

$$\frac{1}{2} \cdot 0.00956 \cdot (11.2 \times 10^{-6}) \cdot (1.2 \times 10^{-6}) = \boxed{64.25 \text{ femtofarads}}$$

(25) For the diode circuit shown, what will the maximum output voltage, Vo, be in volts if the input voltage, V, is a square wave which varies between +3.6V and -8.6V? Assume that when the diode is turned on the voltage across it will be 0.7V.

$3.6V - (-8.6) - 0.7 = \boxed{11.5V}$



(31) A full-wave diode rectifier circuit is driven by a 60Hz sine wave with a peak value of 10V. If the load resistance this circuit drives is $4.4k\Omega$ and the ripple voltage at the output is 0.13 Vpp, then what is the average current in the diode in milliamps?

$$I_{DAVG} = \frac{V_P}{R_L}\left(1 + \pi\left(\sqrt{\frac{V_P}{2V_{PP}}}\right)\right) \rightarrow \frac{10}{4400}\left(1 + \pi\left(\sqrt{\frac{10}{2 \cdot 0.13}}\right)\right) = 0.04655A \rightarrow \boxed{46.55mA}$$

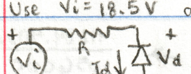
(23) If the DC bias voltage, Vd, across a forward biased PN junction is equal to 732mV then what is the current flowing through this diode, Id, in milliamps? Assume that the saturation current for the diode, Is, is equal to 1 femtoamp. Also assume that the thermal voltage is equal to Vt = 26mV.

$Vd = 732mV = 0.732V$ $Vt = 26mV = 0.026V$

$Is = 1fA = (1 \times 10^{-15})A$

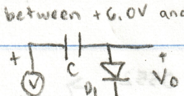
$$Id = Is\left[e^{Vd/Vt} - 1\right] \quad Id = (1 \times 10^{-15})\left[e^{0.732/0.026} - 1\right] = 0.0016867 = \boxed{1.686mA}$$

(24) The diode in the circuit shown has a reverse breakdown voltage $V_Z = 6.8V$ at $I_Z = 1.4mA$ and an incremental resistance of $r_Z = 97\Omega$. If this circuit is used as a simple voltage regulator with Vd as the output voltage, then what will the Line Regulation be in mV/V? Use $V_i = 18.5V$ and $R = 731\Omega$.



$$\Delta V_o = \frac{r_Z}{(r_Z + R)} = \frac{97}{(97 + 731)} = 0.117149 \rightarrow \boxed{117.149\, mV/V}$$

(25) For the diode circuit shown, what will the maximum output voltage, Vo, be in volts if the input voltage, v, is a square wave which varies between +6.0V and -7.2V? Assume that when the diode is turned on the voltage across it will be 0.7V.



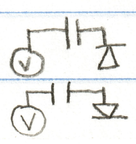
$\boxed{0.7}$

(30) If a NMOS FET with $W/L = 27.6$ has $V_{gs} = 0.95$ and $V_{ds} = 1.53$, what is the drain current in microamps? Use $V_{TN} = 0.5V$, $k'n = 100\mu A/V^2$, $\lambda = 0.22$

$$I_D = \frac{1}{2}k'n(W/L)(V_{gs} - V_{tn})^2(1 + \lambda V_{DS}) \longrightarrow \frac{1}{2}(100 \times 10^{-6})(27.6)(0.95 - 0.5)^2(1 + (0.22 \cdot 1.53)) = 0.000373_5 A = \longrightarrow$$

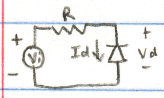
$\boxed{373.5\mu A}$

SQUARE WAVE



	max	min
(upper circuit)	eqn	-0.7
(lower circuit)	0.7	eqn

24 The diode in the circuit shown has a reverse breakdown voltage $V_Z = 6.0V$ at $I_Z = 7.9mA$ and an incremental resistance of $r_Z = 95\Omega$. What will the voltage across the diode, V_d, be in volts if $V_i = 11.6V$ and $R = 602\Omega$?



$$V_{Z0} = V_Z - I_Z r_Z$$

$$6 - (0.0079)(95) = 5.2495V$$

$$V_d = \left[\frac{V_i - V_{Z0}}{R + r_Z}\right] r_Z + V_{Z0} \rightarrow \left[\frac{11.6 - 5.2495}{602 + 95}\right] 95 + 5.2495$$

$$\boxed{V_d = 6.12V}$$