WS 20.2 Pulse modulator waveforms

This Mathcad 14 worksheet is designed to accompany the author's book "Microwave and RF Vacuum Electronic Power Sources", Cambridge University Press (2018). The section, equation, and figure numbers refer to the corresponding sections, equations, and figures in the book. Data input fields are highlighted in yellow and output fields are highlighted in green.

This sheet illustrates the properties of pulse modulators (see Section 20.3)

Active-switch modulator with a resistive load (Section 20.3.1)

Circuit specification

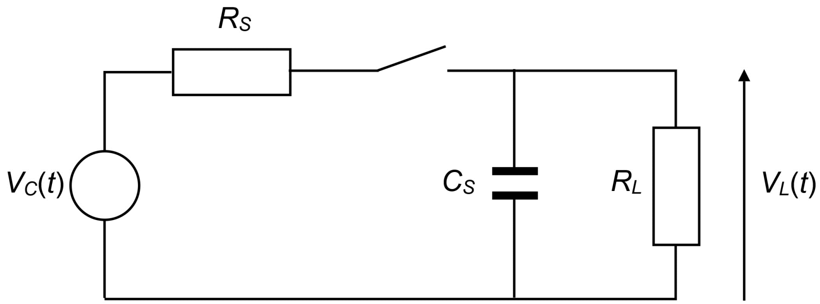
Source impedance $R_S := 2 \cdot k\Omega$

Load impedance $R_L := 10 \cdot k\Omega$

Pulse length $t_1 := 10 \cdot \mu s$

Rise time $t_r := 0.5 \cdot \mu s$

Droop $Droop := 0.9$



(a)

$R_1 := \frac{R_L \cdot R_S}{R_L + R_S}$ $R_1 = 1.67 \cdot k\Omega$ $\alpha := \frac{-\ln(\text{Droop})}{t_1}$ $\frac{1}{\alpha} = 94.9\,\mu s$

$C_S := \frac{t_r}{R_1}$ $C_S = 300\,pF$ $\alpha_1 := \frac{1}{R_1 \cdot C_S}$ $\frac{1}{\alpha_1} = 0.50\,\mu s$

$C_0 := \frac{1}{(R_L + R_S) \cdot \alpha}$ $C_0 = 0.008 \cdot \mu F$ $\alpha_2 := \frac{1}{R_L \cdot C_S}$ $\frac{1}{\alpha_2} = 3.00\,\mu s$

$$V_L(t) := \left| \begin{array}{l} V_L(t) \leftarrow \left[\frac{R_L}{R_L + R_S} \cdot \exp(-\alpha \cdot t) \cdot (1 - \exp(-\alpha_1 \cdot t)) \right] \\ V_L \leftarrow \left| \begin{array}{ll} V_L(t) & \text{if } t < t_1 \\ V_L(t_1) \cdot \exp\left[-\alpha_2 \cdot (t - t_1)\right] & \text{otherwise} \end{array} \right. \\ V_L \end{array} \right.$$

Equation 20.6

Equation 20.8

$t := 0, 0.01 \cdot t_1 .. 4 \cdot t_1$

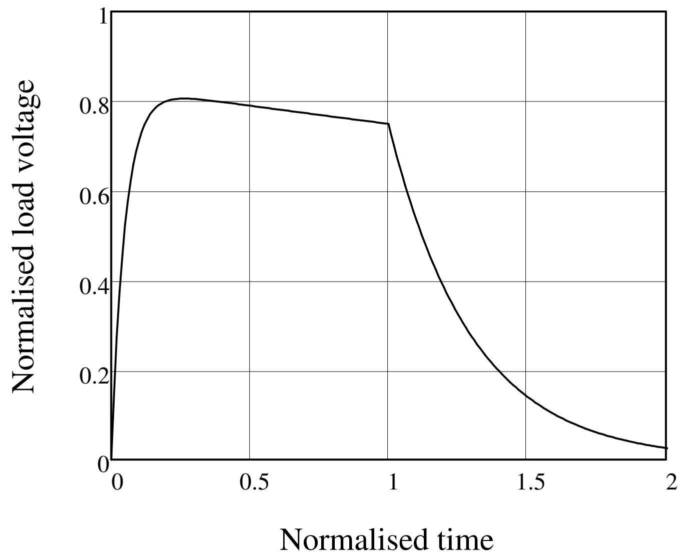
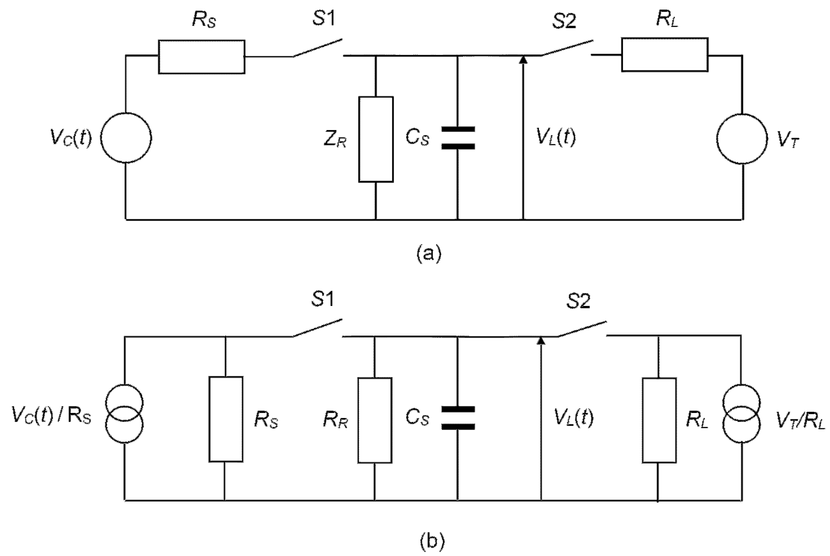


Figure 20.8(b)

Active-switch modulator with a biased diode load (Section 20.3.2)

Define the parameters of the circuit



$R_S := 1\cdot k\Omega$ $\quad R_R := 5\cdot k\Omega$ $\quad R_L := 200\cdot\Omega$

$C_0 := 1\cdot\mu F$ $\quad C_S := 300\cdot pF$ $\quad V_T := 0.7$

Pulse length $\quad t_2 := 10\cdot\mu s$

i) From t = 0 to t = t_1 when $V_L = V_T$

$$R_1 := \frac{R_R\cdot R_L}{R_R + R_L}$$ Equation 20.12

$$\alpha := \frac{1}{(R_1 + R_S)\cdot C_0}$$ Equation 20.11

$$\frac{1}{\alpha} = 94.9\cdot\mu s$$

$$\alpha_1 := \frac{R_R + R_S}{R_R\cdot R_S\cdot C_S}$$ Equation 20.14

$$\frac{1}{\alpha_1} = 0.25\cdot\mu s$$

$$V_{L1}(t) := \frac{R_R}{R_R + R_S}\cdot\exp(-\alpha\cdot t)\cdot\left(1 - \exp\left(-\alpha_1\cdot t\right)\right)$$ Equation 20.13

ii) From $t = t_1$ until $t = t_2$

$$R_2 := \left(\frac{1}{R_S} + \frac{1}{R_R} + \frac{1}{R_L}\right)^{-1}$$ Equation 20.16

$$\alpha_2 := \frac{1}{R_2 \cdot C_S}$$ Equation 20.17 $\frac{1}{\alpha_2} = 0.0 \cdot \mu s$

$$t_0 := \frac{1}{\alpha_1} \qquad t_1 := \mathrm{root}\left(V_{L1}(t_0) - V_T, t_0\right)$$ $t_1 = 0.459 \cdot \mu s$

$$V_{L2}(t) := \left(\frac{1}{R_S} \cdot \exp(-\alpha \cdot t) + \frac{V_T}{R_L}\right) \cdot R_2 \cdot \left[1 - \exp\left[-\alpha_2 \cdot \left(t - t_1\right)\right]\right] + V_T \cdot \exp\left[-\alpha_2 \cdot \left(t - t_1\right)\right]$$ Equation 20.15

iii) From $t = t_2$ until $t = t_3$ when $V_L = V_T$

$$\alpha_3 := \frac{1}{R_1 \cdot C_S}$$ Equation 20.20 $\frac{1}{\alpha_3} = 0.058 \cdot \mu s$

$$V_{L3}(t) := \frac{V_T \cdot R_R}{R_L + R_R} \cdot \left[1 - \exp\left[-\alpha_3 \cdot \left(t - t_2\right)\right]\right] + V_{L2}(t_2) \cdot \exp\left[-\alpha_3 \cdot \left(t - t_2\right)\right]$$ Equation 20.19

iv) From $t = t_3$ onwards

$$\alpha_4 := \frac{1}{R_R \cdot C_S}$$ Equation 20.22 $\frac{1}{\alpha_4} = 1.5 \cdot \mu s$

$$t_3 := \mathrm{root}\left(V_{L3}(t_2) - V_T, t_2\right)$$ $t_3 = 10.037 \cdot \mu s$

$$V_{L4}(t) := V_T \cdot \exp\left[-\alpha_4 \cdot \left(t - t_3\right)\right]$$ Equation 20.21 $V_{L1}(t_1) = 0.7$ $V_{L2}(t_2) = 0.724$ $V_{L3}(t_3) = 0.7$

Construct the whole pulse

$$V_L(t) := \begin{cases} V_{L1}(t) & \text{if } t < t_1 \\ V_{L2}(t) & \text{if } t \ge t_1 \wedge t < t_2 \\ V_{L3}(t) & \text{if } t \ge t_2 \wedge t < t_3 \\ V_{L4}(t) & \text{otherwise} \end{cases}$$

$$t := 0, 0.001 \cdot t_2 .. 2 \cdot t_2$$

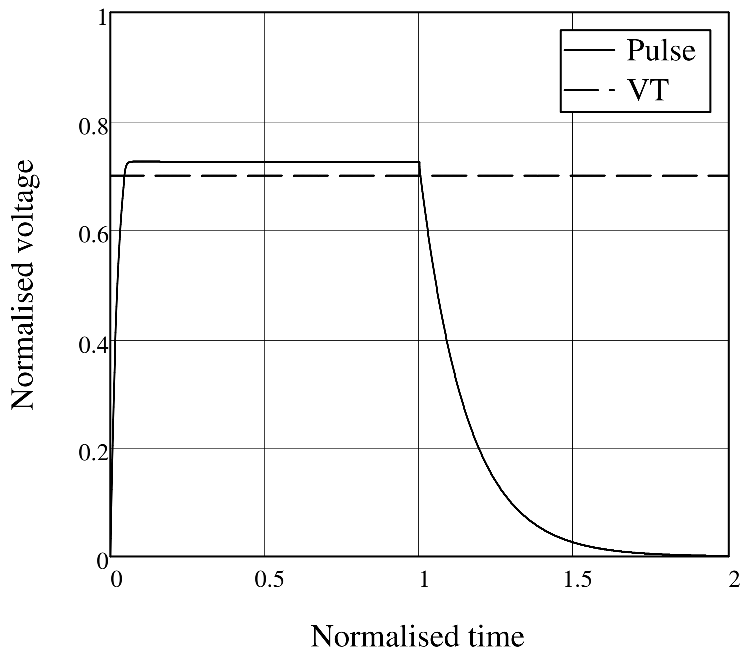


Figure 20.10