Pulse Generators

Any of the following calculations may be asked in the midterms/exam.

1. a) A capacitor of what capacitance forms an RC circuit of 1 s time constant with a 10 MΩ resistor?
   b) What percentage of the initial voltage will remain after 2 seconds between the plates of the capacitor when this RC circuit is discharged?

2. The time constant of an RC circuit is 0.6 seconds.
   a) To what voltage will the capacitor be charged in 1 s if the charging voltage is 100 V?
   b) In what time will the capacitor discharge to the half of the calculated voltage?

3. To what voltage should the 20 μF capacitor of a defibrillator be charged so that the energy of the defibrillating pulse is 160 J.

4. What is the pulse duration of a monostable multivibrator, if the time constant of the switch circuit is 5 ms and the $U_{trigger}$ switch voltage is level is $U_0/2$?

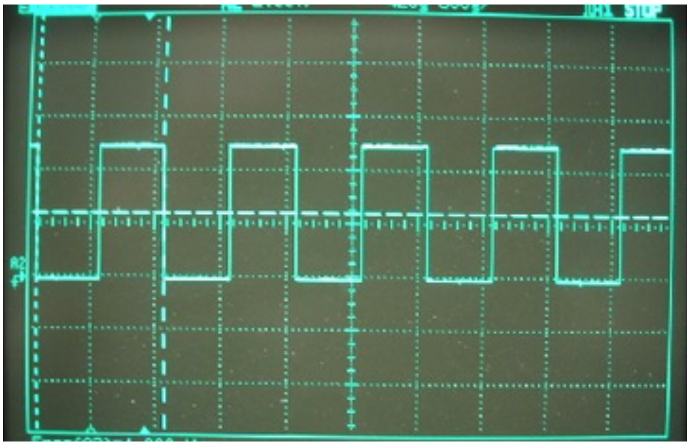
5. By what factor does the energy of a capacitor change if it is charged to double voltage?

6. To how many times greater voltage should a capacitor be loaded so that its energy is doubled?

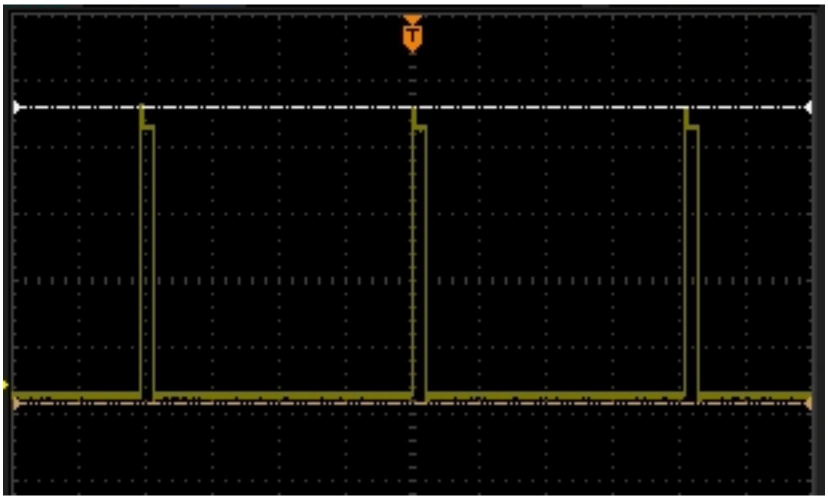
7. A smaller and a bigger capacitor is loaded to the same voltage. The capacitance of the bigger capacitor is twice as much as that of the smaller one. How many times greater is the energy stored in it?

8. The duration of the square pulse of a pacemaker is 1 ms while its voltage amplitude is 4 V. Give the energy of a pulse if the resistance of the stimulated area is 800 Ω.

9. The horizontal division of the oscilloscope shown in the figure is 500 ms/DIV while its vertical division is 1 mV/DIV. The resistance of the stimulated area is 2 kΩ. Find
   a) the duration of the active and
   b) the passive state,
   c) the time period,
   d) the duty cycle ("space factor"),
   e) the frequency,
   f) the amplitude, and
   g) the energy of a pulse.
   h) What are the time constants of the switch circuits if the switch voltage is $U_0/10$?



10. The horizontal division of the oscilloscope shown in the figure is 10 ms/DIV while its vertical division is 0,5 V/DIV. The resistance of the stimulated area is 0,8 kΩ. Find
a) the duration of the active and
b) the passive state,
c) the time period,
d) the duty cycle,
e) the frequency,
f) the amplitude, and
g) the energy of a pulse.
h) What are the time constants of the switch circuits if the switch voltage is $U_0/5$?



11. The switch circuit for the active state of an astable multivibrator consists of a 1 kΩ resistor and a 1 μF capacitor while that of its passive state consists of a 10 kΩ resistor and a 100 μF capacitor. The switch voltage is $U_0/4$ for both states; the pulse amplitude is 2 V; the resistance of the stimulated area is 2,5 kΩ. Calculate
a) the duration of the active state and
b) the passive state,
c) the time period,
d) the frequency,
e) the duty cycle, and
f) the energy of a pulse.

12. For how long does a pacemaker work if a single pulse carries 4 μC charge and it contains a 500 mAh battery with an efficiency of 40%? Be the average heart frequency 72/minute.

13. At least how many mAh battery is required to operate a pacemaker for 10 years if the average current during its 2,5 ms pulses is 1,6 mA? The efficiency of the battery is 50%, and the average heart rate is 75/min.

14. The duration of the active state of an astable multivibrator is 2 ms while that of its passive state is 18 ms.
a) Find the duty cycle.
b) Find the frequency.

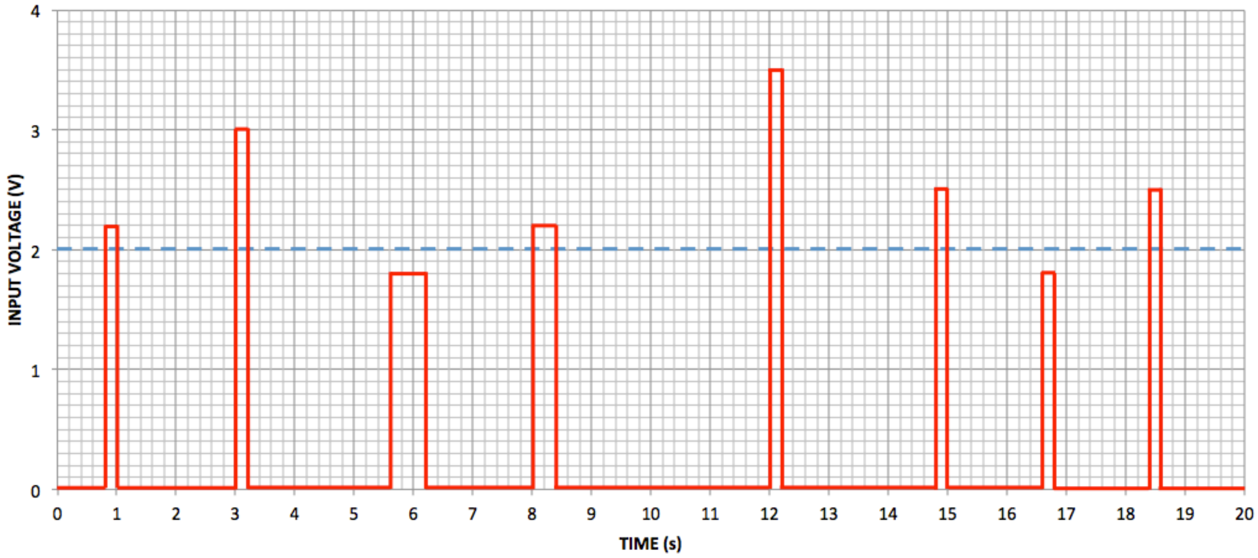
15. The time period of an astable multivibrator is 20 ms, its duty cycle is 5%. Find the duration of the passive state.

16. The frequency of an astable multivibrator is 10 Hz, its duty cycle is 10%. Find the duration of the active state.

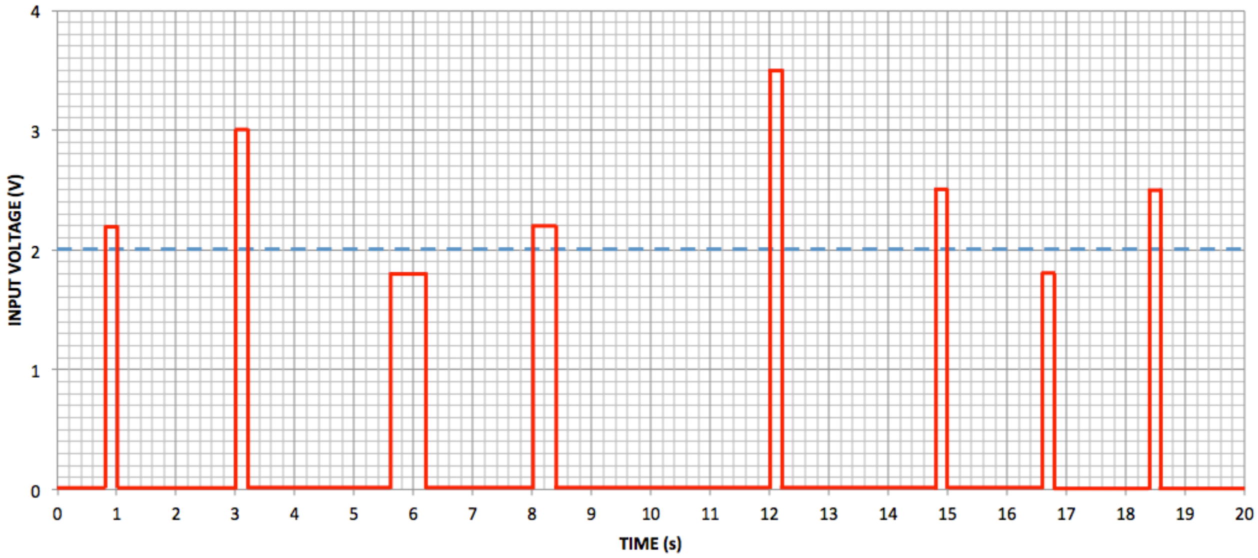
17. What is the maximum count of a binary counter consisting of eight bistable multivibrators?

18. At least how many bistable multivibrators are needed to build a binary counter if the maximum count we want to register is one thousand?

19. The graph below shows the input voltage of a monostable multivibrator as function of time. The voltage threshold of the multivibrator is 2 V and it is sensitive only for the trailing edge of the input voltage signal. The duration of the active state is 0.6 s, the voltage of its active state is 2.5 V while that of its passive state is 0 V. Plot the output voltage as function of time.



20. The graph below shows the input voltage of a bistable multivibrator as function of time. The voltage threshold of the multivibrator is 2 V and it is sensitive only for the trailing edge of the input voltage signal. The voltage of its active state is 2.5 V while that of its passive state is 0 V, the multivibrator is initially in the passive state. Plot the output voltage as function of time.



Formulæ

$I = \frac{\Delta q}{\Delta t}$ (electric current)

$U = \Delta \phi = \frac{\Delta E}{\Delta q}$ (voltage)

$R = \frac{U}{I}$ (resistance)

$P = \frac{\Delta E}{\Delta t}$ (power)

$P_{el} = UI = \frac{U^2}{R} = I^2 R$ (electric power)

$E_C = \frac{1}{2} C U^2$ (energy stored in a capacitor)

$\tau = RC$ (time constant of an RC-circuit)

$U = U_{t=\infty} \cdot \left(1 - e^{-\frac{t}{\tau}} \right)$ (voltage of capacitor during charging an RC-circuit)

$U = U_{t=0} \cdot e^{-\frac{t}{\tau}}$ (voltage of capacitor during discharging an RC-circuit)

$T_{AMV} = t_A + t_P$ (time period of an astable multivibrator)

$f = \frac{1}{T}$ (frequency)

$D = \frac{t_A}{T_{AMV}} = \frac{t_A}{t_A + t_P}$ (duty cycle or “space factor”)

Solutions

1. a) $\tau = RC \Rightarrow C = \frac{\tau}{R} = \frac{1s}{10^7\Omega} = 10^{-7}F = \underline{\underline{0.1\mu F}}$

   b) $U = U_{t=0} \cdot e^{-\frac{t}{\tau}} \Rightarrow \frac{U}{U_{t=0}} = e^{-\frac{t}{\tau}} = e^{-\frac{2s}{1s}} = 0.135 = \underline{\underline{13.5\%}}$

2. a) $U = U_{t=\infty} \cdot \left(1 - e^{-\frac{t}{\tau}}\right) = 100V \cdot \left(1 - e^{-\frac{1s}{0.6s}}\right) = \underline{\underline{81.11V}}$

   b) $U = U_{t=0} \cdot e^{-\frac{t}{\tau}}$

   $\frac{U}{U_{t=0}} = e^{-\frac{t}{\tau}}$

   $\ln\left(\frac{U}{U_{t=0}}\right) = -\frac{t}{\tau}$

   $t = -\tau \cdot \ln\left(\frac{U_{t=0}}{U}\right) = -0.6s \cdot \ln\left(\frac{1}{2}\right) = \underline{\underline{0.416s}}$

3. $E_C = \frac{1}{2}CU^2 \Rightarrow U = \sqrt{\frac{2 \cdot E_C}{C}} = \sqrt{\frac{2 \cdot 160J}{20 \cdot 10^{-6}F}} = \underline{\underline{4000V}} = 4kV$

4. $U = U_{t=0} \cdot e^{-\frac{t}{\tau}}$

   $\frac{U_{t=0}}{2} = U_{t=0} \cdot e^{-\frac{t}{5ms}}$

   $\frac{1}{2} = e^{-\frac{t}{5ms}}$

   $2 = e^{\frac{t}{5ms}}$

   $\ln 2 = \frac{t}{5ms}$

   $5ms \cdot \ln 2 = t$

   $t = \underline{\underline{3.466ms}}$

5. $U_2 = 2U_1$, consequently:

   $E_{C,1} = \frac{1}{2}C(U_1)^2$

   $E_{C,2} = \frac{1}{2}C(U_2)^2 = \frac{1}{2}C(2U_1)^2 = 4\frac{1}{2}C(U_1)^2 = \underline{\underline{4E_{C,1}}}$, that is, it increases fourfold.

6. $E_{C,2} = 2E_{C,1}$, as well as

$$E_C = \frac{1}{2}CU^2 \Rightarrow U = \sqrt{\frac{2E_C}{C}}$$; consequently:

$$U_1 = \sqrt{\frac{2E_{C,1}}{C}}$$

$$U_2 = \sqrt{\frac{2E_{C,2}}{C}} = \sqrt{\frac{2(2E_{C,1})}{C}} = \sqrt{2}\cdot\sqrt{\frac{2E_{C,1}}{C}} = \underline{\underline{\sqrt{2}\cdot U_1}}$$, that is, it must be charged to a square root two times greater voltage.

7. $C_2 = 2C_1$, consequently:

$$E_{C,1} = \frac{1}{2}C_1U^2$$

$$E_{C,2} = \frac{1}{2}C_2U^2 = \frac{1}{2}(2C_1)U^2 = 2\cdot\frac{1}{2}C_1U^2 = \underline{\underline{2E_{C,1}}}$$, that is, the energy stored in it is twice as much.

8. $$P_{el} = \frac{U^2}{R} = \frac{(4V)^2}{800\Omega} = 0.02W$$

$$P = \frac{\Delta E}{\Delta t} \Rightarrow \Delta E = P\cdot\Delta t = 0.02W\cdot 0.001s = 2\cdot 10^{-5}J = \underline{\underline{20\mu J}}$$

9. a) $t_A = 1DIV\cdot 500ms/DIV = 500ms = \underline{\underline{0.5s}}$

b) $t_P = 1DIV\cdot 500ms/DIV = 500ms = \underline{\underline{0.5s}}$

c) $T_{AMV} = t_A + t_P = 0.5s + 0.5s = \underline{\underline{1s}}$

d) $D = \frac{t_A}{T_{AMV}} = \frac{0.5s}{1s} = 0.5 = \underline{\underline{50\%}}$

e) $f = \frac{1}{T_{AMV}} = \frac{1}{1s} = 1s^{-1} = \underline{\underline{1Hz}}$

f) $U = 2.5DIV\cdot 1mV/DIV = \underline{\underline{2.5mV}}$

g) $P_{el} = \frac{U^2}{R} = \frac{(0.0025V)^2}{2000\Omega} = 3.125\cdot 10^{-9}W$

$$P = \frac{\Delta E}{\Delta t} \Rightarrow \Delta E = P\cdot\Delta t = P_{el}\cdot t_A = 3.125\cdot 10^{-9}W\cdot 0.5s = 1.56\cdot 10^{-9}J = \underline{\underline{1.56nJ}}$$

h) Since the duration of both the active and the passive state is 0.5 s the time constant will also be the same:

$$U = U_{t=0} \cdot e^{-\frac{t}{\tau}}$$

$$\frac{U_{t=0}}{10} = U_{t=0} \cdot e^{-\frac{0.5s}{\tau}}$$

$$\frac{1}{10} = e^{-\frac{0.5s}{\tau}}$$

$$10 = e^{\frac{0.5s}{\tau}}$$

$$\ln 10 = \frac{0.5s}{\tau}$$

$$\tau \cdot \ln 10 = 0.5s$$

$$\tau_A = \tau_P = \frac{0.5s}{\ln 10} = \underline{\underline{0.217s}}$$

10. a) $t_A = 0.2DIV \cdot 10ms / DIV = \underline{\underline{2ms}}$

b) $t_P = 3.9DIV \cdot 10ms / DIV = \underline{\underline{39ms}}$

c) $T_{AMV} = t_A + t_P = \underline{\underline{41ms}} = 0.041s$

d) $D = \frac{t_A}{T_{AMV}} = 0.0488 = \underline{\underline{4.88\%}}$

e) $f = \frac{1}{T_{AMV}} = \underline{\underline{24.39Hz}}$

f) $U = 4.2DIV \cdot 0.5V / DIV = \underline{\underline{2.1V}}$

g) $P_{el} = \frac{U^2}{R} = 5.51 \cdot 10^{-3} W$

$\Delta E = P_{el} \cdot t_A = \underline{\underline{11\mu J}}$

h) Active state: $\tau_A = \frac{2ms}{\ln 5} = \underline{\underline{1.243ms}}$; passive state: $\tau_P = \frac{39ms}{\ln 5} = \underline{\underline{24.232ms}}$

11. a) $\tau_A = R_A C_A = 1000\Omega \cdot 10^{-6} F = 10^{-3} s = 1ms$

$$U = U_{t=0} \cdot e^{-\frac{t_A}{\tau_A}}$$

$$\frac{U_{t=0}}{4} = U_{t=0} \cdot e^{-\frac{t_A}{\tau_A}}$$

$$t_A = \tau_A \cdot \ln 4 = 1ms \ln 4 = \underline{\underline{1.386ms}}$$

b) $\tau_P = 1s = 1000ms$

$t_P = \tau_P \cdot \ln 4 = 1000ms \ln 4 = \underline{\underline{1386.294ms}}$

c) $T_{AMV} = t_A + t_P = \underline{\underline{1387.681ms}} = 1.387681s$

d) $f = \frac{1}{T_{AMV}} = \frac{1}{1.387681s} = \underline{\underline{0.721Hz}}$

e) $D = \frac{t_A}{T_{AMV}} = 0.001 = \underline{\underline{0.1\%}}$

f) $P_{el} = \frac{U^2}{R} = 1.6mW$

$\Delta E = P_{el} \cdot t_A = \underline{\underline{2.22\mu J}}$

12. $q_{pulse} = 4 \cdot 10^{-6} C$

$q_{total} = 500mAh \cdot 40\% = 0.5A \cdot 3600s \cdot 0.4 = 720C$

$n_{pulse} = \frac{q_{total}}{q_{pulse}} = \frac{720C}{4 \cdot 10^{-6} C} = 1.8 \cdot 10^8$

$t_{pulse} = \frac{1\min}{72} = \frac{60s}{72} = 0.8333s$

$t = t_{pulse} \cdot n_{pulse} = 0.8333s \cdot 1.8 \cdot 10^8 = 1.5 \cdot 10^8 s \approx \underline{\underline{4.753 years}}$

13. $I = \frac{\Delta q}{\Delta t} \Rightarrow q_{pulse} = I \cdot \Delta t = 0.0016A \cdot 0.0025s = 4 \cdot 10^{-6} C$

$n_{pulse} = 10yr \cdot 365.25 \frac{d}{yr} \cdot 24 \frac{h}{d} \cdot 60 \frac{\min}{h} \cdot 75 \frac{pulses}{\min} = 3.945 \cdot 10^8 pulses$

$q_{total} = q_{pulse} \cdot n_{pulse} = 4 \cdot 10^{-6} C \cdot 3.945 \cdot 10^8 = 1578C$

$q_{battery} = \frac{q_{total}}{\eta} = \frac{1578C}{50\%} = 3156C = \underline{\underline{877mAh}}$

14. a) $D = \frac{t_A}{t_A + t_P} = \frac{2ms}{2ms + 18ms} = 0.1 = \underline{\underline{10\%}}$

b) $f = \frac{1}{T_{AMV}} = \frac{1}{t_A + t_P} = \frac{1}{2ms + 18ms} = \frac{1}{20ms} = \frac{1}{0.02s} = 50 \frac{1}{s} = \underline{\underline{50Hz}}$

15. $D = \frac{t_A}{T_{AMV}}$

$0.05 = \frac{t_A}{20ms}$

$t_A = 0.05 \cdot 20ms = 1ms$

$T_{AMV} = t_A + t_P$

$t_P = T_{AMV} - t_A = 20ms - 1ms = \underline{\underline{19ms}}$

16. $f = \frac{1}{T_{AMV}}$

$T_{AMV} = \frac{1}{f} = \frac{1}{10 \frac{1}{s}} = 0.1s$

$D = \frac{t_A}{T_{AMV}}$

$t_A = D \cdot T_{AMV} = 10\% \cdot 0.1s = 0.01s = \underline{\underline{10ms}}$

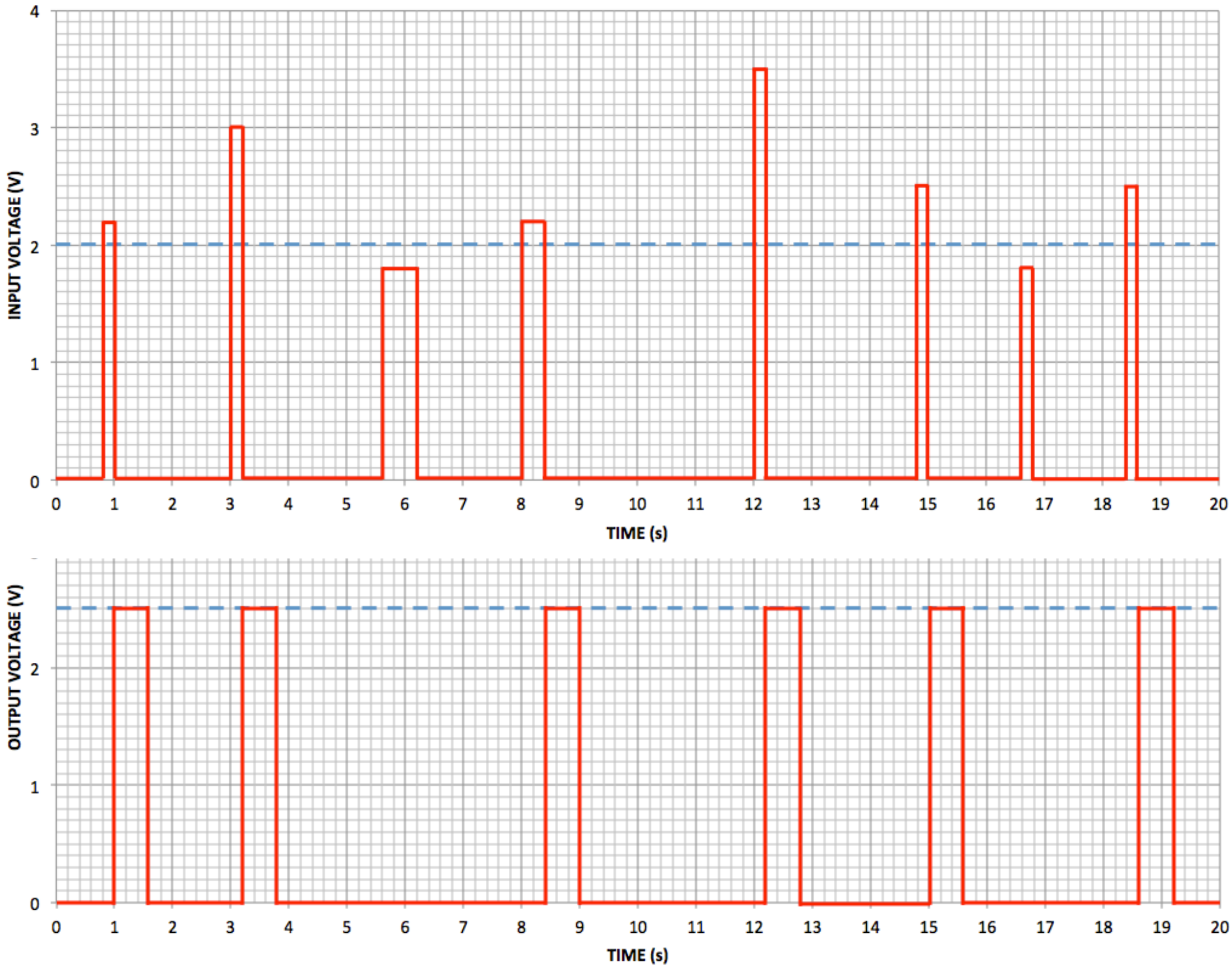
17. $1 \cdot 2^0 + 1 \cdot 2^1 + 1 \cdot 2^2 + 1 \cdot 2^3 + 1 \cdot 2^4 + 1 \cdot 2^5 + 1 \cdot 2^6 + 1 \cdot 2^7 = 2^8 - 1 = \underline{\underline{255}}$

18. $2^n - 1 = 1000$

$2^n = 1001$

$n = \log_2 1001 = 9.9672 \rightarrow \underline{\underline{10}}$

19. To the trailing edge of every over-the-threshold voltage pulse input (at 1 s; 3.2 s; 8.4 s; 12.2; 15 s; and 18.6 s) belongs a 0.6 s long active state. The trailing edges at 6.2 s and 16.8 s belong to below-the-threshold voltage pulses so they will not trigger a response.



20. To the trailing edge of every over-the-threshold voltage pulse input (at 1 s; 3.2 s; 8.4 s; 12.2; 15 s; and 18.6 s) belongs a transition between the active and passive states. The trailing edges at 6.2 s and 16.8 s belong to below-the-threshold voltage pulses so they will not trigger a response.