dummy

Student Group

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Exercise E1 Machine-Vision Strobe: Capacitor Charging and Safe Discharge

[illegible: several overlapping lines of exercise statement text] ... voltage ... 100 ... resistance of ... MΩ ... After ... is disconnected ... charged ... stored energy ... hold ... drop to one half, and be safely discharged before maintenance.

Solution

Data: \begin{align*} C &= 1~{\rm \mu F} \\ W &= 0.1~{\rm J} \\ I_{\rm max} &= 100~{\rm mA} \end{align*}

\begin{align*} u_C(t) &= U_0\left(1-e^{-t/(RC)}\right) \\ u_R(t) &= U_0 e^{-t/(RC)} \end{align*}

Assume the DC charging source is adjusted to the required final capacitor voltage.

\begin{align*} I_{\rm max} &= \frac{U}{R} \end{align*} A practical standard value would be about $4.7~{\rm k\Omega}$.

1. What voltage must be present across the capacitor so that it stores the required energy?

with

\begin{align*} u_C(t) &= U_0 e^{-t/(RC)} \end{align*}

In engineering practice, a capacitor is usually considered fully charged after about 5τ.

\begin{align*} U_0 &= 447.2~{\rm V} \\ RC &= 4.47~{\rm ms} \end{align*}

\begin{align*} W(t) &= \frac{1}{2} C u_C^2(t) \end{align*}

Initial and final values:

\begin{align*} t_{\rm charge} &\approx 5\tau \approx 5 \cdot 4.47~{\rm ms} \approx 22.4~{\rm ms} \end{align*}

\begin{align*} \tau &= RC \approx 4.47~{\rm ms} \end{align*}

\begin{align*} u_C(0) &= 0, & u_C(\infty) &= U_0 \\ u_R(0) &= U_0, & u_R(\infty) &= 0 \end{align*}

\begin{align*} W &= \frac{1}{2} C U^2 \\ U &= \sqrt{\frac{2W}{C}} = \sqrt{\frac{2 \cdot 0.1~{\rm J}}{1~{\rm \mu F}}} = \sqrt{200\,000}~{\rm V} \approx 447.2~{\rm V} \end{align*}

Thus, the capacitor voltage rises exponentially, while the resistor voltage falls exponentially.

The energy stored initially in the capacitor is

\begin{align*} \frac{1}{2} &= e^{-2t/(R_i C)} \\ t &= \frac{R_i C}{2}\ln(2) \end{align*}

\begin{align*} W_0 &= 0.1~{\rm J} \end{align*}

With

After full discharge, the capacitor energy is zero, so the entire initial energy is converted into heat in the resistor.

\begin{align*} R_i C &= 10~{\rm M\Omega} \cdot 1~{\rm \mu F} = 10~{\rm s} \end{align*}

\begin{align*} W_R &= W_0 = 0.1~{\rm J} \end{align*}

we get

In a real design, the resistor must therefore be checked for pulse-load capability.

\begin{align*} t &= \frac{10~{\rm s}}{2}\ln(2) \approx 3.47~{\rm s} \end{align*}

The voltage at this instant is

\begin{align*} u_C &= U_0 \cdot \frac{1}{\sqrt{2}} = \frac{447.2~{\rm V}}{\sqrt{2}} \approx 316.2~{\rm V} \end{align*}