Switched Mode Power Conversion

Capacitors

Devices for Efficient Power Conversion

Switches
Inductors
Transformers
Capacitors

Switched Mode Power Conversion

Capacitors

Capacitors Store Energy

Capacitors Store Energy in an Electric Field

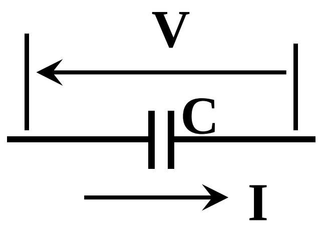
Switched Mode Power Conversion
Capacitors

Capacitors are also used as Switch-Protection Elements

In Switching Aid Networks Capacitors Provide Turn-Off dv/dt Protection

Switched Mode Power Conversion

Capacitors



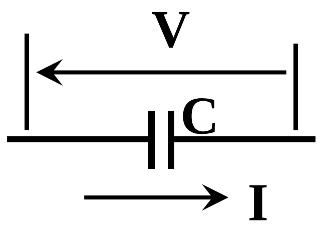
$$I = C\frac{dV}{dt}\ ;\ V(t) = V_I + \frac{1}{C}\int_0^t I\,dt$$

Electrical Circuit Element Equation

V, C, I are Electrical Circuit Quantities

Switched Mode Power Conversion

Capacitors

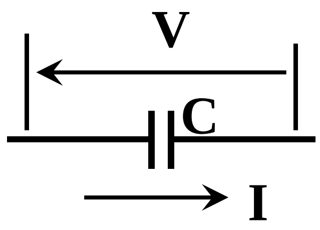


$$V(t) = V_I + \frac{1}{C}\int_0^t I\,dt = V_I + \frac{Q}{C}$$

Capacitor Accumulates Charge to Store Energy

Switched Mode Power Conversion

Capacitors – Charge Balance in AC



$$V(t) = V(t+T)$$

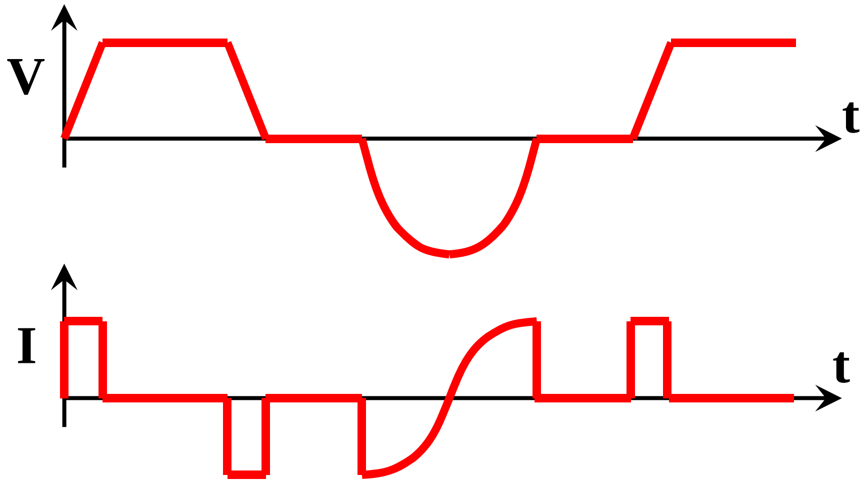
$$\frac{1}{C}\int_{t}^{t+T} I\,dt = 0 \; ; \; \int_{t}^{t+T} I\,dt = 0$$

In Periodic AC Application Net Charge Accumulation Per Cycle is Zero

Switched Mode Power Conversion

Capacitors

$$V(t) = V(t+T)$$

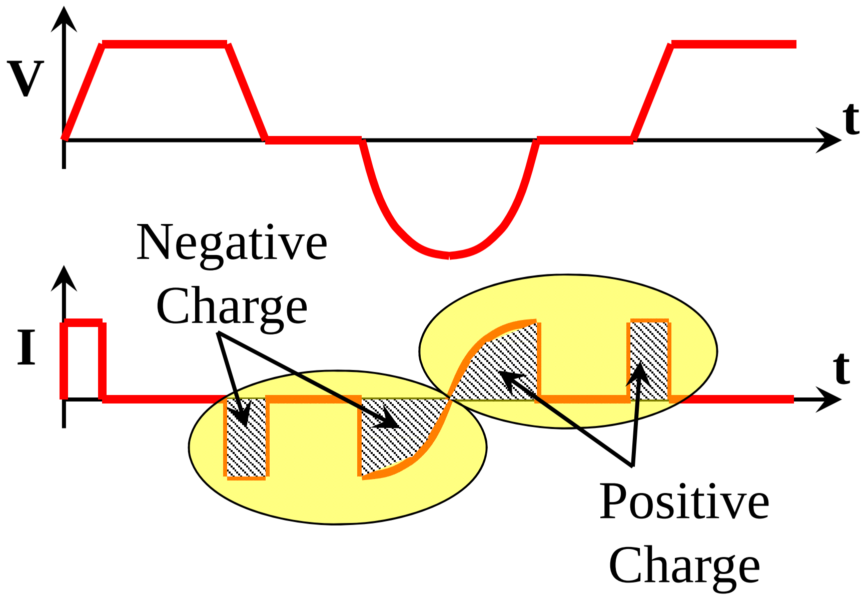


Capacitor Current is Proportional to dV/dt

Switched Mode Power Conversion

Capacitors

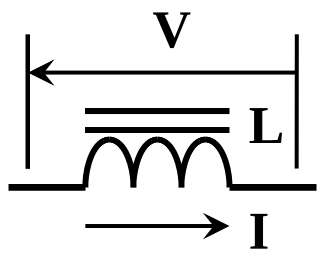
$$V(t) = V(t+T)$$



Charge Balance

Switched Mode Power Conversion

Inductor – Flux Balance



$$I(t) = I(t+T)$$

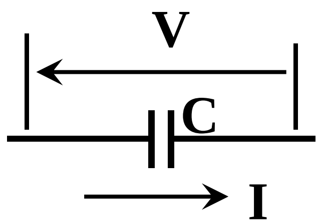
$$\frac{1}{L}\int_{t}^{t+T} V\,dt = 0\ ;\ \int_{t}^{t+T} V\,dt = 0$$

In Periodic AC Application Net Flux Accumulation Per Cycle is Zero

Volt-Sec Balance in an Inductor

Switched Mode Power Conversion

Capacitors

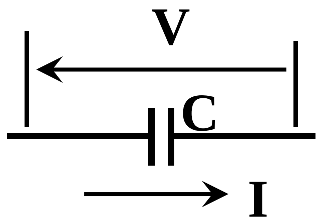


$$V(t) = V_I + \frac{1}{C}\int_0^t I\,dt = V_I + \frac{Q}{C}$$

Capacitor Accumulates Charge to Store Energy

Switched Mode Power Conversion

Capacitors

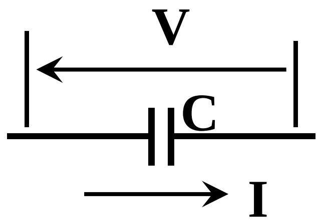


$$E = \frac{1}{2} C V^2$$

Stored Energy Relationship

Switched Mode Power Conversion

Capacitors

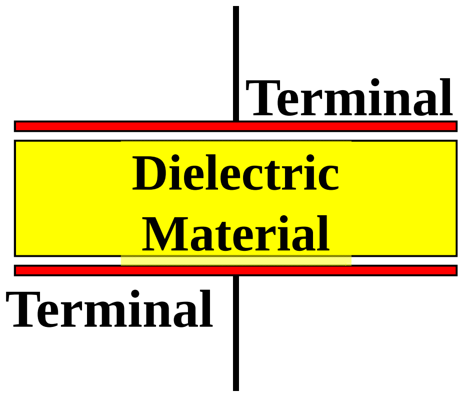


$$E = \frac{1}{2} C V^2$$

Capacitors are
Selected from Manufacturer's
Catalogue

Switched Mode Power Conversion

Capacitors – Construction



$$D = \varepsilon E$$

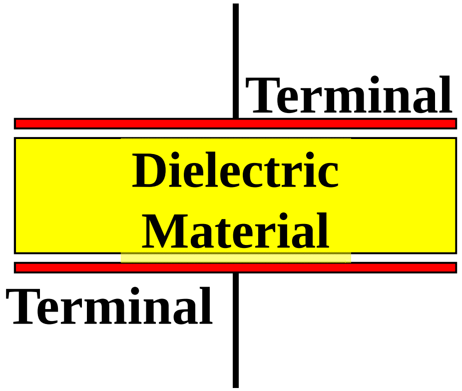
Electric Flux Density: (D)

Dielectric Permittivity: (ε)

Electric Field Intensity: (E)

Switched Mode Power Conversion

Capacitors – Value

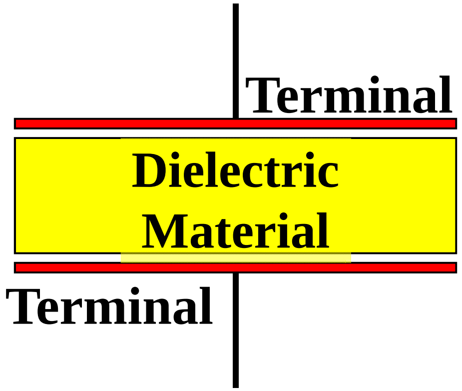


$$\frac{Q}{A} = \varepsilon \frac{V}{d} \qquad \frac{Q}{V} = C = \varepsilon \frac{A}{d}$$

Capacitance is Defined as Charge (Q) per Volt (V)

Switched Mode Power Conversion

Capacitors – Stored Energy

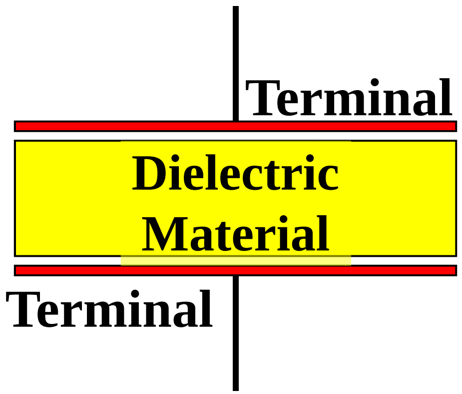


$$E = \int_0^V Q\,dV = \int_0^V CV\,dV = \frac{1}{2}CV^2$$

Energy is Work Done to Separate the Charge Through a Potential of V

Switched Mode Power Conversion

Capacitors – Energy Density

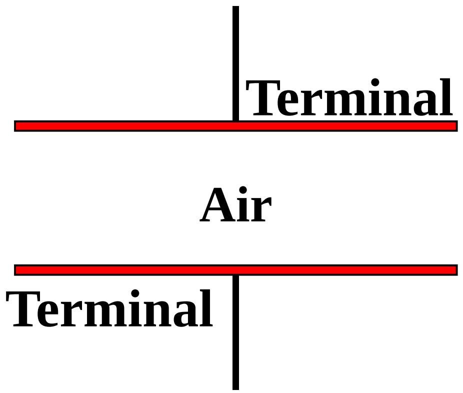


$$E = \frac{1}{2} C V^2 = \frac{1}{2} \frac{\varepsilon A}{d} E^2 d^2 = 0.5 \varepsilon E^2 (\text{Volume})$$

Energy Density is 0.5 ε E^2 Joule/m^3

Switched Mode Power Conversion

Capacitors – Energy Density in Air



$$E = \frac{1}{2} C V^2 = \frac{1}{2} \frac{\varepsilon A}{d} E^2 d^2 = 0.5 \varepsilon E^2 (\text{Volume})$$

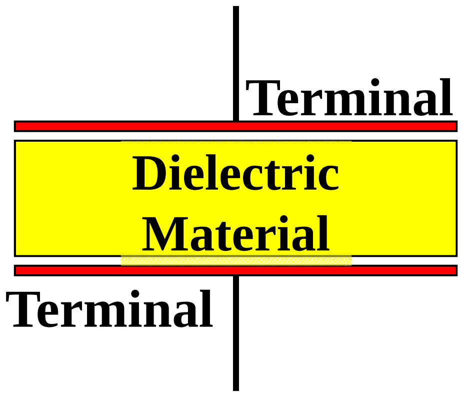
$\varepsilon = 8.854\ 10^{-12}$ F/m

$E = 3\ 10^{6}$ V/m

Energy Density = 39.84 J/m^3

Switched Mode Power Conversion

Capacitors – Energy Density in Polyester



$$E = \frac{1}{2} C V^2 = \frac{1}{2} \frac{\varepsilon A}{d} E^2 d^2 = 0.5 \varepsilon E^2 (\text{Volume})$$

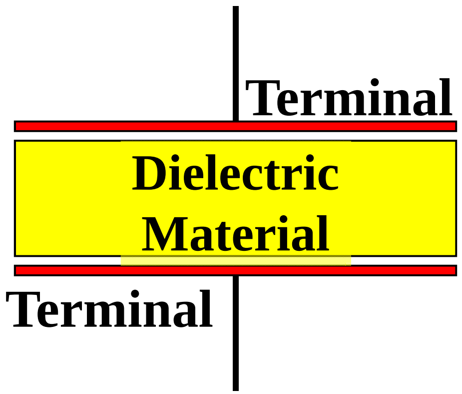
ε = 4 * 8.854 10^{-12} F/m

E = 275 10^{6} V/m

Energy Density = 1.34 MJ/m^3

Switched Mode Power Conversion

Capacitors – Energy Density (Bipolar)



$$E = \frac{1}{2} C V^2$$

MKV

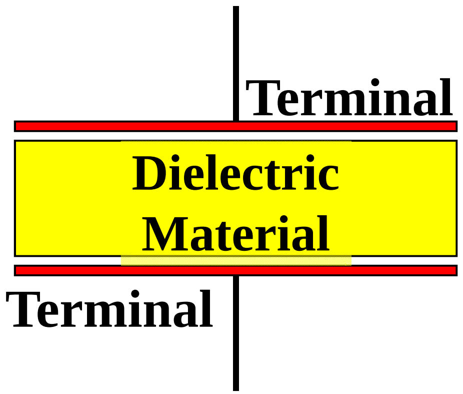
Energy = 65 J

Volume: 0.07 m3

Energy Density: 0.94 kJ/m^3

Switched Mode Power Conversion

Capacitors – Energy Density (Electrolytic)



$$E = \frac{1}{2}CV^2$$

Electrolytic

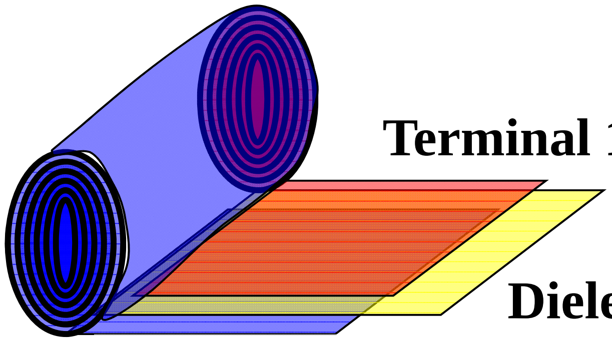
Energy = 243 J

Volume: 0.04 m^3

Energy Density: 6.1 kJ/m^3

Switched Mode Power Conversion

Capacitors – Packaging

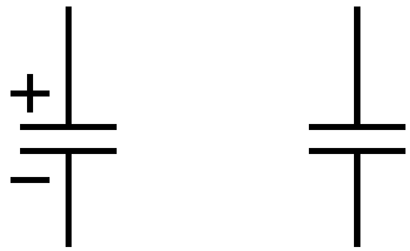


MKV Electrolytic

Cylindrical Geometry

Switched Mode Power Conversion

Types of Capacitors



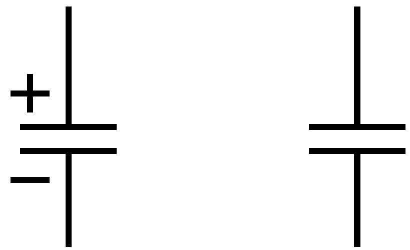
Ultra-Capacitors

Electrolytic – Unipolar Capacitors

Metallised Dielectric – Bipolar Capacitors

Switched Mode Power Conversion

Capacitors - Specification

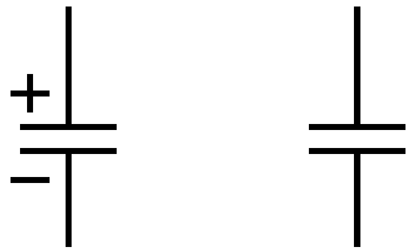


Voltage Rating – Volt

Capacitance Value – Farad

Switched Mode Power Conversion

Capacitors – Life

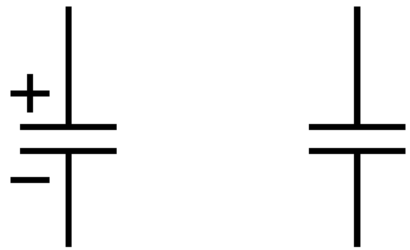


Electrolytic

Standard Life: 105 ^{o}C, 8000 hrs

Switched Mode Power Conversion

Capacitors – Nonidealities



Electrolytic MKV

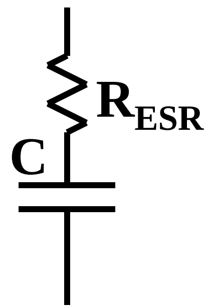
Equivalent Series Resistance: ESR

Equivalent Series Inductance: ESL

Leakage Current: I_{lk}

Switched Mode Power Conversion

Capacitors – Nonidealities

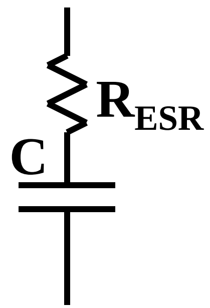


$$P = I^2 R_{ESR}$$

Equivalent Series Resistance: ESR

Switched Mode Power Conversion

Capacitors – Thermal Design



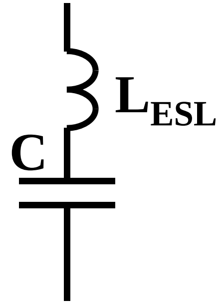
$$\theta_{rise} = P\,R_{th}$$

Thermal Resistance: R_{th} °C/W

Capacitor

Switched Mode Power Conversion

Capacitors – Nonidealities



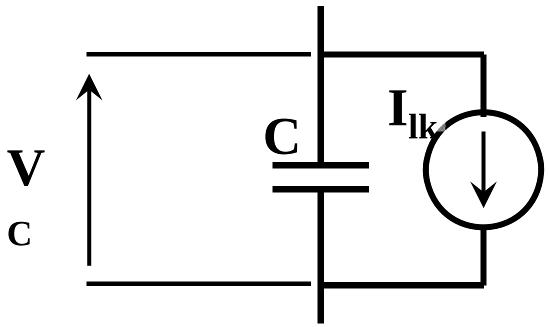
$$\omega_O = \frac{1}{2\pi\sqrt{CL_{ESL}}}$$

Equivalent Series Inductance: ESL

Capacitor

Switched Mode Power Conversion

Capacitors – Nonidealities

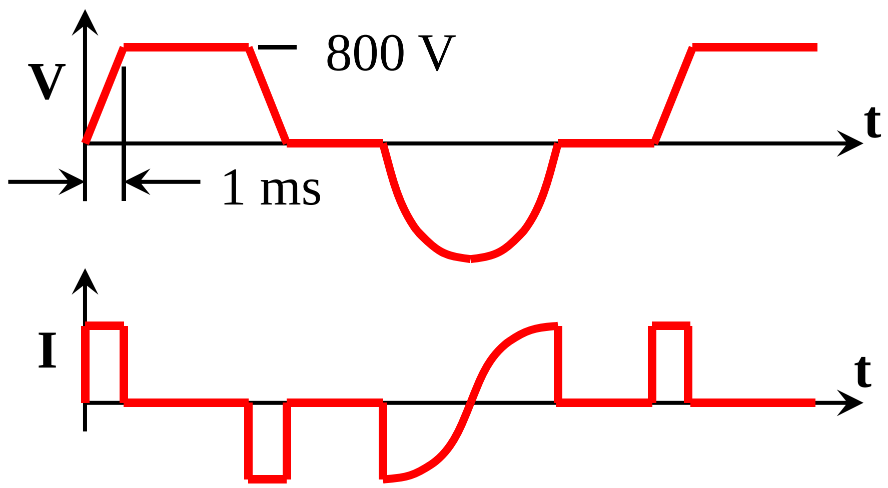


Leakage Current: I_{lk}

Shunt Loss: $V_C\ I_{lk}$

Switched Mode Power Conversion

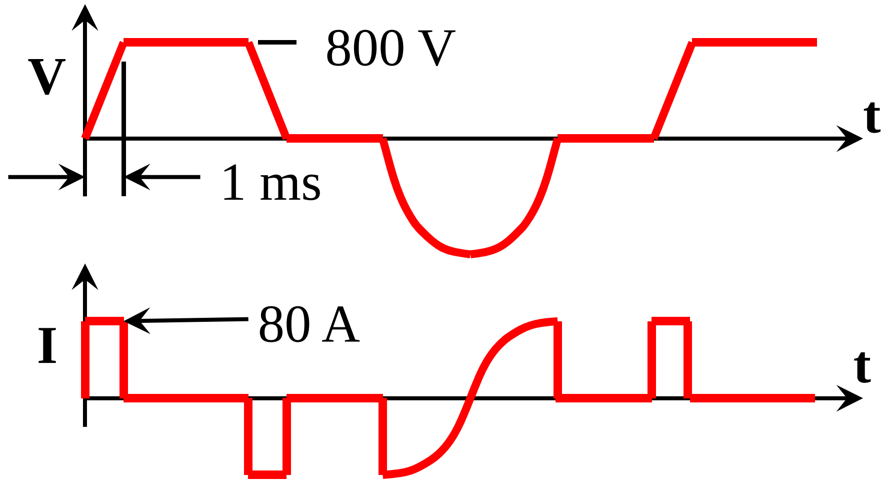
Capacitors – Some Calculations



C = 100 μF

Switched Mode Power Conversion

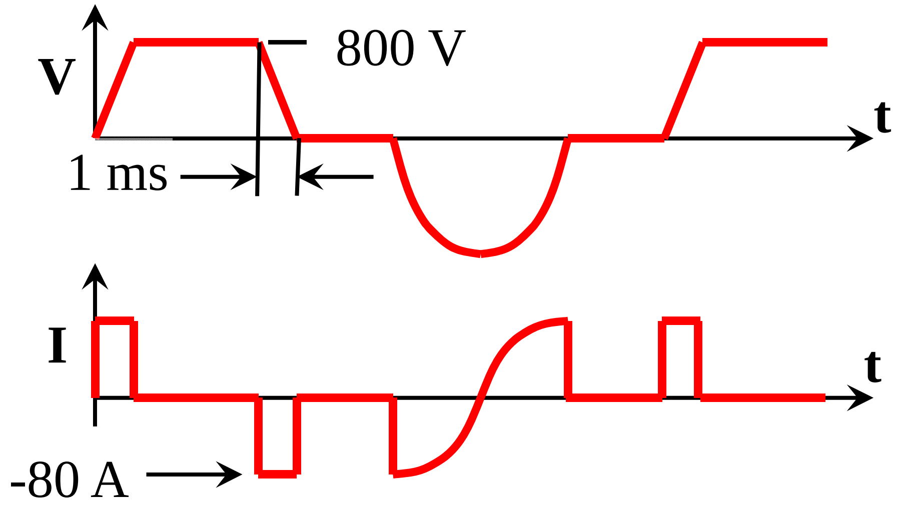
Capacitors – Current Calculations



C = 100 μF

Switched Mode Power Conversion

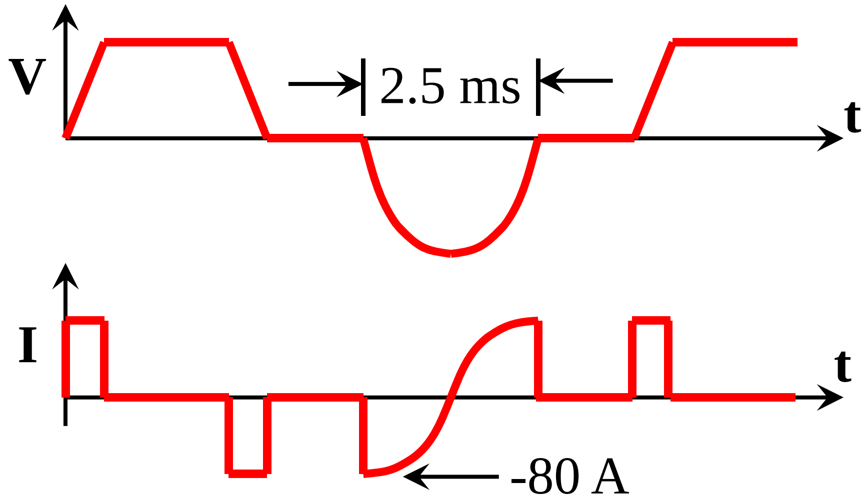
Capacitors



C = 100 μF

Switched Mode Power Conversion

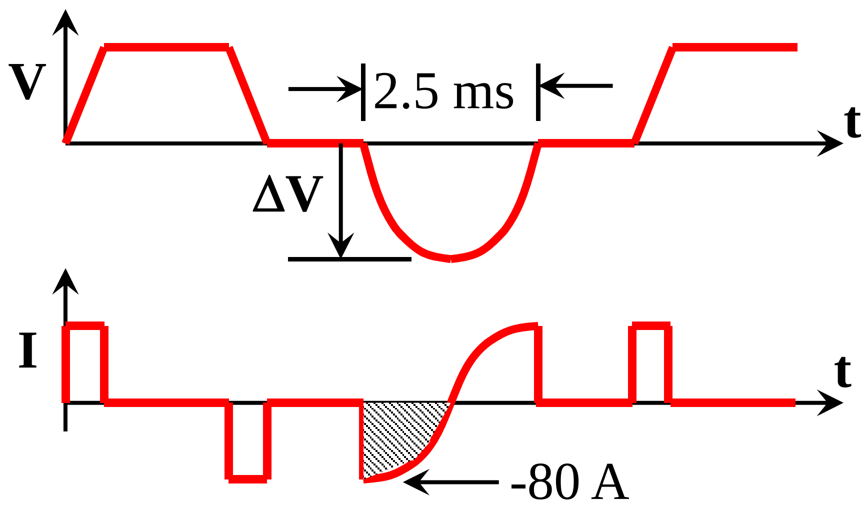
Capacitors – Voltage Calculations



C = 100 μF

Switched Mode Power Conversion

Capacitors – Voltage Calculations

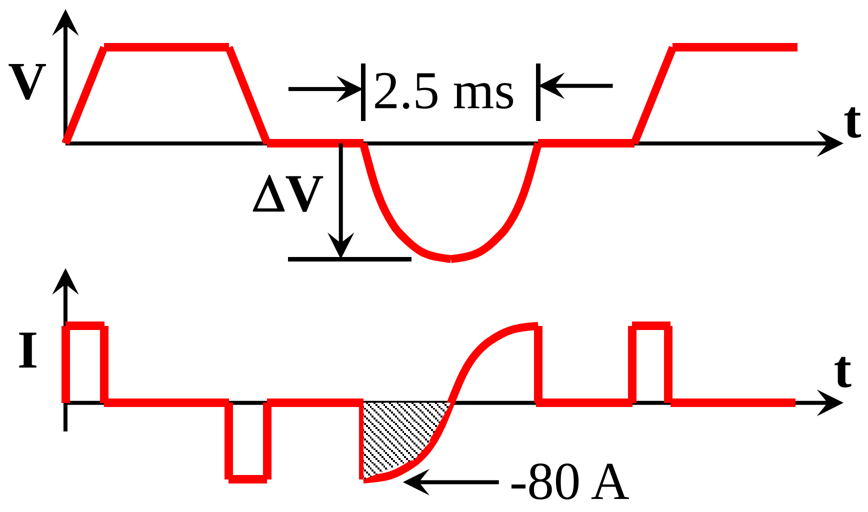


$$\Delta V = \frac{1}{C}\int_{0}^{1.25\,ms} 80\cos(\omega t)\,dt;\ \ \omega = 2*\pi*200\ rad/sec$$

C = 100 μF

Switched Mode Power Conversion

Capacitors – Voltage Calculations

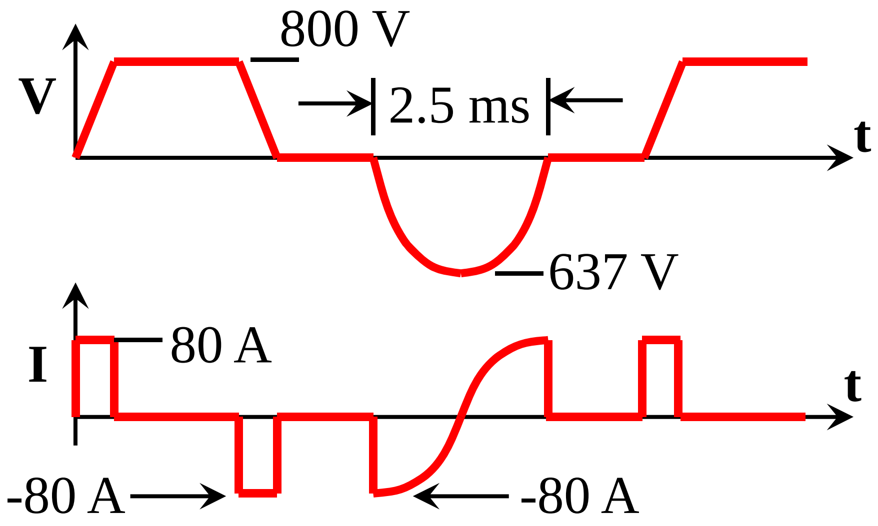


$$\Delta V = \frac{80}{100\mu}\frac{1}{400\pi}\left[\sin(\omega t)\right]_0^{\pi/2} = 637\,V$$

C = 100 μF

Switched Mode Power Conversion

Capacitors – Current & Voltage Calculations

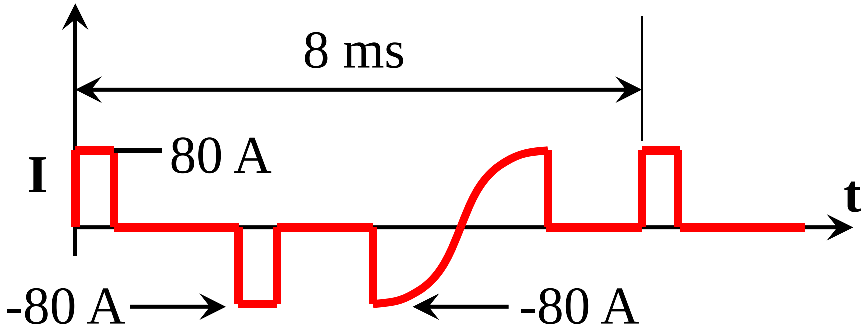


$$\Delta V = 637\,\mathrm{V}$$

C = 100 μF

Switched Mode Power Conversion

Capacitors – Dissipation Calculations



$$I_{rms}^2 = \left[80^2\,0.125\right] + \left[80^2\,0.125\right] + \left[80^2\,0.5\,0.31\right] = 80^2\,0.41$$

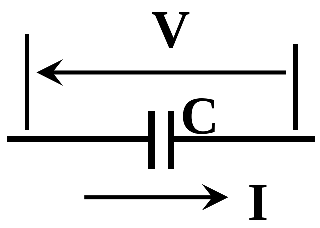
$$P = 80^2\,0.41\,1.4\,m = 3.67\,W$$

MKV

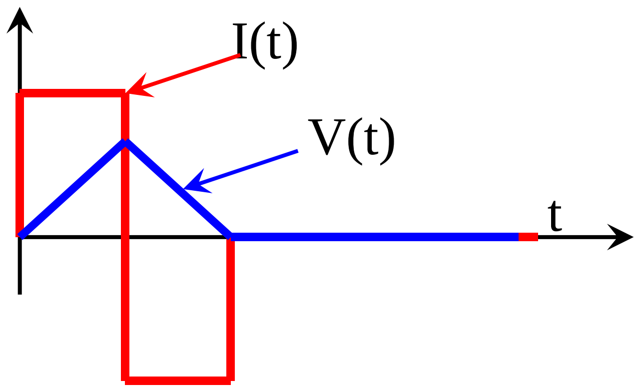
C = 100 μF ; R_S = 1.4 mΩ

Switched Mode Power Conversion

Measurement of C



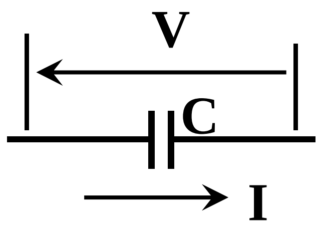
$$I = C\frac{dV}{dt}$$



Pulsed Current and Voltage Rise

Switched Mode Power Conversion

Measurement of C with LCR Meter



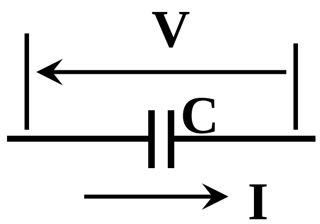
$$\vec{I} = \frac{\vec{V}}{j\omega L}$$

$$\frac{|V|}{|I|} = \frac{1}{\omega C}$$

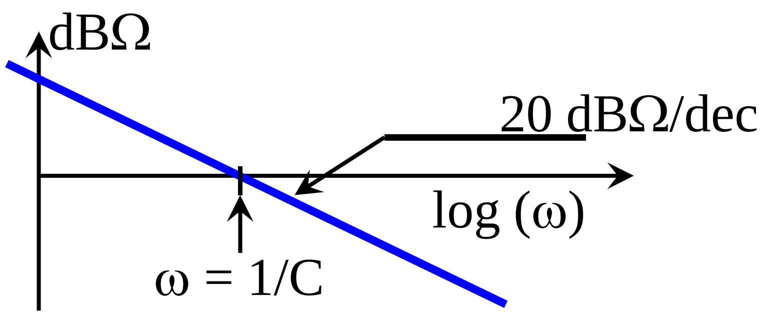
Sinusoidal Voltage and Current

Switched Mode Power Conversion

Impedance as a Function of ω



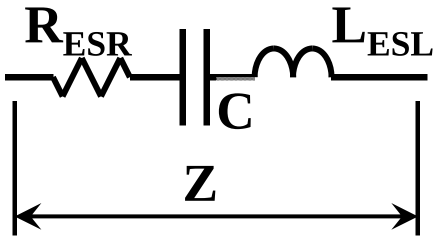
$$\vec{Z} = \frac{\vec{V}}{\vec{I}} = j\omega L$$



Impedance Plot [dBΩ vs log (ω)]

Switched Mode Power Conversion

Impedance with Non-idealities



R_{ESR} = 1.4 mΩ

L_{ESL} = 180 nH

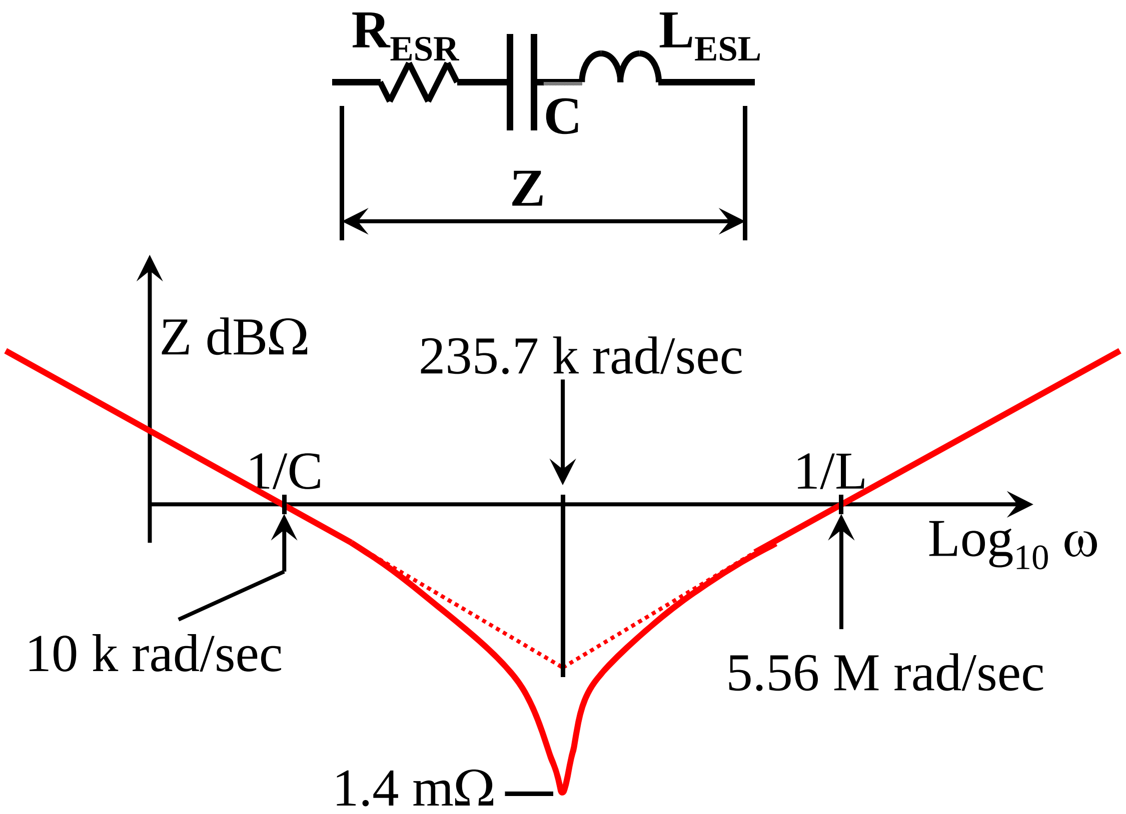
C = 100 μF

ω_O = 235.7 krad/sec

MKV

Switched Mode Power Conversion

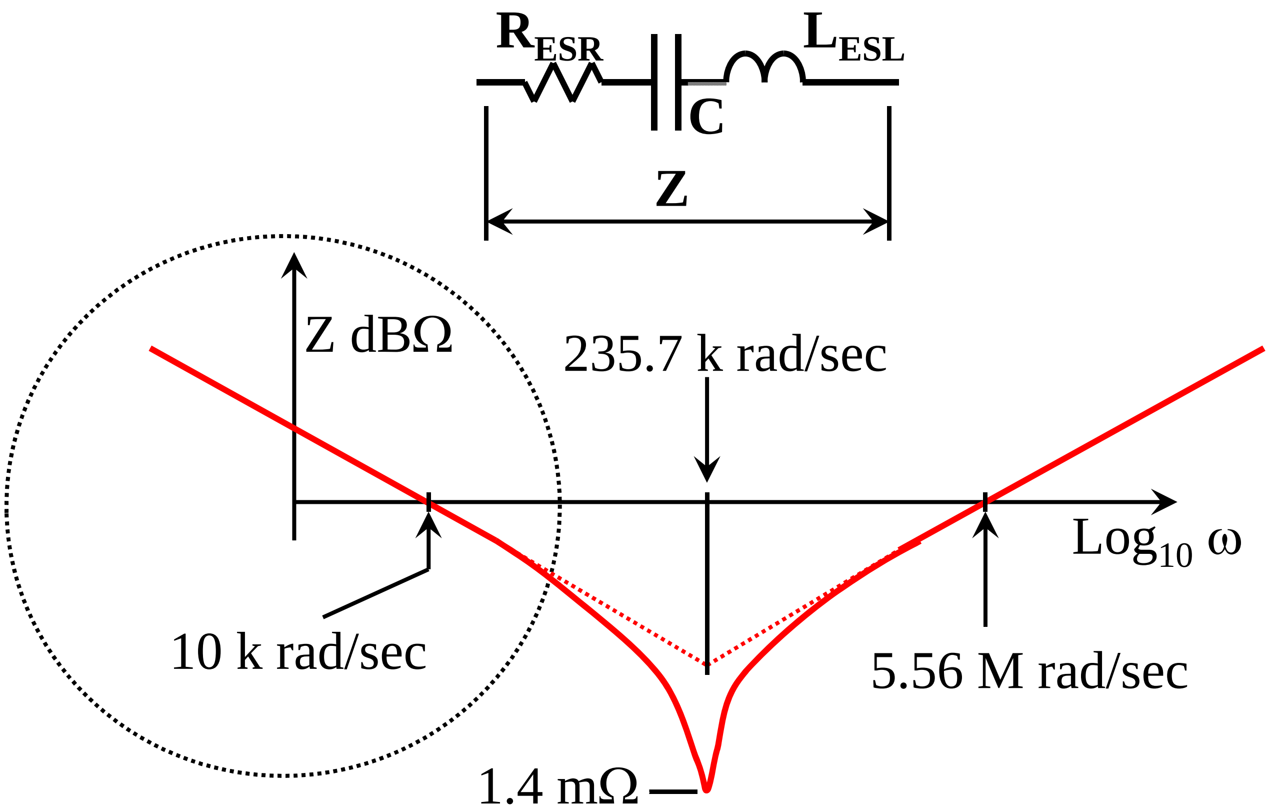
Impedance with Non-idealities



Impedance Plot [dBΩ vs log (ω)]

Switched Mode Power Conversion

Impedance with Non-idealities



Impedance Plot [dBΩ vs log (ω)]

Switched Mode Power Conversion

Capacitors - Safety

Charge Holding

Discharge Time Constant

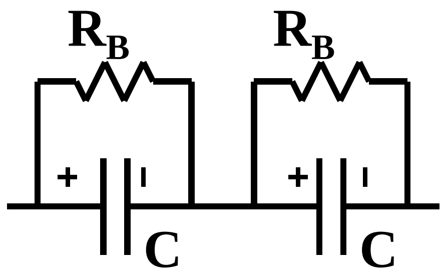
> 10000 s : 3 Hours

Switched Mode Power Conversion

Capacitors – Series Operation

Electrolytic

Capacitors May be Operated in Series
To Obtain Higher Voltage Rating.
(specially for Electrolytic)

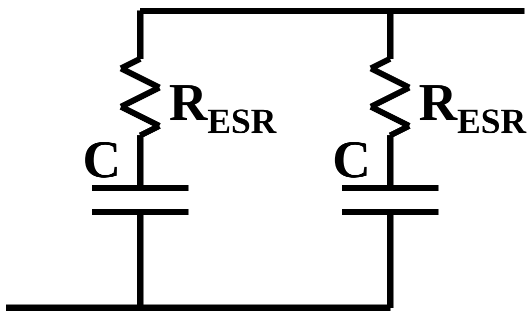


Bleeder Current is Chosen Higher than Leakage Current

Switched Mode Power Conversion

Capacitors – Parallel Operation

Capacitors May be Operated in Parallel
To Obtain Higher Ripple Current Rating



MKV

Physical Layout to Obtain Symmetry

Switched Mode Power Conversion
Capacitors

Devices for Efficient Power Conversion

Switches
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