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Resistors

Purpose of this content

- This series of content is aimed at supporting engineers to gain a solid foundational knowledge on electrical and electronic components.
- Every Electrical and electronics product development starts with components. The components can be
  - **Passives :** Resistors, Inductors, Capacitors
  - **Semiconductor Discrete devices :** Various types of Diodes, Transistors, FET/MOSFETs, IGBT, Thyristors etc.,
  - **Semiconductor ICs (Actives) :** Analog, Power management, Interface ICs, MCUs, MPU, FPGAs, Sensors etc.,
- So, the first step is to get a deep knowledge on components.
  - Kowing various components available, their specifications and characteristics.
- Next step is designing circuits using components.
  - For creating and simulating the behavior of your circuits before you go for the final board design, there are few free and many paid software tools available. Getting familiar with these tools is essential optimize the development time.
  - https://www.analog.com/en/resources/design-tools-and-calculators/ltspice-simulator.html
  - https://www.ti.com/tool/PSPICE-FOR-TI

Audiences for this content

To whom this content can be useful?

- Undergraduate Engineering students from E&E, ECE, Instrumentation, Mechatronics, Computer Science or students
- Postgraduate engineering students who wants to focus on electrical, electronics products design.
- Students who are in Arts college / Diploma studying electrical, electronics subjects
- Professionals who are starting their career in embedded electronics, hardware design and system design.

Details on content creator & Request to the learner

Content put together by

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A humble Request: If you like this content, and you want to share this useful information to someone else, *please share the weblink of this material.*

Because when different users visits the weblink, that will give us an idea on the number of users consuming this content and that may encourage us to continue spend time to create more such useful content and maintain this website.

Note: This content uses references to some of the great materials out there on the internet from several component manufacturers and other websites etc., We humbly recognize and thank all of those efforts which brings clarity to engineers and help making the product development great.

In case if you are an owner of such content and for some reasons you do not want the references to be a part of these slides, please feel free to write an e-mail to us to remove those references: e-mail: seekerssignpost@gmail.com

Please send us your comments, feedback, content requirement.

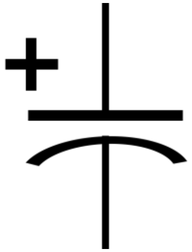
Why is it essential to learn in depth about Resistors?

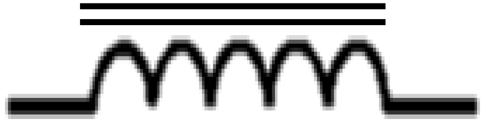
- **Ensure Design Precision:** Selecting correct resistor value, tolerance, and power rating are critical for accurate performance and preventing failures.
- **Manage Power and Heat:** Engineers need to calculate power dissipation to avoid overheating, ensure reliability and safety during entire product operating conditions (Design for wide range of operating temperature, altitude, humidity, overvoltage and surge conditions).
- **Mitigate Parasitic Effects:** Resistors exhibit parasitic inductance and capacitance, impacting high-frequency performance; engineers must account for these to ensure circuit stability
- **Optimize Signal Integrity:** Used in filtering, impedance matching, and noise reduction, resistors maintain the signal quality in sensitive circuits.

List of topics

- Introduction to passive components
- Resistors, Resistance, Resistivity
- Resistors Categorization – Linear, Non-linear resistors, Fixed, Variable resistors
- Ohms Law, Simple resistor-based circuits and waveforms
- Various specifications of Resistors
- Resistor Tolerance and it's impact on circuit design
- Heat generation and power rating of resistor
- Temperature co-efficient of Resistor and it's impact on circuit design
- Parasitic elements in resistor: ESL, ESR
- Resistors for Microwave frequencies
- Pulse withstanding resistor
- High voltage resistors
- Shunt Resistors
- Noise in resistors
- Varistors for surge protection
- NTC Thermistor as temperature sensors
- PTC resistor as resettable fuse

Short Introduction to functions of R, C, L





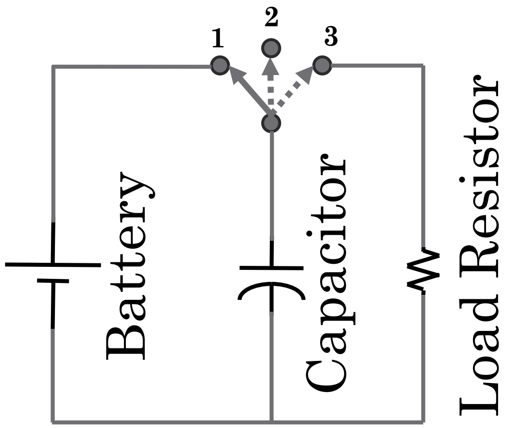
Resistor is a component that helps decide the magnitude of current flow in a circuit.

Capacitor is a component that can store energy, hold on to it and release it when demanded.

Inductor is a component which can store energy, release it, but cannot hold on it for long like a capacitor.

Functions of Capacitor

3 Position Switch



Switch on Position 1:

Assuming the capacitor was not having initial charge, the moment switch is moved to position "1", the capacitor gets charges to battery voltage.

Switch on Position 2:

The capacitor holds on to the charge already stored in it.

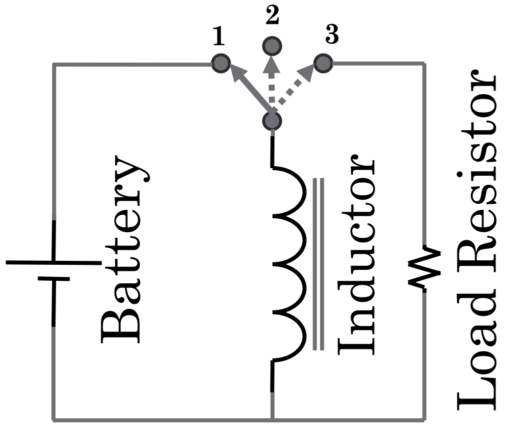
Switch on Position 3:

The load resistor drains the energy stored in the capacitor and that energy is lost as heat in the resistor.

So, a capacitor can **"get charged", "hold the charge"** and **"discharge it to a load"** whenever needed.

Functions of Inductor

3 Position Switch



Switch on Position 1:

The moment switch is moved to position "1" the current in the inductor keeps increasing and energy stored in the inductor increases with respect to time (Here, assume the current through inductor has not reached saturation value)

Switch on Position 2:

As far as an Inductor is concerned, it cannot hold on to the stored energy for long time like a capacitor. So, if the switch is brought to position 2, the inductor will create a very high voltage to create an arc between position 1 and 2 and will release the energy stored.

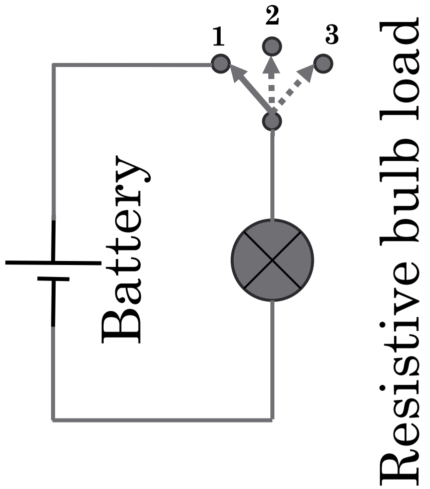
Switch on Position 3:

In case if switch position is moved from 1 to 3 directly, then the inductor will discharge the energy stored in its magnetic field through the load resistor

So, an inductor can store energy in its magnetic field, but it cannot hold on to it when it is not removed from the source or load. Before disconnecting the inductor from the source, we need to ensure that, the Inductor has a desirable path available to release the energy stored.

Functions of Resistor

3 Position Switch



Switch on Position 1:

The moment switch is moved to position “1” the voltage source causes a current to flow into the resistive bulb (current value given by I = V/R)

Switch on Position 2:

Once the position switch is moved to position”2” the current through the resistive bulb immediately comes to zero

So, a resistor is a lossy element, and it doesn’t store energy like in a capacitor or Inductor.

Simple formulas to start with

Formula Description	Resistor	Inductor	Capacitor
Defining Equation	$R = \frac{V}{I}$ (Ohm's Law)	$L = \frac{V}{\frac{di}{dt}}$	$C = \frac{Q}{V}$
Physical Property Formula	$R = \rho \frac{l}{A}$	$L = \frac{\mu N^2 A}{l}$ (solenoid)	$C = \epsilon \frac{A}{d}$
Series Connection	$R_{total} = R_1 + R_2 + R_3 + \ldots$	$L_{total} = L_1 + L_2 + L_3 + \ldots$	$\frac{1}{C_{total}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots$
Parallel Connection	$\frac{1}{R_{total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots$	$\frac{1}{L_{total}} = \frac{1}{L_1} + \frac{1}{L_2} + \frac{1}{L_3} + \ldots$	$C_{total} = C_1 + C_2 + C_3 + \ldots$
Energy Stored	Not typically stored (dissipated as heat)	$E = \frac{1}{2} L I^2$	$E = \frac{1}{2} C V^2$
AC Reactance	None (constant resistance)	$X_L = 2\pi f L$	$X_C = \frac{1}{2\pi f C}$
Power Dissipation (DC)	$P = I^2 R$ or $P = \frac{V^2}{R}$	None (no power dissipation in ideal case)	None (no power dissipation in ideal case)
Time Constant	Involved in RC and RL circuits	$\tau = \frac{L}{R}$ (in RL circuit)	$\tau = RC$ (in RC circuit)

- "ρ = resistivity, μ = permeability, ϵ = permittivity"
- Units: Time constant (τ) is in seconds (s), with R in Ohms (Ω), C in Farads (F), and L in Henries (H).
- Time Constant For Capacitor: τ=RC is the time constant in an RC circuit, representing the time it takes for the capacitor to charge to ~63% of its final voltage (or discharge to ~37%).
- For Inductor: τ=L/R is the time constant in an RL circuit, indicating the time for the current to reach ~63% of its final value (or decay to ~37%).

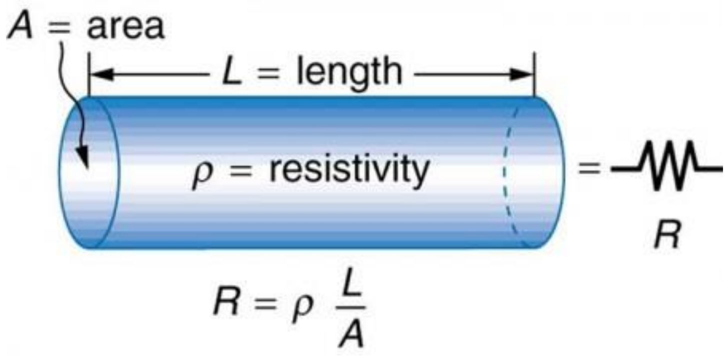
Resistance property of a material (Ω, Ohms)

The formula for resistance of a material is:

$$R = \rho * L / A$$

Where:

- ρ (rho): Resistivity of the material (Ω·m).
  - For example, copper has a low resistivity ($\rho \approx 1.68 \times 10^{-8}$ Ω·m), while rubber has a very high resistivity (10^{12} to 10^{15} Ω·m.)
- L: Length of the conductor (in meter).
- A: Cross-sectional area of the conductor (in square meters).



$$R \propto l$$

That means, longer the conductor, higher the resistance value.

$$R \propto 1/A$$

That means, bigger the conductor cross section, lower the resistance value.

Image Courtesy: https://courses.lumenlearning.com/suny-physics/chapter/20-3-resistance-and-resistivity/

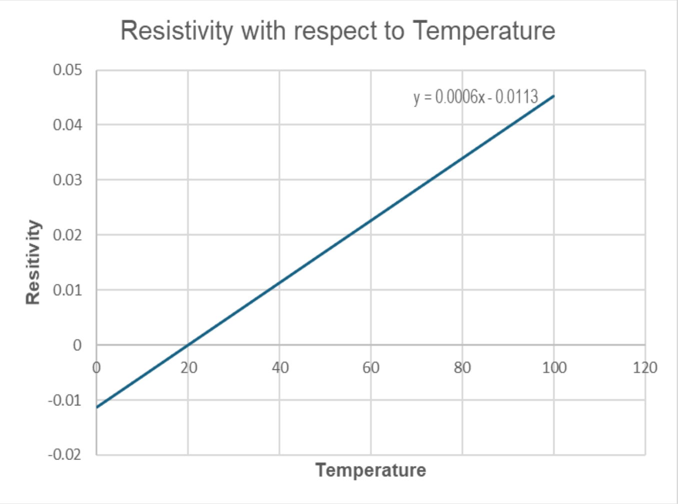
Resistivity of the material

- Resistivity ρ is temperature dependent.
  - $\rho_t = \rho_0\ [1 + \alpha\ (T - T_0)]$.
  - α is the temperature coefficient of the resistivity
  - T_0 is the reference temperature
  - ρ_0 is the resistivity at a standard temperature (typ. 20^0C or 25^0C)
  - T is the temperature at which we calculate the resistivity
  - ρ_t is the resistivity at T^0C (Unit is Ω.m)

Material	Resistivity @20^0C
Copper	0.017μΩm
Aluminium	0.026μΩm
Carbon (graphite)	0.10μΩm
Glass	10000μΩm
Mica	10000000μΩm

Metal	Resistivity /(Ωm)	Material	Resistivity /(Ωm)
silver	1.6×10^{-8}	carbon	35 to 5000×10^{-8}
copper	1.7×10^{-8}	graphite	800×10^{-8}
aluminium	3.2×10^{-8}	germanium	0.65
lead	21.0×10^{-8}	silicon	2.3×10^{-3}
manganin (alloy)	44.0×10^{-8}	pyrex glass	10^{12}
eureka (alloy)	49.0×10^{-8}	PTFE	10^{12} to $\times 10^{16}$
steel (varies)	10 to 100×10^{-8}	quartz	5×10^{16}

Table 3. Resistivity values at room temperature. For metals, resistivity increases as temperature increases. For semiconductors and many insulators, the opposite is true.



Keep in mind the resistivity ρ varies as the operating temperature varies. So, as $R=\rho * L / A$, the resistance also will change as the operating temperature changes !

Resistors - Introduction

- **Resistor : A component that is made of certain material to offer a known resistance of choice.**
- **Function:** Controls / resists the flow of electric current by introducing resistance to it.
- **Characteristic:** *Dissipates the energy as heat.*
- **Behavior:**
  - Obeys **Ohm's Law**: V=I * R or R = V/I
  - **Supposed to be Independent of frequency** (ideal resistor has no reactance).
  - Converts electrical energy into **heat**. Power loss = I^2R
- **Key Parameter:** Resistance R (in ohms, Ω)
- **Use Cases of resistors:**
  - Limiting current in a circuit.
  - Voltage / Potential dividers.
  - Pull-up or pull-down resistors etc.,


Resistor symbol (US and Japan)


Resistor symbol (Europe)

Ohm’s law

Georg Simon Ohm;
16 March 1789;
German Mathematician & Physicist

Ohm's law states that the electric current through a conductor between two points is directly proportional to the voltage across the two points. Introducing the constant of proportionality, the resistance, one arrives at the three mathematical equations used to describe this relationship.

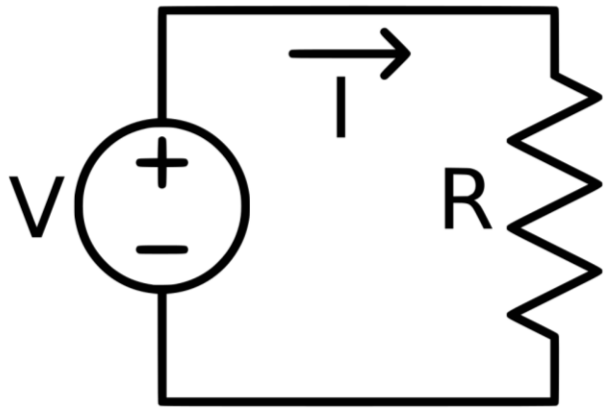
$$V = IR \quad \text{or} \quad I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I}$$

V is in Volts; I is in Amps; R is in Ohms

Courtesy: https://en.wikipedia.org/wiki/Georg_Ohm

Relation of I with V and R

$$V = IR \quad \text{or} \quad I = \frac{V}{R} \quad \text{or} \quad R = \frac{V}{I}$$



Current "I" through a load resistor is

1) *directly proportional to the applied voltage across it and*
2) *inversely proportional to its resistance*

$$I = \frac{V}{R}$$

Keeping R Constant, say 1 Ohms

If V = 1 volts; then I = 1 Amps
If V = 2 volts; then I = 2 Amps
If V = 0.5 volts; then I = 0.5 Amps

Keeping V Constant, say 1 Volts

If R = 1 Ohms; then I = 1 Amps
If R = 2 Ohms; then I = 0.5 Amps
If R = 0.5 Ohms; then I = 2 Amps

Power Loss in a Resistor

Equation for power in DC circuits, P = V * I (V in volts, I in Amps, P in Watts)

In the given circuit, the voltage across the resistor is V, current through it is I, and hence the power loss is

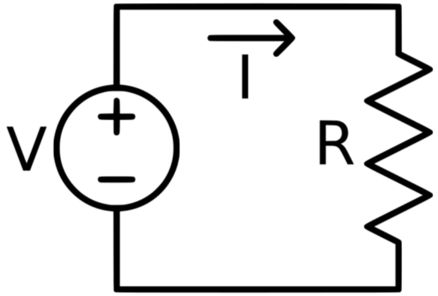
P = V * I

or, substituting $I = \frac{V}{R}$ from Ohm's law

$P = V^2 / R$

or, substituting $V = I * R$ from Ohm's law

$P = I^2R$



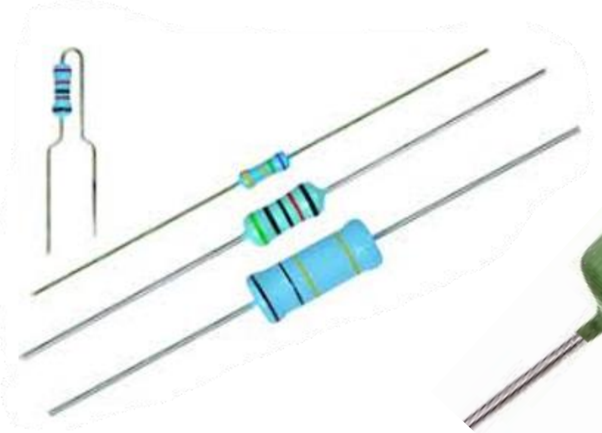
Keeping R Constant, say 1 Ohms If I = 1 Amps; then P = 1 Watts If I = 2 Amps; then P = 4 Watts If I = 0.5 Amps; then P = 0.25 Watts

$$\boxed{P \propto I^2}$$

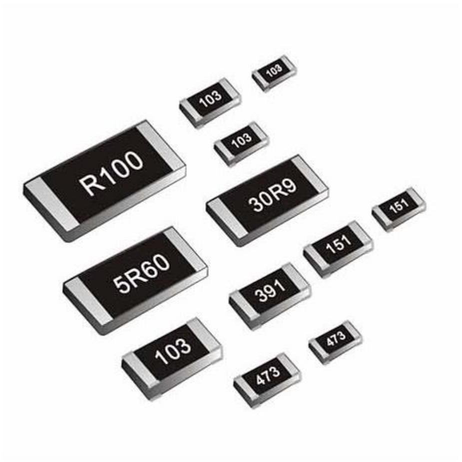
Categorization of resistors

Resistors	Linear	Fixed	Carbon
			Wire wound
			Thick film
			Thin Film
		Variable	Trimmer
			Potentiometer
			Rheostat
	Non-Linear	MOV	
		NTC, PTC thermistor	
		LDR	

Fixed Value Resistors - Sizes

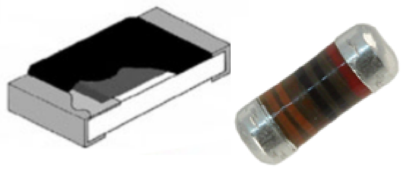




SMD Resistor materials and characteristics

- **Thick Film** (Chip Resistors/Chip Arrays/Networks)
  - Specially built surface-mount film resistor that carries high power for the part size. For thick film resistors, the ruthenium oxide “film” is applied using traditional screen-printing technology onto the surface of a substrate.

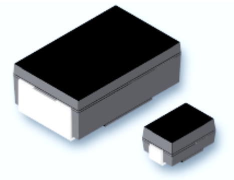


0.1 Ω to 50 GΩ
± 1 Tolerance
± 100 ppm

- **Thin Film** (Chip Resistors/Chip Arrays/Networks)
  - A type of surface-mount film resistor with a relatively thin resistive element, measured in angstroms (millionths of an inch). Thin film resistors are made by sputtering (also known vacuum deposition) a resistive material, such as nichrome or tantalum nitride, onto the surface of a substrate.

0.03 Ω to 3 GΩ
± 0.011 Tolerance
± 5 ppm

- **Metal Film** (Chip Resistors/Leaded/MELF)
  - A type of cylindrical resistors made by depositing a resistive element made of a thin conducting film of a metal or metal alloy, such as nichrome, onto a cylindrical ceramic or glass core. The resistance is controlled by cutting a helical groove through the conducting film.

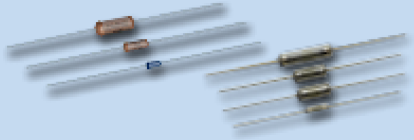
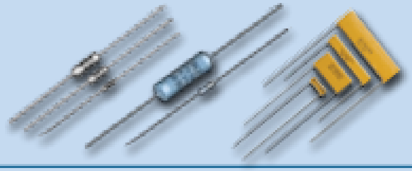
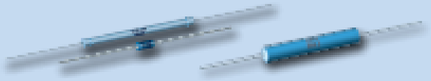
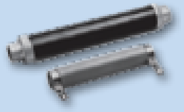


5 Ω to 100 KΩ
± 0.01 Tolerance
± 5 ppm

Courtesy: https://www.vishay.com/docs/49562/49562.pdf

Leaded Resistors and characteristics

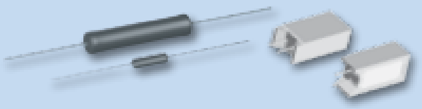
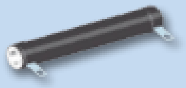
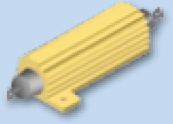
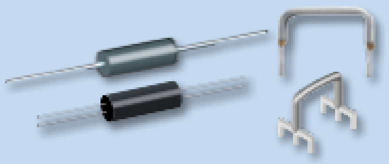
0.1 Ω to 50 GΩ
± 1 Tolerance
± 100 ppm

Technology *	Examples of Vishay Models	Resistance Range	Best Tolerance (%)	Best TCR (ppm/°C)	Strengths
Metal Film 	CMF, PTF, CCF, ERL, ERC, GSR, HDN	0.1 Ω to 50 MΩ	± 0.01	± 5	• General purpose • Wide resistance range • Good high frequency characteristics
High Voltage, High Pulse Films 	CPF, FP, HVW, MVW, TR, TD, FHV	0.1 Ω to 3 TΩ	± 0.1	± 25	• Pulse resistant • Flameproof • Good high frequency characteristics • High power
Metal Oxide 	ROX, RNX, RJU	100 Ω to 3 GΩ	± 0.5	± 50	• High voltage • High resistance values
Carbon Film 	G, D, B, T, SPW	50 Ω to 500 MΩ	± 5	> ± 250	• High power • High wattages • High resistance values

Courtesy: https://www.vishay.com/docs/49562/49562.pdf

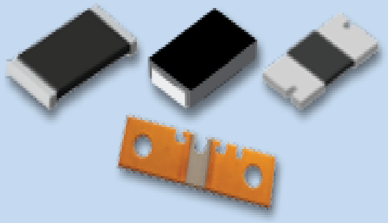
Leaded Resistors and characteristics

0.1 Ω to 50 GΩ
± 1 Tolerance
± 100 ppm

Technology *	Examples of Vishay Models	Resistance Range	Best Tolerance (%)	Best TCR (ppm/°C)	Strengths
Wirewound 	RW, RWR, G, RS, CW, CP, CA, CPR, CPL, CPCx, MR, MRA	0.01 Ω to 6 MΩ	± 0.005	± 2	• Wide power ranges • Wide resistance range • Excellent overload capabilities
Wirewound (Tubular) 	HL, HLW, HLZ, FxE, FxT, AxE, AxT, CMx, Fx	0.05 Ω to 645 kΩ	± 5	± 30	• Wide power ranges • Wide resistance range • Excellent overload capabilities
Wirewound (Housed) 	RH, RE, RER	0.01 Ω to 273 kΩ	± 0.05	± 20	• Wide power ranges • Wide resistance range • Excellent overload capabilities
Metal Element 	LVR, SR, SPU Open, SPU Molded	0.001 Ω to 0.8 Ω	± 0.1	± 30	• Wide power ranges • Excellent overload capabilities • Low ohmic values

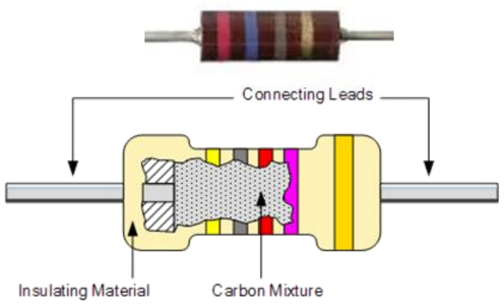
Courtesy: https://www.vishay.com/docs/49562/49562.pdf

Current sense resistors

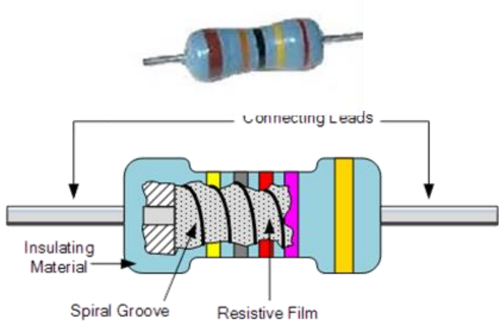
Technology *	Examples of Vishay Models	Resistance Range	Best Tolerance (%)	Best TCR (ppm/°C)	Strengths
Power Metal Strip® 	WSL, WSR, WSK, WSH, WSLP, WSLT, WSLS, WSBS, WSMS	0.00005 Ω to 1 Ω	± 0.1	± 30	• Current sensing • Ultra low values

Courtesy: https://www.vishay.com/docs/49562/49562.pdf

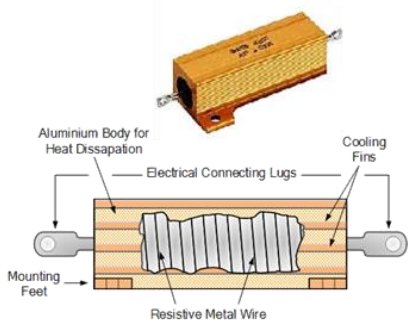
Fixed Resistor Construction details



Carbon resistor

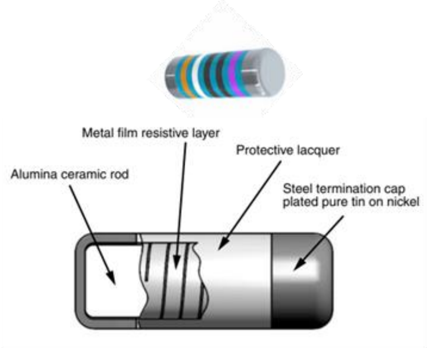


Metal film resistor

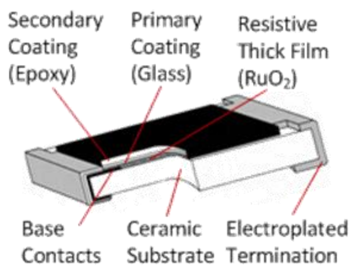


Wire wound resistor

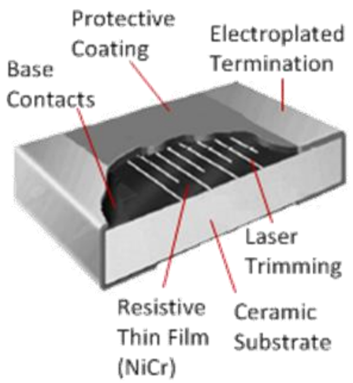
Wire wound resistor



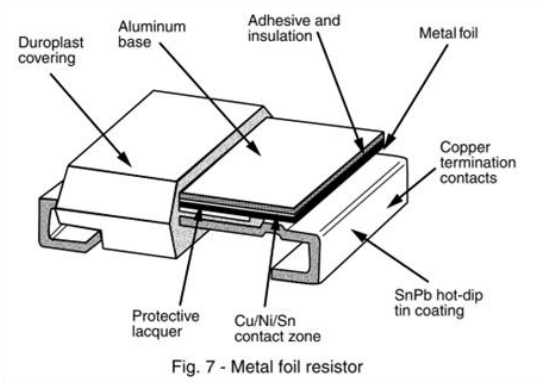
Metal electrode leadless face (**MELF**)



Thick film resistor



Thin film resistor



Metal electrode leadless face (**MELF**)

*Image courtesy : Application Note - Vishay

Available resistor values

How many different resistor values available for purchase? (From 0.1 Ohm to 10G Ohm)

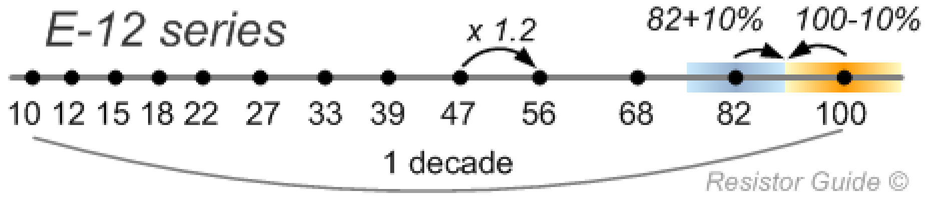
- IEC (International Electrotechnical Commission) has defined the resistance and tolerance values into a norm, to ease the mass manufacturing of resistors.
- These are referred to as "preferred values" or "E-series", and they are published in standard IEC 60063:1963.
- These standard values are also valid for other components like capacitors, inductors and Zener diodes.
- This helps the supplier to limit the number of different values that must be produced or kept in stock.
- By using standard values, resistors from different manufacturers are compatible for the same design, which is favorable for the electrical engineer

pico	10^{-12}
nano	10^{-9}
micro	10^{-6}
milli	10^{-3}
kilo	10^{+3}
mega	10^{+6}
giga	10^{+9}
tera	10^{+12}

Resistors are available from few milli ohms to meg ohms

E-12 series of resistor values

- E12 means that every decade (0.1 to 1.0, 1 to 10, 10 to 100, etc.) is divided in 12 steps on a logarithmic scale. The size of every step is equal to $10^{\left(\frac{1}{12}\right)} = 1.21$
- Thus, every value is 1.21 times higher than the previous value in the series, rounded to whole numbers. Because of this, all resistors with a tolerance of 10% overlap. The series looks as follows: 1– 1.2 – 1.5 – 1.8 – 2.2 – 2.7 – 3.3 – 3.9 – 4.7 – 5.6 – 6.8 – 8.2 – 10 etc. All of these values can be powers of ten (1.2 – 12 – 120, etc.).
- While the E12 series is the most common, other series are also available. It is a good practice to specify resistors from a low series when tolerance requirements are not high. The most common series are:



- E6 : 20% tolerance; E12 :10%; E24 : 5% (also available with 1%); E48 : 2%; E96 : 1%; E192 : 0.5% (also used for resistors with 0.25% and 0.1%).

Courtesy: https://eepower.com/resistor-guide/resistor-standards-and-codes/resistor-values/#

SMD "0 Ohm" / "Jumper" resistance

Often a "0 Ohm" / "Jumper" resistance becomes essential in PCB designs. For example, two connect two separate ground planes at the power source point, or connect a configuration like a pull up +5V or pull down to ground of an I/O pin, provide a resistor in series with the power pin using which during initial testing a known resistor can be populated to know measure the current consumption and later use the zero-ohm resistor etc.,

These resistors exist both as rectangular thick film chips as well as metal film MELFs. Max resistance for the thick film chips usually is ≤50 mΩ at sizes between 0603 and 2010. Thin film MELFs in typical sizes of L x D ≈ 2 x 1.4 to 6 x 2.4 mm are specified for ≤10 mΩ.

As well as maximum resistance a maximum current is also specified for these components.

Resistor color coding

To remember the color sequence :

B (Black)

B (Brown)

ROY of (Red, Orange, Yellow)

Great (Green)

Britain had (Blue)

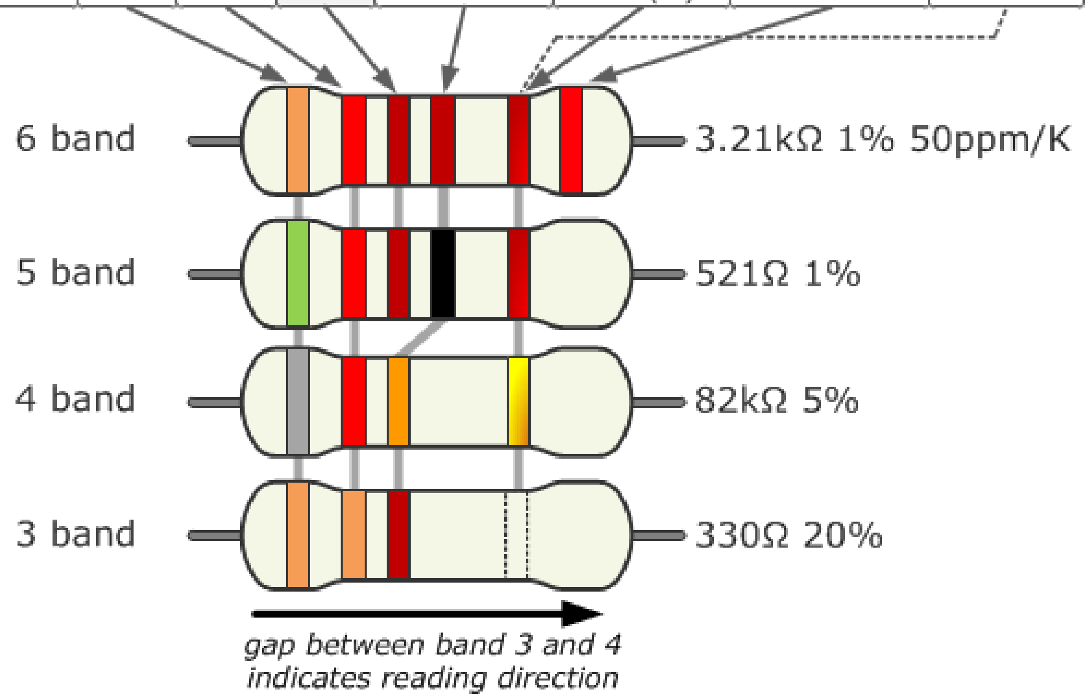
Very (Violet)

Good (Grey)

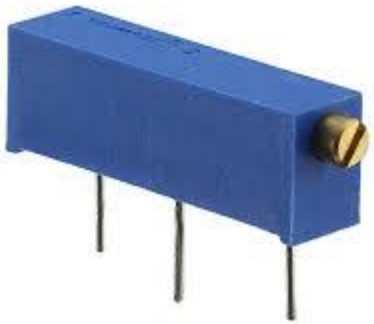
Wife (White)

BBROYGreatBritainVeryGoodWife

Color	Signficant figures			Multiply	Tolerance (%)	Temp. Coeff. (ppm/K)	Fail Rate (%)
black	0	0	0	x 1		250 (U)	
brown	1	1	1	x 10	1 (F)	100 (S)	1
red	2	2	2	x 100	2 (G)	50 (R)	0.1
orange	3	3	3	x 1K		15 (P)	0.01
yellow	4	4	4	x 10K		25 (Q)	0.001
green	5	5	5	x 100K	0.5 (D)	20 (Z)	
blue	6	6	6	x 1M	0.25 (C)	10 (Z)	
violet	7	7	7	x 10M	0.1 (B)	5 (M)	
grey	8	8	8	x 100M	0.05 (A)	1(K)	
white	9	9	9	x 1G			
gold			3th digit only for 5 and 6 bands	x 0.1	5 (J)		
silver				x 0.01	10 (K)		
none					20 (M)		



Variable Resistors

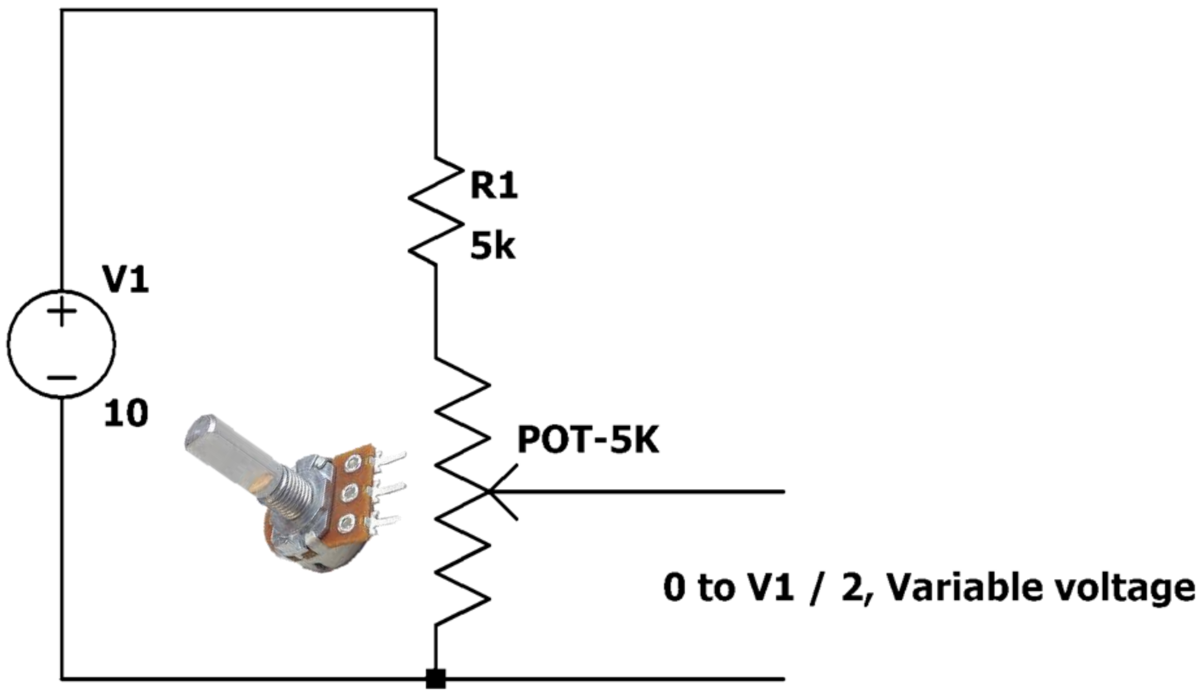




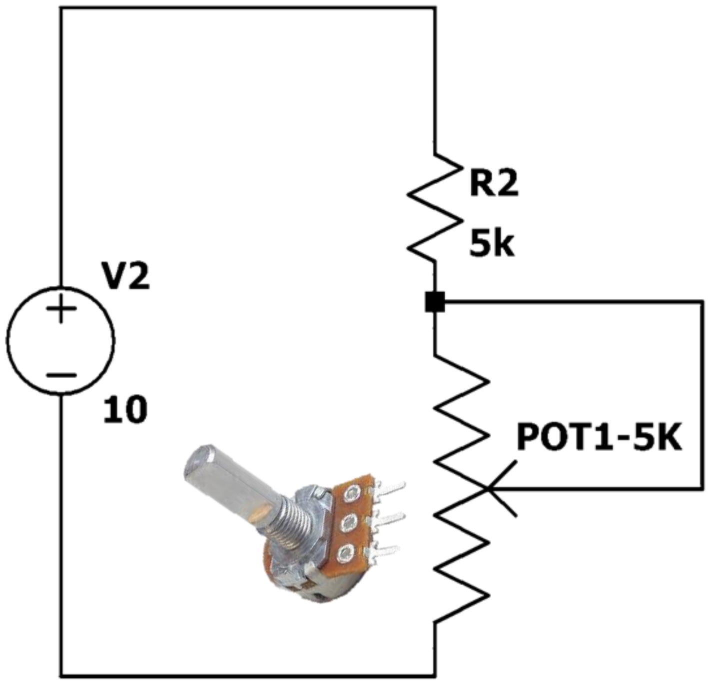


Applications of Variable Resistor

Potentiometer mode

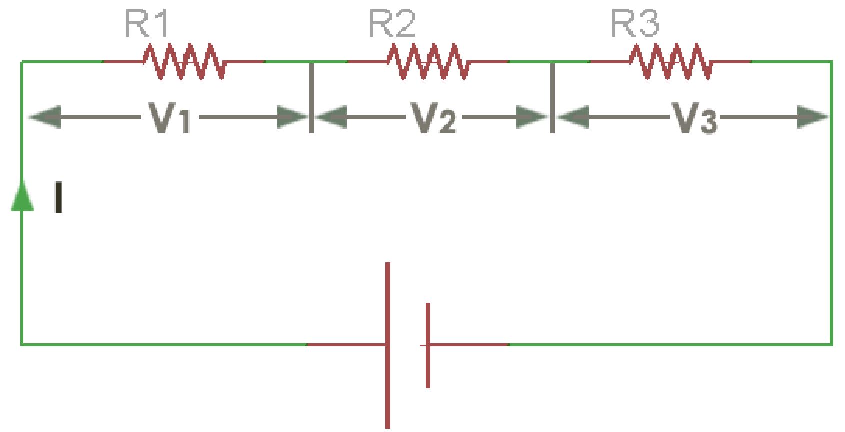


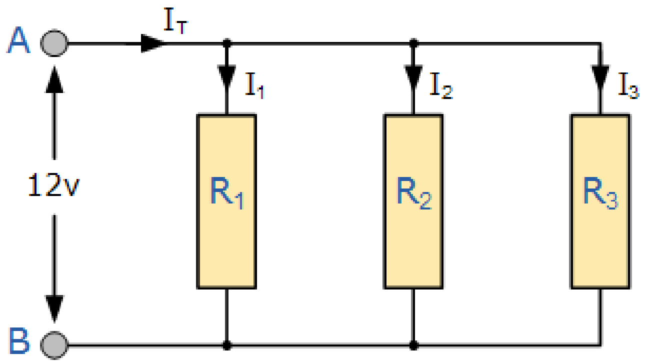
Variable resistance mode

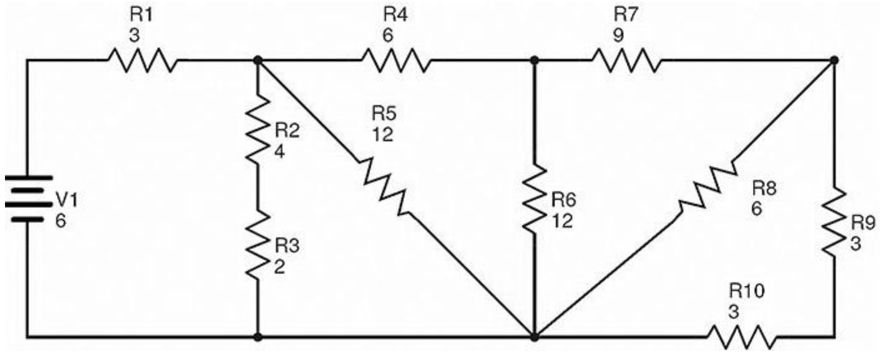


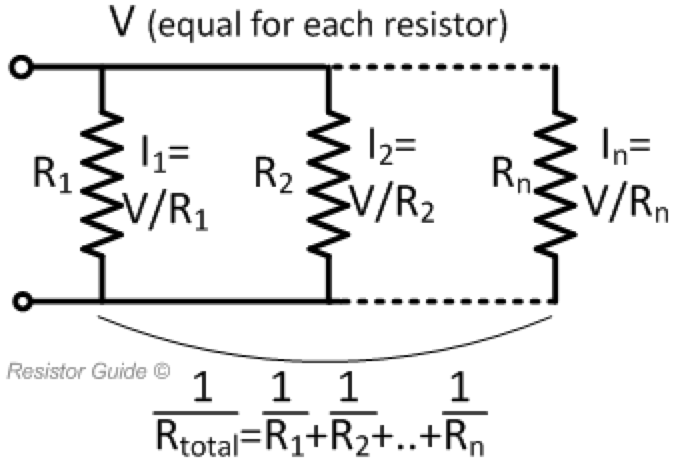
- "Potentiometer mode" is the common application, to create variable voltage inputs.
- Potentiometer change can be linear or Logarithmic. Logarithmic pots are used in audio applications as our ear response to sound is logarithmic in nature.
- The number of turn of potentiometer can be single or multi turn (ex: 10 turns)

Resistors in Series and Parallel





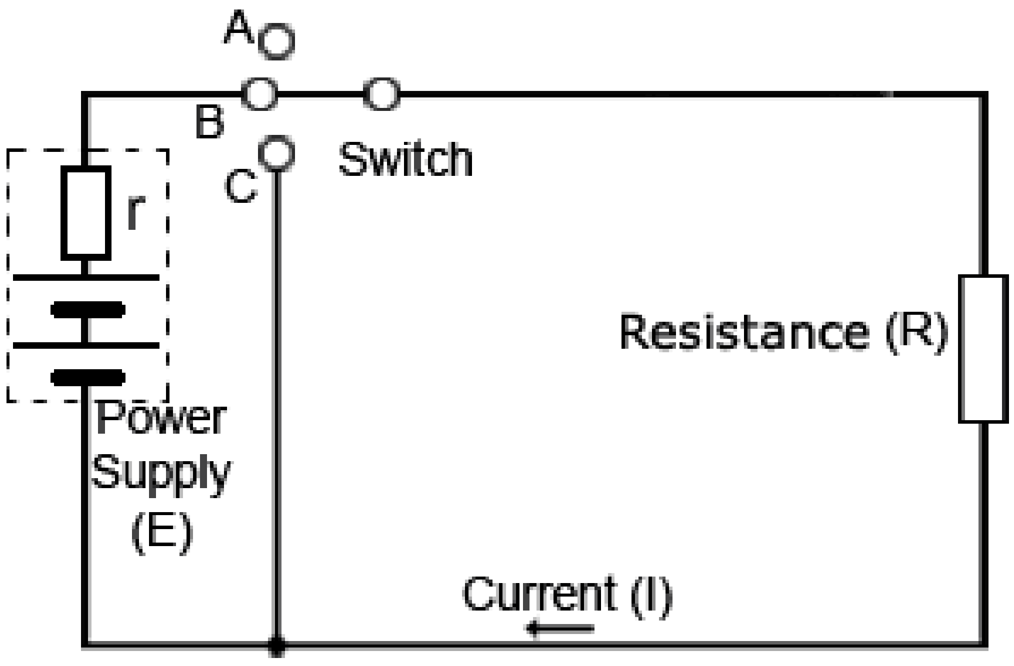


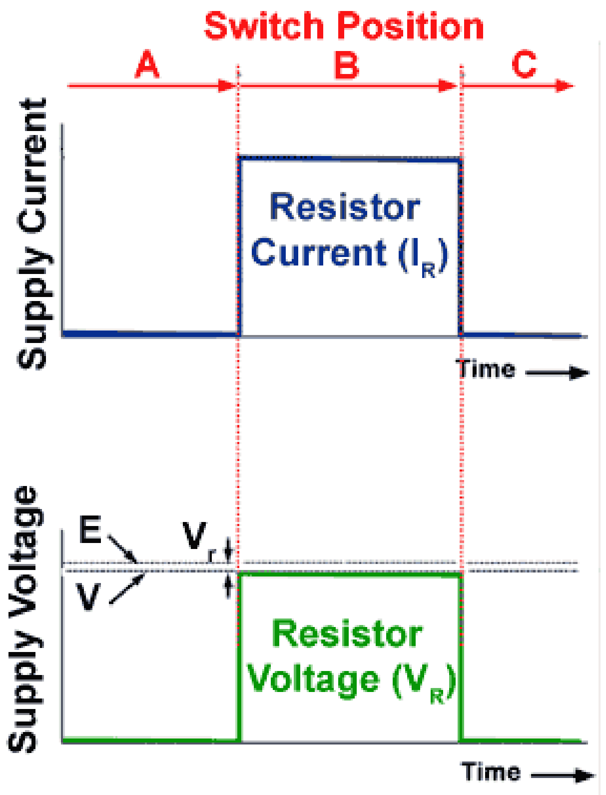


Courtesy: https://www.bourns.com/pdfs/mfsolgd.pdf

Voltage and current waveforms of Resistor in DC

Both voltage and current waveforms are in phase. (i.e., There is no phase shift between the voltage and current waveform). Magnitude of current as per Ohm's law.

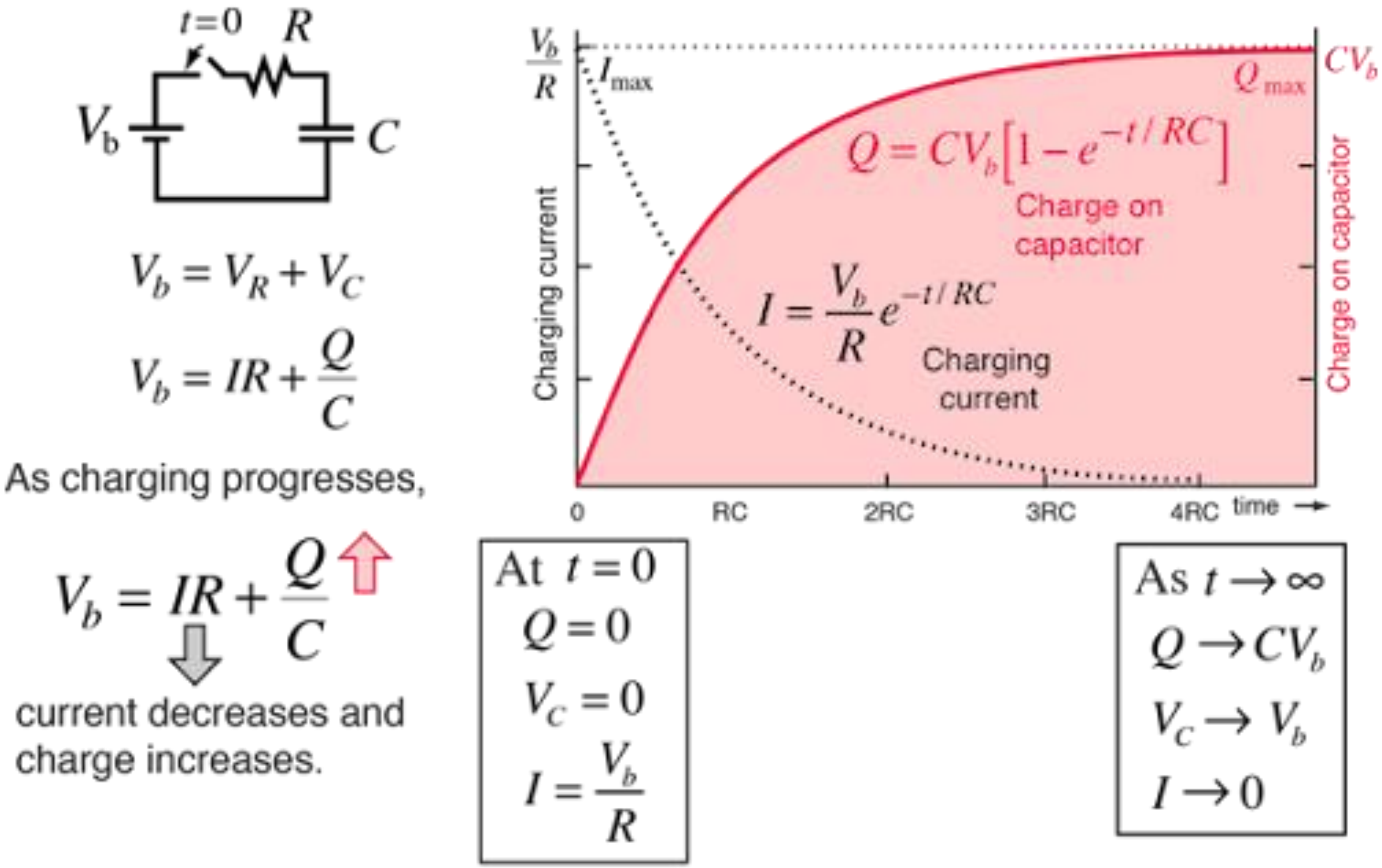




Courtesy: https://learnabout-electronics.org/ac_theory/dc_ccts41.php

RC series circuit voltage and current waveforms

Waveforms for a step DC input voltage to a capacitor through a series resistor



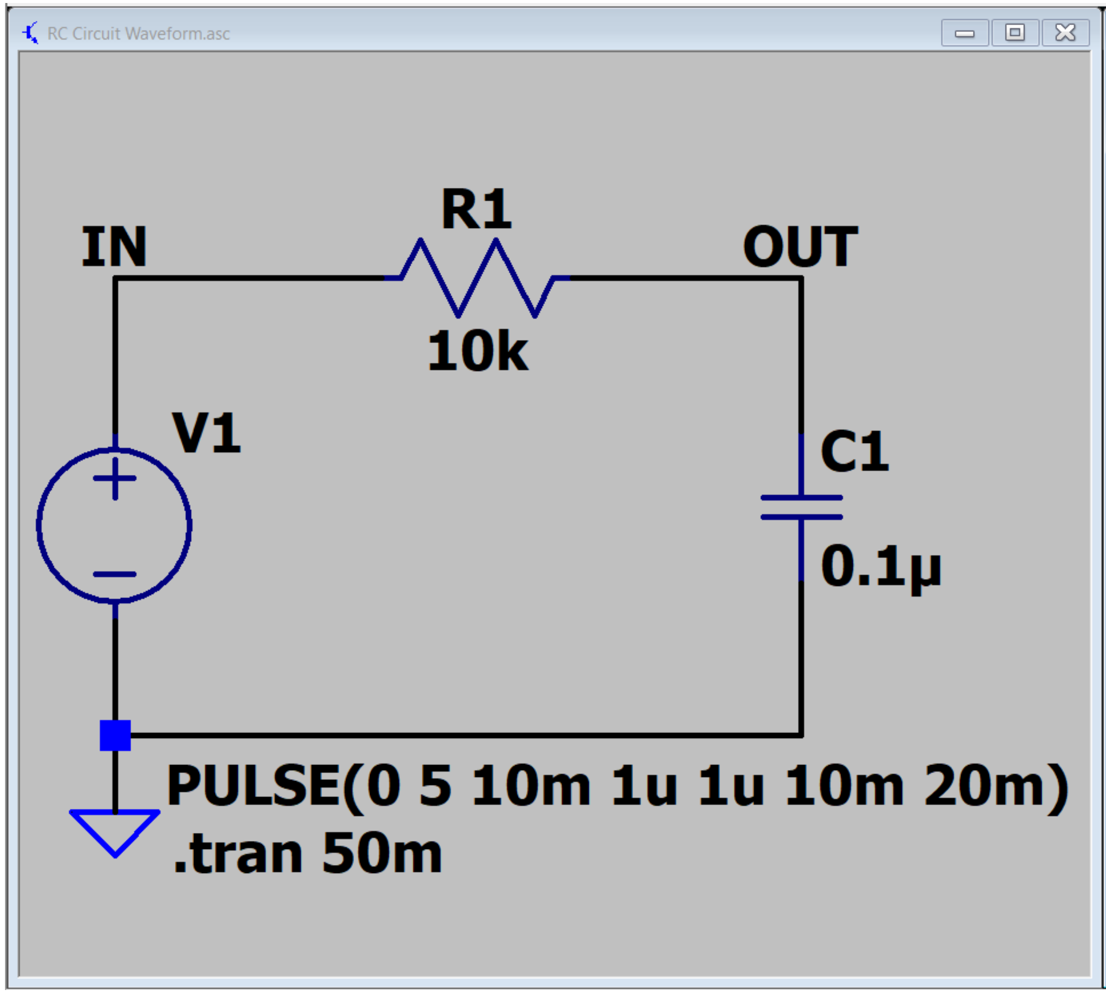
$C = \frac{Q}{V};\ \mathrm{V} = \frac{Q}{C};$
$\mathrm{CV} = Q;$

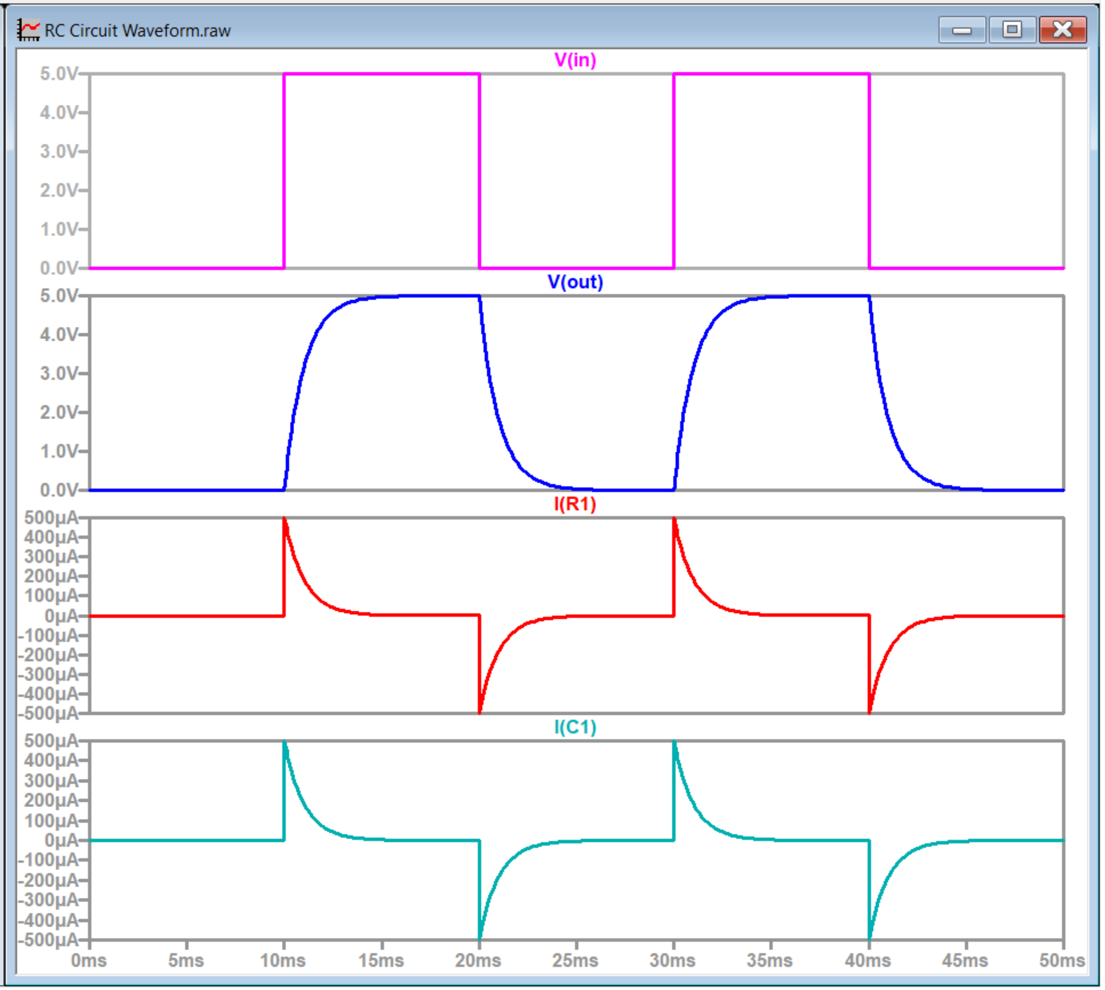
Time Constant
$\tau = R * C$

In an RC circuit, the voltage across the capacitor becomes almost equal to the input in “5 τ “ time

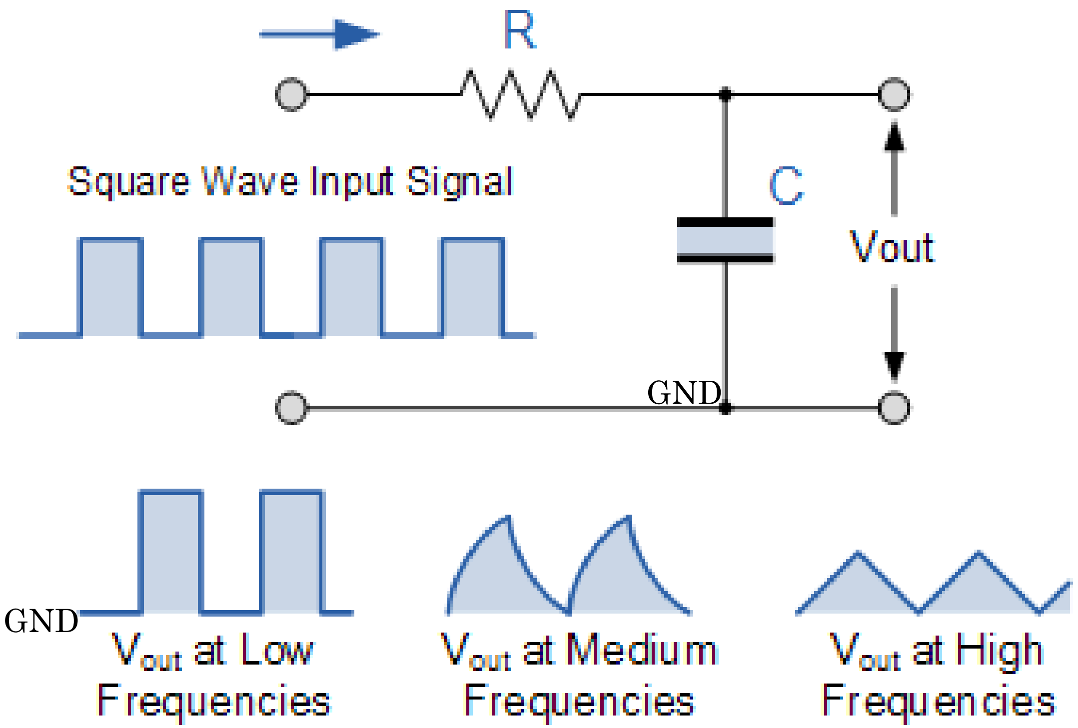
RC circuit voltage and current waveforms

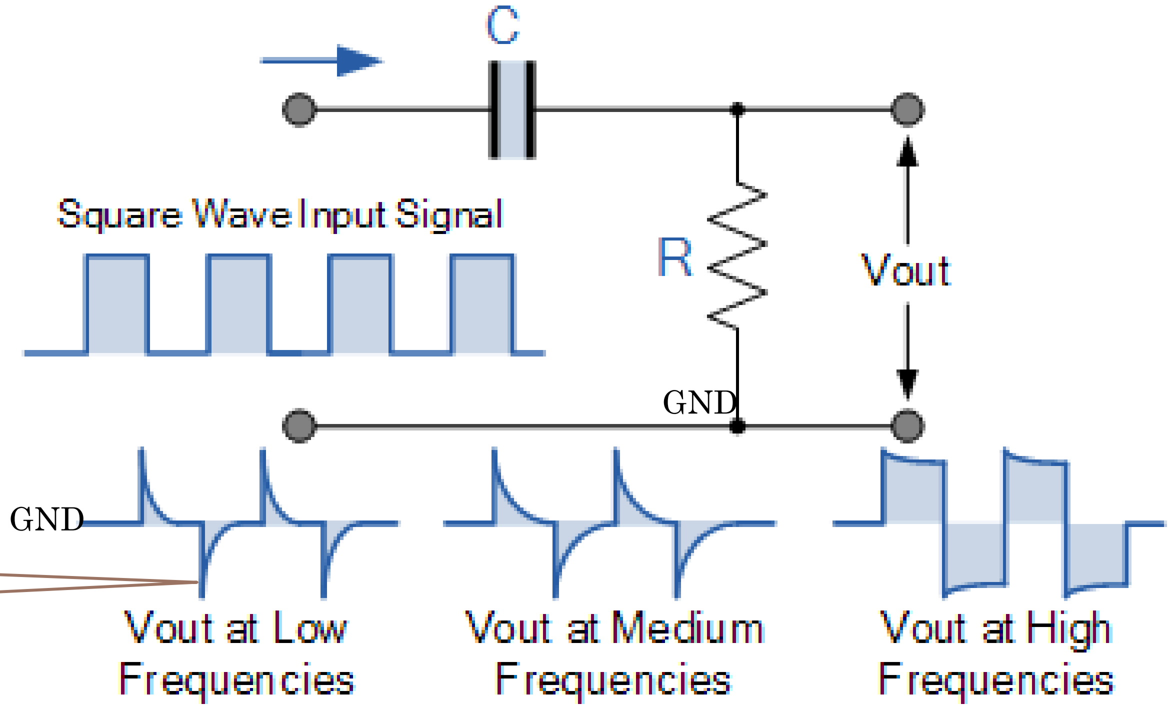
Waveforms for a DC PWM voltage to a capacitor through a series resistor





Waveforms in RC(Low pass), CR(High Pass) circuits

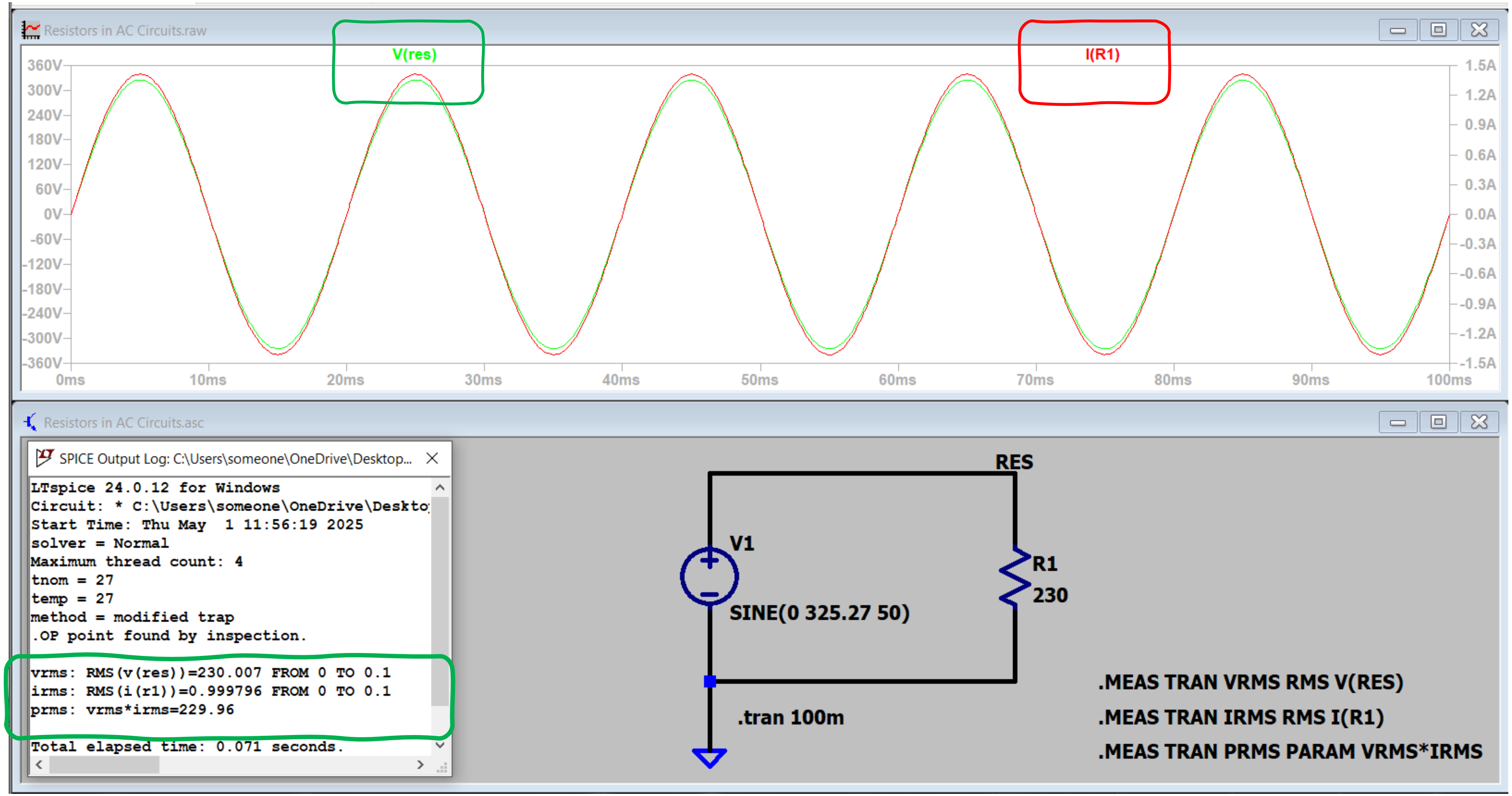




Note: Vout across R goes negative as well

Waveforms in AC circuits

In case of AC, voltage and current waveforms are in phase. Hence power = V_{RMS} * I_{RMS}



Resistor datasheets

- Yes, Resistors do have the datasheet.
- It is a must to read, understand each specification and the characteristics data curves.
- https://www.mouser.in/c/ds/passive-components/resistors/

Resistors Datasheets

Products (11,54,754) | Datasheets | Images | Newest Products

Types of Resistors List Images

- Carbon Composition Resistors (4)
- Ceramic Composition Resistors (1,893)
- Chassis Mount Resistors (20,055)
- Current Sense Resistors (42,700)
- Film Resistors (9,13,254)
- High Frequency/RF Resistors (1,323)
- MELF Resistors (19,508)
- Metal Foil Resistors (2,274)
- Metal Oxide Resistors (10,568)
- Resistor Hardware (134)
- Resistor Kits (245)
- Resistor Networks & Arrays (33,147)
- SMD Resistors / Chip Resistors (8,46,158)
- Through Hole Resistors (1,86,327)
- Variable Resistors (45,731)
- Wirewound Resistors (80,524)

Results: 4,000

Applied Filters: None Selected change filters

Mfr.: Vishay
Part No in Datasheet: 3,436


VISHAY. www.vishay.com
MMU 0102, MMA 0204, MMB 0207 - Precision
Vishay Beyschlag
Precision Thin Film MELF Resistors
FEATURES
- IECQ-CECC approved according to EN 140401-803
- AEC-Q200 qualified
- Advanced metal film technology
- Superior stability: class 0.05

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Mfr.: Vishay
Part No in Datasheet: 497


VISHAY. www.vishay.com
D/CRCW-IF e3
Vishay
Pulse Proof Thick Film Chip Resistors
FEATURES
- High pulse performance, up to 10 kW
- High pulse voltage up to 4 kV, 1.2 µs / 50 µs
- Stability at different environmental conditions $\Delta R/R \leq 1$ % (1000 h rated power at 70 °C)
- AEC-Q200 qualified

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Mfr.: Vishay
Part No in Datasheet: 159


VISHAY. www.vishay.com
RPS 250
Vishay Sfernice
Power Resistor for Mounting Onto a Heatsink Thick Film Technology
FEATURES
- Compliant with requirement #26 of NF-EN45545-2
- High power rating: 250 W

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Mfr.: Vishay
Part No in Datasheet: 191


VISHAY. www.vishay.com
R
Vishay D
High Voltage (Up to 2 kV) Thick Film Chip Resistors
FEATURES
- High operating voltage (up to 2 kV)
- Low voltage coefficient of resistance (VCR): 25 ppm/V

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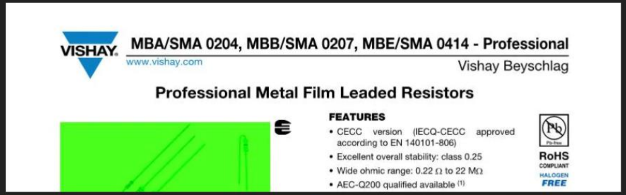
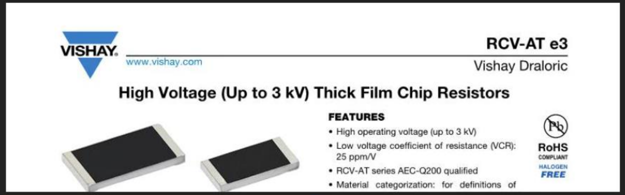
Mfr.: Vishay
Part No in Datasheet: 8,778


VISHAY. www.vishay.com
MBA/SMA 0204, MBB/SMA 0207, MBE/SMA 0414 - Professional
Vishay Beyschlag
Professional Metal Film Leaded Resistors
FEATURES
- CECC version (IECQ-CECC approved according to EN 140101-806)
- Excellent overall stability: class 0.25
- Wide ohmic range: 0.22 Ω to 22 MΩ
- AEC-Q200 qualified available

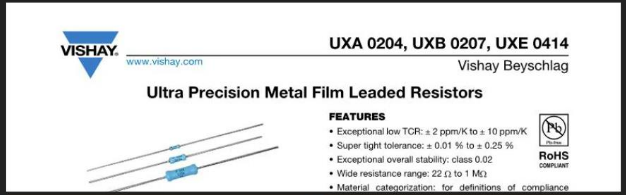
View | Download

Mfr.: Vishay
Part No in Datasheet: 116


VISHAY. www.vishay.com
RCV-AT e3
Vishay Draloric
High Voltage (Up to 3 kV) Thick Film Chip Resistors
FEATURES
- High operating voltage (up to 3 kV)
- Low voltage coefficient of resistance (VCR): 25 ppm/V
- RCV-AT series AEC-Q200 qualified

View | Download

Mfr.: Vishay
Part No in Datasheet: 363


VISHAY. www.vishay.com
UXA 0204, UXB 0207, UXE 0414
Vishay Beyschlag
Ultra Precision Metal Film Leaded Resistors
FEATURES
- Exceptional low TCR: ± 2 ppm/K to ± 10 ppm/K
- Super tight tolerance: ± 0.01 % to ± 0.25 %
- Exceptional overall stability: class 0.02
- Wide resistance range: 22 Ω to 1 MΩ

View | Download

Mfr.: Vishay
Part No in Datasheet: 67


VISHAY. www.vishay.com
Model 533, 53
Vishay S
$^7/_8$" (22.2 mm) Multi Turn Wirewound Potentiometer - 533: 3 Turns / 534: 10 Turns / 535: 5 Turns
FEATURES
- Bushing and servo mount designs available
- Special resistance tolerances to 1 %

View | Download

Mfr.: Vishay
Part No in Datasheet: 14,122


VISHAY. www.vishay.com
TNPW e3
Vishay
High Stability Thin Film Flat Chip Resistors
FEATURES

Mfr.: Vishay
Part No in Datasheet: 3,946


VISHAY. www.vishay.com
RH, NH
Vishay Dale
Wirewound Resistors, Industrial Power, Aluminum Housed, Chassis Mount
FEATURES

Mfr.: Vishay
Part No in Datasheet: 3,230


VISHAY. www.vishay.com
MCS 0402, MCT 0603, MCU 0805, MCA 1206 - Precision
Vishay Beyschlag
Precision Thin Film Chip Resistors
FEATURES

Mfr.: Vishay
Part No in Datasheet: 319


VISHAY. www.vishay.com
P16,
Vishay S
Knob Potentiomete
FEATURES

https://www.mouser.in/c/passive-components/resistors/

Specifications of a Resistor

Standard specifications:

- Resistance “R” of the component at 25 ^{0}C temperature (Ohms / Kilo / Mega / Giga Ohms)
- Initial resistance tolerance (0.1% / 0.5% / 1% / 5% / 10% / 20%)
- Temperature Coefficient of Resistance (10 / 50 / 100 / 200 / 500 ppm/^{0}C)
- Power rating (1/16th / 1/8th / 1/4th / ½ / 1 / 2 / 3 / 5 / 10Watts etc.,)
- Operating voltage
- Operating temperature range
- Automotive or special qualification if available

Advanced data:

- Parasitic Inductance and Capacitance
- Thermal Noise and Current Noise

Multiple	Prefix	Symbol
10^{15}	Peta	P
10^{12}	Tera	T
10^{9}	Giga	G
10^{6}	Mega	M
10^{3}	Kilo	k
10^{-3}	milli	m
10^{-6}	micro	µ
10^{-9}	nano	n
10^{-12}	pico	p
10^{-15}	femto	f

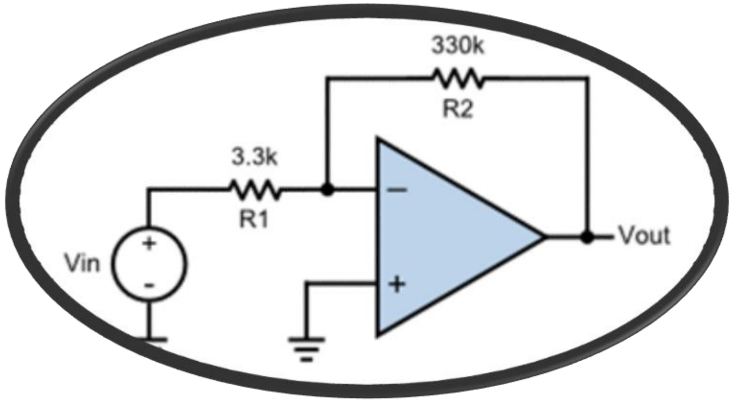
Note: The power jumps in +3 or -3 (Thousandth’s or 1/thousandth’s).

Impact of resistor tolerance on circuit design?

Tolerance: The tolerance of a resistor is the maximum difference between its actual value and the required value and is generally expressed as a +/-%.

For example, a 1kΩ ±20% tolerance resistor may have a maximum and minimum resistive value of:

- Maximum Resistance Value 1kΩ or 1000Ω + 20% = 1,200Ω
- Minimum Resistance Value 1kΩ or 1000Ω – 20% = 800Ω



Let's consider an example of a non-inverting amplifier circuit with a required gain of "100" and understand how tolerance can affect the actual gain.

R_{in}	R_f	%tolerance(+/-)	Actual R_{in} min	Actual R_{in} max	Actual R_f min	Actual R_f max	Gain R_f/R_{in}
3,300	3,30,000	20%	2,640	3,960	2,64,000	3,96,000	150.00
3,300	3,30,000	10%	2,970	3,630	2,97,000	3,63,000	122.22
3,300	3,30,000	1%	3,267	3,333	3,26,700	3,33,300	102.02
3,300	3,30,000	0.1%	3,297	3,303	3,29,670	3,30,330	100.20
3,300	3,30,000	0.010%	3,300	3,300	3,29,967	3,30,033	100.02

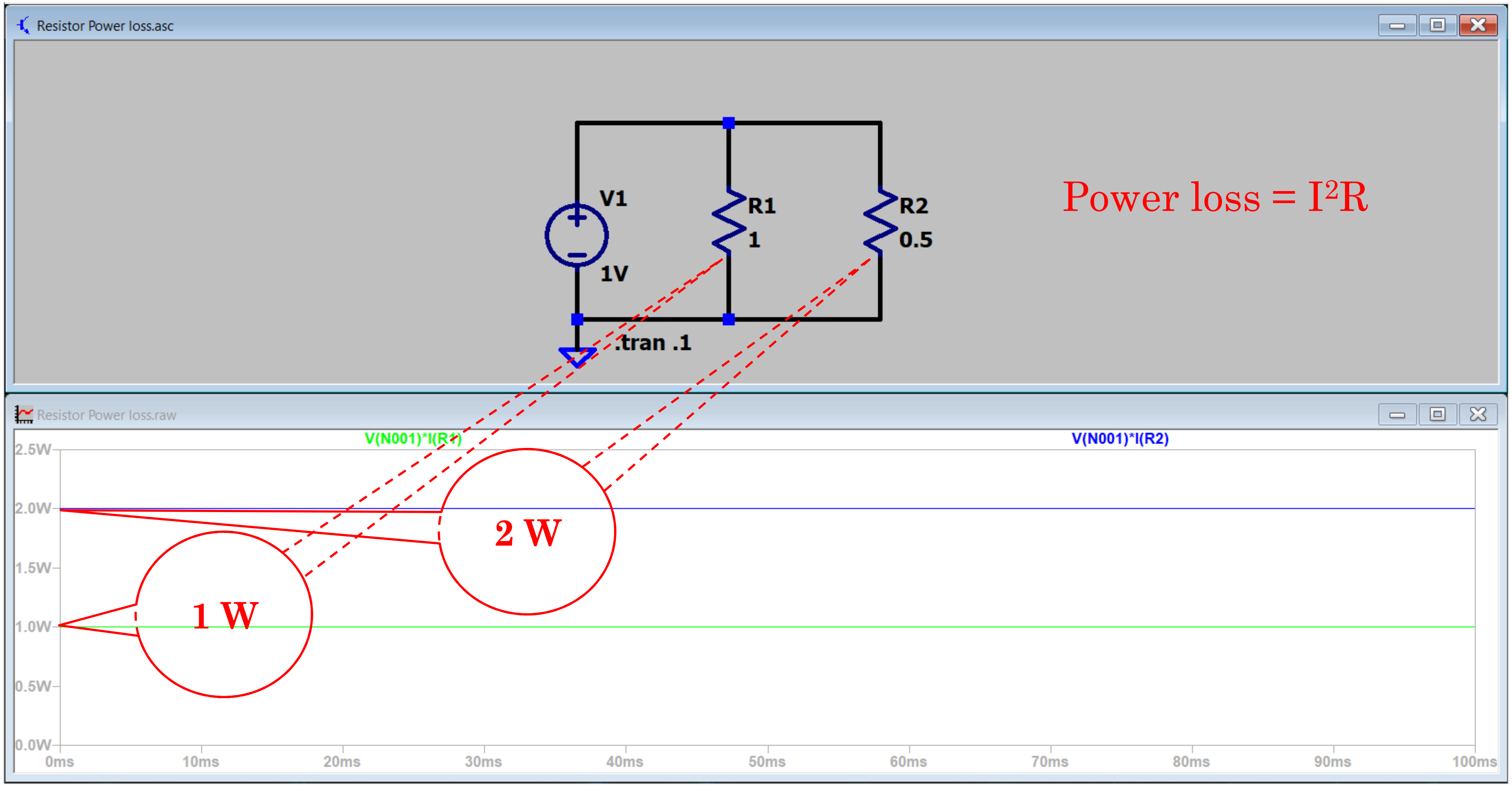
So, never forget to analyze, how the resistor tolerance can impact your circuits, then decide what tolerance levelis acceptable to your application requirements.

Selection consideration: Resistor Tolerance Vs Cost

- **Design aspect of Tolerance:** Higher tolerance of resistor can affect the gain of an amplifier; or affects the output voltage in case of an adjustable linear regulator or switching regulator etc.,
  - For ex: when we buy 5000 units of resistors, they are all not going to be of exact same value, due to the tolerance spec. Hence every board is going to have variation from the ideal value.
- **Cost aspect of Tolerance:** In general, resistors of lower tolerance value are costlier.
  - Hence, the designer needs to strike a balance between price and the circuit performance requirements

Go to https://www.digikey.in and https://www.mouser.in/ and go to section "Passives→ Resistors→ Through hole resistors" to experience what are all the difference tolerances are available and how are they priced

Heat generation in Resistors due to power loss



So, when you want to buy the resistor for R1, R2, how will you specify the power rating?

Importance of power rating of a resistor

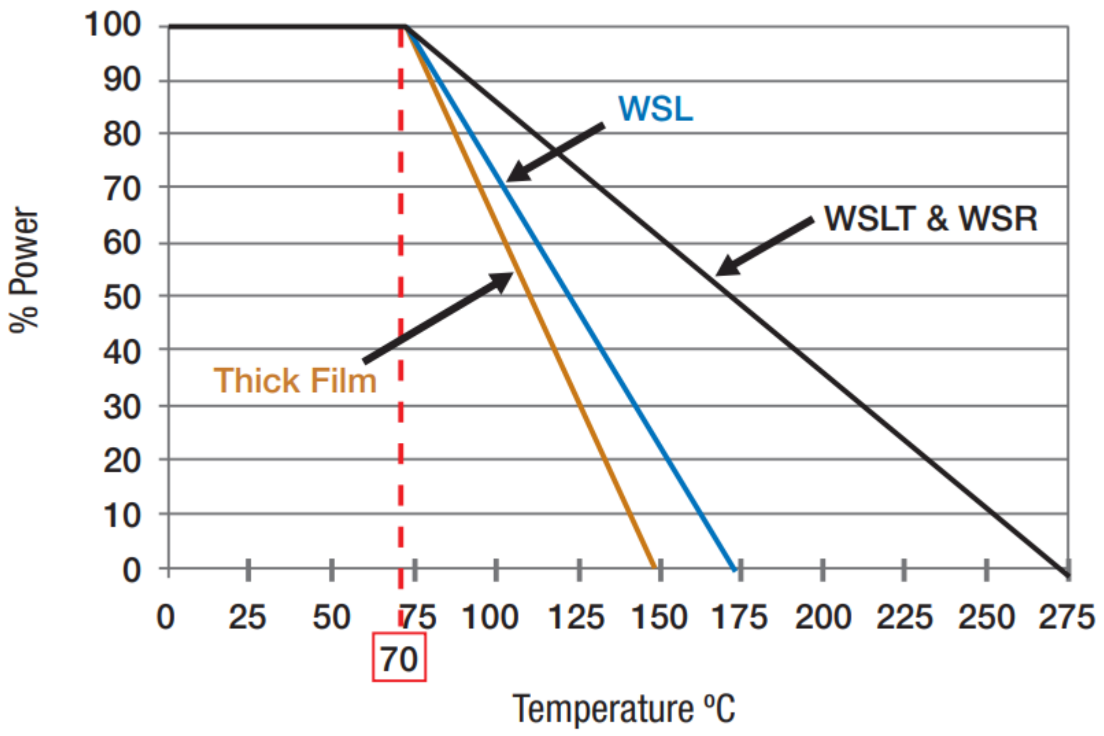
Power Rating: The power rating of a resistor indicates the maximum power it can dissipate as heat without being damaged. It is crucial because:

- Exceeding the power rating can cause the resistor to overheat, leading to failure or fire hazards. Staying within the rating ensures the resistor operates reliably over its intended lifespan.

Remember, the power loss and thereby the heat generated from a resistor won't be desirable as it increases the overall temperature of all the components surrounding it.

Power resistor derating for temperature

- Power rating of a resistor specifies what is the “safe power loss”, it can handle during operation without failure due to over temperature.
- Ex: Some of Vishay resistors can be operated at full rated power up to 70°C. Beyond this temperature, the part will need to be derated. (Derate linearly to 0 W at 150 °C (Thick film), at 175°C (WSL series), 275 °C (WSR series)



Assume you are using a thick film resistor at an ambient or environment temperature of 70°C and the component temperature rise is 30°C above ambient, what will be your power derating factor?

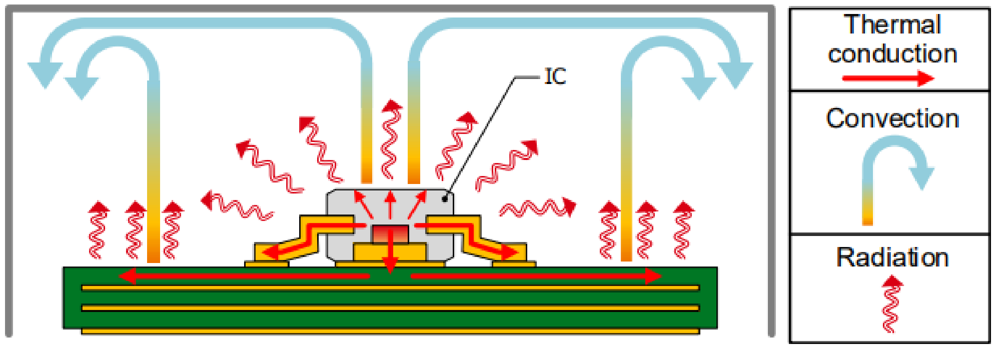
https://www.vishay.com/docs/30138/wslt2010.pdf

Temperature rise of a resistor

The temperature rise in a resistor depends on

1. The power loss and time (I^2R * T, T is Time in seconds)
2. How much of the heat generated in the resistor is taken away through Conduction, convection and radiation.

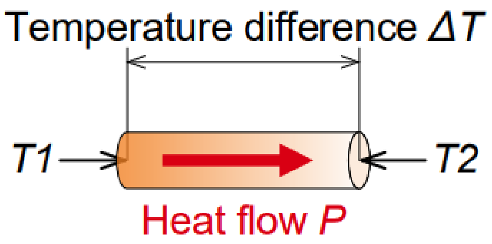
- **<u>Conduction:</u>** Spreading of the heat through the terminal of the component to the PCB. So larger the area of the PCB trace, higher the thickness of the trace, better is the heat transfer.
- **<u>Convection:</u>** Convection of the heat from the resistor to the fluid. Yes, the fluid here is "Air". So larger the surface area of the component, better will be the convection. Larger the flow of air around the component, better the heat transfer will be.
- **<u>Radiation:</u>** How much of heat is radiated from the component.



Overall, if more temperature is lost by conduction, convection and radiation, the absolute temperature of the component will be lesser. Component temperature = Ambient temperature in deg C + Heat rise in component in Deg C

What specs determines the temperature rise?

Thermal Resistance

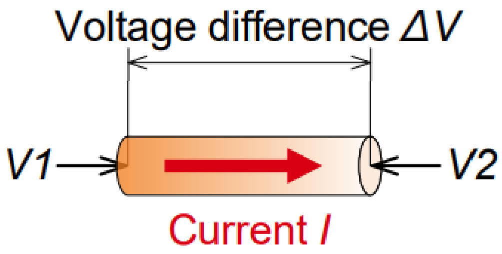


$$Thermal\ resistance\ Rth = \frac{T1 - T2}{Heat\ flow\ P}$$

$$= \frac{Temperature\ difference\ \Delta T}{Heat\ flow\ P} \quad [°C/W]$$

Electric	Voltage difference ΔV (V)	Electric resistance R (Ω)	Current I (A)
Thermal	Temperature difference ΔT (°C)	Thermal resistance Rth (°C/W)	Heat flow P (W)

Ohm's law analogy



$$Electric\ resistance\ R = \frac{V1 - V2}{Current\ I}$$

$$= \frac{Voltage\ difference\ \Delta V}{Current\ I} \quad [V/A]$$

Electric	$\Delta V = R \times I$	$R = \frac{\Delta V}{I}$	$I = \frac{\Delta V}{R}$
Thermal	$\Delta T = Rth \times P$	$Rth = \frac{\Delta T}{P}$	$P = \frac{\Delta T}{Rth}$

Courtesy: https://fscdn.rohm.com/en/products/databook/applinote/common/basics_of_thermal_resistance_and_heat_dissipation_an-e.pdf

How to calculate the temperature rise?

Change in temperature of the component can be found from

$$\Delta T = R_{thja} * P$$

ΔT = Change in temperature in deg C

R_{thja} = Thermal resistance from junction or heat source to ambient (Generally mentioned in the datasheet)

P = Power loss in the component

Absolute temperature of component = $\Delta T + T_{amb}$

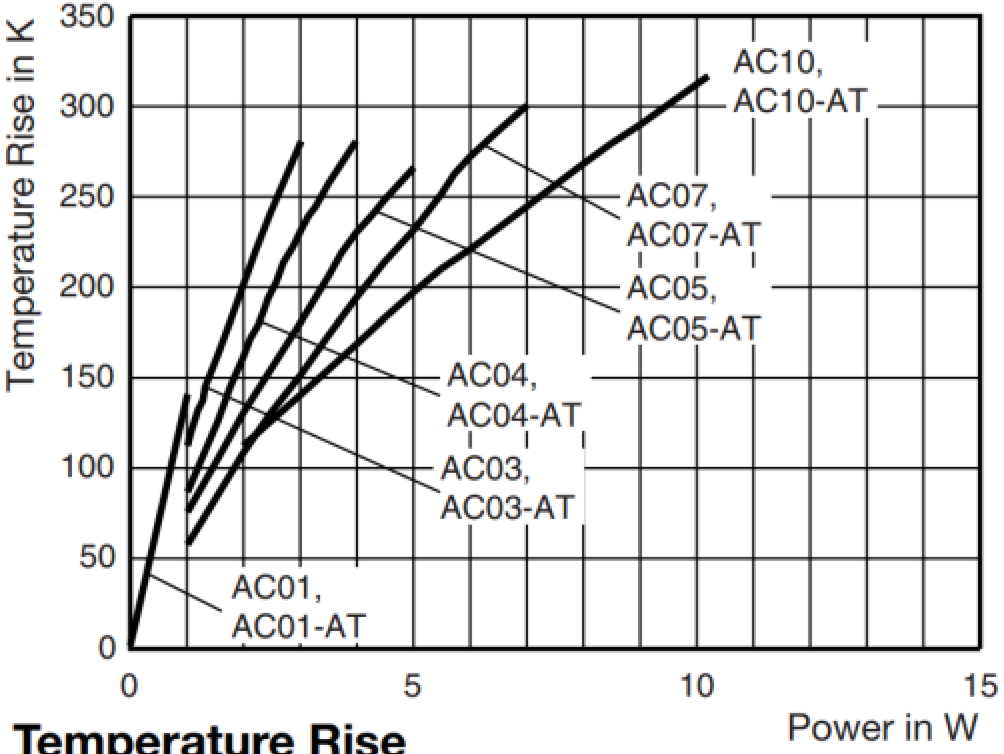
T_{amb} = The Max ambient temperature at which your end product is supposed to work

Consumer-grade : 0°C and 70°C.

industrial-grade: -40°C to +85°C.

Automotive-grade : -40°C to +105°C or even up to +125°C)

If is R_{thja} not available in the datasheet, look for this characteristics

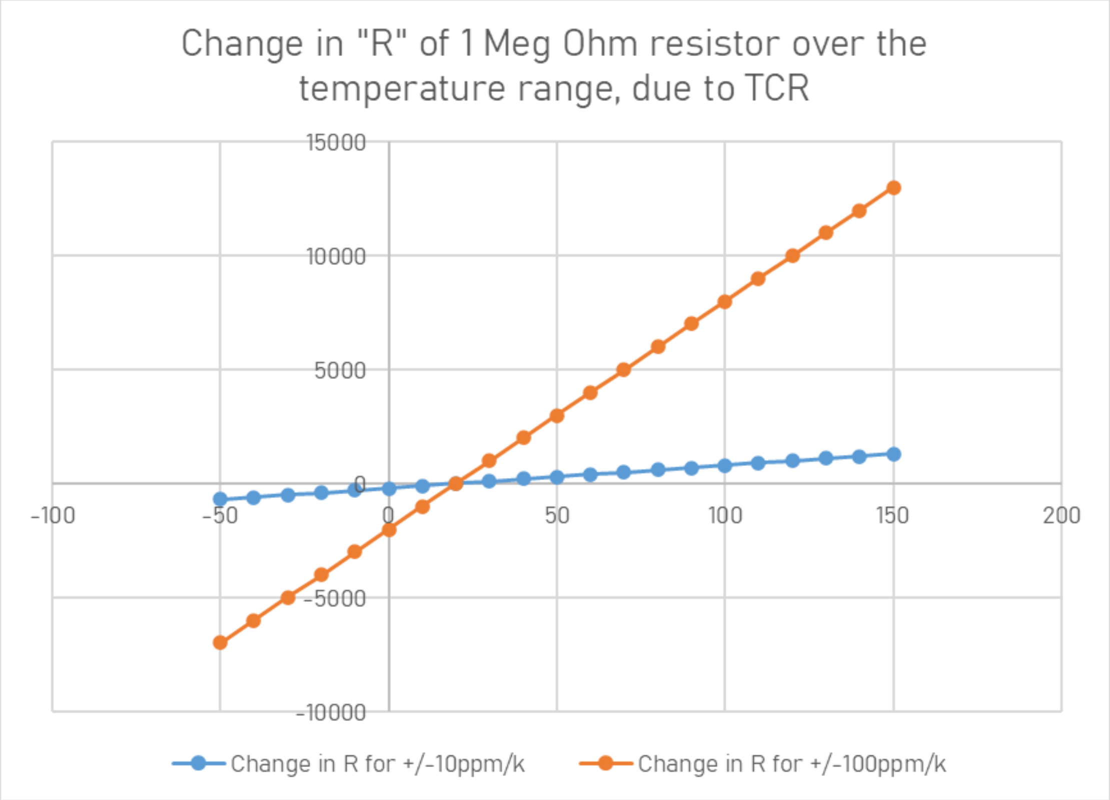


Temperature Rise

https://www.vishay.com/docs/28730/ac_ac-at_ac-ni.pdf

Temperature Co-efficient of Resistance

- TCR is a measure of how much a material's electrical resistance changes with temperature, typically expressed in **parts per million per degree Celsius (ppm/°C)**
- $TCR = \frac{\Delta R/R_0}{\Delta T} \times 10^6$ (in ppm/°C)
- ΔR = Change in resistance
- R_0 = Resistance at the reference temperature (for ex: at 25°C)
- ΔT = Change in temperature with respect to the reference temperature ($T-T_0$)



The product design may need to operate for commercial / Industrial / Automotive / Military temperature grades. So do the analysis on how the TCR of resistors selected can impact the circuit operation and choose the right component. Also remember, low TCR resistances can be costlier.

Change in R due to TCR

Example Scenario:
Initial Resistance (R_0): **10,000** ohms (at a reference temperature of 25°C)
TCR: +200 ppm/°C (positive, meaning resistance increases with temperature)
Temperature Change (ΔT): The temperature rises from 25°C to 75°C, a change of 50°C.

Step-by-Step Calculation:
TCR of +200 ppm/°C = 200×10^{-6} °C^{-1} = 0.0002 °C^{-1}

Change in Resistance (ΔR):
The change in resistance is given by: $\Delta R = R_0 \times \text{TCR} \times \Delta T$
Plugging in the values: $\Delta R = 10{,}000 \times 0.0002 \times 50 = 100$ ohms

New Resistance (R):
The new resistance after the temperature change is: $R = R_0 + \Delta R = 10{,}000 + 100$ = **10,100** ohms
So the resistance has changed by +1%

Applications where low TCR is critical:
- High-precision instrumentation
- Precision Current sensing
- Laser Driver

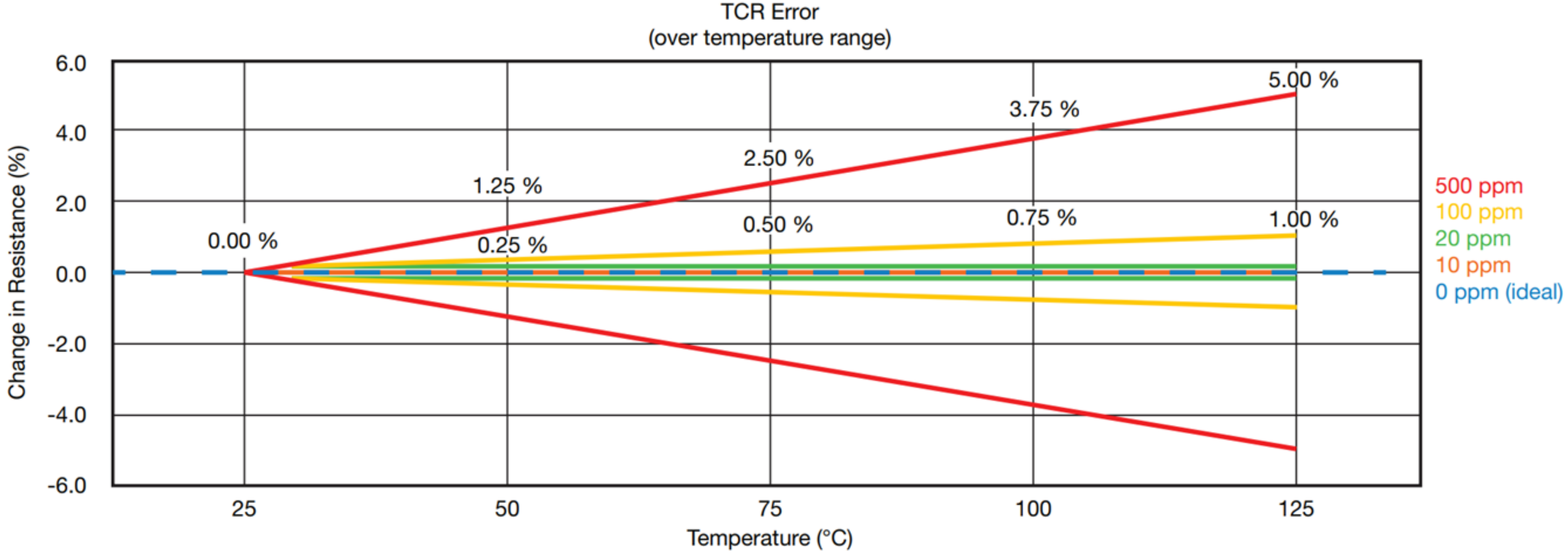
Never forget to analyze, how the TCR can impact your circuit, then decide what is acceptable to your application requirements.

https://www.vishay.com/docs/60131/pltu.pdf

TCR of different resistor materials

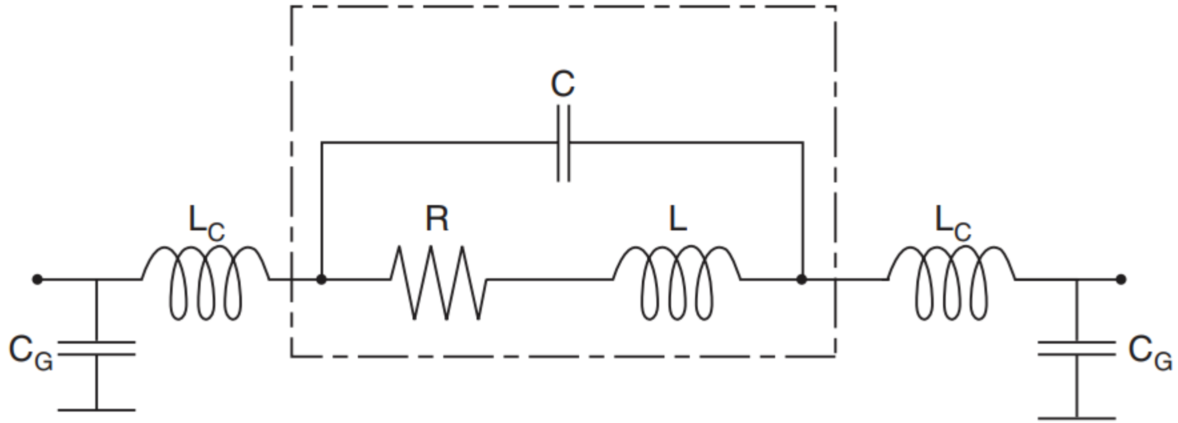
TCR, ppm/°C OF VARIOUS RESISTOR ELEMENT MATERIALS				
Temperature range	-55 °C to +25 °C	0 °C to +25 °C	+25 °C to +60 °C	+25 °C to +125 °C
Manganin	+50	+10	-5	-80
Zeranin	+20	± 2.5	± 5.0	+10
Evanohm	+5.0	+2.5	-2.5	-5.0
Foil	-1.0	-0.3	+0.3	+1.0
Thin film	-10	-5.0	+5.0	+10
Thick film	-100	-25	+50	+100

The following graph compares different TCR levels as a percentage change in resistance versus increasing temperature from 25 °C.



Parasitic L and C in Resistors

- Resistor does possess a small amount of parasitic inductance and capacitance due it's construction. Although this does no harm at low frequency circuits, at high frequencies the impedances of these parasitic elements start dominating.



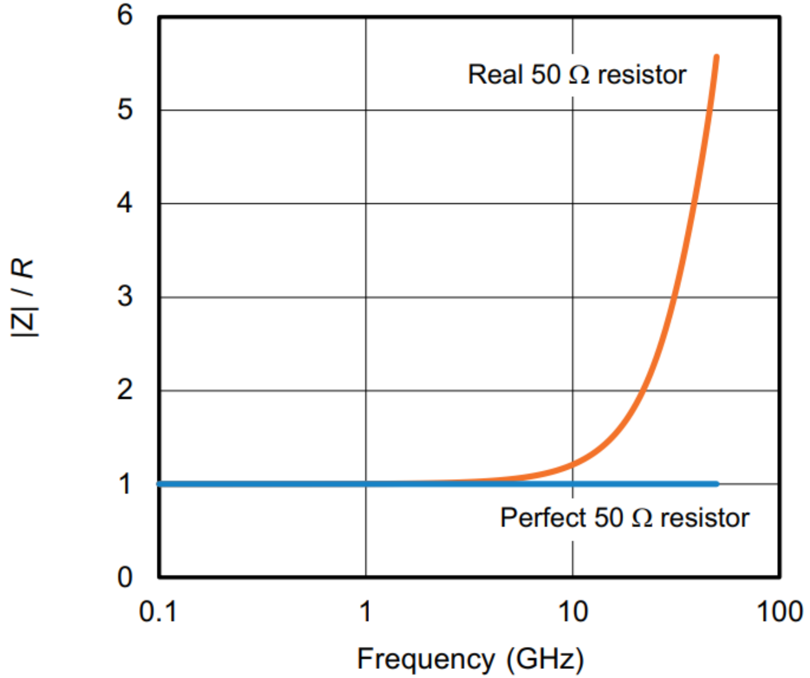
C: internal shunt capacitance

L: internal inductance

R: resistance

L_C: external connection inductance

C_G: external capacitance to ground

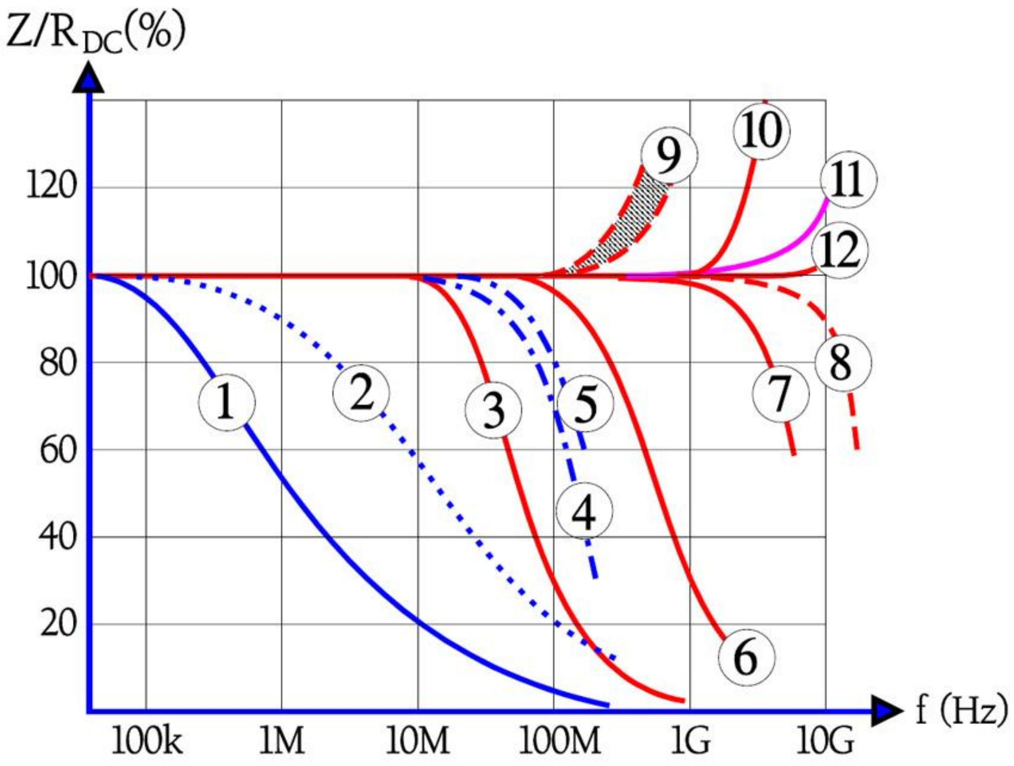


As the frequency increases, the impedance deviates from 50 Ω

Courtesy: https://www.vishay.com/docs/60107/freqresp.pdf

Courtesy: https://www.vishay.com/docs/53077/microwavethinfilmres.pdf

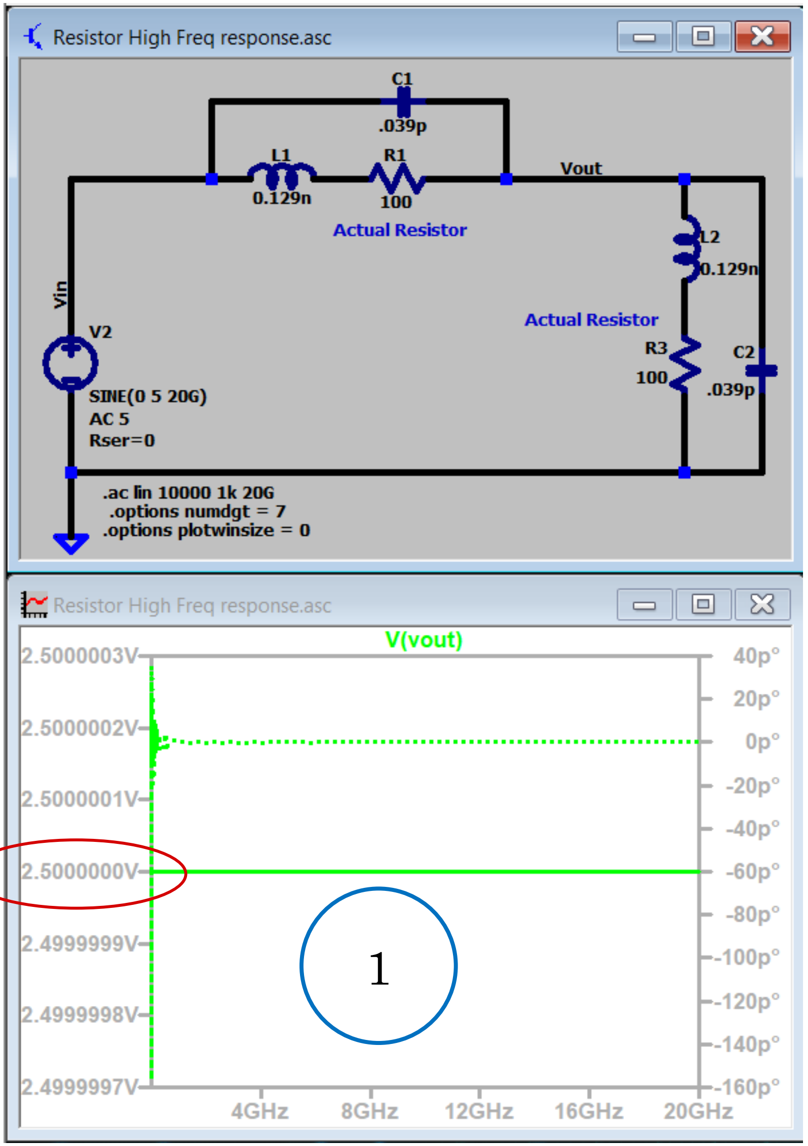
Z/R of characteristics of resistance

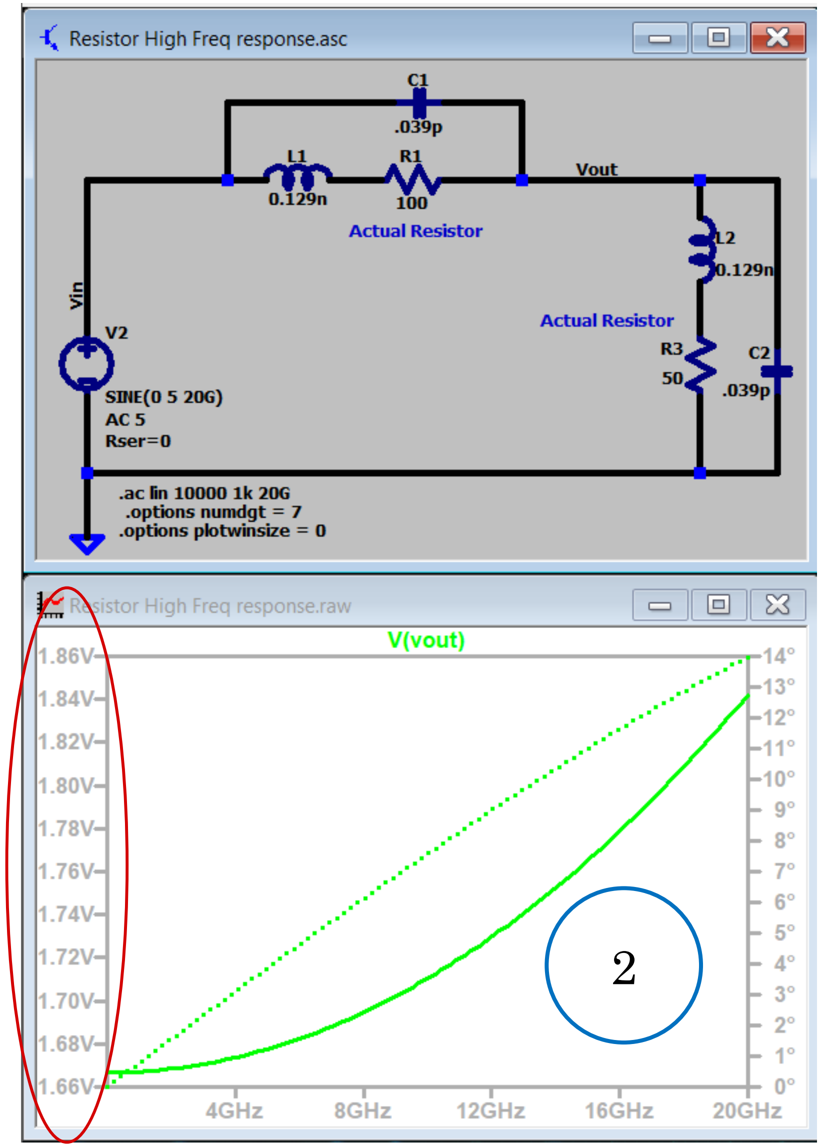


Examples of frequency dependence as the ratio of AC impedance through DC resistance for different resistor types:

- Carbon composition, ¼ W, 1 MΩ .
- Carbon composition, ¼ W, 100 kΩ .
- Chip, thick film, EIA size 0603, 100 kΩ ; c » 0.05 pF; L » 0.4 nH.
- Metal glaze or metal film, DIN size 0207, 100 kΩ ; c » 0.4 pF.
- MELF, DIN size 0204, 10 kΩ .
- Chip, thick film, EIA size 0603, 10 kΩ ; c » 0.05 pF; L » 0.4 nH.; Chip, metal foil, EIA size 1210, 10 kW.
- Chip, thick film, EIA size 0603, 1 kΩ ; c » 0.05 pF; L » 0.4 nH.
- MELF, DIN size 0102, high frequency design, 10 Ω ; c » 0.035 pF; L » 0.8 nH.
- MELF, DIN size 0204, 10 Ω .
- Chip, thick film, EIA size 0603, 10 Ω ; c » 0.05 pF; L » 0.4 nH.
- Chip, thin film, EIA size 0603, 100 Ω ; c » 0.035 pF; L » 1.2 nH.
- Chip, thick film, EIA size 0603, 100 Ω ; c » 0.05 pF; L » 0.4 nH.

Frequency response of a Resistor





- 1) When both voltage divider resistors are of same value, say 100 Ohms, the voltage across them is equal for frequencies from 1KHz to 20GHz. The change in impedance in both resistors cancels each other. (Although current through the circuit will change).
- 2) When one of them is changed to say 50 Ohms, the voltage across them is no more balanced. This is due to different Z/R for each resistors. This is one example where parasitic in resistor can affect intended circuit response

Construction to reduce Parasitic L in Resistors

- Manufacturer utilise certain techniques to reduce the parasitic inductance and capacitance. For use in RF, high speed circuits, look for resistors specific for high frequency applications.

TABLE 1 - PARAMETERS FOR DIFFERENT CASE SIZES UTILIZED

CASE SIZE	LENGTH (inch/ mm)	WIDTH (inch/ mm)	RESISTOR AREA (inch²/ mm²)	MODEL INTERNAL COEFFICIENTS	
				C (pF)	L (nH)
0201	0.02/ 0.51	0.01/ 0.25	0.00004/ 0.02581	0.0206	1.73×10^{-5}
0402	0.04/ 1.02	0.02/ 0.51	0.000352/ 0.22710	0.0262	1.89×10^{-3}
0402 (wrap)	0.04/ 1.02	0.02/ 0.51	0.000352/ 0.22710	0.0392	0.1209
0603	0.064/ 1.626	0.032/ 0.813	0.000816/ 0.52645	0.0403	0.0267

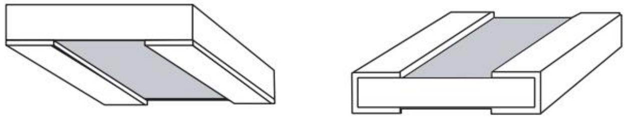


Fig. 1 - Termination styles:
Left - flip chip, resistor down
Right - wrap around, resistor up

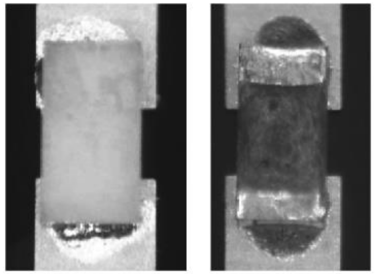
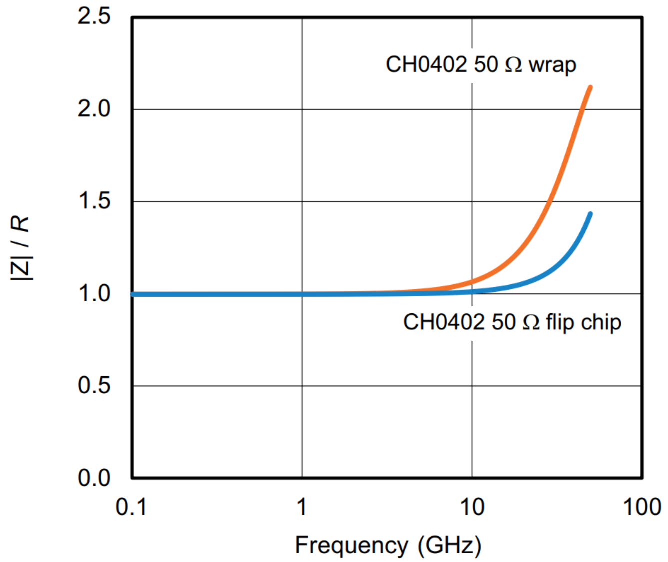
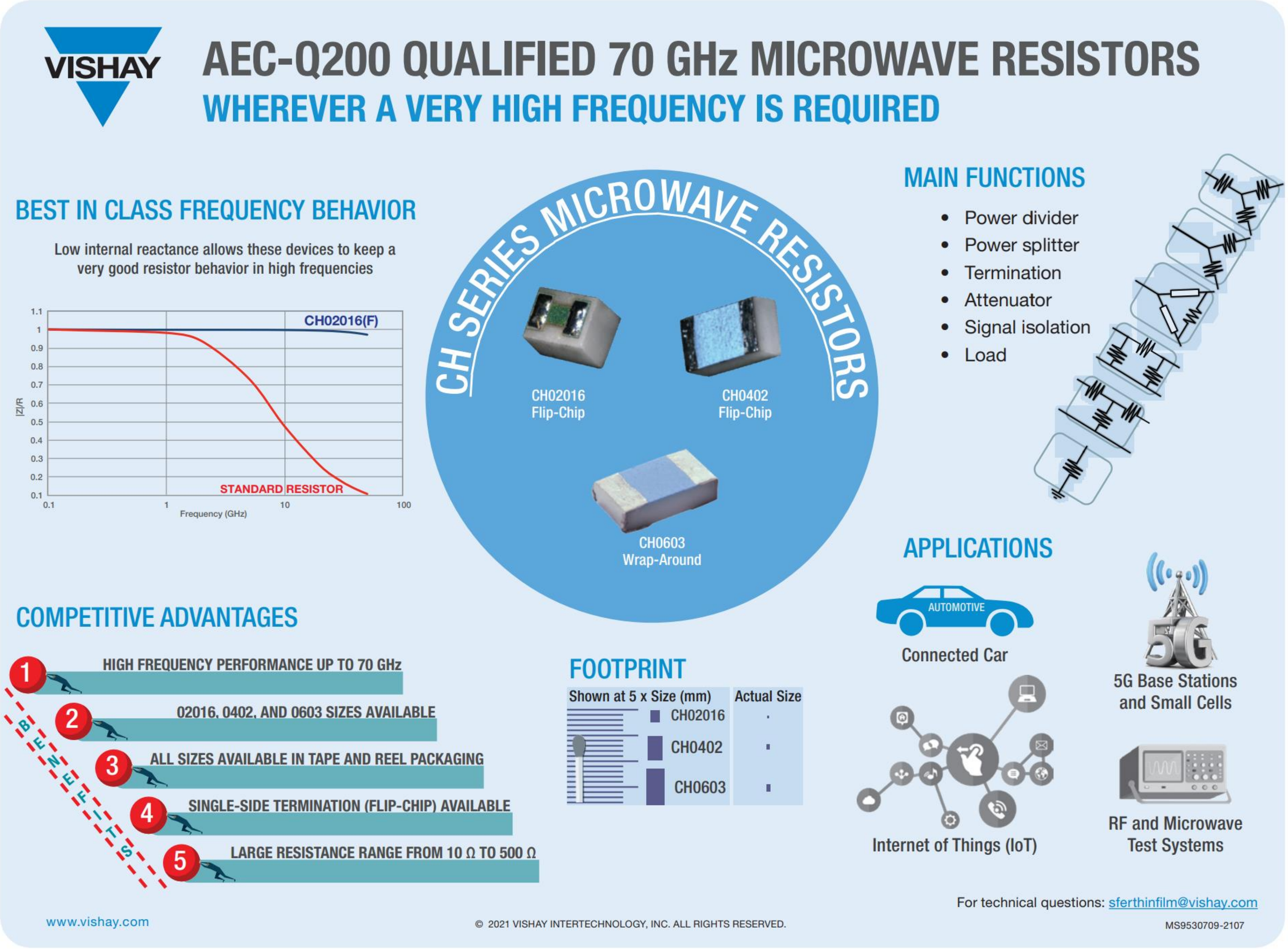


Fig. 2 - Mounting on resistors on RF grounded quartz substrates for testing
Left - flip chip, resistor down
Right - wrap around, resistor up



https://www.vishay.com/docs/53077/microwavethinfilmres.pdf

Courtesy: https://www.vishay.com/docs/60107/freqresp.pdf

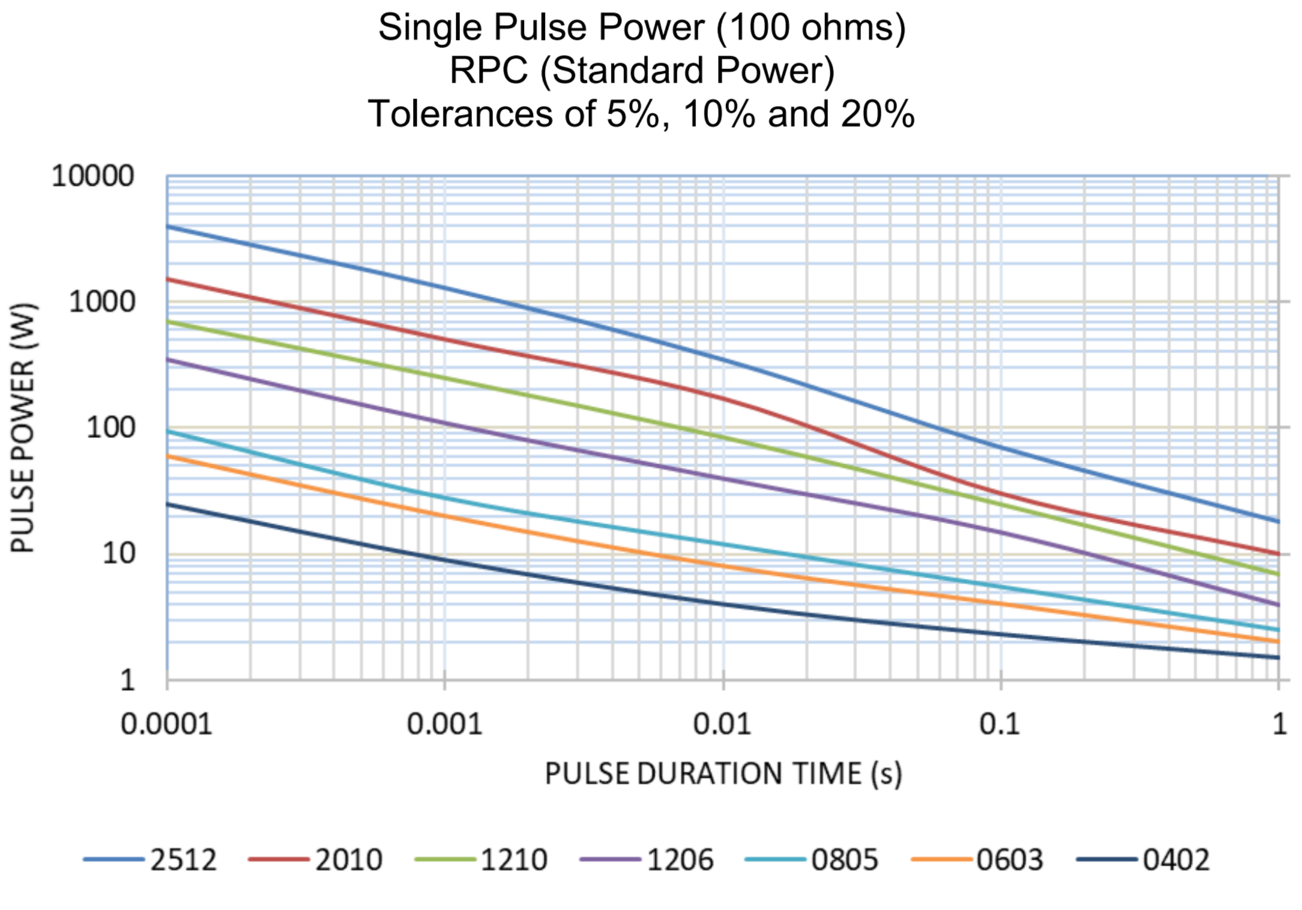


Courtesy: https://www.vishay.com/docs/48510/_ms9530709-2106-infographic_ch.pdf

Pulse withstanding Resistors

- There are applications where the peak power to be handled by a resistor can be several 100 times of its maximum continuous power rating. (Surge protection, inrush current limiting, Pre-charge circuits
- For example, when an automotive BMS needs to power the load, as the load may have a higher capacitance due to loads (10's of milli farads), we need to connect the load first through a pre-charge resistor and once the load voltage reaches a level, the main contactor can be closed bypassing the pre-charge resistor.
- Assuming a pre-charge resistor of 10 Ohms, and load capacitance of 30 milli Farads, At t = 0ms P = 230.4W; At t = 300ms P= 31.1W; At t = 600ms P=4.15W; At t = 900ms P = 0.58W; At t = 1500ms P = 0W.
- In this case, the peak power goes up to 230W and within a second, it comes down to 0.5W. So what power rating of resistor can be used here?

Pulse withstanding Resistors - Specs

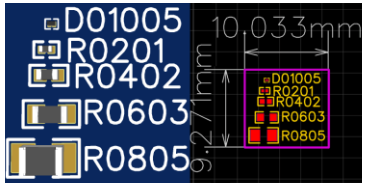


https://www.seielect.com/catalog/sei-rpc.pdf

- As per the pulse withstanding graph from “Stackpole Electronics” either the 2010 or 2512 package SMD resistor can easily handle the requirement discussed before.
- The continuous power rating of RPC2512 is just 1.5W, however this resistor can safely handle the pulse power requirement previously
- Note: Do check the Power Derating Curve to ensure safe operation within your operating temperature condition.

But what if the load has a short circuit fault when the Pre-charge circuit is turned on ?!

Voltage rating of Resistors



- **Maximum Rated voltage:** Voltage that can be applied safely (without arcing) which is limited by size of the resistor is referred to as the max working voltage.

- It is an important rating to observe, especially in SMD resistors as the pad-to-pad distance/gap gets smaller with smaller dimension resistors.

Code		Length (l)		Width (w)		Height (h)		Power
Imperial	Metric	inch	mm	inch	mm	inch	mm	W
0201	0603	0.024	0.6	0.012	0.3	0.01	0.25	1/20
0402	1005	0.04	1.0	0.02	0.5	0.014	0.35	1/16
0603	1608	0.06	1.55	0.03	0.85	0.018	0.45	1/10
0805	2012	0.08	2.0	0.05	1.2	0.018	0.45	1/8
1206	3216	0.12	3.2	0.06	1.6	0.022	0.55	1/4
1210	3225	0.12	3.2	0.10	2.5	0.022	0.55	1/2
1812	3246	0.12	3.2	0.18	4.6	0.022	0.55	1
2010	5025	0.20	5.0	0.10	2.5	0.024	0.6	3/4
2512	6332	0.25	6.3	0.12	3.2	0.024	0.6	1

Max Working Voltage

(Unit: V)

Item \ Dim	0402 (01005)	0603 (0201)	1005 (0402)	1608 (0603)	2012 (0805)	3216 (1206)	3225 (1210)	5025 (2010)	6432 (2512)
Max Working	15	25	50	50	150	200	200	200	200

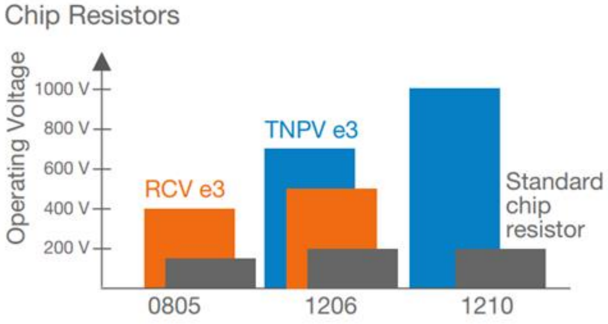
Assume 1000V DC needs to be measured by an ADC which can accept 5V max. Can we use just two resistors (100KOhm, 2K Ohm) to attenuate 1000V to 5V?

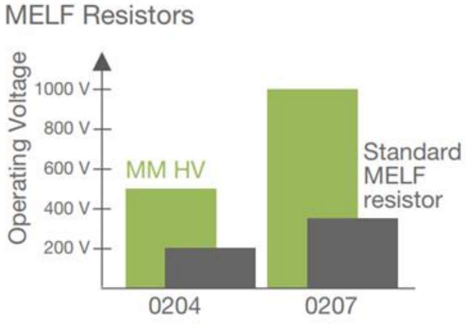
Courtesy: https://www.samsungsem.com/resources/file/global/support/product_catalog/Chip_Resistor.pdf

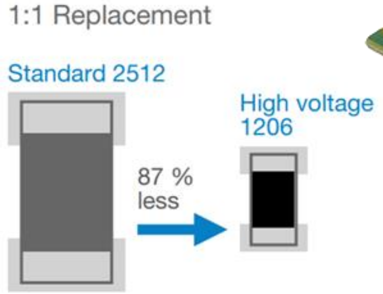
High Voltage resistors

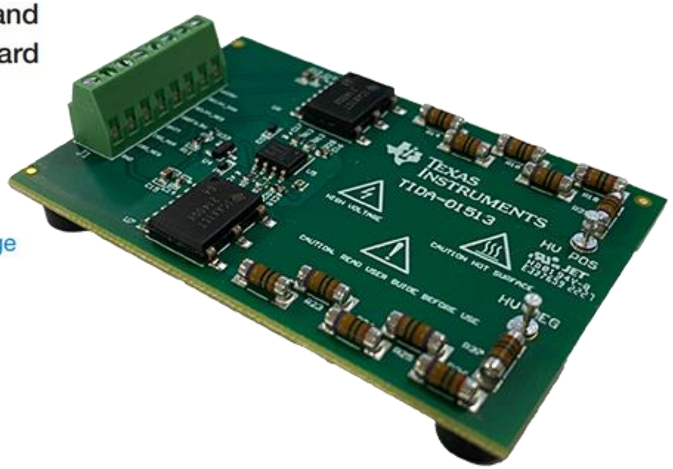
Today, various industrial and automotive applications operate at high voltages, which are significantly larger than the permissible operating voltage of a single SMD resistor. Thus, multiple resistors are typically used in series to distribute the voltage load. This workaround becomes unnecessary with the use of high voltage resistors, which combine a high operating voltage rating with a low voltage coefficient.

Operating Voltage — The significantly increased operating voltage allows up to five standard components to be replaced by a single high voltage resistor of the same case size. Besides component count reduction, board space will be saved and placement costs reduced. Since the voltage rating even exceeds that of standard components in the next case size, board space savings can also be achieved by 1:1 replacement with a smaller component.

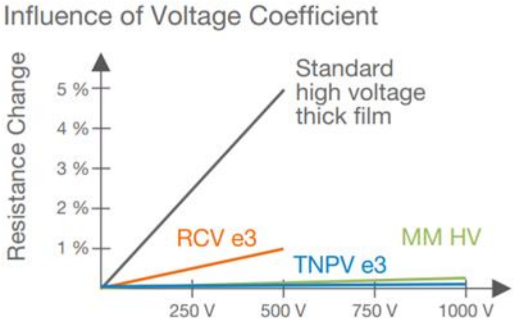








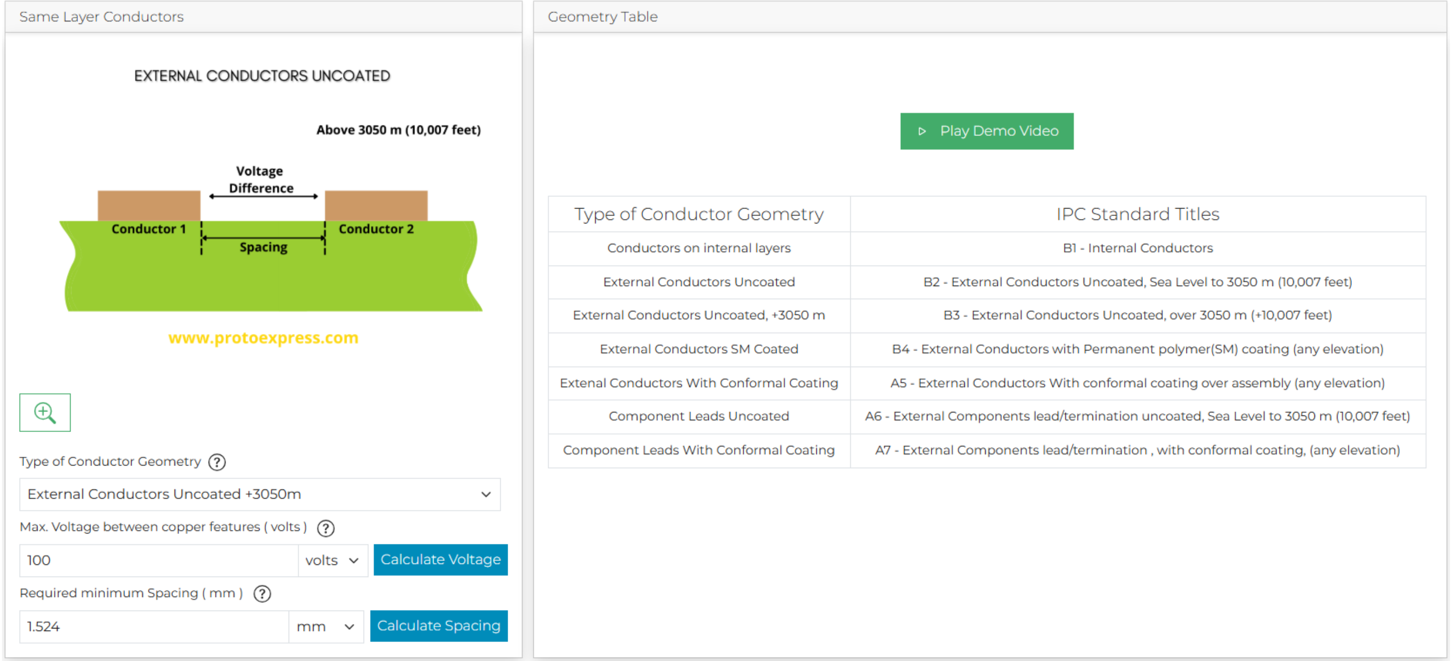
Voltage Coefficient — The voltage coefficient of resistance (VCR) indicates the resistor's permissible change of resistance, depending on the operating voltage. Hence, using high voltage resistors at the allowed elevated voltage levels may cause a significant resistance change. Thus, high precision applications will benefit from thin film resistors, which feature an especially low VCR of ≤ 2 ppm/V.



https://www.vishay.com/docs/48552/_ms11394929-1905-did_you_know-_smd_hv_resistors.pdf

Minimum trace spacing requirements in a PCB

Like resistor packages have a definite max working voltage, while doing PCB Layouts, for a given voltage between two adjacent traces, there must be a minimum spacing to be provided for safe operation. This distance value is influenced by whether the conductors are in the internal layer or external layer, if it is external layer, whether it has a protective coating on the components or not, what is the altitude of operation for the PCB etc.,(As per IPC2221 standard for creepage and clearance)



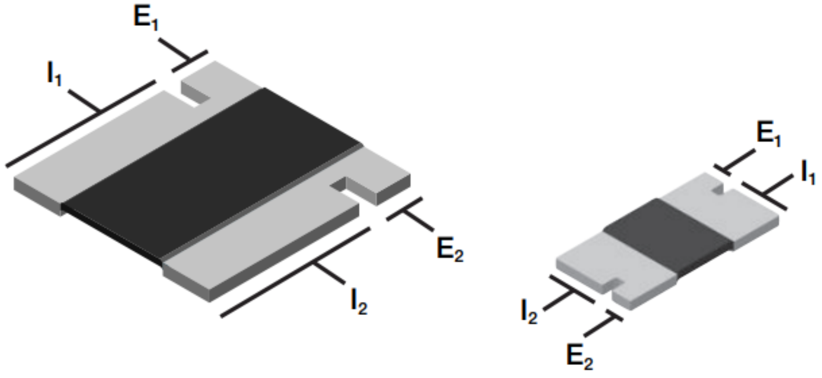
Type of Conductor Geometry	IPC Standard Titles
Conductors on internal layers	B1 - Internal Conductors
External Conductors Uncoated	B2 - External Conductors Uncoated, Sea Level to 3050 m (10,007 feet)
External Conductors Uncoated, +3050 m	B3 - External Conductors Uncoated, over 3050 m (+10,007 feet)
External Conductors SM Coated	B4 - External Conductors with Permanent polymer(SM) coating (any elevation)
Extenal Conductors With Conformal Coating	A5 - External Conductors With conformal coating over assembly (any elevation)
Component Leads Uncoated	A6 - External Components lead/termination uncoated, Sea Level to 3050 m (10,007 feet)
Component Leads With Conformal Coating	A7 - External Components lead/termination , with conformal coating, (any elevation)

Try the online tool “PCB Conductor Spacing and Voltage Calculator” from Sierra Circuits

[PCB Conductor Spacing and Voltage Calculator | Sierra Circuits]

Courtesy: https://www.protoexpress.com/blog/importance-pcb-line-spacing-creepage-clearance/

Current Shunts / Shunt Resistors



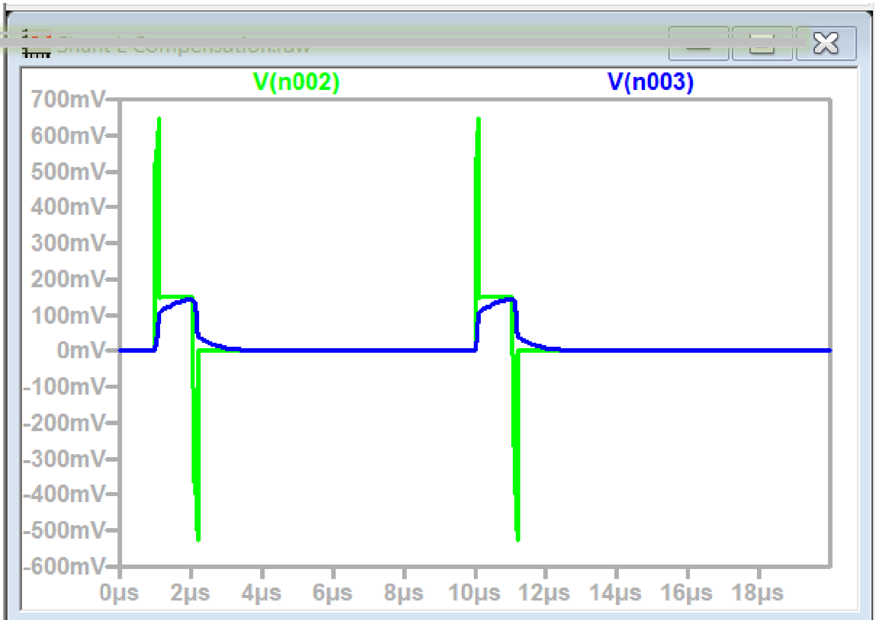
(E_1 & E_2 Voltage Connections, I_1 & I_2 Current Connections)

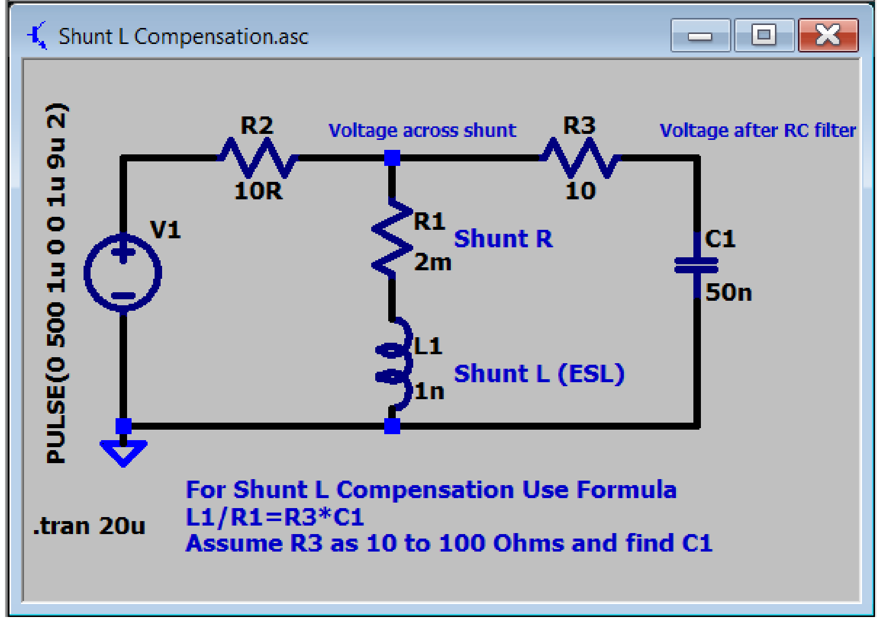
- Resistor used for current measurement. (Measure voltage drop and use I = V/R)
- Very low resistance value to keep the power loss minimal (0.1 milli ohms to 10's of milli Ohms), capable of carrying higher current.
- For high frequency switching applications, ESL should be low.

https://www.vishay.com/docs/30304/currentmeasurement.pdf

Effect of ESL in shunts due to fast switching currents

- Current shunts are used for current sensing in Motor inverters, Battery management systems, DC-DC Converters, etc.,
- High current shunts being metal, they inherently have parasitic inductance (ESL). This is typically around 1nH~5nH
- While this inductance may not be an issue in DC current measurements, in high frequency circuits with fast rise and fast fall of current, the ESL causes positive voltage spike while the current rises and negative spike when the current tries to become zero. (Counter emf = -L*di/dt)
- This needs to be eliminated to protect the ADC input, from excessive positive and negative voltage spikes.





Construction of Shunt for low ESL

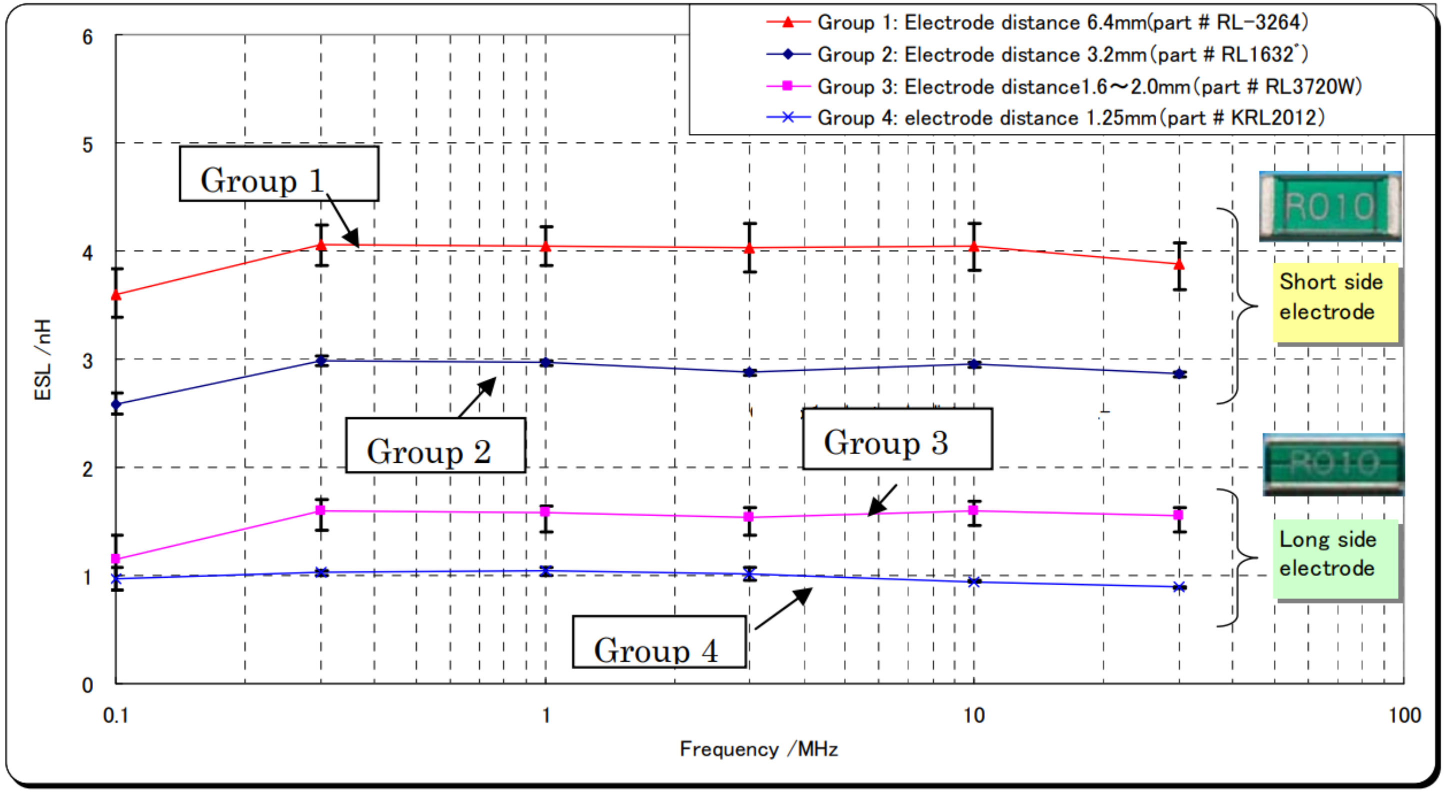
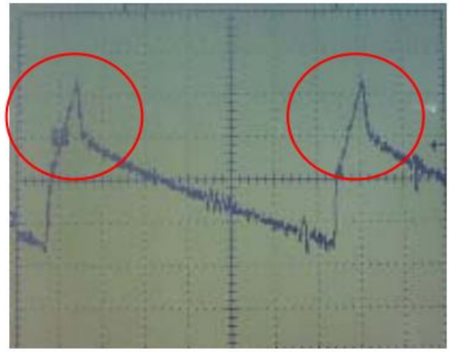


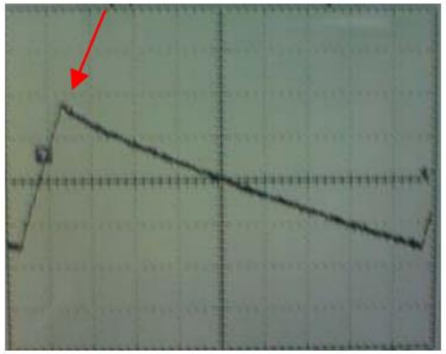
Figure 2 ESL comparison: long side terminal vs. short-side terminal

Actual measurement example



Picture 1 with short side terminal

Reduced noise



Picture2 with long side terminal

https://www.newark.com/pdfs/techarticles/susumu/LowESLCurrentSensingChipResistor.pdf

Noise in Resistors

- Noise in resistors arises from the physical processes within the resistive material and its interaction with the environment.

- Resistor noise has several components. The most relevant for audio, medical, high precision instrumentation applications, are "thermal noise" and "current noise".

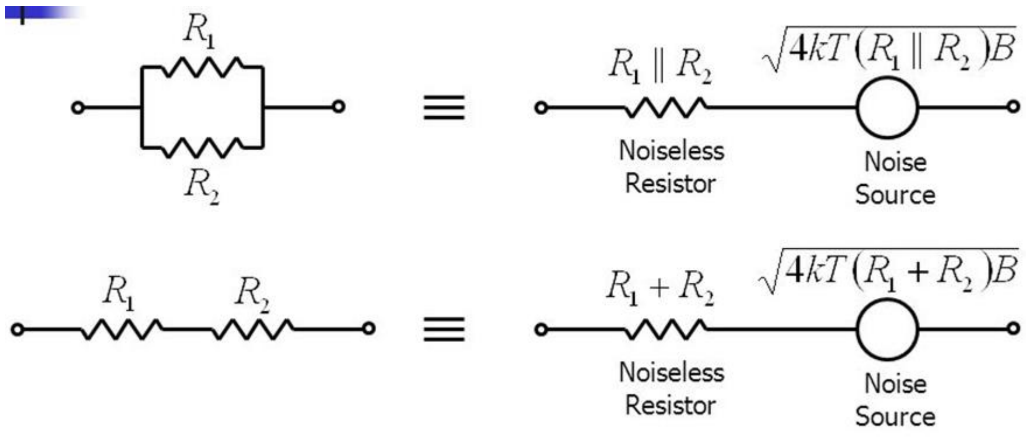
- Resistors, like other passive components, are noise sources to various degrees, depending upon resistance value, temperature, applied voltage, and resistor type.

Thermal / Johnson's noise

- The random thermal movement of charge carriers in a conductor always produces electrical noise of value

$$\sqrt{4kTBR}$$

- k is Boltzmann's Constant (1.38065 x 10^{-23} J/K),
- T is the absolute temperature in Kelvin,
- B is the bandwidth in Hz and
- R the resistance in Ohms.



NB. When adding noise sources, the result is the root of the sum of squares.

1/f or Current noise

- If we record a DC current through an electrical conductor, we would at a sufficiently high amplification be able to see small randomly occurring ripples on the "surface".
- Current noise, has a direct relationship to the type of resistive material. The spectral density of voltage of current noise S_E is found experimentally to be directly proportional to the square of DC voltage drop U across the resistor and inversely proportional to the frequency f
- $S_E = C * U2 / f$
- C is a constant that depends on material of the resistive element and its manufacturing process

Current, Thermal noise in resistors

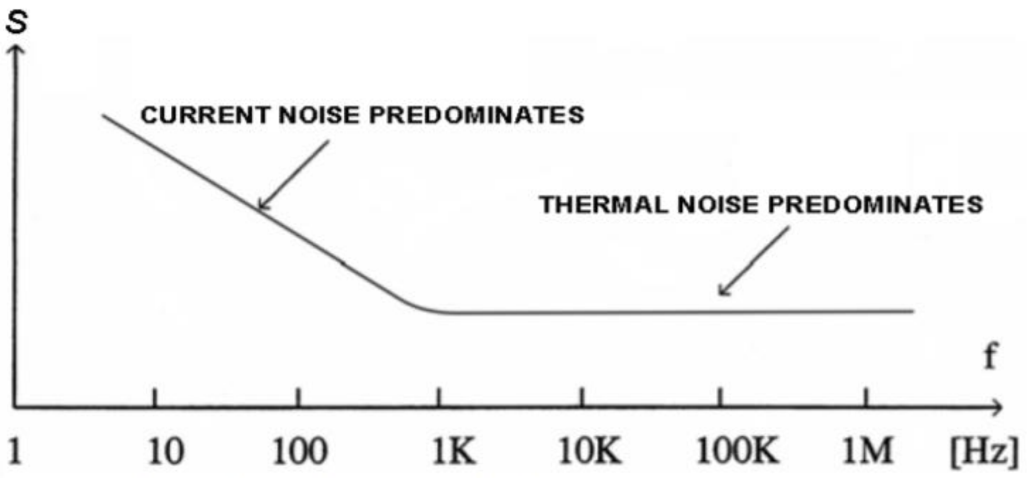
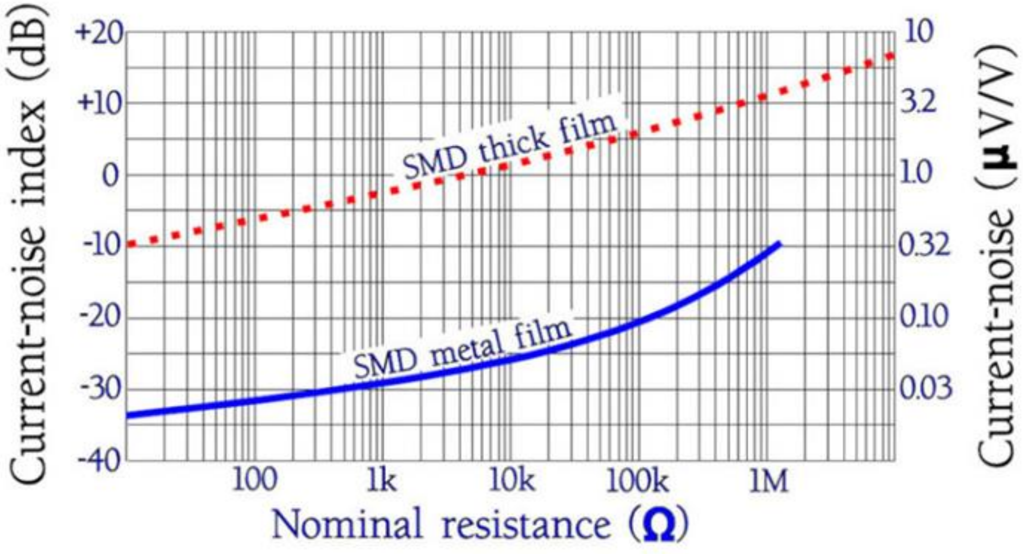


Fig.1: Spectral density of total noise voltage in resistor.

- RESISTOR NOISE EXAMPLE
- For a 100 kΩ resistor, let's find its power spectral density
- S = 4 k T R
  = 4 x1.38 x10^{-23} x 300 x 100k
  = 1.66 x 10^{-15} (V2 / Hz)
- and voltage spectral density
- N = S ½
  = (4 k T R) ½
  = 40.7 x 10^{-9} (V / Hz½)
- At first, 40 nV/Hz½ doesn't sound like much. But suppose you are designing a low-noise design amplifier using a quiet op amp with an input voltage noise of only 4 nV/Hz½ . You wouldn't want to kill the party by using a 100k boom box as a feedback resistor. Smaller R values around 1k would be a better choice.

Courtesy: http://www.ecircuitcenter.com/Circuits/Noise/Noise_Analysis/res_noise.htm

Noise of different materials



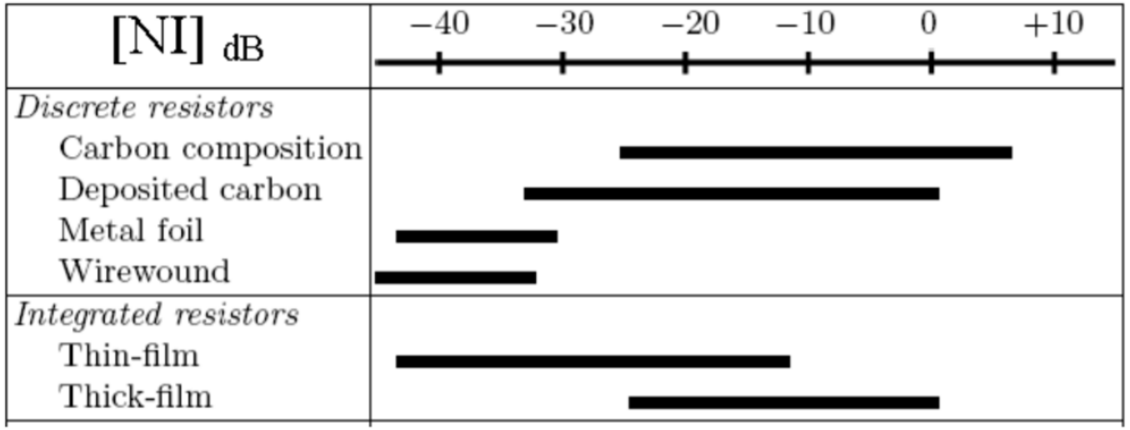


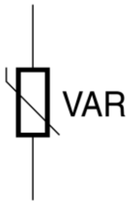
Fig.2: Average noise indexes of commercial resistors [2, p.168].

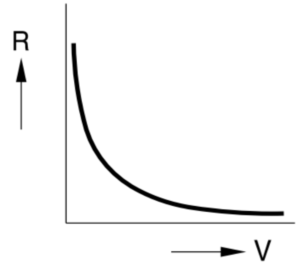
So which material type has the lowest current noise / Noise Index?

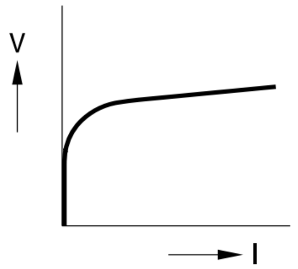
Metal Oxide Varistors (MOV)

- MOV (Metal Oxide Varistor) is a voltage-dependent resistor used for overvoltage protection.
- Exhibits nonlinear resistance: high resistance at normal voltage, low resistance during surges.
- Composed of zinc oxide (ZnO) grains with metal oxide additives, sintered into a ceramic disc.
- Operates by clamping excess voltage and diverting surge current to ground.
- Widely used in electronic circuits to safeguard against lightning, transients, and power surges.

- AC Power Lines: Surges from lightning strikes or switching operations can exceed 1KV, damaging equipment unless mitigated by MOVs or surge arresters.
- Across a Relay coil: Coil de-energization induces back-EMF surges (up to 10x operating voltage), risking relay or circuit damage without flyback diodes or MOVs.

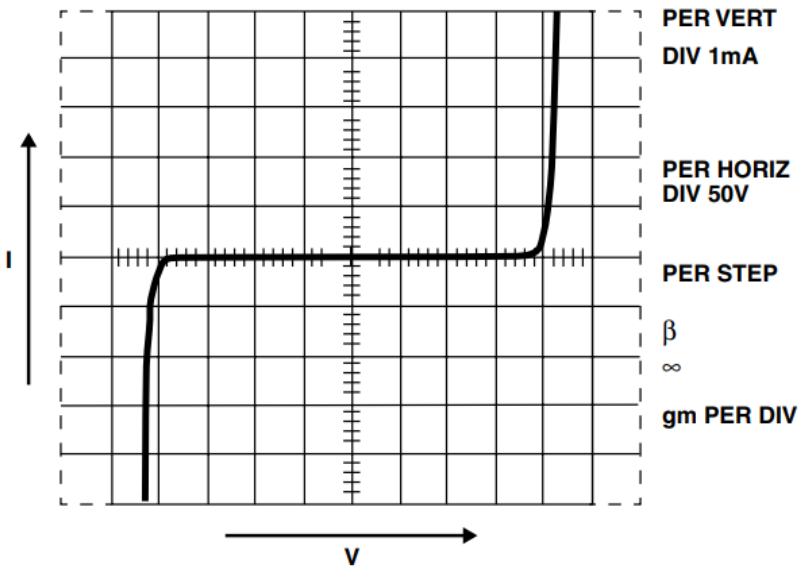




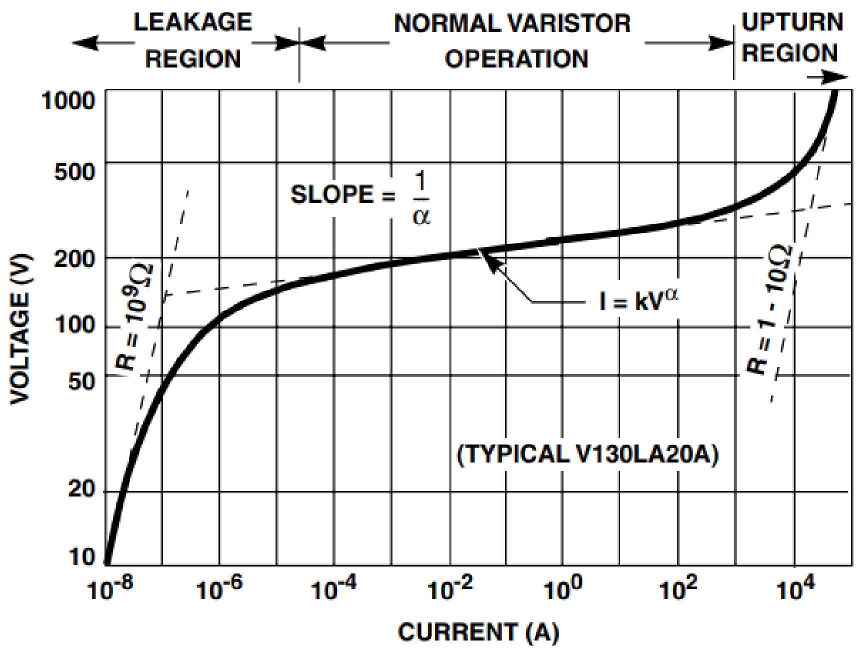


Characteristics of Varistor

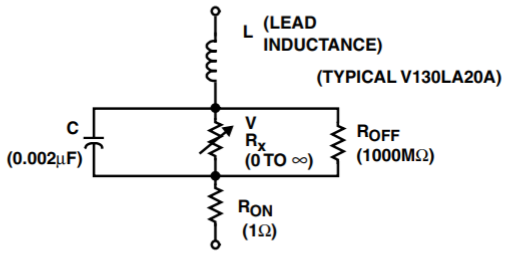
TYPICAL VARISTOR V-I CHARACTERISTIC



TYPICAL VARISTOR V-I CURVE



VARISTOR EQUIVALENT CIRCUIT MODEL



Varistors are voltage dependent, nonlinear devices which have an electrical behavior like a back-to-back Zener diodes. The potentially destructive energy of the incoming transient pulse is absorbed by the varistor, thereby protecting vulnerable circuit components.

Courtesy: http://educypedia.karadimov.info/library/an9767.pdf

What is Surge and what causes it

In AC power supply lines, a temporary increase in the supply voltage is called as “Surge”.

Surges are caused by switching events and insulation faults in AC power distribution networks and also by the switching of reactive loads such as motors or power factor capacitor banks.

When a line fault occurs, the short circuit can be huge causing the circuit breaker or fuse to open the circuit. When the protective device opens the circuit, the high current together with line inductance causes a very high flyback voltage as surge.

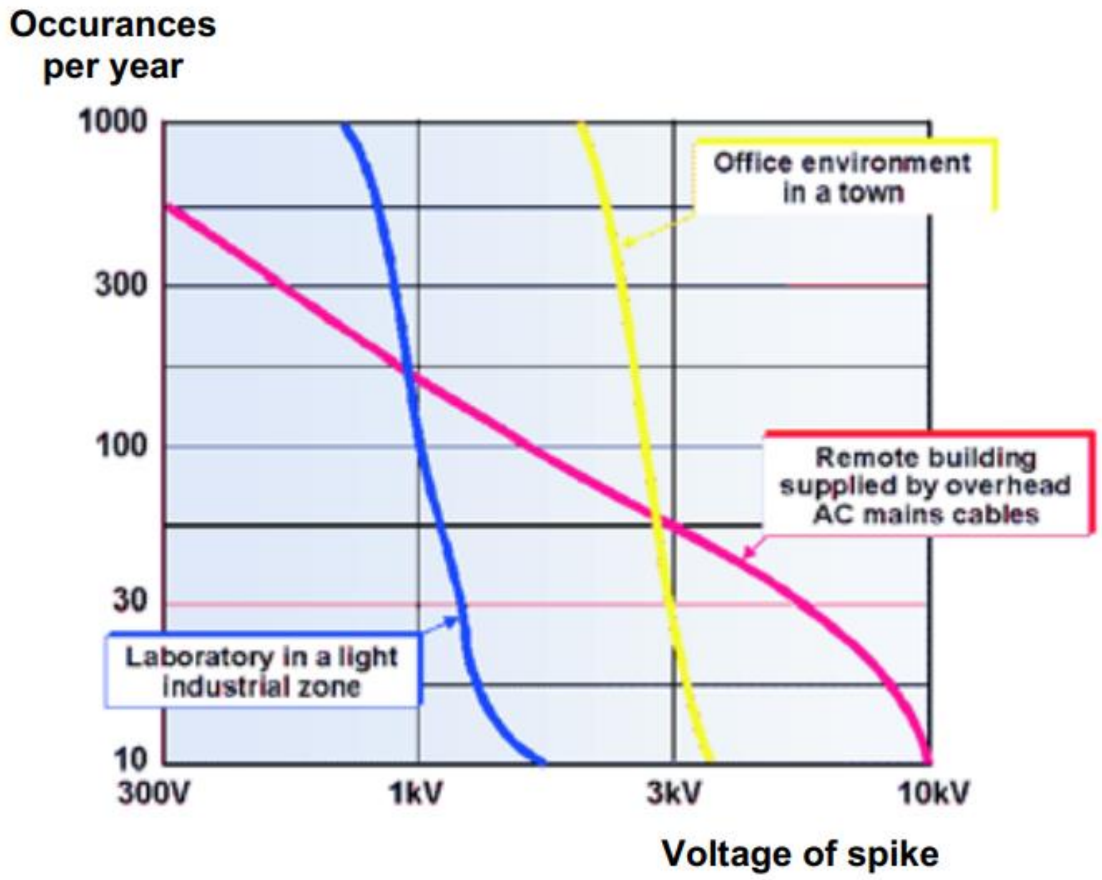
Surges are also created by lightning. Surge test standards such as ISO / EN 61000-4-5 only address the indirect effects of lightning which is due to the induction of voltages and currents or earth potential lift due to the impedance of earthing structure.

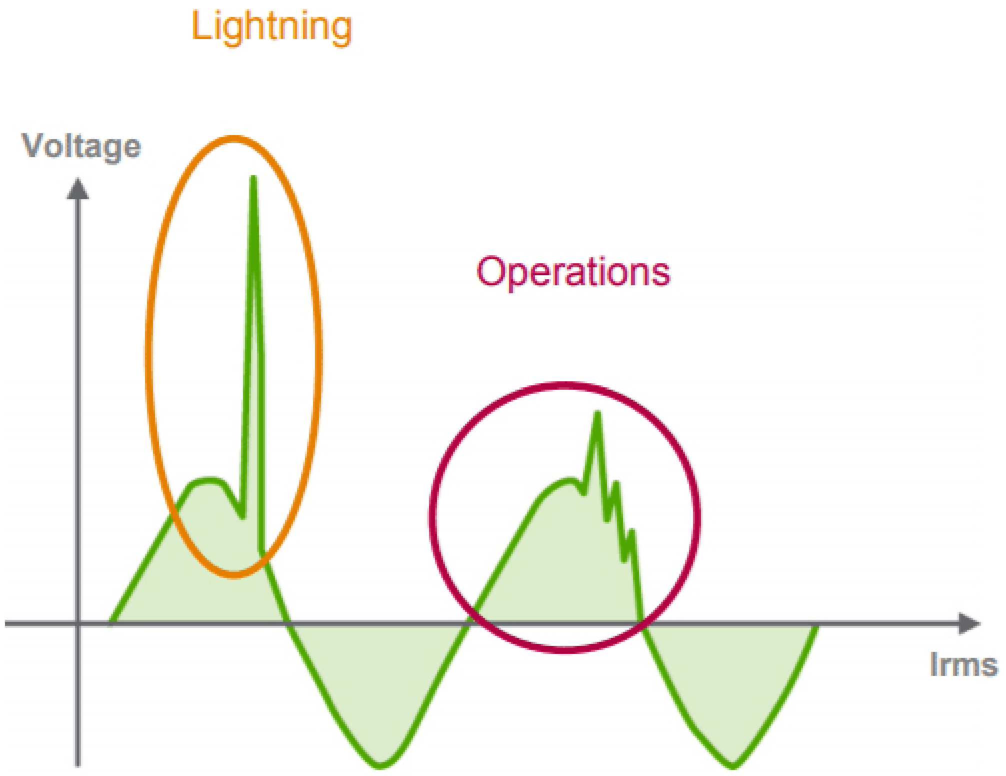
This high voltage surge can be destructive to electronic components used in consumer, Industrial equipments.

Similar surge events also happen in automotive applications (ICE Engines)due to a phenomenon called “Load dump”.

Courtesy: https://cherryclough.com/media/file/REO%20Guidebooks/61000-4-5_immunity%20to%20surges.pdf

Surge magnitude and occurrences per year





Courtesy: https://cherryclough.com/media/file/REO%20Guidebooks/61000-4-5_immunity%20to%20surges.pdf

Surge protection compliance testing

Every electronic product needs to have necessary protection components to protect the equipment from surge.

To test and certify the equipment is passing the surge tests, the EMC standard ISO 61000-4-5 defines the surge voltage, current level and waveforms.

Equipment suppliers must get their equipment certified as per this standard from certified agencies like TUV.

One of the compliance test service provider in India and worldwide
Product Testing Service | TUV India

https://emcfastpass.com/wp-content/uploads/2017/04/surge_overview.pdf

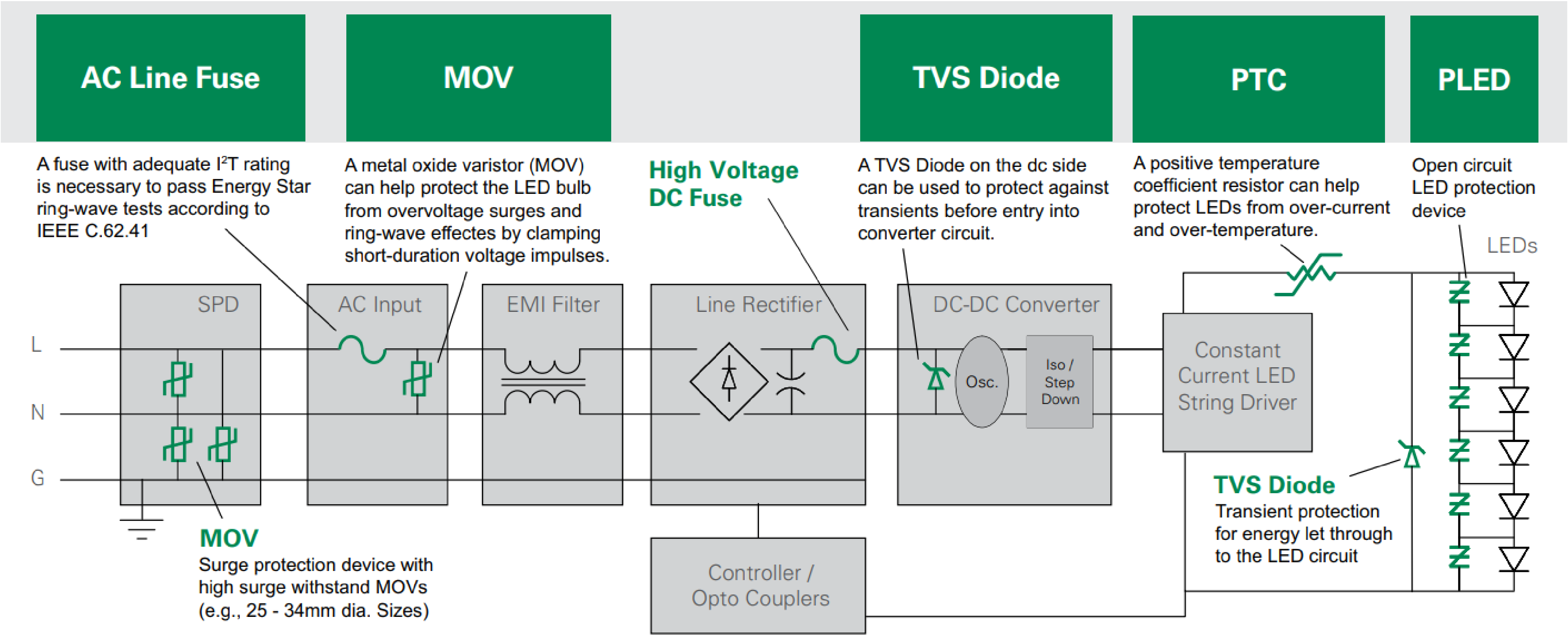
How to select Varistor for power line surge

To learn more about how to select the surge protection Varistor for a given mains operating voltage and surge level, check out these documents

Wurth Electronik : ANP015 | 1-Phase Line Filter Design

Littelfuse: LED Design Guide

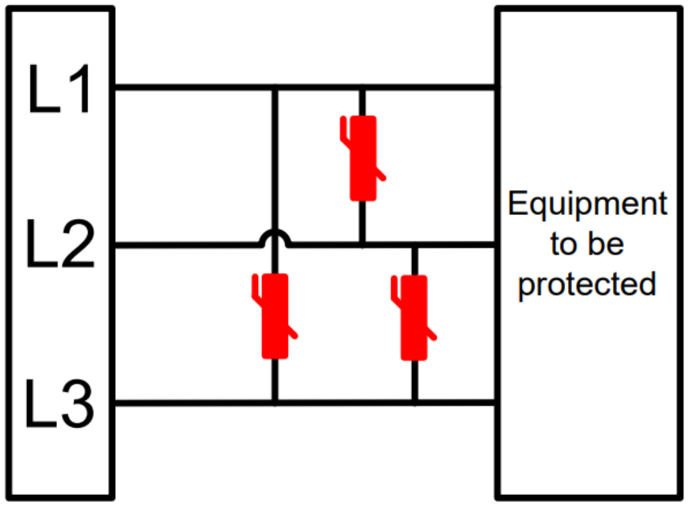
Surge protection for an Outdoor LED Luminaire

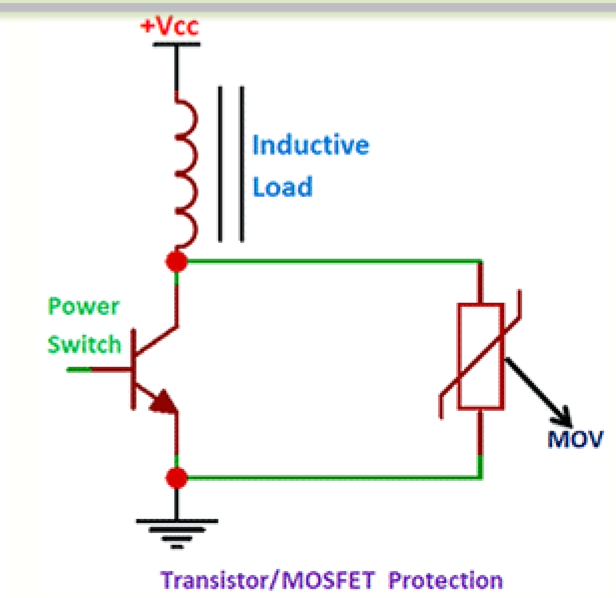


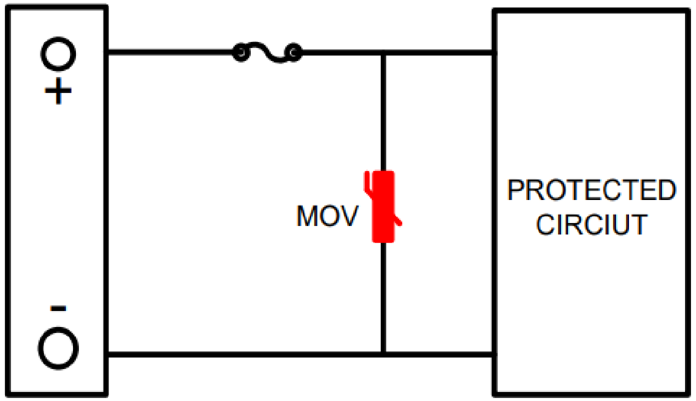
LED Street lamps are highly prone to failure due to high voltage surges induces due to Lightning and hence needs sufficient level of surge protection. MOVs are commonly used for the surge protection device.

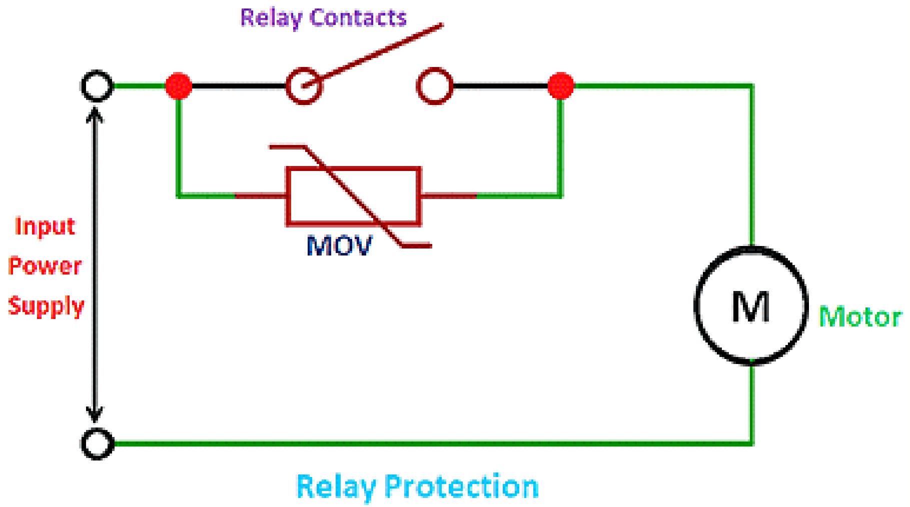
Courtesy: https://electronicscatalogs.littelfuse.com/led/data/lid15flx/011/html/export.pdf

Example MOV Applications





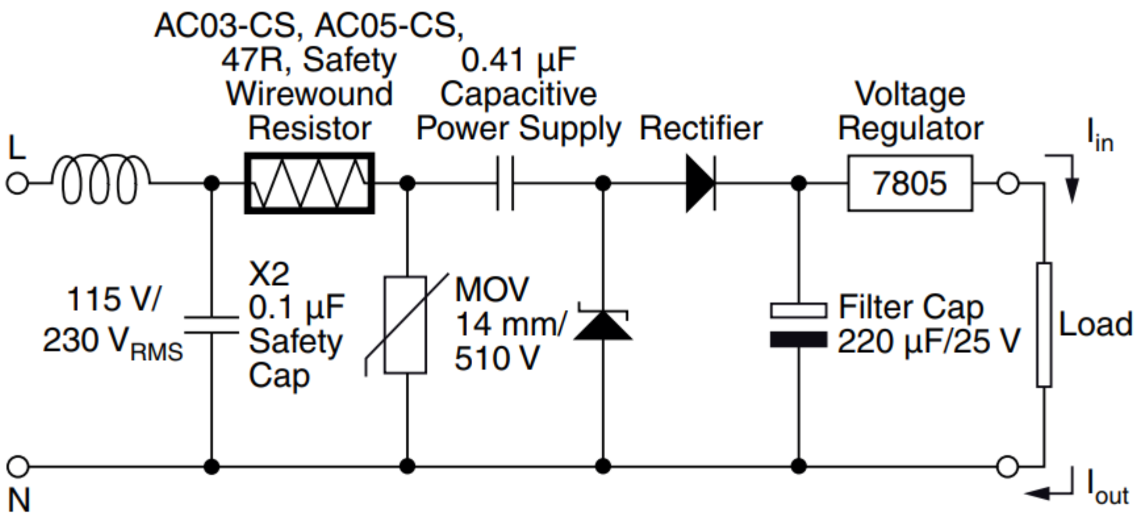




Combining Pulse withstanding Resistors and Varistors

Combining a pulse withstanding resistor along with Varistor helps in reducing the power rating and hence the size of MOV, as the pulse withstanding resistor can dissipate a significant potion of the surge energy, thereby increasing the number of safe operation of Varistor

Capacitive Power Supply for 1-Phase Energy Meter with AC03-CS, AC05-CS Safety Wirewound Resistor



Courtesy: https://www.vishay.com/docs/28897/ac0xcsenrgymet.pdf

MOV Specifications - 1

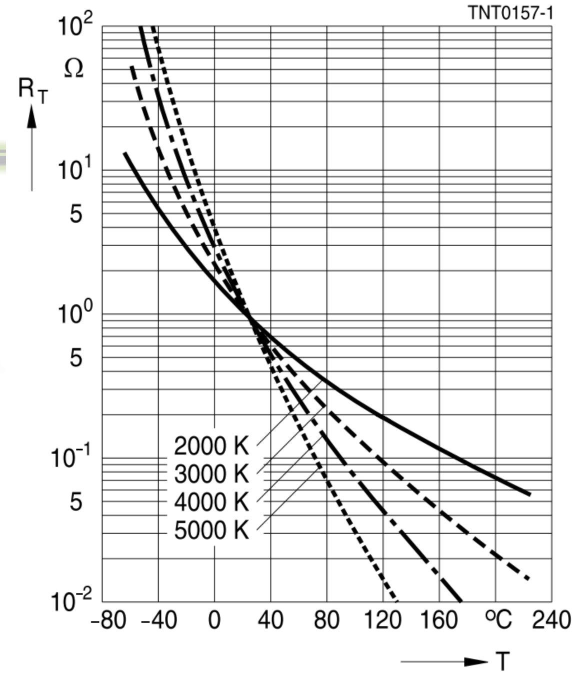
- **Maximum Continuous Operating Voltage (MCOV):** The maximum RMS or DC voltage the MOV can withstand continuously without degradation. Should exceed the normal operating voltage of the circuit (e.g., 130V MCOV for a 120V AC line).
- **Clamping Voltage (V_C):** The voltage at which the MOV starts conducting significant current to clamp the surge. Typically specified at a given current (e.g., 1mA or 1kA peak). Must be higher than the circuit's operating voltage but lower than the equipment's damage threshold.
- **Energy Absorption Capability (W_s or Joules):** The maximum energy (in joules) the MOV can absorb in a single surge event without failure. Depends on surge duration and waveform (e.g., 8/20μs pulse). Choose based on expected surge energy (e.g., 100J for small appliances, 1000J+ for industrial use).
- **Peak Pulse Current (I_TM):** The maximum surge current the MOV can handle for a specified duration (e.g., 8/20μs or 10/1000μs waveform). Must exceed the anticipated peak current (e.g., 10kA for lightning protection).
- **Response Time:** The time taken for the MOV to transition from a high-resistance to a low-resistance state (typically <25ns). Critical for fast transients like ESD or switching surges.

MOV Specifications - 2

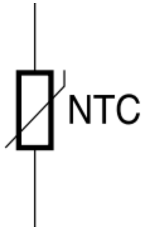
- **Operating Temperature Range:** The temperature range over which the MOV maintains performance (e.g., -40°C to +85°C). Select based on the environmental conditions of the application.
- **Capacitance:** The parasitic capacitance of the MOV (e.g., 100pF to 5000pF), which can affect high-frequency circuits. Lower capacitance is preferred for data lines or RF applications.
- **Disc Diameter and Size:** Physical size (e.g., 7mm, 14mm, 20mm) impacts energy handling and current capacity. Larger discs handle higher surges but require more space.
- **Leakage Current:** The small current that flows through the MOV at normal operating voltage (e.g., <1μA). Lower leakage is better to avoid power loss or heating.
- **End-of-Life Degradation:** Indicates how the MOV's performance degrades after multiple surge events. Check manufacturer data for lifetime ratings (e.g., number of surges at a given energy level).
- **Standards Compliance:** Ensure the MOV meets relevant standards (e.g., UL 1449 for surge protective devices, IEC 61000-4-5 for surge immunity) for safety and reliability.

NTC Thermistors

- NTC Thermistor is a temperature-sensitive resistor with a negative temperature coefficient.
- Made from ceramic materials like manganese, nickel, and cobalt oxides, exhibiting decreased resistance as temperature rises.
- Operates based on the exponential relationship between resistance and temperature (R ∝ e^(β/T)).Offers high sensitivity and accuracy for temperature measurement and compensation.
- Widely used in circuits to detect, monitor, or stabilize temperature variations.



Resistance/temperature characteristics (parameter: B value)



$$R_T = R_R \cdot e^{B \cdot \left(\frac{1}{T} - \frac{1}{T_R}\right)}$$

R_T	NTC resistance in Ω at temperature T in K
R_R	NTC resistance in Ω at rated temperature T_R in K
T	Temperature in K
T_R	Rated temperature in K
B	B value in K, material-specific constant of NTC thermistor
e	Euler number (e = 2.71828)

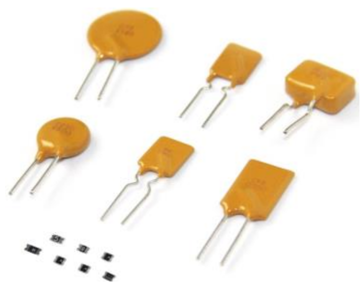
https://www.tdk-electronics.tdk.com/download/531116/19643b7ea798d7c4670141a88cd993f9/pdf-general-technical-information.pdf

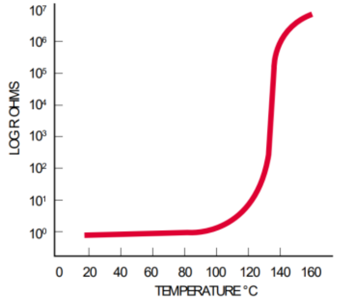
Applications of NTC Thermistors

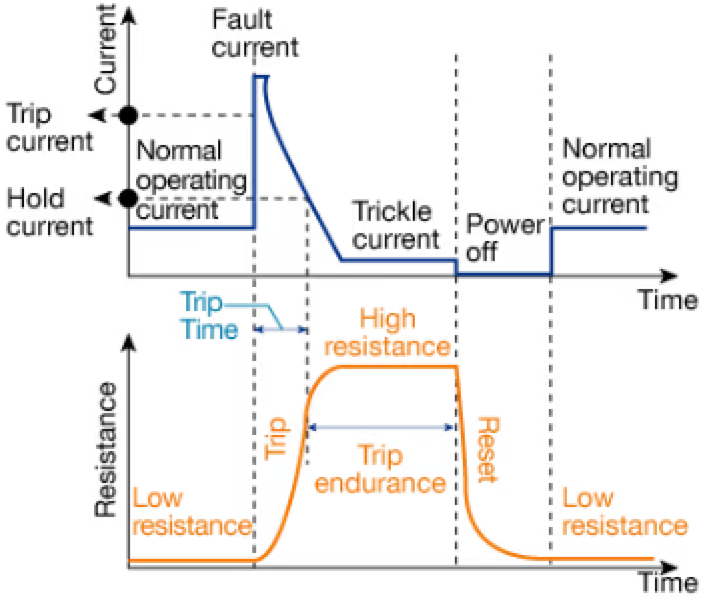
- **Temperature Sensing:** Monitors and controls temperatures in HVAC systems and thermostats.
- **Automotive:** Measures coolant or air temperature in engines and climate control units.
- **Medical Devices:** Ensures precise temperature regulation in incubators and patient monitoring equipment.
- **Consumer Electronics:** Protects batteries and circuits by detecting over-temperature conditions in smartphones and laptops.
- **Inrush Protection in SMPS Inputs:** Limits initial current surge in switched-mode power supplies during startup, preventing damage to components.

PTC Resettable Fuse (PPTC)

- A resettable fuse is a device that protects electronic circuits from damage caused by overcurrent conditions, overloads, overheating, or short circuits.
- There are two types of resettable fuses: traditional radial lead and SMD chip packages.
- Resettable fuses have a Positive Temperature Coefficient (PTC), which means that a rise in temperature is followed by an increase in resistance. When a rise in temperature occurs due to an overcurrent or similar fault state, resistance in the fuse increases, reducing the current.
- Once the fault is rectified, the PTC's core cools and contracts, allowing the current to flow normally. This ability to reset differentiates a resettable fuse from a regular fuse, which must be replaced after a fault condition.







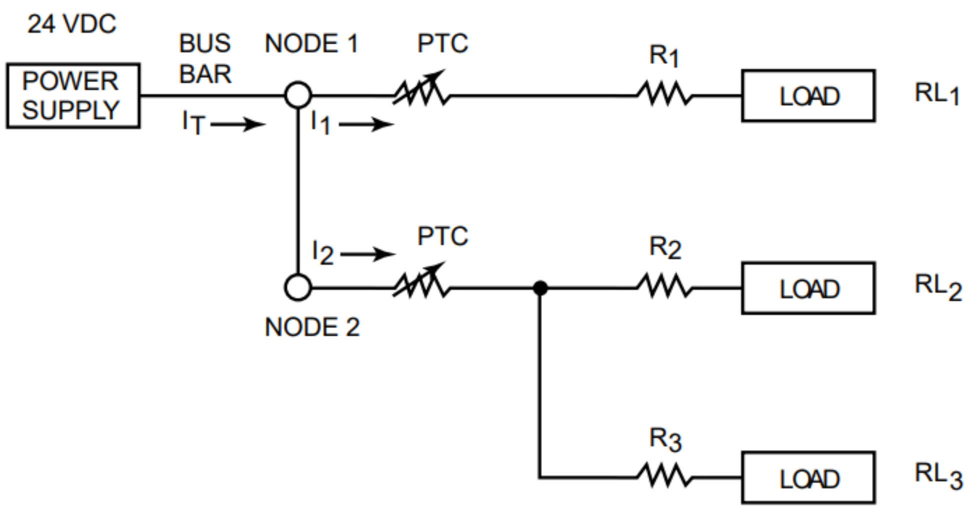
Courtesy: https://community.element14.com/technologies/experts/b/comprehensive-guides/posts/a-comprehensive-guide-to-resettable-fuses

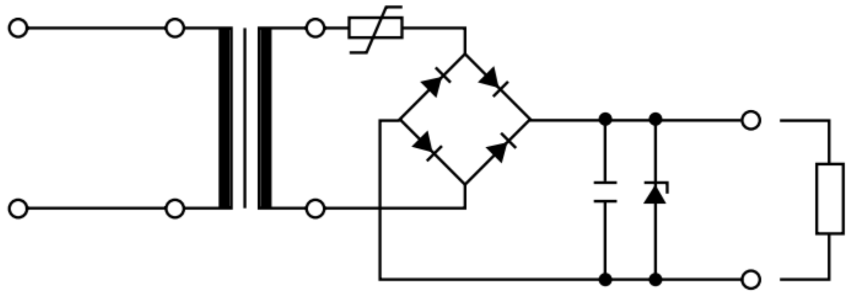
PTC Specifications

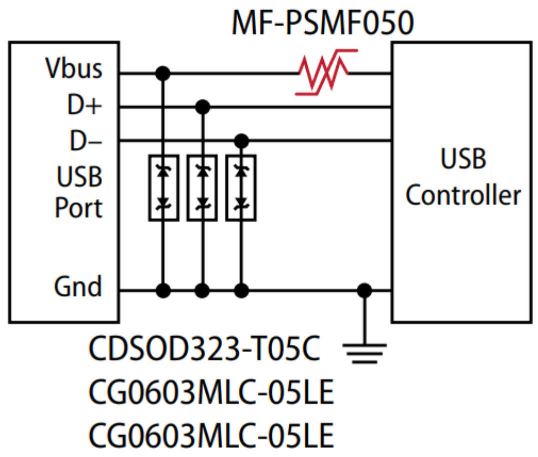
- **Holding Current:** the maximum amount of current a resettable fuse can tolerate before tripping and transitioning from a low-resistance state to a high-resistance state. The fuse's holding current higher than the maximum amount of electricity in a circuit, so that it doesn't trip during normal operation.
- **Trip Current:** the amount of current that will trip the fuse and open the circuit. Resettable fuses have a higher trip current than traditional fuses, and they are designed to trip quickly in response to overcurrent conditions. The trip current generally surpasses the holding current.
- **Rated Voltage:** the maximum voltage a fuse can safely operate without breaking down. The selected fuse's voltage rating must match or exceed the circuit voltage being used.
- **Maximum Current:** the largest amount of electricity that can pass through the fuse which would cause it to overheat, possibly causing damage. The maximum current rating is typically specified by the thermistor manufacturer and is based on the thermistor's size, materials, and design.
- **Max Time to Trip (MTT):** the maximum amount of time it takes for the device to switch from a low-resistance state to a high-resistance state when a fault current occurs. The time-to-trip of a PPTC device is defined as the time required to trip the device starting at the onset of a fault current. The time is dependent on the magnitude and duration of the fault current and the ambient temperature.
- **Typical Power:** the amount of power typically dissipated by the fuse when in tripped state, in a 23°C still air environment.

Courtesy: https://community.element14.com/technologies/experts/b/comprehensive-guides/posts/a-comprehensive-guide-to-resettable-fuses

PTC - few Application examples







Courtesy: https://www.bourns.com/pdfs/mfsolgd.pdf

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https://www.seekerssignpost.com

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