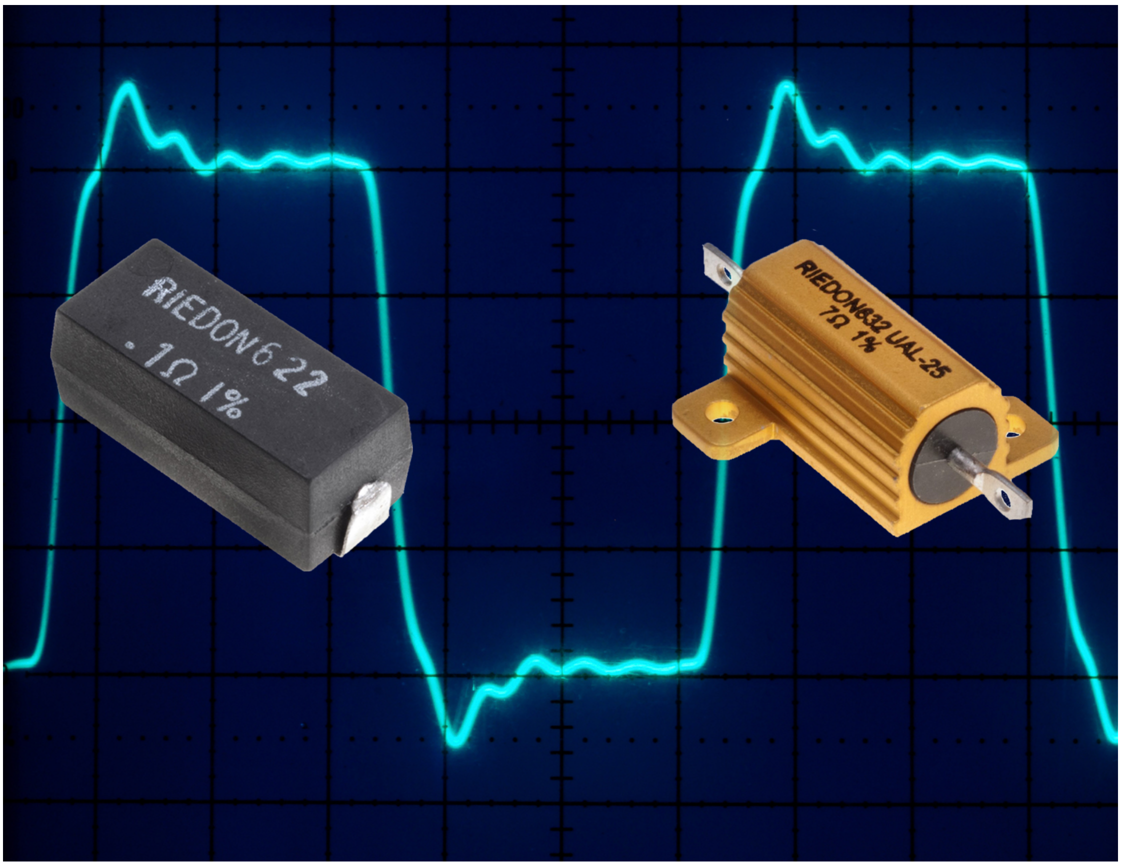
White Paper

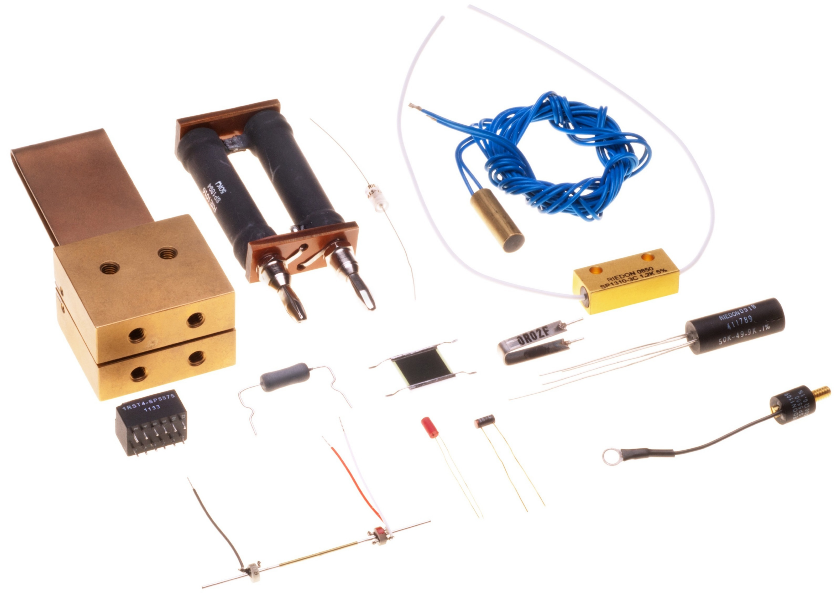
Custom Resistors for High Pulse Applications

Issued in June 2017



Custom Resistors for High Pulse

By Phil Ebbert, VP Engineering, Riedon Inc.



Voltage spikes and current surges may often be thought of as the consequence of poor circuit design, perhaps brought about by a transient event that either shouldn't have occurred or at least should have been anticipated and taken care of with appropriate design measures. In some cases, this may be true but in other instances the transient might be induced by some external event - although again, arguably, this could be mitigated for within the design.

Indeed, protecting electronic circuits against the potentially damaging effects of static discharge or the surges induced by lightning are established practices. Similarly, it is good practice to take precautions to reduce or limit surges caused by switching power sources and loads, especially inductive loads such as motors or supplies that are maintained by capacitor banks. Making or breaking such circuits can easily give rise to transient voltages or currents that exceed their nominal values several-fold and sometimes by an order of magnitude or more. The distinction between the terms 'spike' and 'surge' is that 'spike' is typically used to describe a fast transient, lasting 3ns or less, while a longer duration transient is considered to be a 'surge'.

Understanding Transient Protection

Circuits designed to protect against external pulse events will typically use some combination of inductive, capacitive and resistive components. The intent is to smooth out the transient and reduce its magnitude using the characteristics of inductors, which limit the rate of change of a current, and capacitors, which limit the rate of voltage change.

Figure 1 shows a typical EMI filter design where, in a steady-state condition, there will be no voltage drop across the inductors and no current through the capacitors. Here, a voltage spike occurring at the input will attempt to charge the first capacitor but initially the resistor will be subjected to the full voltage of the spike and the resulting current surge (I=V/R). If the duration of the spike is significantly less than the time constant of the input resistor-capacitor combination then the impact on the filter's output will be minimal and the protection circuit will have done its job, using the resistor to absorb and dissipate the energy contained in the spike.

What's important to realize in this solution is that the resistor must be capable of withstanding the transient voltage, the current it produces (in addition to the normal load current it is carrying), and be able to handle the pulse energy, which is voltage x current x time (E = V x I x t). For a non-rectangular pulse waveform, the energy can be determined by integrating the area under the curve although for the purposes of maximum component ratings the simpler calculation of peak voltage x peak current x duration will provide a useful margin of error.

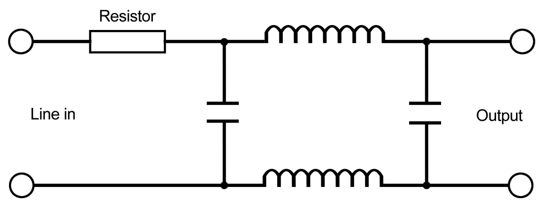


Figure 1: Typical EMI filter used in power supplies and lighting circuits

In applications where transients occur as a result of switching power sources or loads, the circuits most likely already contain inductive or capacitive elements, making it possible to design pulse suppression around those elements using suitable pulse-handling resistors to absorb the surge energy. Some applications generate repetitive pulses, making it important to choose a resistor technology that is suitable for high pulse-rate applications, not just for its high pulse-voltage or high pulse-energy capability.

RIEDON®

The Right Resistor Technology Matters

In the world of electronic components, the technologies employed to produce resistors have evolved to address ever more demanding requirements. Most resistor types aim to meet the basic needs for everyday circuit designs, i.e. a wide range of resistance values, accuracy to ±10% or better, and typically capable of dissipating up to 0.5W. Cost, as always, is another key consideration, which is why one of the earliest types, the axial-leaded carbon composition resistor, was for many years the mainstay of the industry.

This form of resistor is made by combining conductive carbon powder in a resin with an insulating material, such as ceramic, in suitable proportions to achieve the desired resistance value. However, initial accuracy tolerance is poor (±5% at best) as is their temperature stability (typical TCR of 1000ppm/C) and stability over time. Carbon composition resistors also suffer from high current noise (-12 dB to +6 dB) although they can meet high surge energy requirements where there is also a need for low inductance.

Thick-film resistors provide an alternative to carbon composition and, while the resistive thick-film material can be applied to an axial-leaded ceramic core, the technology really became popular with the move to surface-mount components, where it enabled lower power resistors in smaller packages. Resistances from 1 to 10M with tolerances of 1% and a TCR of 50ppm/C are commonly available with power dissipations up to 1W or more. Some ranges go down to 0.1 and up to 100M, while others offer even lower TCR specifications.

Unfortunately, standard thick film resistors achieve their accuracy by laser trimming the width of the resistive element, creating a point of weakness that generally makes them unsuitable for high pulse handling. Also, the smaller package size means less thermal mass to absorb the pulse energy. Another aspect of film resistor technology that needs to be appreciated is the different requirement for withstanding high voltage rather than high power or high current. With high voltage, a longer element allows a lower voltage stress per unit length whereas for power or current handling a wider element is clearly better for reducing current density. Nevertheless, in more cost-conscious commodity markets, untrimmed thick-film resistors do provide acceptable pulse-withstanding performance.

Wirewound resistors are another type that has been around for a very long time and one reason for their survival is that most other resistor fabrication techniques have various disadvantages. The drawbacks of carbon composition resistors have already been outlined above as have some of those of thick-film technology which, while offering better initial tolerances and TCR specifications, still has a limited pulse handling capability and suffers a relatively high current noise (typically -18 dB to -10 dB). Even the better-performing metal-film resistors, that offer tolerances as low as 0.01%, TCRs from 10 to 200ppm/C, and a stability of 200 to 600ppm/year, only start to get close to the performance wirewound resistors can offer but still suffer significantly inferior pulse-handling.

RIEDON®

So, What Makes Wirewound the Pulse-Handling Technology of Choice?

It is the construction and materials used in producing wirewound resistors that enable them to achieve superior performance to all other resistor types. This is why, despite the significant contribution that resistive films have made to the cost-effective mass production of increasingly miniaturized resistors, wirewound resistors remain the best solution for many specialized applications, even though there are now far fewer manufacturers.

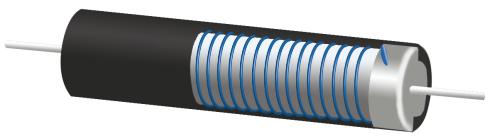


Figure 2: The basic structure of a wirewound resistor

As shown in figure 2, the fundamental construction of a wirewound resistor, which is based on a resistance wire wound around a central core, has remained unchanged for many years. The resistance wire is terminated by welding it to axial-leaded metal end-caps that are pressed onto the central core or former, which is usually made of ceramic. This assembly is then encapsulated to protect the device from moisture and physical damage. Wirewound resistors like this can dissipate substantial amounts of power, with some designs capable of handling 2.5kW, and can be made with great precision, with initial tolerances down to 0.005%. Their use of stable materials also means wirewound resistors maintain their precision over time, e.g. achieving 15 to 50ppm/year, and they are among the lowest current noise resistors available, at -38dB.

Most importantly in the context of this discussion, because power handling is linked to their physical construction, a particular strength of wirewound resistors is their ability to withstand high level pulses and transients, especially as devices with a larger mass can generally safely absorb and dissipate more energy. Before expanding on the pulse handling performance of wirewound resistors, another key benefit of their construction that needs to be appreciated is the ease with which their design can be customized.

Customization – Not Just Any Color as Long as it is Black!

The simple construction of a wirewound resistor makes it easy to customize and this can be economic in far smaller quantities, even just hundreds of pieces, than other resistor technologies. This is not to suggest that the technology hasn't advanced – new materials, including a wider choice of metal alloys, have brought benefits, such as the ability to achieved tightly controlled performance across a range of temperatures with a temperature coefficient of resistance (TCR) as low as 1ppm/°C.

The resistance of a wirewound device is determined by the length and cross-sectional area of the wire together with the resistivity of the material the wire is made from. So, for example, a thin copper wire that is 30m long may have a resistance of just a few ohms whereas using a higher resistivity, nickel-chrome alloy wire of similar diameter and length, may produce a resistance of several thousand ohms. The material choices together with wire size and length enables the wide range of resistance values that is possible with wirewound resistors. It is also a mechanism that determines precision, since the use of longer resistance wires allows them to be trimmed more accurately, with tolerances of 0.01% being commonplace.

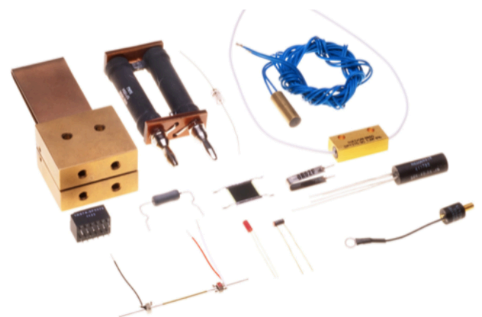


Figure 3: These wirewound resistors from Riedon exemplify the ease of customization this technology offers

Material choice is also a factor that determines other key performance characteristics of wirewound resistors and enables the manufacturer to fine tune their specifications for specific applications. So, to achieve a low TCR, the alloy “RO-800”, which is formulated to have a TCR of 5 to 10ppm/°C may be the answer compared to copper, whose TCR is 3900ppm/°C, or pure nickel with a TCR of 6700ppm/°C. The opposite may be true in certain applications, such as temperature sensing and compensation, where higher TCRs are more appropriate.

Operation at extreme temperatures is another reason for choosing wirewound resistors. Riedon’s UT series of axial resistors, for example, will operate from −55°C to 275°C and, with de-rating, will continue to function at even higher temperatures, making this technology ideal for use in the aerospace industry, and in applications such as fire suppression systems.

Wirewounds Deliver on Pulse Performance

The construction of wirewound resistors, which allows them to absorb and dissipate more energy, also allows for further optimization for pulse handling requirements. The need to withstand high voltages can be met using wires that are coated to prevent arcing between adjacent turns or, by using higher resistivity wire so that fewer turns are required, the gap between windings can be increased. Even the self-inductance of wirewound resistors, which is commonly a disadvantage in high frequency applications but may also be a concern in pulse handling circuits, can be overcome by using the bifilar winding technique show in figure 4. This reduces the inductance of a wirewound resistor by 90%, compared to a standard part, simply by arranging the turns in different

RIEDON®

directions to create two opposing magnetic fields that cancel out each winding's inductance.

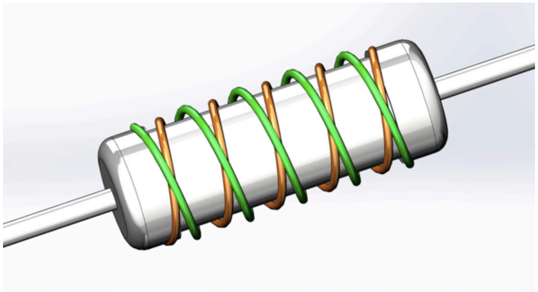


Figure 4: Non-inductive winding can produce wirewound resistors with minimal self-inductance.

The common use of pulse withstanding resistors to protect against transients induced by external events such as lightning and static discharges, and internal events such as load switching has already been covered but there are two further use cases worthy of mention:

Some protection circuits, such as those deployed to protect the metering module in solid-state electricity meters, use metal oxide varistors (MOVs, also known as voltage dependent resistors or VDRs) to clamp any voltage surge on the grid, typically diverting the current to ground. Rather than relying on the MOV to absorb all this pulse energy it is more usual to use a pulse handling resistor to absorb most of it.

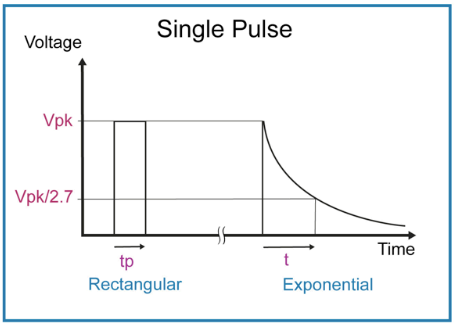
Some applications, such as medical defibrillators deliberately generate large amounts of energy that needs to be dissipated in a very short time. This can significantly stress its electrical components and so designers typically incorporate a high pulse handling resistor that can absorb this energy during the critical millisecond duration discharge period.

Resistors in the UT series mentioned above are well-suited to these applications as they can withstand over 1000 Joules. Their values range from 0.02 Ohms to 260 kΩ, with tolerances down to ±0.01% and a TCR as low as ±20ppm/°C. Understanding the pulse handling capabilities required by different applications and relating that to the datasheet specification is not always straightforward. Consideration needs to be given to the pulse's characteristic, distinguishing between a fast high-voltage transient or an inrush current. The pulse shape - square, triangular or irregular – and whether it is a repetitive pulse also have to be taken into account in determining the energy handling capability of a resistor.

The industry standard specification for pulses of up to five seconds is that the resistor must be capable of withstanding five-times its rated power for that period. So, regardless of package size or resistance value, a 5W resistor must be able to handle 25W for 5 seconds, which is 125 Joules. For shorter pulses, the Joule rating is determined by the mass of the resistance wire, which is then dependent upon resistor value and package type, including its size and whether it's an axial or surface mount component.

RIEDON®

Energy = Power x Time = Pt



Single Square Wave Pulse $P = V^2t/R$
Exponential Pulse = $P = V^2t/2R$

Figure 5: Pulse shape, repetition rate and duration all need to be understood in order to calculate the required energy handling capabilities

Conclusion

Wirewound resistors provide the ideal solution for high pulse applications. Their ability to withstand high voltages and high currents, and absorb and dissipate the energy induced by transient events is unrivaled when compared to other resistor technologies. The characteristics of wirewound resistors also excel in most other areas, from the wide range of values available and their initial accuracy through to the low temperature coefficients, long term stability and high power dissipations. The ease with which wirewound resistors can be customized is a further benefit that extends the choice available to designers beyond standard catalog parts.

ABOUT THE AUTHOR

Phil Ebbert is in charge of resistor development at Riedon Inc. He is also responsible for our technology projects, including equipment, testing and process design.

Mr. Ebbert has 15 years' resistor engineering experience and led Riedon's expansion from wirewound resistors into related film and foil technologies. He studied physics, optics and computer science at Carnegie Mellon University.

Riedon Inc

US Manufacturing and Sales

300 Cypress Avenue Alhambra, CA 91801
USA

Tel: +1 (626) 2849901

(Monday – Friday 6am-5pm PST)

Fax: +1 (626) 2841704

Email: sales@riedon.com