APPLICATION NOTE

How Protective and EMI Suppression Components Help Increase Permanent Magnet DC Motor Safety and Noise Suppression

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

INTRODUCTION

Permanent Magnet (PM) DC motors are used as actuators, which are essential electronic control system elements in many automotive and transportation applications including electric windows, windshield and rear window wipers, seat positioning, sunroofs, and automatic door openers to name a few. The relative low cost and abundant supply of PM DC motors, along with their ability to utilize simple control electronics when more precise field controls are not required make these types of motors an optimal solution for many applications.

A PM motor is typically constructed with a stator that features a permanent magnet and a rotor. For safety reasons, manufacturers add protection to the motor in the event that the rotor locks or an overload condition occurs during operation. This application note provides an overview of how PM DC motors work and compares the two most common forms of thermal protection for DC motors – bimetal and polymer PTC protection devices.

In addition, dual function capacitor-varistor filter solutions are presented that provide transient overvoltage protection against load dump and jump start transients in automotive applications. These components also help to suppress electromagnetic interference (EMI) in automotive and industrial applications caused by DC motor rotating rotors and brushes.

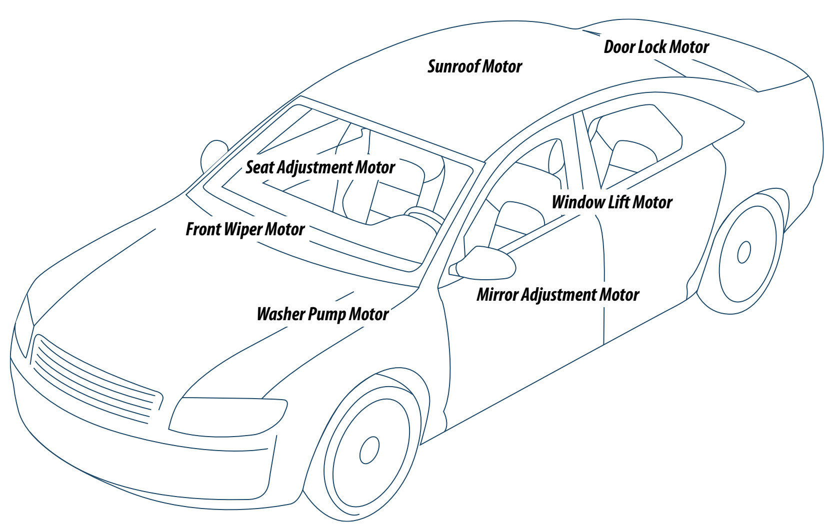

Figure 1. Typical PM DC motor applications

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

OPERATIONAL CHARACTERISTICS OF PM DC MOTORS

Along with the stator with permanent magnets inside and the rotor, the structure of a PM DC motor includes a commutator with coils electrically connected to an electronic circuit. The rotor rotates when an electric current passes through the winding coils, producing a magnetic field that is attracted to the Permanent Magnet with an opposite pole to the field of the winding. The timing of the current in each winding is designed so that its pole is always opposite the pole of the successive stator magnet. In this way, the rotor continues to rotate due to being continuously attracted to the magnet in the stator.

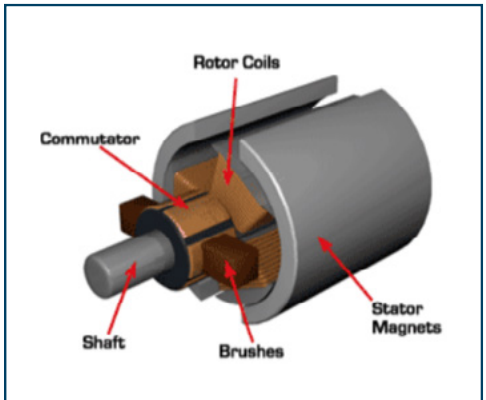

Figure 2. Structure of a PM DC motor

Figure 3 illustrates when the lowest efficiency of the PM DC motor occurs. Reduced efficiency happens at no load and at zero work or at the maximum current and maximum torque. However, at a certain defined current and very low efficiency, the magnetic field density experiences very large electrical current swings around the windings. These swings (Faraday's law of induction) induce large eddy currents in the windings, eventually leading to overheating if the motor is not disconnected from its power source. The same phenomenon occurs in transformer windings located too close to the gap in a core and is known as fringing. Windings have been known to melt under such circumstances causing the rotor to stall due to an overload (mechanical blockage). Motor manufacturers will define how much time a motor design can safely withstand motor jams or rotor block conditions.

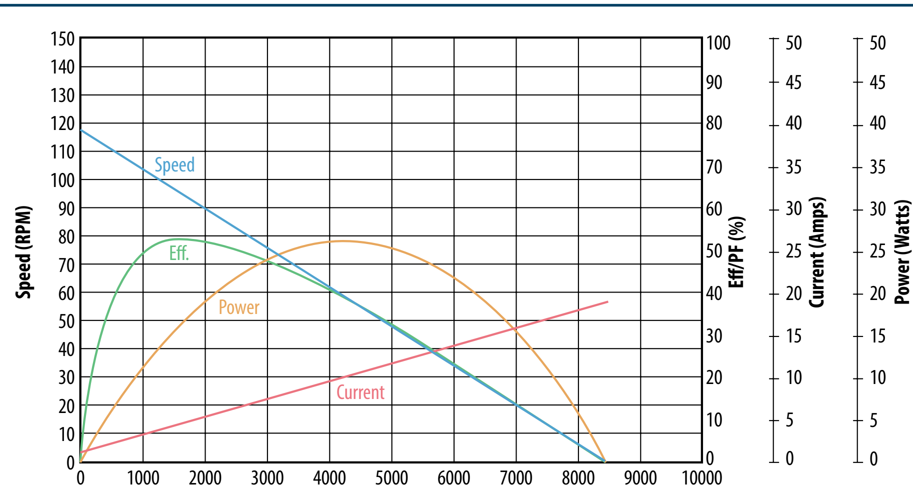

Figure 3. PM DC motor efficiency

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

REQUIREMENTS FOR PROTECTION

Improved materials and design techniques have led to lower profile, more efficient and more cost-effective motors. Nevertheless, motor designers still need to account for two key elements when considering motor protection:

1. **Trip Time:** A DC motor will have its own characteristic curve. The time to trip and the trip current of the protector need to be tailored to each motor's characteristics. Testing to ensure trip times are coordinated with the protector are performed in the motor with the rotor locked. The desirable outcome is a minimal variation in trip times.

2. **Cycle Life:** A typical cycle life will be a short motor rotation followed by a short stall and a period of rest. A motor may undergo hundreds or even thousands of cycles with the pass criteria being that the protection should never trip. Figure 4 is an example of how the protector can be checked for nuisance tripping.

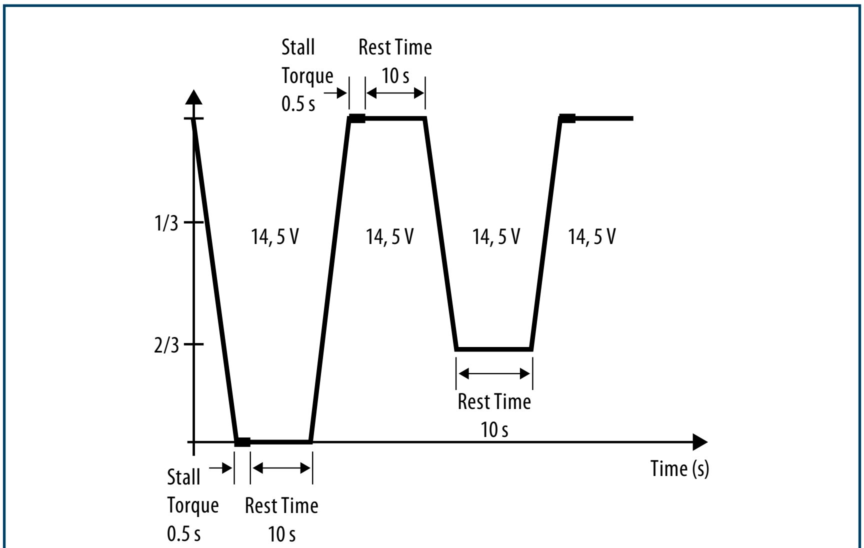

Figure 4. PM DC cycle life

Motor manufacturers also need to be concerned about two critical motor conditions:

- A locked rotor condition can result in the burnout of the coil caused by the high locked rotor current that can flow through the coil. This is mainly caused by a mechanically locked motor.
- An overload condition that can also cause a burnout happens if the coil temperature increases, if a heavy load condition occurs, or if the supply voltage is too low.


Permanent Magnet DC Motor


Permanent Magnet DC Motor


MV Series


OV Series


SC Series


MF-RHT Series


MF-DC Series

REQUIREMENTS FOR PROTECTION (CONTINUED)

These conditions call for the motor to have sensing for both overcurrent and thermal protection of the motor coil.

Motor protection drives are directly coupled to a rotor as shown in the photos in Figure 5. Each drive will have an insert to accommodate a protection device, which can be plugged in during motor drive assembly. Examples of typical interconnects that are generally stamped out of brass are also illustrated in Figure 5.

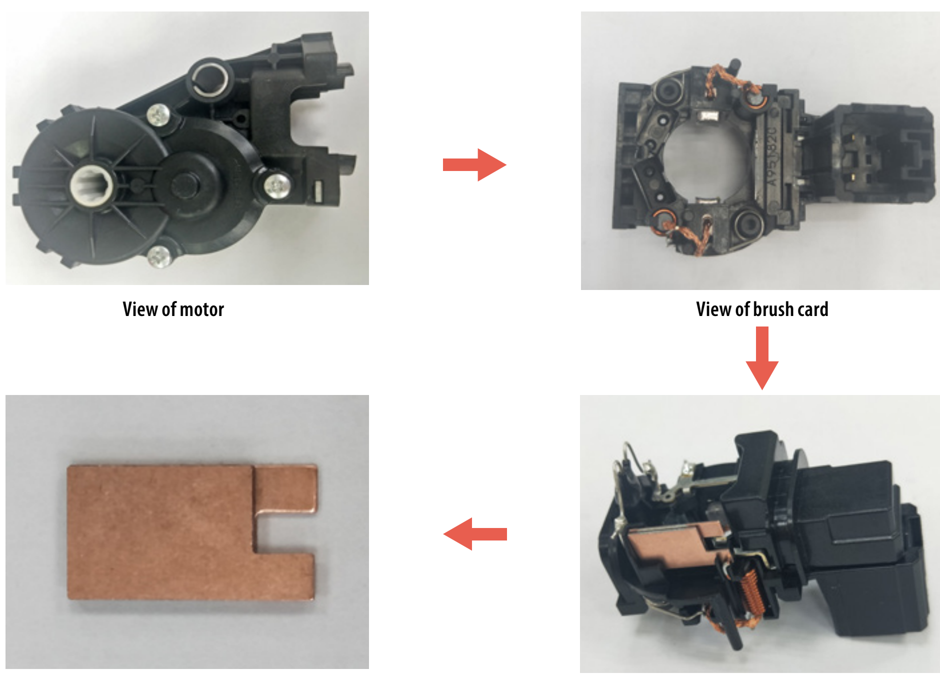

Figure 5. Typical rotor interconnects

Testing DC motor protection inside the motor itself is always required. Bourns has a DC motor testing laboratory with UL certification that can perform the following typical motor protection tests:

- Locked Rotor
- Thermal Protection (Winding Temperature Measurement)
- Time to Trip (TTT)
- Reset Times
- Cycle Life
- Trip Endurance

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

REQUIREMENTS FOR PROTECTION (CONTINUED)

Load-dump transients in automotive electronics occur when the vehicle battery being charged by the alternator is abruptly disconnected (Figure 6). Consequently, loads connected to the alternator experience overvoltage surges (V_P) as high as 120 V, which may need 400 ms (t_f) to decay (Figure 7). These transients need to be suppressed and are typically clamped to 40 V in 12 V systems and to 60 V in 24 V systems.

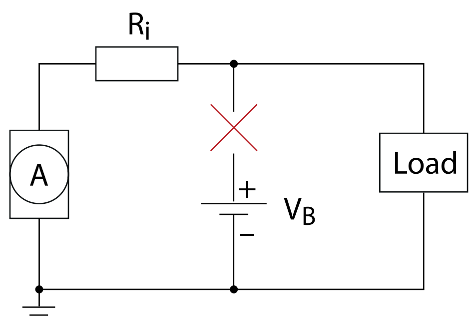

Figure 6. Load-dump occurrence

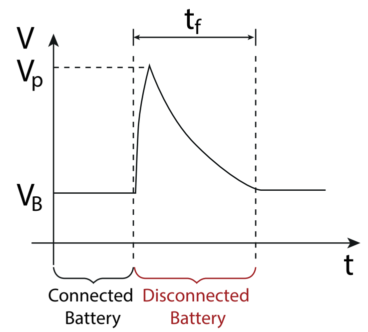

Figure 7. Typical alternator's output voltage after battery disconnection

DC motors are a common source of EMI that may result in performance degradation of other electronic systems, and can also be the cause of data corruption. In worst cases, EMI may cause electronic systems to fail completely. DC motors can generate both conducted and radiated emissions (Figure 8). Therefore, it is recommended that this unwanted EMI noise be suppressed below the requested values to guarantee electromagnetic compatibility.

Figure 8. Setup for noise emission test

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

OVERVIEW OF PROTECTION TECHNOLOGIES

Bimetal

Bimetals for small automotive DC motors are compact devices usually 3 to 5 mm thick, offering a range of different terminals from which to choose to facilitate insertion into the DC motor. Bimetal protectors are typically designed to operate in ambient temperatures up to 80 ˚C, and like polymer PTCs, are purposefully designed with slower reaction times to avoid nuisance tripping.

Unlike polymer PTC devices, many bimetal devices on the market today will cool once they have tripped since there is no leakage current flow. The construction of a bimetal device physically interrupts the contact. This structure can lead to the following disadvantages with these types of bimetal protectors compared to polymer PTC thermistors:

- Higher peak temperatures on the windings can take place if the bimetal device cools and resets while the rotor is still locked.
- The windings can experience a higher average temperature on the windings if the bimetal device is unstable, causing several current inrushes into the winding as shown in Figure 9.
- The device can generate higher emissions and increased noise if the bimetal device is unstable. A polymer PTC thermistor is designed to remain in a high impedance state.
- The device can experience premature end-of-life caused by contact welding from continuous cycling.

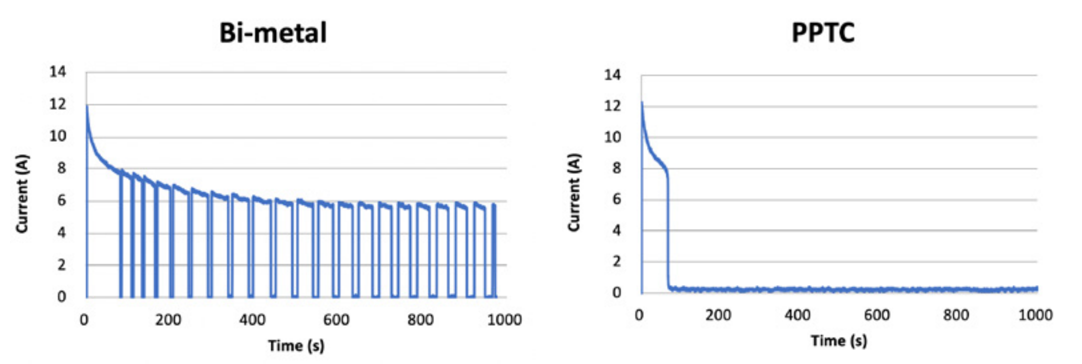

Figure 9. The constant open-close cycling of bimetal protectors creates a risk of arcing and contact welding. By comparison, there are no moving parts in a Multifuse® Polymer PTC Resettable Fuse, so the risk of contact welding is eliminated.

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

OVERVIEW OF PROTECTION TECHNOLOGIES (CONTINUED)

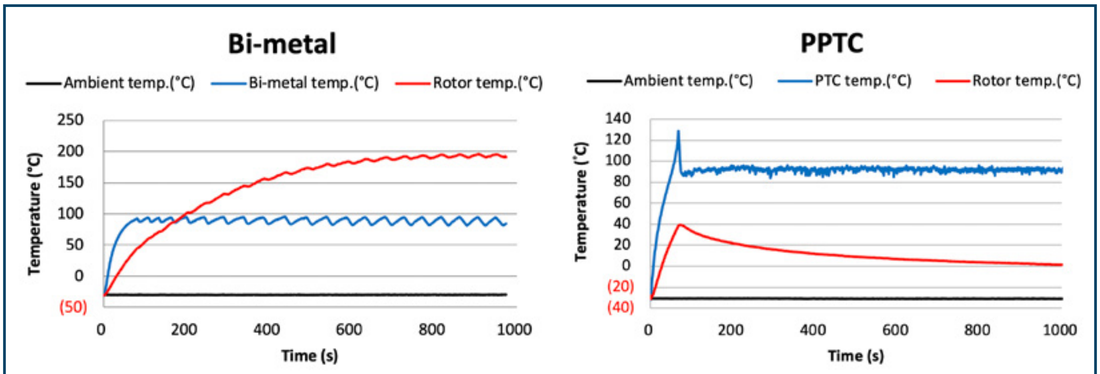

Figure 10. The open-close flickering of bi-metal protectors allows rotor temperatures to rise above desired levels, whereas Multifuse® Polymer PTCs allow rotor temperatures to stabilize at lower levels.

It is important to note that Bourns offers a range of thermal cutoff (TCO) mini-breakers that utilize bimetal technology. Currently, these devices are primarily used for lithium-ion battery protection, but there is growing interest in using them in DC motor applications.

The design of Bourns® TCO mini-breakers is different than the design described above and does not experience the mentioned disadvantages. Bourns® TCO devices are constructed with a separate bimetal trigger mechanism and current-carrying arm, which improves long-term reliability and impedance values. Bourns® TCO devices also incorporate an internal ceramic PTC that keeps the arm mechanism open when tripped. This allows the circuit to operate significantly cooler and prevents the open/close chattering effect.


Permanent Magnet DC Motor


Permanent Magnet DC Motor


MV Series


OV Series


SC Series


MF-RHT Series


MF-DC Series

OVERVIEW OF PROTECTION TECHNOLOGIES (CONTINUED)

Polymer PTC Thermistors

A Polymer Positive Temperature Coefficient (PPTC) thermistor is a resistive component with a nonlinear temperature resistance curve. The temperature can be increased either by controlling the ambient temperature in a chamber or by self-heating, which occurs when current is conducting (power = current squared x resistance). The resistance of the thermistor is dependent on the physical dimensions of the component and the resistivity of the material.

$$R = \frac{\rho . L}{A}$$

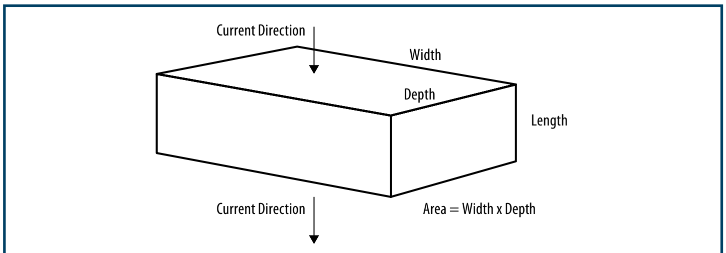

Figure 11. PPTC Thermistor Resistivity

The resistivity of the material is controlled by the dosage of conductive particles (typically, carbon black). The resistance, therefore, is inversely related to the dimensions of the terminals and proportional to the thickness of the device.

PPTC devices for DC motors typically use a polyvinylidene difluoride (PVDF) high temperature polymer formulation that allows operation at ambient temperatures up to 125 ˚C. One benefit of high temperature polymers is their enhanced resistance drift performance over temperature compared to polymers with lower melting points that typically have a maximum rated operating temperature of 85 ˚C.

For a PPTC device to be suitable for PM DC motors, it must have stable low resistance (typically milliohms) with very tight tolerances (in the order of ±17 %). Therefore, PPTC thermistor protection devices (including lead frame) are very thin (on the order of 1-2 mm) which also assists in designing them into motor brush cards.

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

OVERVIEW OF PROTECTION TECHNOLOGIES (CONTINUED)

In recent years, the size of automotive DC motors is getting smaller and lighter weight to meet improved mileage goals. The smaller footprint of PPTC protection devices compared to bimetal protectors make them an ideal solution to meet the limited space within motor brush cards.

Since resistance is expected to be very stable over a PPTC device's operational life, designers will often specify various temperature stress tests in order to simulate resistance drift over the life of the component. A typical specification could be:

- Measure resistance for 500 hours at 90 ˚C before and after.
- Measure resistance for 100 hours at 80 ˚C and for 10 cycles at 80 ˚C to 40 ˚C.

Customers expect the resistance drift to stay within 12 % (typical).

As PM DC motor manufacturers continue to develop smaller, lighter, more efficient, and lower cost motors, the trend is to require smaller, lighter and ultimately more cost-effective protection devices, as well.

The advantages of utilizing Bourns® PPTC protection in DC motors:

- **Economic:** Bourns® PPTC devices offer a low-cost solution. Designers are able to customize the resistance characteristics, offering fast time-to-trip and a cost-effective process without the need for expensive tooling.
- **Small size:** Bourns® PPTC devices are low profile solutions enabling them to meet space constraints in the drive.
- **Low temperature sensitivity:** The advanced high temperature materials used in Bourns® PPTC thermistors allow operation at higher ambient temperatures. Furthermore, the construction of Bourns® PPTC devices help to maintain the windings at a low temperature during a locked rotor test.

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

OVERVIEW OF PROTECTION TECHNOLOGIES (CONTINUED)

Hybrid Dual-function Suppressors

Bourns offers a line of hybrid dual-function capacitor-varistor suppressors that consist of a multilayer ceramic capacitor (MLCC) and a multilayer varistor (MLV). These hybrid components are optimal solutions for transient protection and EMI filtering. Both suppression functions are integrated in a single radial leaded package, thereby, eliminating the need for two separate discrete components and helping to significantly reduce the space required for mounting to the brush card (Figures 12 & 13).

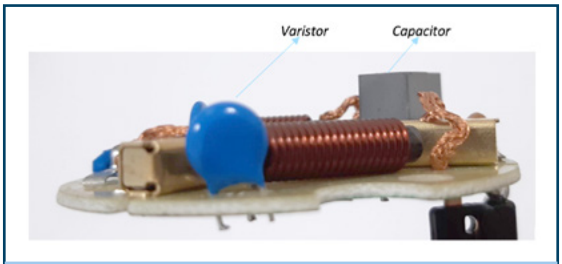

Figure 12. Traditional DC motor brush card with capacitor and varistor as separate components

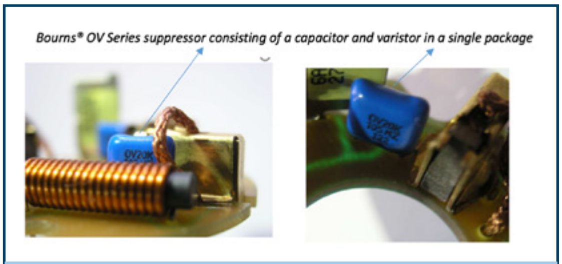

Figure 13. Advanced DC motor brush card with a single hybrid dual-function Bourns® OV Series component

Bourns offers two model families of dual-function suppressors for overvoltage protection and EMI noise suppression.

The standard MV Series offers voltage ratings from 14 VDC to 125 VDC and capacitance ratings from 10 nF to 1000 nF. AEC-Q200 testing and compliance is available upon request.

- DC voltage range: 14 V – 125 V
- Capacitance range: 10 nF – 1000 nF
- Surge current capability (8/20 µs): 150 A
- Temperature range: -40 °C to +125 °C

The AEC-Q200 compliant OV Series is available for 12 V, 24 V and 42 V voltage supply systems.

- DC voltage range: 16 V – 56 V
- Capacitance range: 470 nF – 1500 nF
- Surge current capability (8/20 µs): 800 A – 1200 A
- Load dump capacity (WLD): 6 J – 12 J
- Temperature range: -40 °C to +125 °C
- AEC-Q200 compliant

APPLICATION NOTE

How Protective and EMI Suppression Components Help Increase Permanent Magnet DC Motor Safety and Noise Suppression

Permanent Magnet DC Motor

Permanent Magnet DC Motor

MV Series

OV Series

SC Series

MF-RHT Series

MF-DC Series

Benefits of Bourns® DC Motor Protection Solutions

Low-voltage DC motors are used in a multitude of vehicle applications for the movement of seats, sunroofs, windows, mirrors or door locks. To help ensure the safe operation of DC motors it is recommended to protect the motor windings from overheating during a locked rotor or overload condition. Bourns® PPTC products offer an optimal protection solution that can be added to the drive of the motor.

Customers have access to Bourns' UL certified lab for testing DC motors with Bourns® PPTC devices. The ability to match customer requirements with the exact data on the protection device's performance helps to speed design cycles. As DC motors are a low-cost component produced in high volumes, Bourns® PPTC devices are ideally suited to these designs both from an economic and a technical features point of view.

In addition, the PPTC solutions from Bourns can be cost-effectively and quickly formulated to meet customers' requirements. Plus, they are generally lower profile than bimetal devices and, when tripped, keep windings at a lower average temperature during the event of a locked rotor or overload condition. As DC motor technology advances, the requirements from customers will be for smaller, lighter and more cost-effective components. Bourns is committed to offering continual technology enhancements to meet these requirements.

Based on a design's transient voltage protection and EMI suppression requirements, Bourns also can customize both its MV and OV Series products as well as develop more complex customized filters that combine varistor and several capacitors onto a single compact PCB (Figure 14).

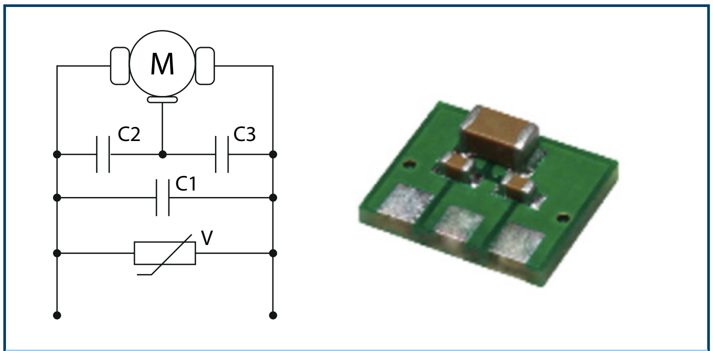

Figure 14. Customized PCB-based suppressor

BOURNS®

Americas: *Tel* +1-951 781-5500
Email americus@bourns.com

EMEA: *Tel* +36 88 885 877
Email eurocus@bourns.com

Asia-Pacific: *Tel* +886-2 256 241 17
Email asiacus@bourns.com