Broadband Interference Suppressor Modules

Franz Wurmser, Dietmar Zeidler, Davide Montanari

KEMET Electronics GmbH, Rudolf-Diesel-Str. 21, 86899 Landsberg am Lech, Germany
Phone: +49 8191/335032 Fax: +49 8191/335064, e-mail: FranzWurmser@kemet.com

Abstract
On the electric motors in cars, like those used in windshield wipers, cooling fans, seat positioning etc., capacitors have been used for radio frequency filtering for many years. Typically these capacitors are connected to the motor as individual components rather than via a printed wiring board. The requirements of voltage peak limitation have become more and more important because of the increasing number of voltage transient sensitive electronics in vehicles. Very high transient voltages are generated, when a motor is switched off. To meet these requirements, it is necessary to use in addition to a capacitor also a transient voltage limiting element, such as a varistor or a bidirectional TVS diode. Multicomponent modules with integrated film capacitors and varistors or TVS diodes can be used to solve both transient and interference problems. Film capacitors are used due to their self healing ability, which makes them capable of withstanding high voltage peaks.

KEMET’s F5A series consists of a MKT film capacitor and a ceramic varistor in a single box, the F5B series of a MKT film capacitor and a bidirectional TVS diode. A diode switches faster than a varistor and thus can support a better performance when strong limiting is required.

Mobile phones and other applications, using very high frequencies, require limitation of EMI also at these frequencies. A new multicomponent module F5D combines a MKT film capacitor for the low frequency EMI filtering, and an integrated Multilayer ceramic capacitor with small capacitance for the high frequency EMI filtering.

This paper will discuss technical advantages of each of these module types inside the circuit, and give some guidance on the optimum areas (capacitance, voltage and frequency) for the application of each technology.

Introduction
The standard ISO 7637 defines different test pulses for components in automotive applications and consists of the following parts, under the general title Road vehicles — Electrical disturbances from conduction and coupling:
— Part 1: Definitions and general considerations
— Part 2: Electrical transient conduction along supply lines only
— Part 3: Vehicles with nominal 12 V or 24 V supply voltage — Electrical transient transmission by capacitive and inductive coupling via lines other than supply lines

The standard ISO7637 describes the factual situation:
“Electrical and radio-frequency disturbances occur during normal operation of many items of motor vehicle equipment. They are generated over a wide frequency range, and can be distributed to on-board electronic devices and systems by conduction, coupling, or radiation.

In recent years, an increasing number of electronic devices for controlling, monitoring and displaying a variety of functions have been introduced into vehicle designs. It is necessary to consider the electrical and electromagnetic environment in which these devices operate and, in particular, the disturbances generated in the vehicle electrical system itself. Such disturbances can cause degradation (temporary malfunction or even permanent damage) of the electronic equipment. Moreover, “worst-case” situations are usually those resulting from disturbances generated inside the vehicle by, for example, ignition systems, generator and alternator systems, electric motors and actuators.
All OEMs are recognizing that protection from such potential disturbances has to be considered as part of total system certification."
The basic filtering component on electric motors is the capacitor. It lowers the self-inducted voltage peaks of a motor. A high capacitance capacitor is a better filter than a low capacitance one, because of: \( v = i\sqrt{LC} \). But with increasing capacity, the component body size grows and the filtering of high frequency interferences gets worse. Based on the market demands, in our experience, the most useful capacities are around 1 µF. There are lots of influences, which can require another value, like conducted energy, required qualification tests, or the distance between motor and suppressor component. The optimum value must be evaluated during the development process of the motor.

The nominal voltage of the capacitor must be chosen in accordance to the emitted transient peaks of the motor. These peaks can easily reach more than 350V, in 24V wirings of trucks even more than 400V. By using an additional voltage limiting element it is possible to use capacitors with lower nominal voltage and thus with smaller body size and lower weight.

**Capacitor and Varistor Multi-component**

In combination with a varistor, the nominal voltage of the used film capacitor can be decreased to 63Vdc. In our series F5A (as shown in Fig.1) we are using ceramic multilayer varistors in size 1206, which offer the capability to absorb between 0.3 and 1.0 J of transient energy, depending on the nominal value of varistor voltage. In combination with the integrated capacitor, this is sufficient for most of the electric motors in cars, only very powerful motors, i.e. cooling fan motors, can also generate higher transient energy.

Per definition, the nominal varistor voltage is the value, at which a varistor conducts 1 mA, when this voltage is applied. To select the correct varistor voltage for a new project, it is necessary to check some basic matters. Obviously the varistor voltage must be chosen to be higher than the power supply voltage of the motor, otherwise the varistor would immediately start to conduct and would be destroyed. Important to take into account are the test voltages for the motor during the approval process. The varistor voltage must be selected to be above the highest continuous test voltage, paying attention to the 10% tolerance of the varistor voltage. These evaluations show the lowest possible varistor voltage to be used: the lower the varistor value, the better the voltage clamping. However the higher is also the energy absorption. For this reason, in case the self-heating of the component is too high, but the clamping voltage is well below the target, it is better to select a higher value of varistor voltage.

Another possible approach is to select the varistor by its clamping voltage value. However, this is not the real clamping voltage of the application, but for the defined 1 A pulse of 8x20 µs only. It gives an indication, but the performance of the multi-component depends mainly on the generated energy of the motor, with which it is connected.

The KEMET series F5A is tested according AEC-Q200 standard.
Capacitor and Bidirectional TVS Diode Multi-component

Fig. 2: KEMET Series F5B - Film capacitor and transient voltage suppressor (TSV) diode.

For applications, where the F5A component cannot fulfill the requirement of transient voltage clamping, because value of the varistor voltage can’t be chosen, but still the transient voltage peak is above the limit, a possible solution is to use a multi-component of film capacitor and transient voltage suppressor diode of the series F5B (as shown in Fig.2). The TVS diode has to be bipolar, because the multi-component must perform in both polarities. Similar to the varistor voltage, the diode can be selected by the breakdown voltage, which is also defined to be the value of voltage, applied to the component when the diode current is 1 mA.

The semiconductor manufacturers give another definition for the clamping voltage, than the ceramic varistor manufacturers do: For TVS diodes the clamping voltage is the peak voltage, which remains on the component, when a voltage pulse of 10/1000 µs is applied to it with the maximum peak pulse current. Again, it gives an indication, but the performance of the multi-component depends mainly on the generated energy of the motor, with which it is connected.

Test of Different Suppressor Elements on a Wiper Motor (turn off response)

Fig. 3. Circuit principle for the recording of the following transients.
Using the circuit shown in Fig.3, a power turn-off of the wiper motor can generate high level voltage peaks. The following oscilloscope views show the performance of different EMI suppressor elements on the same motor to be able to compare them easily:

A) No EMI Filter: Peak voltage -340V (Fig. 4)
B) With 1µF Capacitor: Peak voltage: -129V (Fig.5)
C) With 1µF Capacitor and Varistor with Varistor Voltage 39V: Peak voltage: -62V (Fig. 6)
D) With Capacitor 1µF and Varistor with Varistor Voltage 27V: Peak voltage: -46V (Fig. 7)
E) With Capacitor 1µF and Bidirectional TVS Diode 39V: Peak voltage: -41.2V (Fig. 8)

![Fig. 4: No EMI Filter, V_{Peak} = -340V.](image)

![Fig. 5: With 1µF capacitor, V_{Peak} = -129V.](image)

![Fig. 6: With 1µF capacitor, 39V varistor, V_{Peak} = -62V.](image)  ![Fig. 7: With 1µF capacitor, 27V varistor, V_{Peak} = -46V.](image)
Film Capacitor and Ceramic Capacitor Multi-component

Applications, using very high frequencies, require a limitation of EMI also at these frequencies. But still there is the need for the low frequency EMI filtering, too. With an integrated film capacitor and a multilayer ceramic capacitor with small capacitance for the high frequency EMI filtering both high and low frequency filtering can now be done with only one single component of the series F5D (as shown in Fig.9). Many OEMs are using central voltage clamping devices and the motors don’t need an additional clamping element themselves. Therefore a nominal voltage of 63V for the film capacitor is sufficient in such cases. The value of the capacitance is again the same as in the other multi-components, around 1 µF. The value of the ceramic capacitor must be found by tests in an EMI laboratory with the insertion loss measurement over the full bandwidth, over which the system must fulfil the interference limits. A very rough estimation can be somewhere between 10pF and 10nF.

The KEMET series F5D is tested according to AEC-Q200 standard.

Comparison Between Film Capacitor and Combined Film and Ceramic Capacitor on a Wiper Motor

The measurement recording of the insertion loss (setup scheme in Fig. 11) on a standard wiper motor for cars shows the insertion loss over the frequency range of 30 to 1000 MHz. Most radiated and conducted limits in electromagnetic compatibility (EMC) testing are based on quasi-peak detection mode. Quasi-peak detectors weigh signals according to their repetition rate, which is a way of measuring their "annoyance factor." They do this by having a charge rate much faster than the discharge rate. Therefore as the repetition rate increases, the quasi-peak detector does not have enough time to discharge as much, resulting in a higher voltage output (response on spectrum analyzer). For continuous wave (CW) signals, the peak and the quasi-peak response are the same. The quasi-peak
detector also responds to different amplitude signals in a linear fashion. High amplitude low repetition rate signals could produce the same output as low amplitude high repetition rate signal. In figure 10 the marked quasi peak limits for certain frequencies show the requirements of the car manufacturers. In the below example a single Capacitor with 1µF cannot fulfill these requirements at frequencies between 800 and 900MHz. The recorded quasi peak level is higher than the limit line. A combination of the 1µF capacitor and a 1nF capacitor ensures the level to be well below the limit line.

**Fig. 10. Radiated emission measurement**

**Fig. 11. Set up of the radiated emission measurement system**
Summary

KEMET’s interference suppressor modules for Automotive- and Industrial Applications can meet all the requirements of the valid EMC restrictions on small electric motors.

- Transient peak limitations can be achieved together with the RFI filtering with only one component (Fig. 6, 7)
- All components can be supplied and configured according to the customer’s specifications
- For normal transient voltage limits a combined capacitor and varistor is sufficient
- A combined capacitor and bidirectional TVS diode in one component can achieve even lower limits (Fig. 8)
- HF filtering can be achieved with a combined pair of capacitors with high and low capacity in a single case (Fig. 10)