Bourns Circuit Conditioning

Short Form Brochure

BOURNS®

Introduction

Circuit conditioning examines solutions for challenges in modifying voltage or current, such as noise filtering or voltage converters. It also applies to circuit protection solutions for isolating mains voltage or DC voltages with the goal of protecting electronics from damage. The Discovery Chart, beginning on page ten, for mains voltage rated components and DC circuit components is a useful tool for identifying the proper component series for the application's requirement. The Bourns® product portfolio contains many components for AC/DC conversion (both isolated and non-isolated) and switching power supplies (buck and boost converters). This short form brochure will demonstrate the potential solutions Bourns offers.

Boost Converters

A boost converter is used when a power supply needs to increase or boost an input voltage to a higher voltage. For example, a PWM motor drive would be driven from a DC link of several hundred volts. The boost converter, in this case, would convert the input to the desired level to run the motor.

The basic function of a boost converter is shown in figure 1. It consists of an input voltage (V1), a repetitively pulsed switch (V2 and Q1) and an inductor, capacitor, and diode. The output voltage across the capacitor can be increased by changing the rate at which the transistor is switched on and off.

If the switch is open (transistor is off), the output will be equal to the input. If the switch is pulsed like a square wave, the output voltage across the load resistor can be calculated by $V_{out} = V_i / ((1-D))$ where D is the duty cycle of the square wave and V_i is the input voltage. The duty cycle is given by the equation $(1-T_{off} / T)$ where T is the period of the switched pulse and T_{off} is the time that the transistor or switch is off.

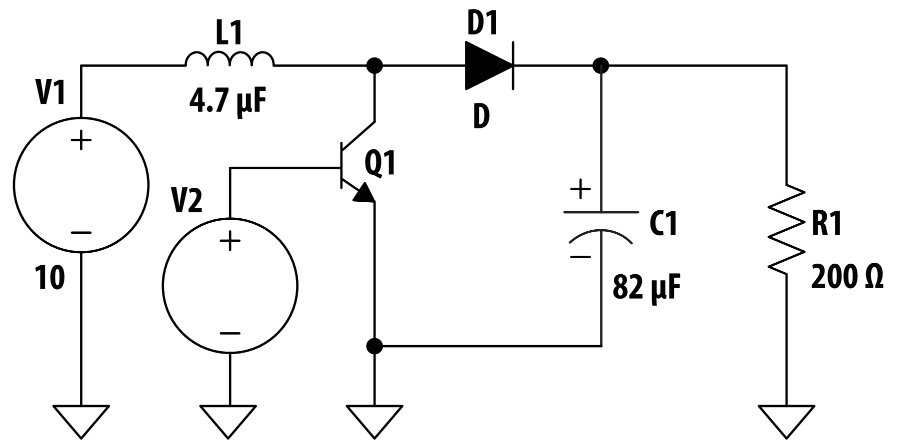


Figure 1 Basic Layout of a Boost Converter

As an example, let us pulse the switch with a duty cycle D of 0.5 (T = 10 µs, T_{off} = 5 µs). In this case, the output voltage will be 22 V which is proportional to 10 V / 0.5. The output response after 10 ms is shown in figure 2. The shape of the curve shown in the figure can be described by the term “under-damped” as it rises above its steady state level before settling down. Very often the shape of the curve can be determined by the load that the converter is connected to.

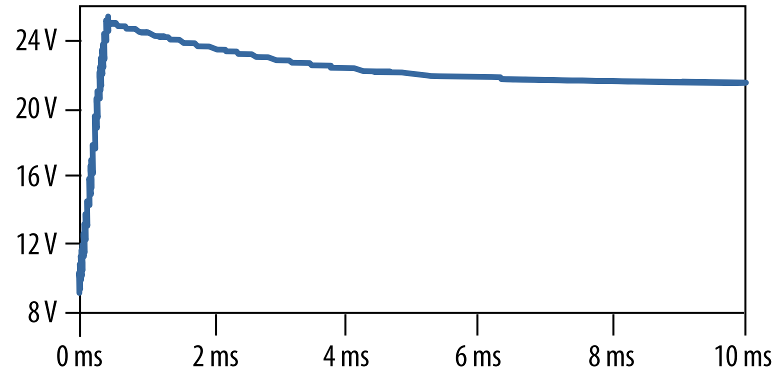


Figure 2 Underdamped Response with a Duty Cycle of 0.5 and Frequency of 100 KHz

If the duty cycle is increased to D = 0.8, the output of the converter should be Vi / ((1-0.8)) = 50 V. In fact, the output is slightly larger than 50 V as seen in figure 3.

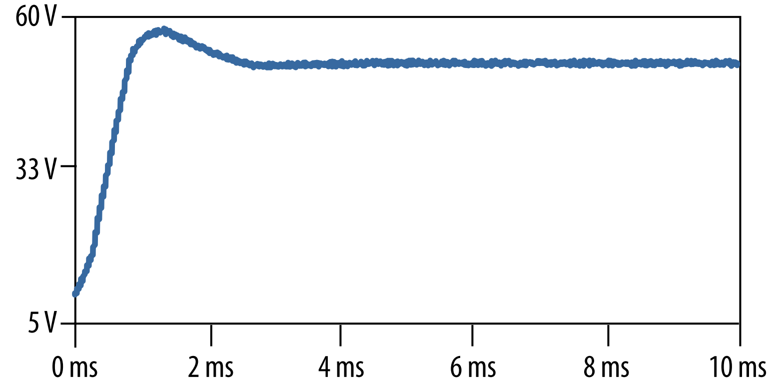


Figure 3 Underdamped Response with a Duty Cycle of 0.8 and a Frequency of 100 KHz

Buck Converters

Buck converters are the opposite of boost converters, taking an input DC voltage and converting it to a lower level. Applications include solid-state drives, appliance control boards, notebook power supplies and many more. The output could be used for driving a microcontroller or an LED display, for example. The basic layout of a buck converter is shown in figure 4.

The output of a buck converter, unlike a boost converter, is proportional to V2 times D (D = duty cycle). In this case, V2 is a square wave of period T, and D is represented by ($1-T_{off}/T$). V2 would be generated by the power supply switching regulator chip which uses a DC voltage from a rectified mains voltage or a battery as its input. Bourns offers both discrete PN junction and Schottky rectifier diodes and bridges in surface mount packages.

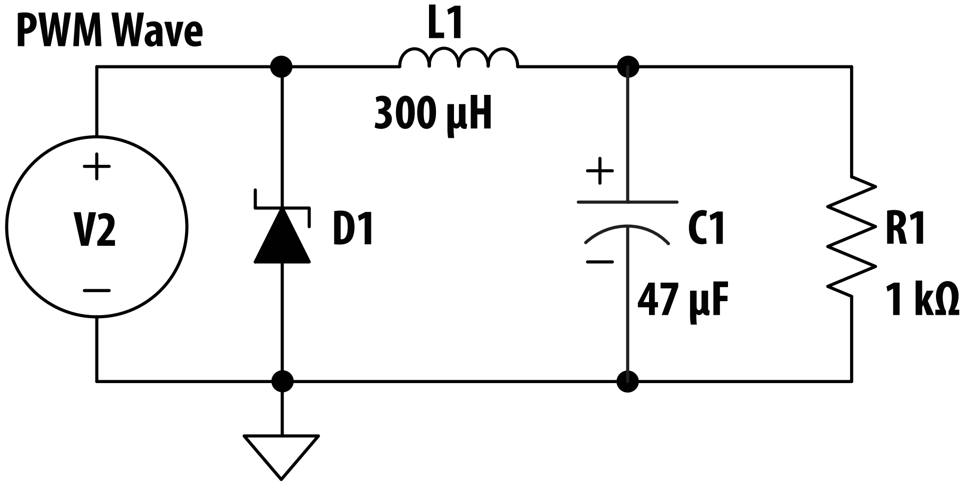


Figure 4 Basic Functional Layout of a Buck Converter

Figure 5 is a typical representation of V2 coming out of the switching regulator chip. In this example the frequency of V2 is 100 KHz.

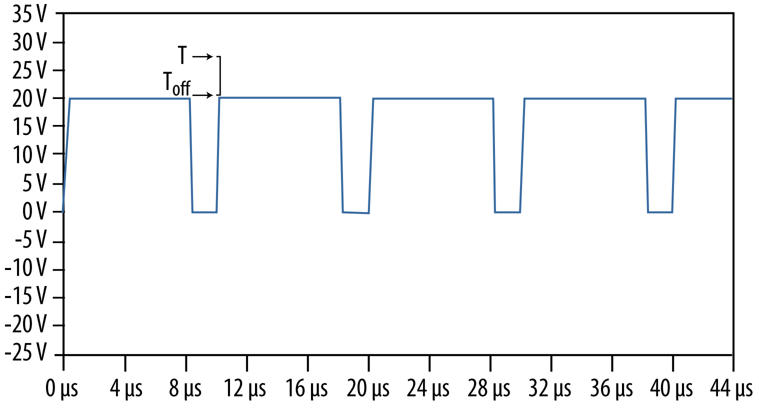


Figure 5 Typical Switching Voltage Showing T and T_{off}

Figure 6 is the subsequent output of the buck converter if T_{off} is 1 µs.

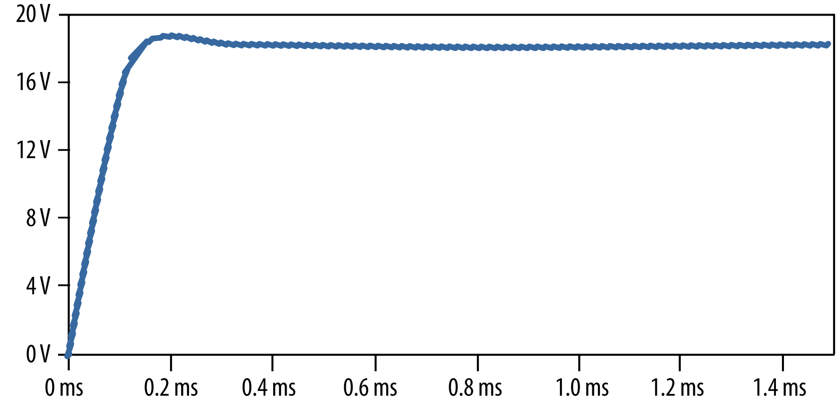


Figure 6 Output of a Buck Converter (Input 20 V and Duty Cycle 0.9)

However, if we increase T_{off} to 9 µs the output decreases as shown in figure 7.

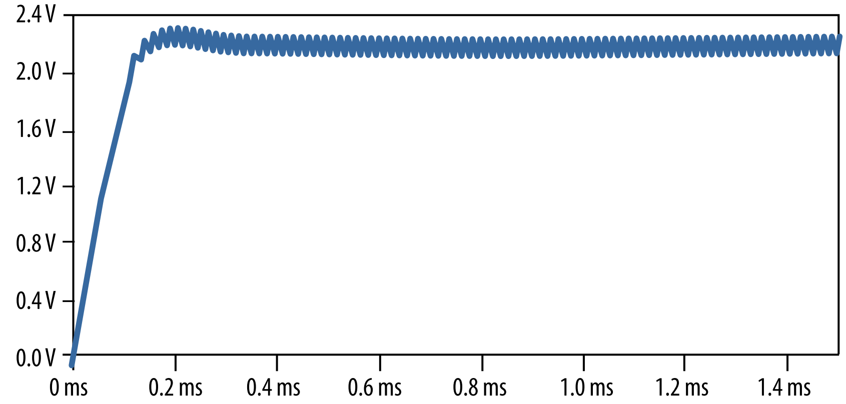


Figure 7 Underdamped Output of a Buck Converter (Input 20 V and Duty Cycle 0.1)

The inductor is a key component in both buck and boost converters and its selection involves various aspects which will affect the performance of the power supply. Let us consider the current in the inductor which is given by the formula, I (current) = (V*T) / L, where I = current (Amps), V = voltage (Volts), L = inductance (Henrys), and T = time (Seconds) that the inductor is conducting current. Due to the switching nature of the circuit, the current will look like a triangular wave as the current ramps up linearly and then ramps down. The graph in figure 8 shows the current in the inductor of figure 4.

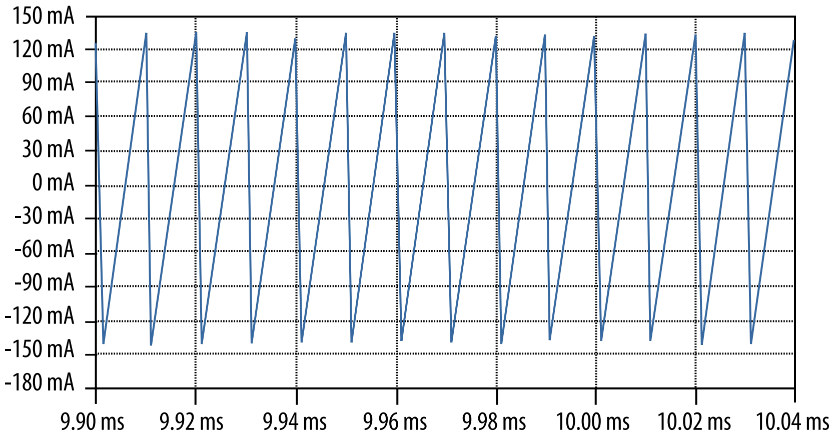


Figure 8 Current Waveform in Inductor of Buck Converter using L1 = 87 μH

The frequency will determine how long the inductor is “on” and, therefore, the peak current. The inductor’s saturation current should be higher than the peak current in the design. The peak current should be less than the maximum current that the switching chip can handle. The inductance will also affect the peak current; the higher the inductance, the lower the peak current. If L1 in figure 4 is increased to 220 μH the peaks are greatly reduced.

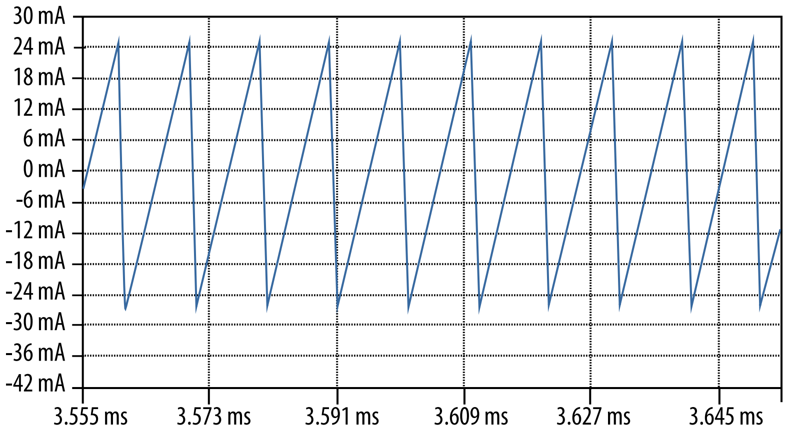


Figure 9 Current Waveform in Inductor of Buck Converter using L1 = 220 μH

However, larger inductance values will increase the average current conducted by the chip. The resistance of the inductor will be higher so the amount of heat generated will be higher. The efficiency of the power supply will, therefore, suffer. The other aspect to consider is the switching frequency itself. Given the current in the inductor is I = (V*T) / L, the current will drop in the inductor as the frequency increases (frequency f = 1 / T). The net effect of this is that at higher switching frequencies, designers can use lower inductor values. This means that one can use smaller components with lower serial resistance values saving cost, space and heat loss.

The downside to this is that there are side effects to using higher switching frequencies. One is the increase in the quiescent current going through the switching chip's MOSFET which lowers power supply efficiency. The other side effect to consider is the increase in EMI (Electromagnetic Interference), which would require intervention either in the use of extra filtering components or a review of the switching frequency. At this point, the designer needs to look carefully at the quality of the shielding of the inductor.

The chart in figure 10 shows the buck converter drawn in figure 4 with a 4.7 µH inductor switching at 100 KHz. There is a sizeable ripple in the voltage and current. By increasing the frequency to 1 MHz the ripple is considerably reduced.

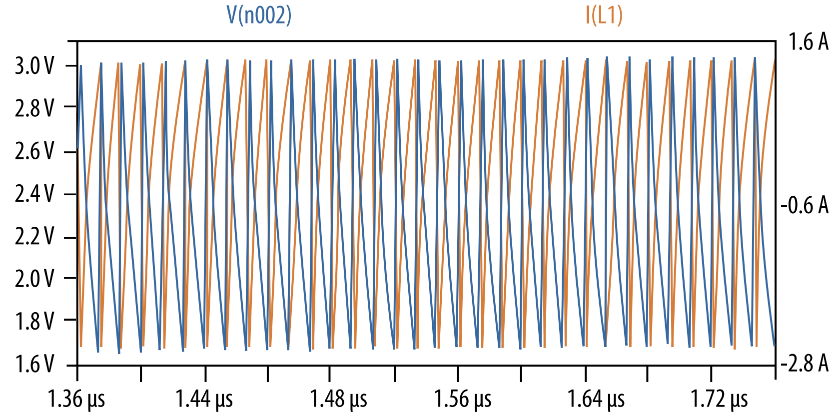


Figure 10 Output Voltage and Current Ripple using a Frequency of 100 KHz and Inductance of 4.7 µH

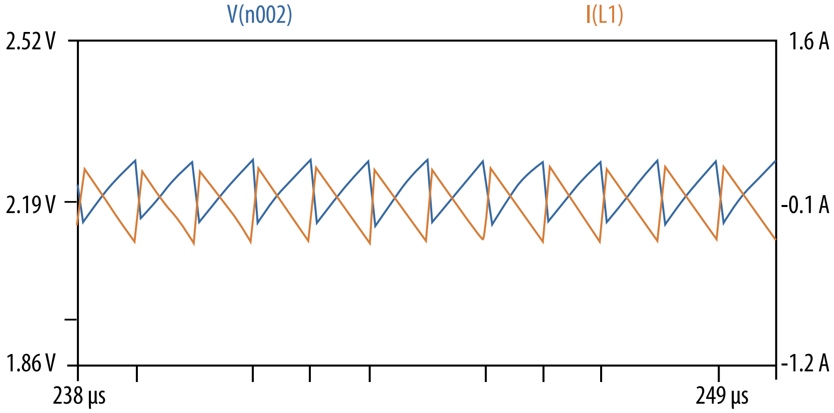


Figure 11 Output Voltage and Current Ripple using a Frequency of 1 MHz and Inductance of 4.7 µH

Overview of Regulations

Designers of power supplies for automotive and consumer power applications will design their circuits so that they can withstand various immunity tests, allowing them to conform to various EMC and EMI directives such as the 89/336/EEC of the European Union. The immunity standards are as follows:

- EN61000-4-2 Electrostatic Discharge (Immunity. 8 kV Air Discharge Applied to Enclosure. 6 kV Contact with Enclosure)
- EN61000-4-3 Radiated Electromagnetic Field 10 Volts/Meter - 80 MHz to 2.5 GHz Applied to Enclosure
- EN61000-4-4 Fast Transients - Burst Immunity ±2 kV
- EN61000-4-5 Input Surge Immunity ±2 kV Common Mode 1.2/50 S (Voltage); 8/20 µS (Current) ±1 kV Differential Mode 1.2/50 S (Voltage); 8/20 µS (Current)
- EN61000-4-6 Conducted Immunity 10 V/Meter - 150 KHz to 80 MHz EN61000-4

EMI regulations for consumer power are based on EN55022 class B. The switching frequency has a direct relationship with the levels of EMI emissions. Designers may have to balance the benefits from higher frequencies (smaller inductors and smaller ripple) with higher EMI emissions. Shielded inductors reduce the emissions, and RF chokes (together with some capacitors in the form of a pi network) filter out unwanted harmonics. A typical pi filter with a cut-off frequency of 10 MHz is shown in figure 12. Assuming that a switching frequency induces harmonics of up to 10 MHz onto the line and back to the rectifier and eventually the mains, the filter in figure 12 would remove those harmonics.

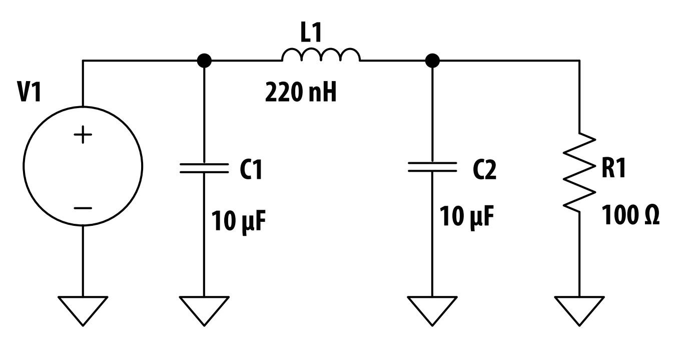


Figure 12 L C Filter Designed to Filter Out Frequencies 10 MHz and Higher

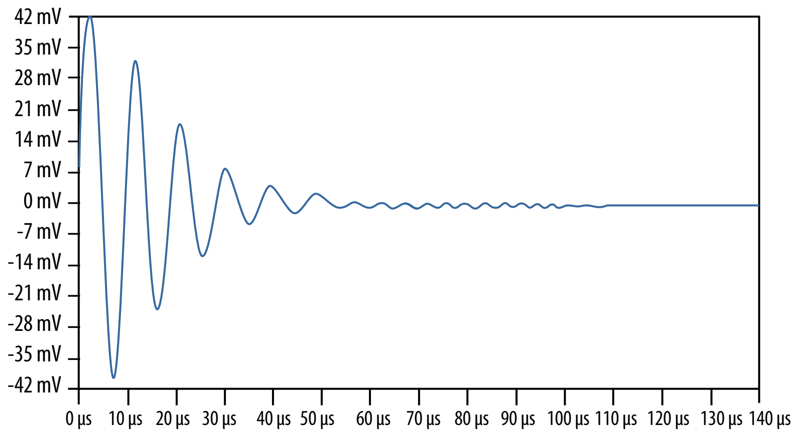


Figure 13 Response of Filter in Figure 12 to a 5 V 10 MHz Sine Wave

Current Limiting

Putting an inrush current limiting resistor in series can reduce the stress placed on the inductors and capacitor as well as change the cut-off frequency of the filter to improve the EMI performance. This is useful in switching power supplies using less than 1 amp for consumer power applications such as 12 V, 300 mA supplies for driving a microcontroller or a relay. For safety reasons, if the customer requires a fuse, the Model FW series of fusible resistors provide inrush limiting and they are listed per UL 1412 fusing functions.

Transient Protection

Transient protection is required under the EMC directive. Metal Oxide Varistors (MOVs) will limit the voltage during an event such as a high voltage surge per the EMC immunity test IEC 61000-4-5. However, for safety reasons MOVs may be placed in series with thermal fuses or alternatively with gas discharge tubes. If an MOV is over-stressed with a continuous voltage higher than its rated voltage, it will overheat and could burst or burn. This event can occur in power supplies where the neutral conductor is interrupted or where the power supply voltage is very high. The function of the thermal fuse is to protect the MOV from overheating. Gas Discharge Tubes (GDTs) can be used instead of thermal fuses to protect the MOV. A GDT placed in series with the MOV will not allow any leakage current unless the voltage rises above its DC breakdown voltage. In the event that the MOV is damaged and loses its high resistance, the GDT in series will still prevent leakage current from flowing through the MOV to ground. A thermal fuse designed to carry up to 2 kA during a level 4 surge without opening would be quite large and comparable in size if not larger than a GDT.

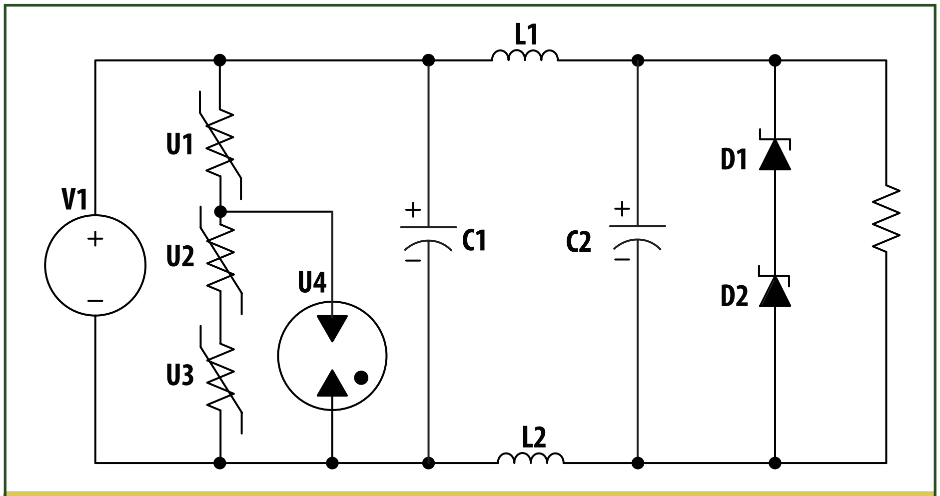


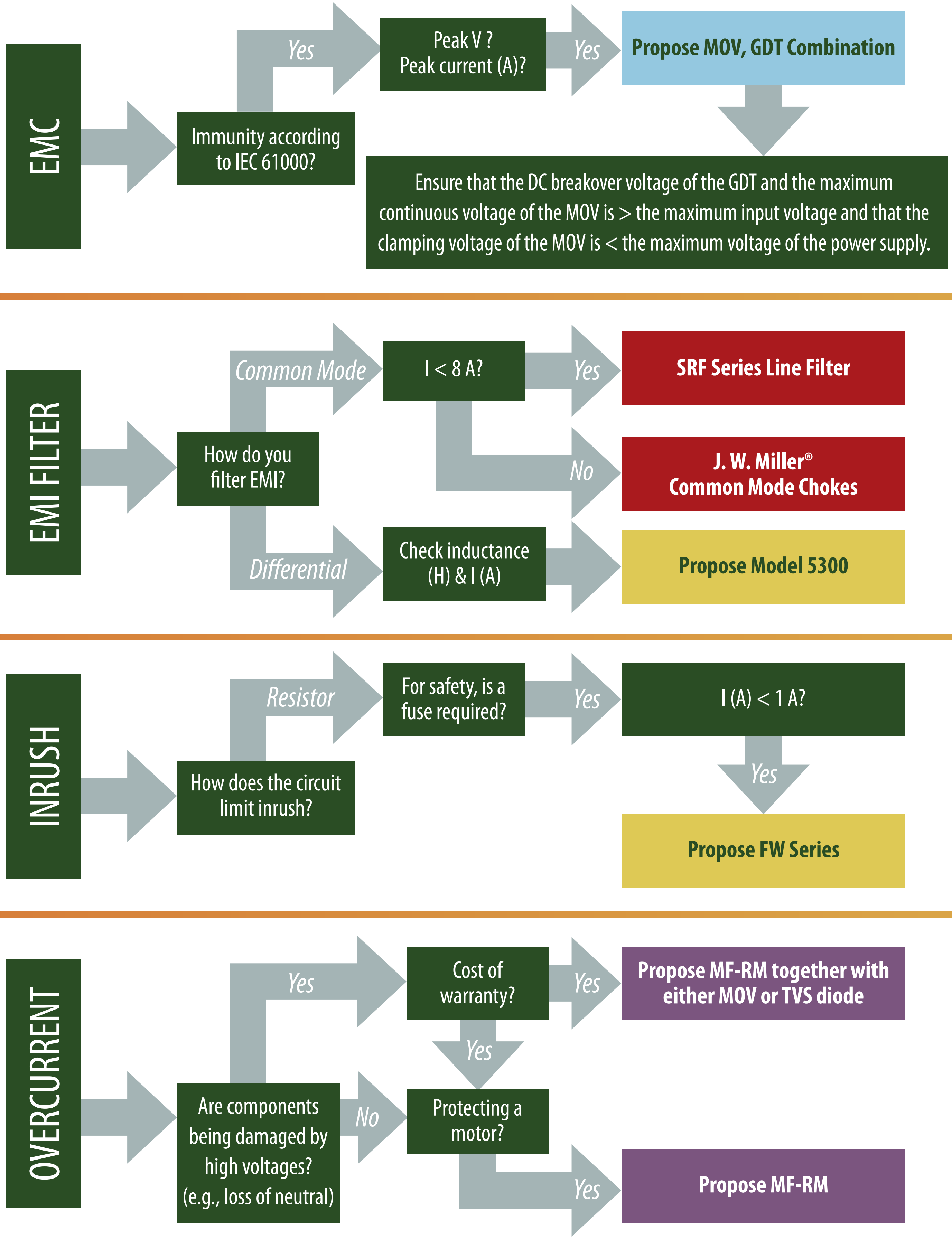
Figure 14 Power Supply EMC/EMI Suppression Circuit

GDTs placed in parallel with MOVs help reduce stress on the MOVs. They are slower to ionize and go into breakdown than MOVs but they can be used as backup protection if the power supply suffers a loss of neutral or if the customer requires the power supply to have very high isolation levels, such as consumer power equipment applications like air conditioners.

Transient Voltage Suppressor (TVS) diodes, which are either unidirectional or bidirectional, are used for general transient suppression. These are basic avalanche voltage clamp devices with high transient capability. They have the advantage of very fast clamping and low slope resistance in the active region. This means that the terminal voltage increases only by a few volts at the transient currents.

Power supplies may be exposed to stress conditions in the form of transient voltages and currents that can reach 6000 V and 3000 A. IEEE standard 587-1980 describes the typical amplitudes and wave shapes at different locations that arise from different sources. Indoor systems (AC less than 600 V) must protect against oscillatory transients which can have different amplitudes and wave shapes at different locations in the power bus. The frequencies of these surges can be up to 500 KHz and the voltage can reach 6 KV with a current of 500 A. Using a combination of MOVs, GDTs, TVS diodes, inductors and capacitors it is possible to clamp high energy surges and filter out common mode noise. Figure 14 is an example of such a circuit.

120 V / 220 V$_{rms}$ Circuit Conditioning Discovery Chart



EMC

Immunity according to IEC 61000?

Yes

Peak V ? Peak current (A)?

Yes

Propose MOV, GDT Combination

Ensure that the DC breakover voltage of the GDT and the maximum continuous voltage of the MOV is > the maximum input voltage and that the clamping voltage of the MOV is < the maximum voltage of the power supply.

EMI FILTER

How do you filter EMI?

Common Mode

I < 8 A?

Yes

SRF Series Line Filter

No

J. W. Miller® Common Mode Chokes

Differential

Check inductance (H) & I (A)

Propose Model 5300

INRUSH

How does the circuit limit inrush?

Resistor

For safety, is a fuse required?

Yes

I (A) < 1 A?

Yes

Propose FW Series

OVERCURRENT

Are components being damaged by high voltages? (e.g., loss of neutral)

Yes

Cost of warranty?

Yes

Propose MF-RM together with either MOV or TVS diode

Yes

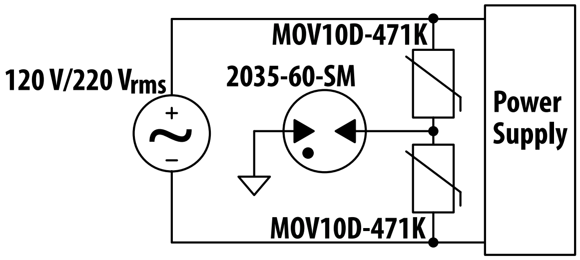
No

Protecting a motor?

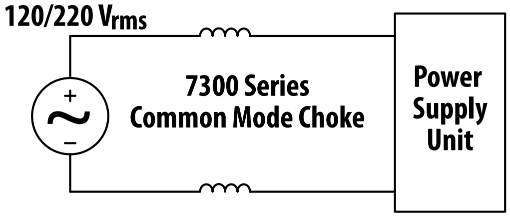
Yes

Propose MF-RM

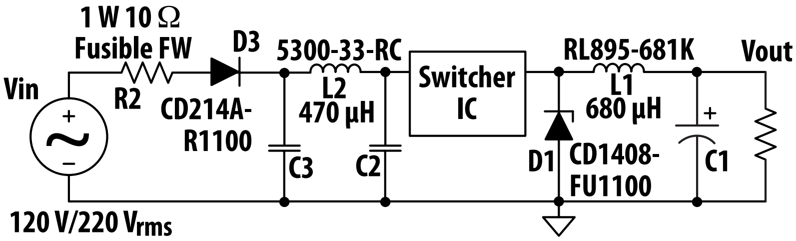
MOV, GDT



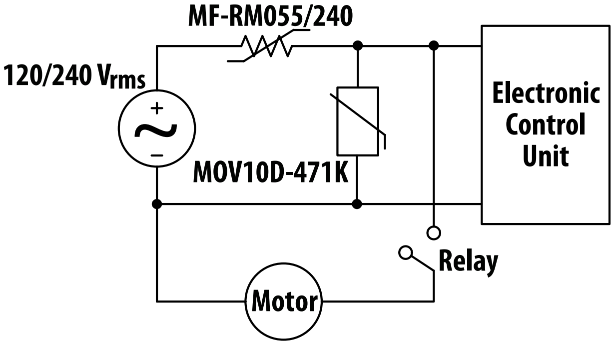
MAGNETICS



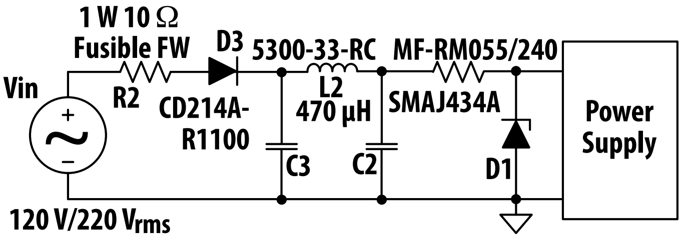
FW, DIODE



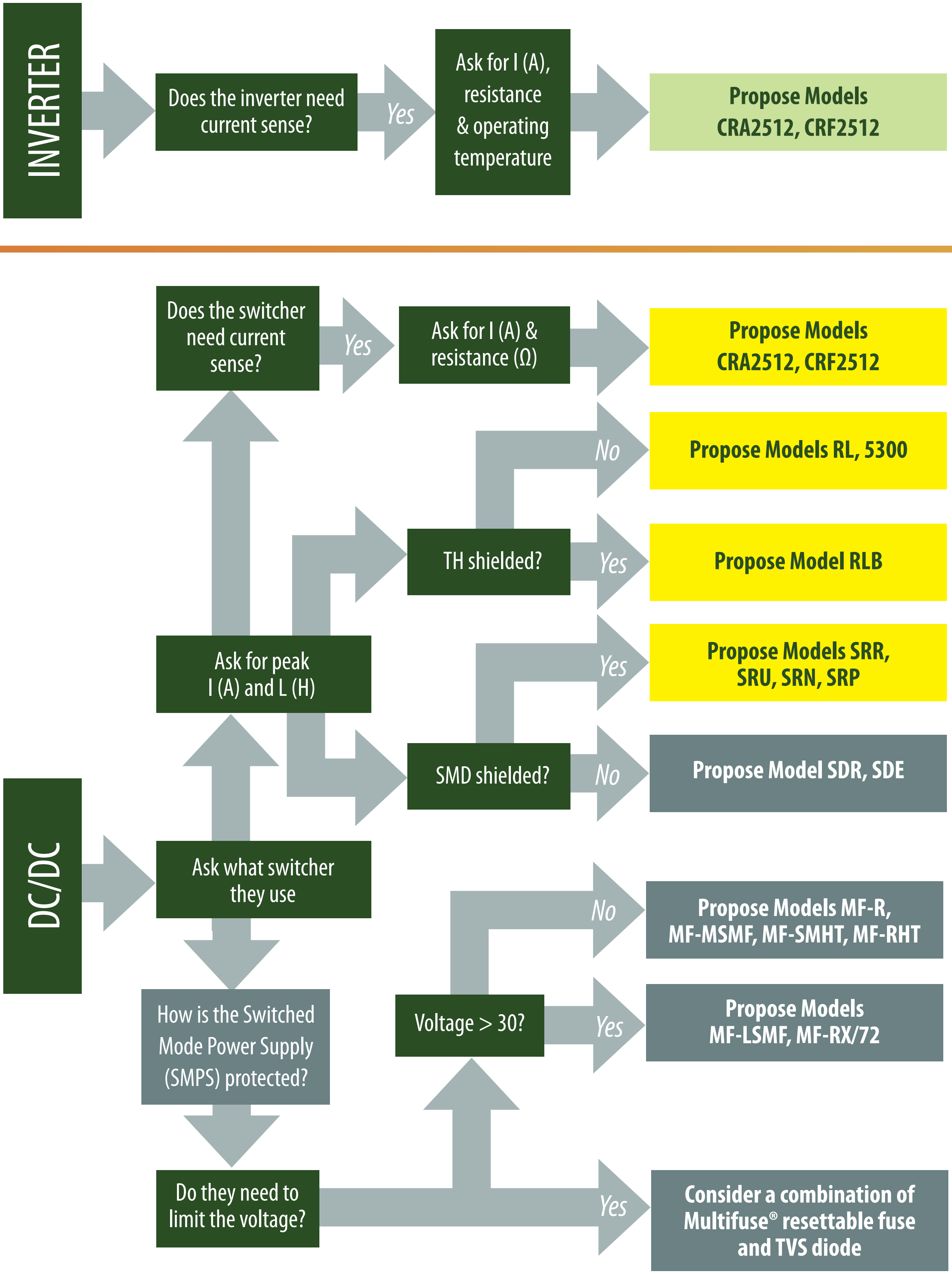
MOV, MULTIFUSE® PPTC DEVICE



MULTIFUSE® PPTC DEVICE, TVS DIODE



DC Circuit Conditioning Discovery Chart



INVERTER

Does the inverter need current sense?

Yes

Ask for I (A), resistance & operating temperature

Propose Models CRA2512, CRF2512

DC/DC

Ask what switcher they use

Does the switcher need current sense?

Yes

Ask for I (A) & resistance (Ω)

Propose Models CRA2512, CRF2512

Ask for peak I (A) and L (H)

TH shielded?

No

Propose Models RL, 5300

Yes

Propose Model RLB

SMD shielded?

Yes

Propose Models SRR, SRU, SRN, SRP

No

Propose Model SDR, SDE

How is the Switched Mode Power Supply (SMPS) protected?

Do they need to limit the voltage?

Voltage > 30?

No

Propose Models MF-R, MF-MSMF, MF-SMHT, MF-RHT

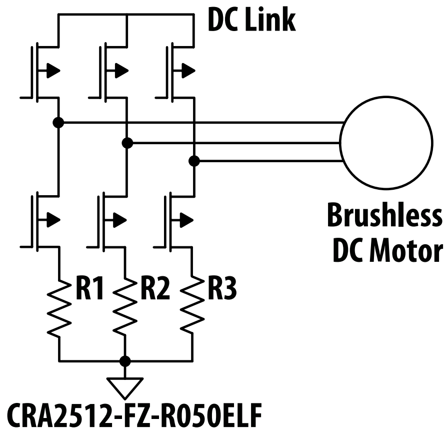
Yes

Propose Models MF-LSMF, MF-RX/72

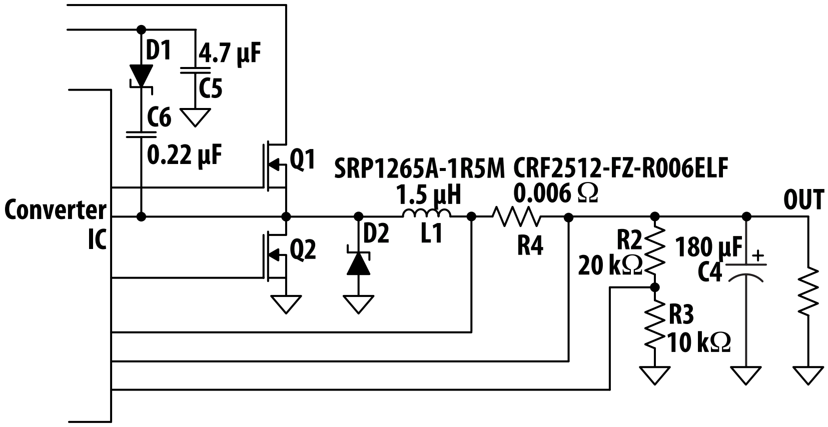
Yes

Consider a combination of Multifuse® resettable fuse and TVS diode

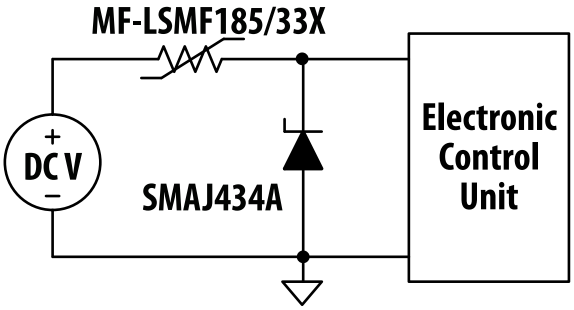
CRA



SRP, CRF



MULTIFUSE® PPTC DEVICE, TVS DIODE



Bourns® Product Offering

Inductors

SRP Inductor

Inductance	Current	Temperature
Max. 47 µH	Max. 55 A	Max. 150 °C

SDR Inductor

Inductance	Current	Temperature
Max. 15000 µH	Max. 16 A	Max. 125 °C

SRU Inductor

Inductance	Current	Temperature
Max. 330 µH	Max. 8 A	Max. 125 °C

RL Inductor

Inductance	Current	Temperature
Max. 100,000 µH	Max. 10 A	Max. 105 °C

RLB Inductor

Inductance	Current	Temperature
Max. 82000 µH	Max. 10 A	Max. 105 °C

SRR Inductor

Inductance	Current	Temperature
Max. 10,000 µH	Max. 20 A	Max. 125 °C

SRN Inductor

Inductance	Current	Temperature
Max. 470 µH	Max. 10 A	Max. 125 °C

SRF Inductor

Inductance	Current	Temperature
Max. 6500 µH	Max. 8.94 A	Max. 125 °C

7100 Inductor

Inductance	Current	Temperature
Max. 2000 µH	Max. 11 A	Max. 105 °C

5300 Inductor

Inductance	Current	Temperature
Max. 10000 µH	Max. 3.3 A	Max. 105 °C

Gas Discharge Tubes

2035 Gas Discharge Tube

Sparkover Voltage	Peak Surge Current
Max. 600 V	10000 A

2039 Gas Discharge Tube

Sparkover Voltage	Peak Surge Current
Max. 1100 V	5000 A

2089 Gas Discharge Tube

Sparkover Voltage	Peak Surge Current
Max. 3600 V	3000 A

Fusible Wirewound Resistors

FW Fusible Wirewound Resistor

Power	Resistance
Max. 7 W	Max. 100 Ω

Metal Oxide Varistors

MOV Metal Oxide Varistor

Surge Current	Operating Voltage
Max. 6500 A	Max. 1100 V

PPTC Thermistors

MF-LSMF PPTC Thermistor

Voltage	Hold Current	Temperature
Max. 33 V	Max. 3 A	Max. 85 °C

MF-MSMF PPTC Thermistor

Voltage	Hold Current	Temperature
60 V	Max. 2.6 A	Max. 85 °C

MF-USMF PPTC Thermistor

Voltage	Hold Current	Temperature
30 V	Max. 1.75 A	Max. 85 °C

MF-RM PPTC Thermistor

Voltage	Hold Current	Temperature
$240\ V_{rms}$	Max. 550 mA	Max. 85 °C

MF-RX/72 PPTC Thermistor

Voltage	Hold Current	Temperature
72 V	Max. 3.75 A	Max. 85 °C

MF-RHT PPTC Thermistor

Voltage	Hold Current	Temperature
16 V	Max. 13 A	Max. 125 °C

Current Sense Resistors

CRA2512 Current Sense Resistor

Power	Min. Resistance
3 W	0.01 Ω

CRF2512 Current Sense Resistor

Power	Min. Resistance
2 W	0.001 Ω

Power Resistors

PWR263S Power Resistor

Max. Power	Pulse
35 W	10 J in 0.1 sec

Rectifier Diodes

CDNBS04 Rectifier Diode

Max. Current	Max. Voltage
1 A	1000 V

Transient Voltage Suppressor (TVS) Diodes

SMAJ TVS Diode

Peak Power	Breakdown Voltage
400 W	Max. 522 V

SMBJ TVS Diode

Peak Power	Breakdown Voltage
600 W	Max. 522 V

SMCJ TVS Diode

Peak Power	Breakdown Voltage
1500 W	Max. 522 V

SMLJ TVS Diode

Peak Power	Breakdown Voltage
3000 W	Max. 522 V

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Specifications are subject to change without notice. The device characteristics and parameters in this brochure can and do vary in different applications and actual device performance may vary over time. Users should verify actual device performance in their specific applications.

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