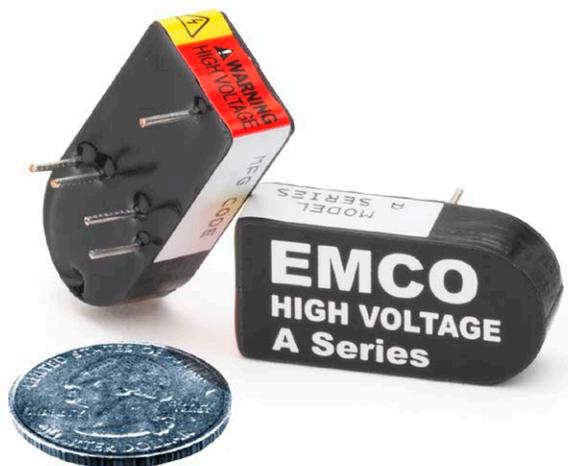


## Minimizing the Impact of Source Resistance on High-Voltage DC to DC Converters

A primer for system designers

### Synopsis

Resistance between a low-voltage power supply and the input terminals of a DC to HV-DC converter results in not only power-loss but reduced long-term reliability in the converter. The impact of source resistance to a converter is measured using XP EMCO A-Series models. Design guidelines are given to minimize reliability impact due to source resistance.



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## Minimizing the Impact of Source Resistance on High-Voltage DC to DC Converters

Source resistance ( $R_s$ ) can reduce the efficiency of a DC to DC converter by 10% or more and impact the converter's reliability. In extremely small converters, such as XP EMCO's newest A Series ultra-miniature, DC to high-voltage (HV) DC converters, engineers need to pay special attention to this design aspect because of the low capacitance values that must be used in the converter to achieve a small footprint. This application note shows system designers how to cope with different  $R_s$  values using visual measurements from XP EMCO's newest A Series converters and provides recommendations for highly efficient and reliable operation. It assumes the user is not a power conversion expert, but rather a system expert who has to use power conversion technology as part of his or her design. As a result, it avoids design equations and focuses on empirical analysis. However, the measurements also provide helpful visual guidelines for power system experts regarding how the converter should operate in an application.

### Avoiding Efficiency Loss

XP EMCO's A Series high-voltage DC to DC converters provide system designers with easy-to-use power conversion in a volume of less than 0.10 cubic inches with a profile of only 0.25 inches. Within this form factor, 0 to 5, 12 or 24V input voltages can be converted to high voltages that range from 100 to 6,000V in both 1-watt and 1.5-watt models.

A simple block diagram of XP EMCO's transformer-isolated high-voltage DC to DC converter is shown in Figure 1. The design has an oscillator, a transformer, and a rectifier as well as capacitors on both the input and output. The input capacitor is effectively a decoupling capacitor across the input and ground terminals of the DC to DC converter.

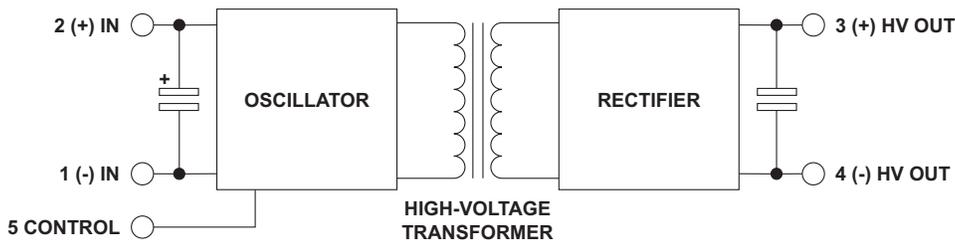


Figure 1. XP EMCO's transformer-isolated DC to DC converter topology includes capacitors for both the input and the output.

The A Series small size obviously limits the size of its input capacitor ( $<10 \mu\text{F}$ ). For those applications with a source resistance of less than 5 ohms, this is not a problem. However, those applications with a higher source resistance need additional design considerations. To determine the correct design values for the maximum source resistance, a series of measurements were made on production A Series products.

Examples of the waveform measurements are shown in Figure 2 and Figure 3. Figure 2 shows a current waveform for an A Series unit with zero source resistance. This input current waveform is quite distinctive and clearly shows the converter's operation. The waveform changes considerably with a higher source resistance as shown in Figure 3. With a 10-ohm source resistance, the current is much less distinct than the zero resistance waveform. It actually is difficult to determine when the converter is drawing current from the external supply.

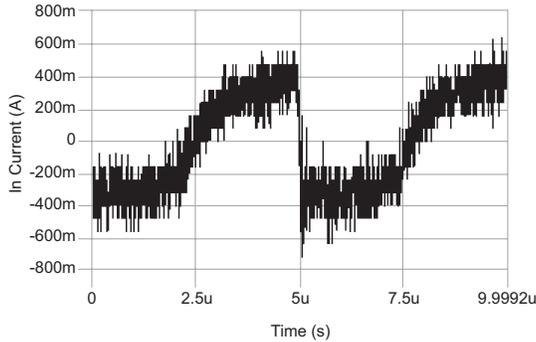


Figure 2. The current draw from the input voltage source of an A Series unit with RS equal to 0 ohms.

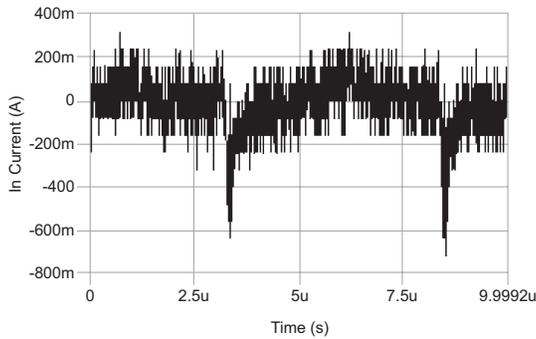


Figure 3. The current waveform change in an A Series unit based on RS equal to 10 ohms.

Figure 4 shows a summary of the two measurement conditions. Because of the source resistance, there is a significant efficiency impact to the converter's operation. Due to the power dissipated in the source resistance, achieving the same output voltage and delivered power requires a higher voltage from the source. As a result, the same test unit with a source resistance of 10 ohms loses about 10% efficiency.

Vin	Iin	Vout	Iout
12 V	166 mA	427 V	3.87 mA
Eff = 0.83			

Vin	Iin	Vout	Iout
13.7 V	163 mA	427 V	3.86 mA
Eff = 0.74			

Figure 4. The comparison of the impact of source resistance on efficiency. The top values are based on a source resistance of zero ohms and the lower values are from a source resistance of 10 ohms.

## Ensuring Reliability

In addition to efficiency, there is a reliability impact from the source resistance on the converter's operation. XP EMCO converters contain input decoupling capacitors to handle transient currents that are inherent in the operation of the oscillator/transformer combination. The source resistance increases the oscillator-frequency component of the current that leads to additional stress on the input capacitor.

As part of the final qualification of the A Series converter design, testing was performed to determine acceptable values for the source resistance for converter reliability. Proper values limit the oscillator frequency current demand on the internal decoupling capacitor that could lead to a longterm reliability problem. Measurements of the decoupling current were made for various values of source resistance (from 0 to 55 ohm) with and without an external decoupling capacitor. The magnitude of the fundamental frequency current component was compared against component data sheet specifications including a guard band for added safety to verify that the internal capacitor has sufficient RMS current ( $I_{RMS}$ ) margin.

The measurements demonstrate that a properly sized external decoupling capacitor effectively limits the fundamental frequency current component magnitude in the presence of increasing values of external source resistance, mitigating reliability stress on the internal capacitor. Ideally, a very low equivalent series resistance (ESR) electrolytic capacitor would be used to maximize the effectiveness of the additional capacitance.

Based on the complete analysis, an external capacitor is recommended for practical source resistance values above 5 ohms to ensure converter reliability. The range that a board designer should consider for an external A-Series capacitor is 1 to 20 uF, depending on converter input voltage.

## Summary/Recommendations

The measured decoupling capacitor fundamental frequency  $I_{RMS}$  values were used to establish the 5-ohm maximum-source resistance guideline for the A Series family. A properly sized external decoupling capacitor effectively limits the base-frequency current component magnitude for higher values of external source resistance.

In summary, source resistance reduces the efficiency and stresses the converter's internal decoupling capacitor, which decreases the converter's long-term reliability. For the A-Series, source resistances below 5 ohms have no effect on reliability. The reliability impact of high source resistance can be minimized by placing an external low-ESR capacitor at the converter's input pins.

## Appendix

### Additional Measurement Data

The following measurements provide additional insight to power system experts regarding the DC to DC converter's operation under different source resistance and input capacitance conditions.

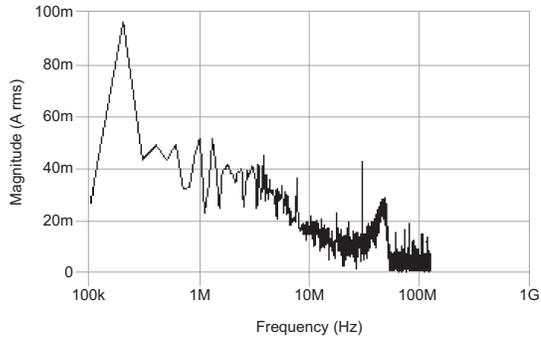


Figure 5. Measurement of the decoupling-capacitor current magnitude versus frequency for zero source resistance and zero external capacitance ( $C_{ext}$ ) shows a large component at the converter oscillator frequency. This measurement was performed on the same setup as Figure 2.

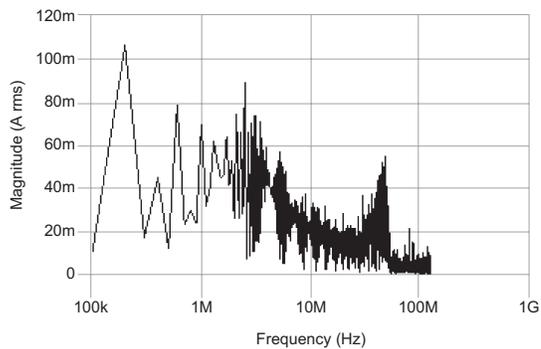


Figure 6. Measurement of the decoupling capacitor current magnitude versus frequency for 15-ohm source resistance and zero external capacitance shows increased current components at oscillator harmonic (3X, 12X) frequencies. This measurement was performed on the same setup as Figure 3.

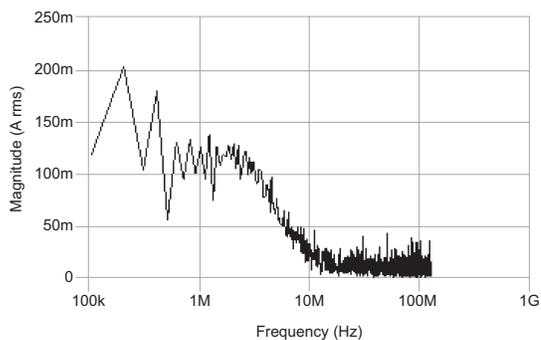


Figure 7. Measurement of the decoupling capacitor current versus frequency for a 10-ohm  $R_s$  with 22  $\mu\text{F}$   $C_{ext}$  shows a significant 2nd harmonic current component. The base-frequency magnitude is insensitive to variations in  $R_s$ .



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## About XP EMCO

XP EMCO is an innovative, industry-leading developer of high voltage power supplies. During the past 40+ years, XP EMCO has received many prestigious accolades and awards including:

“Product of the Year” (2 times) from Electronic Products Magazine

“Key Partner Award” from the University of Wisconsin for Project ICECUBE

“Most Innovative New Product of the Year” from the University of California, Davis

“Product Technology Award” from ECN Magazine

“Runner-Up Product of the Year” from Electronic Engineering Product News

“Editor’s Choice Awards” (6 times) from Electronic Products Magazine

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