

High Voltage and Load Current Monitors

This Application Note describes how high voltage and load current monitors work with all XP EMCO products.

Safety Warning

High voltage power supplies present a serious risk of personal injury if not used in accordance with design and/or use specifications, if used in applications on products for which they are not intended or designed, or if they are used by untrained or unqualified personnel.

For more information, please refer to the XP EMCO Safety Warning and Disclaimer located at:

<http://www.xppower.com/High-Voltage/Safety-Warning-Concern-HV.pdf>

Scope/Overview

XP EMCO HV DC-DC converters generate a high-voltage output based on the voltage at the input pin (for proportional models) or the programming pin (for regulated models). Since the relationship between input or programming voltage and the high voltage output is a linear function, it's sufficient in most cases to set and verify the input (or programming) voltage. Once the input voltage is set, output voltage remains constant if the load impedance is stable. For applications where output voltage monitoring is required, either to verify that critical limits are not exceeded or to control a proportional unit through a feedback loop, simple OP-AMP based circuits can provide the functionality. In applications where output current sensing is required to detect fault or threshold limit conditions, the OP-AMP circuits for voltage monitoring can be modified slightly to provide the current monitor functionality. This application note will describe simple voltage and current monitor circuits and provide measured performance data for specific implementations.

Voltage Monitoring

Output voltage monitoring is accomplished by dividing the high-voltage (HV) at the output terminal by a large-ratio resistor divider and then buffering the resulting voltage with a voltage-follower. A high value resistance for the divider will minimize current draw from the converter and maximize current available to the load. A sample voltage monitor circuit for positive output models is shown in Figure 1.

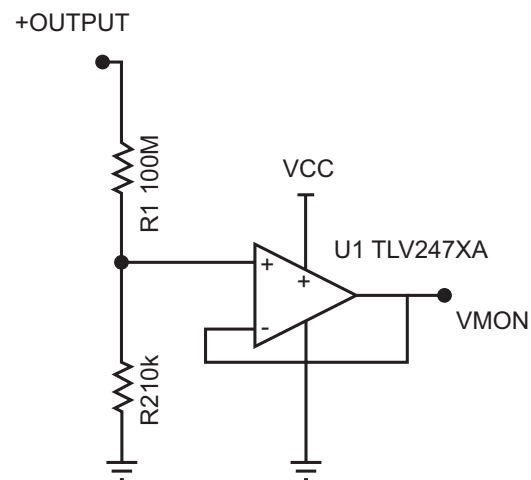


Figure 1. Positive Output Voltage Monitor

Voltage Monitor – Positive Output

In this specific voltage monitor implementation, the divider ratio is 1:10000 and a +10kV output from an XP EMCO converter is reduced to 1V at the input to the voltage follower. The tolerance of the resistors is the primary factor affecting the accuracy of the monitor. A cost-effective tradeoff is to use 1% resistors which leads to a ~1% accuracy in the monitor voltage. The 100M resistor needs to have a voltage rating exceeding the maximum voltage of the HV converter. In this case, a 20kV-rated axial thick-film resistor is suitable. As XP EMCO HV converters require input voltages ranging from 5 to 24V, the monitor circuit uses a single-supply OP-AMP to avoid requirement of a negative supply voltage. In using a single-supply OP-AMP to buffer a voltage near ground, it's important that the OP-AMP have rail-to-rail inputs and outputs. For XP EMCO models operating from a 5V input, the TLV247X OP-AMPs enable a linear transfer function in the voltage follower for HV output from 500V to 10kV. The low input bias current and low input offset voltage of this OP-AMP family aid to keep the accuracy at ~1%. For XP EMCO models operating at 12V, 15V, or 24V, an OPA171/2171 OP-AMP can be used in the voltage follower. This family of OP-AMPs operates from 2.7V to 36V and tight performance specifications are maintained for an input voltage from the negative rail to within 2V of the positive rail.

Voltage Monitor – Negative Output

For XP EMCO models with a negative high voltage output, the monitor circuit may need to generate a positive monitor voltage from a divided negative output voltage. A single-supply inverting amplifier is sufficient for this purpose if the OP-AMP has rail-to-rail inputs and outputs. A sample voltage monitor circuit for negative output models operating from 5V is shown in Figure 2.

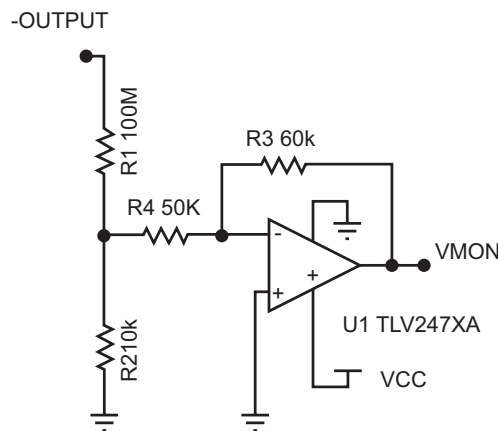


Figure 2. Negative Output Voltage Monitor

The input impedance of the inverting amplifier affects the resistor divider accuracy and reduces the divided voltage from the intended 1:10000 ratio. The gain of the inverting amplifier is adjusted to greater than unity to compensate for the reduced divider voltage. The result is a monitor circuit with a linear transfer function for HV output from -500V to -10kV. For negative-output XP EMCO models operating at 12V, 15V, or 24V, an OPA171/2171 OP-AMP can be used in the inverting amplifier. For protection of the OP-AMP at power-down, a Schottky diode to ground can be placed at the inverting input. To minimize the impact on monitor accuracy, the diode should have low leakage current ($\leq 0.5\mu\text{A}$).

Voltage Monitor Prototypes and Test Results

Voltage monitors were built for a positive and a negative Q-Series model. One unit per model was tested using the XP EMCO production test bench. A voltage transfer function under full load was captured using both the test bench and the voltage monitor circuit. The production test bench results are considered accurate. The difference between the two sets of measured voltages is the voltage monitor error.

The voltage monitor readings and error percentages for the Q12-5 and Q20N-5 DC-DC converters are plotted below. The monitor error is worst at DC-DC converter turn-on and decreases to less than 2% when V_{in} is half the rated input voltage. (As rated output voltage for the selected models is much less than 10kV, adjustments were made to resistor values in the schematics above to scale the monitor voltage to >1V).

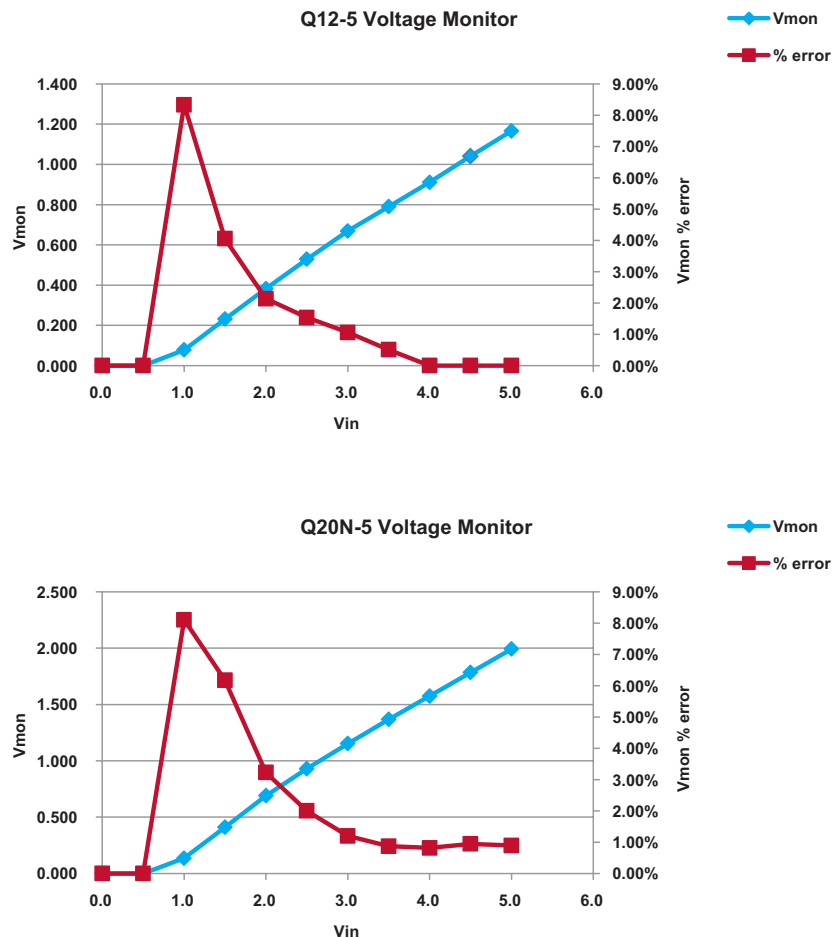


Figure 3. Voltage Monitor Test Results

Current Monitoring

In applications where output current sensing is required, the voltage monitor circuits described can be modified to measure current. It is quite difficult to employ high-side sensing techniques to measure current because of the high voltages involved. As such, only low-side sensing circuits are presented here. For XP EMCO proportional DC-DC converters, low-side sensing does not compromise the accuracy of the results because the HV return is isolated from the input side ground. For XP EMCO regulated converters, low-side sensing is accurate only if the output load is simple and the return current path can be confined to one PCB trace.

Current Monitor – Positive Output

Low-side current monitoring is accomplished by placing a sense resistor between the load and the HV return (or GND). The voltage across the sense resistor is then scaled by an appropriate OP-AMP based amplifier. A sample current-monitor circuit for positive output models is shown in Figure 4.

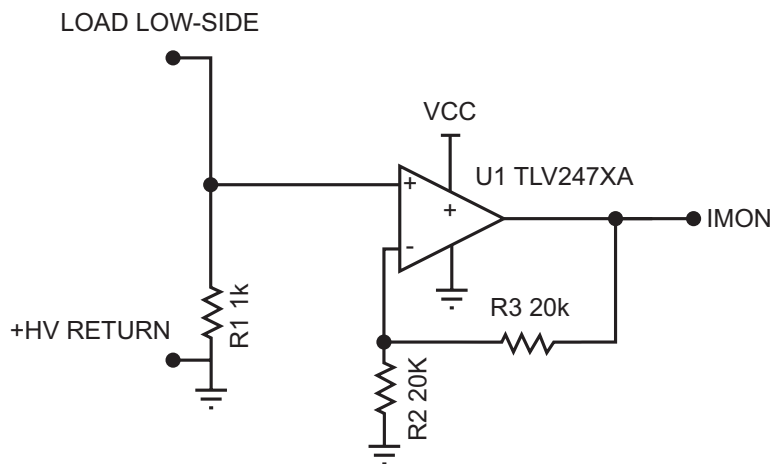


Figure 4. Positive Output Current Monitor

In this specific current monitor implementation, a 0.5mA output current from an XP EMCO converter is converted to 0.5V at the input to the non-inverting amplifier and 1V at the monitor output. As is the case for the voltage monitor, the tolerance of the resistors is the primary factor affecting accuracy. The use of 1% tolerance resistors results in ~1% accuracy in the circuit. The sense resistor should raise the voltage on the low side of the load by the minimum value possible. In most cases, the voltage rise is very small relative to the HV output magnitude and the maximum sense resistor value is limited by the supply voltage of the OP-AMP. For XP EMCO models operating from a 5V input, this current monitor using a TLV247X family OP-AMP has a linear transfer function for current values from 50uA to 0.5mA. For XP EMCO models operating at 12V, 15V, or 24V, an OPA171/2171 OP-AMP can be used in the non-inverting amplifier.

Current Monitor – Negative Output

To sense current from a HV converter with a negative output, a single-supply inverting amplifier is once again employed. A sample current monitor circuit for negative output models operating from 5V is shown in Figure 5.

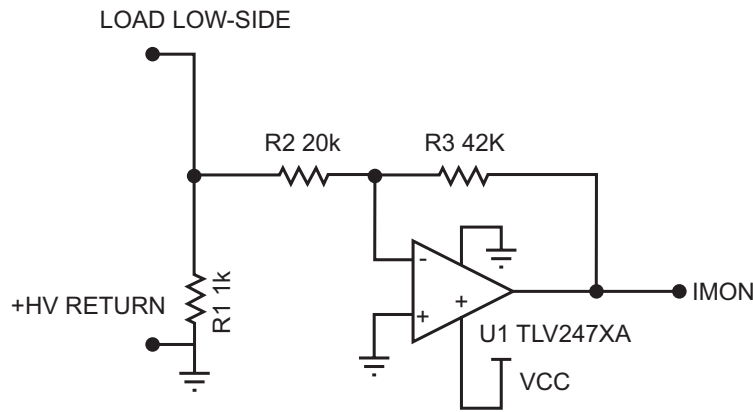


Figure 5. Negative Output Current Monitor

The input impedance of the inverting amplifier effectively shunts the current sense resistor and affects the accuracy of the current monitor. The gain of the inverting amplifier is adjusted to compensate for the current shunt. The result is a monitor circuit with a linear transfer function for output current from -50 μ A to -0.5mA. For protection of the OP-AMP at power-down, a Schottky diode can be placed at the inverting input. To minimize the impact on monitor accuracy, the diode should have low leakage current ($\leq 0.5\mu$ A).

Current Monitor Prototypes and Test Results

Current monitors were built for a positive and a negative Q-Series model. One unit per model was tested using the XP EMCO production test bench. A voltage-to-current transfer function under full load was captured using both the test bench and the current monitor circuit. The production test bench results are considered accurate. The difference between the two sets of measured currents is the current monitor error.

The current monitor readings and error percentages for the Q12-5 and Q20N-5 DC-DC converters are plotted below. The monitor error may be large at DC-DC converter turn-on but drops quickly as V_{in} approaches half the rated value. The negative current monitor is more accurate than the positive current monitor.

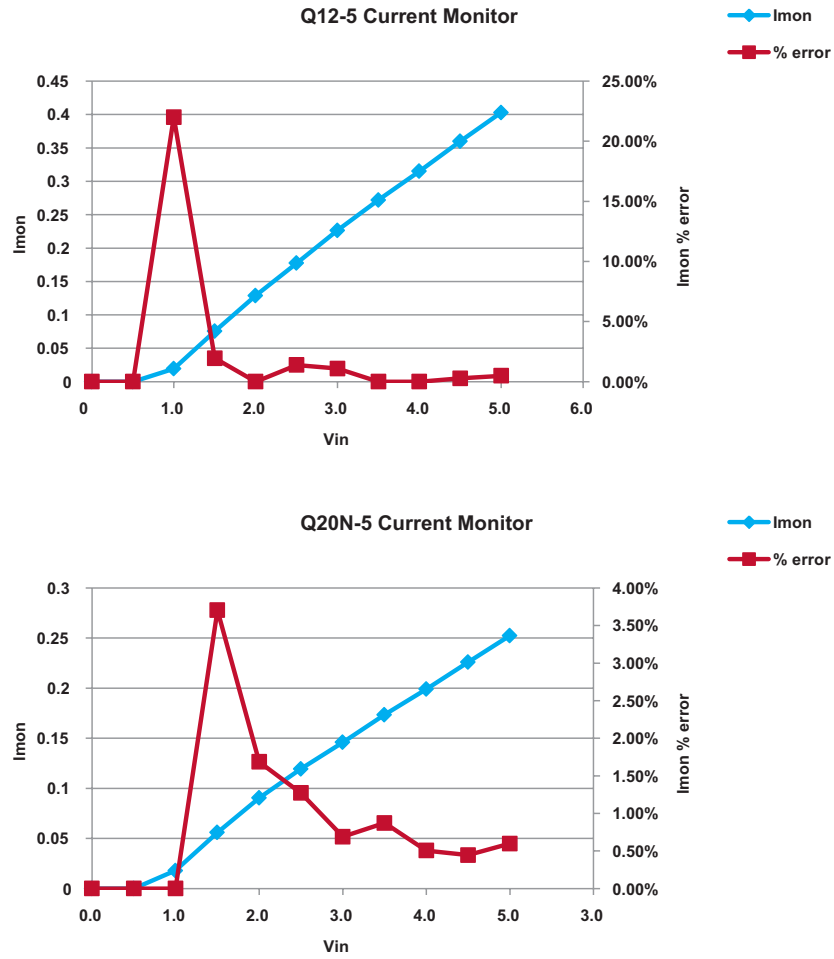


Figure 6. Current Monitor Test Results

Summary

In summary, low cost OP-AMP based circuits can be constructed to monitor the output voltage and current levels from XP EMCO HV DC-DC converters. The monitor circuits are accurate to +/- 2% when the output voltage or current is at half the rated value or greater.

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