

# Benefits of a Low Inductive Shunt for Current Sensing in PWM Applications

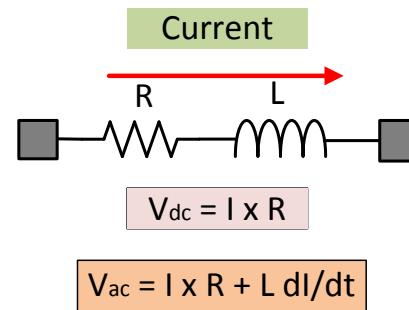
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Current sensing in a Pulse Width Modulation (PWM) systems presents challenge due to large change in common mode voltage(s). In PWM systems, for in-line current sensing the current sense amplifier should have the ability to reject high  $dv/dt$  common mode signals and accurately measure the voltage drop across the shunt which will produce the  $di/dt$  information of the load, which is predominantly inductive.

INA240 current sense amplifier was specifically designed to work in PWM applications that can reject the high  $dv/dt$  signals and accurately measure the  $di/dt$  information. The fast PWM rejection feature assists in fast settling of  $dv/dt$  signals so the amplifier can accurately track the  $di/dt$  information. INA240 can provide very accurate fast real time current in a PWM switching signal. The key to achieving accuracy in PWM system is a combination of INA240 and a very precise high accuracy, low ohmic, low temperature drift and low inductive shunt. The INA240 amplifies the signal across the shunt and produces the output. As PWM switching signals have sharp edges a series parasitic capacitance or inductance introduced by the shunt is directly seen at the input of the INA240 which is hence amplified at the output. This is one of the common examples of reduced current accuracy.

One of the key system requirements for accurate current sensing in a PWM application is the low inductive shunt. Shunt resistors are comprised of metal, ceramic compound and carbon materials. The ceramic and carbon components add additional parasitic inductance to the effective shunt of the amplifier. Shunt manufacturers do produce low-inductive shunts, these should be chosen for accurate PWM current measurements. For DC current measurements the parasitics of the inductance can be ignored because at DC the inductance acts as a short and it behaves as a parasitic resistor. The effective parasitic resistance of the inductor is insignificant compared to the value of the shunt. Typically if the PWM signals are  $<1\text{KHz}$  the parasitic inductance of the shunt can be ignored.



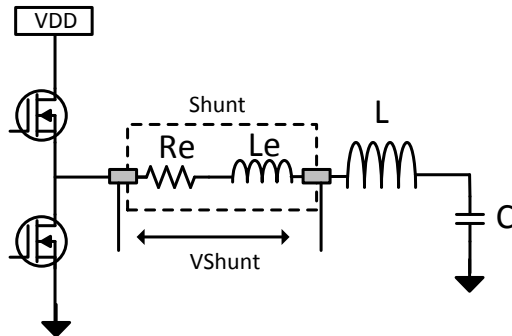
**Figure 1. Effective Impedance of a Shunt Resistor**

Figure 1 illustrates the effective impedance of shunt resistor. For DC measurements the voltage across the shunt resistor is  $V = I \times R$ . For AC and PWM currents the voltage developed across the shunt resistor will be  $V = I \times R + L \times di/dt$ . As the inductance of the shunt increases the error voltage developed across the shunt increases and as the PWM frequencies increase the voltage error further increases. For accurate PWM current measurements a system with a shunt resistor with low inductance is required. When identifying a shunt, the data sheet will have a specification of inductance. A typical low inductive shunt from shunt manufacturers ranges from 3nH to 5nH. Shunt manufacturers use low inductive ceramic and carbon materials to achieve such low inductance. Few manufacturers do produce shunt using special metal alloys with low temperature drift which are trimmed. These shunts are bulky and often used for applications that require 500A of current or higher.

## Current Sensing in a DC-DC Converter

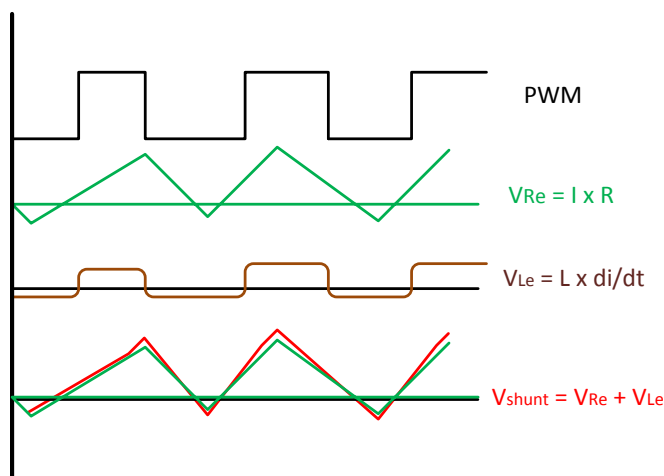
Figure 2 illustrates an example of in-line current sensing for a DC-DC converter. The PWM switching frequencies can be in the order of 100KHz to 1Mhz. At such high frequencies the parasitics related to board layout and type of shunt selected plays a crucial role in achieve high accuracy. Any additional large inductance in series with the PWM node shunt introduces glitches and overshoot. These glitches and the overshoot which will be at the input of the current sense amplifier. A current sense amplifier with a gain will amplify the overshoot and corrupting the signal

integrity. One technique to minimize input glitches to the current sense amplifier is to add additional input filter but such implementation reduces the bandwidth and hence lowers the response time for critical alert techniques.



**Figure 2. Current Sensing in a DC-DC Converter**

Figure 3 describes the waveforms in a DC-DC converter system. The waveform includes the PWM input to the shunt and the various voltage errors developed across the shunt with parasitic inductance. Ideally if the shunt has no parasitic inductance the voltage developed across the shunt will be proportional to output load current. Since the shunt has a finite parasitic inductance the total error developed across the shunt will be a summation of load current and the current developed across the parasitic inductance ( $L_e$ ). The error in the current measurement can be minimized by lowering the inductance in the shunt.



**Figure 3. Output Waveforms in DC-DC Converter**

## Low inductive Shunt in Motor Control

In a motor control application, as the motor windings age due to continuous usage the efficiency of the motor drops. This is usually an indication of early failure of the motor. One of the benefits of low inductive current shunt is a motor control is to identify and detect winding to winding shorts. The effective inductance in the motor is made up of copper wire wound over several times across the core. If a short exists between the windings, detecting a change in inductance of the motor can help identify motor failures and can prevent costly system downtime and permanent motor damage. A low inductive shunt in series with the PWM can benefit in detecting minor changes in inductance.

INA240 is a high precision, bi-directional current sense amplifier with low input offset and gain drift across temperature range making it an ideal device for measuring currents in a PWM application. The INA240 is specifically designed to work in switched node environments where the common mode transients will have large  $dv/dt$  signals. The ability to reject high  $dv/dt$  signals enables accurate current measurements. The true performance benefits of the current sensing can be achieved in combination with a low inductive shunt. The INA240 has low maximum input offset voltage of  $25\mu V$  and a maximum gain error of 0.2% allowing for smaller shunt resistance values to be used without sacrificing measurement accuracy. The offset drift and gain error drift is as low as  $0.25\mu V/^{\circ}C$  and  $2.5ppm/^{\circ}C$  respectively enabling accurate and stable current measurements across temperature.

**Table 1. Alternate Device Recommendations**

| Device  | Optimized Parameter                    | Performance Trade-Off                    |
|---------|--|--|
| INA168  | Bandwidth : 800kHz,<br>Package: SOT-23 | Adjustable gain,<br>external components  |
| LMP8601 | $V_{CM}$ -22V to 60V                   | Offset voltage: 1mV,<br>bandwidth: 60kHz |
| INA282  | DC CMRR: 140dB                         | Bandwidth: 10kHz                         |

**Table 2. Related TI TechNotes**

|         |  |
|---------|--|
| SBOA174 | Current Sensing in an H-Bridge                                 |
| SBOA176 | Switching Power Supply Current Measurements                    |
| SBOA166 | High-Side Drive, High-Side Solenoid Monitor With PWM Rejection |
| SBOA162 | Measuring Current To Detect Out-of-Range Conditions            |

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