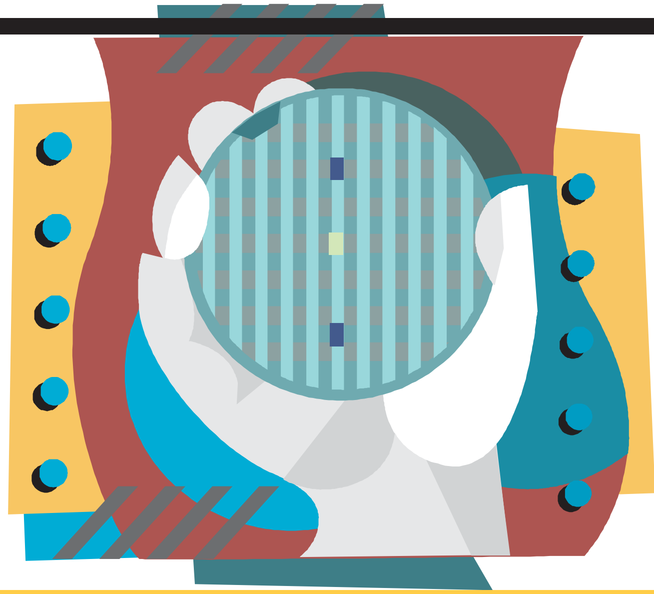

SEMICONDUCTOR TEMPERATURE MEASUREMENT IN A FLYBACK POWER SUPPLY

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Testing a switch mode power supply is not an easy task. While procedures may be well defined for EMI and electrical measurements, semiconductor junction temperature is often overlooked. This article describes a practical, non-invasive method to measure the junction temperature of the switching transistor and output diode of a flyback SMPS.

Thermocouple Measurements

Thermocouples are not the right solution for accurate measurements. First, you have to fix the thermocouples to the device. You can drill a small hole in the heatsink and insert the tip of the probe but face the risk that the thermocouple becomes loose. Also, you can solder the tip to the drain of the FET, as shown in Figure 1, or the cathode of the diode, but J probes (Iron-Constantan) are very difficult to solder.

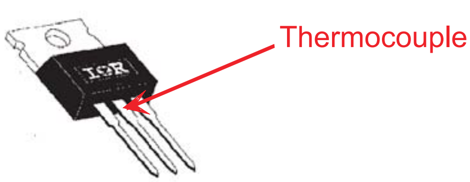

Figure 1 : Thermocouples must be attached to the lead most tightly thermally coupled to the semiconductor dice. Even then, measurements are subject to error.

Thermocouples are often connected to hazardous live parts. Power supplies can became unstable using this method. The thermocouple connected to the FET drain may introduce noise that affects stable operation. The thermocouple may also be sensitive to noise produced by the circuit, and give erroneous readings. Even if EMI problems are avoided, you are still not measuring the junction temperature of the device, since there may be a substantial temperature gradient from the junction to the measurement point.

Diode Forward Voltage Measurements

A better approach is to measure the forward voltage of the reverse diode of the MOSFET or output diode. You need two digital multimeters with a diode threshold measurement (generally performed at 1 mA) and a data-logger function. If the DMMs have no built-in data-logger, measurements can be taken manually at timed intervals.

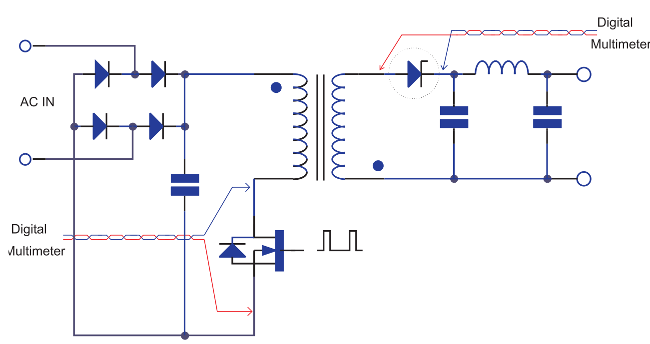

Figure 2 :Attach short twisted-wire test leads to critical components, ready to measure forward voltages of diodes. Do NOT attach instrumentation until circuit is turned off. After turn-off, you have 20 seconds to attach meters.

First, solder two insulated wires on the PCB as shown in Figure 2. These wires must be twisted together so that EMI problems are minimized. In cold conditions, with power off and the load disconnected, record the ambient room temperature and forward voltages.

Disconnect the DMMs, and run the power supply at the desired test condition. When the SMPS has reached steady-state thermal conditions, it is time to make new forward voltage. Turn off the power supply at the same time as you start the data logger (with its timer set at 20 s intervals).

You then have 20 seconds to unplug the power supply, disconnect the load (the load will affect the diode measurements), and connect the DMMs to the circuit. At t = 20 s, you make a 1st measurement, at t = 40 s a 2nd, at t = 60 s a 3rd , etc. What we really want to know is the junction temperature at time t = 0 s, and we compute this from the measured data. The best way to do this is with curve-fitting software or a graph trendline analysis. Sample data is shown in Figure 3 for an off-line adaptor (7.5V 3.5A).

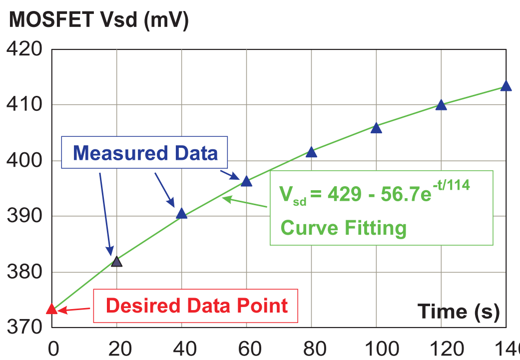

Figure 3a: MOSFET diode data plotted versus time after turning off the power supply. Curve-fitting projects the start voltage at t=0 to be 373 mV.

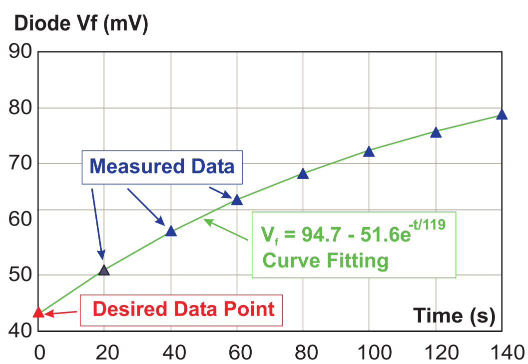

Figure 3b: Diode data plotted versus time after turning off the power supply. Curve-fitting projects the start voltage at t=0 to be 43.1 mV.

Table 1: Temperature coefficient for Vsd of various power MOSFETs.

MOSFET	TempCo
IRFB9N65A	-2.35 mV/C
IRFB11N50A	-2.47 mV/C
IRF830A	-2.40 mV/C
1N60	-2.25 mV/C
IRFBC30	-2.33 mV/C
CEP04N6	-2.29 mV/C
AP04N70BP	-2.29 mV/C

Now, you need to know the value of the temperature coefficient of the measured diodes to calculate the temperature rise, according to the equation:
$\Delta T = [(V_{f\ Hot} - V_{f\ Cold})/TempCo] - (T_{Amb\ Hot} - T_{Amb\ Cold})$

For quick calculation, a value of TempCo = -2 mV/°C can be used. Measurements have been made to verify this value. Samples of MOSFETs and diodes were placed in a temperature chamber and the voltages for different temperatures (between 25°C to 150°C with step of 25°C) were recorded. Results were surprising. For MOSFETs, the temperature coefficient is constant with temperature, but slightly higher than -2 mV/°C, as shown in Table 1. Note that the coefficient is different

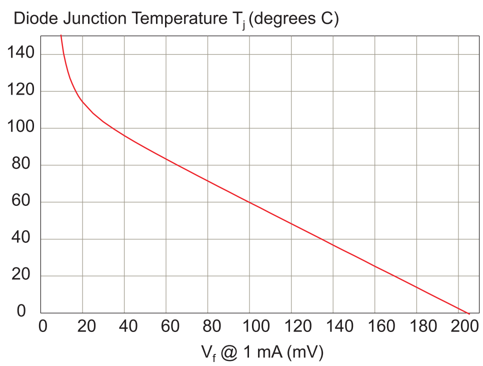

Figure 4: Diode forward drop plotted versus junction temperature.

for different parts.

When using -2 mV/°C the calculated temperature rise is worse than the true value. If you want to have a quick assessment of temperature rise, use this value, and your design will be conservative. If you have a crucial application where you are pushing temperature ratings hard, it is better to calibrate to the specific device you are using by measuring the junction voltage versus temperature yourself.

Diodes are more complex. For Schottky diodes, the temperature coefficient can be modeled with a function such as: $a+bx+c/x^2$ or $(ab+cx^d)/(b+x^d)$.

For a junction temperature lower than 100°C the TempCo is constant and is slightly lower than -2 mV/°C. For junction temperatures between 100°C and 150°C, the temperature coefficient is no longer constant, as can be seen in Figure 4.

The temperature coefficient for various parts is shown in Table 2 for temperatures below 100 °C.
Once you have the proper temperature coefficient, you can calculate the operating junction temperature of the

semiconductor devices, as shown in Tables 3 and 4. In summary, conventional techniques tell us to use a thermocouple to measure semiconductor junction temperatures. However, this results in inaccurate values, and commonly causes problems with power supply operation and stability.

A much better approach is to measure the junction temperature via the forward drop of the diode in a semiconductor. This is done with a sequence of measurements after a power supply is turned off. This technique provides an accurate and noninvasive method for accurate measurements, and is very useful for all

Diode	TempCo (mV/°C)
MBR1060	-1,8 for 0 < T_J < 100°C
1N5822	-1,6 for 0 < T_J < 100°C
MBR1660	-1,7 for 0 < T_J < 100°C
PBYR10100	-1,88 for 0 < T_J < 100°C

Table 2: Temperature coefficient for V_f of various power diodes.

Table 3: Junction temperature calculation for power MOSFET of flyback circuit.

MOSFET (IRFB9N65A)	T_{Amb}	V_{sd}
Cold	22.9	505.0
Hot	23.4	373.1
ΔT = [(373.1- 505.0)/-2.35]-(23.4 - 22.9) = **56°C**		

DIODE (MBR1060)	T_{Amb}	V_F
Cold	22.9	164.3
Hot	23.4	43.1
ΔT = [43.1- 164.3)/-1.7]-(23.4 -22.9) = **71°C**		

Table 4: Junction temperature calculation for power diode of flyback circuit.