

Introduction

Many of the more recent applications of PowerMOS transistors, particularly low voltage devices, have been as solenoid drivers. In this type of application the device is simply used as a switch to turn the current through a solenoid, relay or other inductive load on and off (Figure 1). Since the dissipation is low, a very small or no heat sink will be required. This note will cover the application of the rating and characteristics of PowerMOS transistors to that type of application and illustrate the process of selecting a suitable transistor.

Defining the Problem

The circuit used in most solenoid switch applications is very simple. It simply consists of an inductor and resistance in series with the drain and a gate drive circuit (Figure 2). Analyzing this circuit can lead to some simplifications that will speed design efforts.

There are three circuit states that we should analyze. The simplest state is when the PowerMOS transistor is "off", when the gate and source are at the same potential. Under this condition the dissipation in the device is simply the leakage current times the supply voltage V_{CC} . Usually this is negligible. The second state we should consider is when the gate drive is "on". The PowerMOS transistor can best be represented as a series resistor. The current through that resistor is:

$$I_T = \frac{V_{CC}}{R_L + r_{DS(ON)}} \quad (EQ. 1.1)$$

The dissipation (P_T) in the PowerMOS transistor while the device is "on" is:

$$P_T = (I_T)^2 \times r_{DS(ON)} \quad (EQ. 1.2)$$

If we make the simplifying assumption that $R_L \gg r_{DS(ON)}$ this is:

$$P_T = \left(\frac{V_{CC}}{R_L}\right)^2 \times r_{DS(ON)} \quad (EQ. 1.3)$$

where $r_{DS(ON)}$ is the worst case resistance of the PowerMOS transistor at its operating junction temperature. PowerMOS

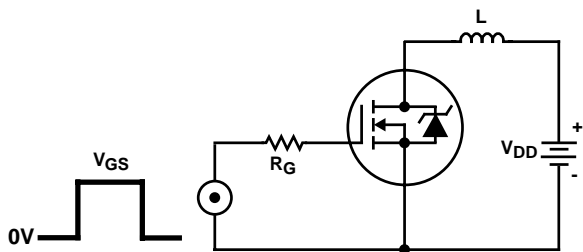


FIGURE 1. TYPICAL INDUCTIVE SWITCHING CIRCUIT

transistors all exhibit an increase in $r_{DS(ON)}$ with temperature. Usually this is given in the form of a curve of $r_{DS(ON)}$ vs temperature on the datasheet. The worst case $r_{DS(ON)}$ at any elevated junction temperature is determined as follows. First, using the $r_{DS(ON)}$ vs temperature curve for the device, obtain the multiplicative factor at the expected operating junction temperature. Finally multiply the maximum 25°C $r_{DS(ON)}$ rating by the previously determined factor.

The third state we should consider is when the switch transitions from "on" to "off" or vice versa. In many solenoid switch applications the major dissipation occurs while the PowerMOS transistor is "on", but turn on and turn off also dissipate power in the transistor. The switching speed of most PowerMOS transistors is so fast that turn on losses are usually very small. An exception is when the drive current available is very very small. Usually this does not occur in the real world. For example the Intersil RFP70N06 PowerMOS transistor requires a maximum of 115nC of gate charge to transition from "off" to fully "on". For a gate drive which supplies 1.0mA this would mean that the transition would take less than 115µs. This will make a negligible change in the junction temperature of the PowerMOS transistor.

Turn-off subjects the PowerMOS transistor to Unclamped Inductive Switching. Modern PowerMOS transistors can withstand this type of stress and give clear ratings in their datasheets to let customers calculate whether or not they are operating within the devices' capability. The energy dissipated in the PowerMOS transistor each time the current is interrupted is:

$$E_T = \left(\frac{L \times I_T \times V_{DSS}}{R_L}\right) \times \left[1 - K \times \ln\left(1 + \frac{1}{K}\right)\right] \quad (EQ. 1.4)$$

See Intersil Application Note AN9321

Where:

$$K = \frac{V_{BRK} - V_{CC}}{I_T \times R_L}$$

Please note that the V_{BRK} used here is the rated breakdown voltage, since that is worst case, rather than the 1.3 x rated breakdown voltage used in Application Note AN9321.

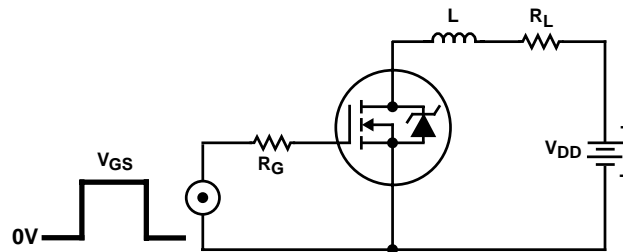


FIGURE 2. SOLENOID SWITCHING APPLICATION CIRCUIT

The power dissipated in the device due to UIS will be directly proportional to the number of times the interruption could occur per second. If a human provides the interruptions, 5 times per second would probably be sufficient.

All of the losses in the PowerMOS transistor summed, multiplied by the total thermal resistance (junction to case, case to heat sink and heatsink to ambient) gives the rise in junction temperature above the ambient. From that temperature the operating $r_{DS(ON)}$ can be determined and the calculations iterated. Sometimes several iterations are required.

Example 1

The following example assumes a set of operating conditions and computes the suitability of various Intersil PowerMOS devices to operate under those assumed conditions.

The assumed circuit conditions are:

$L = 50\text{mH}$, $V_{CC} = 16\text{V}$, $R_L = 4\Omega$, IERC PSD1-2U Heat sink.

In addition, the following operational conditions are assumed:

Rep Rate = 5 pulses/s, $T_A = 125^\circ\text{C}$, charged current level $\approx 4\text{A}$. Sufficient time was allotted for the inductor to charge; we chose ten time constants (125ms). The inductor also had to discharge to less than 1% of the charged current level between pulses, and finally; 10ms of deadtime were allotted between pulses.

Please note: the number of significant figures in all intermediate calculation values were truncated to aid readability.

Check UIS capability and verify junction temperature is less than 175°C .

A. Try RFP3055

Assume $T_J = 175^\circ\text{C}$.

Check to be sure UIS stress is within RFP3055 capability.

$$t_{AV} = \left(\frac{L}{R_L}\right) \times \ln \left[\left(\frac{I_T \times R_L}{1.3 \times V_{BRK} - V_{CC}} \right) + 1 \right] \quad (\text{EQ. 1.5})$$

(Reference AN9321.)

$$t_{AV} = \left(\frac{0.05}{4}\right) \times \ln \left[\left(\frac{4 \times 4}{1.3 \times 60 - 16} \right) + 1 \right]$$

$$t_{AV} = 2.9\text{ms}$$

Capability at 4.0A, 175°C is 0.04ms. (From Figure 13, RFP3055, File #3648, Intersil Databook DB223B.)

(Unit is not suitable for this application!)

B. Try RFP22N10

Assume $T_J = 175^\circ\text{C}$.

Check to be sure UIS stress is within RFP22N10 capability.

$$t_{AV} = \left(\frac{L}{R_L}\right) \times \ln \left[\left(\frac{I_T \times R_L}{1.3 \times V_{BRK} - V_{CC}} \right) + 1 \right] \quad (\text{EQ. 1.5})$$

$$t_{AV} = \left(\frac{0.05}{4}\right) \times \ln \left[\left(\frac{4 \times 4}{1.3 \times 100 - 16} \right) + 1 \right]$$

$$t_{AV} = 1.64\text{ms}$$

Capability at 4.0A, 175°C is 0.9ms. (From Figure 2, RFP22N10, File #2385.1, Intersil Databook DB223B.)

(Unit is not suitable for this application!)

C. Try RFP45N06

Assume $T_J = 175^\circ\text{C}$.

Check to be sure UIS stress is within RFP45N06 capability.

$$t_{AV} = \left(\frac{L}{R_L}\right) \times \ln \left[\left(\frac{I_T \times R_L}{1.3 \times V_{BRK} - V_{CC}} \right) + 1 \right] \quad (\text{EQ. 1.5})$$

$$t_{AV} = \left(\frac{0.05}{4}\right) \times \ln \left[\left(\frac{4 \times 4}{1.3 \times 60 - 16} \right) + 1 \right]$$

$$t_{AV} = 2.9\text{ms}$$

Capability at 4.0A, 175°C is 3.2ms. (From Figure 13, RFP45N06, File #3574, Intersil Databook DB223B.) OK for UIS.

Check to see if $T_J \leq 175^\circ\text{C}$.

$$r_{DS(ON)} = 2.1 \times 0.028 \quad (\text{See Figure 7, RFP45N06 datasheet.})$$

$$r_{DS(ON)} = 0.059\Omega$$

Dissipation during conduction:

$$P_T = \left(\frac{V_{CC}}{R_L}\right)^2 \times r_{DS(ON)} \quad (\text{EQ. 1.3})$$

$$P_T = \left(\frac{16.0}{4}\right)^2 \times 0.059$$

$$P_T = 0.941\text{W}$$

Dissipation due to UIS:

$$E_T = \left(\frac{L \times I_T \times V_{DSS}}{R_L}\right) \times \left[1 - K \times \ln \left(1 + \frac{1}{K} \right) \right] \quad (\text{EQ. 1.4})$$

Where

$$K = \frac{V_{DSS} - V_{CC}}{I_T \times R_L}$$

$$K = \frac{60 - 16}{4 \times 4}$$

$$K = 2.75$$

$$E_T = \frac{0.05 \times 4 \times 60}{4} \times [1 - 2.75 \times \ln(1.36)]$$

$$E_T = 0.441 \text{ J}$$

Dissipation due to UIS = $E_T \times \text{Rep Rate}$: (EQ. 1.6)

$$P_T = 0.441 \times 5 = 2.206 \text{ W}$$

$$P_{TOTAL} = 0.941 + 2.206 = 3.147 \text{ W}$$

$$\theta_{JA} = \theta_{JC} + \theta_{CHS} + \theta_{HS} \quad (\text{EQ. 1.7})$$

$$\theta_{JC} = 1.14^\circ\text{C/W} \text{ (See page 2, RFP45N06 datasheet).}$$

$$\theta_{CHS} = 1.0^\circ\text{C/W} \text{ (estimated)}$$

$$\theta_{HS} = 14.4^\circ\text{C/W} \text{ (IERC short form catalog dated 8/93.)}$$

$$\theta_{JA} = 16.54^\circ\text{C/W}$$

$$\Delta T_{JUNCTION} = \theta_{JA} \times P_{TOTAL} \quad (\text{EQ. 1.8})$$

$$\Delta T_{JUNCTION} = 3.147 \times 16.54 = 52.05^\circ\text{C}$$

$$\Delta T_{JUNCTION} = 125 + 52.1 = 177.1^\circ\text{C}$$

(Unit is not suitable for this application!)

But we could use a lower thermal resistance heat sink and make it work.

C. Try RFP50N06

Assume $T_J = 175^\circ\text{C}$.

Check to be sure UIS stress is within RFP50N06 capability.

$$t_{AV} = \left(\frac{L}{R_L}\right) \times \ln\left[\left(\frac{I_T \times R_L}{1.3 \times V_{BRK} - V_{CC}}\right) + 1\right] \quad (\text{EQ. 1.5})$$

$$t_{AV} = \left(\frac{0.05}{4}\right) \times \ln\left[\left(\frac{4 \times 4}{1.3 \times 60 - 16}\right) + 1\right]$$

$$t_{AV} = 2.9 \text{ ms}$$

Capability at 4.0A, 175°C is 3.2ms. (From Figure 13, RFP50N06, File #3575, Intersil Databook DB223B.) OK for UIS.

Check to see if $T_J \leq 175^\circ\text{C}$.

$$r_{DS(ON)} = 2.1 \times 0.022 \text{ (See Figure 7, RFP50N06 datasheet.)}$$

$$r_{DS(ON)} = 0.046 \Omega$$

Dissipation during conduction:

$$P_T = \left(\frac{V_{CC}}{R_L}\right)^2 \times r_{DS(ON)} \quad (\text{EQ. 1.3})$$

$$P_T = \left(\frac{16.0}{4}\right)^2 \times 0.046$$

$$P_T = 0.739 \text{ W}$$

Dissipation due to UIS:

$$E_T = \left(\frac{L \times I_T \times V_{DSS}}{R_L}\right) \times \left[1 - K \times \ln\left(1 + \frac{1}{K}\right)\right] \quad (\text{EQ. 1.4})$$

Where

$$K = \frac{V_{DSS} - V_{CC}}{I_T \times R_L}$$

$$K = \frac{60 - 16}{4 \times 4}$$

$$K = 2.75$$

$$E_T = \frac{0.05 \times 4 \times 60}{4} \times [1 - 2.75 \times \ln(1.36)]$$

$$E_T = 0.441 \text{ J}$$

Dissipation due to UIS = $E_T \times \text{Rep Rate}$: (EQ. 1.6)

$$P_T = 0.441 \times 5 = 2.206 \text{ W}$$

$$P_{TOTAL} = 0.739 + 2.206 = 2.945 \text{ W}$$

$$\theta_{JA} = \theta_{JC} + \theta_{CHS} + \theta_{HS} \quad (\text{EQ. 1.7})$$

$$\theta_{JC} = 1.14^\circ\text{C/W} \text{ (See page 2, RFP50N06 datasheet.)}$$

$$\theta_{CHS} = 1.0^\circ\text{C/W} \text{ (estimated)}$$

$$\theta_{HS} = 14.4^\circ\text{C/W} \text{ (IERC short form catalog dated 8/93.)}$$

$$\theta_{JA} = 16.54^\circ\text{C/W}$$

$$\Delta T_{JUNCTION} = \theta_{JA} \times P_{TOTAL} \quad (\text{EQ. 1.8})$$

$$\Delta T_{JUNCTION} = 2.945 \times 16.54 = 48.7^\circ\text{C}$$

$$\Delta T_{JUNCTION} = 125 + 48.7 = 173.7^\circ\text{C}$$

OK for both UIS and T_J .

D. Try RFP70N03

Assume $T_J = 175^\circ\text{C}$.

Check to be sure UIS stress is within RFP70N03 capability.

$$t_{AV} = \left(\frac{L}{R_L}\right) \times \ln\left[\left(\frac{I_T \times R_L}{1.3 \times V_{BRK} - V_{CC}}\right) + 1\right] \quad (\text{EQ. 1.5})$$

$$t_{AV} = \left(\frac{0.05}{4}\right) \times \ln\left[\left(\frac{4 \times 4}{1.3 \times 30 - 16}\right) + 1\right]$$

$$t_{AV} = 6.6\text{ms}$$

Capability at 4.0A, 175°C is 24ms. (From Figure 2, RFP70N03, File #3404, Intersil Databook DB223B.) OK for UIS.

Check to see if $T_J \leq 175^\circ\text{C}$.

$$r_{DS(ON)} = 1.6 \times 0.010 \text{ (See Figure 7, RFP70N03 datasheet.)}$$

$$r_{DS(ON)} = 0.016\Omega$$

Dissipation during conduction:

$$P_T = \left(\frac{V_{CC}}{R_L}\right)^2 \times r_{DS(ON)} \quad (\text{EQ. 1.3})$$

$$P_T = \left(\frac{16.0}{4}\right)^2 \times 0.016$$

$$P_T = 0.256\text{W}$$

Dissipation due to UIS:

$$E_T = \left(\frac{L \times I_T \times V_{DSS}}{R_L}\right) \times \left[1 - K \times \ln\left(1 + \frac{1}{K}\right)\right] \quad (\text{EQ. 1.4})$$

Where

$$K = \frac{V_{DSS} - V_{CC}}{I_T \times R_L}$$

$$K = \frac{30 - 16}{4 \times 4}$$

$$K = 0.875$$

$$E_T = \frac{0.05 \times 4 \times 30}{4} \times [1 - 0.875 \times \ln(2.143)]$$

$$E_T = 0.500\text{J}$$

$$\text{Dissipation due to UIS} = E_T \times \text{Rep Rate:} \quad (\text{EQ. 1.6})$$

$$P_T = 0.500 \times 5 = 2.500\text{W}$$

$$P_{TOTAL} = 0.256 + 2.500 = 2.756\text{W}$$

$$\theta_{JA} = \theta_{JC} + \theta_{CHS} + \theta_{HS} \quad (\text{EQ. 1.7})$$

$$\theta_{JC} = 1.0^\circ\text{C/W (See page 2, RFP70N03 datasheet.)}$$

$$\theta_{CHS} = 1.0^\circ\text{C/W (estimated)}$$

$$\theta_{HS} = 14.4^\circ\text{C/W (IERC short form catalog dated 8/93.)}$$

$$\theta_{JA} = 16.4^\circ\text{C/W}$$

$$\Delta T_{JUNCTION} = \theta_{JA} \times P_{TOTAL} \quad (\text{EQ. 1.8})$$

$$\Delta T_{JUNCTION} = 2.756 \times 16.4 = 45.2^\circ\text{C}$$

$$\Delta T_{JUNCTION} = 125 + 45.2 = 170.2^\circ\text{C}$$

OK for both UIS and T_J .

E. Try RFP70N06

Assume $T_J = 175^\circ\text{C}$.

Check to be sure UIS stress is within RFP70N06 capability.

$$t_{AV} = \left(\frac{L}{R_L}\right) \times \ln\left[\left(\frac{I_T \times R_L}{1.3 \times V_{BRK} - V_{CC}}\right) + 1\right] \quad (\text{EQ. 1.5})$$

$$t_{AV} = \left(\frac{0.05}{4}\right) \times \ln\left[\left(\frac{4 \times 4}{1.3 \times 60 - 16}\right) + 1\right]$$

$$t_{AV} = 2.9\text{ms}$$

Capability at 4.0A, 175°C is 9.0ms. (From Figure 2, RFP70N06, File #3206, Intersil Databook DB223B.) OK for UIS.

Check to see if $T_J \leq 175^\circ\text{C}$.

$$r_{DS(ON)} = 2.1 \times 0.014 \text{ (See Figure 7, RFP70N06 datasheet.)}$$

$$r_{DS(ON)} = 0.0294\Omega$$

Dissipation during conduction:

$$P_T = \left(\frac{V_{CC}}{R_L}\right)^2 \times r_{DS(ON)} \quad (\text{EQ. 1.3})$$

$$P_T = \left(\frac{16.0}{4}\right)^2 \times 0.0294$$

$$P_T = 0.470\text{W}$$

Dissipation due to UIS:

$$E_T = \left(\frac{L \times I_T \times V_{DSS}}{R_L} \right) \times \left[1 - K \times \ln \left(1 + \frac{1}{K} \right) \right] \quad (\text{EQ. 1.4})$$

Where

$$K = \frac{V_{DSS} - V_{CC}}{I_T \times R_L}$$

$$K = \frac{60 - 16}{4 \times 4}$$

$$K = 2.75$$

$$E_T = \frac{0.05 \times 4 \times 60}{4} \times [1 - 2.75 \times \ln(1.36)]$$

$$E_T = 0.441 \text{ J}$$

$$\text{Dissipation due to UIS} = E_T \times \text{Rep Rate:} \quad (\text{EQ. 1.6})$$

$$P_T = 0.441 \times 5 = 2.206 \text{ W}$$

$$P_{\text{TOTAL}} = 0.470 + 2.206 = 2.676 \text{ W}$$

$$\theta_{JA} = \theta_{JC} + \theta_{CHS} + \theta_{HS} \quad (\text{EQ. 1.7})$$

$$\theta_{JC} = 1.14^\circ\text{C/W (See page 2, RFP50N06 datasheet.)}$$

$$\theta_{CHS} = 1.0^\circ\text{C/W (estimated)}$$

$$\theta_{HS} = 14.4^\circ\text{C/W (IERC short form catalog dated 8/93.)}$$

$$\theta_{JA} = 16.54^\circ\text{C/W}$$

$$\Delta T_{\text{JUNCTION}} = \theta_{JA} \times P_{\text{TOTAL}} \quad (\text{EQ. 1.8})$$

$$\Delta T_{\text{JUNCTION}} = 2.676 \times 16.54 = 44.3^\circ\text{C}$$

$$\Delta T_{\text{JUNCTION}} = 125 + 44.3 = 169.3^\circ\text{C}$$

OK for both UIS and T_J .

Conclusion

This leaves us with the result that the smallest device that will safely handle a 4A switch application under these ground rules is a 50A rated device.

Example 2

The following example assumes a set of operating conditions and computes the suitability of various Intersil Power-MOS devices to operate under those assumed conditions.

The assumed conditions are:

$L = 10\text{mH}$, $V_{CC} = 24\text{V}$, $R_L = 24\Omega$, rep rate = 5/s, No Heat sink, ambient = $+125^\circ\text{C}$, $I \approx 1\text{A}$, Check UIS capability and verify junction temperature is less than $+175^\circ\text{C}$.

A. Try RFD3055

Assume $T_J = 175^\circ\text{C}$.

Check to be sure UIS stress is within RFP3055 capability.

$$t_{AV} = \left(\frac{L}{R_L} \right) \times \ln \left[\left(\frac{I_T \times R_L}{1.3 \times V_{BRK} - V_{CC}} \right) + 1 \right] \quad (\text{EQ. 1.5})$$

$$t_{AV} = \left(\frac{0.01}{24} \right) \times \ln \left[\left(\frac{1 \times 24}{1.3 \times 60 - 24} \right) + 1 \right]$$

$$t_{AV} = 0.172 \text{ ms}$$

Capability at 1.0A, $+175^\circ\text{C}$ is 0.6ms. (From Figure 13, RFD3055, File #3648, Intersil Databook DB223B.)

Unit is OK for UIS.

Check to see if $T_J \leq +175^\circ\text{C}$.

$$r_{DS(ON)} = 2.1 \times 0.150 \text{ (See Figure 7, RFD3055 datasheet.)}$$

$$r_{DS(ON)} = 0.315 \Omega$$

Dissipation during conduction:

$$P_T = \left(\frac{V_{CC}}{R_L} \right)^2 \times r_{DS(ON)} \quad (\text{EQ. 1.3})$$

$$P_T = \left(\frac{24.0}{24} \right)^2 \times 0.315$$

$$P_T = 0.315 \text{ W}$$

Dissipation due to UIS:

$$E_T = \left(\frac{L \times I_T \times V_{DSS}}{R_L} \right) \times \left[1 - K \times \ln \left(1 + \frac{1}{K} \right) \right] \quad (\text{EQ. 1.4})$$

Where

$$K = \frac{V_{DSS} - V_{CC}}{I_T \times R_L}$$

$$K = \frac{60 - 24}{1 \times 24}$$

$$K = 1.5$$

$$E_T = \frac{0.01 \times 1 \times 60}{24} \times [1 - 1.5 \times \ln(1.667)]$$

$$E_T = 5.84 \text{ mJ}$$

Dissipation due to UIS = $E_T \times \text{Rep Rate}$: (EQ. 1.6)

$$P_T = 0.00584 \times 5 = 0.029W$$

$$P_{TOTAL} = 0.315 + 0.029 = 0.344W$$

$$\theta_{JA} = \theta_{JC} + \theta_{CA} \quad (\text{EQ. 1.7})$$

$$\theta_{JC} = 2.8^\circ\text{C/W} \text{ (See page 2, RFD3055 datasheet.)}$$

$$\theta_{CA} = 100^\circ\text{C/W} \text{ (See page 2, RFD3055 datasheet.)}$$

$$\theta_{JA} = 102.8^\circ\text{C/W}$$

$$\Delta T_{JUNCTION} = \theta_{JA} \times P_{TOTAL} \quad (\text{EQ. 1.8})$$

$$\Delta T_{JUNCTION} = 102.8 \times 0.344 = 35.4^\circ\text{C}$$

$$\Delta T_{JUNCTION} = 125 + 35.4 = 160.4^\circ\text{C}$$

OK for both UIS and T_j .

Conclusion

It is not necessary to use a larger device to switch this current.

Example 3

Example 1 concludes we need a device with an on resistance of less than 50mΩ and a 30A continuous current rating at +125°C case temperature. This seems to be a bit of overkill, since the application has a peak current of 4A. The possibility of a more cost-effective alternative should be investigated. A circuit configuration using a smaller MOSFET and a commutating diode will be examined to determine if that is a better solution.

The assumed circuit conditions are:

$$L = 50\text{mH}, V_{CC} = 16\text{V}, R_L = 4\Omega, \text{ IERC PSD1-2U Heat sink.}$$

In addition, the following operational conditions are assumed:

Rep Rate = 5pulses/s, ambient temperature = +125°C, charged current level ≈ 4A. Sufficient time was allotted for the inductor to charge; we chose ten time constants (125ms). The inductor also had to discharge to less than 1% of the charged current level between pulses, and finally; 10ms of deadtime were allotted between pulses.

The selection process can be divided into two parts; MOSFET and diode, as each will perform different functions. The MOSFET will function as a switch, the diode as a discharge path for the inductor.

Since the MOSFET is only a switch in this configuration, we need only be concerned with the conduction dissipation

when selecting the proper device. Equation 2.3 provides a basis for determining the MOSFET using the relationship of on resistance and thermal resistance to conduction dissipation and operating temperature.

The supply voltage, load resistance and junction and ambient temperatures are defined and therefore constant. The on resistance multiplied by the thermal resistance must be less than or equal to this constant. The equation to calculate the dissipation (P_T) in the PowerMOS transistor while the device is "on" assuming that $R_L \gg r_{DS(ON)}$ was given on Page 1 as:

$$P_T = \left(\frac{V_{CC}}{R_L} \right)^2 \times r_{DS(ON)} \quad (\text{EQ. 1.3})$$

Substituting terms in the equation:

$$\frac{T_J - T_A}{R_{\theta JA}} = \left(\frac{V_{CC}}{R_L} \right)^2 \times r_{DS(ON)} \quad (\text{EQ. 2.1})$$

Where

$$P_T = \frac{T_J - T_A}{R_{\theta JA}} \quad (\text{EQ. 2.2})$$

and rearranging as follows:

$$r_{DS(ON)} \times R_{\theta JA} \leq \left(\frac{R_L}{V_{CC}} \right)^2 \times T_J - T_A \quad (\text{EQ. 2.3})$$

provides the equation for device selection.

A. Try the RFP3055

$$r_{DS(ON)} \times R_{\theta JA} \leq \left(\frac{R_L}{V_{CC}} \right)^2 \times T_J - T_A \quad (\text{EQ. 2.3})$$

$$0.315\Omega \times 18.2^\circ\text{C/W} \leq \left(\frac{4\Omega}{16\text{V}} \right)^2 \times 175^\circ\text{C} - 125^\circ\text{C}$$

$$5.733\Omega^\circ\text{C/W} > 3.125\Omega^\circ\text{C/W}$$

The on resistance thermal resistance product is greater than the constant. (This unit is not suitable!)

B. Try the RFD16N05

$$r_{DS(ON)} \times R_{\theta JA} \leq \left(\frac{R_L}{V_{CC}} \right)^2 \times T_J - T_A \quad (\text{EQ. 2.3})$$

$$0.999\Omega \times 17.5^\circ\text{C/W} \leq \left(\frac{4\Omega}{16\text{V}} \right)^2 \times 175^\circ\text{C} - 125^\circ\text{C}$$

$$1.733\Omega^\circ\text{C/W} < 3.125\Omega^\circ\text{C/W}$$

This unit is capable of dissipating the conduction losses!

With a suitable MOSFET selected a diode is next.

The energy dissipated by the diode due to one UIS pulse is calculated as follows:

$$E = I_0 \times V_D \times \left(\frac{L}{R}\right) \times k \quad (\text{EQ. 2.4})$$

Where

I_0 = the current level at the time the MOSFET was turned off

V_D = the voltage across the diode

$$k = 1 + \frac{\ln(1/(1+s))}{s}$$

$$s = \frac{I_0 \times R}{V_D}$$

$$E = 4A \times 0.84V \times \left(\frac{50mH}{4\Omega}\right) \times 0.843$$

$$E = 35.4mJ$$

The total power dissipation due to the 5 UIS pulses is calculated; using the calculated value, determine a thermal resistance necessary to dissipate the power. The thermal resistance of the device, interface and heat sink must be less than or equal to the calculated value.

$$P_T = E \times 5 \text{ pulses/s} \quad (\text{EQ. 1.5})$$

$$P_T = 177mW$$

$$R_{\theta JA} = \frac{T_{JMAX} - T_A}{P_T}$$

$$R_{\theta JA} = \frac{175^{\circ}C - 125^{\circ}C}{0.177W}$$

$$R_{\theta JA} \leq 282^{\circ}C/W$$

C. Try the RURD410

$$R_{\theta JA} = R_{\theta JC} + R_{\theta CHS} + R_{\theta HS} \quad (\text{EQ. 1.7})$$

$$R_{\theta JA} = 5.0^{\circ}C/W + 1.0^{\circ}C/W + 14.4^{\circ}C/W$$

$$R_{\theta JA} = 20.4^{\circ}C/W$$

The RURD410, interface and heat sink junction to ambient thermal resistance are less than the requirement. This unit is suitable.

The next consideration is to determine the time necessary for the inductor to fully discharge. Earlier we established the conditions for discharge. The current level must decay to 1%

of its initial value, the discharge time to the 1% current level must be no greater than the pulse width of one pulse minus the sum of the charge time and 10ms. In this illustration the discharge time could be no greater than:

$$t \leq \text{Pulse Width (1 pulse)} - (\text{Charge Time} + 10ms)$$

$$t \leq 200ms - (125ms + 10ms)$$

$$t \leq 65ms$$

If parasitic inductances and resistances are negligible; a useful approximation of the discharge time can be calculated as follows:

$$t = \frac{L}{R_L} \times \ln(1+s)$$

Note the s term is the same as in the previous column. V_D (0.44V) is determined using Figure 3 from the RURD410 datasheet, page 5-23 Databook DB309.

$$t = \frac{0.05mH}{4\Omega} \times \ln(1+36.4)$$

$$t = 45.3ms$$

The discharge time is less than the allowable 65ms. This approach will work. The inductor would discharge to less than 1% of the initial current level between each pulse.

Conclusion

A properly selected MOSFET, capable of withstanding operation in the avalanche mode was the best choice of the solutions examined for this application. The MOSFET operating as a switch dissipates little power while “on” and provides a means of discharging the inductor between pulses; making it functionally compatible for the application. Finally and equally important; the avalanche rated MOSFET is also the most economical choice of the solutions evaluated.

The selected MOSFET diode combination is also functionally compatible for this application. The combination selected in this example is more expensive than the stand alone MOSFET. However, the thermal resistance calculated for the diode suggests a smaller less expensive diode could be substituted. The cost reduction from the substitution of a less expensive diode may make the combination a more attractive solution. The examination of more economical diodes is left to the reader.

In this application; functionality, economics and a defined set of operating conditions were the constraints to the eventual solution. Rather than reach a rigid conclusion; the Application note intended to illustrate a methodology to determine the best solution for a set of design constraints.

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