AN1193

MOSFET Selection Guide for Ideal Diode Controllers

Isaac Sibson and Eduard Santa, Automotive BU, Diodes Incorporated

Wherever there is access to the batteries of a device, there is a risk that users might install or connect them the wrong way around. Replacing batteries is an occasional task complicated by the fact that the two battery terminals can be of similar size and shape. Connecting a car battery incorrectly can be especially damaging. Because of the risk that end-users might connect batteries incorrectly, system designers need to ensure that the extremely expensive electronic modules in a car are not damaged from reverse polarity.

Input reverse polarity protection, also known as input reverse voltage protection, can be achieved using a simple series diode. However, many designers are looking to reduce energy waste in order to achieve more efficient solutions, especially when systems have increasingly higher current demands. At a high current, the power dissipation of the diode could result in it overheating. For more in-depth information on input reverse polarity protection solutions, see application note AN1192: *Understanding the Different Approaches to Input Reverse Voltage Protection (RVP)*.

Today's car infotainment systems have a large bright screen, use a powerful processor, and have multiple channels of audio amplification. With these considerations, power input levels of 300-500W are not at all unrealistic, and all of this is fed from a 12V DC battery. You could be considering currents of 20-40A, maybe even more.

At 20A, a diode with a forward voltage (V_F) of 0.7V would dissipate 14W of power, which is undesirable from both thermal management as well as efficiency viewpoints. This is even more important now as we look for ever greater efficiencies, for example, to maximize range in Electric Vehicles (EVs).

A good solution for high-current applications like EVs is the ideal diode controller, such as Diodes Incorporated's (Diodes) AP74700AQ combined with an N-channel MOSFET (nMOS) on the high side (Figure 1). The AP74700AQ will regulate an nMOS as a diode with a V_F of 20mV, if possible (explained further in this application note). Otherwise, the MOSFET will be driven to a fully-ON state where the V_F is dictated by the drain-source on-resistance ($R_{DS(ON)}$) of the chosen MOSFET. For example, a 10mΩ MOSFET would have a voltage drop of 0.2V at 20A and dissipate 4W, a significant reduction compared to a diode.

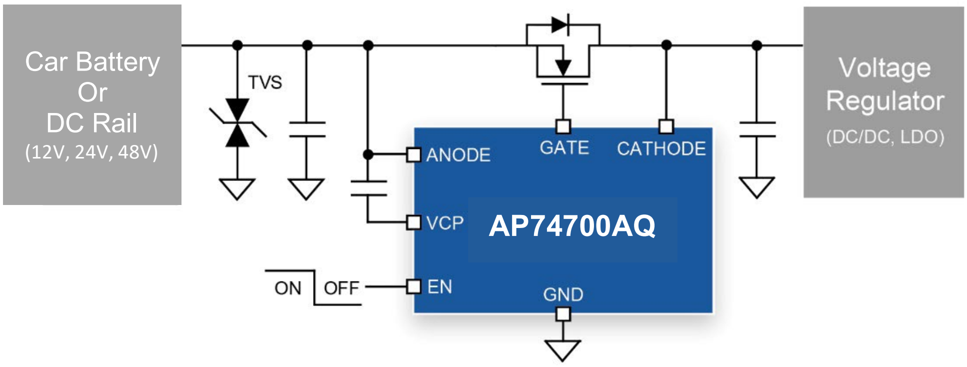


Figure 1: Typical Circuit Schematic for the AP74700AQ Ideal Diode Controller

In this application note, we discuss some of the design considerations that should be accounted for in the MOSFET selection process for a high-side ideal diode controller, such as the AP74700AQ.

During normal operation, the current in the MOSFET flows from source to drain. If the MOSFET is not enabled by the ideal diode controller, the current will still be able to flow in the forward direction (i.e. from input to load) through the body diode. Therefore, the AP74700AQ is not able to provide the load switch functionality.

Voltage Rating

All N-channel MOSFET (nMOS) devices used with the AP74700AQ should have a maximum gate-source voltage (V_{GS}) rating of at least ±20V. With that in mind, you can then select the maximum drain-source voltage (V_{DS}) for the MOSFET.

The MOSFET's V_{DS} must be able to withstand the normal battery voltage. However, there could be a case where a large capacitance on the load side could be fully charged (i.e. at +12V). When the input is connected to a reverse polarity (-12V), the voltage is effectively doubled. Therefore, the MOSFET selected should have a V_{DS} of at least twice the maximum nominal voltage rating of the system.

Additionally, standards ISO7637-2 and ISO16750-2 define a series of pulses and spikes that an automotive system must withstand, which means users typically select devices with a higher voltage rating. Consequently for automotive applications, it's recommended to use 40V parts for a 12V nominal rail, 60V parts for a 24V nominal rail, and 80V or 100V parts for a 48V nominal rail.

The AP74700AQ ideal diode controller is rated at 65V (max) and can also withstand a -65V rail voltage. Because of the possibility of a doubled reverse voltage, you may want to choose a 60V MOSFET, even for a 12V nominal rail.

Diodes recommends that the AP74700AQ is combined as follows:

Application Voltage	Battery Type	MOSFET V_{DS}	Example Application
3.7V	Li-Ion	≥12V	Handheld device
7.4-14.8V	Li-Ion 2-4 cell	≥30V	Cordless power tools
12-14.4V	Lead acid	≥40V	12V automotive
24-28V	Lead acid	≥60V	24V commercial vehicle

Table 1: Recommended MOSFET V_{DS} for Different Applications

Current and $R_{DS(ON)}$

The next parameter to decide upon is the $R_{DS(ON)}$ of the MOSFET, which is required to support the load current of the application.

A fully enabled (i.e. V_{GS} = 10V) nMOS will act as a resistor, where the resistance is the $R_{DS(ON)}$ parameter of that device. The voltage drop across the device is calculated by Ohm's law.

The AP74700AQ ideal diode controller will drive the gate of the nMOS to regulate the voltage across its source and drain to a minimum of 20mV at low load currents. At higher currents, the voltage across the nMOS will be limited by the $R_{DS(ON)}$.

Figure 2 illustrates two modes of operation:

1. "Regulated" mode, where the AP74700AQ maintains the 20mV drop across the nMOS
2. "$R_{DS(ON)}$ limited" mode, where the nMOS acts as a resistor

The slope of the $R_{DS(ON)}$ limited mode is determined by the MOSFET chosen.

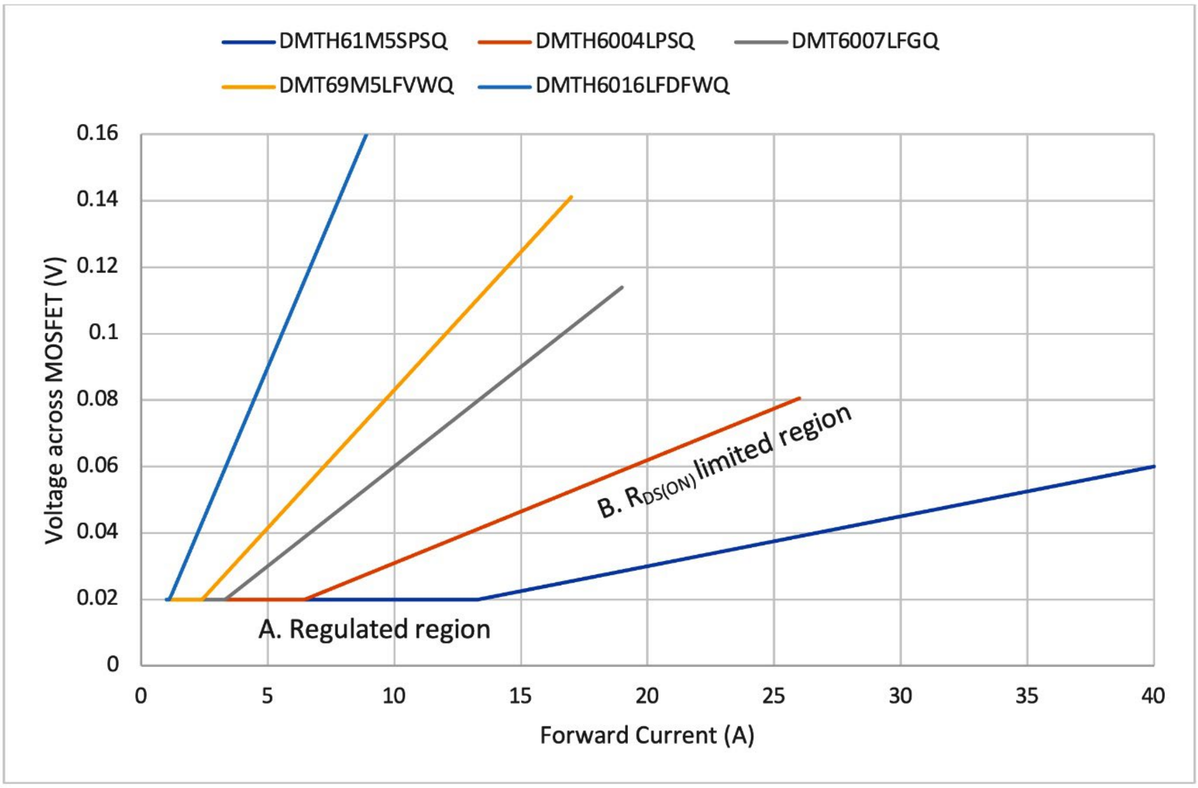


Figure 2: Voltage Drop Across Various MOSFETs Against Current

Generally, a lower $R_{DS(ON)}$ of a MOSFET leads to larger die size, larger packaged device, and higher cost. In low-current conditions where the voltage drop across the MOSFET stays regulated around 20mV, there is no advantage of using a very low $R_{DS(ON)}$ device because of the extra cost.

When selecting a MOSFET, begin with the intended load current and then consider any peaks. Must the voltage drop across the MOSFET remain steady, or is it acceptable to have some increase in voltage drop during brief current peaks?

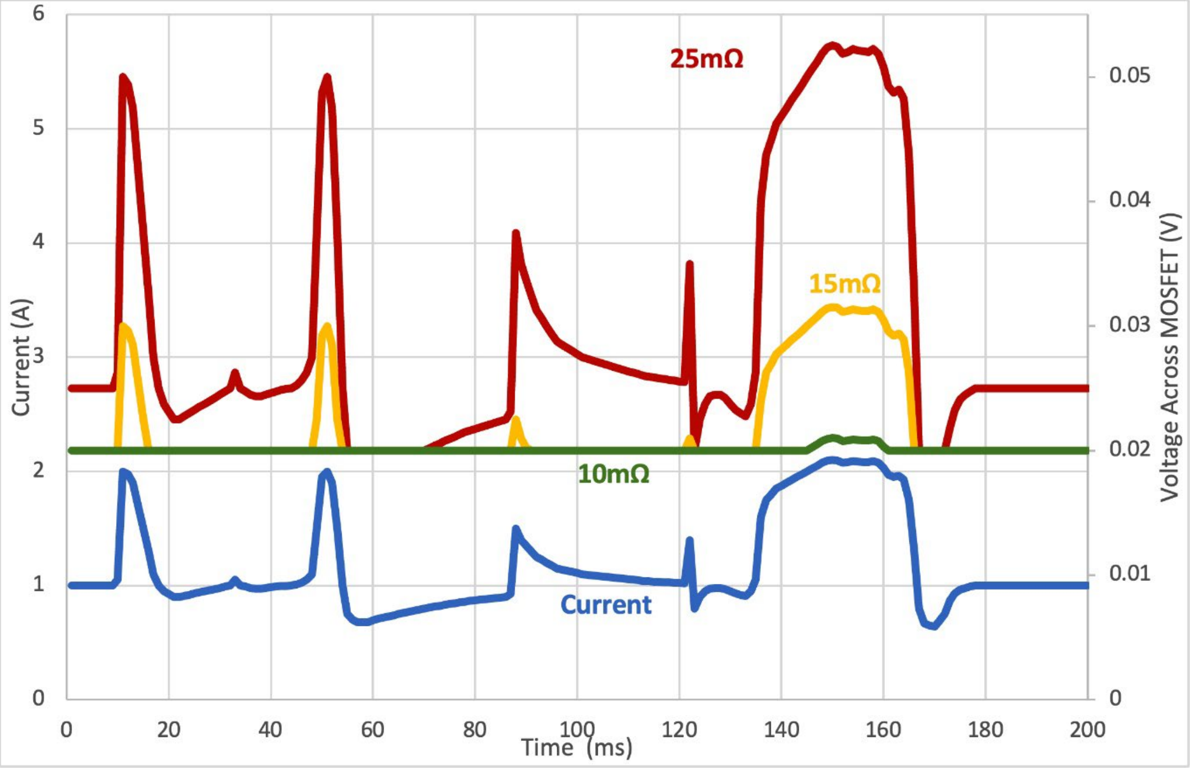


Figure 3: MOSFET Voltage Ripple with Varying Current

Figure 3 shows how three different MOSFET devices will behave in conjunction with the AP74700AQ, with a varying current between approximately 1-2A. The three MOSFETs have $R_{DS(ON)}$ values of 10mΩ, 15mΩ, and 25mΩ, and show three different behaviours:

1. The **red trace** shows a 25mΩ MOSFET that is almost entirely $R_{DS(ON)}$ limited and acts as a resistor, except for the occasional current dip when it hits the 20mV regulation mode.
2. The 15mΩ device (**yellow trace**) is mostly regulated at 20mV and drops just a bit more voltage when the current peaks above 1.3A.
3. The **green trace** shows a 10mΩ device, which is almost entirely regulated at 20mV, with only the slightest increase when the current exceeds 2A.

A regular diode would typically drop 700mV. It is clear that the 25mΩ MOSFET represents a significant improvement in efficiency compared to a diode, and while the 10mΩ device improves further, it might not be cost-effective at this current level. This decision on which option to choose is up to the designer: whether the goal is to maximize efficiency or trade-off against cost.

If the load current were 20A, then you would look to lower $R_{DS(ON)}$ devices again, around the 1-3mΩ level.

Table 2 lists suggested MOSFETs that are a good match to selected currents:

V_{DS} (V)	Load Current (A)	$R_{DS(ON)}$ (mΩ)	Part Number	Package
30	3	25	DMN3028LQ	SOT23
	5	17	DMT3020LFDFQ	U-DFN2020-6
	8	12	DMN3016LFDFQ	
	10	7	DMT3006LFDFQ	
	20	3.2	DMT3003LFGQ	PowerDI3333-8
	30	1.7	DMTH31M7LPSQ	PowerDI5060-8
40	8	11.5	DMTH4008LFDFWQ	U-DFN2020-8
	10	7.5	DMT47M2SFVWQ	PowerDI3333-8
	15	5.5	DMTH45M5LFVWQ	
	20	3	DMTH43M8LFGQ	
	30	1.2	DMTH41M2SPSQ	PowerDI5060-8
	50	0.7	DMTH4M70SPGWQ	PowerDI8080-5
60	5	18	DMTH6016LFDFWQ	U-DFN2020-6
	10	8.3	DMT69M5LFVWQ	PowerDI3333-8
	15	6	DMT6007LFGQ	
	20	3.1	DMTH6004LPSQ	PowerDI5060-8
	30	1.5	DMTH61M5SPSWQ	

Table 2: MOSFET Recommendations for High-Current Applications

Packaging and Layout

The MOSFET package and the amount of copper area on the PCB influence its thermal performance. When selecting a MOSFET to partner with the AP74700AQ, it is worth thinking about the MOSFET package and how it aligns with the pins on the controller.

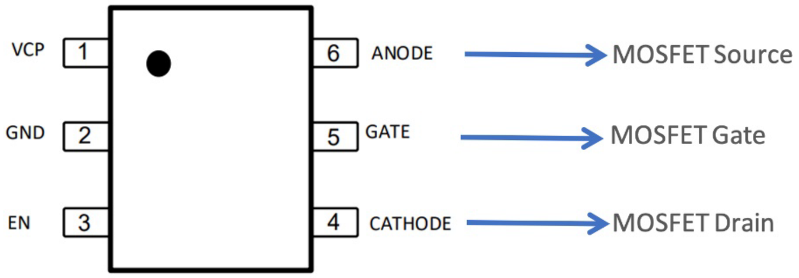


Figure 4: AP74700AQ Pin Order and Connection to MOSFET Pins

The PowerDI®3333 and PowerDI5060 packages easily and neatly connect neatly with the AP74700AQ (Figure 5, right-side image).

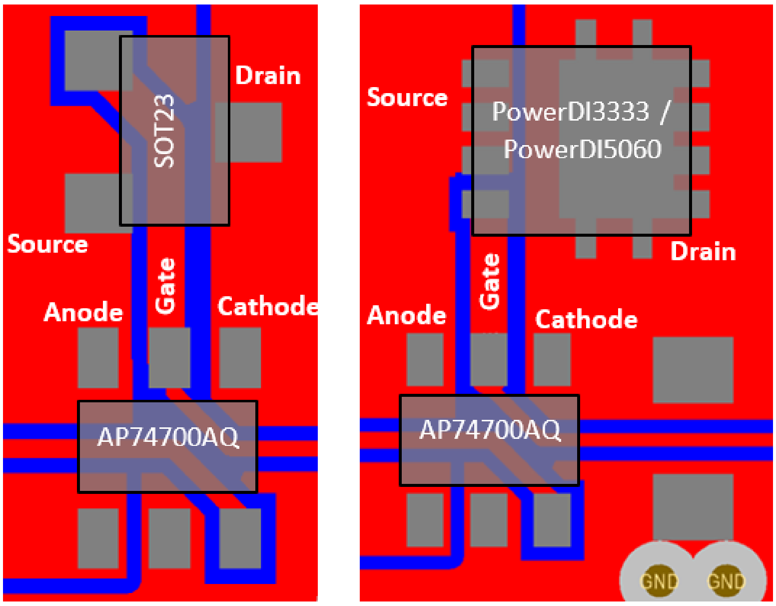


Figure 5: AP74700AQ PCB Layout with SOT23 MOSFET (Left) and PowerDI3333/PowerDI5060 MOSFET (Right)

However, be aware that some packages are different and may be more difficult to connect. The U-DFN2020-6 package, for example, requires a layer change for the gate (Figure 6, left-side image).

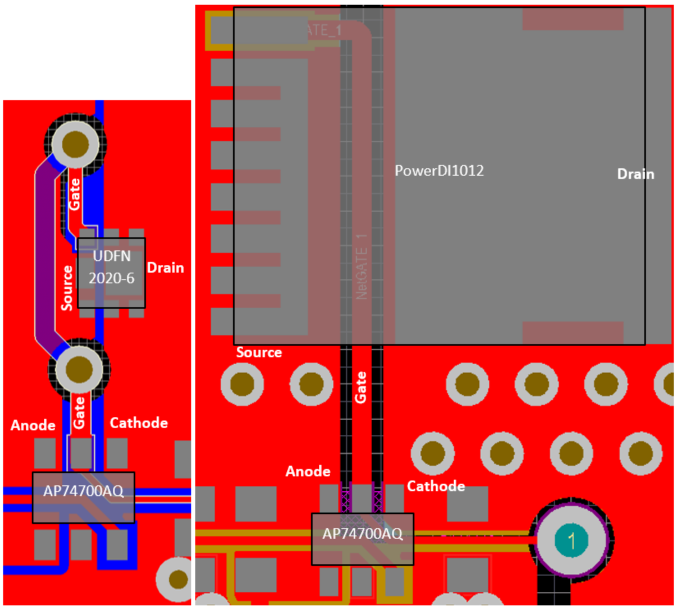


Figure 6: AP74700AQ PCB Layout with DFN-2020 MOSFET (Left) and PowerDI1012 MOSFET (Right)

If you are designing a solution for a product range or want to reuse the same circuit blocks again and again in different products, then it is worth selecting a MOSFET footprint that offers a wide range of $R_{DS(ON)}$ and voltage options. The PowerDI3333 is a good choice as it covers a wide range from less than 70mΩ down to 2mΩ, and offers a compact solution. For higher power solutions, the PowerDI5060 can go below 1mΩ, and the PowerDI8080 and PowerDI1012 devices go lower still.

MOSFET Thermals

Once the $R_{DS(ON)}$ has been selected, you need to consider the thermal behavior of the MOSFET. By understanding whether it is operating in the regulated region or if the $R_{DS(ON)}$ is limited, you can determine the worst-case power dissipation as a simple VI (regulated region) or I^2R ($R_{DS(ON)}$ limited region) calculation. From that, and the ambient temperature, you can determine the thermal headroom and required junction-to-ambient thermal impedance ($R_{\theta JA}$), which can be used to determine the most appropriate package.

When using an I^2R calculation, it is important to consider the thermal coefficient (α) of the device. This effect of $R_{DS(ON)}$ increasing with temperature can be seen in Figure 7, which is a graph taken from a MOSFET datasheet.

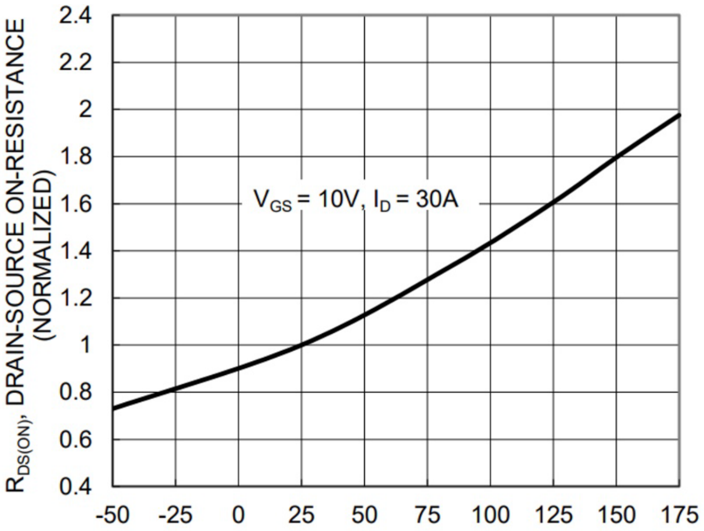


Figure 7: Example MOSFET ON-state Resistance Variance with Die Temperature

For more information on copper areas and thermal resistances, see Diodes' application note AN1157: *Understanding Thermal Resistance in the Real World*. The copper area provided and PCB construction (in terms of layers, vias, copper weights, etc.) will have a significant impact on the real-world thermal performance of the system.

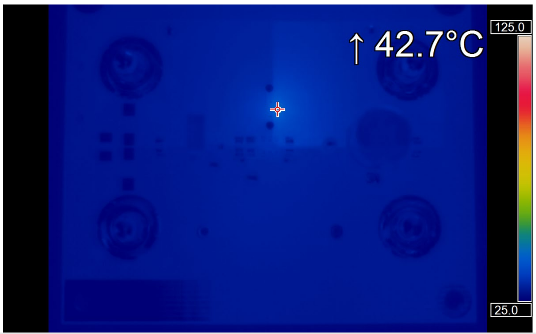
Example:

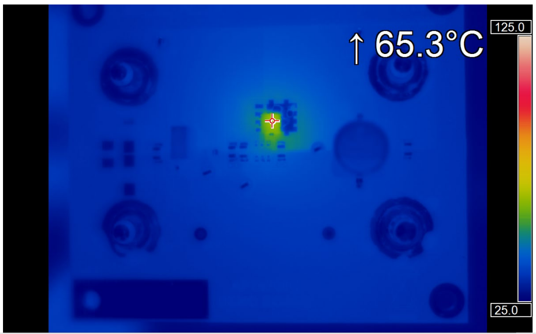
$$\Delta T_{BUDGET} = T_{j(MAX)} - T_{AMBIENT} = 175°\mathrm{C} - 85°\mathrm{C} = 90°\mathrm{C} \tag{1}$$

$$P_D = \begin{cases} I \times V_{DROP} \\ OR \\ \alpha \times \mathrm{R_{DS(ON)MAX}} \times \mathrm{I}^2 \end{cases} = \begin{cases} 20A \times 50mV \\ OR \\ 1.25 \times 0.002\Omega \times 20\mathrm{A}^2 \end{cases} = 1W \tag{2}$$

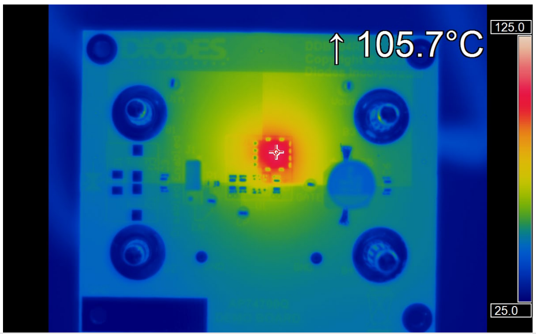
$$Target\ R_{\theta JA} = \frac{\Delta T_{BUDGET}}{P_D} \overset{(1)}{\underset{(2)}{\Rightarrow}} \frac{90°C}{1W} = 90\ {}^{°C}/_{W} \tag{3}$$

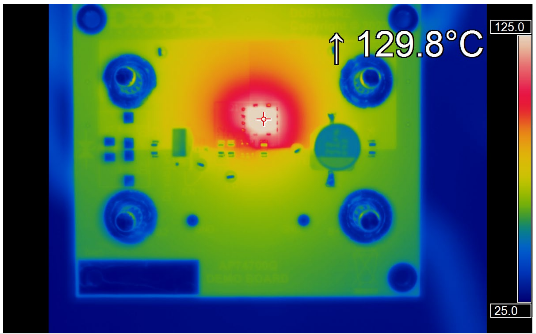
Taking some real-life measurements from the DDB104R3 and DDB106R1 demo boards, using some of the 60V MOSFETs detailed in Table 2, yields the following results:





Device	**DMTH6016LFDFWQ**	**DMT69M5LFVWQ**
T_A	25°C	25°C
T_D	42.2°C	65.1°C
I_{OUT}	5A	10A
P Calc	$1.05 \times 0.018 \times 5^2$	$1.2 \times 0.0083 \times 10^2$
P_D	0.4725W	0.996W
°C/W	36.4°C/W	40.2°C/W





Device	**DMTH6004LPSQ**	**DMTH61M5SPSWQ**
T_A	25°C	25°C
T_D	105.6°C	129.1°C
I_{OUT}	25A	35A
P Calc	$1.4 \times 0.0031 \times 25^2$	$1.6 \times 0.0015 \times 35^2$
P_D	2.7125W	2.94W
°C/W	29.7°C/W	35.4°C/W

Table 3: Real-world Examples of AP74700AQ Controlling Different MOSFETs

Summary

The ideal diode controller is an efficient solution to providing input reverse polarity protection. Choosing the right MOSFET to go with the ideal diode controller is just as important and, by following some simple steps, it can be quite easy. Diodes Incorporated produces a wide range of appropriate MOSFETs for this purpose, and Table 2 provides a set of suggested devices covering a wide range of load currents.

IMPORTANT NOTICE

1. DIODES INCORPORATED (Diodes) AND ITS SUBSIDIARIES MAKE NO WARRANTY OF ANY KIND, EXPRESS OR IMPLIED, WITH REGARDS TO ANY INFORMATION CONTAINED IN THIS DOCUMENT, INCLUDING, BUT NOT LIMITED TO, THE IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION).

2. The Information contained herein is for informational purpose only and is provided only to illustrate the operation of Diodes' products described herein and application examples. Diodes does not assume any liability arising out of the application or use of this document or any product described herein. This document is intended for skilled and technically trained engineering customers and users who design with Diodes' products. Diodes' products may be used to facilitate safety-related applications; however, in all instances customers and users are responsible for (a) selecting the appropriate Diodes products for their applications, (b) evaluating the suitability of Diodes' products for their intended applications, (c) ensuring their applications, which incorporate Diodes' products, comply the applicable legal and regulatory requirements as well as safety and functional-safety related standards, and (d) ensuring they design with appropriate safeguards (including testing, validation, quality control techniques, redundancy, malfunction prevention, and appropriate treatment for aging degradation) to minimize the risks associated with their applications.

3. Diodes assumes no liability for any application-related information, support, assistance or feedback that may be provided by Diodes from time to time. Any customer or user of this document or products described herein will assume all risks and liabilities associated with such use, and will hold Diodes and all companies whose products are represented herein or on Diodes' websites, harmless against all damages and liabilities.

4. Products described herein may be covered by one or more United States, international or foreign patents and pending patent applications. Product names and markings noted herein may also be covered by one or more United States, international or foreign trademarks and trademark applications. Diodes does not convey any license under any of its intellectual property rights or the rights of any third parties (including third parties whose products and services may be described in this document or on Diodes' website) under this document.

5. Diodes' products are provided subject to Diodes' Standard Terms and Conditions of Sale (https://www.diodes.com/about/company/terms-and-conditions/terms-and-conditions-of-sales/) or other applicable terms. This document does not alter or expand the applicable warranties provided by Diodes. Diodes does not warrant or accept any liability whatsoever in respect of any products purchased through unauthorized sales channel.

6. Diodes' products and technology may not be used for or incorporated into any products or systems whose manufacture, use or sale is prohibited under any applicable laws and regulations. Should customers or users use Diodes' products in contravention of any applicable laws or regulations, or for any unintended or unauthorized application, customers and users will (a) be solely responsible for any damages, losses or penalties arising in connection therewith or as a result thereof, and (b) indemnify and hold Diodes and its representatives and agents harmless against any and all claims, damages, expenses, and attorney fees arising out of, directly or indirectly, any claim relating to any noncompliance with the applicable laws and regulations, as well as any unintended or unauthorized application.

7. While efforts have been made to ensure the information contained in this document is accurate, complete and current, it may contain technical inaccuracies, omissions and typographical errors. Diodes does not warrant that information contained in this document is error-free and Diodes is under no obligation to update or otherwise correct this information. Notwithstanding the foregoing, Diodes reserves the right to make modifications, enhancements, improvements, corrections or other changes without further notice to this document and any product described herein. This document is written in English but may be translated into multiple languages for reference. Only the English version of this document is the final and determinative format released by Diodes.

8. Any unauthorized copying, modification, distribution, transmission, display or other use of this document (or any portion hereof) is prohibited. Diodes assumes no responsibility for any losses incurred by the customers or users or any third parties arising from any such unauthorized use.

9. This Notice may be periodically updated with the most recent version available at https://www.diodes.com/about/company/terms-and-conditions/important-notice

The Diodes logo is a registered trademark of Diodes Incorporated in the United States and other countries.
All other trademarks are the property of their respective owners.
© 2025 Diodes Incorporated. All Rights Reserved.

www.diodes.com