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AN-4191

Advanced GreenBridge™ Technology Enables Efficient Power over Ethernet System Designs

Abstract

This application note introduces the second-generation of the innovative GreenBridge module series, FDMQ8205. The FDMQ8205 is a full bridge Multi-Chip Module (MCM) switch that regulates the polarity of the input power source. Regulation is mandatory in Power over Ethernet (PoE) Powered Device (PD) applications where the power is delivered via a network cable. The FDMQ8205 integrates the gate driver circuits and four MOSFETs into the thermally enhanced MLP 4.5x5.0 package enabling a simple and clean circuit layout. It achieves high power density due to low on-resistance ($R_{DS(ON)}$) switches from the Fairchild shielded gate power trench MOSFET technology; and also provides compliance with the PoE standard described in IEEE802.3at. The validation of the FDMQ8205 increased efficiency in PoE PD applications is verified and compared with the conventional diode bridge.

1. Introduction

In recent years, PoE powered devices (PDs) have received a lot of attention due to convenient installation without needing a nearby AC outlet. PoE is wildly used in a variety of applications such as IP phone, network security camera, wireless access point, micro cell as well other devices and is continually finding more and more applications in facilitating and extending the network. These PD applications are provided with power and data from the PSE via the network cable. Recently, PDs are consuming more power due to the more complex functions requested by the customer. The higher power density is one of the most important challenges in the power circuit design because of the limited power that is allowed according to the power classification defined by the PoE standard.

The diode bridge used for polarity rectification resides after the RJ-45 connector in PoE PD applications. In order to reduce bridge power losses, some applications replaced the diode bridge with the first GreenBridge series module, which is a full-bridge configuration using dual P-channel MOSFETs and N-channel MOSFETs into an MLP 4.5x5.0 package.[1] The major downside of the original GreenBridge modules is the requirement for external components to self-drive the MOSFET gate. The latest GreenBridge FDMQ8205 module solves this issue by consolidating the proprietary MOSFETs and gate driving circuits into a single MLP 4.5x5.0 package. This results in a simple design solution without using any additional external components. The FDMQ8205 also increases power density compared to the previous GreenBridge series by using lower $R_{DS(ON)}$ MOSFETs.

In Section 2, the features and block diagram are described. The measured power losses and voltage drop of the FDMQ8205 compared with Schottky diode bridge are presented in the Section 3. Section 4 illustrates PoE PD application diagram with the GreenBridge module and the application note is summarized in Section V.

2. Features and Block Diagram

One major feature of the advanced GreenBridge series is that it must not compromise the 25 KΩ resistance detection, or the PD power classification procedure defined by the PoE standard, since it resides between the PSE and PD interface controllers. Figure 1 illustrates the simplified PoE system diagram and the current path from PSE to PD during both procedures.

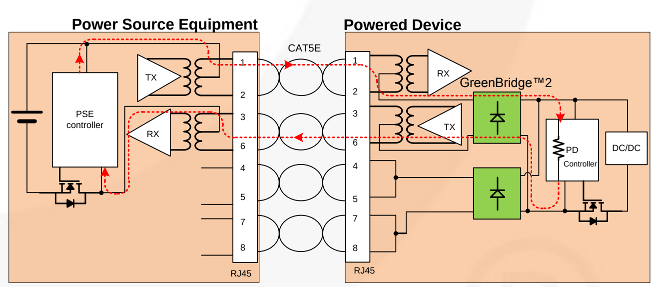


Figure 1. PoE System Diagram

The purpose of the resistance detection procedure is for the PSE to recognize if the PD is available and how much power the PD consumes when the PD is connected to PSE. During the resistance detection period, the PSE delivers two consecutive voltages, V1=2.7 V and V2=10.1 V, shown in Figure 2, and then records the measured currents of I1 and I2 by V1 and V2 respectively while PD presents 25 KΩ.

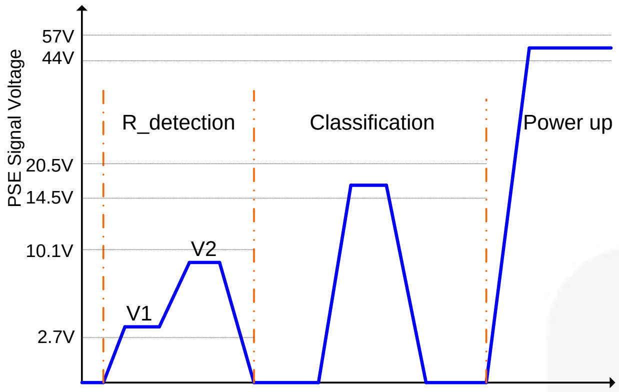


Figure 2. PSE Signal at initial operation

If the computed ΔV/ ΔI equals 25 KΩ, with tolerance from 23.7 KΩ to 26.3 KΩ, the PSE ensures the presence of a PD. The PSE then moves to the power classification mode to identify the PD power class using the same method. The PSE provides a single voltage in the range from 14.5 V to 20.5 V and then measures the current to calculate the present resistance. Using the computed resistance, the PSE recognizes the PD power class, where the PD power classes ranges from class 0 to class 4, where maximum power consumption is defined by IEEE802.3af/at.[1] During these two stages, the FDMQ8205 must maintain low current consumption and not interfere with the 25 KΩ resistance detection and power classification. In order to do this, the internal bridge MOSFETs used in the FDMQ8205 module are initially turned off. This allows the GreenBridge module to momentarily operate as a conventional diode bridge by only using the body diode of the MOSFET, which reduces the quiescent current.

Table 1 shows the low quiescent current of FDMQ8205, which does not compromise the resistance detection or the classification detection.

Table 1. Quiescent Current in FDMQ8205

Parameter	Conditions	Max	Unit
Quiescent Current	Detection mode 1.5 V < V_{INPUT} < 10.1 V	5	µA
	Classification mode 10.2 V < V_{INPUT} < 23.9 V	400	µA

After passing the PoE detection processes, the input voltage from the PSE goes up. The proprietary gate driver turns on the diagonal MOSFETs according to the polarity of the power source. Figure 3 illustrates the block diagram of the GreenBridge2 FDMQ8205.

The internal 80 V or 100 V P- and N-channel MOSFETs (FDMQ8205; 80 V MOSFETs, FDMQ8205A; 100 V MOSFETs) incorporate the Fairchild shielded gate power trench MOSFET technology, which results in extremely low $R_{DS(ON)}$.[2] The power saving from conduction loss is greatly improved compared to the previous generation GreenBridge module.

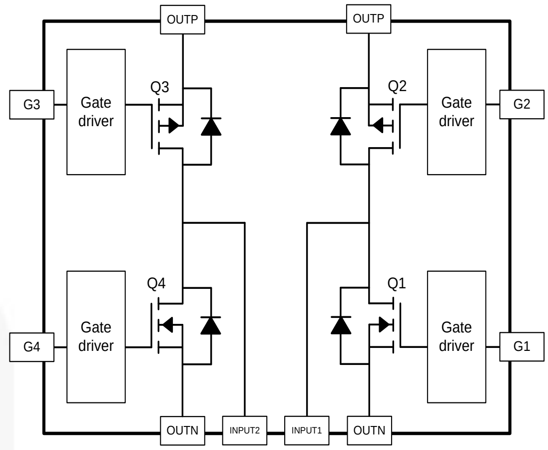


Figure 3. Block Diagram

Table 2 summarizes the low typical and maximum values of $R_{DS(ON)}$ for the P- and N-channel MOSFETs.

Table 2. $R_{DS(ON)}$ of P- and N-channel MOSFETs

Parameter	Conditions	Typ	Max	Unit
N-ch MOSFET (Q1, Q4)	V_G = 48 V, I_{INPUT} = 1.5 A, T_A = 25°C	29	44	mΩ
P-ch MOSFET (Q2, Q3)	V_G = 48 V, I_{INPUT} = 1.5 A, T_A = 25°C	83	125	mΩ

Figure 4 describes the application diagram of the GreenBridge module for the polarity protection. Compared to the earlier generation, the new GreenBridge module does not need external components to drive the internal MOSFETs. INPUT +/- are connected to each INPUT1 and INPUT2 pin(s) respectively. G1 and G2 of gate driver pins are directly tied to INPUT2. The other G3 and G4 are connected to INPUT1 as shown in Figure 4. The simple configuration of the application diagram enables a reduced solution size while saving design time.

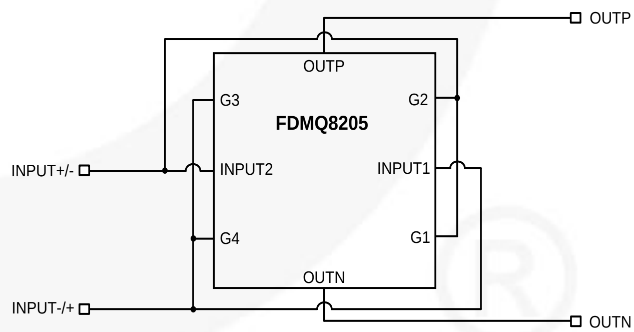


Figure 4. Application Diagram of Polarity Protection

The power loss in the application is calculated by:

$$= [\text{MOSFET Conduction loss}] + [\text{Gate driving loss}]$$
$$= [I_{IN}^2 \times R_{DS(ON)\_}Pch + I_{IN}^2 \times R_{DS(ON)\_}Nch] + [V_{IN} \times I_G] \quad (1)$$

where I_{IN} is the input current and I_G is the consumed current by the gate driver which is around 2 mA at 48 V of the typical input voltage. For example, when the PoE power class is CLASS 4, the allowed maximum input power delivered by the PSE is 25.5 W. The FDMQ8205 dissipates 0.12 W of the power losses and then delivers 25.38 W to the system load, whereas the Diode Bridge dissipates 0.64 W and delivers only 24.86 W of power to the load. Therefore, the FDMQ8205 lowers power dissipation by 81% compared to the diode bridge. FDMQ8205 improves power density by using the same package footprint as the original GreenBridge modules but reduces power losses.

Regarding voltage drop at OUTP referred to OUTN, a generic PN diode bridges reduces the input voltage to the load by 1.4 V, whereas the voltage drop of FDMQ8205 is only 0.063 V and is a 95% improvement. The voltage drop in the application is simply estimated by:

$$= I_{IN} \times R_{DS(ON)\_}Pch + I_{IN} \times R_{DS(ON)\_}Nch \quad (2)$$

IEEE802.3at specification mandates the leakage current through the unused bridge cannot generate more than 2.8 V across a 100 KΩ resistor when applying 57 V between OUTP and OUTN. The FDMQ8205 has low leakage current between POUT and NOUT and the backfeed voltage is maintained under 2.8 V in the operating temperature from -40°C to +85°C satisfying the leakage specification.

The package is the other effective way to improve power capability, mainly by reducing the package thermal impedance. The thermally enhanced MLP 4.5 x 5 mm package is shown in Figure 5. The exposed bottom pads are used for INPUT1 and INPUT2. This lowers the thermal resistance from the MOSFET silicon to the PCB.

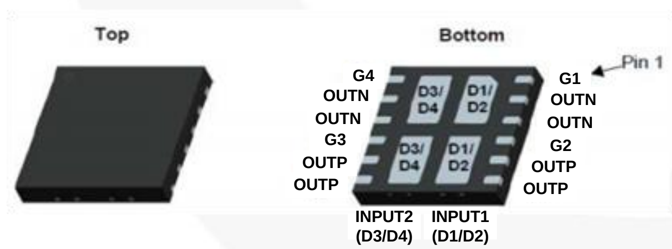


Figure 5. MLP 4.5 x 5 mm Package

The thermal resistance from the MOSFET silicon junction to 25°C ambient temperature is specified at 50°C/W and 160°C/W depending on PCB board copper area and thickness, Table 3.

Table 3. Thermal characteristics of MLP 4.5x5.0

Parameter	Conditions	Typ	Unit
$R_{\Theta JA}$	Thermal Resistance, Junction to Ambient (1in^2 pad of 2oz copper)	50	°C/W
$R_{\Theta JA}$	Thermal Resistance, Junction to Ambient (Minimum pad)	160	°C/W

3. Experiment Data

Table 4 summarizes the measured power dissipation and voltage drop of the FDMQ8205 compared to a commonly used and commercially available 100 V, 2 A Schottky Diode (S210) at 25°C ambient temperature. The results are summarized by the PoE power class and input voltage, which are defined by the PoE standard.

Table 4. FDMQ8205 Power Loss and Voltage Drop comparison to Diode Bridge

Power Classification	Input Power (W)	Input Voltage (V)	Input Current (A)	Power Dissipation (W) FDMQ8205		Power Dissipation (W) Diode bridge (S210)	Voltage drop (V) FDMQ8205		Voltage drop (V) Diode bridge (S210)
CLASS 4	25.5	42.5	0.600	0.102	↓86%	0.731	0.081	↓93%	1.218
		48	0.531	0.120	↓81%	0.642	0.063	↓95%	1.208
		57	0.447	0.173	↓67%	0.517	0.049	↓96%	1.157
PoH	47.5	50	0.950	0.189	↓85%	1.235	0.114	↓91%	1.300
4-pairs	60	42.5	1.412	0.237	↓87%	1.769	0.096	↓92%	1.253
		48	1.250	0.269	↓83%	1.542	0.077	↓94%	1.233
		57	1.053	0.347	↓72%	1.259	0.060	↓95%	1.196
	95	42.5	2.235	0.392	↓87%	2.915	0.156	↓88%	1.304
		48	1.979	0.365	↓86%	2.561	0.124	↓90%	1.294
		57	1.667	0.420	↓80%	2.126	0.095	↓93%	1.275

The test results show that the FDMQ8205 delivers over 80% improvement in power savings compared to the Schottky Diode Bridge at all operating conditions.

The high power PoE application, which is also commonly referred to as the 4-PAIR architecture, uses all four pairs of wire in the network cable. The 4-PAIR architecture utilizes two bridges that are simultaneously operated in parallel in order to deliver a power higher than the 25.5 W of the maximum power allowed in IEEE 802.3at.[3]

The test results show the FDMQ8205 reduces power dissipation by 87% at 95 W and 42.5 V input voltage in 4-PAIR configuration compared to the Schottky Diode Bridge. The voltage drop of FDMQ8205 is 0.156 V, which is an 88% improvement. The test results clearly show the

FDMQ8205 delivers higher available power to the PD system.

Figure 6 summarizes the thermal performance of the FDMQ8205. When two FDMQ8205 rectify 95 W of the input power in the 4-pair architecture, the top case temperature is maintained to less than 40°C at 25°C ambient temperature. The GreenBridge module is an excellent solution for customers having challenges in developing high power PoE PD applications that suffer from limited PCB area and thermal challenges.

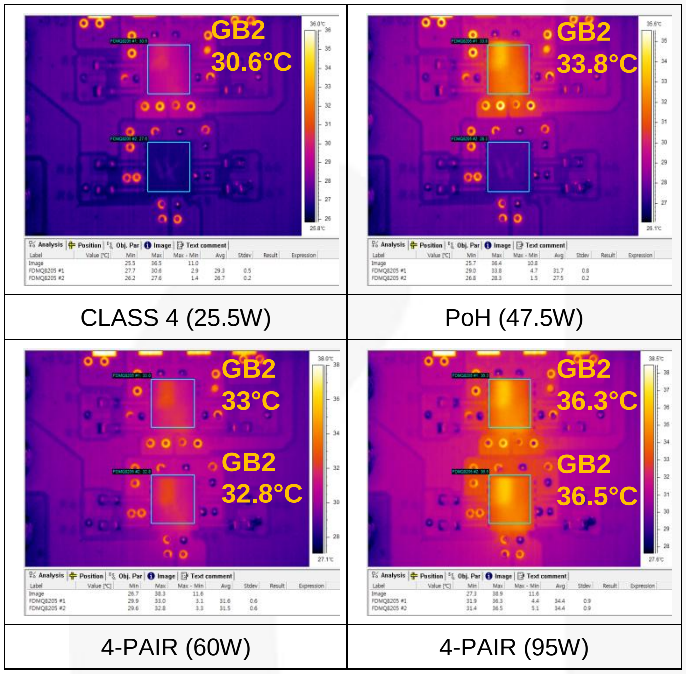


Figure 6. FDMQ8205 Thermal Performance (48Vin / 25°C)

Designers should also consider paralleling challenges when simultaneously using two bridges with the 4-PAIR architecture. Each current in the parallel-connected bridges should be equally shared and well balanced in order to avoid a thermal hot spot. In the case of the bridge diode, the forward voltage of the diode has the negative temperature coefficient. This can create a thermal runaway situation. If one of the diode bridges becomes hotter due to an imbalance in current sharing between the two bridges, then the forward voltage of the hotter diode bridge decreases more. The result is a less even current flow with more current flowing in the hotter diode bridge. The net result can be a thermal runaway as the hotter bridge conducts more current.

On the other hand, the GreenBridge module conducts using the MOSFET $R_{DS(ON)}$. Since the $R_{DS(ON)}$ of a MOSFET has a positive temperature coefficient, the hotter GreenBridge module will increase the $R_{DS(ON)}$ of the internal MOSFETs and the cooler module will conduct more current.[4] This will provide a more stable and safer thermal operation, and aid in achieving a well balanced current share in the 4-PAIR architecture.

Measured results show the top case temperature difference between two FDMQ8205 modules operating in the 4-PAIR architecture is less than 1°C.

4. PoE PD Application Diagram

With the integrated gate driver circuit, the FDMQ8205 enables simple and efficient PoE PD designs. Figure 7 illustrates the PoE PD application diagram. According to the PoE standard, two FDMQ8205 are applied to cover two types of PSE such as Mid-span PSE and End-span PSE. Also, two bridges can be used simultaneously for high power PoE applications. Each wire pair of the network cable is connected to the input 1 or input 2 of the FDMQ8205 through an RJ45 connector. Each positive output (POUT) and negative output (NOUT) of both FDMQ8205 is connected respectively.

When implementing the auxiliary power source such as DC adaptor or AC wall power to PD applications as well as PoE power source, a reverse current from an auxiliary power source to PSE passing through the FDMQ8205 needs to be considered. If the voltage of an auxiliary power is higher than 44 V of the minimum voltage of PSE, the reverse current from the auxiliary power source flows to PSE due to the bidirectional conduction of the internal MOSFETs. The proposed simple circuits illustrated at Figure 8 can prevent this problem. The external simple circuits detect the auxiliary power voltage and then turn off the internal MOSFETs of the module.

When inserting the auxiliary power, the external NPN transistors (Tr1 and Tr2) turn on. Each voltage of the gate driver pins (G1 and G4) falls down below the turn-on voltage of MOSFETs in Table 5 and then the internal N-ch MOSFETs (Q1 and Q4) becomes turned off in order to block the reverse current from the auxiliary power source to PSE.

Table 5. MOSFET Turn-on voltage

Parameter	Conditions	Min	Typ	Max	Unit
Turn-on voltage	Turn-On while V_G increases.	32		36	V

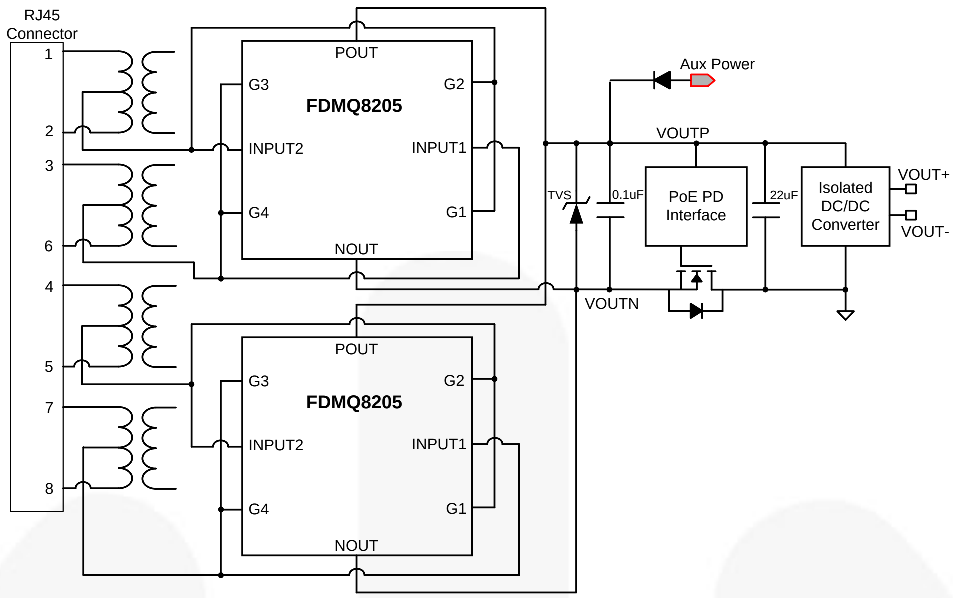
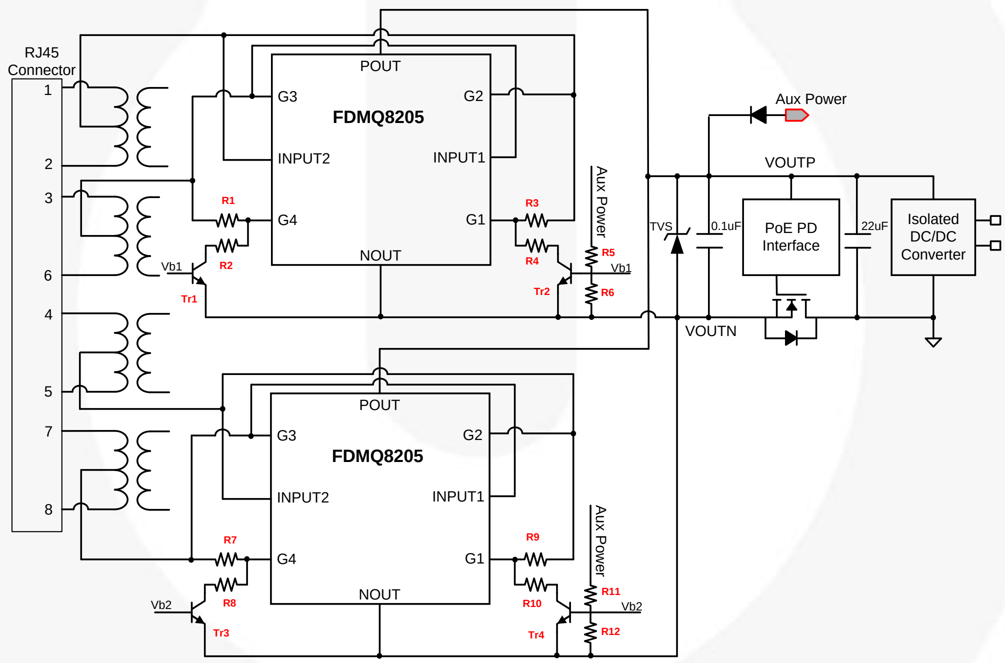


Figure 7. Power over Ethernet Power Device Application diagram



R1, R3, R7, R9	6.8Kohm / 1206 size
R2, R4, R8, R10	8.2kohm / 1206 size
R5, R6, R11, R12	20kohm / 0603 size
Tr1, Tr2, Tr3, Tr4	MMBTA06

Figure 8. PoE PD Power block diagram when Vaux > 44 V

5. Summary

In PoE applications, the PSE provides the limited power defined by the PoE power class. The PD should be designed carefully to maximize the efficiency. The enhanced GreenBridge FDMQ8205 module has proven to be a high power density and cost-effective solution. In the case of high power PoE (60 W ~ 95 W) utilizing all 4-PAIR in the network cable, GreenBridge technology eliminates thermal design problems and achieves well balanced current sharing. The integrated gate driving circuits saves PCB size and enables an easier design. An efficient and cost-effective PoE system can be achieved with Fairchild's innovative GreenBridge solutions.

Authors

Sungjin Kuen – iFET Applications Engineer

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[2] AN-9762 "Mid-Voltage Shielded PowerTrench® MOSFET in High Step-Up DC-DC for Edge-Lit LED TV Backlighting", Fairchild Semiconductor
[3] AN-4154 "MOSFETs for 60 W High-Power PoE Applications", Fairchild Semiconductor
[4] AN-4163 "Shielded Gate PowerTrench® MOSFET Datasheet Explanation", Fairchild Semiconductor

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