Automotive-grade P-channel Power MOSFETs for Static, Dynamic and Repetitive Reverse Polarity Protection

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Abstract
The latest P-channel trench technology qualified for automotive applications (according to AEC Q101) from STMicroelectronics is able to provide an outstanding performance in terms of:
- low Q_{rr} which allows a quick current flowing interruption in case of reverse polarity events
- high ruggedness versus repetitive pulse sequence, according to **ISO 7637** Pulse 1 condition [1, 2].

Introduction
To avoid that reverse voltages can be applied to automotive systems thus causing fatal errors on the electronics of a car and even the ECUs burning because of the permanent short circuit of the battery (body-drain diodes of the power stage FETs permanently ON due to forward bias), different solutions can be adopted.
As well known in literature, for high power applications the use of a diode is not feasible for reverse battery protection, since power losses are very high.
The N-channel MOSFET solution offers the highest efficiency with the drawback of additional circuit requirements like a charge pump circuit and EMI filter.
A very simple solution still with an excellent efficiency would be the P-channel approach since requires nearly no additional circuit effort compared to the diode and only a slightly worse efficiency in comparison to the N-channel MOSFET [3, 4].
By using the Automotive-grade P-channel Power MOSFETs from STMicroelectronics, three different reverse polarity conditions have been evaluated with experimental data: static, dynamic, and repetitive reverse polarities.

Reverse Polarity Condition Testing
The P-channel Power MOSFET is used with the function to protect the TCUs (Transmission Control Units) when a reverse polarity event occurs. In general the device is connected in series between the battery and TCU, as shown in Fig.1.

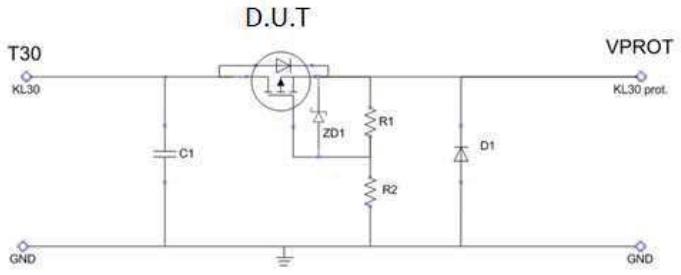


Figure 1: Circuit schematic with a P-Channel power MOSFET used for reverse polarity protection.

ISBN 978-3-8007-4186-1

Under normal operation the P-channel device is turned-on and offers a low impedance path thanks to its low R_{DSon}. When the reverse polarity occurs, the device has to be switched off in order to stop the short circuit and avoid the TCU damage.
The P-channel Power MOSFETs used are the following (Tab.1):
- STD28P3LLH6AG
- STD15P6F6AG

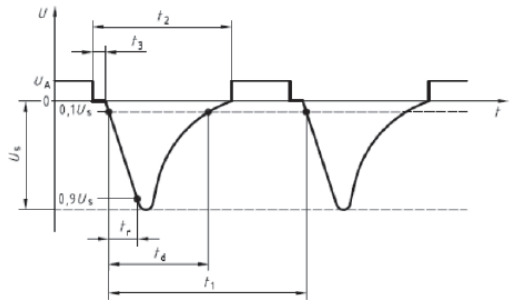
	STD28P3LLH6AG	**STD15P6F6AG**
Package	**DPAK (TO-252)**	**DPAK (TO-252)**
BV_{DSS} @ - 250 mA	- 30V	- 60V
R_{DSon}	@ V_{GS} = - 4.5V, I_D = - 6A max 50 mΩ @ V_{GS} = - 10V, I_D = - 6A max 30 mΩ	@ V_{GS} = -10V, I_D = - 5A max 160 mΩ
$V_{GS(th)}$ @ - 250 mA	- 1V ÷ - 2.5V	- 2V ÷ - 4V

Table 1: STD28P3LLH6AG and STD15P6F6AG main parameters.

The three different reverse polarity conditions have been tested at the following conditions, respectively:
a) static reverse polarity – a disconnected TCU is connected to reverse polarity for 1 minute
   - T30 = 0 V (not connected device)
   - T30 = -17 V @ 1 min

b) dynamic reverse polarity – a TCU in active operation is connected to reverse polarity for 1 minute
   - T30 = 13.5 V (TCU active)
   - T30 = -17 V @ 1 min

c) repetitive reverse polarity – **ISO 7637** Pulse 1 conditions are applied to the T30 line as shown in Fig.2



U_A = 13.5 V ± 0.5 V
U_S = -100 V
t_d = 2 ms
t_r = 1 µs
t_1 = 5 s
t_2 = 200 ms
t_3 < 100 µs
number of pulses: 5000

Figure 2: ISO 7637 Pulse 1 conditions applied to test the repetitive reverse polarity protection.

Measured Data for Reverse Polarity Conditions

In order to perform both the static and dynamic test, a specific circuit has been implemented in lab able to produce a positive and negative voltage supply. This voltage supply is applied to the terminals of the testing schematic shown in Fig.1.
The voltage applied for the dynamic test is shown in Fig.3, where the voltage is initially +13.5V and after is reversed at -17.5V.

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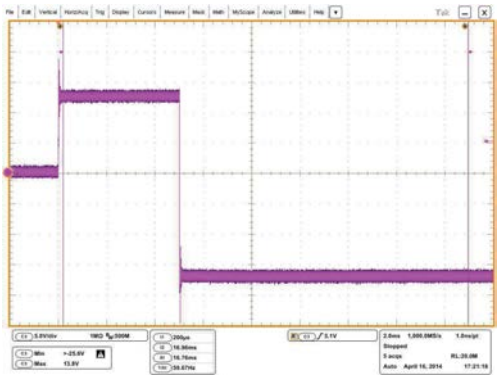

Figure 3: The voltage signal applied for the dynamic test.

The voltage applied for the static test is different because the testing circuit is initially submitted to 0V and after to -17.5V.
In both cases, the reverse polarity voltage has to be sustained by D.U.T. for 60s time.
By using the P-channel power MOSFET STD15P6F6AG, the measured waveforms for both the static and dynamic test are shown in Fig.4 (with a zoom over the red area).

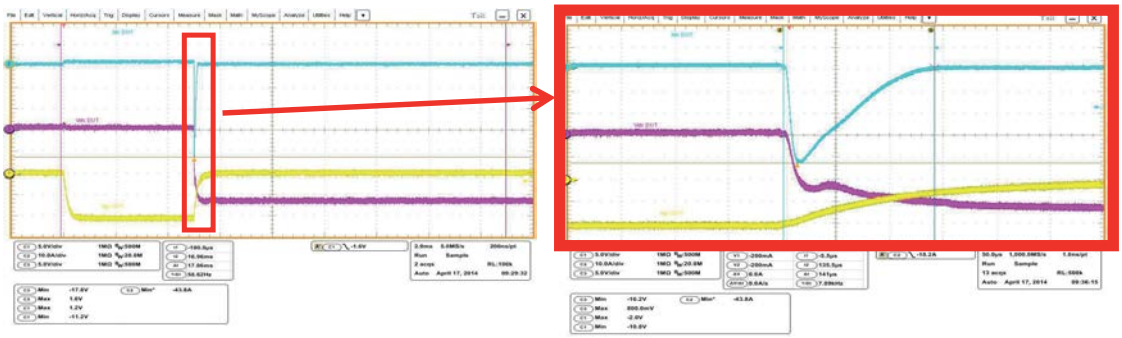

Figure 4: The measured waveforms for both static and dynamic test by using automotive STD15P6F6AG P-channel power MOSFET.

The above measured curves are relevant to I_{DS}, V_{DS}, and V_{GS} of STD15P6F6AG.
When the voltage is reversed, STD15P6F6AG switches off in about 140µs with a -43.5A current peak. After that, the negative voltage is sustained for all the remaining time.
If the P-channel power MOSFET STD28P3LLH6AG is used, the measured waveforms for both the static and dynamic test are shown in Fig. 5 (with a zoom on the switching).

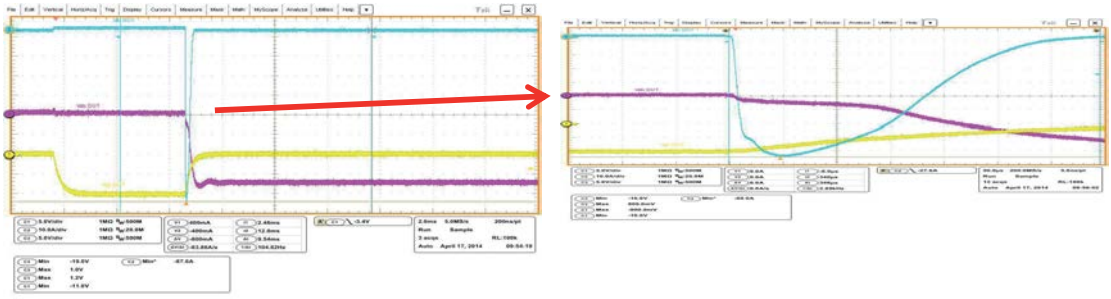

Figure 5: The measured waveforms for both static and dynamic test by using automotive STD28P3LLH6AG P-channel power MOSFET.

ISBN 978-3-8007-4186-1

The above measured curves are relevant to I_{DS}, V_{DS}, and V_{GS} of STD28P3LLH6AG.
When the voltage is reversed, STD28P3LLH6AG switches off in about 346us with a -87A current peak. After that, the negative voltage is sustained for all the remaining time.

Repetitive reverse polarity – ISO 7637 Pulse 1 test

In order to check whether the device is able to sustain this kind of stress, a 5000 pulse sequence has been submitted and the main electrical parameter values have been measured before and after the stress sequence.
The provided pulse has to match the below reported conditions (Tab. 2):

Pulse type	Number	U_S (V)	t_d (µs)	t_r (µs)	Generator R (Ω)		Note
					12V	42V	
Pulse 1	5000	-100	2000	1	4	10	t_2 = 200 ms

Table 2: ISO 7637 Pulse 1 conditions.

with the relevant shape (Fig. 6).

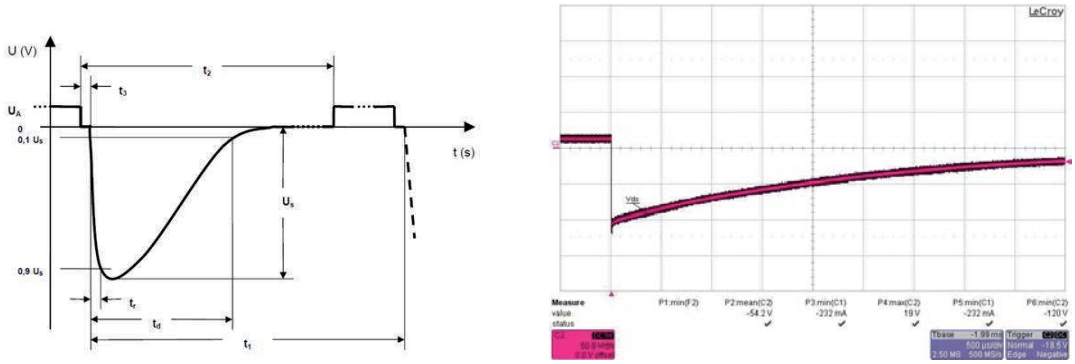

Figure 6: ISO 7637 Pulse 1 voltage and timing details (spec requirement on the left, actual waveform on the right).

The following picture (Fig. 7) shows the measured waveforms relevant to the single pulse event applied to the automotive P-channel MOSFET.
A constant 2.5A current flows through the body-drain diode of the power MOSFET under the forward bias condition.
Once the negative voltage pulse is applied, the device clamps the voltage to the avalanche value which is set by the body-drain diode. This clamping voltage is about 48V when the current peak reaches about 7A.

ISBN 978-3-8007-4186-1

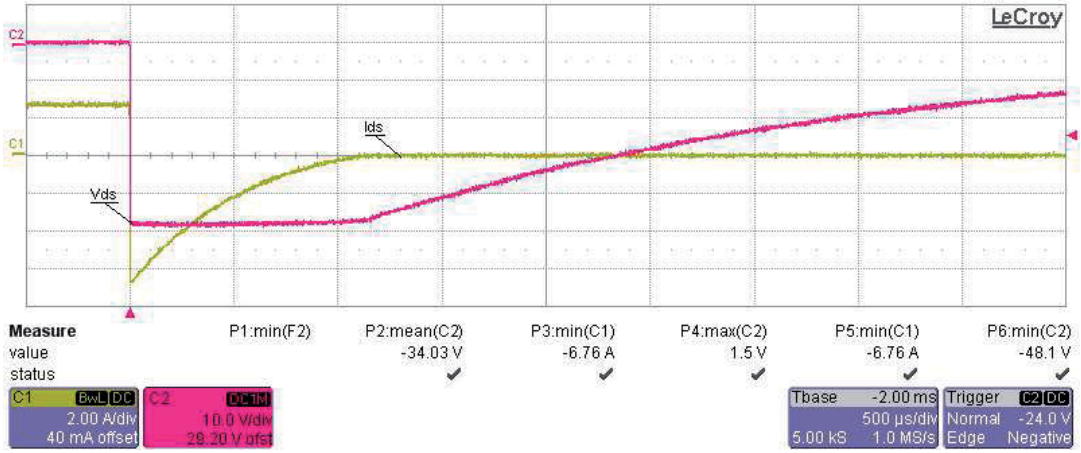

Figure 7: Clamping voltage and reverse current peak of the reverse polarity MOSFET.

This pulse type has been applied 5000 times to the device diode with a time gap of 5s.
In order to verify the device ruggedness, the main electrical parameters have been measured before and after the pulse sequence and no significant variations have been observed (Tab. 3).

	Pre-Test	Post-Test
V_{th} @ 250µA [V]	1.68	1.69
BV_{dss} @ 250µA [V]	41.1	41.35
V_{sd} @ 25mA [mV]	592	600

Table 3: Measured power MOSFET parameters before and after the pulse sequence.

Then the tested automotive P-channel power MOSFET can sustain a 5000 pulse sequence at -100V, according to the **ISO Pulse Test 1** (spec. ISO_7637_2 - 2004 ed.) without any drift on the main electrical values.

Conclusions

it has been verified that the two Automotive-grade P-channel power MOSFETs STD28P3LLH6AG and STD15P6F6AG from STMicroelectronics can easily withstand the negative voltages in static, dynamic and repetitive reverse polarity.
Then the new STMicroelectronics trench P-channel devices are good candidates to be used as reverse polarity protection switches for automotive applications.

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