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# LED Compatibility with Automotive EMC Transients

## Application Brief A03

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### Introduction

The automobile provides a harsh environment for electronic components. Electronic components are subjected to a number of high voltage transients caused by inductive switching, switch arcing, and alternator load dumps. The characteristics of the transient pulses are well understood. Several automotive specifications have been written that define these transients:

ISO-7647-1  
DIN 40839  
SAE J1113

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Working with Delco Electronics, a wide variety of LED lamps were stressed against the GM specification, GM9105P. This spec is patterned after the ISO, DIN, and SAE specifications. Lamps tested included TS AlGaAs, AS AlGaAs, AlInGaP, GaP, and SiC.

LED lamps were driven in two configurations. The first configuration simulates a switch or telltale application with a resistor (510 or 560 ohm) in series with a single LED. The second configuration simulates a HMSL application with a resistor (120 or 180  $\Omega$ ) in series with 4 LEDs.

The circuits survived positive transients well. No catastrophic or parametric failures were observed for the worst case GM9105P pulses.

The circuits had mixed results with negative transients. No failures were observed for low energy transients (GM9105P Pulse 3). The Orange GaP, LPE Green GaP, and Emerald Green GaP survived even the worst case negative transients. When tested in a telltale circuit configuration, TS AlGaAs, AS AlGaAs, AlInGaP, and SiC had either parametric or catastrophic failures at some of the levels of GM9105P Pulse 1 and 6. In the HMSL circuit configuration, both TS AlGaAs and Orange AlInGaP passed GM9105P Pulse 1, but had either parametric or catastrophic failures for GM9105 Pulse 6. A summary of these results is given in Tables 1 and 2.

In all cases, the failure mode was a significant reduction in reverse breakdown voltage. In addition, the catastrophic failures had a significant reduction in luminous intensity and a slight reduction in forward voltage. In no cases did the lamp

fail open. Samples of these lamps are being analyzed to determine the failure mechanism.

If the LED lamp circuit must be capable of worst case positive and negative transients, a high voltage silicon diode can be connected in series with the LED lamp assembly. This diode would protect the LED lamps from high voltage negative transients. Note that the Orange GaP, LPE Green GaP, and Emerald Green GaP are capable of surviving even the worst case automotive EMC transients. Although not specifically tested, the HER and Yellow GaP are expected to also survive automotive EMC transients because they have similar reverse voltage breakdown and die construction technology as the Orange GaP.

**Table 1. LED Telltale Configuration.**

GM9105P Pulse			LED Material Tested							
Pulse #	Level	Voltage	Red TS	Red AS	Or AL	Yel AL	Or GaP	Yg GaP	Eg GaP	Bl SiC
Pulse 1	4	-100 V, 2 ms	P	OK	P	OK	OK	OK	OK	OK
Pulse 2	4	+100 V, 50 $\mu$ s	OK	OK	OK	OK	OK	OK	OK	OK
Pulse 3	4	-150 V, 100 ns	OK	OK	OK	OK	OK	OK	OK	OK
Pulse 4	4	+100 V, 100 ns	OK	OK	OK	OK	OK	OK	OK	OK
Pulse 5	1	-120 V, 300 $\mu$ s	OK	OK	P	OK	OK	OK	OK	OK
	2	-180 V, 300 $\mu$ s	OK	OK	C	OK	OK	OK	OK	P
	3	-240 V, 300 $\mu$ s	P	OK	P	C	OK	OK	OK	C
	4	-300 V, 300 $\mu$ s	P	P	P	P	OK	OK	OK	C
Load Dump	II	+50 V, 250 ms	OK	OK	OK	OK	OK	OK	OK	OK
Cumulative			OK	OK	OK	OK	OK	OK	OK	P

Note: 560 ohm resistor in series with LED (510 ohm for Blue)

**Table 2: LED HMSL Configuration.**

GM9105P Pulse			LED Material Tested	
Pulse #	Level	Voltage	Red TS AlGaAs	Orange AllnGaP
Pulse 1	4	-100 V, 2 ms	OK	OK
Pulse 2	4	+100 V, 50 $\mu$ s	OK	OK
Pulse 3	4	-150 V, 100 ns	OK	OK
Pulse 4	4	+100 V, 100 ns	OK	OK
Pulse 5	1	-120 V, 300 $\mu$ s	P	OK
	2	-180 V, 300 $\mu$ s	OK	P
	3	-240 V, 300 $\mu$ s	P	P
	4	-300 V, 300 $\mu$ s	C	P
Load Dump	II	+50 V, 250 ms	OK	OK
Cumulative			C	C

Notes: 180 ohm resistor in series with 4 TS AlGaAs LED string.  
120 ohm resistor in series with 4 Orange AllnGaP LED string.

**Abbreviations Used for Tables 1 and 2.****LED Materials**

TS = TS AlGaAs

AS = AS AlGaAs

AL = AllnGaP

**Failures**

OK = Passed

P = Parametric Failure

C = Catastrophic Failure

## Theory of Operation

LEDs have similar electrical characteristics to other electronic diodes. When a positive voltage is applied to the LED, current flows through the device and the LED lights up. Current starts flowing through the LED when the voltage is greater than about 1.6 V. The current increases rapidly as higher voltages are applied. For this reason, an external current limiting resistor is normally put in series with the LED. When a reverse voltage less than the breakdown voltage is applied to the LED, negligible current flows through the LED. When the breakdown voltage is exceeded, the LED experiences an “avalanche” breakdown and current flows through the LED. At voltages above the breakdown voltage, the current increases rapidly as higher voltages are applied. The breakdown voltage varies significantly for the different LED materials technologies. The LED lamps used for this test had breakdown voltages ranging from 7 - 220 V. See Table 3.

When positive transients are applied to the LED and series resistor string, a high peak current pulse flows through the LED and resistor. In a telltale application, the peak current is equal to:

$$I_F = \frac{V_{PEAK} - V_F}{R}$$

Where:

$V_F$  is the forward voltage of the LED.

$R$  is the current limiting resistor.

**Table 3. LED Lamp Breakdown Voltages**

LED Material	Lamp P/N	Average $V_{BR}$ (10 $\mu$ A)
TS AlGaAs	HLMP-8100	31 V
AS AlGaAs	HLMP-D101	20 V
Orange AlInGaP	HLMA-D600	22 V
Orange GaP	HLMP-D400	207 V
Yellow AlInGaP	HLMA-DL00	30 V
LPE Green GaP	HLMP-3507	117 V
Emerald Green GaP	HLMP-D600	26 V
Blue SiC	HLMP-DB15	71 V

Using a  $V_F$  of 2.1 V and  $R$  of 560 ohm,  $I_F$  is equal to 20 mA at 13.5 V. At  $V_{PEAK}$  of 100 V,  $I_F$  is equal to 175 mA.

In a HMSL application, typically several LEDs are connected in series and driven from a single current limiting resistor. Thus, the peak current is equal to:

$$I_F = \frac{V_{PEAK} - nV_F}{R}$$

Where  $n$  is the number of LEDs connected in series.

Using a  $V_F$  of 1.9 V,  $R$  of 180 ohm, and  $n$  of 4,  $I_F$  is equal to 33 mA at 13.5 V. At a  $V_{PEAK}$  of 100 V,  $I_F$  is equal to 500 mA. (These calculations assume that  $V_F$  is independent of current, in actuality  $V_F$  does vary with current. At 500 mA, the TS AlGaAs forward voltage is 6.2 V.)

LEDs are quite capable of withstanding these high peak transient currents, provided that the average power dissipation and peak energy transients are small.

When negative transients are applied to the LED and series

resistor, negligible current flows for voltages less than the breakdown voltage (or  $nV_{BR}$  for a HMSL). At higher voltages, a high peak current flows. The equations are the same as the equations given previously, where  $V_{BR}$  is substituted for  $V_F$ .

For a 100 V negative transient, the peak reverse current in an LED telltale is equal to 125 mA, using the assumptions of  $V_{BR}$  of 30 V, and  $R$  of 560 ohm.

Negative transients tend to be more harmful to LEDs than forward transients. This is because for a given pulse amplitude and duration, higher levels of energy are dissipated in the LED chip (provided that the pulse amplitude is greater than the breakdown voltage).

## EMC Transient Tests

Working with Delco Electronics, a wide variety of T1-3/4 LED lamps were tested against the GM EMC specifications, GM9105P. This spec is similar to the ISO, DIN, and SAE specifications. The GM9105P pulses are defined in Table 4:

**Table 4. GM9105P EMC Pulses.**

Pulse Name	GM9105P	ISO-7647-1	Peak (Level 4)	Pulse Width (Note 1)	Decay Time (Note 2)
Inductive Switch Transient	Pulse 1	Pulse 1	-100 V	2 ms	0.86 ms
Inductive Switch Transient	Pulse 2	Pulse 2	+100 V	50 $\mu$ s	21.7 $\mu$ s
Switch Arcing Transient	Pulse 3	Pulse 3a	-150 V	100 ns	42.3 ns
Switch Arcing Transient	Pulse 4	Pulse 3b	+100 V	100 ns	42.3 ns
Alternator Load Dump	Load Dump	Pulse 5	+50 V	250 ms	115 ms
Ignition Coil Transient	Pulse 5	Pulse 6	-300 V	300 $\mu$ s	104 $\mu$ s

Note 1: Time between 10% maximum peak amplitude and 10% maximum peak amplitude for a decaying exponential shaped waveform.

Note 2: Time constant for decaying exponential waveform.

These lamps were installed on pcbs with 1/2 W carbon composition resistors for current limiting. The lamps were tested for  $I_V$ ,  $V_F$ , and  $V_{BR}$  (10 V compliance). Each 9105P pulse was applied 10 times to each LED/resistor string. Following EMC testing, the lamps were retested for  $I_V$ ,  $V_F$ , and  $V_{BR}$  (10 V compliance). Additional testing was done of  $V_F$  at 500  $\mu$ A, and  $V_{BR}$  at 10  $\mu$ A. The failure criteria are listed below:

#### Catastrophic Failure Criteria

$I_V < 0.5$ mcd	C [1]
Delta $I_V \leq -90\%$	C [2]
$V_F \leq 0.2$ V	C [3]
$V_F \geq 4.9$ V	C [4]

#### Parametric Failure Criteria

Delta $I_V \leq -50\%$	P [1]
Delta $I_V \geq +40\%$	P [2]
$V_F \leq V_{MIN}$	P [3]
$V_F \geq V_{MAX}$	P [4]
$V_{BR} \geq -5$ V	P [5]

**Table 5.**

Part Number	LED Material	Test Current	$V_{MIN}$	$V_{MAX}$
HLMP-8100	TS AlGaAS	20 mA	1.5 V	4.0 V
HLMP-D101	AS AlGaAS	20 mA	1.4 V	2.4 V
HLMA-D600	Orange AlInGaP	20 mA	1.5 V	3.5 V
HLMP-D400	Orange GaP	10 mA	1.5 V	3.0 V
HLMA-DL00	Yellow AlInGaP	20 mA	1.5 V	3.5 V
HLMP-3507	LPE Green GaP	10 mA	1.5 V	3.5 V
HLMP-D600	Emerald Green GaP	10 mA	1.5 V	3.5 V
HLMP-DB15	Blue SiC	20 mA	1.5 V	4.0 V

The complete test results are shown in Tables 6 and 7.

**Table 6: LED Telltale Configuration. 560 ohm resistor (510 ohm for Blue) in series with LED.**

GM9105 Pulse			Failures							
Pulse #	Lev.	Voltage	Red TS AlGaAs	Red AS AlGaAs	Orange AlInGaP	Or. GaP	Yellow AlInGaP	Gr.E. GaP	Gr. GaP	Blue Si
Pulse 1	4	-100 V, 2 ms	0/7	0/7	3P[5]/7	0/7	0/7	0/7	0/7	0/7
Pulse 2	4	+100 V, 50 μs	3P[5]/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7
Pulse 3	4	-150 V, 100 ns	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7
Pulse 4	4	+100 V, 100 ns	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7
Pulse 5	1	-120 V, 300 μs	0/7	0/7	2P[5]/7	0/7	0/7	0/7	0/7	0/7
Pulse 5	2	-180 V, 300 μs	0/7	0/7	1C, 1P/7 (Note 2)	0/7	0/7	0/7	0/7	2P[5]/7
Pulse 5	3	-240 V, 300 μs	1P[5]/7	0/7	1P[5]/7	0/7	1C[2]/7	0/7	0/7	1C,1P/7 (Note 3)
Pulse 5	4	-300 V, 300 μs	4P/7 (Note 1)	1P[1,5]/7	2P[5]/7	0/7	3P[5]/7	0/7	0/7	2C, 4P/7 (Note 4)
Load Dump	II	+50 V, 250 ms	0/7	0/7	0/7	0/7	0/7	0/7	0/7	0/7
Cumulative			0/7	0/7	0/7	0/7	0/7	0/7	0/7	1C, 1P/7 (Note 5)

Note 1: 2P[1], 2P[5]  
 Note 2: 1C[2], 1P[5]

Note 3: 1C[2], 1P[5]  
 Note 4: 2C[2], 4P[5]

Note 5: 1C[2], 1P[5]

**Table 7. LED HMSL Configuration. 180 ohm resistor (TS AlGaAs), 120 ohm resistor (Orange AlInGaP) in series with 4 LED lamps.**

GM9105P Pulse			Failures	
Pulse #	Level	Voltage	Red TS AlGaAs	Orange AlInGaP
Pulse 1	4	-100V, 2ms	0/8	0/8
Pulse 2	4	+100V, 50μs	0/8	0/8
Pulse 3	4	-150V, 100ns	0/8	0/8
Pulse 4	4	+100V, 100ns	0/8	0/8
Pulse 5	1	-120V, 300μs	3P[5]/8	0/8
Pulse 5	2	-180V, 300μs	0/8	5P[5]/8
Pulse 5	3	-240V, 300μs	2P[5]/8	2P[5]/8
Pulse 5	4	-300V, 300μs	1C[2], 1P[1], 4P[5]/8	5P[5]/8
Load Dump II		+50V, 250ms	0/8	0/8
Cumulative			3C[2], 1C[3], 4P[5]/8	1C[2], 5P[5]/8

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 5964-8919E (11/99)