LED Compatibility with Automotive EMC Transients

Application Brief A03

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

Working with Delco Electronics, a wide variety of LED lamps were stressed against the GM specification, GM9105P. This specification 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 Ω) in series with a single LED. The second configuration simulates a HMSL application with a resistor (120 or 180 Ω) in series with four 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 µs	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 µs	OK	OK	P	OK	OK	OK	OK	OK
	2	-180 V, 300 µs	OK	OK	C	OK	OK	OK	OK	P
	3	-240 V, 300 µs	P	OK	P	C	OK	OK	OK	C
	4	-300 V, 300 µs	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 Ω resistor in series with LED (510 Ω for Blue)

Table 2. LED HMSL Configuration.

GM9105P Pulse			LED Material Tested	
Pulse #	**Level**	**Voltage**	**Red TS AlGaAs**	**Orange AlInGaP**
Pulse 1	4	-100 V, 2 ms	OK	OK
Pulse 2	4	+100 V, 50 µs	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 µs	P	OK
	2	-180 V, 300 µs	OK	P
	3	-240 V, 300 µs	P	P
	4	-300 V, 300 µs	C	P
Load Dump	II	+50 V, 250 ms	OK	OK
Cumulative			C	C

Notes: 180 Ω resistor in series with four TS AlGaAs LED string.
120 Ω resistor in series with four Orange AlInGaP LED string.

Abbreviations used for Tables 1 and 2.

LED Materials	**Failures**
TS = TS AlGaAs	OK = Passed
AS = AS AlGaAs	P = Parametric Failure
AL = AlInGaP	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.

Using a V_F of 2.1 V and R of 560 Ω, 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.

Table 3. LED Lamp Breakdown Voltages

LED Material	Lamp P/N	Average VBR (10 μA)
TS AlGaAs	HLMP-C124	31 V
AS AlGaAs	HLMP-D101	20 V
Orange AlInGaP	HLMA-D600	22 V
Orange GaP	HLMP-D401-D0000	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-DB25	71 V

Using a V_F of 1.9 V, R of 180 Ω, 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 Ω.

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 specification 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 μs	21.7 μs
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 μs	104 μs

Notes:
1. Time between 10% maximum peak amplitude and 10% maximum peak amplitude for a decaying exponential shaped waveform.
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 μA, and V_{BR} at 10 μA. 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]
$V_{BR} \geq = -5V$	P [5]

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

Table 5.

Part Number	LED Material	Test Current	V_{MIN}	V_{MAX}
HLMP-C124	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-D401-D0000	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-DB25	Blue SiC	20 mA	1.5 V	4.0 V

Table 6. LED Telltale Configuration. 560 Ω resistor (510 Ω 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)

Notes:
1. 2P[1], 2P[5]
2. 1C[2], 1P[5]
3. 1C[2], 1P[5]
4. 2C[2], 4P[5]
5. 1C[2], 1P[5]

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

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

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