

ALTERNATOR LOAD DUMP PROTECTION WITH APC CONCEPT

INTRODUCTION

In an automotive network, all the electronic modules are supplied with the battery voltage, directly on the supply rail or through the ignition switch. Both are polluted by various surges coming from different origins. The analysis of the energy involved for each of these disturbances shows the LOAD DUMP as the most energetic one. Then one of the major engineer tasks is to suppress this infrequent but very aggressive surge.

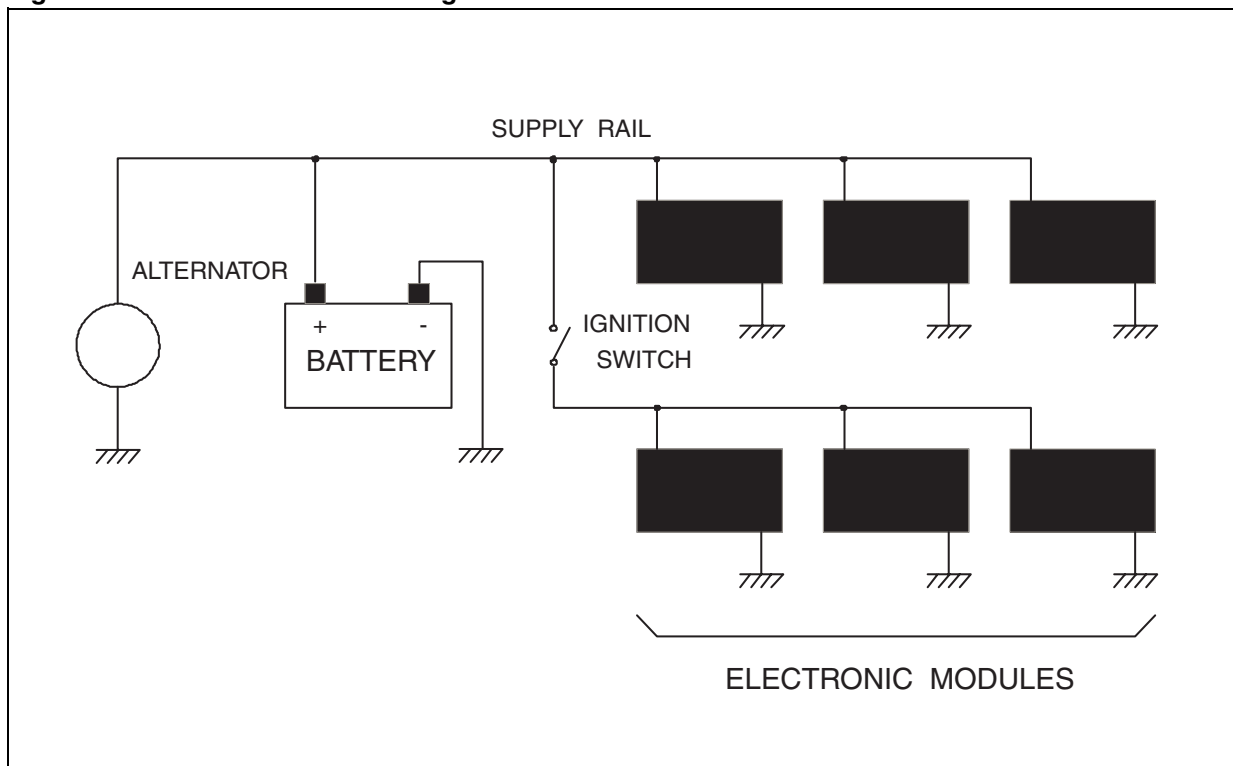
Two protection topologies are today used to avoid electronic modules destruction:

- One to split the LOAD DUMP protectors on each electronic module.
- The other to suppress the LOAD DUMP surge at the alternator level.

For the first protection mode, there are several existing products able to clamp this overvoltage at the board level, for example the LDP24 or RBO series. The protection at the alternator level is a quite new concept and all the technical problems do not seem to be completely solved.

The purpose of this paper is to describe the LOAD DUMP phenomenon, to analyze the present protection solution and to propose a new surge suppression concept.

Figure 1. Automotive electrical diagram



LOAD DUMP PHENOMENON

Figure 2. Alternator charging circuit

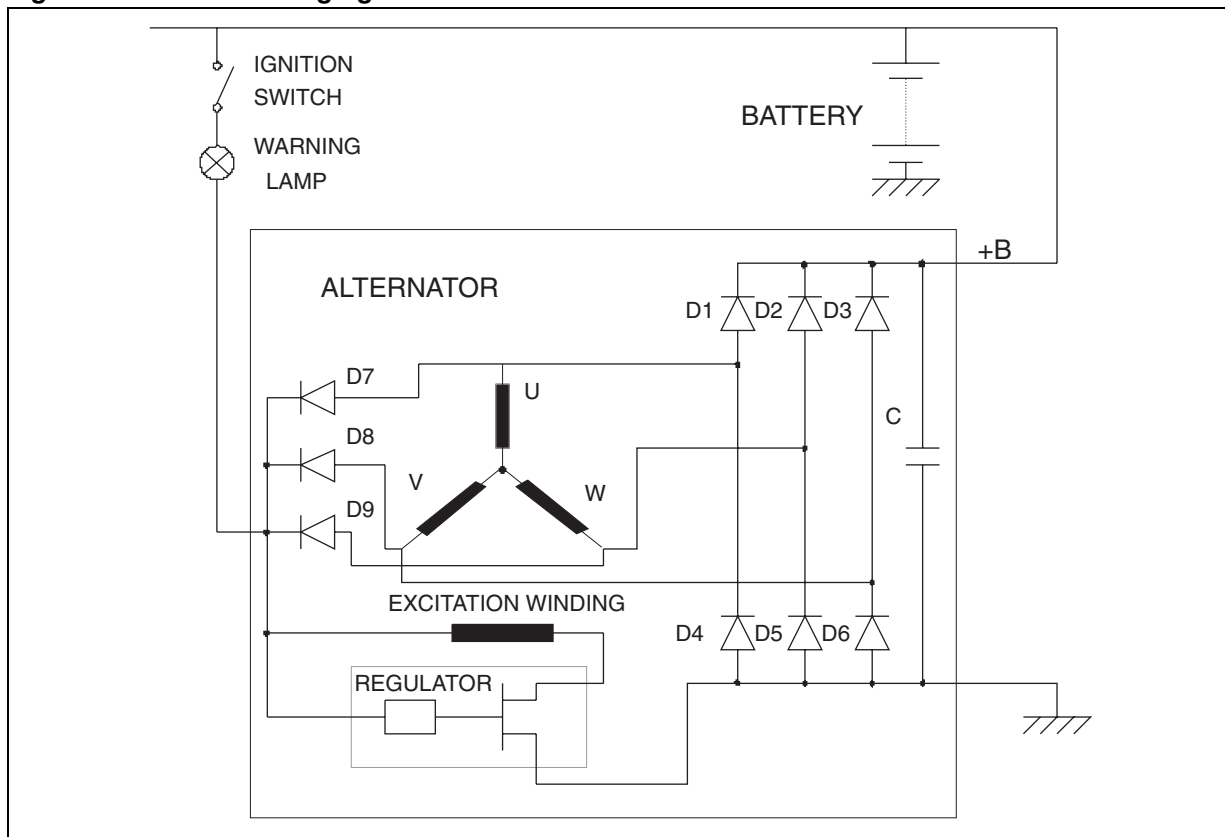


Figure 2 shows a car charging circuit using a classical three phase alternator, where the power rectifier bridge is done by the diodes D1 to D6 while D7 to D9 are used for the secondary bridge (trio diodes).

In normal operation, the ignition switch is ON and the engine is running. So two cases can be taken into account:

- The battery voltage applied on the regulator is over the high threshold, then no current flows through the excitation winding and the alternator is non acting.
- The battery voltage is lower than the low threshold, then a current given by the regulator flows through the excitation winding.

Now the alternator generates a current that charges the battery.

If during this charging phase the battery is disconnected from the network, the alternator output voltage increases. The regulator reacts immediately by cancellation of the current through the excitation winding. But due to the internal constant time of the alternator the overvoltage decreases slowly.

This overvoltage is named the LOAD DUMP and can be defined by the following figures:

- Peak voltage 80 to 100 volts
- Duration 300 to 400 ms
- Series resistance 0.2 to 1 Ohms

It is not necessary to precise that this surge is lethal for all non protected automotive electronic modules.

THE TODAY ALTERNATOR PROTECTION SOLUTION

Today a growing part of the produced automotive alternator has got an internal protection against the LOAD DUMP surge. In fact the fourth generation of regulator (integrated version) is more sensitive than the previous one and then more fragile.

The present protection topology consists of an autoprotected power bridge as shown in figure 4.

The 6 diodes of the bridge have got a reverse characteristic based on zener effect and generally clamp the overvoltage above 24 volts (see Figure 3).

Figure 4 shows the current behavior in the bridge when LOAD DUMP occurs.

During the LOAD DUMP the difference between two phases reaches up the breakdown voltage of the diodes and then they act as clamping parts.

For example if V phase is more positive than the W phase, the diode D4 clamps over 24 volts while D5 is forward biased (see Figure 4). As the difference of potential between each phase is alternative then D1, D2, D3, D4, D5 and D6 act in clamping mode as well as in forward bias.

Figure 3. I/V characteristics of the autoprotected bridge diodes

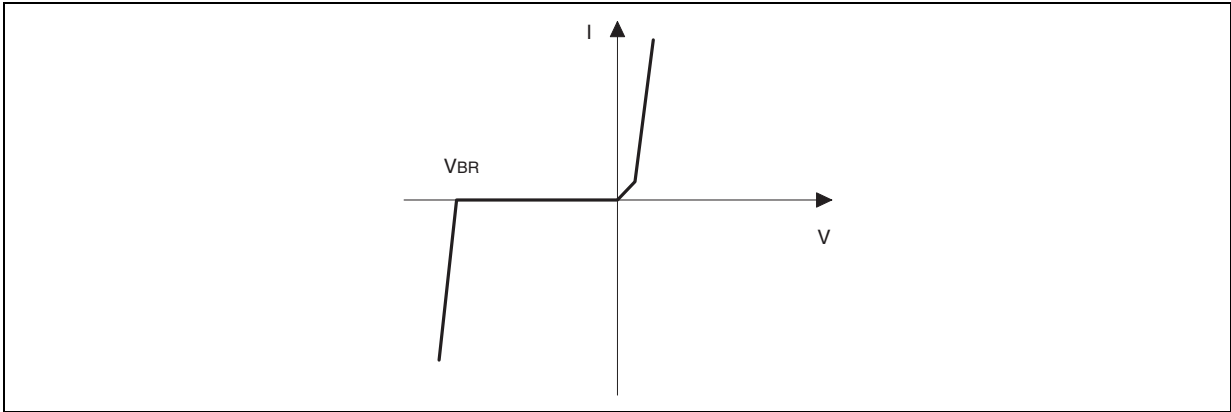
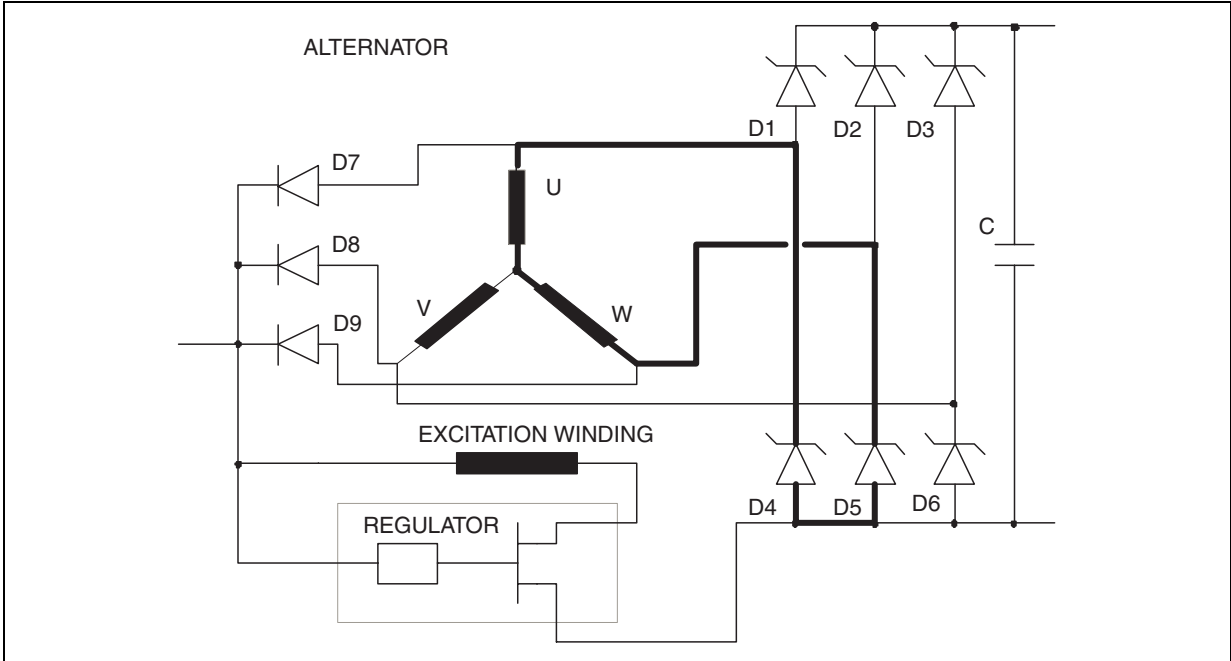


Figure 4. Behavior of autoprotected bridge during the LOAD DUMP



MAJOR DRAWBACK OF THIS SOLUTION

Figure 5. CLAMPING diode junction temperature

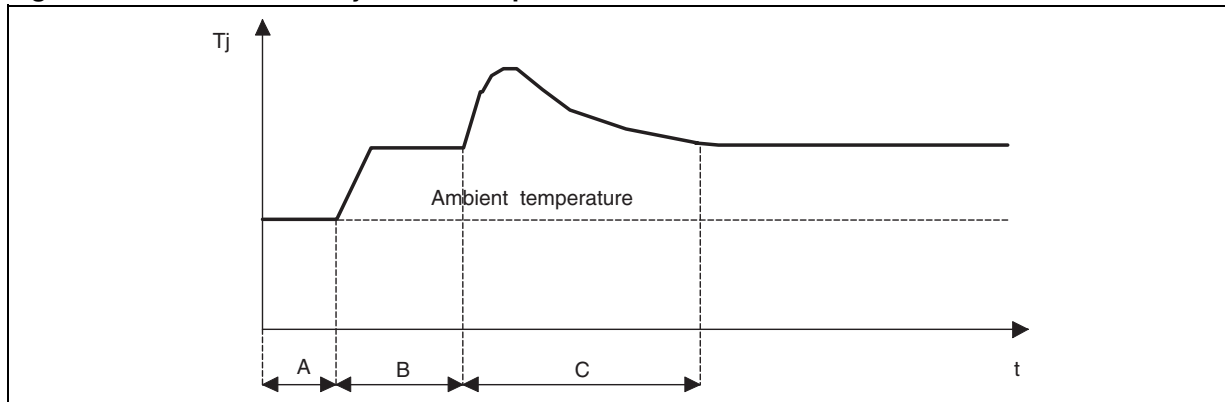


Figure 5 shows the junction temperature behavior of the power bridge diodes.

- **Phase A:**
When no current is produced by the alternator, the junction temperature of diodes is equal to the ambient temperature close to the engine. (generally greater than 100°C)
- **Phase B:**
When current is needed by the network or the battery, the junction temperature T_j of the diode increases due to the conduction losses. At this time T_j is already at high value. (for example 170°C)
- **Phase C:**
During the LOAD DUMP an extra energy, due to the clamping voltage across the diodes and the current through them, is dissipated in the bridge.

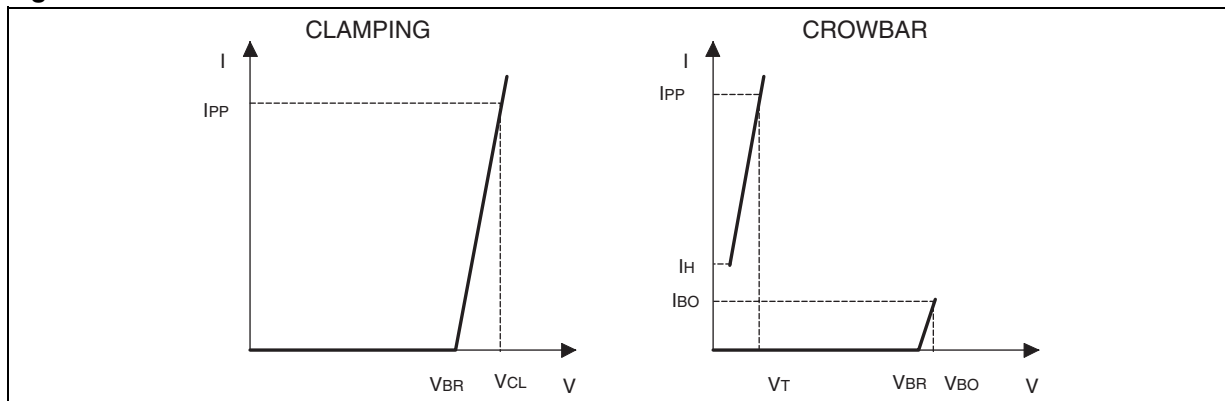
The silicon size has to be increased to avoid the melting of the solder alloy used for the connections. If there is a beginning of solder fusion, the reliability of diodes and then of the alternator is hardly affected.

THE STMICROELECTRONICS SOLUTION

The analyses we did on the present solution based on autoprotected bridge showed us that this topology does not always guarantee the reliability level required by automotive market.

The trend is to increase the current capability of the alternator and then this solution will be overreached. For this application we adapted a protection topology used in telecommunication. This concept is named **CROWBAR** protection.

Figure 6. CLAMPING / CROWBAR characteristics



CLAMPING / CROWBAR COMPARISON

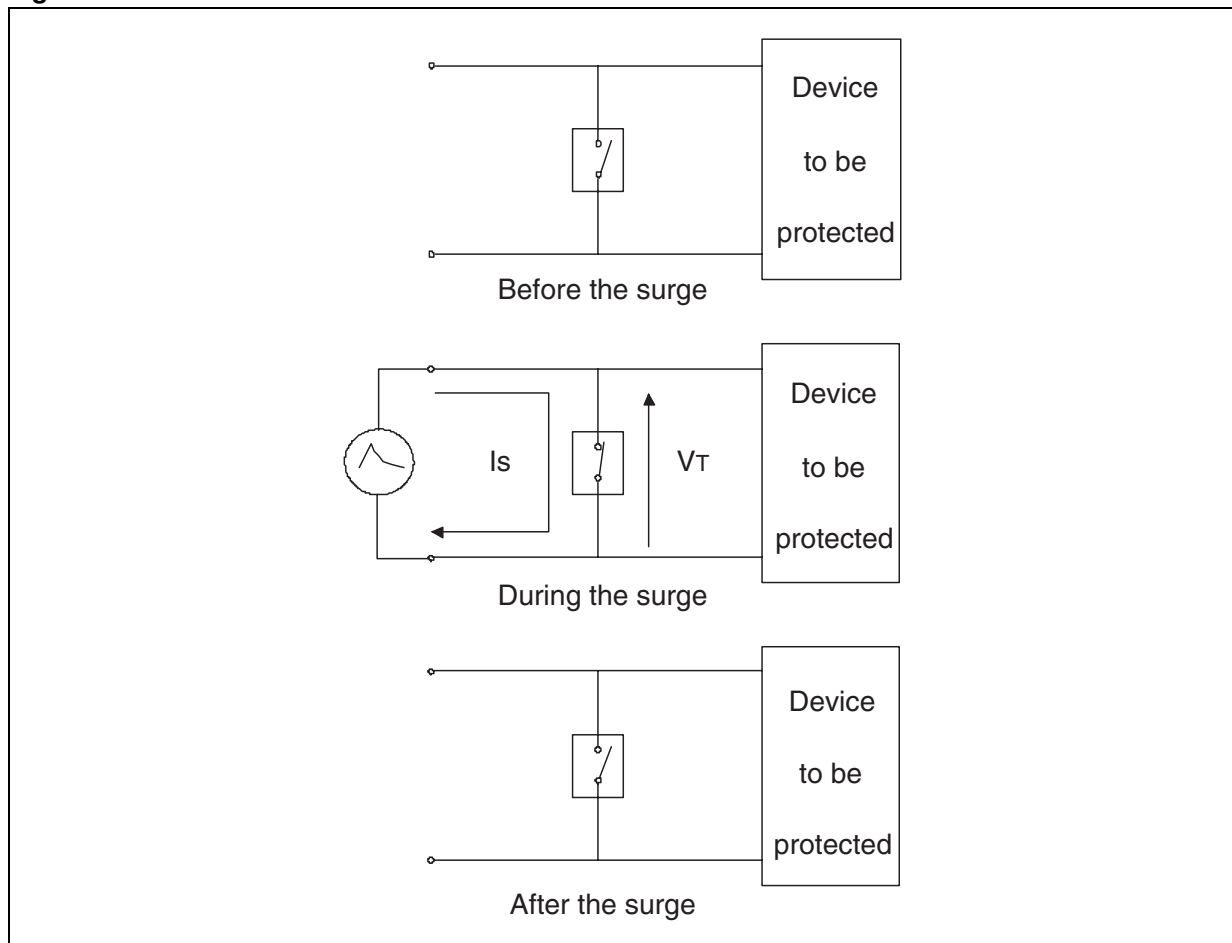
- The CLAMPING devices suppress all overvoltages reaching the knee of the curve (VBR). During the surge suppression the working point is defined by the couple I_{PP} , V_{CL} .
- The CROWBAR devices act by short circuiting the line during the surge. During the overvoltage suppression the working point is defined by the couple I_{PP} , V_T .

As shown in figure 7 the CROWBAR protection device can be compared to a switch.

- Before the surge the switch is open and no current is flowing through it.
- When overvoltage exceeds the breakover voltage of the device, the switch turns on and then the surge current is derived through it. During this phase the voltage V_T across the device is very low (few volts) and then the dissipated power is low too.
- After the surge, when the current through the CROWBAR device goes down the holding current I_H , the switch turns off.

THE MAIN ADVANTAGE OF THE CROWBAR TOPOLOGY IS THE LOW POWER DISSIPATION ON THE SILICON DURING THE SURGE SUPPRESSION.

Figure 7. CROWBAR behavior



ALTERNATOR PROTECTION BASED ON CROWBAR

Figure 8. Alternator protection with CROWBAR module

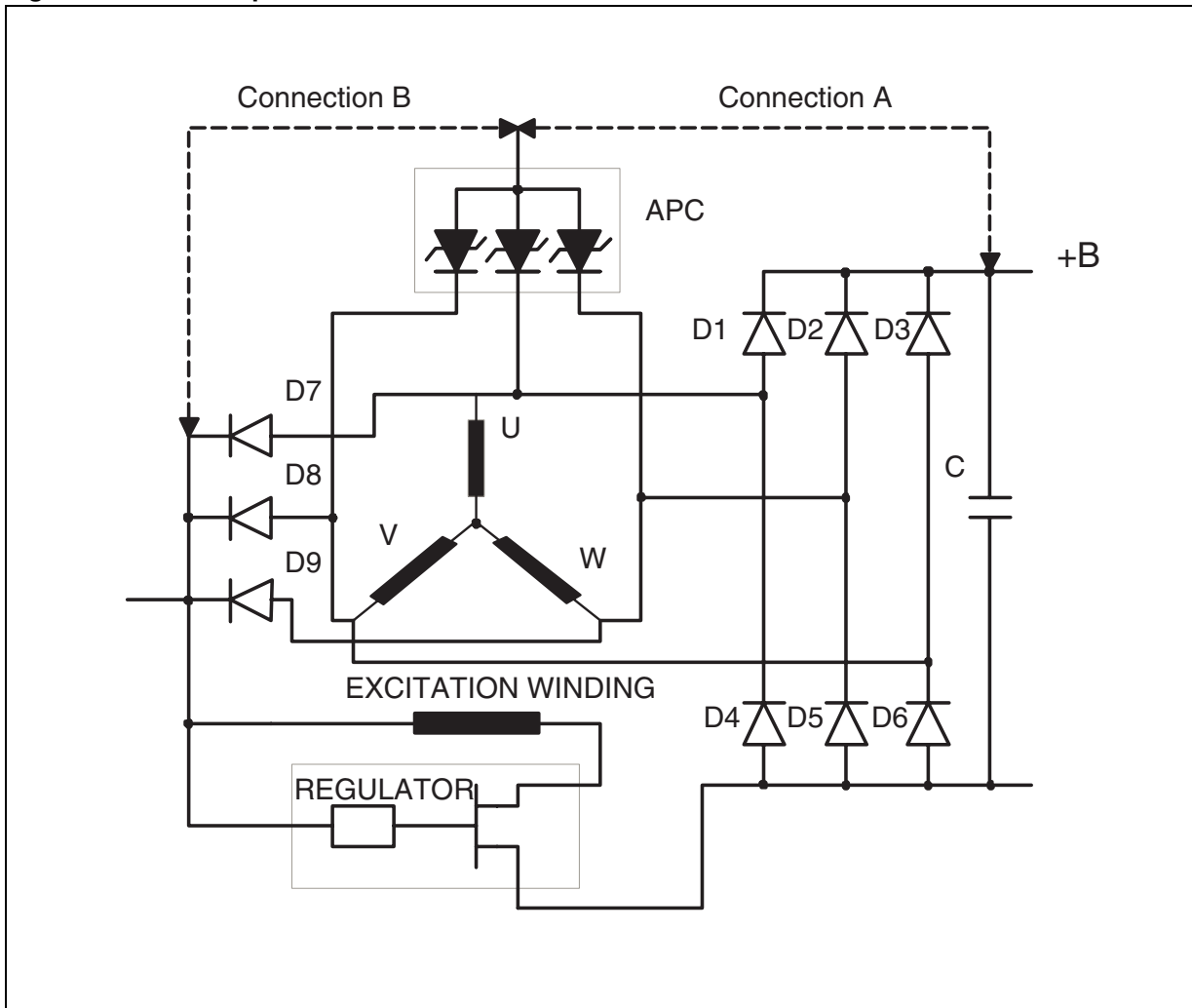


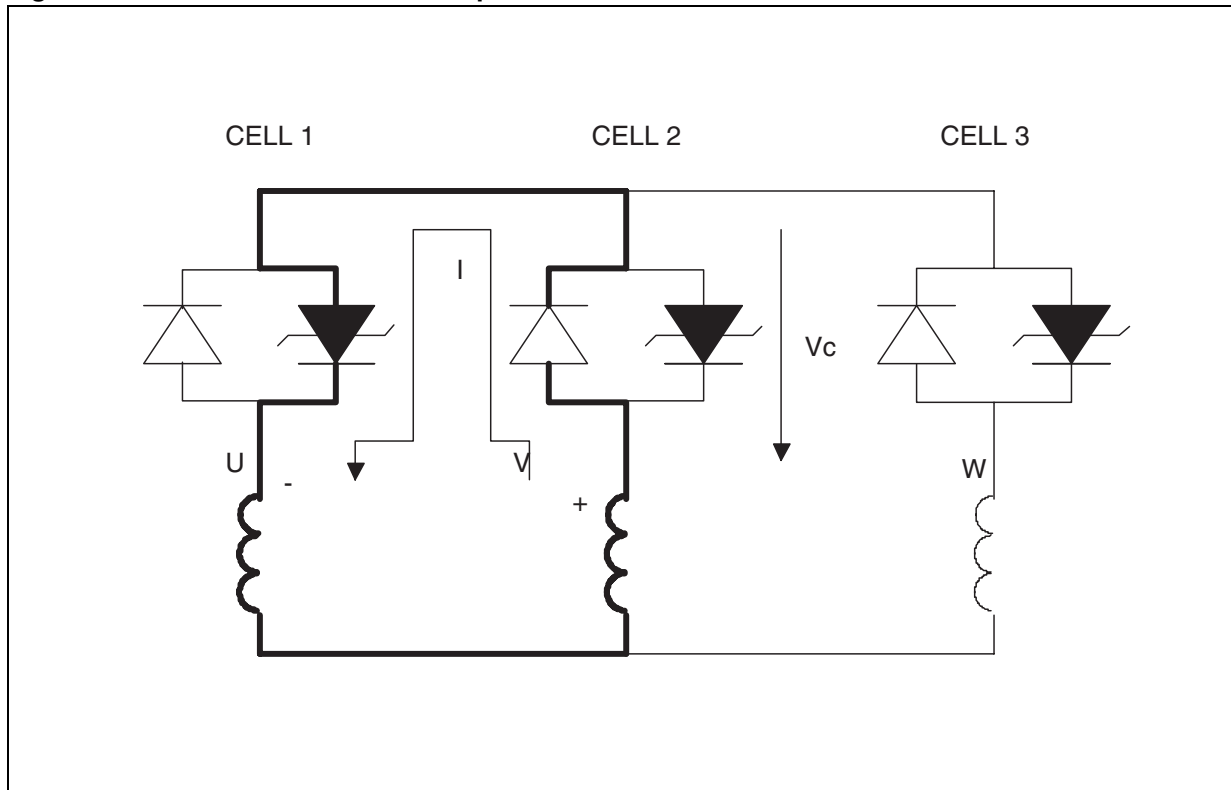
Figure 8 shows both possibilities to use the CROWBAR protection topology.

We named this concept APC and this type of protection module is always connected between the 3 phases (U, V and W) and + output of one of both diode bridges (power or secondary).

In figure 8 the two choices are drawn, connection A for the power bridge option and connection B for the other one.

HOW DOES THIS CONCEPT WORK?

Figure 9. Behavior of the CROWBAR protection

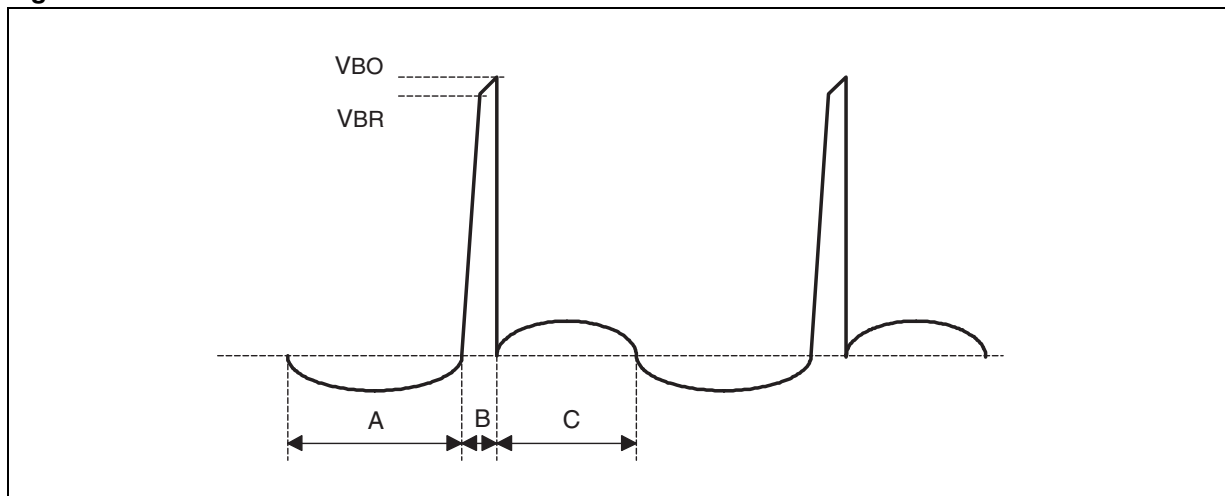


In both connection possibilities (A or B, see Fig. 8) we find a diode in reverse parallel with one CROWBAR part of the APC device. Figure 9 shows these couples diode / APC part and their connection to the 3 phases (U, V and W).

- Before the LOAD DUMP effect the voltage difference between 2 phases is lower than the breakdown voltage VBR of the CROWBAR part and then only the diodes act.
- During the LOAD DUMP the voltage difference between 2 phases reaches up the breakover voltage of the CROWBAR part and then the cell is shorted.

In the example of figure 9 the difference between the phases U and V is greater than the breakover of the APC. The CROWBAR part of the cell 1 is fired while the diode of the cell 2 conducts. Then the phases U and V are short circuited and **all the extra energy due to the LOAD DUMP effect is reinjected and dissipated in the alternator wiring.**

Figure 10. Cell behavior



NB: The energy of the LOAD DUMP is dissipated alternatively on each phase.

Figure 10 shows the voltage VC across the cell 2 of the figure 9. This waveform can be split in 3 stages.

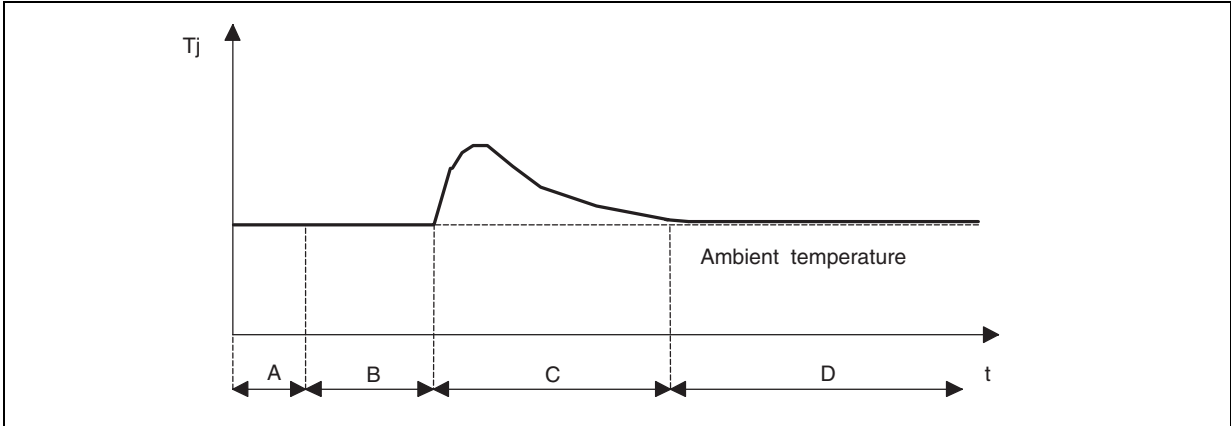
- **A/ Phase V positive while phase U is negative.**
The diode conducts and the voltage across the cell is its own forward drop voltage.
- **B/ Phase V is negative while phase U is positive.**
The diode is blocked and the voltage increases across the CROWBAR part.
When the voltage reaches up the APC breakdown voltage VBR, the wave is clamped up to the APC breakover value VBO, then the CROWBAR device fires.
- **C/ Phase V is always negative and U positive.**
The CROWBAR device is fired and we find its on-state drop voltage across the cell.

MAJOR BENEFIT OF THIS SOLUTION

Figure 11 shows the junction temperature behavior of the APC. In comparison with the CLAMPING behavior, please refer to end of chapter 3.

- **Phase A:**
When no current is produced by the alternator, the APC junction temperature is equal to the ambient temperature close to the engine (generally greater than 100C).
- **Phase B:**
When current is needed by the network or the battery, the APC stays non acting and then its junction temperature remains unchanged.
- **Phase C:**
During the LOAD DUMP the APC junction temperature increases because of the current through it.
- **Phase D:**
After the LOAD DUMP the APC goes back in off state and then return in the phase A.
During the life of the APC, its junction temperature is equal to the ambient temperature. This fact guarantees a high reliability level of this part in accordance with the automotive world requirement.

Figure 11. CROWBAR part junction temperature



TEST RESULTS

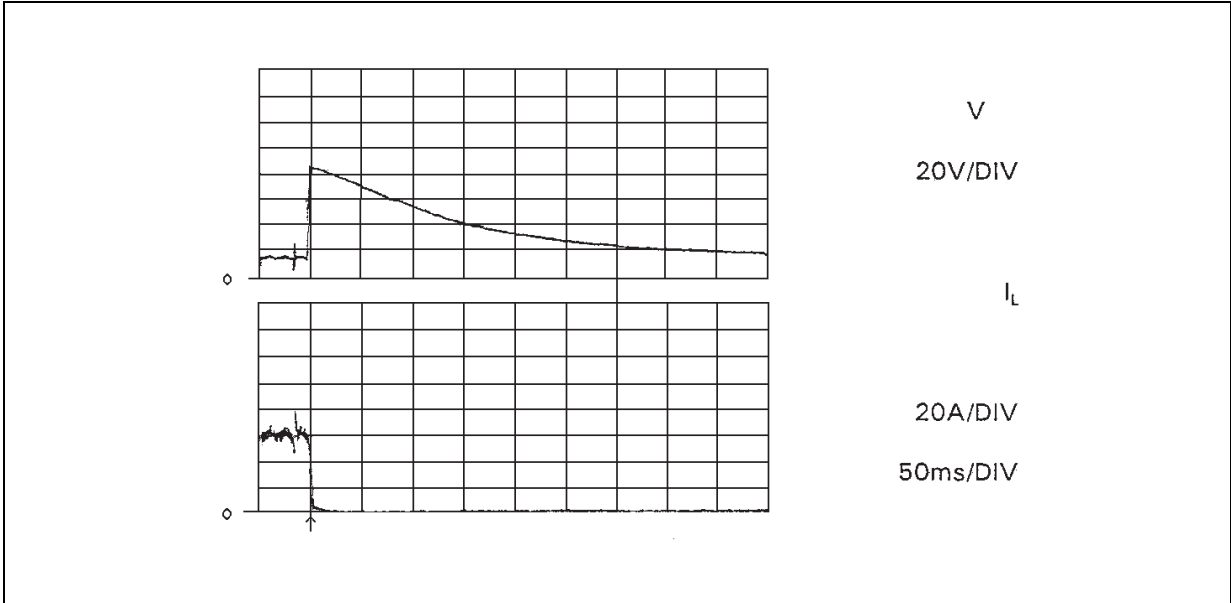
The purpose of this chapter is to summarize the tests of the centralized LOAD DUMP protection based on CROWBAR effect. These tests have been done on an alternator of 14V, 70A.

WITHOUT THE PROTECTION

The tests done without the protection confirm that the worst case occurs for the maximum speed and the maximum load current (10 000 RPM, 70A).

Figure 12 shows the case with 10 000 RPM and load current $I_L = 70A$. In this case the peak voltage at the alternator output is 85V and a duration of 350ms at 20V.

Figure 12. Alternator output voltage and load current at 10 000 RPM and 70 A



WITH APC CONCEPT

The second curve shows the output current of the alternator Figure 13 gives the protection topology used for these tests. During the LOAD DUMP suppression, the 3 parts of the APC module operate alternatively.

Figure 13. APC concept location used

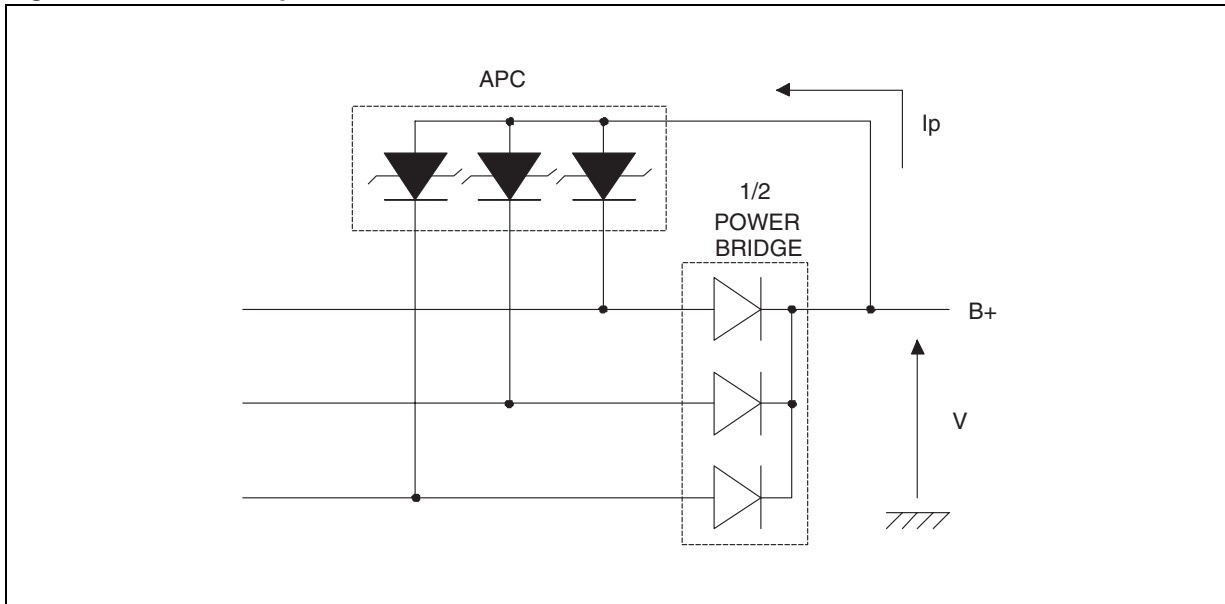
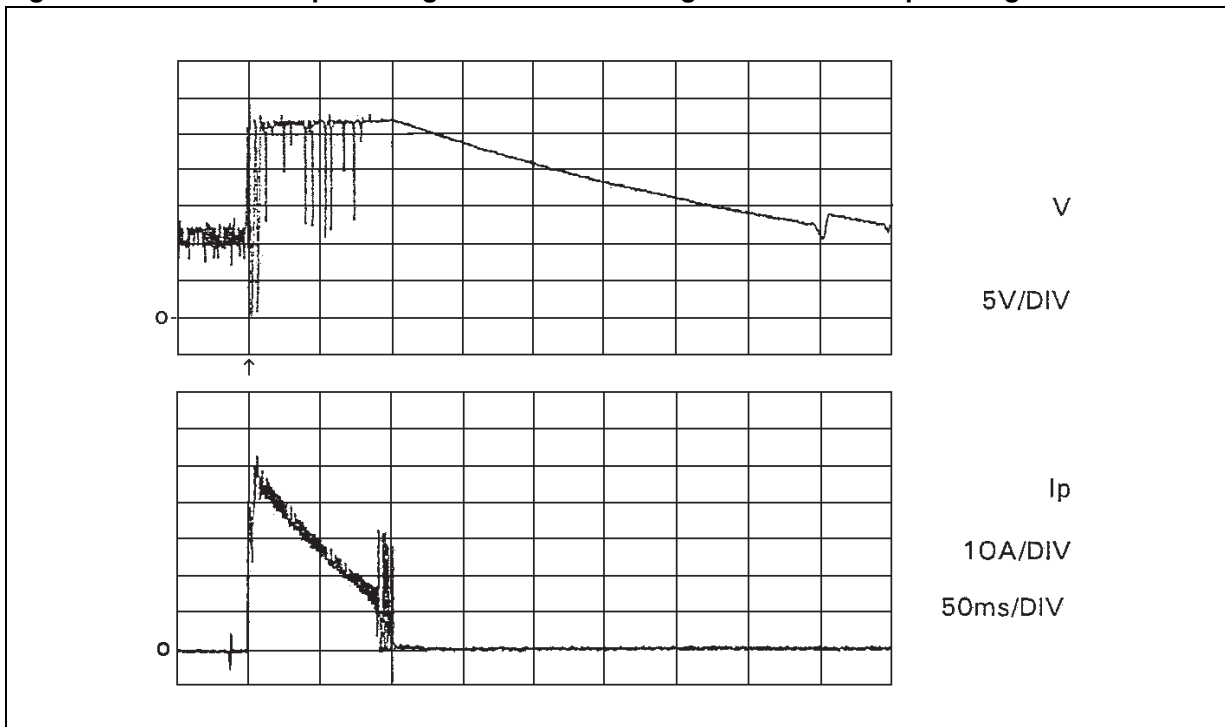


Figure 14. Alternator output voltage and current through the APC concept during the LOAD DUMP



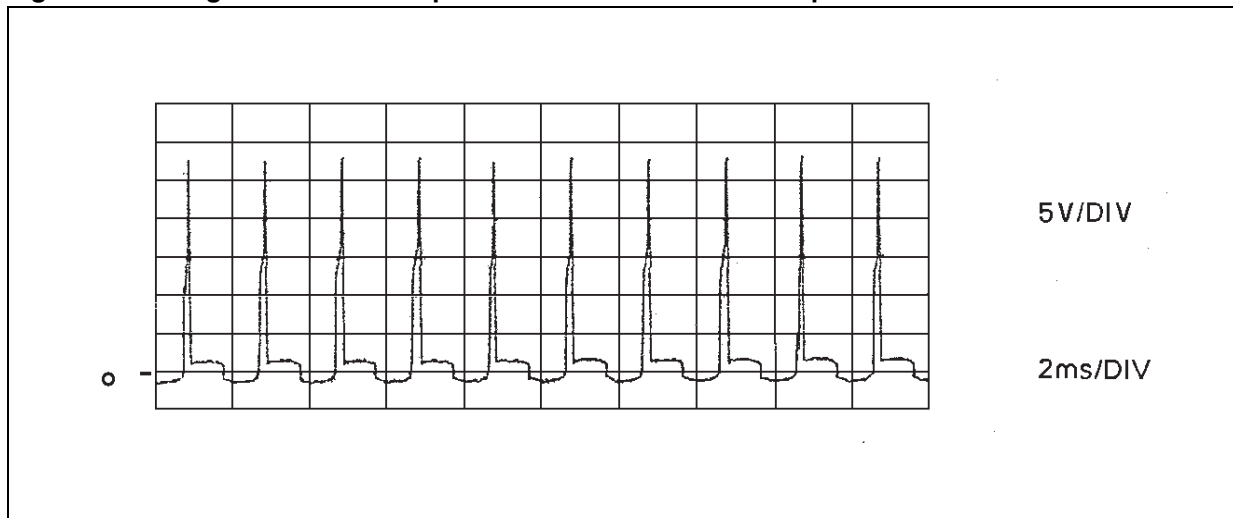
The curves given by figure 14 shows the alternator output voltage behavior and IP the sum of the currents flowing through the 3 CROWBAR parts of the APC concept.

The APC module used for these tests series have got a breakdown voltage value VBR of 27V and then the remaining output voltage is roughly the same. The current through the APC module is about 60A peak for 100ms duration.

Figure 15 shows the voltage across the couple rectifier diode / CROWBAR part (see Fig. 9) during the surge suppression phase. We find the 3 phases described in the chapter related to figure 10.

- The maximum forward voltage of the diode is : 1V.
- The breakover voltage VBO of the CROWBAR part is : 28V.
- The on-state voltage VT of the CROWBAR part is : 1.5V.

Figure 15. Voltage across the couple rectifier diode CROWBAR part



CONCLUSION

NB: Other tests done with the common point of the APC module connected to the + of the secondary bridge gave the same results.

- The automotive supply network is polluted by several disturbances where the most aggressive is the LOAD DUMP.
- Two protection possibilities are available: * The protection split on each car electronic module. * The protection centralized directly in the alternator.
- For the next years, it is clear that the LOAD DUMP protection will be an integral part of the alternator, especially due to the sensitivity of the new regulator technology.
- Today an alternator protection topology exists and is based on CLAMPING effect. This solution is located at the power bridge level.
- This solution seems quite at the limit of the reliability level imposed by the automotive market. It will be overreached with the future high current alternators.
- STMicroelectronics proposes a new protection approach based on the CROWBAR effect.
- This solution named APC consists in short circuiting the alternator phases during the LOAD DUMP. This induces that the major part of the LOAD DUMP energy is dissipated on the copper of the alternator and not in the silicon.
- Contrary to the CLAMPING solution, the CROWBAR is used only during the LOAD DUMP. This means that the silicon die is submitted only to the ambient temperature and then its reliability is guaranteed.
- Tests have been done on several alternators, coming from different manufacturers, in the

REVISION HISTORY**Table 1. Revision History**

Date	Revision	Description of Changes
August-1995	1	First Issue
10-May-2004	2	Stylesheet update. No content change.

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