

## NEW LEVELS OF INTEGRATION IN AUTOMOTIVE ELECTRONICS

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*One of the fastest growth areas today in electronics is in the automotive field. In this note the authors describe the particular needs of this field and some typical dedicated ICs developed by SGS-THOMSON.*

### INTRODUCTION

Since the early seventies, more and more functions have been added to our cars not only with the purpose of guaranteeing a better comfort to drivers and passengers, but also to reduce operating costs and finally to ensure compliance with new regulations concerning noise and pollution are concerned. Because of all these needs, cars have to house more and more modules designed to perform more or less complex operations (Fig. 1).

This growth makes more and more evident the need to reduce the room taken by each module, with the double target of minimizing the cost of the particular function and increasing the number of functions in a specific car; in parallel, by increasing the number of modules, it becomes mandatory to increase the reliability of each of them, otherwise the reliability of the total car would be badly affected.

All these issues recently pushed the manufacturers of automotive systems to refer very often to producers of integrated circuits asking for the de-

velopment of monolithic devices capable of replacing effectively a number of discrete components, passive parts included; anyway the trend to a total integration is not over by just designing onto a simple piece of silicon a complete function, but it carries on implementing in the same device a number of auxiliary services, that would add a substantial cost if achieved by discrete components, that can easily find place on a few extra square millimeters of silicon.

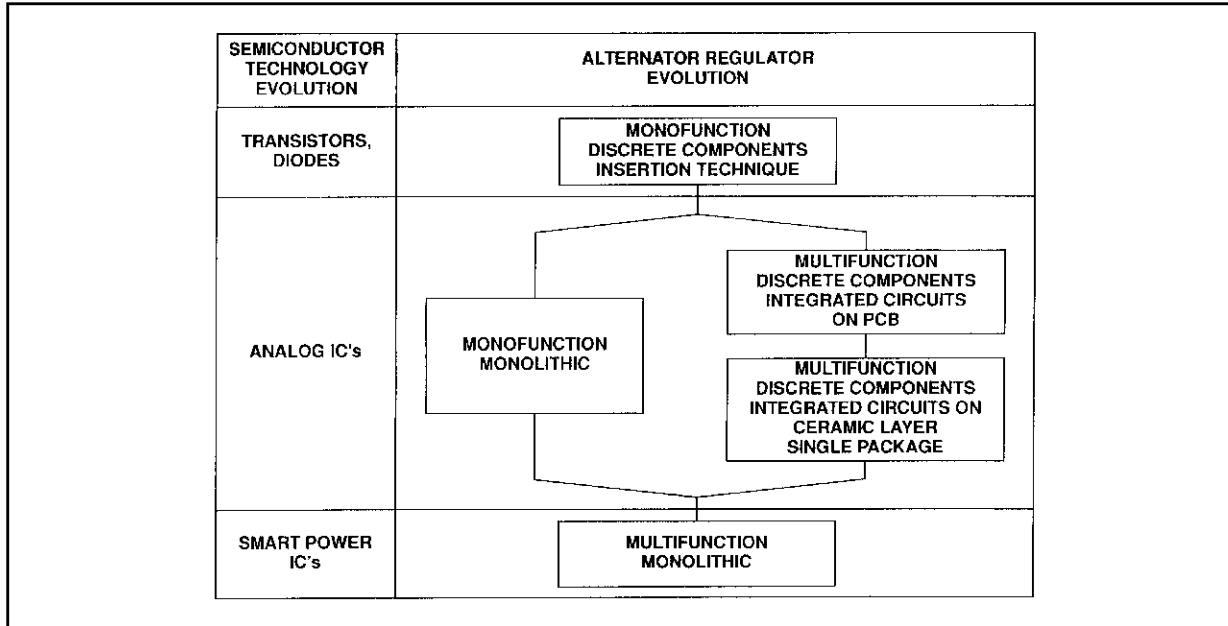
To that purpose the example given by the alternator regulator, subject of a specific description in the following pages, is particularly enlightening. Figure 2 shows briefly the evolution of the alternator regulator paralleled with the evolution of the silicon technology; it is evident that the key issue to pursue the monolithic design of very complex functions in the automotive environment is the availability of process capable to host on the same chip high density signal circuitry, together with power stages managing currents of several amperes; a process with these characteristics is usually called "smart power" process.

**Figure 1:** Electronics in present and future automobiles.

SAFETY & CONVENIENCE	BODY CONTROL	POWER TRAIN	DRIVER INFORMATION
Rear Window Defogger	Cruise Control	Ignition	Digital Gauges
Climate Control	Intermittent Wiper	Spark Timing	Digital Clock
Keyless Entry	Antitheft Devices	Voltage Regulator	Multitons Alarms
Automatic Door Lock	Electr. Suspension	Alternator	Engine Diagn. Results
Light Dimmer	Electr. Steering	Idle Speed control	Service Reminders
Traction Control	Multiplex Wiring	Turbo Control	Miles to Empty
Antiskid Braking	Module to Module	Emission System	Shift Indicator
Window Control	Communications	Transmiss. Control	Head-up Display
Memory Seat	Load Sensit. Braking	Diagnostics	CRT Display
Heated Windshield	Hard/Soft Ride Control		Audio Annunciator
Voice Controlled Trunk			
Airbag Restraints			

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**Figure 2:** Alternator regulator evolution.

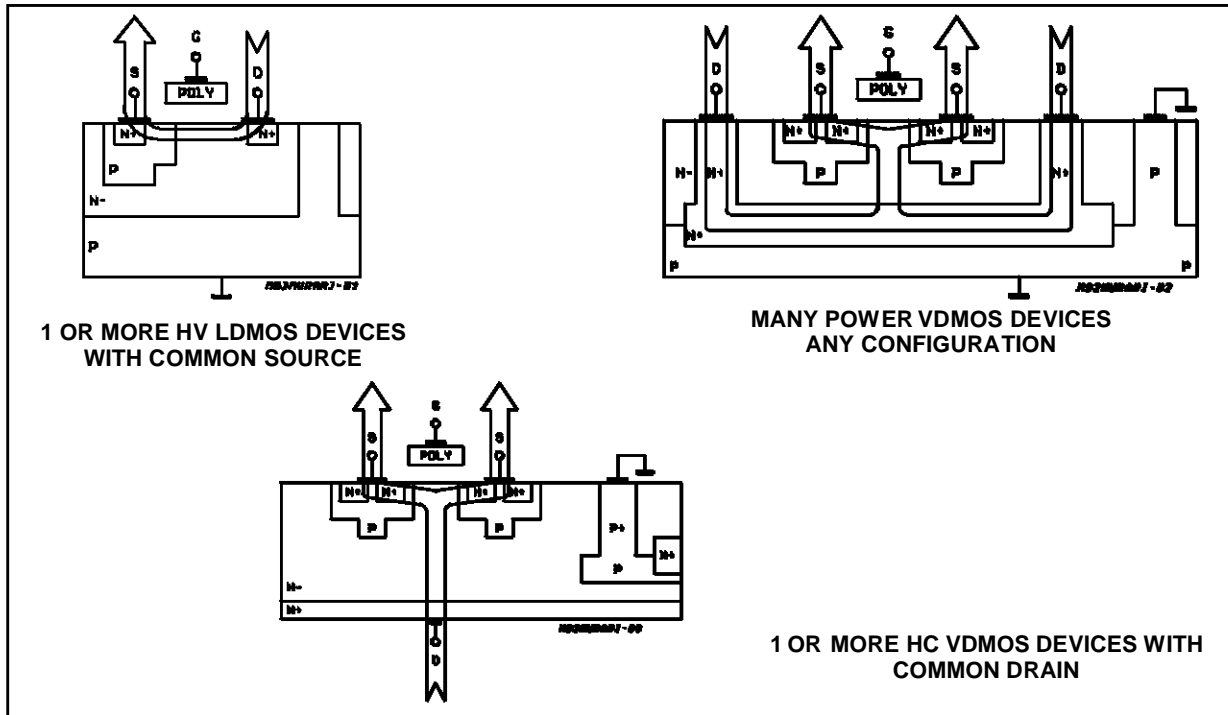


## TECHNOLOGY OVERVIEW

Over the years SGS-THOMSON has developed various technologies that allow the realization of smart power circuits. The simplest way to classify these technologies is to refer to the process type, which can be purely bipolar or mixed, that is, including on a single piece of silicon both MOS structures (of control and power) and bipolar structures.

Another method (figure 3) is to examine the way in which the current flows through the power section; horizontal, with the current entering and leaving through the upper surface, or vertical, where the current enters through the upper surface and leaves through the lower surface; for this lower connection, instead of wire, the tie bar of the package is used.

**Figure 3:** Integrated DMOS structures.



**MULTIPOWER BCD/60 vs. BCD60II**

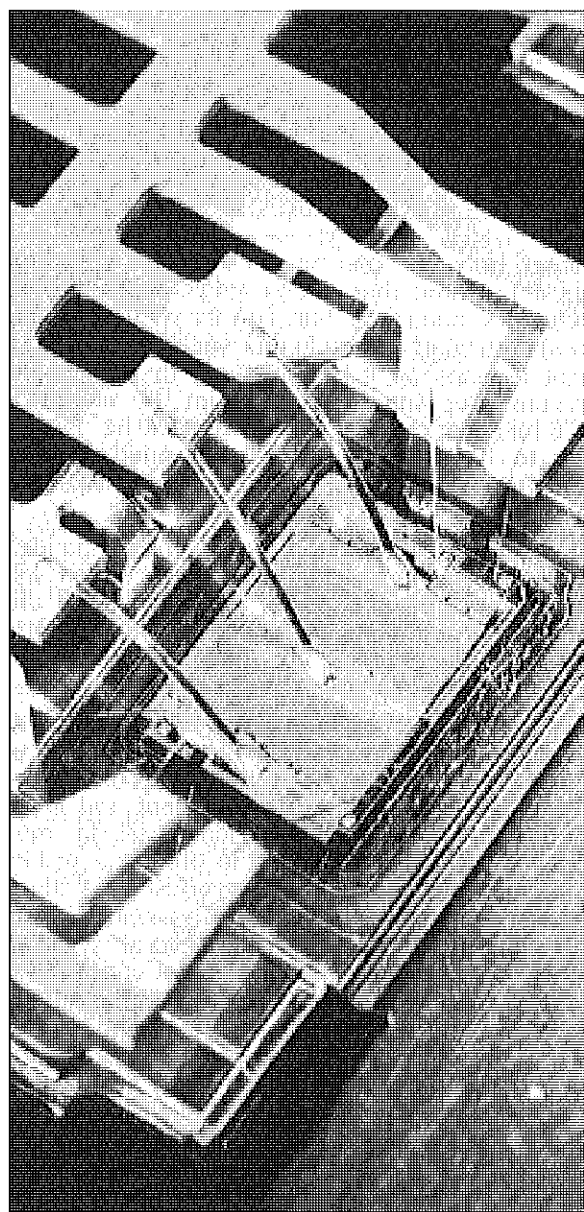
	<b>BCD20/60</b>	<b>BCD60II</b>
Junction isolation	down	up and down
Field oxide	Tapered oxide	Locos + field implant
VDMOS R on* Area ( $\Omega \cdot \text{mm}^2$ )	0.9	0.5
LDMOS R on* Area ( $\Omega \cdot \text{mm}^2$ )	0.6	0.25
CMOS tr. density ( $\text{mm}^2$ )	650	1500
CMOS thres. voltage (V)	1.3	1
min. NPN area ( $\text{mil}^2$ )	11	4
min. PNP area ( $\text{mil}^2$ )	15	5
Number of masks	12/14	13/15

The choice of one technology rather than another depends on various elements. By simplifying as far as possible the criteria, we can say that vertical technologies can guarantee, for a given area, lower resistances but they have the limitation of being able to include just one power device per circuit (or more than one, but always with the collectors or drains short-circuited). Horizontal technologies instead make it possible to have power structures that are completely independent. It is therefore evident that a vertical technology will give excellent results in the design of a light switch, while a horizontal technology will be equally well suited to the design of a multiple actuator.

Finally we have to underline that the continuous evolution of the silicon technologies has already made available, for the design activity, second generation processes, offering to the user both higher component density in the signal section and higher current density in the power area, so that in some cases the limit to achieve very low values of resistance does not come from the silicon, but from the bonding wires. An example of comparison between a first generation smart power technology - today in full industrial production - and a second generation one - today available for new designs - is given in Table 1: the way is open to processes that will allow the design - on the same chip-actuators - of several amperes together with microcontroller of not negligible power.

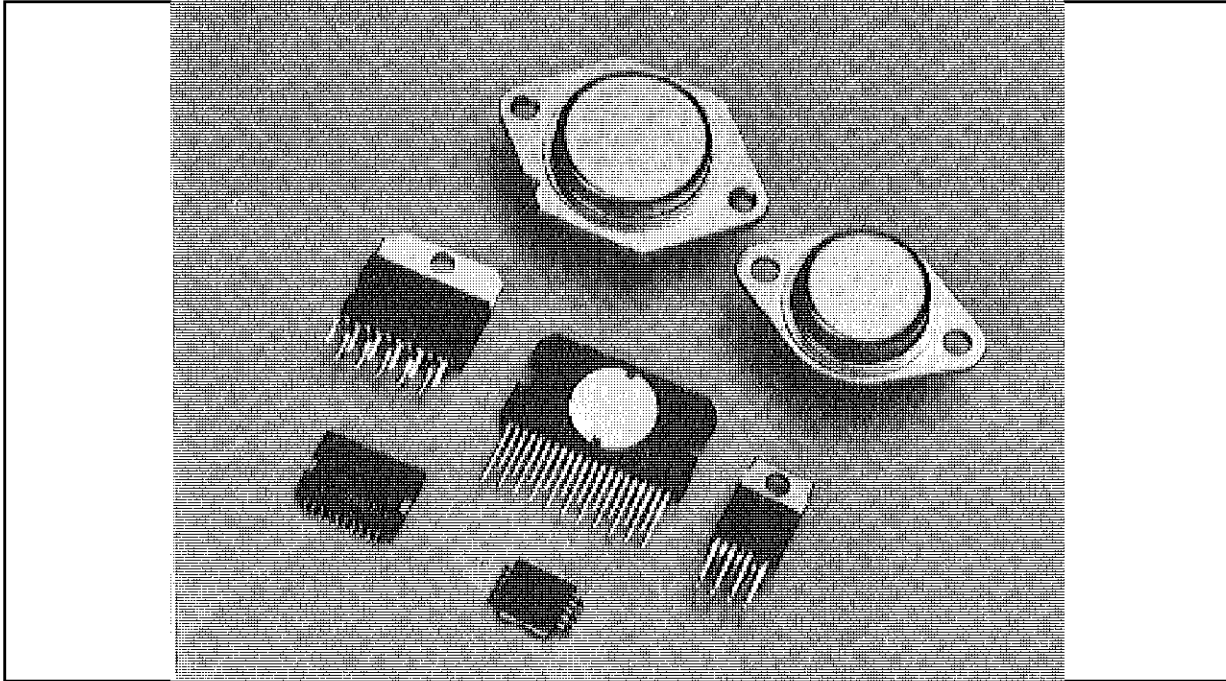
It is important at this point to underline that a smart power circuit does not consist of just silicon technology, but relies heavily on package technology. In fact it is well known that a signal device is bonded using gold wires with a diameter of 25 microns; however, gold wires can be used effectively up to diameters of 50 microns, which allows reliable operations with currents up to 2A, provided that the wire is surrounded by resin (the current capacity drops by 50% for wires in free air - that is, in the case of hermetic packages).

**Figure 4:** Mixed bonding technology.



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**Figure 5:** Power packages.



When, however, one has to deal with very high currents (more than 5A in single-point injection actuators, and more than 10A for window lift motors) gold wires are no longer suitable for obvious cost reasons so it is necessary to turn to aluminum wires with a diameter from 180 microns to 375 microns; clearly in this case it will be necessary to have adequately dimensioned bonding pads on the die, with a significant waste of silicon area.

Optimization is obtained with a mixed bonding technology where signal pads are bonded with thin gold wires and power pads with thick aluminum wires (figure 4). A further optimization is obtained by orienting the pads in the pad-to-bond-post direction.

Finally, another key area for a real industrial implementation of a smart power device is packaging; SGS-Thomson has a reputation of unparalleled excellence in the development and in the production of packaging techniques to meet power dissipation even in the presence of high pin count, and several innovative SGS-Thomson packages have been adopted as worldwide industry standards; in Figure 5 several types are displayed, including hermetic metal can, particularly suitable for components, such as the alternator regulators, that have to operate at a rather high temperature, with junction temperature that may exceed 150°C, in an extremely severe environment, since the regulator is usually exposed to any kind of dangerous element, such as grease, sand, dust, salt water and so on. A quite original power package for surface mounting, combining

a low  $R_{th\ j-case}$  (less than 3°C) with a small geometry, is under development in our laboratory.

### THREE EXAMPLES

#### THE ALTERNATOR REGULATOR.

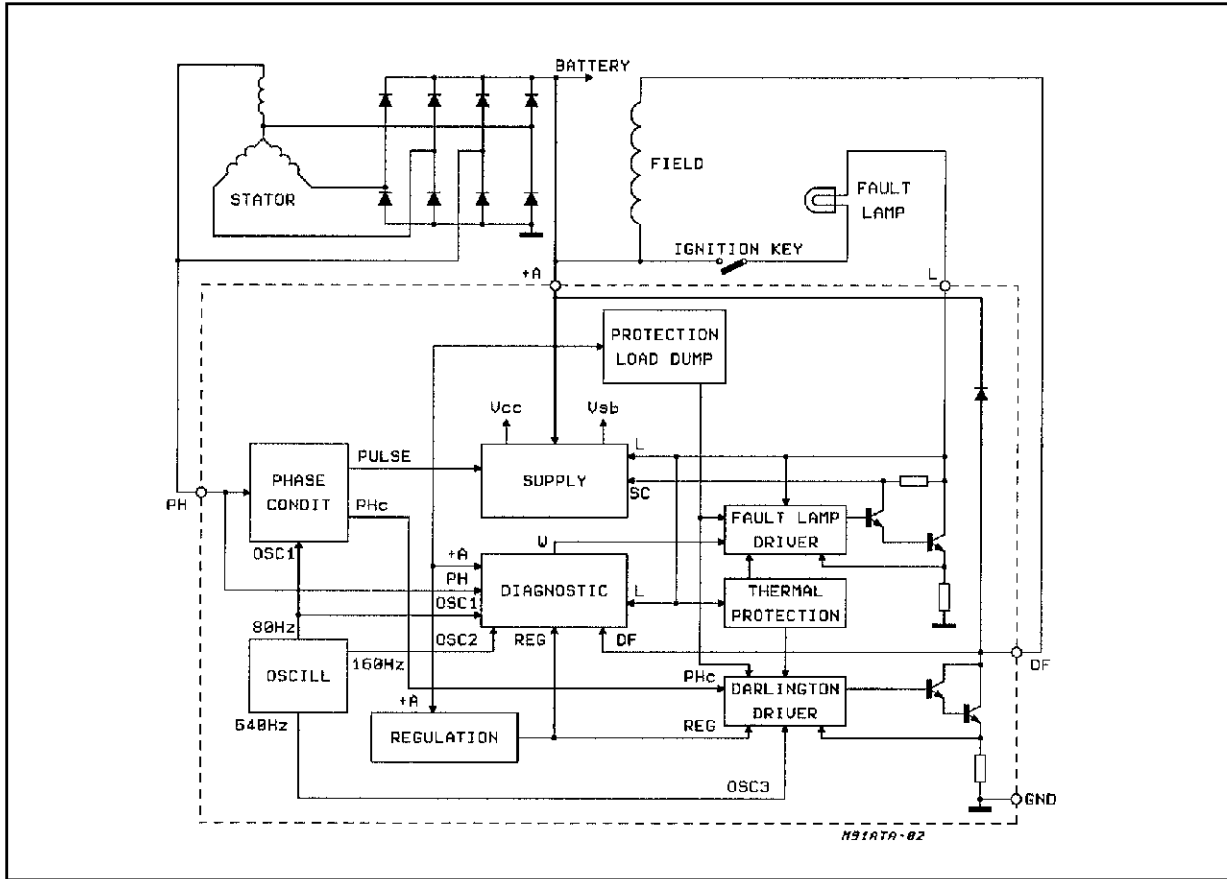
We have already briefly mentioned the evolution of the alternator regulator, but it is worth covering with some more details the history of this function.

Since the simple realization of so-called monofunction regulators by means of discrete components - diodes, transistors and resistors - the progress of the technology allowed the design of a monolithic component, still monofunction: in parallel, to provide the driver with more information about the status of the charging function, multifunction regulators were designed, but the power remained external, on a separate component.

A further improvement came with the assembly technology on a ceramic substrate, housed in a single package, but still several chips of silicon were needed.

Now SGS-Thomson has reached the maximum level of integration by designing a monolithic multifunction regulator and offering to the customer a device that minimizes the assembly operations and maximizes the reliability because of the single piece of silicon and the minimum number of connections between the silicon itself and the rest of the system: nevertheless the accuracy of the regulation and the number of possible malfunctions monitored by the circuit are well above what offered so far by the market.

Figure 6: Block diagram of alternator regulator.



The main characteristics of the device are summarized in Table 2 and the block diagram of the circuit is displayed in Figure 6.

The choice of the technology required a particular care and was driven by the following factors:

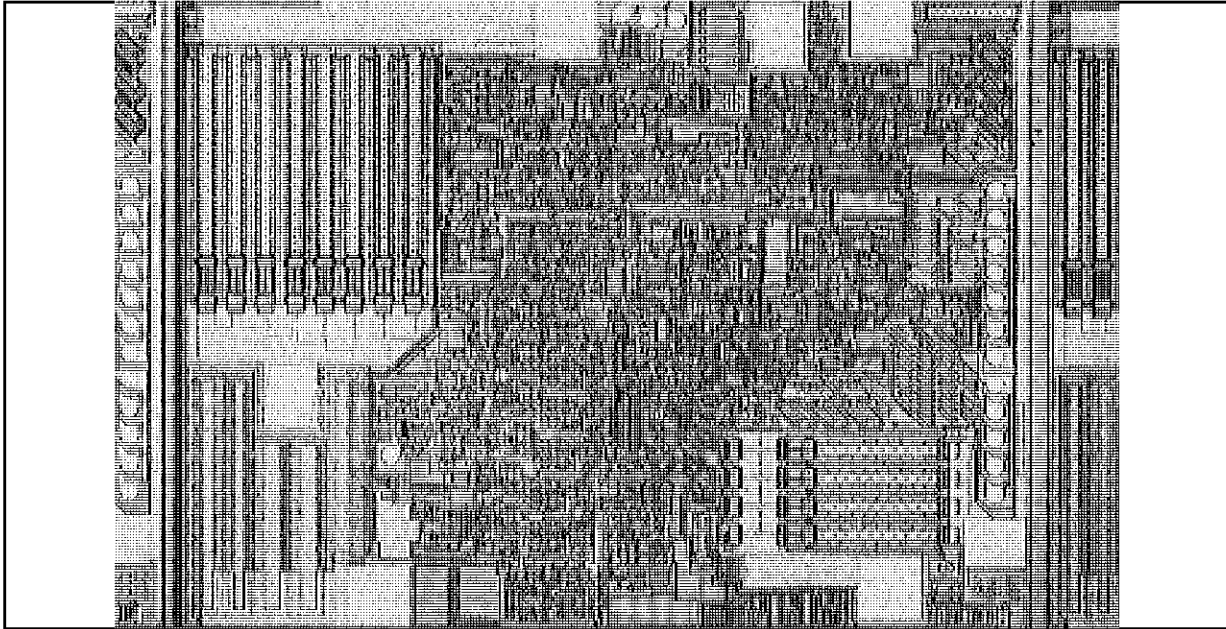
- 1) A circuit for the regulation of the alternator voltage, even if equipped with a complex diagnostic, is however a circuit where the power section, including the field drive in low side configuration and the free wheeling diode plus a big active zener diode, takes a significant share - about one third of the total, (see Figure7); therefore a bipolar process has been selected.
- 2) On the other side, about 600 small signal devices had to be integrated, and because of that a technology with a good intensity was mandatory, otherwise the total economy of the program would have been affected.
- 3) Finally an alternator regulator must be able to withstand very severe voltage transients, as fixed by ISO 7637/1, with voltages up to 270V and energy up to 50 joule, that arise on the car electrical network, for instance, if a sudden misconnection of the alternator occurs.

Table 2: MONOLITHIC ALTERNATOR REGULATOR

- Low side configuration
- No external component
- Accuracy on regulated voltage better than 1%
- Precise temperature coefficient
- Self-oscillating analog regulation loop
- Minimized field current at alternator stopped (500 mA max)
- Maximum field current trimmed at 5A, with 1.5V saturation voltage
- Full Diagnostic: alternator stopped
  - Broken belt
  - Extravoltage
  - Broken wire alternator-battery
- Protected against short circuit (current limitation and thermal shutdown)
- Protected against short circuit of fault lamp driver
- Protected against extravoltages according to ISO 7637/1

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**Figure 7:** Die of the alternator regulator.



Considering all of the above, SGS-Thomson has selected a high voltage process, internally named BSOII, fully bipolar, horizontal, with lithography of 3 $\mu$ m, and more than 100V of breakdown voltage in the VCBO condition.

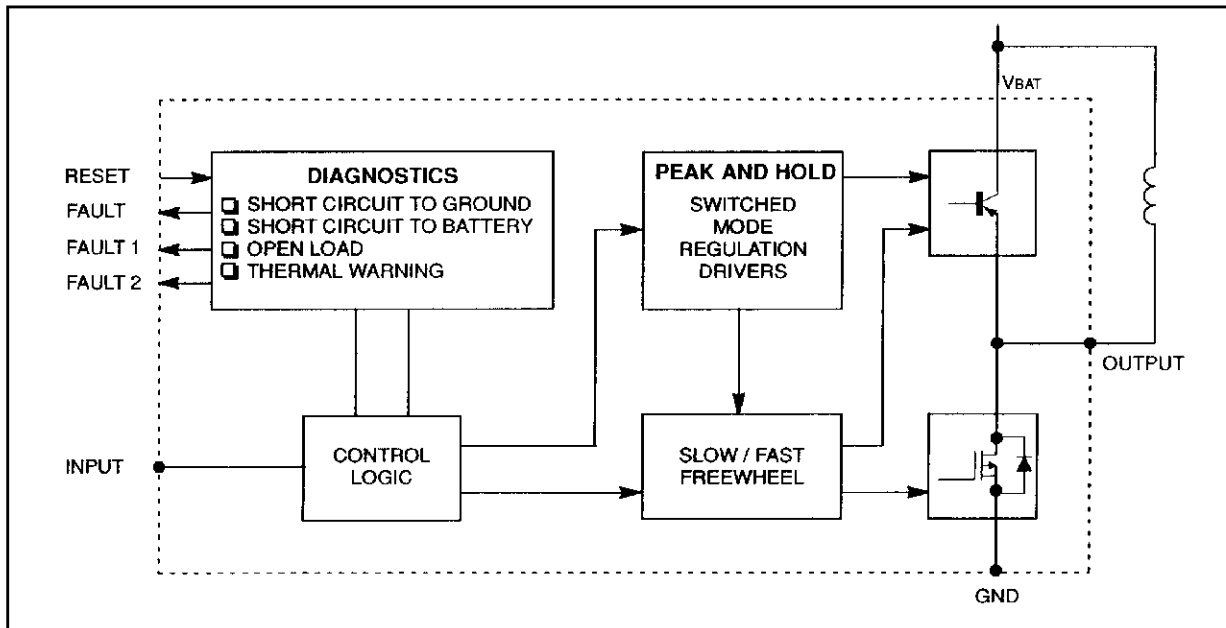
The device is encapsulated in an hermetic package, TO-3 multileads, with bonding wires of 5 mils, able to carry continuous current up to 7 amperes (see again Figure 7).

### THE PEAK & HOLD INJECTOR DRIVER

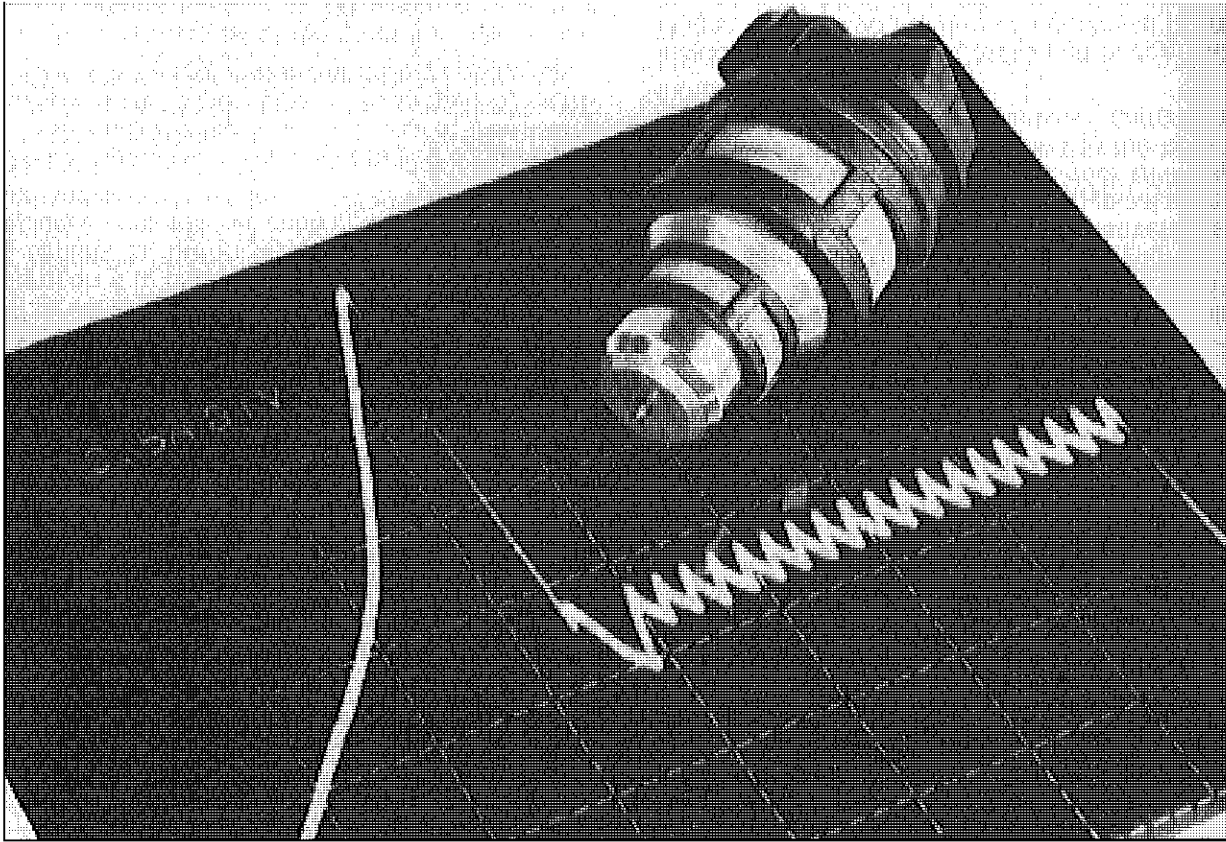
Let us now consider the U140, another component designed by SGS-Thomson to make available to the user a complex function on a simple chip; it is an actuator to drive in low side configuration the fuel injector in "single point" injection system.

As it is well known, quite essential for a good efficiency of the injection system is the capability to fix in the best way the time while the injector is opened, since that time is directly proportional to

**Figure 8:** Injector driver.



**Figure 9:** The injector drive is totally autonomous in fixing the current levels in the different phases, as well as the sampling of the holding current.



the quantity of fuel transferred to the intake manifold.

Particularly important to fix the fuel volume are the opening and the closing time of the nozzle, since both must be extremely fast; now, a single point injector needs a consistent current in the opening phase - up to 5A at the "PEAK" - but once opened, less current is enough to maintain the status - "HOLD" -. At the end of the cycle, finally the driving current must be switched off in a time as short as possible. The U140 meets all the above mentioned requirements: in addition, in the "HOLD" phase a further reduction of the current is achieved by switching on and off the driver stage (Figure 8), so reducing the power consumption and, as a consequence, the junction temperature.

A special mention shall be paid to the transition from "HOLD" to the "OFF" condition; as already said, it is quite important to reduce as much as possible this time; in the U140 that is achieved by discharging the inductor through an active zener set at a quite high voltage (about 70V), and that guarantees the closing of the injector in less than 50 sec. The same diode is set at 3V in the HOLD time. No external component is required by this circuit, that interfaces directly the microcontroller of the engine management system; by the way, the microcontroller has just to fix the start and the

end of the injection time, since the U140 is totally autonomous in fixing the current levels in the different phases, as well as the sampling of the holding current. (Figure 9).

The device incorporates a very sophisticated diagnostic (see again Figure 8), and transfers to the microcontroller all the relevant information on the status of the load.

The advantages of this monolithic devices are quite evident, if compared with existing solutions which need not less than 15 components including at least one IC and two discrete transistors, but are not limited to cost and room reduction, and to a consistent increase of the reliability: as a matter of fact the monolithic design allows to get, practically at zero cost, a very accurate value of the voltage of the recirculation diode, improving the accuracy on the ON time of the injector, and, last but not least, a diagnostic covering all the possible failure modes of the load.

The circuit is realized with SGS-Thomson's BCD technology, a mixed process including Bipolar, CMOS, and DMOS structures on the same chip; the input section is therefore able to interface directly a microcontroller, and the low side driver is designed with a DMOS having an  $R_{DS(ON)}$  of less than 0.5 ohm. As already explained the recirculation diode is set at 70 volt in the transition from

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**Table 3: MONOLITHIC PEAK AND HOLD INJECTOR DRIVER**

- Low side configuration
- Peak current function of battery voltage to provide a constant charging time
- Fast recirculation voltage independent from battery voltage
- Slow recirculation at max 3V
- Off time and peak current in hold condition internally fixed
- Full diagnostic: - open load  
- short circuit to ground and battery  
- thermal warning

HOLD to OFF; because of that we selected the BCD100, an option with a minimum breakdown Drain-Source voltage of 100V.

All the main features of this innovative device are listed in Table 3.

### REARVIEW MIRROR DRIVING

While we are on the subject of higher levels of integration it is useful to mention the development of circuits for the multiplex wiring system, which replaces conventional cabling with a common bus and "intelligent" switches.

The intelligent switch circuits are key components for the multiplex system, and one of these is a multiple driver IC, the L9946, developed by SGS-THOMSON for rearview mirror driving applications.

This IC integrates all of the control functions and power circuits needed in the electronic external rear-view mirror unit now being adopted for high end cars and is the first chip to integrate these

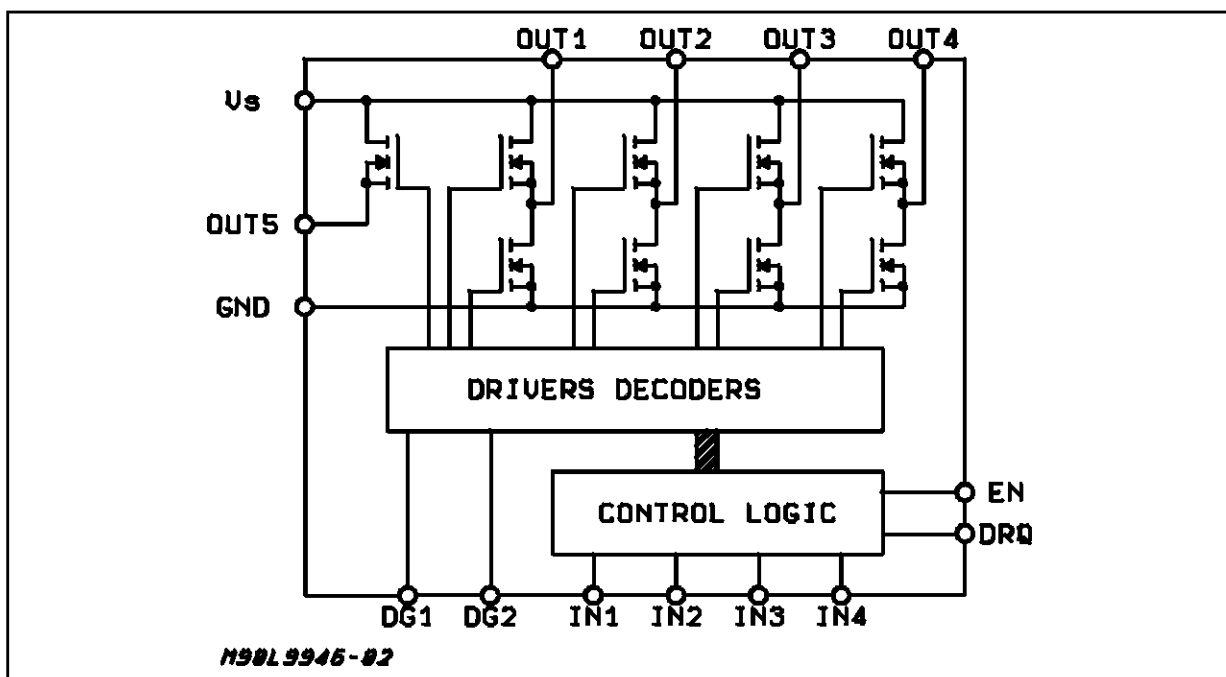
functions. (see Figure 10).

An important feature is that the IC is controlled directly by a microprocessor — all of the possible drive conditions are controlled by loading 4-bit commands and the L9946 generates the appropriate motor control signals.

No external power circuits are needed because the L9946 drives directly the two motors used for mirror orientation (up/down and left/right), the motor that "folds" the mirror for maneuvering and the demister heating element. In a typical application the chip is used in multiplex door wiring system where the door is connected to the body by three wires and all door functions controlled remotely using smart chips.

Inside the chip are four DMOS half bridge power stages which drive the three bidirectional DC motors, plus a DMOS high side driver that drives the demister element. Control logic integrated on the

**Figure 10: Block Diagram of the L9946.**





**Table 4: MULTIPLE HALF-BRIDGE DRIVER**

- 4.75A TOTAL OUTPUT CURRENT
- VERY LOW CONSUMPTION IN OFF STATE
- OVERLOAD DIAGNOSTIC
- OPEN LOAD DIAGNOSTIC
- GROUNDED CASE

chip decides how these transistors are to be switched to achieve the desired motion — including rapid braking. Two of the half bridges are rated at 1A output current; the other two half bridges and the high side driver are capable of delivering up to 4.75A.

In common with many other dedicated automotive ICs the L9946 incorporates diagnostic functions. Conditions such as overload and open load are signalled to the control micro so that appropriate action can be taken. In addition there is a standby pin that allows the micro to put the L9946 into a dormant state when it is not needed.

### CONCLUSIONS

We think we have demonstrated that the industrial availability of processes capable to match, on the same silicon, high power and complex control functions is the key element to the integration of completed functions on a single chip of silicon. The examples described demonstrate that SGS-

Thomson has developed a technology portfolio that can offer different answers for different applications, always optimizing the trade-off among the various needs.

On the other side, all the above considerations would have a merely academic interest if they were not associated with a convenient cost. It is clear that the monolithic integration of complex functions implies the use of not negligible areas of silicon, and that even in presence of high density processes.

It is therefore important to devote adequate resources to the diffusion technique, to increase the yield of each process.

Today's chips, up to 30mm<sup>2</sup> (and all the three examples are below that limit) can be produced at prices competitive with an equivalent discrete solution, and in the second half of the 90's the target will be expanded up to areas of 40mm<sup>2</sup>, giving a green light to the monolithic design of complete modules.

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