APPLICATION NOTE

AN INTRODUCTION TO INTELLIGENT POWER

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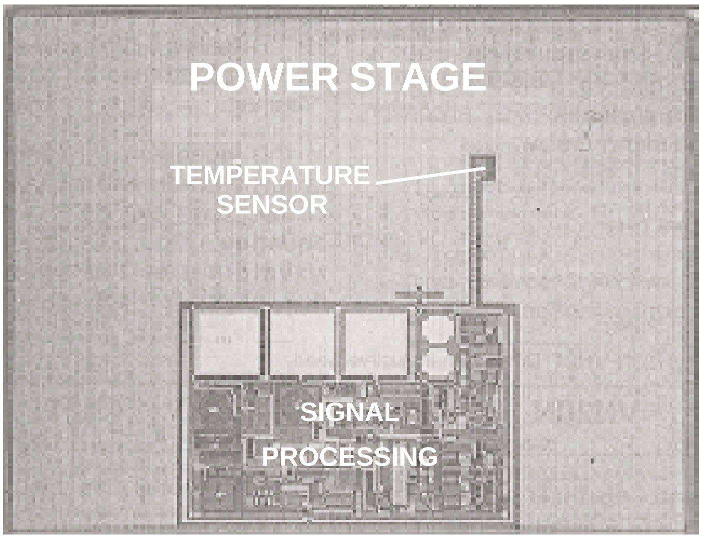
ABSTRACT

This paper gives an overview of one of the fastest growing and most exciting areas of power electronics: Intelligent Power technology. It explains what the term Intelligent Power means, why intelligent power is needed, where it is applied, and finally the technologies involved in its construction.

1. INTRODUCTION

To achieve optimum performance, the power element of a system may require a considerable amount of supplementary circuitry: circuits to protect it from harsh conditions, circuits to ensure that it switches in the most efficient way possible, and, increasingly, circuits to feed back information on the status of the power stage back to

Figure 1: Layout of an Intelligent Power chip



control logic. The need for these circuits can make the design of the power stage complex, and can require a lot of components and board space.

One solution to this problem is to integrate all of the protection, drive and feedback circuitry along with the power element on a single chip - in effect giving the device “intelligence”. This concept forms the basis of intelligent power technology.

2. WHAT IS INTELLIGENT POWER?

The additional circuits required for safe, reliable and efficient operation of a power transistor fall into three basic categories:

i) Circuits to drive the device, compensate for different types of loads (inductive, capacitive etc.), to reduce losses and optimize switching speed.

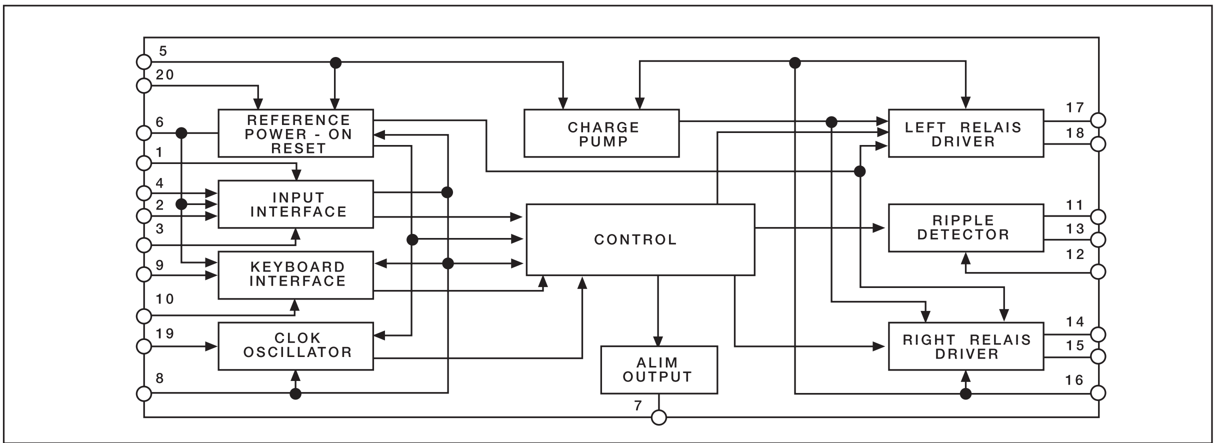
ii) Circuits to protect the chip (and surrounding components) from destruction by, for example, excessive current, voltage or temperature.

iii) Logic level control and interface circuits: the use of simple logic-level systems, microprocessors and microcontrollers in the control of power systems has become widespread, and it is often necessary for the power stage to interface with logic-level devices to allow transfer of information; both control information passed from the controller to the power stage, and status information (for example fault alarms) passed back from the power stage to the controller. Standard power MOSFETs and bipolar transistors require driving voltages or currents greater than those which can be supplied by logic level circuits.

If the demands placed on the protection and drive circuitry are particularly severe (for example when the system operates in a harsh environment), or where the application imposes a particularly exacting set of constraints, design of these circuits may require considerable effort on the part of the designer, and may result in a high component count, with attendant problems of large board space requirement, reduced circuit reliability and increased assembly costs.

Intelligent Power technology eases these problems by integrating both low voltage interface, drive, protection and control circuitry, and high power transistors on the same chip. This gives the system designer a device which will protect itself, switch efficiently and allows easy and flexible control, that is enclosed in a single package and requires only a few external components. This can help to reduce system design time considerably. The functional blocks of a typical device are shown in fig. 2.

Figure 2: Functional blocks of a typical Intelligent Power device - car window lift controller



3. AREAS OF APPLICATION

Intelligent Power devices find most use where there is a need for good protection, high reliability and compactness, and where logic level compatibility is required. In some cases the protection features they offer, for example over temperature protection, are difficult or impractical to implement with discrete components (it is impossible to monitor the junction temperature of the power switch in any other method), and so they are the only real option.

3.1 Automotive systems

Electronic systems contained within cars must be able to withstand very harsh conditions. Physically, they are subjected to vibration and extremes of temperature, while electrically, inductances such as those in the ignition system and the alternator give rise to large voltage spikes and interference. Short circuits can easily occur, causing large currents to flow.

These conditions can make the design of a reliable circuit using conventional parts difficult in automotive systems: a great deal of protection must be built in, leading to a large number of components. This gives rise to two problems: firstly, the space to mount such a circuit may be restricted; and secondly, the larger the number of components, the greater the risk of system breakdown due to failure of solder joints caused by the vibration. The possibility of system breakdown also means that ease of replacement and hence system simplicity are an advantage. Thus Intelligent Power devices offer an attractive alternative to conventional devices, and in some cases are the only alternative to a mechanical solution.

Additionally, as the price of microprocessors falls, they are increasingly being used to control automotive systems (in particular engine management systems), and so direct logic-level interfacing is an advantage.

The processing and problem solving power available in the microprocessor, in conjunction with the fault detection and reporting capabilities of intelligent power devices (which are effectively acting partly as sensors) means that the whole process can be carefully controlled and adjusted, and it may even be possible for adaptive changes to be made in the case of faults to ensure continued safe operation. Thus intelligent power devices help to improve engine efficiency and system reliability.

The use of intelligent power devices will increase dramatically with the development of multiplexed automotive systems. In conventional systems, a large amount of wiring is required to carry information between all the electronic control elements and the central controller. In multiplexed systems, instead of employing a set of wires for each individual electronic element, a single digital serial communications bus connected to all elements is used. This bus is constantly monitored by all the elements of the system, which identify the commands relevant to them by means of an individual code.

By reducing the amount of wiring in the car, this technology improves system reliability and flexibility, cuts hardware, assembly and testing costs, and reduces the car’s weight. However, its digital nature means that the ability of the power devices of the system to interface with and preferably interpret digital signals is very important, and so intelligent power devices will be very attractive in this field.

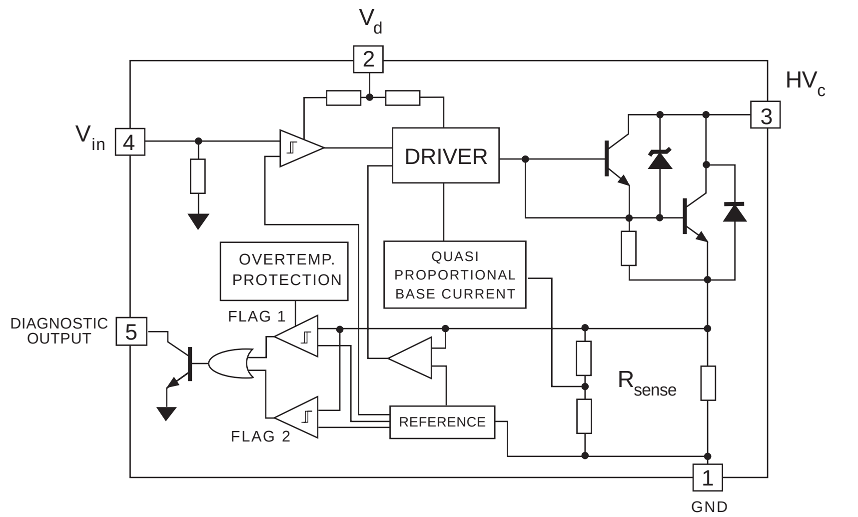
The most common automotive applications of Intelligent Power are ignition systems, where they replace either mechanical systems or discrete IGBTs or bipolar transistors, as transducer drivers, where they replace mechanical relays for switching loads (for example lamps, motors, and solenoids), and in car entertainment systems.

3.1.1 Automotive ignition

Electronic ignition systems replace the conventional mechanical distributor with an electronic switch to provide controlled current to the primary side of the ignition coil transformer, which is switched off at a precisely timed instant to generate a voltage spike across the coil and consequently the ignition spark. This operation is usually under the control of a microprocessor (as part of the Engine Management System) which adjusts the system to obtain maximum efficiency.

This sector is currently dominated by the discrete Darlington bipolar transistor. However, the harsh conditions encountered by the device (voltage spikes, vibration etc), the high power levels involved (500V, 10A, with consequences for the design of protection circuitry) and the common requirement to interface directly with a microprocessor, mean that Intelligent Power devices are becoming increasingly popular. The functional block diagram of a typical device is shown in figure 3.

Figure 3: Functional blocks of an electronic ignition device - the VB027



3.1.2 Transducer Drivers

The modern automotive system typically includes a variety of transducers: for example lamps, window lift motors, electric door locks, fuel injection systems etc. Intelligent power components can be used to form the interface between these electro-mechanical devices and the car control system, providing appropriate control voltages and currents while monitoring for faults, giving safe, reliable system operation.

Their main advantages over mechanical relays are the ability to drive them directly from logic level signals, their protection and diagnostic facilities, and their reduced size and weight.

3.1.2.1 High side drivers

In an automotive system, a control switch is generally placed between the positive rail and the load, see figure 4.

The first reason for this is that because a large area of the car (the body and the chassis) is effectively ground, keeping the load at a low potential when turned off reduces the risk of a short circuit accidentally turning it on.

The second is that an automotive component is particularly susceptible to electrochemical corrosion, because of the conditions of heat, humidity and salt in which it exists. Because of this, when the component is turned off (which will be the majority of its lifetime), it is desirable that it should remain at as low an electrical potential as possible.

Figure 5 illustrates the problems incurred by this requirement, using a Power MOSFET switch as an example.

Figure 4: Power switch placed on the high side of the load

Figure 5: Problems with driving high side switches

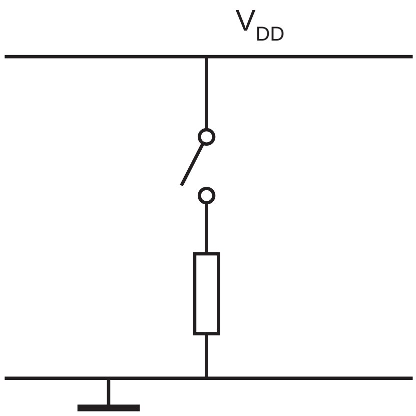


Figure 4

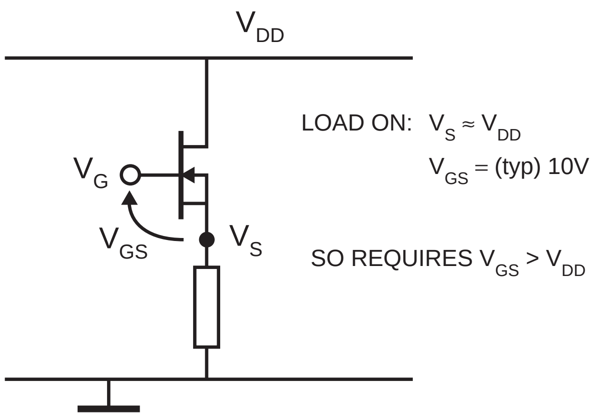


Figure 5

When the switch is turned on, the drain-source voltage falls to approximately zero, and so the source voltage rises to a value close to the level of the positive rail. However, a gate-source voltage of typically 10V for a standard device is needed to keep the switch turned on, and so the gate voltage required is higher than the level of the positive rail. A level shifter is thus needed to drive the device.

Care must also be taken in the design of this drive. As an example, if the source voltage of the switch rises to 12V after turn-on, and a gate-source voltage of 10V is required to keep the device turned on, the gate must be driven with 22V relative to ground while turned on. However, if this voltage is applied to the device before it is turned on, when the source voltage is close to zero, there is a risk that the gate-source breakdown voltage will be exceeded, and the device will be destroyed. Hence the device must always be driven with a voltage referenced to the source voltage, rather than referenced to ground.

The complexity of the circuits required for this drive, along with the adverse conditions discussed previously, and the increasing need for status feedback, means that Intelligent Power components will in the future replace electromechanical relays in this application.

3.1.3 In-Car Entertainment Systems

The circuits contained within a car stereo or similar system exist in a completely different environment to that of a domestic system. They must function in the presence of a significant amount of electrical interference, and remain reliable despite sustained vibration, but must be squeezed into a very limited space. For these reasons Intelligent Power devices are ideal for these applications.

3.2 Regulators and power supplies

Devices using intelligent power technologies can offer compact circuits with a high degree of efficiency and good protection in power supply and regulation applications.

The efficiency and flexibility of single-chip linear regulation devices can be improved by integrating control circuits onto the chip to implement switch mode techniques, while medium-power power supply systems be fully integrated. Integrated power devices can incorporate for example a half bridge along with all the necessary drive and protection circuits.

Higher power systems can employ devices to drive, monitor and regulate the power switches, for example the PWM controller circuits, and bipolar base or MOSFET gate drivers along with other circuits to form the basis of a switch-mode power supply.

Although most of the components for a high power off-line (that is one powered from rectified AC mains) switch mode power supply can be incorporated onto a single chip, it is not yet commercially practicable to construct a high power off-line supply using intelligent power technology for a number of reasons. The first is that the noise levels generated by the power stage make reliable fault-free operation of the signal stage very difficult to achieve - an ever-present problem in the design of intelligent power devices. The second is due to the fact that a high power system requires a high degree of device optimisation and quality, and accuracy in all stages of the system. To produce an acceptable yield of multiple high accuracy stages on a single chip at a cost to compete with a discrete solution is a significant technical challenge. Additionally, as the device technologies available to construct each stage of the system are limited by the intelligent power fabrication process, it may be difficult to achieve the required accuracy (for example of a regulation stage) while keeping the area of silicon used small (to keep costs down and reduce the incidence of random defects).

However these problems will be overcome in the future, when the increased system reliability offered by integrated power solutions over their discrete counterparts will make them very attractive.

3.2.1 Battery chargers

Battery chargers represent a special case of power supplies. Simple chargers may just supply the battery with a constant current, but higher performance chargers must carefully monitor and control the charging current throughout the charging cycle to charge the batteries as quickly and efficiently as possible without shortening their lifetime. To supply the battery with the optimal current, and to stop charging before damage occurs, a number of factors must be monitored, most importantly the voltage across the battery (which varies throughout charging cycle, reaching a maximum when the battery is optimally charged but falling when the battery becomes overcharged), and the battery temperature (if this becomes too high due to too large a charging current the battery will be damaged). The charging process is often overseen by a microcontroller, and this along with the complex control circuitry required means that Intelligent Power devices are often used in these applications.

3.3 Motor control and servo drivers

Many motor control applications require a great deal of circuitry to regulate the motor, and in servo applications, monitor and feed back information on the status of the device. Intelligent power is used to improve the compactness of the circuits and reduce system design time. Intelligent power solutions can eliminate bulky PCBs, and can even shrink the electronics enough to be placed actually inside the shaft of the motor.

In servo applications, circuits to monitor the status of position and status sensors, microprocessor feedback circuits, and the power switches to drive the motor can be integrated onto a single chip. Stepper motors are often used in these applications, and the designer can use standard intelligent power devices incorporating all of the circuits required to drive and control the stepper motor (for example the generation of signals in appropriate phases to drive the motor, position control etc) along with the power stage to reduce the complexity of the design and speed up system design time.

In motor control applications, devices range from simple protected transistors to complete bridge drivers with full open- or closed-loop control circuits, monitoring for example the torque delivered by the motor, regulating the current and / or voltage, and providing feedback to a microprocessor controller.

Applications-specific intelligent power devices can integrate all the control and power functions of specialised applications onto a single chip, for example a typewriter controller, incorporating motor drives for carriage positioning, paper feed, and daisy-wheel control, plus a solenoid driver for the hammer and a switch-mode power supply for the typewriter's microprocessor. Again, the integration of all these facilities leads to increased system reliability and reduced material and assembly costs.

3.4 Audio amplifiers

Intelligent Power audio amplifiers integrate protection circuits along with the transistors for the power amplifier, offering a compact and reliable alternative to discrete solutions.

3.5 Protected Power MOSFETs

Intelligent Power devices exist which under normal circumstances behave exactly as normal Power MOSFETs, and are packaged in the same three pin packages. However, a number of protection features are integrated onto the wafer - over temperature, over current, and voltage clamping. These devices can be used as direct replacements for standard power MOSFETs in any application where there is a requirement for compact, reliable, cost-effective protection.

3.6 Other applications

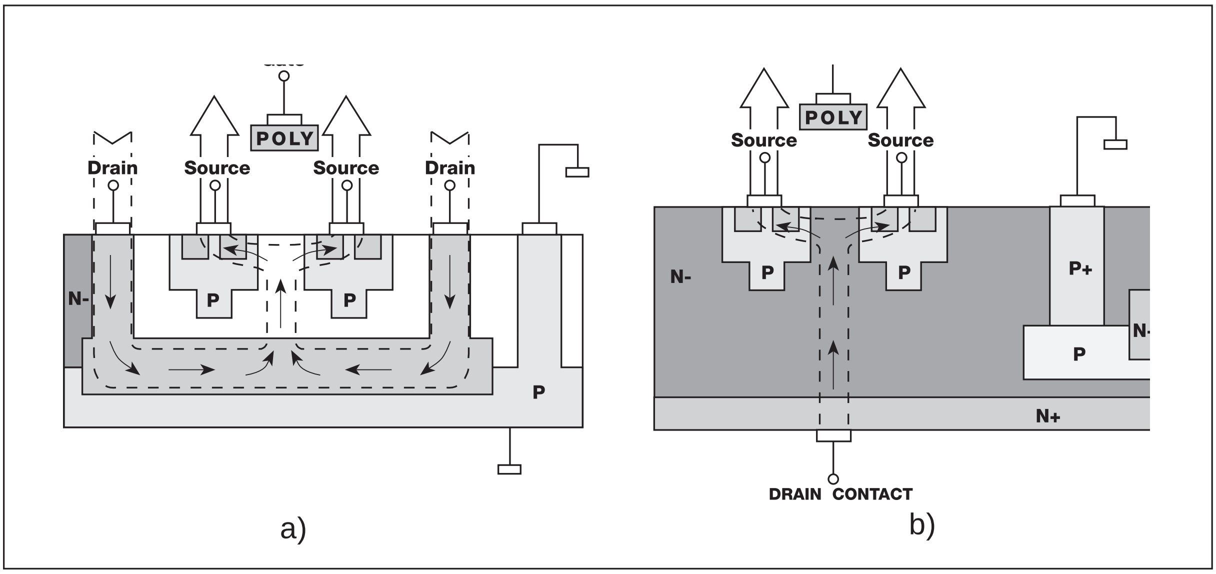
Intelligent power can be used in many other areas using standard or application-specific circuits with special protection requirements or need for compactness. The nature of intelligent power also lends itself to easy design of application specific devices.

Examples are lamp ballast circuits, incorporating drivers for power switches, with starter and oscillator circuits, display drivers, solid state relays, process control high side drivers, telecommunication circuits, and many others.

4. TECHNOLOGIES

Intelligent Power technologies can be split into two basic categories: those which use horizontal power current flow (ie the power current flows parallel to the surface of the silicon wafer), and those which use vertical power current flow - see figure 6. Examples of these technologies are SGS-THOMSON's BCD and VIPower technologies respectively.

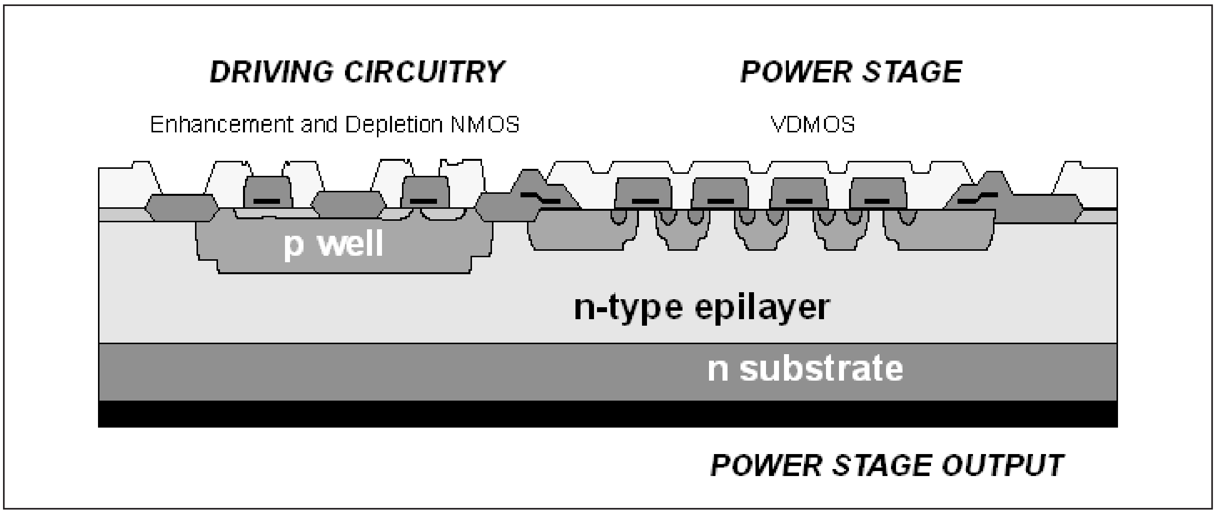
Figure 6: Current flows: a) Horizontal current flow
b) Vertical current flow



4.1 Vertical technology - VIPower

An example of the basic VIPower structure is shown in figure 7. The signal stage grown in a p-type well to isolate it from the power stage. The current enters the lower surface of the wafer, and flows vertically through the power stage, as it does in a conventional discrete power semiconductor. This means that they have voltage and current ratings similar or even equal to discrete devices, for example devices are available with Bipolar outputs with blocking voltage ratings of 1200V, and MOSFET devices with output current ratings of 100A.

Figure 7: Basic VIPower structure: VIPower M0 technology



Depending on the particular technology used, the devices employ NMOS, DMOS, CMOS and/or bipolar type transistors for the signal stages, and high voltage bipolar or VDMOS transistors for the outputs.

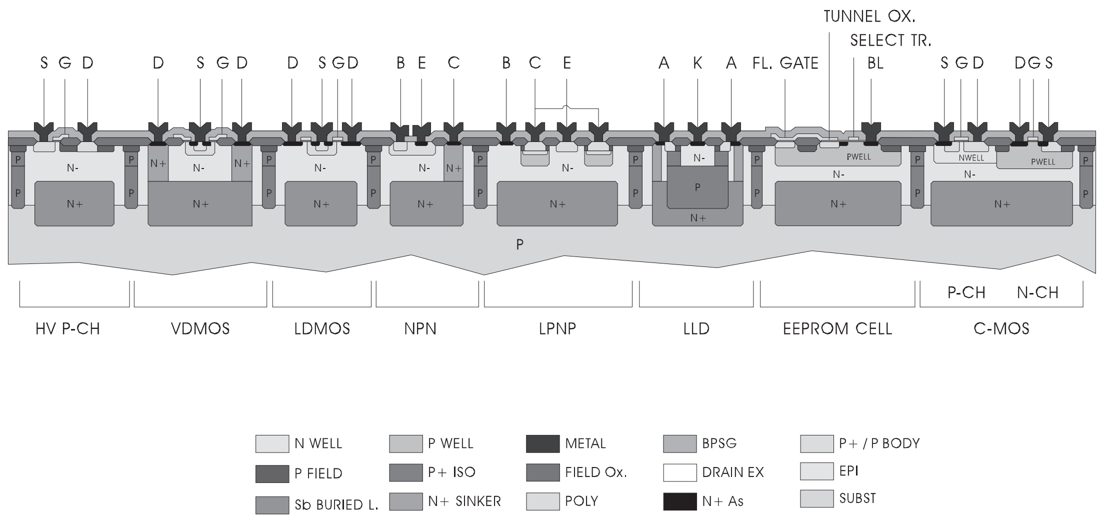
4.2 Horizontal technology - Multipower-BCD

This structure employs the integration of Bipolar, CMOS and DMOS (hence the name) type transistors on the same wafer.

The chip designer is thus able to select the appropriate type of transistor for each part of their design: bipolar for linear functions where high precision is required, CMOS for high density logic and analogue circuits, and DMOS for power stages. The breakdown voltage of this type of device is currently limited to around 250V.

The underlying structure of Multipower-BCD devices is shown in figure 8.

Figure 8: Multipower-BCD structure



4.3 Comparison of vertical and horizontal technologies

Because of the wider conduction path allowed by vertical conduction through the wafer, VIPower gives lower specific conduction resistance and so is able to handle higher power than the BCD approach. However, as the power current flows through the substrate of the device, it is only possible to have multiple power outputs if the power elements of each output have shared collectors/drains (this is possible in some applications, for example high side drivers).

The complexity of the control circuitry that can be integrated onto the chip is also limited because of the chip area occupied by the p-type isolation well.

BCD can be more complex, and can have multiple power outputs, but the use of horizontal current flow results in an $R_{DS(on)}$ per unit area higher than that of vertical technologies, and hence higher costs or higher losses.

These properties mean that as a general rule Multipower-BCD is used to produce complex medium power devices, possibly with multiple power outputs and perhaps a custom or application specific design, while VIPower is suitable for more general devices with greater power handling capability and simpler design. For example VIPower is often used to produce high current car ignition drivers, while a typical Multipower-BCD application may be a computer hard disk drive controller, incorporating a multiple-output motor drive, feedback and a large amount of control circuitry.

4.4 BCD3

The development of BCD3 technology is a further step toward the goal of full integration of power and signal systems. The use of advanced integration technology in these devices allows the construction of an 8 bit microcontroller and supplementary circuitry (for example EEPROM memory) on the same chip as 60V power stages. This opens the door for the production of a whole new generation of highly adaptable and user configurable power devices. Example applications include programmable single-chip power supplies, or families of general purpose very intelligent power drivers.

The incorporation of a microprocessor means that the characteristics of the device can be completely changed at any time, simply by loading the appropriate software into the memory.

5. FUTURE DEVELOPMENTS

The future of intelligent power will see more complexity and more power handling capability, at lower prices. High power single chip switch mode power supplies will be developed, as well as simple 3 pin devices which behave exactly like standard discrete power transistors, but include a comprehensive range of protection features. Mechanical power switches will increasingly be replaced by electronic devices. The distinction between power stages and controllers will become less distinct as more intelligence and logic, microprocessors and microcontrollers, are integrated onto the same chip as high power transistors.

6. CONCLUSION

Intelligent Power bridges the traditional gap between small signal and true power devices. It makes the job of designing reliable, compact power circuits easier. As technology improves, devices becoming more complex, more capable both in terms of the number of control functions and the power they can handle, and the prices are falling. The traditional dividing line between small signal or logic level devices and power devices will become increasingly blurred.