MIXED BIPOLAR-CMOS-DMOS SMART POWER IC TECHNOLOGY

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Abstract: First introduced in the mid eighties, mixed bipolar-CMOS-DMOS (BCD) smart power IC technology has brought significant advances in the art of integrating signal and power circuits on the same chip. This paper describes the origin and evolution of the BCD technology family from the beginning to the present day, using as examples some practical integrated circuit designs that exploit effectively its benefits.

Mešana bipolarna - CMOS - DMOS tehnologija za pametna močnostna integrirana vezja

Ključne besede: polprevodniki, vezja integrirana, BCD tehnologija, transistorji močnostni, transistorji bipolarni, CMOS vezja, DMOS vezja, vezja močnostna, vezja signalna

Povzetek: Od sredine osemdesetih let, ko se je prvič pojavila, pa do danes, je mešana bipolarna - CMOS - DMOS (BCD) tehnologija omogočila izreden napredek in prinesla nove možnosti pri integraciji digitalne in močnostne elektronike na enem čipu. V tem prispevku opisujemo začetke in razvoj družin BCD tehnologij do danes. Obenem predstavljamo nekaj načrtanih in izdelanih integriranih vezij kot praktične primere vseh možnosti, ki jih ta tehnologija ponuja.

INTRODUCTION

In the early eighties power integrated circuits were produced using pure bipolar technology. These devices, mainly operating in switching mode, were severely limited by the poor efficiency of bipolar power transistors. This poor efficiency meant that a significant amount of power was dissipated inside the device, and since there is a limit to the dissipation capacity of an IC package this represented a fundamental limitation on the delivered power available. Pure bipolar power ICs suffer from another limitation: the poor density of bipolar logic.

Clearly the answer to these problems was to use DMOS/CMOS technology. DMOS power devices solved the dissipation problem, while CMOS provided very high density signal circuits. However, at the same time it was necessary to guarantee the high-precision analog performance that only bipolar technology can provide. Consequently the ideal solution was to combine bipolar, CMOS and DMOS on the same chip. This was achieved by SGS-THOMSON in 1986 with the introduction of a new technology called Multipower-BCD.

While most smart power IC processes are created by adding power elements to an existing signal process or vice-versa, "BCD" technology emerged from a project to develop a completely new, optimal process. Borrowing elements from junction- isolated IC technology and discrete DMOS technology, it allowed the integration of bipolar, CMOS and DMOS structures on the same chip (figure 1).

IC technologies combining power DMOS with signal circuits had existed previously, but where this technology differed lay in the use of isolated DMOS power transistors having all of the contacts on the top surface. In contrast, other processes used discrete-type DMOS structures where the lower surface of the die is the drain contact, so that two or more DMOS devices can only be placed on the same chip if they have a common drain contact. In contrast, with Multipower-BCD designers were free for the first time to integrate any number of DMOS power transistors connected in any way including bridge configurations.

In the first version of BCD technology, now called BCDI, the minimum breakdown voltage was specified at 60V, a figure defined by the original target application of the

MULTIPOWER BCD 20/60 II

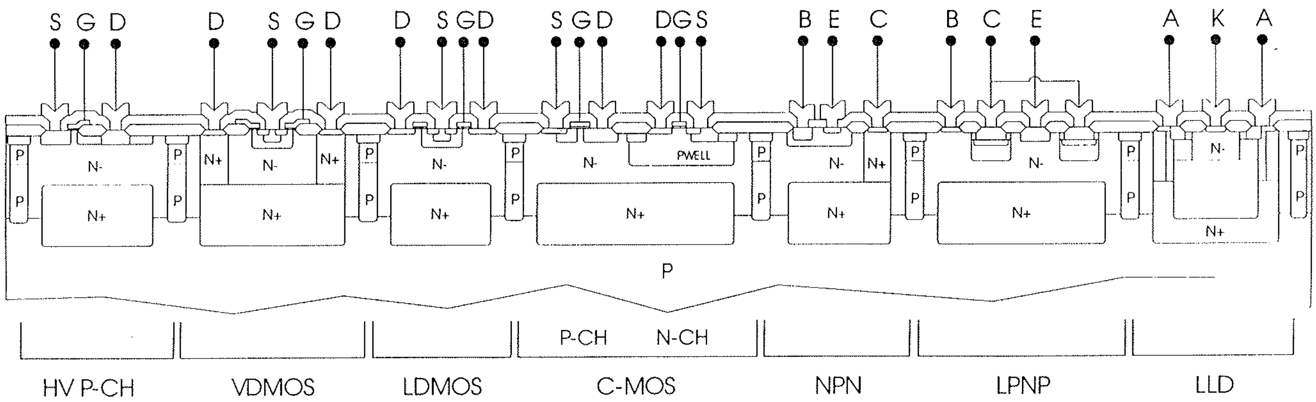

Fig. 1 *"BCD" technology, developed in the mid-eighties, combined vertical DMOS and junction isolation technologies. Since the DMOS transistors are fully isolated and have all contacts on the top surface any kind of power stage can be integrated.*

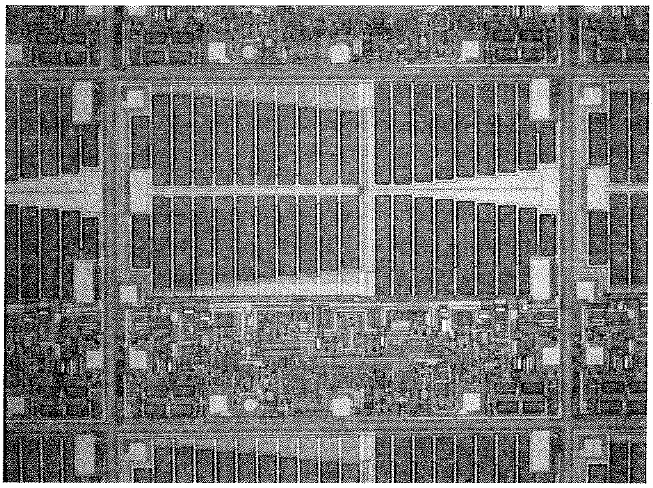

Fig. 2 *Because BCD technology allows the integration of isolated DMOS transistors it became possible to realize integrated circuits like this H bridge motor driver, the first BCD IC to be marketed.*

technology. BCDI was developed at a time when most smart power devices were used in applications like motor and solenoid driving in computer peripherals, where supplies for 30-50V are commonly used.

The first commercial product to be developed using this technology was the L6202 H-bridge motor driver (figure 2). A bipolar bridge with identical power performance was designed at the same time for the purpose of comparison. Both chips operated on 48V supplies and delivered 1.5A continuous output current. But while the L6202 was assembled in a DIP package and needed no heatsink, its bipolar counterpart needed a power package and a hefty heatsink. Eliminating this heatsink was a dramatic demonstration of the importance of reduced dissipation in power ICs.

There were other advantages in favor of the BCD version, too. Since a DMOS power stage has intrinsic recirculation diodes no external discrete diodes were needed, saving components. Moreover, the BCD version offered CMOS logic, which allowed designers to consider the use of complex logic in power ICs.

Though the BCD IC had many advantages over a bipolar equivalent it should be emphasized that the die size of the two chips was almost identical. And since the BCD process uses standard production equipment and is roughly equivalent in terms of process complexity this means that the die cost was comparable.

HIGHER CURRENT

Having demonstrated the benefits of low dissipation, designers set out to explore other limits of power IC technology, beginning with output current. The first BCD

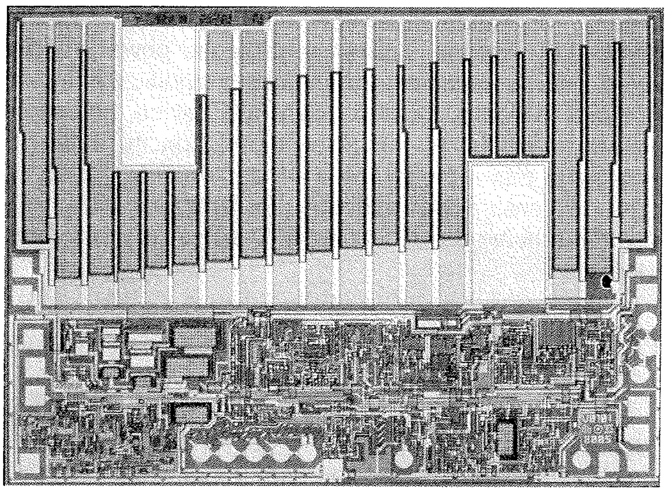

Fig. 3 *BCD technology has also been applied effectively in the power supply field. This high power switching regulator IC delivers 10A output current, more than twice that of an equivalent bipolar power IC.*

IC to enter this unexplored territory was the L4970 switching regulator, a one-chip switchmode power supply delivering 10A output current (figure 3).

To deal with current levels this high it was necessary to have two thicknesses of interconnect metal: a thin layer for normal signal interconnections and a thicker layer for the main connections to the DMOS power transistor. This thicker metal reduced the voltage drop on the metal tracks inside the chip, while the thinner signal metal allowed the use of finer pitches, hence greater density.

A new bonding technique was developed, too, to reconcile the conflicting needs of power and signal connections. Thick aluminum bonding wires are needed for the high current connections because a single gold wire would be insufficient and multiple wires inherently unreliable. However, these thicker wires need a larger bonding pad on the die so if they were used for all of the connections silicon area would be wasted. The answer to this problem was to use thick aluminum wires just for the power connections and thin gold wires for the signal connections.

Operating at switching frequencies up to 500kHz the L4970 also demonstrated the speed advantage of DMOS power transistors in fast switching designs. Even at high frequencies the efficiency of the device is high enough to allow a DIP- packaged version to deliver 4A the output current capability of a similar bipolar device in a Multiwatt power package.

HIGHER VOLTAGE

After raising the current limits, smart power designers turned towards higher voltages to extend the range of applications. The first step was the development of a 100V version, designed to satisfy the needs of applica-

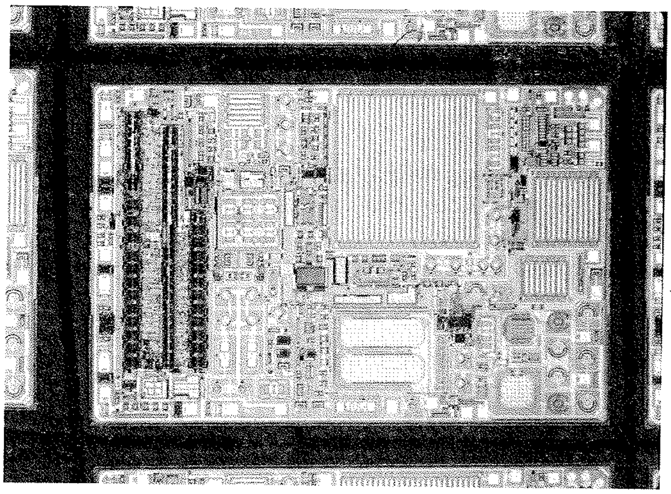

Fig. 4 *High voltage technology is useful in both industrial and telecom applications. This IC, produced with 250V BCD technology, is a solid-state hook switch for telephone sets.*

tions in telecommunications and automotive. Though the battery voltage in automotive applications is only 12V this higher voltage capability is needed to ensure survival in an environment where high voltage transients occur.

The 100V process was followed by a 250V version, aimed at telecom and industrial applications. While it was sufficient to increase the epitaxial layer thickness to reach 100V, more substantial changes were required to reach 250V. Most important of these is the use of a technique where the isolation diffusions are made in two parts. A seed of dopant is implanted in the substrate before epi growth; during subsequent processing this expands, meeting a conventional diffusion from above (figure 5).

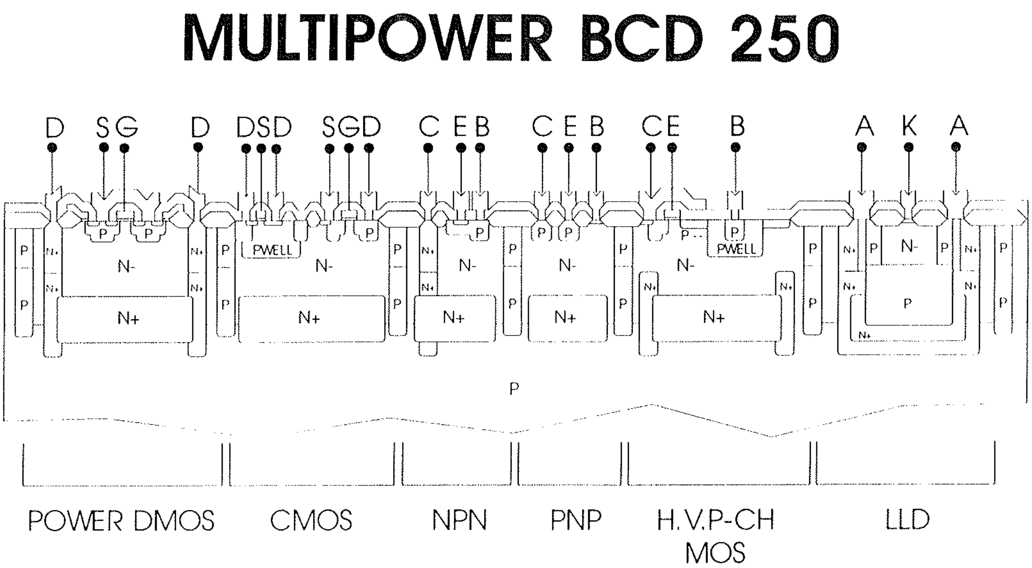

Fig. 5 *Cross section of the BCD250 technology. Compared to the lower voltage versions, this 250V technology has a thicker epitaxial layer so the top- bottom isolation technique is used.*

An example of the application of high-voltage technology in the telecom field is the telephone hook switch shown in figure 4.

In the high voltage field another version called BCD-Offline extends the capability of the technology to "offline" voltages (up to 700V). This process exploits the reduced surface field approach to integrate lateral DMOS high-voltage transistors.

BCD-Offline combines on a single chip low voltage CMOS and bipolar control circuits with high-voltage grounded-source lateral double-diffused MOS transistors (HV LDMOS) and grounded-source lateral insulated gate bipolar transistors (HV LIGBT). In source-follower configuration the source can float up to 20V.

A full custom circuit for a fluorescent lamp application is the first circuit in BCD- Offline technology to be qualified for production. This circuit, shown in figure 6, includes all of the functions for a fluorescent lamp driver in the preheat, ignition and on-state phases, driving two external MOS transistors.

Other products in development or qualification include a custom lamp driver with power factor correction and a high voltage half bridge driver aimed at appliance motor applications. This motor driver will be a standard part sold on the merchant market. BCD-Offline circuits are also in development for other applications such as power supplies.

SGS-THOMSON has derived lower voltage versions of this technology, rated at 300V and 170V, which will be suitable for application fields such as telecom, where circuits using high voltage technology are used to produce subscriber line interface circuits and hook switches.

HIGHER COMPLEXITY

While the trends towards higher current and voltage were easily predictable, at the end of the eighties a new trend emerged that was not expected by most experts in the field: the advent of high complexity smart power ICs.

Two factors made this possible. Firstly, the fact that BCD technology allowed the integration of isolated DMOS transistors meant it was possible not only to integrate any kind of power stage, but also any number of power stages. Second, the dissipation of power DMOS transistors was low enough to ensure that when multiple power stages are integrated the overall power dissipation is within the limits of normal packages.

High complexity smart power reached the market in 1988 when SGS-THOMSON introduced a single IC that integrated two 1A stepper motors drivers, a 3A solenoid driver and a 5V switchmode power supply (figure 7). This

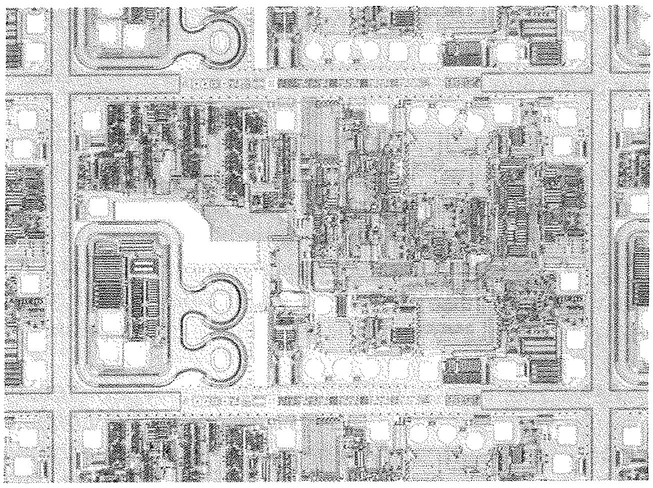

Fig. 6 *A new development, "BCD-Offline" technology is suitable for offline supply circuits or fluorescent lamp ballast circuits, like the proprietary device shown in this photo.*

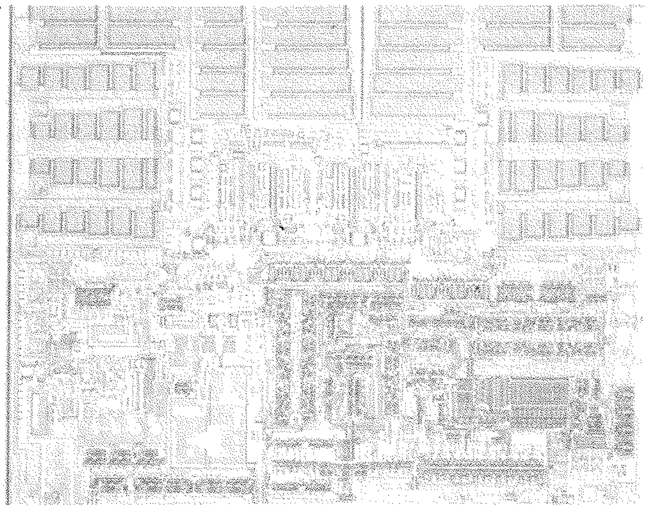

Fig. 7 *The first example of an LSI smart power IC, this circuit integrates two 1A motor drivers, a 3A solenoid driver and a 5V switching power supply.*

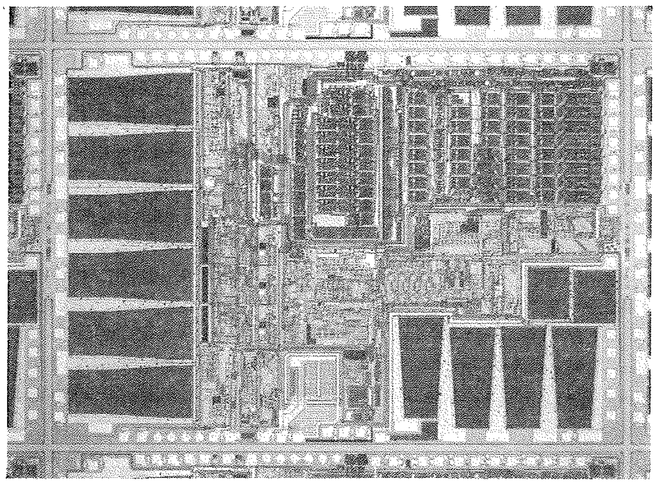

Fig. 8 *When the second generation 2.5 μm BCD technology was introduced it was applied to make very complex ICs like this disk drive circuit that integrates the spindle motor driver and head positioner of a hard disk drive.*

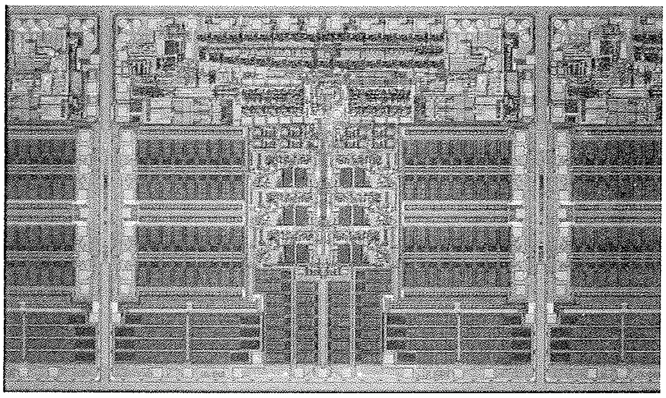

Fig. 9 *Another example of LSI smart power is this IC that controls and drives the three motors of a fax machine. Because of the very low dissipation of the power DMOS output stage this IC is packaged in a plastic PLCC package.*

chip, designed for a portable typewriter application, was controlled by loading commands through a bus into a set of internal registers. Among the innovative features of this device was the use of output stages that could be configured under software control.

The arrival of complex smart power chips prompted an acceleration of the trend towards finer lithographies. In fact soon after the introduction of the L6280 a second generation BCD process was introduced with 2.5m lithography. This doubled both the current density in the power stages and the component density in the signal section. As a result complex chips became much more cost effective.

This second generation BCD technology has found applications in many fields. One area where it has had the greatest impact is in hard disk drives for computers. Very little space is available in 2.5" and sub 2.5" drives, so

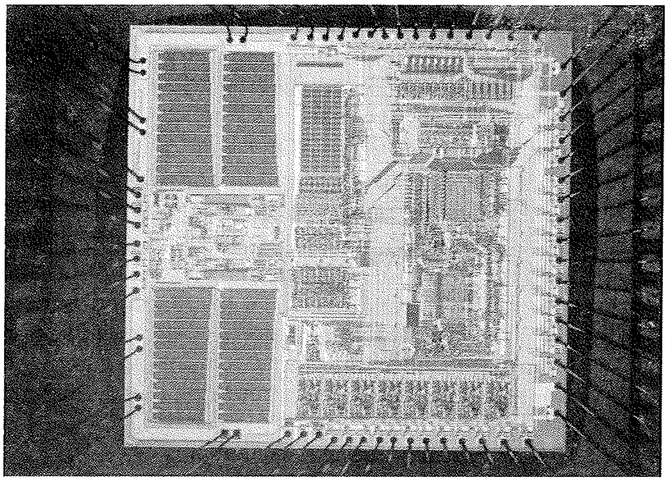

Fig. 11 *The first smart power IC to integrate a microcontroller, this technology demonstrator IC combines an 8-bit microcontroller core plus a 3A/60V power section.*

drive designers are always looking for new ways to reduce the component count. With BCD2 they were able to integrate all of the circuits for controlling the spindle motor and head positioner on a single chip. Figure 8 shows a circuit that integrates this function.

Similar circuits are used in other products where several motors must be driven. An example is the complex IC shown in figure 9, which was developed for a Japanese fax machine application. This IC drives the scanner, paper feed and cutter motors.

In 1993 a third generation BCD technology was announced (figure 10). Compared to the second generation this version offered a significant gain in density, thanks to a shrink from 2.5 to 1.2 μm lithography. More importantly, however, it brought the process into line with SGS-THOMSON's CMOS processes used for logic and memory circuits. Consequently, this version not only allows the integration of bipolar, CMOS and DMOS, but

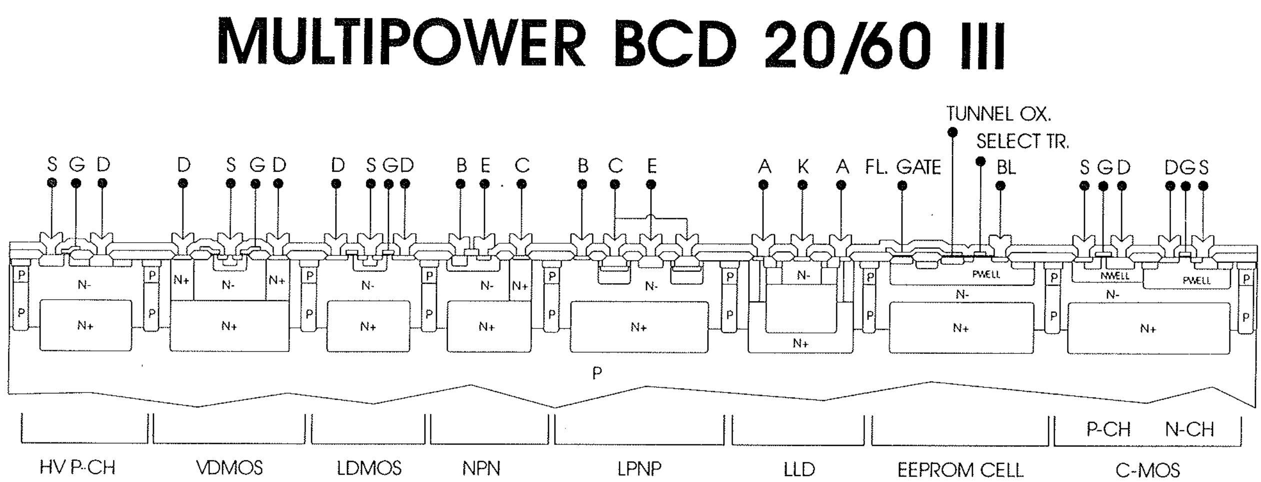

Fig. 10 *In the third generation BCD technology minimum linewidths of 1.2 μm are used. Other important characteristics are two levels of polysilicon, three levels of metal and a modular process structure that permits the inclusion of additional functions like EEPROM to the basic flow chart.*

it also lets designers insert in a BCD chip any cell or macrocell available within the company, including micro cores and advanced non-volatile memories.

Designers have been wary of the idea of integrating a micro on a power chip, expressing concerns that high voltage, high current pulses might disturb the micro. To allay these fears a demonstrator chip was produced in the spring of 1993 that integrated a 60V/3A bridge and a standard SGS-THOMSON ST6 microcomputer core (figure 11). Since this was a demo chip designed to demonstrate feasibility the program memory was external. In fact all of the internal connections in this chip are available externally for evaluation purposes.

Future evolutions of BCD technology, already planned, will reduce the lithography to 0.8 then 0.5 μm. In addition, new functionalities like flash memory will be added.

Technologies like BCD3 make it possible to reduce the component count of applications by integrating a microcontroller with the circuits it controls. However, the technology also allows designers to create a completely new type of general purpose power integrated circuit that is completely defined by software. Such circuits will have a microcontroller, memory, supply and some uncommitted power DMOS devices. Through software it will be possible to define the output configurations and define the functionality of the circuit. These general purpose circuits will become the power equivalent of PLDs, and greatly simplify small production runs or prototyping where a large volume custom circuit is unthinkable.

EMERGENT APPLICATIONS

In parallel with the development of these very high complexity circuits, there has also been an increase in the number of application fields where smart power technologies like BCD are applied.

While the technology was first applied in computer peripherals, it has spread to other sectors such as automotive, telecom and consumer. Automotive applications are primarily in the control and driving of motors, solenoids and relays, all applications that are growing very rapidly as electronic engine controls and electronic-based systems like ABS become more common. In addition, though, smart power is also a key technology behind multiplex wiring schemes. Telecom applications of smart power technologies include functions like the telephone hook switch, and subscriber line interface components for switching systems. Consumer applications include audio power amplifiers, like the 100W/100V device shown in figure 12, and power circuits for monitors, TVs and VCRs.

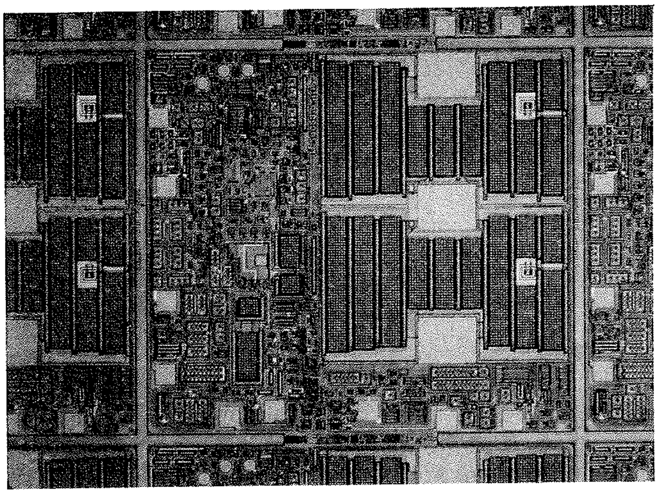

Fig. 12 *In addition to the trend towards greater complexity, there is also a trend to use smart power technologies in new application areas. This audio power amplifier, for example, uses BCD100 technology to achieve an unprecedented 100W output power (180W peak).*

Additionally there are some important new application areas related to the development of high voltage technology: fluorescent lamp driving and motor control for appliances. In both cases there is a major new market driving technology and product development.

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