Chapter 4
High Voltage and Power

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Abstract High voltage and power are essential for successful MtM product creation. This chapter gives an introduction for the basics of high-voltage and power technologies. Application examples of solid-state lighting and hybrid cars are presented.

Keywords High voltage • Power • Solid-state lighting • Hybrid car

4.1 Introduction

High voltage (HV) and power can be defined as any voltage higher than that used in the classical digital I/Os within the state-of-the-art semiconductor processes, i.e., starting at 3.3 or 5 V. HV interfaces and functions are important parts of most (small) systems, usually as part of an input/output (IO) system that interfaces the system to the real world.

They are usually needed when the I/O device requires a high-power or high-voltage drive (e.g., electromechanical actuators or LCD displays) or when high-voltage capability is required in protection circuitry that allows sensitive electronic circuits to be used in harsh environments. High-voltage capabilities are also required in power management, power conversion, and power distribution circuits. Power management solutions are necessary to drive low-voltage CMOS circuitry from battery or AC-line power sources in a wide range of consumer products. Automotive systems need to drive electromechanical actuators such as fuel injection systems, solenoids, start motors, and electric windows but are also increasingly typified by

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low-voltage electronic systems in body control and safety systems that need protection circuit from voltage spikes.

The high-voltage and power technologies can help to solve some grand social and economic problems, such as energy, healthcare, and environment protection. Examples are energy saving by solid-state lighting (SSL) systems, health assistance by electro-biomedical systems, and pollution reduction by hybrid/electric cars or energy harvesting. Examples of existing and emerging applications of HV include the following:

- Power management solutions to drive low-voltage CMOS from a variety of sources. This includes a large range of applications, from battery-powered mobile gadgets to mains-powered consumer products.
- Car systems:
  - Conventional electric systems based on 42/14-V car batteries, driving mechanical actuators such as in fuel injection systems, solenoid drivers, starter engines, and electric windows.
  - Emerging technologies such as x-by-wire, EVT.
  - Hybrid car electronics, involving 200-V (and above) electric motor driver circuits.
- Solid-state lighting
- Power supplies for PCs
- Climate control
- Industrial applications
- Electrical power generation and distribution:
  - Battery chargers
  - New portable energy sources, e.g., microfuel cells, microbatteries
  - High-power DC-to-AC converters (e.g., for solar cells)
  - Decentralized and regenerative energy supply (wind power plant, fuel cell, microturbine, photovoltaic, etc.)

The application parameters are as follows:

- On-state resistance (Rds, on) and breakdown voltage (BVds)
- Switching performance (Qgd)
- Robustness
- Operation temperature range
- Integration density when combined within a CMOS environment
  - Logic density (gate/mm^2, Mbit/mm^2)
  - Current density in metallization layers
- Parasitic effect immunity

All these parameters contribute on device level to an overall system performance that can be classified with respect to energy conversion efficiency and cost efficiency.

4.2 SSL Technology

4.2.1 General Lighting Technology

During the last 10 years the enormous business of portable systems such as mobile phones, PDAs, portable computers, IPods, etc. has focused the research on finding solutions that could provide a longer battery life.

Obviously big improvements have been obtained in battery chemistry and in the efficiency of energy management, but especially on the utilization devices such as microprocessors, displays, speaker drivers, and mainly on the lighting.

The utilization of portable systems in dark environments was and continues to be the most critical condition of power consumption for many reasons. One among these is the difficulty in matching between the source's electrical parameters (voltage and current) and the lighter's parameters.

The classical incandescent lamp, based on an electrical resistor heated by the joule effect generated by current flow, generally is the easiest load that can well be matched to the source's characteristics. It is easy to design a lamp with the optimum electrical resistivity adaptable to the voltage level of the main supply networks of portable systems. It can cover a very wide range of supply voltages, from hundreds of millivolts up to hundreds of volts.

Other advantages are low cost and the simple production technology. Unfortunately, many drawbacks affect this object, starting from high temperature generated and, as immediate consequence, the extremely low light efficiency, the limited lifetime, and the poor white light quality.

If the lamp is designed for high voltage and medium-low power, fragility becomes an issue. In fact the very thin resistive wire required can be easily broken by a simple shock, especially when incandescent. Because of the high-temperature range the "package" is generally glass and this is another source of fragility.

It is easy to understand that the extremely low cost of incandescent light systems has been the main reason of their enormous diffusion in all application fields, for sure where the energy source is unlimited but in the past also in portable equipment due to missing alternative technology.

The strong need to light small watches and mobile phones has encouraged the research to work and develop new lighting technology with the key target of light efficiency and quality.

4.2.2 New Technology

Many new lighting methodologies based on different physics phenomena have been developed: everybody remembers the first generation of digital wristwatches based on a red LED (light-emitting diode), shown in Fig. 4.1. The LED typical supply voltage is from 1.2 to 2.1 V.

Fig. 4.1 Digital wristwatch implementing red LED display

Fig. 4.2 An example of NIXIE tube with numerical digits

Before the LCD technology based on a liquid crystal display that does not emit light, the alphanumerical displays were based on a NIXIE technique (Figs. 4.2 and 4.3) widely used in watches, pocket calculators, electronic balances, and typically in flippers.

A nixie tube [1] is an electronic device used to information. The glass tube contains a wire-mesh anode and multiple number-shaped cathodes. The tube is filled with a gas at low pressure, usually neon with a little percentage of mercury and/or argon.

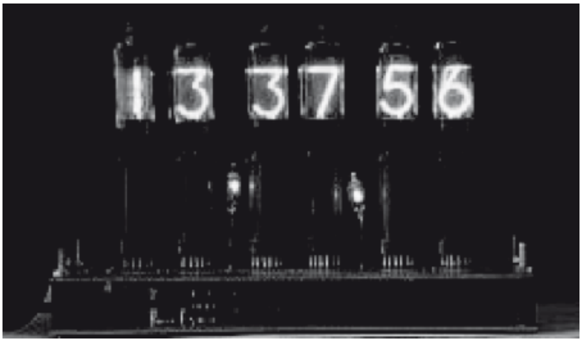

Fig. 4.3 Watch based on nixie display

Fig. 4.4 Electroluminescent display

Average longevity of nixie tubes varied from about 5,000 h for the earliest devices to 200,000 h or more for some of the last introduced ones. It should be noted that there is no formal definition for what constitutes the "end of life" of nixies (mechanical failure excepted) but a continuous reduction of light intensity.

The nixie tube requires a main supply voltage in the range of 120–200 V plus some other bias and control voltage lines.

Electroluminescence (EL) [2] is an optical and electrical phenomenon of light emission in response to an electric current or a strong electric field applied to a particular material. This is different from light emission resulting from heat (incandescence) or from the action of chemicals (chemoluminescence). Electroluminescence (Fig. 4.4) is the result of irradiative recombination of electrons and holes in a material (usually a semiconductor). The excited electrons release their energy as photons - light. Before recombination, electrons and holes are separated either as a result of doping of the material to form a p-n junction (in semiconductor electroluminescent devices such as LEDs) or being excited by the impact of high-energy electrons accelerated by a strong electric field (as with the phosphors in electroluminescent displays).

4.2.3 Fluorescent Lamps and Driving Methodology

We can find an important example of battery-supplied object on space satellites with humans on board, where light is required to have a good comfort. Since the first satellites were realized in sixties, lighting has been generated by fluorescent lamps (Figs. 4.5 and 4.6).

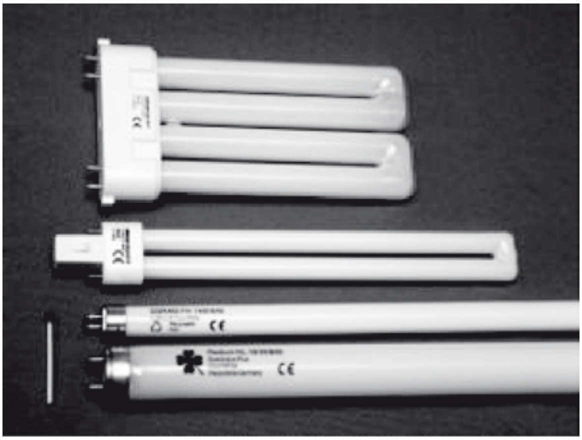

Fig. 4.5 Driverless fluorescent lamps

Fig. 4.6 Fluorescent lamp with modern electronic driver

Nowadays these kinds of lamps are widely diffused in private houses and especially in public structures or offices – thanks to their relatively low cost and their improved light efficiency, higher than classical incandescent lamps.

Unfortunately, the main AC (alternate current) supply networks cannot directly drive these lamps because they need a series of nondissipative current limiters and dedicated start-up circuits.

Where the space around the lamp is not a problem the driver is very simple and composed of two main passive devices; a simple coil usually called reactor realizes the current limiter. The start-up is performed with a nonlinear component called “starter” that generates with the reactor an overvoltage pulse able to trigger the discharging through the low-pressure gas inside the tube. Once discharging has been triggered, the tube behaves as if it has low impedance, due to the good conductivity of the ionized gas, and so a current limiter is mandatory and it is realized by the coil.

A power factor corrector (PFC), simply implemented by a normal capacitor, is also needed to rephase the voltage and the current.

A typical driving circuit is shown in Fig. 4.7.

About 20 years ago electronically driven fluorescent lamps, represented in Fig. 4.6, have been introduced in the consumer market with a big success, mainly due to the possibility to replace classical incandescent lamps through the same standard connector.

This has been made possible - thanks to the electronic driving that allows to place in a small volume the reactor and the start-up circuitry. The base of the lamp contains an integrated circuit (IC), and few discrete components such as a small coil and a capacitor are also present. The IC drives the coil with high-frequency voltage pulses to generate the extra voltage necessary to trigger the gas discharge. With increase in the frequency, the dimensions of the coil and the capacitor automatically scale down to few cubic centimeters.

The IC makes also possible all the optimizations such as the immediate ignition without flickers and the adaptive power factor correction. These lamps are 2–3 times more efficient than incandescent ones and have longer lifetime.

To support this business some silicon companies have invested in high-voltage technology, allowing the design of ICs directly supplied by the network power line (off line) without any scaling down of transformers or preregulators.

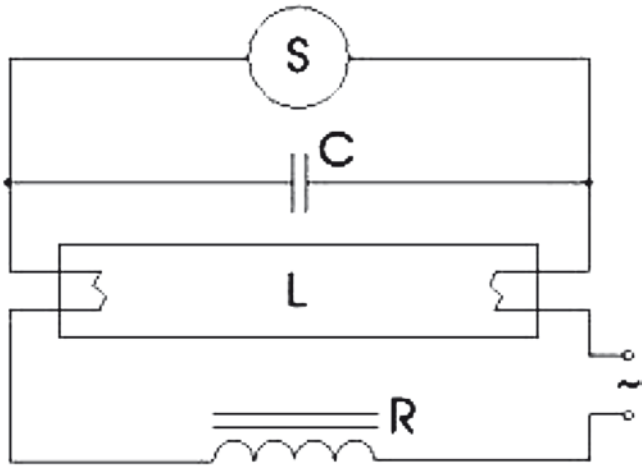

Fig. 4.7 Full passive fluorescent tube driving circuit

Obviously, these technologies do not follow the Moore's law, because these are not driven by low lithography but by all the isolation techniques that allow high electrical field in micrometric dimensions. A deep analysis of the silicon technology for fluorescent and LED lamps will be presented in the following section.

4.2.4 IC for the Fluorescent Lamps

Figure 4.8 shows an example of IC for lighting applications that is integrated in one small package with all the functions required for the correct operation of the electronic ballast and the PFC function.

The PFC provides the rephasing of the supply power line, assuring no noise injection on the domestic network. That means no more interference on television or radio when fluorescent lamps are powered. Moreover, it contributes in keeping high overall efficiency.

The electronic ballast is an adaptive current limiter able to optimize lamp's lighting, its fast ignition, and mainly the lamp's life. A half-bridge drives and controls the management of the preheating and the ignition pulse for the lamp as well.

The silicon technology, needed to design these drivers, integrates mainly CMOS plus high voltage (up to 700 V) DMOS or IGBT.

These kinds of ICs are able to guarantee flexibility, protection, and optimum internal signal management between the PFC section and the current controller during the ignition sequence, delivering the right current level and shape according to the lamp's characteristics (aging) and ambient environment (temperature).

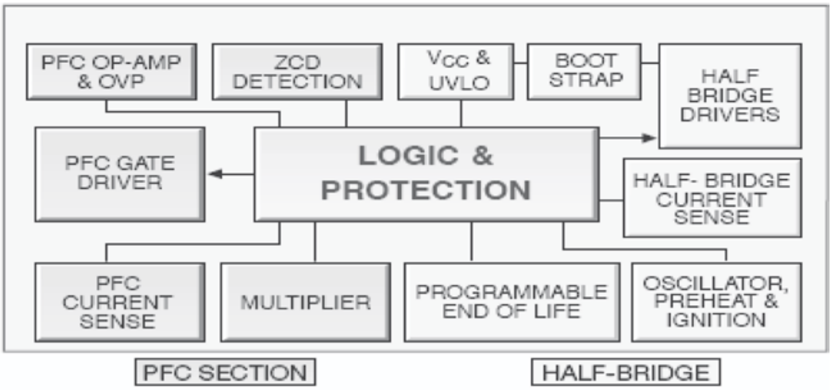

Fig. 4.8 A fluorescent lamp driver IC for OFF line connection

These driving devices are not simply a sum of two different ICs (a PFC and a half-bridge controller), but include functionalities that increase the system reliability, protecting the ballast in case of bad design or external component failures. As an example, the saturation of the PFC coil is prevented and its correct operation is constantly monitored; this is an important feature for general safety of high-voltage systems.

Many patents protect the integrated circuitry that controls the aging of the lamp installed in different configurations.

During lamp's aging, the end-of-life detection is performed by monitoring the current variation needed to keep the lamp switched on at the optimum light level. When this current becomes too high, causing a huge drop in efficiency, the IC controller can be programmed to switch off the lamp.

The main features and characteristics of the fluorescent offline lamp drivers can be summarized as follows:

- Since preheating and ignition phases are independently programmable, a unique IC is suitable for different lamp types/sizes.
- The controlled lamp voltage/current during ignition and the overcurrent protection during running mode increase the ballast reliability.
- The programmable end-of-life detection (Fig. 4.9), compliant to the two standard ballast configurations, allows flexible design (lamp to ground or block capacitor to ground).
- Overvoltage and feedback disconnection detection on the PFC stop the IC, avoiding ballast damage.
- PFC current sense and inductor saturation detection considerably increase the system safety.

These complete high-voltage ICs make easy to build high-performance electronic ballasts for fluorescent lamps.

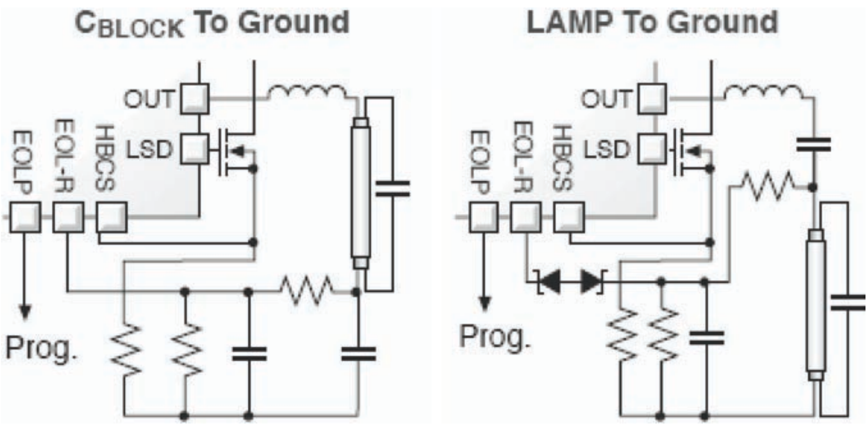

Fig. 4.9 Ballast and PFC configuration for end-of-life detection

4.2.5 LED Lighting

The LEDs perfectly respect the definition of SSL. Many are the uses of LEDs, organic LED (OLED), or polymer light-emitting diodes (PLED) as sources of illumination rather than that of electrical filaments or gas.

The term “solid state” refers to the fact that the light in a LED is emitted by a solid object - a block of semiconductor – rather than a vacuum or gas tube, as in the case of traditional incandescent light bulbs and fluorescent lamps.

Unlike traditional lighting, however, SSL creates a visible light with reduced heat generation or parasitic energy dissipation. The light emitted by the traditional incandescent lamp is a consequence of the high temperature reached by the filament, so 90% of the power is wasted in thermal effect; in other words, it is lost.

Commercial white LEDs provide more than 40 lumens/W compared with 8–15 lumens/W provided by incandescent lighting. This can be considered the most important parameter that has been encouraging the continued research investment on these kinds of light sources.

This high efficiency obviously means a longer battery life in portable applications; this is a very important parameter but not the only one. If a light source generates high heating power, a large heat sinker is also needed to dissipate the thermal energy in an adequate volume.

The LED lamps can be very compact and useful in portable equipment by placing many LEDs to distribute light on the wide display or on the keyboard.

In the house lighting system, today this concept seems not to be relevant, because there is enough room and especially because the LED lamps can replace the traditional solutions (Fig. 4.10).

For sure, architects have already thought about new forms of lighting art using these very compact light sources distributed in an ambience to generate different atmospheres or to capture eyes’ attention on some particular objects.

Fig. 4.10 An example of commercial LED lamp compatible with the existing lamp connectors

Solid state also means very high reliability and strong mechanical robustness; LEDs are going to replace stop lights of the car, not only because of the insensitiveness to vibrations, but, most of all, for their quickness (order of microseconds) in turning on. An incandescent lamp takes 150 ms to turn on: during this time the following car, at 80 Km/h, has covered another 3.5 m before starting to brake.

Moreover, LED's lifetime typically lasts for 100,000 h or more, reducing maintenance costs. In comparison, an incandescent light bulb lasts approximately for 1,000 h. In other words, considering a daily operative duty of 3–4 h, LEDs would be replaced every 30 years while an incandescent lamp every year.

LED lighting systems have already proved to be very effective in indicator applications where brightness, visibility, and long life are important, such as in traffic signals. Becoming the high voltage and power technologies with the white LED more powerful and effective, LEDs are going to be used in more general applications such as the home lighting.

The modern illumination systems have to do more than just switch light on and off: they have to enable programmed lighting situations integrating settings depending on human presence and on daylight intensity.

HV and power technologies will thus allow not only a substantial energy saving but also comfort and flexibility, smaller dimensions and weights. To illuminate an ambience also the "light color," measured by the correlated color temperature (CCT), is important in achieving the right comfort.

While filament lamps provide different CCT from warm white to bluish light, today the research on LEDs is widening the color range, extending from classical bluish toward warm white.

Another actual and important aspect of this lighting system is the dimming, that is, the possibility to program or adjust the light intensity according to the situation. For example, in the dining room and when watching the television, a soft light is preferable, but to read a newspaper during the frequent advertisement breaks, the user would need to increase light density.

Incandescent LED lighting can be dimmed easily. Dimming of fluorescent lighting is more expensive because of the cost of the dimming components required.

In the following, the driving methodology and electronic technology needed to perform the system key parameters will be described.

4.2.6 IC for LED Driving

There are two main categories of LEDs: the white-blue LEDs, with a typical voltage drop of 3 – 4 V, and the green-red-yellow LEDs, with a typical voltage drop of 2 V or less.

It is possible to make another distinction based on the forward current, that is, the low-current LEDs, from 15 to 50 mA and the high-current LEDs, from 350 to 1,000 mA.

When LEDs do not come from a special selection based on their voltage drop, if connected in parallel, they have different brightnesses depending on the individual voltage drop. The result could be not acceptable in many applications.

The solution is to connect LEDs in series. In this way, they are driven by the same current and so no difference in brightness is present. The disadvantage of this solution is that a high voltage is required.

A typical way to realize a constant current source to keep constant the brightness is to use a DC-DC converter (Fig. 4.11). The current loop can be obtained simply connecting a resistor between the voltage feedback pin and GND. The DC-DC converter will adjust the output voltage (V_{out}) in order to control and keep constant the V_{FB}, so the LED's current will be automatically controlled by the Ohm's law. Some tricks can be used to reduce the voltage drop across the sense resistor in order to increase the whole efficiency. The output voltage can be in the range of tens of volts depending on the number of LEDs in series and on the current level.

To modulate the brightness it is possible to act in two ways: by varying the DC value of I_{LED} or by modulating the constant current level in PWM mode.

According to the level of the main supply voltage and the number of LEDs in series, the DC–DC converter topology can be a boost converter, a buck-boost converter, or a simple buck converter. This choice has an important impact not only on the converter topology but mainly on the silicon technology.

When batteries supply the LEDs, the driver IC is designed in a low-voltage mix mode technology, integrating high-quality power DMOS able to guarantee high efficiency and driving capability with low supply. Considering a supply based on a double NiMH (nickel metal hydride) battery, the input voltage range is 1.8–2.4 V; it means that the DMOS used to drive the external coil has to guarantee low $R_{ds,on}$ with just 1.8 V applied to its gate source.

The generated output voltage depends on the number of LEDs in series and can reach 20–30 V; this fixes the technology voltage class that is, in any case, in the range of few tens of volts. The previous example is referred to as boost topology.

An interesting and actual application of LEDs is the wireless optic mouse supplied by one or two NiMH cells or one LiIon (lithium Ion) cell, while the main supply voltage range is between 0.9 and 5.2 V and the load is composed by just one

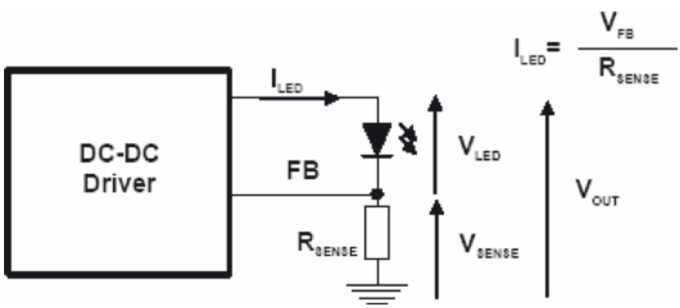

Fig. 4.11 Current mode driver for LEDs

LED with a typical voltage of 1.6–2.1 V. Here, a 7-V high-performance mix mode technology is the best choice.

The most interesting emerging application is the LEDs' driver supplied directly by the main domestic electric line in the range of 175-V AC or 230-V AC (depending on country standards) that becomes 175-V DC and 326-V DC, respectively, after rectification.

In the field of MtM application this is the most interesting LED driving methodology, and the circuitry will be a quasi-conventional step-down AC/DC current mode converter, but the silicon technology must be of high voltage (generally up to 700 V) to have enough capability to manage and survive to the noise spikes and overvoltages present on the "dirty" domestic power lines.

In Figs. 4.12 and 4.13, two examples of HV ICs are shown, designed on a junction-isolated technology based on a 2-μm minimum lithography. It is easily

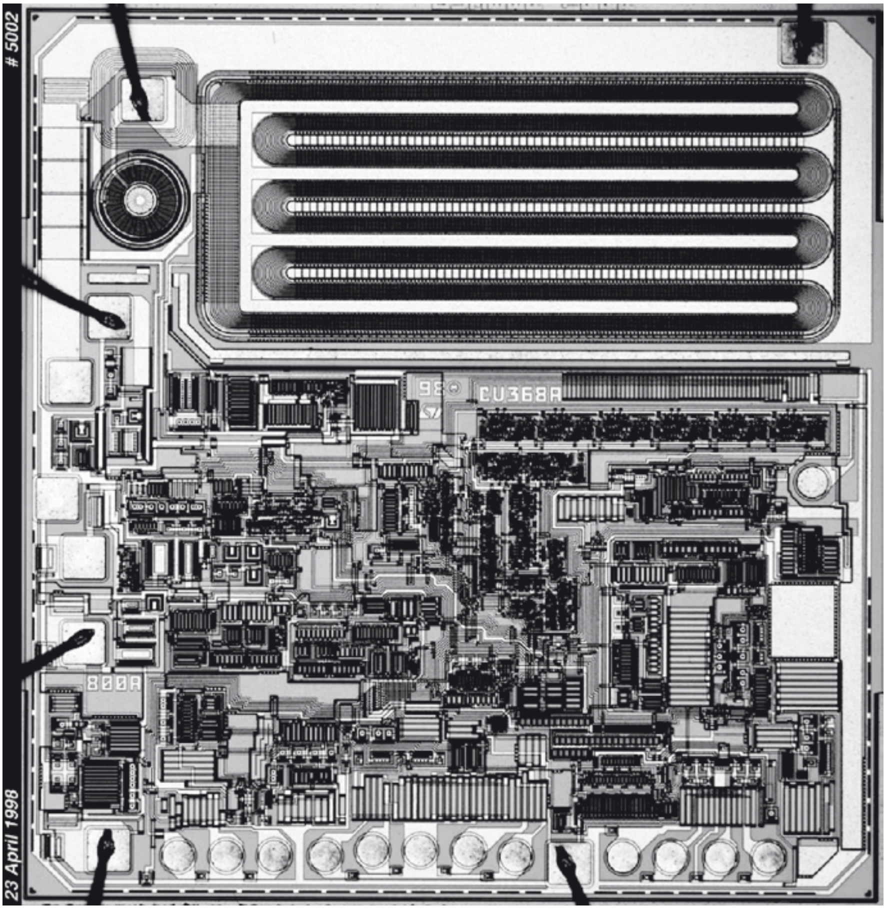

Fig. 4.12 An example of a HV integrated circuit on a junction-isolated technology

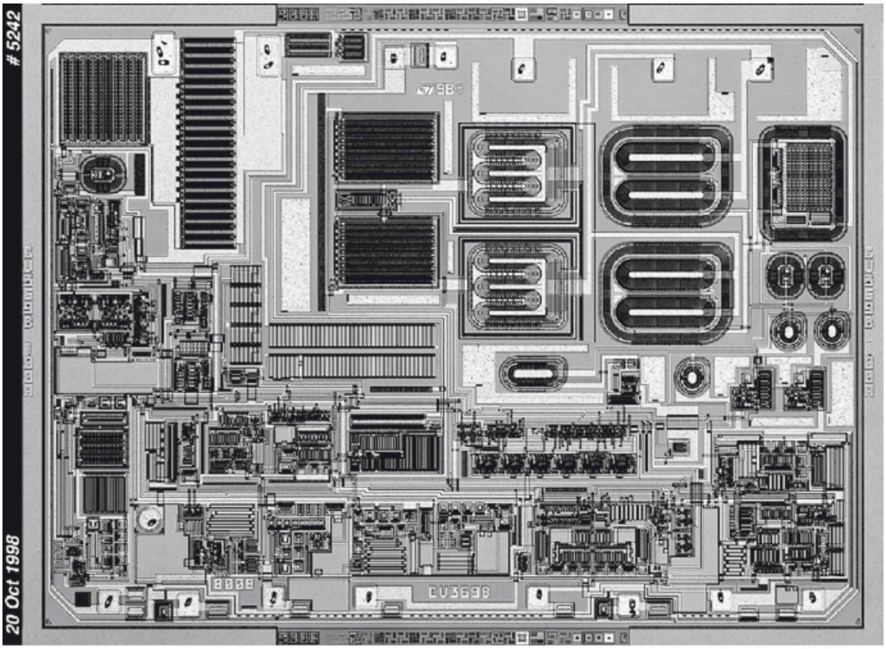

Fig. 4.13 An example of a HV integrated circuit on a junction-isolated technology

visible that the rounded geometry of the HV transistors is adopted to avoid the concentration of electric field like the "tip effect."

The right technology could be the SoI (silicon on insulator) that can allow high-voltage components in a very dense layout, because an oxide guarantees the isolation between the active devices in a deep trench instead of classical reverse-biased diodes. This will allow to integrate also a large-sized logic to interface a power line modem able to receive and respond to the commands delivered through the power line by a central box of the future (and actual) domotic systems.

4.3 Automotive IC Technology

4.3.1 Introduction and General Automotive Survey

Generally speaking, car systems nowadays are not so different from the ones put into production more than a century ago with a thermal engine working with crude oil derivatives. Although big improvements have been done in general performances, internal combustion engines still suffer from relative low efficiency and high-pollution production.

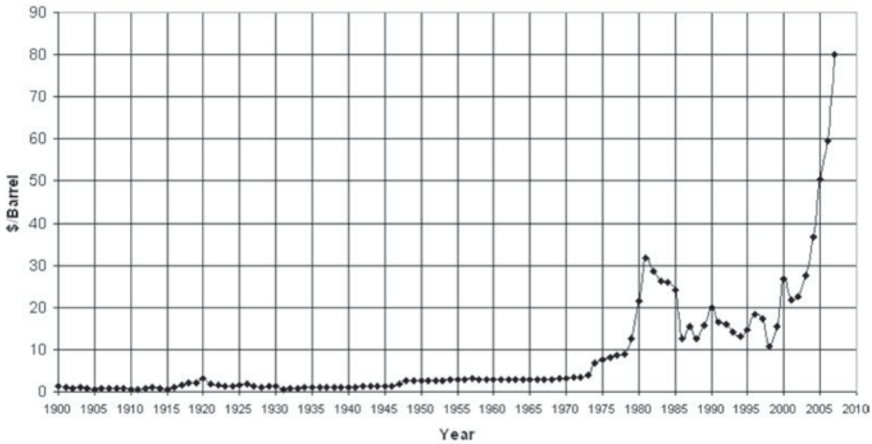

Fig. 4.14 Crude oil price history

Modern engines have an average efficiency of only 25–40%; this means that 60–75% of energy is dissipated in heat or friction losses. Global efficiency is also related to the use range of the car: idle, urban driving, and highway conditions have big difference in terms of engine performance.

Another source of inefficiency in car system is the amount of auxiliaries such as pumps, fans, and actuators normally driven by mechanical link.

As far as production of pollutant gases is concerned a big discussion is now in place on global worming and transportation contribution, despite the fact that more than 95% of greenhouse gasses is due to natural water vapor; carbon dioxide (CO_2) is the another major contributor (70% excluded water vapor).

Transportation system plays a significant role in CO_2 pollution (15% of total anthropogenic CO_2 production). For example, when burning 1 L of gasoline 2.3 Kg of CO_2 is produced. This becomes 2.7 Kg for diesel engines. When you drive a distance of 500 Km with your gasoline car, assuming an average fuel consumption of 7 L/100 Km the CO_2 production will be $7 \times 5 \times 2.3 = 80.5$ Kg. This figure is one of the key drivers for future engine efficiency improvement.

This tough situation is becoming difficult to sustain also due to the price of crude oil that was historically few dollars per barrel till the 1970s but starting from that point, driven by political and production strategy reasons, it is projected near $100 per barrel at the end of this decade (Fig. 4.14).

For the discussed reasons the car system is in a breakpoint; the automotive application driving forces are related to pollution and fuel consumption reduction.

A lot of research activity is in the power train arena, which is following the engine efficiency evolution. Figure 4.15 describes the evolution of the engine typology where the most important trend is the replacing of standard indirect diesel and

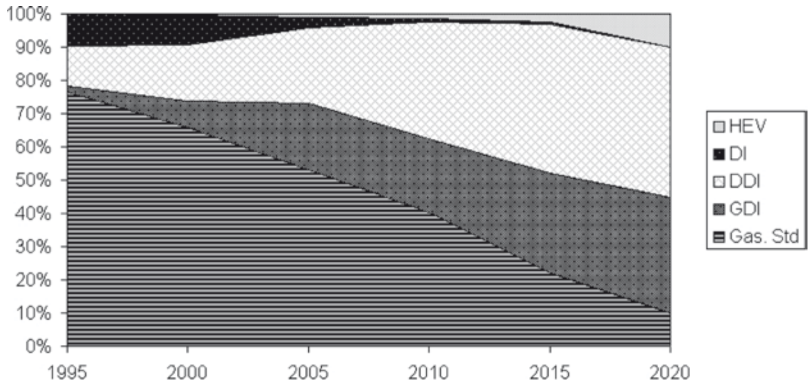

Fig. 4.15 Engine evolution

gasoline systems with direct injection in the combustion chamber and the increasing use of electrical and hybrid cars.

The key drivers of this evolution are the environmental care, the strict pollution regulations, the high fuel price, and the public/private financial incentives.

4.3.2 Engine Evolution: Major Trends

4.3.2.1 Gasoline Engine

The spark-ignited engine toward meeting the Euro6 pollution standard will be downsized, with a turbocharger and direct injection fuel loading.

This big change will force an evolution of the solenoid injectors that will be capable to inject fuel in the cylinder in high-pressure condition; the standard 14-V power supply will be increased to 80–150 V trough on-board DC/DC converter.

4.3.2.2 Diesel Engine

As regards air pollution caused by diesel engines, the main problems arise from the presence, in the exhaust gas, of nitric oxides (NOx), particulate matter, carbon monoxides (CO), and hydrocarbons (HC).

The direct injection with solenoid injectors in diesel engine is nowadays a common standard but is facing a technical limitation when fast multiple injections are necessary in very low emission conditions because of the slowness of the injectors themselves.

The pressure of common rail system is in the range of 1,800–2,000 bar; a key feature of high-pressure systems is that they can provide good fuel spray formation, which is needed for low particulate and hydrocarbon emissions.

To fulfill latest emission legislation, multiple injections in the same combustion cycle and very short actuation timing are necessary; in high-performance platform up to seven multiple injections with minimum timing of less than 100 μs have been achieved.

A possible solution is the use of faster piezoelectric injectors; also in this case the needed supply voltage will be higher than the standard 14-V battery line and will be in the range of 300 V.

4.3.2.3 Hybrid Cars

This is the most promising engine technology in terms of pollution content and driving comfort and is the combination of an internal combustion engine and an electrical motor controlled by an electronic system able to share the two power contributions, taking care of the driving conditions so as to minimize the fuel consumption.

This technology allows functionalities not possible in a conventional system, such as the start/stop driving, the energy recovery during the braking phase, and the improvement of standing-start performance and torque management (smooth or boost capability).

The standard hybrid drive train system includes a high-voltage battery pack (150–300 V), the main inverter for traction (400–600 V), and the buck and boost DC/DC converters for auxiliary loads (lamps, entertainment, etc.) and for the inverter supply.

In all the new power train systems, an updated HV power silicon technology will be necessary allowing higher integration to minimize the cost and the wiring, thereby increasing the reliability and the electromagnetic compatibility.

4.3.2.4 Engine Auxiliaries

The service system in a car is becoming important in overall car efficiency due to the increased numbers of nodes following the drivability, safety, and convenience request.

There are tens of actuations in a modern car (pumps, fans, compressors, etc.), most of them mechanically linked to the engine with pinions or belts.

Mechanical actuation suffers from low reliability, weight, and poor regulation performance; the actual trend in car systems is the replacement of mechanical and hydraulic components by electrical ones.

The most important advantage of this solution is the possibility to put the auxiliary loads in the complete regulation loop to minimize fuel consumption acting "on-demand" actuation instead of constant delivery.

In Fig. 4.16 there are some examples of new systems that have migrated in the electrical or regulated domain and their direct impact on the fuel consumption efficiency. This big change will involve the usage of electrical motors that, for permanent

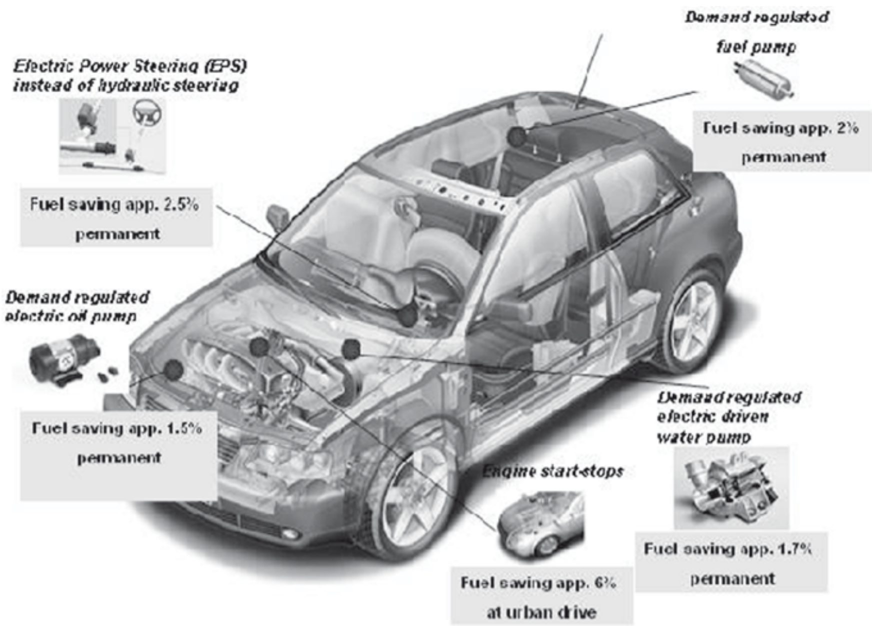

Fig. 4.16 Auxiliaries evolution

use and safety applications, will be brushless DC (BLDC) for achieving better long-term reliability than the standard one.

Future service systems ask for high-power IC technology capable of driving these actuators that are ranging between 10 and 30 A and can easily integrate high-voltage gate driver for high-current motors of 100–200 A.

4.3.3 High-Voltage and High-Power Silicon Technology

Following the big change in the car system IC technologies for automotive are following a different road map compared with other applications where CMOS-based scalability is well established. The new requirement in terms of power and voltage is setting a specific trend; new driver families require a combined technology platform where digital content, energy capability, and high voltage and high current will survive in a single chip.

In Fig. 4.17 the automotive standard voltages are depicted: on the left side there is the battery voltage range for standard single battery and double battery systems, and on the right side there are the common voltage ranges required for the output stages. The output working voltage range (in the past limited to 70 V) is now extended up to 300 V and is more due to the beginning of a new age in the engine concept.

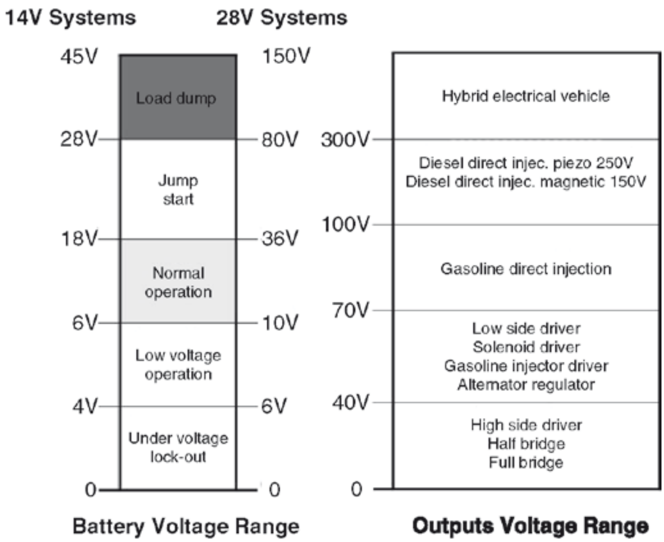

Fig. 4.17 Automotive voltages

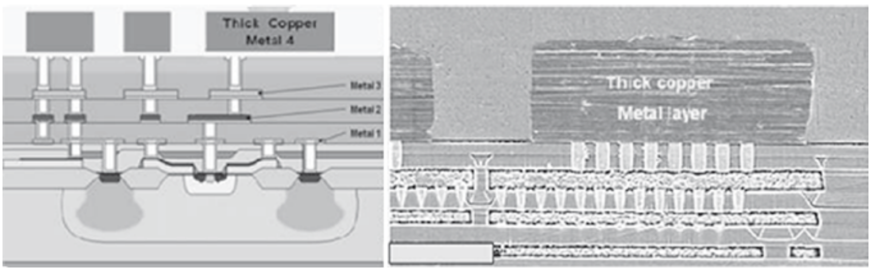

Fig. 4.18 Thick copper metal

The extended voltage range is not the only new requirement for the newcomer automotive smart power devices; the increase of current content with the rise of energy clamp capability requires a dedicated approach to realize robust power elements in a way to guarantee long-term reliability performances.

One of the possible solutions for devices capable of 10–20 A is the introduction of thick copper for the final routing level; the advantage of this process module is the lower resistance of copper compared with aluminum and the possibility to reach relatively high thickness in the range of 5–10 μm, allowing more easy chip floor plan and facilitating bonding on active area.

Figure 4.18 shows a 0.35-μm BCD process metals scheme and the relative microscope picture; the latest layer is a 6-μm copper trace.

The extended voltage range capability of automotive devices is the latest request from the market following the demand of injector predriver for diesel and gasoline direct injection systems.

The BCD roadmap normally includes a family of processes capable of 700 V, used mainly for industrial and consumer purpose. A typical IC realized with this technology is the electronic ballast for lamp application. This type of device is quite simple; a very limited analog CMOS portion and a pulse level shifter with a HV "resurf" lateral DMOS (Fig. 4.19) will form the main building blocks.

For this reason the technology used was not updated during the years for these kinds of devices – being a submicron solution not economically justified.

This solution in any case is not suitable for modern automotive predriver because the complexity needed for this device is much higher; the pulse level shifter suffers from poor common mode transient immunity and low latch-up performances.

Another drawback of pulse level shifter is the lack of real isolation between signal low-voltage circuitry and high-voltage floating epitaxial pocket, since the quasi-isolation is made by the two DMOSs loaded by two resistors in the pulse generator schematic.

The new challenge in smart power BCD process is the ability to integrate a coreless transformer (Fig. 4.20) that allows to overcome the mentioned weakness of pulse level shifter.

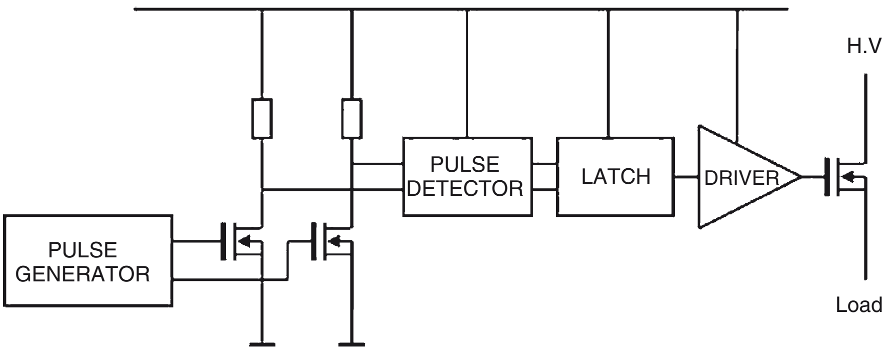

Fig. 4.19 BCD-offline level shifter

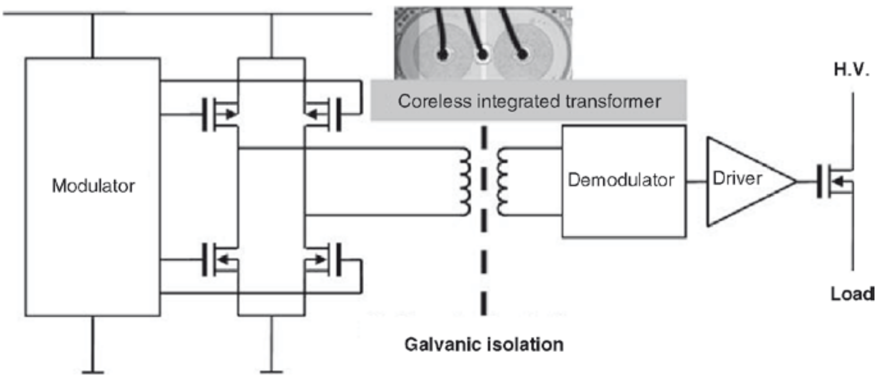

Fig. 4.20 Transformer level shifter

In fact in the transformer topology, the transient immunity and the latch-up performance are much higher, allowing a very high data rate and a real galvanic isolation.

This kind of structure can be imported in a submicron BCD platform using standard process steps and material and can be an interesting module for the future automotive process.

4.4 Research Subjects

The following subjects related to HV and power deserve more attention from R&D community:

- Reduction of transistor on-state resistance to reduce power losses and breakdown voltage.
- Improve switching performance for higher switching efficiency. Improve electrical robustness (e.g., reverse voltage, ESD, etc.) and operating temperature range.
- Optimise R_{on} versus voltage.
- Density of HV components.
- Surface or vertical device.
- Type of isolation (component pitch).
- Current density in metals.
- Parasitic effect immunity.
- Develop high-voltage/high-current interconnect architecture with thick Cu metallization.
- Develop new isolation technologies, such as selective SOI, to allow more flexible integration of HV devices with CMOS, lower leakage, and higher operating frequency.
- Develop energy scavenging systems for autonomous systems.

4.5 Energy and Efficiency [3]

4.5.1 Energy Generation

The specificity of the energy at the microscopic scale lies in the spread aspect of the energy needs. This spreading is linked to the tremendous increase of autonomous and portable systems (telephones, computers, robots, etc.), and soon to the generalization in the Ambient Intelligence environment of autonomous microsystems, microsensors, and microactuators. The development of batteries and fuel cells is a very important research area not only for chemistry but also for micro/nanoelectronics industry because the use of planar and collective processes (flexible supports, or compatible with integration on silicon) can provide cost-effective solutions. Thermal micromachines and microgenerators are also possible solutions even if these remain rather complex to be integrated. Among the low-power sources, the photovoltaic generation still raises many practical problems (packaging, manufacturing) or problems connected to the low conversion yield and to the very weak level of energy storage. The research on thermoelectric generation should be mainly oriented on materials and their integration in actual microsystems. Finally, the recovery of mechanical energy (vibrations, flow, or compression of fluids), with electrostatic, magnetic, piezoelectric, or magnetostrictive devices is a research subject with increasing attention. But since this domain is extremely large in terms of possibility of power sources and recovery principles, the best orientations remain unclear.

4.5.2 Energy Efficiency

The rising demand for energy in all forms and the decreased traditional energy resources have made it evident that energy must be used more efficiently. With the dramatic increase of leakage currents, design for high-power efficiency becomes an even more challenging task, due to the introduction of Cu/low-*k* CMOS technologies. In idle and shut-off mode, remedies such as MTCMOS, back biasing, etc. can be leveraged to reduce the impact of leakage power dissipation. However, most of these strategies are not applicable in active mode and in challenging future applications, e.g., in 10 GBASE-T Ethernet-over-Copper echo cancellation, leakage contribution to total active power becomes dominating in worst case leakage process and application corner. In such designs the low-power design space features many dimensions (e.g., multi/adaptive VDD, multi-VT including random modulation on extra stack level, device sizing/stacking including long Le, clock frequency optimization by parallelism/pipelining on architecture level, etc.). Navigating in this design space to minimize total active power dissipation is challenging due to strong interactions with timing, yield, and especially with noise margin. This consequently affects reliability. It has already been shown here in a 90-nm design featuring nearly 100 millions of transistors and operating at 800-MHz sample rate that careful optimization can yield huge savings in total power dissipation. Nevertheless, there is still a need for comprehensive optimization strategy taking all these interactions into account. The associated research subjects are as follows:

- Development of a framework on challenging applications in 65- and 45-nm CMOS technologies as well as in applying predictive technology models for future CMOS generations
- Dynamic control of digital supplies
- PMU adapting to analog dynamic range
- Low power or batteryless devices
- Ultralow-voltage/ultralow-power digital circuits
- New transceiver techniques to deal with lower voltage of new CMOS technologies while maintaining required dynamic ranges

4.5.3 Power for Mobile Communication

Future mobile communication systems require low-power implementation of complex functionality with highly efficient and highly linear CMOS solutions well beyond state of the art. The overall trust is dedicated to significantly improve the power/performance as well as the cost efficiency balance compared with current architectures. Total power efficiency, standby management, and deep-sleep current consumption effect battery size, bill-of-material cost, and product acceptance especially once portable electronics equipment, audio players, mobile phones, or digital cameras are envisaged. Mobile devices beyond third-generation (3G) products are all multistandard. They are expected to become more power hungry and they will require highly integrated power management solutions within separate power domains. One needs to meet the overall design requirements within the thermal envelopes for maximum battery lifetime and smallest chip and PCB area.

Major innovations to create more efficient overall platforms are expected to come from separation of power domains, unorthodox voltage regulators, use of sleep transistors, or running multiple power supply rails. Innovations for power management units are expected to be the integration of power circuits in deep-submicron technologies and the integration of external components on chip. Application and architectural savings are quantified using the product of the energy and the performance denoted (energy × performance). Work will concentrate on the feasibility, design, and development of power-efficient information technology devices and systems using approaches that extend beyond traditional CMOS scaling to achieve low-cost, reliable and fast systems. There are at least two aspects of power efficiency to enhance: back-off efficiency and peak efficiency. The associated research subjects are as follows:

- (Non)scaling effects calling for variation-tolerant design or soft-error mitigation
- Embedding power management and power output functions while obeying analog dynamic range restrictions
- Decreasing analog chip area and power consumption while concurrently removing OPAmp structures
- Inhibiting Vdd reduction with scaling, leakage (Vt), interconnect, and costs
- Implementing adaptive body biasing - reverse versus forward, supply gating, and active management methods.

References

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