

Role of Semiconductor Devices in Portable Electronics Power Management

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Abstract

Semiconductor devices continue to play a major role in enabling the realization of new portable products, which at present is one of the fastest growing segments in the electronics industry. To address key portable system requirements such as lighter weight, reduced size and heat dissipation, semiconductor devices associated with power management functions have become increasingly application-specific. In this paper, power devices and high voltage ICs that target power management related functions are examined. Tradeoffs in device design parameters related to various applications such as voltage regulation, battery and load management are outlined. Of particular interest is the area of off-line AC-DC conversion that employs mixed-signal Bipolar-CMOS-DMOS (BCDMOS) technology. Examples of switched AC-DC converters used in portable products and utilize cost-effective high voltage integrated circuits are presented.

Introduction

Over the last few years the continuing advancements in semiconductor device technology have fueled the development of many electronic products that are small and light enough to be classified as portable. Such smaller, lighter and feature-rich portable products have found widespread use in many applications particularly in computing and telecommunications. Examples of such products include notebook computers, Personal Communication Services (PCS) and Personal Digital Assistants (PDAs).

As battery powered portable products continue to evolve in features, performance and miniaturization their power consumption has increased significantly. Therefore, power management has become of paramount importance in order to maximize battery life, prolong product operation and reduce heat dissipation. Performance improvement of low voltage DC-DC converters has received a lot of attention and presently efficiencies higher than 94% have been realized. At the opposite end of the spectrum, the same portable requirement for weight and size reduction is driving developments in high voltage off-line Switch-Mode Power Supply (SMPS) that power battery chargers and are used in ac adapters. This point is well illustrated in Figure 1 that shows a linear power supply and a corresponding SMPS that uses a high voltage Three-terminal Off-line PWM Switch (TOPSwitch) power IC [1a,b].



Figure 1. Linear vs. Switch-Mode Power Supply (SMPS) using a high voltage TOPSwitch IC.

Innovative semiconductor technologies have enabled the increasing demands in system power management and are used to realize cost-effective system solutions. This paper reviews recent developments in silicon technology that target various power management system issues, particularly off-line integrated switchers, and outlines device parameters tradeoffs to optimize system performance.

Power Management System Architecture

A block diagram of a generic power system is shown in Figure 2. The main functional blocks of a power management system can be grouped primarily into voltage regulation, battery management and load management.

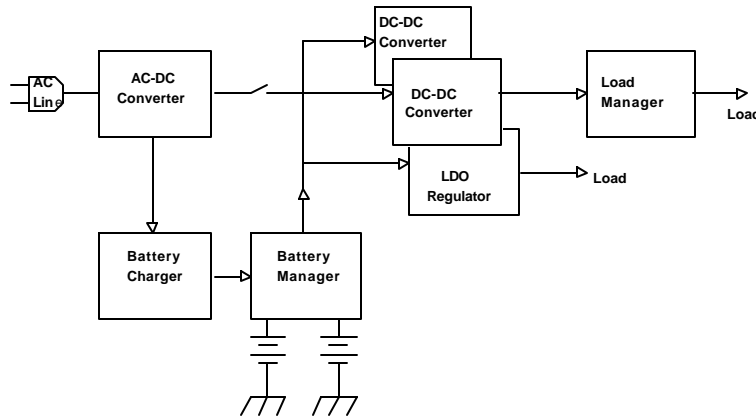


Figure 2. A block diagram of a generic power management system.

The broad function of voltage regulation includes both off-line (AC-DC), switch-mode (DC-DC) converters and low dropout regulators (LDOs). The AC line supply of 115V/220V is rectified, filtered and converted to a lower level supply rail and/or charges the battery. Power is supplied via a main power bus from an AC-DC converter or battery and feeds a number of SMPS DC-DC converters and/or LDOs that deliver several regulated supply rails. For example, 5V, 3.3V and 1.8V supply rails are generated from a variable battery voltage such as a three-cell Li-Ion battery pack that varies from 12.6V to 7.5V during its discharge cycle. The second main function is battery management and that includes battery control, sequencing of charge and discharge cycles of a single or multiple batteries and reverse battery protection. Finally, the function of load management is to shutdown power in unused parts of the system in order to reduce wasted energy and may include additional features such as level shifting, over-current protection and slew rate control.

To implement the above power management functions, a controller IC is usually used in conjunction with power transistors. The most widely used power semiconductor switch in portable power management is DMOS transistor where ultra low on-resistances have been realized using trench MOSFETs [2]. Recent advances in trench MOSFETs have come mainly from shrinking the device and increasing cell density. A cell density of 82 Mcell/in² with specific on-resistance of 26 mΩ.mm² at 4.5V gate bias and breakdown voltage of 30V has been recently reported [3]. In the case of DC-DC converters, n-channel power MOSFETs are used with low on-resistance as low as 8 mΩ at breakdown voltage of 30V. Devices are optimized for maximum efficiency since at high switching frequencies of about 300 kHz both switching and gate power losses become comparable to conduction losses. Therefore, gate-drain capacitance and gate resistance are minimized in addition to on-resistance. For battery management the dominant power switch is P-channel MOSFET and its low on-resistance is particularly important. Two back to back power MOSFETs with common source configuration provide the bidirectional blocking and bidirectional conduction (i.e. AC switching capability). In load management applications P-channel MOSFETs are usually used and in this case, in addition to on-resistance, maximum gate bias capability is important, since these devices are driven rail to rail.

A wide range of discrete, hybrid (multi-chip package) and integrated circuit components are available to power management system designers. Because of the power transistors very low on-resistance required in DC-DC conversion, battery and load management either discrete switches and a separate controller IC or a hybrid solution become cost-effective. In contrast, a higher level of integration can be cost-effective in off-line AC-DC switch-mode converters since a relatively higher on-resistance can be tolerated. In the following section the AC-DC conversion segment of power management is described in more detail.

Off-Line Low Power IC Converters

A primary goal in portable systems design is to reduce system weight and size. Therefore, the use of a linear power supply that weighs more than the system itself is an unacceptable design solution. Alternatively, a SMPS

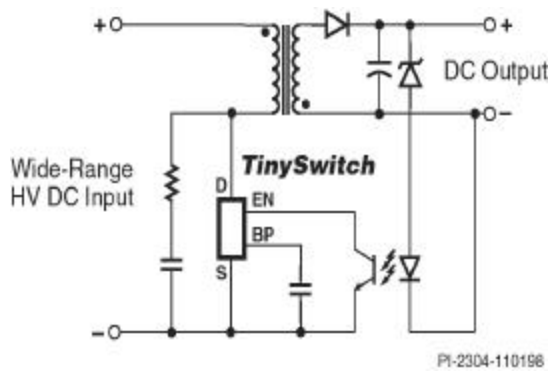


Figure 3. Basic TinySwitch Flyback power stage.

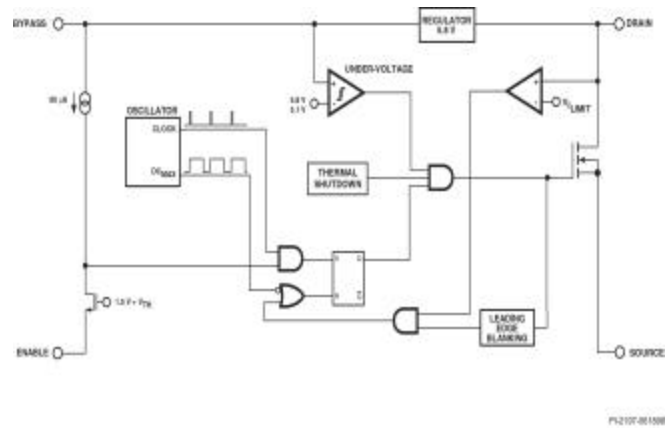


Figure 4. Functional Block Diagram of TinySwitch

which generally consists of a transformer, a Pulse Width Modulator (PWM), a power transistor and feedback circuitry provides better regulation, efficiency and reduced size. While a conventional 265V to 12V, 60 Hz steel transformer with 12W output measures 5 in³ and weighs 0.7 lb, a 100kHz transformer made of a ferrite material has a volume of 0.25in³ and weighs 0.03lb [4]. Furthermore, using a High Voltage (HV) IC technology to integrate the controller and power switch on the same chip provides even more efficient, lighter and smaller SMPS that can possibly be embedded within portables. The combined effects of integration, elimination of numerous discrete components, by utilizing innovative circuit design techniques, together with using a higher frequency transformer explain the drastic improvement in size and weight reduction illustrated in Figure 1.

The above objectives have been achieved in an integrated off-line power switcher like the 700V TinySwitchTM IC [5], shown in Figure 3. System size is reduced by the reduction of the number of external components and by a higher frequency operation of up to 130kHz. Figure 4 illustrates a functional block diagram of the most important features of the high voltage IC shown in Figure 3. The IC integrates a 700V power MOSFET, oscillator, high voltage switched current source, a voltage regulator, under voltage lock-out, current limit and thermal shutdown circuitry. Start-up bias is provided by the high voltage power MOSFET. This eliminates the need for a transformer bias winding and additional related circuitry. Moreover, the circuit uses a simple ON/OFF control to regulate the output voltage instead of conventional PWM and it consumes only 80mW at no load from 265V AC input.

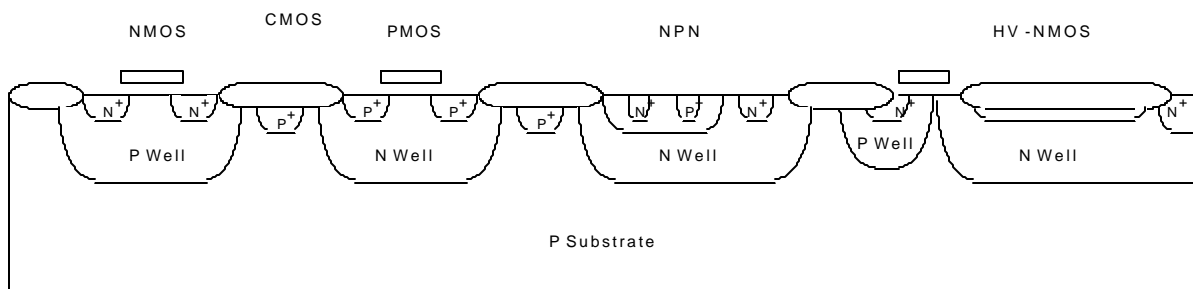


Figure 5. 700V BCDMOS technology device arsenal

The development of Bipolar-CMOS-DMOS (BCDMOS) high voltage integrated circuit technology [6] that combines high voltage (700V) MOSFET capability on the same chip with low voltage 5V CMOS and Bipolar analog and digital circuits has facilitated the implementation of off-line power switchers like that shown in Figure 4. Such BCDMOS technology has to be cost-effective when compared with discrete power switch solutions it is trying to replace. The technology is based on a double Resurfed high voltage lateral NMOS transistor with a low $R_{ds,A}$ of 17 $\Omega \cdot \text{mm}^2$ at a breakdown voltage of 700V. The process flow is similar to a conventional CMOS with few additional features. The devices are built on a high resistivity p-type substrate with n-well and p-well layers. Using the same oxide thickness for both the high voltage NMOS and low voltage CMOS results in threshold voltages of ± 1 V which makes the high voltage transistor fully on at logic level voltages.

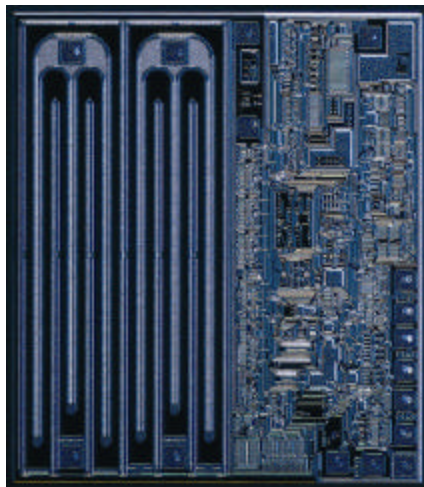


Figure 6. Micrograph of a 700V Three-terminal Off-line PWM Switch (TOPSwitch) IC.

Other advantages of the high voltage NMOS transistor is the lower miller capacitance which results in lower switching losses. Furthermore, the high voltage NMOS transistor's on-resistance exhibits less sensitivity to temperature variations than corresponding discrete devices because of the higher doping density used in the drift region.

Figure 6 shows a micrograph of a Three-terminal Off-line PWM (TOPSwitch) die. This high voltage IC uses a lateral 700V n-channel power MOSFET that roughly occupies 50% of the total die area. The low voltage section includes the digital and analog circuitry needed for power device controlled turn-on, gate drive, voltage mode PWM controller, oscillator, high voltage start-up bias circuit, temperature compensated current reference, bias shunt regulator and protection functions.

Conclusions

Advances in power semiconductor devices and high voltage integrated circuits continue to drive the fast evolution in portable products power management. Application-specific power MOS devices combined with controller ICs and high voltage ICs cost-effectively meet key portable power management system requirements of high efficiency, lighter weight, reduced size and heat dissipation. Primary device design parameters in main power management functions such as voltage regulation, battery and load management have been outlined. Particular emphasis was placed on off-line AC-DC conversion using cost-effective high voltage integrated circuit Bipolar-CMOS-DMOS (BCDMOS) technology. Examples of innovative high voltage ICs, already proven in the field and employed in AC-DC conversion were presented.

Acknowledgements

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