LOW VOLTAGE ELECTRONICS FOR PORTABLE WIRELESS APPLICATIONS: AN INDUSTRIAL PERSPECTIVE

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ABSTRACT

This paper provides an overview of low voltage/low power electronics developments and issues for portable RF wireless applications. Issues discussed include: semiconductor materials, device technologies, device modeling, circuit approaches, and system architectures. Finally, issues that impact the lower limits achievable in DC power and voltage reductions are discussed.

INTRODUCTION

The basic components required for wireless applications are undergoing a revolutionary change in terms of DC power consumption. Figure 1 shows the historical development of commercial GPS DC power requirements as a function of the year of introduction of the product. Over approximately the same period of time, the supply voltage for handheld cellular telephone products has seen a similar decline from 7 to 3 volts.

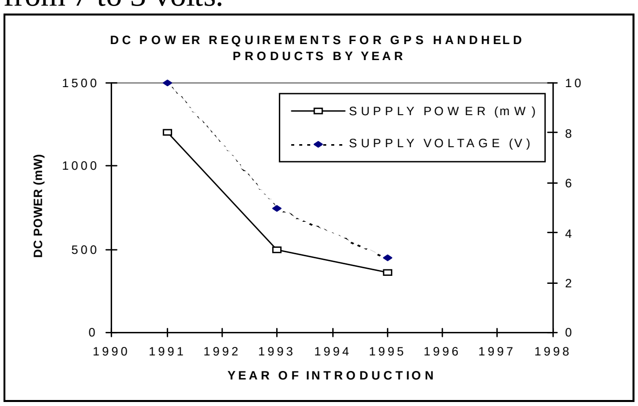

Figure 1. DC power consumption & battery voltage for hand held GPS units.

There are several drivers for this power consumption revolution, but the main drivers are a desire for longer battery lifetimes accompanied by a simultaneous desire for smaller, lighter batteries. At present, the single largest volume and weight component in most portable wireless products is the battery, yet the consumer finds the available talk and standby times for batteries to be undesirably short. To achieve desired improvements requires that the power consumption of the individual components, and thus, the overall hand held unit be reduced.

Although the reductions in supply voltage and power consumption of wireless products has been dramatic, further reductions will be increasingly difficult to achieve. The constraints implied by the low voltage imperative need to be examined as they apply to every aspect of RF/microwave component development.

MATERIALS TECHNOLOGY ISSUES

Low voltage/low power operation requires improved efficiency, low parasitic resistance and precise control of on-voltage. Each of these requirements is improved through the use of appropriate materials and material structures. Improvements in efficiency and reductions in parasitic resistance can be achieved by using materials that exhibit increased carrier mobility and velocity. The requirement for precise control of the on-voltage clearly favors a bipolar (vs. a FET) structure. When other considerations indicate that a FET structure is appropriate, however, heterostructure buffer layers improve the on-voltage control of FETs.

From a purely technical point of view, the above discussion argues for the use of III-V heterostructure devices. But these arguments ignore the overwhelming importance of cost and schedule to the development of many

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commercial wireless products. It is a dramatically superior process maturity and low cost that has allowed Silicon devices to continue to provide competitive performance, fast development cycle times and inexpensive parts for RF wireless applications.

There is no short cut for the development of experience and maturity with advanced III-V material structures. As demand for diminishing power consumption RF products continues to grow, however, experience will be gained and an increasing number of III-V heterostructure devices will gain entry into wireless products.

DEVICE TECHNOLOGY ISSUES

Device technology decisions affect many of the same performance metrics that are affected by material decisions. For example, efficiency, parasitic resistance and on-voltage control are all affected by the choice of device. Additional device considerations include linearity, breakdown voltage/power density tradeoffs and single vs. dual polarity supply requirements.

Table 1 presents a listing of device types that exhibit particular advantage or disadvantage with respect to the important characteristics for low voltage wireless applications. As is readily seen from the table, no particular device type excels in all areas and all device types exhibit at least some significant disadvantages.

Again, as in the case of material considerations, all of the technical considerations must be weighed against the demanding cost and schedule requirements for wireless product development.

TABLE 1. Important performance characteristics for low voltage wireless applications.

PERFORMANCE METRIC	DEVICES WITH ADVANTAGE	DEVICES WITH DIS-ADVANTAGE
High Efficiency	HEMTs	BJTs
Low Parasitic Resistance	HEMTs	BJTs & MOSFETs
On-Voltage Control	BJTs & HBTs	HEMTs & MESFETs
Linearity	epi-MESFETs and HEMTs	MOSFETs
High Breakdown with High Power Density	HBTs, HEMTs & doped chnnl MESFETs	conventional MESFETs
Single Polarity Supply	HBTs, BJTs & MOSFETs	MESFETs & HEMTs

MODELING ISSUES

Although device models for low voltage RF applications are required to predict the same performance figures (gain, saturated power, harmonic distortion, efficiency, etc.) as those required for other applications, the low voltage/low power operation does place additional constraints on modeling activities. In particular, operation at low current leads to the need for more accurate subthreshold, more realistic breakdown and improved temperature models.

Low current biasing means that the device is operated in the subthreshold region where many models fail. Harmonic content prediction of devices operated in this region exhibit particularly poor correlation to measured data.

When devices are operated near the onset of breakdown, leakage currents and device noise increase. These increases can have significant effects on PA design, but are not well predicted by DC breakdown models.

Device current levels can vary by an order of magnitude at low current bias when typical temperature variations are considered. Temperature models that are adequate for higher current bias levels, may fail to predict low current variations adequately.

CIRCUIT TECHNOLOGY ISSUES

In general, RF circuit performance is not improved by the reduction of voltage or current. A typical low voltage, low current amplifier exhibits a significant reduction in gain and

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linearity as either supply voltage or current is reduced. In addition, low voltage/low power circuit designers face difficult issues related to decreasing impedance levels of PA devices, limits to device stacking and difficult power-efficiency tradeoffs.

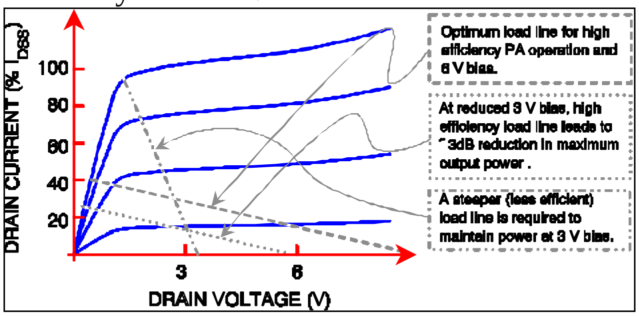

Figure 2. Illustration of the low impedance problem caused by low voltage operation.

Low voltage devices require higher peak currents to achieve equivalent Pout. This is accomplished, in practice, by increasing the device periphery. Figure 2 illustrates the problems encountered in circuit design if device sizes are not scaled up when voltage is decreased. Larger devices, however, exhibit lower impedance that must be matched. Thus, low voltage power amplifier parts have high transformation ratios. Typical 1- 4 Watt power amplifier parts for commercial cellular phones exhibit output impedance of less than a few ohms. High Q matching elements provide some advantage in achieving required transformations but come at high cost and reduced integration.

SYSTEM DESIGN ISSUES

Communication systems continue to require greater bit rates and bandwidths which leads to greater required linearity and higher frequency operation. Similarly, greater functionality requirements leads to greater circuit complexity. Each of these trends makes reductions in power consumption more difficult and places even more emphasis on the importance of low voltage/low power consumption design.

Other system trends, such as the movement toward digital modulation, can ease the low voltage/low power design issues. Because digitally modulated products are pulsed (vs. CW) the power consumption of the RF components represents a smaller percentage of the overall product power requirements.

Some proposed system innovations would have a dramatic effect on the war on power consumption -- changing the requirements (and the technologies of choice) entirely. Micro-cell telephone systems, for example, would dramatically reduce the battery requirements for cellular phone systems. Power consumption of the PA for such a system becomes inconsequential. In contrast, direct-to-satellite systems present significant challenges due to the high instantaneous output power requirements of the PA and low minimum noise figure of the front end LNA.

These system architecture issues are likely to have greater impact on the ultimate battery reduction limits than any of the material, device or circuit issues discussed.

LIMITS TO VOLTAGE REDUCTION

Since the reduction of battery size and weight is the goal of low voltage/low power electronics strategies, it is important to examine some fundamental issues related to batteries and the RF circuits they power.

Issues that limit DC power requirements for RF circuits are fundamentally different than those that limit DC power requirements for associated digital circuits. Digital circuitry is required to store and analyze information that is encoded in a binary manner. This can be accomplished theoretically by the presence or absence of a small charge (single electron). Although practical considerations make a single electron memory improbable, and movement of even one electron into and out of storage still requires energy, it is clear that binary data can be manipulated with extremely small amounts of energy. The system architecture does not impose arbitrary power requirements on the strength of the digital signal.

In contrast, the RF portion of radios is required to transmit and/or receive signals over a distance. Because power is lost in the radiation process, RF circuits must be able to handle power levels that are determined by the propagation media and transmitter-to-receiver separation. Thus, for RF circuitry, a reduction in voltage must be accompanied by increased efficiency and/or increased current. Since many portable units are already operating at efficiency levels near theoretical limits, voltage reductions nearly always involve increased current requirements.

As battery current requirements are increased, the internal resistance of the battery becomes a limiting factor in the total power the battery is capable of delivering. Figure 3 presents the maximum power capability for a battery as a function of nominal voltage and internal resistance. Although internal resistance is a function of the chemistry, number and size of the battery cells, the values used in Figure 3 are typical for nickel-metal-hydride batteries in common use for cell phones today and the trends plotted in the figure will hold for all batteries. It is clear from the figure that as battery voltages are reduced below ~3 volts, the maximum power available from them is reduced to levels on the order of that required from a portable cellular PA alone. When efficiency and other circuit requirements are considered, battery power levels are inadequate.

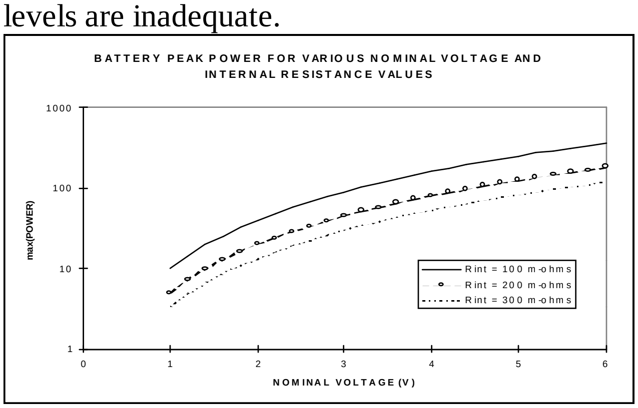

Figure 3. Maximum battery power (defined as nominal voltage x short circuit current) as a function of nominal battery voltage plotted for typical internal resistance values.

SUMMARY

Reductions in voltage and power consumption is important to the development of portable wireless products that are smaller, lighter and require less battery maintenance. Reductions can be achieved by careful consideration and improvement in the choice of semiconductor material, device type, models, and circuit topology. Further reductions may come with the emergence of innovative system architectures. The ultimate limit to decreasing battery voltage, however, will be determined by transmitter power requirements and achievable internal resistance of batteries.