University of Arkansas Microelectronics-Photonics Graduate Program
PhD Candidacy Exam – March 14, 2003
Microelectronics Area of Emphasis Exam

I) BACKGROUND:

As integrated circuit (IC) operating voltage decreases, clock speed increases, and supply current increases, it becomes increasingly important to provide localized conversion for IC power. That is, rather than having a large power source supplying 2.5 V at 50 A or more for an entire motherboard or other digital system, localized DC/DC converters will be used to supply 2.5 V to an individual IC or set of ICs. The principal distributed voltage from the main power supply might be 12 or 24 volts, and the localized power converters, known as voltage regulator modules (VRMs) will take that distributed input voltage and convert to 2.5 V. This avoids trying to distribute a low voltage at high current (which takes a lot of copper) as well as the problem of switching noise from one IC getting back into the power distribution system and affecting other ICs, even though many decoupling capacitors are used.

Typically, DC/DC down-conversion is done with a "buck" regulator, which uses an inductor, a switching transistor, a flyback diode, input and output energy storage capacitors, and a feedback control system to regulate the output voltage. Another DC/DC converter topology, the switched capacitor boost converter, has been used to produce voltages higher than the source, but at fairly low current. In this converter, capacitors are charged in parallel from the supply, then switched to discharge in series into an energy storage capacitor.

A recent research breakthrough at the University of Arkansas (where else?) may allow a variation of the switched capacitor topology to be used for high power down-conversion. A new thin film capacitor dielectric, with a dielectric constant of 200 and dissipation factor of .01%, has been developed. The breakdown voltage is 3 MV/cm, and the dielectric fabrication method (anodization) allows nearly defect-free films 400 angstroms thick to be deposited. This dielectric will allow a high capacitance density in single layer, thin film capacitors, so that a switched capacitor down-converter, charging capacitors in series and discharging them in parallel, should be a feasible way to build a 2.5 V, 10 A VRM operating from 12 V. The dielectric is created by sputtering a metallic layer, then anodizing using a wet process. You do not need to worry about the science of the dielectric itself. Take it as a given.

A UA spinoff company wants to get into the VRM business. One attractive way to build a converter would be to fabricate the capacitors directly on an IC die that contains the switching transistors and control circuitry. The packaged die (system on chip) would be a great product. Another way would be to fabricate the capacitors on a piece of Kapton™ flex, use that flex as a package substrate for the switch/control IC die, and then encapsulate the assembly of IC and substrate. Capacitors on flex substrates have previously been developed at UA. All processing on flex would be done reel-to-reel.

Your job, as chief engineer of the new company, is to come up with the one right product approach that will allow you and your partners to sell the company off in five years and retire to the Bahamas. But before you start counting your stock options, there is a lot of work to be done.

II) SCIENCE BASIS AND PROPOSED SOLUTION: (Science emphasis)

A. Establish the Science basis

In this first part, examine and report on the current science of the use of switched capacitor technology for voltage down-conversion, and its limitations. Begin with a general discussion of the system but also describe in detail the theoretical aspects of the system and each of its components. The current state-of-the-art should be described, making use of diverse resources such as science literature, journals, conference proceedings, the Internet, patents or other sources of existing public knowledge. Be sure to cite all references used. Demonstrate an up front understanding of the science limits behind the technology, making rigorous theoretical arguments leading to a proposed solution.

B. Compare and Contrast

Compare and contrast the traditional buck converter and the switched capacitor, or inductorless approach in terms of power density, conversion efficiency, switching losses, operating frequency, and the other appropriate metrics. Distinguish the on-chip and in-package capacitor approaches in terms of fabrication process, yield, size, capacitance density, etc. One of the products described above should then be selected on the basis of criteria you define, defended logically, and a research/development plan should be proposed to fully develop the product.

List the advantages and disadvantages of each. Provide details on the figures of merit used to compare the two approaches.

C. System

Elaborate on the selected solution, defend it logically, and propose a research plan to test the solution. Include a detailed description of the circuit operation and the physical configuration of the VRM. Include at least one diagram of the system being proposed. Cite references that provide similar systems to the one proposed. Although a literature review is required and expected, some originality is expected when designing the system.

III) DEMONSTRATION OF A NEW PLATFORM: (Entrepreneurial engineering emphasis)

In this section, you should demonstrate your understanding of how the technical issues interplay with the business, marketing, manufacturing and economic issues involved in launching a new product.

You should perform a cost analysis from front end to back end - that is, from acquisition of raw materials, labor rates, costs per operation, etc. assuming quantities of 1 million parts per year. You may exclude from your analysis possible additional costs in such infrastructure areas as human resources, facilities engineering, janitorial and grounds, upper level management, etc. You must include all direct manufacturing costs, both startup and continuing; and you must discuss explicitly space and personnel requirements to set up a stand-alone product line. Generic per process costs for various manufacturing methods can be used, as long as they are rationally applied.

In short, tell us everything that needs to happen to make your company, and the product you have chosen to develop, a roaring success. Make sure the logic you employ comes through in your writing, which should be carefully proofread. You will have to make lots of assumptions given the vague nature of the problem definition; this is OK as long as you state what those assumptions are and why you made them. Real life is a lot like that.

A. Prototype

Provide a detailed set of performance specifications of the system. This should include voltage regulation, power density, etc. Discuss the steps necessary to package the system for commercialization. Define specific reliability testing that will be completed prior to market introduction, along with the justification for each test.

B. Intellectual property

List all IP sources that were consulted while formulating the answer, and include the full list of examined documents as an appendix to this exam. (The full list will not be counted as part of the 15-page limit.)

C. Marketing analysis

Discuss the business, marketing, manufacturing and economic issues involved in launching a serious investigation of the proposed solution. Sources of available components and the cost should be listed. Identify potential customers of this system and how the technology will be applied. Estimate the number of customers and the number of systems that will be sold.

D. Broader impacts, future directions or new markets where concepts can be easily applied

In one or two paragraphs, discuss the impact and benefit to society and how to broaden the impact and to disseminate information as the research proves to be successful. Finally, you should make recommendations on future directions for investigation.