

## **CSE464, Spring 2004, Homework #0.5, Due 2004.01.26, 4:00PM**

**Important:** Please list at top of first sheet of homework submission anyone or anything from which you obtained any help for this homework assignment other than the text and class notes/discussion. Please give a word or two as to the nature of the help (e.g.: discussed problems, copied verbatim, whatever). Acknowledging source of help is a requirement for this assignment, and for all assignments in CSE464. It has no effect on your grade (unless you fail to do it).

An opportunity to apply a little network theory and math to simple DC power distribution circuits.

Note: These calculations are also applicable to capacitance, characteristic impedance, plane-spreading inductance, and temperature rise due to power dissipation. Learn one technology, apply widely.

It is important in engineering to have “ball park” estimates, to be able to do quick “back of the envelope” calculations, and be able to calculate accurate values. It is surprising how back of the envelope calculations occasionally show some proposals or circuits are doomed to failure, sometimes ones in which substantial effort has already been invested.

1. Before reading further, estimate/guess the resistance between two 2 mm diameter vias spaced 280 mm apart on a PC board copper plane (if it helps, consider the plane to be infinite in extent).

Modern ICs can require up to 100 A of current at approximately  $V_{dd}=1.2$  V. Connection of power supply to IC provides a significant challenge to designers. Although the most difficult challenges are due to inductance and are at high frequency, even DC requires some consideration. Note that even 1 mOhm of resistance in the path between supply and IC will give an 8.3% loss in  $V_{dd}$  for above conditions, not to mention 10 W power dissipation. Common PC board copper thickness is 1/2 oz (weight of 1 sq-ft of copper, the not yet obsolete way of specifying copper thickness for PC boards) or 18  $\mu$ m, and this has a sheet resistance of about 1 mOhm/square. 1.5 cm wide by 15 cm long conductors between IC and power supply would have 20 mOhms (10 mOhm for  $V_{dd}$ , 10 for GND) resistance, much too large. Many options are available to obtain improved power distribution including remote sensing, thicker copper, more copper layers, and alternative geometries (using entire planes for VDD and GND). Because remote sensing does not reduce the power dissipation (and has high-frequency issues) and because thicker copper compromises manufacturing we will concentrate on the later two. Within limits, more copper layers may be readily available because they are also needed for signal return currents.

Consider a highly idealized distribution system for either VDD or GND in which the power supply has a pin of radius  $r_1$ , and the load is uniformly distributed in a ring of radius  $r_2$ , both with the same center. We can find the resistance between the inner and outer ring by considering a small differential annular ring of width  $\Delta r$ , calculating its resistance from inner edge to outer edge, and then integrating from  $r_1$  to  $r_2$ . We find the total resistance is proportional to  $\ln(r_2/r_1)$ . Ignoring resistance in the power supply pin (it is much thicker than the PC board copper and is reasonable to ignore), a larger pin makes as much difference as a smaller outer radius.

2. What is the formula for resistance of a plane from  $r_1$  to  $r_2$  with resistance of  $R_s$  per square?

3. What is the resistance for 1/2 oz. copper plane from a power supply pin of diameter 2 mm, to a radius of 280 mm (ball park estimate for PC board conditions given above)? 280 mm is the center to center distance of the pins. What is the voltage across your calculated resistance (times 2 for VDD and GND) with 100 A current?

4. Now repeat your estimate for the conditions of problem 1 with your increased knowledge based on above calculations. What is voltage for this resistance (VDD and GND) as in problem 3?

Now for two vias or pins of equal or unequal size. Assumption: vias are small enough with respect to their separation that we can ignore their disturbance to the field/voltage of each, due to the other. Find the voltage from one via to the other with a 1 A current in each in turn. Use superposition to get voltage due to both, divide voltage by current to get the resistance.

5. Find the resistance for PC board case above (problem 1) and the loss in voltage at 100 A assuming the planes are infinite.

6. More accurate results can be obtained using field solvers such as Ansoft's Maxwell (student version is MaxwellSV). Find the resistance between two 2 mm (diameter) vias with 280 mm center to center distance in a 300 mm by 300 mm 1/2 oz. copper plane using MaxwellSV. Is this result exact? What error(s) do you expect? The goal of this exercise is not to learn how to use MaxwellSV (which you really won't), but for you to understand that such programs exist, their capabilities, and their limitations.

7. Put all your estimated and calculated values in a table and compare. Comments?