This Month's Quiz

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OK. Here's this month's quiz.

In **Figure 1** there are two IC switches, U1 and U2, and two bypass capacitors, C1 and C2. C1 is adjacent to U1 and C2 is adjacent to U2. There is a power supply (PS) at a corner of the board. Power and ground planes exist.

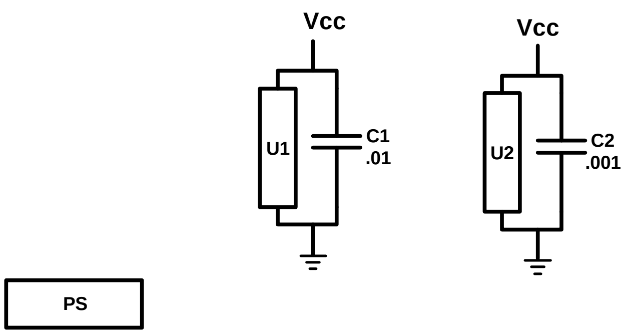

Figure 1
Device placement on a hypothetical board.

The question is this: When U2 switches (say in a nanosecond) and draws a *sudden* surge of current, where does the *initial* (first increment) of charge to support that current surge come from?

a. C2 because it is closer to U2?
b. C1 because it is larger than C2?
c. The power supply?
d. The capacitance between the power and ground planes?
e. All of the above?
f. It isn't that simple?

Before we consider C1 and C2 as the source, let's review a little basic DC theory. Consider **Figure 2**. A fixed load draws 10 ma. There are two separate supplies that provide current. One consists of a 5 V. battery and a 100 Ohm resistor, the other a 5 V. battery and a 900 Ohm resistor. In this example, 1 ma is drawn through the 900 Ohm resistor creating a .9 V. drop across it. In addition, 9 ma. is drawn through the 100 Ohm resistor creating a .9 V. drop across it. The two currents combine to provide the 10 ma. required by the load, and the voltage across the load is 4.1 V.

This figure illustrates several *truths*. First, the current through the load must equal the sum of the currents in the other two legs. Second, since the batteries are equal voltage, the voltage drop across each resistor must also be equal. In this example, the current through the resistors will divide in a manner that is inversely proportional to their resistance.

Bypass capacitors store charge. In doing so, they look like little batteries. When they are connected between Vcc and ground, they look like little batteries charged to a level of Vcc. But bypass capacitors store *significantly less* charge than batteries do. So, using the battery analogy, they will "run down" quickly. Nevertheless, for the first nanosecond, we can usually consider them to be charged enough to hold and maintain a constant voltage.

Therefore, all other things being equal, the *initial* charge will come from **both** C1 and C2 in inverse proportion to the impedances between their (capacitive) plates and the load (U2). The primary source of this impedance is the inductance associated with the capacitors' internal terminations, leads (if any), and the PCB's pads and vias. In general, larger capacitors have more inductance, and therefore more initial impedance, than smaller ones. Therefore, C2 will (probably) supply more initial charge than will C1, not because it is closer or smaller, but because it (probably) has less lead inductance.

C1, however, will probably supply more *total* charge, because it is larger.

One of the qualifications above, however, is "all other things being equal." One thing that may *not* be equal is the distance to the load (U2). If U2 switches in one nanosecond, then the sources of charge supporting the switching requirement must be less than one nanosecond away! Since elec-

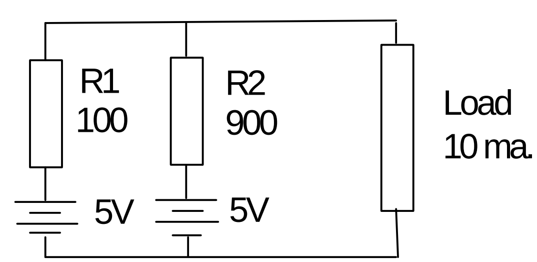

Figure 2
Currents will divide inversely proportional to resistance.

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trons on a PCB travel at approximately 6” per nanosecond (in FR4), any source more than 6” away can’t be supportive (at least in the first nanosecond.) In fact, if the switching requirement *completes* itself in the first nanosecond, the initial charge is needed much *sooner* than this, and the supporting device must be *much closer* than 6”.

Since the power supply is (probably) too far away, it probably doesn’t supply any initial switching charge support. In fact, its biggest role may be in simply recharging the bypass capacitors!

And plane capacitance? Well, first there must be some! That usually means we have intentionally structured the board stack-up to provide capacitance between the power and ground planes. And *that* means placing the planes suitably close together (say less than 10 mils apart.) Such capacitance *can* be very effective because there is very little inductance (impedance) associated with it.

But plane capacitance also tends to be very small. So the amount of charge it can store is limited. Furthermore, that charge is *distributed* across the surface area of the plane. Some of that charge will (probably) be more than one nanosecond away from U2. Charge that can’t move across the plane to U2 within one nanosecond (certainly that charge more than 6” away, probably even closer) can’t be effective in supporting U2’s switching requirement in the first nanosecond. So we can only consider a portion of the plane’s capacitance, if any, to be available for support.

So the answer to this month’s quiz? Well, it is sort of a combination of e and f. Support may come from “all of the above”, but it isn’t that simple!