Brookspeak

Ground Plane 101

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One day at my office we received an e-mail that asked the following question: "What is the primary use of a ground plane and when should it be used?"

One of my smart-aleck partners looked up and said, "A ground plane is where the airplane lands." Another said, "A ground plane is used if there isn't enough room for an air plane." But then we realized that there was a time in our careers when we might have asked a question like this. And, as we thought about it, many people may not recognize ALL the kinds of benefits a ground plane offers.

If your circuit is characterized by low power requirements, and signals with slow rise times and large signal levels, the power distribution system may not be too critical. But as any of these factors change, power conditioning requirements increase. There are several effective methods for distributing power around a PCB without using planes. But at some point, planes become a necessity. So here it is: Ground Plane 101.

In the PCB world, a plane is a solid sheet of copper. It is a ground plane if it is connected to ground, and it is a power plane if it connected to a power supply voltage. But since there are usually many bypass capacitors between power and ground, the distinction between power and ground has no meaning for AC signals. AC signals can and do travel on either type of plane.

In high speed designs, it is usually desirable that the plane be as solid as possible. Vias and through holes unavoidably put holes in the planes, but these effects are usually (but not always!) minor. Things such as slots and voids in planes can and do cause real problems and should be avoided.

Non-paired planes should never overlap. If there are, for example, both 5 volt and 12 volt planes, these should not overlap each other, and neither one should be allowed to overlap the "other's" ground plane. The reason is that the planes will capacitively couple at the overlap, allowing noise from one power supply system to couple into the other power supply system.

Some circuits result in large signal currents switching rapidly at the same time. Any inductance in the path of these current swings will result in noise voltages being generated across the inductance. The concept of "ground bounce" relates to this issue. Planes generally provide the lowest inductance paths for these currents. Therefore, planes are used to reduce noise when there are high current flows in power distribution systems.

Even if large current swings are not present, small signals in very fast switching circuits can also be affected by noise caused by currents flowing through "stray" inductance. Planes generally provide the lowest inductance paths in these environments also.

Properly designed planes will act like very small capacitors. The do not offer enough capacitance to substitute for bypass capacitors in the medium frequency ranges, but they can offer enough capacitance to provide the initial charge required by very fast leading edge switching transients when ordinary bypass capacitors have to much lead inductance to respond.

All signals MUST have a return signal. As frequency harmonics get higher, the path for the return signal will want to be directly underneath the signal trace. This can be on EITHER a power or a ground plane. Consider the concept of a loop. The signal trace and the return signal on the plane comprise a loop. If there is no obstruction anywhere on the plane, then the area of this loop will be small. If the return signal must take a circuitous path --- because, perhaps, the plane is not solid and there are voids on the plane --- the loop area will be larger. EMI emissions are directly related to this loop area. Therefore, one reason for designing in planes is for control of EMI emissions. And one reason for avoiding slots and voids in planes is to minimize loop area.

In the high speed world we are often concerned about crosstalk between parallel traces. Crosstalk is proportional to $H^2/(H^2 + D^2)$. Intuitively, crosstalk diminishes as the separation between traces (D) increases. But, all other things equal, crosstalk will decrease as the distance between the trace and the plane (H) decreases. So, planes are helpful in reducing and controlling crosstalk. (Note the relationship between this and the concept of loop area in the previous paragraph. Crosstalk and EMI are somewhat related issues.)

By now, most of our readers have at least heard that PCB traces can take on the characteristics of transmission lines. The point at which this happens (the "critical length") is usually defined as when "the two way delay of the line is more than the rise time of the pulse." (See, for example, Motorola "MECL System Design Handbook", p 35.) The critical length is approximately 3" for a signal with a 1 ns rise time in FR4. The problem caused by transmission line effects is reflection. If the line is not terminated some way in

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its characteristic impedance (referred to as Zo), or if the characteristic impedance is not controlled, reflections will occur which can cause noise voltages and false signals that will cause the circuit to fail.

The characteristic impedance of a transmission line is a function of its geometry. In PCB applications, it is a function of several variables, two of which are the width of the line and the height of the line above the plane. If signal trace lengths are greater than the "critical length", and if there were no plane for the trace to reference to, it is likely that there could be no control over Zo, no way to terminate the trace, and therefore no way to control reflections. So, one purpose for the plane is to provide control over the characteristic impedance of traces in order to minimize noise caused by reflections.

The common denominator in all these instances is noise reduction. Planes minimize noise caused by currents switching through stray inductance, help control noise caused by crosstalk, and help control noise caused by reflections. In addition, they can help control noise emitted outside the system (EMI). Obviously the planes don't do this magically by themselves --- other good design rules must also be followed. To paraphrase a term we used in economics: in the world of high speed design, planes are *necessary* but not *sufficient* for noise control.