ferent voltage regions are created by splitting the plane. Return path discontinuities may result if the split plane is used as an AC ground for adjacent signal layers as shown in Fig. 18.16. As with a via, the return current finds the path of least impedance. An isolated split plane will force the return current to find an alternate path. Ideally, this should not be done, and planes should be continuous. Most engineers strive to never route a trace across a plane split so that potential signal integrity problems are minimized. If a plane does need to be split, it can be isolated from adjacent signal layers with additional solid ground planes. Alternatively, an adjacent plane spaced very close to the split plane can provide high interplane capacitance and therefore serve as a low-impedance path for the return current. Practical economic concerns often require engineers to employ nonideal approaches and still deliver a working system. An isolated split plane requires more careful trace layout to absolutely minimize the number of signals that cross the break. When signals must cross a break on a layer adjacent to the split plane, the return path discontinuity can be minimized by placing bypass capacitors across the break in close proximity to the traces. The mechanism at work here is the same where a signal changes layers through a via. If an explicit return path is not created by a capacitor of your choosing, the current will necessarily find its own path, which may be surprisingly long.

A special type of plane split, called a *moat,* is usually employed to isolate a small area of the PCB for noise-sensitive circuitry. Moats can be fully isolated islands or partially connected islands as shown in Fig. 18.17. When the moat is completely separate, routing concerns exist as for a split plane. A partially connected moat eases the routing burden somewhat by allowing a small “drawbridge” across which signals can travel with an unbroken return path. The idea behind a partially connected island is that stray currents do not flow across the island, because a less inductive path exists around the moat. Any noise that does make it into the island is attenuated somewhat as it passes

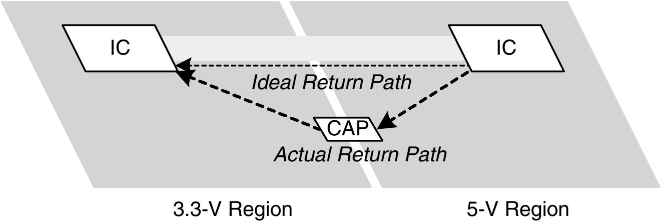

FIGURE 18.16 Split-plane return path discontinuity.

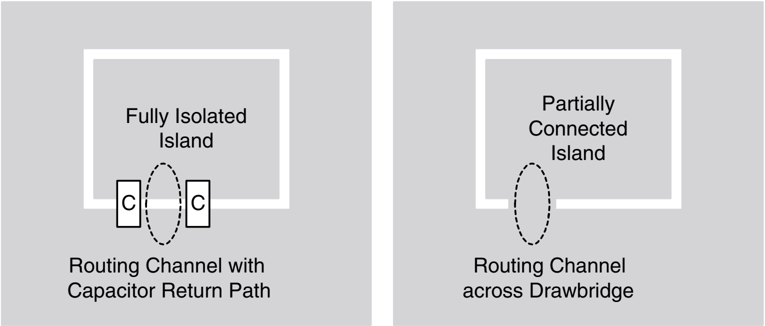

FIGURE 18.17 Moat routing.

through the thin drawbridge. A fully isolated island requires power and ground to be supplied through passive filters or some other connection.

Remember that a key goal in designing for signal integrity is to minimize loop area and return path discontinuities so that less energy is radiated from a wire when it is driven, and less energy is picked up as noise when other wires in the system are being driven.

18.5 GROUNDING AND ELECTROMAGNETIC COMPATIBILITY

By now it should be clear that grounding is a critical aspect of system design. Grounding becomes more important as speeds increase, because more intense electromagnetic fields are present, and higher frequencies radiate more efficiently from smaller antennas. *Electromagnetic compatibility* (EMC) is the ability of a system to peacefully coexist with other systems so that it neither malfunctions because of excessive EMI susceptibility nor causes other systems to malfunction as a result of excessive electromagnetic field radiation. In most situations, EMC means being a good neighbor and complying with governmental regulations on how much electromagnetic energy an electronic system can radiate. The Federal Communications Commission governs such regulations in the United States. Most digital systems applications are not particularly sensitive to ambient electromagnetic energy. The chances are pretty low that a computer will malfunction during normal use because of excessive ambient fields. Of course, this does not hold true in some demanding applications such as aerospace and military electronics.

Our discussion is concerned with basic techniques for reducing a system's radiated electromagnetic emissions in the context of complying with government regulations. EMI reduction through minimizing loop area and removing return path discontinuities is a fundamental starting point for EMC. Reasonable steps should be taken up front to minimize the energy that a circuit board radiates. If a sloppy design radiates significant energy, it may be difficult or impossible to effectively contain these fields to the point of regulatory compliance.

Electromagnetic energy can escape from a circuit board by radiating into space or conducting onto a cable. Radiated emissions can be blocked by enclosing the circuit board in a grounded metal enclosure. This is why many computers and other electronic equipment have metal chassis, even though the metal may be hidden under a plastic frame or bezel. Most metal enclosures are not perfect closed surfaces, because slots and holes are necessary for cables, switches, airflow, and so on. Enclosures also must be assembled and are often opened for service, so there are numerous seams, hinges, and joints that connect one sheet of metal to another. All openings in the metal are potential leakage points for radiation, depending on their size. A hole forms a slot antenna whose efficiency is a function of its size and the wavelength, λ, of energy being radiated. When engineers construct antennas, $\lambda \div 4$ and $\lambda \div 2$ are typical dimensions that radiate most efficiently. Clearly, slots and holes whose largest dimensions approach $\lambda \div 4$ are undesirable. Limiting chassis openings to be substantially smaller than $\lambda \div 4$, perhaps $\lambda \div 20$, is necessary.

Keep in mind that the frequencies that must be shielded are not just the highest system clock frequencies but also higher-order harmonics determined by the Fourier representation of a square wave. It is not uncommon to find energy violating emissions limits at the eleventh, thirteenth, or fifteenth harmonic of a digital clock. Therefore, it is best to make openings as small as possible. A rough starting point might be the assumption that, for a typical system, harmonics above 1 GHz will not be strong enough to cause problems. This may or may not be true, depending on the specific circumstance. The wavelength corresponding to 1 GHz in free space is 30 cm, and $\lambda \div 20 = 1.5$ cm, or about 0.6 in (1.5 cm). It is not as difficult as it may first appear to keep all openings smaller than that. Gaps for airflow are easily implemented using fine grilles formed in the sheet metal with holes far smaller than 0.6 in. Notice the grilles on computers, microwave ovens, and consumer electronics products.