Sniffer probe locates sources of EMI

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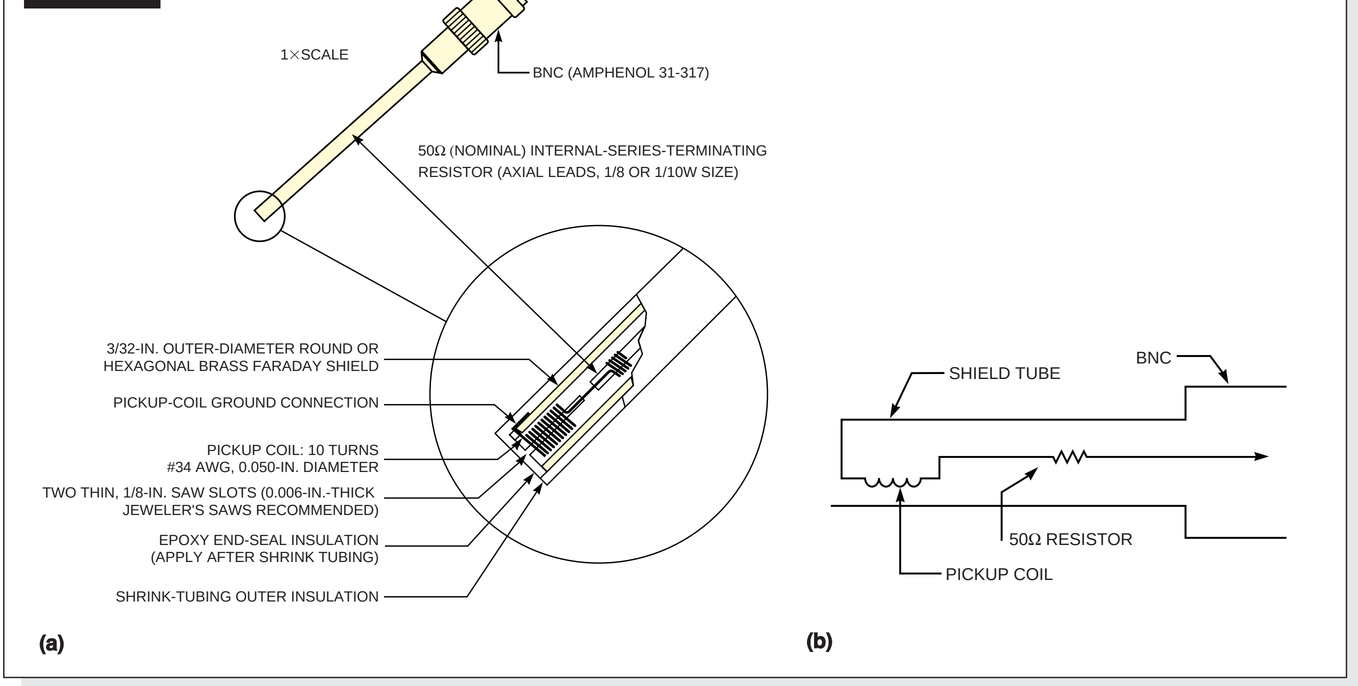
A miniature EMI "sniffer probe" and an oscilloscope can help to locate and identify magnetic-field sources of EMI. Small size with relatively high sensitivity and electrostatic shielding enable the probe to provide much more information than other available probes.

Electromagnetic interference (EMI) can be difficult to locate and correct in electronic equipment, but a small "sniffer probe" can help. The EMI sniffer probe's original and primary use was to diagnose sources of EMI in switch-mode power converters. However, the probe is also useful for high-speed logic systems and other electronic equipment. For applications that have many adjacent and similar sources of EMI, you can use a related "high-discrimination" sniffer probe to further localize the EMI-generating currents.

Although a number of other H-field probes are available, they are generally large, ranging from 1 cm in diameter upward, and do not always have sufficient shielding against spurious pickup of electric fields.

The principal advantages of the miniature multiturn probe over other H-field probes and simple pickup loops include a spatial resolution of approximately 1 mm; relatively high sensitivity for a small coil; a 50Ω source termination, which minimizes cable reflections with unterminated scope inputs; and Faraday shielding, which minimizes

FIGURE 1



The EMI sniffer probe comprises a miniature pickup coil in the end of a small shielded tube with an attached BNC (a). The corresponding electrical circuit includes the coil and a 50Ω termination resistor (b).

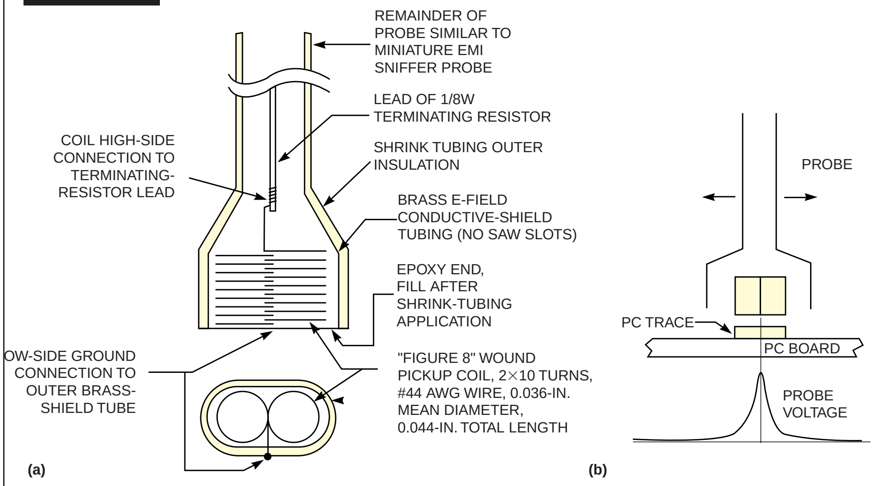
sensitivity to electric fields.

Sources of EMI

Rapidly changing voltages and currents in electrical and electronic equipment can easily result in radiated and conducted noise. Switch-mode power converters, for example, generate the most EMI during switching transients, when power transistors turn on or off. You can readily use conventional oscilloscope probes to see dynamic voltages, which are the principal sources of common-mode-conducted EMI. High dV/dt signals can also feed through poorly designed filters as normal-mode voltage spikes and may radiate fields from a circuit without a conductive enclosure.

Dynamic currents produce rapidly changing magnetic fields, which radiate far more easily than electric fields, because magnetic fields are more difficult to shield. These changing magnetic fields can also induce low-impedance voltage transients in other circuits, resulting in unexpected normal-mode- and common-mode-conducted EMI. Voltage probes can't directly sense these high dI/dt currents and the resultant fields, but the sniffer probe can. Although current probes can sense currents in discrete conductors and wires, they are of little use with pc traces or for detecting dynamic magnetic fields.

FIGURE 2



A high-discrimination sniffer probe has a very different response profile (a) from that of the miniature probe (b).

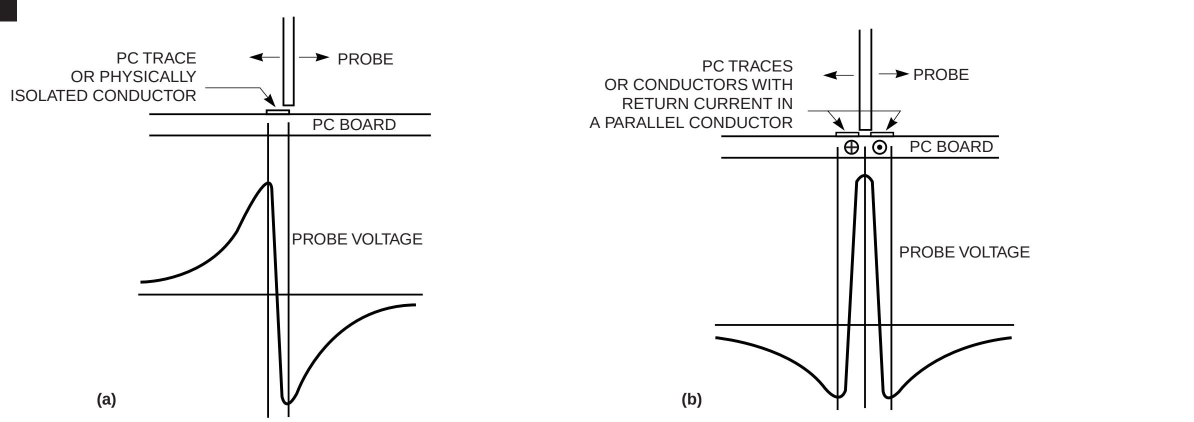
Construct the probe

The basic probe consists of a miniature pickup coil of typically 10 turns in the end of a small shielded tube with a BNC for attachment to a coaxial cable (ϕigure `). The sniffer probe's output voltage is essentially proportional to the rate of change of the ambient magnetic field and thus to the rate of change of nearby currents.

A high-discrimination probe has a similar construction, differing primarily in its use of a dual coil and its use of a shield tube without "flux-entry" saw slots (ϕigure ´). For this probe, all flux comes in from the open end of the shield tube.

Few of the miniature probe's construction details are critical; you can modify the probe's coil-wire size, diameter, and number of turns without a significant impact on perform-ance. However, three aspects are important: outer-probe insulation to avoid short circuits while probing; one (or preferably two) thin saw slot in the coil end of the shield tube to allow entry of the magnetic field at high frequencies; and a ground connection between the shield

FIGURE 3



For a physically isolated conductor or pc-board trace, the sniffer probe's response exhibits a sharp null when you center the probe over the conductor (a). For pc traces or conductors with return current in a parallel conductor, the probe's response is greatest between the two conductors (b).

tube and the exposed end of the pickup coil near the shield end, which minimizes E-field pickup.

The 50Ω internal terminating resistor is not essential. However, if you don't include this resistor, you must then use the probe with a 50Ω load termination to avoid transmission-line resonance, which completely distorts the pickup waveform.

Probe response characteristics

The basic sniffer probe is sensitive to magnetic fields only along the probe's axis. This directionality is useful in locating the paths and sources of high dI/dt currents. The resolution is usually sufficient to locate the pc-board trace or component-package lead that conducts the EMI-generating current.

For isolated single conductors or pc-board traces, the probe's response is greatest just to either side of the conductor where the magnetic flux exists along the probe axis (ϕigure ‥a). The probe's response may be a little greater with the axis tilted toward the center of the conductor. A sharp response null occurs in the middle of the conductor, with a 180° phase shift to either side and a decreasing response with distance. The response increases at the inside of a bend where the flux lines crowd together, and the response is lower on the outside of a bend where the flux lines spread apart.

When the return current is in an adjacent parallel conductor, the probe's response is greatest between the two conductors (ϕigure ‥b). A sharp null and phase shift occur when the probe is over each conductor. When you move the probe outside the conductor pair, the peak response goes down and continues to decrease with distance.

The response to a trace with a return current on the opposite side of the board is similar to that of a single isolated trace except that the response may be greater when the probe's axis tilts away from the trace. A ground plane below a trace has a similar effect, because there is a counterflowing "image" current in the ground plane.

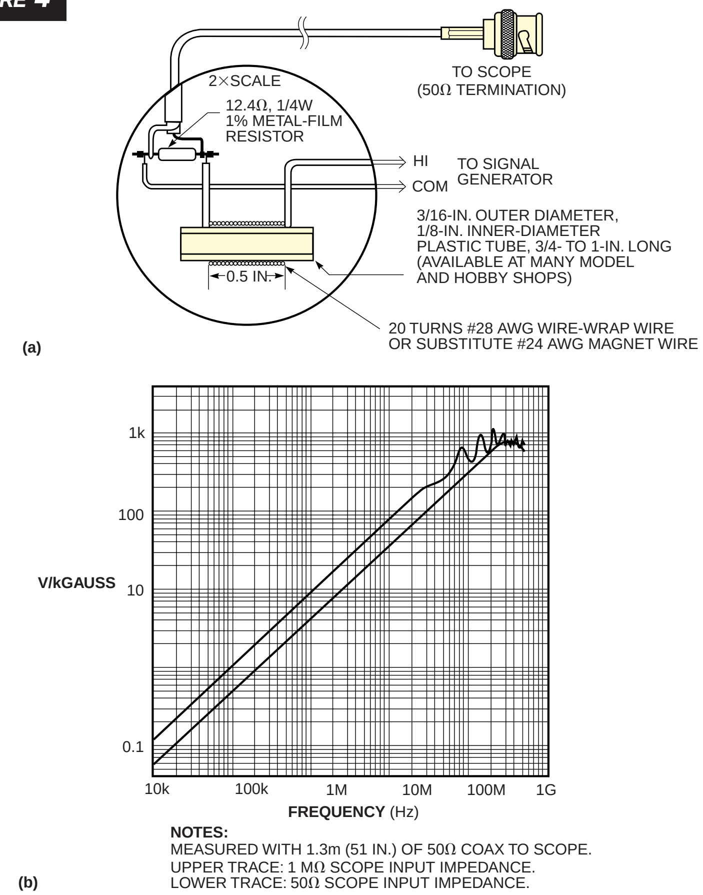
Test the sniffer probe

You can functionally test the sniffer probe using a small coil and current-sensing resistor (ϕigure _a). The 12.4Ω resistor in parallel with a termination impedance of 50Ω provides close to a 10Ω current shunt, with the impedance rising about 10% (+1 dB at 50 MHz). For this test, you center the EMI probe in the coil for maximum response and calculate the field intensity using the following equation:

$$B=H=1.257 \times N \times I/l,$$

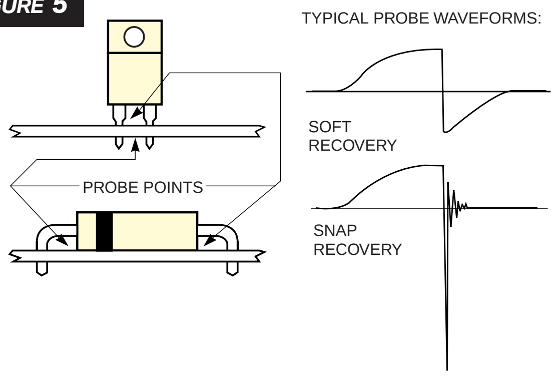
where N is the number of turns of the test coil, I is the current in

FIGURE 4



A test coil (a) helps to determine the probe's frequency response (b).

FIGURE 5



Reverse recovery of rectifiers is the most common source of dI/dt-related EMI. For diodes with a soft recovery, the reverse current decays gradually; for diodes with a snap recovery, the reverse current stops quickly.

the coil, and l is the length of the coil.

For testing between 1 and 500 MHz, you can use a 1.5-turn coil in the center conductor of a coaxial transmission line between a generator output and a 50γ oscilloscope or voltmeter input. For a 1.27-cm-long, 20-turn test coil, the flux density is about 20 gauss/A. At 1 MHz, the sniffer probe's voltage is 19 mV p-p ±10% per 100 mA p-p for a 1-Mγ load impedance. A 50γ load impedance reduces this voltage by half.

The setup in φigure _a allows you to test the probe's frequency response to a uniform magnetic field (φigure _b). Because of large variations in field strength around a conductor, you should consider the probe only as a qualitative indicator and make no attempt to calibrate it. The response's roll-off near 300 MHz results from the pickup coil's inductance of 75 nH driving the total terminated impedance of 100γ; transmission-line reflections cause the mild resonant peaks, with a 1-Mγ scope termination, at multiples of 80 MHz.

The response of the high-discrimination probe is quite different (φigure ´b). The response has a sharp peak when the probe centers on the trace with one coil to each side of the center line. This probe has an extremely small response to ambient magnetic fields, so it is of limited use in the initial localization of EMI sources.

How to use the sniffer probe

Using the sniffer probe requires at least a two-channel oscilloscope: one channel to view the noise whose source you want to locate, which may also provide the scope trigger, and the other channel for the sniffer probe. The probe's response nulls make it inadvisable to use the probe's channel for triggering.

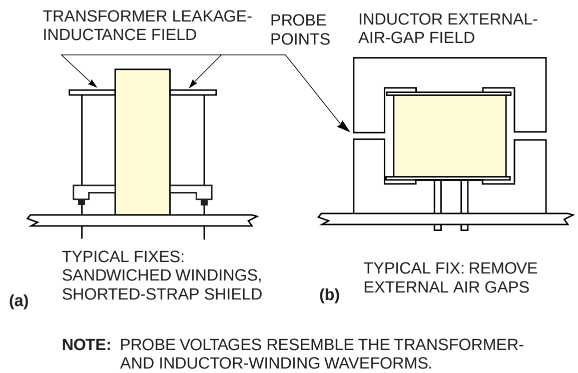
A third scope trigger channel or an external trigger can be useful, particularly if triggering on the noise is difficult. Transistor-drive waveforms or their predecessors in the upstream logic are ideal for triggering; these waveforms are usually stable and allow you to see events that are immediate precursors of the noise.

Start with the probe at some distance from the circuit, with the probe's channel set at maximum sensitivity. Move the probe around the circuit, and "sniff around" for something happening in *precise* synchronization with the noise transient. A precise time-domain correlation between EMI noise transients and internal circuit fields is fundamental to the diagnostic approach. The probe's waveform is not identical to the noise transient, but the waveform usually has a strong resemblance to the transient.

As you locate a noise-source candidate, move the probe closer while decreasing the oscilloscope's sensitivity to keep the probe's waveform on-screen. Then, you should be able to quickly bring the probe down to the pc-board trace (or wiring) where the probe signal seems to be a maximum. This spot may not be near the point of EMI generation but should be near a pc-board trace or other conductor carrying the current from the EMI source. You can verify the location by moving the probe back and forth in several directions; when the probe crosses the appropriate pc-board trace at roughly right angles, the probe output goes through a sharp null over the trace, with an evident phase reversal in probe voltage on each side of the trace.

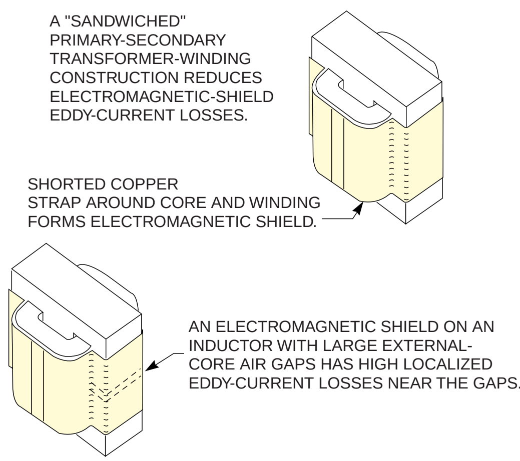
You can follow this EMI "hot" trace—like a bloodhound on the trail of a scent—to find most or all of the EMI-generating current loop. Trace out the noise-current path as much as possible, and identify the current path on the schematic. If the trace is hidden on the back of or inside the board, mark its path with a felt pen, and locate the trace on disassembly, on another board, or on the artwork. From the current path and the timing of the noise transient, the source of the problem usually becomes almost self-evident.

FIGURE 6



Transformer leakage-inductance fields emanate from be-tween primary and secondary windings (a). External air gaps in an inductor (b) can also be a major source of EMI.

FIGURE 7



There are two principal fixes for transformer leakage-inductance fields: Split the primary or secondary in two to sandwich the other winding, or place a shorted copper-strap electromagnetic shield around the complete core and winding assembly.

Typical dI/dt EMI problems

The sniffer probe diagnoses several problems—some of which are more common than others. Familiarizing yourself with these problems and their suggested fixes may help you to more quickly solve your own EMI problems.

In power converters, reverse recovery of rectifiers is the most common source of dI/dt-related EMI; the charge that P-N junction diodes store during conduction causes a momentary reverse-current flow when the voltage reverses. For diodes with a "snap" recovery, which is more likely in devices that have a PIV rating of less than 200V, this reverse current may stop in less than 1 nsec. Alternatively, the reverse current may decay more gradually with a "soft" recovery (фigure).

The sudden change in current creates a rapidly changing magnetic field, which causes the radiation of external fields and induces low-impedance voltage spikes in other circuits. This reverse recovery can shock parasitic L-C circuits into ringing, which produces oscillatory waveforms with varying degrees of damping when the diode recovers. A series R-C damper circuit in parallel with the diode is the usual solution.

Output rectifiers generally carry the highest currents and are thus the most prone to this problem. Designers often anticipate this problem and design sufficient snubber networks for these rectifiers. Thus, catch or clamp diodes with no snubber networks can be more of an EMI problem. The fact that a diode in an R-C-D snubber may need its own R-C snubber is not always self-evident, for example.

You can usually identify the problem by placing the sniffer probe near a rectifier lead. The signal is strongest either on the inside of a lead bend in an axial package or between the anode and cathode leads in a TO-220, TO-247, or similar type of package (фigure).

Using softer recovery diodes is a possible solution, and Schottky diodes are ideal in low-voltage applications. However, unlike a diode with a snap recovery, a P-N diode with soft recovery is also inherently lossy because the diode simultaneously develops a reverse voltage while still conducting current. The fastest possible diode, which results in the lowest recovered charge with a moderately soft recovery, is usually the best choice. Sometimes a faster, slightly snappy diode with a tightly coupled R-C snubber works as well as or better than a soft but excessively slow recovery diode.

If significant ringing occurs, a quick-and-dirty R-C snubber design approach works fairly well; place increasingly large damper capacitors across the diode until the ringing frequency reduces by half. The total ringing capacity is now quadruple that of the original ringing frequency, or, to put it another way, the original ringing capacity is one-third of the added capacity. The necessary damper resistance is approximately equal to the capacitive reactance of the original ringing capacity at the original ringing frequency. Then, you connect the frequency-halving capacitor in series with the damping resistance and place the pair across the diode as tightly coupled as possible.

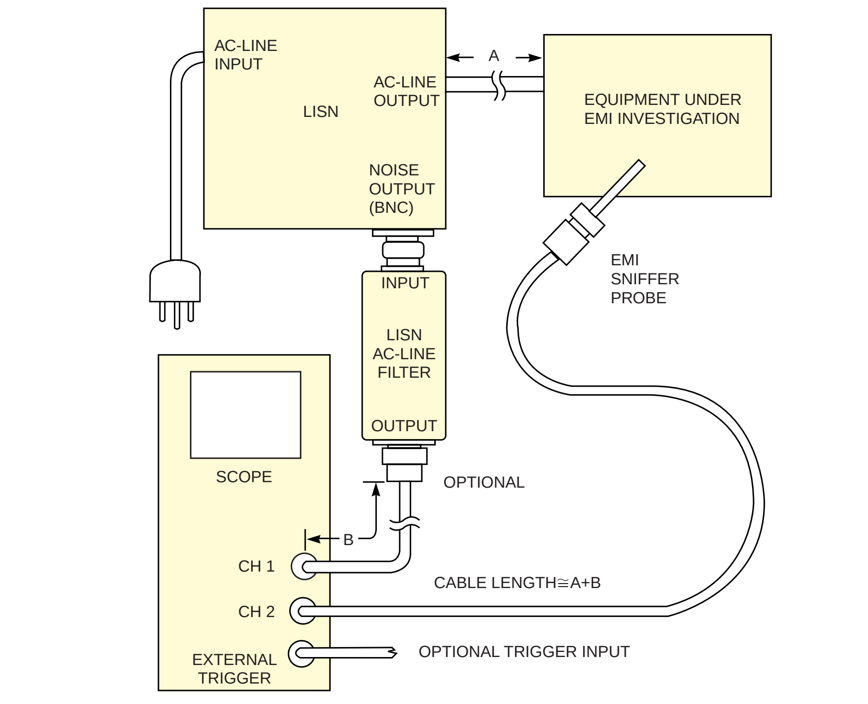
Snubber capacitors must have a high pulse-current capability and low dielectric loss. Temperature-stable-disc, multilayer-ceramic, silvered-mica, and some plastic film-foil capacitors are suitable. Snubber resistors should be noninductive; metal-film, carbon-film, and carbon-composition resistors work well, but you should avoid using wirewound resistors. The product of the damper capacity, switching frequency, and the square of the peak snubber-capacitor voltage provides an estimate of the maximum snubber-resistor dissipation.

Snubbers on passive switches (essentially diodes) or active switches (essentially transistors) should always have close coupling—as much as is physically possible—with minimal loop inductance. This arrangement minimizes the radiated field that arises when the current path changes from the switch to the snubber. Close coupling also minimizes the turn-off-voltage overshoot that's necessary to force the current to change paths through the switch-snubber loop inductance.

Leakage-inductance fields

Transformer leakage-inductance fields emanate from between primary and secondary windings. Single primary and secondary

FIGURE 8



You can use the sniffer probe with a line-impedance stabilization network (LISN). The optional LISN ac-line filter reduces ac-line-voltage feedthrough, which simplifies EMI diagnosis when a suitable dc voltage source is unavailable or unsuitable.

EMI SNIFFER PROBE

windings create a significant dipole field, which you can see by placing the sniffer probe near the winding ends (ϕigure ˇa). If this field is generating EMI, there are two principal fixes: split the primary or secondary in two to sandwich the other winding or place a shorted, copper-strap electromagnetic shield around the complete core and winding assembly (ϕigure ˜). Eddy currents in the shorted strap largely cancel the external magnetic field.

The first approach, which creates a quadrapole instead of a dipole leakage field, significantly reduces the distant field intensity. This approach also reduces the eddy-current losses in any shorted-strap electromagnetic shield you use, which may be an important consideration.

External-air-gap fields

External air gaps in an inductor, such as those in open bobbin-core inductors or those with E cores spaced apart, can be a major source of external magnetic fields when significant ripple or ac currents are present (ϕigure ˇb). The sniffer probe can also easily locate these fields; the response is a maximum near an air gap or near the end of an open-inductor winding.

Open-inductor fields are difficult to shield, and, if they present an EMI problem, redesigning the inductor to reduce external fields is usually necessary. Placing all of the air gap in the center leg virtually eliminates the external field around spaced E cores. If eddy-current losses are low enough, the shorted-strap electromagnetic shield of ϕigure ˆ can minimize fields due to a possibly intentional residual or minor outside air gap.

A less obvious problem can occur when you use inductors with open cores as second-stage filter chokes. The minimal ripple current may not create a significant field, but such an inductor can pick up external magnetic fields and convert them to noise voltages or can create an EMI-susceptibility problem.

Poorly bypassed high-speed logic

Ideally, all high-speed-logic designs should include tightly coupled bypass capacitors for each IC, and all multilayer pc boards should have power and ground distribution planes. Unfortunately, poor design practices still exist, such as using just one bypass capacitor at the power entrance to a logic board and routing power and ground to the ICs from opposite sides of the board. This faulty distribution scheme creates large spikes on the logic supply voltage and produces significant electromagnetic fields around the board.

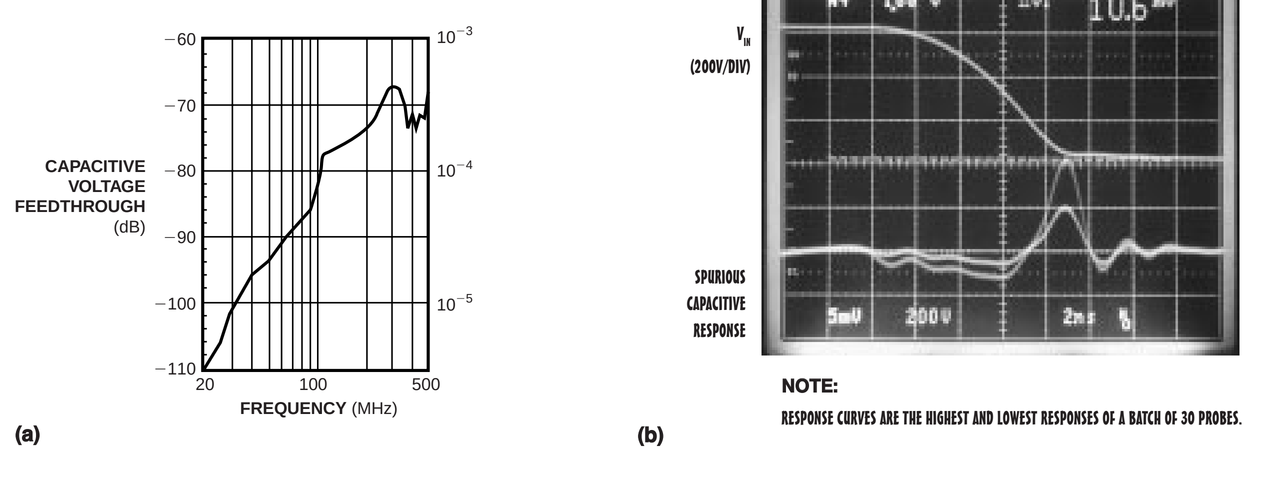
With a sniffer probe, you can determine which pins of which ICs have the largest current transients that are synchronous with the supply-voltage transients. In one case, using the sniffer probe set some logic-design engineers straight. The engineers accused the power supply of creating the noise. However, the probe helped to determine that the supplies were fairly quiet; it was the poorly designed logic power-distribution system that was the problem.

A sample test setup uses the sniffer probe with a line-impedance stabilization network (LISN) (ϕigure ˚). The optional LISN ac-line filter reduces ac-line-voltage feedthrough from a few hundred millivolts to microvolt levels, simplifying EMI diagnosis when a suitable dc voltage source is unavailable.

The electrostatic Faraday shielding of the sniffer probe is excellent, despite the open end of the probe. This end of the pickup coil connects to ground to enhance shielding. The spurious capacitive pickup is only about 4 fF, or 0.004 pF, based on the measured capacitive feedthrough and the shielded coil inductance of 75 nH (ϕigure ˛a). The effect is so slight that you can ignore it in virtually all applications. The capacitive response is actually very difficult to measure; the test requires a special test jig to minimize pickup of associated capacitive displacement currents in the vicinity while maximizing the true capacitive coupling with a flat surface—typically a 0.18-in.-diameter disc—against the open end of the probe tip.

Because of the inductive loading of the pickup coil—at least below 200 MHz and even with a 50γ termination—the capaci-

FIGURE 9



The probe's capacitive voltage feedthrough (a) is so slight that you can ignore it in virtually all applications. The capacitive response (b) is proportional to the second derivative of the voltage.

tive response is not proportional to the derivative of the voltage, dV/dt, but to the second derivative of the voltage. You can see this effect in the probe's response to a voltage slewing 600V with a 90 to 10% fall time of 5.2 nsec (ϕigure ̗b). The probe's capacitive response is proportional to the second derivative, or curvature, of the voltage wave, and not to the first derivative, or slope. This response is greatest at the bottom "corner" of the input-voltage waveform, where the probe shows its peak response. Slower voltage changes result in a dramatic decrease of the response.

The spurious capacitive response of the probe can often appear much higher because of capacitive displacement currents near the probe. Displacement current is proportional to dV/dt, and the probe is sensitive to the displacement current, dI/dt, which is proportional to the second derivative of the voltage. Thus, the displacement-current response is the same as that for true parasitic capacitive coupling.

Finally, you may wonder about the sniffer probe's ability to inject a signal. You can use some EMI-sensing probes to test for EMI susceptibility by injecting a current into the probe and placing it near potentially sensitive circuits. However, this miniature probe is not particularly suitable for this application because of its small coil and limitation to low drive levels; more than a 1/8W input, which is equivalent to 2.5V rms, can overheat the internal terminating resistor. e

Author's biography

Bruce Carsten is president of Bruce Carsten Associates Inc (Corvallis, OR), where he is an applied-research and design consultant, primarily for switch-mode power supplies. He has published more than 40 papers, holds seven patents, and has 28 years of experience in power conversion.