5 High Frequency Measurements

INPUT LOADING

When you touch a probe to the circuit under test, the probe will affect your measurement because of the probe's input impedance introduced into the circuit. All probes present resistive, capacitive and inductive loading.

INDUCTIVE LOADING (LEAD LENGTH)

A significant element in this circuit is the inductance shown in the input ground leads of the oscilloscope probe.

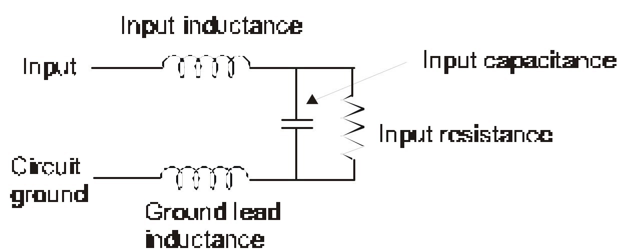

Figure 5-1. Probe Input Equivalent Circuit

The ground lead is the primary return path for the current resulting from the input voltage acting on the probe's input impedance. The ground lead and input lead inductances act with the probe's input capacitance to form series L-C network. The impedance of a series LC network will drop dramatically at its resonant frequency. This is the cause of the "ring" we often see after the leading edge of pulses in measured waveforms. This effect is referred to as ground lead corruption. Because it is impossible to eliminate either the L or C from this circuit, the method to improve waveform fidelity is to raise the resonant frequency beyond the bandwidth of interest in the measurement.

The resonant frequency of a simple LC circuit can be represented by:

$$F_{Resonance} = \frac{1}{2\pi\sqrt{LC}}$$

The resonant frequency of a series LC circuit can be raised by decreasing the inductance, capacitance or both.

Since the input capacitance is already very low and cannot be reduced, you can only try to reduce the inductance. This can be accomplished by using the shortest possible input lead as well as the shortest possible ground lead.

For example, to obtain the shortest possible ground lead when measuring IC related signals, attach a small piece of copper clad material to the top of the IC package and connect this to the package grounding wires. Using the shortest ground lead and input lead available makes probing signals on the package easier and makes for the shortest lead length for the best signal fidelity.

To illustrate how dramatic this effect is, we will work a simple example.

Assuming an input capacitance of 0.7 pF and a total lead length (input and ground) of 2 inches (inductance of ≈ 25 nH/inch) such a setup may cause ringing with a resonant frequency (f_0) of:

$$f_0 = \frac{1}{2\pi\sqrt{50 \times 10^{-9} \times 0.7 \times 10^{-12}}} = 851\ MHz$$

This frequency is well within the passband of the probe and will therefore show up as part of the measured signal at faster time/div settings.

To determine how fast a waveform to be measured can be without causing ringing on a probe like, this divide the BW (ringing frequency) of the probe into 0.35:

$$t_{rise} = \frac{0.35}{BW} = \frac{0.35}{851MHz} = 0.4\ nsec$$

Any input signal with a rise time faster than 0.4 nsec can cause ringing.

CAPACITIVE LOADING

Capacitive loading is usually the most troublesome of the three loading effects.

It can affect the rise time, bandwidth and delay time measurements.

At higher frequencies the capacitive loading can affect the amplitude as well as the waveshape of the measured signal by introducing an exponential response to the waveform.

For a simple RC network the time constant of this exponential response is:

$$t_{rise} = 2.2 \times C_{total} \times R_{total}$$

where C_{total} is the combined probe and circuit capacitance and R_{total} is combined circuit and probe resistance.

In a setup where C_t = 0.7 pF and the source resistance is 100 Ω, the measured rise time will be 0.154 nsec, which will correspond to a bandwidth of 2.27 GHz, assuming no inductive loads.

(t_{rise}=2.2 x 0.7 X 10^{-12} x 100 Ω = 0.154 nsec)

(parallel combination of 100 Ω and 100 kΩ is still 100 Ω)

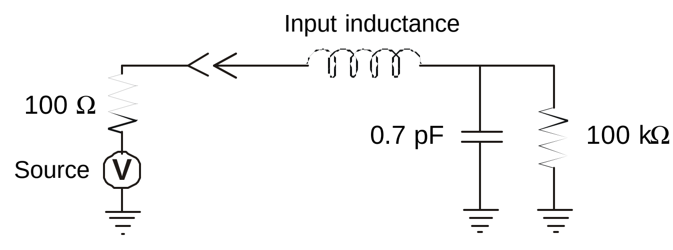

Figure 5-2. Probe input equivalent circuit

To illustrate the effect of capacitive loading at higher frequencies:

At a frequency of 851 MHz the reactance of the 0.7 pF capacitance is 267 Ω, and at 2.5 GHz the reactance has been lowered to 91 Ω

If, at a given frequency, the source impedance is large with respect to the input impedance, a measurable reduction in the output signal amplitude may occur.

$$V_{out} = \frac{Z_{probe}}{Z_{probe} + Z_{source}} \times V_{in}$$

where: Z_{probe} is the probe's input impedance and

Z_{source} is the source impedance

As an example:

At 851 MHz, where the probe input impedance has reduced to 267 Ω, and a source resistance of 250 Ω the probe output amplitude is reduced to:

$$V_{out} = \frac{267}{267 + 250} = 0.52 \times V_{in}$$

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