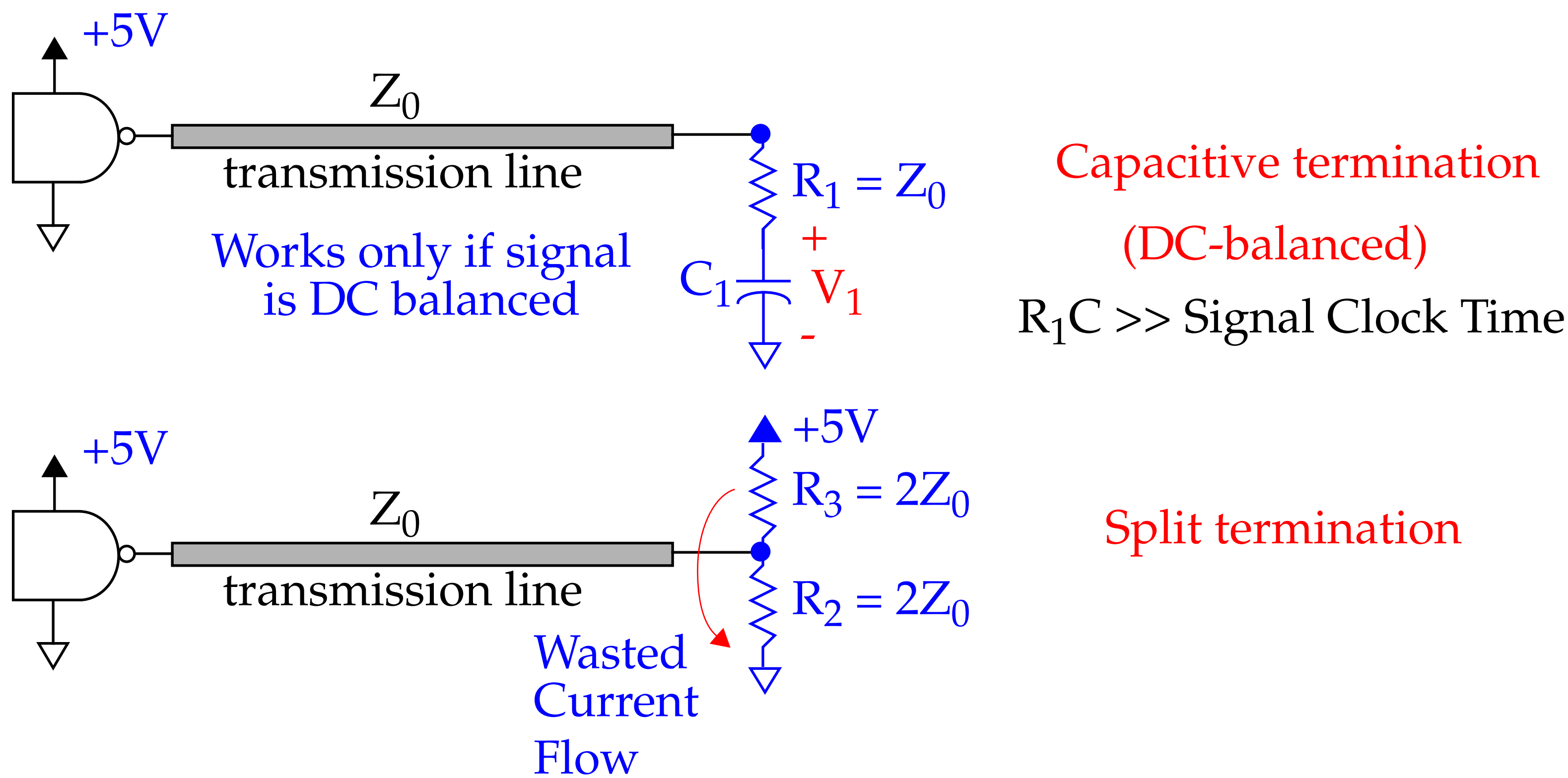
AC Biasing for End Terminators

Capacitors are used in end-terminations to reduce the quiescent power dissipation.



If the drive circuit spends half its time in each state (also called *DC-balanced*), the average value accumulated on C_1 will be halfway between HI and LO voltages.

AC Biasing for End Terminators

The voltage across R_1 will be $\Delta V/2$. The power dissipated in R_1 will be

$$P_{R1} = \frac{(\Delta V/2)^2}{Z_0} = \frac{\Delta V^2}{4Z_0}$$

where
ΔV= HI-LO Logic voltages, V
Z_0 = Value of terminating resistor, Ω

In the split terminator either R_2 or R_3 always has the full ΔV across it, but each resistor is twice as big as R_1 so, the average power dissipation is

$$P_{R_2 + R_3} = \frac{(\Delta V)^2}{2Z_0}$$

Twice the power of DC-balanced

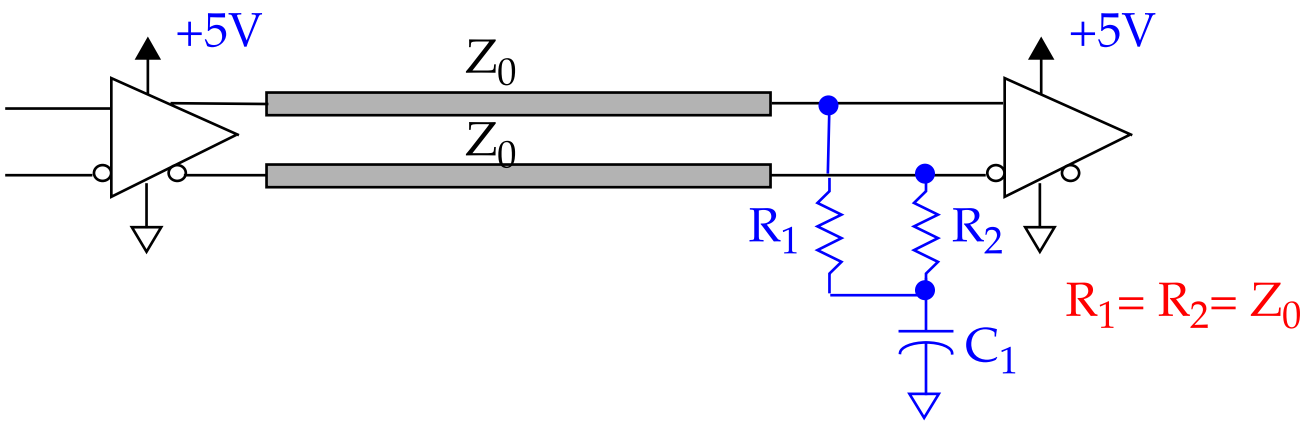
The additional wasted power dissipation flows from V_{CC} directly to ground through R_2 and R_3.

From driving circuit's perspective, the two terminations are indistinguishable w.r.t. power dissipation.

Only the dissipation in the terminating resistors differs.

End Terminations for Differential Lines

Given two signals which are complementary (a differential pair), we can connect their end-terminating resistors together onto a single capacitor.



This provides a power saving end terminator with a guaranteed correct voltage always present on C_1.

Resistor Selection: Accuracy in Terminating Resistors

Purpose of terminating resistor is to reduce/eliminate unwanted reflections on a Tx-line.

Resistor Selection

This is possible only when its value matches the characteristic impedance of the Tx-line (Z_0).

To compute the *worst-case* terminating mismatch, the uncertainty in Z_0 is added to the uncertainty in the terminating resistor.

The uncertainty in Z_0 is usually larger than that of the terminating resistor.

- E.g., with a 10% uncertainty in Z_0, designers would use a resistor with a 1% tolerance.

For high fidelity signal requirements, use both source and end terminations.

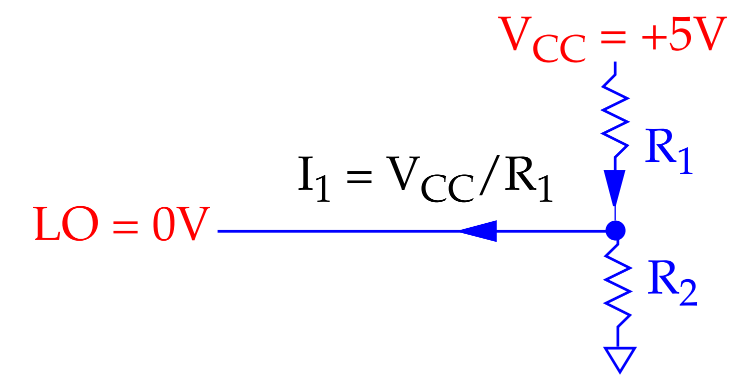
- Cuts the received signal in half, but reflections are *greatly* reduced.
- Also, this relaxes the tolerance required for termination matching at either end.

This technique is used extensively in microwave circuits but for digital electronics, *receivers* must be able to discriminate between reduced levels.

Resistor Selection

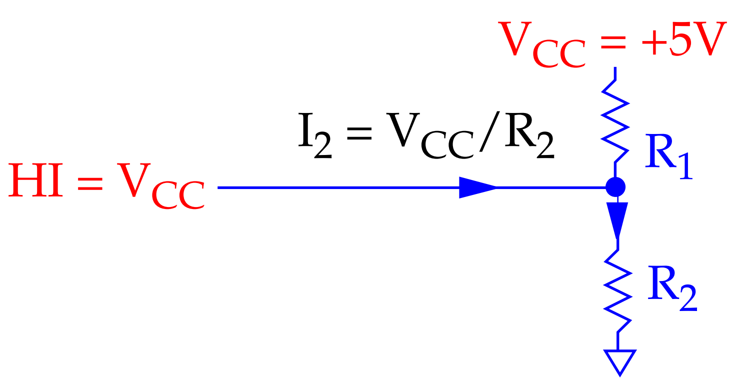
Always calculate the *worst-case* power dissipation in each terminator regardless of the operating speed, i.e., do not assume 50% duty cycle.

Worst case for *split termination*



$P_{R1} = I_1 V_{CC} = 0.25W$ ($R_1 = 100\Omega$)

No Current Flow in R_2



No Current Flow in R_1

$P_{R2} = I_2 V_{CC} = 0.25W$ ($R_2 = 100\Omega$)

The worst case power dissipation $\longrightarrow$ $P_{worst} = \frac{(5V)^2}{100\Omega}$

Power Dissipation in Terminating Resistors

Standard 1/8-W resistors will over heat in this case at room temperature.

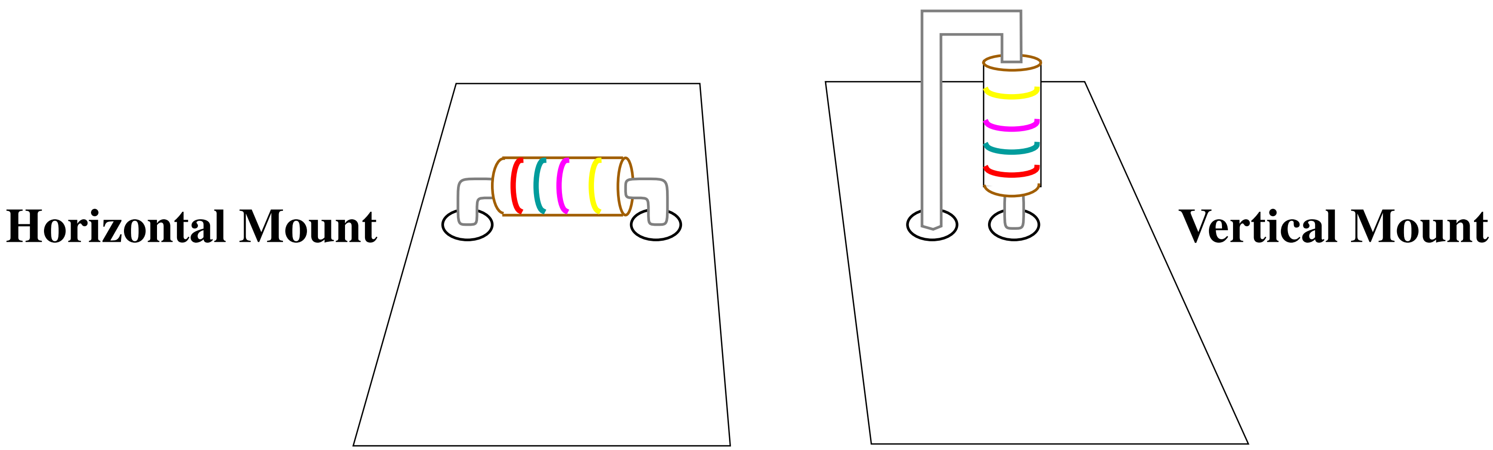
Even 1/4-W resistors may overheat at elevated ambient temperatures.

Power handing capacity of many resistors declines at elevated temperatures.

Resistor bodies have thermal resistance rating (Degree Celsius rise per Watt) just like IC packages.

However, resistors (especially ceramic) can tolerate much higher operating temperatures than ICs.

Unlike IC packages, resistors can be mounted in two different configurations:



Power Dissipation in Terminating Resistors

The vertical mount has a lower thermal resistance in still air than the horizontal mount.

The **VERY** short leg between the resistor and circuit board reduces thermal resistance.

The horizontal mount has a *lower inductance* because the leads stay low.

As a consequence of overheating, the resistance value may drift, causing reflections.

In extreme cases a resistor may crack open, unterminating the circuit.

Along with resistance value, a tolerance, and power rating, the next most important factor is the parasitic *series inductance*.

Every resistor has a parasitic series inductance depending on its internal construction, external lead type, and mounting configuration.

Series Inductance of Terminating Resistors

The effect of series inductance is a function of operating frequency.

The magnitude of inductive reactance seen by a rising edge as a function of rise time is given by:

$$|X(T_r)| = \frac{\pi L}{T_r}$$

Parasitic inductance causes termination mismatch just like an error in the terminating resistance.

Every 1% of reactance causes 1/2% of reflection.

E.g., when $|X(T_r)|$ equals 10% of terminating resistance, the reflection is 5%.

Typical series inductance of resistors:

Resistor Type	Series Inductance (nH)
1/4-W axial	2.5
1/8-W axial	1.0
1/8-W 1206, surface-mount	0.9

(1/4-W axial and 1/8-W axial) → 2.2Ω carbon-film

(1/8-W 1206, surface-mount) → 0Ω 0.12"x0.06"

Series Inductance of Terminating Resistors

Lab Experiment using:

- 1/8-W axial resistors to terminate a signal with rise and fall time of 1ns.
- Split termination of 100Ω to V_{CC} (5V) and 100Ω to ground.
- Transmission line impedance of 50Ω.

Magnitude of *inductive reactance*:

$$|X(T_r)| = \frac{\pi(1nH)}{1ns} = 3.14\Omega$$

Calculate the inductive reactance magnitude to resistance ratio $|X(T_r)|/R$:

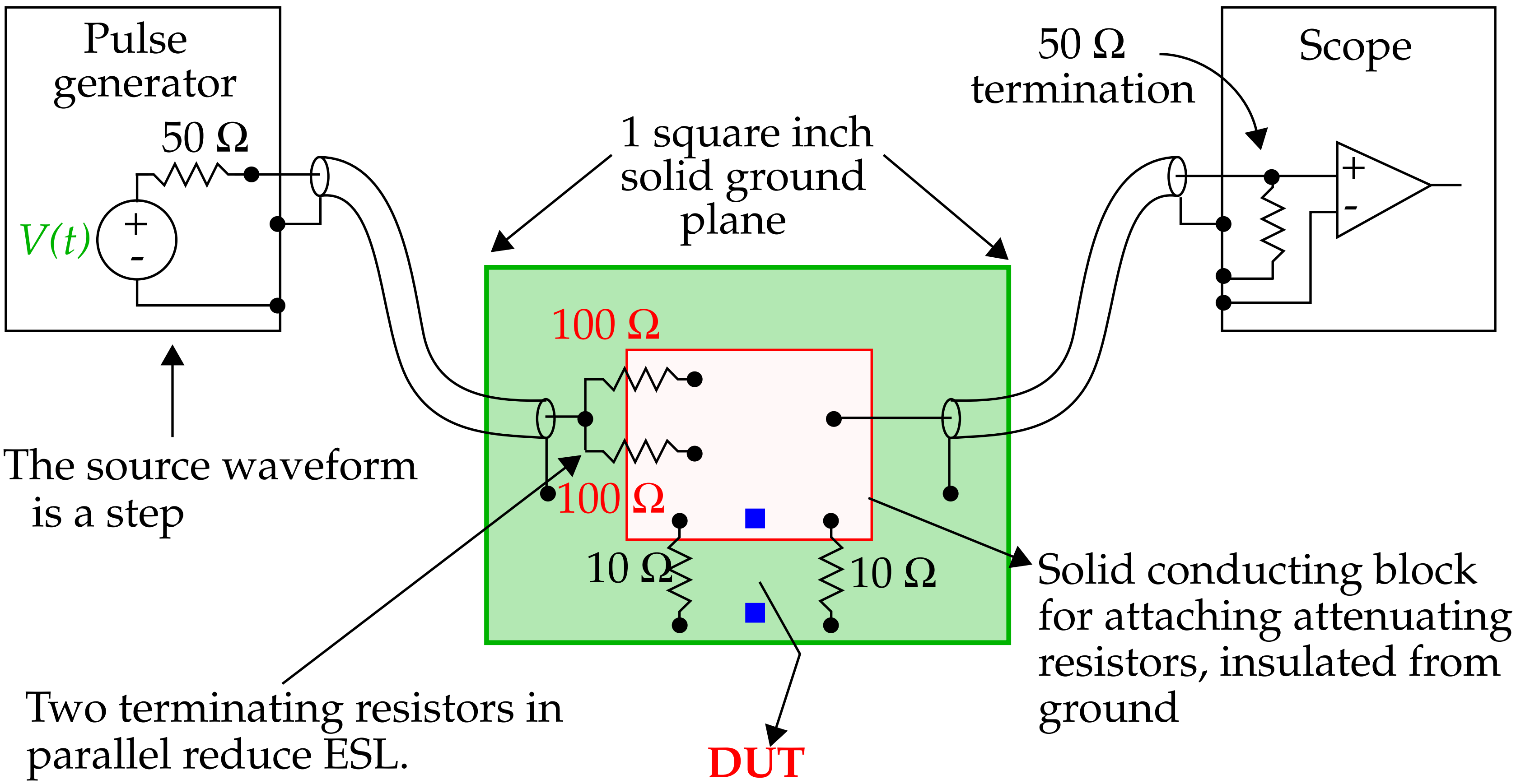
$$\frac{|X(T_r)|}{100\Omega} = 3.14\%$$

The reflection due to this inductance is 1.5% because of the parallel, split termination (single terminating resistor of 50 Ohms twice as much -> 3.14% because of 50 in demoninator).

In general, putting resistors in parallel is a good way to make low inductance structures.

Effect of Inductance of Terminating Resistance

Test gig for measuring parasitic inductance



The inductance measuring jig has a 4.3 Ω source impedance.

Effect of Inductance of Terminating Resistance

When testing a pure inductance, we expect the area of an inductive spike:

$$Area = \frac{L}{R_S}\Delta V$$

R_S = Test jig source resistance

When testing a pure resistance, we expect a step value of:

$$\text{Final Value} = \frac{R_1}{R_1 + R_S}\Delta V$$

R_1 = Resistance under test

We expect to see both superimposed for a physical resistor.

Use the test jig source resistance and final output value to solve for the unknown resistance (R_1) or measure R_1 with a DC ohmmeter.

Subtract the computed output from the measured waveform to obtain the inductive spike.

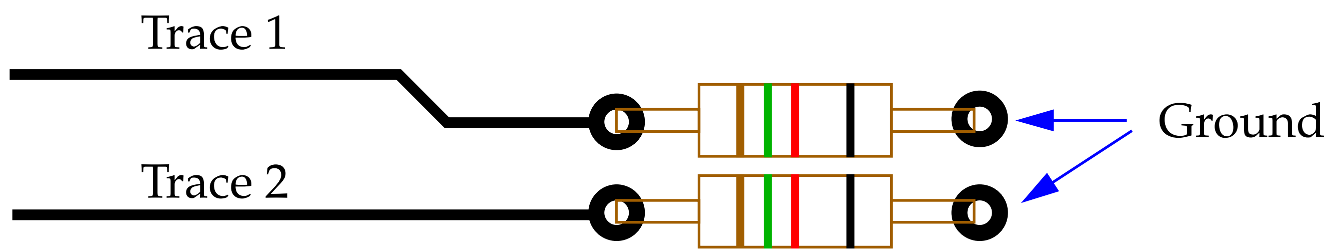
We can then compute the unknown inductance using:

$$L = (\text{spike area})\frac{R_1 + R_S}{\Delta V}$$

Accounts for resistance of DUT

Crosstalk in Terminations

The adjacent **terminating circuits** cross-couple signal energy between circuit traces.



The cross-coupling can be worse than the coupling between adjacent transmission lines.

Crosstalk in terminations is due to both mutual inductive and mutual capacitive coupling (inductive is usually larger).

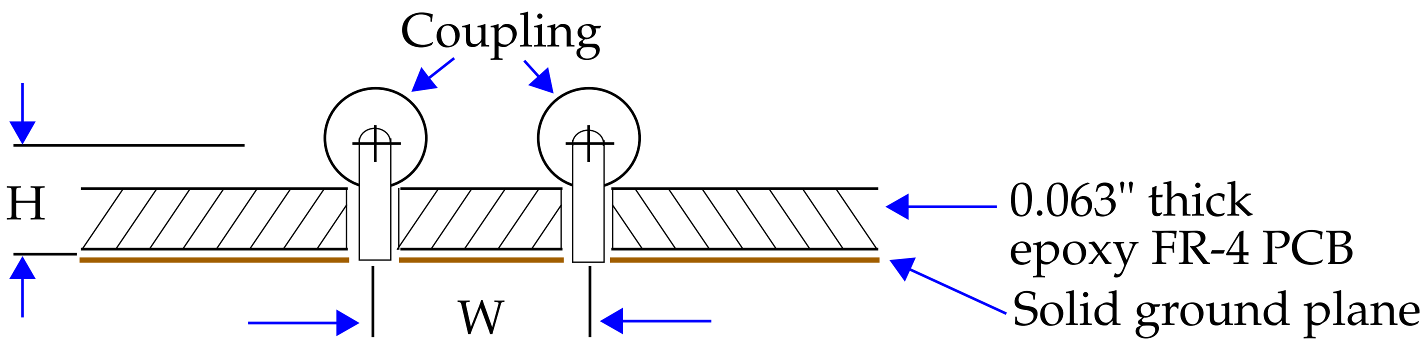
Both proportional to the derivative of the applied input signal.

$$\text{Noise Voltage} = \frac{K}{R}\left(\frac{\Delta V}{T_{10-90}}\right)$$

Noise voltage is peak crosstalk coupled onto trace 2

K = Overall cross-coupling coefficient (ohm-seconds or H)

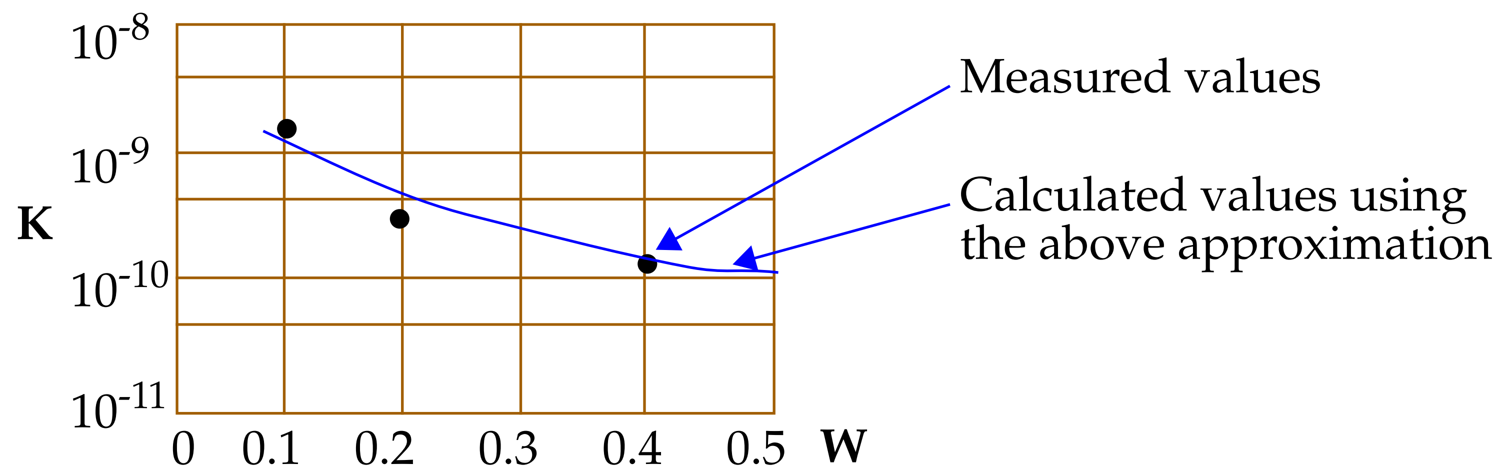
Crosstalk in Terminations



The crosstalk coefficient (K) can be computed using this approximation:

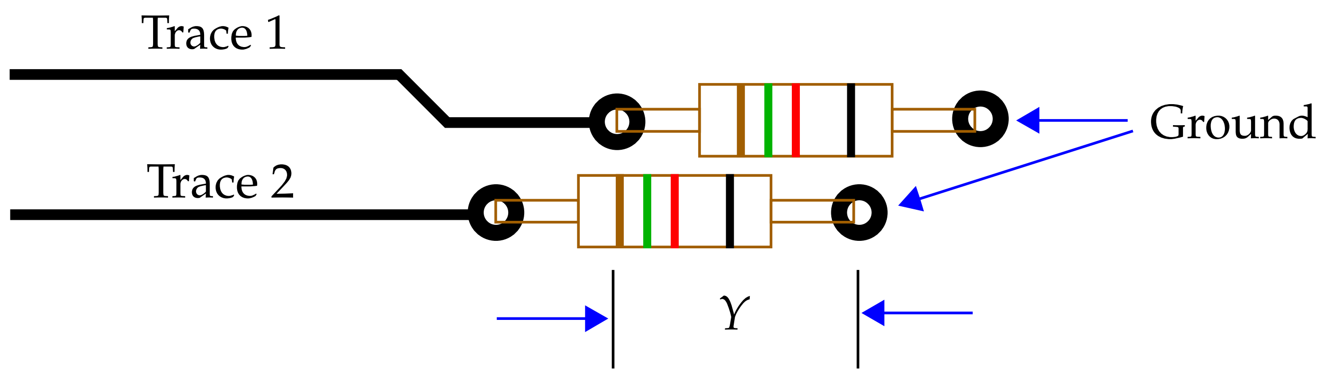
$$K = (5.08 \times 10^{-9}) Y \frac{1}{1 + \left(\frac{W}{H}\right)^2}$$

Y = len. of resistors between through-holes (in.)
H = centerline height above ground plane (in.)
W = separation between resistor centerlines (in.)



Crosstalk in Terminations

Use overlap length for the parameter Y for calculation of K if resistors are staggered in the layout:



Crosstalk from Adjacent Surface-Mounted Resistors

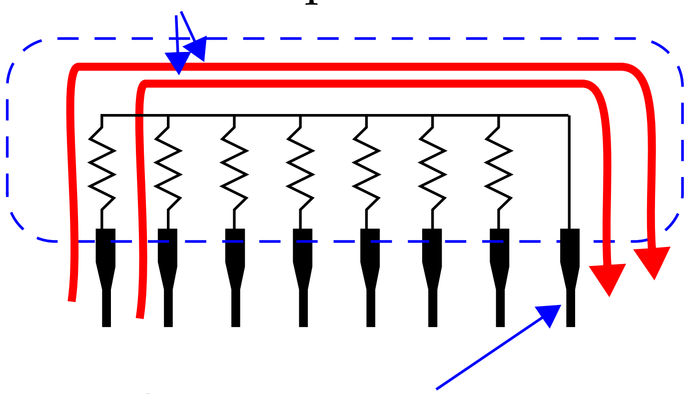
They exhibit lower crosstalk coefficient than axial components since they are closer to the board.

To reduce H and lower crosstalk, put the ground plane layer near the circuit board outer surface directly underneath the surface-mounted parts.

Crosstalk from SIP Terminating Resistors

Internal wiring has a dramatic impact on single inline packages (SIP).

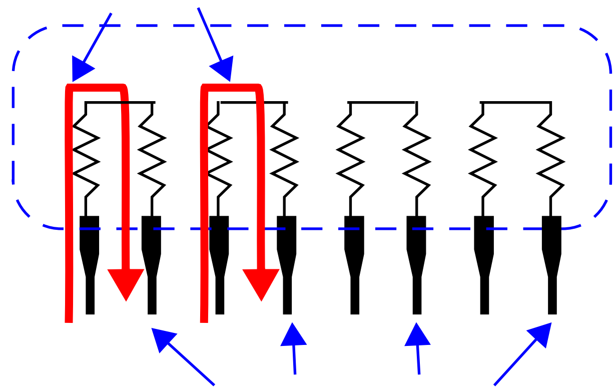
Overlapping current paths cause inductance loop



Common return pin

SIP-A

Current paths do not overlap
Mutual inductance is small



Separate return pins

SIP-B

For SIP-A, the current path is shared by all the terminators, increasing mutual inductance between resistors in the package.

For SIP-B, each resistor has a separate return pin improving its performance by a factor of 100.