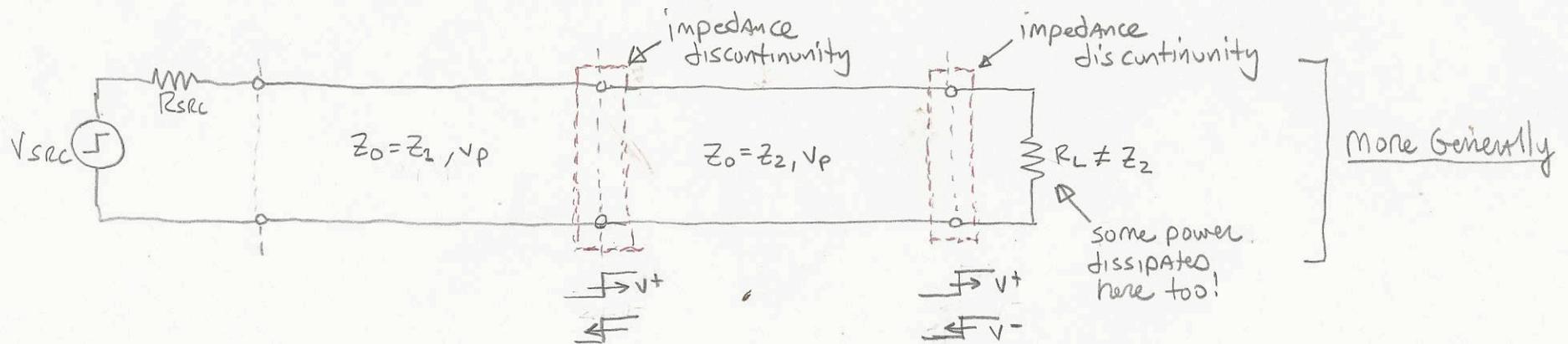
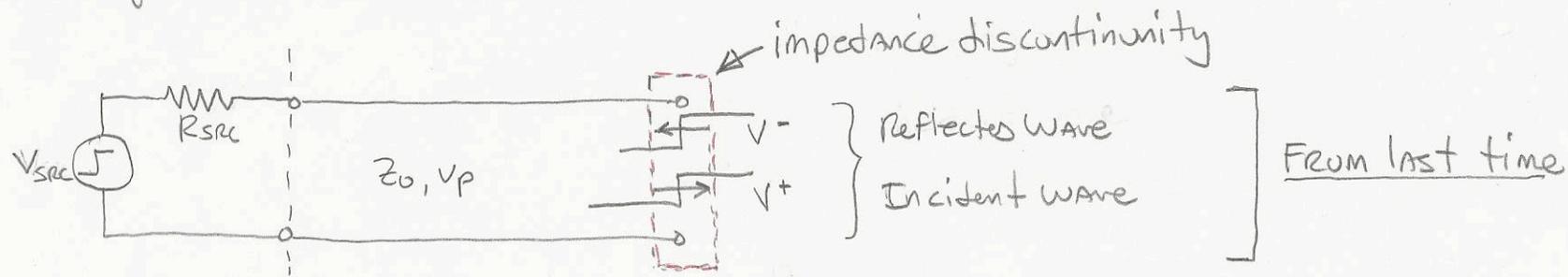


Reflections on Finite Length Lines

As signals propagate down a uniform T-Line, they "see" a constant Z_0 .

If, at some point, the signal encounters a different impedance than the Z_0 it has been traveling through, we say it has encountered a discontinuity.

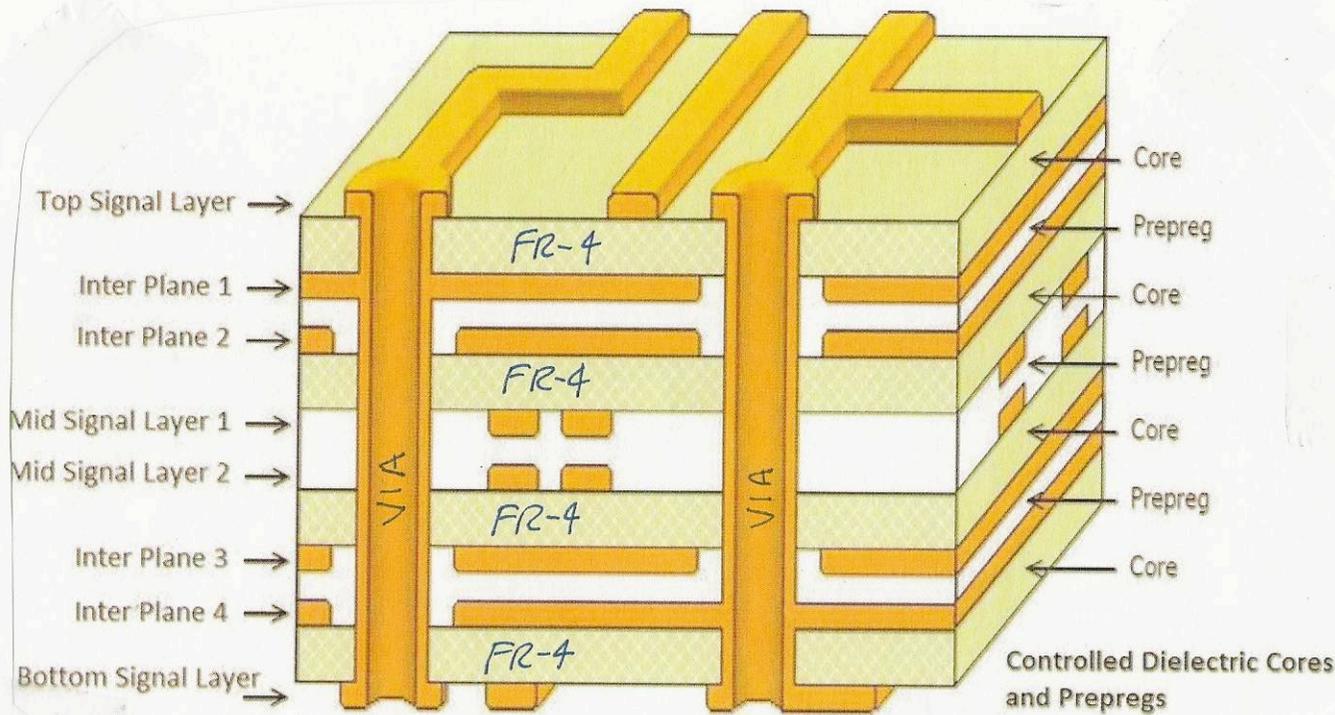
At the discontinuity we will have an incident wave, a reflected wave, and the remaining energy may be dissipated at the load or may continue on along another T-Line with different Z_0 .



Every impedance discontinuity generates a reflected wave.

Reflections on Finite Length Lines

Impedance Discontinuities occur in many places.



"STACK-UP" FOR 8-LAYER PCB

Top + Bottom Traces may have different Z_0 than inner layers (effective ϵ_r)

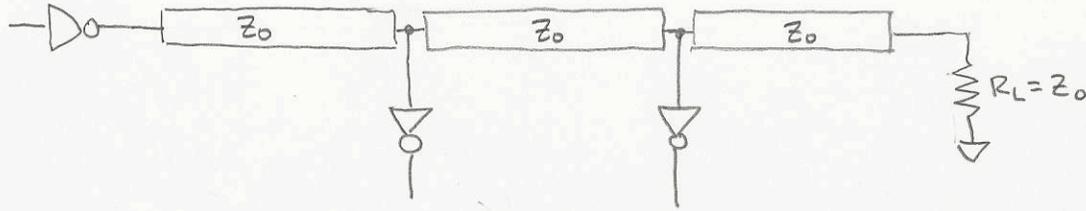
Vias have very different Z_0 than traces

Each layer transition is a impedance discontinuity

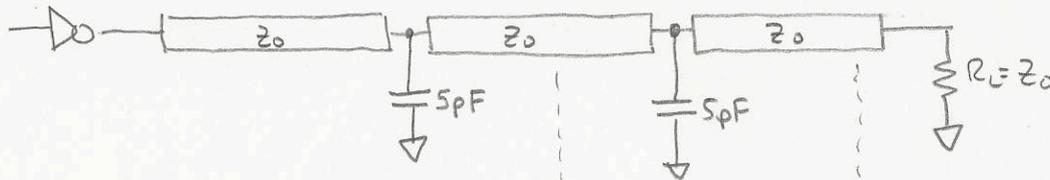
Why might you want the inner planes (power + ground) adjacent?

Reflections on Finite Length Lines

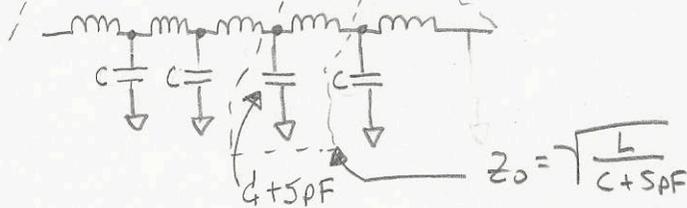
"Tapped" T-Line



EQUIVALENT TO:



Remember the Model?

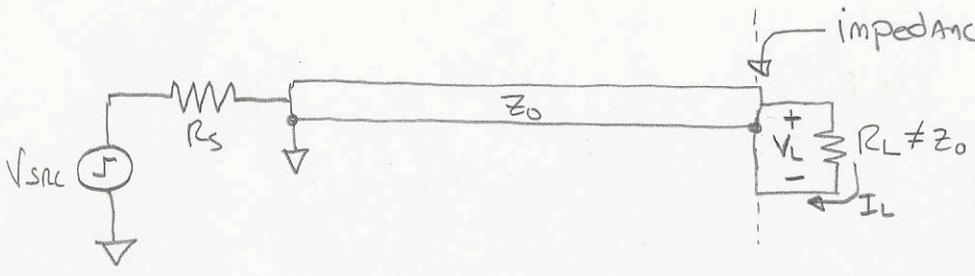


Each "tap" on the T-Line forms a "point discontinuity"
What about a corner?

Reflections On finite Length Lines

We have determined the Amplitude of An incident wave

Let's determine the size of a reflected wave for a simple case V^- relative to V^+ : ρ (rho) ↓



At the boundary: $V^+ + V^- = V_L$ (1)
 $I^+ - I^- = I_L$ (2) } note*

Also, $\left\{ \frac{V^+}{I^+} = Z_0, \frac{V^-}{I^-} = Z_0, \frac{V_L}{I_L} = R_L \right\}$

Starting with (2)

$$I^+ - I^- = I_L$$

$$\frac{V^+}{Z_0} - \frac{V^-}{Z_0} = \frac{V_L}{R_L}$$

$$\frac{V^+}{Z_0} - \frac{V^-}{Z_0} = \frac{V^+ + V^-}{R_L}$$

$$\frac{R_L V^+}{Z_0 R_L} - \frac{R_L V^-}{Z_0 R_L} = \frac{Z_0 (V^+ + V^-)}{Z_0 R_L}$$

$$R_L V^+ - R_L V^- = Z_0 (V^+ + V^-)$$

$$R_L V^+ - R_L V^- = Z_0 V^+ + Z_0 V^-$$

$$R_L V^+ - Z_0 V^+ = R_L V^- + Z_0 V^-$$

$$V^+ (R_L - Z_0) = V^- (R_L + Z_0)$$

$$\frac{R_L - Z_0}{R_L + Z_0}$$

$$= \frac{V^-}{V^+} = \rho$$

(rho) the reflection coefficient

substitute

note*: currents here were chosen in style more familiar to circuit analysis. Typically, with T-lines we let the current arrow on the signal (not return) line indicate the current reference direction.

here we are coming up with a relationship between ρ + the relative values of $R_L + Z_0$

derives result

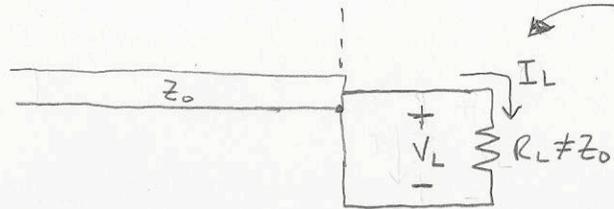
definition of ρ

The reflection coefficient tells us how much of the incident wave is reflected.

Later, we will expand the reflection coefficient into a transmitted + reflected form.

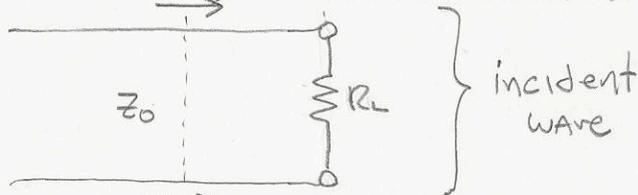
Current Confusion - Resolves (I hope!)

At the impedance discontinuity: $I^+ - I^- = I_L$. This is not immediately apparent, even contradictory. Let's break up the currents flowing at the discontinuity into incident + reflected currents. Use a two-wire representation for clarity. Assume positive reflection.



Also known AS I^+

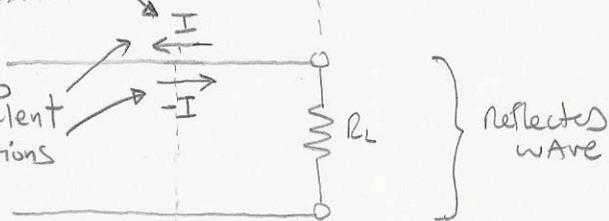
current reference is towards the right



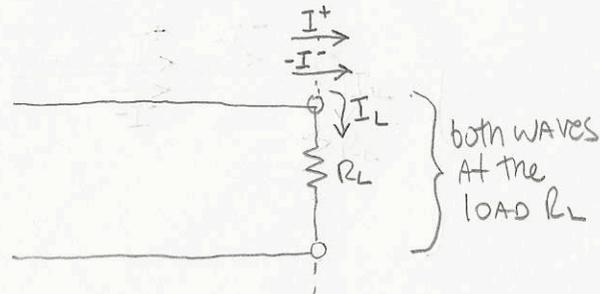
Also known AS I^-

WAVE movement

these two are equivalent representations



WAVE movement



Both currents flowing down the T-line travel together in time. Current does not flow down the top wire first, go through the resistor and then return. The bottom current arrow is identical to our reference current arrow on the top conductor.

Both currents exist at the load when the reflected voltage leaves R_L . The current on the top wire could be also written AS \overleftarrow{I} . The reflected current we call I^- .

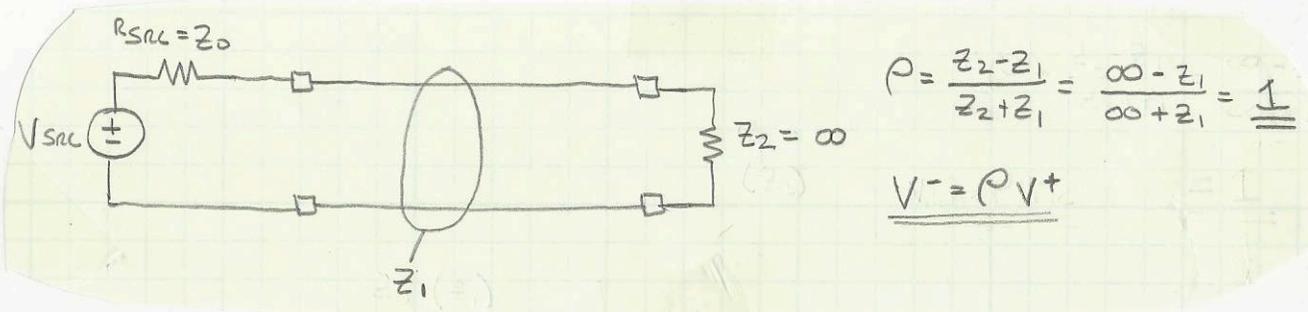
At the load, I_L will be the sum of I^+ and $-I^-$ since all the currents are referenced to the same direction.

$$I_L = I^+ - I^-$$

Reflections on Finite Length Lines

Let's go back and correlate these results with our 3 previous cases:

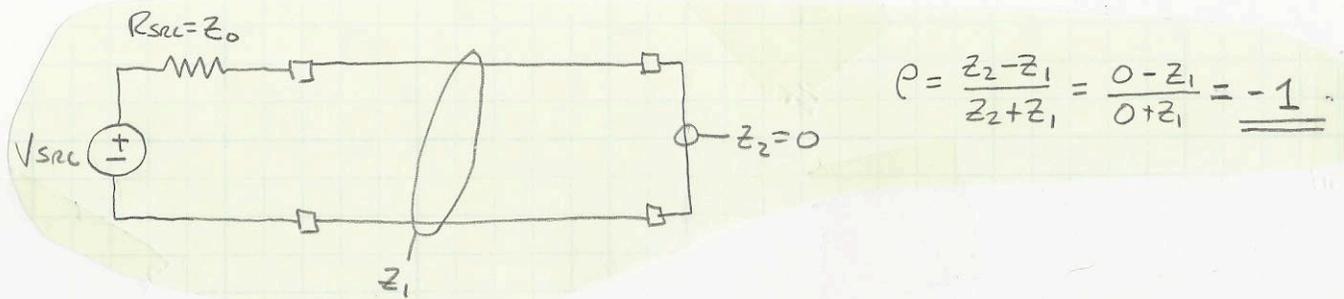
Open circuit:



- A $\rho = 1$ indicates that the reflected wave will be equal in magnitude and of the same polarity as the incident wave.
- Furthermore, since $\rho = \frac{R_L - Z_0}{R_L + Z_0}$, for this simple (but common!) case, whenever $R_L > Z_0$ we will see a positive reflection.

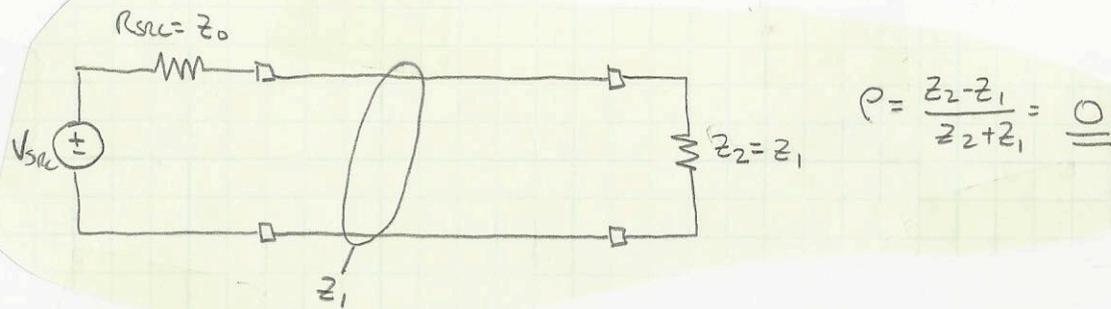
Reflections on Finite Length Lines

Short Circuit Case



- A ρ of -1 indicates the reflected wave will be equal in amplitude and of the opposite polarity of the incident wave.
- Furthermore, it follows from $\rho = \frac{R_L - Z_0}{R_L + Z_0}$, that when $R_L < Z_0$, a negative reflection will be generated.

Reflections on Finite Length Lines



A $\rho = 0$ indicates that no reflected wave will be generated.

Recap:

When $\text{LOAD } Z < \text{line } Z \Rightarrow$ inverted reflection

$\text{LOAD } Z > \text{line } Z \Rightarrow$ non-inverted reflection

This holds true at both ends of the T-line. (Source + Load)

The source of reflections on T-lines is an impedance discontinuity.