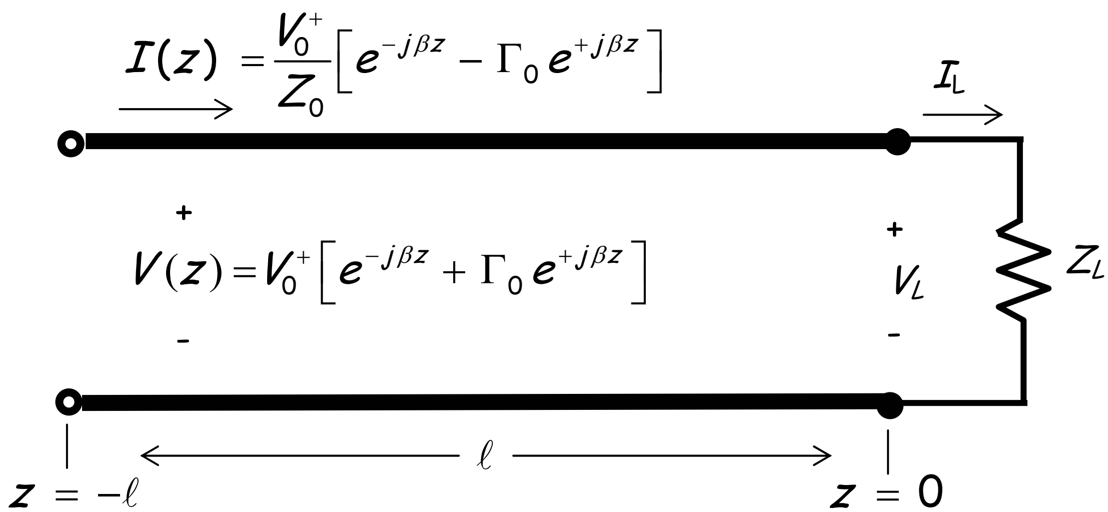
Power Flow and Return Loss

We have discovered that **two waves propagate** along a transmission line, one in each direction ($V^+(z)$ and $V^-(z)$).



The result is that electromagnetic energy flows along the transmission line at a given rate (i.e., **power**).

Q: *How much power flows along a transmission line, and where does that power go?*

A: We can answer that question by determining the power **absorbed** by the **load**!

The **time average** power absorbed by an impedance Z_L is:

$$\begin{aligned} P_{abs} &= \frac{1}{2}\mathrm{Re}\left\{V_L I_L^*\right\} \\ &= \frac{1}{2}\mathrm{Re}\left\{V(z=0)\,I(z=0)^*\right\} \\ &= \frac{1}{2Z_0}\mathrm{Re}\left\{\left(V_0^+\left[e^{-j\beta 0} + \Gamma_0 e^{+j\beta 0}\right]\right)\left(V_0^+\left[e^{-j\beta 0} - \Gamma_0 e^{+j\beta 0}\right]\right)^*\right\} \\ &= \frac{\left|V_0^+\right|^2}{2Z_0}\mathrm{Re}\left\{1-\left(\Gamma_0^* - \Gamma_0\right) - \left|\Gamma_0\right|^2\right\} \\ &= \frac{\left|V_0^+\right|^2}{2Z_0}\left(1-\left|\Gamma_0\right|^2\right) \end{aligned}$$

The significance of this result can be seen by **rewriting** the expression as:

$$\begin{aligned} P_{abs} &= \frac{\left|V_0^+\right|^2}{2Z_0}\left(1-\left|\Gamma_0\right|^2\right) \\ &= \frac{\left|V_0^+\right|^2}{2Z_0} - \frac{\left|V_0^+\Gamma_0\right|^2}{2Z_0} \\ &= \frac{\left|V_0^+\right|^2}{2Z_0} - \frac{\left|V_0^-\right|^2}{2Z_0} \end{aligned}$$

The two terms in above expression have a very definite **physical meaning**. The first term is the time-averaged **power of the wave** propagating along the transmission line **toward the load**.

We say that this wave is **incident** on the load:

$$P_{inc} = P_{+} = \frac{\left|V_0^+\right|^2}{2Z_0}$$

Likewise, the second term of the P_{abs} equation describes the **power of the wave** moving in the other direction (**away from the load**). We refer to this as the wave **reflected** from the load:

$$P_{ref} = P_{-} = \frac{\left|V_0^-\right|^2}{2Z_0} = \frac{\left|\Gamma_0\right|^2\left|V_0^+\right|^2}{2Z_0} = \left|\Gamma_L\right|^2 P_{inc}$$

Thus, the power **absorbed** by the load (i.e., the power **delivered to** the load) is simply:

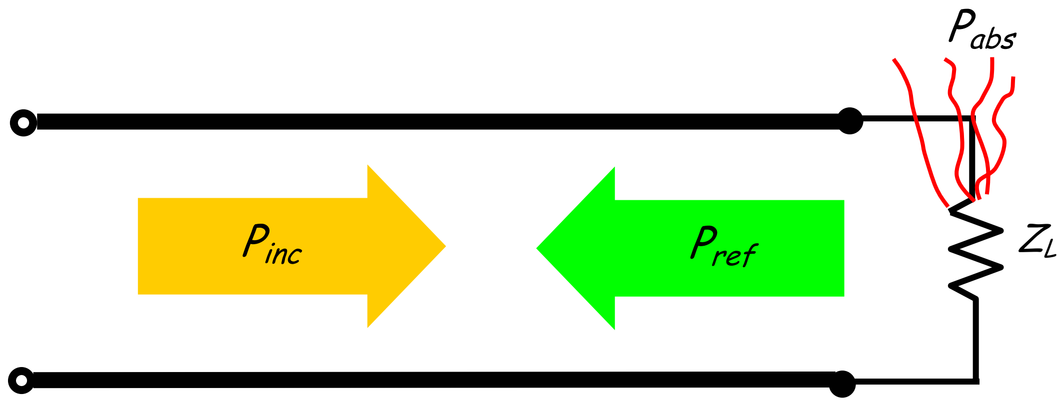
$$P_{abs} = P_{inc} - P_{ref}$$

or, rearranging, we find:

$$P_{inc} = P_{abs} + P_{ref}$$

This equation is simply an expression of the **conservation of energy** !

It says that power flowing **toward** the load (P_{inc}) is either **absorbed** by the load (P_{abs}) or **reflected** back from the load (P_{ref}).



Note that if $\left|\Gamma_L\right|^2 = 1$, then $P_{inc} = P_{ref}$, and therefore **no power** is absorbed by the **load**.

This of course **makes sense** !

The magnitude of the reflection coefficient ($\left|\Gamma_L\right|$) is equal to one **only** when the load impedance is **purely reactive** (i.e., purely imaginary).

Of course, a purely reactive element (e.g., capacitor or inductor) **cannot** absorb any power—**all** the power **must** be reflected!

Return Loss

The **ratio** of the reflected power to the incident power is known as **return loss**. Typically, return loss is expressed in **dB**:

$$R.L. = -10\ \log_{10}\left[\frac{P_{ref}}{P_{inc}}\right] = -10\ \log_{10}\left|\Gamma_L\right|^2$$

For **example**, if the return loss is **10dB**, then **10%** of the incident power is **reflected** at the load, with the remaining **90%** being **absorbed** by the load—we "lose" 10% of the incident power

Likewise, if the return loss is **30dB**, then **0.1 %** of the incident power is **reflected** at the load, with the remaining **99.9%** being **absorbed** by the load—we "lose" 0.1% of the incident power.

Thus, a **larger** numeric value for return loss **actually** indicates **less** lost power! An **ideal** return loss would be ∞ dB, whereas a return loss of 0 dB indicates that $\left|\Gamma_L\right| = 1$--the load is **reactive**!