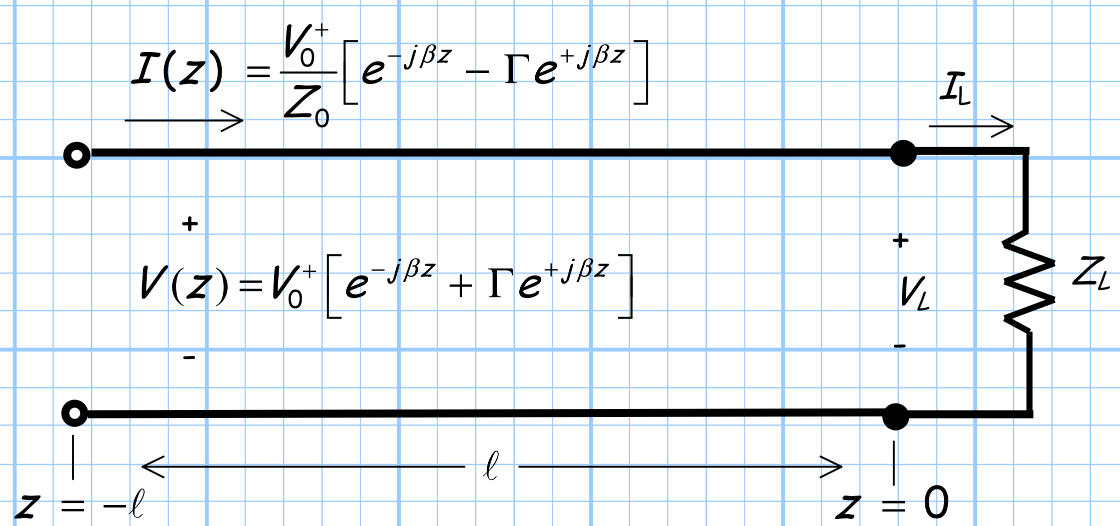
Power Flow and Return Loss

We have discovered that **two waves propagate** along a transmission line, one in each direction ($V_0^+ e^{-j\beta z}$ and $V_0^- e^{+j\beta z}$).



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:

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

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

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

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:

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

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:

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

Thus, the power absorbed by the load is simply:

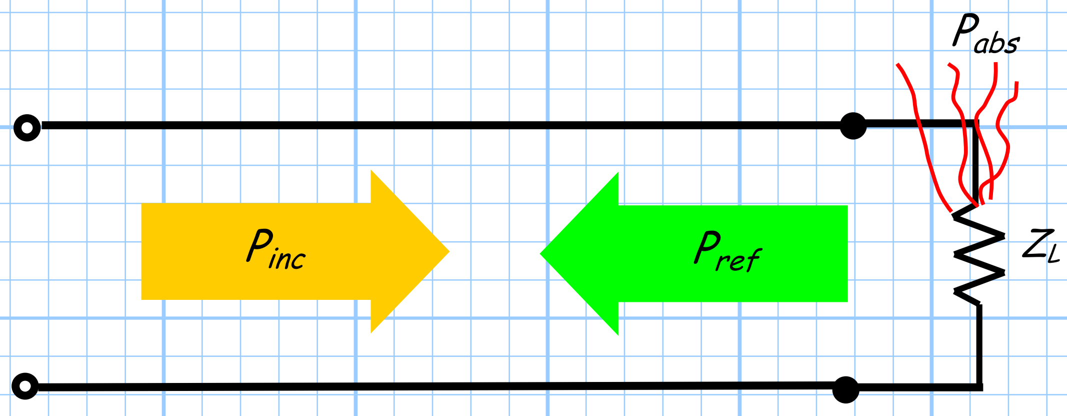
$$P_{abs} = P_{inc} - P_{ref}$$

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 $|\Gamma|^2 = 1$, 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 ($|\Gamma|$) 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!

<u>Return Loss</u>

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

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

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 $|\Gamma| = 1$--the load is **reactive**!