**Power Flow and Return Loss**

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

\[
I(z) = \frac{V_0^+}{Z_0} \left[ e^{-jβz} - \Gamma e^{jβz} \right]
\]

\[
V(z) = V_0^+ \left[ e^{-jβz} + \Gamma e^{jβz} \right]
\]

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:

$$
\rho_{abs} = \frac{1}{2} \Re\{V_L I_L^*\}
$$

$$
= \frac{1}{2} \Re\{V(z = 0) I(z = 0)^*\}
$$

$$
= \frac{1}{2 Z_0} \Re\left\{\left(\frac{V_0^+}{2 Z_0} \left[ e^{-j \beta_0} + \Gamma e^{+j \beta_0} \right] \left(\frac{V_0}{2 Z_0} \left[ e^{-j \beta_0} - \Gamma e^{+j \beta_0} \right]\right)^*\right\}
$$

$$
= \frac{|V_0^+|^2}{2 Z_0} \Re\left\{1 - (\Gamma^* - \Gamma) - |\Gamma|^2\right\}
$$

$$
= \frac{|V_0^+|^2}{2 Z_0} \left(1 - |\Gamma|^2\right)
$$

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

$$
\rho_{abs} = \frac{|V_0^+|^2}{2 Z_0} \left(1 - |\Gamma|^2\right)
$$

$$
= \frac{|V_0^+|^2}{2 Z_0} \frac{|V_0^+\Gamma|^2}{2 Z_0}
$$

$$
= \frac{|V_0^+|^2}{2 Z_0} \frac{|V_0^-|^2}{2 Z_0}
$$

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:

\[ P_{inc} = P_+ = \frac{|V_0^+|^2}{Z_0} \]

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:

\[ P_{ref} = P_- = \frac{|V_0^-|^2}{2Z_0} = \frac{|\Gamma|^2 |V_0^+|^2}{2Z_0} = |\Gamma|^2 P_{inc} \]

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!

**Return Loss**

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

$$R.L. = -10 \log_{10} \left[ \frac{P_{ref}}{P_{inc}} \right] = -10 \log_{10} |\Gamma|^2$$
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 |Γ|=1—the load is reactive!