Lesson #3: How do we represent reflections?

Lesson #3 Learning Objectives: Upon successfully completing this lesson and the associated homework, students will be able to:

1. Identify microwave ports and transmissions lines.
2. Analyze microwave systems consisting of transmission lines and loads by calculating the reflection coefficient at a port.
3. Examine the effects of frequency and component value on reflection coefficients.

1.1 Microwaves

Just so you know, we are not talking about small hands saying "Hi".

Nor are we talking about those things on Lake Michigan.

And most certainly not anything involving GE or something found in a bargain bin at Home Depot.

The **microwaves** will be talking about are frequencies with a wavelength that falls in the range from **1 m** (300 MHz) to **1 mm** (300 GHz). Your microwave oven operates near 2.45 GHz, so it is appropriately named. Engineers distinguish microwave systems from other, lower frequency systems since the rules are just a little bit different up here. We need to carefully consider line lengths and things like cable impedances that we can usually ignore in traditional circuit design.

1.2 Some Microwave definitions

A microwave **port** is any connection from one microwave environment to another. For example, consider a cable that connects to an antenna. The signal leaves the first environment — the cable — and enters the second — the antenna — forming a port.

A **transmission line** is a cable or any other signal-carrying electrical connection whose properties are well-defined and don't change along its length. By this definition, just about anything can be considered a transmission line. A paper clip, copper wire, PCB traces, and of course coaxial cables. A signal traveling down a transmission line ideally doesn't change shape as it moves down the line. It will only change phase. Transmission lines also have a **characteristic impedance**.

Question: What is impedance?

So impedance is just a ratio of voltage to current. If we examine a signal on a cable, we see that we could inject a current into the cable and measure the voltage due to the current travelling down the line. If we take the ratio of the voltage due to current over the current, we find the characteristic impedance of the line — which is a real resistance (i.e., measured in Ohms). 50 Ω is a very common impedance in most equipment[1].

1.3 So what about reflections again?

As we saw last lecture, if we don't match properly, we are going to have reflected power traveling back towards us. It's not impossible to visualize what will happen when we have a short or an open — both full reflections of energy. At the matched state, there won't be any reflections. But what about the in-between cases?

[1] In fact, some awesome folks at Bell labs ran many different experiments and found that 50 Ω offered a great compromise between signal strength, efficiency, and achievable distance for things like the telephone. We have just kept using their stuff to this day (as I type this on a Unix-variant, another case-in-point that Bell Labs was amazing).

The **reflection coefficient** is defined as the ratio of the reflected signal to the incident signal.

$$\Gamma = \frac{v_{ref}}{v_{inc}}$$

The letter for this is a capital Gamma (Γ), and many times the reflection coefficient is just referred to as "Gamma." Γ (the reflection coefficient) is in general complex since the phase of the incident wave and the reflected wave may not be the same.

Let's derive it!

Just looking at this, we can quickly get some insight.

Find the reflection coefficient, Γ, when $Z_L = \infty$

Find the reflection coefficient, Γ, when $Z_L = 0$

Find the reflection coefficient, Γ, when $Z_L = Z_0$

When a circuit has only passive components such as:

And when we take the magnitude of Γ and plotting in decibels (dB), we find **return loss**. This is interpreted as the loss suffered when making the return trip to the instrument or generator. We will revisit this parameter later when we discuss antennas.

So Γ is not too difficult to calculate and tells us a lot about the system. We can know how much energy is being reflected at a port, how much is being absorbed into the load and also see the phase difference being reflected!

For now, recall now that the impedance of

A capacitor is: and an inductor is:

And let's get to work calculating some Γ's.

1.4 Key Take-Aways

1. A microwave port exists at the points of transition in a circuit. Transmission lines carry energy and have an associated characteristic impedance.
2. The reflection coefficient can be calculated knowing the characteristic impedance and load impedance.
3. The reflection coefficient is generally complex.
4. The reflection coefficient for a system will vary greatly with both frequency as well as component value.
5. The reflection coefficient defines and characterizes system performance.