# ECE 4880: RF Systems

## Fall 2016

## Lab 3: Splitters and Directional Couplers

### 1 Learning Objectives

The students will learn to:

1) Use the network analyzer (NA) to measure the splitter and directional coupler as a **three**-port RF modules
2) Estimate the path loss and impedance match from the S parameters
3) Understand the broadband operation in microwave transmission lines and narrow band operation in LC lumped circuits
4) Build Simulink modules for signal path with check points

### 2 Background Information

### 2.1 RF modules with three ports and four ports

We have measured 1-port and 2-port RF modules in Labs 1 and 2. To create more functional signal chains, 3 and 4 ports are needed for driving multiple paths, feedback, testing with minimal impact, isolation and self cancellation. We will measure some of the most popular 3-port or 4-port RF modules, and leave the signal chain design for your future free labs. This lab will be relatively short, but just to build your practical handling in multi-port RF handling.

There are two fundamental ways to build such 3 or 4 port passive modules: by transmission lines (similar to a parallel or series stub line) or by LC tanks. For transmission line structures, when we do not need precise control of the phase offset, often the module can operate within a very large bandwidth, often just limited by the external isolation properties just like RF cables and connectors. For LC tank structures, similar to filters, the operation bandwidth is often limited to be kept in the desirable path loss and isolation.

#### 2.1.1 Signal splitters

The first 3-port module we will measure is the RF power splitter, as shown in Fig. 1. This is often a passive transmission-line structure, similar to the impedance-matched stub lines. Recall that if the stub line has a matched termination, the physical length will not matter for the impedance sake (always at the center of the Smith Chart). This allows wavelength-unspecific, i.e., broadband, operation.

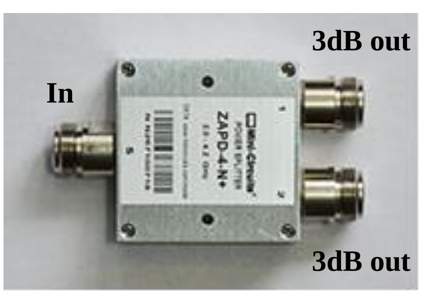
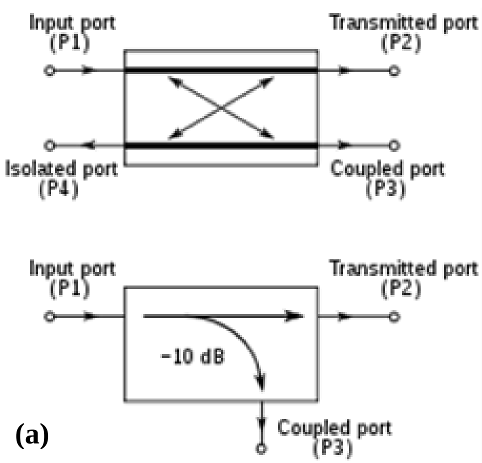



**Fig. 1.** Simple broadband signal splitter based on microwave transmission lines. Detailed waveguide structures, instead of lumped LC elements, are used to create the splitting functions and impedance matching. Most often the two output ports have 3dB loss due to splitting, i.e., half of the input power going to each output port. There can be an identical phase shift to the two output ports.

As half of the input power is sent to each of the two output splits, for the passive signal splitter, this means the output is a copy of the input with 3dB loss (3dB = 2×). There can be a small phase offset for each of the output ports, but symmetry is usually performed very carefully that the phase offset is identical for the two output ports. The splitter is often used in the signal chain to create identical splits, such as in the consideration of the quadrature scheme in the receiver.

### 2.1.2 Directional couplers

We will introduce a four-port RF element, the directional coupler, as shown in Fig. 2. The four ports are In, Out, Coupled and Isolate. The basic function is to propagate In to Out with minimal loss and maximum reverse isolation (so it is directional). The port Coupled is often a small copy of In with said 10dB loss, so that the coupler remains passive. Isolate is a port to dump excessive RF power during any mismatch, and is often not used in signal chains, but just a matched termination.




(b)


**Fig. 2**. Microwave/RF directional coupler based on transmission lines: (a) Schematic where P1 ↔ P2 is about –0.5dB (top bidirectional and bottom directional) and P1 → P3 is about –10dB and P2 → P3 is about –50dB (directional); (b) A commercial sample with dual bands of operations.

The directional coupler is often implemented by transmission line structures, and hence has a broadband operation. The sacrifice will be the reverse isolation from Out to In, which sometime may not have high loss.

## 2.2 Other popular three-port or four-port RF modules (not measured in this lab)

We will not make measurements for the following modules in this lab, but they are very similar in construct and functions to splitters and couplers.

### 2.2.1 Quadrature coupler

A variation of the directional coupler is the 3dB quadrature coupler, as shown in Fig. 3. We will not measure this structure in this lab. As the name suggests, this is most often used in the quadrature scheme for noise cancellation. As the phase needs to be precisely controlled, the quadrature coupler has often small bandwidth of operation.

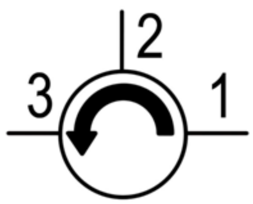
### 2.2.2 RF circulators

The next element is the circulator, which provides minimal loss for signal connection in one direction and large isolation in the other, as shown in Fig. 2. The circulator is an important element for Tx/Rx isolation in duplex radio links, where both Tx and Rx need good coupling to the shared antenna (very often the largest element in size in a mobile unit such as in your smart phone), but good isolation in between.

Circulators cannot be readily done in transmission-line structure for the large isolation, and is most often by LC tanks.  This means the operation bandwidth is often limited.


(a) (b) (c)

**Fig. 3.** 3dB quadrature hybrid coupler (aka 90° hybrid) where both inputs are split equally and sent to the both outputs with in phase horizontally and with a –90° phase shift diagonally: (a) Schematic; (b) A commercial sample with directivity for In and Out; (c) A possible transmission line implementation.




$$S = \begin{pmatrix} 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix}$$

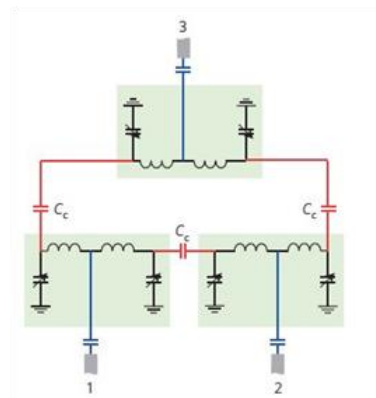




**Fig. 4.** Circulator symbol, ideal function and possible LC lumped element implementation.  Circulators cannot be easily implemented by transmission lines and are often in LC tanks similar to filters. Thus the operational bandwidth is limited.

## 3 Lab Procedures

### 3.1 Characterization of splitter and directional coupler

1. Obtain the splitter (ZFRSC-42+) and directional coupler (ZFDC-10-182+) from the TA.  The testing order does not matter, so we will share the components.
   Splitter characteristics:
   - Resistive, wide frequency range, DC to 4200 MHz
   - 2 Way – 0°

   Directional Coupler characteristics:
   - Frequency range, 10 to 1800 MHz
   - -25 dB coupling
   - Internal termination (3-port device)
2. Perform the TL de-embedding measurements for the connector you will use for the 3-port connection for the frequency range from 200 to 3000 MHz.  Notice that the frequency range can be different for different parts, while de-embedding.
3. As our vector NA has only two ports (expandable to 4 or 6 ports in other module), we will make each pair of the two ports sequentially (three combinations for 3 ports).  Ignore Isolate coupling to

other ports except In. Use proper terminations for the open ports, as required and mentioned in the lab.

### 3.2 Simulink module

1. Figure out the necessary measurements for your splitter and directional coupler to describe them in Simulink. Use Simulink then to generate the signal propagation through the splitter and coupler.

## 4 Optional Explorations

1. In your measurements of splitters and couplers, does power always preserve, in what operational conditions that there would significant power dissipation within the Mini-Circuit module.
2. Is the phase shift in the directional coupler constant? Compare both Out and Coupled.

## 5 Report Guidelines

In addition to the NA measurements, there are significant post processing of data you need to perform in Matlab or Excel. You will need to use the de-embedding routines you developed in Lab 2 if the connection parasitic is of concern.

The main purpose of the lab report is to present findings (and enable people to trace, and repeat if necessary) of your results. Therefore, the ambient information can be as important as the direct results from the instrument. The following content is suggested, but not meant as a template or limitation.

1. Brief description of the lab
2. Brief description of instruments
3. Brief description of the procedures
4. Measurement results in 3.1. Determine if the de-embedding procedure is needed.
5. Present your argument about the impedance matching for each port in splitters and couplers.
6. Describe your splitter and coupler in Simulink, and then use Simulink to generate the S parameters. How does it compare with your measurements?

For report submission, please name your lab reports as: netid_netid_netid_ECE4880_Lab3 for three students in a lab group. Submit your final report in Word or pdf to kan@ece.cornell.edu. The report should be by each group. Include your Simulink screen capture in your report.