Fields and Waves I

Lecture 8

Matching Stubs

J. Dylan Rees
Electrical, Computer, and Systems Engineering Department
Rensselaer Polytechnic Institute, Troy, NY

These slides were prepared through the work of the following people:

- Kenneth A. Connor – ECSE Department, Rensselaer Polytechnic Institute, Troy, NY (Emeritus)
- J. Darryl Michael – GE Global Research Center, Niskayuna, NY
- Thomas P. Crowley – National Institute of Standards and Technology, Boulder, CO
- Sheppard J. Salon – ECSE Department, Rensselaer Polytechnic Institute, Troy, NY (Emeritus)
- Lale Ergene – ITU Informatics Institute, Istanbul, Turkey
- Jeffrey Braunstein – ECE Department, University at Albany
- James Lu - ECSE Department, Rensselaer Polytechnic Institute, Troy, NY
- James Dylan Rees - ECSE Department, Rensselaer Polytechnic Institute, Troy, NY

Materials from other sources are referenced where they are used.
Those listed as Ulaby are figures from Ulaby's textbook.

Review

- The Smith Chart allows the graphical solution of the transmission line equation for *Z.*
- The Chart gives direct conversion between Γ and *Z.*

https://em8e.eecs.umich.edu/ulaby_modules_choice.html

Review

Studio Session 3

- Why did the long spool of cable (almost) completely block a specific frequency?
- What happened when you attached the 50Ω resistor at the end of the cable?
- What behavior did you see at 50% and 90% of the blocked frequency?

Smith Chart

- What do you notice about the relationship between these two real impedances' magnitudes and positions on the Smith Chart?

Smith Chart

- What do you notice about the relationship between these two real impedances' magnitudes and positions on the Smith Chart?

Inverse, and half a revolution apart.

Smith Chart

- Quick reminder: what is the relationship between impedance and admittance?

Smith Chart

- Quick reminder: what is the relationship between impedance and admittance?

Inverse.

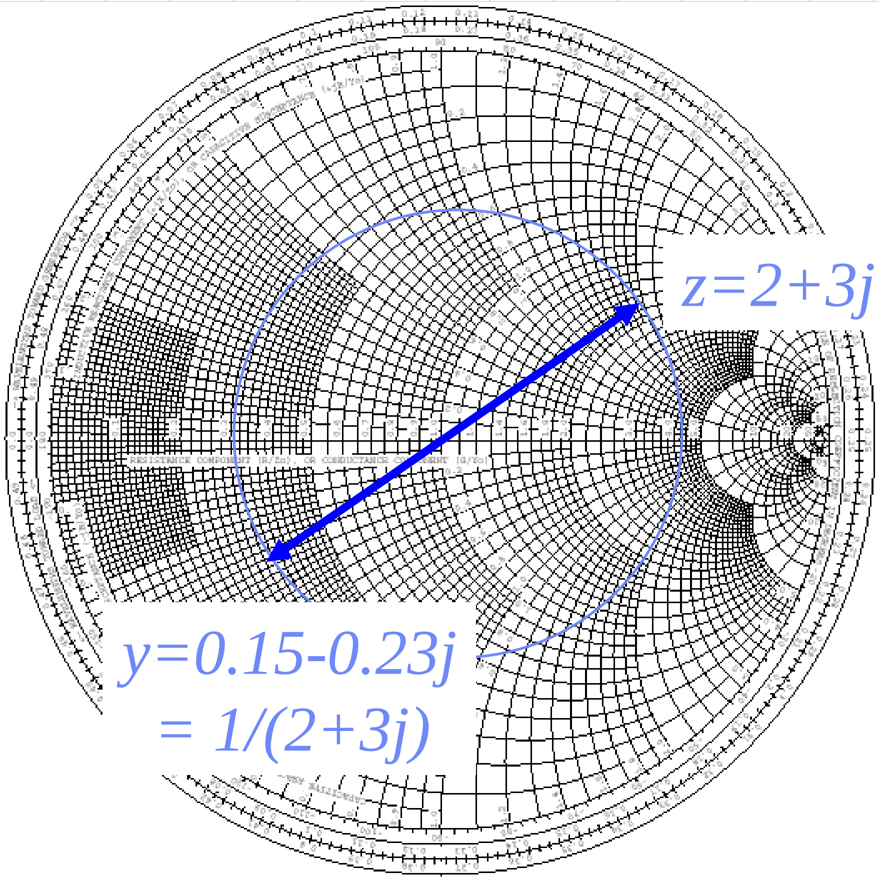
Smith Chart

Any point reflected through the centre point converts admittance to impedance and vice versa.

Top Half: inductive reactance
or
capacitive susceptance

usually marked on charts

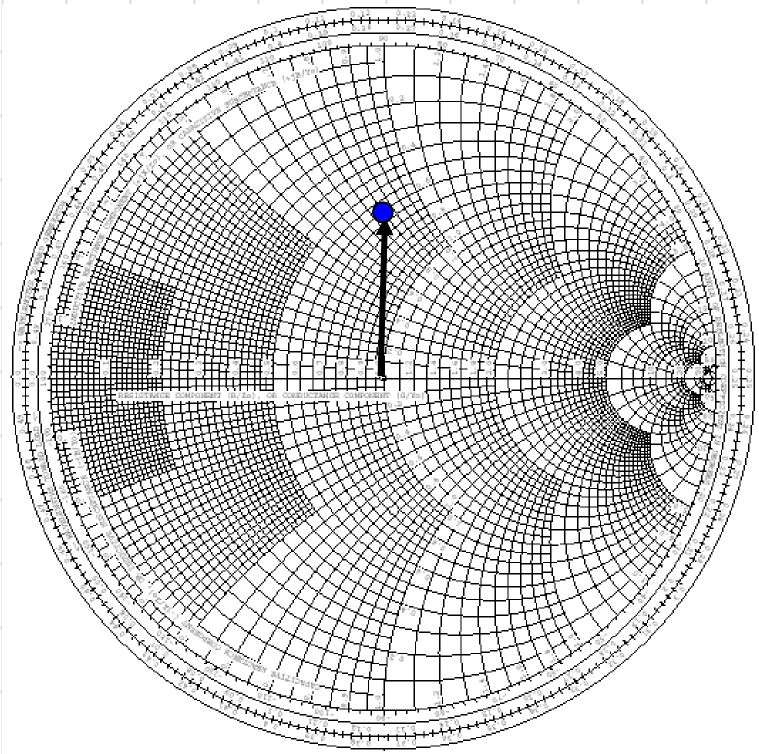
Bottom Half: capacitive reactance
or
inductive susceptance



Ulaby

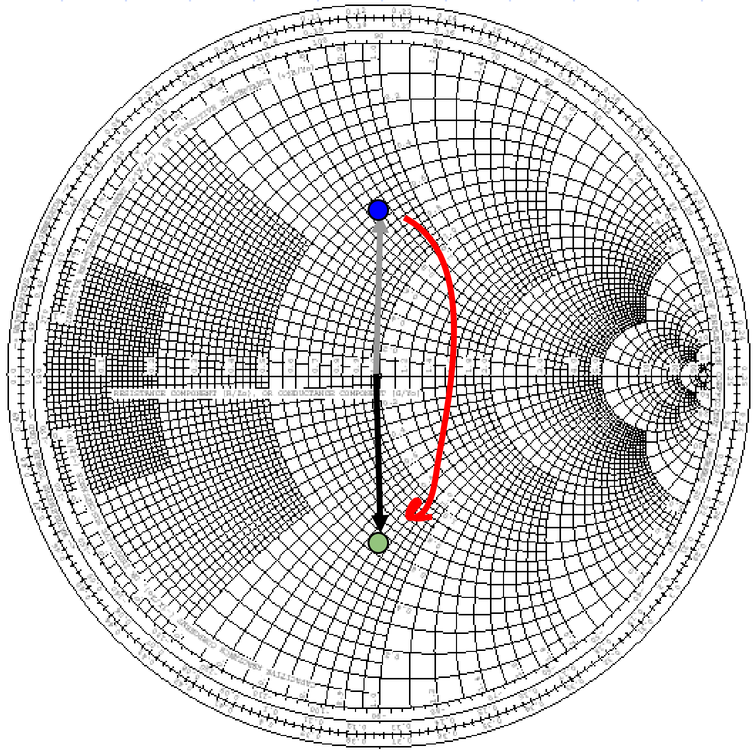
Smith Chart

- Consider this example again. The blue dot represents the input impedance at the end of a λ/8 transmission line. How do we find the input admittance?



Smith Chart

- Consider this example again. The blue dot represents the input impedance at the end of a λ/8 transmission line. How do we find the input admittance?



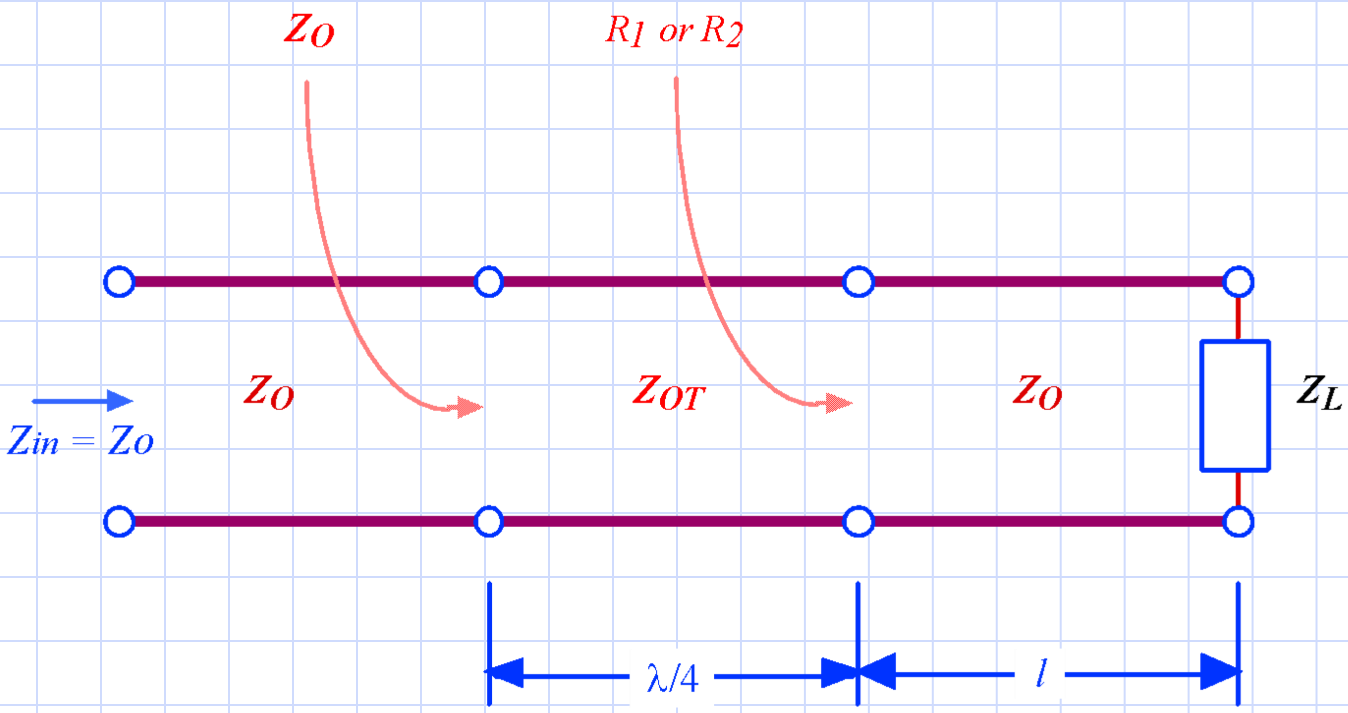
Flip across the origin / rotate 180 degrees.

Smith Chart

Do Lecture 8 Exercise 1 in groups of up to 4.

Smith Chart

Recall that in Lecture 5 we discussed a method of impedance-matching a load to a transmission line using a specific length of t-line followed by a quarter wavelength t-line with a special characteristic impedance.



Smith Chart

- Let’s say you only have one type of cable and can’t design a quarter-wavelength transformer with arbitrary Z_0. How do you match?

Smith Chart

- Let's say you only have one type of cable and can't design a quarter-wavelength transformer with arbitrary Z_0. How do you match?
- You could add inductors or capacitors to the network in order to match impedance. But in practice, we can't always get the L and C values that we need to match properly.

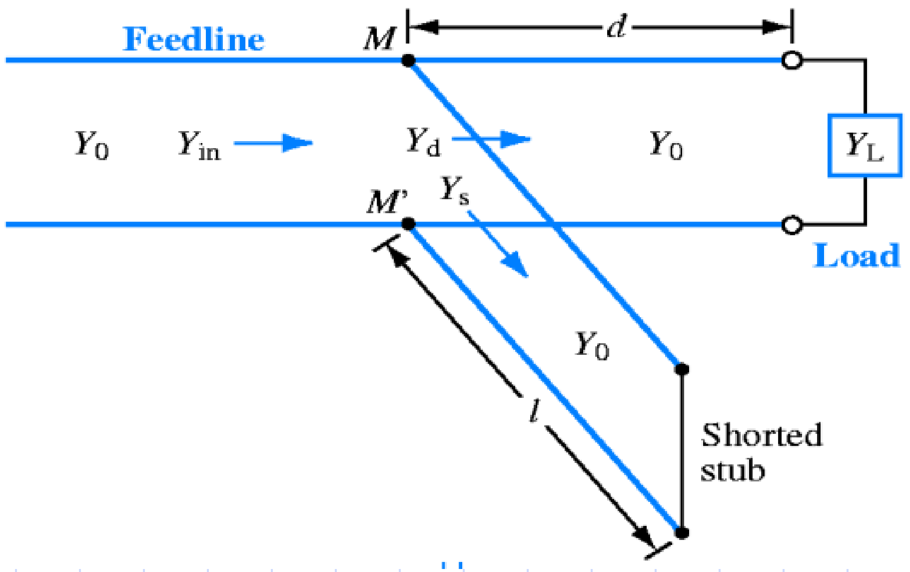
Smith Chart

- Let's say you only have one type of cable and can't design a quarter-wavelength transformer with arbitrary Z_0. How do you match?

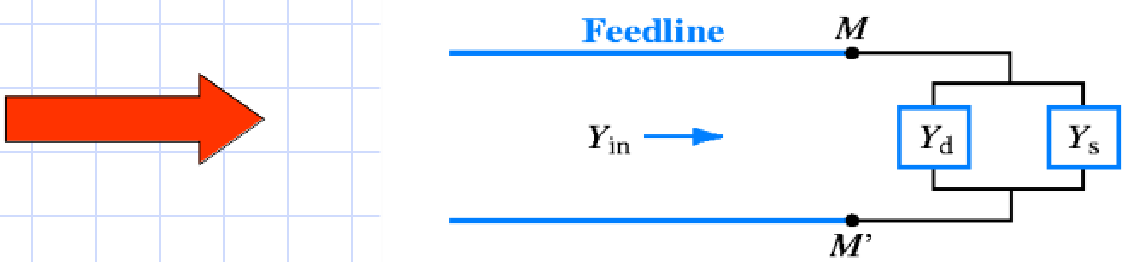
- You could add inductors or capacitors to the network in order to match impedance. But in practice, we can't always get the L and C values that we need to match properly.

- Another approach is to use a parallel stub of cable.

Single Stub Matching

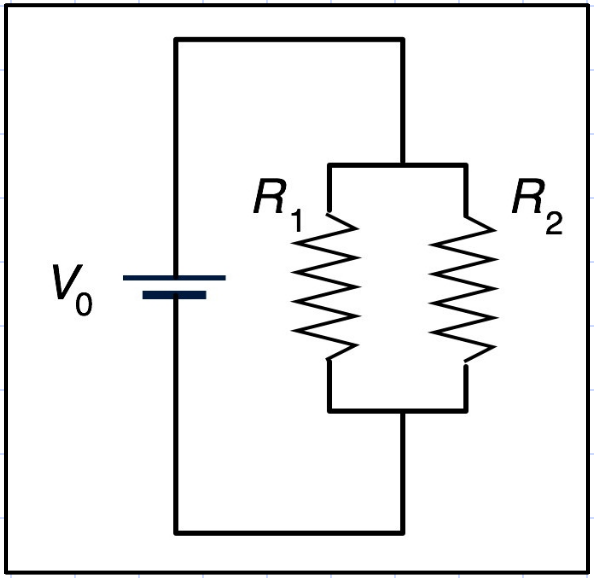


Ulaby



Single Stub Matching

A quick reminder: admittances are very useful when working with parallel circuit elements because parallel admittances simply add together.



$$Z_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

$$Y_{eq} = \frac{1}{R_1} + \frac{1}{R_2} = Y_1 + Y_2$$

Single Stub Matching

Using algebra and trigonometry (Ulaby pg. 76), we can write this as:

$$Z_{in}(z=0) = Z_o \cdot \frac{Z_L + j \cdot Z_o \cdot \tan(\beta \cdot L)}{Z_o + j \cdot Z_L \cdot \tan(\beta \cdot L)}$$

Special Case example: Z_L=0 (short circuit)

Can change Z_{in} by changing these two parameters

$$Z_{in}(z=0) = Z_o \cdot \frac{0 + j \cdot Z_o \cdot \tan(\beta \cdot L)}{Z_o + j \cdot 0 \cdot \tan(\beta \cdot L)} = j \cdot Z_o \cdot \tan(\beta \cdot L)$$

Single Stub Matching

Using algebra and trigonometry (Ulaby pg. 76), we can write this as:

$$Z_{in}(z=0) = Z_o \cdot \frac{Z_L + j \cdot Z_o \cdot \tan(\beta \cdot L)}{Z_o + j \cdot Z_L \cdot \tan(\beta \cdot L)}$$

Special Case example: $Z_L = \infty$ (open circuit)

$$Z_{in}(z \to \infty) = Z_0 \frac{Z_L}{j Z_L \cdot tan(\beta l)} = -j Z_0 cot(\beta l)$$

Single Stub Matching

$$Z_{in}(z=0) \;= j \cdot Z_o \cdot \tan(\beta \cdot L)$$

$$Z_{in}(z \rightarrow \infty) = \; -jZ_0 cot(\beta l)$$

- At any given frequency, by choosing L, we can cause a stub of t-line with either a short circuit or an open circuit at the end to have literally any impedance we want (provided that it is reactive, i.e. imaginary).

Single Stub Matching

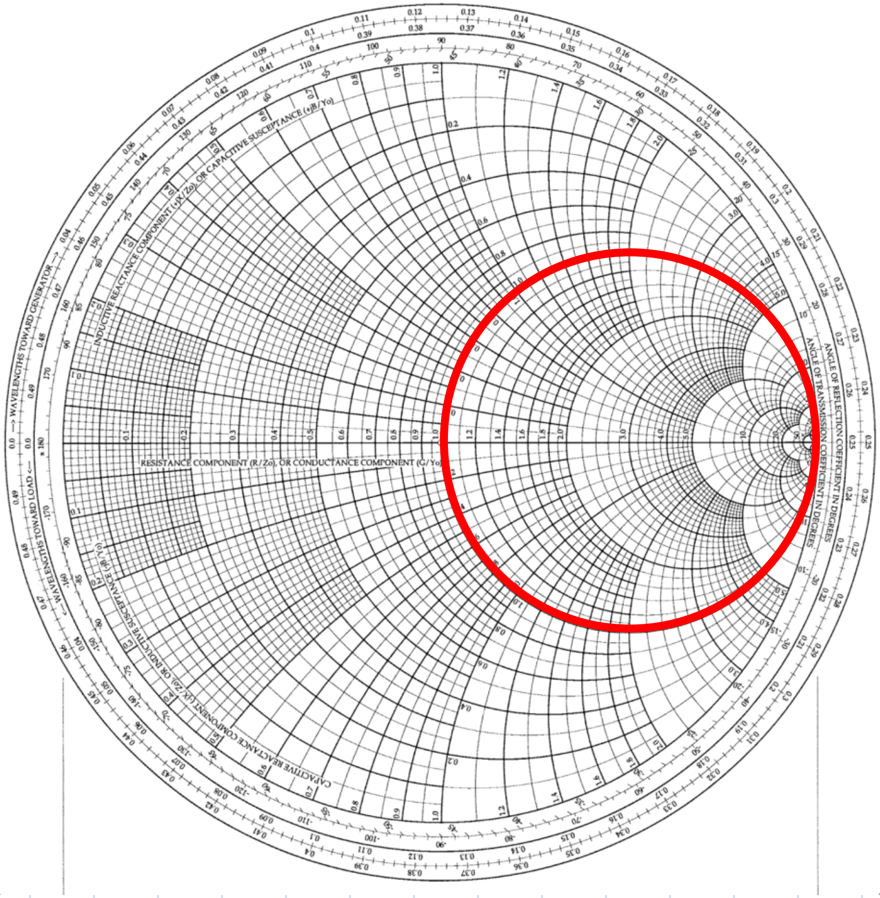
$$Y_{in}(z=0) = -j \cdot Y_0 \cdot cot(\beta l)$$

$$Y_{in}(z \to \infty) = j \cdot Y_0 \cdot tan(\beta l)$$

- The same is true of admittance. We can use a short or open-circuit stub with a specific L to add an arbitrary susceptance (imaginary admittance) to a network.

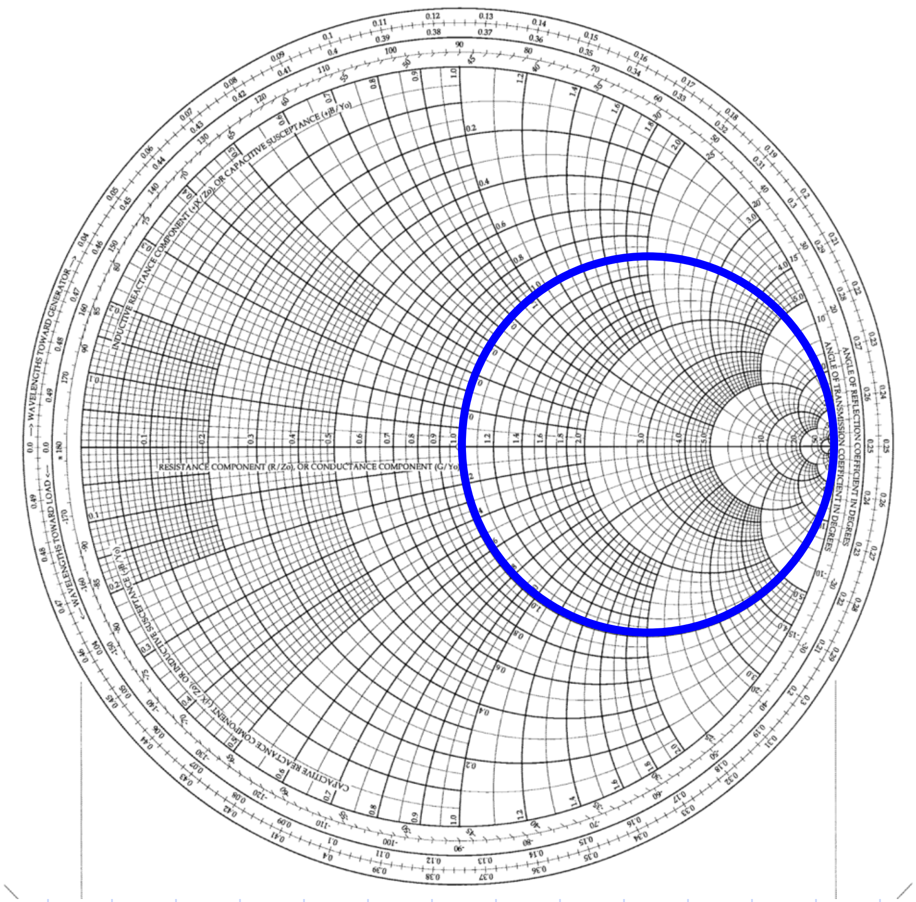
Single Stub Matching

- Consider this circle on the Smith Chart. Its leftmost edge touches the origin of the chart and its rightmost edge touches the rightmost edge of the chart (corresponding to an open circuit.)
- The impedances that land on this circle are all those impedances of form 1+jA (i.e. Z_0 plus some reactive impedance.)
- We call this the "matching circle".



Single Stub Matching

- It works for admittances as well. All admittances of the form Y_0+jB (where Y_0 is the inverse of Z_0 and B is some arbitrary susceptance) will fall on this circle.

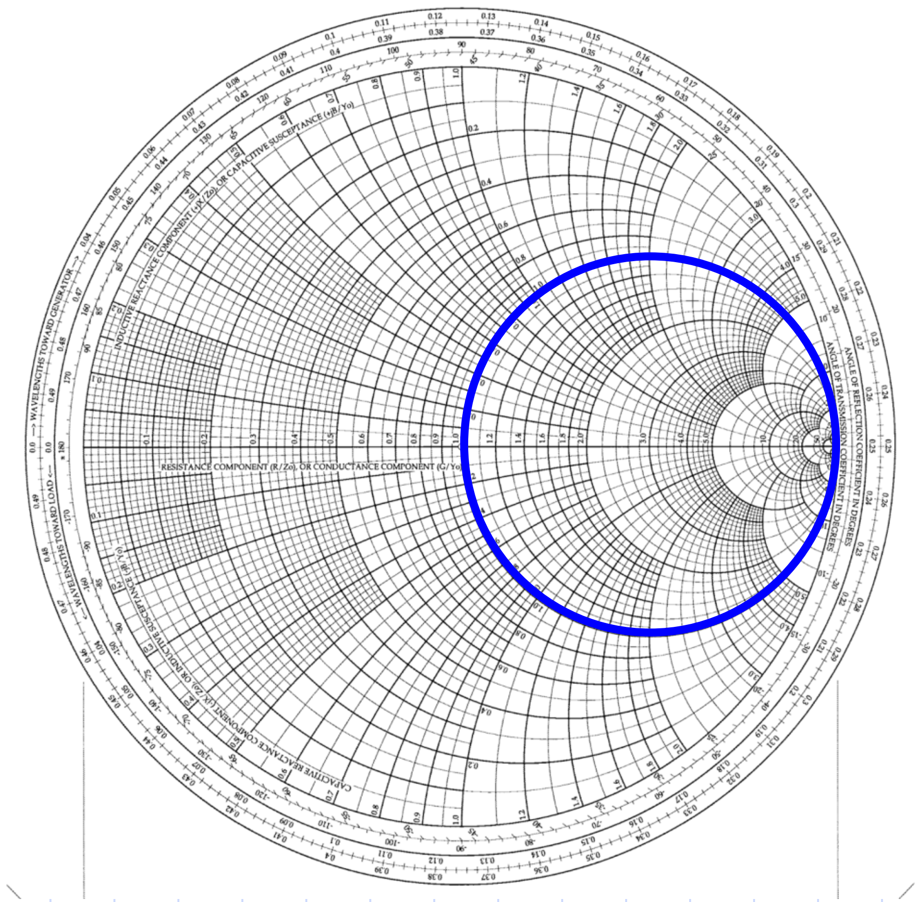


Single Stub Matching

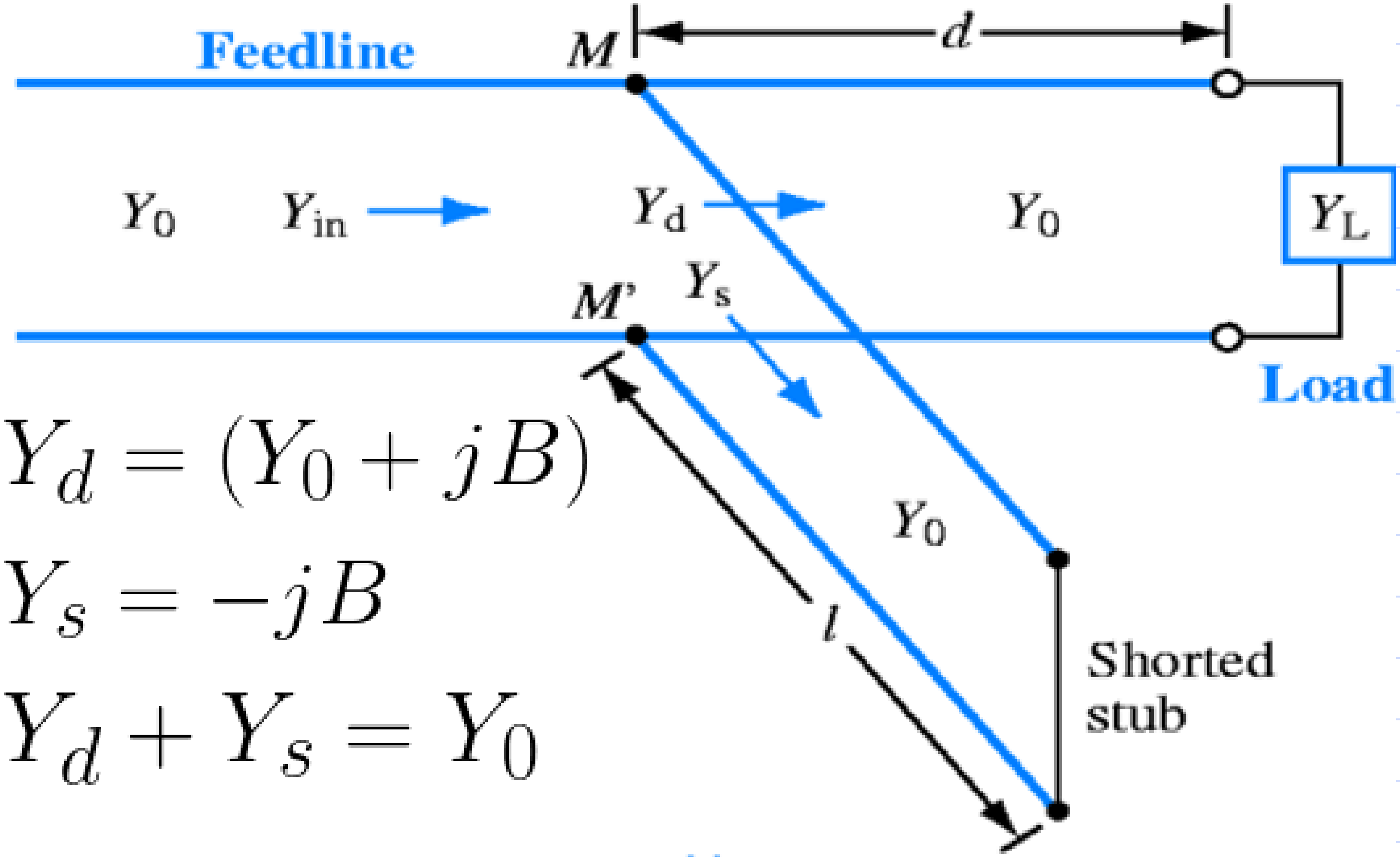
- This means that this circle contains all admittances such that you can match them to Z_0 with some parallel stub.

$$(Y_0 + jB) - jB = Y_0$$

the stub



Single Stub Matching



$$Y_d = (Y_0 + jB)$$

$$Y_s = -jB$$

$$Y_d + Y_s = Y_0$$

Single Stub Matching

Design Method

- Convert the load impedance Z_L to an equivalent admittance $Y_L = 1/Z_L$.
- Use a length of line of characteristic impedance Z_o to transform Y_L to $Y_d = Y_o + jB$.
  - ***Note*** $Y_o = 1/Z_o$
- Combine a stub in parallel which has an input admittance $Y_s = -jB$.
- Therefore, the total admittance at MM′ is:

$$\boxed{Y_{in} = Y_d + Y_s = Y_o + jB - jB = Y_o}$$

i.e. we have an impedance match!

Single Stub Matching

- Load of 100 + j100 Ohms on 50 Ohm Transmission Line
- The frequency is 1 GHz = 1×10^9 Hz
- Want to place an open circuit stub somewhere on the line to match the load to the line, at least as well as possible.
- First the line and load are specified. Then the step by step procedure is followed to locate the open circuit stub to match the line to the load

Single Stub Matching

- Load of 100 + j100 Ohms on 50 Ohm Transmission Line

What is the normalized impedance?

Single Stub Matching

- Load of 100 + j100 Ohms on 50 Ohm Transmission Line

What is the normalized impedance?

2+j2

Single Stub Matching

- Load of 100 + j100 Ohms on 50 Ohm Transmission Line

What is the normalized impedance?

2+j2

What is the normalized admittance?

Single Stub Matching

- Load of 100 + j100 Ohms on 50 Ohm Transmission Line

What is the normalized impedance?

2+j2

What is the normalized admittance?

0.25-j0.25

Single Stub Matching

How much t-line do we need to transform the admittance 0.25-j0.25 into the admittance 1+jB?

Single Stub Matching

How much t-line do we need to transform the admittance 0.25-j0.25 into the admittance 1+jB?

Rotate about 0.22λ toward the generator and 0.25-j0.25 becomes 1+j1.6.

Single Stub Matching

How much t-line do we need to transform the admittance 0.25-j0.25 into the admittance 1+jB?

Rotate about 0.22λ toward the generator and 0.25-j0.25 becomes 1+j1.6. (Note that 1-j1.6 would also be valid)

This means that we need a stub of admittance -j1.6 to match. If it's an open circuit stub, what length does it need to be?

Single Stub Matching

How much t-line do we need to transform the admittance 0.25-j0.25 into the admittance 1+jB?

Rotate about 0.22λ toward the generator and 0.25-j0.25 becomes 1+j1.6. (Note that 1-j1.6 would also be valid)

This means that we need a stub of admittance -j1.6 to match. If it's an open circuit stub, what length does it need to be?

0.34λ. (Start at left hand side (0 admittance) and rotate until you get to -1.6)

(If we had chosen to transform the load into 1-j1.6 instead of 1+j1.6, this answer would be different)

Single Stub Matching

We said that this circuit is operating at 1GHz. How do we figure out the actual length of 0.36λ of stub?

Single Stub Matching

We said that this circuit is operating at 1GHz. How do we figure out the actual length of 0.36λ of stub?

Use the 1GHz frequency and the t-line velocity to figure out what the wavelength is, then multiply by 0.36.

Single Stub Matching

- A single-stub matching network design can lead to 4 possible solutions. In the example just completed, we could have selected:
  - $y_d = 1 + j1.6$ OR $y_d = 1 - j1.6$
  - a short circuit terminated stub OR an open circuit terminated stub

Single Stub Matching

- Which you choose depends upon practical considerations:
  - Can I use open or short circuit terminations in the transmission line I am using?
  - Does it matter if there is a voltage maximum on the line between the stub and the load termination?
  - Is the physical length of line between the stub and the load termination too short/long?
- As an engineer, these are the decisions you must be able to make!

Single Stub Matching

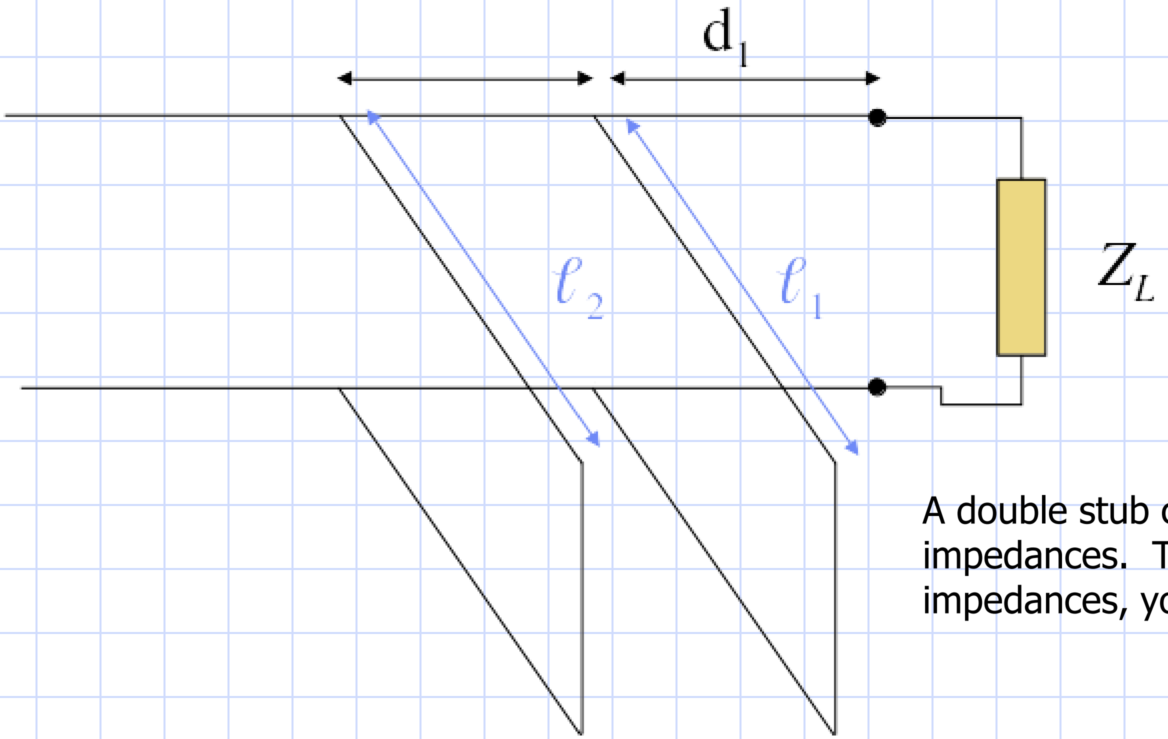
- Single stubs also have a disadvantage: they must be a specific distance from the load in order to work. This isn't always practical.
- Furthermore, what if the frequency or load changes? In practice, this would mean completely disassembling and reassembling the line in order to match it correctly.
- Is there a better way?

Single Stub Matching

- Single stubs also have a disadvantage: they must be a specific distance from the load in order to work. This isn't always practical.
- Furthermore, what if the frequency or load changes? In practice, this would mean completely disassembling and reassembling the line in order to match it correctly.
- Is there a better way? **Yes: the double stub.**

Double Stub Matching

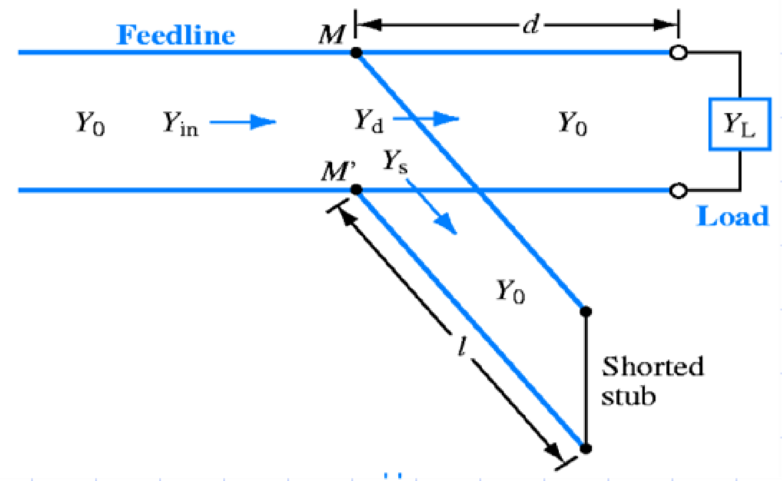
In essence: Use the first stub to transform ZL into an impedance **that can be matched by the second stub.**



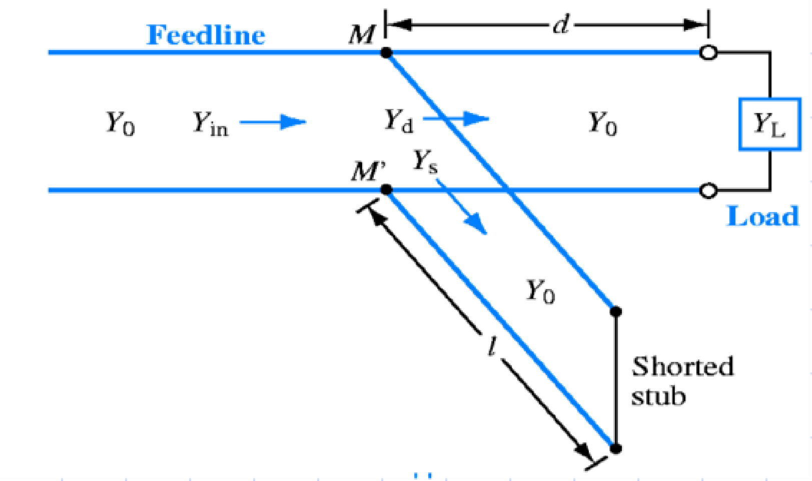
A double stub can match most impedances. To match **all** impedances, you need a triple stub.

Studio Session 4-6

- Stubs can be for more than just matching. They can be used as filters too.
- The quarter-wavelength open circuit stub has zero admittance at the load and infinite admittance at the input. (It's a short circuit.)



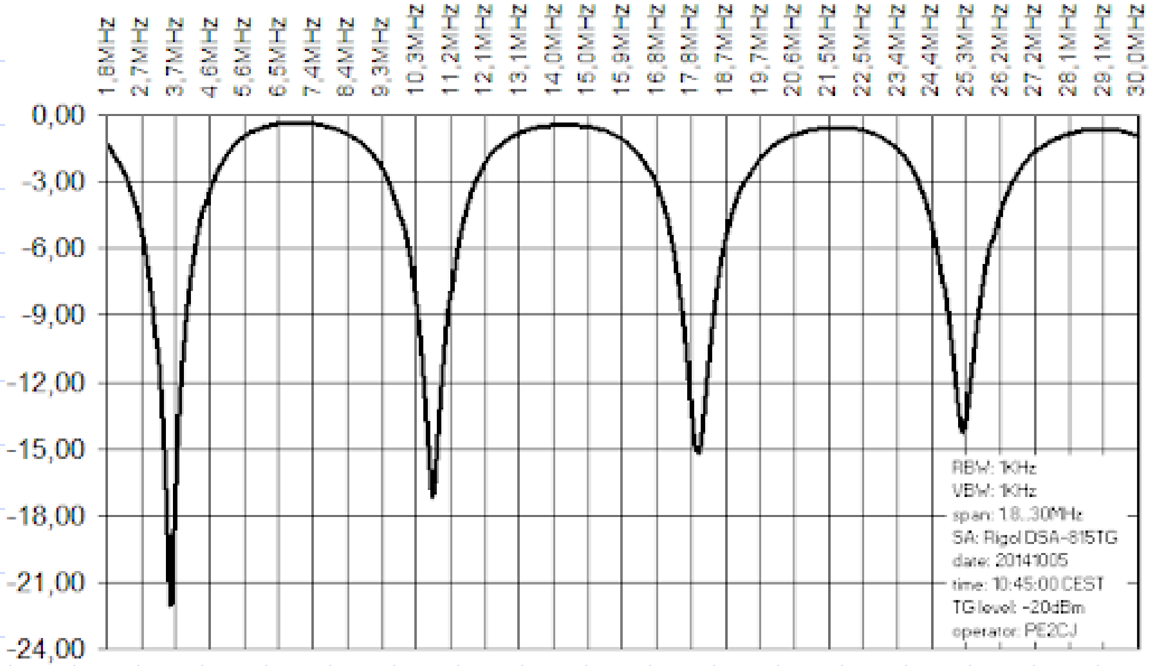
Studio Session 4-6



- This also works for a half-wavelength short circuit stub.
- This only works at one specific frequency. But there's something useful we can do with this: when we have a band of frequencies on a t-line, we can use the stub to "short" (filter out) one specific frequency.

Studio Session 4-6

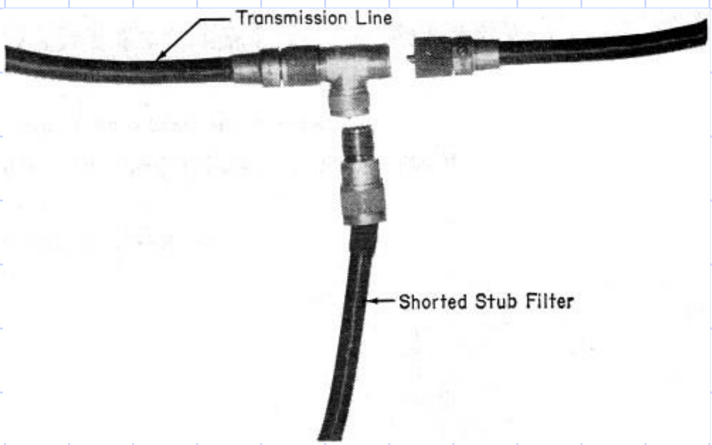
- In practice, this also attenuates frequencies near the blocked frequency (for which the sub has a non-infinite but very large admittance.)



amateurtele.com

Studio Session 4-6

- Our current Studio Session explores this.
- Students will attempt to block TV cable and radio channels using a stub of coaxial cable.



rfcafe.com