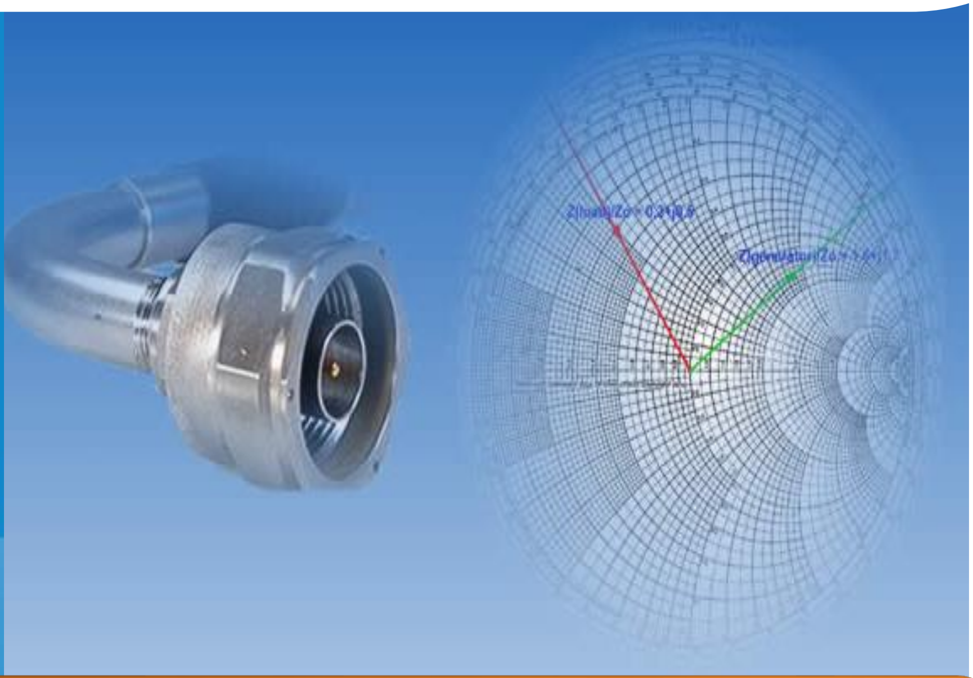
Lecture 8

T-Line Matching

~~EE221~~

Electromagnetic Field Theory (2-B)

Spring 2020



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Impedance Matching

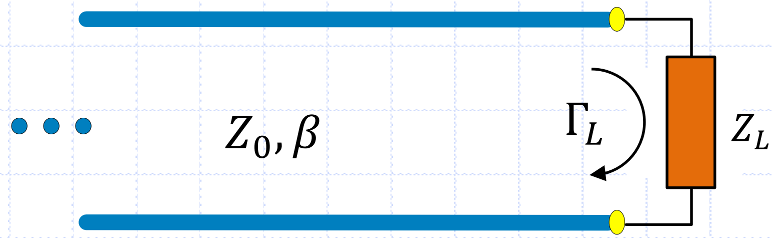
- **Impedance matching** (simply **matching**) one portion of a circuit to another is an immensely important part of MW engineering.
- **Additional circuitry** between the two parts of the original circuit may be needed to achieve this matching.

Why is impedance matching so important?

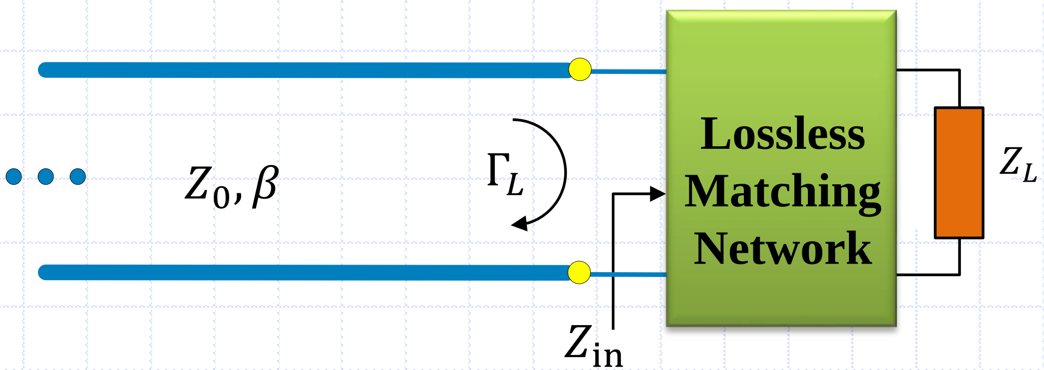
- **Maximum power** is delivered to a load when the TL is matched at both the load and source ends.
- With a properly matched TL, more signal power is transferred to the load, which increases the **sensitivity** of the device and improve the **SNR ratio** of the system.
- Some equipment (such as certain amplifiers) can be **damaged** when too much power is reflected back to the source.
- **Minimize** reflections.

Impedance Matching

- Consider the case of an arbitrary load that terminates a T-Line:



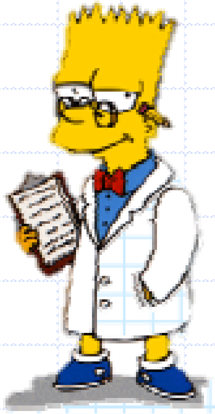
- To match the load to the T-Line, we require $\mathbf{\Gamma_L = 0}$.
- However, if $Z_L \neq Z_0$, **additional circuitry** must be placed between Z_L and Z_0 to bring the VSWR = 1, or least approximately so:



- For $\Gamma_L = 0$, this implies $Z_{\text{in}} = Z_0$. In other words, $R_{\text{in}} = \Re e[Z_0]$ and $X_{\text{in}} = 0$, if the TL is lossless.

Impedance Matching

- We will discuss **three methods** for impedance matching in this course:
  - Matching with **L-Sections** (lumped elements)
  - **Stub** tuners (T-line/distributed elements)
  - **Quarter wave** impedance transformers.



- **Factors** that influence the choice of a matching network include:
  - Physical complexity
  - Bandwidth
  - Adjustability (to match a variable load impedance)
  - Implementation

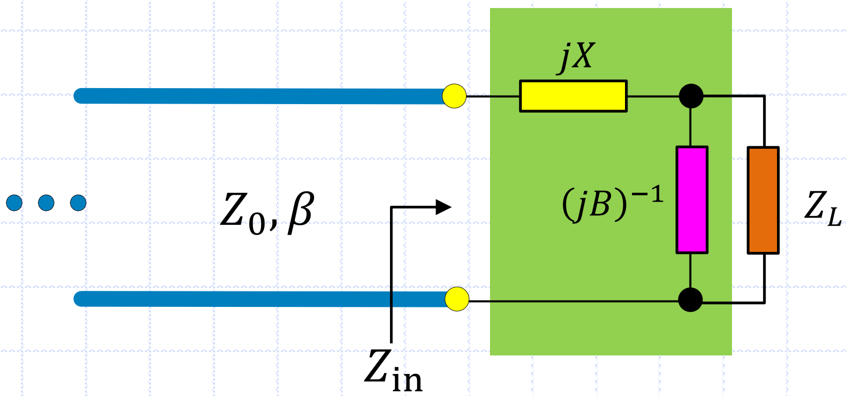
Lumped Element matching network

- Add an element in series or parallel to Z_L so that the
  - impedance at the input of the line is $z_1 = 1 + jx$ or $1 - jx$ (make the resistance = 50 Ω)
  - OR admittance at the input of the line is $y_1 = 1 + jb$ or $1 - jb$ (make the conductance 1/50 Si.
- Then add a lumped element in series or parallel to remove the reactive part of the impedance.

Matching with L-Sections

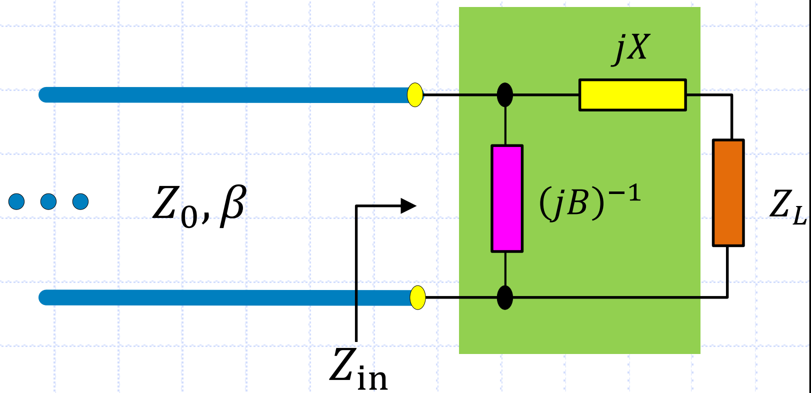
- This network topology gets its **name** from the fact that the series and shunt elements of the matching network form an **“L” shape**.
- Since it uses lumped elements, it is applicable **only** if the frequency is low enough, or the circuit size is small enough
- Two possible L-Sections:

$$R_L > Z_0$$



$$Z_{\text{in}} = Z_0 = jX + \left(jB + \frac{1}{\underbrace{R_L + jX_L}_{Z_L}}\right)^{-1}$$

$$R_L < Z_0$$

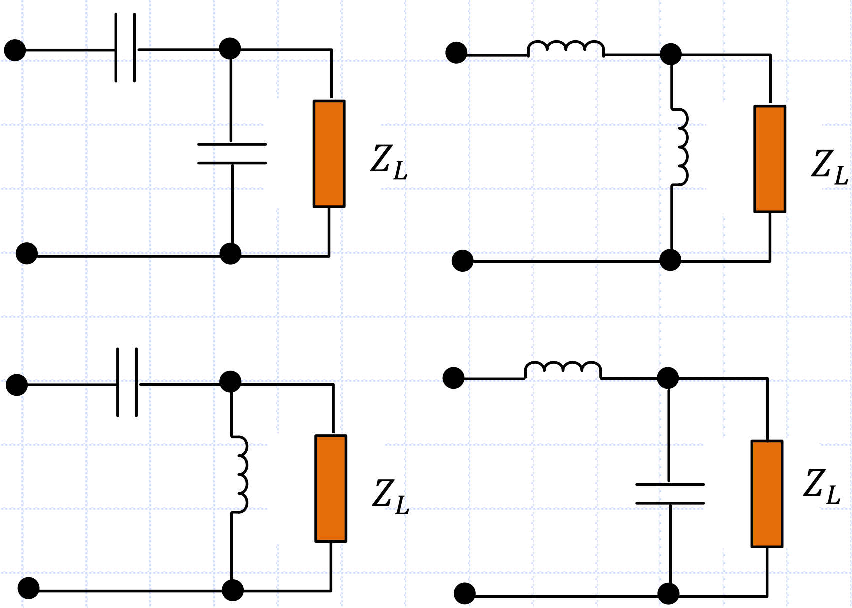


$$Z_{\text{in}} = Z_0 = \left(jB + \frac{1}{\underbrace{Z_L + jX}_{Z_L}}\right)^{-1}$$

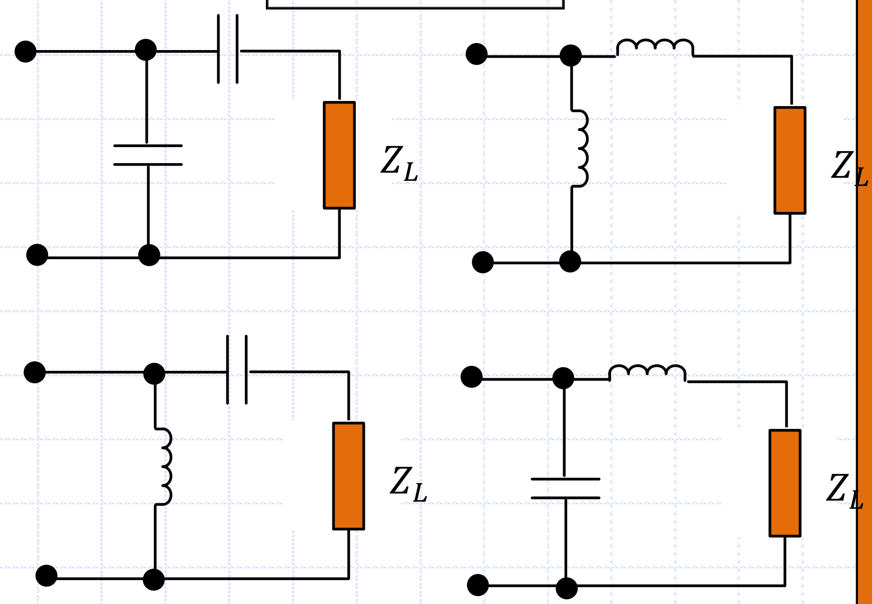
Matching with L-Sections

- There are **eight possible combinations** of inductors and capacitors in the L network:
  - If $\boldsymbol{X > 0}$, X is an inductor; if $\boldsymbol{X < 0}$, X is a capacitor
  - If **B > 0**, B is an capacitor; if $\boldsymbol{B < 0}$, B is an inductor

$R_L > Z_0$



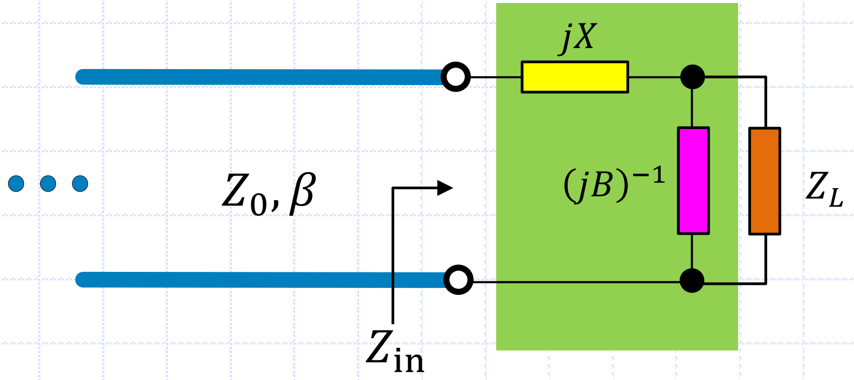
$R_L < Z_0$



Example 5.1

- **Design an L-section matching network to match a load with an impedance $Z_L = 200 - j100\ \Omega$ to a 100 Ω line at a frequency of 500 MHz.**

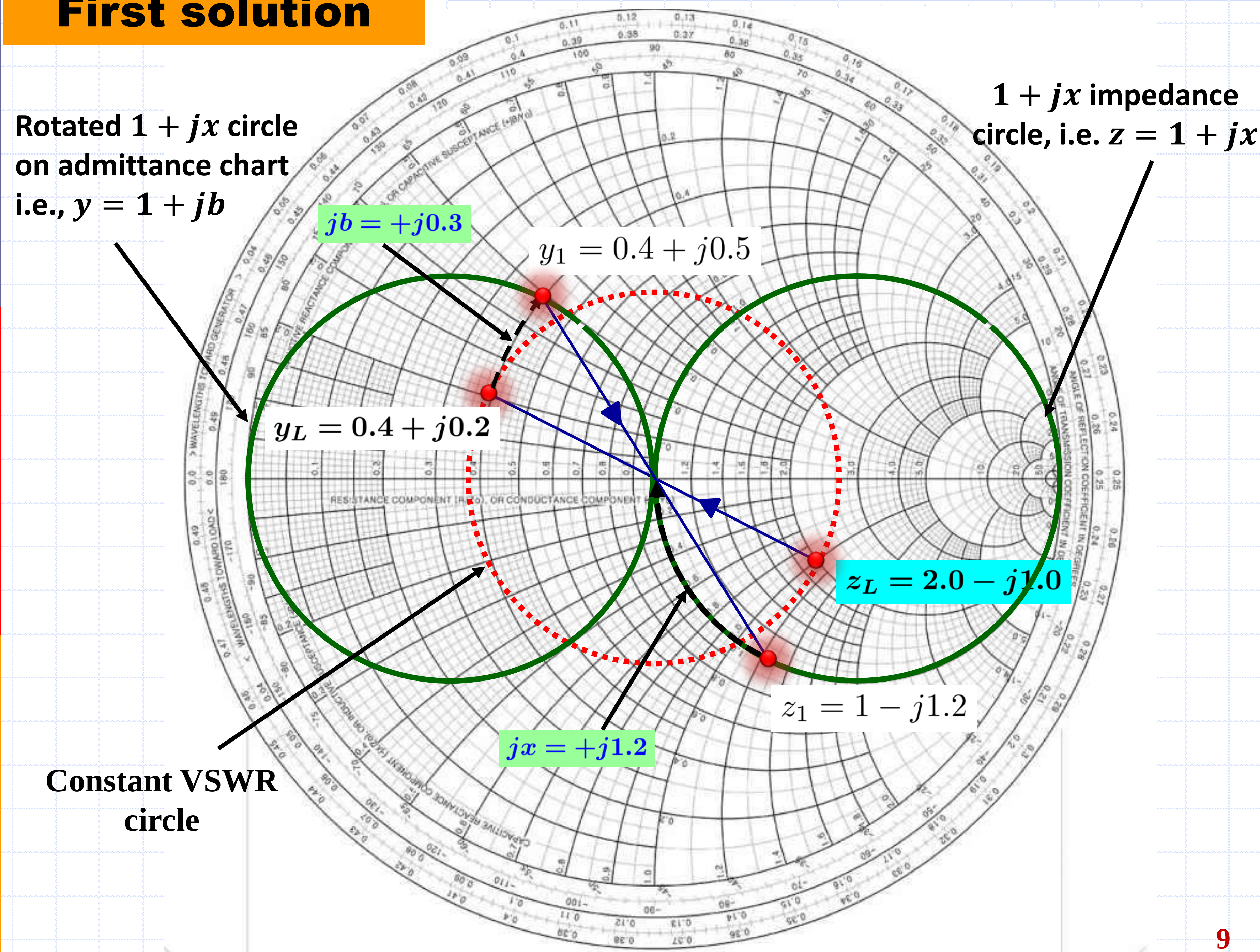
- Since $R_L > Z_0$, we'll use the following circuit topology:



$$Z_{\text{in}} = Z_0 = jX + \left(jB + \frac{1}{\underbrace{R_L + jX_L}_{Z_L}}\right)^{-1}$$

- **Normalization:** $z_L = \dfrac{Z_L}{Z_0} = 2 - j1$ p.u.Ω

First solution

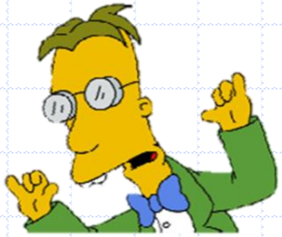


Solution

- Un-normalizing, we find that

$$jB = jb \cdot Y_0 = j0.3 \cdot \frac{1}{100} = j0.003 \text{ S}$$

$$jX = jx \cdot Z_0 = j1.2 \cdot 100 = j120\ \Omega$$



- What are the L and C values of these elements?

  - We can identify the type of element by the **sign of the reactance or susceptance**:

	Inductor	Capacitor
X	$Z_L = jwL$	$Z_C = \frac{1}{jwC} = \frac{-j}{wC}$
B	$Y_L = \frac{1}{jwL} = \frac{-j}{wL}$	$Y_C = jwC$

Solution

- Since $\boldsymbol{B > 0}$, we identify this as a **capacitor**. Therefore,

$$jB = jwC = j0.003\ \mathrm{S}$$

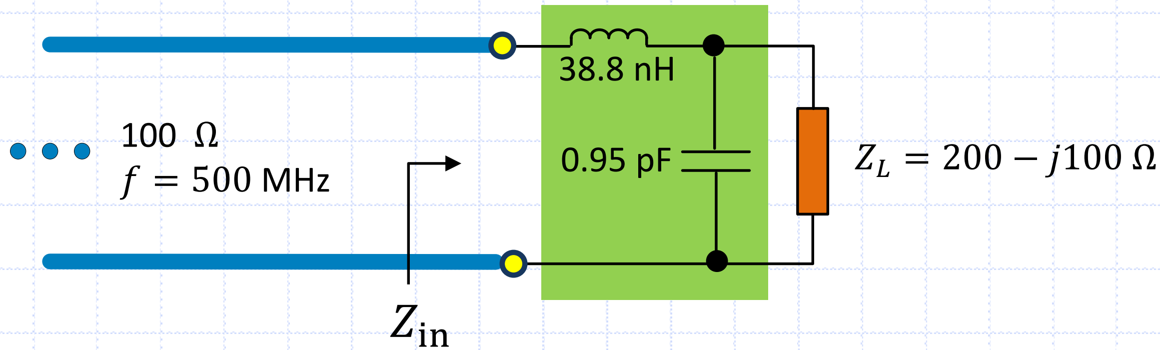
- For operation at 500 MHz, we need $$C = \frac{0.003}{2\pi f} = 0.95\ \mathrm{pF}$$

- Since $\boldsymbol{X > 0}$, we identify this as a **inductor**. Therefore,

$$jX = jwL = j120\ \Omega$$

- For operation at 500 MHz, we need $$L = \frac{120}{2\pi f} = 38.8\ \mathrm{nH}$$

The final circuit is:

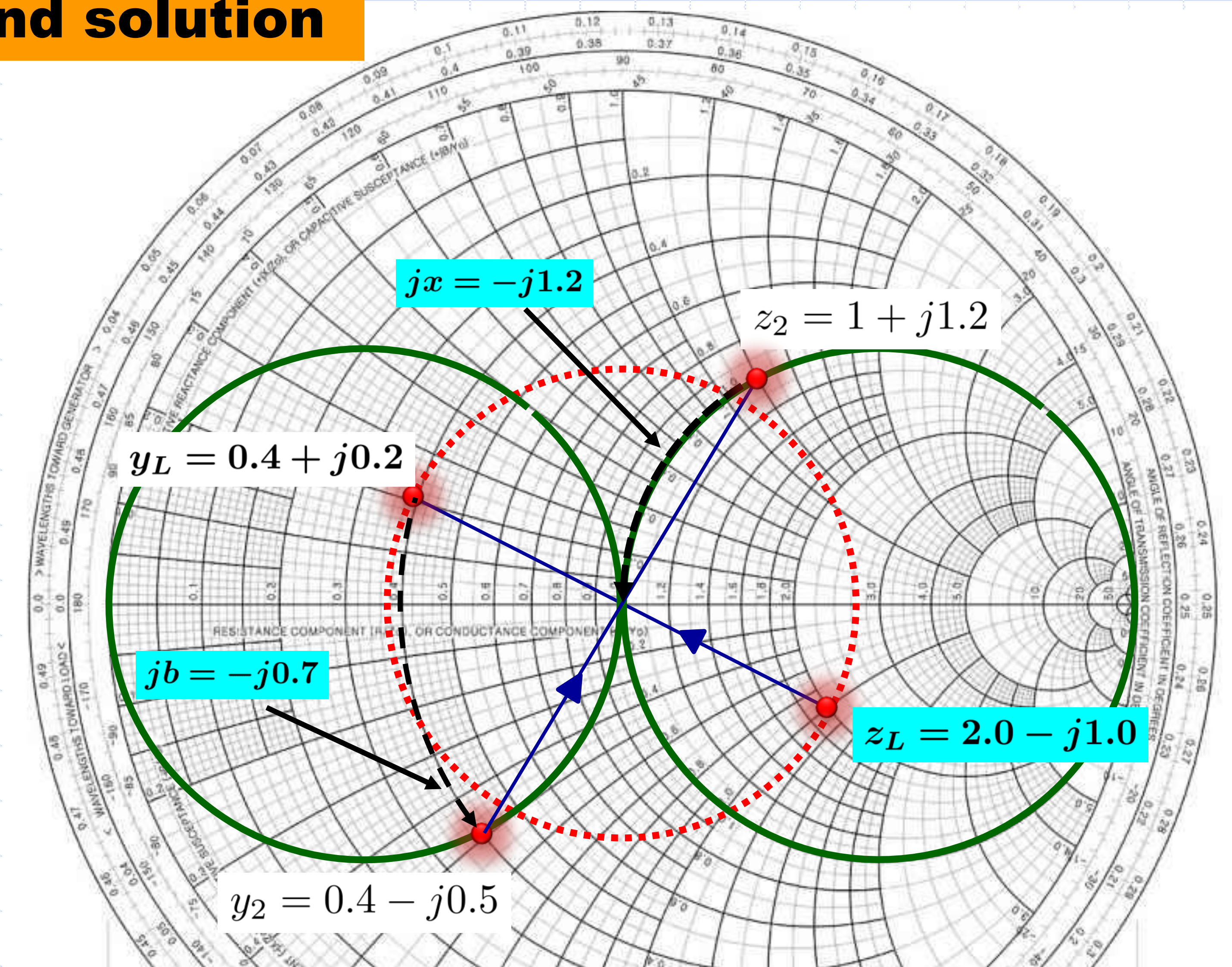


- Let's check to see if we have really achieved a match at 500 MHz:

$$Z_{\text{in}} = j2\pi f L + \left(j2\pi f C + \frac{1}{Z_L}\right)^{-1}$$

$$= j120 + 100 - j120 = 100 + j0\Omega$$

Second solution



$$jB = jb \cdot Y_0 = -j0.7 \cdot \frac{1}{100} = -j0.007\ \text{S}$$

$$jX = jx \cdot Z_0 = -j1.2 \cdot 100 = -j120\ \Omega$$

Solution

- Since ***B* < 0**, we identify this as a **inductor**. Therefore,

$$jB = \frac{-j}{wL} = -j0.007\ \text{S}$$

- For operation at 500 MHz, we need $L = \dfrac{1}{2\pi f B} = 45.47\ \text{nH}$

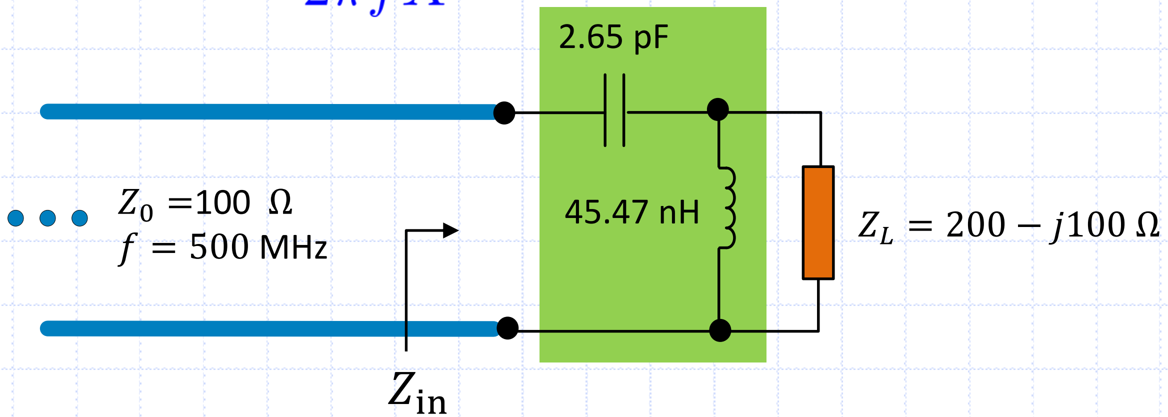
- Since ***X* < 0**, we identify this as a **capacitor**. Therefore,

$$jX = \frac{-j}{wC} = -j120\ \Omega$$

- For operation at 500 MHz, we need

$$C = \frac{1}{2\pi f X} = 2.65\ \text{pF}$$

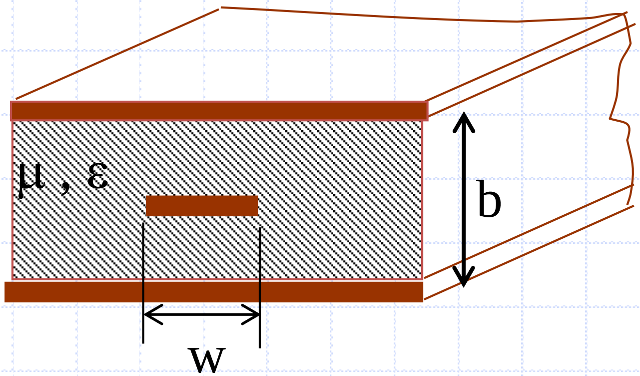
The final circuit is:



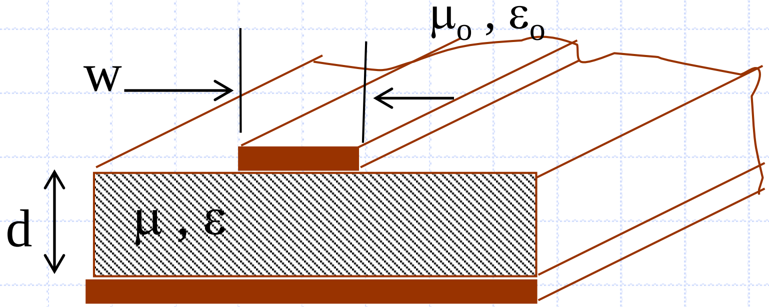
Single-Stub Tuner (SST) Matching

- The SST uses a **shorted or open section** of T-Line attached at **some position** along another T-Line.
- It does **not** require lumped elements.
- It can be used for **extremely high** frequencies.
- It uses segments of T-lines with the **same Z_0** (**not necessary**) used for the feeding line.
- **Easy** to fabricate, the length can easily be made **adjustable** and little to **no power is dissipated** in the stub. (An open stub is sometimes easier to fabricate than a short.)
- It is **very convenient** for microstrip and stripline technologies.

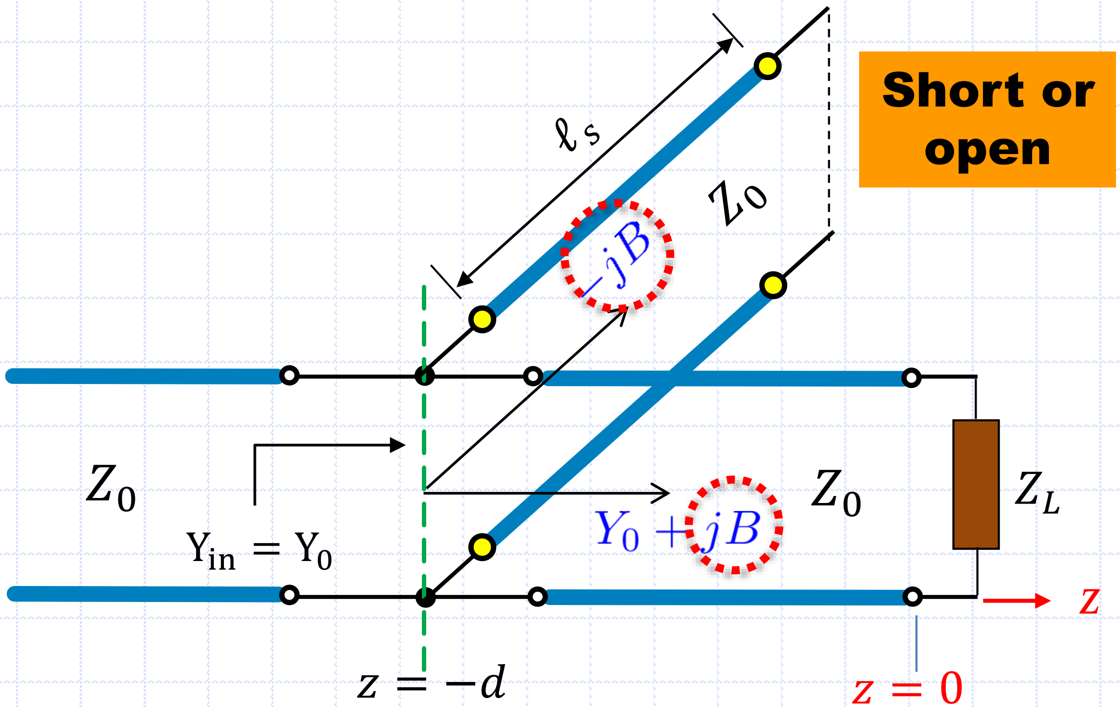
Stripline

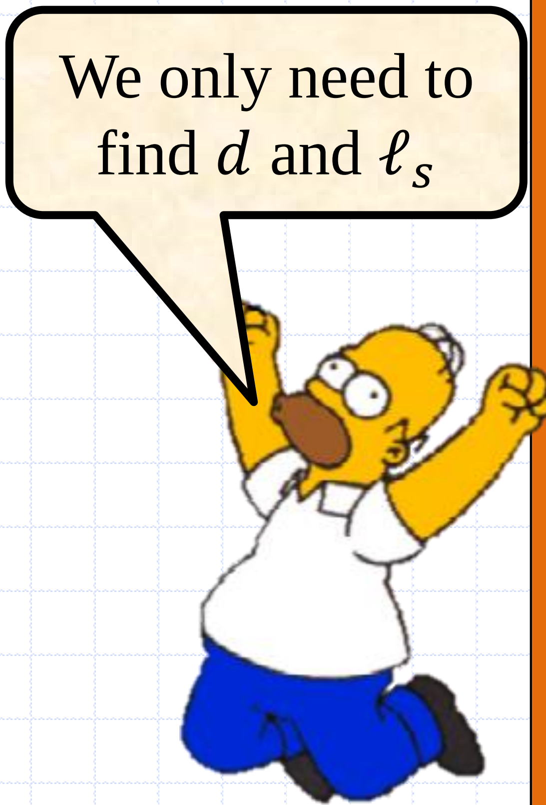


Microstrip line



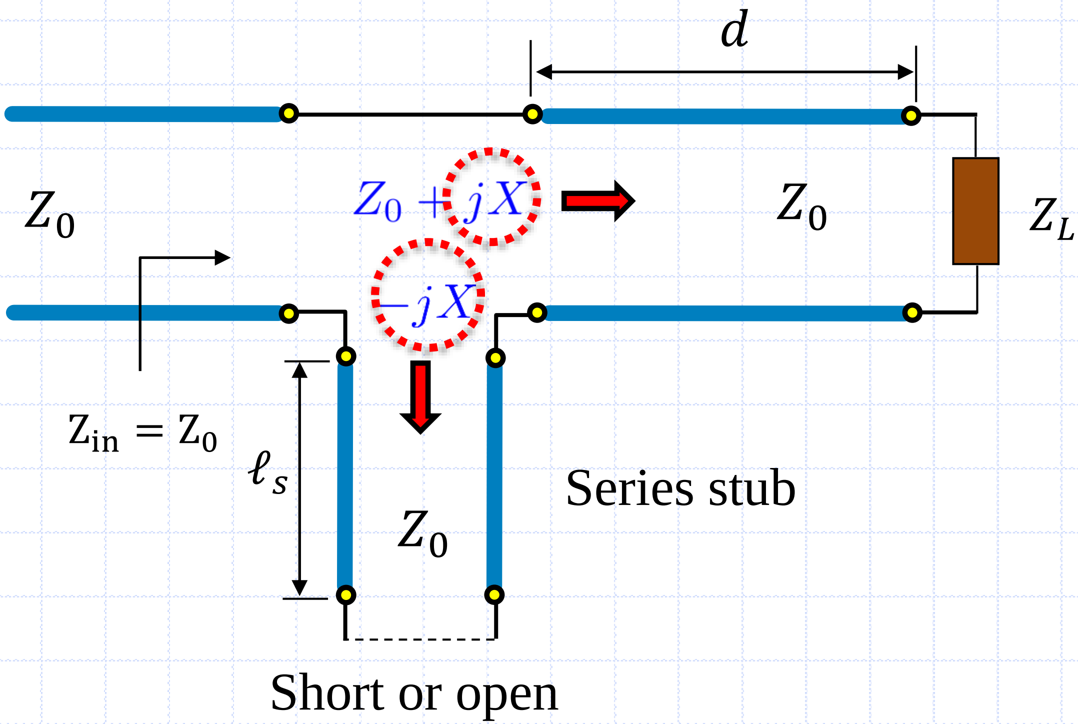
Single-Stub Shunt Matching





- First T-Line converts $Y_L = 1/Z_L$ to an admittance $Y_0 + jB$
- Second T-Line converts a short or an open to an admittance $-jB$

Single-Stub Series Matching

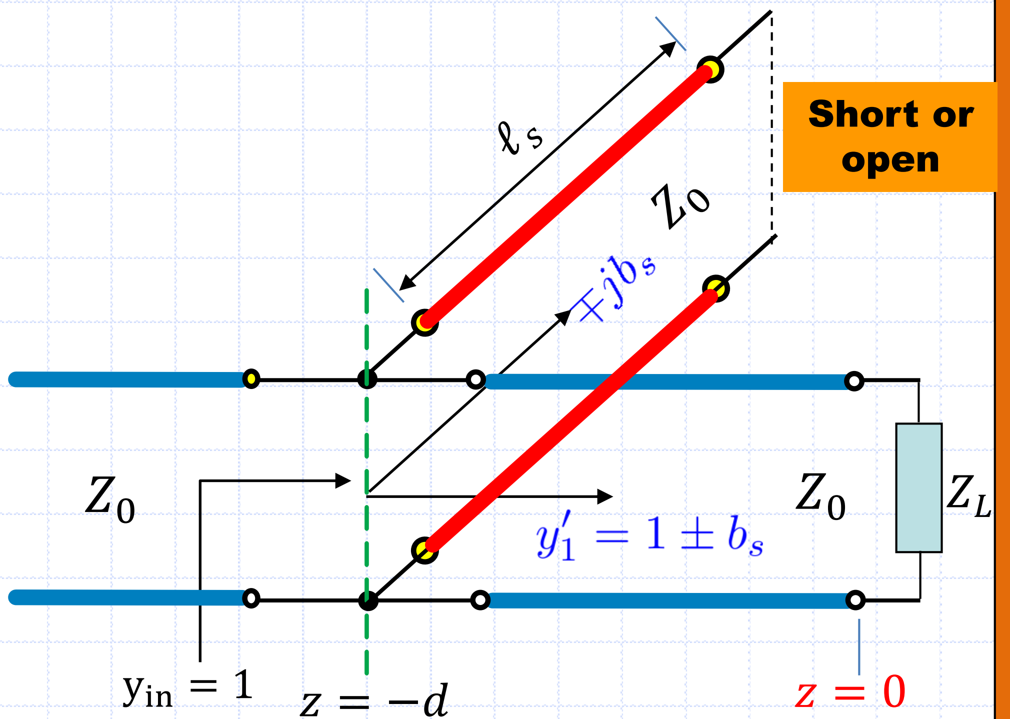


- **First** T-Line converts Z_L to an impedance $Z_0 + jX$
- **Second** T-Line converts a short or an open to an impedance $-jX$
- We only need to find d and ℓ_s

SST Using the Smith Chart

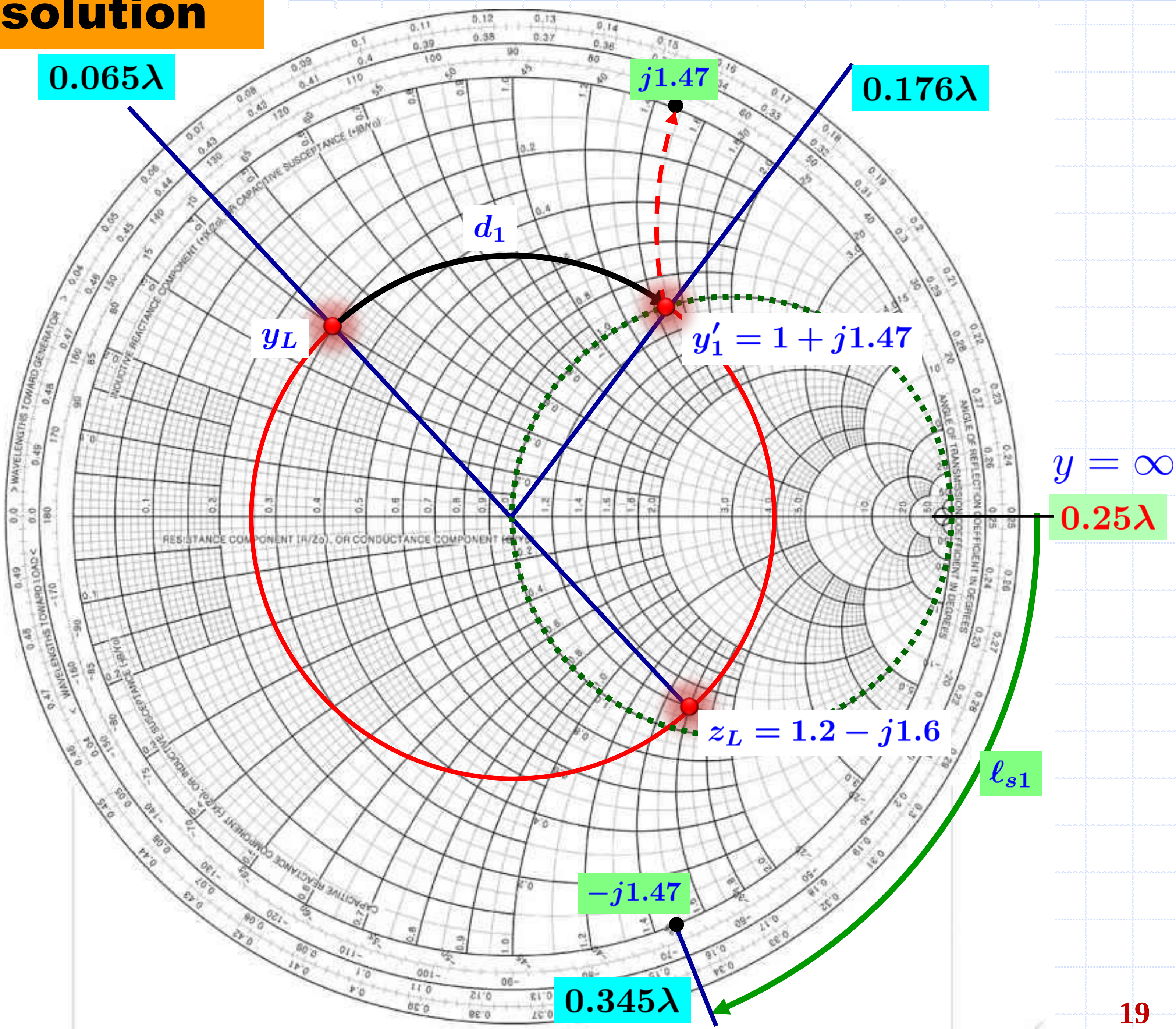
- In terms of quantities **normalized** to Z_0 or Y_0, the geometry is

- Recall that the operation of the SST requires that
  1. d is chosen such that y_1' has a **real part = 1,** i.e., $y_1' = 1 \pm jb_s$.
  2. The imaginary part of y_1' is **removed** by the stub susceptance after choosing the proper length ℓ_s.
- This produces $y_{in} = 1$, which is the **matched state**.

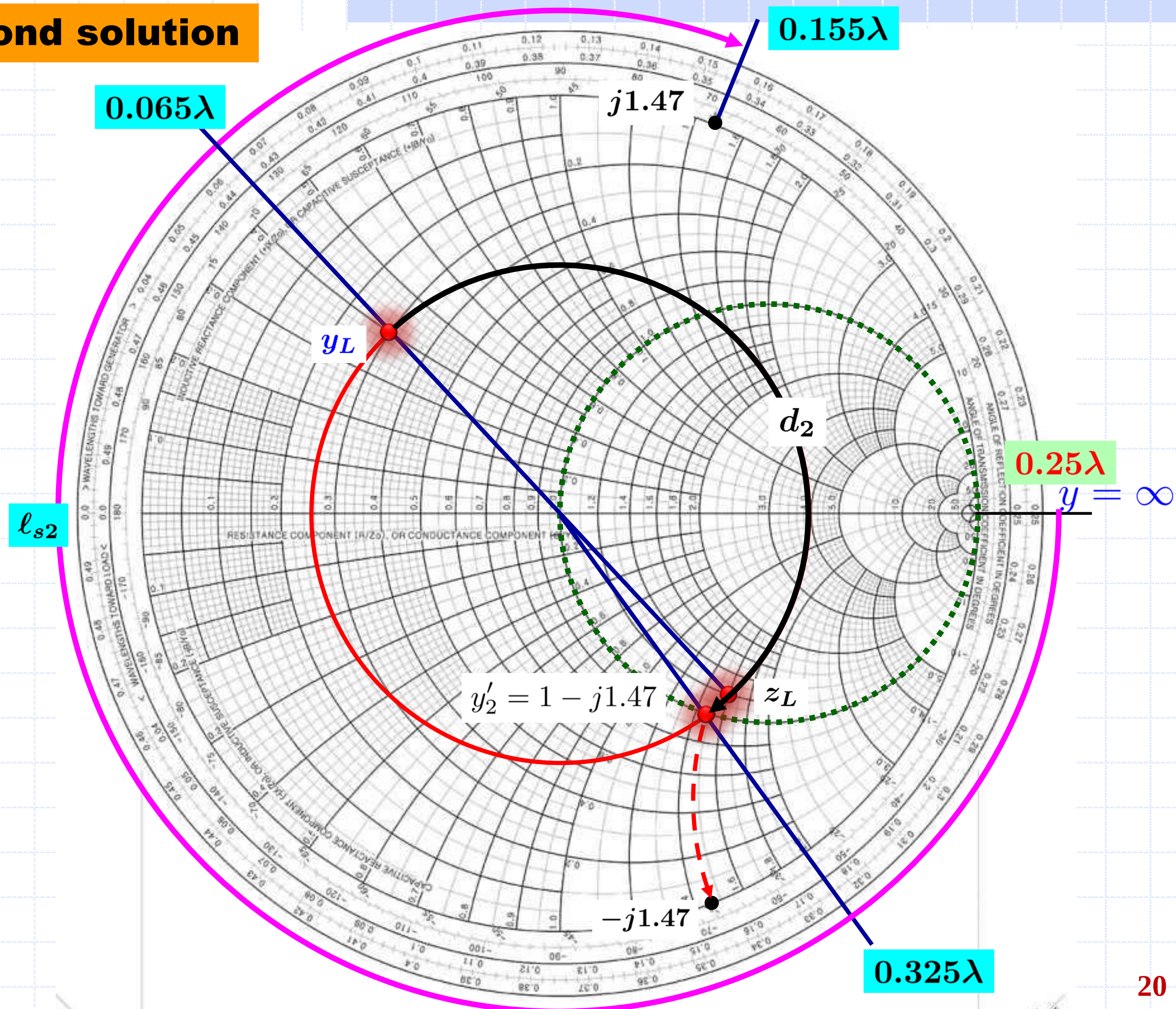


- **Example 5.2: Using the Smith chart, design a shorted shunt, single-stub tuner to match the load $Z_L = 60 - j80\ \Omega$ to a T-Line with characteristic impedance $Z_0 = 50\ \Omega$.**
- The normalized load impedance is: $z_L = 1.2 - j1.6$ p.u.Ω

First solution



Second solution



Solution: Smith

- There will be **two solutions**. Both of these give $y' = 1 \pm jb_s$.
- For this example, we find from the Smith chart that

  (I) $y_1' = 1 + j1.47$

  (II) $y_2' = 1 - j1.47$

- From these rotations we can compute d as

  (I) $d_1 = 0.176\lambda - 0.065\lambda = 0.110\lambda$

  (II) $d_2 = 0.325\lambda - 0.065\lambda = 0.260\lambda$

- Next, find the stub lengths ℓ_s:

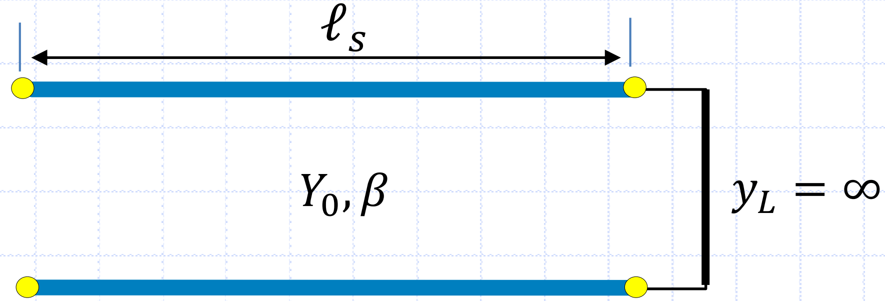
  (I) want $b_{s1} = -1.47$

  (II) want $b_{s2} = 1.47$

When either of these two susceptances is added to y_1', then $\boldsymbol{y_{in} = 1}$.

Solution: Smith

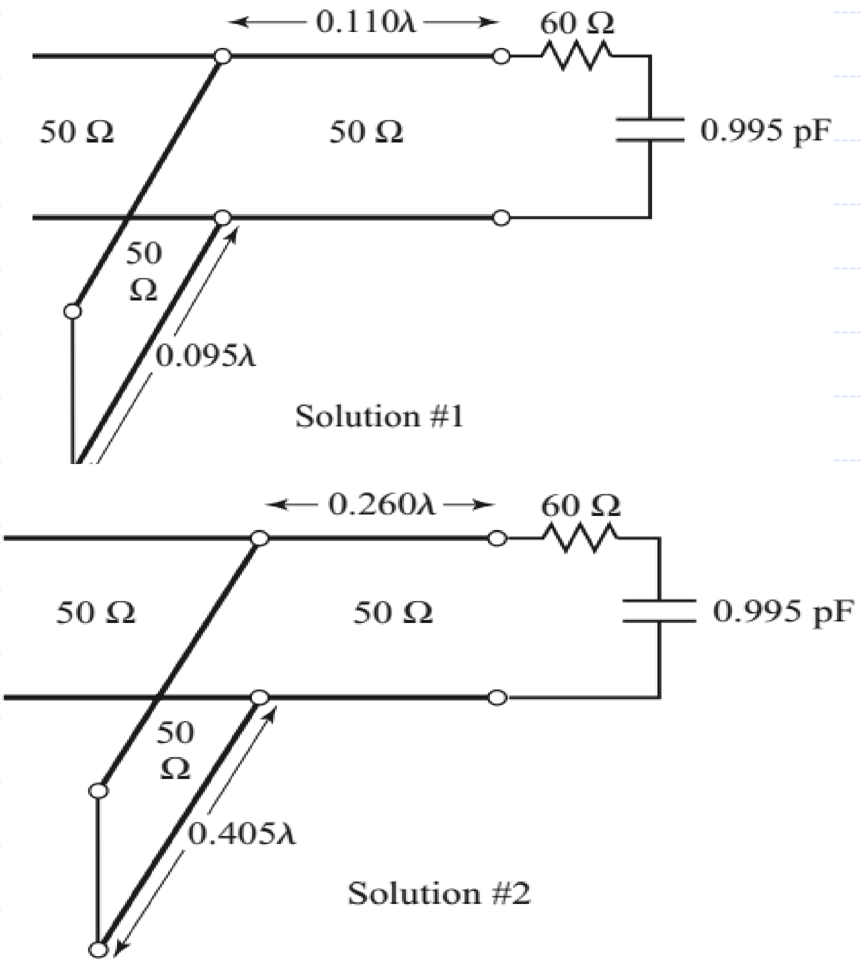
- The stub lengths can be determined directly from the Smith chart.

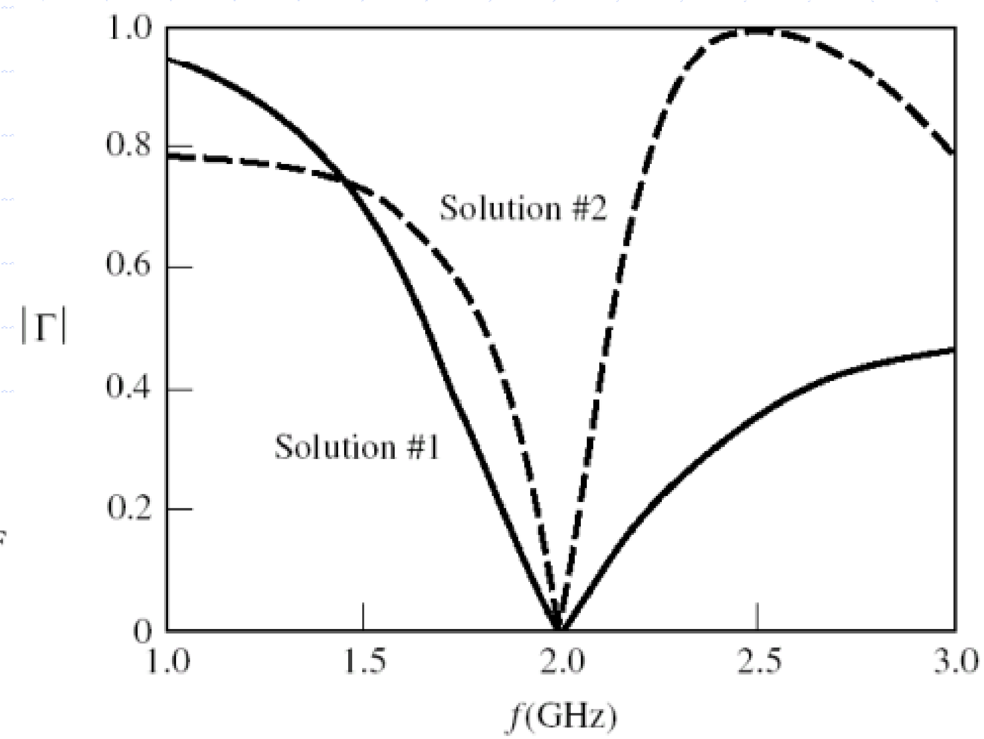


- On the Smith admittance chart, $\boldsymbol{y_L = \infty}$ **is located at** $\boldsymbol{\Re e\{\Gamma\} = 1}$**,** $\boldsymbol{\Im e\{\Gamma\} = 0}$. From there, rotate "wavelengths towards generator" to:
  (I) $b_s = -1.47 \;\Rightarrow\; \ell_{s1} = 0.345\lambda - 0.25\lambda = 0.095\lambda$
  (II) $b_s = +1.47 \;\Rightarrow\; \ell_{s2} = 0.25\lambda + 0.155\lambda = 0.405\lambda$

- The final two solutions are:
  (I) $d_1 = 0.110\lambda$ and $\ell_{s1} = 0.095\lambda$
  (II) $d_2 = 0.260\lambda$ and $\ell_{s2} = 0.405\lambda$

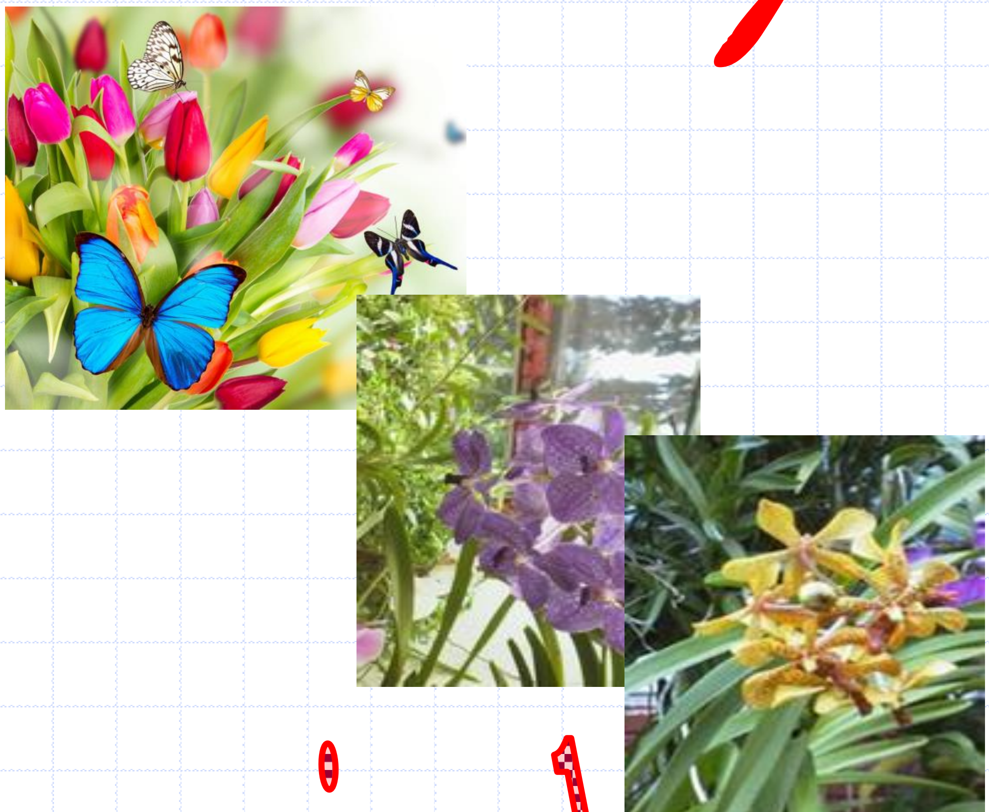
Solution: Smith





- **Solution 1** has a significantly better bandwidth than solution 2.
- Shorter stub produces wider bandwidth.

Thank you



Have a nice day.