Impedance Matching

Microwave Seminar

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Outline

T-lines, Loads, and Input Impedance

- Transmission Line Types (many more than listed here)
  - Coaxial Line
  - Twin Lead
  - Microstrip, Stripline, etc.
- The Load: Z_L
- Input Impedance:

$$Z_{in} = R_o \frac{Z_L + jR_o \tan \beta\ell}{R_o + jZ_L \tan \beta\ell}$$

Narrow-Band Methods

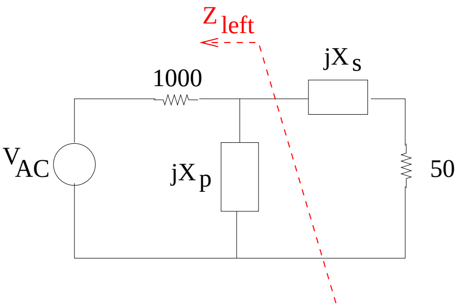
- Matching can easily be accomplished at one specific frequency.
- The design depends on component values or lengths
  - Then, the bandwidth is generally narrow and depends to some extent on how far apart R_o and Z_L are from each other.

Outline

Lumped Element Matching

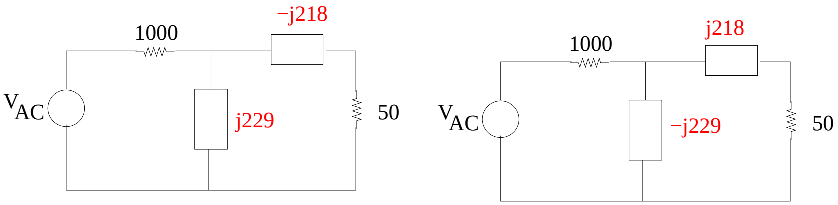
- Adjusting impedances to get maximum power transfer
- Can be used at higher frequencies now due to surface-mount technology
- Component losses can limit usefulness of matching network

L-Nets: Analytic Considerations



- Note how jX_p pulls $1k\Omega$ down since in parallel
- Choose X_p so that $R_{left} = 50\Omega$ (to match).
- Then, jX_s used to cancel jX_{left}

Answers to Prev. Problem



- On left, 0 output at DC
- On right, 0 output at infinite frequency

Analysis

- Let us define

$$Q_{EL} = \sqrt{\frac{R_{high}}{R_{low}} - 1}$$

- Then, we have

$$\frac{X_s}{R_{low}} = \frac{R_{high}}{X_p} = Q_{EL}$$

- However, Q_{EL} is not the $Q = f_o/\Delta f$ but it can be shown that

$$\frac{1}{Q} = \frac{2}{Q_{EL}}$$

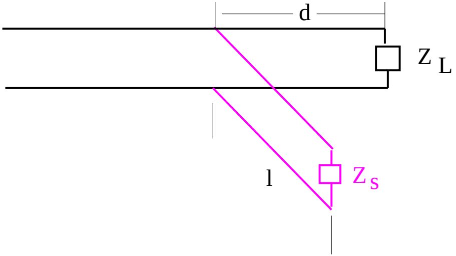
- Note that as R_{high}/R_{low} increases, the Q increases.

L-Nets on a Smith Chart

- Need impedance Smith chart with $g = 1$ circle added
- Example
  - $Z_L = 200 - j100$, 100Ω line, $f = 500$ MHz.
  - $z_L = 2 - j1$
  - inside $r = 1$ circle$\rightarrow$ high impedance $\rightarrow X_p$ first.
  - (see chart)

Outline

Single Stub Tuner



- There are two variables, d and ℓ.
- Z_s is either an open circuit or a short circuit
- The stub adds only reactance
- Principle
  - Find d so that $y_{in} = 1 \pm jx$
  - Find ℓ so that $y_{in,stub} = 1 \mp jx$

Example

- $Z_L = 60 - j80$ ($R = 60\Omega$, C=0.995pF at 2 GHz)
- $Z_o = 50\Omega$
- $z_L = 1.2 - j1.6$
- see Smith chart

Outline

Quarter-Wave Transformer

- Recall the input impedance relation:

$$Z_{in} = R_o \frac{Z_L + jR_o \tan \beta\ell}{R_o + jZ_L \tan \beta\ell}$$

- if Z_L, R_o are real, and $\ell = \lambda/4$, then, $\beta\ell = (2\pi/\lambda)(\lambda/4) = \pi/2$ and $\tan(\pi/2) \rightarrow \infty$.
- Therefore,

$$Z_{in} = \frac{R_o^2}{Z_L}$$

Quarter-Wave Transformers, Part II

- Recall:

$$Z_{in} = \frac{R_o^2}{Z_L}$$

- This relationship can be used to define a section of transmission line with impedance R' which is $\lambda/4$ long and has characteristic impedance:

$$R' = \sqrt{R_o R_L}$$

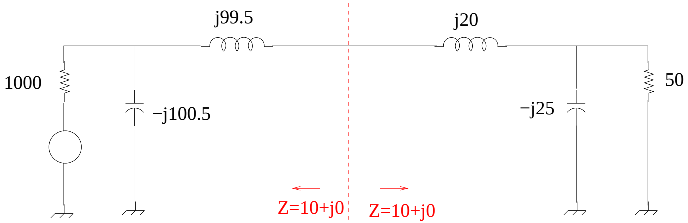
and there will be no reflections at the center frequency.

Bandwidth Considerations

- In all of the methods discussed, the match is “perfect” at a single frequency.
- Sometimes, the bandwidth of the match is important.
- There are instances where a narrower bandwidth or a wider bandwidth is desired.
- For the rest of the presentation, we will investigate techniques (mostly based on previous methods) that provide either a wider or a narrower bandwidth.
- The Bode-Fano Criterion also helps us understand some of the fundamental limitations of wide-band matching networks.

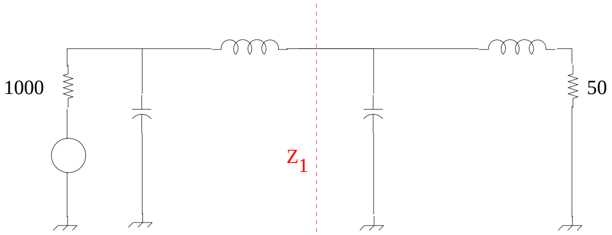
Outline

Lumped Element Methods: Narrower Bandwidth



- Pi net will have narrower BW
- Intermediate impedance is additional degree of freedom
- Can also choose $Z > R_{high}$, then, L-nets flip and have T-net

Lumped Element Methods: Wider Bandwidth



$50 < Z_1 < 1000$

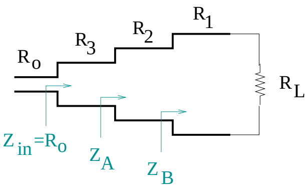
- Multiple Sections can be used
  - Many sections and structure begins to look like tapered t-line

Outline

Multiple Quarter-wave Section

- Can use multiple sections to create wider bandwidth match
  - Each section has length $\lambda/4$
  - Each section has impedance between R_o and R_L
- Structure will take more space (length)
- More t-line will also mean more loss in structure

Example



- For example, suppose have 3 sections. Let

$$r = \frac{R_L}{Z_B} = \frac{Z_B}{Z_A} = \frac{Z_A}{R_o} \quad \text{or} \quad \frac{R_L}{R_o} = \frac{Z_A}{R_o}\frac{Z_B}{Z_A}\frac{R_L}{Z_B} = r^3$$

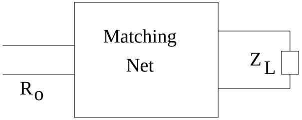
- Therefore, use

$$r = \sqrt[3]{\frac{R_L}{R_o}}$$

Outline

Bode-Fano Criterion: Introduction

- Bode-Fano Criterion answers:
  - Can we achieve perfect match ($\Gamma = 0$) over a bandwidth (BW)?
  - If not, how well can we do?
  - What is tradeoff between $|\Gamma|$ and BW?
  - How complex must matching net be?
- Bode-Fano gives theoretical limit on $|\Gamma|_{min}$



Bode-Fano Criterion

- Criterion related to

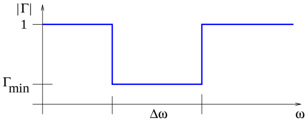
$$\int_0^\infty \ln \frac{1}{|\Gamma(\omega)|} d\omega$$

For example, with a parallel RC load (ICBST):

$$\int_0^\infty \ln \frac{1}{|\Gamma(\omega)|} d\omega \leq \frac{\pi}{RC}$$

- if $|\Gamma(\omega)| = 1$, have complete reflection and contribution to integral is zero.
- Thus, criterion is concerned with pass band

Simple Example



- Using $|\Gamma|$ as shown,

$$\int_0^\infty \ln \frac{1}{|\Gamma|} d\omega = \int_{\Delta\omega} \ln \frac{1}{\Gamma_{min}} d\omega = \Delta\omega \ln \frac{1}{\Gamma_{min}} \leq \frac{\pi}{RC}$$

- Conclusions:
  - For a given load, as $\Delta\omega$ increases, Γ_{min} increases
  - Γ in passband cannot be zero unless $\Delta\omega = 0$.
  - as R or C increase, $\Delta\omega$ or $1/\Gamma_{min}$ must decrease (higher Q implies harder to match)

Outline

Conclusions

- Many methods available for impedance matching
  - narrow-band methods
  - wider-band methods
- Bode-Fano Criterion helps us understand the fundamental limits of wide-band matching
- (not covered) Theory of small reflections can be used to create filter-like designs that both match the load to the line and provide filtering.