6.5 Filter Design

Module:6 Microwave Passive circuits

Course: BECE305L – Antenna and Microwave Engineering

-Dr Richards Joe Stanislaus

Assistant Professor - SENSE

Email: richards.stanislaus@vit.ac.in

VIT
Vellore Institute of Technology
(Deemed to be University under section 3 of UGC Act, 1956)
CHENNAI

Module:6 Microwave Passive circuits 7 hours

- T junction and resistive power divider, Wilkinson power divider, branch line coupler (equal & unequal), Rat Race Coupler, Filter design: Low pass filter (Butterworth and Chebyshev) - Richards transformation and stepped impedance methods.

- Source of the contents: Pozar

1. Introduction to filters

- **Filter** is a two-port network

  used to control the frequency response at a certain point in an RF or microwave system

  by providing transmission at frequencies within the passband of the filter

  and

  attenuation in the stopband of the filter.

1. Introduction to filters

- **Typical frequency responses (**characteristics)

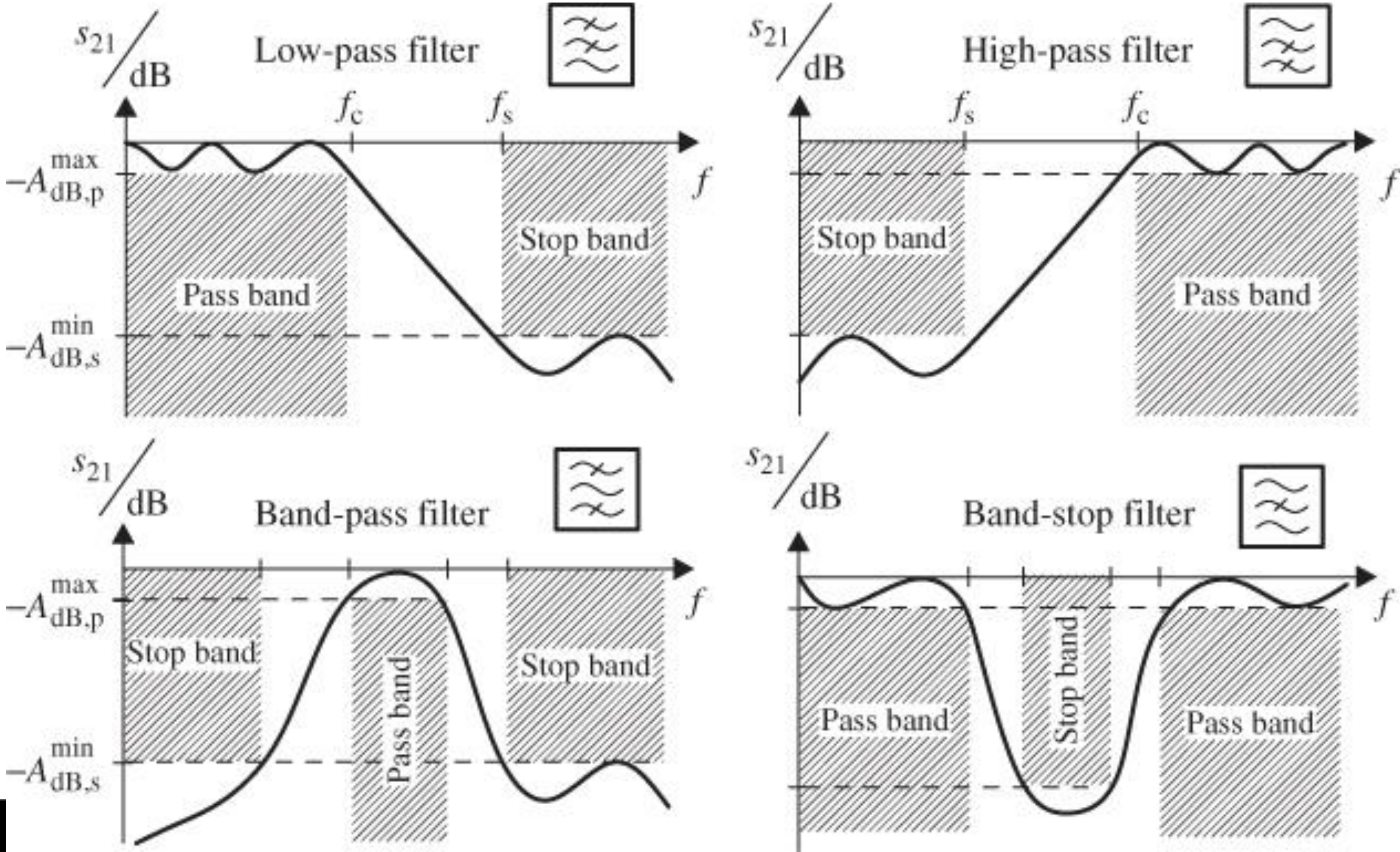
  low-pass,
  high-pass,
  bandpass, and
  band-reject

Source:
https://www.oreilly.com/library/view/rf-and-microwave/9781118349571/c06_level1_4.xhtml

1. Introduction to filters

- **Typical frequency responses (**characteristics)

  low-pass,
  high-pass,
  bandpass, and
  band-reject



Source: https://www.oreilly.com/library/view/rf-and-microwave/9781118349571/c06_level1_4.xhtml

1. Introduction to filters

- Applications can be found in virtually any type of **RF or microwave communication**, **radar**, or **test and measurement system**
-

1. Introduction to filters

- Applications can be found in
  virtually any type of RF or microwave communication,
  radar, or
  test and measurement system
- A more modern procedure, called the **insertion loss method**, uses **network synthesis techniques to design filters** with a **completely specified frequency response**.

1. Introduction to filters

- Applications can be found in
  virtually any type of RF or microwave communication,
  radar, or
  test and measurement system
- A more modern procedure, called the insertion loss method, uses network synthesis techniques to design filters with a completely specified frequency response.
  The design is **simplified** by beginning with **low-pass filter prototypes that are normalized in terms of impedance and frequency**.
  Transformations are then applied to **convert the prototype designs to the desired frequency range and impedance level**.

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- A **perfect filter** would have
  zero insertion loss in the **passband**,
  infinite attenuation in the **stopband**,
  and a **linear phase response** (to avoid signal distortion) in the **passband**.

- ;

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- A perfect filter would have
  zero insertion loss in the passband,
  infinite attenuation in the stopband,
  and a linear phase response (to avoid signal distortion) in the passband.

- Such filters **do not exist in practice**,
- so **compromises** must be made;

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- The insertion loss method, however, **allows a high degree of control over the passband** and **stopband amplitude** and **phase characteristics**, with a systematic way to synthesize a desired response.

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- The insertion loss method, however,
  allows a high degree of control over the passband and stopband amplitude
  and phase characteristics, with a systematic way to synthesize a desired response.
  The necessary design trade-offs can be evaluated to best meet the application requirements.
-

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- The insertion loss method, however,
  allows a high degree of control over the passband and stopband amplitude
  and phase characteristics, with a systematic way to synthesize a desired response.
  The necessary design trade-offs can be evaluated to best meet the application requirements.
- If, for example, a **minimum insertion loss is most important**, a **binomial response could be used**;

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- The insertion loss method, however,
  allows a high degree of control over the passband and stopband amplitude
  and phase characteristics, with a systematic way to synthesize a desired response.
  The necessary design trade-offs can be evaluated to best meet the application requirements.
- If, for example, **a minimum insertion loss is most important, a binomial response could be used**;
  a **Chebyshev response would satisfy a requirement for the sharpest cutoff**.

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- The insertion loss method, however,
  allows a high degree of control over the passband and stopband amplitude
  and phase characteristics, with a systematic way to synthesize a desired response.
  The necessary design trade-offs can be evaluated to best meet the application requirements.
- If, for example, a minimum insertion loss is most important, a binomial response could be used;
  a Chebyshev response would satisfy a requirement for the sharpest cutoff.
  If it is possible to sacrifice the attenuation rate, a **better phase** response can be obtained by using **a linear phase filter design**.

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- In addition, in all cases,
- the insertion loss method allows filter performance to be improved in **a straightforward manner**,
  at the expense of a higher order filter.

2. FILTER DESIGN BY THE INSERTION LOSS METHOD

- In addition, in all cases,
- the insertion loss method allows filter performance to be improved in a straightforward manner,
  at the expense of a higher order filter.
- For the filter prototypes to be discussed below, **the order of the filter is equal to the number of reactive elements**.

2. FILTER DESIGN BY THE INSERTION LOSS METHOD: Characterization by Power loss ratio

- Insertion loss method:
  a filter response is defined by its insertion loss, or power loss ratio, P_{LR}:
- $P_{LR} = \dfrac{Power\ available\ from\ source}{Power\ delivered\ to\ the\ load} = \dfrac{P_{inc}}{P_{load}} = \dfrac{1}{1-|\Gamma(\omega)|^2}$

2. FILTER DESIGN BY THE INSERTION LOSS METHOD: Characterization by Power loss ratio

- Insertion loss method:
  a filter response is defined by its insertion loss, or power loss ratio, P_{LR}:
- $P_{LR} = \frac{Power\ available\ from\ source}{Power\ delivered\ to\ the\ load} = \frac{P_{inc}}{P_{load}} = \frac{1}{1-|\Gamma(\omega)|^2}$
- This quantity is reciprocal of $|S_{12}|^2$ if both load and source are matched. **<u>For Matched condition only</u>**, $P_{LR} = \frac{1}{|S_{12}|^2}$
- Insertion loss (IL)=$10\log_{10} P_{LR}$

2. FILTER DESIGN BY THE INSERTION LOSS METHOD: Characterization by Power loss ratio

- Insertion loss method:
  a filter response is defined by its insertion loss, or power loss ratio, P_{LR}:
- $P_{LR} = \frac{Power\ available\ from\ source}{Power\ delivered\ to\ the\ load} = \frac{P_{inc}}{P_{load}} = \frac{1}{1-|\Gamma(\omega)|^2}$
- This quantity is reciprocal of $|S_{12}|^2$ if both load and source are matched.
- Insertion loss (IL)=$10\log_{10} P_{LR}$
- $|\Gamma(\omega)|^2$ is an even function of ω. It can be expressed as polynomials M and N in ω^2: $|\Gamma(\omega)|^2 = \frac{M(\omega^2)}{M(\omega^2)+N(\omega^2)}$

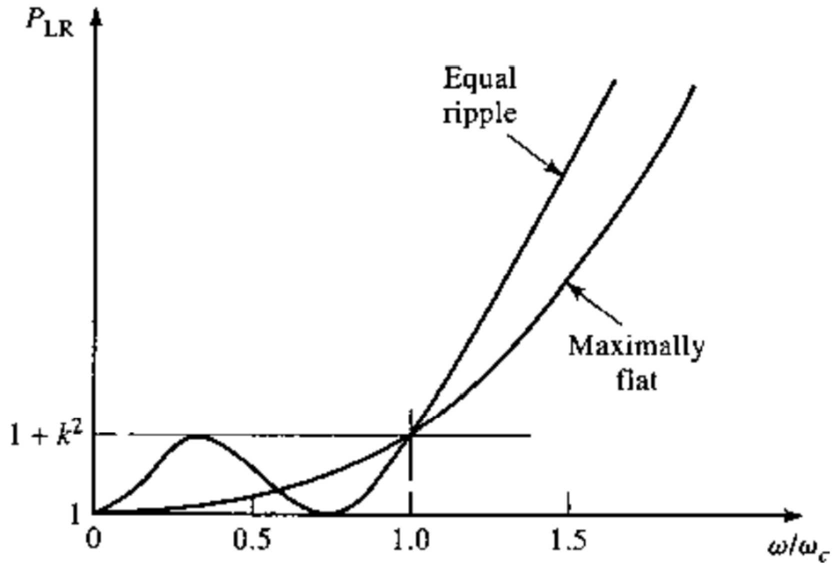
2. FILTER DESIGN BY THE INSERTION LOSS METHOD: Characterization by Power loss ratio

- Insertion loss method:
  a filter response is defined by its insertion loss, or power loss ratio, P_{LR}:
- $P_{LR} = \frac{Power\ available\ from\ source}{Power\ delivered\ to\ the\ load} = \frac{P_{inc}}{P_{load}} = \frac{1}{1-|\Gamma(\omega)|^2}$
- This quantity is reciprocal of $|S_{12}|^2$ if both load and source are matched.
- Insertion loss (IL)=$10\log_{10} P_{LR}$
- $|\Gamma(\omega)|^2$ is an even function of ω. It can be expressed as polynomials M and N in ω^2: $|\Gamma(\omega)|^2 = \frac{M(\omega^2)}{M(\omega^2)+N(\omega^2)}$
- $P_{LR} = 1 + \frac{M(\omega^2)}{N(\omega^2)}$ Reflection ratio is also constrained.

2.1 Characterization by Power loss ratio:
a) Maximally flat **(Binomial or Butterworth response)**

- **Provides flattest possible passband response** for given filter complexity.
- Low pass filter, it is specified by

$$P_{LR} = 1 + k^2 \left(\frac{\omega}{\omega_c}\right)^{2N}$$

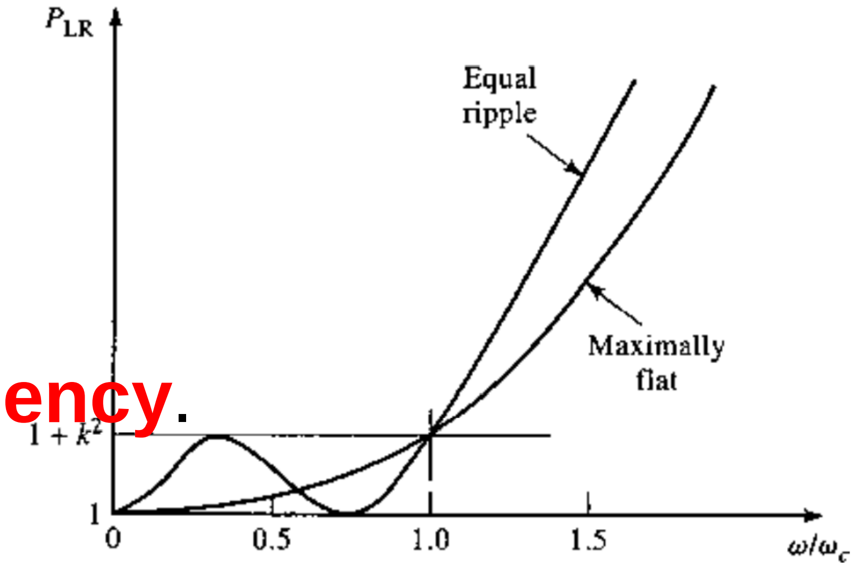


2.1 Characterization by Power loss ratio:
a) Maximally flat **(Binomial or Butterworth response)**

- Provides flattest possible passband response for given filter complexity.
- Low pass filter, it is specified by

$$P_{LR} = 1 + k^2 \left(\frac{\omega}{\omega_c}\right)^{2N}$$

- **N is order of the filter** and ω_c **is cutoff frequency**.
- **Pass band** extends from $\omega = 0$ **to** $\omega = \omega_c$

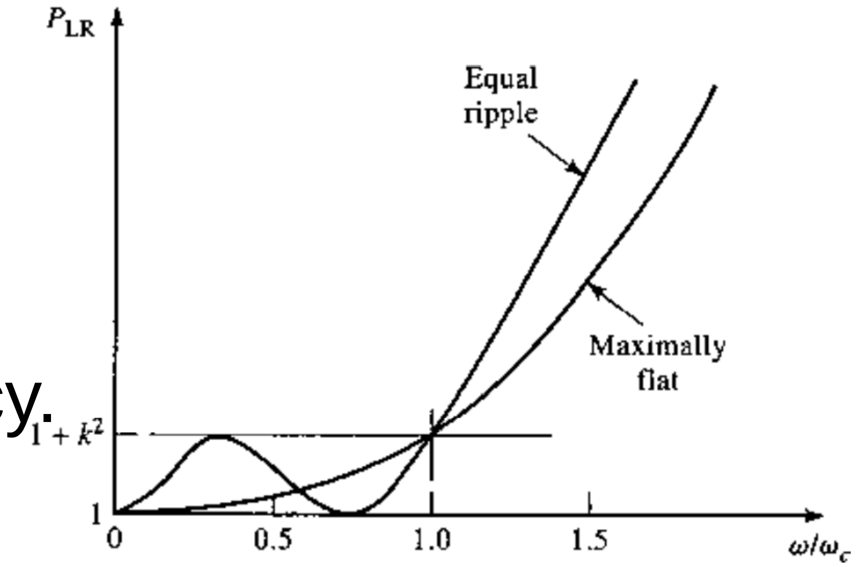


2.1 Characterization by Power loss ratio:
a) Maximally flat **(Binomial or Butterworth response)**

- Provides flattest possible passband response for given filter complexity.
- Low pass filter, it is specified by

$$P_{LR} = 1 + k^2 \left(\frac{\omega}{\omega_c}\right)^{2N}$$

- N is order of the filter and ω_c is cutoff frequency.
- Pass band extends from $\omega = 0$ to $\omega = \omega_c$
- **At the edge**, the **power loss ratio is 1** $+ \boldsymbol{k^2}$
  (If **-3dB point**, $\boldsymbol{k} = \mathbf{1}$, $P_{LR} = 1 + 1 = 2 = \frac{P_{inc}}{P_{load}}$)



2.1 Characterization by Power loss ratio:

a) Maximally flat **(Binomial or Butterworth response)**

- For $\omega > \omega_c$, **attenuation increases monotonically with frequency**.

2.1 Characterization by Power loss ratio:
a) Maximally flat **(Binomial or Butterworth response)**

- For $\omega > \omega_c$, attenuation increases monotonically with frequency.
- For $\omega \gg \omega_c$, $P_{LR} \approx k^2 \left(\frac{\omega}{\omega_c}\right)^{2N}$ (**Insertion loss increases at rate of 20dB/decade**
- .

2.1 Characterization by Power loss ratio:
a) Maximally flat **(Binomial or Butterworth response)**

- For $\omega > \omega_c$, attenuation increases monotonically with frequency.
- For $\omega \gg \omega_c$, $P_{LR} \approx k^2 \left(\frac{\omega}{\omega_c}\right)^{2N}$ (Insertion loss increases at rate of 20dB/decade
- Like binomial response, for multisection quarter-wave matching transformer, the **first $(\mathbf{2N-1})$ derivatives are zero at $\boldsymbol{\omega} = \mathbf{0}$**.

2.1 Characterization by Power loss ratio: b) Equal ripple (Chebyshev)

- Chebyshev polynomial is used to specify insertion loss $\boldsymbol{Nth}$ **order low pass filter** as

$$P_{LR} = 1 + k^2 T_N^2 \left(\frac{\omega}{\omega_c}\right)$$

2.1 Characterization by Power loss ratio:
b) Equal ripple (Chebyshev)

- Chebyshev polynomial is used to specify insertion loss Nth order low pass filter as
  $P_{LR} = 1 + k^2 T_N^2\left(\frac{\omega}{\omega_c}\right)$
  Results in a sharper cutoff but **with ripples in passband**
  Ripple amplitude $1 + k^2$, with $T_N(x)$ oscillates between ± 1 for $|x|^2 < 1$
- Thus **Passband ripple level are dependent on $\mathbf{k}^2$**

2.1 Characterization by Power loss ratio:
b) Equal ripple (Chebyshev)

- Chebyshev polynomial is used to specify insertion loss Nth order low pass filter as
  $P_{LR} = 1 + k^2 T_N^2 \left(\frac{\omega}{\omega_c}\right)$
  Results in a sharper cutoff but with ripples in passband
  Ripple amplitude $1 + k^2$, with $T_N(x)$ oscillates between ± 1 for $|x|^2 < 1$
- Thus Passband ripple level are dependent on k^2
- For **large** $\boldsymbol{x}$, $\mathrm{T_n}(\mathrm{x}) \approx \frac{1}{2}(2x)^N$
  For $\boldsymbol{\omega} \gg \boldsymbol{\omega_c}$, insertion loss $P_{LR} \approx \frac{k^2}{4}\left(\frac{2\omega}{\omega_c}\right)^{2N}$

2.1 Characterization by Power loss ratio:
b) Equal ripple (Chebyshev)

- Chebyshev polynomial is used to specify insertion loss Nth order low pass filter as

  $$P_{LR} = 1 + k^2 T_N^2\left(\frac{\omega}{\omega_c}\right)$$

  Results in a sharper cutoff but with ripples in passband

  Ripple amplitude $1 + k^2$, with $T_N(x)$ oscillates between ± 1 for $|x|^2 < 1$
- Thus Passband ripple level are dependent on k^2
- For **large *x***, $\mathrm{T_n(x)} \approx \frac{1}{2}(2x)^N$

  For $\boldsymbol{\omega \gg \omega_c}$, insertion loss $P_{LR} \approx \frac{k^2}{4}\left(\frac{2\omega}{\omega_c}\right)^{2N}$

  Chebyshev case's Insertion loss is >$\frac{2^{2N}}{4}$ times binomial case insertion loss
- This also increases at $20N\ dB/decade$