Microwave Filter Design

Recall that a **lossless** filter can be described in terms of either its power transmission coefficient $\mathcal{T}(\omega)$ **or** its power reflection coefficient $\Gamma(\omega)$, as the two values are completely **dependent**:

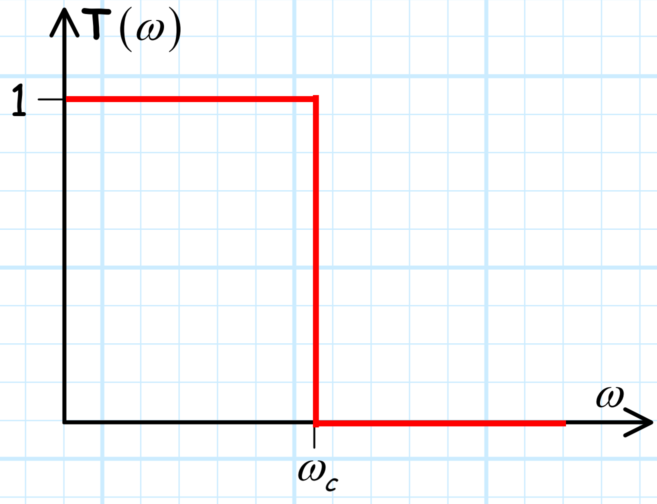
$$\Gamma(\omega) = 1 - \mathcal{T}(\omega)$$

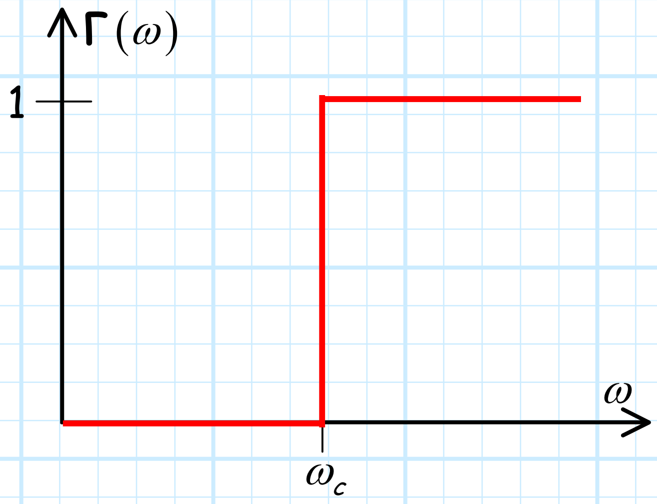
Ideally, these functions would be quite **simple**:

1. $\mathcal{T}(\omega) = 1$ and $\Gamma(\omega) = 0$ for **all** frequencies within the **pass**-band.

2. $\mathcal{T}(\omega) = 0$ and $\Gamma(\omega) = 1$ for **all** frequencies within the **stop**-band.

For example, the **ideal** low-pass filter would be:





Add to this a **linear phase** response, and you have the **perfect** microwave filter!

There's just one small problem with this **perfect** filter→ It's **impossible** to build!

Now, if we consider only possible (i.e., **realizable**) filters, we must limit ourselves to filter functions that can be expressed as **finite polynomials** of the form:

$$\mathbf{T}(\omega) = \frac{a_0 + a_1\,\omega + a_2\,\omega^2 + \cdots}{b_0 + b_1\,\omega + b_2\,\omega^2 + \cdots + b_N\,\omega^N}$$

The **order** N of the (denominator) polynomial is likewise the **order** of the filter.

There are many different **types** of polynomials that result in good filter responses, and each type has its own set of **characteristics**.

The type of **polynomial** likewise describes the type of microwave **filter**. Let's consider **three** of the most popular types:

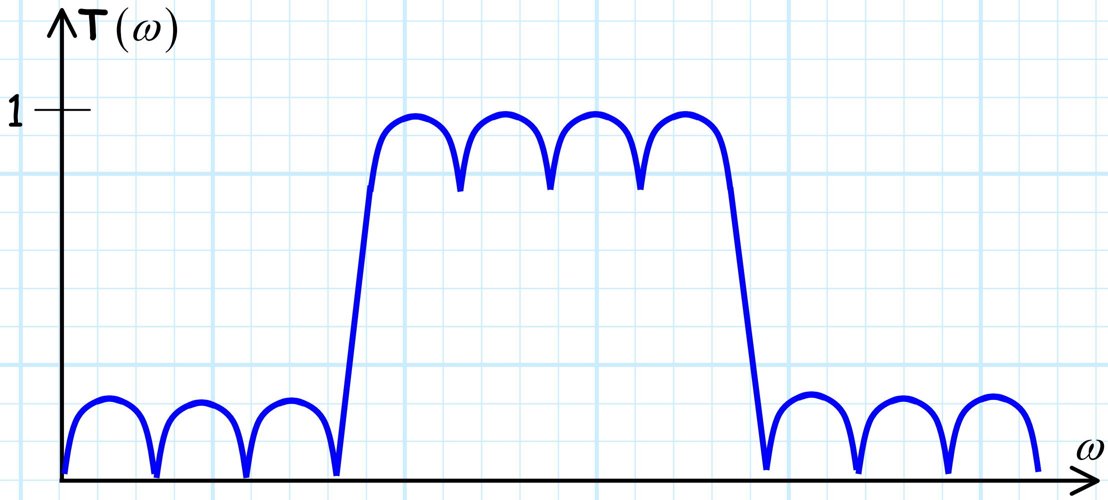
1. Elliptical

Elliptical filters have three primary characteristics:

a) They exhibit very **steep "roll-off"**, meaning that the transition from pass-band to stop-band is very rapid.

b) They exhibit **ripple** in the **pass**-band, meaning that the value of **T** will vary slightly within the pass-band.

c) They exhibit ripple in the **stop**-band, meaning that the value of **T** will vary slightly within the stop-band.



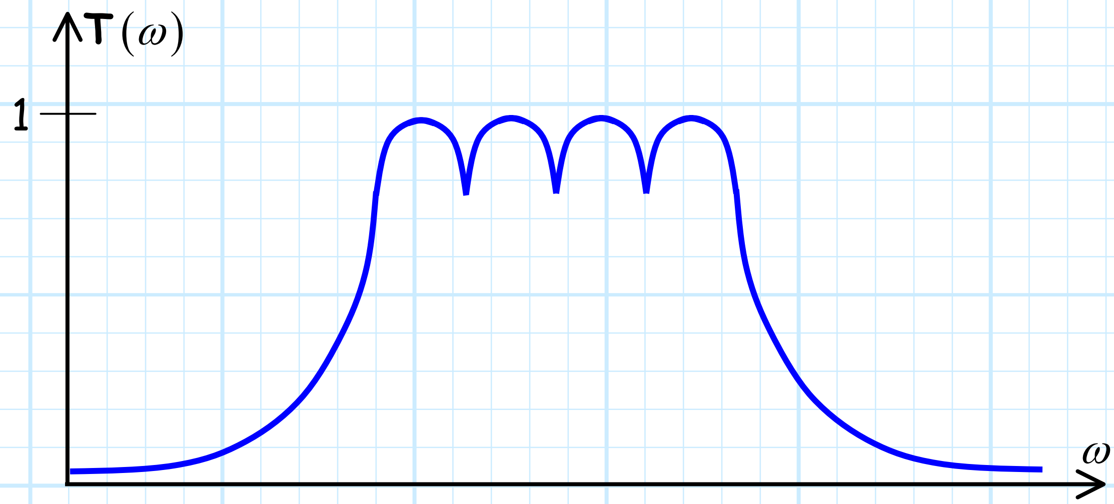
We find that we can make the roll-off **steeper** by accepting more **ripple**.

2. Chebychev

Chebychev filters are also known as **equal-ripple** filters, and have two primary characteristics

a) **Steep** roll-off (but not as steep as Elliptical).

b) Pass-band **ripple** (but not stop-band ripple).



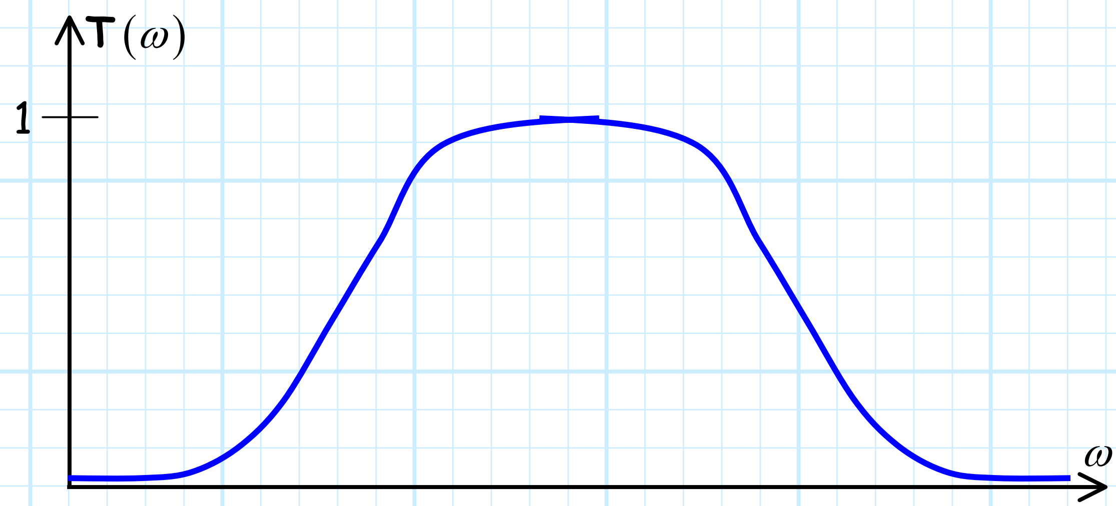
We likewise find that the roll-off can be made steeper by **accepting** more ripple.

3. Butterworth

Also known as **maximally flat** filters, they have two primary characteristics

a) **Gradual** roll-off .

b) **No ripple**—not anywhere.



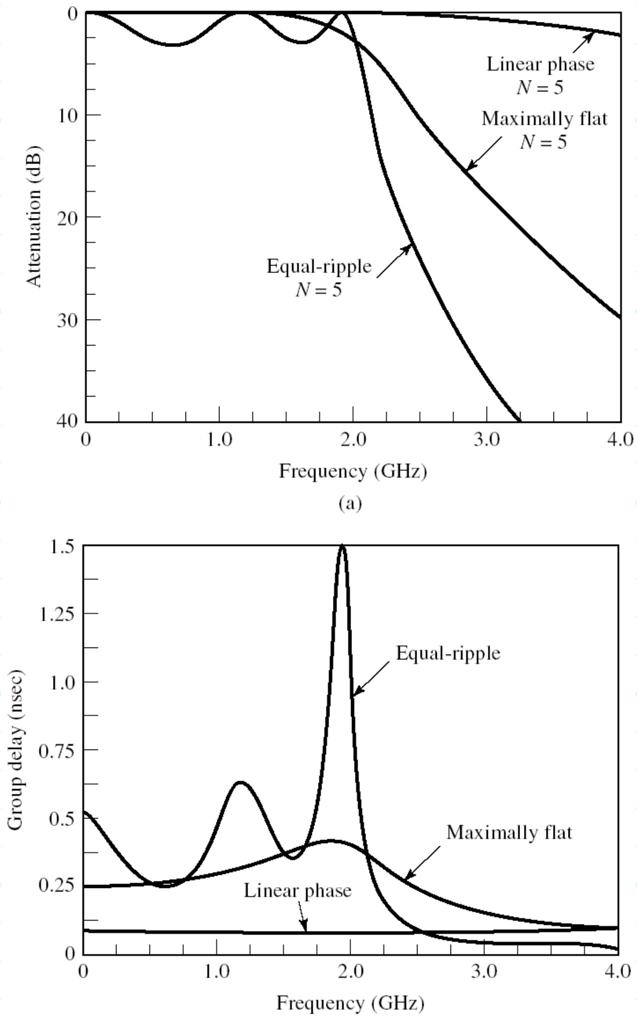
Q: *So we always chose **elliptical** filters; since they have the steepest roll-off, they are **closest** to ideal—**right**?*

A: Ooops! I forgot to talk about the **phase response** $\angle S_{21}(\omega)$ of these filters. Let's examine $\angle S_{21}(\omega)$ for each filter type **before** we pass judgment.

Butterworth $\angle S_{21}(\omega)$ → **Close** to linear phase.

Chebychev $\angle S_{21}(\omega)$ → **Not** very linear.

Elliptical $\angle S_{21}(\omega)$ → A big non-linear **mess**!



Thus, it is apparent that as a filter roll-off **improves**, the phase response gets **worse** (watch out for **dispersion!**).

→ There is **no** such thing as the "**best**" filter type!

Q: *So, a filter with **perfectly** linear phase is impossible to construct?*

A: No, it **is** possible to construct a filter with **near** perfect linear phase—but it will exhibit a **horribly** poor roll-off!

Now, for any **type** of filter, we can **improve** roll-off (i.e., increase stop-band attenuation) by **increasing the filter order** N. However, be aware that increasing the filter order likewise has these **deleterious** effects:

1. It makes **phase response** $\angle S_{21}(\omega)$ worse (i.e., more non-linear).

2. It increases filter **cost**, **weight**, and **size**.

3. It increases filter **insertion loss** (this is bad).

4. It makes filter performance more **sensitive** to temperature, aging, etc.

From a **practical** viewpoint, the **order** of a filter should typically be kept to $\boldsymbol{N} < \mathbf{10}$.

Q: *So exactly what* ***are*** *these filter polynomials* $\mathbf{T}(\omega)$*? How do we* ***determine*** *them?*

A: Fortunately, **radio engineers** do not need to determine specific filter polynomials in order to **specify** (to filter manufacturers) what they want built.

Instead, radio engineers simply can specify the **type** and **order** of a filter, saying things like:

"I need a ***3rd-order Chebychev*** *filter!"*

or

"Get me a ***5th-order Butterworth*** *filter!"*

or

"I wish I'd paid ***more*** *attention in EECS 622!"*

Thus, the most **important** filter specifications are:

1. Filter bandwidth and center frequency

2. Filter type and order.

However, there are **many more** important filter specifications!