

# Insertion Loss

**Ideally**, for every filter, there would be at least one frequency within its pass-band where the transmission is a perfect value of zero. I.E. :

$$T(\omega) = 1.0 \quad \text{for at least one frequency } \omega \text{ within the pass-band.}$$

For an **ideal** band-pass filter, this would occur (except for some Chebychev) at the **center** of the pass-band, i.e., at frequency  $\omega = \omega_0$  :

$$T(\omega)|_{\omega=\omega_0} = 1.0 \quad (\text{ideally})$$

The **disappointing reality**, however, is that for **real** (read: **non-ideal**) microwave filters, this value will be slightly less than one:

$$T(\omega)|_{\omega=\omega_0} < 1.0 \quad (\text{realistically})$$

## You better know the reasons!

**Q:** *Yikes! Why does this occur?*

*Why doesn't **all** the available power from the matched source reach the matched load?*

**A:** You **know** the reasons!

Either:

- a)** the incident (i.e., available power) is **reflected** by a (slightly) **mismatched** filter input impedance, **or**
- b)** some of the delivered power is **absorbed** by a (slightly) **lossy** filter.

## Low loss is desirable

The **power loss** due to **mismatch** can be quantified using **Return Loss**:

$$\text{Return Loss} = -10\log_{10}\left[\frac{P_{ref}^{in}}{P_{inc}^{in}}\right] = -10\log_{10}\left[\frac{P_{ref}^{in}}{P_{avl}^{in}}\right]$$

The power loss due to **absorption**, however, is quantified using **Insertion Loss**.

$$\text{Insertion Loss} = -10\log_{10}\left[\frac{P_{abs}}{P_{del}^{in}}\right] = -10\log_{10}\left[\frac{P_{inc}^{out}}{P_{del}^{in}}\right]$$

Note this ratio uses the power **delivered** by the source—not its **available power**!

Since  $P_{abs} < P_{del}$  for lossy devices, we see that Insertion Loss is a **positive value**.

Note also that a **lower value** of Insertion Loss is **desirable**, with a **perfect** value of **0 dB** for the **lossless case**!

## A reason to keep your filter order small

**Q:** *So what **value** of Insertion Loss do we **typically** see for a microwave filter?*

**A:** The Insertion Loss of a microwave filter generally gets **worse** (i.e. gets numerically **larger**) as:

- a)** the **filter order increases**, and as
- b)** the **center frequency increases**.

Additionally, insertion loss will depend on the **materials** used to construct the filter.

So, we **typically** see filter insertion losses from **roughly 0.2 dB (good) to 3.5 dB (bad)**.

## We don't really need to determine delivered power

**Q:** *Insertion Loss requires knowledge of the **delivered** power  $P_{del}$ .*

*Just **how** do we determine this value?*

**A:** Recall the power delivered by the **matched source** is:

$$P_{del} = P_{avl} - P_{ref}^{in} = P_{avl} - P_{avl} |\Gamma_{in}|^2 = P_{avl} (1 - |\Gamma_{in}|^2)$$

Thus, we **could** use the Return Loss to find  $|\Gamma_{in}(\omega)|_{\omega=\omega_0}^2$ , and then “convert” available power to **delivered power**.

→ We could do that—but we **typically don't!**

## Delivered is approximately available

**Instead**, we note that—for frequencies within the pass-band of a **well-designed** microwave filter—the input is **well-matched**, such that this input reflection coefficient  $|\Gamma_{in}(\omega)|_{\omega=\omega_0}^2$  is **very small**.

Thus, applying the **approximation**:

$$|\Gamma_{in}(\omega)|_{\omega=\omega_0}^2 \approx 0$$

We find:

$$P_{del} = P_{avl} \left( 1 - |\Gamma_{in}|^2 \right) \approx P_{avl}$$

And so:

$$\frac{P_{abs}}{P_{del}} \approx \frac{P_{abs}}{P_{avl}} = T(\omega)$$

## How we calculate Insertion Loss

The **Insertion Loss** of a filter can thus be (and usually is) **approximated** as:

$$\text{Insertion Loss} \cong -10\log_{10} [T(\omega)]_{\omega=\omega_0}$$

## This confuses the heck out of students

**Q:** *I don't understand!*

- \* *You said **Insertion Loss** provides a indication of the power **absorbed** by the filter (and thus **not absorbed** by the load).*
- \* *You said **small** numerical values are **good**, with **0 dB** the **ideal** value.*
- \* *You also said that **Return Loss** provides an indication of the power **reflected** at the input port (and thus **not absorbed** by the load).*
- \* *But, you **then** said that **large** numerical values of Return Loss is **good** with **infinity** being the **ideal** value!*

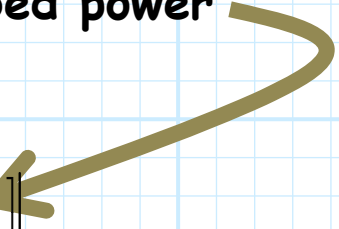
*Isn't this a contradiction?*

**A:** No contradiction!



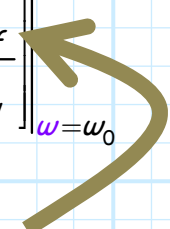
## They're just so different

**Insertion Loss** is a **direct indication** of the reduction in **absorbed power** by the matched load, due to power "lost" by a **lossy filter**.

$$\text{Insertion Loss} \cong -10\log_{10}\left[T(\omega)\right]_{\omega=\omega_0} = -10\log_{10}\left[\frac{P_{abs}}{P_{avl}}\right]_{\omega=\omega_0}$$


For **example**, if the **Return Loss** is **2 dB**, then the power **absorbed** by the matched load is **2 dB less** than it would have been, had the filter been instead **lossless**.

However, pass-band **Return Loss** is **not** a **direct indication** of the reduction in absorbed power by the matched load, due to power "lost" by a **mismatched filter**.

$$\text{Return Loss} = -10\log_{10}\left[\frac{P_{ref}^{in}}{P_{avl}}\right]_{\omega=\omega_0}$$


Instead, **Return Loss** is an indication of the **reflected power**, **not** the **absorbed power** of the matched load.

## Mismatch reduces absorbed by this much

If we wished to **directly** express the reduction in **absorbed power** by the matched load, due to power "lost" by **reflection** at the input, we would use a "loss" value:

$$\begin{aligned}
 \text{"Reflection Loss"} &= -10\log_{10}\left[\frac{P_{del}}{P_{avl}}\right]_{\omega=\omega_0} \\
 &= -10\log_{10}\left[\frac{P_{avl} - P_{ref}^{in}}{P_{avl}}\right]_{\omega=\omega_0} \\
 &= -10\log_{10}\left[1 - \left|\Gamma_{in}(\omega)\right|_{\omega=\omega_0}^2\right]
 \end{aligned}$$

Note for a **well-matched** filter, this value will be **very small** (e.g., 0.02 dB or less), and so this loss is **not generally used** in microwave engineering.