

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. :

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

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

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

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

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

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**.

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

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:

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

Thus, we **could** use the Return Loss to find $|\Gamma_{in}(w)|^2_{w=w_0}$, 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 $|\Gamma_{in}(\omega)|^2 \Big|_{\omega=\omega_0}$ is **very small**.

Thus, applying the approximation:

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

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:

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

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!

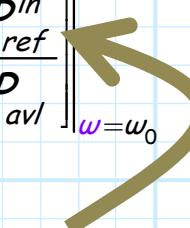
They're just so different

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

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


For example, if the Return Loss is 2dB, 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.

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


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:

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

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.