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 $\omega = \omega_0$:

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

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

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

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**:

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

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:

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

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

Thus, applying the **approximation**:

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

We find:

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

And so:

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

How we calculate Insertion Loss

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

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

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**.

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

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**.

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

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:

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

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.