The Ideal Gain Element

Recall that the maximum possible transducer gain, **given a specific gain element**, and a source and load impedance of Z_0 is:

$$G_{T\,max} = \frac{1}{1-\left|\Gamma_s\right|^2}\left|S_{21}\right|^2\frac{1-\left|\Gamma_L\right|^2}{\left|1-\Gamma_L S_{22}\right|^2}$$

By properly constructing input and output matching networks, we can maximize the transducer gain—it's the largest value that we can get for **that particular gain element**.

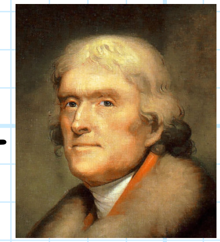
→But what if this gain is **insufficient**?

In that case we must **change the gain element**, but what should we change the gain element to? What are the characteristics of an **ideal gain element**?

The answers to these questions are best determined by examining the maximum **unilateral** transducer gain:

$$G_{UT\,max} = \frac{1}{1-\left|S_{11}\right|^2}\left|S_{21}\right|^2\frac{1}{1-\left|S_{22}\right|^2}$$

Recall that for most gain elements, $\left|S_{12}\right|$ **is** small (i.e., approximately unilateral), and in fact $S_{12}=0$ is **one** ideal characteristic of an **ideal gain element**.



From the maximum unilateral gain expression, we can determine the remaining **ideal characteristics** of a gain element. Some of these results are rather **self-evident**, but others are a bit **surprising**!

For example, it is clear that **gain** is increased as $|S_{21}|$ is **maximized**—no surprise here. What might catch you off guard are the conclusions we reach when we observe the **denominator** of $G_{UT\,max}$:

$$G_{UT\,max} = \frac{1}{1-|S_{11}|^2}|S_{21}|^2\frac{1}{1-|S_{22}|^2}$$

It appears that the gain will go to **infinity** if $|S_{11}|=1$ and/or $|S_{22}|=1$!

Q: *But that would mean the input and/or output impedance of the gain element is **purely reactive** (e.g. and open or a short). Is this conclusion **accurate**?*

A: Yes and no.

Remember, this maximum gain is achieved when we establish a **conjugate match**. The equation above says that this maximum gain will increase to infinity if we match to a **reactive** input/output impedance.

And **that's** the catch.

→ It is **impossible** to match Z_0 to load that is purely reactive!

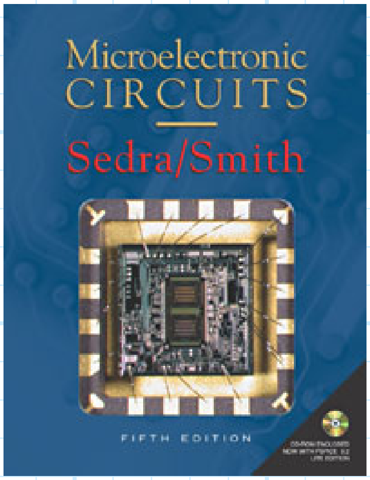
We can only match to an impedance that has a **non-zero resistive component** (i.e., $|\Gamma| < 1$); otherwise, there's no way for the available power can be **absorbed!**

Still, it is quite evident that—all other things being equal—a gain element with **larger values** of $|S_{11}|$ and $|S_{22}|$ will produce **more gain** than gain elements with smaller values of $|S_{11}|$ and $|S_{22}|$.

Q: *This seems very **counter intuitive**; I would think that an inherently **better-matched** gain element (e.g., $|S_{11}| \approx 0$ and $|S_{22}| \approx 0$) would provide **more gain**.*

A: It does doesn't it?

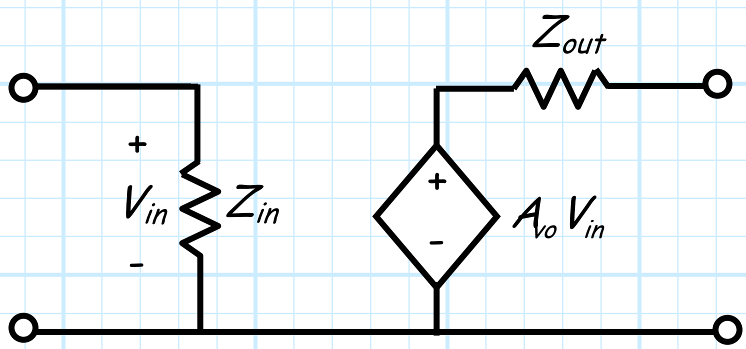
But remember back to your initial academic discussion of amplifiers (probably **way** back in an undergraduate **electronics course**).



Recall you studied **four types** of amplifier (gain element) models: voltage gain, current gain, trans-impedance, and trans-conductance. Each of these amplifiers was likewise characterized in terms of its **input impedance** and its **output impedance**.

Recall also that for each of these models, the **ideal** values of input/output impedance was **always** either zero (a short) or infinity (an open)!

In other words, **ideal** amplifiers (**gain elements**) always have $S_{11} = S_{22} = 0$!



Ideally:

$|Z_{in}|$ very small

$|Z_{out}|$ very small

$|A_{vo}|$ very small

For example, an **ideal voltage amplifier** has a **high input** impedance ($|S_{11}| \approx 1$) and a **low output** impedance ($|S_{22}| \approx 1$). If we construct matching networks on either side of this ideal gain element, the result is an amplifier with **very** high transducer gain !

Q: *So how do we "**change**" a gain element to a **more ideal** one?*

A: Of course we could always select a **different** transistor, but we also could simply change the **DC bias** of the transistor we are using!

Recall the **small-signal parameters** (and thus the scattering parameters) of a transistor change as we modify the **DC bias** values. We can select our DC bias such that the value of G_{TUmax} **is maximized.**

Q: *Is there any **downside** to this approach?*

A: Absolutely! Recall that we can theoretically match to a very low or very high resistance—at precisely **one frequency**! But we found that the resulting match will typically be **extremely narrowband** for these cases.

Thus, we might consider **reducing** the amplifier gain (i.e., reducing the values $|S_{11}|$ and $|S_{22}|$), in return for achieving a more moderate gain over a **wider frequency bandwidth**!

Additionally, DC bias likewise affects **other** amplifier characteristics, including compression points and noise figure!