Design for Specified Gain

The **conjugate matched** design of course **maximizes** the transducer gain of an amplifier. But there are times when wish to design an amplifier with **less** than this maximum possible gain!

Q: *Why on Earth would we want to design such a **sub-optimal** amplifier?*

A: A general characteristic about amplifiers is that we can always trade **gain** for **bandwidth** (the gain-bandwidth product is an approximate **constant**!). Thus, if we desire a **wider** bandwidth, we must **decrease** the amplifier gain.

Q: *Just **how** do we go about doing this?*

A: We simply design a "matching" network that is actually **mismatched** to the gain element. We know that the **maximum** transducer gain will be achieved if we design a matching network such that:

$$\Gamma_s = \Gamma_{in}^* \qquad \text{and} \qquad \Gamma_L = \Gamma_{out}^*$$

Thus, a **reduced gain** (and so wider bandwidth) amplifier must have the characteristic that:

$$\Gamma_s \neq \Gamma_{in}^* \qquad \text{and} \qquad \Gamma_L \neq \Gamma_{out}^*$$

Specifically, we should select Γ_s and Γ_L (and then design the matching network) to provide the **desired** transducer gain G_T:

$$G_T = \frac{\left(1-|\Gamma_s|^2\right)|S_{21}|^2\left(1-|\Gamma_L|^2\right)}{|1-\Gamma_s\Gamma_{in}|^2\,|1-\Gamma_L S_{22}|^2} < G_{T\,max}$$

We find that there are **many values** of Γ_s and Γ_L that will provide this sub-optimal gain.

Q: *So **which** of these values do we choose?*

A: We choose the values of Γ_s and Γ_L that satisfies the above equation, **and** has the **smallest** of all possible magnitudes of $|\Gamma_s|$ and $|\Gamma_L|$.

→ Remember—**smaller** $|\Gamma|$ leads to **wider** bandwidth!

This design process is much easier if the gain element is **unilateral**. Recall for that case we find that the transducer gain is:

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

We can **rewrite** this gain as a product of **three terms**:

$$G_{UT} = G_S\, G_0\, G_L$$

where:

$$G_S = \frac{1-|\Gamma_s|^2}{|1-\Gamma_s S_{11}|^2}$$

$$G_0 = |S_{21}|^2$$

$$G_L = \frac{1-|\Gamma_L|^2}{|1-\Gamma_L S_{22}|^2}$$

Notice that the value of Γ_s affects G_S **only**, and the value of Γ_L affects G_L **only**. Therefore, the unilateral case again decouples into two **independent** problems.

We can compare the values above with their **maximum** values (when $\Gamma_s = S_{11}^*$ and $\Gamma_L = S_{22}^*$):

$$G_{Smax} = \frac{1}{1-|S_{11}|^2}$$

$$G_0 = |S_{21}|^2$$

$$G_{Lmax} = \frac{1}{1-|S_{22}|^2}$$

Thus, to increase the bandwidth of an amplifier, we **select** values of G_S and G_L that are **less** (typically by a few dB) than the maximum (i.e., matched) values G_{Smax} and G_{Lmax}.

Unlike the values $G_{S\max}$ and $G_{L\max}$—where there is precisely **one** solution for each ($\Gamma_s = S_{11}^*$ and $\Gamma_L = S_{22}^*$)—there are an **infinite** number of $\Gamma_s(\Gamma_L)$ solutions for a specific value of $G_S(G_L)$.

Q: *So **which** do we choose?*

A: We choose the solutions that have the **smallest magnitude**! This will maximize our amplifier **bandwidth**.

Q: *How do we **determine** what these values are?*

A: We can solve these equations to determine all Γ_s and Γ_L solutions for **specified** design values of G_S and G_L.

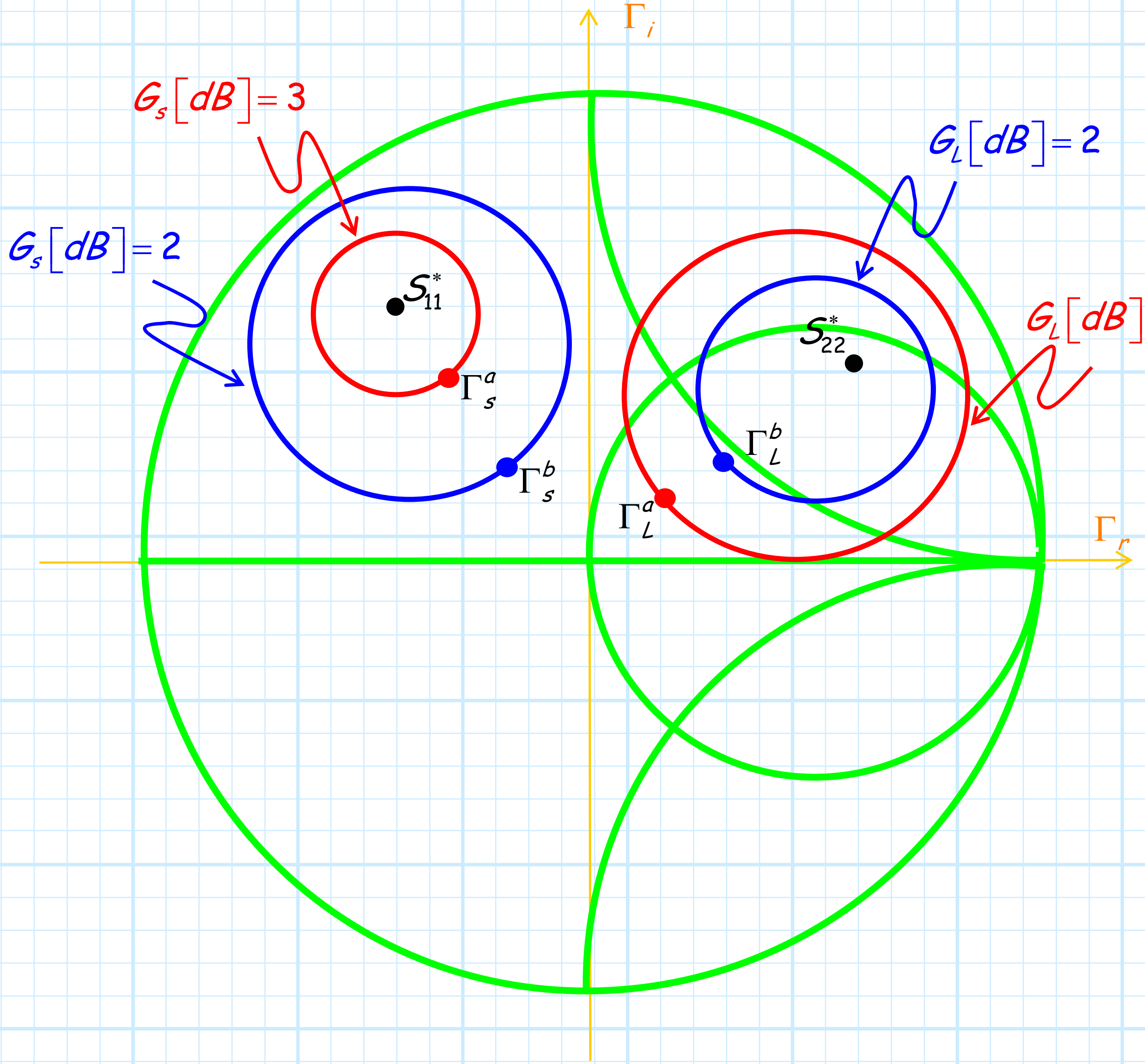
$$G_S = \frac{1-|\Gamma_s|^2}{|1-\Gamma_s S_{11}|^2} \qquad\qquad G_L = \frac{1-|\Gamma_L|^2}{|1-\Gamma_L S_{22}|^2}$$

Just as with our stability solutions, the solutions to the equations above form **circles** when plotted on the **complex** Γ **plane**.

These circles are known as **constant gain circles**, and are defined by two values: a **complex** value $C_s(C_L)$ that denotes the **center** of the circle on the complex Γ plane, and a **real** value $R_s(R_L)$ that specifies the **radius** of that circle.

These solutions are provided on pages 554 and 555 of your text.

Any Γ point **on** (not inside!) a constant gain circle denotes a value of Γ that will provide the requisite gain. To minimize the bandwidth we should choose the point on the circle that is **closest to the center** of the complex Γ plane!



For **example**, say we have an amplifier with:

$$G_{Smax}[dB]=4.0 \qquad G_0[dB]=7.0 \qquad G_{Lmax}[dB]=3.0$$

such that its transducer gain is **14 dB** at its design frequency. To increase the **bandwidth** of this amplifier, we decide to **reduce** the gain to 11 dB.

Thus, we find that our design goal is:

$$G_S[dB] + G_L[dB] = 4.0$$

From the gain circles on the Smith Chart above (assuming they represent the gain circles for this gain element), we find there are **two solutions**; we'll call them **solution *a*** and **solution *b*.**

Solution *a*

We determine the values Γ_s^a and Γ_L^a from the gain circles:

$$G_S[dB] = 3.0 \qquad \text{and} \qquad G_L[dB] = 1.0$$

so that $G_S[dB] + G_L[dB] = 4.0$.

Solution *b*

We determine the values Γ_s^b and Γ_L^b from the gain circles:

$$G_S[dB] = 2.0 \qquad \text{and} \qquad G_L[dB] = 2.0$$

so that $G_S[dB] + G_L[dB] = 4.0$.

There are of course an **infinite** number of possible solutions, as there are an infinite number of solutions to $G_s[dB] + G_L[dB] = 4.0$. However, the two solutions provided here are fairly **representative**.

Q: *So **which** solution should we use?*

A: That choice is a bit **subjective**.

We note that the point Γ_L^a is **very close** to the center, while the point Γ_s^a pretty **far away** (i.e., $|\Gamma_L^a|$ is small and $|\Gamma_s^a|$ is large).

In contrast, both Γ_s^b and Γ_L^b are **fairly close** to the center, although neither is as close as Γ_L^a.

To get the widest bandwidth, I would choose **solution *b***, but the only way to know for sure is to design and **analyze both solutions**.

Often, the design with the widest bandwidth will depend on how you **define** bandwidth!

Q: *So we reduce the transducer gain by designing and constructing a **mismatched** matching network. Won't that result in **return loss**?*

A: Absolutely!

We find for these wideband antennas that **neither** S_{11}^{amp} **nor** S_{22}^{amp} are equal to **zero**. However, there is a bit of a **silver lining**.

A conjugate matched amplifier is not only narrow band with regard to gain, it is also **narrow band** with regard to **return loss**. **Only** at the design frequency will the amplifier ports be perfectly matched. As we move away from the design frequency, the return loss **quickly degrades!**

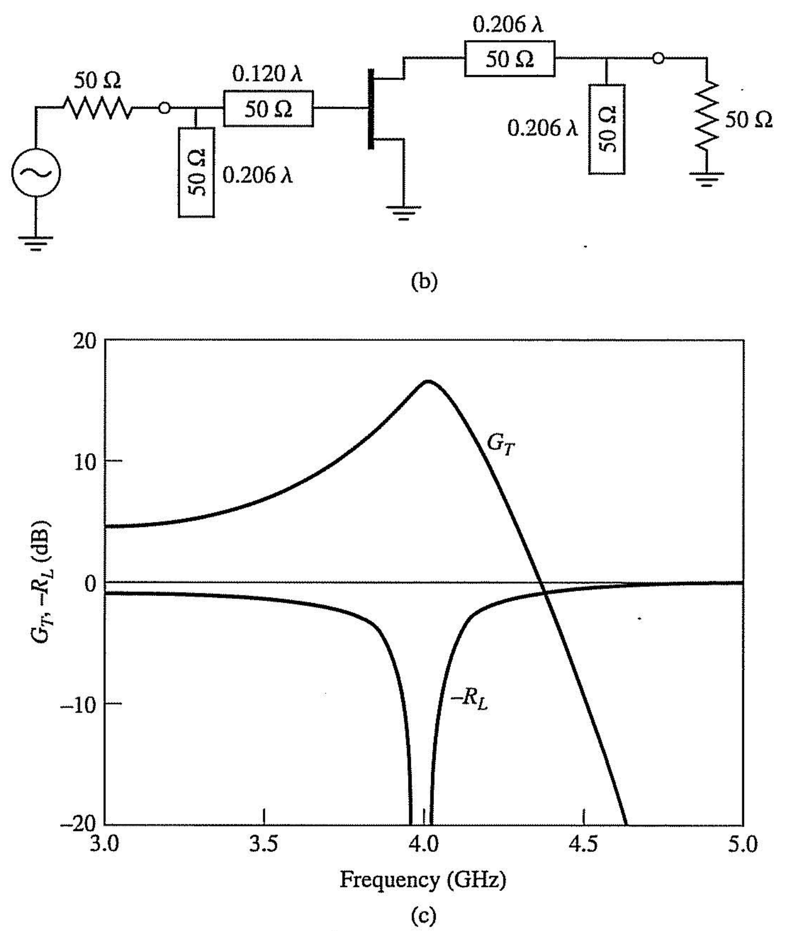


FIGURE 11.7 Continued. (b) RF circuit. (c) Frequency response.

With the "mismatched" design, we typically find that the return loss is **better** at frequencies away from the design frequency (as compared to the matched design), although at **no frequency** do we achieve a **perfect match** (unlike the matched design).

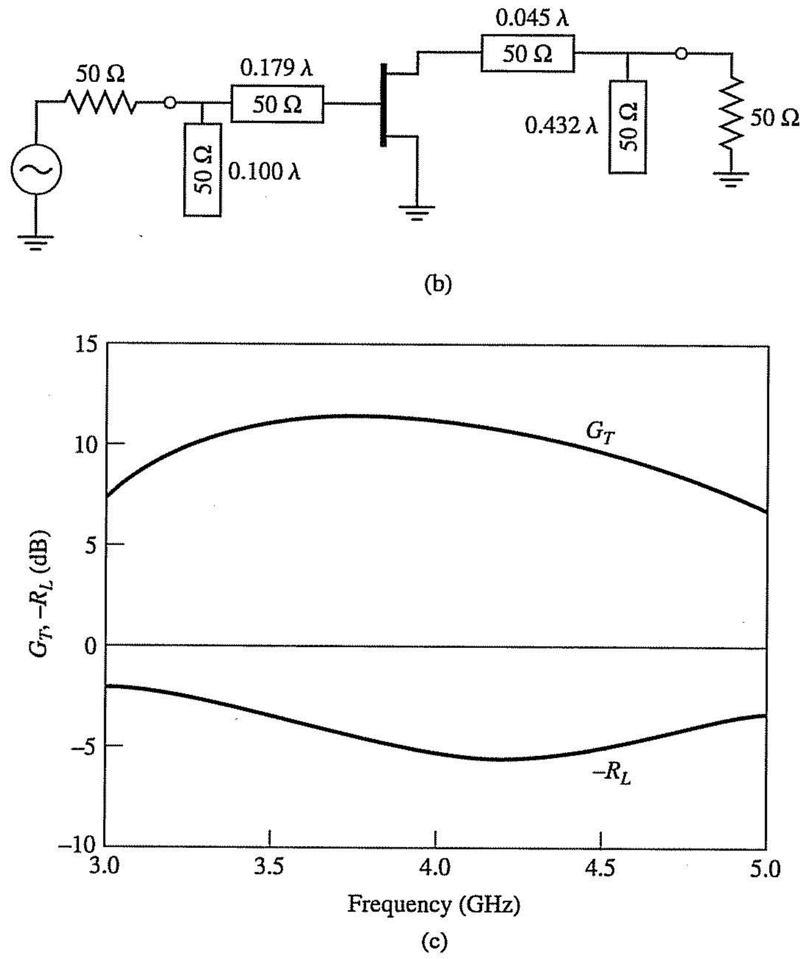


FIGURE 11.8 Continued. (b) RF circuit. (c) Transducer gain and return loss.

Generally speaking, a good (i.e., **acceptable**) return loss over a wide range of frequencies is **better** than a perfect return loss at one frequency and poor return loss everywhere else!

Q: *Won't you **ever** stop talking??*

A: Yup. I'm all done.