E. Receiver Gain and AGC

We find that a **detector/demodulator** likewise has a dynamic range, a value that has important ramifications in receiver design.

HO: Instantaneous Dynamic Range

Q: *We have calculated the overall gain of the receiver, but what should this gain be?*

A: HO: Receiver Gain

Q: *How can we build a receiver with variable gain? What microwave components do we need?*

A: HO: Automatic Gain Control (AGC)

HO: AGC Dynamic Range

Q: *How do we implement our AGC design?*

A: HO: AGC Implementation

We're done with receivers! Let's summarize our knowledge with the **Receiver Spec Sheet**:

HO: Rx Specification Sheet

Instantaneous Dynamic Range

Q: *So, let's make sure I have the right—**any** input signal with power exceeding the receiver sensitivity but below the saturation point **will** be adequately demodulated by the detector, right?*

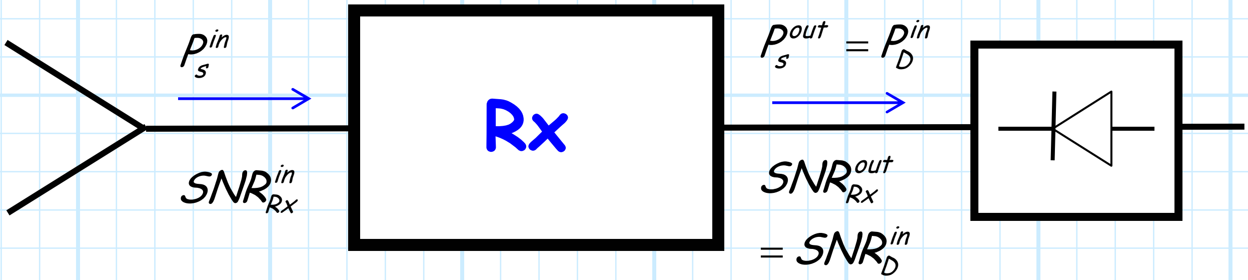
A: Not **necessarily!** The **opposite** is true, any signal with power **outside** the receiver dynamic range **cannot** be properly demodulated. However, signals **entering** the receiver within the proper dynamic range will be properly demodulated **only** if it **exits** the receiver with the proper **power**.

The reason for this is that **demodulators**, in **addition** to requiring a minimum SNR (i.e., SNR_{min}), **likewise** require a certain amount of **power**.

If the signals enters the receiver with power greater that the MDS, then the signal will **exit** the receiver with **sufficient SNR**. However, the signal power **can** (if the receiver was **designed improperly**) be **too large** or **too small**, depending on the overall receiver gain G.

Q: ***How** can the exiting signal power be too large or too small? What would **determine** these limits?*

A: Recall that the signal **exiting** the receiver is the signal **entering** the detector/demodulator. This **demodulator** will have a **dynamic range** as well!



Say the signal **power** entering the **demodulator** (i.e., exiting the receiver) is denoted P_D^{in}. The **maximum** power that a demodulator can "handle" is thus denoted P_D^{max}, while the **minimum** amount of power required for proper demodulation is denoted as P_D^{min}. I.E.,:

$$P_D^{min} \leq P_D^{in} \leq P_D^{max}$$

Thus, every **demodulator** has its own dynamic range, which we call the **Instantaneous Dynamic Range** (IDR):

$$\boxed{IDR = \frac{P_D^{max}}{P_D^{min}} \quad or \quad IDR(dB) = P_D^{max}(dBm) - P_D^{min}(dBm)}$$

Typical IDRs range from 30 dB to 60 dB.

To differentiate the Instantaneous Dynamic Range from the receiver dynamic range, we refer to the **receiver** dynamic range as the **Total Dynamic Range** (TDR):

$$TDR = \frac{P_{in}^{sat}}{MDS} \quad or \quad TDR(dB) = P_{in}^{sat}(dBm) - MDS(dBm)$$

Q: *How do we insure that a signal will exit the receiver within the dynamic range of the demodulator (i.e., within the IDR)?*

A: The relationship between the signal power when **entering** the receiver and its power when **exiting** the receiver is simply determined by the **receiver gain** G_{Rx} :

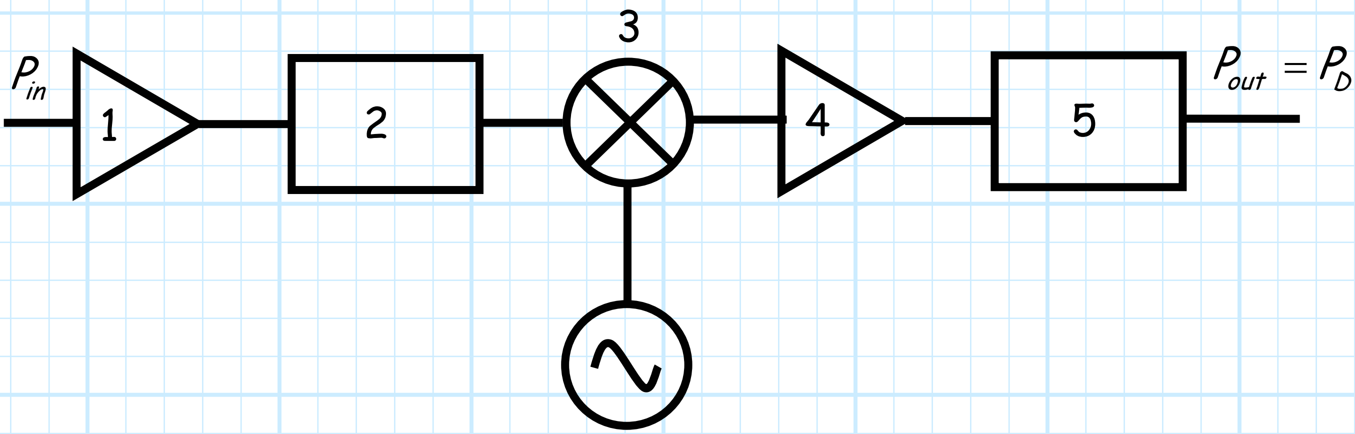
$$P_D^{in} = G_{Rx}\, P_s^{in}$$

We simply need to design the receiver gain such that P_D lies within the IDR for **all** signals P_s^{in} that lie within the TDR.

Big Problem → We find that almost always TDR >> IDR. This can make setting the receiver **gain** G_{Rx} very **complicated**!

Receiver Gain

Let's consider **each element** of a **basic** super-het receiver:



1. LNA - Required to make the receiver **noise figure** F as small as possible, thus making the receiver very **sensitive.**

2. Preselector – Required to **reject** all spurious-signal creating frequencies, while simultaneously letting the desired RF bandwidth pass to the mixer.

3. Mixer - Required for down-conversion; often sets the receiver **compression point**.

4. IF Filter - Required to **suppress** all mixer IF output signals, with the **exception** of the one desired signal that we wish to demodulate. Also determines the **noise bandwidth** B of the receiver.

5. IF Amp - **Q:** ***Why*** *is this device required?* ***What*** *receiver parameter does it determine?*

A: It **is** true that the IF amplifier does **not** generally affect receiver bandwidth, or sensitivity, or saturation point, or image rejection.

→ However, the IF amp **is** the component(s) that we use to properly set the overall **receiver gain**.

Say that we have designed a receiver with some specific *TDR* (i.e., *MDS* and P_{in}^{sat}). This receiver will be connected to a demodulator with a specific *IDR* (i.e., P_D^{min} and P_D^{max}). All we have left to do is determine the proper gain of the **IF amplifier** to give us the **required gain** of the overall receiver.

This gain must satisfy **two requirements**:

Requirement 1 -We know that the overall receiver gain G_{Rx} must be **sufficiently large** such that the **smallest** possible receiver input signal ($P_s^{in} = MDS$) is boosted **at least** to the level of the smallest required demodulator signal (P_D^{min}). Thus, the receiver gain G_{Rx} is **required** to be **larger** than some **minimum** value G_{Rx}^{min}:

$$\boxed{G_{Rx}^{min} \doteq \frac{P_D^{min}}{MDS} \quad or \quad G_{min}(dB) \doteq P_D^{min}(dBm) - MDS(dBm)}$$

Requirement 2 - Likewise, the overall receiver gain G_{Rx} must be **sufficiently small** to insure that the **largest** possible receiver input signal (i.e., $P_s^{in} = P_{in}^{sat}$) arrives at the demodulator with a power **less** than to the maximum level P_D^{min}. Thus, the receiver gain G_{Rx} is also **required** to be **smaller** than some **maximum** value G_{Rx}^{max}:

$$\boxed{G_{Rx}^{max} \doteq \frac{P_D^{max}}{P_{in}^{sat}} \quad or \quad G_{Rx}^{max}(dB) \doteq P_D^{max}(dBm) - P_{in}^{sat}(dBm)}$$

Q: *Seems **simple** enough! Just select an **IF amplifier** so that the overall receiver gain lies **between** these two limits:*

$$G_{Rx}^{min} < G_{Rx} < G_{Rx}^{max}$$

Right?

A: Not exactly. We are typically faced with a **big problem** at this point in our receiver design. To illustrate this problem, let's do an **example**.

Say our receiver has these **typical** values:

$$P_{in}^{sat} = -10dBm \qquad P_D^{max} = -20dBm$$

$$MDS = -90dBm \qquad P_D^{min} = -60dBm$$

Note then that $TDR = 80dB$ and $IDR = 40dB$.

Thus, the receiver gain is required to be larger than this minimum value of:

$$
\begin{aligned}
G_{Rx} > G_{Rx}^{min}(dB) &= P_D^{min}(dBm) - MDS(dBm) \\
&= -60 - (-90) \\
&= 30\,dB
\end{aligned}
$$

Any receiver gain **larger** than 30 dB will satisfy this **requirement**!

But, the gain is also required to be smaller then this maximum value of:

$$
\begin{aligned}
G_{Rx} < G_{Rx}^{max}(dB) &= P_D^{max}(dBm) - P_{in}^{sat}(dBm) \\
&= -20 - (-10) \\
&= -10\,dB
\end{aligned}
$$

Any receiver gain **smaller** than -10 dB will satisfy this **requirement**!

So **here's** our solution! The receiver gain must be any value **greater than 30 dB**, as long as it is simultaneously **less than -10dB**:

$$30dB < G_{Rx}(dB) < -10dB$$

Hopefully, it is evident that there are **no solutions** to the equation above!!

Q: *Yikes! Is this receiver **impossible** to build?*

A: Note that the values used in this example are are very **typical**, and thus the problem that we have encountered is likewise **very typical**.

We almost **always** find that $G_{Rx}^{min} > G_{Rx}^{max}$, making the solution G_{Rx} to the equation $G_{Rx}^{min} < G_{Rx} < G_{Rx}^{max}$ **non-existent**!

To see why, consider the **ratio** $G_{Rx}^{max} / G_{Rx}^{min}$:

$$\frac{G_{Rx}^{max}}{G_{Rx}^{min}} = \frac{P_D^{max} / P_{in}^{sat}}{P_D^{min} / MDS} = \frac{P_D^{max} / P_D^{min}}{P_{in}^{sat} / MDS} = \frac{IDR}{TDR}$$

In other words, for G_{max} to be **larger** than G_{min} (i.e., for $G_{max}/G_{min} > 1$), then the IDR must be **larger** than the TDR (i.e., $IDR/TDR > 1$).

But, we find that almost always the demodulator dynamic range (IDR) is **much less** than the receiver dynamic range (TDR), thus G_{max} is **almost never** larger than G_{min}.

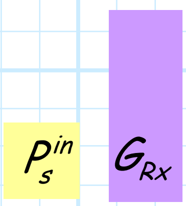
$$\text{Typically,} \qquad TDR >> IDR$$

Big Solution → However, there is **one** fact that leads to a solution to this **seemingly** intractable problem.

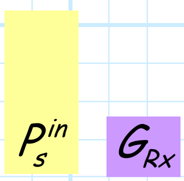
> The **one** desired input signal power can be as small as MDS **or** as large as P_{in}^{sat}—but it cannot have **both** values **at the same time**!

Thus, the receiver gain G_{Rx} may need to be **larger** than G_{Rx}^{min} (i.e., when $P_s^{in} = MDS$) or **smaller** as G_{Rx}^{max} (i.e., when $P_s^{in} = P_{in}^{sat}$), but it does **not** need to simultaneously satisfy both requirements!

In other words, we can make the gain of a receiver **adjustable** (i.e., adaptive), such that:



1. the gain increases to a sufficiently **large** value ($G_{Rx} > G_{Rx}^{min}$) when the input signal power P_s^{in} is **small**, but:



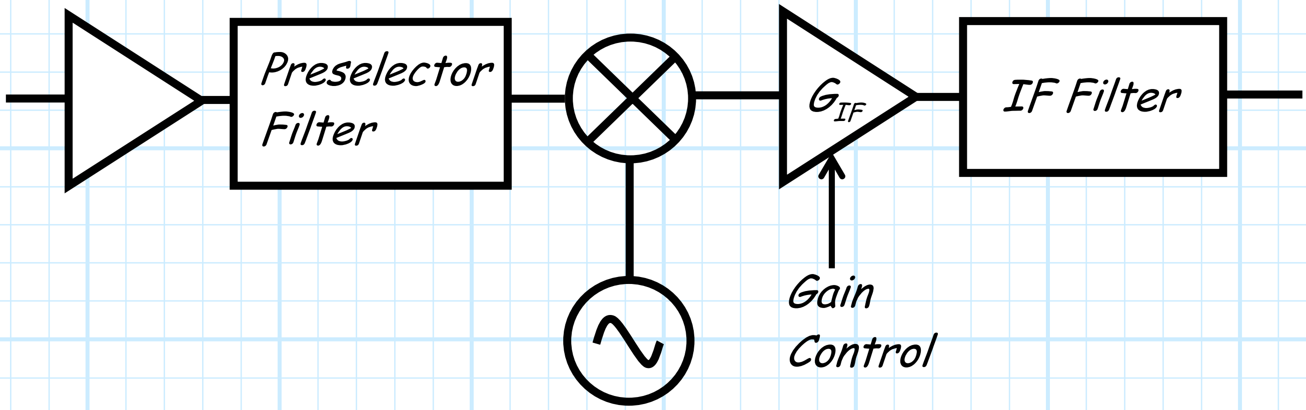
2. the gain reduces to a sufficiently **small** value ($G_{Rx} < G_{Rx}^{max}$) when the input signal power P_s^{in} is **large**.

Q: ***Change*** *the gain of the receiver, how can we possibly do* ***that?***

A: We can make the gain of the **IF** amplifier **adjustable**, thus making the overall receiver gain adjustable. This gain is automatically adjusted in response to the signal power, and we call this process **Automatic Gain Control** (AGC).

Automatic Gain Control

To implement **Automatic Gain Control** (AGC) we need to make the gain of the IF amplifier **adjustable**:

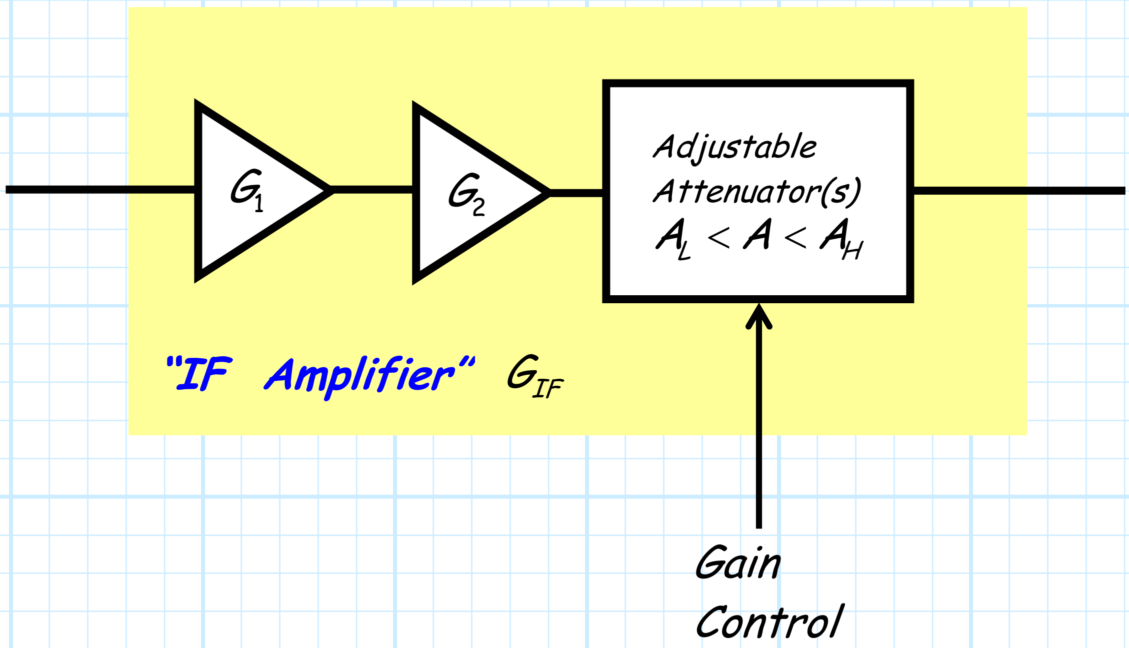


Q: ***Are** there such things as **adjustable gain** amplifiers?*

A: Yes and no.

Typically, voltage controlled amplifiers work **poorly**, have **limited** gain adjustment, or **both**.

Instead, receiver designers implement an adjustable gain amplifier using **one or more** fixed gain amplifiers and **one or more** variable attenuators (e.g., digital attenuators).



Two amplifiers are used in the design above, although one, two, three, or even four amplifiers are sometimes used.

The adjustable **attenuator** can likewise be implemented in a number of ways. Recall the attenuator can be either **digital** or **voltage controlled**. Likewise, the attenuator can be implemented using either **one** attenuator, or with **multiple** cascaded attenuator components.

However it is implemented, the **gain** of the overall "IF amplifier" is simply the **product** of the fixed amplifier gains, **divided** the total attenuation A. Thus, for the **example above**:

$$G_{IF} = \frac{G_1 G_2}{A} \qquad G_{IF}(dB) = G_1(dB) + G_2(dB) - A(dB)$$

Now, the key point here is that this gain is **adjustable**, since the attenuation can be varied from:

$$A_L < A < A_H$$

Thus, the "IF amplifier" gain can **vary** from:

$$G_{IF}^{L} < G_{IF} < G_{IF}^{H}$$

Where G_{IF}^{L} is the **lowest** possible "IF amplifier" gain:

$$G_{IF}^{L} = \frac{G_1 G_2}{A_H} \qquad\qquad G_{IF}(dB) = G_1(dB) + G_2(dB) - A_H(dB)$$

And G_{IF}^{H} is the **highest** possible "IF amplifier" gain:

$$G_{IF}^{H} = \frac{G_1 G_2}{A_L} \qquad\qquad G_{IF}(dB) = G_1(dB) + G_2(dB) - A_L(dB)$$

Note the **gain** is the **highest** when the **attenuation** is the **lowest**, and vice versa (this should make **perfect** sense to **you**!).

However, recall that the value of the **lowest attenuation** value is **not equal to one** (i.e., $A_L > 1$)! Instead A_L represents the **insertion loss** of the attenuators when in their minimum attenuation state. The **highest** attenuation value A_H must likewise reflect this insertion loss!

Recall also that the **total receiver gain** is the product of the gains of **all** the components in the receiver chain. For example:

$$G_{Rx} = G_{LNA}\, G_{preselector}\, G_{mixer}\, G_{IF}\, G_{IFfilter}$$

Note, however, that the only **adjustable** gain in this chain is the "**IF amplifier**" gain G_{IF}, thus the remainder of the receiver gain is **fixed**, and we can thus define this **fixed gain** G_{Rx}^{fixed} as:

$$G_{Rx}^{fixed} \doteq \frac{G_{Rx}}{G_{IF}}$$

Thus, G_{Rx}^{fixed} is simply the gain of the entire receiver, with the **exception** of the "IF amplifier".

Since the gain of the "**IF amplifier**" is adjustable, the gain of **entire receiver** is likewise adjustable, varying over:

$$G_{Rx}^{L} < G_{Rx} < G_{Rx}^{H}$$

where:

$$G_{Rx}^{L} = G_{Rx}^{fixed}\; G_{IF}^{L}$$

and:

$$G_{Rx}^{H} = G_{Rx}^{fixed}\; G_{IF}^{H}$$

Q: *So what should the values of G_{IF}^{L} and G_{IF}^{H}* ***be?*** *How will I know if my design produces a G_{IF}^{L} that is* ***sufficiently*** *low, or a G_{IF}^{H} that is* ***sufficiently*** *high?*

A: Let's think about the requirements of each of these **two** gain values.

1: G_{IF}^{H}

Remember, a receiver designer must design their "IF Amplifier" such that the **largest possible** receiver gain G_{Rx}^{H} **exceeds** the minimum gain requirement (i.e., $G_{Rx}^{H} > G_{Rx}^{min}$)—a requirement that is necessary when the receiver input signal is at its **smallest** (i.e., when $P_s^{in} = MDS$).

To accomplish this, we find that:

$$\begin{aligned} G_{Rx}^{H} &> G_{Rx}^{min} \\ G_{Rx}^{fixed}\, G_{IF}^{H} &> G_{Rx}^{min} \\ G_{IF}^{H} &> \frac{G_{Rx}^{min}}{G_{Rx}^{fixed}} \end{aligned}$$

Thus, since $G_{Rx}^{min} = P_D^{min} / MDS$ we can conclude that our "IF amplifier" **must be designed** such that its **highest possible** gain G_{IF}^{H} **exceeds**:

$$\boxed{G_{IF}^{H} > \frac{P_D^{min}}{G_{Rx}^{fixed}\; MDS}}$$

or

$$\boxed{G_{IF}^{H}(dB) > P_D^{min}(dBm) - G_{Rx}^{fixed}(dB) - MDS(dBm)}$$

2: G_{IF}^{L}

Additionally, a receiver designer must design their "IF Amplifier" such that the **smallest possible** receiver gain G_{IF}^{L} is **less** that the maximum gain requirement (i.e., $G_L < G_{max}$)—a requirement that is applicable when the receiver input signal is at its **largest** (i.e., when $P_{in} = P_{in}^{sat}$).

To accomplish this, we find that:

$$G_{Rx}^{L} < G_{Rx}^{max}$$

$$G_{Rx}^{fixed}\, G_{IF}^{L} < G_{Rx}^{max}$$

$$G_{IF}^{L} < \frac{G_{Rx}^{max}}{G_{Rx}^{fixed}}$$

Thus, since $G_{Rx}^{max} = P_{D}^{max} / P_{in}^{sat}$ we can conclude that our "IF amplifier" **must be designed** such that its **lowest possible** gain G_{IF}^{L} is below:

$$G_{IF}^{L} < \frac{P_{D}^{max}}{G_{Rx}^{fixed}\; P_{in}^{sat}}$$

or

$$G_{IF}^{L}\,(dB) < P_{D}^{max}\,(dBm) - G_{Rx}^{fixed}\,(dB) - P_{in}^{sat}\,(dBm)$$

Q: *I'm still a bit confused. Now what is the* ***difference*** *between $G_{Rx}^{min}, G_{Rx}^{max}$ and G_{Rx}^{L}, G_{Rx}^{H}?*

A: The values G_{Rx}^{min} and G_{Rx}^{max} are in fact **requirements** that are placed on the receiver designer.

* In other words, there **must** be some IF gain setting that will result in a receiver gain G_{Rx} **greater** than G_{Rx}^{min} (a requirement for detecting $P_s^{in} = MDS$), and there **must** be some IF gain setting that will result in a receiver gain G_{Rx} **less** than G_{Rx}^{max} (a requirement for detecting $P_s^{in} = P_{in}^{sat}$)

* In contrast, the values G_{IF}^{L} and G_{IF}^{H} are the **actual** minimum and maximum values of the receiver gain. They state the performance of a **specific receiver design**.

Properly designed, we will find that $G_{Rx}^{H} > G_{Rx}^{min}$, and $G_{Rx}^{L} < G_{Rx}^{max}$. However, this is true **only** if we have properly design our "IF Amplifier"!

AGC Dynamic Range

Now let's consider the **dynamic range** of our **AGC**, defined as:

$$AGC \text{ Dynamic Range} = \frac{G_{Rx}^{H}}{G_{Rx}^{L}} = \frac{G_{Rx}^{fixed}\ G_{IF}^{H}}{G_{Rx}^{fixed}\ G_{IF}^{L}} = \frac{G_{IF}^{H}}{G_{IF}^{L}}$$

Therefore:

$$\begin{aligned} AGC \text{ Dynamic Range}(dB) &= G_{Rx}^{H}(dB) - G_{Rx}^{L}(dB) \\ &= G_{IF}^{H}(dB) - G_{IF}^{L}(dB) \end{aligned}$$

Q: *Just how much dynamic range do we **need**?*

A: Since for a **properly designed** receiver, $G_{Rx}^{H} > G_{Rx}^{min}$ and $G_{Rx}^{L} < G_{Rx}^{max}$, we can conclude that for a **properly designed** receiver:

$$AGC \text{ Dynamic Range} = \frac{G_{Rx}^{H}}{G_{Rx}^{L}} > \frac{G_{Rx}^{min}}{G_{Rx}^{max}}$$

Meaning that, since $G_{Rx}^{min} = P_D^{min} / MDS$ and $G_{Rx}^{max} = P_D^{max} / P_{in}^{sat}$:

$$\begin{aligned} AGC \text{ Dynamic Range} &> \frac{P_D^{min}}{MDS} \frac{P_{in}^{sat}}{P_D^{max}} \\ &> \frac{P_D^{min}}{P_D^{max}} \frac{P_{in}^{sat}}{MDS} \\ &> \frac{TDR}{IDR} \end{aligned}$$

Thus, we conclude that for a **properly designed** receiver:

$$AGC \text{ Dynamic Range} > \frac{TDR}{IDR}$$

or

$$AGC \text{ Dynamic Range}(dB) > TDR(dB) - IDR(dB)$$

From the standpoint of "IF Amplifier" **design**, this result has a **specific** meaning.

Since the gain of the **amplifiers** used in the "IF Amplifier" design is fixed (e.g., G_1 G_2), the **ratio** of the largest and smallest IF amplifier gain is simply the ratio of the largest and smallest **attenuator** values:

$$AGC \text{ Dynamic Range} = \frac{G_{IF}^H}{G_{IF}^L} = \frac{G_1 G_2}{A_L} \frac{A_H}{G_1 G_2} = \frac{A_H}{A_L}$$

or

$$AGC \text{ Dynamic Range}(dB) = A_H(dB) - A_L(dB)$$

Thus, we can conclude that the variable attenuator(s) in an "IF amplifier" **must** be selected such that the **range of attenuation**, from A_H to A_L satisfies:

$$\frac{A_H}{A_L} > \frac{TDR}{IDR}$$

or

$$A_H(dB) - A_L(dB) > TDR(dB) - IDR(dB)$$

Note this is a necessary requirement for proper receiver operation, but it is not a sufficient one!

In other words, the expression above provides only **one** "IF Amplifier" design equation. We must **also** select the gains of the **amplifiers** in the "IF Amplifier" such that:

$$G_{IF}^{H} = \frac{G_1 G_2}{A_L} > \frac{G_{Rx}^{min}}{G_{Rx}^{fixed}}$$

where we recall that G_{Rx}^{fixed} represents the gain of all the receiver components, **except** those components comprising the "IF Amplifier".

AGC Implementation

So we now know that the AGC **adapts** to signal power. If the signal power is **small**, the receiver gain is **increased**; if the signal power is **large**, the receiver gain is **decreased**.

Q: *But, **what** actually is changing this gain; **how** is this gain controlled?*

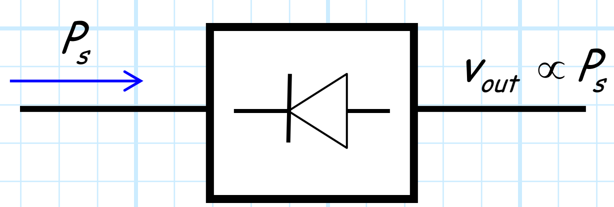
A: Look at the name: **Automatic** Gain Control → The gain is controlled **automatically**!

In engineering terms, this means that the AGC is implemented using a **feedback loop**!

To implement this loop, we need **two** microwave components:

1. Amplitude Detector

An amplitude detector is a device that produces a **voltage output** that is proportional to the time-averaged **power** of the **incident** microwave signal.



2. Directional Coupler

To perform AGC, we need a **directional coupler** to couple out a **small** amount of power from the IF chain.

Q: *A **small** amount of power? Why not couple out a **large** amount of power?*

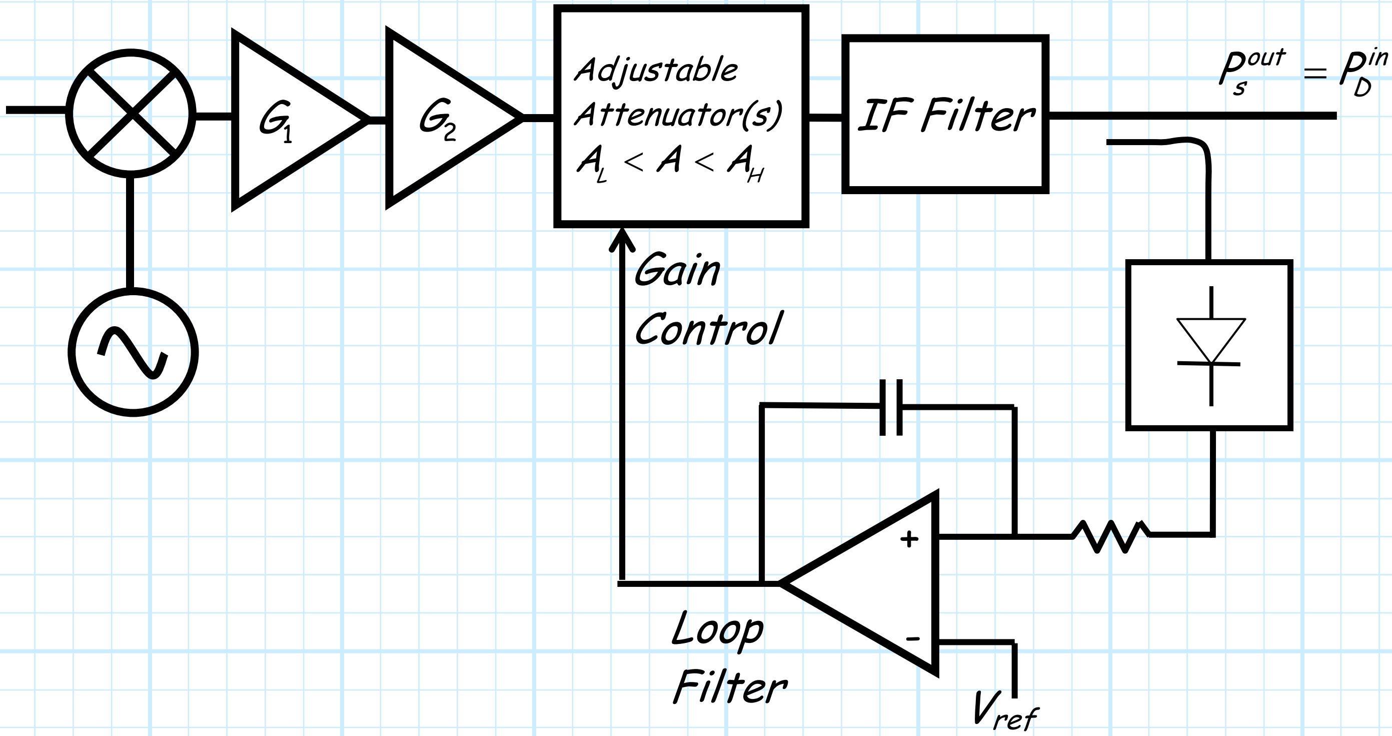
A: Remember, we are trying to get our signal energy to the detector/demodulator at the end of the receiver. Any amount that we couple out (to use for AGC) results in some **loss** of signal power at the demodulator!

Thus, we **couple** out a small amount of power, then we determine the **value** of this power using an amplitude detector.

* If this value is too **small**, then we turn **up** the receiver gain (i.e., **reduce IF attenuation**).

* If the detected signal power is too **large**, we turn **down** the receiver gain (i.e., **increase IF attenuation**).

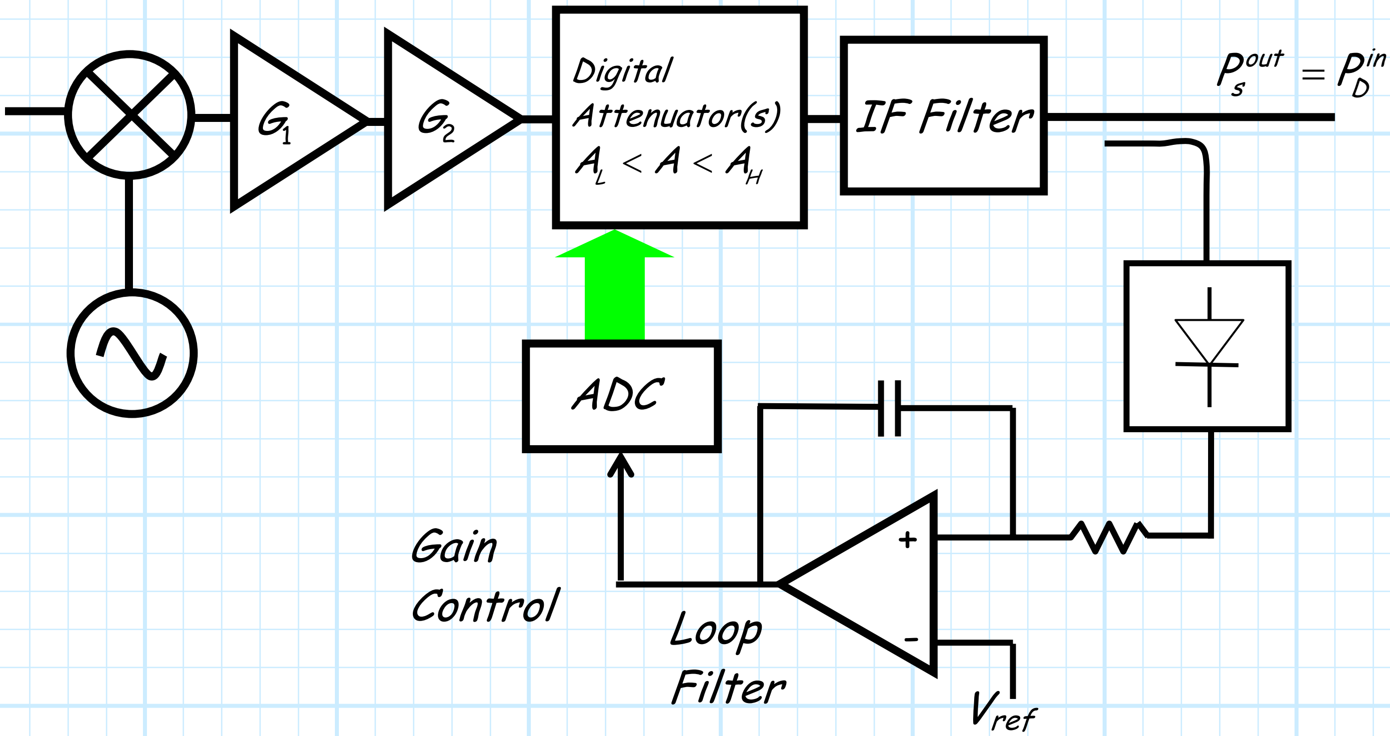
This is done automatically by "closing the loop"—we connect the output of the amplitude detector to the attenuator control port through a suitable **loop filter**.



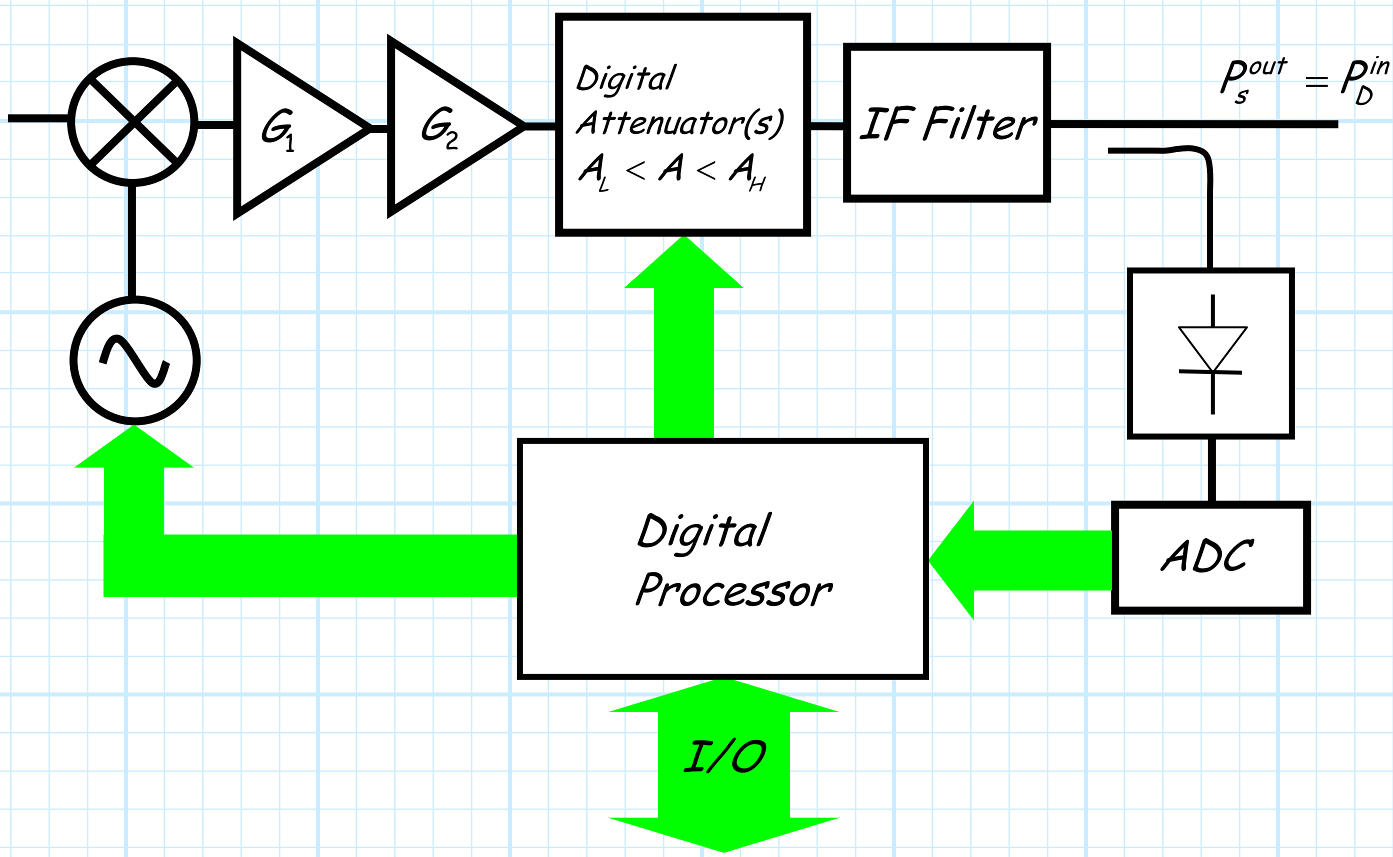
If our loop filter has been properly designed, the result will be a **stable feedback system**!

Note the loop shown above provides an **analog** (i.e., continuous voltage) control signal. Thus, this design would require **voltage controlled attenuators** to implement.

If we use **digital attenuators**, the loop **could** be implemented using a **Analog to Digital Converte**r (ADC):



However, we often find that digital attenuators are directly controlled by the **digital processor** (i.e., computer) that controls all receiver functions (e.g., tuning, AGC, I/O, etc.).



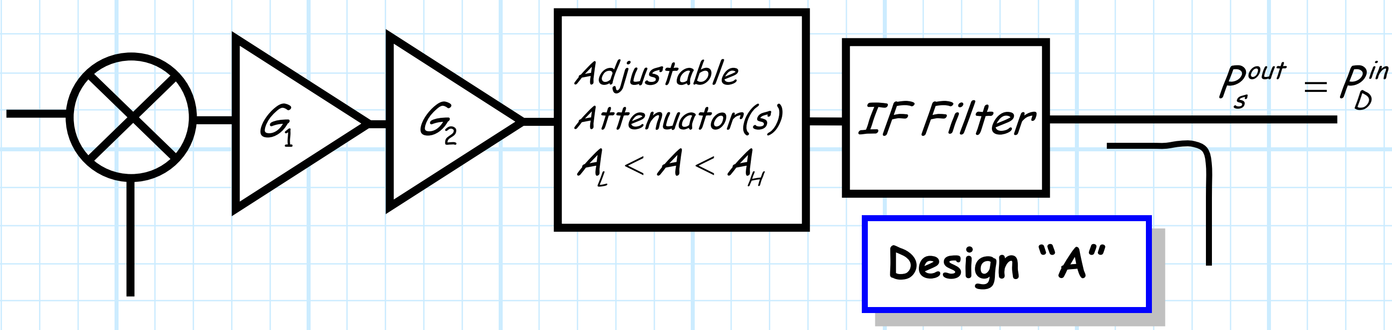
For this case, we have a **digital control** problem, and the **control loop** is implemented in the processor **software**. Make sure all your **poles** are **inside** the unit circle!

Q: *Does it make any difference how we **arrange** the IF chain? Does the **order** of the devices matter?*

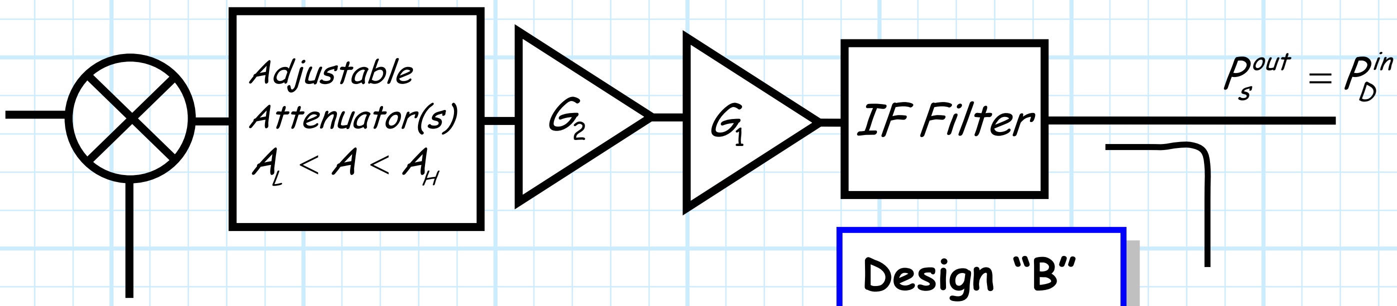
A: Yes **and** no!

Obviously, the coupler must always be placed **after** the attenuators and the fixed amplifiers (do **you** see why??).

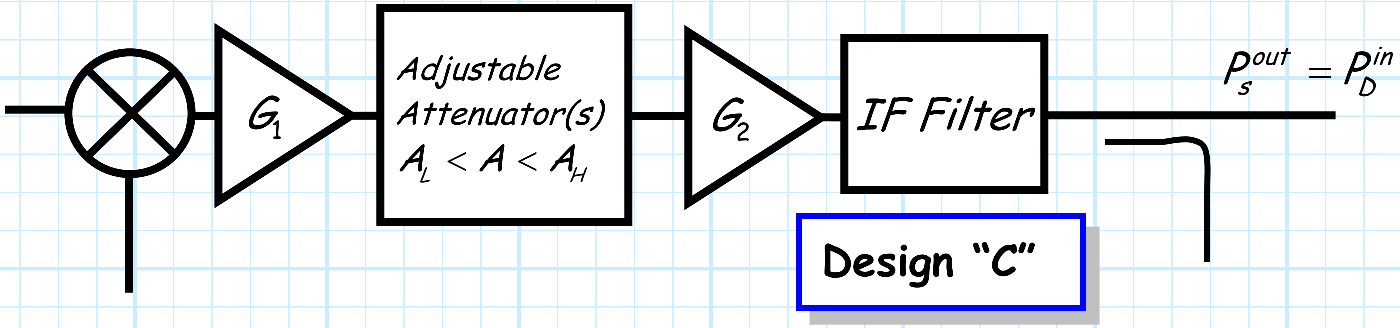
But the **gain** of the IF chain is unaffected by the arrangement of its components! For example, with respect to **gain**, there is no difference between this design:



And this one:



Or this one:



Q: *So you're saying these three designs are all the **same**?*

A: **Just** with respect to **gain**! With respect to receiver sensitivity and compression point, these designs are all **quite different**!

Q: *Say, that raises an interesting question. The attenuator(s) are **adjustable**, so what **value** of attenuation (A) should we use when determining receiver **noise figure** and **saturation point**? Do we need to calculate these parameters for **both** A_L and A_H, or should we take some **average** value?*

A: **THINK** about this!

The receiver noise figure (in part) determines the receiver **sensitivity**—we desire a **small** noise figure so we can adequately demodulate the smallest of input signals.

Now let **me** ask **YOU** a **question:** what will the attenuator **value** be set to when we seek to detect the **smallest** of input signals?

A: $A =$

When we wish to detect the **smallest** of signals, we use the **largest** of receiver gains—the **attenuation** should be set to $A = A_L$! Therefore:

We compute the receiver **noise figure** (and thus receiver sensitivity) using the value $A = A_L$.

Conversely, we desire a receiver compression point that is as large as possible so we can adequately demodulate the **largest** of input signals.

My Question: What will the attenuator value be set to when we seek to detect the **largest** of input signals?

A: $A =$

When we wish to detect the **largest** of signals, we use the **smallest** of receiver gains—the attenuation should be set to $A = A_H$! Therefore:

We compute the receiver **compression point** using the value $A = A_H$.

Q: *But, the receiver **noise figure** I calculate with $A = A_H$, is **terrible**. Shouldn't we use this "worse case" value?*

A: **Nope!** With all the attenuation "kicked in", the receiver noise figure will indeed be **awful** (try it!). But remember, this case occurs **only** if the input signal power is **very large**.

As a result, the **input** SNR is likewise **very** large (e.g., 100 dB or more!). Thus, although the receiver (with **maximum** attenuation) does degrade the SNR a large amount, it still reaches the demodulator with **plenty** of SNR—typically much, much larger than SNR_D^{min}.

Q: So, **now** that we know how to properly calculate sensitivity and noise figure, I'll again ask the question: how does the **arrangement** of the devices matter? Which of the three designs lead to the **best compression point**? the **best sensitivity**?

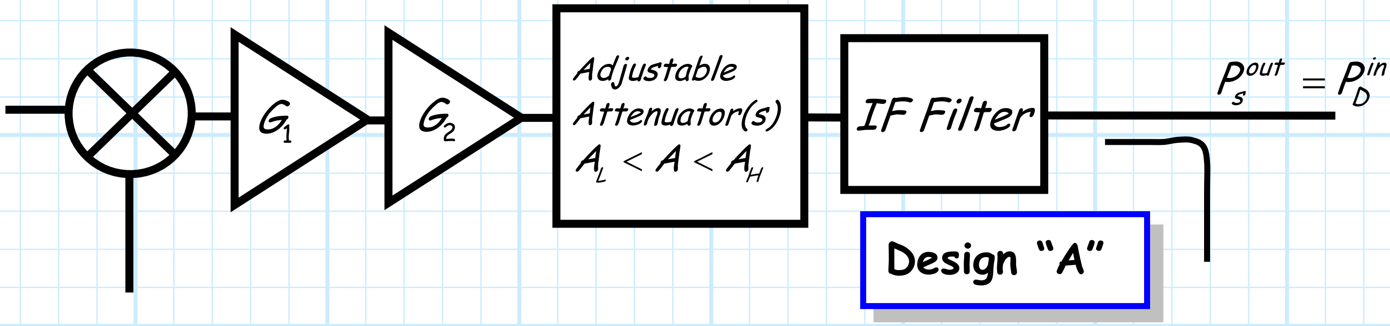
A: Let's discuss these **one at a time**!

1. Receiver Sensitivity

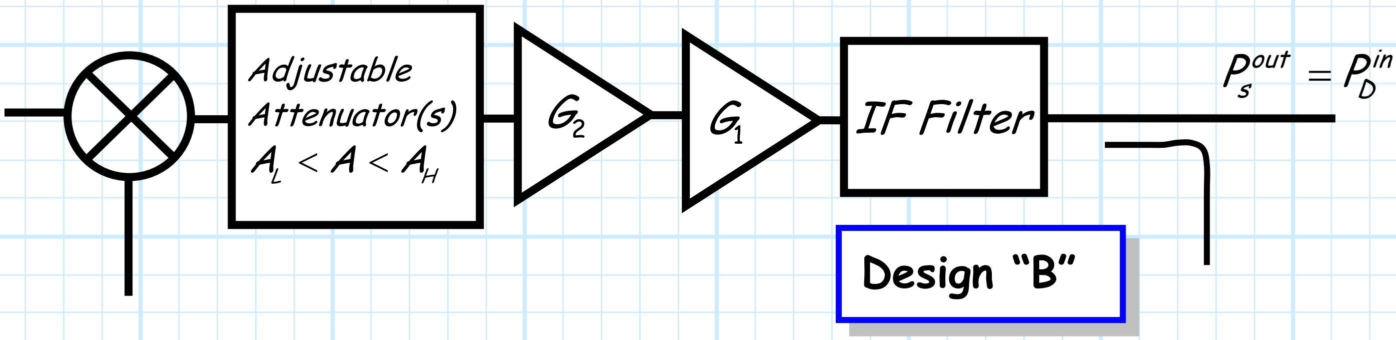
Recall that we improve receiver sensitivity by decreasing the noise figure, and our noise figure improves as we move higher gain devices toward the beginning of the receiver, and lower gain devices toward the end.

Q: *This would suggest that **Design "A"** is best??*

A: That's is true, although **Design "C"** would likely be nearly as good (e.g., with 0.1 dB or less).



Design "B" is really the only IF design that **might** significantly degrade the receiver noise figure. Generally speaking, following one lossy device (the mixer) with another (the insertion loss of the attenuators) will cause **some** degradation in receiver noise figure.



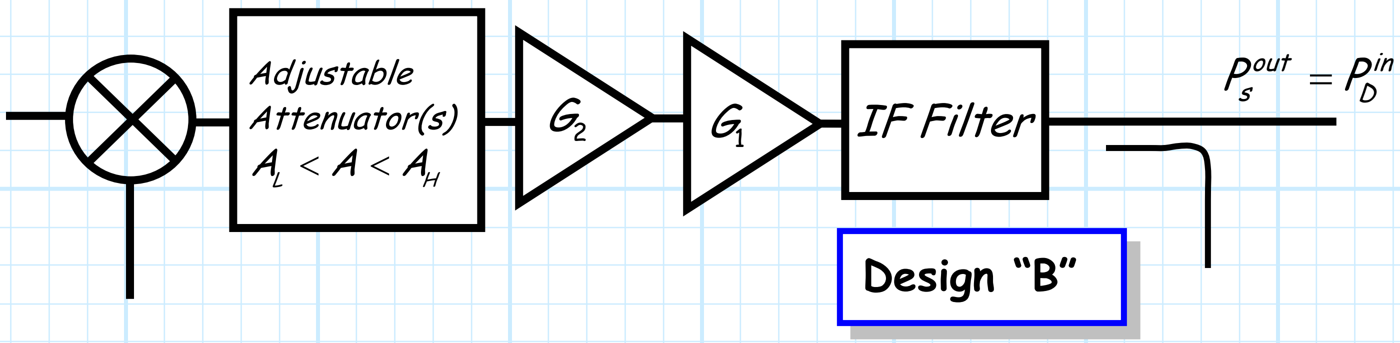
How much degradation is largely dependent on the quality of your **LNA**! However, it is often a **good idea** to follow your mixer with an IF amplifier possessing a moderately small noise figure (e.g., designs **"A"** and **"C"**).

2. Receiver Sensitivity

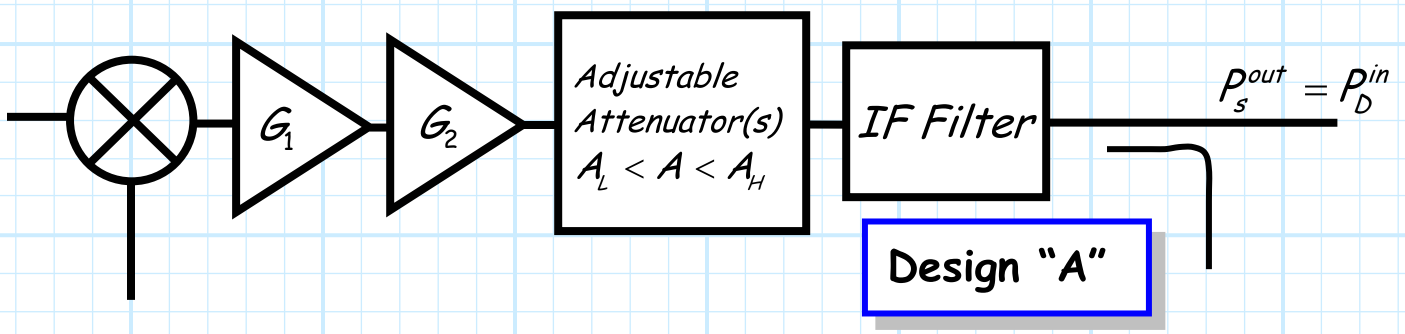
Recall that we can often improve the receiver compression point by moving high gain/high compression point devices toward the **end** of the receiver, and low gain devices toward the **beginning**.

Q: *Hey! When all the attenuation is "kicked in" (i.e., $A = A_H$) the attenuator is a **fantastically** low gain device. Doesn't that mean design "B" is optimal for maximizing the receiver compression point??*

A: Certainly, design **"B"** will insure that neither of the IF amplifiers will saturate—**nothing** that appears **after** the attenuators will **ever** saturate!



Conversely, the IF amps in designs **"A"** and **"C"** **might** saturate. The **second** amplifier in **design "A"** is particularly at risk.



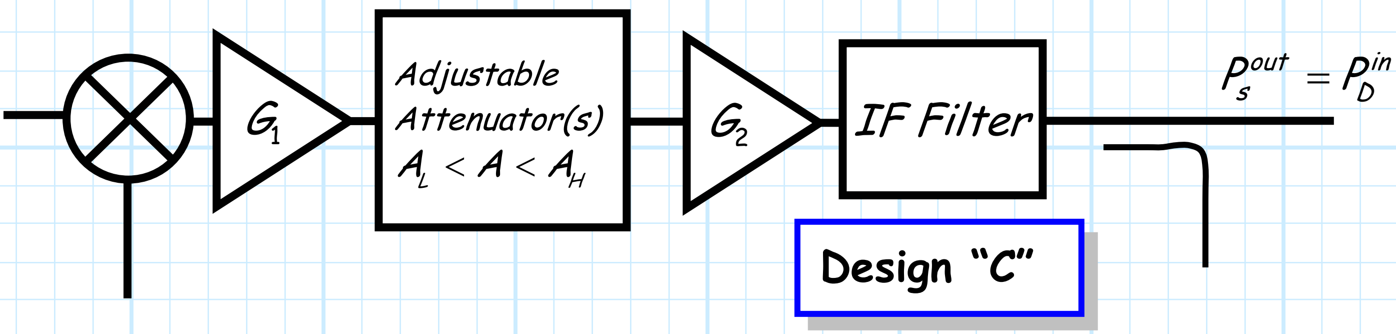
Q: *What do you mean **"might"** saturate—**will** it or **won't** it?*

A: It all **depends** on your entire receiver design! You just have to do the **complete** compression calculation and find out.

But remember, in a **properly** designed receiver, the device that determines the receiver compression point (i.e., device that saturates first) is **almost always** the LNA or the mixer.

→ If one of your **IF devices** is saturating, then you can almost always **redesign** to improve your receiver compression point!

Q: *It appears to me then that design* ***"C"*** *is somewhat optimal; that* ***distributing*** *the IF gain along the IF chain will provide good noise figure* ***and*** *compression point. Is my analysis correct?*



A: Yes—and there is **one more** reason why distributing the gain along the IF chain is optimal!

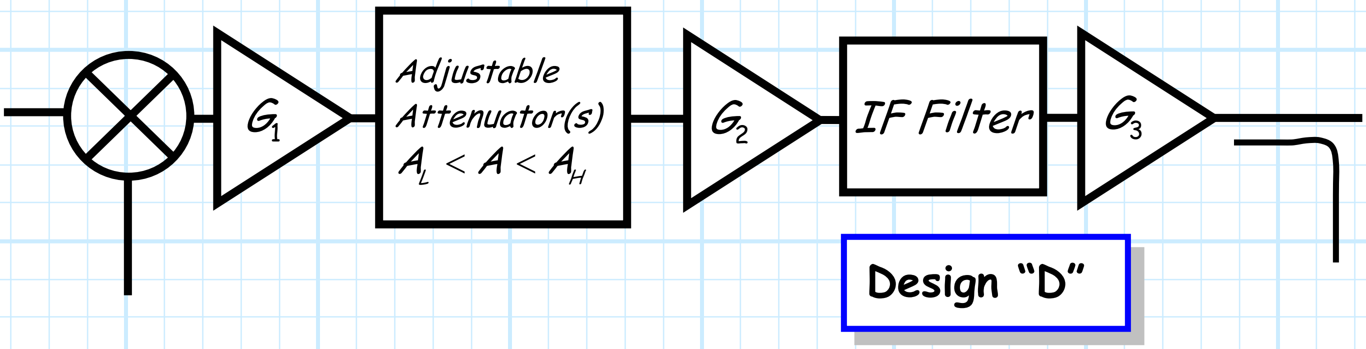
The reason is: **isolation.**

Recall that an amplifier likewise makes a **great isolator**. This is important because the performance of the attenuator and filter depend on having **well-matched** sources and loads!

In addition, recall that the **mixer** ports are **poorly matched**. Thus, it is (again) a **good idea** to place an IF amplifier just after the mixer.

In fact, it is a good idea to isolate the **filter** from the attenuator as well. This of course is precisely what is done by design **"C"**.

In fact, designers often use several **low-gain** stages and **distribute** them throughout the IF chain:



The big disadvantage to this strategy is **cost and complexity**.