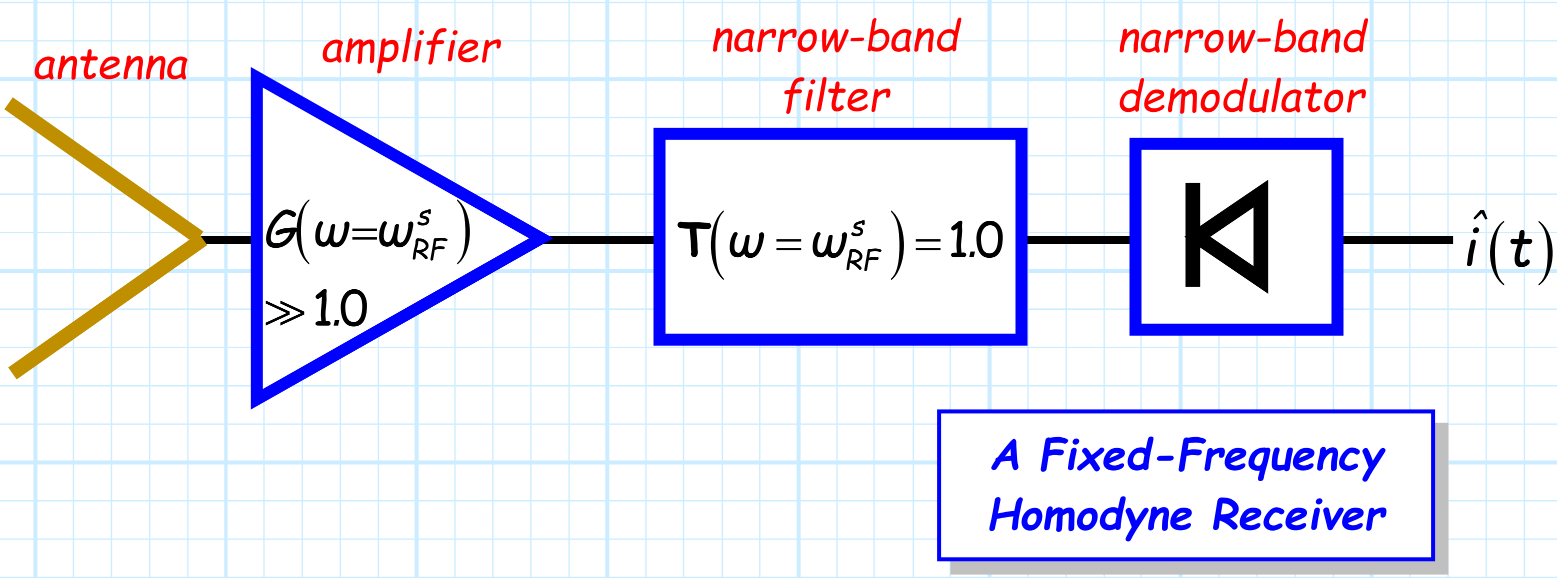
# The Super-Heterodyne Receiver

Say we **always** want to "tune" to **just one** particular signal frequency (e.g., our **favorite** radio station).

Say we denote this **desired signal** frequency as $\omega_{RF}^{s}$

Note that—since we only ever wish to demodulate this one specific signal—the **homodyne** receiver would be an **excellent** design (no tuning required!).



# Why this works well—for just one freq.

Note for this fixed-frequency receiver, **neither** the amplifier **nor** the demodulator need be **wideband**.

Instead, their performance can be optimized for just **one**—and **only one**—signal frequency (i.e., $\omega_{RF}^{s}$).

Moreover, the band-pass filter has **no need to be tuned**!

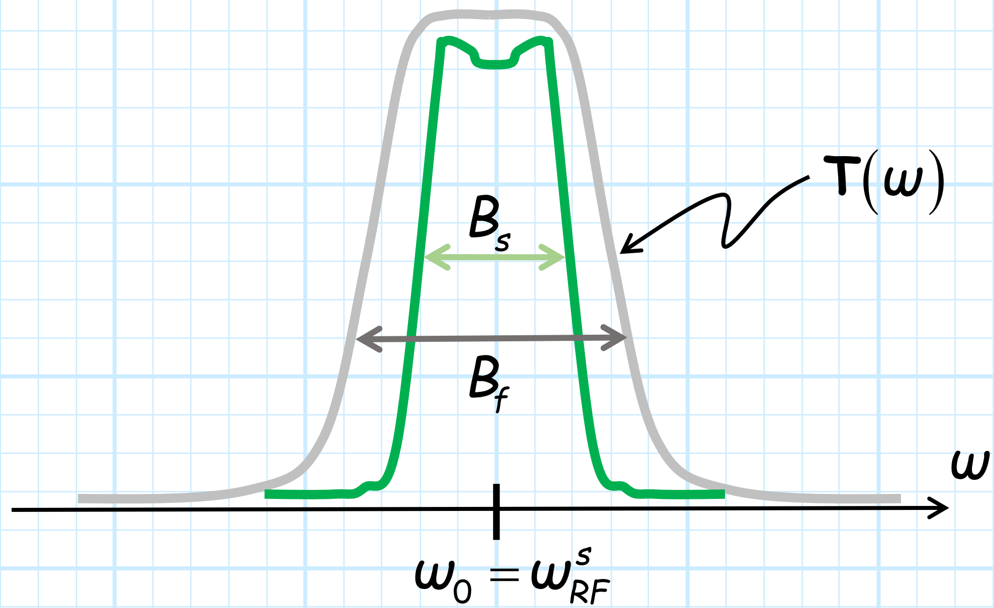
Instead, the **center frequency** $\omega_0$ of the filter must simply be equal to the **desired signal** frequency $\omega_{RF}^{s}$:

$$\omega_0 = \omega_{RF}^{s}$$

And, the **bandwidth** of the filter $\Delta f = B_f$ should be approximately equal (i.e., slightly larger) to the **bandwidth** $B_s$ of our **desired signal**:

$$B_f \cong B_s$$

# I wish you would pay attention




**Q:** *Do we **really** need to make the filter bandwidth **so narrow**?*

*Isn't it **sufficient** to just make the filter bandwidth $B_f$ **wide enough** for the **desired** signal spectrum to **pass through**?*

**A:** Remember:

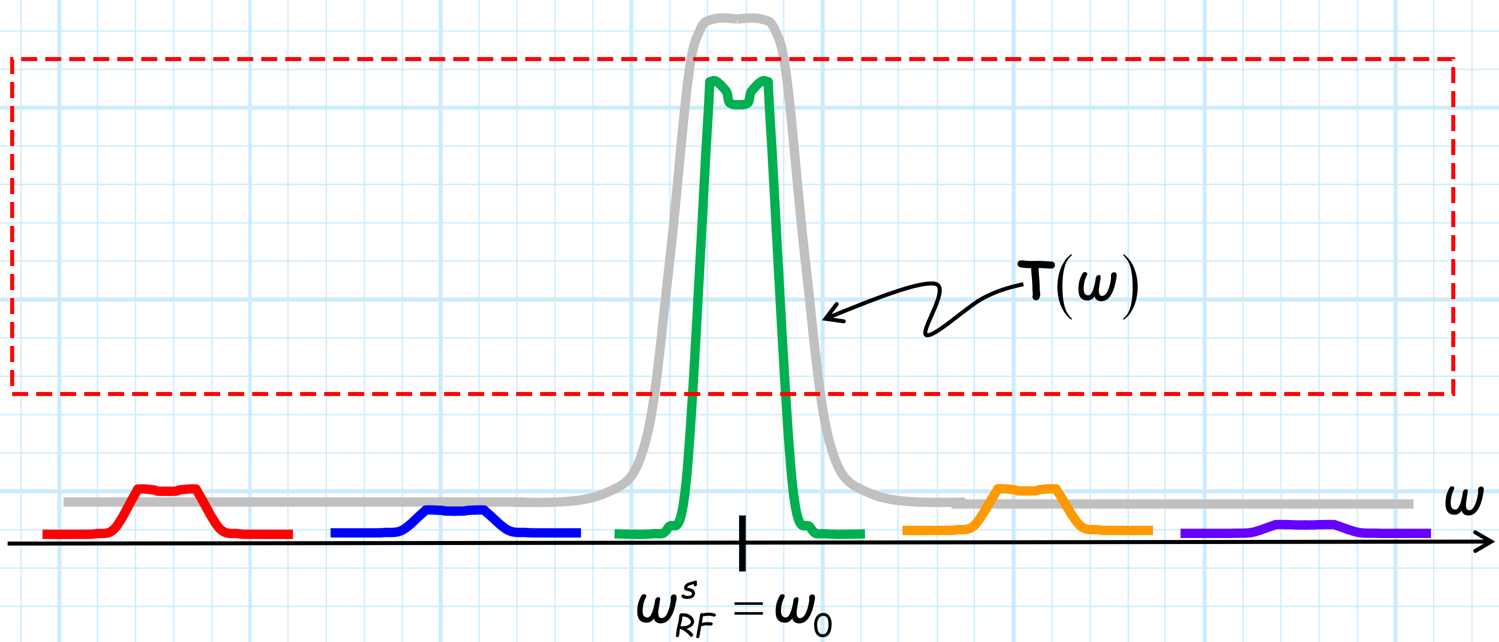
*"The signal to be demodulated must be the **ONLY** signal at the input to the demodulator!"*

# Wide enough—BUT NO WIDER!

The bandpass filter **must** let the **entire spectrum** of the desired signal to pass through—but **ONLY** the desired signal should pass through!

Thus, the bandpass filter should have a bandwidth **wide enough** to accommodate the desired signal—**BUT NO WIDER**!

The job of the bandpass filter is to **attenuate all signals** except the lone **desired one**—the job of the filter is to provide **receiver selectivity!**



# A Channelized Receiver

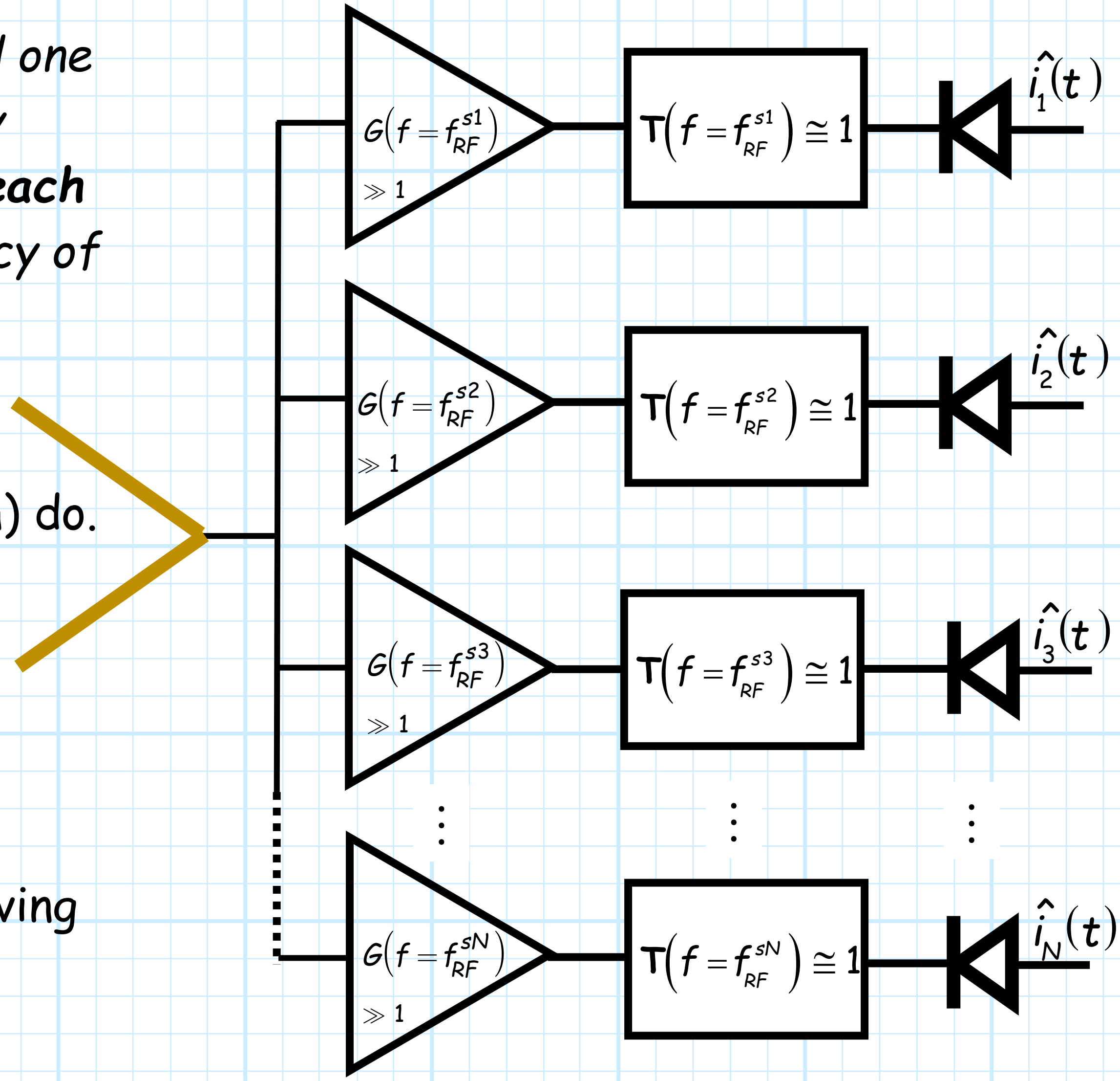
**Q:** *Couldn't we just build one of these fixed-frequency homodyne receivers for **each** and **every** signal frequency of interest?*

**A:** Absolutely! And we sometimes (but **not** often) do.

We call these receivers **channelized receivers**.

But, there are several important **problems** involving channelized receivers.

→ They're big, power hungry, and **expensive**!




*A Channelized Receiver*

# A Channelized FM Receiver

For **example**, consider a design for a channelized FM radio.

The FM band has a **bandwidth** of 108-88 = 20 MHz, and a channel spacing of 200 kHz.

By Mario Gervais (Own work) [CC-BY-SA-3.0 (http://creativecommons.org/licenses/by-sa/3.0)], via Wikimedia Commons

Thus we find that the **number** of FM **channels** (i.e., the number of possible FM radio stations) is:

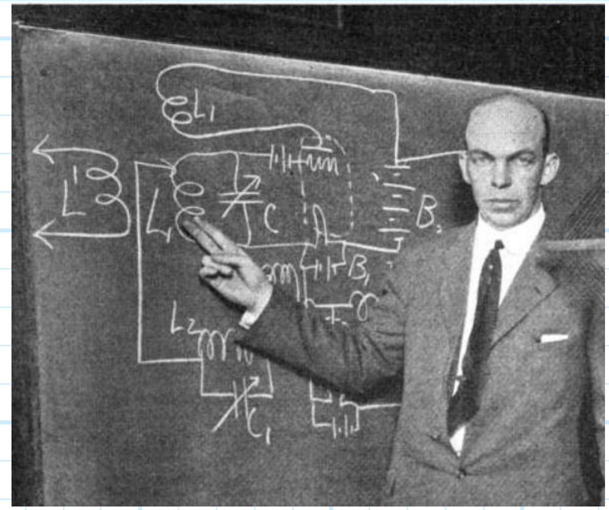
$$\frac{20\ MHz}{200\ kHz} = 100 \text{ channels !!!}$$

**Thus, a channelized FM radio would require 100 homodyne receivers!**

# Edwin Howard Armstrong: need I say more?

**Q:** *Yikes! Aren't there **any** good receiver designs!?!*

**A:** Yes, there is a **great** receiver solution, one developed more than 80 years ago by (surprise!)—**Edwin Howard Armstrong**!

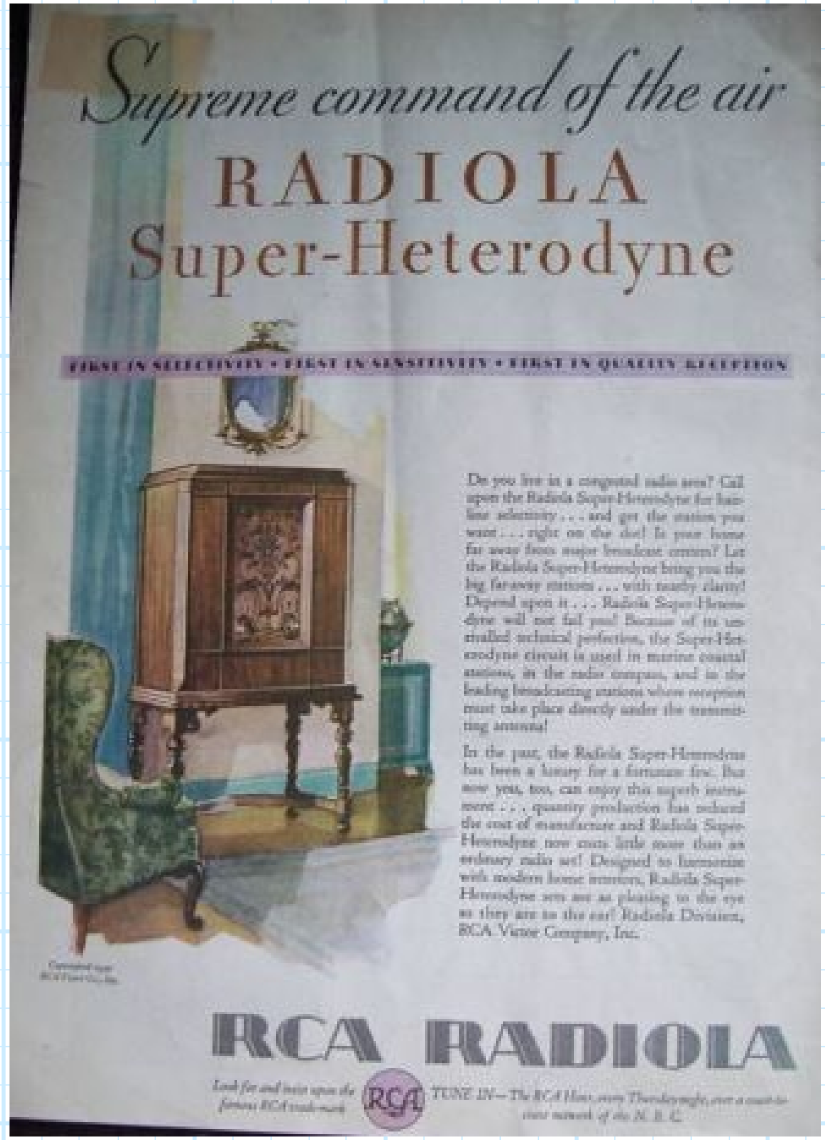


In fact, is was such a good solution that it is **still** the **predominant** receiver architecture used today.

Armstrong's approach was both **simple** and **brilliant**:

**Instead** of changing (tuning) the receiver hardware to align with the **desired signal**, we should change the **desired signal** frequency to align with the receiver **hardware**!

# The Super-Heterodyne




**Q:** *Change the signal **frequency**?*

*How can we possibly do **that**?*

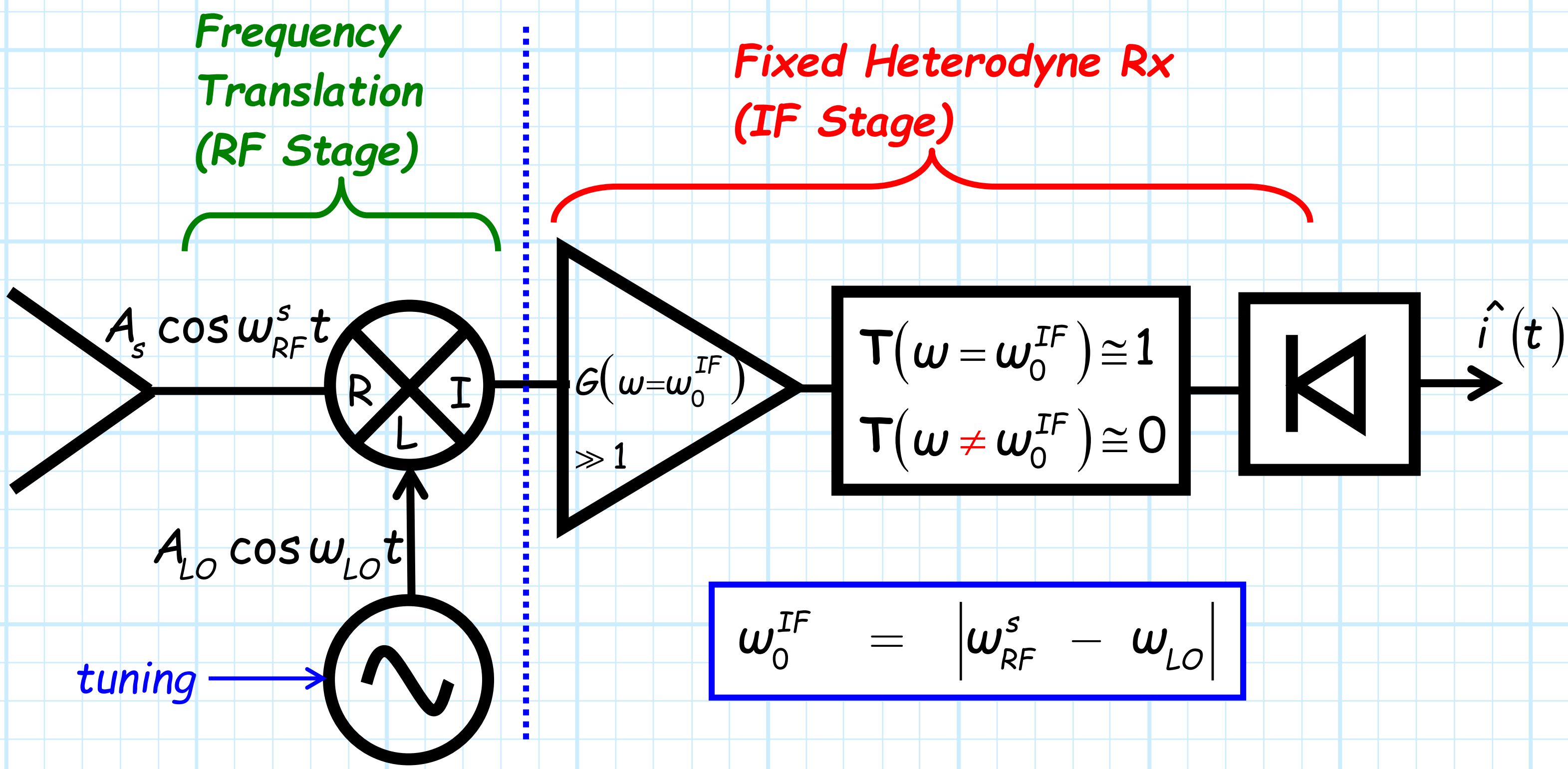
**A:** We **know** how to do this!

We **mix** the signal with a **Local Oscillator**!

We call this design the **Super-Heterodyne Receiver**!

# A super-simple super-het

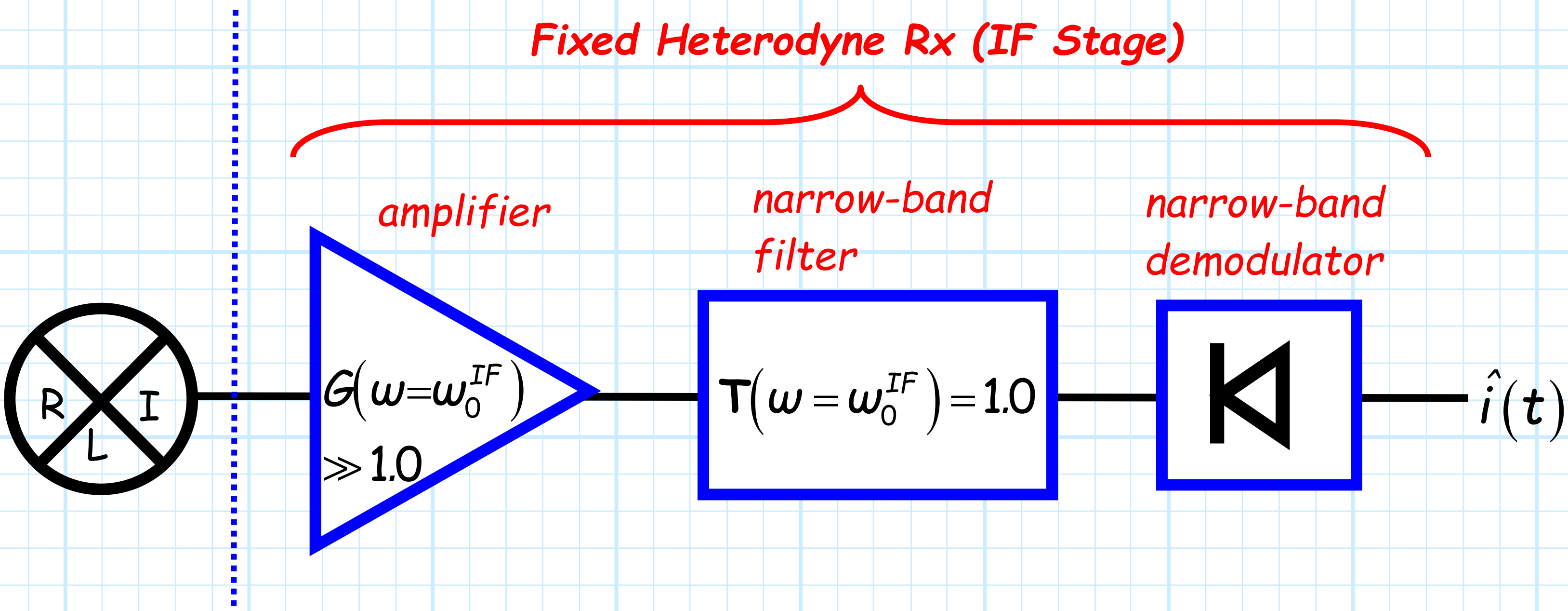
A super-heterodyne receiver can be viewed as simply as a **fixed frequency homodyne** receiver, proceeded by a **frequency translation** (i.e., down-conversion) stage.




A Simple Super-Het Receiver Design

# Selecting the right IF is crucial, critical, and really, really important

The **fixed** homodyne receiver is known as the **IF stage**.




The **fixed-frequency** $\omega_0^{IF}$ for which this homodyne receiver is designed (and **optimized**!) is called the **Intermediate Frequency** (IF).

# Selecting the right IF is crucial, critical, and really, really important

Note well that $\omega_0^{IF}$ (the **Intermediate Frequency**) is the **center-frequency** of the narrow-band filter!!!!!!!

Thus, the **only** sinusoids that will reach the demodulator are sinusoids oscillating **precisely** at a frequency of $\omega_0^{IF}$ !!!!!!!

**Q:** *So what is the **value** of this Intermediate Frequency $f_0^{IF}$ ??*

*How does a receiver design engineer **choose** this value?*

**A:** **Selecting** the "IF frequency" $f_0^{IF}$ value is perhaps the **most important** choice that a "super-het" receiver designer will make.

# The Intermediate Frequency should be low

The value of $\omega_0^{IF}$ has **many** important ramifications, both in terms of **performance** and **cost**.

We will discuss most of these ramifications **later**, but right now let's simply point out that the IF should be selected such that **both**:

**a)** the **cost**, and

**b)** performance

of the (IF) **amplifier**, (IF) **filter**, and detector/**demodulator** are **good**.

**Generally** speaking, as we make Intermediate Frequency $\omega_0^{IF}$ **lower**:

**a)** the cost of IF components goes **down**, and

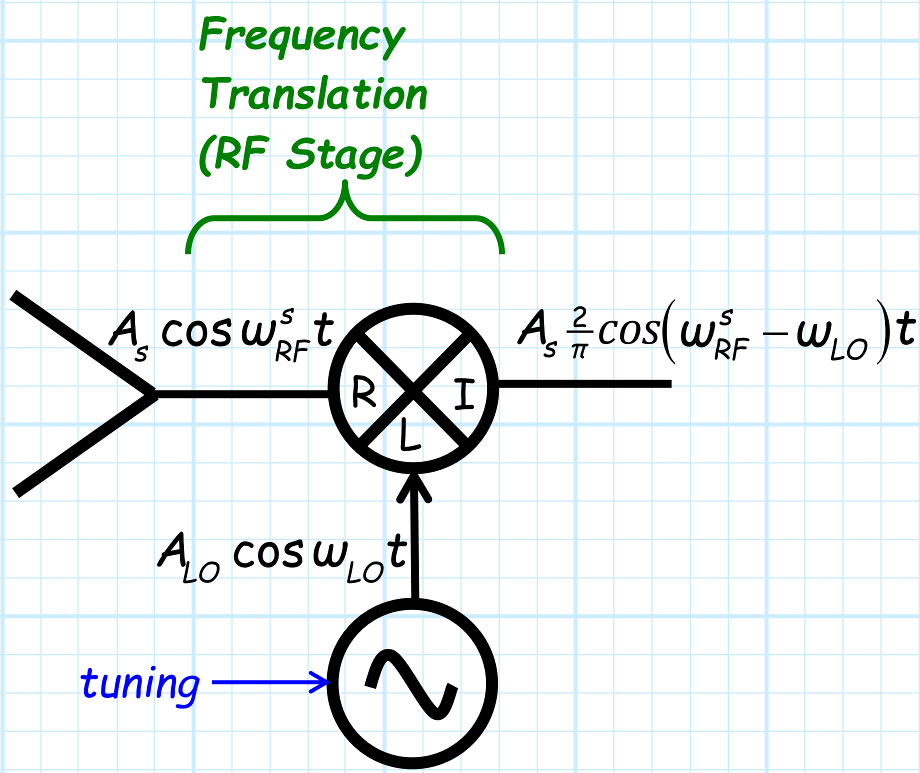
**b)** their performance **increases**.

→ These are both **good things**!

# Thus, we need to down-convert

As a result, the IF frequency $\omega_0^{IF}$ is **typically** (but **not** always!) selected such that it is much **less** (perhaps an order of magnitude or more) than the **RF signal** frequencies we are attempting to demodulate.

Therefore, we generally use the mixer/LO to **down-convert** the signal frequency from its relatively **high RF** frequency to a relatively **low IF** frequency.




→ We are thus interested in the **ideal** switched mixer term—the one that creates a signal at the **IF port** of frequency $\left|\omega_{RF}^s - \omega_{LO}\right|$.

# Tune the LO to satisfy this equation

To **down-convert** the **desired RF signal** (at frequency $f_{RF}^{s}$), to the **IF filter center frequency** (at $f_0^{IF}$), the LO frequency must be **tuned** so that this equation is **satisfied**:

$$\boxed{\left|f_{RF}^{s} - f_{LO}\right| = f_0^{IF}}$$

For **example**, say there exits radio signals (i.e., radio stations) at 95 *MHz*, 100 *MHz*, and 103 *MHz*.

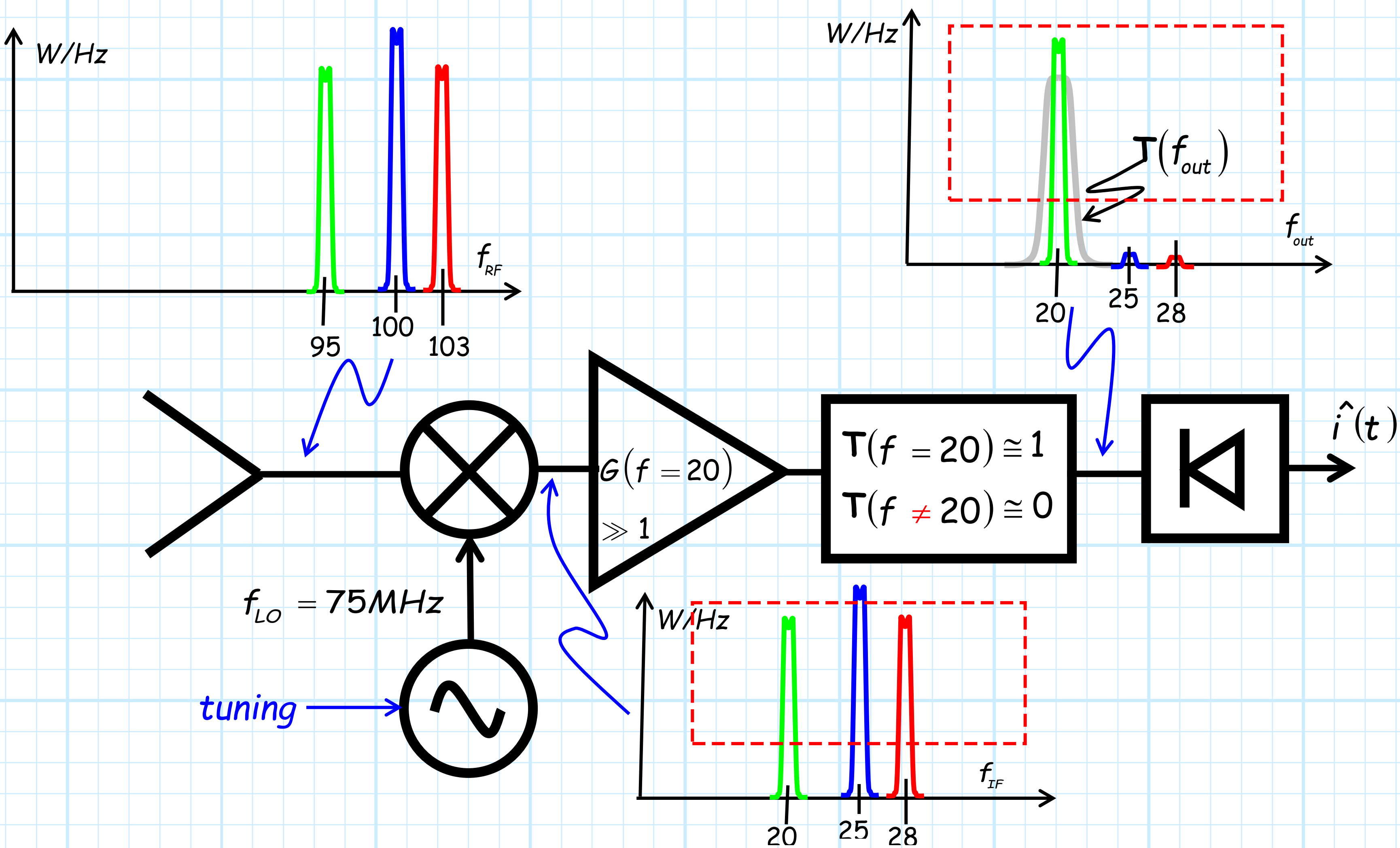
Likewise, say that the **IF center frequency** selected by the receiver design engineer is:

$$f_0^{IF} = 20\ MHz\ .$$

# This example illustrated

We can tune to the station at **95 *MHz*** by setting the Local Oscillator to:

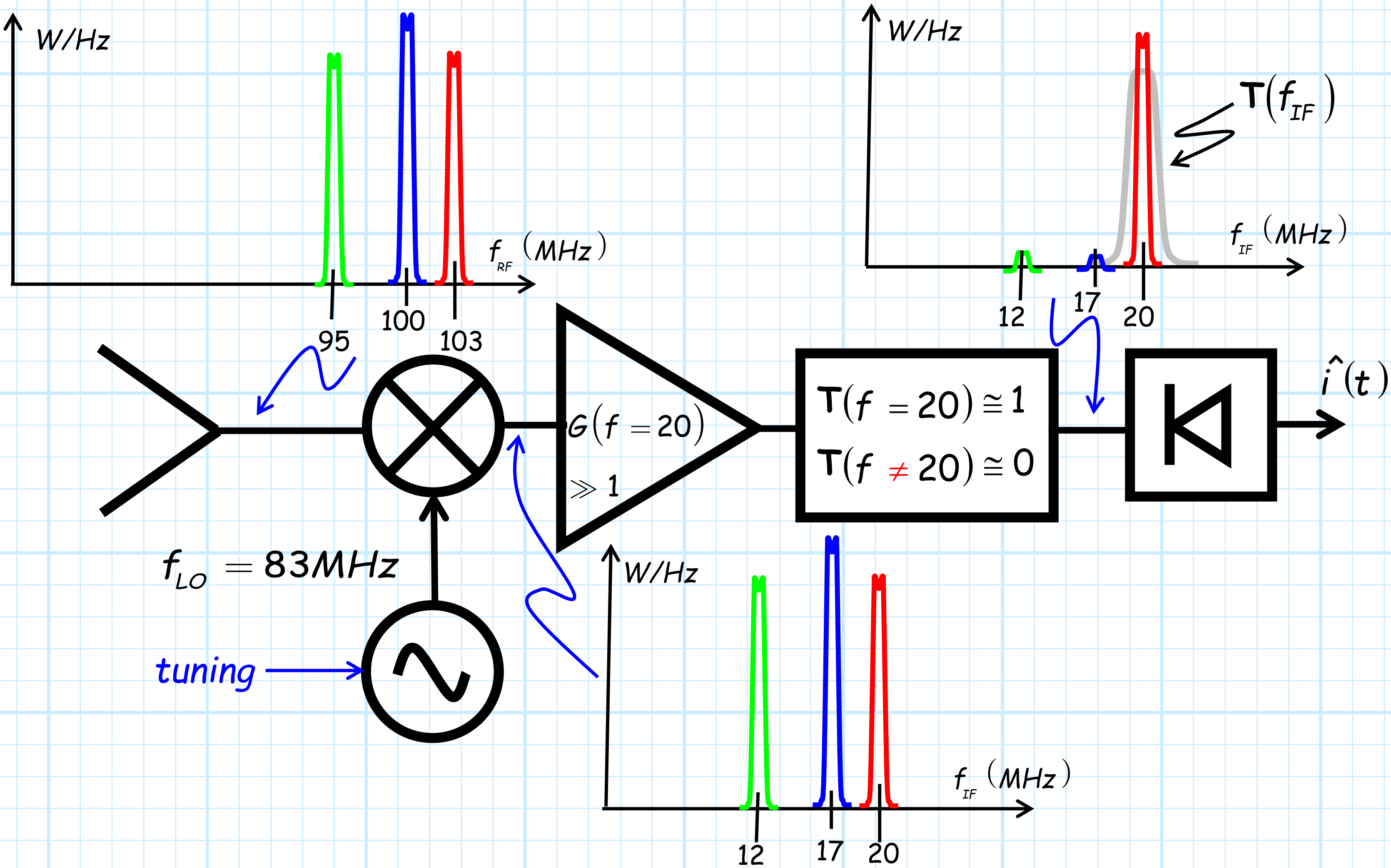
$$f_{LO} \;=\; f_s - f_0^{IF} \;=\; 95 - 20 \;=\; 75\ MHz$$



# Another example

**Or**, we could **instead** tune to the station at **103 MHz** by tuning the **Local Oscillator** to **83 MHz**:

$$f_{LO} = f_s - f_0^{IF} = 103 - 20 = 83\ MHz$$



# Tuning an oscillator is relatively easy…

**Q:** *Wait a second!*

*You mean we need to **tune** an oscillator.*

*How is that any **better** than having to **tune** an amplifier and/or filter?*

**A:** Tuning the LO is **much** easier than tuning a **band-pass filter**.

For an oscillator, we just need to change a **single** value—its **carrier frequency**!


→This can typically be done by changing a **single** component value (e.g., a **varactor diode**).

# ...but you can't tune a filter (or a fish)


Contrast that to changing the center frequency of **filter**; say for example, a **5th order** filter.

We must somehow **change** its center frequency, **without** altering its bandwidth, roll-off, or phase delay.

Typically, this requires that **every** reactive element in the filter be altered or changed as we modify the center frequency (remember all those **control knobs**!).

# Not to brag, but I make *twice* this much!


*A 1934 advertisement enticing "men" to enter the* ***glamorous*** *and* ***lucrative*** *field of radio engineering.*