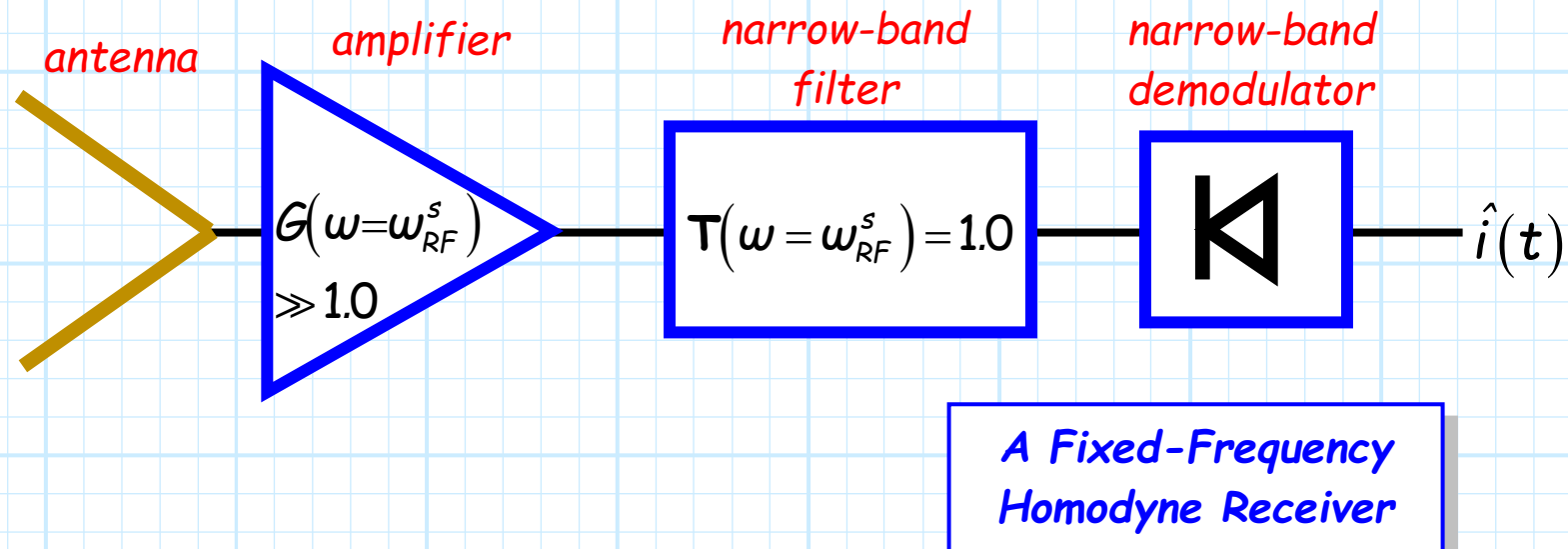


# The Super-Heterodyne Receiver

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!**

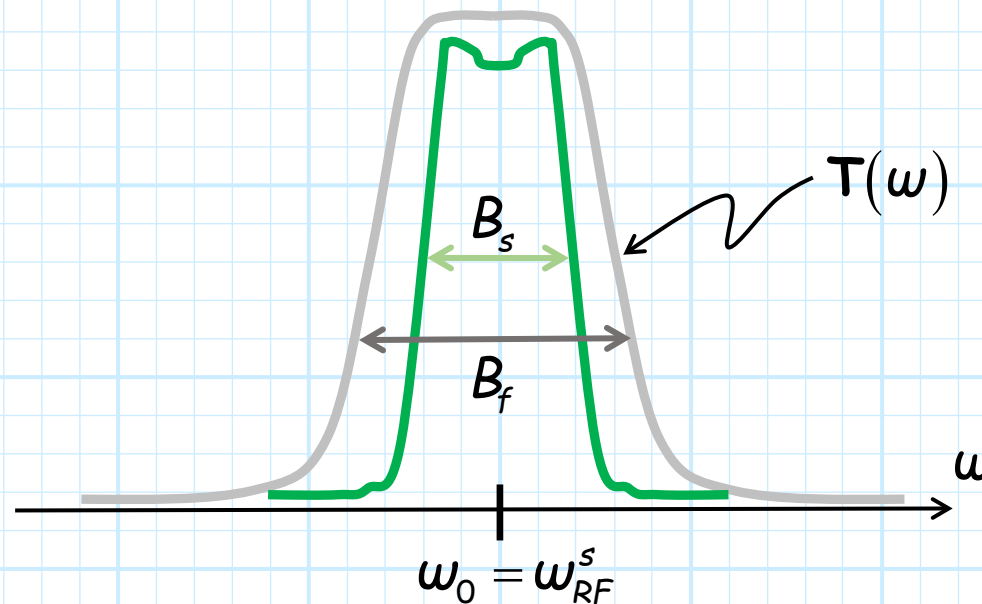
Instead, the **center frequency**  $\omega_0$  of the filter must simply be equal to the **desired signal** frequency  $\omega_{RF}^s$ :

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

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:

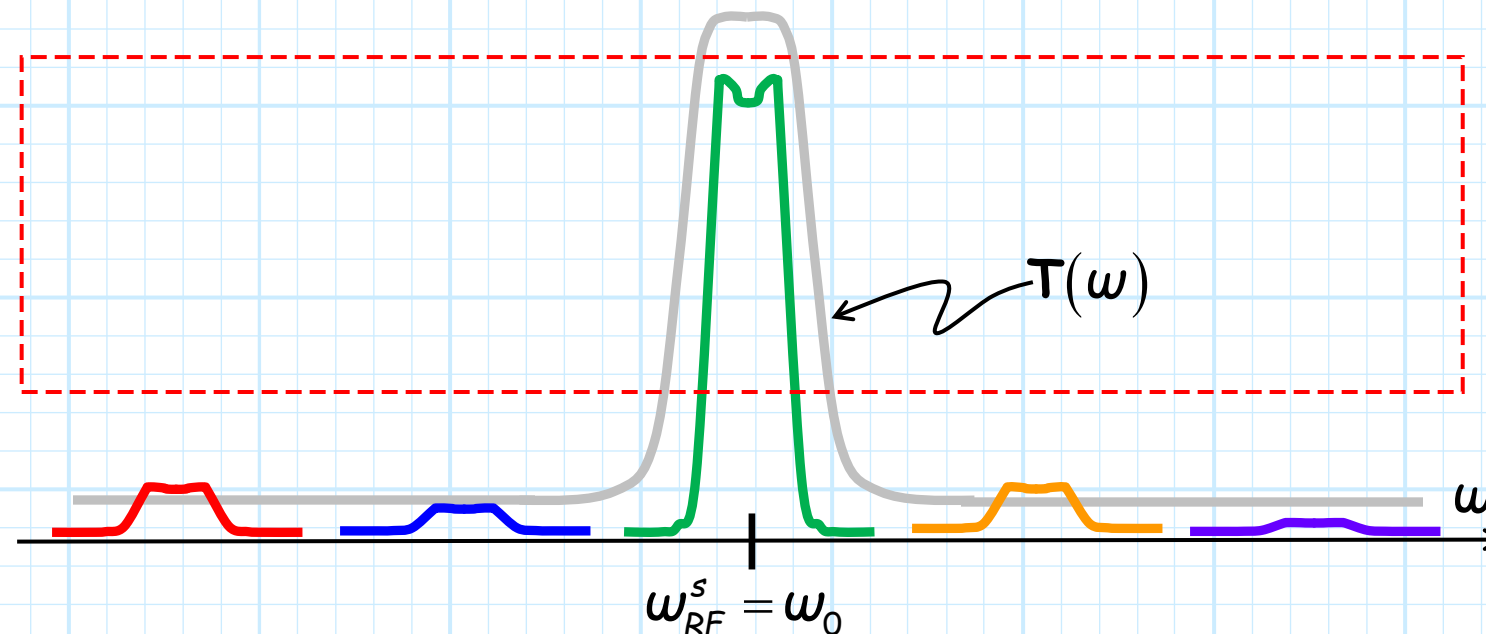
"The signal to be demodulated must be the **ONLY** signal at the input to the demodulator!"

## 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

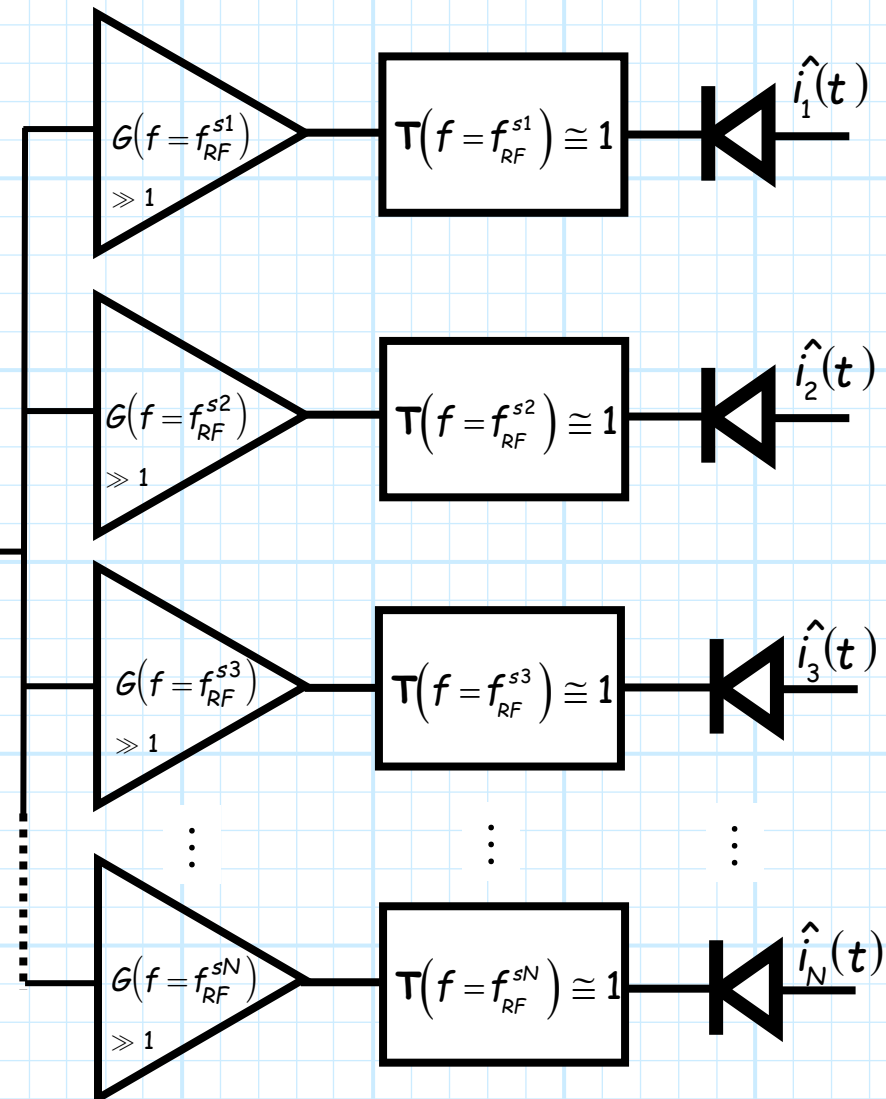
**Q:** Couldn't we just build one of these fixed-frequency homodyne receivers for **each** and **every** signal frequency of interest?

**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!**

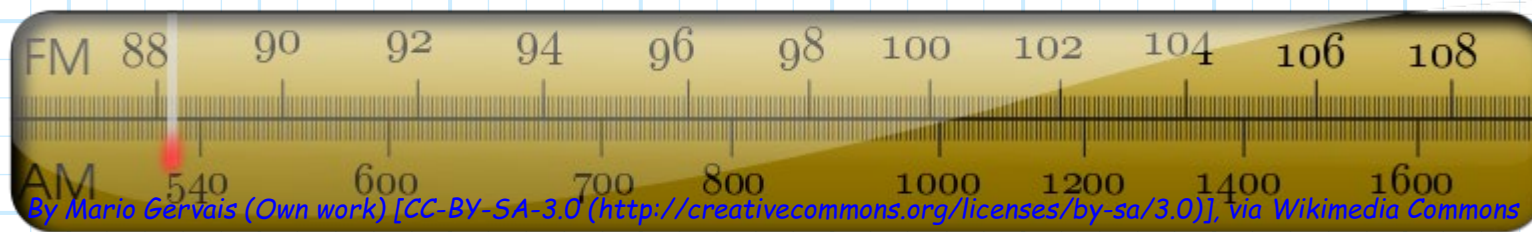


**A Channelized Receiver**

## 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.



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

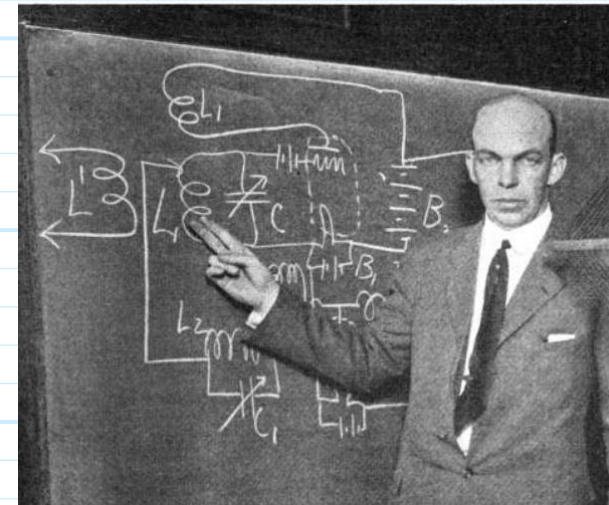
$$\frac{20 \text{ MHz}}{200 \text{ kHz}} = 100 \text{ channels !!!}$$

**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, it 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**!



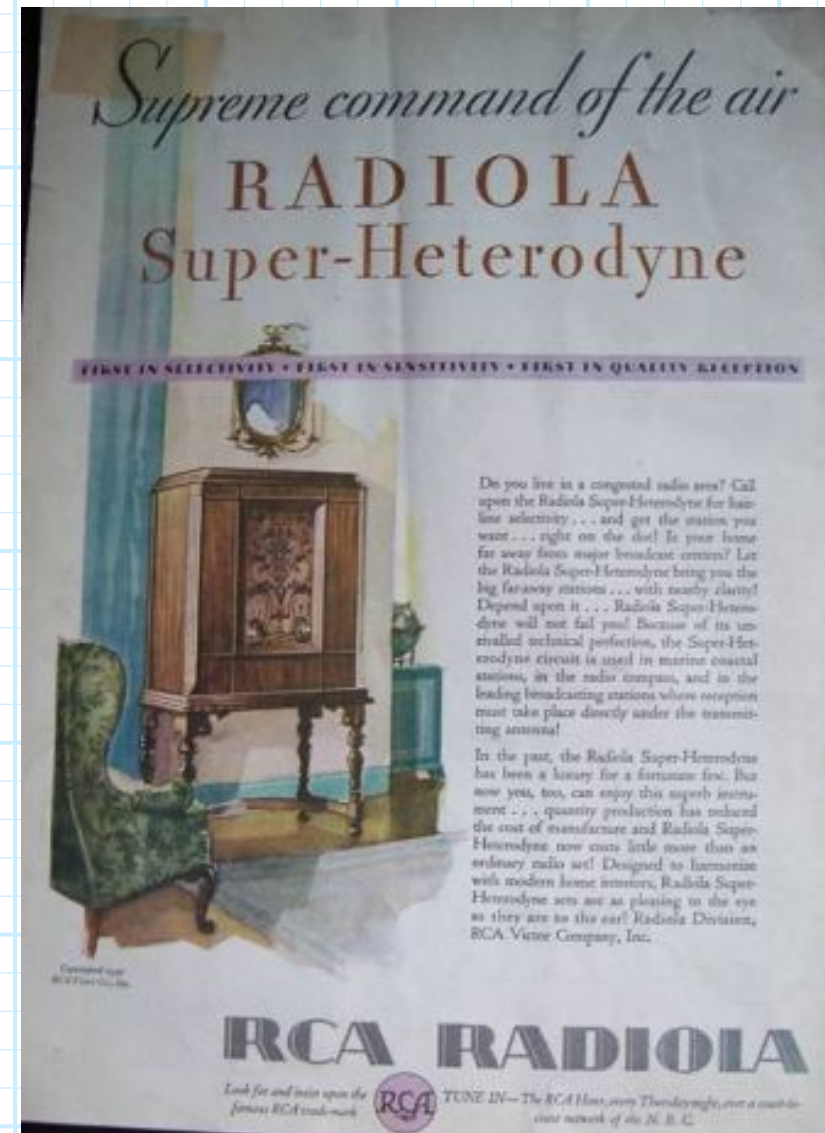
# The Super-Heterodyne

**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!**

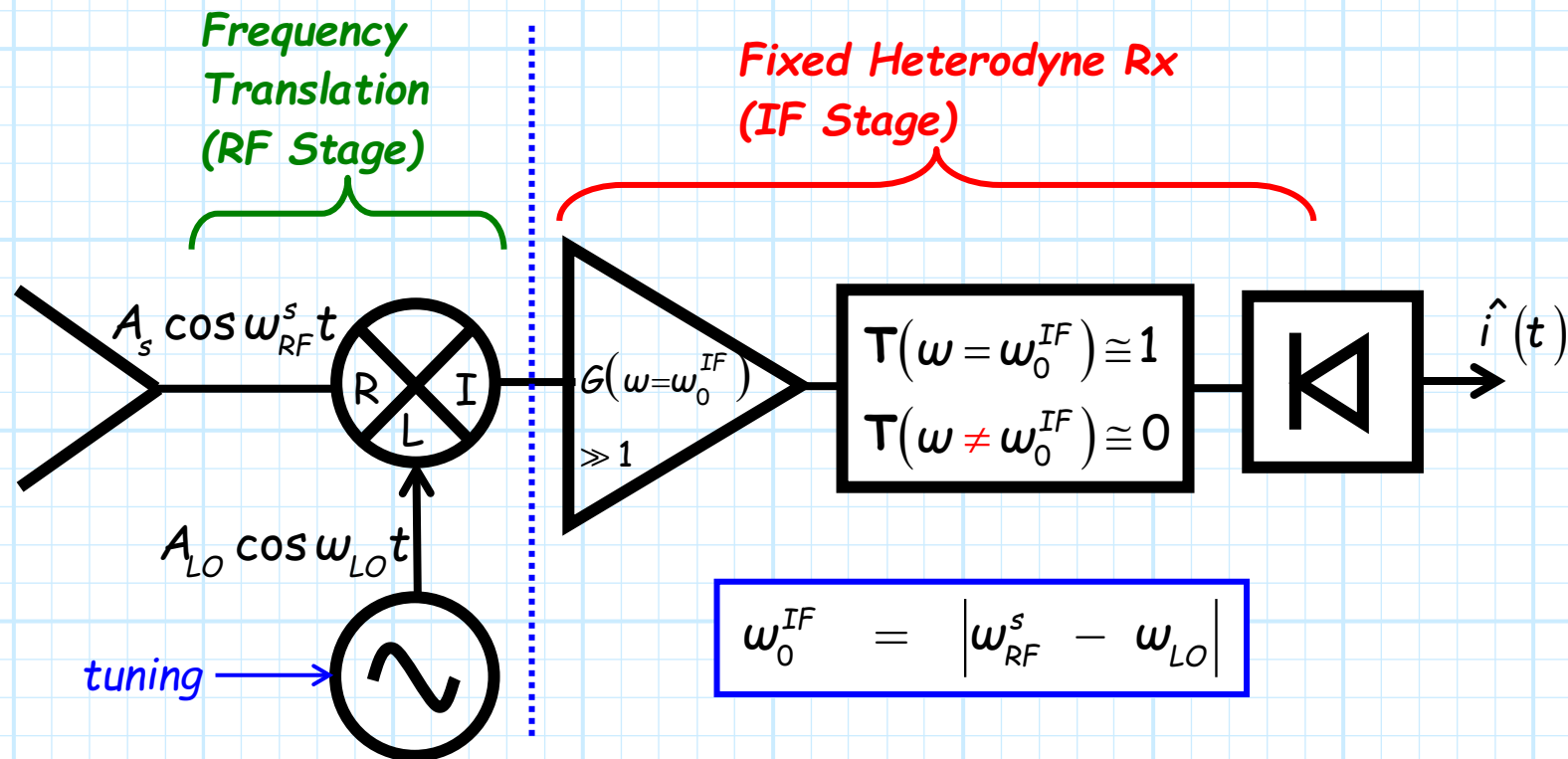


We call this design the **Super-Heterodyne Receiver!**



## A super-simple super-het

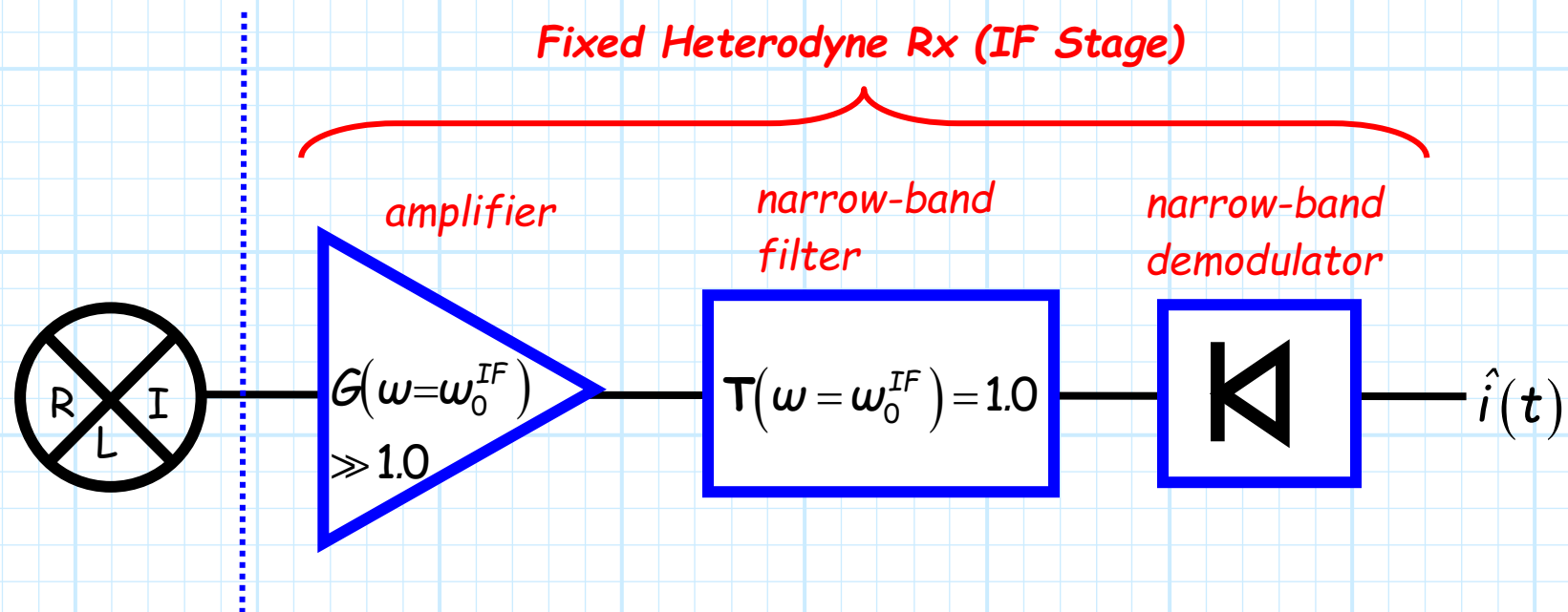
A super-heterodyne receiver can be viewed as simply as a **fixed frequency homodyne** receiver, preceded by a **frequency translation** (i.e., down-conversion) stage.



**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

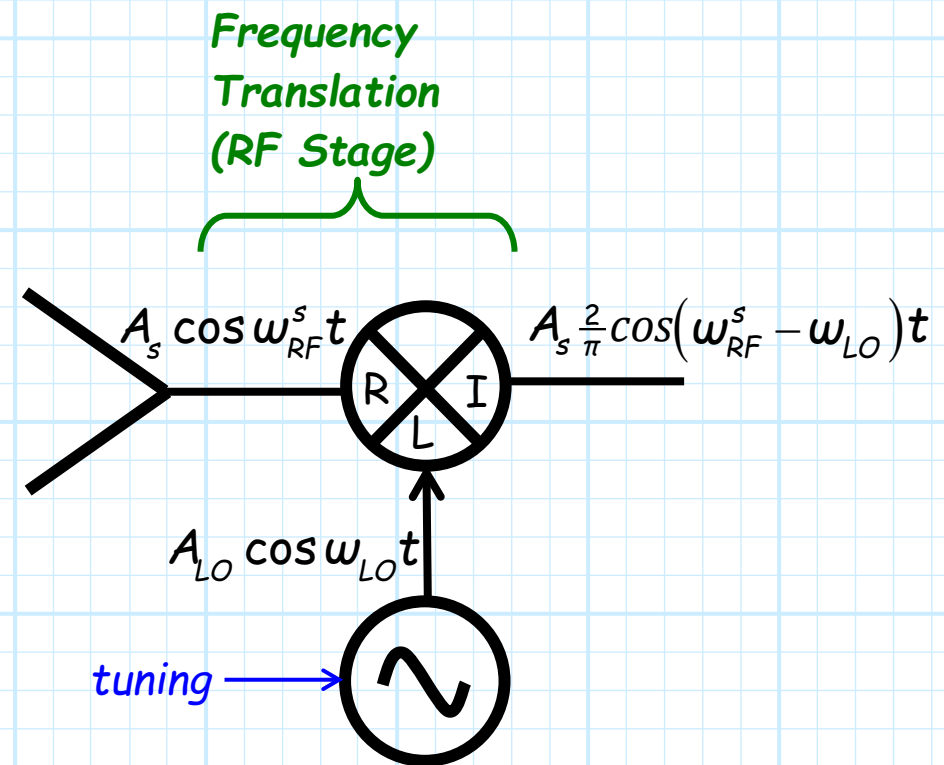
b) their performance **increases**.

→ 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  $|\omega_{RF}^s - \omega_{LO}|$ .

## 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**:

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

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

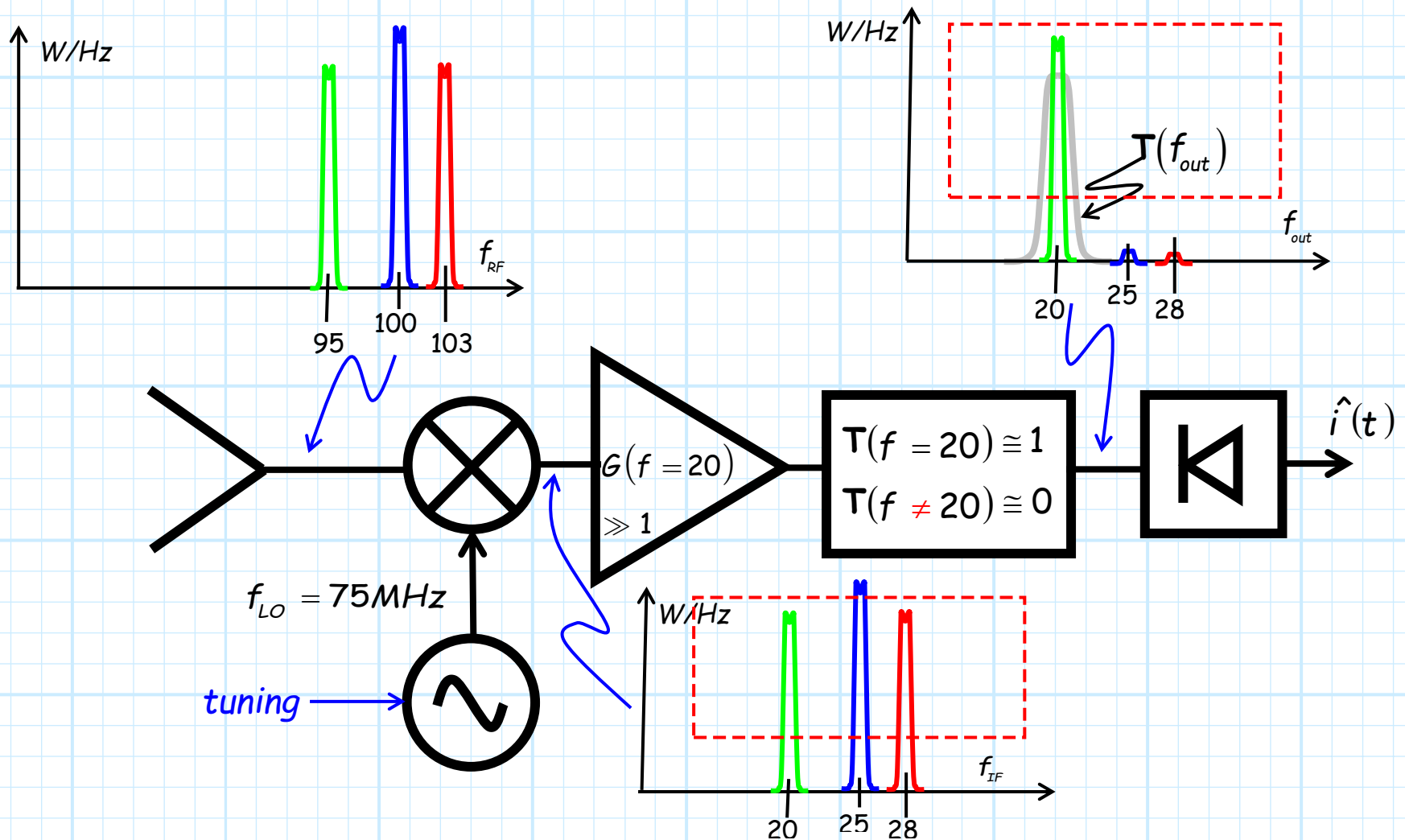
Likewise, say that the **IF center frequency** selected by the receiver design engineer is:

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

## This example illustrated

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

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

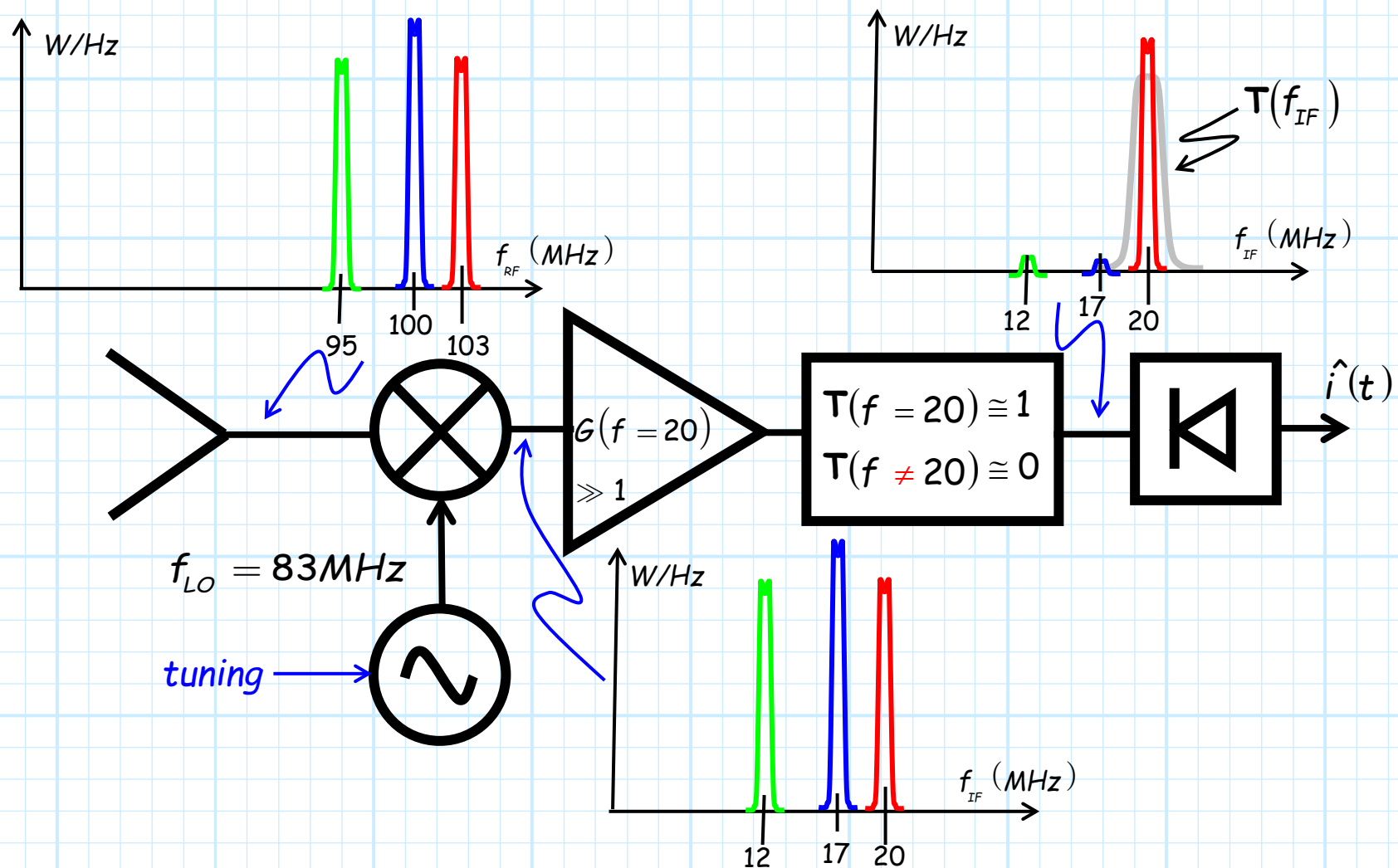




## Another example

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

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



## Tuning an oscillator is relatively easy...

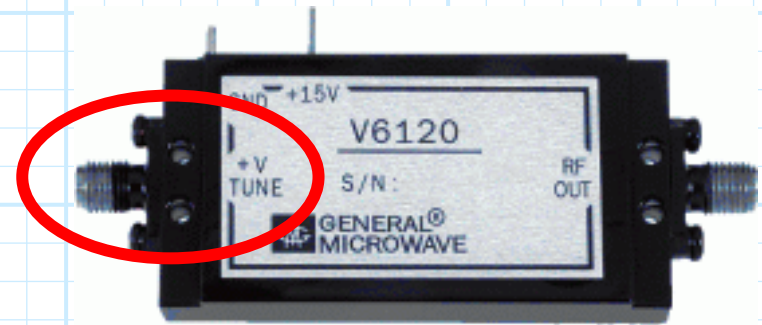
**Q:** *Wait a second!*

*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 **5<sup>th</sup> 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!

RADIO NEWS FOR FEBRUARY, 1934 453

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