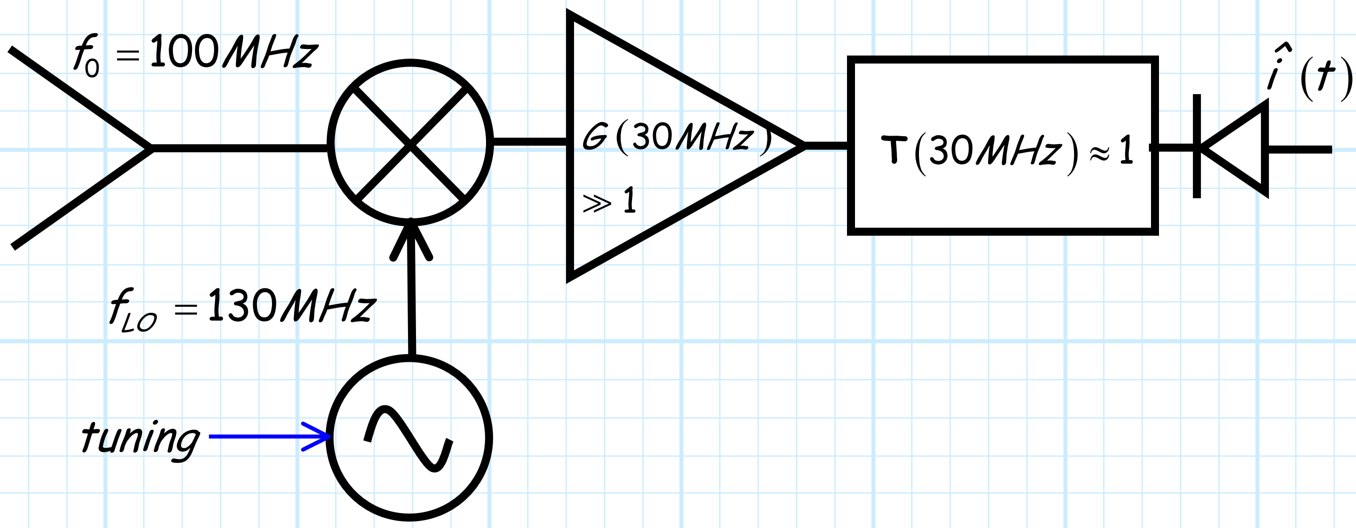
# The Preselector Filter

Say we wish to **tune** a super-het receiver to receive a **radio station** broadcasting at **100 MHz**.

If the receiver uses and **IF** frequency of $f_{IF} = 30\ MHz$, and uses **high-side** tuning, we must adjust the **local oscillator** to a frequency of $f_{LO} = 130\ MHz$.




Thus, the **desired** RF signal will be **down-converted** to the IF frequency of **30 MHz**.

But **BEWARE**, the desired radio station is **not** the only signal that will appear at the output of the mixer **at 30 MHz**!

**Q:** *Oh yes, **we** remember. The mixer will create all sorts of nasty, non-ideal **spurious** signals at the mixer IF port. Among these are signals at frequencies:*

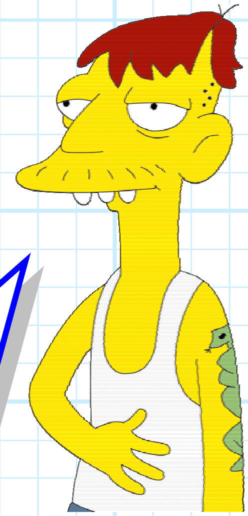
**1st order:** $f_{RF} = 100MHz\,,\, f_{LO} = 130MHz$

**2nd order:** $2f_{RF} = 200MHz\,,\, 2f_{LO} = 260MHz\,,$
$f_{RF} + f_{LO} = 230MHz$

**3rd order:**

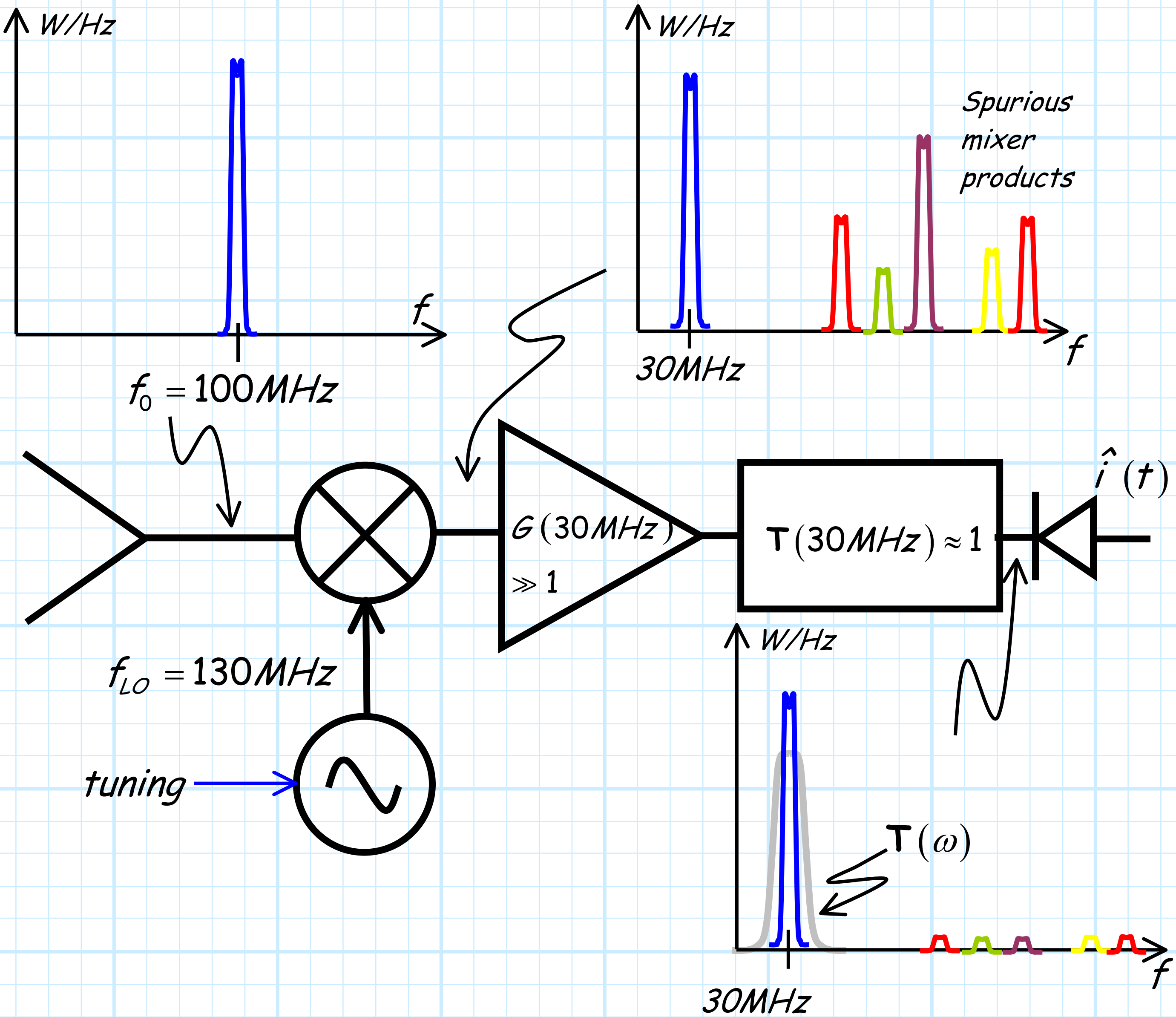
$$\left|2f_{RF} - f_{LO}\right| = 70MHz\,,$$
$$\left|2f_{LO} - f_{RF}\right| = 160MHz\,,$$
$$3f_{RF} = 300MHz\,,\, 3f_{LO} = 390MHz\,,$$
$$2f_{RF} + f_{LO} = 330MHz\,,$$
$$f_{RF} + 2f_{LO} = 360MHz$$

***Right?***



**A:** Not exactly. Although it **is** true that all of these products **will** exist at the IF mixer port—they will **not** pose any particular problem to us as radio engineers. The reason for this is that there is a narrow-band **IF filter** between the mixer IF port and the demodulator!

Look at the **frequencies** of the spurious signals created. They are all quite a bit **larger** than the filter center frequency of **30MHz**. All of the spurious signals are thus **rejected** by the filter—**none** (effectively) reach the detector/demodulator!

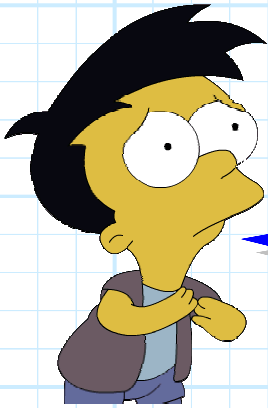



Look **again** at the statement I just made:

"But **BEWARE**, the desired radio station is **not** the only signal that will appear at the output of the mixer **AT 30 MHz**!"

In other words, there can be **spurious signals** that appear **precisely** at our IF frequency of **30 MHz**. The IF filter will **not** of course filter **these** out (after all—they're at **30 MHz**!), but instead let them pass through **unimpeded** to the **demodulator**.

The **result** → demodulated signal $\hat{i}(t)$ is an inaccurate, distorted **mess**!



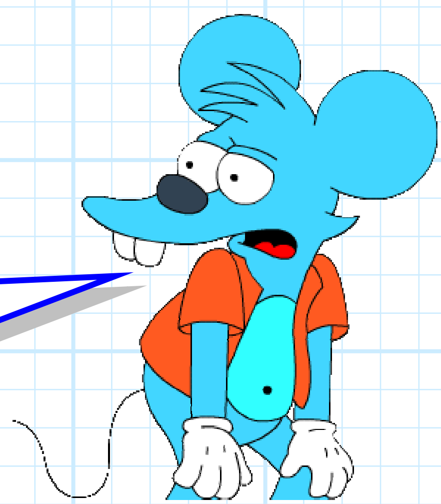
**Q:** *I'm just* ***totally*** *baffled!* ***Where*** *do these unfilterable signals come from?* ***How*** *are they produced?*

**A:** The answer is a **profound** one—an **incredibly important** fact that every radio engineer worth his or her salt must keep in mind at **all** times:

> *The electromagnetic spectrum is* ***full*** *of radio signals. We must* ***assume*** *that the antenna delivers signals operating at* ***any*** *and* ***all*** *RF frequencies!*

In other words, we are only **interested** in a signal at 100 MHz; but that does **not** mean that other signals don't exist. **You** must always consider this fact!

**Q:** *But I'm* ***still*** *confused. How do all these RF signals cause multiple signals* ***at*** *our IF frequency?*



**A:** Remember, **each** of the RF signals will mix with the LO drive signal, and thus **each** RF signal will produce its very **own** set of **mixer products** ($1^{st}$ order, $2^{nd}$ order, $3^{rd}$ order, etc.)

Here's the **problem**→ some of these mixer products might lie **at** our IF frequency of **30 MHz**!

* To see **which** RF input signal frequencies will cause this problem, we must **reverse** the process of determining our mixer output products.

* Recall earlier we started with **known** values of $f_{RF}$ (100 MHz) and $f_{LO}$ (130 MHz), and then determined all of the spurious signal frequencies created at the mixer IF port.

* Now, we start with a know $f_{LO}$ (130 MHz), and a know value of the **spurious IF signal frequency** (30 MHz), and try to determine the frequency of the **RF** signal that would be required to produce it.

For example, let's start with the $3^{rd}$ order product $\left|2f_{RF} - f_{LO}\right|$. In order for this product to be equal to 30 MHz, we find that:

$$
\begin{aligned}
\left|2f_{RF} - 130\right| &= 30 \\
2f_{RF} - 130 &= \pm 30 \\
2f_{RF} &= 130 \pm 30 \\
f_{RF} &= \frac{130 \pm 30}{2} \\
f_{RF} &= 50,\, 80
\end{aligned}
$$

Thus, when attempting to tune to a radio station at 100 MHz, we find that radio stations at both **50 MHz** and **80 MHz** could **create** a 3rd order product at **30 MHz**—precisely at our **IF** filter center frequency!

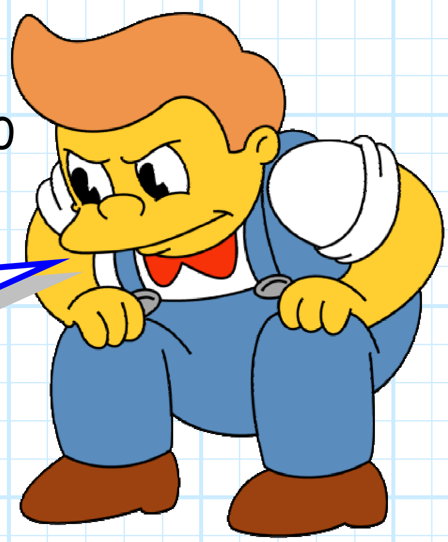
But the **bad** news continues—there are **many** other mixer products to consider:

$\underline{\left|2f_{LO} - f_{RF}\right|}$

$$
\begin{aligned}
\left|2(130) - f_{RF}\right| &= 30 \\
260 - f_{RF} &= \pm 30 \\
f_{RF} &= 260 \mp 30 \\
&= 290, 230
\end{aligned}
$$

$\underline{2f_{LO} + f_{RF}}$

$$
\begin{aligned}
2(130) + f_{RF} &= 30 \\
260 + f_{RF} &= 30 \\
f_{RF} &= 30 - 260 \\
&= -230
\end{aligned}
$$



**Q:** *What?! A radio station operating at a **negative** frequency of -230 MHz? Does this have any meaning?*

**A:** Not in any **physical** sense! We **ignore** any **negative** frequency solutions—they are **not** a concern to us.

$2f_{RF} + f_{LO}$

$$
\begin{aligned}
2f_{RF} + f_{LO} &= 30 \\
2f_{RF} + 130 &= 30 \\
f_{RF} &= \frac{30-130}{2} \\
f_{RF} &= -50
\end{aligned}
$$

Again, a **negative** solution that we can **ignore**.

$3f_{RF}$

$$
\begin{aligned}
3f_{RF} &= 30 \\
f_{RF} &= \frac{30}{3} \\
f_{RF} &= 10
\end{aligned}
$$

OK, that's all the **3rd order** products, now let's consider the **second-order** terms:

$|f_{LO} - f_{RF}|$

$$
\begin{aligned}
|130 - f_{RF}| &= 30 \\
130 - f_{RF} &= \pm 30 \\
f_{RF} &= 130 \mp 30 \\
&= 100, 160
\end{aligned}
$$

* Note that this term is the term created by an **ideal** mixer. As a result, we find that **one** of the RF signals that will create a mixer product at 30 MHz is $f_{RF}$ = **100 MHz** – the frequency of the **desired** radio station !

* However, we find that even this **ideal** mixer term causes **problems**, as there is a **second** solution. An RF signal at **160 MHz** would likewise result in a mixer product at 30 MHz—even in an **ideal** mixer!

* We will find this **second** solution to this **ideal** mixer (i.e., down-conversion) term can be particularly **problematic** in receiver design. As such, this solution is given a specific name—the **image frequency**.

For this example, 160 MHz is the **image frequency** when we tune to a station at 100 MHz.

$\underline{f_{LO} + f_{RF}}$

$$
\begin{aligned}
130 + f_{RF} &= 30 \\
130 f_{RF} &= 30 - 130 \\
f_{RF} &= -100
\end{aligned}
$$

**No** problem here!

$\underline{2f_{RF}}$

$$
\begin{aligned}
2f_{RF} &= 30 \\
f_{RF} &= \frac{30}{2} \\
f_{RF} &= 15
\end{aligned}
$$

Finally, we must consider **one** 1st order term:

$\underline{f_{RF}}$

$$f_{RF} = 30$$

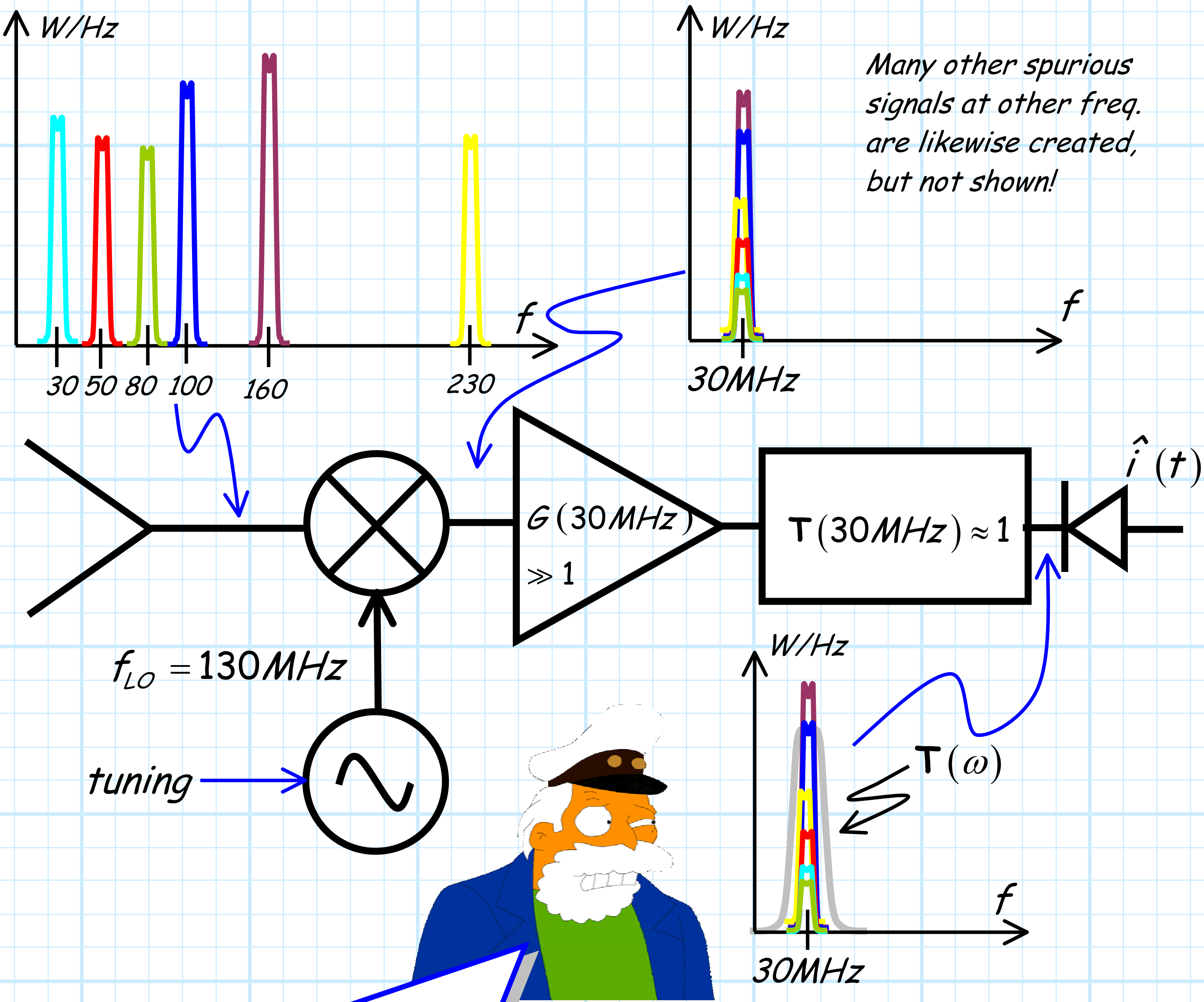
In other words, an RF signal at 30 MHz can "**leak**" through the mixer (recall mixer **RF isolation**) and appear at the IF port—after that there's **no stopping** it until it reaches the demodulator!

In **summary**, we have found that that:

1. An RF signal (e.g., radio station) at **30 MHz** can cause a **1st-order** product at our IF filter frequency of 30 MHz.

2. RF signals (e.g., radio stations) at either **15 MHz** or **160 MHz** can cause **a 2nd -order** product at our IF filter frequency of 30 MHz.

3. RF signals (e.g., radio stations) at **10 MHz**, **50MHz**, **80 MHz**, **230 MHz**, or **290 MHz** can cause a **3rd -order** product at our IF filter frequency of 30 MHz.




**Q:** *I now **see** the problem! There is **no** way to separate the **spurious** signals at the IF frequency of 30 MHz from the **desired** station at 30 MHz. Clearly, your hero **E.H. Armstrong** was **wrong** about this Super-Heterodyne receiver design!*

**A:** Armstrong **wrong** !?!

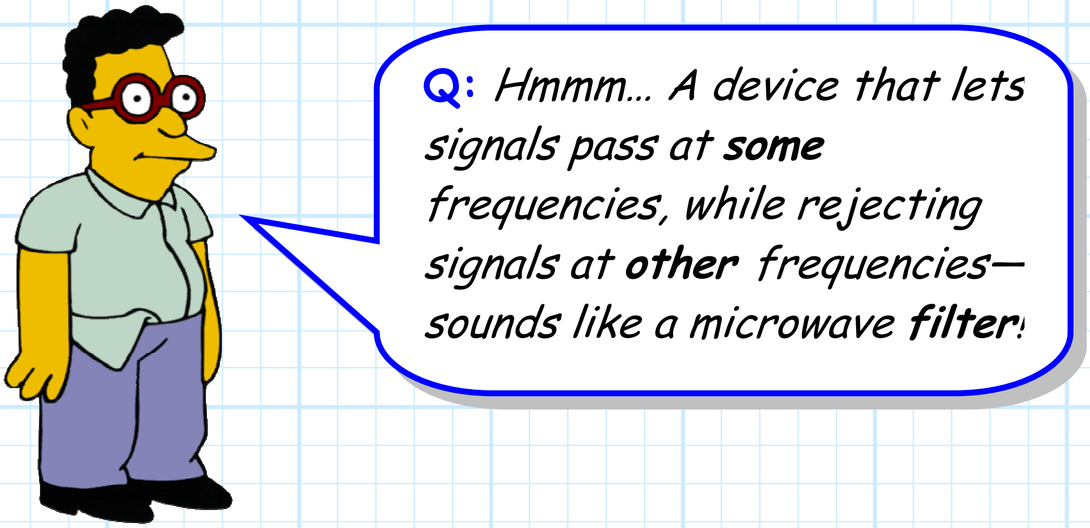
→ **NEVER!**

There is an **additional** element of Armstrong's super-het design that we have **not** yet discussed.

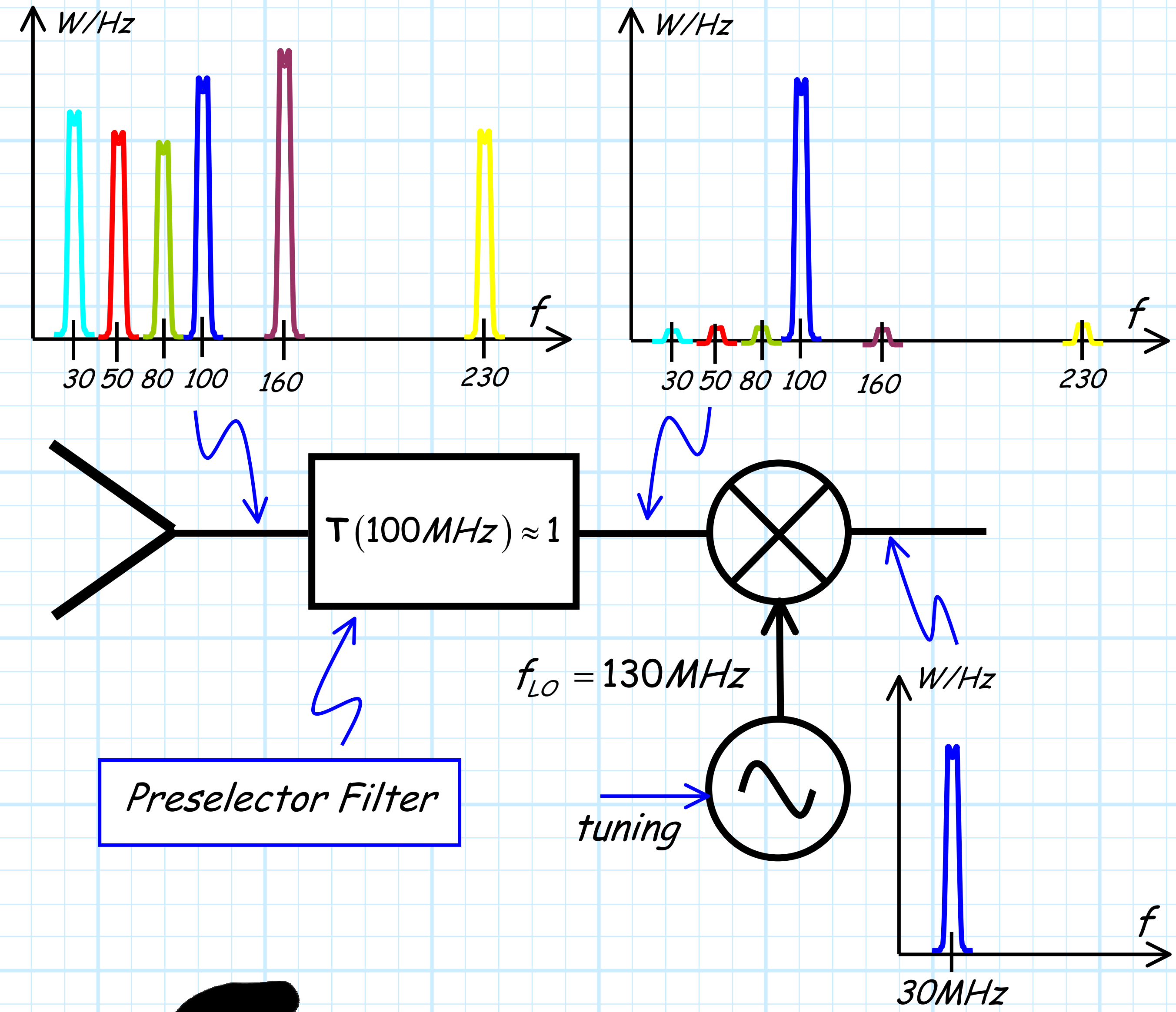
→ The **preselector filter**.

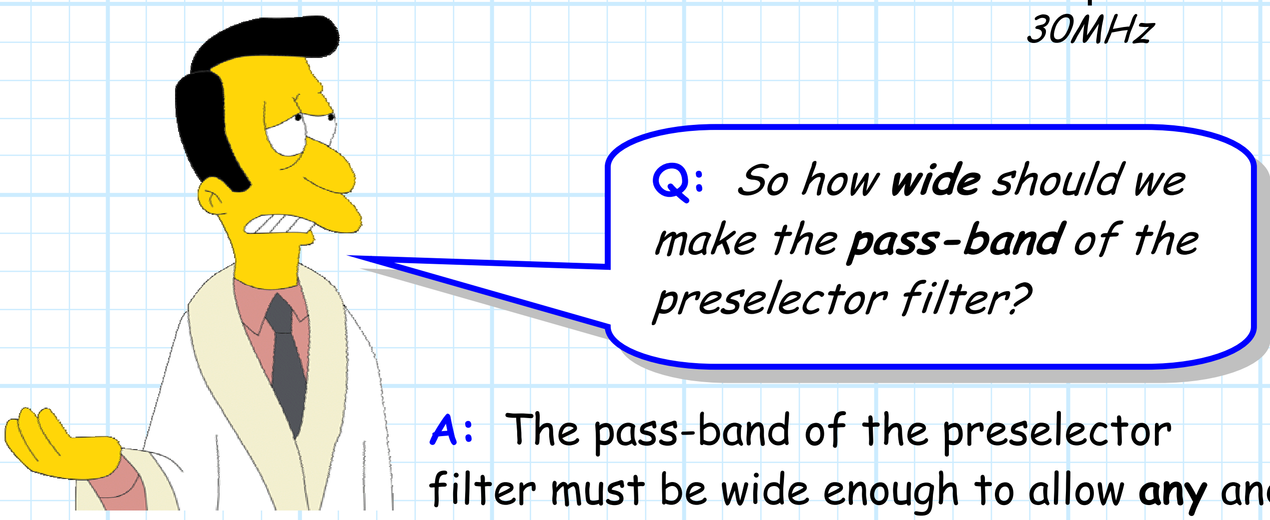
The **only** way to keep the mixer from **creating** these spurious signals at our IF filter center frequency is to **keep** the RF signals that produce them **from** the mixer!

Of course, we must **simultaneously** let the desired station reach the mixer.




**A:** That's correct! By inserting a **preselector filter** between the antenna and the mixer, we can **reject** the signals that create spurious signals at our IF center frequency, while **allowing** the desired station to pass through to the mixer unimpeded.




**A:** The pass-band of the preselector filter must be wide enough to allow **any** and **all** potential **desired** signals to pass through.

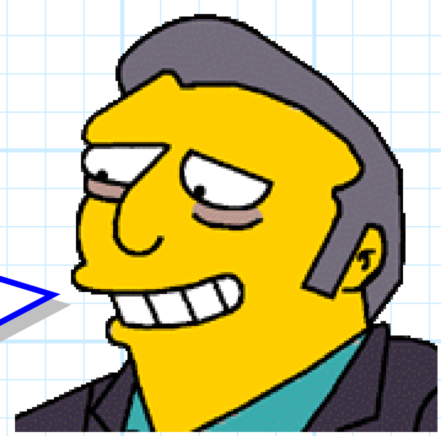
* Consider our example of $f_0$= 100 MHz. This signal is **smack-dab** in the middle of the **FM radio band**, and so let's assume it is an **FM radio station** (if it were, it would actually be at frequency 100.1 or 99.9 MHz).

* If we are interested in tuning to **one** FM station, we might be interested in tuning into **any** of the others, and thus the preselector filter pass-band **must** extend from 88 MHz to 108 MHz (i.e., the FM band).

* Note we would **not** want to extend the pass-band of the preselector filter any wider than the FM band, as we are (presumably) **not** interested in signals outside of this band, and those signals could **potentially** create spurious signals at our IF center frequency!

> As a result, we find that the **preselector filter** effectively defines the **bandwidth** of a super-heterodyne receiver.

**Q:** *OK, **one** last question. When calculating the products that could create a spurious signal **at** the IF center frequency, you **neglected** the terms $f_{LO}$, $2f_{LO}$ and $3f_{LO}$. Are these terms **not** important?*



**A:** They are actually **very** important! However, the value of $f_{LO}$ is **not** an unknown to be solved for, but in fact was (for our example) a **fixed** value of $f_{LO} = 130 MHz$.

Thus, $2f_{LO} = 260 MHz$, and $3f_{LO} = 390 MHz$—**none** of these are anywhere near the **IF** center frequency of **30 MHz**, and so these products are easily **rejected** by the **IF filter**. However, this need not **always** be true!

* Consider, for example, the case were we again have designed a receiver with an IF center frequency of **30 MHz**. This time, however, we desire to tune to radio signal operating at **60 M**Hz.

* Say we use **low-side** tuning in our design. In that case, the **LO** signal frequency must be $f_{LO} = 60 - 30 = 30 MHz$.

* Yikes! You **must** see the problem! The Local Oscillator frequency is **equal** to our IF center frequency ($f_{LO} = f_{IF}$). The LO signal will "**leak**" through mixer (recall mixer LO isolation) and into the IF, where it will pass **unimpeded** by the IF filter to the demodulator (this is a very **bad** thing).

Thus, when designing a receiver, it is **unfathomably important** that the LO frequency, along with **any** of its harmonics, lie **nowhere** near the **IF** center frequency!