The Super-Heterodyne Receiver

Note that the heterodyne receiver would be an excellent design if we **always** wanted to receive a signal at one particular signal frequency ($\omega_1$, say):

No tuning is required!

Moreover, we can optimize the amplifier, filter, and detector performance for one—and only one—signal frequency (i.e., $\omega_1$).

**Q:** Couldn’t we just build one of these fixed-frequency heterodyne 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!

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 heterodyne receivers!

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

A: Yes, there is a good receiver solution, one developed more than 80 years ago by—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 match the desired signal frequency, we should change the signal frequency to match the receiver hardware!
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-heterodyne receiver can be viewed as simply as a fixed frequency heterodyne receiver, proceeded by a frequency translation (i.e., down-conversion) stage.

\[
\begin{align*}
\text{IFG} = \hat{a} \cos \omega_1 t \\
A \cos \omega_{LO} t
\end{align*}
\]

\[
\omega_{IF} = |\omega_1 - \omega_{LO}|
\]

A Simple Super-Het Receiver Design
The fixed heterodyne receiver (the one that we match the signal frequency to), is known as the IF stage. The fixed-frequency $\omega_{IF}$ that this heterodyne receiver is designed (and optimized!) for is called the Intermediate Frequency (IF).

Q: So what is the value of this Intermediate Frequency $\omega_{IF}$?? How does a receiver design engineer choose this value?

A: Selecting the “IF frequency” value is perhaps the most important choice that a “super-het” receiver designer will make. It 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 the cost and performance of the (IF) amplifier, (IF) filter, and detector/demodulator is good.

* Generally speaking, as we go lower in frequency, the cost of components go down, and their performance increases (these are both good things!). As a result, the IF frequency is typically (but not always!) selected such that it is much less (e.g., an order of magnitude or more) than the RF signal frequencies we are attempting to demodulate.

* Therefore, we typically 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 second-order mixer term $|\omega_{RF} - \omega_{LO}|$. 
As a result, we must **tune** the LO so that $|\omega_1 - \omega_{LO}| = \omega_{IF}$—that is, if we wish to demodulate the RF signal at frequency $\omega_1$!

For example, say there exists radio signals (i.e., radio stations) at 95 MHz, 100 MHz, and 103 MHz. Likewise, say that the IF frequency selected by the receiver design engineer is $f_{IF} = 20$ MHz.

We can tune to the station at **95 MHz** by setting the Local Oscillator to $95-20=75$ MHz:
Or, we could tune to the station at 103 MHz by tuning the Local Oscillator to 103-20=83 MHz:

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).
Contrast that to a 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!).