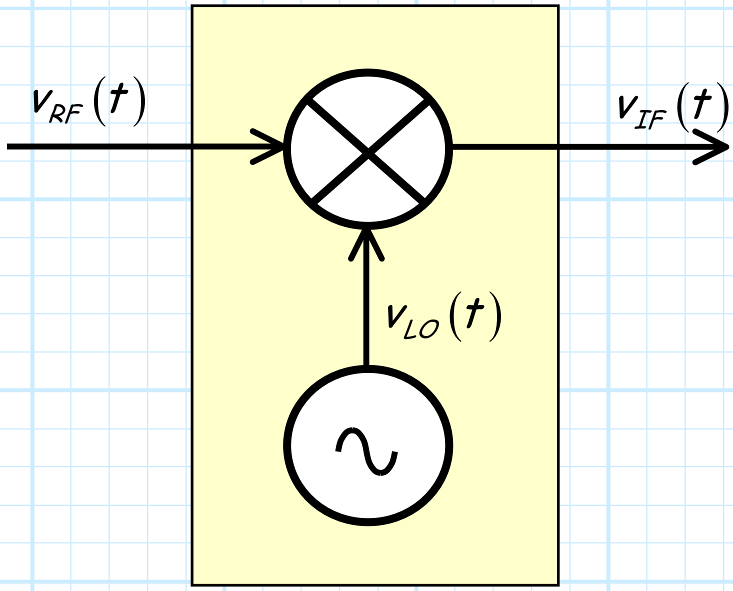
Mixer Conversion Loss

Let's examine the **typical application** of a mixer.



Generally, the signal delivered to the Local Oscillator **port** is a **large**, pure tone generated by a device called—a **Local Oscillator**!

$$v_{LO}(t) = A_{LO} \cos \omega_{LO} t$$

Additionally, we will find that the local oscillator is **tunable**—we can **adjust** the frequency ω_{LO} to fit our purposes (this is **very** important!).

Typically, every mixer will be **paired** with a local oscillator. As a result, we can view a mixer as a non-linear, **two**-port device! The **input** to the "device" is the RF port, whereas the **output** is the IF port.

In contrast to the LO signal, the **RF input signal** is generally a low-power, modulated signal, operating at a carrier frequency ω_{RF} that is relatively large—it's a **received** signal!

$$v_{RF}(t) = a(t)\cos\left(\omega_{RF} + \phi(t)\right)$$

where $a(t)$ and $\phi(t)$ represent amplitude and phase **modulation**.

Q: *So, what "output" signal is created?*

A: Let's for a second **ignore** all mixer terms, **except** for the **ideal** term:

$$v_{IF}(t) \approx K\, v_{RF}(t) v_{LO}(t)$$

where K is indicates the **conversion** factor of the mixer (i.e, $K = a_4$).

Inserting our expressions for the RF and LO signals, we find:

$$\begin{aligned} v_{IF}(t) &= K\, v_{RF}(t) v_{LO}(t) \\ &= K\, a(t)\cos\left(\omega_{RF} t + \phi(t)\right) A_{LO} \cos \omega_{LO} t \\ &= \frac{K\,A_{LO}}{2} a(t)\cos\left[\left(\omega_{RF} - \omega_{LO}\right)t + \phi(t)\right] \\ &\quad + \frac{K\,A_{LO}}{2} a(t)\cos\left[\left(\omega_{RF} + \omega_{LO}\right)t + \phi(t)\right] \end{aligned}$$

As we expected, we generate **two** signals, one at frequency $\left|\omega_{RF} - \omega_{LO}\right|$ and the other at frequency $\omega_{RF} - \omega_{LO}$.

Typically, the high frequency term is **filtered** out, so the IF output is:

$$v_{IF}(t) = \frac{K\,A_{LO}}{2}\,a(t)\cos\left[\left(\omega_{RF} - \omega_{LO}\right)t + \phi(t)\right]$$

Look at what this means!

It means that the output **IF** signal is nearly **identical** to the input **RF** signal. The **only** differences are that:

1) The IF signal has different **magnitude** (typically, a smaller magnitude).

2) The IF signal has a different **frequency** (typically, a much lower frequency).

Thus, the modulation **information** has been **preserved** in this "mixing" process. We can accurately **recover** the information $a(t)$ and $\phi(t)$ from the IF signal!

Moreover, the RF signal has been "**downconverted**" from a high frequency ω_{RF} to a typically **low** signal frequency $\left|\omega_{RF} - \omega_{LO}\right|$.

Q: ***Why*** *would we every want to "downconvert" an RF signal to a* ***lower*** *frequency?*

A: Eventually, we will need to process the signal to recover $a(t)$ and $\phi(t)$. At lower frequencies, this processing becomes **easier**, **cheaper**, and more **accurate**!

Now, we **additionally** want our IF signal to be as **large** as possible. It is evident that if:

$$v_{IF}(t) = \frac{K\,A_{LO}}{2}\,a(t)\cos\left[(\omega_{RF} - \omega_{LO})t + \phi(t)\right]$$

the local oscillator **magnitude** A_{LO} needs to be as **large** as possible!

But, we find that there is a **limit** on how large we can make the LO signal power. At some point, the mixer LO port will **saturate**—increasing the LO power further will not result in an increase in $v_{IF}(t)$.

We call this LO maximum the **LO drive power**. For diode mixers, we find that this power is **typically** in a range from **+5.0 to +20.0 dBm.**

→ It is **very** important that the local oscillator power **meet** or **exceed** the LO drive power requirement of the mixer!

Now, let's consider the "**gain**" of this 2-port device:

$$\text{Mixer "Gain"} = \frac{P_{IF}}{P_{RF}} = \left(\frac{K\,A_{LO}}{2}\right)^2$$

We find that **typically**, when the LO drive power requirement for a diode mixer is met, that:

$$K\,A_{LO} \approx 1$$

And thus, the mixer **gain** for a properly driven diode mixer will be **roughly**:

$$\text{Mixer "Gain"} = \frac{P_{IF}}{P_{RF}} \approx \left(\frac{1}{2}\right)^2 \approx \frac{1}{4}$$

Therefore, we find that a diode mixer gain will be in the range of **-6.0 dB**. This is a **rough** approximation, and **typically** we find the "gain" of a properly driven diode mixer **ranges** from about **-3.0 dB to -10 dB**.

Note that this mixer "gain" is actually a **loss**. This makes sense, as most mixers are, after all, **passive** devices.

Thus, mixers are not specified in terms of their gain, but instead in terms of its **conversion loss**:

$$\text{Conversion Loss} \doteq -10 \log_{10}\left(\frac{P_{RF}}{P_{IF}}\right)$$

Note that conversion loss is simply the **inverse** of mixer gain, and thus we find that **typical** values of conversion loss will range from **3.0 dB to 10.0 dB**.

→ We want a mixer with as **low** a conversion loss as **possible**!

* One final note, we find that if the LO power drops **below** the required mixer drive power, the conversion loss will increase **proportionately**.

For **example**, say a mixer requires an LO drive power of +12.0 dBm, and exhibits a conversion loss of 6.0 dB. If we **mistakenly** drive the mixer with an LO signal of only +5 dBm, we will find that the mixer conversion loss will **increase** to 13.0 dB!

In other words, if we **"starve"** our mixer LO by 7.0 dB, then we will increase the **conversion loss** by 7.0 dB.

* OK, one **more** final note. We have focused on the **desired** IF output signal, the one created by the **ideal** mixer term. Recall, however, that there will be many more **spurious** signals at our IF output!

Likewise, we have assumed that there is only **one** signal present at the **RF** port. We find this is **rarely** the case, and instead there will be at the RF port a whole **range** of different received signals, spread across a wide **bandwidth** of RF frequencies.

For example, at the RF port of a mixer in an **FM radio** receiver, **all** of the radio stations within the FM band (88 MHz to 108 MHz) will be present! As a result, **each** of these stations will be down-converted, **each** of these stations will appear at the IF output, and each will create there own set of **spurious** signals!