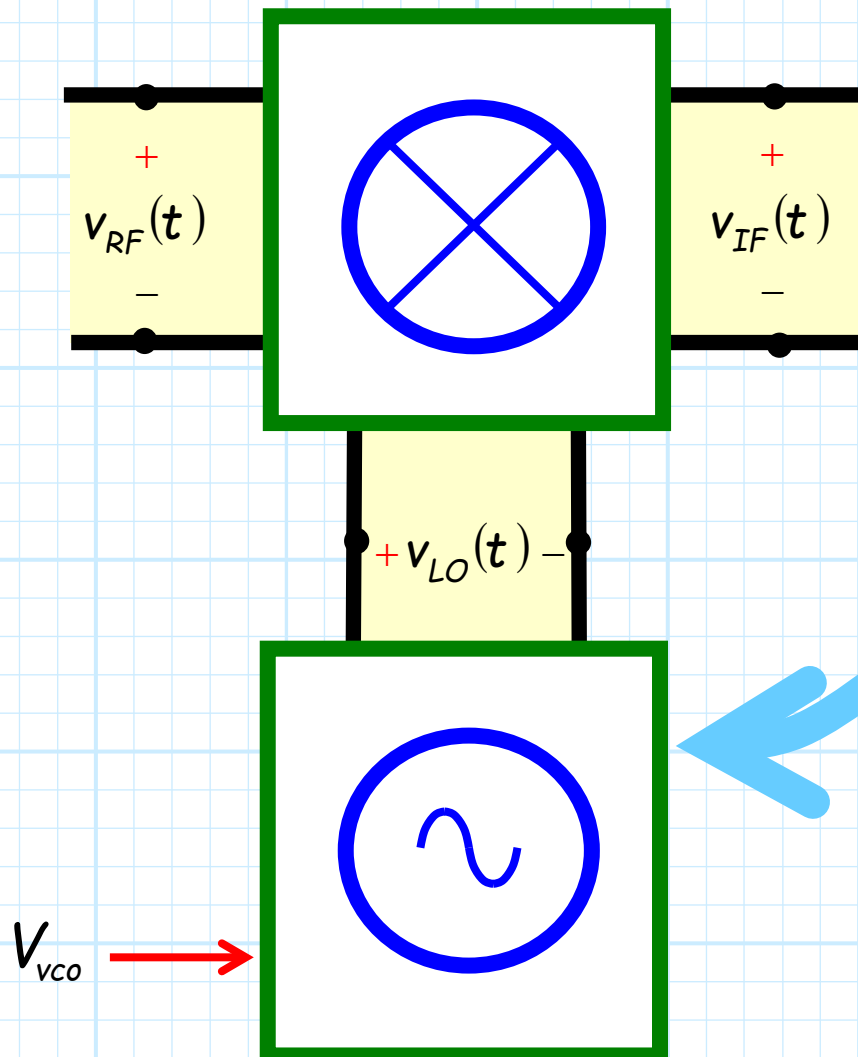# Signal Conversion

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 **matched** device—a device called **Local Oscillator (LO)**!

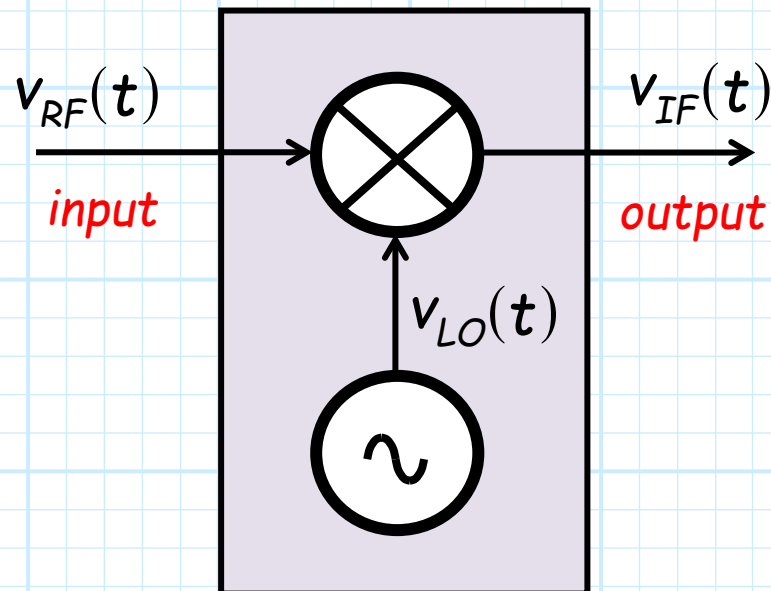$$v_{LO}(t) \; = \; A_{LO} \cos\left[\omega_{LO} t\right]$$

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

A mixer with LO:
A non-linear, 2-port device

Typically, every mixer will be **paired** with a local oscillator.

As a result, we can view a mixer/LO pair as a **non-linear, two-port device**!

The **input** to the "device" is the RF port, whereas the **output** is the IF port.

$v_{RF}(t)$ $v_{IF}(t)$

input   *output*

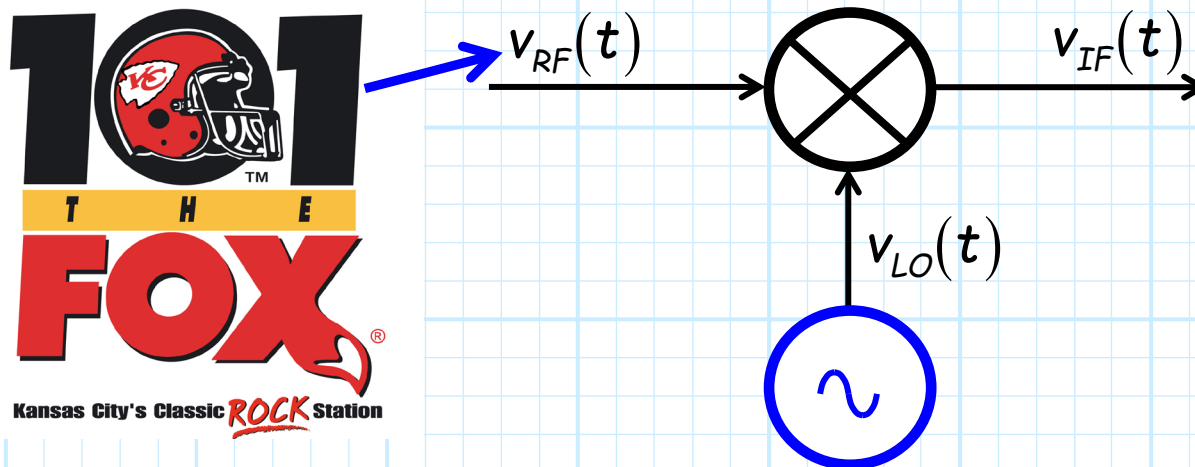$v_{LO}(t)$

The RF input is a received radio signal

In contrast to the LO signal, the **RF input signal** is generally a low-power, **modulated** signal:

$$v_{RF}(t) \; = \; a_{RF}(t) \; cos\Big[w_{RF} \, t \; + \; \varphi_{RF}(t) \Big]$$

where $a_{RF}(t)$ and/or $\varphi_{RF}(t)$ represent amplitude and phase **modulation**.

Likewise, the "carrier" frequency w_{RF} is **relatively high**.

→ The signal $v_{RF}(t)$ is typically a **received radio signal**!

$v_{RF}(t)$ $v_{IF}(t)$

$v_{LO}(t)$

If an ideal balanced mixer

Q: *So, what "output" signal* $v_{IF}(t)$ *is* **created?**

A: Let's assume we have a **balanced mixer**, so if:

$$v_{RF}(t) \; = \; a_{RF}(t) \, cos\left[\, \omega_{RF} \, t \, + \, \varphi_{RF}(t)\right]$$

Then the **IF output signal** is (ideally):

$$v_{IF}(t) \; \cong \; a_{RF}(t) \, \frac{2}{\pi} \, cos\left[(\omega_{RF} - \omega_{LO})t \, - \, \varphi_{RF}(t)\right]$$

$$+ \, a_{RF}(t) \, \frac{2}{\pi} \, cos\left[(\omega_{RF} + \omega_{LO})t \, - \, \varphi_{RF}(t)\right]$$

<u>Not much has changed</u>
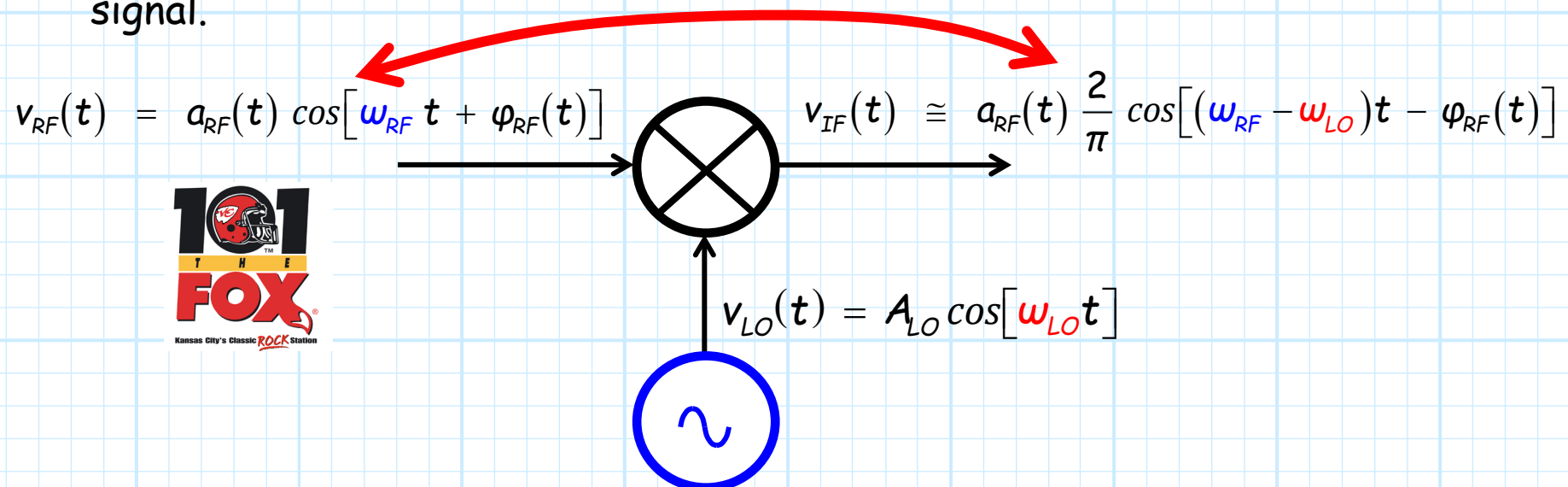
Frequently, the high frequency ($w_\Sigma = w_{RF} + w_{LO}$) term is **filtered** out, so the IF output is approximately just the **lower frequency** w_Δ term:

$$v_{IF}(t) \cong a_{RF}(t) \frac{2}{\pi} \cos\Big[(w_{RF} - w_{LO})t - \varphi_{RF}(t)\Big]$$

→ Look at what **this means**!

Q: *???*

A: It means that the output **IF** signal is **nearly** identical to the input **RF** signal.

$$v_{RF}(t) = a_{RF}(t) \cos\Big[w_{RF}\, t + \varphi_{RF}(t)\Big]$$ $$v_{IF}(t) \cong a_{RF}(t) \frac{2}{\pi} \cos\Big[(w_{RF} - w_{LO})t - \varphi_{RF}(t)\Big]$$

$$v_{LO}(t) = A_{LO} \cos\big[w_{LO}t\big]$$

Slightly smaller, and lower in frequency

The **only** differences between the input RF signal $v_{RF}(t)$ and the output IF signal $v_{IF}(t)$ are:

a) The IF signal has different (**smaller**) **magnitude**:

$$\left| v_{RF}(t) \right| = a_{RF}(t) \qquad \text{and} \qquad \left| v_{IF}(t) \right| = \frac{2}{\pi} a_{RF}(t)$$

b) The IF signal has a different **frequency** (typically, a **much lower** frequency):

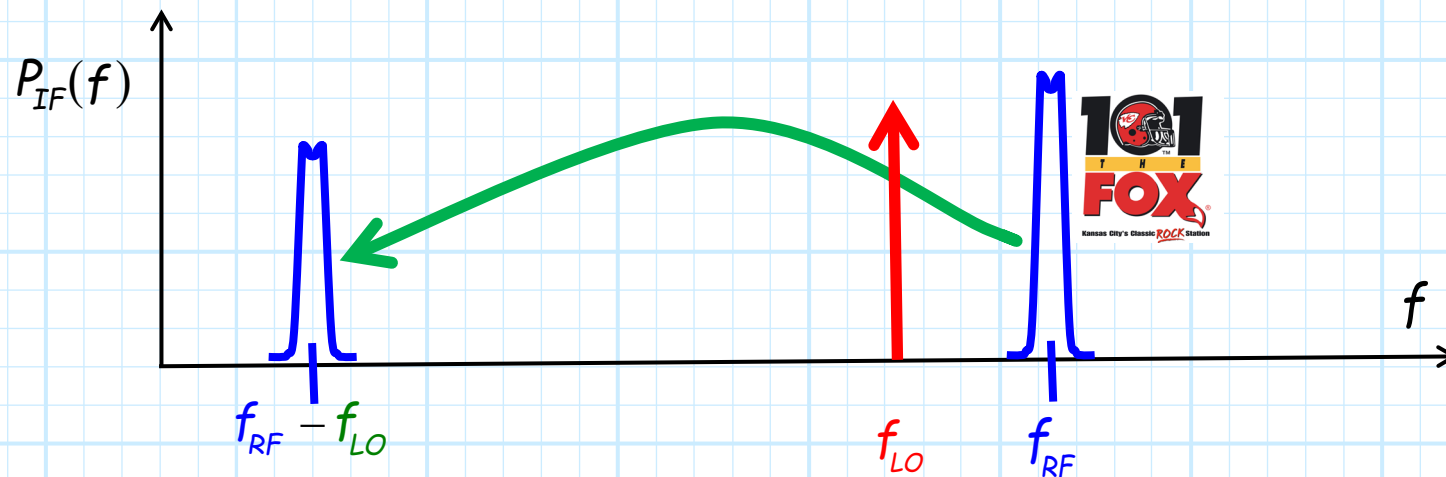$$v_{RF}(t) = a_{RF}(t) \cos\left[\omega_{RF} t + \varphi_{RF}(t) \right]$$

$$v_{IF}(t) = a_{RF}(t) \frac{2}{\pi} \cos\left[(\omega_{RF} - \omega_{LO}) t + \varphi_{RF}(t) \right]$$

It's called "down conversion"

The RF signal has been "**down converted**" from a **high** frequency w_{RF} to a typically **low** signal frequency $\left| w_{RF} - w_{LO} \right|$.

<u>Information is preserved</u>

But.

The modulation **information** $a_{RF}(t)$ and $\varphi_{RF}(t)$ has been **unaltered** in this down-conversion process!

$$v_{IF}(t) = a_{RF}(t) \frac{2}{\pi} cos\left[(\omega_{RF} - \omega_{LO})t + \varphi_{RF}(t)\right]$$

We thus can accurately **recover** the information $a_{RF}(t)$ and $\varphi_{RF}(t)$ from the IF signal—we can discern clearly the voices of both **Mitch** and **Kendall**!

Down-conversion: What's up with that?

Q: But **why** would we every want to "down-convert" an RF signal to a **lower** frequency?

A: Because eventually, we will need to **process** the signal to **recover the information** in $a_{RF}(t)$ and $\varphi_{RF}(t)$.

At lower frequencies, this processing becomes **easier**, **cheaper,** and more **accurate**!
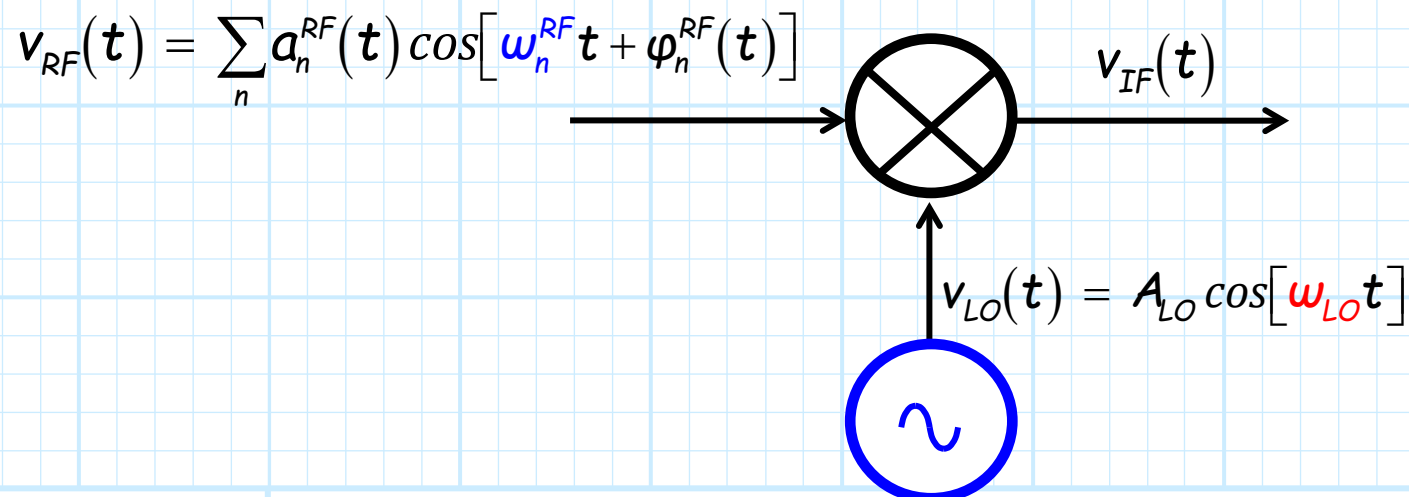
There's often a *bunch of* different signals at the input...

We have so far assumed that there is only **one signal present** at the **RF** port:

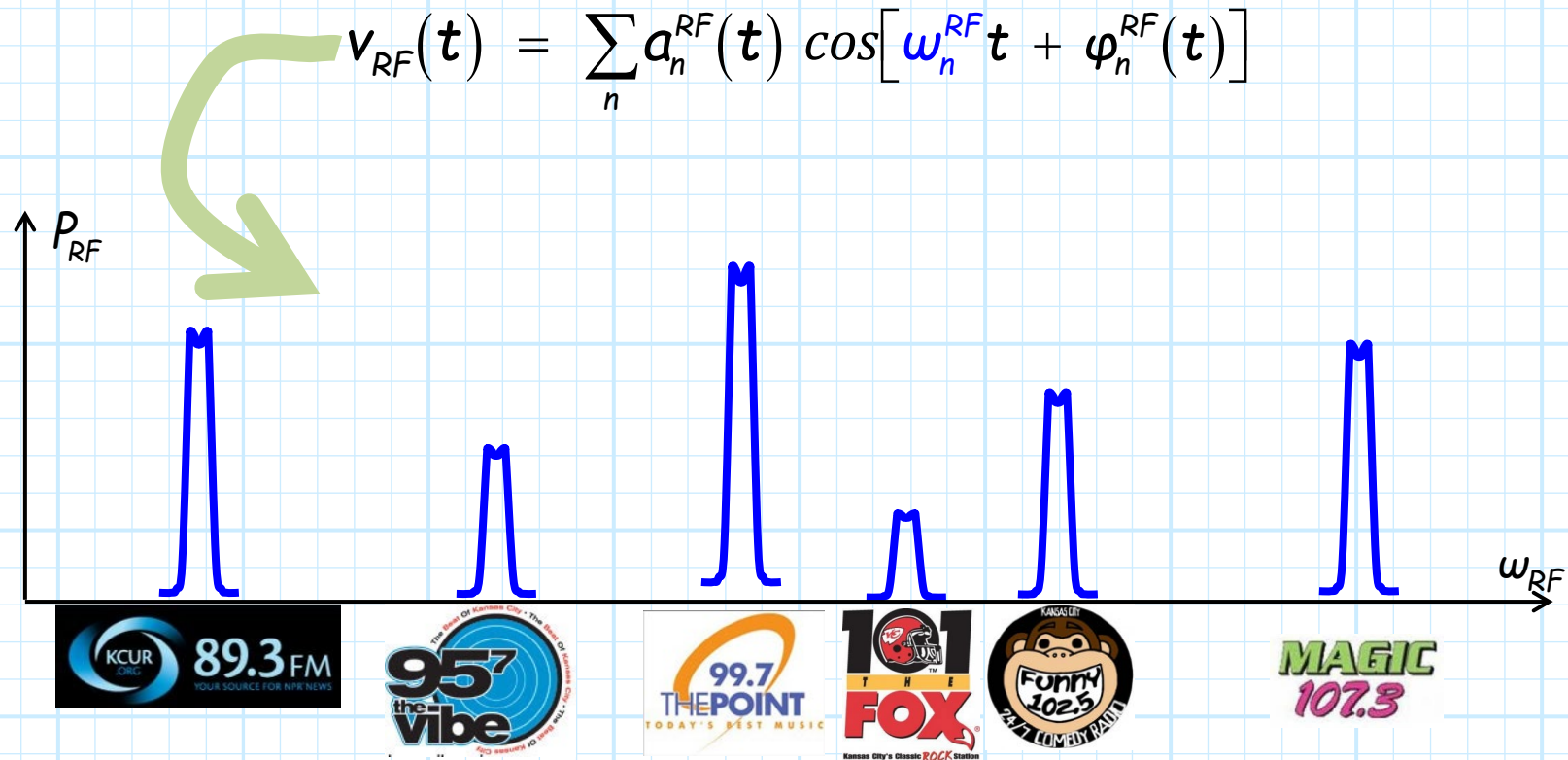$$v_{RF}(t) = a_{RF}(t)\, cos\big[\, \omega_{RF} t + \varphi_{RF}(t)\big]$$

But in actuality, this is **rarely** the case!

Instead, there usually will be at the mixer **RF port** a whole **range** of different received signals, spread across **a wide bandwidth** of RF frequencies:
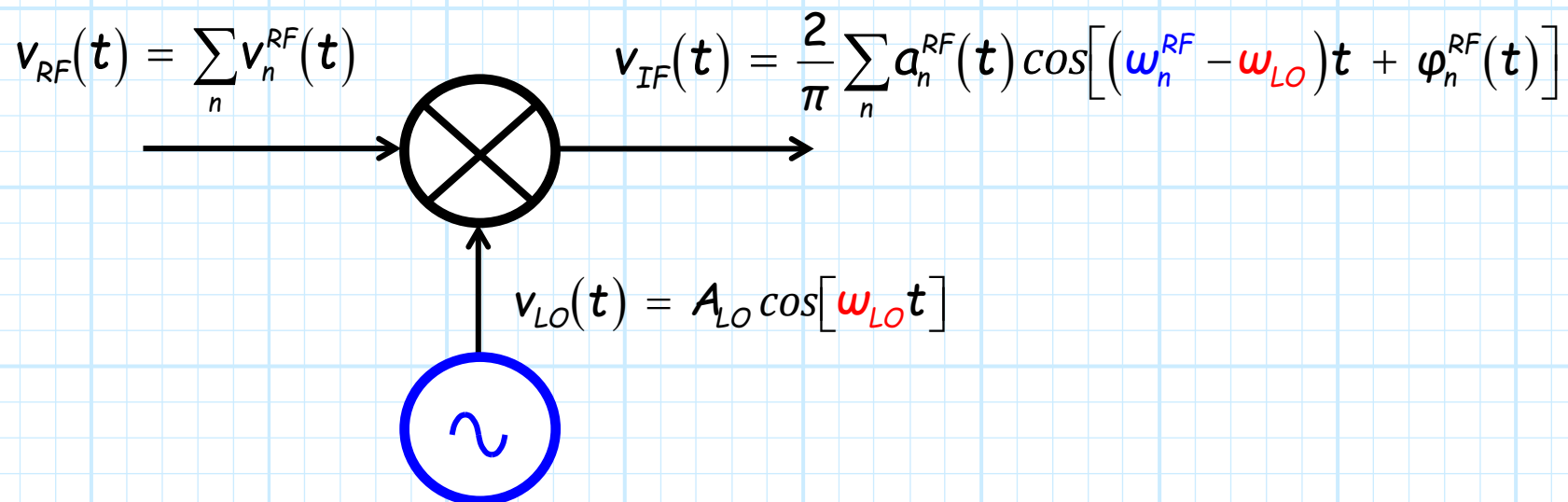
$$v_{RF}(t) = \sum_{n} a_n^{RF}(t)\, cos\big[\, \omega_n^{RF} t + \varphi_n^{RF}(t)\big]$$

$v_{IF}(t)$

$$v_{LO}(t) = A_{LO}\, cos\big[\, \omega_{LO} t\big]$$

..and that's because there's lots of "radio stations"

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!

$$v_{RF}(t) = \sum_n a_n^{RF}(t) \cos\left[\omega_n^{RF} t + \varphi_n^{RF}(t)\right]$$
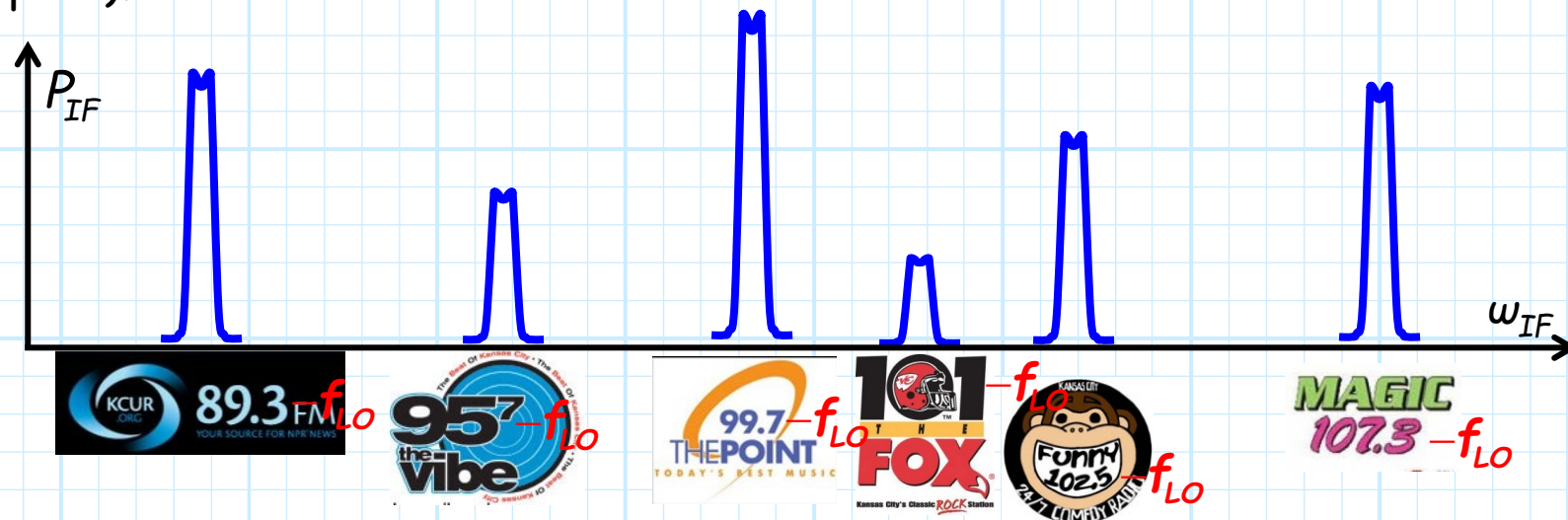
A mixer down-converts ALL these signals!

As a result, **each** of these stations will be down-converted, and so **all** of these stations will appear at the **IF output**:

$$v_{RF}(t) = \sum_n v_n^{RF}(t)$$

$$v_{IF}(t) = \frac{2}{\pi} \sum_n a_n^{RF}(t) \cos\left[\left(\omega_n^{RF} - \omega_{LO}\right)t + \varphi_n^{RF}(t)\right]$$

$$v_{LO}(t) = A_{LO} \cos\left[\omega_{LO} t\right]$$

The *entire* spectrum down-converted

Note **each** of these down-converted **radio signals** will occupy **distinct frequencies** at the IF port of the mixer (just as they did at the RF port).

Each radio signal **at the IF port** will occupy a frequency that is precisely the value of ω_{LO} **lower** than its transmitted frequency ω_n^{RF}:

$$\omega_n^{IF} \;=\; \omega_n^{RF} \;-\; \omega_{LO}$$

However, the **modulation information** $a_n^{RF}(t)$ and $\varphi_n^{RF}(t)$ (e.g., audio, video) remain (ideally) **unaltered** by this down-conversion process!