Last time we were considering mixers. There are many different mixer designs available. Generally, the more complex the mixer the higher its performance (in one respect or another). However, the greater the complexity (generally speaking), the lower the frequency of operation.
Let's look at several different types. We showed one example of a singly balanced mixer earlier. Another example is shown below:

Transmission-line transformer. Purpose of RFC is to maintain balance w.r.t ground.
This arrangement provides almost no isolation of the LO signal to the IF port. Isolation between LO to RF is expected to be very limited as well. The degree of isolation is heavily dependent on:

1) performance of the transmission-line transformer.

2) degree of match (in characteristics) of the two diodes.
Most often, higher performance receivers use at least a double balanced mixer circuit. (This arrangement can be thought of as a balance on top of a balance.)
The second balance is obtained via the incorporation of 2 additional diodes and 1 additional transmission line transformer.

Consider the following description of performance: First, for the single-balanced mixer. As the LO potential increases (positive phase of LO), current through D1 increases. The transmission-line
transformer tries to force the current through D2 to be the same. However, it can't due to the polarity of D2. Since the currents through D1 and D2 are different a significant fraction of LO energy appears at the IF port, and at the RF port.
Now, for the double-balanced mixer, consider how the second balance helps improve isolation. In this case, as the LO potential becomes positive, current flows through D1 and D3. The transmission-line transformer at the IF port tries to force the current through
D₁ and D₂ to be the same. The transmission-line transformer at the RF port also encourages these 2 currents to be the same. As a result the IF and RF ports are well isolated from the LO port. Just as indicated before the degree of balance depends on the quality of the transformers and on...
the match between diodes. Higher order balancing is sometimes, but that is not so common. There are a few other aspects of mixers that we'll consider. These include:
- IP3 performance
- impedance matching
- active mixers
- specialized mixer circuits
IP3 performance

Recall that IP3 is an important parameter for estimating intermodulation between two signals input to the mixer on the same port, usually the rf port. One way of increasing IP3 over that of a standard double-balanced mixer is to place diodes in series, e.g., replace
individual diodes in the
diode ring with 2 series
diodes.

Circuit for improved
IP3 response.

This is rather simple to
see by considering the
slope of the responses of the following circuits:

\[ \frac{dI}{dV} = \frac{I_s}{V_T} (e^{\frac{V}{V_T}} - 1) \]

\[ \frac{dI}{dV} = \frac{I_s}{V_T} (e^{\frac{V}{2V_T}} - 1) \]

Since the slope of the response decreases as the number of diodes in series increases, the sensitivity of the diode response \( I \) to changes in \( V \) is reduced. As a
result IP3 is expected to primary increase. The drawback with using multiple diodes in series is the required LO power (for a given conversion loss) increases. For example, whereas a typical double-balanced mixer may require LO power of 7-10 dBm, the higher IP3 mixer just shown may require 17 dBm LO power.
Impedance Matching

A standard mixer's spurious response level is greatly affected by the quality of terminations (impedance) provided to the ports of the mixer. Although this may not seem difficult to achieve, consider that the input to the rf port of the mixer is often the output of a filter, and
the output from the IF port is often the input of a filter. The impedance of a typical bandpass filter looks like:

\[ A_o \]  

Notice that the termination is good (low reflection) close to \( f_0 \) but poor outside the filter passband.
For better results a diplexing type of filter may be used.

Example

Standard mixer

Bandpass Filter

IF amp

RF

IF

LO

Complementary band reject filter.

For cases where loss is acceptable, impedance
matching quality can be maintained by placing an attenuator between the IF port and IF amplifier.

**Example**

Note that the attenuator reduces signal level while maintaining impedance matches at input and output.
Active mixers

For cases where frequencies aren't too high (GHz and above), active mixers are often used. This can lead to lower parts count, improved gain, efficiency, and enhanced performance. A single-balanced active mixer can look much like a differential amplifier.
For example

The quality of performance is affected substantially by the degree of balance maintained at the LO and IF ports. Notice that the transistor action provides some isolation between RF and LO ports.
A circuit which provides substantially improved isolation between RF and IF ports, and between RF and LO ports is the double-balanced arrangement shown in the figure below.
Specialized mixer circuits

SSB mixer circuit

Assume \( RF = C \cos \omega_{RF} \)
\( LO = D \cos \omega_{LO} \)

and find the signals delivered to ports A and B.
RF1 = \frac{C}{\sqrt{2}} \cos \omega_{RF} t

RF2 = \frac{C}{\sqrt{2}} \cos (\omega_{RF} t - \frac{\pi}{2})
= \frac{C}{\sqrt{2}} \sin (\omega_{RF} t)

LO1 = \frac{D}{\sqrt{2}} \sin (\omega_{LO} t)

LO2 = \frac{D}{\sqrt{2}} \cos (\omega_{LO} t)

IF1 = \frac{CD}{2} \left[ \sin \omega_{LO} t \cos \omega_{RF} t \right]

IF2 = \frac{CD}{2} \left[ \cos \omega_{LO} t \sin \omega_{RF} t \right]

A = \frac{1}{\sqrt{2}} \left( \frac{CD}{2} \right) \left[ IF1 + IF2 \right]
= \frac{1}{\sqrt{2}} \left( \frac{CD}{2} \right) \sin \left( (\omega_{LO} + \omega_{RF}) t \right) (USB)
\[ B = \frac{1}{\sqrt{2}} \left( \frac{CD}{2} \right) \left[ IF1 - IF2 \right] \]

\[ = \frac{1}{\sqrt{2}} \left( \frac{CD}{2} \right) \sin \left( (\omega_{LO} - \omega_{RF})t \right) \]

\((LSB)\)

Image rejection mixer

\[ RF1 = \frac{C}{\sqrt{2}} \left[ \cos \left( (\omega_{LO} + \omega_{IF})t \right) \right. \]
\[ + \cos \left( (\omega_{LO} - \omega_{IF})t \right) \]
\[ RF2 = \frac{C}{\sqrt{2}} \left[ \sin \left( (\omega_{LO} + \omega_{IF})t \right) \right. \]
\[ + \sin \left( (\omega_{LO} - \omega_{IF})t \right) \]
\[ L01 = L02 = \frac{D}{\sqrt{2}} \cos(\omega_{lo} t) \]

\[
IF1 = \frac{CD}{2} \left[ \cos(\omega_{lo} t) \left\{ \cos(\omega_{lo} + \omega_{IF} t) \right. \\
+ \cos((\omega_{lo} - \omega_{IF} t) \left) \right] \\
= \frac{CD}{4} \left[ \cos((\omega_{lo} + \omega_{RF1} t)) \\
+ \cos((\omega_{lo} - \omega_{RF1} t)) \\
+ \cos((\omega_{lo} + \omega_{RF2} t)) \\
+ \cos((\omega_{lo} - \omega_{RF2} t)) \right] \\
\]
\[ IF = \frac{CD}{2} \left[ \cos(w_{\text{LO}} t) \left\{ \sin((w_{\text{LO}} + \omega_{\text{IF}}) t) + \sin((w_{\text{LO}} - \omega_{\text{IF}}) t) \right\} \right] \]

\[ = \frac{CD}{4} \left[ \sin((w_{\text{LO}} + \omega_{\text{RF}}) t) + \omega_{\text{IF}} \sin((w_{\text{LO}} - \omega_{\text{RF}}) t) + \sin((w_{\text{LO}} + \omega_{\text{RF}}) t) \right] \]

\[ IF = \frac{1}{\sqrt{2}} \frac{CD}{4} \left[ -\cos((w_{\text{LO}} + \omega_{\text{RF}}) t) + \omega_{\text{IF}} \cos((w_{\text{LO}} - \omega_{\text{RF}}) t) \right] \rightarrow \]
\[ - \cos \left( \frac{(w_{lo} + w_{RF_2}) t}{2} \right) + \cos \left( (w_{lo} - w_{RF_2}) t \right) + \cos \left( (w_{lo} + w_{RF_1}) t \right) + \cos \left( (w_{lo} - w_{RF_1}) t \right) + \cos \left( (w_{lo} + w_{RF_2}) t \right) + \cos \left( (w_{lo} - w_{RF_2}) t \right) \]

\[ IF = \frac{1}{\sqrt{2}} \frac{C D}{2} \cos \left( (w_{lo} - w_{RF_2}) t \right) \]

If we take the output from the terminated port and terminate the previous
IF port, then we have

\[ IF = \frac{1}{2} \frac{CD}{2} \cos ( (\omega_{lo} - \omega_{RF}) t) \]

Discuss termination insensitive mixer on pg.

287 Fig. 6.8.

Oscillators and synthesizers

Characteristics of an oscillator signal:
A practical oscillator signal is subject to many nonideal affects:

- drift in frequency (time and temperature)
- other responses in addition to the desired frequency

\[ H(f) \]

Spurious responses

\[ f_0 \] noise sidebands
Other affects that may occur in poorly designed oscillator:

- squeeging (motorboating) this is due multiple oscillations trying to occur in the oscillator at the same time.

- crystal oscillator may switch from one resonance (or antiresonance) somewhat erratically.

- oscillator may not start up predictably.
Mechanisms responsible for drift:

- inadequate Q of tuned circuit (or crystal)
- tolerances in components
- temperature effects
- variations in power supply voltages or in load impedances.

Degree of drift is largely determined by:
- Quality of power supply
- Stability of load impedance
- Stability of the tuned circuit
- Q of tuned circuit.

Free running oscillations are seldom found in modern day communication systems due to strict requirements on spectral control.
Example of degree of stability:
free running oscillator
$10^{-4}$ or $10^{-5}$
crystal oscillators can easily achieve $10^{-6}$.
$10^{-8}$ is possible with ovenized crystal oscillators.

Noise effects
These cause the spectrum to be nonideal.
Phase noise is due to $1/f$ noise, Johnson noise
and Barkhausen noise.

Spurious responses may be a result of harmonics, effects of synthesizer circuit, and power supply effects.

Simple types of synthesizers:

Synthesizer helps us have variable frequency capability with drift (noise) characteristics comparable to those of a crystal osc.
\[ \frac{f_{\text{VCO}}}{f_{\text{XTAL}}} = N \]

\[ \frac{f_{\text{VCO}}}{f_{\text{XTAL}}} = \left( \frac{M}{N} \right) \]

Fractional \(-N\) synthesis