ECE 453
Wireless Communication Systems

Mixers

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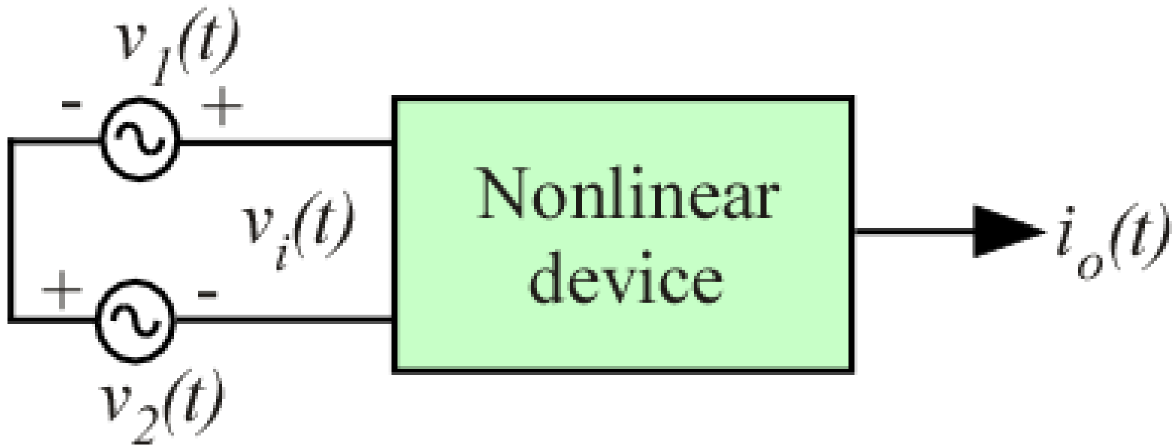
Mixers

Frequency translation modules used in receivers to produce baseband signals

- Frequency can be higher (up-conversion) or lower (down-conversion)
- Make use of nonlinearities in devices
- Can be based on passive or active devices
- Used in receivers, transmitters and instrumentation
- Superheterodyne receivers combines RF and LO signals to produce IF

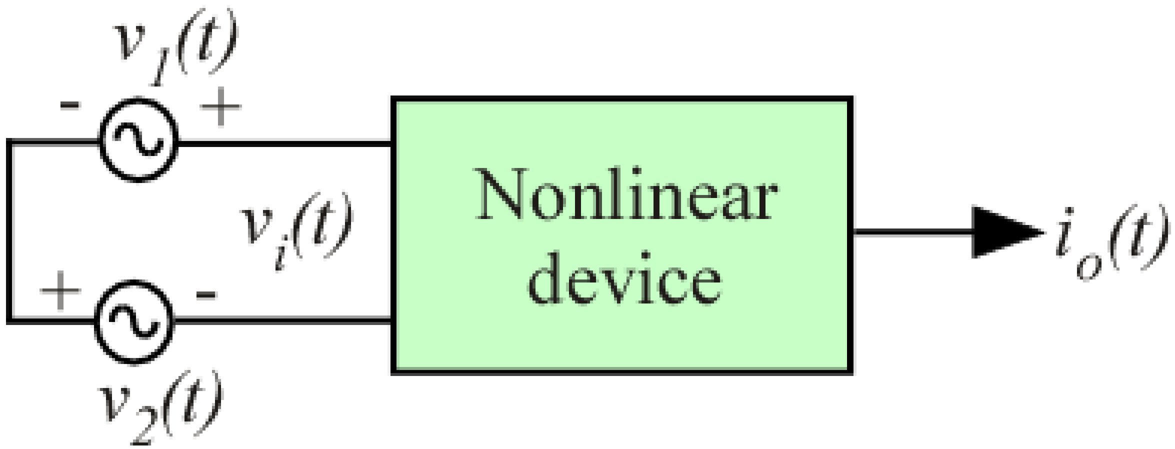
Nonlinear Behavior



$$i_o(t) = I_0 + a v_i(t) + b\left[v_i(t)\right]^2 + c\left[v_i(t)\right]^3 + \ldots$$

- **If input has one frequency, harmonics will be generated**
- **If several input frequencies are used, sum and difference frequencies are generated**

Nonlinear Behavior



Square-law behavior is ideal for mixer since the least number of undesired frequencies are produced

$$i_o(t) = av_i(t) + b\left[v_i(t)\right]^2$$

Mixer Principles

$$v_i(t) = V_1 \cos\omega_1 t + V_2 \cos\omega_2 t$$

$$i_o(t) = aV_1 \cos\omega_1 t + aV_2 \cos\omega_2 t + bV_1^2 \cos^2 \omega_1 t$$
$$+ bV_2^2 \cos^2 \omega_2 t + 2bV_1V_2 \cos\omega_1 t \cos\omega_2 t$$

- **The final term (or *product term*) yields the desired output**

$$2bV_1V_2 \cos\omega_1 t \cos\omega_2 t =$$
$$bV_1V_2\left[\cos(\omega_1 - \omega_2)t + \cos(\omega_1 + \omega_2)t\right]$$

Mixer Principles

If filter is used to remove unwanted terms:

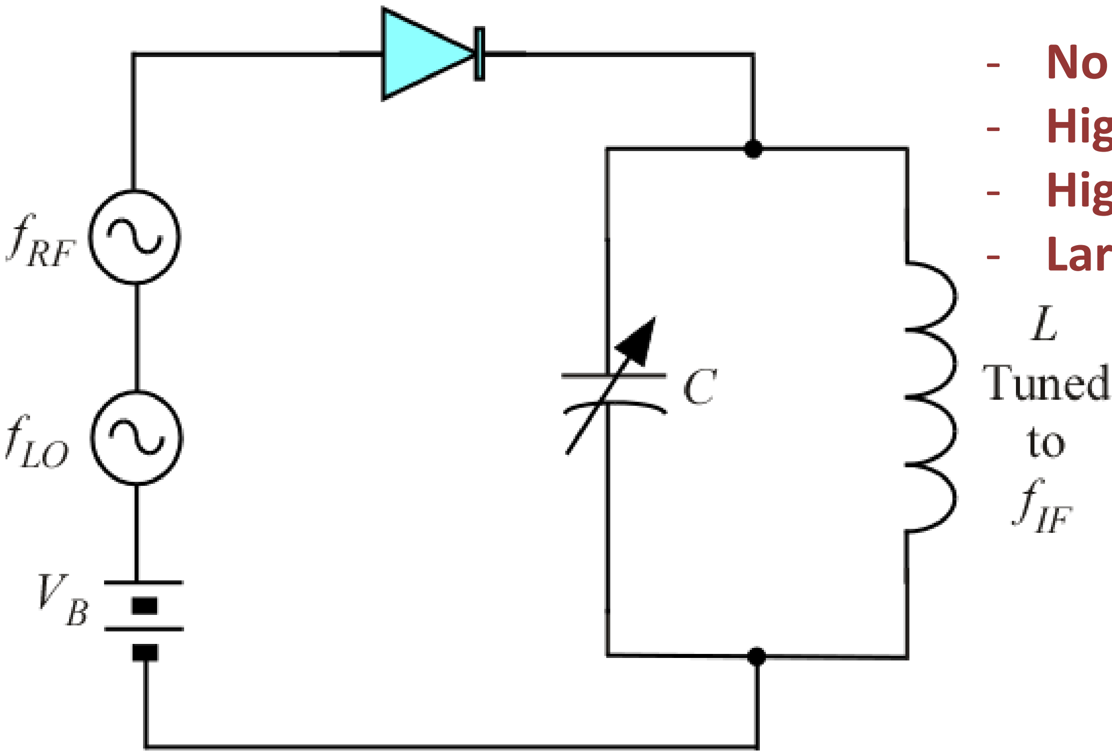
$\omega_1 \rightarrow \omega_{LO}$: local oscillator frequency

$\omega_2 \rightarrow \omega_{RF}$: RF frequency

$$i_o(t) = bV_1V_2\left[\cos\underbrace{\left(\omega_{LO} - \omega_{RF}\right)}_{\omega_{IFL}}t + \cos\underbrace{\left(\omega_{LO} + \omega_{RF}\right)}_{\omega_{IFH}}t\right]$$

Filter can be used to choose IF frequency

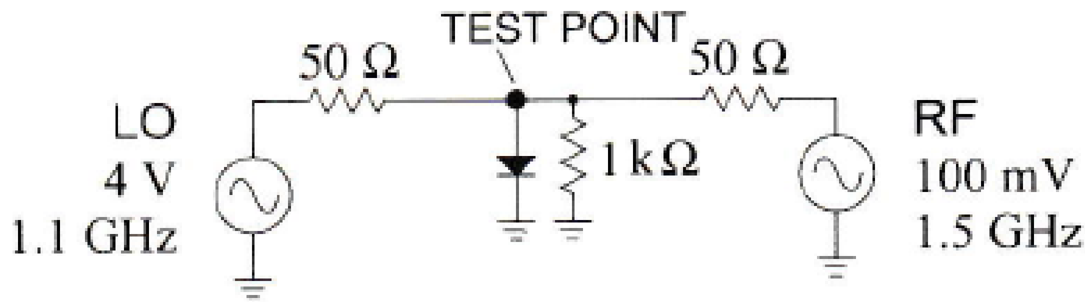
Single-Ended Mixer

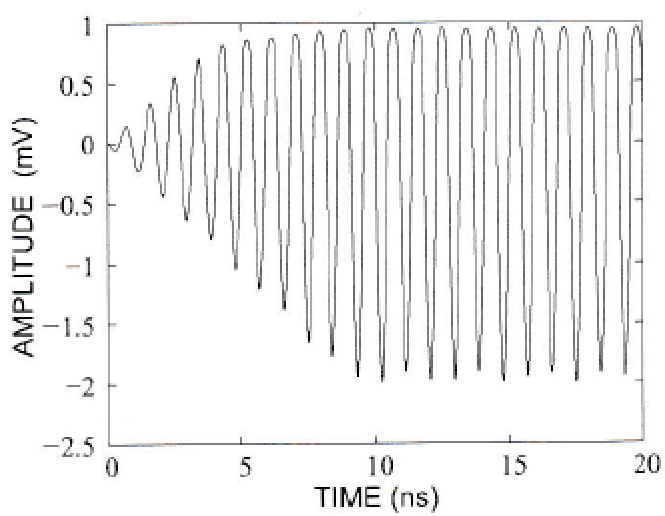


Limitations

- No isolation between LO and RF
- High-order nonlinearities
- High noise figure
- Large output LO current

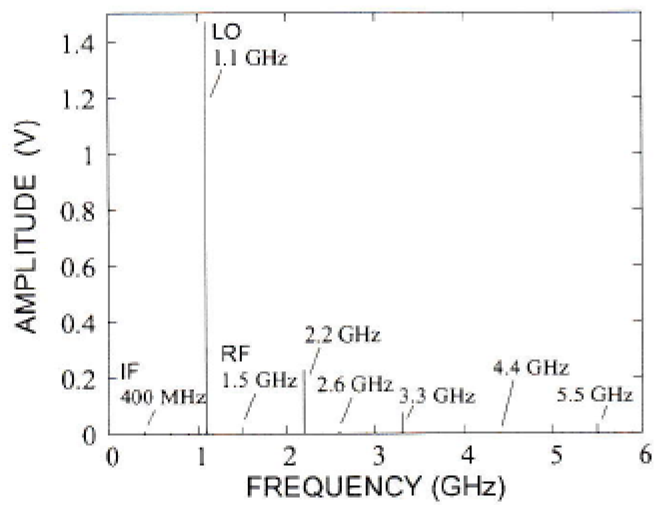
Single-Ended Mixer



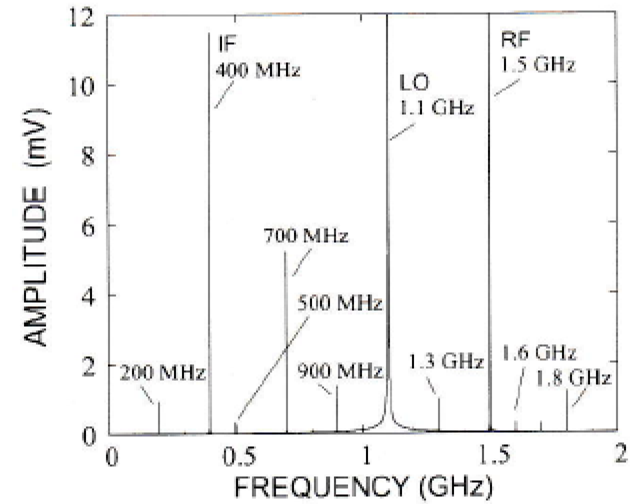


Waveform at test point

Single-Ended Mixer



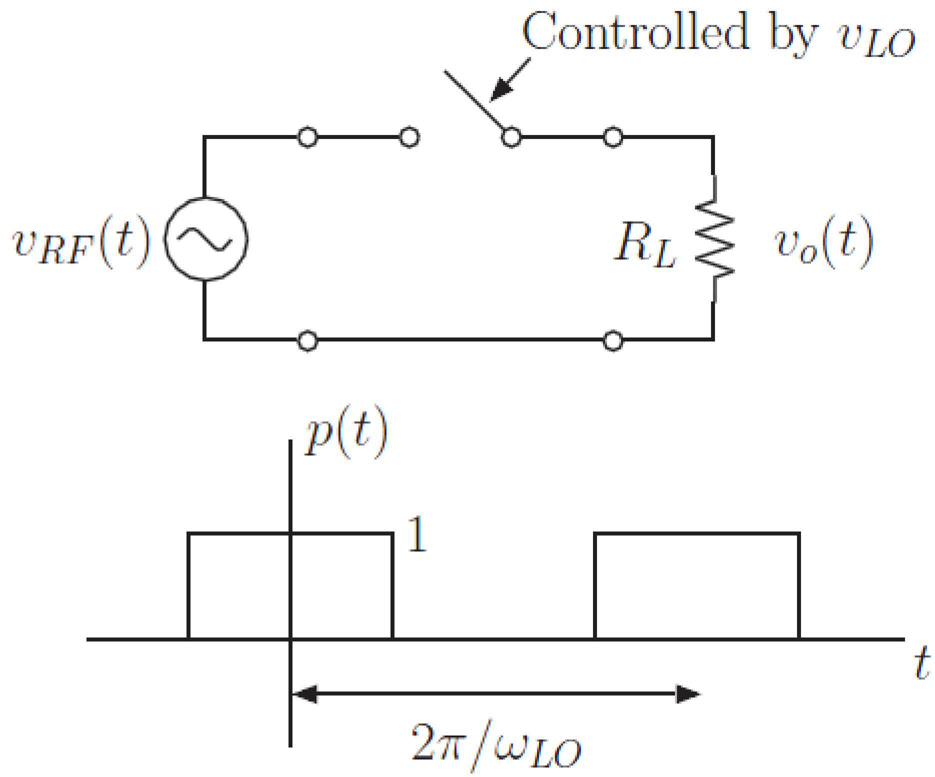
Spectrum at test point



Expanded spectrum at test point

Desired signal is IF at 400 MHz

Switching Principle



Simple switch exhibits strong nonlinearities

Switching Principle

$$S(t)=\frac{1}{2}+\sum_{n=1}^{\infty}\frac{\sin n\pi/2}{n\pi/2}\cos n\omega_{LO}t$$

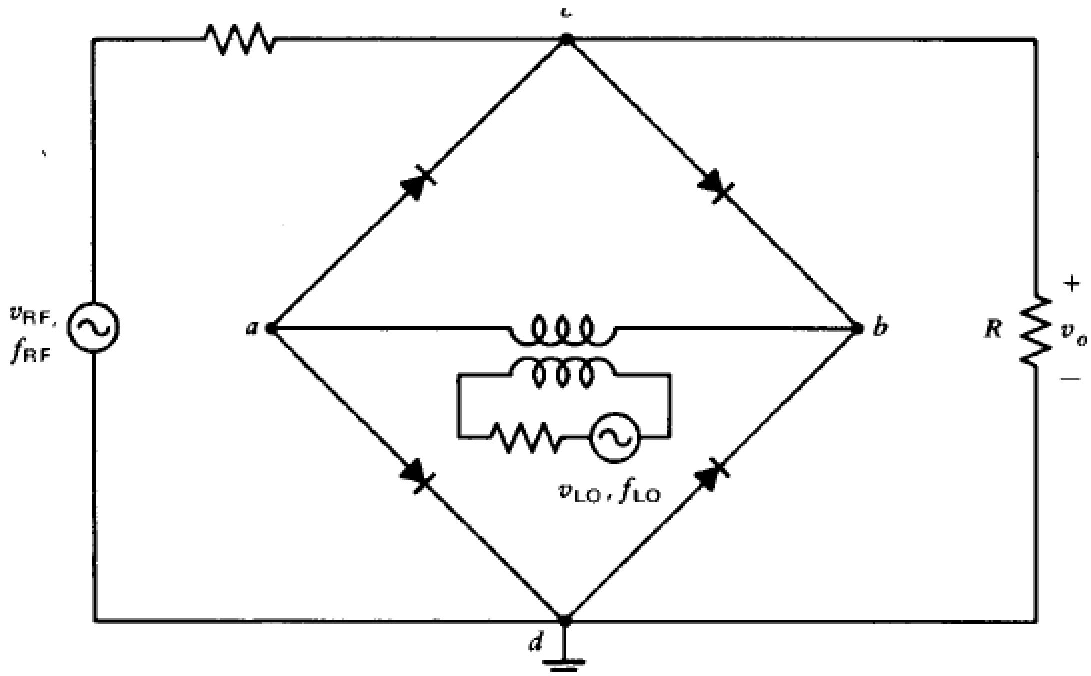
$$v_{RF}(t)=V_{RF}\cos\omega_{RF}t$$

$$v_o(t)=v_{RF}(t)\times S(t)=V_{RF}\cos\omega_{RF}t\left(\frac{1}{2}+\sum_{n=1}^{\infty}\frac{\sin n\pi/2}{n\pi/2}\cos n\omega_{LO}t\right)$$

- **Even harmonics of f_{LO} disappear since $sin(n\pi/2)/n\pi/2 = 0$ when n is even**
- **No frequency terms in f_{LO} and its odd harmonics**
- **Only terms due to $\cos\omega_{RF}t$ x $\cos n\omega_{LO}t$ with n odd**

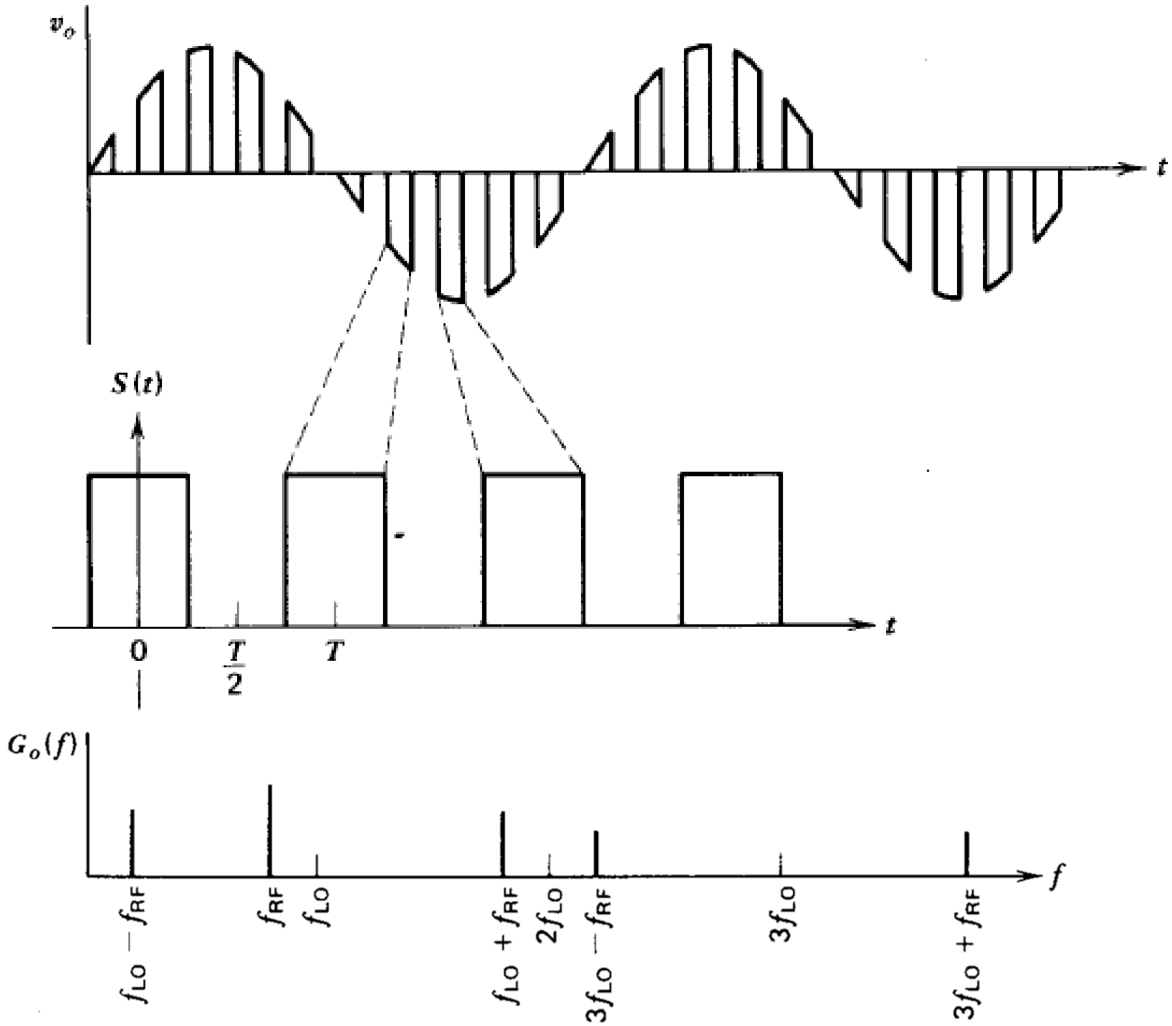
Filter can be used to select $\left|f_{RF}\pm f_{LO}\right|$

Single-Balanced Diode Mixer

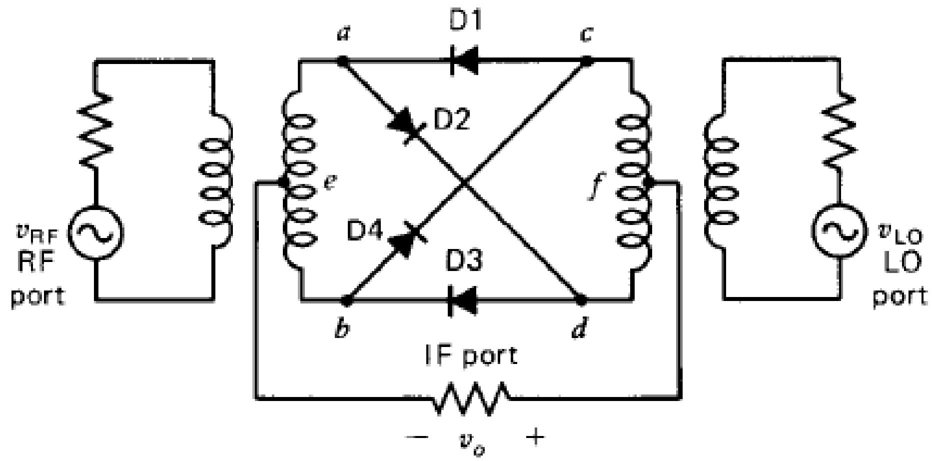


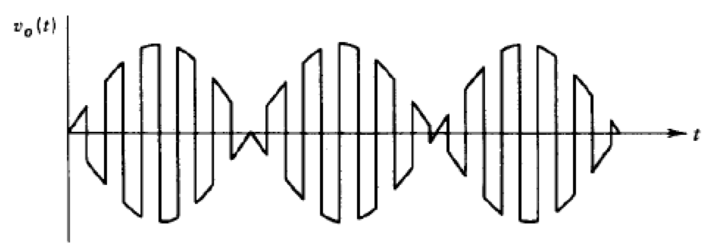
- $v_{LO} >> v_{RF}$ so LO signal controls diode states
- Diodes act like switches

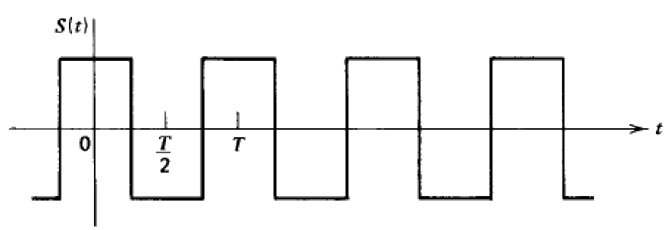
Single-Balanced Diode Mixer Operation



Double-Balanced Diode Mixer

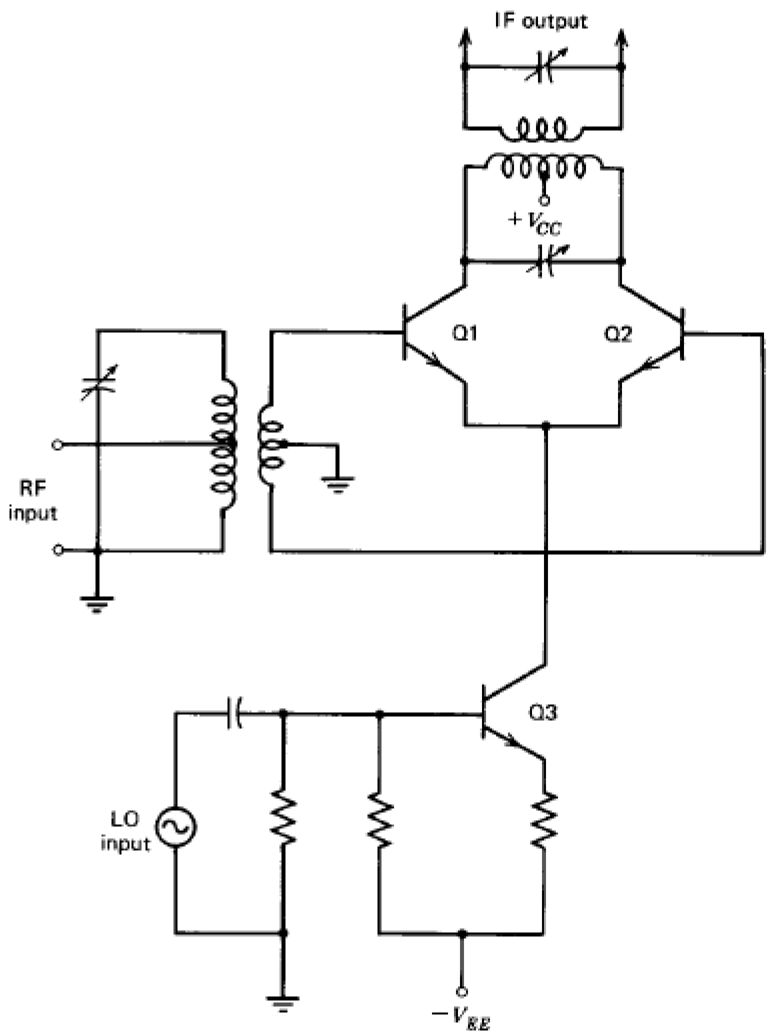






Currents due to v_{RF} are small compared to those due to v_{LO}.

Balanced BJT Mixer

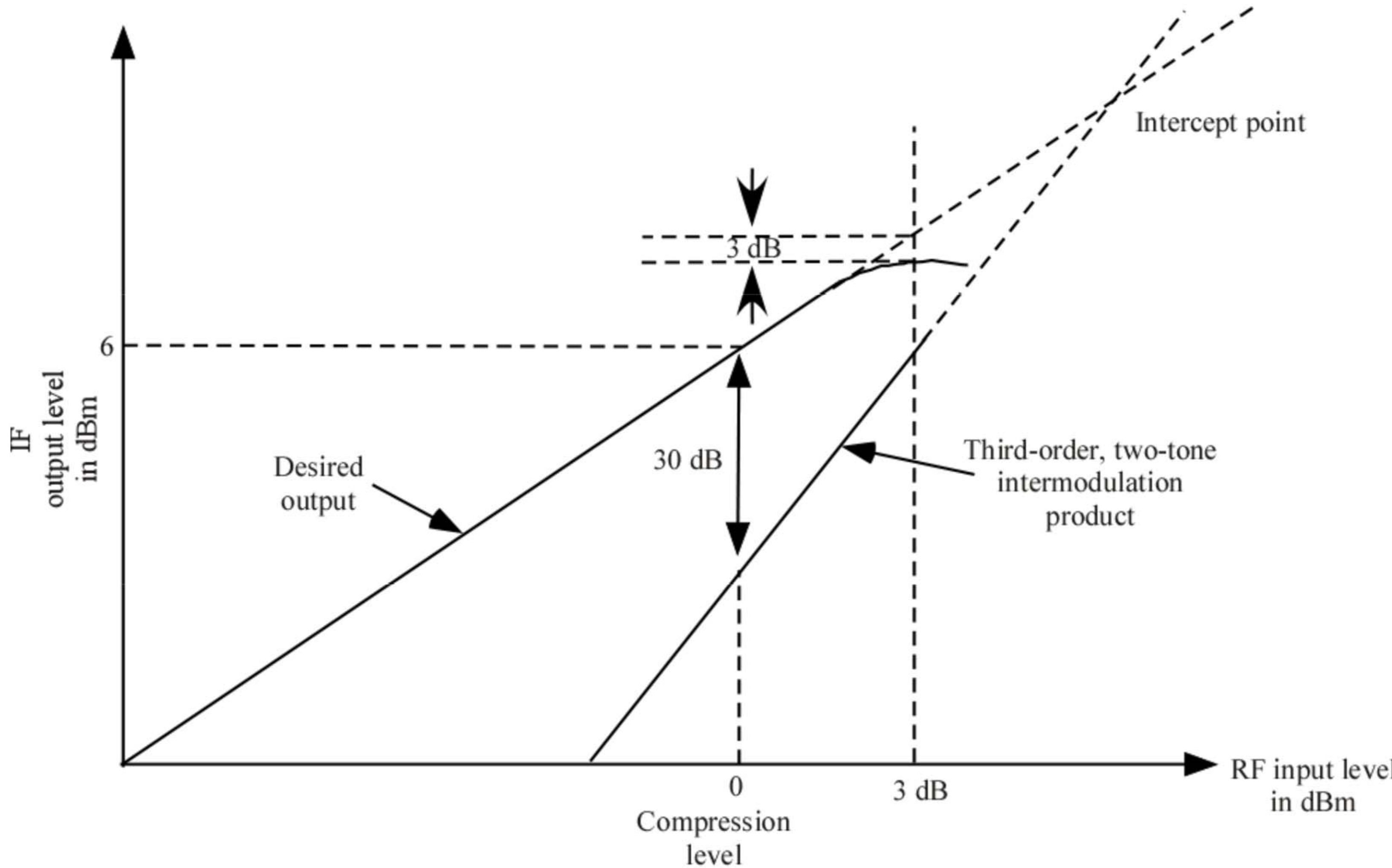


If transistors are matched, LO signal does not reach RF or IF ports.

Mixer Performance

- **Conversion Gain (Loss) – ratio of IF power to RF power**
- **Noise Figure - ratio of SNR_{in} to SNR_{out}**
- **Isolation - amount of leakage or feedthrough between mixer ports**
- **Conversion Compression - deviation of IF output power from linearity**
- **Dynamic Range – amplitude range over which mixer can operate**
- **Two-Tone, Third-Order Intermodulation Distortion – distortion caused by second received RF signal**
- **Intercept Point – measures third-order suppression**
- **Desensitization – compression of signal at adjacent frequency**
- **Harmonic Intermodulation Distortion – mixing of harmonics**
- **Cross-Modulation Distortion – transfer from modulated to unmodulated carrier**

Mixer Performance Terminology



Mixer Topologies

Mixer type	Advantages	Disadvantages
Active (vs. passive)	• Conversion gain • Better linearity • Lower LO power • Simpler to implement	• Typically higher noise figure • Less-predictable performance • Limited to lower frequencies
Unbalanced (active)	• Lowest noise figure • Ali ports single-ended	• Poor port-to-port isolation • Poor linearity • Difficult to implement
Single-balanced (active)	• LO-to-RF isolation • RF-to-IF isolation • Best linearity • Good noise figure	• Differential IF output • LO-to-IF feed-through
Double-balanced (active)	• LO-to-RF, LO-to-IF and RF-to-IF isolation • Good spurious product rejection • Good linearity • Simple to implement	• High noise figure • High power consumption