

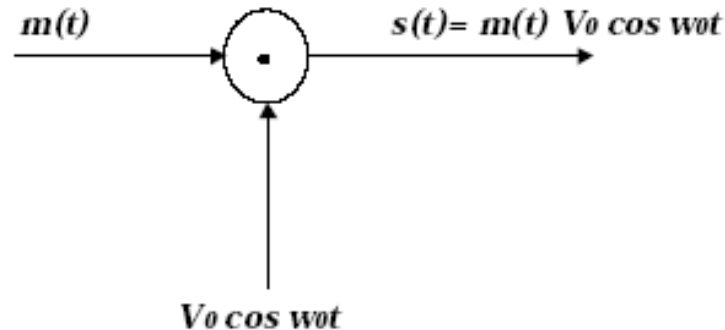


Radiofrequency Measurements

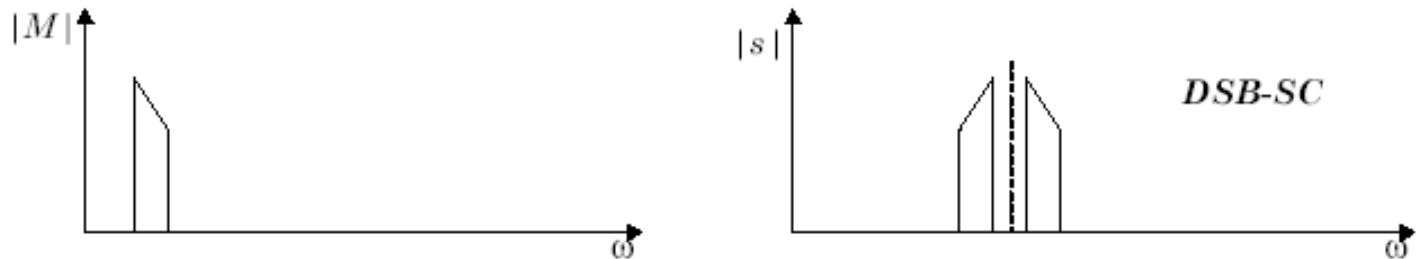
Mixers

Mixer

A mixer is a circuit used for frequency conversion, needful for telecommunications, but also for radiofrequency measurements. The typical operations of a mixer are modulation, demodulation, and frequency multiplication. The main function of a mixer is a product block, symbolized, usually, by a circle with a dot in the center a point or a "x", as shown in the following figure



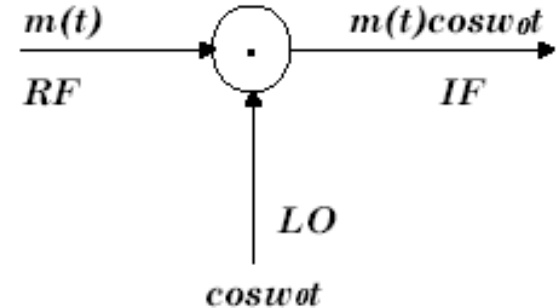
The product block allows, for example, achieving amplitude modulation of a carrier, obtaining as output a modulated signal $s(t)$. Looking at the spectra, we have:



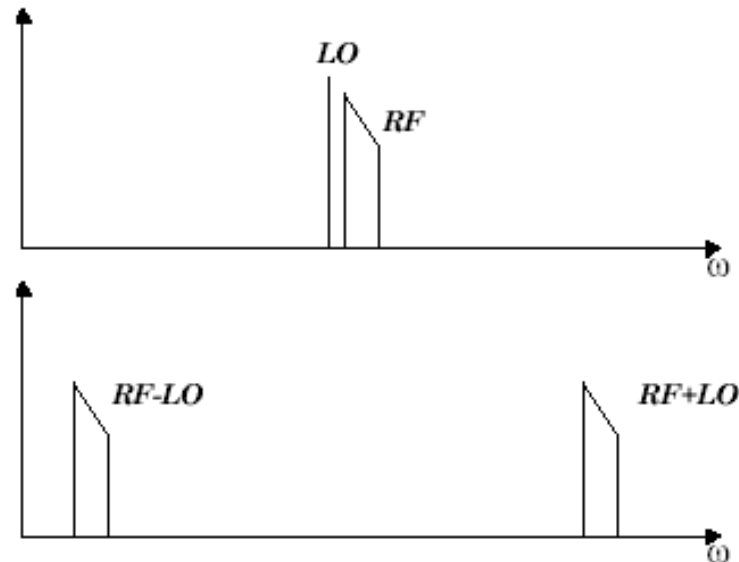
Frequency conversion

The nomenclature for the 3 mixer ports are the Local Oscillator (LO) port, the Radio Frequency (RF) port, and the Intermediate Frequency (IF) port.

The LO port is typically driven with either a sinusoidal continuous wave (CW) signal or a square wave signal.



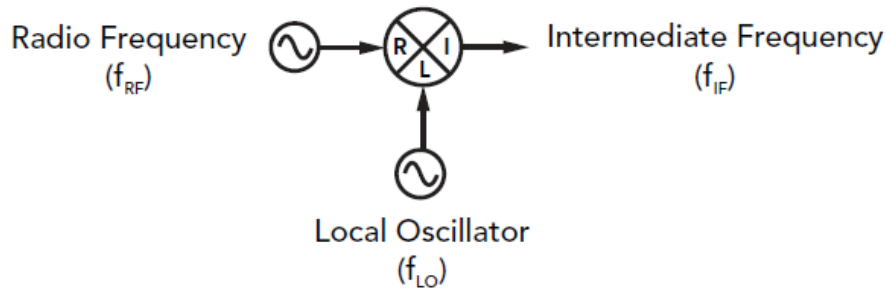
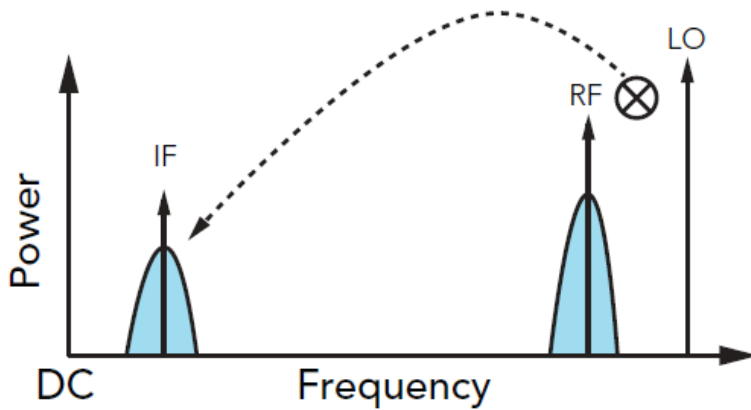
$$f_{IF} = f_{LO} \pm f_{RF}$$



Frequency conversion

DOWNCONVERSION

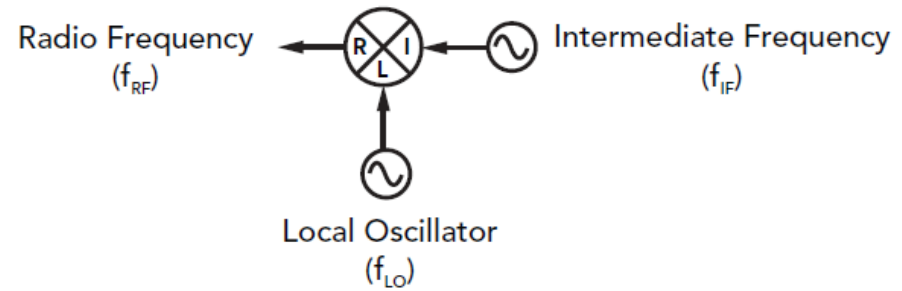
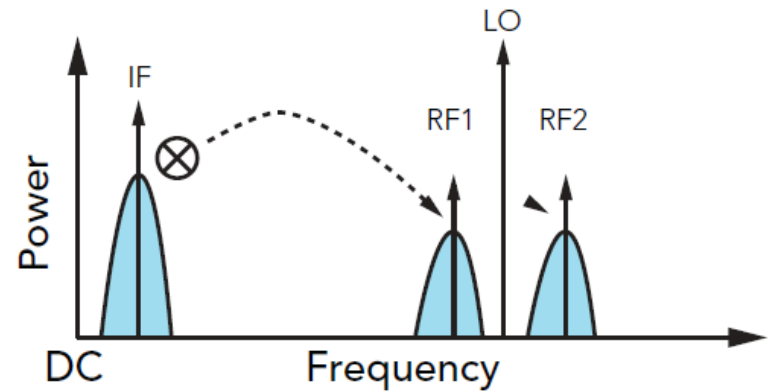
$$f_{IF} = |f_{LO} - f_{RF}|$$



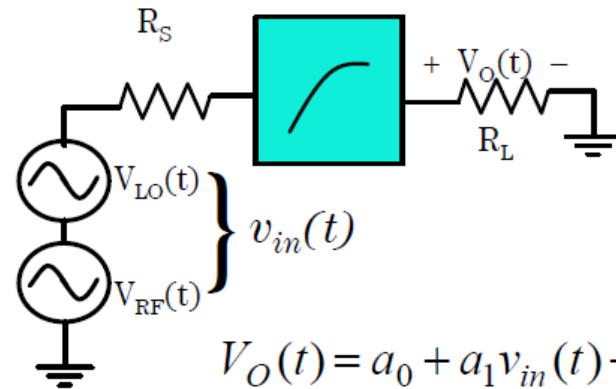
UPCONVERSION

$$f_{RF1} = f_{LO} - f_{IF}$$

$$f_{RF2} = f_{LO} + f_{IF}$$



Mixer as non-linear circuit



second-order product term

$$v_u = f(v_m, v_c)$$

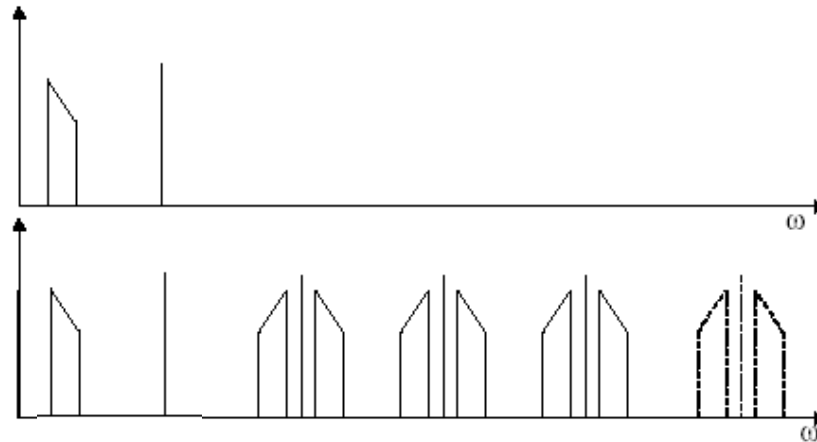


$$V_O(t) = a_0 + a_1 v_{in}(t) + a_2 v_{in}^2(t) + a_3 v_{in}^3(t) + \Lambda$$

$$v_u = a_{00} + a_{10} v_m + a_{01} v_c + a_{11} v_m v_c + a_{21} v_m^2 v_c + a_{12} v_m v_c^2 + \dots + a_{20} v_m^2 + a_{02} v_c^2 + \dots$$



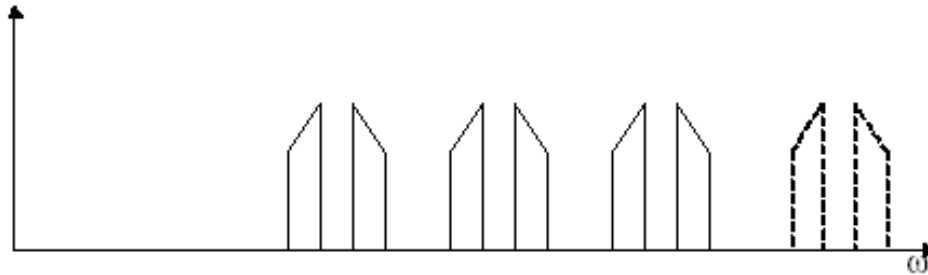
$$[v_m \ll] \quad v_u \cong b_0 + b_1 v_c + b_2 v_c^2 + b_3 v_c^3 + \dots + [c_0 + c_1 v_c + c_2 v_c^2 + c_3 v_c^3 + \dots] v_m \quad \rightarrow \quad v_u = B[v_c] + C[v_c] v_m$$



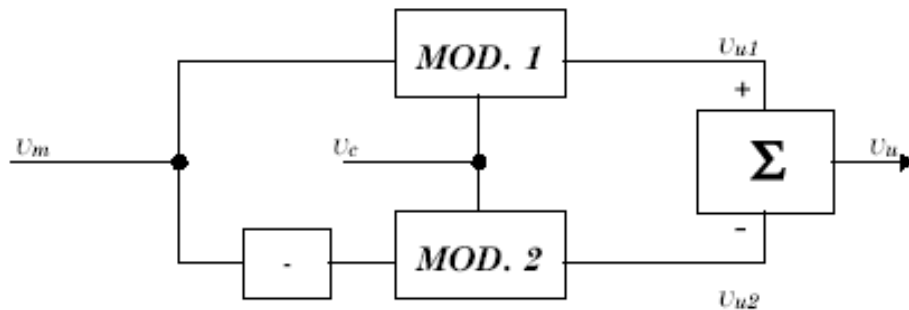
(Simply) Balanced Mixer

A mixer is **balanced** (or simply balanced) if

$$B[v_c]=0 \quad \longleftrightarrow \quad \text{if } v_m=0, v_u=0.$$

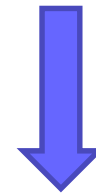


$$v_u = B[v_c] + C[v_c]v_m$$



$$v_{u1} = B[v_c] + C[v_c]v_m$$

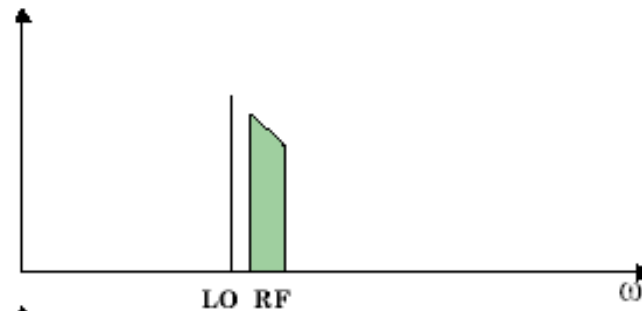
$$v_{u2} = B[v_c] - C[v_c]v_m$$



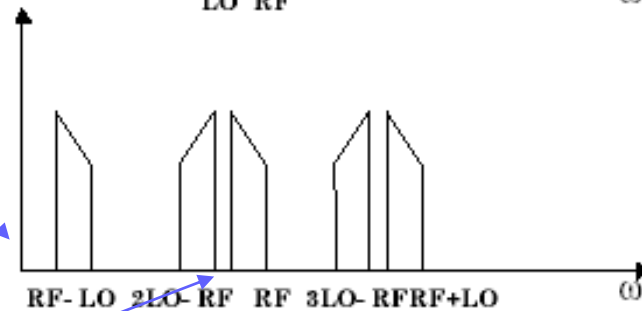
$$v_u = v_{u1} - v_{u2} = B[v_c] + C[v_c]v_m - B[v_c] + C[v_c]v_m = 2C[v_c]v_m$$

Down converter (balanced)

No more DC component



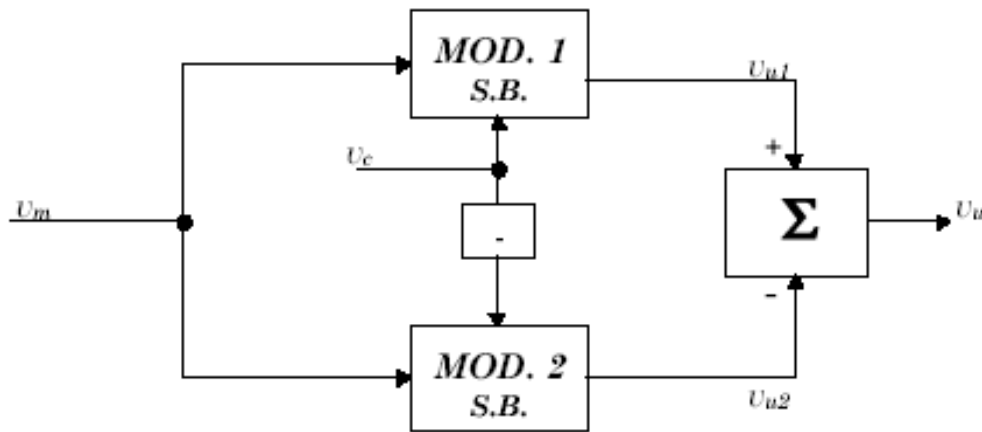
No more LO harmonics



Double Balanced Mixer

$$v_u = B[v_c] + C[v_c]v_m$$

A mixer is **double balanced** if it is balanced ($B[v_c]=0$) and $C[v_c]$ is an ODD function



$$v_{u1} = 2C[v_c]v_m$$

$$v_{u2} = 2C[-v_c]v_m$$

$$v_u = v_{u1} - v_{u2} = 2v_m \{C[v_c] - C[-v_c]\}$$

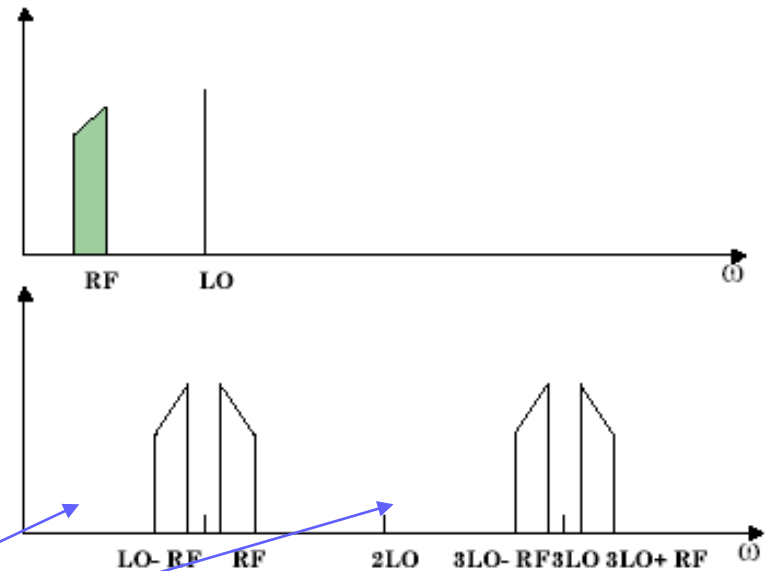
$$C[v_c] = c_0 + c_1v_c + c_2v_c^2 + c_3v_c^3 + \dots$$

$$C[-v_c] = c_0 - c_1v_c + c_2v_c^2 - c_3v_c^3 + \dots$$

$$v_u = 2v_m [2c_1v_c + 2c_3v_c^3 + \dots]$$

Up converter (double balanced)

No DC component (balanced)
No LO harmonics (balanced)

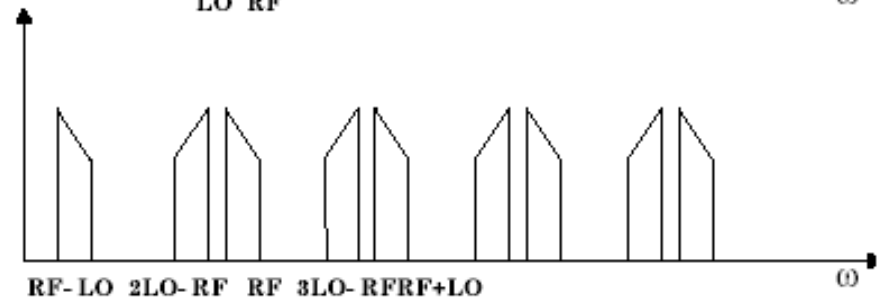


No more RF signal at LO even harmonics positions (including baseband)

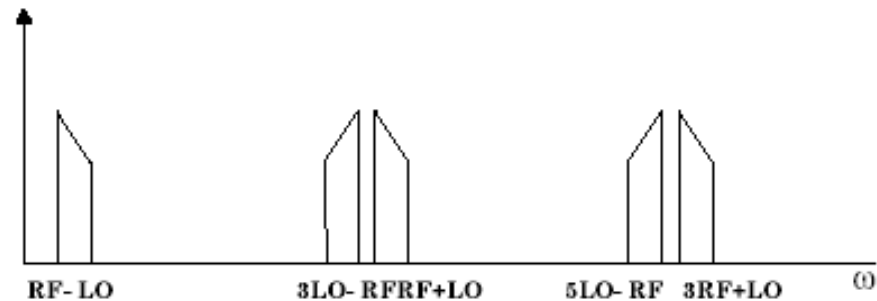
Down converter (double balanced)



Simple balanced

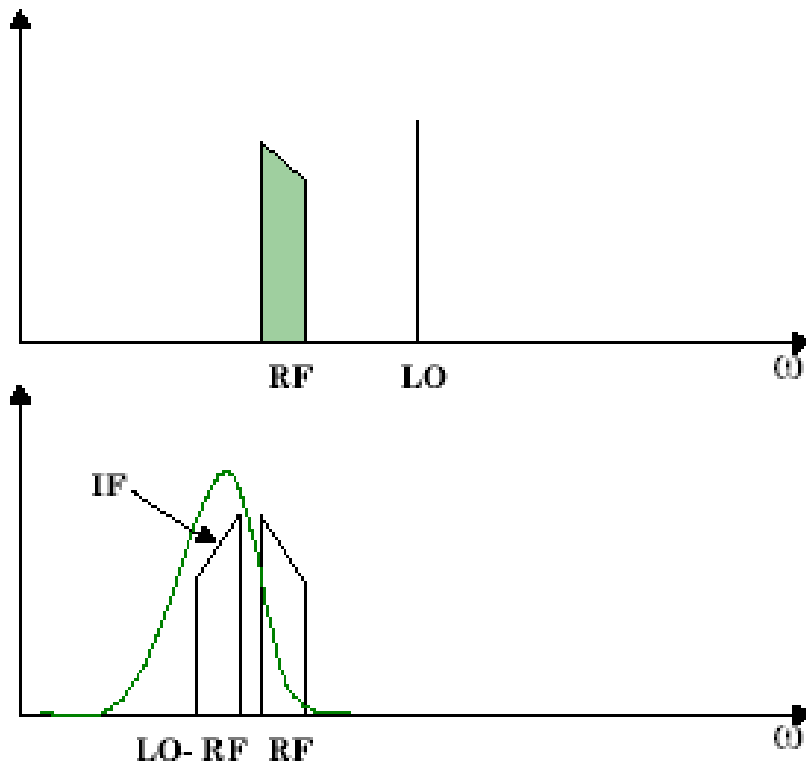


Double balanced



Double balancing advantages

No more need for demanding filtering

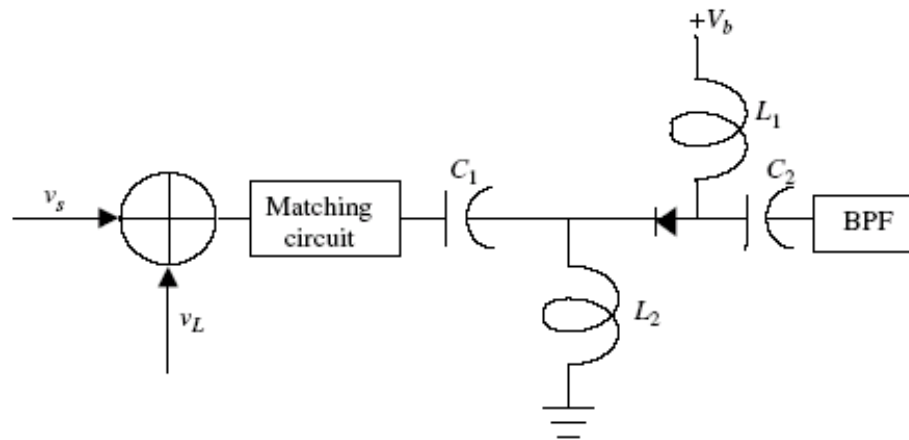


Mixer implementation: non-linear circuits

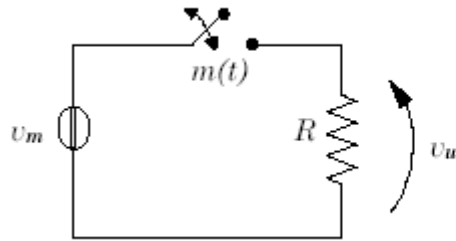


$$v_{out} = f(v_C + v_m) = \alpha(v_C + v_m)^2 + f_1(v_C + v_m) = \underline{2\alpha v_C v_m} + \alpha v_C^2 + \alpha v_m^2 + f_1(v_C + v_m)$$

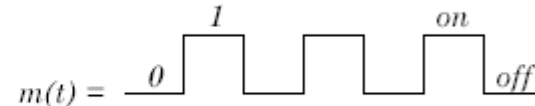
Example: diode



Mixer implementation: switching circuits



$$v_u = m(t)v_m$$



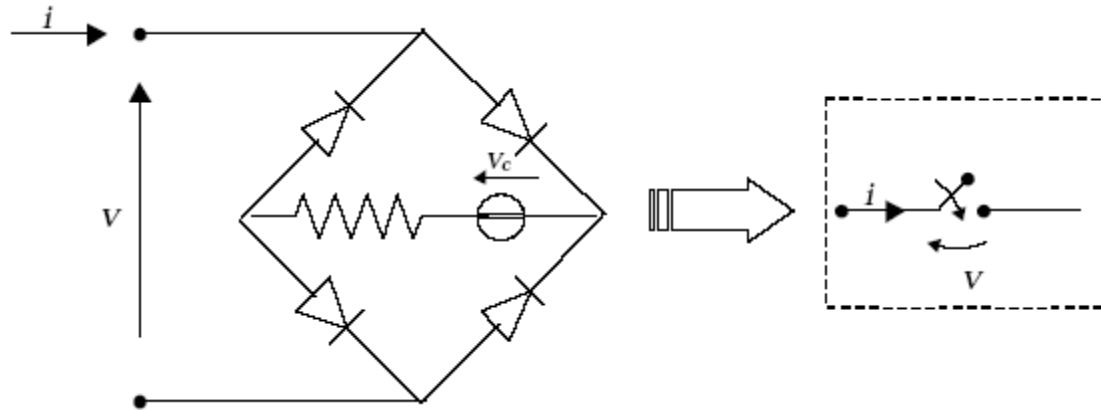
$$m(t) = 1 \quad \Rightarrow \quad v_u = v_m$$

$$m(t) = 0 \quad \Rightarrow \quad v_u = 0$$

$$m(t) = M_0 + \sum_{k=1}^{\infty} M_k \cos(k\omega_0 t)$$

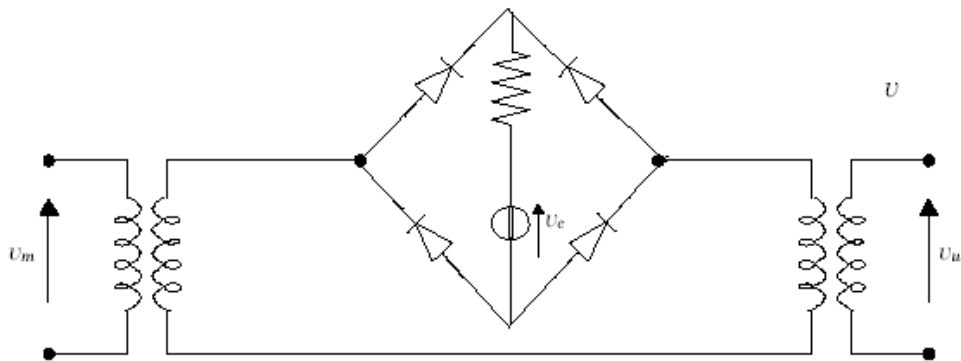
$$\left\{ \begin{array}{l} M_0 = \frac{1}{2} \\ M_k = \frac{2}{k\pi} \quad k \text{ odd} \\ M_k = 0 \quad k \text{ even} \end{array} \right.$$

High-Speed Switch: Diode Bridge



$$\begin{cases} v_c > 0 & \Rightarrow & v = 0 \\ v_c < 0 & \Rightarrow & i = 0 \end{cases}$$

Mixer implementation: Diode Bridge

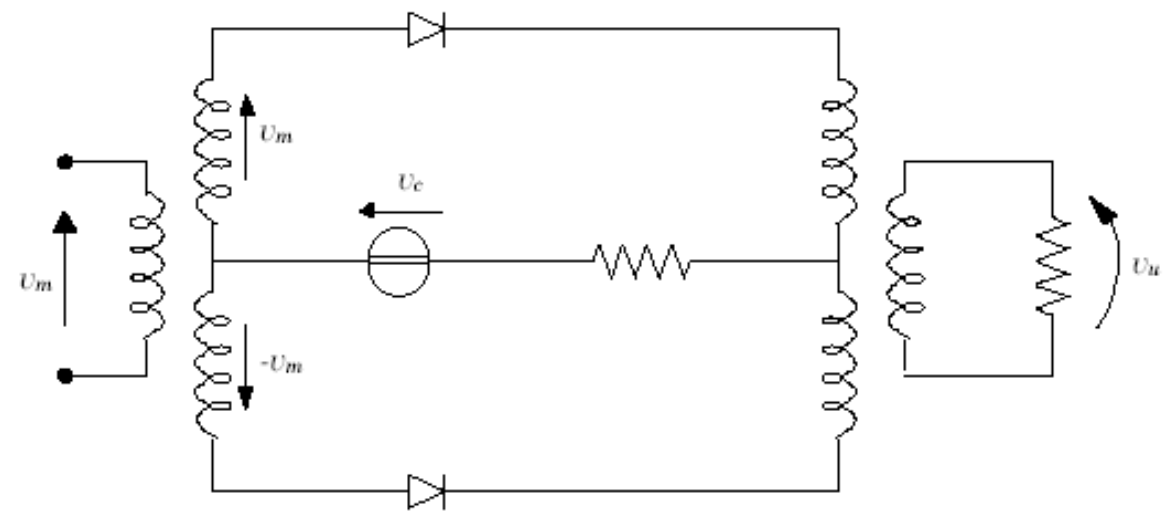


$$v_u(t) = m(t)v_m(t)$$

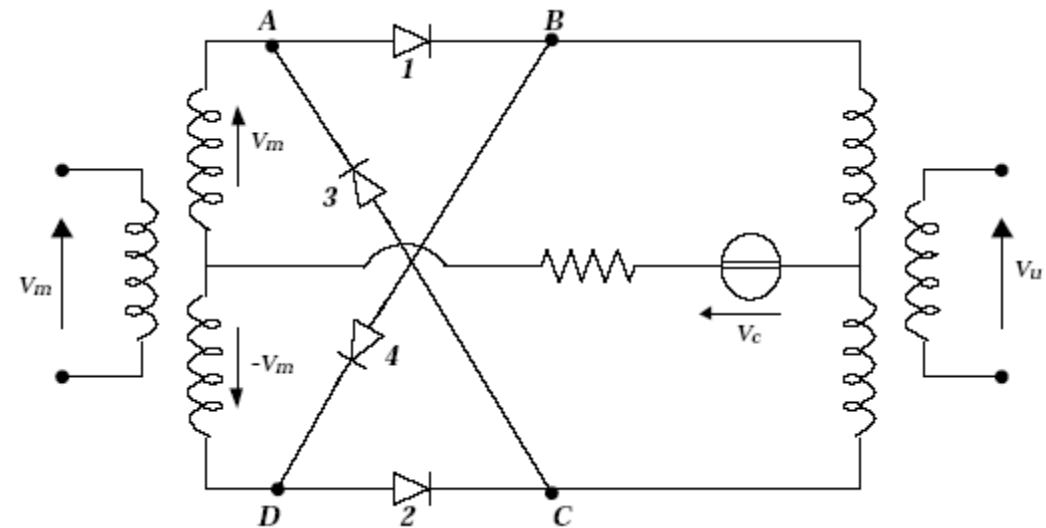
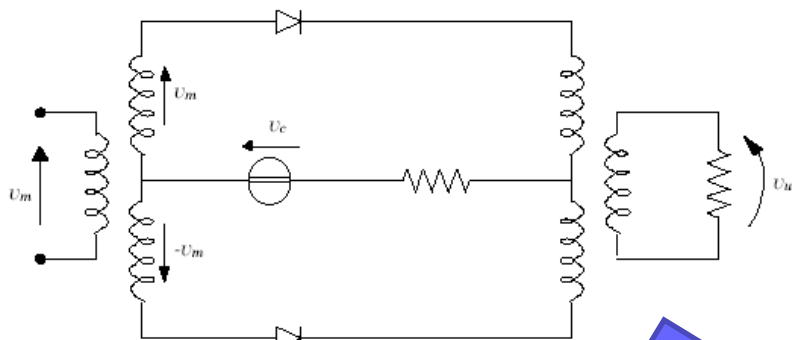
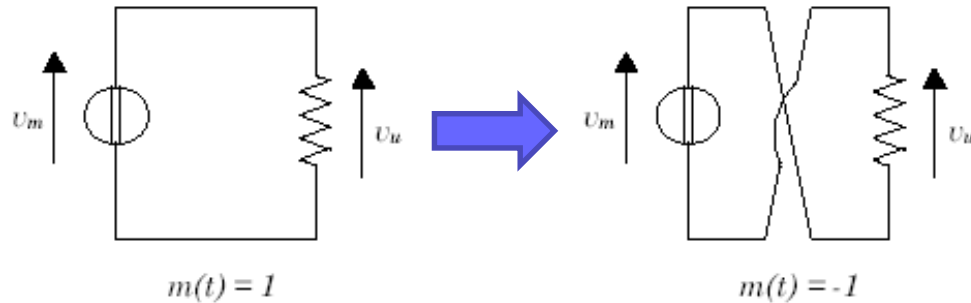


$$\begin{cases} v_u(t) = v_m(t) \\ v_u(t) = 0 \end{cases}$$

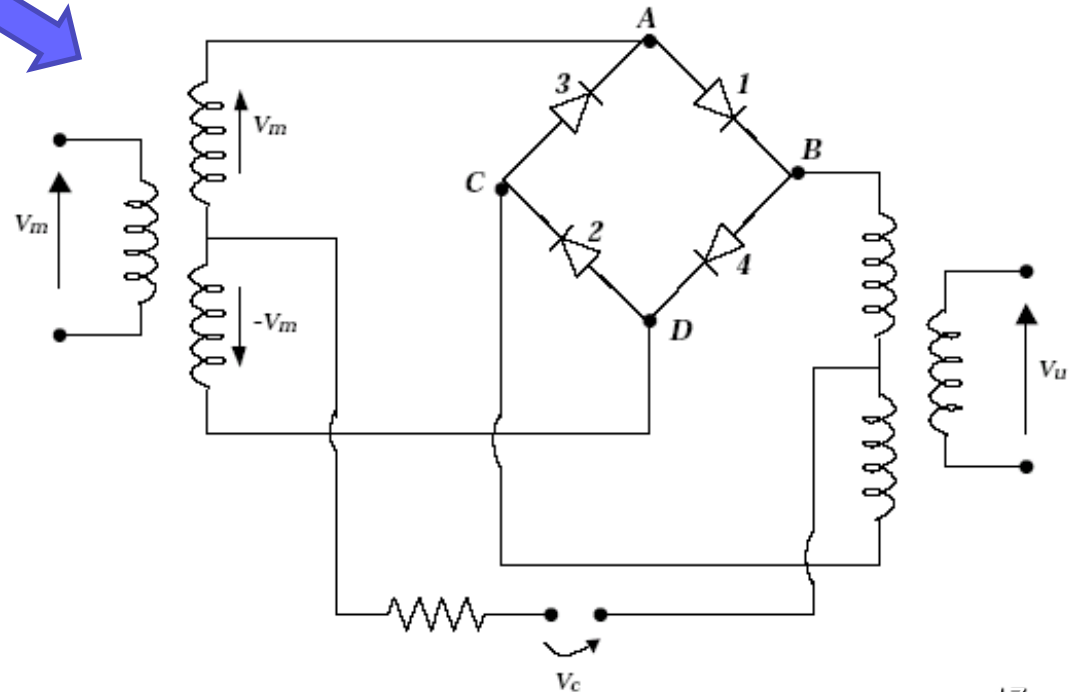
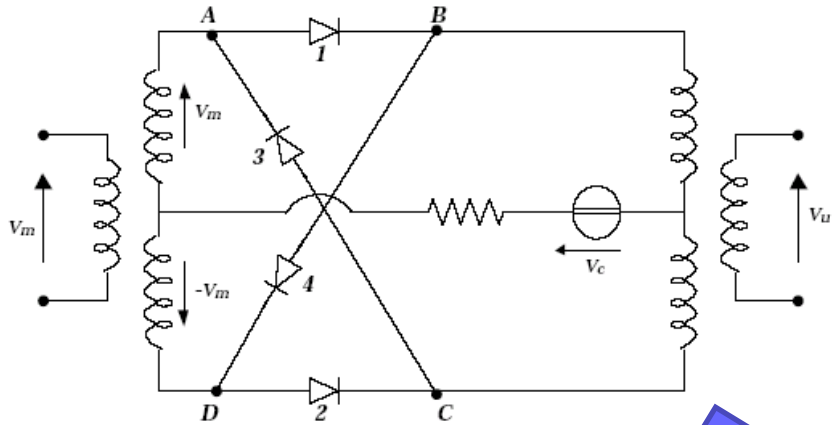
$$\begin{aligned} \text{se } m(t) = 1 &\Rightarrow v_c(t) > 0 \\ \text{se } m(t) = 0 &\Rightarrow v_c(t) < 0 \end{aligned}$$



Double balanced Mixer



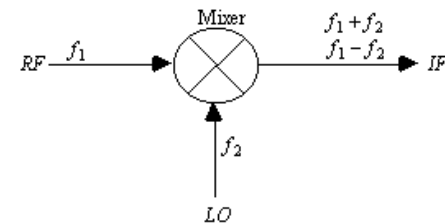
Ring Mixer



Mixer parameters

Conversion loss:

is defined as the difference in dB between the received signal power entering the RF-port and the output IF power of the desired IF sideband exiting the IF-port.



Isolation:

Interport isolation is the measure of insertion loss between any two mixer ports. It is measured in dB and usually specified over a given bandwidth as a function of LO drive and temperature. Maximizing isolation between ports in mixers is necessary because unwanted signal feedthrough wastes RF power and can obscure the desired IF output, as well as cause electromagnetic interference.

Noise Figure:

is defined as the ratio between the input and output S/N ratio.

Conversion loss for a ring mixer

Lets consider the multiplication with a perfect square wave with level +1 an -1.

The IF component at frequency f_1-f_2 has amplitude equal to the input amplitude multiplied by:

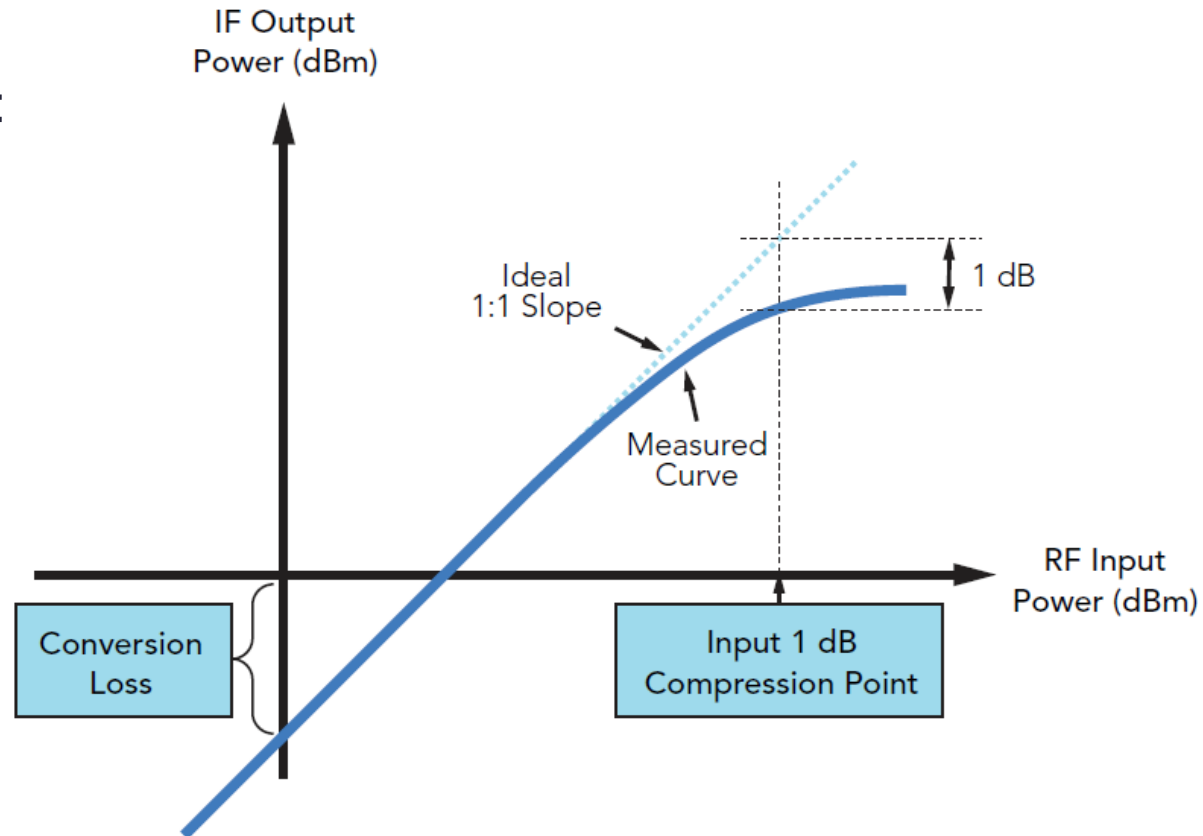
$$\frac{1}{2} \times 2M_1 = M_1 = \frac{2}{\pi} \cong 0.64 \quad \longrightarrow \quad \text{min. conversion loss} = \mathbf{4 \text{ dB}}$$

The first factor $\frac{1}{2}$ is due to the prosthaphaeresis formula, the factor 2 is given by the square wave amplitude (± 1) and M_1 is the first coefficient of the Fourier series for the square wave with amplitude 1.

$$m(t) = M_0 + \sum_{k=1}^{\infty} M_k \cos(k\omega_0 t) \quad \left\{ \begin{array}{ll} M_0 = \frac{1}{2} \\ M_k = \frac{2}{k\pi} & k \text{ odd} \\ M_k = 0 & k \text{ even} \end{array} \right.$$

Mixer parameters

1dB Compression point:
the input RF power level
at which conversion loss
increases by 1 dB



Dynamic range:

Dynamic range is measured in dB and is the input RF power range over which the mixer is useful. The lower limit of dynamic range is the noise floor, which depends on the mixer and system. The upper limit of dynamic range is generally taken to be the mixer 1-dB compression point.

Mixer parameters

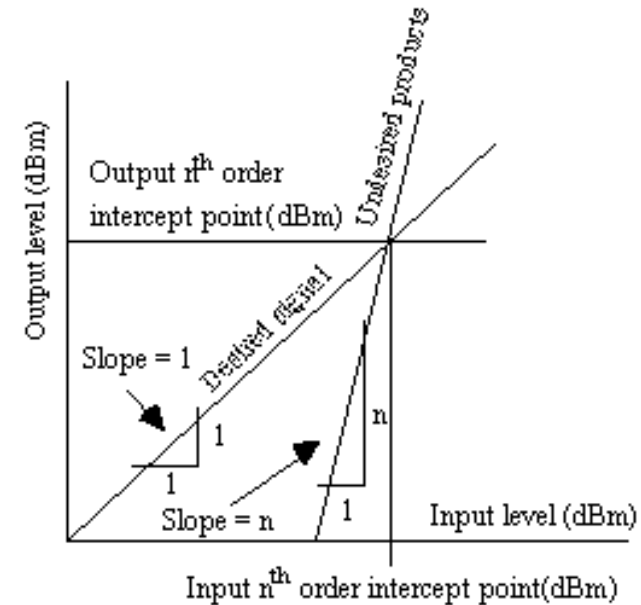
Intercept Point:

Intercept point, measured in dBm, is a figure of merit for intermodulation product suppression. Two types are commonly specified: input and output intercept point (IIP and OIP, respectively). Input intercept point is the level of input RF power at which the output power levels of the undesired intermodulation products and IF products would be equal; that is, intercept each other if the mixer did not compress.

This output power level is the output intercept point, and equals the input intercept point minus conversion loss. defined as the difference in dB between the input and output S/N. The most common one is the third-order intercept point (TOI).

Matching:

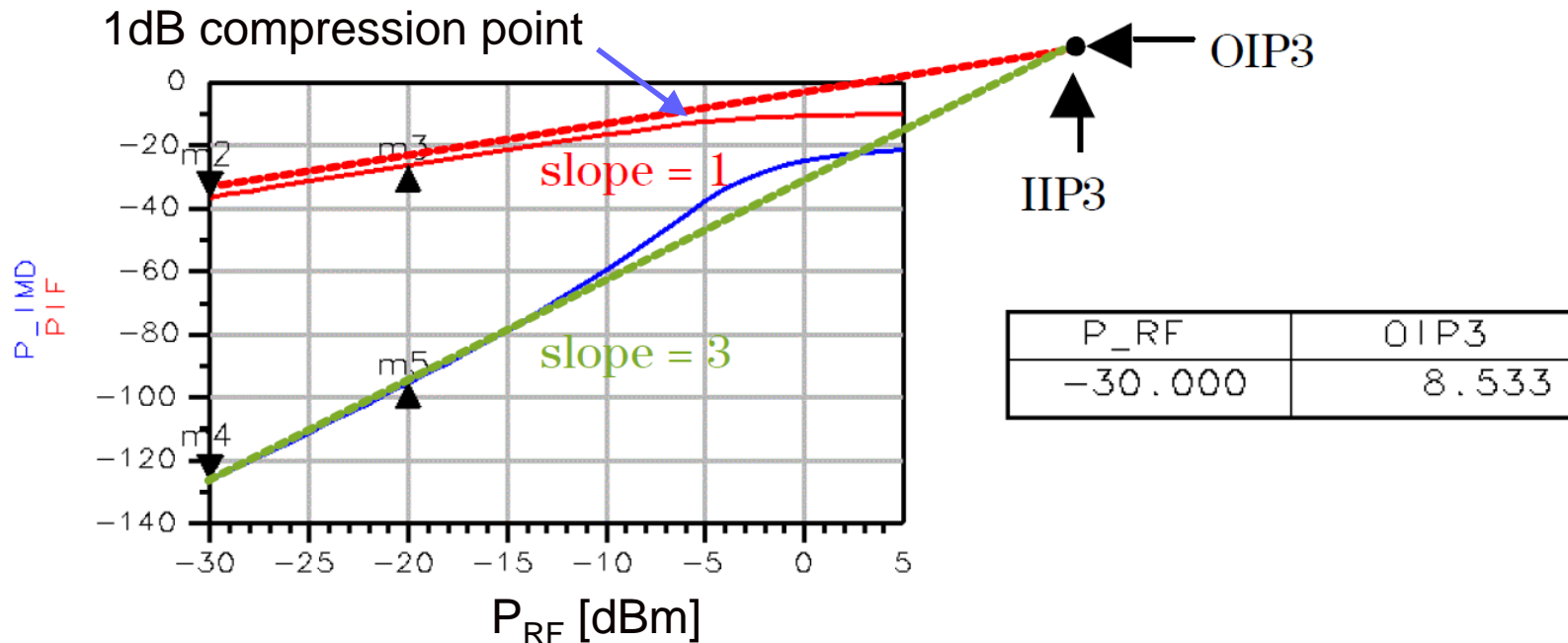
Typically indicated by the input VSWR, as a function of the frequency



Third-order intercept point

A widely-used figure of merit for IMD is the *third-order intercept* (TOI) point. This is a fictitious signal level at which the fundamental and third-order product terms would intersect. In reality, the intercept power is 10 to 15 dBm higher than the 1dB gain compression power, so the circuit does not amplify or operate correctly at the IIP3 input level.

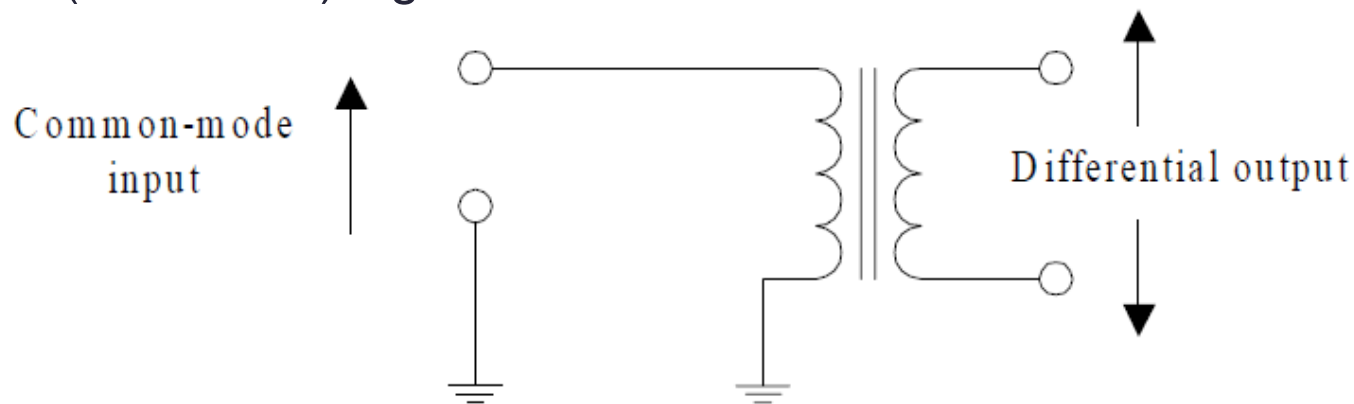
The higher the TOI, the better the large signal capability of the mixer.



BALUNS

A balun is used to transform a signal between BALanced and UNbalanced modes. An unbalanced signal is referenced to a ground plane, as in a coaxial cable or microstrip. A balanced signal is carried on two lines and is not referenced to a ground plane. Each line can be considered as carrying identical signal but with 180° of phase.

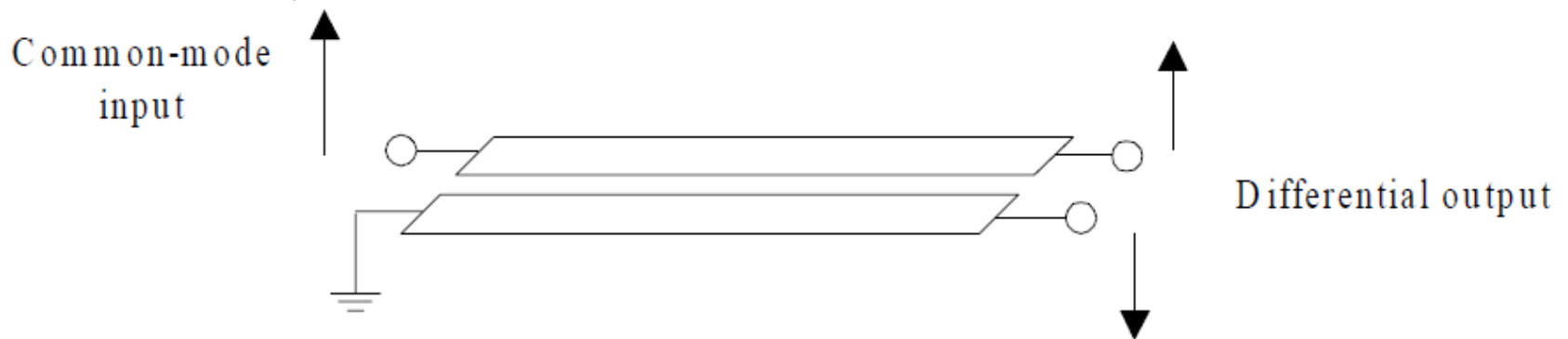
A wire-wound transformer provides an excellent balun. Miniature wirewound transformers are commercially available covering frequencies from low kHz to beyond 2GHz. They are often realized with a centre-tapped secondary winding, if grounded this provides a short circuit to even-mode (common-mode) signals whilst having no effect on the differential (odd-mode) signal.



Printed baluns

There are a wide range of printed balun topologies. They have the advantage of being inexpensive, realized as they are on the Printed Circuit Board (PCB) or Microwave Integrated Circuit (MIC) substrate. On the downside they can be quite large, particularly at lower RF frequencies.

The simplest printed balun is the coupled line balun, also called a parallel-line balun. The structure is a quarter of a wavelength long at the center frequency.



It is capable of bandwidths of over an octave, provided the coupling between the lines is high enough.