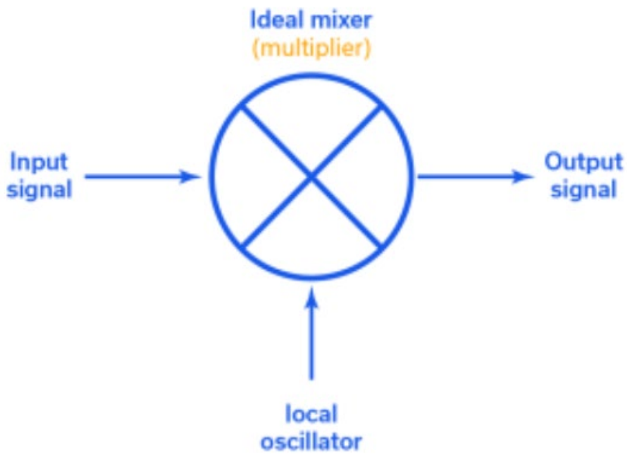
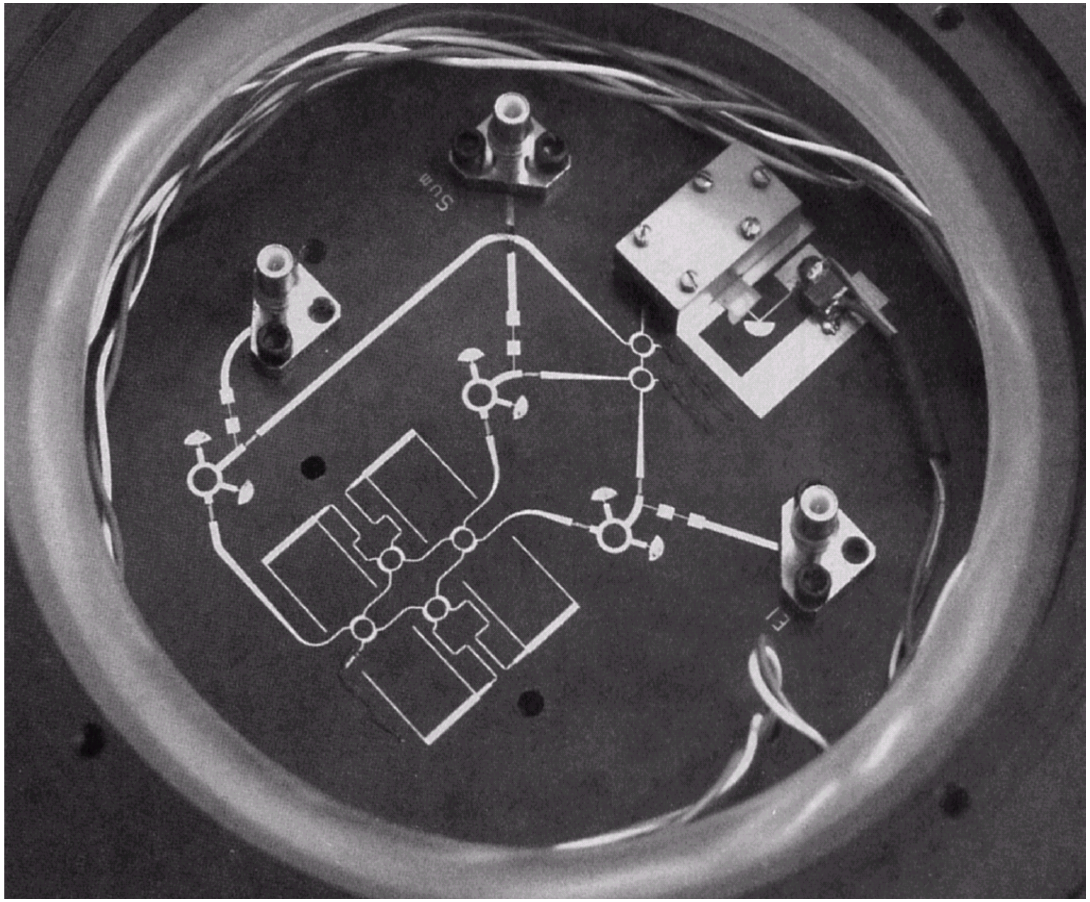
MICROWAVE MIXERS

EE5303 – Part 2



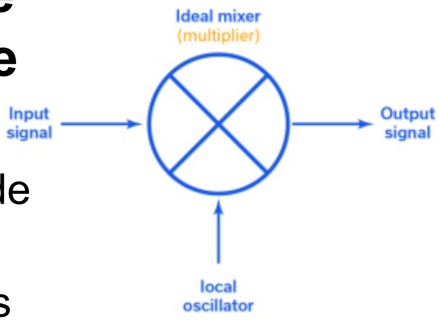
Photograph of a 35 GHz microstrip monopulse radar receiver circuit. **Three balanced mixers** using ring hybrids are shown, along with three stepped-impedance low-pass filters, and six quadrature hybrids. Eight feedlines are aperture coupled to microstrip antennas on the reverse side. The circuit also contains a Gunn diode source for the local oscillator. *Courtesy of Millitech Corporation.*



Introduction

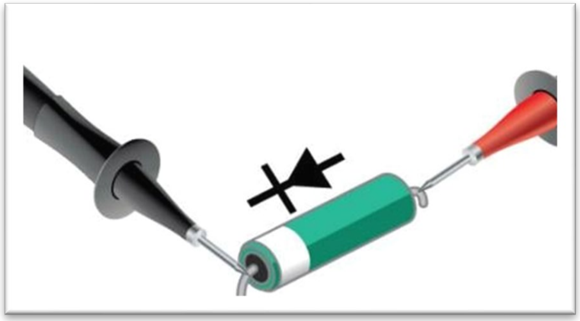
Microwave Mixers

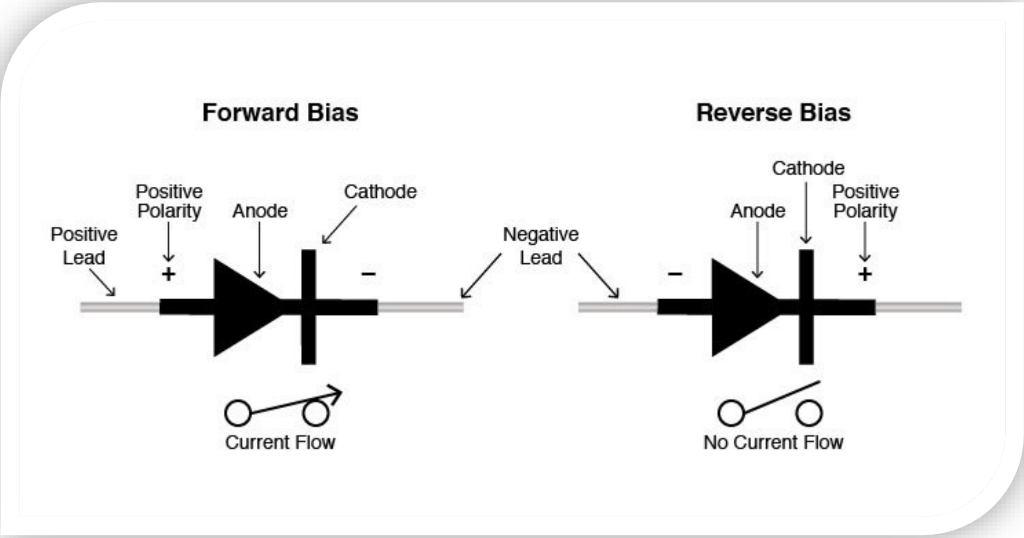
A nonlinear three-port (two inputs & one output) device using a nonlinear or time-varying element to achieve frequency conversion



- The nonlinearity comes from its nonlinear components, such a diode or a transistor
- As nonlinear components can generate a wide variety of harmonics and other products of input frequencies, so filtering must be used to select the desired frequency.

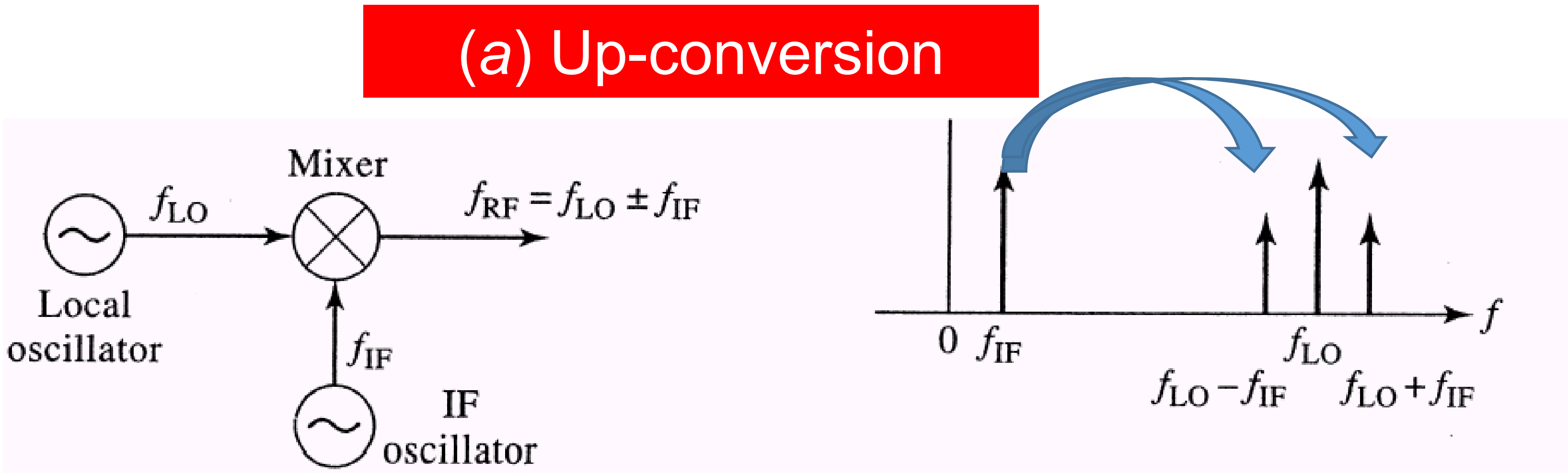
A **diode** *is a semiconductor device that essentially acts as a one-way switch for current. It allows current to flow easily in one direction, but severely restricts current from flowing in the opposite direction.*

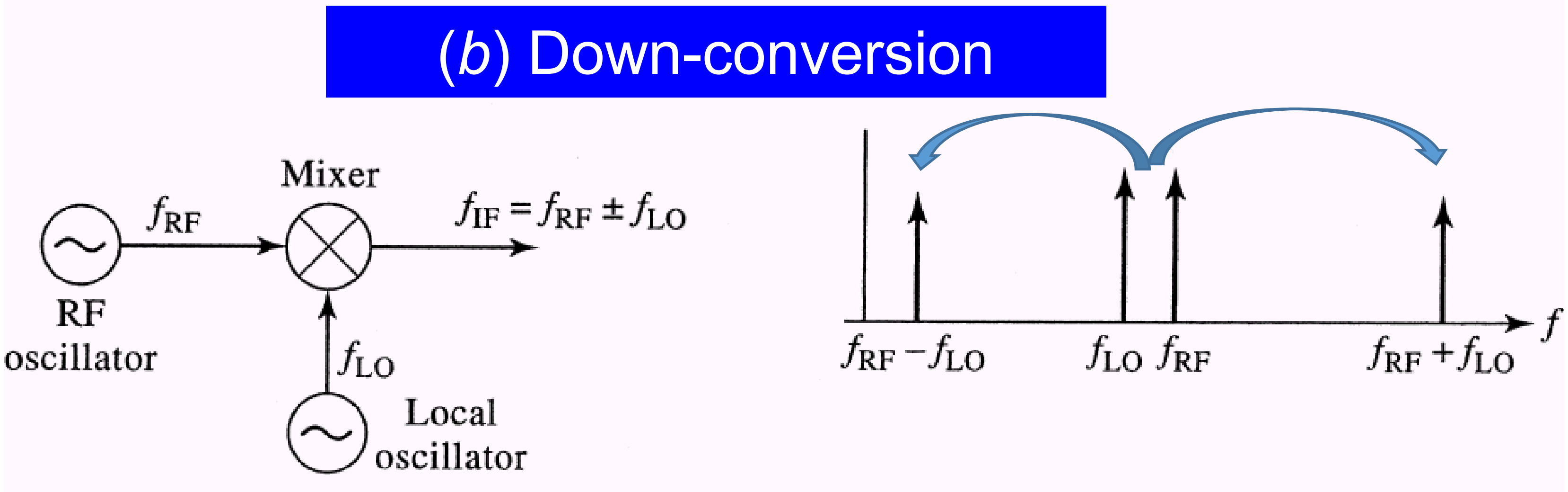




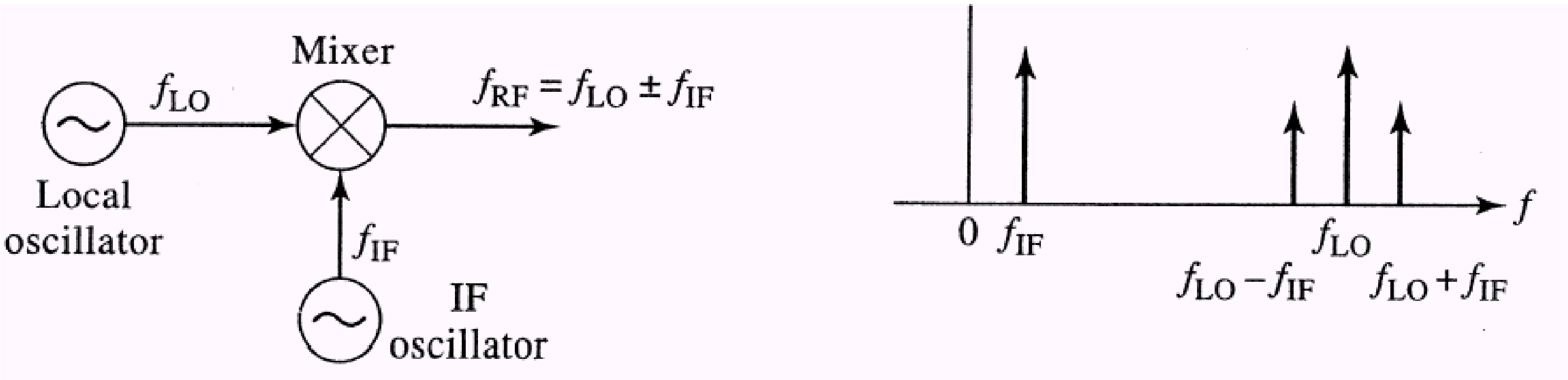
Frequency conversion using a mixer

An ideal mixer produces an output consisting of the **sum and difference frequencies** of its two input signals.





Frequency Up-Conversion



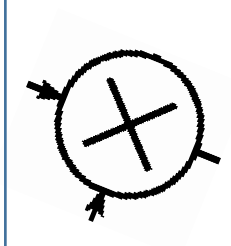
Operation of *frequency up-conversion* as in a transmitter.

A local oscillator (LO) signal at high frequency f_{LO}

$$v_{LO}(t) = \cos 2\pi f_{LO} t$$

A lower frequency baseband or intermediate frequency (IF) signal with the info. or data to be transmitted

$$v_{IF}(t) = \cos 2\pi f_{IF} t$$



output is proportional to the product of the two input signals

The RF output

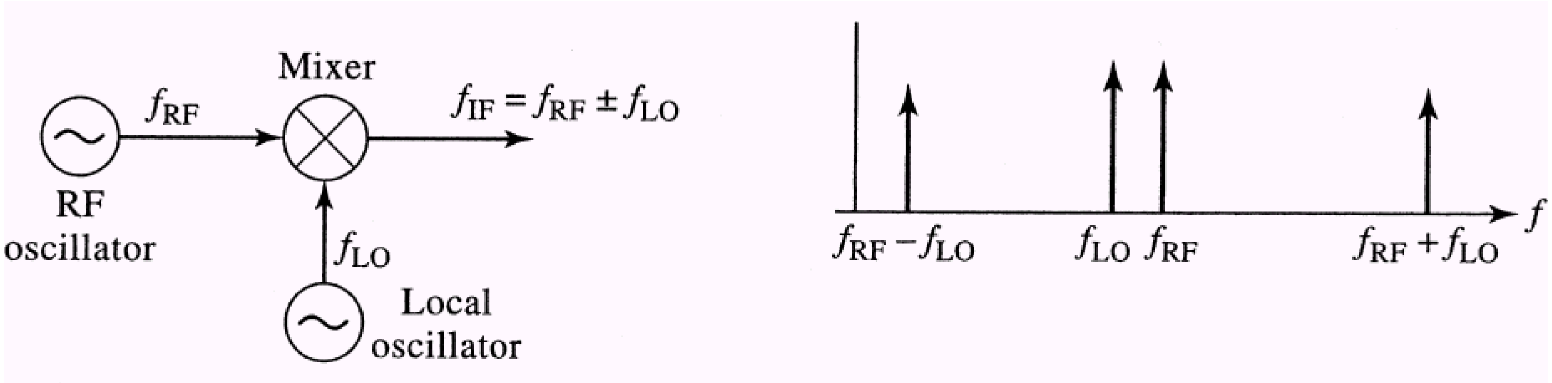
$$v_{RF}(t) = K v_{LO}(t) v_{IF}(t) = K \cos 2\pi f_{LO} t \cos 2\pi f_{IF} t$$

$$= \frac{K}{2}[\cos 2\pi (f_{LO} - f_{IF})t + \cos 2\pi (f_{LO} + f_{IF})t]$$

the **difference and sum** of the input signal frequencies

Where K is a constant accounting for the voltage conversion loss of the mixer

Frequency Down-Conversion



Operation of *frequency down-conversion* as in a receiver

The IF output

$$v_{IF}(t) = K v_{RF}(t) v_{LO}(t) = K \cos 2\pi f_{RF} t \cos 2\pi f_{LO} t$$

$$= \frac{K}{2}[\cos 2\pi (f_{RF} - f_{LO})t + \cos 2\pi (f_{RF} + f_{LO})t]$$

Where K is a constant accounting for the voltage conversion loss of the mixer

The desired IF output in a receiver is the difference frequency, by way of low-pass filtering:

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

Up- Down Conversion with examples

Down Converters:

A down converter is a mixer that with the help of LO, shifts the frequency of the RF signal substantially down to IF signal. Such mixers are used in receiver as a demodulator to remove the carrier wave from the transmitted signal in order to obtain the information carrying signal.

$$\omega_{IF} = |\omega_{RF} - \omega_{LO}|$$

E.g. RF signal of 14.1 GHz & LO signal of 14 GHz will produce IF of 100 MHz

Up Converters:

An up converter is a down converter in reverse order. The desired information signal is modulated on the IF signal, which in turn is mixed with the local oscillator producing a signal. It is used in the transmitter to modulate a carrier wave (LO) with an information signal (IF) in order to generate the RF signal for transmission

$$\omega_{RF}=\omega_{IF}+\omega_{LO}$$

E.g. IF signal of 100 MHz & LO signal of 14 GHz will produce RF of 14.1 GHz

DSB & SSB Signals

Double side band (DSB) signal:

- An AM signal that consist of two sidebands --- upper and lower.
- The upper side band (USB) is sum of the LO signal and the RF signal
- The lower side band (LSB) is the difference of the LO and the RF.

Double side band or DSB ($\omega_{IF} = \omega_{RF} + \omega_{LO}$,
$\omega_{IF} = \omega_{RF} - \omega_{LO}$)

Down- and upconverted spectral products

Single side band (SSB) signal:

An AM signal in which either one of the two sidebands of a DSB signal is suppressed.

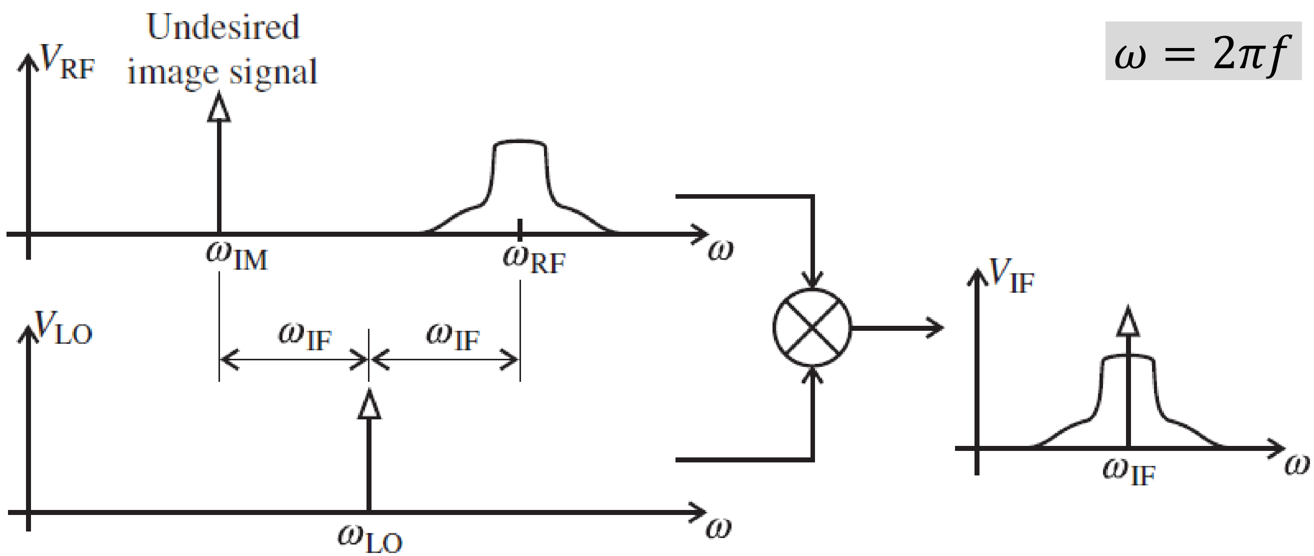
Lower side band: or LSB ($\omega_{IF} = \omega_{RF} - \omega_{LO}$)

OR

Upper side band or USB ($\omega_{IF} = \omega_{RF} + \omega_{LO}$)

Image Frequency

- Two inputs (RF & image) will mix to the same output frequency
- The image frequency must be removed by filtering
- f_{LO} and f_{IF} must be selected carefully



$\omega = 2\pi f$

- In an ideal multiplier, there are two RF input frequency (F_{RF} & F_{IM}) whose second order product has the same difference IF frequency

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

Image Frequency in a Receiver

- Example: Down-conversion Mixer

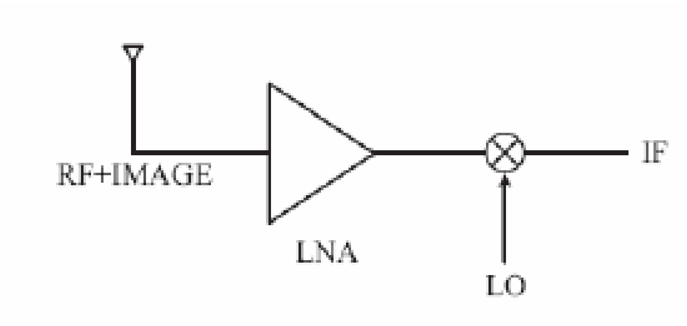
  RF = 1000MHz

  IF = 100MHz

  Let's say we choose a low-side injection:

  LO = 900 MHz

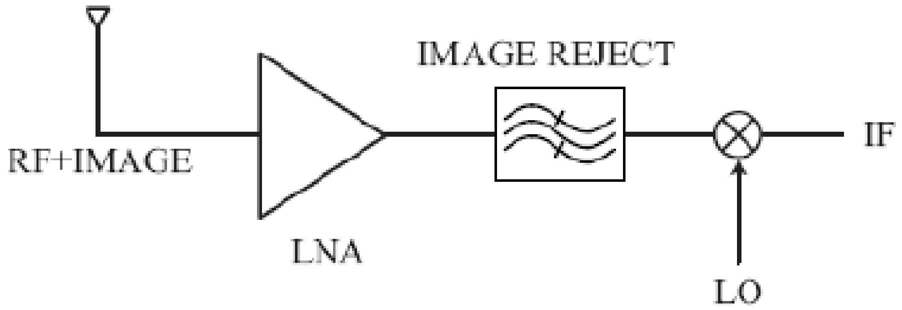
  That means that any signals or noise at 800 MHz will also be down-converted to the same IF



- The image frequency is the second frequency that also down-converts to the same IF. This is undesirable because the noise and interference at the image frequency can potentially overwhelm the receiver.

- One solution is to filter the image band. This places a restriction on the selection of the IF frequency due to the required filter Q.

Image Rejection Filter



- Suppose that RF = 1000MHz, and IF = 1MHz.
- In general, the filter Q is given by Q= RF/BW
- Let's design a filter with f_0 = 1000 MHz and f_{cutoff} = 1001 MHz.
- But the Q for such a filter is Q= 10^3 MHz / 1MHz = 1000!

Conversion Loss for Mixers

- **Conversion loss, L_c**

  The conversion loss L_c of a mixer is generally defined in dB as the ratio of supplied RF input power P_{RF} over the obtained IF power

$$L_c\,(\mathrm{dB}) = 10\log_{10}\,(P_{RF}/P_{IF})$$

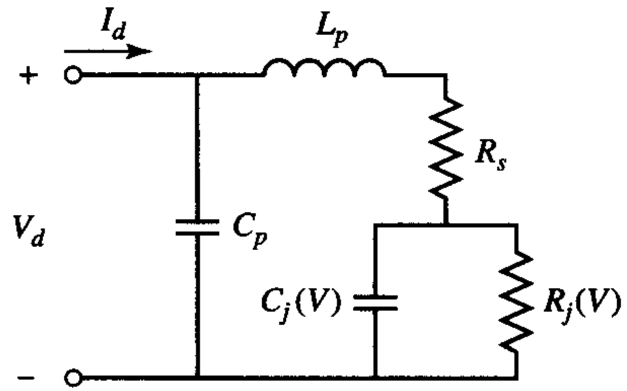
Typical values of the conversion loss are in the range of 4 to 7 dB

The conversion loss of the mixer is made up of the following 3 types of losses

$$L_c = L_d + L_m + L_h \qquad \textit{(in dB)}$$

1) **Diode Loss, (L_d)**

$$L_d = 10\log\left[1 + \frac{R_s}{R_j} + (\omega C_j)^2 R_s R_j\right]$$



Equivalent Circuit of a Diode
(See the PPT slide after next two slides)

Conversion Loss for Mixers

2) **Mismatch Loss, L_m**

$$L_m = 10\log\left[\left(1-|\Gamma_{RF}|^2\right)\left(1-|\Gamma_{IF}|^2\right)\right]^{-1}$$

3) **Harmonic Loss or Intrinsic Loss, L_h**

Due to diode non linear I-V curve many harmonic signals are generated but only ω_{RF}- ω_{LO} (down conversion) & ω_{RF}+ ω_{LO} (up conversion) are useful. Therefore, not all of the signals are converted to the desired signal which lead to concept of harmonics or intrinsic loss

Therefore the conversion loss in dB is

$$L_c = L_d + L_m + L_h$$

Conversion Loss for Mixers

SSB versus DSB Conversion Loss:

- DSB signal has both side-bands so it has twice as much power compared to SSB signal.
- Conversion loss is 3 dB less than that of SSB signal

$$(P_{IF})_{DSB} = 2\,(P_{IF})_{SSB}$$

$$(L_C)_{DSB} = (L_C)_{SSB} - 3\ (\text{dB})$$

Assume down-conversion:

$$(L_c)_{DSB} = 10\log\frac{P_{RF\_input}}{P_{IF\_output}}$$
$$= 10\log\frac{P_{RF\_input}}{2*(P_{IF\_output})_{SSB}}$$
$$= 10\log\frac{P_{RF\_input}}{(P_{IF\_output})_{SSB}} + 10\log\frac{1}{2}$$
$$= (L_c)_{SSB} - 3\ (dB)$$

SSB versus DSB Noise Figure:

- Noise figure for DSB is lower than SSB by 3 dB

$$(F_m)_{DSB} = (F_m)_{SSB}/2$$

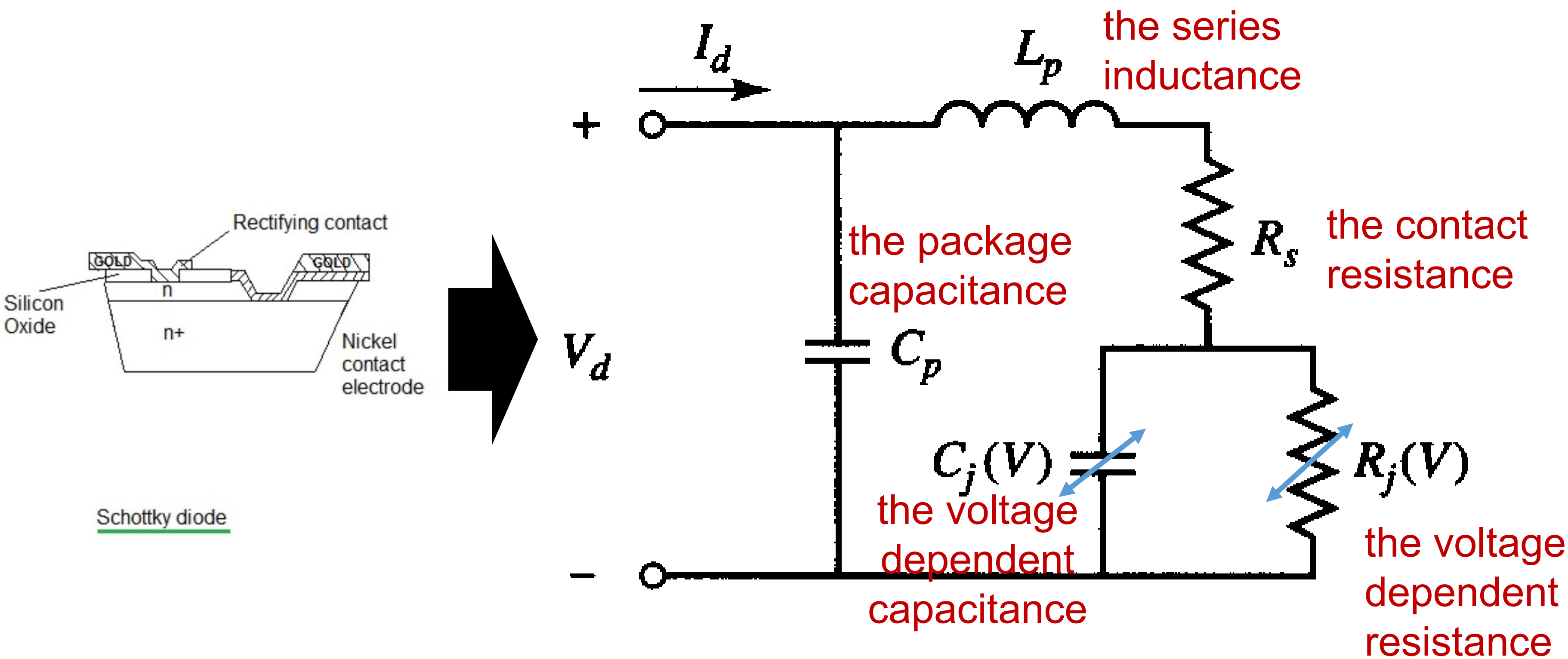
$$(F_m)_{DSB} = (F_m)_{SSB} - 3\ (\text{dB})$$

DSB → less loss; less noise

Microwave Mixer Diode

- Shottky diode, due to its low capacitance, is the most commonly used diode for microwave mixer applications
- The gate-channel junction of a GaAs FET is a Schottky diode junction.

The equivalent circuit of a diode consists of parasitic as follows:



Small Signal Analysis of a Diode

A Diode is basically a non-linear device and DC *V-I* expressed as

$$I = I(V) = I_s\left(e^{qV/\eta kT} - 1\right) \qquad (1)$$

where I_s=diode saturation current

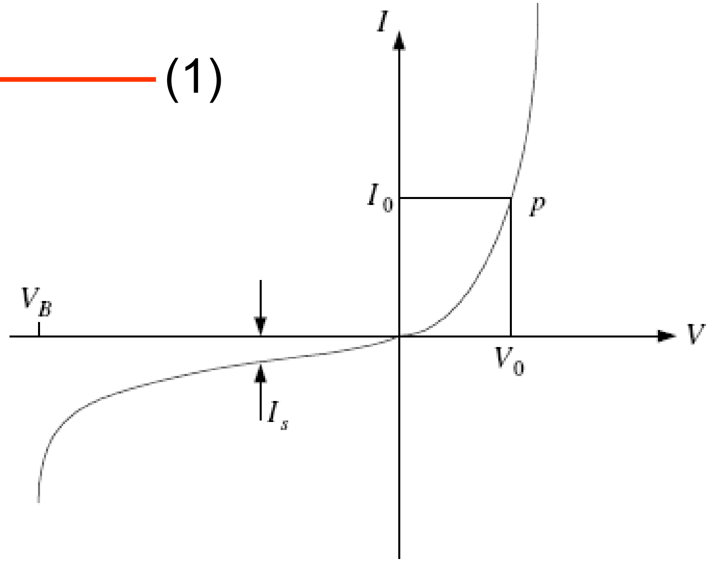
q=charge of an electron

V=voltage across junction

η= a constant between 1 and 2

k=Boltzmann's constant

T=absolute temperature



Small Signal Analysis of a Diode

Let the diode voltage be

$$V = V_0 + v, \tag{2}$$

where V_o is a DC bias voltage and v is small AC signal voltage. Then Equ. (1) can be expanded in Taylor series about V_o as follows

$$I(V) = I_0 + v\frac{dI}{dV}\bigg|_{V_0} + \frac{1}{2}v^2\frac{d^2I}{dV^2}\bigg|_{V_0} + \cdots, \tag{3}$$

where $I_o = I(V_o)$ is a DC bias current. The first derivative is evaluated as

$$\frac{dI}{dV}\bigg|_{V_0} = \alpha I_s e^{\alpha V_0} = \alpha(I_0 + I_s) = G_d = \frac{1}{R_j},$$

which defines R_j, the junction resistance of the diode, and $G_d = 1/R_j$ and is called the dynamic conductance of the diode.

Small Signal Analysis of a Diode

The second derivative is,

$$\left.\frac{d^2I}{dV^2}\right|_{V_0} = \left.\frac{dG_d}{dV}\right|_{V_0} = \alpha^2 I_s e^{\alpha V_0} = \alpha^2(I_0 + I_s) = \alpha G_d = G'_d.$$

Equ. (3) can be rewritten as the sum of the DC current, I_0 and the AC current, i:

$$I(V) = I_0 + i = I_0 + vG_d + \frac{v^2}{2}G'_d + \cdot \qquad (4)$$

The three term approx. for the diode current in Equ. (4) is called the "*small signal approximation*". The small signal approx is based on the DC voltage –current relationship of Equ. (1) . In practice, the AC characteristics of diode also involve reactive effects due to packaging.

Small Signal Analysis of a Diode

In rectifier application, a diode is used to convert RF signal into DC power. If the diode voltage consist of DC bias voltage & RF voltage

$$V = V_0 + v_0 \cos \omega_0 t,$$

Then according to Eqn. (4) the diode current is given as,

$$\begin{aligned} I &= I_0 + v_0 G_d \cos \omega_0 t + \frac{v_0^2}{2} G'_d \cos^2 \omega_0 t \\ &= I_0 + \frac{v_0^2}{4} G'_d + v_0 G_d \cos \omega_0 t + \frac{v_0^2}{4} G'_d \cos 2\omega_0 t. \end{aligned}$$

I_0 is the bias current and $v_o{}^2 G'_d/4$ is the DC rectified current.

The current sensitivity, β_i can be defined as a measure of the change in DC output current for a given input RF power.

$$\beta_i = \frac{\Delta I_{\text{dc}}}{P_{\text{in}}} = \frac{G'_d}{2G_d} \text{ A/W}.$$

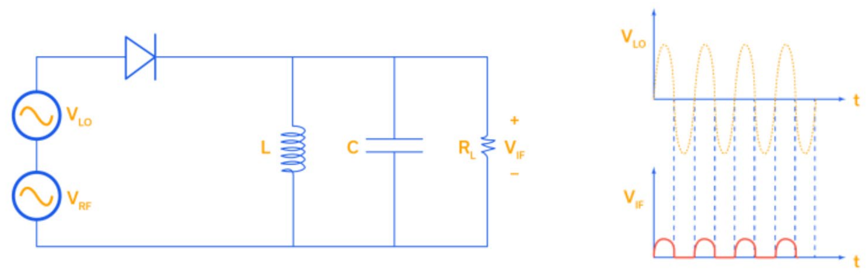
Mixer Types

- **Non linear operation mechanism:**
  - Single ended mixer
  - Single balanced mixer
  - Double balanced mixer
  - Double double balanced mixer

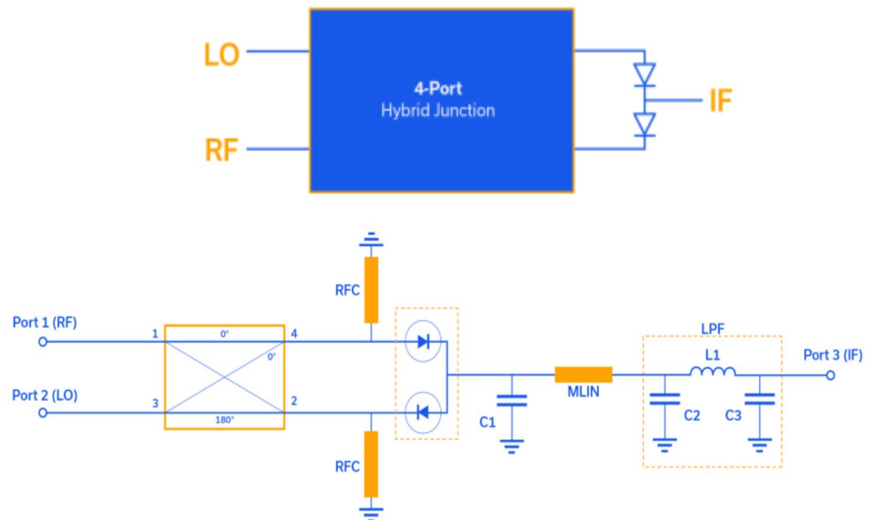
- **Specifications:**
  - Image rejection, Conversion loss, isolation
  - Large signal performance: gain compression (1- dB), intermodulation distortion: third order intercept point (TOI)
  - Small signal performance: noise figure
  - Operating range: Spurious free dynamic range

Types of Mixers

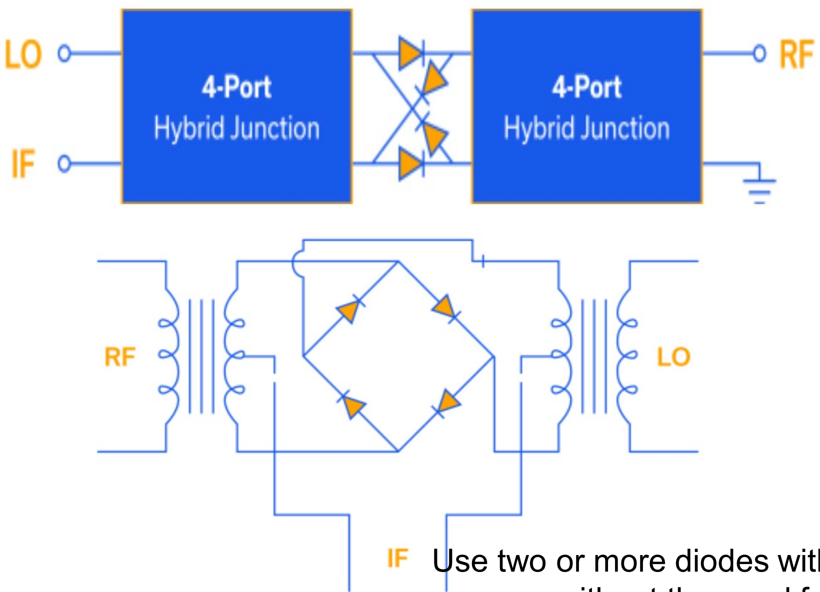
Unbalanced (Single Diode) Mixers



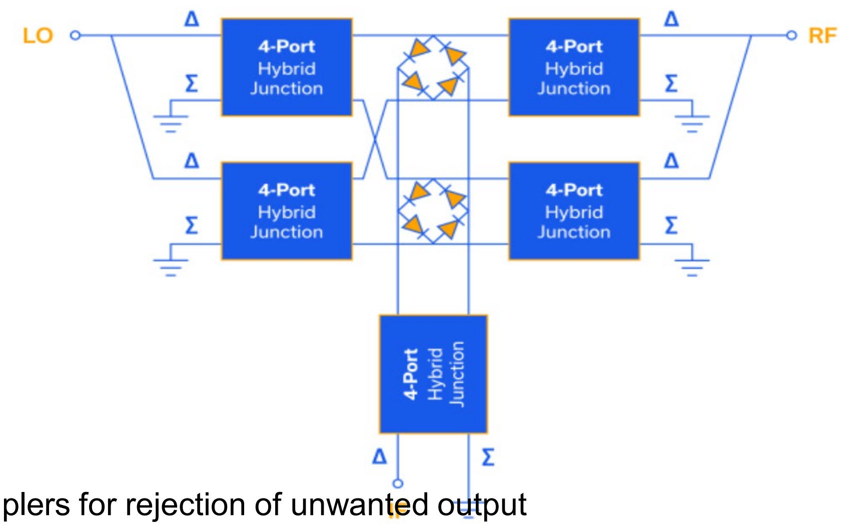
Single Balanced Mixers



Double Balanced Mixers



Triple-Balanced Mixers



Use two or more diodes with baluns/couplers for rejection of unwanted output without the need for filtering, or for improvement on linearity

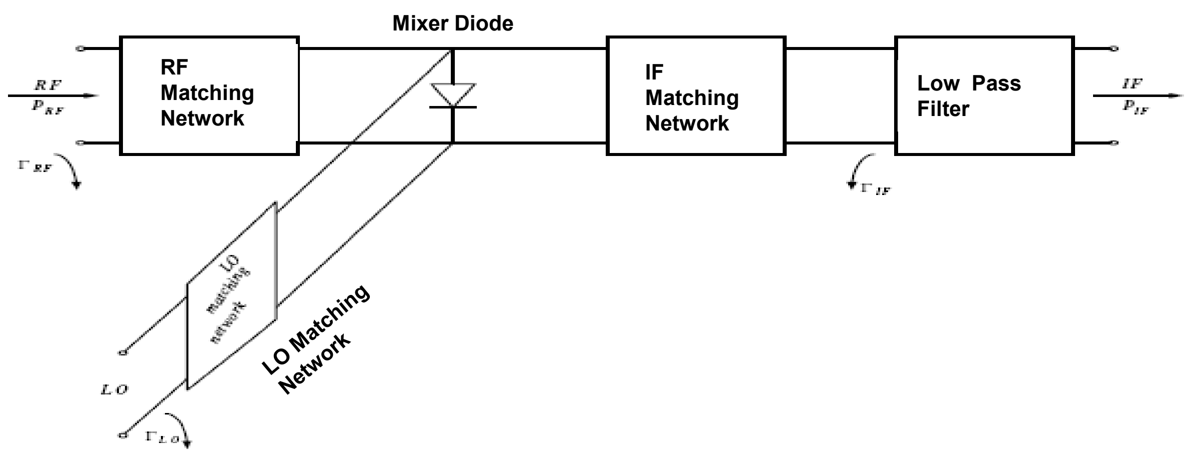
Additional Self-Reading Material

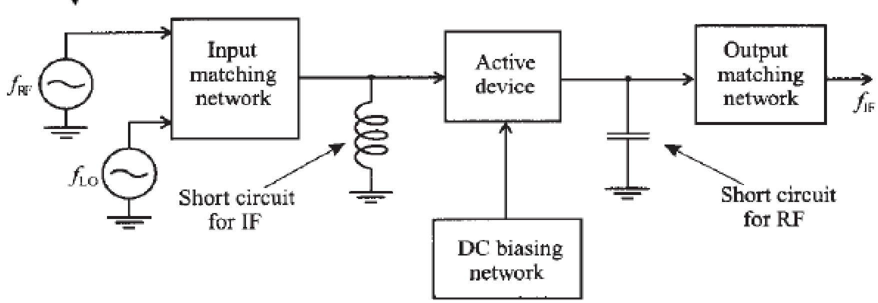
Details of Different Mixers

- **Single ended mixer**
- **Single balanced mixer**
- **Double balanced mixer**
- **Double double balanced mixer**

Single Ended Mixer

- **Single Ended Mixer:**
  - Mixer that use only one diode to generate the IF signal frequency
  - The combiner combines the two input signals with the help of matching network
  - The combined signal is fed into diode for mixing
  - The diode is biased at the desired Q point





Single Ended Mixer

$$v = v_{RF}\sin\omega_{RF}t + v_{LO}\sin\omega_{LO}t$$ Input signal to mixer

$$i = a_1 v + a_2 v^2 + \cdots$$

$$= a_1\left(v_{RF}\sin\omega_{RF}t + v_{LO}\sin\omega_{LO}t\right) + a_2\left(v_{RF}\sin\omega_{RF}t + v_{LO}\sin\omega_{LO}t\right)^2\cdots$$

$$= a_1\left(v_{RF}\sin\omega_{RF}t + v_{LO}\sin\omega_{LO}t\right) + a_2\left\{\frac{1}{2}v_{RF}^2\left(1-\cos 2\omega_{RF}t\right) + v_{LO}v_{RF}\left[\cos\left(\underbrace{\omega_{RF}-\omega_{LO}}\right)t\right.\right.$$

$$\left.\left.-\cos\left(\underbrace{\omega_{RF}+\omega_{LO}}\right)t\right] + \frac{1}{2}v_{LO}^2\left(1-\cos 2\omega_{LO}t\right)\right\} + \cdots$$

- **Drawbacks:**
  - **The difficulty providing LO energy while maintaining separation/ isolation b/w LO & RF plus the impedance matching**
  - **Single ended mixer can not suppress noise and spurious mode rejection**

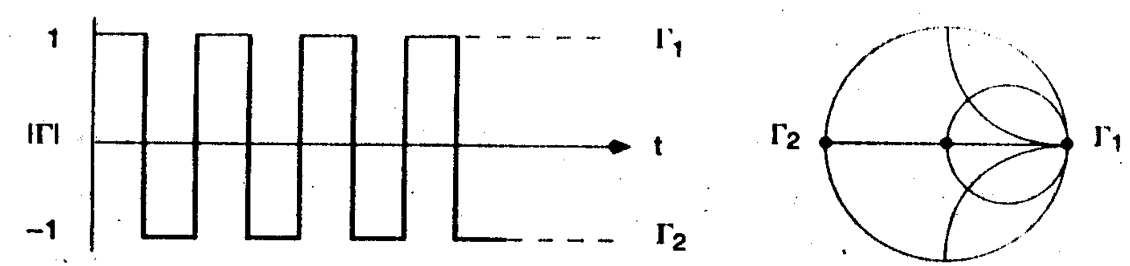
Single Ended Mixer

- An ideal mixer consist of non-linear element & behaves like ideal switch with two distinct states.

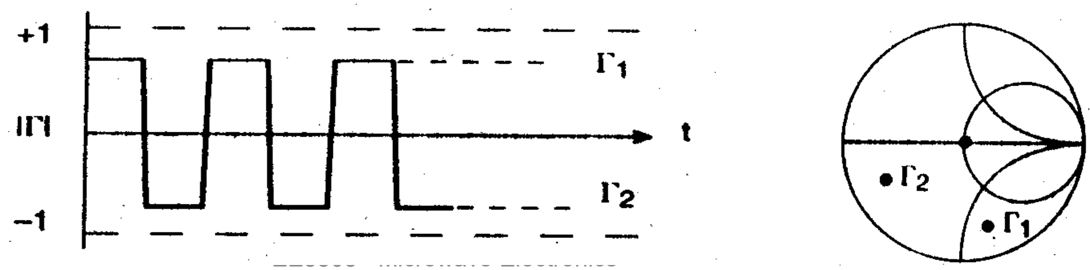
  - "ON" (Z_{ON} = 0, Γ = -1) , "OFF" (Z_{OFF} = ∞)

- It is observed that they have reflection coefficient of unity and 180 degrees apart on smith chart.
- But in actual they have different states, and the conversion loss of diodes determines it.

Ideal

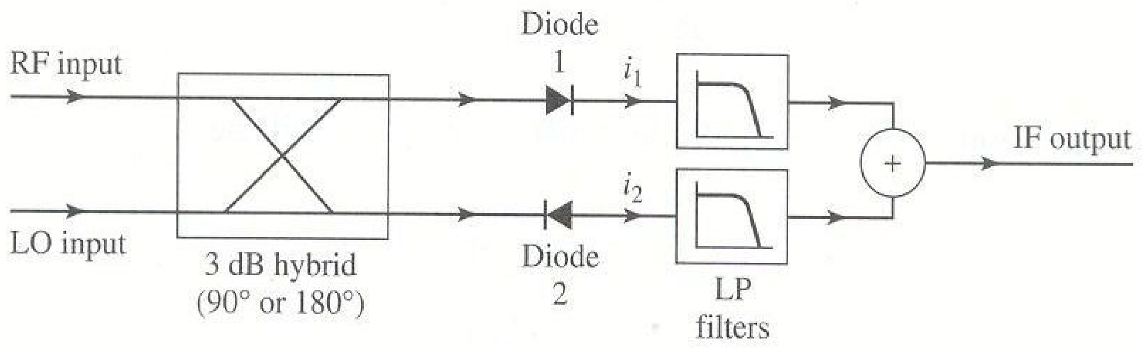


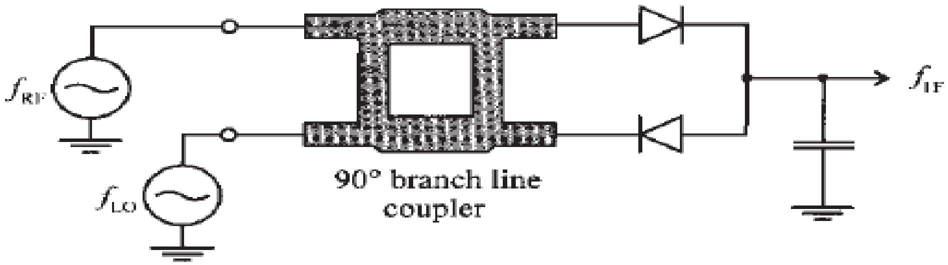
Non- Ideal



Single Balanced Mixer

- **Single balanced Mixer**
  - **A balanced mixer combines two single ended mixer with a 3 dB hybrid junction**
  - **It gives better input SWR or better RF/LO isolation**
  - **The spurs arise in oscillator & amplifiers due to parasitic resonance and non linearities.**
  - **The balanced mixer can cancel AM noise generated**





Single Balanced Mixer

We consider a small random noise voltage is superimposed on LO signal

$$\left.\begin{aligned} v_{\mathrm{RF}}(t) &= v_r \cos \omega_r t, \\ v_{\mathrm{LO}}(t) &= [v_0 + v_n(t)] \cos \omega_0 t, \end{aligned}\right\} \longleftarrow \text{Input signal to mixer}$$

where $v_r << v_0$, and $v_n(t) << v_0$. If we have a 90° hybrid, the voltages across the two diodes are

$$\begin{aligned} v_1(t) &= v_r \cos(\omega_r t - 90^\circ) + (v_0 + v_n)\cos(\omega_0 t - 180^\circ) \\ &= v_r \sin\omega_r t - (v_0 + v_n)\cos\omega_0 t, \\ v_2(t) &= v_r \cos(\omega_r t - 180^\circ) + (v_0 + v_n)\cos(\omega_0 t - 90^\circ) \\ &= -v_r \cos\omega_r t + (v_0 + v_n)\sin\omega_0 t. \end{aligned}$$

The quadratic term of the diode V-I characteristic will give rise to the desired mixer products, so we will consider only this term and assume identical diodes so that diode currents can be represented as

$$\begin{aligned} i_1 &= k v_1^2, \\ i_2 &= -k v_2^2, \end{aligned}$$

The negative sign account for reversed diode polarity

$$\begin{aligned} i_1 &= k[v_r^2 \sin^2\omega_r t + (v_0 + v_n)^2 \cos^2\omega_0 t - 2v_r(v_0 + v_n)\sin\omega_r t \cos\omega_0 t], \\ i_2 &= -k[v_r^2 \cos^2\omega_r t + (v_0 + v_n)^2 \sin^2\omega_0 t - 2v_r(v_0 + v_n)\cos\omega_r t \sin\omega_0 t]. \end{aligned}$$

Single Balanced Mixer

After low-pass filtering, the remaining terms will be DC, noise, and IF frequency terms:

$$i_1 = k\left[\frac{1}{2}v_r^2 + \frac{1}{2}(v_0 + v_n)^2 - v_r(v_0 + v_n)\sin\omega_i t\right],$$

$$i_2 = -k\left[\frac{1}{2}v_r^2 + \frac{1}{2}(v_0 + v_n)^2 + v_r(v_0 + v_n)\sin\omega_i t\right],$$

where $\omega_i = \omega_r - \omega_0$ is the IF frequency. Combining these currents gives the IF output as

$$i_{\mathrm{IF}} = i_1 + i_2 = -2kv_r(v_0 + v_n)\sin\omega_i t \simeq -2kv_r v_0 \sin\omega_i t,$$

since $v_n << v_0$. This result shows that the first-order terms in the noise voltage are canceled by the mixer, while the desired IF signals combine in phase. Practical mixers can give from 15 to 30 dB of AM noise rejection.

- The reflections at the LO and RF port are given as

$$V_\Gamma^{\mathrm{RF}} = \frac{V_{\Gamma 1}}{\sqrt{2}} - j\frac{V_{\Gamma 2}}{\sqrt{2}} = \frac{1}{2}\Gamma V_r - \frac{1}{2}\Gamma V_r = 0,$$

$$V_\Gamma^{\mathrm{LO}} = \frac{V_{\Gamma 2}}{\sqrt{2}} - j\frac{V_{\Gamma 1}}{\sqrt{2}} = -\frac{1}{2}j\Gamma V_r - \frac{1}{2}j\Gamma V_r = -j\Gamma V_r.$$

- The RF input is matched but reflected wave appears at the LO port

Single Balanced Mixer

Advantages:

- Provide either LO or RF Rejection (20-30 dB) at the IF output
- Rejection of certain mixer spurious products depending on the exact configuration
- Suppression of Amplitude Modulated (AM) LO noise

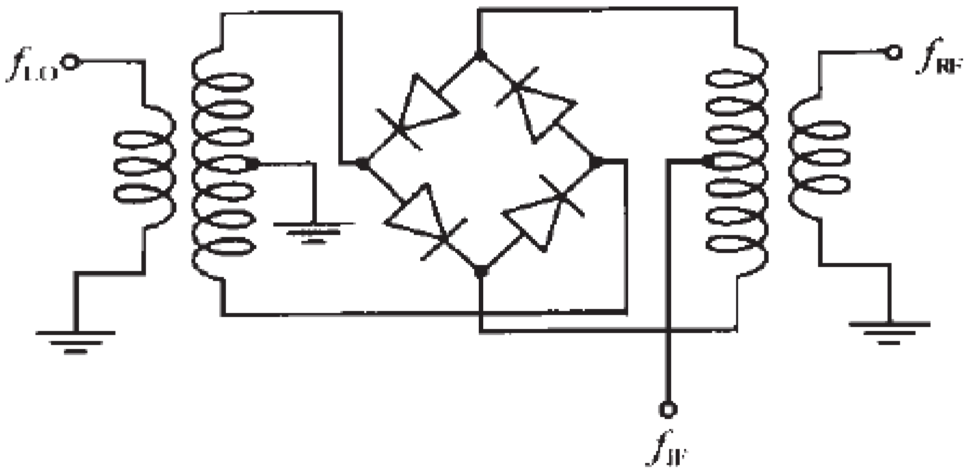
Disadvantages:

- Require a higher LO drive level

Double Balanced Mixer

➢ **Double balanced Mixer**

- **A double balanced mixer uses a diode ring and two hybrid 180 degree couplers for RF and LO ports**
- **The added diodes provides better isolation and an improved suppression of spurious modes**
- **It eliminates even harmonics of both LO and RF signals**



Double Balanced Mixer

Advantages:

- Both LO and RF are balanced, providing both LO and RF Rejection at the IF output
- All ports of the mixer are inherently isolated from each other
- Increased linearity compared to singly balanced
- Improved suppression of spurious products (all even order products of the LO and/or the RF are suppressed)
- Reasonable conversion loss on signal RF
- Consumes no power except for the losses incurred in conversion
- Broadband in nature and therefore suited to multi-band designs
- High intercept points

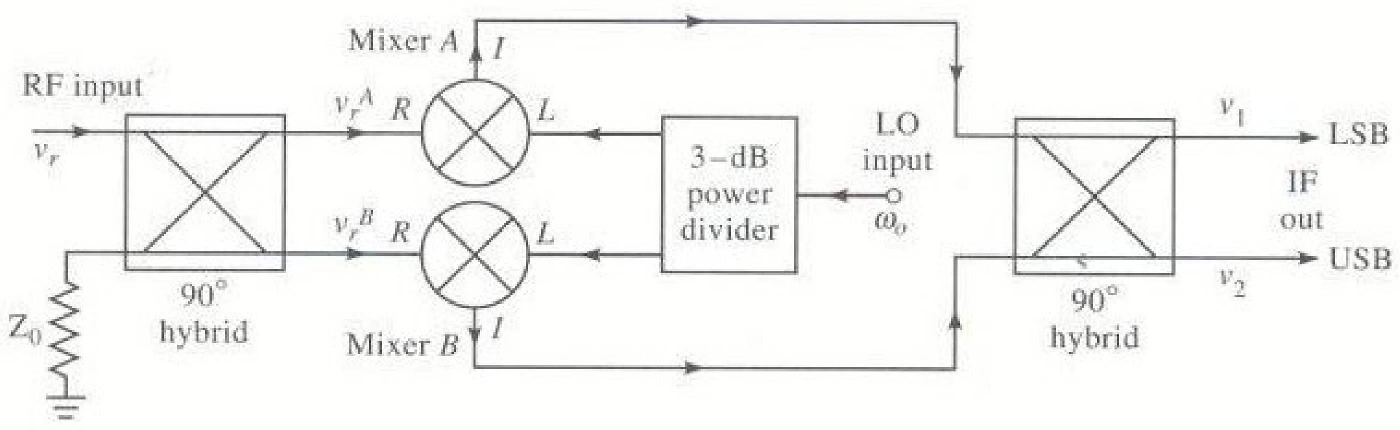
Disadvantages:

- Require a higher LO drive level
- Require two baluns
- Relative high noise figure, about the same as the conversion loss

Double Double Balanced Mixer

- **Double double balanced Mixer**

- **Two diode quad rings are fed via two RF and LO input hybrid couplers & the result of mixing at the output of the IF hybrid coupler**
- **It is mostly used as image rejection mixer**
- **Through intelligent RF and LO signal combination with proper phase such that image response is isolated and properly suppressed**



Double Double Balanced Mixer

$$v_r = v_U \cos(\omega_0 + \omega_i)t + v_L \cos(\omega_0 - \omega_i)t.$$

Input signal to mixer

Then the input to the two mixers is

$$v_r^A = \frac{v_U}{\sqrt{2}} \cos(\omega_0 + \omega_i)t + \frac{v_L}{\sqrt{2}} \cos(\omega_0 - \omega_i)t,$$

$$v_r^B = \frac{v_U}{\sqrt{2}} \cos[(\omega_0 + \omega_i)t - 90^\circ] + \frac{v_L}{\sqrt{2}} \cos[(\omega_0 - \omega_i)t - 90^\circ].$$

After mixing with an LO signal of $\cos\omega_0 t$, the IF outputs of the mixers are

$$v_i^A = \frac{kv_U}{2\sqrt{2}} \cos\omega_i t + \frac{kv_L}{2\sqrt{2}} \cos\omega_i t,$$

$$v_i^B = \frac{kv_U}{2\sqrt{2}} \cos(\omega_i t - 90^\circ) + \frac{kv_L}{2\sqrt{2}} \cos(\omega_i t + 90^\circ).$$

Combining these two signals in the 90° hybrid at the IF output gives the top output signal as

$$v_1 = \frac{k}{4}[v_U \cos\omega_i t + v_L \cos\omega_i t + v_U \cos(\omega_i t + 180^\circ) + v_L \cos\omega_i t]$$

$$= \frac{kv_L}{2} \cos\omega_i t,$$

which is the LSB component. The bottom IF output is

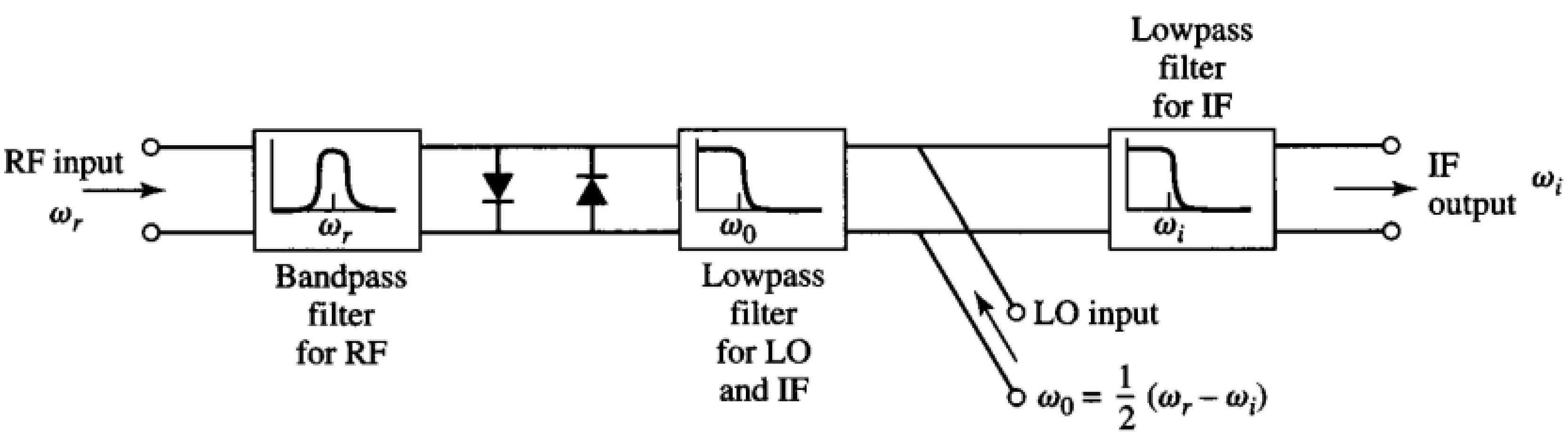
Double Double Balanced Mixer

$$v_2 = \frac{k}{4}[v_U \cos(\omega_i t - 90^\circ) + v_L \cos(\omega_i t + 90^\circ)$$
$$+ v_U \cos(\omega_i t - 90^\circ) + v_L \cos(\omega_i t - 90^\circ)]$$
$$= \frac{k v_U}{2} \sin \omega_i t,$$

which is the USB component.

Sub-harmonics Diode Mixer

- **Sub-harmonics (Anti-parallel) Diode Mixer**
  - **This configuration is in the anti-parallel mixer are commonly used for millimeter wave applications.**
  - **Due to diode nonlinearity, a second harmonic of the LO will be generated that will mix with RF signal to produce desired output frequency**
  - **The local oscillator frequency is half of the "usual LO frequency"**
  - $$\omega_0 = (\omega_r - \omega_i)/2$$
  - **Example: f_r = 64GHz, f_i = 2 GHz, f_0 = (64-2)/2 = 31 GHz**



Comparison

Mixer Type	Number of Diodes	RF SWR	RF/LO Isolation	L_C	Third-Order Intercept
Single ended	1	Poor	Fair	Good	13 dBm
Balanced (90°)	2	Good	Poor	Good	13 dBm
Balanced (180°)	2	Fair	Excellent	Good	13 dBm
Double balanced	4	Poor	Excellent	Excellent	18 dBm
Image rejection	8	Good	Good	Good	15 dBm

The End

Summary of Topics Covered in Part II of the EE5303 Module

(a) Amplifiers
(b) Oscillators
(c) Mixers
(d) Input/ output matching network (continued from Part 1)

Key words:

I. Stability, circle, stable/unstable region
II. Gain, noise figures
III. Multistage devices (Amplifier/mixers)
IV. Reflection coefficients and impedances (Output/input/source/load)

Sub-Topics:

(a) Amplifiers

I. Stability check, stability regions
II. Unilateral design: maximum power/gain
III. Power gain, power gain circle
IV. Constant gain circle
V. Noise Figure
VI. Impedance matching (input/output matching network); Single-stub matching; working principle of filters

(b) Oscillators

I. Un-Stability
II. Oscillating conditions
III. Max power

(c) Mixers

I. Conversion loss
II. Up/down conversion, image frequency

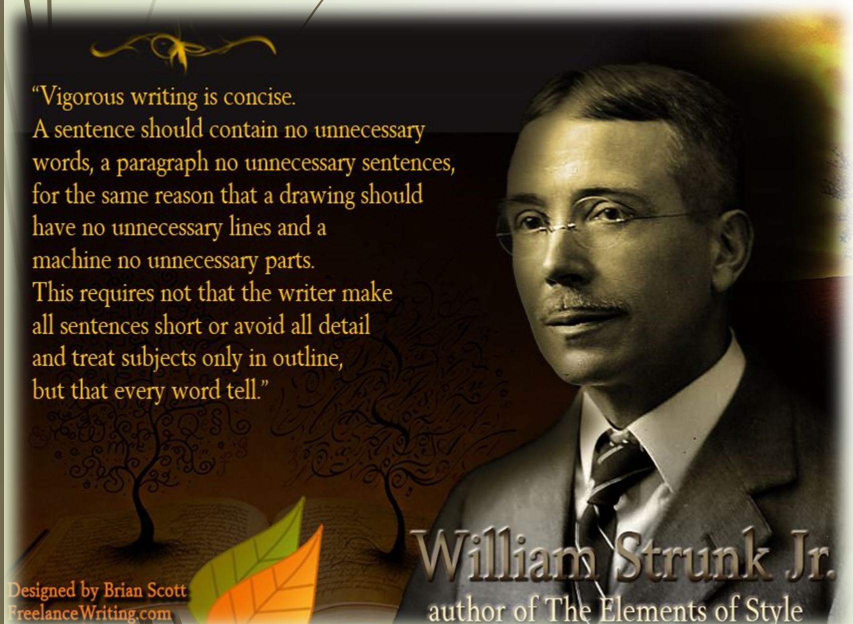
1918
Strunk

1959
Strunk &White

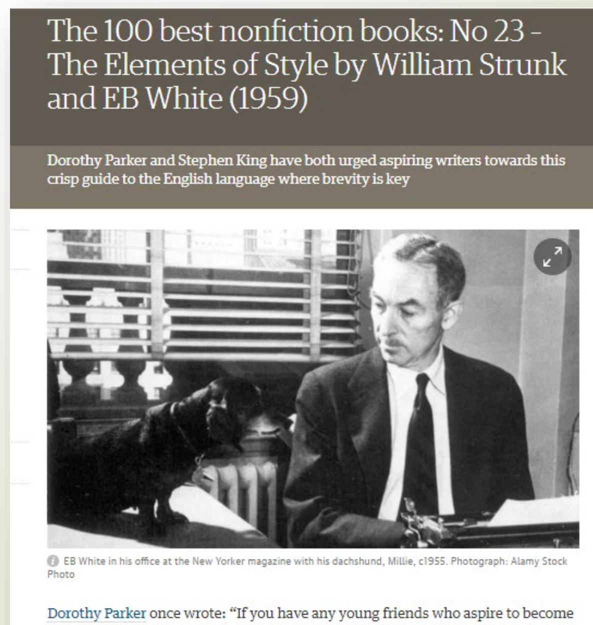
4th edition,1999

https://zhuanlan.zhihu.com/p/64998628 *(in Chinese)*

5th
edition
?



http://biblioresearching.blogspot.com/2009/05/my-elements-of-style-collection.html

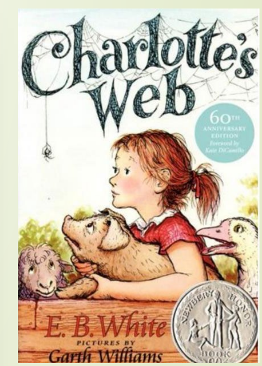


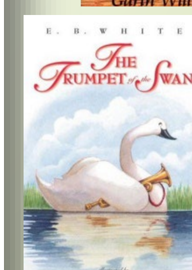
The 100 best nonfiction books: No 23 – The Elements of Style by William Strunk and EB White (1959)

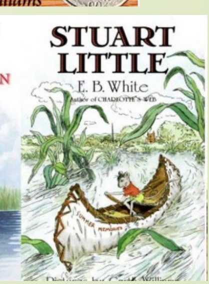
Dorothy Parker and Stephen King have both urged aspiring writers towards this crisp guide to the English language where brevity is key

EB White in his office at the New Yorker magazine with his dachshund, Millie, c1955. Photograph: Alamy Stock Photo

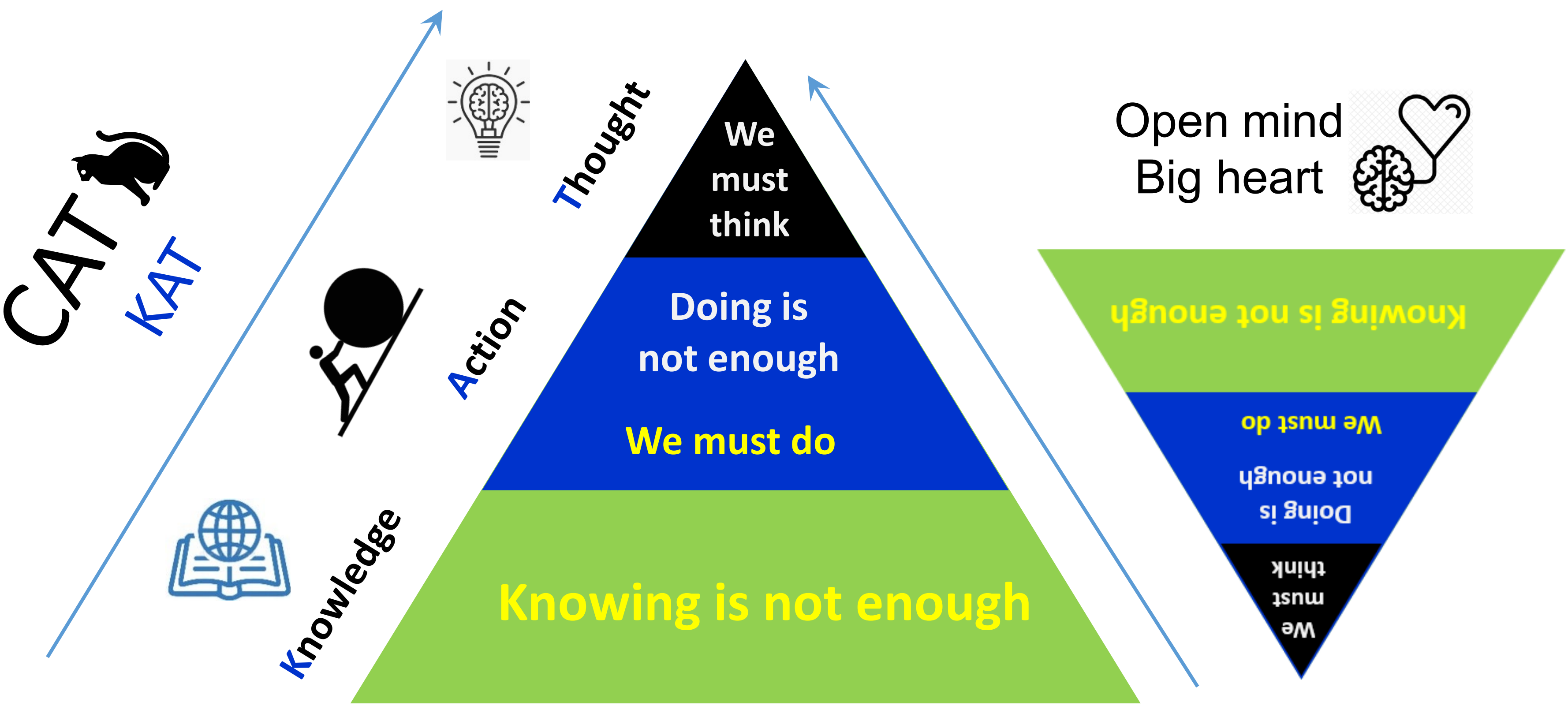
Dorothy Parker once wrote: "If you have any young friends who aspire to become writers, the second greatest favour you can do them is to present them with







Catch the C.A.T.



Curiosity killed the CAT
-but-
a CAT has nine lives

"A cat has nine lives. For three he plays, for three he strays, and for the last three he stays."
Cats are popularly known to have nine lives because of their agility and dexterity. Shakespeare also refers to the nine lives in his play Romeo and Juliet.