RF/Microwave Circuit and System

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Mixer

The ideal mixer (A reminder)

An ideal mixer multiplies rather than adds waveforms.

In a moment we will look at the electronics of mixers.

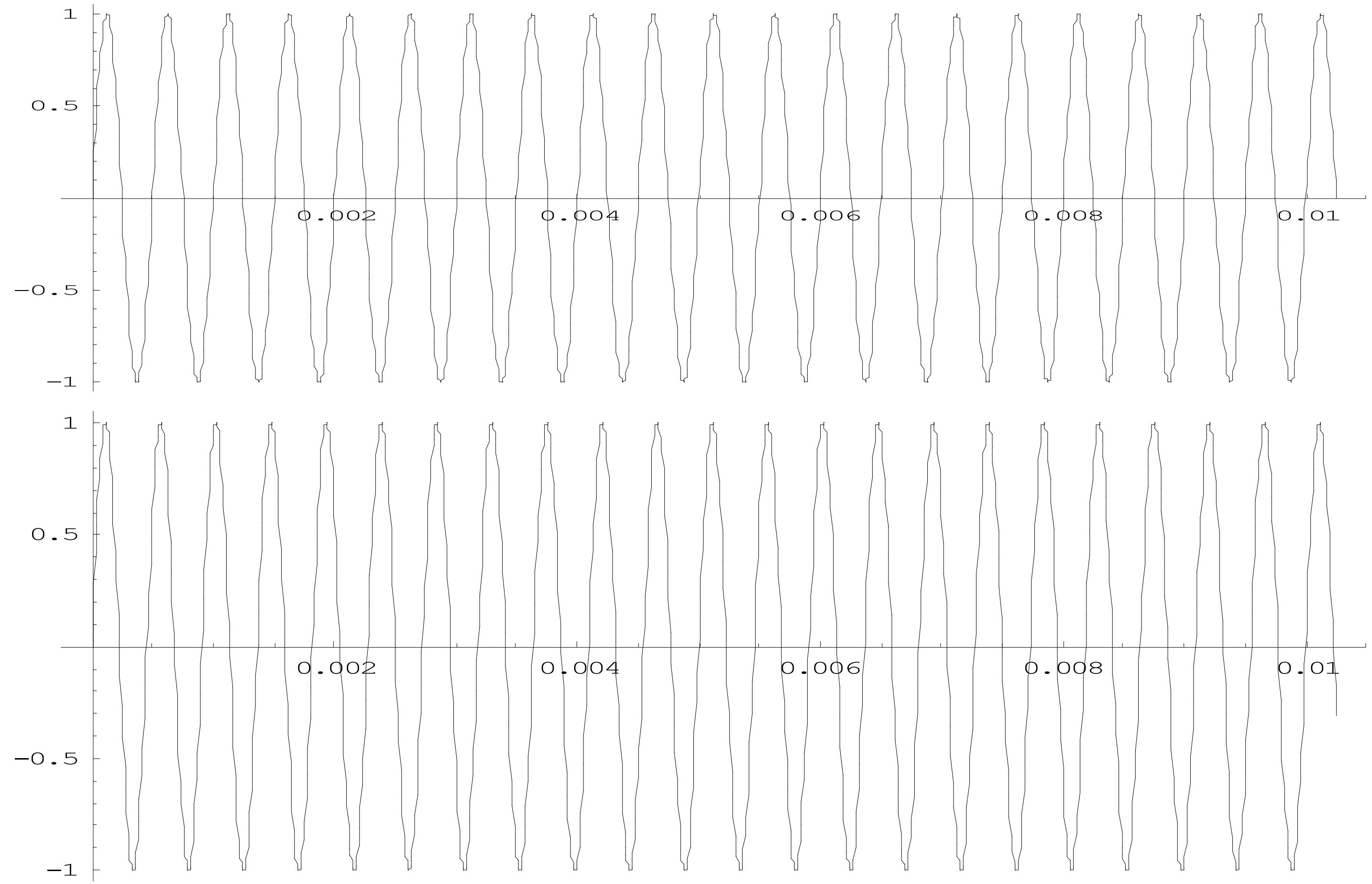
If you feed two sine waves at frequencies F and G into a multiplier you just get sine waves at frequencies F+G and F-G and no harmonics.

Lets remind ourselves what these waveforms are like before we look in more detail at real mixers.

The inputs to the ideal mixer

2000Hz

2200Hz

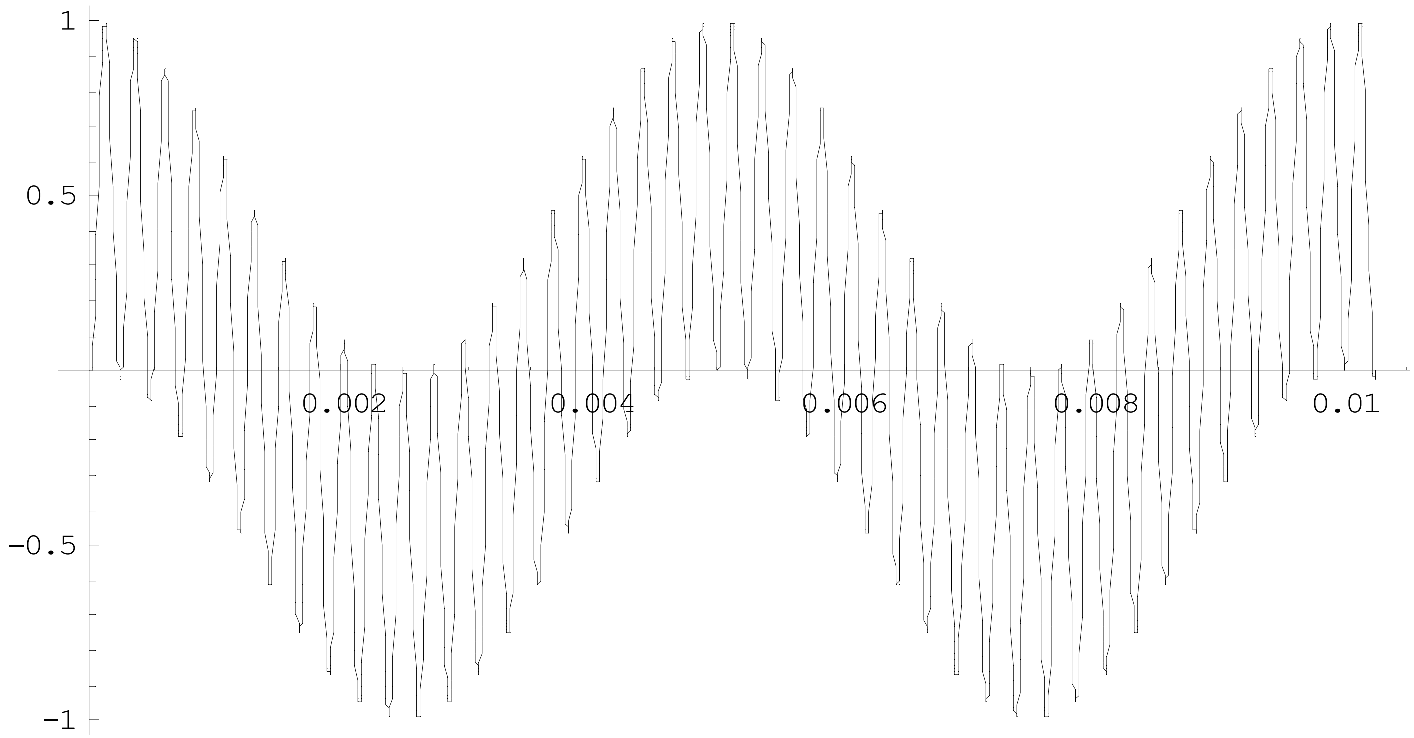


The output from the ideal mixer

200Hz

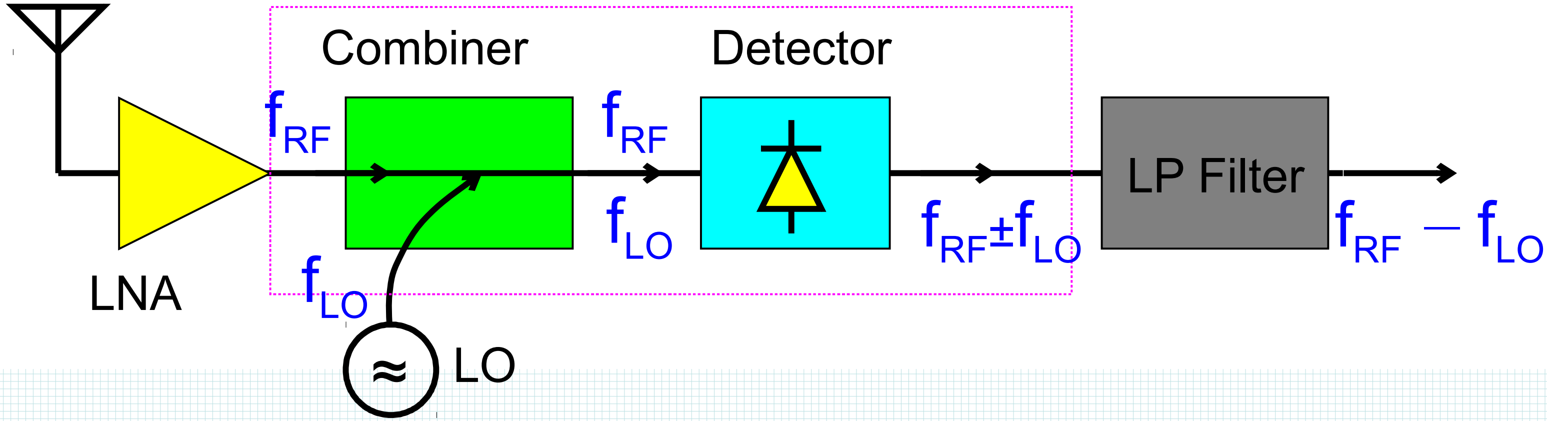
and

4200Hz



10.3 Basic Characteristics of Mixers

Mixer are commonly used to multiply signals of different frequencies in an effort To achieve frequency translation.

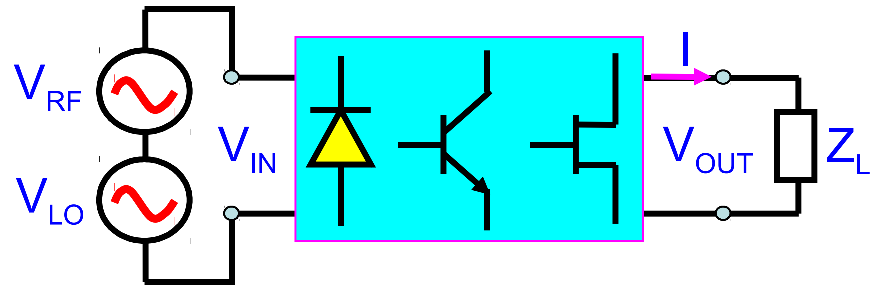


10.3.1 Basic Concepts

The RF input voltage signal is combined with the LO signal and supplied to a Semiconductor device with a nonlinear transfer characteristic at its output side driving a current into the load.

Diode and BJT: $I = I_0\left(e^{V/V_T} - 1\right)$

MOSFET: $I(V) = I_{DSS}\left(1 - V/V_{T0}\right)^2$



Input voltage: $V = V_Q + V_{RF}\cos(\omega_{RF}t) + V_{LO}\cos(\omega_{LO}t)$

The output characteristic can be found via a Taylor series expansion around the Q-point:

$$I(V) = I_Q + V\left(\frac{dI}{dV}\right)\Bigg|_{V_Q} + \frac{1}{2}V^2\left(\frac{d^2I}{dV^2}\right)\Bigg|_{V_Q} + \cdots = I_Q + VA + V^2B + \cdots$$

Neglecting the constant bias V_Q and I_Q

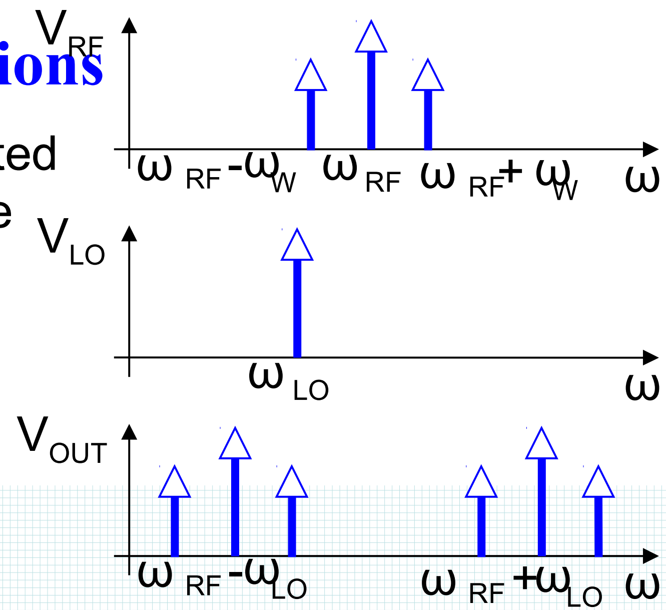
$$\begin{aligned} I(V) &= A\{V_{RF}\cos(\omega_{RF}t) + V_{LO}\cos(\omega_{LO}t)\} \\ &+ B\{V_{RF}^2\cos^2(\omega_{RF}t) + V_{LO}^2\cos^2(\omega_{LO}t)\} \\ &+ 2BV_{RF}V_{LO}\cos(\omega_{RF}t)\cos(\omega_{LO}t) + \cdots \end{aligned}$$

Thus: $I(V) = \cdots + BV_{RF}V_{LO}\{\cos[(\omega_{RF} + \omega_{LO})t] + \cos[(\omega_{RF} - \omega_{LO})t]\} + \cdots$

10.3.2 Frequency Domain Considerations

Typically the upconversion process is associated with the modulation in a **transmitter**, whereas the downconversion is encountered in a **receiver**.

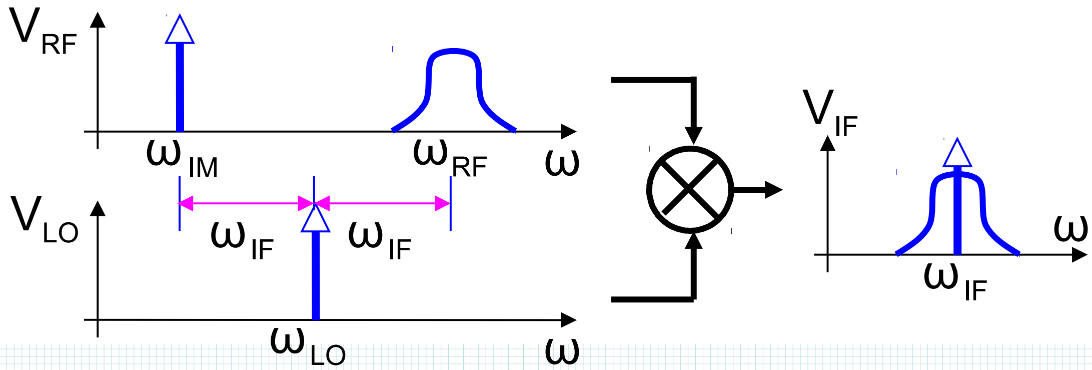
A critical question to answer is the choice of an LO frequency that shifts the RF frequency to a suitable IF level.



An interrelated issue is the problem of image frequencies mapping into The same downconverted frequency range.

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

$$\omega_{IM} - \omega_{LO} = \left(\omega_{LO} - \omega_{IF}\right) - \omega_{LO} = -\omega_{IF}$$



Since $\cos(-\omega_{IF}t) = \cos(\omega_{IF}t)$, both frequency spectra are shifted to the same Frequency location.

To avoid the presence of undesired image signals that can be greater in magnitude than the RF signal, a so-called image filter is placed before the mixer circuit to suppress this influence, provided sufficient spectral separation is assured. More sophisticated measures involve an image rejection mixer.

Mixer Metrics

- Conversion gain – lowers noise impact of following stages
- Noise Figure – impacts receiver sensitivity
- Port isolation – want to minimize interaction between the RF, IF, and LO ports
- Linearity (IIP3) – impacts receiver blocking performance
- Spurious response
- Power match – want max voltage gain rather than power match for integrated designs
- Power – want low power dissipation
- Sensitivity to process/temp variations – need to make it manufacturable in high volume

Conversion Gain

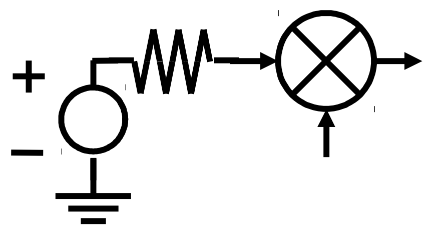
- Conversion gain or loss is the ratio of the desired IF output (voltage or power) to the RF input signal value (voltage or power).

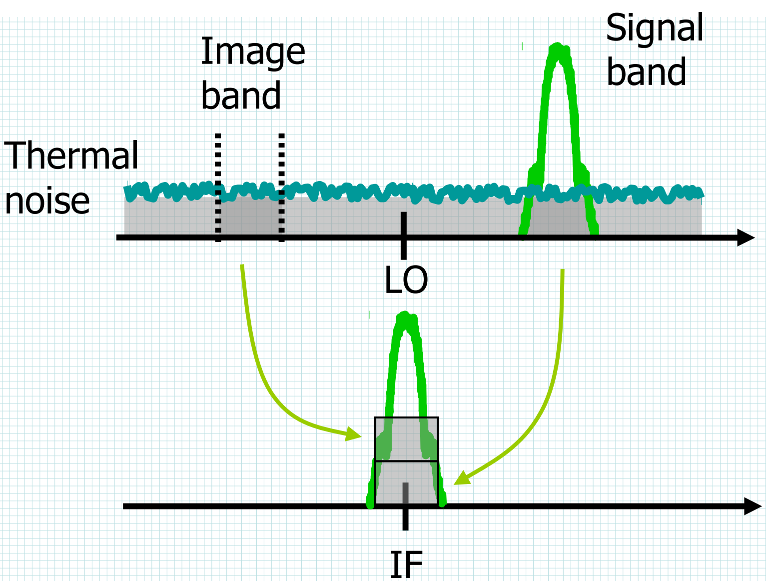
$$\text{Voltage Conversion Gain} = \frac{\text{r.m.s. voltage of the IF signal}}{\text{r.m.s. voltage of the RF signal}}$$

$$\text{Power Conversion Gain} = \frac{\text{IF power delivered to the load}}{\text{Available power from the source}}$$

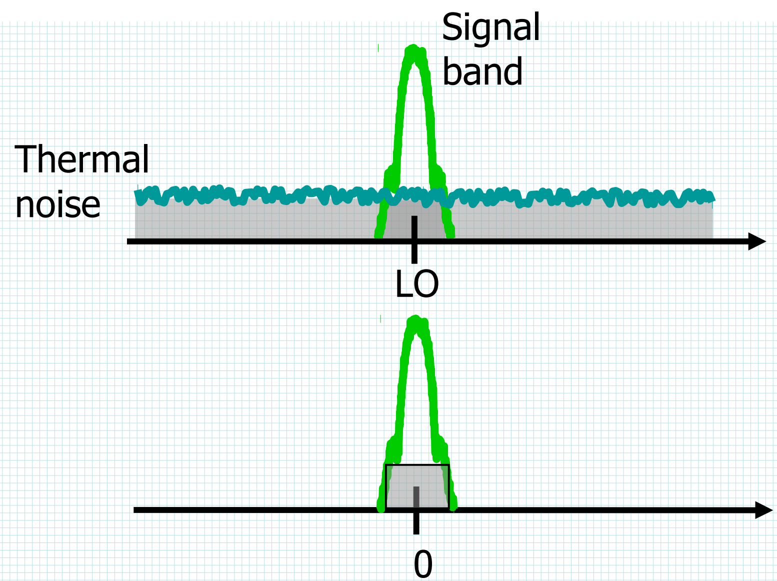
If the input impedance and the load impedance of the mixer are both equal to the source impedance, then the voltage conversion gain and the power conversion gain of the mixer will be the same in dB's.

Noise Figures: SSB vs DSB



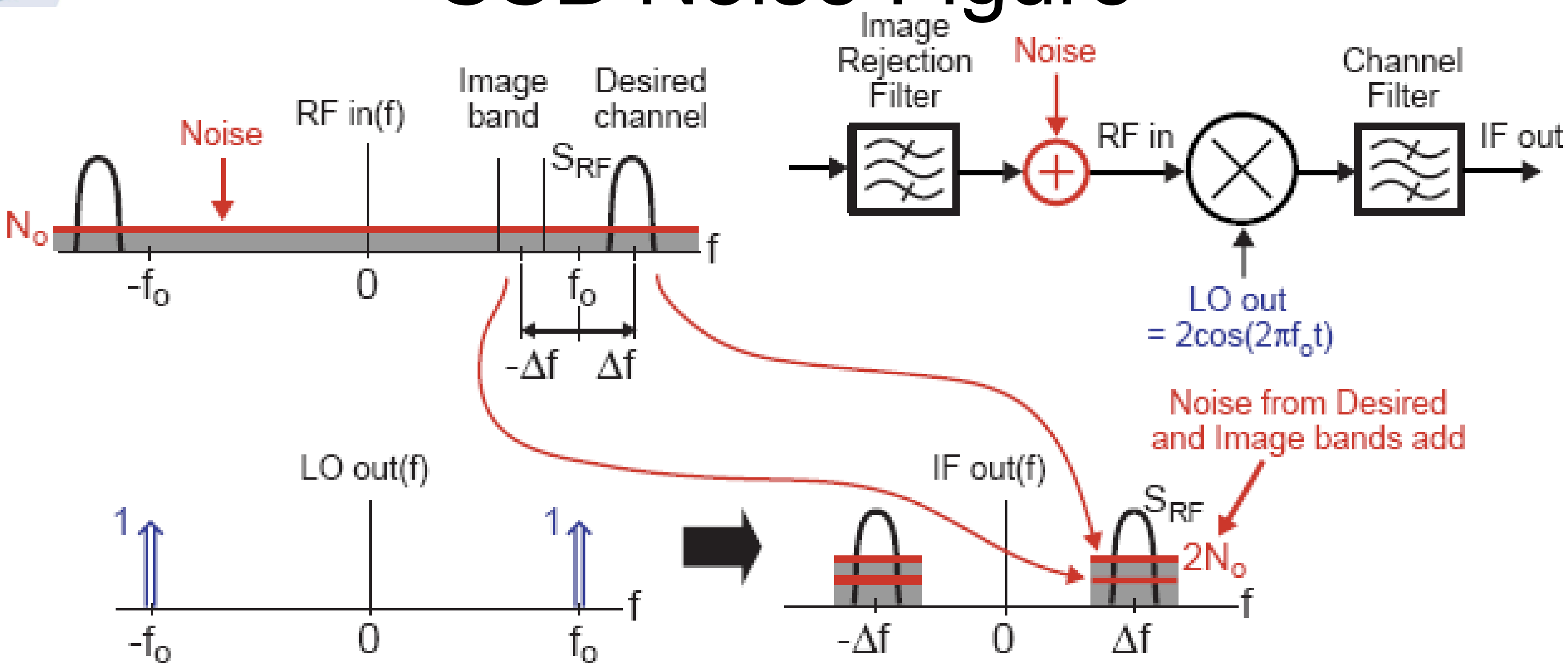


Single side band



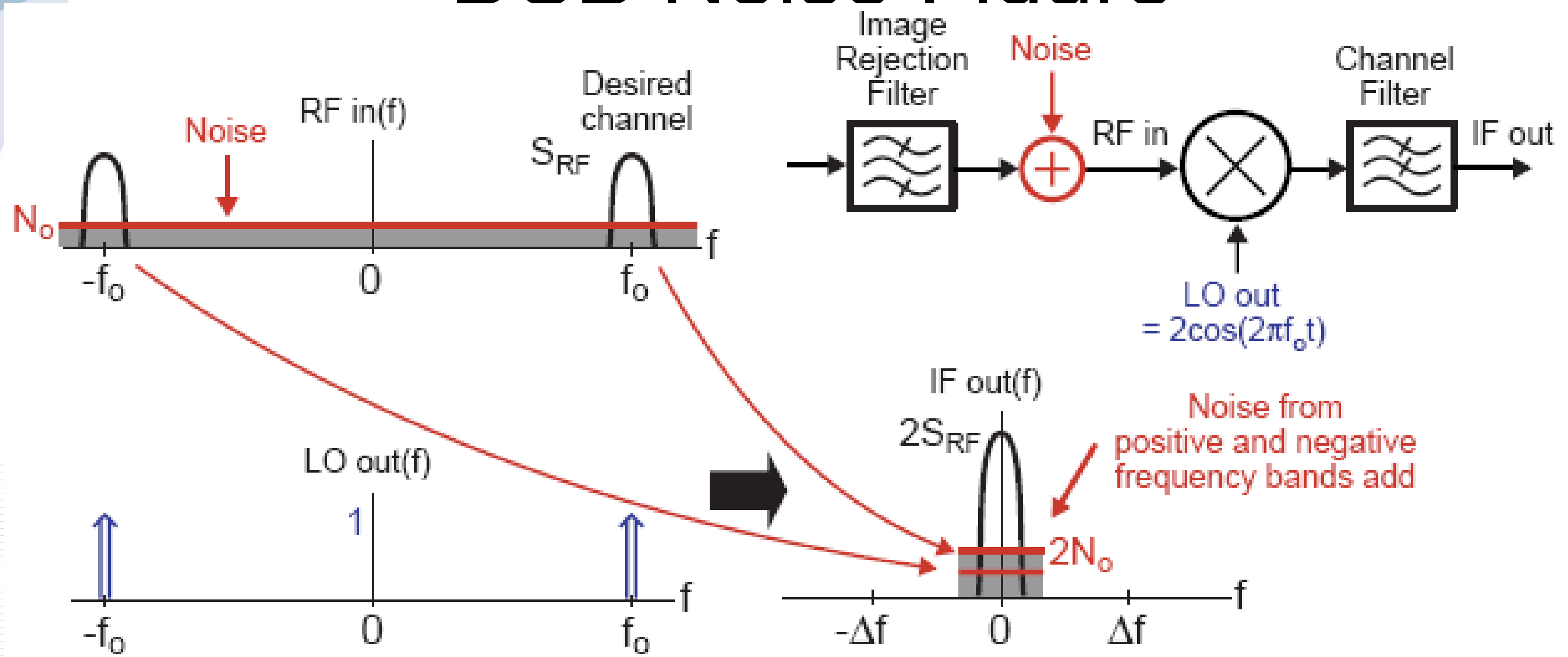
Double side band

SSB Noise Figure



- Broadband noise from mixer or front end filter will be loc ated in both image and desired bands
- Noise from both image and desired bands will combine i n desired channel at IF output
  - Channel filter cannot remove this

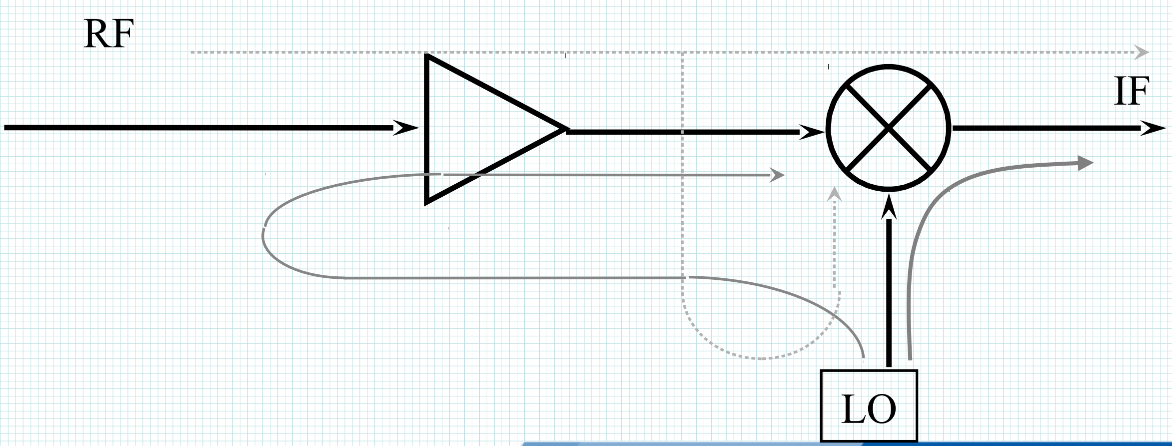
DSB Noise Figure



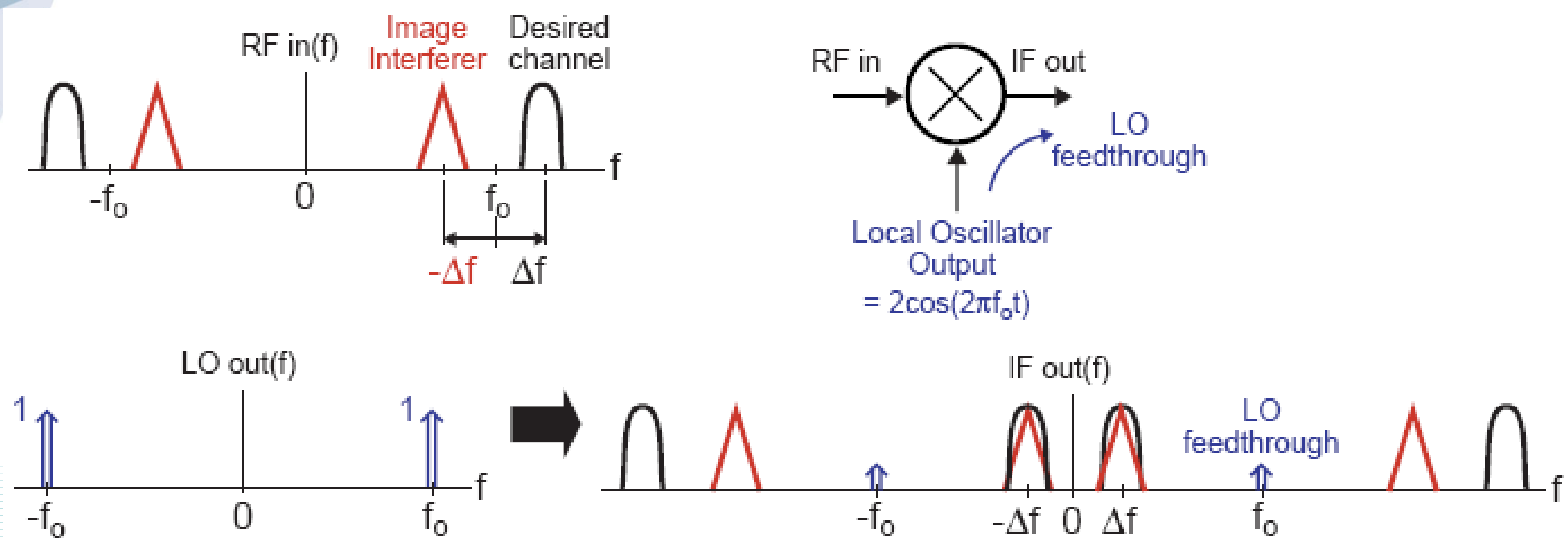
- For zero IF, there is no image band
  - Noise from positive and negative frequencies combine, but the si gnals combine as well
- DSB noise figure is 3 dB lower than SSB noise figure
  - DSB noise figure often quoted since it sounds better

Port-to-Port Isolations

- Isolation
  - Isolation between RF, LO and IF ports
  - LO/RF and LO/IF isolations are the most impo rtant features.
  - Reducing LO leakage to other ports can be so lved by filtering.

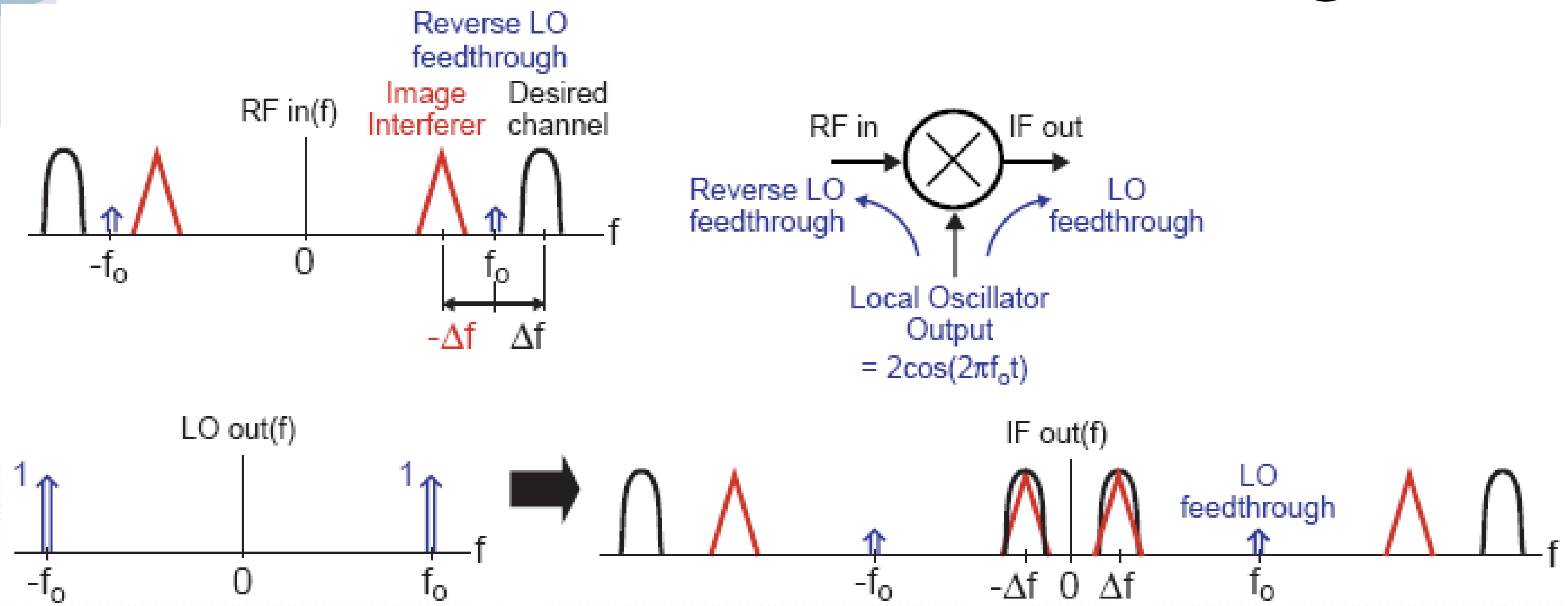


LO Feed through



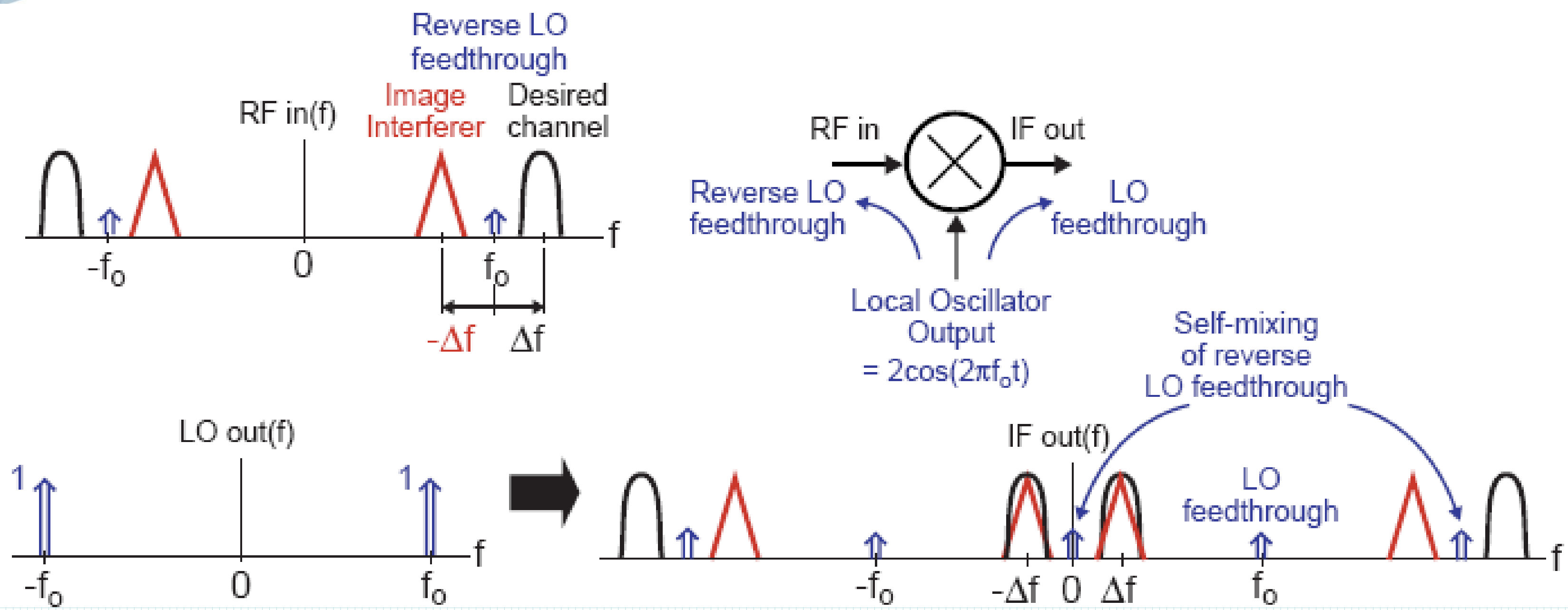
- Feed through from the LO port to IF output port due to parasitic capacitance, power supply coupling, etc.
- Often significant due to strong LO output signal
  - If large, can potentially desensitize the receiver due to the extra dynamic range consumed at the IF output
  - If small, can generally be removed by filter at IF output

Reverse LO Feed through



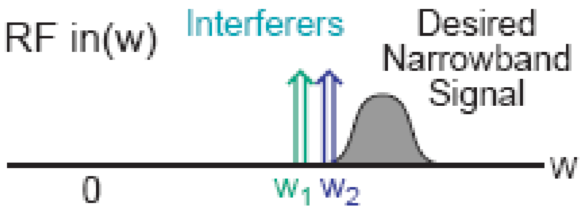
- Reverse feed through from the LO port to RF inp ut port due to parasitic capacitance, etc.
  - If large, and LNA doesn't provide adequate isolation, t hen LO energy can leak out of antenna and violate e mission standards for radio
  - Must insure that isolation to antenna is adequate

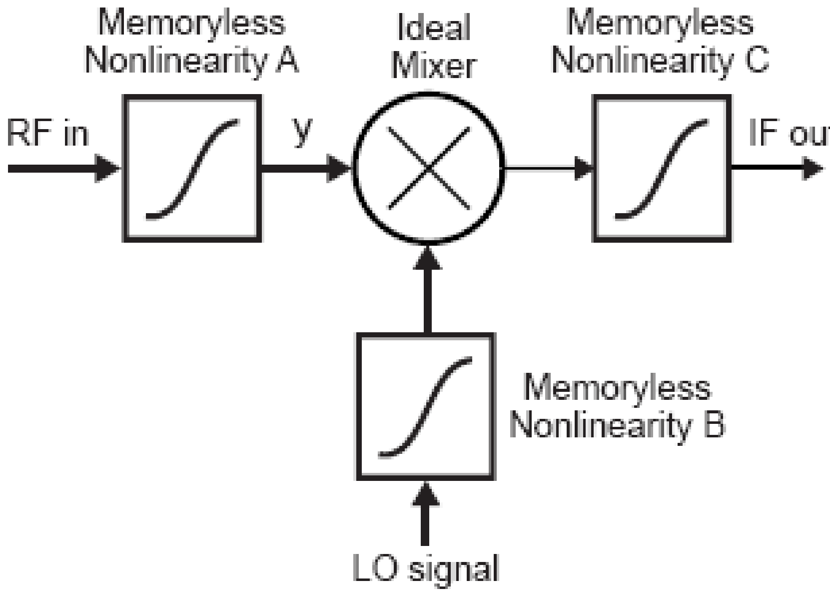
Self-Mixing of Reverse LO Feedthrough



- LO component in the RF input can pass back through the mixer and be modulated by the LO signal
  - DC and 2fo component created at IF output
  - Of no consequence for a heterodyne system, but can cause problems for homodyne systems (i.e., zero IF)

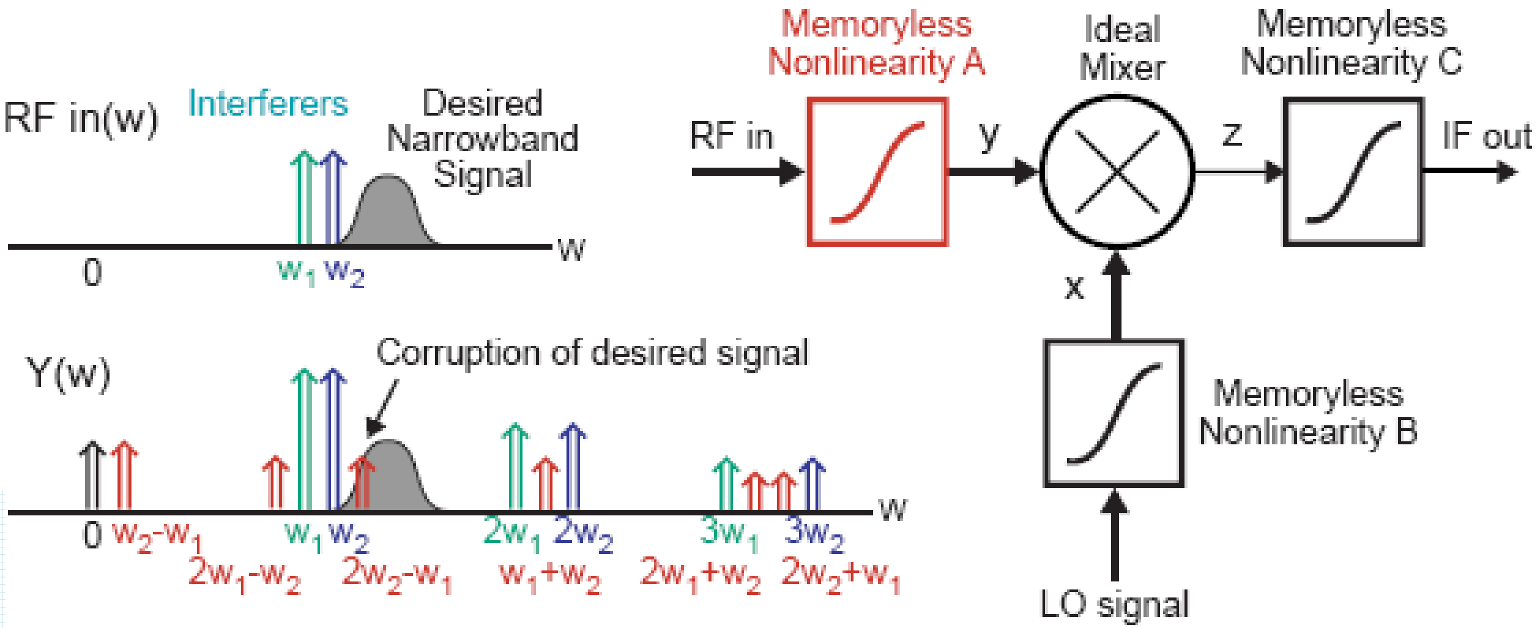
Nonlinearity in Mixers





- Ignoring dynamic effects, three nonlinearities around an i deal mixer
- Nonlinearity A: same impact as LNA nonlinearity
- Nonlinearity B: change the spectrum of LO signal
  - Cause additional mixing that must be analyzed
  - Change conversion gain somewhat
- Nonlinearity C: cause self mixing of IF output

Focus on Nonlinearity in RF Input Path

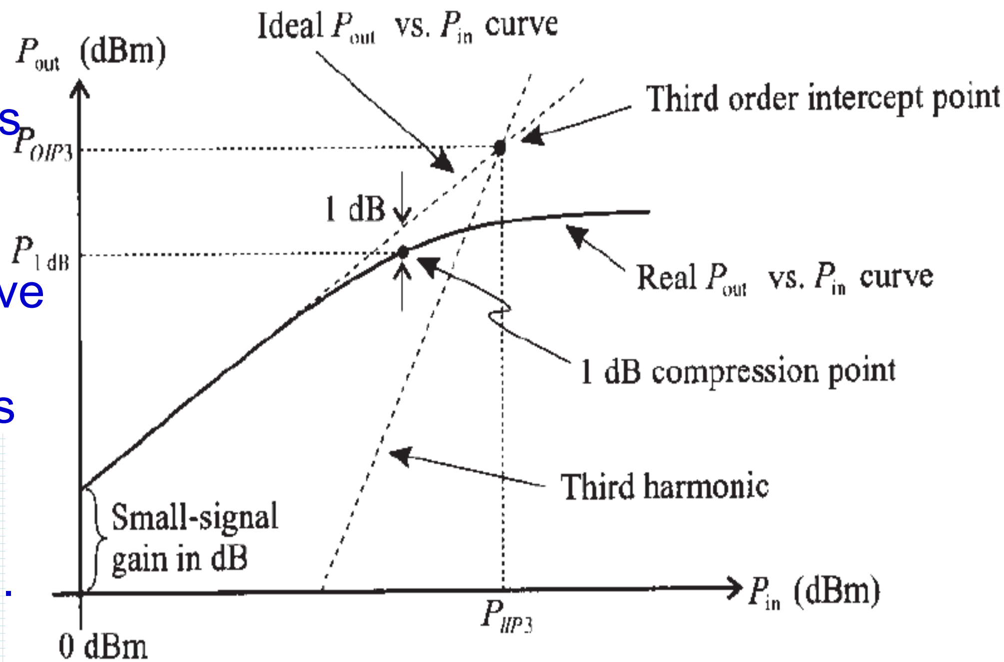


- Nonlinearity B not detrimental in most cases
  - LO signal often a square wave anyway
- Nonlinearity C avoidable with linear loads
- Nonlinearity A can hamper rejection of interferers
  - Characterize with IIP3 as with LNA designs
  - Use two-tone test to measure (similar to LNA)

Nonlinearities of mixer are customarily quantified in terms of conversion Compression and intermodular distortion(IMD).

Conversion compression relates to the fact that the IF output power as a function of RF input power begin to deviate from the linear curve at a certain point.

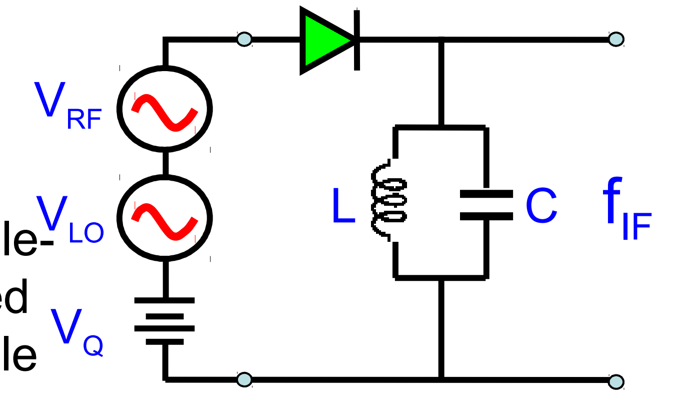
The intermodulation distortion is related to the influence of a second frequency component in the RF input signal, giving rise to distortion.



The intercept point between the desired linear output response and the undesirable third-order IMD response is a common figure of merit, indicating the ability of a mixer to suppress this influence.

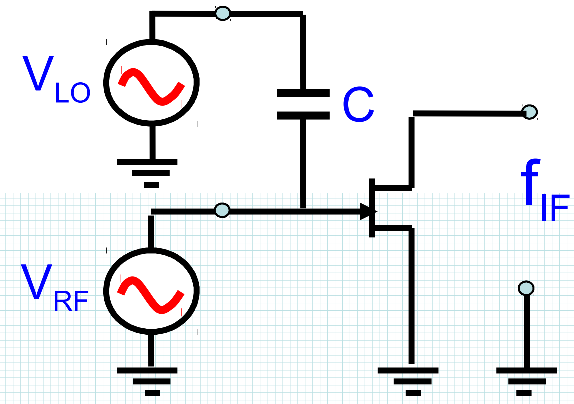
10.3.3 Single-Ended Mixer Design

The simplest and least efficient mixer is the Single-ended design involving a Schottky diode. An improved design involving a FET, which, unlike the diode, is able to provide a gain to the incoming RF and LO signals.



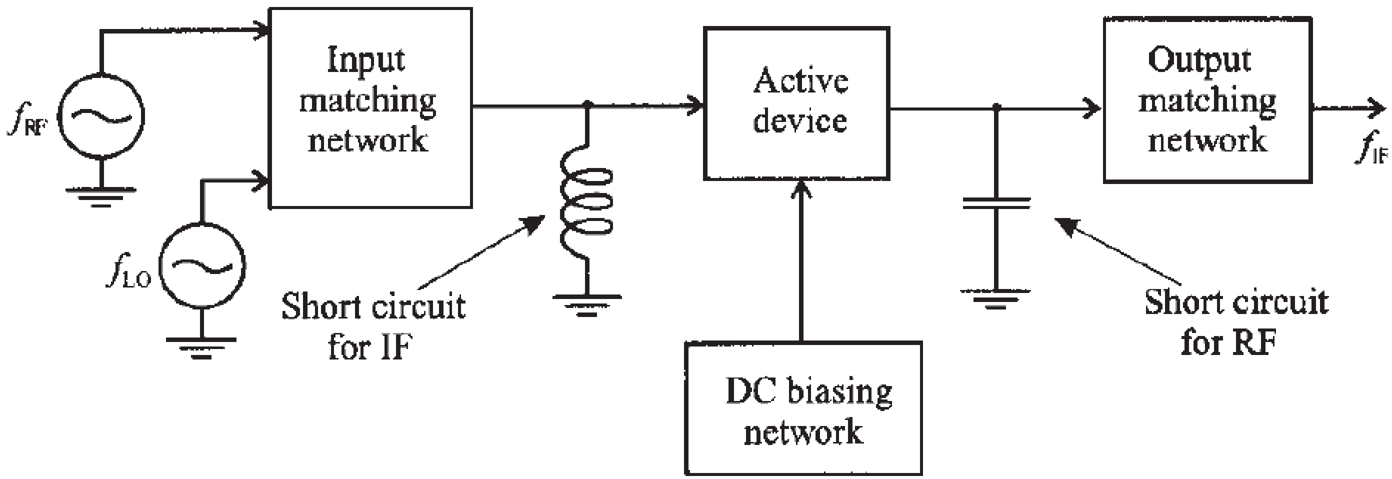
Conversion loss: $$CL = 10\log\frac{P_{RF}}{P_{IF}} = \frac{1}{CG}$$

Noise figure: $$F = \frac{P_{n_{out}}}{CGP_{n_{in}}}$$



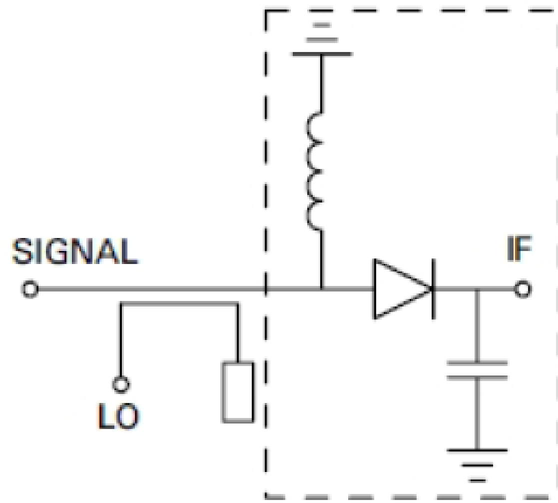
With CG being the conversion gain, and $P_{n_{out}}$, $P_{n_{in}}$ the noise power at the output due to the RF signal input(at RF) and the total noise power at the output(at IF)

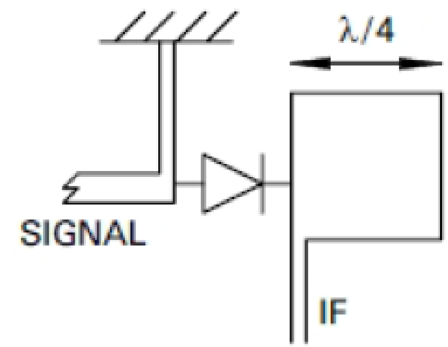
Unbalanced Mixer



The circuit design of an RF mixer follows a similar approach as discussed when dealing with an RF amplifier. As for the matching network, one has to pay special attention to the fact that there is a large difference in frequencies between RF, LO on the input side, and IF on the output side, since both sides have to be matched to the typical 50Ω line impedance, the transistor port impedances at these two different frequencies have to be specified. Furthermore, to minimize interference at the output side of the device, it is important to short circuit the input to IF, and conversely short circuit the output to RF.

Diode Mixer

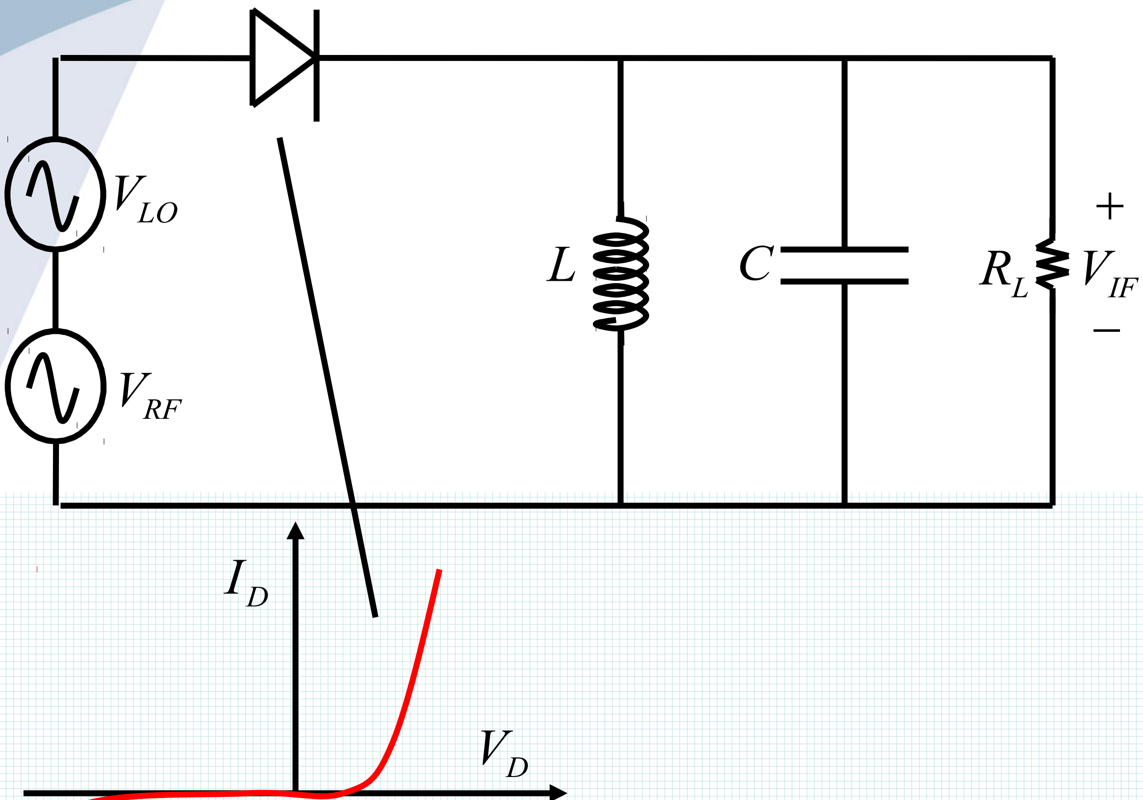


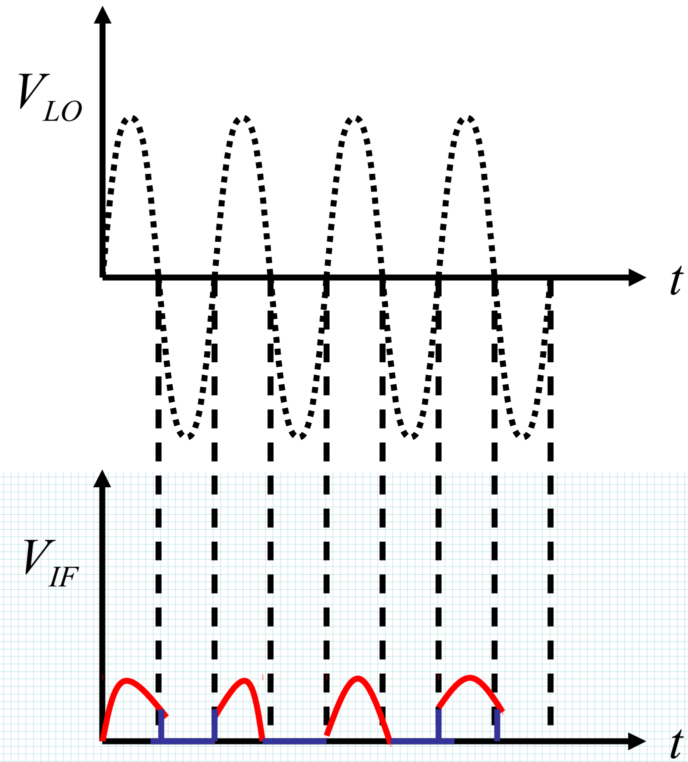


Single-device Mixer using one diode is primarily a process of matching the pumped diode to the RF input and IF output, terminating the diode properly at LO harmonics and unwanted mixing frequencies (other than the RF and IF), and isolating the RF, LO, and IF ports

Isolation, and in some cases the termination, can be provided by using filters, a balanced structure, or both

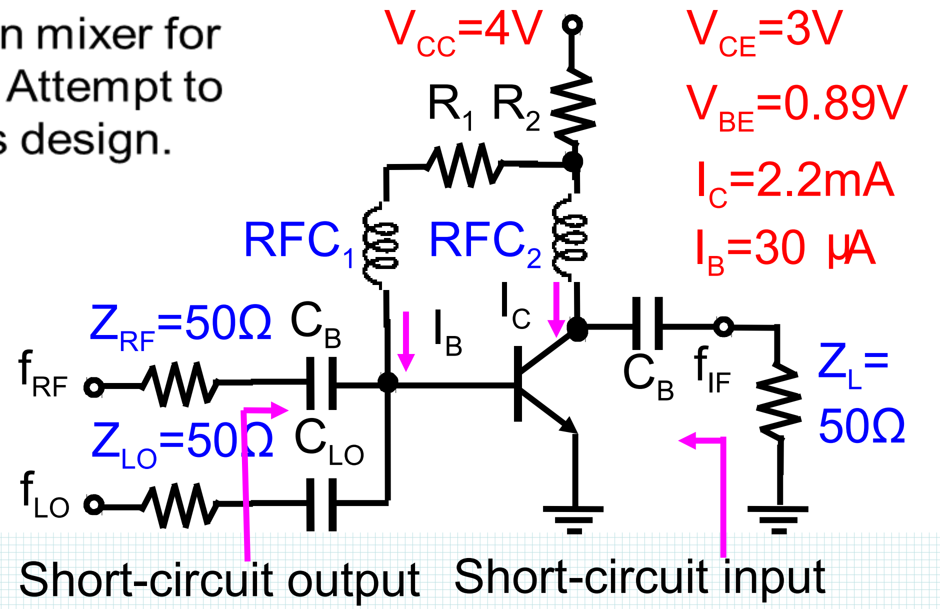
The choice depends on the frequency range and the intended application.





- Simplest and oldest passive mixer
- The output RLC tank tuned to match IF
- Input = sum of RF, LO and DC bias
- No port isolation and no conversion gain.
- Extremely useful at very high frequency (millimeter wave band)

Example 10-9: Compute the values of the resistor R_1 and R_2. Design a low-side injection mixer for $f_{RF} = 1900\ MHz$ and $f_{IF} = 200\ MHz$. Attempt to minimize the component count in this design.



Solution:

$$R_2 = \frac{V_{CC} - V_{CE}}{I_C + I_B} = 448\Omega$$

$$R_1 = \frac{V_{CE} - V_{BE}}{I_B} = 70.3k\Omega$$

$Z_{in}(f_{RF}) = 77.9\text{-}j130.6\Omega$ $Z_{out}(f_{IF}) = 677.7\text{-}j2324\Omega$

1. Decide on how to supply the LO signal

The simplest arrangement is to connect the LO source directly to the base of The transistor via a decoupling capacitor. The value of this capacitor C_{LO} has to be Chosen small enough so as to prevent RF signal coupling into the LO source. Pick $C_{LO} = 0.2pF$.

Return loss: $RL_{RF} = -20\log|\Gamma_{LO}|_{f_{RF}}| = -20\log(0.9727) = 0.24dB$

The LO frequency is very close to f_{RF} so that the same capacitance will Attenuate not only the RF signal but the LO as well.

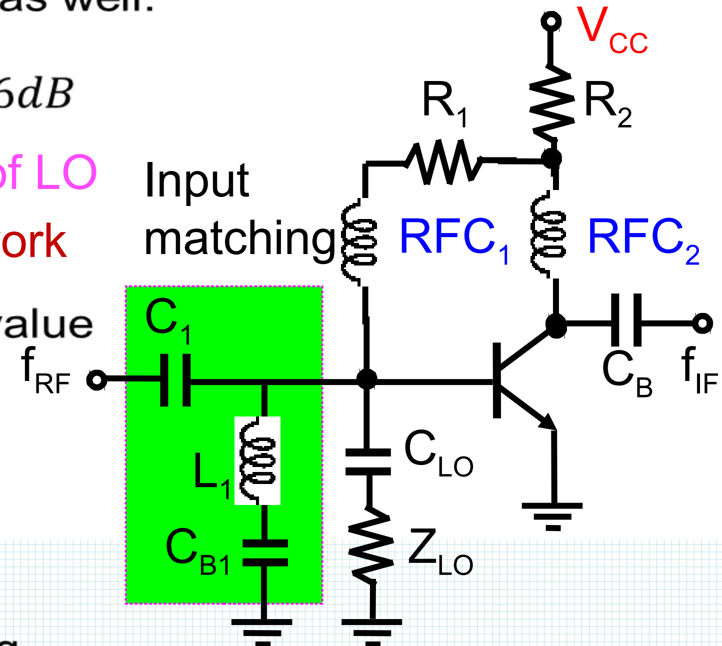
$$IL_{RF} = -10\log\left(1 - |\Gamma_{LO}|^2|_{f_{RF}}\right) = 13.6dB$$

adjust the power of LO

2. Design the input and output matching network

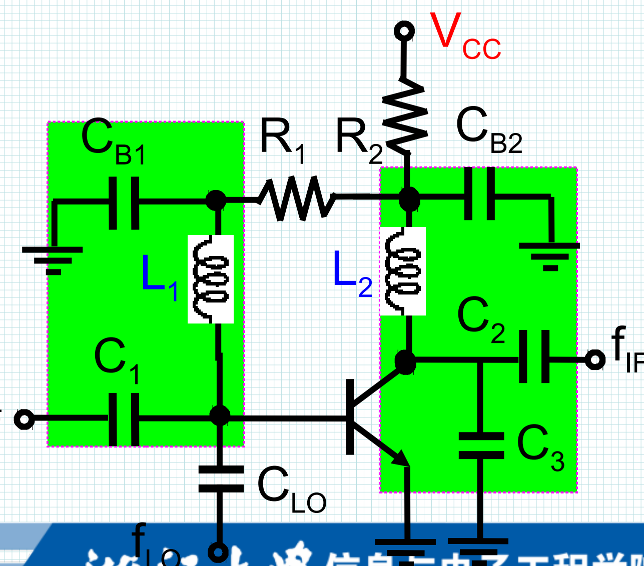
The presence of C_{LO} and Z_{LO} modifies the value of the input impedance.

$$Z'_{in} = \left(Z_{LO} + \frac{1}{j\omega_{RF}C_{LO}}\right) // Z_{in} = 47.2 - j103.5\Omega$$

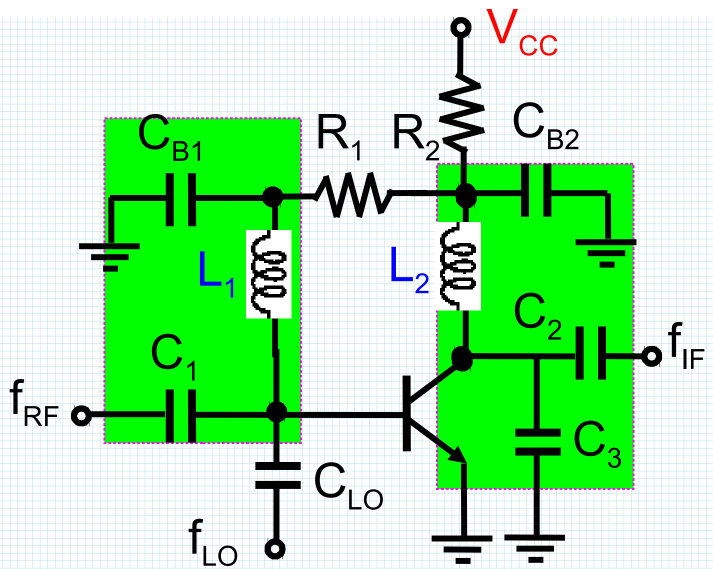


Knowing Z'_{in}, we can design an input matching network. One of the possible topologies consists of a Shunt inductor followed by a series capacitor, Add the blocking capacitor C_{B1} to prevent DC short circuit to ground.

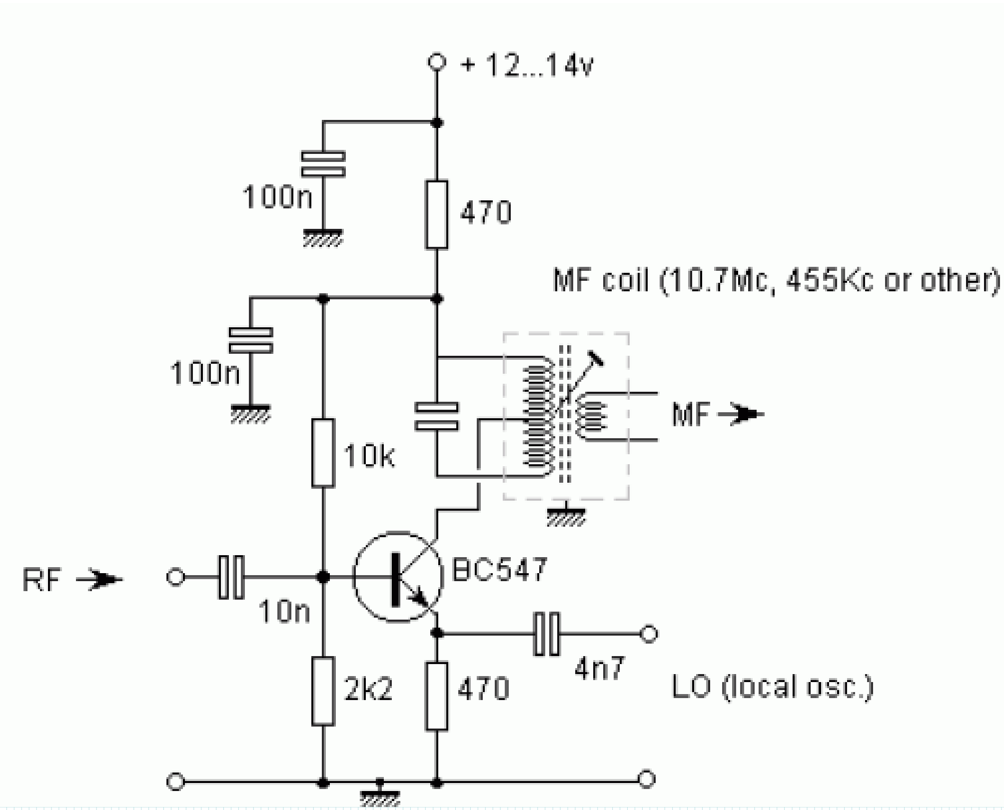
For the improved solution, connect R_1 directly to the contact between L_1 and C_{B1}. Bias the base of the transistor through L_1 and maintain isolation of the RF signal through C_{B1}, and provide a short-Circuit condition for the IF signal (L_1 and C_{B1} exhibit a series resonance at IF).



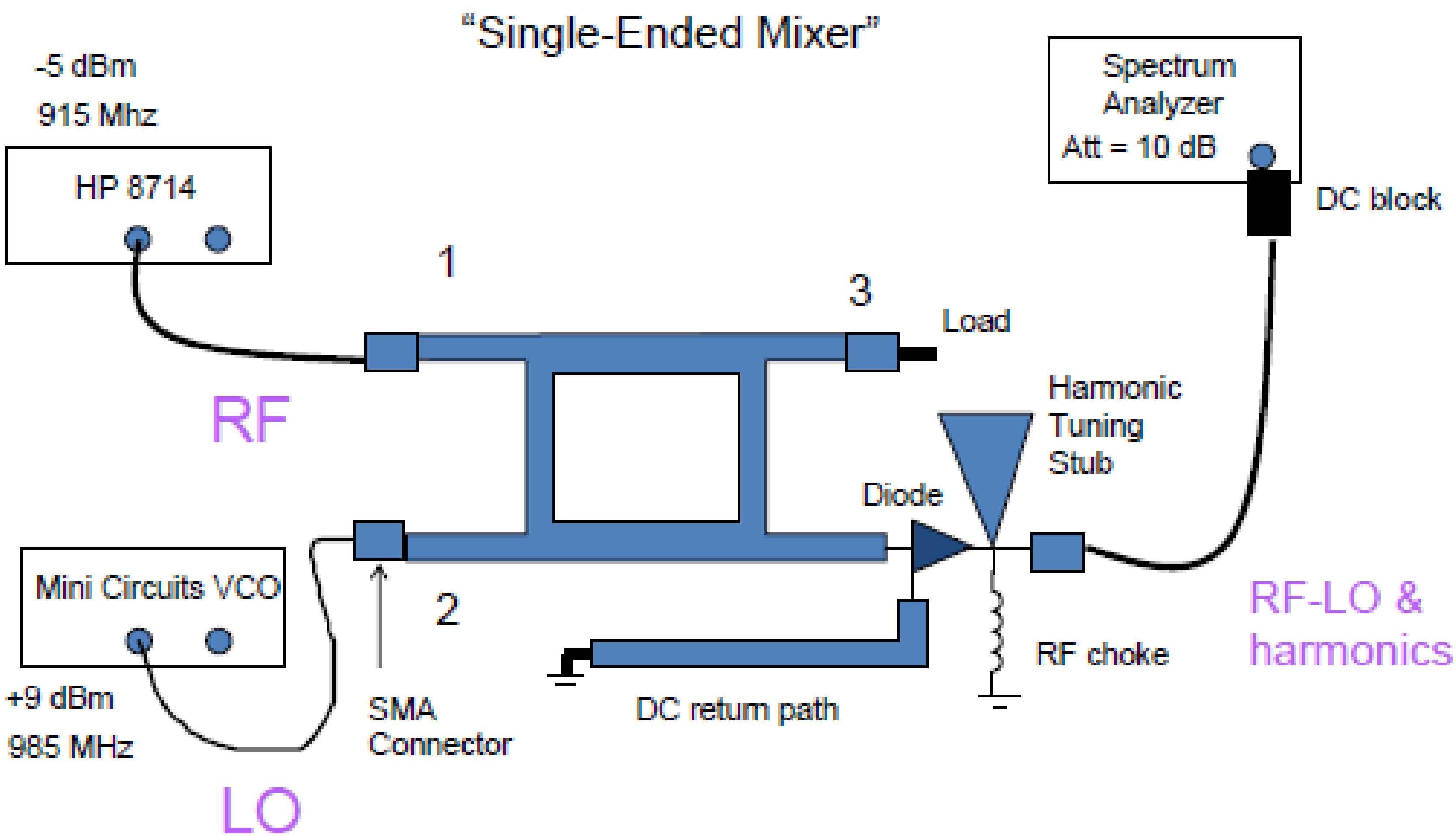
The output matching network is developed using a similar approach. Mainly Consisted of a shunt inductance L_2 followed by a series capacitance C_2. And The additional capacitance C_3 is chosen to provide solid ground condition for The f_{RF} signal.



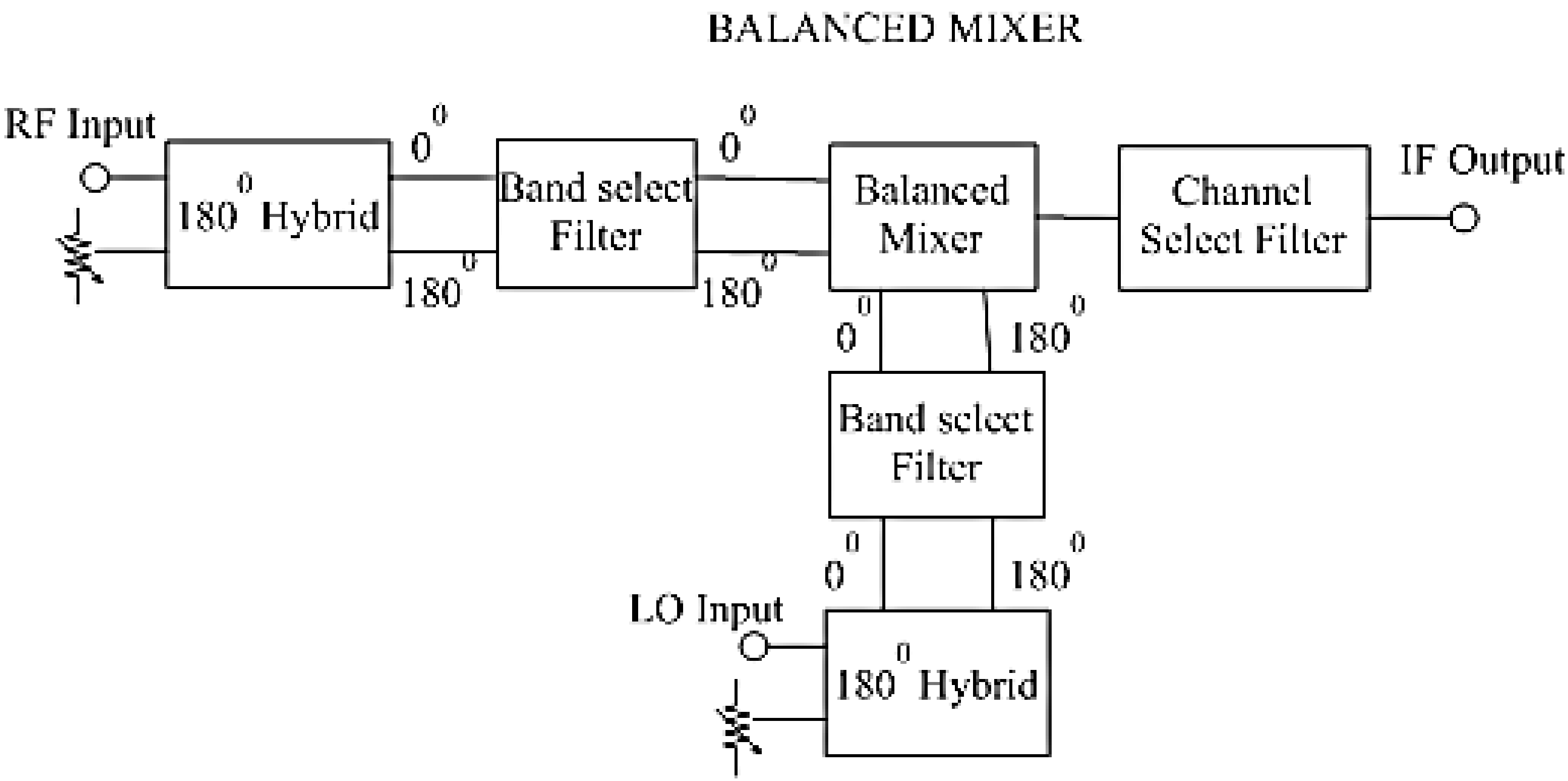
Single Balanced Active Mixer



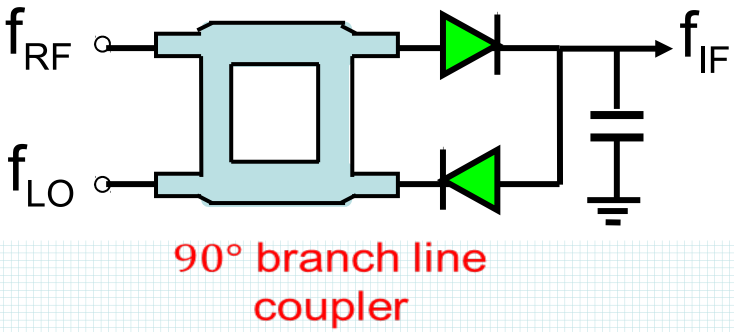
- This configuration provides gain
- More noisy at higher frequencies
- No isolation
- Simple and used low end application


"Single-Ended Mixer"
-5 dBm
915 Mhz
HP 8714
1
3
Load
Spectrum
Analyzer
Att = 10 dB
DC block
RF
Harmonic
Tuning
Stub
Diode
Mini Circuits VCO
2
RF choke
RF-LO &
harmonics
+9 dBm
985 MHz
SMA
Connector
DC return path
LO

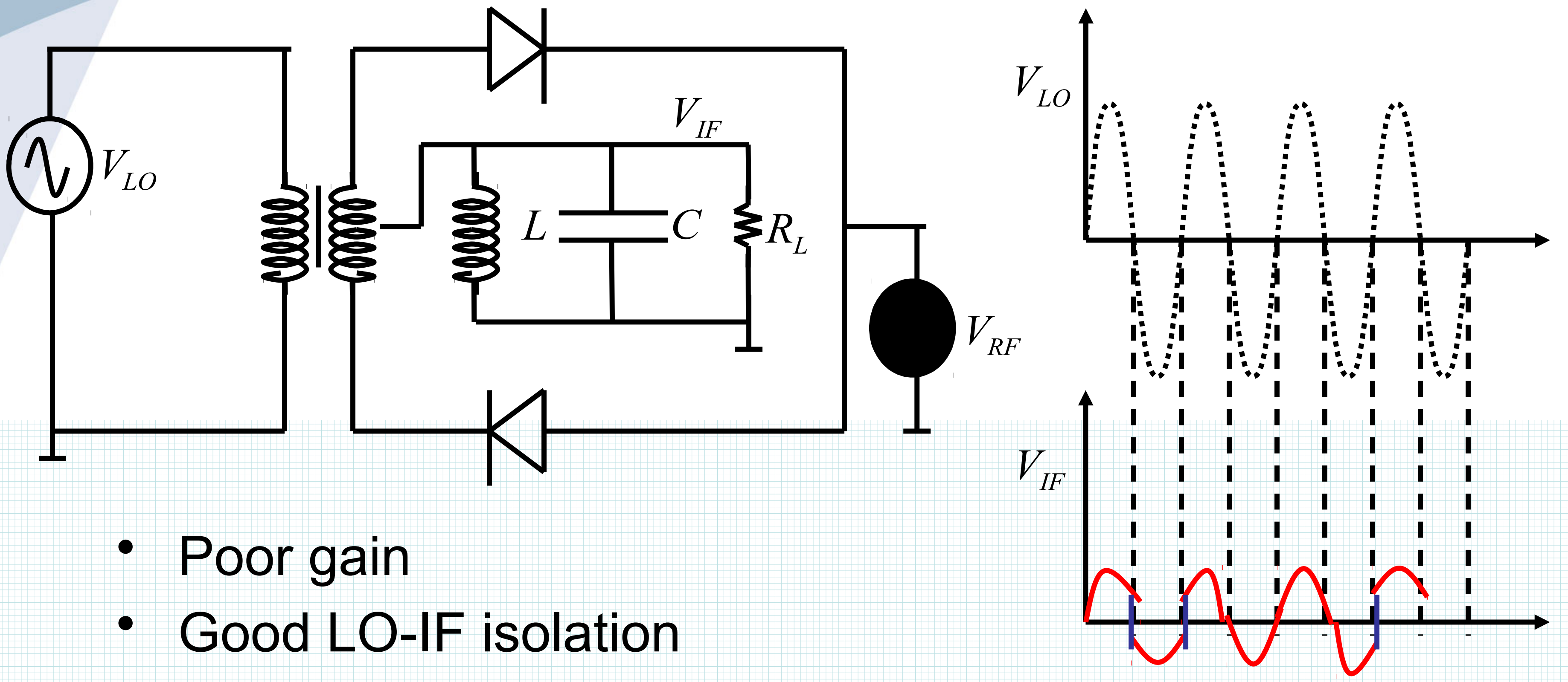
Balance Mixer



10.3.4 Single-Balanced Mixer

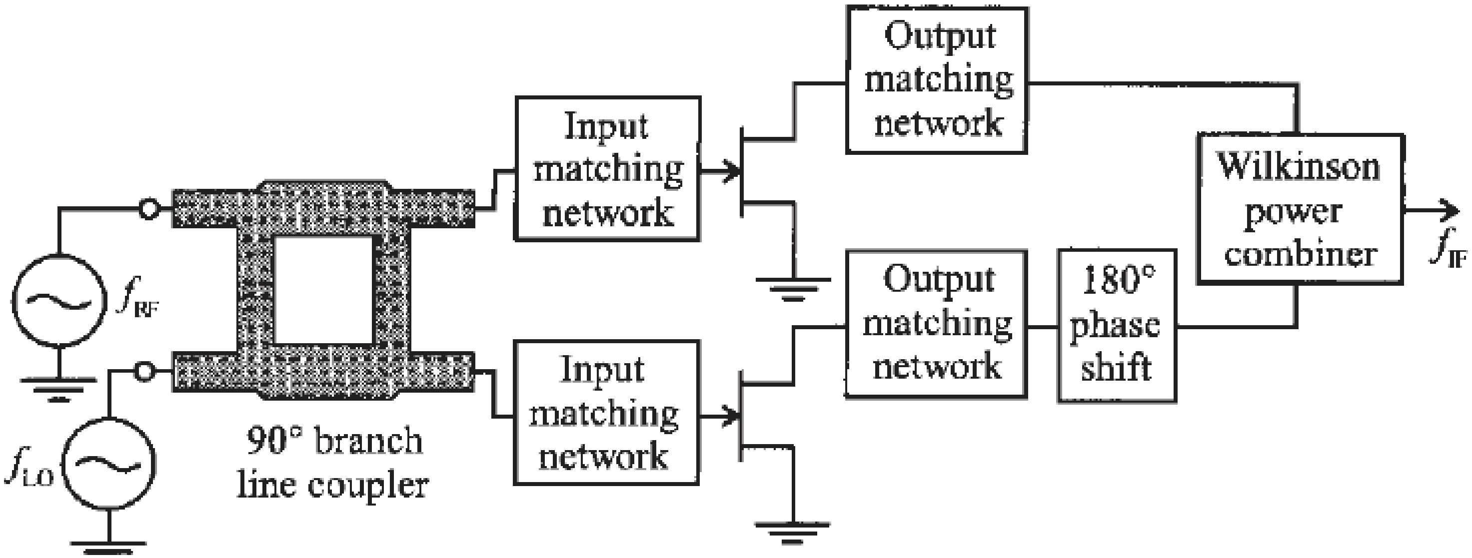


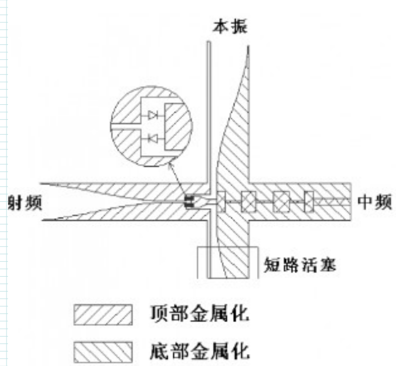
The single-ended mixer are rather easy to Construct circuits. The main disadvantage of These designs is the difficulty associated with Providing LO energy while maintaining separation Between LO, RF, and IF signals for broadband Applications. The balanced dual-diode or dual-Transistor mixer in conjunction with a hybrid coupler offers the ability to conduct Such broadband operations. Moreover, it provides further advantages related to Noise suppression and spurious mode rejection.

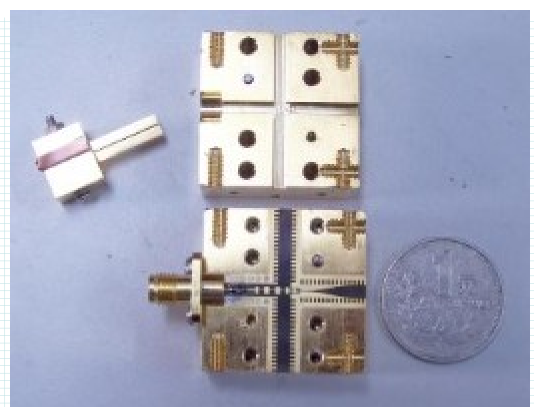


- Poor gain
- Good LO-IF isolation
- Good LO-RF isolation
- Poor RF-IF isolation
- Attractive for very high frequency applications where transistors are slow.

10.3.4 Single-Balanced Mixer

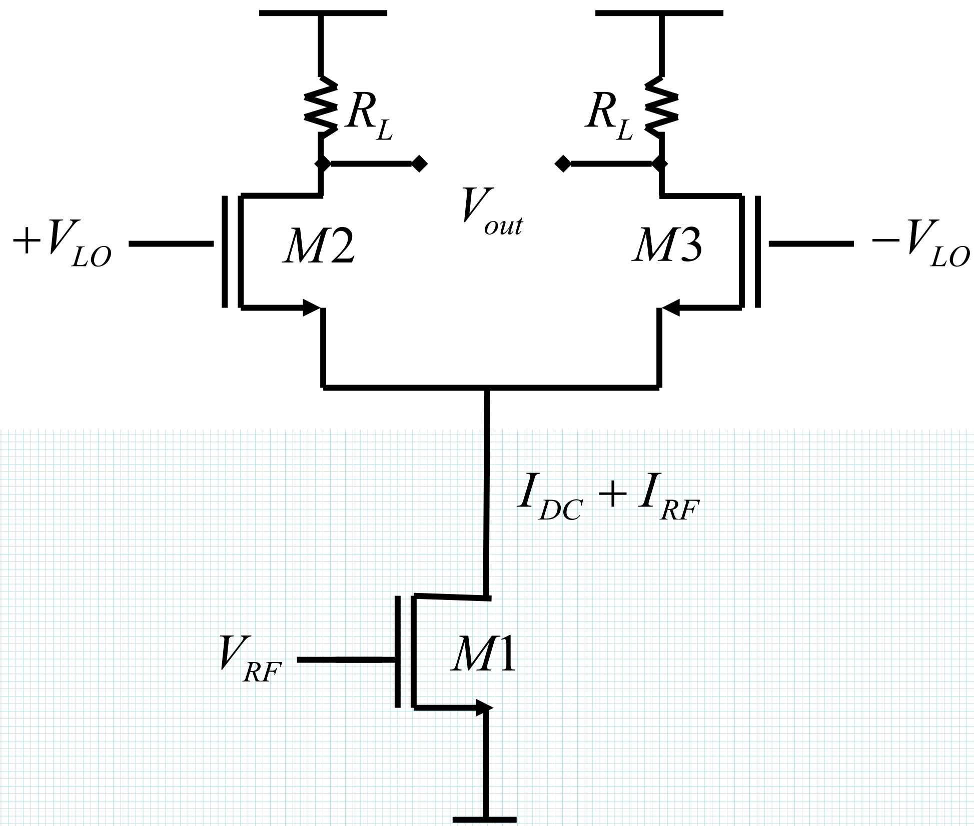






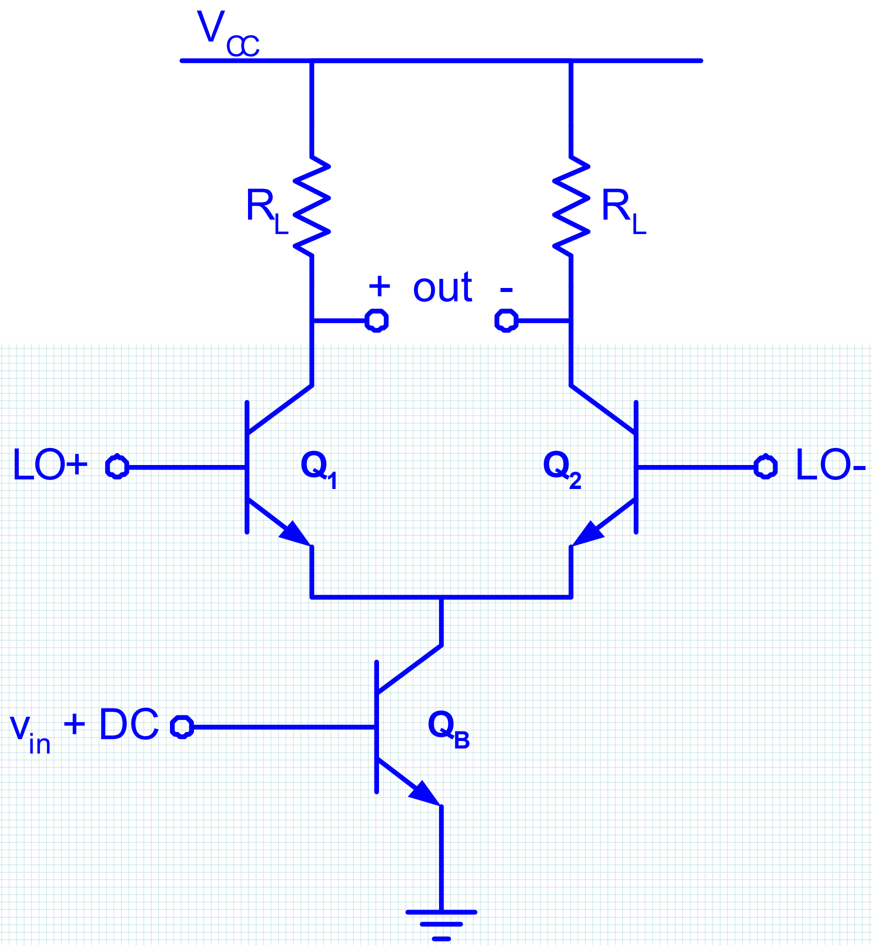
Simple Switching Mixer (Single Balanced Mixer)

- The transistor M1 converts the RF voltage signal to the current signal.
- Transistors M2 and M3 commute the current between the two branches.



Single balanced active mixer, BJT

- Single-ended input
- Differential LO
- Differential output
- Q_B provides gain fo r v_{in}
- Q_1 and Q_2 steer the current back and fo rth at ω_{LO}

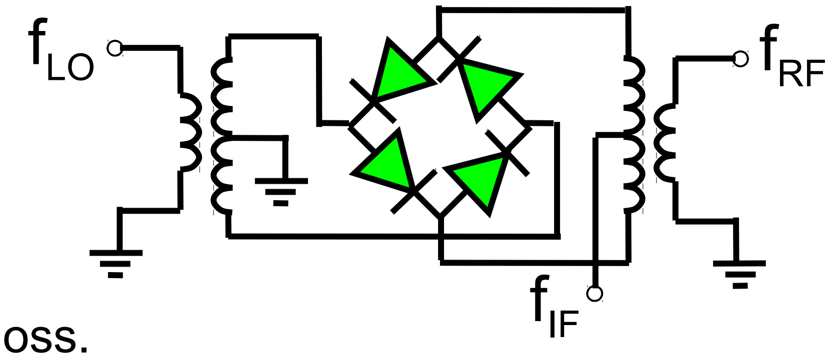


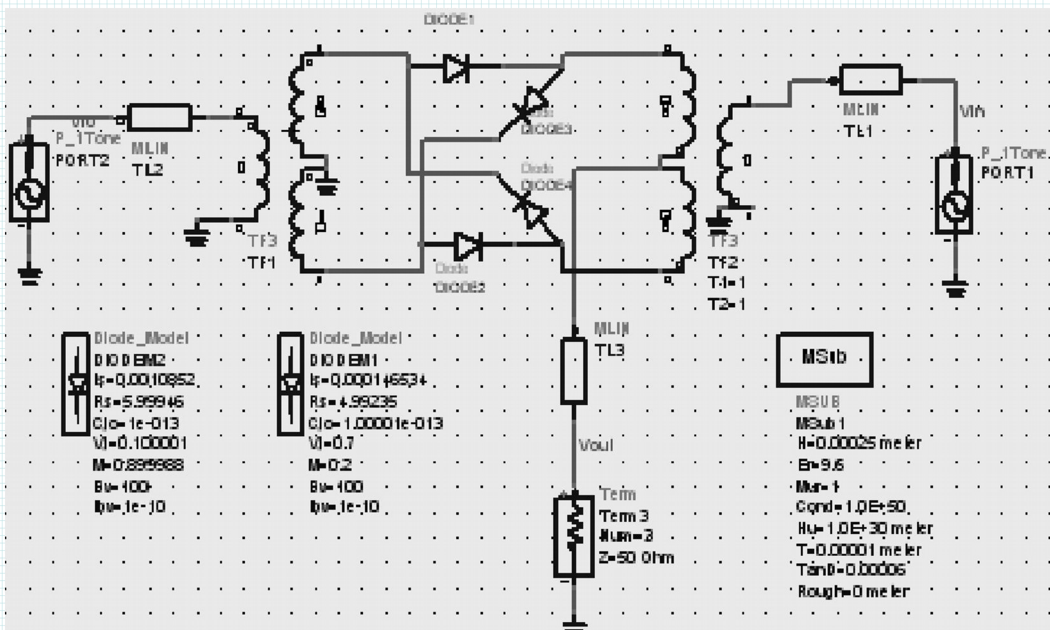
$$v_{out} = \pm g_m v_{in} R_L$$

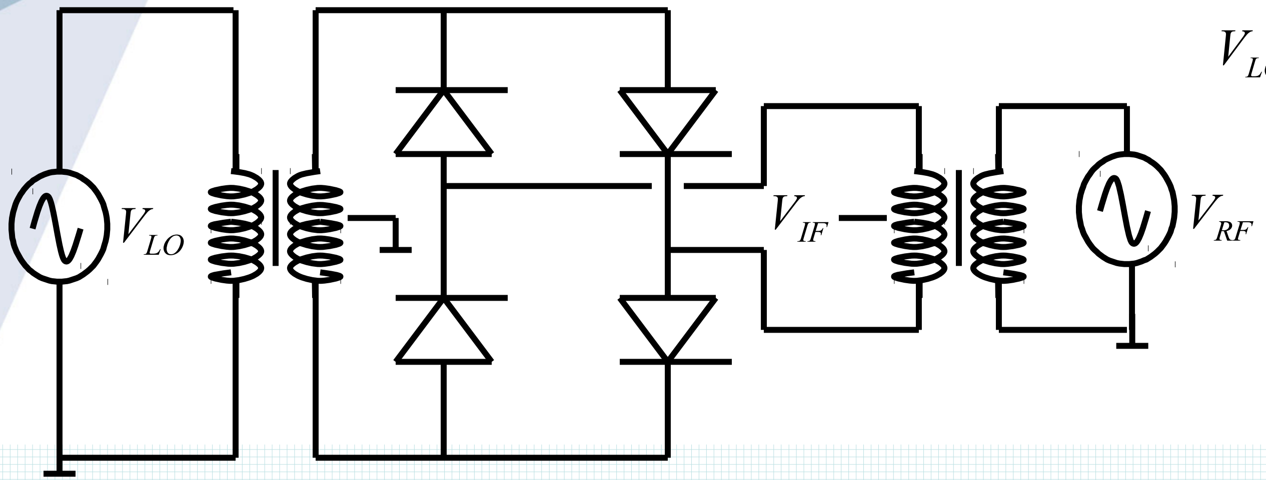
ISEE

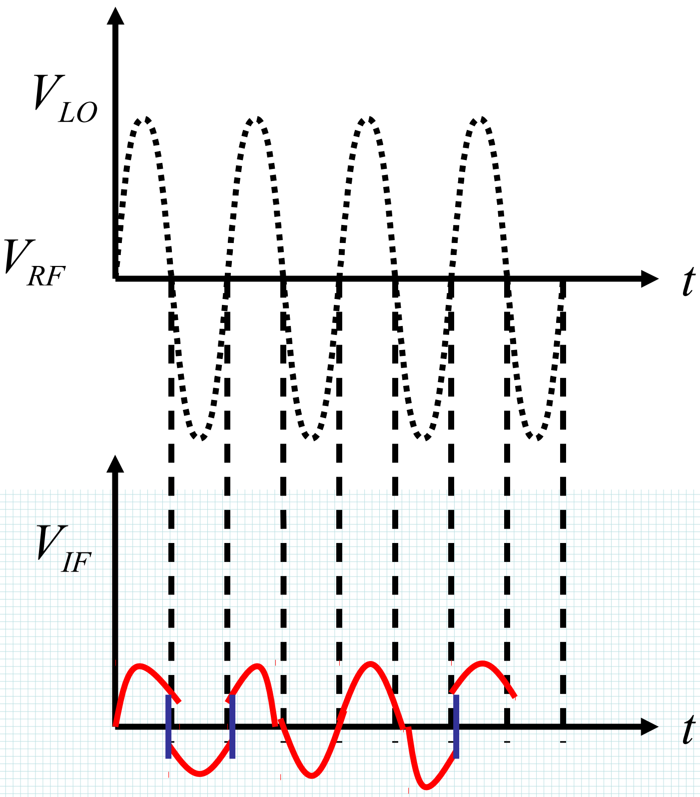
10.3.5 Double-Balanced Mixer

The additional diodes provided better isolation and an improved suppression of spurious modes. The double-balanced design eliminates all even harmonics of both the LO and RF signals. However, the disadvantages are a considerably higher LO drive power and increased conversion loss.



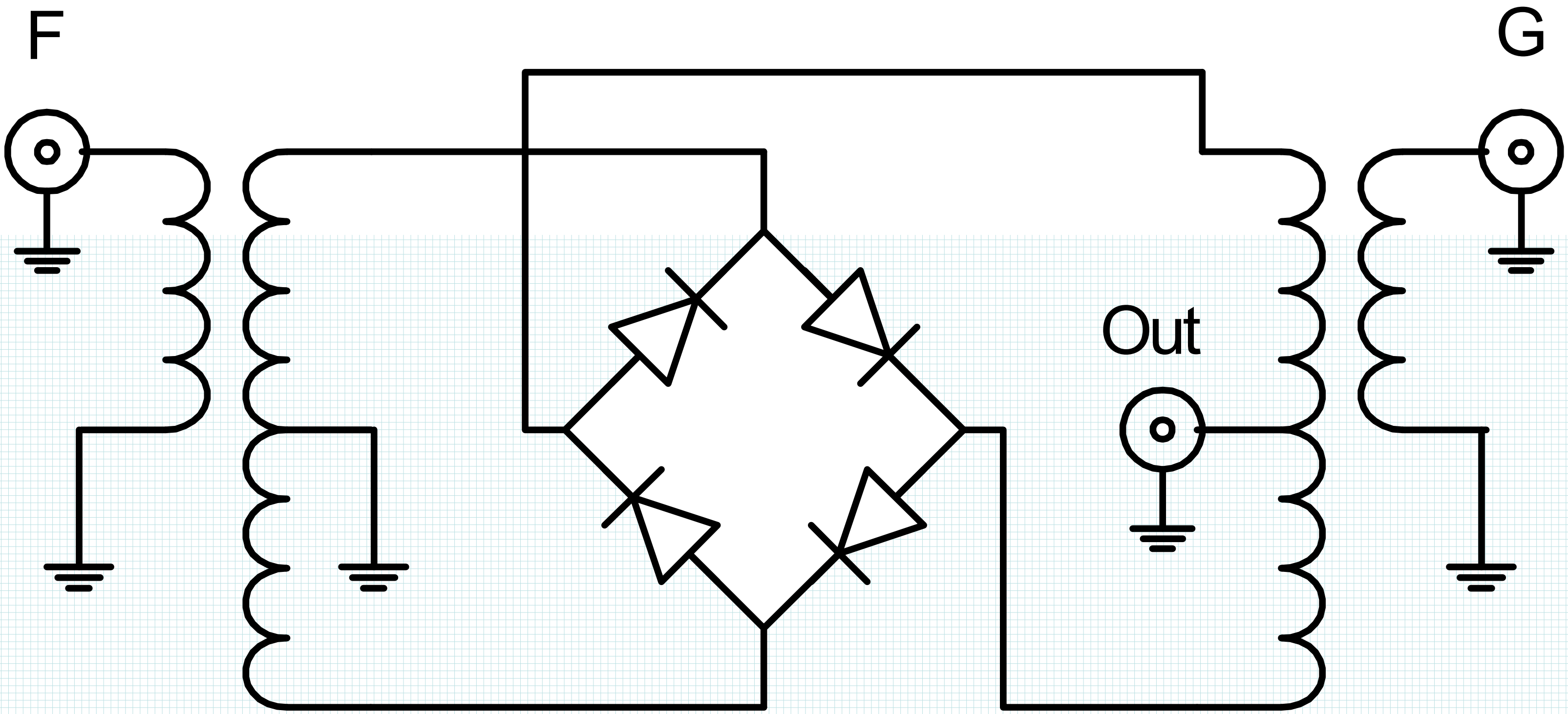




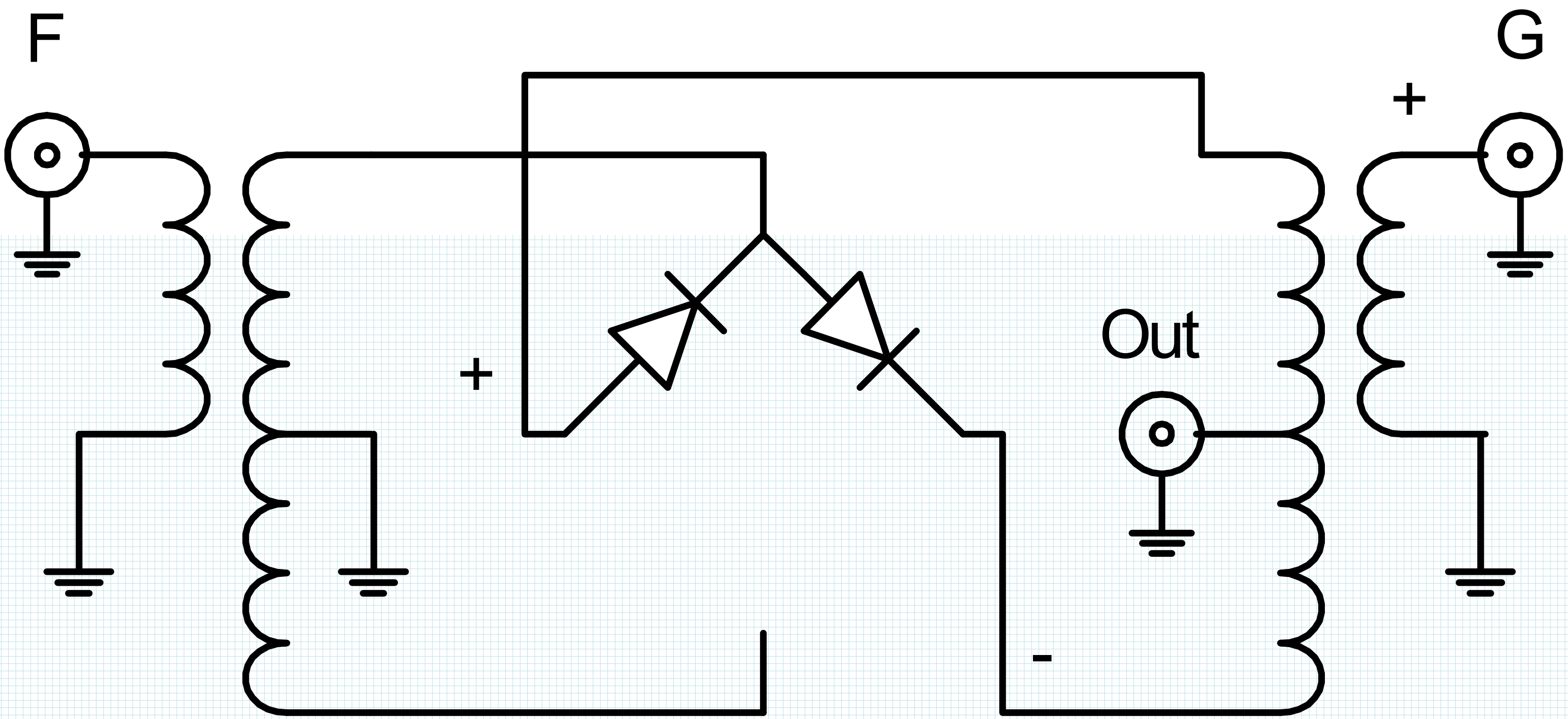


- Poor gain (typically -6dB)
- Good LO-IF LO-RF RF-IF isolation
- Good linearity and dynamic range
- Attractive for very high frequency applications where transistors are slow.

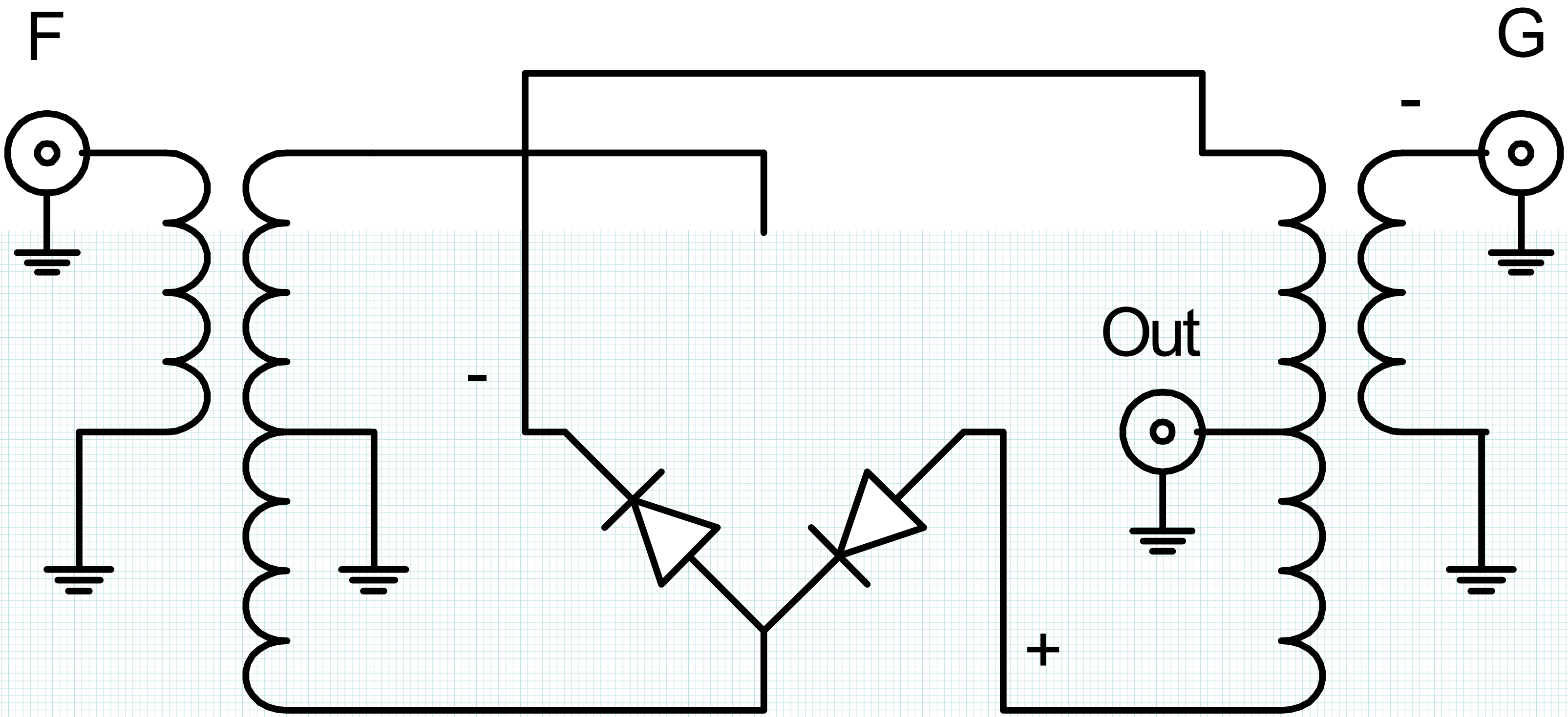
A diode ring Mixer



Ring Mixer G Positive



Ring Mixer G Negative

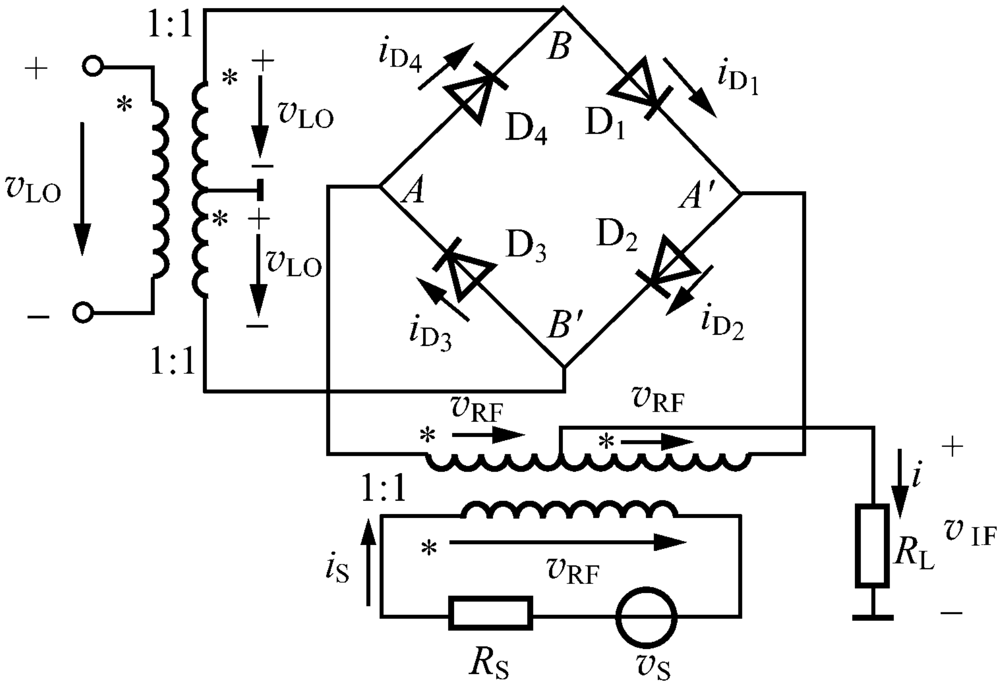


LO $v_{LO}(t) = V_{LO}\cos\omega_{LO}t$

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

Linear time-varying conditions

$V_{LO} >> V_{RF}$



$$v_{D1} = \boxed{v_{LO}} - v_{IF} + v_{RF}$$
$$v_{D2} = \boxed{v_{LO}} + v_{IF} - v_{RF}$$

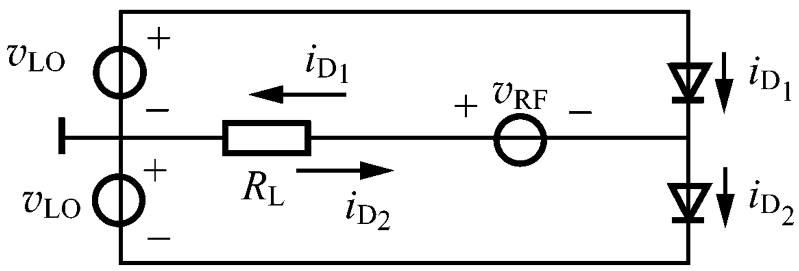
$$v_{D3} = \boxed{-v_{LO}} - v_{IF} - v_{RF}$$
$$v_{D4} = \boxed{-v_{LO}} + v_{IF} + v_{RF}$$

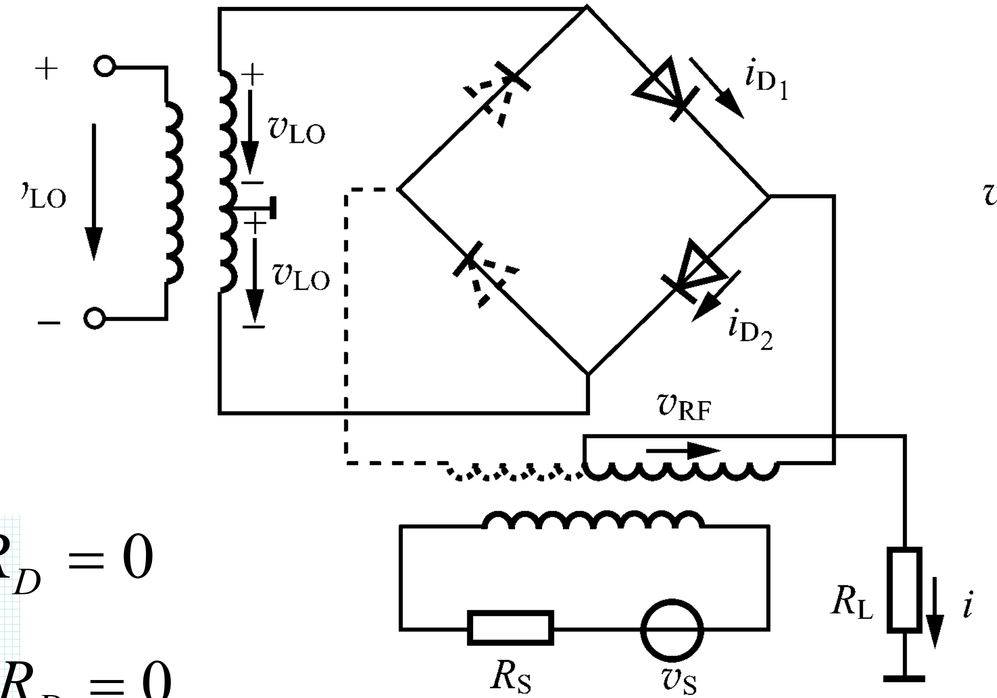
when $v_{LO}(t)$ positive， $D_1\,D_2$ active

when $v_{LO}(t)$ negative， $D_3\,D_4$ active

- Positive and negative Half-Cycle Equivalent Circuit

$v_{LO}(t)$ positive， D_1 D_2 active， D_3 D_4 Non-conduction





$$v_{LO} + v_{RF} + (i_{D2} - i_{D1})R_L - i_{D1}R_D = 0$$

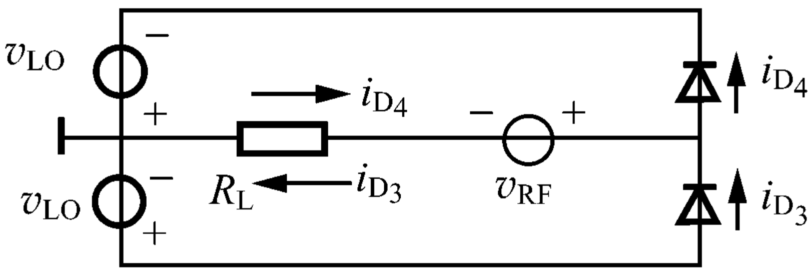
$$-v_{LO} + v_{RF} + (i_{D2} - i_{D1})R_L + i_{D1}R_D = 0$$

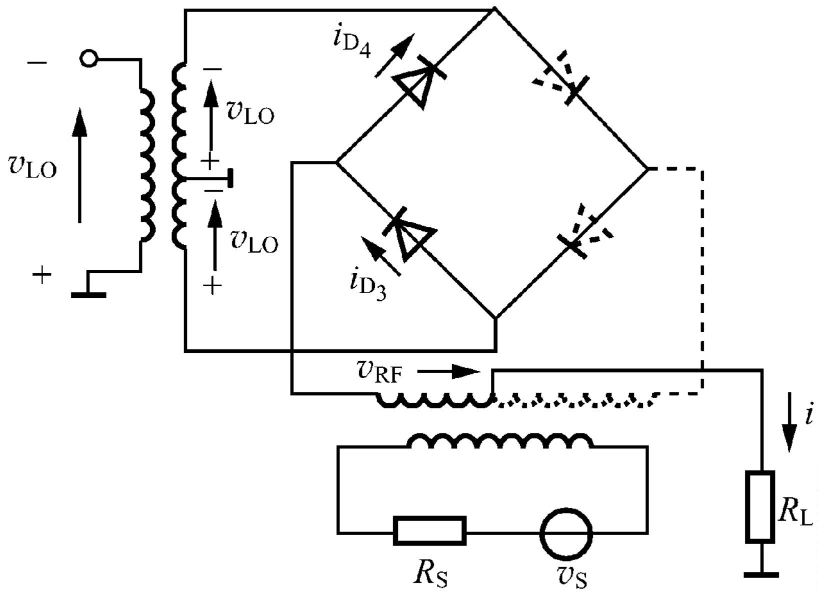
Attation

so：

$$i_{D2} - i_{D1} = \frac{2v_{RF}(t)}{2R_L + R_D}\underline{S_1(\omega_{LO}t)}$$

$v_{LO}(t)$ negative， D$_3$ D$_4$ active





$$i_{D3} - i_{D4} = \frac{2v_{RF}(t)}{2R_L + R_D} S_1(\omega_{LO}t + \pi)$$

Attation

$$i_{D2} - i_{D1} = \frac{2v_{RF}(t)}{2R_L + R_D} S_1(\omega_{LO}t)$$

- Both coefficients are the same.
- the lead-on time is different.

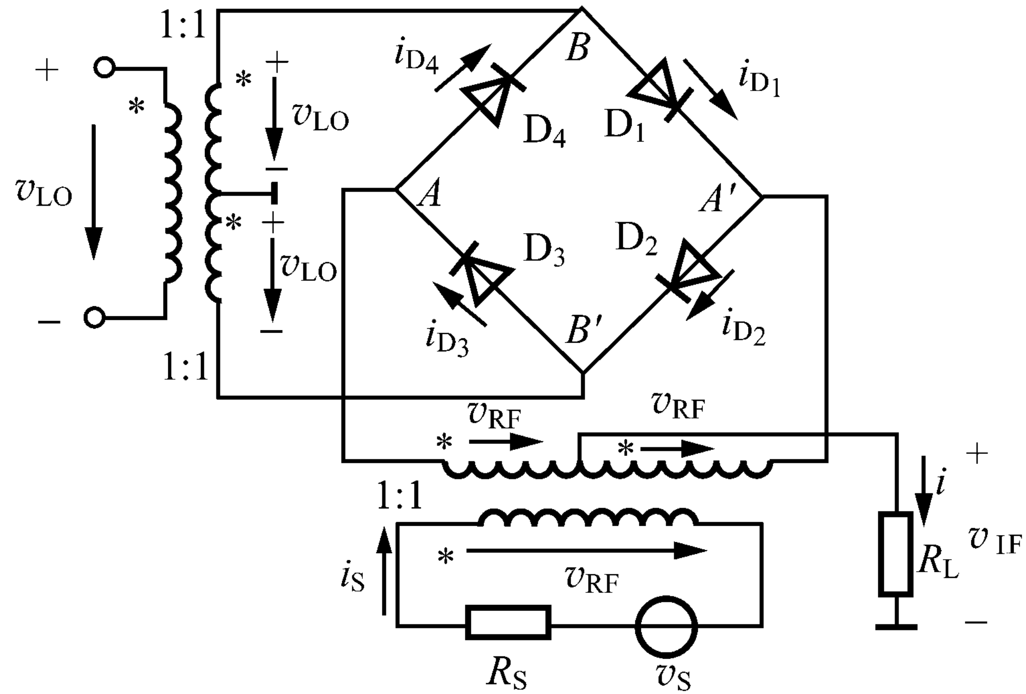
IF current

$$i = (i_{D3} - i_{D4}) - (i_{D2} - i_{D1})$$

$$= \frac{2v_{RF}(t)}{2R_L + R_D}\left(S_1(\omega_{LO}t + \pi) - S_1(\omega_{LO}t) \right)$$

$$= \frac{2v_{RF}(t)}{2R_L + R_D} \underline{S_2(\omega_{LO}t)}$$

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



IF current : $i_{IF}(t) = \frac{4}{\pi} \frac{V_{RF}}{R_D + 2R_L} \cos\omega_{IF}t$

IF voltage : $v_{IF}(t) = R_L \frac{4}{\pi} \frac{V_{RF}}{R_D + 2R_L} \cos\omega_{IF}t$

when $R_L >> R_D$ $v_{IF}(t) \approx \frac{2}{\pi} V_{RF} \cos\omega_{IF}t$

RF current and imped

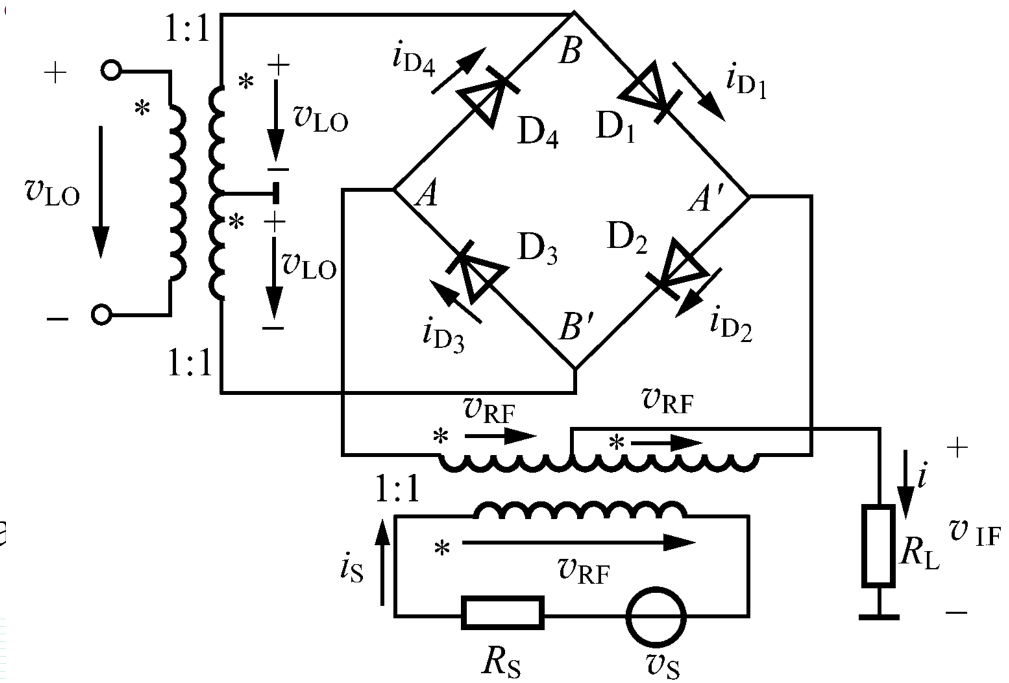
RF input v_s

RF current i_S

RF impedance R_S

Primary winding voltage v_{RF}

Radio Frequency Transformer 1:1, Unba



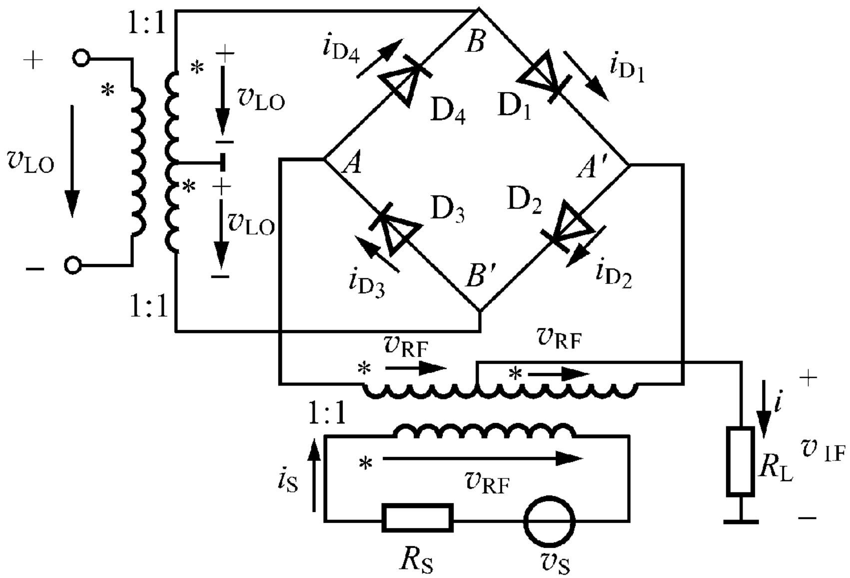
$$i_S = (i_{D1} - i_{D2}) - (i_{D3} - i_{D4}) = \frac{2v_{RF}(t)}{2R_L + R_D} \approx \frac{v_{RF}(t)}{R_L}$$

RF input $R_{RFi} = \dfrac{V_{RF}}{I_S} = R_L$ —— matching $R_S = R_{RFi}$

Isolation

IF current

$$i_{IF}(t) = \frac{4}{\pi}\frac{V_{RF}}{R_D + 2R_L}\cos\omega_{IF}t$$



No RF and LO

RF current： $i_S = \dfrac{2v_{RF}(t)}{2R_L + R_D} \approx \dfrac{v_{RF}(t)}{R_L}$

No RF and IF

Port-port well isolation——circuit balance

- Four diodes are identical
- Balance Transformer are identical

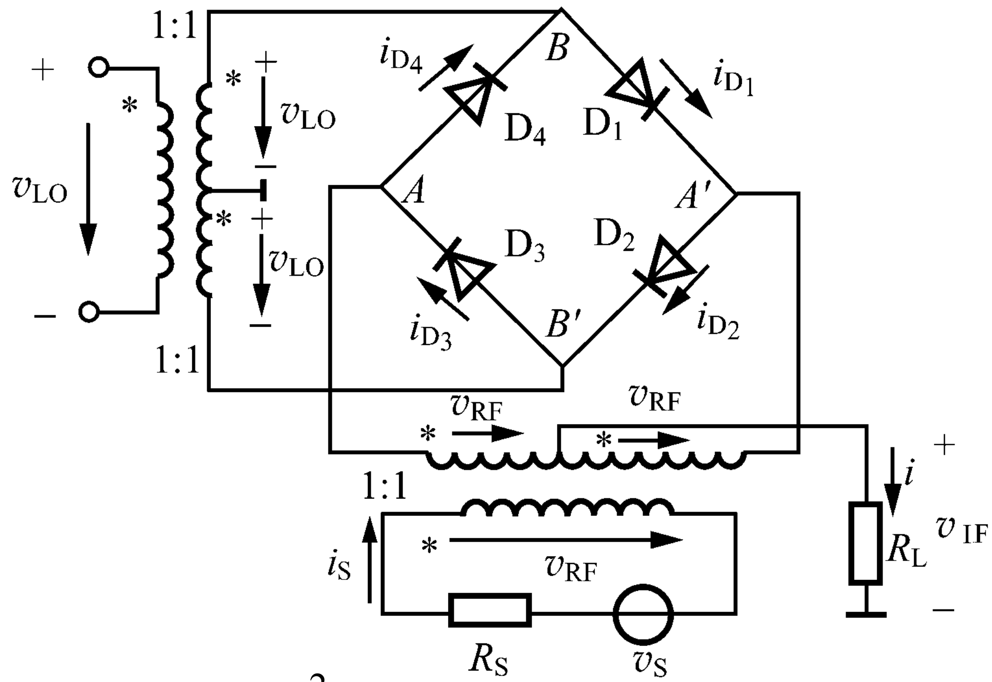
LO port

- B and B' to RF is virtual ground
- A and A' to LO is virtual ground

Frequency conversion loss

RF matched： $R_S = R_{RFi} = R_L$

So $V_S = 2V_{RF}$



RF input power：

$$P_S = \frac{1}{2}\frac{V_S^2}{4R_S} = \frac{1}{2}\frac{V_{RF}^2}{R_L}$$

IF power： $$P_{IF} = \frac{1}{2}\left(\frac{2}{\pi}\frac{V_{RF}}{R_L}\right)^2 R_L = \frac{2}{\pi^2}\frac{V_{RF}^2}{R_L}$$

Mixer loss： $$L = 10\lg\frac{P_S}{P_{IF}} = 10\lg\frac{\pi^2}{4} \approx 4dB$$

Advantages of the ring mixer

- Good carrier rejection
- Good Input rejection

Disadvantages of the ring mixer

- High drive current needed on carrier input
- Harmonic distortion (on carrier input)
- Expensive discrete components
- Needs transformers to work properly

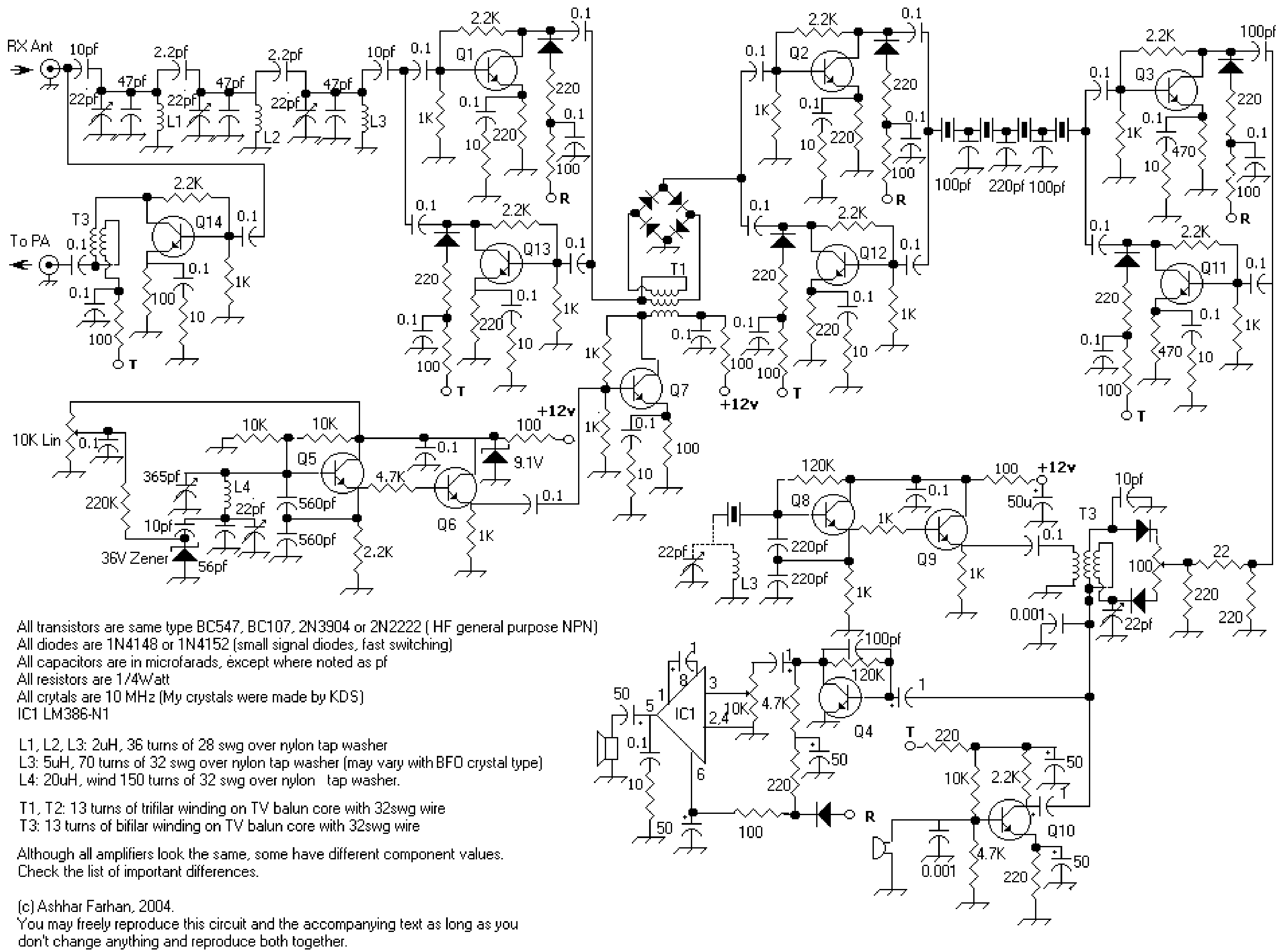
mini-circuits

型号	Freq （MHz） LO/RF IF	Loss （dB））	LO-RF (dB)	LO-IF (dB)
RAY-1	5-500 DC-500	6.57	40	40
RAY-2	10-1000 DC-1000	6.89	40	35
ZMY-1	5-500 DC-500	6.62	40	40
ZAY-1	5-500 DC-500	6.57	40	40

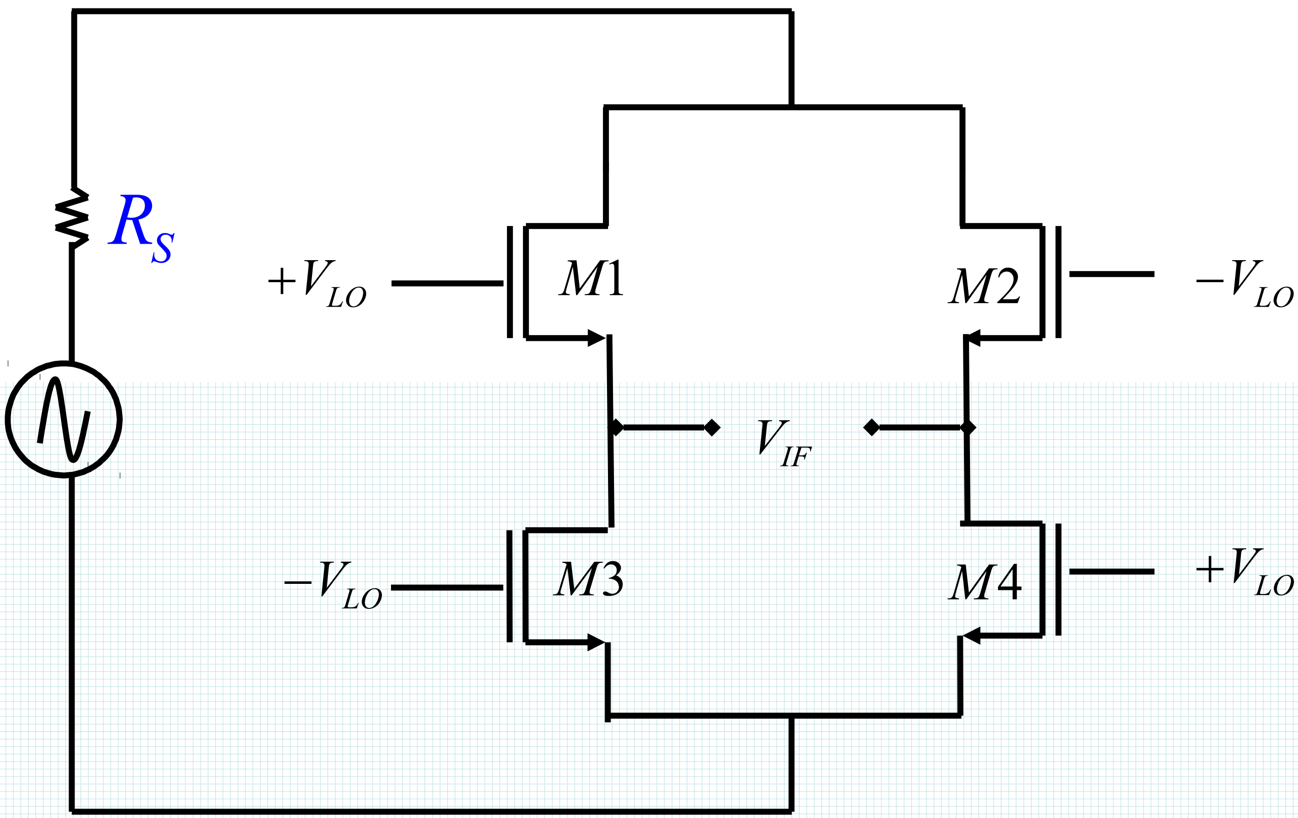
LO +23dBm， RF+15dBm 。

ISEE

BITX20 bidirectional SSB transceiver

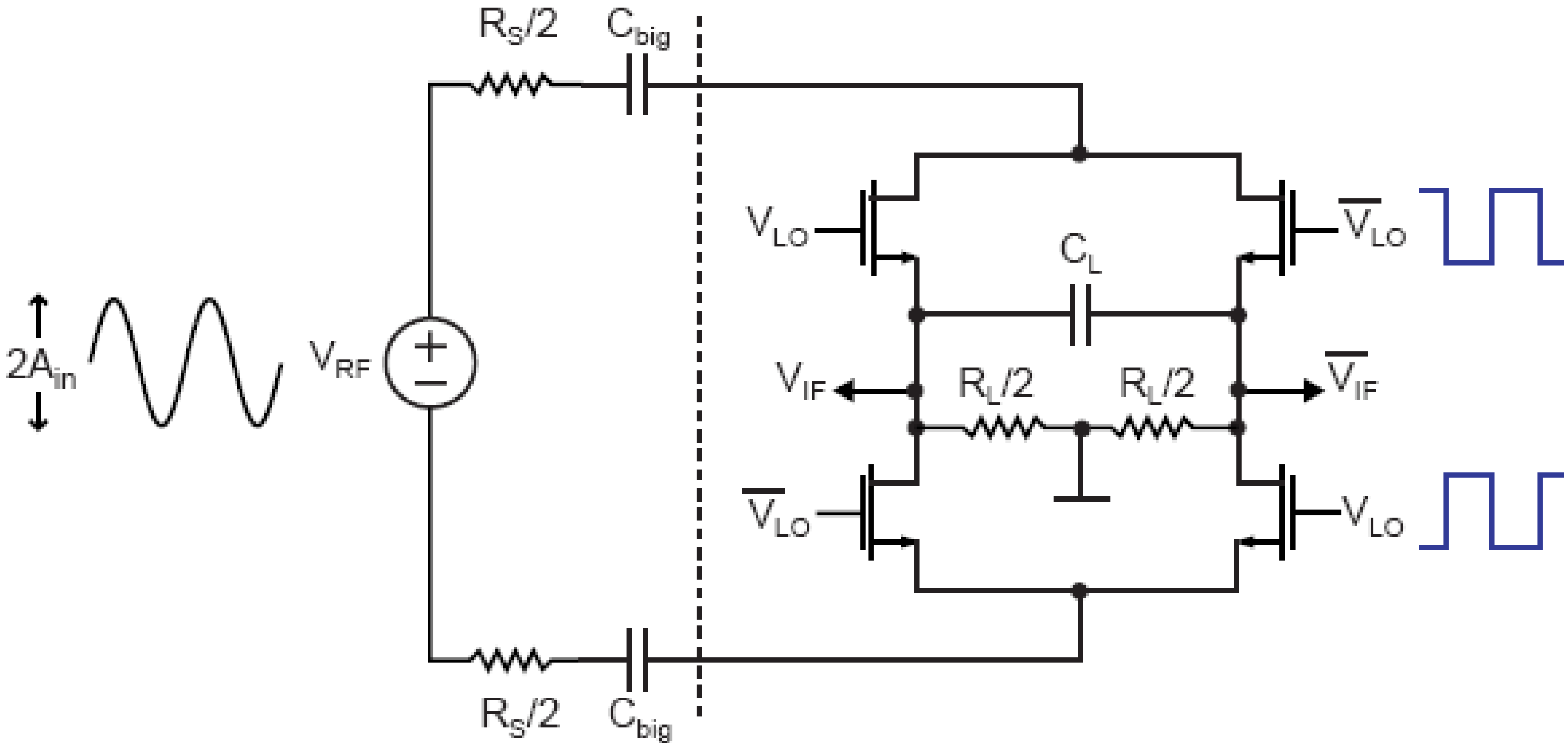


CMOS Passive Mixer



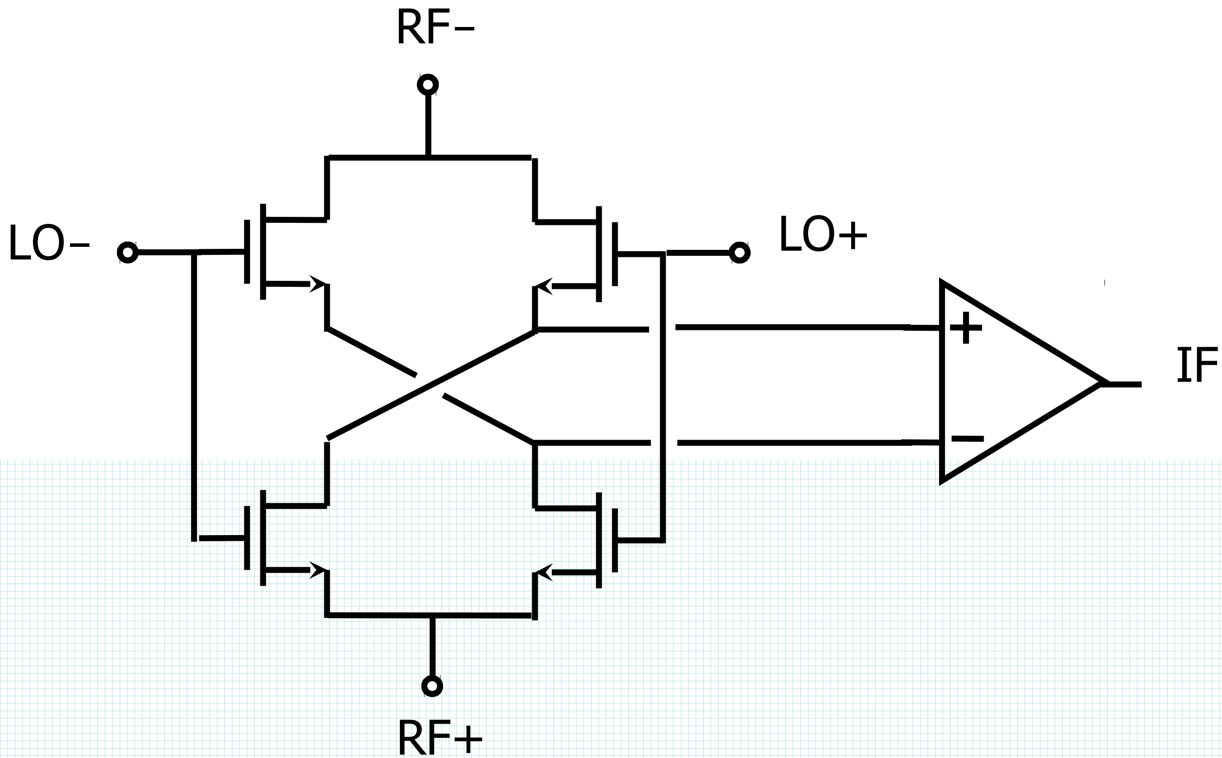
- M1 through M4 act as switches

CMOS Passive Mixer



- Use switches to perform the mixing operation
- No bias current required
- Allows low power operation to be achieved

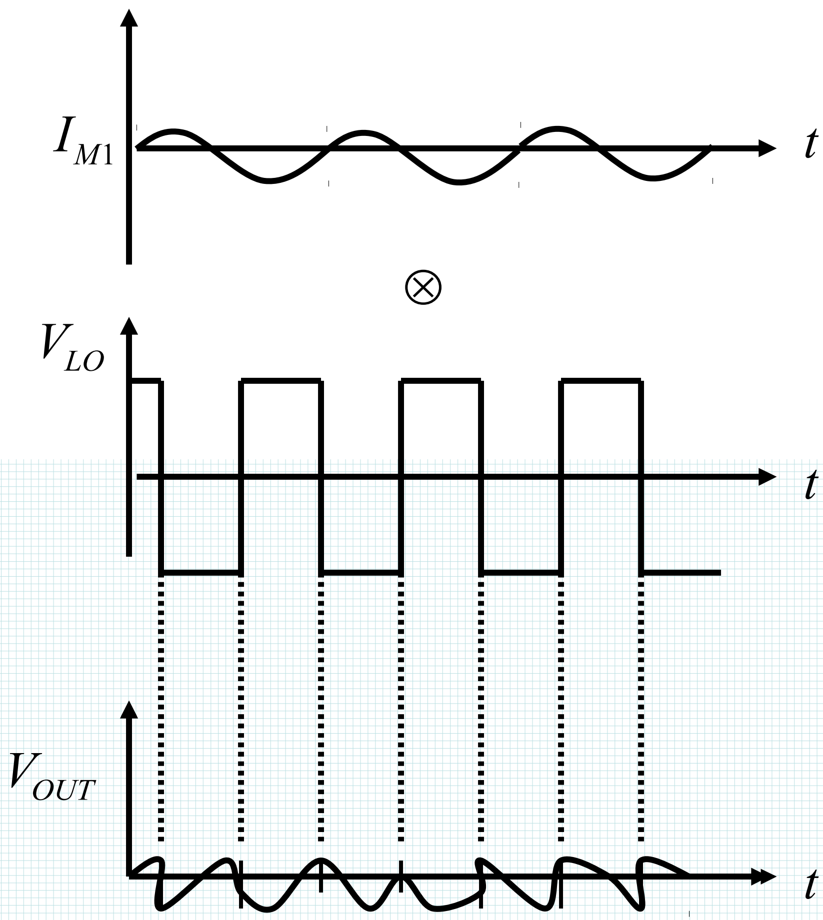
CMOS Passive Mixer

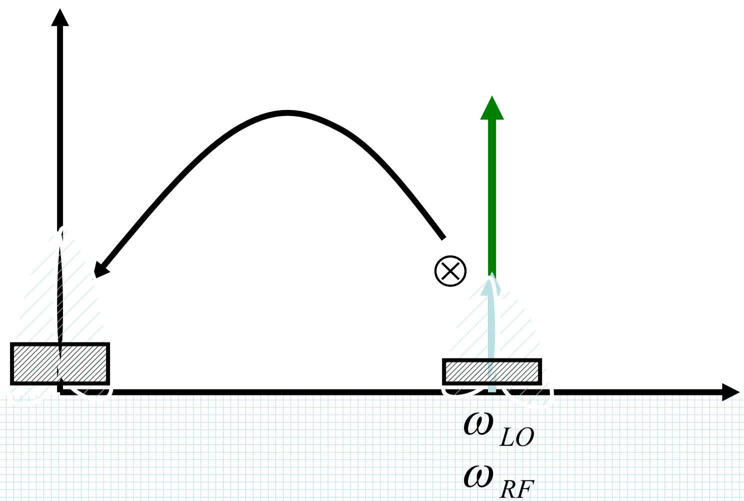


Same idea, redrawn
RC filter not shown
IF amplifier can be frequency selective

[*] T. Lee

CMOS Passive Mixer



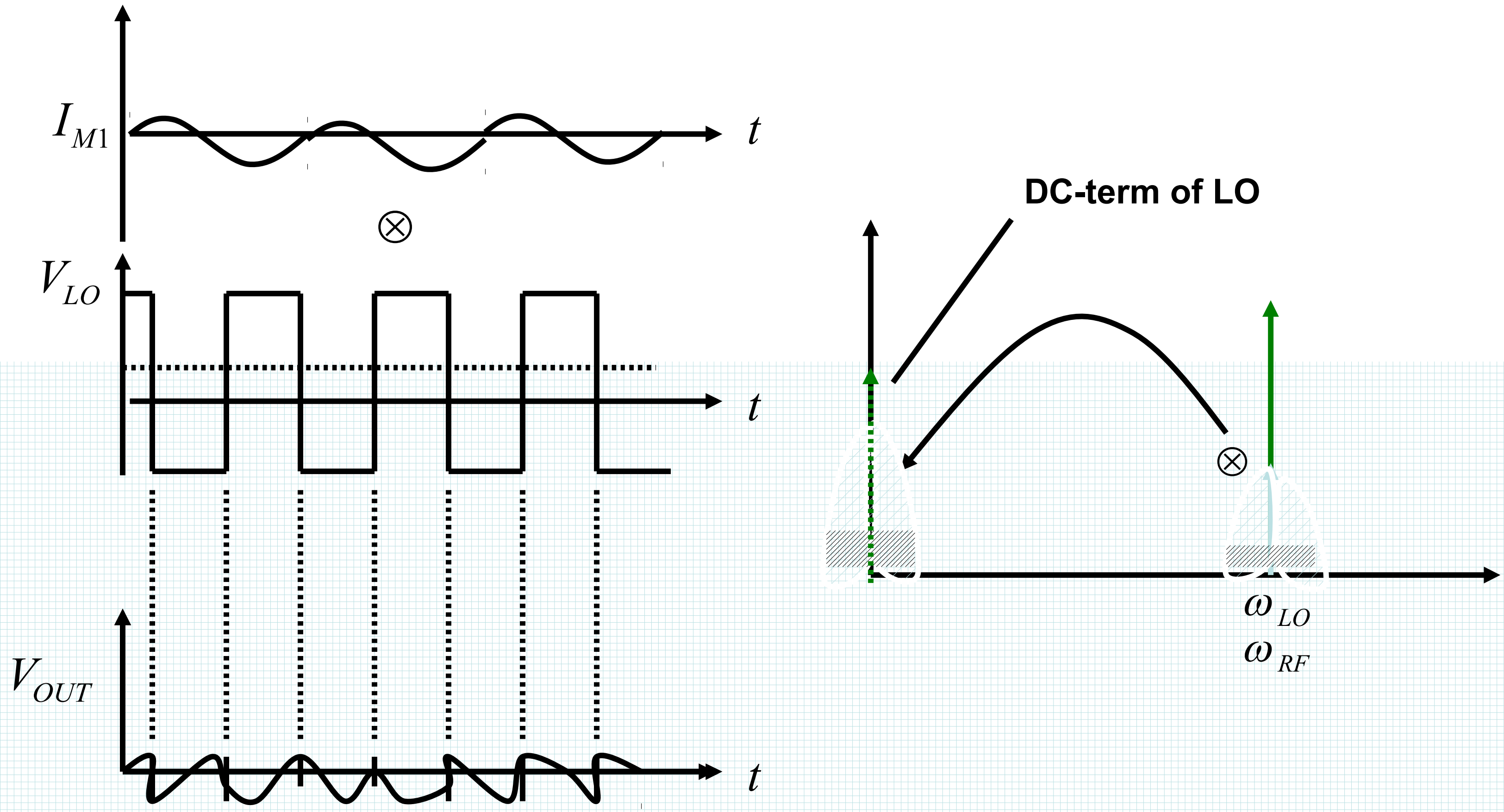


$$G_C = \frac{V_{out}(\omega_{IF})}{V_{RF}(\omega_{RF})} = \frac{4}{\pi}$$

$$V_{out} = V_{RF}.Cos(\omega_{RF}t) \otimes \left\{ \frac{4}{\pi}Cos(\omega_{LO}t) - \frac{4}{3\pi}Cos(3\omega_{LO}t) + \frac{4}{5\pi}Cos(5\omega_{LO}t) - \ldots \right\}$$

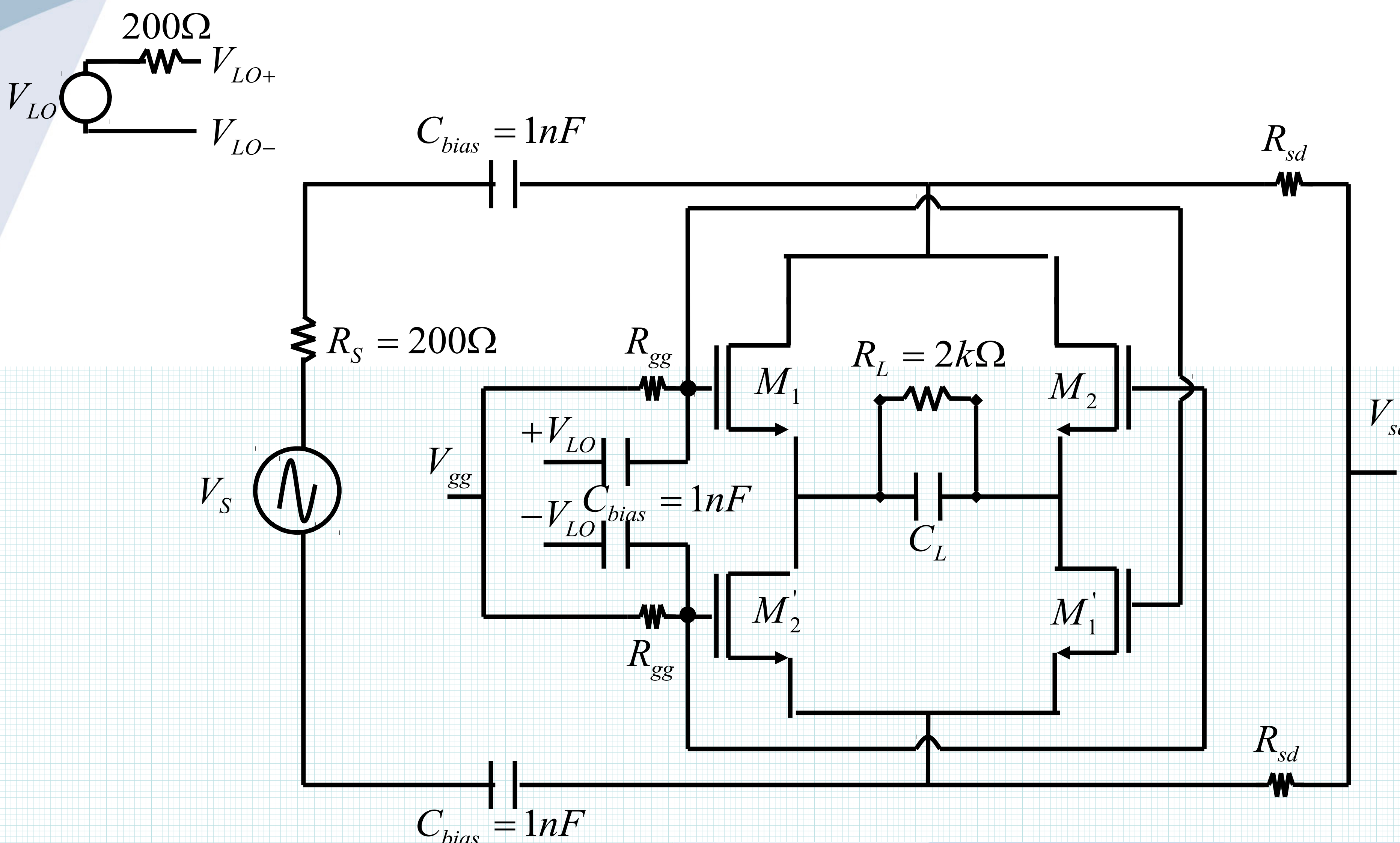
CMOS Passive Mixer

- Non-50% duty cycle of LO results in no DC offsets!!

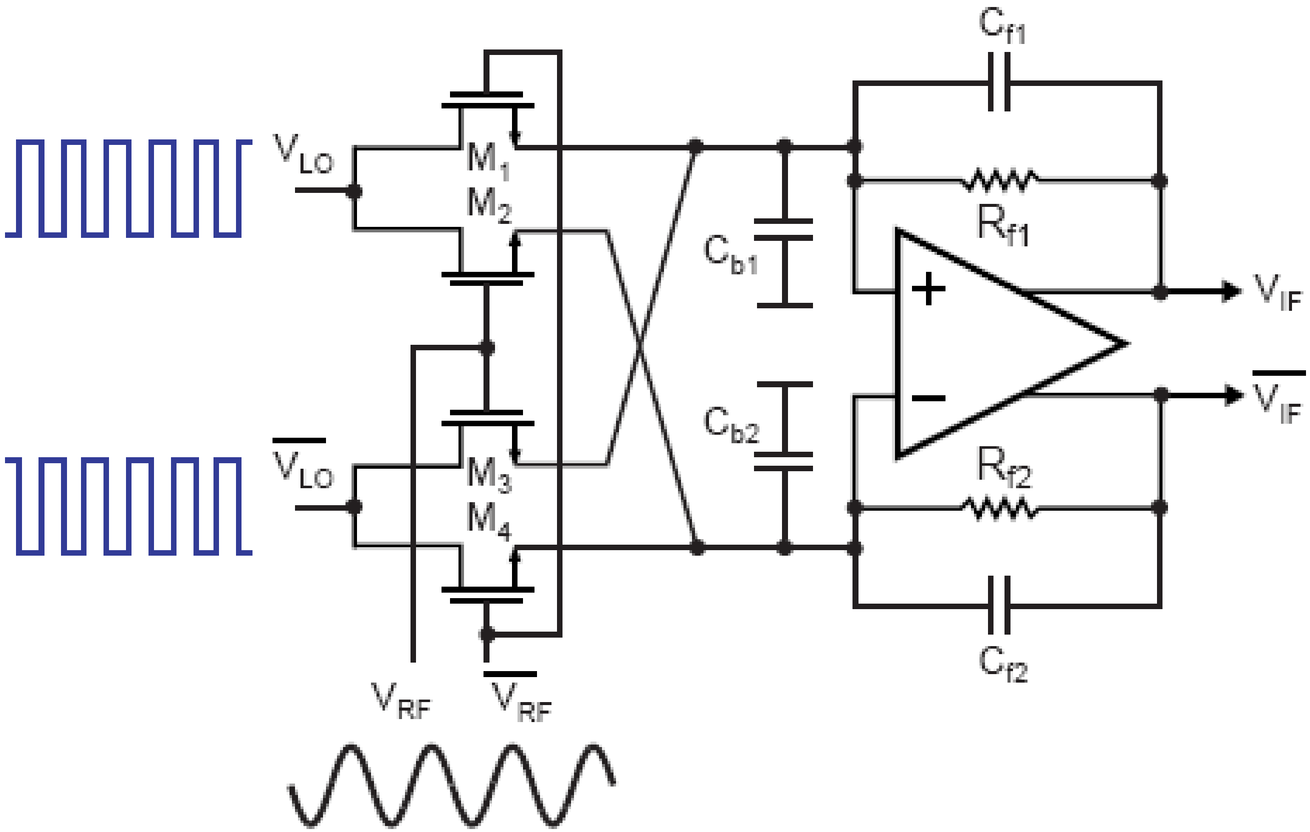


$$V_{out} = V_{RF}.Cos\left(\omega_{RF}t\right) \otimes \left\{ DC + \frac{4}{\pi}Cos\left(\omega_{LO}t\right) - \frac{4}{3\pi}Cos\left(3\omega_{LO}t\right) + \frac{4}{5\pi}Cos\left(5\omega_{LO}t\right) - \ldots \right\}$$

CMOS Passive Mixer with Biasing

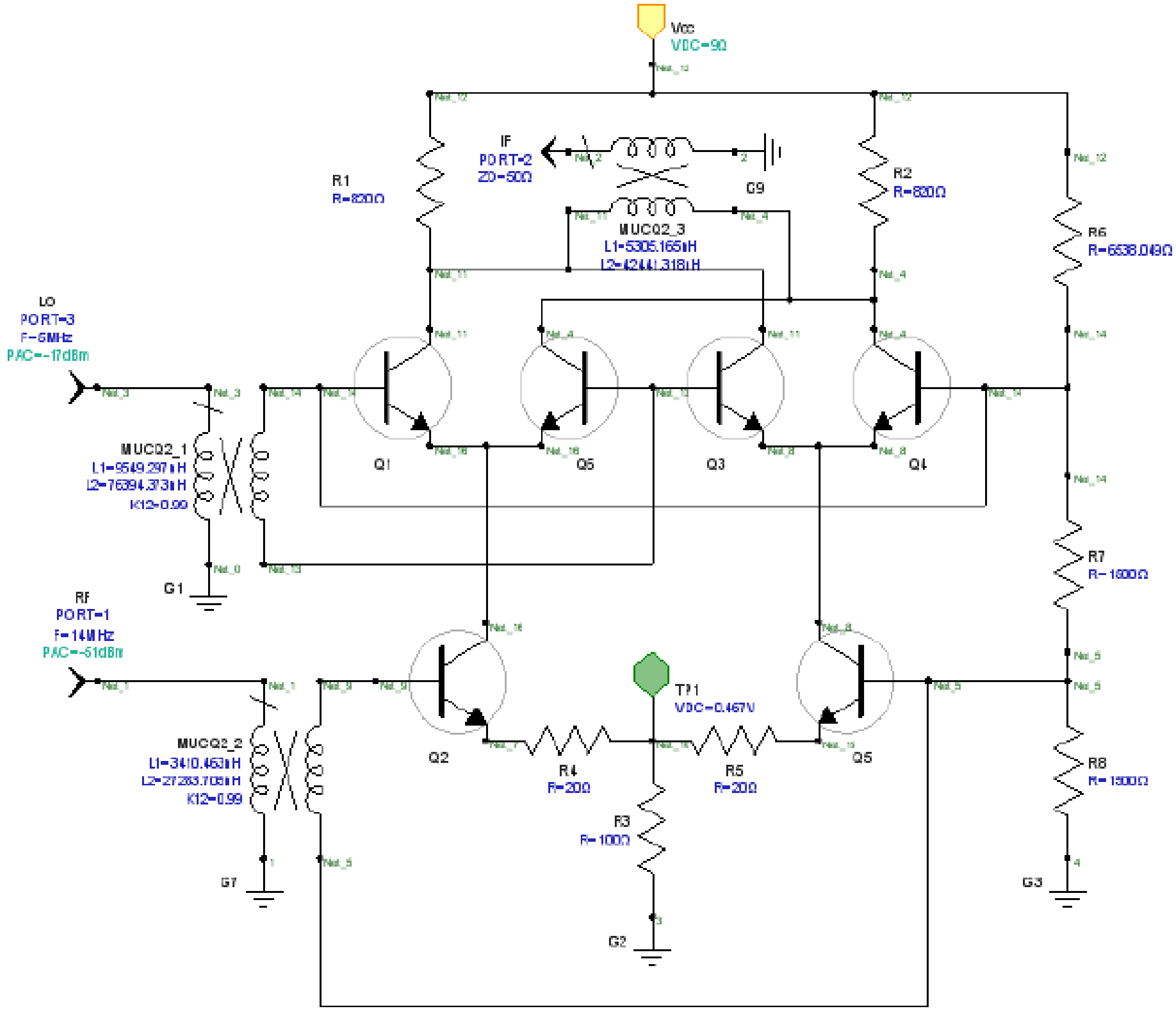


A Highly Linear CMOS Mixer



- Transistors are alternated between the off and triode regions by the LO signal
- RF signal varies resistance of channel when in triode
- Large bias required on RF inputs to achieve triode operation
  - High linearity achieved, but very poor noise figure

Balanced Mixer Gilbert Cell



Gilbert Cell

- This Bipolar Double Balanced Gilbert Cell mixer is sometimes referred two as a four-quadrant multiplier because when signals are "multiplied" their frequencies are mixed
- This mixer is realized using two differential transistor pairs that share a current source controlled by one of the input signals
- Implementation involves the differential current sources are driven by the RF signal using a transformer as a balun
- The LO drive is also applied using a transformer and the IF output is taken with a transformer

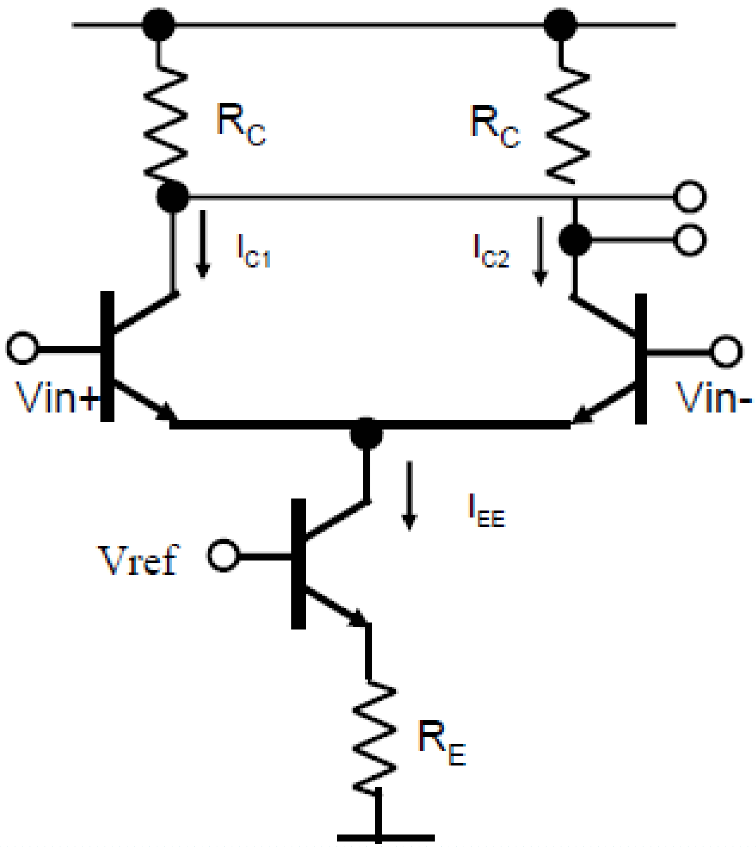
Gilbert Cell

- The impedance level of all ports is generally higher than 50 ohms, particularly at lower frequency
- The baluns may also serve as impedance transformers
- The term Zo is the port impedance and the terms Zif, Zrf and Zlo in the equations are factors that affect the port impedance up to the internal impedances of the mixer
- This mixer exhibits conversion gain at frequencies where the device gain overcomes the loss associated with the mixing process
- The differential pair transistors provide gain so the required LO drive level is as low as -20 dBm at low frequencies

- Easily integrated with other circuits
- Better isolation than the DB diode or FET mixers
- Requires less LO power than the passive mixers
- Less fussy about IF termination impedance than the passive mixers due to the better isolation

- Its main liability is large signal handling capability
  - IIP_3 is much lower than passive mixers

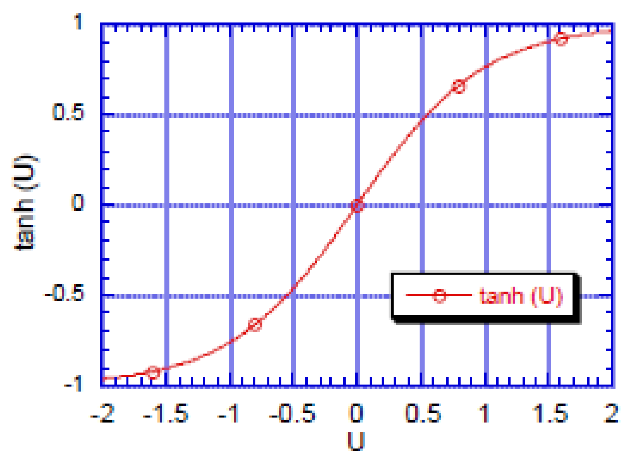
Diff pair is basis for active mixer

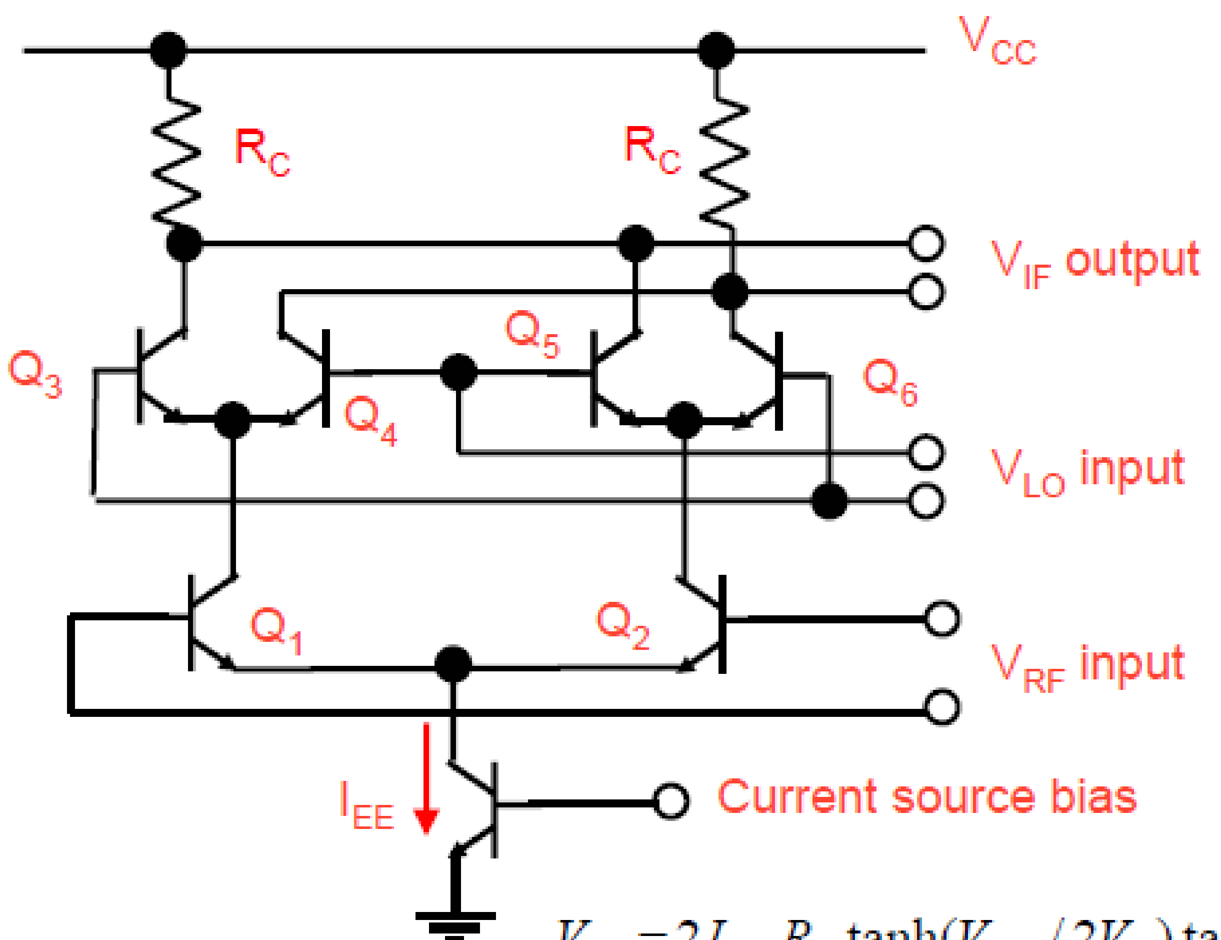


$$\Delta I_C = I_{C1} - I_{C2} = I_{EE}\tanh(V_{id}/2V_T)$$

$$V_{id} = V_{in+} - V_{in-}$$

$$U = V_{id}/2V_T$$





$$V_{IF} = 2I_{EE}R_C \tanh(V_{RF}/2V_T)\tanh(V_{LO}/2V_T)$$

1. Q3 - Q6 provide a fully balanced, phase reversing switch. When $V_{RF} = 0$, I_{OUT} also is 0 regardless of the status of V_{LO}. This is because I_{C3-5} and I_{C4-6} each will add up to $I_{EE}/2$ in this condition.
2. When $V_{LO} \neq 0$, the same condition applies. Therefore, there is never any LO component in the output differential current. The upper tier of BJTs only provides the phase reversal of the RF signal as controlled by the LO voltage.
3. The mixer can provide conversion gain - depending on the load impedance presented to the collectors and I_{EE}.
4. The signal handling capability is still limited below V_T, but we can use emitter degeneration to improve linearity.
5. The distortion is entirely odd-order for perfectly matched transistors.

ISEE

output $v_o = iR_L$

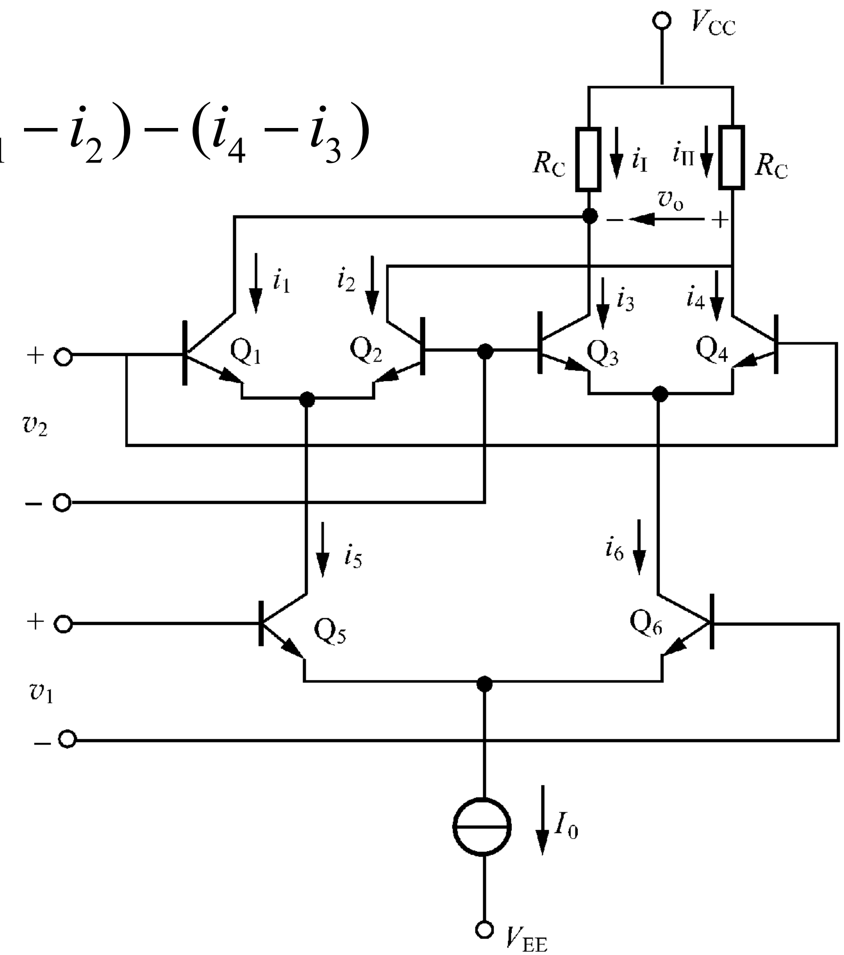
$$i = i_I - i_{II} = (i_1 + i_3) - (i_2 + i_4) = (i_1 - i_2) - (i_4 - i_3)$$

$$i_1 - i_2 = i_5 th(\frac{qv_2}{2KT})$$

$$i_4 - i_3 = i_6 th(\frac{qv_2}{2KT})$$

$$i_5 - i_6 = I_0 th(\frac{gv_1}{2KT})$$

$$i = I_0 th(\frac{qv_1}{2KT}) \cdot th(\frac{qv_2}{2KT})$$



v_1 v_2 Noni

Multiplication

small

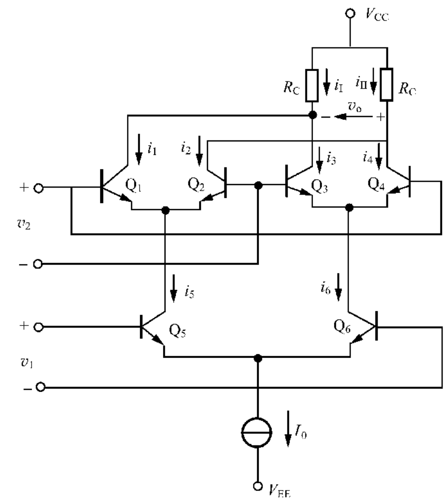
$$th\frac{qv}{2KT} \approx \frac{q}{2KT}v$$

RF and LO are small signals

Output current： $$i = I_0(\frac{q}{2KT})^2 v_1 v_2$$

big

$$th(\frac{q}{2KT}v_2) \approx S_2(\omega_2 t)$$



RF small and LO big signals

Output current： $$i = I_0 \frac{q}{2KT} v_{RF} \cdot S_2(\omega_{LO} t) = g_m v_{RF} \cdot S_2(\omega_{LO} t)$$

RF and LO big signals

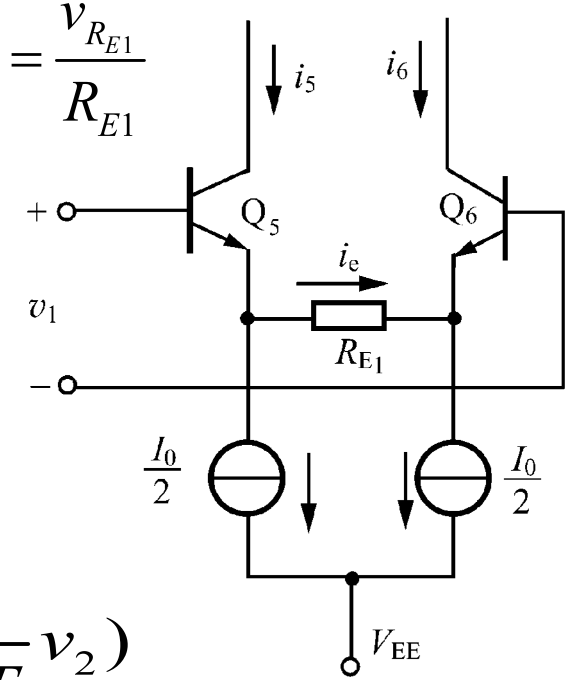
$$i = I_0 th(\frac{qv_1}{2KT}) \cdot th(\frac{qv_2}{2KT}) \Rightarrow i = I_0 S_2(\omega_1 t) \cdot S_2(\omega_2 t)$$

ISEE

extend v_1 dynamic range——Emitter negative feedback resistance

voltage $\quad v_1 = v_{BE5} + v_{R_{E1}} - v_{BE6}$

current $\quad i_5 = \frac{1}{2}I_0 + i_e \qquad i_6 = \frac{1}{2}I_0 - i_e \quad$ and $\quad i_e = \frac{v_{R_{E1}}}{R_{E1}}$



when R_{E1} big enough $\longrightarrow$ i_e small $\longrightarrow$ $i_5 \approx i_6$

$\longrightarrow$ $v_{BE_5} - v_{BE_6} \approx 0$ $\longrightarrow$ $v_1 \approx v_{R_{E1}}$

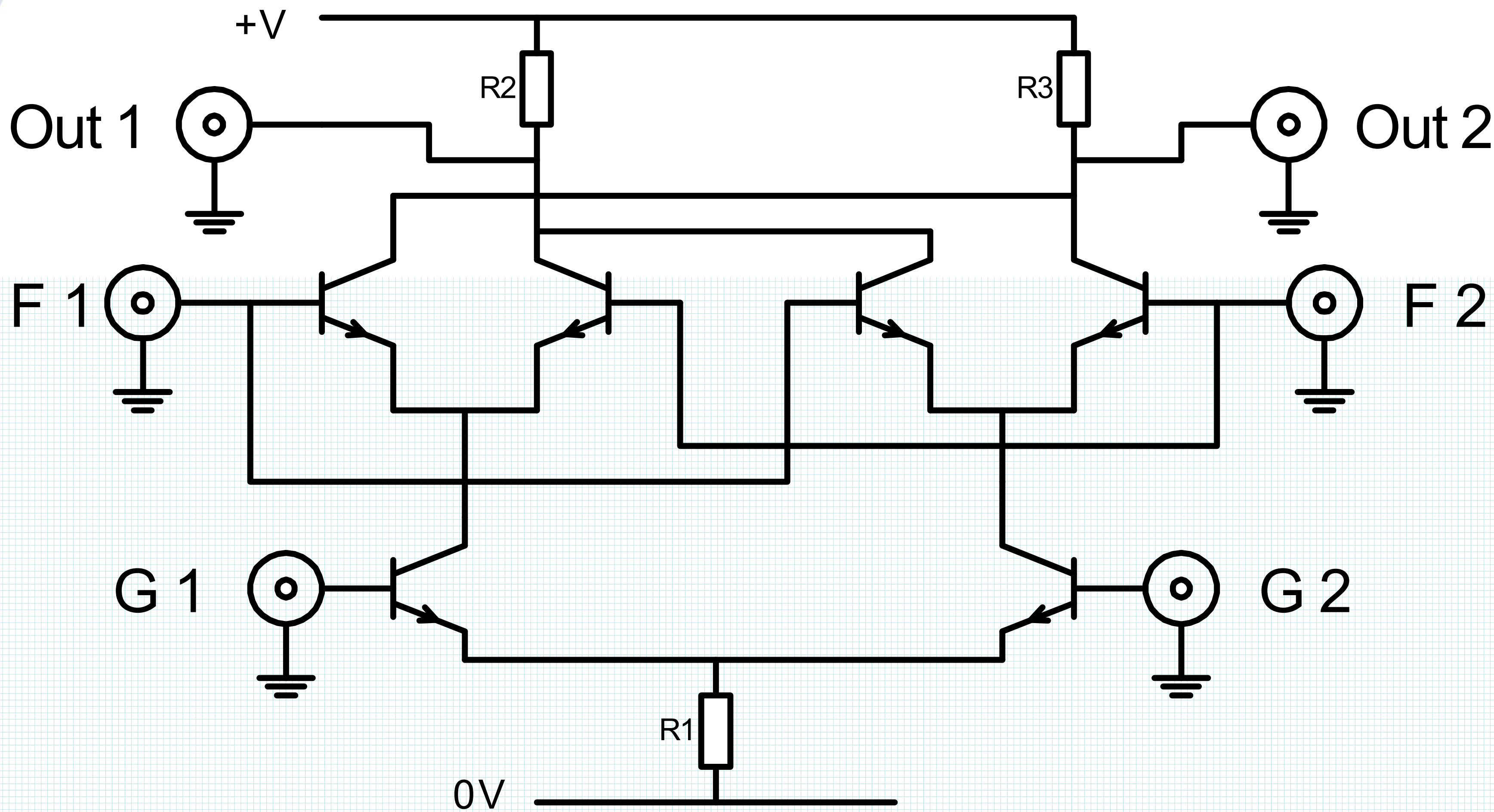
$$(i_5 - i_6) = 2i_e = 2\frac{v_{R_{E1}}}{R_{E1}} \approx \frac{2v_1}{R_{E1}}$$

output current

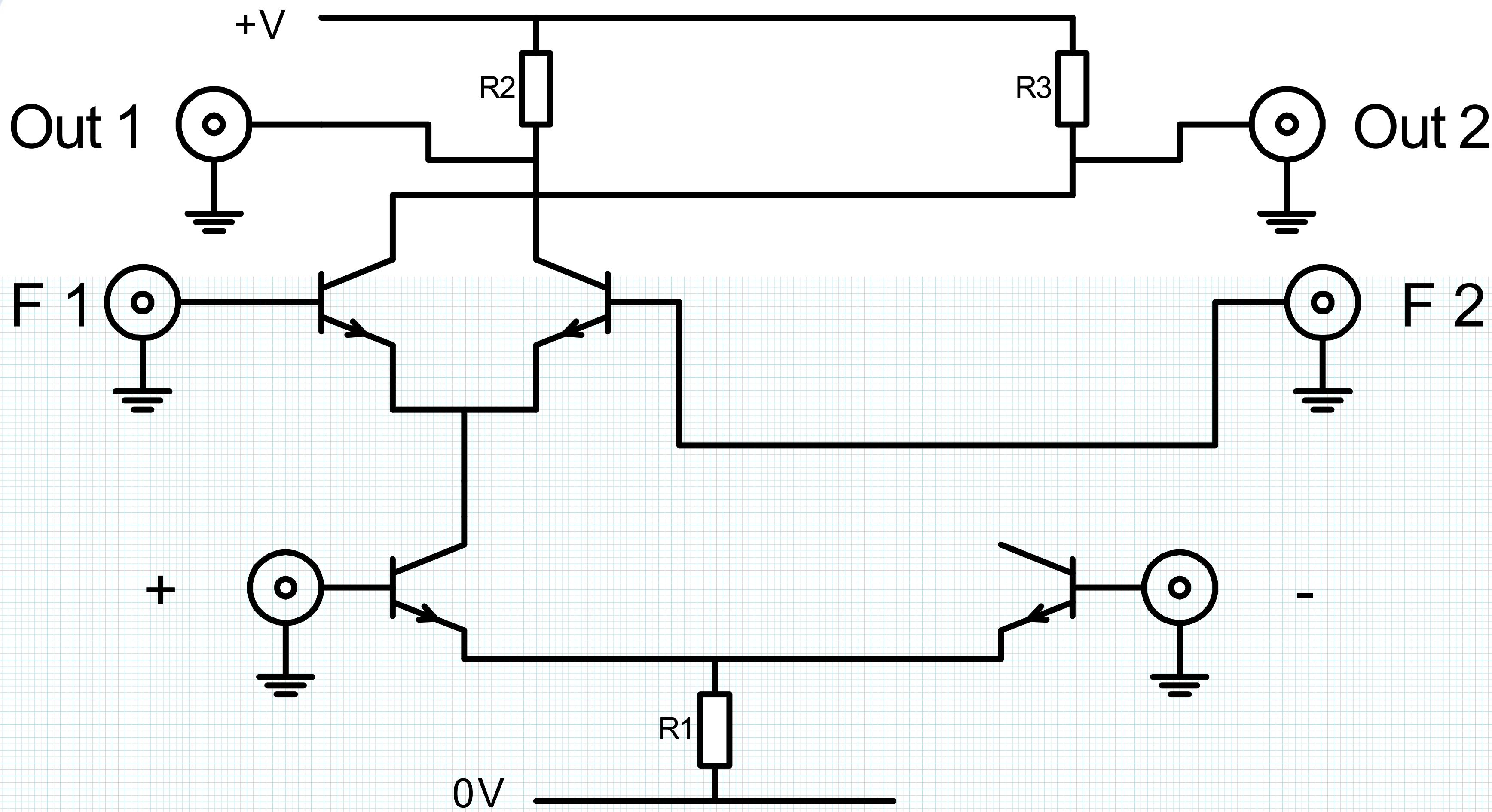
$$i = (i_5 - i_6)th(\frac{q}{2KT}v_2) \approx \frac{2v_1}{R_{E1}}th(\frac{q}{2KT}v_2)$$

Range of v_1 : $\quad \frac{1}{2}I_0 \geq \frac{v_1}{R_{E1}} \geq -\frac{1}{2}I_0 \quad$ （ i_5 、 i_6 must positive ）

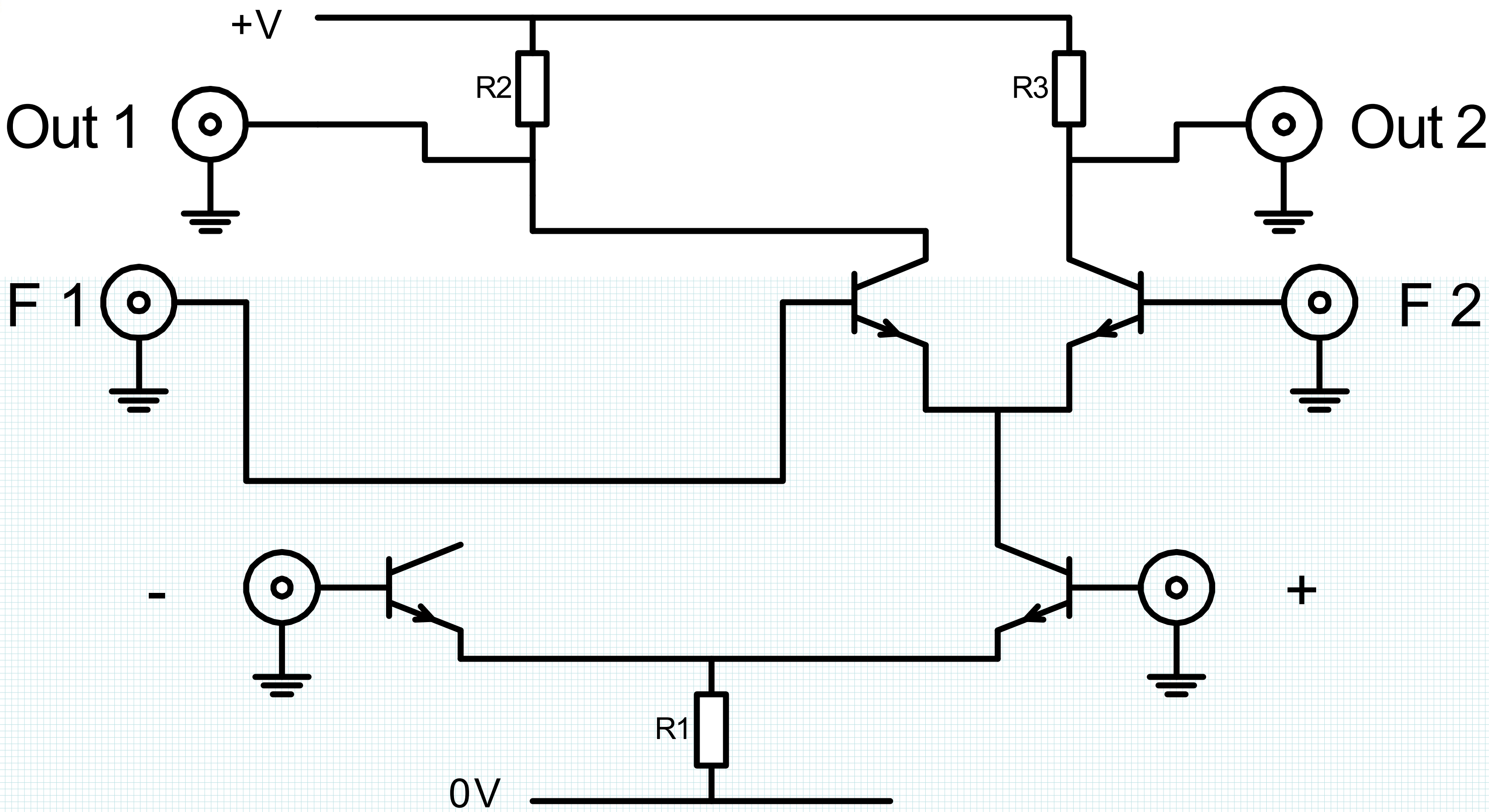
A Double balanced Mixer



G input positive on left



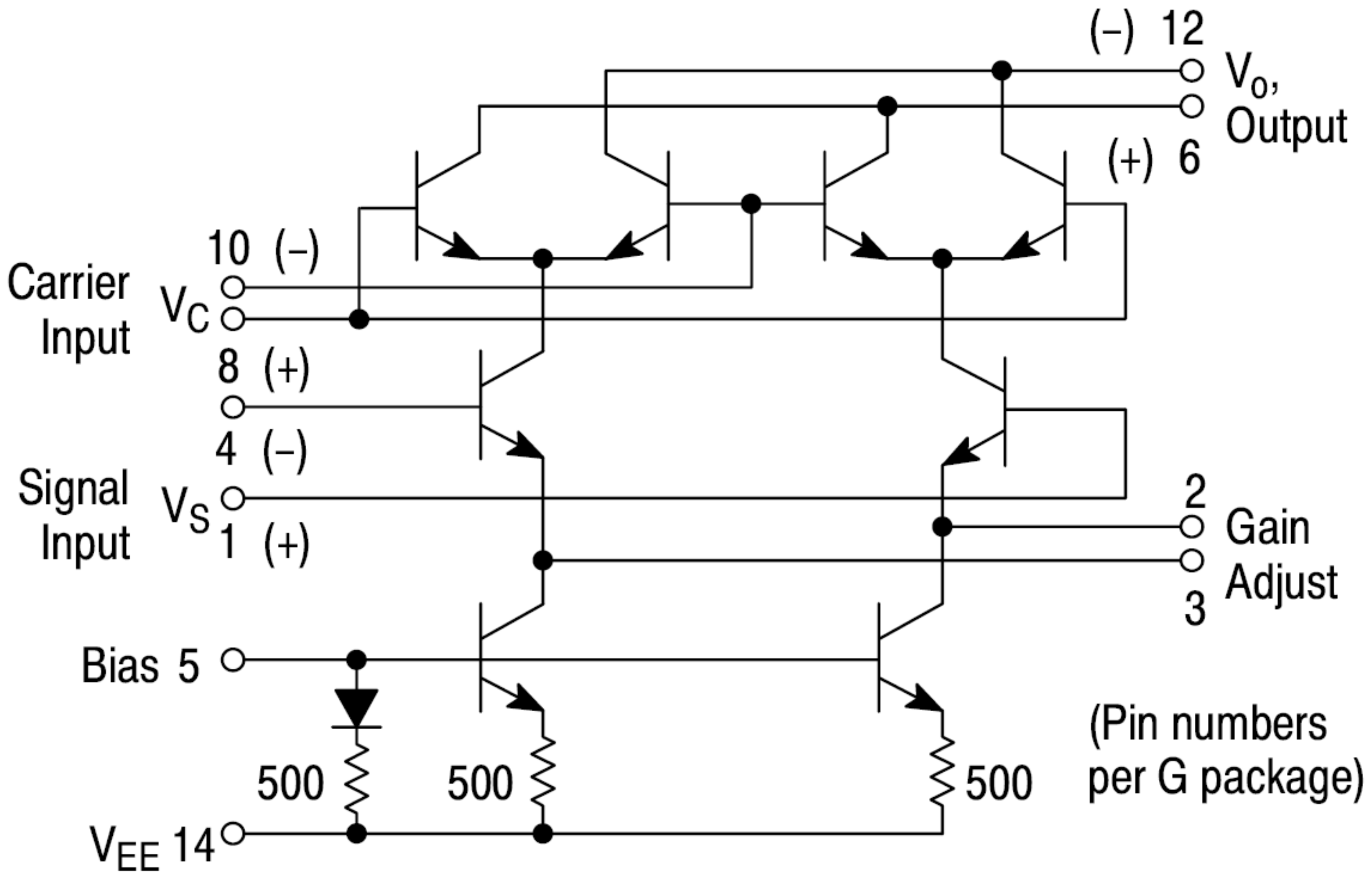
G input positive on Right



Advantages of the double balanced mixer

- Almost linear on each input
- Great carrier and input rejection
- Low drive signals needed.
- Low harmonic distortion on both inputs
- Well suit to IC manufacture
- No transformers
- Cheap (due to IC process)

Real devices: MC1496



Real devices:SA602A

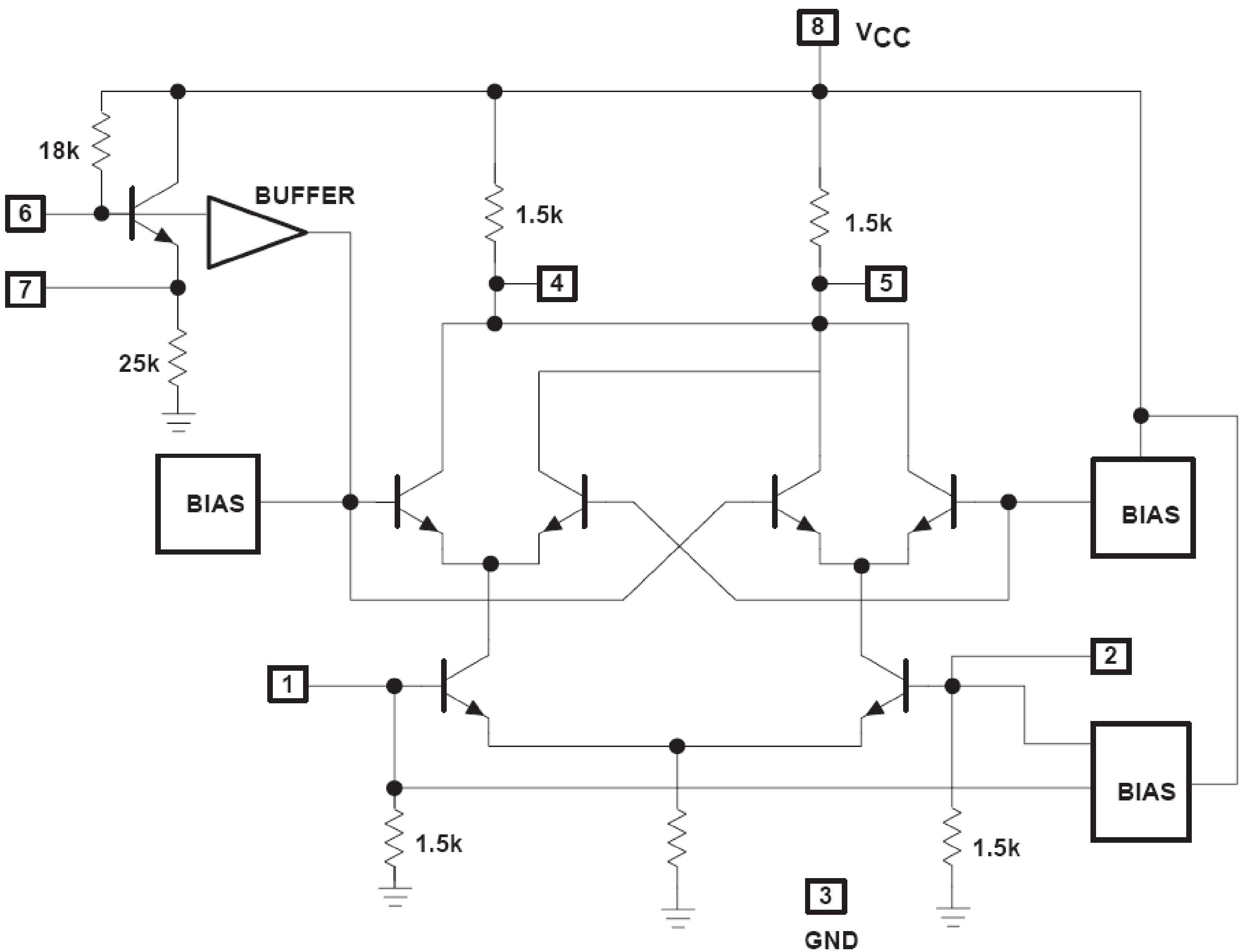


Image Reject Architectures

- A single stage mixer is susceptible to image distortions corrupting the IF signal and making the detection of signal difficult
- The concept of image rejection was realized out of dire necessity
- Traditional mixers used a SAW bandpass filter for image frequency rejection
- Image Rejection Mixers are useful particularly when the desired and image are very close (low IF frequencies) and a narrow-band channel pre-selector (SAW) renders impracticable

Image Rejection Mixer

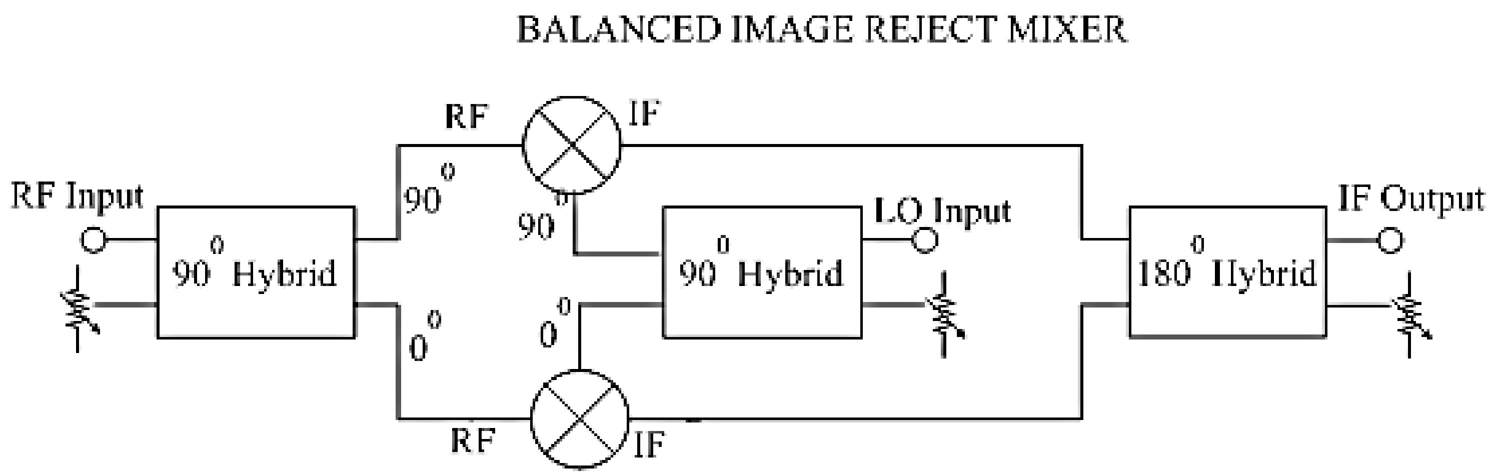
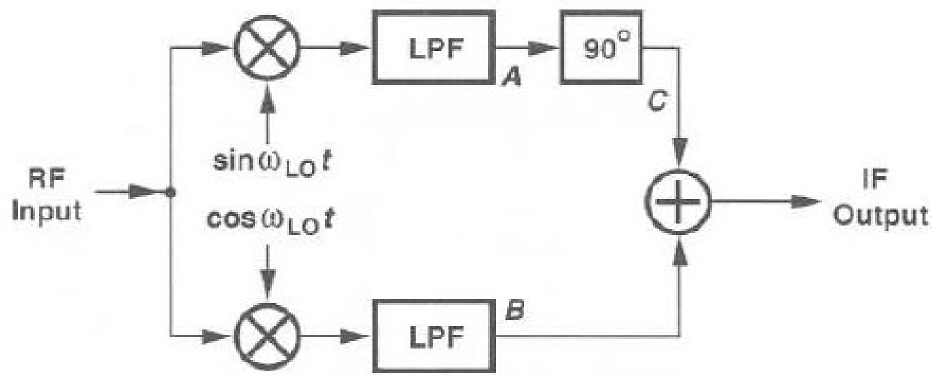
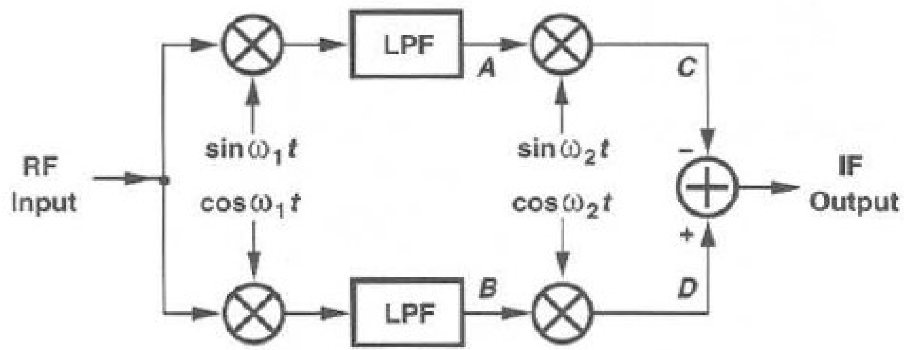


Image Reject Mixer Topologies

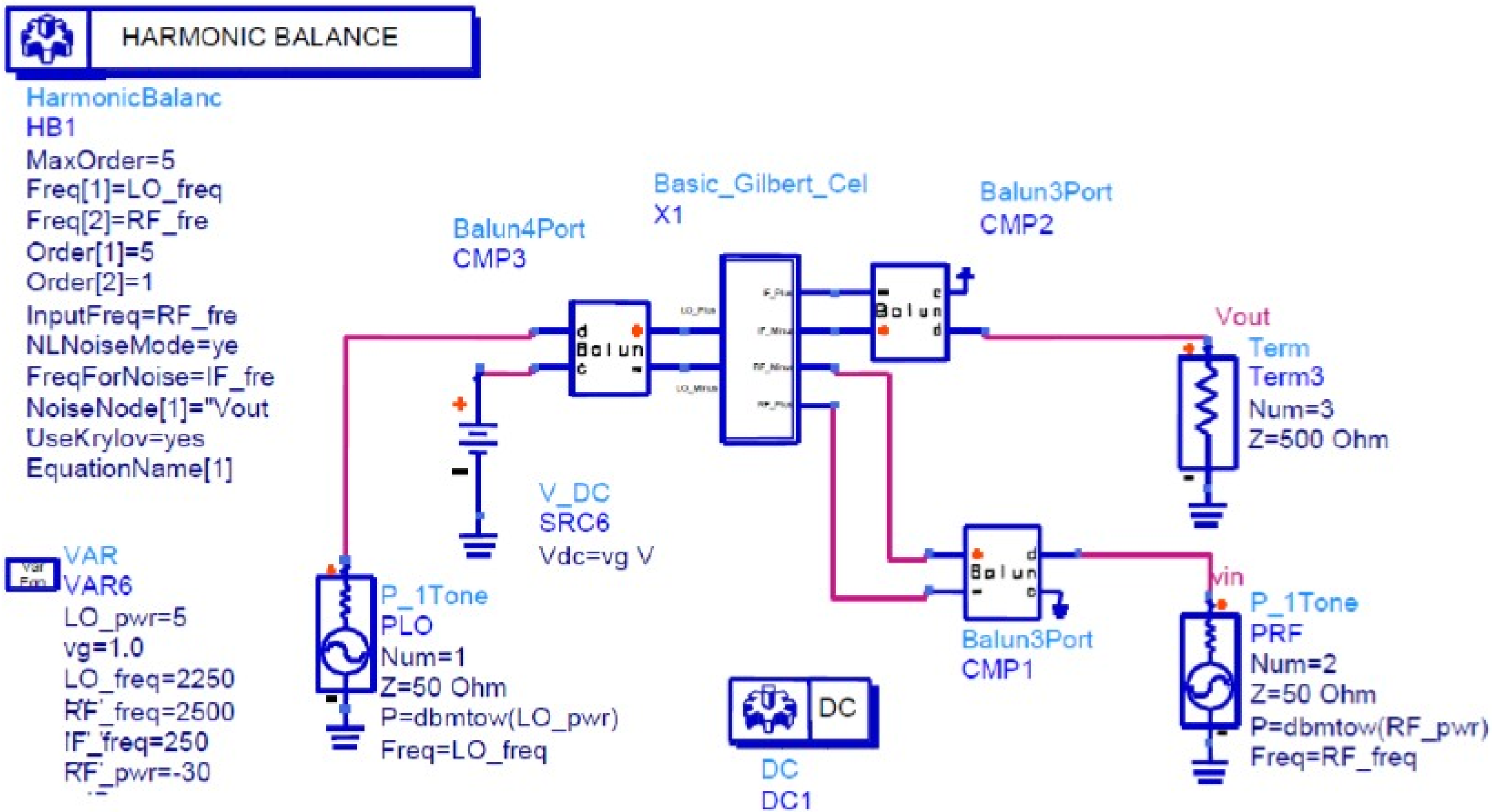


Hartley Architecture



Weaver Architecture

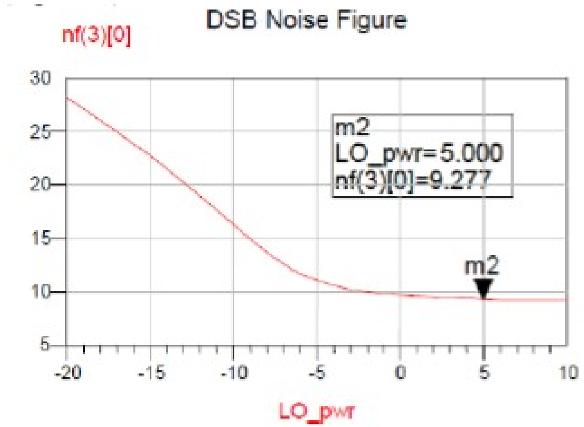
Test setup

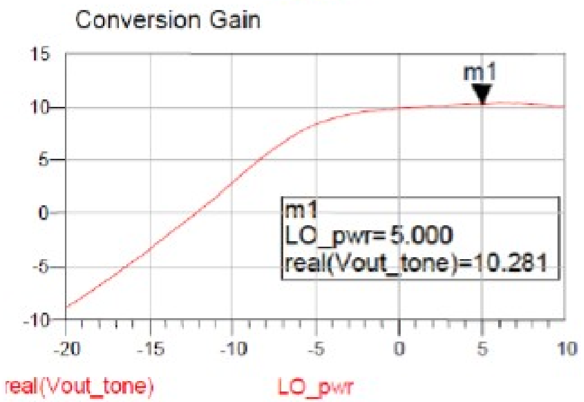

HARMONIC BALANCE
HarmonicBalanc
HB1
MaxOrder=5
Freq[1]=LO_freq
Freq[2]=RF_fre
Order[1]=5
Order[2]=1
InputFreq=RF_fre
NLNoiseMode=ye
FreqForNoise=IF_fre
NoiseNode[1]="Vout
UseKrylov=yes
EquationName[1]
Balun4Port
CMP3
Basic_Gilbert_Cel
X1
Balun3Port
CMP2
Vout
Term
Term3
Num=3
Z=500 Ohm
V_DC
SRC6
Vdc=vg V
VAR
VAR6
LO_pwr=5
vg=1.0
LO_freq=2250
RF_freq=2500
IF_freq=250
RF_pwr=-30
P_1Tone
PLO
Num=1
Z=50 Ohm
P=dbmtow(LO_pwr)
Freq=LO_freq
Balun3Port
CMP1
vin
P_1Tone
PRF
Num=2
Z=50 Ohm
P=dbmtow(RF_pwr)
Freq=RF_freq
DC
DC
DC1

Inputs to mixer

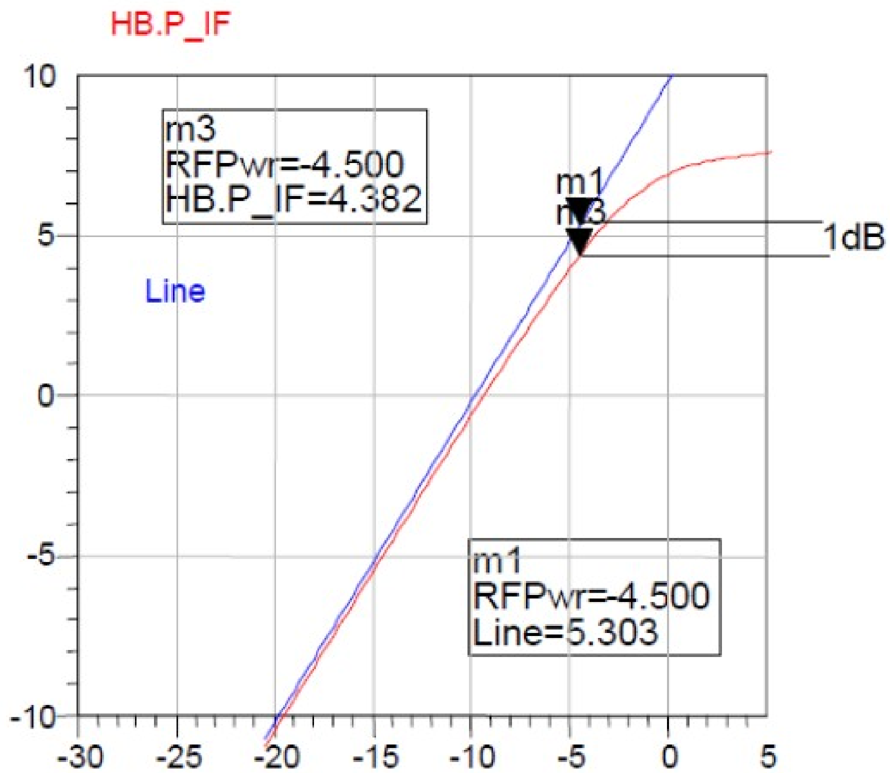
- As the inputs and outputs are differential balun trans-formers have been added to convert to single ended inputs and outputs.
- The 500-ohm load Term3 correctly terminates the mixer 500-ohm output impedance.
- The RF frequency is set to 2500MHz (RF_freq), Local oscillator frequency to 2250MHz (LO_freq) , resulting in an IF frequency of 250MHz (IF_Freq)..
- For correct switching of the LO transistors the variable vg needs to be set to 1V – running the simulation this gives Vgs across the switching transistor of ~ 1V.

Simulation Results

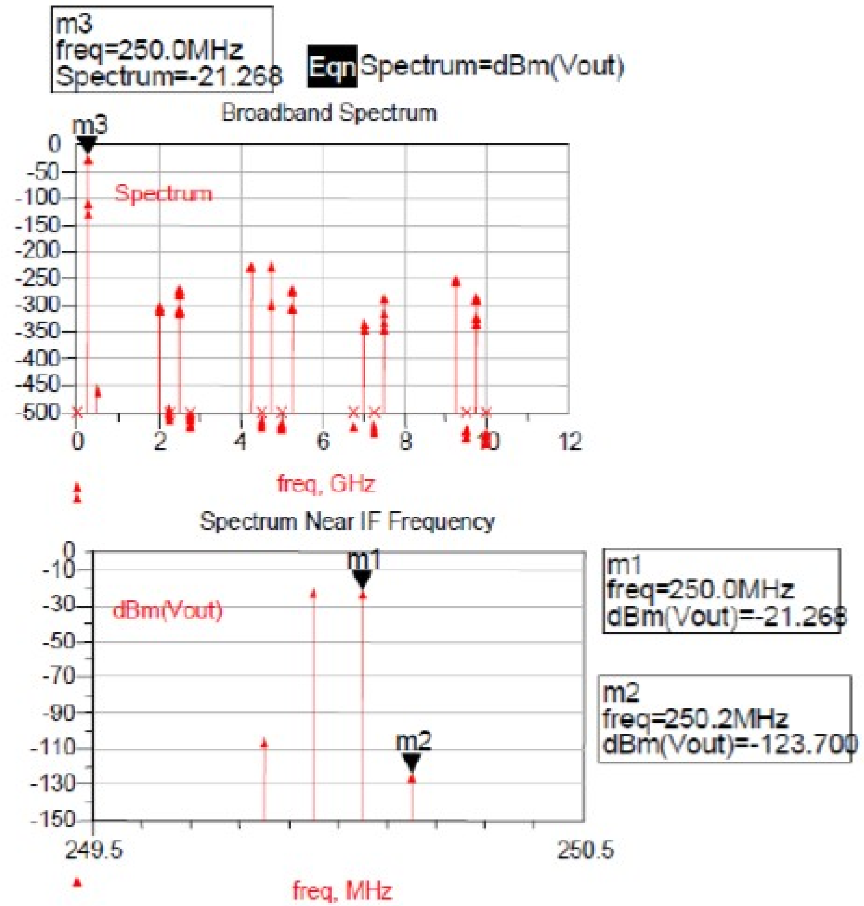




Simulation Results



Simulation Results



Eqn TOIoutput=1.5*m1-0.5*m2

TOIoutput
29.948

ConvGain	Input_IM3	Output_IM3
8.732	21.216	29.948

Simulation Results

Parameter	Specification	Predicted	Units
Frequency	2.45 to 2.85	2.45 to 2.85	GHz
Noise Figure	< 10	10.3	dB
IM3 Intercept Point (Intput)	>20	21.2	dBm
Voltage Gain	>8	8.2	dB
Power consump-tion	<100	90	mW
Source impedance	50	50	ohms
Load impedance	500	500	ohms
Voltage Supply	± 2.5	± 2.5	V