DESIGN OF RF MIXER IN 2.4 GHZ ISM BAND FOR ZIGBEE

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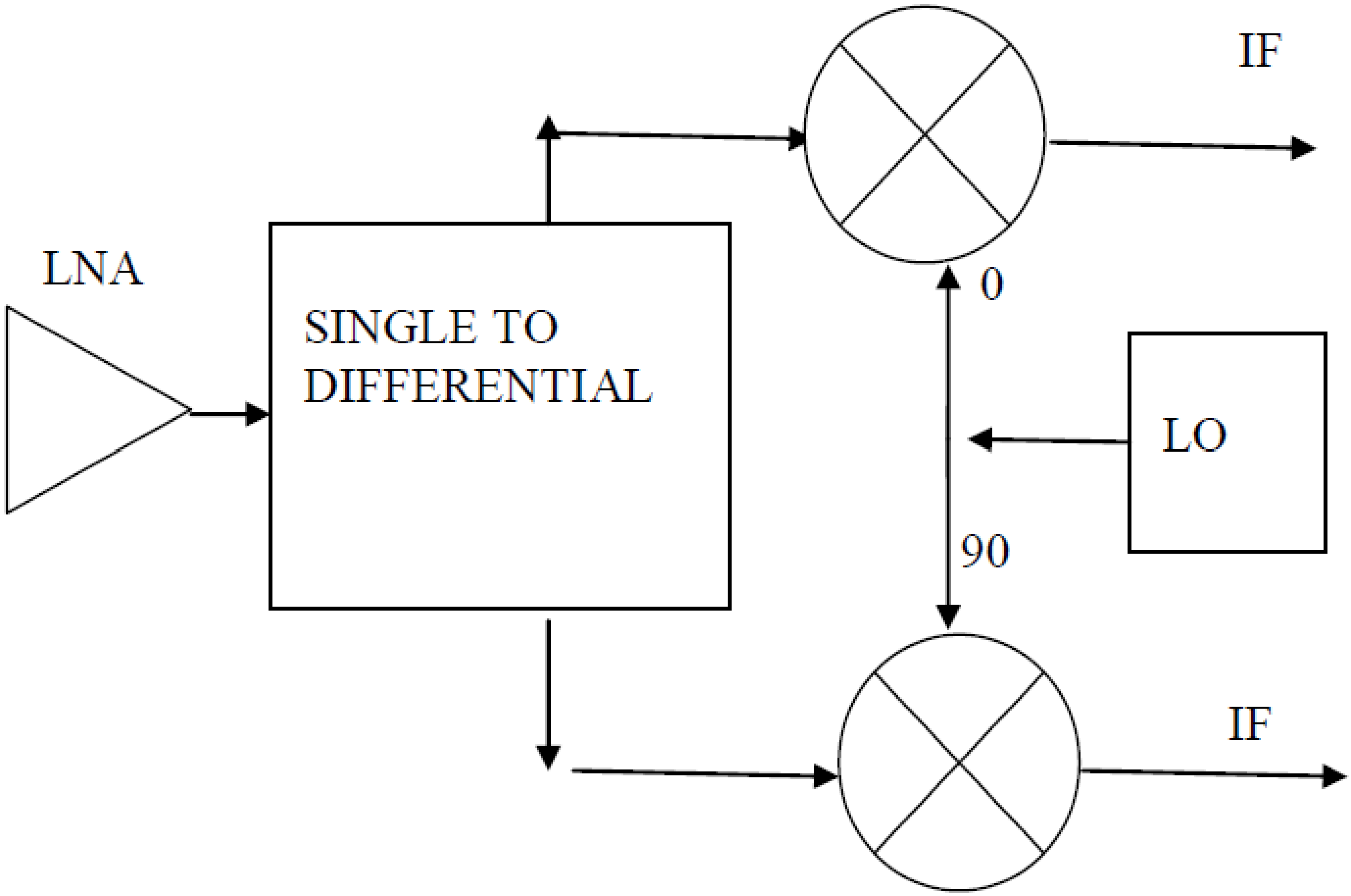
Outline

- Introduction
- Background Study
- Specification
- Active vs Passive Mixers
- Literature Survey
- Design

Introduction

Mixer-Creative use of Non Lineari



Introduction(contd..)
Zigbee

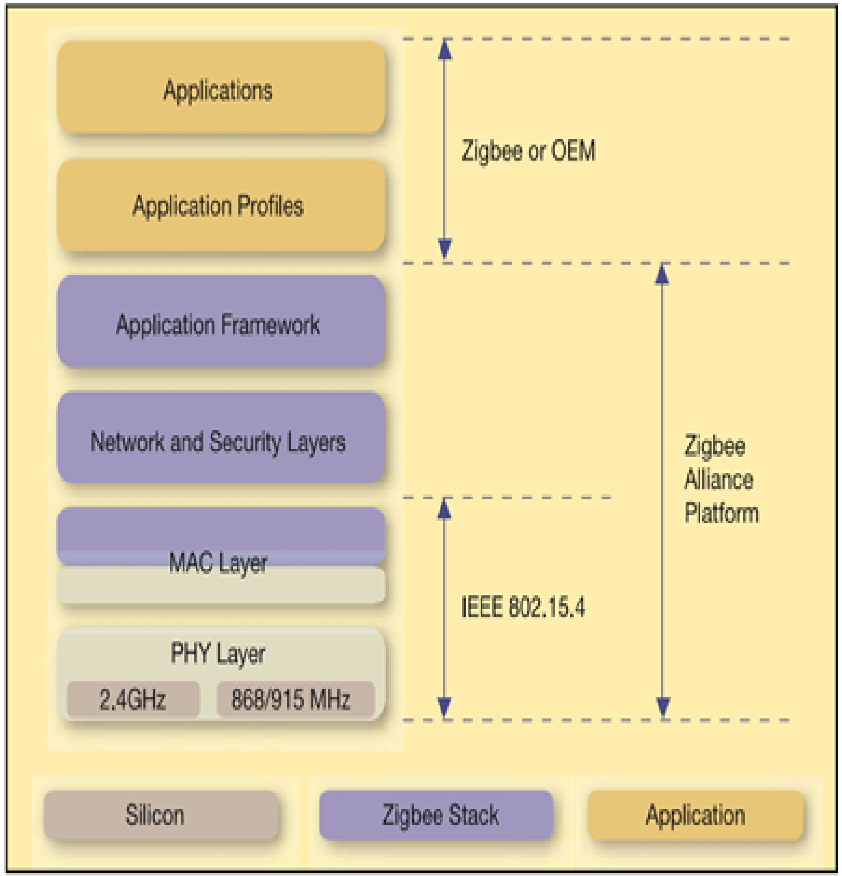


Fig: IEEE 802.15.4 and ZigBee working model

Parameter	2.4 GHz PHY	868/915 MHz PHY
Sensitivity @ 1% PER	-85 dBm	-92 dBm
Receiver Maximum Input Level	-20 dBm	
Adjacent Channel Rejection	0 dB	
Alternate Channel Rejection	30 dB	
Output Power (Lowest Maximum)	-3 dBm	
Transmit Modulation Accuracy	EVM<35% for 1000 chips	
Number of Channels	16	1/10
Channel Spacing	5 MHz	single-channel/2 MHz
Transmission Rates Data Rate Symbol Rate Chip Rate	 250 kb/s 62.5 ksymbol/s 2 Mchip/s	 20/40 kb/s 20/40 ksymbol/s 300/600 kchip/s
Chip Modulation	O-QPSK with half-sine pulse shaping (MSK)	BPSK with raised cosine pulse shaping
RX-TX and TX-RX turnaround time	12 Symbols	

Fig: IEEE 802.15.4 PHY parameters

$$\text{Sensitivity} = -174\ \text{dBm/Hz} + 10 \cdot \log(\text{BW}) + \text{NF} + \text{SNR}_{\text{OUT}}$$

Introduction(contd..)
Zigbee

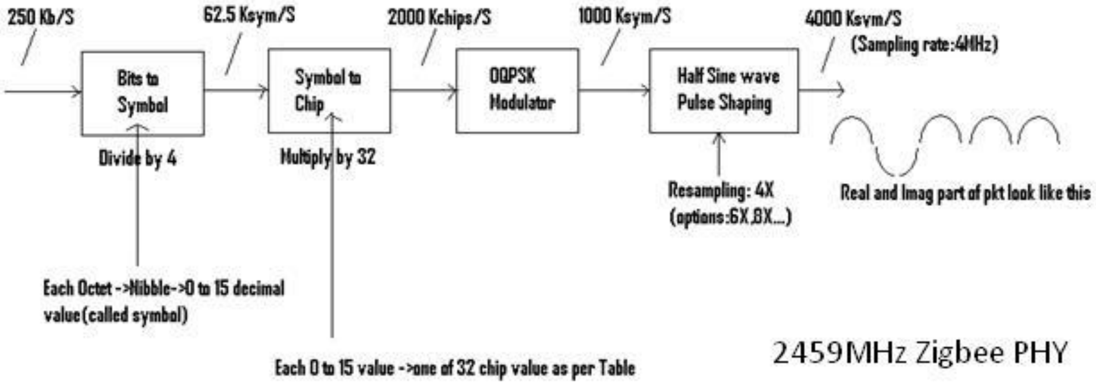
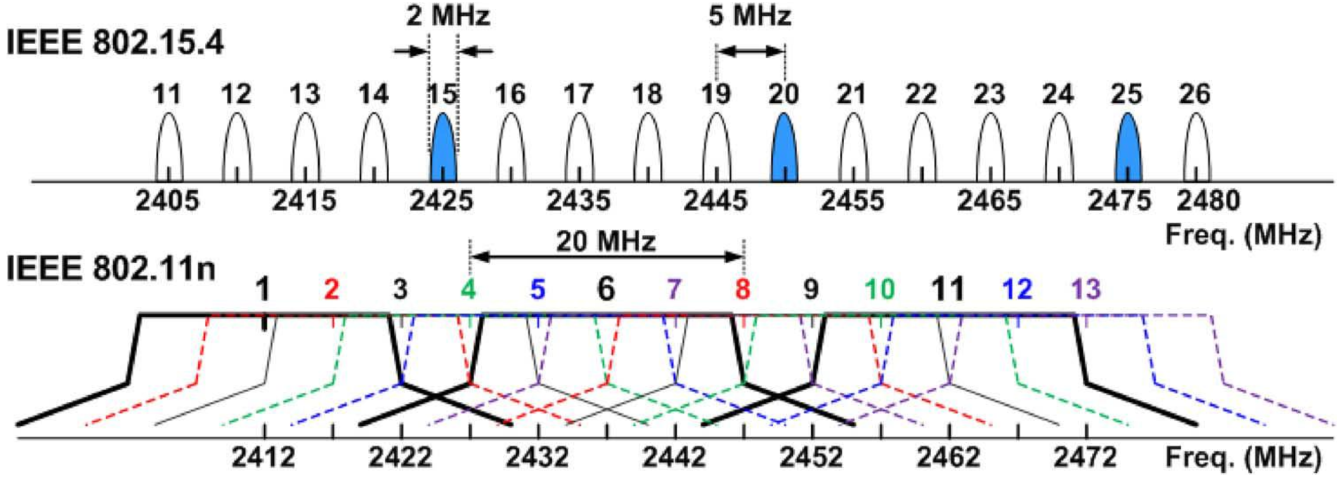


Fig: 2450 PHY layer



Background Study

Heterodyne Receivers

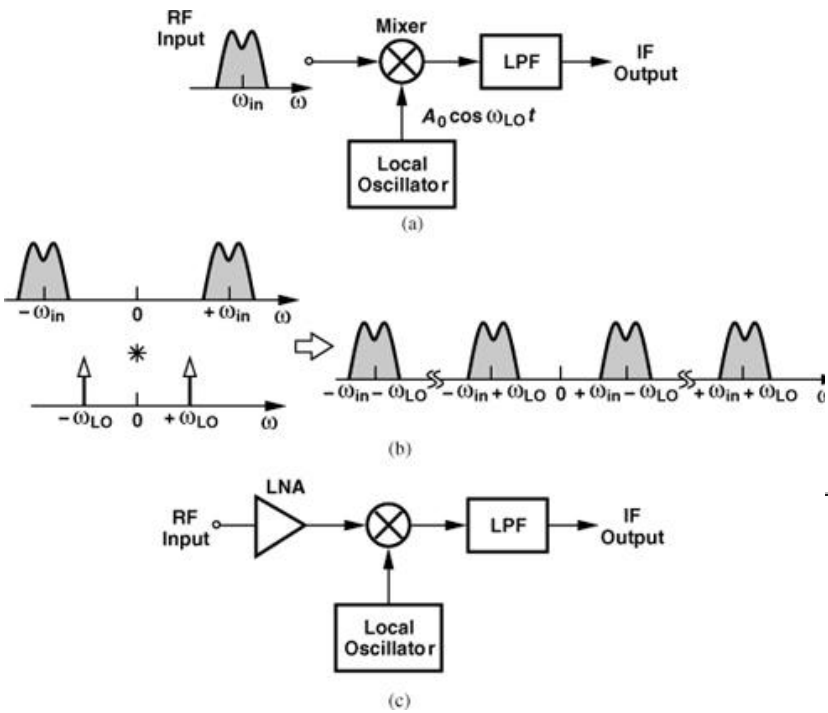


Fig: Working

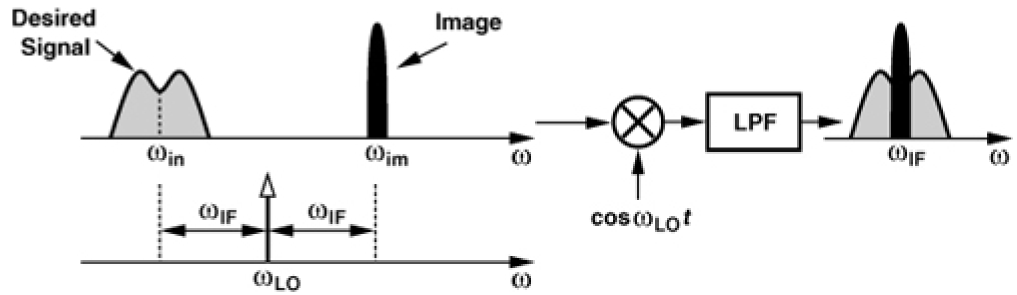


Fig: Image Problem

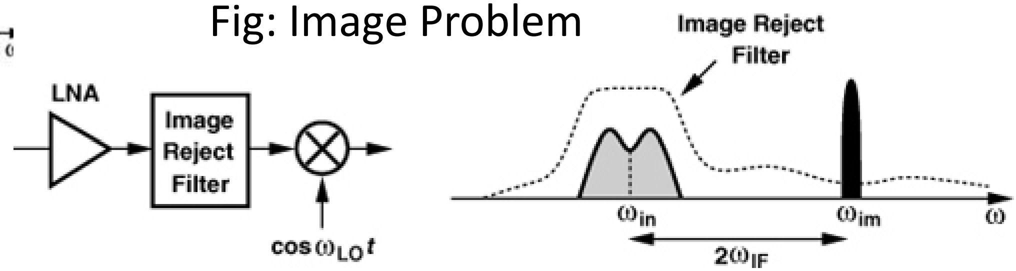


Fig: Image Reject Filter

Background study(contd..)

Heterodyne Receivers

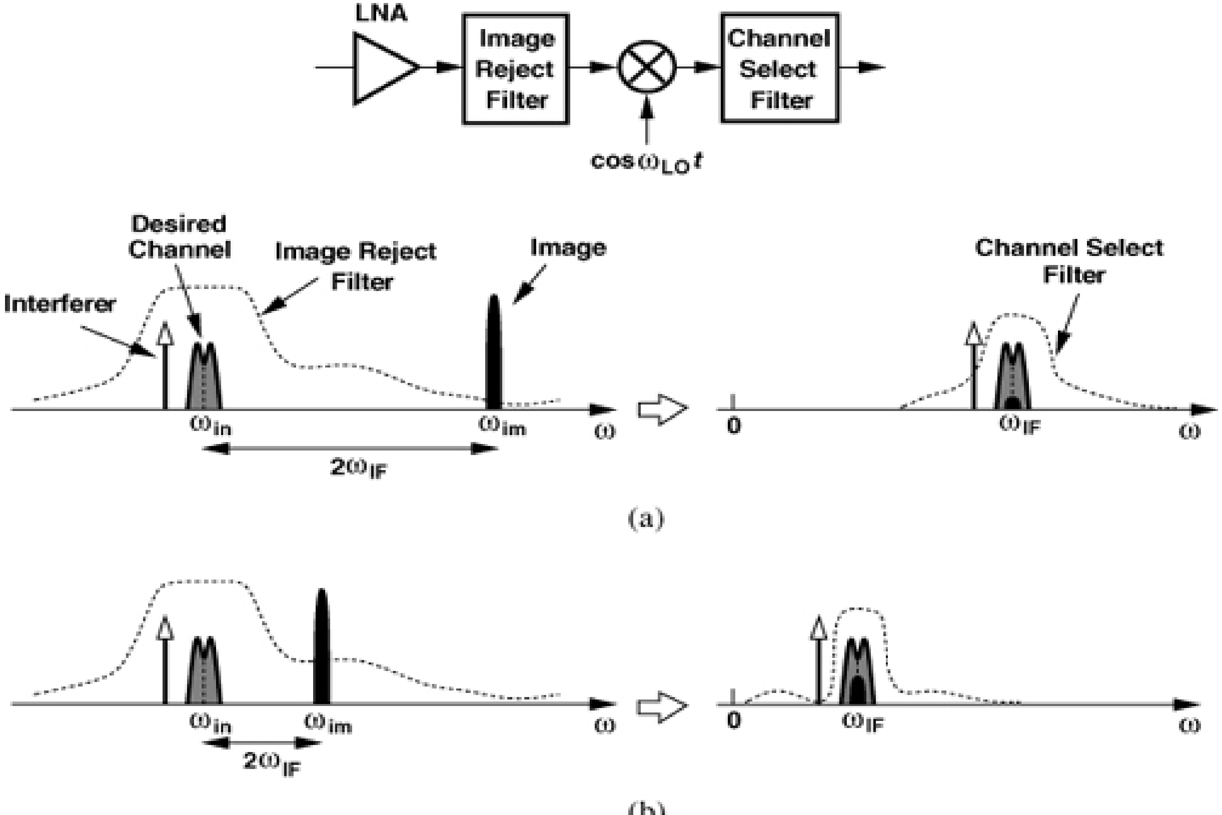


Fig: Trade Off btw channel selection and image rejection

Background study(contd..)

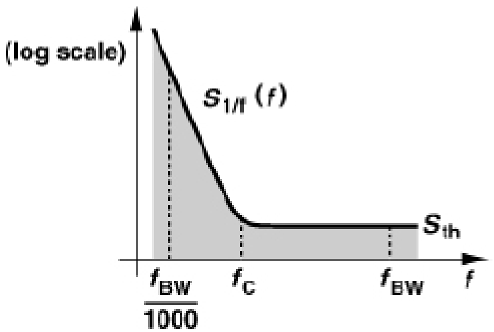
Homodyne Receivers

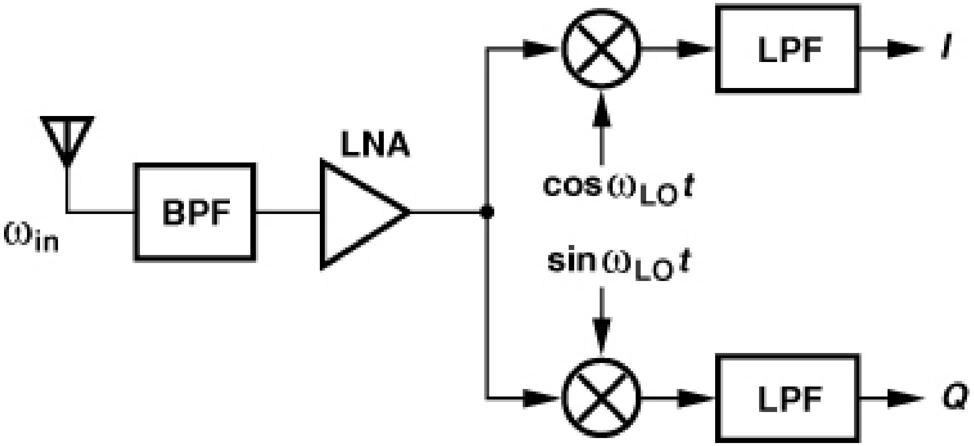
Advantages:

- Zero IF
- No image problems
- High level of integration
- Low Flicker noise

Drawbacks:

- DC Offsets
- Self Mixing
- I & Q mismatch





Background study(contd..)

Non Linearity

Effects of Non Linearity:

- Harmonic Distortion
- Gain Compression
- Desensitization
- Intermodulation(2^{nd} order and 3^{rd} order)

Y(t)=a1x(t)

$$y(t) = \alpha_0 + \alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t) + \cdots,$$

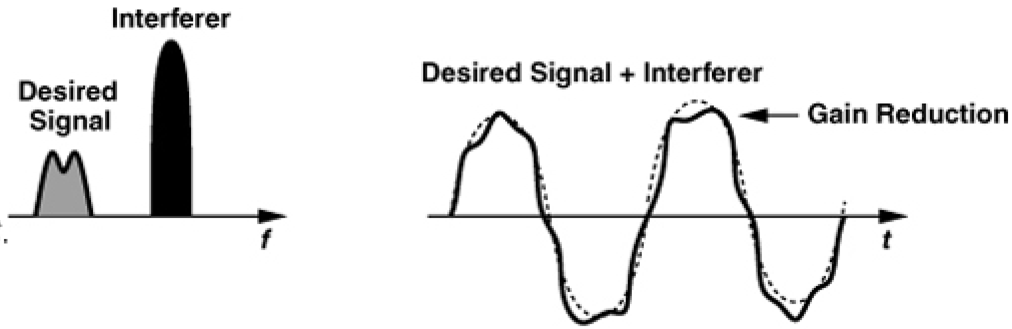
$$y(t) \approx \alpha_1 x(t) + \alpha_2 x^2(t) + \alpha_3 x^3(t).$$

Background study(contd..)

Effects of Non Linearity: Harmonic Distortion

$$y(t) = \alpha_1 A\cos\omega t + \alpha_2 A^2\cos^2\omega t + \alpha_3 A^3\cos^3\omega t$$
$$= \alpha_1 A\cos\omega t + \frac{\alpha_2 A^2}{2}(1+\cos 2\omega t) + \frac{\alpha_3 A^3}{4}(3\cos\omega t + \cos 3\omega t)$$
$$= \frac{\alpha_2 A^2}{2} + \left(\alpha_1 A + \frac{3\alpha_3 A^3}{4}\right)\cos\omega t + \frac{\alpha_2 A^2}{2}\cos 2\omega t + \frac{\alpha_3 A^3}{4}\cos 3\omega t.$$

Effects of Non Linearity: Desensitization

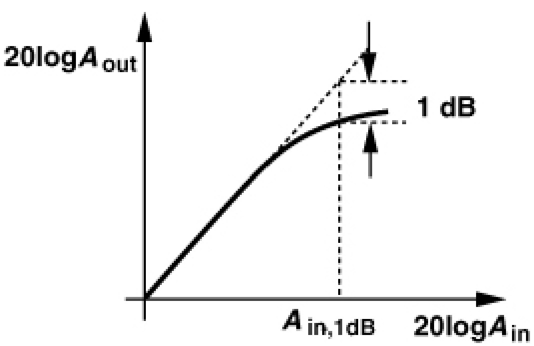


(a) (b)

$$y(t) = \left(\alpha_1 + \frac{3}{4}\alpha_3 A_1^2 + \frac{3}{2}\alpha_3 A_2^2\right)A_1\cos\omega_1 t + \cdots.$$

$$y(t) = \left(\alpha_1 + \frac{3}{2}\alpha_3 A_2^2\right)A_1\cos\omega_1 t + \cdots.$$

Effects of Non Linearity: Gain Compression



$$A_{in,1dB} = \sqrt{0.145\left|\frac{\alpha_1}{\alpha_3}\right|}.$$

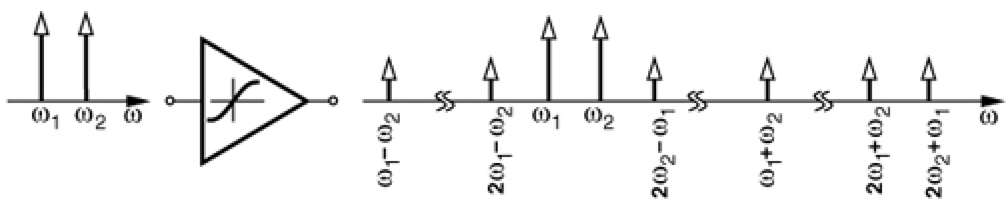
Background study(contd..)

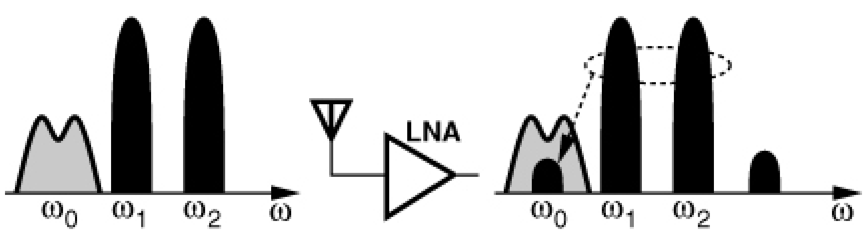
Effects of Non Linearity: Intermodulation

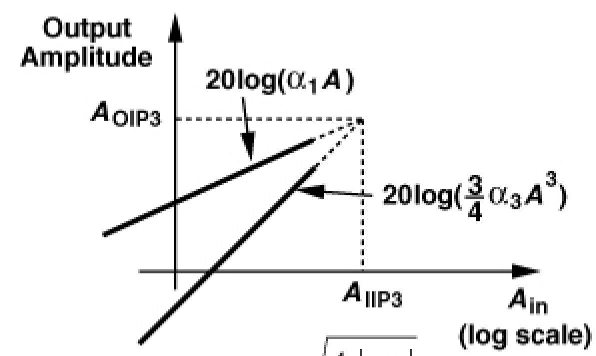
$$y(t) = \alpha_1(A_1\cos\omega_1 t + A_2\cos\omega_2 t) + \alpha_2(A_1\cos\omega_1 t + A_2\cos\omega_2 t)^2 + \alpha_3(A_1\cos\omega_1 t + A_2\cos\omega_2 t)^3.$$

$$\omega = 2\omega_1 \pm \omega_2 : \frac{3\alpha_3 A_1^2 A_2}{4}\cos(2\omega_1+\omega_2)t + \frac{3\alpha_3 A_1^2 A_2}{4}\cos(2\omega_1-\omega_2)t$$

$$\omega = 2\omega_2 \pm \omega_1 : \frac{3\alpha_3 A_1 A_2^2}{4}\cos(2\omega_2+\omega_1)t + \frac{3\alpha_3 A_1 A_2^2}{4}\cos(2\omega_2-\omega_1)t$$







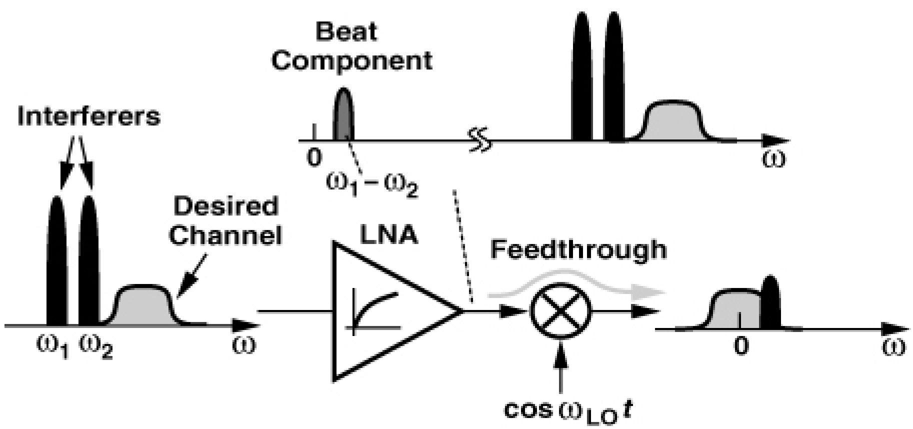
$$A_{IIP3} = \sqrt{\frac{4}{3}\left|\frac{\alpha_1}{\alpha_3}\right|}.$$

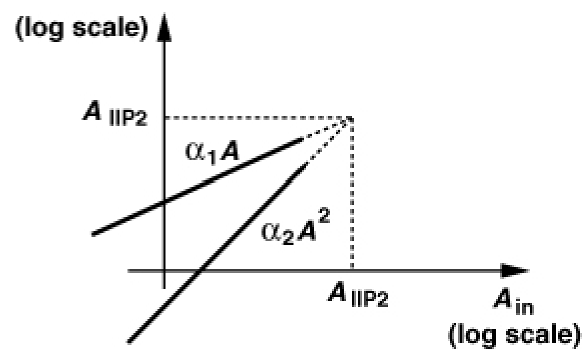
Background study(contd..)

Effects of Non Linearity: Second Order Distortion

Y(t)=a1x(t)+a1x(t)^2

$$V_{out}(t) = \alpha_1 V_{in}(t) + \alpha_2 V_{in}^2(t)$$
$$= \alpha_1 A(\cos\omega_1 t + \cos\omega_2 t) + \alpha_2 A^2 \cos(\omega_1 + \omega_2)t$$
$$+ \alpha_2 A^2 \cos(\omega_1 - \omega_2)t + \cdots ,$$





Specifications

The project focuses on designing the RF mixer in 180nm technology which incorporates necessary RF functionality needed for IEEE 802.15.4/ZigBee RF, wireless sensor network, and any other wireless systems in the 2.4GHz ISM band which is a worldwide standard for ZigBee wireless communication. Following are some of the desired specifications:

Mixer Technical Parameters (VDD=1.8V, T=25°C)

Parameters	Units	Minimum	Typical	Maximum
LO frequency	GHz	2.4		2.5
IF	MHz	1		2
Noise Figure	dB		5	
Conversion Gain	dB		-1	
Input referred 1dB	dBm		-5	
Isolation LO-RF	dB		60	
Isolation LO-IF	dB		60	
Isolation IF-RF	dB		60	
Input/Output Impedence	Ω		50	

Nominal Operating Conditions

Parameters	Units	Minimum	Typical	Maximum
DC VDD voltage	V		1.8	
Control voltage "High"	V		1.8	VDD
Control voltage "Low"	V		0	0.3
Operating Ambient Temperature	°C	-30		85

Mixers: Performance Parameters

- Conversion Gain(Rms voltage of IF/Rms Voltage of RF)(10dB)
- Noise Figure(SSB and DSB)(12dB)
- Port Isolation(10-20 dB)
- P-1bd point(Compression point)

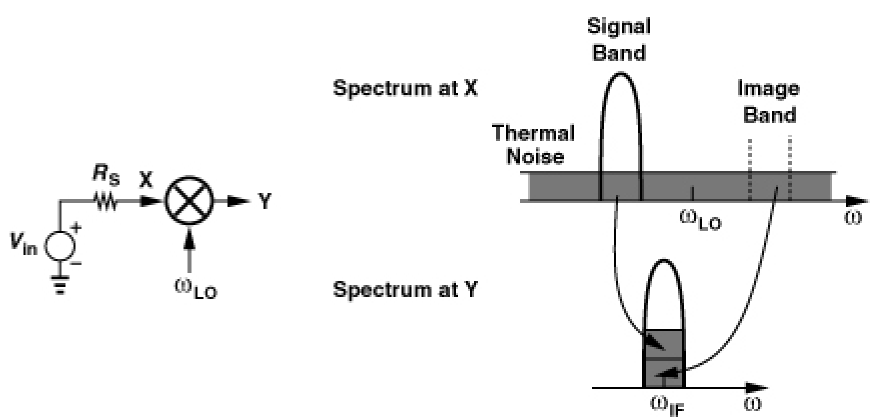


Fig: Heterodyne(SSB)

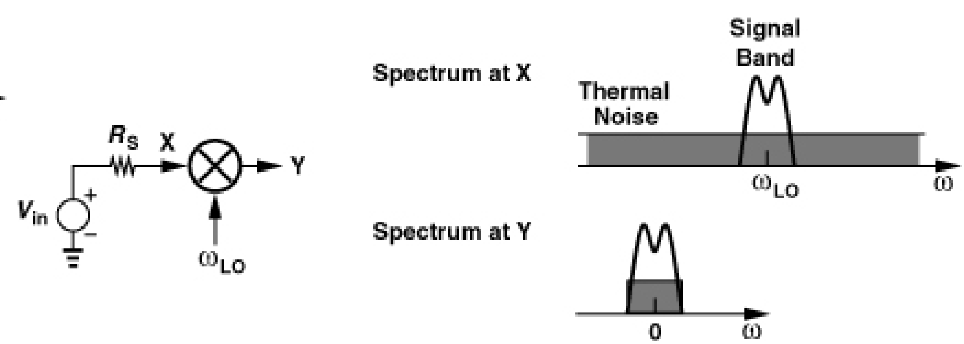


Fig: Homodyne(DSB)

Mixers: Passive Mixers

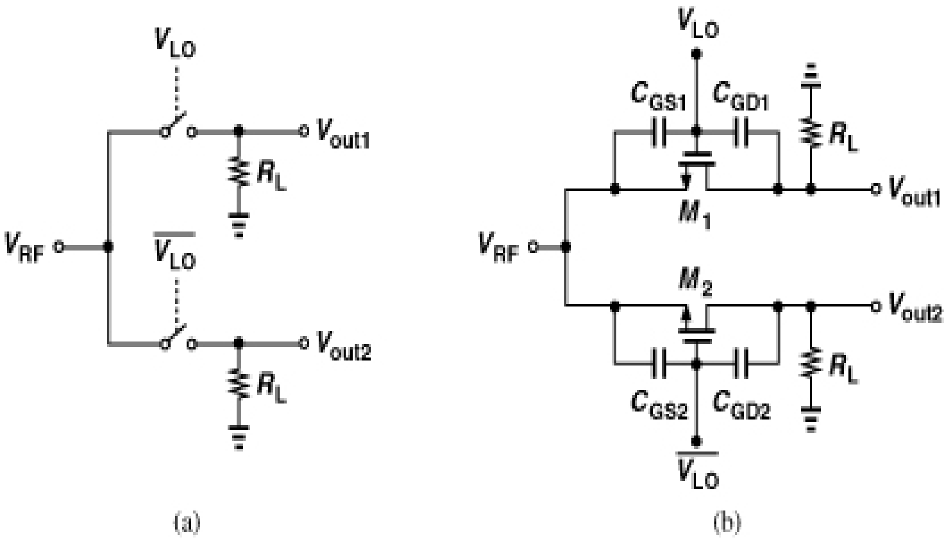


Fig: Single balanced

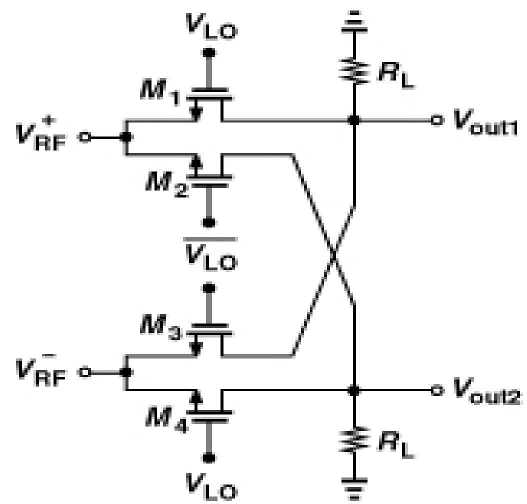
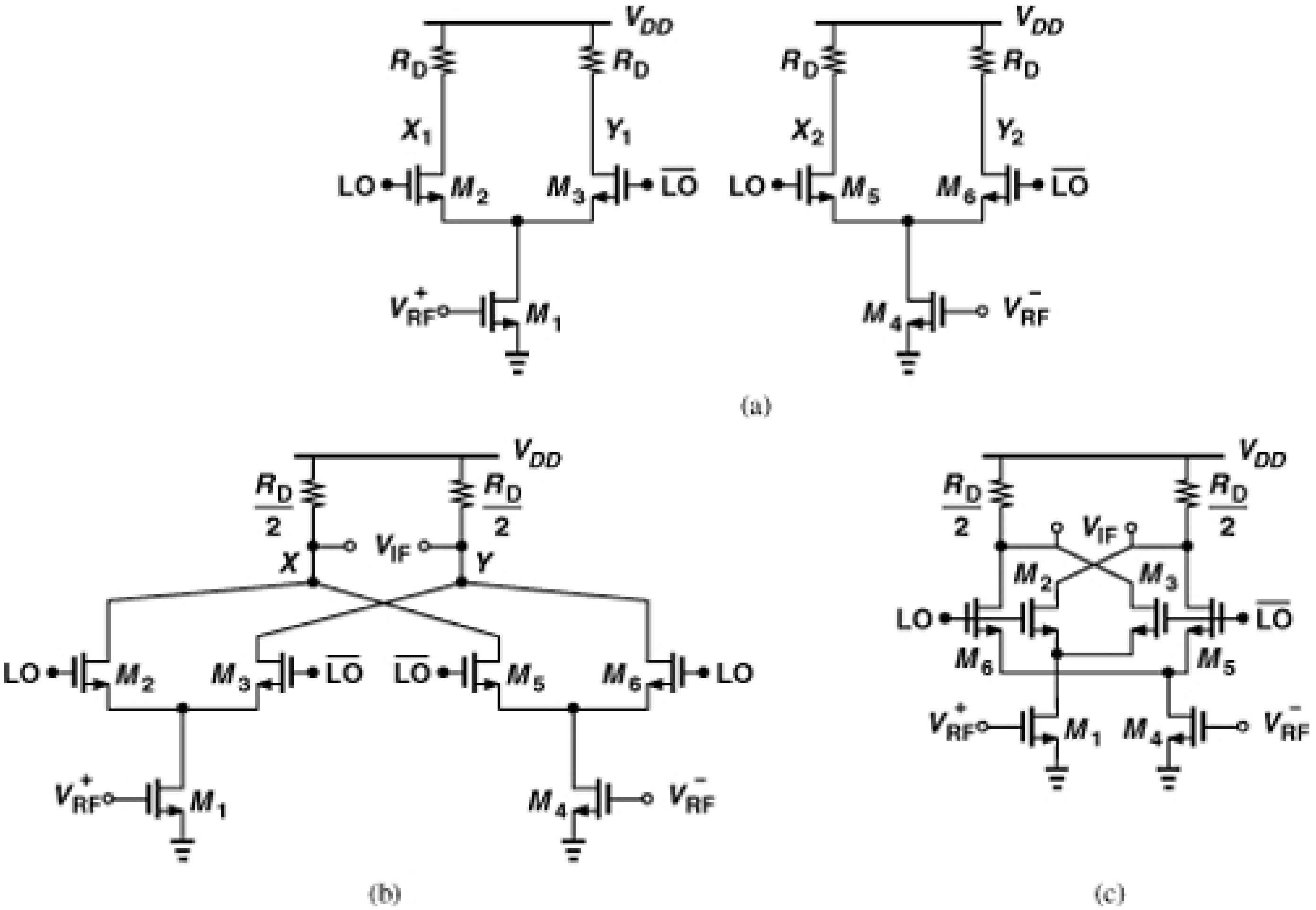


FIg: Double balanced

$$r_{ds} = \frac{L}{\mu_n C_{ox} W[(V_{gs} - V_{th}) - V_{ds}]},$$

Active(Basic Gilberts Cell)



Active vs Passive

- No DC bias
- Better Linearity
- Low flicker
- Low power consumption
- Simplicity

Passive Mixer Important Specs

- Conversion Gain
- DSB NF
- Port Isolations
- Flicker noise corner frequency
- IIP3
- A1dB

Integrated 130 nm CMOS Passive Mixer for 5 GHz WLAN Applications

- 2005
- Dissipates no DC power
- Layout helps in Port to port isolation? How?
- Gain can be easily compensated with the help of an IF amplifier
- Also Called FET resistive mixers(Pg 547)
- Microwave mixer design by Stephen a Maas ?
- Agilent ADS used and virtuoso layout tool by cadence
- RF power level set to 40dBm
- How to measure conversion losses ?
- Conversion loss can be lowered if higher LO drive voltages are spent
- Careful extraction of smallest parasitic capacitances which lead to electrical layout imbalances is important

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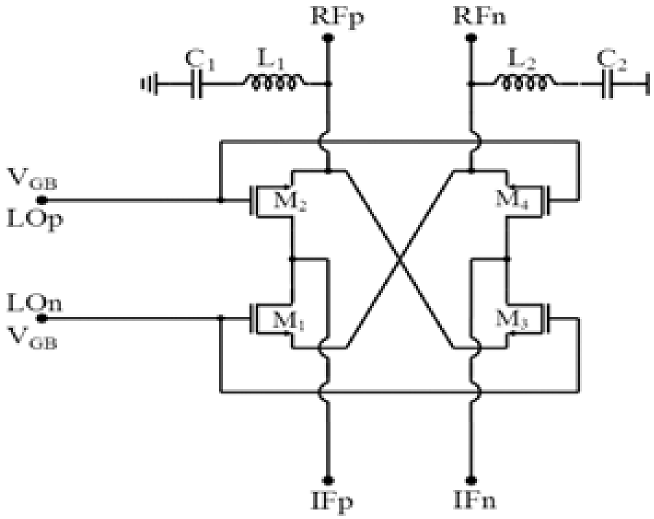


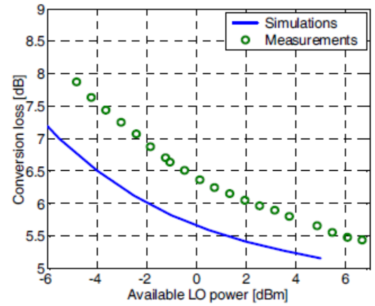


Fig. 3. Conversion loss versus available LO power, gate bias voltage = 0.3 V, IF frequency = 2.5 GHz, RF frequency = 5.5 GHz, LO frequency = 3 GHz.

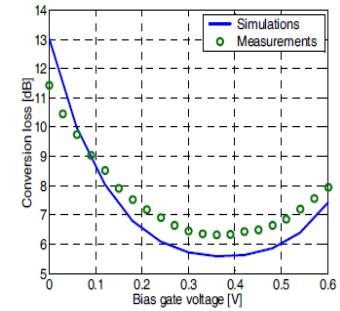


Fig. 4. Conversion loss versus gate bias voltage. available LO power = 0 dBm, IF frequency = 2.5 GHz, RF frequency = 5.5 GHz, LO frequency = 3 GHz.

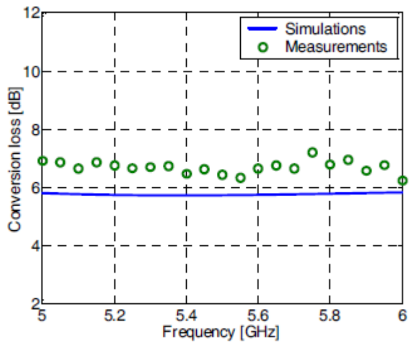
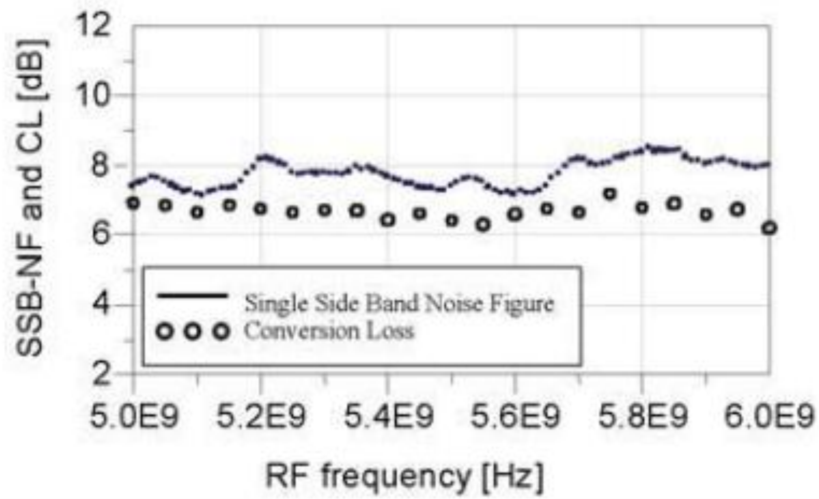


Fig. 2. Conversion loss versus RF frequency, available LO power = 0 dBm, gate bias voltage = 0.3 V, IF frequency = 2.5 GHz.



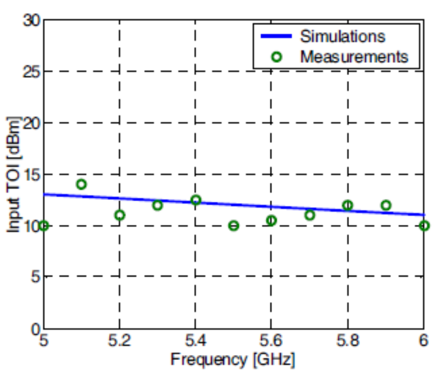


Fig. 6. Input third order intercept point vs. RF frequency.

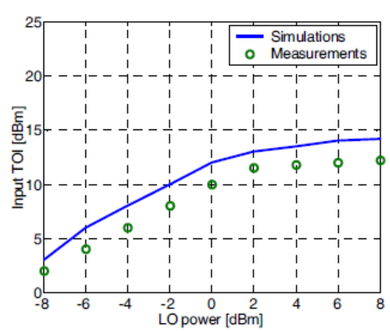


Fig. 7. Input third order intercept point vs. avail. LO

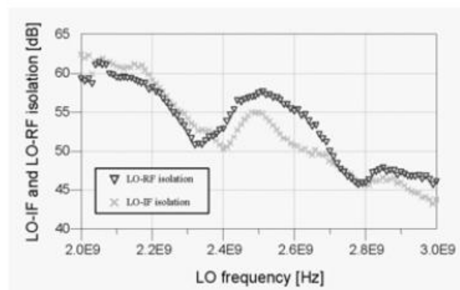


Fig. 9. Measured LO-RF and LO-IF port isolation vs. LO frequency.

RFIC TECHNOLOGIES

Gate Bias Voltage	0.3 V
RF power level	-40dBm
Return loss at RF and IF	>15dB
Conversion loss	7dB
Noise Figure(SSB)	<8dB
Flicker Noise Corner F	8 Khz
IIP3	>10dBm
LO-IF, LO-RF	>45dB
IF	2.4Ghz

Wide-band 0.25µm CMOS Passive Mixer

RFIC TECHNOLOGIES

- 2009
- A small bias at LO will help achieve better conversion loss
- Wideband, high linearity and impedance matching essential
- In this paper RF and LO impedance have been changed to optimize
- Size of NMOS chosen to match best cl, rf and If imp matching
- Larger device will contribute to lower cl, but larger input and output parasitic cap will degrade BW and imp matching
- Thus gate width of 180um adopted
- With mos design size if imp matching was achieved. How ?
- Parasitic like substrate series resistance also taken into consideration
- Agilent tool used
- Not understanding the Resistance equation and the role of LO. Paragraph highlighted in paper.
- Implemented in multifingered gate array to reduce gate resistance
- Two tone test with 2Khz difference was employed.

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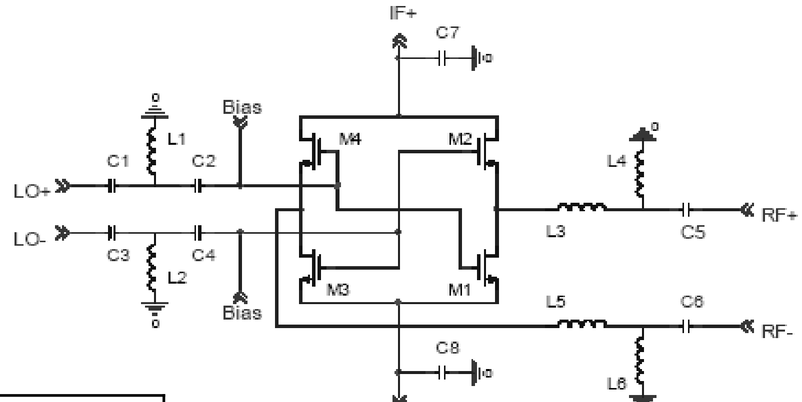

RF Return Loss	<10dB
IF Return loss	Better than -8dB
P1db	4dBm
IIP3	11.4dBm
LO-RF	-51dB
LO-IF	-36dB
CL	6.4dB

COMPARISON OF PUBLISHED CMOS WIDE-BAND RESISTIVE MIXERS

	[9]	[10]	[11]	[12]	[13]	This Work
Technology	CMOS 130 nm	CMOS 130 nm	CMOS 0.18 µm	CMOS 90 nm	CMOS 65 nm	CMOS 0.25 µm
Topology	Double Balanced	Double Balanced	Double Balanced	Single Ended	Singly Balanced	Double Balanced
RF Frequency (GHz)	5 - 6	2 - 3	1 - 11	57 - 63	54 - 64	2 - 9
IF Frequency (MHz)	2500	~ 0	500	2000	2000	0.1
Gate Bias (V)	0.3	0.33	-	0.45	0.5	0.45
Lowest CL* (dB)	6	5.6	6.5	11.6	12.5	6.4
IP1dB (dBm)	-	0 @ 2.5 GHz	4 – 6**	6 @ 62 GHz	5 @ 60 GHz	4 - 6.5
IIP3 (dBm)	10 - 14	10 @ 2.5 GHz	9 – 13**	16.5 @ 62 GHz	-	11.4 - 14.3
Min. LO-IF Isolation (dB)	-44	-52	-	-	-	-36
Min. LO-RF Isolation (dB)	-45	-48	-36	-	-	-51
Min. RF Return Loss (dB)	-15	-	-4	-	-	-8.6
Max. RF Return Loss (dB)	-	-	-32	-	-	-18
Min. IF Return Loss (dB)	-15 @ 2.5 GHz	-	-	-	-	-8 @ 135 MHz
Pwr Dissipation (mW)	0	0	3	0	0	0

* Lowest conversion loss (CL) versus RF frequency.
** IP1dB and IIP3 were measured between 1 and 12 GHz.
\- Not specified.

1-11 GHz Ultra-Wideband Resistive Ring Mixer in 0.18-µm CMOS Technology

- Fet act like variable resistor when biased in linear region with channel resistance modulated by LO signal
- W/L= 20um/0.18um the turn on R=10ohm
- Increasing device size would decrease the BW of the ckt , decreasing device size would be detrimental to conversion loss. By device size they mean w/l or only l?
- This tradeoff helps decide transistor size.
- 1.4nH, 90fF, 250 ohm for input matching used(RF)
- LO not matched because to reduce chip area but more LO power reqd to save conversion loss
- Shunt capacitors help improve isolation
- DC blocker cap to output in series

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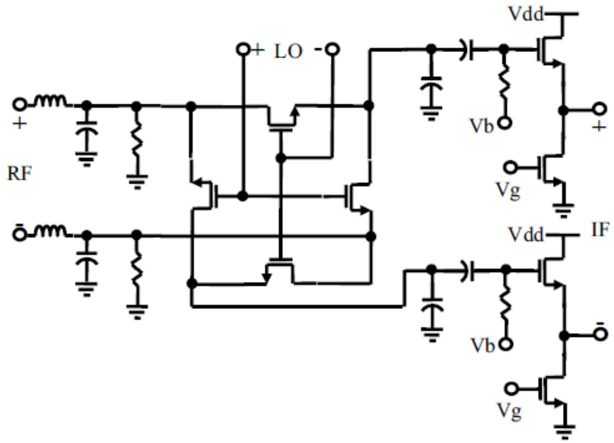
Parameter	Value
Conversion loss	7+-0.5dB
IF	500Mhz
Vdd	1V(more than this no issues)
Current consumtion	3mA
Lo power	9dBm
P1db	5+-1dBm
IIP3	9-13dBm
RF-LO isolation	40dB
LO-RF	38dB



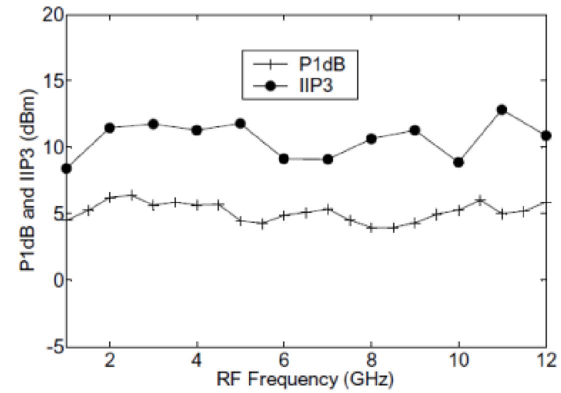


Fig. 4. Input P_{1dB} and IIP3 versus RF frequency.

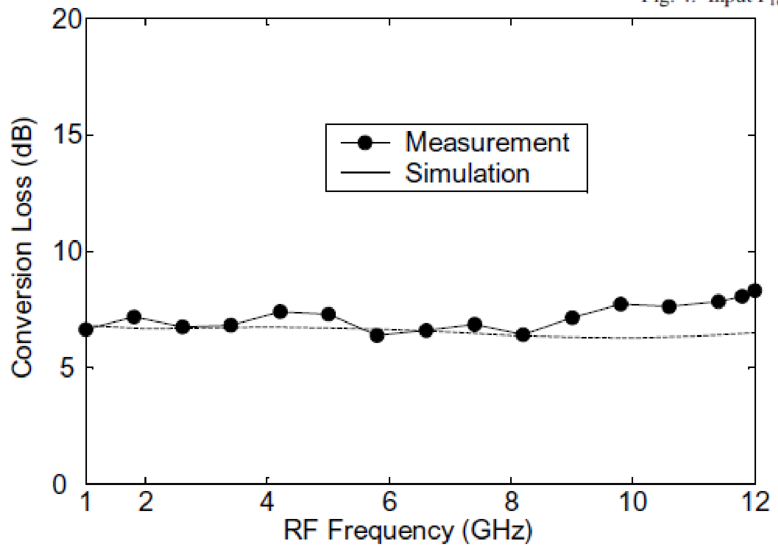


Fig. 3. Measurement and simulation results of conversion loss versus RF frequency with fixed IF frequency 500MHz.

2.4 GHz 0.18µm CMOS Passive Mixer with Integrated Baluns

- Microwave Symposium Digest, 2009. MTT '09. IEEE MTT-S International
- With Balun Integrated
- No passive components required for matching lo and rf
- The size of the NMOS device is chosen for the best CL, RF impedance matching, and IF matching?
- Agilent ADS tool for simulation?
- LO power level set at 10dBm, RF power level set at -40dBm? Wat r the general numbers ?
- Input return loss was measured using Agilent 8510C vector network analyzer
- A high return coefficient at LO port is seen in graph . Which leads to high vgs ? Why should LO port be nearly open ?

$$R \approx \frac{L}{W * I_t * n}\left[n * V_{ds} - V_{gs} + V_T\right]$$

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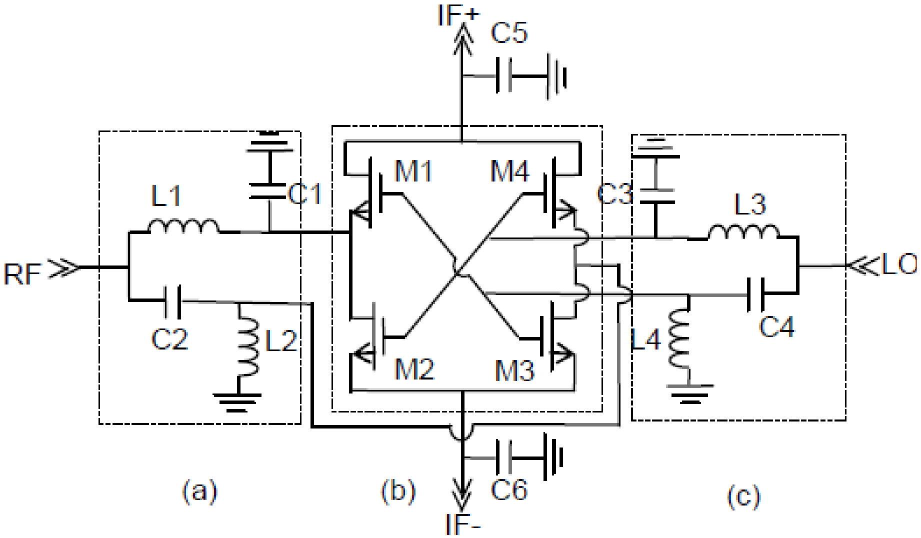
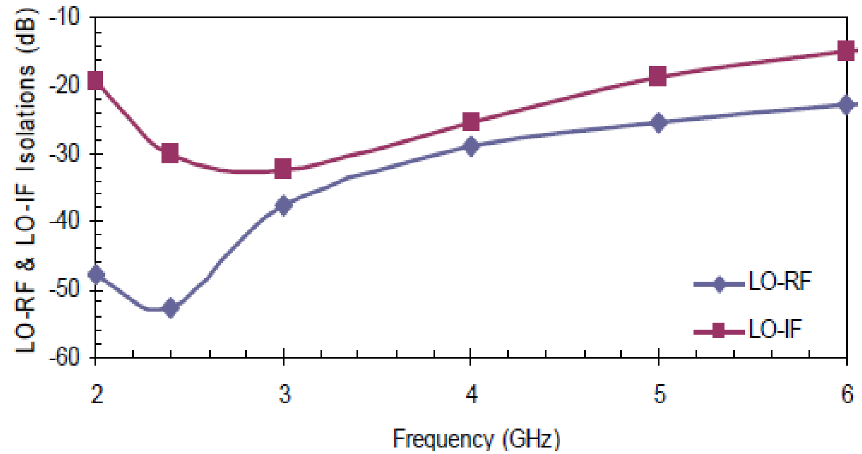
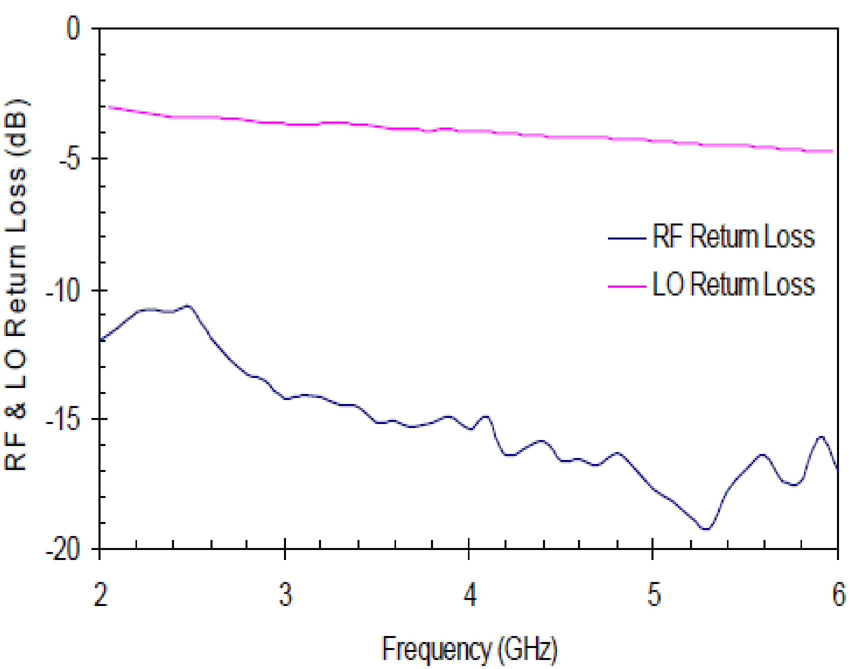
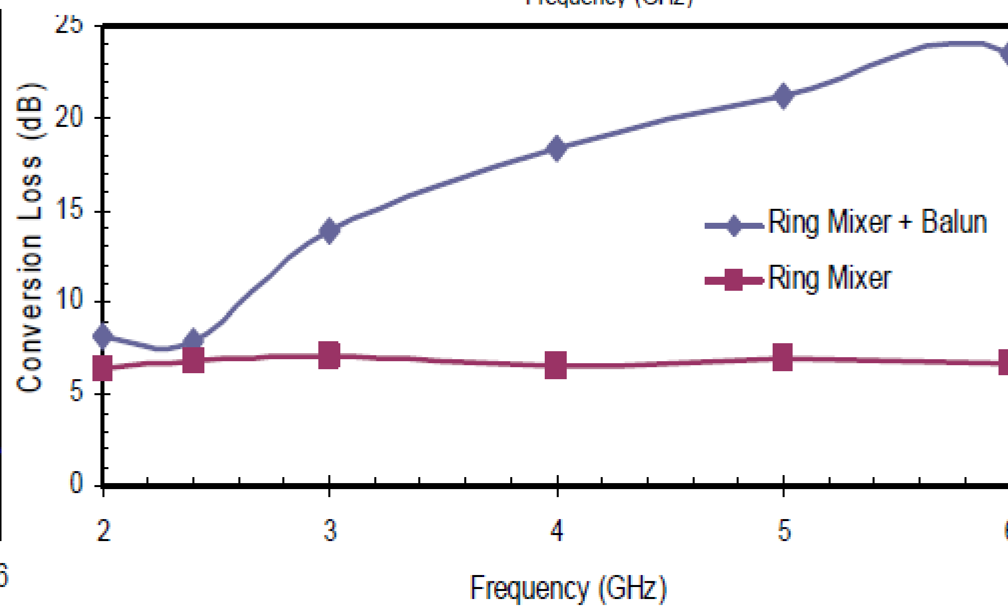

IF+
C5
L1
C1
M1
M4
C3
L3
RF
LO
C2
L2
M2
M3
L4
C4
C6
IF-
(a)
(b)
(c)


LO-RF & LO-IF Isolations (dB)
-10
-20
-30
-40
-50
-60
2
3
4
5
6
Frequency (GHz)
LO-RF
LO-IF


RF & LO Return Loss (dB)
0
-5
-10
-15
-20
2
3
4
5
6
Frequency (GHz)
RF Return Loss
LO Return Loss


Conversion Loss (dB)
25
20
15
10
5
0
2
3
4
5
6
Frequency (GHz)
Ring Mixer + Balun
Ring Mixer

SUMMARIZED PERFORMANCES OF THIS MIXER AND ITS COMPARISON WITH PREVIOUSLY PUBLISHED DATA

	This work		[6]	[7]	[8]	[9]	[10]
	Mixer Core	Mixer + Balun					
Technology	BiCMOS 0.18μm	BiCMOS 0.18μm	BiCMOS 0.25μm	CMOS 130nm	CMOS 130nm	CMOS 0.25μm	CMOS 0.18μm
Topology	Double balanced	Double balanced	Double balanced	Double balanced	Double balanced	Double balanced	Double balanced
Matching Circuit	No	No	RF and LO	No	No	RF and LO	RF and IF
On-Chip Balun	No	Yes	No	No	No	No	No
RF* Frequency (GHz)	2 – 6	1.8 – 2.6	1.8	2 – 3	5 – 6	2 – 9	1 – 11
IF Frequency (MHz)	10	10	170	~0	2500	0.1	500
LO Power (dBm)	10	10	14	0	0	10	9
Gate bias (V)	0	0	0	0.33	0.3	0.45	—
CL (dB)	6.8 @ 2.4 GHz	7.8 @ 2.4 GHz	5.8**	5.6**	6**	6.4**	6.5**
IP1dB (dBm)	7 @ 2.4 GHz	6 @ 2.4 GHz	10	0 @ 2.5 GHz	—	4 – 6.5	4 – 6***
IIP3 (dBm)	14 @ 2.4 GHz	13.4 @ 2.4 GHz	19.5	10 @ 2.5 GHz	10 – 14	11.4 – 14.3	9 – 13***
LO-RF Isolation (dB)	-58 @ 2.4 GHz	-52.7 @ 2.4 GHz	—	-48	-45	-51	-36
LO-IF Isolation (dB)	-20 @ 2.4 GHz	-30 @ 2.4 GHz	43	-52	-44	-36	—
RF Return Loss (dB)	-6 – -8 @ 2 – 6 GHz	-19.3 – -10.3 @ 2 – 6 GHz	—	—	< -15	-18 – -8.6	-32 – -4
IF Return Loss (dB)	< -6.9 @ DC – 1 GHz	< -8 @ DC – 150 MHz	—	—	—	< -8 @ DC – 135 MHz	—
Power Consumption (mW)	0	0	0	0	0	0	3

* Estimated 3dB bandwidth based on the data in Fig.5.
** Lowest conversion loss (CL) versus RF frequency.
*** IP1dB and IIP3 were measured between 1 and 12 GHz.
— Not specified.

A Resistively Degenerated Wide-Band Passive Mixer with LowNoise Figure and +60dBm IIP2 in 0.18μm CMOS

RFIC TECHNOLOGIES

- Source degen method to improve NF and linearity
- Uses Transimpedence Amp to provide a low impedence node at mixer output. Why ?

IIP3	9dBm
NF(DSB)	8dB
Gain	24dB

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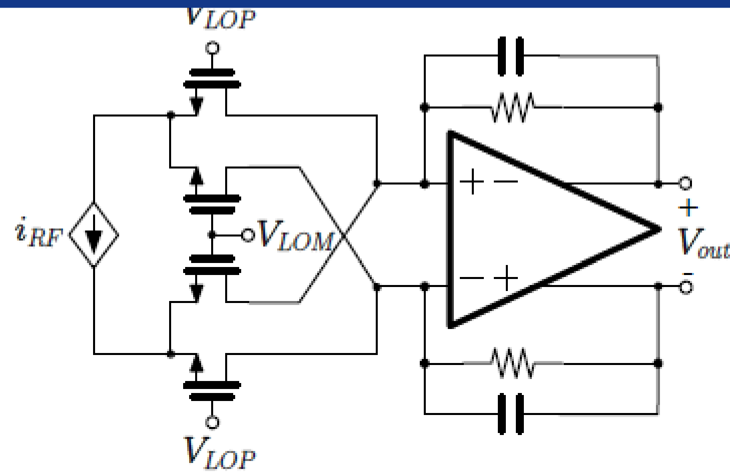
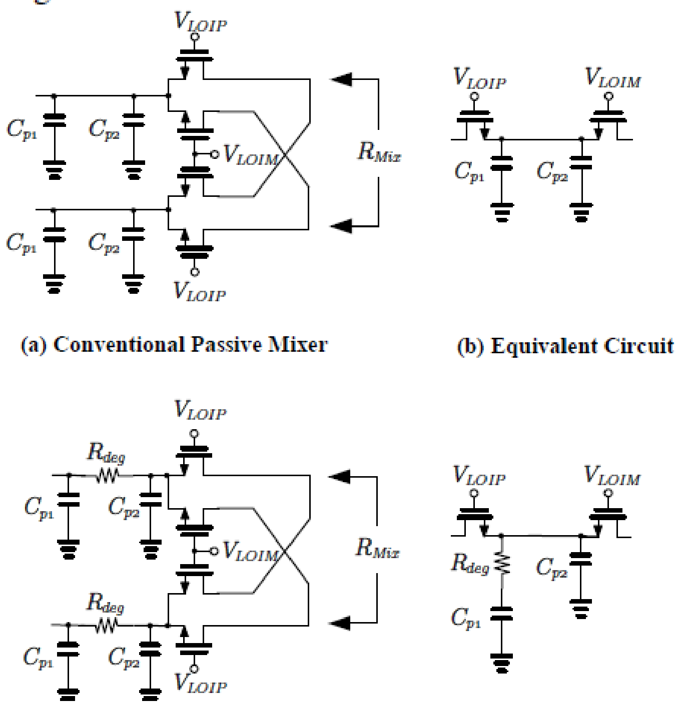


Fig. 1. Conventional Passive Mixer with TIA.



(a) Conventional Passive Mixer

(b) Equivalent Circuit

(c) Source degenrated Passive Mixer

(d) Equivalent Circuit

Fig. 3. Difference between Conventional and Proposed Mixer

$$\overline{v_{no\_TIA}^{2}} = \left(1+\frac{2\cdot R_{TIA}}{R_{Mix}}\right)^{2}\cdot\overline{v_{ni\_TIA}^{2}}$$

$$R_{Mix} = \left(f_{LO}\cdot\alpha\cdot\left(C_{p1}+C_{p2}\right)\cdot\left(1-e^{\frac{-T_{LO}}{\alpha\cdot\left(C_{p1}+C_{p2}\right)\beta\cdot R_{on}}}\right)\right)^{-1}$$

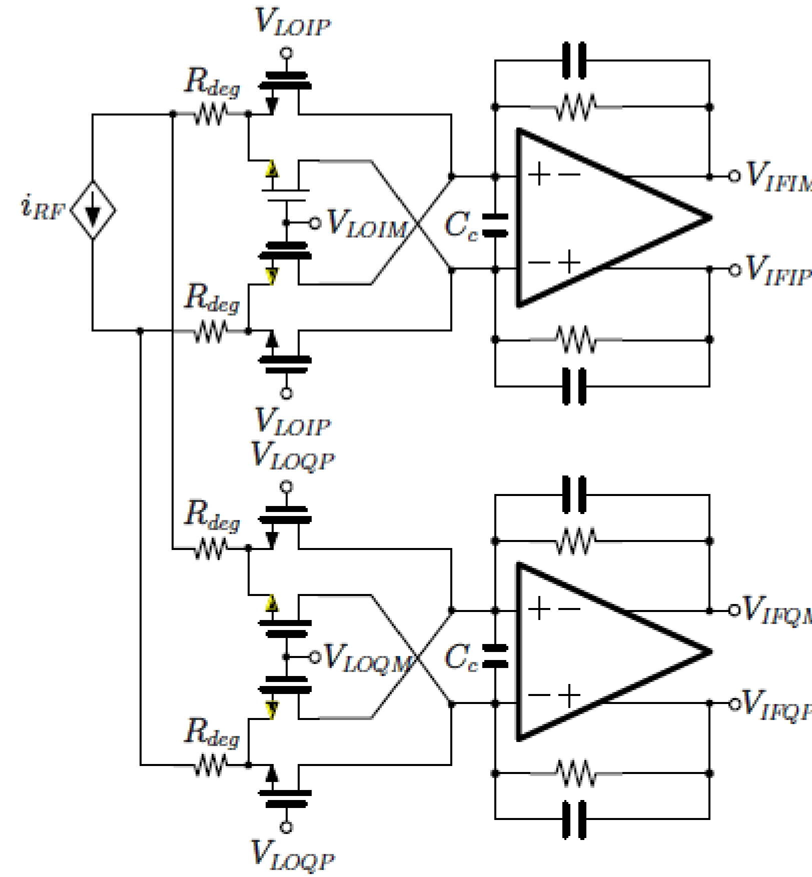


Fig. 2. Proposed Resistively Degenerated Passive Mixer

Design: Modelling, Simulation and Implementation of a Passive Mixer in 130nm CMOS Technology and Scaling Issues for Future Technologies

RFIC TECHNOLOGIES

- Figure of Merit for Mixer (Characterized by 1dB compression point, SSB, NF):

$$FOM_{MIXER}(dBm/Hz) = G_c - SSB\,NF + P_{1-dB} - P_{CONSUMED} \quad (1) \quad P_{CONSUMED} = V_{DD}I_{DC} + P_{LO}$$

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- The conversion gain of a double balanced passive mixer is as follows:

$$R_{ON} = r_{ds} = \frac{L_g}{\mu_n C_{OX} W\left(\left(V_g - g_c \cdot v_{RF}\right) - V_{th} - V_{ds}\right)}$$

$$Z_{OFF} = 1\Big/\left(j\omega_{RF}\left(C_{GS\,(V_{GS}=0)} \,||\, C_{GD\,(V_{GS}=0)}\right)\right)$$

$$G_C = 20\log_{10}\left(\frac{2}{\pi}\left(\frac{Z_L}{Z_L + R_{ON} \,||\, Z_{OFF}}\right) - \frac{2}{\pi}\left(\frac{Z_L}{Z_L + Z_{OFF}}\right)\right)$$

- Channel length, mobility, and oxide capacitance affect the on resistance.
- Transmission gates and bootstrapping techniques can be used to improve linearity of passive mixer
- P1db point:

$$v_{IF} = g_C \cdot v_{RF} \qquad v_{IF} = c_0 + c_1 v_{RF} + c_2 v_{RF}^2 + c_3 v_{RF}^3 + \cdots$$

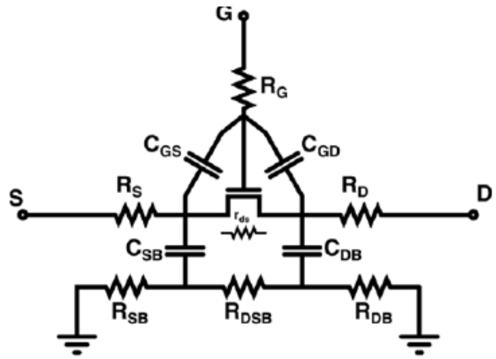
$$|c_1/c_3| = \frac{Z_L\left(Z_{OFF} - \frac{L_g}{\mu_n C_{OX} W\left(V_g - V_{th} - V_{ds}\right)}\right)\left(Z_L + \frac{L_g}{\mu_n C_{OX} W\left(V_g - V_{th} - V_{ds}\right)}\right)^2}{-\frac{L_g}{\mu_n C_{OX} W\left(V_g - V_{th} - V_{ds}\right)} \cdot \left(Z_L \cdot \frac{1}{\left(V_g - V_{th} - V_{ds}\right)}\right)^2 \left(Z_L + Z_{OFF}\right)}$$

$$P_{1-dB} = 10\log_{10}\left(\frac{1000 \cdot \left(\sqrt{0.145\left|c_1/c_3\right|}/\sqrt{2}\right)^2}{4 \cdot Z_S}\right) dBm$$

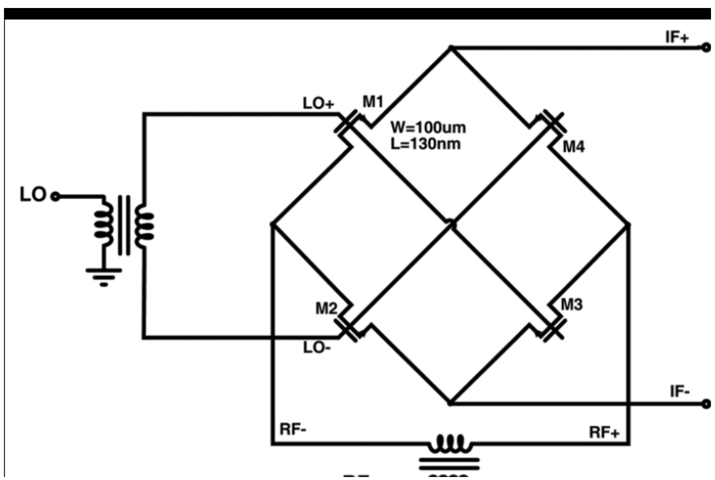
- As cmos tech scales down the NF improves due to ft of the device.

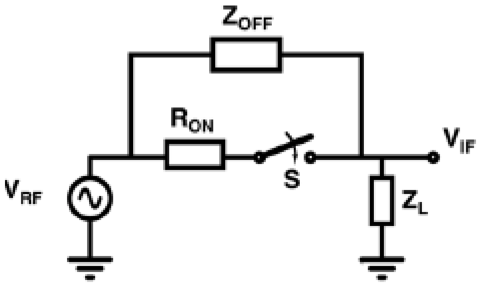
$$F = \frac{1}{g_C^2} + \frac{F_{MIX}}{g_C^2 \cdot kT_0 R_S} = \frac{1}{g_C^2} + \frac{8kT_0 / g_{ds}}{g_C^2 \cdot kT_0 R_S}$$

$$\Rightarrow SSB\ NF = 10\log_{10}\left(\frac{1}{g_C^2} + \frac{2}{g_C^2 \cdot g_{ds} \cdot R_S}\right)$$



LO power	7dBm
CG	-5.2dB
1dB compression point	0.4dB
SSB NF	9.2dB
Impedence	50ohm





RF mixers using standard digital CMOS 0.35ym process

RFIC TECHNOLOGIES

- Active and Passive comparison
- What are multifinger transistor structures?

$$r_{ds} = \frac{L}{\mu_n C_{ox} W [(V_{gs} - V_{th}) - V_{ds}]},$$

- Ron can be minimum by using low L and higher W, but cgd and cgs increase.

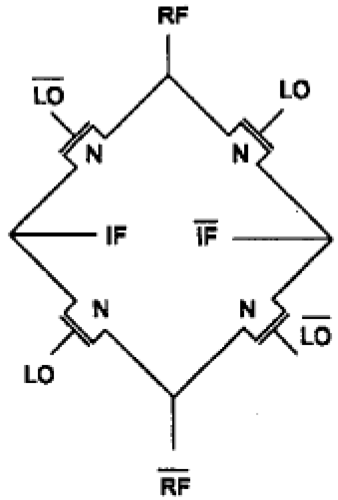


Fig. 6. The passive mixer schematic.

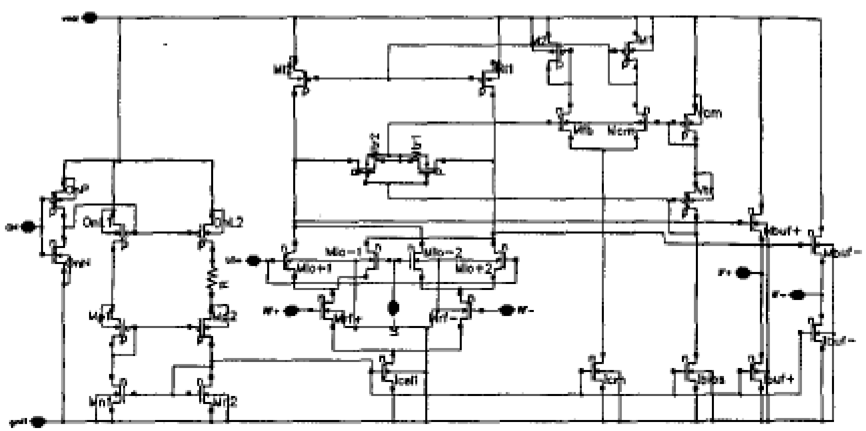


Fig. 2. The active mixer schematic.

TABLE I
SUMMARY OF BOTH MIXER PERFORMANCES

	Passive Mixer	Active Mixer
Supply voltage (V)	-	3
DC Power consumption (mW)	0	29
RF-to-IF conversion gain (dB)	-7.5	10.4
SSB noise figure (dB)	10	7.2
P_{-1dB} (dBm)	+1	-19
Input IP3 (dBm)	+16	-6
LO power level (dBm)	+7	-2
LO frequency (GHz)	1.65	1.65
RF frequency (GHz)	1.8	1.8
LO-to-RF isolation (dB)	32	42
LO-to-IF isolation (dB)	27	28
RF-to-IF isolation (dB)	23	33

RFC TECHNOLOGIES

Valuable suggestions

Thank You