Workshop WME

2009 International Microwave Symposium

History of Sub-Harmonic Pumped Mixers:

From Tubes to CMOS

Edmar Camargo

DBA Consulting

San Jose – California

www.edmarcamargo.com

IEEE

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Outline

- Early Radio Days Vacuum Tubes … 1924
- Early Differential BJT … 1965
- APDP –Anti Parallel Diode Pair … mid 70's
- Market Evolution: Cell Phone, Wireless & mmWave
- System Review
- APDP Single, Balanced and Double Balanced Applications: 1990 – 2008
- APDP – Transistor Equivalent, BJT and FET
- Single Ended Transistor Mixers
- Differential SH Transistor Mixers, BJT and CMOS
- Conclusions

Motivation

"The objective is to introduce the milestones for the concepts and circuit ideas on SHP"

Early Radio Days …

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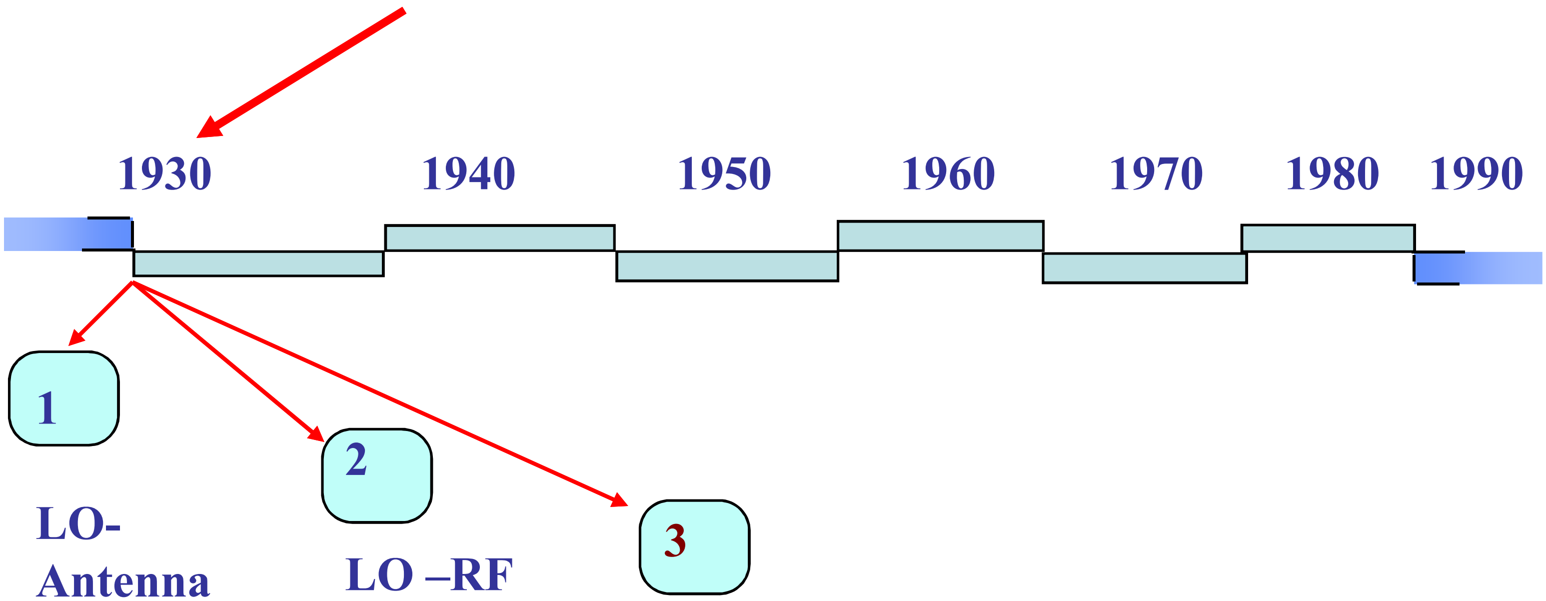
Issues on Heterodyne Receivers



LO-
Antenna
Coupling
$f_{LO} \approx f_{RF}$
Radiation

LO –RF
Circuit
Coupling
$f_{LO} \approx f_{RF}$
Tuning

Parasitic L's and C's
Difficult to handle
At high freq

Early Radio Days …

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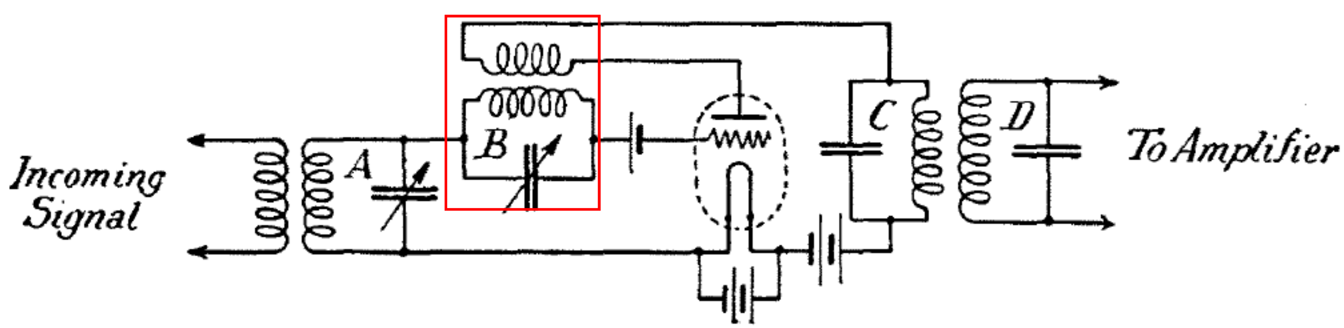
- **Vacuum tube triode receiver**

  RCA_1924 – "Radiola Super-Heterodyne Second Harmonic Receiver" by Harry W. Houck

  Self Oscillating Mixer

  - **Circuit A tuned to incoming signal (RF- Amp)**
  - **Circuit B tuned at fLO = one-half the incoming signal +/- IF**
  - **Circuits C & D tuned to IF (IF – Amp)**



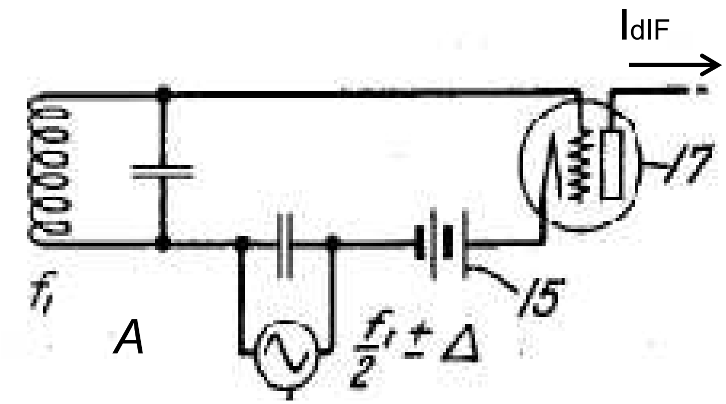
The Super-Heterodyne – Its Origin, Development, And Some Recent Improvements. Proceedings of The Institute of Radio Engineers, New York, March 5, 1924.

Early Radio Days …

- **First Sub-Harmonic Mixer Patent?**

Patent #1813923, applied on Feb 1929 granted July 1931

<u>Single Ended Vacuum Tube Triode</u>



- **Circuit A tuned at incoming RF signal**
- **LO signal at** $f_{LO} = \frac{f_{RF}}{2} \pm IF$ **applied in series with RF signal to the grid**
- **Rectified currents circulate from plate to output load**

$$gm(t) = gm_0 + gm_1\cos(\omega_{LO}t) + gm_2\cos(2\omega_{LO})t + \ldots$$

$$i_{dIF0}(t) = \frac{gm_1 V_{RF}}{2}\cos(\omega_{LO} - \omega_{RF})t$$

$$i_{dIF1}(t) = \frac{gm_2 V_{RF}}{2} V_{RF}\cos(2\omega_{LO} - \omega_{RF}t)$$

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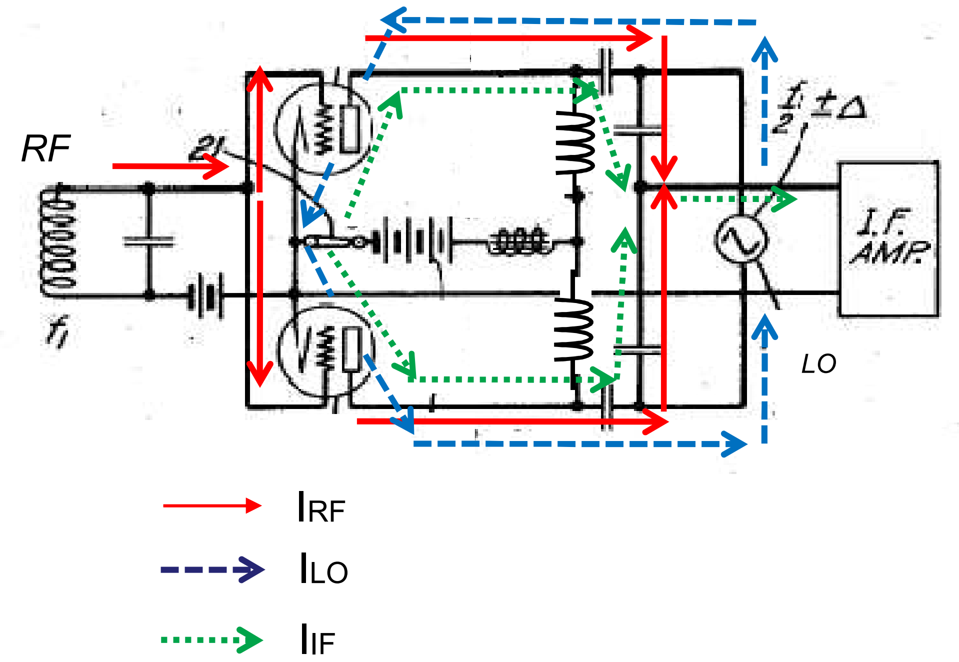
- **Patent #1813923**

  <u>Single Balanced Triode</u>



$$i_p a(t) = [I_{p1}\cos(\omega_{LO}t) + I_{p2}\cos(2\omega_{LO}t) + \ldots]\cos(\omega_{RF}t)$$

$$i_p b(t) = [-I_{p1}\cos(\omega_{LO}t) + I_{p2}\cos(2\omega_{LO}t) + \ldots]\cos(\omega_{RF}t)$$

$$i_p(t) = i_p a(t) + i_p b(t)$$

$$i_p(t) = I_{p2}[\cos(2\omega_{LO}t)\cos(\omega_{RF}t)]$$

- **RF applied in phase to each tube**
- **LO signal applied to the plates in push-pull modulating plate current**
- **Grid is virtual ground for fLO**
- **RF at the same phase at both plates, so no need for IF balun**

Early Radio Days …

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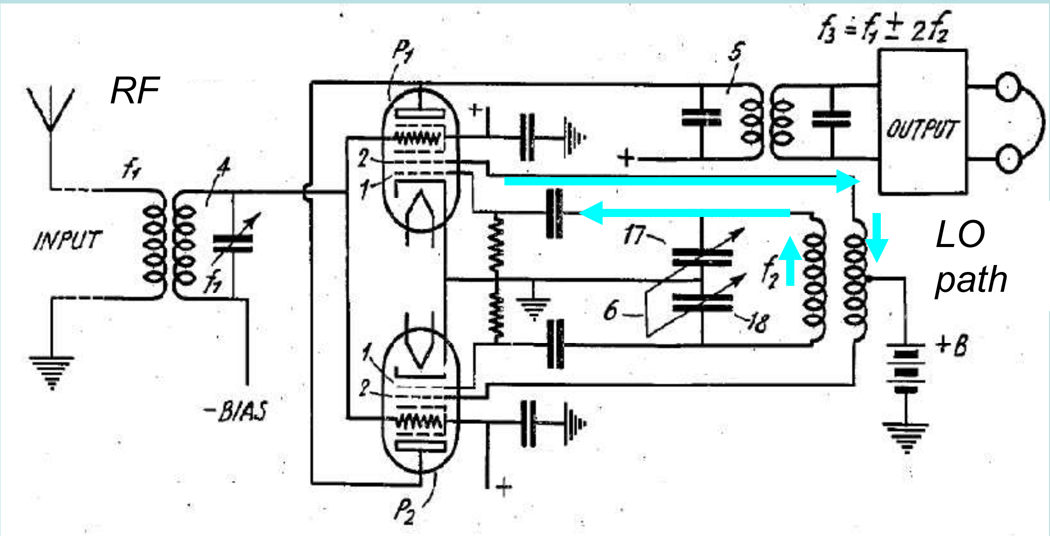
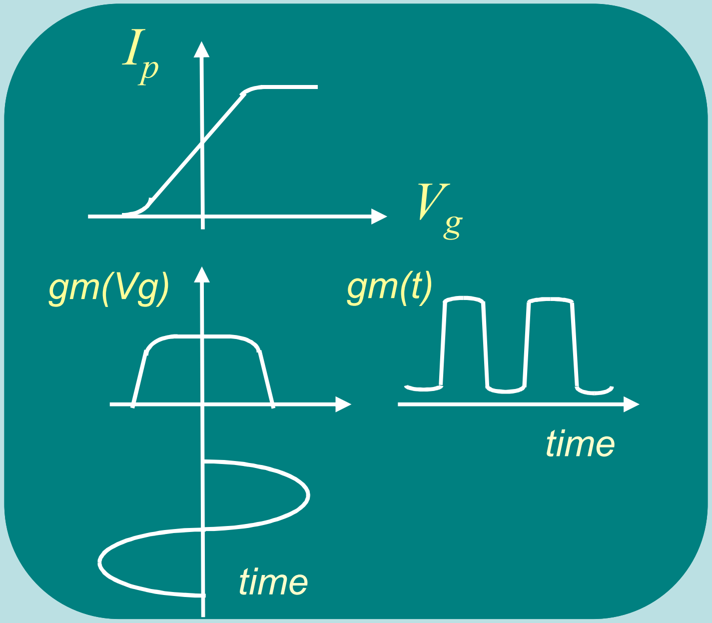
- **Patent #2088432,** applied Fed 1934, granted July 1937

Single Balanced Octode(?) Example:





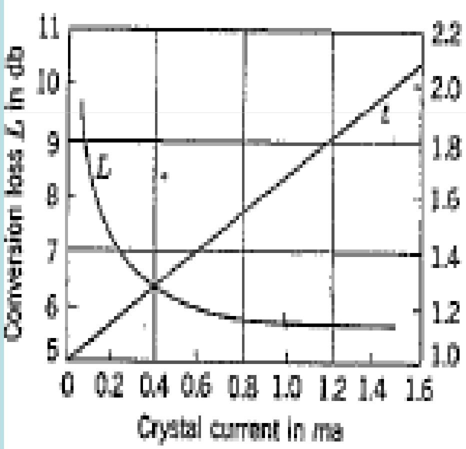
- Grids 1,2 enough gain to sustain oscillations in push-pull
- RF signal applied to grid 3 in parallel to each tube
- IF signals in phase, plates paralleled
- LO modulates tube trans-conductance at twice LO frequency

Early Radio Days …

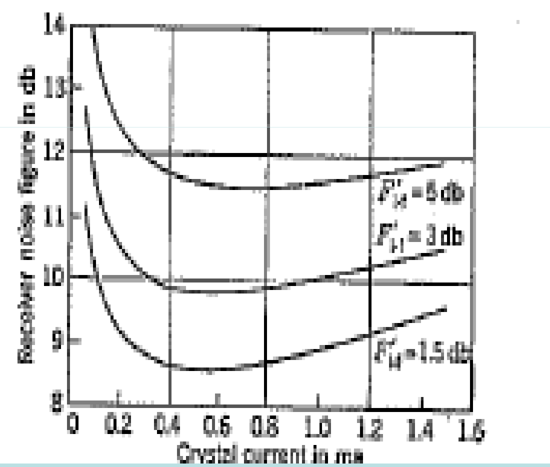
- **SHM: Bad Noise Figure in late 40's …**

Crystal Rectifiers book by Torrey & Whitmar: Loss and NF for tube: 1N23B

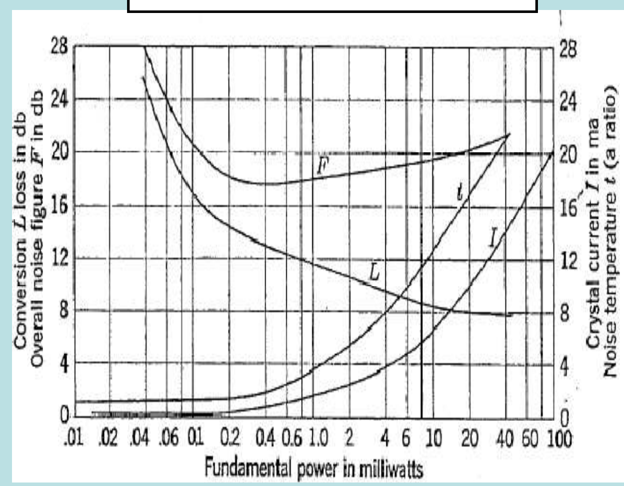
Conversion Loss



Noise Figure



Conversion & Noise Figure



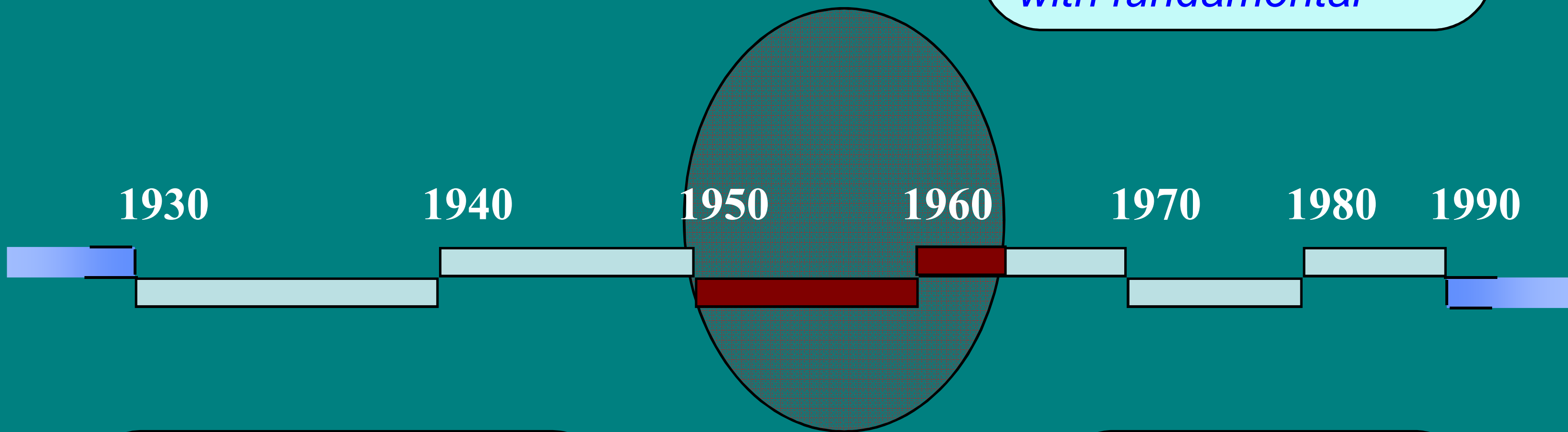
Fundamental mixer at 3.2 cm
NF = 7.3 dB measured with NF_{IF} = 1.5 dB

Sub-harmonic mixer at 3.2 cm
LO at 6.4 cm
NF = 18 dB at CL = 13 dB

11 dB difference in NF!!!

Status from …1950 - 1965

Sub-harmonic mixers compared poorly with fundamental

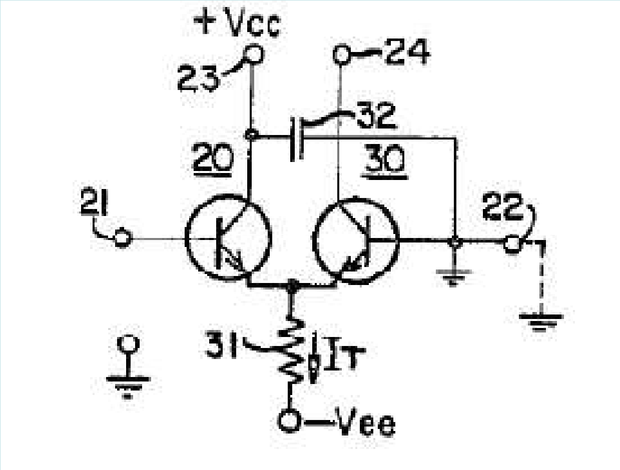


No patents or papers Found during this period

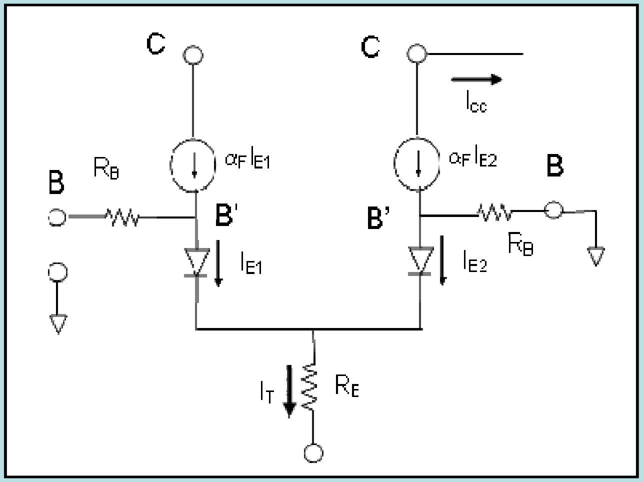
Obsolete Technology?

Early Differential BJT Mixer 1965

- **Patent # 3491301 applied on Oct 1965 granted in Jan 1970**
  - Differential pair connected as single ended.



Differential pair



Non-Linear T model

  - Large signal LO voltage applied to input terminal 21, along with small signal RF voltage. The current at the output terminal 24, contains $2f_{LO}$, f_{RF} and mixing products. Fundamental mixing is suppressed.

Early Differential BJT Mixer 1965

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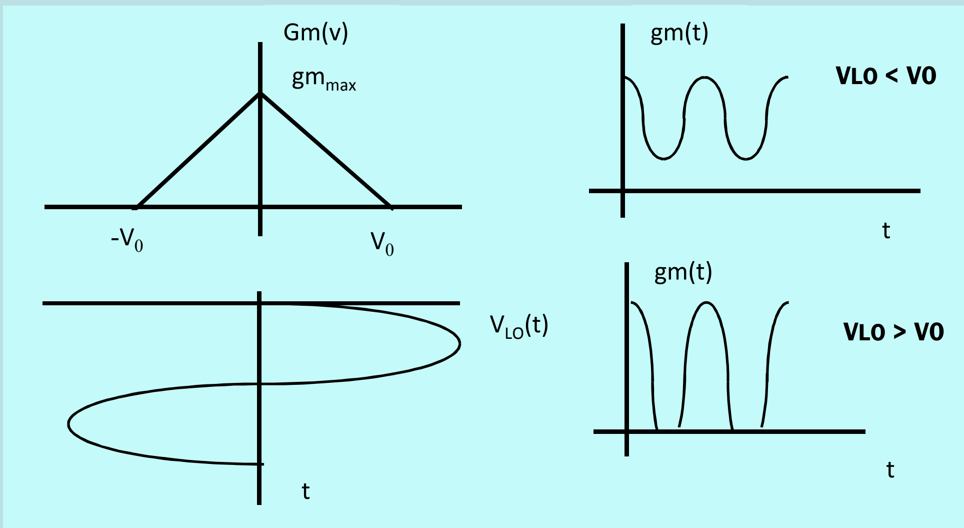

$$gm = \frac{di_{E2}}{dV} = \frac{qI_T}{KT}\frac{e^{\frac{qV}{KT}}}{\left[1+e^{\frac{qV}{KT}}\right]^2}$$

Gm(v), trans-conductance approximated by a triangular shape. The resulting gm(t) has two cycles for each LO cycle

$$i_{CC}(t) = [gm_0 + gm_2\cos(2\omega_{LO}t)]\cos(\omega_{RF}t)$$

$$i_{CC}(t) = \frac{gm_2 V_{RF}}{2}\cos(2\omega_{LO} - \omega_{RF}t)$$

The output current in terms of frequency components is given by the product gm(t) x Vin(t):

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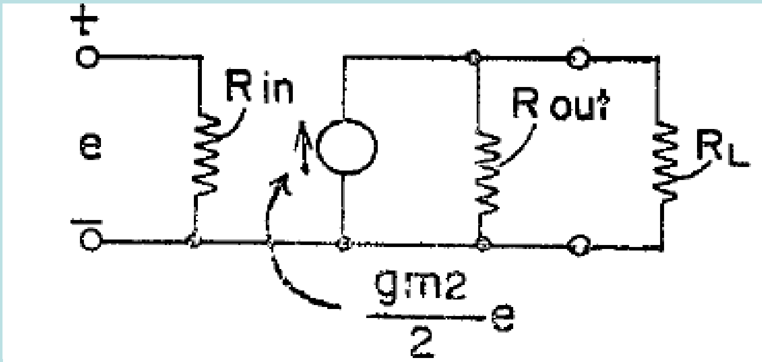
Early Differential BJT Mixer 1965

- Equivalent circuit :



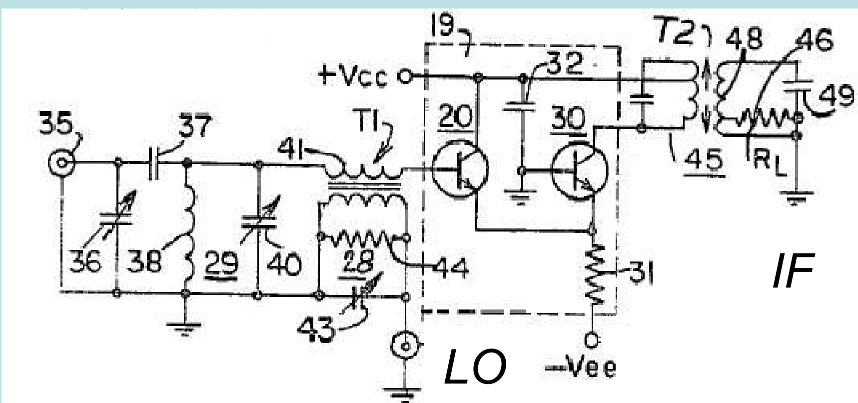
Power gain for matched conditions:

$$PG = \left(\frac{gm_2}{2}\right)^2 R_L R_{in} \left(\frac{R_{out}}{R_{out} + R_L}\right)^2$$

Gain = 33 dB
Fsignal = 120 MHz
F_{LO} = 65.35 MHz

- Final schematic used by the authors :

RF



APDP – Anti-Parallel Diode Pair … mid 70's

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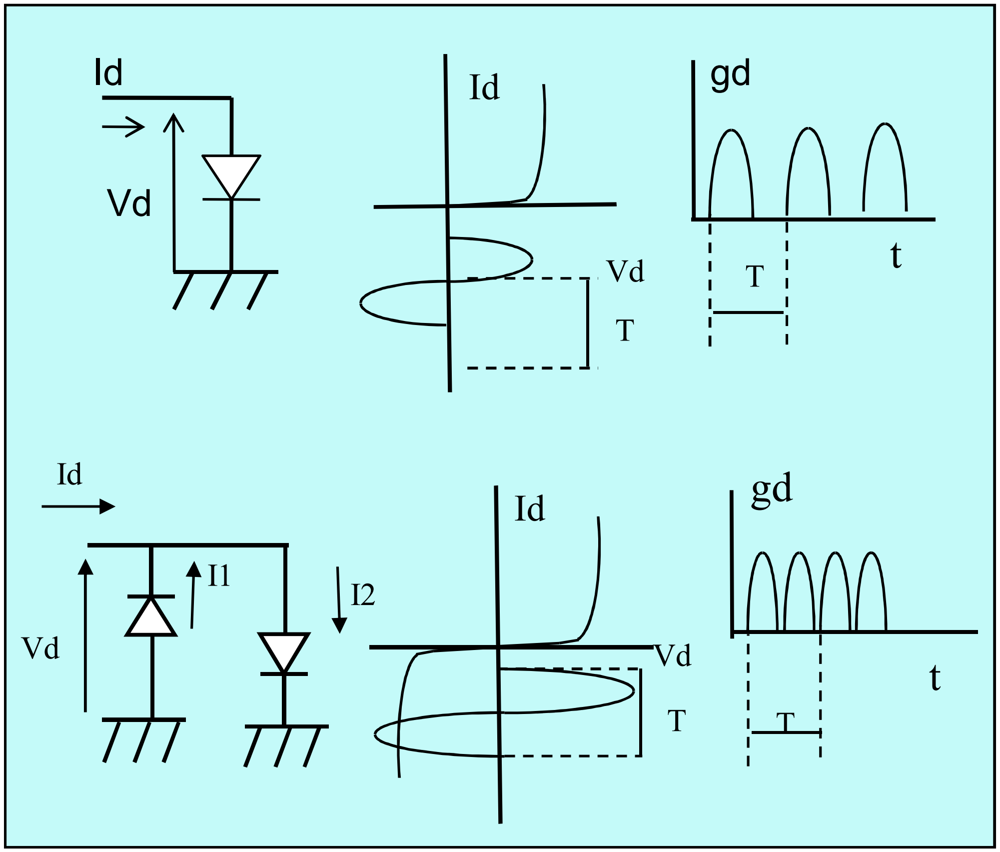
- **APDP - Waveforms**



$$id_1 = [(gd_0 - gd_1\cos(\omega_{LO}t) + gd_2\cos(2\omega_{LO}t)\ldots]V_{RF}\cos(\omega_{RF}t + \pi)$$

$$id_2 = [(gd_0 + gd_1\cos(\omega_{LO}t) + gd_2\cos(2\omega_{LO}t)\ldots]V_{RF}\cos(\omega_{RF}t)$$

$$id(t) = id_2 - id_1$$

$$id(t) = [(gm_0 + gm_2\cos(2\omega_{LO}t) + \ldots]V_{RF}\cos(\omega_{RF}t)$$

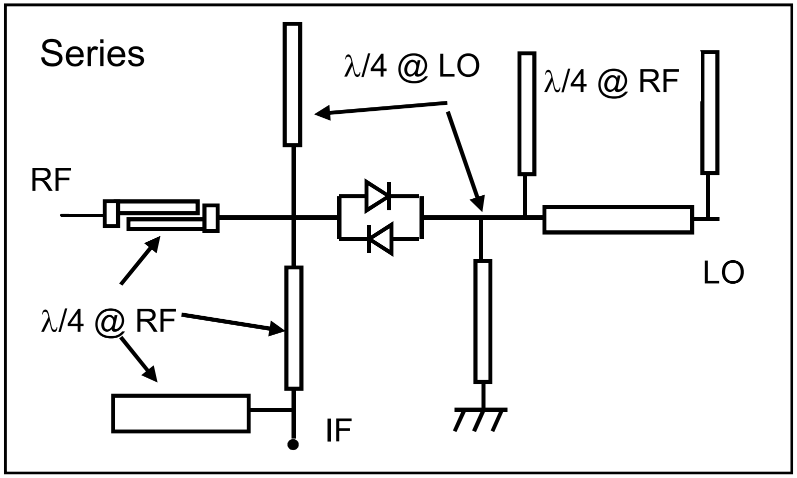
1.Harmonic Mixing with an Antiparallel Diode Pair - M. Cohn, J. E. Degenford and B. A. Newman. IEEE – MTT Transactions – Vol MTT-23, No 8, Aug 1975, pp 667 – 673. 2. Harmonically Pumped Stripline Down-Converter - M. V. Schneider Jr and W. W. Snell - 2. IEEE – MTT Transactions, Vol MTT-23, No 3, Mar 1975, pp 271 - 275

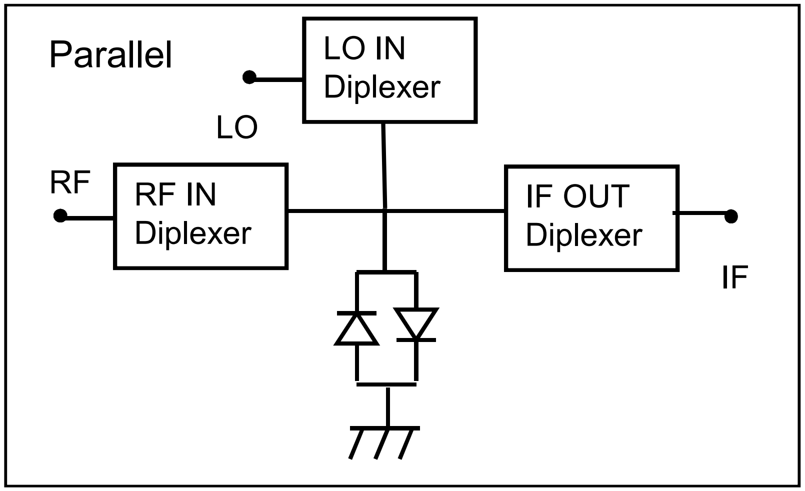
APDP – Properties

- Conversion loss is improved by minimizing fundamental mixing products
- No need for balun
- Suppression of LO noise sidebands (similar to SBM)
- Suppression of LO & RF even harmonics in the external circuit
- Suppression of dc current – no detection

APDP – General Topologies

- Used on majority of APDP sub-harmonic mixers
- Also applicable to X4 and X8 mixers.
- Series configuration: easier to design the diplexer; better RF – LO isolation
- Parallel configuration: easier to provide DC return; more difficult to design diplexers





A Novel General Approach for the Optimum Design of Microwave and Millimeter Wave Sub-harmonic Mixers - A. Madjar – IEEE Trans. Micro. Theo. Techniques, Vol 44, No 11, Nov 1996, pp 1997 - 1999

APDP – Results … 1975

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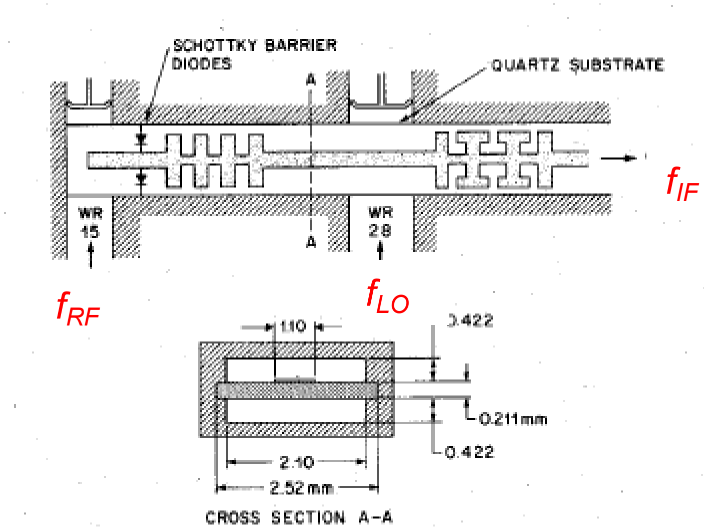
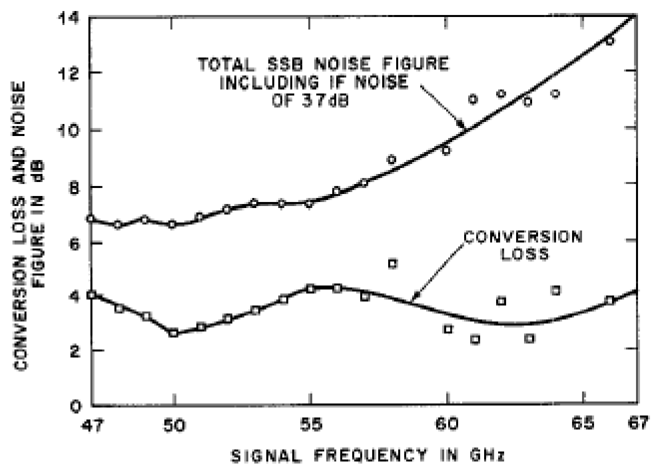
- **Sub-harmonic mixer for operation at 50 GHz**





- **Circuit proposed on suspended transmission line**

- **!!!CL = 4.5 dB at 50 GHz**
- **NF = 7.0 dB including IF amp noise!!!**

Millimeter-Wave Receivers with Sub-harmonic Pump - T. F. McNaster, W. Snell Jr and M. V. Schneider. IEEE – MTT Transactions – December 1976

APDP – Patents … 1975

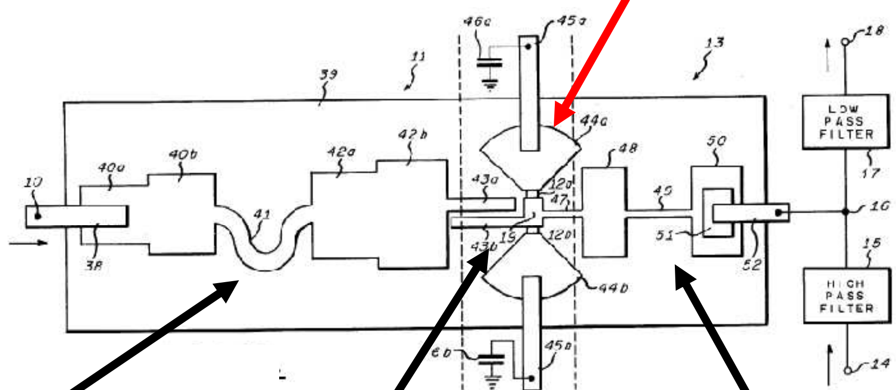
- **Patent # 3890573 – 1975 by H. F. Strenglein**

  Practical realization using chip& wire technology of shunt ADPD topology

Diode virtual grounding

RF Signal

IF out



LO Drive

RF Matching

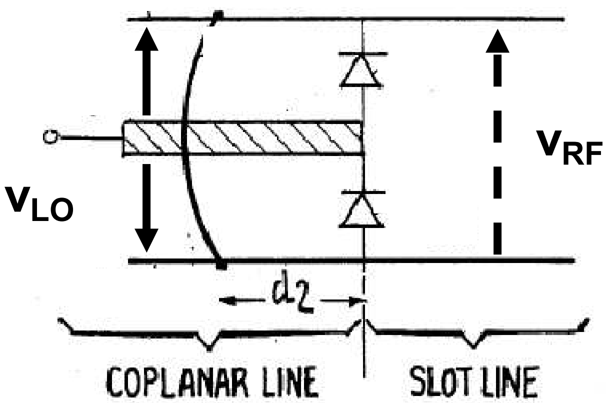
High Pass filter

Low Pass filter

Adequate for single or "T" beam lead Schottky diodes

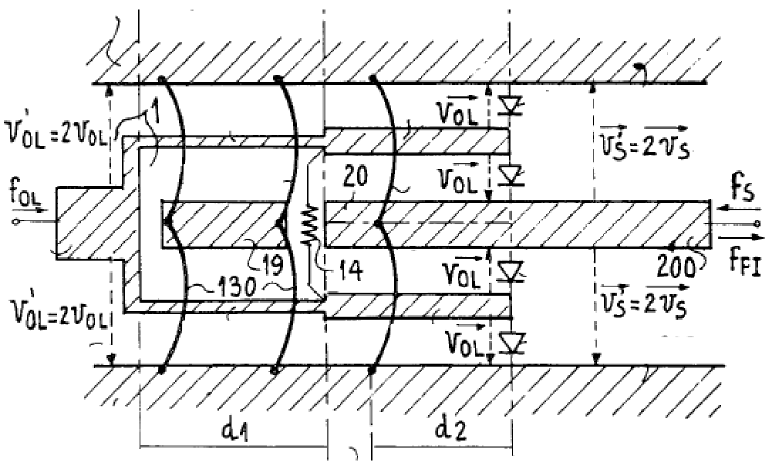
APDP – Patents … 1984

- **Patent # 4485488 – 1984 by M. Houdart**



LO signal propagates asymmetrically in the coplanar line and is suppressed at the slotline section. RF signal propagates symmetrically in the slotline and is suppressed in the coplanar structure.

Wire bond shorts the slotline propagation and is located at $\lambda_{RF}/4$ from the diodes location creating high impedance at diode locations

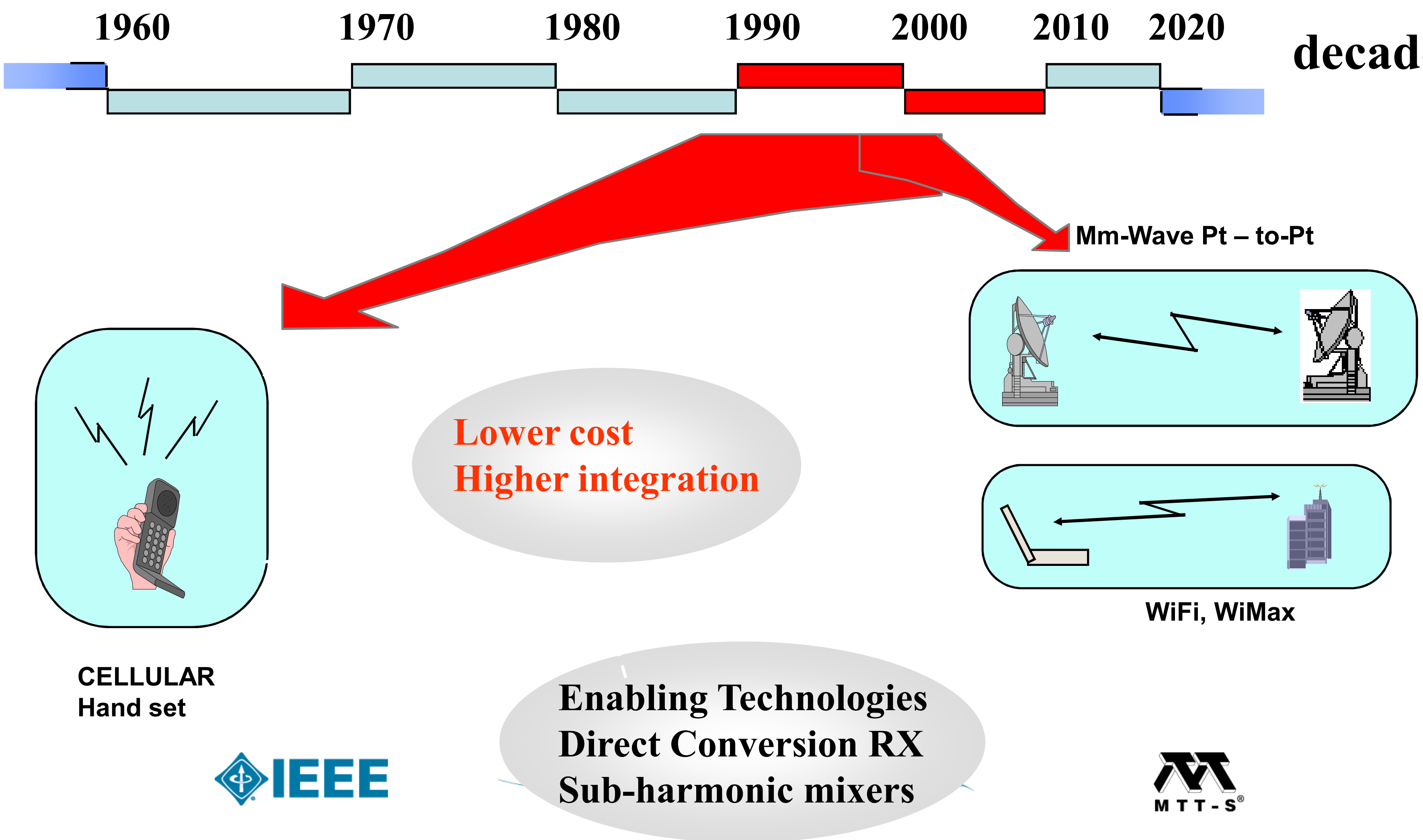


$$I = I_s[e^{\alpha(V_{RF}+V_{LO})} - 1]$$

Adding currents from each diode using Bessel's functions, the largest signal is:

$$I = Ik\cos[2\pi(2f_{LO} \mp f_{RF})t]$$

Cell Phone, Wireless & mmWave



System Review: Super Heterodyne – fundamental

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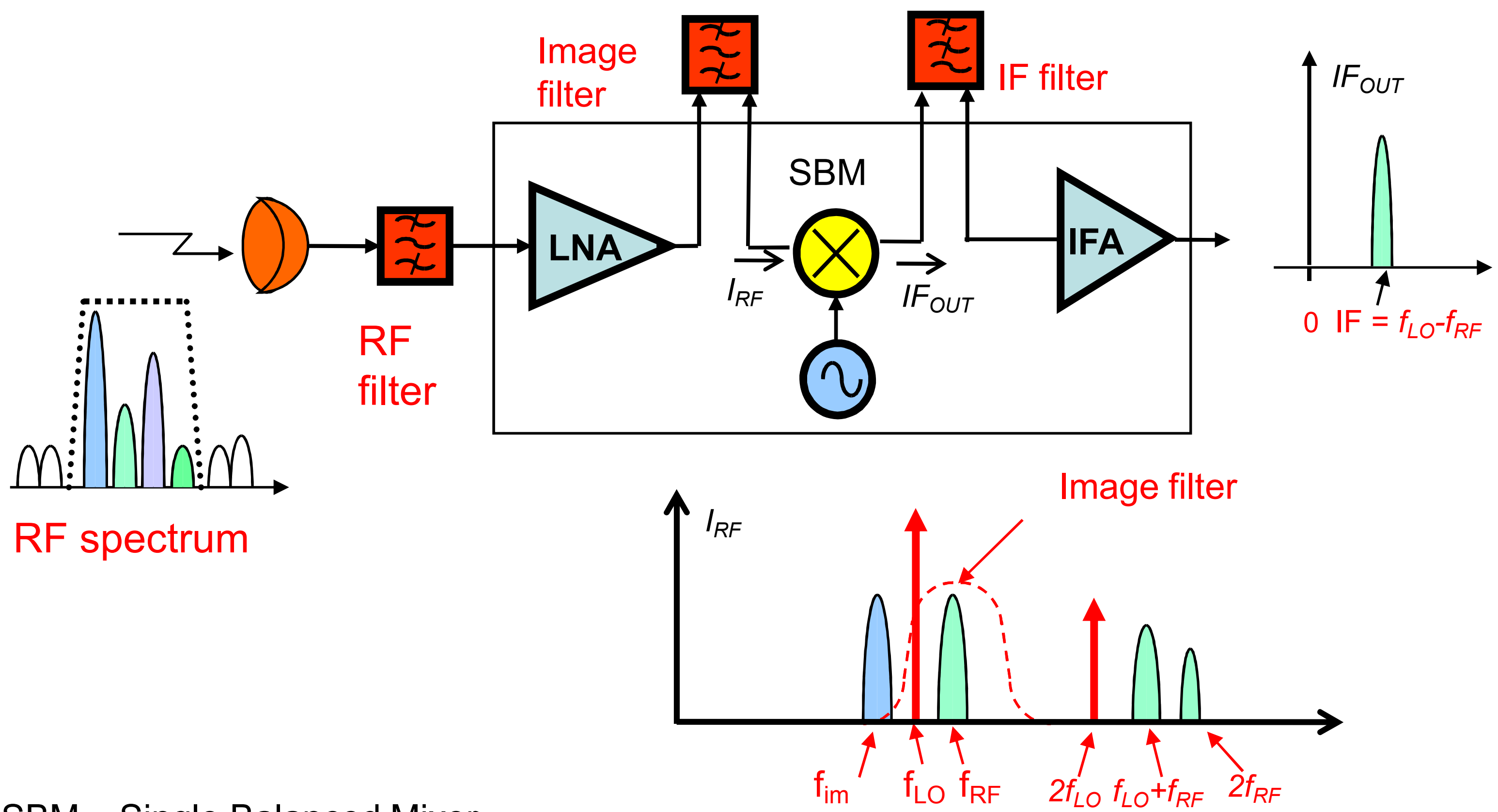
Down-Converter

Advantages:
LO harmonics fall outside IF band
High Selectivity

Disadvantages:
LO Leakage to LNA and IFA
High-Q filters → difficult on IC



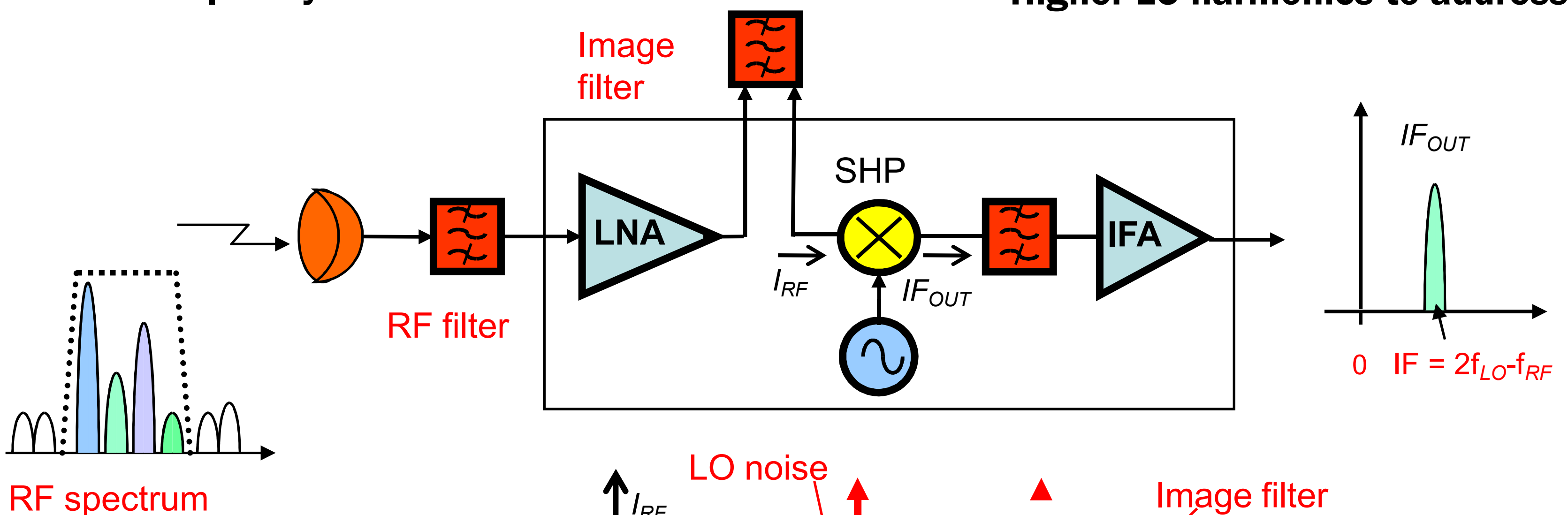
SBM – Single Balanced Mixer

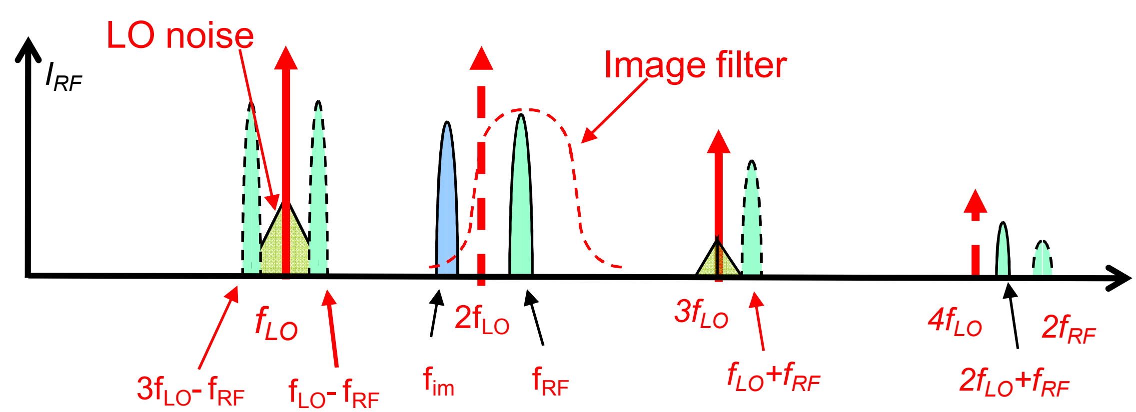
System Review: Super Heterodyne – sub-harmonic

Down-Converter

Advantages:
Low LO Leakage → Low-Q filters
Immune to LO Noise → like SBM
LO at half frequency → Lower cost LO

Disadvantages:
Higher Sensitivity to LO drive
Lower Power compression
Higher LO harmonics to address





I_{RF} signals at APDP ports
Solid lines: real signals

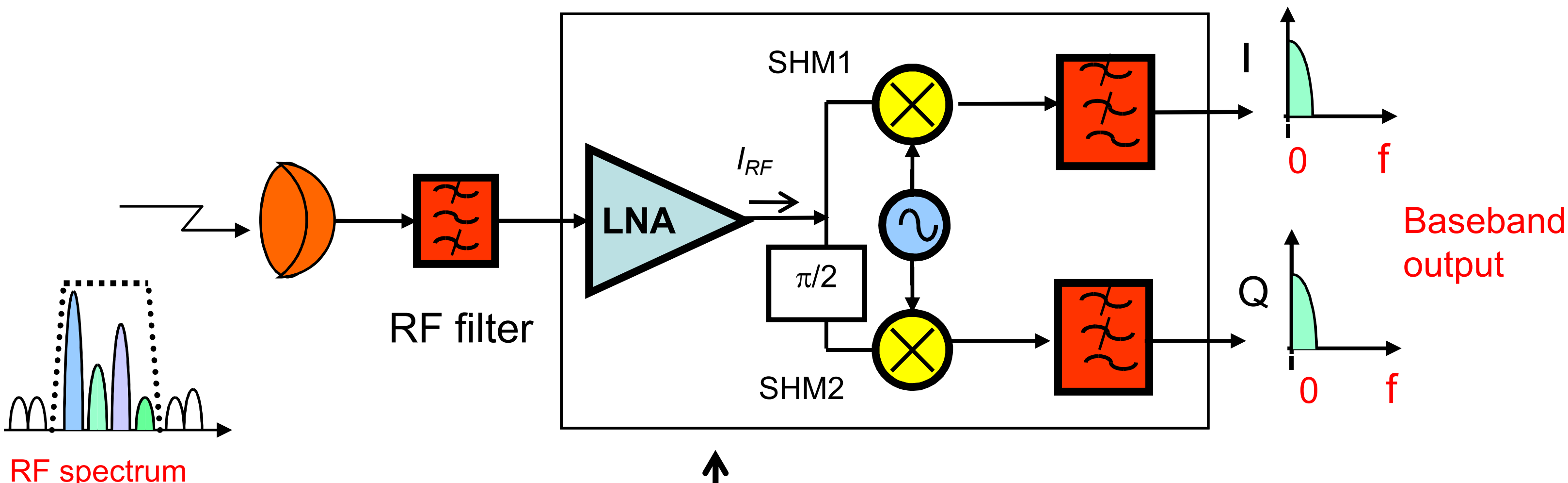
SHP – Sub Harmonic Mixer

System Review: Direct Conversion – sub-harmonic

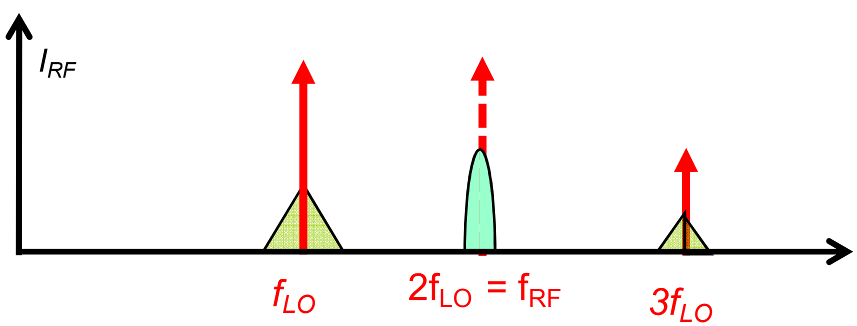
Down-Converter

Advantages:
No IF → Signals converted directly to baseband
Lower cost: No image filter; LO at half frequency
Lower DC detected
Improved IP2

Disadvantages:
Higher LO harmonics to address
Lower Dynamic Range
Higher sensitivity to LO drive for APDP



I_{RF} signals at APDP ports
Solid lines: real signals
Dashed lines: virtual signals



APDP – Patents … 1990

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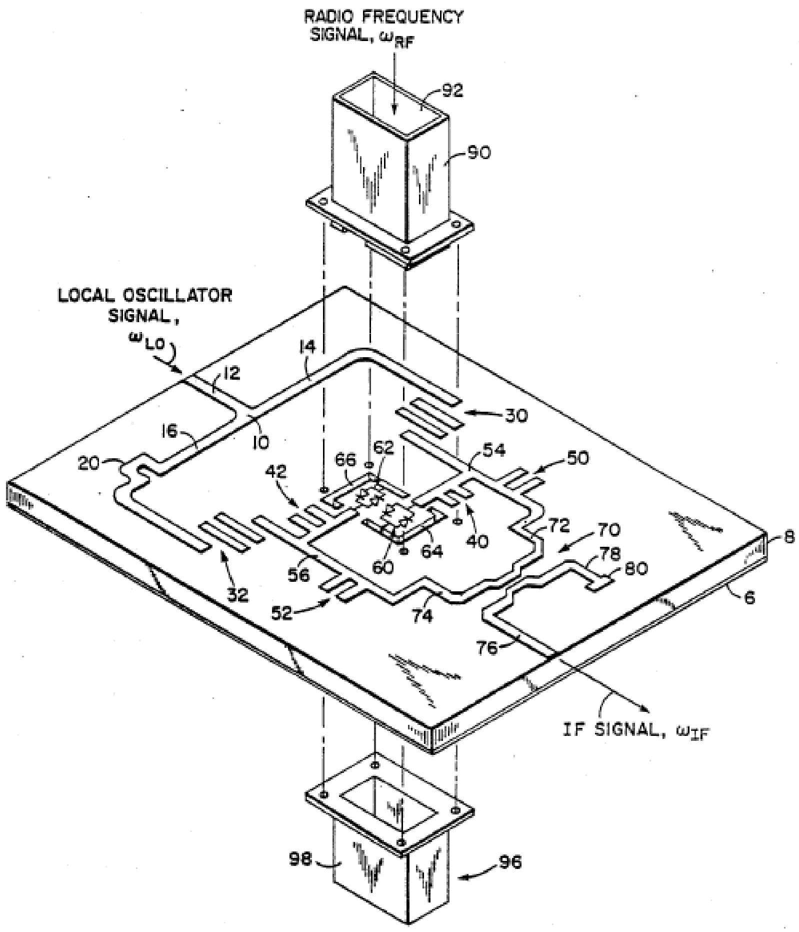
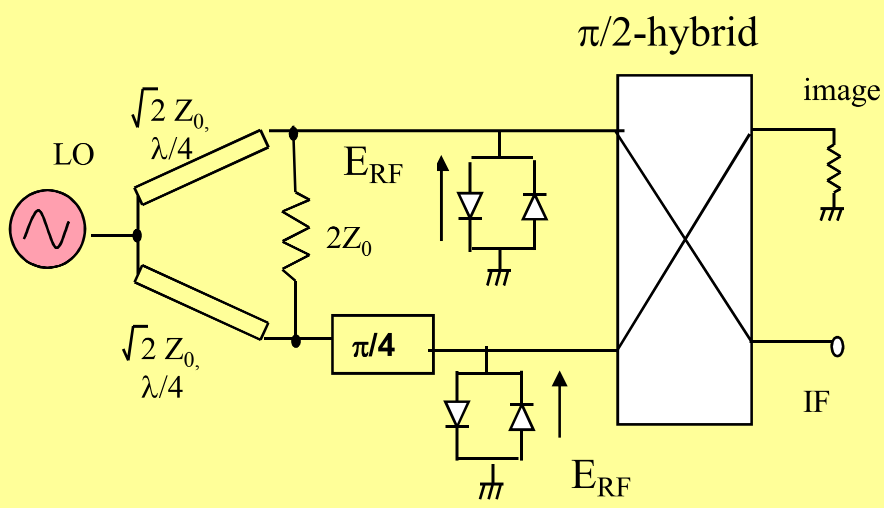
- **Patent # 4955079 – 1990 by W. R. Connerney et al**

•Even-Harmonic Quadrature Mixer





- **LO applied in 45° phase**
- **RF applied in phase from waveguide**
- **IF in quadrature to separate image and signal**

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APDP – Single Balanced/SHP … 1993

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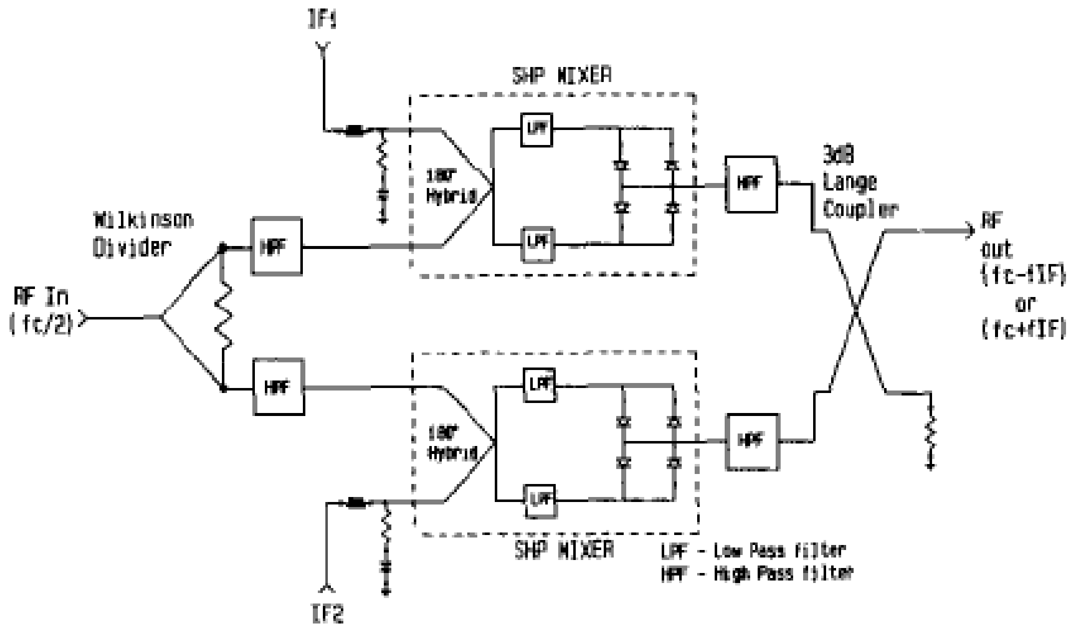
•Even-Harmonic Quadrature Mixer/SSB Modulator



- A MMIC Sub-Harmonically Pumped SSB Modulator – 1993
- f_{RF} = 13 – 23 GHz @ PLO = 15 dBm; CL = 8.0 – 10.0 dB
- Image/sideband suppression = 25 to 30 dBc
- Carrier suppression = 30 to 55 dBc
- GaAs MSAG

A MMIC Sub-harmonically Pumped SSB Modulator - A. Pospishil, M. Russo and M. Singh. 1993 – MTT-Symposium Digest

APDP – Single Ended/SHP … 1997

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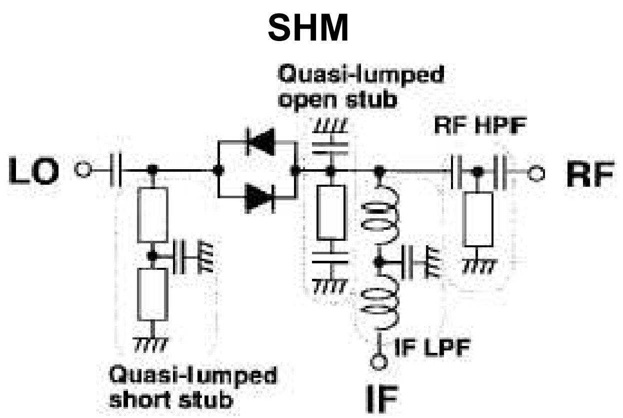
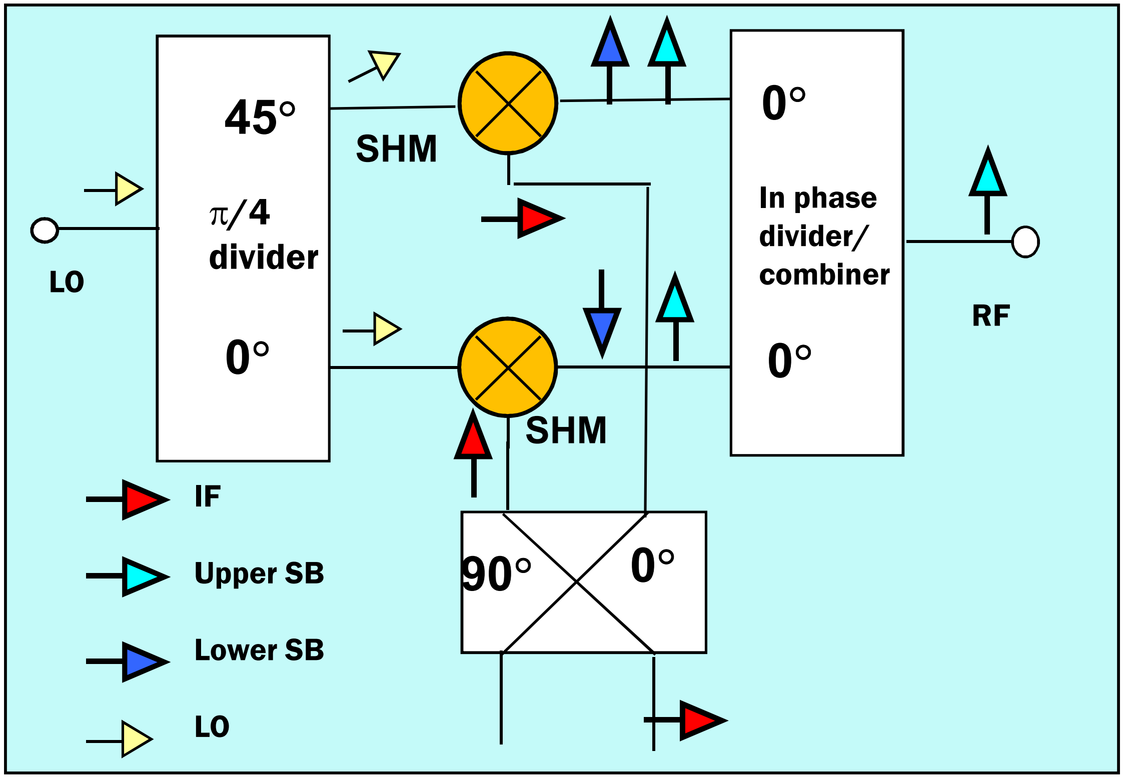
•Even-Harmonic Quadrature Mixer/IRM



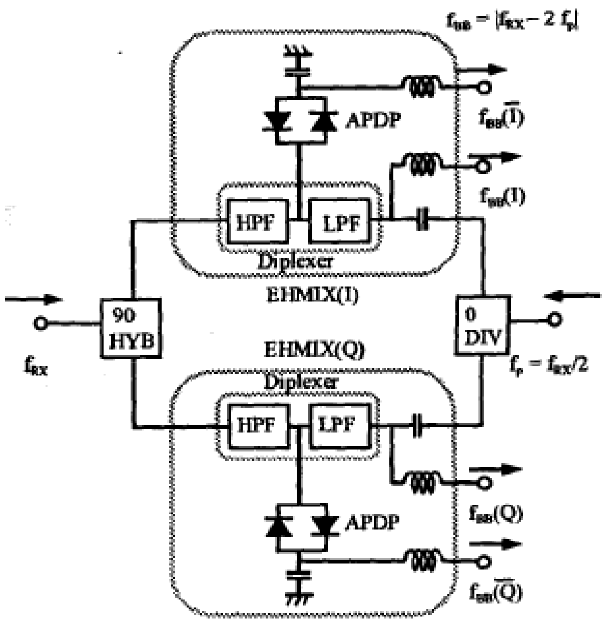


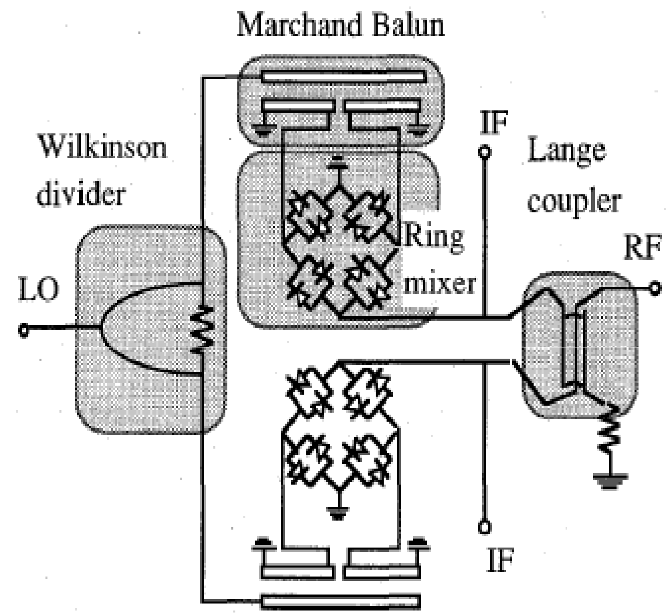
RF freq - GHz	21.6 to 30.8
LO freq - GHz	10 to 14.6
CG - dB	-12
image rejection - dB	17
PLO - dBm	11
P 1dB - dBm	3

Wide-Band SSB Sub-harmonically Pumped Mixer MMIC – H. Okazaki and Y. Yamaguchi. IEEE Trans. Micro. Theory and Techniques, VOl 45, No 11, Dec 1977, pp 2375 - 2379

APDP – Single Ended & Double Balanced/SHP

•Even-Harmonic Quadrature Mixer/IRM





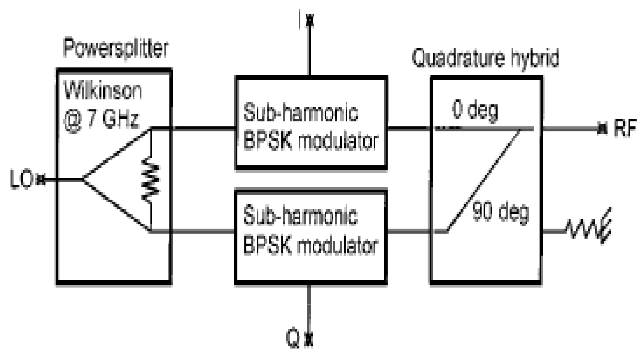
1. Even-Harmonic Quadrature Mixer - 2000
.f_{RF} = 2110 – 2170 MHz
•Differential baseband signals (I, I, Q, Q)
•Baseband Load = 220 Ohms (Opt NF, Gain and tradeoff IP2, IP3)

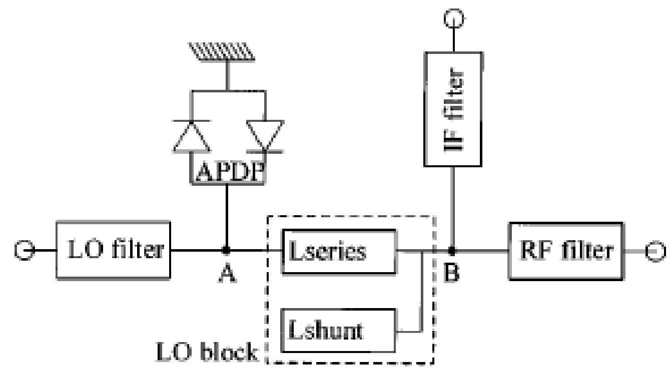
2. mmWave MMIC Even-Harmonic Quadrature Mixer 1998
•f_{RF} = 24 – 44 GHz
•Marchand Balun & Lange coupler → Broadband
•CL = 14.5 dB with PLO = 16 dBm

1. 2 GHz Band Even Harmonic Type Direct Conversion Receiver with ABB-IC for WCDMA Mobile Terminal – K. Itoh, T. Katsura, H. Nagano, T. Yamaguchi, Y. Hamade, M. Shimozawa, H. Suematsu, R. Hayashi, W. Palmer and M. Goldfarb – 2000 IEEE MTT-S Digest, pp 1957 – 1960;
2. A mm-Wave broadband monolithic even harmonic image reject mixer - K. Kawakami, M. Shimozawa, H. Ikematsu, K. Itoh, Y. Isota and O. Ishida. – 1998 IEEE MTT-S Digest, - pp 1443 - 1446

APDP – BPSK … 2001

•Direct Ku-Band Sub-Harmonic BPSK IQ Modulators





•f_{RF} = 14 – 14.5 GHz (VSAT Band)
•CL = 11 dB @ P_{LO} = 16 dBm
•Pout 1dB = - 10 dBm
•Suppression (2LO – RF) = 40 dB in band
•Vector amplitude phase error = 0.2 dB and 2º

•IF Filter = fourth order low pass Z(RF) = open
•RF Filter = fourth order low pass filter cascaded with third order high pass
•LO filter = Lshunt is $\lambda/4$ at 7.1 GHz short for LO and odd harmonics; Lseries = tuning for optimal third harmonic phase at A.

A Direct Ku-band Linear Sub-harmonically Pumped BPSK and I/Q Modulator in Multilayer Thin-Film MCM-D - G. J. Carchon,D. M. M. P. Schreurs, W. De Raedt. – IEEE MTT-Trans Vol 49, No 8 Aug 2001, - pp 1374 - 1382

APDP – Milestones ... 1991 - 2005

TABLE _I - X2 SHM

	APDP - X2 Mixers					
Diode Technology	Mitsubishi GaAs MMIC (1) 1991	Alpha DMK2308 - GaAs (2) 2003	OMMIC- GaAs PHEMT 0.18 um (3) 2004	MAE2039 - GaAs Beam Lead (4) 2005	WIN GaAs PHEMT 0.15 um (5) 2005	Agilent HSCH-5510 GaAs Beam Lead (6)
RF Frequency Range (GHz)	36 - 40	9 - 12.6	43.5 - 45.5	22.1 - 23.5	38 - 48	33 - 34
LO Fequency (GHz)	18.5	5.5	43.6 - 45.4	10	19	16.5
Conversion Loss (dB)	9.5 to 10.5	3.8	8	8.7	12 - 14	8
PLO - (dBm)	6	4.5	9.1	13	10	6
P1 dB (dBm)	-15.7	7.5 (LO=6.5)	-2.1	-	-	3
RF to 2LO isolation (dB)	-75	-45	-17	-84.8	-55	-
Configuration	Series	Series	Shunt	Series	Series	Series
Application	up	down	down	down	up	down

- **Table compares single APDP device in classical topology**
- **Conversion loss is in general 3dB lower than fundamental mixers**
- **Power performance is about 8 dB lower compared with fundamental mixers**

APDP – Milestones … 2001 - 2008

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TABLE _II – 4X SHM

	APDP - Series configuration X4 Mixer			
Diode Technology	MACOM - MSAG - 5 (1) 2001	GaAs MESFET 0.5 um (3) 2002	GaAs DMK2308 (2) 2003	DMK2308 - GaAs (4) 2008
RF Frequency Range (GHz)	58.5 - 60.5	94	34 - 36	28.4 - 30.4
LO Fequency (GHz)	14 - 15.5	23.5	8.5	7.1
Conversion Loss (dB)	9.5 - 10.5	11.4	11 - 15	9
PLO - (dBm)	3	10	11	12
P1 dB (dBm)	-	-4	-	-
Application	down	down	down	down

- **Similar topology can provide a respectable Times Four mixer**
- **Conversion losses are about 2 to 3B higher than sub-harmonic**
- **Power performance is similar to X2 SHM**

APDP – Milestones … 2006 - 2008

TABLE _III – X2 Sub mmWave

	APDP - Submillimeter X2 Mixers			
Diode Technology	Schottky DBES105a (1) 2006	JPL GaAs Schottky (2) 2007	JPL GaAs Schottky (3) 2008	GaAs SC1T9 - D20 from VDI (4) 2008
RF Frequency Range (GHz)	183	530 - 590	800 - 856	640
LO Fequency (GHz)	92	255 - 300	400 - 428	321
Conversion Loss (dB)	6.85	12 - 14	10.2 - 12	9
PLO - (mW)	5	6	3	3.5
Noise Figure - DSB - (dB)	6.5	11	10	9.8

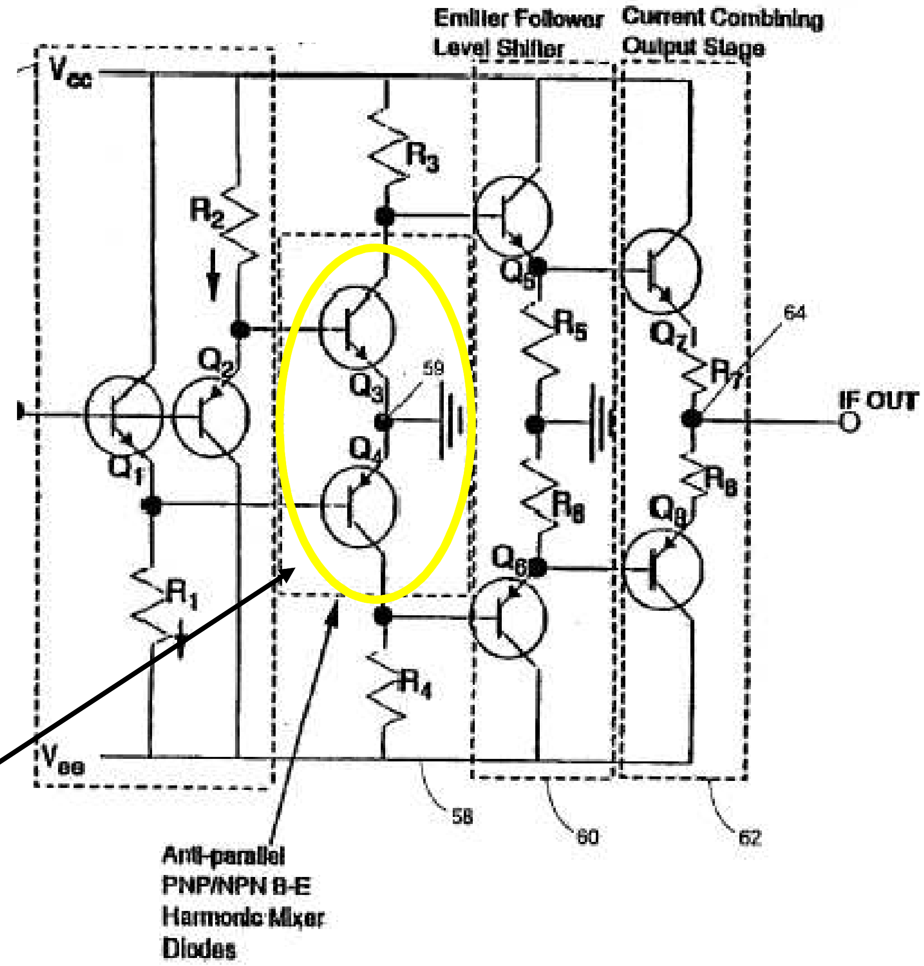
- **Sub-millimeter mixers with Schottky diodes**
- **Conversion losses in the order of 10 to 14 dB. Noise figure below 11 dB**
- **Frequency of operation, 180, 500, 880 GHz!!**

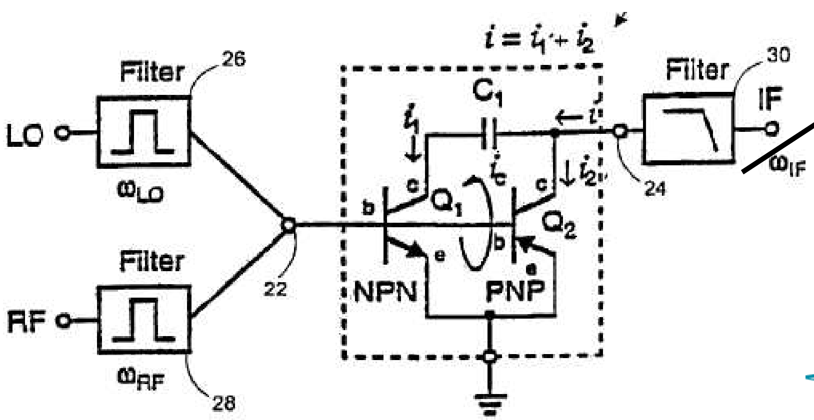
APDP – BJT Equivalent … 2005

Patent #6901249 granted in May 2005

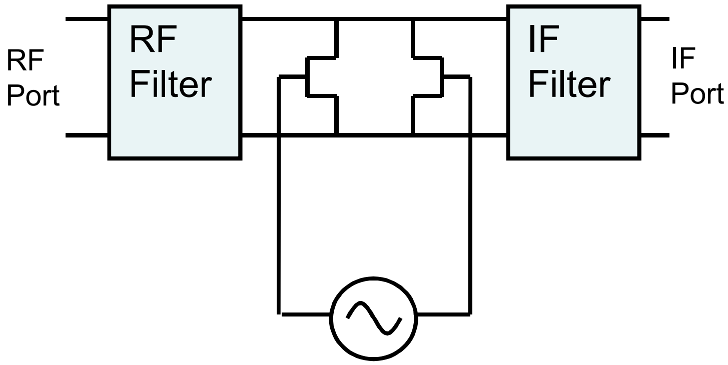
by Kobayashi. HBT equivalent to APDP

- P_{LO} = +5 dBm
- P_{RF} = -10 dBm
- f_{IF} = 7 MHz
- CG → down = 0 dB (2 to 3 GHz)
  - → up = - 10 dB (2 to 3 GHz)



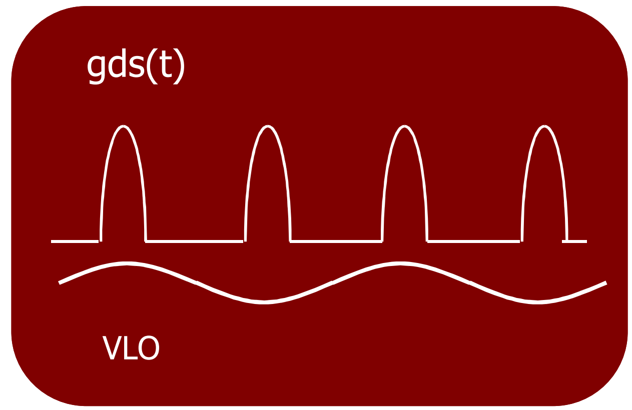


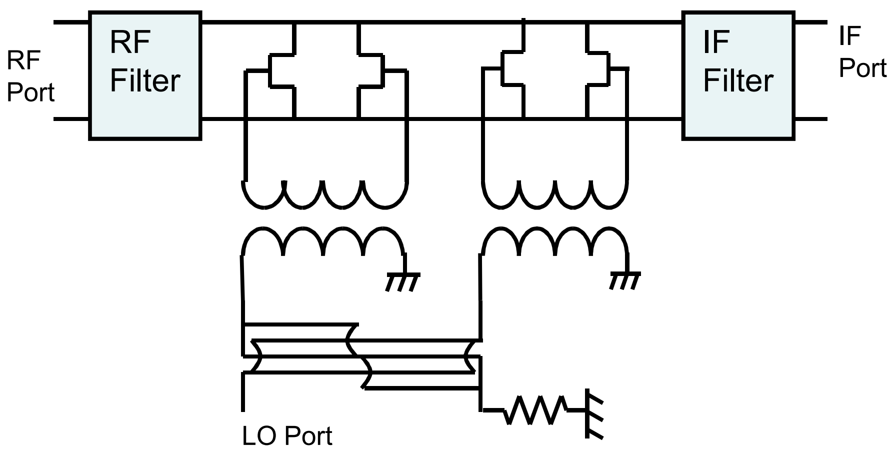
APDP – FET Equivalent ...



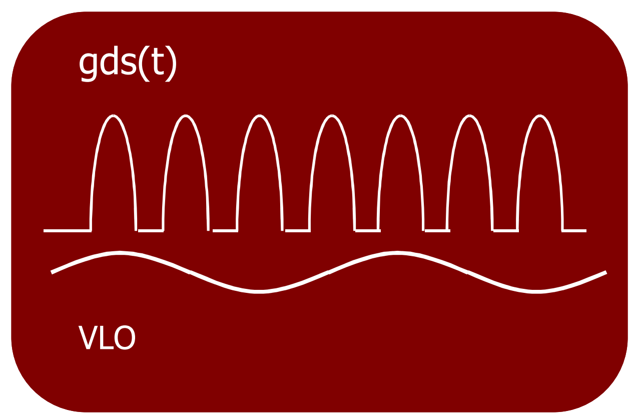
FET APDP Equivalent

X2 Mixer - 1991





X4 Mixer - 2008



A Sub-harmonically Pumped Resistive Dual-HEMT-Mixer – H. Zirath, IEEE MTTS, 1991. 2. Analysis and Design of a Novel X4 Sub-Harmonically Pumped Resistive HETM Mixer – S. Gunnarsson - IEEE Trans. Micro. Theo. Techniques, Vol 56, N4, Apr 2008

APDP – FET Equivalent …

FET APDP Equivalent

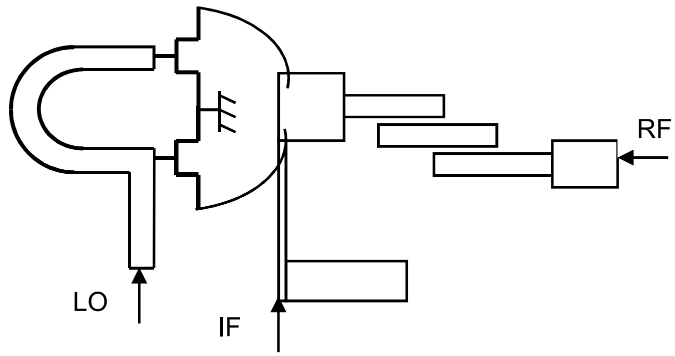
X2 Mixer - 1991

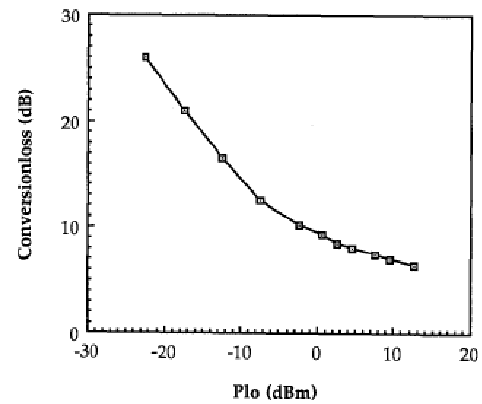
Lc = 6.5 dB

PLO = + 12.0 dBm

RF freq = 10 – 12 GHz

LO freq = 5 GHz





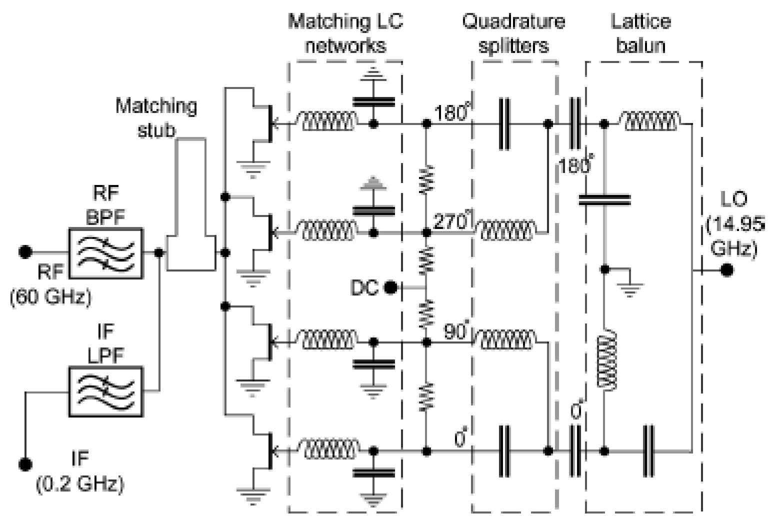
X4 Mixer - 2008

Lc = 15 dB

PLO = + 14.0 dBm

RF freq = 57 – 62 GHz

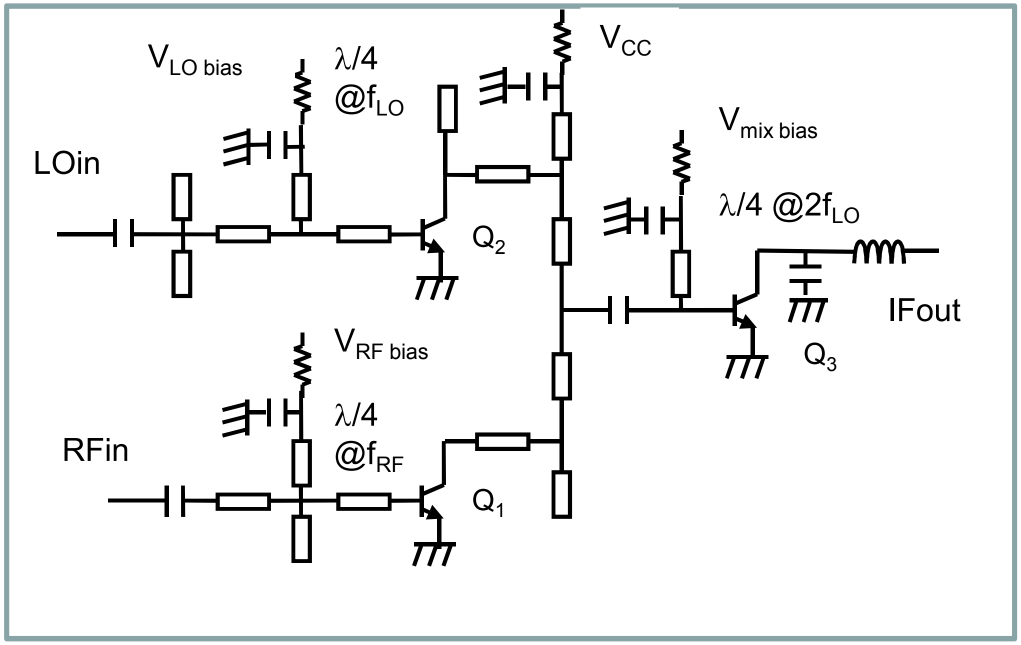
LO freq = 15 GHz



A Sub-harmonically Pumped Resistive Dual-HEMT-Mixer – H. Zirath, IEEE MTTS, 1991. 2. Analysis and Design of a Novel X4 Sub-Harmonically Pumped Resistive HETM Mixer – S. Gunnarsson - IEEE Trans. Micro. Theo. Techniques, Vol 56, N4, Apr 2008

Single Ended BJT Mixer … 2008

•LO Doubling + fundamental Mixing



Transistor Technology	InP - DHBT
RF Frequency Range (GHz)	35 - 50
LO Fequency (GHz)	16.25 - 23.75
Conversion Gain (dB)	8.0 - 10.0
PLO - (dBm)	0
Noise Figure - DSB - (dB)	11
P 1 dB	2.0 - 4.0

- **LO doubling section**
- **RF Section.**
- **BJT is an active mixer - 2008**

A High Conversion-Gain Q-Band InP DHBT Sub-Harmonic Mixer Using LO Frequency Doubler – T. K. Johansen, J. Vidkjaer, A. Konczykowska, M. Riet, F. Jorge and T. Djurhuus – IEEE Trans. Micro. Theo. Techniques, Vol 56, No3 March 2008.

Single Ended FET Mixer … 2006

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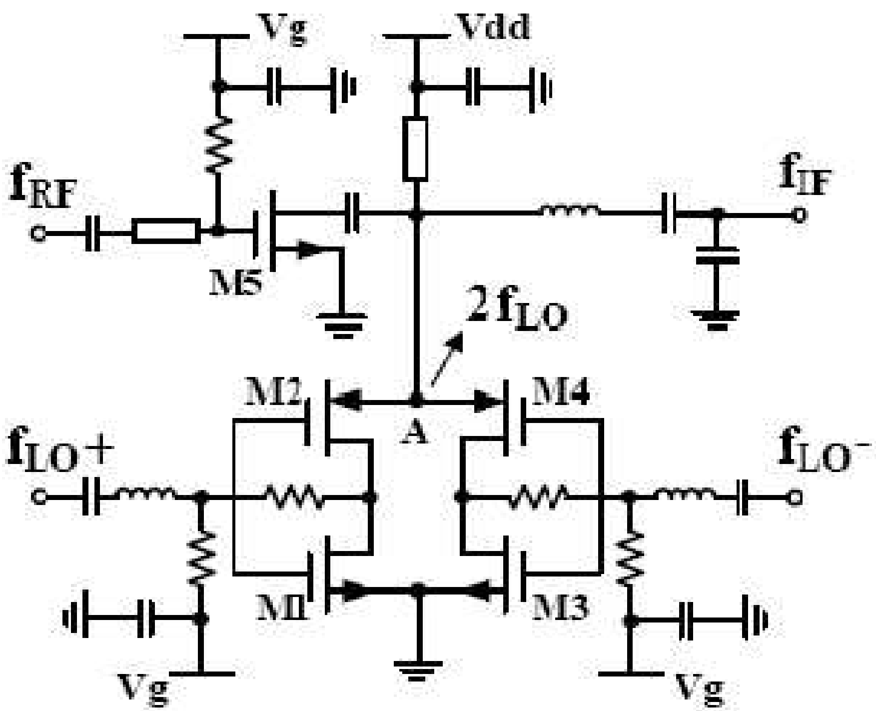
•LO Doubling + fundamental Mixing

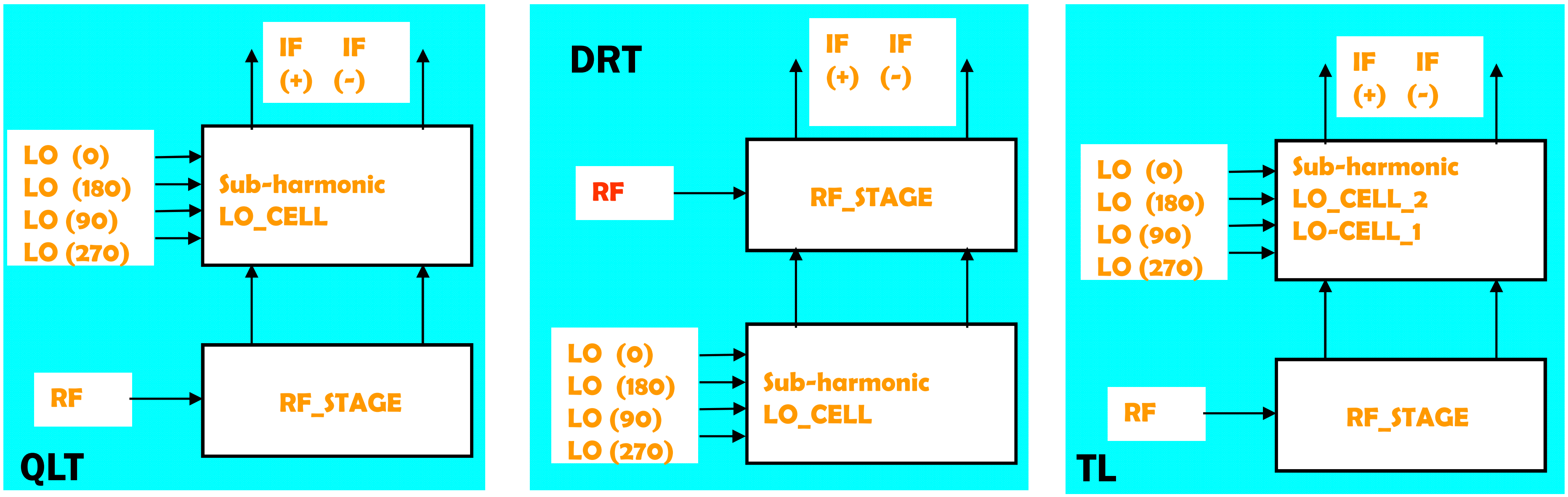


Transistor Technology	0.18 um CMOS
RF Frequency Range (GHz)	22 - 32
LO Fequency (GHz)	10.0 - 16.0
Conversion Loss (dB)	11.0 - 14.0
PLO - (dBm)	13
Noise Figure - DSB - (dB)	11.0 - 14.0
P 1 dB	-2.8

- **LO doubling section**
- **RF Section.**
- **FET is a Resistive mixer - 2006**

A 28 GHz Sub-Harmonic Mixer Using LO Doubler in 0.18 um CMOS Technology - Tsung-Yu Yang and Hwann-Kaeo Chiou. Microwave and Optical Technology Letters/ Vol 48 No 12 December 2006.

Differential SHP Transistor Mixers …



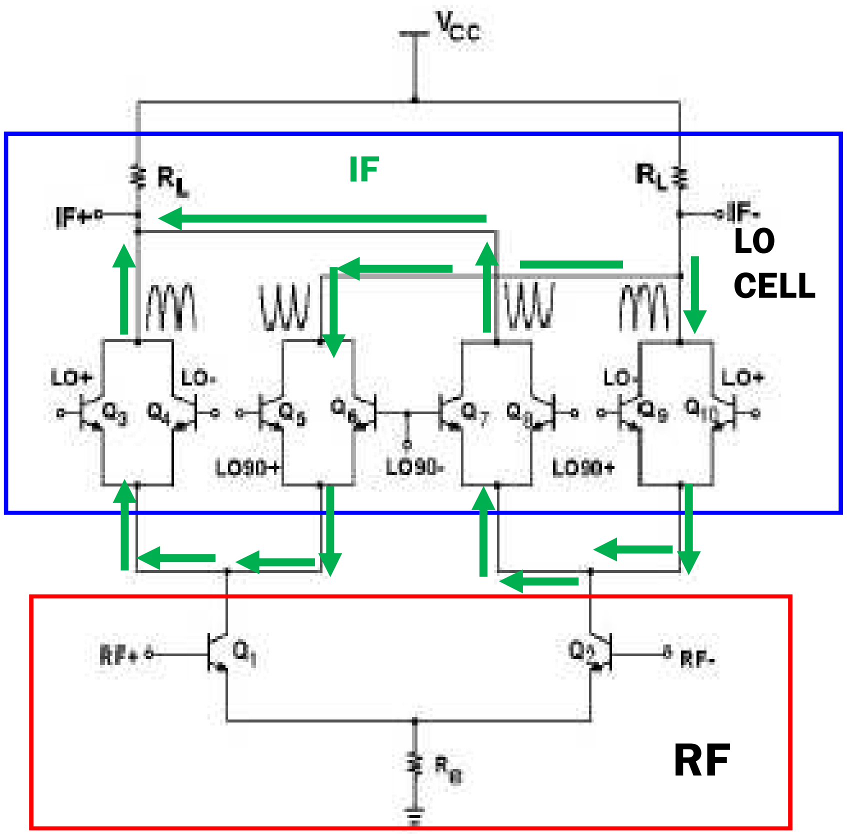
There are three generic approaches:

QLT_Quadrature LO on top. Sub-harmonic LO cell stacked on top of RF stage
DRT_Differential RF on top. RF amplifier cell stacked on top of LO doubler cell
TL_Triple level. Dual sub-harmonic LO-cells stacked on top of RF stage

*LO-cells can be active or passive in any mode

Differential BJT Type QLT

- Quadrature LO on top: 50 GHz 0.12 μm SiGe



Notes:

- .LO, 2LO signal cancels at collector of LO pairs and collector of RF devices.
- .IF current cancels at collector of RF device
- .Large LO amplitude, makes RF current multiplied by +/- 1 at twice the LO freq
- .Conversion gain is approximately equal to Gilbert Cell Mixer

$$G_C = \frac{2}{\pi} g_m R_L$$

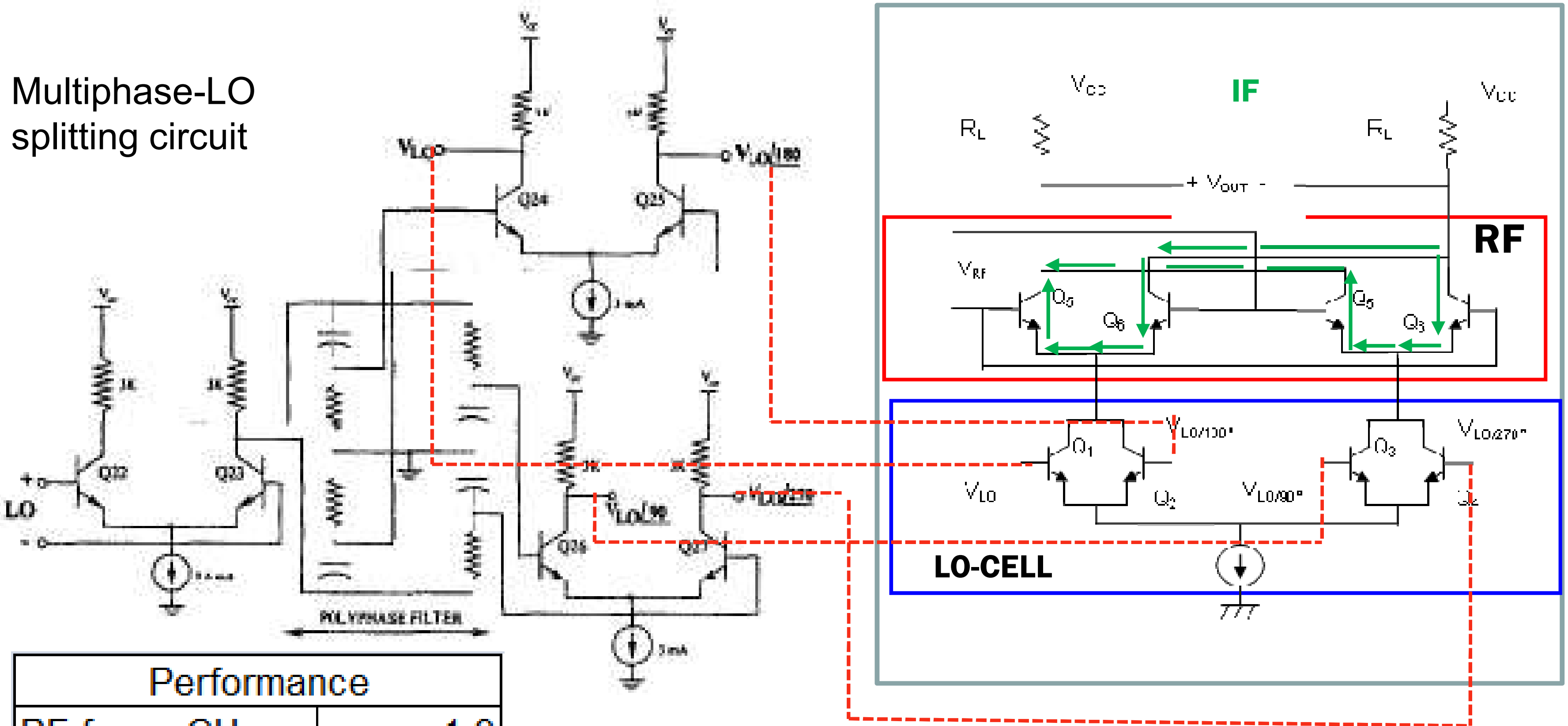
Performance	
RF range - GHz	48 - 51
CG - dB	8.0 - 9.0
NF -dB(SSB)	12
P1dB - dBm	-16.5

An Integrated 50 GHz SiGe Sub-Harmonic Mixer/Down Converter with a Quadrature Ring VCO – R. M. Kodkani and L. E. Larson. 2007 Topical Meeting on Silicon Monolithic Integrated Circuits in RF Systems. Jan 2007 pp 223 – 226.

Differential BJT Type DRT

•Differential RF on top: Doubling HBT Mixers

Multiphase-LO
splitting circuit

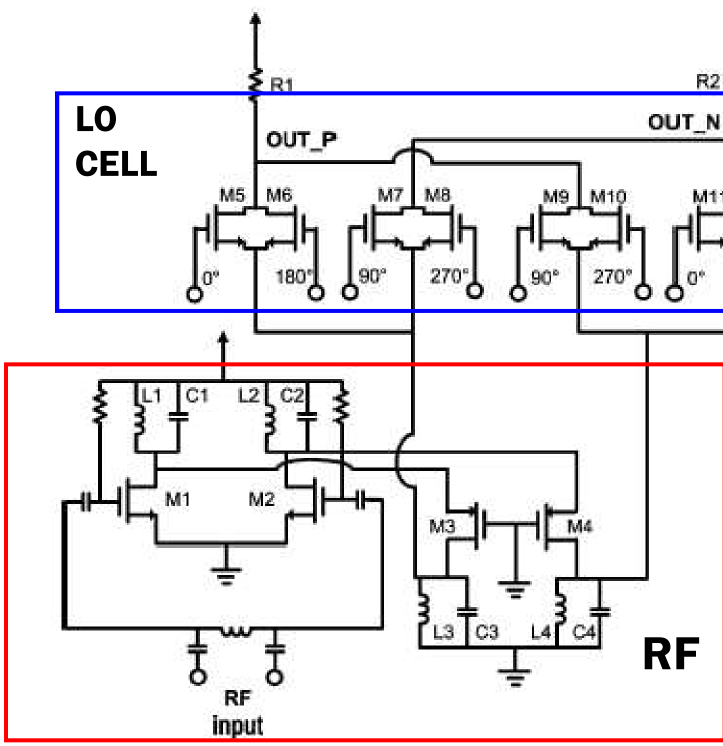


Performance	
RF freq - GHz	1.9
LO Freq - MHz	900
CG - dB	7.5
NF -dB(SSB)	10
P 1dB - dBm	-3

A 1.9 GHz Double-Balanced Subharmonic Mixer fo Direct Conversion Receivers – K. Nimmagadda and G. M. Rebeiz. IEEE RFIC Symposium Phoenix, 2001

Differential FET Type QLT

•Quadrature LO on top: CMOS 5.6 GHz SHM for Direct Conversion



0.18 um CMOS

Performance

RF freq - GHz	5.2
Flicker noise - MHz	3.5
CG - dB	12.9
NF -dB(SSB)	17.3
IIP2 - dBm	45.9
IIP3 - dBm	2.8
P 1dB - dBm	-22

Features:

- Operation at VCC= 1V/13 mA
- RF section = CS and CG FETs
- tank circuits/bias

A 5 - 6 GHz 1-V CMOS Direct Conversion Receiver with an Integrated Quadrature Coupler - H-Chin Chen, T. Wang and S-Shi Lu. IJSSC/ Vol 42, No 9, September 2007 pp 1963 - 1975

Differential FET Type QLT

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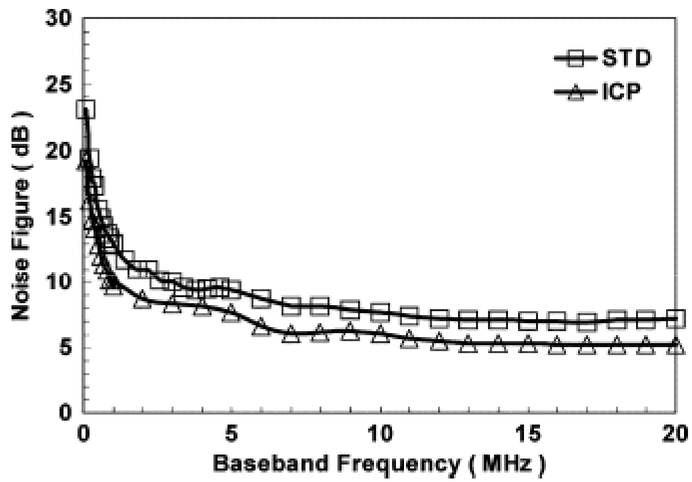
•Quadrature LO on top: CMOS 5.6 GHz SHM for Direct Conversion



Flicker noise at 3.5 MHz:

.NF at DC = 24 dB (due to self LO mixing)

.ICP (inductive coupled plasma)

removal of substrate under inductors/transformers

.NF improved by 5 dB.

A 5 - 6 GHz 1-V CMOS Direct Conversion Receiver with an Integrated Quadrature Coupler - H-Chin Chen, T. Wang and S-Shi Lu. IJSSC/ Vol 42, No 9, September 2007 pp 1963 - 1975

Differential FET Type DRT

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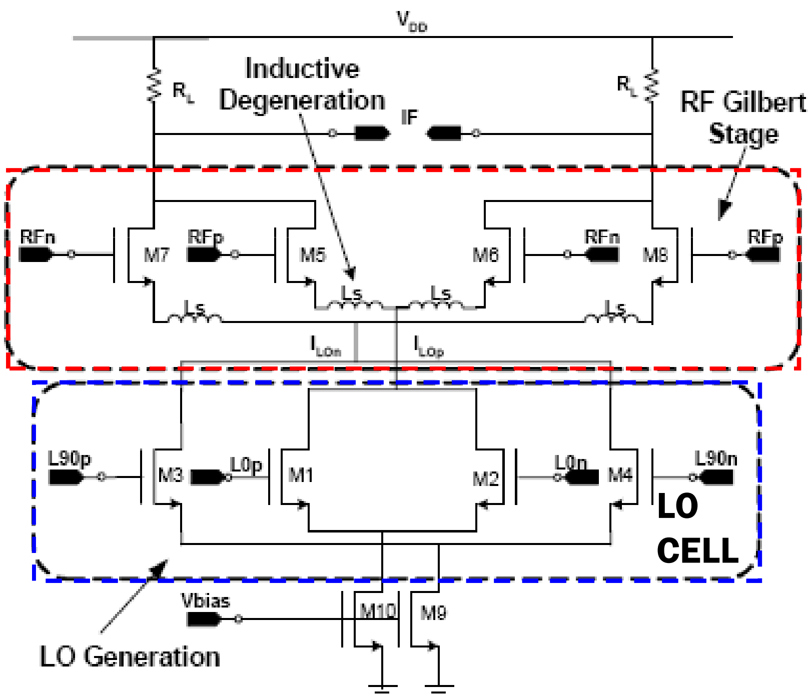
•Differential RF on top: 0.25 um 5.5 GHz CMOS Mixers



Performance

RF freq - GHz	5.6
CG - dB (voltage)	8.0
NF -dB(SSB)	6.0
IIP2 - dBm	55.3
IIP3 - dBm	-6.5
P 1dB - dBm	-12

Features:

- Operation at VCC= 3V/1.75 mA
- RF section, Ls for IIP2, IIP3
- tank circuits/bias

A New 5 GHz ISM Band CMOS Doubly Balanced Sub-Harmonic Mixer for Direct Conversion Receiver - P. Upadhyaya, M. Rajasherkharaiah, D. Heo and Y. J. E. Chen. European Conference on Wireless Technology, 2004 Amsterdan, pp 65 - 68

Differential Type _TL

•Three Level Sub-Harmonic Mixers

- Three Level Analog Multiplier (JSSC_Aug - 1981 by Choma) as an extension of Gilbert multiplier where Vout = VxVyVz
- Dual Conversion Mixer (Patent # 5448772 by Grandfield) for fundamental conversion . Proposed use of two conventional Gilbert core cells stacked on top of each other. The first mixer down-converts to a first IF and the second mixer down-converts to a second IF or no IF .
- Successive Mixing (JSSC_Sep - 2000 by Sheng, Jensen and Larson) for sub-harmonic conversion. Uses similar topology and was developed specifically for direct conversion receiver.

Differential HBT Type TL

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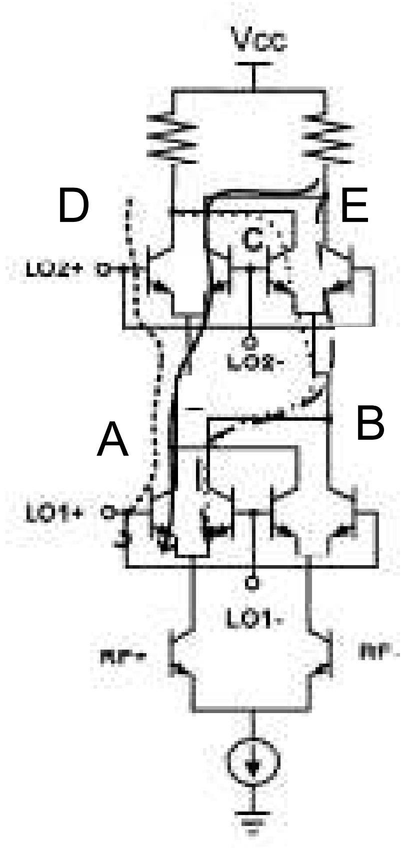
•Three Level Sub-Harmonic Mixers



AD+BC $= \cos(2\omega_{LO} - \omega_{RF})t + \cos(2\omega_{LO} + \omega_{RF})t$

AD+BC $= 2\cos(\omega_{RF}t).\sin(2\omega_{LO}t)$

BC $= -2\cos(\omega_{RF}t).\cos(\omega_{LO}t)(-1)\sin(\omega_{LO}t) = \cos(\omega_{RF}t).\sin(2\omega_{LO}t)$

AD $= 2\cos(\omega_{RF}t).\cos(\omega_{LO}t)\sin(\omega_{LO}t) = \cos(\omega_{RF}t).\sin(2\omega_{LO}t)$

A: $= 2\cos(\omega_{LO}t).\cos(\omega_{RF}t)$

B: $= -2\cos(\omega_{LO}t).\cos(\omega_{RF}t)$

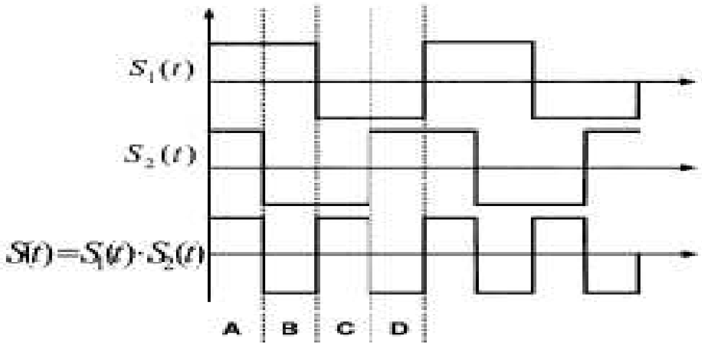
$= \cos(\omega_{RF}t)$

The output signal at E is equal to D but in counter-phase. A balun is used to combine the output currents; First level converts to fundamental frequency, second level down-converts to IF.

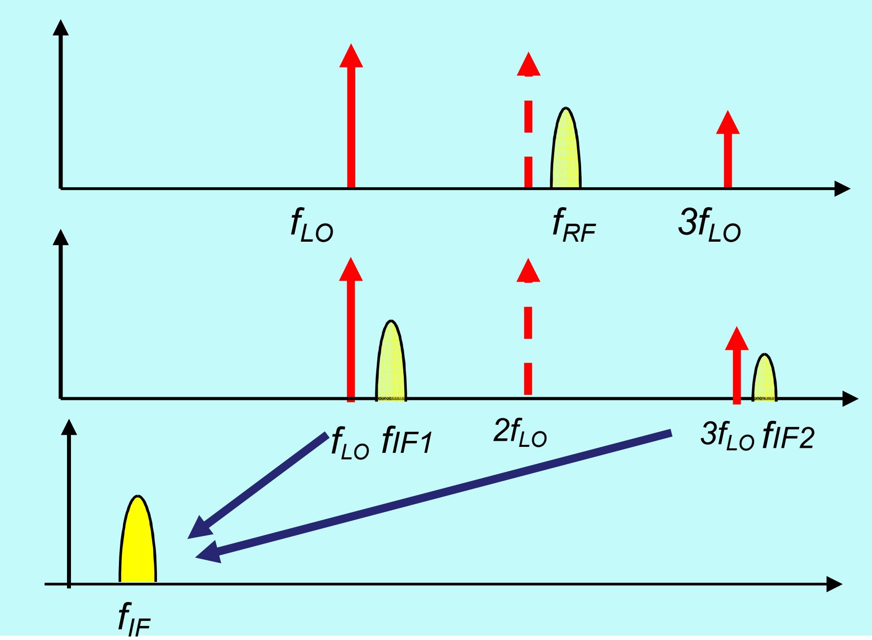
Differential HBT Type TL

•Three Level Sub-Harmonic Mixers

Successive Mixing



- S1(t) → LO1(+) and LO1(-) switching
- S2(t) → LO2(+) and LO2(-) switching
- Effective switching is S(t) = S1(t).S2(t)
- Switch waveform can be square or rounded



Input Spectrum

First conversion – fundamental mixing:

$$f_{IF1} = f_{RF} - f_{LO}$$

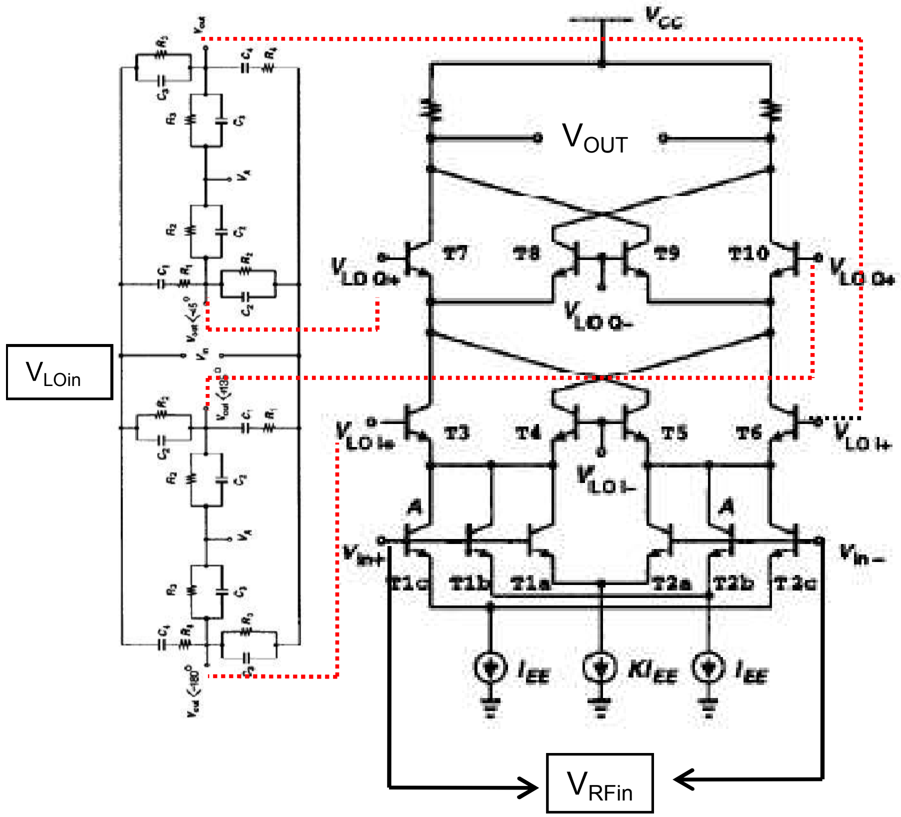
$$f_{IF2} = f_{RF} + f_{LO}$$

Second conversion - fundamental and third harmonic mixing

$$f_{IF} = (f_{IF1} - f_{LO}) + (f_{IF2} - 3f_{LO})$$

Differential HBT Type TL

•SiGe Type T SHM/HBT



Performance

Technology	SiGe f_T = 52 GHz
RF freq - GHz	2.1
CG - dB	17.2
NF -dB(DSB)	9.8
IIP2 - dBm	31.7
IIP3 - dBm	-5.1

Features:

- **Operation at VCC= 3.3V/2.8mA**
- **RF section, multi tanh stage**
- **LO phase shifter**
- **Differential I-Q output**

A Wide Bandwidth Si/SiGe HBT Direct Conversion sub-Harmonic Mixer/Downconverter – L. Sheng, J. C. Jensen and L. E. Larson. IEEE JSSC Vol. 35 No 9 Sep 2000, pp 1329 – 1337.

Differential R-FET Type TL

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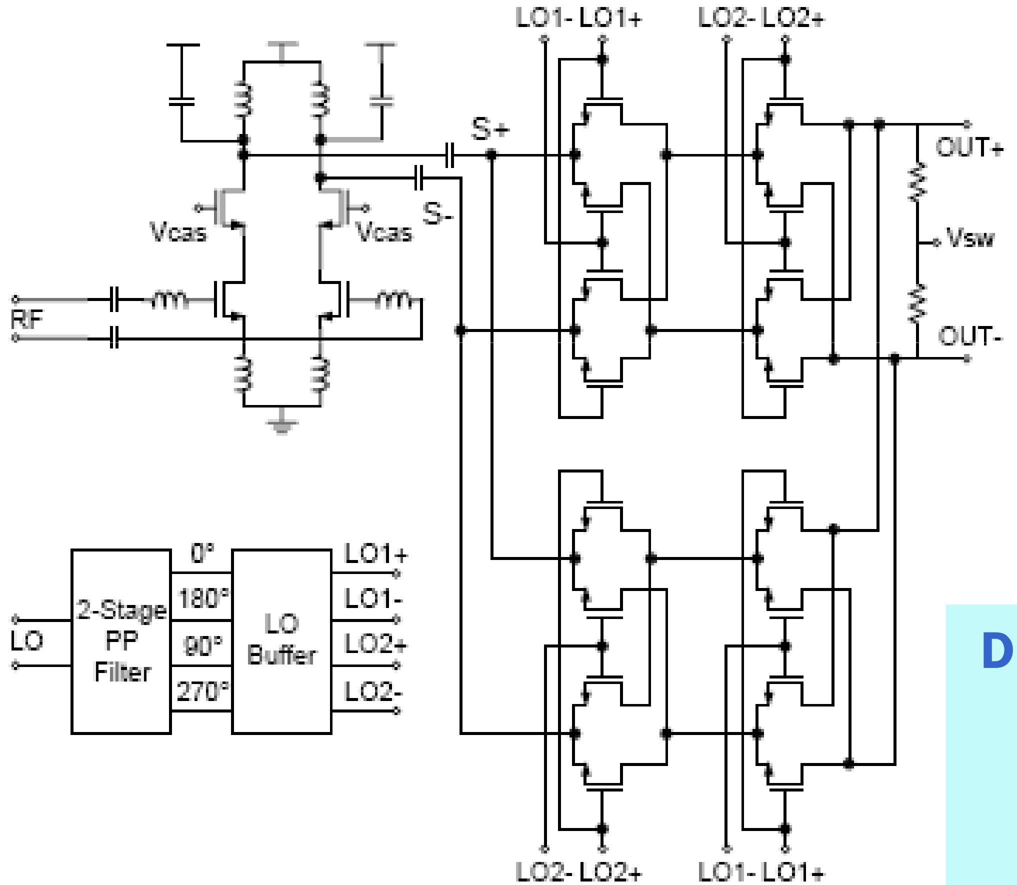
•0.13 CMOS Successive Mixer Type TR

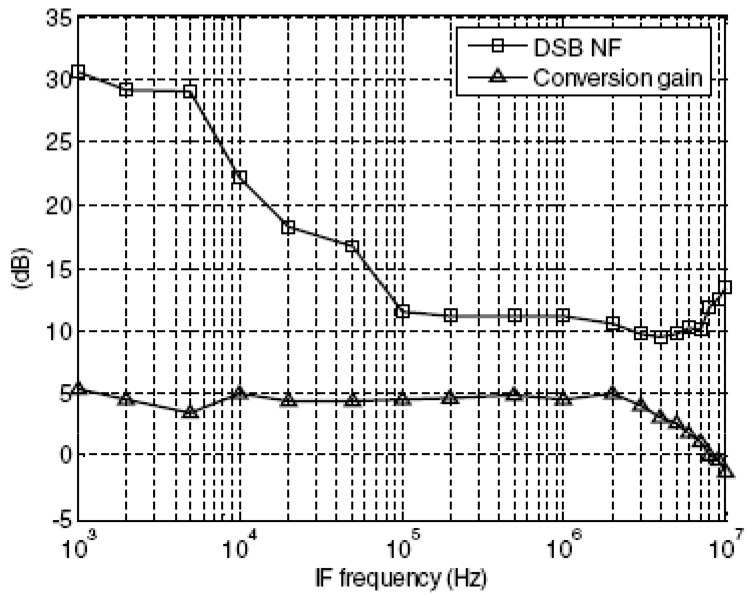


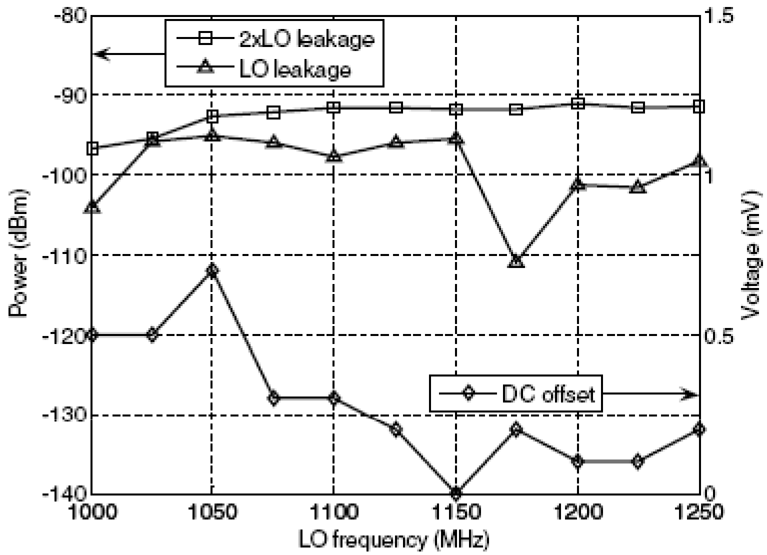
Dual core cells Features:

.opposed phase for LO and 2LO leak on each half

A 2.2 GHz Sub-Harmonic Mixer for Direct-Conversion Receivers in 0.13 um CMOS - H. C. Jen S. C. Rose and R. G. Meyer. ISSCC/ 2006 Int. Solid State Circuits Conference, 25.5

Differential R-FET Type TL





Performance	
RF freq - GHz	2.2
Flicker noise - KHz	100
CG - dB	5.0
NF dB(DSB >100KHz)	10.0
IIP2 - dBm	35.0
IIP3 - dBm	0.0

Conclusions

- Evolution of SHP Mixers over the years from Tubes to CMOS
- Application in up-down conversion, mmWave, modulators, demodulators & Systems
- Made Direct Conversion Receivers a reality
- Simple Circuitry: Lower Costs

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Table_I

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3. A Novel Uniplanar 44 GHz MMIC Sub harmonic Mixer Using CPW Series Stubs – K. Hettak, C. J. Verver, G. A. Morin and M. G. Stubbs – 2004 IEEE – MTT-Symposium Digest, pp 1157 – 1160
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5. A 38 – 48 GHz Miniature MMIC Subharmonic Mixer – W. C. Chen, S. Y. Chen, J. H. Tsai, T. W. Huang and W. Wang – 13 th GaAs Symposium, Paris 2005 – pp 437 – 440
6. Harmonic Mixing with the HSCH – 5500 Series Dual Diode – Application note 991 from Hewlett Packard

Table_II

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3. A 94 GHz High Performance Quadruple Subharmonic Mixer MMIC – K. Kanaya, T. Hisaka, T. Ishikawa and S. Sakamoto – 2002 IEEE – MTT-Symposium Digest, pp 1249 – 1252
4. A Low Conversion Loss mm_Wave Fourth Subharmonic Mixer – Y. Xu, - 2008 ICMMT, International Conference on Microwave and mmWave Technology – Vol 2, pp 843 - 845

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Table_III

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2. A Unique 520 – 590 GHz Biased SubHarmonically Pumped Schottky Mixer – E. Schlecht, J. Gill, R. Dengler, R. Lin, R, Tsang and I. Mehdi – IEEE Micro. And Wireless Components Letters, Vol 17, No 12, Dec 2007, pp 879 – 881
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