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Advances in Active Microwave Frequency Multipliers

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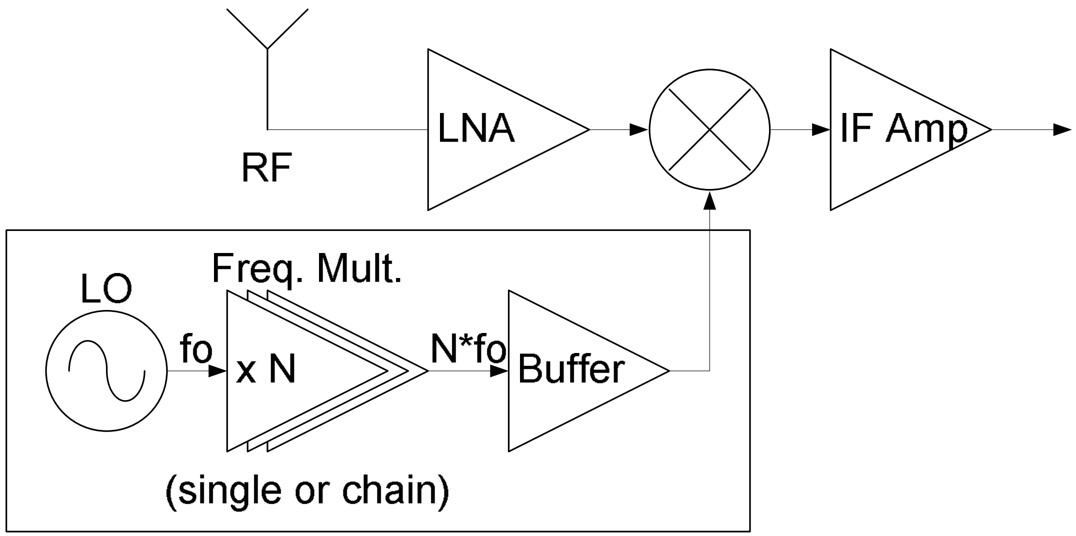
Outline

- Introduction
- System Development
- Technologies
- Topologies
- State of the Art
- Conclusions

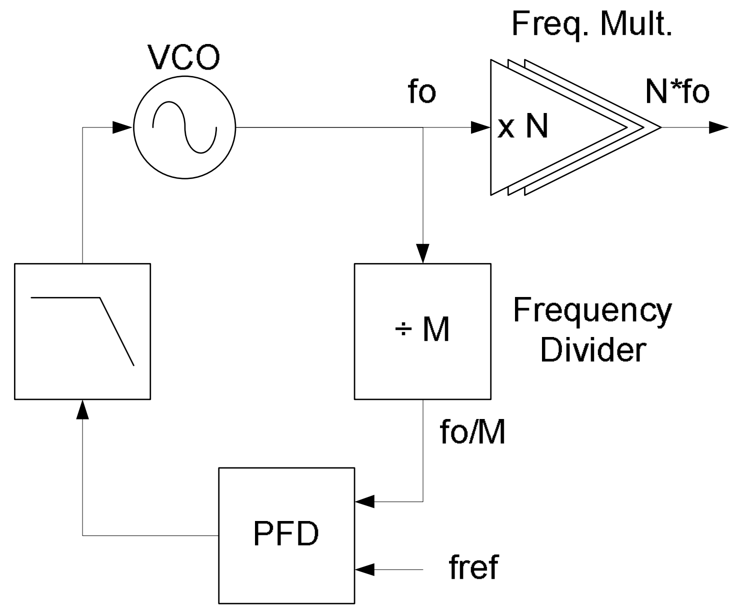
Introduction

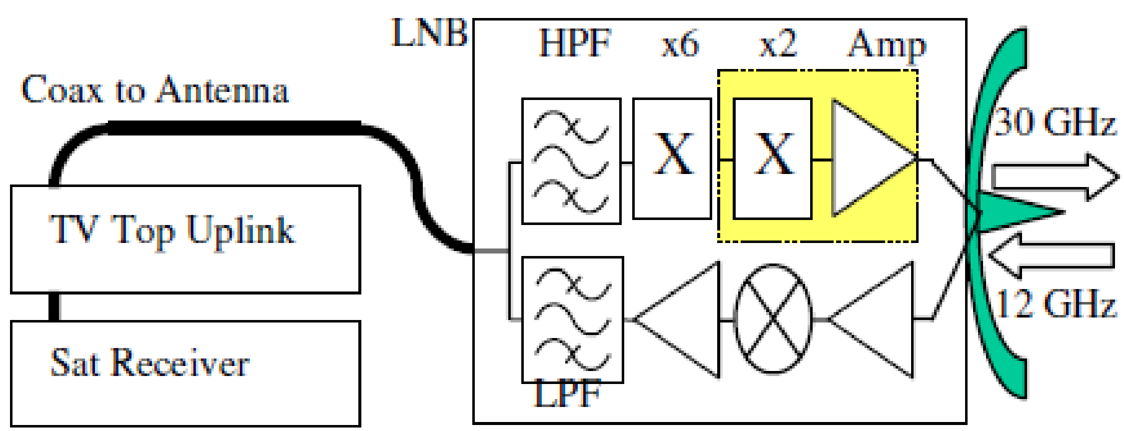


- **Frequency multipliers + LO used for signal generation in transceivers**
  - **Enable LO to be used at higher micro-/mm-wave**
  - **Alleviate system level freq constraints**
  - **Improves stability/phase noise performance [1] [34]**
- **This work overviews the state of the art**
  - **Conversion gain (CG), output power (Pout)**
  - **Millimeter-wave operation**

System Development 1

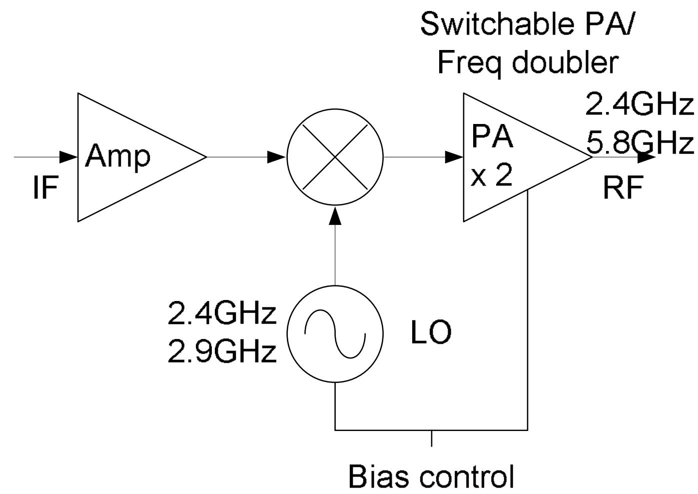
- **Building block of comm. systems**
- **Frequency synthesizer [2]**
  - **Phase-locked loop**
  - **Design constraints**
- **Digital Broadcast Systems (DBS) [5]**
  - **Shared Uplink/downlink**



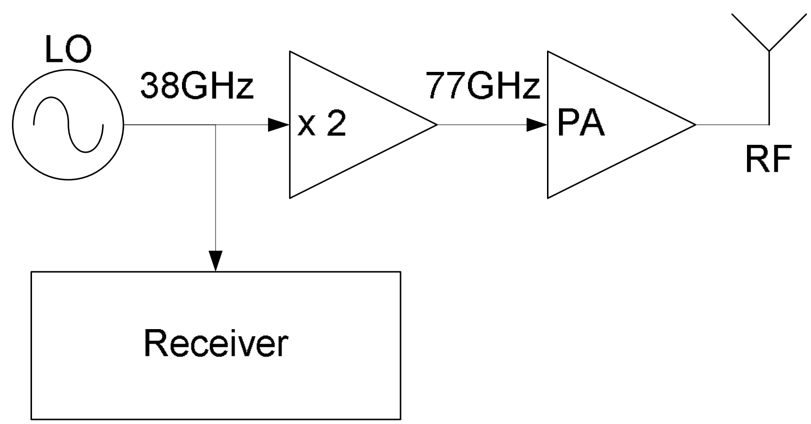


System Development 2

- **Dual-band Wifi transmitters [4]**
  - **IEEE 802.11: 2.4GHz/5.8GHz**
  - **Switchable dual-band LO + PA/frequency multiplier**
  - **Two modules in one**



- **Automotive radar 77GHz [7]**
  - **Close to fT of some technologies**
  - **Noise performance of MMIC LO's designed directly at 77GHz suffers**
  - **Use freq doublers**



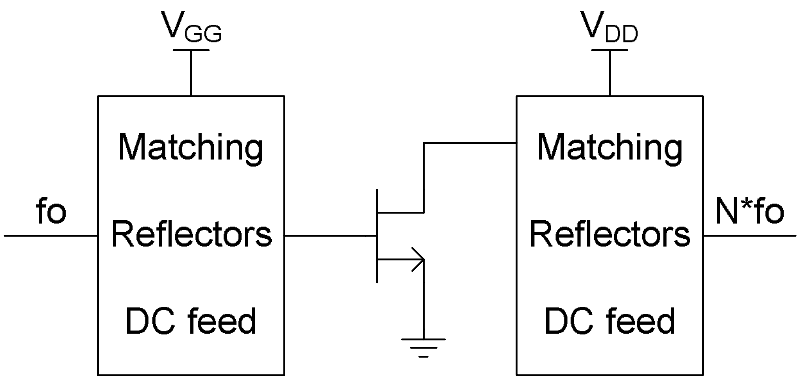
Technologies 1

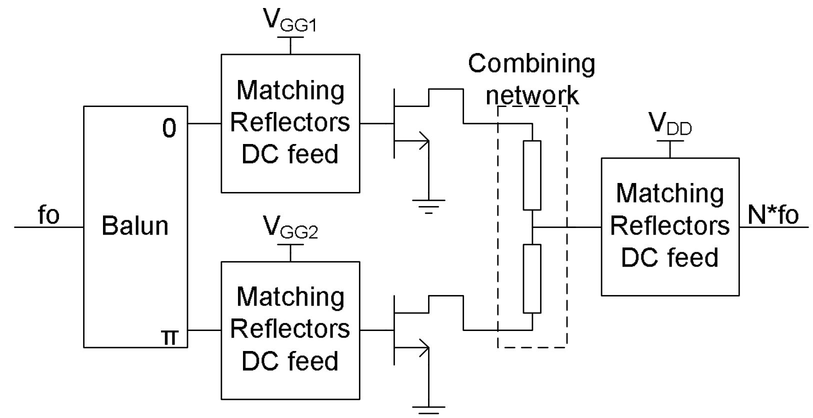
- Many advances are due to technology
- Indium phosphide (InP)
  - Very high freq applications >100GHz
  - Less dc power, less heat, better CG
  - MMIC-capable
- GaAs metamorphic HEMT (mHEMT)
  - GaAs substrate + InP-heterostructure
    - Metamorphic buffer layer (graded composition) [32]
  - better mechanical stability, larger wafer size availability, lower cost than InP [24]

Technologies 2

- Silicon-based
  - Low cost, high volume commercial availability
  - CMOS
  - SiGe BiCMOS
    - Very high frequency operation
    - Integration with CMOS
- GaAs
  - Good balance between frequency and power
- AlGaN/GaN HEMT
  - High conversion gain
  - Unparalleled output power

Topologies 1



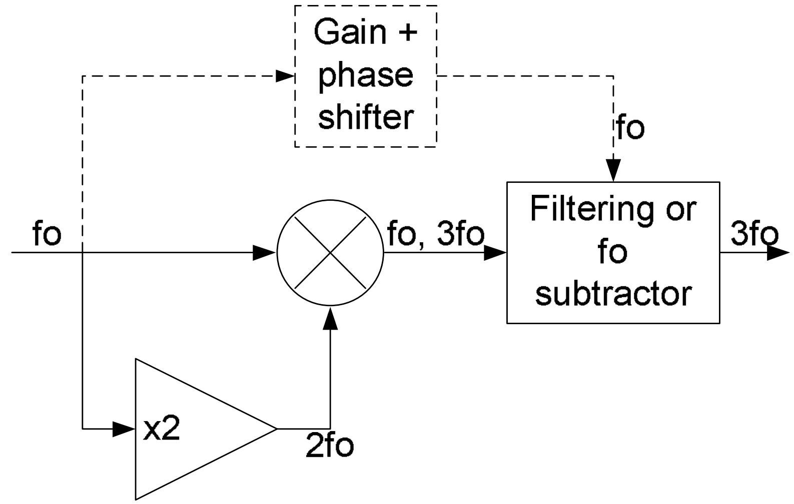


- **Single-Ended (S.-E.)**
  - **Single device**
  - **Biased using conduction angle**
  - **Utilizes tuned networks for harmonic rejection, matching**
  - **Narrowband**

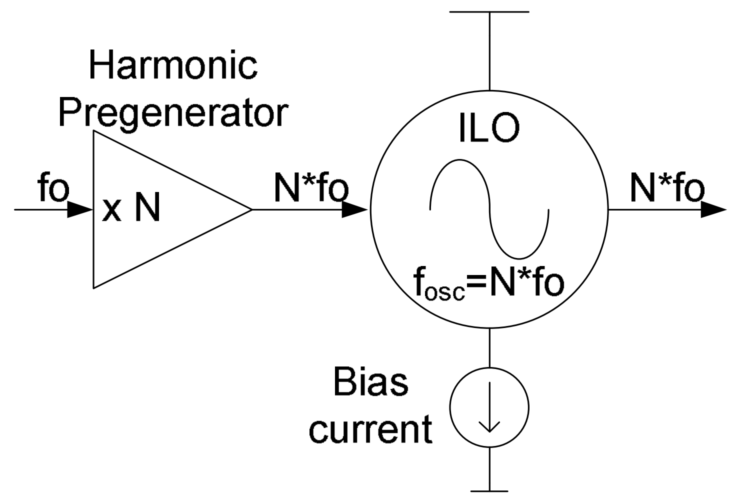
- **Balanced (Bal.)**
  - **Two devices**
  - **Biased using conduction angle**
  - **Doubler:**
    - **Input balun, combining network**
    - **2fo adds, 1fo cancels**
  - **Broadband performance**
  - **More complex, mismatch**

Topologies 3

- **Subharmonic mixer-based triplers (SHM) [10]**
  - **Output of a doubler mixed with fedforward fo**
  - **Filter out fo**

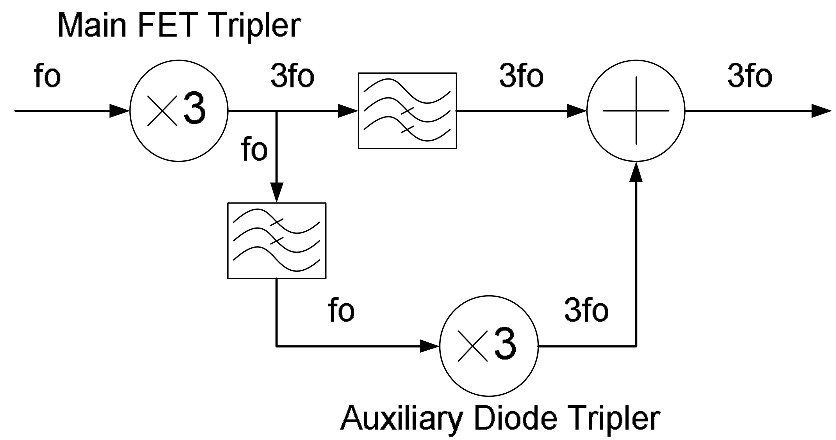


- **Injection-locked frequency multipliers (ILFM) [12]**
  - **Two-stage: harmonic pre-generator, injection-locked oscillator**
  - **Well-suited for CMOS**

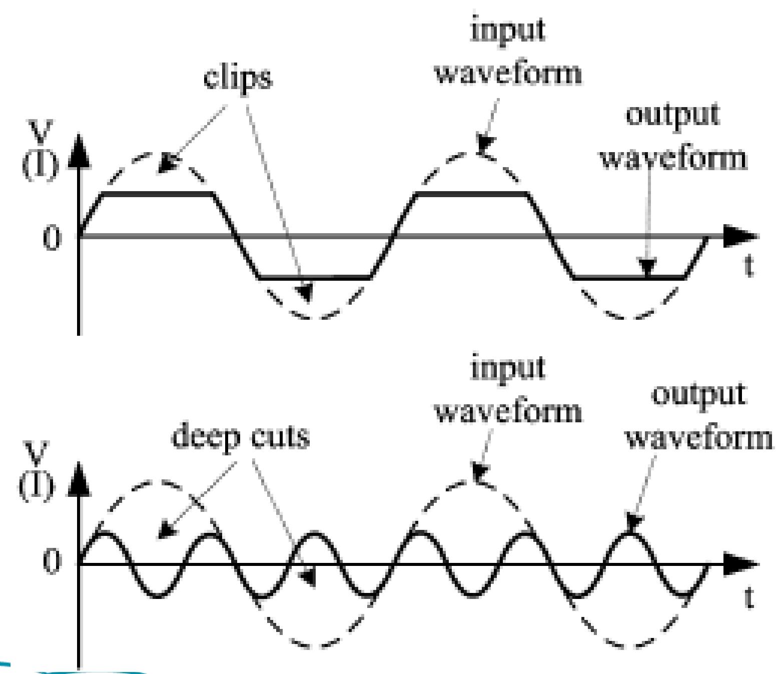


Topologies 4

- **Active tripler + Auxiliary diode tripler [17]**
  - **Provides supplementary 3fo from residual fo of active tripler**
  - **Improves dynamic range**



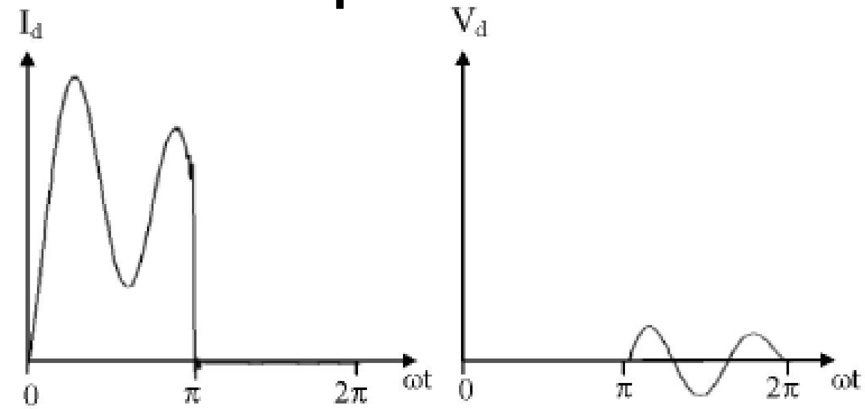
- **Enhanced tripler technique using waveform "deep cuts" [16]**
  - **Create deep cuts in fo for strong 3fo**
  - **CMOS nonlinear combiner perform operation**



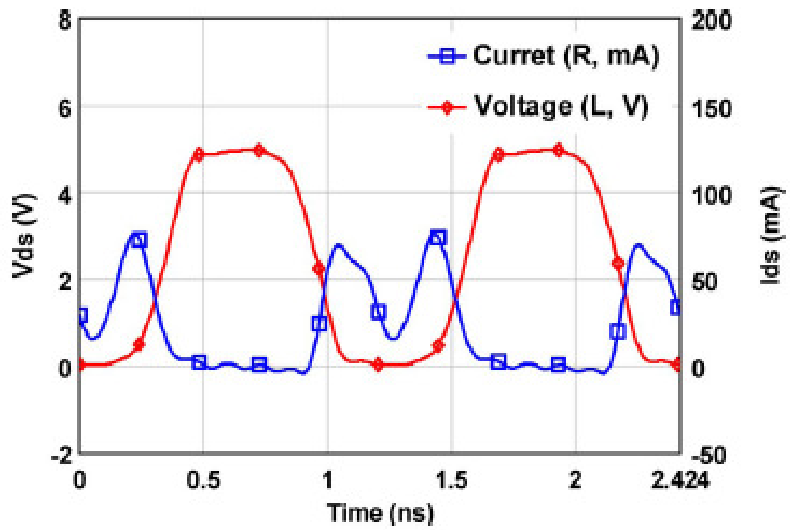
Topologies 5

- **Application of PA techniques, descriptions and classifications to increase efficiency**
- **Class E frequency tripler [18]**
  - Eta= 57%
- **Class F frequency doubler [19]**
  - Eta=22%
- **Narrowband**

Class E tripler I-V waveforms



Class F doubler I-V waveforms



High CG/Pout Freq. Mult.

Ref.	Technology	Top./ Real.	N	Freq Out GHz	CG dB	Pout dBm
[20]	0.15um GaAs pHEMT	Bal.*/MMIC	2	15-50	**16**	**18**
[21]	0.5um GaAs FET	Bal.*/MMIC	2	20-42	**15**	**18**
[22]	0.15um GaAs pHEMT	Bal.*/MMIC	2	12-16	**8**	**12**
[23]	2um GaAs HBT	Bal.**/MMIC	2	29-33	**6.1**	**10.1**
[15]	GaAs FET	Bal. w LHM-TL/Hybrid	2	1.8	**4.93**	**9.93**
[24]	2um InGaP/GaAs HBT	Bal.*/MMIC	2	4-12	**14**	**14**
[25]#	AlGaN/GaN HEMT	S-E/Hybrid	2	6.66	**14.80**	**36.17**
[26]#	0.18um GaAs HEMT	S-E/Hybrid	3	5.34-6.75	**0.5**	**6**
[27]#	GaAs pHEMT	S-E/Hybrid	3	8.82	**3.67**	**9.17**
[28]#	0.15um GaAs pHEMT	Bal./MMIC	3	12-36	**-8.1**	**-0.4**
[18]	0.25um GaAs pHEMT	S-E/Hybrid	3	3	**5.5**	**6**
[19]	GaAs E-pHEMT	S-E/Hybrid	3	2.475	**9**	**12**
[29]#	AlGaN/GaN HEMT	S-E/Hybrid	3	10	**-2.9**	**30.0**
[30]#	0.15um GaAs pHEMT	Bal.**/MMIC	3	27-42	**-6.7**	**5**

#meas. vs. sim, *w/buffer amp., **w/ cascode

mm-wave Freq. Mult.

Ref.	Technology	Top./ Real.	N	Freq GHz	CG dB	Pout dBm
[31]#	0.1um InP HEMT	S-E/MMIC	2	**157-171**	-2	5
[32]#	GaAs mHEMT	S-E/MMIC	2	**125**	-2.4	2.6
[9]	InP DHBT	Gilb./MMIC	2	**DC-120**	-0.25	-8.25
[33]	50nm GaAs mHEMT	Bal./MMIC	2	**150-220**	-6	4
[34]#	50nm GaAs mHEMT	S-E/MMIC	2	**180-220**	-7	-4
[35]	50nm GaAs mHEMT	S-E/MMIC	2	**250-310**	-7.4	-6.4
[36]	0.8um SiGe BiCMOS	Bal./MMIC	2	**64-86**	-4.5	-3.4
[12]	65nm CMOS	IL*/MMIC	2	**106-128**	—	-2.6
[37]	0.13um SiGe BiCMOS	Bal.**/MMIC	2	**118-122**	-6	-3
[38]#	0.13um SiGe BiCMOS	S-E/MMIC	2	**128-138**	-3.2	-2.9
[34]#	50nm GaAs mHEMT	S-E/MMIC	3	**140**	-11	-1.5
[39]	90nm CMOS	IL*/MMIC	3	**56.4-64.5**	--	-24.7
[40]	0.18um CMOS	IL*/MMIC	3	**60**	--	-9.4
[41]	0.15um GaAs pHEMT	S-E/F-C	3	**93-99**	-19	-12
[42]	0.15um GaAs mHEMT	Bal./MMIC	3	**71-76,81-86**	-11.5, -14	-2
[43]	0.18um CMOS	BPSK/MMIC	3	**56-63**	-9.4	-7
[44]	130nm GaAs mHEMT	S-E*/MMIC	3	**77**	1	1
[45]	65nm CMOS	IL*/MMIC	3	**85-95.2**	--	-13.53
[46]#	0.13um CMOS	SHM/MMIC	3	**36-48**	-11.4	-15
[17]#	0.15um GaAs pHEMT	S-E+diode/MMIC	3	**60**	-1.6	-0.6

#meas. vs. sim, *w/buffer amp., **w/ cascode

Conclusion

- Advancements in freq. mult. for micro- and milli-meter wave systems summarized
  - Applications
  - Technologies
  - Topologies
  - Innovative techniques
- Numerous research avenues have been identified
- An evaluation of the current state of the art
- Growing potential for high output and mm-wave operation

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Topologies 2

- **Gilbert-cell doubler [9]**
  - **fo at RF and LO mixes with itself → 2fo output**
  - **Suitable for fully differential CMOS MMICs**
  - **Limited CG (not hard limiting)**
  - **Class A bias**
    - **Higher DC power dissipation**
    - **Lower efficiency**