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
• Building block of comm. systems
• Frequency synthesizer [2]
  - Phase-locked loop
  - Design constraints
• Digital Broadcast Systems (DBS) [5]
  - Shared Uplink/downlink
• **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
• 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]
• 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
• 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 $f_0$
  - Filter out $f_0$

- **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
• 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
<table>
<thead>
<tr>
<th>Ref.</th>
<th>Technology</th>
<th>Top./ Real.</th>
<th>N</th>
<th>Freq Out GHz</th>
<th>CG dB</th>
<th>Pout dBm</th>
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<tbody>
<tr>
<td>[20]</td>
<td>0.15um GaAs pHEMT</td>
<td>Bal.*/MMIC</td>
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<td>8</td>
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#meas. vs. sim, *w/buffer amp., **w/ cascode
## mm-wave Freq. Mult.

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Technology</th>
<th>Top./ Real.</th>
<th>N</th>
<th>Freq GHz</th>
<th>CG dB</th>
<th>Pout dBm</th>
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<td>0.1um InP HEMT</td>
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<td>60</td>
<td>-1.6</td>
<td>-0.6</td>
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</tbody>
</table>

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

• Advancements in freq. mult. for micro- and millimeter 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


[44] Y. Kim, Y. Koh, Y. Park, K. Seo, Y. Kwon, “A CPW-based 77 GHz frequency tripler MMIC using a 130 nm In0.8GaP/In0.4AlAs/In0.35GaAs MHEMTs,” IRMMW-THz Conf., pp. 1-2, 2009.


• 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