A Multiband LTE SAW-less CMOS Transmitter with Source-Follower-Driven Passive Mixers, Envelope-Tracked RF-PGAs, and Marchand Balun

T. Kihara, T. Sano, M. Mizokami, Y. Furuta, T. Nakamura, M. Hokazono, T. Maruyama, K. Toyota, K. Maeda, Y. Akamine, T. Yamawaki, T. Heima, K. Hori, H. Sato,

Renesas Electronics Corporation

(RTU2B-3)

Outline

- Background
- Transmitter architecture
- Circuit topologies:
  - Quadrature modulator (QMOD)
  - RF programmable gain amplifier (RF-PGA)
  - Balun
- Measurement results
- Summary

Background

- Long Term Evolution (LTE):
  - Higher data transfer rate (>10 Mbps) than W-CDMA and HSPA
  - Higher PAPR signals and more frequency bands

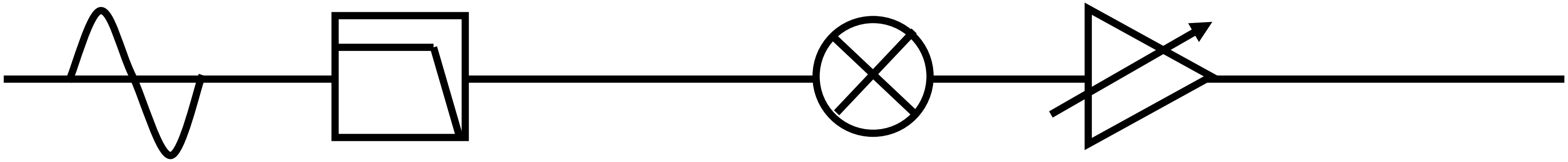
➡ High linearity (ACLR<–42 dBc) and multi-band operation (700 MHz – 2.6 GHz)

- SAW-less operation desired for low cost

➡ Low RX-band noise (<–158 dBc/Hz)

PAPR: Peak-to-average power ratio, SAW: Surface Acoustic Wave, ACLR: Adjacent channel leakage ratio,

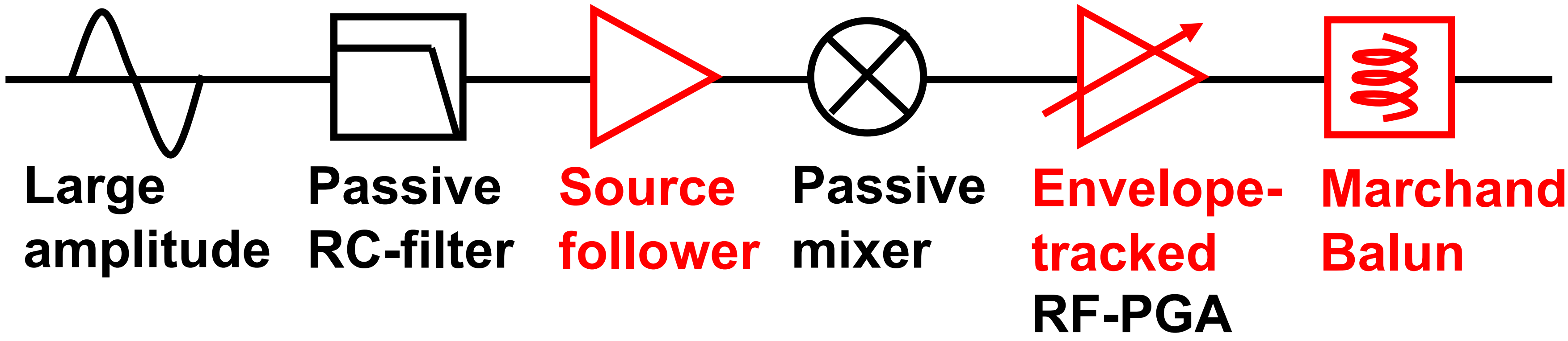
Approach



For low noise

- Large amplitude base-band signal
- Passive RC-filter
- Passive mixer
- One-stage RF-PGA

Approach



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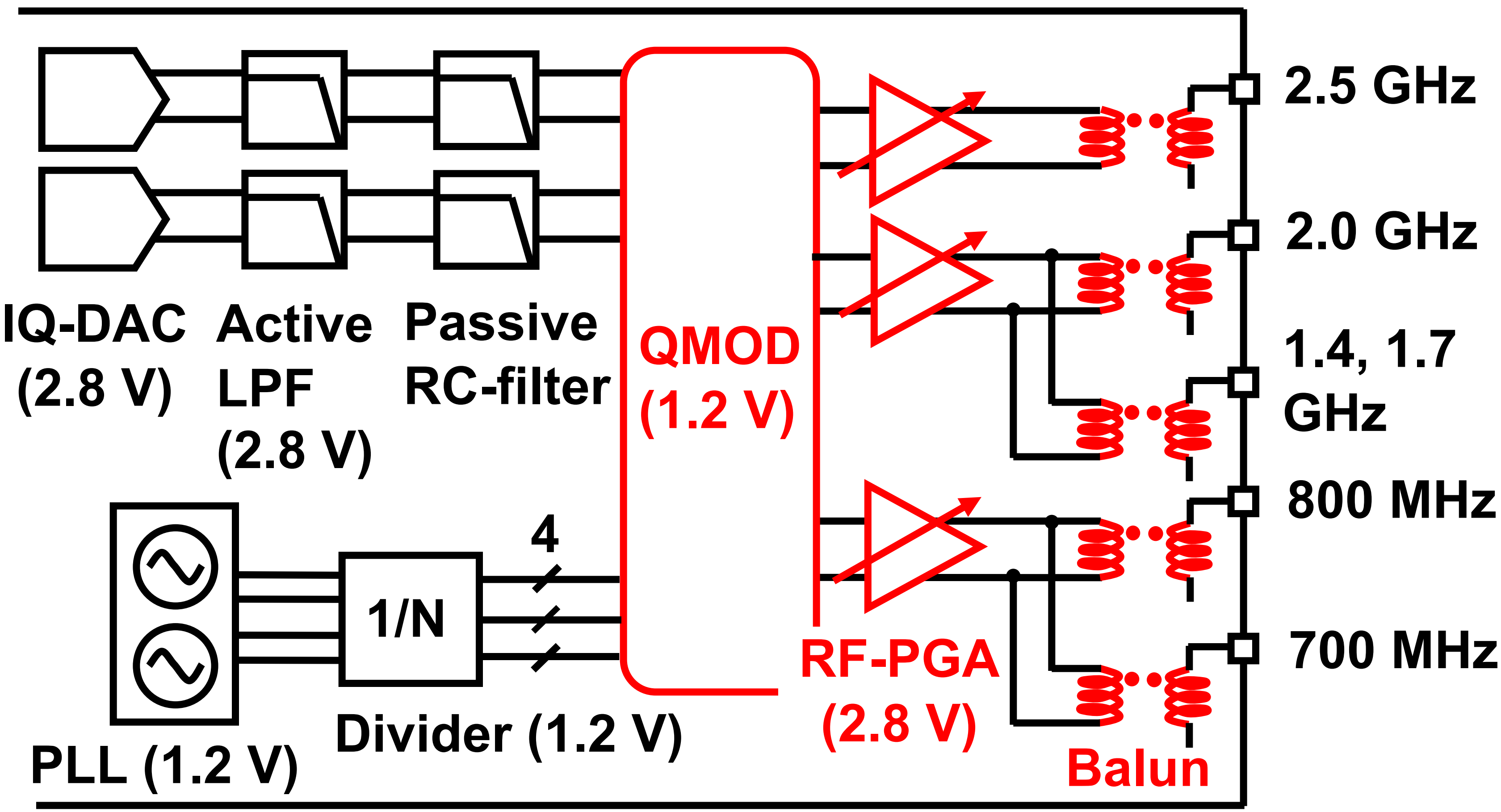
New topologies

- Source-follower-driven passive mixer
- Envelope-tracked RF-PGA
- Marchand balun

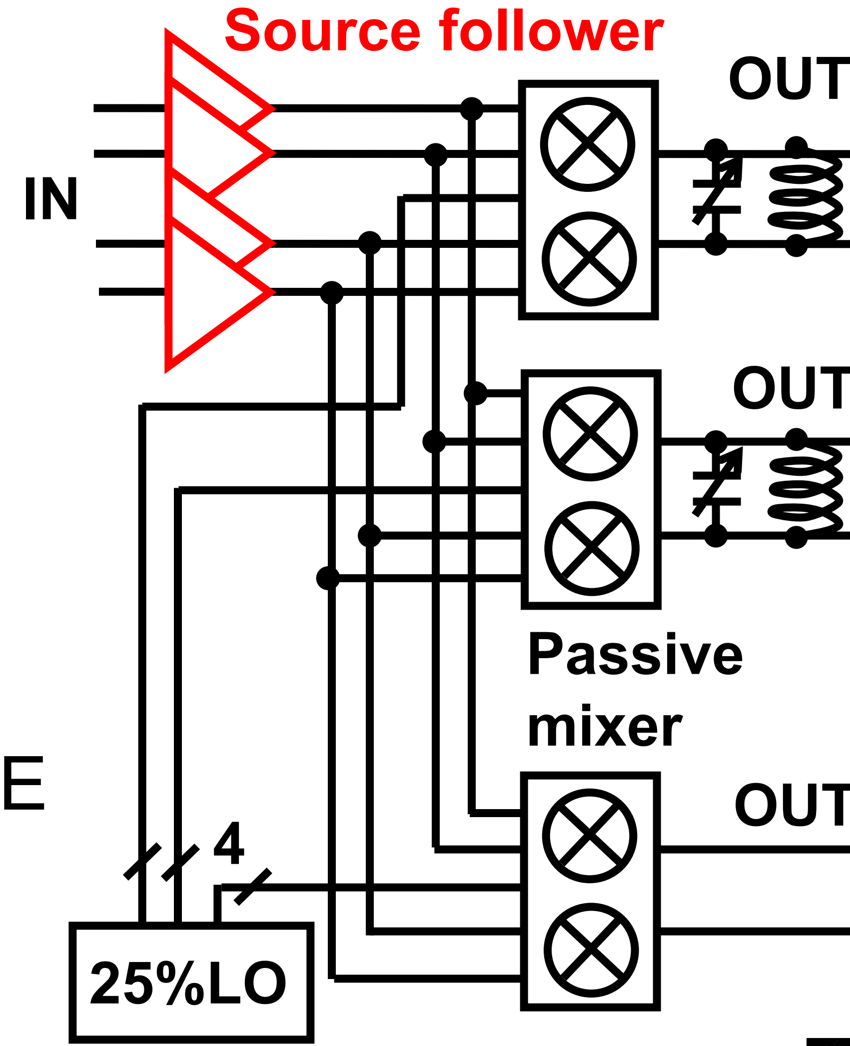
Block Diagram of Transmitter



- IQ direct conversion architecture
- New topologies: QMOD, RF-PGA, and balun

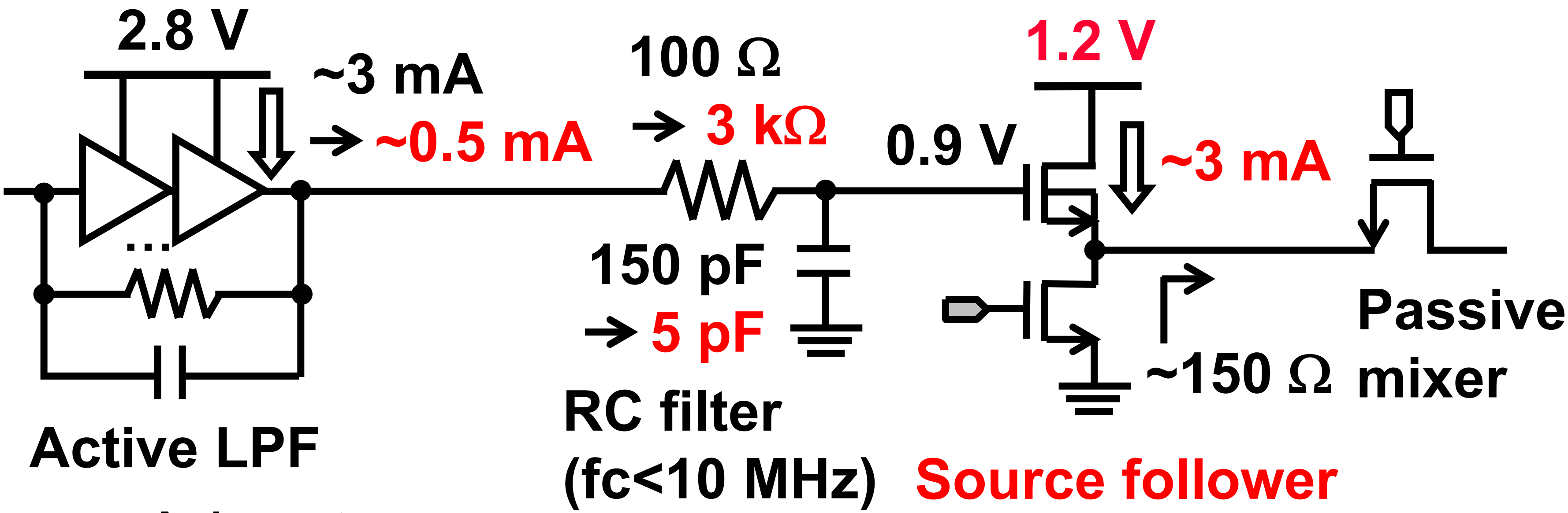
Quadrature Modulator

- Circuit topology:
  - Source follower
  - Passive mixer
  - 25%-duty-cycle LO
- Performance:
  - –163 dBc/Hz noise
  - –48 dBc ACLR for LTE
  - 17.5 mA from 1.2 V (Band 1)



Source followers are used as driver for passive mixers

Advantages of Source Follower



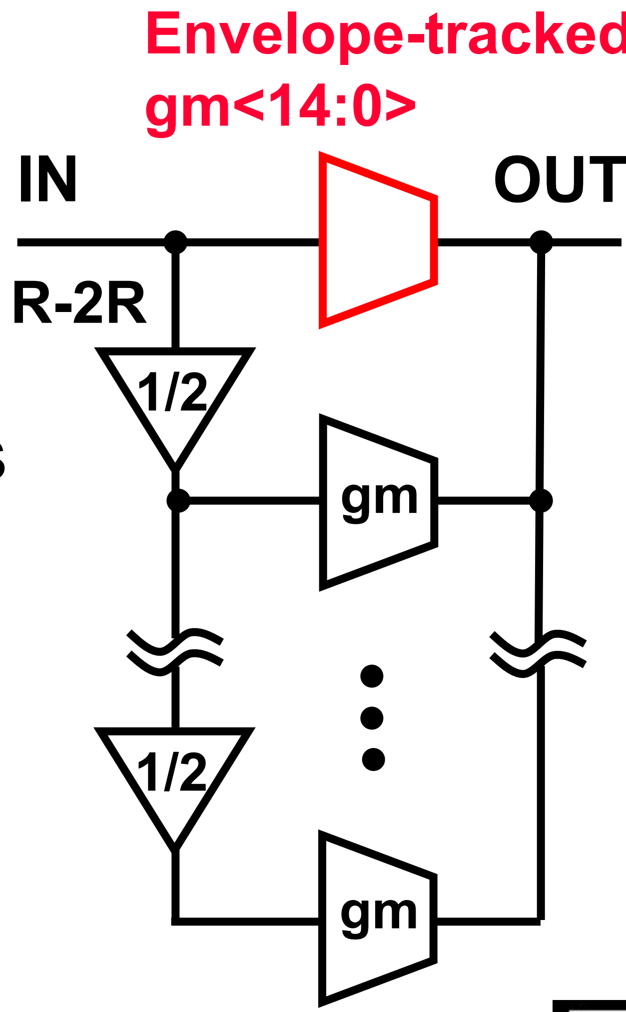
- Advantages:
  - Small power consumption to drive mixer (~3 mA from 2.8 V → 1.2 V, –13 mW)
  - Small capacitor for RC-filter (150 pF → 5 pF, –0.2 mm^2)

➡ Low-power and small-area transmitter

Envelope-Tracked RF-PGA

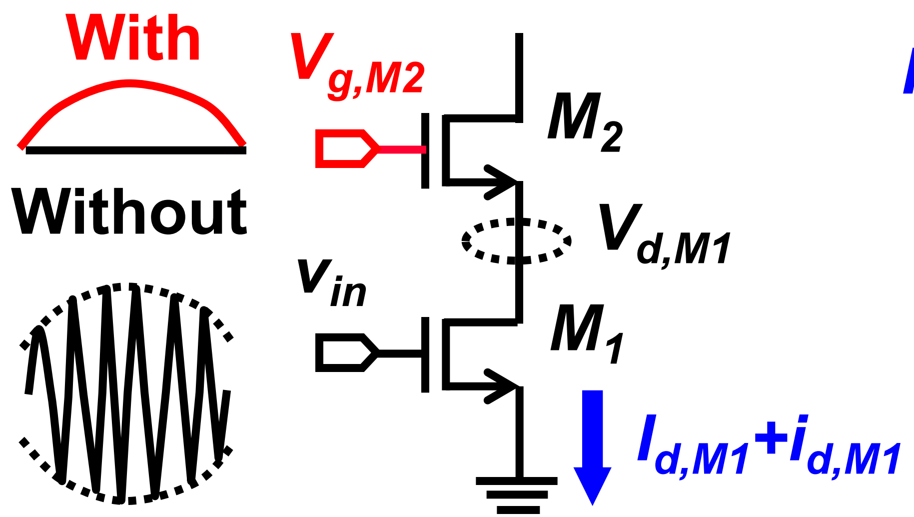
- Circuit topology:
  - 15 thermometer-weighted transconductors
  - 14 binary-weighted trans-conductors with R-2R ladders
- Performance:
  - 74 dB gain control range
  - 32 mA for 3 dBm output power (Band 1)

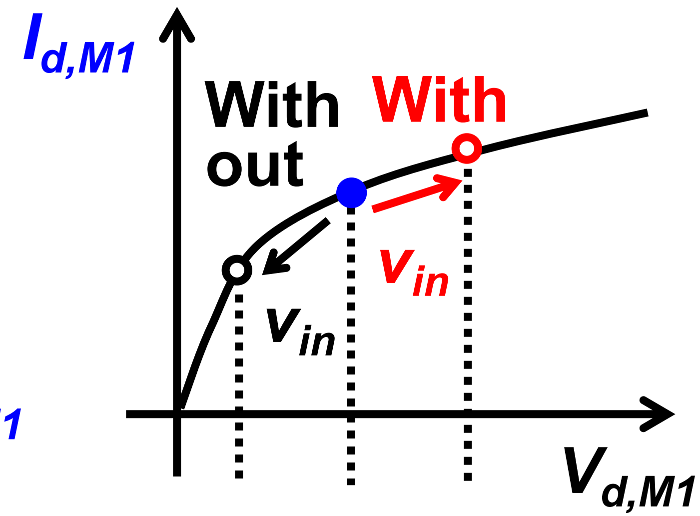
Envelope-tracked biasing is employed on transconductors

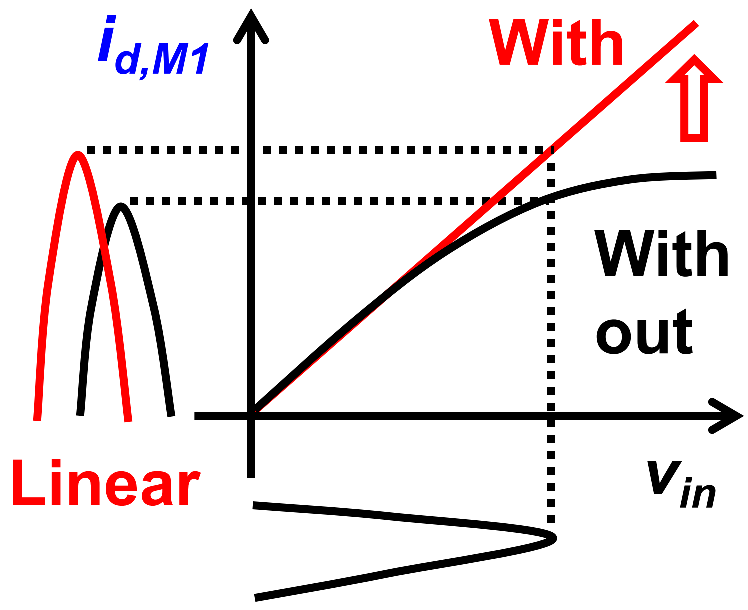


Ref. VLSI 2010, Renesas

Envelope-Tracked Biasing

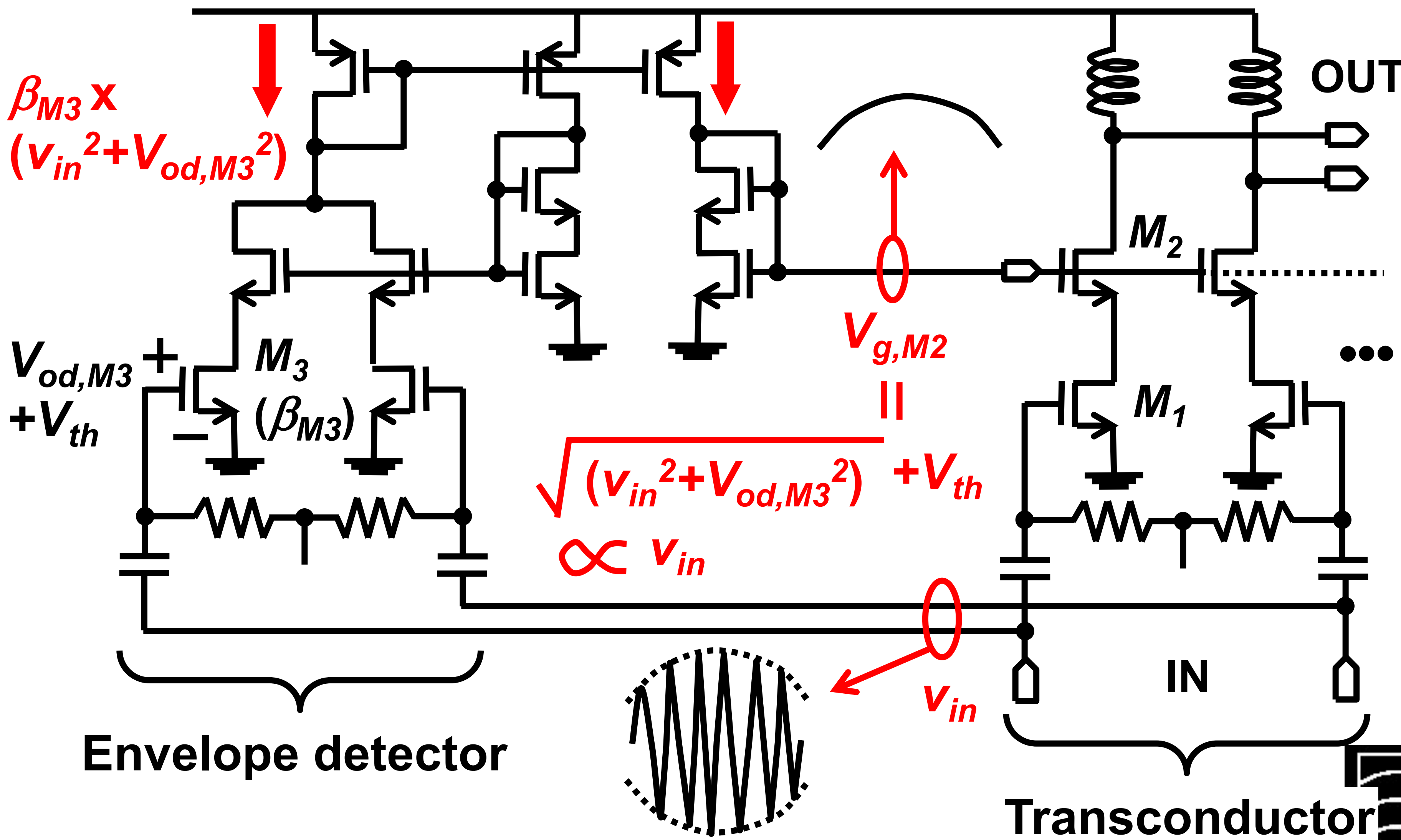




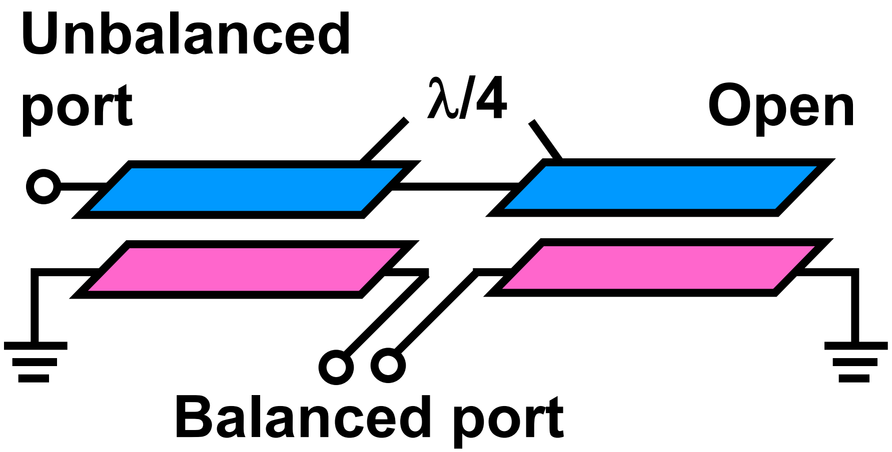


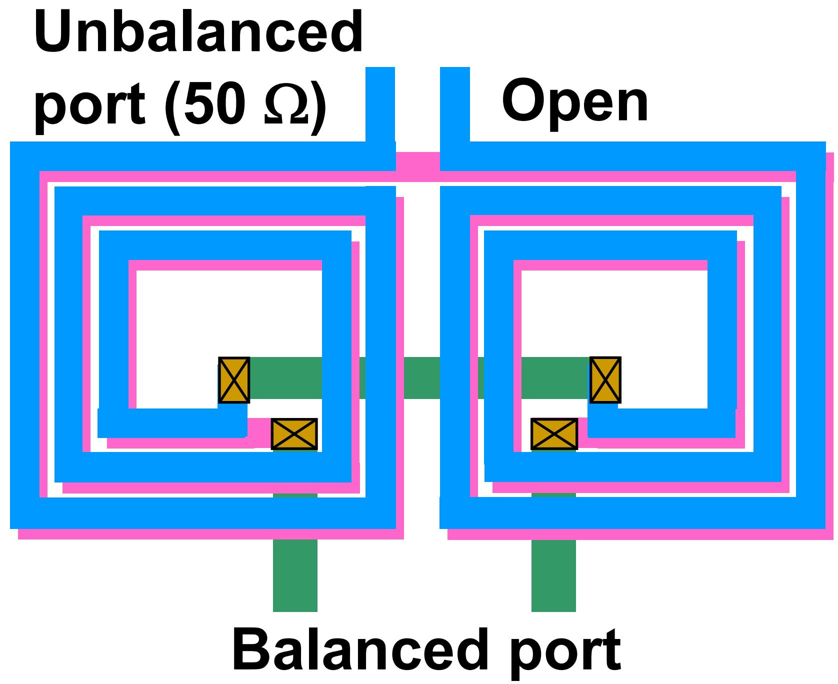
$V_{g,M2}$ tracks to envelope signal and the linearity of transconductor improves (OCP1dB=11 dBm → 14 dBm)

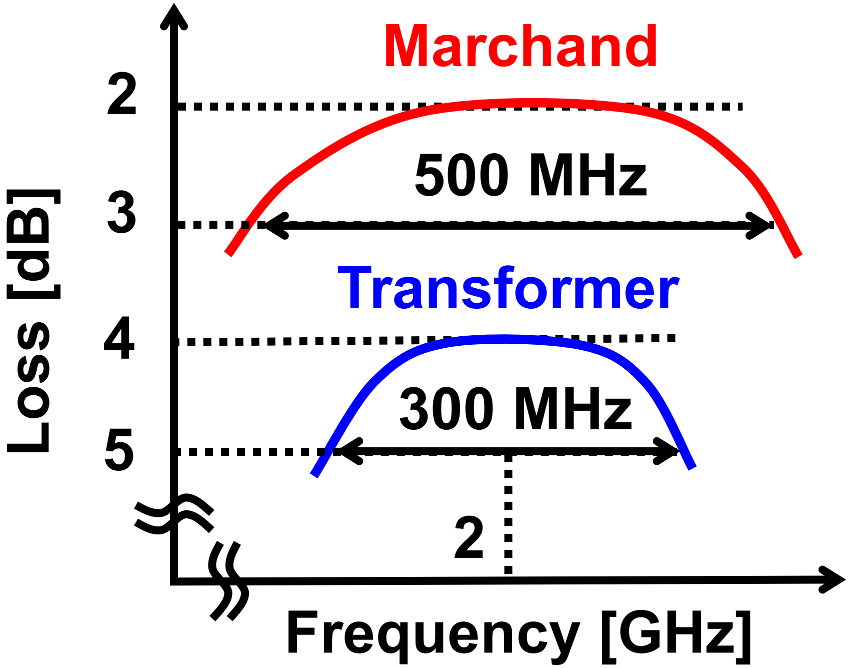
Envelope-Tracked Biasing Circuit



Marchand Balun



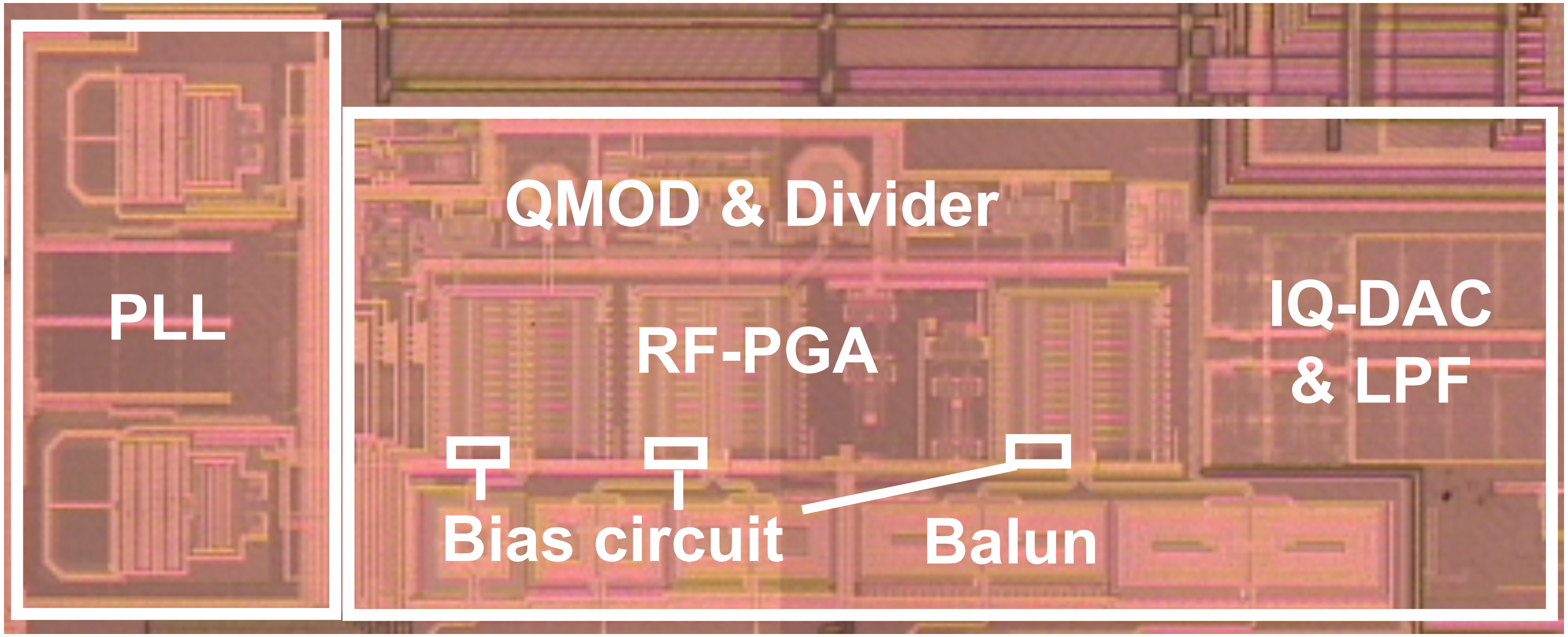




Marchand balun provides:

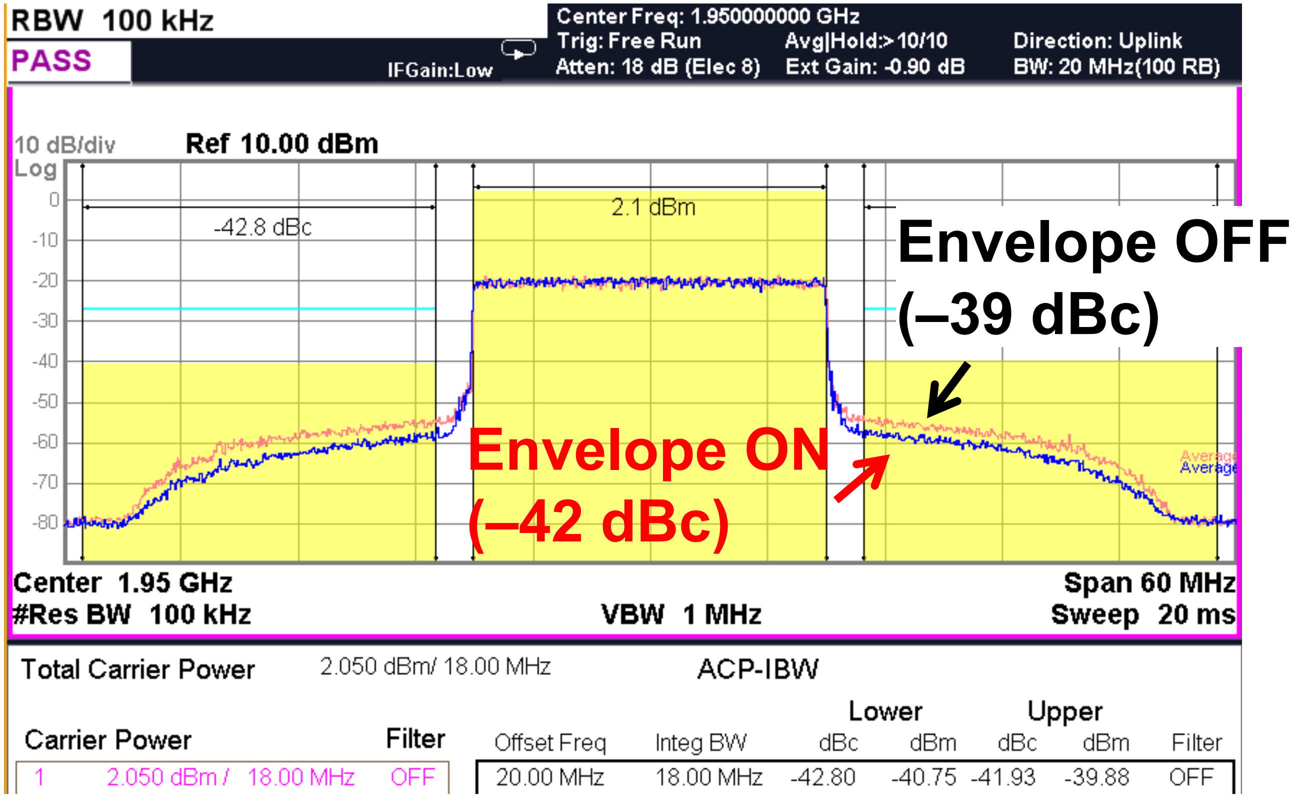
- Less loss (~2 dB)
- Broader 1-dB bandwidth (~500 MHz)

Microphotograph



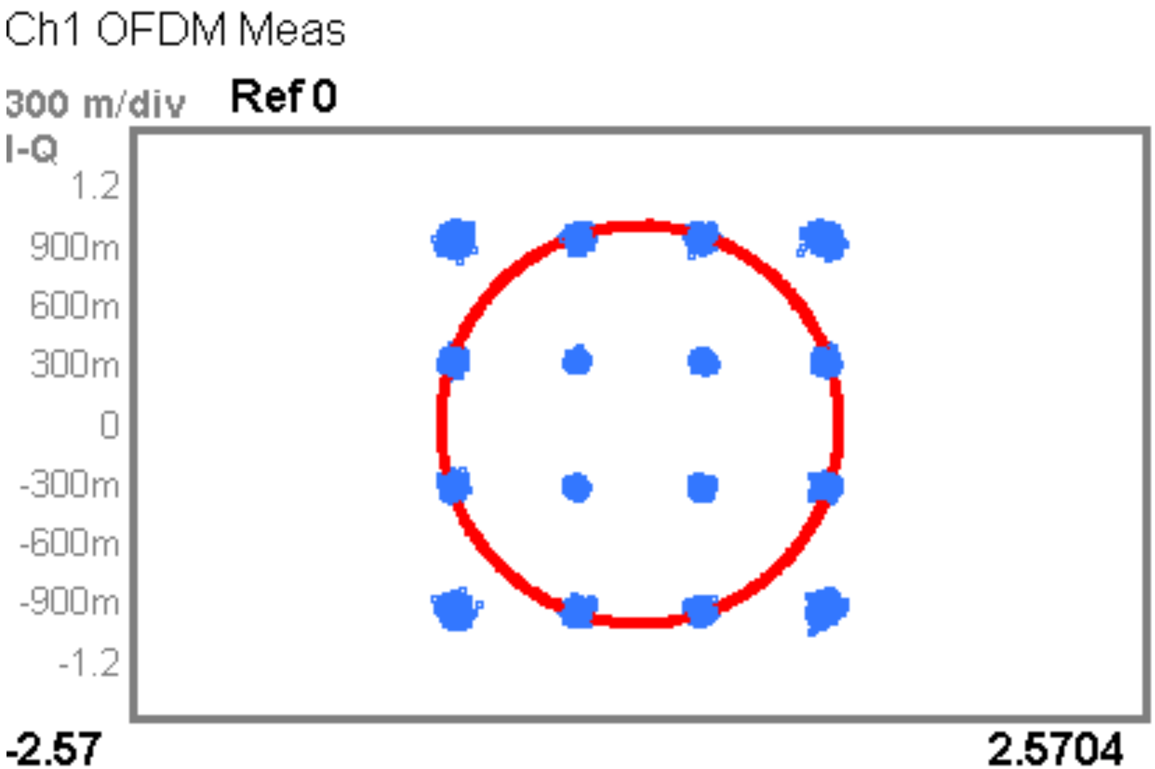
- 65-nm CMOS technology
- Chip area: 4.5 mm^2
- Ball grid array (BGA) package

Output Spectrum for LTE Signal



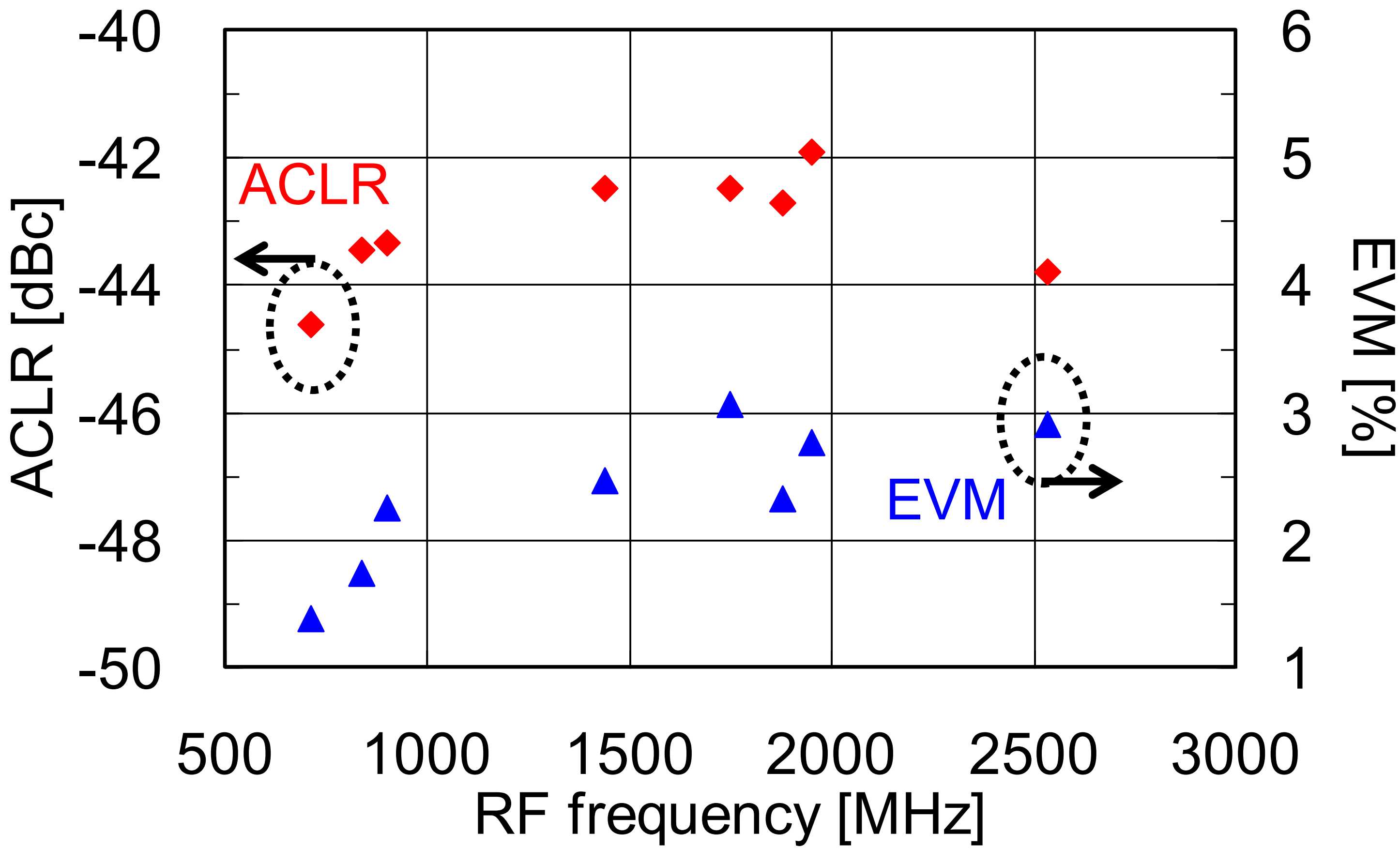
- LTE signal: 16 QAM and 20 MHz bandwidth
- Band 1 (1.95 GHz) and 2 dBm output power
- ACLR=–42 dBc (Envelope ON), –39 dBc (Envelope OFF)

EVM for LTE Signal



- LTE signal: 16 QAM and 20 MHz bandwidth
- Band 1 (1.95 GHz) and 2.1 dBm output power
- EVM=2.8% (Envelope ON)

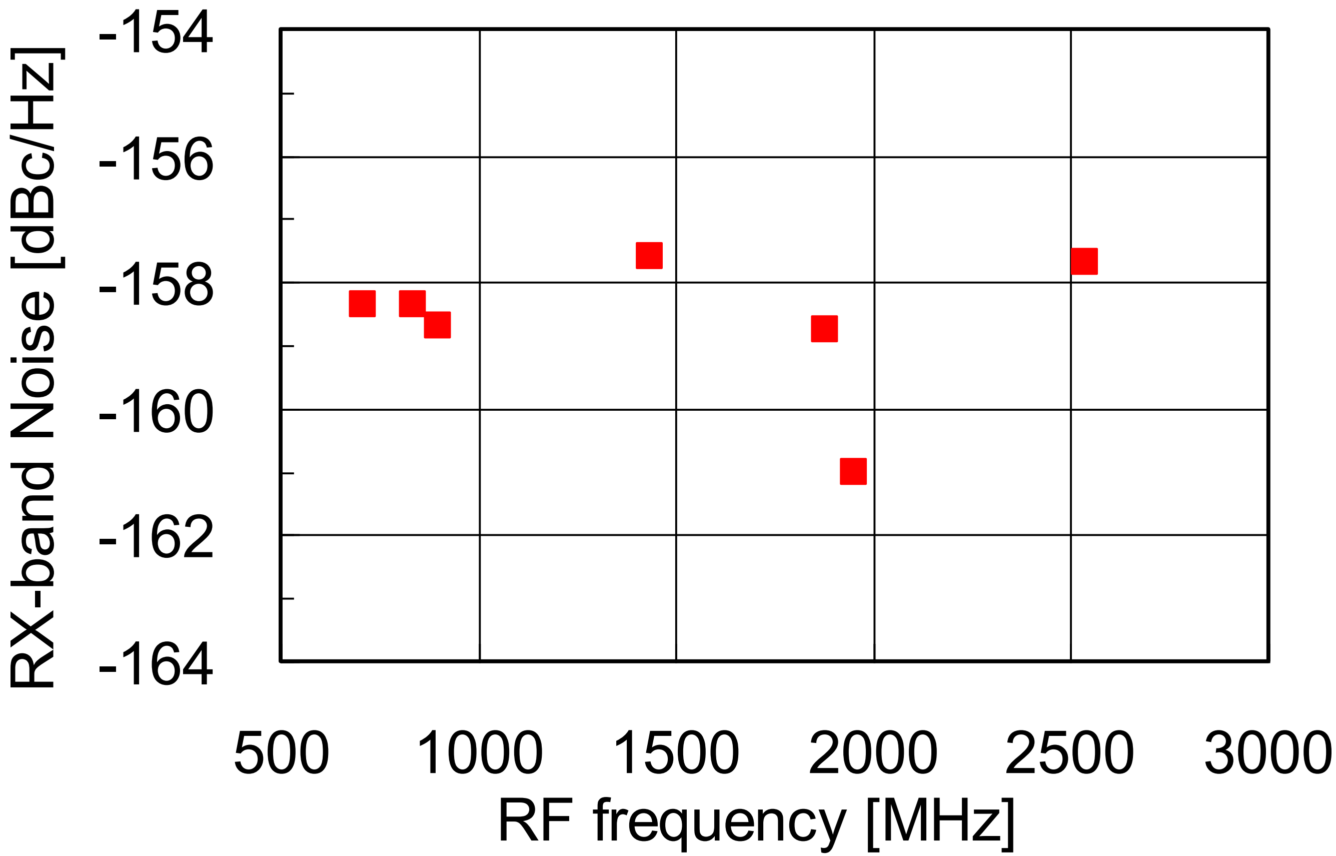
Measured ACLR and EVM



From 700 MHz to 2.6 GHz,

- ACLR<–42 dBc (3GPP ACLR spec.<–30 dBc)
- EVM<3% (3GPP EVM spec.<12.5%)

Measured RX-band Noise



From 700 MHz to 2.6 GHz,

- RX-band noise<–158 dBc/Hz

Performance Comparison for Band 1

Performance	This work	IMEC / Renesas* (ISSCC 2011)
Pout [dBm]	2.1	1.7
ACLR [dBc]	–42	–39
EVM [%]	2.8	2.5
RX-band noise [dBc/Hz]	–161	–160
Current [mA]	27/44 (1.2 V/2.8 V)	25/40 (1.1 V/2.5 V)

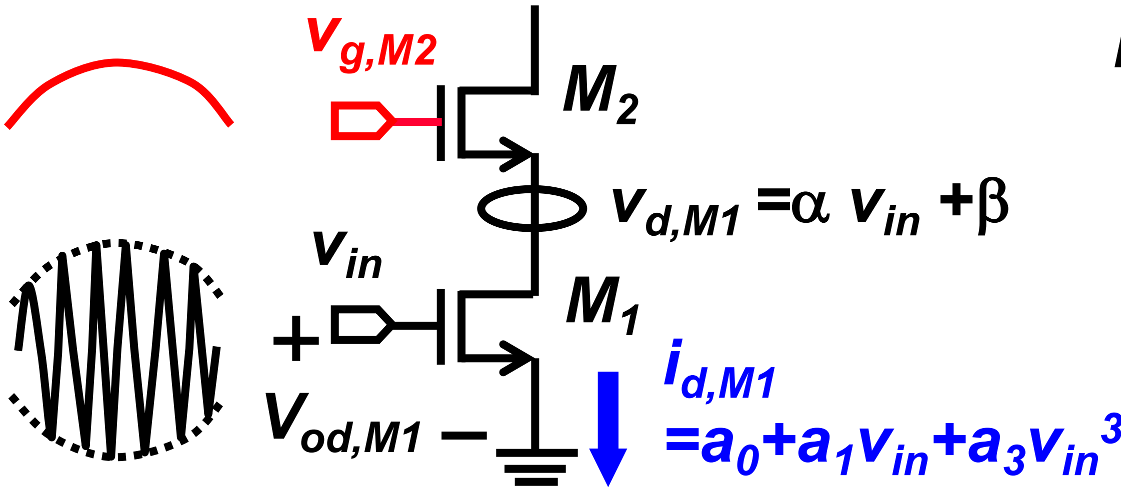
*: Without IQ-DAC and PLL

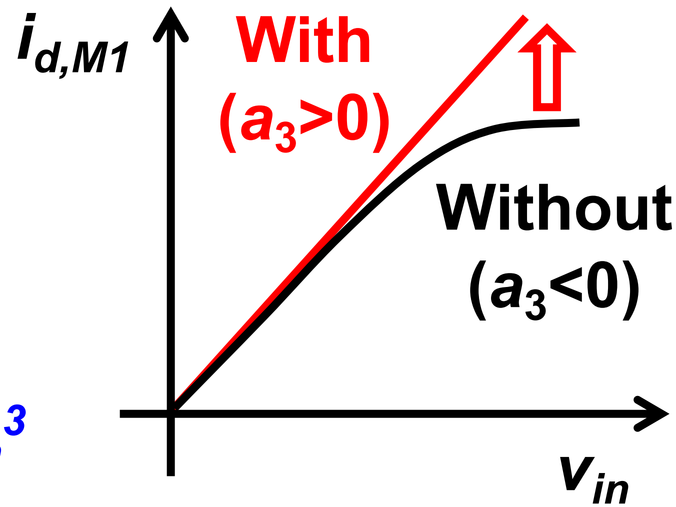
Summary

Multiband LTE SAW-less transmitter demonstrated:

- Source-follower-driven passive mixer
  - Reduces chip area (0.2 mm^2) and power consumption (13 mW)
- Envelope-tracked basing for RF-PGA
  - Improves ACLR by 3 dB
- Marchand balun
  - Provides less loss and broader 1-dB bandwidth than transformer
- ACLR<–42 dBc, EVM<3%, and RX-band noise <–158 dBc/Hz from 700 MHz to 2.6 GHz

Envelope-Tracked Biasing



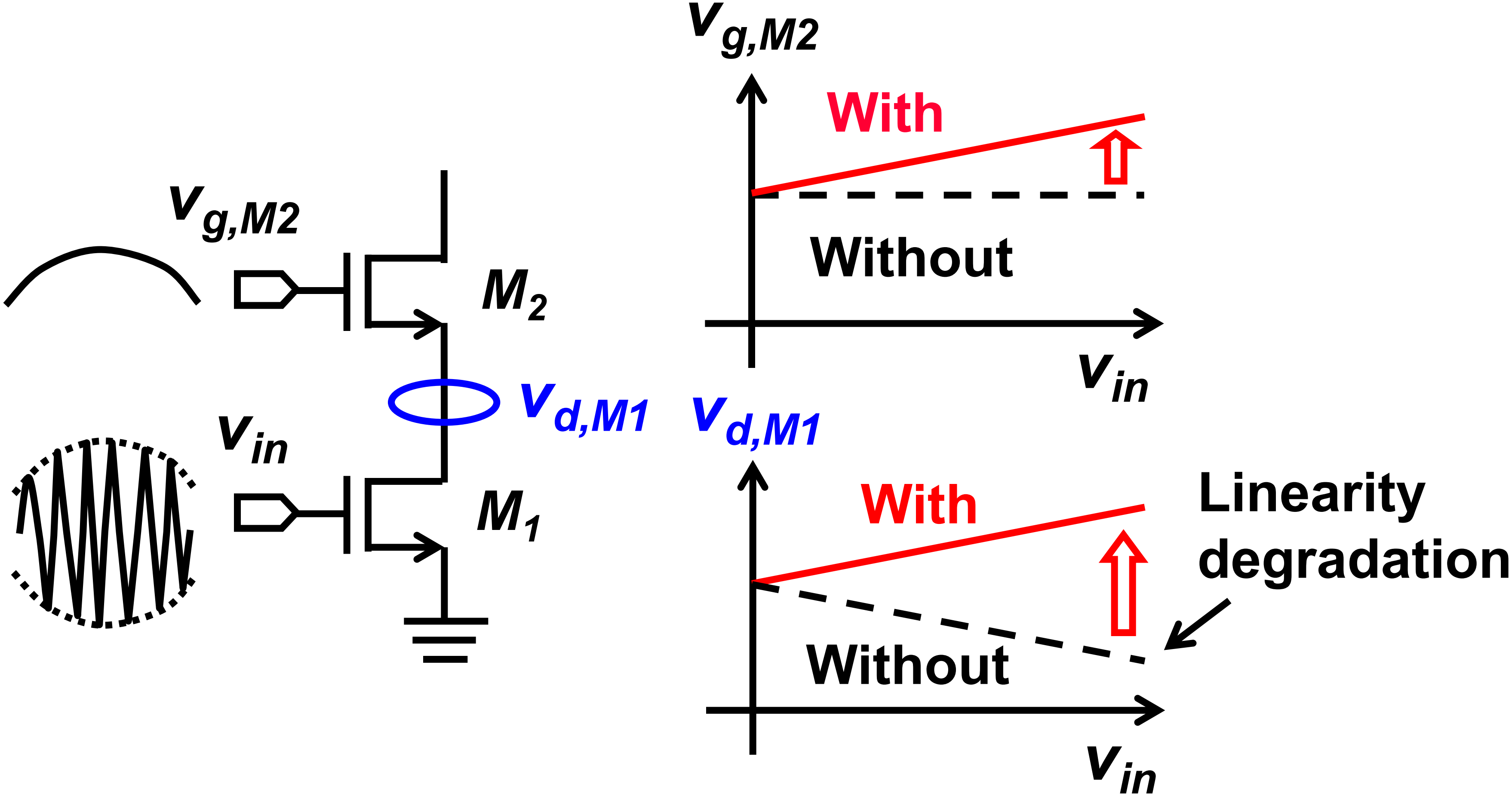


	With	Without
$\frac{a_1}{a_3}$	$V_{od,M1}^2 + \frac{1}{\alpha}\left(2\beta + \frac{2}{\lambda}\right)V_{od,M1}$	$V_{od,M1}^2 - \left(2\beta + \frac{2}{\lambda}\right)V_{od,M1}$

λ: Channel-length modulation coefficient

The gate voltage of M2 ($v_{g,M2}$) tracks to envelope signal and the linearity of transconductor improves

Envelope-Tracked Biasing (1)



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