

Lecture 02a 5G Smartphone RF Front End Technology

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11. Summary

Acronyms

1. 4G/5G Dual Connectivity

EPC: Evolved Packet Core (LTE Core Network)

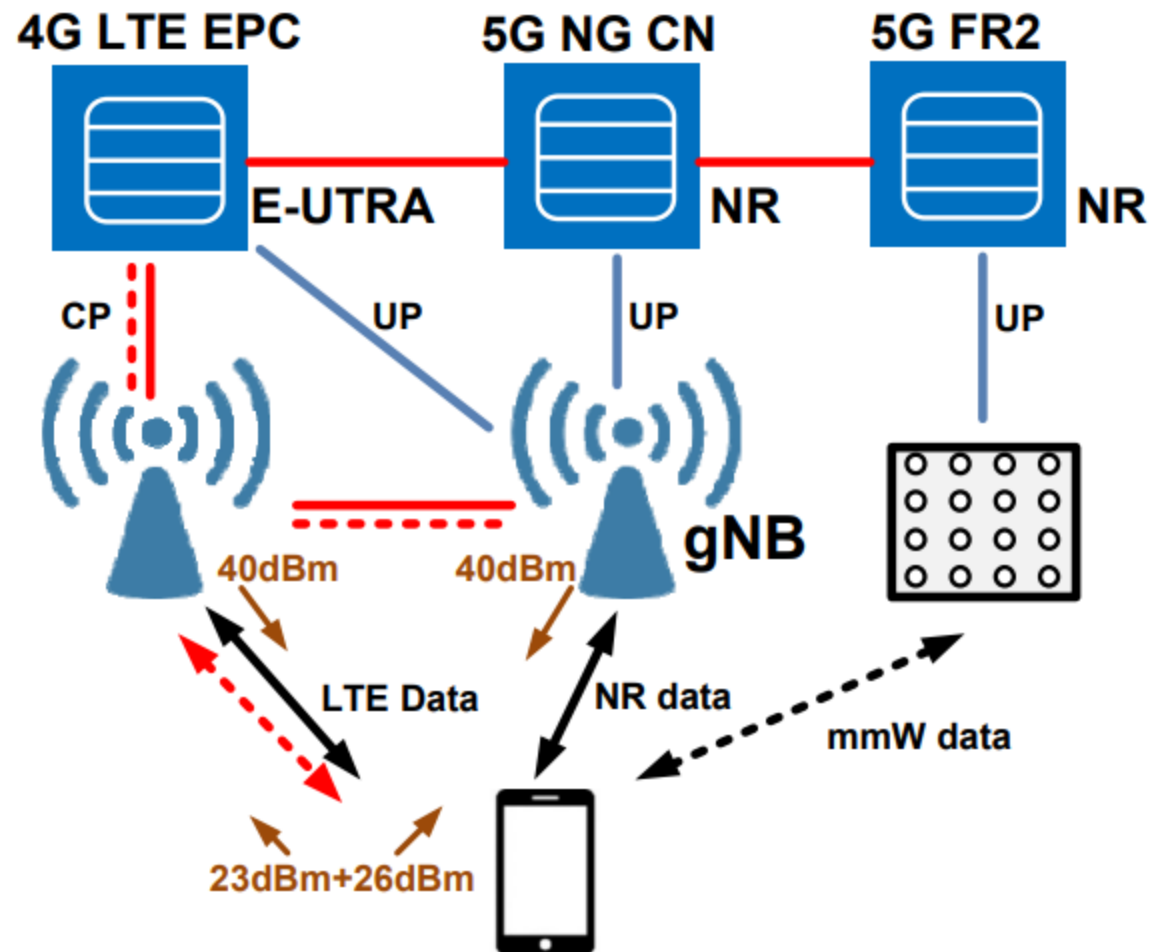
NG CN: New Generation Core Network, 5G-CN

eNb: eNodeB, 4G LTE basestation

gNb: gNodeB, 5G NR basestation

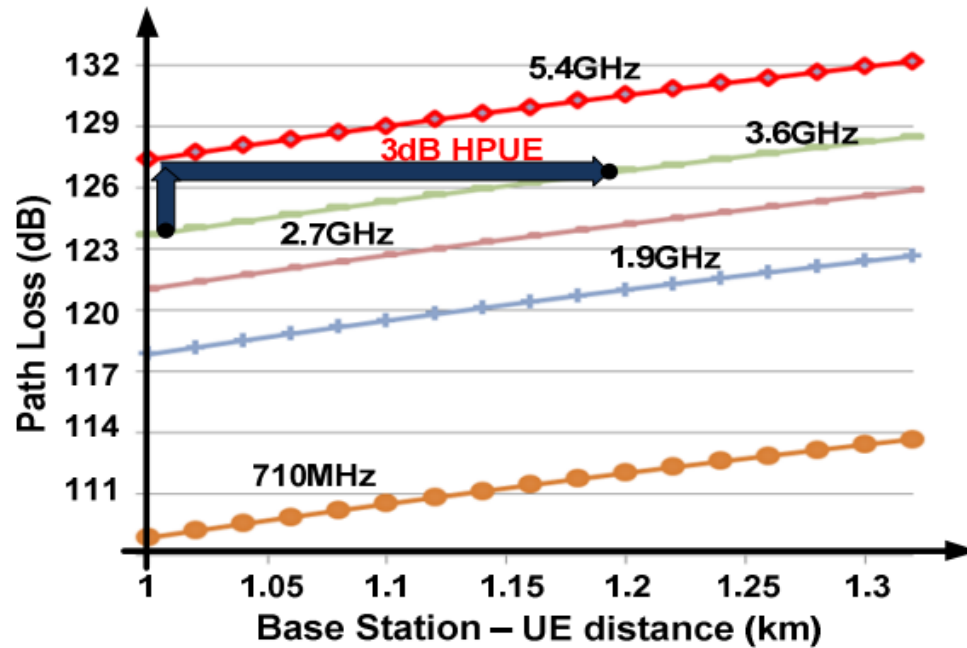
UP/CP: User-Plane/Control-Plane

mmW: 5G mmW Core Network



2. Path Loss in Radio Links

- Path loss (PL): Loss of received power due to distance
- 15-m height base-station to mobile path loss



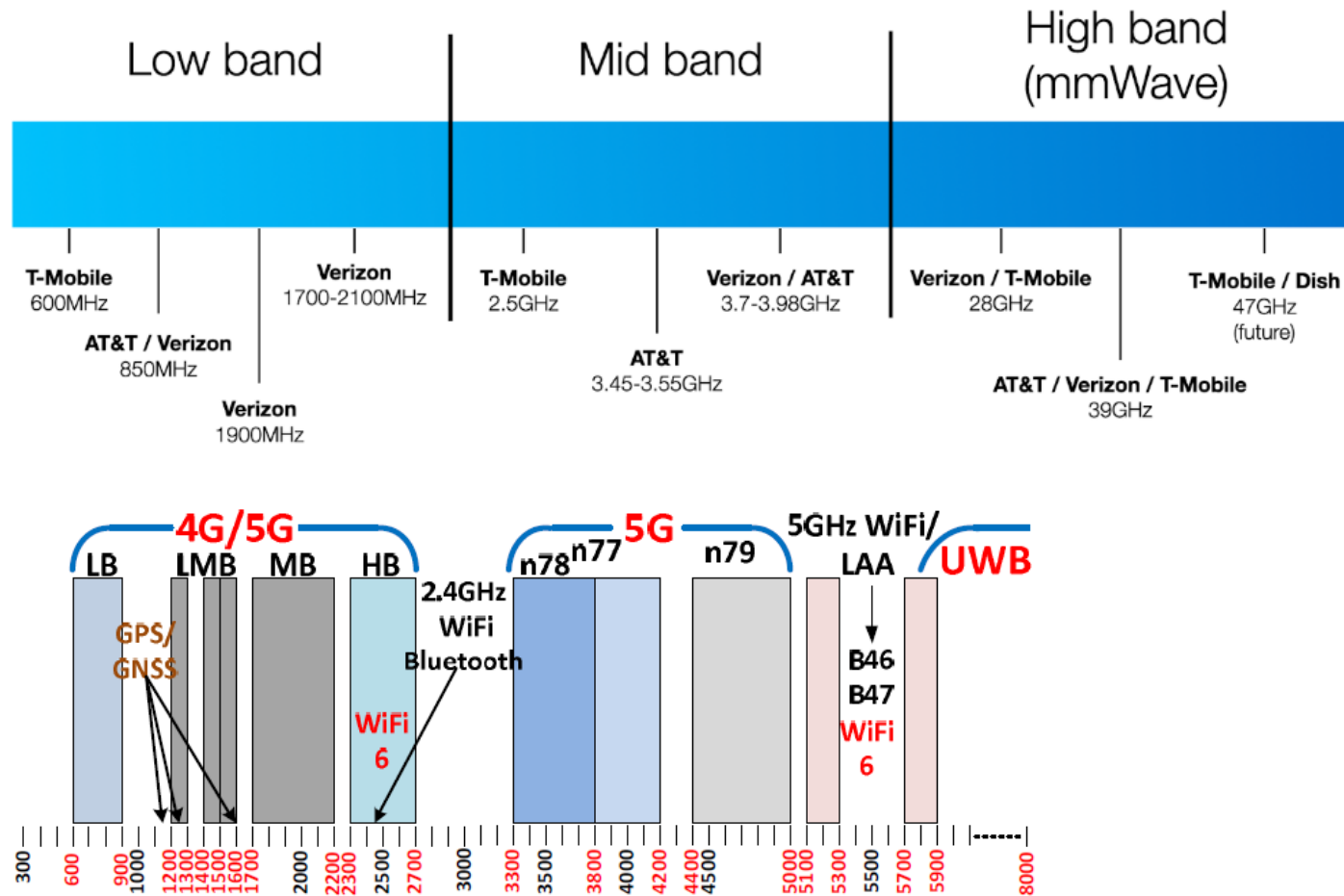
$$PL_{dB} = 10\log_{10} R^4 + 21\log_{10} f + K \quad (2)$$

- Distance dependence: $1/R^4$
- Frequency dependence: Different for different propagation scenarios

Outdoor-to-outdoor: $1/f^2$

Outdoor-to-indoor: $1/f^3$

3. 4G/5G Frequency Plan



- 5G NR (New Radio) bands are defined with prefix of "n".
- n77/n78: 3.3-4.2 GHz, n79: 4.4-4.5 GHz
- 5G UW, 5G UWB: Verizon's version of mmWave and mid-band 5G

3. 4G/5G Frequency Plan

- iPhone 15 (2023-10-13 on the market) cellular and wireless functionality

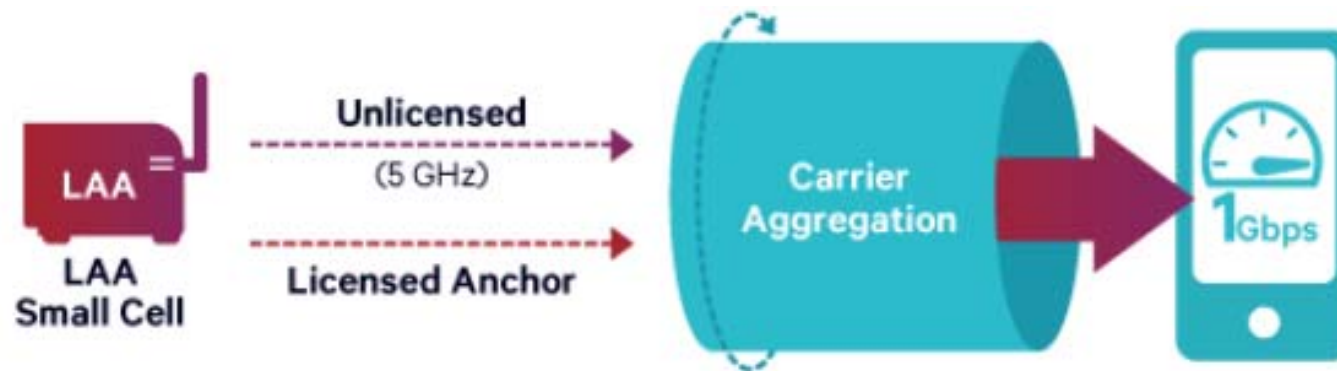
Model A2846*	5G NR (Bands n1, n2, n3, n5, n7, n8, n12, n14, n20, n25, n26, n28, n29, n30, n38, n40, n41, n48, n53, n66, n70, n71, n75, n76, n77, n78, n79)
Model A2847*	5G NR mmWave (Bands n258, n260, n261)
	FDD-LTE (Bands 1, 2, 3, 4, 5, 7, 8, 12, 13, 14, 17, 18, 19, 20, 25, 26, 28, 29, 30, 32, 66, 71)
	TD-LTE (Bands 34, 38, 39, 40, 41, 42, 46, 48, 53)
	UMTS/HSPA+/DC-HSDPA (850, 900, 1700/2100, 1900, 2100 MHz)
	GSM/EDGE (850, 900, 1800, 1900 MHz)

All models	5G (sub-6 GHz and mmWave) with 4x4 MIMO ¹⁰
	Gigabit LTE with 4x4 MIMO and LAA ¹⁰
	Wi-Fi 6 (802.11ax) with 2x2 MIMO
	Bluetooth 5.3
	Second-generation Ultra Wideband chip ¹¹
	NFC with reader mode
	Express Cards with power reserve

Location	GPS, GLONASS, Galileo, QZSS, and BeiDou
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3. 4G/5G Frequency Plan

- License Assisted Access (LAA)



License Assisted Access (LAA) is a feature of LTE that leverages the unlicensed 5 GHz band in combination with licensed spectrum to deliver a performance boost for mobile device users. It uses carrier aggregation in the downlink to combine LTE in unlicensed 5 GHz band with LTE in the licensed band to provide better data rates and a better user experience.

Since this technology operates in the 5 GHz band where Wi-Fi operates, it must be able to co-exist with Wi-Fi by avoiding channels that are being used by Wi-Fi users. LAA uses a concept called Listen-before-talk (LBT) which dynamically selects channels in the 5 GHz band which are not being used by Wi-Fi users. If there is no clear channel available, LAA will share a channel fairly with others.

4. Channel Capacity

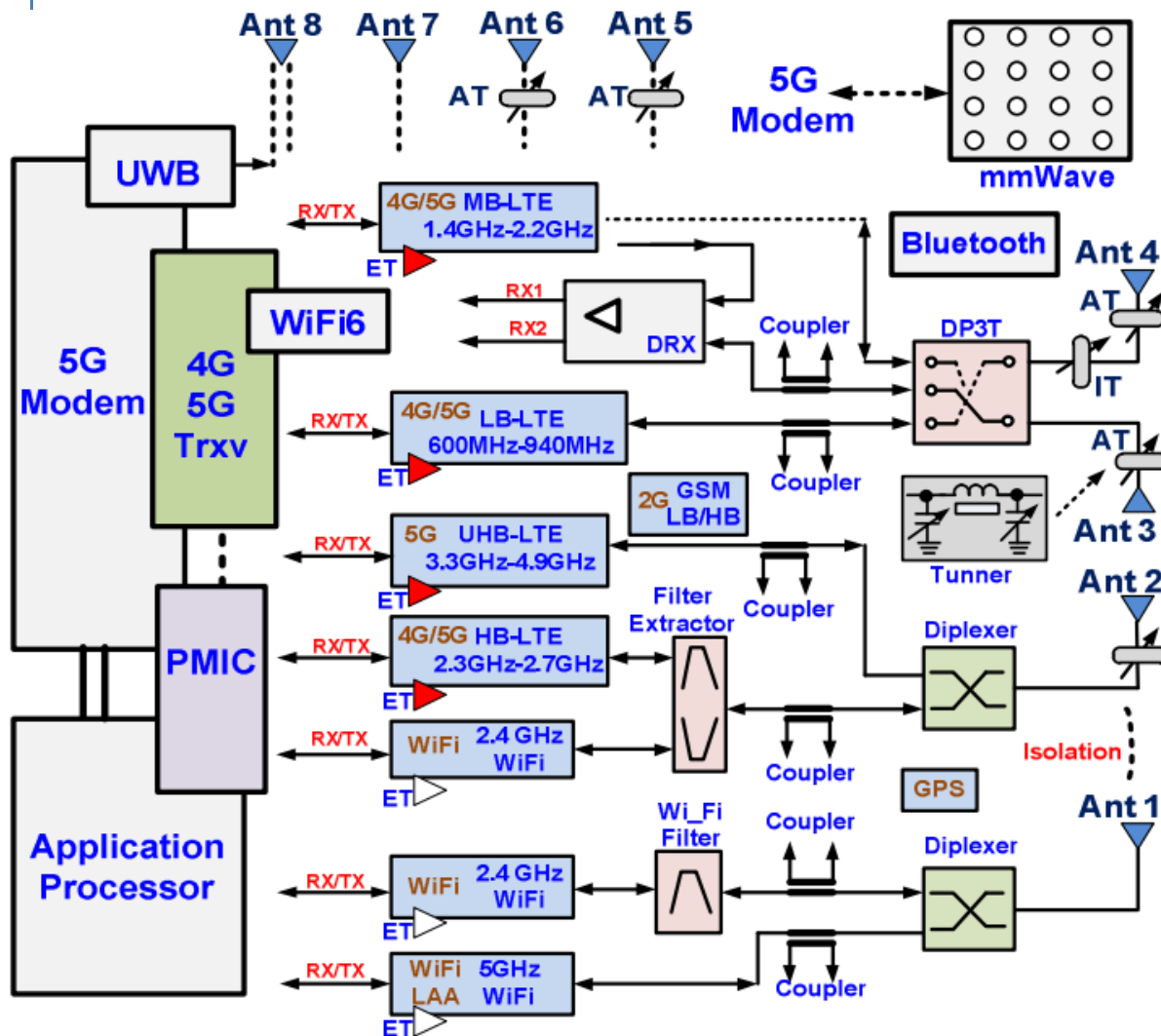
- Shannon formula for channel capacity (bps)
- ET (Envelope Tracking)

$$C = B_w \sum_{k=1}^k \log_2 \left(1 + \frac{en * S_k}{N_x + I_k} \right) \quad (1)$$

To achieve higher capacity following Eq.1 these are the techniques which are incorporated in 5G:

- increase channel bandwidth B_w ; eg 100MHz LTE.
- increase spatial multiplexing level k through MIMO
- increase the transmit power; such as 26dBm (HPUE).
- decrease noise N_x and improve receive sensitivity.
- reduce in-band interference on link k , especially in multiple UL Tx such as CA and MIMO.
- higher order modulation such as 256QAM for UL
- increase signal S_k through use of ET – en factor.

5. 4G/5G Front End Architecture

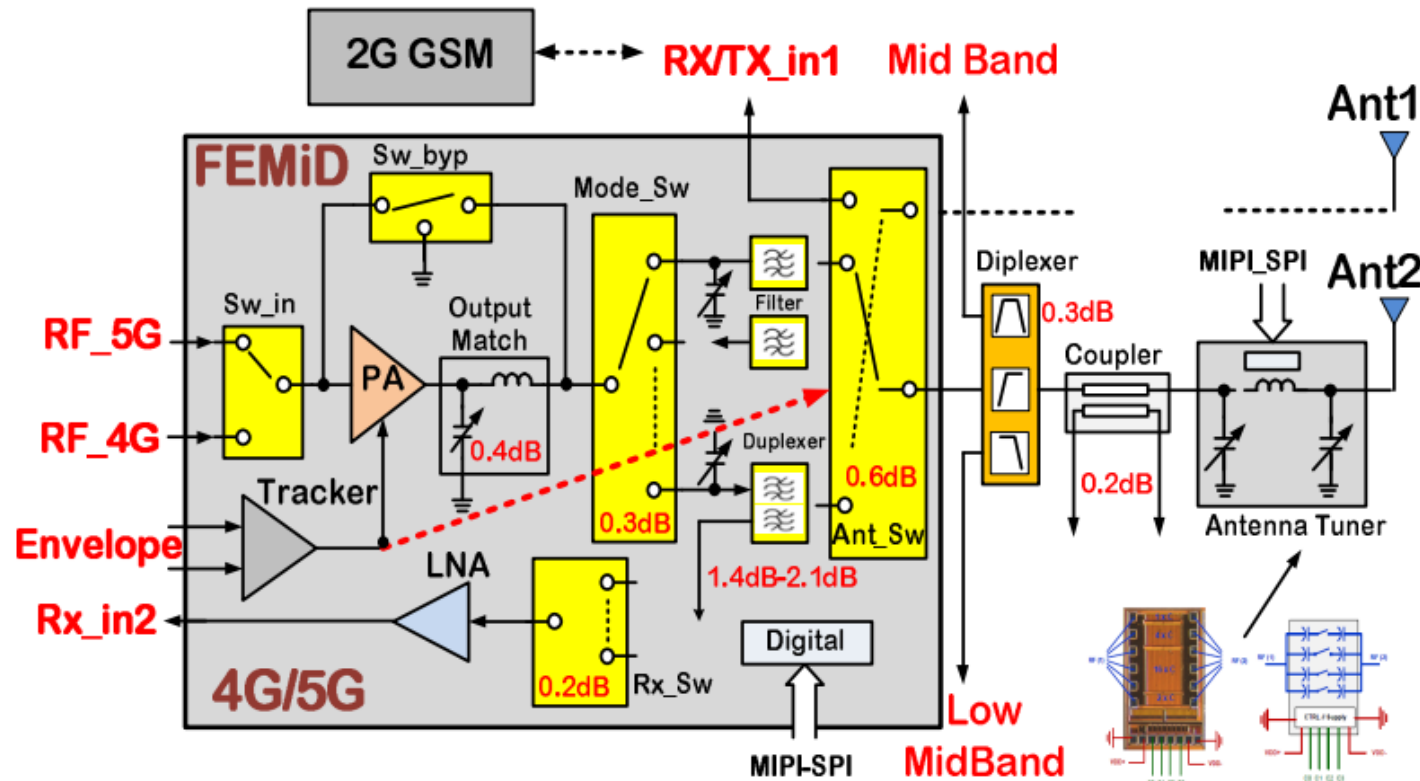


- Ant: Antenna
- AT: Attenuator
- IT: Isolator
- Coupler: Directional coupler
- DRx: Diversity receiver
- Tx: Transmit, transmitter
- Rx: Receive, receiver
- PMIC: Power management IC
- Modem: Modulator-demodulator
- UWB: Ultrawideband, 5G UW

6. 5G RF Front End Features

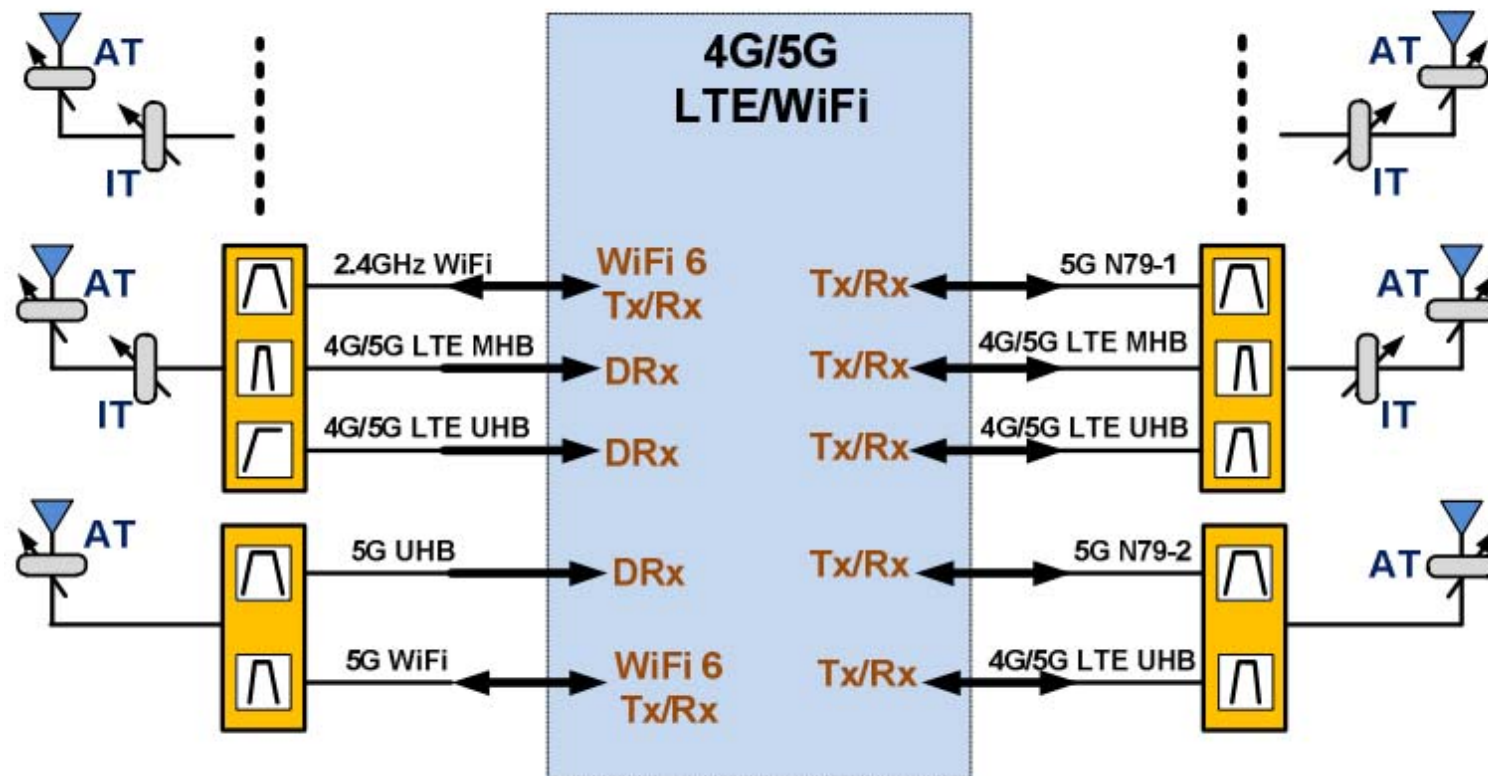
- Wider channel bandwidth: Up to 100 MHz
- HPUE (High Power User Equipment): 26 dBm = 400 mW
- Modulation: 64-QAM, 256-QAM
- 2 x 2 UL (Uplink) MIMO
- New 5G dedicated bands for sub-6 GHz: n77/n78, n79

7. 4G/5G Front End Module Architecture



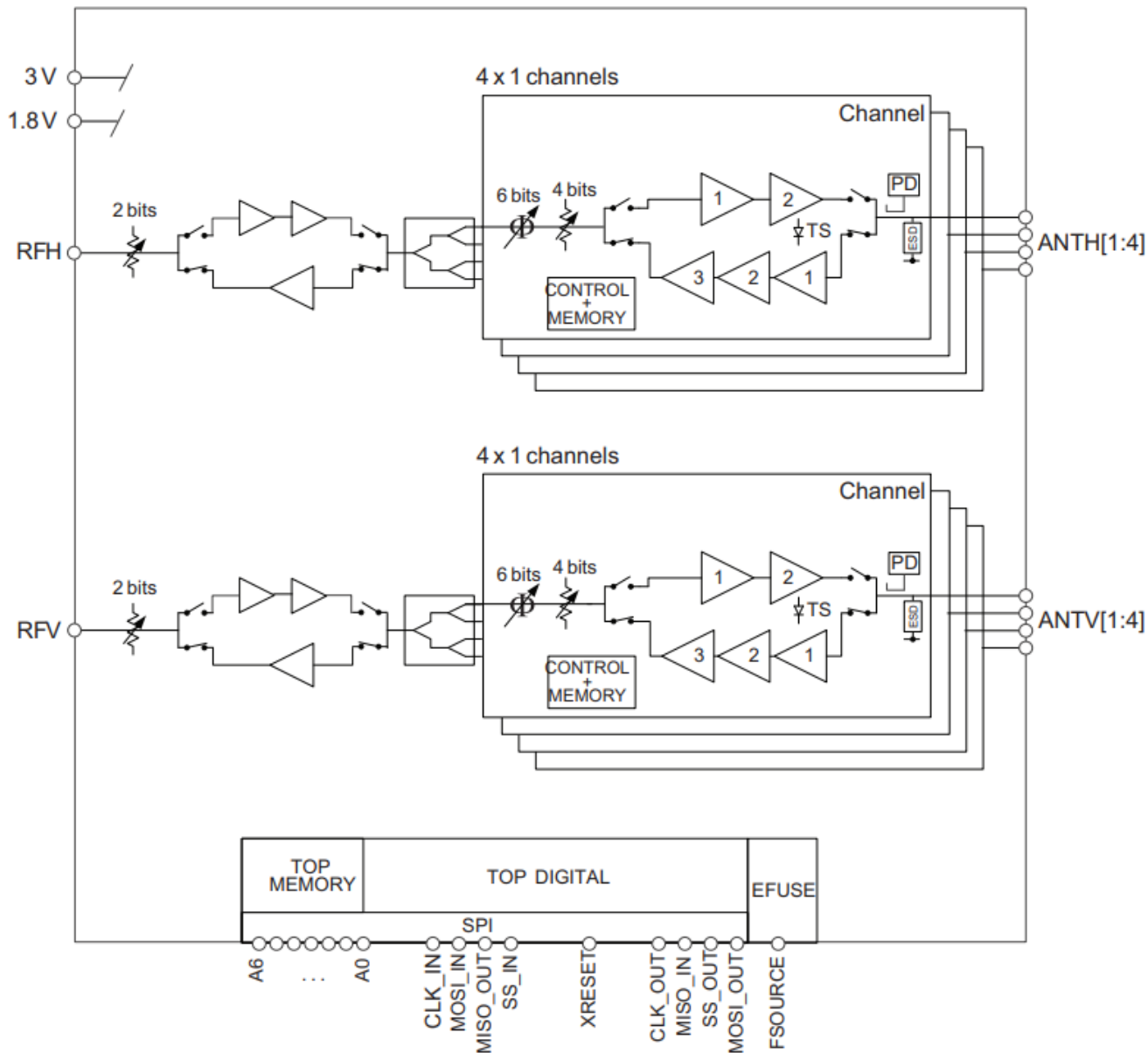
- FEM: Front End Module
- PA: Power Amplifier
- SW: Switch
- LNA: Low Noise Amplifier
- Ant: Antenna
- MIPI-SPI: Mobile Industry Processor Interface - Serial Peripheral Interface

8. MIMO Front End Module

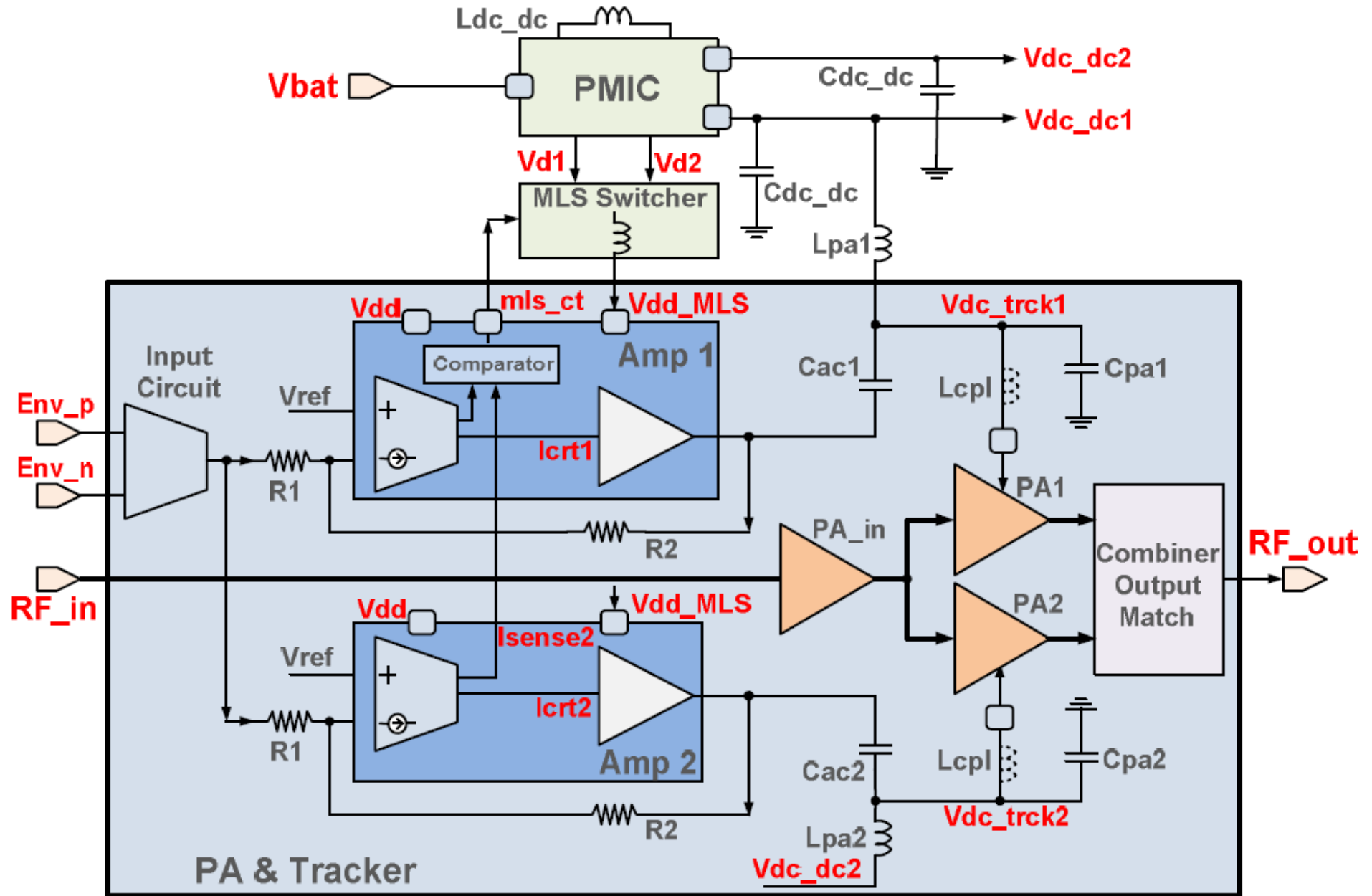


8. MIMO Front End Module

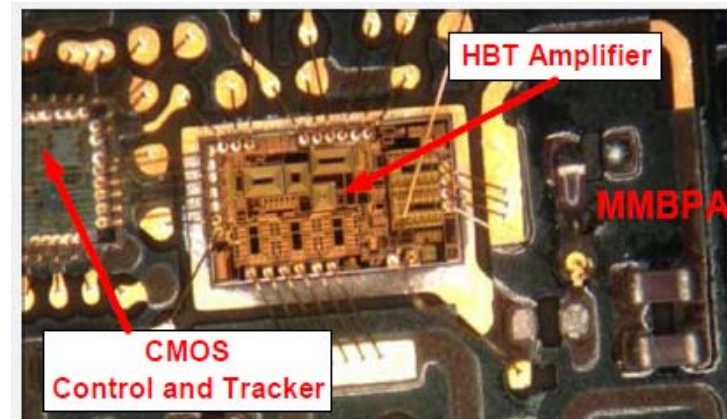
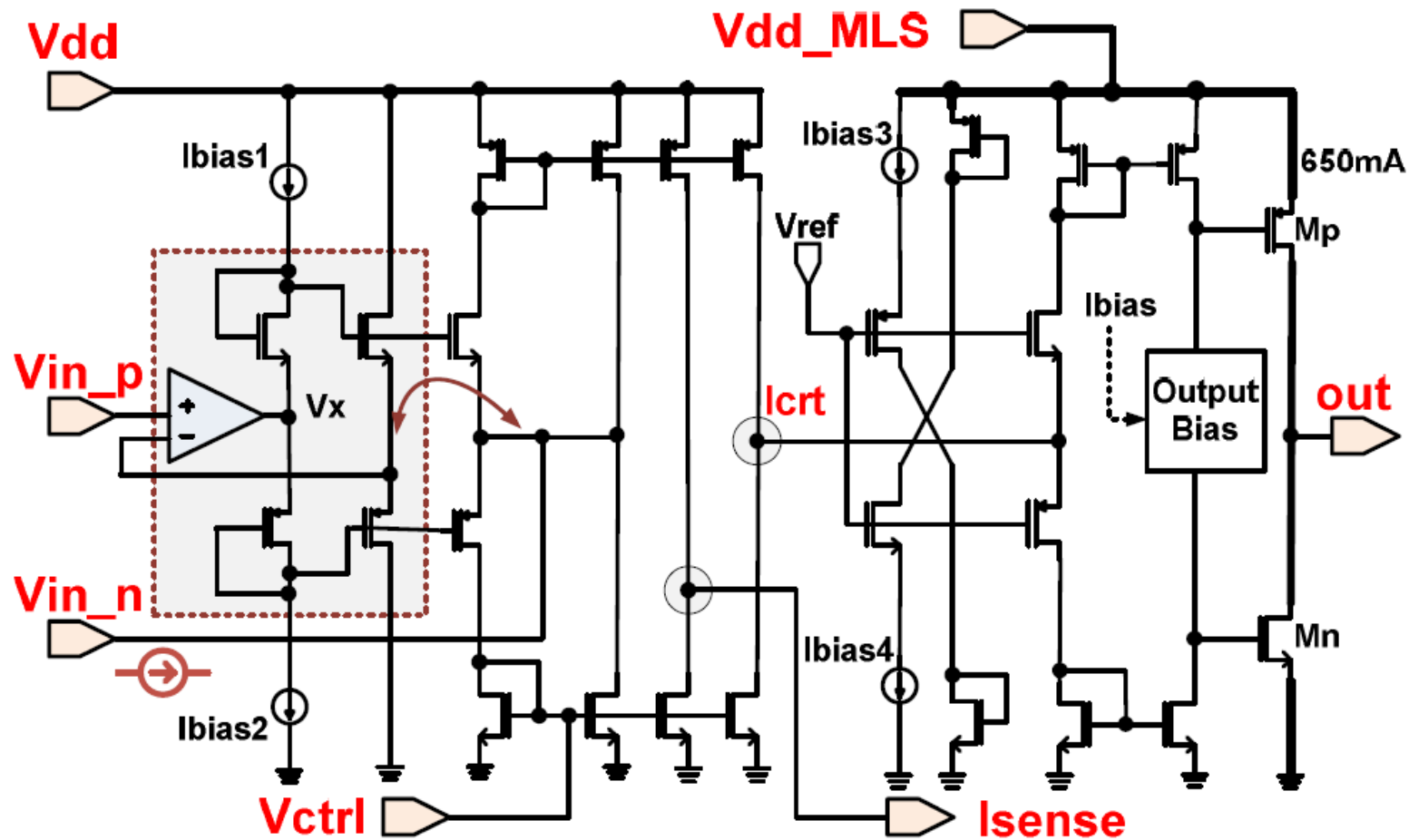
- PSemi (a Murata company) PE188100 8-ch beamforming front end
- TDD SW, PA, LNA, Splitter, Combiner, AT, Phase shifter, PD



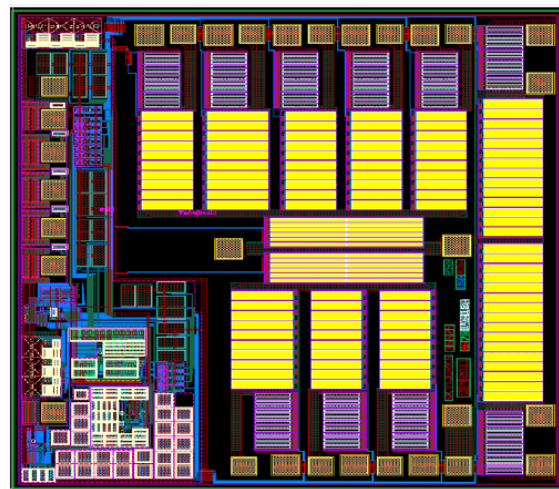
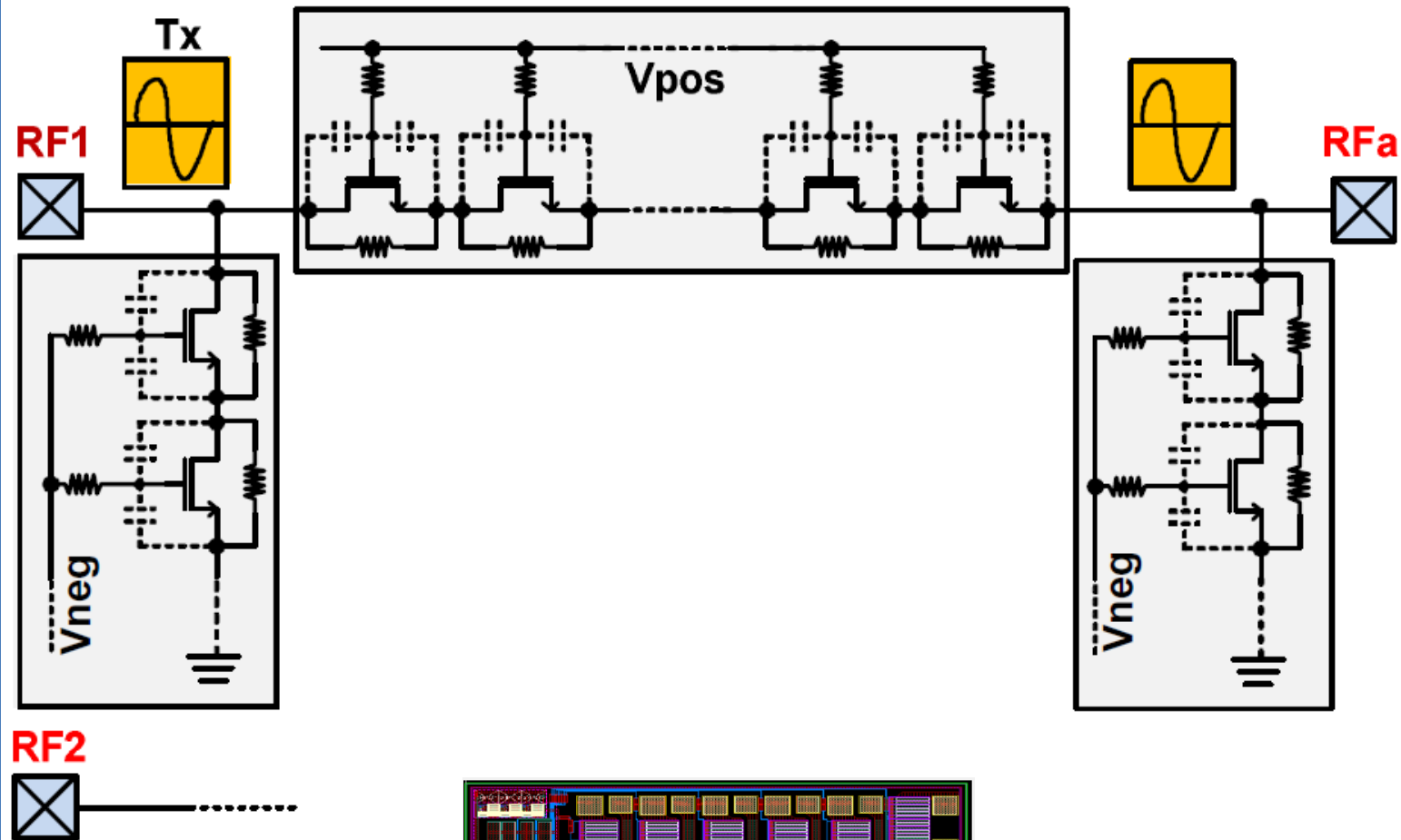
9. Envelope Tracking Power Amplifier



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10. Silicocon-On-Insulator Switch



SOI 1.5mm x 1.3mm

11. Summary

- Radio technology: As important as camera technology in smartphones
- Why?: It determines the speed and cost of communications.
- Why speed?: Huge data retrieval from servers for ever-evolving applications
- Why cost?: Infrastructure cost, user device cost

- RFFE:

Active components: PA, LNA

Passive components: SW, AT, IT, Coupler, Duplex

Digital control

- In semiconductor perspective:

Analog IC, RFIC

Major companies:

Infineon, Qualcomm, Broadcomm (Avago)

Qorvo, Skyworks, NXP, STMicro, Renesas

Acronyms

5G NR: Fifth Generation New Radio

5G UC: 5G Ultra Connectivity, low latency & high speed

bps: bit per second, a unit for channel capacity or communication speed

CA: Carrier Aggregation

CMOS: Complementary Metal Oxide Semiconductor

DL: Downlink

DRx: Diversity Receiver

DSP: Digital Signal Processing

eMBB: Enhanced Mobile Broadband

ET: Envelope Tracking

FEM: Front-End Module

FR1: Frequency Range 1

LAA: License-Assisted Access

LNA: Low Noise Amplifier

MCM: Multi-Chip Module

MHB: Mid-High Band, n41

MIMO: Multiple Input Multiple Output

MMB: Millimeter Wave Mobile Broadband

Acronyms

mMTC: Massive Machine-Type Communications

mmWave: Millimeter Wave, > 24 GHz or 30 GHz

PA: Power Amplifier

PMIC: Power Management Integrated Circuit

RF: Radio Frequency

SOI: Silicon On Insulator

TDD: Time Division Duplex

Tx: Transmitter

UHB: Ultra-High Band, n77/n78, n79

UL: Uplink

URLLC: Ultra Reliable Low Latency Communications

UWB: Ultra-Wide Band

USIM: Universal Subscriber Identification Module

V2X: Vehicle To Everything

Fin
(End)