An HCI-Healing 60GHz CMOS Transceiver

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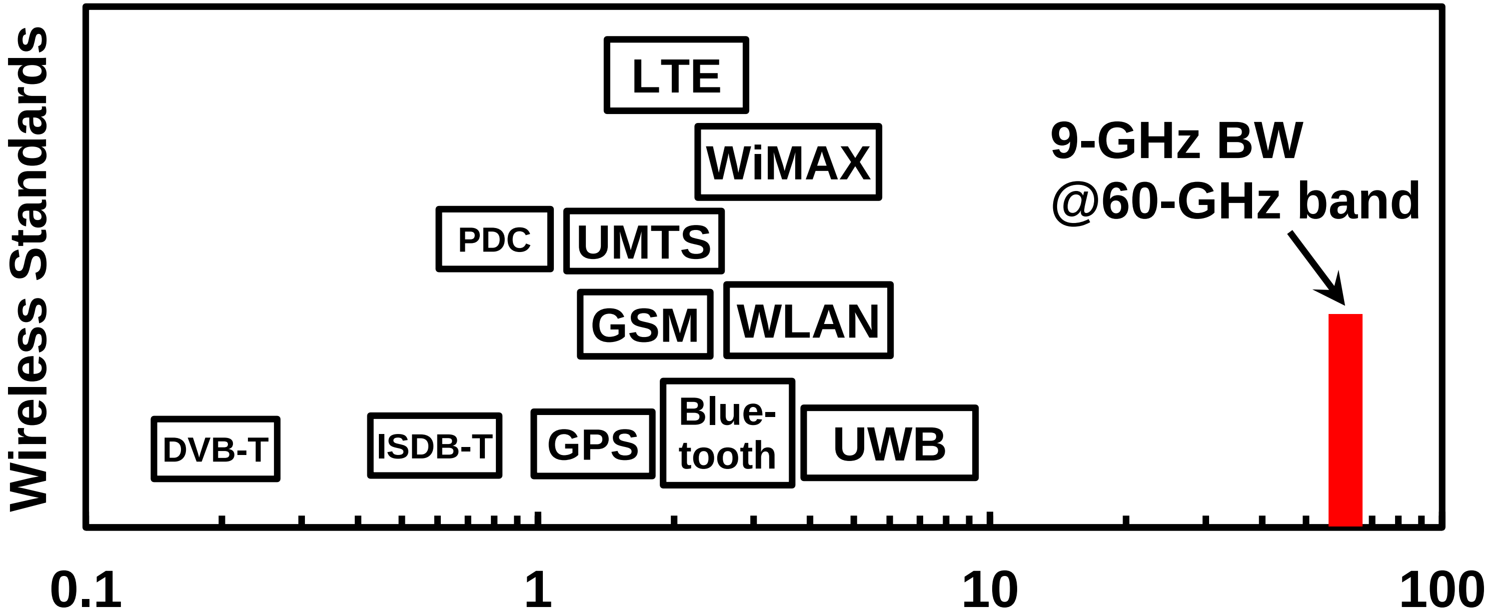
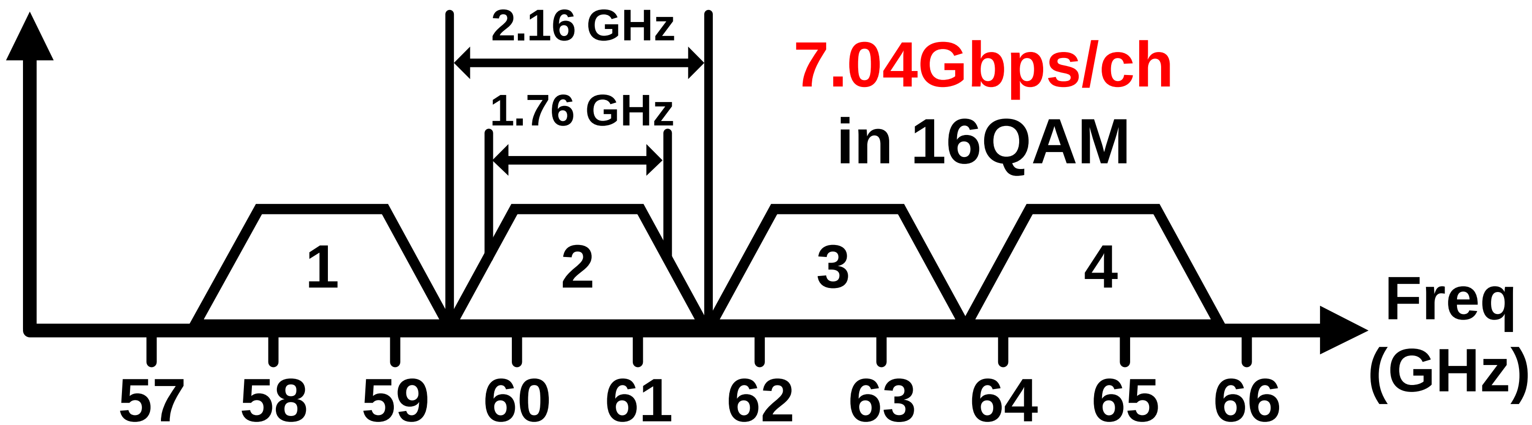
Outline

- Motivation
- Hot-Carrier-Injection Issues,
  Prior Arts and Proposed Solution
- Proposed HCI-Healing 60GHz TRX
  - Detailed circuit implementation
- Measurement and Comparison
- Conclusion

60GHz-Band Capability



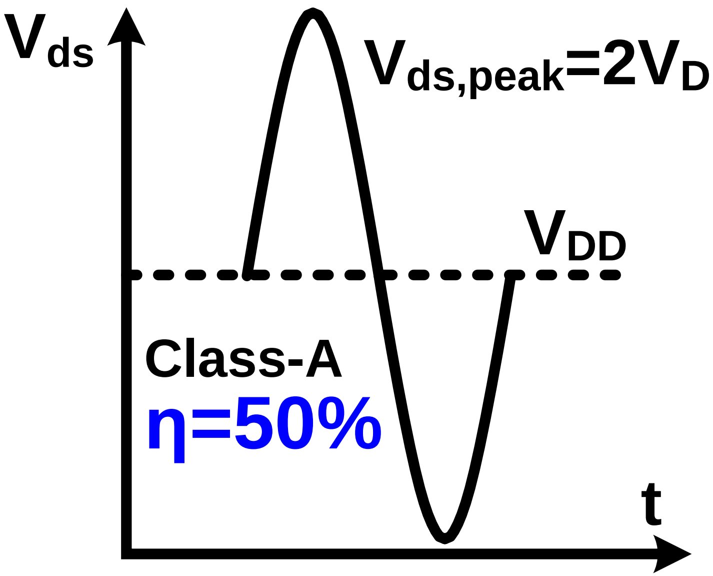


Channels of IEEE 802.11ad standard

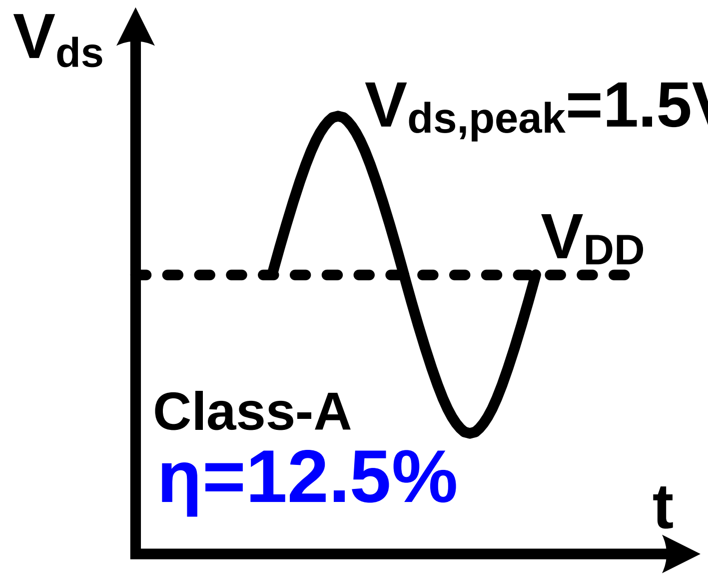
Hot-Carrier-Injection Issue in CMOS (1/2)

CMOS power amplifier

Drain efficiency: $\eta = P_{out}/P_{DC}$

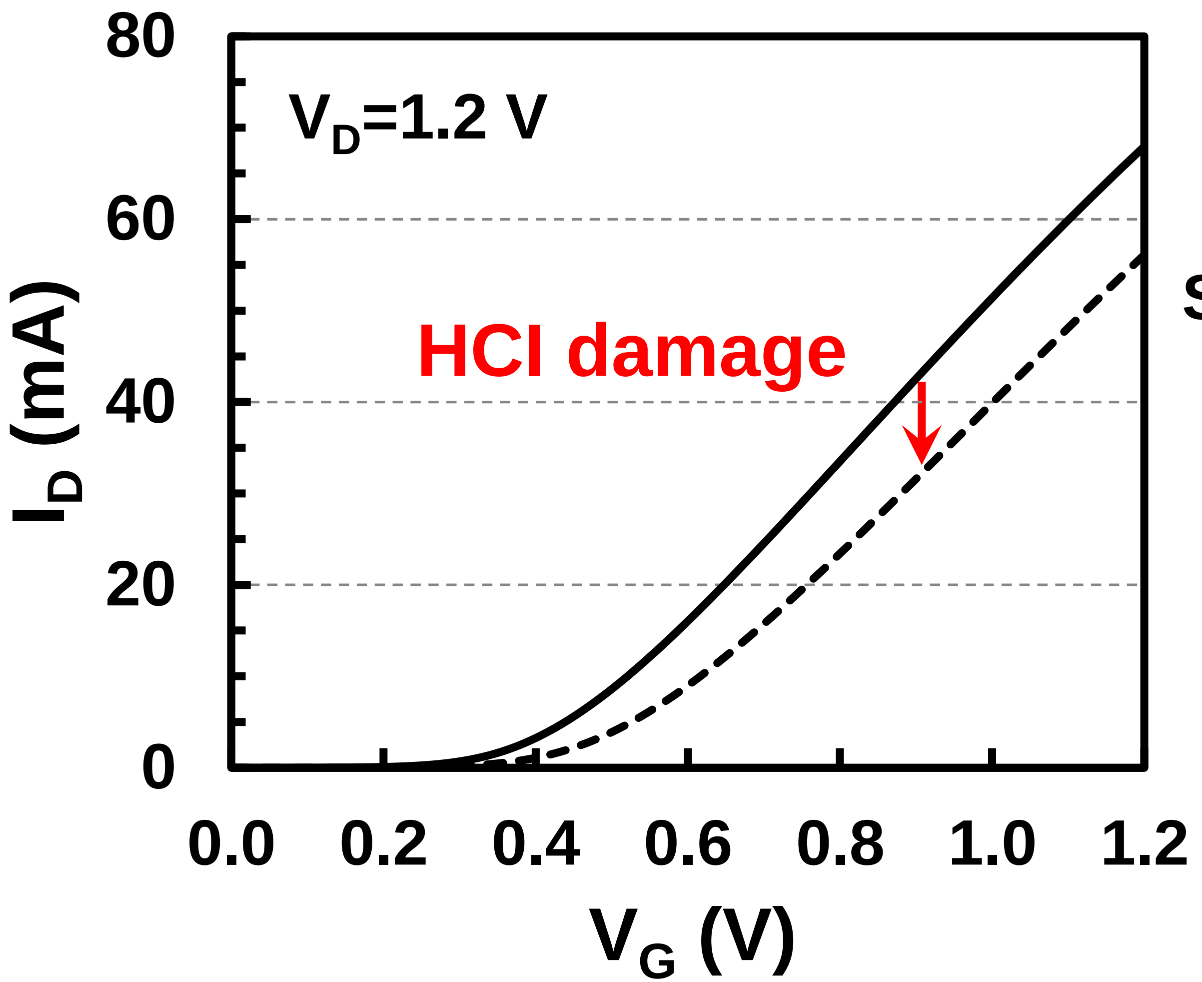


Large $V_{ds,peak}$
HCI damage



Small $V_{ds,peak}$
Low efficiency

Hot-Carrier-Injection Issue in CMOS (2/2)

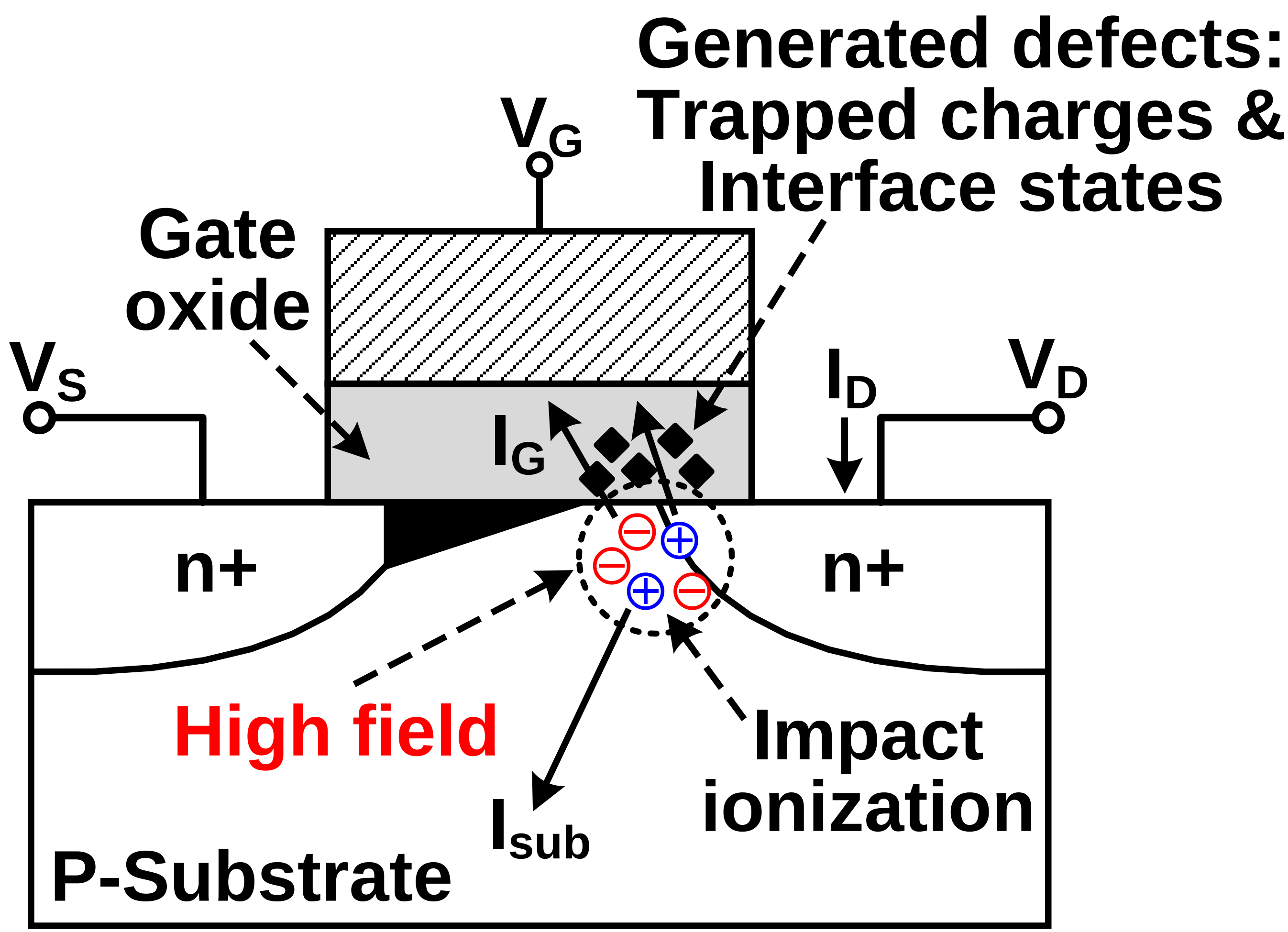


Stress cond.

V_D=2.4V
V_G=0.8V
1 hour

Lifetime: the time when ΔI_{DS} = 10% @ saturation

Hot-Carrier-Injection Mechanism

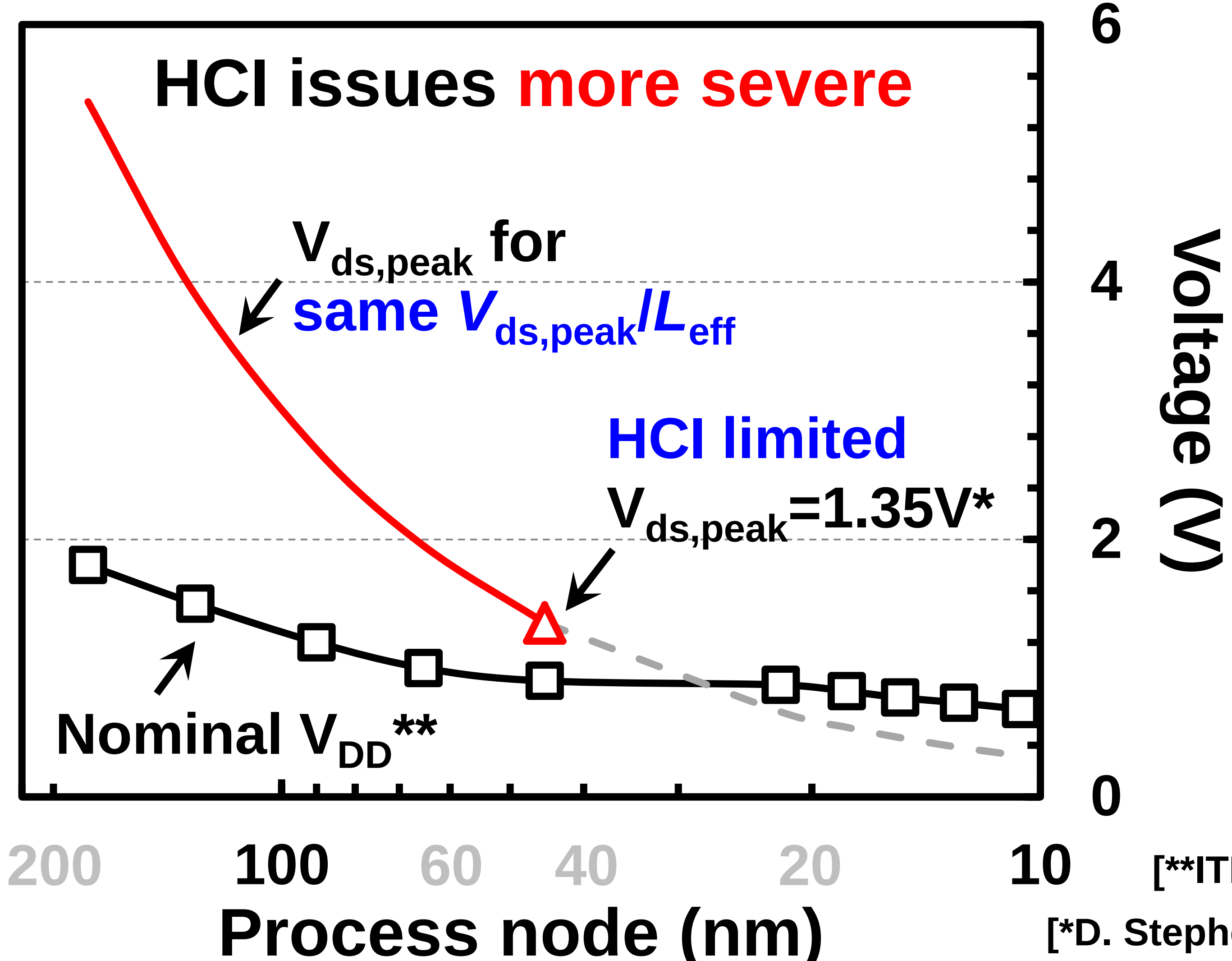


[*Y. Leblebici *et al*., JSSC 1993]

Degrade V_t, μ_n, g_m, I_D, and lifetime

HCI Issue in Advanced CMOS

HCI aging $\propto E_{\mathrm{lateral}} \propto V_{\mathrm{ds}}/L_{\mathrm{eff}}$

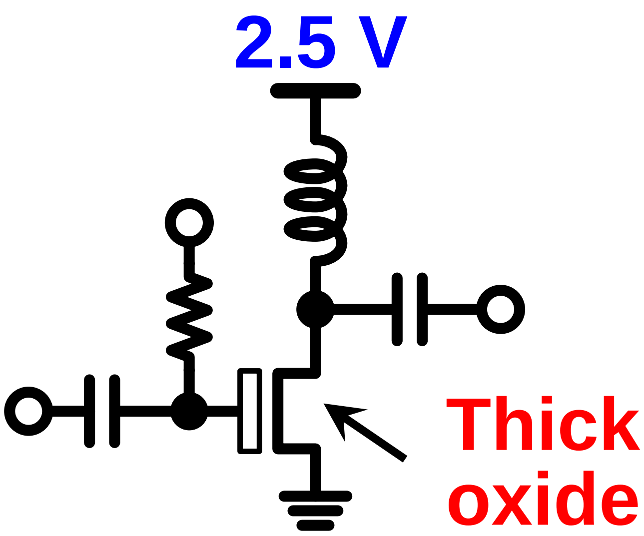


[**ITRS2013]

[*D. Stephens *et al*., RFIC 2009]

HCI Issues for 60-GHz Applications

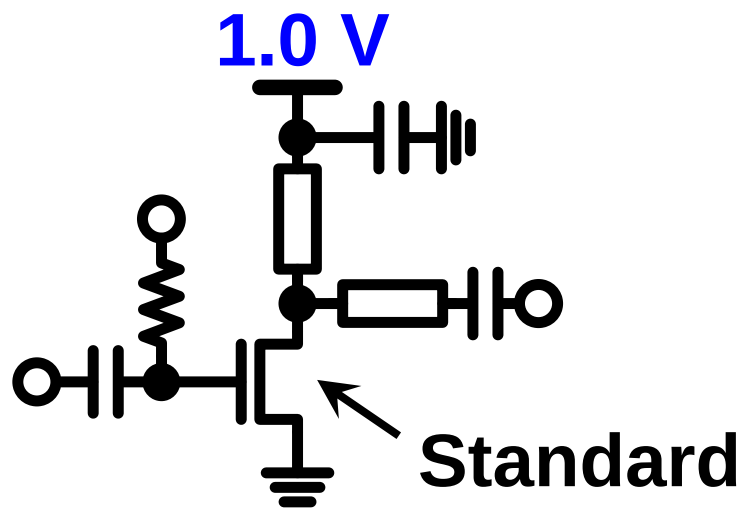
2.4-GHz power amplifier



L=250 nm (I/O Tr.)

f_{max}=40 GHz

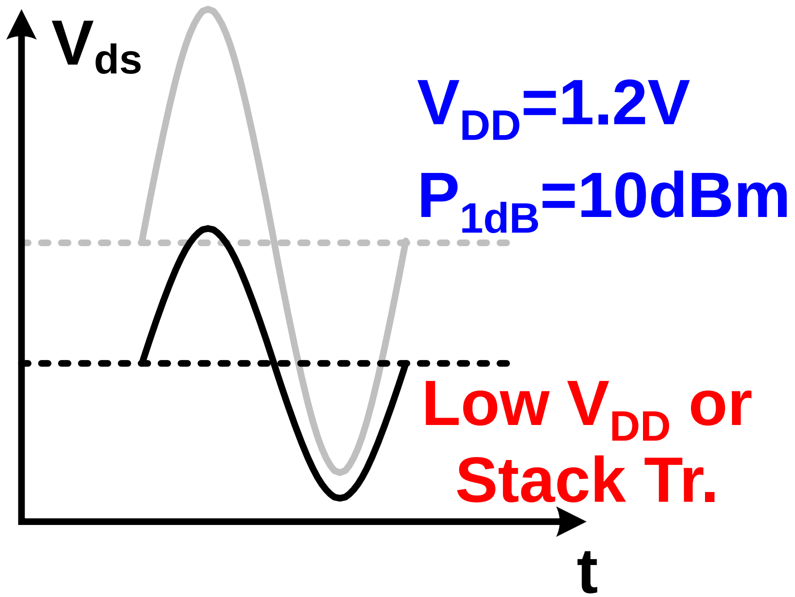
60-GHz power amplifier



L=65 nm (core Tr.)

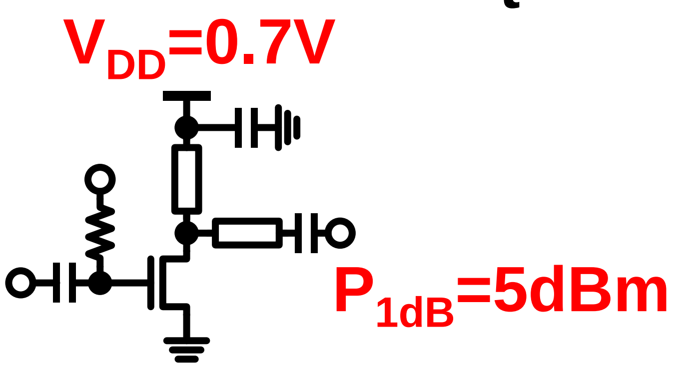
f_{max}=220 GHz

Summary of Prior HCI Solutions@60GHz

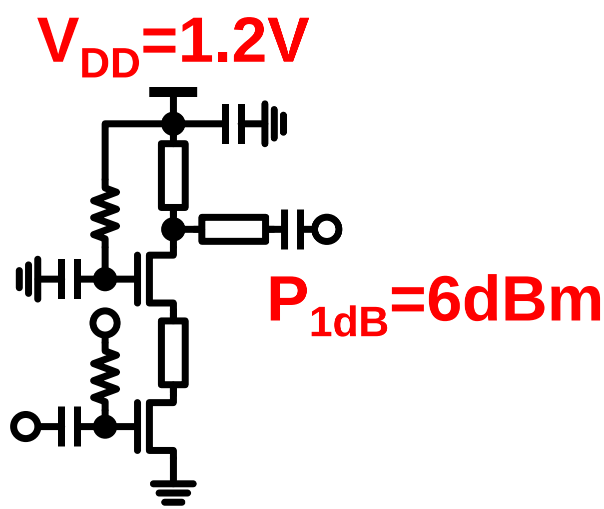


☺ Better lifetime

☹ Degraded output power, linearity and efficiency



Low V_{DD}*

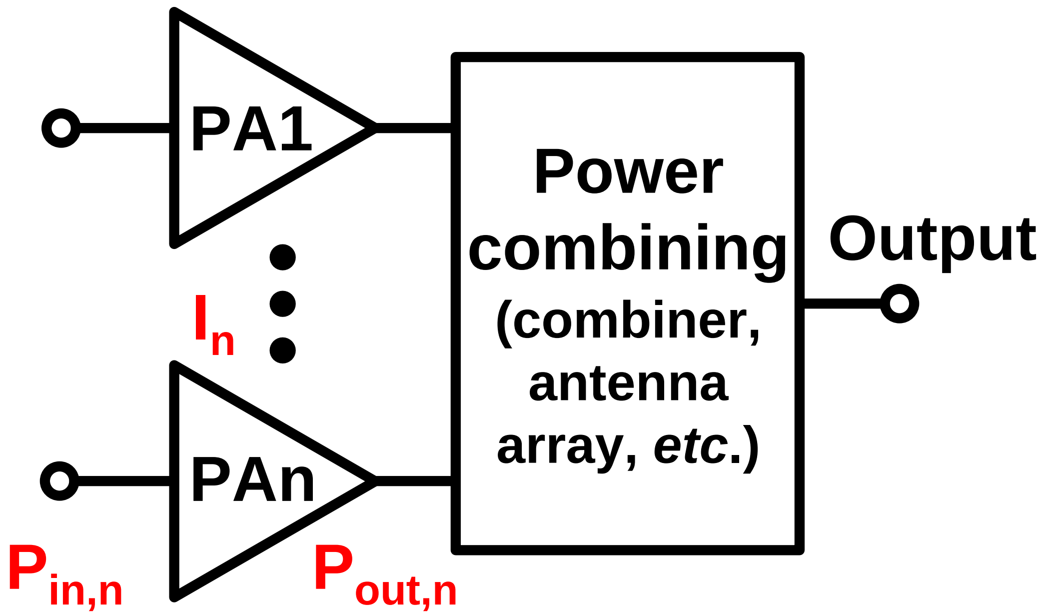


Stack Transistor**

[*M. Tanomura *et al*., ISSCC 2008]

[**A. Siligaris *et al*., JSSC 2010]

Power Combining Techniques

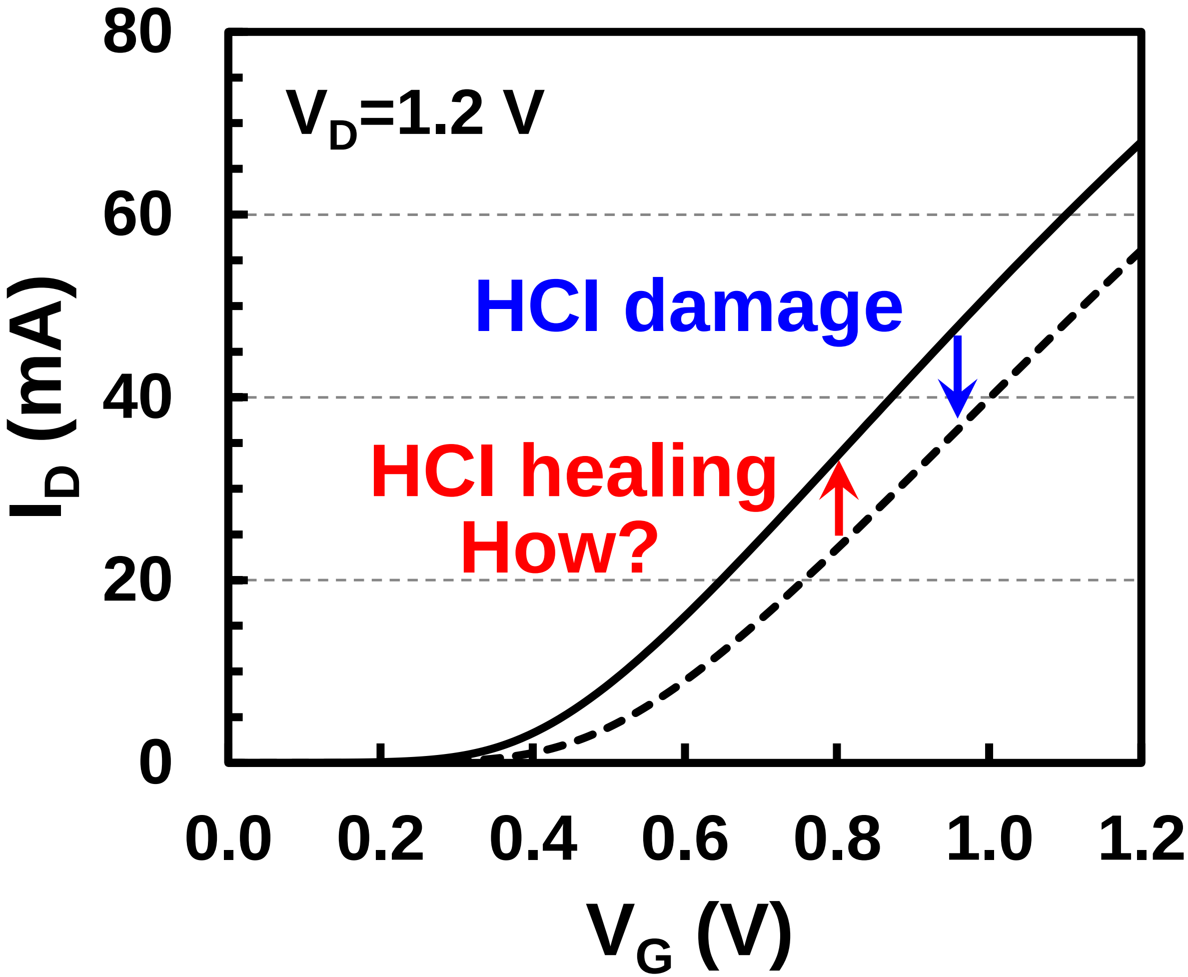


[*J. Chen *et al*., ISSCC 2011]

Individual: $\mathrm{PAE} = \frac{P_{\mathrm{out,n}} - P_{\mathrm{in,n}}}{I_{\mathrm{n}} V_{\mathrm{DD}}}$ ≈ Combined: $\mathrm{PAE} = \frac{n \times (P_{\mathrm{out,n}} - P_{\mathrm{in,n}})}{n \times I_{\mathrm{n}} V_{\mathrm{DD}}}$

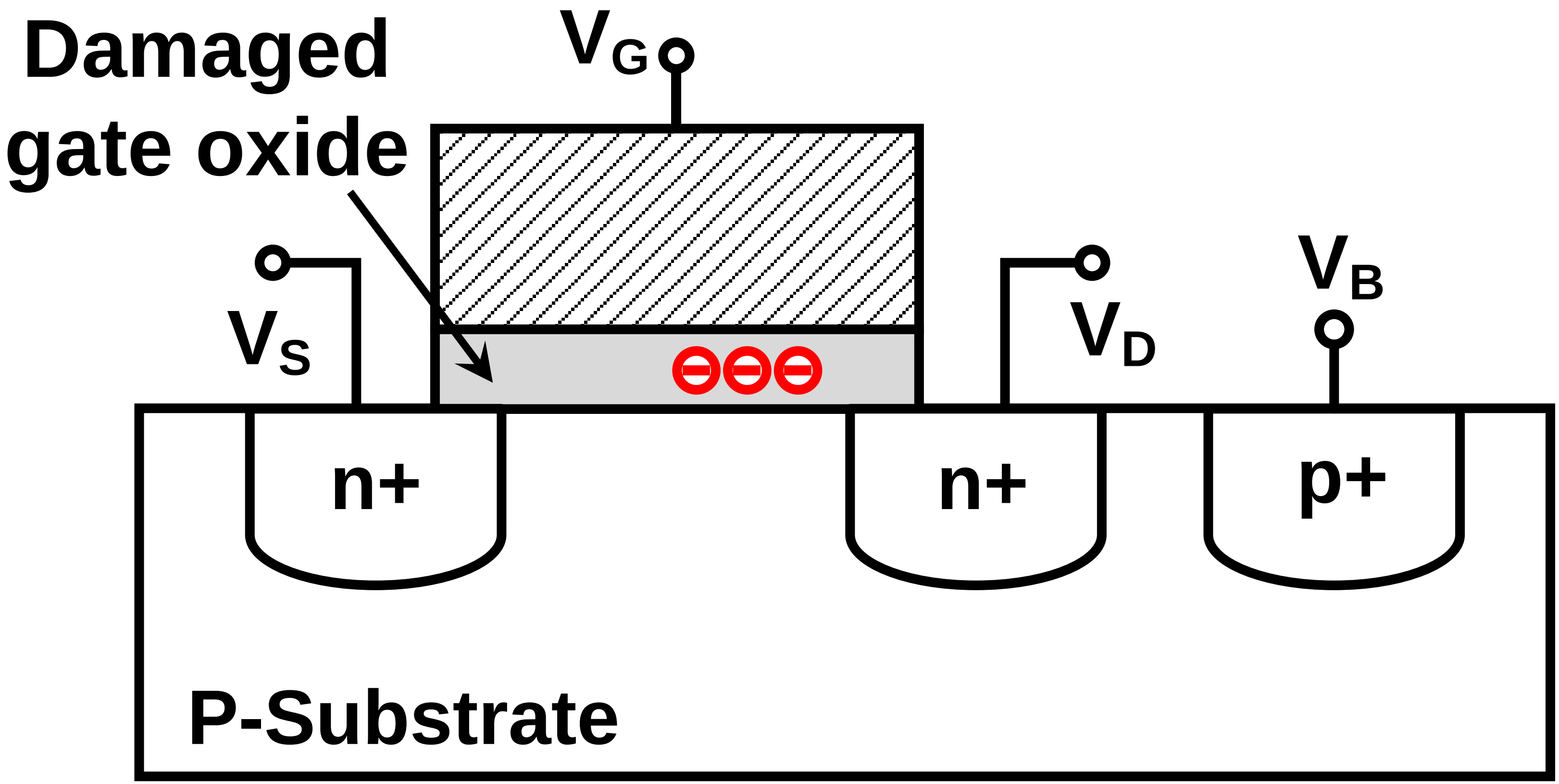
- ☺ Compensate output power and linearity
- ☹ Deteriorated efficiency can not be improved

Proposed HCI-Healing Technique



Ultimate solution: Physically heal HCI damage

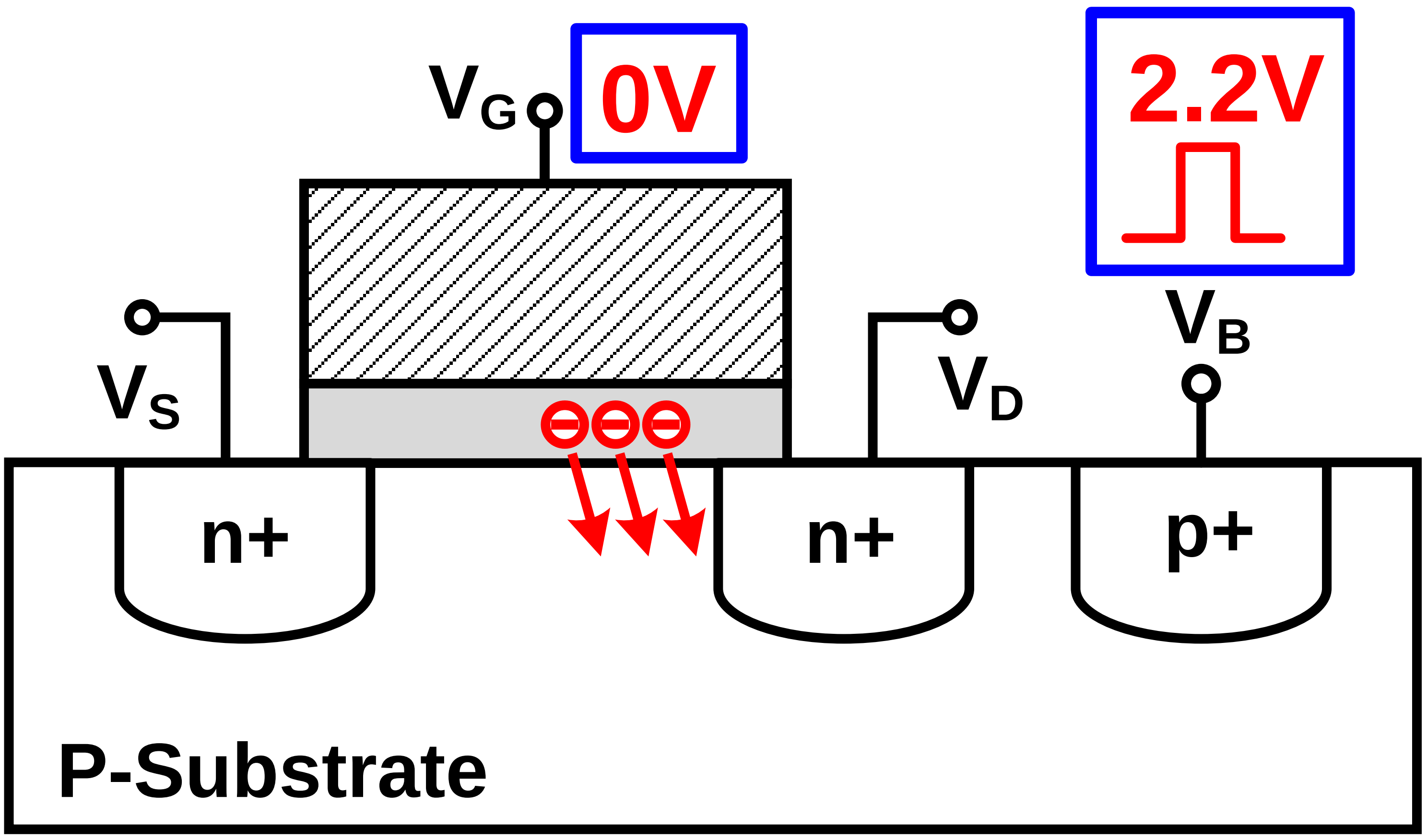
Proposed HCI Healing Mechanism (1/2)



Damage mechanism: trapped electrons

[Y. Leblebici *et al.*, JSSC 1993]

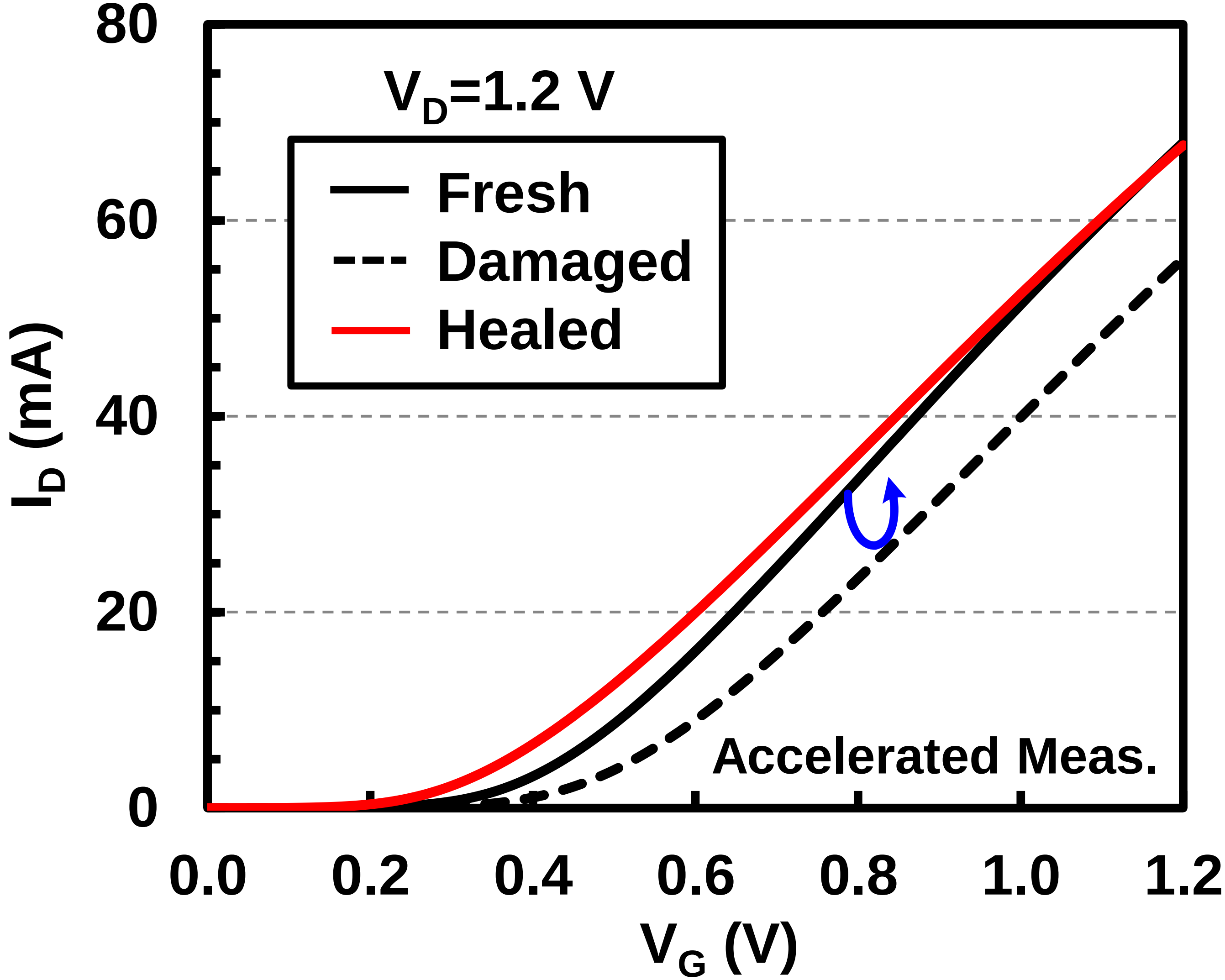
Proposed HCI Healing Mechanism (2/2)



Possible solution: charge ejection

Measured HCI-Healing I_D-V_G Curves

First HCI healing demonstration



Stress cond.

V_D=2.4V
V_G=0.8V
1 hour

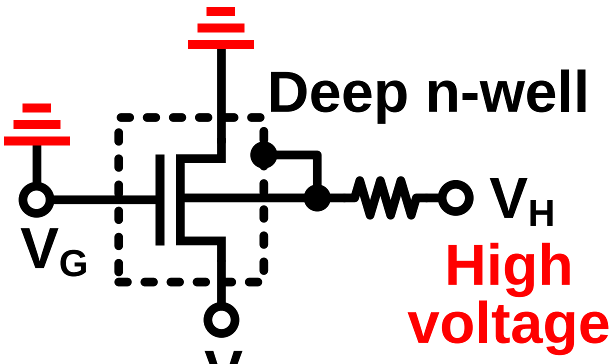
Heal cond.

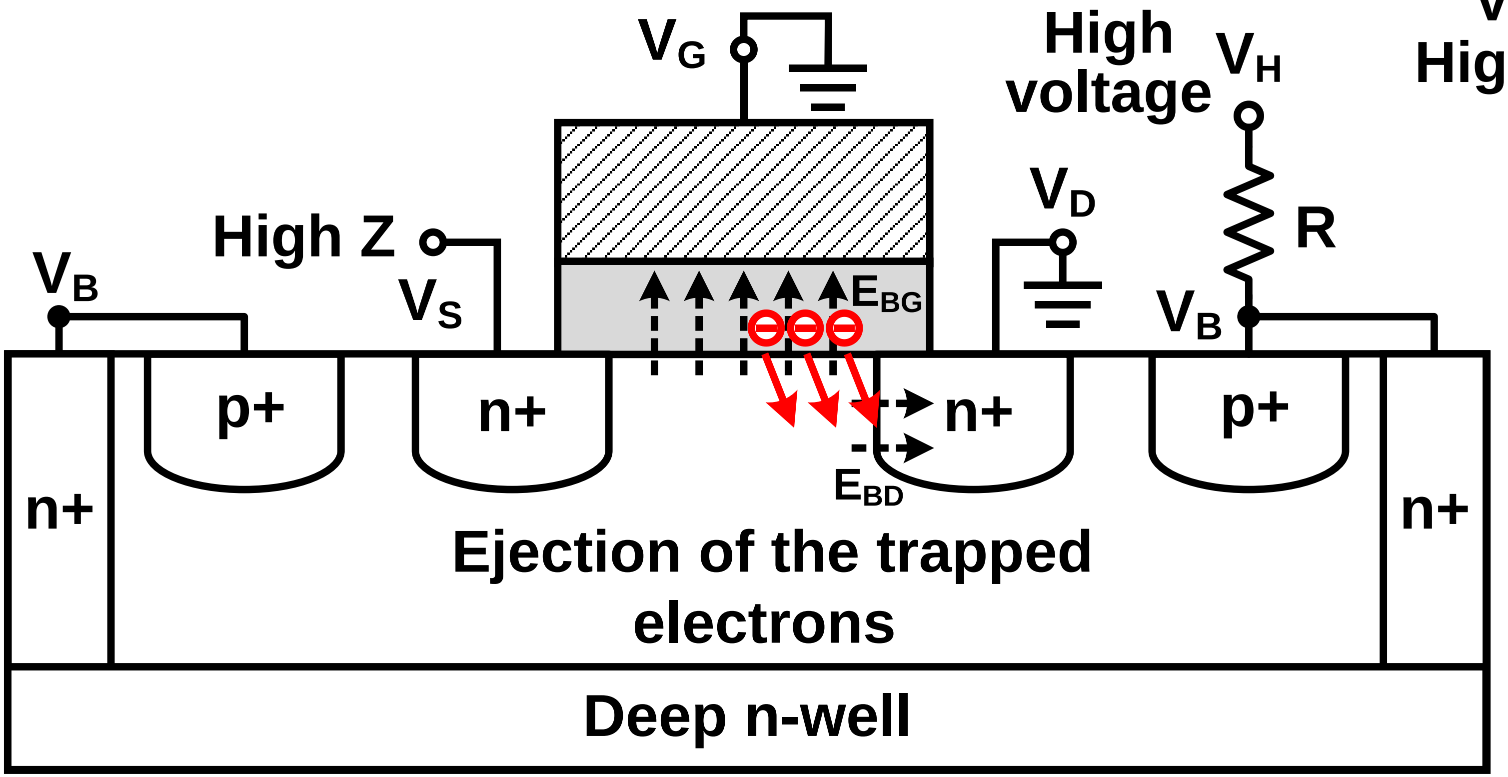
V_B=2.2V
V_G=V_D=0V
1 second

HCI-Healing Function in Transistor

First HCI healing transistor

Floating source* & low drain bias**
assisting ejection (memory cells)

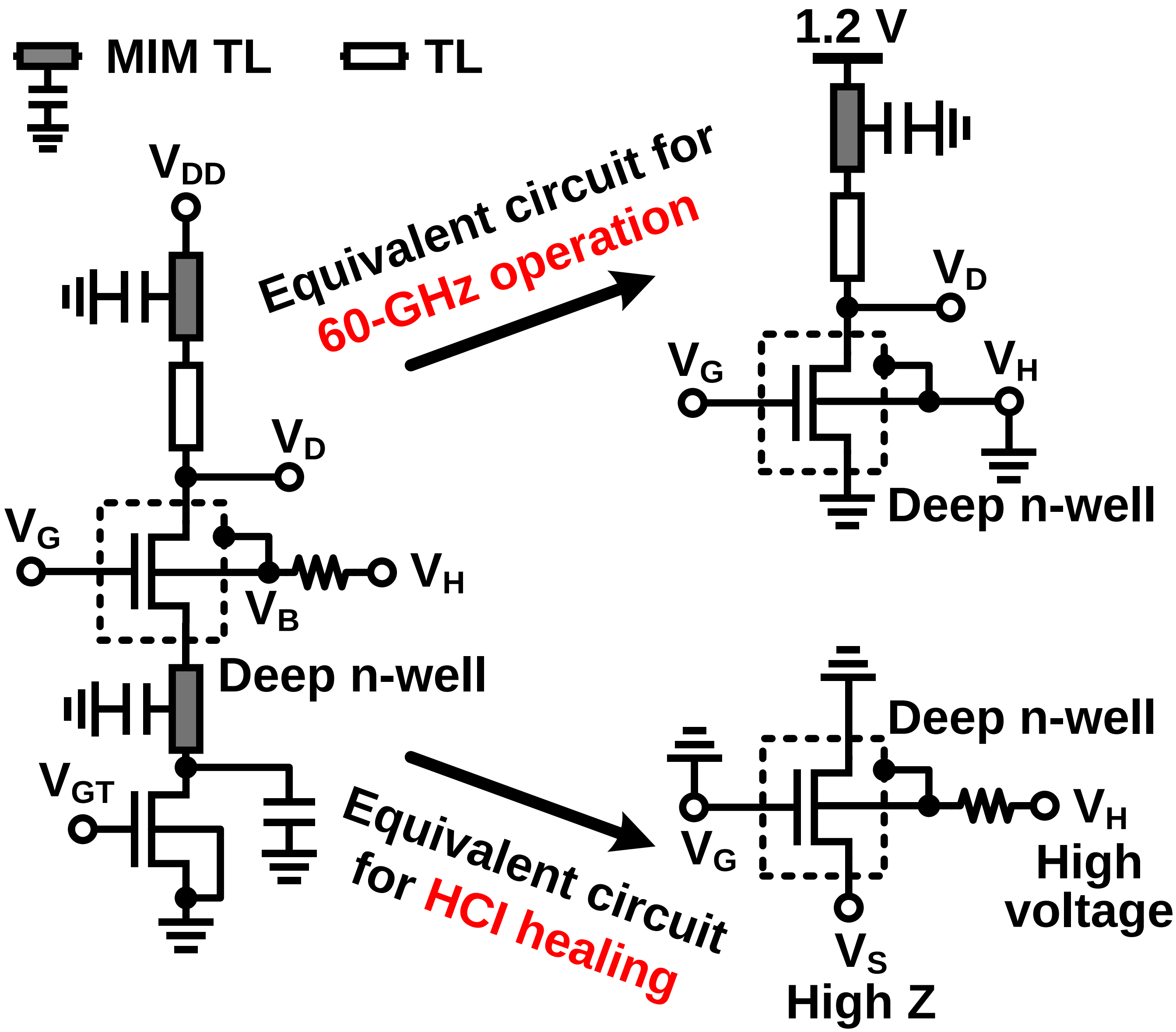




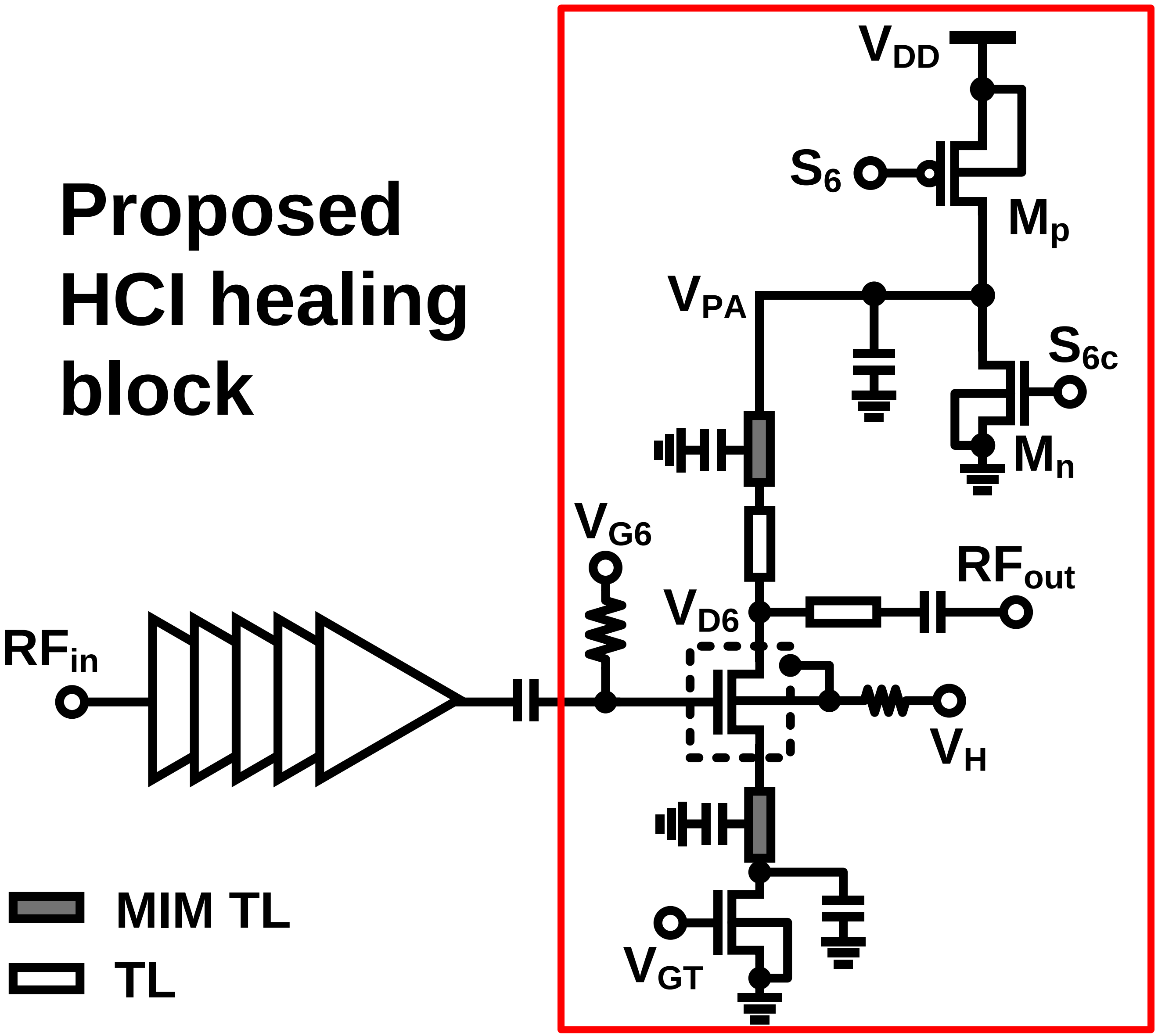
[*T. Endoh *et al.*, IEDM 1989]

[**K. Miyaji *et al.*, JJAP 2012]

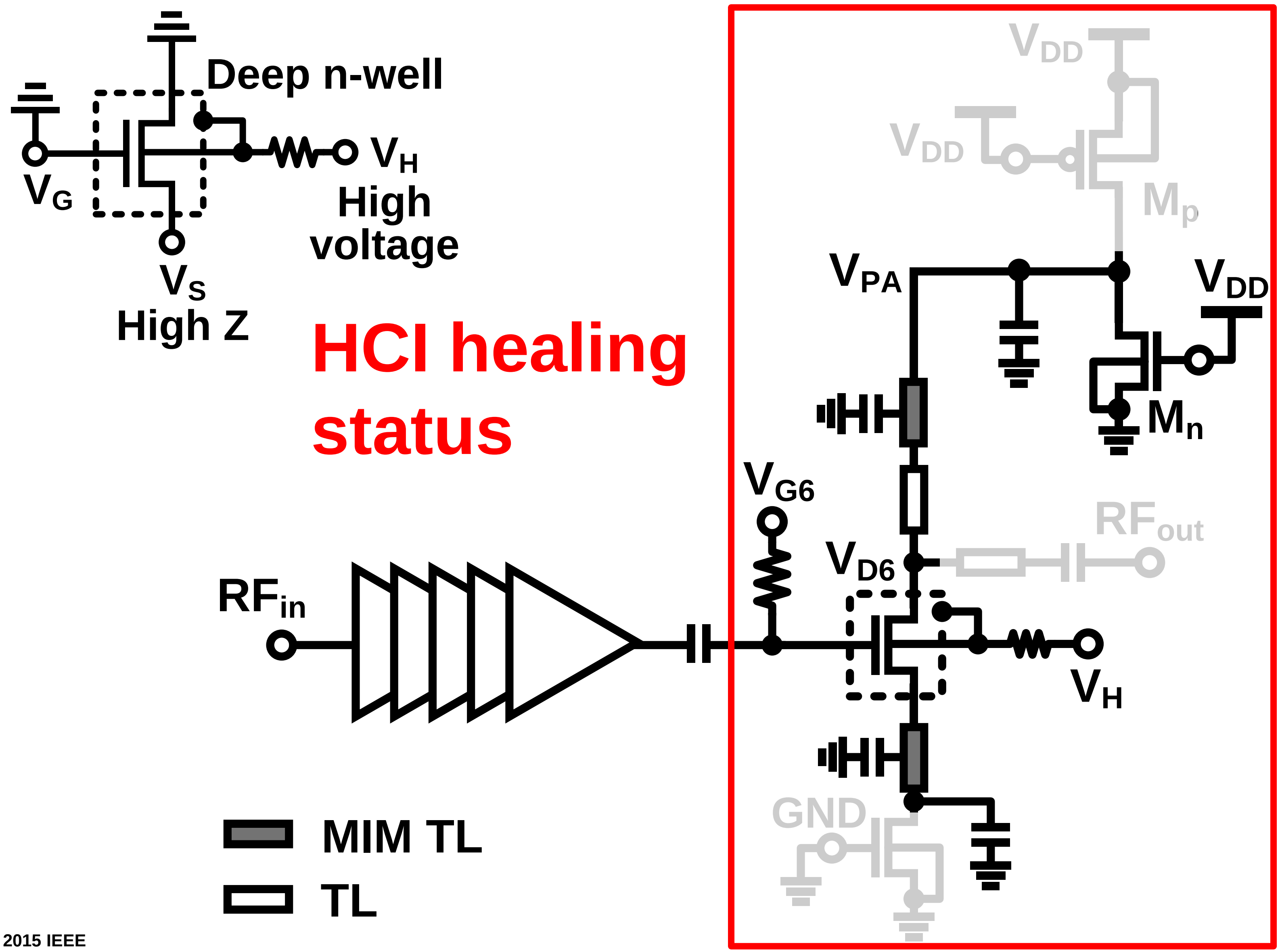
HCI-Healing Transistor Module



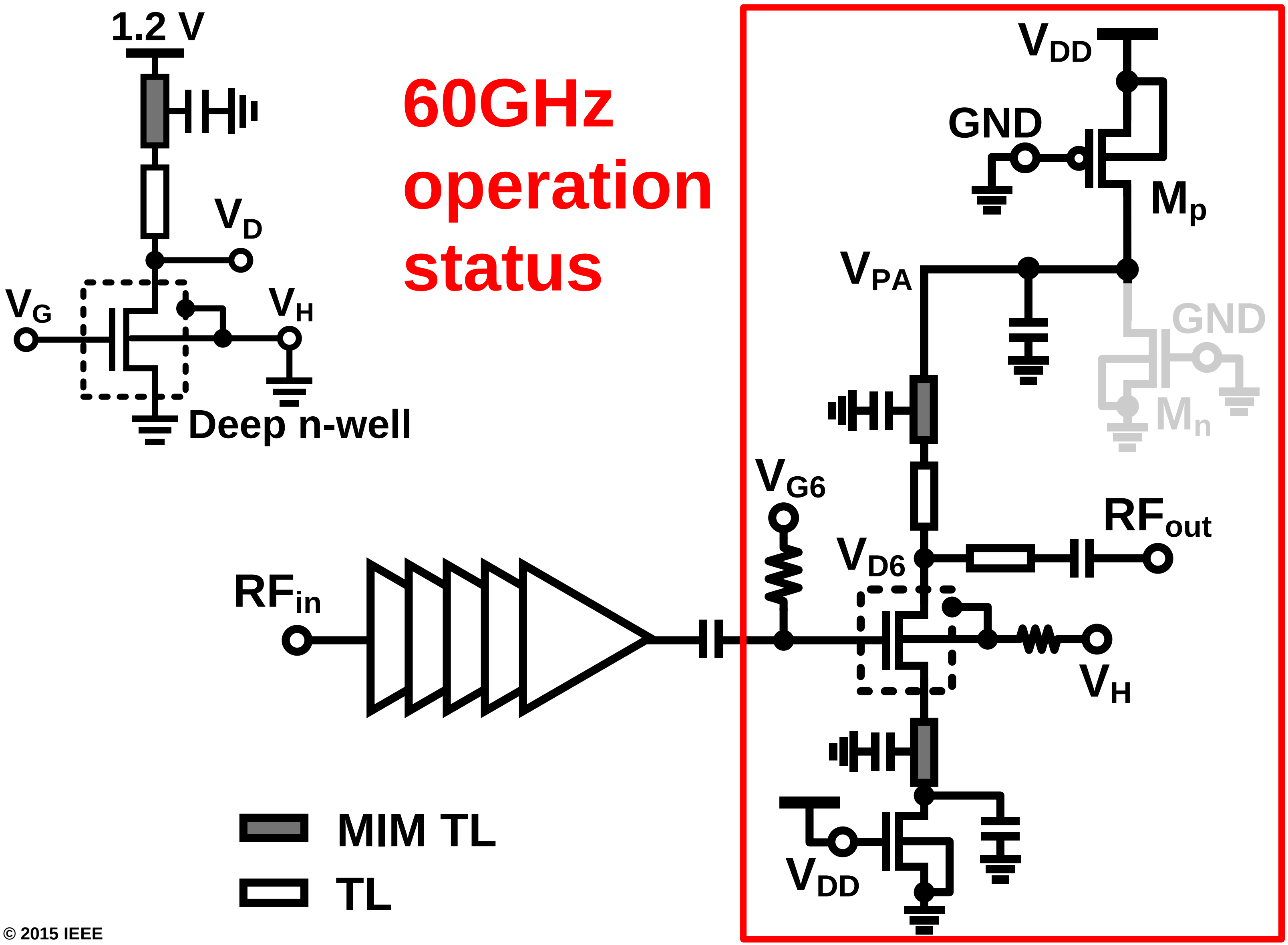
HCI-Healing Power Amplifier (1/3)



HCI-Healing Power Amplifier (2/3)



HCI-Healing Power Amplifier (3/3)

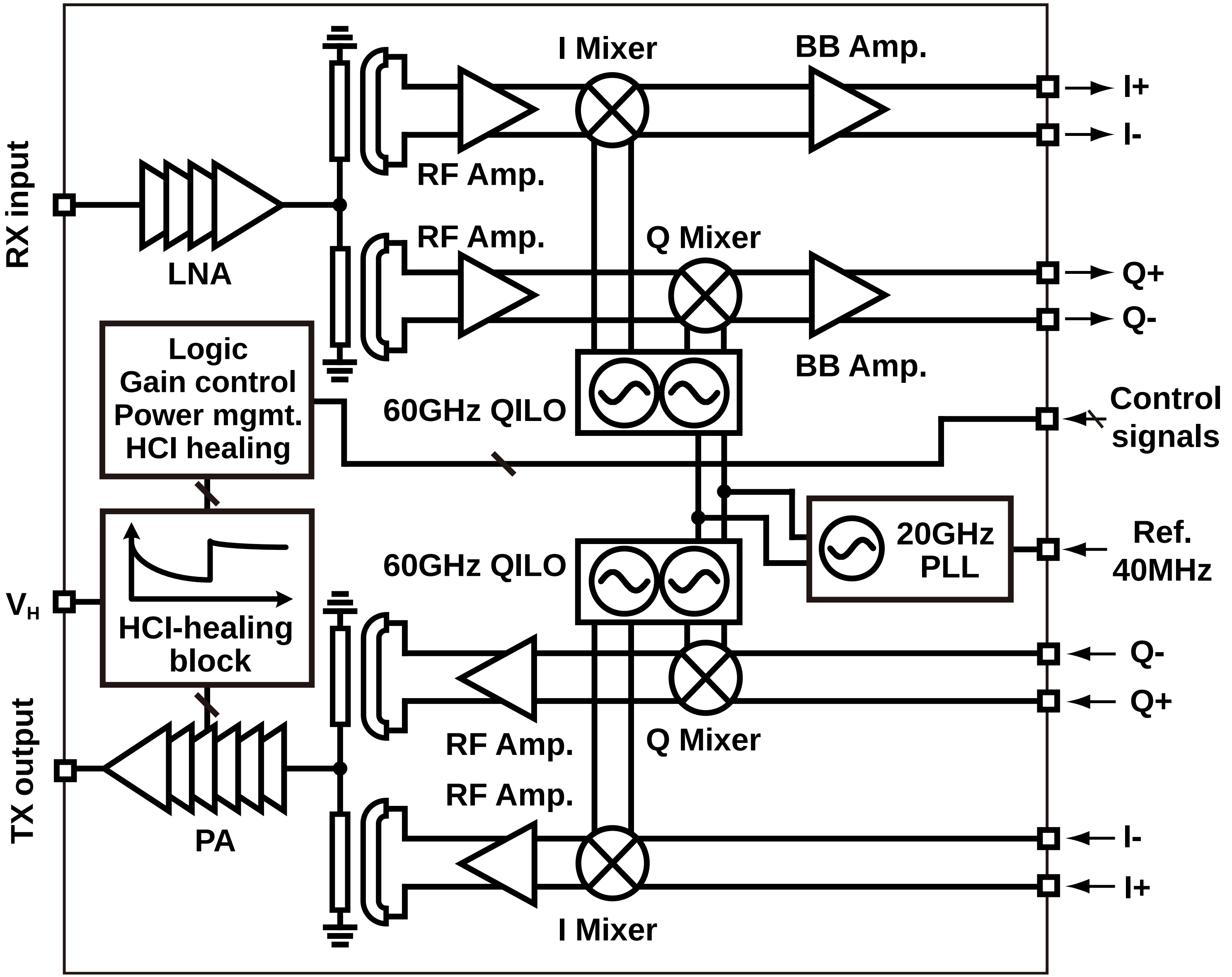


HCI-Healing TRX Block Diagram

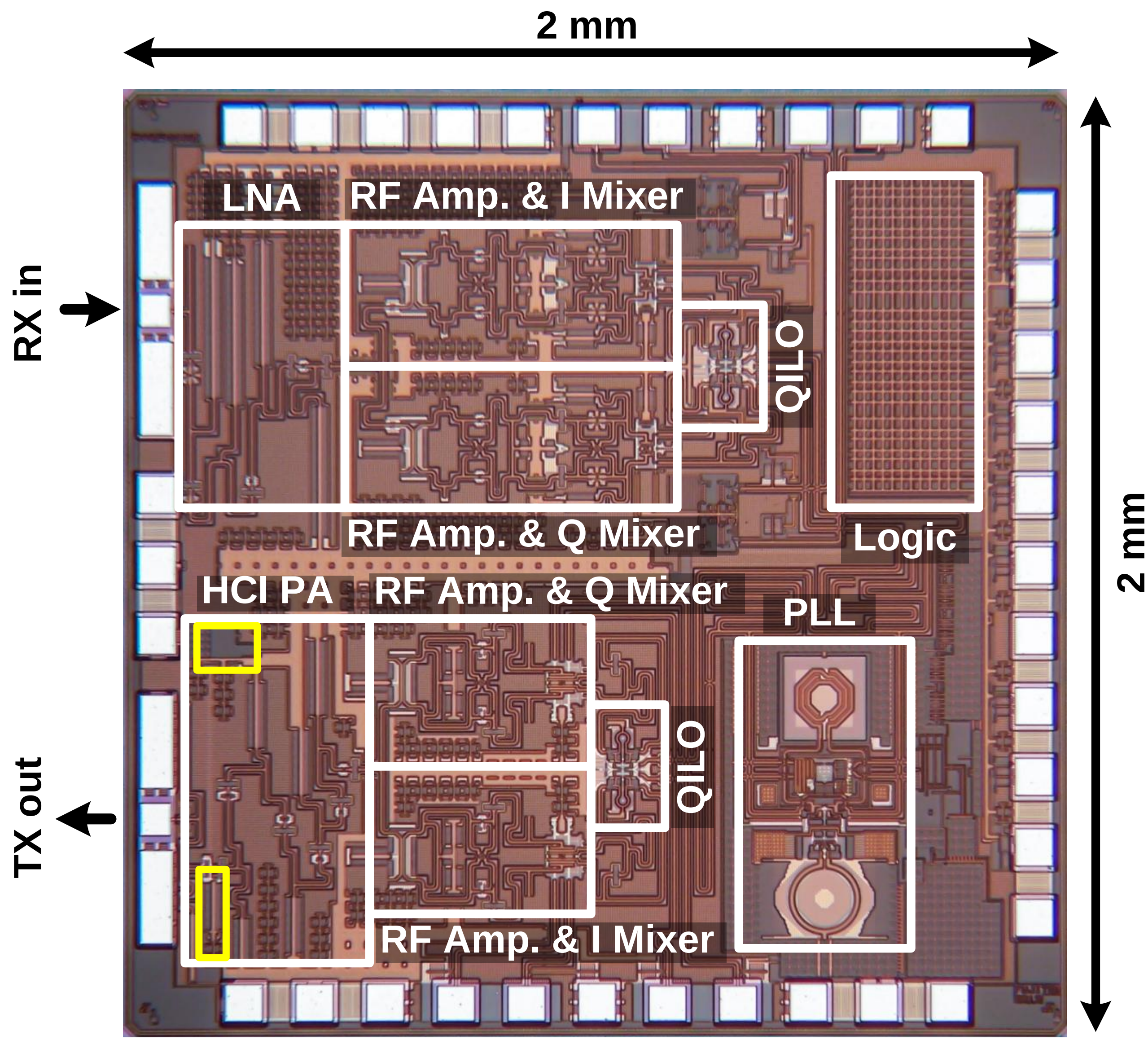
Direct Conversion

20GHz PLL+ 60GHz QILO

Integrated HCI-healing function



Die Micrograph



Standard

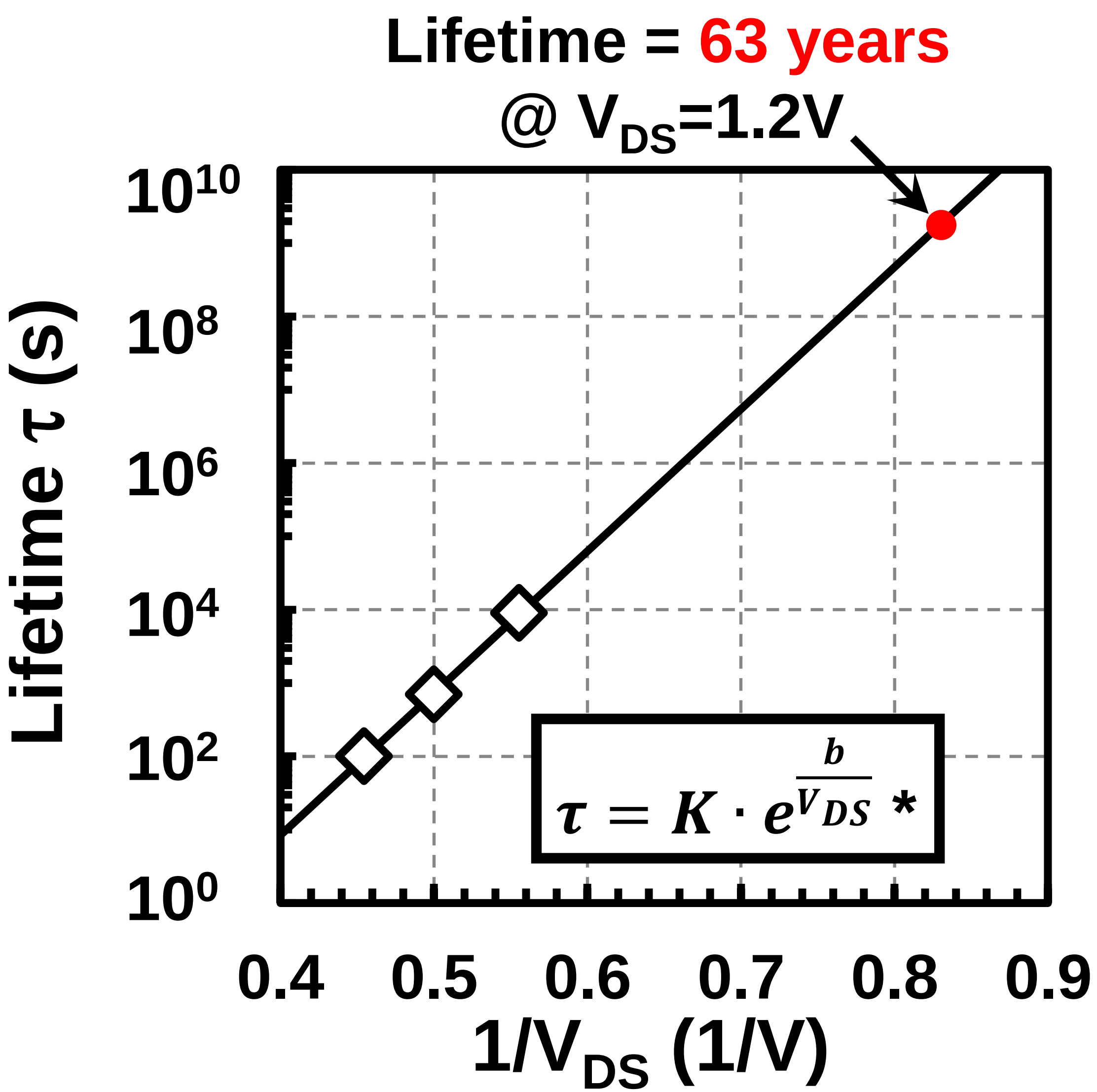
65 nm CMOS

Block	Area (mm^2)
TX	0.79
RX	1.01
PLL	0.27
Logic	0.21

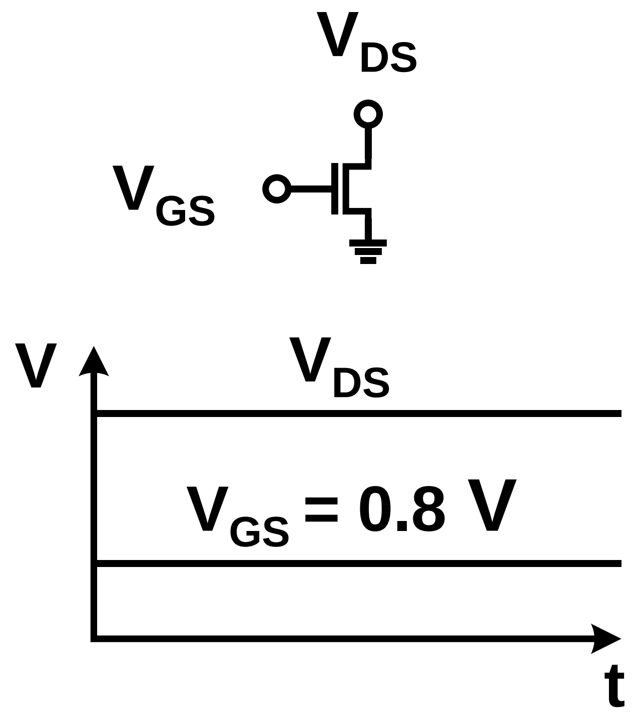
Measurements

- **Transistor TEG**
  - DC stress lifetime
  - AC stress lifetime
- **Stand-alone PA TEG**
  - P_{in}-P_{out} with healing
  - AC stress lifetime with healing
- **TRX Board**
  - EVM versus P_{out} with healing

65 nm NMOSFET DC Stress Lifetime



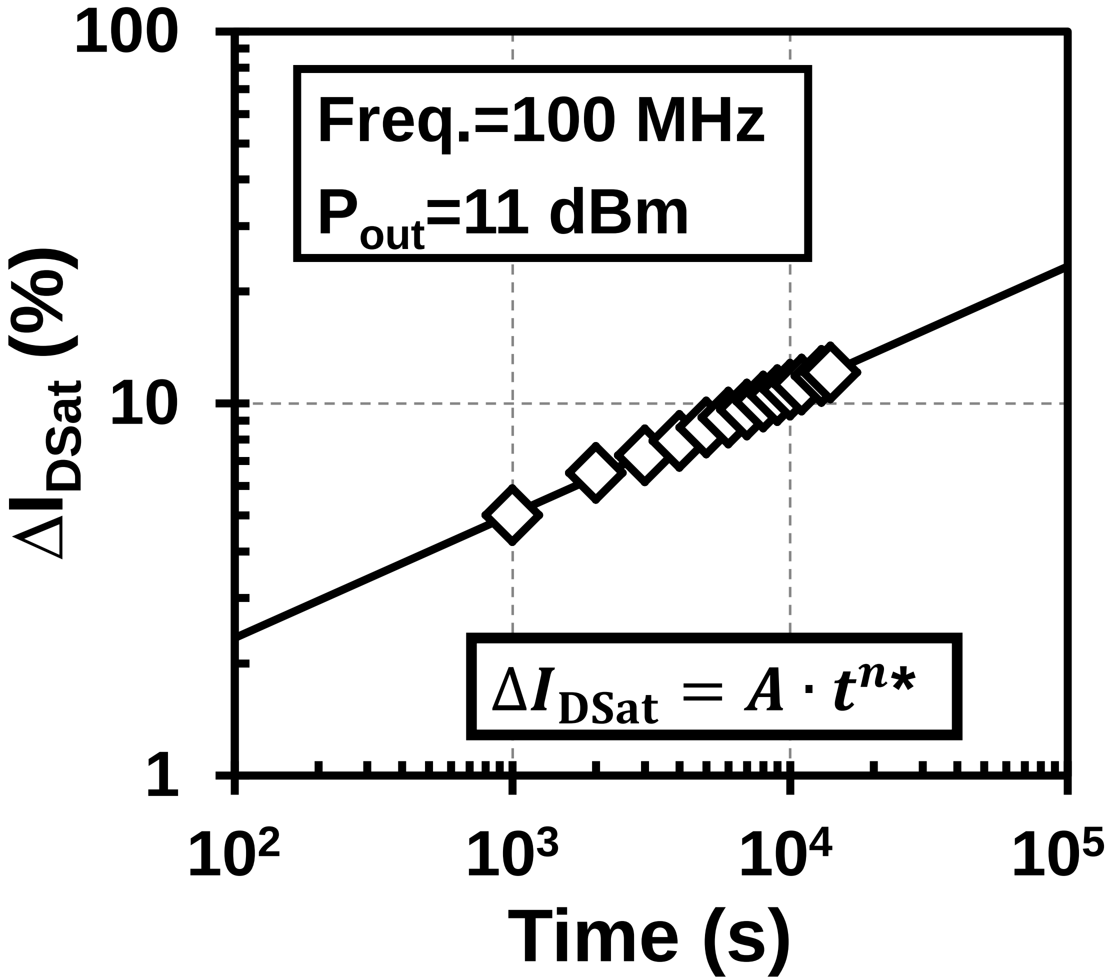
Stress condition



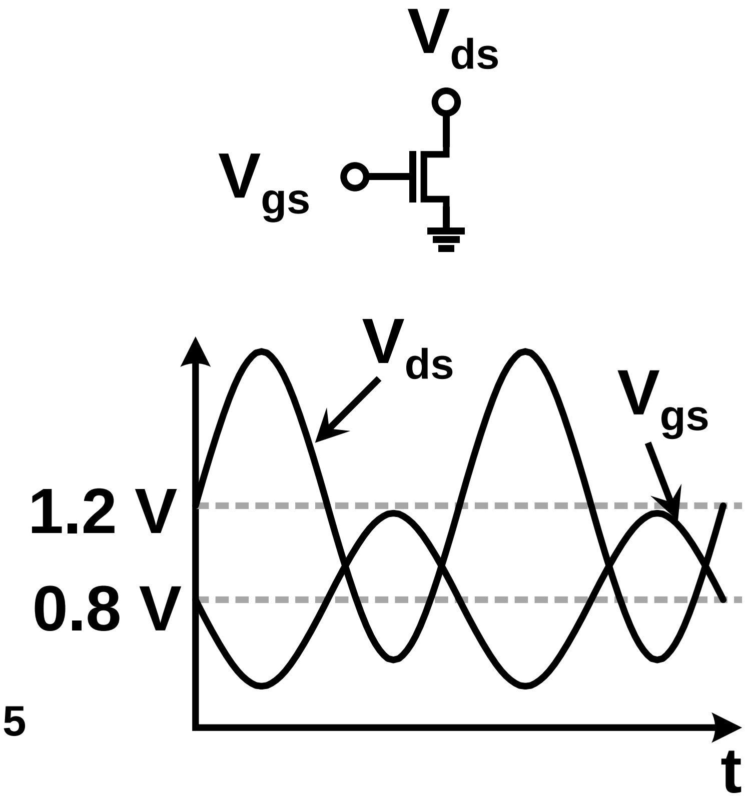
[*E. Takeda *et al.*, EDL 1983]

65 nm NMOSFET RF Stress Lifetime

Lifetime = 2 hours

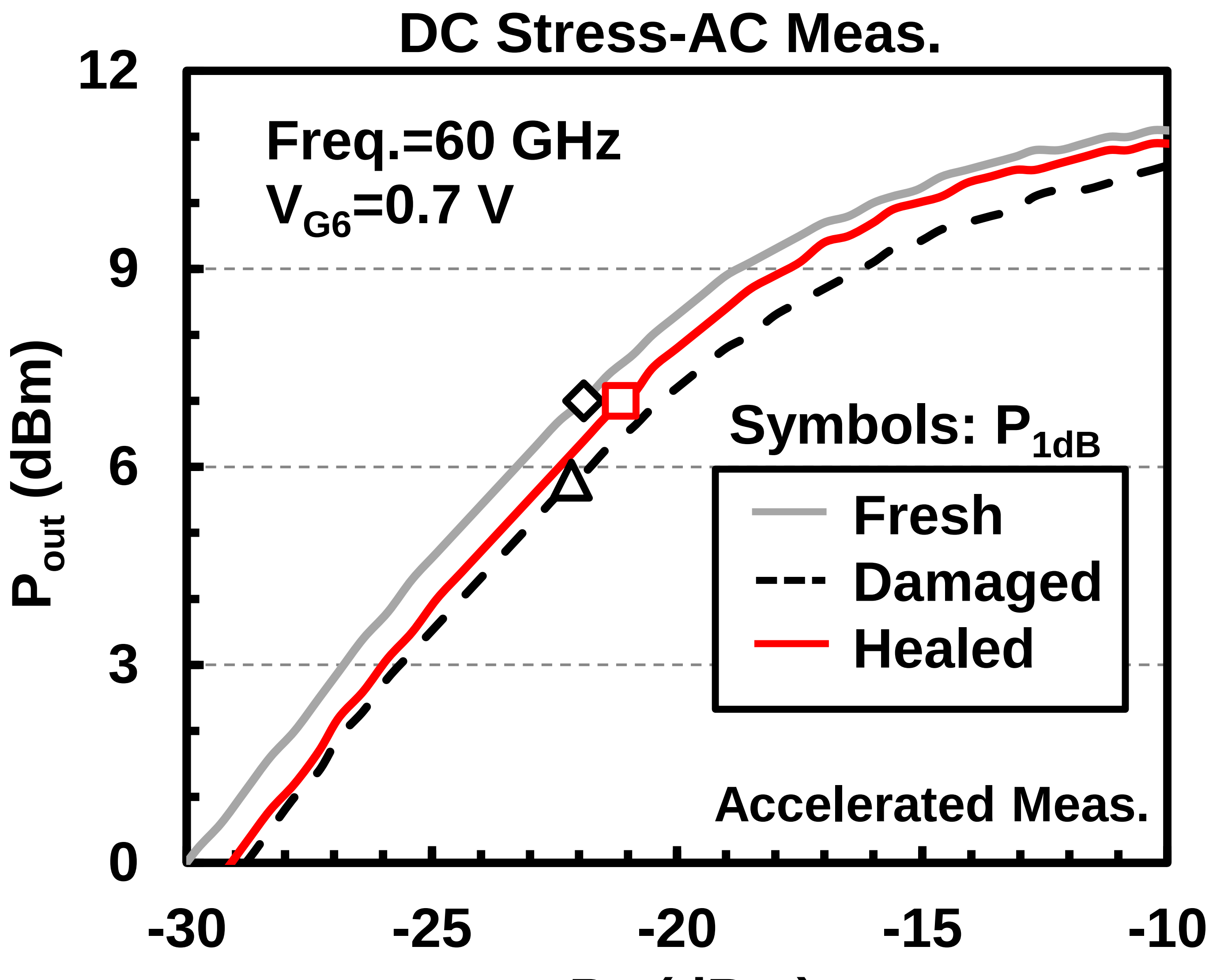


Stress condition

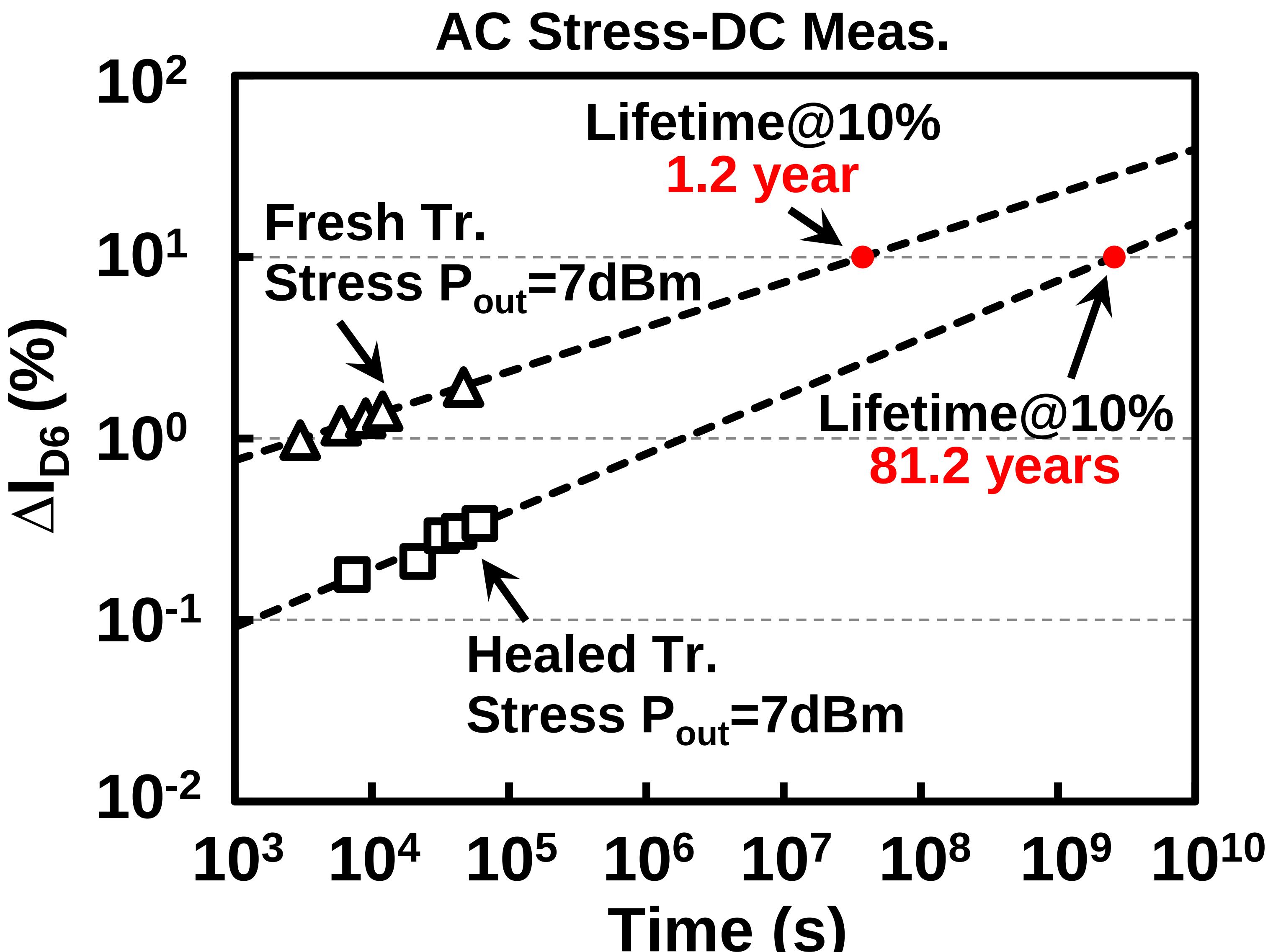


[*L. Negre *et al*., JSSC 2012]

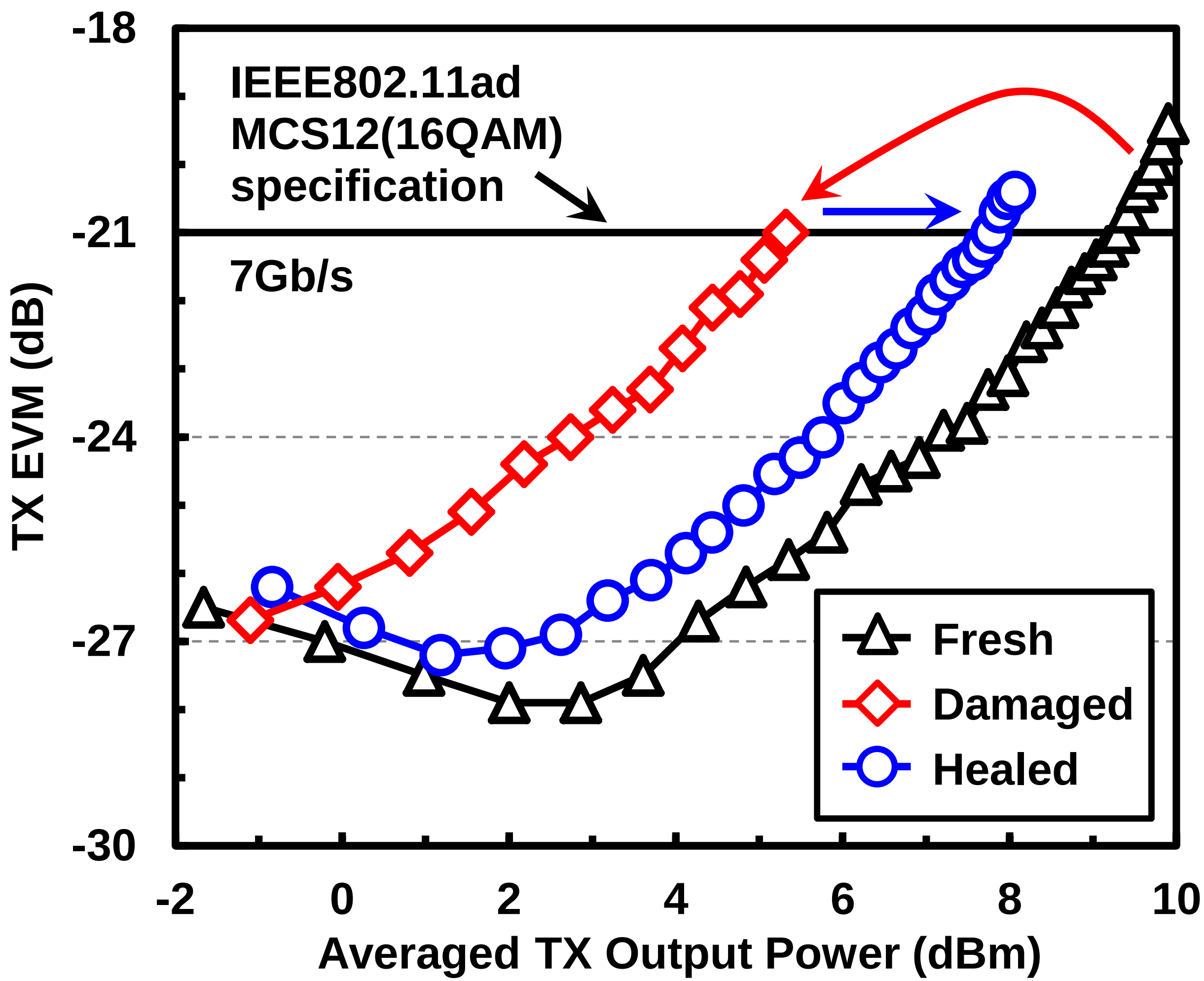
Measured P_{in}-P_{out} of the PA



Measured Lifetime of the PA



Measured TX EVM versus P_{out}



Fresh 9dBm

Stress cond.
12.5dBm with
V_{DD}=1.5V (40hr)

Damaged 5dBm

Healing cond.
V_B=2.2V 1sec.

Healed 8dBm

60GHz TRX Performance Comparison

Ref.	CMOS Process	Data rate (Modulation)	P_{out} /each PA (dBm)	TX efficiency P_{out}/P_{DC} (%)	HCI healing	Core area (mm^2)	Power Consumption
Tokyo Tech [1]	65nm	10.56Gb/s (64QAM) 28.16Gb/s (16QAM)	8.5* @TX EVM = -21dB	2.8	NO	3.9	TX: 251mW RX: 220mW
NEC [2]	90nm	2.6Gb/s (QPSK)	6	3.0 w/o PLL	NO	3.4	TX: 133mW RX: 206mW w/o PLL
Panasonic [3]	90nm	2.5Gb/s (QPSK)	1.9 @TX EVM = -19.6dB	0.4	NO	5.7	TX: 361mW RX: 260mW
Broadcom [4]	40nm	4.6Gb/s (16QAM)	-4* @TX EVM = -23dB	0.5	NO	26.3†	TX: 1190mW RX: 960mW 16x16 array
This work	65nm	7Gb/s (16QAM)	9.3 @TX EVM = -21dB	3.9	YES	2.3	TX: 218mW RX: 188mW

*Estimated from literature †Chip area

Conclusions

- 60-GHz CMOS transceiver with HCI damage healing function by using charge ejection technique.
- 81-year lifetime without sacrificing the output power and efficiency
- The transceiver demonstrates an EVM of -27.9dB and can transmit 7Gb/s in 16QAM within 2.16GHz bandwidth.

Acknowledgement

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