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Submission Title: [Behavioral model of 60GHz-band power amplifier for SYS/PHY evaluation]
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Abstract: [This contribution describes a behavior model of 60GHz power amplifier.]

Purpose: [Contribution to mmW TG3c meeting.]

Behavioral model of 60GHz-band power amplifier for TG3c system/PHY evaluation

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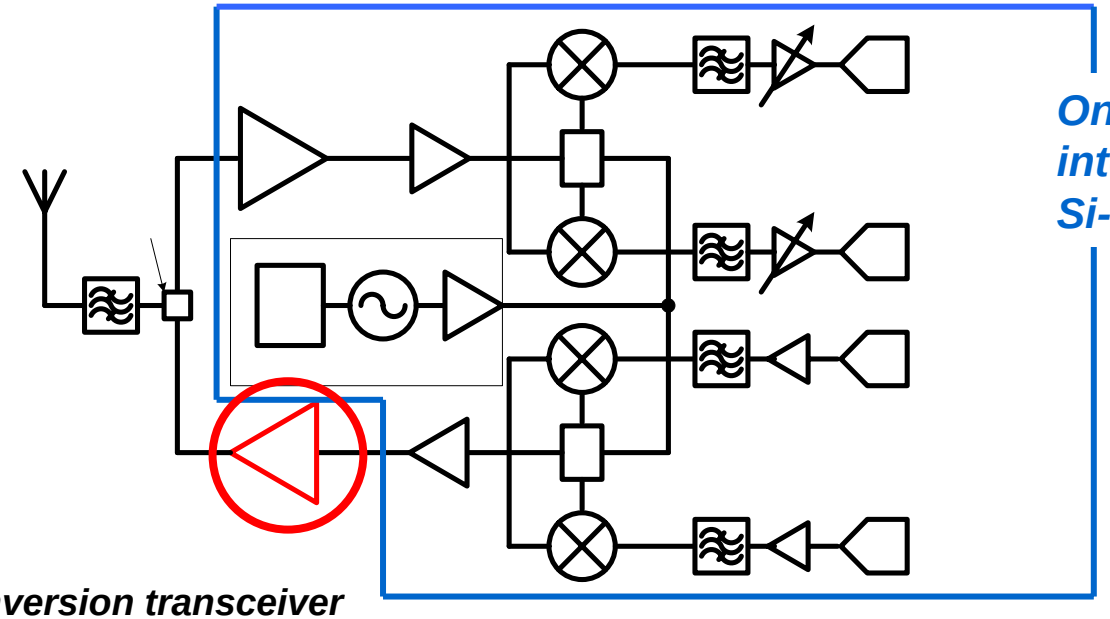
Power amplifier in RF front/end

High Power Amplifier (HPA) is, generally,

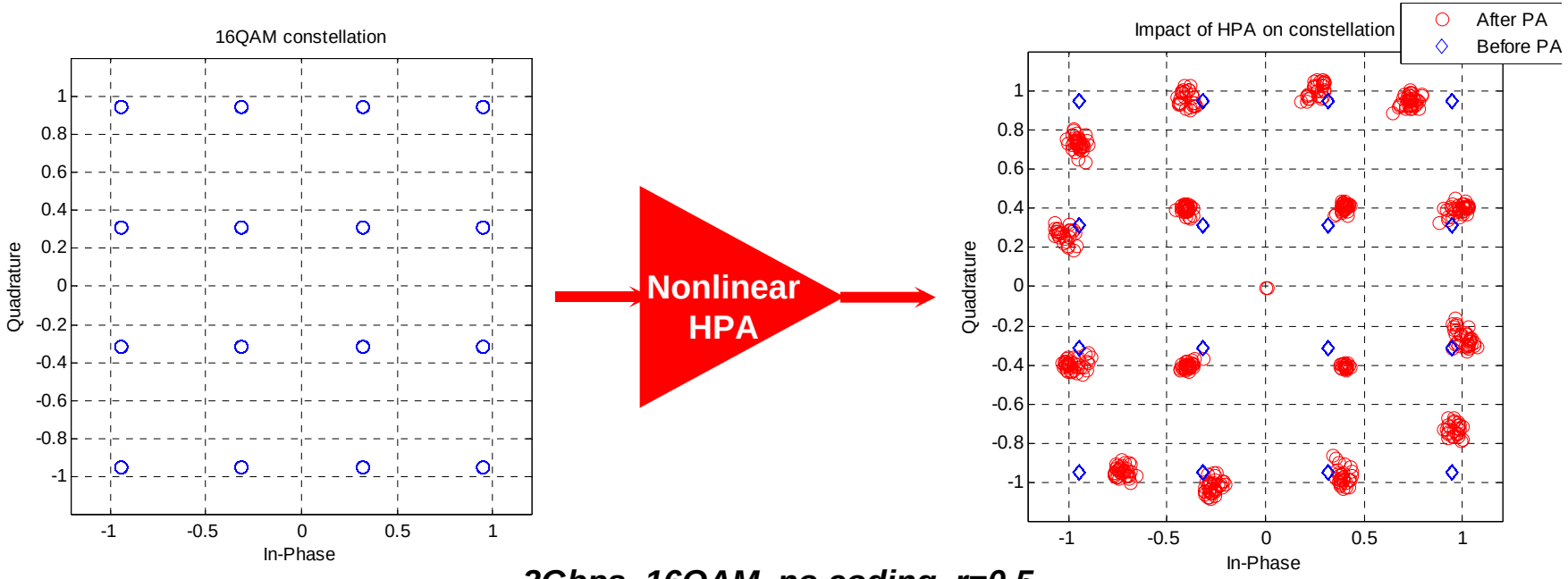
the most expensive,
the most power consuming device in transceiver, and
difficult to be integrated into one-chip



Direct-conversion transceiver

Impact of HPA on system performance:
(1) performance degradation

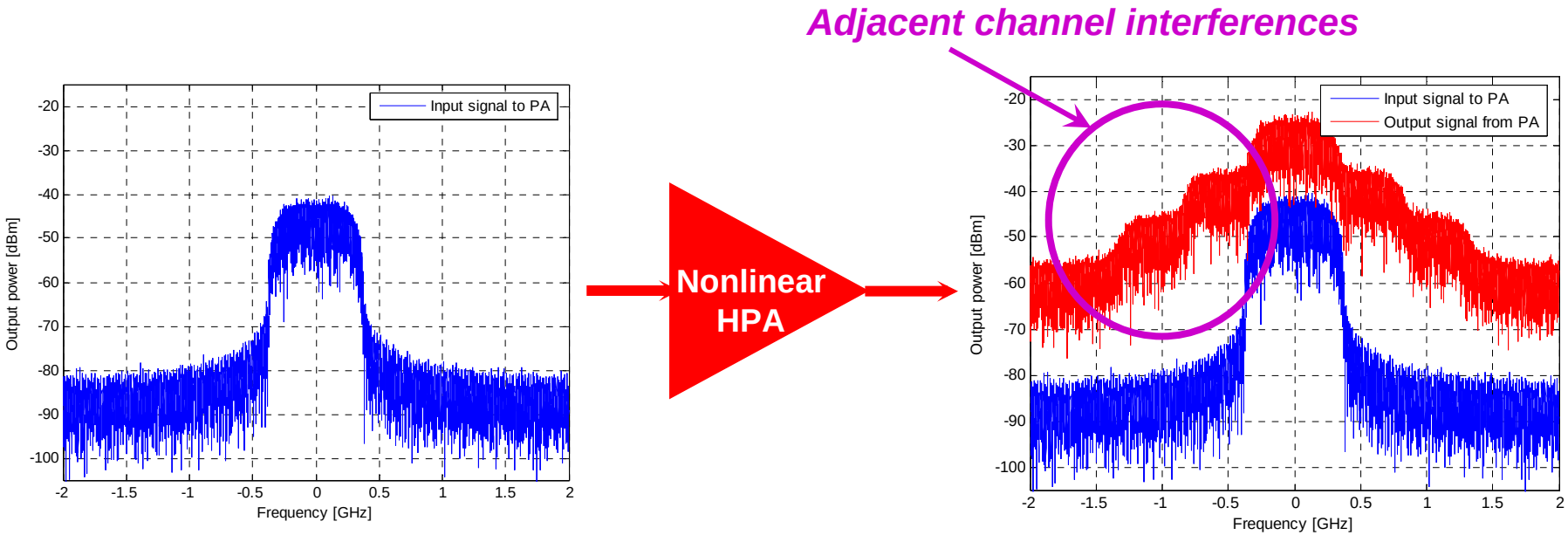
1. Performance degradation (deteriorated EVM, BER)



2Gbps, 16QAM, no coding, r=0.5

- HPA has an large impact on system performance due to its nonlinearities.

Impact of HPA on system performance:
(2) adjacent channel interference



2Gbps, 16QAM, no coding, r=0.5

- Nonlinearity of HPA seriously increases adjacent channel interference power

Power amplifier in 60GHz band

More serious in 60GHz WPAN because…

1) Decreased intrinsic gain of semiconductor devices in 60GHz

Ex.) If changing from 5GHz to 60GHz, the current gain of device reduces by larger than 20dB

2) For low power consumption of WPAN, we can operate HPA at saturation point to get high power added efficiency (PAE)

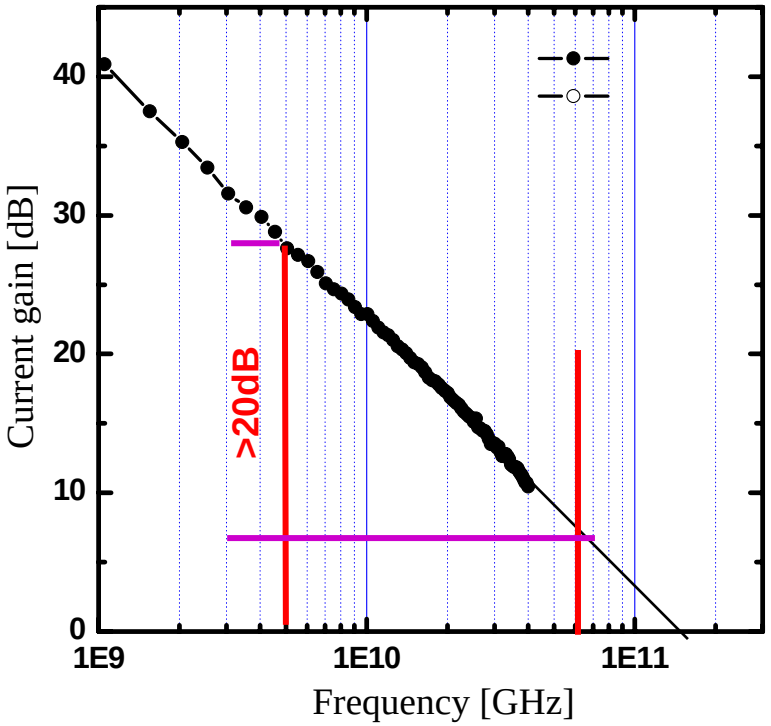


FIGURE: Current gain of InP HEMT

For accurate 60GHz WPAN system evaluation, we have to consider the nonlinear behavior of HPA

Nonlinearity of power amplifier

- Output signal of PA is reproduced with amplified magnitude and shifted phase

$$A_0(t) = G_0 e^{j\vartheta_0} A_i(t)$$

- This complex gain of nonlinear amplifier is dependent on input signal amplitude

$$A_0(t) = G(|A_i(t)|) e^{j\vartheta(|A_i(t)|)} A_i(t)$$

  - AM-AM distortion (affecting amplitude)
  - AM-PM distortion (affecting phase)

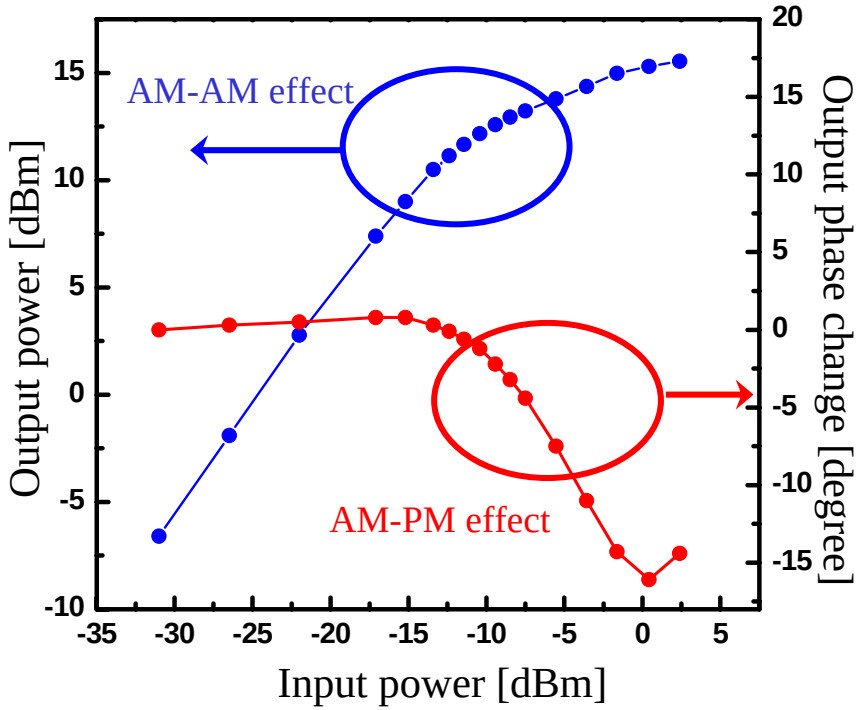
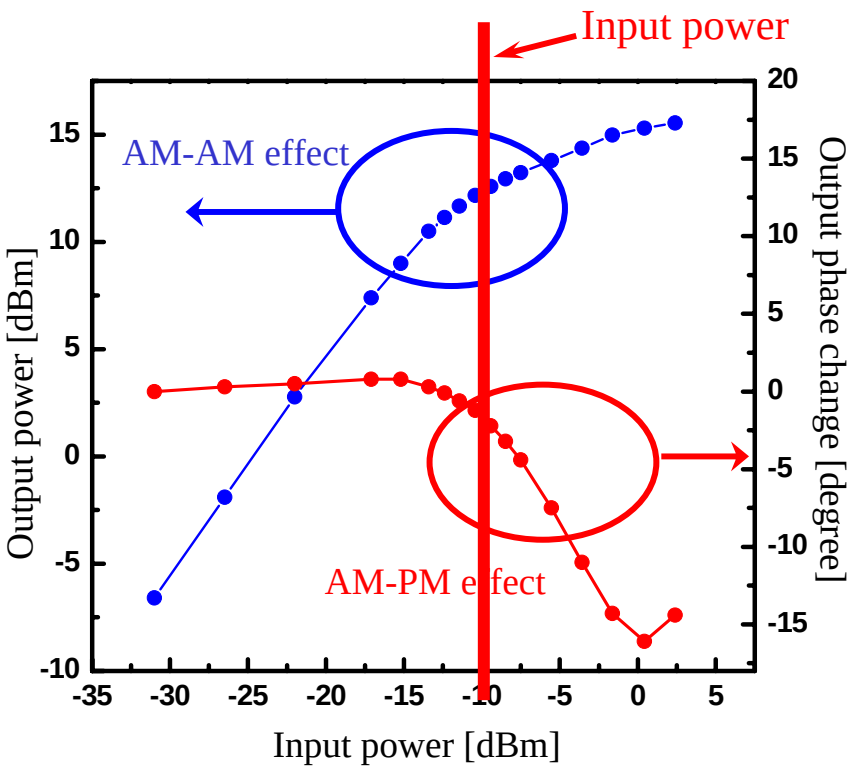


FIGURE: AM-AM and AM-PM results of GaAs pHEMT 60GHz HPA (from NEC)

Q. Do we need to consider BOTH effects?

Impacts of AM-PM effect (1) – GaAs HPA

- YES, we have to consider AM-PM effect as well !!



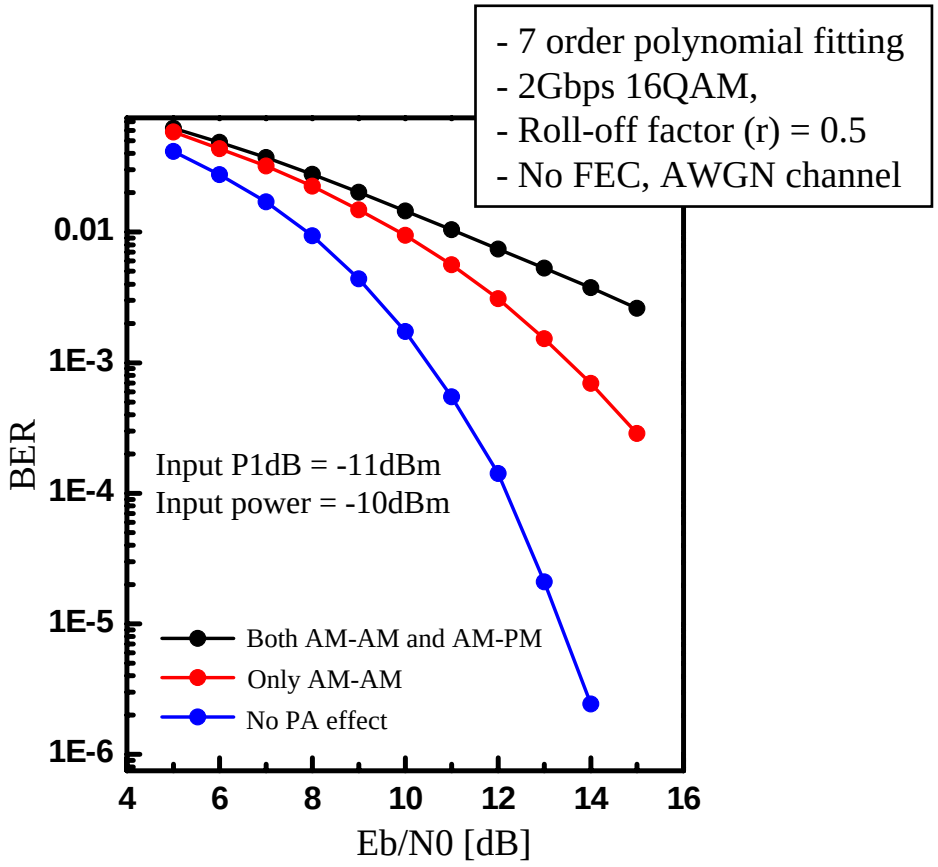
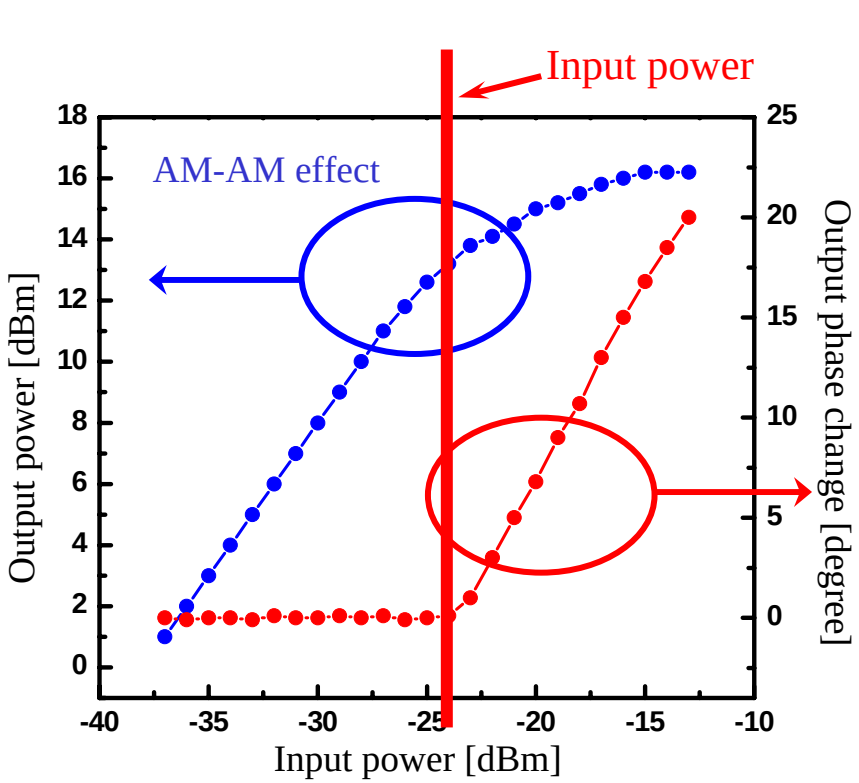


FIGURE: AM-AM and AM-PM results of GaAs pHEMT 60GHz HPA (from NEC)

Impacts of AM-PM effect (2) – SiGe HPA



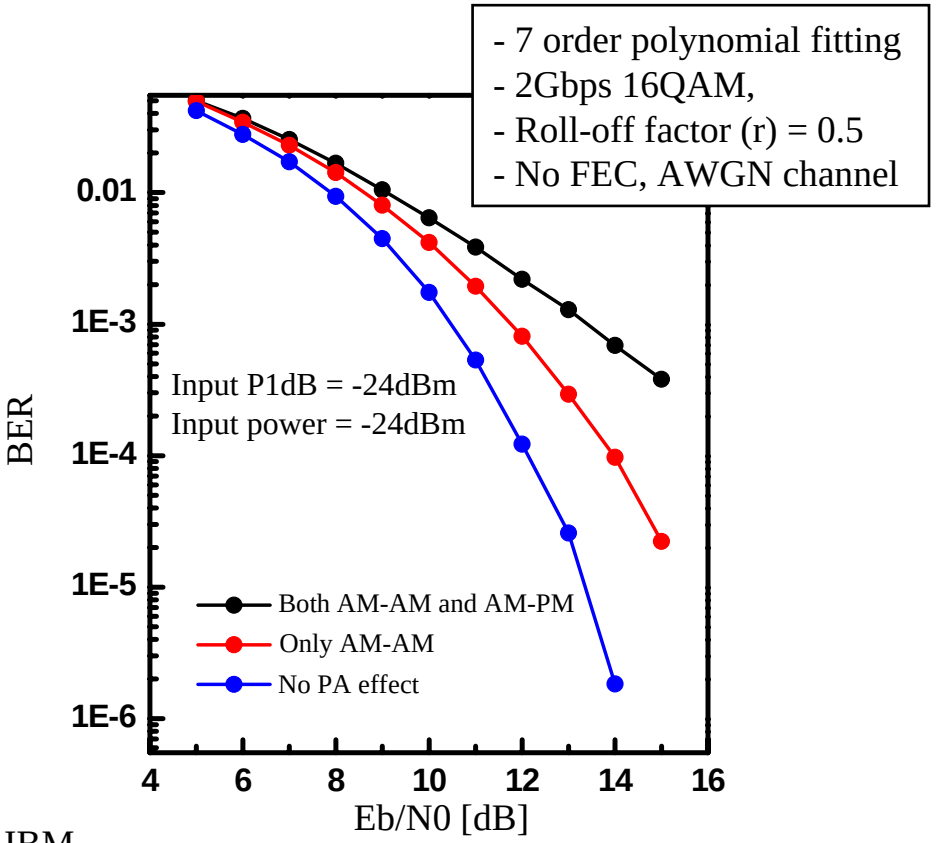


FIGURE: AM-AM effect adapted from 60GHz SiGe PA by IBM
AM-PM effect adapted from 5GHz SiGe PA (See references)

→ ***We should consider AM-PM effect as well for 60GHz system/PHY sim.***

Conventional power amplifier models

1. Rapp model (used in 802.11a)

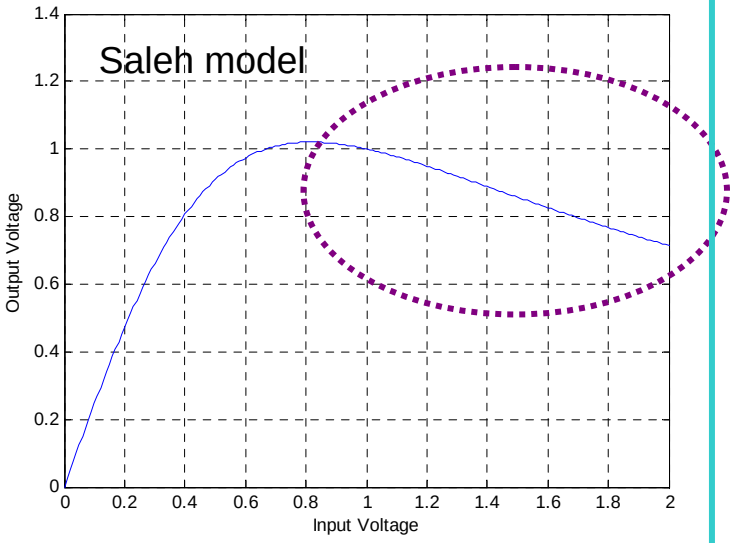
$$F_{AM/AM}(u) = \frac{u}{\left(1+\left(\frac{u}{O_{sat}}\right)^{2S}\right)^{1/2S}}$$

Problem: ***Only AM-AM effect. No AM-PM effect***

2. Saleh model (used in 802.16)

$$F_{AM/AM}(u) = \frac{\alpha_1 \cdot u}{1+\beta_1 \cdot u^2} \qquad F_{AM/PM}(u) = \frac{\alpha_2 \cdot u^2}{1+\beta_2 \cdot u^2}$$

- Increasing input power, output signal can decreases



Problem: ***Originally suggested for TWT amplifier, Not suitable for semiconductor amplifier***

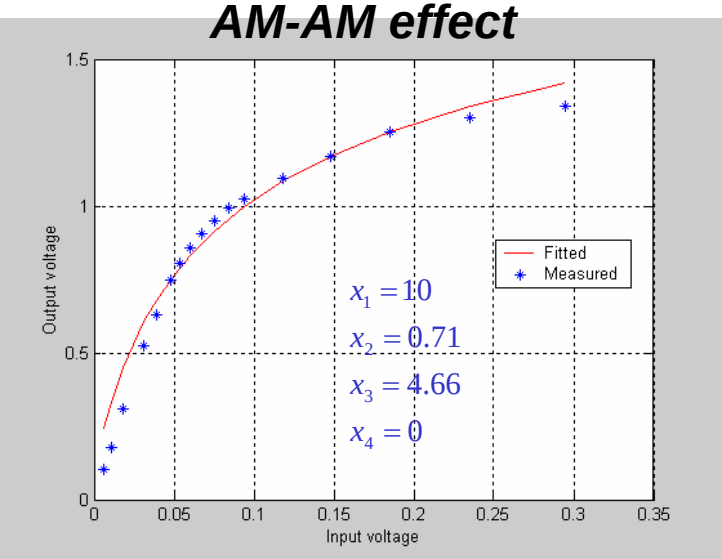
Proposed power amplifier model for TG3c

3. Ghorbani model: well express AM-AM and AM-PM effects

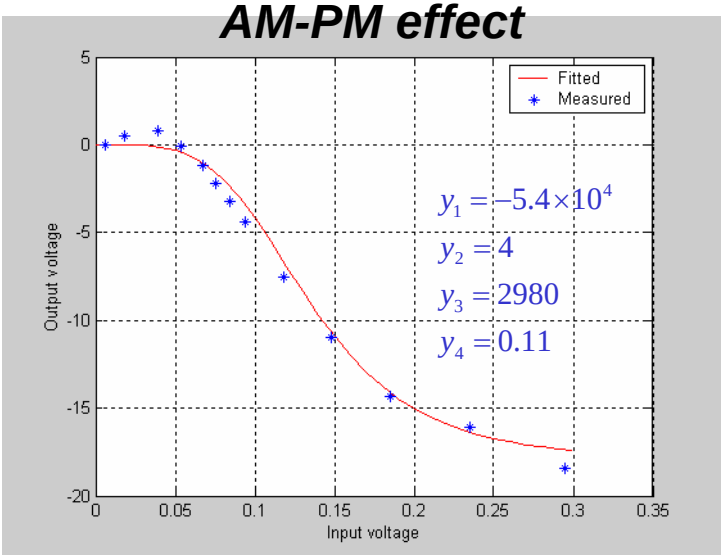
$$F_{AM/AM}(u) = \frac{x_1 \cdot u}{1 + x_3 \cdot u^{x_2}} + x_4 u$$

$$F_{AM/PM}(u) = \frac{y_1 \cdot u}{1 + y_3 \cdot u^{y_2}} + y_4 u$$

AM-AM effect



AM-PM effect

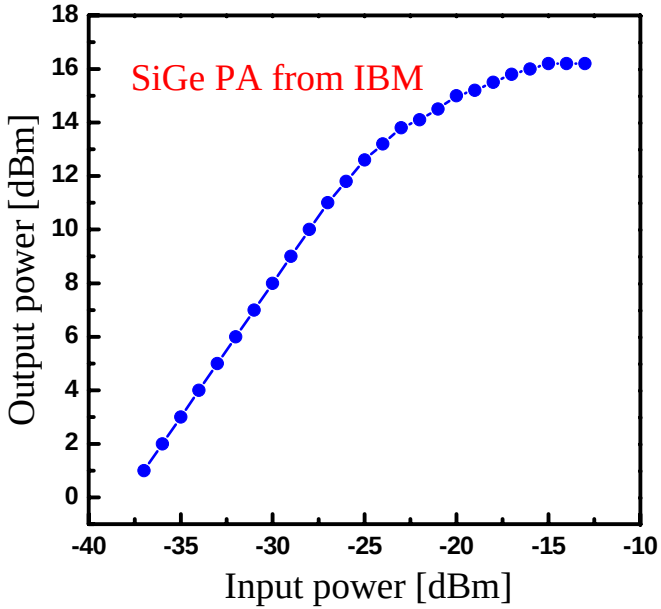


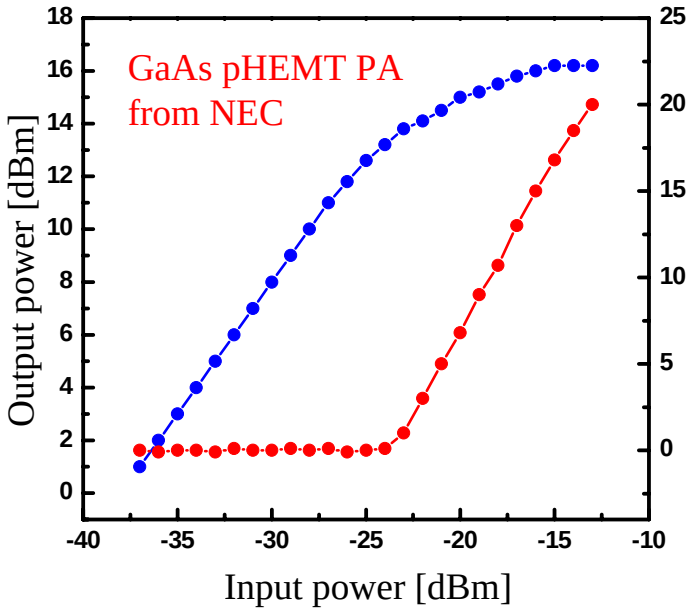
Measurement: AM-AM and AM-PM results of GaAs pHEMT 60GHz HPA (from NEC)

→ ***Ghorbani model is suitable for TG3c PHY evaluation***

SiGe and GaAs-based HPA

- SiGe/Si-PA is the best for low-cost and integration
- GaAs PA is mature technology and good for high power added efficiency





→ ***Let's use parameters of SiGe PA and GaAs PA***

→ ***Problem: No available AM-PM measurement result for SiGe PA***

Conclusion

- AM-PM effect should be also considered for accurate PHY evaluation
- Ghorbani model is suitable for TG3c PHY evaluation
- SiGe and GaAs HPAs are possible candidates
- We can provide the parameters for GaAs HPA, however no AM-PM measurement result for SiGe PA is available.

References

- Brian Floyd, et al., “A Silicon 60GHz receiver and transmitter chipset for broadband communication,” ISSCC 2006.
- Aaron Walker, et al.,”A Vector intermodulation analyzer applied to behavioral modeling of nonlinear amplifier with memory,” IEEE Trans. Microwave Theory Tech., 2006

Memory or Memory-less ?

- Memory effects in a circuit results in frequency dependent and asymmetric distortion

- A number of different origin, so difficult to anticipate
- This complicates any attempts to linearize HPA

- Not higher than 10mW output power in TG3c
- Memory-less model is enough

Output power vs. PA efficiency