

# **A fast modulator for dynamic supply linear RF power amplifier**

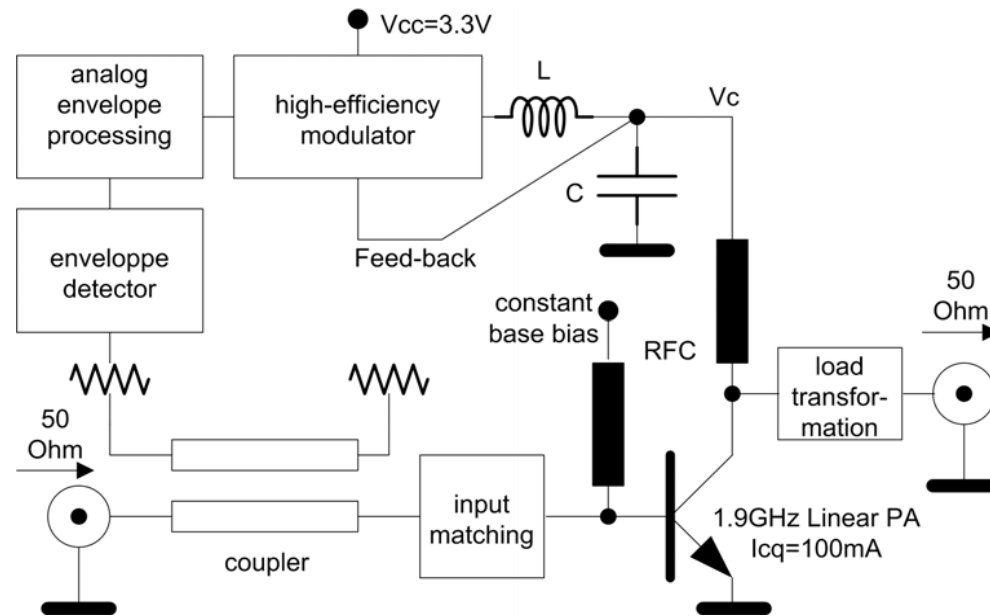
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# Presentation Outline

- Remind the principle of the dynamic supply linear RF PA
- RF Distortion added by this principle
- Modulator and CMOS circuit design
- Measurement results
- Conclusion

# Principle of dynamic supply linear RF PA

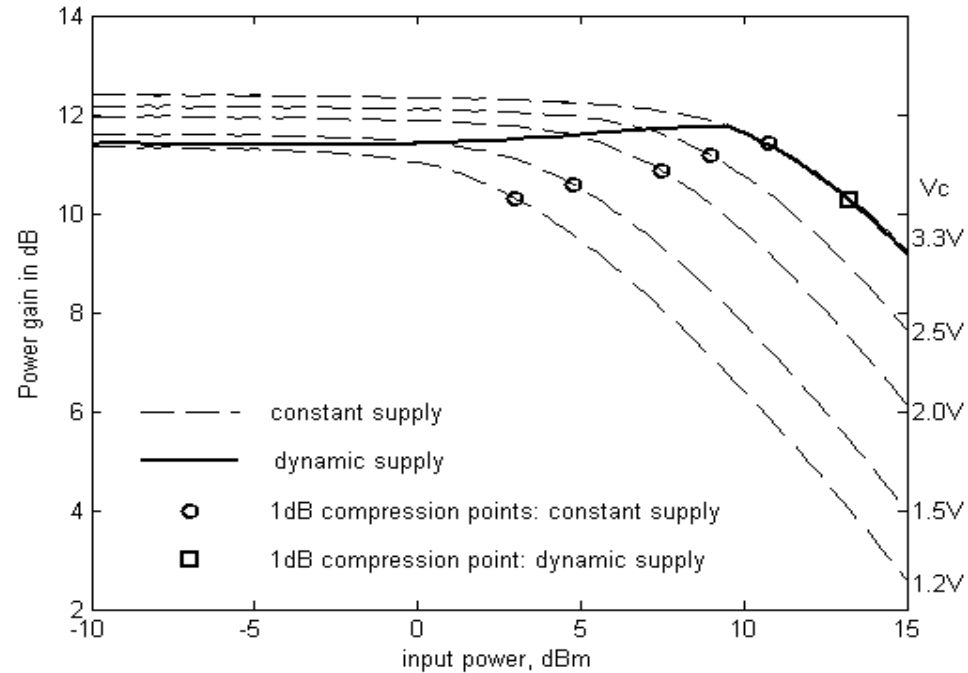


PA supply dynamically adapted to peak RF envelope power  
→ overall PA efficiency is maintained

## Signal processing

- forward input coupled voltage detection
- envelope amplification
- high efficiency conversion of constant supply into dynamic supply

# Static PA power gain vs supply voltage ( $V_c$ )



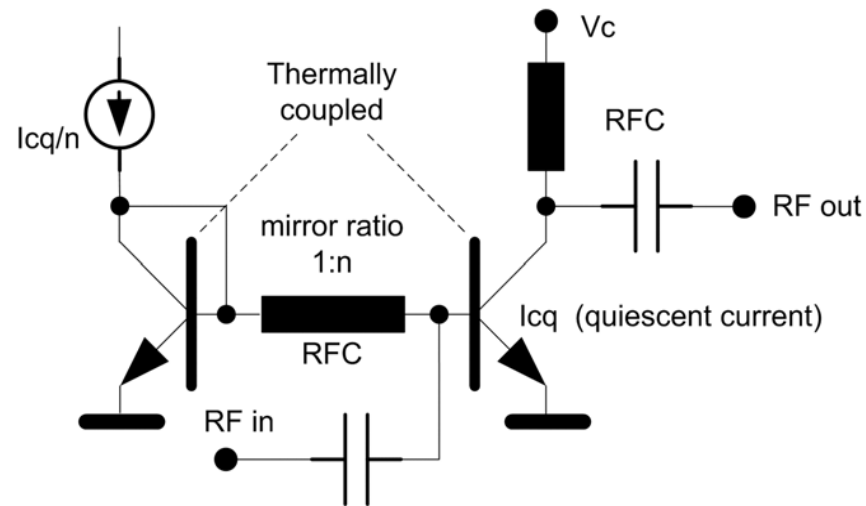
- 1dB power compression point improves with power supply voltage  $V_c$
- Slight dependence of power gain with supply voltage  $V_c$
- Dynamic adjustment of  $V_c$  improves overall efficiency and linearity

## *Key issues:*

- High efficiency supply conversion to improve overall PA efficiency
- High speed to track rapid envelope variations

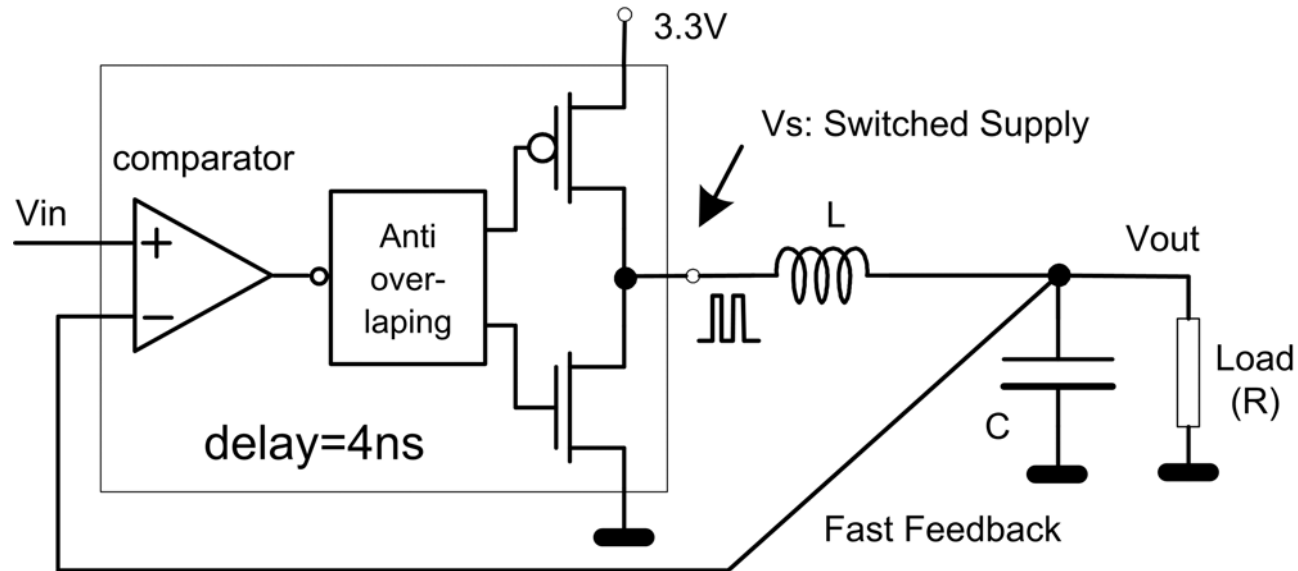
# Distorsion added by the dynamic supply principle

- Static power gain measurement can differ from dynamic power gain
  - $V_c$  variation induces large thermal variation in the PA
  - Thermal bias point modulation and distortion
    - use of a mirrored PA configuration reduces distortion

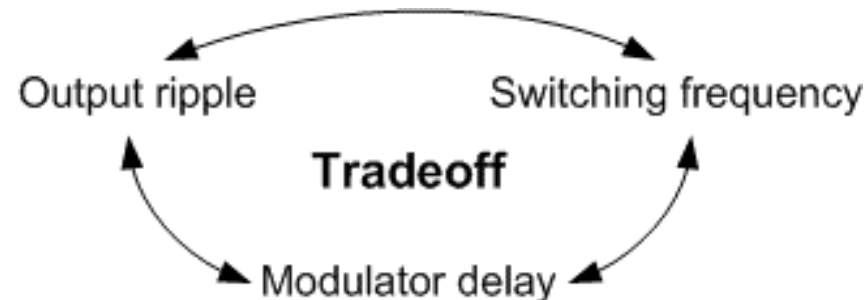


- Phase lag and large amplitude error of  $V_c$  generates distortion
  - use of a fast modulator architecture reduces distortion

# Fast sliding mode modulator architecture



- Fast feedback architecture: output rise time depends on LC filter
- Output replicates input with filtered switched supply superimposed
- For a given output ripple: modulator delay  $\downarrow$ , switching frequency  $\uparrow$
- For a given delay: switching frequency  $\uparrow$ , output ripple  $\uparrow$
- **Minimizing delay is a key issue**



# PA DC current drawn under CW RF signal

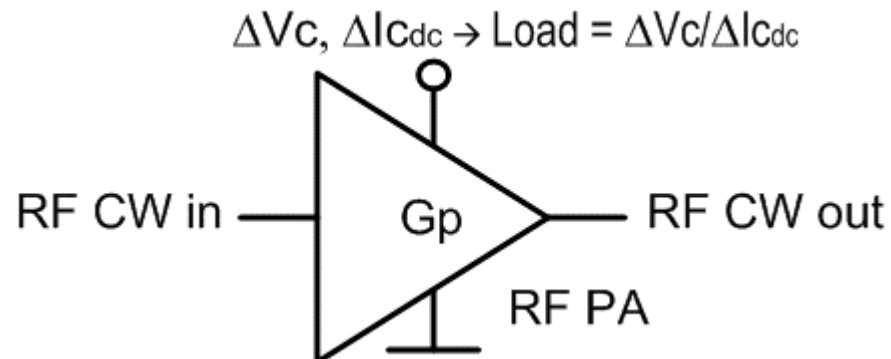
- PA with exponential law (BJT)

$$I_{c_{dc}} = I_{c_q} \cdot \left(1 + \frac{A^2}{4} + \dots\right) \quad \text{with} \quad A = \frac{V_{in_{CW}}}{U_t}$$

PA Quiescent current                      RF CW input Amplitude  
normalized to  $U_t$  (26mV)

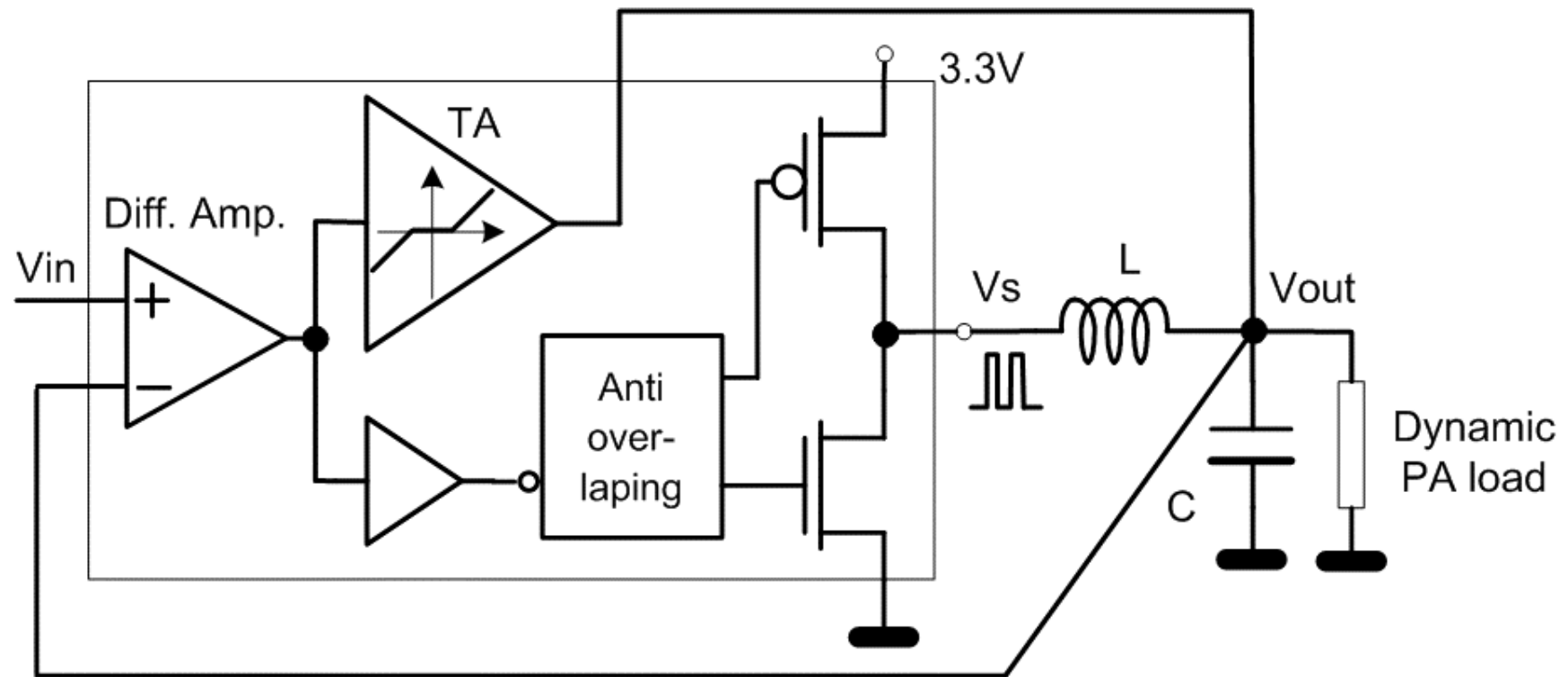
- DC current  $\div$  input power
- DC current increases for PA with reduced conduction angle

**PA is a dynamic load for the modulator**



- $\Delta V_c \div A$  (avoid RF output voltage saturation)
- $\Delta I_{c_{dc}} \div A^2$
- $\rightarrow$  load is dynamic

# Modulator with Transconductance Amplifier (TA)

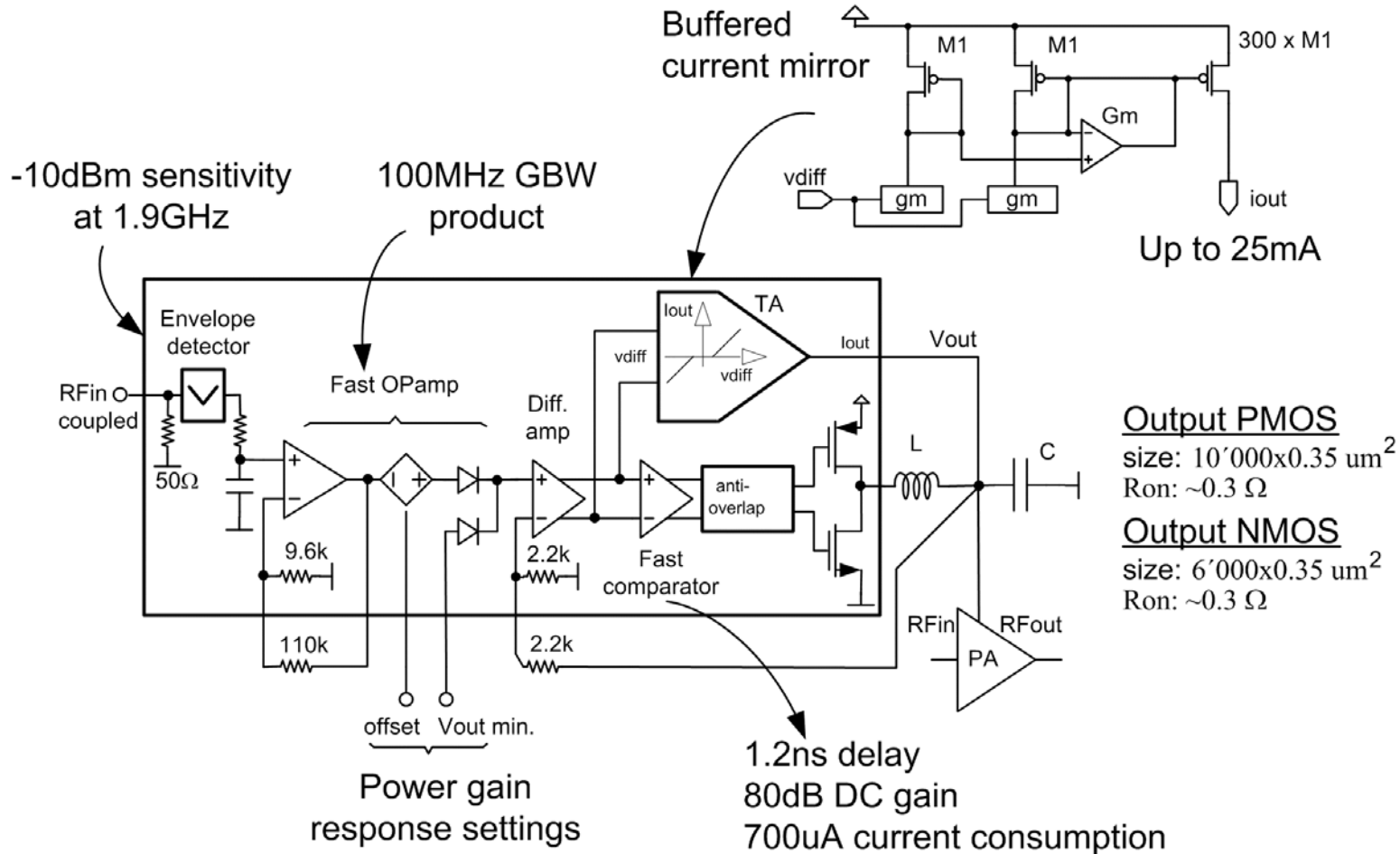


- Variation of inductor current limited by:  $\Delta I = (V_s - V_{out}) \cdot \Delta T / L$
- Dynamic PA load with inductor  $\rightarrow$  slew rate limitation

## Solution:

- Transconductance amplifier
  - Supply load current only for large voltage error ( $>$  output ripple)

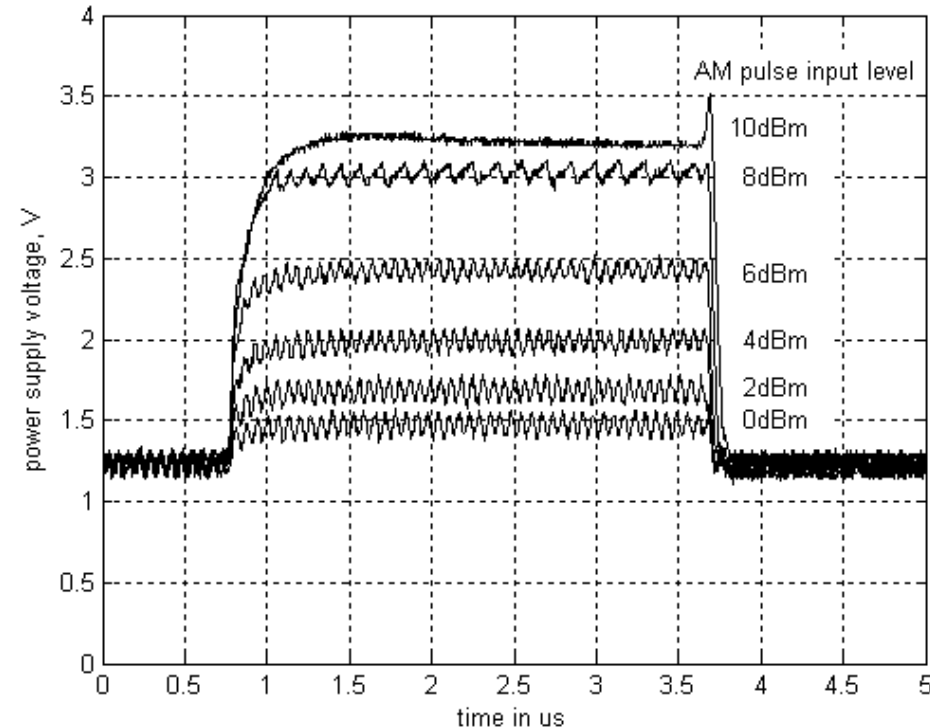
# 0.35um CMOS circuit design



## Typical performances:

- Supply voltage: 3.3V
- Overall delay:  $\sim 4\text{ns}$
- Idle current consumption: 2mA
- Dynamic current consumption: 3.5mA ( $f_s=20\text{MHz}$  & 100mA load)
- Efficiency: 85% (100mA load current & 1.25V output voltage)

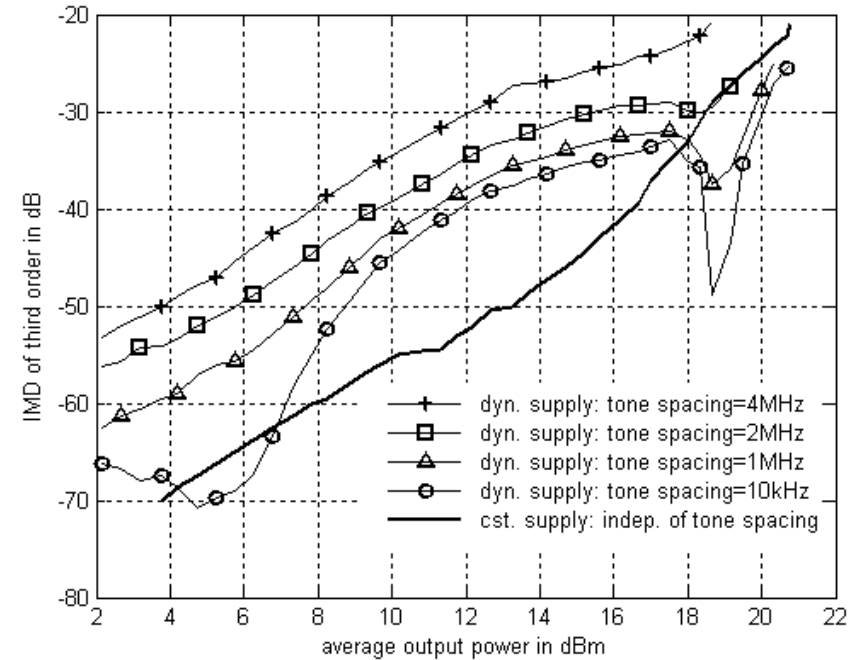
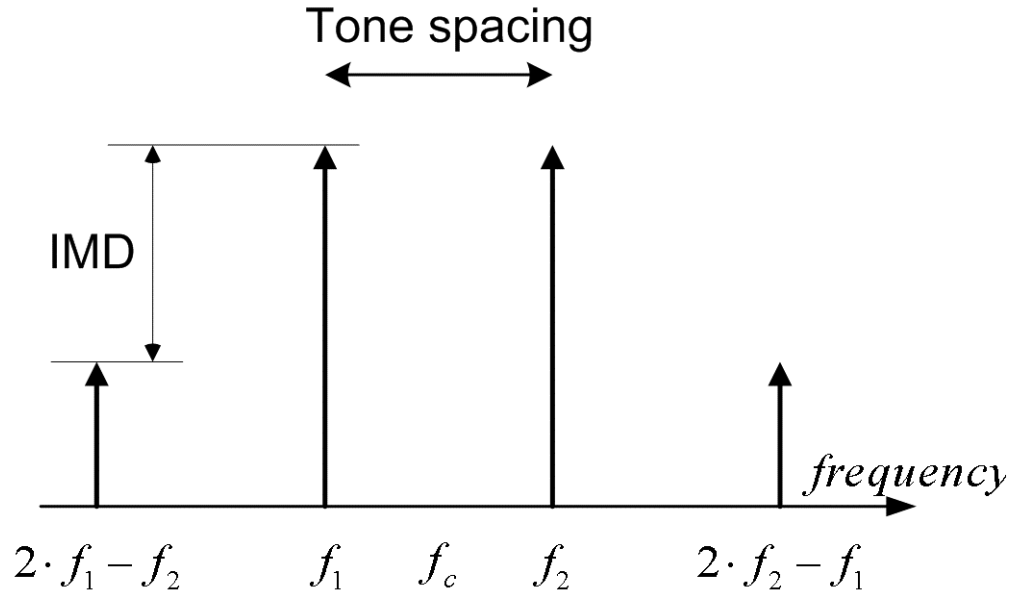
# Experimental measurement: 1.9GHz pulsed AM voltage supply response



- Rise time  $\leq 200\text{ns}$   $\rightarrow$  envelope tracking up to about 2MHz
- Switching frequency : 16MHz
- Typical output ripple : 180mVpp

# Experimental measurement: 1.9GHz two tones linearity test

→ Comparison of constant 3.3V and dynamic supply PA

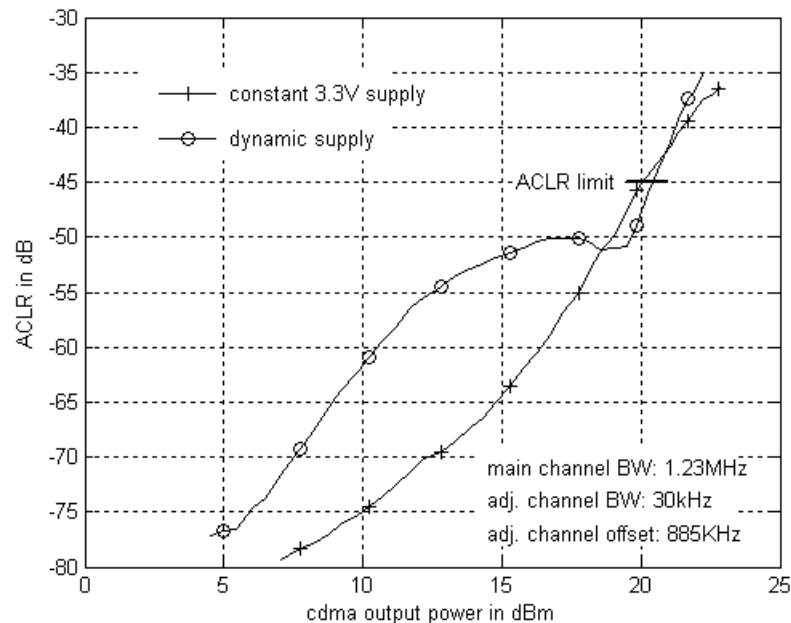


- IMD start to degrade quickly for tone spacing > 2MHz
- Tone spacing < 2MHz → dynamic supply has better linearity at high output levels!

# Experimental measurements: IS-95 CDMA signal

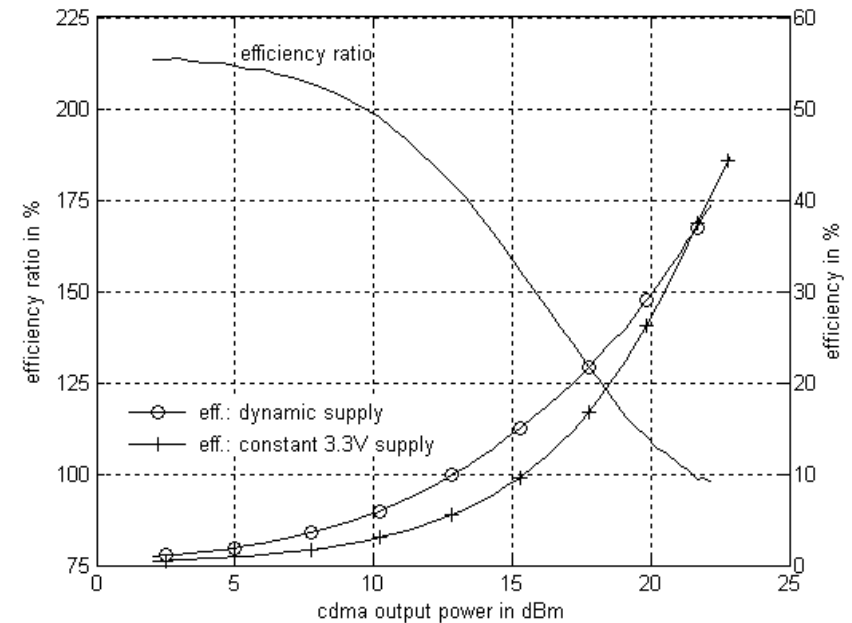
→ Comparison of constant 3.3V and dynamic supply PA

## Linearity (ACLR)



- Dynamic supply PA: better linearity at high output power level
- + Constant supply PA: useless higher linearity at low output power level

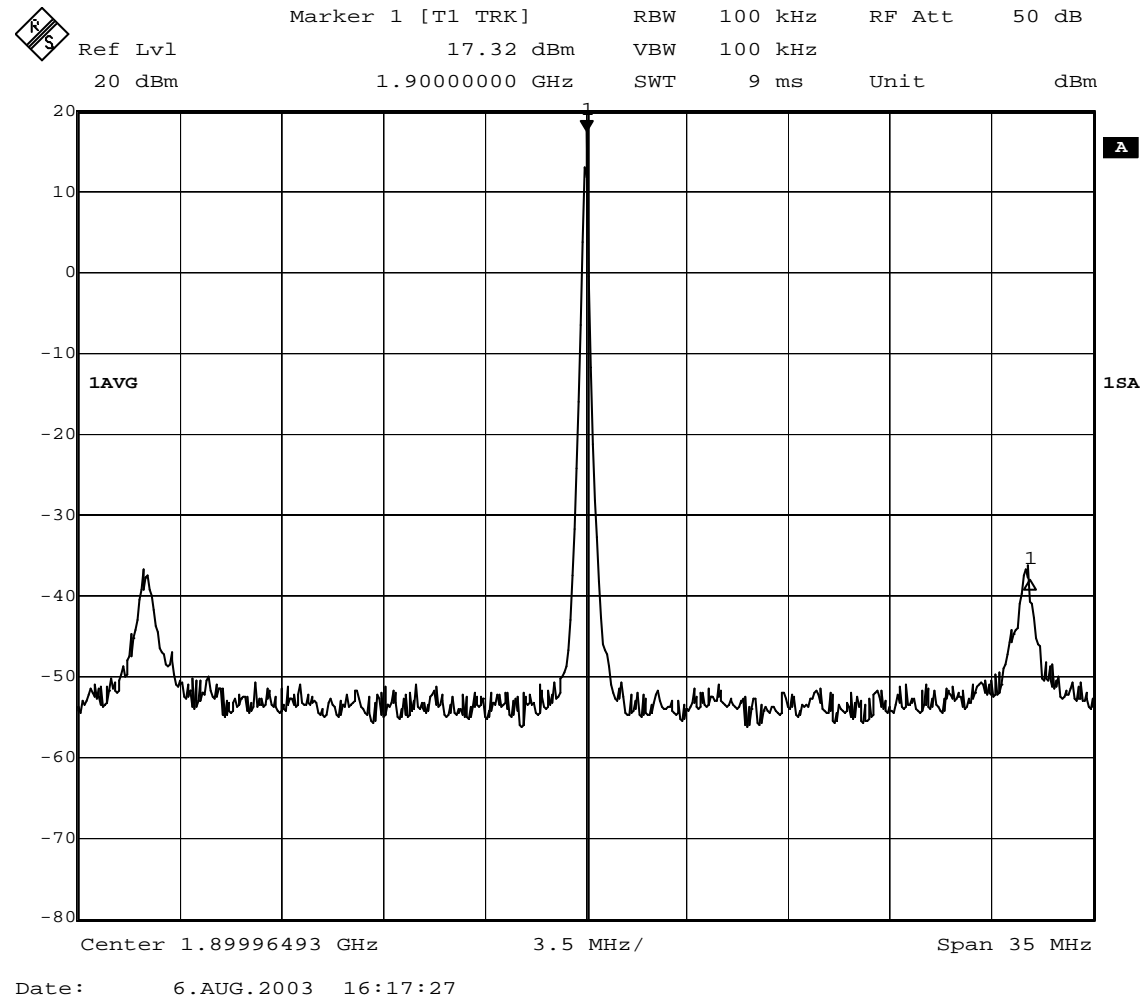
## Efficiency



- Dynamic supply PA: maintains efficiency at a higher level in the whole linear range

# Switching noise output spectrum

Input signal: 5 dBm IS-95 CDMA, BW=1.23MHz



- Switching noise leakage approximately 55dB lower than the fundamental

# Conclusion

## Main advantages of Dynamic supply PA vs constant supply PA

- + maintains efficiency of linear PA below maximum linear output power
- + better linearity at high output power for envelope BW up to 2MHz

## Drawbacks of Dynamic supply PA vs constant supply PA

- slew rate limitation for reduced conduction angle PA
- switching noise leakage
- envelope BW limitation

CMOS modulator  
(COB assembly)

6.8uH inductor  
Coilcraft 1812PS

Microstrip 1.9GHz  
12 dB coupler

PA (BGB550 of  
Infineon)

