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Hughes

UCSB

Capacitive-Division Traveling-Wave Amplifier with 340 GHz Gain-Bandwidth Product

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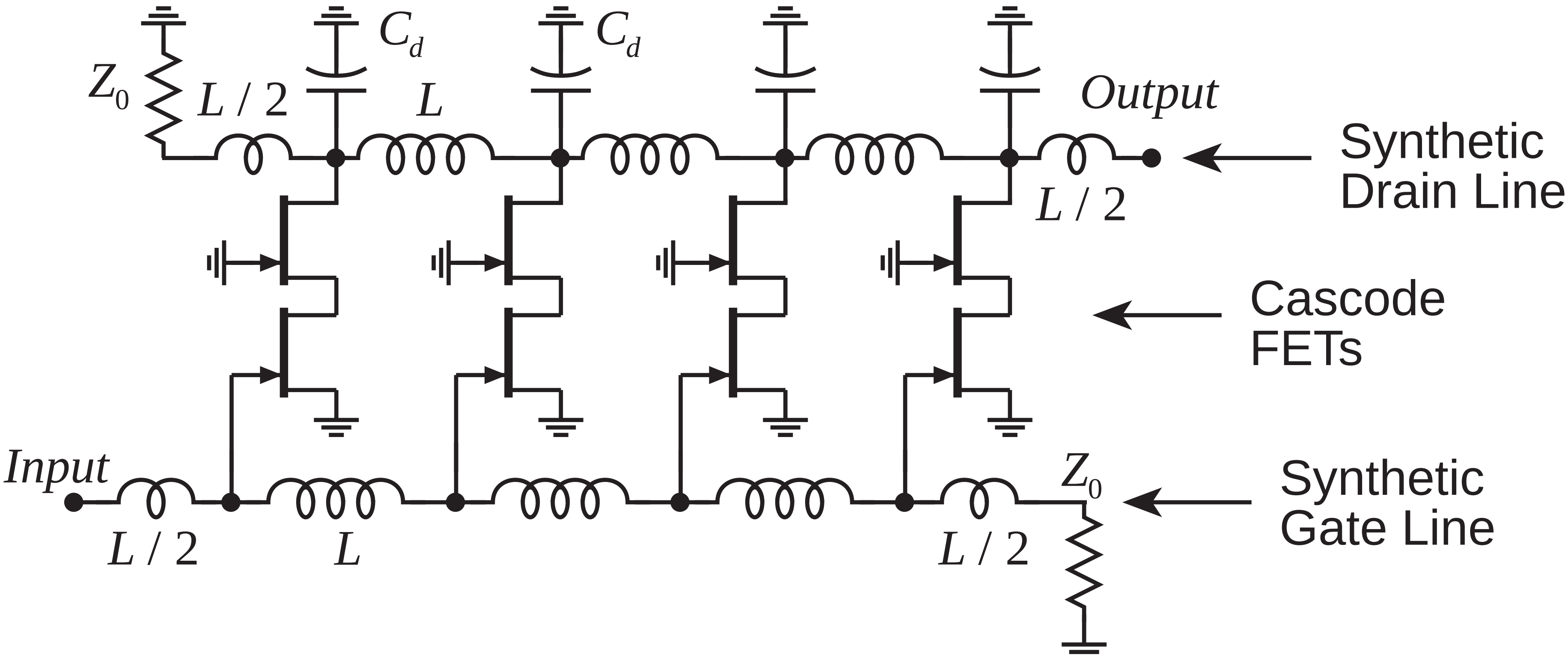
Capacitive-Division Traveling-Wave Amplifier

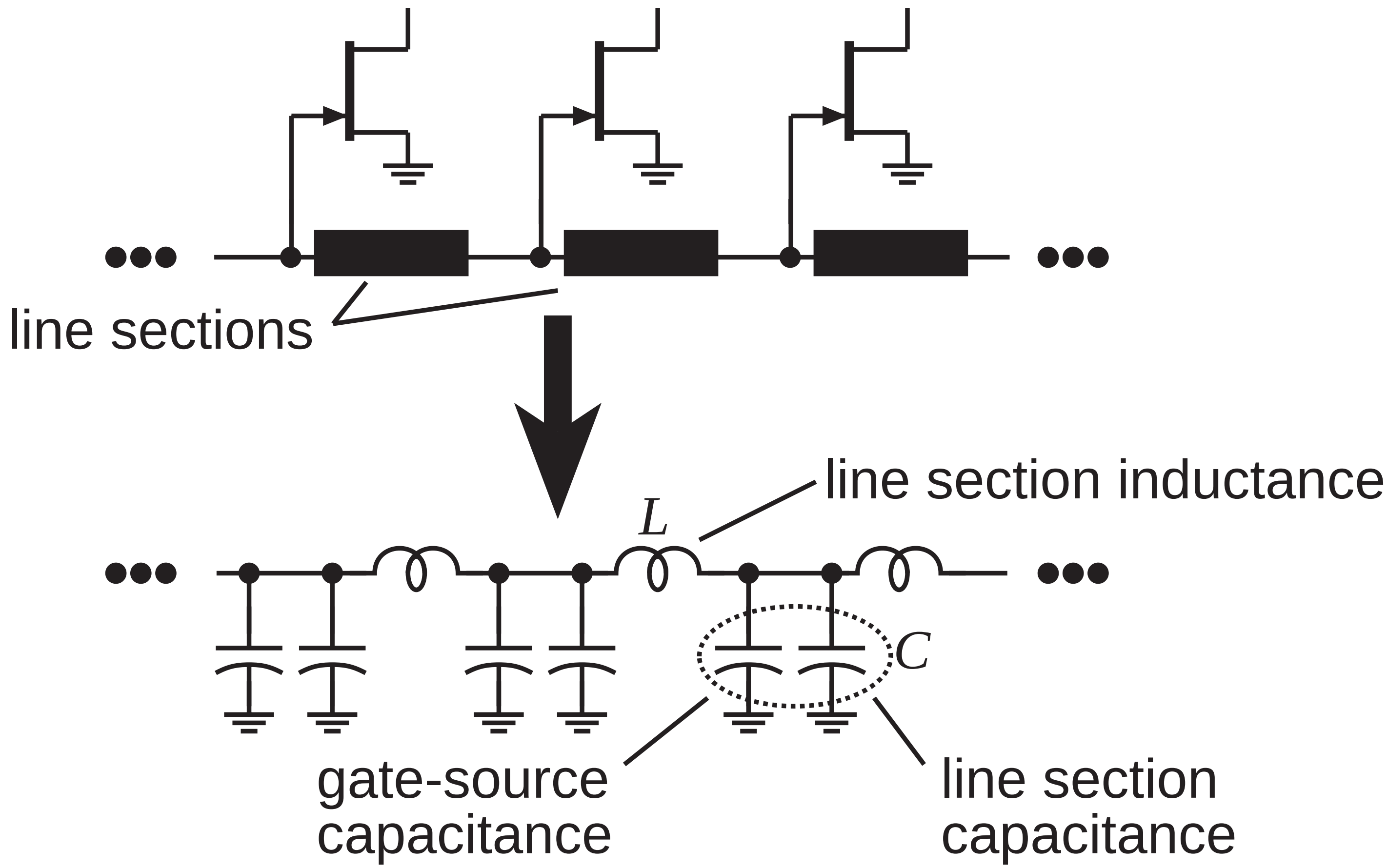
- Traveling-wave (distributed) amplifier :
  standard broadband IC
- Capacitive division TWA:
  Ayasli, 1988
  broadband power
- Capacitive division TWA:
  significantly larger gain-bandwidth product
- This work: InGaAs/InAlAs HEMT CDTWAs
- Result: 11 dB gain, 96 GHz bandwidth
- Record 340 GHz gain-bandwidth product

Principles of Traveling-Wave Amplifiers



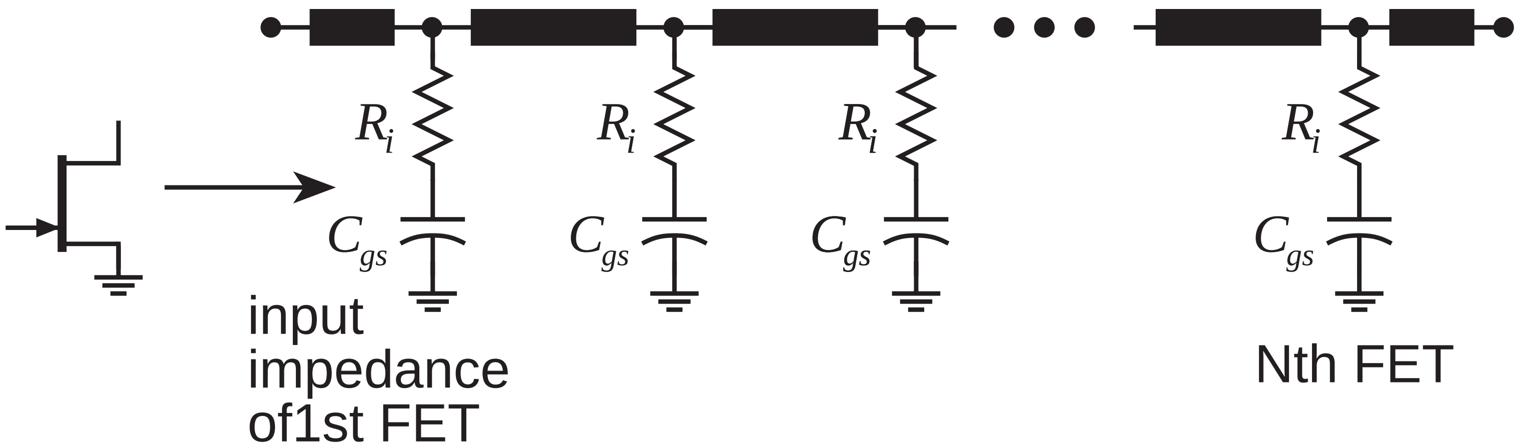
- Broadband circuit.
- FET input / output capacitances absorbed into synthetic transmission lines.
- Gain-bandwidth limited by line losses resulting from FET resistive parasitics.

Synthetic Transmission Lines in TWAs



- Characteristic impedance: $Z_0 = \sqrt{L/C}$
- Cutoff frequency: $f_{cutoff} = 1/\pi\sqrt{LC}$

TWA Bandwidth Limited by Gate-Line Losses

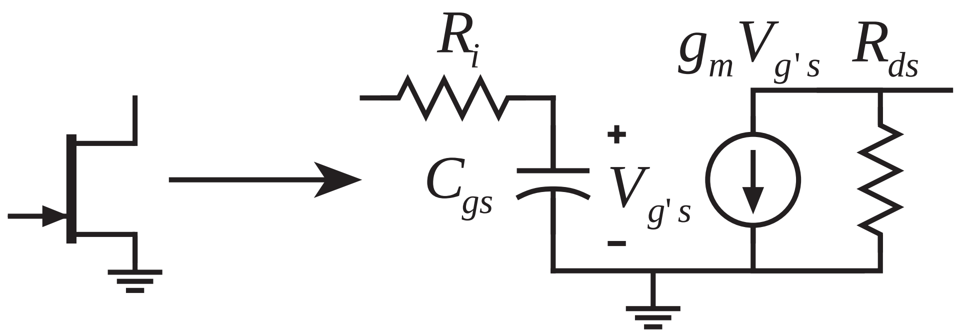


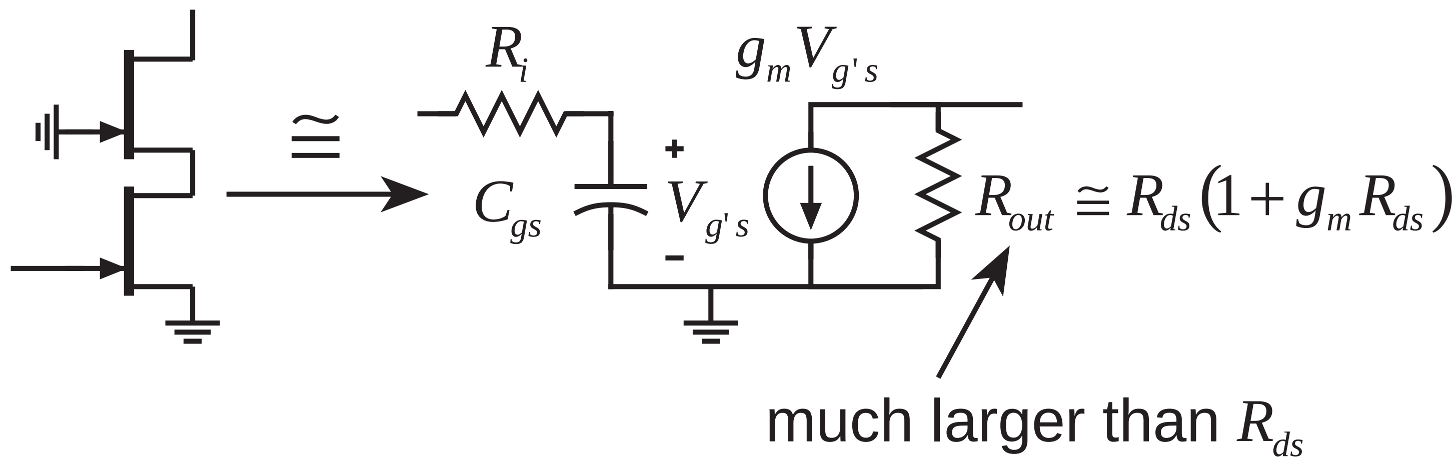
- FET input resistance Ri causes gate line attenuation
- transistors far from input not driven at high frequency
- this limits gain-bandwidth (Ayasli, 1982):

$$|S_{21}|\, f_{high}^{2} \le \frac{f_\tau}{4\pi R_i C_{gs}}$$

...if drain line losses are small (cascode TWA)

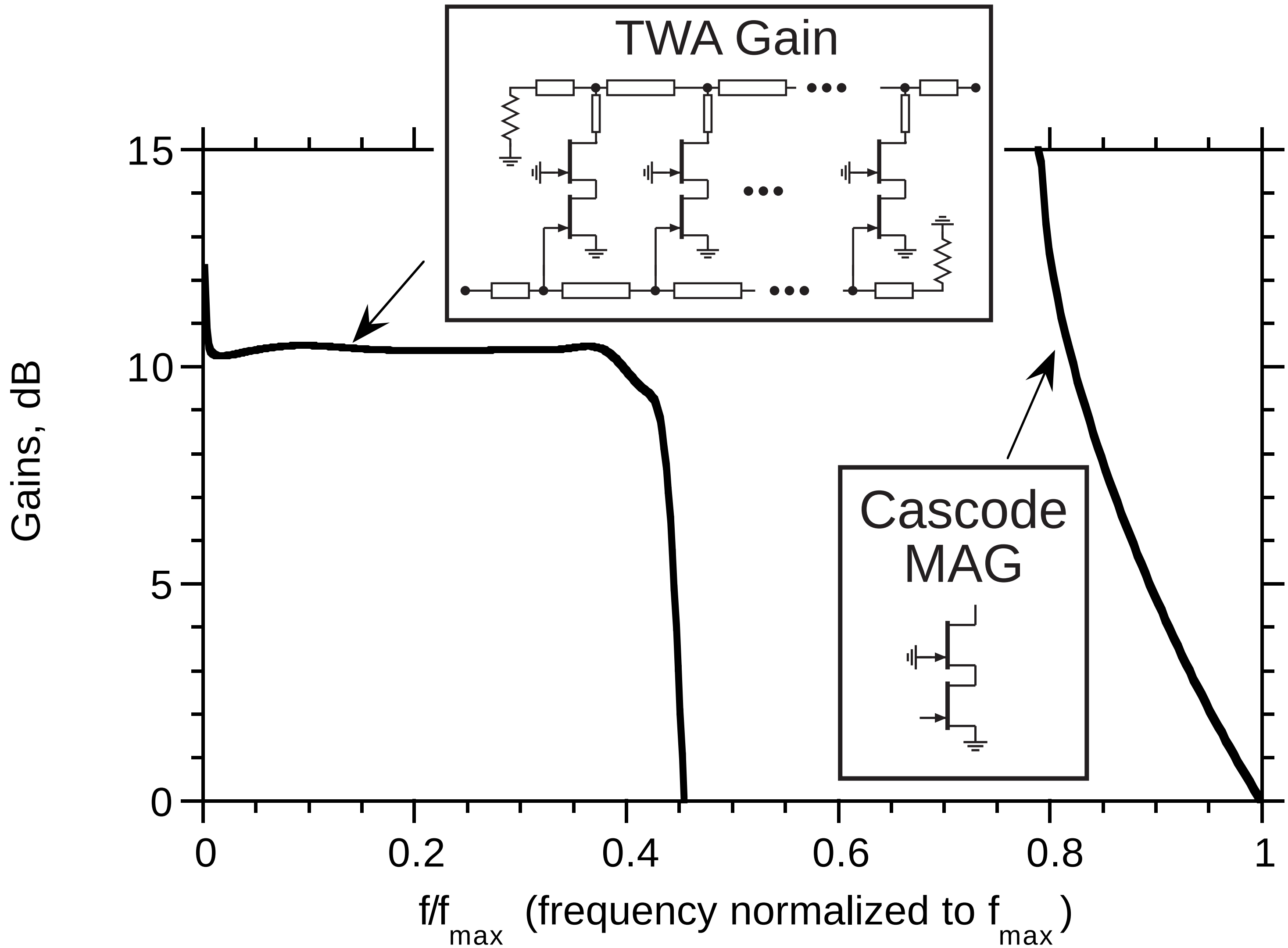
Cascode Cell: Negligible Drain-Line Losses





- Cascode cell:
  very large output resistance
  drain line losses nearly eliminated
  model valid for frequencies significantly below fmax

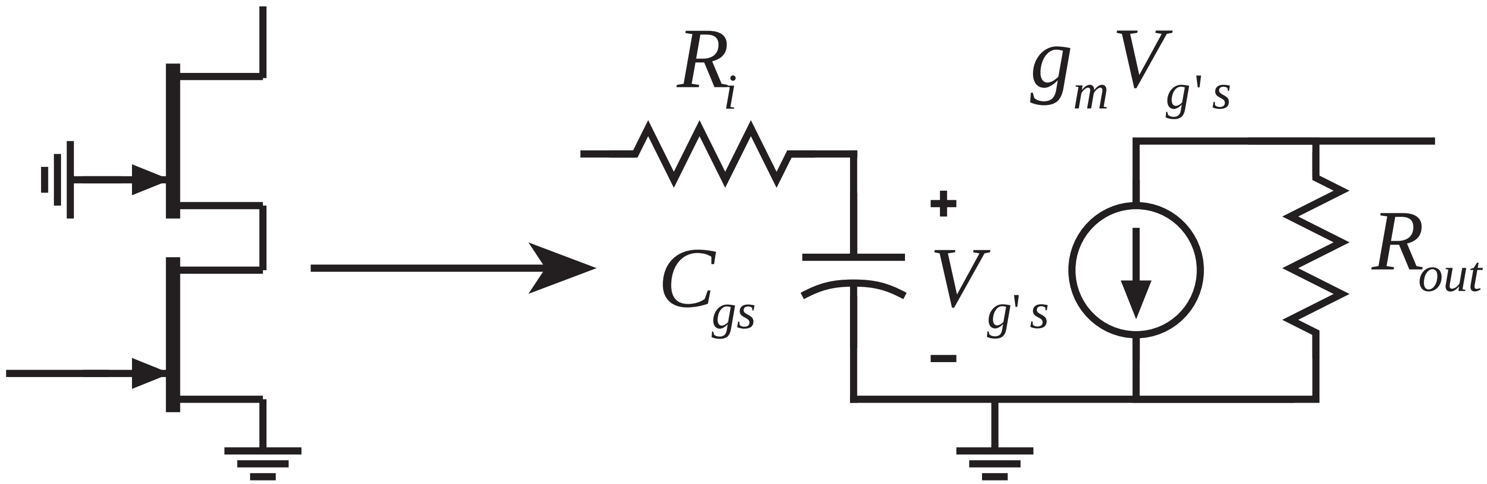
Normal cascode TWAs are not optimal designs



- Gain-bandwidth is well below MAG of cascode cell because 50Ω load much smaller than cascode R_{out}

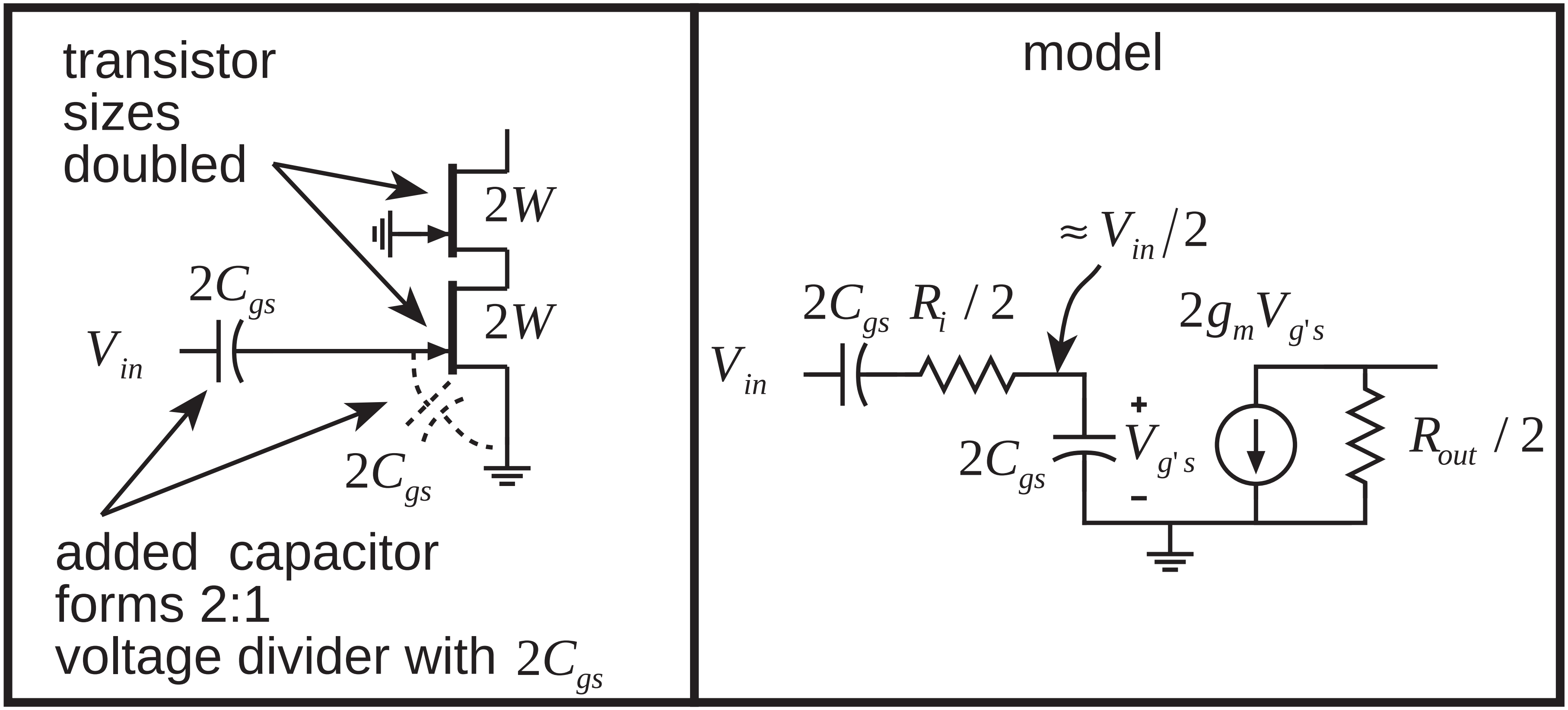
Examine the Gain-Bandwidth Limit:

$$\left|S_{21}\right| f_{high}^{2} \leq \frac{f_{\tau}}{4\pi R_i C_{gs}}$$



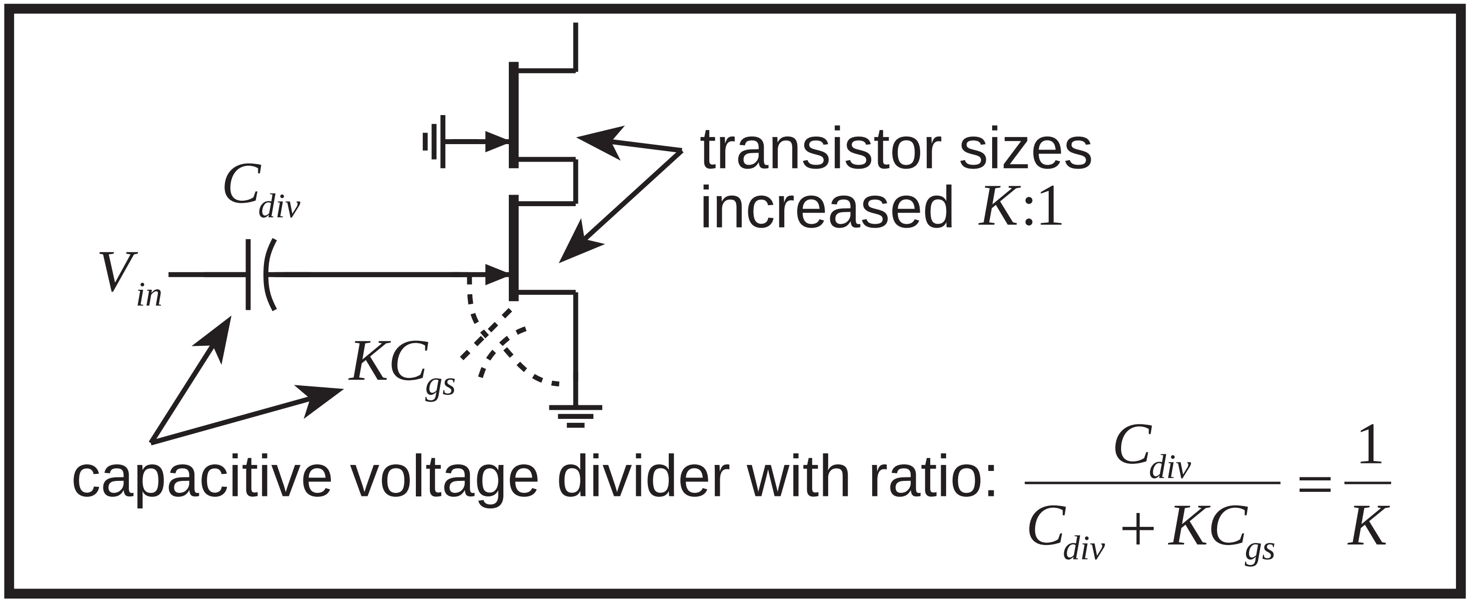
- Decreasing Ri increases gain-bandwidth...
- How can we decrease input resistance Ri?

Capacitive Division Reduces Input Resistance



- same input capacitance,
- same net transconductance
- input & output resistances reduced 2:1
- 2:1 division shown; higher ratios possible

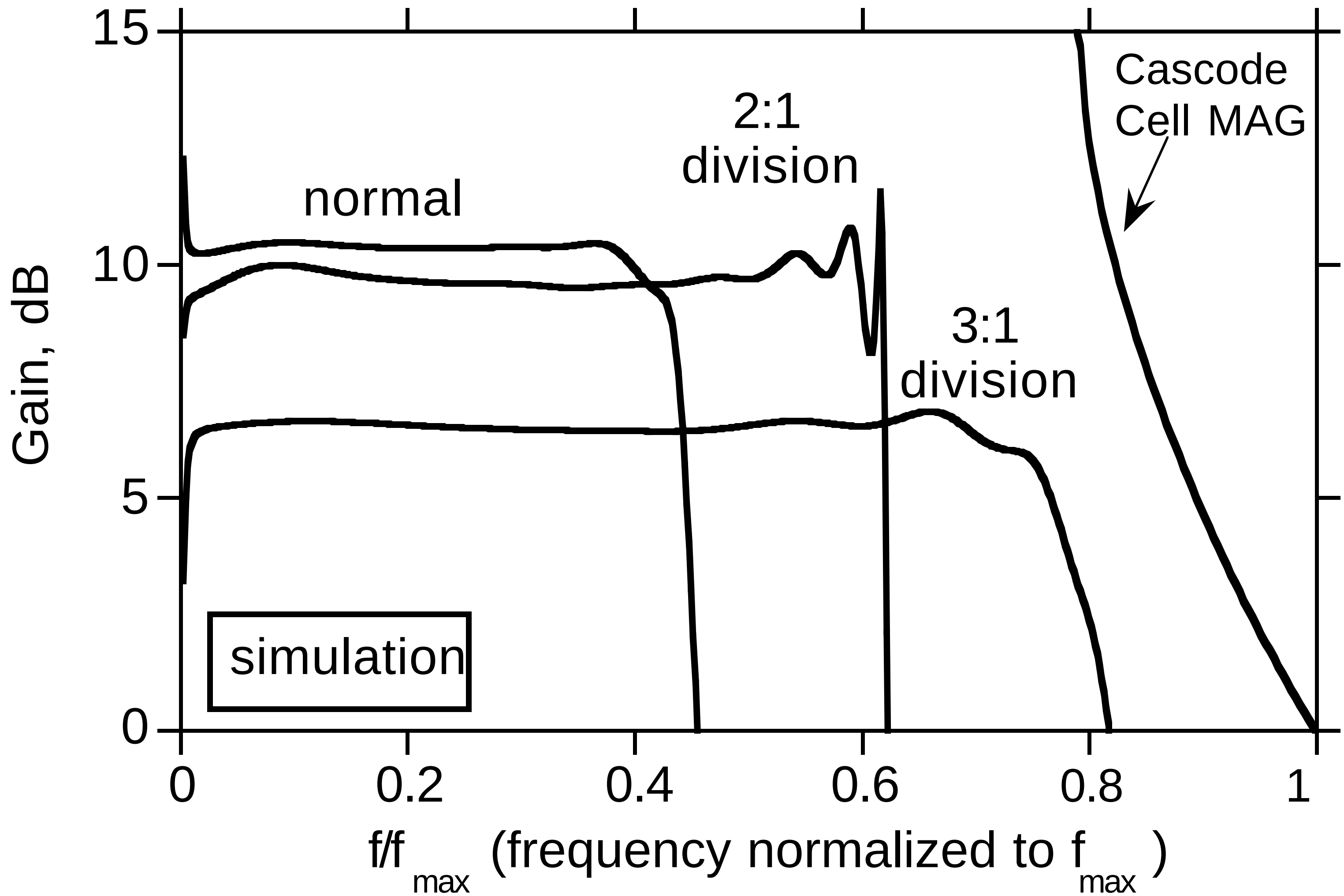
Capacitive Division Increases TWA Gain-Bandwidth



- input & output resistances reduced K:1
- gate line losses reduced K:1
- K:1 more stages can be used: more gain
- at any design bandwidth, gain improved K:1

$$\left\| S_{21} \right\| f_{high}^{2} \le K \cdot \left(\frac{f_{\tau}}{4\pi R_i C_{gs}} \right)$$

How Much Can Gain-Bandwidth Be Improved?



Large division ratios:

- drain losses now significant, limits gain-bandwidth
- gain-bandwidth approaches MAG limit– *optimal circuit*
- big FETs, difficult layout

Implementation / Design Features

Hughes Research Laboratories low noise HEMT

- InAlAs / InGaAs / InP HEMT
- 0.15 μm gate length
- $f_t = 160$ GHz, $f_{\max} = 260$ GHz

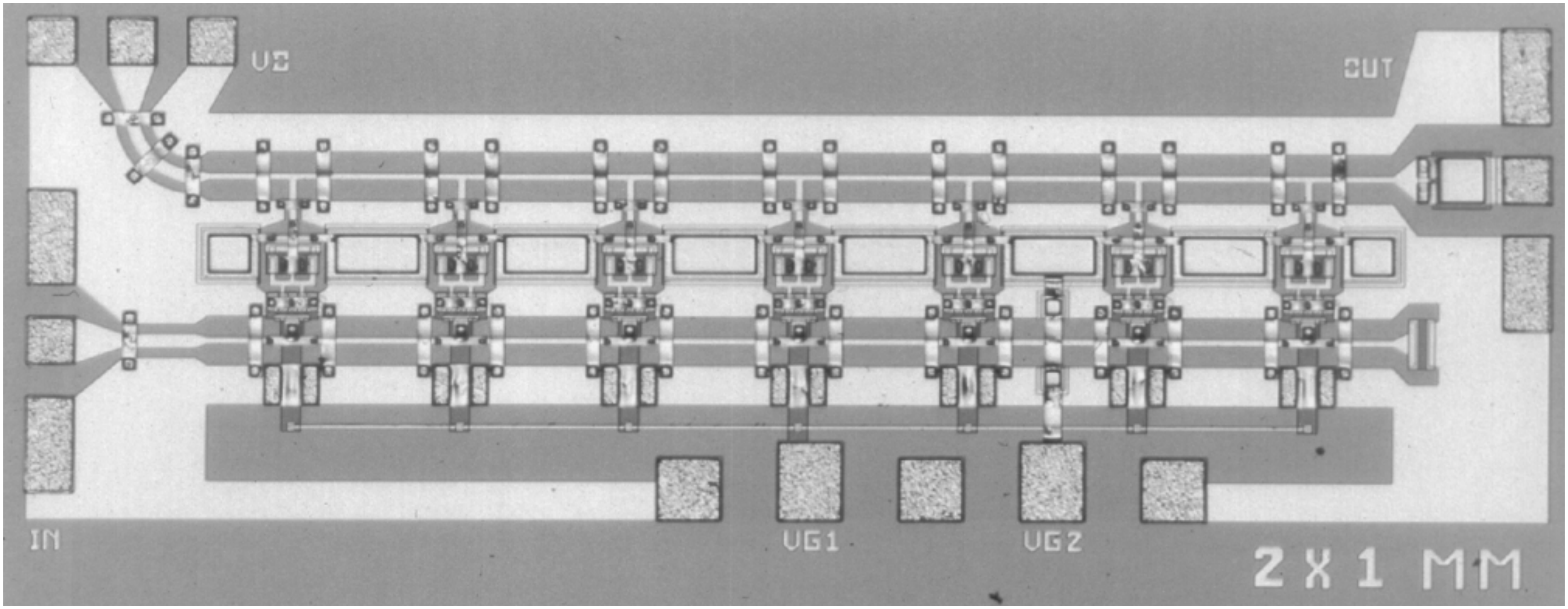
Regular, periodic structure:

- element values from design equations
- not computer optimized
- all cells have same FET sizes, same line lengths

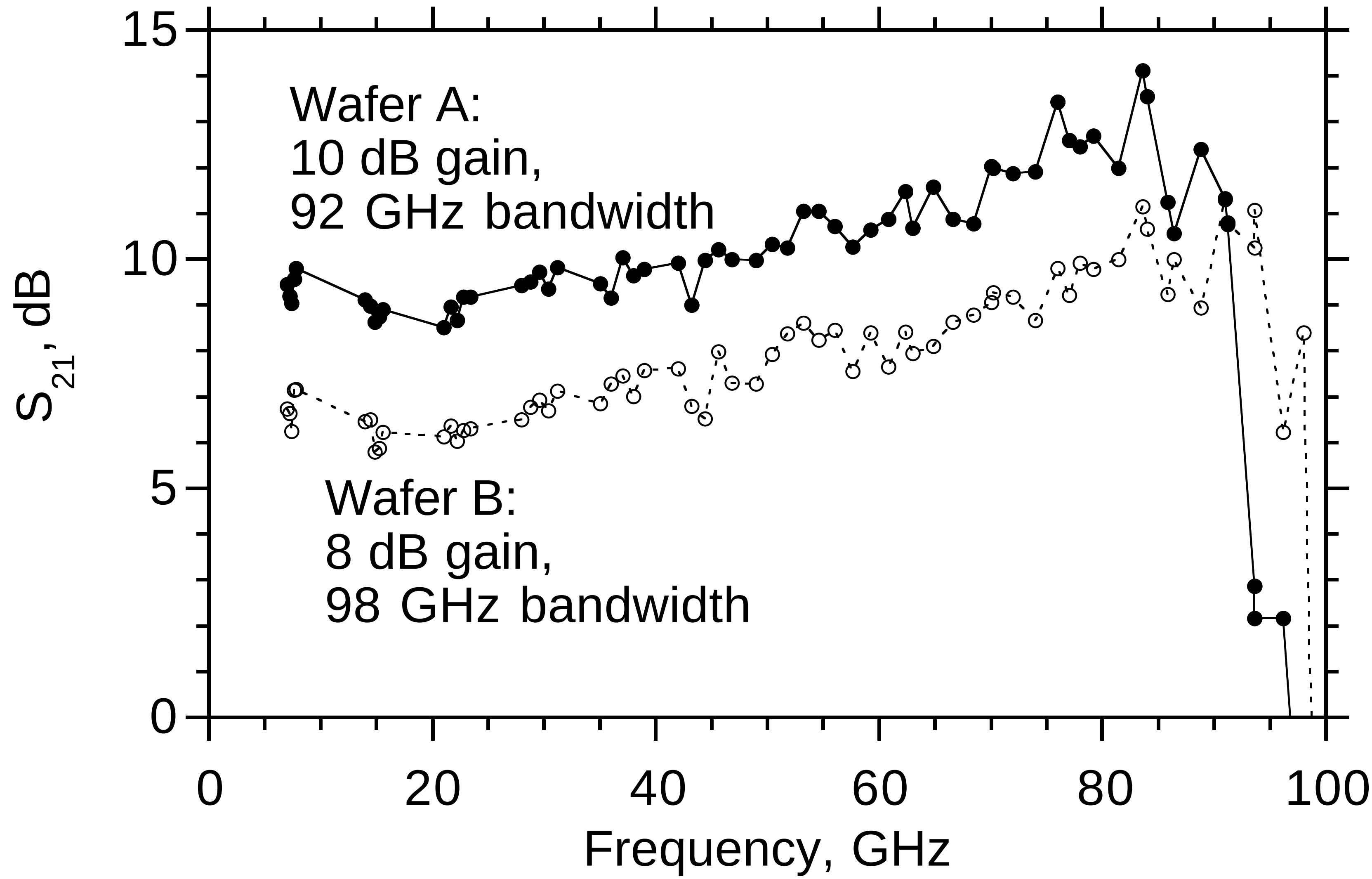
Conservative design:

- 2:1 capacitive division ratio
- designed for positive gain slope vs. frequency
- design gain-bandwidth well below MAG limit
- common-gate damping resistors: stabilization

Die Photo

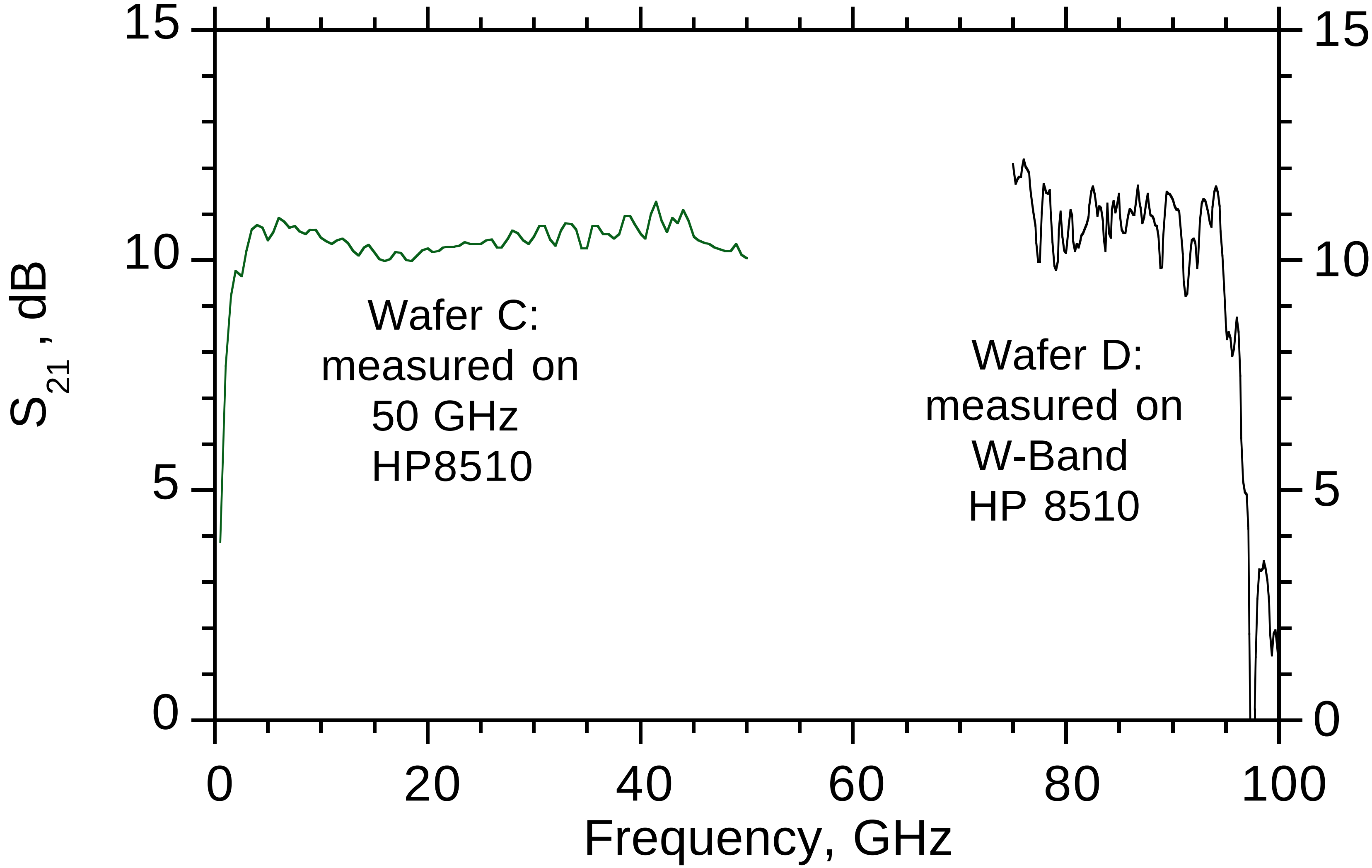


Measured Results: InP Capacitive-Division TWA



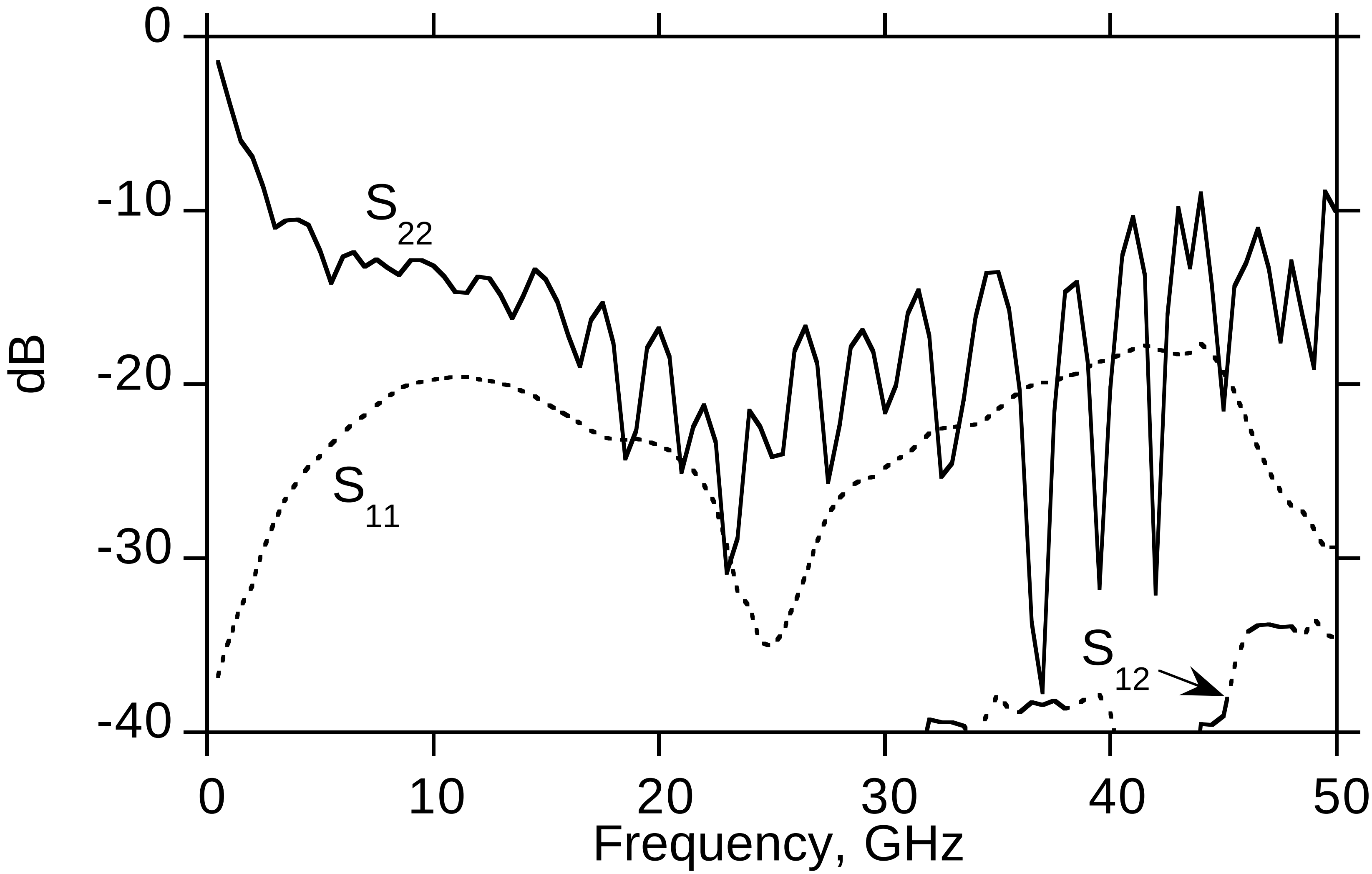
- Measured by UCSB 200 GHz on-wafer network analyzer
- Difference due to variation in Cgs & gm

Measured Results: InP Capacitive-Division TWA



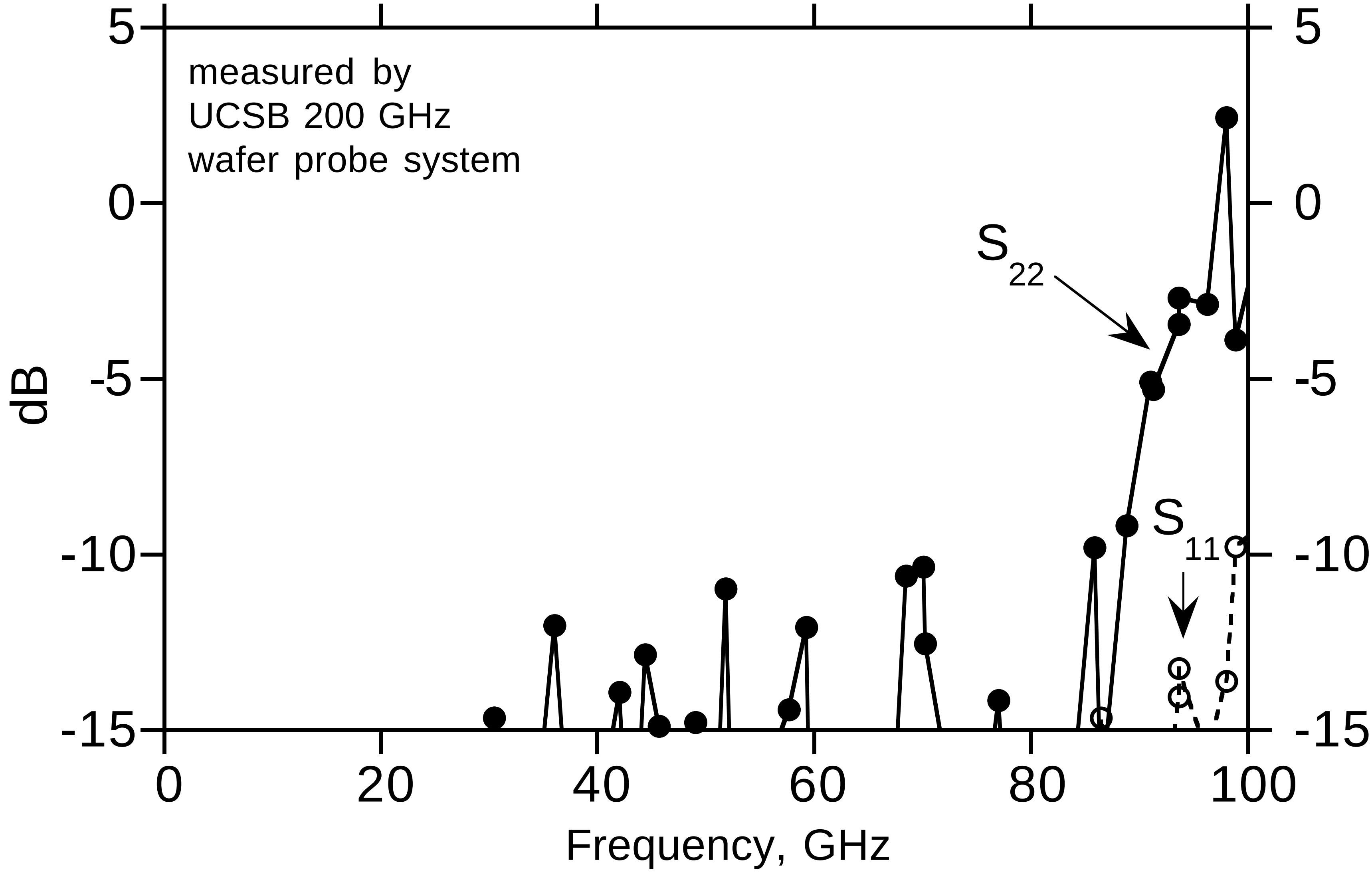
- 11 dB gain, 96 GHz bandwidth
- 340 GHz gain-bandwidth product

DC-50 GHz Return Losses & Reverse Isolation



- S22 resonances due to test configuration (bias probe)
- Good input and output return losses

7-100 GHz Return Losses & Reverse Isolation



• S12 better than –15 dB below 100 GHz

Capacitive-Division TWA with 340 GHz Gain-Bandwidth Product

- Traveling-wave amplifier: broadband gain block
- Ayasli, 1988: capacitive division TWA
- Capacitive division can sizably improve
  gain-bandwidth product
- Results for InGaAs/InAlAs amplifier:
  11dB gain, 96 GHz bandwidth
  record 340 GHz gain-bandwidth product
- This work:
  conservative design
  results below limits of device technology
- Designs with 150 & 200 GHz target bandwidths
  currently in fabrication.