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

J. Pusl\textsuperscript{1,2}, B. Agarwal\textsuperscript{1}, R. Pullela\textsuperscript{1}, L. D. Nguyen\textsuperscript{3}, M. V. Le\textsuperscript{3}, M. J. W. Rodwell\textsuperscript{1}, L. Larson\textsuperscript{3}, J. F. Jensen\textsuperscript{3}, R. Y. Yu\textsuperscript{1,4}, M. G. Case\textsuperscript{1,3}.

\textsuperscript{1} University of California, Santa Barbara
\textsuperscript{2} Now with Hughes Space & Communications Company
\textsuperscript{3} Hughes Research Laboratories
\textsuperscript{4} Now with Rockwell International Science Center

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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: \( f_{\text{cutoff}} = \frac{1}{\pi \sqrt{LC}} \)
TWA Bandwidth Limited by Gate-Line Losses

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

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

...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 $f_{\text{max}}$

\[
R_{\text{out}} \cong R_{ds} \left(1 + g_m R_{ds}\right)
\]

much larger than $R_{ds}$

- Cascode cell:
  very large output resistance
  drain line losses nearly eliminated
  model valid for frequencies significantly below $f_{\text{max}}$
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:

\[ |S_{21}| f_{\text{high}}^2 \leq \frac{f_\tau}{4\pi R_i C_{gs}} \]

- 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

$$\|S_{21}\|f_{\text{high}}^2 \leq K \cdot \left( \frac{f_\tau}{4\pi R_i C_{gs}} \right)$$
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, $f_{\text{max}} = 260$ 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
Measured Results: InP Capacitive-Division TWA

- Wafer A: 10 dB gain, 92 GHz bandwidth
- Wafer B: 8 dB gain, 98 GHz bandwidth

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