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10W Ultra-Broadband Power Amplifier

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Outline

- Introduction
- Two-Step Design Concept:
  - Step-1: 50-ohm unit-cell PA design
  - Step-2: Power combiner / impedance transformer design
- Measured results
- Conclusion

Introduction

- Broadband PA (f_2 / f_1 >/= 100) design is a major challenge
- Common approach is Traveling Wave Amplifier (TWA)
- This paper presents an alternative approach, which uses smaller semiconductor real estate, smaller PA size, and lower cost.
- This PA has several potential applications for broadband communications, Software radio, Broadband jammer, Instrumentations …etc

Basic Design Concept

- The design concept uses a 2-step approach:
- Step-1: Design a unit-cell PA with optimal output 50Ω impedance, such that no matching is required. We use HIFET technique to maximize the output power.
- Step-2: Use broadband push-pull power combiner/ impedance transformer to power combine the unit-cell PA, in low impedance environment, to achieve high power.

Output power of unit-cell FET

- Assuming a DC-to-RF power efficiency of 50% we have:

  $P_{rf} = 0.5\ V_{dc} \times I_{dc}$ ..... (1)

- The optimal RF output impedance is proportional to:

  $R_{opt} = V_{dc} / I_{dc}$ ..... (2)

- Substituting equation (2) into equation (1), we have:

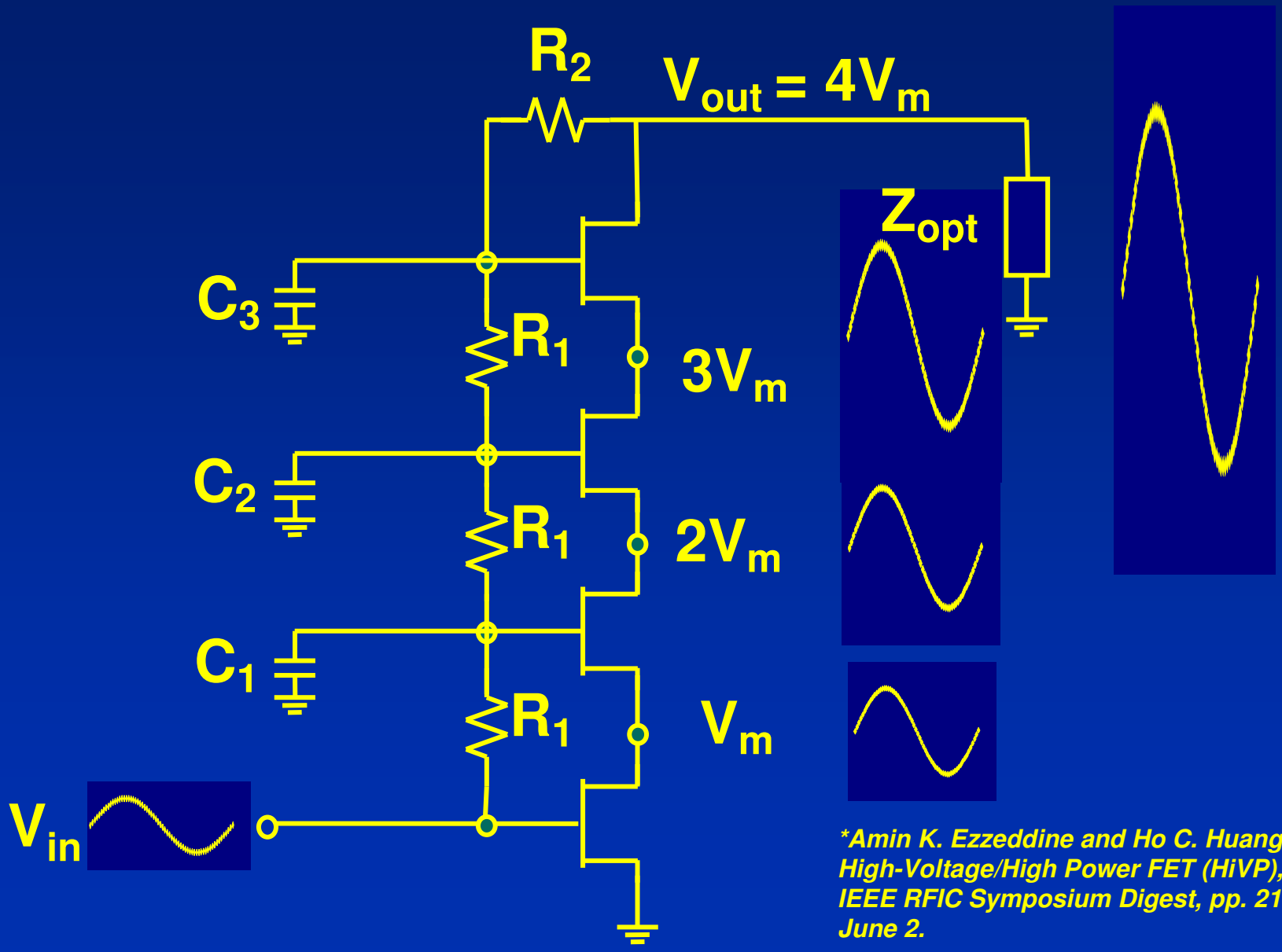
  $P_{rf} = V_{dc}^2 / (2\ R_{opt})$ ..... (3)

- Therefore, the device output power capability is proportional to the square of DC bias voltage and inversely proportional to the circuit impedance.

Step 1: Use HIFET to increase Vd and Tailor Zopt to be 50-ohm

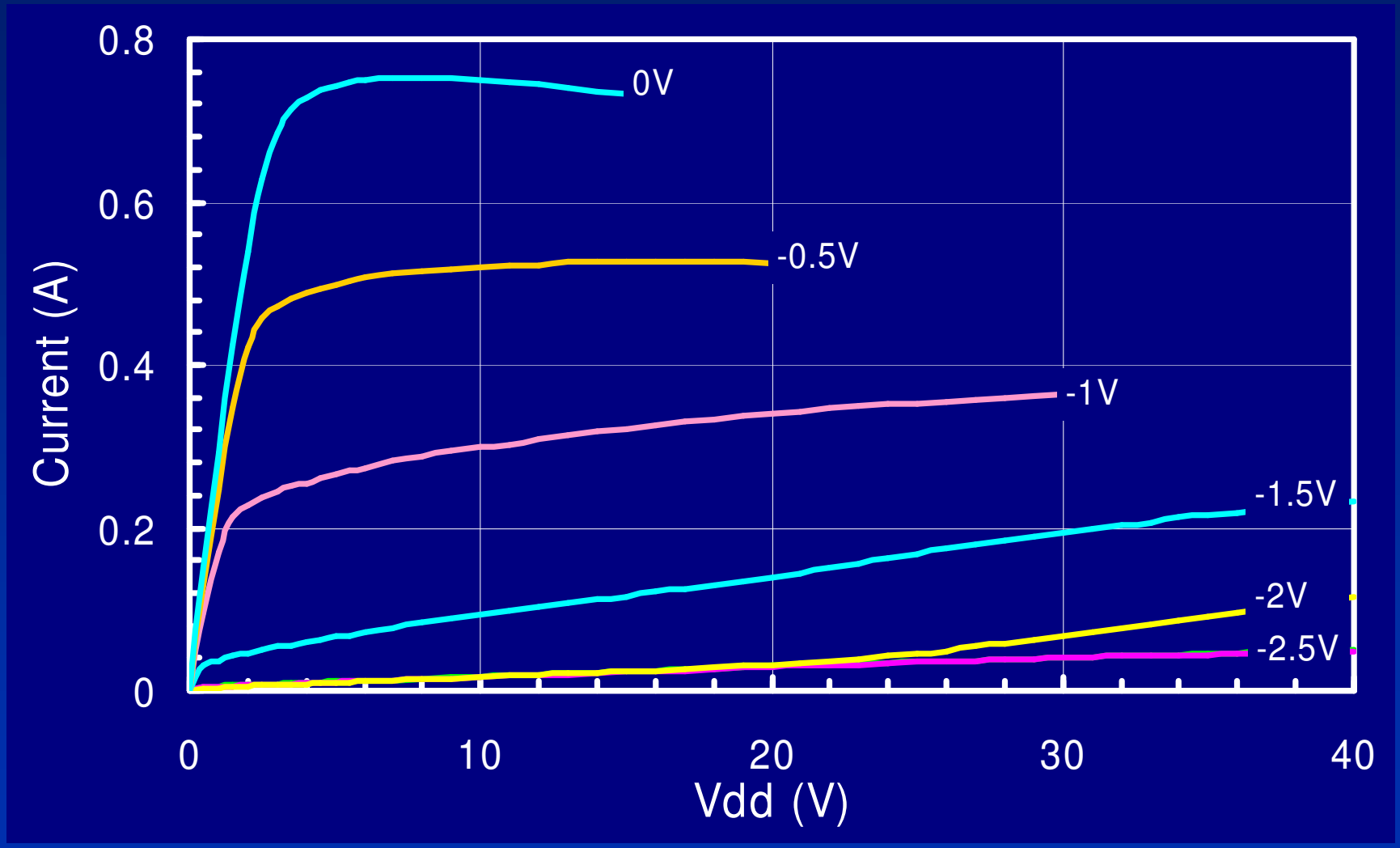
- HIFET is an innovative power combining technique, connecting unit-cell FETs RF & DC in series, yet thermally in parallel
- DC bias voltage and Zopt are proportional to the number of unit cells. Output impedance could be tailored to be 50Ω Hence no output matching
- HIFET enjoys a bonus gain of 10 $Log_{10}(N)$ dB.
- HIFET concept applies to all devices such as MESFET, CMOS, LDMOS, GaN, SiC …etc.

HIFET Voltage Waveforms*



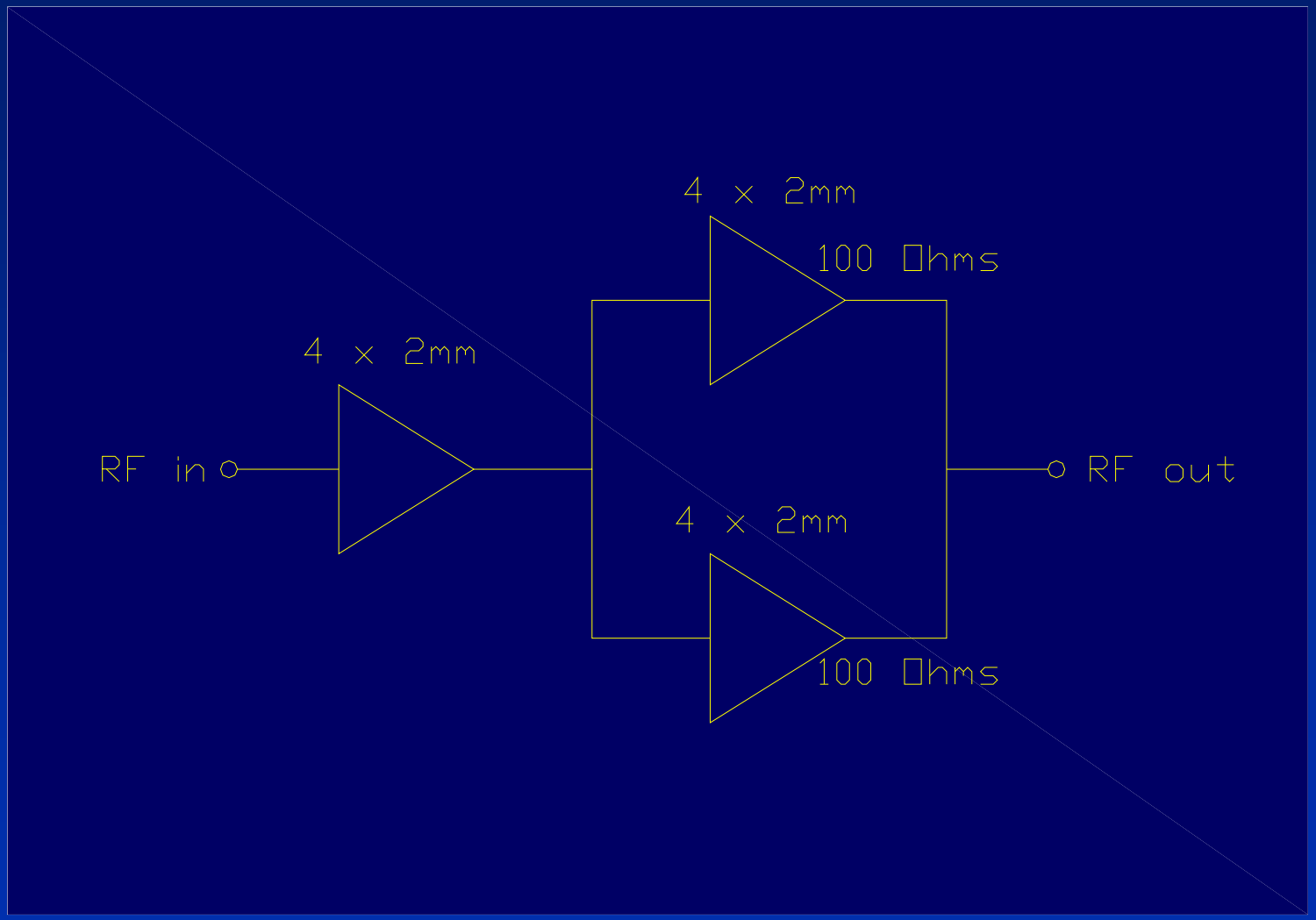
*Amin K. Ezzeddine and Ho C. Huang, "The High-Voltage/High Power FET (HiVP)," 2003 IEEE RFIC Symposium Digest, pp. 215-218, June 2.

I-V of a 3mm x 4 MESFET HIFET

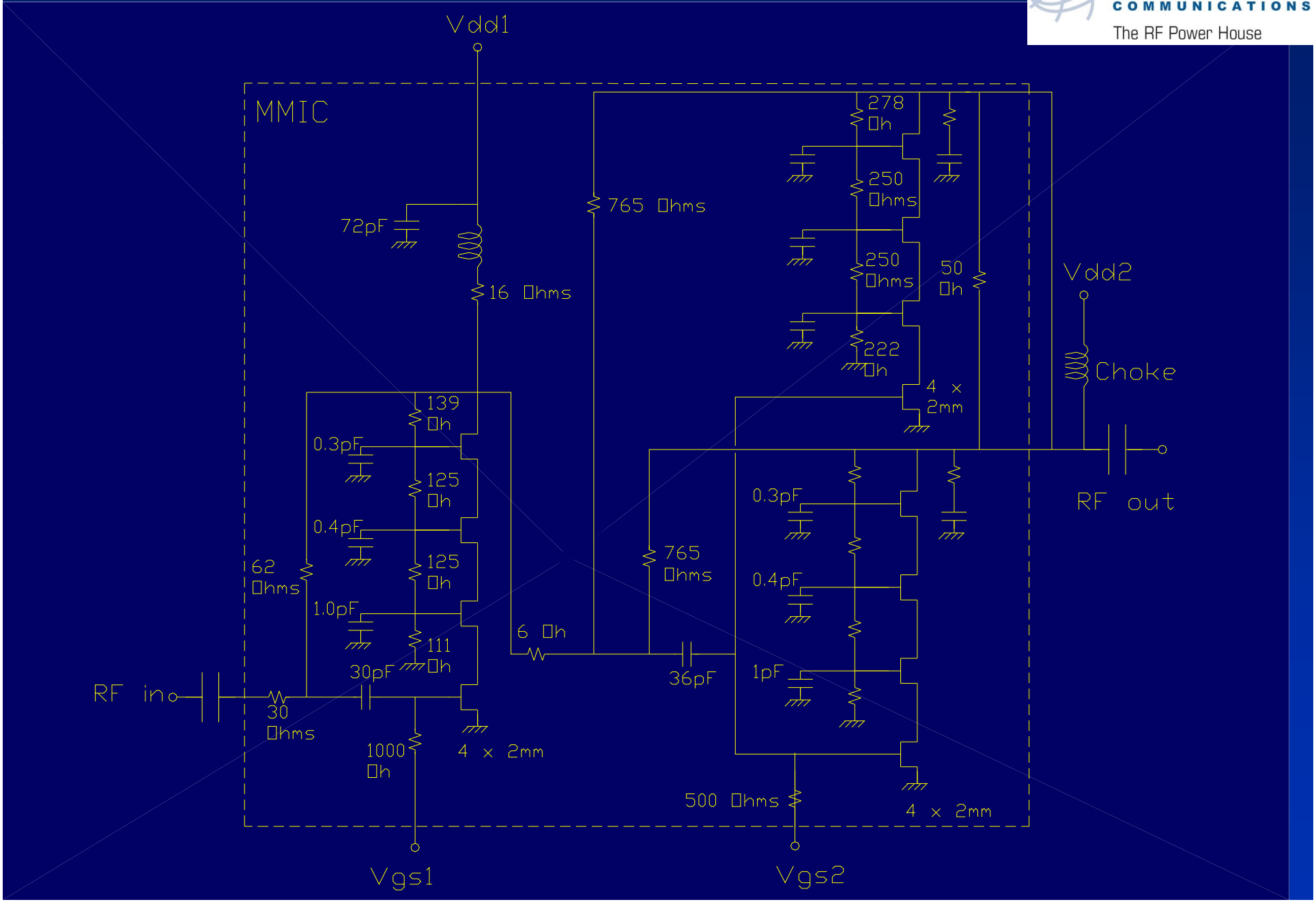


Doesn't it look like a GaN HEMT?

MMIC Block Diagram



MMIC Schematic



HIFET MMIC PA Design

- 1st stage: 4 x 2mm; 2nd stage: 2 x (4 x 2mm)
- Feedback resistors for: gain flatness, good input & output VSWR and stability
- Input series resistor and inter-stage series resistors for good gain flatness and stability
- Bias provided thru external chokes
- Large blocking capacitors for maximum bandwidth
- $P_{out} = (N \cdot V_{ds})^2 / 2 * Z_{out}$
- Stability & device thermal considerations

Output Matching Circuit

- $Z_{opt} = N (V_{ds}-V_{knee}) / I_{ds}$
- We have 2 degrees of freedom: N & I_{ds} (Device size)
- In this 2-stage MMIC PA: output stage is 2 x (4 x 2mm). Hence V_{ds} = 5V, I_{ds} = 0.36A, V_{knee} = 0.5V
- $Z_{opt} = 4 (5 - 0.5) / 0.36 = 50\ \Omega$
- No output matching is needed because the device output impedance is designed to be 50Ω
- Very small chip size: 2.30 x 2.27 mm

MMIC Process (WIN, PHEMT)

- 0.5µm gate length (Ti-W), double-recess
- Epitaxial and thin film Nichrome resistors
- Silicon Nitride capacitor and passivation
- I_{dss} ~ 200 – 250mA/mm
- 4 mils substrate
- Via hole for source ground

MMIC Photo

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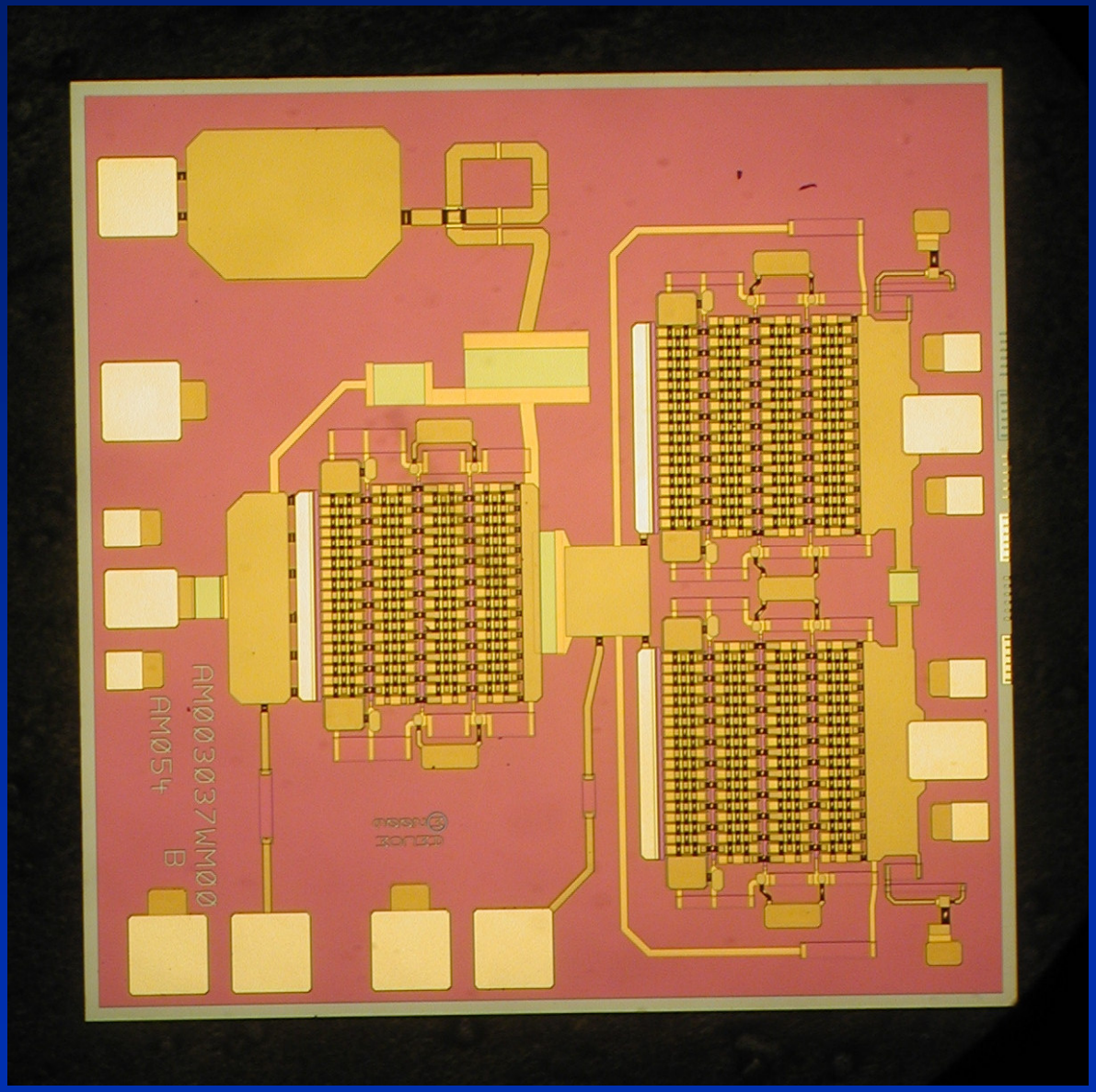

Packaged MMIC & Test Fixture

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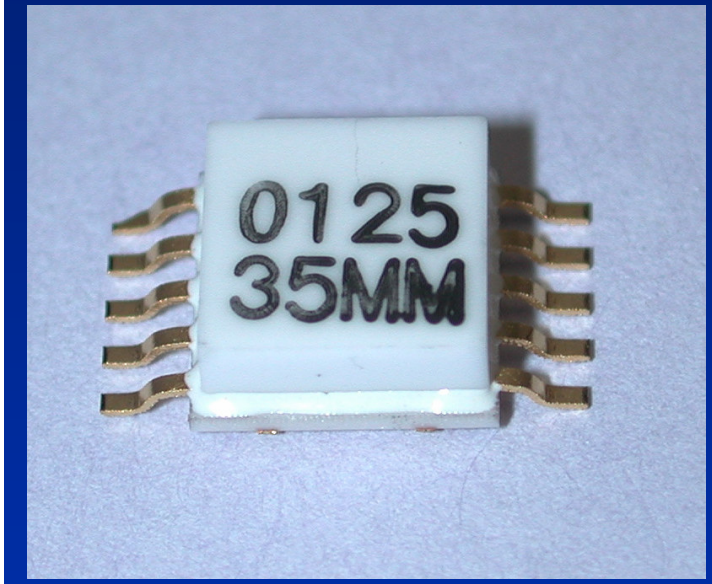
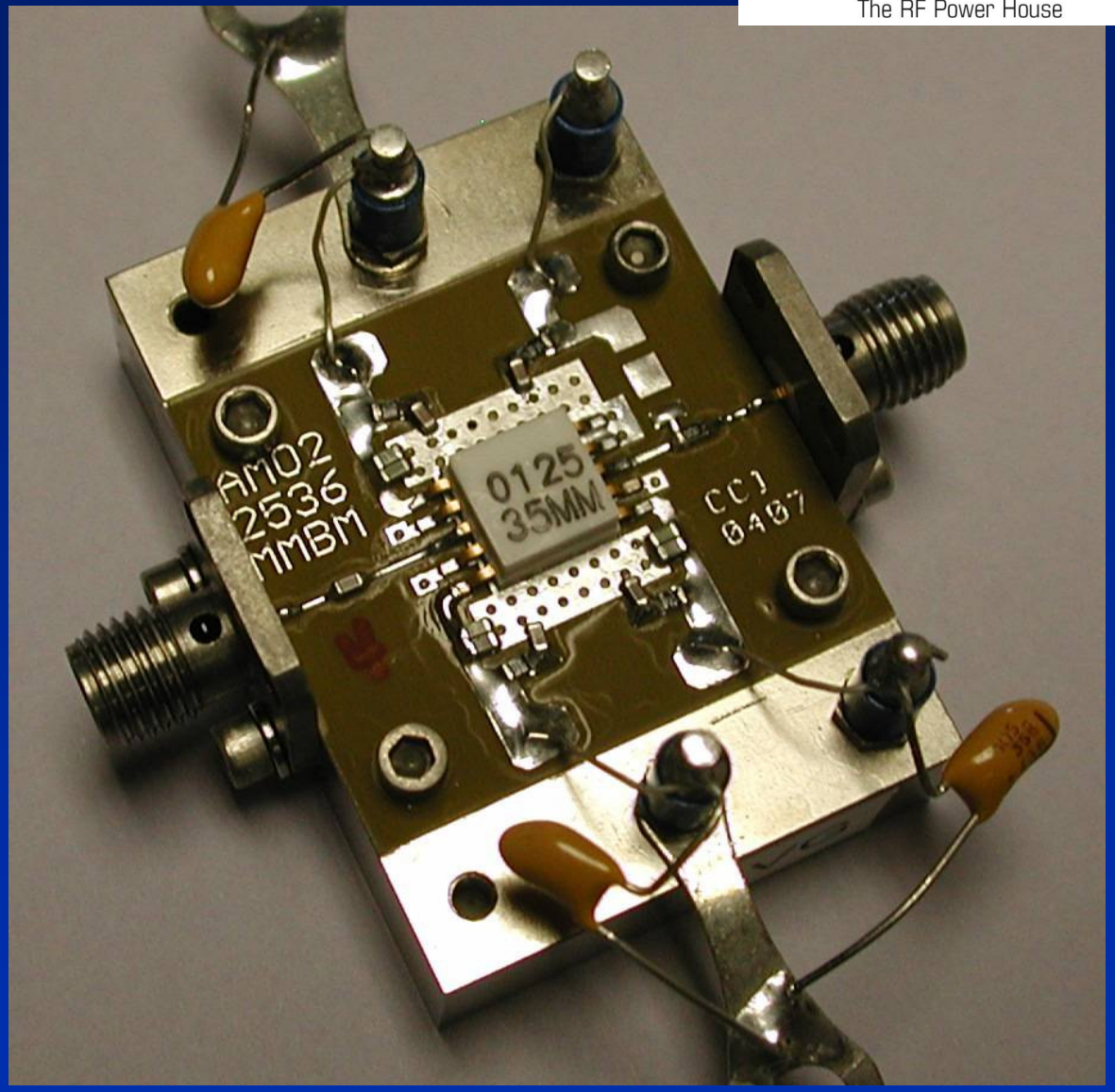
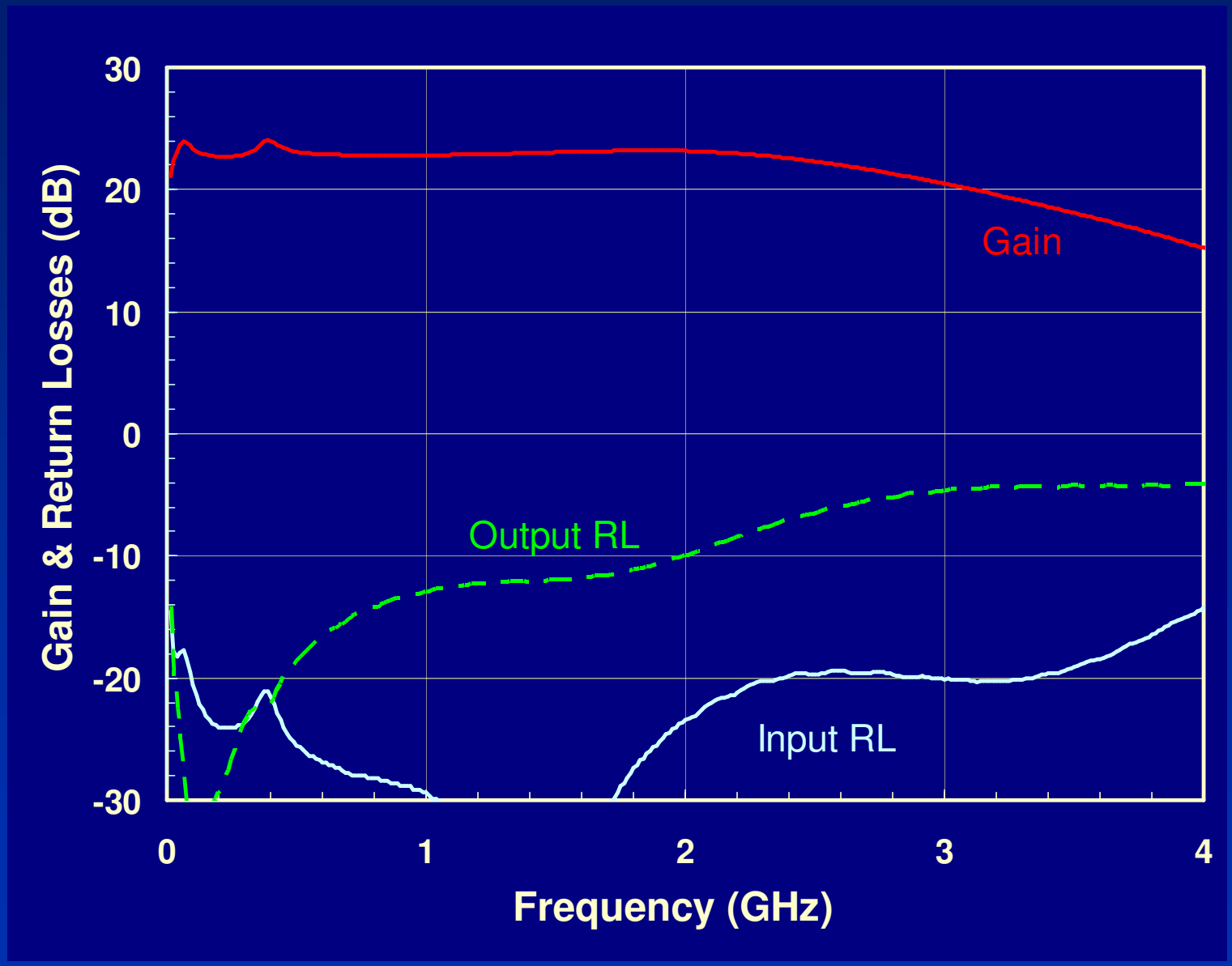


Package size
7 x 7 mm

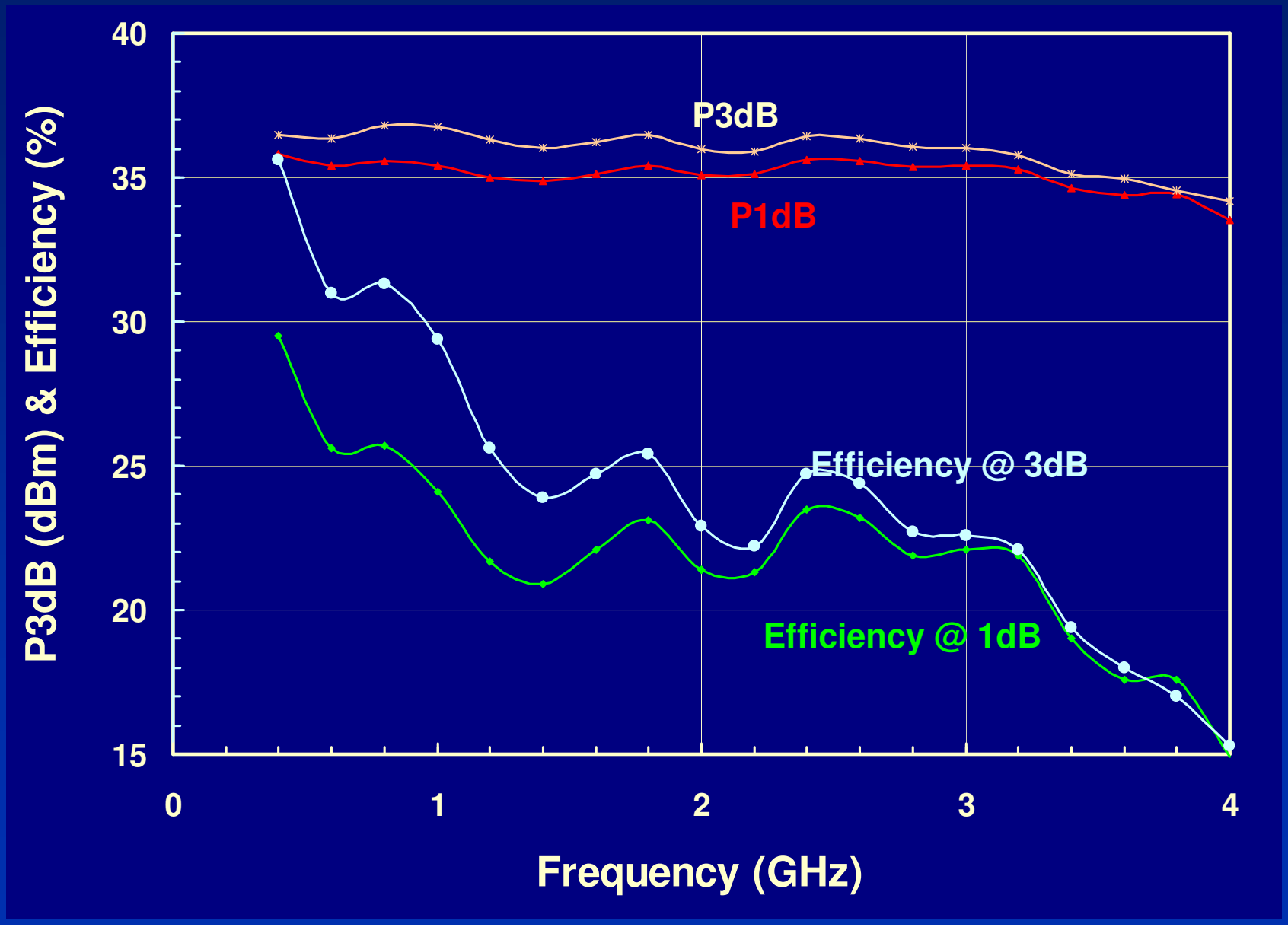


10mils FR4 substrate

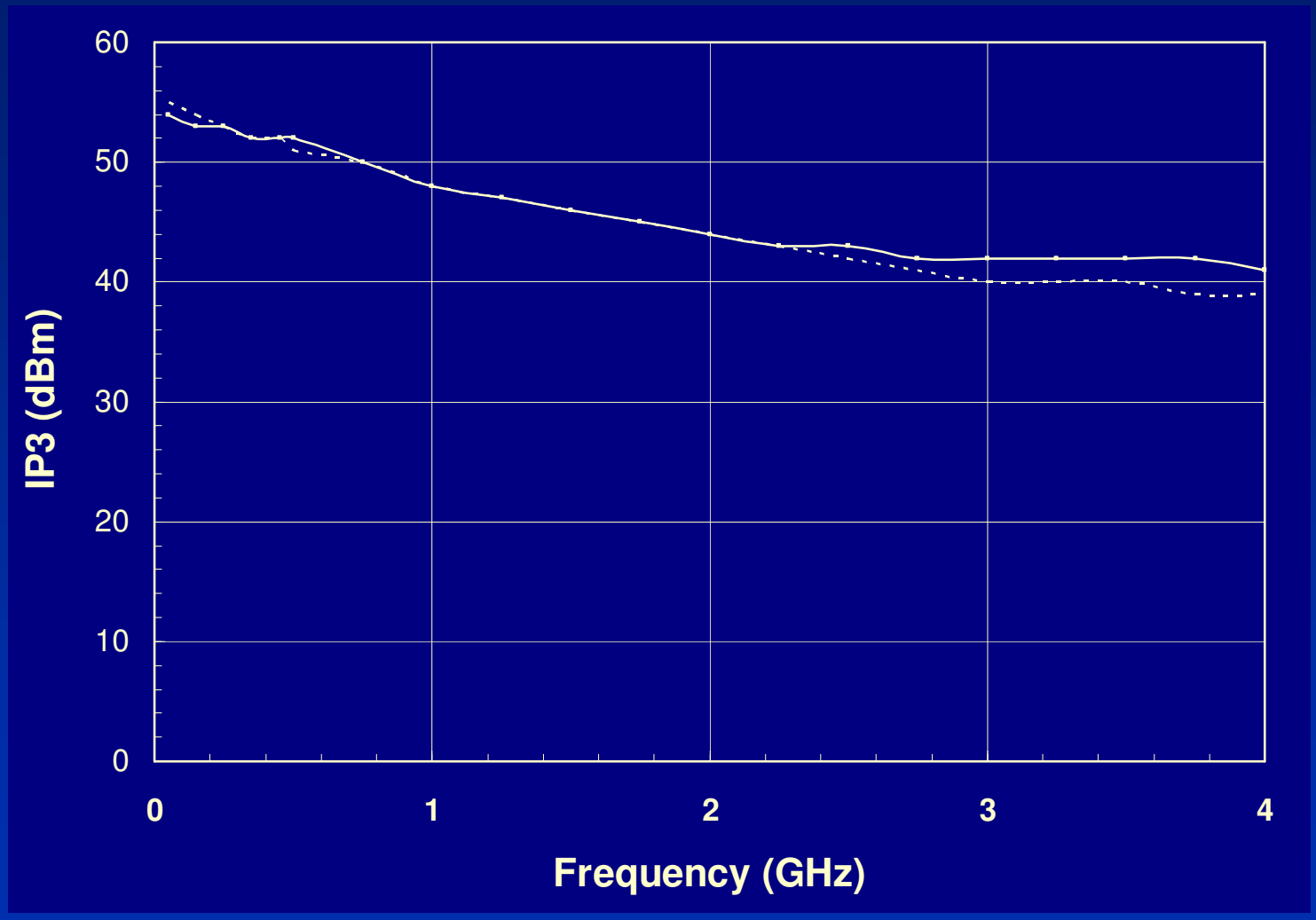
S21, S11 & S22 vs Frequency



Power and Efficiency vs Freq. (20V/ 650mA)



IP3 vs Frequency



Step 2 – Broadband Power combiner / Impedance transformer

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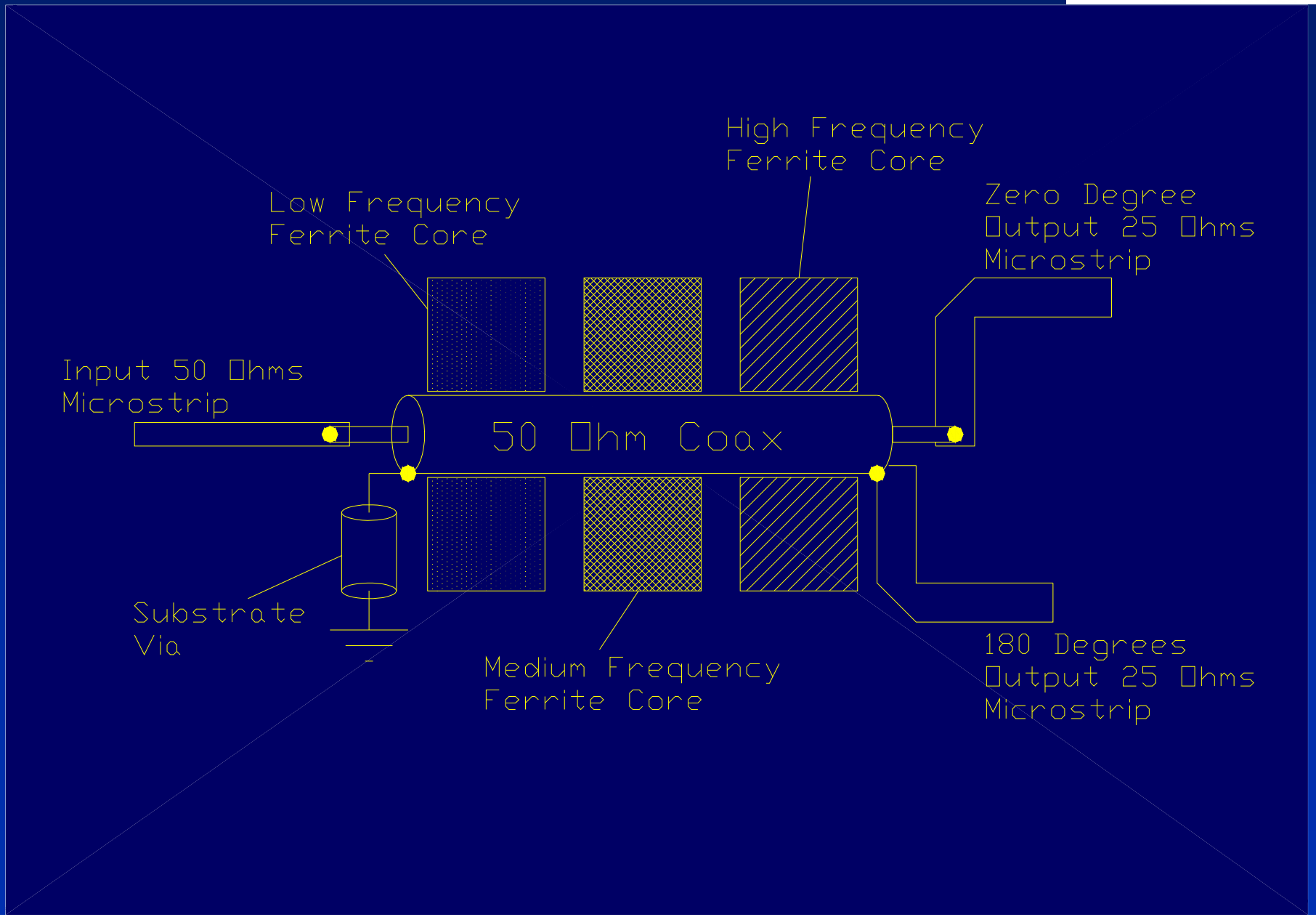

8-Way Combiner/Divider

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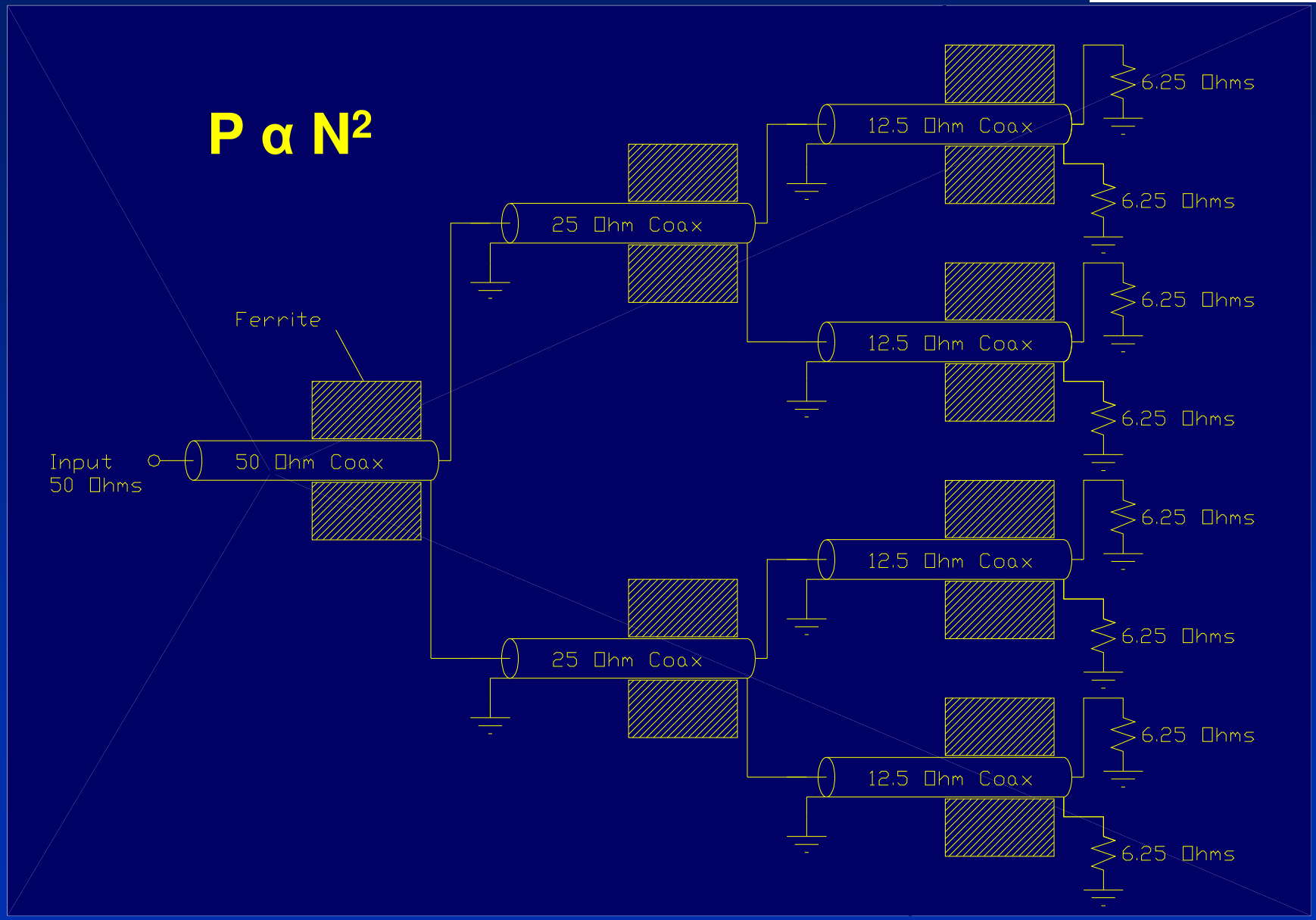

2-Way Combiner/Impedance transformer (Back to Back)

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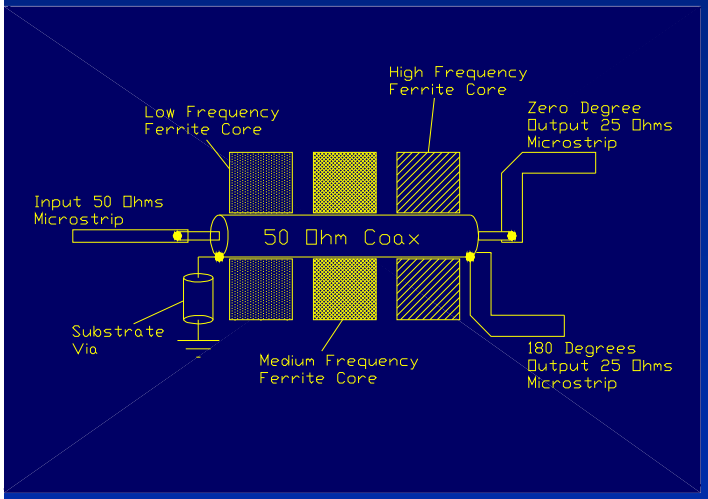

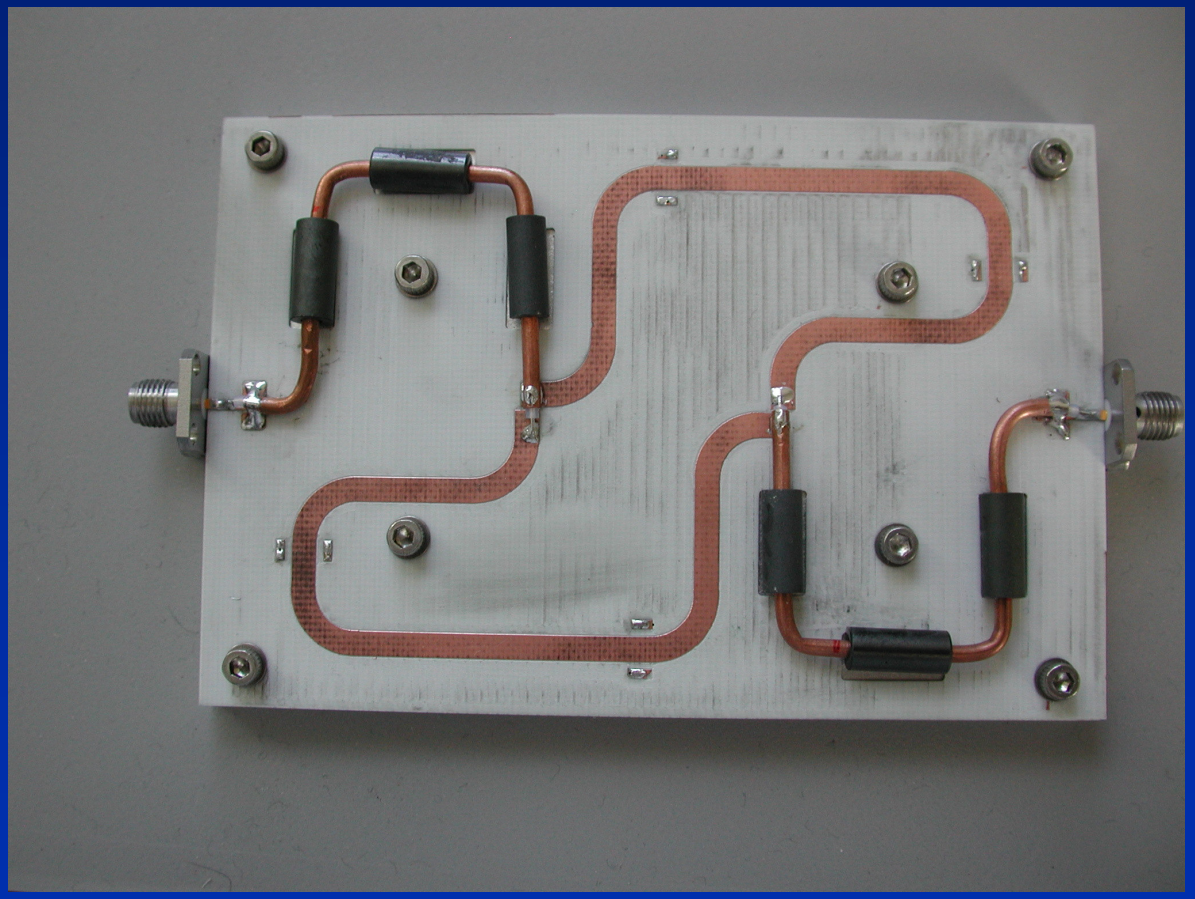

Performance of 2 Broadband Baluns Back-to-Back

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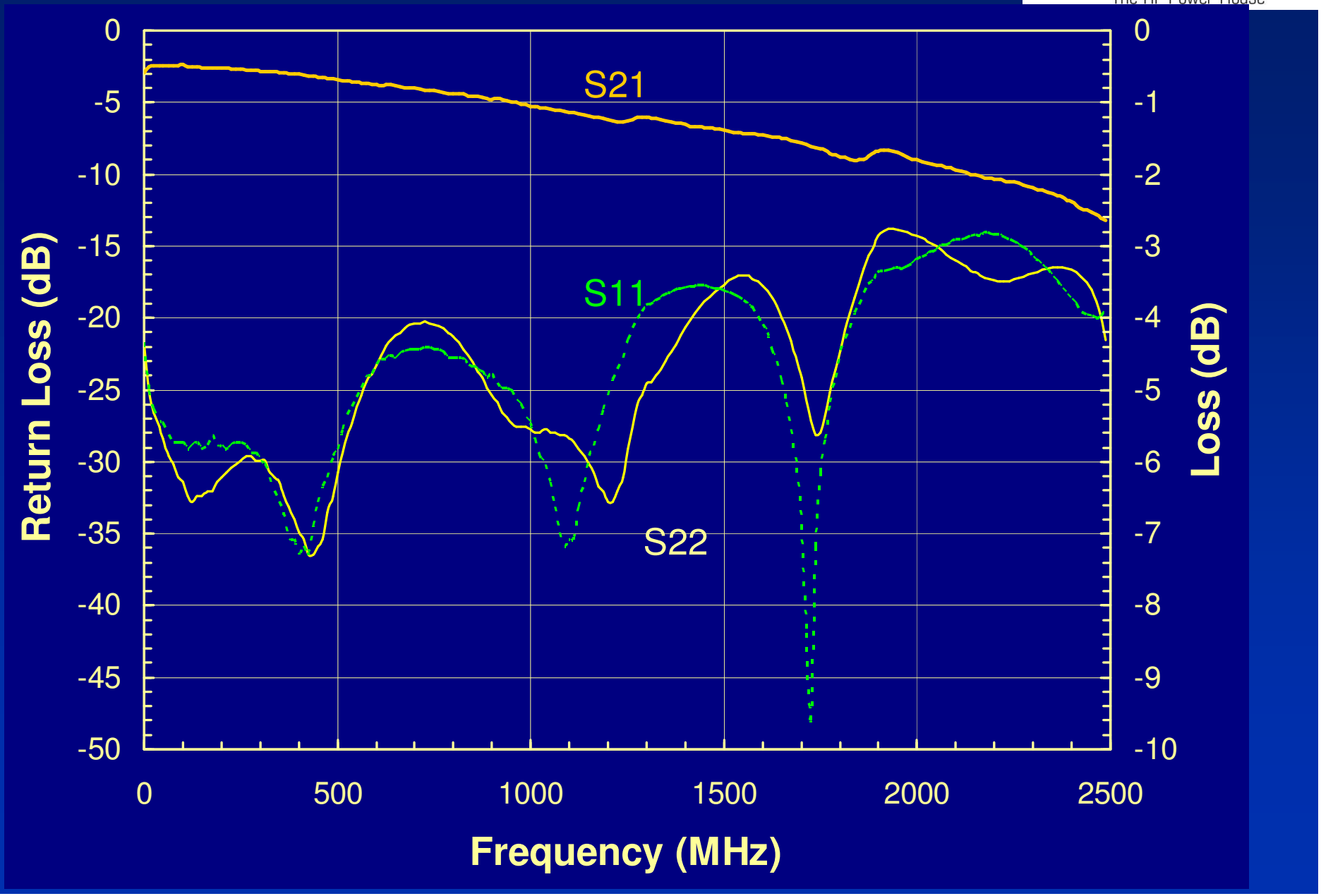

Schematic of 10W BB PA

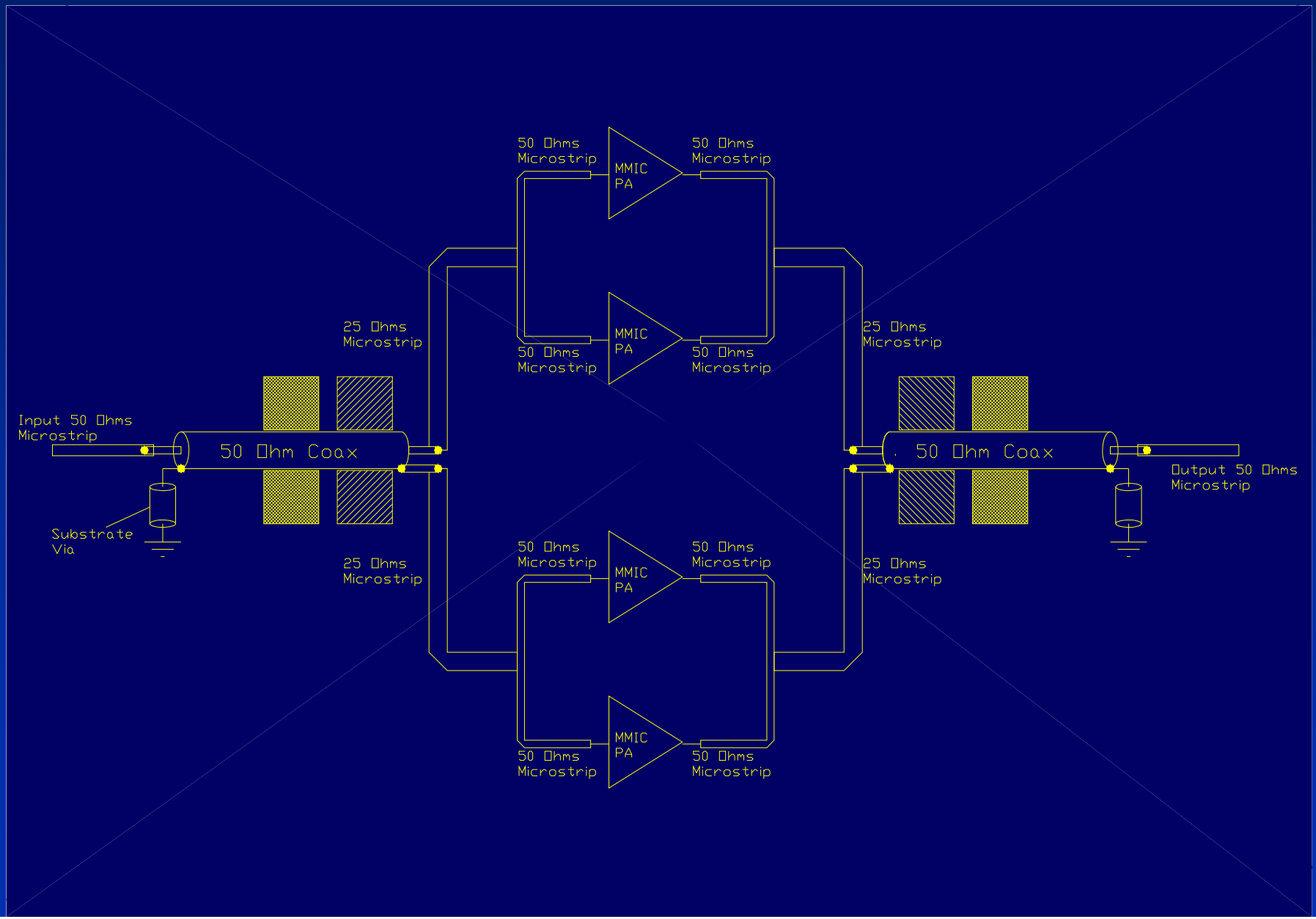

Photo of 10W BB PA

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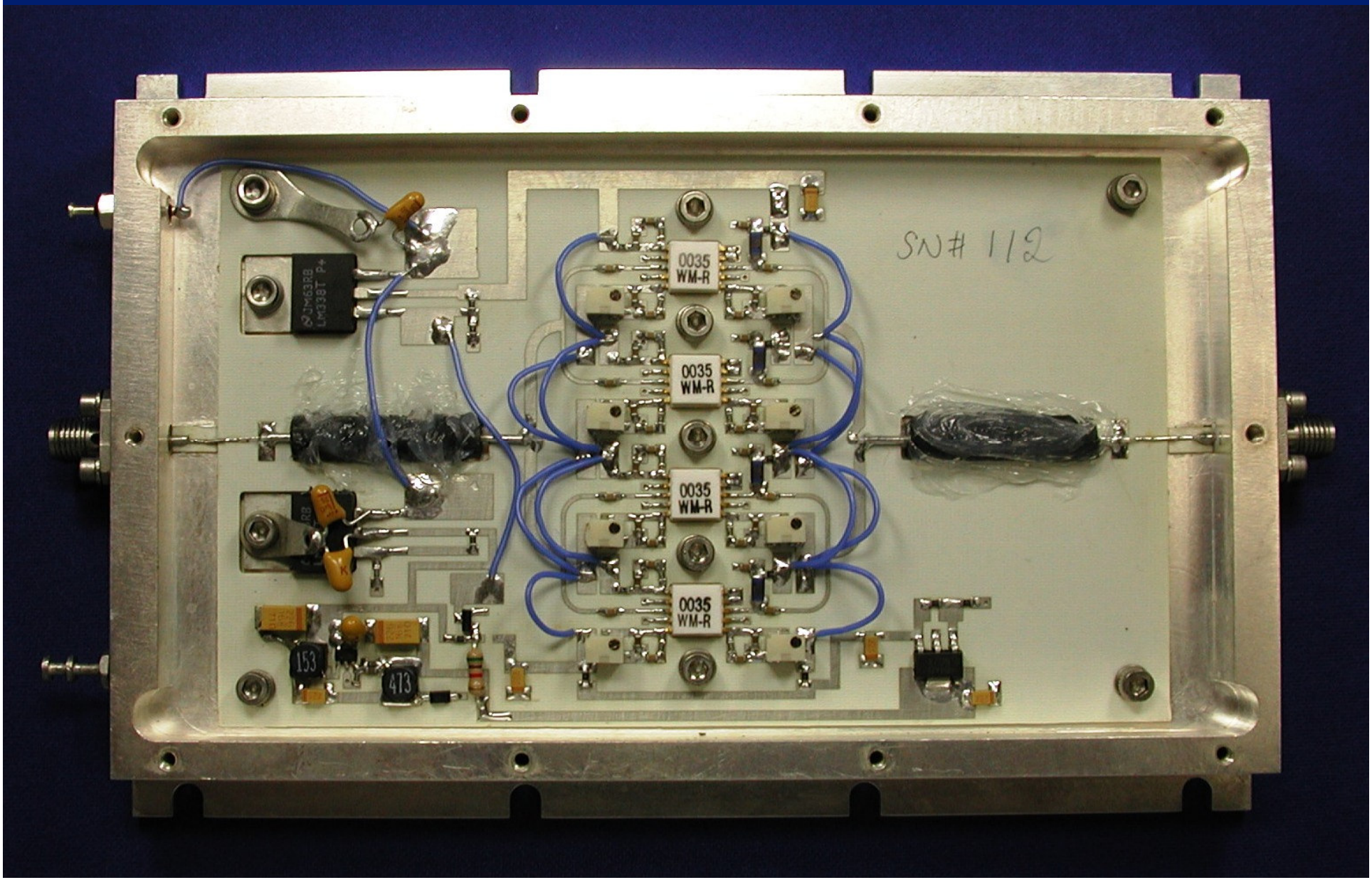

Small Signal Gain, Return Loss vs Frequency (24V/2.9A)

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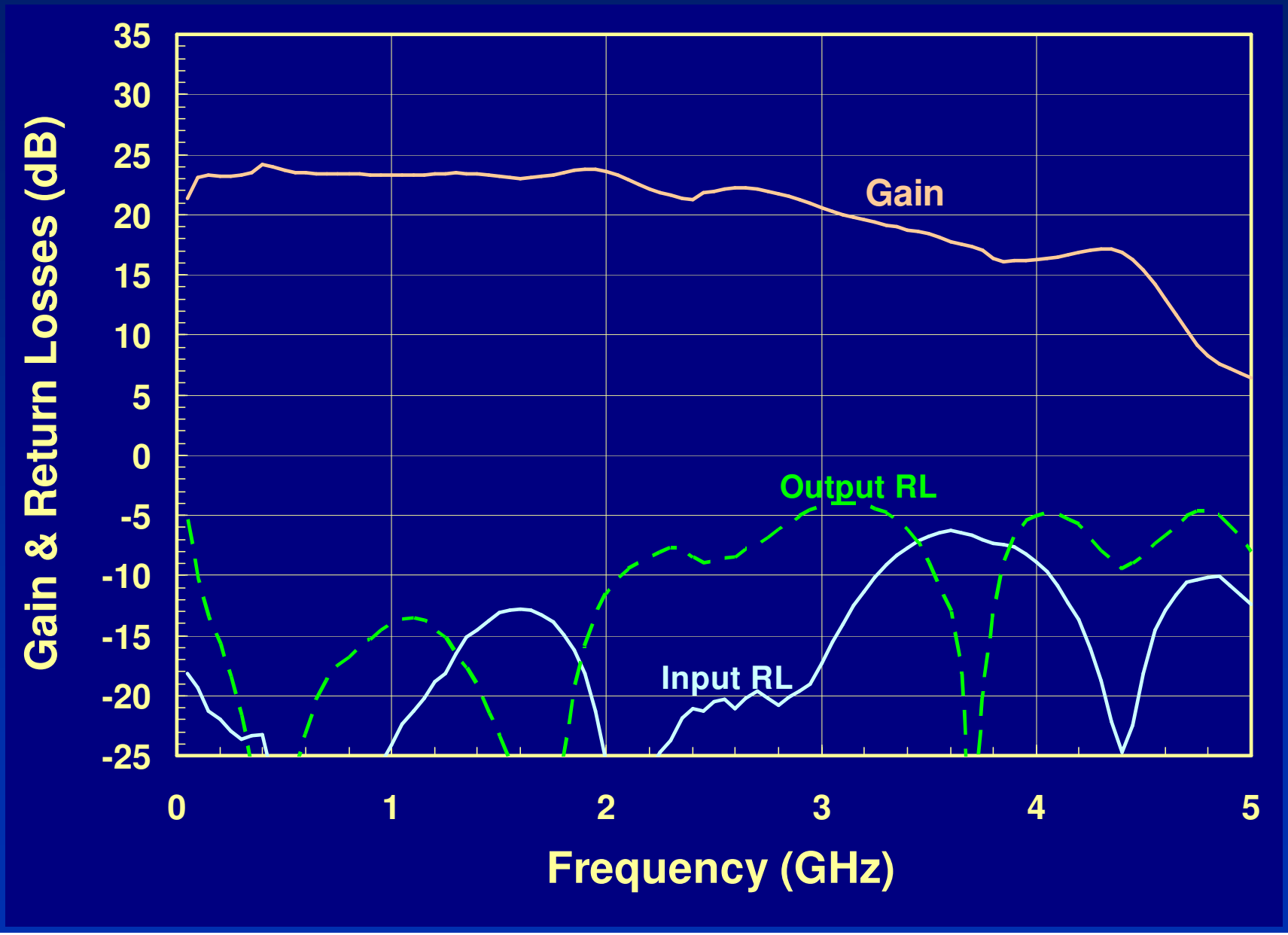
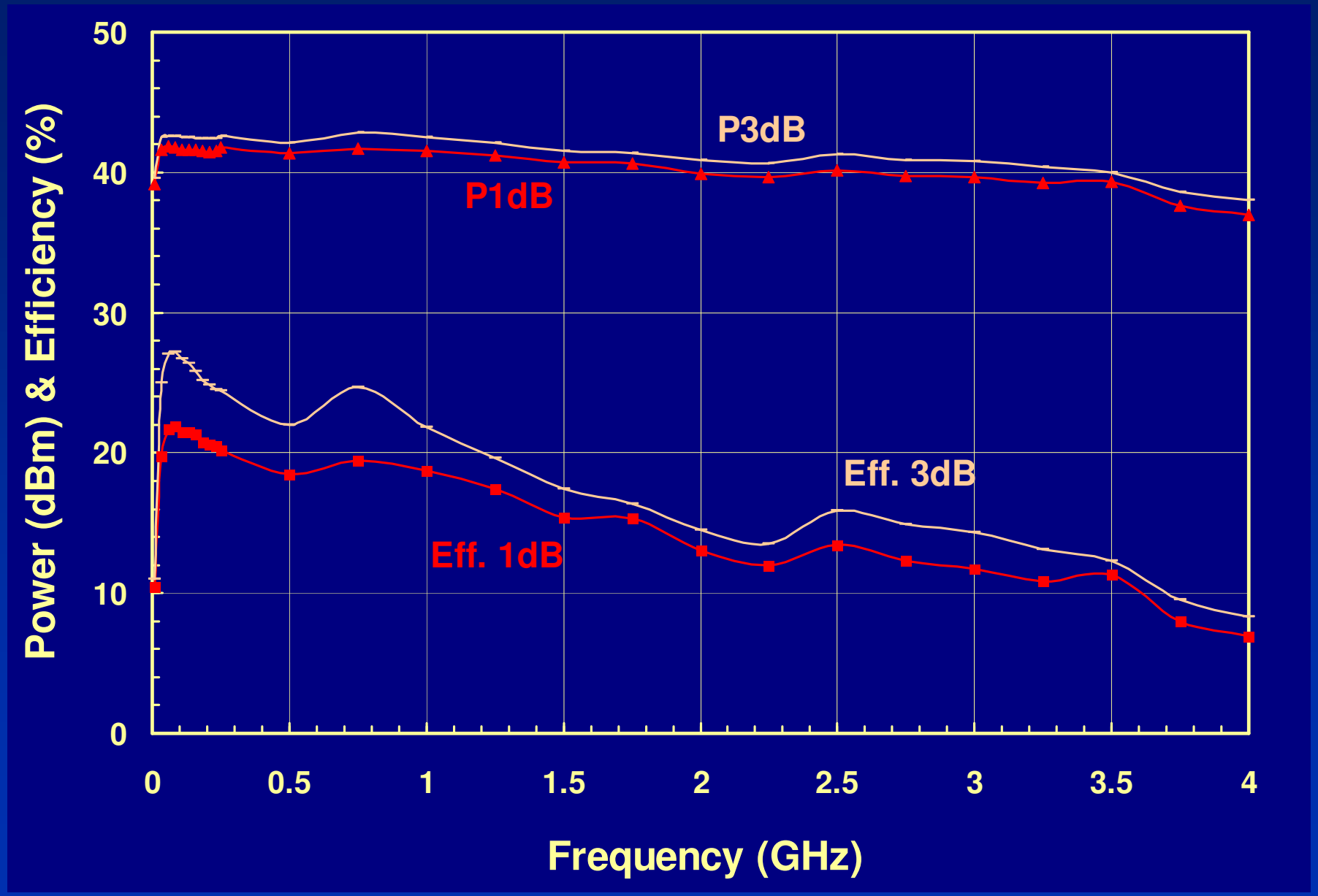
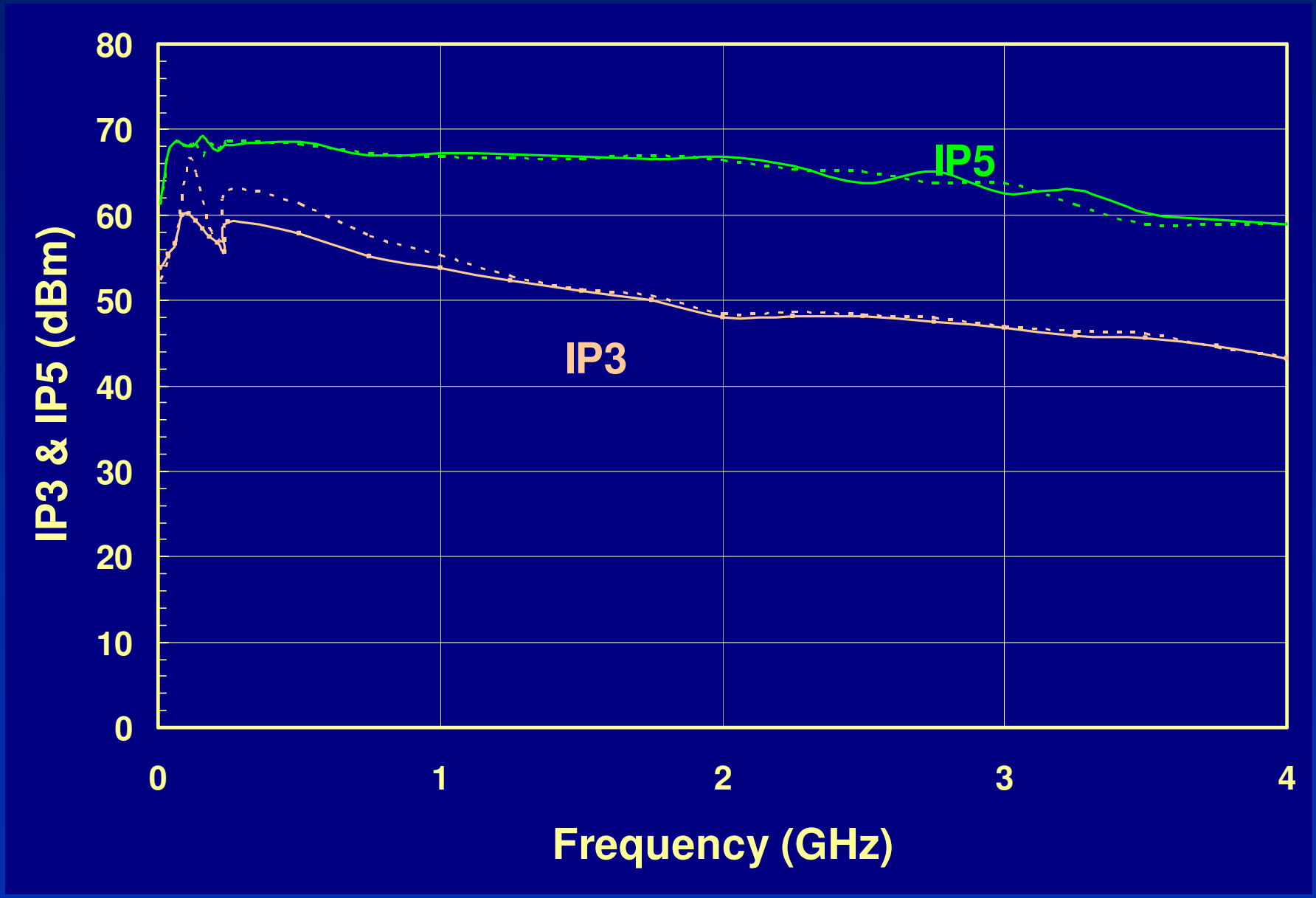


Output Power, Gain vs Frequency



IP3, IP5 versus Frequency



Conclusion

- We presented the approach to achieving ultra-broadband. High-power PA, as well as the measured state-of-the-art results.
- The basic approach is to develop a HIFET 50-ohm device (Unit-cell PA), then use push-pull combiner / impedance transformer to power combine the unit-cell PA's.
- The unit-cell MMIC PA has 3W P1dB from 20 to 3500MHz with 24dB gain and good linearity
- The power combined PA module has 10W P1dB from 20 to 3500MHz with 23dB gain and good linearity
- This design concept can be applied to GaN HEMT for very high power, and to CMOS to overcome low-voltage operation

Low Frequency Small Signal