

Advanced Power Amplifier Design Using Doherty Configurations

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Ansoft Corporation

Ansoft 2003 / Global Seminars: Delivering Performance



DELIVER

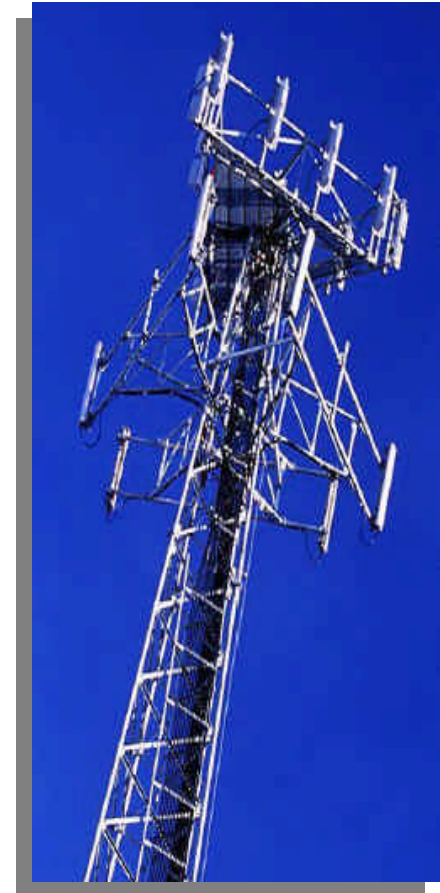
Outline

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NEXT GENERATION DESIGN

- ▶ **Introduction**
- ▶ **Motorola MET Model Design Kit in Ansoft Designer**
 - ▶ Model consideration and validation
- ▶ **Matching Techniques for Power Amplifier Design**
 - ▶ Load-pull analysis
 - ▶ Lowpass multi section, transmission line, and low Q matching technique
- ▶ **Doherty Amplifier Design**
 - ▶ Doherty amplifier overview
 - ▶ Carrier amplifier design
 - ▶ Peak amplifier design
 - ▶ 90° hybrid coupler, offset line, and impedance transformer design
- ▶ **Balanced Amplifier Design**
- ▶ **Doherty and Balanced Amplifier Comparison**
- ▶ **Conclusion**
- ▶ **References**

Introduction

- ▶ **Why a power amplifier is important?**
 - ▶ Power amplifier is a key element to build a wireless communication system successfully.
 - ▶ There is a trade-off between power per cost vs. efficiency and linearity.
 - ▶ Digital communications require more peak power for the same bit error rate.
 - ▶ To minimize spectral re-growth and interferences, transmitters have to be more linear.
 - ▶ Clear modulation scheme requires more higher power and broader bandwidth.
- ▶ **What is a solution from Ansoft?**



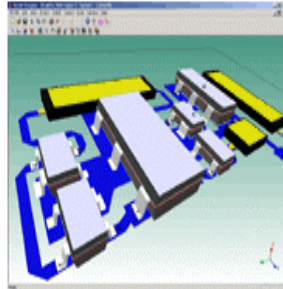
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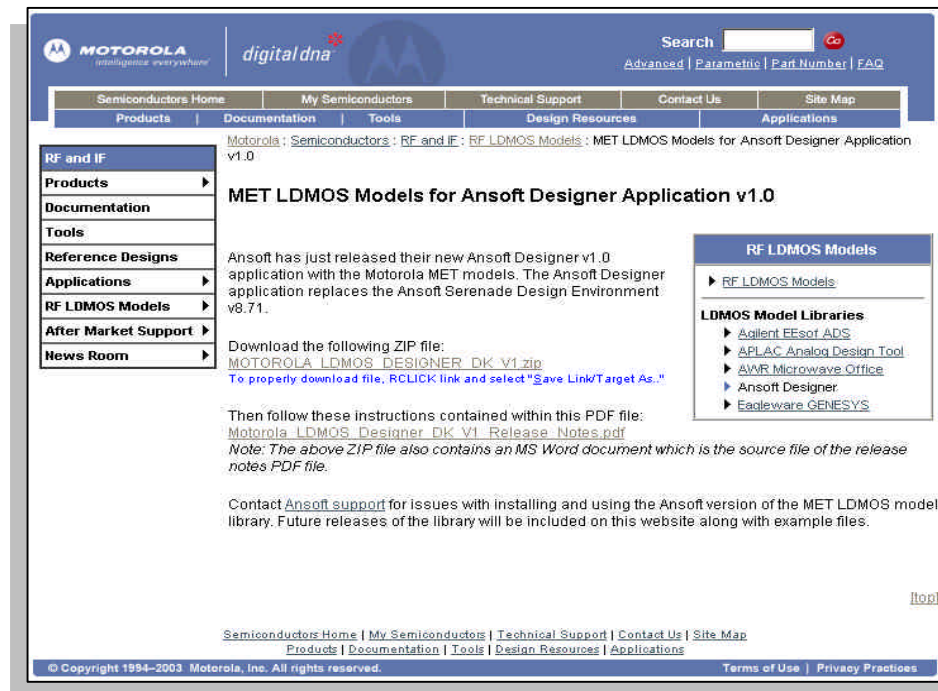
▶ Power Amplifier Design

- ▶ DC network analysis
- ▶ Stability analysis
- ▶ Harmonic balanced analysis
- ▶ Transient analysis
- ▶ Convolution analysis
- ▶ Modulation envelop analysis
- ▶ 3D EM analysis
- ▶ Load-pull analysis
- ▶ Motorola MET model
- ▶ Smith-Tool utility
- ▶ Transmission Line Utility

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LDMOS MET Model Design Kit

- ▶ **MET (Motorola Electro Thermal) Model** is available from Ansoft
 - ▶ Nonlinear model for high power RF LDMOS transistor
 - ▶ Calculate both electrical and thermal phenomena
- ▶ **LDMOS (Laterally Diffused Metal- Oxide- Semiconductor)**
 - ▶ Used in making high power, high frequency RF amplifier



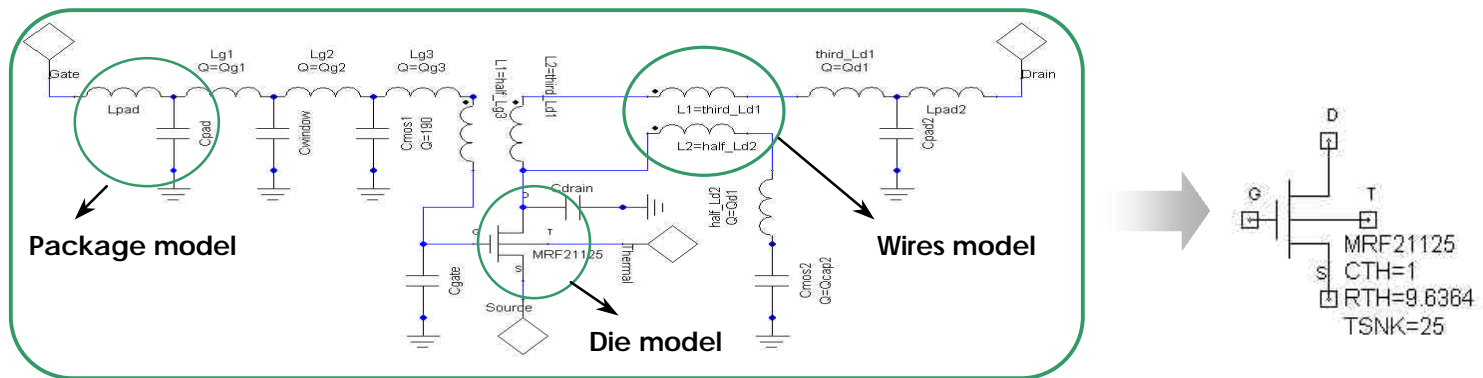
The screenshot shows a Motorola website page titled "MET LDMOS Models for Ansoft Designer Application v1.0". The page features a navigation menu on the left with categories like "RF and IF", "Products", "Documentation", "Tools", "Reference Designs", "Applications", "RF LDMOS Models", "After Market Support", and "News Room". The main content area includes a search bar, a breadcrumb trail, and a detailed announcement. The announcement states that Ansoft has released their new Ansoft Designer v1.0 application with the Motorola MET models. It provides instructions on how to download the ZIP file and follow the included PDF file. A sidebar on the right lists "RF LDMOS Models" and "LDMOS Model Libraries" with sub-links for Agilent EEsof ADS, APLAC Analog Design Tool, AWR Microwave Office, Ansoft Designer, and Eagleware GENESYS. The footer contains copyright information and links to Terms of Use and Privacy Practices.

http://www.ansoft.com/products/hf/ansoft_designer

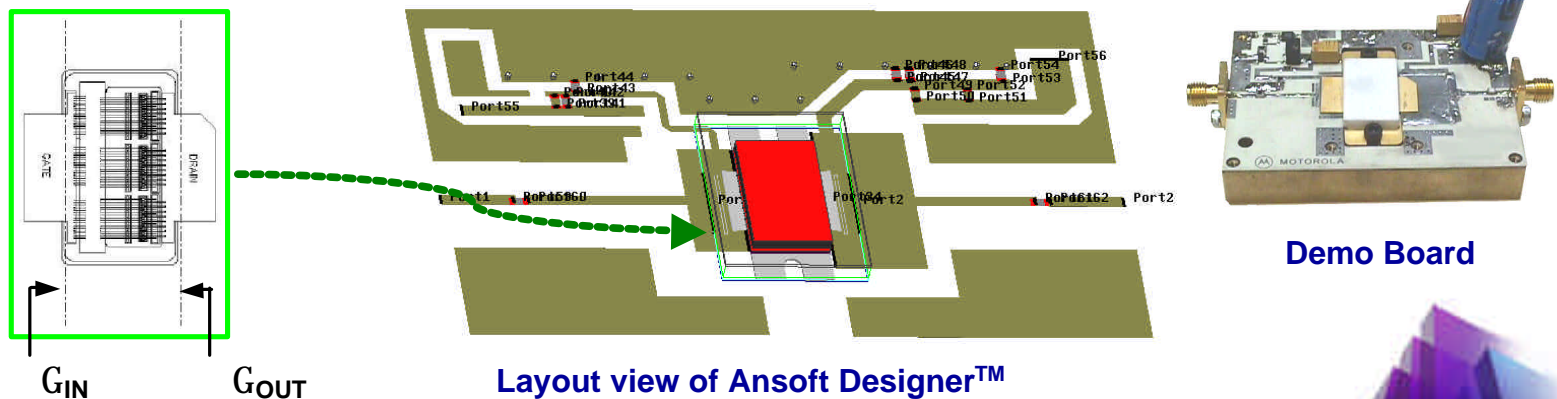
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MET Model Considerations

- Capable of performing
 - Small and Large Signal HB, Noise, and Transient Simulations
 - More accurate because of its ability to simulate self-heating effects
- All transistors model include die, package, and bond wire models.

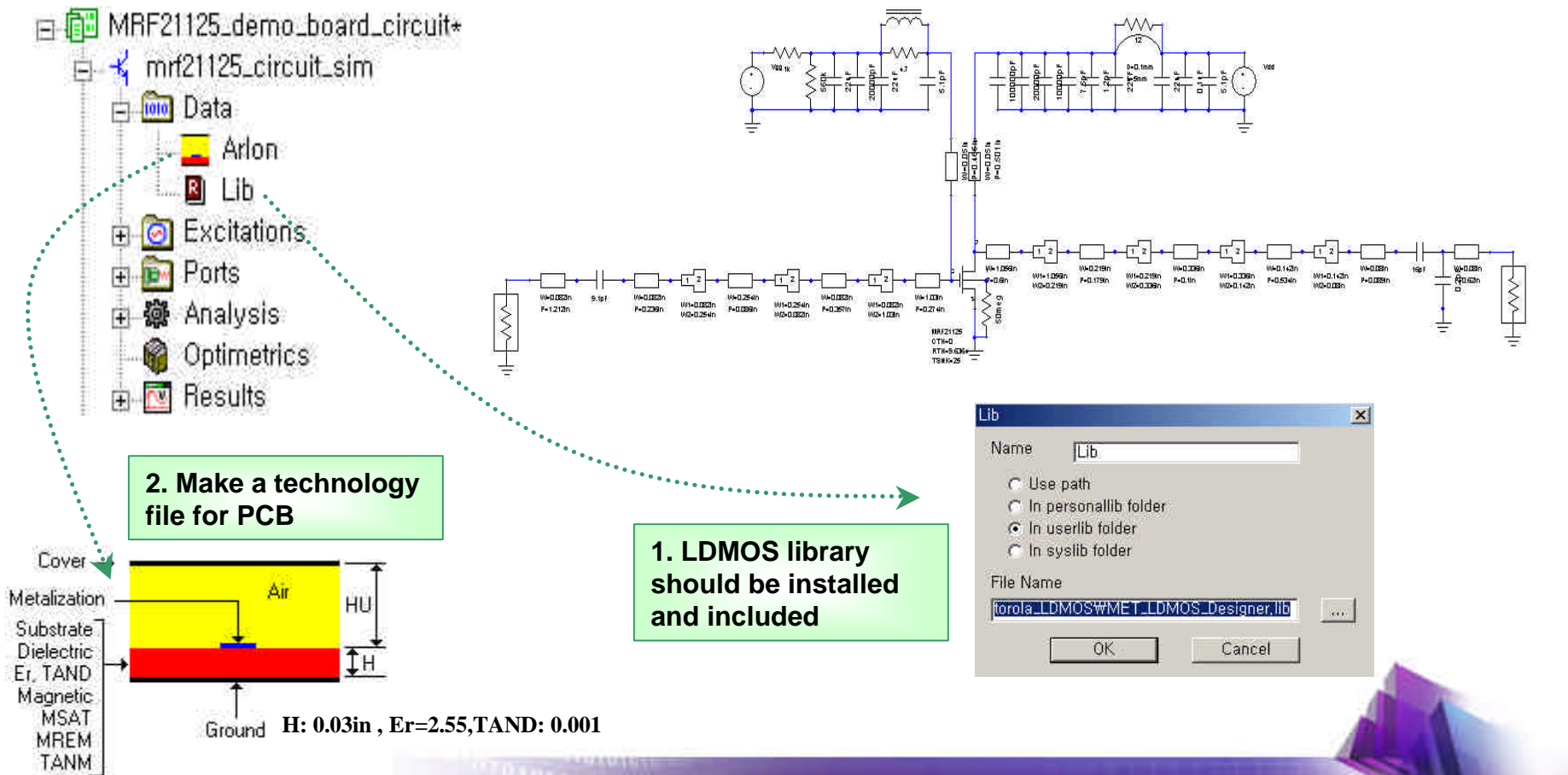


- Reference planes are defined without leads.



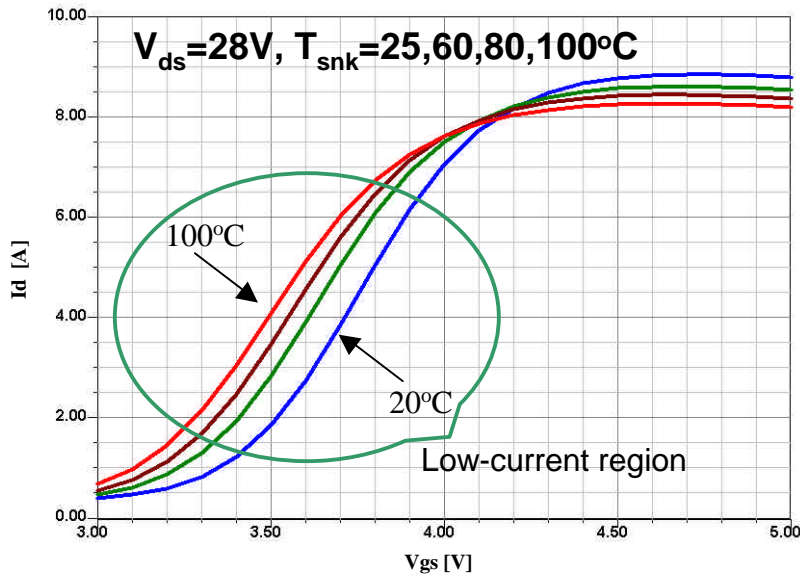
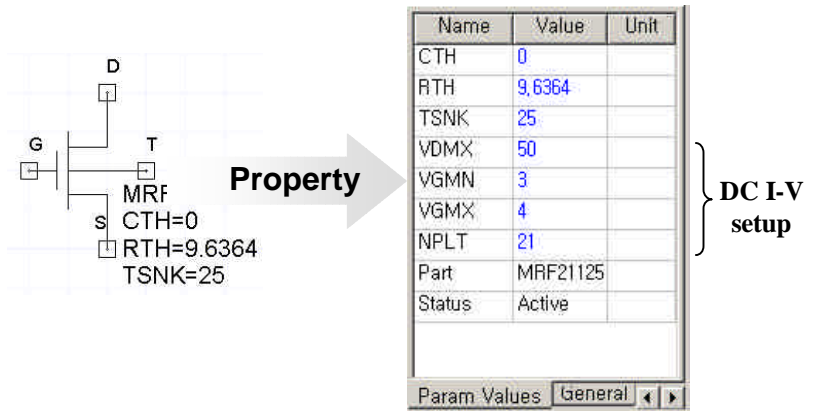
Schematic for MET Model Validation

- ▶ Ansoft Designer™ Circuit Simulator is used to valid MET model.
- ▶ MRF21125 was used.

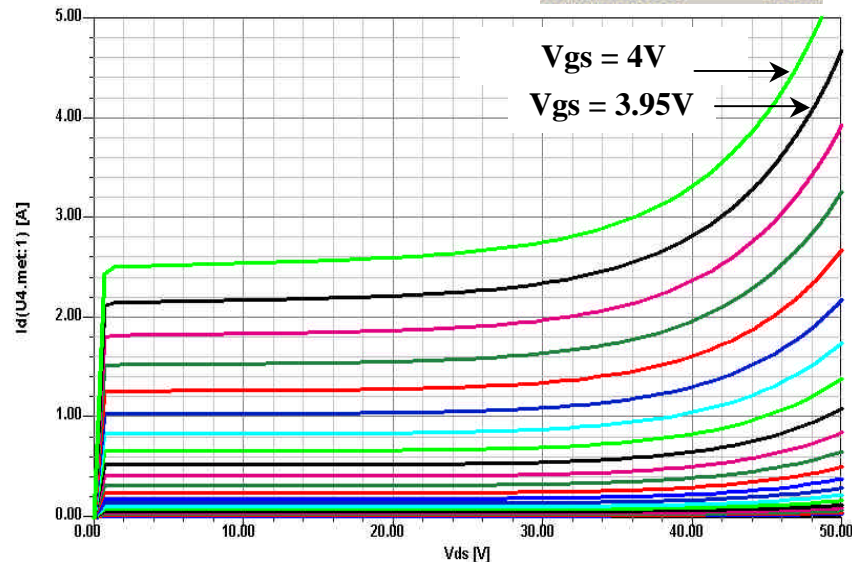


DC I-V Characteristics

- The rise of temperature increases the drain current at a low-current region and decreases it at a high-current region.
- Simulation can predict thermal effects of the LDMOS by tuning T_{snk} .



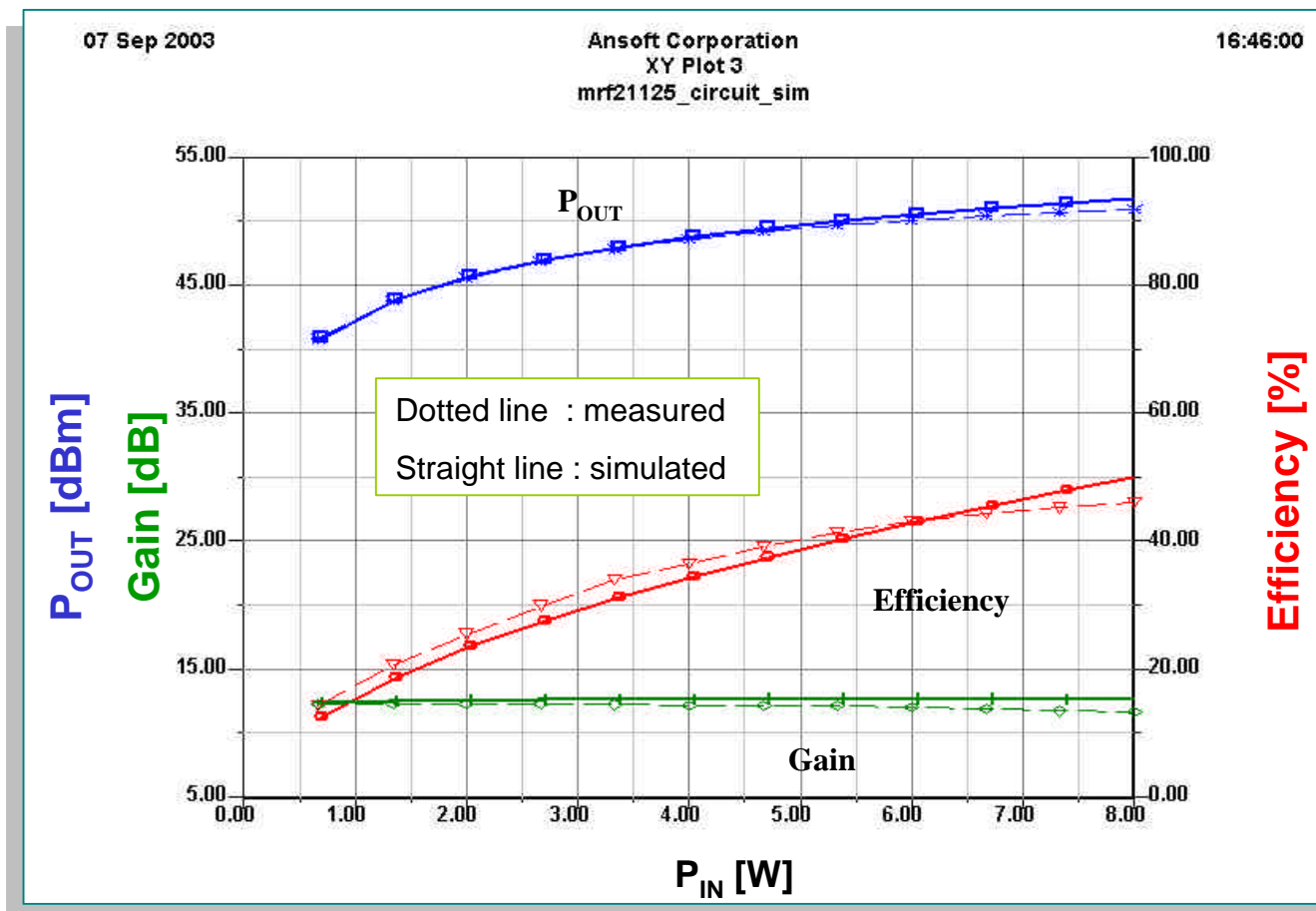
Input Transfer Characteristics



Output Transfer Characteristics

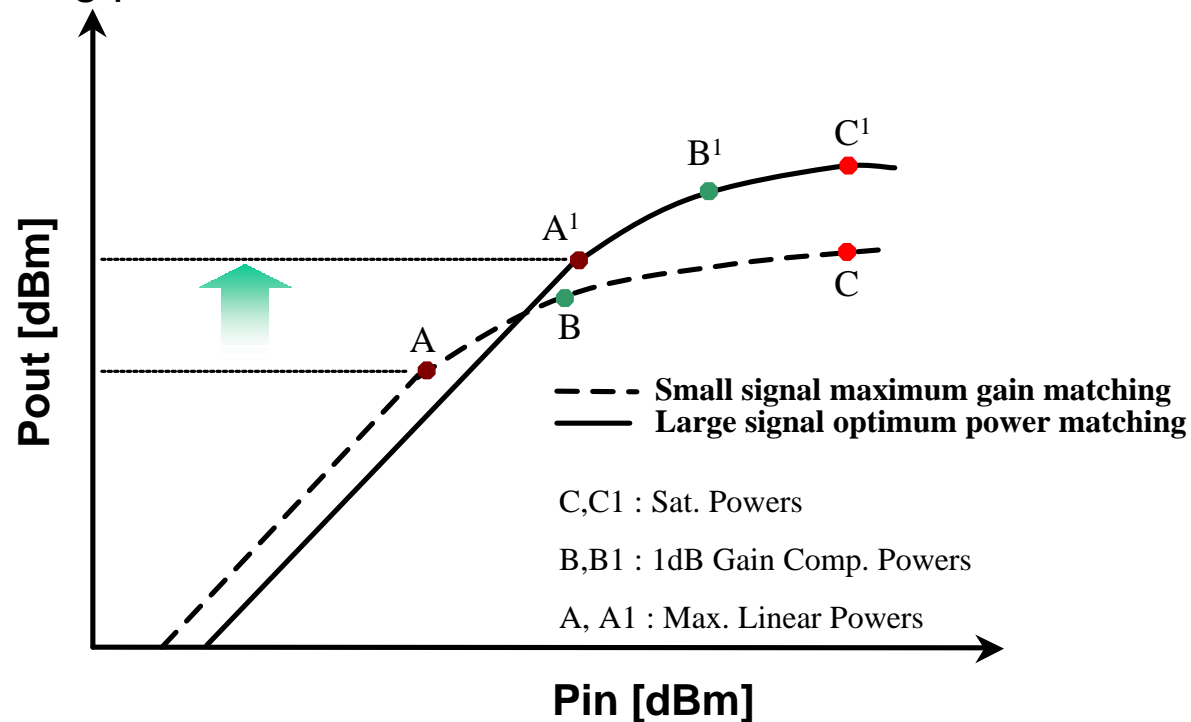
MET Model Validation

- ▶ MRF21125 performances were compared with measurements.
 - ▶ $V_{ds}=28V$, $I_{dq}=1600mA$, $f = 2120MHz$
 - ▶ HB1Tone analysis , Linear sweep with Pin



Matching for Power Amplifier

- ▶ Maximum gain matching based on the small signal S- parameters is not useful to design power amplifier.
- ▶ The information of source and load reflection coefficients as a function of output power is useful to get higher power output.
- ▶ **Load-pull Analysis** is a method to obtain an optimum power matching point



Load-pull Analysis Setup

1. Add Tone1

2. Add HB1Tone Analysis

3. Create Load-pull Tuner in Port definition

4. Add Load-pull Analysis

Loadpull Analysis

Tuner: LoadPullTuner1

HB Analysis to Analyze: HB:HB1Tone1

Harmonic / Harmonic Cluster to Tune: 1

Name	Sweep/Value	Sy...
ZRho	LIN 0.1 1 0.1	
ZAng	LIN 0.340 10	

Port Definition

Port name: Port1

Port number: 2

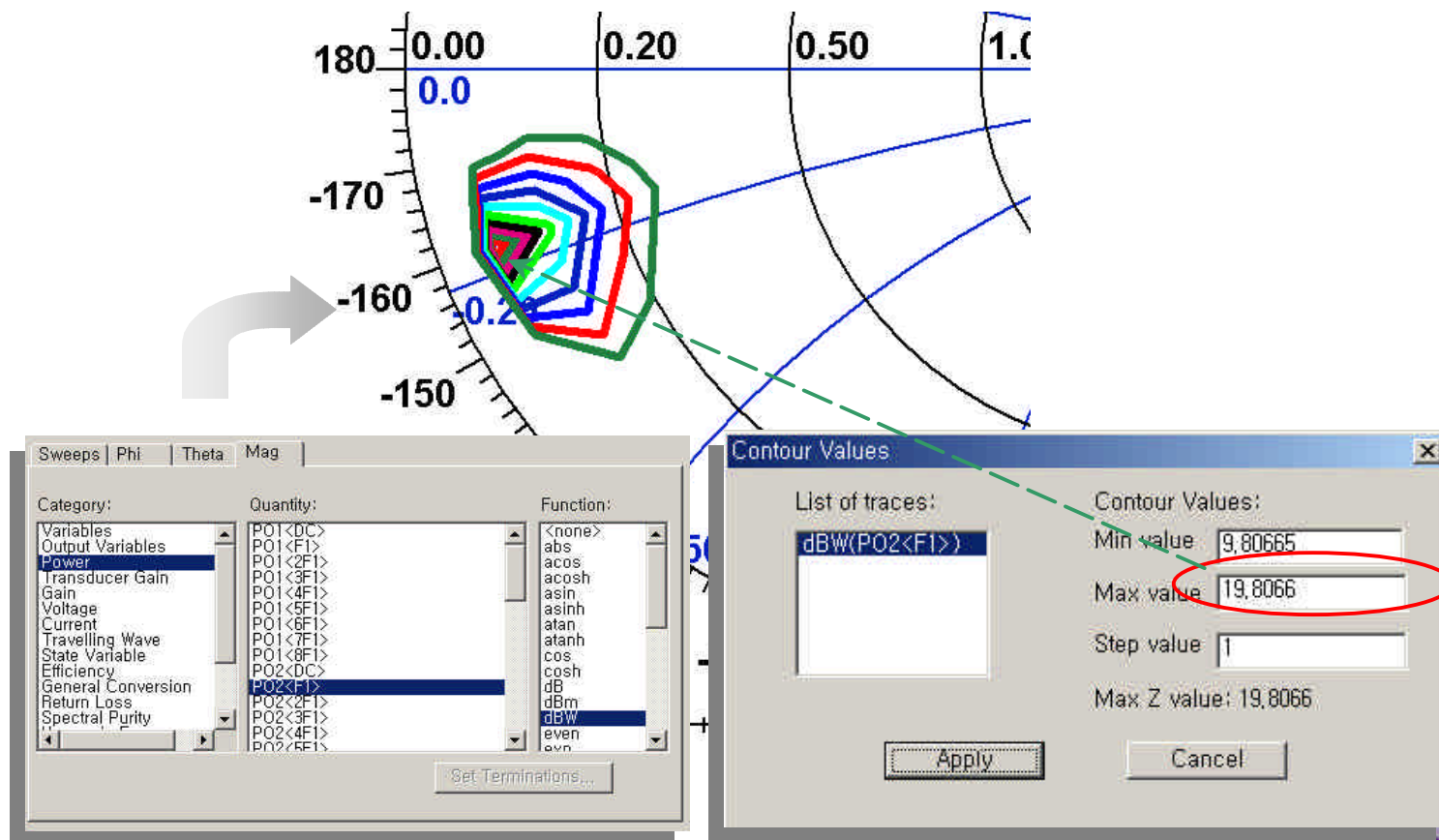
Termination: Simple termination: Re: 50 Im: 0 Impedance

Source Definition: Source type: Power

Load Pull Tuner and Reference Node: Load Pull Tuner: LoadPullTuner1 Reference Node: Ground

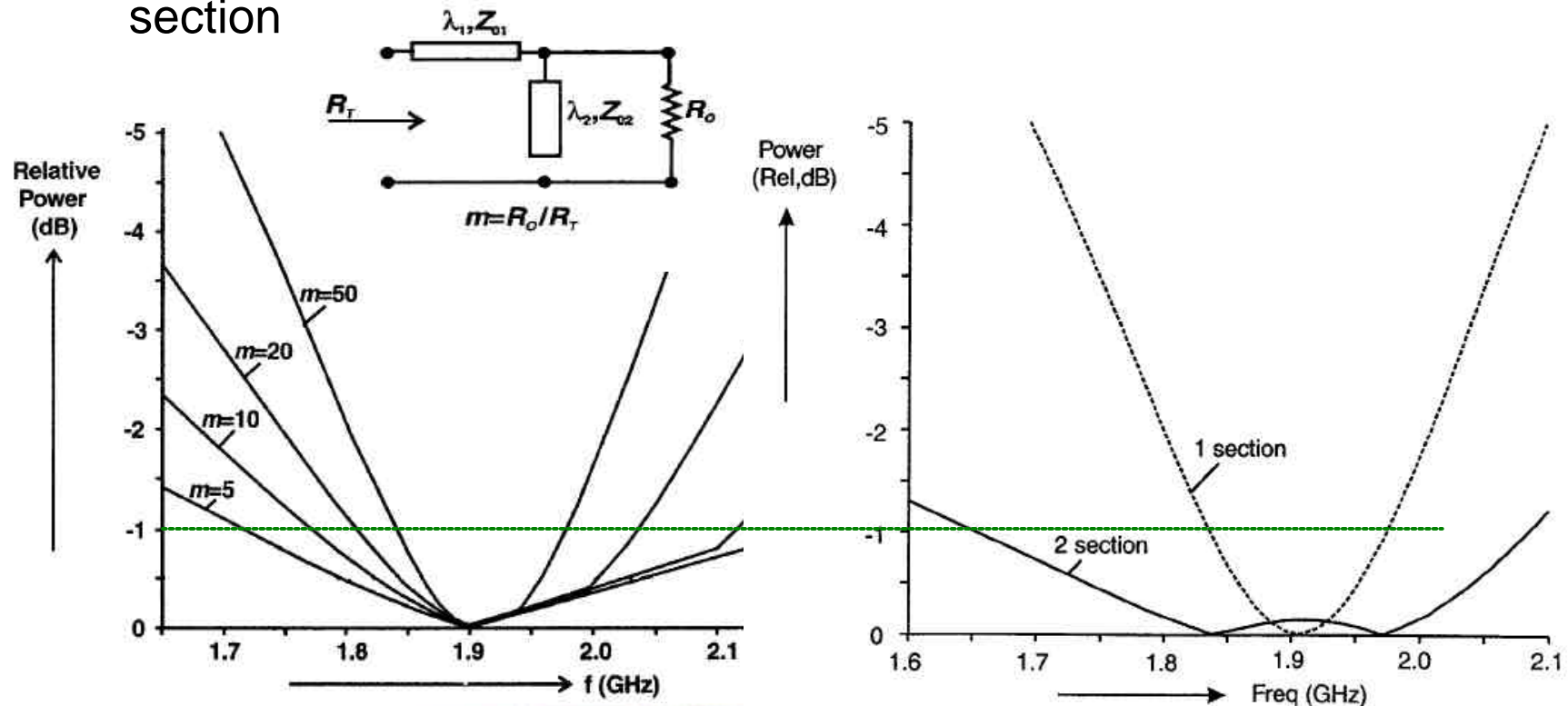
Load-pull Contours

- ▶ Output power, efficiency, and harmonic contours can plot
- ▶ Max, Min, Step value can be assigned



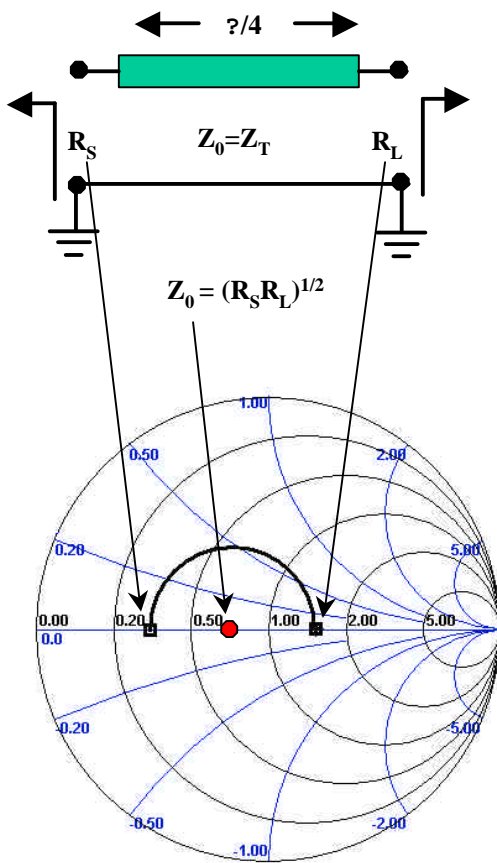
Lowpass Multi Section Matching

- Lowpass networks suppress harmonics and improve linearity
- RF power transistor usually has a small input impedance ($R_T \approx 2$ or 3)
- Large ratio of $m=R_0/R_T$ decrease PA's bandwidth (R_0 is 50ohm)
- Bandwidth of matching networks can be increased by lowpass multi section

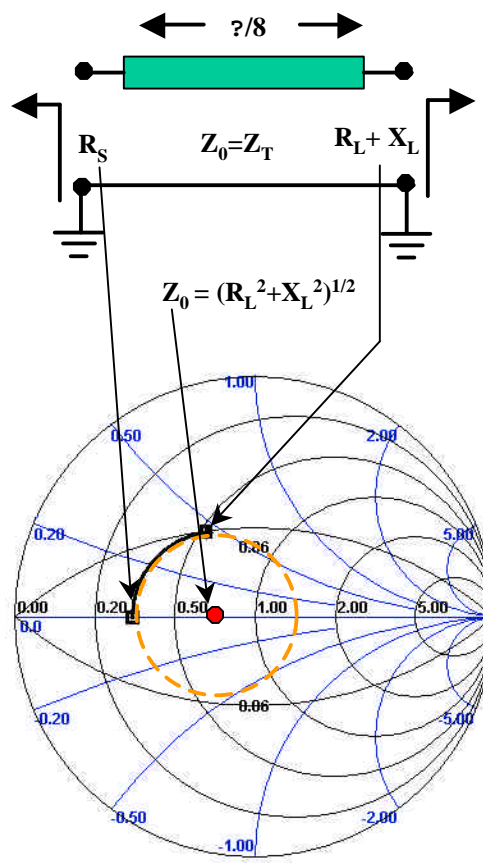


Transmission Line Matching(1)

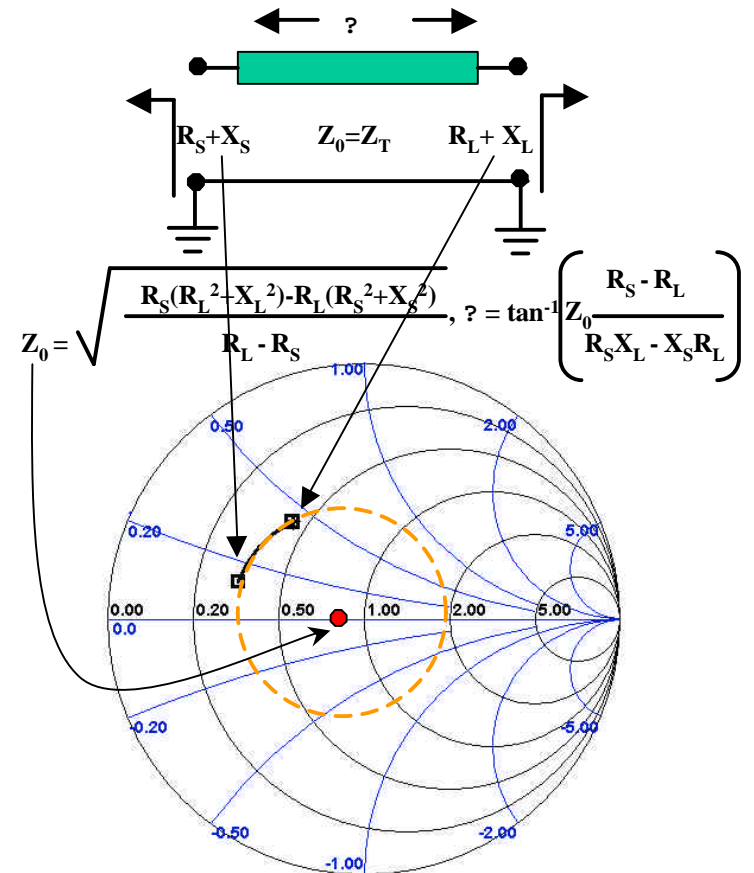
- Matching networks can be realized by using transmission lines such as $\lambda/4$, $\lambda/8$, and λ/n .



$\lambda/4$ transformer : any $R_S \rightarrow$ any R_L



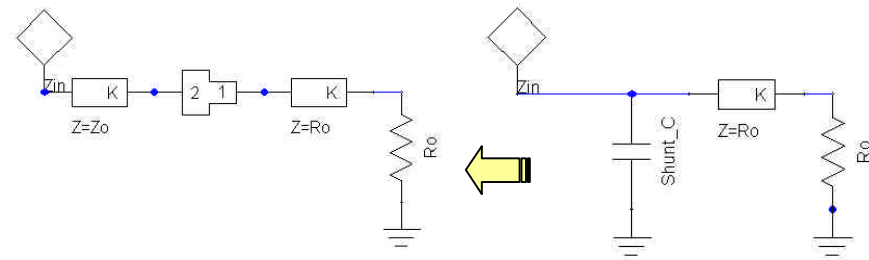
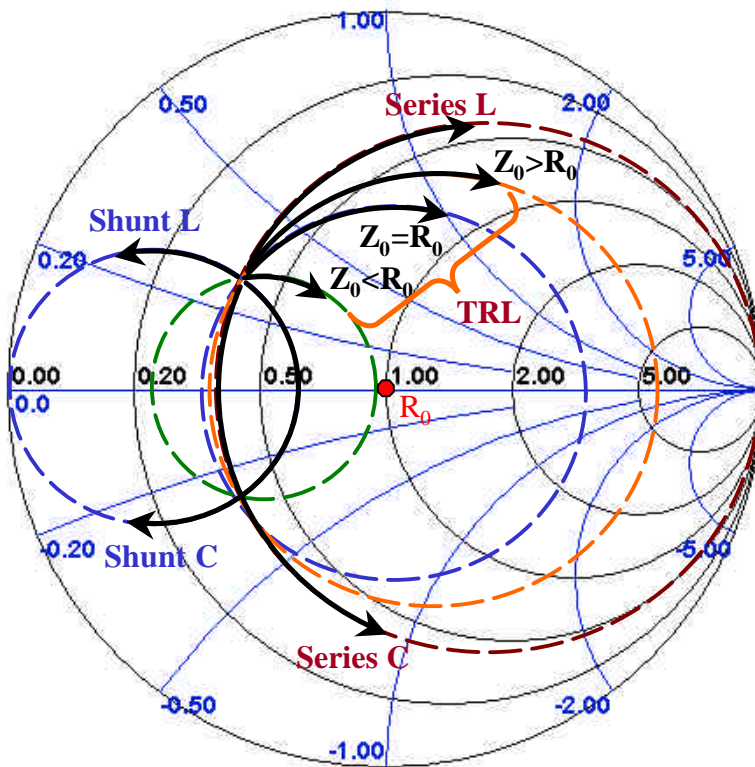
$\lambda/8$ transformer : any $R_S \rightarrow$ any Z_L



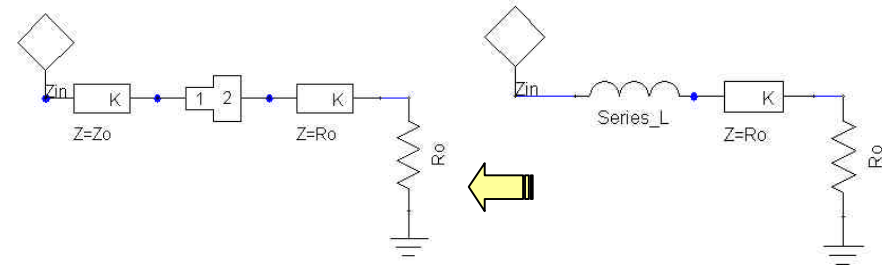
Arbitrary transmission line : any $Z_S \rightarrow$ any Z_L

Transmission Line Matching(2)

- Shunt C and Series L can be replaced by series low impedance line and series high impedance line respectively.



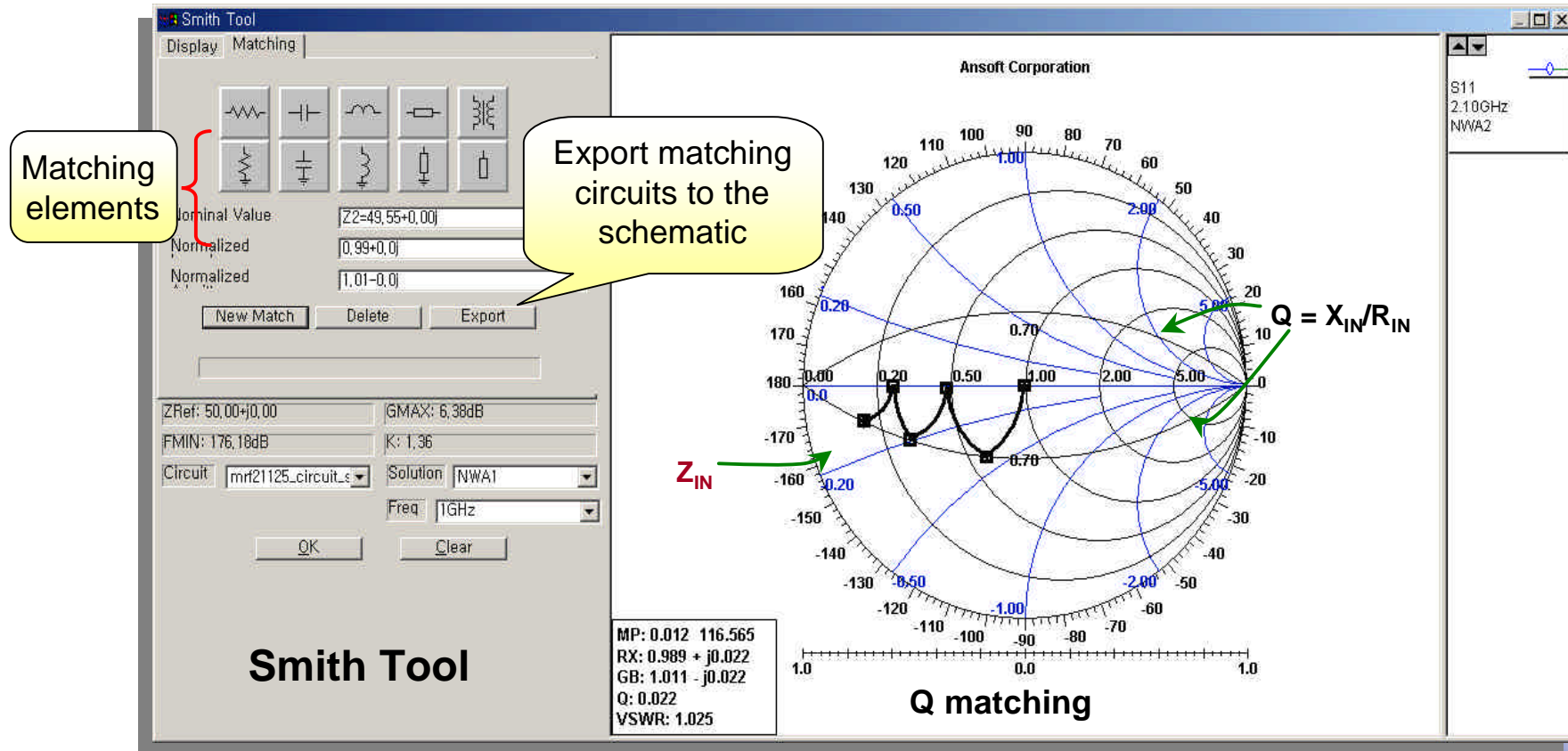
$Z_0 < R_0$: Transmission Line ~ Shunt C



$Z_0 > R_0$: Transmission Line ~ Series L

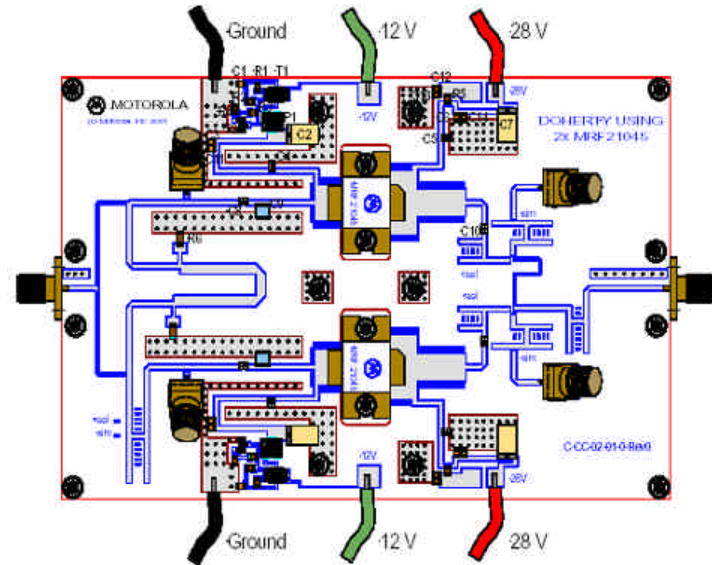
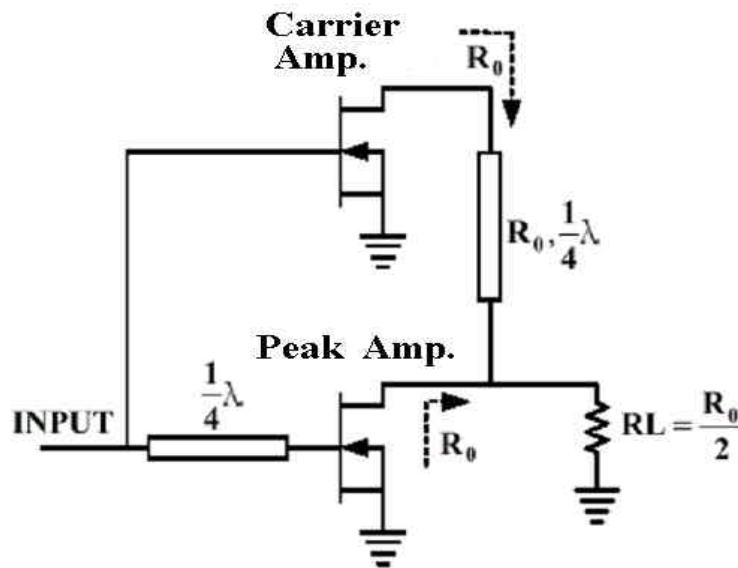
Low Q Matching technique

- ▶ Conventional approach to design matching circuits which uses analytical equations to calculate the circuits elements is very time consuming.
- ▶ **Smith Tool** in **Ansoft Designer™** is a powerful solution to design arbitrary matching networks.



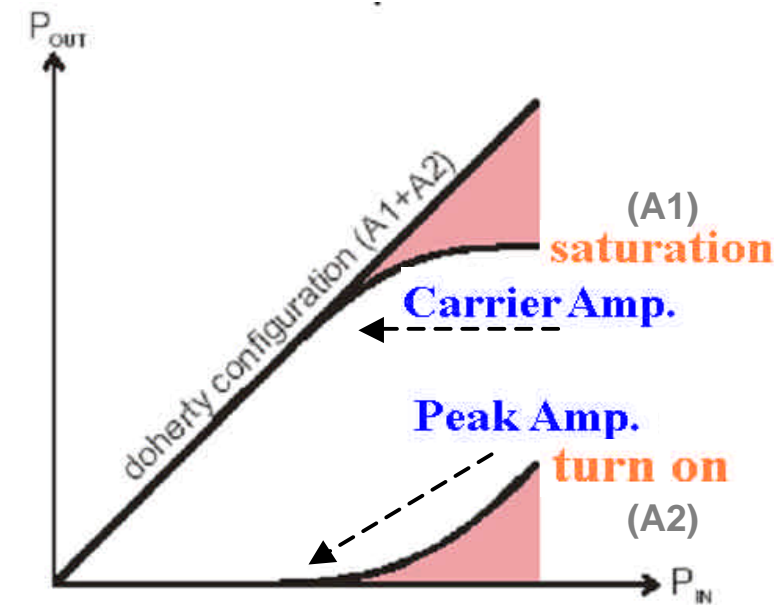
Doherty Amplifier Overview

- A Doherty amplifier consists of a carrier and a peak amplifiers.
- There are two quarter-wave transformers: input of the peak amplifier, output of the carrier amplifier.
- **Advantage:** Simple and ease of additional linearization using conventional methods such as feed-forward, envelope, and feed-back.
- **Disadvantage:** Narrow bandwidth and Gain degradation

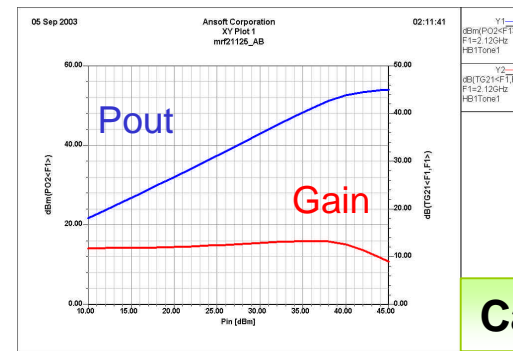


Doherty Amplifier Basic Operation

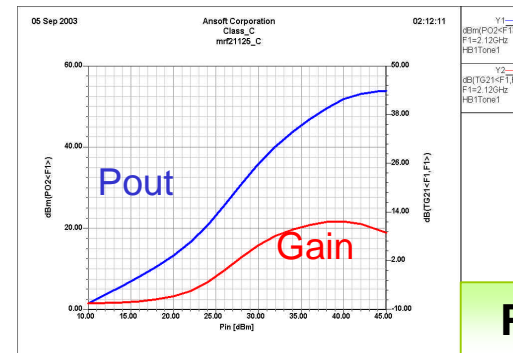
- ▶ **Carrier amplifier:** Class AB (Saturates at the high power input)
- ▶ **Peak amplifier:** Class C (Turn on at the high power input)
- ▶ Doherty configuration improves the linearity at the high power input by complementing the saturation of the carrier amplifier with the turn on characteristics of the peak amplifier.



Basic operation Characteristic

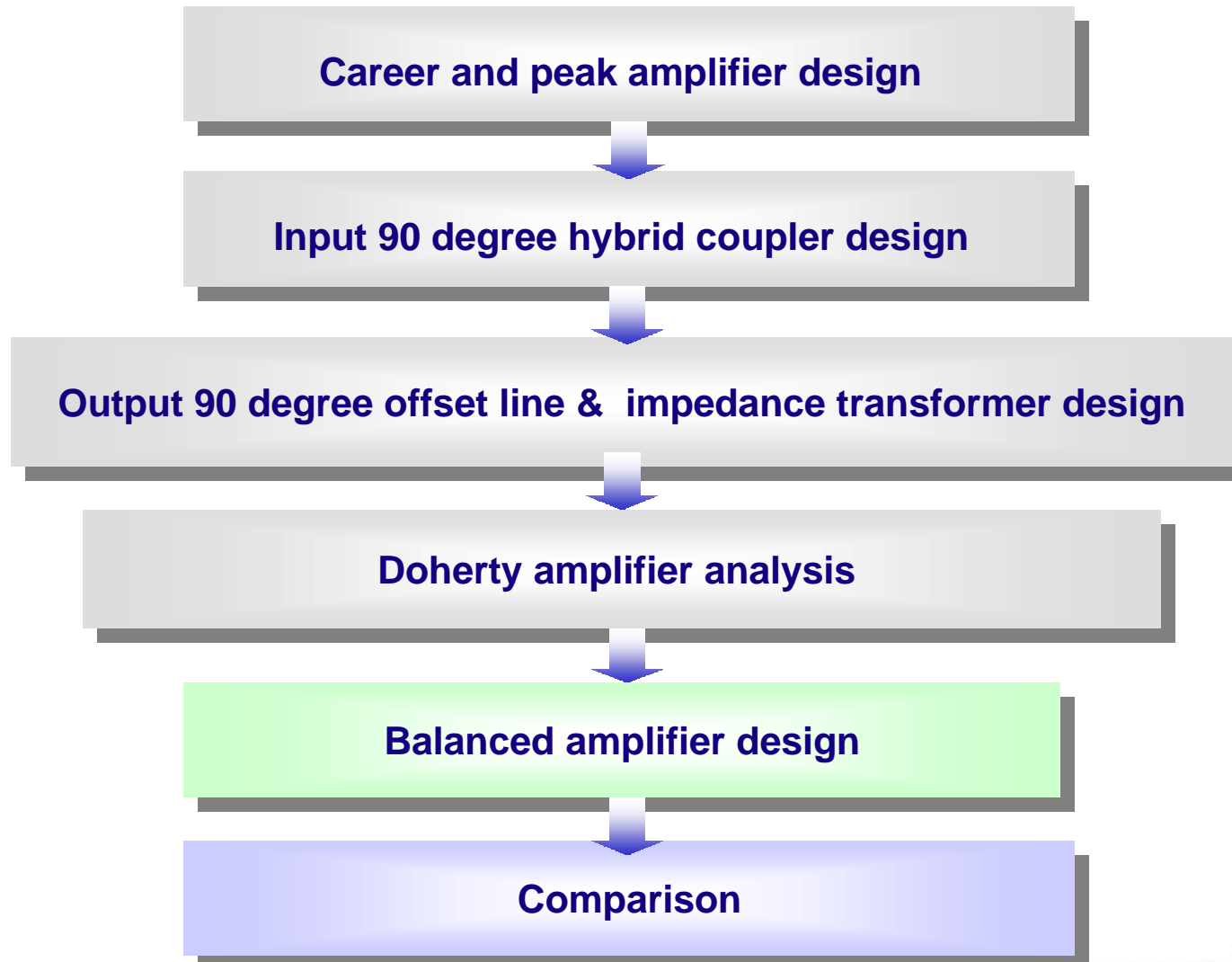


Carrier Amp.



Peak Amp

Doherty Amplifier Design



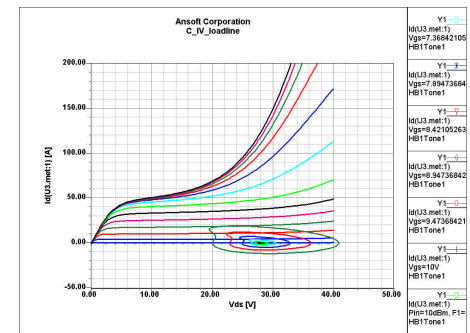
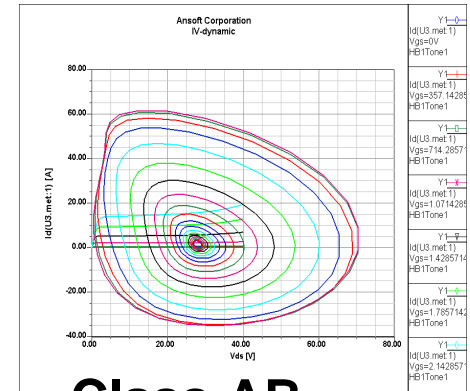
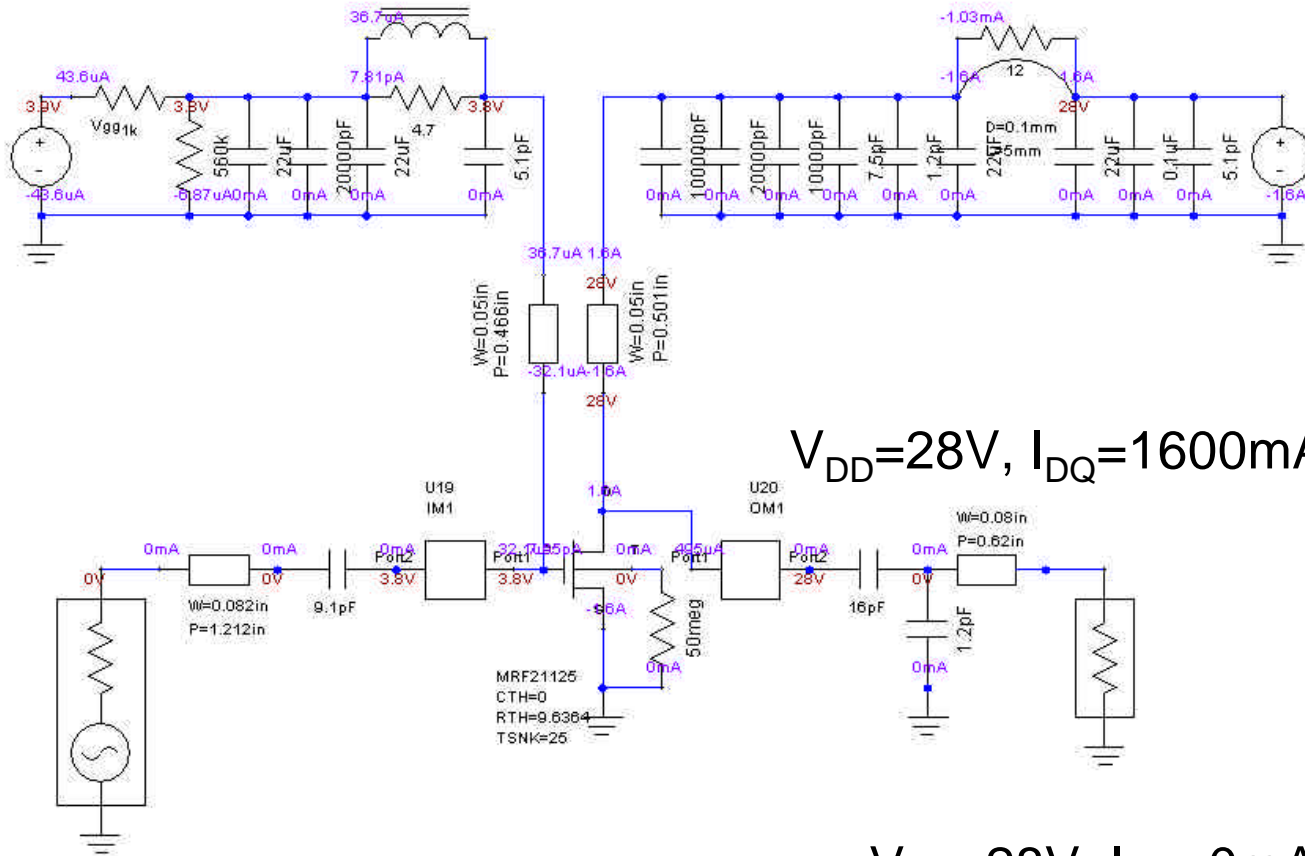
Carrier Amplifier Design Procedure

1. **Bias analysis : Class AB operation mode**
2. **Load-pull analysis : Finding optimum matching point**
3. **Input & output matching circuit generation**
4. **EM planar analysis : Matching network verification**
5. **Modulation envelope analysis**
6. **Reports (gain, ACPR, Pout, efficiency, PSD)**
7. **PCB layout**



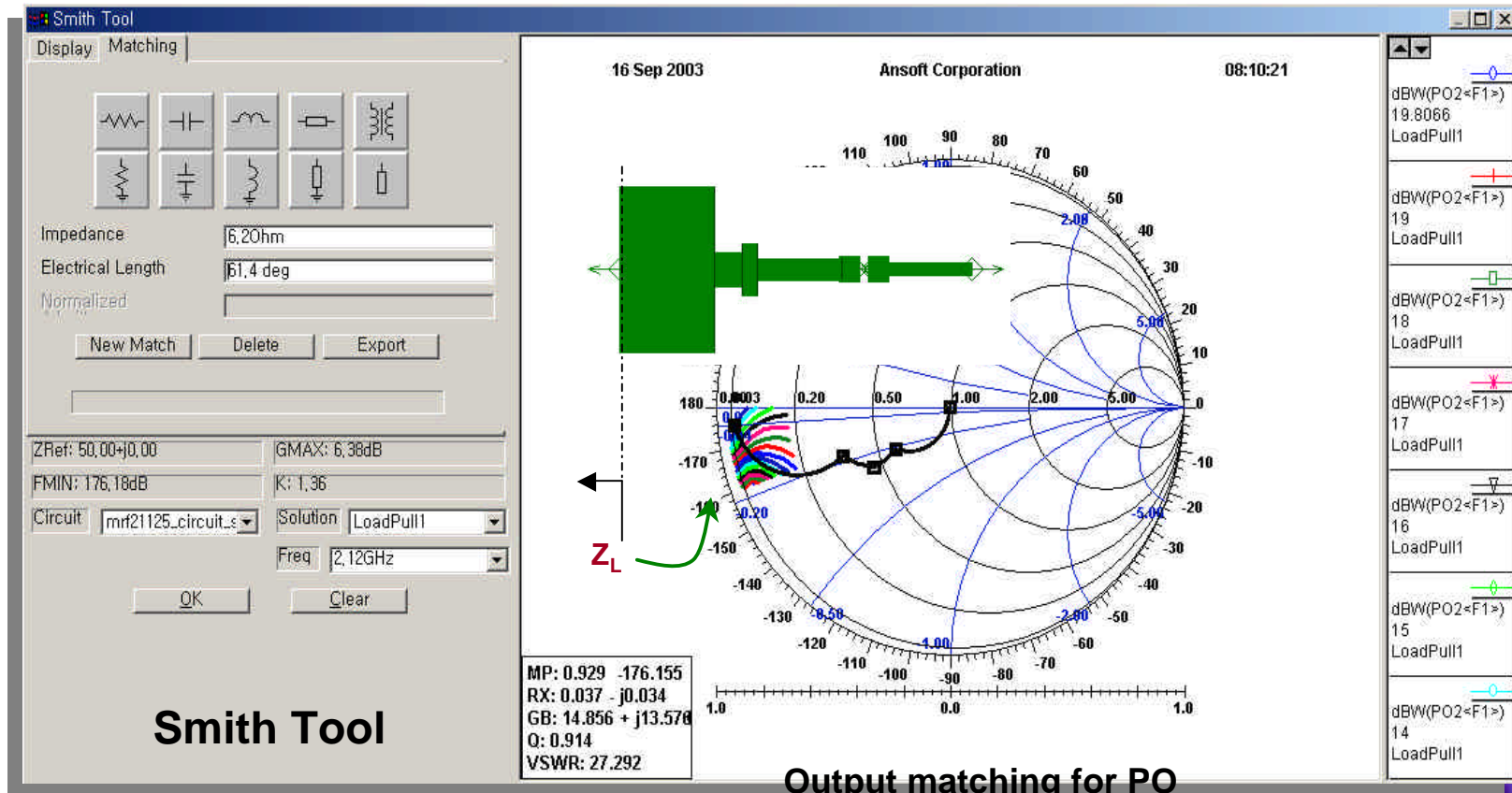
DC Bias Network Analysis

Carrier amplifier IV-curve & dynamic load line



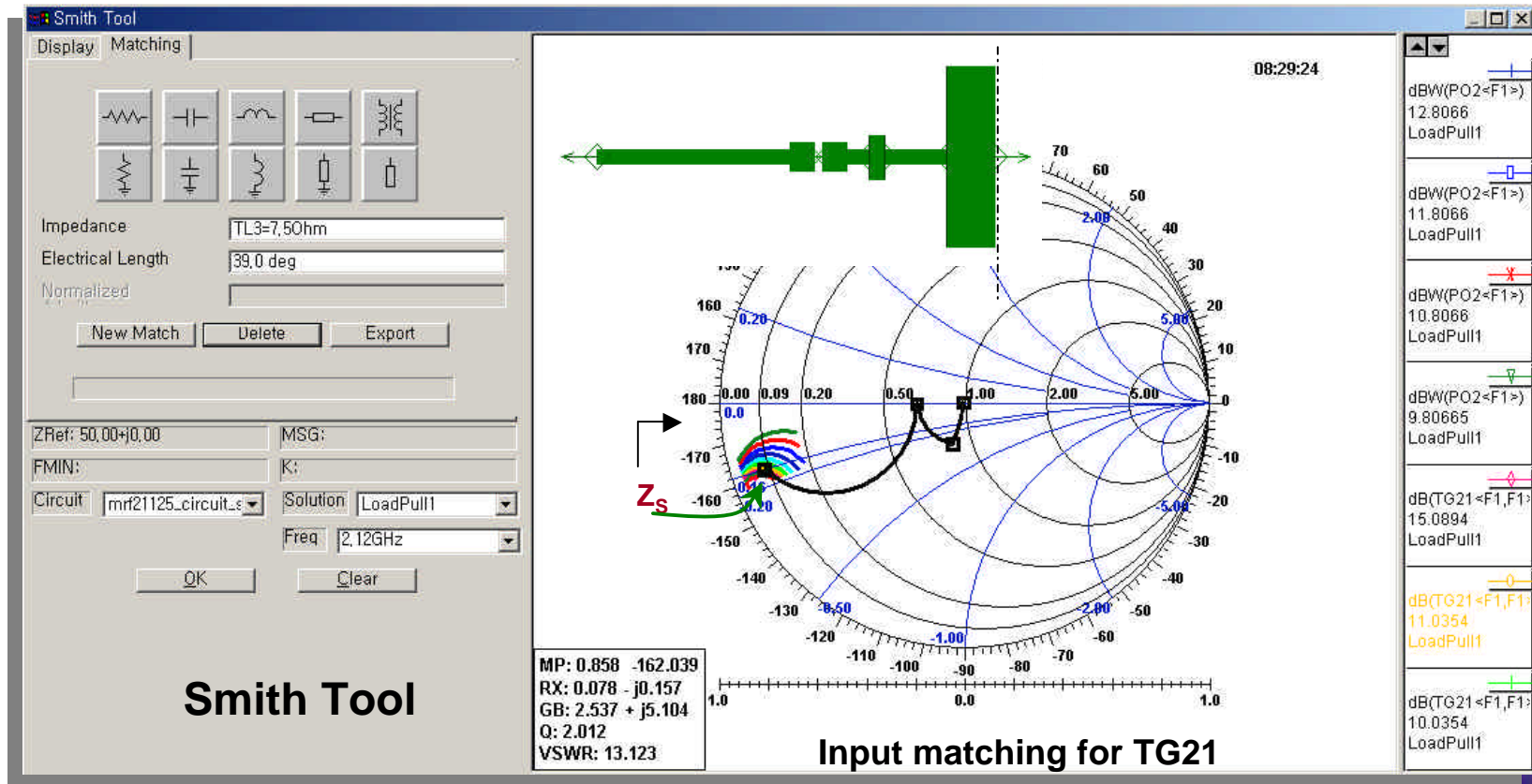
Output Matching

- ▶ Output matching circuit, $V_{DD}=28V$, $I_{DQ}=1600mA$
- ▶ Load Impedance matching for optimum $PO2<F1>$
- ▶ Transmission line matching with **Smith Tool**



Input Matching

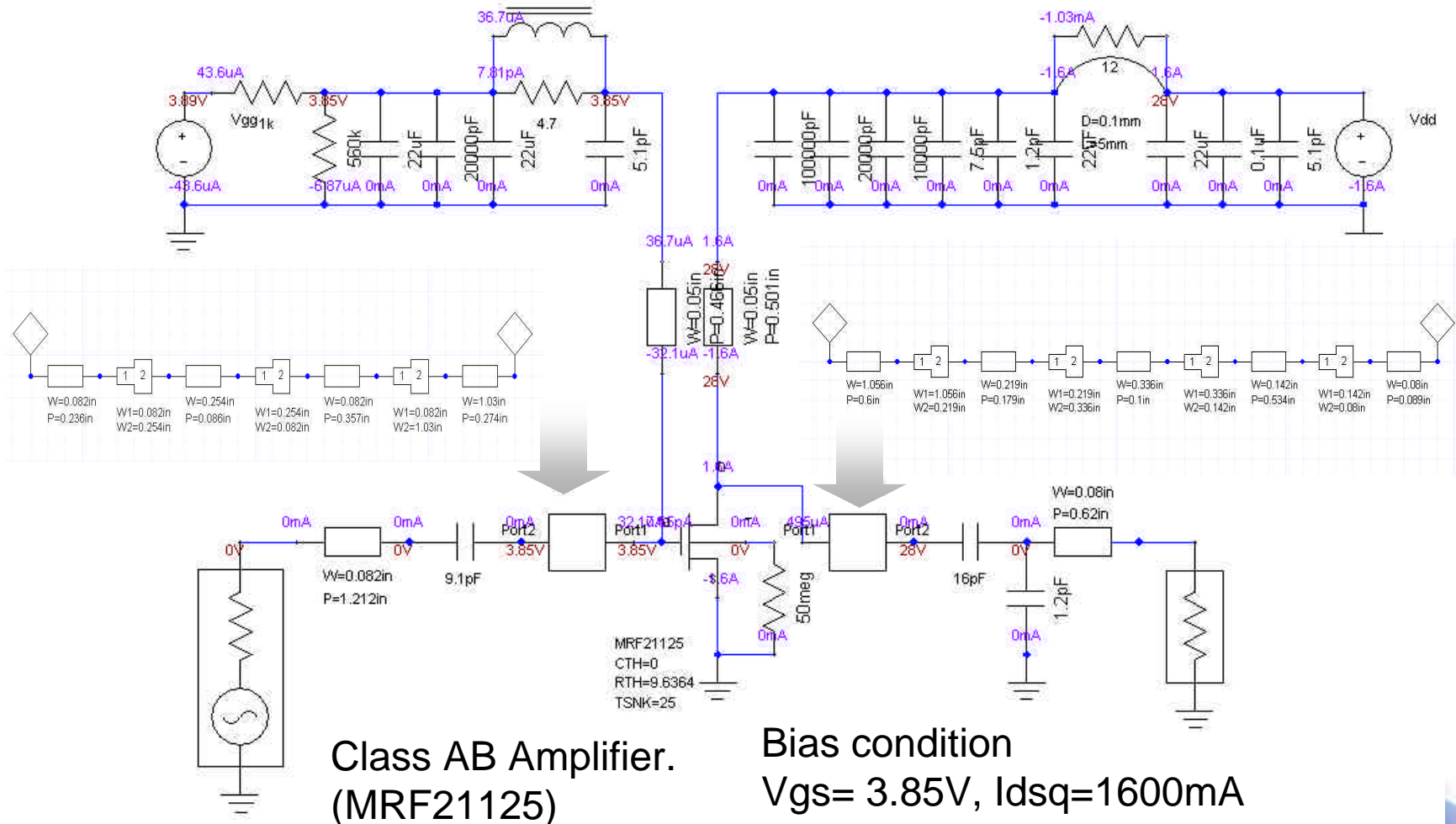
- ▶ Input matching circuit, $V_{DD}=28V$, $I_{DQ}=1600mA$
- ▶ Source Impedance matching for optimum $TG_{21}\langle F1,F1\rangle$
- ▶ Transmission Line matching with **Smith Tool**



Smith Tool

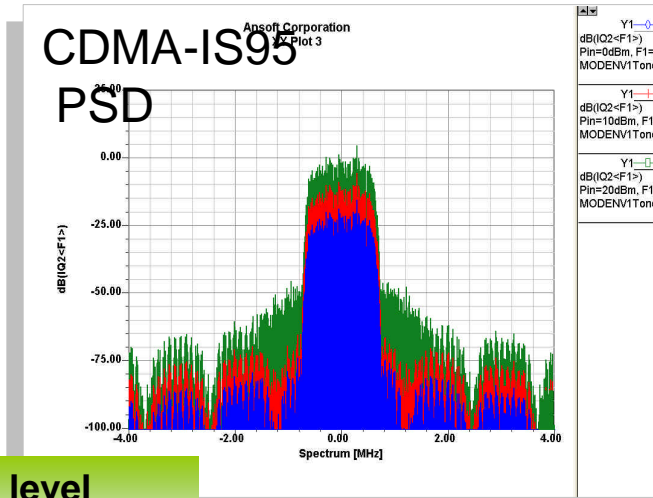
Carrier Amplifier Analysis

Input and output matching circuits were included

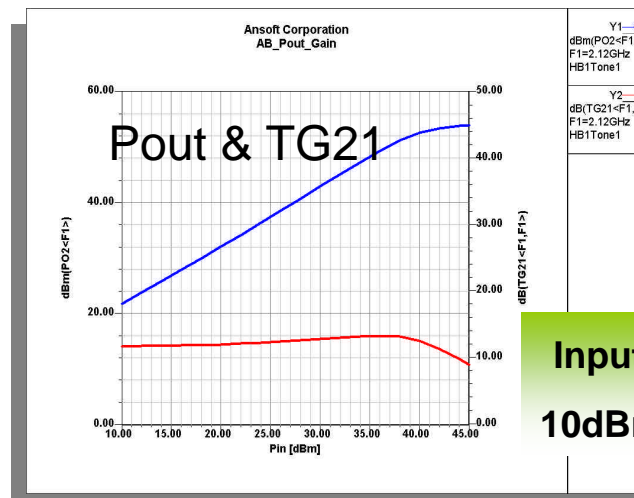


Modulation Analysis

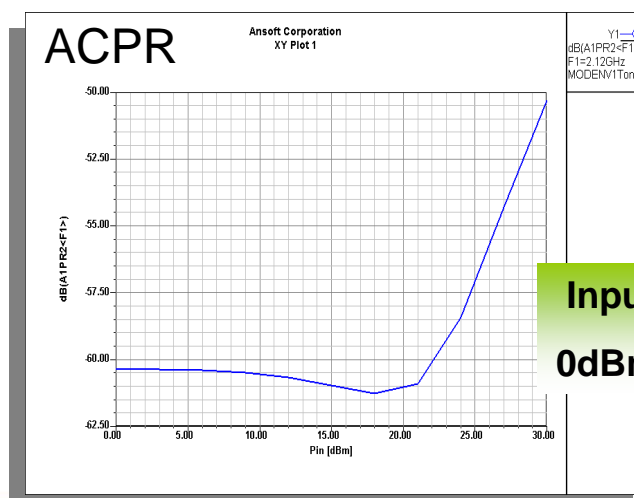
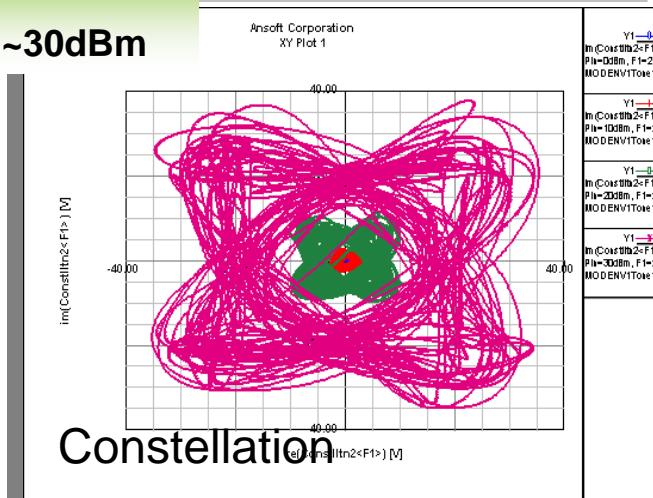
Carrier amplifier characteristics: AB Class operation mode



Input level
0dBm~30dBm



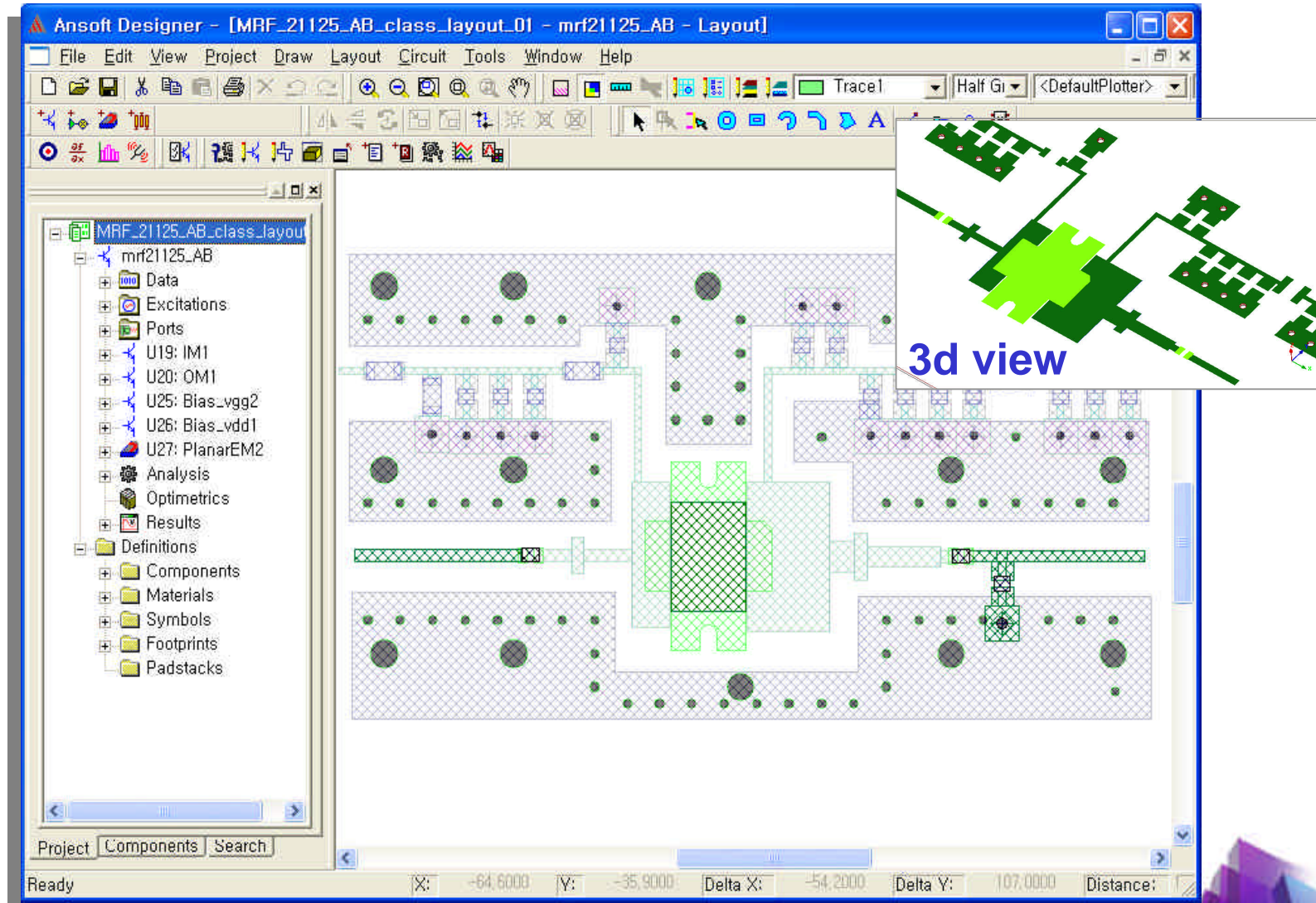
Input level
10dBm~45dBm



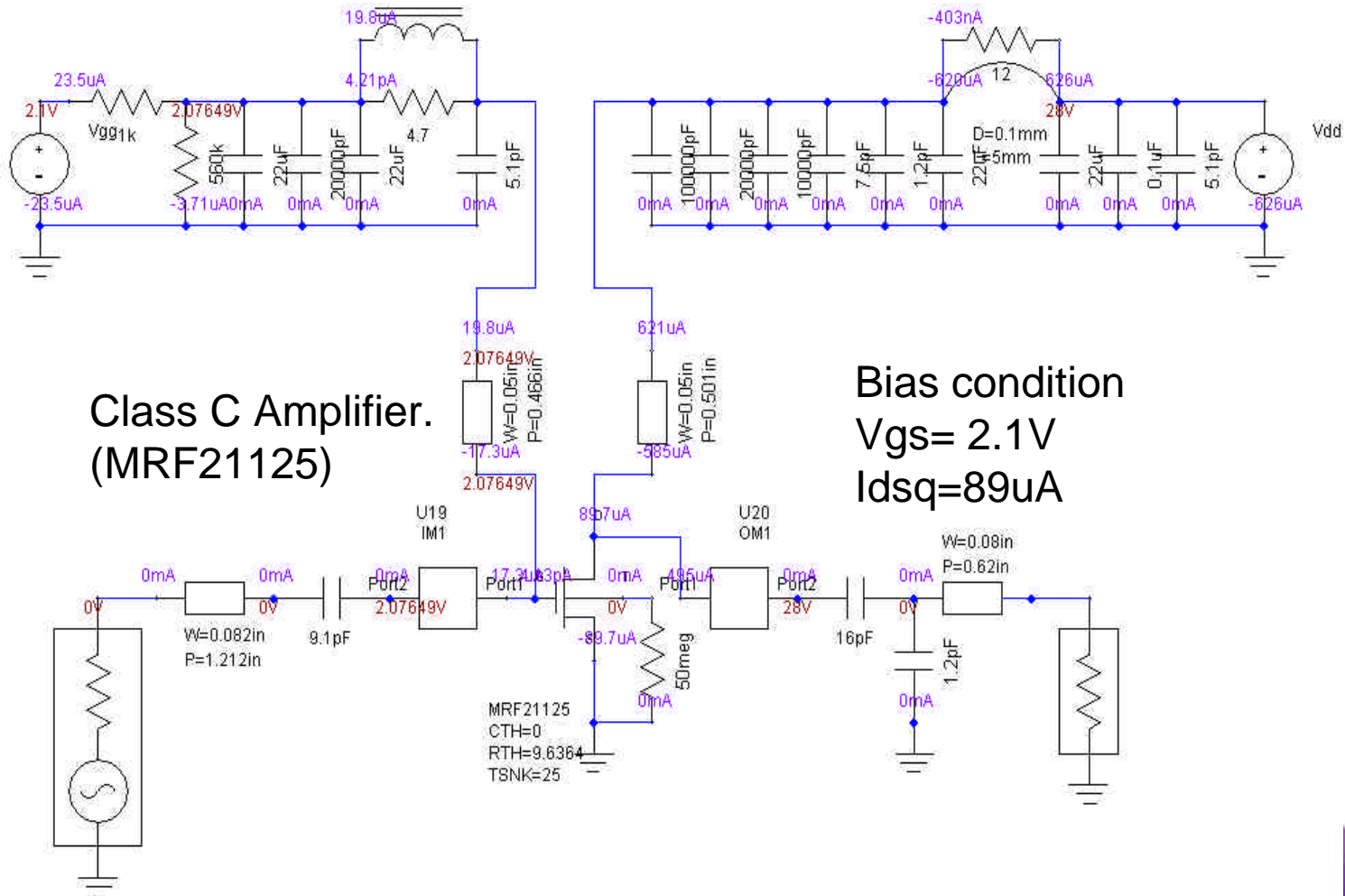
Input level
0dBm~30dBm



Carrier Amplifier PCB Layout

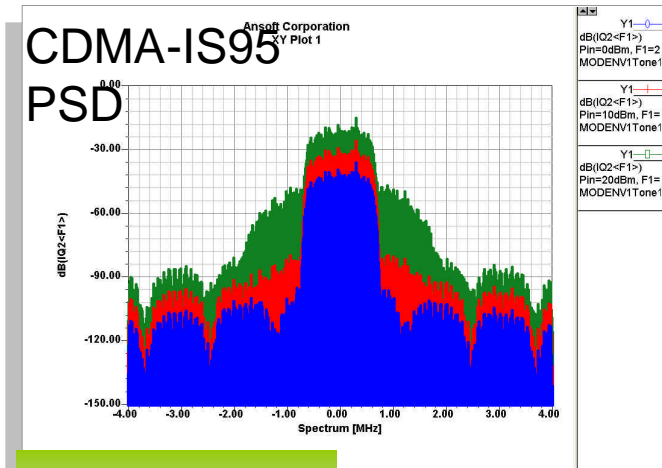


Peak Amplifier Operation



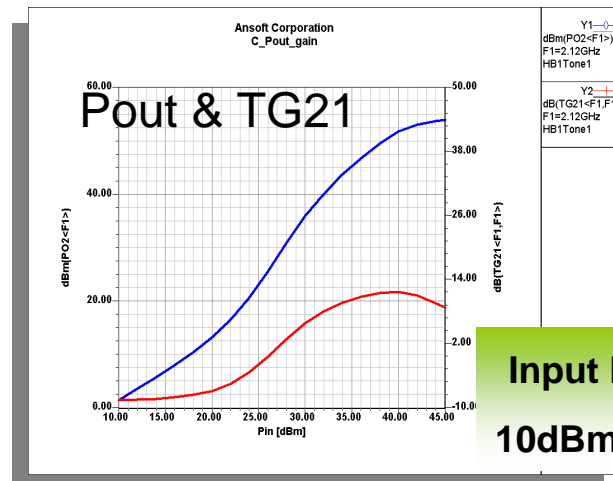
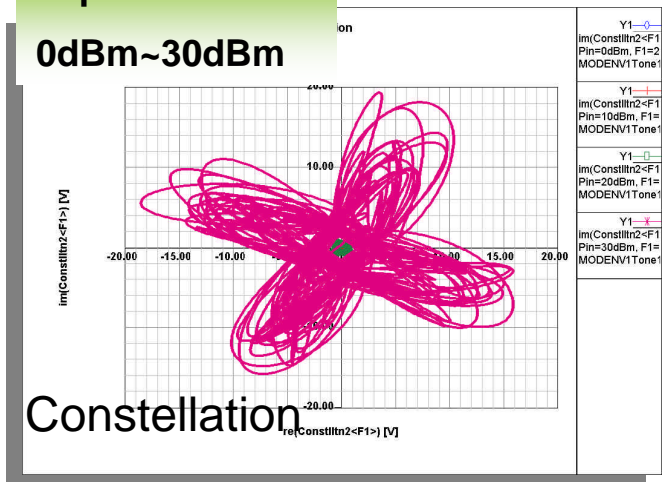
Modulation Analysis

Peak amplifier : Class C operation mode

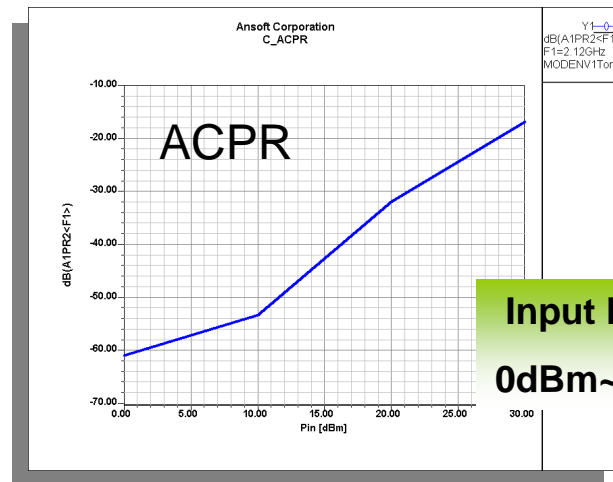


Input level

0dBm~30dBm



Input level
10dBm~45dBm



Input level
0dBm~30dBm

90° Hybrid Coupler Design

The screenshot displays the Ansoft Designer interface for a 90-degree hybrid coupler design. The main workspace shows a schematic with a central red-outlined coupler structure. It is connected to three ports: Port1, Port2, and Port3. Various transmission line segments are labeled with parameters like W (width) and P (pitch). A central table lists these parameters:

W1	2.11	mm
W2	2.11	mm
W3	2.11	mm
W4	3.46	mm
W5	2.11	mm
L1	26	mm
L2	13	mm
L3	13	mm

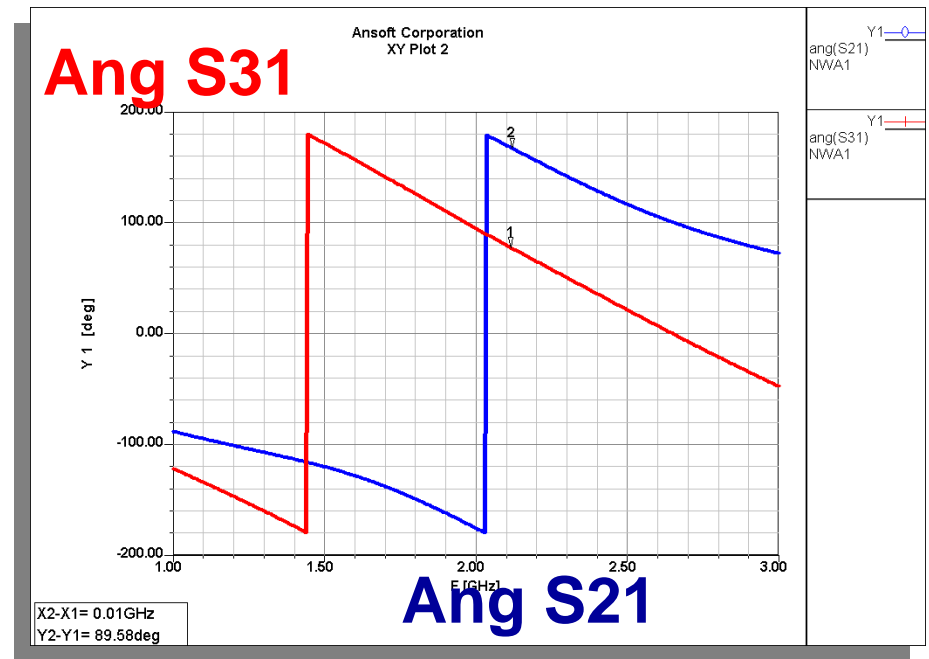
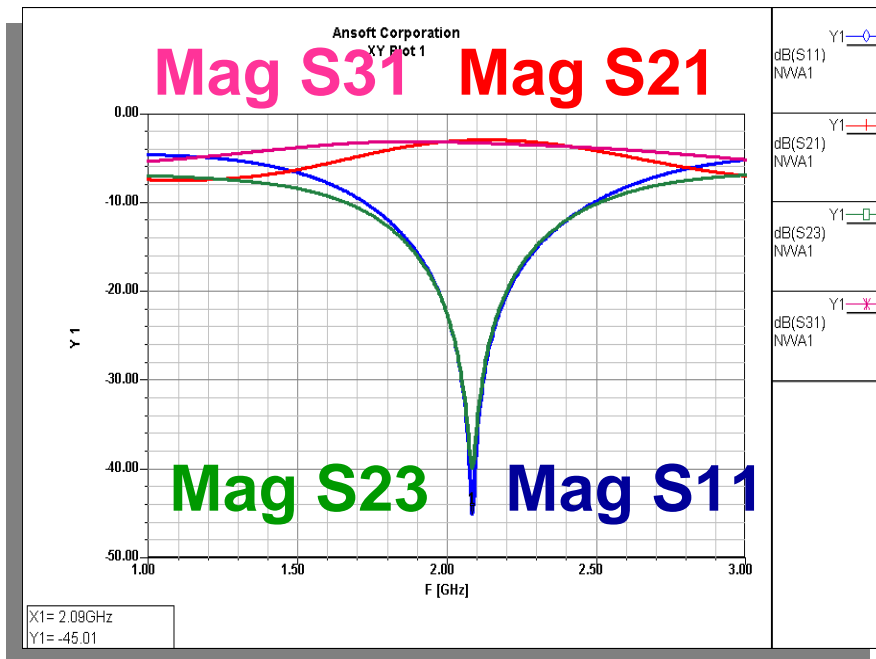
A 'Properties' dialog box is open, showing the 'Parameter Values' tab. It lists simulation settings:

Name	Value
L3	13
SUB	Arlon
CoSimulator	Planar EM
CoSimStackup	Circuit
CoSimDeembe...	Planar EM
Status	Active
Info	MSCOUPB

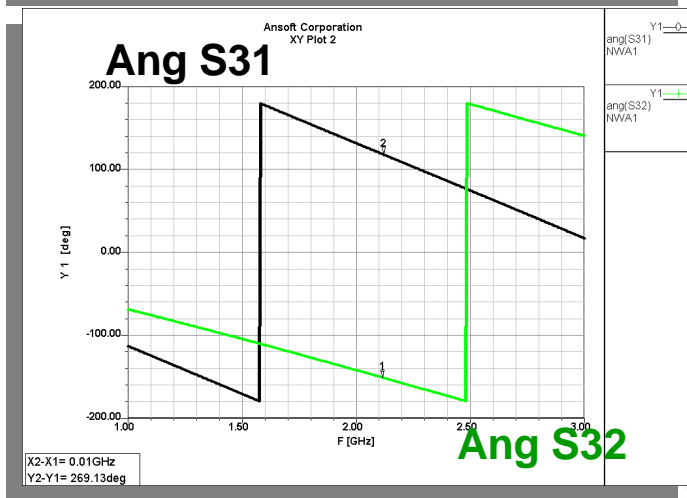
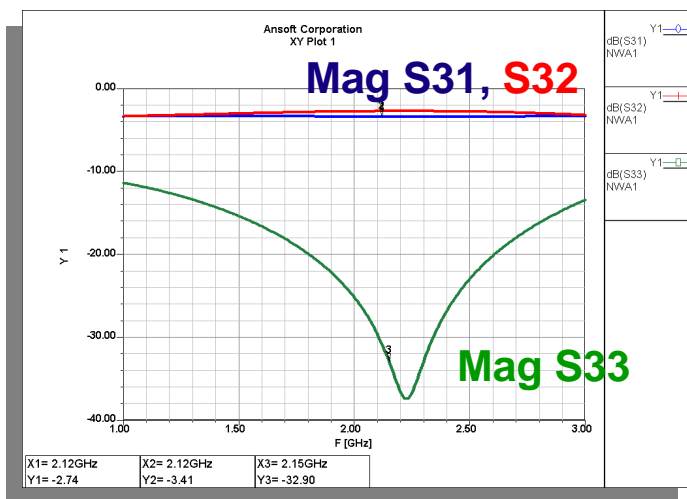
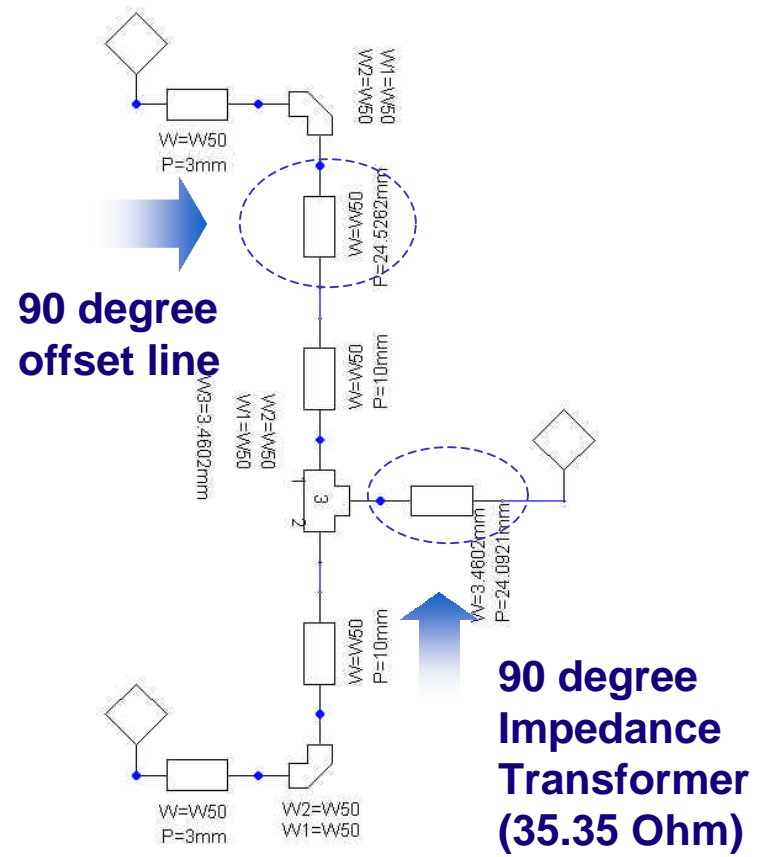
A blue arrow points from the 'Planar EM' selection in the properties dialog to the text 'Solver on demand' at the bottom right of the interface.

Solver on demand

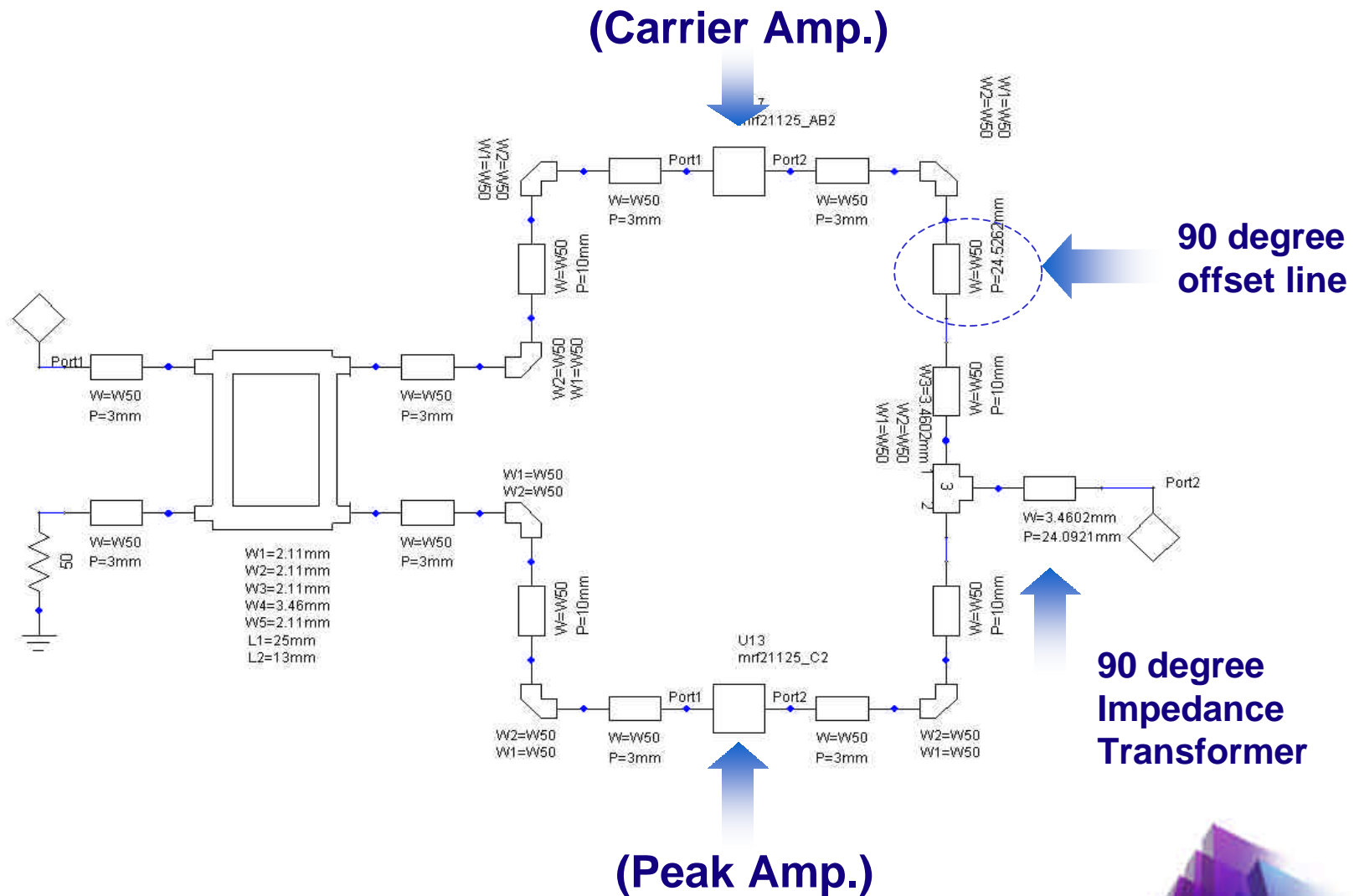
90° Hybrid Coupler Design



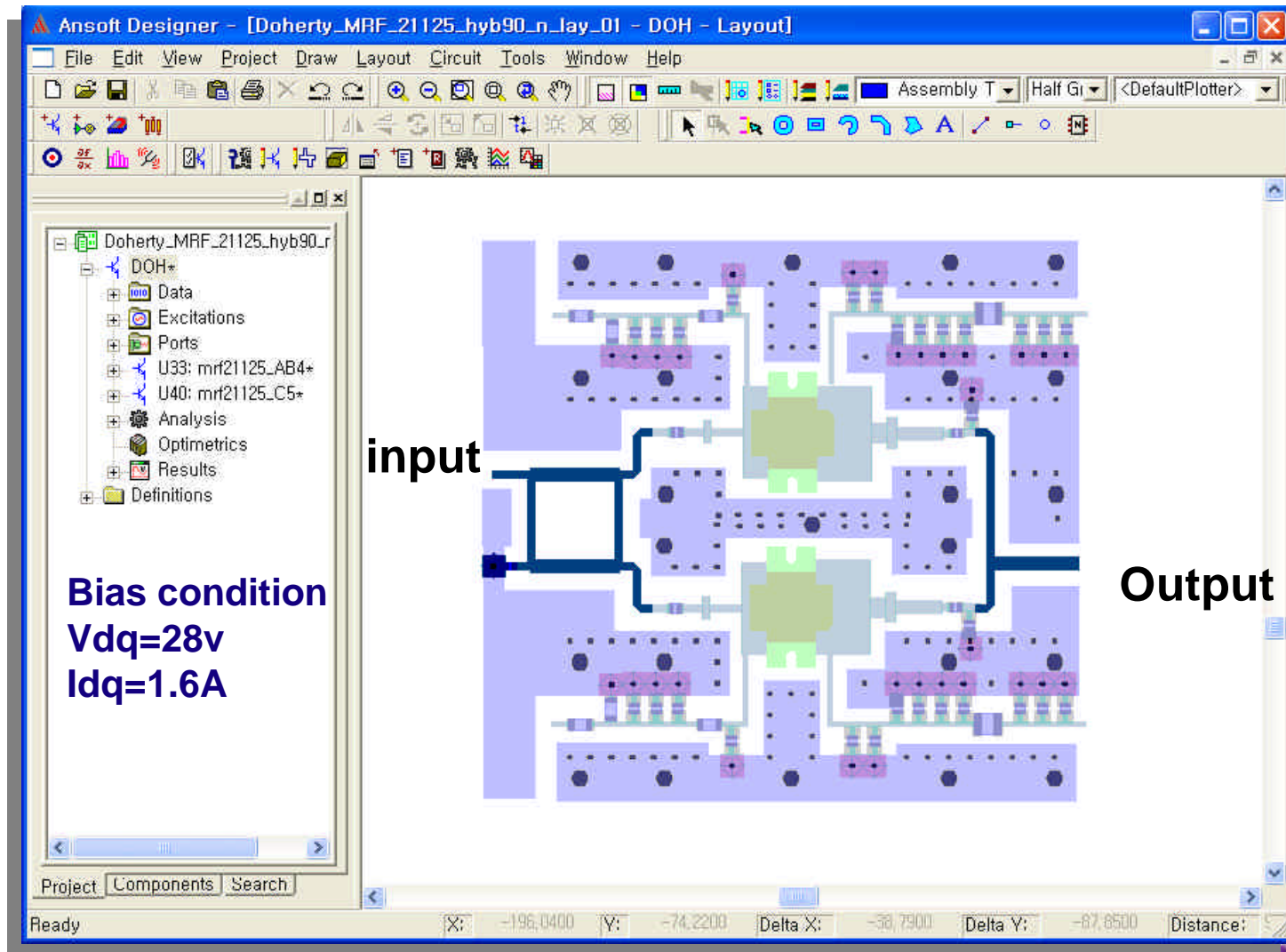
90 ° Offset and Transformer Line



Doherty Amplifier Schematic

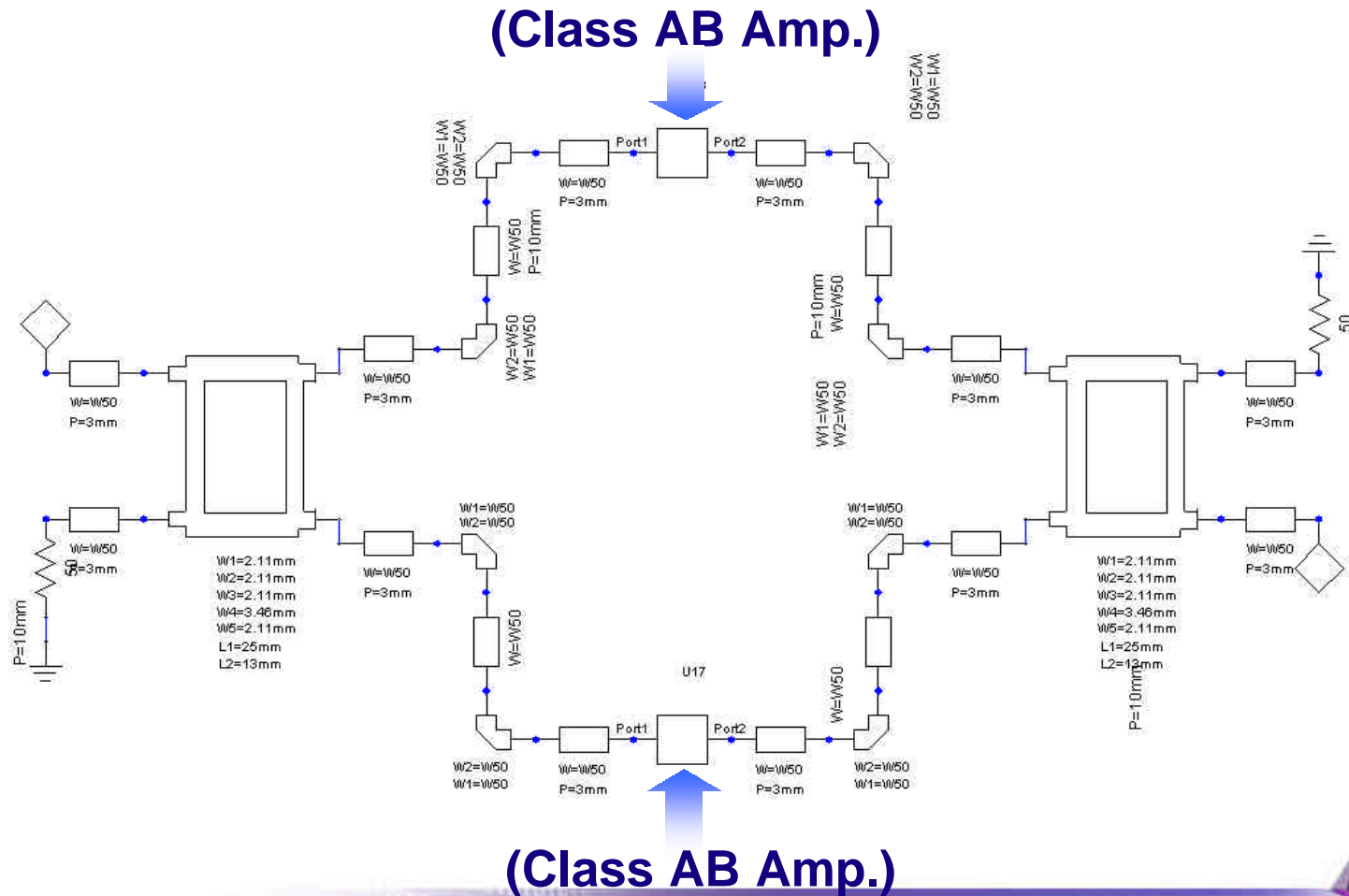


Doherty Amplifier Layout

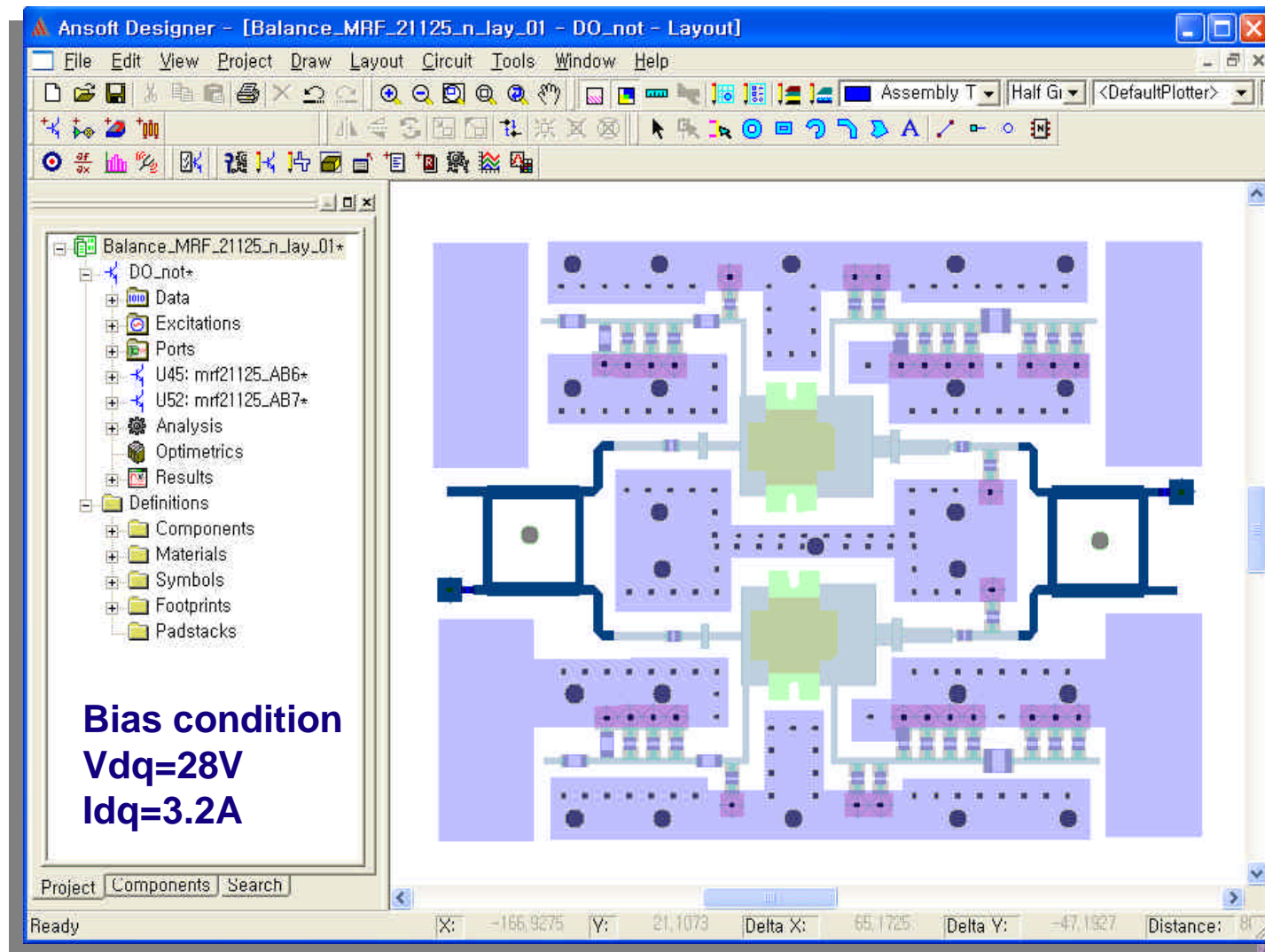


Balanced Amplifier Schematic

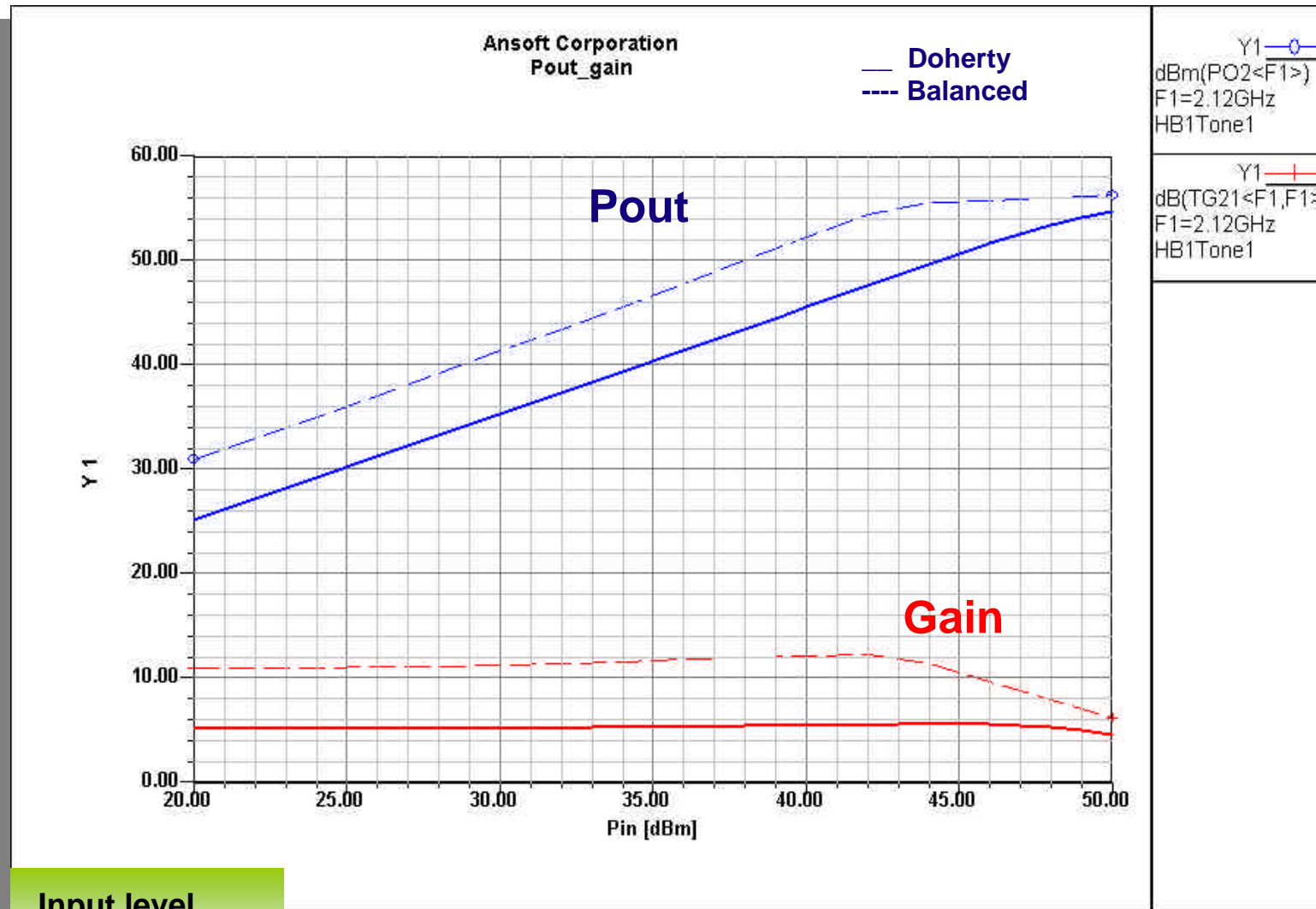
- Conventional balanced amplifier can be realized by combining two class AB amplifiers as shown below.



Balanced Amplifier Layout



Pout and Gain Comparison

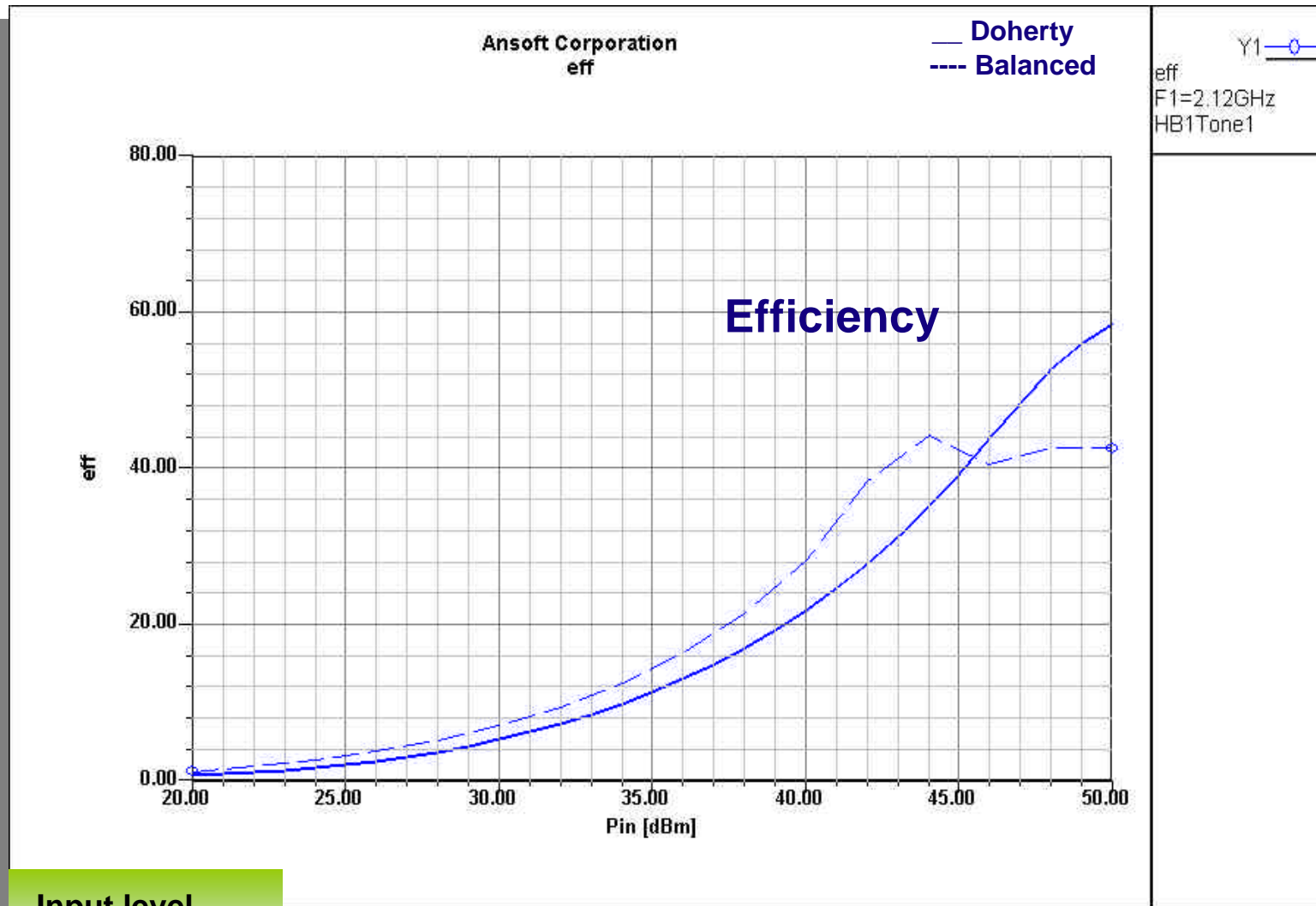


Input level

20dBm~50dBm

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Efficiency Comparison

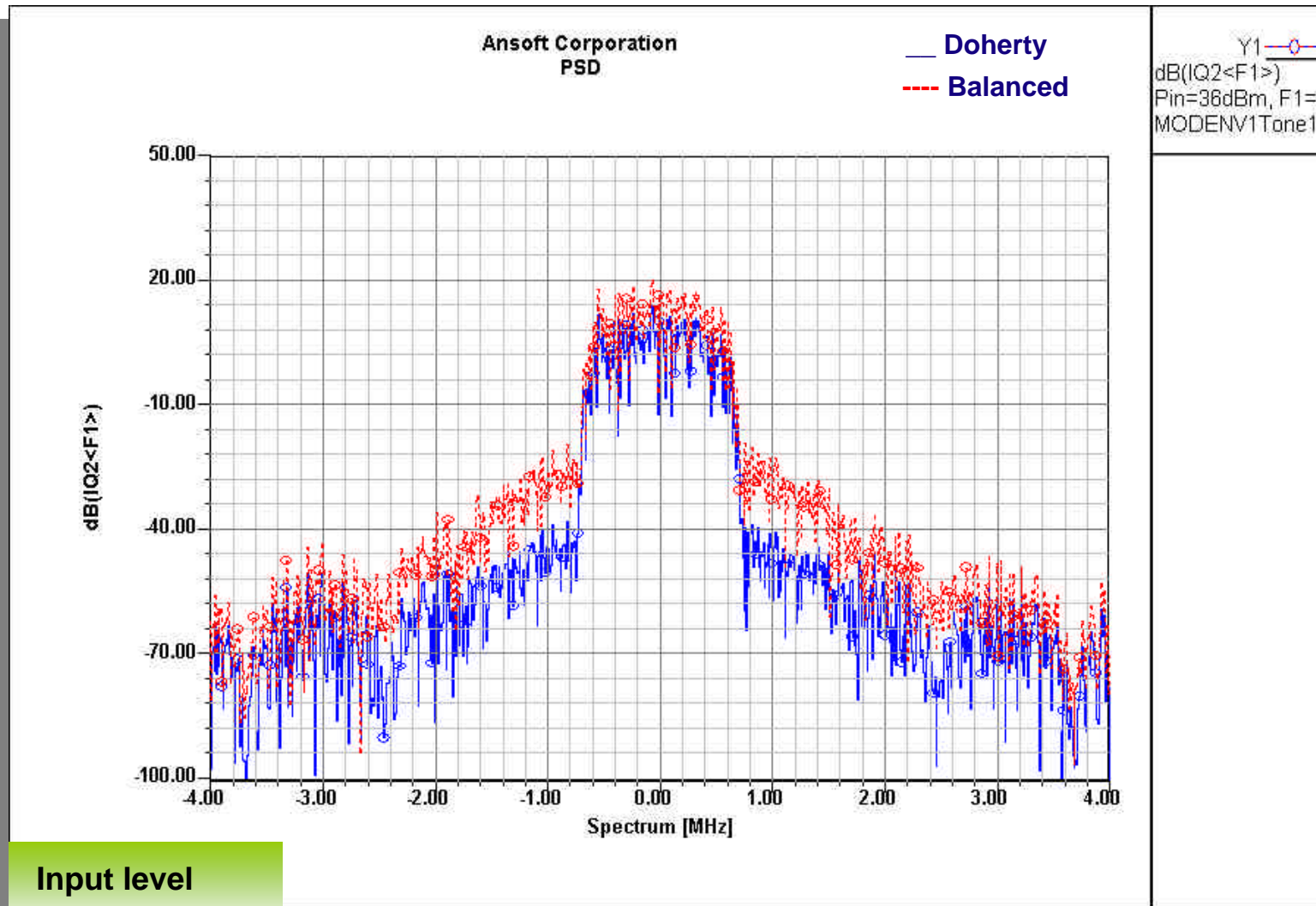


Input level

20dBm~50dBm

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PSD Comparison

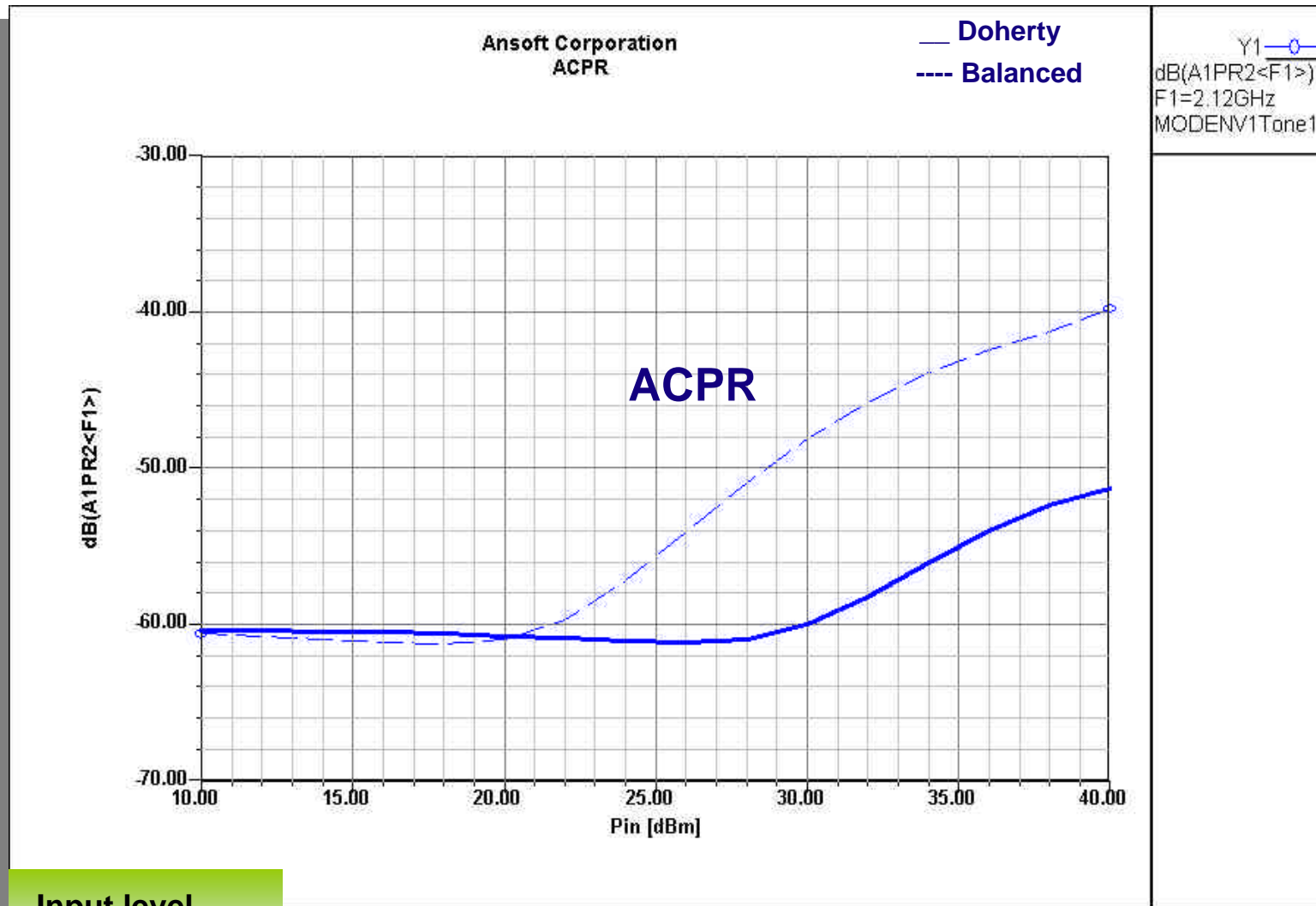


Input level

36dbm

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ACPR Comparison

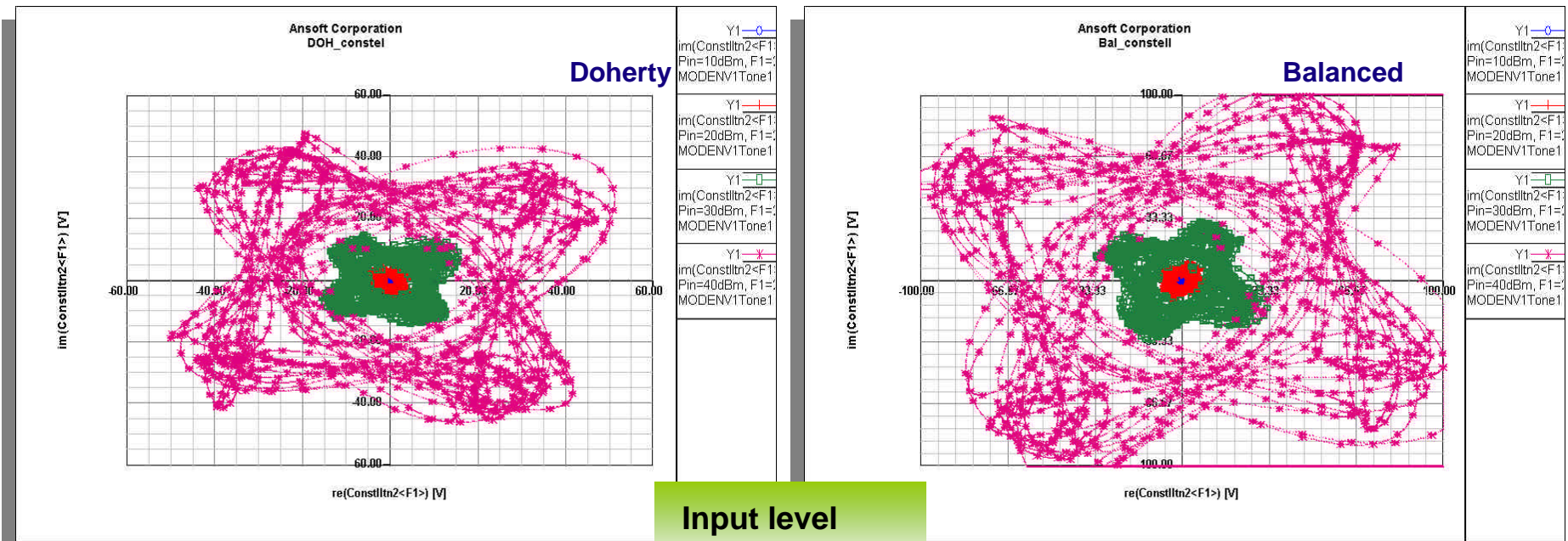


Input level

10dBm~40dBm

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Constellation Comparison



Input level
10dBm~40dBm

Conclusion

▶ **Technical Summary**

- ▶ Motorola MET model validation was checked
- ▶ Various matching techniques were presented.
- ▶ Load-pull analysis was shown in Ansoft Designer.
- ▶ Doherty amplifier was designed using Motorola MET model in Ansoft Designer™
- ▶ Results of the Doherty amplifier were compared with conventional balanced power amplifier

▶ **Power Amplifier Design Solution : Ansoft Designer™**

- ▶ Motorola MET models are available
- ▶ DC, Stability, Load-pull, harmonic balanced, and transient analysis
- ▶ Smith Tool, Transmission line utility
- ▶ Automated tuning, parameter-sweep, optimization, and post-processing
- ▶ Dynamic link between schematic and layout
- ▶ Integrated design environment with Planar EM, Circuit, System, and HFSS

▶ **Ansoft Products applied in this presentation**

- ▶ Ansoft Designer™ Planar EM
- ▶ Ansoft Designer™ Circuit
- ▶ Ansoft Designer™ System

References

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