Introduction of Doherty Amplifiers

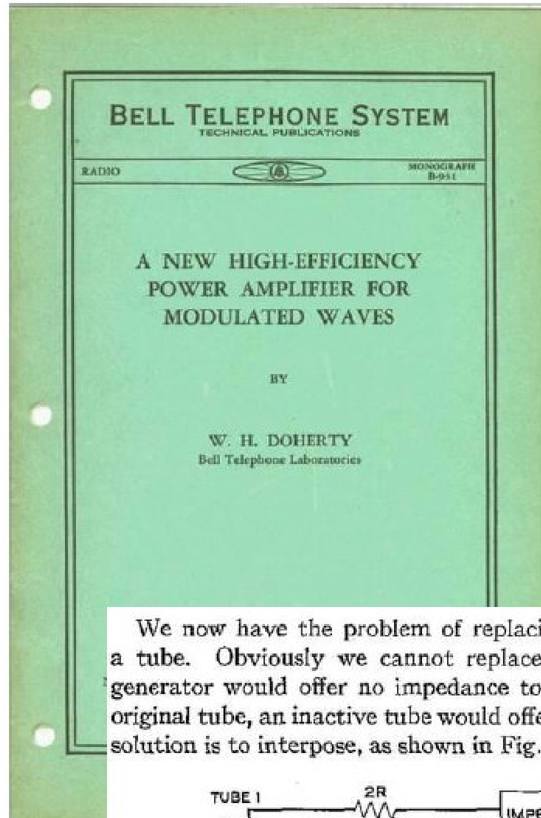
Xin Liu Shanghai WPC Team

Early days of Doherty Amplifier

WILLIAM H. DOHERTY

Recipient, Morris Liebmann Memorial Prize, 1937

Employed by Western Electric and Bell Laboratories



AM Radio Transmitters

- Invented in 1936
- Patented in 1940
- Improved Conversion Efficiency by a factor of 2 to over 60%

Technique adopted by Western Electric, RCA, Continental and Marconi

We now have the problem of replacing this added generator with a tube. Obviously we cannot replace it directly, because while a generator would offer no impedance to the flow of current from the original tube, an inactive tube would offer an infinite impedance. The solution is to interpose, as shown in Fig. 3, a network having a certain

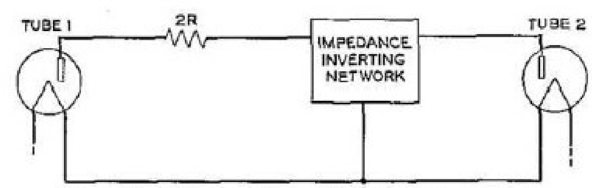


Fig. 3—Fundamental form of a high-efficiency circuit.

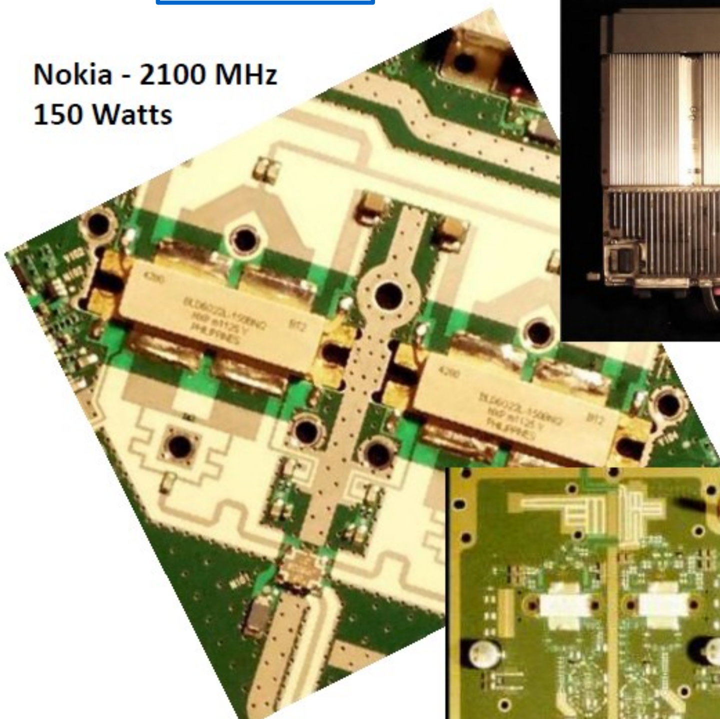
property, namely, that the impedance at the sending end is inversely proportional to the terminating impedance. This is a familiar property of quarter-wave transmission lines and their equivalent networks.

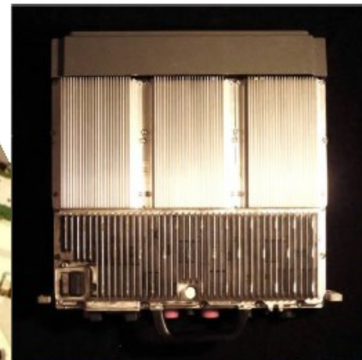
Doherty PA is Widely Used in Cellular Infrastructure Transmitter Now

MACOM

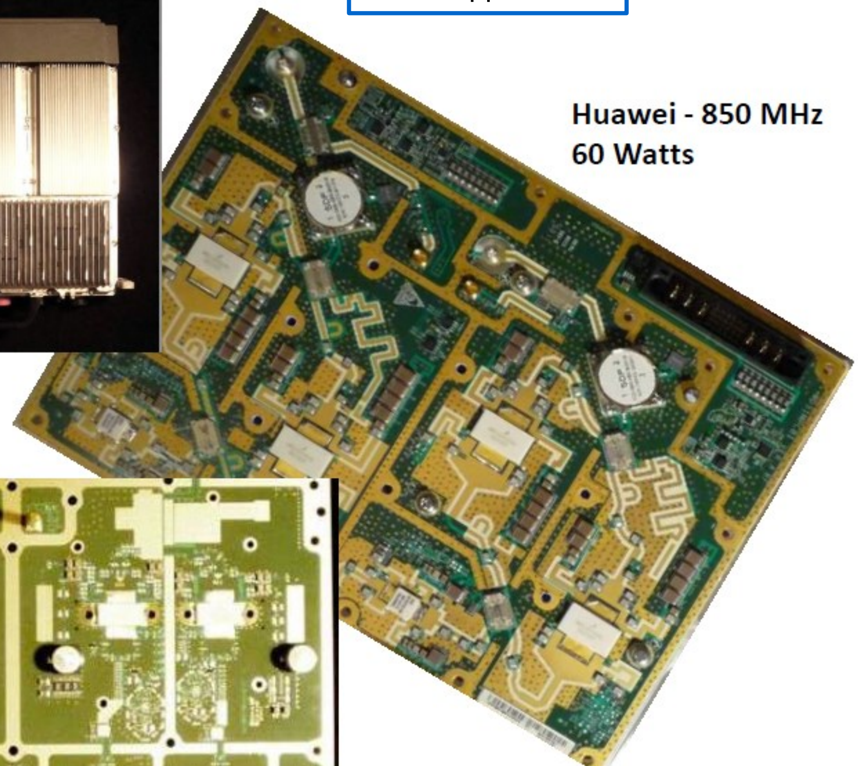
Pre 2003	2003-2005	2005	2010	2010-present
Feed-forward Class AB	Class AB with DPD	Doherty with DPD	Enhanced VBW	Doherty and its Novel approaches

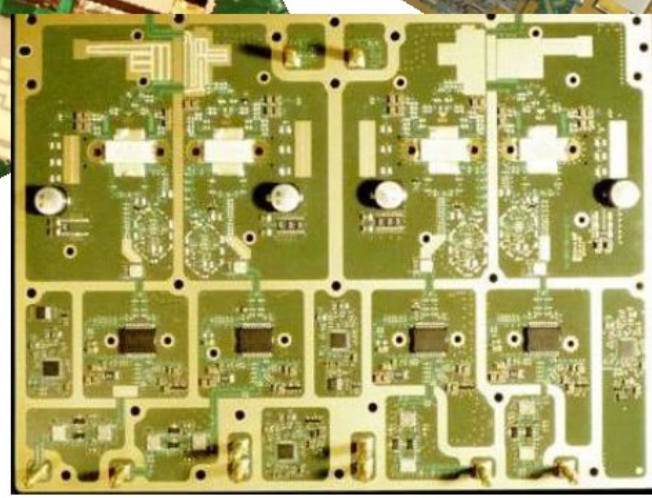
Nokia - 2100 MHz
150 Watts





Huawei - 850 MHz
60 Watts

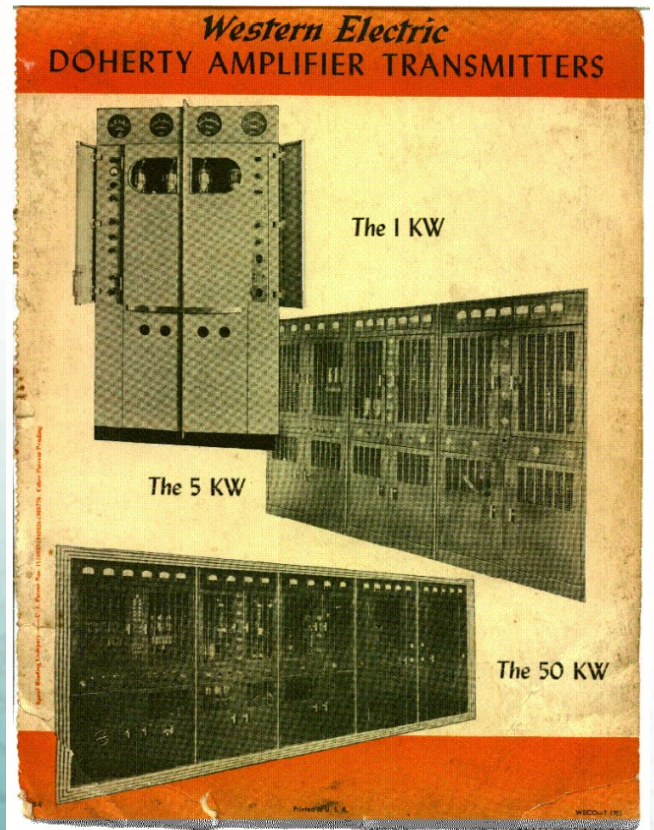




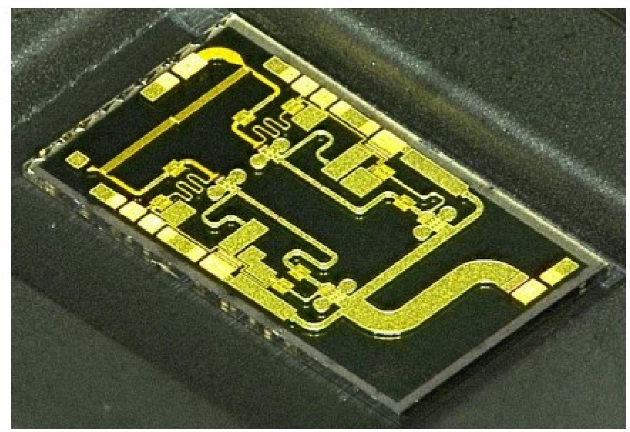
All units averaged > 40% overall efficiency

Ericsson - 2100 MHz 80 Watts

Doherty PA From Old Time to Now:



2.14GHz N ways Doherty
4*25 W Cree HEMTs
Eff=61%@ Pout=20 W

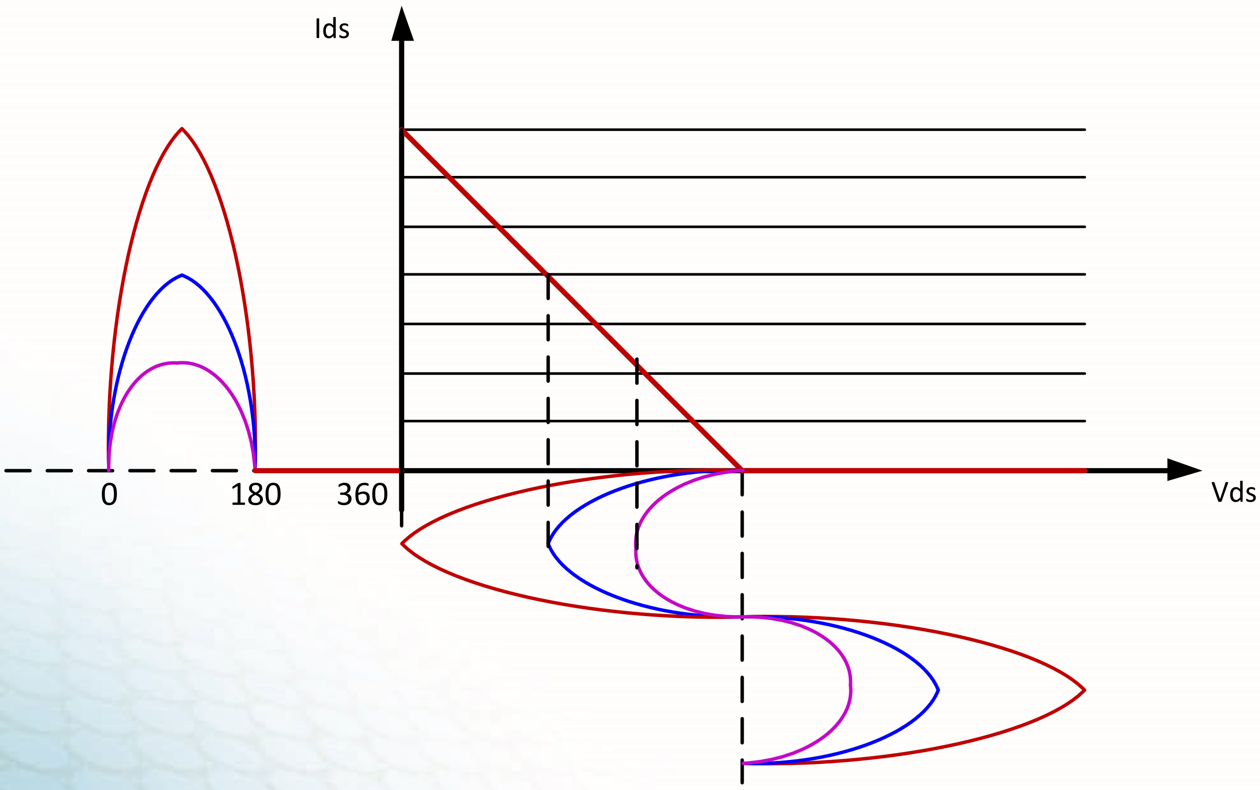


mm Wave Doherty

A K-Band(22-24GHz) 5W Doherty Amplifier MMIC
Utilizing 0.15µm GaN on SiC HEMT Technology
Size: 3.4 mm x 2 mm

Basic Conceptions(1)

For Ideal Class B Amplifier:

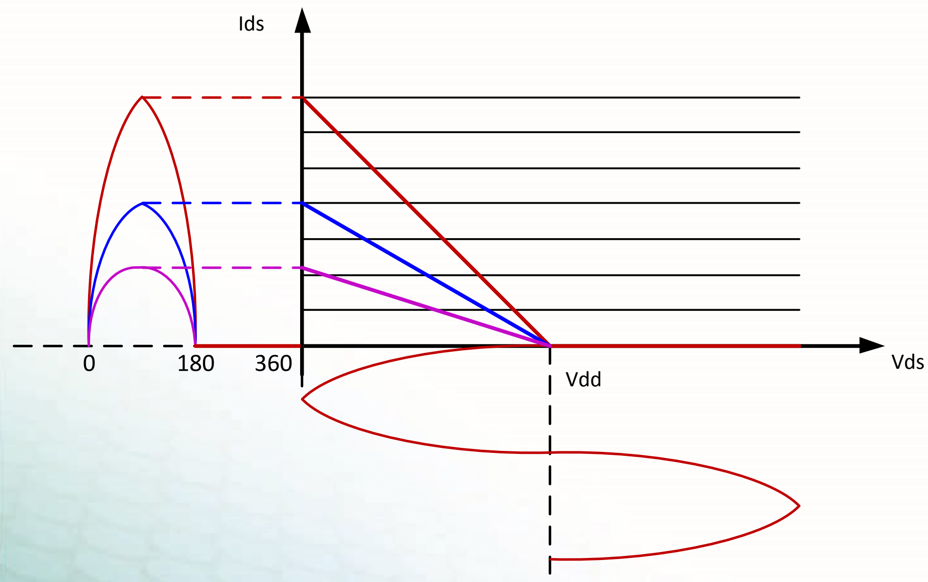


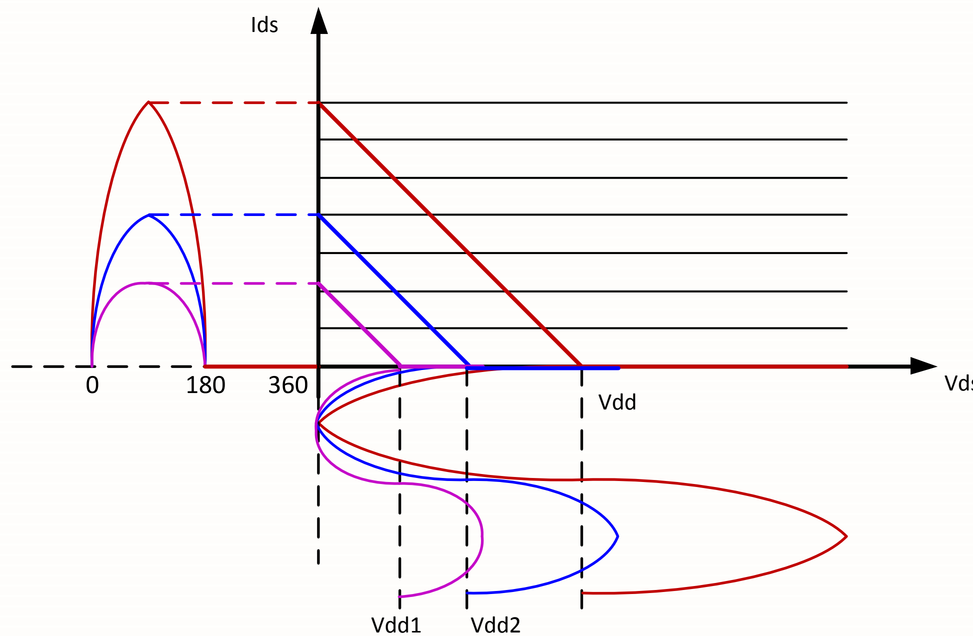
$$\eta = \frac{\pi}{4} \cdot \frac{V_{RF}}{V_{dd}}$$

MAX EFF only happens when MAX V_{RF} reaches;

Basic Conceptions(2)

Two ways to Enhance Back Off Efficiency





$$\eta = \frac{\pi}{4}$$

When Vin drops, V_{RF} still equal to V_{dd}
By Changing Z_Load, Which is also called: "Load Modulation"

W.H. Doherty Use This Way

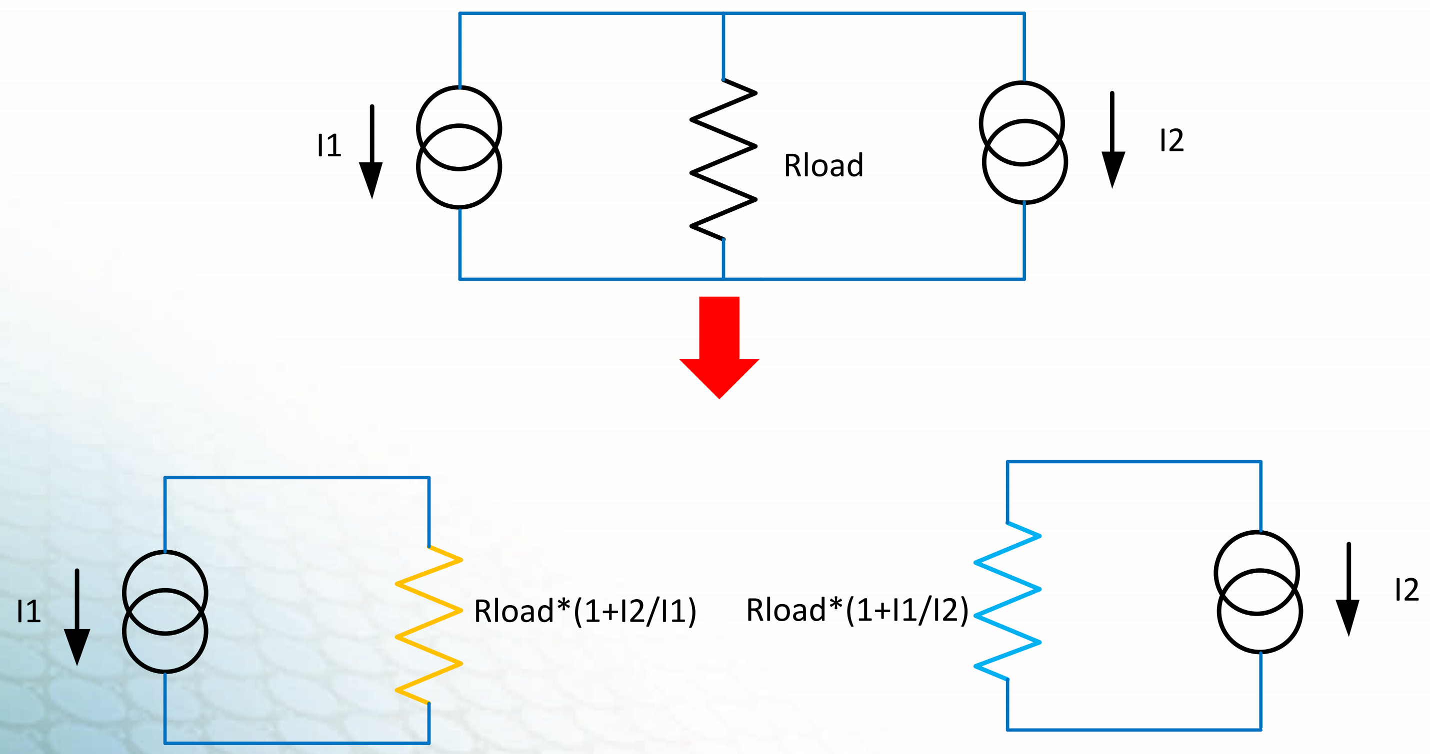
$$\eta = \frac{\pi}{4}$$

When Vin drops, V_{RF} still equal to MAX Voltage Swing
By Changing Vdd

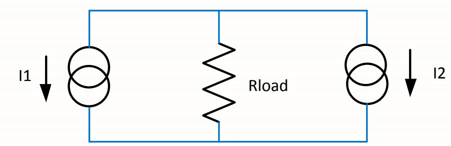
E.T. Use This Way

Basic Conceptions(3)

W.H. Doherty had thought about Active Load Modulation:

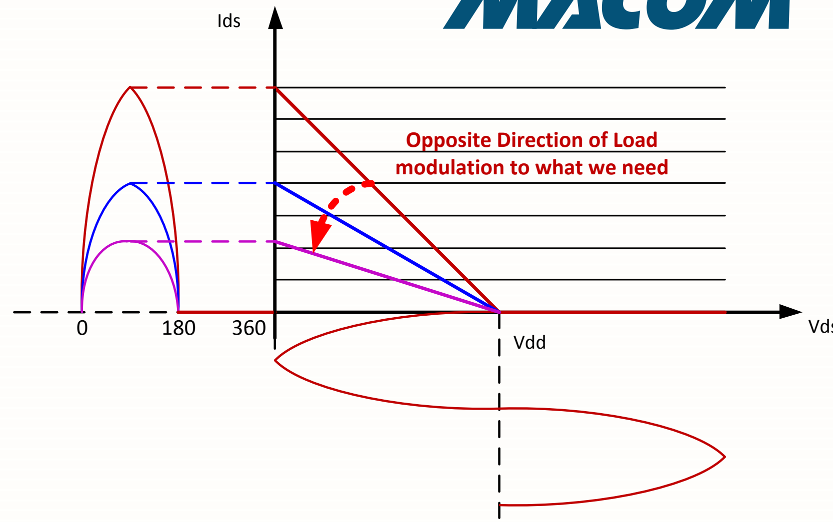


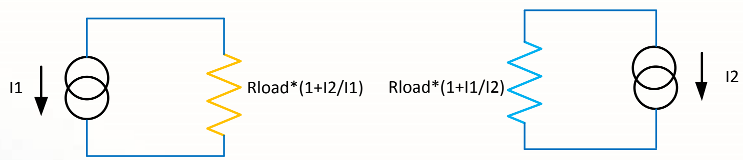
Basic Conceptions(4)



I2: 0→I1

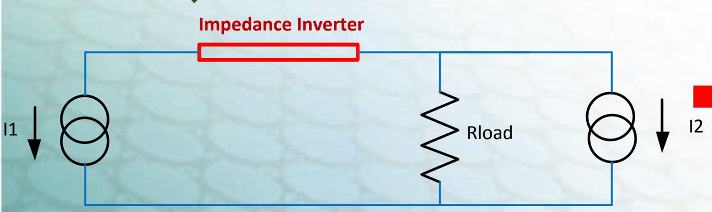
Load Modulation





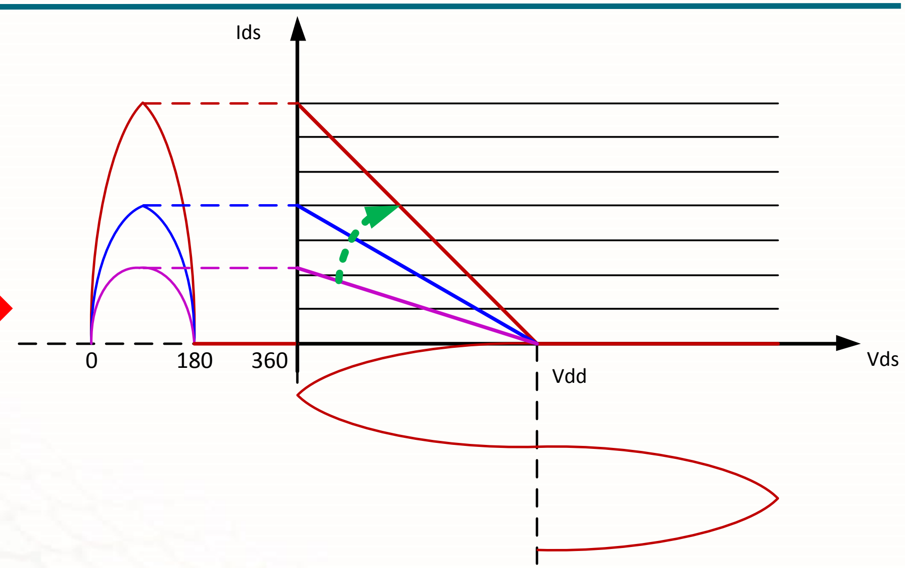
I2: 0→I1, Zload of Carrier: Rload → 2*Rload: Wrong Direction of Load Modulation!

Add Impedance Inverter



I2: 0→I1

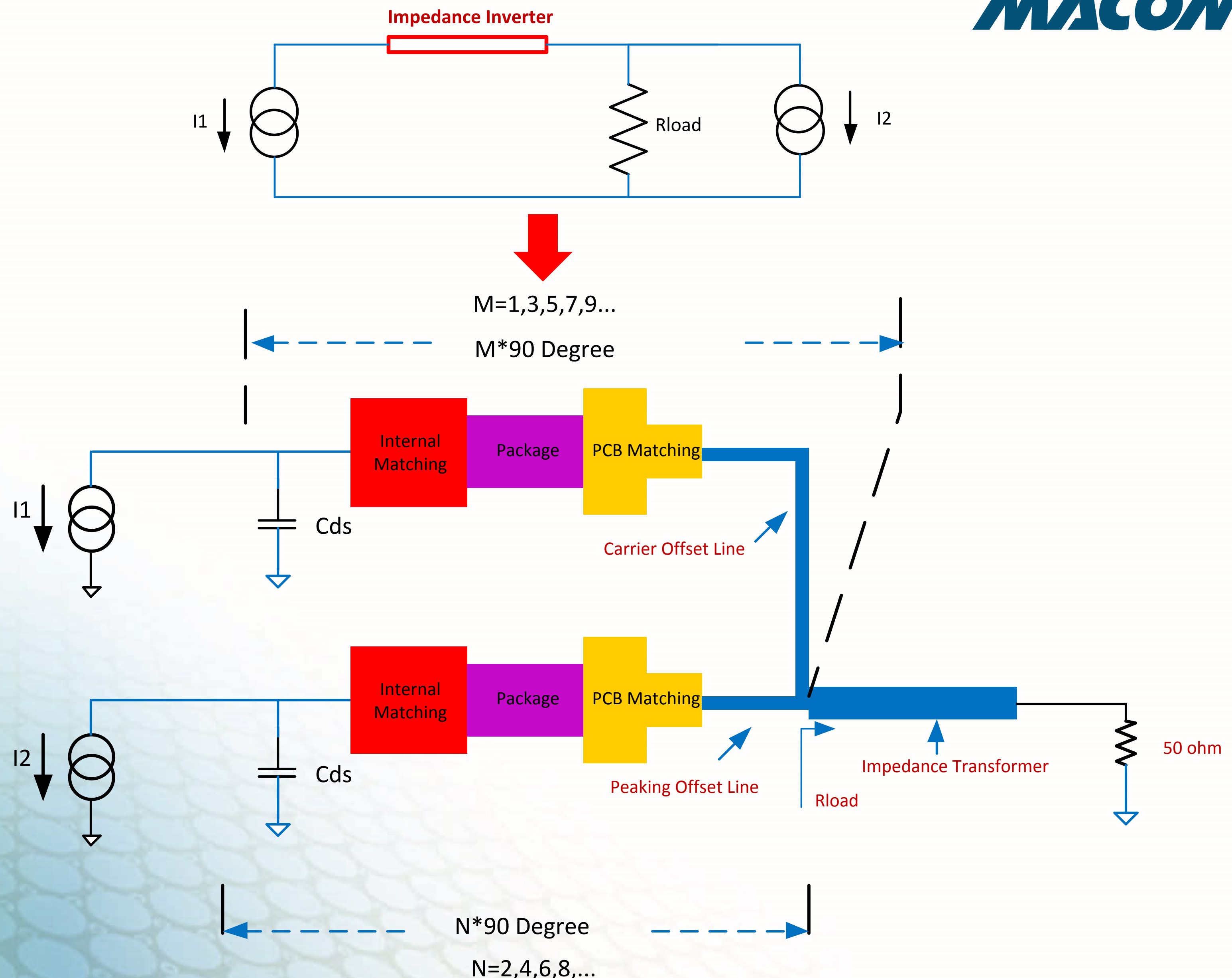
Load Modulation



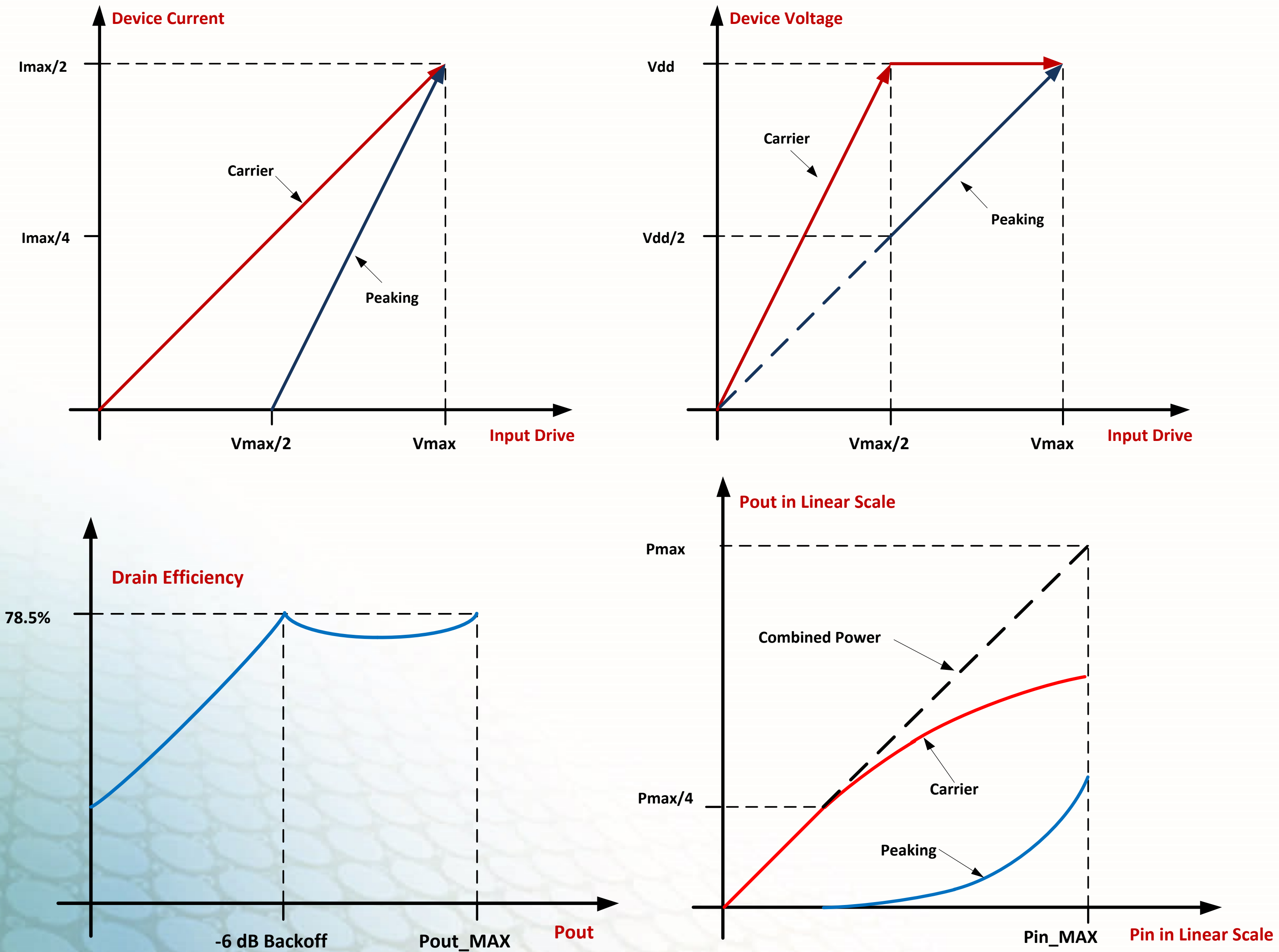
Impedance inverter makes load modulation into the correct direction:

I2: 0→I1, Z_Load of Carrier : 2*Rload → Rload

A Real Doherty Circuit Diagram



Behavior of An Ideal Symmetrical Doherty PA



Some Key Parameters

1. β: the ratio of peak fundamental current of Carrier and Peaking Amplifier

$$\beta = \frac{\mathrm{Ip}}{\mathrm{Ic}}$$

2. α: Normalize the input signal to be 0<Vin<1,

   and define the transition at which Ip starts to flow is Vin= α

3. α & β have the relationship:

$$\alpha = \frac{1}{1+\beta}; \beta = \frac{1-\alpha}{\alpha}$$

4. α & β can determine Back Off point for MAX efficiency

$$Back\_off(dB) = 20 \cdot \log(\alpha) = 20 \cdot log\left(\frac{1}{1+\beta}\right)$$

Doherty Parameters Calculation Flow:

Step1: Choose the required back of point for MAX efficiency: **Back_off(dB)**

Step2: Calculate α **&** β

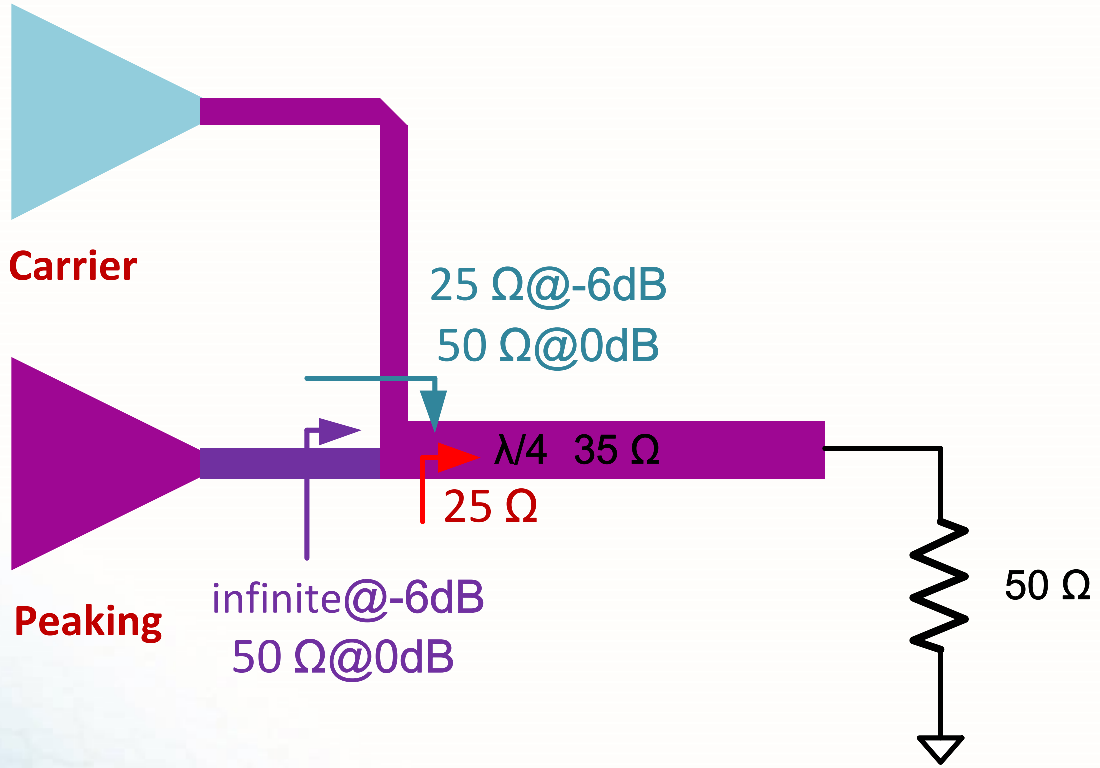
$$\alpha = 10^{\frac{Back\_off(dB)}{20}} \qquad \beta = \frac{1-\alpha}{\alpha}$$

Step3: Choose system reference value **Z0**

Step4: Calculate the load resistor value:

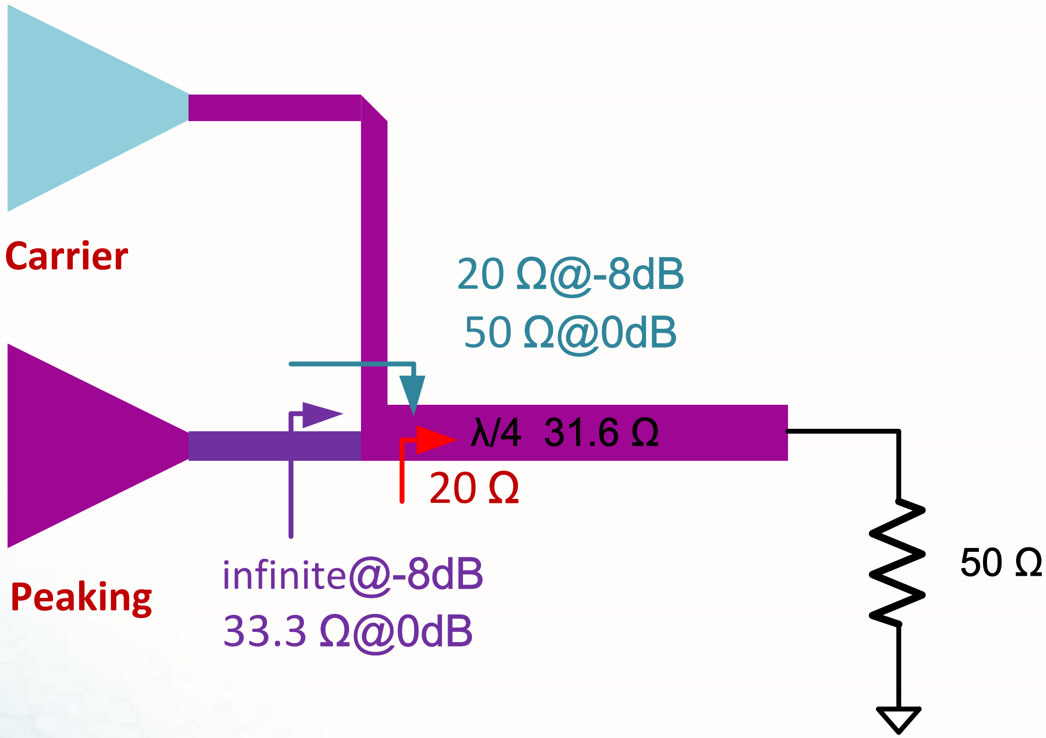
$$R = \alpha \cdot Z0$$

Ex1: Symmetrical Doherty Calculation



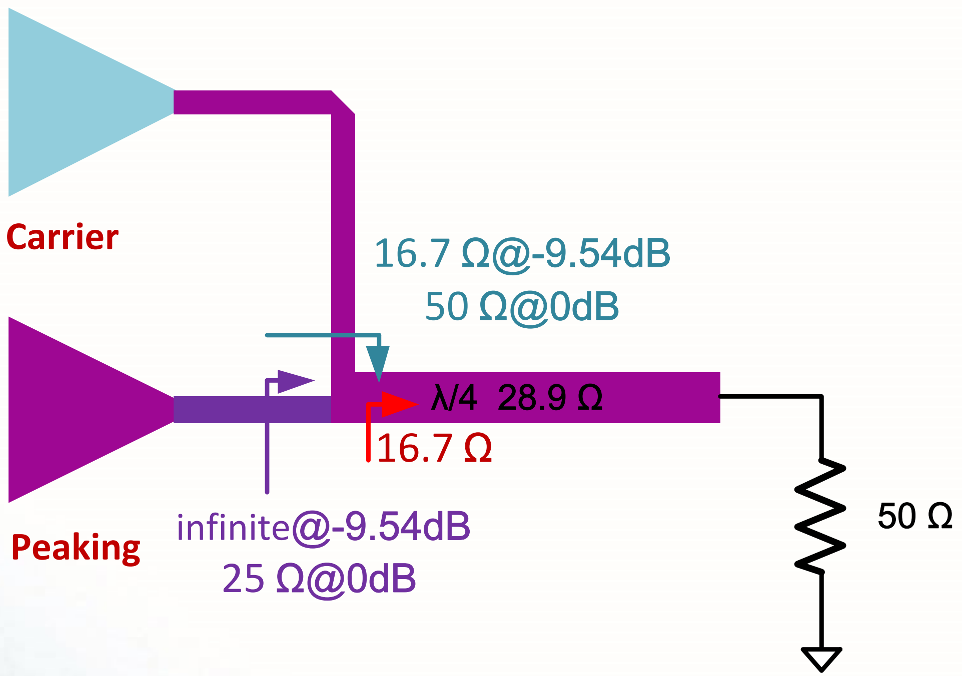
1. For Symmetrical Doherty, Ic=Ip,β=1;
2. $\alpha = \frac{1}{1+\beta} = \frac{1}{2} = 0.5, \mathrm{Back}_{\mathrm{off(dB)}} = 20 * \log(0.5) = -6\ \mathrm{dB}$
3. Choose Z0=50 ohm as the system reference impedance
4. R= α ·Z0=0.5*50 ohm= 25 ohm

EX2: Asymmetrical Doherty Calculation(1)



1. For Asymmetrical Doherty, Ip=1.5*Ic,β=1.5;
2. $\alpha = \frac{1}{1+\beta} = \frac{1}{2.5} = 0.4, \mathrm{Back}_{\mathrm{off(dB)}} = 20 * \log(0.4) = -7.96\ \mathrm{dB}$
3. Choose Z0=50 ohm as the system reference impedance
4. R= $\alpha \cdot$Z0=0.4*50 ohm=20 ohm

EX3: Asymmetrical Doherty Calculation(2)

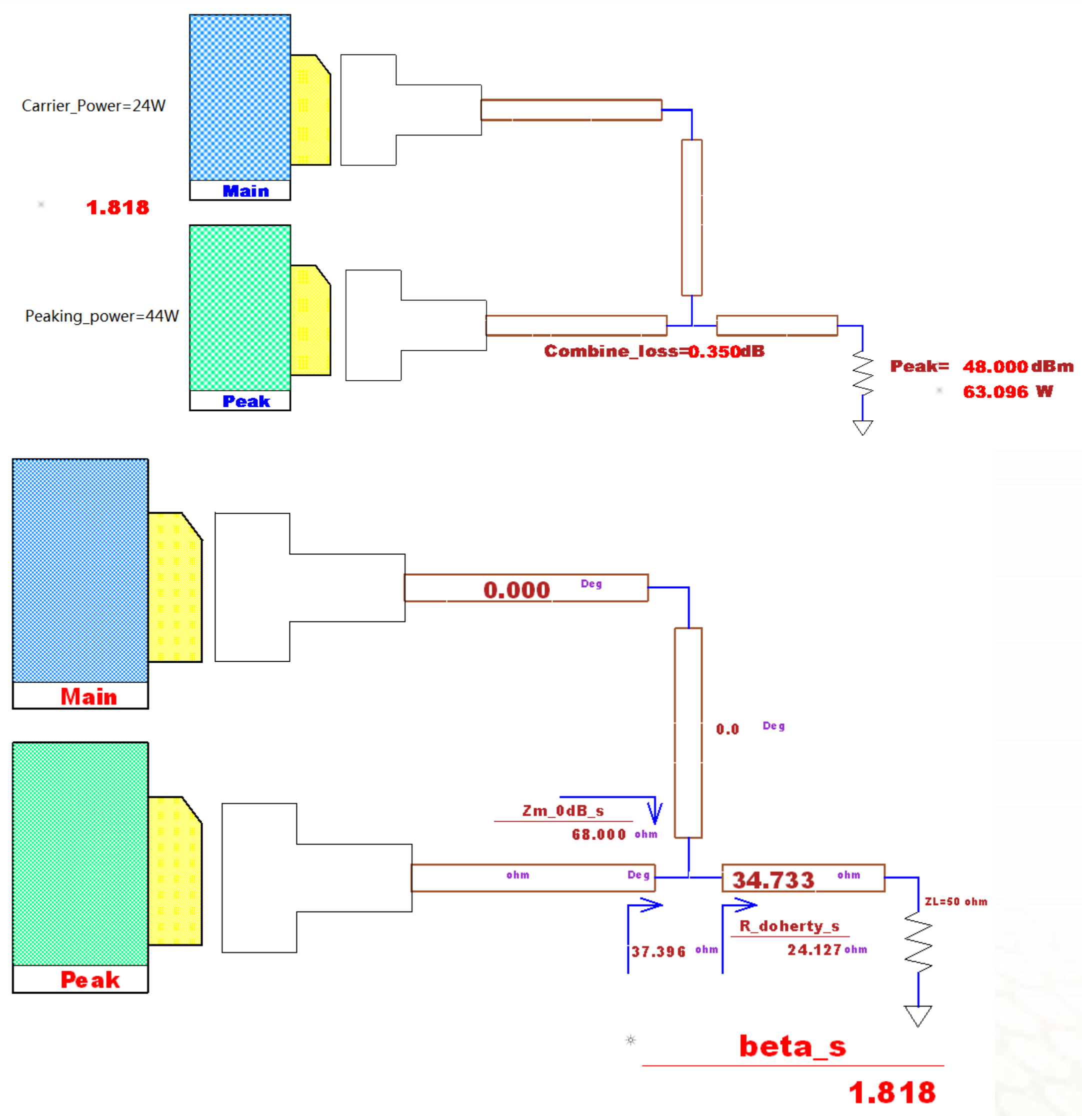


1. For Asymmetrical Doherty, Ip=2*Ic,β=2;
2. $\alpha = \frac{1}{1+\beta} = \frac{1}{3} = 0.33, \mathrm{Back}_{\mathrm{off(dB)}} = 20 * \log(0.33) = -9.54\mathrm{dB}$
3. Choose Z0=50 ohm as the system reference impedance
4. R= α ·Z0=0.33*50 ohm=16.7 ohm

Doherty Design Example

A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

Step1: Doherty Topology Selection



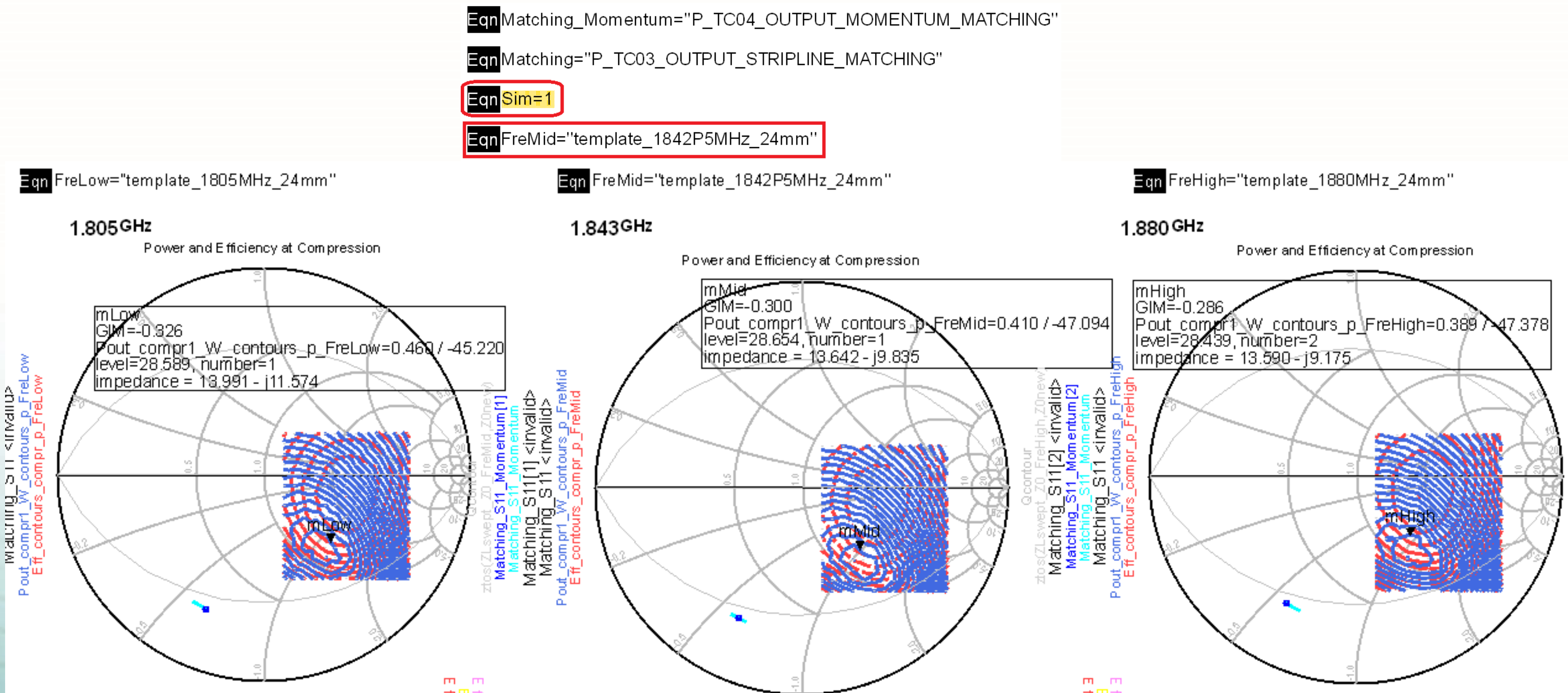
Ppeak= 48 dBm;
Pav= 39dBm
9 dB Back_Off Design;

Z0=68 ohm;

Doherty Design Example

A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

Step2: Impedance Selection for Carrier Side



Backoff point	1.805GHz	1.843GHz	1.880GHz
Pout	44.69dBm	44.52dBm	44.59dBm
Pout	29.44W	28.34W	28.77W
Eff	62.78%	64.94%	64.37%
Gain	19.39dB	19.82dB	19.43dB

Doherty Design Example

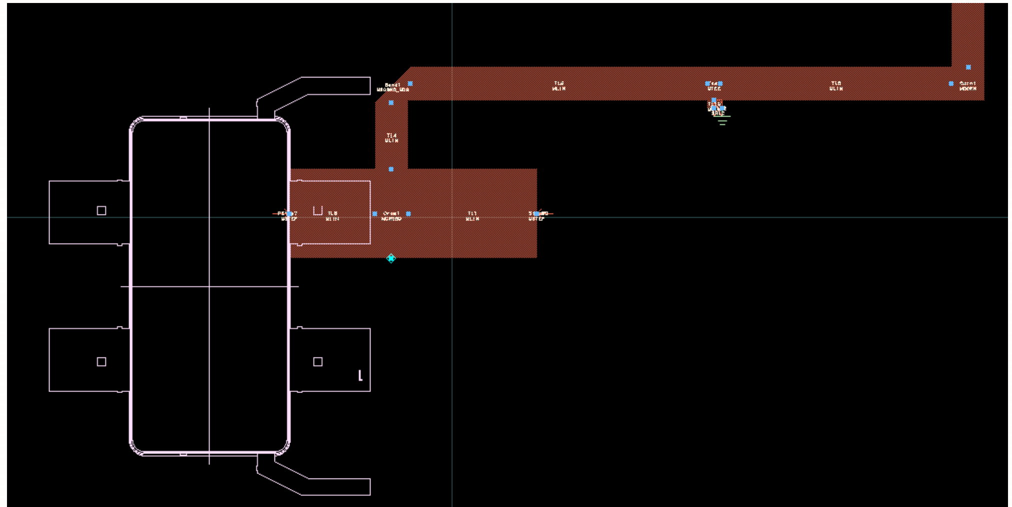
A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

Step3: PCB Matching for Carrier Amplifier

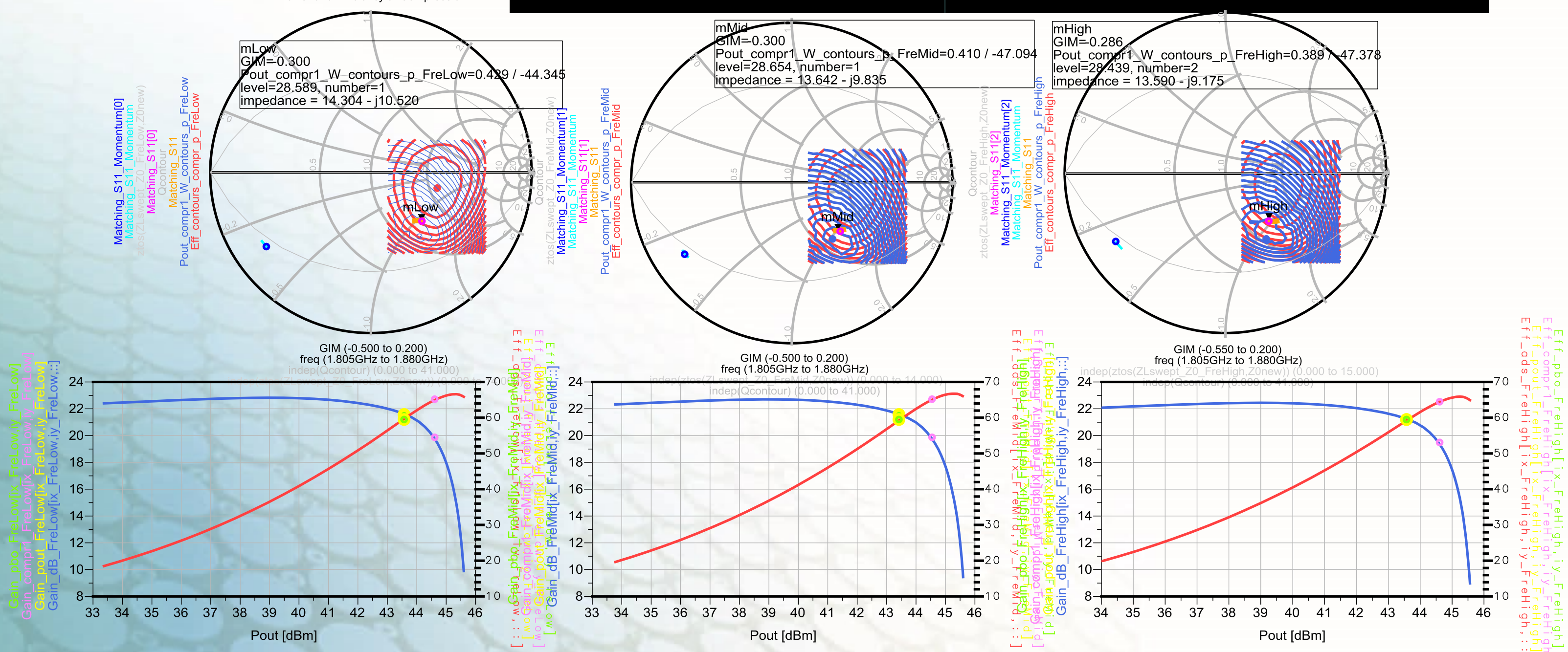
Var Eqn VAR
Source_Load2
Z_low=13.991+j*11.574
Z_mid=13.642+j*9.835
Z_high=13.59+j*9.175

freq	Zmatch_lead
1.80 GHz	14.56 - j10.57
1.84 GHz	13.89 - j10.06
1.88 GHz	13.28 - j9.54

MSub
MSUB
MSub1
H=30 mil
Er=3.66
Mur=1
Cond=57.15E6
Hu=3.9e+34 mm
T=35 um
TanD=0.0031
Rough=0.00 mm
Bbase=
Dpeaks=



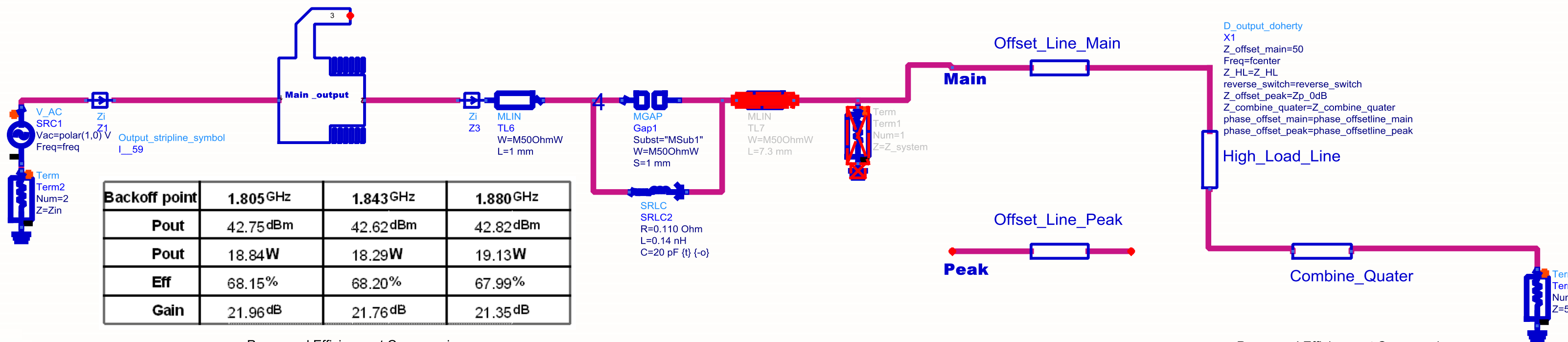
Power and Efficiency at Compression



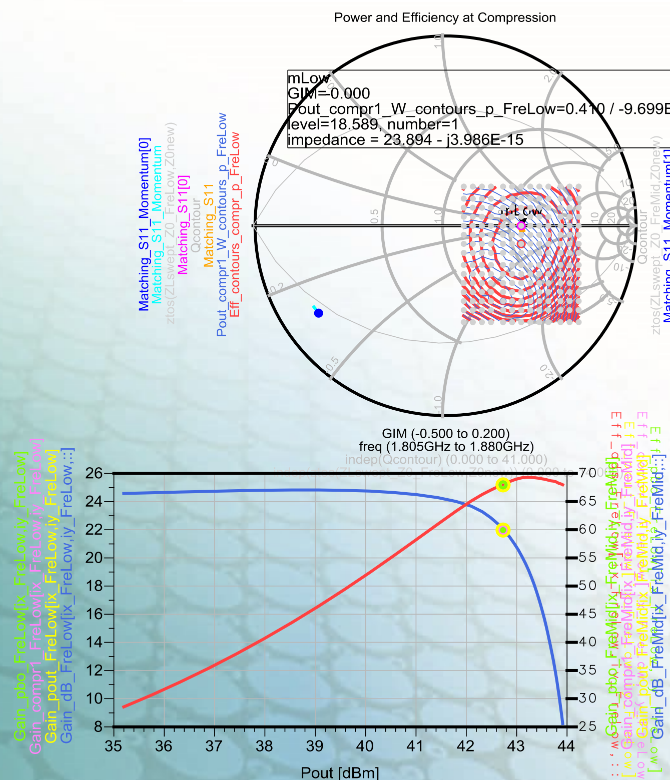
Doherty Design Example

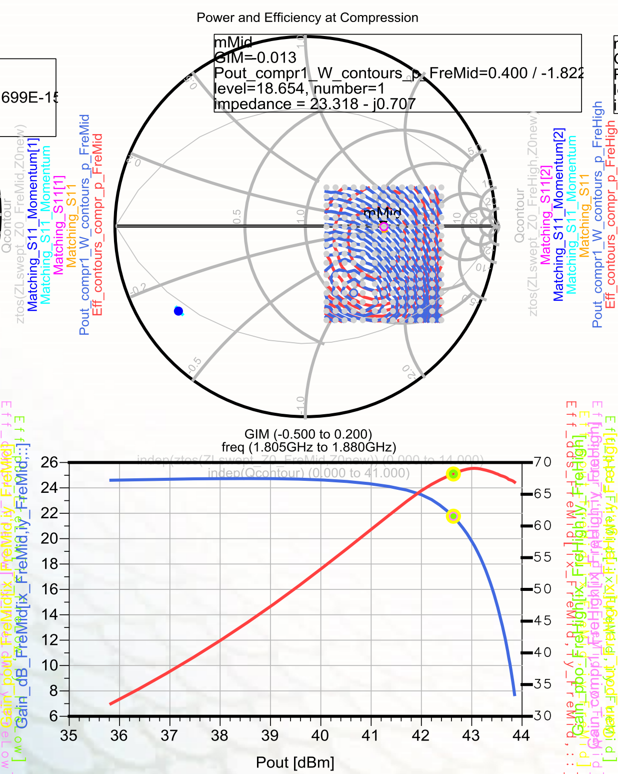
A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

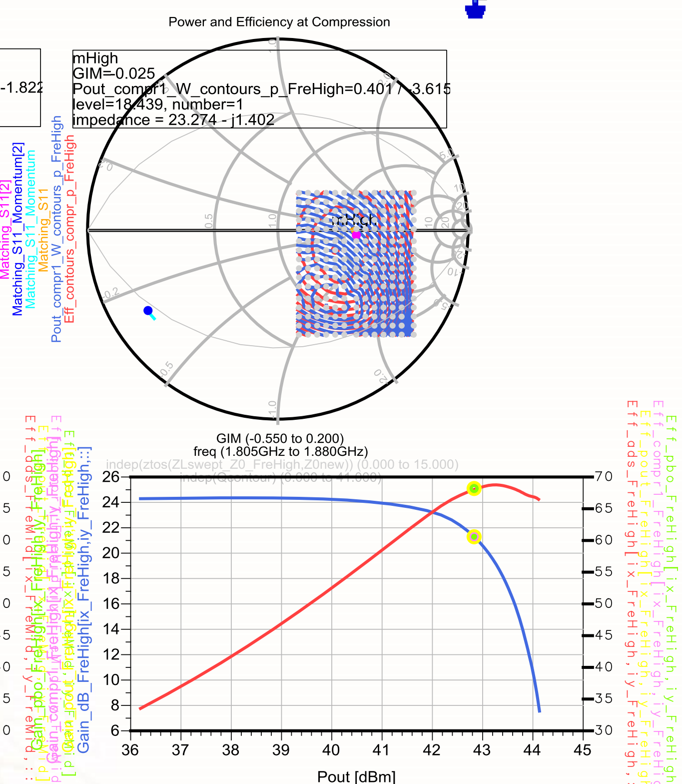
Step4: High Load Performance Checking



Backoff point	1.805 GHz	1.843 GHz	1.880 GHz
Pout	42.75 dBm	42.62 dBm	42.82 dBm
Pout	18.84 W	18.29 W	19.13 W
Eff	68.15 %	68.20 %	67.99 %
Gain	21.96 dB	21.76 dB	21.35 dB



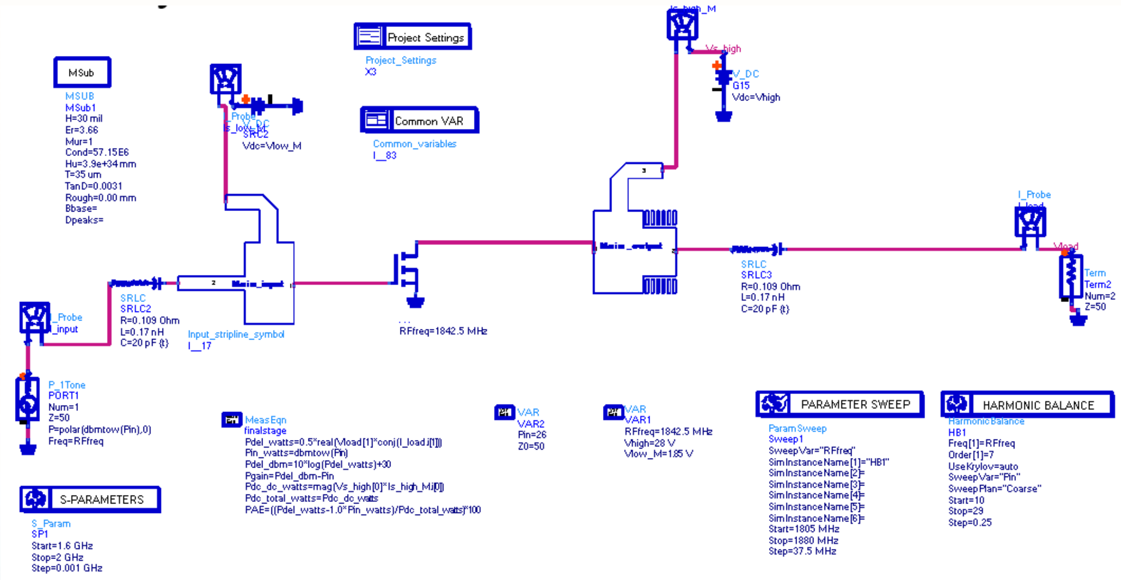


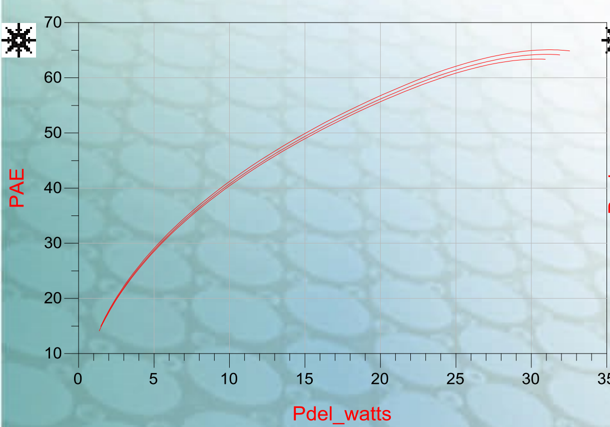


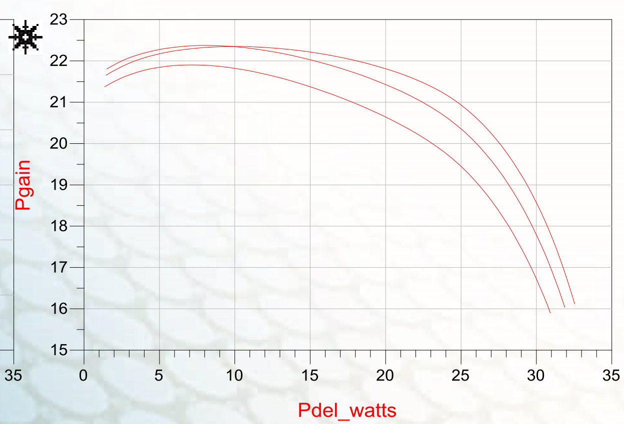
Doherty Design Example

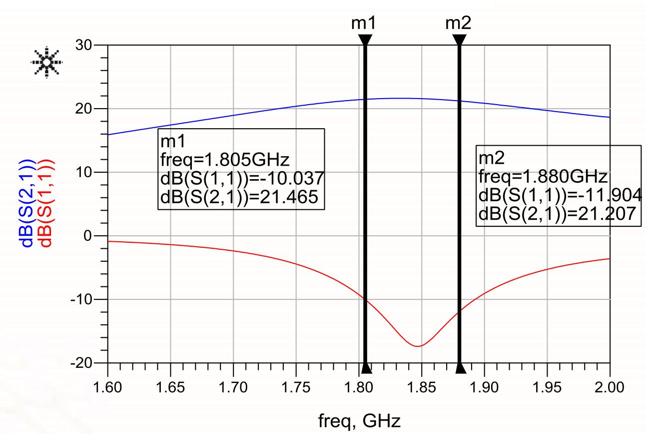
A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

Step5: HB Simulation for Carrier Amplifier





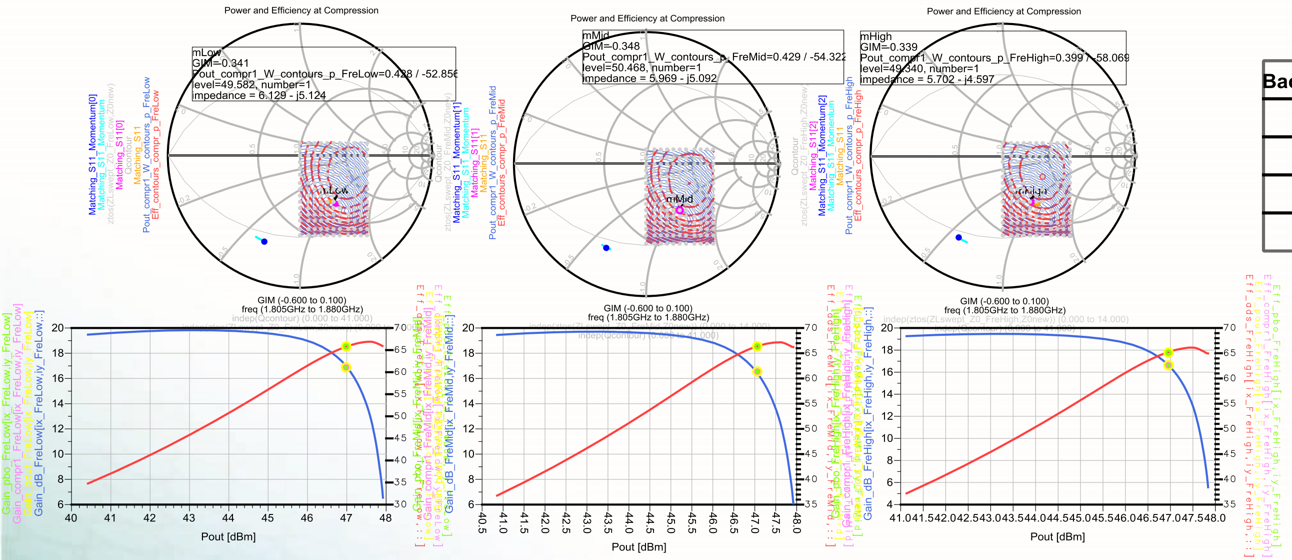




Doherty Design Example

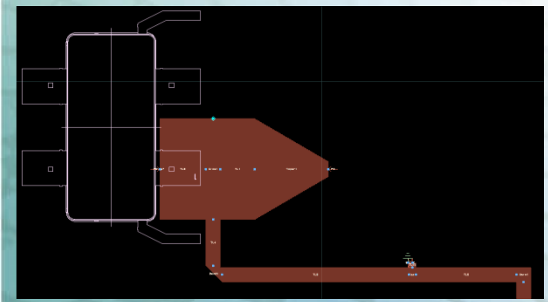
A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

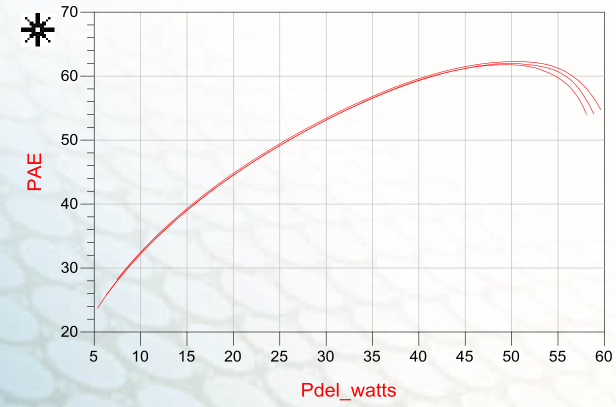
Step6: PCB Matching Design for Peaking Amplifier

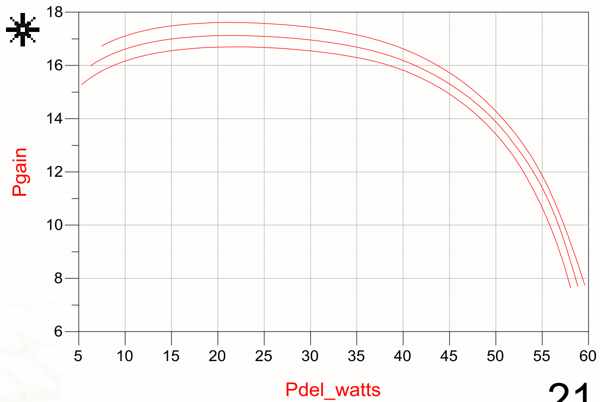


Backoff point	1.805GHz	1.843GHz	1.880GHz
Pout	46.99dBm	47.04dBm	46.98dBm
Pout	50.03W	50.54W	49.85W
Eff	65.80%	66.32%	65.29%
Gain	16.95dB	16.52dB	16.55dB

Active model simulated Class C results



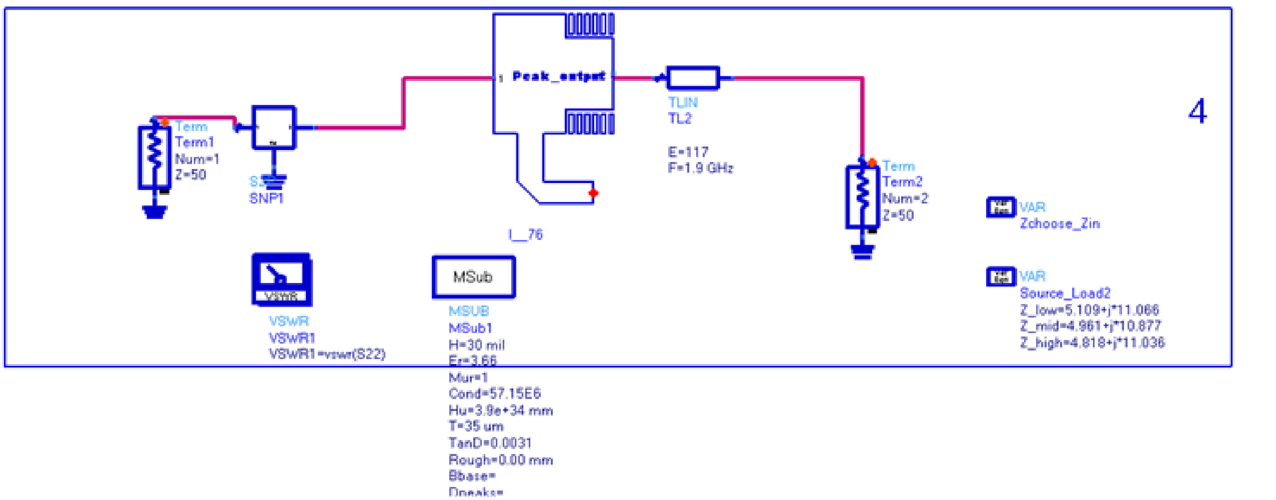


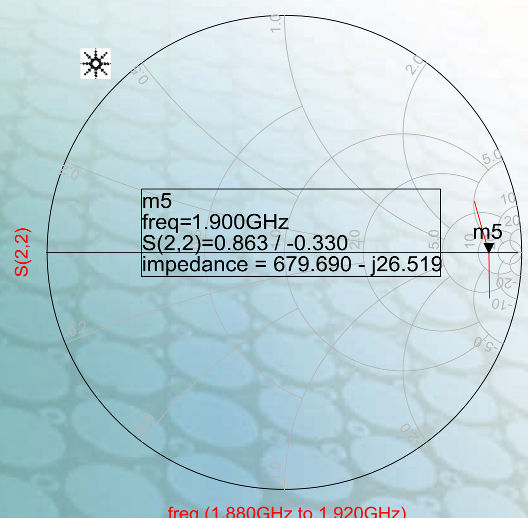


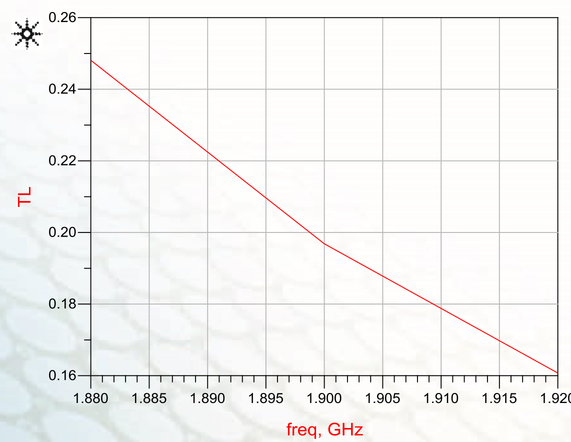
Doherty Design Example

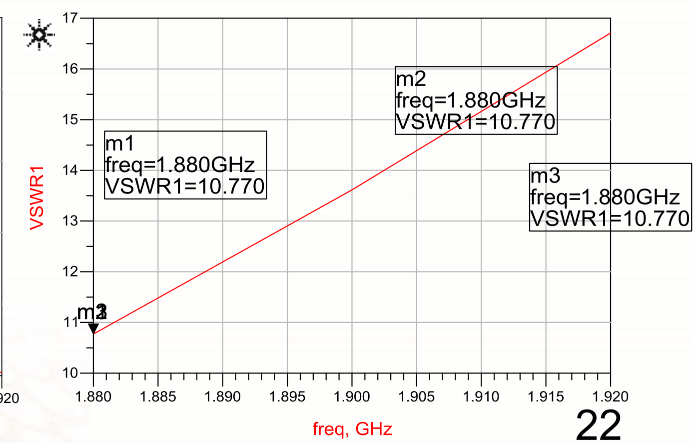
A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

Step7: Calculation the Length of Off State Offset Line for Peaking Amplifier (Base on Off State S parameter of Peaking Transistor)





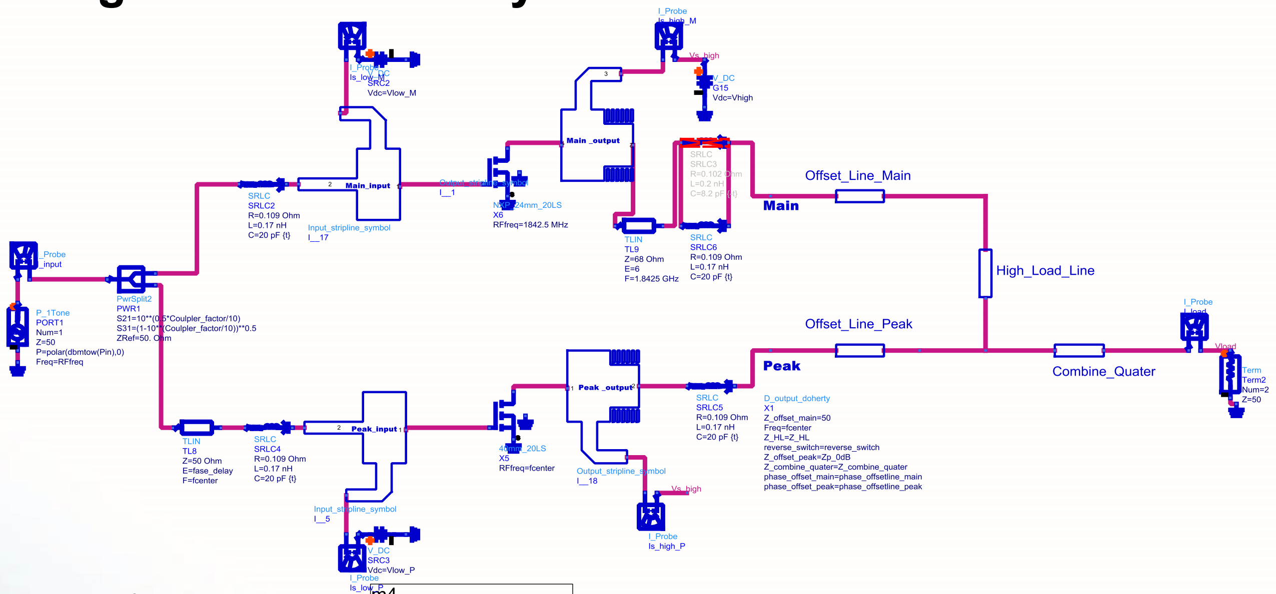


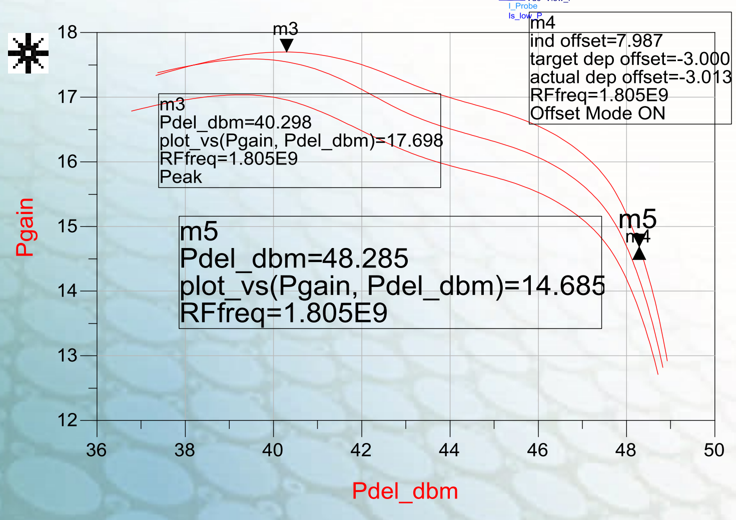


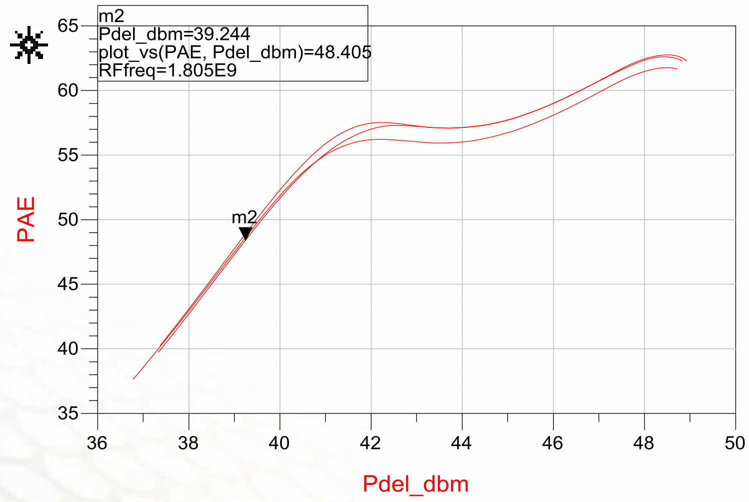
Doherty Design Example

A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

Step8: Fine Tuning of Whole Doherty Based on HB Simulation





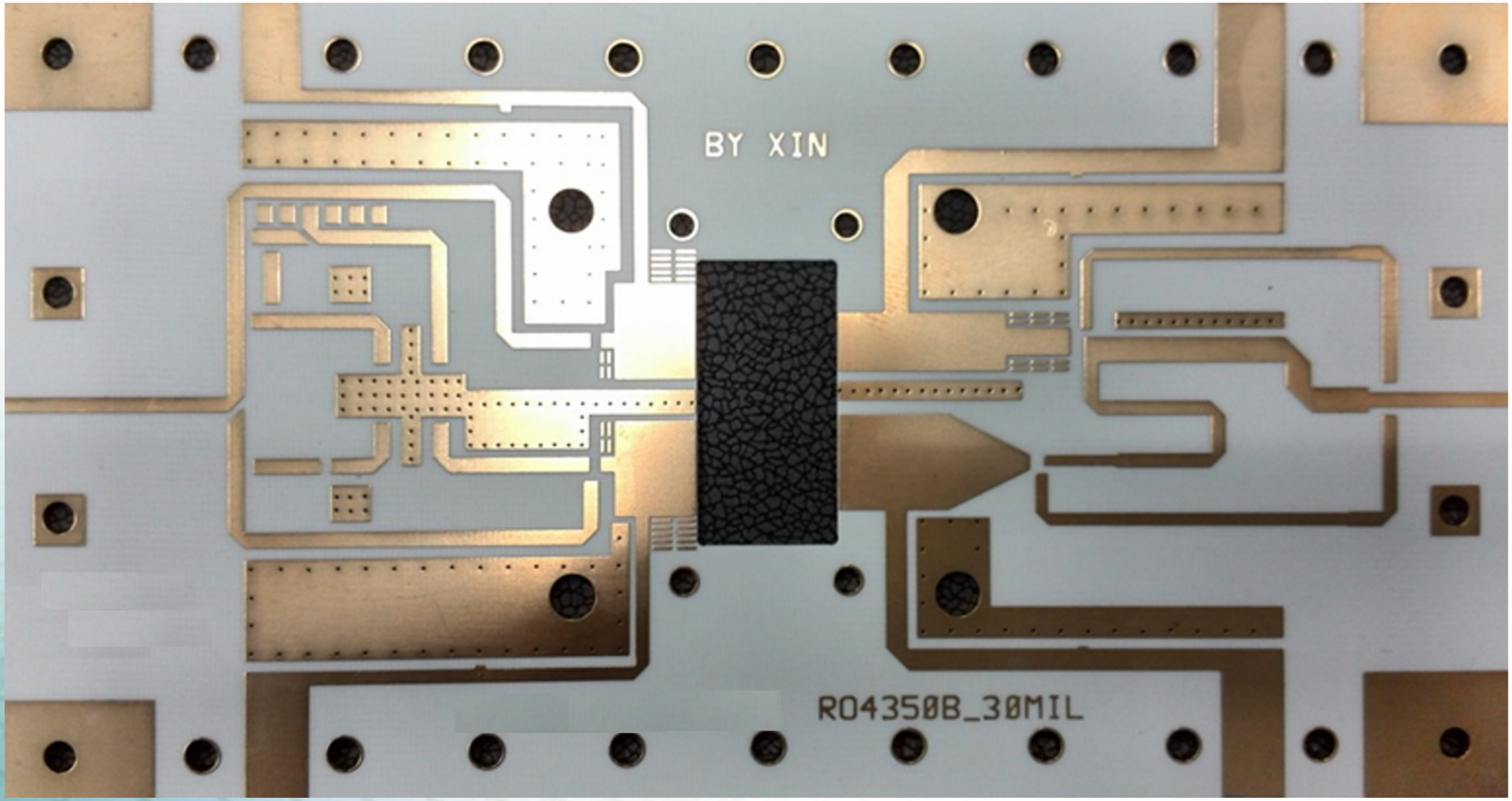


Ppeak=48.3 dBm, EFF=48%@ 9dB Back off

Doherty Design Example

A 1.8GHz 60W Asymmetrical Doherty Amplifier Design

Step9: Final PCB Layout



Any Questions?

Thanks

Reference:

[1] Cripps, S., “Doherty RF Power Amplifiers, Theory and Practice”, *Short Course SC-4, 2009 International Microwave Symposium*, Boston, June 2009

[2] Cripps, S., *RF Power Amplifiers for Wireless Communications*, Artech House, 1999, p 225-235

[3] Son, J., Kim, I., Mon, J., Lee, J., Kim, B., “A Highly Efficiency Asymmetric Doherty Power Amplifier with a New Output Combining Circuit,” *2011 IEEE COMCAS,* Tel Aviv, November 2011.

[4] Charles F. Campbell, Kim Tran, Ming-Yih Kao and Sabyasachi Nayak, “K-Band 5W Doherty Amplifier Using 0.15um GaN on SiC HEMT Technology”.