Doherty Power Amplifier Design

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Microwave Monolithic Integrated Circuit (MMIC) Course
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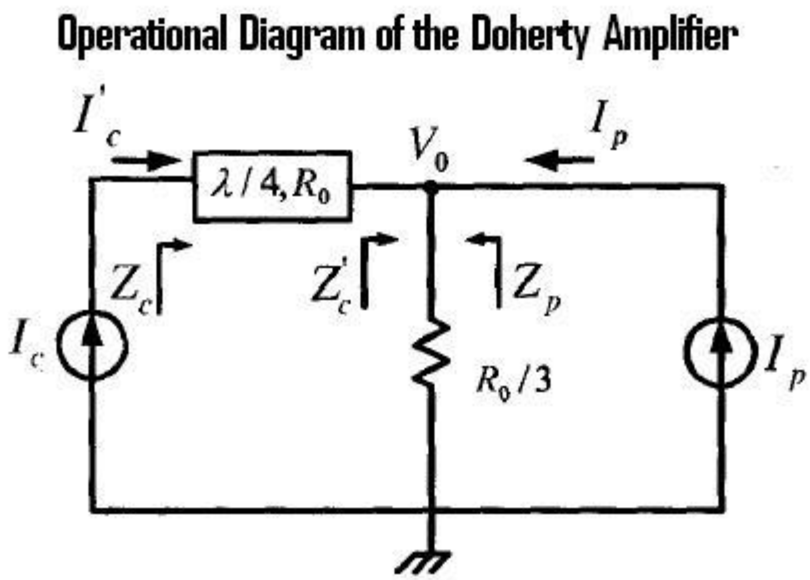
Abstract

A Doherty Amplifier operating at 2.4 GHz and a supply voltage of 3-3.6V is described in this paper. The amplifier was designed in the Triquent GaAs process using the ADS software package. Simulation results show high output power and good power gain linearity up to the 3dB compression point. The results also show good 2^{nd} and 3^{rd} harmonic suppression. A physical layout of the design is also included in this paper.

Introduction

Doherty amplifiers have demonstrated high efficiency over a wide output power range. These structures can also be used to meet high Linearity specifications over a wide output power range. It is difficult to simultaneously get high efficiency, high output power and good linearity in the same design. This design focuses on high output power and good linearity over an extended output power range. The Doherty amplifier consists of carrier and peaking amplifiers connected by a quarter-wave transmission line. The carrier amplifier is typically biased class A or class A-B and the peaking amplifier is typically biased at class C so that the peaking amplifier turns on at the power on just before the carrier amplifier starts to go into compression. The current contribution from the peaking amplifier reducing the effective load impedance of the carrier amplifier and drawing more current from the the device.



The simulation results show close to a 4dBm improvement in output power and more than 30dB suppression of 2nd and 3rd order harmonics.

Design Approach

The Doherty amplifier was implemented using a class A structure and class C joined by the lumped element equivalent of a quarter-wave transmission line. The two amplifiers were driven from a Wilkinson power splitter with a 3dB attenuator preceding the class C amplifier. The preliminary specifications for the design were as follows.

Frequency	2.3GHz to 2.5GHz
PAE	> 50%
Gain	20dB
Pout	> 20dBm
VSWR	< 1.5:1
Vsupply	3V to 3.6V

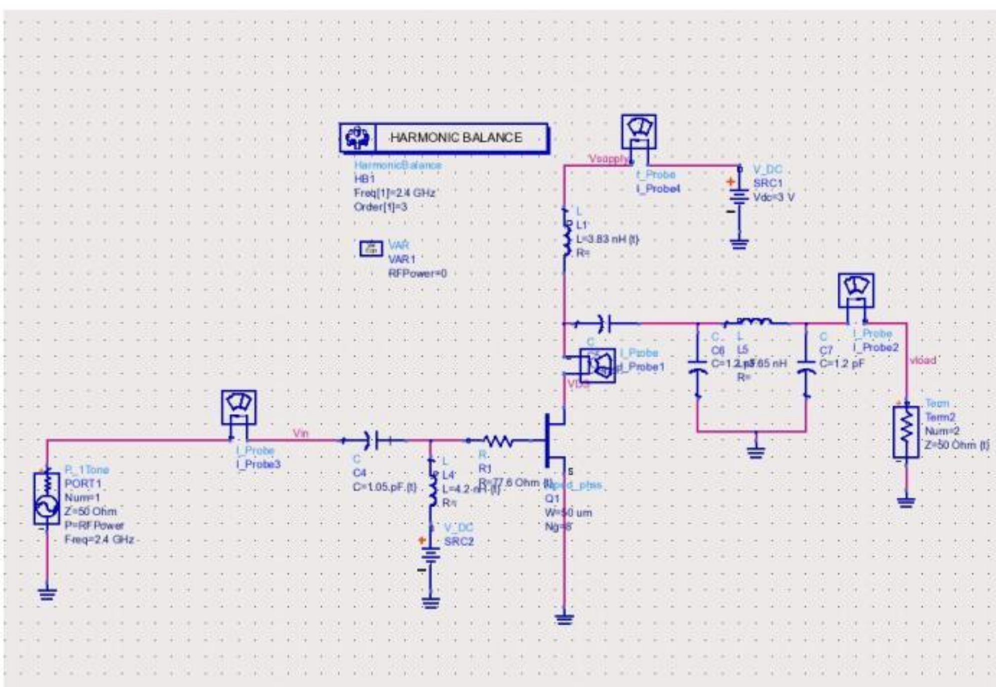
During the design process, I realized that I could not achieve output power in access of 20dBm and achieve a power gain of 20dB with a single-stage amplifier. A cascade structure would provide 20dB of gain but not over 20dBm of power with a 3V supply. I opted to go with lower gain and lower efficiency numbers while achieving higher output power. Inserting a driver amplifier will compensate for the lower gain and the lower efficiency performance is a design tradeoff. The final performance is as follows.

Frequency	2.3GHz to 2.5GHz
PAE	43.6%
Gain	10dB
Pout	25dBm
VSWR	< 1.5:1
Vsupply	3V to 3.6V

The class C amplifier topology is standard. The device is biased in the pinch off region and conducts as the input signal increases. The pull up inductor is used resonate out the drain to bulk capacitance and to provide current to the load via a dc blocking cap. Since the operation of the class C amplifier is non-linear, I needed a network to filter out the higher order harmonics of the output voltage. I used the low pass quarter-wave equivalent network for this purpose.

I could tune the characteristic impedance of this network for optimum power or efficiency for the class C amplifier.

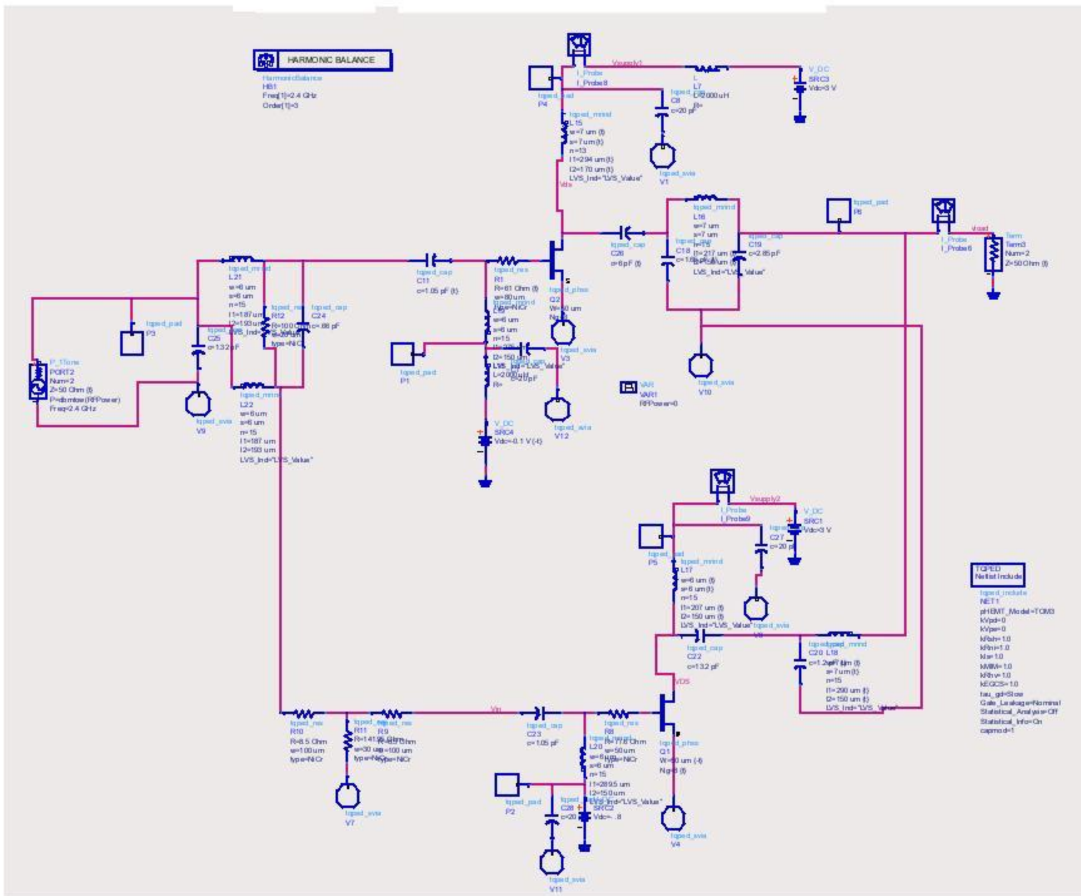
Class C Amplifier Schematic



I used a similar approach for the class A amplifier. Initially, I used the pull up inductor to resonate out the drain to bulk capacitance. I connected the quart-wave equivalent directly to the pull up and tuned the characteristic impedance such that the parallel equivalent of Rds and the network impedance equaled the Cripps resistance. I later included the dc blocking cap in the class A amplifier because I noticed that I could get more power out of the amplifier as I drove it harder. Basically I left the class A operating regime as I got closer to saturation for the Doherty Amplifier.

The Doherty Amplifier schematic shows the class C amplifier at the bottom and the class A amplifier at the top. Both structures are the same but biased in different regimes. I've also included an attenuator before The class C amplifier in order to control the turn on voltage with respect To the class A structure. This "turn on" point determines the overall linearity of the output versus input power curve.

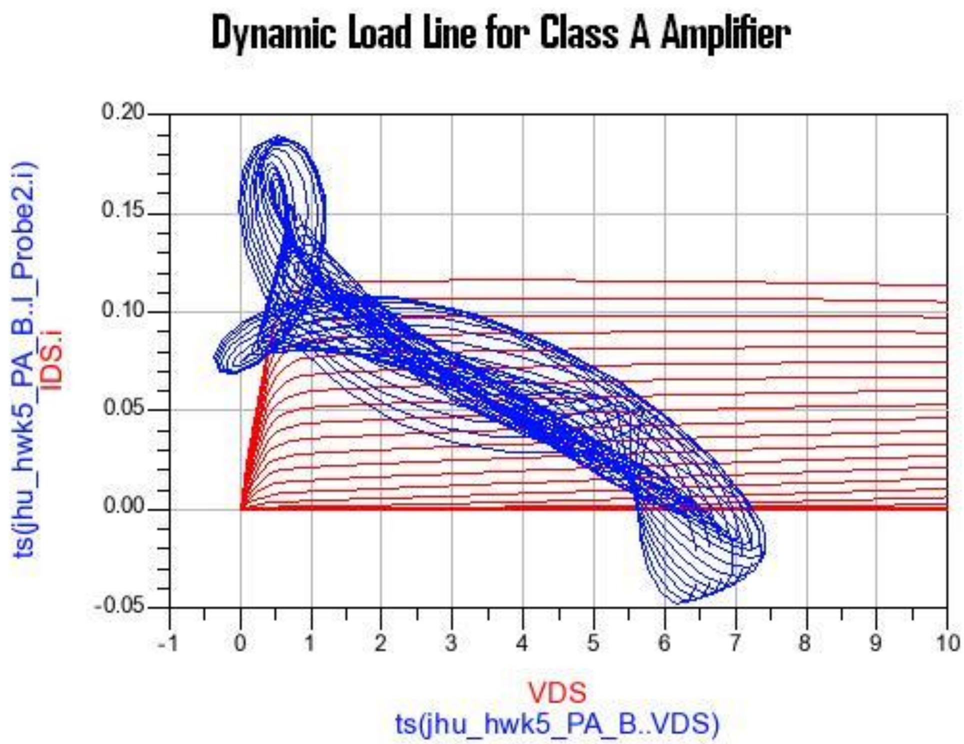
Doherty Amplifier Schematic



Simulations

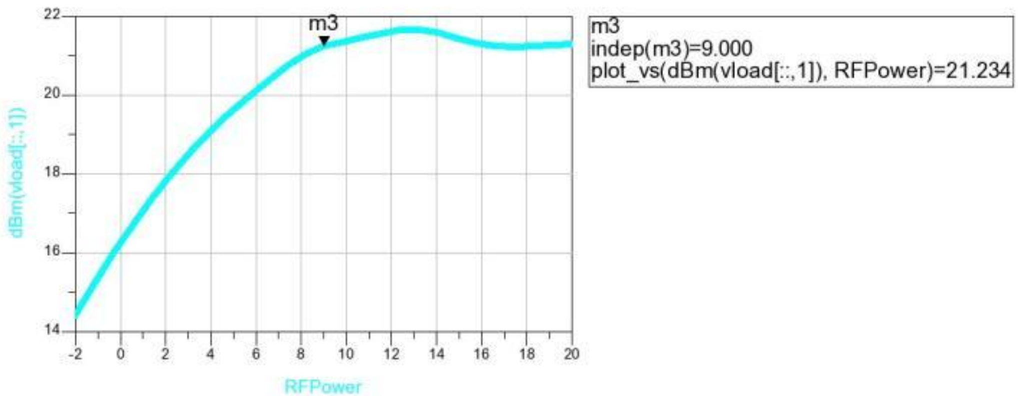
Class A Amplifier

DC Simulations:

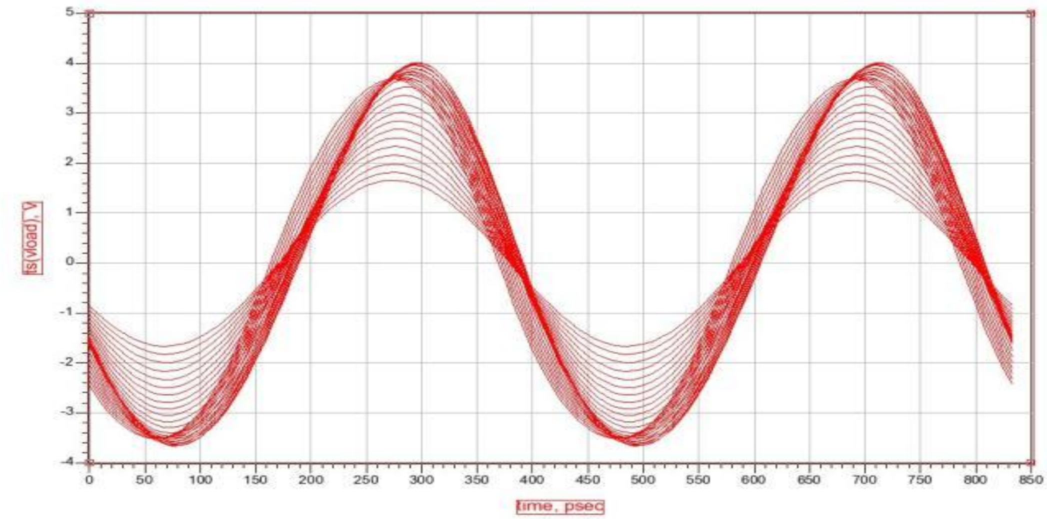


PAE for Class A Amplifier

Pout vs Pin for Class A Amplifier

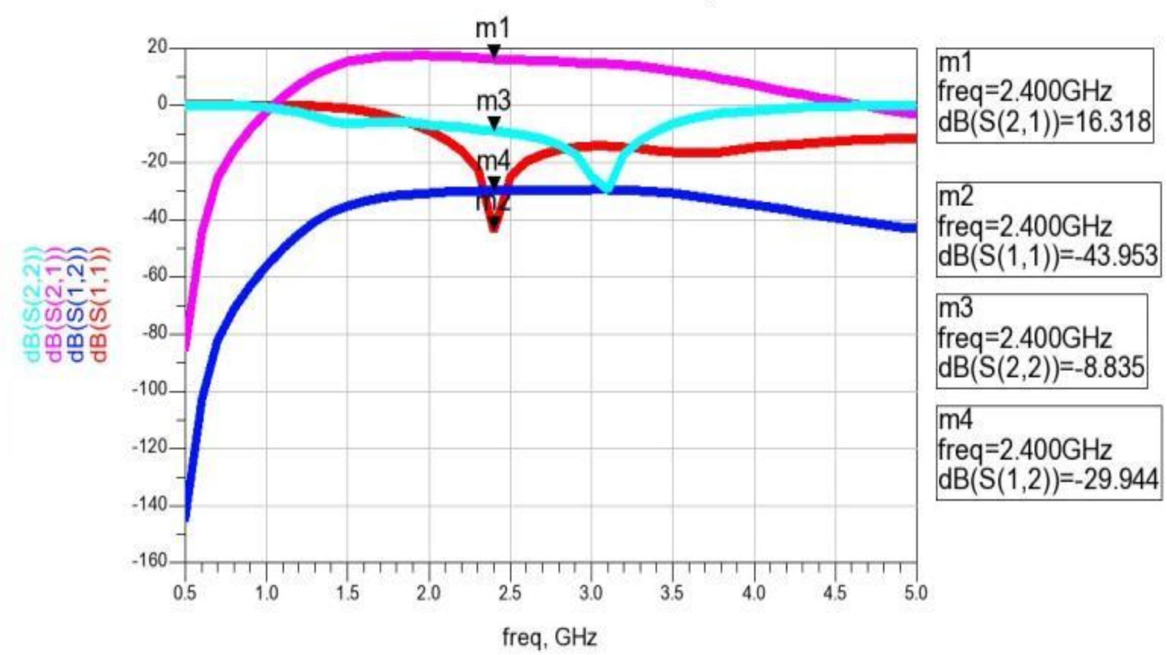


Vload for the Class A Amplifier

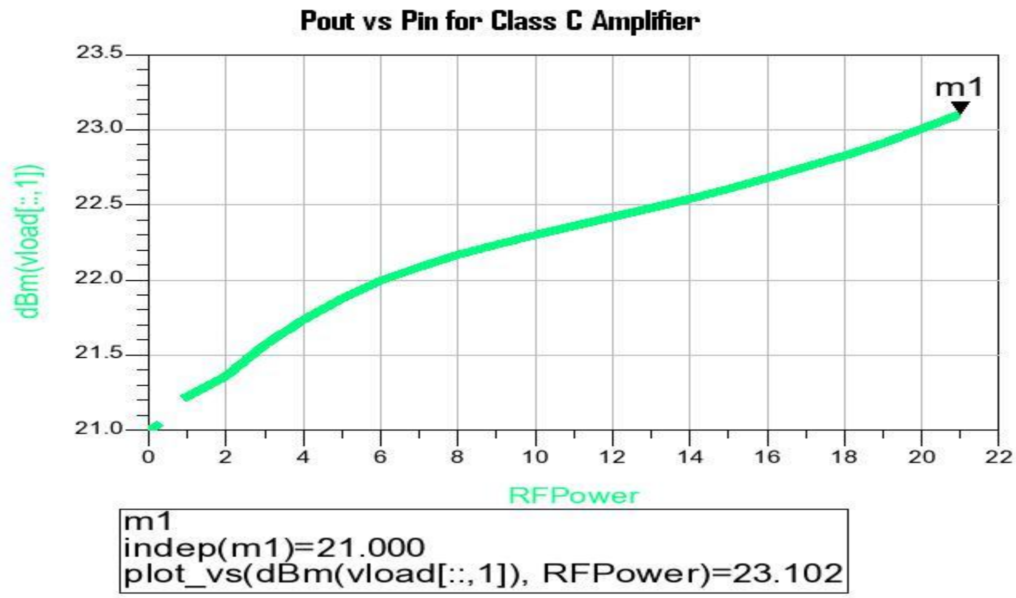


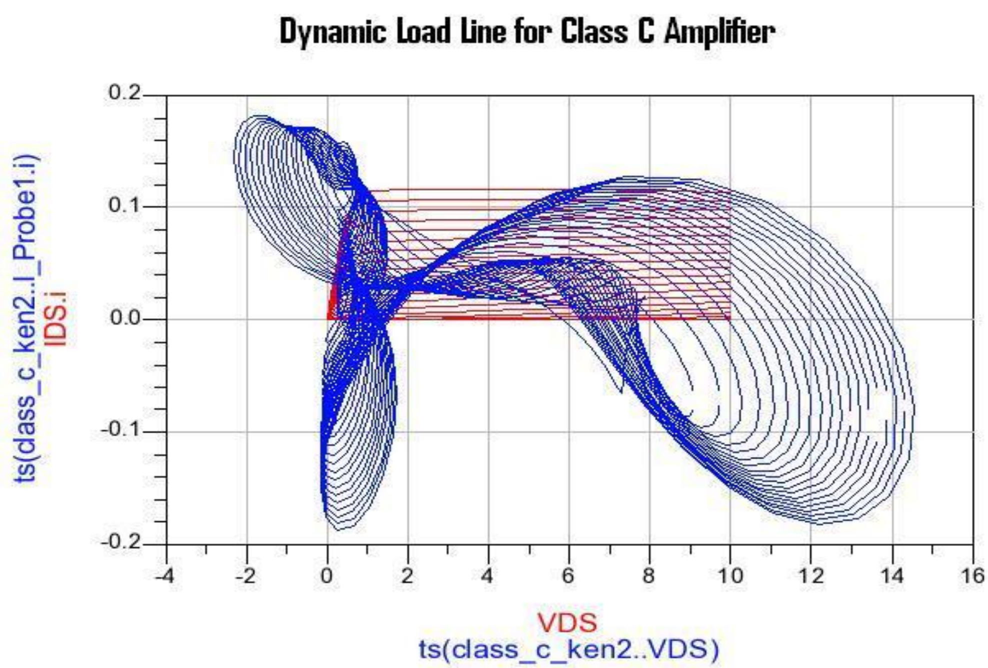
AC Simulations:

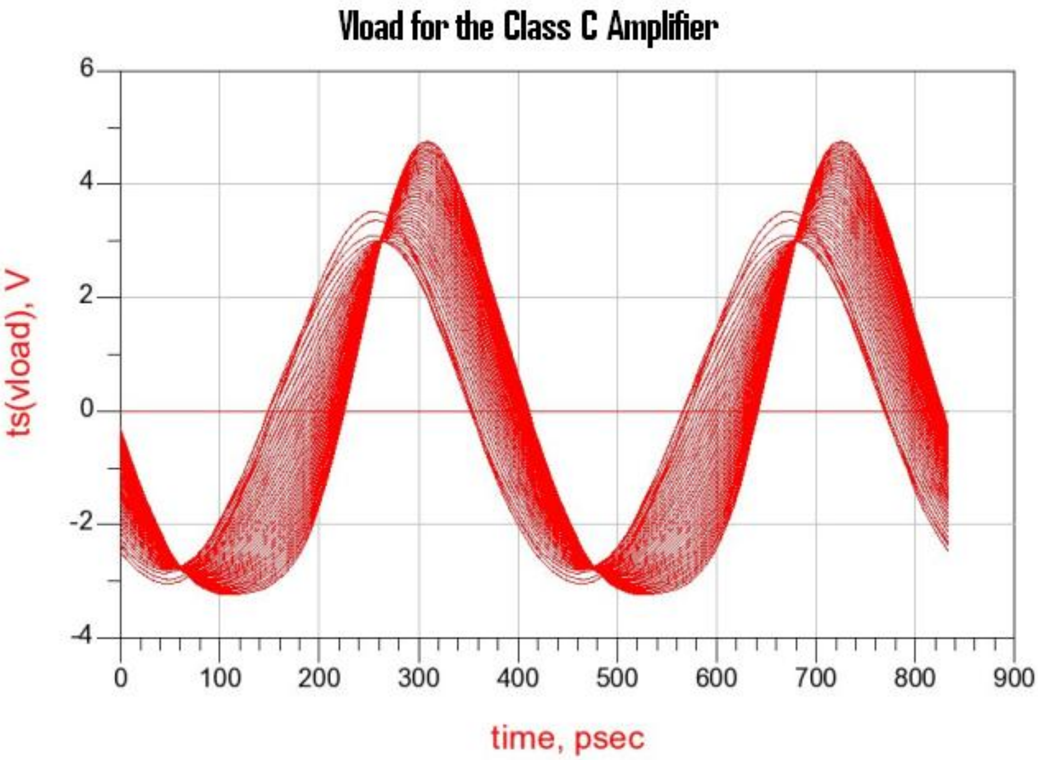
S Parameters for the Class A Amplifier



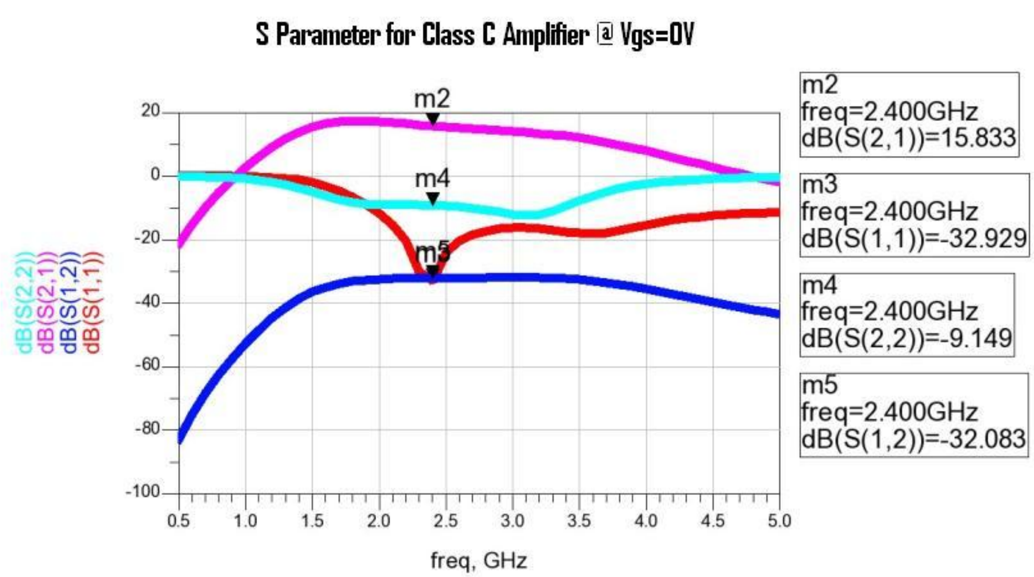
<u>Class C Amplifier</u>





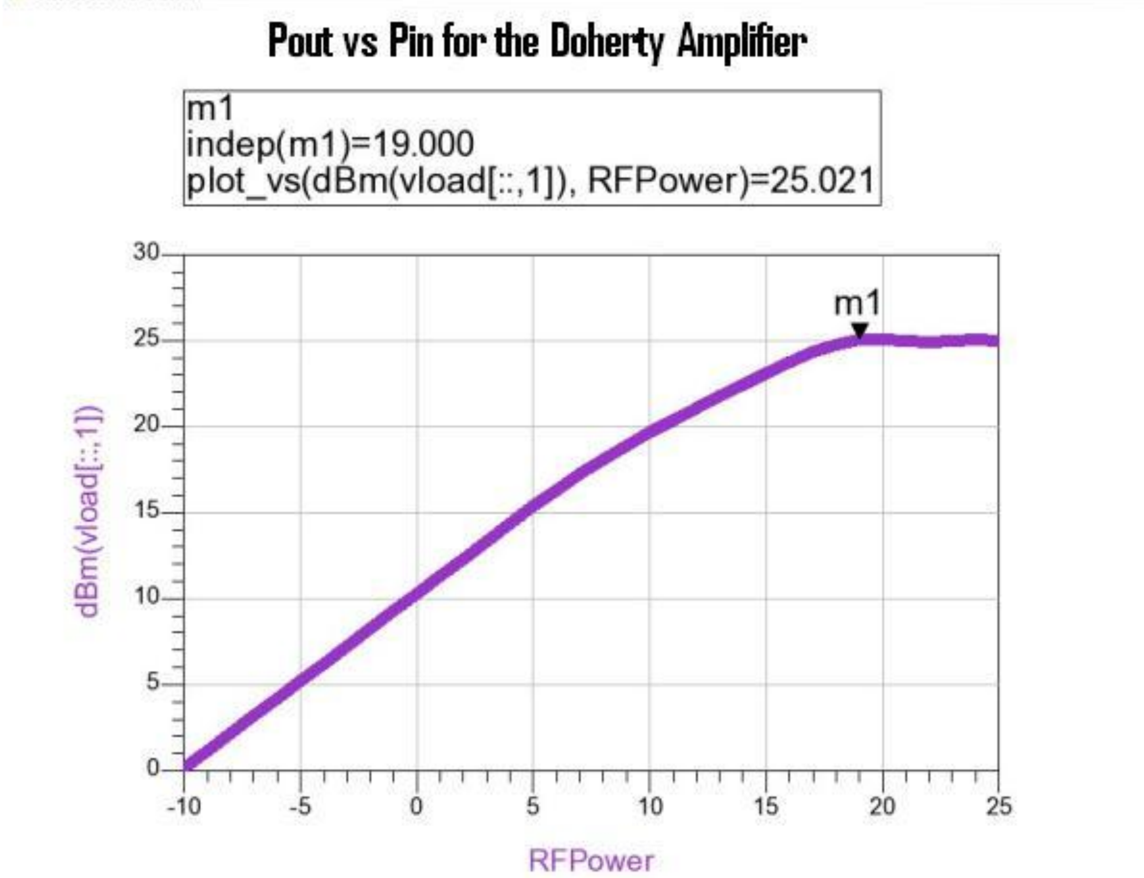


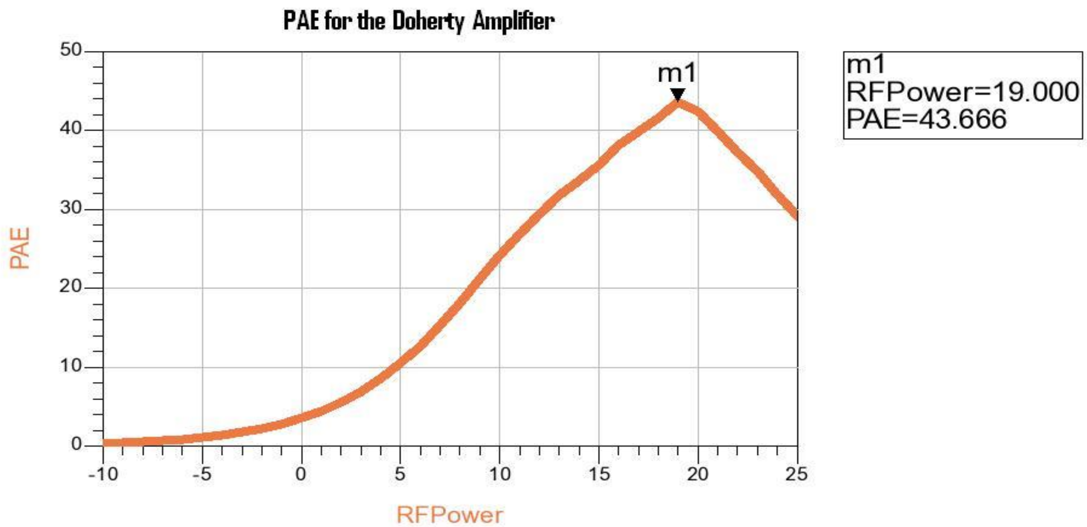
AC Simulations



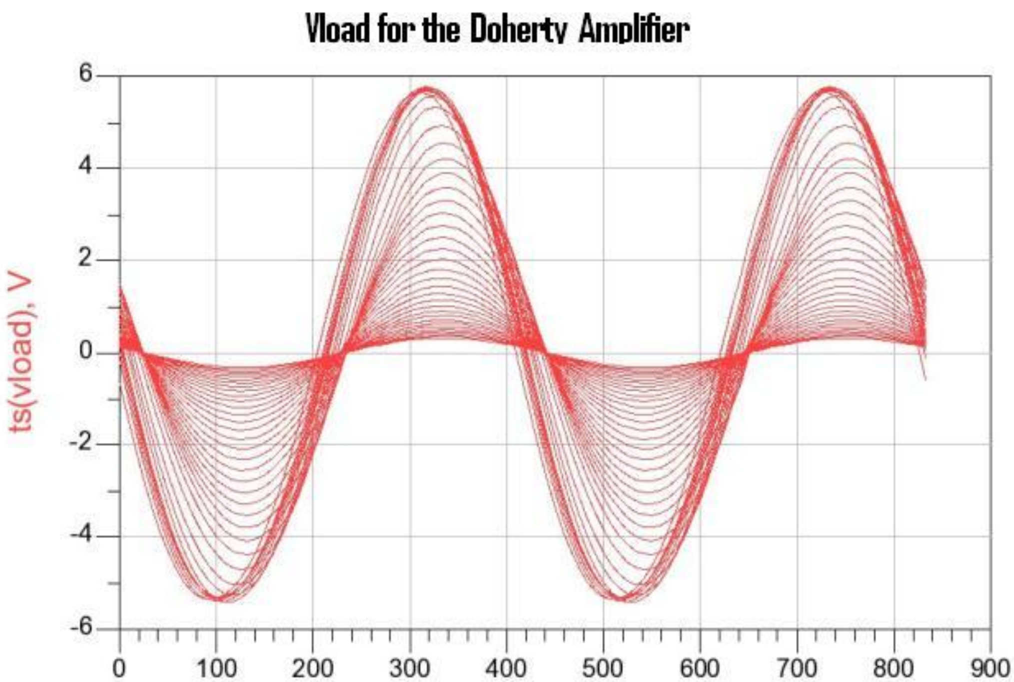
Doherty Amplifier

DC Simulations:



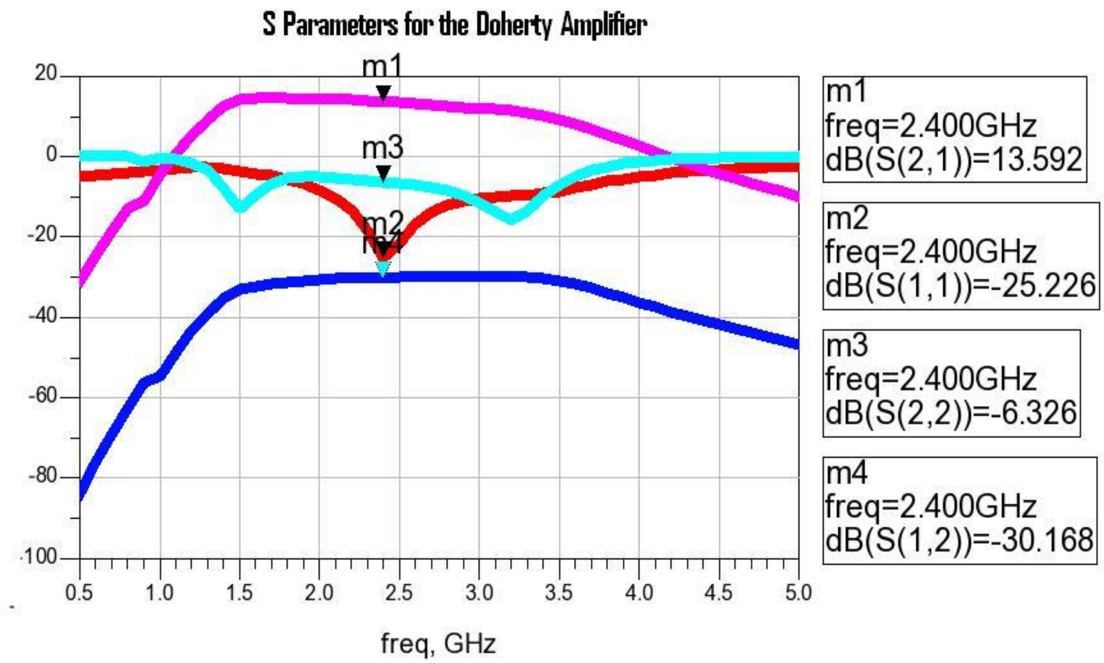


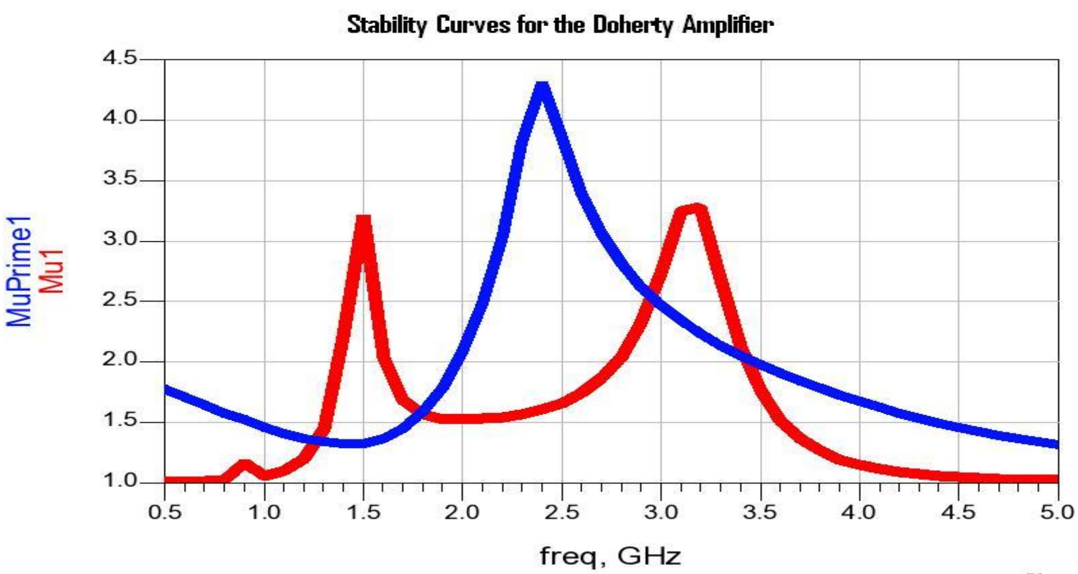
PAE for the Doherty Amplifier
m1
RFPower=19.000
PAE=43.666
PAE
RFPower
50
40
30
20
10
0
-10
-5
0
5
10
15
20
25



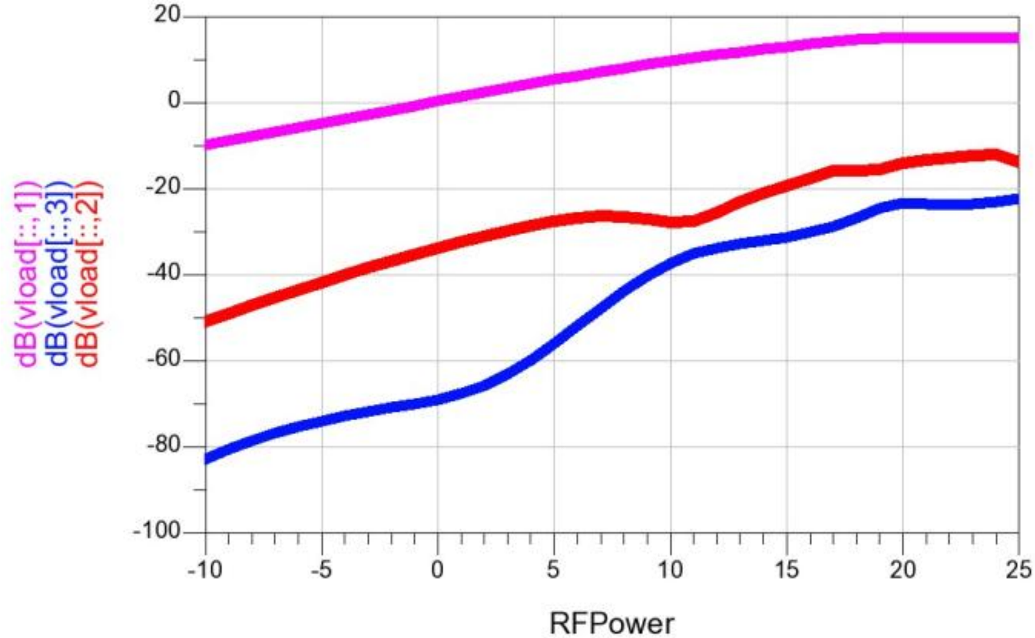
Vload for the Doherty Amplifier
ts(vload), V
6
4
2
0
-2
-4
-6
0
100
200
300
400
500
600
700
800
900

AC Simulations:



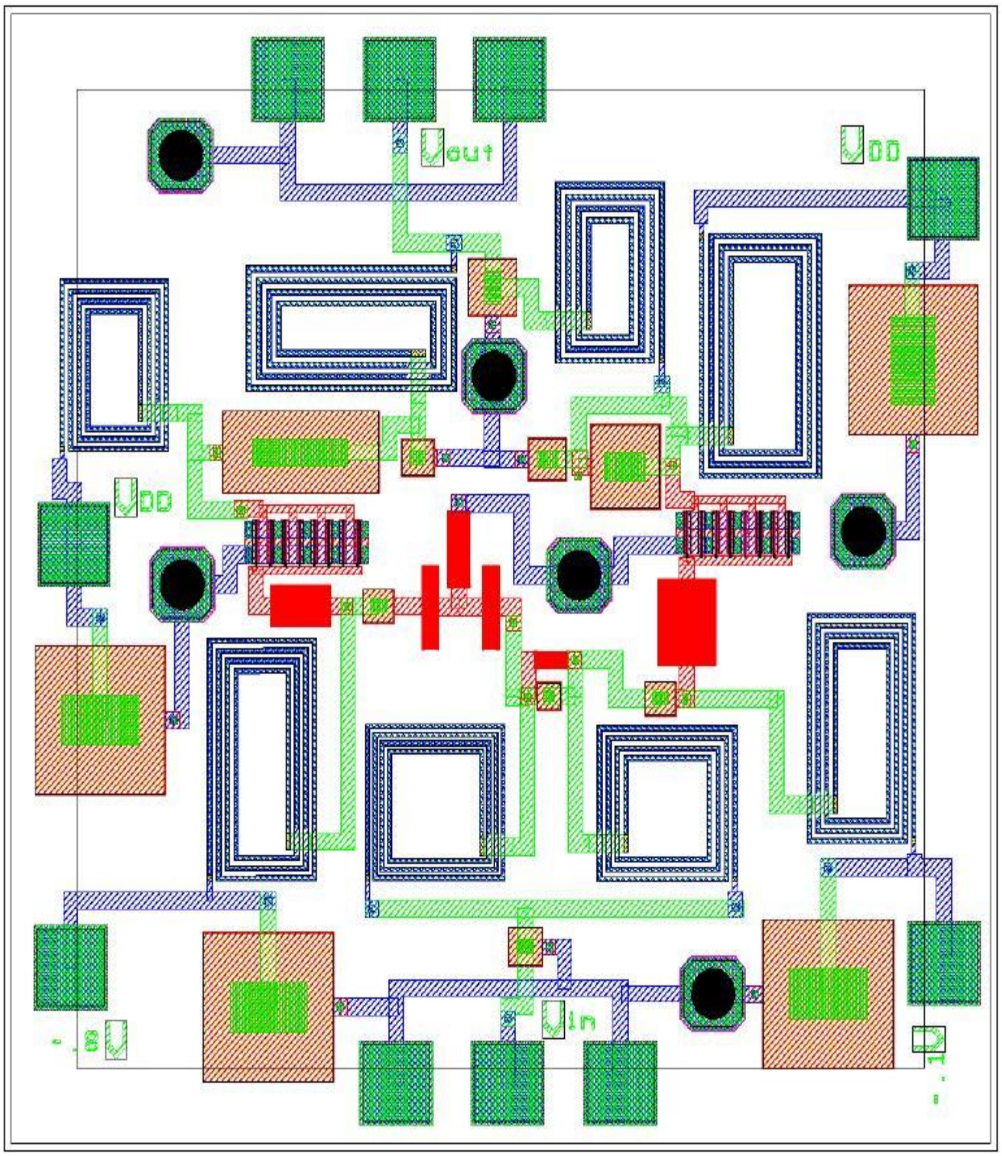


The 1st, 2nd and 3rd Harmonics of Vload for the Doherty Amplifier



Layout:

Final Layout for Doherty Amplifier



Test Plan:

1. Power Out versus Power In measurements.
2. S-parameter Measurements
3. Measure 2nd and 3rd Harmonics
4. Power Out versus Vsupply.

Equipment Needed.

1. 8510 Network Analyzer
2. Probe Station + Probes
3. Dc Power Supply (2 Supply probes, 2 gate bias probes)
4. Spectrum Analyzer
5. Current meter
6. High Frequency Source.

Summary

Tradeoffs were made in the design of the power amplifier. It is extremely hard to get both high efficiency and high output power. The Doherty amplifier is a good structure to use when high power and high linearity are the design goals. Even though the Doherty structure is 70 years old, it still has use in today’s MMIC design.