Master Thesis

RF Electronic Active Load for 7-Tesla MRI Smart Power Amplifier

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Outline

- Motivation and Introduction
  - Smart amplifier in MRI
  - Need to a variable load
- Load-pull
  - Passive
  - Active
- Elements of the Active load-pull
  - Internal amplifier
  - Coupler
  - I/Q modulator
  - Control boards
- Simulation
- Measurement
- Summery and conclusion

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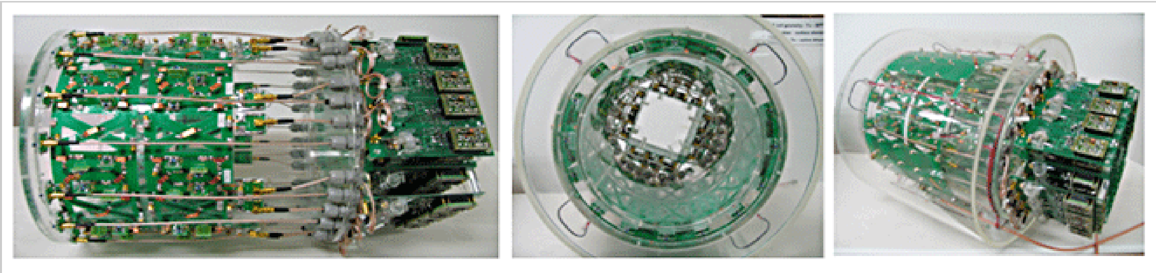
Smart power amplifier in MRI

- MRI= Magnetic Resonance Imaging
  - Excite the nuclei to produce the image
  - Specific phase and amplitude of the RF signal for the excitation
  - Smart power amplifier to generate the RF signal

Bloch.swf

- Real load in the MRI
  - Different patient bodies = Different impedances
  - Effect of other channels = Different reflection coefficient
  - Therefore load is very variable!
- RF amplifiers must be tested for all types of the impedances may be seen in the MR coil



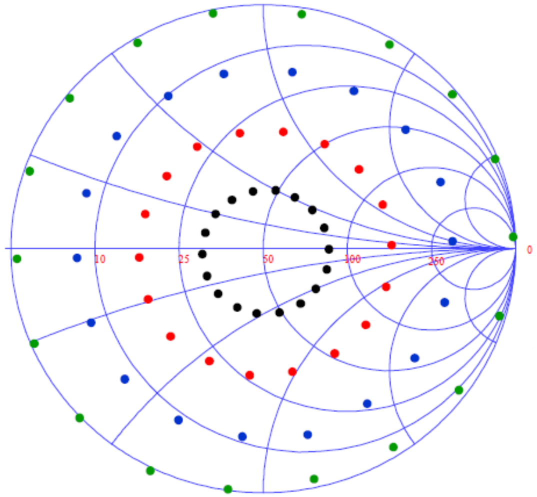
Variable load

- To test the stability and evaluate the functionality of the the smart power amplifiers for different impedances/reflection coefficients a variable load is needed.

Goal: building a system to generate the desired reflection coefficients covering all the phases and amplitudes in 300 MHz

Smart Power amplifier: DUT

Variable load: load-pull



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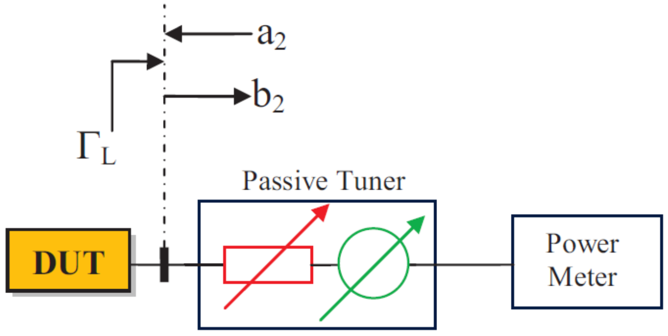
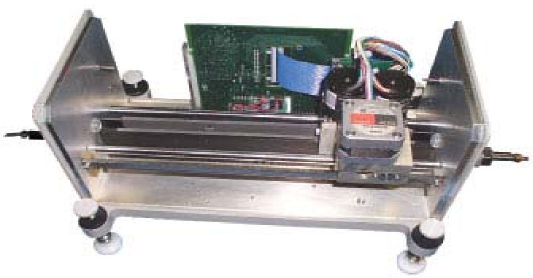
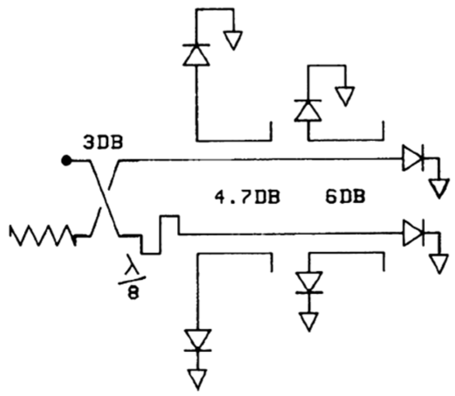
Different approches for the load-pull

- Passive:
  - Electromechanical tuner (EMT)
    - Suitable for high frequancy
    - Reflection coefficient till one
    - Precious but slow
  - Electronic tuner system (ETS)
    - Suitable for low power
    - Reflection coefficient till one
    - Not very precious but fast

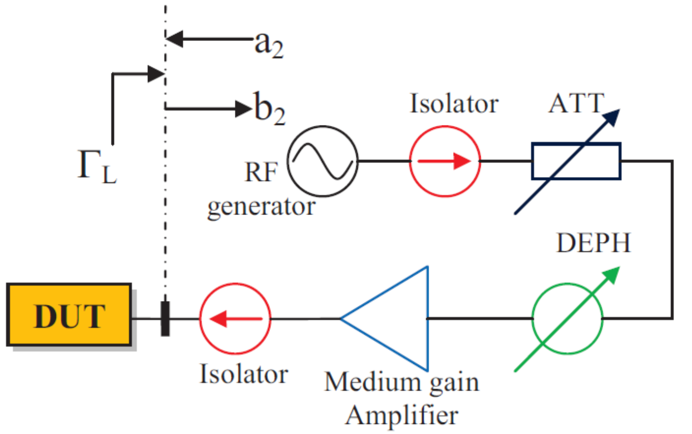




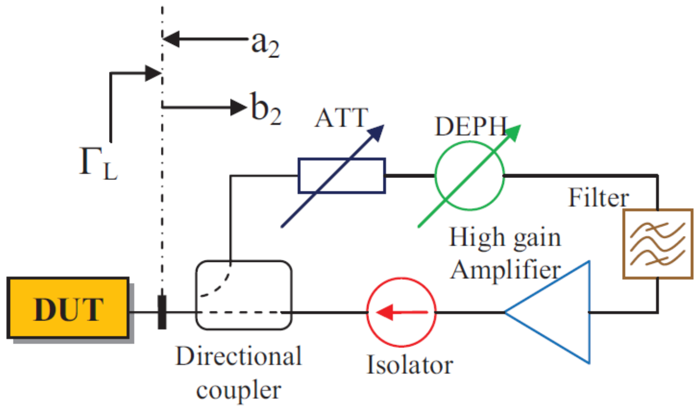


Different approches for the load-pull (cont.)

- Active:
  - Open-loop
    - Separate oscillator is needed



  - Closed-loop
    - Risk of instability



- We go for the closed-loop Active load-pull
- Mismatch between the elements can be a problem!

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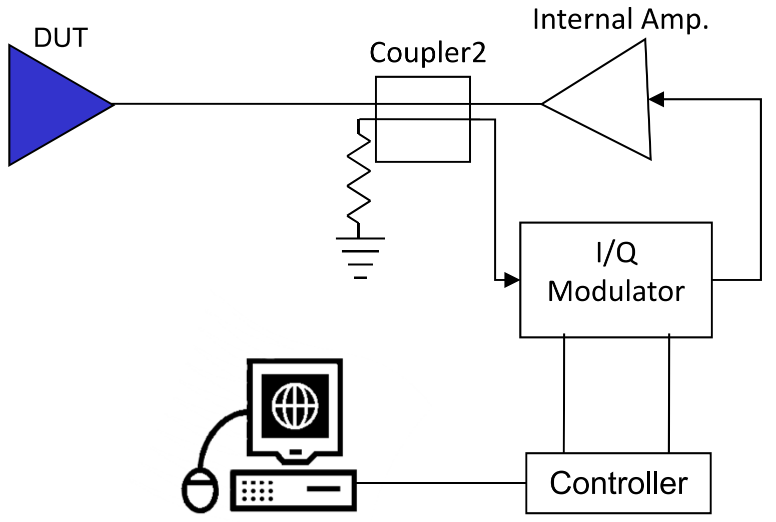
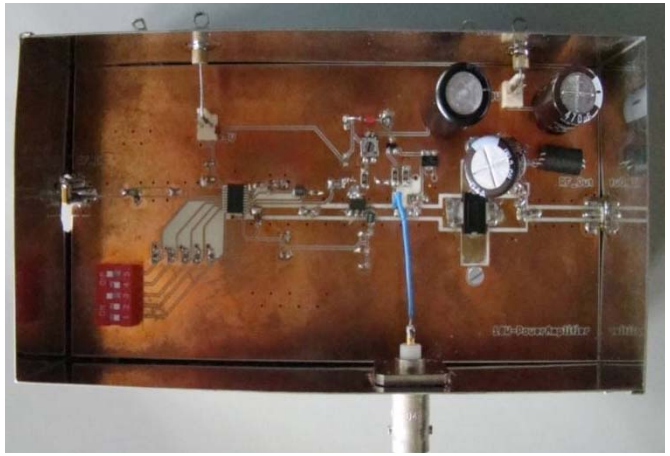
Elements of the load-pull

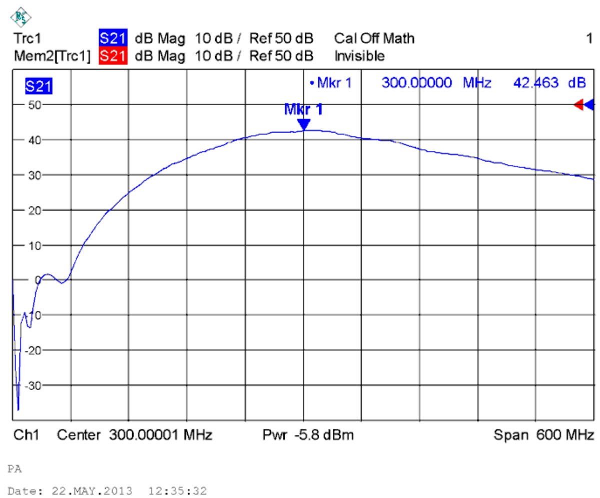
- Elements of the Active load-pull
  - Internal amplifier
  - Coupler
  - I/Q modulator
  - Control boards



Internal amplifier

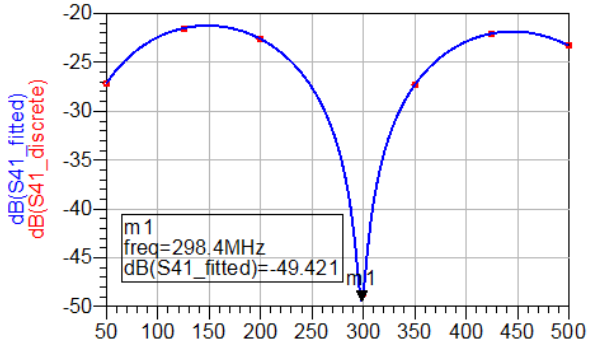
- Designed by Ouajdi Ochi in *“Aufbau und Untersuchung einer Verstärkerschaltung mit kartesischer Rückkopplung“*
- Maximum output power: 10 Watt
- Variable gain
- Maximum gain: 40 dB

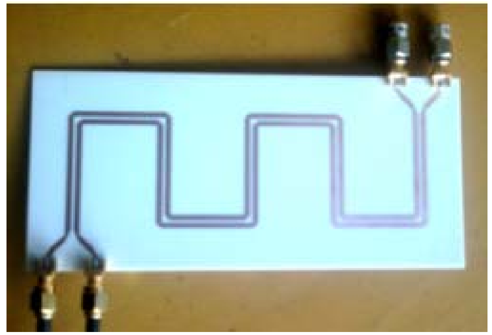


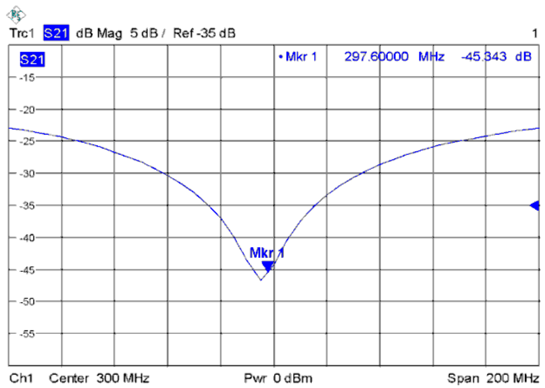


Coupler

- Coupled line coupler
- LineCalc
  - –To calculate the width and the space between lines based on the even and odd impedances
- Simulation
  - –Parametric simulation to get the maximum isolation in 298 MHz
  - –EM simulation for the board shows 50 dB isolation
- Measurement at 298 MHz:
  - –45 dB isolation
  - –20 dB coupling







I/Q modulator

•Passive modulator

•Components:

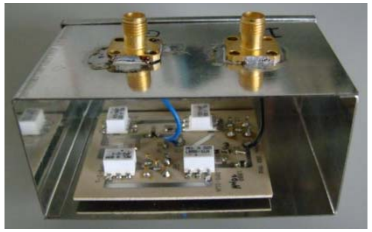
– LRPQ-320 (Power splitter)

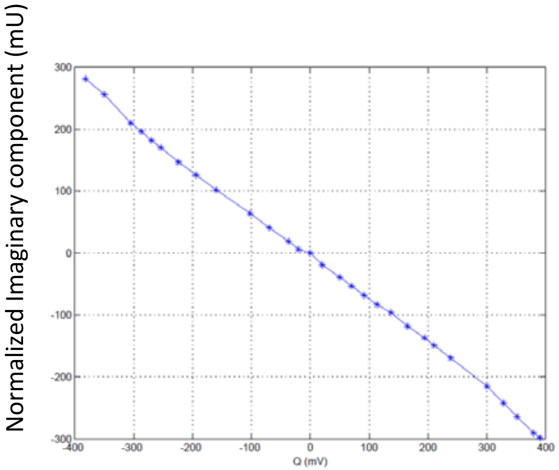
–JPS-2-1 (combiner)

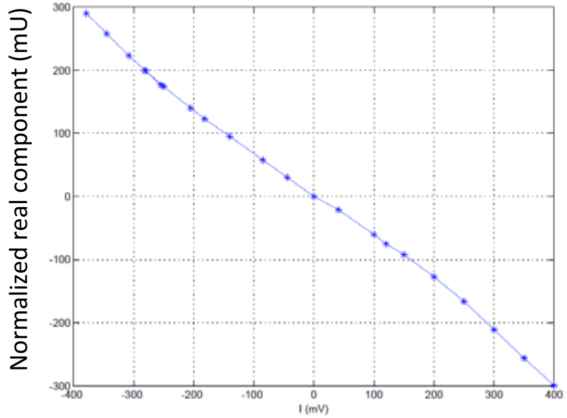
–2 x LRMS-1LH (mixer)

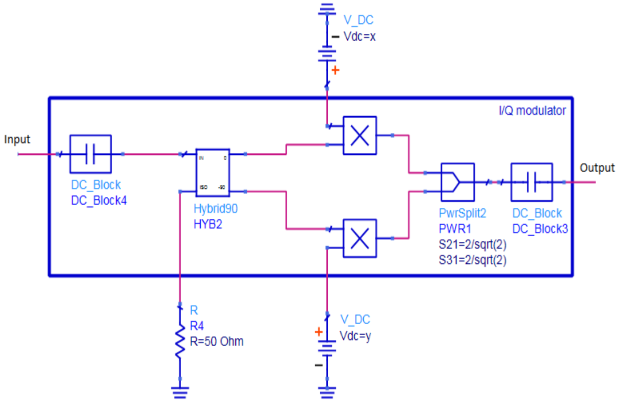
•Minimum loss= 7dB

•Saturation voltage = 450 mV



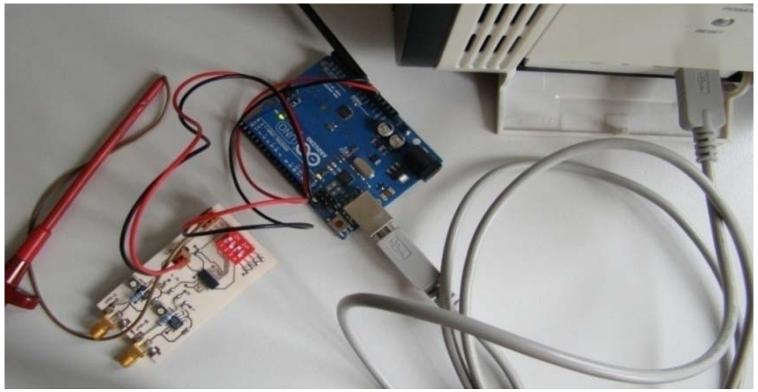


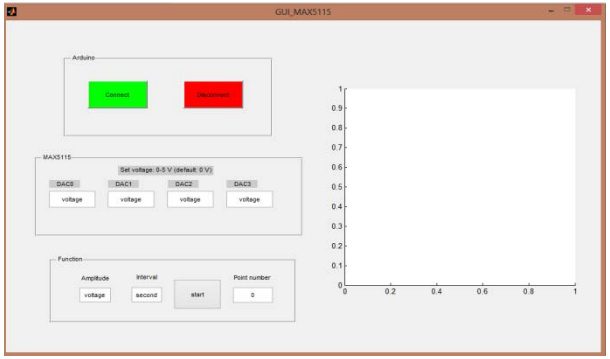


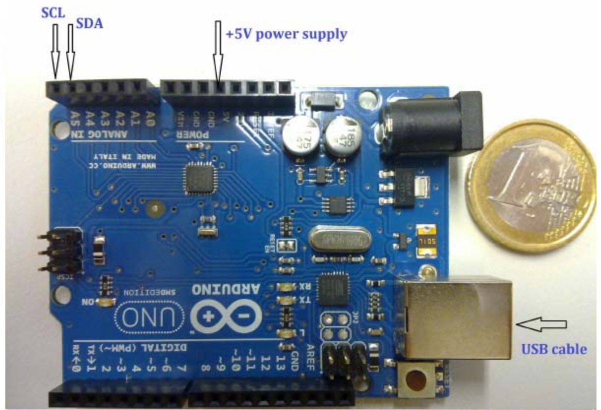


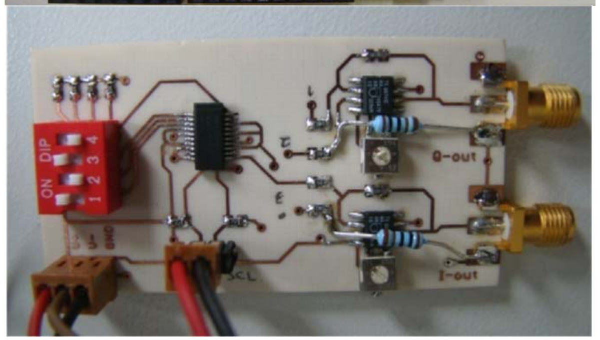
Controller

- MATLAB software
  - Calculate the *I* and *Q* values
  - Point-by-point or circular
- Arduino board
  - Connection from USB to DACs
- DAC board
  - Convert the received digital numbers to analogue voltages (*I*/*Q*)









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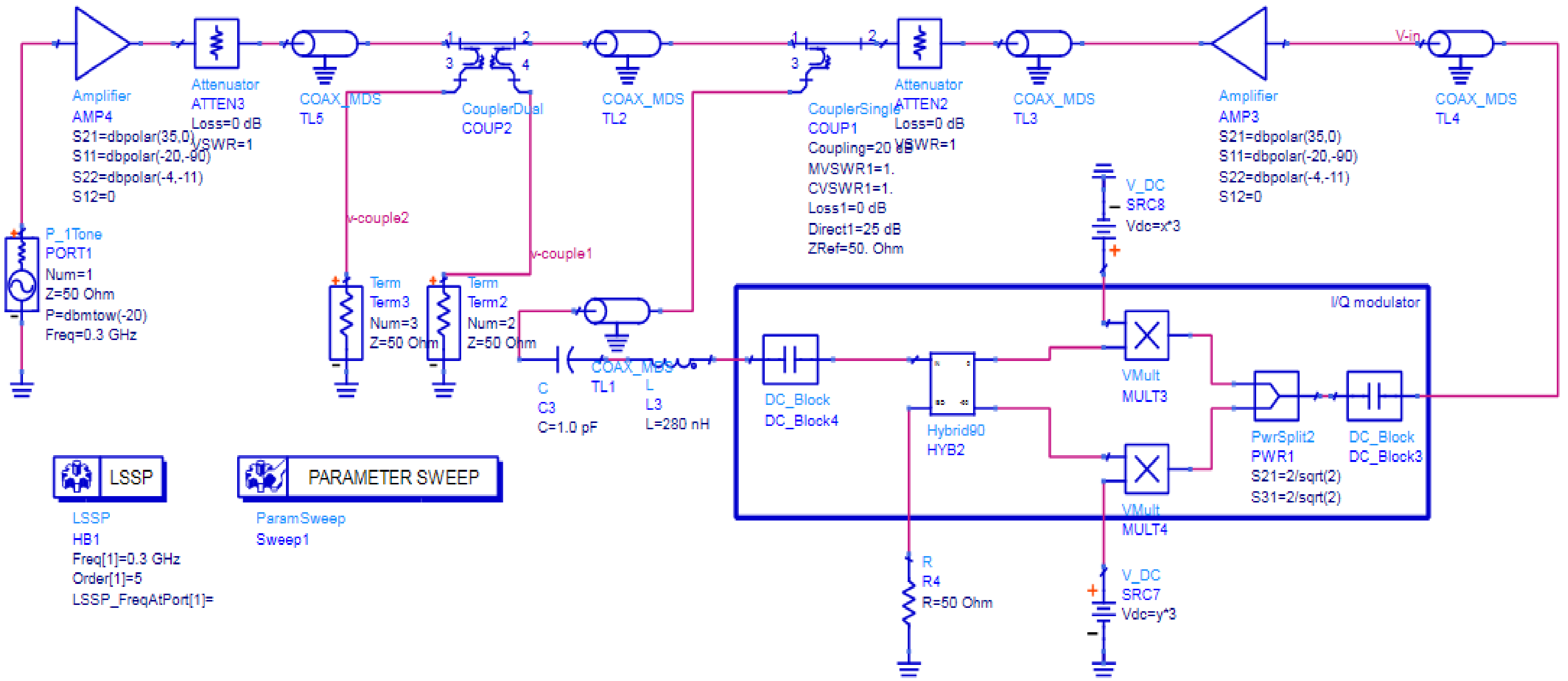
Simulation

Simulation setup for the initial structure

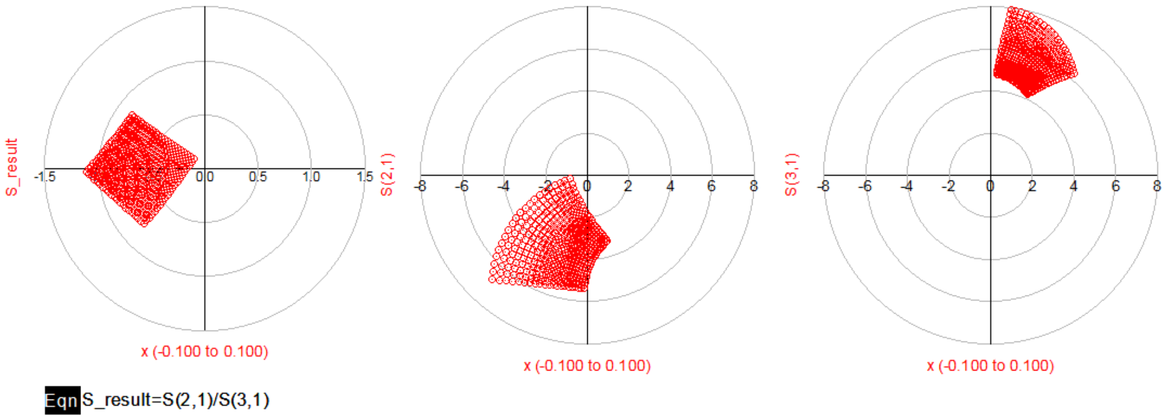
- –Large signal S-parameter
- –Sweep on in-phase and quadrature voltage
- –Model of the amplifier from the measurement

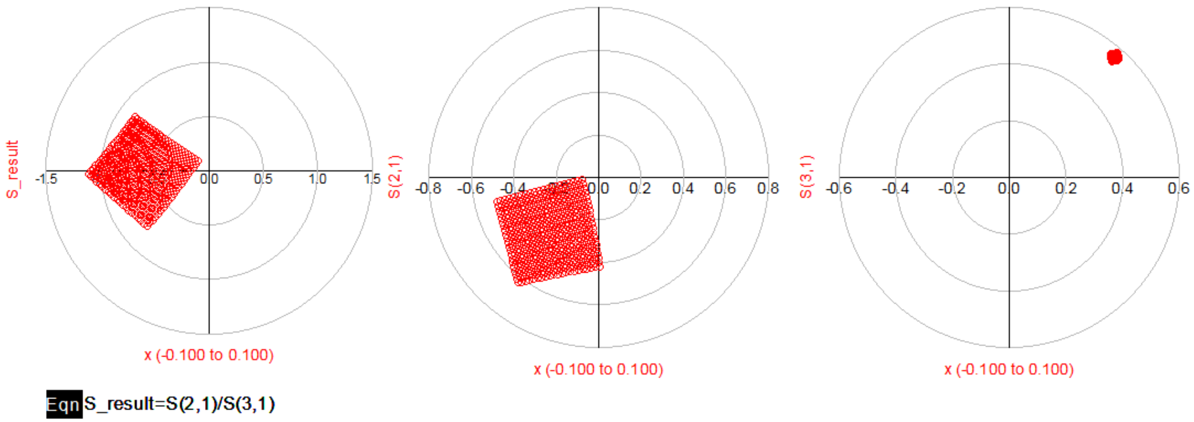


Simulation

Simulation results

- –without attenuator (up)
- –with attenuator (down)





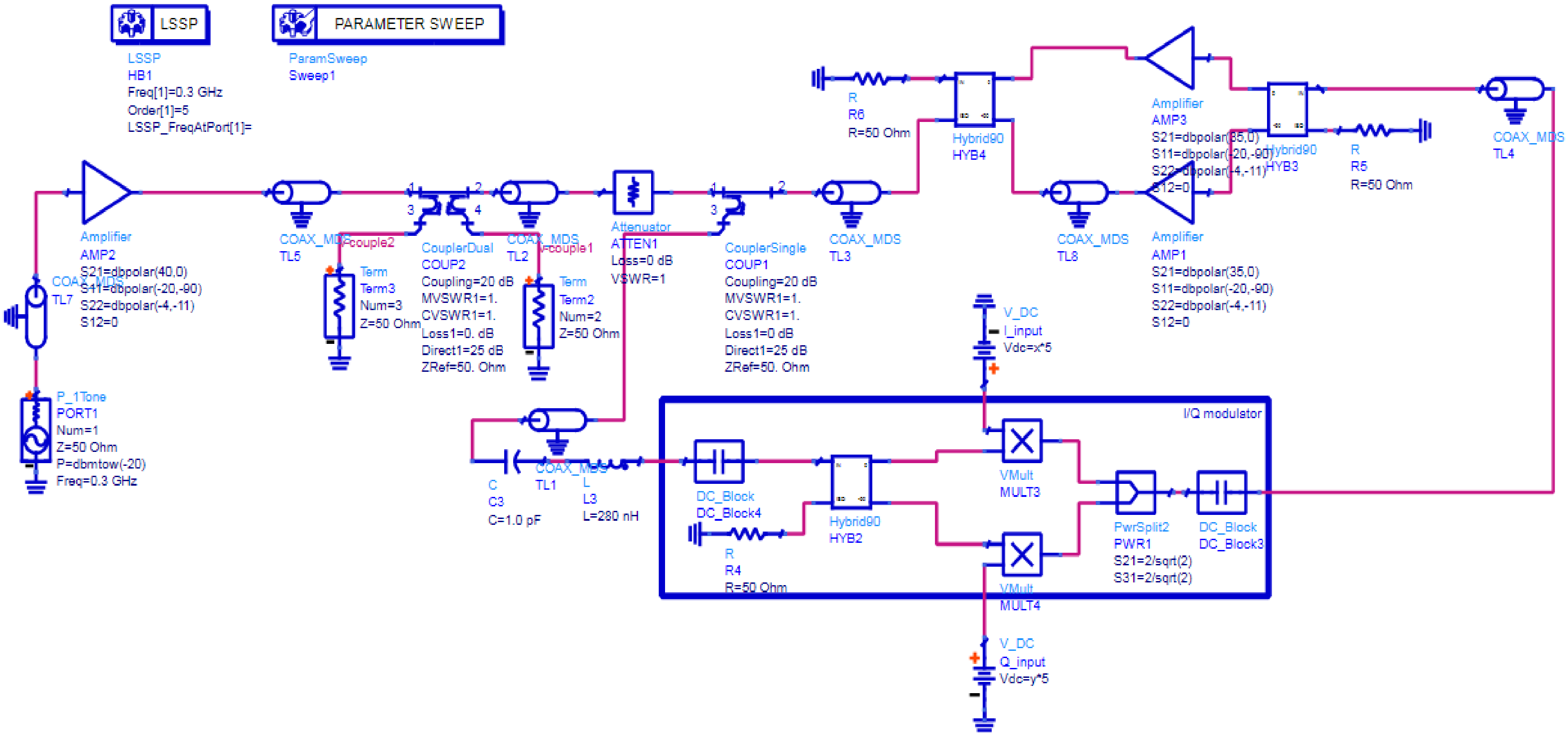
Forward signal (right) and backward signal (middle)

S_{11} = (Backward signal)/(Forward signal)

Simulation

Simulation setup for enhanced structure

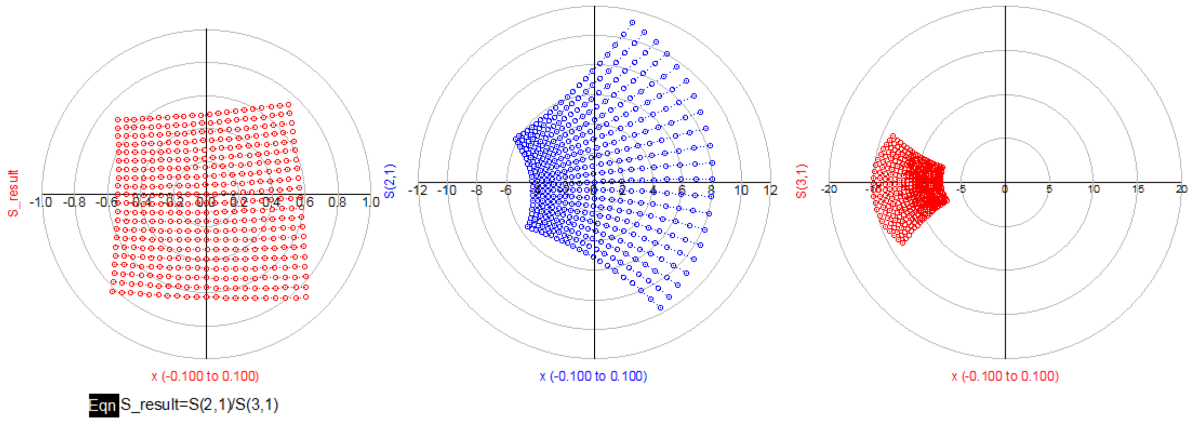
–Using two amplifiers connected to a 90-degrees coupler can eliminate the effect of reflected signal from the DUT

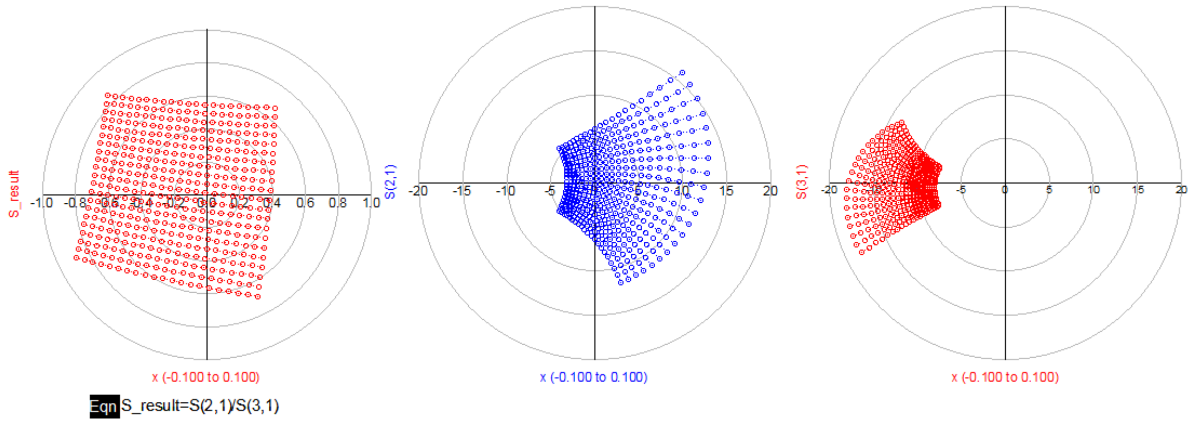


Simulation

Simulation results

- –Same amplifiers
- –Amplifiers with different phase





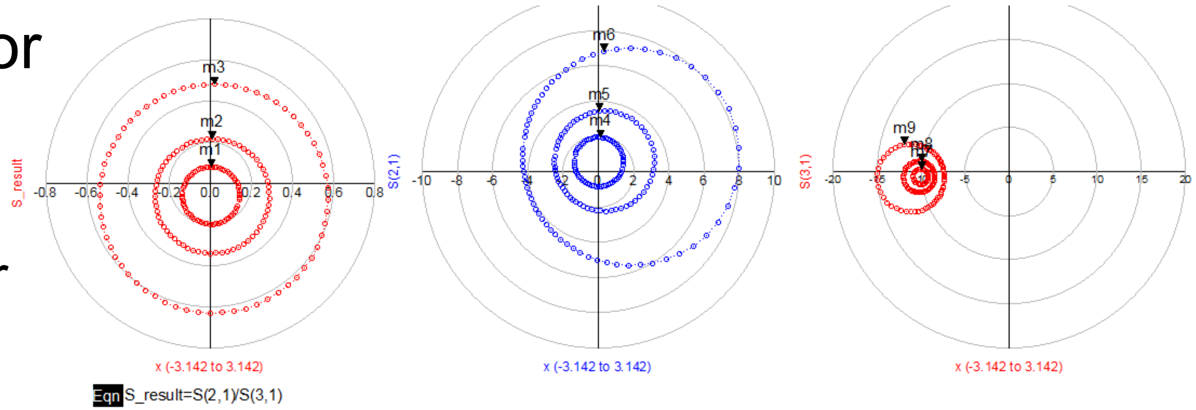
Forward signal (right) and backward signal (middle)

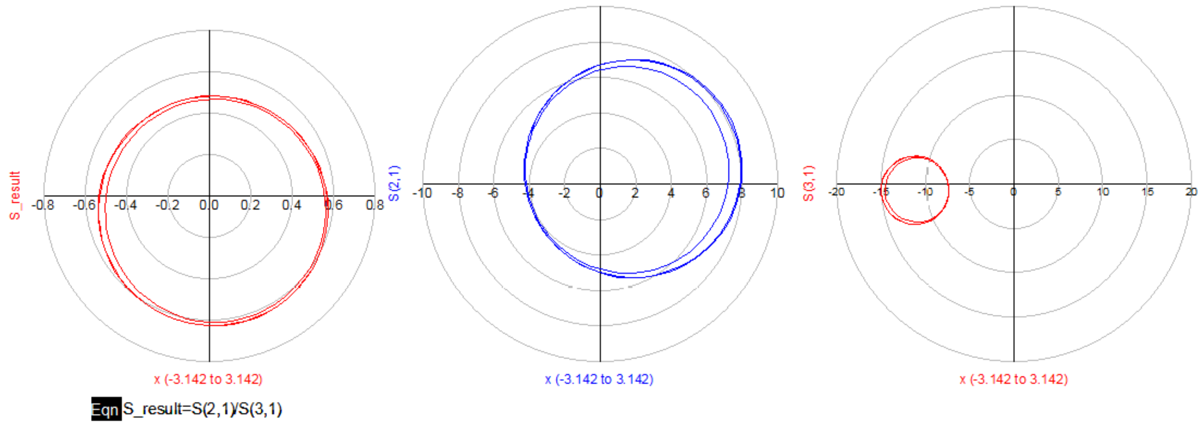
S_{11} = (Backward signal)/(Forward signal)

Simulation

Simulation results for circular points

- Different attenuation
  - –Inner circle=higher attenuation
- Different input power
  - –Almost the same results till the saturation point





Forward signal (right) and backward signal (middle)

S_{11} = (Backward signal)/(Forward signal)

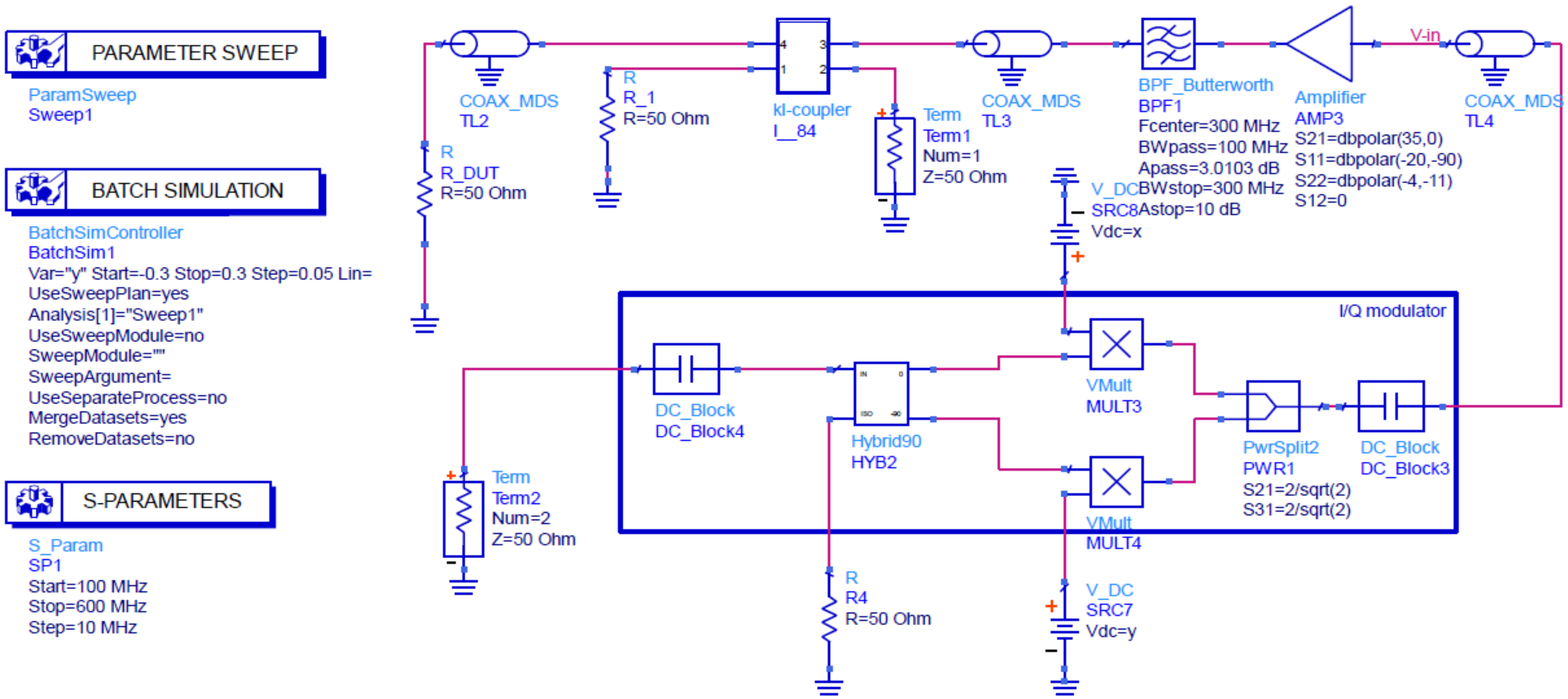
Simulation

Stability simulation

–Loop is opened to simulate the loop-gain

–S-parameter simulation solver

–Sweep over frequency and I/Q values (real model of coupler)

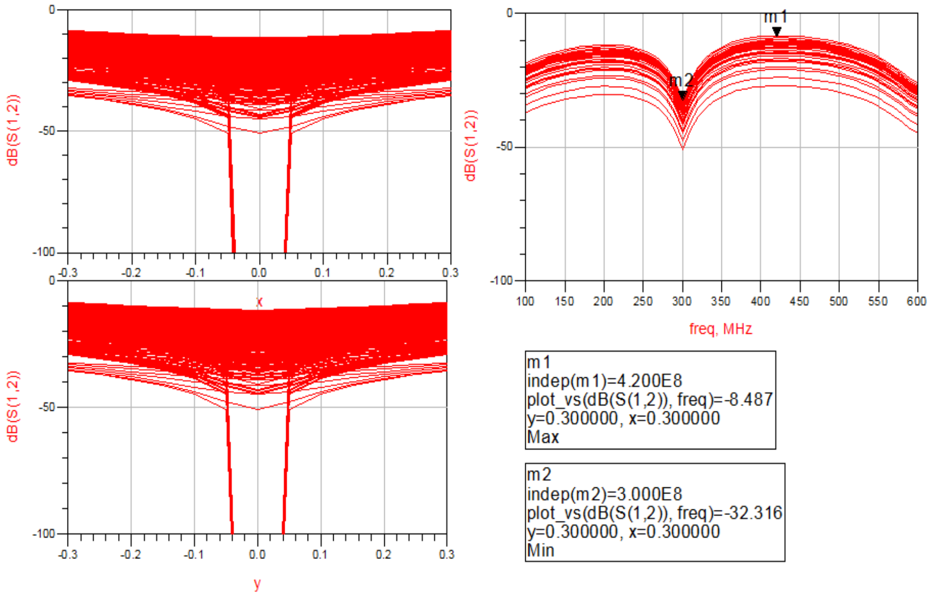


Simulation

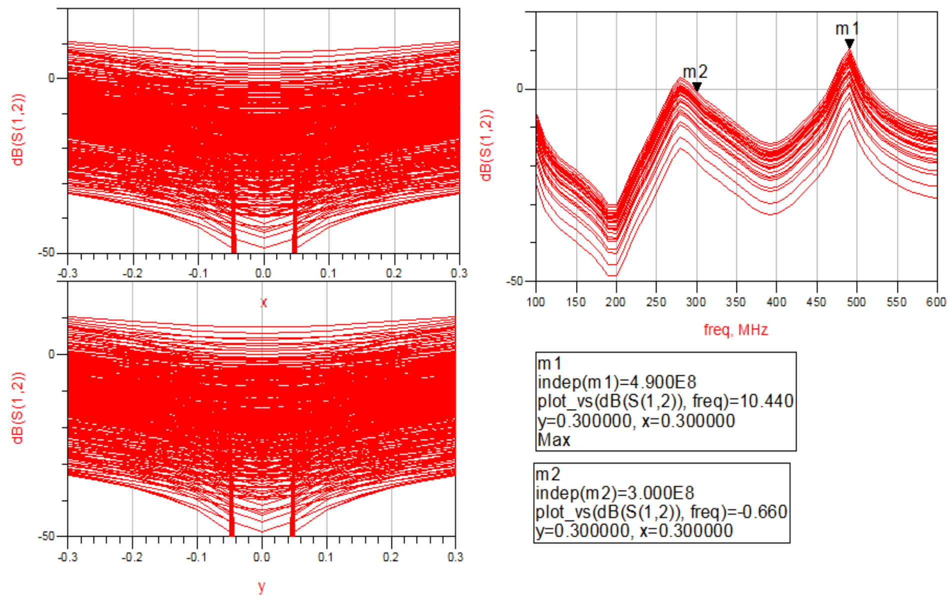
Simulation results

–S(1,2) represents the Loop-gain

–Result for two extreme cases of short circuit and 50 Ω



R_DUT=50 Ω



R_DUT=0 Ω

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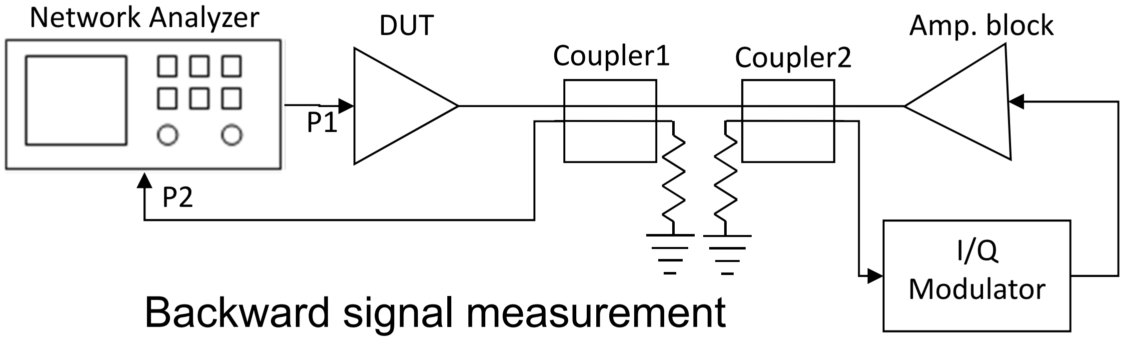
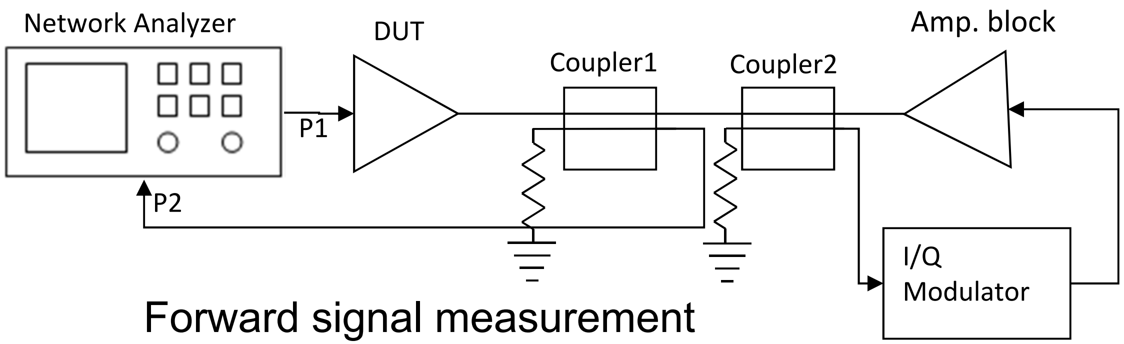
Measurement

Setup for the reflection coefficient measurement

•I/Q modulator is controlled via computer



Backward signal measurement



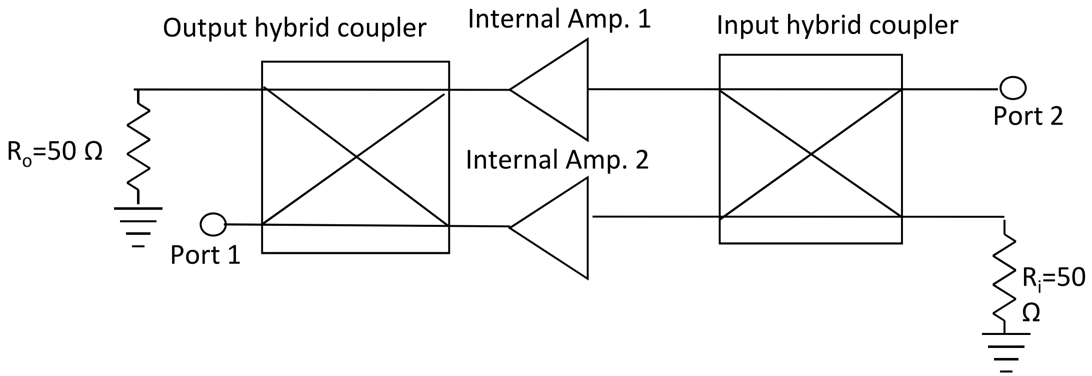
Forward signal measurement

Measurement

Setup for the reflection coefficient measurement

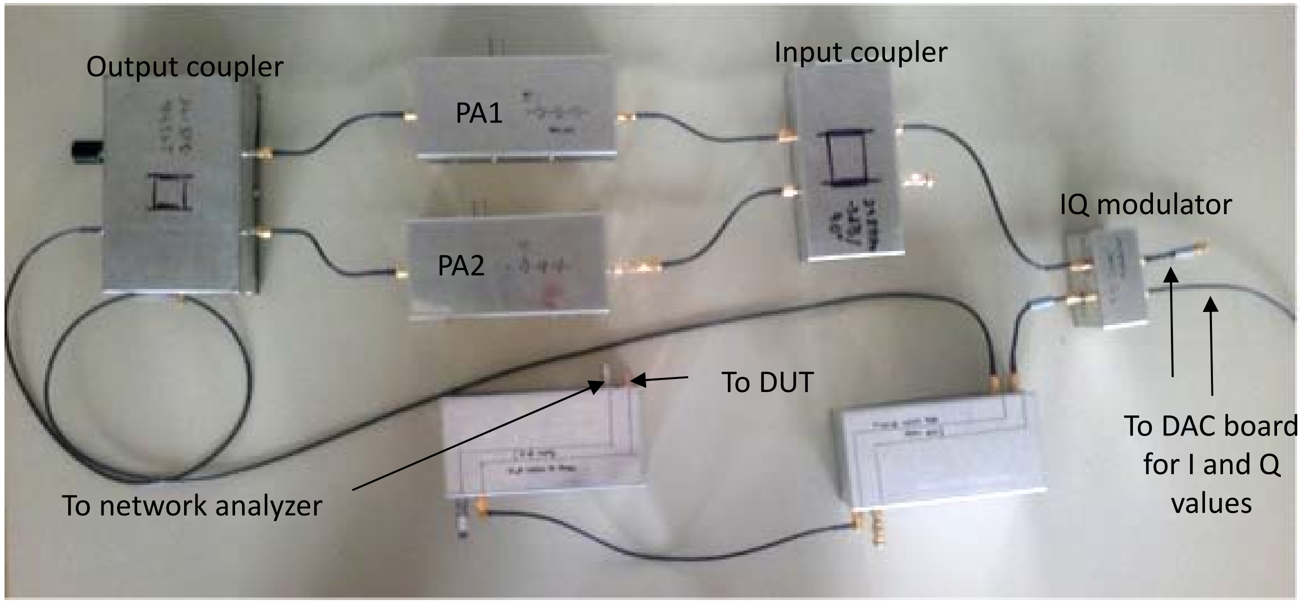
•Amplifier block include two similar amplifier

•Similarity in phase by changing the cable length



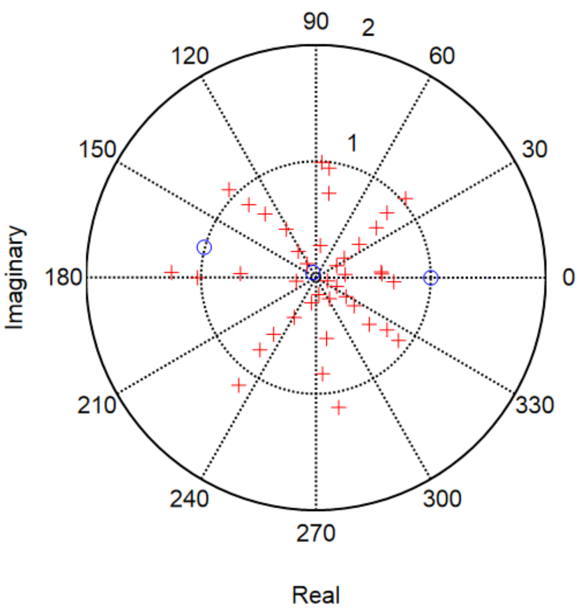
Measurement

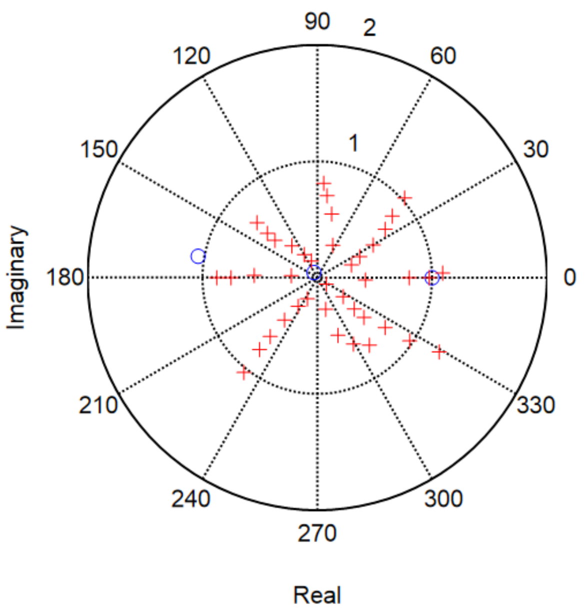
Setup for the reflection coefficient measurement

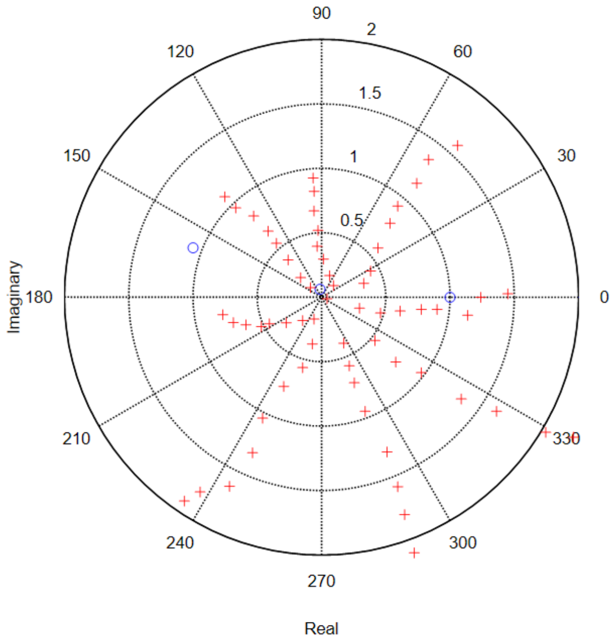


Measurement

- Reflection coefficients (S_{11}) for different amplitudes and π/4 phase steps
- Normalized to open-circuit
- Higher reflection coefficients can be obtained by increasing the gain of the amplifiers



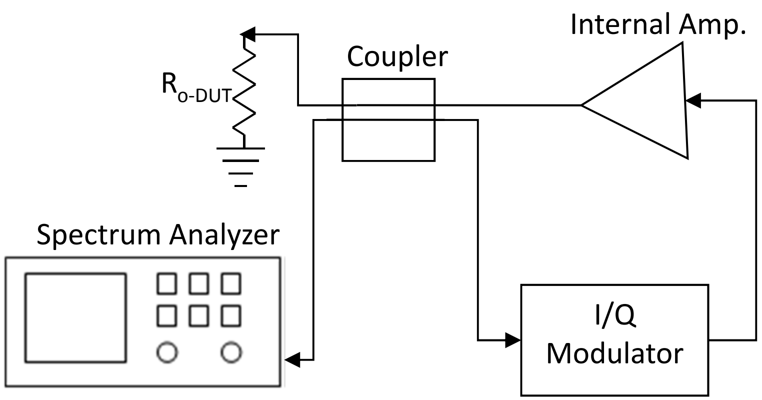




Measurement

Setup for stability measurement

- Single amplifier instead of the block
- Measurement via spectrum analyzer over frequency
- Different reflection factors of the DUT

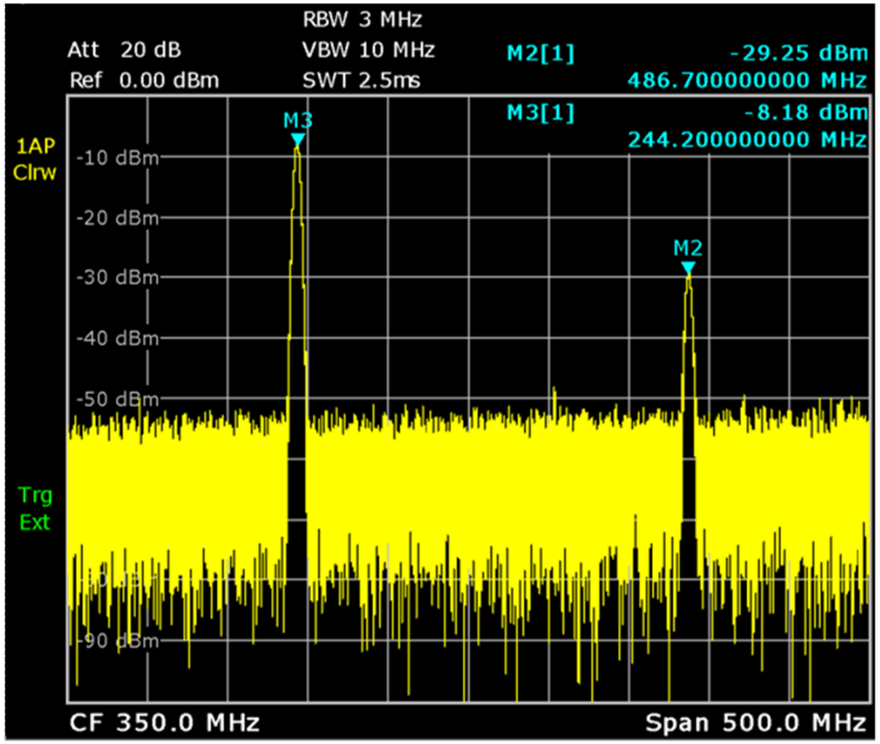


Measurement

Measurement results for stability

–Both in-phase and quadrature are 350 mV

–Instability in two extreme cases, short (left) and open (write)



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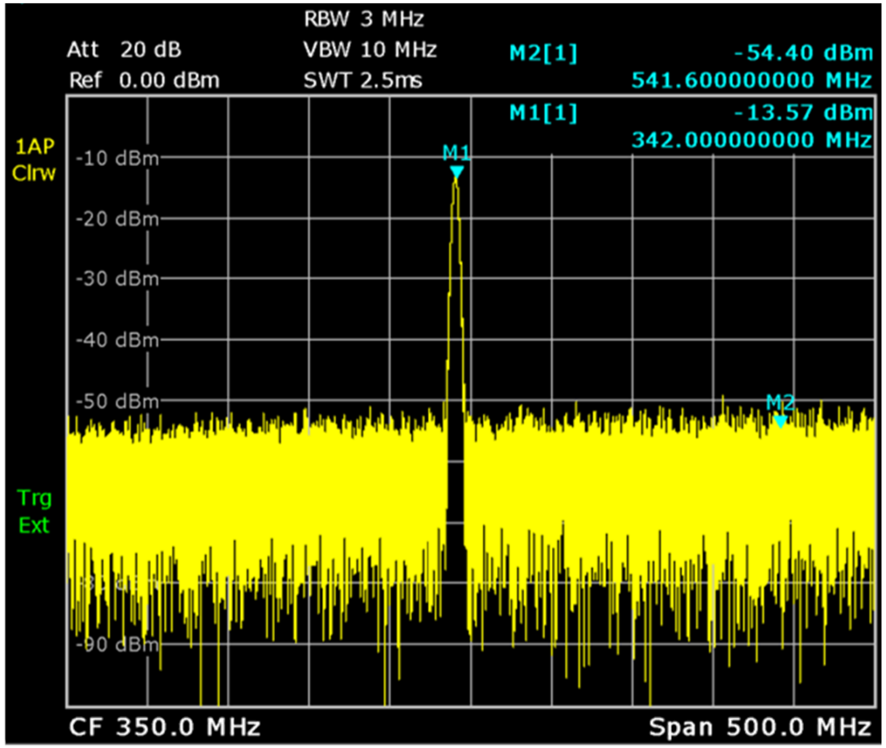

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Conclusion

- The closed-loop active load-pull is a convenient implementation of the load-pull in 300 MHz using passive I/Q modulator, simple coupler and amplifiers
- λ/2 Coupled-line couplers show high isolation (45 dB)
- Enable to produce reflection coefficients greater than one
- Easily programmable via Matlab to sweep the points
- Reliable for the input power up to saturation points of the internal amplifiers (10 watt)
- Reflection of the internal amplifier can be eliminated using the two amplifiers and 90-degrees coupler structure
- More precious results can be obtained using circulator
- Potentially stable at 300 MHz, higher risk of instability for other frequencies and higher value of I/Q and higher DUT reflection coefficients

Reference

- **F.M. Ghannouchi, M.S. Hashmi.** *Load-Pull techniques with applicatons to power amplifier design.* s.l. : Springer Series in Advanced Microelectronics, 2013. 978-94-007-4460-8.
- **Pozar, David M.** *Microwave Engineering,2nd edition.* Massachusetts : John Wiley & Sons Inc., 1998. ISBN 0-471-17096-8.
- ***Ochi,Ouajdi*** *Aufbau und Untersuchung einer Verstärkerschaltung mit kartesischer Rückkopplung,* Duisburg-Essen master thesis report, 2013
- …

Thank you!

Questions?