Presentation of Bachelor Project Work

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Topic:

Development of a Transmit/Receive Switch for ^{23}Na Coils in a 7-Tesla Magnetic Resonance Imaging System (MRI)

Outline

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- **Introduction**
  - ✓ Motivation
  - ✓ Methodology
- **Concept**
  - ✓ MRI
  - ✓ PIN Diodes
  - ✓ S-Parameters
- **Hardware Development**
  - ✓ Schematic design & simulation
  - ✓ Board layout & optimisation
  - ✓ Wire-wound Inductors
- **Measurements & results**
  - ✓ S-Parameter tests
  - ✓ High Power Test
- **Conclusion**
- **Questions**

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Motivation

MRI – Magnetic Resonance Imaging

- Sets the **standard** of care for diagnostic imaging
- One of the **fastest growing** areas in diagnostic imaging
- Needs a **fast switch** between transmission and receive for proper functionality

MRI Scans in Europe Are Increasing 14% Year Over Year

Methodology

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- **RF Simulation of circuit in ADS**
- **Band-pass Filter Optimisation**
- **Realisation of optimised circuit on micro-strip**
- **PCB layout design in EAGLE**
- **Assembly of Circuit**
- **Testing for Impedance/Reflection Coefficients and Insertion Loss**
- **Circuit pass-band frequency tuning**
- **High Power Test**

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MRI - Magnetic Resonance Imaging

- **Imaging technique** used primarily in medical settings
- Produces **high quality images** of the inside of the human body
- Available in different types including **1.5-Tesla**, **3-Tesla** and **7-Tesla**
- **Major manufacturers** include Siemens, GE Healthcare, Phillips, Toshiba and Hitachi

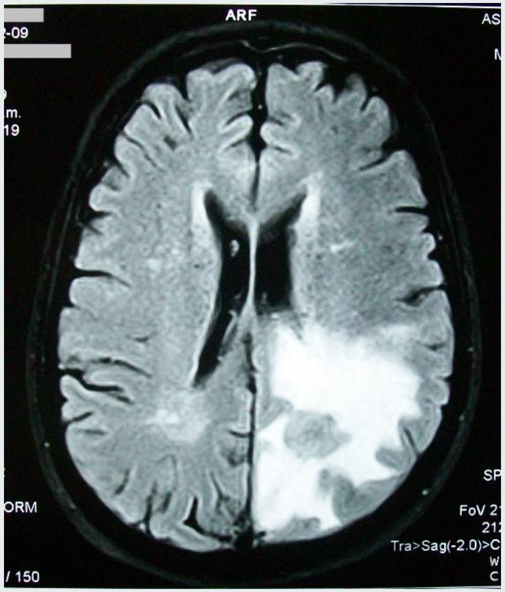
7-Tesla MRI from Siemens

MRI - Magnetic Resonance Imaging

Comparison to CT-Scan

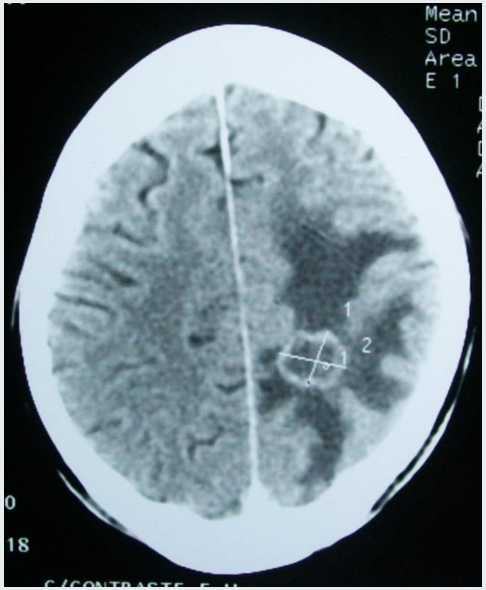
- MRI – **magnetic energy and RF** vs. CT-Scan – Ionisation radiation that means added risk as x-ray dose is cumulative
- MRI – **superior for soft tissue evaluation** vs. CT-Scan – better for bony tissue

MRI Scan Image



VS.

CT-Scan Image



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MRI - Magnetic Resonance Imaging

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Basic Functionality of MRI

Summarised in 5 Steps:

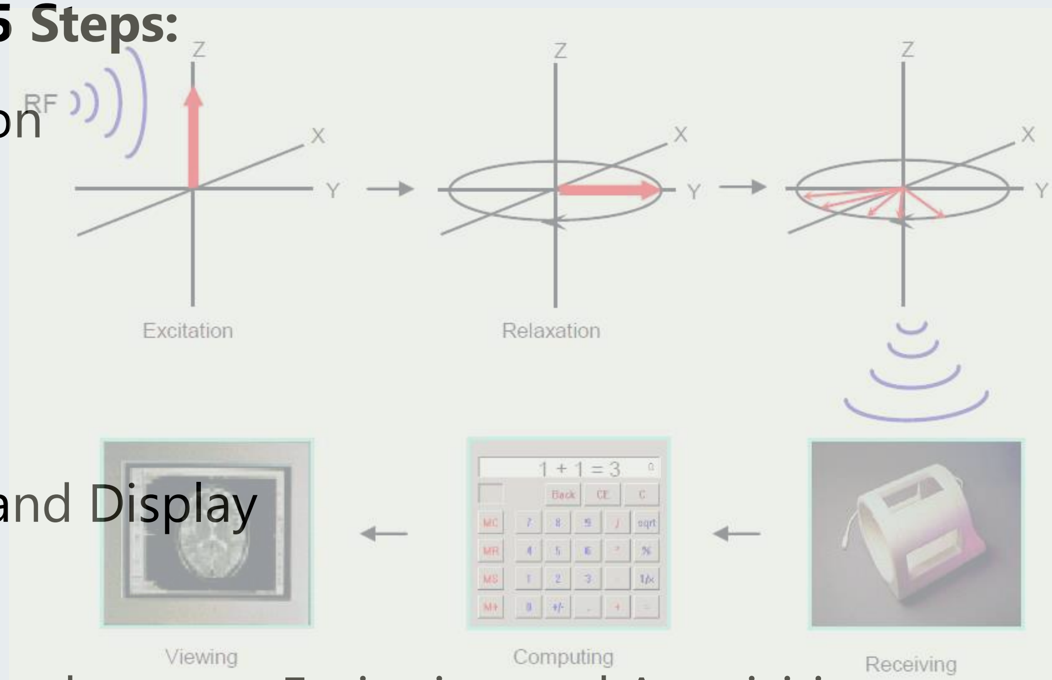
i. Magnetisation

ii. Excitation

iii. Relaxation

iv. Acquisition

v. Computing and Display



Small time frames between Excitation and Acquisition necessitates a **QUICK switch** between **Transmission of RF Pulse** and **Receive of Released RF energy from H-atoms**

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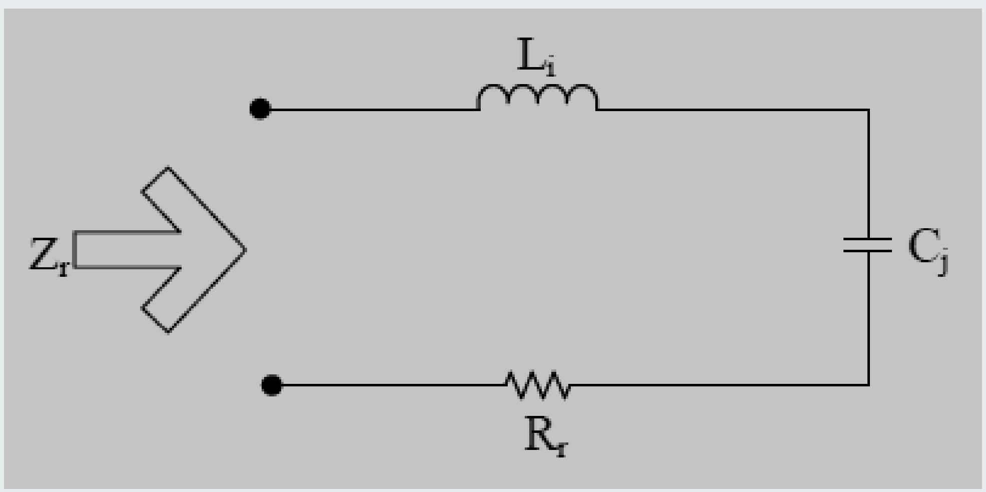
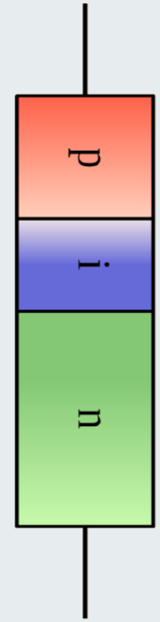
PIN Diodes

- **Wide & lightly doped intrinsic** region between p- and n-type semiconductor regions
- Applications include **RF switches**, power limiters, modulators and variable attenuators
- In **Reverse bias**, a **series capacitance** leads to high **diode impedance**





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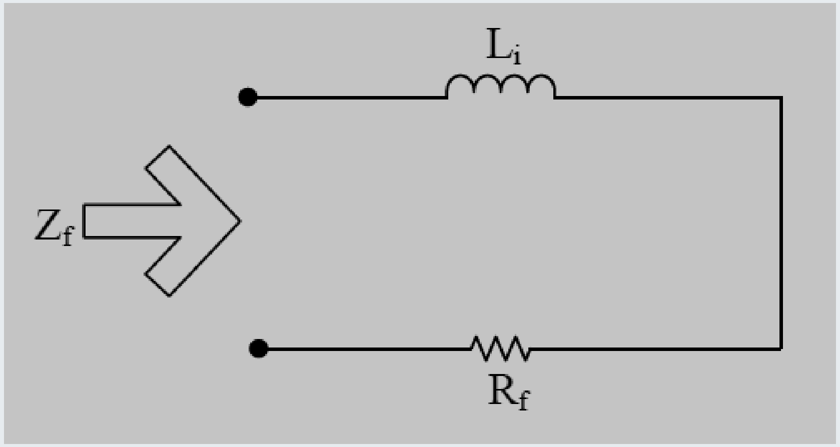
- Reverse bias = **OFF state** in an RF Switch

PIN Diodes

– In **Forward bias**, current removes the junction capacitance and leaves the diode in a **low impedance state**



– Forward bias = **ON state** in an RF Switch

Advantages of PIN Diodes:

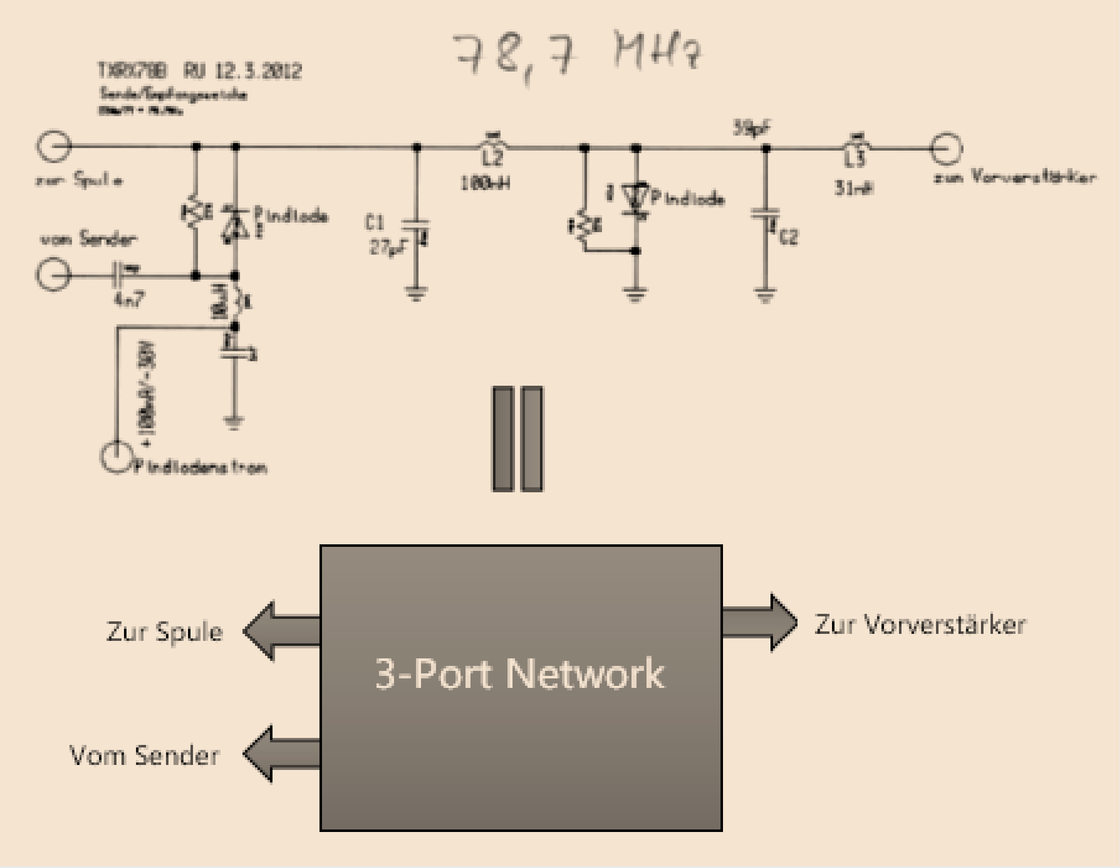
– High operational speeds (range from **1µs to 10µs**)

– Small size ≡ can easily be embedded in RF circuits

– control large RF signals with small DC excitation levels

S-Parameters

– Provide complete description of an N-network as seen from its N-Ports



S-Parameters

- Represented in an S-Matrix

$$(S_{11}) \quad \text{(One-port)}$$

$$\begin{pmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{pmatrix} \quad \text{(Two-port)}$$

$$\begin{pmatrix} S_{11} & S_{12} & S_{13} \\ S_{21} & S_{22} & S_{23} \\ S_{31} & S_{32} & S_{33} \end{pmatrix} \quad \text{(Three-port)}$$

- S(1,1), S(2,2), S(3,3) represent the **Reflection Coefficients** of the network
- S(1,2), S(2,3), S(1,3) represent the **Transmission Coefficients** of the network
- **Insertion Loss** can be calculated using:

$$Insertion\ Loss\ (IL) = -20 log10 |S(1,2)| dB$$

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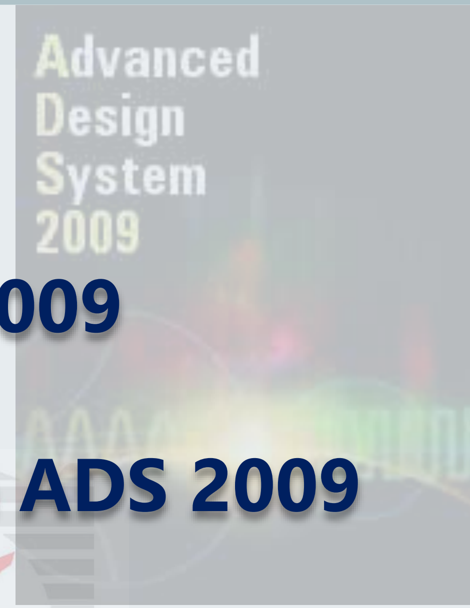
Hardware Development

Involved the following:



- **Schematic Design in ADS 2009**
- **S-Parameter simulations in ADS 2009**
- **Board Layout in EAGLE**
- **Layout Optimisation**
- **Making Wire-wound Inductors**

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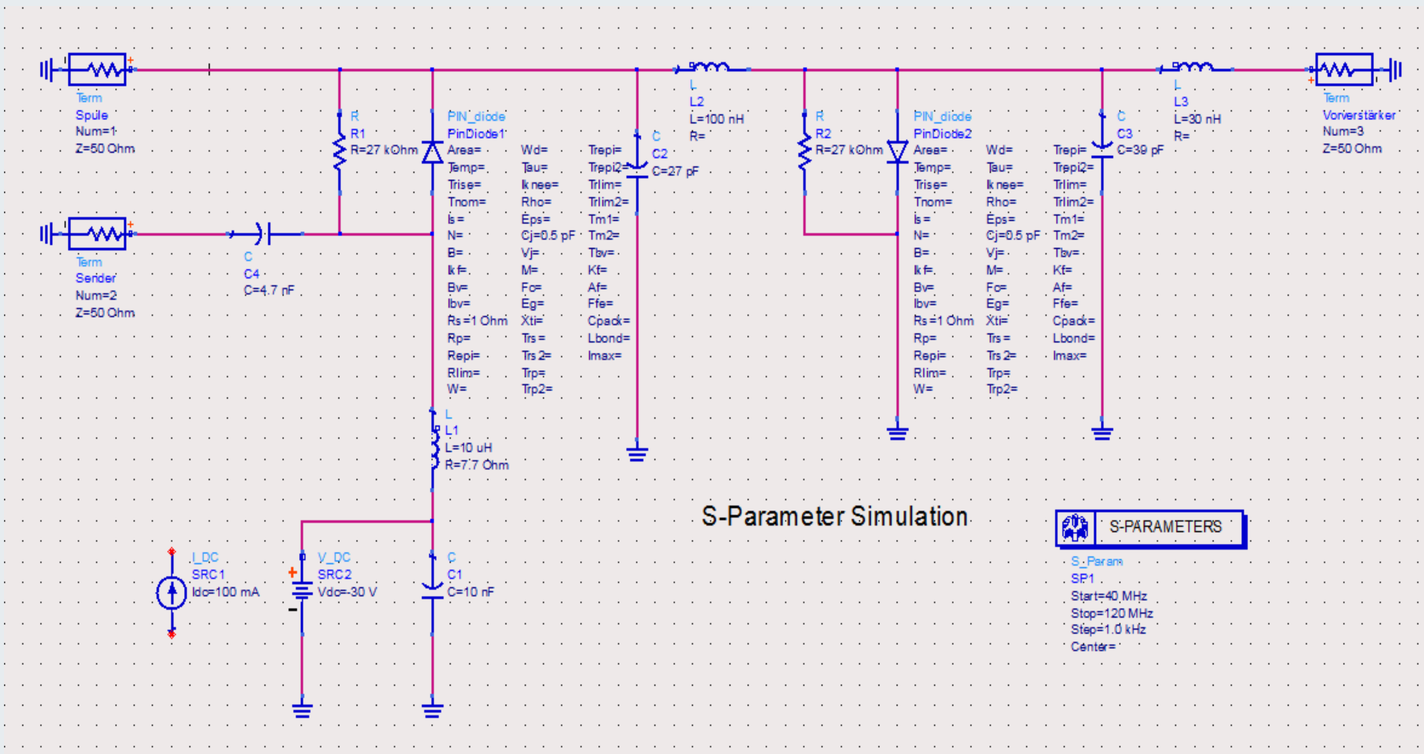
Schematic Design & Simulation

- Carried out using **Advanced Design System**
- Schematic of provided circuit is drawn



- **S-Parameter Simulations** are then carried out using Simulation tool of ADS 2009

ADS 2009 S-Parameter Simulation Results – Forward Biased

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S(1,1) = -15.6dB

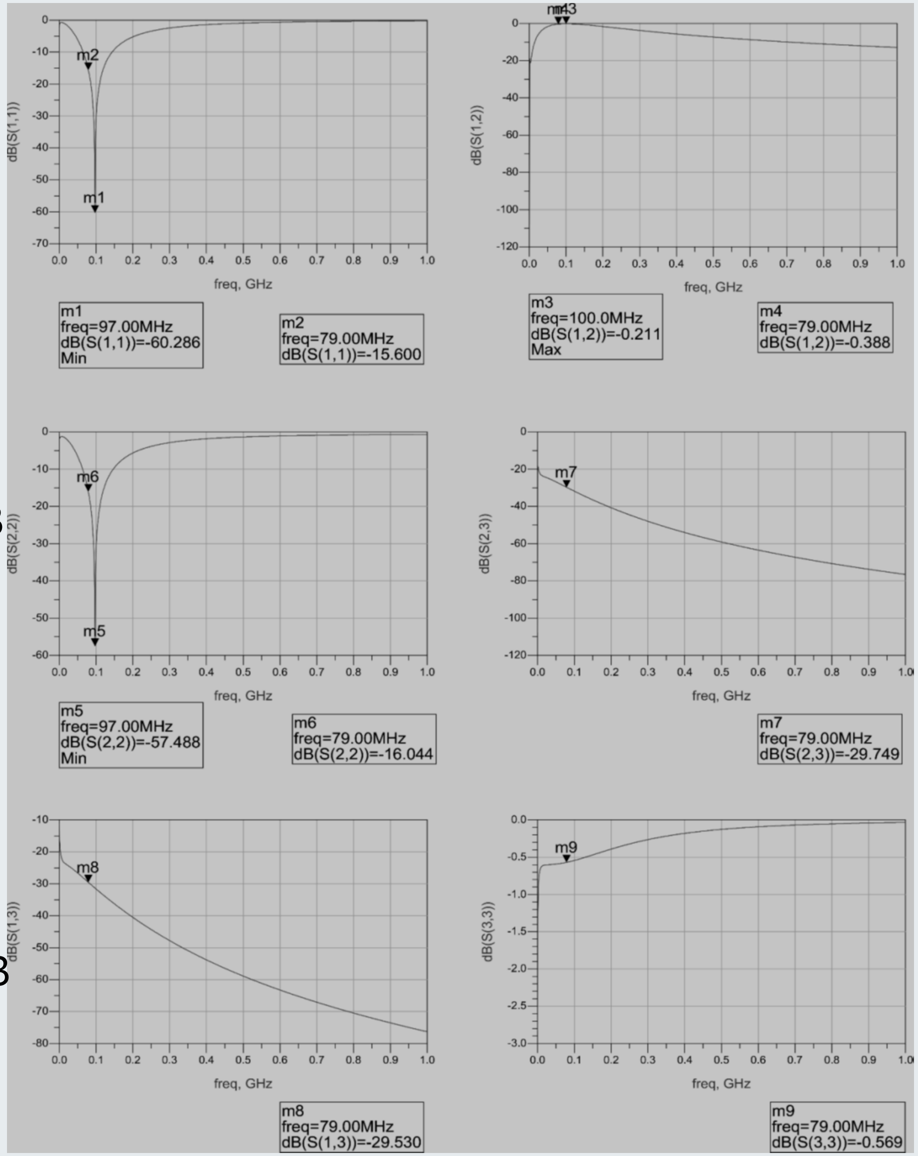
S(1,2) = -0.39dB

S(2,2) = -16.1dB

S(2,3) = -29.7dB

S(1,3) = -29.6dB

S(3,3) = -0.57dB



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ADS 2009 S-Parameter Simulation Results – Reverse Biased

S(1,1) = -45.5dB

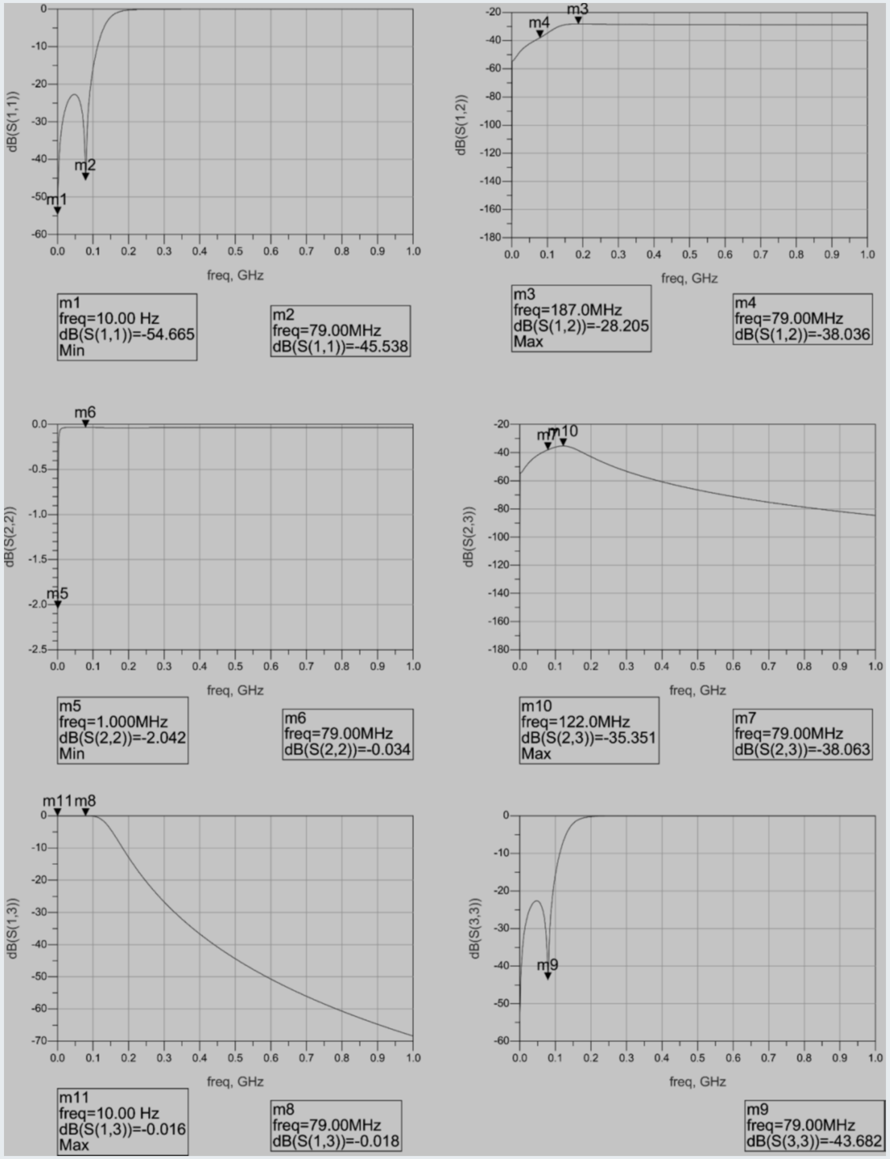
S(1,2) = -38.0dB

S(2,2) = -0.03dB

S(2,3) = -38.0dB

S(1,3) = -0.02dB

S(3,3) = -43.7dB



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Board Layout & Optimisation

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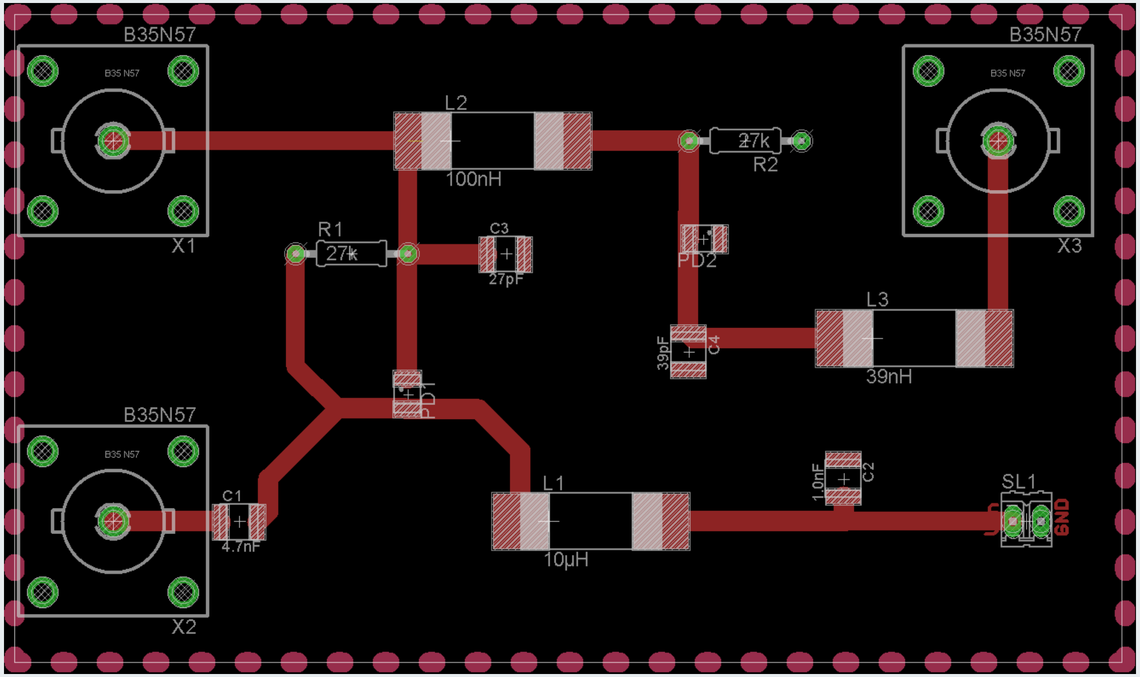
Optimised Circuit layout board drawn using EAGLE

First Version:



– Circuit components way far apart

– Micro-strip width far too small to support 50Ω impedance matching

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Board Layout & Optimisation

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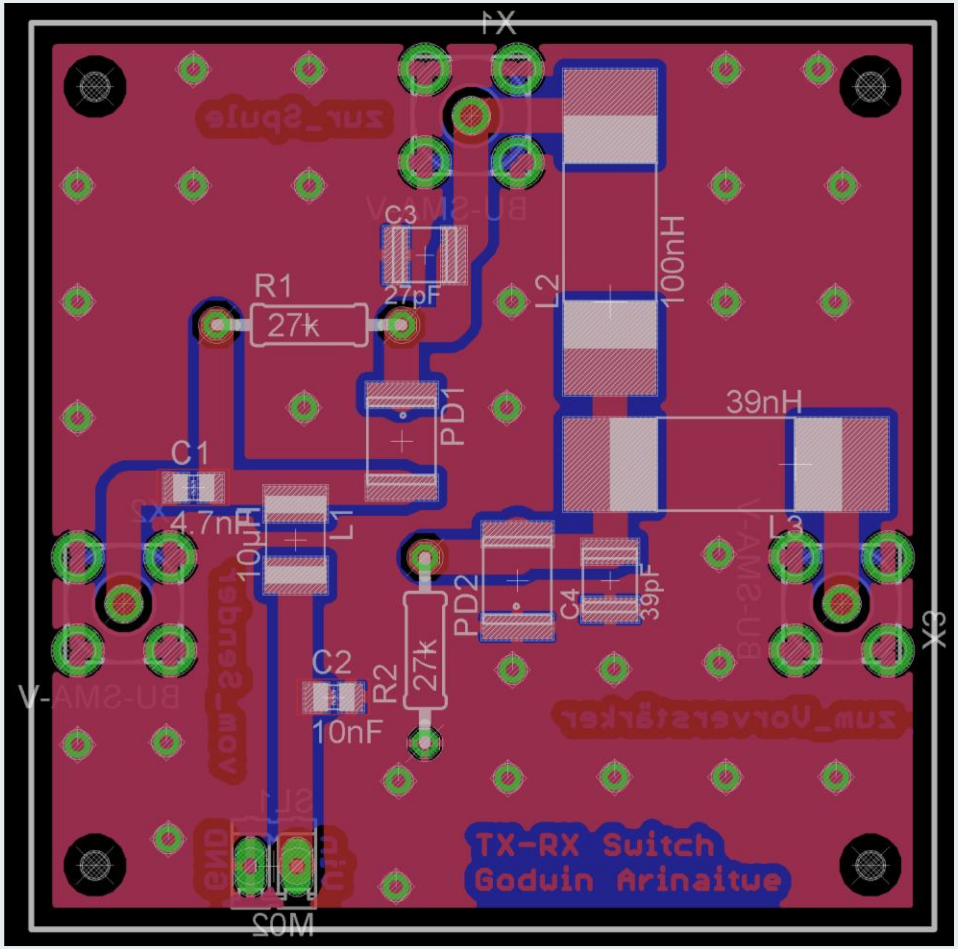
X-Version (Improved & Final Version)



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Wire-wound Inductors

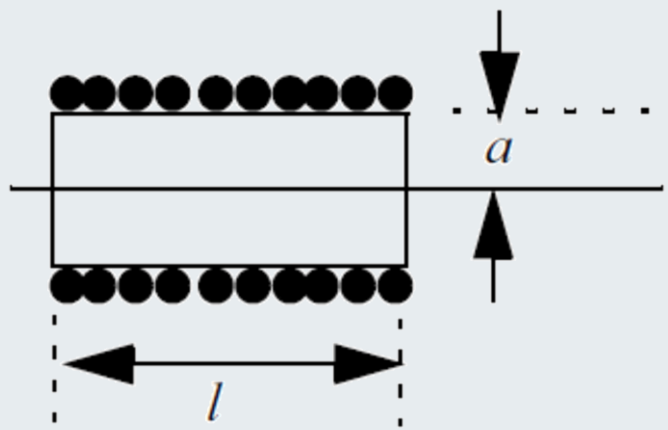
– required number of turns calculated using formula below:

$$N = \frac{1}{a} \cdot \left(\sqrt{\frac{L \cdot (22.9 \cdot a + 25.4 \cdot l)}{10^{-6}}} \right)$$

where;
N = number of turns
l = length in cm
a = radius of coil in cm

– derived from formula to calculate inductance of a circular coil with a single layer turn

$$L = \frac{(a \cdot N)^2}{(22.9 \cdot a + 25.4 \cdot l)} \, \mu H$$



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Wire-wound Inductors – Final Product

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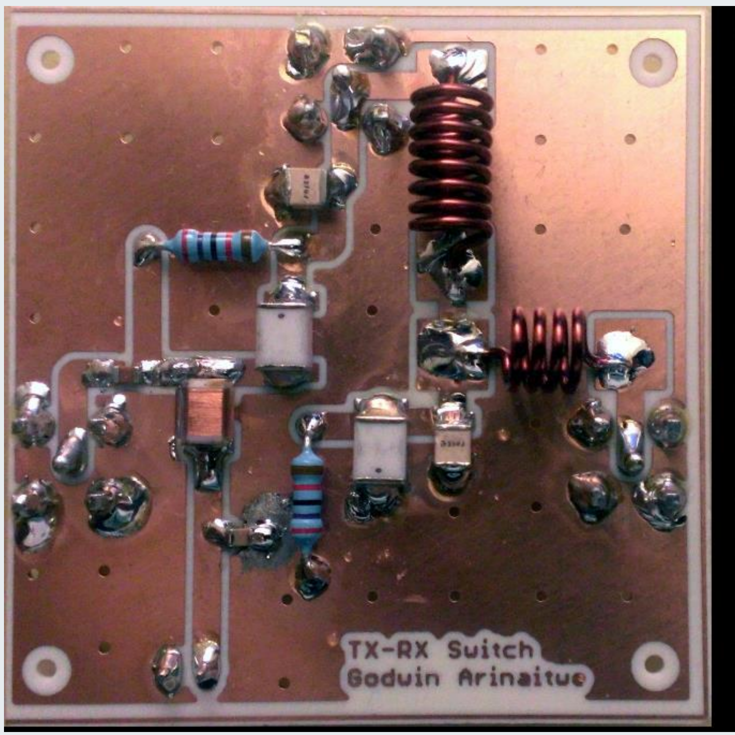
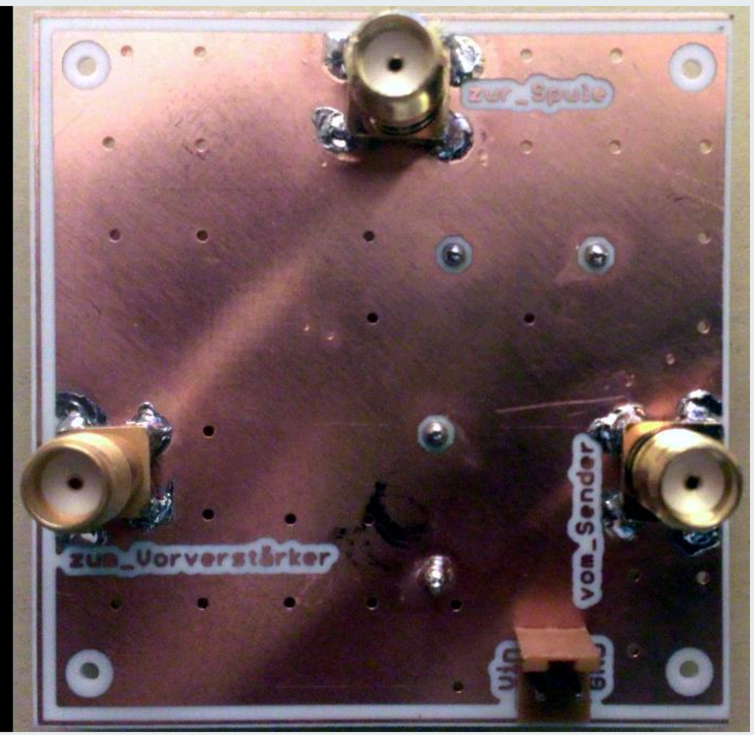
- Inductors (Coils) are wire-wound and finally…
- Circuit components are soldered onto board



Top Layer



Bottom Layer

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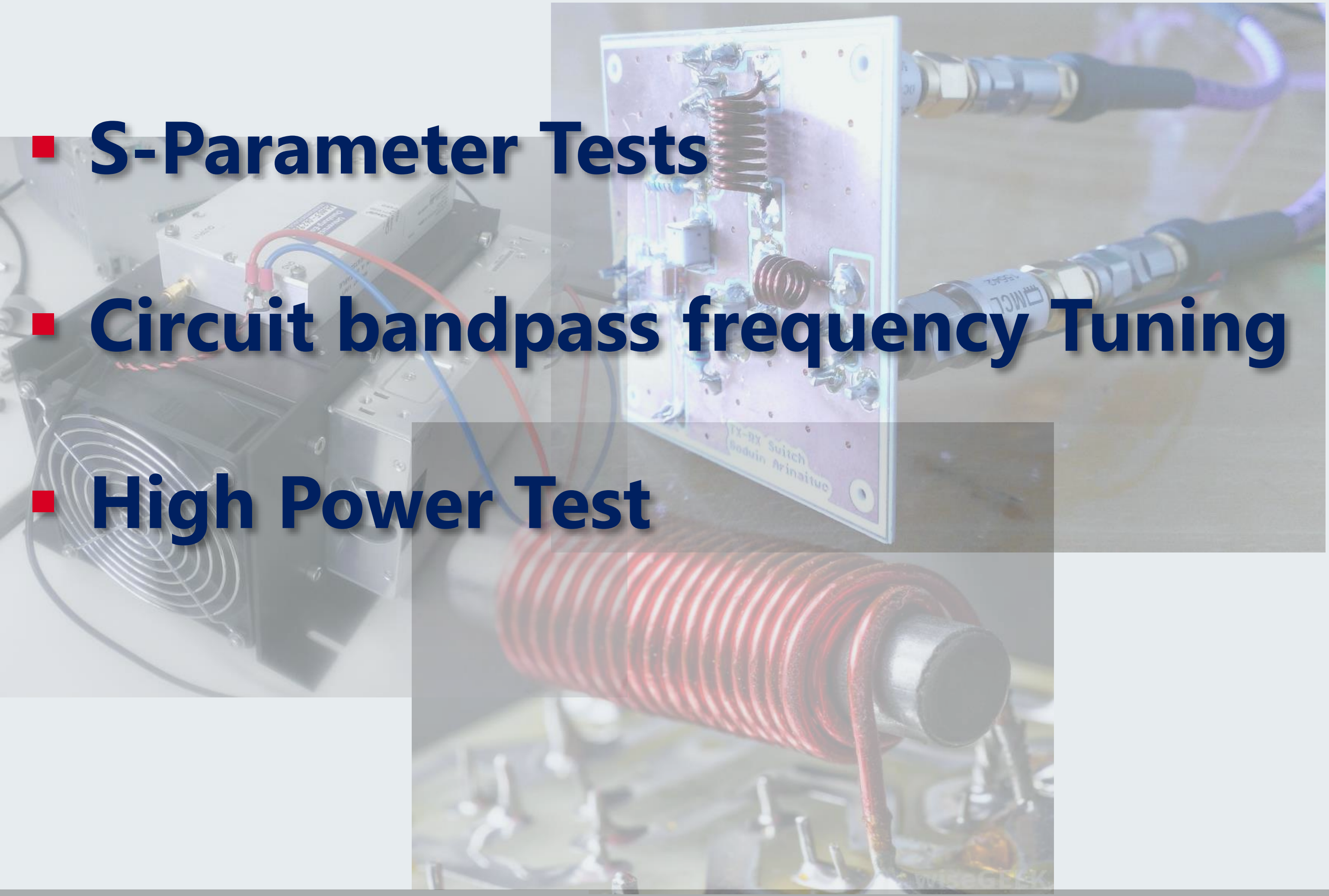
Measurements & Results

Tests carried out on the Tx/Rx switching circuit:



- **S-Parameter Tests**
- **Circuit bandpass frequency Tuning**
- **High Power Test**

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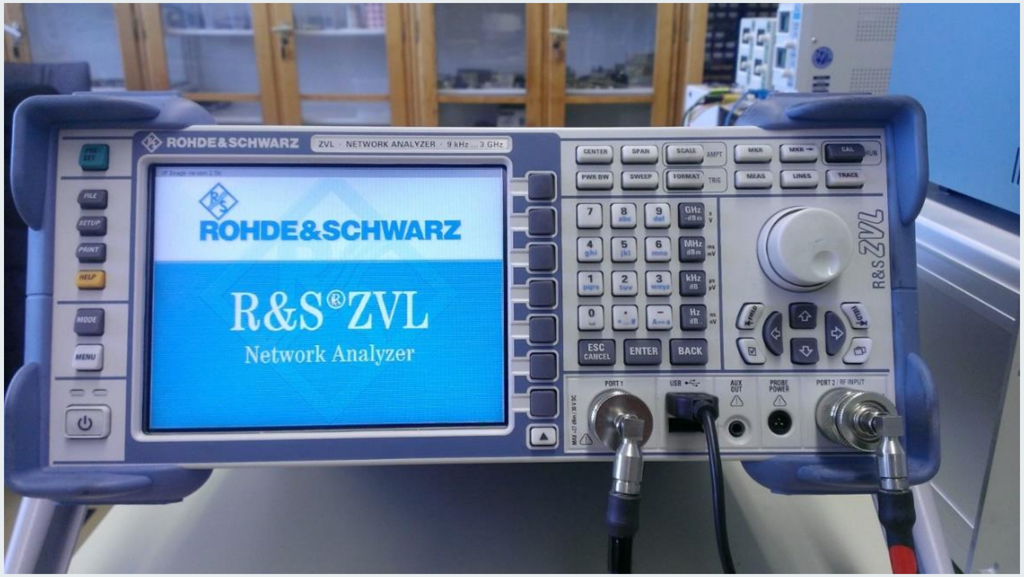
S-Parameter Tests - Setup

- Small-signal Vector network Analyser used to carry out measurements



- Carried out for both Forward Biased state and Reverse Biased State

- 3-Port circuit necessitated additional measurement states like Port-1 Terminated, Port-2 Terminated and Port-3 Terminated states

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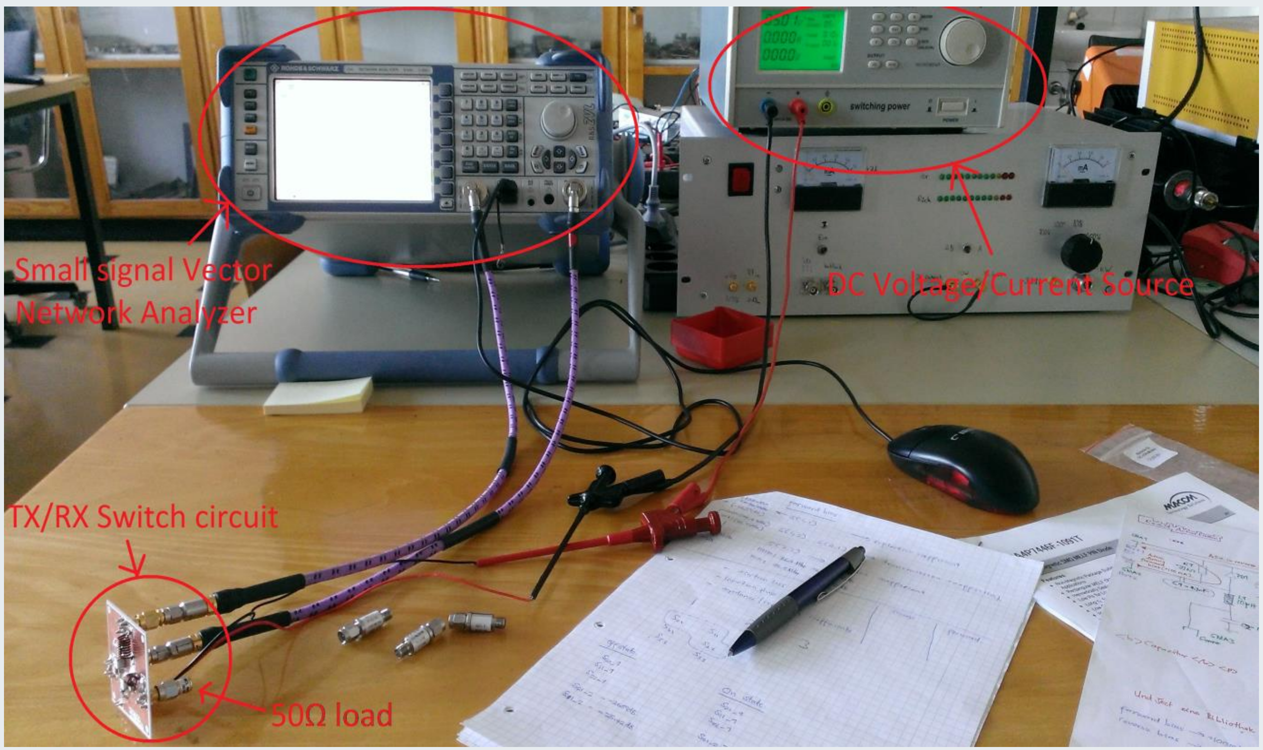
S-Parameter Tests - Setup

- ON state -> Circuit is biased (voltage/current applied)
- OFF state -> Circuit is not biased (floating)

Measurement Setup:



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S-Parameter Tests - Results

Forward biased circuit

Terminated Port	S-Parameter	Magnitude (dB)	
		ON State	OFF State
Port_1 *(Zur Spule)*	S_{22}	-0.211	-16.296
	S_{23}	-34.966	-28.078
	S_{33}	-31.321	-0.267
Port_2 *(vom Sender)*	S_{11}	-28.370	-15.376
	S_{13}	-35.048	-0.279
	S_{33}	-0.180	-14.083
Port_3 *(zum Vorverstärker)*	S_{11}	-26.188	-16.296
	S_{12}	-0.175	-26.464
	S_{33}	-23.973	-0.256

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S-Parameter Tests - Results

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Reverse biased circuit

Terminated Port	S-Parameter	Magnitude	
		ON State	OFF State
Port_1 *(Zur Spule)*	S_{22}	-16.258	-0.284
	S_{23}	-27.978	-27.779
	S_{33}	-16.252	-16.218
Port_2 *(vom Sender)*	S_{11}	-15.549	-15.582
	S_{13}	-0.247	-0.270
	S_{33}	-14.734	-14.741
Port_3 *(zum Vorverstärker)*	S_{11}	-16.509	-16.587
	S_{12}	-26.631	-26.413
	S_{33}	-0.242	-0.289

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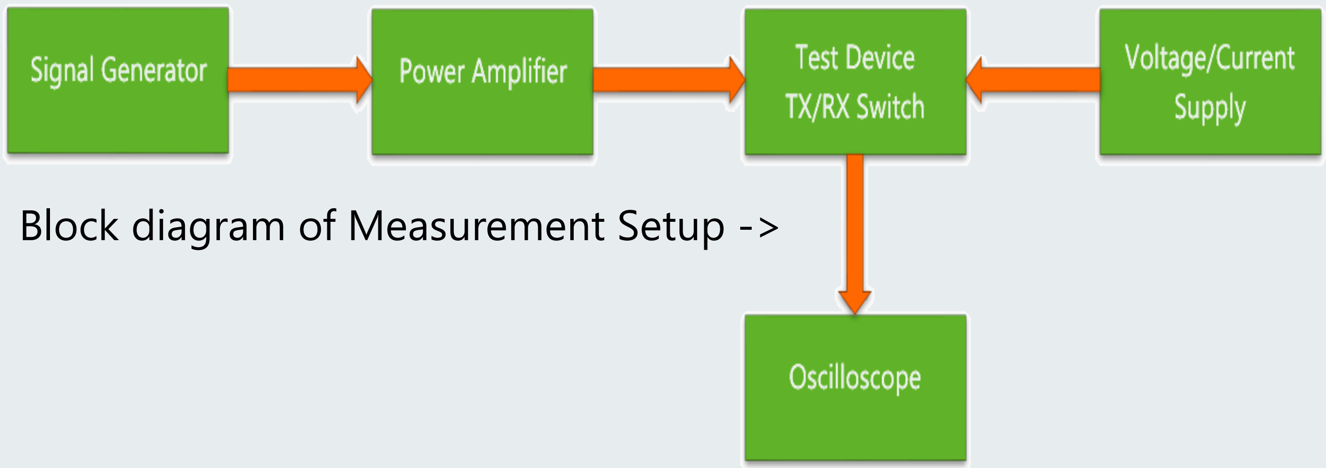
High Power Test – Setup

- Verifies the power handling capabilities of the switch



Block diagram of Measurement Setup ->

- Signal at **78.7 MHz** is generated from an **Agilent N9310A Signal Generator** and is then fed to an amplifier
- Output from the **ZHL-100W-52 amplifier from Mini Circuits Inc.** which can deliver close to 100W RF power CW when driven at 0 dBm input is fed to the switch.
- Switch is biased by applying either **-30V for reverse bias** or **100mA for Forward bias**

High Power Test – Setup

Final measurement setup for High Power Test

The **amplitude of signal generator** is gradually **increased** from **–20 dBm** and observations are made

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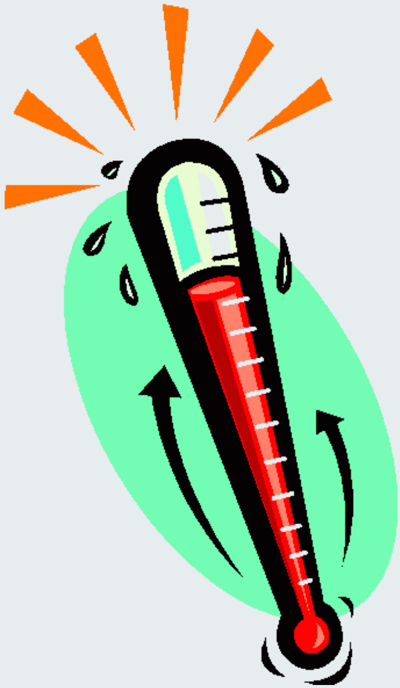
High Power Test – Results



– **Heating** noticed at the PIN diodes

– Signal at oscilloscope gradually fades as the amplitude of signal generator passes **-5dBm** mark or **30W Continuous Wave** output at Amplifier

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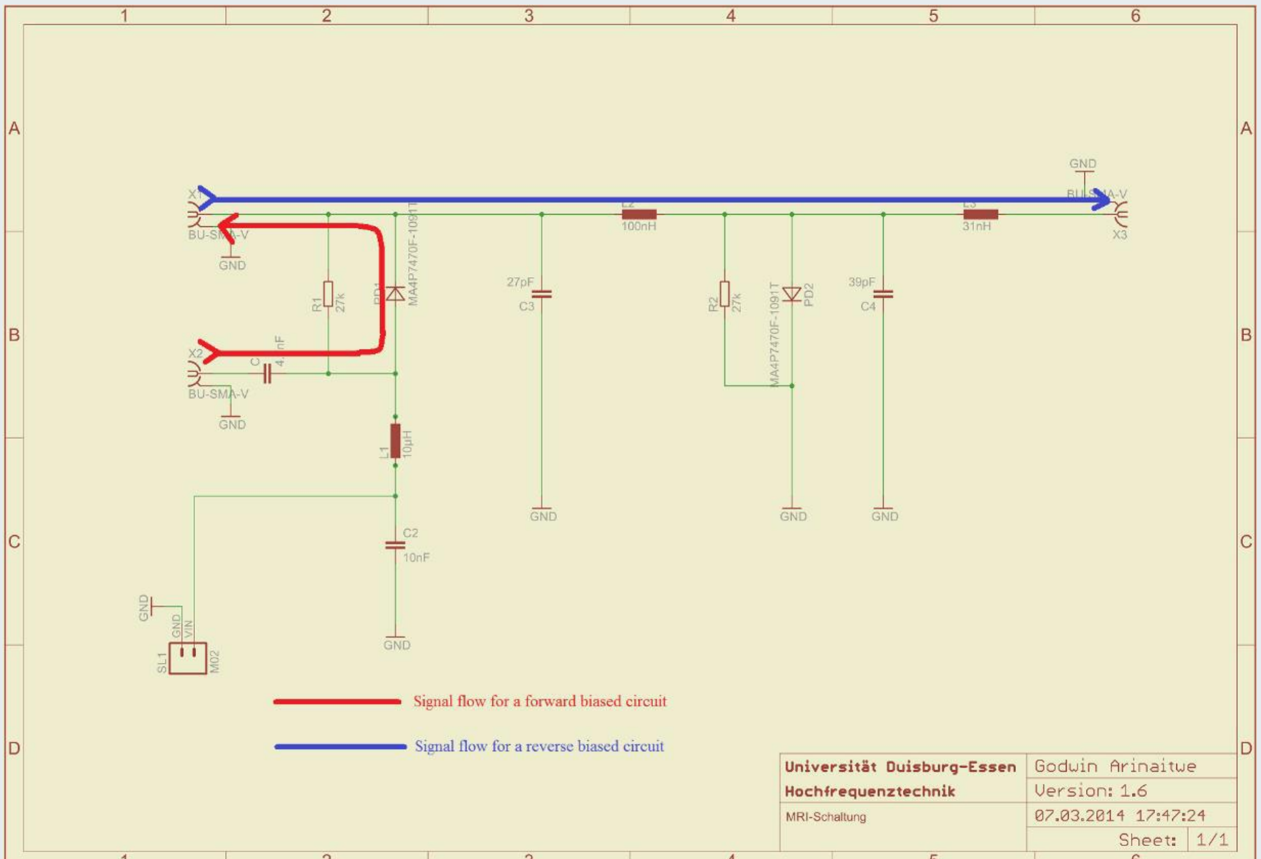
Conclusions – S-Parameters Interpretation

- **S-Parameter Simulations** in ADS and **S-Parameter Measurements** on the Vector Network Analyser show **Circuit Functionality** as illustrated below.



Conclusions

- ✓ Circuit is **feasible** as a fast switch between Transmission and Receive in an MRI **up to about 30W** output at the amplifier
- ✓ This refers to a **Continuous Wave signal** while in reality **Pulsed Wave signals** are sent in an MRI
- ✓ Implies: **Average power** of the MRI < 30W. Such a case could be a **duty cycle of just 3%** and a **peak power of 1kW**

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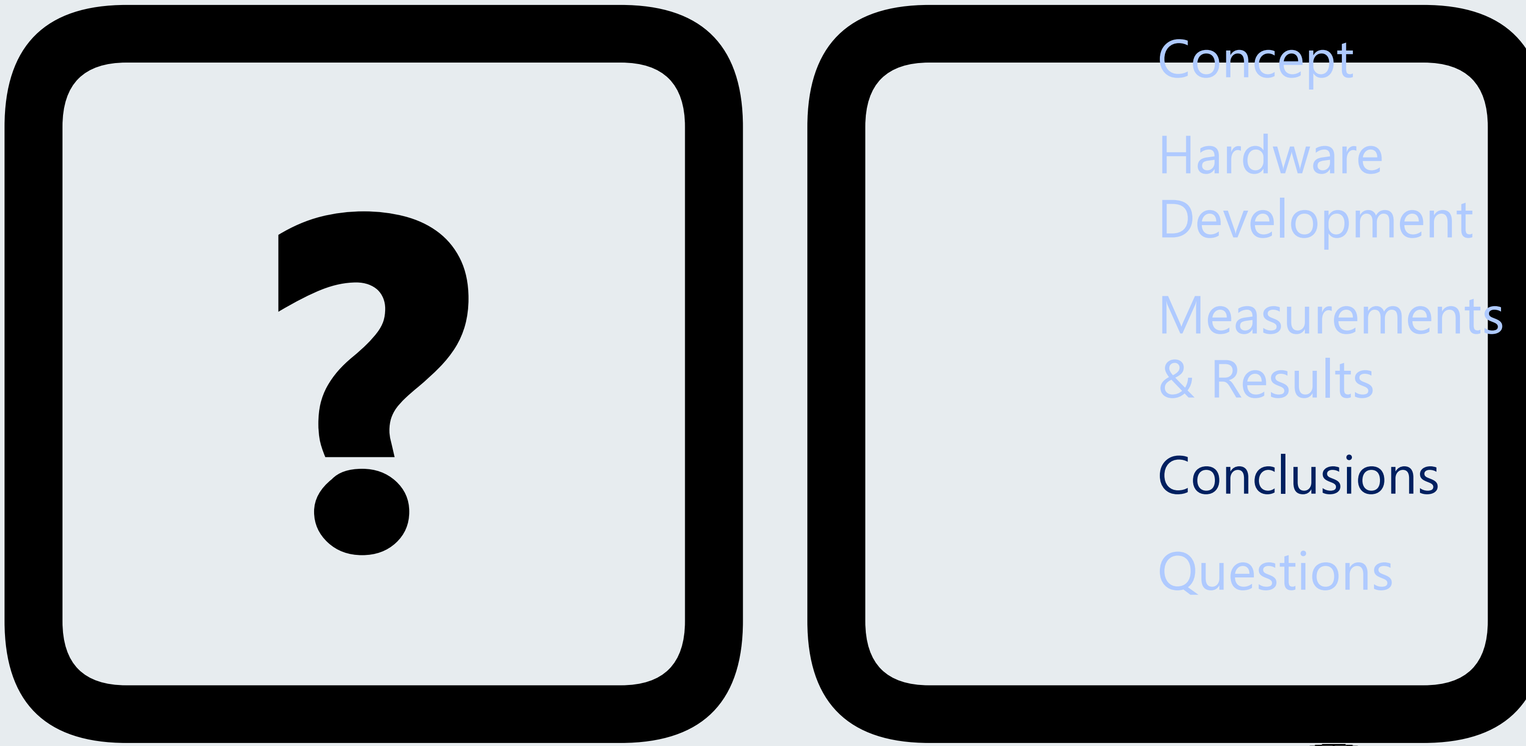
Questions



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