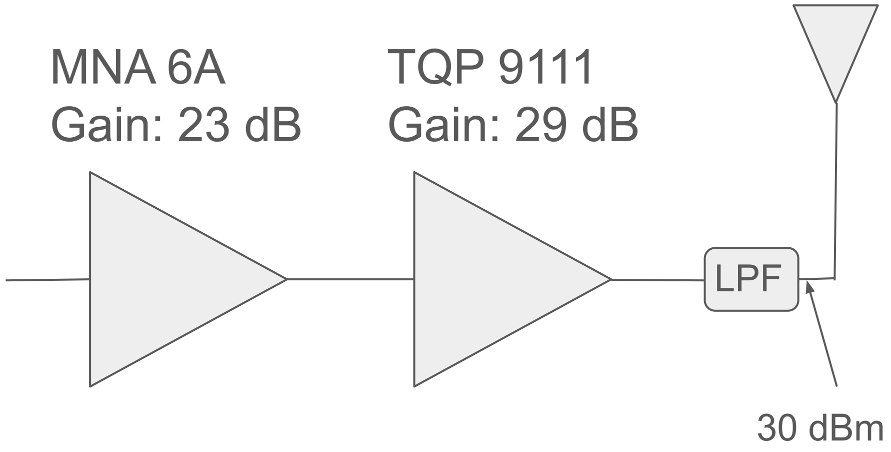
Amplifier for Linear Transponder: Update W3

John Dornbierer Semester Thesis

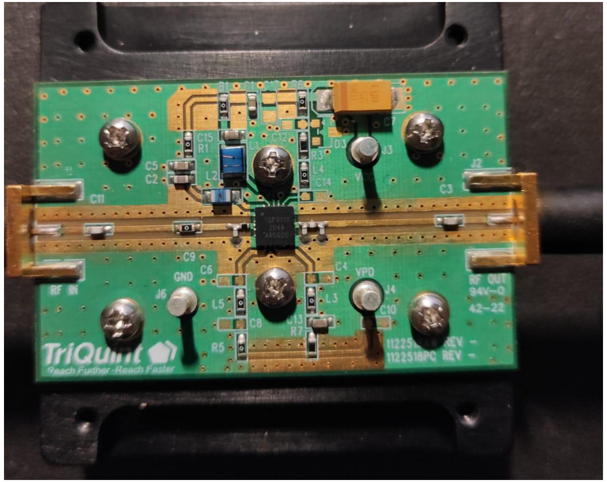
Reminder



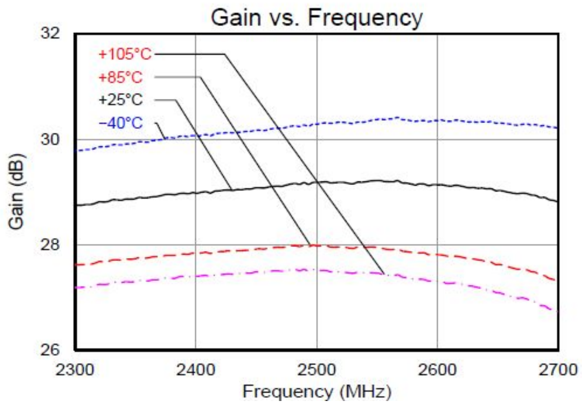
PA devices

Updates

- Ordered Devboard of TQP9111 (main amplifier). It uses an expensive RF substrate (NELCO 4000). Idea: Use it as a reference to measure performance degradation on FR4 7628 substrate (used for linear transponder in Cubesat)



Qorvo PCB2600 Dev Board

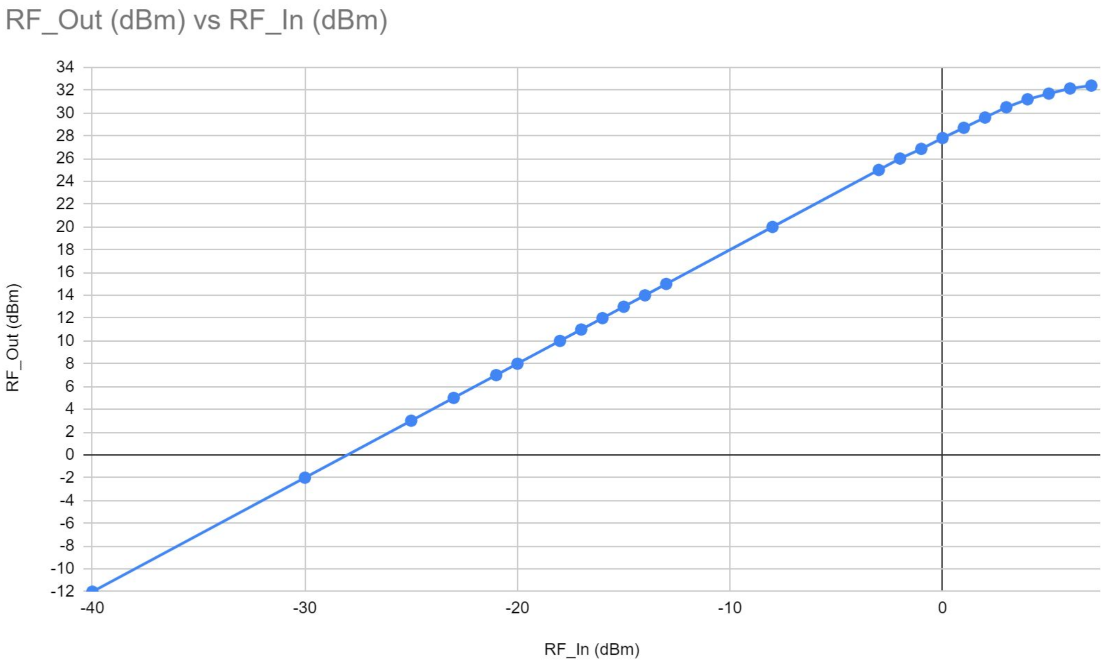


Qorvo PCB2600 Datasheet advertised gain

- Preliminary gain measurements using spectrum analyser. [Thx Marcel ;)]

RF_IN (dBm)	RF_Out (dBm)	Current (mA)	Gain (dB)
-40	-12	550	28
-30	-2	553	28
-25	3	553	28
-23	5	554	28
-21	7	554	28
-20	8	555	28
-18	10	555	28
-17	11	555	28
-16	12	555	28
-15	13	556	28
-14	14	556	28
-13	15	556	28
-8	20	560	28
-3	25	575	28
-2	26	582	28
-1	26.85	595	27.85
0	27.8	615	27.8
1	28.7	645	27.7
2	**29.6**	**686**	**27.6**
3	**30.5**	**733**	**27.5**
4	**31.2**	**780**	**27.2**
5	**31.7**	**822**	**26.7**
6	**32.15**	**866**	**26.15**
7	**32.4**	**900**	**25.4**

Qorvo PCB2600 Dev Board Gain measurements



Results compared to datasheet:

- Gain at low RF input power:

  DevBoard: 28 dB (VCC 5V 550 mA, ~25 °C)

  Datasheet: 29 dB (VCC 5V 545 mA, 25°C)

- Gain at 30.5 dBm RF output power

  DevBoard: 27.5 dB (VCC 5V 733 mA, ~25°C)

- OP1dB

  DevBoard: ~31.2 dBm at ~25 °C

  Datasheet: 33 dBm at 25 °C

- At 30 dBm output the expected gain is 27.5 dB, on FR4 we expect further performance degradation. In order to compensate the loss in gain give us more headroom to play with and make the VGA operate further away from op1dB, I opted to add a preamplifier with more gain (QPA9120 from Qorvo) vs MNA6A+

Stage	Component	Power ratings [dBm]			Power/Gain and Signal strength	
		Max. Input Power	P1dB	IP3	min Sig. strength	max Sig. strength
Antenna	-					
					-100.00	-80.00
PSF	RBP-440+	27.00	-	-	-1.69	-1.69
					-101.69	-81.69
LNA	MAR-6SM+	20.00	-	-	20.65	20.65
					-81.04	-61.04
IRF	RBP-440+	27.00	-	-	-1.67	-1.67
					-82.71	-62.71
Mixer 1	RF2052	15.00	-	18 (IIP3)	-8.00	-8.00
					-90.71	-70.71
HF1	RBP-75+	20.00	-	-	-1.88	-1.88
					-92.59	-72.59
IFA1	PSA-8A+	13.00	12.8 (OP1dB)	25.8 (OIP3)	31.00	31.00
					-61.59	-41.59
IFA2	PSA-8A+	13.00	12.8 (OP1dB)	25.8 (OIP3)	31.00	31.00
					-30.59	-10.59
SBPF	GMCF-HF 70G30B	?	-	-	-3.00	-3.00
					-33.59	-13.59
VGA	AD8367	?	8.5 (OP1dB)	36.5 (OIP3)	39.84	19.84
					6.25	6.25
Mixer 2	RF2052	15.00	-	18 (IIP3)	-8.00	-8.00
					-1.75	-1.75
HF2	RBP-280+	26.00	-	-	-2.70	-2.70
					-4.45	-4.45
Mixer 3	RF2052	15.00	-	18 (IIP3)	-8.00	-8.00
					-12.45	-12.45
HF3	BFCN-2450+	?	-	-	-2.25	-2.25
					-14.70	-14.70
Coupler	CPJC-6-252R+	33.00	-	-	-1.20	-1.20
					-15.90	-15.90
Combiner	SCN-2-27+	40.00	-	-	-3.40	-3.40
					-19.30	-19.30
PA1	MNA-6A+	10.00	19 (OP1dB)	30 (OIP3)	23.20	23.20
					3.90	3.90
PA2	TQP9111	23.00	32.5 (OP1dB)	46 (OIP3)	27.00	27.00
					30.90	30.90
HF4	LFCG-2500+	36.50	-	-	-0.90	-0.90
					30.00	30.00

estimates from manufacturers
measurements on prototype PCB

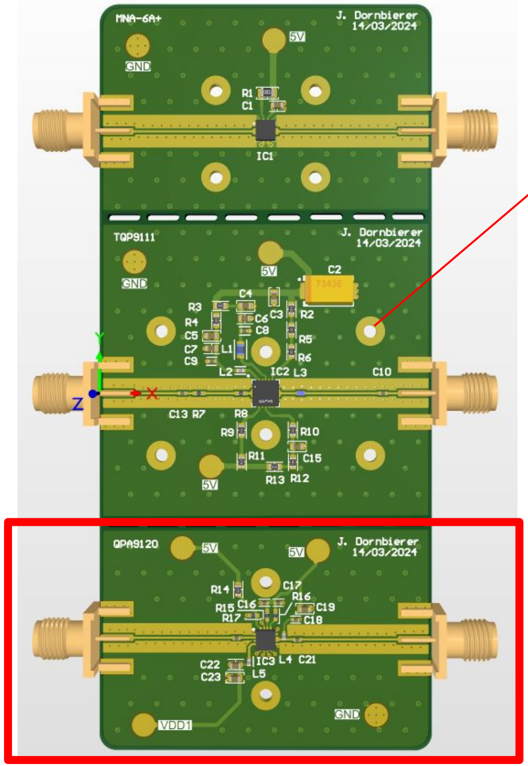
MNA-6A+ & TQP9111 (VGA is loaded a lot)

Stage	Component	Power ratings [dBm]			Power/Gain and Signal strength	
		Max. Input Power	P1dB	IP3	min Sig. strength	max Sig. strength
Antenna	-					
					-100.00	-80.00
PSF	RBP-440+	27.00	-	-	-1.69	-1.69
					-101.69	-81.69
LNA	MAR-6SM+	20.00	-	-	20.65	20.65
					-81.04	-61.04
IRF	RBP-440+	27.00	-	-	-1.67	-1.67
					-82.71	-62.71
Mixer 1	RF2052	15.00	-	18 (IIP3)	-8.00	-8.00
					-90.71	-70.71
HF1	RBP-75+	20.00	-	-	-1.88	-1.88
					-92.59	-72.59
IFA1	PSA-8A+	13.00	12.8 (OP1dB)	25.8 (OIP3)	31.00	31.00
					-61.59	-41.59
IFA2	PSA-8A+	13.00	12.8 (OP1dB)	25.8 (OIP3)	31.00	31.00
					-30.59	-10.59
SBPF	GMCF-HF 70G30B	?	-	-	-3.00	-3.00
					-33.59	-13.59
VGA	AD8367	?	8.5 (OP1dB)	36.5 (OIP3)	34.04	14.04
					0.45	0.45
Mixer 2	RF2052	15.00	-	18 (IIP3)	-8.00	-8.00
					-7.55	-7.55
HF2	RBP-280+	26.00	-	-	-2.70	-2.70
					-10.25	-10.25
Mixer 3	RF2052	15.00	-	18 (IIP3)	-8.00	-8.00
					-18.25	-18.25
HF3	BFCN-2450+	?	-	-	-2.25	-2.25
					-20.50	-20.50
Coupler	CPJC-6-252R+	33.00	-	-	-1.20	-1.20
					-21.70	-21.70
Combiner	SCN-2-27+	40.00	-	-	-3.40	-3.40
					-25.10	-25.10
PA1	QPA9120	22.00	22 (OP1dB)	35 (OIP3)	29.00	29.00
					3.90	3.90
PA2	TQP9111	23.00	32.5 (OP1dB)	46 (OIP3)	27.00	27.00
					30.90	30.90
HF4	LFCG-2500+	36.50	-	-	-0.90	-0.90
					30.00	30.00

estimates from manufacturers
measurements on prototype PCB

QPA9120 & TQP9111 (VGA is loaded less + higher flexibility)

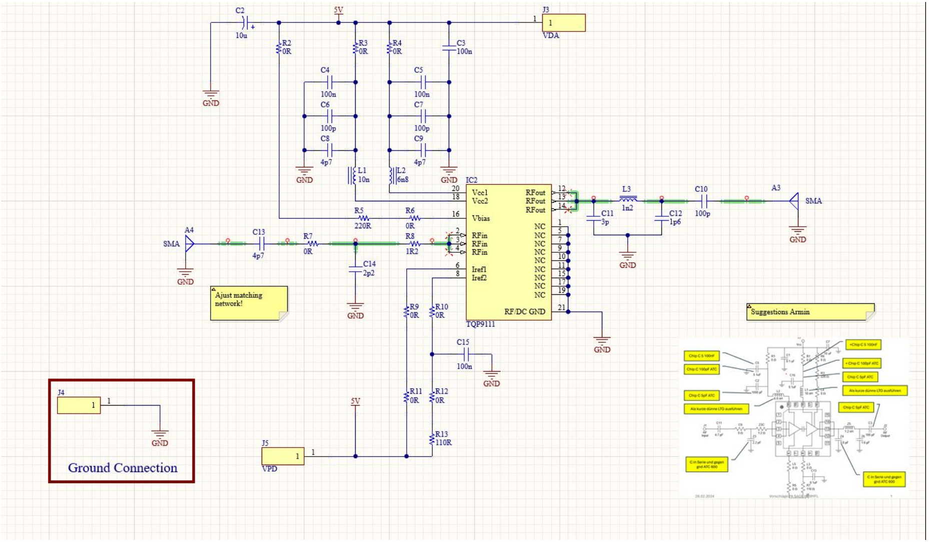
- Created an altium project with amplifiers in order to get an idea about performance degradation using cheap FR4 7628 substrate



Prototype Board on FR4 substrate

- Design is nearly complete
- Matching Circuit still has to be simulated with Keysight ADS and adjusted

Heat sink mounting holes compatible with Qorvo Development Board
Added second preamp → higher gain → gives us more headroom (VGA will operate less closely do P1db for weak signals -> see slide 6)



TQP9111 schematic (Adjusted bias circuit, matching circuit still needs to be adjusted)

Impedance matching circuit

In order to gain more insights into the matching I tried to calculate the optimum source and load impedances for the TQP9111. I used de-embedded S-parameters for this.

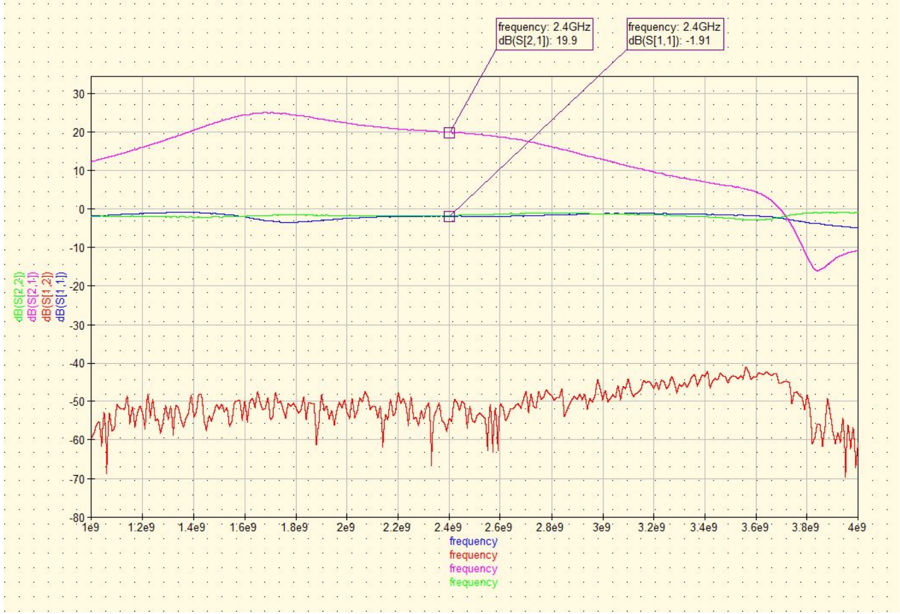
2.4 GHz, 5V, 545 mA at 25°C

S11 = 0.802654 / 162.7281°

S21 = 9.90529 / 79.60395 °

S12 = 0.0019171 / 96.81241 °

S22 = 0.818418 / -178.5883 °



S-parameters from TQP9111 device

Stability:

$Ds = S11 * S22 - S12 * S21 = 0.675474 / -15.5177°$

$K = (1 + |Ds|^2 - |S11|^2 - |S22|^2) / (2*|S12|*|S21|) = 3.74425 > 1$

→ unconditionally stable

Maximum achievable gain:

$B1 = 1 + |S11|^2 - |Ds|^2 - |S22|^2 = 0.51818 > 0$

$MAG = 10 \log(|S21| / |S12|) + 10 \log(K - \sqrt{K^2 - 1}) = 28{,}4678 \text{ dB}$

→ According to datasheet 29 dB is possible

Optimal load impedance calculation:

$C2 = S22 - Ds^*\mathrm{conj}(S11) = 0.276275 \angle -179.26°$

$B2 = 1 + |S22|^2 - |Ds|^2 - |S11|^2 = 0.56929 > 0$

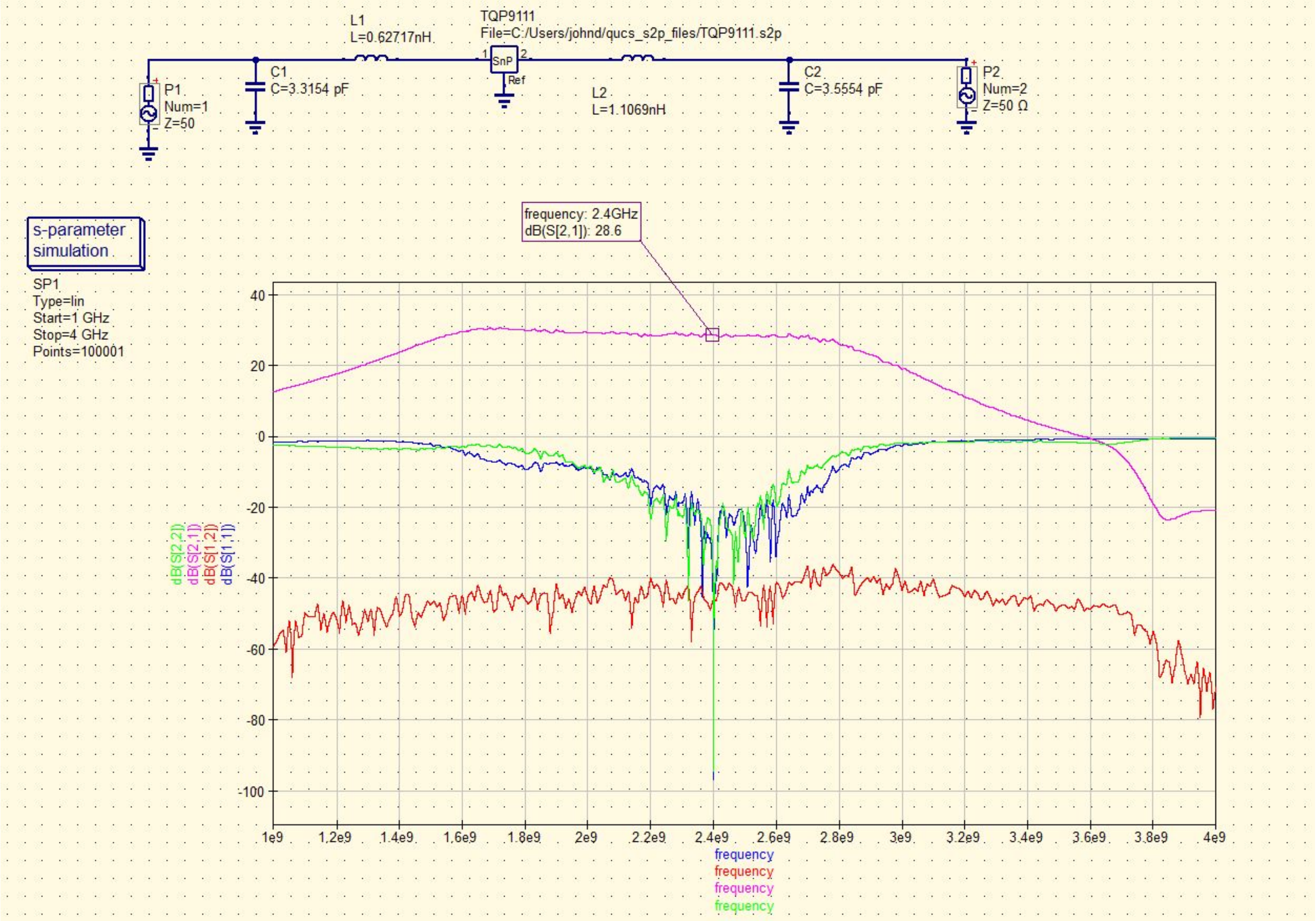
$|\Gamma_L| = (B2 - \sqrt{B2^2 - 4^*|C2|^2}) / 2^*|C2| = 0.782286$, $\mathrm{ang}(\Gamma_L) = 179.26°$

$\rightarrow Z_L = 50 * (1+ \Gamma_L) / (1- \Gamma_L) = 6.10798 + 0.317883^*j$

Optimal source impedance calculation:

$\Gamma_S = S11 + (S12 * S21 * \Gamma_L) / (1 + S22 * \Gamma_L)$

$\rightarrow Z_S = 50 * (1+ \Gamma_s) / (1- \Gamma_s) = 6.89762 - 7.78518^*j$



Optimal Matching circuit Simulation in QUCS (real matching circuit must consider TL and parasitic effects)

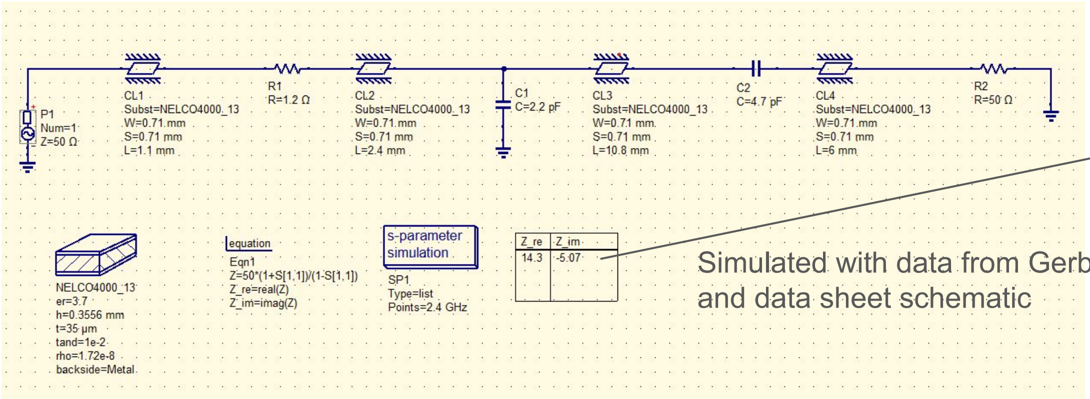
Reverse Engineering of Matching Circuit in datasheet

Input matching circuit

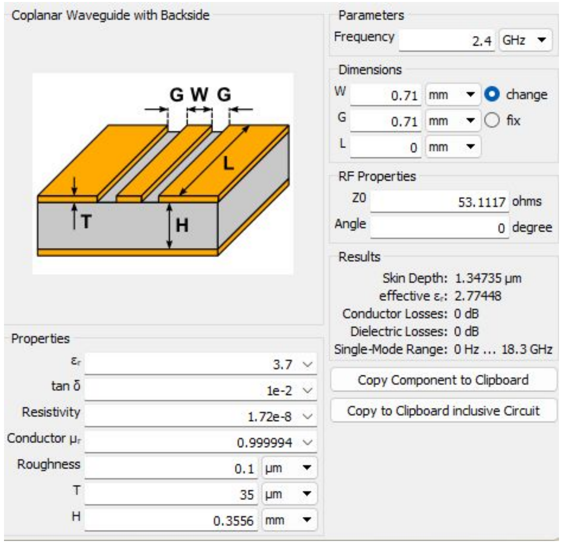
Calculated on slide 10

$Z_{S,\ optimal} = 6.89762 - 7.78518*j$

$Z_{S,\ datasheet} = 14.3 - 5.07*j$

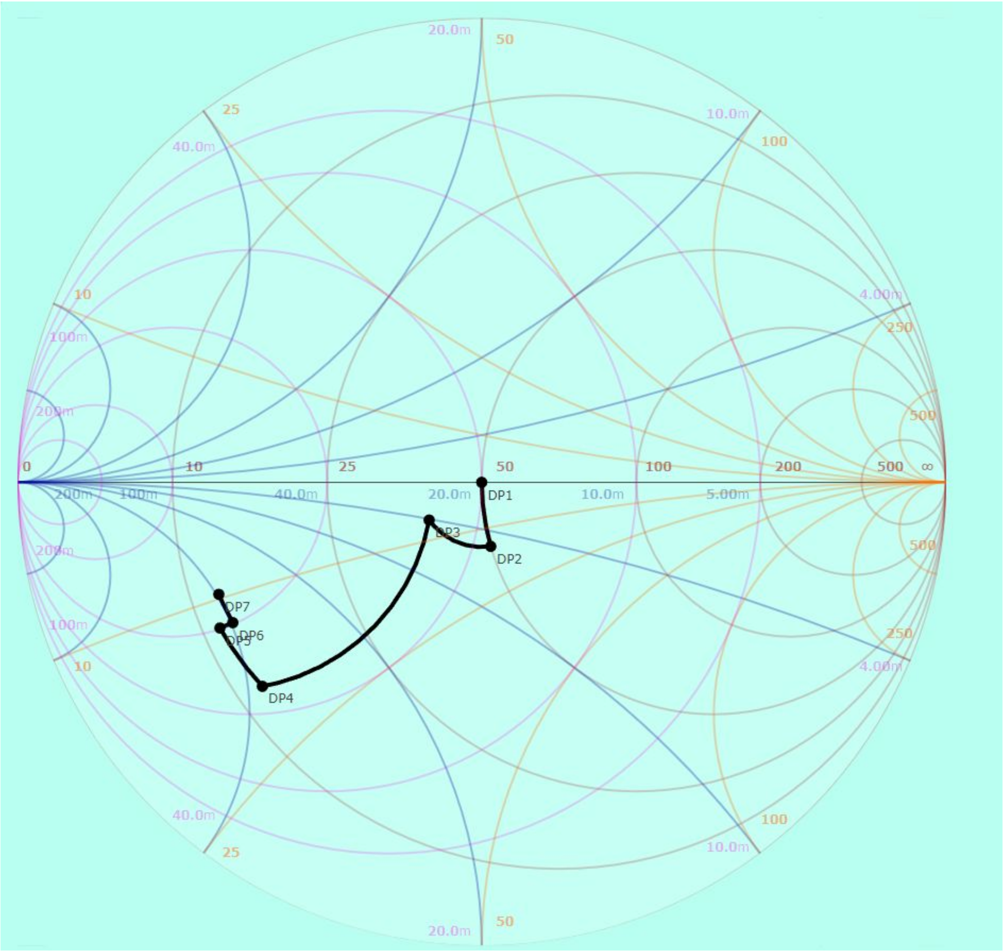


Simulated with data from Gerber files and data sheet schematic

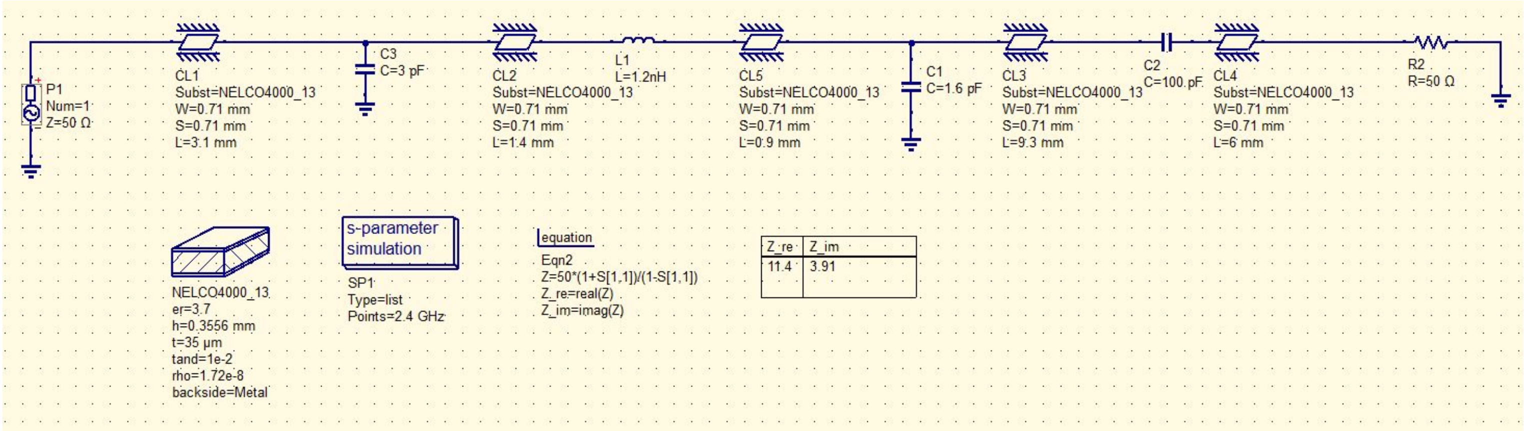


Matching circuit provided in datasheet (I measured dimensions in the gerber files in order to get approx. transmission line lengths)

Smith Chart



Output matching circuit

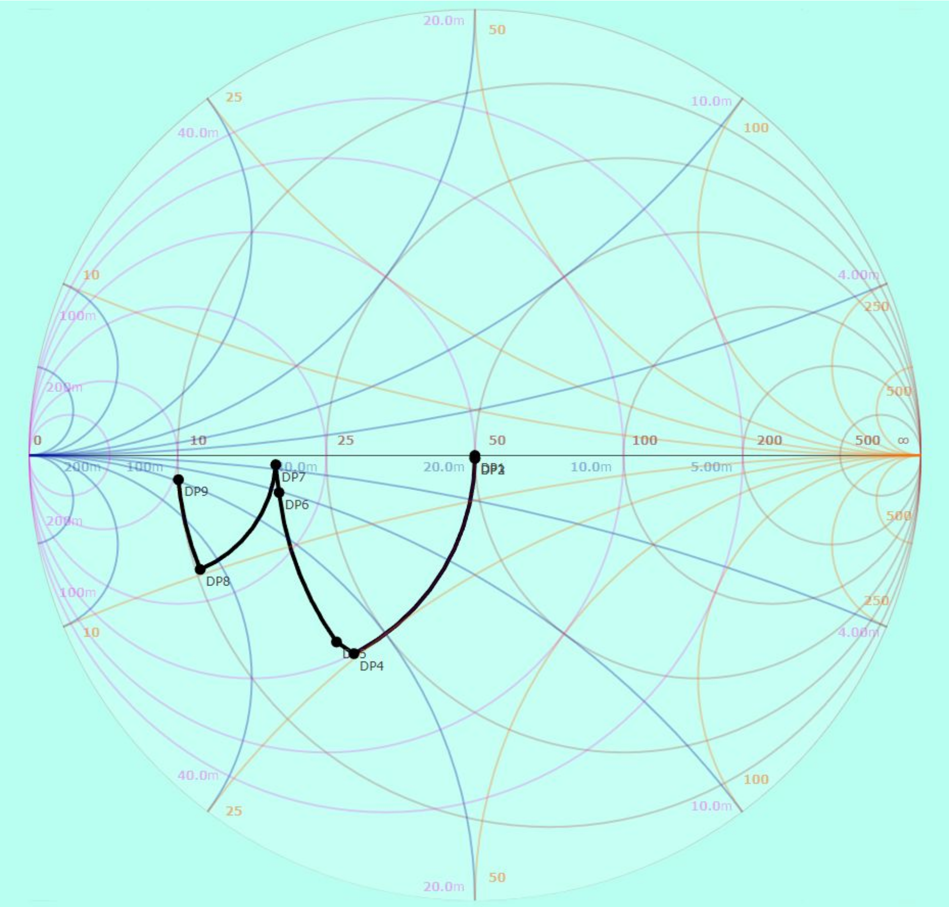


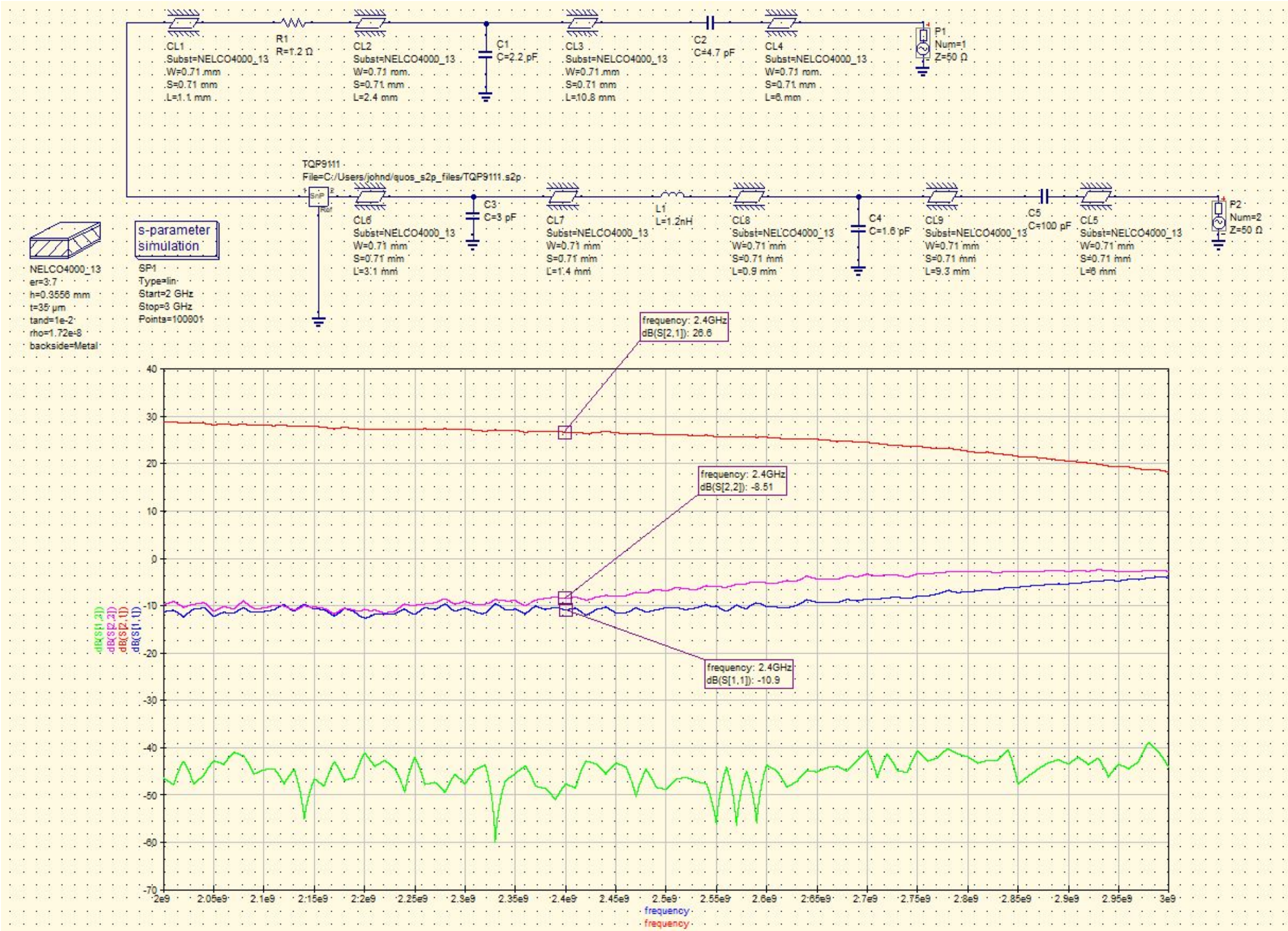
Matching circuit provided in datasheet (I measured dimensions in the gerber files in order to get approx. transmission line lengths)

$$Z_{L,\ opt} = 6.10798 + 0.317883*j$$

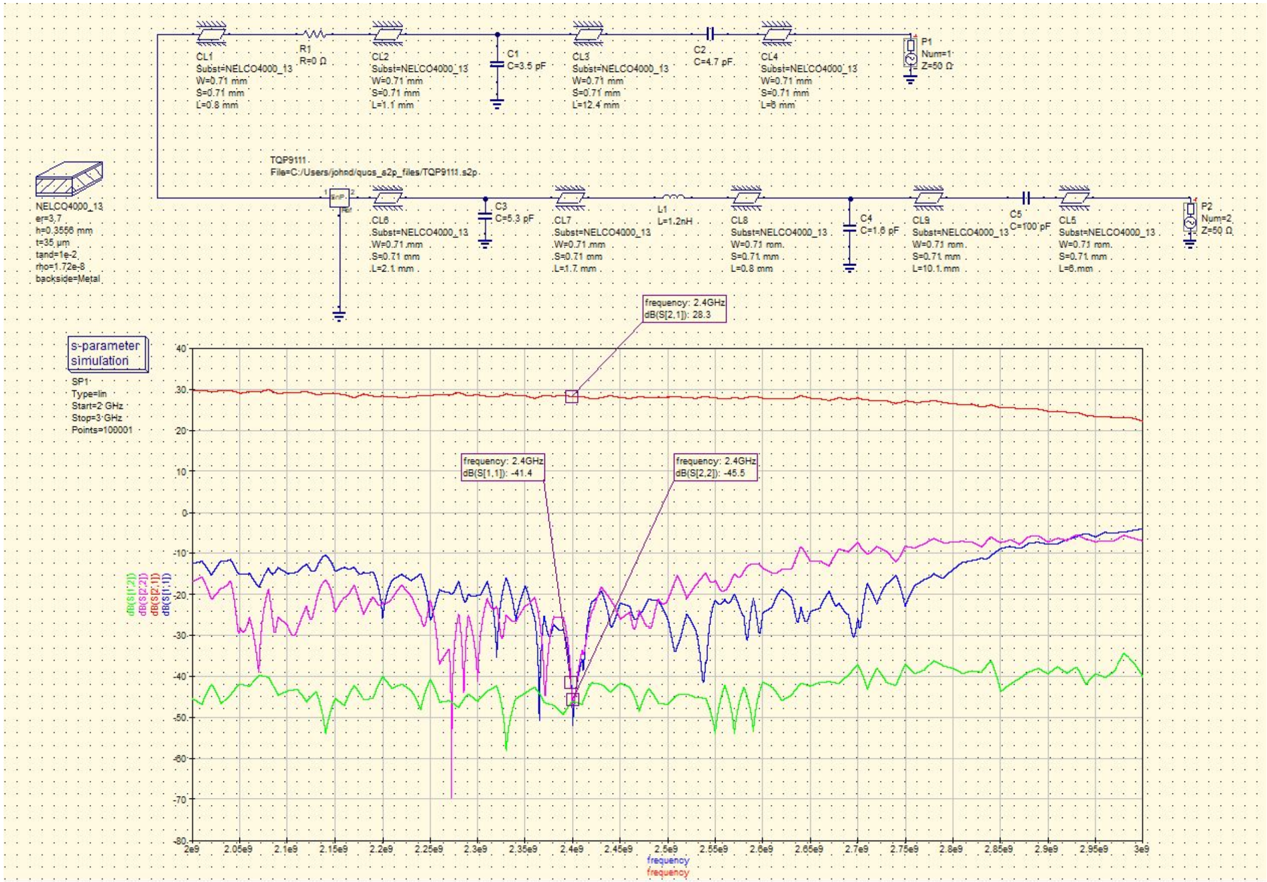
$$Z_{L,\ datasheet} = 11.4 + 3.91*j$$

Smith Chart



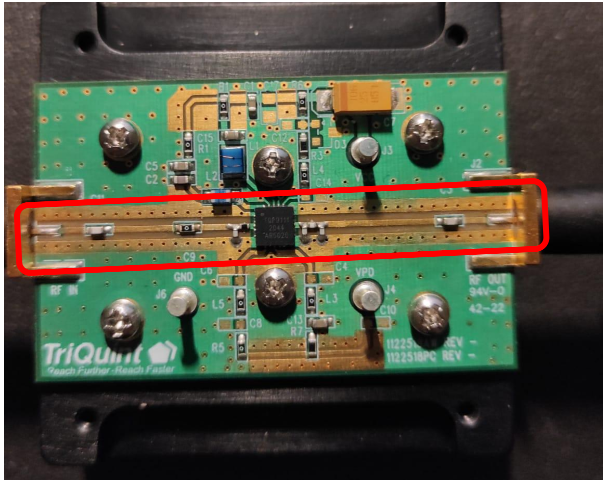


Simulation of datasheet matching circuit

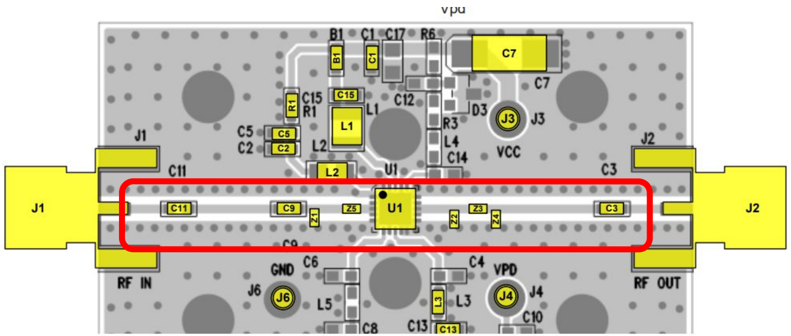


Simulation of modified and optimised datasheet circuit

Matching Circuit on DevBoard

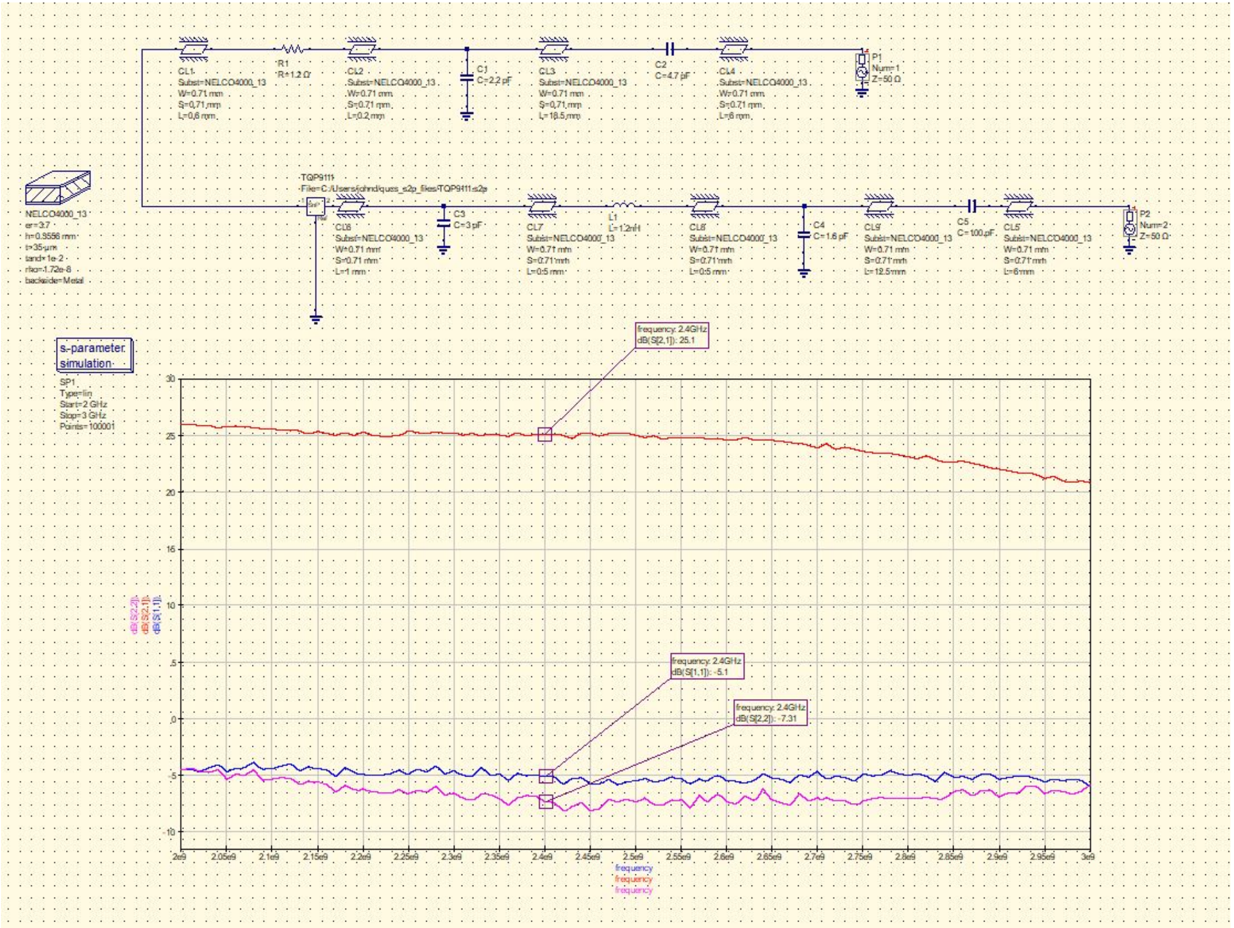


Qorvo PCB2600 Dev Board



Qorvo PCB2600 in datasheet

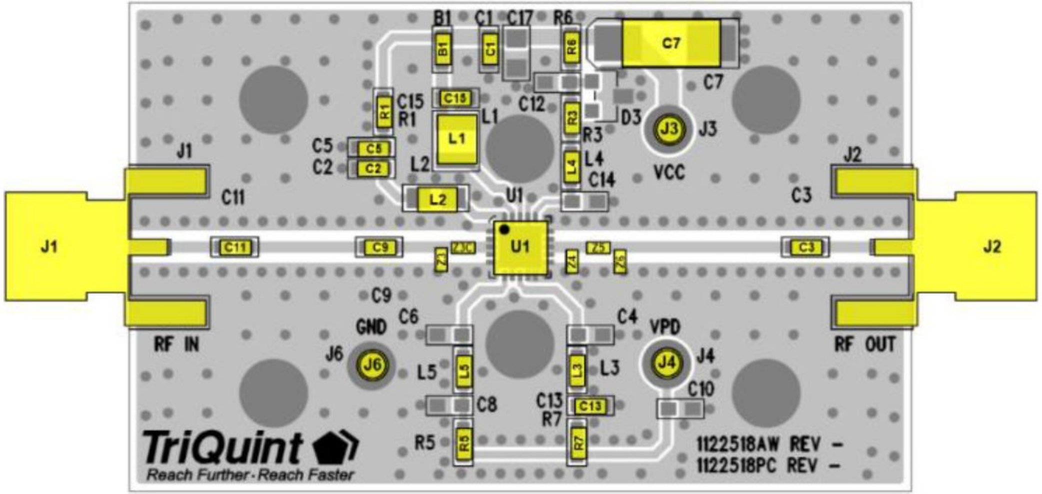
I noticed that the Qorvo PCB2600 Dev Board has same matching topology, but different layout and maybe different components, since simulating the matching of the Dev Board gives bad results. I wrote an E-Mail to Qorvo about this.



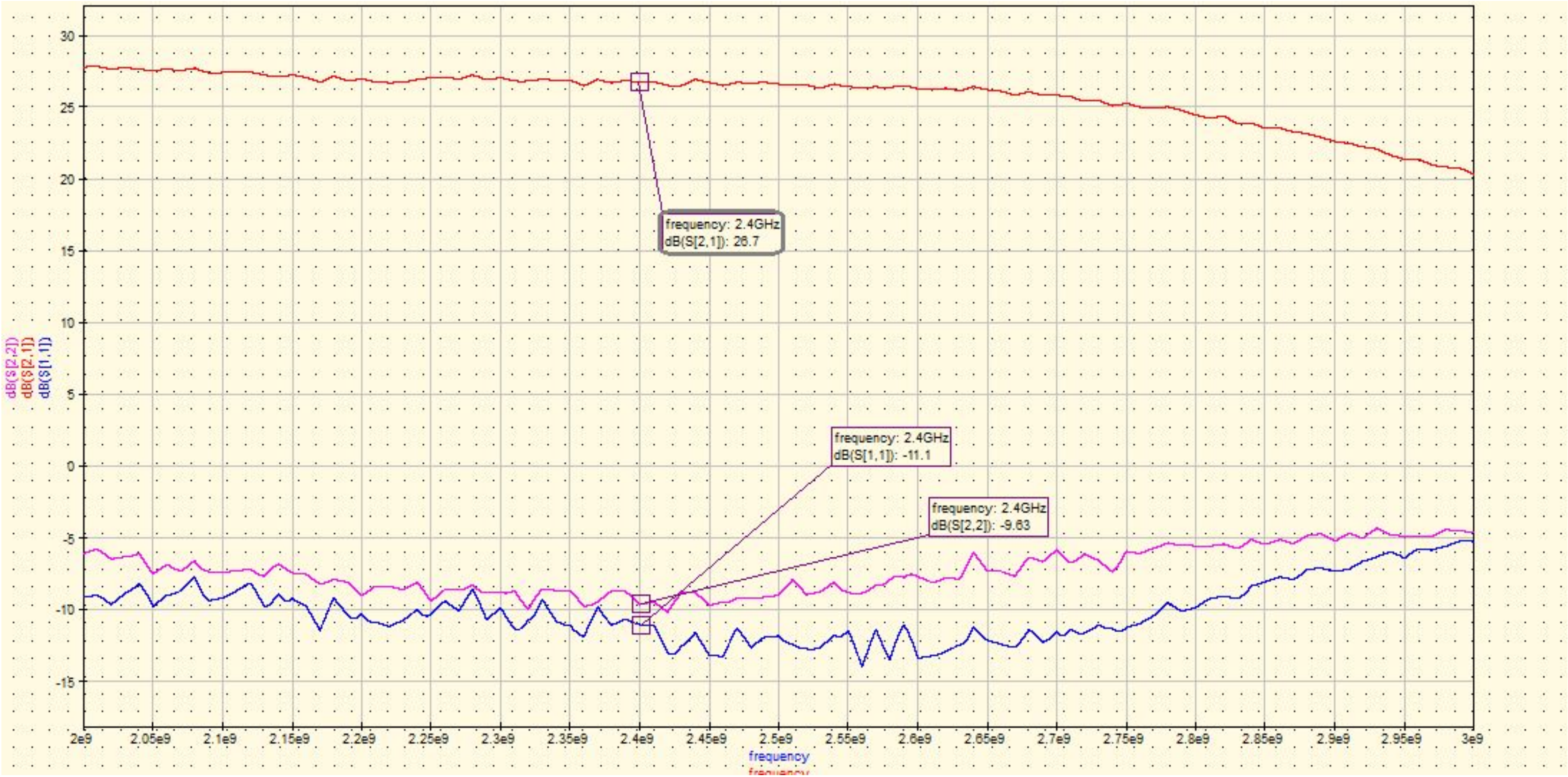
Simulation of PCB2600 matching circuit → bad results

Update: Yes indeed Quorvo responded with a new matching

Some components changed. When I resimulate I get better results!



Updated Matching network of Qorvo Development board



Simulation of updated PCB2600 matching circuit → better results

Matching on FR4 board

What is the loss tangent and electric constant at 2.4 GHz for FR4 7628 from JLCPCB? → No data for 2.4 GHz

Solution: I wrote an E-Mail to JLCPCB, if they could provide information about those values, they said they will check with the manufacturing fab.

For now I just took standard values for FR4 7628 @ 2.4 GHz:

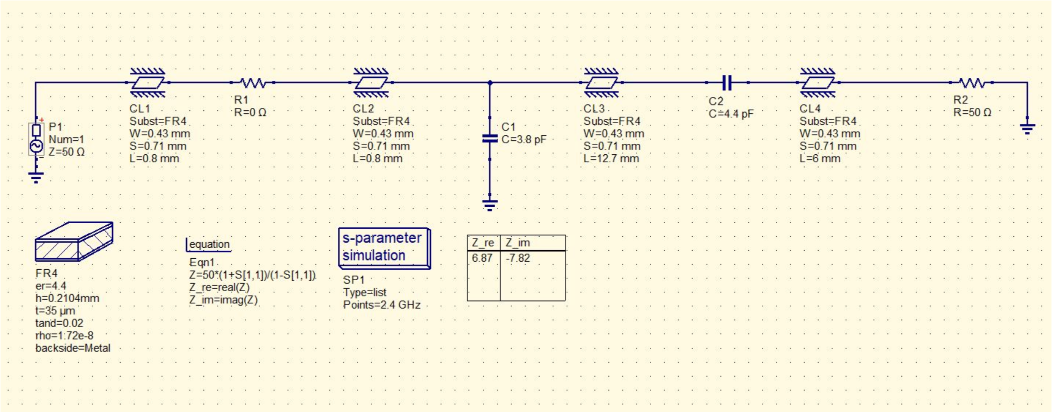
Df = 0.02

E_r = 4.4

I believe that this will not really have a great influence on the final matching, if the numbers in reality are slightly different. This can also be checked while simulating with Keysight ADS!

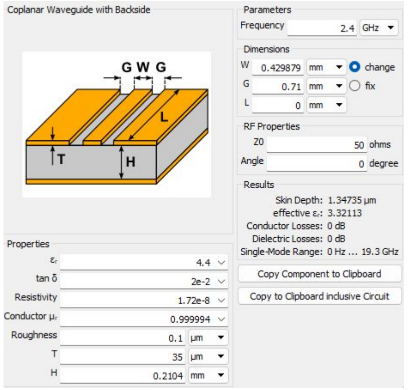
Matching on FR4 board

Input matching circuit



Optimised circuit on FR4 7628 substrate

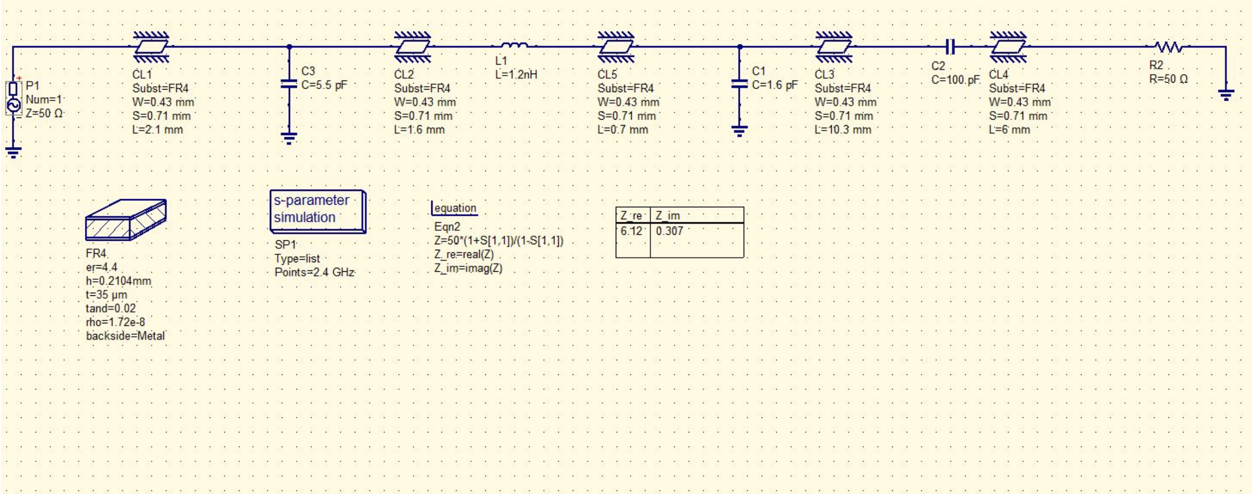
Coplanar waveguide calculator



$$Z_{S,\,opt} = 6.89762 - 7.78518*j$$

$$Z_{S,\,FR4} = 6.87000 - 7.82000*j$$

Output matching circuit



Optimised circuit on FR4 7628 substrate

$Z_{L,\,opt}$ = 6.10798 + 0.317883*j

$Z_{L,\,FR4}$ = 6.1200 + 0.307*j

Complete optimised circuit on FR4 7628 substrate

Conclusions

1) Preliminary calculations and simulations with QUCS make sense
2) With Qucs the SMD pads and many other effects cannot be simulated accurately, which is the reason the simulated impedance of the matching circuit is a bit different from the optimally calculated values
3) In order to get more accurate results, I need to simulate with Keysight ADS

Next steps

- Wait for response from Qorvo and potentially adjust simulated matching circuits in QUCS to new one from Qorvo
- Measure S-parameters of PCB2600 board and compare with simulations
- Get Keysight license and design optimal matching for FR4 7628 substrate
- Adjust matching circuit on prototype board in Altium and send of for manufacturing
- Perform measurements on FR4 board
- Design PA for final board on Cubesat