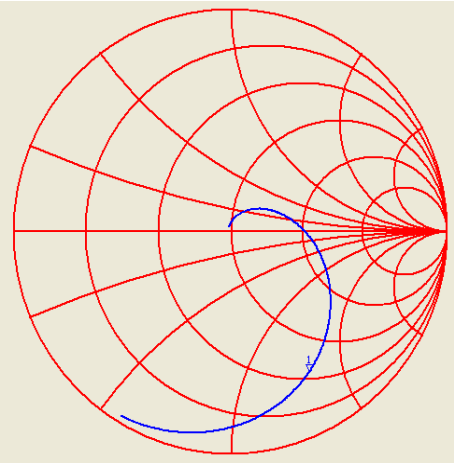
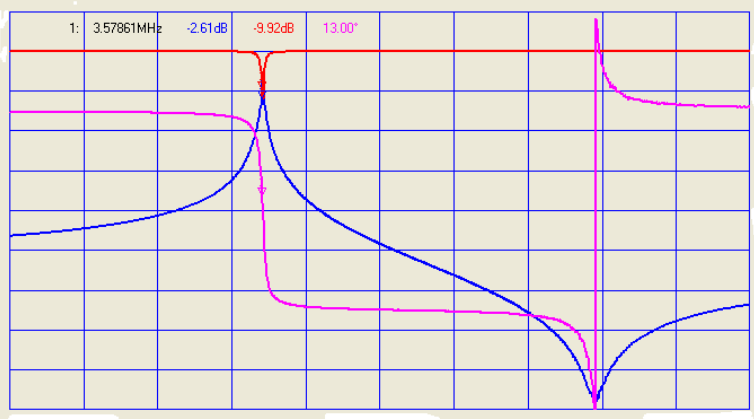
Vector network analyzer
(VNWA – VNA)
Hoe werkt het en wat kun je er mee?



Timo Lampe

PE1FOD

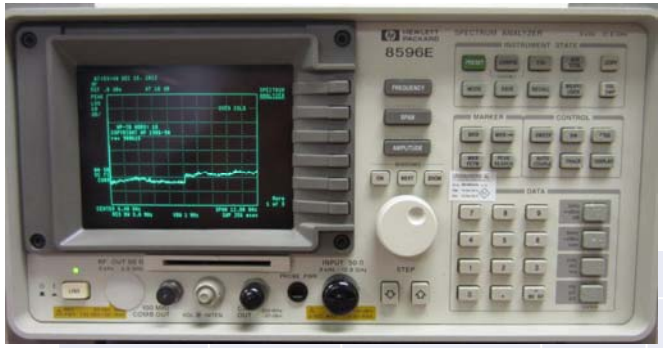
HTC Eindhoven 2019



Introductie

- 1 Algemeen
    - Meetpparaten
    - VSRW brug
    - SWR dB tabel
- 2 VNWA
    - Calibratie
    - Nauwkeurigheid
    - Wat kan er gemeten worden
    - Extra in de DG8SAQ VNA
    - S-Parameters
- 3 Simulatie programma's
- 4 Onbekende Z
- 5 Maak een aanpassing voor deze Z

Spectrum Analyzer



		Dynamisch Bereik	Resolutie		meet:	Basic Funktie Voor het meten van
Spectrum Analyzer	1970-1990	70-90dB	0.1dB	Log (lin)	Level	Het bekijken van spectrum en modulatie spectrum
HP / R&S / Tektronics /	1990-2005	70-100dB	0.01dB		Spectrum	En met gebruikmaking van een Traking generator **:**
Rigol / Siglent	2005-2015	70-110dB	0.001dB		Modulatie	Filters, versterkers
+Trakking generator					Doorlaat	Met Retun loss brug ook Antennes en filters
Signal Analyzer		80-110dB	0.001dB	Log (lin)	Level	Het bekijken van spectrum en modulatie
- betere osc					Spectrum	De modulatie kan hier ook nog geanalyseerd worden,
- lagere faseruis					Modulatie analyse	mesteal met extra opties
Agilent / Keysight / R&S						

Sweep

	Dynamisch bereik	Resolutie			
RF-Sweep Generator	30dB	0.1dB	Linear	Doorlaat met diode detector	Filters, versterkers
			Linear	Return loss/SWR met brug	Filters, versterkers en antennes

Bekende merken

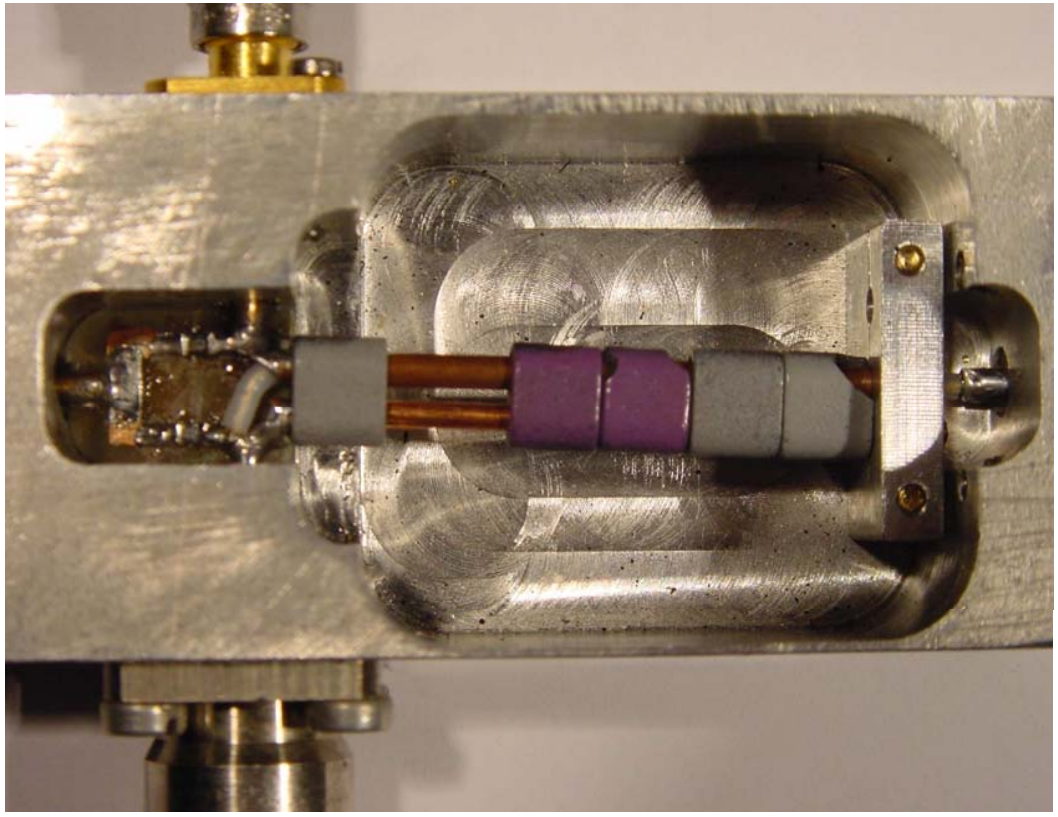
Wavetek HP Wiltron

Vector Netwerk Analyzer

Vector Netwerk Analyzer (Netwerk Analyzer)								
	VNWA = VNA							
			Dynamisch	**Soort**				
Bekende merken			bereik	**meting**				
HP / Agilent / Keysight			>100dB	Doorlaat	Door calibratie meetkabels weg rekenen!			
R&S				Fase	Filters, versterkers en mixers			
			Resolutie	Delay	maar ook antennes en het aan passen er van			
Atvantest			0.001dB	Return loss				
Anritsu				SWR				
DG8SAQ	USB		Log & lin	Smith				
Megiq	USB			TDR	(in DG8SAQ)			
MiniVNA	USB			Xtal	(in DG8SAQ)			
Pico	USB			Simple Spectrum	(in DG8SAQ)			
				Frequentie	(in DG8SAQ)			
Diversen	Antenne	Analyzers		Antenne patroon	(in DG8SAQ)			
				Component test	(in DG8SAQ)			
				Signal Generator	(in DG8SAQ)			

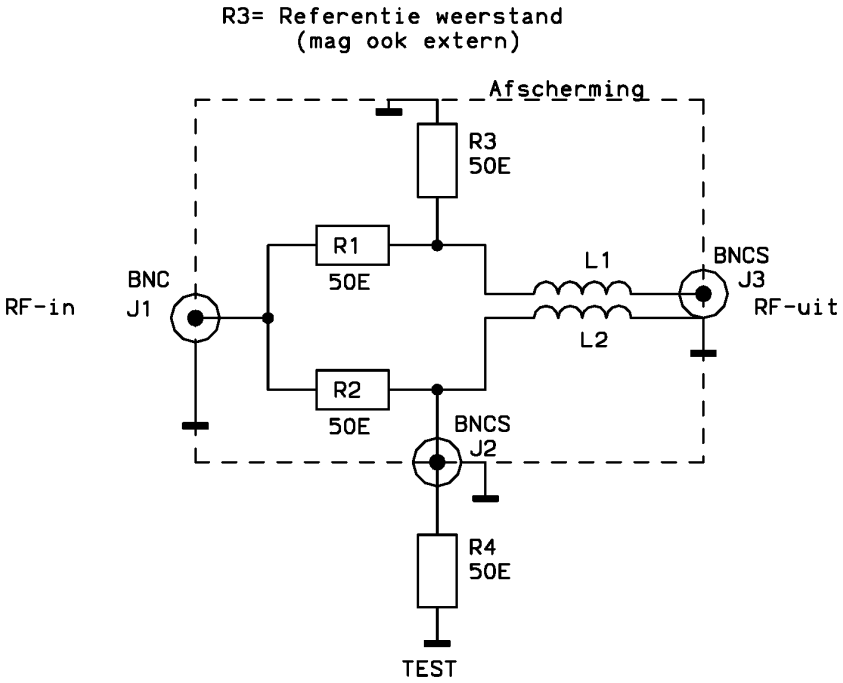
SWR Brug PE1FOD

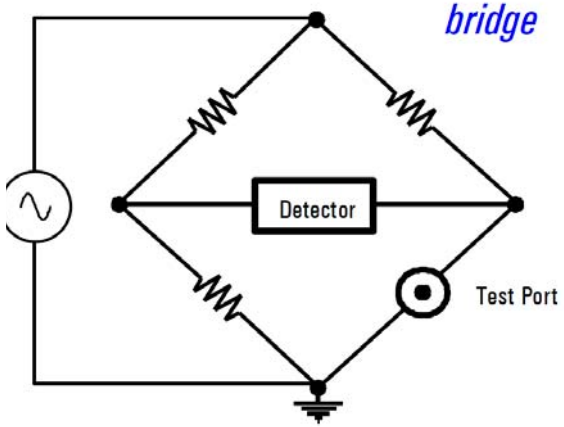
1-600MHz

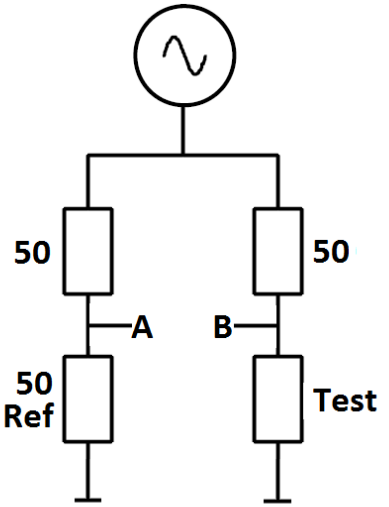


300-3000MHz

Return Loss bridge
(VSWR bridge)







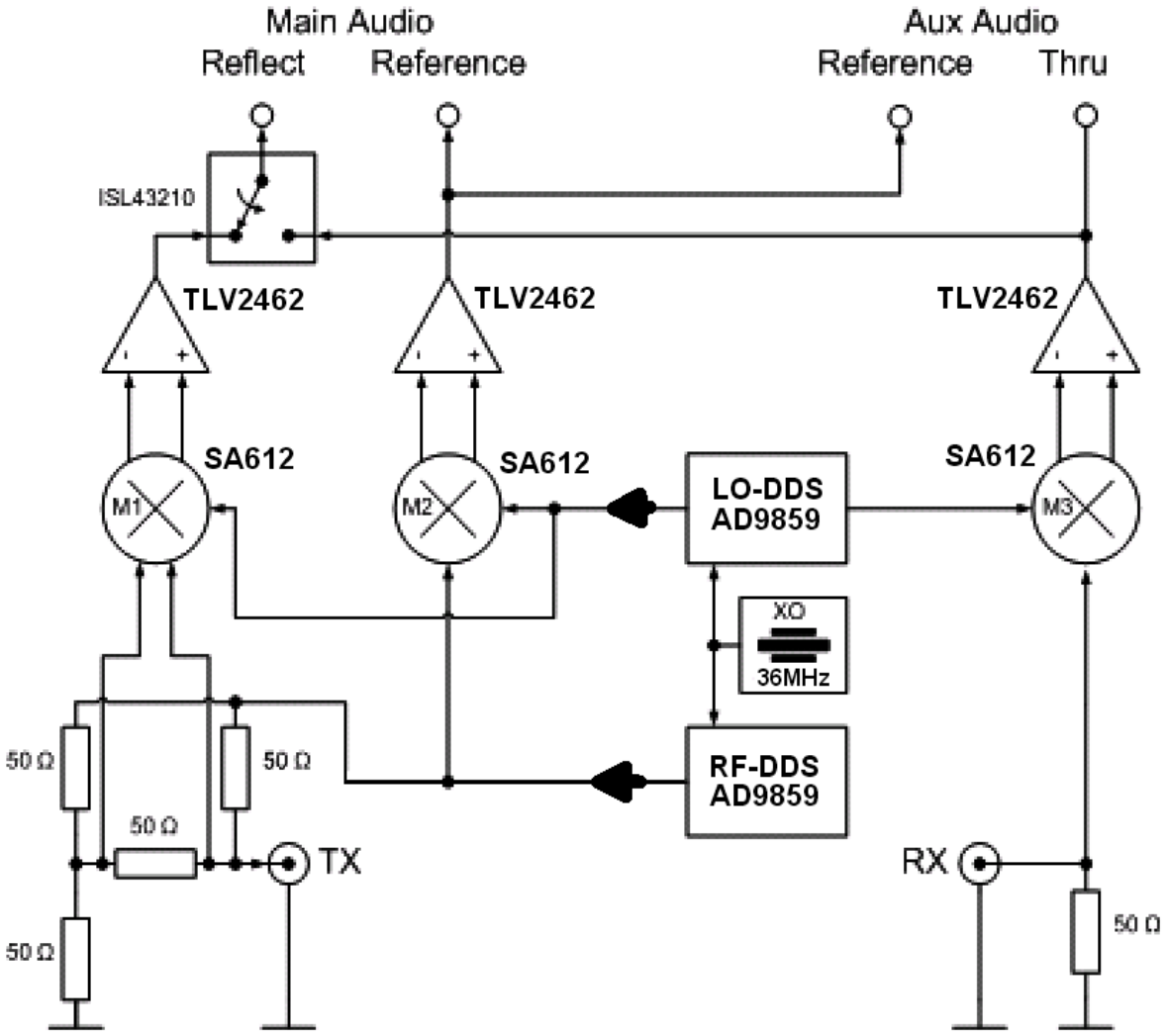
VSWR Tabel

VSWR=Lineair

Return loss=Log(dB)

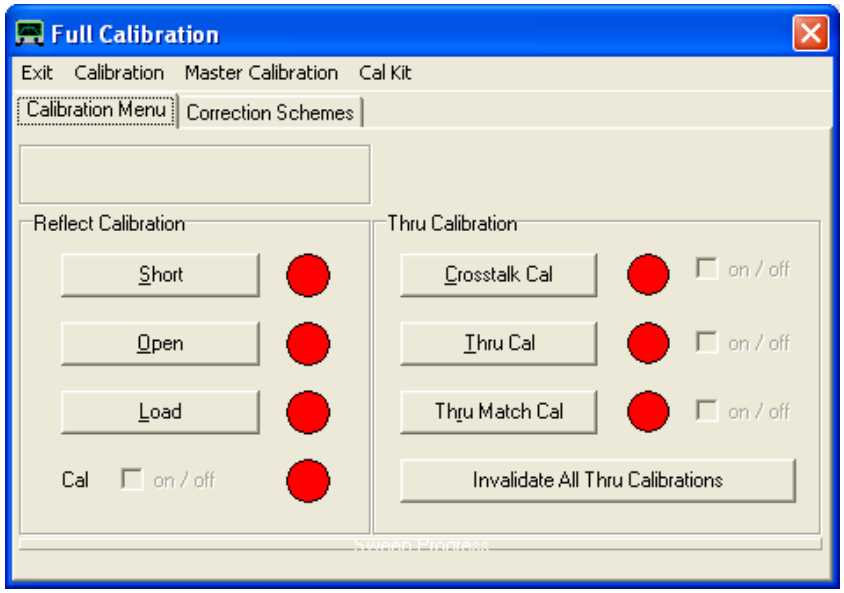
Z1/Z2 VSWR	Returnloss dB	Voltage Reflectie Coëfficiënt x	TxPow %	Refl.pow %	Refl.pow dB	Z1= 50 Z2=	Z1= 50 Z2=
1.020	40	0.010	99.99	0.01	0.000	51.01	49.01
1.065	30	0.032	99.90	0.10	0.004	53.27	46.93
1.119	25	0.056	99.68	0.32	0.014	55.96	44.68
1.152	23	0.071	99.50	0.50	0.022	57.62	43.39
1.222	20	0.100	99.00	1.00	0.044	61.11	40.91
1.253	19	0.112	98.74	1.26	0.055	62.64	39.91
1.499	14	0.200	96.02	3.98	0.176	74.93	33.37
1.577	13	0.224	94.99	5.01	0.223	78.84	31.71
1.671	12	0.251	93.69	6.31	0.283	83.54	29.92
1.785	11	0.282	92.06	7.94	0.359	89.24	28.01
1.925	10	0.316	90.00	10.00	0.458	96.25	25.97
2.000	9.54	0.333	88.88	11.12	0.512	100.02	24.99
2.100	9	0.355	87.41	12.59	0.584	104.99	23.81
2.323	8	0.398	84.15	15.85	0.749	116.14	21.53
2.615	7	0.447	80.05	19.95	0.967	130.73	19.12
3.000	6.02	0.500	75.00	25.00	1.250	150.01	16.67
3.570	5	0.562	68.38	31.62	1.651	178.49	14.01
4.419	4	0.631	60.19	39.81	2.205	220.97	11.31
5.848	3	0.708	49.88	50.12	3.021	292.40	8.55

VNWA Blokschema



Calibratie

- Zonder Cal lijkt het op Spectrum Analyze + TG
- Open
- Short
- Load



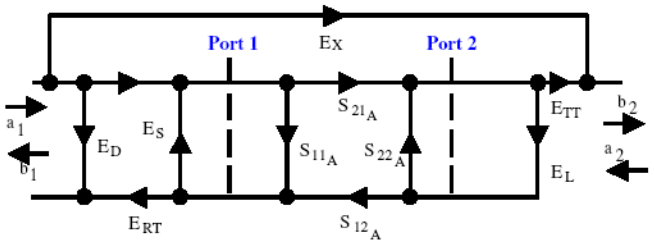
- Coax Kabels weg rekenen
- Laten zien dat het klopt in Smith kaart
- Referentievlak (Reference plane)
- Poort extensie, om extra aansluit kabel te compenseren

Door een 12 voudige term te gebruiken ontstaat de hoge Nauwkeurigheid

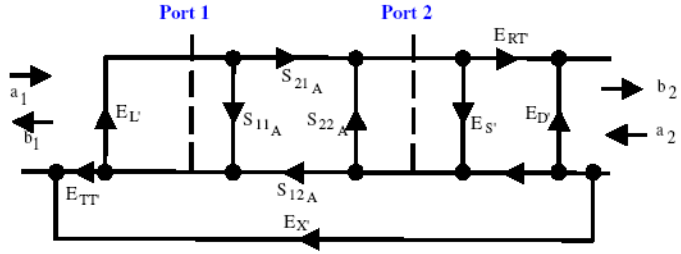
Two-Port Error Correction

BTB_Network_2005-1.pdf

Forward model



Reverse model



E_D	= fwd directivity	E_L	= fwd load match
E_S	= fwd source match	E_{TT}	= fwd transmission tracking
E_{RT}	= fwd reflection tracking	E_X	= fwd isolation
$E_{D'}$	= rev directivity	$E_{L'}$	= rev load match
$E_{S'}$	= rev source match	$E_{TT'}$	= rev transmission tracking
$E_{RT'}$	= rev reflection tracking	$E_{X'}$	= rev isolation

- Each actual S-parameter is a function of all four measured S-parameters
- Analyzer must make forward *and* reverse sweep to update any one S-parameter
- Luckily, you don't need to know these equations to ***use*** network analyzers!!!

$$S_{11a} = \frac{(\frac{S_{11m}-E_D}{E_{RT}})(1+\frac{S_{22m}-E_{D'}}{E_{RT'}}E_{S'})-E_L(\frac{S_{21m}-E_X}{E_{TT}})(\frac{S_{12m}-E_{X'}}{E_{TT'}})}{(1+\frac{S_{11m}-E_D}{E_{RT}}E_S)(1+\frac{S_{22m}-E_{D'}}{E_{RT'}}E_{S'})-E_{L'}E_L(\frac{S_{21m}-E_X}{E_{TT}})(\frac{S_{12m}-E_{X'}}{E_{TT'}})}$$

$$S_{21a} = \frac{(\frac{S_{21m}-E_X}{E_{TT}})(1+\frac{S_{22m}-E_{D'}}{E_{RT'}}(E_{S'}-E_L))}{(1+\frac{S_{11m}-E_D}{E_{RT}}E_S)(1+\frac{S_{22m}-E_{D'}}{E_{RT'}}E_{S'})-E_{L'}E_L(\frac{S_{21m}-E_X}{E_{TT}})(\frac{S_{12m}-E_{X'}}{E_{TT'}})}$$

$$S_{12a} = \frac{(\frac{S_{12m}-E_{X'}}{E_{TT'}})(1+\frac{S_{11m}-E_D}{E_{RT}}(E_S-E_{L'}))}{(1+\frac{S_{11m}-E_D}{E_{RT}}E_S)(1+\frac{S_{22m}-E_{D'}}{E_{RT'}}E_{S'})-E_{L'}E_L(\frac{S_{21m}-E_X}{E_{TT}})(\frac{S_{12m}-E_{X'}}{E_{TT'}})}$$

$$S_{22a} = \frac{(\frac{S_{22m}-E_{D'}}{E_{RT'}})(1+\frac{S_{11m}-E_D}{E_{RT}}E_S)-E_{L'}(\frac{S_{21m}-E_X}{E_{TT}})(\frac{S_{12m}-E_{X'}}{E_{TT'}})}{(1+\frac{S_{11m}-E_D}{E_{RT}}E_S)(1+\frac{S_{22m}-E_{D'}}{E_{RT'}}E_{S'})-E_{L'}E_L(\frac{S_{21m}-E_X}{E_{TT}})(\frac{S_{12m}-E_{X'}}{E_{TT'}})}$$

Network Analyzer Basics

Agilent Technologies

www.agilent.com/find/backtobasics

Two-port error correction is the most accurate form of error correction since it accounts for all of the major sources of systematic error. The error model for a two-port device is shown above. Shown below are the equations to derive the actual device S-parameters from the measured S-parameters, once the systematic error terms have been characterized. Notice that each actual S-parameter is a function of all four measured S-parameters. The network analyzer must make a forward and reverse sweep to update any one S-parameter. Luckily, you don't need to know these equations to use network analyzers!!!

$$S_{11a} = \frac{(\frac{S_{11m} - E_D}{E_{RT}})(1 + \frac{S_{22m} - E_D'}{E_{RT}'} E_S') - E_L(\frac{S_{21m} - E_X}{E_{TT}})(\frac{S_{12m} - E_X'}{E_{TT}'})}{(1 + \frac{S_{11m} - E_D}{E_{RT}} E_S)(1 + \frac{S_{22m} - E_D'}{E_{RT}'} E_S') - E_L' E_L(\frac{S_{21m} - E_X}{E_{TT}})(\frac{S_{12m} - E_X'}{E_{TT}'})}$$

$$S_{21a} = \frac{(\frac{S_{21m} - E_X}{E_{TT}})(1 + \frac{S_{22m} - E_D'}{E_{RT}'} (E_S' - E_L))}{(1 + \frac{S_{11m} - E_D}{E_{RT}} E_S)(1 + \frac{S_{22m} - E_D'}{E_{RT}'} E_S') - E_L' E_L(\frac{S_{21m} - E_X}{E_{TT}})(\frac{S_{12m} - E_X'}{E_{TT}'})}$$

$$S_{12a} = \frac{(\frac{S_{12m} - E_X'}{E_{TT}'})(1 + \frac{S_{11m} - E_D}{E_{RT}} (E_S - E_L'))}{(1 + \frac{S_{11m} - E_D}{E_{RT}} E_S)(1 + \frac{S_{22m} - E_D'}{E_{RT}'} E_S') - E_L' E_L(\frac{S_{21m} - E_X}{E_{TT}})(\frac{S_{12m} - E_X'}{E_{TT}'})}$$

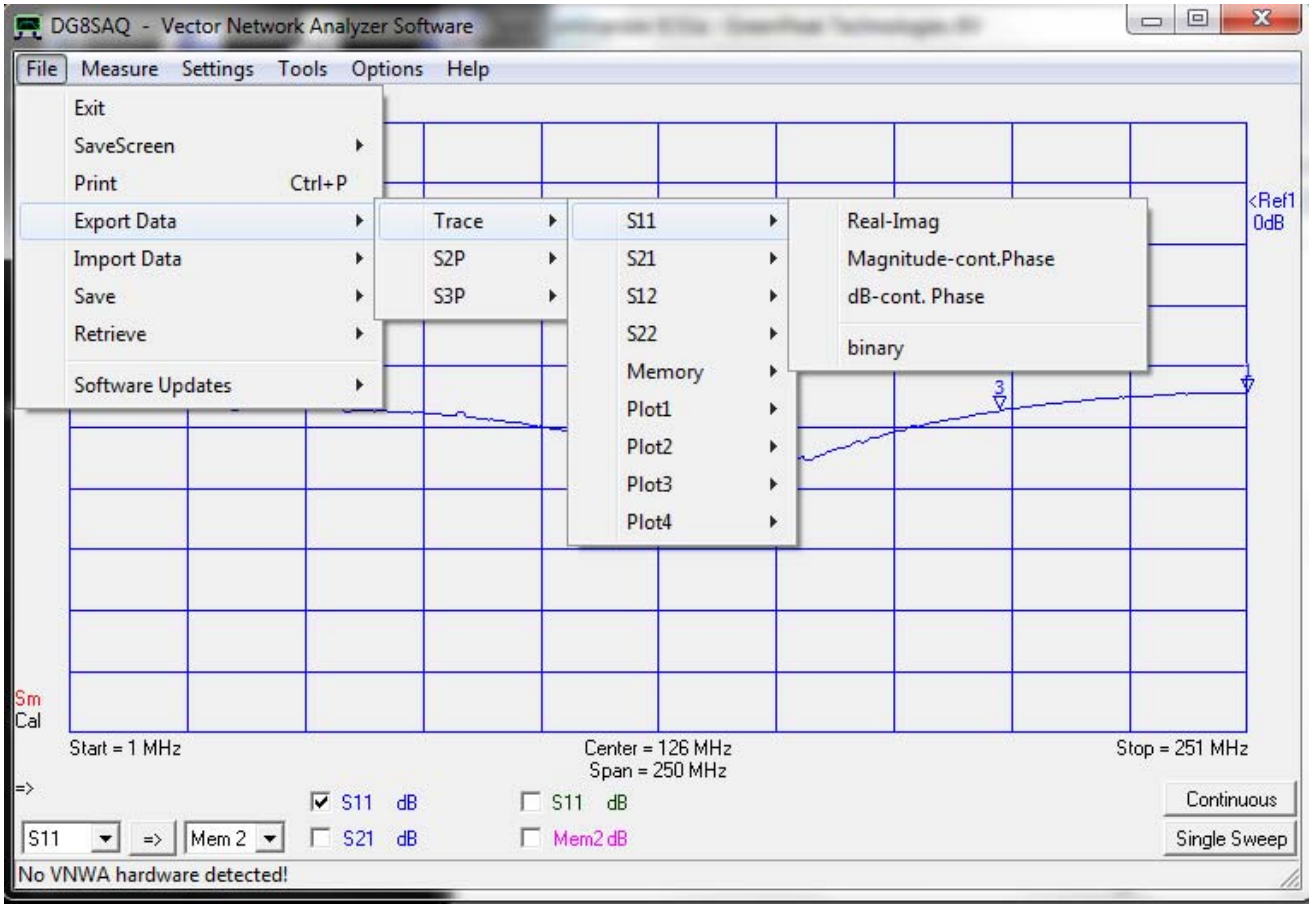
$$S_{22a} = \frac{(\frac{S_{22m} - E_D'}{E_{RT}'})(1 + \frac{S_{11m} - E_D}{E_{RT}} E_S) - E_L'(\frac{S_{21m} - E_X}{E_{TT}})(\frac{S_{12m} - E_X'}{E_{TT}'})}{(1 + \frac{S_{11m} - E_D}{E_{RT}} E_S)(1 + \frac{S_{22m} - E_D'}{E_{RT}'} E_S') - E_L' E_L(\frac{S_{21m} - E_X}{E_{TT}})(\frac{S_{12m} - E_X'}{E_{TT}'})}$$

Wat kan er gemeten worden met een VNA

- Standaard functies
- SWR linear(S11)
- Return loss dB (S11)
- Doorlaat (S21)
- Phase (S21)
- Delay (S21)
- Smith (S11)
- S-parameters opslaan voor gebruik in Excel

- Extra in de DG8SAQ
- Simple Spectrum
- Frequentie
- Antenne patroon
- Component
- Crystal
- Signal Generator
- Full 2 poort optie
- Matching tool

S-parameters opslaan met VNWA DG8SAQ



S-parameter File xx.s1p of xx.s2p (ASCII tekst)

! ListType=Lin **xxx.s1p**

!!test1

MHz S DB R 50

10.0000000 -51.6016145 -81.2734089

12.1535893 -59.1364064 -154.710868

14.3071786 -58.2970539 -212.851123

Frequentie **S21 dB** **S21 Deg**

! ListType=Lin **xxx.s2p**

!!test2

MHZ S DB R 50

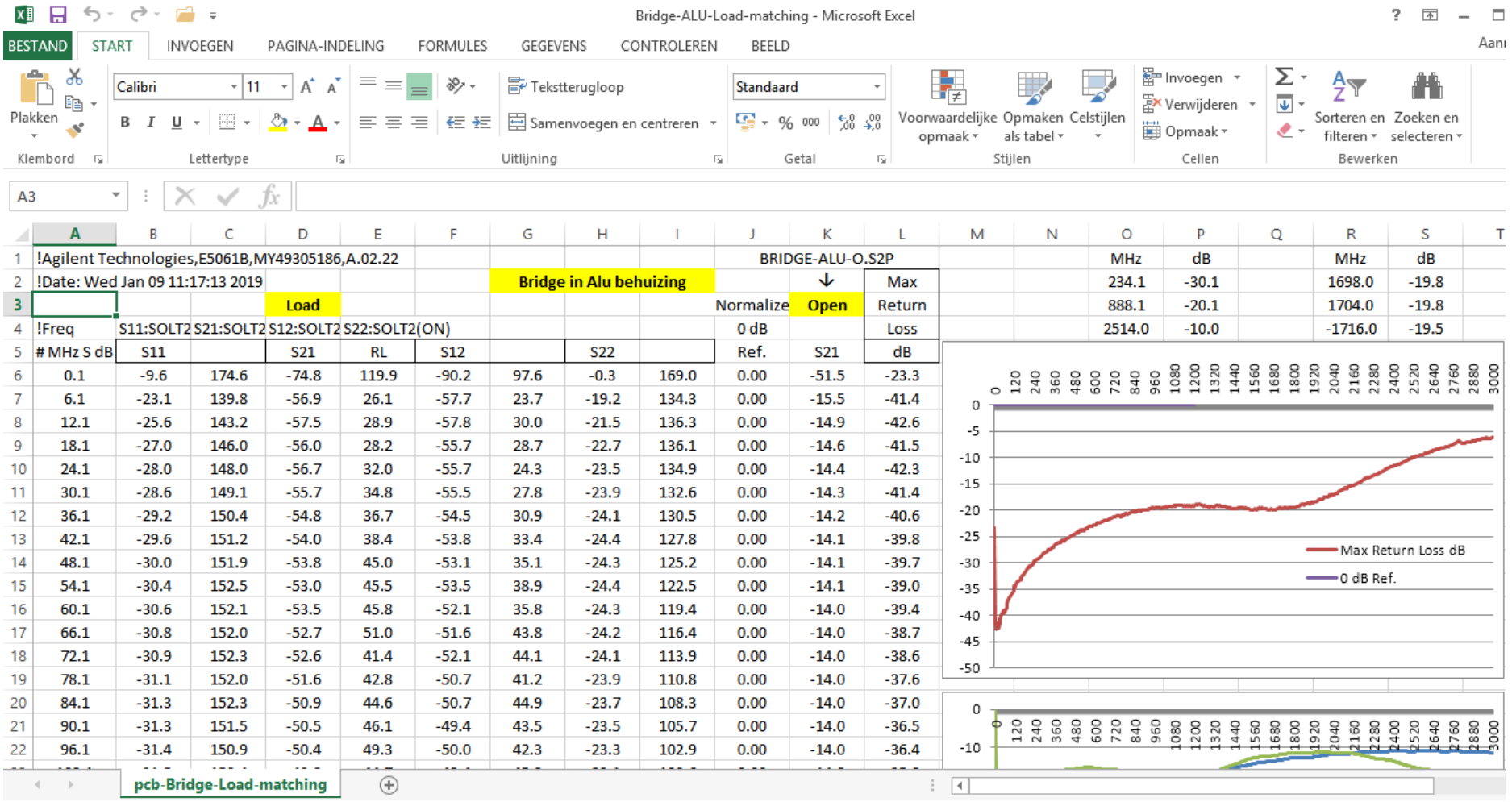
10.0000000 -20.4817515 -55.5086266 -51.6016145 -81.2734089 -3000.0000 -90.0000 -3000.0000 -90.0000

12.1535893 -20.2883544 -65.4789653 -59.1364064 -154.7108687 -3000.0000 -90.0000 -3000.0000 -90.0000

14.3071786 -20.0724426 -75.5834240 -58.2970539 147.1488767 -3000.0000 -90.0000 -3000.0000 -90.0000

Frequentie **S11 dB** **S11 Deg** **S21 dB** **S21 Deg** **S12 dB** **S12 Deg** **S22 dB** **S22 Deg**

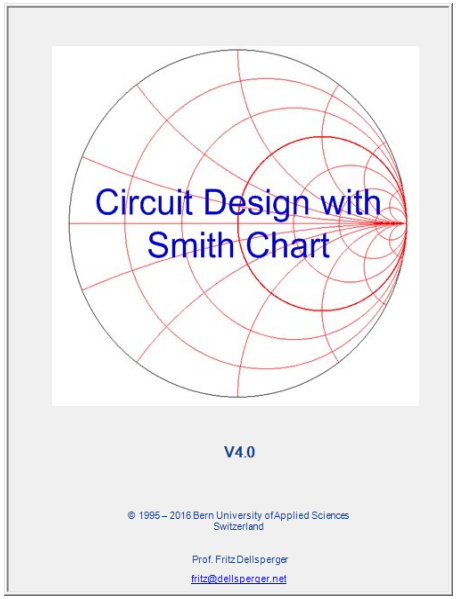
Data in Excel verwerkt

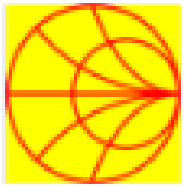


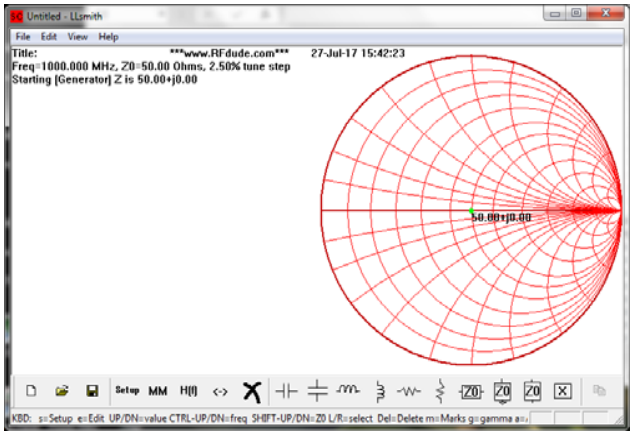
	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
1	!Agilent Technologies,E5061B,MY49305186,A.02.22									BRIDGE-ALU-O.S2P					MHz	dB		MHz	dB	
2	!Date: Wed Jan 09 11:17:13 2019						Bridge in Alu behuizing				↓	Max			234.1	-30.1		1698.0	-19.8	
3				Load						Normalize	Open	Return			888.1	-20.1		1704.0	-19.8	
4	!Freq	S11:SOLT2	S21:SOLT2	S12:SOLT2	S22:SOLT2(ON)					0 dB		Loss			2514.0	-10.0		-1716.0	-19.5	
5	# MHz S dB	S11		S21	RL	S12		S22		Ref.	S21	dB								
6	0.1	-9.6	174.6	-74.8	119.9	-90.2	97.6	-0.3	169.0	0.00	-51.5	-23.3								
7	6.1	-23.1	139.8	-56.9	26.1	-57.7	23.7	-19.2	134.3	0.00	-15.5	-41.4								
8	12.1	-25.6	143.2	-57.5	28.9	-57.8	30.0	-21.5	136.3	0.00	-14.9	-42.6								
9	18.1	-27.0	146.0	-56.0	28.2	-55.7	28.7	-22.7	136.1	0.00	-14.6	-41.5								
10	24.1	-28.0	148.0	-56.7	32.0	-55.7	24.3	-23.5	134.9	0.00	-14.4	-42.3								
11	30.1	-28.6	149.1	-55.7	34.8	-55.5	27.8	-23.9	132.6	0.00	-14.3	-41.4								
12	36.1	-29.2	150.4	-54.8	36.7	-54.5	30.9	-24.1	130.5	0.00	-14.2	-40.6								
13	42.1	-29.6	151.2	-54.0	38.4	-53.8	33.4	-24.4	127.8	0.00	-14.1	-39.8								
14	48.1	-30.0	151.9	-53.8	45.0	-53.1	35.1	-24.3	125.2	0.00	-14.1	-39.7								
15	54.1	-30.4	152.5	-53.0	45.5	-53.5	38.9	-24.4	122.5	0.00	-14.1	-39.0								
16	60.1	-30.6	152.1	-53.5	45.8	-52.1	35.8	-24.3	119.4	0.00	-14.0	-39.4								
17	66.1	-30.8	152.0	-52.7	51.0	-51.6	43.8	-24.2	116.4	0.00	-14.0	-38.7								
18	72.1	-30.9	152.3	-52.6	41.4	-52.1	44.1	-24.1	113.9	0.00	-14.0	-38.6								
19	78.1	-31.1	152.0	-51.6	42.8	-50.7	41.2	-23.9	110.8	0.00	-14.0	-37.6								
20	84.1	-31.3	152.3	-50.9	44.6	-50.7	44.9	-23.7	108.3	0.00	-14.0	-37.0								
21	90.1	-31.3	151.5	-50.5	46.1	-49.4	43.5	-23.5	105.7	0.00	-14.0	-36.5								
22	96.1	-31.4	150.9	-50.4	49.3	-50.0	42.3	-23.3	102.9	0.00	-14.0	-36.4								

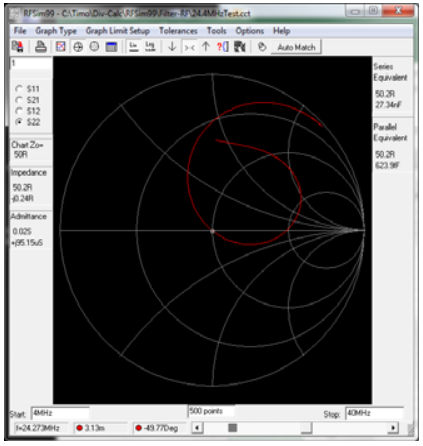
Smith kaart simulatie programma's

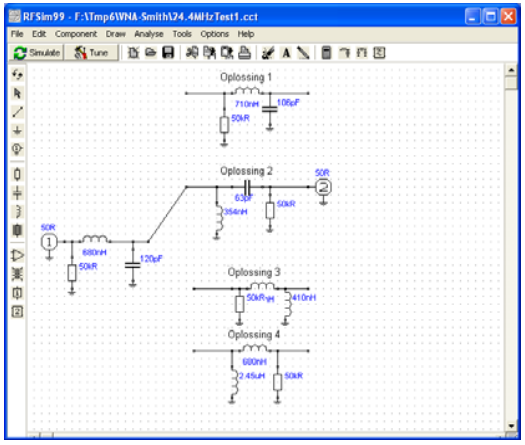
- Fritz dellsperger Smith chart V4.0
- LLSmith
- RFsim99, kan nog veel meer



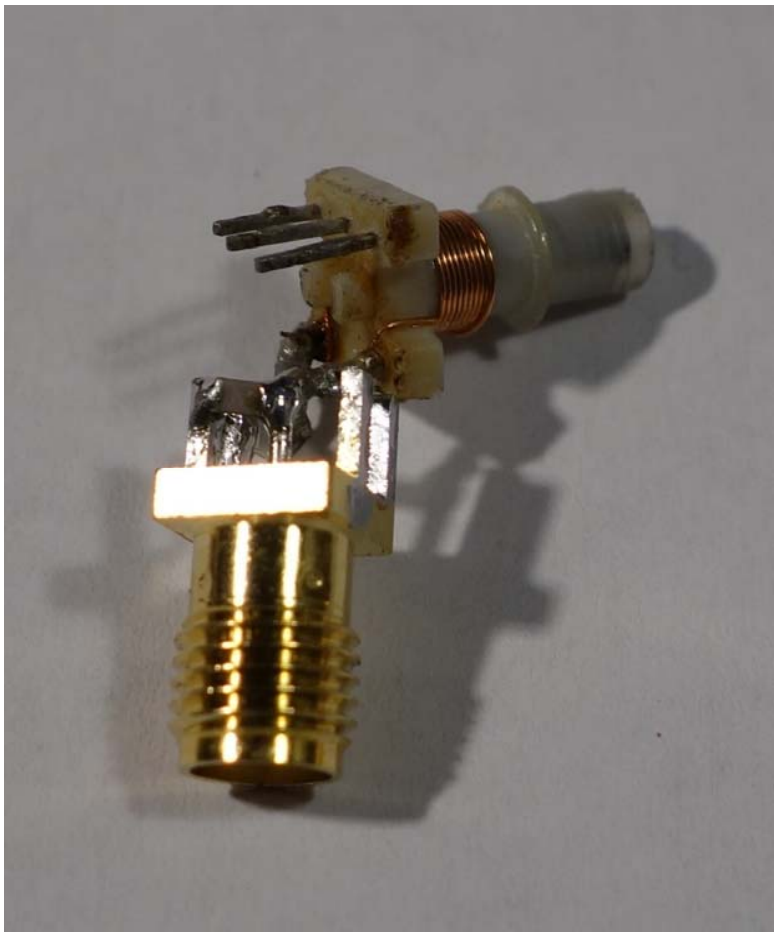


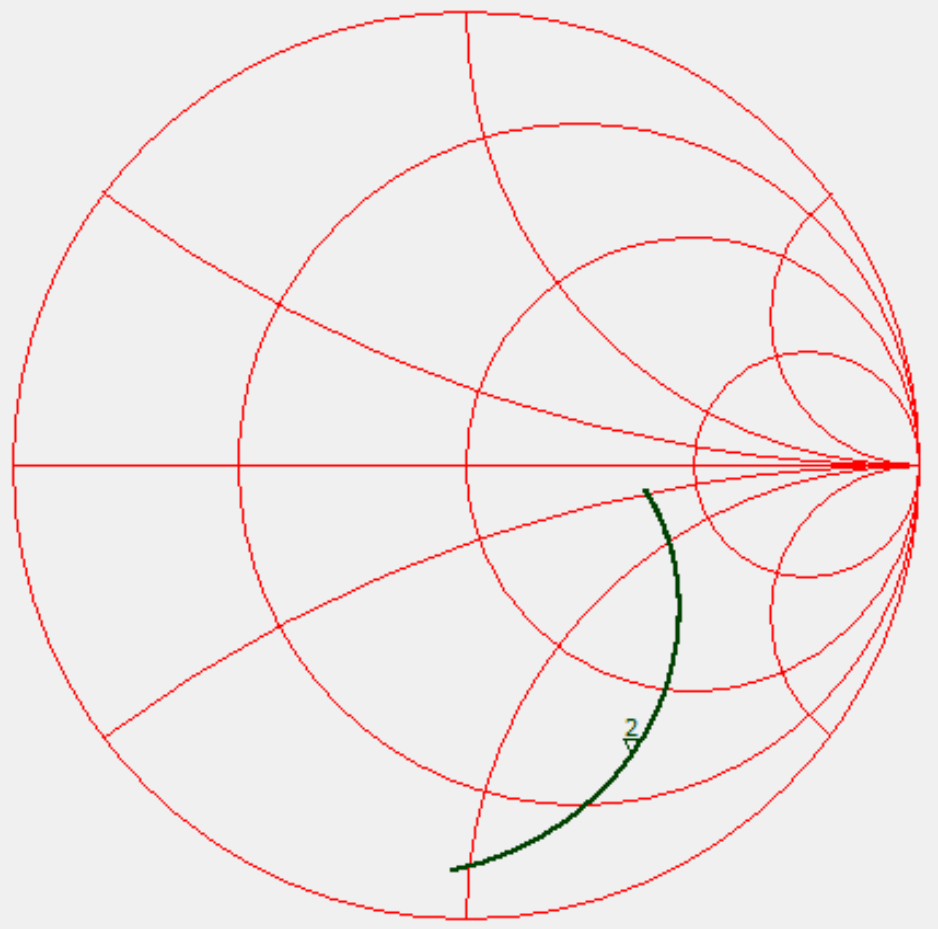






Een onbekende Z

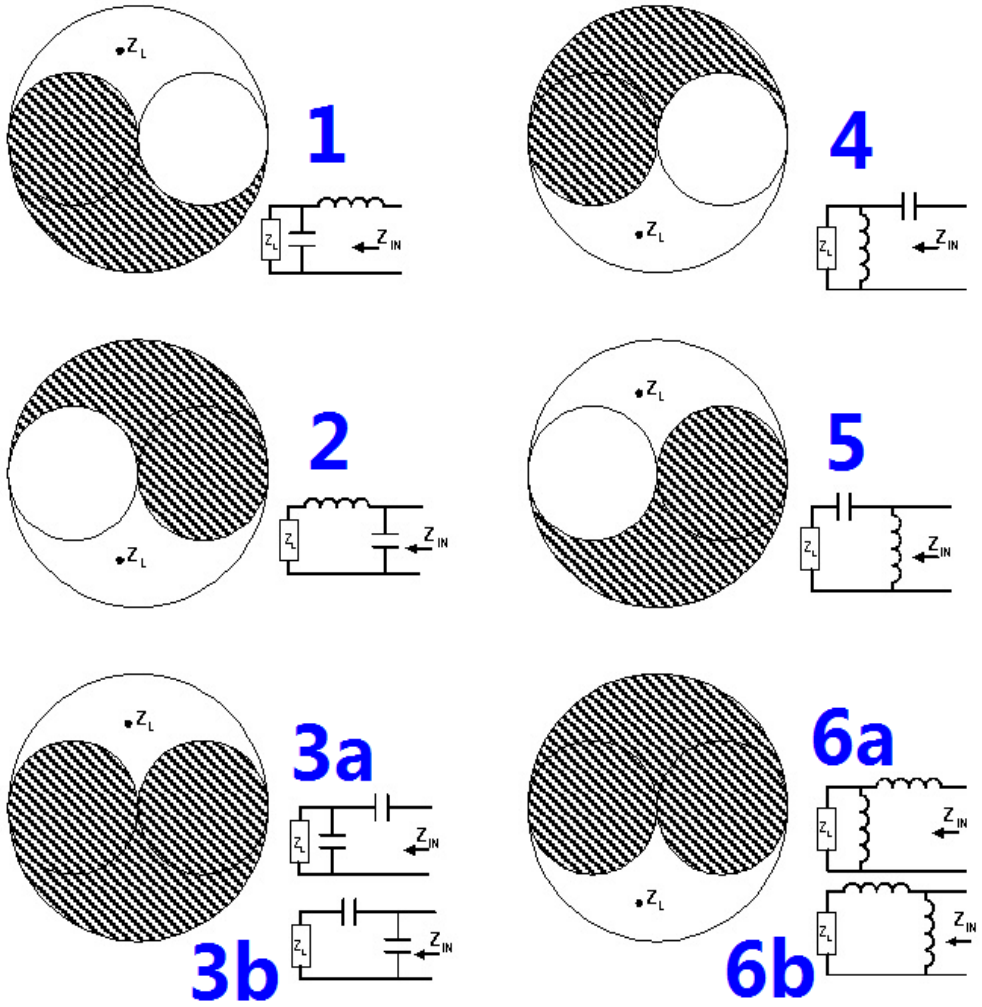




Meet de onbekende Z

Z = 28.3 -J78.9

Mogelijke aanpas netwerken

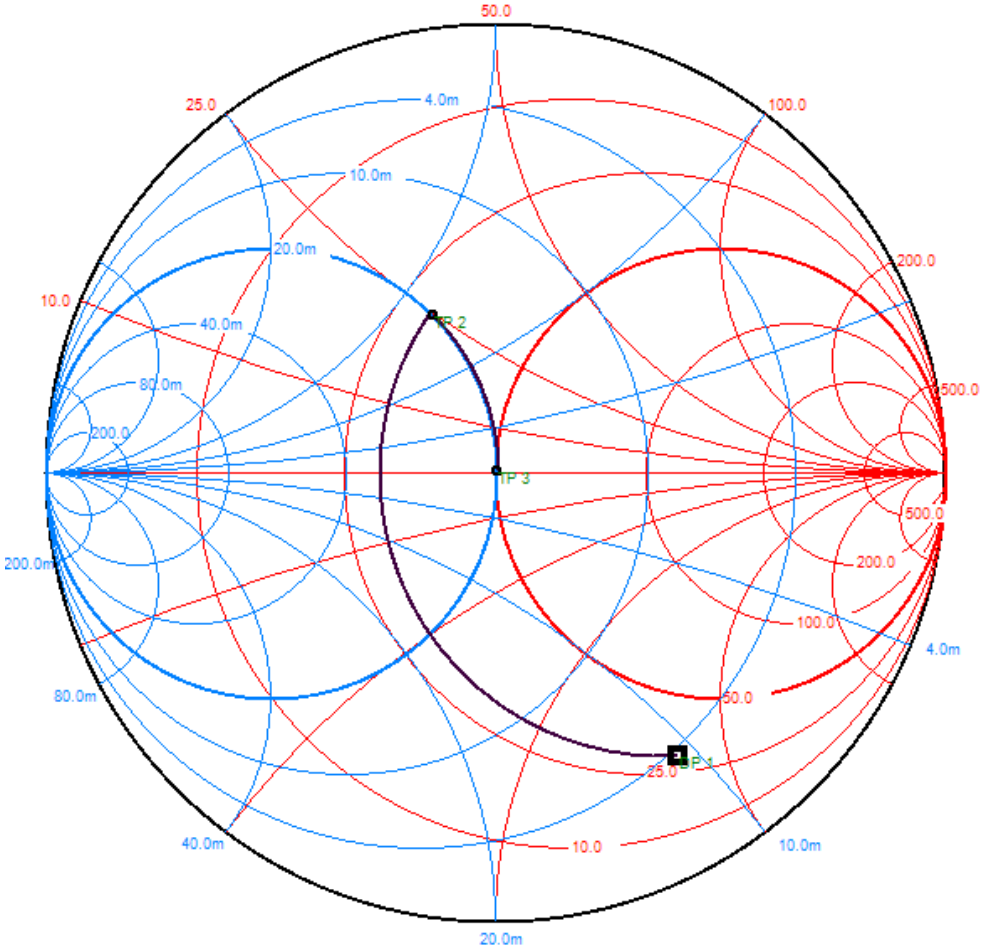


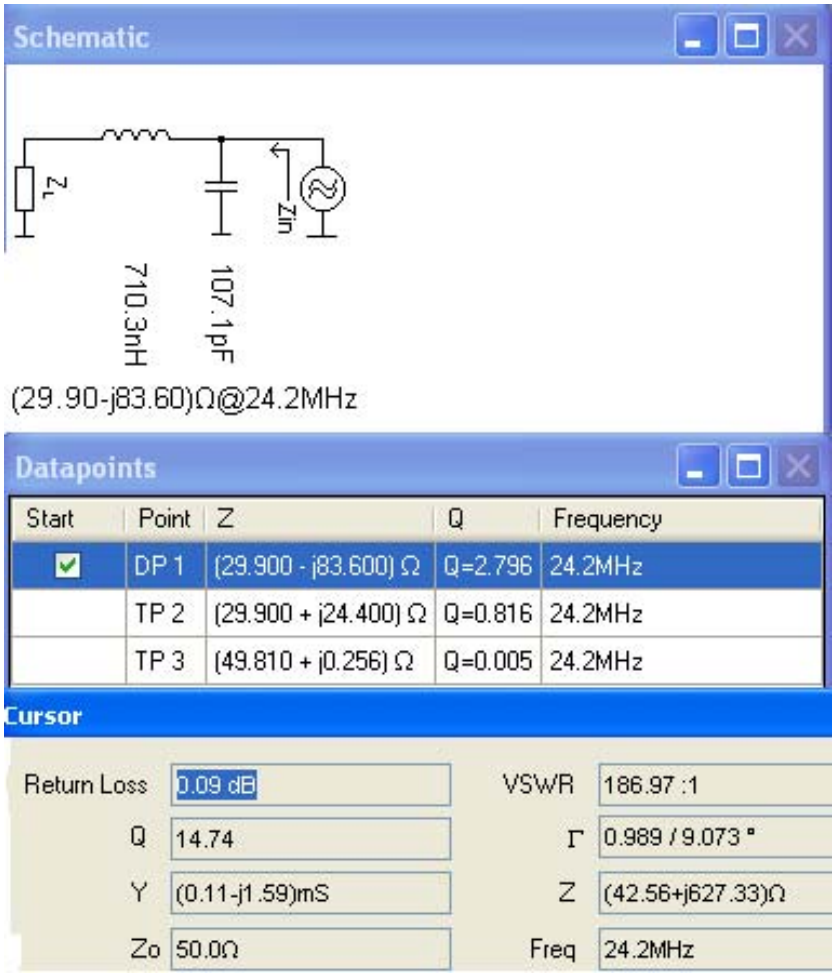
Maak een aanpassing voor
de gemeten Z

$Z = 28.3 - J78.9$

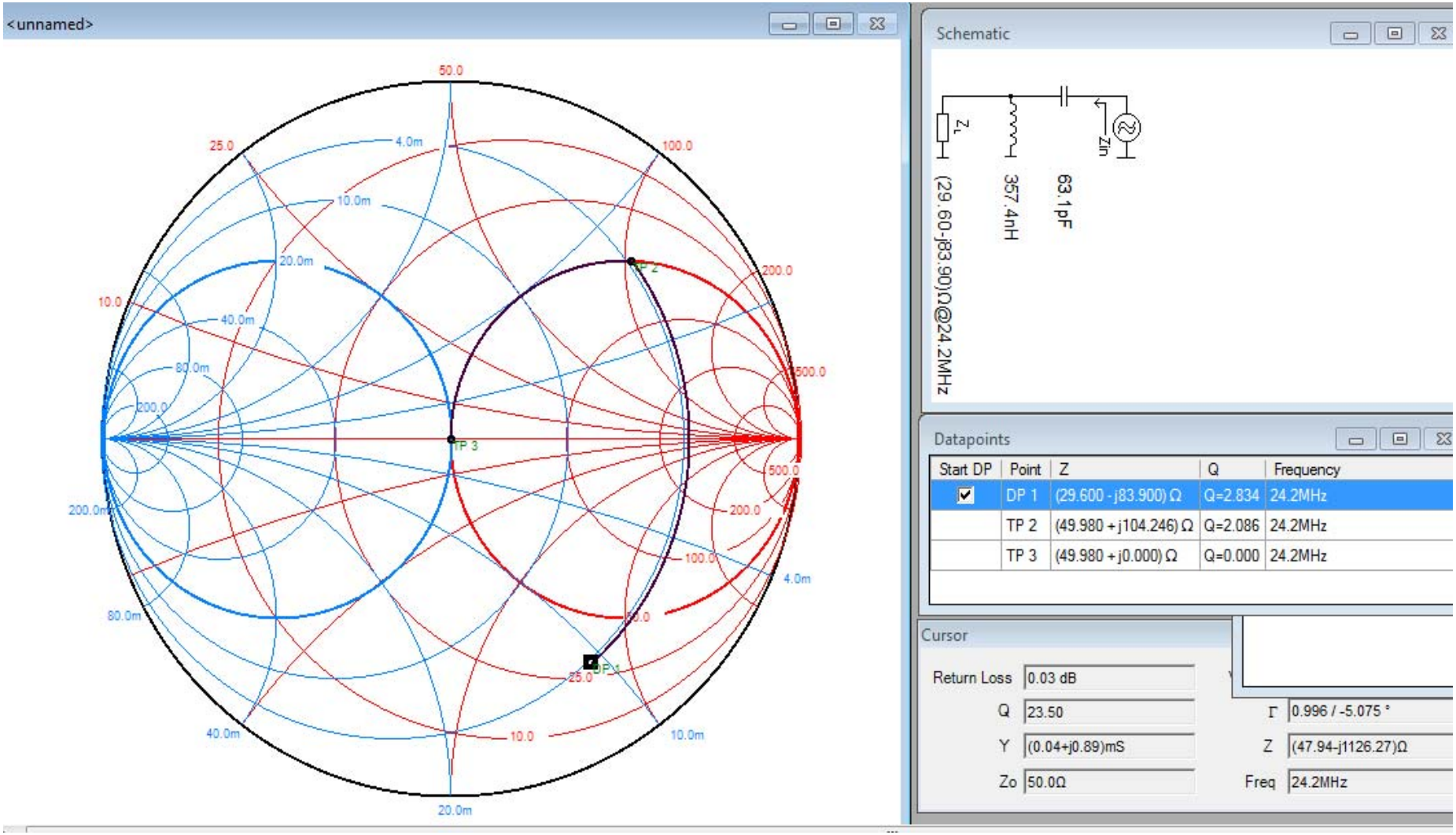
Met het Smith kaart programma

Netwerk 2

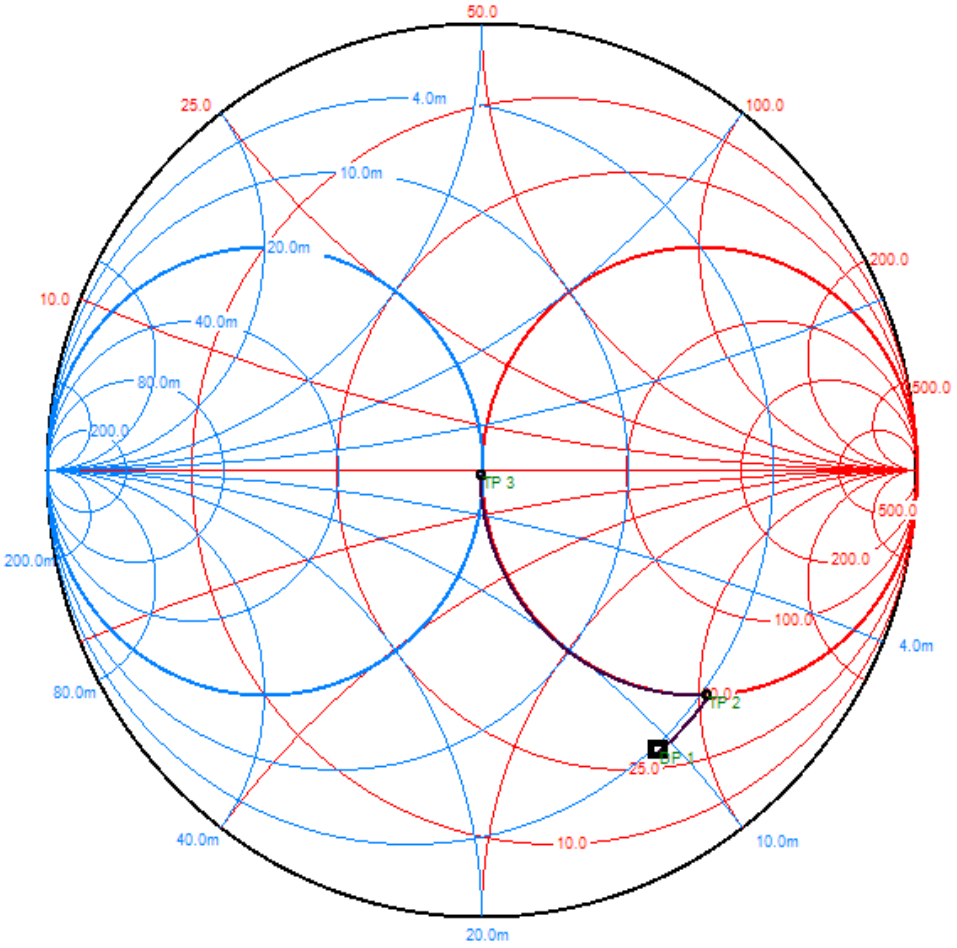

50.0
25.0
4.0m
100.0
10.0m
20.0m
200.0
10.0
40.0m
80.0m
200.0
500.0
200.0m
TP 3
500.0
200.0
100.0
4.0m
80.0m
50.0
25.0
TP 1
40.0m
10.0
10.0m
20.0m


Schematic
ZL
Zin
710.3nH
107.1pF
(29.90-j83.60)Ω@24.2MHz
Datapoints
Start
Point
Z
Q
Frequency
DP 1
(29.900 - j83.600) Ω
Q=2.796
24.2MHz
TP 2
(29.900 + j24.400) Ω
Q=0.816
24.2MHz
TP 3
(49.810 + j0.256) Ω
Q=0.005
24.2MHz
Cursor
Return Loss
0.09 dB
VSWR
186.97 :1
Q
14.74
Γ
0.989 / 9.073 °
Y
(0.11-j1.59)mS
Z
(42.56+j627.33)Ω
Zo
50.0Ω
Freq
24.2MHz

Netwerk 4

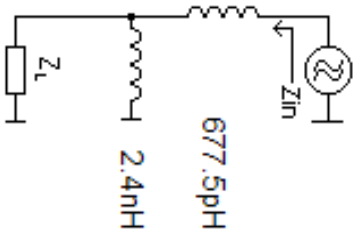

<unnamed>
50.0
25.0
4.0m
100.0
10.0m
20.0m
200.0
10.0
40.0m
80.0m
500.0
200.0
TP 3
200.0m
500.0
200.0
100.0
4.0m
80.0m
25.0
DP 1
40.0m
10.0
10.0m
20.0m
Schematic
Z_L
Z_in
(29.60-j83.90)Ω@24.2MHz
357.4nH
63.1pF
Datapoints
Start DP
Point
Z
Q
Frequency
DP 1
(29.600 - j83.900) Ω
Q=2.834
24.2MHz
TP 2
(49.980 + j104.246) Ω
Q=2.086
24.2MHz
TP 3
(49.980 + j0.000) Ω
Q=0.000
24.2MHz
Cursor
Return Loss
0.03 dB
Q
23.50
Y
(0.04+j0.89)mS
Zo
50.0Ω
Γ
0.996 / -5.075 °
Z
(47.94-j1126.27)Ω
Freq
24.2MHz

Netwerk 6a



Schematic

(29.60-j83.90)Ω@24.2GHz



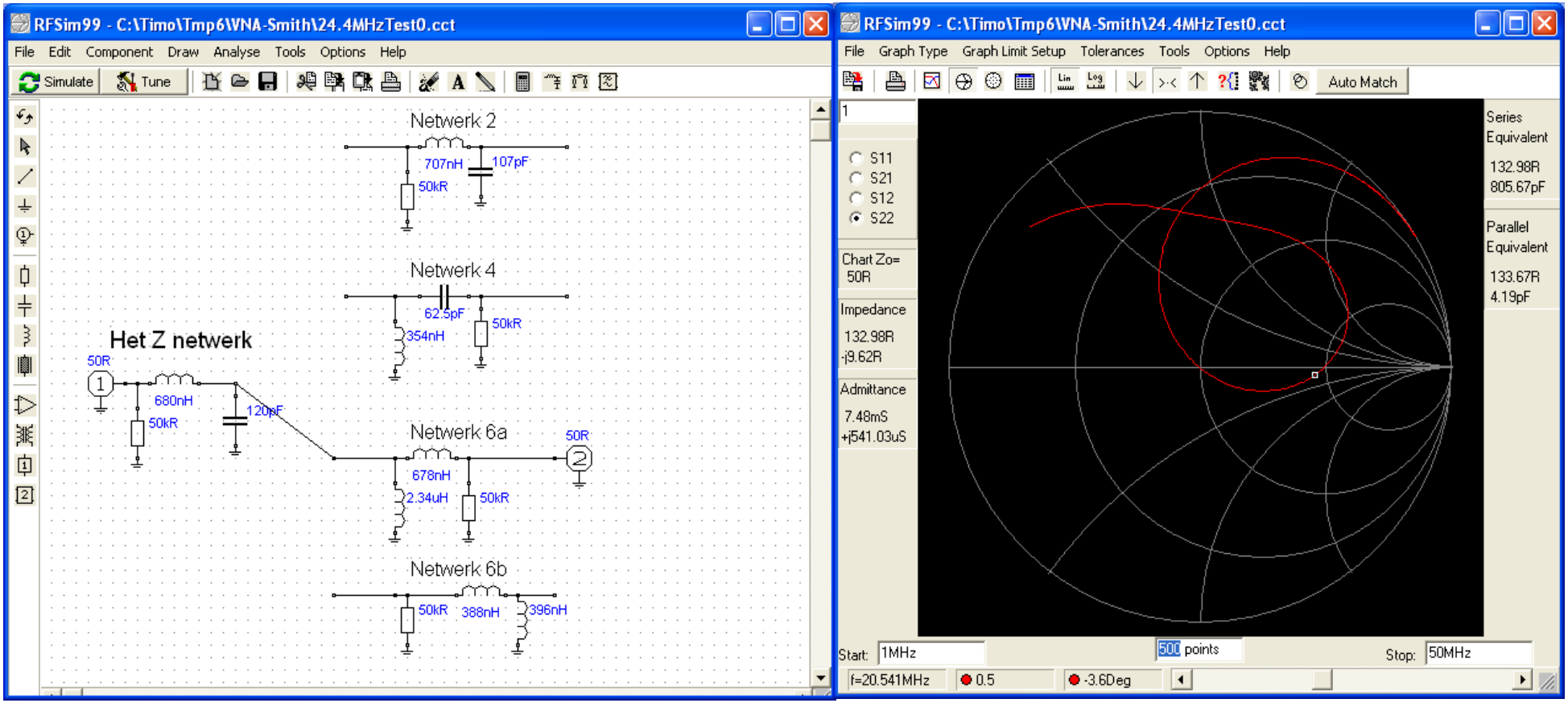
Datapoints

Start DP	Point	Z	Q	Frequency
☑	DP 1	(29.600 - j83.900) Ω	Q=2.834	24.200GHz
	TP 2	(49.428 - j103.800) Ω	Q=2.100	24.200GHz
	TP 3	(49.428 - j0.781) Ω	Q=0.016	24.200GHz

Cursor

Return Loss	0.59 dB	VSWR	29.54 :1
Q	14.74	Γ	0.935 / 88.336 °
Y	(1.31-j19.38)mS	Z	(3.48+j51.35)Ω
Zo	50.0Ω	Freq	24.200GHz

Oplossing met RFsim99



Netwerk 6a

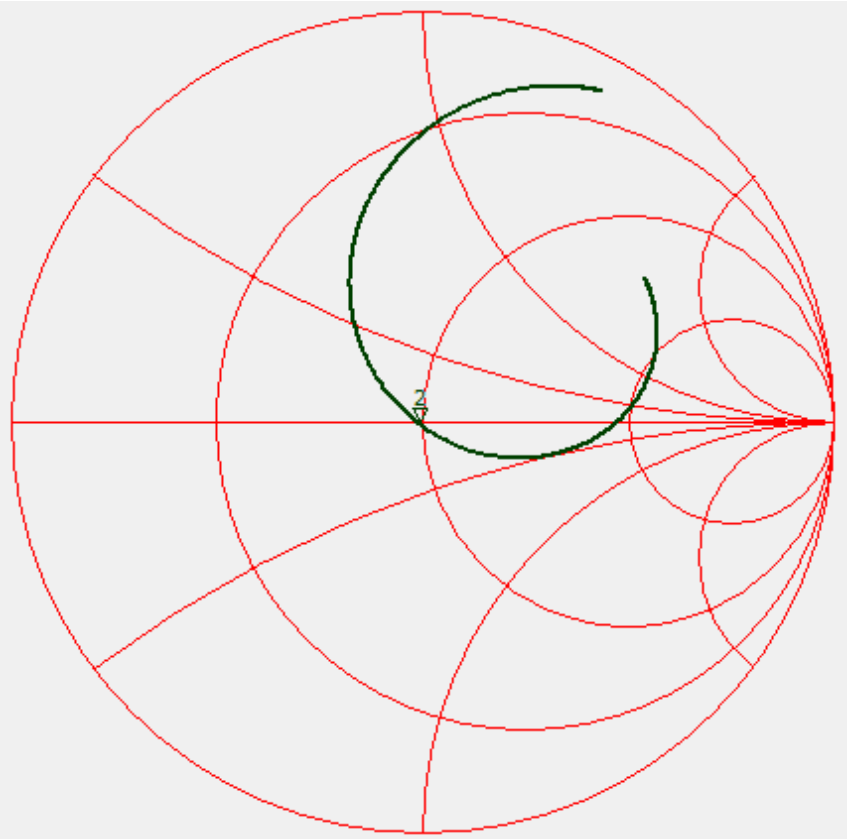
Z = 28.3 -J78.9

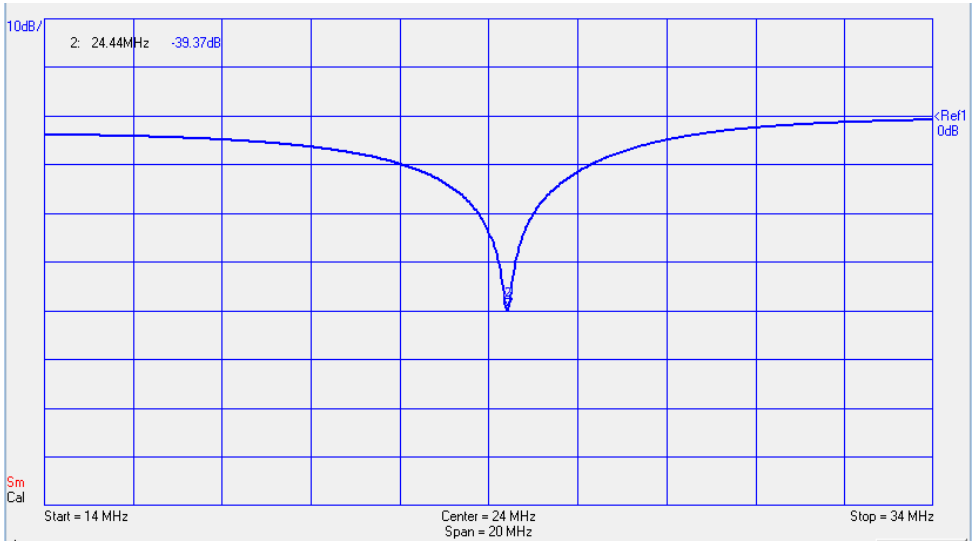
+

=

Z = 49.3 -J0.8

VNWA: Netwerk 6a





De onbekende Z + het aanpasnetwerk vormen samen de perfecte match

Conclusie

- **Een VNA is zeer nauwkeurig**
- **Met een VNA en Simulatie programma's is matching een stuk eenvoudiger**
- **Met een VNA is nog veel meer mogelijk wat de VNA wel erg leuk maakt!**

- Vragen?

www.rfseminar.nl

Internet Links

- **Web shop SDR-Kits voor de VNWA van DG8SAQ**
- https://sdr-kits.net/introducing-DG8SAQ-VNWA3

- **Info over VNA PA4TIM:**
- http://www.pa4tim.nl/?cat=26
- http://www.pa4tim.nl/?p=1594

- Kurt Poulsen OZ7OU doc's → internet....

- En andere VNA bouwprojecten:
- https://hackaday.io/project/26213-vector-network-analyzer
- https://www.eevblog.com/forum/rf-microwave/open-hardware-microwave-vector-network-analyzer/

- http://n2pk.com

- http://hforsten.com/cheap-homemade-30-mhz-6-ghz-vector-network-analyzer.html
- http://hforsten.com/improved-homemade-vna.html

- **Returnlossbrug:** 20dB Cavity Directional Coupler N-female Type 800-2500MHz
- https://www.ebay.nl/itm/20dB-Cavity-Directional-Coupler-N-female-Type-800-2500MHz-Frequency-New/181447941971?ssPageName=STRK%3AMEBIDX%3AIT&_trksid=p2057872.m2749.l2649

- **RF bridge 0.5-3000 MHz, VNA Return Loss VSWR SWR reflection bridge**
- https://www.ebay.nl/itm/RF-bridge-0-5-3000-MHz-VNA-Return-Loss-VSWR-SWR-reflection-bridge-antenna/332052527822?ssPageName=STRK%3AMEBIDX%3AIT&_trksid=p2057872.m2749.l2649
- **Zie meting:**
- https://www.pe1rqm.nl/download/RF-Bridge-pcb-Matching.xls
- **Of voor RL-bridge PE1FOD**
- https://www.hamforum.nl/viewtopic.php?f=2&t=447