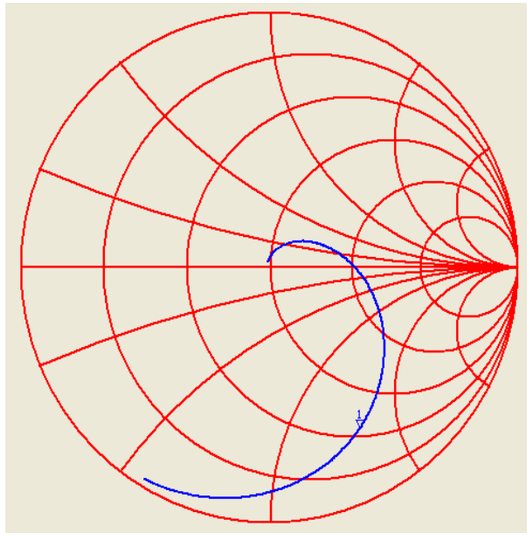
Vector network analyzer

(VNWA – VNA)

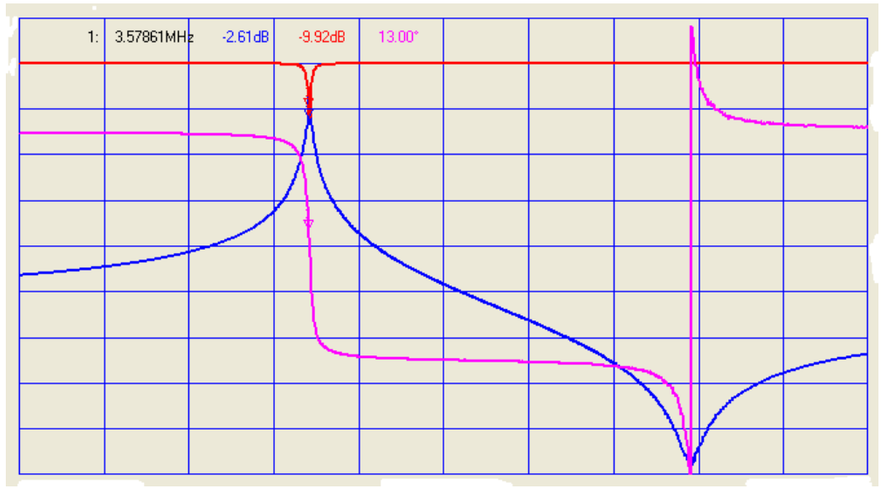
Praktische inleiding voor gebruik



Timo Lampe

PE1FOD

Nov 2020



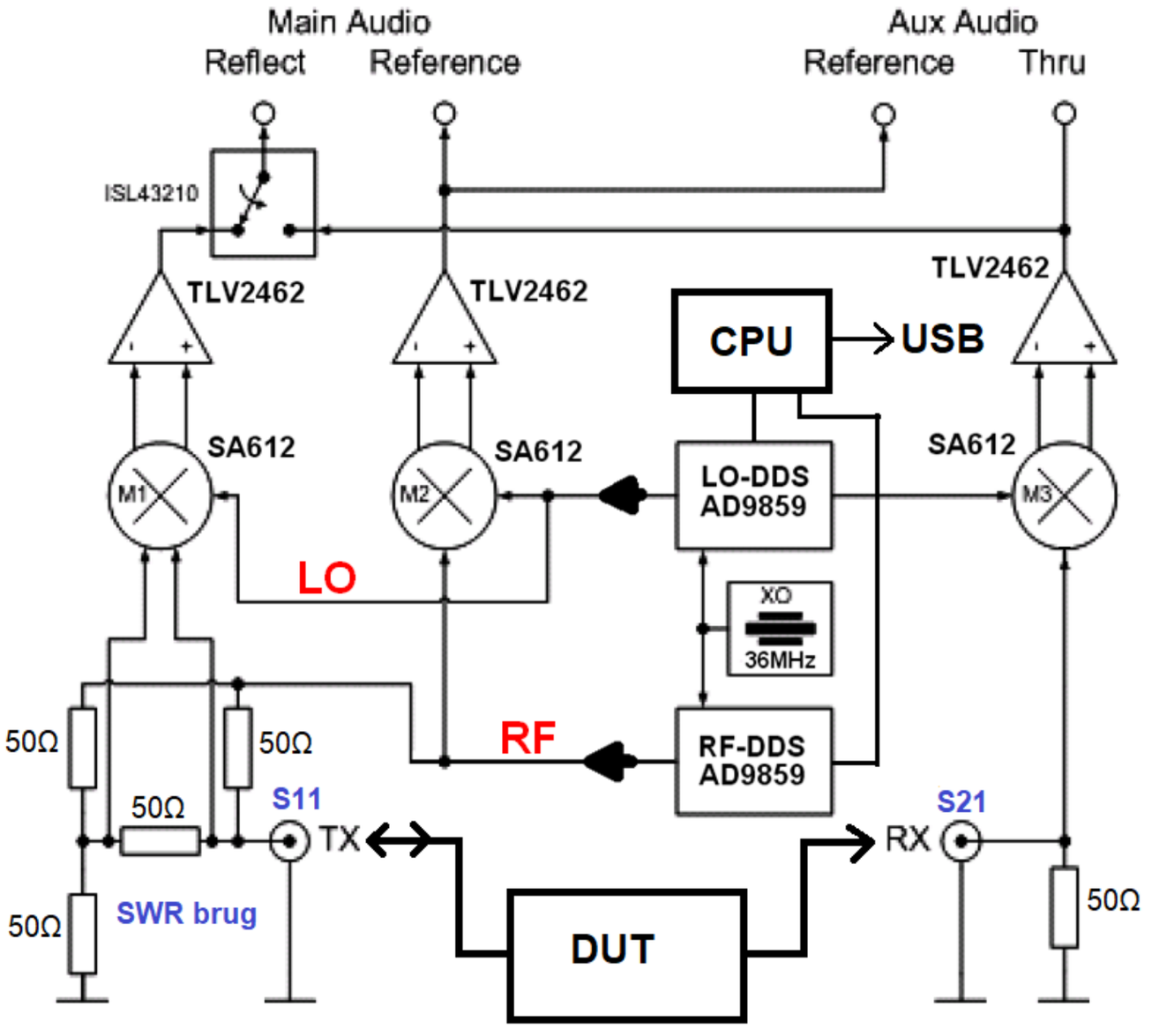
Introductie

- 1 Algemeen
    - Blok schema
    - VSWR brug
    - Wat meet een VNA
    - DG8SAQ <-> nanoVNA
    - Tools, extra in DG8SAQ
- 2 VNWA
    - Kalibratie
    - Cal kit zelf maken
    - Controle of de kalibratie goed werkt
- 3 Tips & hints
    - Zijn de meet coaxkabels goed genoeg?
    - Scherm parameters
    - Het meten van….

VNWA Blokschema

TX out = Port 1 = S11 Rx in = Port 2 = S21

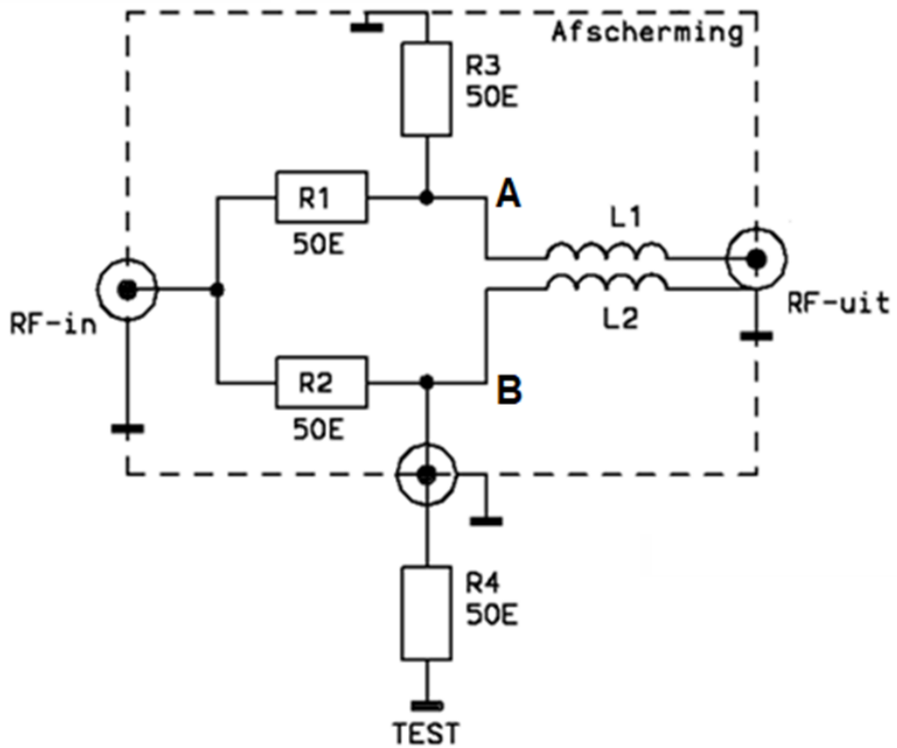
- Sweep van F1(start) tot F2(stop)
- Over een aantal punten en tijd/punt
- 1.5 Port, geen full 2 port (3SE wel)

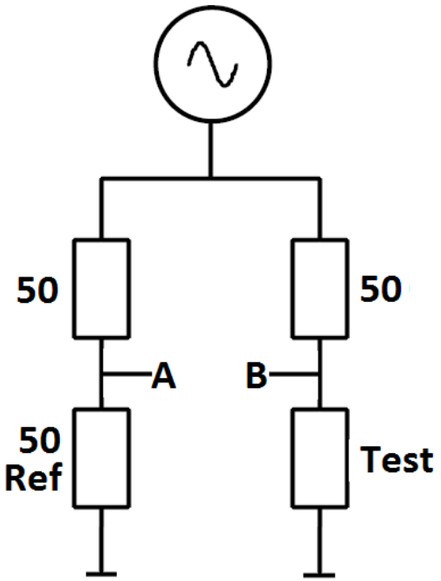


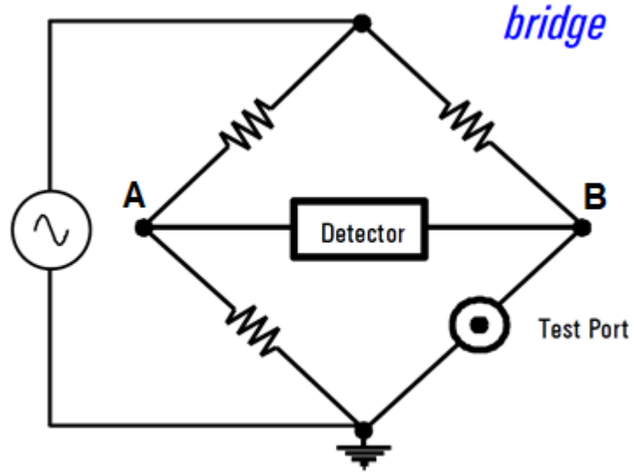
SWR (Return Loss) brug

R3=Referentieweerstand 50Ω

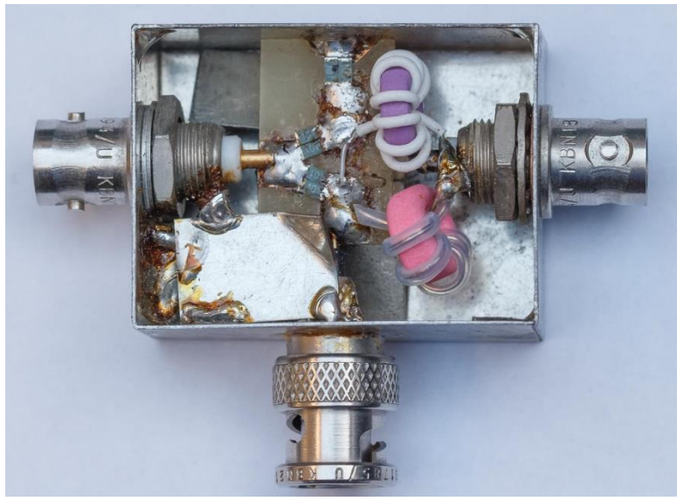
L1 & L2:
Vormen samen een transformator
van symmetrisch naar asymmetrisch.

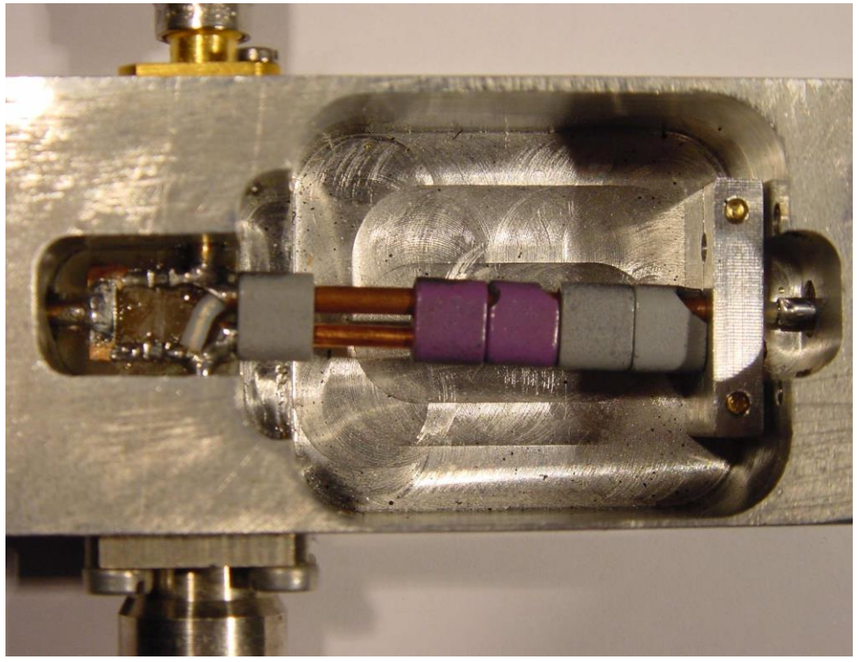


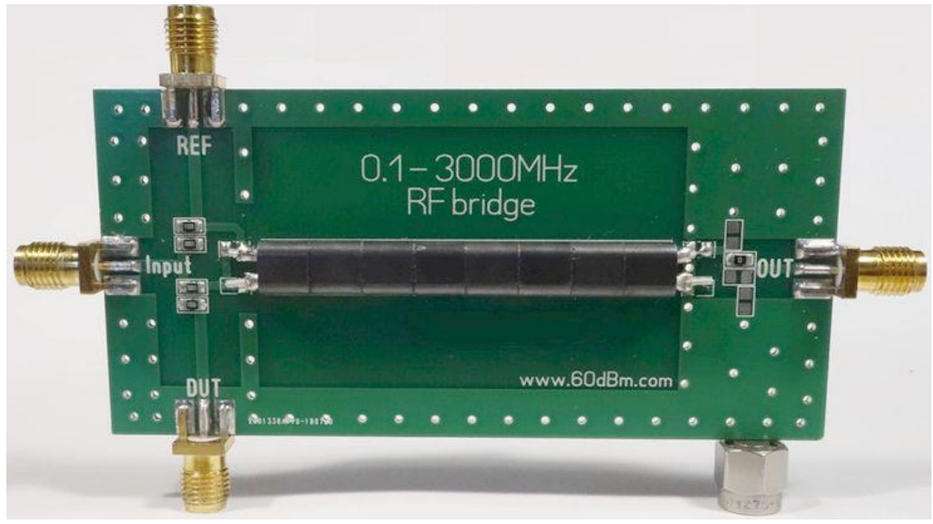




SWR Brug PE1FOD







1-600MHz

300-3000MHz

5 - 2000 MHz

VSWR Tabel

VSWR=Lineair

Return loss=Log, dB

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

Wat meet een VNA

- **Basisfuncties**
- S11 = SWR (RL, Return loss)
- S21 = Doorlaat / level

- De gemeten S-parameter kan vervolgens in vele vormen gepresenteerd worden.
- Lineair / Log (dB)
- Schaal instelling zonder begrenzing
- Als de sw dat ondersteunt
- Zoals →

- Smith

Real	Real Z	
Imag	Imag Z	
Mag	|Z|	
Log Mag	C -	
Real dB	L -	
Imag dB	Real Y	
Phase	Imag Y	
c.Phase	|Y|	
-c.Phase/w	R ||	
Delay	X ||	
	C ||	
	L ||	
	QC	
	QL	
	VSWR	
	signed VSWR	

En nog veel meer !

DG8SAQ <-> nanoVNA

- 0.001 – 1300MHz
- Veel sw opties
- 1.5 port
- USB

Model

- 1 0.1 - 900 MHz
- 2 0.1 - 1500 MHz
- 3 0.1 - 3000 MHz
- Standaard S-parameter sw
- 1.5 port
- Eigen display (portabel)
- Batterij / USB

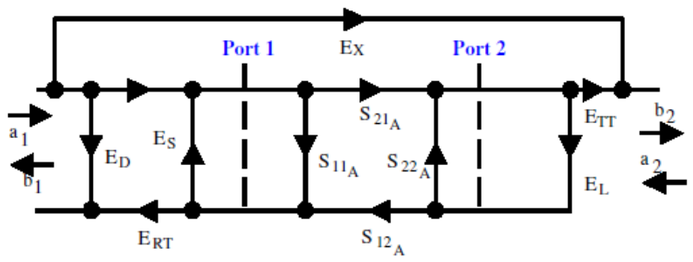
Tools, extra in DG8SAQ

- Simple Spectrum
- Frequentie meten (3E, ext Ref.)
- Antenne patroon (Radar Plot)
- Component LCR / trace
- Kristal analyzer
- Signal generator
- Full 2 port optie
- Matching tool
- Power sweep
- 6 trace
- Veel trace opties (Mem,plot…)
- Realtime custom trace Expression calculator
- Uitgebreide help aanwezig via winhlp32.exe uit 2004

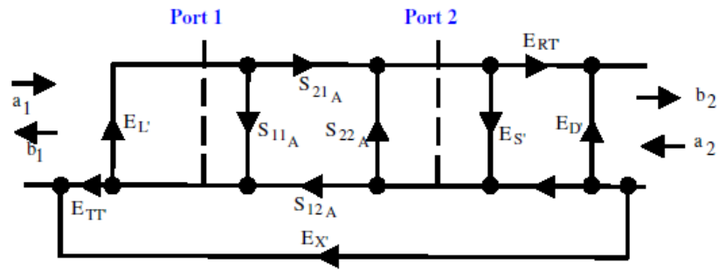
Uit: BTB_Network_2005-1.pdf

Two-Port Error Correction

Forward model



Reverse model



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

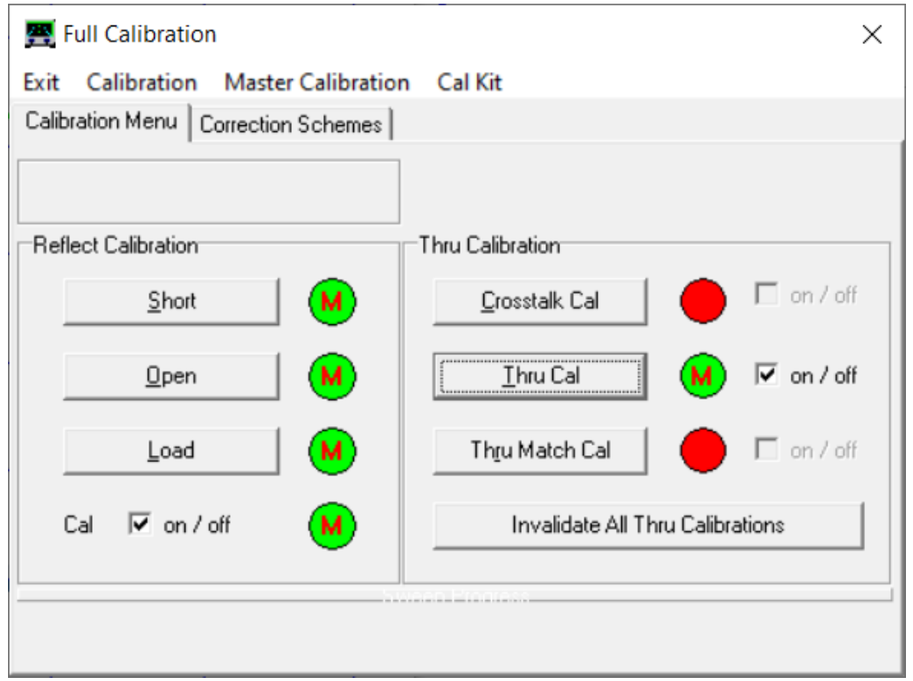
www.agilent.com/find/backtobasics

Kalibreren

- https://nl.wikipedia.org/wiki/Kalibreren
- **Kalibreren** is het vergelijken van een systeem of apparaat met een standaard om de eigenschappen vast te stellen.
- Het af- of instellen om het in overeenstemming te brengen met de specificatie wordt justeren genoemd.
- Een ijking bestaat erin dat er eerst gekalibreerd wordt om dan te justeren

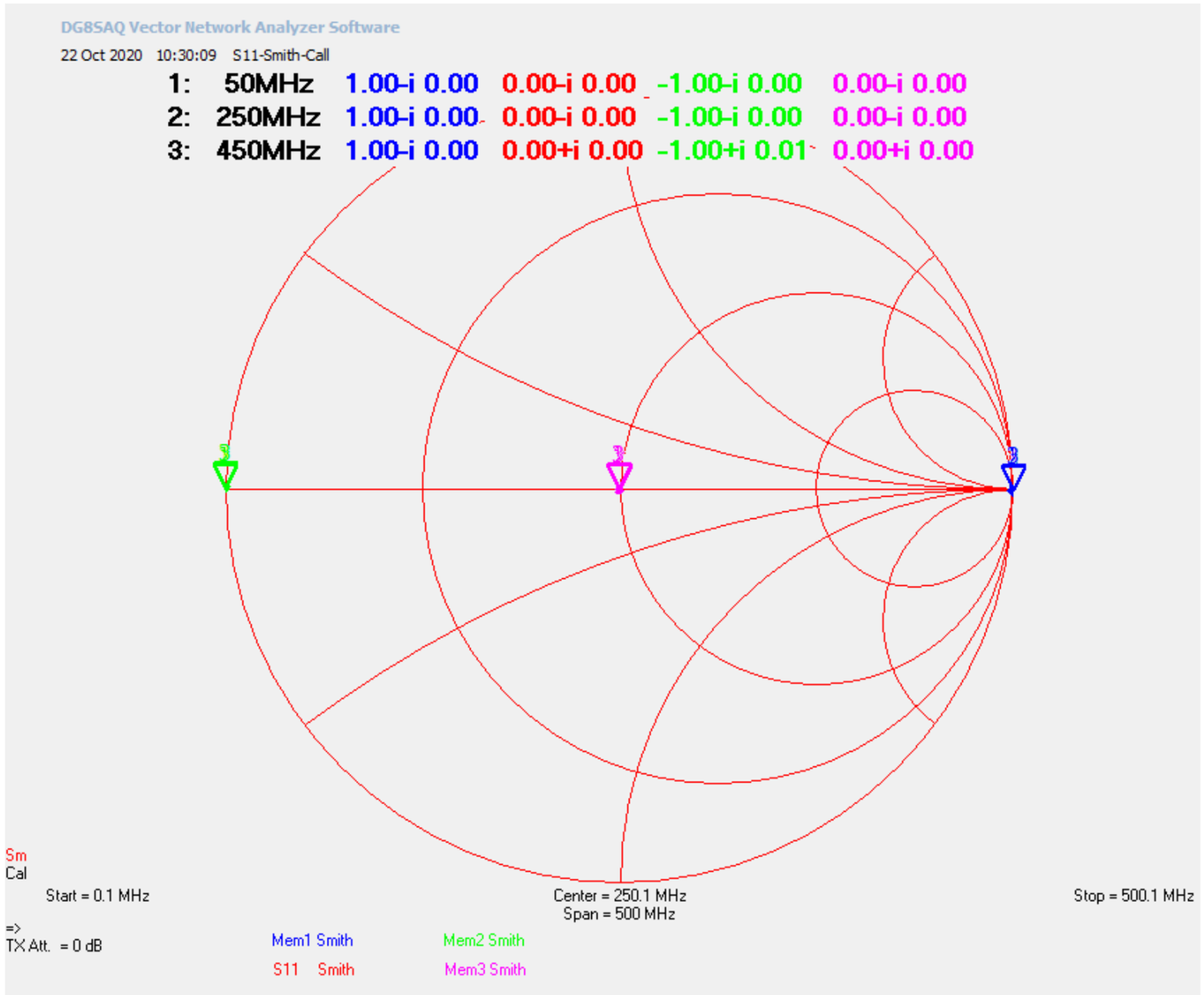
Kalibratie

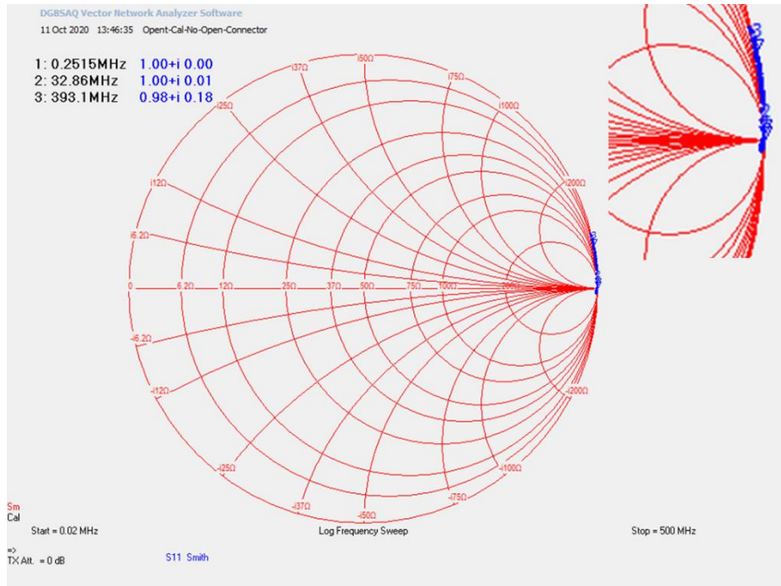
- Zonder werkt het niet, bij een instelling verandering opnieuw!
- Open
- Short
- Load



- Coaxkabels wegrekenen
- Referentievlak (Reference plane)
- Laten zien dat het klopt in Smith kaart
- Poort extensie, om extra aansluit kabel te compenseren
- Cal kit , Load =50.000Ω
- Voor alle connectoren (male/female/SMA/BNC/N) een cal kit!

Short Load Open Na Kalibratie

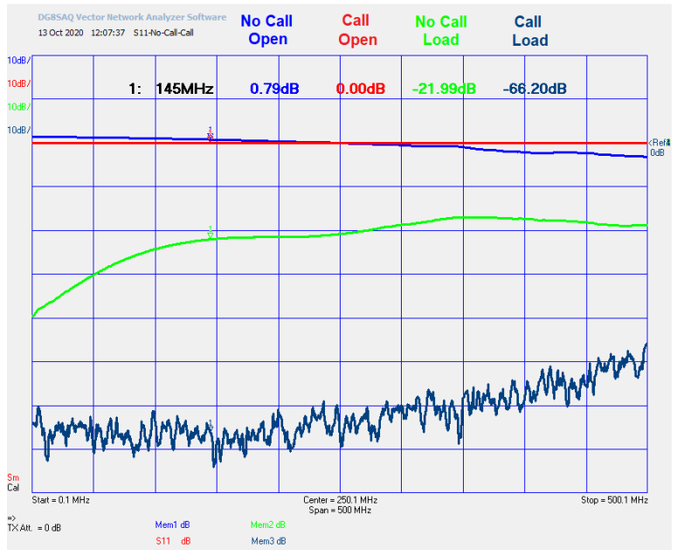




←Geen open connector

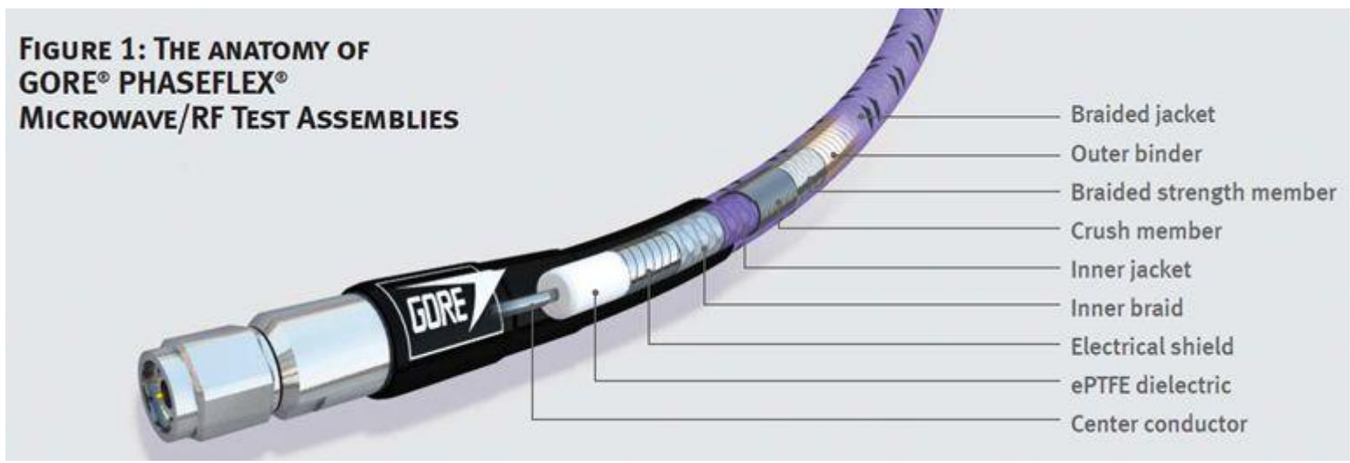
S11 Un-Cal→

S11 Cal→



Coax

- Welke coaxkabel is geschikt voor VNA gebruik
- Fasestabiel
- Zelf check met Smith kaart, open short, Load
- RD316 = RG316 met dubbele mantel (ook wel RG316D).

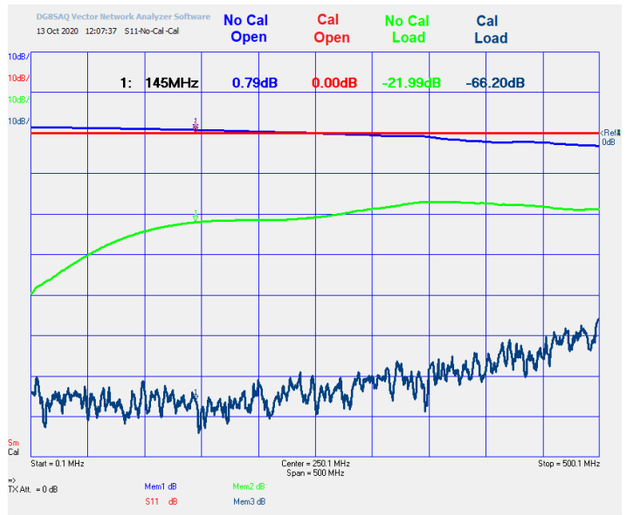


Scherm parameters

DG8SAQ - Vector Network Analyzer Software

File Measure Settings Tools Options Help

1: 0.1033MHz -6.26dB



DG8SAQ Vector Network Analyzer Software

13 Oct 2020 12:07:37 S11-No-Cal -Cal

No Cal Open **Cal Open** **No Cal Load** **Cal Load**

10dB/ ← Set schaal 1: 145MHz 0.79dB 0.00dB -21.99dB -66.20dB

10dB/

10dB/

10dB/

Sm

Cal

Start = 0.1 MHz

Center = 250.1 MHz

Span = 500 MHz

Stop = 500.1 MHz

=>

TX Att. = 0 dB

Trace Setting

Mem1 dB

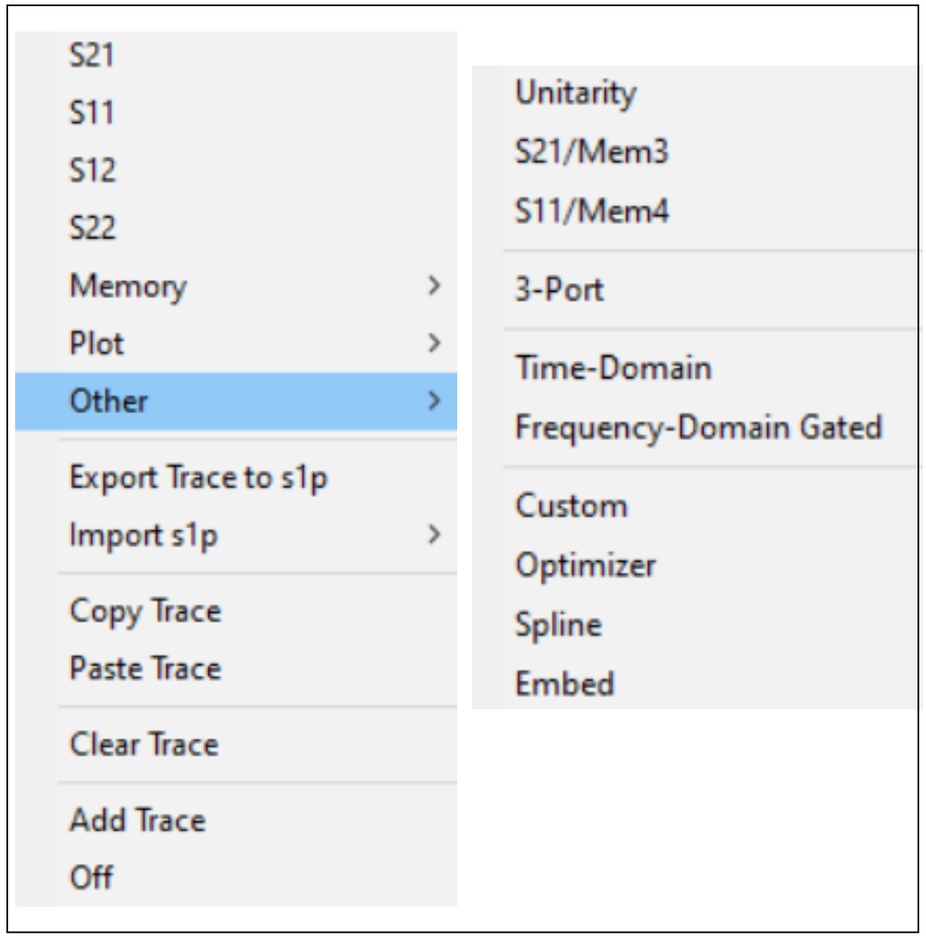
S11 dB

Mem2 dB

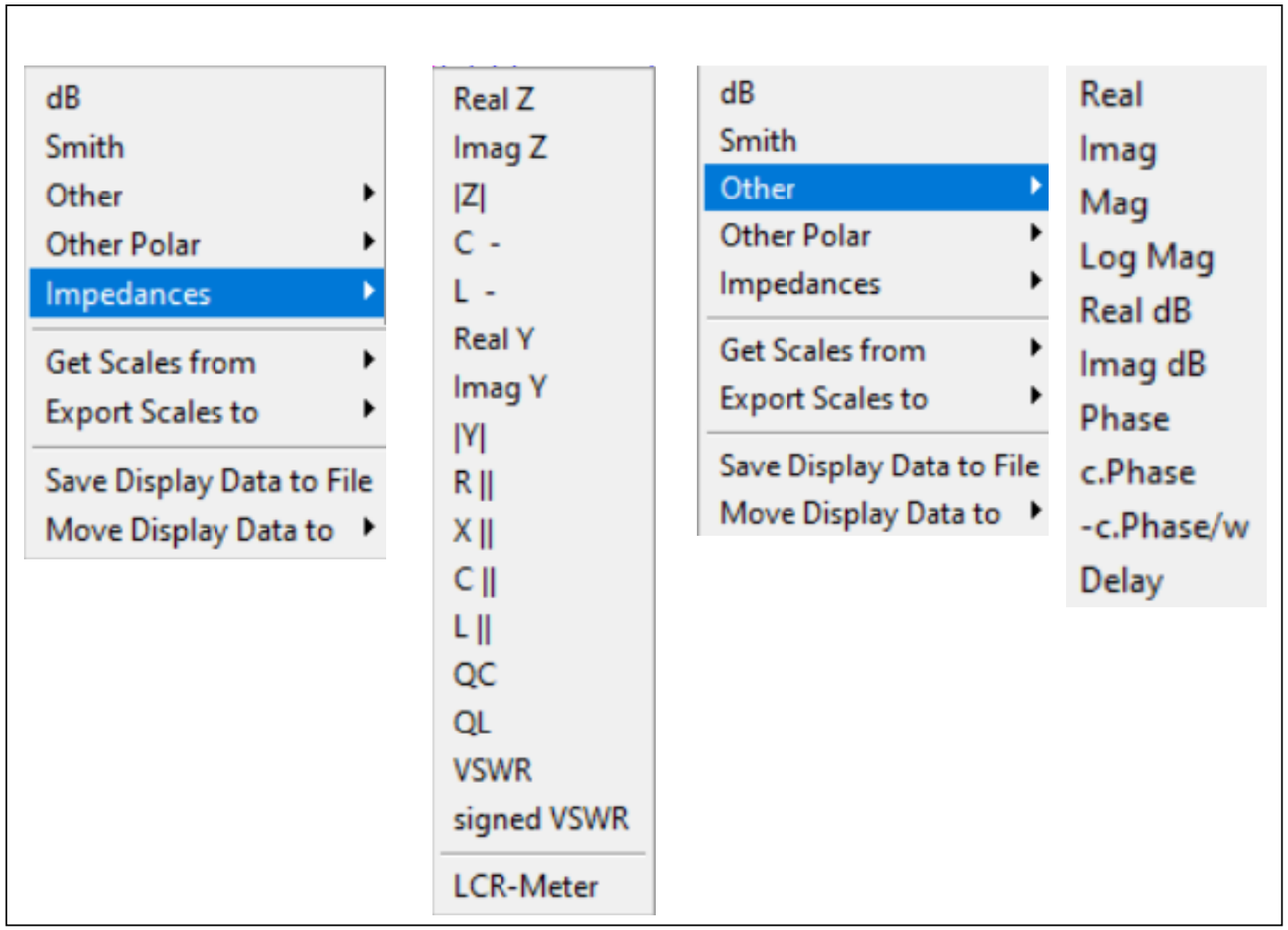
Mem3 dB

Weergave

Trace setting



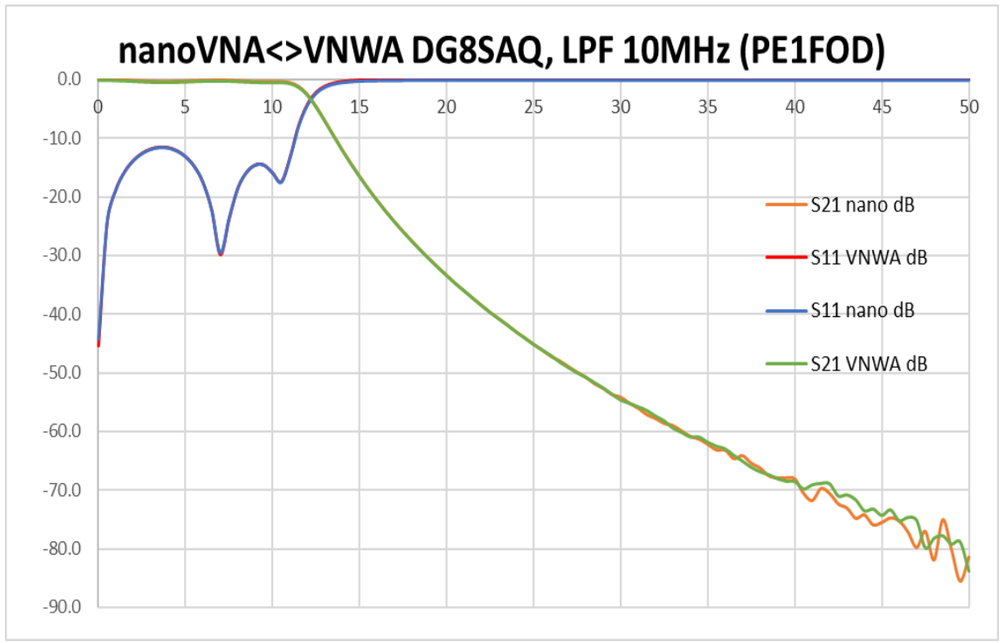
Weergave

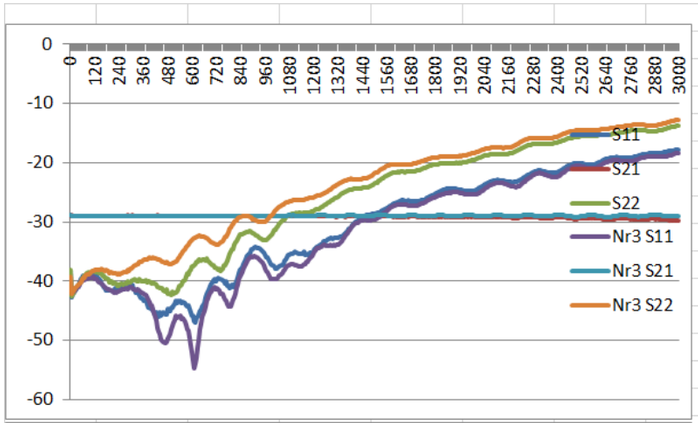


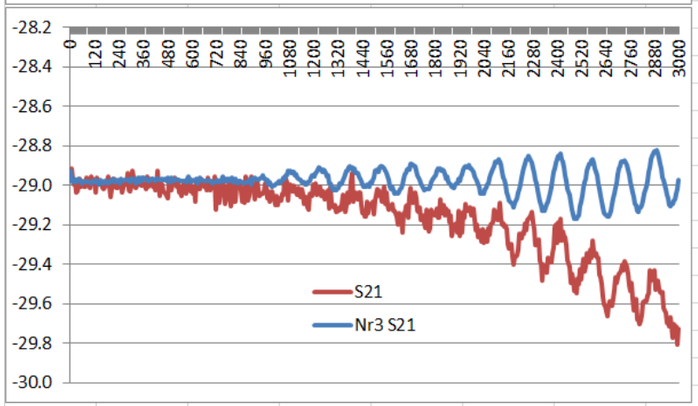
Meten van:

- Passieve onderdelen (doorlaat + SWR, RL) waaronder Filters / verzwakkers en S-Parameters in Excel gebruiken
- Capaciteit / Inductie
- Kristal (filters) / sweep time
- Kristal analyzer
- Frequentie meter
- Directe µ meting van ring kernen
- TDR (lengte tot verstoring, connector, open)

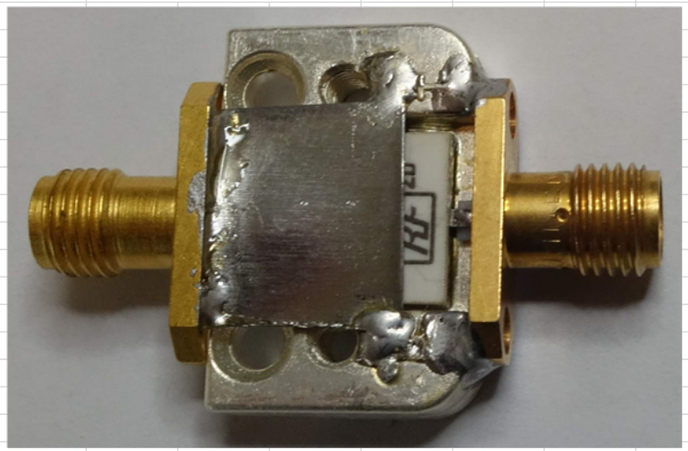
S-Parameters in Excel gebruiken







Stukje blik er op gesoldeerd



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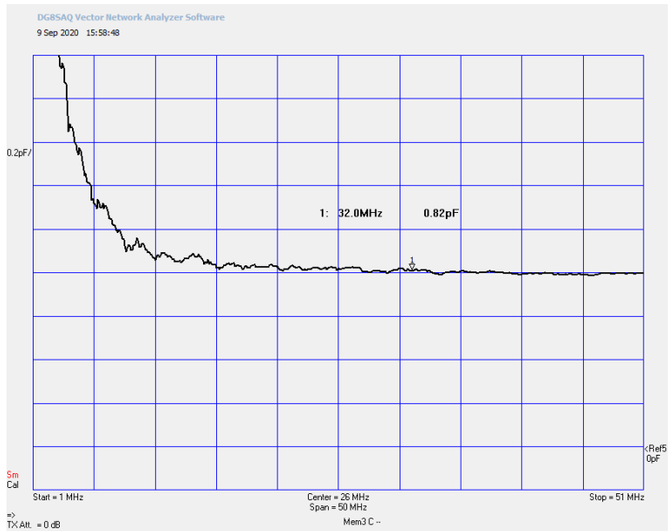
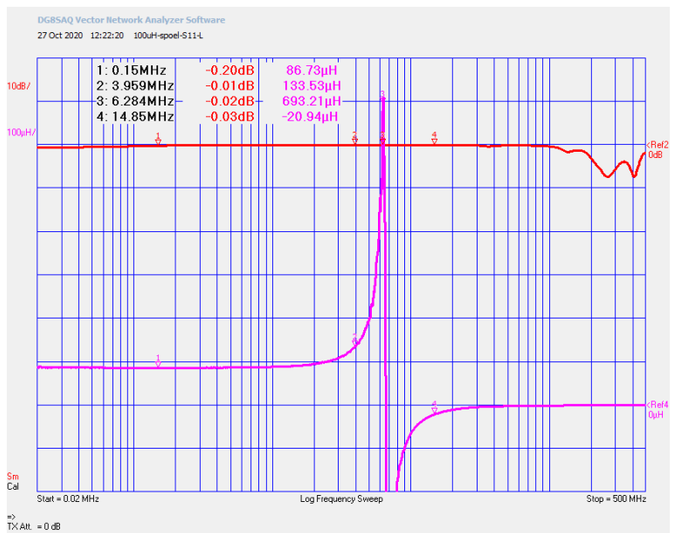
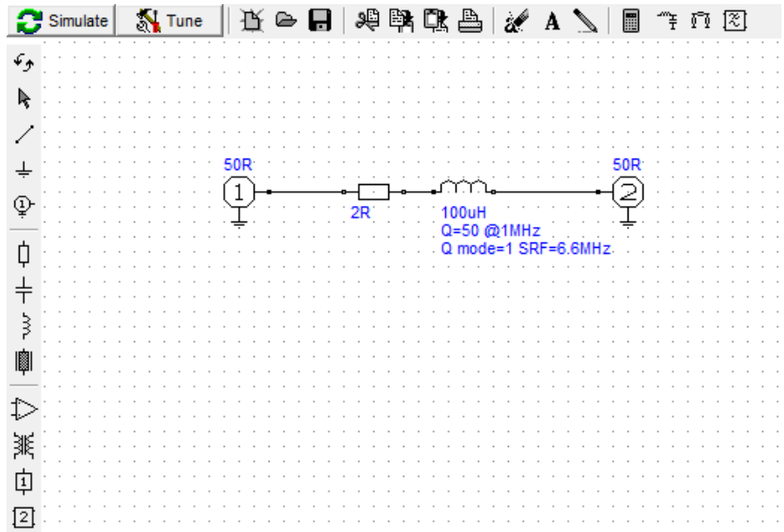
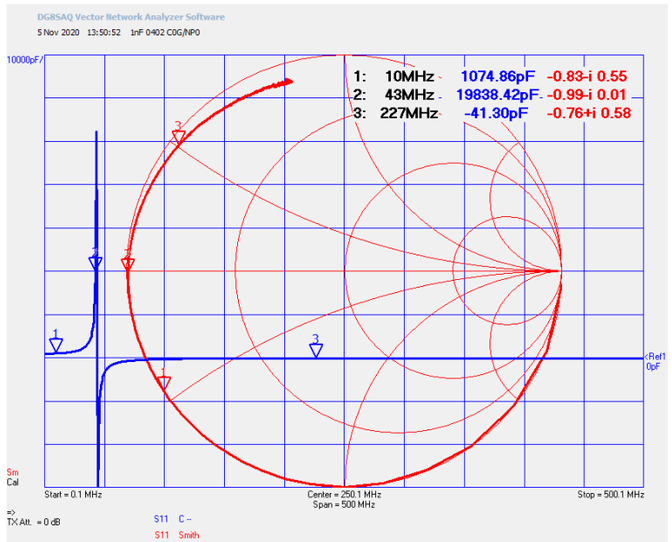
!Date: Mon Nov 11 09:44:17 2019							
				Mod redy			
Nr3		Nr3		Nr3		Nr3	
S11		S21		S12		S22	
-40.82	0.17	-28.92	-0.27	-29.07	0.15	-39.31	-22.48
-42.00	0.07	-28.98	0.12	-28.98	0.09	-42.10	3.17
-41.71	-0.91	-28.99	0.20	-28.98	0.15	-41.88	3.21
-41.76	-4.89	-28.96	0.25	-28.99	0.15	-41.60	2.01
-41.54	-5.48	-28.97	0.36	-28.97	0.36	-41.30	2.70
-41.27	-6.82	-28.99	0.51	-28.96	0.43	-41.00	4.20
-41.07	-7.22	-28.98	0.59	-28.98	0.54	-40.88	4.28
-40.93	-8.46	-28.97	0.66	-28.97	0.60	-40.54	3.46
-40.61	-8.06	-28.97	0.75	-28.98	0.79	-40.46	5.97
-40.09	-8.91	-28.98	0.90	-28.98	0.89	-40.24	5.86
-39.97	-8.14	-28.99	0.97	-28.98	0.96	-39.87	6.78
-39.86	-7.45	-28.98	1.10	-28.98	1.07	-39.54	9.40
-39.89	-7.18	-28.98	1.21	-28.98	1.13	-39.40	8.84
-39.70	-5.75	-28.99	1.33	-28.98	1.32	-39.18	11.44
-39.66	-6.80	-28.98	1.39	-28.98	1.45	-38.86	13.30
-39.51	-5.97	-28.98	1.54	-28.99	1.50	-38.83	14.21
-39.45	-4.63	-28.98	1.57	-28.98	1.52	-38.65	16.53
-39.38	-3.47	-28.99	1.68	-28.98	1.71	-38.52	17.84
-39.41	-2.21	-28.98	1.84	-28.98	1.70	-38.23	21.05
-39.36	-2.56	-28.98	1.93	-28.98	1.88	-38.22	22.40
-39.57	-1.25	-28.98	1.97	-28.99	1.99	-38.09	23.85
-39.65	-0.20	-28.97	2.12	-28.99	2.12	-38.16	25.50
-39.75	-1.00	-28.98	2.20	-28.97	2.20	-38.04	25.86
-40.00	-0.22	-28.99	2.28	-28.98	2.33	-38.06	28.29
-40.22	-0.18	-29.00	2.39	-28.98	2.42	-38.09	29.05
-40.18	-0.10	-28.97	2.53	-28.99	2.59	-38.04	32.09
-40.48	-0.85	-28.98	2.62	-28.98	2.69	-37.98	33.55
-40.70	0.84	-28.98	2.80	-28.97	2.76	-38.14	34.45
-40.90	-1.44	-28.99	2.80	-28.98	2.93	-38.18	35.43
-41.03	-1.06	-28.98	3.01	-28.97	2.99	-38.32	37.41
-41.24	-1.96	-28.98	3.07	-28.98	3.06	-38.21	38.16
-41.34	-3.17	-28.99	3.18	-28.98	3.14	-38.36	39.24
-41.50	-6.33	-28.98	3.32	-28.98	3.34	-38.64	40.36
-41.59	-6.65	-28.98	3.44	-28.97	3.37	-38.57	40.16
-41.63	-6.30	-28.97	3.46	-28.99	3.50	-38.49	41.33
-41.78	-8.33	-28.97	3.61	-28.98	3.45	-38.65	41.69
-41.96	-9.44	-28.98	3.67	-28.97	3.71	-38.61	41.98
-41.88	-12.63	-28.98	3.78	-28.98	3.83	-38.76	43.20
-41.96	-12.77	-28.98	3.86	-28.98	3.86	-38.77	42.63
-41.75	-14.82	-28.97	4.05	-28.97	4.02	-38.88	42.77
-41.74	-17.01	-28.98	4.12	-28.97	4.08	-38.72	44.81
-41.67	-15.78	-28.99	4.21	-28.98	4.22	-38.84	43.96
-41.67	-16.97	-28.97	4.33	-28.97	4.32	-38.79	42.82

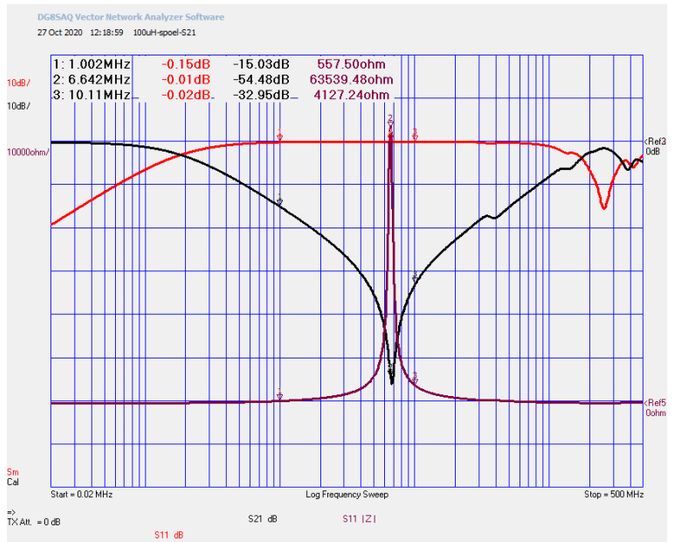
Capaciteit / Inductie / Simulatie met RFsim99

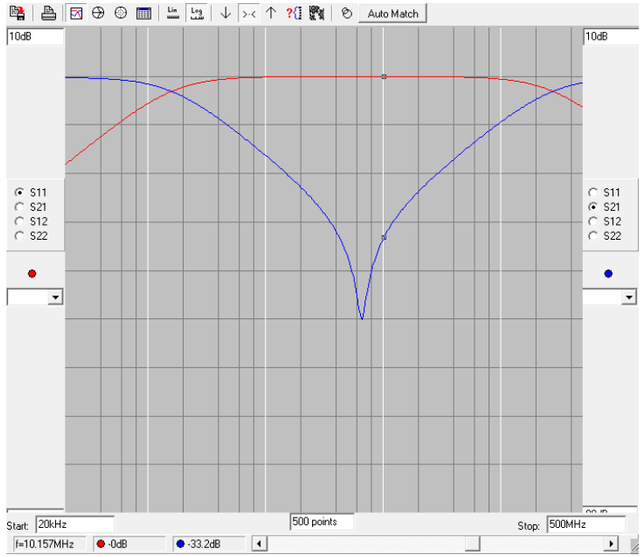




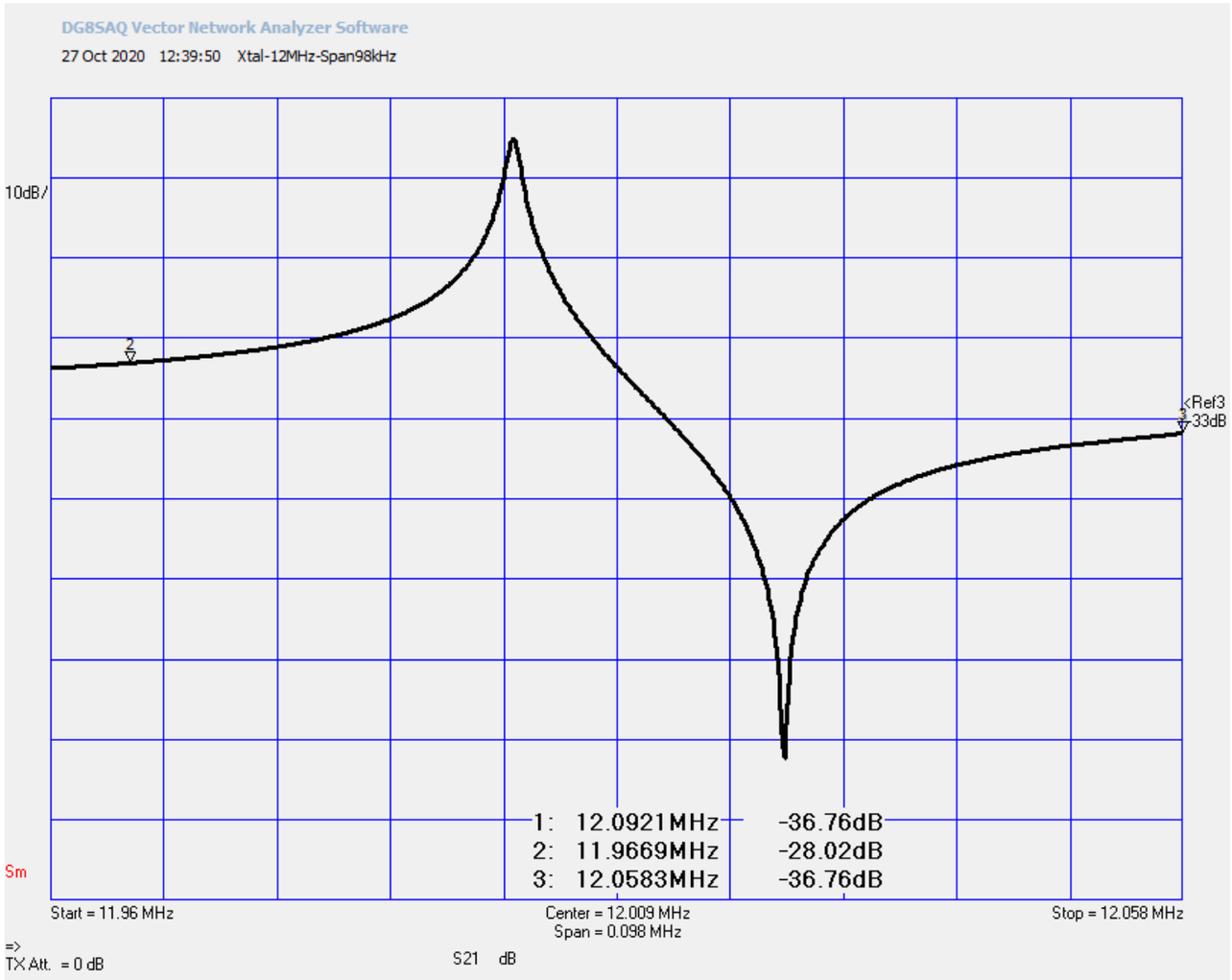


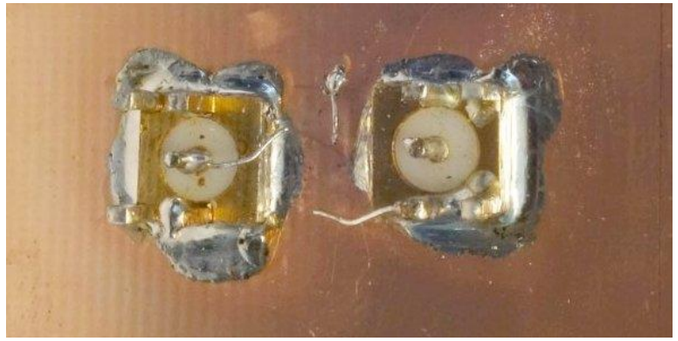




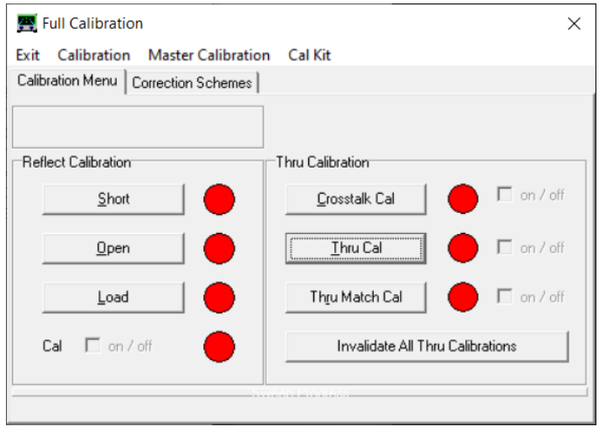


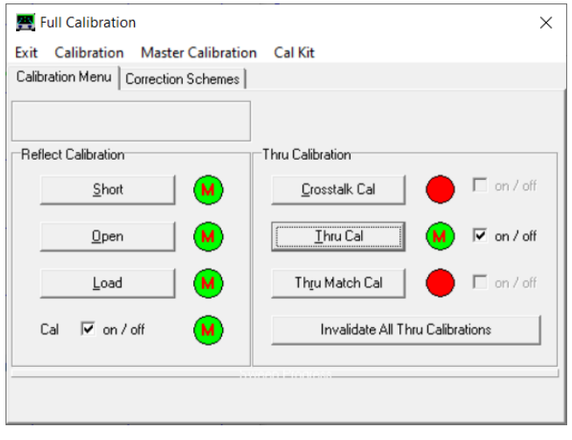
Kristal - filters & sweep time



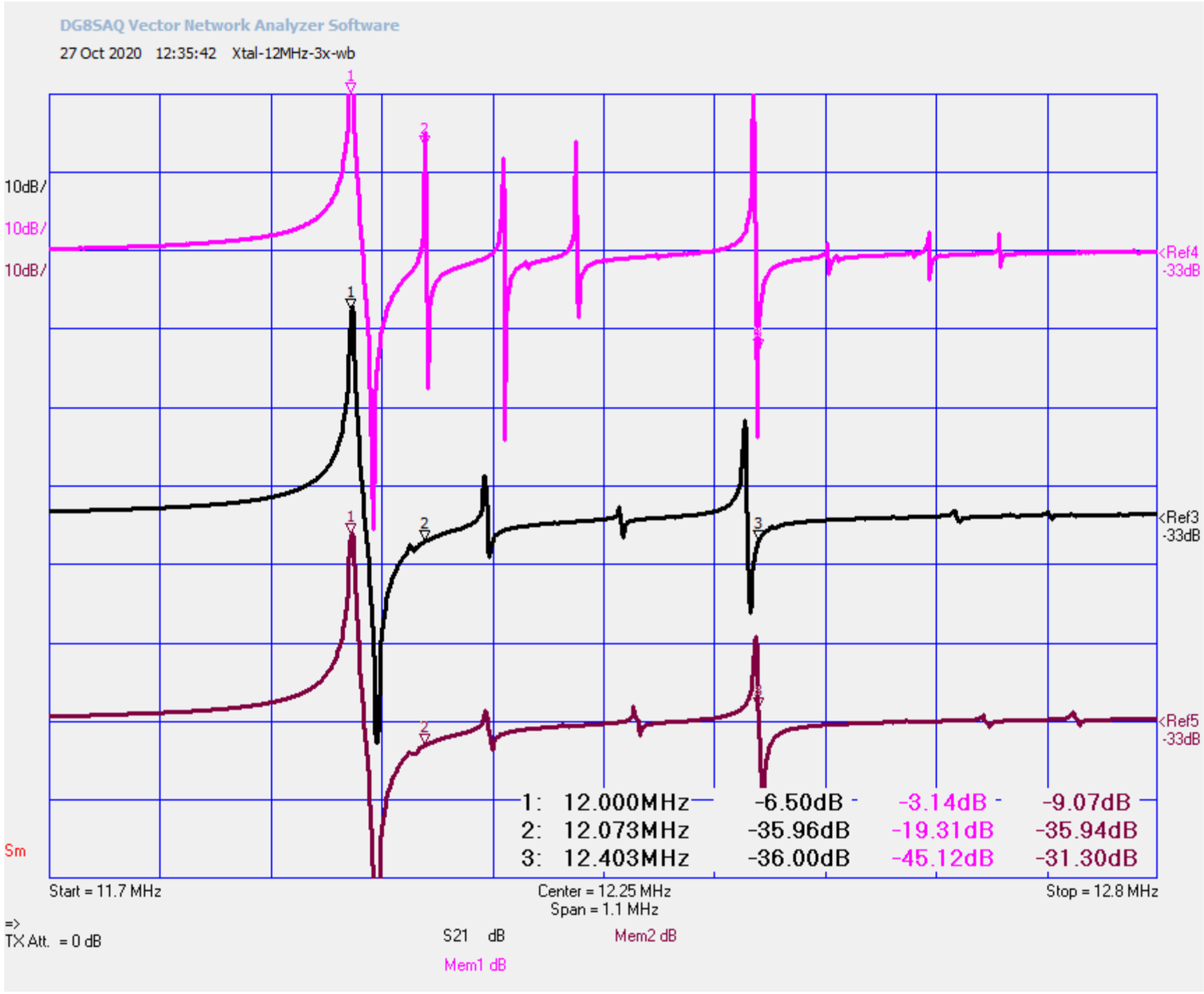


- Test printje met 2x SMA connector
- Niet te snel door hoge Q
- Kalibratie
- Span 98KHz





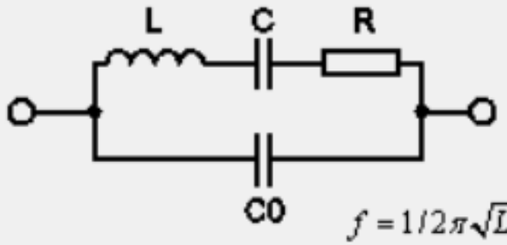
Kristal 12MHz
Span 1.1MHz



Crystal Analyzer

Crystal Analyzer - Analysis will be performed into 3-port data spaces s_11 and s_21 !!!

Equivalent Circuit



L = 16.29086 mH

C = 10.79778 fF

R = 10.670701225994 Ohm

C0 = 3.1026368783582 pF

$f = 1/2\pi\sqrt{L \cdot C}$ = 11.999987223558 MHz

auto-optimize

$R \cdot Q = \sqrt{L/C}$ = 1228.3006829879 x1000

Q = 115109

source = S11

Transmission Test Jig Impedances = 50 Ohms

Recommendation: Start < 11.979 MHz, Stop > 12.042 MHz !

Extended Resonance Info

Model Simulation:
f1: |Z| maximum: 12.0208555 MHz
f2: Im(Z) = 0: 12.0208501 MHz
f3: |Z| minimum: 11.9999859 MHz

Measurement:
f4: |Z| maximum: 12.0208581 MHz
f5: Im(Z) = 0: 12.0210681 MHz
f6: |Z| minimum: 11.9999926 MHz

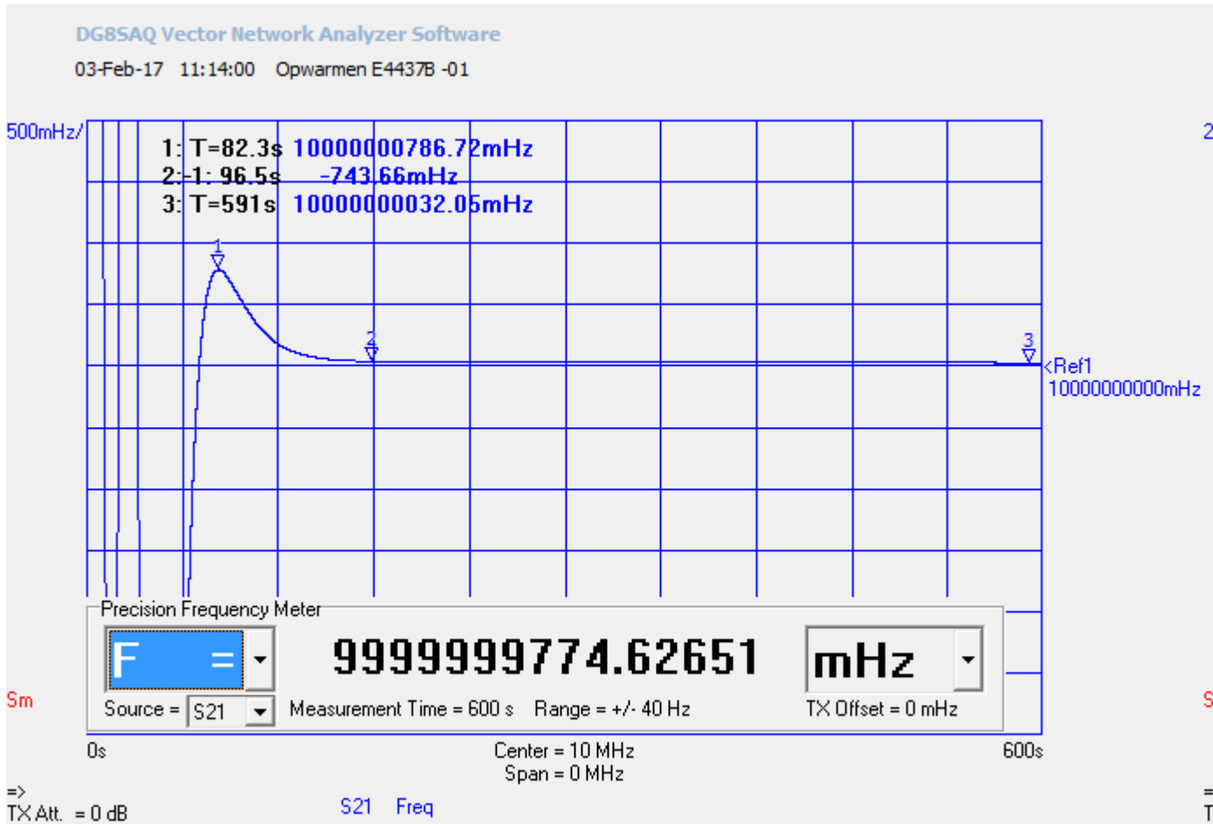
Figure of Merit = 0.0219

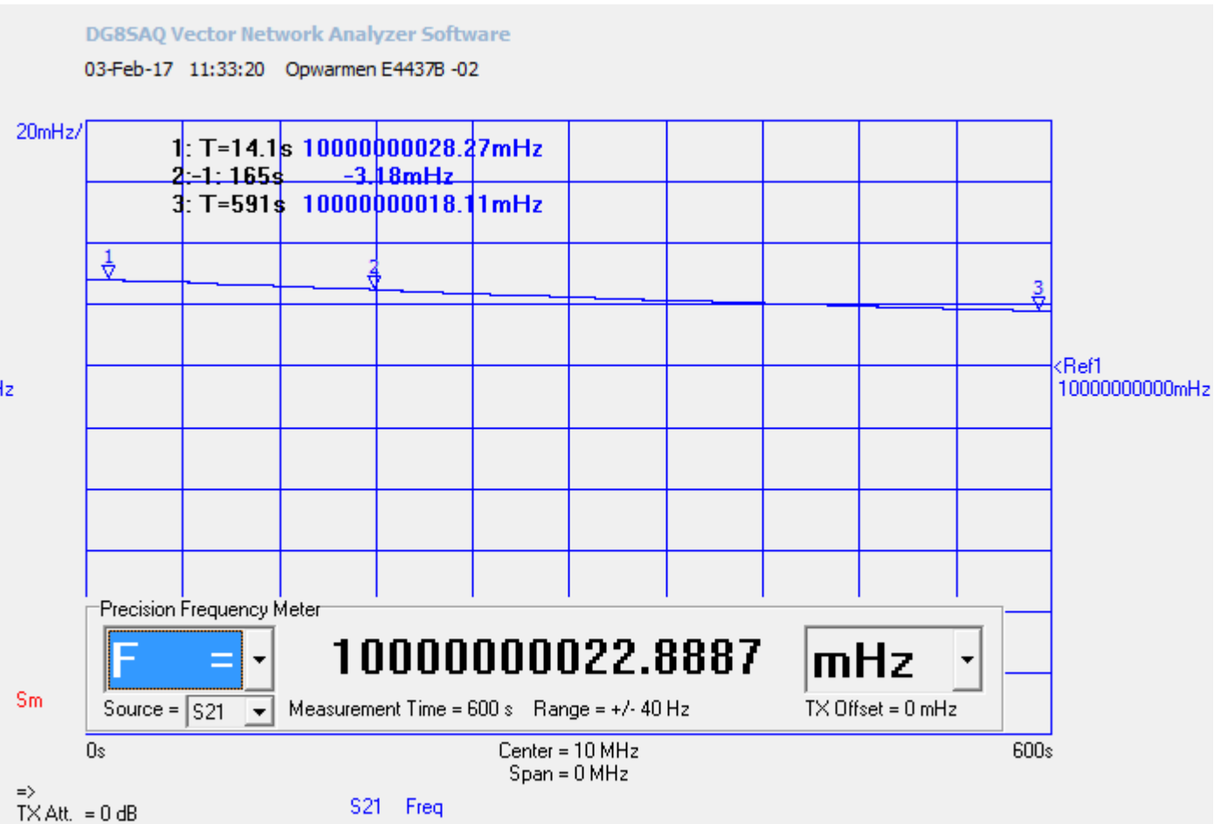
Batch Crystal Analyzer single sweep cont. sweep save list clear list load list

#	f / Hz	Q	L / H	C / F	R / Ohm	C0 / F	figure of merit	F1 / Hz	F2 / Hz
1	11999987.028	115165	0.01629003523	1.079833226E-14	10.67	3.077096533E-12	0.0222	12021039.3	12021024.1
2	11999987.693	114976	0.01628883125	1.079912921E-14	10.68	3.077428872E-12	0.0221	12021039.2	12021024
3	11999987.55	115231	0.01629058032	1.079797E-14	10.66	3.077197381E-12	0.0223	12021038.5	12021023.2
4	11999986.248	115249	0.01629409044	1.079564621E-14	10.66	3.051022135E-12	0.022	12021191.8	12021197.7
5	11999987.421	115118	0.01629100564	1.079768832E-14	10.67	3.115425458E-12	0.0221	12020761.8	12020764.6
6	11999988.161	114943	0.0162902541	1.079818513E-14	10.69	3.090020421E-12	0.0222	12020948.6	12020937
7	11999988.053	114984	0.01628963692	1.079859445E-14	10.68	3.10288349E-12	0.0223	12020855.7	12020850.9
8	11999987.224	115110	0.01629086112	1.079778447E-14	10.67	3.102636878E-12	0.0219	12020855.5	12020850.1

Frequentiemeter

- Ext. Ref.
- 36 , 32 of 10MHz?

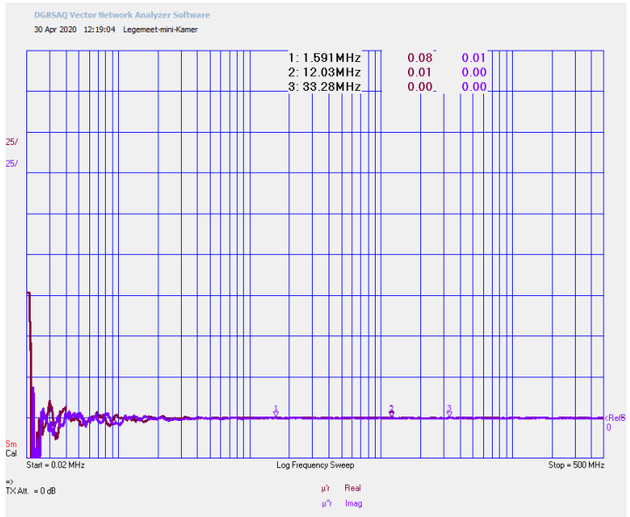




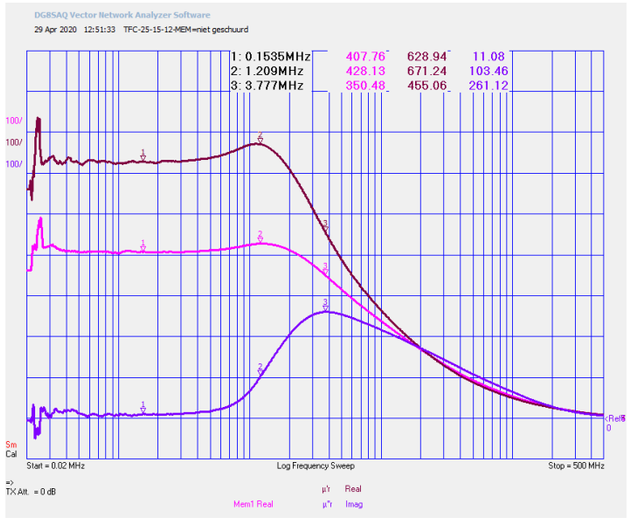
- Schaal = 500mHz

20mHz

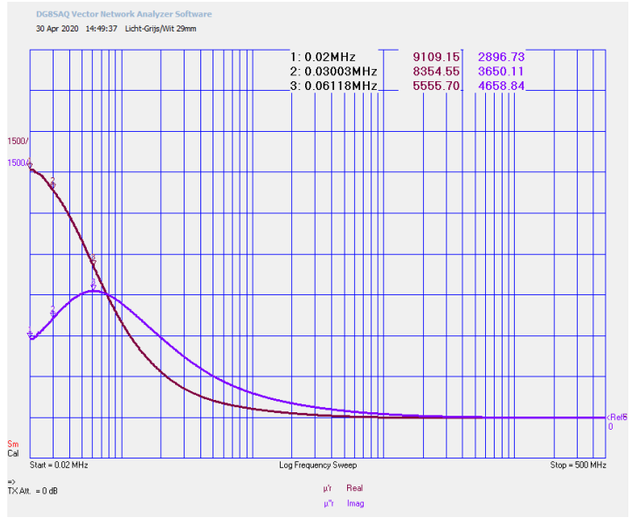
Directe µ meting van ringkernen



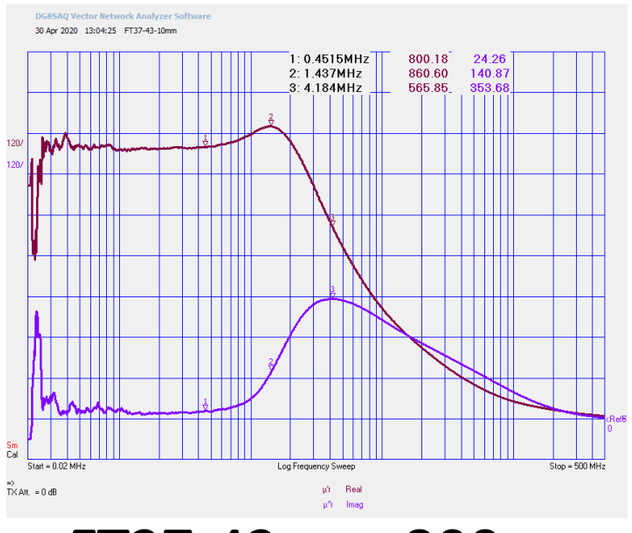
- Lege meetkamer Cal



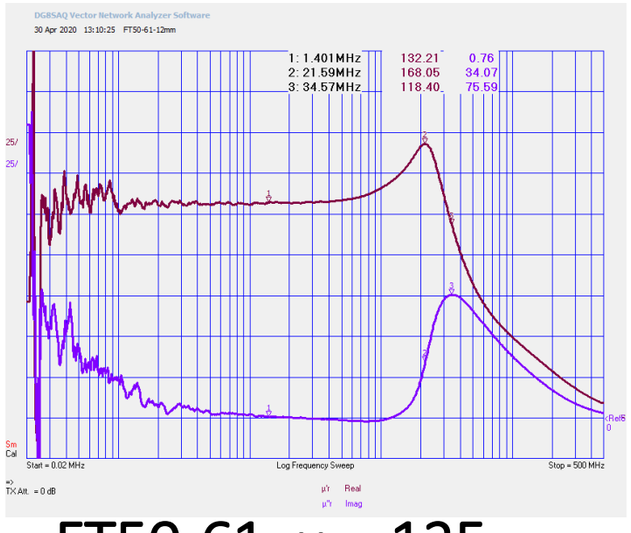
Klapkern (+Schuren)



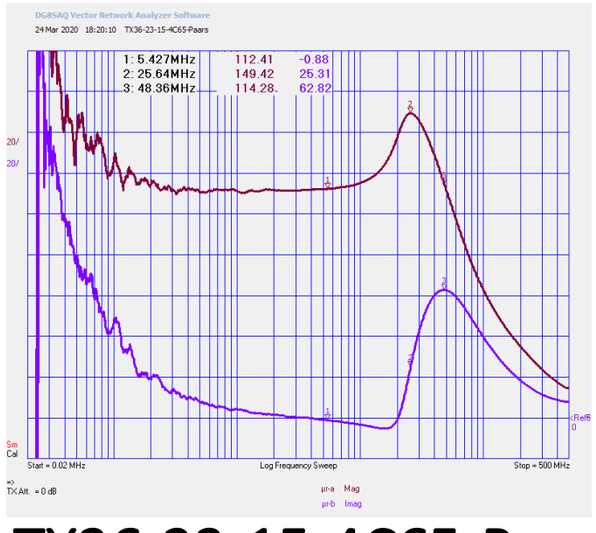
µ = 9000



FT37-43, µ = 800

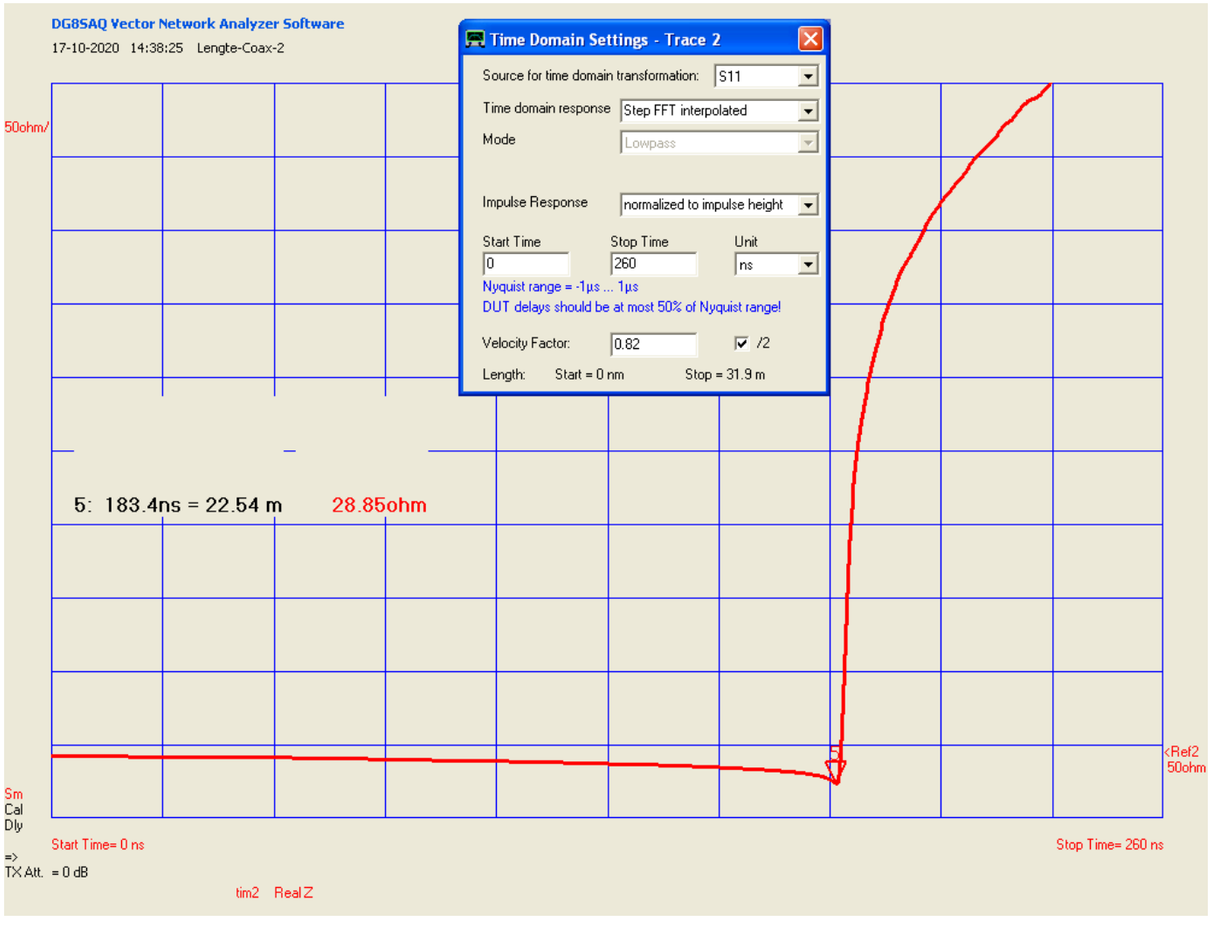


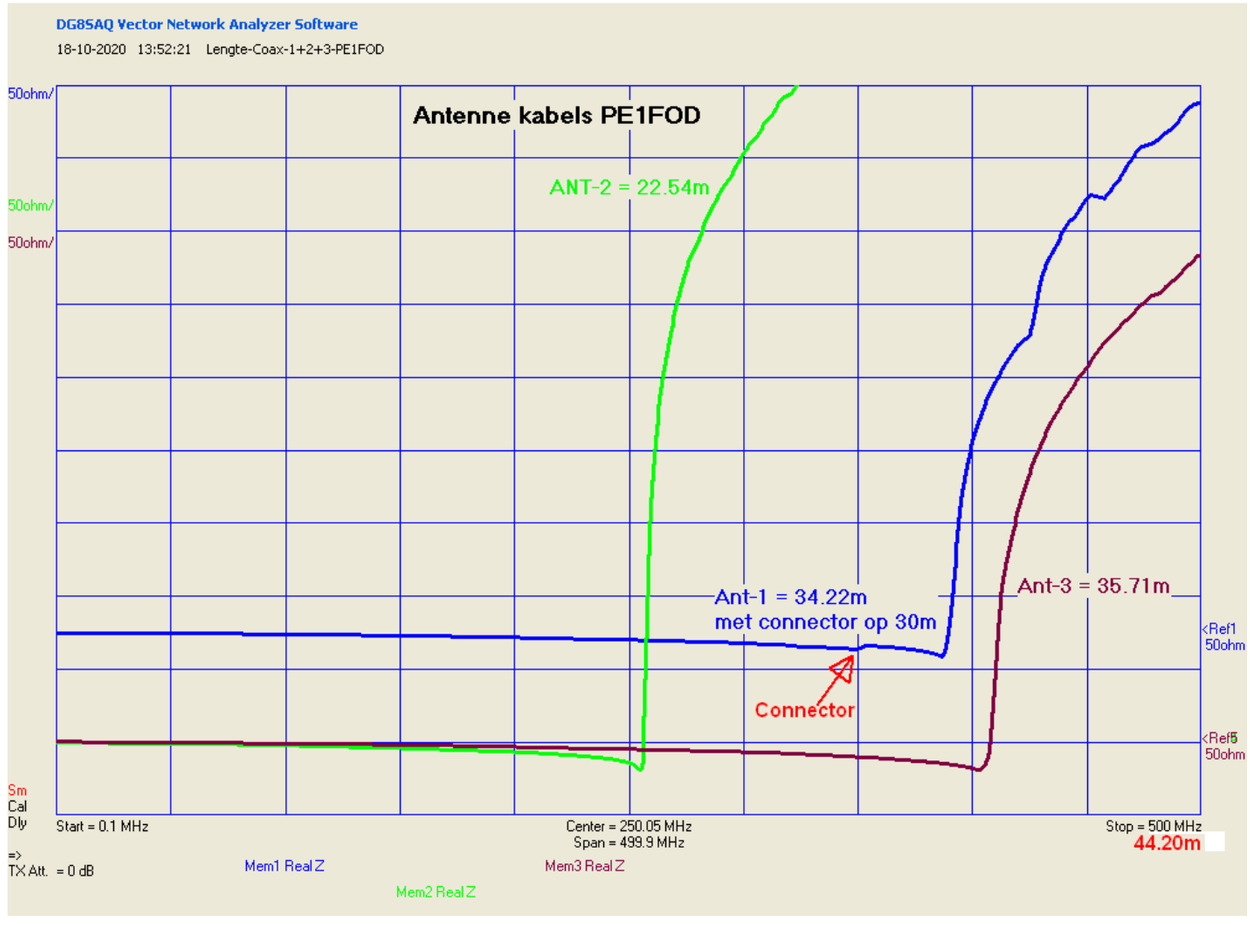
FT50-61, µ = 125



TX36-23-15-4C65-Paars

TDR - lengte tot connector, open, …





Conclusie

- **Een VNA is zo veelzijdig, mag dus niet ontbreken in shack**

- Vragen?

- Links & documentatie: (If no link → copy/past to search engine)
  - 2.VNWA_toepassingen_in_de_praktijk-Timo_Lampe_PE1FOD_update.pdf
  - Het-meten-van-ferrieten-Timo-PE1FOD-RF-webinar-14-jun-2020.pdf
  - BTB_Network_2005-1.pdf
  - https://www.sdr-kits.net/introducing-DG8SAQ-VNWA3
  - https://www.pe1rqm.nl/hamforum/projecten-van-timo-pe1fod/

- Zie ook info van:
  - Kurt Poulsen OZ7OU
  - Fred PA4TIM
  - https://groups.io/g/VNWA
  - https://groups.io/g/nanovna-users