



## Evolution of the DG8SAQ Vector Network Analyzer: New VNWA3 Features & Applications

PROF. DR. THOMAS BAIER

E-mail: [baier@hs-ulm.de](mailto:baier@hs-ulm.de)

DG8SAQ

Hochschule Ulm

Prittwitzstrasse 10

89075 Ulm

English version by

Jan Verduyn G0BBL and Kurt Poulsen OZ7OU

Technik

Informatik & Medien

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University of  
Applied Sciences

# VNWA Presentation - Contents

- **What are S-parameters?**
- **How does the VNWA function and how was it born?**
- **New features**
- **Some novel measurement examples**

Dank an:

- *Eric Hecker*

- *Giuseppe Gristina*

- *Fred Schneider*

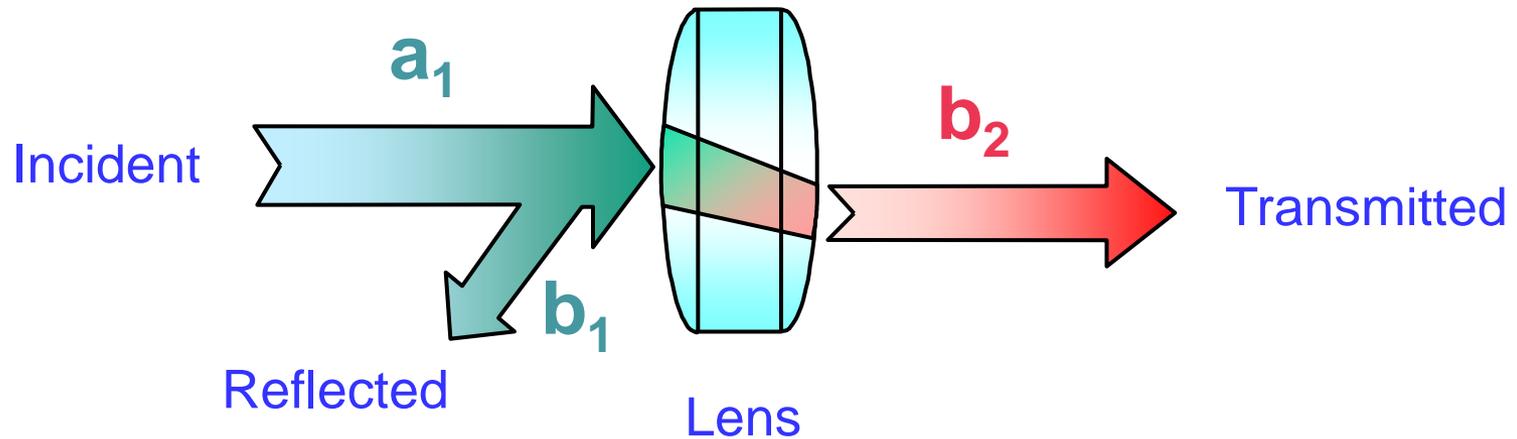
- *Mario Armando Natali*

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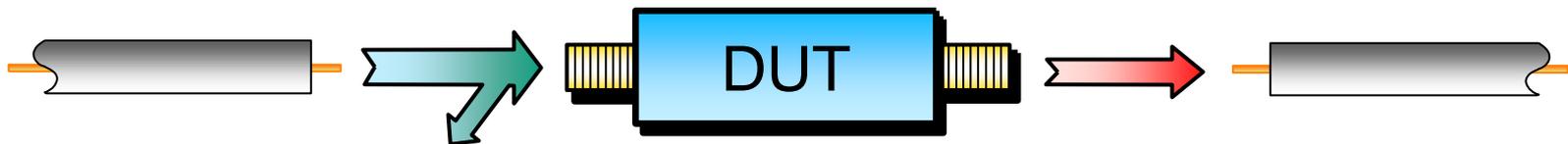


# It is all about scattering of Waves

## Optic



## Electrical

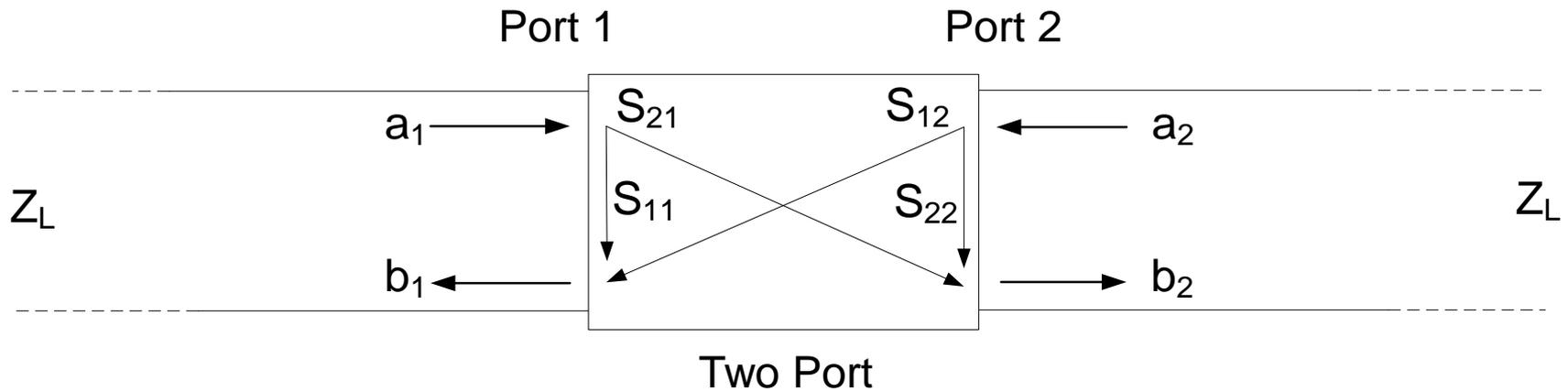


DUT : DEVICE UNDER TEST

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# S-Parameter = Scattering Parameter $S_{ik}$

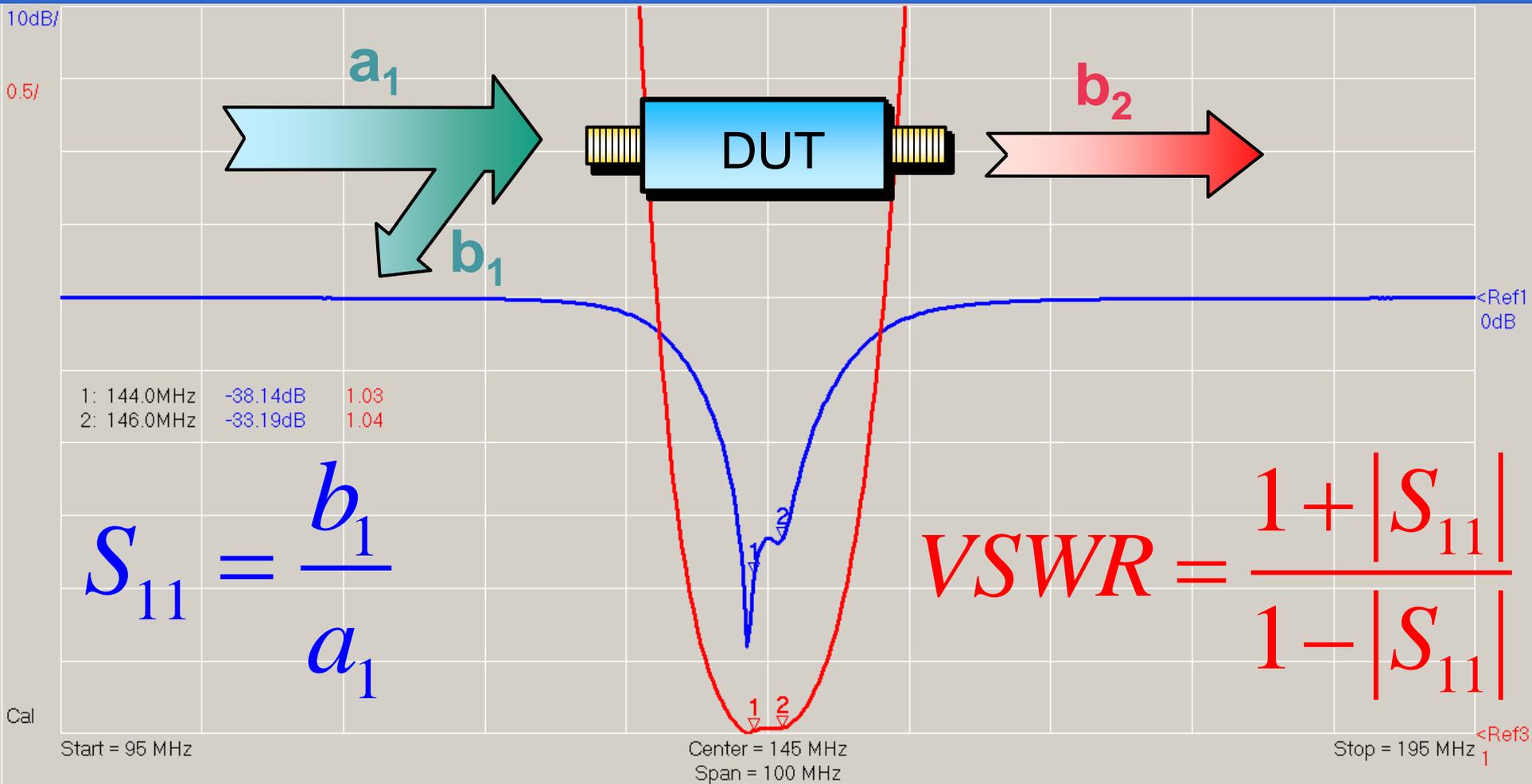


- Complex S-parameters:  $S_{ik} = b_i / a_k$
- $S_{ik}$  are complex numbers consisting of **Magnitude** and **Phase**!



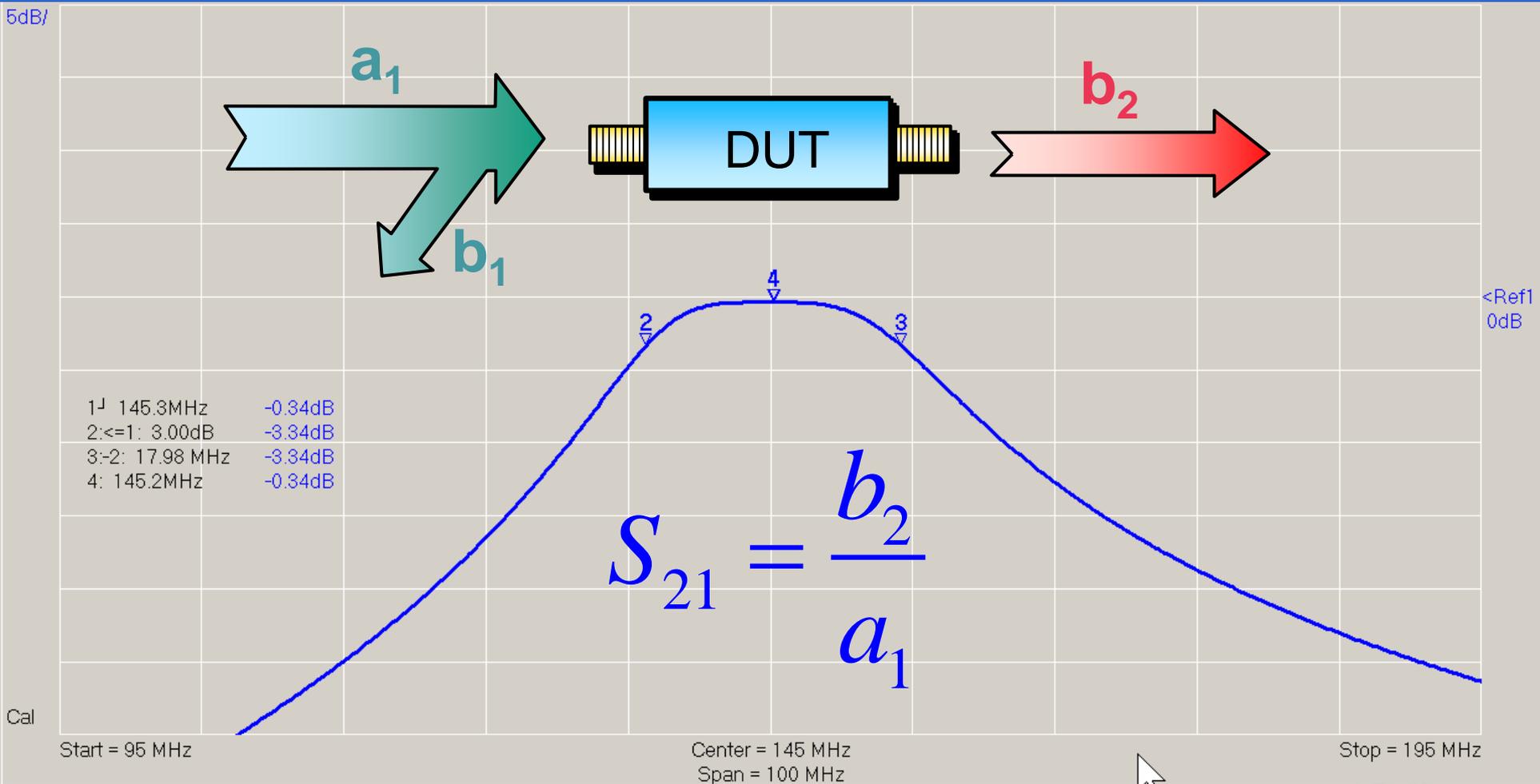
# S-Parameter $S_{11}$

→  $|S_{11}| = \text{Input Return Loss}$

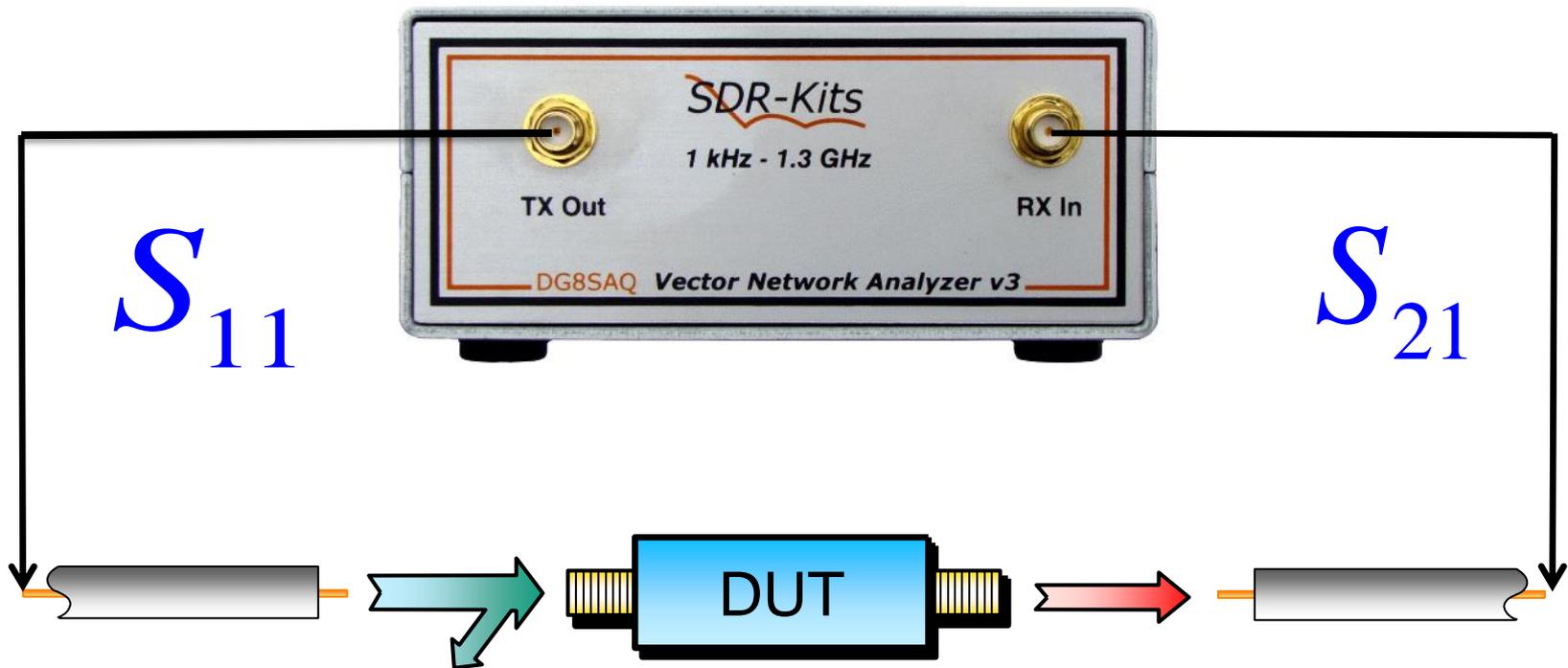


# S-Parameter $S_{21}$

→  $|S_{21}| = \text{Transmission Loss}$



# The VNWA can measure these S-Parameters!



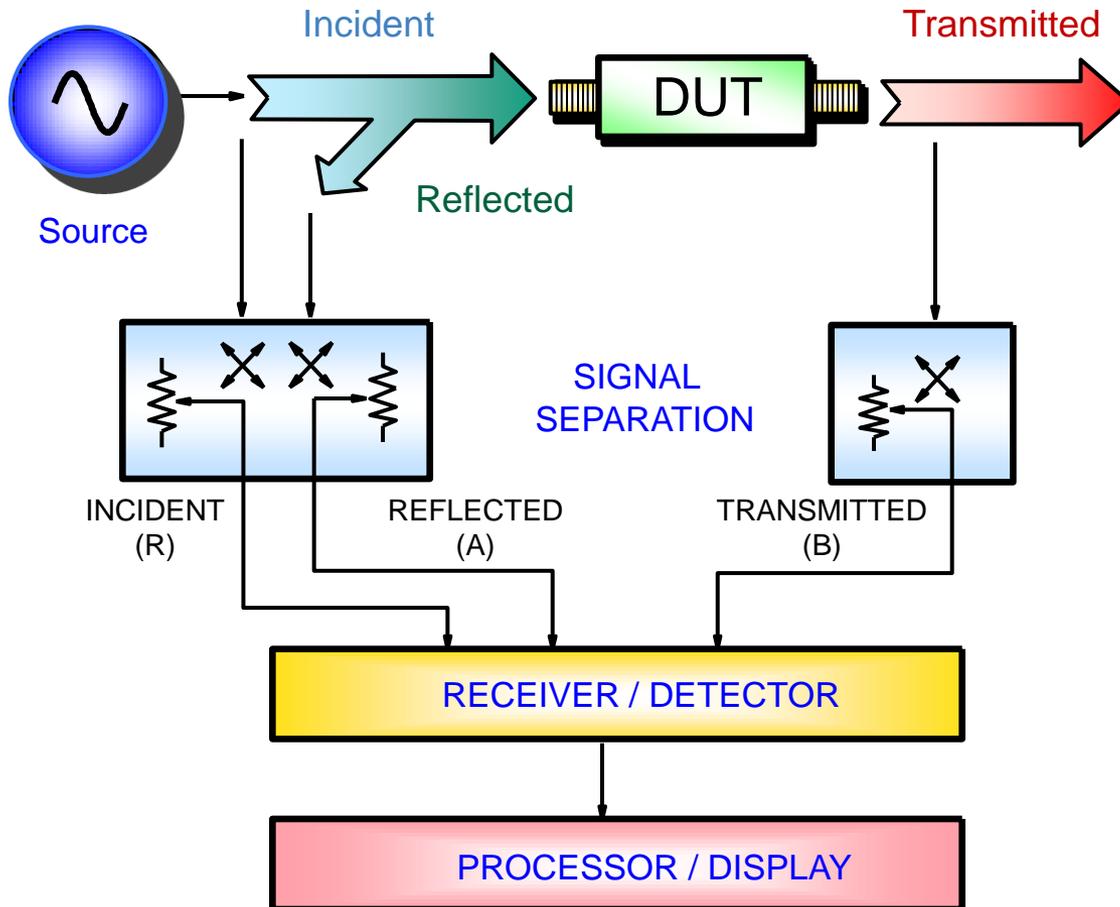
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# Evolution and Principle of Operation (1)

## VNWA Basics



- Tunable Signal Source
- 3 Coherent Receivers
- Device Control
- Data Processing and Graphics

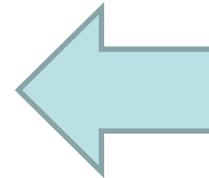
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# Evolution and Principle of Operation (2)

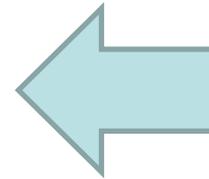
## Functional Diagram

Direct Digital Synthesizer (DDS)

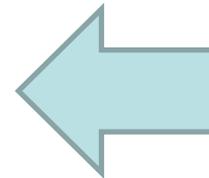


- Tuneable Signal Source

3 Gilbert-Cell Mixers + DDS  
+ PC Sound Card (IF)



- 3 Coherent Receivers



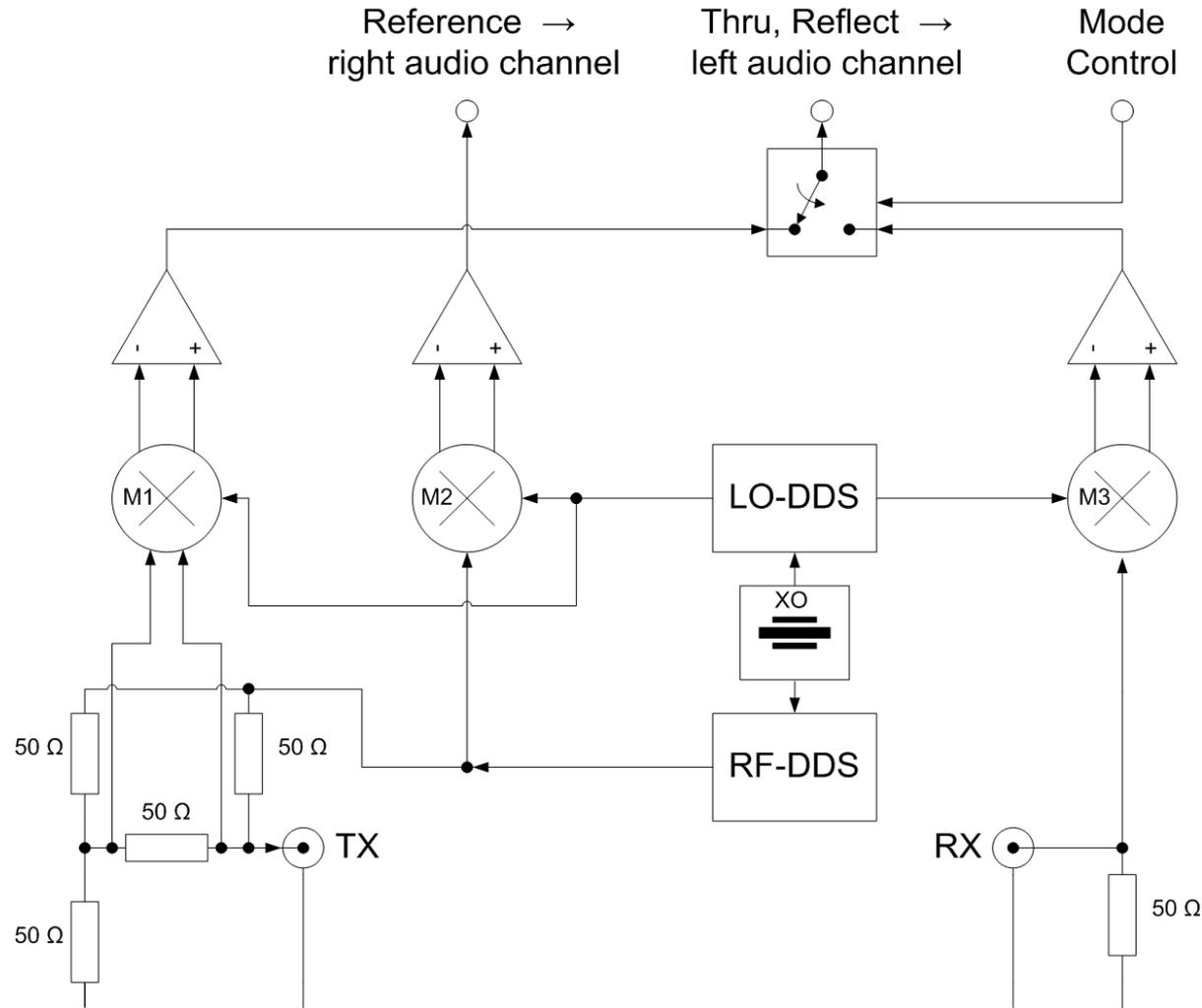
- Device Control
- Dataprocessing and Graphics

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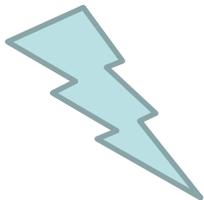
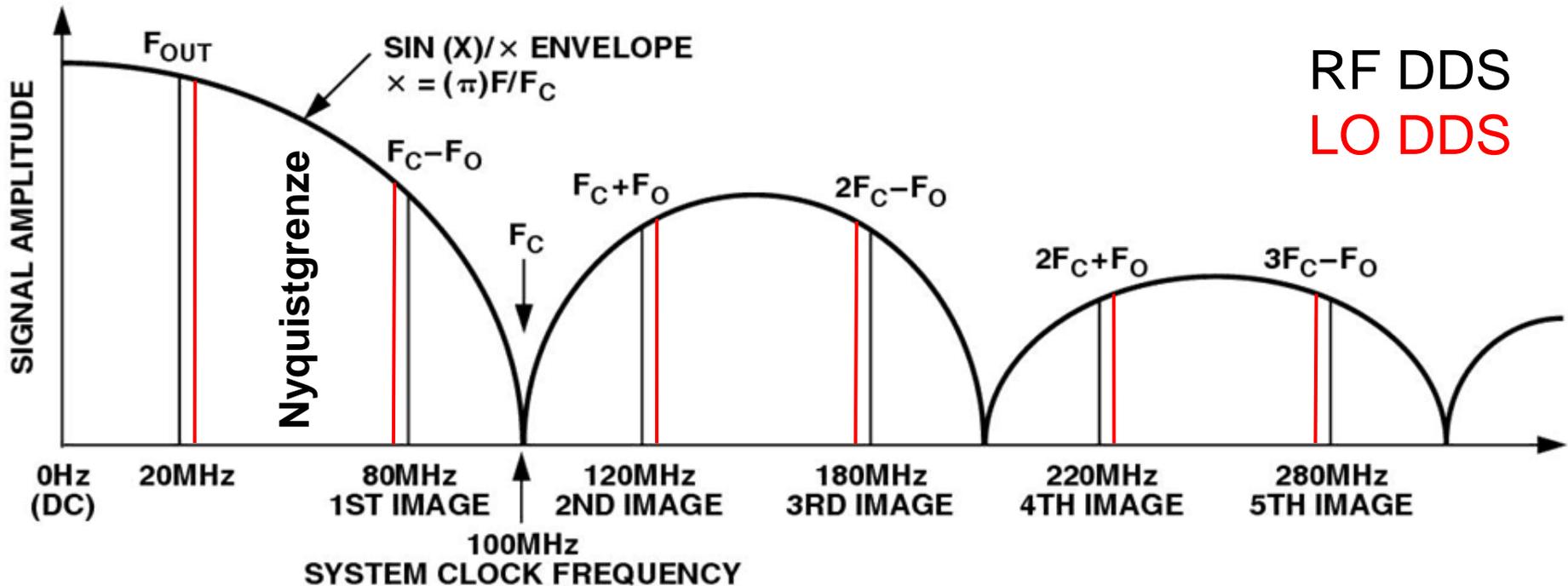
# Evolution and Principle of Operation (3)

## Functional Block Diagram



# Evolution and Principle of Operation (4)

## Problem: DDS Alias Frequencies

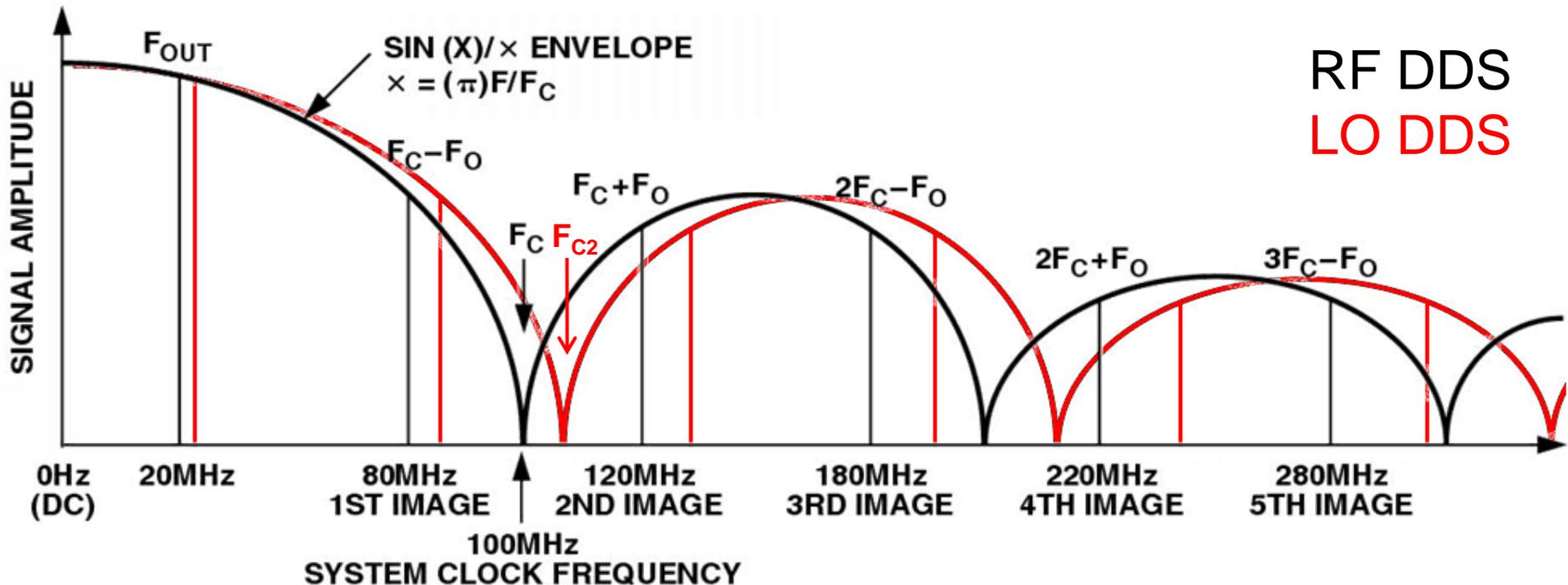


**All Alias-Frequencies mix down to the same Intermediate Frequency → either use Low Pass filter, or...**



# Evolution and Principle of Operation (5)

## ... use LO DDS with Clock Frequency Offset



RF DDS  
LO DDS



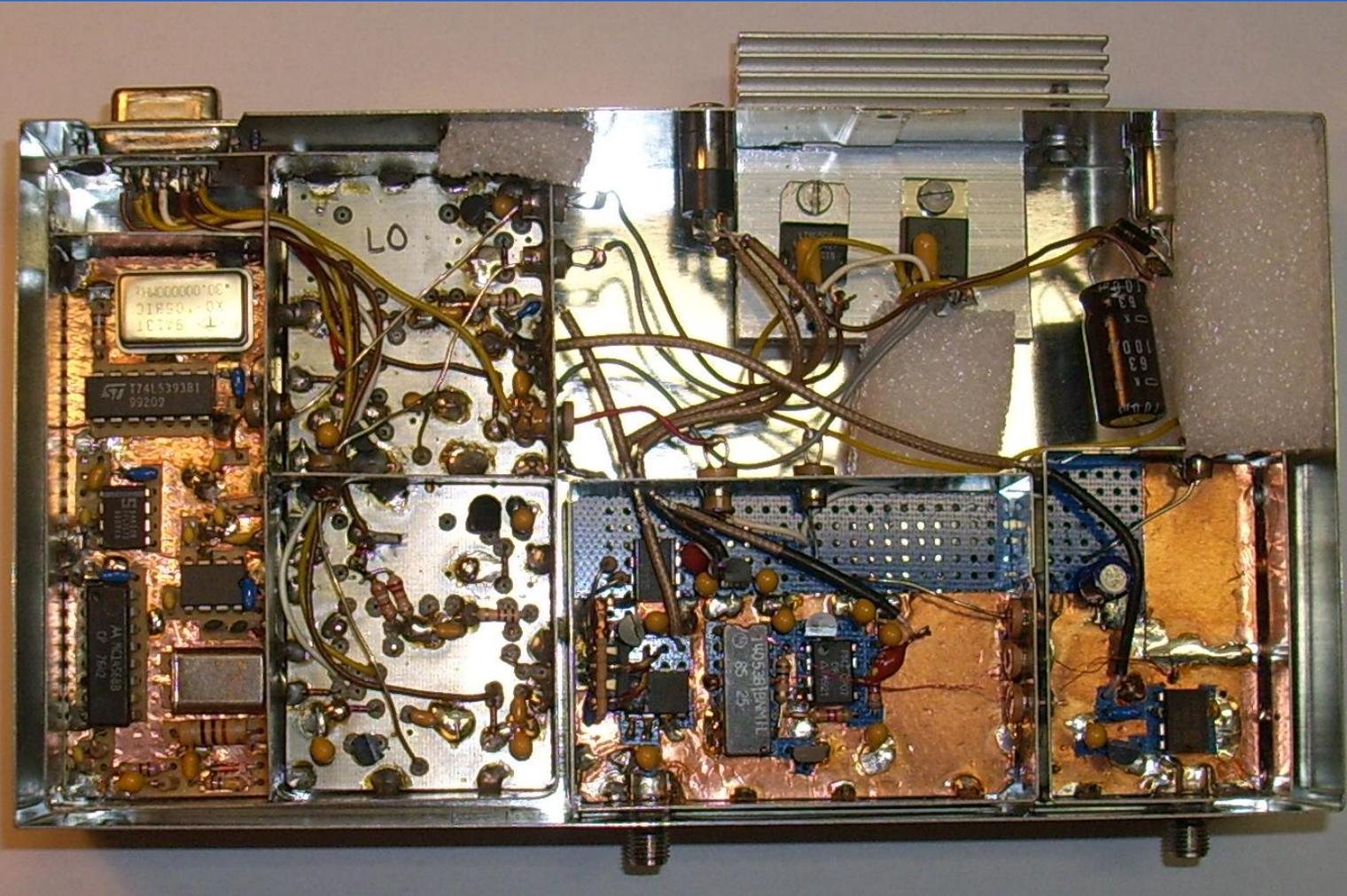
**all Alias-Frequencies can now be used to extend the VNWA Frequency Range**

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# Evolution and Principle of Operation (6)

## Result: VNWA1



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# Evolution and Principle of Operation (7)

## VNWA1 First Practical Use



# Evolution and Principle of Operation (8)

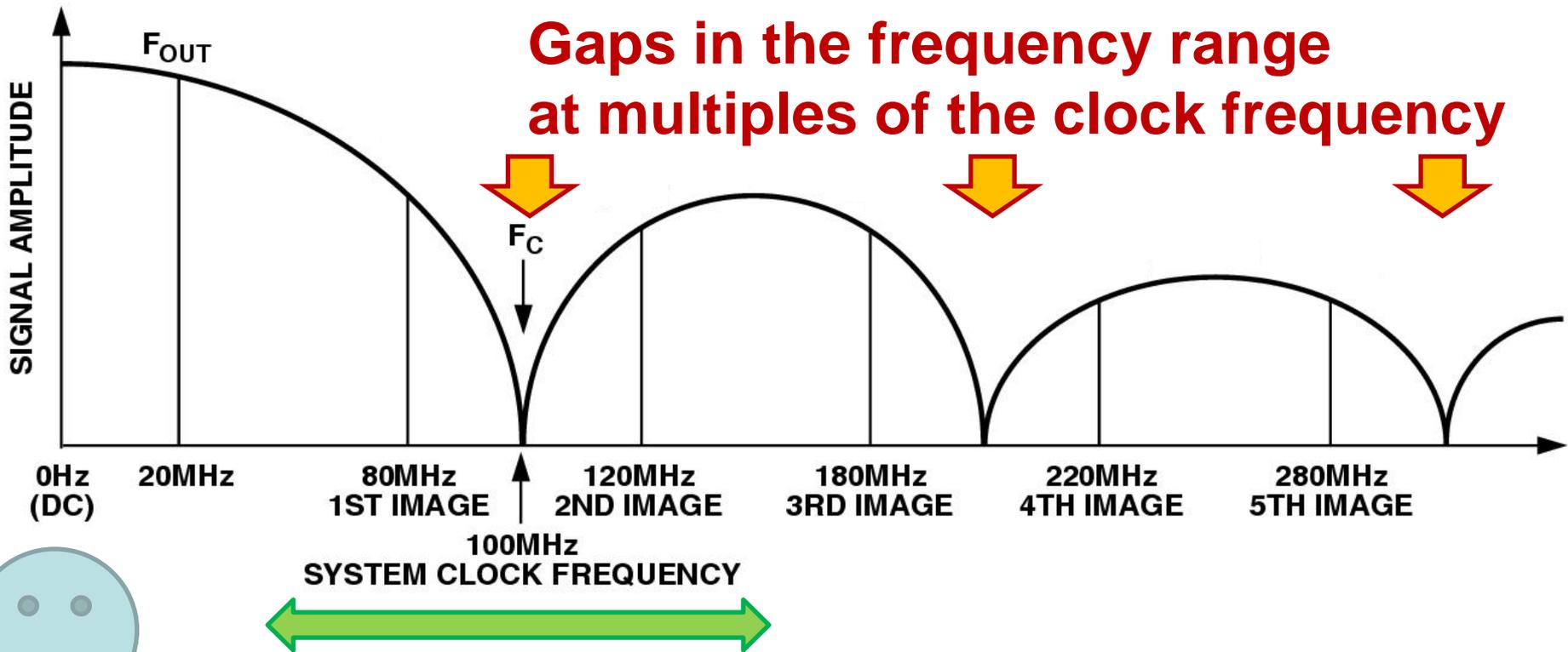
## Updated Development Targets

### ***Main Target: A Tool for Education***

- **Frequency Range > 500 MHz**
- **Continuous Frequency Range – no Gaps**
- **Constructed on PCB / reproducible Design**
- **Lowest possible Cost**

# Evolution and Principle of Operation (9)

## Continuous Frequency Range



**Gaps in the frequency range  
at multiples of the clock frequency**

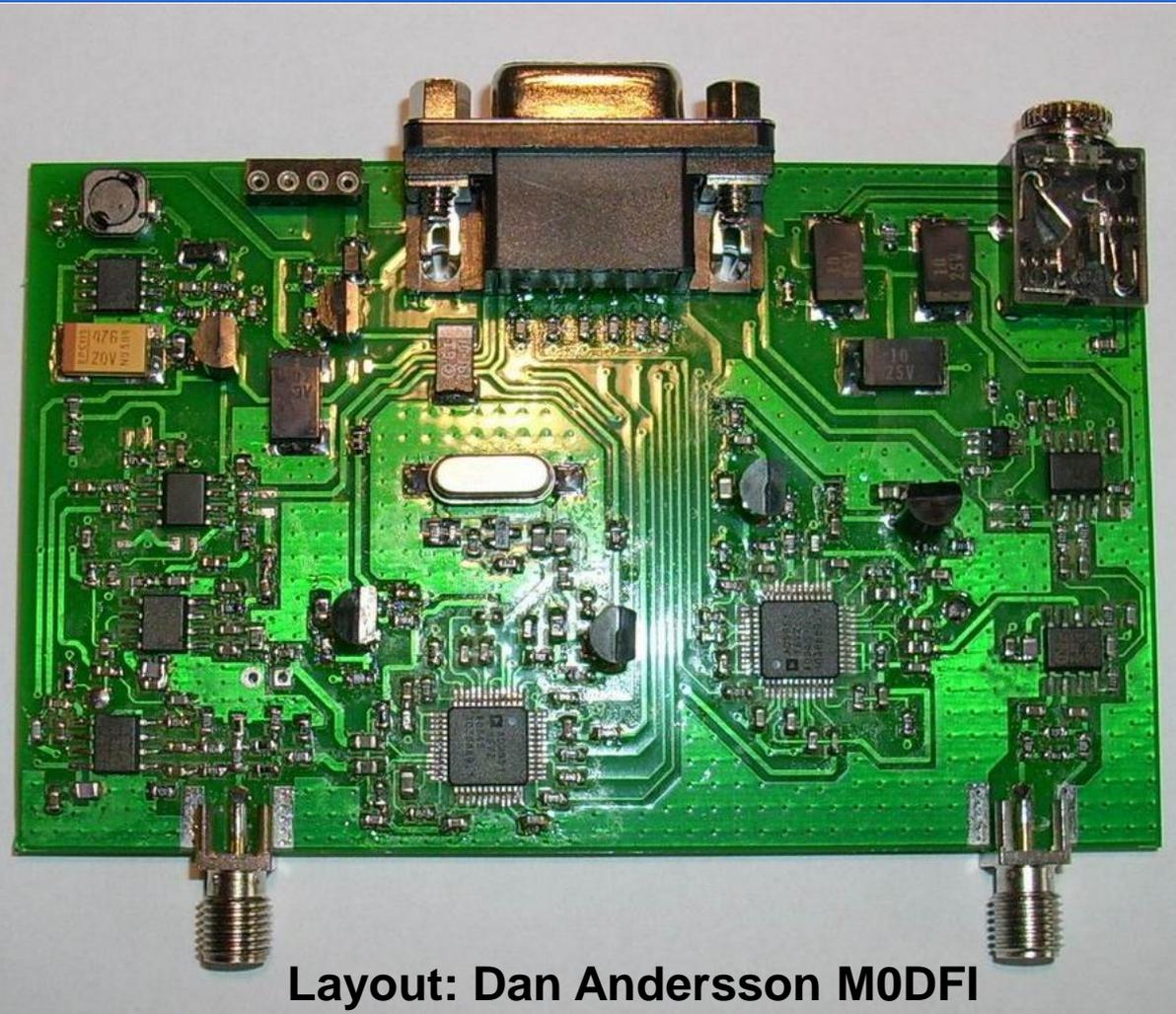
**Solution: variable clock frequencies by changing  
PLL-clock multipliers (integrated in DDS)**

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# Evolution and Principle of Operation (10)

## Result: VNWA2



- Frequency Range:  
1 kHz...>1,3 GHz
- Dynamic Range:  
>90 dB ( $f \leq 500$  MHz)  
>60dB ( $f > 500$  MHz)  
S11, S21 Measurements
- Control via Parallel Port
- Signal processing via external (PC) Sound Card

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# Evolution and Principle of Operation (10)

## Milestone 2009: VNWA from SDR-Kits

**SDRKits**

=

**Jan Verduyn G0BBL**

- **Ex Merchant Navy Radio Officer**
- **Ex Motorola Engineer**
- **Retired and started SDR-Kits**
- **Radio Amateur**



**Halle A1 Stand E812**



# Evolution and Principle of Operation (11)

## Market impact on VNWA2 Developements



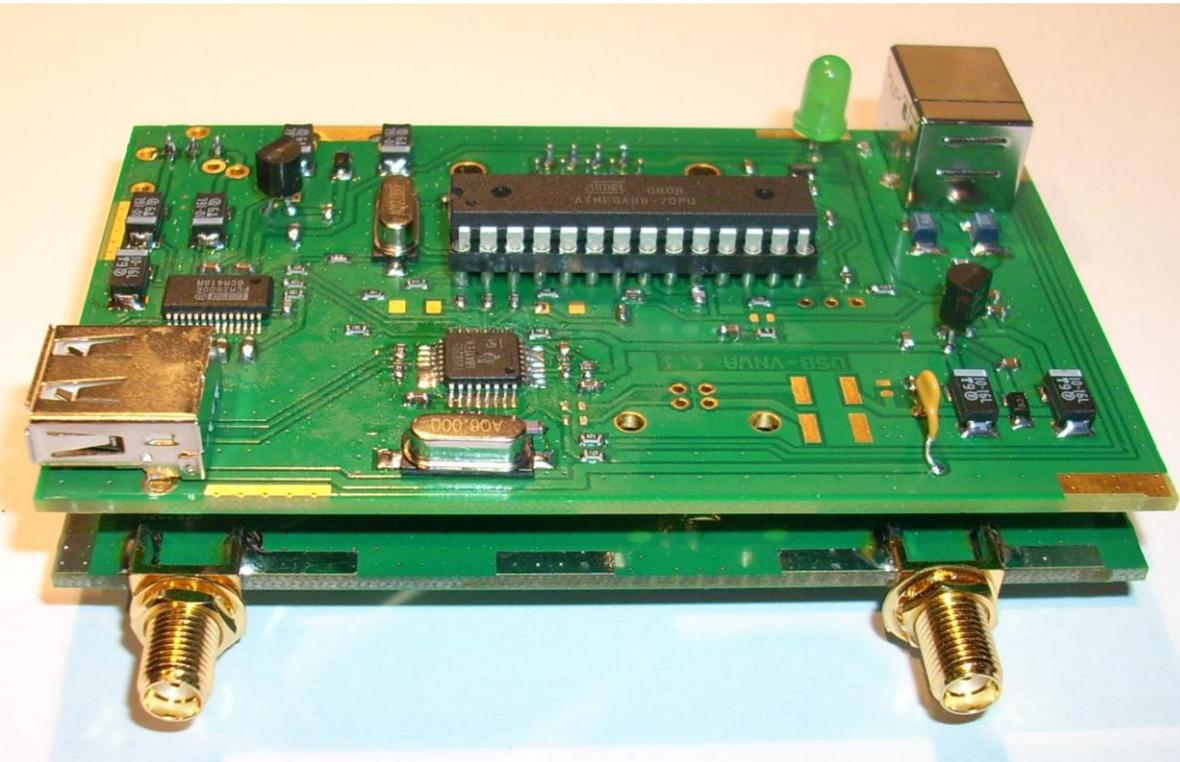
**Fewer Computers with  
*Parallel Port Interface***



**Fewer Computers with  
*Stereo-Line-In***

# Evolution and Principle of Operation (12)

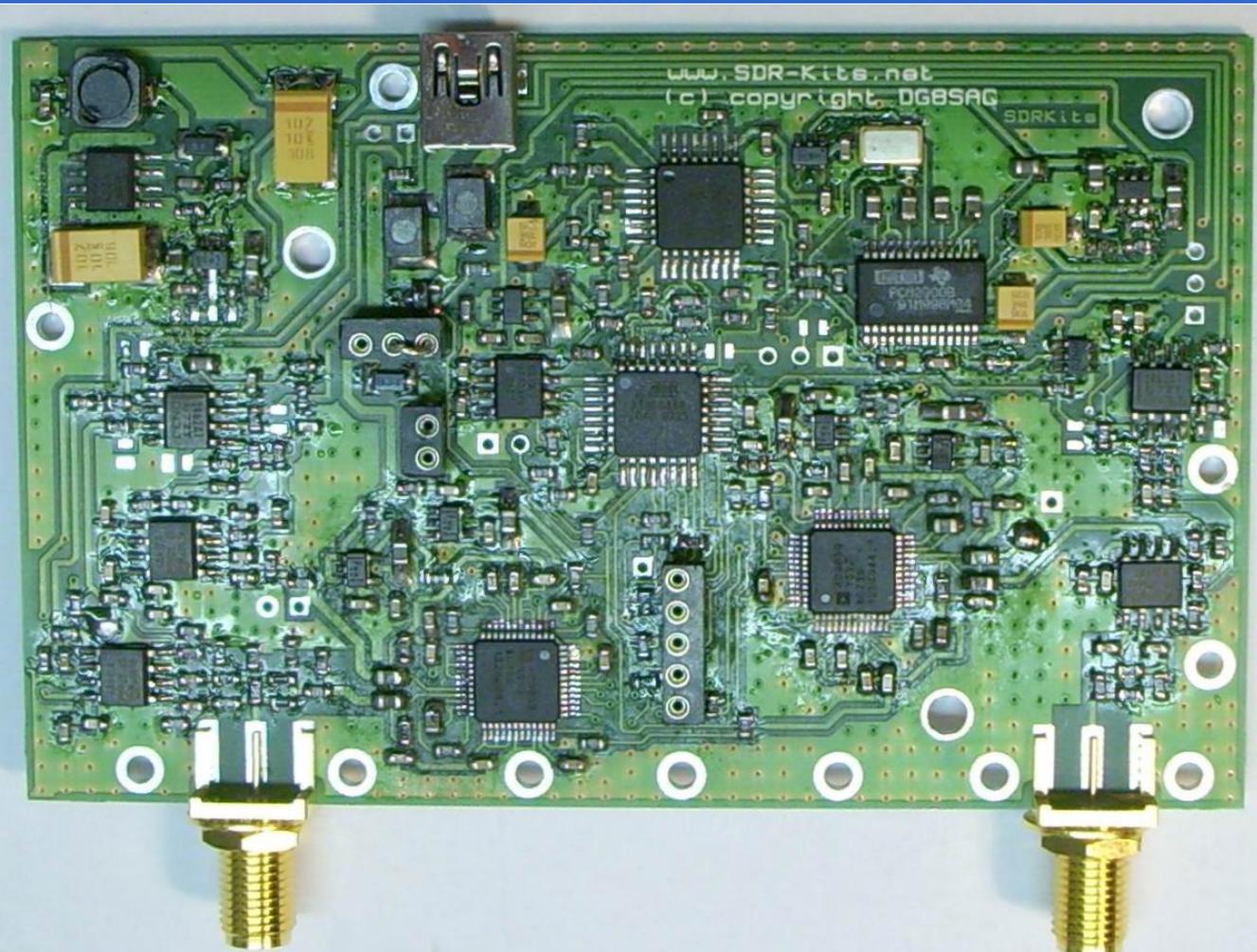
## VNWA2-USB



- USB Interface
  - Controller
  - USB Audio Codec
  - Powered from USB
- Only a USB cable connection to the PC**

# Evolution and Principle of Operation (13)

## VNWA3: Ready Assembled in Factory



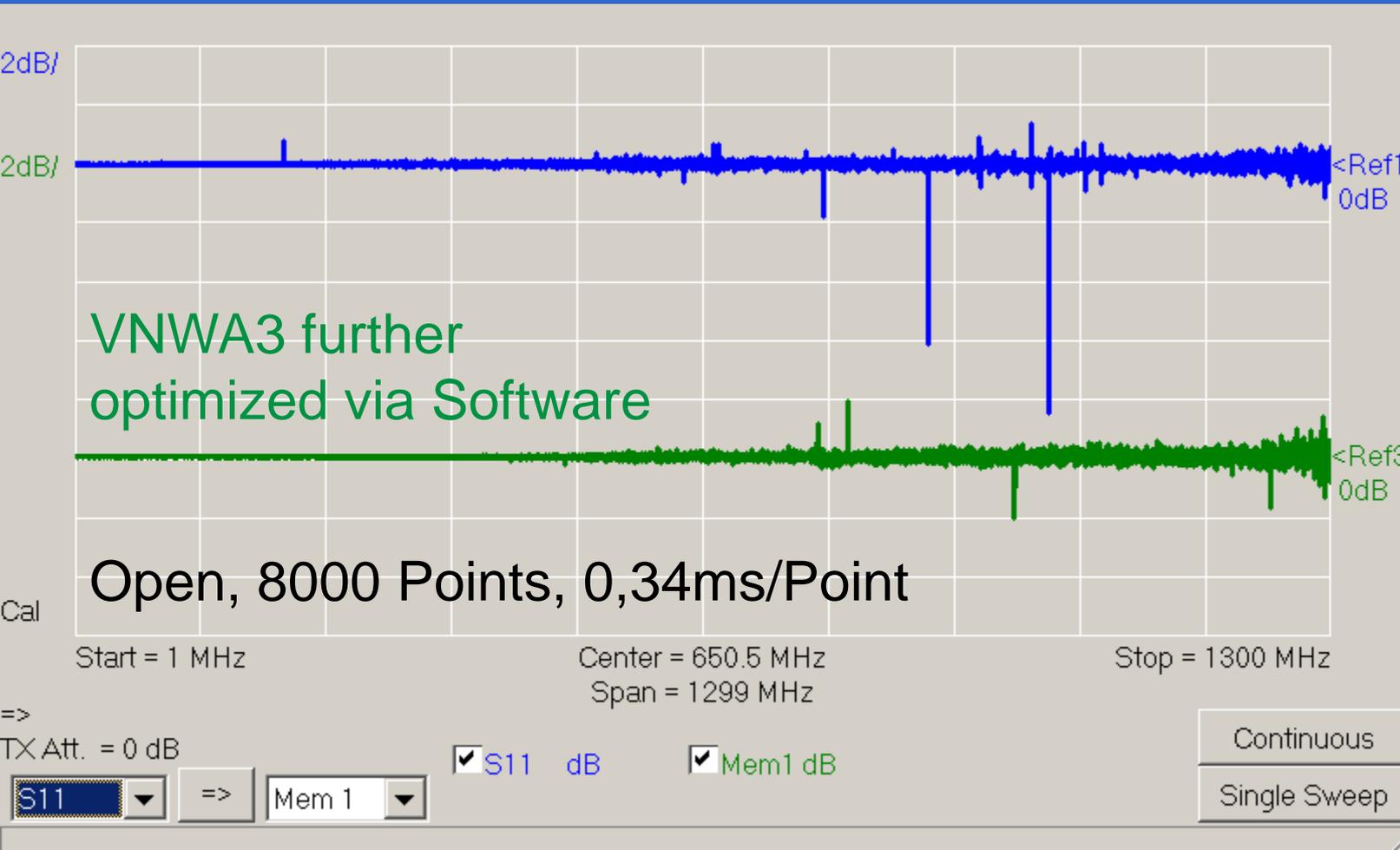
- TCXO
- Additional Clock-PLL!!

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# Evolution and Principle of Operation (14)

## Less Interference with flexible Clock-PLL



VNWA2

VNWA3

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# Evolution and Principle of Operation (15)

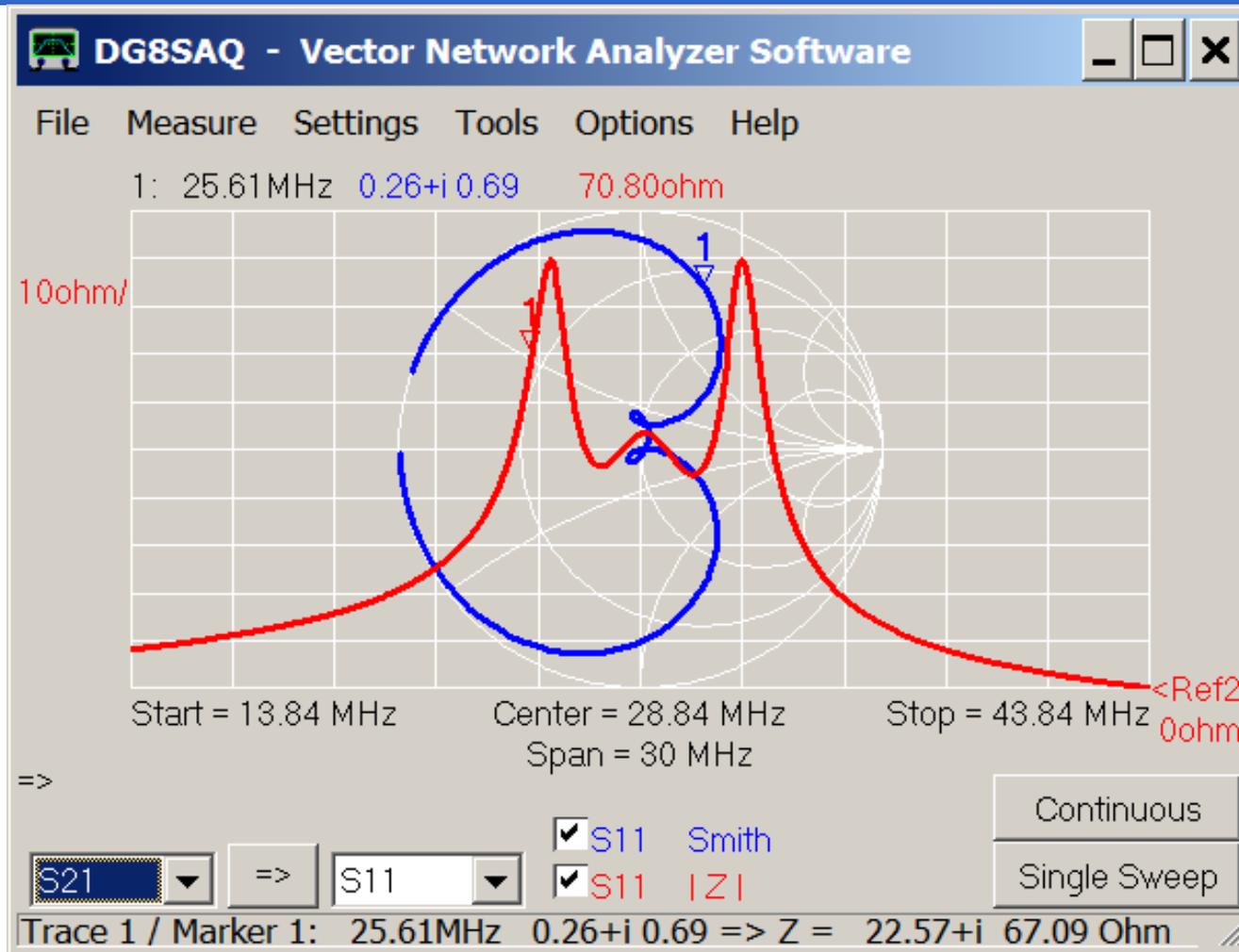
## VNWA3 Options



- New expansion PCB with 2<sup>nd</sup> Audio-Codec to measure  $S_{11}$  and  $S_{21}$  simultaneously
- External Clock Input
- Possible to extend VNWA3 to a fully automatic 2 port Analyzer with an external Transfer Relay

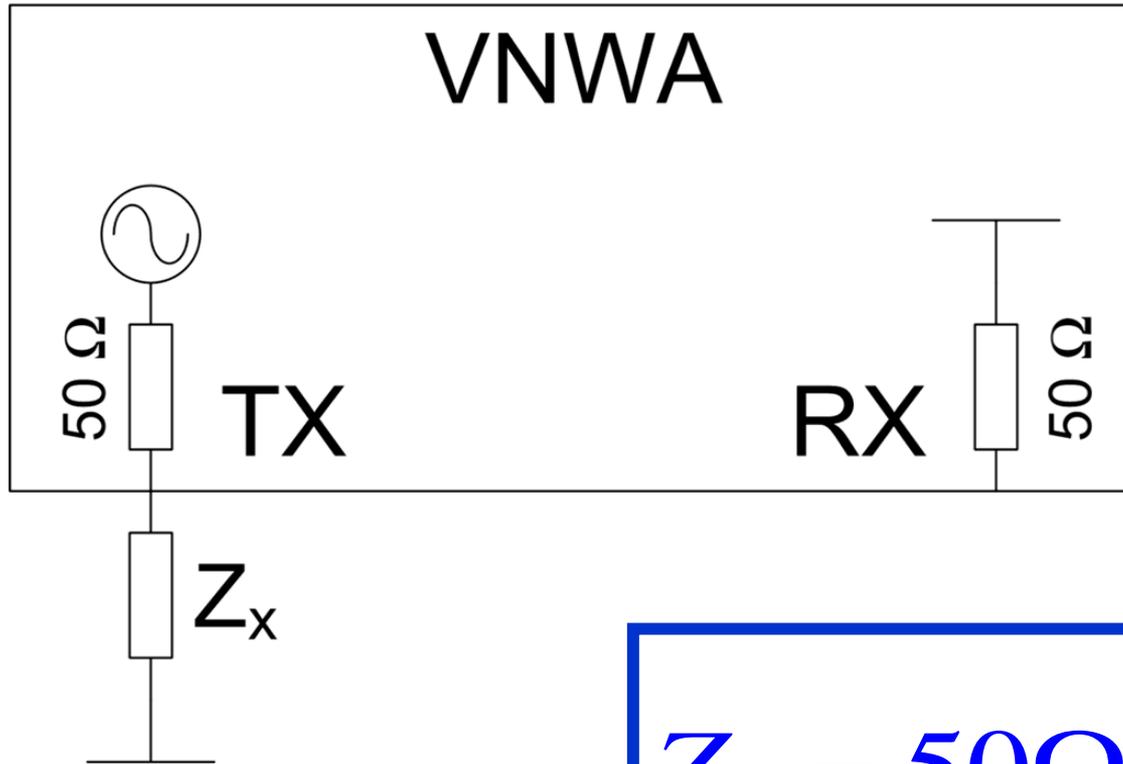


# Applications: Impedance Measurements (1)



# Impedance Measurements (2)

## Variant 1: Return Loss Measurement



**Highest accuracy for  $Z_x$  close to  $50 \Omega$**

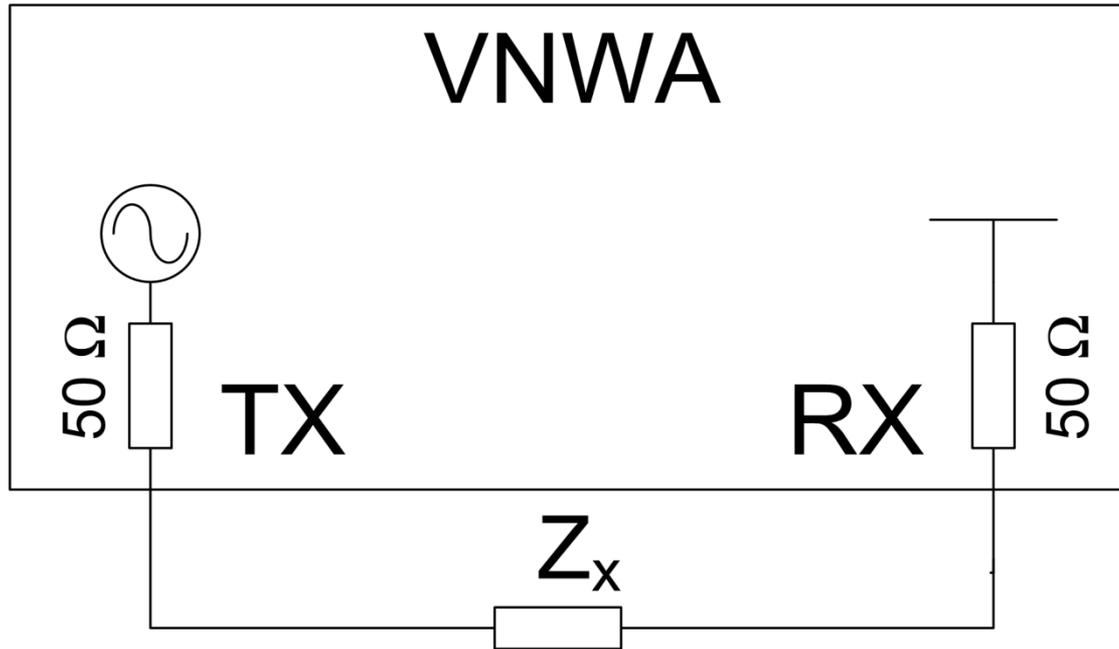
$$Z_x = 50\Omega \cdot \frac{1 + S_{11}}{1 - S_{11}}$$

**Cal: SOL**



# Impedance Measurements (3)

## Variant 2: I-Messung



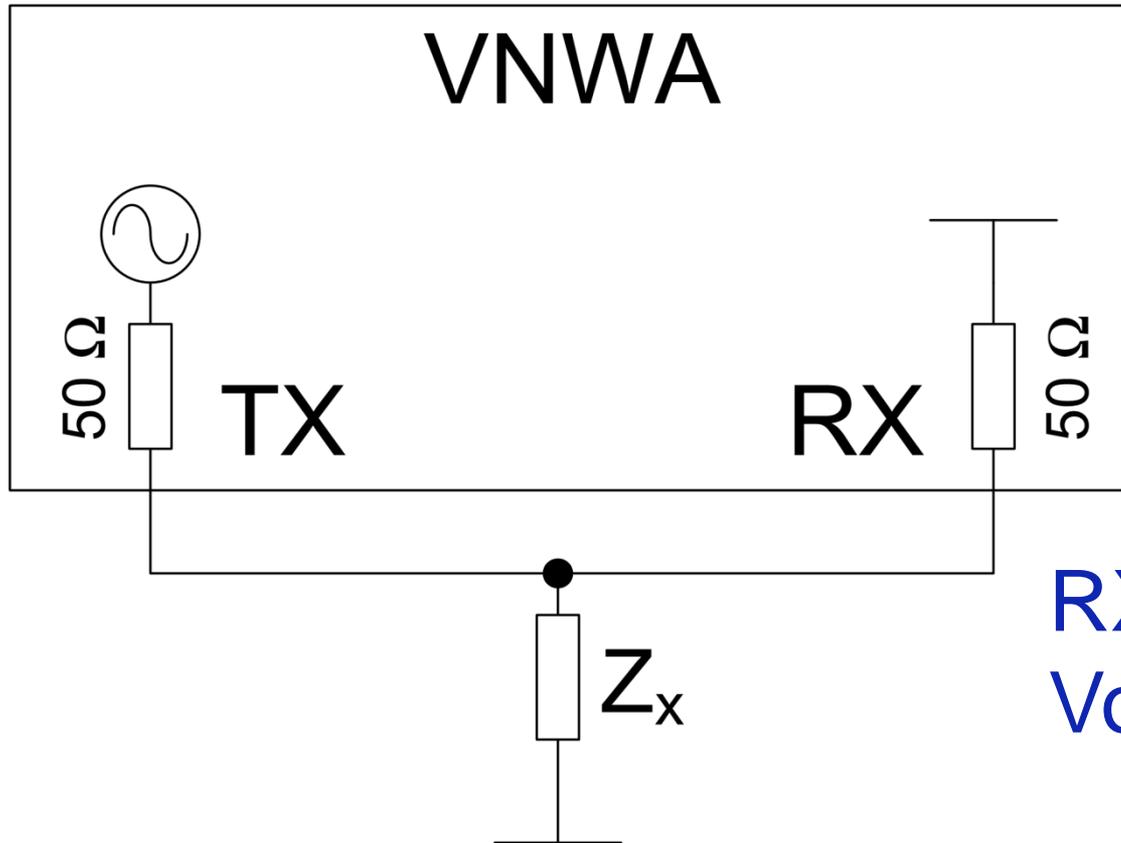
**Highest for  
*large values of  $Z_x$***

**Cal: Thru**

**RX measures current through  $Z_x$**

# Impedance Measurements (4)

## Variant 3: V-Measurement



**Highest for  
*low values of  $Z_x$***

**RX measures  
Voltage across  $Z_x$**

**Cal: SOL**

# Impedance Measurements (5)

## Variante 4: RF-IV Measurement

$$Z_x = \frac{V}{I}$$

Cal: SOL  $Z_x$

Excellent for  
ALL values of  $Z_x$

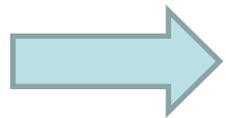
Combination of  
V & I-Measurement

# Impedance Measurements (6)

## Measurement Deviation-Variants 1 - 4

Impact of 10% increase of  $Z_x$  value on measurement result:

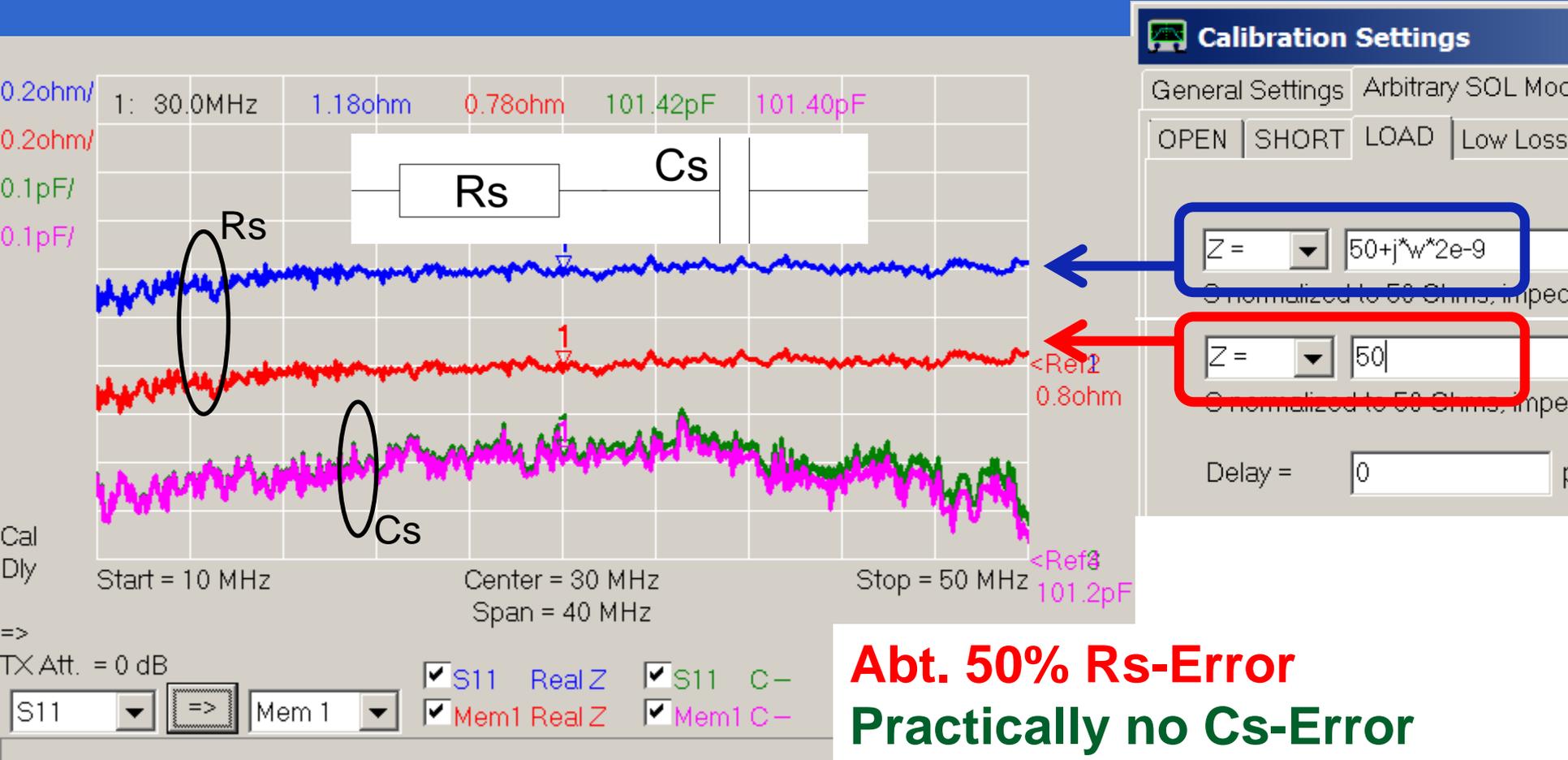
| $Z_x$          | $S_{11}$ | I     | V      | V / I |
|----------------|----------|-------|--------|-------|
| 0,1 $\Omega$   | -0,04%   | 0,01% | -9,96% | 9,97% |
| 51 $\Omega$    | 480,68%  | 3,27% | -3,08% | 6,56% |
| 100 k $\Omega$ | 0,01%    | 9,08% | 0,00%  | 9,99% |



**RF-IV shows best overall sensitivity!**



# Impedance of a 100 pF SMD Capacitor: Effect of 2 nH in Load Standard



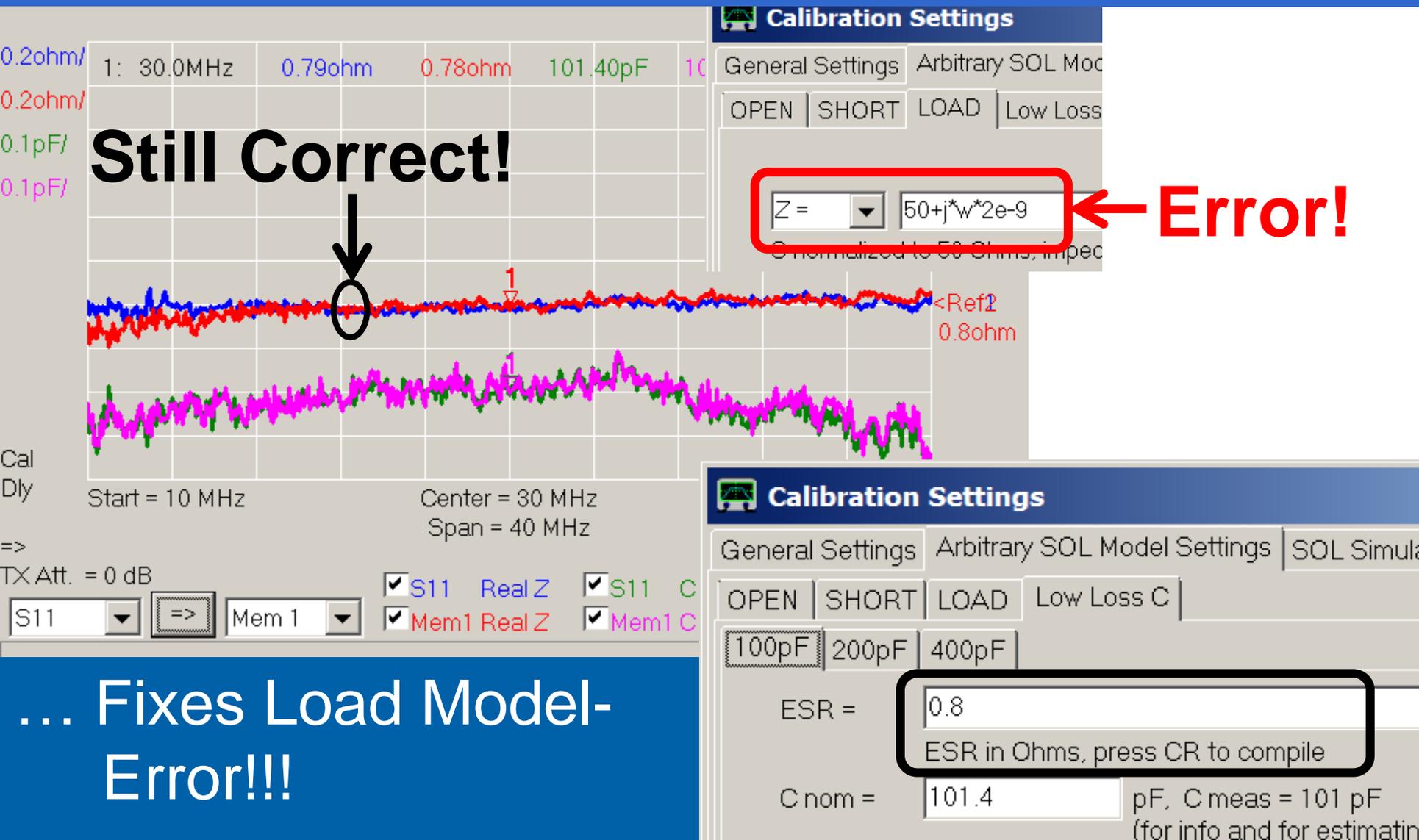
**Abt. 50% Rs-Error**  
**Practically no Cs-Error**



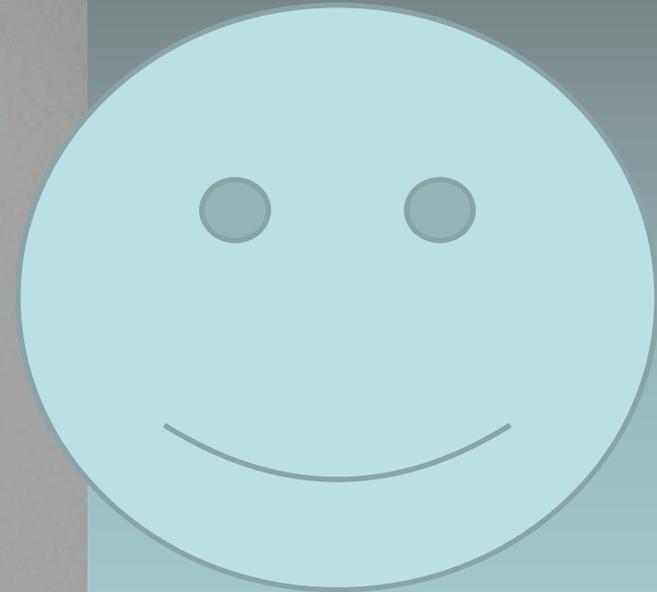
**Load-Model critical for Q measurements!**



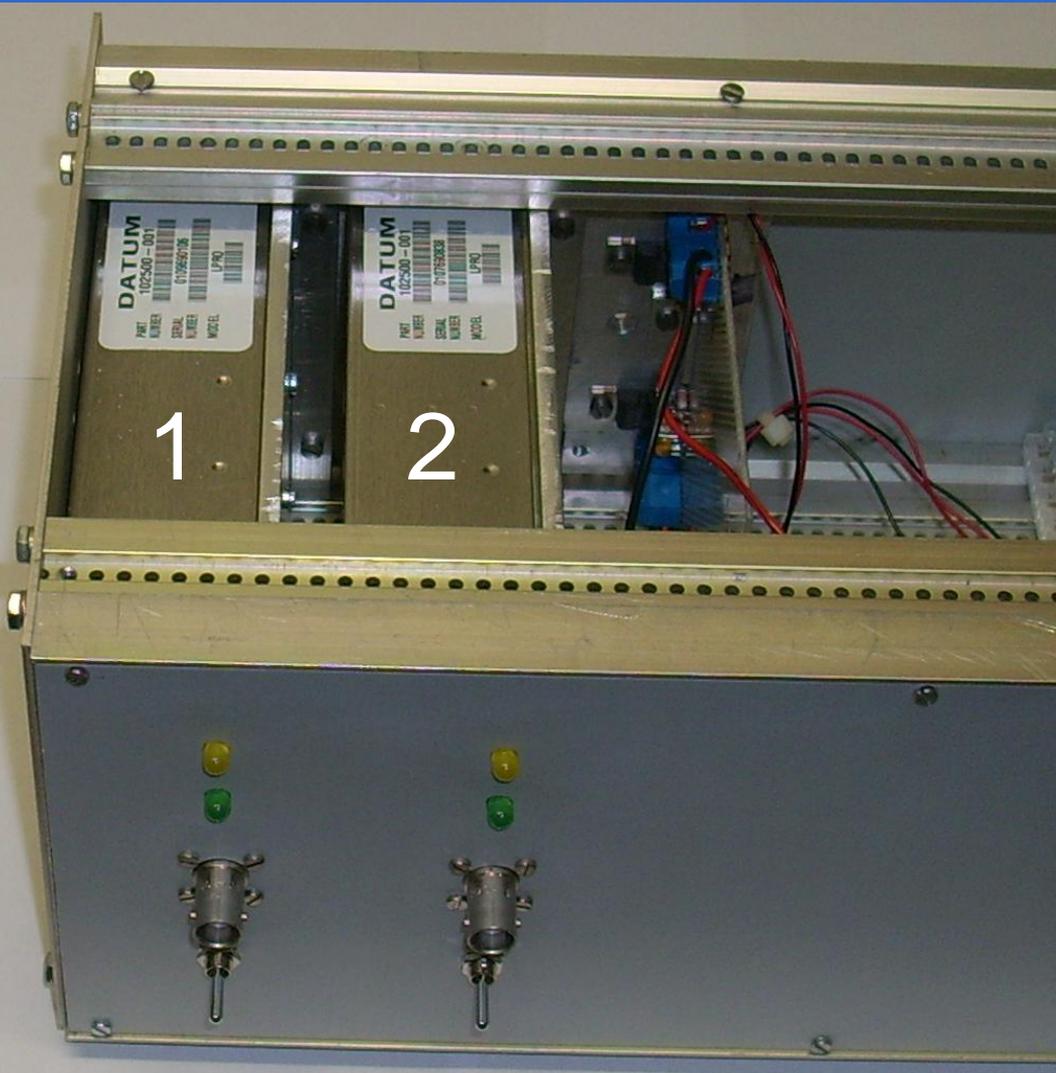
# New: Low Loss Capacitor (LLC) as an additional Calibration Standard...



If you have a clock you always know what time it is ...



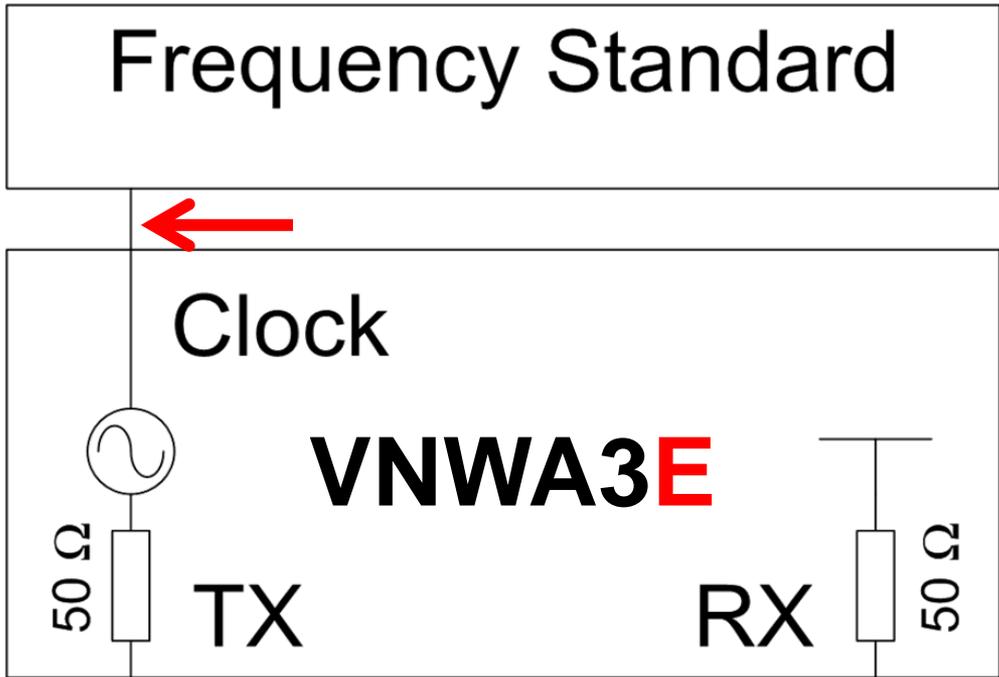
# With TWO Clock you are never quite shure which time is right !



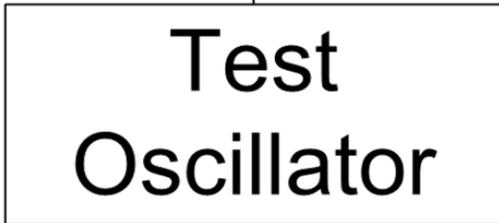
- My two Rubidium Frequency standards:
- **How accurately do they run in sync?**

# Application: Frequency Comparison (1)

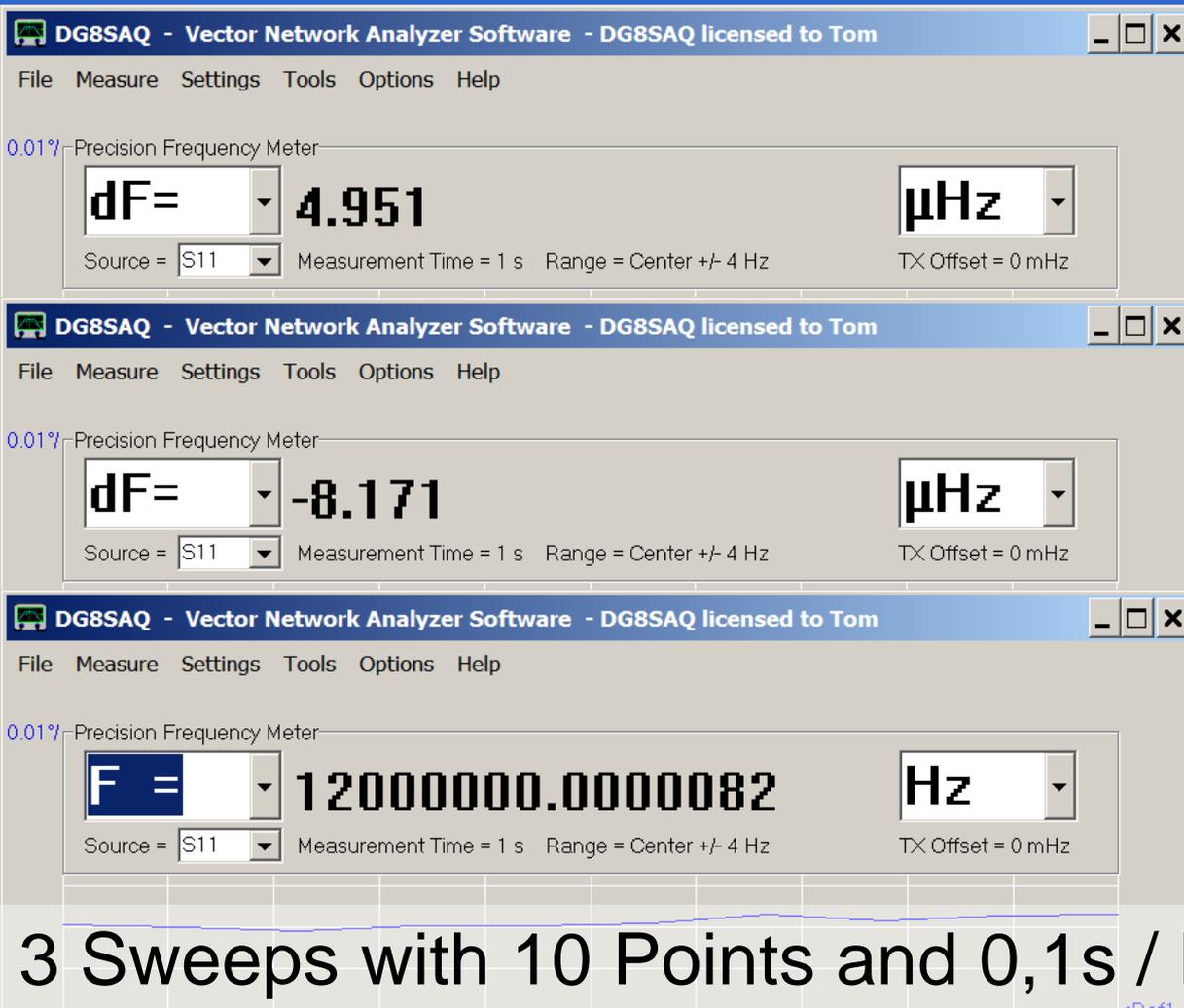
## VNWA3 as Phase Comparator



- Precise Phase Measurement with VNWA3
- Frequency deviation calculated from Phase



# Frequency Comparison (2) Measurement Accuracy



- TCXO compared to itself
- 1s Measurement
- abt  $\pm 10 \mu\text{Hz}$  variation!!!

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3 Sweeps with 10 Points and 0,1s / Point

# Frequency Comparison (3)

## Rubidium 1 vs. Rubidium 2 over 260s

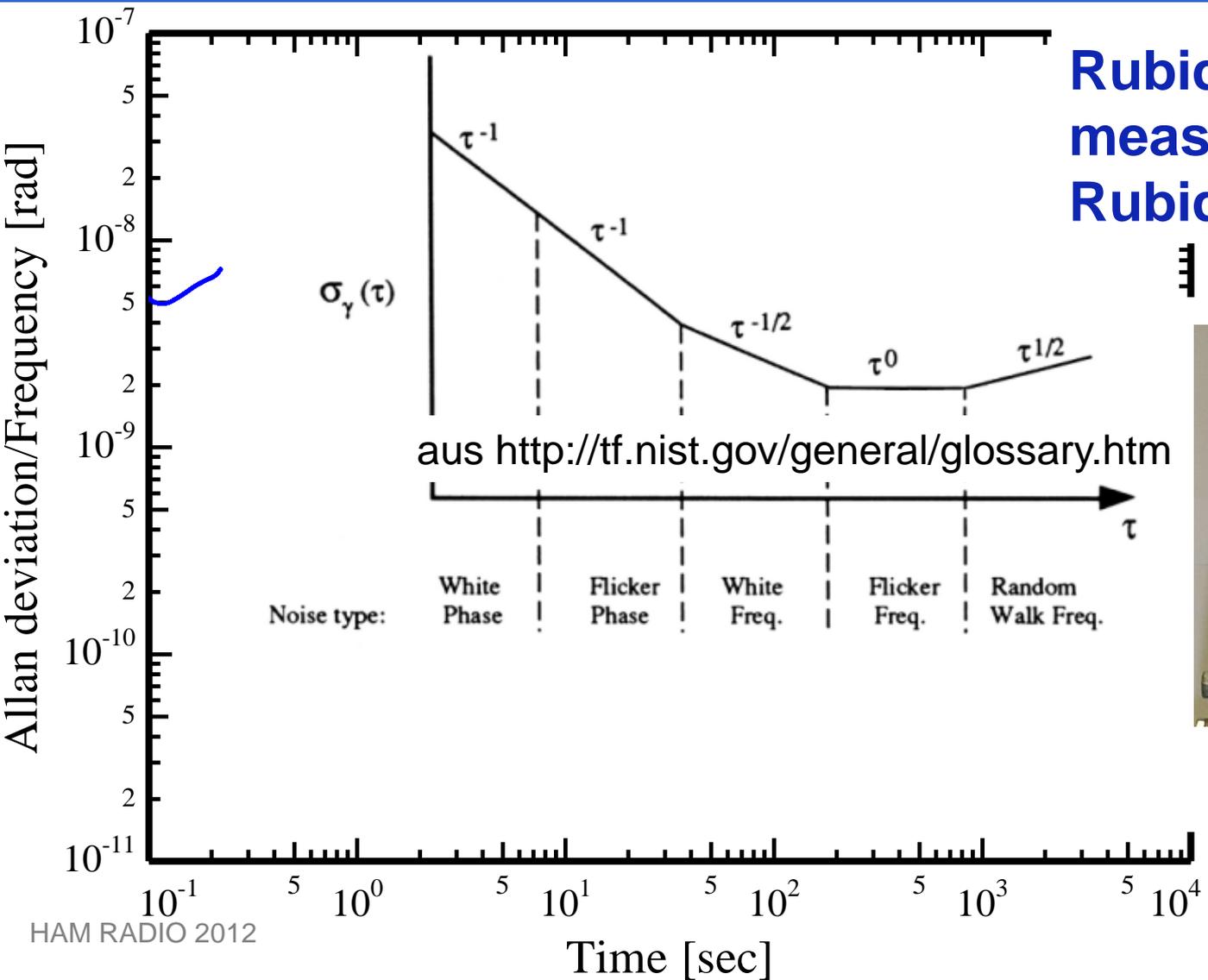


Deviation =  $-0,0025 \text{ Hz} \pm 0,0003 \text{ Hz}$  at 10 MHz  
 $\equiv 2,5 \cdot 10^{-10}$

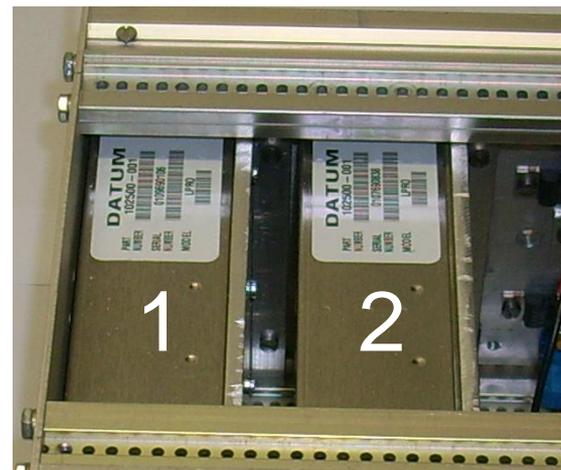


# Frequency Comparison (4)

## Allan Deviation from VNWA-Measurement



**Rubidium Standard 1  
measured against  
Rubidium Standard 2**



# Frequency Comparison (5)

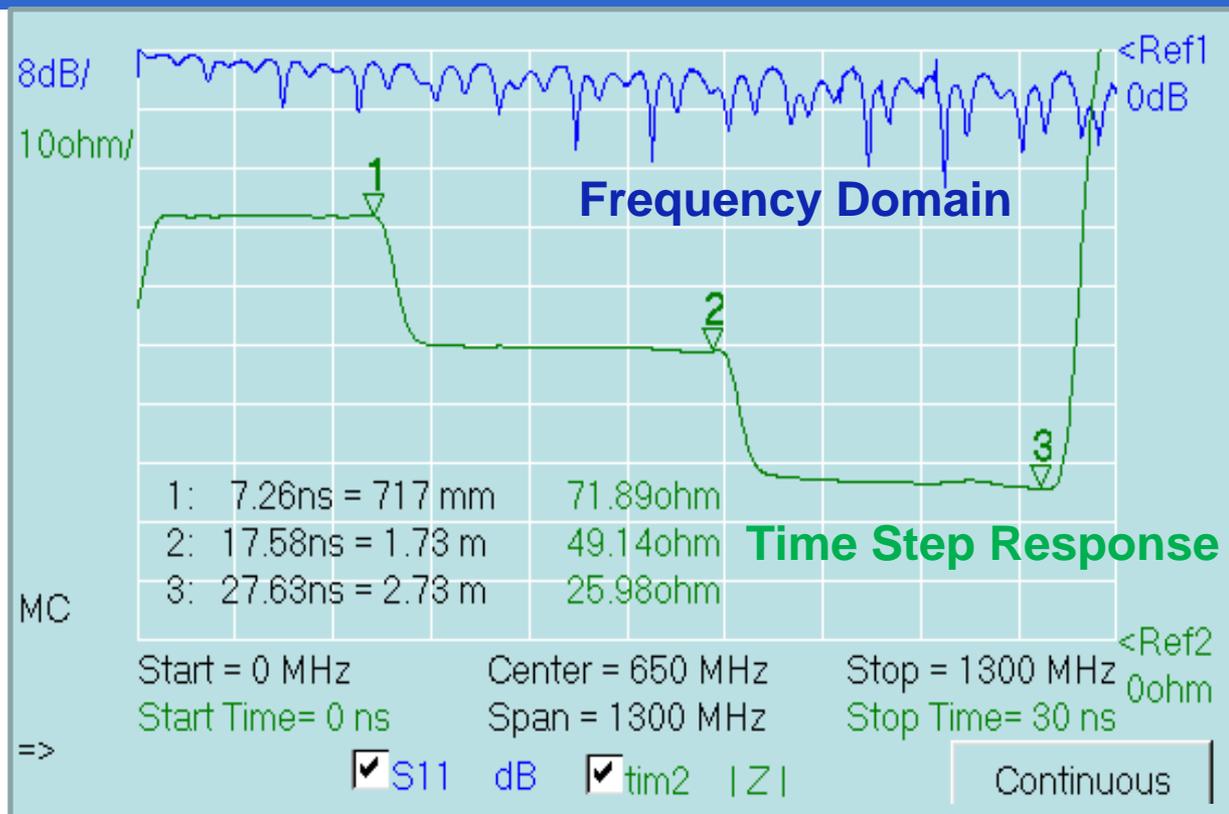
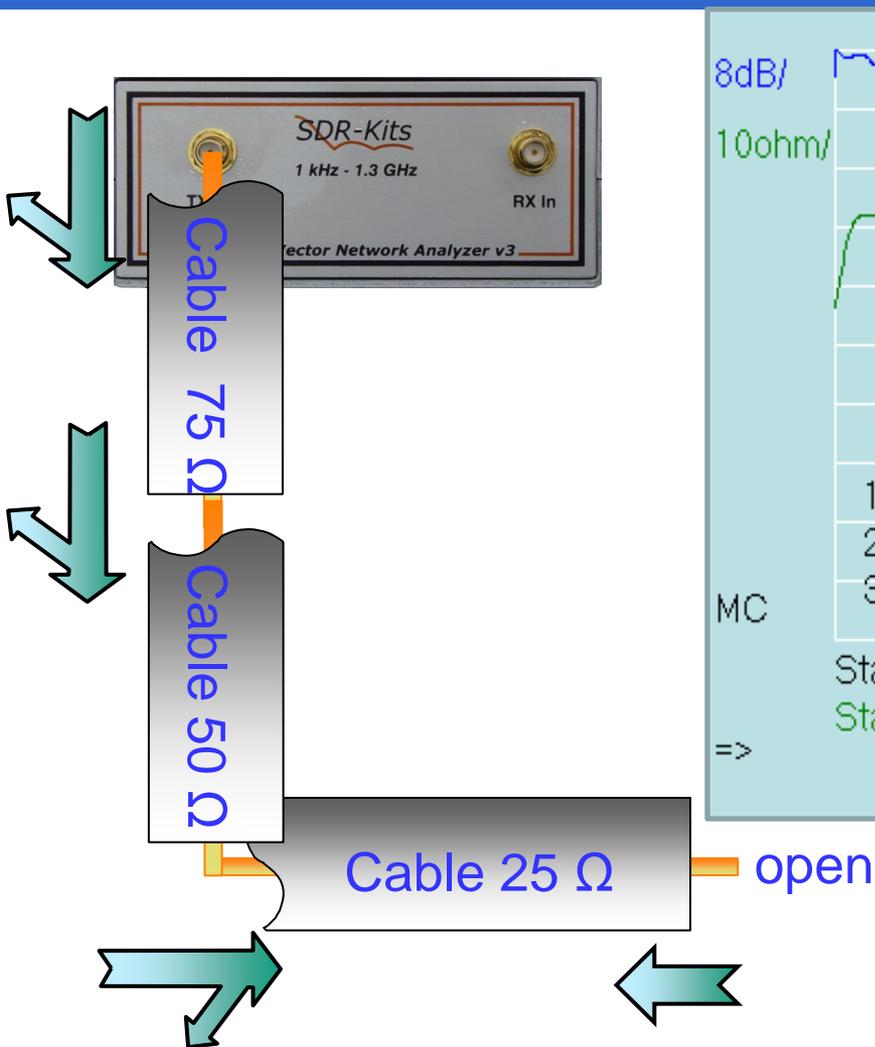
## Rubidium Standard vs. VNWA3 TCXO



Deviation =  $-3 \text{ Hz} \pm 1 \text{ Hz}$  at 10 MHz  $\equiv -0,3 \text{ ppm}$



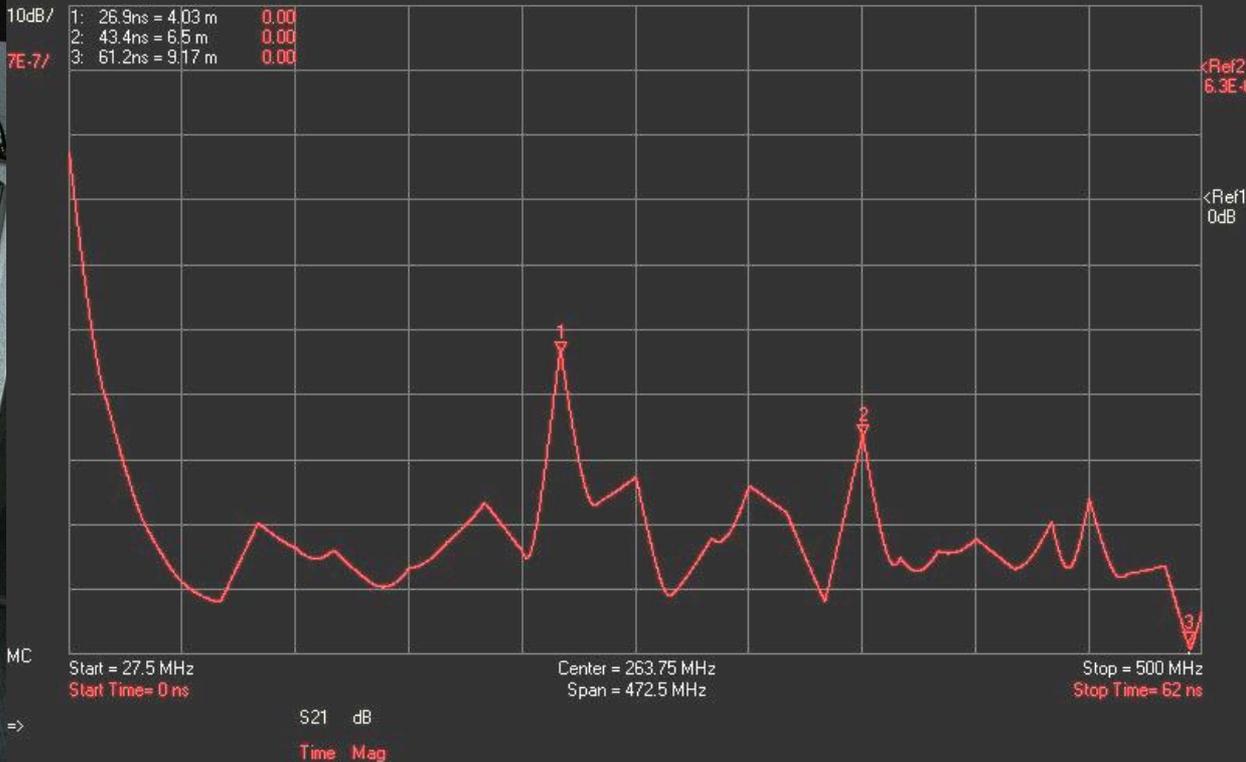
# Application: Time Domain Analysis (1)



# Time Domain Analysis (2)

## Locate the faulty Christmas Tree Light Bulb !!

DG8SAQ Vector Network Analyzer Software Version: Beta 28.14 / 2009.10.18 09:26:05  
11-12-2009 22:05:51 tdr kerstsnoer



<http://www.pa4tim.nl/?p=345>



# Application Example: Cavity Resonance (1)



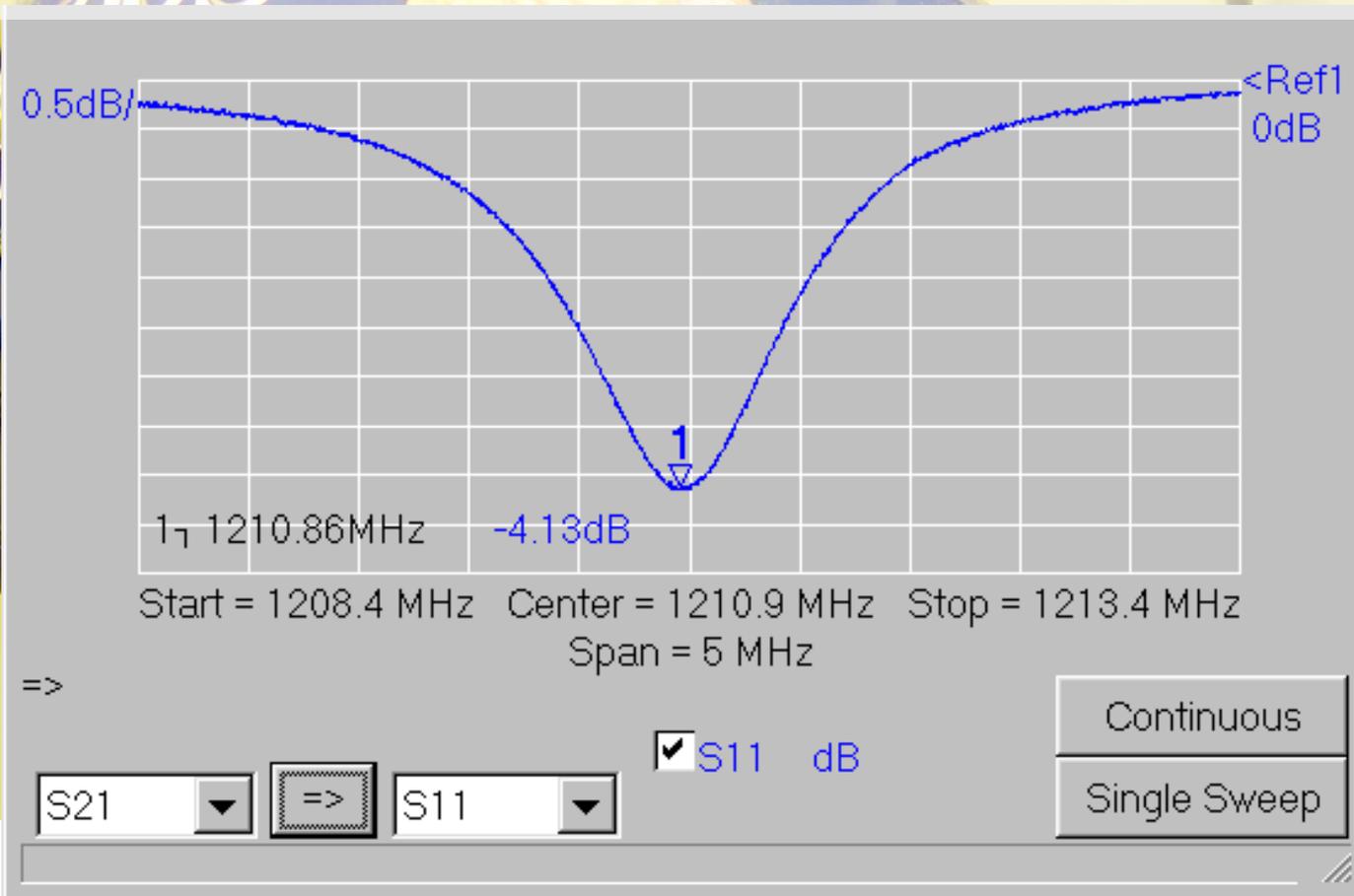
## Cavity Resonance (2)

**Lowest Resonance mode:**

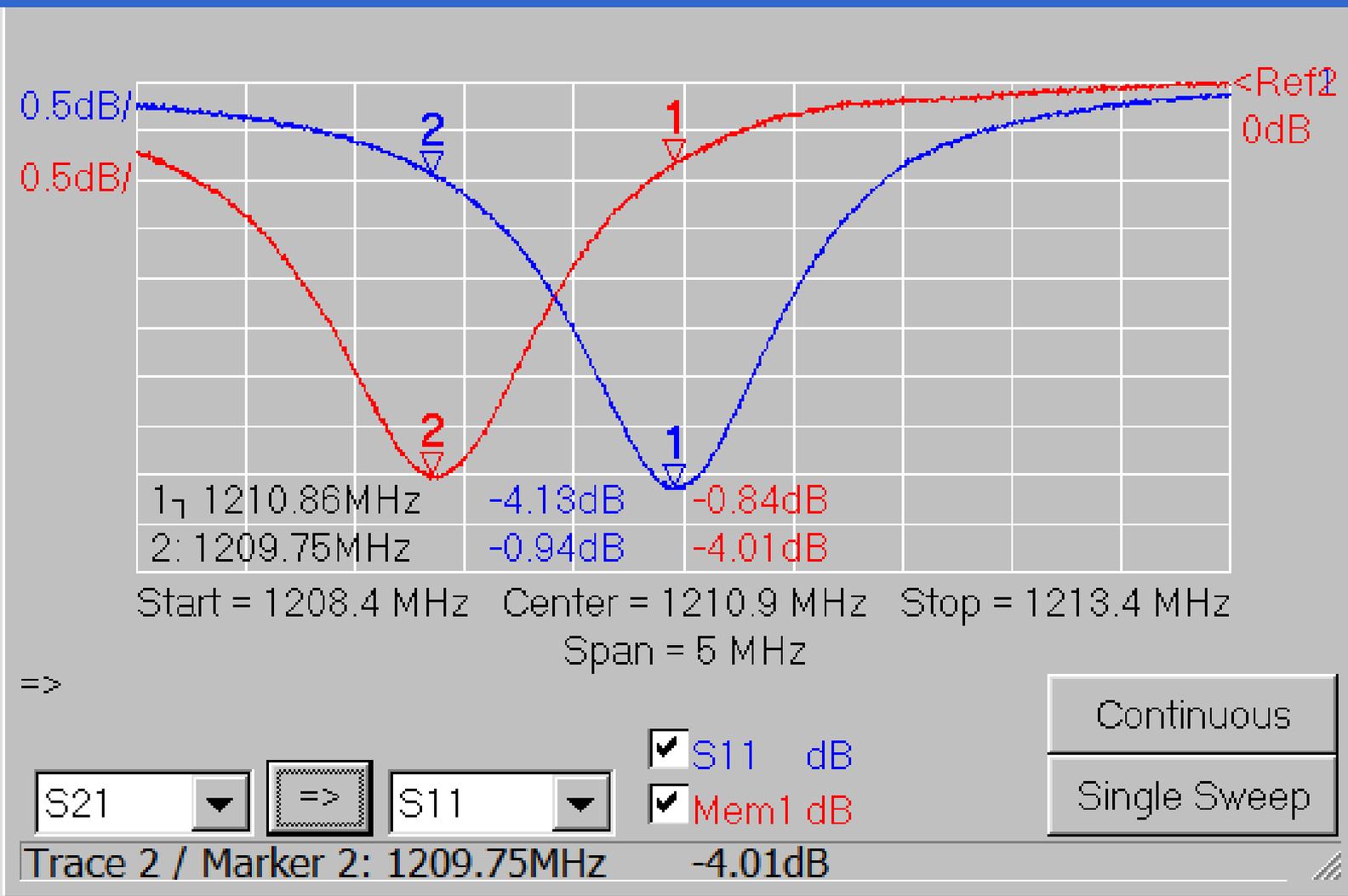
$$f = \frac{c_0}{2\pi r} J_{01} \approx \frac{3 \cdot 10^8 \text{ m/s}}{6,28 \cdot 9,5 \text{ cm}} \cdot 2,405$$
$$\approx 1209 \text{ MHz}$$

# Cavity Resonance (3)

## Lowest Resonance mode:



# Cavity Resonance (4)



**Empty**  
**vs.**  
**Filled**



# Cavity Resonance (5)

NASA/TM—2007-214907

AIAA-2007-1198



## Radio Frequency Mass Gauging of Propellants

*Gregory A. Zimmerli and Karl R. Vaden  
Glenn Research Center, Cleveland, Ohio*

*Michael D. Herlacher  
Analex Corporation, Brook Park, Ohio*

*David A. Buchanan and Neil T. Van Dresar  
Glenn Research Center, Cleveland, Ohio*



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# Cavity Resonance (6)

NASA/TM-



Radio F

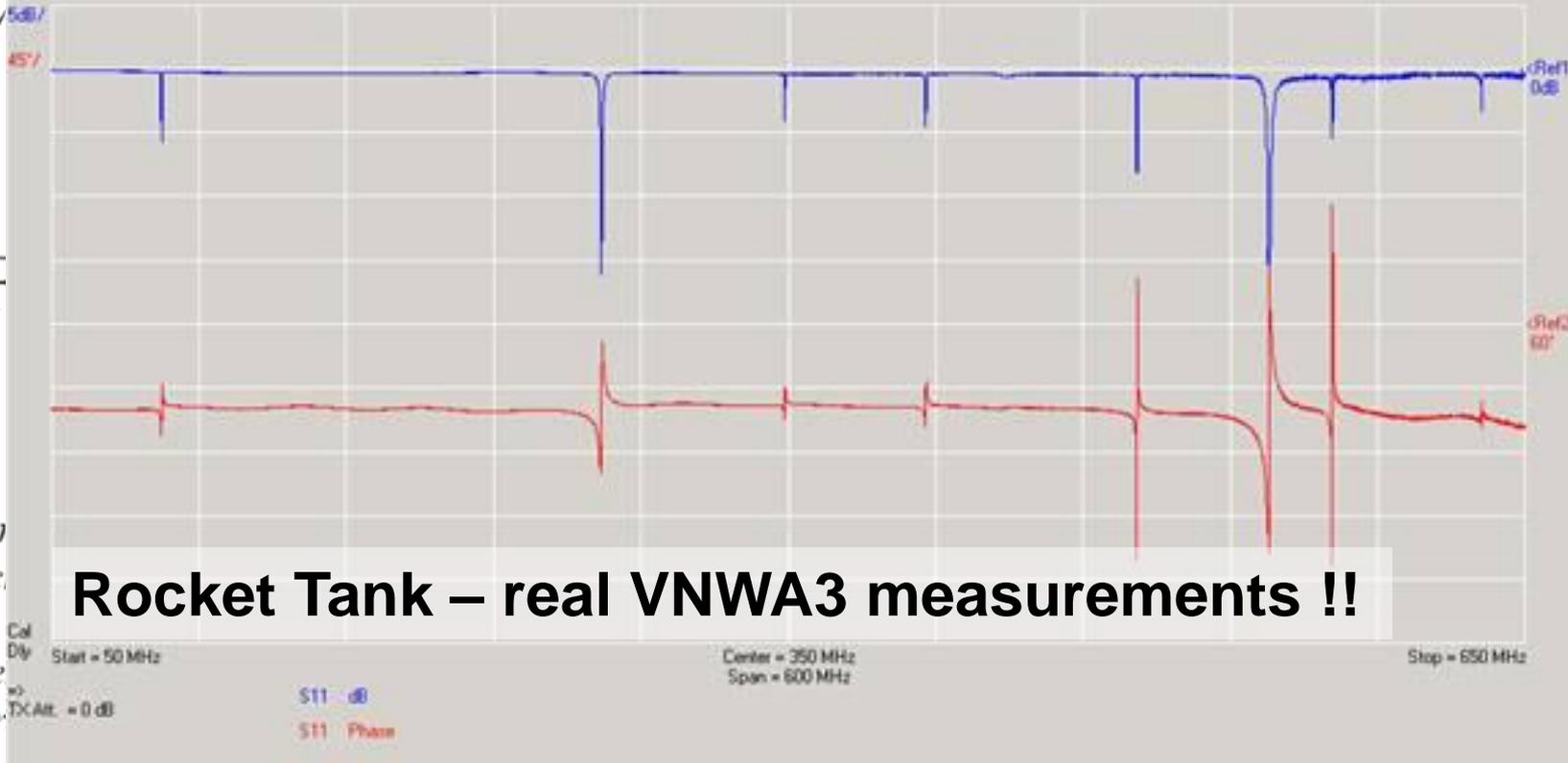
Gregory A. Zin  
Glenn Research

Michael D. He  
Analex Corpor

David A. Buchanan and Neil T. Van Dresar  
Glenn Research Center, Cleveland, Ohio

HAM RADIO 2012

DG8SAQ Vector Network Analyzer Software  
12/12/2011 3:44:04 PM 20111212 op-settings: 50-650MHz 5000pts



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# Summary

- **The VNWA3 is a versatile Test Instrument**
- **Suitable for many - even - professional Applications!**

➔ **VNWA3s are used on 5 Continents**

# The VNWA3 is in use all over the World.

## GERÄTE

Messungen mit dem Vektor-Netzwerkanalysator VNWA 2 (1)

## Netzwerkanalyse und VNWA 2

Dr.-Ing. Bodo Scholz, DJ9CS

In [1] hat Thomas Baier, DG8SAQ, sein Konzept für einen Vektor-Netzwerkanalysator mit minimaler Hardware vorgestellt. Während die damals beschriebene Version noch größtenteils auf Lochrasterplatten aufgebaut und somit nur mit eingeschränkter Sicherheit reproduzierbar war, gibt es jetzt einen Bausatz.



Bild 1: Aufgebaute VNWA 2.3 mit Kugelschreiber zum Größenvergleich

den Typen besser aufzuzeigen, folgt zunächst eine Beschreibung des grundsätzlichen Aufbaus eines skalaren Netzwerkanalysators (Bild 2). Kernelemente sind ein in der Frequenz gesteuerter Sinusgenerator mit konstantem Pegel und normalerweise 50  $\Omega$  Ausgangswiderstand. Gemessen werden die Signale mit einem im Allgemei-

**Zur Person**

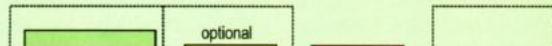
**Dr.-Ing. Bodo Scholz, DJ9CS**  
Jahrgang 1942, DARC-Mitglied seit 1959  
Amateurfunkgenehmigung 1963

Studium der Elektro- und Nachrichtentechnik, Leitender Wissenschaftlicher Direktor a.D.  
Besondere Interessengebiete: Selbstbau, Messtechnik, Software Defined Radio (SDR), QRP

Anschrift  
dj9cs@darcs.de  
<http://dj9cs.raisdorf.org>

nen breitbandigen Pegeldetektor. So lassen sich die Übertragungsfunktion und am Netzwerkeingang das Stehwel-

Aufbau eines skalaren Netzwerkanalysators



Thanks to all  
VNWA Users  
and Supporters!

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# The VNWA3 is in use all over the World.

GERÄTE

Messungen mit dem Vektor-Netz

## Netzwerkanalys

Dr.-Ing. Bodo Scholz, DJ9CS

In [1] hat Thomas Baier, DG8SAQ, sein Ko  
Netzwerkanalysator mit minimaler Hardw  
Während die damals beschriebene Versio  
Lochrasterplatten aufgebaut und somit r  
Sicherheit reproduzierbar war, gibt es jet



Bild 1: Aufgebauter VNWA 2.3 mit Kugelschreiber zum Größenvergleich

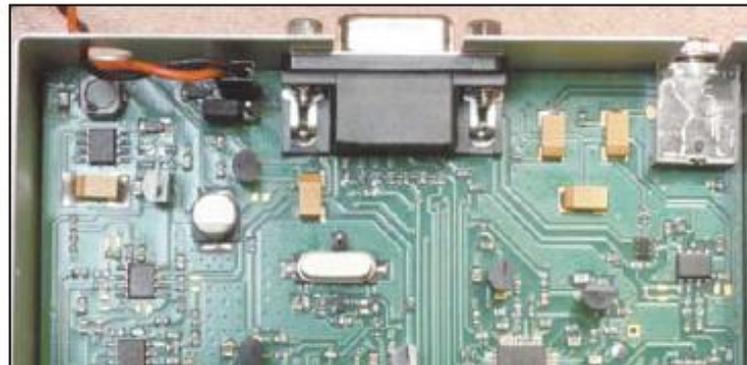
den Type  
zunächst  
grundsätz  
Netzwerk  
Kernelem  
gesteuert  
tantem P  
Ausgangs  
den die S

LABORATORIO-STRUMENTAZIONE

di Vittorio Carboni I6DVX

## Un accurato e prezioso strumento: VNWA2

*Un analizzatore di reti per radioamatori*



sostanza consente di misurare i  
parametri S: S11, S12, S21, S22  
e VSWR. Dei singoli componenti  
può misurare: resistenza, ammet-  
tenza, capacità induttanza e fat-  
tore di qualità (Q). Le misure S12  
e S22 sono effettuate scambiando  
manualmente l'ingresso e  
l'uscita del dispositivo in misura  
(DUT) oppure realizzando una  
commutazione esterna delle por-  
te<sup>(5)</sup>. Le ultime versioni del soft-  
ware di gestione permettono di  
caratterizzare i quarzi ricavando-  
ne automaticamente tutti i para-  
metri. È inoltre prevista la possi-  
bilità di usare il VNWA2 come  
analizzatore di spettro. Tutte que-  
ste informazioni vengono fornite  
dalle elaborazioni del software di  
gestione e sicuramente oggi,  
quando queste note sono lette,  
altre possibilità di misure si sa-  
ranno aggiunte a quelle qui in-  
dicate.

Lo schema a blocchi è visibile  
in Figura 1. La generazione dei  
segnali RF è demandata all'or-  
mai classico DDS, che in questo  
progetto è presente in numero di



# The VNWA3 is in use all over the World..

GERÄTE

Messungen mit dem Vektor-Netz

## Netzwerkanalys

Dr.-Ing. Bodo

In [1] hat The  
Netzwerkanal  
Während die  
Lochrasterpla  
Sicherheit re

LABORATORIO-STRUMENTAZIONE

di Vittorio Carboni I6DVX

## Un accurato e prezioso strumento: VNWA2

sostanza consente di misurare i parametri S: S11, S12, S21, S22 e VSWR. Dei singoli componenti può misurare: resistenza, ammettenza, capacità induttanza e fattore di qualità (Q). Le misure S12 e S21 sono effettuate scambiando periodicamente l'ingresso e l'uscita del dispositivo in misura.

Ankieta czytelników „Świata Radio” (str. 65)

ISSN 1425-1701  
INDEKS 332739

# świat radio 6/2010

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KRÓTKOFALARSTWO CB RADIOTECHNIKA

wewnątrz

KRÓTKOFALOWIEC POLSKI

nr 6 (545)/2010

9,80 zł nakład: 14 500 egz.  
w tym VAT 20%



Bild 1: Aufgebaute VNWA 2.3 mit Kugelschleifkontakt



Analizator wektorowy do 1,3 GHz

ppure realizzando una azione esterna delle portate ultime versioni del software permettono di usare i quarzi ricavando automaticamente tutti i parametri in oltre prevista la possibilità di usare il VNWA2 come analizzatore di spettro. Tutte le operazioni vengono fornite dal software di installazione e sicuramente oggi, queste note sono lette, la possibilità di misure si aggiunge a quelle qui in-

tema a blocchi è visibile in Fig. 1. La generazione dei segnali RF è demandata all'oscillatore DDS, che in questo modo è presente in numero di



# The VNWA3 is in use all over the World.

LABORATORIO-STRUMENTAZIONE

di Vittorio Carboni I6DVX

## Un accurato e prezioso

sostanza consente di misurare i parametri S: S11, S12, S21, S22 e VSWR. Dei singoli componenti può misurare: resistenza, ammettenza, capacità induttanza e fattore di qualità (Q). Le misure S12 e S22 sono effettuate scambiando periodicamente l'ingresso e l'uscita del dispositivo in misura oppure realizzando una connessione esterna delle porte. Le ultime versioni del software di gestione permettono di utilizzare i quarzi ricambiando automaticamente tutti i parametri. Inoltre è prevista la possibilità di utilizzare il VNWA2 come generatore di spettro. Tutte le informazioni vengono fornite dalle elaborazioni del software di gestione e sicuramente oggi, con queste note sono lette, la possibilità di misure si aggiunge a quelle qui in-

tema a blocchi è visibile in figura 1. La generazione del segnale RF è demandata all'oscillatore DDS, che in questo modo è presente in numero di

EQUIPMENT REVIEW

SAM JEWELL, G4DDK ♦ E-MAIL: SAM@G4DDK.COM

DECEMBER 2011 ♦ RADCOM

### DG8SAQ VNWA3 Vector Network Analyser

A compact and versatile unit that measures S parameters, VSWR, reactance and Q up to 1.3GHz

Packard 8753C vector network analyser and S parameter test set, but this combination is large and heavy – definitely not a portable setup. When RadCom asked me if I would like to review the new DG8SAQ VNWA3, I immediately accepted the offer as I had already been thinking about purchasing something similar for use in the field, having tried a number other small analysers. I was particularly keen to see how well the VNWA3 results compared with my own analyser.

to the host computer. A red LED, visible through a hole on the rear panel, indicates that the unit is powered. Photo 2 shows the rear panel of the analyser.

The VNWA uses two Analog Devices AD9859 direct digital synthesisers (DDS). One is used to generate an RF test signal (stimulus) whilst the second generates the test receiver local oscillator signal. These DDS chips specify a maximum 400MHz core clock frequency. However, in this application, both



PHOTO 1: The front panel of the VNWA3 with TX Out and RX In ports.

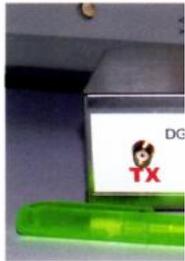
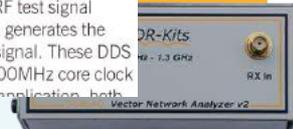


Bild 1: Aufgebaute VNWA3 auf dem Tisch.



14 500 egz.



Analizator wektorowy do 1,3 GHz



# The VNWA3 is in use all over the World.

LABORATORIO-STRUMENTAZIONE

di Vittorio Carboni I6DVX

## Inaccurato e prezioso

sostanza consente di misurare i parametri S: S11, S12, S21, S22. R. Dei singoli componenti misurare: resistenza, ammettenza, capacità, induttanza e fattibilità (Q). Le misure S12 sono effettuate scambiando periodicamente l'ingresso e l'uscita del dispositivo in misura eppure realizzando una connessione esterna delle portate. Le ultime versioni del software permettono di misurare i quarzi ricambiando periodicamente tutti i parametri e inoltre prevista la possibilità di usare il VNWA2 come generatore di spettro. Tutte le operazioni vengono fornite dal software di elaborazione del software di misura e sicuramente oggi, con queste note sono lette, la possibilità di misure si aggiunge a quelle qui in-

tema a blocchi è visibile in fig. 1. La generazione dei segnali RF è demandata all'oscillatore DDS, che in questo modo è possibile il numero di

GERÄTE

Messungen mit dem Vektor-Netzwerkana

## Netzwerkana

EQUIPMENT REVIEW

DG8S  
Vector

A compact  
VSWR, re

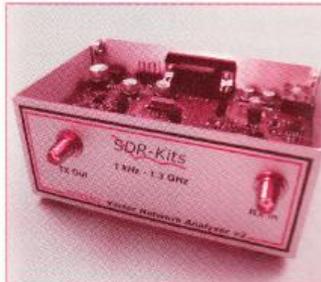


Bild 1: Aufgebaute VNWA2 gleich



PHOTO 1: The front panel

### 製作&実験



USB 接続で使える 1k ~ 1.3GHz までの  
低価格ベクトル・ネットワーク・アナライザ

### “VNWA2”キットの製作・試用記

西村 芳一  
Yoshikazu Nishimura

#### VNWA2とは？

■ ベクトル・ネットワーク・アナライザ(VNA)は高額の花

ちょっとした高周波回路を試作するとき、ネットワーク・アナライザが手元にあるのとないのでは大違いです。とくにマイクロ波などのインピーダンス・マッチングでは、強力なツールとなります。

しかしながら、ネットワーク・アナライザはとて

トワーク・アナライザの製作記事でした。しかも、パソコンとUSBケーブル1本だけでつながり、電源もUSBから供給します。写真1にその外観、パソコンと組み合わせた全体の様子を写真2にそれぞれ示します。

普通のネットワーク・アナライザはとて大きくて重い測定器で、例えば写真3は仕事で使っているアンリツのネットワーク・アナライザですが、気軽に持ち歩くことは不可能です。



Analizator wektorowy  
do 1,3 GHz



# Finally, ... a Warning: VNWA's are Addictive!

Do I get this right? You tell your wife:  
"Sorry dear, not tonight. I have a head-  
ache" and then you can sit all night and  
work with your Vector Network Analyzer!?!

Dipl. Psychologe

Dr. Quack

OMICRON  
LAB