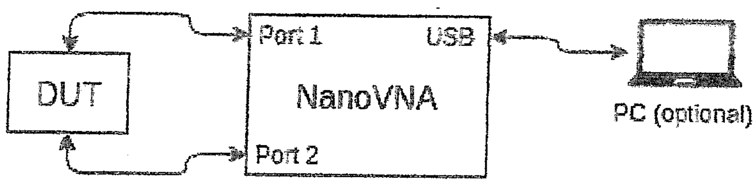
VNA basics

A Vector Network Analyzer (VNA) measures the reflection and transmission behavior of a device under test (DUT) across a configured frequency range.

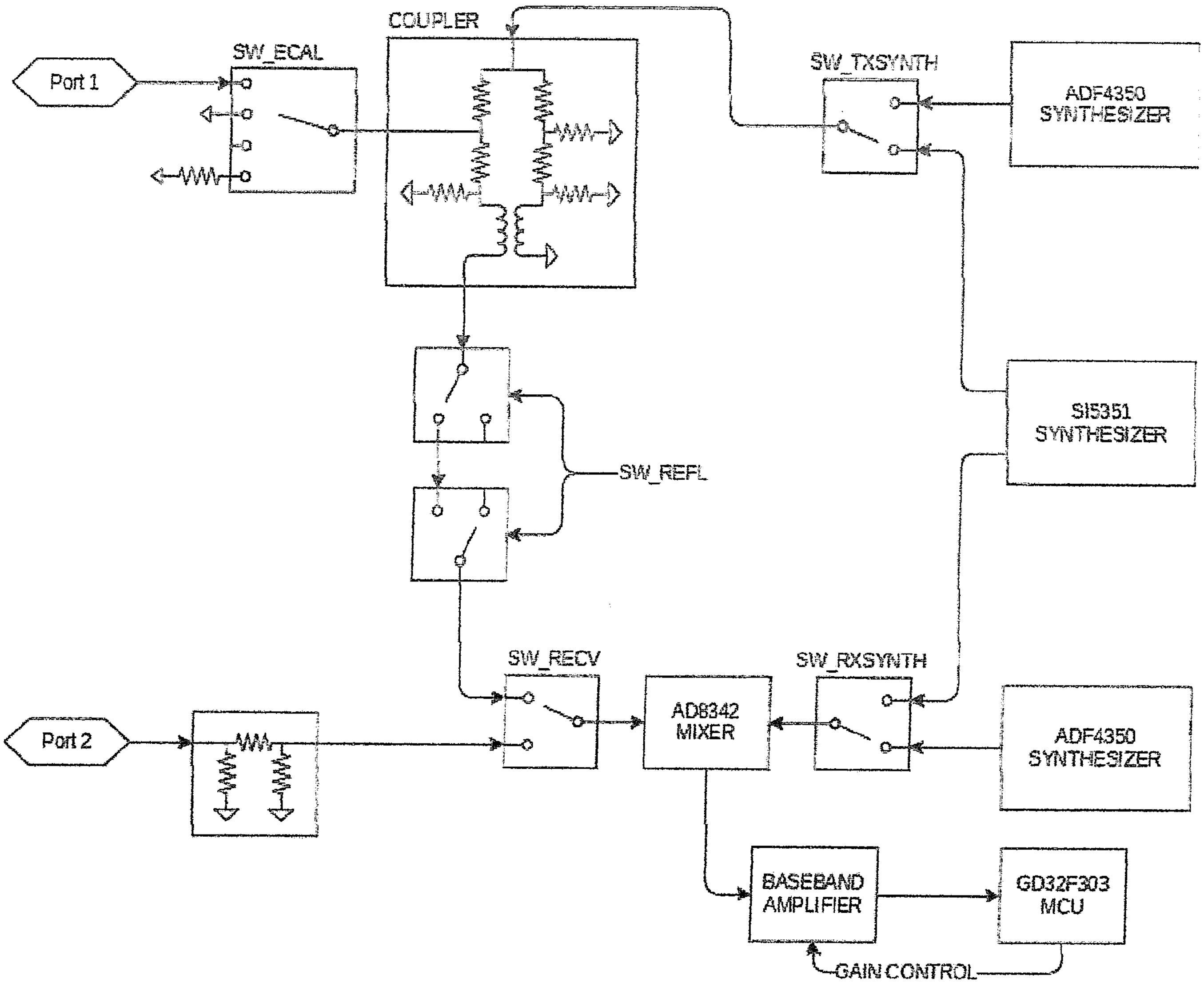
The NanoVNA V2 is a two port T/R (transmission/reflection) VNA which can measure the S parameters S11 and S21 of a two port network, or the reflection coefficient (S11) of a one port network.



Before any measurements are performed, the VNA must be calibrated.

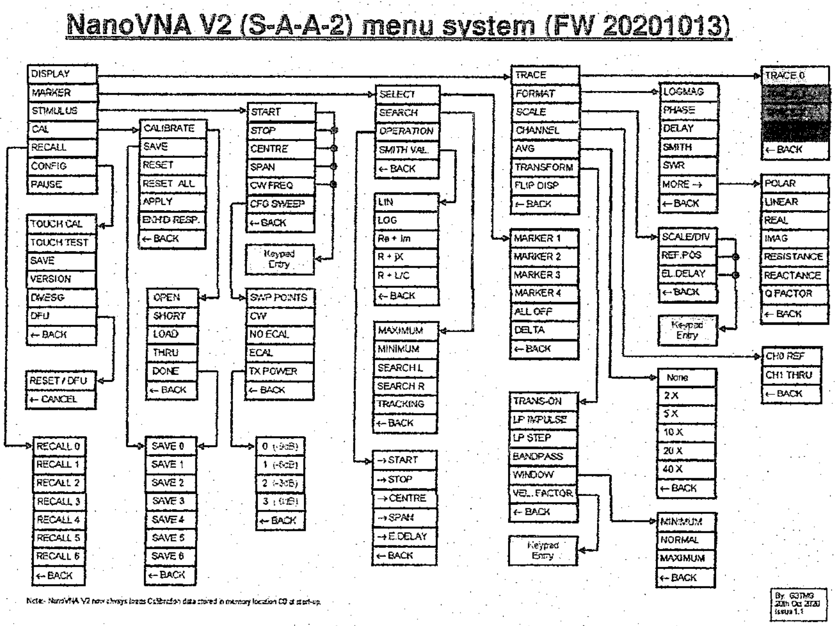
Hardware architecture

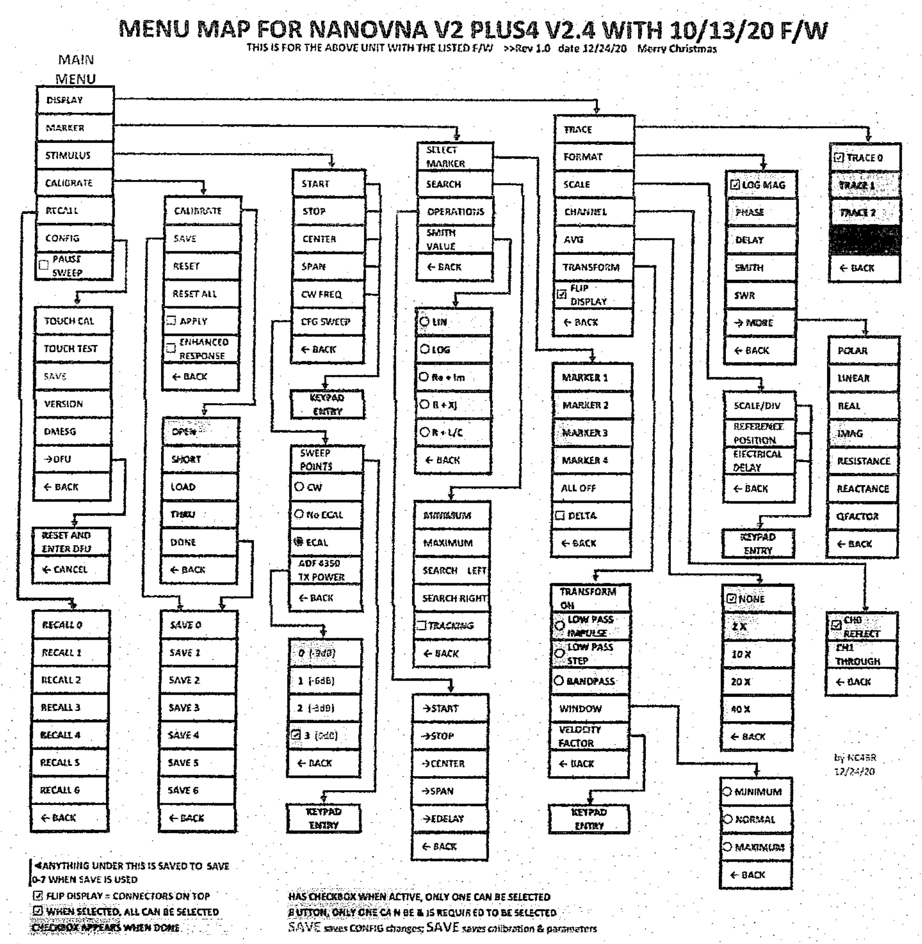
The following block diagram shows a high level overview of the system.



The NanoVNA V2 is a single switched receiver VNA. While the diagram shows only two channels selectable by the receive mixer through SW_RECV, a third channel, the reference channel, is provided by setting SW_ECAL to the "open circuit" position. By controlling these two switches the receiver is able to observe reference, reflected, and thru signals.

Menu map


NanoVNA V2 (S-A-A-2) menu system (FW 20201013)
DISPLAY
MARKER
STIMULUS
CAL
RECALL
CONFIG
PAUSE
TOUCH CAL
TOUCH TEST
SAVE
VERSION
DMESG
DFU
← BACK
RESET / DFU
← CANCEL
RECALL 0
RECALL 1
RECALL 2
RECALL 3
RECALL 4
RECALL 5
RECALL 6
CALIBRATE
SAVE
RESET
RESET ALL
APPLY
ENHD RESP.
OPEN
SHORT
LOAD
THRU
DONE
SAVE 0
SAVE 1
SAVE 2
SAVE 3
SAVE 4
SAVE 5
SAVE 6
START
STOP
CENTRE
SPAN
CW FREQ
CFG SWEEP
Keypad Entry
SWP POINTS
CW
NO ECAL
ECAL
TX POWER
SELECT
SEARCH
OPERATION
SMITH VAL
LIN
LOG
Re + Im
R + jX
R + L/C
MAXIMUM
MINIMUM
SEARCH L
SEARCH R
TRACKING
→START
→STOP
→CENTRE
→SPAN
→E DELAY
TRACE
FORMAT
SCALE
CHANNEL
AVG
TRANSFORM
FLIP DISP
MARKER 1
MARKER 2
MARKER 3
MARKER 4
ALL OFF
DELTA
TRANS-ON
LP IMPULSE
LP STEP
BANDPASS
WINDOW
VEL. FACTOR
LOGMAG
PHASE
DELAY
SMITH
SWR
MORE →
SCALE/DIV
REF.POS
EL.DELAY
None
2 X
5 X
10 X
20 X
40 X
MINIMUM
NORMAL
MAXIMUM
TRACE 0
POLAR
LINEAR
REAL
IMAG
RESISTANCE
REACTANCE
Q FACTOR
CH0 REF
CH1 THRU
← BACK


MENU MAP FOR NANOVNA V2 PLUS4 V2.4 WITH 10/13/20 F/W
THIS IS FOR THE ABOVE UNIT WITH THE LISTED F/W >>Rev 1.0 date 12/24/20 Merry Christmas
MAIN MENU
DISPLAY
MARKER
STIMULUS
CALIBRATE
RECALL
CONFIG
PAUSE SWEEP
TOUCH CAL
TOUCH TEST
SAVE
VERSION
DMESG
→DFU
← BACK
RESET AND ENTER DFU
← CANCEL
RECALL 0
RECALL 1
RECALL 2
RECALL 3
RECALL 4
RECALL 5
RECALL 6
CALIBRATE
SAVE
RESET
RESET ALL
APPLY
ENHANCED RESPONSE
OPEN
SHORT
LOAD
THRU
DONE
SAVE 0
SAVE 1
SAVE 2
SAVE 3
SAVE 4
SAVE 5
SAVE 6
START
STOP
CENTER
SPAN
CW FREQ
CFG SWEEP
KEYPAD ENTRY
SWEEP POINTS
CW
No ECAL
ECAL
ADF 4350 TX POWER
SELECT MARKER
SEARCH
OPERATIONS
SMITH VALUE
LIN
LOG
Re + Im
R + Xj
R + L/C
MINIMUM
MAXIMUM
SEARCH LEFT
SEARCH RIGHT
TRACKING
→START
→STOP
→CENTER
→SPAN
→EDELAY
TRACE
FORMAT
SCALE
CHANNEL
AVG
TRANSFORM
FLIP DISPLAY
MARKER 1
MARKER 2
MARKER 3
MARKER 4
ALL OFF
DELTA
TRANSFORM ON
LOW PASS IMPULSE
LOW PASS STEP
BANDPASS
WINDOW
VELOCITY FACTOR
LOG MAG
PHASE
DELAY
SMITH
SWR
→ MORE
SCALE/DIV
REFERENCE POSITION
ELECTRICAL DELAY
NONE
2 X
10 X
20 X
40 X
MINIMUM
NORMAL
MAXIMUM
TRACE 0
TRACE 1
TRACE 2
POLAR
LINEAR
REAL
IMAG
RESISTANCE
REACTANCE
QFACTOR
CH0 REFLECT
CH1 THROUGH
← BACK
by NC4SR 12/24/20
ANYTHING UNDER THIS IS SAVED TO SAVE 0-7 WHEN SAVE IS USED
FLIP DISPLAY = CONNECTORS ON TOP
WHEN SELECTED, ALL CAN BE SELECTED
CHECKBOX APPEARS WHEN DONE
HAS CHECKBOX WHEN ACTIVE, ONLY ONE CAN BE SELECTED
BUTTON, ONLY ONE CAN BE & IS REQUIRED TO BE SELECTED
SAVE saves CONFIG changes; SAVE saves calibration & parameters

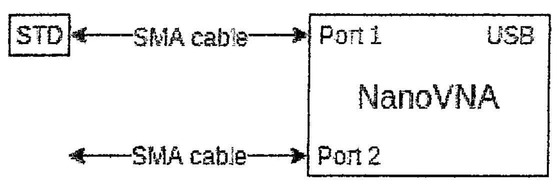
Calibration

Calibration must be performed whenever the frequency range to be measured is changed. When calibration is activated, the left side of the screen should show "Cx" and "D".

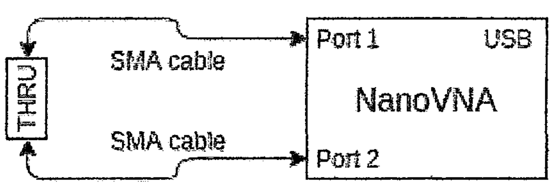
Changing the frequency sweep range always clears the active calibration, if any.

The calibration procedure is as follows:

1. Reset current calibration state. Select menu item **CAL** →**RESET** and then →**CALIBRATE**.
2. Attach a SMA coaxial cable to port 1.
3. (Optional) Attach a SMA coaxial cable to port 2.
4. Connect OPEN standard to port 1 cable and click →**OPEN**. Wait for menu item highlight.
5. Connect SHORT standard to port 1 cable and click →**SHORT**. Wait for menu item highlight.
6. Connect LOAD standard to port 1 cable and click →**LOAD**. Wait for menu item highlight.
7. (Optional) Connect the THRU standard between the port 1 and port 2 cable ends, and click →**THRU**.
8. Click →**DONE**.
9. Specify the dataset number (0 to 4) and save. e.g. →**SAVE 0**.



Measuring a calibration standard

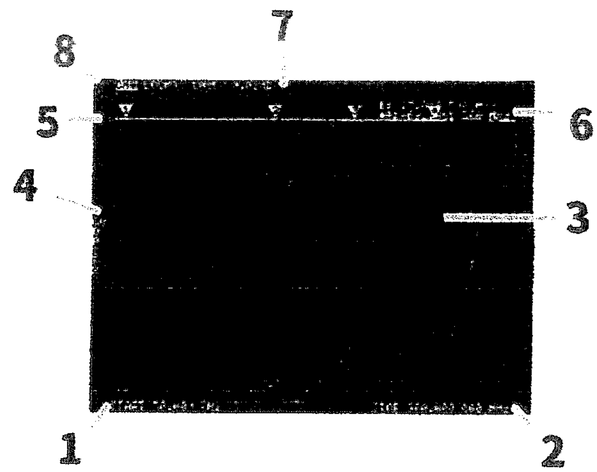


Measuring the THRU standard

Note that there is no need to wait for the plots to fully update after connecting a calibration standard. Clicking any of the OPEN, SHORT, LOAD, THRU calibration menu items will perform a full sweep with 2x averaging. Once the sweep is complete the corresponding menu item will become highlighted, and you may proceed to the next calibration standard.

User interface

Main screen



1. START frequency 2. STOP frequency

The START frequency and STOP frequency are shown at the bottom of the display.

3. Marker

The marker position for each trace is displayed as a small numbered triangle. The selected marker can be moved to any of the measured points in the following ways:

- Drag a marker on the touch panel – best to use a stylus for this.
- Press and hold the JOG LEFT or JOG RIGHT buttons.

4. Calibration status

Displays the saved slot number of the calibration being used and the error correction applied.

- C0 C1 C2 C3 C4 : Each indicates that the corresponding calibration data is loaded.
- D : Indicates that port 1 3-term error model is applied.

5. Reference position

Indicates the reference position of the corresponding trace. You can change the position with:

DISPLAY →SCALE →REFERENCE POSITION.

6. Marker status

The active marker that is selected and one marker that was previously active are displayed top right.

7. Trace status

The status of each trace format and the value corresponding to the active marker are displayed.

For example, if the display is showing: **CH0 LOGMAG 10dB/ 0.02dB** , read it as follows:

Channel CH0 (reflection)

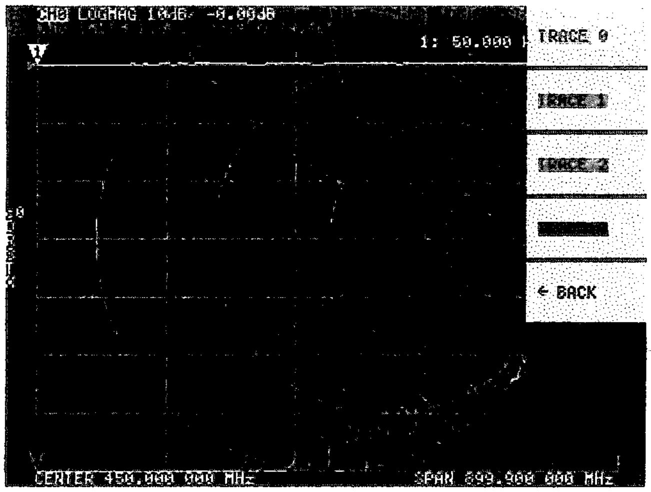
Format LOGMAG

Scale is 10dB

Current value is 0.02dB

For active traces, the channel name is highlighted.

Trace display



Up to four traces can be displayed, one of which is the active trace.

You can turn on/off traces as needed. The menu items **DISPLAY →TRACE →TRACE n** allow you to activate as well as turn on/off traces.

When a trace is active, its channel name at the top of the screen is highlighted. In the image above, TRACE 0 is the active trace.

Clicking **DISPLAY →TRACE →TRACE n** on the current active trace will turn it off. Clicking any other trace activates it.

Trace format

Although each trace can have its own displayed format, you can only change the format of the active trace.

To assign a format, set the trace to active (see above) then select: **DISPLAY →FORMAT**

The description and unit of measurement of each format is as follows:

- **LOGMAG** : Logarithm of absolute value of measured value (dB per div)
- **PHASE** : Phase in the range of -180 ° to + 180 ° (90 degree default)
- **DELAY** : Delay (pico or nano seconds)
- **SMITH** : Smith Chart (Impedance scale is normalized during calibration)
- **SWR** : Standing Wave Ratio (can be scaled to show 1, 0.1 or 0.01 per div)
- **POLAR** : Polar coordinate format (Impedance scale is normalized during calibration)
- **LINEAR** : Absolute value of the measured value

- **REAL** : Real part of measured S parameter
- **IMAG** : Imaginary part of measured S parameter
- **RESISTANCE** : Resistance component of the measured impedance (ohms per div)
- **REACTANCE** : Reactance component of the measured impedance (ohms per div)

Trace channel

The NanoVNA V2 has two channels, **CH0** and **CH1**, corresponding to ports 1 and 2.

CH0 is the S parameter **S11**, while **CH1** is the S parameter **S21**.

Each trace can be set to display data from either channel.

To change the channel used by the currently active trace, select

DISPLAY →CHANNEL →CH0 REFLECT or **DISPLAY →CHANNEL →CH1 THROUGH**.

Time domain operation

The NanoVNA V2 can simulate time domain reflectometry by transforming frequency domain data.

Select **DISPLAY** →**TRANSFORM** →**TRANSFORM ON** to convert measured data to the time domain.

If **TRANSFORM ON** is enabled (Inverted white text on black background), the measurement data is immediately converted to the time domain and displayed. The relationship between the time domain and the frequency domain is as follows.

- Increasing the maximum frequency increases the time resolution
- The shorter the measurement frequency interval (ie, the lower the maximum frequency), the longer the maximum time length

For this reason, the maximum time length and time resolution are in a trade-off relationship. In other words, the time length is the distance.

- If you want to increase the maximum measurement distance, you need to lower the frequency spacing (frequency span / sweep points).
- If you want to measure the distance accurately, you need to increase the frequency span.

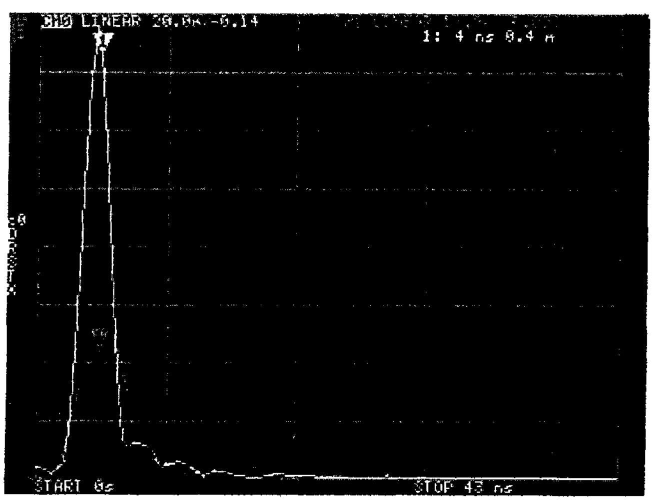
HINT – Use a lower frequency to measure a longer length and a higher frequency to measure a shorter length and adjust accordingly for accurate results.

Time domain bandpass

In bandpass mode, you can simulate the DUT response to an impulse signal.

NOTE: The trace format can be set to **LINEAR**, **LOGMAG** or **SWR**.

The following is an example of the impulse response of a bandpass filter.



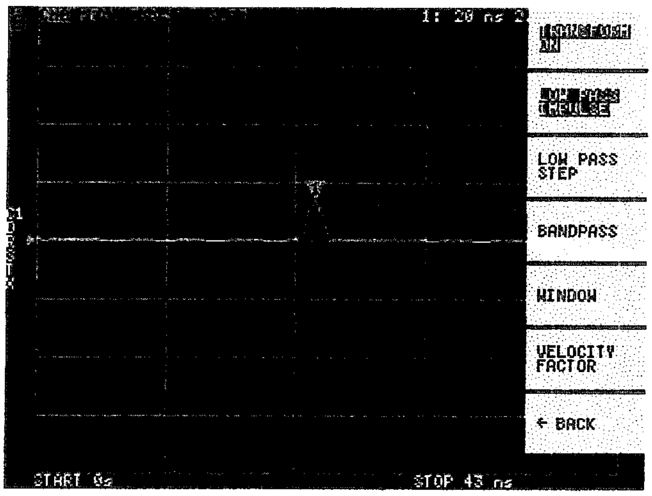
Time domain low pass impulse

In low-pass mode, you can simulate TDR. In low-pass mode, the start frequency must be set to 50 kHz, and the stop frequency must be set according to the distance to be measured.

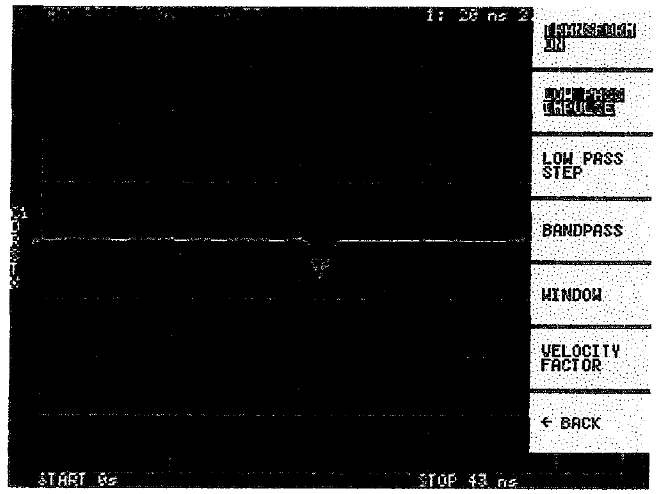
The trace format can be set to **REAL**.

Examples of Impulse response in open state and impulse response in short state are shown below.

Open



Short

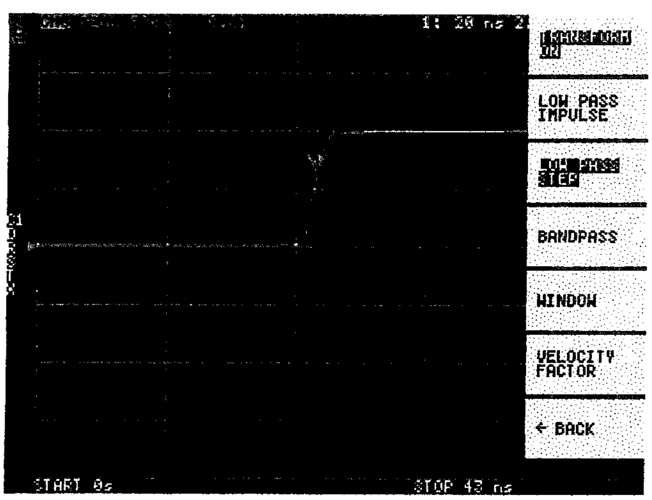


Time domain low pass step

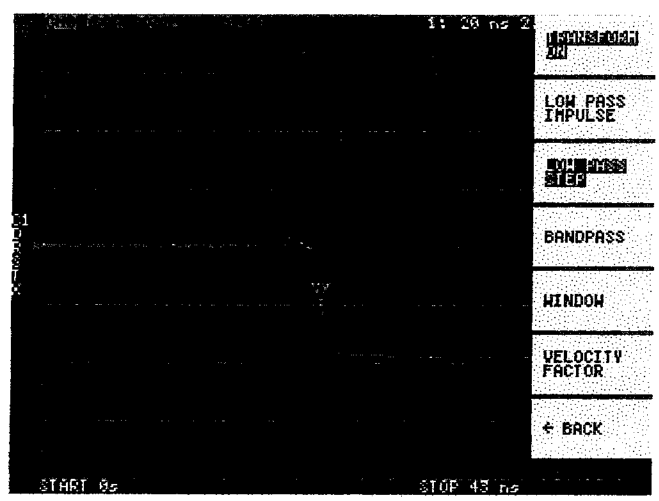
The trace format can be set to **REAL**.

Example measurements of Step response are shown below.

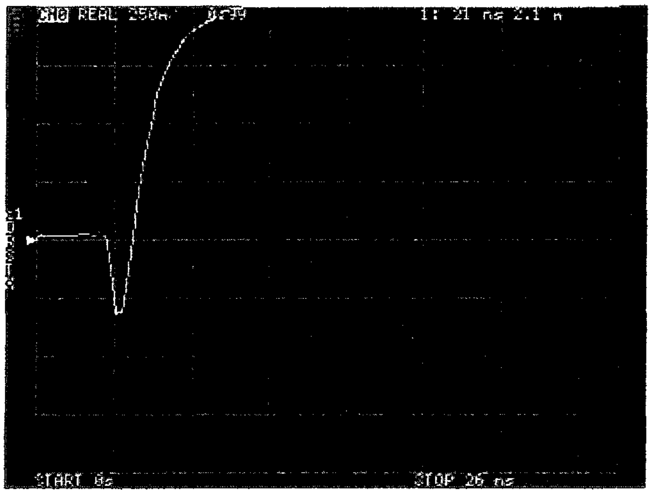
Open



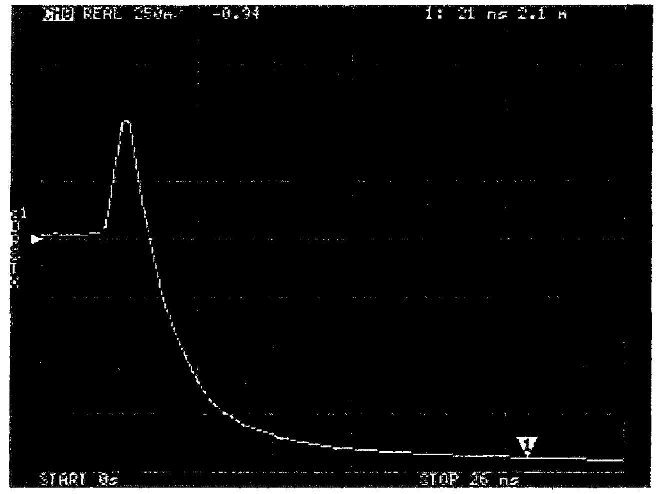
Short



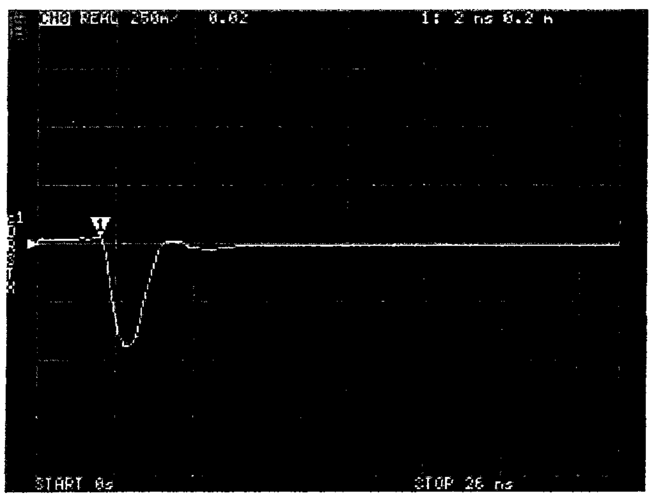
Capacitive short



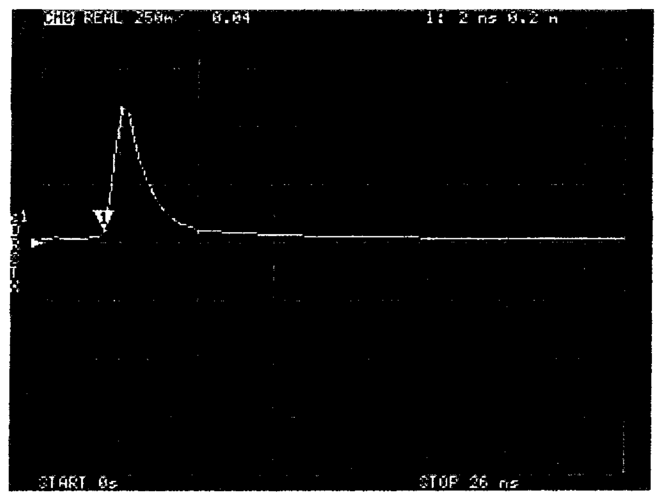
Inductive short



Capacitive discontinuity (C in parallel)



Inductive discontinuity (L in series)



Time domain window

The range that can be measured is a finite number, and there is a minimum frequency and a maximum frequency. A window can be used to smooth out this discontinuous measurement data and reduce ringing.

There are three levels of windowing.

- **MINIMUM** (no window, ie: same as rectangular window)
- **NORMAL** (equivalent to Kaiser window $\beta = 6$)
- **MAXIMUM** (equivalent to Kaiser window $\beta = 13$)

MINIMUM provides the highest resolution and **MAXIMUM** provides the highest dynamic range. **NORMAL** is in the middle.

Setting the velocity factor in the time domain

The transmission speed of electromagnetic waves in the cable varies depending on the material. The ratio to the transmission speed of electromagnetic waves in vacuum is called the Velocity Factor. This is always stated in the cable specifications.

In the time domain, the displayed time can be converted into distance. The wavelength shortening ratio used for distance display can be set with **DISPLAY → TRANSFORM → VELOCITY FACTOR** .

For example, if you measure the TDR of a cable with a wavelength reduction rate of 67%, specify **67** for the **VELOCITY FACTOR**. (Do not use the decimal point).

Signal generators

Two ADF4350 RF synthesizers, plus one Si5351, provide the stimulus and LO signals. The Si5351 covers frequencies up to 140MHz, and the rest are covered by the ADF4350s.

Directional coupler

The coupler is based on a Wheatstone bridge rearranged so that input and DUT ports are referenced to ground. The coupled signal exists as a difference signal and is extracted by baluns. Two stages of baluns are used to achieve the necessary common mode rejection ratio.

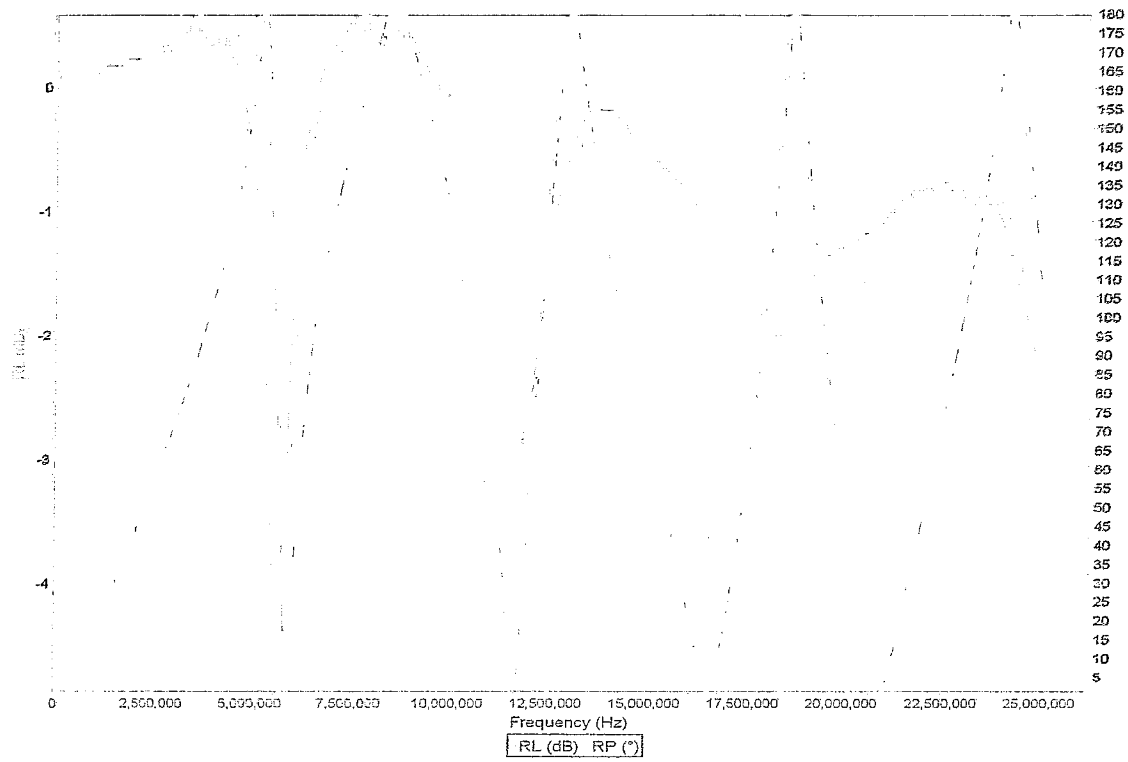
Receiver

The receiver consists of a AD8342 mixer and an op-amp based baseband amplifier.

The mixer downconverts the RF signal to a low but nonzero intermediate frequency (typically 12kHz). The IF signal is digitized using the built in 12 bit ADCs on the GD32 microcontroller.

Firmware on the microcontroller digitially detects the phase and magnitude of the IF, and thus RF signal, which results in superior accuracy compared to VNAs using a phase and magnitude detector IC that does the detection in the analog domain.

Testexport



Marker	Freq. (Hz)	RL (dB)	RP (°)	TL (dB)	TP (°)	SWR	|Z| ()	Rs ()	Xs ()

Comment:

```
Date:       11/25/19 11:13 AM
Mode:       Reflection
Analyser:   miniVNA / mini radio solutions - miniVNA
Scan
  Start:    100000 / 100,000
  Stop:     24999346 / 24,999,346
  Samples:  1098
  Overscan: 1
Calibration
  Samples:  2000
  Overscan: 1
  File:     REFL_miniVNA.cal
User:       HP
```