

## **Hermes VNA User Guide V1.6 11 November 2012 (for PC code V1.6.0)**

### ***Introduction***

This PC software, and associated FPGA code, enables a Hermes board to be used as either a Reflection or Transmission vector network analyser (VNA). VNA measurements can be made over the range 100 kHz to 60 MHz in 1 Hz steps (subject to any frequency limitations of external measurement equipment).

### ***FPGA code***

The Hermes board to be used as a VNA must be loaded with FPGA code V1.8 or higher. All previous functions of V1.6 are retained so this code version can be used for either VNA or transceiver use.

### ***PC Code***

The PC code (VNA.exe) is installed on the PC using an installer which can be obtained here:

<http://openhpsdr.org/download.php>

from the 'Windows' section.

Installer options enable the default installation drive and directory to be changed as well as the installation of start-up and desk-top icons. Any files that are required to run the code, if not already present e.g. .NET 4.0, will be automatically installed.

Each time VNA.exe is run and closed the current settings (e.g. Mode, Calibration file name and path etc) is saved in a file 'VNA.ini'. This file is save here when using XP:

C:\Documents and Settings\<User Name>\Application Data\OpenHPSDR\VNA

or here when using Vista or Win 7

C:\Users\<User Name>\AppData\Roaming\OpenHPSDR\VNA

### ***Operation***

**IMPORTANT:** The maximum Tx output level from Hermes is approximately -10 dBm. In which case with the 20dB Attenuator in circuit on the Rx input then it is safe to connect the Tx output directly to the Rx input. If the Attenuator is not selected then the ADC may be overloaded. This will be indicated by the 'ADC Overload' indicator illuminating Red.

#### **DO NOT OPERATE HERMES WITH THE ADC OVERLOAD INDICATOR ILLUMINATED**

When used for Transmission or Reflection measurements it is recommended that a 6db attenuator be connected directly to the Tx output of Hermes. Alternative the low level output from Hermes (J1 – Transverter output), suitably configured, can be used as the signal source. The attenuator not only prevents possible overload of the ADC but also provides a solid 50 ohm source to the device under test (DUT) or Reflection Bridge. With a 6dB or higher attenuator in circuit then the 20dB attenuator

on Hermes does not need to be selected. Not using the 20dB attenuator is desirable since a larger measurement signal is presented to the Rx input which may increase the measurement accuracy.

If the IP address of the PC Ethernet port that the Hermes is connected to is known then enter it in 'PC IP' in xxx.xxx.xxx.xxx format (e.g. 192.168.1.4). If the IP address is not known then the software will automatically locate the appropriate address.

Before making measurements in transmission mode the VNA needs to be calibrated. Enter the 'Start' Frequency (MHz), 'End' Frequency (MHz) and number of 'Steps' to take. The maximum number of Steps is restricted to 1000. If measurement at only a single frequency is required then leave the End and Steps blank.

*If Hermes is currently being used in Transceiver mode then cycle the power to the board before using it in VNA mode. Similarly, cycle the power before using Transceiver mode again.*

Power on the Hermes board and click the 'ON' button. If the software locates a Hermes board then the ON button will turn green and the 'PC IP', 'Hermes IP', 'Hermes MAC' and 'Code version' will be filled in. If a Hermes can't be located then a warning will be displayed and the user will need to investigate the cause.

#### *Transmission Mode Measurements:*

To make measurements in transmission mode connect the Tx output (via a 6dB attenuator) to the Rx input via a length of coax that represents that which will be used when measuring the DUT.

In the 'Mode' group select 'Transmission' if not already selected.

If the VNA has been previously calibrated, in Transmission mode, over the required frequency range then load the calibration file using the File > Load Calibration menu item at the top of the screen. If the Transmission measurement is to be made over a range within a previous Calibration then enter the desired Start and End frequencies, in MHz, in the boxes below the horizontal axis of the graph.

If a previous Calibration file does not exist then enter the 'Start', 'End' and Steps in the 'Calibrate' Group box. Frequencies should be entered in MHz with a 1 Hz resolution e.g. 14.159001 equates to 14.159001 MHz.

NOTE: each frequency Step takes approximately 40 mS, in which case 100 steps will take 4 seconds, 1000 steps 40 seconds etc.

Click 'Calibrate' and the software will collect data that will be used to calibrate the VNA when the DUT is being measured. The progress of the calibration process will be indicated on the progress bar.

At the end of the calibration process you will be prompted to save the Calibration file. If you intend to make the same, or similar, measurements in the future then it will save time if a suitable calibration file is available. Click 'OK' to save the file and 'Cancel' to ignore.

When saving a calibration file it is useful to save the Start, End and Steps, and the fact it is a transmission file, in the file name e.g. Cal-1-10-100-trans.csv. Note that Transmission and Reflection Calibration files are not interchangeable.

If you would like to use this same Calibration file the next time the software is run then select the 'Auto Load Calibration' check box. This will automatically load the last used Calibration file when the software is first started.

NOTE: the default directory for Calibration files when using XP is:

C:\Documents and Settings\<user name>\My Documents\OpenHPSDR\VNA

and when using Vista or Win 7

C:\Users\<user name>\My Documents\openHPSDR\VNA

Replace the direct connection between the Tx output and Rx input with the DUT and then left click 'Measure'. The progress of the measurement will be displayed on the progress bar.

Once the Measurement is completed a graph will displayed. The left vertical axis displays the Gain (in dB's) of the DUT and the right vertical axis the Phase (degrees). The horizontal axis will contain the Start and End frequencies.

The horizontal axis can be zoomed within the Measurement range by selecting the required Start and End frequencies displayed below the horizontal axis.

If the horizontal axis can be displayed in a log scale by checking the 'Log x Axis' box. The vertical axis can be auto ranged by checking the 'Auto Range' box. The points on the graph can be displayed in Line, Dot or Spline format by selecting the appropriate button.

The frequency at a particular step and the magnitude of the Gain or Phase of that measurement can be displayed by placing the mouse pointer on the step. It maybe necessary to select dot display mode in order to accurately position the mouse cursor on a step.

The current calibration data can be saved at any time using the File > Save Calibration File menu.

The current setting of the '20dB Attenuator' is saved in the Calibration file and set to the saved value when the file is loaded.

The graph can be printed using the 'File' > 'Print' option.

Measurements can be automatically repeated, for example when tuning a filter, by right clicking on the Measure button. In which case the button will turn green; the automatic repeat can be stopped by either left or right clicking on the Measure button.

### *Reflection Mode Measurements:*

To make measurements in reflection mode connect the Tx output (via a 6dB attenuator) and Rx input to a Reflection Bridge. See Appendix A for information regarding constructing a suitable Reflection Bridge.

In the 'Mode' group select 'Reflection Smith' if not already selected.

As per Transmission mode measurements either select a previous Calibration file or within the Calibrate group Insert the 'Start', 'End' and number of 'Steps' required.

Click 'Calibrate' and the software will collect data that will be used to calibrate the VNA. Calibration in Reflection mode is done using three different loads individually connected to the measurement port on the Reflection Bridge, or at the end of a length of coax cable connected to the bridge, if the load to be measured is remote from the Bridge.

The loads are 'Open', 'Short' and 'Load'. The first two are self explanatory whilst the 'Load' is a resistance corresponding to the Impedance at which the VNA is to be operated - typically 50 ohms. The quality, and accuracy, of these three loads will directly affect the accuracy of the measurements.

Once 'Calibrate' has been clicked the software will prompt you to connect the relevant load and then take the necessary measurements. The procedure for saving and restoring Reflection Calibration data is the same as that for Transmission - please refer to that section for additional information.

Connect the load to be measured to the measurement port on the Reflection Bridge and then click 'Measure'. The progress of the measurement will be displayed on the progress bar.

Once the measurement is completed a Smith Chart will be displayed that shows the variation of measured impedance with frequency. The Smith Chart is normalised to the Load value used to calibrate the VNA - in this case 50 ohms.

The impedance at the first (or only) step will be indicated using a green dot in order for the user to easily identify the start of the impedance plot.

The impedance at a particular step, and the frequency of that measurement, can be displayed by placing the mouse pointer on the step. The impedance is displayed in  $R + jX$  format as the actual rather than the normalised impedance.

The Impedance at the final frequency step (or measurement frequency if no steps) along with other derived values will be displayed in the 'Results' area of the display. The Results area displays more details regarding the measurement at a particular frequency e.g.  $R_s$ , SWR, RL etc.

Placing the mouse on a measurement point and left clicking will display the Results at that particular measurement frequency.

A graphical display of various measured and derived values can be displayed by selecting the 'Reflection Chart' button. It is not necessary to re-measure in order to display this data and you can switch between Graph and Smith Chart as desired.

The Graph will initially display the SWR of the load Impedance over the frequency range. Drop down menus are provided at the top of the graph such that other measured and derived results can be displayed independently on the left and right Y axis.

As per the Smith chart display you can also display the frequency and value at a particular step by placing the mouse pointer on the step. It maybe necessary to select dot display mode in order to accurately position the mouse cursor on a step.

Left clicking on a step will show more data at that frequency in the Results display.

The horizontal axis will contain the Start and End frequencies. The 'Display' controls operate in the same manner as described in the Transmission section.

The Smith Chart or graph can be printed using the 'File' > 'Print' option.

### *Saving Results for External Evaluation*

The results of a *Reflection* measurement can be saved to a file and exported for further analysis in an external program. The VNA software saves files in either Zplot (see <http://ac6la.com/zplots.html>) or S Parameter (\*.s1p) format. Once a Reflection measurement has been made select the 'File' menu at the top left of the screen and select the desired file format. See Appendix A for further information regarding the use of S Parameter files.

### *Saving and Retrieving Measurements*

Measurements can be saved and retrieved using the 'File' menu at the top left of the screen. Select 'Load Measure File' to load a previous saved file and 'Save Measure File' to save current results.

Once loaded, a saved file will display in the mode that was used to take the measurements e.g. Transmission or Reflection. If the latter then the data can be displayed using either the Smith Chart or graph.

A Measurement file can be loaded without a Hermes board being connected or the 'ON' button being selected.

The path and name of the Calibration file in use when the Measurement file was saved is attempted to be opened when reading the Measurement file. If the file exists the user will be prompted to open it. In which case the VNA software can be run and additional measurements made.

If the associated calibration file cannot be found then an option to locate the file will be presented.

The default path to the directory that holds the Measurement files is the same as that used for the Calibration files.

When using the Smith Chart display the facility to point the mouse at a step value and display frequency and impedance is available. Left clicking the mouse at a step will display all Results data for that particular frequency.

Note that should a Measurement file be received from another user, or using different hardware, then the associated Calibration file will most likely not be usable. In which case click the 'Calibration' button to generate a new Calibration file based on the Start, End and Steps read from the Measurement file.

### *General Information*

Measurements taken during development indicate that using Hermes as a VNA can result in very accurate and repeatable results. Like any other VNA, the accuracy and quality of the Open, Short and Load devices is critical in order to ensure accurate and repeatable results. Since measurements to less than 0.1 ohm are possible the use of high quality connectors and leads etc. is recommended. The contact resistance of a worn BNC plug and socket is very evident when taking measurements.

Preliminary test results indicate accuracy in the order of 0.5% and in many cases 0.1%.

Measured values do change as the Hermes board heats up once initially powered. For the most accurate results it is recommended that the board be powered for 15 minutes before taking measurements.

Immediately after running a Calibration it is informative to do a measurement and display the results of the direct connection or load. Typically the Transmission display will be very close to 0dB and 0 degrees and the Reflection display very close to the Load resistance used.

## Appendix A

Useful background information regarding how a VNA works and its use:

<http://cp.literature.agilent.com/litweb/pdf/5965-7707E.pdf>

<http://na.tm.agilent.com/8720/applicat/app1.pdf>

If a suitable Bridge is not available, and the user wishes to construct one, then these designs are recommended:

<http://www.wetterlin.org/sam/Reflection/3BeadBalunBridge.pdf>

<http://higsdr.finken-net.de/html/rf-cir.htm>

Sam's web site at:

<http://www.wetterlin.org/sam/>

contains a wealth of useful information relating to VNAs.

An excellent introduction to the Smith Chart and its use is here:

[http://www.ae6ty.com/Smith\\_Charts.html](http://www.ae6ty.com/Smith_Charts.html)

### *Using S Parameter files*

The Hermes VNA software enables measurements to be saved in s1p format files for import to external programs. The s1p format is a standard interchange format used by many professional RF design programs.

In very useful, and free, RF design and analysis program is RFSim99 which can be obtained here:

<http://electroschematics.com/835/rfsim99-download/>

Please see the notes on the above page regarding the use of RFSim99 under Windows 7 64 bit.