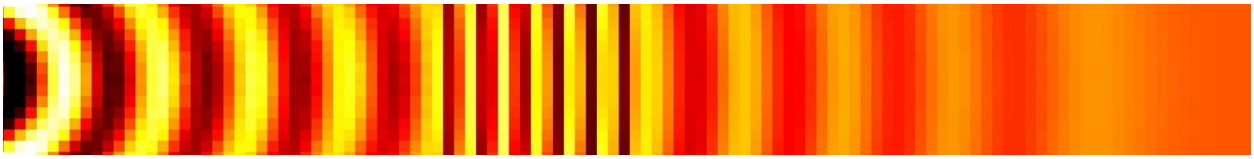
Rthetaphi Waveguide Sample Analyzer (WSA)

User Manual

Version 1.0



Published by: Rthetaphi

Revision History:

Version	Date	Changes
1.0	August 2026	Initial release

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Table 1. Common Abbreviations Used in This Manual

Abbreviation	Description
EM	Electromagnetic
EMCP	Electromagnetic Characterization Platform
WSA	Waveguide Sample Analyzer
WSH	Waveguide Sample Holder
WCA	Waveguide Coax Adapter
CLS	Calibration Line Section
SP	Shorting Plate
SUT	Sample Under Test
NRW	Nicolson-Ross-Weir [1–3]
SM	Supporting Member
HM	Holding Member
GUI	Graphical User Interface

1. Introduction

Rthetaphi Portable Electromagnetic Characterization Platform (EMCP) is a modular measurement platform that integrates hardware and software for electromagnetic characterization of materials. The current platform implements the Nicolson–Ross–Weir (NRW) method [1–3] for waveguide-based material characterization.

Rthetaphi Waveguide Sample Analyzer (WSA) is the software component of the platform. It provides functions for measurement data import, electromagnetic property extraction, result visualization, measurement quality diagnostics, and data export. This manual describes the system requirements, hardware configuration, software operation, analysis workflow, and interpretation of characterization results.

WSA is designed to operate with the Rthetaphi Portable Electromagnetic Characterization Platform (EMCP). However, ownership of the complete platform is **not** required. Users with compatible waveguide measurement hardware may also use WSA by configuring their measurement system according to the hardware requirements described in this manual. WSA also supports the import of simulated S-parameter data, enabling electromagnetic characterization of numerical models using the same analysis workflow as experimental measurements.

1.1. Software Editions

This manual applies to both the Trial Edition and the Licensed Edition unless otherwise stated.

The Trial Edition provides the core Waveguide Sample Analyzer functionality and may include certain functional limitations.
The Licensed Edition provides the full functionality available under a purchased license.

The Trial Edition and Licensed Edition use the same software installation.

A valid purchased license can be activated on an existing Trial Edition installation to enable the Licensed Edition.

Features available only in the Licensed Edition are identified in Table 2.

Table 2. Feature Availability by Software Edition.

Feature	Trial	Licensed
Export characterization data	✗	✓
Display high-resolution plots for characterization results	✗	✓
Display number of full waves propagating through the SUT	✗	✓
Display imaginary, magnitude, and phase formats for permittivity and permeability of the SUT	✗	✓

2. Installation

2.1. System Requirements

Supported Operating Systems

- Microsoft Windows 10/11 (64-bit)
- Ubuntu Linux (64-bit) (under development)

Processor

- Intel or AMD 64-bit processor or equivalent

2.2. Downloading the Software

Visit https://www.rthetaphi.com to download the Waveguide Sample Analyzer.

The downloaded software may initially operate as the Trial Edition.

A valid purchased license can be activated within the software to enable the Licensed Edition.

Ubuntu Linux (64-bit) support is currently under development and will be available in a future release.

2.3. Installing the Software

Follow the installation instructions provided with the downloaded software.

After installation, launch the Waveguide Sample Analyzer from the desktop shortcut or the Windows Start menu.

The software may initially operate in Trial Mode.

If you have purchased a license, the Licensed Edition can be activated from within the software using the license key provided by Rthetaphi.

2.4. License Activation

The Trial Edition does not require license activation. Simply launch the software to begin using the Trial Edition.

To activate the Licensed Edition:

- Launch the Waveguide Sample Analyzer.
- Open License → Activate License.
- Enter the license key received after purchase.
- Read the Rthetaphi Software License Agreement and Privacy Notice.
- Confirm acceptance of the Software License Agreement.
- Click Activate.
- Upon successful activation, the software automatically restarts and launches in the Licensed Edition.

An Internet connection is required for initial activation of the Licensed Edition.

2.5. Uninstalling the Software

To uninstall the Waveguide Sample Analyzer, use the standard Windows uninstall procedure:

Windows Settings → Apps → Installed Apps
→ Waveguide Sample Analyzer → Uninstall

3. Required Hardware Components

3.1. Required Hardware Components

Rthetaphi Waveguide Sample Analyzer (WSA) requires S-parameter measurement data acquired from a waveguide-based measurement system. The measurement system consists of a vector network analyzer (VNA) and waveguide components configured according to the waveguide-based Nicolson–Ross–Weir (NRW) measurement method [1–3]. The required hardware components are listed in Table 3.

Table 3. Required Hardware Components

Component	**Description**
Vector Network Analyzer (VNA)	Used to measure S-parameters of the configured waveguide system
Waveguide Coax Adapter (WCA)	Provides the interface between the VNA coaxial ports and the waveguide structure
Waveguide Sample Holder (WSH)	Holds the sample under test (SUT) during measurement
Calibration Line Section (CLS)	Provides the line configuration required for NRW characterization
Shorting Plate (SP)	Provides short-circuit reference measurements

WSA supports electromagnetic characterization of samples measured using a compatible waveguide measurement configuration. The software can process data from both single-layer samples and multilayer sample stacks. Samples under test (SUTs) should satisfy the requirements listed in **Table 4**.

Table 4. Sample Requirements

Parameter	**Requirement**
Sample structure	Single-layer or multilayer stack consisting of different materials
Measurement method	Waveguide-based NRW method
Sample thickness	The sample thickness should be compatible with the selected waveguide configuration
Sample width and height	The sample width and height should be compatible with the selected waveguide configuration, as shown in Fig. **1**.

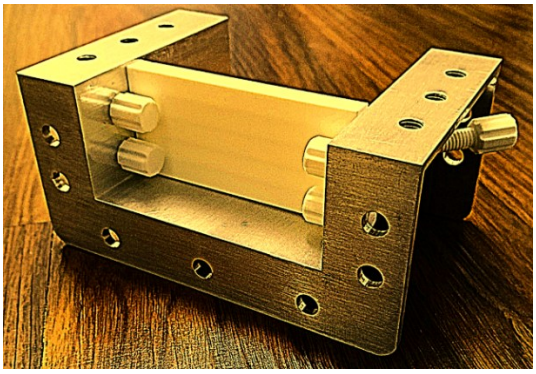

Fig. 1. A sample under test (SUT) secured within an Rthetaphi WSH (patent-pending).

3.2. Hardware Configuration Overview

The measurement system consists of a VNA connected to the waveguide structure through waveguide coax adapters. Different hardware configurations are used to acquire the reference and sample measurement data required for electromagnetic characterization. A typical waveguide measurement configuration is:

VNA Port 1 → WCA → Waveguide Structure → WCA → VNA Port 2

Before performing electromagnetic (EM) characterization, S-parameter measurements must be acquired for the following five (5) hardware configurations, as shown in Fig. 2 and listed in Table 5. These datasets are required inputs for WSA analysis.

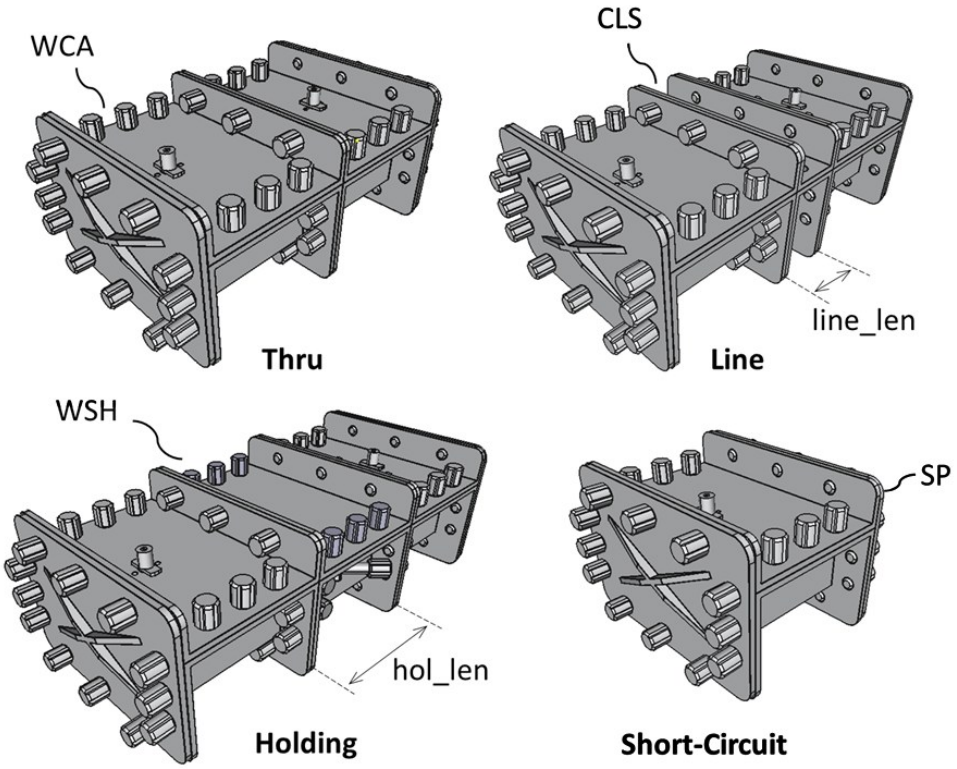

Fig. 2. Hardware configurations for electromagnetic characterization.

Table 5. Required S-Parameter Measurement Configurations

Configuration	**Connection**	**purpose**
Thru	WCA–WCA	Thru reference measurement

Line	WCA–CLS–WCA	Line reference measurement
Holding	WCA–WSH–WCA	Sample holder measurement
Short-Circuit-I	WCA–SP	Short-circuit reference measurement
Short-Circuit-O	WCA–SP	Short-circuit reference measurement

3.3. Measurement Workflow

The overall workflow from hardware measurement preparation to electromagnetic characterization is illustrated in Figure 3.

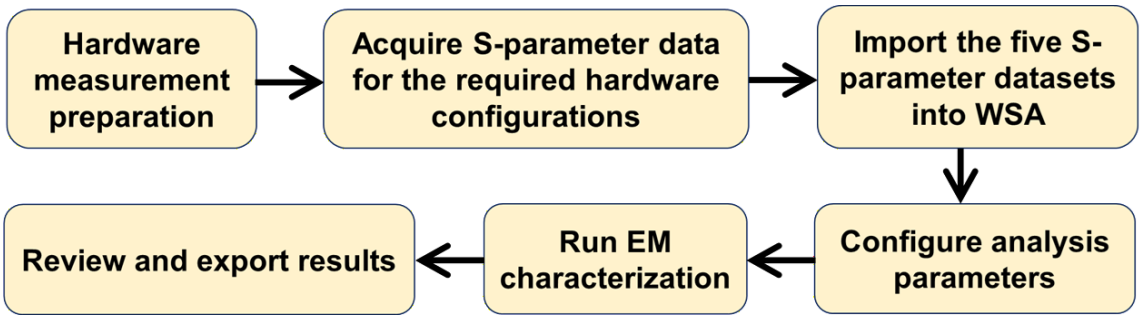

Fig. 3. Measurement workflow for acquiring S-parameter datasets and performing electromagnetic (EM) characterization.

The five (5) S-parameter datasets should be acquired before starting EM characterization in WSA. All measurements should use consistent measurement settings, including frequency range, frequency resolution, and VNA configuration. The following chapters describe the software workflow for importing measurement data, configuring analysis parameters, and obtaining EM characterization results.

4. Software Overview

Rthetaphi Waveguide Sample Analyzer (WSA) is software designed for waveguide-based electromagnetic characterization using the NRW method [1–3]. WSA provides functions for measurement data import, electromagnetic (EM) property extraction, result visualization, measurement validation, and report generation.

Fig. 4. Graphical user interface (GUI) of WSA

Fig. 4 shows the user interface of the Rthetraphi Waveguide Sample Analyzer (WSA). The interface is organized into functional regions ① to ⑦ for data import, parameter configuration, electromagnetic characterization, result visualization, and data export.

Table 6. Description of the GUI Components

No.	GUI Component	Description
①	Workflow Status Bar	Guides the user through the analysis workflow by indicating the next required task (e.g., Load Thru, Load Line, …).
②	Test Setup Panel	Specifies measurement parameters, including waveguide dimensions, sample thickness, sample location, and frequency range used for analysis.
③	Plot Configuration Panel	Selects the output parameter to display and configures the plotting format (e.g., dB, Phase, …).
④	Main Toolbar	Provides access to the primary software functions, including Load Files, Characterize, …
⑤	Plot Navigation Toolbar	Provides tools for plot interaction, including Home, Pan, …
⑥	Plot Display Area	Displays the selected electromagnetic (EM) parameter as a function of frequency and presents the characterization results graphically.
⑦	Operation Status Bar	Displays software operation status, progress, warnings, and error messages generated after user actions.

5. Importing Measurement Data

Before performing electromagnetic characterization, the required S-parameter measurement files must be imported into WSA. Five (5) measurement files are required and must be loaded in the following order (see Table 7).

Table 7. Required Measurement Files

Order	Measurement File	Description
1	Thru (.s2p)	Thru configuration measurement (2-port)
2	Line (.s2p)	Line configuration measurement (2-port)
3	Holding (.s2p)	Holding configuration measurement (2-port)
4	Short P1 (.s1p)	Short-circuit measurement at Port 1 (1-port)
5	Short P2 (.s1p)	Short-circuit measurement at Port 2 (1-port)

All measurement files must contain the same frequency points and frequency range to ensure consistent electromagnetic characterization.

Click **Load File** to import the required .s2p and .s1p measurement files. The **Workflow Status Bar** (region ① in Fig. 4) indicates the next measurement file to be loaded (e.g., **Load Thru**, **Load Line**, **Load Holding**, **Load Port 1 Short**, and **Load Port 2 Short**) and confirms when all required files have been successfully imported.

6. Configuring Test Setup Parameters

Before running electromagnetic characterization, enter the required measurement parameters in the **Test Setup Panel** (region ② in Fig. 4). These parameters describe the waveguide configuration, sample geometry, and frequency range used for the analysis.

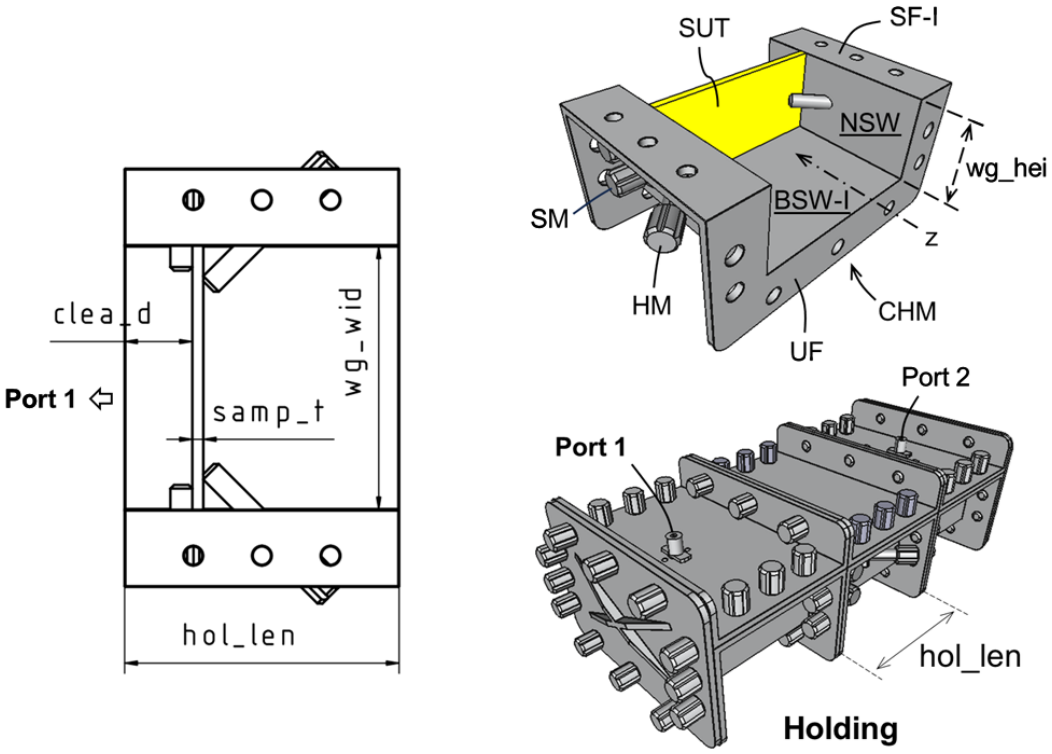

Fig. 5. Physical dimensions of the Waveguide Sample Holder (WSH).

Examples of the physical dimensions on the Waveguide Sample Holder (WSH) are illustrated in Fig. 5.

In Fig. 5, “clea_d” is the clearance distance, in millimeter (mm), from the supporting member (SM) contact points on the SUT to the open end of the waveguide sample holder. When fully assembled, this open end is engaged with the input waveguide coax adapter, which is terminated with the coaxial port, Port 1.

The descriptions of these dimensions and frequency range are listed in Table. 8.

Table 8. Test Setup Parameters

Parameter	**Description**
wg_wid (mm)	Waveguide width (mm)
wg_hei (mm)	Waveguide height (mm)
line_len (mm)	Line length (mm)
hol_len (mm)	Length of the waveguide sample holder (mm)
samp_t (mm)	Thickness of the sample under test (SUT) measured along the waveguide propagation direction (mm)
clea_d (mm)	Clearance distance from the supporting member (SM) contact points on the SUT to the open end of the waveguide sample holder (mm)
f1 (MHz)	Start frequency used for delay estimation
f2 (MHz)	End frequency used for delay estimation

7. Configuring Plotting Options

7.1. Selecting Output Parameters

The **Select Parameter(s)** drop-down list provides a list of available measurement quantities and electromagnetic (EM) properties that can be selected for visualization.

Table 9. Available Output Parameters

Category	**Available Parameters**	**Description**
Thru	s11, s12, s21, s22	Measured S-parameters of the Thru configuration
Line	s11, s12, s21, s22	Measured S-parameters of the Line configuration
Holding	s11, s12, s21, s22	Measured S-parameters of the Holding configuration
Short Port 1	short-p1	Short-circuit measurement at Port 1
Short Port 2	short-p2	Short-circuit measurement at Port 2
Waveguide	wg-gam (ideal), wg-gam (meas)	Ideal and measured hollow waveguide propagation constants
Holder–SUT	s11, s12, s21, s22	Calibrated S-parameters of the Waveguide Sample Holder loaded with the SUT
SUT	s11, s12, s21, s22	Calibrated S-parameters of the SUT
SUT	full-wave_p1, full-wave_p2	Number of full-waves propagating through the SUT characterized using the Port 1 (or Port 2) return-loss measurement

SUT	spatial-gam_p1, spatial-gam_p2	Spatial propagation constant in the SUT characterized using the Port 1 (or Port 2) return-loss measurement
SUT	epsilon_p1, epsilon_p2	Relative permittivity characterized using the Port 1 (or Port 2) return-loss measurement
SUT	mu_1, mu_p2	Relative permeability characterized using the Port 1 (or Port 2) return-loss measurement

7.2. Selecting the Display Format

The **Format** drop-down list specifies how the selected parameter is displayed in the plotting area.

Table 10. Plot Display Formats

Format	**Description**
Real	Real part, Re{·}
Imaginary	Imaginary part, Im{·}
Linear Magnitude	Magnitude, $\lvert\cdot\rvert = \sqrt{(Re^2 + Im^2)}$
dB Magnitude	Magnitude in decibels, $20\cdot\log_{10}(Mag)$
Phase (deg)	Phase angle, Arg(·), in degrees

8. Runing EM Characterization and Generating Graphs

After the required measurement data have been imported and the analysis parameters and plotting options have been configured, click **Characterize** to perform electromagnetic characterization.

WSA processes the input measurement data, computes the selected electromagnetic parameters, and updates the plotting area with the characterization results.
During the analysis, the **Operation Status Bar** (region ⑦ in Fig. 4) displays the current processing status and reports any warnings or errors detected in the measurement data.

To save the displayed graph, click the **Save Figure** button in the **Plot Navigation Toolbar** (region ⑤ in Fig. 4). The current plot is saved as an image file.

9. Generating Graphs and Exporting Results

To export the numerical data corresponding to the displayed graph, click **Export Data** in the **Main Toolbar** (region ④ in Fig. 4).

10. Resetting the Workspace

Click the **Reset** button to clear the currently loaded measurement data and displayed results. After resetting, WSA returns to the initial state and is ready for a new characterization workflow.

11. Troubleshooting

This section provides solutions for common issues encountered during measurement data import, electromagnetic (EM) characterization, and result visualization.

11.1. File Import and Configuration Issues

- Port Mismatch Error
  - Possible causes:
    - An .s2p file does not contain exactly two ports.
    - An .s1p file does not contain exactly one port.
  - Solutions:
    - Verify the port configuration of the Touchstone files.
    - Ensure that the correct file type is loaded for each measurement configuration.

- Frequency Points Mismatch Warning
  - Possible causes:
    - Imported measurement files use different frequency points or frequency ranges.
  - Solutions:
    - Ensure that all measurement files have identical frequency points.
    - Re-save Touchstone files using the same frequency sweep settings.

- Plot not Updating
  - Possible causes:
    - Required measurement files have not been completely loaded.
    - No output parameter has been selected.
    - Required analysis parameters are missing.

- Solutions:
  - Verify that all five (5) required measurement datasets have been loaded successfully using the **Workflow Status Bar** (region ① in Fig. 4).
  - Select at least one output parameter from the Select Parameter(s) drop-down list.
  - Check the values entered in the **Test Setup Panel** (region ② in Fig. 4).

11.2. Measurement Quality Issues

Some warnings indicate limitations in the measurement quality rather than software errors. These issues are typically related to VNA calibration, hardware connections, or measurement setup.

Table 11. Measurement Quality Diagnostics and Recommended Actions

Warning	Possible Cause	Recommended Action
High systematic error	Inaccurate VNA calibration or measurement setup	Verify the VNA calibration and measurement setup before repeating the measurement.
Large gain ripple	Poor VNA measurement quality	Verify the VNA performance or repeat the measurement using a higher-quality VNA.
Unexpected electromagnetic properties	Incorrect sample dimensions or insufficient measurement quality	Verify sample parameters and repeat measurement if necessary

11.3. Tips and Best Practices

- Verify that all measurement files have consistent frequency ranges and frequency points before loading.
- Use consistent naming conventions for measurement files.
- Enter physical dimensions accurately to ensure reliable electromagnetic characterization.
- Minimize systematic residual errors by maintaining good VNA calibration and repeatable hardware connections.

12. References

[1]. A. M. Nicolson and G. F. Ross, "Measurement of the Intrinsic Properties of Materials by Time-Domain Techniques," *IEEE Transactions on Instrumentation and Measurement*, vol. IM-19, no. 4, pp. 377–382, Nov. 1970.

[2]. W. B. Weir, "Automatic Measurement of Complex Dielectric Constant and Permeability at Microwave Frequencies," *Proceedings of the IEEE*, vol. 62, no. 1, pp. 33–36, Jan. 1974.

[3]. F. Costa, A. Monorchio, and G. Manara, "Electromagnetic Characterisation of Materials by Using Transmission/Reflection (T/R) Devices," *Electronics*, vol. 6, no. 4, Art. 95, 2017.

13. Contact Us

For product information, software updates, and technical support, please visit:

Website: https://www.rthetaphi.com

Email: help@rthetaphi.com