PowTrans Help

User's Handbook

S-TEAM

Jul-2025

Contents

Introduction

Welcome to PowTrans – Power Transmission Calculator Help!

The program allows you:

- To simulate power flows between a signal source (e.g., magnetron) and a load (working space).
- To estimate measurement errors when measuring powers and load reflection coefficient.

For theoretical background, you are invited to break your head by studying the document

Power Transmission in Microwave Systems

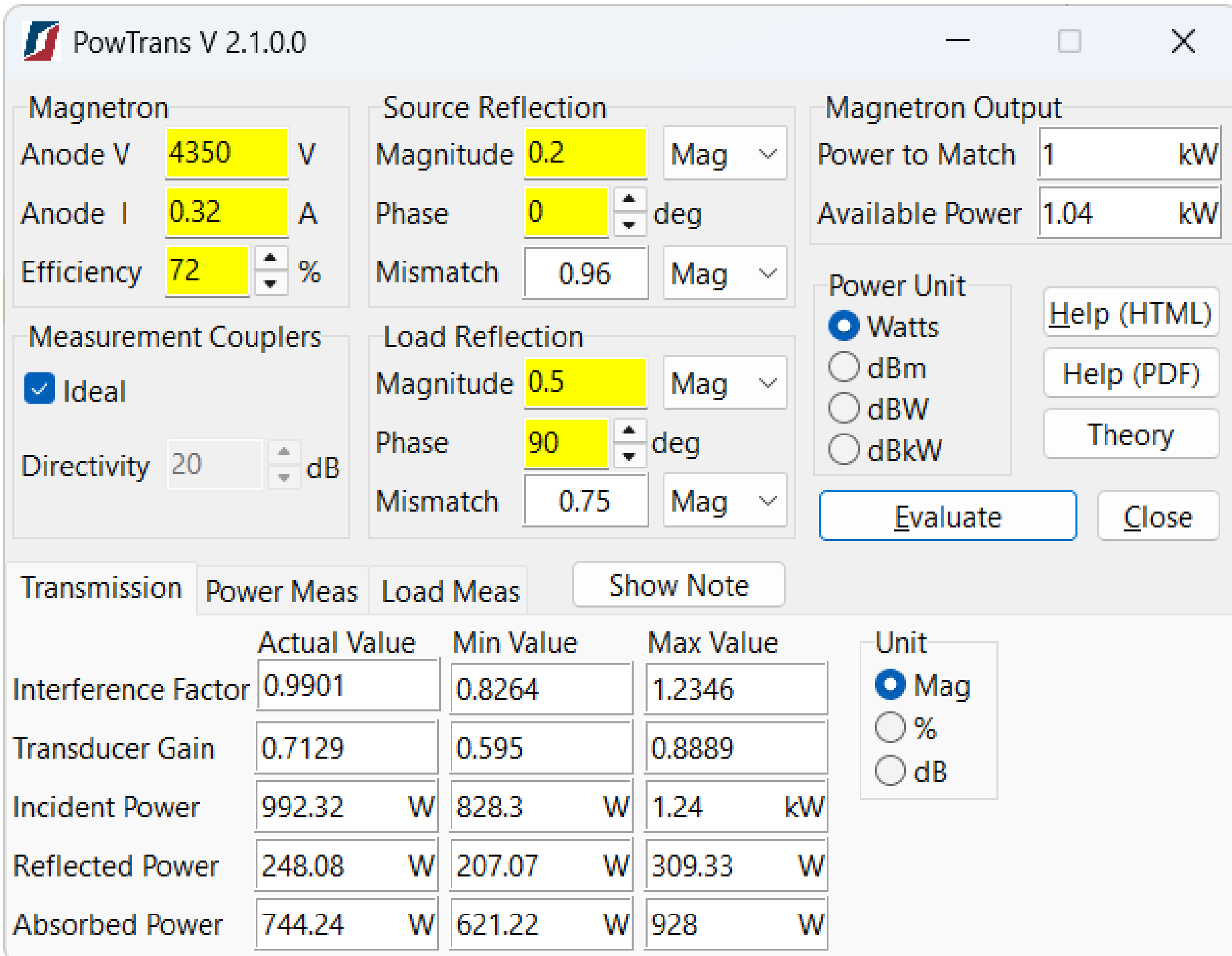
perpetrated by Vladimir Bilik.

How to Use the Program

The program window (Fig. 1 on the next page) contains:

- Yellow edit boxes.
- White text boxes.
- Up-down controls for step-wise changing of reflection coefficient phase and magnetron efficiency.
- Pull-down selection boxes.
- Buttons, including radio buttons.
- Three-page tabbed container at the bottom of the window.

Fig. 1. The PowTrans window.



The yellow edit boxes, pull-down selection boxes, up-down controls and radio buttons are used for entering user input data. There are three groups of input data defining the system: **Magnetron**, **Load Reflection**, and **Measurement Couplers**.

The white text boxes display computed results. The final results are logically grouped in the pages of the tabbed container at the bottom.

Using the program is simple:

- In the tabbed container at the bottom, select the group of results you wish to observe (**Transmission**, **Power Measurement**, or **Load Measurement**).
- Enter one or more input values. You can do it as follows:
  - Edit a yellow edit box.
  - Click an up-down control.
  - Click a radio button.
- Click the Evaluate button to compute results. In most cases, clicking this button is unnecessary because the computation takes place automatically after changing an input.

The source or load reflection coefficient magnitude can be entered

- as a linear value (values 0 to 1),
- in decibels (values ≤ 0),
- as a Voltage Standing Wave Ratio VSWR (values ≥ 1).

To enter a reflection coefficient in a desired format in the **Source Reflection** or **Load Reflection** group:

- Select the desired format in a pull-down selection box on the right of the **Magnitude**.
- Type in the value into the associated edit box.

Note: Changing the format recalculates the current reflection coefficient value to the new format, so this procedure may also serve as a tool to convert linear reflection coefficient to decibels, VSWR, or vice versa.

Buttons

This topic describes the roles of some of the program buttons.

Evaluate

Clicking the Evaluate button:

- Computes the results based on the contents of the inputs, i.e., yellow edit boxes, up-down controls and radio buttons.
- Fills the white text boxes with the computed results.

Note that this also happens when you:

- Type a new value in an edit box and exit the box by clicking another control.
- Click an up-down control.
- Click a radio button.

Help

Clicking the Help button opens this Help (what a surprise!).

Close

Clicking the Close button terminates the program execution.

Read Note

Clicking the Read Note displays brief information about how the values in the bottom tabbed container were obtained.

Radio Buttons

The radio buttons do not affect the input data but only control the format of the displayed results. There are four groups of radio buttons: the **Power Unit** radio-box in the main window and one radio-box on each page of the bottom tabbed container.

Power Unit Radio-Box

Clicking a button in the **Power Unit** radio-box affects the following quantities:

- In the main window: Power values in the **Magnetron Output** group.
- In the **Transmission** tabsheet: All values in the **Incident Power**, **Reflected Power**, and **Absorbed Power** rows.
- In the **Power Meas** tabsheet:
  - The values in the **True Value** column.
  - If the **Error Unit** radio-box is set to **= P Unit**, all the remaining values are also affected.

Unit Radio-Box on Transmission Page

The **Unit** radio-box in the **Transmission** tabsheet affects the values in the **Interference Factor** and **Transducer Gain** rows.

Error Unit Radio-Box on Power Meas Page

If the **Error Unit** radio-box is set to **= P Unit**, then format of ***all*** displayed powers is equal to that selected in the **Power Unit** radio-box of the main window.

Otherwise, only the **True Value** column format is determined by **Power Unit** radio-box; the format of the remaining (**Min** and **Max**) displays is defined by the **Error Unit** radio-box.

Magnetron

The magnetron is not a simple linear signal source. Its parameters (efficiency, internal impedance, generated power and frequency, etc.) are interrelated and depend on many factors, such as anode voltage, applied DC magnetic field intensity (or electromagnet current), filament current, and even microwave load impedance.

Nevertheless, for the purpose of this program, the magnetron is simulated as a conventional linear signal source, defined by the following parameters:

- Anode voltage V_a
- Anode current I_a
- Efficiency, relating the input DC power to the RF power delivered to a matched load (see *Power to Match* below).
- Internal impedance, expressed in terms of source reflection coefficient magnitude and phase. For a system with a circulator, the source reflection coefficient Γ_S is the one that would be seen when looking *into* the magnetron through the circulator.

The following program controls pertain to the magnetron:

Anode V

The **Anode V** edit box is used for entering the magnetron DC anode voltage in volts.

Anode I

The **Anode I** edit box is used for entering the magnetron DC anode current in amperes.

Efficiency

The **Efficiency** edit box is used for entering the magnetron efficiency as a percentage. The value can also be incremented by the attached up-down control. Efficiency relates the DC input power to the RF power delivered to a matched load.

The controls contained in the Source Reflection box are related to the magnetron reflection coefficient (or that of a magnetron-circulator combination):

Magnitude

The **Magnitude** edit box is used for defining the source reflection coefficient magnitude $|\Gamma_S|$. Depending on the setting of the attached pull-down selection box (Mag, dB, SWR), the value can be typed in as follows:

Mag Linear reflection coefficient magnitude (0 to 1)

dB Reflection coefficient magnitude in dB (negative of return loss)

SWR Voltage Standing Wave Ratio VSWR of the source (values ≥ 1)

Note that changing the format recalculates the current reflection coefficient to the new format, so this can also serve as a tool for converting reflection coefficient to return loss or to VSWR, or vice versa.

Phase

The **Phase** edit box is used for defining the source reflection coefficient phase angle in degrees (-180 to 180). The value can also be stepped by the attached up-down control.

Mismatch

The **Mismatch** text box displays the computed source *mismatch factor* m_S. The source mismatch factor is a figure representing the fraction of the power of an external wave incident on the source that is absorbed within the source. It is computed as

$$m_s = 1 - \left|\Gamma_S\right|^2$$

where Γ_S is the source reflection coefficient.

The mismatch factor can be displayed as a linear dimensionless quantity, in dB, or in percent. To change the format, select it from the attached pull-down selection box.

Two characteristic powers that a source can deliver are displayed in the following text boxes:

Power to Match

Power to Match box displays the power that a source would deliver to a matched load (i.e., a load with zero reflection coefficient). Magnetron efficiency is related to this power, hence Power to Match is computed as the product of the DC input power and magnetron's efficiency.

Available Power

Available Power box displays the maximum power a linear source is capable of delivering when varying its load impedance (load reflection coefficient). It is the power absorbed in the load with the reflection coefficient Γ_L equal to the complex conjugate of the source reflection coefficient Γ_S:

$$\Gamma_L = \Gamma_S^*$$

The available power (P_{av}) and the power delivered to a matched load (P_m) are related by source mismatch factor (m_S) as

$$P_m = P_{av} m_s$$

However, there is a catch when using the available power in connection with magnetrons (and, generally, high-power generators).

To achieve high magnetron efficiency, its internal reflection coefficient must be high (otherwise a large portion of the generated power would convert to heat within the magnetron itself). Magnetrons therefore act as very mismatched signal sources.

As a result of this excessive source mismatch, the available power turns out to be much higher than the power delivered to a load, even higher than the input DC power! The term available power therefore loses its physical meaning and becomes only a fictitious quantity: an extrapolation, useful only for mathematical analysis. Therefore, do not worry about the energy conservation law violation.

In order that high-power magnetrons appear matched, they are combined with circulators. For an ideal circulator, this has the following consequences:

- The magnetron always looks into a nearly-matched load. This is the load magnetrons have been optimized for.
- The power that the magnetron delivers is always equal to the power deliverable to a matched load (regardless of actual load reflection coefficient).
- Looking from outside, the magnetron-circulator combination appears well-matched ($\Gamma_S \approx 0$).
- Any power reflected from the actual load is fully absorbed in the circulator (diverted to an auxiliary load).

Note: In practice, however, no circulator is *perfectly* matched, and therefore variations of the incident power with load will be experienced. Depending on conditions, it may be even ±10% or more.

Load Reflection

The load (working space, applicator) is represented by its reflection coefficient Γ_L. The load is assumed to be connected directly to the magnetron, and therefore, it implicitly includes any transmission line interconnecting the actual load and the magnetron.

The load reflection coefficient can be defined by the controls contained in the **Load Reflection** group:

Magnitude

The **Magnitude** edit box is used for defining the load reflection coefficient magnitude. Depending on the setting of the attached pull-down selection box (Mag, dB, SWR), the value can be typed in as follows:

Mag Linear reflection coefficient magnitude (0 to 1)

dB Reflection coefficient magnitude in dB (negative of return loss)

SWR Voltage Standing Wave Ratio VSWR (values ≥ 1)

Note that changing the format recalculates the current reflection coefficient to the new format, so this can also serve as a tool for converting reflection coefficient to return loss or to VSWR, or vice versa.

Phase

The **Phase** edit box is used for defining the load reflection coefficient phase angle in degrees (-180 to 180). The value can also be stepped by the attached up-down control.

Varying the phase may reflect varying the signal frequency or the length of the interconnecting waveguide.

Mismatch

The **Mismatch** text box displays the computed load *mismatch factor* m_L. The load mismatch factor is a figure representing the fraction of the incident power that is absorbed in the load. It is computed as

$$m_L = 1 - |\Gamma_L|^2$$

where Γ_L is the load reflection coefficient.

The mismatch factor can be displayed as a linear dimensionless quantity, in dB, or in percent. To change the format, select it from the attached pull-down selection box.

Measurement Couplers

The powers of waves travelling in a waveguide in each direction can be sampled by means of *directional couplers*. From the coupled powers (measured, e.g., by a standard power meter), quantities of interest can be computed. These are, in particular:

- Powers carried by the waves incident on and reflected from the load.
- Net power absorbed in the load.
- Magnitude of the load reflection coefficient.

An ideal coupler:

- Responds only to a wave travelling in one direction.
- Does not affect the sampled field (does not cause additional reflections).

If a coupler is not ideal, it introduces systematic errors in the computed results. The main factor affecting the accuracy with which a load reflection coefficient can be measured is the coupler’s *directivity*, usually expressed in dB. An ideal coupler has infinite directivity. On the other extreme, when a “coupler” responds equally to waves travelling in both directions, its directivity is 0 dB.

Two couplers are needed to simultaneously sample the waves travelling in both directions. For the purpose of this program, these two couplers are supposed to be:

- Identical.
- Causing no reflections.
- Characterized only by their directivity.

The **Measurement Couplers** group box enables the user to select the coupler directivity or “make” the coupler ideal. The coupler settings affect only the results displayed in the **Power Meas** and **Load Meas** pages of the bottom tabbed container.

Ideal

Check this box to consider the coupler to be ideal. Uncheck it to consider the coupler having a finite directivity.

Directivity

Enter a nonideal coupler’s directivity in dB (or step it by the attached up-down control). The directivity controls are disabled for an ideal coupler.

Results and Uncertainties

The measurement uncertainties of the arrangement simulated by the ***PowTrans*** originates from two sources:

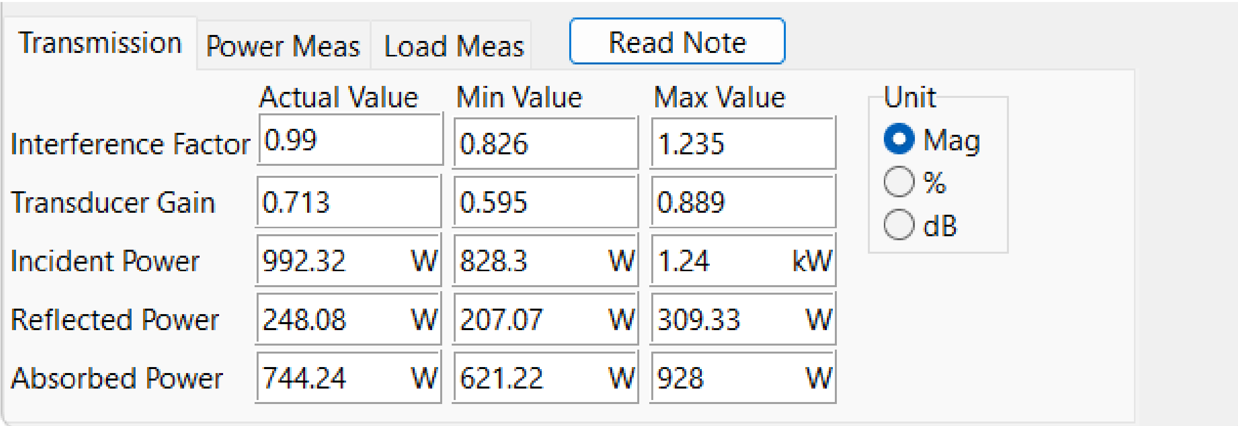
1. The source and load mismatches.
2. Finite directivity of the directional couplers used for sampling the level of the incident and reflected powers in the main transmission line.

The simulated results and uncertainties are displayed in various forms in the tabbed container at the bottom of the main program window. The data are logically grouped into three pages: **Transmission**, **Power Meas**, and **Load Meas**.

Transmission Tabsheet

The **Transmission** tabsheet (Fig. 2 on the next page) groups the quantities related to power transmission in the system, and the load-related powers.

Fig. 2. Transmission tabsheet.



Interference Factor

In the source-to-load power transmission formula (transducer gain), the interference factor accounts for multiple reflections between the source and the load.

If neither the source nor the load are perfectly matched, a wave travelling between them theoretically experiences an infinite number of re-reflections. The resulting wave propagating in one direction can be thought of as consisting of the primary wave and an infinite number of additional contributions with ever decreasing amplitudes. The magnitude of the resulting wave, and hence the transmitted power, both depend on the phases of the individual contributions. These phases, in turn, depend on:

- The source and load reflection coefficients.
- The electric length of the interconnecting waveguide.

This resonator-like effect, modifying the source-to-load power transmission, is expressed mathematically in terms of the *interference factor*.

If at least one of the transmission line ends is matched, the infinite series does not exist since the matched end completely absorbs the wave incident upon it, thus prohibiting the buildup of the series. In such case, the interference factor is unity.

The interference factor and its bounds for varying phases are displayed in the **Interference Factor** row of the **Transmission** page. The factor can be displayed as a linear magnitude (dimensionless), in dB, or in percent. To change the format, click a button in the **Unit** radiobox.

For background theory, please refer to the document suggested in the Introduction.

Actual Value, Min Value, Max Value

The **Actual Value** shows the actual interference factor for the current phases of the source and load reflection coefficients. (The phases also implicitly incorporate the phase shift caused by the interconnecting waveguide.)

If the phases were unknown (which is a common case in practice), we can only determine the limits between which the interference factor must lie given the source and load reflection coefficient magnitudes. These limits are the **Min Value** and **Max Value**. The **Max Value** is obtained by assuming that all higher-order reflection contributions are in-phase with the primary wave; the **Min Value** assumes the terms shifted by 180 degrees relative to the primary wave.

These values can be displayed as linear magnitudes (dimensionless), in dB, or in percent. To change the format, click a button in the **Unit** radio-box.

The bounds of the interference factor impose bounds also on the other quantities displayed on the **Transmission** page.

Brief information about the origin of these bounds can be invoked by clicking the Read Note button.

Transducer Gain

The transducer gain is the basic quantity describing the power transfer between a signal source and load. By definition, it is the ratio of the power absorbed in the load to source available power. It can be computed as the product of the source mismatch factor, the load mismatch factor, and the interference factor.

Transducer gain is displayed in the **Transducer Gain** text box. It can be displayed as a linear magnitude (dimensionless), in dB, or in percent. To change the format, click a button in the **Unit** radio-box.

Incident Power

The **Incident Power** row displays the power carried by the wave incident on the load. Also shown are its bounds, imposed by the variation of the interference factor.

The incident power can be computed as the product of the source available power, source mismatch factor, and interference factor.

Can the incident power exceed the magnetron power?

Absolutely! Please be aware that if both the source and the load are mismatched, the incident power may be greater than the "magnetron power" specified in the magnetron datasheets (which is the "power to match"). In this sense, the incident power is only a measure of the local field build-up due to the resonator-like effect mentioned above.

This effect may lead to an apparent paradox when you sample only the incident power (e.g., by a single coupler) and think of it as a measure of the power delivered to the load. You can easily simulate the situation using the ***PowTrans*** calculator.

The "real quantity" is the net power absorbed in the load (see below).

Reflected Power

The **Reflected Power** row displays the power carried by the wave reflected from the load. It also shows its bounds, imposed by the variation of the interference factor.

The ratio of the reflected to incident power is equal to the squared magnitude of the load reflection coefficient.

Absorbed Power

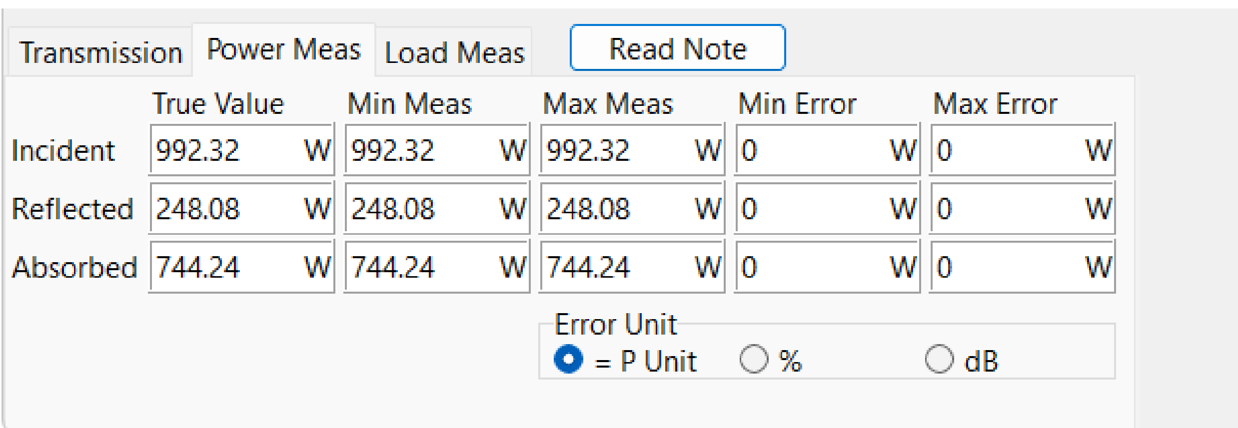
The **Absorbed Power** text box displays the net power absorbed in the load, which is the difference between the incident power and the reflected power. This, unlike merely the incident power, is the correct quantity for the evaluation of the power delivered to your process.

We need two couplers (or a device capable of measuring the incident power and the load reflection coefficient, such as a Homer Analyzer or Autotuner) to obtain the absorbed power.

Power Meas Tabsheet

The **Power Meas** tabsheet (Fig. 3 below) contains the simulated measurement results for load-related powers as obtained by using either ideal or non-ideal couplers. The displayed measurement uncertainties are solely due to the finite directivity of the couplers. Both couplers in consideration (one for sensing the incident power, one for the reflected power) are assumed to be identical; their parameters are defined in the Measurement Couplers group box.

Fig. 3. Power Meas tabsheet.



True Value

The values displayed in the **True Value** column are copies of those shown in the **Actual Value** column of the **Transmission** page. They would be measured if the couplers were ideal.

Min Meas, Max Meas

The values displayed in the **Min Meas** and **Max Meas** columns show the measurement uncertainty limits of a given quantity arising from a finite directivity of the couplers.

Min Error, Max Error

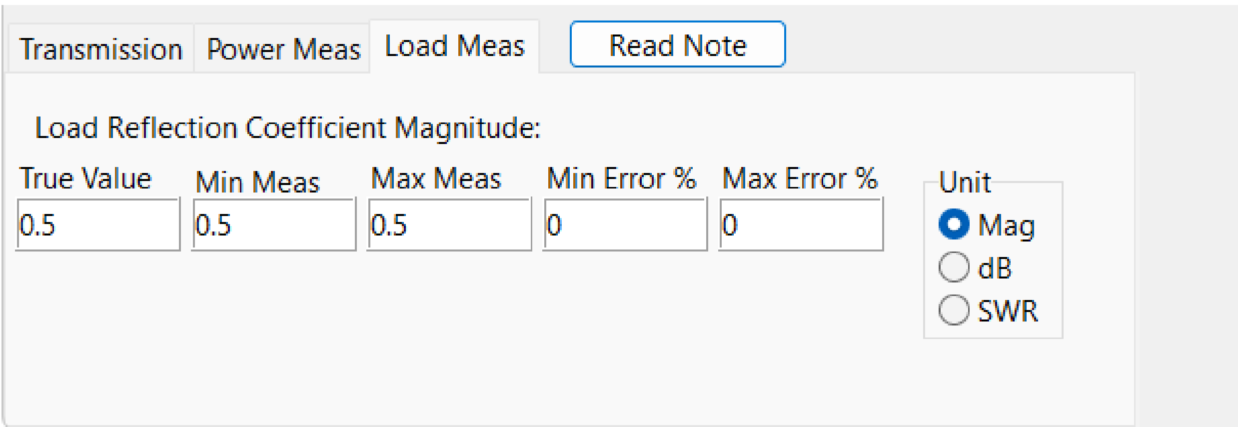
The values displayed in the **Min Error**, **Max Error** columns are bounds on the measurement errors, i.e., the deviations of **Min Meas** and **Max Meas** from **True Value**.

The values can be displayed in power units, as percentage, or in dB. To change the format, click a radio button in the **Error Unit** radio-box.

Load Meas Tabsheet

The **Load Meas** tabsheet (Fig. 4 below) contains the simulated results for the load reflection coefficient magnitude measurement as obtained by using either ideal or non-ideal couplers. The displayed uncertainties are solely due to the finite directivity of the couplers. Both couplers in consideration (one for sensing the incident power, one for the reflected power) are assumed identical; their parameters are defined in the Measurement Couplers group box.

Fig. 4. Load Meas tabsheet.



True Value

The **True Value** is the copy of the actual load reflection coefficient magnitude from the **Magnitude** edit box in the Load Reflection group box. This value would be measured if the couplers were ideal.

Both the true value and the uncertainty bounds can be displayed as a linear magnitude (Mag), a value in dB, or as VSWR. To change the format, click a button in the **Unit** radio-box.

Min Meas, Max Meas

The **Min Meas** and **Max Meas** boxes show the uncertainty bounds of the measured reflection coefficient. The uncertainty is caused by finite directivity of the couplers.

Min Error %, Max Error %

The values displayed in the **Min Error %**, **Max Error %** boxes are deviations of the **Min Meas** and **Max Meas** from **True Value**. Since the computation of such deviations for the dB and VSWR format has little meaning, the values are only shown for the Mag format, and are multiplied by 100.