1603 St-Regis
D.D.O, Quebec H9B 3H7, Canada
Tel 514-684-4554 Fax 514-684-8581
E-mail: info@ focus-microwaves.com
Website: http://www.focus-microwaves.com

Application Note 57

*i*Tuners for Production Testing

Production testing of microwave devices and assemblies has traditionally been performed under matched conditions, and most of the specifications had been defined for a quite narrow VSWR range, since isolators were often used to embed the assemblies.
Today, specifications have to be verified for a much wider VSWR range and test stations have to be retrofitted to allow ongoing testing under variable 'load' (and sometimes also 'source') conditions.

Mechanical microwave slide screw tuners are well suited for such application, since they offer comprehensive and solid performance over a wide VSWR tuning range and a wide frequency band. Mechanical tuners exhibit very low loss at the low VSWR setting, thus the test station can be used to perform under 50Ω conditions, as before incorporating the tuners. Tuner loss increases with increasing VSWR and has to be known (calibrated) in order to de-embed the test results to the device reference plane. Manual tuners allow coarse adjustment of the VSWR, but require permanent manual operator interaction and the actual tuner loss is unknown.

Figure 1: 0.8-18GHz microwave iTuner

Computer controlled electro-mechanical microwave tuners have been available since almost 20 years, but generally require an external controller and application software to set the tuner and calculate VSWR and loss. In 2003 Focus Microwaves has introduced its ***iTuner*** product line.
The iTuner is a traditional electro-mechanical slide screw tuner but includes sophisticated control electronics, which allow it to become a self-contained and fully calibrated test instrument, that is ideally suited for integration into an existing or new test station. A powerful micro-controller inside the tuner housing is used to administer

[1] *A simple wideband tuner requires 2 motors, an ultra wideband tuner 3 motors and a biharmonic (fo, 2fo, 3fo) tuner requires 4 motors.*

ASCII format communication via an industry standard TCP/IP interface, to control up to 6 stepper motors[(1)], and to perform mathematical operations in order to determine the stepper motor positions required for user specified values of VSWR and impedances at the device reference plane.

Calibration data for hundreds of frequency points can be stored on a removable on-board flash memory. Interpolation routines, which are part of the tuner firmware, allow it to calculate VSWR (magnitude and phase) and full 2-port S-Parameter of the tuner for any physical position of the tuning probes (not only the discrete calibration positions). Figure 2 shows a typical setup.

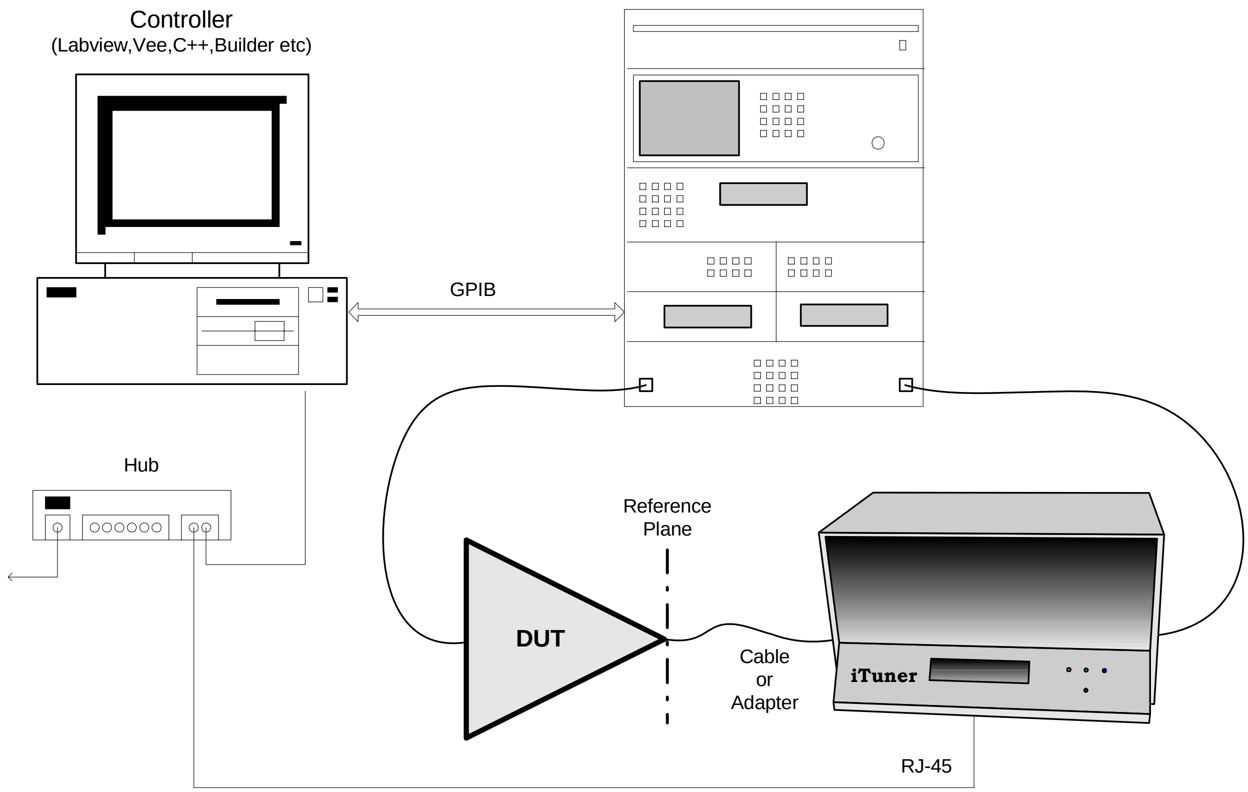


Figure 2: Typical Test Setup

The *iTuner* is inserted into the setup immediately after the DUT. When the tuner is initialized it has very low loss and behaves like an ordinary transmission line, thus only the phase of the test signal going to the test equipment is modified. The additional loss, caused by the tuner, is taken into account when performing the system calibration. Further, mechanical slide screw tuners, such as the *iTuners*, are low-pass and very wide-band and do not interfere abnormally with out-of-band signals, such as intermodulation products and spurious oscillations that may have to be detected and measured.

Controlling the *iTuner*

The *iTuner* is controlled via a TCP/IP connection to the host computer. The TCP/IP interface is compatible with almost any operating system (Windows, Unix, Linux, Mac) and programming language (MS C++, Borland Builder, Delphi, LabView, Agilent VEE).
No additional hardware beyond a network card in the controlling computer and a RJ-45 network cable is required to operate the tuner. Each tuner has its own user-settable IP address, thus multiple tuners can be controlled simultaneously by using an Ethernet hub.

Commands are sent to the iTuner in ASCII string format, and the *iTuner* replies with a result string to acknowledge reception. The result string contains an error message if validation and syntax checking of the command line has failed.

The following table shows a partial list of the tuner control and 'tuning' commands:

Command	**Description**
INIT	initialize tuner
POS axis pos	move axis to specified position
POS? axis	query position of axis
DIR	display directory of calibration files
LOADCAL index	load tuner calibration data from flash memory, 'index' defines frequency
FREQ?	query active calibration frequency
TUNETO mag [phase]	tune to specified Γ (DUT reference plane)
TUNEVSWR mag [phase]	tune to specified VSWR (DUT reference plane)
GAMMA?	query current Γ (DUT reference plane)
SPAR?	query current 2-port S-parameter of Tuner
LOSS?	query the current loss of Tuner
STATUS?	query status of the tuner [bit masked status of all motors]

Several administrative commands are available:

- Set and display current configuration (limits, backlash)
- Set IP address
- Maintain Calibration Data File System (Upload, Erase, Compact, Dir)
- Adjust motor speed
- List all commands and their parameters (HELP)

Tuning and Testing in DUT Reference plane

Specifications and test conditions are generally defined in the DUT input or output reference plane, and the test setup is calibrated to allow correction of the raw test results measured with standard microwave test instruments, such as a power meter (see figure 3). Traditional calibrations assume a fixed signal path with well defined loss, but tuning the signal path will void the calibration since the losses change when tuning to different VSWR values. Adapters and cables are often used to connect the DUT to the test setup, adding additional loss.
Although the iTuner is fully calibrated with respect to its input and output port, the VSWR reference plane for testing is located at the output of the DUT. The iTuner firmware has been extended to allow such reference plane shifting. Further, a non-perfect load impedance Γ_{LOAD} , as shown in figure 3, is also taken into account when adjusting the VSWR value in the DUT reference plane.

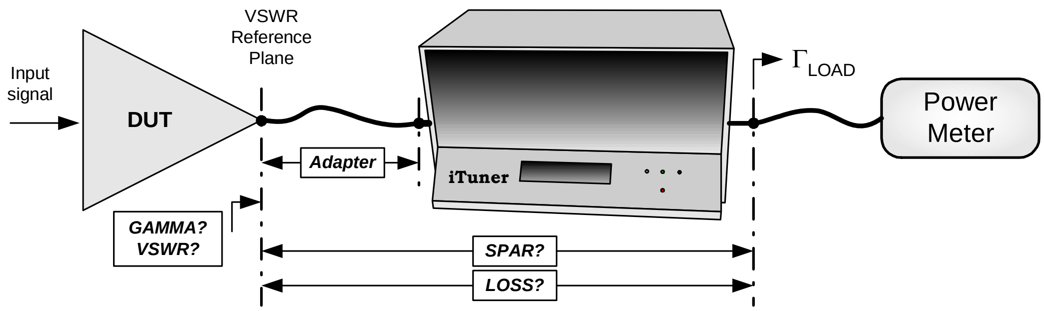


Figure 3: Tuning in DUT Reference plane

Two commands have been added to the iTuner firmware to allow reference plane shifting:

Command	Description
ADAPTER s11,s12..	defines S-parameter of adapter/cable between DUT and tuner
TERM mag phase	defines load (Γ_{LOAD}) connected to tuner Γ_{LOAD}

Once the adapter and/or termination are defined, all subsequent tuning command are referenced to the DUT plane, as well as the query commands shown below.

Command	Description
GAMMA?	query current Γ (DUT reference plane)
SPAR?	query current 2-port S-parameter of Adapter **and** Tuner
LOSS?	query the current loss of Adapter **and** Tuner
VSWR?	query current VSWR (DUT reference plane)

By default, both adapter and termination are assumed ideal (S_{11}=S_{22}=0, S_{12}=S_{21}=1, Γ_{LOAD} =0).

The tuner losses depend on the actual probe position, and are calculated internally using the power gain definition:

$$Loss\ (Tuner\ ) = \frac{1}{\left|S_{21}\right|^2} * \frac{\left|1 - \Gamma_{LOAD} * S_{22}\right|^2 * (1 - \left|\Gamma_1\right|^2)}{1 - \left|\Gamma_{LOAD}\right|^2}$$

where

Sij = s-parameter of tuner & adapter

and

$$\Gamma_1 = S_{11} + \frac{S_{12} * S_{21} * \Gamma_{LOAD}}{1 - S_{22} * \Gamma_{LOAD}}$$

In case of $\Gamma_{LOAD} = 0$, i.e. the network connected to the output of the tuner is well matched, the loss calculation can be simplified:

$$Loss\ (Tuner\ ) = \frac{1 - \left|S_{11}\right|^2}{\left|S_{21}\right|^2} \qquad \text{for } \Gamma_{LOAD} = 0$$

When using the tuner as part of the input network, the definition of available gain is used for the loss calculation.

Constant VSWR testing

A special group of commands are designed to make constant VSWR testing straightforward while taking full advantage of the *iTuners'* tuning and de-embedding capabilities. Although the tuner itself is well matched in its initialized state, adding adapters and cables between the tuner and the DUT results in a VSWR shift (Point A in figure 3). Moving the horizontal axis of the tuner while keeping the vertical axis at a fixed position would result in a non-constant VSWR in the DUT reference plane because of this mismatch. (dashed circle in figure 3).

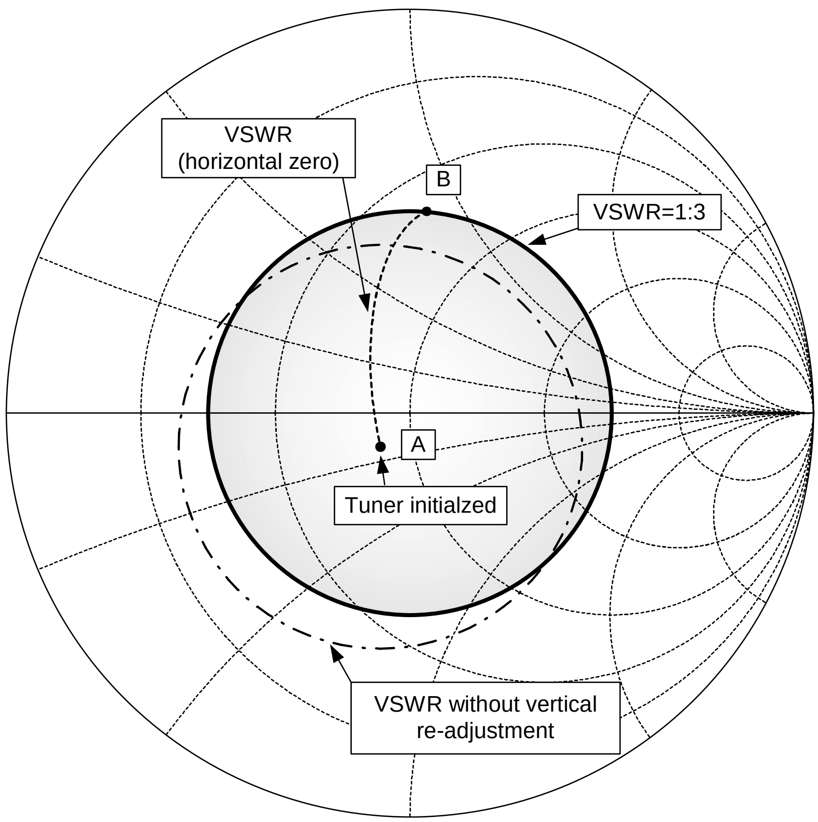


Figure 3: Constant VSWR testing

The *VSWR* family of commands of the *iTuner* automatically re-adjust the vertical probe position to keep the VSWR seen by the DUT constant during phase sweep.

Constant VSWR testing generally requires a full 360^o phase sweep, thus a λ/2 horizontal movement of the probe inside the tuner. The 'starting phase' is not important. The VSWR tuning routines always start testing at the 'horizontal zero' position for several reasons:

- Maximum achievable VSWR is always highest when the probe is positioned as close as possible to the DUT.
- A complete 360^o phase sweep can be executed without having to perform a time consuming 'return to horizontal zero' operation during the test that may be required when the tuner reaches its physical limit or enters a non-calibrated section of its horizontal axis.

The following summarizes the available VSWR based commands and their operation:

Command	Description
VSWR_AUTO *mag*	Initializes horizontal axis to zero, adjust vertical axis to obtain specified VSWR in DUT reference plane, and then performs a full 360^o phase sweep with maximum horizontal motor speed while continuously adjusting vertical position to keep VSWR constant. Initializes all axis after phase sweep
VSWR_INIT *mag*	Initializes horizontal axis to zero, adjust vertical axis to obtain specified VSWR in DUT reference plane (Point B in figure 3)
VSWR_INC *degrees*	Used after VSWR_INIT to increment phase by the specified amount. VSWR is kept constant while adjusting phase
VSWR_DO360	Used after VSWR_INIT to performs a full 360^o phase sweep with maximum horizontal motor speed while continuously adjusting vertical position to keep VSWR constant.

Application example 1: Amplifier Output Power Variation Test (VSWR < 1:3)

Lets assume that specifications are requiring a minimum delivered output power for any VSWR of up to 1:3. A power meter is used to measure the output power, as shown in figure 4.

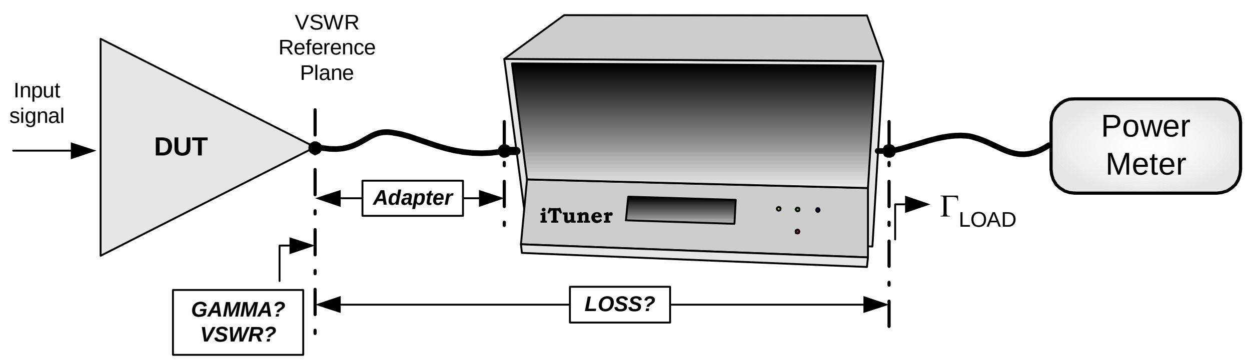
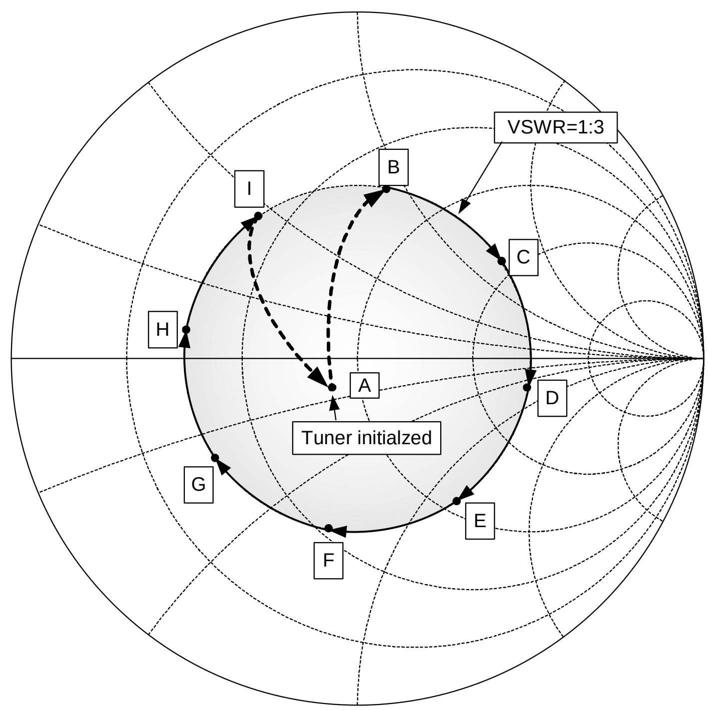


Figure 4: Output Power Variation Test Setup

We have measured the S-parameter of the adapter/cable inserted between the device and the DUT, as well as the Γ_{LOAD} seen by the tuner at its output port.
Readings taken from the power meter have to be corrected for the losses of the output network, including the tuner. The Adapter/Tuner loss is calculated internally and can be queried by sending the ***LOSS?*** command. The DUT ouput power can then be calculated as:

$$P_{DUT}[dB] = P_{MEAS}[dB] + Loss[dB]$$

We decide to verify the output power at 8 points (45^{o} phase increments) on the constant VSWR circle having a magnitude of 3 (see figure 5).
The test procedure starts at point A, with the tuner at its initialized position. A power measurement is taken to verify that the device is operating correctly.
Next, we issue a VSWR_INIT command to move to point B, and determine the DUT output power by taking power meter reading and calculating the output network loss using the actual tuner s-parameter.
Using the VSWR_INC command, we step through points C to I and repeat the power measurement and loss correction.
After testing at point I, we first reduce the VSWR by positioning the vertical axis to zero. Finally we return to point A using the INIT command. Note that the horizontal axis has to move back by $\lambda/2$.

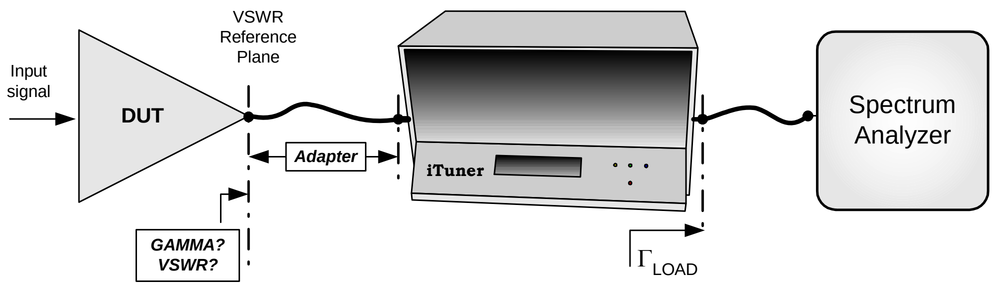


The following table shows a commented command sequence of the complete test procedure:

Command	**Description**
INIT	initializes tuner (all axis)
LOADCAL 2	load tuner calibration
ADAPTER .1 123 .95 15 .95 ….	define Adapter
TERM .2 45	define termination Γ_{LOAD}
LOSS?	get current loss (adapter and tuner)
take power reading, calculate total output network loss, to verify device operation	
VSWR_INIT 3	moves to point B
GAMMA? (or VSWR?)	verify actual VSWR
LOSS?	get current s-parameter
take power reading and calculate total output network loss to determine DUT output power	
VSWR_INC 45	moves to point C
execute Output Power Test	
VSWR_INC 45	Moves to point D…….I
………..	
………..	
POS 2 0	Set vertical axis to zero position (low VSWR)
INIT	initialize tuner
verify test results	

Application example 2: Amplifier Stability Test (VSWR < 1:5)

Amplifier Stability is easily verified with an iTuner. A CW or modulated signal source is used to generate the input signal. The output signal is monitored with a spectrum analyzer to detect undesired signal outside the operation band. The spectrum analyzer is set to fast continuous sweep and peak-hold mode.

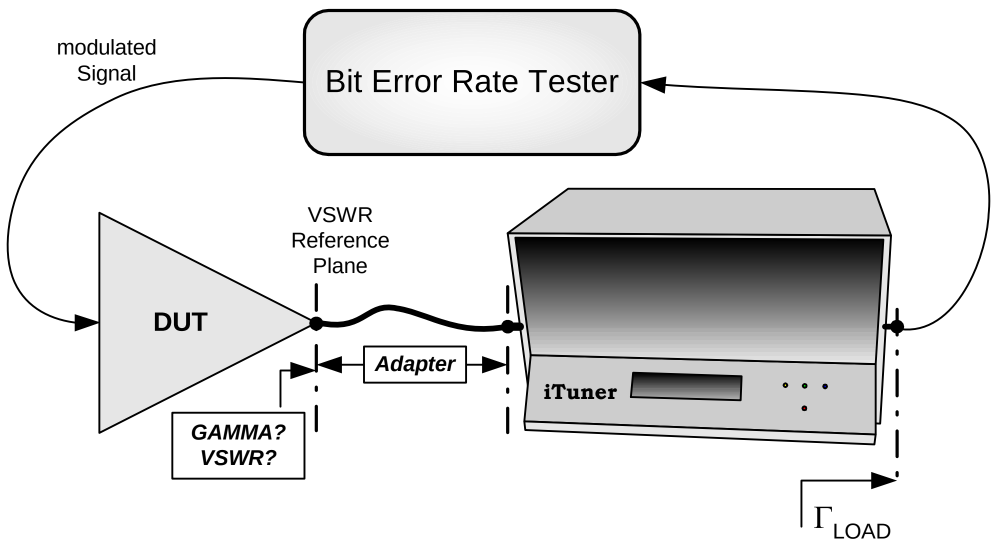


We are using the VSWR_INIT first to adjust VSWR at the desired level. Next, we issue the VSWR_DO360 command to perform a full 360^o phase sweep at maximum tuning speed. The spectrum analyzer is set to monitor output power in the frequency band of interest.
Spurious and intermodulation signal levels are usually measured relative to the signal level (dBc), therefore we do not have to correct for losses in the network inserted between the DUT and the spectrum analyzer. Further, output network losses are considered constant over frequency.

Command	Description
INIT	initializes tuner (all axis)
LOADCAL 2	load tuner calibration
ADAPTER .1 123 .95 15 .95 ….	define Adapter
TERM .2 45	define termination Γ_{LOAD}
VSWR_INIT 3	Adjusts VSWR at 3:1 in DUT reference plane
Initialize Spectrum Analyzer	Fast continious sweep, peak-hold, clear screen
VSWR_DO360	Perform high-speed 360^o phase sweep while keeping VSWR constant at 3:1
STATUS?	Read status of tuner to detect completion of phase sweep
read spectrum analyzer	Evaluate maximum peak power detected to determine of out-of-band spurious oscillations occurred
INIT	initialize tuner
verify test results	

Application example 3: Antenna Mismatch Tolerance Test

Wireless communication networking devices have to be tested for Antenna mismatch tolerance. A Bit Error Rate (BER) tester is used in conjunction with the microwave tuner.



Command	Description
INIT	initializes tuner (all axis)
LOADCAL 2	load tuner calibration
ADAPTER .1 123 .95 15 .95 ….	define Adapter
TERM .2 45	define termination Γ_{LOAD}
VSWR_INIT 3	Adjusts VSWR at 3:1 in DUT reference plane
Initialize BER	Set data rate, reset error count
VSWR_DO360	Perform high-speed 360^{o} phase sweep while keeping VSWR constant at 3:1
STATUS?	Read status of tuner to detect completion of phase sweep
read BER error count	
INIT	initialize tuner
verify test results	

We have to make sure that the signal power incident to the BER tester is sufficiently high to perform accurate measurements during the phase sweep.