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Application Note 42

Using Stub Tuners and Slide Screw Tuners

Mechanical Stub and Slide Screw Tuners are designed for critical RF impedance matching operations, like Load Pull and Noise measurements and are widely used in both laboratories and production applications, where continuous utilization of automatic measurement systems is not required, besides offering a lower cost alternative.

During these measurements the Load (or Source) impedance is modified using a tuner (pull the stub of a tuner).

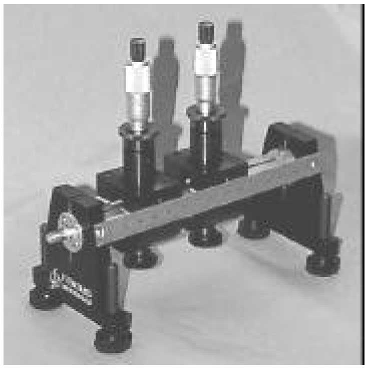

Figure 1: One Triple Stub tuner (left) and two Slide Screw tuners (right)

Slide Screw Tuners

Slide **S**crew **T**uners from Focus use parallel plate airlines (slablines) and one or two sliding carriages with one vertical micrometer screw and a microwave probe (slug) each. The microwave probes and slablines are designed to generate high reflection factors over a very wide frequency band (such as 0.8 to 18 GHz with typical VSWR of 20:1). The smooth sliding mechanism and the probe layout provides high tuning stability and ensures long lasting operation, high reproducibility and insensitivity to vibrations. Manual Microwave Tuners, model family MMT-xxyy, where xx is the highest and yy the lowest frequency of operation, are manufactured for frequencies from 400 MHz to 50 GHz, using a variety of connector types from 7/16 to 2.4 mm. When one of the two wideband probes is replaced by a resonant head the manual tuners can be used for independent tuning of the harmonic impedance at 2fo with very high VSWR (>30:1).

Tuner Operation

Reflection in a slide screw tuner is created by positioning the RF probe (slug) close to the central conductor (capacitive coupling). For reasonably high reflection the probes must be positioned very close to the central conductor, typically 0.05 to 1 mm away (2 to 40 thousands of an inch). The vertical position controls the amplitude and the horizontal position the phase of the reflection factor. Therefore the most critical dimension in accurate tuner positioning is the **vertical** axis, whereas the horizontal reading is not very critical. The phase error amounts to 2.4° per Millimeter at 1 GHz. Focus tuners are supplied with a horizontal ruler that allows easy positioning within 0.1 mm or better. A digital horizontal movement reading feature, offered by some tuner manufacturers, does not add much to precision.

A fine micrometer screw provides vertical positioning. There again there are differences: Focus uses bulkier and longer micrometer screws that have a non-rotating axis, whereas others use shorter screws and have a rotating link between micrometer screw and RF probe. This latter one is often cause of backlash in the, much more critical, vertical direction and inaccuracies in the measurement.

In any case, when repositioning a manual tuner it is very **important to come always from the same direction, in order to compensate for any backlash.**

RF reproducibility of manual Focus tuners is remarkable. Please refer to Product Note 45 for actual test data.

Further Features of Focus Tuners

Focus tuners have a unique **Prematching** capability, i.e. the two independently adjustable carriages can generate very high reflections up to 0.98 (VSWR≈100:1), depending on frequency range and connectors used (higher frequency and consequently smaller size airlines have more insertion loss and thus provide less reflection). This feature is very important in order to match low noise transistors and high power transistors both at their input and output ports. Please read more about Focus' prematching tuners in Product Notes 45 (Manual Tuners) and 52 (Prematching Tuners).

Dual or Multiple Stub Tuners

Stub **T**uners are impedance transformers that are designed to introduce variable shunt susceptances into a coaxial transmission line at fixed distances to each other. They consist of two or more short-circuited, variable length lines (stubs) connected at right angles to the primary transmission line [1]. These tunable shorts are driven over at least one half wavelength at the lowest operating frequency. They introduce **simultaneous adjustment** of both phase and amplitude of the reflection coefficients. The spacing between the stubs of multiple-stub tuners determines the range of impedances that can be matched and the ease of tuning.

It is being argued that stub tuners could make higher reflection than the simple slide screw tuners (not the Focus tuners, since they have the prematching feature!). The problem with multi-stub tuners is that their reflection behavior is **unpredictable**. The user cannot optimize the phase and then the amplitude alternatively, as he can do with slide screw tuners. So he may have a hard time optimizing his devices.

Multi-stub tuners have more disadvantages:

- They represent a DC short to the device, so bias tees must be included **between** tuner and DUT, which may create all various problems and reduces the effective reflection factor at DUT reference plane.
- Multi-stub tuners present to the DUT uncontrolled reflections at lower frequencies, which may vary from 0 (50Ω) to 1 (Short – Open etc..), depending on the distance and positioning of the shunted shorts. This is a dangerous operation that will cause parasitic oscillations more often than not.

In conclusion it is not recommended to use multi-stub tuners in critical measurement applications, unless it is a pure a budgetary issue, since multi-stub tuners are still cheaper than slide screw tuners.

Using manual tuners for Noise and Load Pull

Manual tuners can be used both for noise and load pull measurements. In both cases the tuning happens before the tuners are characterized in the network analyzer.

In both cases it is recommended to measure at several impedances around the optimum impedance and take note of the mechanical positions. Then reproduce the positions with the tuner connected to the network analyzer and measure the four S-parameters of the tuner twoport.

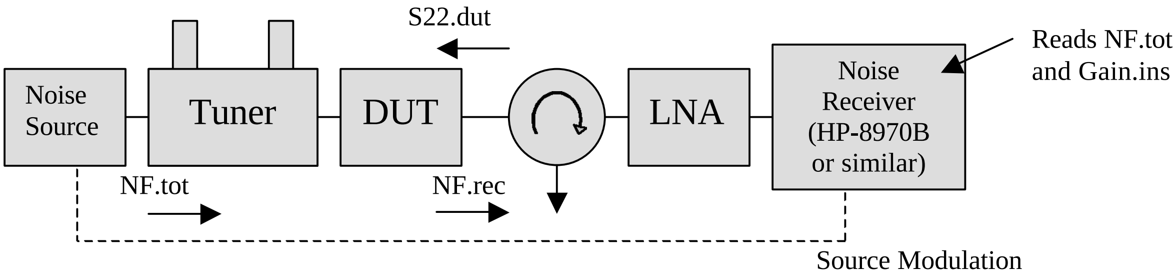

Figure 2: Typical noise figure and noise parameter setup

For **Noise** measurements we must know the S-parameters of the DUT and the noise figure of the receiver NF.rec, at the input of the isolator, measured at 50Ω directly with the noise source. Then we measure the total noise figure NF.tot and compute the noise figure of the DUT as follows:

$$\mathrm{NF.dut} = \mathrm{NF.tot} / \mathrm{Loss.av.tuner} - (\mathrm{NF.rec} \cdot \mathrm{M} - 1) / \mathrm{Gain.av.dut}$$

Well known formulas can be used to calculate the various quantities in this equation using the S-parameters of the tuner twoport and the DUT. It is clear that the calculation of the tuner losses etc. has to be performed for each tuner position.
The following (approximate) relations apply:

$\mathrm{M} = 1 / (1 - |\mathrm{S22.dut}|^2)$ [Mismatch factor at DUT output]

$\mathrm{Gain.av.dut} = \mathrm{Gain.ins} \cdot \mathrm{M} \cdot \mathrm{Loss.av.tuner}$ [Available Gain of DUT, Gain.ins = Insertion Gain measured by the Noise Receiver]

$\mathrm{Loss.av.tuner} = (1 - |\mathrm{S22.tun}|^2) / |\mathrm{S21.tun}|^2$

Once the Noise Figure has been calculated and associated with the source reflection factors (S22 of the tuner), known algorithms [2,3] can be implemented to linearize the equations and compute the four noise parameters of the DUT. It is a tedious technique, but it works when carried through carefully.

In **Load Pull** it is recommended to measure at the optimum point or close around it. It is theoretically impossible to find exactly the optimum power matching point using a manual tuner, except in an infinite series of trial and error. This is because the power loss of the tuner changes as we tune and we do not get the optimum net result at DUT reference plane but at tuner reference plane. However, if the mismatch range is not very high (5Ω transistors or higher) the chances for a reasonable accuracy are high. Below that it becomes again a tedious procedure of searching around the optimum.

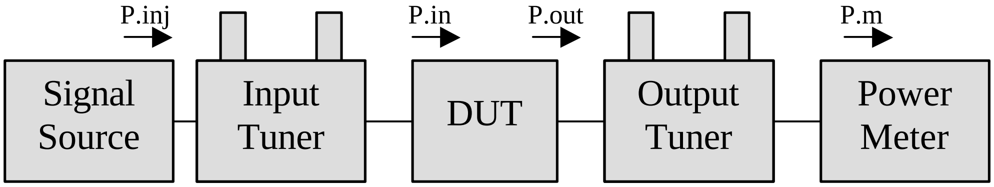

Figure 3: Typical manual Load Pull setup

This setup can measure the Transducer Gain (not the Power Gain) and the Delivered Output Power of the DUT.
The injected power P.inj can be measured by means of a directional coupler. In this case it is recommended to add an isolator before the input tuner, to make sure the coupler readings are not falsified by limited directivity in the coupler and the power reflected at the input of the tuner back to the source.
Assuming C to be the coupling of the input coupler then we can calculate:

P.in = P.inj / Loss.av.inp [**available** power at DUT input]

P.inj = Reading at Coupler · C

P.out = P.m · Loss.pwr.out [**delivered** power at load]

G.t = P.out / P.in [transducer gain]

The available loss of the input tuner and power loss of the output tuner, including any other components, like adapters, fixture and bias tees, can be calculated at each position from its S-parameters (port 1 is at signal entry, port 2 is at signal exit).

$\text{Loss.av.inp} = (1-|S22|^2) / |S21|^2$ [Sij of input tuner]

$\text{Loss.pwr.out} = (1-|S11|^2) / |S21|^2$ [Sij of output tuner]

References

[1] Maury Microwave Product Catalogue 1998/99, page 148
[2] R.Lane, “The determination of Device Noise Parameters”, Proc. IEEE, vol. 57, p.1461-1462, 8/1969
[3] Appl. Note 19, “On Wafer Noise Parameter Measurements using..”, Focus Microwaves, 1994