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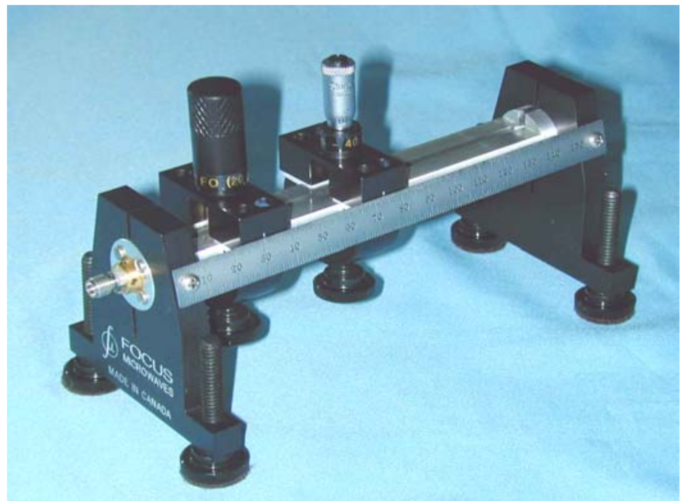
Product Note 67

Millimeterwave Manual and Harmonic Tuners With Prematching Capability

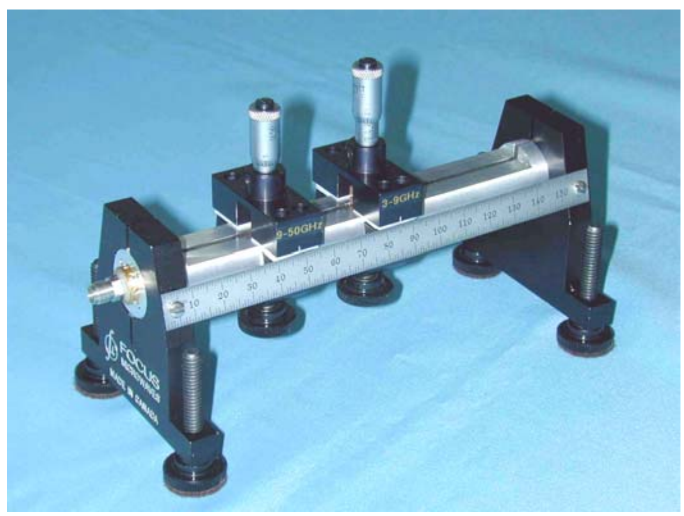
Focus Manual Microwave Tuners are designed for critical RF impedance matching operations, like Load Pull and Noise measurements. Manual Tuner models MMT-4006-2H and MMT-5003 cover 6 to 40 and 3 to 50 GHz and may generate SWR between 20:1 and 40:1 depending on the operation frequency. Model 4006-2H has also 2fo harmonic tuning capability, which is frequency selective and independent on fundamental tuning. This note describes these two tuner models and also provides guidelines on how to use them in manual Load Pull and Noise measurements.



Manual Prematching Tuner 3-50 GHz

Manual Tuners 6-40 and 3-50 GHz at a glance

Frequency Range	6.0 to 40.0 or 3.0 to 50 GHz
SWR Tuning Range	1.15:1 to 15:1
Phase Tuning Range	0 to 360°
Prematching capability (Narrow band)	SWR ≤ 40:1
Connectors	2.9(K) or 2.4mm
Connector height	Adjustable 2”- 3.5”
Insertion Loss (probes extracted)	0.1-0.9 dB
Horizontal movement Teflon sliding bearing	Continuous
Horizontal Resolution	Analog 0.002”, Digital 0.001”
Vertical Resolution	Micrometer screw, 0.0005”
Overall Dimensions	L=7.5”, W=3”, H=4.5-6”



Manual Harmonic Tuner 6-40 GHz; 2fo set to 20 GHz

 January 2000

Discussing the Prematching 3-50 GHz Manual Tuner

Ultra wideband Focus' Manual Microwave Tuners (MMT's) use parallel plate airlines (slablines) precisely machined out of a solid aluminum rod and one or two independent 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 wide frequency band and are used to allow either mutual prematching of the probes and thus generate, in a narrow band, very high SWR, or allow selective harmonic tuning at a user selected 2fo or 3fo, independent on fundamental tuning.

The tuners use either 2.92 mm (K) or 2.4 mm connectors, depending if they operate to 40 or 50 GHz. The insertion loss of the 7" long transmission line is kept very low by appropriate polishing of the parallel plates and a combination of silver/gold plating of the central conductor. Because of dispersion in the properties of 2.4mm connectors and adapters available on the market, we machine and use only preselected units. The typical insertion loss of such a tuner at 50 GHz, with the RF probes retracted, does not exceed 0.9dB.

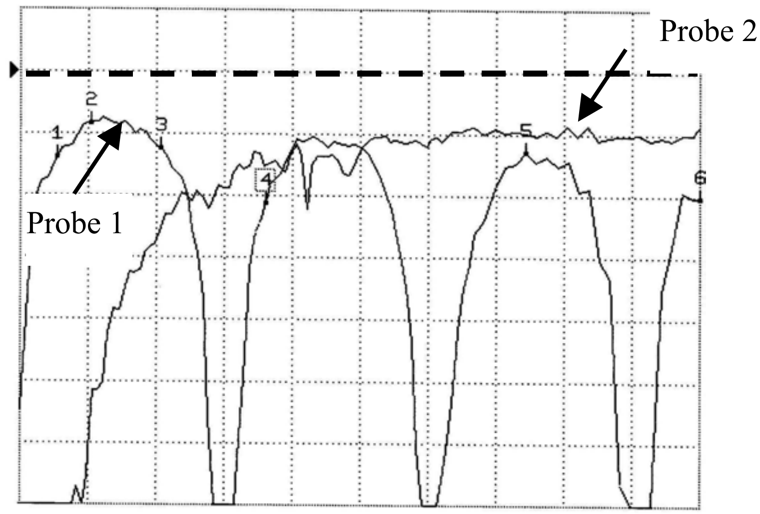


Figure 2: Total Reflection (Return Loss) of individual MMT-5003 probes (probes inserted to maximum depth); Horizontal axis 1 to 50 GHz
Vertical axis 1dB/division

This low loss behaviour is very important for the prematching capability of the tuners as will be shown later on. Even though a maximum reflection factor close to 1 can be generated at the reference plane of the first probe (when both probes are used for resonance tuning) the insertion loss of the connector facing the DUT and the transmission line up to the first probe is the main limiting factor of Gamma.

The total reflection of MMT-5003 is created using both independently movable RF probes: Probe 1 is larger and generates alone high reflection between 3 and 9 GHz; probe 2 is smaller and creates reflection from 9 to 50 GHz (figure 3). The combination of both probes creates high reflection at frequencies in between, reaching very high SWR (up to 40:1).

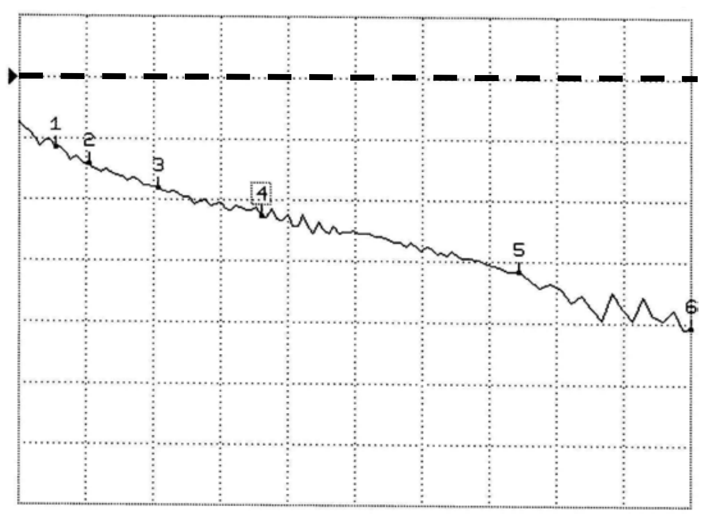


Figure 3: Insertion loss of MMT-5003 (RF probes retracted); Horizontal axis 1 to 50 GHz (4.9GHz/div); Vertical axis 0.2dB/div.

Prematching works as follows:
The first probe (closest to the DUT) generates a reflection vector with a

magnitude of about 0.8 to 0.85 in the right direction (phase) for matching the device. If this level of reflection is not high enough to match the device, then the second probe generates an additional reflection vector that adds to the first one. This second vector allows for full phase control around the tip of the first vector and a limited amount of amplitude control (figure 4), the vector sum of both reflections reaching very high values (Γ >0.95 at a large part of the bandwidth).
In fact the maximum reflection obtained at the reference plane of the first probe is very close to one (Short circuit), but the actual reflection at the input port of the tuner is limited by the insertion loss of the input section of the tuner, including the 2.4mm connector and part of the transmission airline. As table 1 shows the maximum reflection factor that can be reached is very sensitive to these losses and it is imperative to select the best connectors for the "active" port, if Prematching is important for the tuner application.

Insertion Loss [dB]	Equivalent Series Resistance [mΩ]	Maximum |Γ| / SWR
0.010	115	0.998 / 250:1
0.025	291	0.994 / 84:1
0.050	573	0.989 / 46:1
0.100	1,163	0.977 / 22:1

Table 1: Maximum reflection of a prematching MMT as a function of insertion loss between input connector and actual location of the first probe

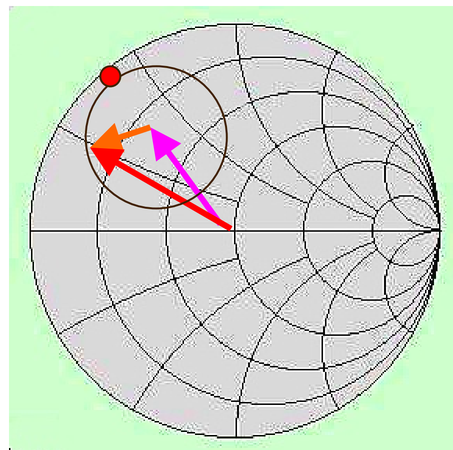
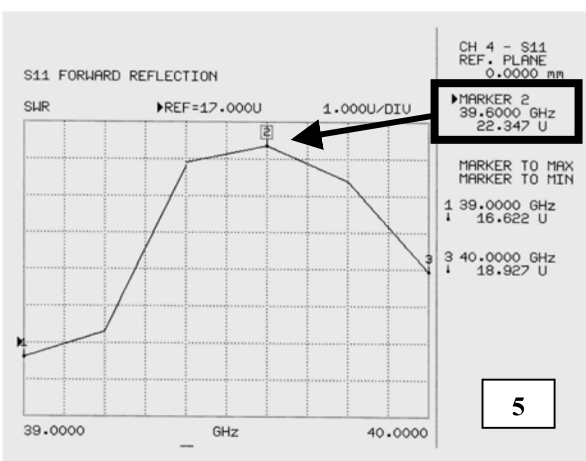
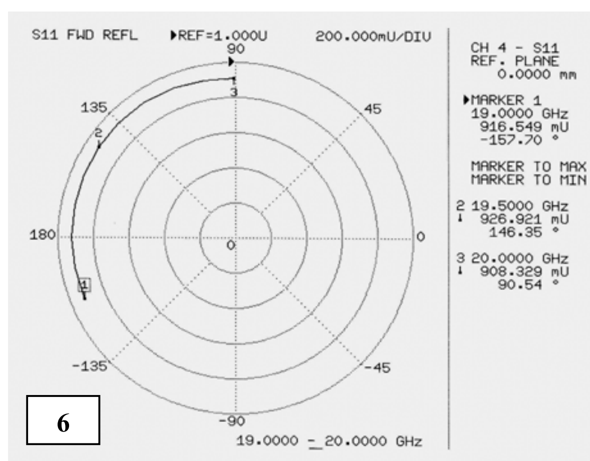
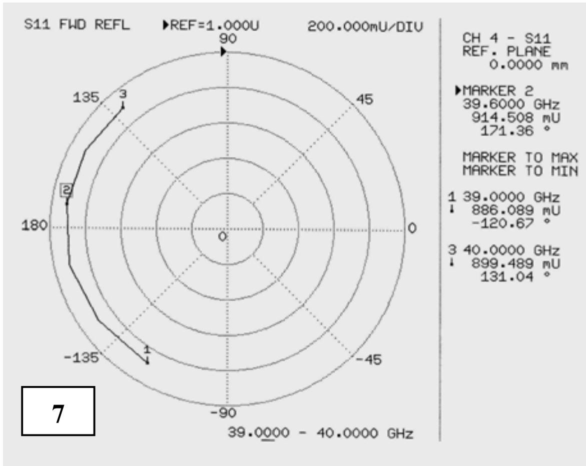


Figure 4: Operation of Prematching in Dual Carriage Tuners

Because approximately 1/4 of the insertion loss of the transmission airline is associated with each of the two 2.4 mm connectors (figure 3) and the remaining with the airline, using table 1, we should expect about 1/4 to 1/5 of 0.45dB loss (or 0.09 to 0.1dB) at 20 GHz to be limiting Γ; this corresponds to a maximum SWR of 22:1 to 26:1, in good agreement with the plots 5 and 6.







Plots 5, 6 and 7 show examples of the prematching capability of MMT-5003 centered around the frequencies of 20 (SWR=26:1) and 40 GHz (SWR=22:1).

Discussing the Harmonic Tuner MMT-4006-2H

The fundamental/harmonic ("Combo") tuner MMT-4006-2H has fundamental tuning capability between 6 and 40 GHz and an independent carriage allows to position harmonic resonators such as to tune the phase of the second (or third) harmonic impedance at high SWR at a "user defined" frequency between 12 and 44 GHz. The upper frequency limit is determined by some undesired modes in the 2.92 mm (K) connectors.

Operation of MMT-4006-2H is as follows:

The tuner is connected to the DUT with the harmonic resonator coming first and the fundamental probe afterwards. This allows tuning the harmonic impedance fully independently of the fundamental impedance. If the fundamental impedance is already tuned changing the harmonic impedance may require a minor back tuning to restore the original fundamental impedance. Figure 8 shows the tuning range and selectivity of MMT-4006-2H. If another harmonic frequency is required the operator can easily exchange the harmonic resonator. If the harmonic resonator is totally removed then the full range of 6 to 40 GHz tuning capability is available.

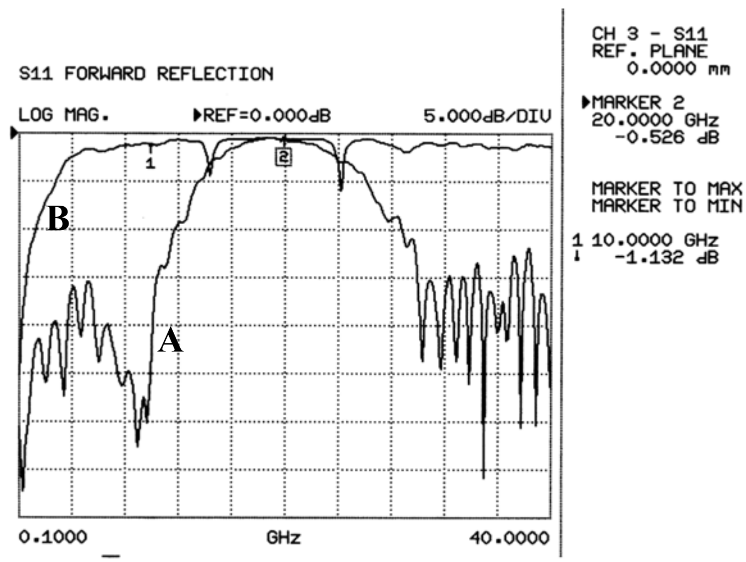


Figure 8: Fundamental and harmonic tuning of MMT-4006-2H. <u>Trace A:</u> Fundamental probe extracted (Return Loss RL(fo)≈25dB, Γ(fo)≈0.06). <u>Trace B:</u> Fundamental probe fully inserted (RL(fo)≈1.13dB, Γ(fo)≈0.88). In both cases RL(2fo) is constant and equal to 0.53dB or Γ(2fo)≈0.94.

MMT tuning Repeatability (MMT-4006-2H with analog scale)

MMT tuning repeatability is measured semi-automatically:
A software programme is communicating with a calibrated VNA tuned to a fixed frequency; on a programme prompt the operator can move the tuner axis back and forth to a previously marked position and pressing a computer key triggers a GPIB reading of the four S-parameters of the tuner two-port. The read data are saved sequentially line by line in a "repeatability" file. The test can be repeated at will for any combination and distance of axis movements and directions. Depending on the direction of tuning and the condition to move a single axis or both axes simultaneously, the result varies.

Manual Tuner Repeatability: Model 4006/5003

Frequency = 30.0000 GHz

Set	|S11|	φ11	|S21|	φ21	|S12|	φ12	|S22|	φ22	Tuner Loss
Horizontal and Vertical Movement, medium SWR									
001:	0.599	42.9	0.657	102.6	0.659	102.0	0.569	-33.2	L=1.725
002:	0.609	42.2	0.662	101.7	0.664	101.3	0.579	-30.9	L=1.570
003:	0.608	42.3	0.671	101.0	0.674	100.5	0.579	-30.6	L=1.460
004:	0.602	44.2	0.666	101.5	0.669	101.0	0.575	-33.3	L=1.569
005:	0.612	42.8	0.664	101.4	0.666	101.0	0.583	-31.1	L=1.521
006:	0.615	42.6	0.663	101.2	0.666	100.8	0.585	-30.9	L=1.506
007:	0.616	41.3	0.668	100.8	0.671	100.3	0.585	-29.4	L=1.431
008:	0.613	44.5	0.663	100.8	0.666	100.3	0.589	-33.3	L=1.521
009:	0.599	45.2	0.657	101.9	0.660	101.4	0.572	-36.4	L=1.722
010:	0.597	41.5	0.649	102.4	0.652	102.0	0.564	-34.2	L=1.839
011:	0.598	41.3	0.657	102.4	0.659	101.9	0.559	-32.4	L=1.728
012:	0.612	40.9	0.642	101.7	0.645	101.3	0.568	-34.3	L=1.808
013:	0.602	41.5	0.651	101.8	0.654	101.4	0.569	-33.9	L=1.774
014:	0.604	42.8	0.646	101.9	0.649	101.5	0.573	-35.3	L=1.823
015:	0.609	41.6	0.664	101.0	0.666	100.6	0.577	-31.4	L=1.552
016:	0.621	42.4	0.657	100.1	0.659	99.6	0.591	-32.9	L=1.539
Vertical Movement only, high SWR									
030:	0.801	39.6	0.352	108.9	0.354	108.4	0.748	-31.7	L=4.607
031:	0.816	39.8	0.325	107.7	0.327	107.2	0.768	-34.2	L=4.986
032:	0.809	40.3	0.341	107.3	0.342	106.8	0.761	-34.5	L=4.736
033:	0.805	39.3	0.352	108.1	0.354	107.6	0.754	-31.7	L=4.545
034:	0.811	38.8	0.344	107.8	0.346	107.3	0.759	-31.1	L=4.599
035:	0.819	38.8	0.332	107.2	0.333	106.7	0.767	-31.9	L=4.762
036:	0.817	39.3	0.338	107.3	0.340	106.8	0.765	-31.6	L=4.631
037:	0.815	38.8	0.335	107.9	0.336	107.4	0.763	-31.7	L=4.761
038:	0.809	39.9	0.350	108.3	0.351	107.8	0.758	-30.6	L=4.504
039:	0.799	39.4	0.372	108.3	0.373	107.7	0.747	-29.1	L=4.186
040:	0.804	40.3	0.358	107.0	0.360	106.6	0.757	-32.9	L=4.400
041:	0.812	38.6	0.349	107.8	0.350	107.3	0.757	-30.0	L=4.477
042:	0.810	40.7	0.354	107.4	0.355	106.9	0.760	-31.9	L=4.400
043:	0.820	40.4	0.341	106.4	0.342	105.9	0.772	-32.3	L=4.495

Table 2: Manual tuning repeatability at 30 GHz

Table 2: Shows four S-parameter readings on a calibrated VNA at 30 GHz, after the tuner has been manually repositioned at two different SWR levels and using two different movement procedures: one moving both axis and a second moving only the vertical (and more critical) axis. The results suggest that, even at this very high frequency, the tuning repeatability, the reflection factor and the tuner loss are within reasonably accurate limits, even using simple mechanical positioning means. Results published before show a higher repeatability at lower frequencies [Manual Microwave Tuners, Product Note 45, Focus Microwaves]. Because of the nature of the tuning mechanism in slide screw tuners like these, an error in horizontal positioning causes an error in phase and an error in vertical positioning causes an error in amplitude of the reflection factors and in tuner loss.
We observe good phase repeatability within 1-2.5° meaning that costly digital reading accessories can safely be omitted up to at least 20 GHz. The amplitude repeatability is also acceptable and there are no techniques available to improve this, because the vertical axis is already controlled by a fine micrometer screw with a reading resolution of 0.0005" (12.7µm).

Using MMTs for manual Load Pull measurements

Manual tuners can be used for noise and load pull measurements. In both cases the tuning happens before the tuners are characterized (calibrated) on the network analyzer.
It is recommended to measure at several impedances at and 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 at once.
It is theoretically impossible to find the exact optimum power and 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 observe the optimum net result at DUT reference plane but at tuner reference plane. However, if the mismatch range is not very high (transistors with 5Ω output impedance or higher) the chances for a reasonably accurate determination of the maximum power are good. Below that impedance value manual search becomes an increasingly tedious procedure of searching around the optimum point.

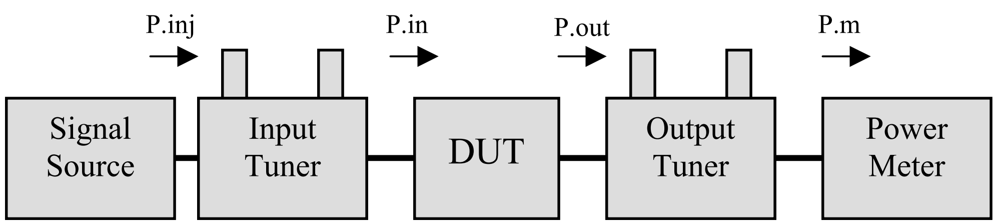


Figure 9: Typical manual load pull measurement setup

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 use the following relations:

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).

Loss.av.inp = $(1-|S22|^2) / |S21|^2$ [Sij of input tuner]
Loss.pwr.out = $(1-|S11|^2) / |S21|^2$ [Sij of output tuner]

Using MMTs for manual Noise measurements

When executing noise measurements using manual tuners two approaches are possible, depending on the expected result. If we want information about the Optimum Noise Figure only then 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. Subtracting the available loss of the tuner from the actually measured noise figure gives a reasonably accurate number for NF.min.
If we need the four noise parameters NF.min, R.n and Y.opt then we must measure also at tuner positions further away from the optimum. After the tuner is characterized the resulting "net" noise figure data and associated tuner impedance and loss can be used in a noise parameter extraction algorithm [3] to provide the four noise parameters.

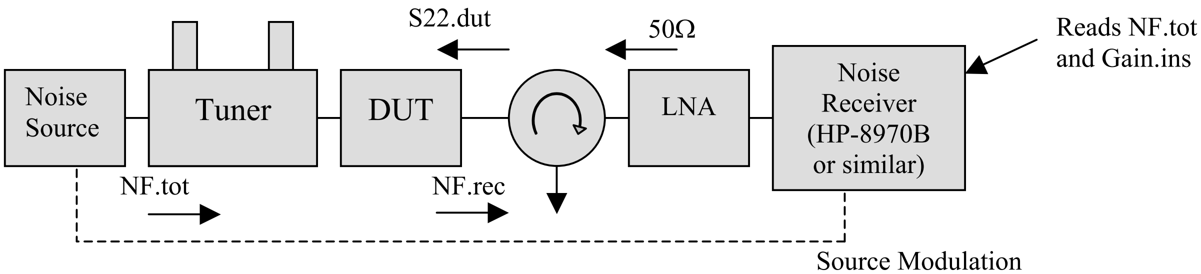


Figure 10: Typical "hot/cold source" noise figure and noise parameter measurement setup

The S-parameters of the DUT must also be known, and the noise figure of the receiver NF.rec at the input of the isolator, must be 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:

NF.dut = NF.tot / Loss.av.tuner – (NF.rec · M –1) / 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:

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

Gain.av.dut = Gain.ins · M · Loss.av.tuner [Available Gain of DUT, Gain.ins = Insertion Gain measured by the Noise Receiver]

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

It is a tedious technique, but it works when carried through carefully.

References

[1] Appl. Note 42, "Using Stub Tuners and Slide Screw Tuners", Focus Microwaves, 1999
[2] Product Note 45, "Manual Microwave Tuners, model MMT", Focus Microwaves, 1997
[2] R.Lane, "The determination of Device Noise Parameters", Proceedings of the IEEE, vol. 57, p.1461-1462, 8/1969