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***Product Note 54***

# MLTF, a Minimum Loss Transistor Test Fixture for Sub 1Ω Load Pull Measurements

**MLTF is an extremely low loss test fixture, as required for load pull measurements of packaged high power RF transistors. The low loss is obtained by exclusively using air as dielectric[1]. The test fixture can be used up to 5 GHz and includes a main body with coaxial connectors and connector flanges and a set of TRL calibration standards and measurement inserts, one set per transistor package type.**

## Description of the Fixture

MLTF is a test fixture designed in order to make load pull measurements of high power RF and microwave transistors with very low internal input and output impedances possible without using impedance transformers. The most important characteristic of MLTF is its <u>extremely low insertion loss</u> (S21 of each section ≈-0.035dB at 5 GHz).

An innovative transition technique between coaxial and microstrip structures in used and has been optimized for each particular transistor package, in order to provide very low insertion loss and maximum return loss (RL better than 30dB up to 5 GHz). A number of commonly used transistor packages are supported and more are under development on customer request.

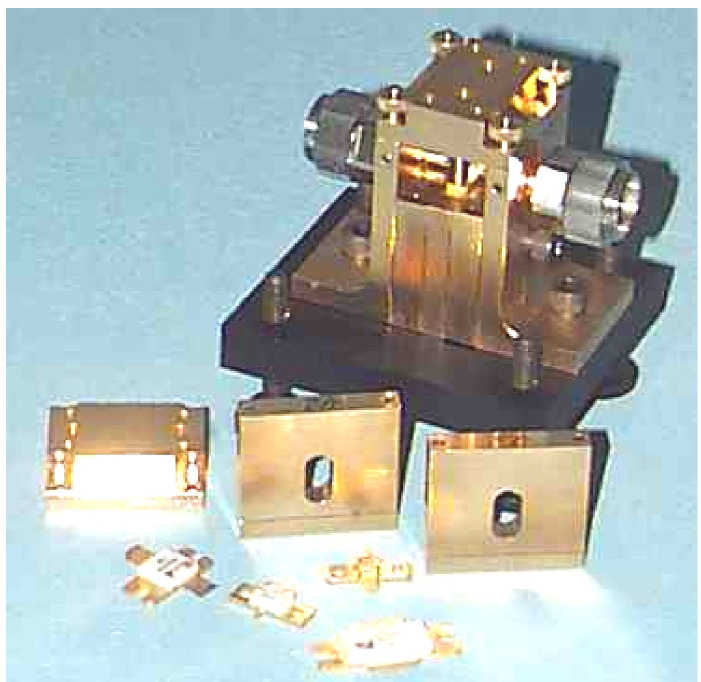

Figure 1: MLTF with extra calibration inserts, cover and some supported transistor packages

MLTF is made out of the following parts:

- The fixture base with adjustable feet
- The two connector brackets, one fixed on the base and one sliding

[1] *patent pending*

- One measurement set for each transistor package, including an insert and a cover
- One TRL calibration set for each transistor package, including a Thru and a Delay Line
- One Thru and one Delay lead equivalent to the transistor leads.

## Background

Load Pull as well as Noise measurements are possible using, preferably automatic, tuners. Noise being a small signal phenomenon it is possible to determine the optimum noise figure without having to tune to exactly the optimum impedance, because there is a formula relating the noise parameters to the source impedance. Load pull however is a typical non-linear phenomenon and there are no analytical formulas describing the relation between source (or load) impedance and device power, gain, PAE or else. In this case, if we want to determine the exact power delivered by the device we must tune to the optimum impedance.

Modern multicell power transistors have very low internal impedances both on the input (gate, base) and the output (drain, collector) sides, in general of the order of 1Ω or less, which have to be matched with a tuner in order to make sure that the exact value of the parameter to be measured has been determined.

Modern automatic tuners may generate VSWR around 20:1 with acceptable accuracy. VSWR up to 50:1 are possible but both calibration and tuning accuracy are unreliable and should be avoided. As a rule of thumb we can say that good and reliable load pull measurements can be done up to VSWR=15:1 at tuner reference plane. De-embedded to the transistor reference plane this number is reduced by twice the insertion loss of the test fixture, or other parts, inserted between DUT and tuner, like diplexers or triplexers in case of some harmonic load pull setups. This insertion loss reduces the effective VSWR at DUT reference plane to, in general, unacceptable levels for high power transistors, as can be seen from table I. This table shows the reduction in effective reflection factor (or minimum tuneable impedance $R_{min}$) at DUT reference plane as a function of the insertion loss of the output section of the test fixture in two cases: 1) when we connect a Short Circuit ($\Gamma_{max}$=1) at the end of the fixture and 2) when we connect an average tuner with $\Gamma_{max}\approx 0.85$. The reality lies in-between and rather close to the second case with Γ=0.85 (VSWR=12.3).

The numbers in table I show how sensitive the insertion loss of the test fixture is for load pull measurements and why this specific characteristic was the main design target for MLTF.

| S21[dB] | $R_{min}$[Ω] | $\Gamma_{max}$ @1.0 | $R_{min}$[Ω] | $\Gamma_{max}$ @0.85 |
|---|---|---|---|---|
| 0.00 | 0.00 | 1.000 | 4.05 | 0.850 |
| -0.025 | 0.14 | 0.994 | 4.20 | 0.845 |
| -0.05 | 0.29 | 0.989 | 4.30 | 0.842 |
| -0.075 | 0.43 | 0.983 | 4.50 | 0.835 |
| -0.10 | 0.58 | 0.977 | 4.61 | 0.831 |
| -0.15 | 0.86 | 0.966 | 4.91 | 0.821 |
| -0.20 | 1.15 | 0.954 | 5.19 | 0.812 |
| -0.50 | 2.87 | 0.891 | 6.82 | 0.760 |

Table I: Impact of fixture loss on minimum tuneable impedance. Column 1 is the insertion loss of the fixture; columns 2 and 3 the minimum resistance and maximum Γ when connected to a short and columns 3 and 4 when connected to a real tuner.

# Calibration and Performance

MLTF must be fully characterized using TRL. It is a mistake to assume that, since its insertion loss is so low and its return loss so high, MLTF could be described by a loss-less transmission line. This would be acceptable for S-parameter or Load Pull measurements using tuners with moderate reflection factors less than Γ≈0.82 (VSWR=10:1). Beyond this point any insertion loss rapidly increases to important power loss with increasing $\Gamma_{tuner}$ , and this falsifies the measurement results, if the "loss-less line" approach is adopted.

This is particularly true if MLTF is connected to a prematching Tuner (PMT[1]) which generates Γ higher than 0.99.

Table II below shows an example of MLTF connected to a PMT tuner:

| S21 | Φ21 | $\Gamma_{DUT}$ | $R_{min}$ | Loss |
|---|---|---|---|---|
| 0dB | -90.0 | 0.992 | 0.2Ω | 2.24dB |
| -0.017dB | -90.0 | 0.986 | 0.36Ω | 4.76dB |

Table II: Effect of Fixture loss on Power Loss of Tuner+Fixture combination.

In table II the first row corresponds to the "loss-less" approximation (fixture loss =0dB) whereas in the second row the real loss is 0.017dB, which for other, non high VSWR load pull applications, could be considered as an ideal transmission. The error in power loss would be 2.5dB; this would critically falsify the measurement. For this reason it is <u>imperative for MLTF to be very accurately characterized using TRL</u>.

MLTF is supplied with a Thru, a Delay and the corresponding leads and covers. It can be characterized using FOCUS generic TRL software. Results are shown in figures 2 – 4.

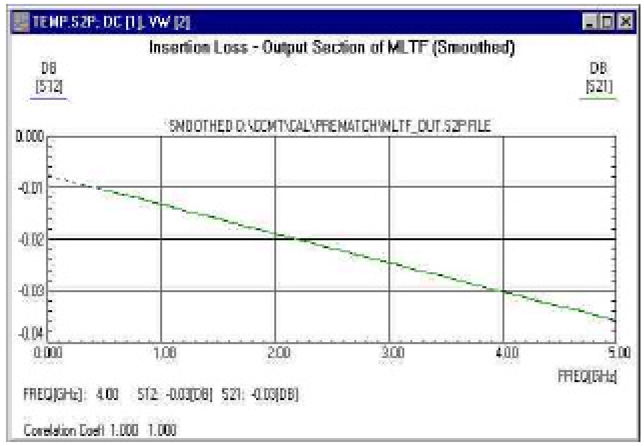


Figure 2: S12/S21 of output section of MLTF (smoothed data)

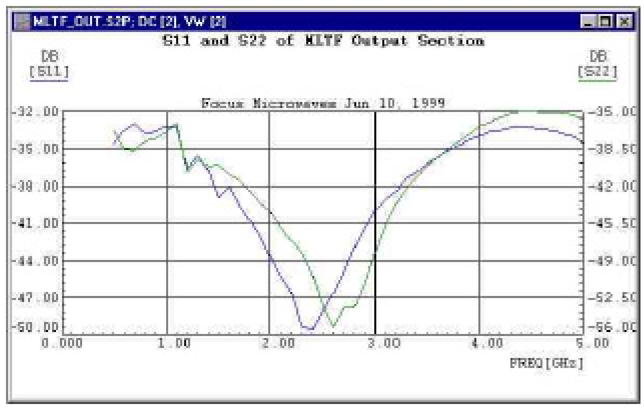


Figure 3: S11/S22 of output section of MLTF (rough data)

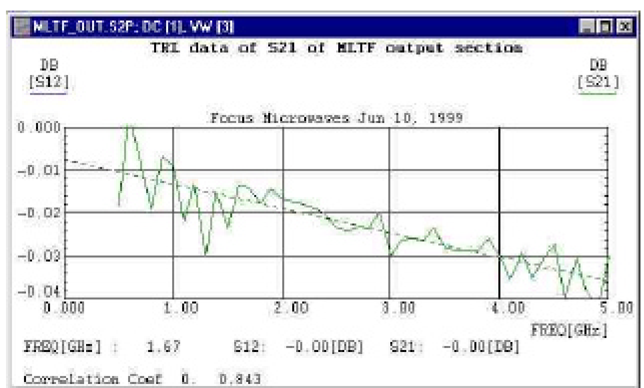


Figure 4: S12/S21 of output section of MLTF (rough data)

The ripple in un-smoothed data of figure 4 is due to the very small numbers involved.

## Tuning for Load Pull using MLTF and PMT

MLTF is especially valuable when used with the Prematching Tuners PMT. The PMT tuners themselves can generate reflection factors bigger than 0.99 (see table II, first row) and allow then to synthesize very low impedances at DUT reference plane, if the transistor is mounted in a MLTF.
The plots below demonstrate this effect:

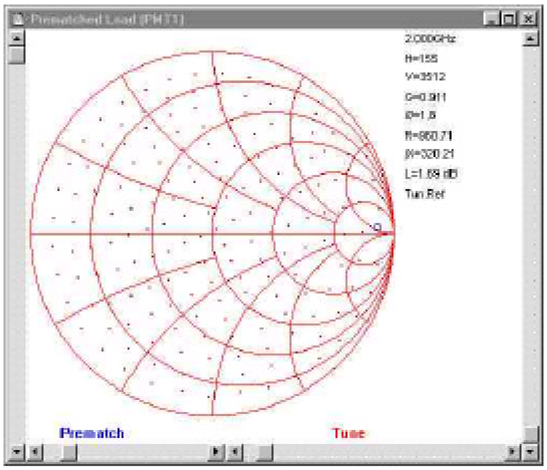


Figure 5: Cal points of PMT without Pre-matching and MLTF ($\Gamma_{max}$=0.911)

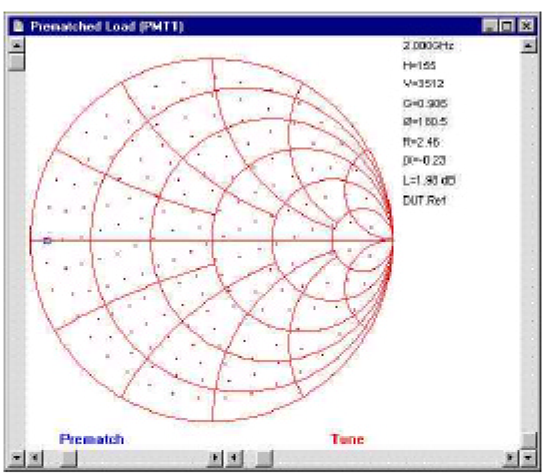


Figure 6: Cal points with MLTF and no Prematching ($\Gamma_{max}$=0.906).

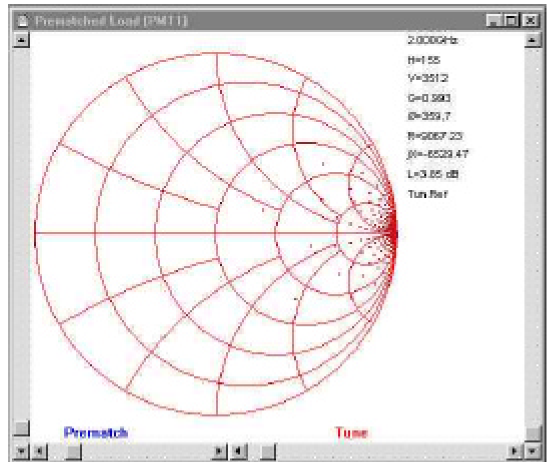


Figure 7: Cal points with high Prematching and no MLTF ($\Gamma_{max}$=0.993)

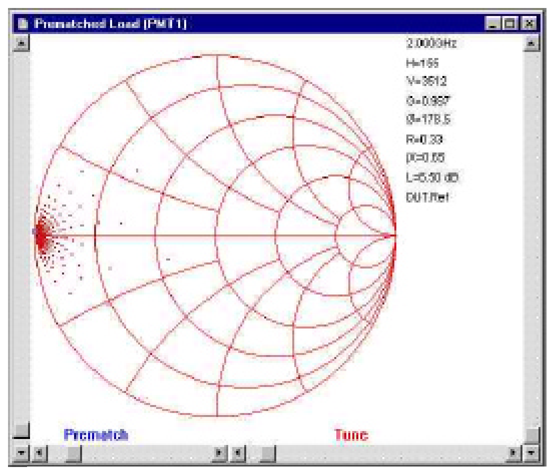


Figure 8: Cal points with MLTF and high Prematching ($\Gamma_{max}$=0.987); final and real measurement situation.

## Literature

[1] Product Note 52: "Prematching Tuners for Very High VSWR and Power Load Pull Measurements", Focus Microwaves, February 1999.