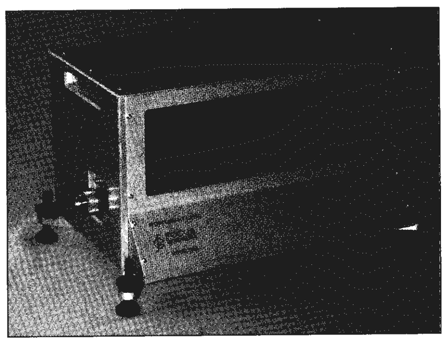
Instruments Simplify Load Pull Testing Of High Power Transistors

Focus Microwaves introduces equipment for flexible, accurate and fast load pull testing of very low (0.5 ohm) impedance power transistors

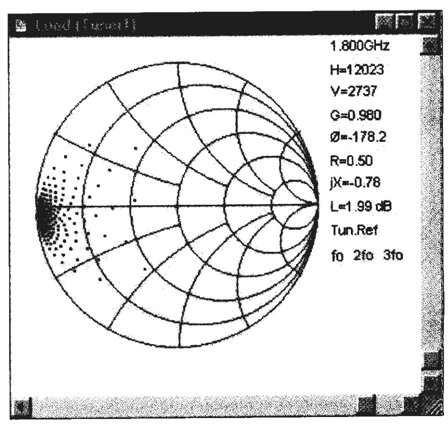
Competition in supplying "high-performance, low-cost" amplifiers for high quantity commercial use in cellular and PCS applications progressively forces designers away from pure computer modeling and back to the measurement bench. Increased requirements for accurate power characterization data for new high performance devices (LDMOS and others) can only be provided by measuring high power transistors using the load pull method. The key requirement for power load pull is accurate, very low impedance synthesis at high RF power levels. Automatic testing in itself is also very important for timely data acquisition, for which computer controlled electromechanical slide screw tuners have been for some time the designated state-of-the-art solution (Figure 1).



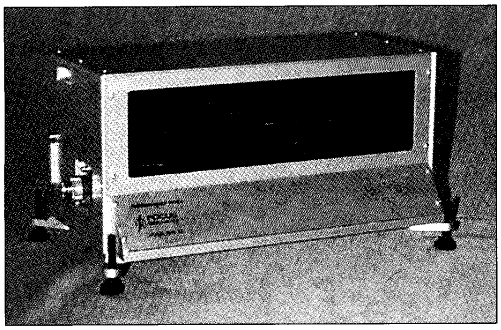
▲ **Figure 1. Computer controlled electromechanical slide screw tuner.**

The present situation

The best electromechanical tuners may accurately generate maximum VSWR >>15:1, which corresponds to the real part of the internal impedance of the transistors, about 3.3 ohms or a reflection coefficient of Γ = 0.875). Beyond this reflection coefficient level, the calibration and repeatability of the tuners may cause accuracy and measurement repeatability problems. Some lossy test fixtures will further reduce the available reflection factor at the DUT reference plane to unacceptable values (VSWR >>10:1 or R_{min} >>5 ohms). For testing very low impedance power transistors there are actually only two solutions possible: One is to use $\lambda/4$ microstrip transformers on the test fixture at the test frequency [1], and the other is to use "active" systems, such as "active modules" [2] combined with passive tuners or entirely "active" load pull systems [3]. Active systems



▲ **Figure 2. Once the transformers are made, tuning outside the prematched area of the Smith Chart is impossible.**



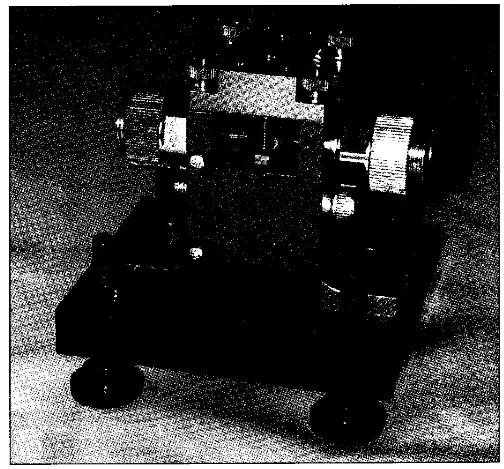
▲ **Figure 3. High VSWR prematching tuner.**

reveal that they are inadequate for packaged high power transistor testing, because of power limitations and notorious parasitic oscillation problems. The only remaining solution is the $\lambda/4$ transformer solution, which is affordable and easy to design and build, but has the shortcomings of being cumbersome, frequency selective and may have to be redesigned for each particular DUT. By there nature, the transformers pre-tune only into a specific area of the Smith Chart, which is normally, but not always, the area around a short circuit (ϕ = 180°). The problem is that, once the transformers are made, tuning "outside" the prematched area of the Smith Chart is impossible (Figure 2).

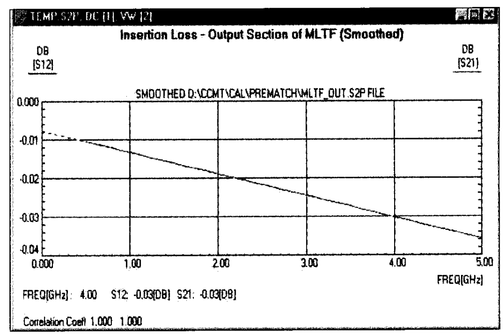
A new solution

Focus Microwaves has developed a completely new solution to this problem using traditional techniques, i.e. both minimizing the test fixture losses and increasing the maximum reflection coefficient of the tuners. This solution consists of simultaneously employing very high VSWR Prematching Tuners (PMT, Figure 3) with maximum VSWR >>150:1 and Minimum Loss Test Fixtures (MLTF, Figure 4) with insertion loss of 0.02 dB at 2 GHz (Figure 5). The consequent combination of these two new components allows the synthesis of very low impedances (or high VSWR) at the DUT reference plane with excellent tuning accuracy, high power handling capability and low overall loss, without the requirement of $\lambda/4$ transformers, which until now have been the only practical way to approach this kind of load pull testing.

Using this technique, resistances of less than 0.4 ohms can be synthesized at the DUT reference plane at cellular and PCS frequencies (equivalent VSWR >100:1).



▲ **Figure 4. Minimum loss test fixtures.**



▲ **Figure 5. The results of employing a very high prematching tuner and minimum loss test fixture with insertion loss of 0.02 dB at 2 GHz.**

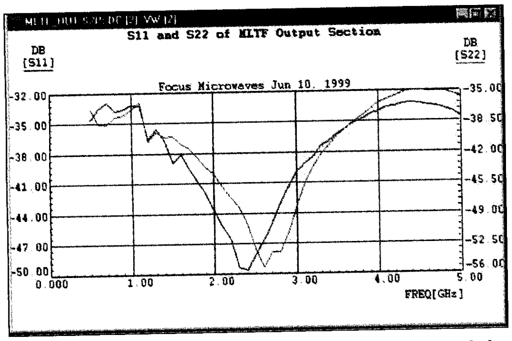
Advantages

The proposed solution, combining high VSWR prematching tuners and ultra low loss test fixtures, has many natural advantages.

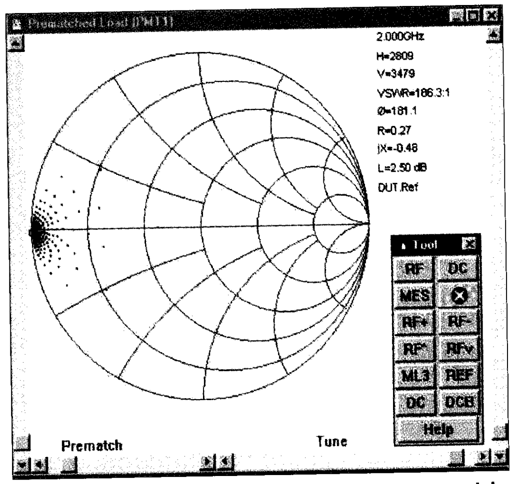
First, the total system can be calibrated easily, quickly and accurately. This is due to the fact that the total reflection of the tuners is generated by cascading two medium-sized reflections of VSWR >>12:1, resulting in a total VSWR >>150:1 at tuner reference plane.

Second, the system can handle significantly more power at the same level of VSWR, because the probes in the slide screw tuners stay further away from the center conductor, since each individual probe needs to generate a lower individual VSWR.

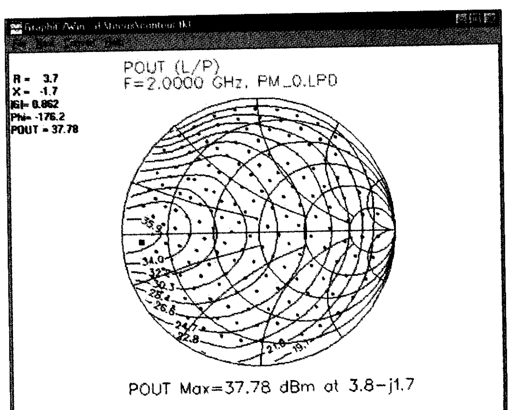
Third, the tuning area can be pointed to any angle of the Smith Chart (not only around 180°, as is the case with $\lambda/4$ transformers). Finally, the transforming ratio and, consequently, the surface of the tuning area and Γ_{max} can be freely adjusted.



▲ **Figure 6. Insertion loss and reflection coefficient of the output half of a Minimum Loss Test Fixture (MLTF).**



▲ **Figure 7. Maximum tuning range of the Focus prematching tuner (PMT).**



▲ **Figure 8. Load pull using a normal tuner and microstrip with 50 ohm microstrip lines. Z_0=50 ohms.**

Low loss test fixture, MLTF

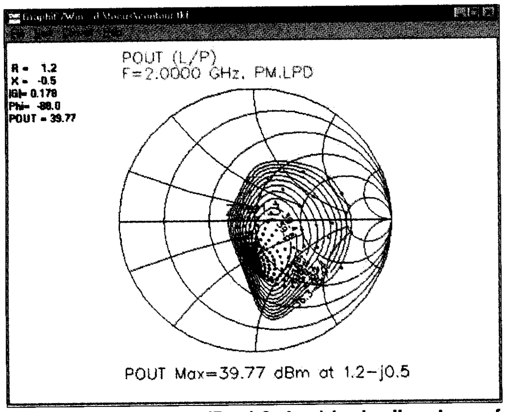
Extremely low loss test fixtures must use air as a dielectric. The only commercially available transistor test fixture using air as a dielectric is the TTF [4]; but this fixture is coaxial and supports only small signal transistors with packages from 0.05 to 0.1 inches in width (1.3 to 2.5 mm).This fixture can only be used for low noise transistor measurements.

Focus' MLTF is made differently. It also uses air as a dielectric but is not a coaxial structure. Rather, it adapts to the nature of power transistor packages to be tested, which basically use a microstrip configuration, since their final destination in circuits is a microstrip matching network. In other words, MLTF uses a non-symmetrical transmission structure in which the metallic cover is at a different distance than the ground plane. Proprietary designed clamps (patent pending) attach the transistor leads firmly to the central conductors of the coaxial connectors of the fixture in order to minimize losses and, more important, DC residual resistances, which would dissipate power and heat and possibly thermally destroy the RF connectors.

The test fixture uses two connector launchers, a common base on which one launcher is sliding and one is fixed, a fixture cover, and calibration and measurement inserts. The cover and inserts are made individually for each transistor package, and handle packages from 0.1 to more than 1 inch (2.5 to 25 mm) wide. The calibration inserts include THROUGH and DELAY TRL standards, because the most accurate way to characterize this fixture is the TRL (Through-Reflect-Line) technique, supported by the Focus calibration software. The measurement inserts can have the option of being fitted for cooling water flow for extremely high power applications between 50 and 250 watts RF. MLTF uses either 7 mm precision (GPC-7) or type N connectors. Both connector systems have inner conductors with the same diameter (3 mm) and are therefore fully compatible with the present layout of MLTF. MLTF for 7/16 connector types (7 mm inner conductor diameter) are in development, allowing RF power testing beyond 100 watts.

Insertion and return loss of MLTF is excellent. After calibration, using TRL, the s_{21} and s_{11} of each half of the test fixture are plotted separately (Figures 5 and 6). MLTF has been tested up to 6 GHz and higher frequency units are in work.

Mounting transistors into MLTF is easy: Remove the cover using four knurled screws, unclamp the transistor package, insert a new one, fasten the package leads and



▲ Figure 9. Normalized (Z_0=1.3 ohms) load pull contours of the same transistor as Figure 8, using a PMT-MLTF setup.

replace the cover. The body of the package is pressed firmly to the ground of the measurement insert by two adjustable screws in the cover for good RF return and heat dissipation.

High VSWR prematching tuner, PMT

Normal slide screw tuners, as available on the market today, use one or two microwave probes (slugs) to generate high reflection (Figure 1). Using two rather than one probe normally serves the purpose of increasing instantaneous operation bandwidth. The probes are independent in the vertical direction but move together horizontally. A single probe can instantaneously cover up to a 3 octave frequency range (f_{max}/f_{min} = 8), whereas the combination of two probes covers four to five octaves. Examples for such tuners are available from Focus Microwaves and operate in the frequency range of 0.2 to 6 GHz or 2 to 40 GHz [5, 6]. However, using two parallel probes does not raise the reflection factor itself dramatically, even if both probes are mounted close together to increase the capacitive effect.

R (ohms)	jX	$\|\Gamma\|$	Φ	$\Delta\Gamma$ (dB)
	Area 1: tuning around 1 ohm			
0.986	0.0918	0.961	179.8	–47.26
0.996	0.2147	0.961	179.5	–49.35
0.949	–0.0245	0.963	180.1	–53.10
0.977	0.3455	0.962	179.2	–45.05
0.845	0.2406	0.967	179.5	–50.32
0.798	–0.0107	0.969	180.0	–47.06
1.093	–0.1666	0.957	180.4	–47.32
1.359	0.4402	0.947	179.0	–55.03
	Area 2: Tuning around 0.4 ohm			
0.414	–0.1211	0.984	180.3	–47.43
0.409	–0.0106	0.984	180.0	–54.03
0.408	0.0954	0.984	179.8	–51.13
0.406	0.2044	0.984	179.5	–55.49
0.407	0.3217	0.984	179.3	–45.48
0.418	0.4574	0.983	179.0	–51.18
0.428	0.6284	0.983	178.6	–45.02
0.453	0.8637	0.982	178.0	–51.74

▲ Table 1. Tuning accuracy of PMT at very low impedances.

The prematching tuners developed for the present application use two fully independent microwave probes, both horizontally and vertically (Figure 3). Their synchronization creates a resonant effect that generates extremely high reflection coefficients (Γ), practically equal to 0.995. Performance beyond this is limited in measurement accuracy by the available Network Analyzers. Calibration of such high reflections is, obviously, a difficult operation. Focus provides a specially designed algorithm for calibrating prematching tuners in very short time (about 10 minutes per frequency point) enabling the measurement software to synthesize any impedance on the Smith Chart with $\Gamma \leq 0.99$ (or VSWR $\leq$200:1) combining the reflections of both microwave probes. Tuning accuracy of such a tuner has been verified at very low impedances and we measure deviations between synthesized and measured reflection coefficients of –40 to –55 dB around 0.4 ohm (V >>0.985) [7]. Table 1 shows the impedance and reflection factor of a PMT as tuned by the software and as measured on the calibrated network analyzer. The difference Δ between measured and synthesized reflection factor is calculated using the formula:

$$\Delta\Gamma = 20 \log|s_{11meas} - s_{11calc}| \quad (1)$$

The first set of data, "Area 1: Tuning around 1 ohm," in Table I means that the tuning section of PMT (probe 2) moves around vertical zero (initialized), while the prematching section (probe 1) stays put to high VSWR. The second set of data, "Area 2: Tuning around 0.4 ohm," is the final tuning area, when probe 2 (tuning probe) is close to the central conductor. This is the real operation area of PMT. The tuning accuracy shown varies between –40 and –55 dB which is excellent for this type of operation.

Experimental results

We measured high power transistors using a traditional setup and compared the same transistor measured with the new technique. The effect is especially significant when the traditional setup cannot reach the low impedance required by the transistor (Figure 8). In this case the optimum reflection factor is at the edge of the calibration region of the tuners and test fixture (R_{min} >>3.8 ohms). As we can see the contours are not closing around the optimum point and, by comparison with the contours of Figure 9, we understand that the transistor has not yet been effectively power matched. When we employ a MLTF-PMT combination, however, we can envelop the optimum Γ with calibrated points. The contours are closed around the optimum point and the measurement accuracy is increased. We also obtain a much higher value for maximum power, nearly 2 dB more (Figure 9).

Conclusion

New equipment presented by Focus Microwaves allows fast, accurate and easy load pull testing of high power packaged transistors at very low impedance levels. This equipment includes extremely low loss test fixtures (MLTF), compatible with most power transistor packages, and high VSWR programmable prematching tuners, PMT. Impedances as low as 0.35 ohm at DUT reference plane are possible at cellular and PCS frequencies. ■

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