Prematching Tuners Advance Load-Pull Testing

The next generation of load-pull test equipment has arrived in the form of prematching microwave tuners with calibrated SWRs of 150:1 and higher.

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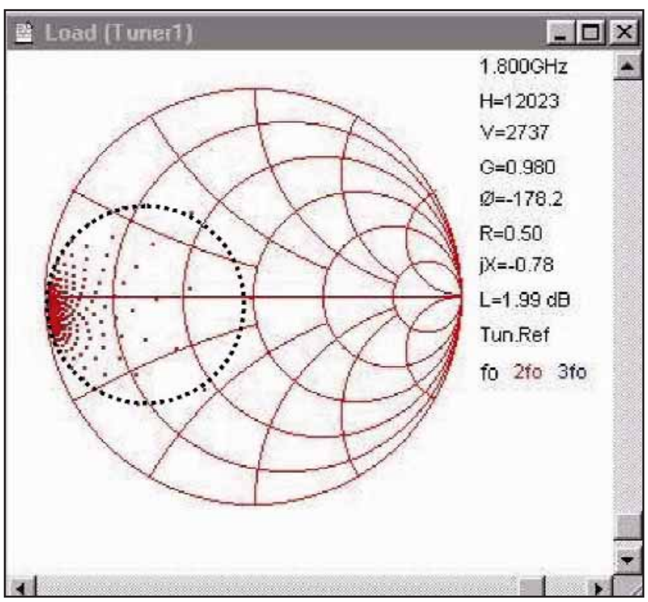
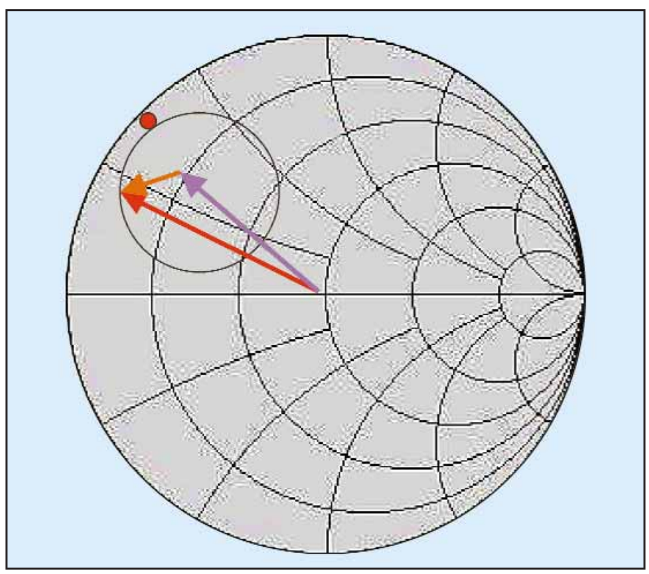
NONLINEAR characterization of power transistors is critical for progress in commercial markets such as cellular communications. In addition to forcing designers away from pure computer modeling and back to the measurement benches, sophisticated "device engineering" in numerous laboratories employs load-pull data to modify and optimize doping profiles and transistor layout designs for higher efficiency, linearity, and output power. To aid this revolution, a family of programmable impedance tuners based on prematching concepts has been developed by Focus Microwaves (St. Laurent, Quebec, Canada) to improve the measurement accuracy of even the lowest-impedance power transistors, including laterally-diffused-metal-oxide-semiconductor (LDMOS) high-power transistors for cellular base stations.

Power transistors used in cellular and personal-communications-services (PCS) base stations are inherently low-impedance devices that require the synthesis of the appropriate low-impedance matching networks. Ten years ago, transistors with internal impedances of 5 Ω were considered state of the art. Now, high-power transistors exhibit internal impedances below 1 Ω. These transistors are characterized with the aid of adjustable, calibrated load-pull impedance tuners that must provide accurate low-impedance synthesis at high power levels. Automatic testing is also important for timely data acquisition (DAQ), where computer-controlled electromechanical



1. These are the tuner calibration points as seen by a DUT through a quarter-wave transformer.



2. The programmable prematching tuners make it a simple matter to tune around any point on the edge of the Smith Chart.

slide-screw tuners have been used for some time due to their superior power-handling capability, high resolution, and dynamic tuning range, and large bandwidth.

Commercial automatic slide-screw tuners use one or two microwave probes (slugs) to generate high reflection states. The best electromechanical coaxial tuners may accurately generate maximum SWRs of approximately 15.0:1 (corresponding to a real part of the internal resistance of the transistors of approximately 3.3 Ω or a reflection coefficient, Γ, of 0.875). Using two probes rather than one increases the instantaneous operating bandwidth. The probes are independent in vertical direction but move together horizontally. A single probe can provide an instantaneous frequency range to three octaves ($f_{max}/f_{min} = 8$), whereas the combination of two probes may cover more than a decade in bandwidth. Examples of these tuners are available from Focus Microwaves and span the frequency range of 0.2 to 6.0 GHz, 0.8 to 18 GHz, or 2 to 40 GHz.[1-3]

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. Beyond a reflection level of Γ = 0.875, network-analyzer calibration and impedance-tuner repeatability may cause accuracy and measurement repeatability problems. Many commonly used lossy test fixtures will further reduce the available reflection factor at the reference plane of the device under test (DUT) to unacceptably low values of approximately 10.0:1 for SWR and about 5 Ω for the minimum impedance. The situation can be improved somewhat by the use of quarter-wave microstrip transformers on the test fixture at the test frequency[4], the use of "active" load-pull modules[5] combined with passive tuners, or the use of an entirely active load-pull systems.[6]

MANY COMMONLY USED LOSSY TEST FIXTURES WILL FURTHER REDUCE THE AVAILABLE REFLECTION FACTOR AT THE REFERENCE PLANE OF THE DEVICE UNDER TEST TO UNACCEPTABLY LOW VALUES OF APPROXIMATELY 10.0:1 FOR SWR AND 5 Ω FOR THE MINIMUM IMPEDANCE.

Unfortunately, active systems, either complete active load-pull setups or active modules, are not adequate solutions for characterizing packaged high-power transistors due to

3. Programmable prematched tuners in the PMT line are currently available for applications to 18 GHz, with models soon available for use to 50 GHz.

high-power limitations and parasitic oscillation problems. The only remaining realistic solution is the quarter-wave transformer method, which is affordable, simple to design, and easy to realize, but also has the shortcomings of being cumbersome, frequency selective, and must be redesigned for each particular DUT. Quarter-wave transformers pretune by nature into a restricted specific area of the Smith Chart, normally (although it may vary from transistor to transistor) the area around a short circuit (where Φ = 180 deg.). One problem is that once the quarter-wave transformers have been fabricated, tuning outside of this prematched area of the Smith Chart is impossible (Fig. 1).

NEW SOLUTION

The new tuner family from Focus Microwaves is based on prematching principles. This means that a first probe raises the reflection factor to a considerably high value. Then a second probe tunes around this level and very close to $|\Gamma| \cong 1$. Since the phase of the first reflection factor vector can be adjusted arbitrarily, it is a simple matter to tune around any point at the edge of the Smith Chart (Fig. 2).

Prematching can also be viewed as a resonance phenomenon where the only limiting factor for obtaining a reflection factor of $|\Gamma| = 1$ is the transmission line losses between the input connector of the tuner and the first (prematching) probe. For probe posi-

FOR PROBE POSITIONS OF TUNERS USING GPC-7 CONNECTORS THAT ARE VERY CLOSE TO THE INPUT PORT (PREMATCHING SECTION INITIALIZED HORIZONTALLY), IT HAS BEEN POSSIBLE TO OBTAIN REFLECTION COEFFICIENTS OF BETTER THAN 0.998.

tions of tuners using GPC-7 connectors that are very close to the input port (prematching section initialized horizontally), it has been possible to obtain |Γ| > 0.998. Since this position is not necessarily the one required to tune around Φ = 180 deg. and the first probe must be moved away from the connector, practical maximum values of |Γ| are approximately 0.99 to 0.995, values which are equivalent to SWRs of 200:1 to 400:1 (Figs. 3 and 4).

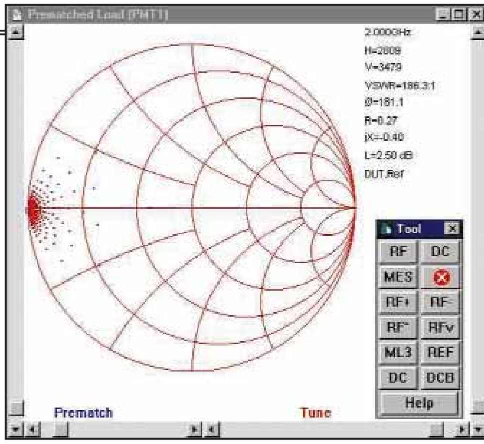
Measurements beyond these levels are limited in measurement accuracy by the choice of vector network analyzer (VNA). Calibration of these high reflections is, obviously, a difficult operation. Focus Microwaves provides a specially designed algorithm for calibrating prematching tuners in a relatively short time (approximately 20 min. per frequency point) enabling the measurement software to synthesize any impedance on the Smith Chart with Γ ≤ 0.99 (or SWR ≤ 200:1) combining the reflections of both microwave probes.

Tuning accuracy of PMT at very low impedances

R(Ω)	jX	|Γ|	Φ	Δ(Γ)[dB]
Area 1: tuning around 1.0 Ω				
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 Ω				
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

The tuning accuracy of these tuners has been verified at very low impedances. Measurements have been made on deviations between synthesized and measured reflection coefficients of –40 to –55 dB around 0.4 Ω (which is equivalent to Γ ≅ 0.985).[7] The table shows the impedance and reflection factors of a prematched microwave tuner as tuned by the associated software and measured with a calibrated VNA. The difference (ΔΓ) between the measured ($S_{11\,meas}$) and synthesized (S_{11} calc) reflection factors is calculated using the simple formula: $\Delta\Gamma = 20\log|S_{11\,meas} - S_{11\,calc}|$

The first set of data in the table (area 1, tuning around 1 Ω) means that the tuning section of

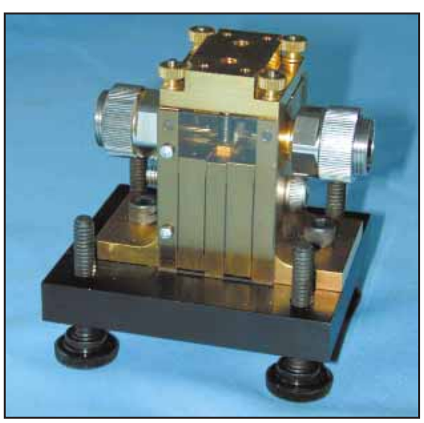


4. The maximum tuning range of the PMT tuners approaches an equivalent SWR of 200:1 at 2 GHz.

the prematched microwave tuner (probe 2) moves around vertical zero (initialized), while the prematching section (probe 1) remains set to a high SWR. The second set of data in the table (area 2, tuning around 0.4 Ω) is the final tuning area, when probe 2 (the tuning probe) is close to the central conductor. This is the real operation area of the PMT. The tuning accuracy exhibited by the PMT varies between –40 and –55 dB, which is excellent for this type of operation.

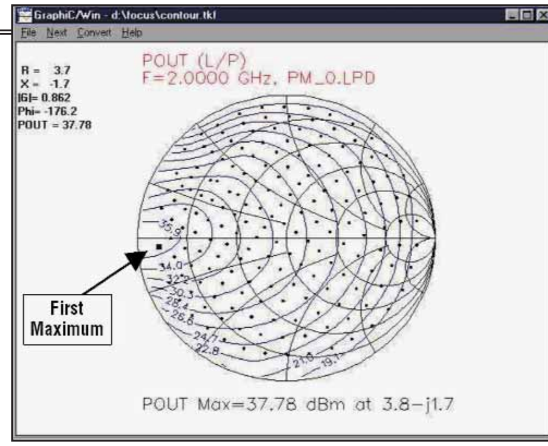
Of course, the advantage of generating high-SWR tuning would be compromised by the use of lossy test fixtures, especially those with low-quality microstrip-transmission materials. To avoid this and take full advantage of the PMT's capabilities, Focus has developed a minimum loss test fixture (MLTF) with an extremely low insertion loss of less than 0.02 dB at 2 GHz (Fig. 5).[8] It is the only commercial test fixture of this kind that is compatible with most power transistor packages. It is available with through-reflect-line (TRL) calibration standards and is simple to use. The MLTF employs proprietary connector clamps to minimize RF and DC contact losses and can be used to maximize the SWR at the device-under-test (DUT) reference plane to values of approximately 100:1 or minimum tunable resistances of 0.4 Ω, without using any transformers, active loads with amplifiers, closed gain loops, or other additional networks.

The prematching tuners offer few shortcomings and many advantages. Using special proprietary techniques



5. A model MLTF minimum loss test fixture has been developed for use with the PMT tuners. The fixture exhibits less than 0.02-dB loss at 2 GHz.

developed by Focus Microwaves, the total load-pull system can be calibrated easily, quickly, and very accurately. The tuners themselves are fully characterized at a combination of 400 × 400 impedance points in approximately 20 min. per frequency point around 1 GHz. At higher frequencies, the calibration time is even less. The calibration of prematching tuners is very accurate, despite the extremely high reflections involved. The main reason for this is that the total reflection of the tuners is generated by cascading two medium size reflections with SWR ≅ 12:1, resulting in a total SWR of more than 150:1 at the tuner reference plane. Interpolation routines available in the Focus measurement software support the accurate synthesis of millions of impedances at any point of the Smith Chart, corresponding to reflection factors up to $\Gamma \cong 0.995$. The tuners can handle significantly more power than simple tuners at the same level of SWR, because both probes in the prematching slide-screw tuners stay further away from the central conductor, since each probe needs to generate a lower individual SWR. The tuning area can be pointed at will to any angle of the Smith Chart (not only around 180 deg., as is the case with quarter-wave transformers). The transforming ratio and, consequently, the surface of the tuning area and Γ_{max} can be freely adjusted.



6. These load-pull measurements performed with a normal tuner and microstrip test fixture show that the DUT, a power transistor, has not been properly matched.

To evaluate the new prematching tuners, high-power transistors were measured with a traditional test setup, then compared to results taken with the new prematching tuners. The comparison is especially telling when the traditional setup cannot reach the low impedance required by

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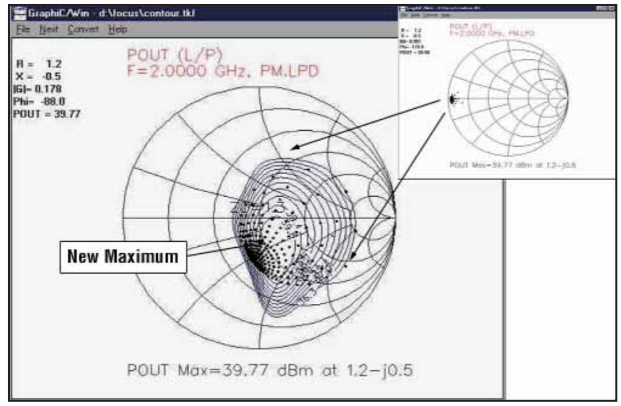
the transistor (Fig. 6). In this case, the optimum reflection factor is at the edge of the calibration region of the tuners and test fixture ($R_{min} \approx 3.8$ Ω). As can be seen, the contours are not closing around the optimum point in the traditional setup and, by comparison with the contours of Fig. 6, the transistor has not been effectively power matched. Using a combination of the PMT and the MLTF, however, it is possible to envelope the optimum Γ with calibrated points. The contours are closed around the optimum point and the measurement accuracy is increased. In addition, a much higher value is achieved for maximum power (Fig. 7), close to 2 dB more.



7. In contrast to the results of Fig. 6, these normalized load-pull contours, measured with the PMT/MLTF combination, yield +39.8-dBm output power instead of +37.8 dBm with the contours of Fig. 6. The inset shows the non-normalized measurement points.

The new automatic prematching microwave tuners can generate high SWRs of 200:1 in any area of the Smith Chart and at any frequency from 0.4 to 18 GHz. In the near future, additional PMT models will be available with top frequencies that consist of 26.5, 40, and 50 GHz. When used with the firm's low-loss microwave test fixtures, load-pull testing of packaged power transistors is possible at impedances below 0.5 Ω at cellular and PCS frequencies without the use of transformers or active systems. **Focus Microwaves, Inc., 970 Montee de Lisse, St. Laurent, Quebec, Canada PQ H4T 1W7; (514) 335-6227, FAX: (514) 335-6287, e-mail: christos@focus-microwaves.com, Internet: http://www.focus-microwaves.com.**

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