cover story

Three-Probe Tuner Tackles Multiple Tasks

This combination of software and a versatile three-probe tuner system provides true broadband prematching, harmonic, and zero-vibration tuning without a change in hardware.

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electromechanical impedance tuners provide the appealing combination of extremely high VSWR (to 200:1) and high power-handling capability (to 400 W CW). Until now, electromechanical slide screw tuners have been built as wideband models (with two probes of different lengths), as high-VSWR systems (with a prematching stage), or as harmonic rejection tuners, although not with all three characteristics at the same time. The MPT Multi-Purpose Tuners from Focus Microwaves (Montreal, Quebec, Canada) change all that by combining multioctave tuning, high VSWR, stable performance with wide-instantaneous-bandwidth harmonic load-pull capability from a single, compact system.

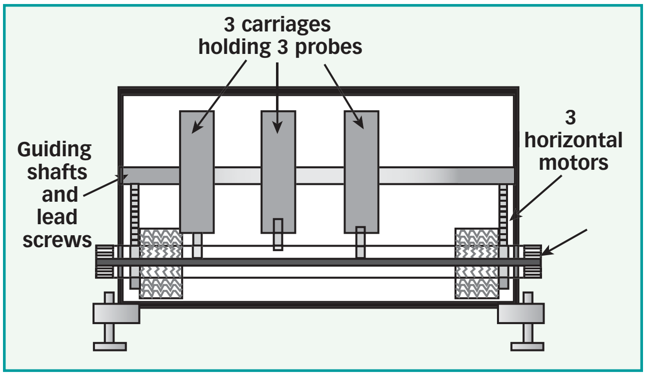
Electromechanical tuners provide excellent resolution, with several million tunable points at any frequency. Interpolated tuning allows adjustment to almost any impedance over a wide range, with almost ideal lowpass behavior (because they use a 50-Ω transmission airline as default media) and comprehensive harmonic tuning using

1. The MPT-1840 is an example of the Multi-Purpose Tuner line with three-probe coverage from 4 to 18 GHz that allows impedance tuning at a fundamental frequency and two harmonics simultaneously.

harmonic rejection tuners or frequency discriminators (triplexers).[1] Wideband tuners can pose a problem when used for load-pull testing of highly compressed transistors without separate harmonic tuning. The effect of uncontrollably dangling harmonic impedances generates nonquantifiable and noncorrectable systematic measurement errors, which falsify the basic form of the load-pull contours.[2] To avoid such errors, complex harmonic load-pull setups have been using, some with frequency triplexers and a trio of tuners[3] and some with one wideband and one harmonic-rejection tuner per device under test (DUT).[4]

The MPT is an important evolution of the slide-screw electromechanical tuner, with three cascaded and independent wideband probes. The patent-pending MPT can be used as a harmonic tuner (covering the fundamental, second-harmonic, and third-harmonic frequencies) over the full bandwidth of the probes, as a high-VSWR prematching tuner, as an ultrawideband tuner for continuous frequency coverage, and as an ultrastable tuner for on-wafer applications. One example of the MPT series is the model MPT 1840, with frequency coverage from 4 to 18 GHz **(Fig. 1)**.

Slide-screw tuners create a variable reflection factor by means of a metallic probe, capacitively coupled to the center conductor of a slotted airline (slabline). The amplitude of the reflection factor is increased by inserting the probe into the slotted airline **(Fig. 2)**. By moving the probe horizontally, the phase is adjusted. A movement of one-half wavelength at a given frequency along the slabline accounts for 360 deg. control of phase. As a result, any impedance up to the maximum tuning range ($VSWR_{max}$) of the tuner can be created.



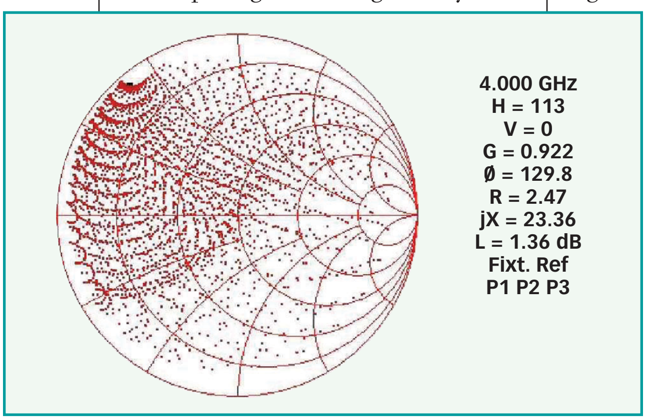
2. This cross-sectional view of a three-probe MPT shows the horizontal and vertical motion of the probes.

Typical values of $VSWR_{max}$ vary between 12.0:1 and 30.0:1 for single-probe tuners (Γ = 0.846 to 0.935). Dual-probe tuners, if configured properly (prematching) may create VSWRs to 200.0:1 (Γ = 0.99) at C-band frequencies.

Arbitrary reflection factors can also be generated by using three variable stubs at a fixed distance to each other (mechanical variable stub tuner),[5] or an array of PIN diodes that can be switched on and off electrically.[6] These approaches are optimum when the electrical distance between individual reflection factors is 120 deg. Assuming each one of three independent probes (slugs) P1, P2, P3 are positioned 120 deg. from each-other and their amplitudes (vertical positions) are changed independently, every point on the Smith Chart can be attained as a vector combination of two reflection factors at a time (P3a + P2b= A and P1=0). Of course, that optimum spacing of 120 deg. is only valid for a single frequency, limiting coverage on the Smith Chart for other frequencies. Also, the shorted stubs of traditional multistub tuners act either as capacitors or inductors, depending on the frequency, and thus change the basic tuning behavior.

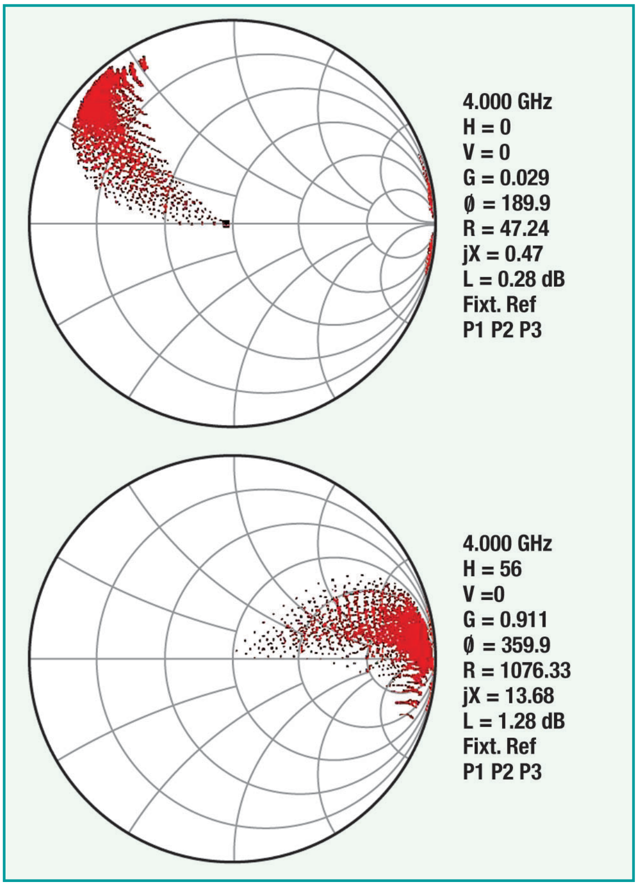
The MPT approach allows free positioning of each probe horizontally and thus selecting the optimum phase between probes at every frequency. MPT tuners can be manufactured using existing technology. The system calls for a minimum of three independent carriages and probes (slugs), but uses the same design as used in traditional slide-screw tuners. The MPT systems do require three independent horizontal drives, since the company's tuners are based on a lead screw centered on each mobile carriage. But using three smaller-than-normal axes centered in the carriage has made this possible.

The MPT tuners are calibrated using a precalibrated commercial vector network analyzer (VNA). VNA calibration must be carried out previously, using through-reflect-line (TRL) calibration techniques and meticulous verification. MPT calibration can be performed in situ (with) or by connecting the MPT tuner directly to the VNA. In situ calibration performs measurements on other test-related components remaining connected to the measurement setup, and then dembeds the electrical contributions of these additional components from the S-parameter measurements through specialized algorithms. In-situ techniques are more delicate to execute, but provide better accuracy due to fewer disconnections; they are recommended for measurements above 10 GHz.

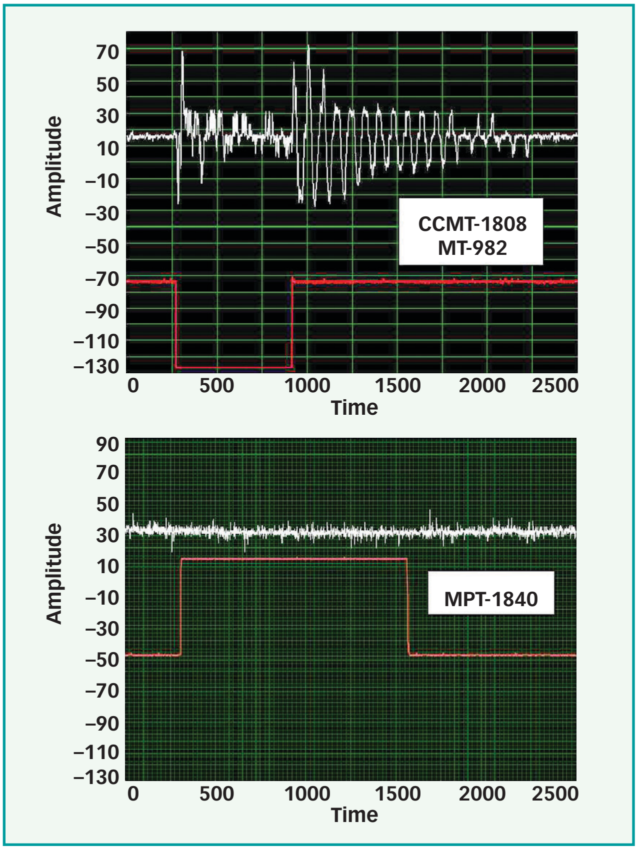


3. Vertical MPT probe movement along resulted in this impedance spacing around the Smith chart at 4 GHz.

The MPT has three independent cascaded tuning sections. The total combined calibration points, if each section



4. These tightly spaced calibration points were created at 4 GHz by only changing the vertical position of the three probes.



5. Measurements on a standard slide-screw tuner (top) in horizontal motion show this response (the lower trace plots the stepper motor motion), while the vertical-only motion of the MPT tuner shows very little vibration (bottom).

were calibrated at 455 points, is $(455)^3 = 94,196,375$ per harmonic frequency. Because of the difficulty in calibrating so many points even with fast computers and VNAs, the Focus MPT software incorporates a calibration algorithm which generates all 94 million possible combinations of points per set of fundamental and harmonic frequencies in less than 30 minutes. With second-order interpolation, even more impedance states can be synthesized, limited only by the mechanical resolution of the stepper motors and translation gears. A full MPT calibration, including calibration points for three tuning sections and a set of harmonic frequencies (f_0, $2f_0$, and $3f_0$) is saved in a tuner calibration file (typically only 60 to 120 kB). The calibration data are retrieved in memory during the operation and impedances for each harmonic frequency can be synthesized by using one of the possible combinations of the large number of tuner positions.

MPT reflection factors are created either by a single probe or by combining two or three individual reflection vectors **(Fig. 3)**. After the MPT has been calibrated it can be used either as a

- single probe or ultrawideband tuner, if two probes are initialized and one probe used at a time,
- prematching tuner, if one probe is initialized and two probes used,[4] or a
- vibration-free tuner when all three probes are moved vertically only, and
- amplitude and phase harmonic tuner, when all three probes are inserted into the slabline.

Vibration-free operation can be achieved by eliminating horizontal tuner movement. In this approach, the horizontal distance between the three probes is fixed (typically 120 deg. apart) and calibration points are distributed by means of vertical probe movement only [**Figs. 4(a)and 4(b)**]. Of course, if both horizontal and vertical movements are used for all three probes, then several million impedance states are available for f_0, $2f_0$, and $3f_0$ frequencies.

All tuning patterns can be controlled by the WinPower load-pull measurement software supplied with the MPT system. The software supports wideband tuning, vibration-free and harmonic tuning, and prematching tuning. In particular, full load-pull testing at the fundamental frequency can be performed without moving any of the three probes horizontally and thus eliminating any cause of vibration. The large amount of tuning points at all harmonic frequencies offers the possibility of simultaneous harmonic tuning of individual impedances at f_0, $2f_0$, and $3f_0$. The technique consists in searching within the large amount of calibrated points for the appropriate sets of probe positions.

Because of the huge amount of calibrated points (if each section is calibrated at 200 points, a total of 8,000,000 calibrated points results and if each section is calibrated at 400 points, a total of 64,000,000 calibrated points results), it is a near statistical certainty that several tuner positions will generate harmonic impedances satisfying certain tuning conditions. The "tuning conditions" define the acceptable tolerance, in terms of reflection factor units, between the target and the attained reflection factors at the three harmonic frequencies. For smaller tuning tolerances, higher tuning resolutions are needed and the more time consuming the "tuning search" algorithm becomes. Appropriate file segmentation and fast computers [faster than 2.4 GHz and at least 1 GB of random-access memory (RAM) are required] allow fine harmonic tuning in a matter of seconds.

Harmonic tuning may not always be possible in every corner of the Smith Chart. This may happen if the effective bandwidth of the probes does not cover f_0 to $3f_0$ simultaneously. Because of this, the size and frequency range of the probes must therefore be carefully chosen.

A simple software dialog box allows the user to generate the search files needed for different harmonic tuning accuracies with an MPT tuner. The maximum accuracy corresponds to the total of calibrated points [in this case $(455)^3$ = 94,196,375 points]. Medium accuracy uses 11,774,546 points and so on. The highest accuracy requires the maximum amount of storage and processing time, roughly 4 to 5 minutes. Once the data is created, it is saved and used for harmonic tuning, which in itself takes typically 3 seconds per tuned point.

When tuning with only vertical movements, MPTs do not suffer tilting or unwanted long-term motion. Since the probes in such an application move only vertically, the center of gravity is fixed during an entire load-pull measurement cycle. The only possible cause of vibration is therefore the vertical stepper motors (short-term vibrations). Such vibration has been evaluated with noncontacting Hall effect sensors and a dual-channel digital storage oscilloscope (DSO).

Figure 5 (top) shows typical short-term vibrations of standard single-carriage electromechanical tuners while Fig. 5 (bottom) compares the stable performance of the MPT system. The lower trace in both figures shows the motor activity (in this case the horizontal motor moves 100 steps and stops). The upper trace shows the short-term vibration of the tuner housing transferred to the probe via the rigid airline. The scale is in micrometers (maximum amplitude of 100 μm). This type of behavior has been measured on all commercial electromechanical tuners of this type. In contrast to the single-carriage tuner, an MPT system in vertical-only model shows no measurable vibration. In addition, the tuning probes are extremely well isolated from each other. As a result, load-pull tuning at a fundamental frequency (f_0) will have negligible effect on the tuning of the second- ($2f_0$) and third-harmonic ($3f_0$) probes. Measurements have shown about 25-to-30-dB isolation between the f_0 and $3f_0$ probes, and about 40-dB isolation between the f_0 and $2f_0$ probes **(Fig. 6)**.

In short, the MPT tuners offer the functionality of several different impedance-tuning systems, and with broadband frequency coverage. Because the MPT tuners employ microprocessor-based, control electronics (TCP/IP or iTuner), users can develop their own automated applications using LabView™, Visual Basic™, Agilent Vee™, and other test programming solutions. **Focus Microwaves, Inc., 1603 St-Regis, D.D.O, Quebec H9B 3H7, Canada; (514) 684-4554, FAX: (514) 684-8581, e-mail: info@ focus-microwaves.com, Internet: www.focus-microwaves.com.**

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