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cover story

Load-Pull Tuners Are Frequency Selective

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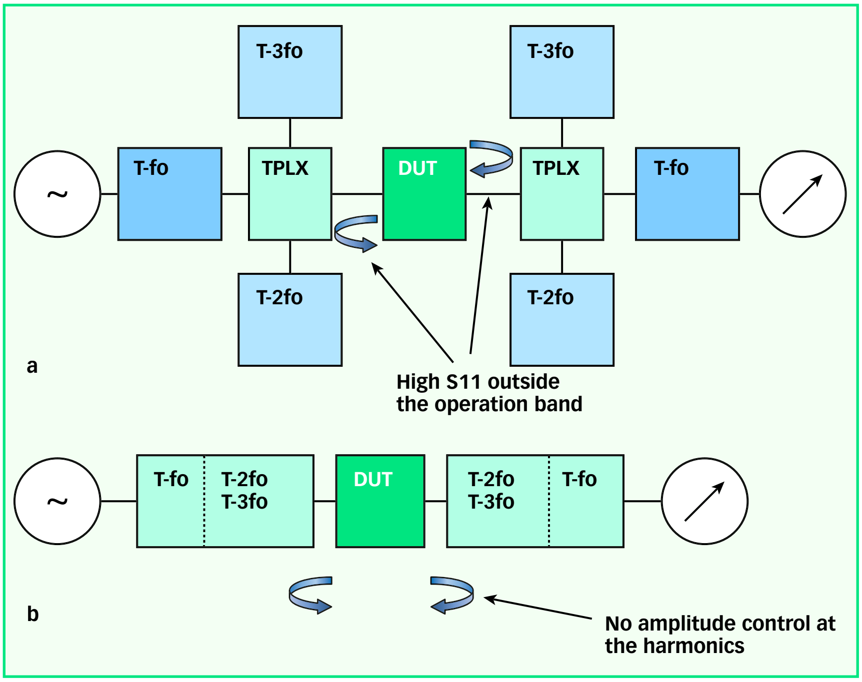
These precision computer-controlled tuners allow independent control of impedance at a fundamental frequency and two or more harmonic frequencies.

Power-amplifier (PA) designers must constantly strive for improved linearity and efficiency to meet the needs of current and emerging communications standards. High-data-rate digital modulation formats require nearly distortion-free performance from a PA, requiring the amplifier designer to fully characterize active devices before developing matching networks. Fortunately, a new series of frequency-selective tuners from Focus Microwaves, Inc. (Dollard-des-Ormeaux, Quebec, Canada) provide PA designers with the ability to create independently controllable impedances at three different frequencies for unprecedented insight into the nonlinear behavior of large-signal active devices.

The new frequency-selective tuners (FSTs) greatly simplify amplifier amplitude and phase tuning at fundamental and several harmonic frequencies **(Fig. 1)**. The tuners, which are compact enough for positioning with wafer-probing equipment, provide a high reflection coefficient at the reference plane of a device under test (DUT), whether in a test fixture or on wafer. The tuners feature low out-of-band reflections to minimize the change of DUT oscillation or spurious generation. Resonator cells are relatively transparent out of band and thus can be readily cascaded for true multifrequency harmonic tuning. The tuners are currently available for frequency ranges from 1.8 to 18.0 GHz.

Modern PA designers require the most accurate possible transistor data for a wide range of RF and DC parameters as functions of DC bias, RF impedance (at different frequencies), source power, and other variables. For example, power transistors are often driven into regions of strong nonlinearity in order to achieve high power-added efficiency (PAE). One way to reach the maximum PAE for given levels of linearity and output power involves using harmonic-load pull measurements to determine the impedance conditions at the fundamental frequency and the second-harmonic frequency that result in the best

1. The model FST-1818 is a frequency-selective tuner (a) designed for use from 1.8 to 18 GHz, with separate resonators (b) for independent impedance control at a fundamental and two harmonic frequencies.



2. A traditional harmonic load-pull system (a) can involve as many as six impedance tuners and supporting hardware, which can be simplified through the use of combination fundamental/harmonic tuners (b).

compromise among PAE, linearity, and output power. By optimizing the RF impedance at the second harmonic frequency, it is not uncommon to double the PAE compared to nonoptimized conditions.

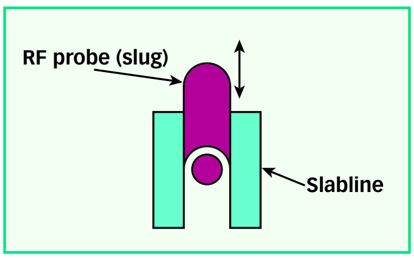
A full harmonic load-pull measurement system for testing at fundamental, second-harmonic, and third-harmonic frequencies incorporates DC sources, RF signal sources, power meters, driver amplifiers, passive signal-coupling components, analyzers, and six impedance tuners [**Fig. 2(a)**]. The complex setup is expensive and tedious to calibrate and operate, especially when running on-wafer measurements. A more practical system employs just two combination tuners capable of impedance tuning at the fundamental and harmonic frequencies [**Fig. 2(b)**], an approach developed several years ago by Focus Microwaves. Unfortunately, the concept of harmonic tuning used in these components only provides control of the phase of the reflection factor at harmonic frequencies, albeit at a very high reflection coefficient. For full amplitude control at all harmonic frequencies, a test set requires the use of triplexers or active loads, which yield a limited range of reflection coefficient, have inconveniently high reflection at lower frequencies (triplexers) with the associated risk of spurious oscillations with high-gain devices, or active loads, which are complex and expensive.[1]

Traditional microwave tuners employ a movable metallic and RF grounded probe inside a high-frequency slab line **(Fig. 3)**. The distance between the probe and the center conductor of the line (the vertical position) determines the amplitude of the reflection coefficient seen at the tuner's ports. Moving the probe along the center conductor (the horizontal position) adjusts the phase. In general, such tuners provide almost constant VSWR over wide frequency ranges, such as 0.8 to 3.0 GHz and 3 to 18 GHz, with gradually roll off of VSWR at the high end of low reflection at frequencies below the specified operating range. Although wideband performance is desirable for generic test equipment, it often creates instability problems when performing variable impedance tests on high power/gain devices.

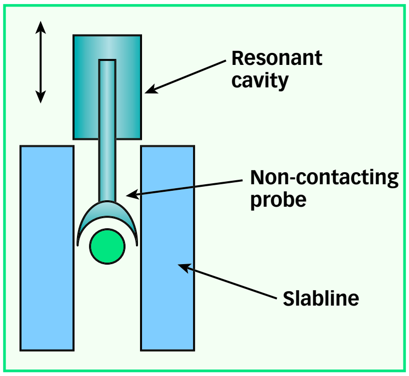
The frequency-selective tuners (FSTs) were developed to combine the advantages of frequency-selective frequency discriminators with lowpass tuners. The new tuners employ noncontacting resonant probes (slugs) at all frequencies **(Fig. 4)** and allow independent adjustment of reflection factors at a fundamental and two or three harmonic frequencies. Depending on the fundamental frequency, harmonics as high as the fourth or fifth harmonic can be selected. The limitation of two or three harmonic frequencies is due to the required travel of the probes (for 360-deg. phase coverage) and the allowable overall size of the tuner.

When the resonant probe is moved closer to the central conductor, coupling increases and so does the reflection factor. Due to the high quality factor (Q) of the resonator, the overall resonant frequency is not significantly affected (shifted), allowing a fairly well controlled tuning scheme for the fundamental frequency and second- and third-harmonic frequencies **(Fig. 5)**. The tuner is calibrated at each frequency in the manner of an ordinary wideband tuner, resulting in well-behaved calibration patterns for amplitude and phase **(Fig. 6)**. The company's load-pull software allows accurate interpolation and tuning to any point of the Smith Chart, and includes the capability of "back-tuning" to reduce the harmonic cross-tuning below –20 dB.

Spurious oscillations can be a problem when performing load-pull tests on high-gain transistors in a narrow frequency band of interest (usually at the low-frequency bandedge where the gain is highest). During testing, the input and output impedances seen by the DUT are well known, due to the previous tuner calibration, but reflections are also generated by the test setup, including the tuners, and these are not controllable. Because of these reflec-



3. A precision slide-screw tuner can provide a large range of reflection coefficients over a wide band of frequencies.



4. The FSTs employ noncontacting resonant probes for independent control of impedances at fundamental and harmonic frequencies.

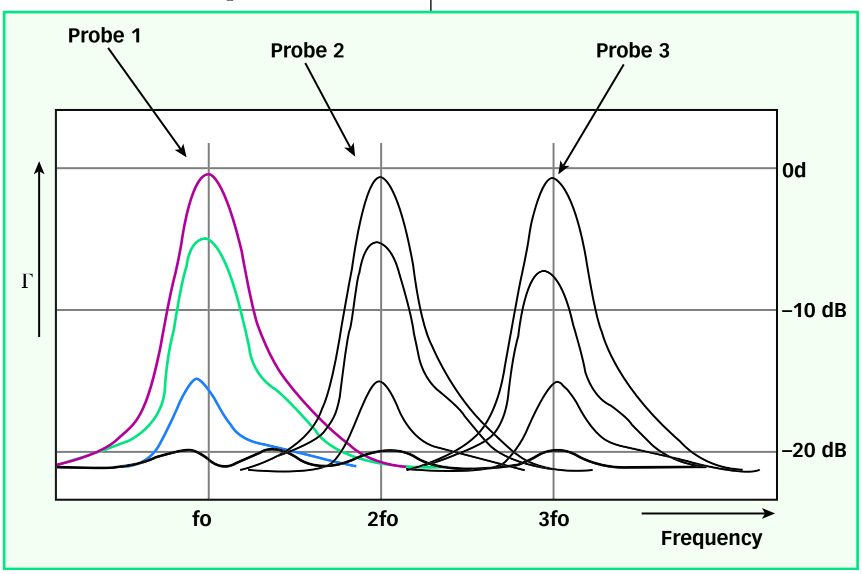
tions, a high-gain DUT may start oscillating at any frequency where the oscillation conditions are fulfilled at its input or output port, and this is typically not the test frequency.

Typical microwave transistors are stable when loaded with an impedance of 50 Ω at one of their ports. Oscillations most often occur when a DUT is presented with a high reflection coefficient; oscillations will start at frequencies where the phase of the DUT and the tuner satisfy the oscillation condition. Fortunately, an FST, which maintains low reflection at all frequencies except in a narrow band of operation, safely solves the out-of-band instability problem when testing high-gain DUTs.

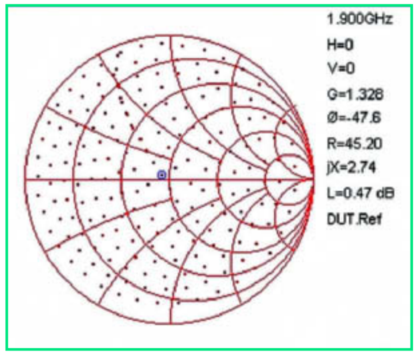
Passive components in the traditional harmonic load-pull measurement setup, such as narrowband isolators and low-loss triplexers, generate reflections outside their normal band of operation. Although isolators are needed for the harmonic load-pull system to operate properly and generate moderate reflections (with reflection coefficient values of 0.5 to 0.6) outside the band of interest, the triplexers (which generate reflection coefficient values close to 1) can be replaced by harmonic tuners.

The FSTs employs the company's iTuner controller. The powerful real-time microprocessor controls the six stepper motors required to adjust magnitude and phase at three frequencies simultaneously. The controller is connected directly to the computer's network card and commands are exchanged via TCP/IP. A nonvolatile 4K electronically erasable programmable read-only memory (EEPROM) is used to store operational parameters, such as model, serial number, and IP address. A removable data flash-memory card (as much as 64 MB) contains tuner calibration data, which can also be uploaded after recalibrating the system.

The microcontroller autonomously determines the positions of the three probes required to present a given reflection coefficient at the DUT reference plane. The positions are calculated based on calibration data for a given frequency, and take into account user-defined test-



5. The tuning scheme of an FST is designed to alter the amplitude without detuning the resonator frequency.



6. The plot shows FST amplitude/phase tuning at harmonic frequencies.

fixtures and cables inserted between the DUT and the tuner reference plane. The stepper motors are controlled via dedicated control ICs directly connected to the processor input/output (I/O) port. The acceleration/deceleration profile of the motors has been fine tuned to minimize vibration.

The tuners are factory calibrated, with calibration data are stored on internal flash memory. The system software allows re-calibration of the tuner using a calibrated vector network analyzer (VNA). A novel calibration technique coordinates a three-probe calibration resulting in a high-resolution 400 × 400 × 400 calibration data grid in less than 15 minutes for each fundamental frequency. The internal microprocessor uses the calibration data and second-order interpolation routines to calculate the reflection coefficient seen be the DUT for any valid probe position.

The FSTs operate via an enhanced version of the company's standard "WinPower" load-pull software for Windows-based personal computers. A toggle switch in the software's on-screen toolbox selects the resonator to tune. The corresponding frequency, axis positions, setup and tuner losses and actual impedance seen by the DUT are automatically switched and displayed on a Smith Chart. **Focus Microwaves, Inc., 1603 St. Regis, Dollard-des-Ormeaux, Quebec H9B 3H7, Canada; (514) 684-4554, FAX: (514) 684-8581, e-mail: christos@focus-microwaves.com, Internet: www.focus-microwaves.com.**

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