

Coaxial Tuners Control Impedances To 65 GHz

High-power harmonic load-pull tuners complement a line of coaxial millimeter-wave impedance tuners capable of measurements from 10 through 65 GHz.

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evice characterization at precisely controlled source and load impedances provides insights into the nonlinear behavior of both low-noise and power transistors. For transistors used in wireless amplifiers, this capability can reveal the impedance values needed for optimum linearity and highest efficiency, for example.

Having continuous bandwidth from 10 to 65 GHz allows a wideband look at transistor behavior. Having independent control over impedances at fundamental, second-harmonic, and third-harmonic frequencies makes it possible to evaluate and optimize nonlinear transistors and the effects of harmonic terminations. Fortunately, with the introduction of CCMT-6510 65-GHz coaxial tuner and a line of biharmonic combination tuners from Focus Microwaves (Dollard des Ormeaux, Quebec, Canada), engineers can now learn about device characteristics not apparent from even the best models.

The CCMT-6510 coaxial millimeter-wave tuner (**Fig. 1**) provides a minimum VSWR control range of 10.0:1 (and typically 15.0:1) at frequencies from 10 to 65 GHz. It offers better than 40-dB repeatability with fine stepper-motor-driven control of phase. The phase tuning resolution is 0.076 deg./step at 10 GHz and 0.49 deg./step at 65 GHz. The CCMT-6510 offers 7 million tunable points at 10 GHz and 1.1 million tunable points at 65 GHz.

The CCMT-6510 utilizes the coaxial 1.85-mm V-connector for continuous frequency coverage, in comparison to a waveguide tuner, which is restricted to waveguide-band frequency coverage, such as

JACK BROWNE
Publisher/Editor

1. Model CMT-6510 is a coaxial programmable tuner capable of providing precise control of impedance over a frequency range of 10 to 65 GHz.



33 to 50 GHz or 50 to 75 GHz. Although limited in power-handling capability compared to a waveguide tuner, the continuous bandwidth of the CCMT-6510 allows harmonic tuning at precisely controlled impedance/phase states. The use of coaxial lines also allows DC bias to be passed along to an active device under test (DUT), such as a transistor or amplifier.

The CCMT-6510 makes use of a high-quality-factor (high-Q) resonator or probe that slides along a low-loss transmission line, under the control of a programmable stepper motor, to achieve different impedance (VSWR) states. The tuner achieves a reflection factor or gamma of about 0.9 (a gamma = 1 would represent total reflection, with no power delivered to the load) due to small losses in the transmission line and the probe, which is equivalent to a VSWR of typically about 15.0:1. The tuning resolution of the CCMT-6510 is simply the smallest possible movement offered by the stepper motor, which is about 3 μm .

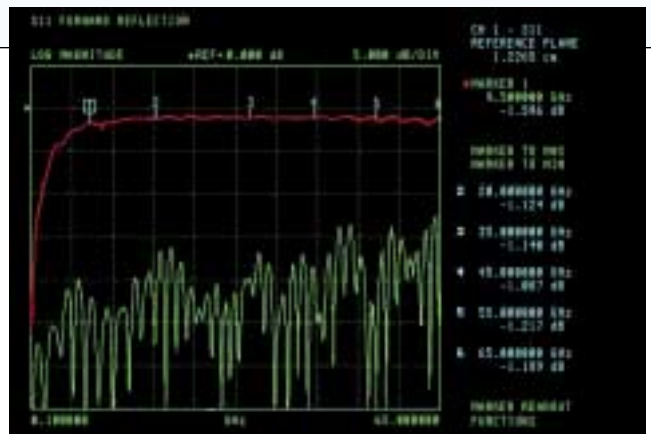
The CCMT-6510 probe is calibrated on a vector-network analyzer (VNA) at any number of frequencies in a sweep or list mode. The user can select the number of calibration points from 100 to 800. The measurement software interpolates with better than 40-dB accuracy to millions of tuning points. The calibration per frequency requires about 4 minutes per frequency. The end result of the precision calibration

is a tuning range that is accurate and predictable, as evidenced by measurements of S_{11} forward reflection across the full tuning range (Fig. 2). The repeatability of the CCMT-6510 is also outstanding, regardless of measurement power level (Fig. 3).

The CCMT-6510 coaxial millimeter-wave impedance tuner, which is ideal for noise and load-pull testing, is supported by a 65-GHz through-reflect-line (TRL) calibration kit for proper setup with a coaxial millimeter-wave VNA from Agilent Technologies (Santa Rosa, CA) or Anritsu Co. (Morgan Hill, CA). The calibration kit includes a delay line, precision shorts, a 50- Ω line, and loads. In addition, the computer-controlled-microwave-tuner (CCMT) software allows operators to define their own instrument drivers. As a result, test equipment associated with the CCMT-6510, such as signal generators and VNAs, can be controlled from a personal computer (PC) running the CCMT software.

Harmonic Tuning

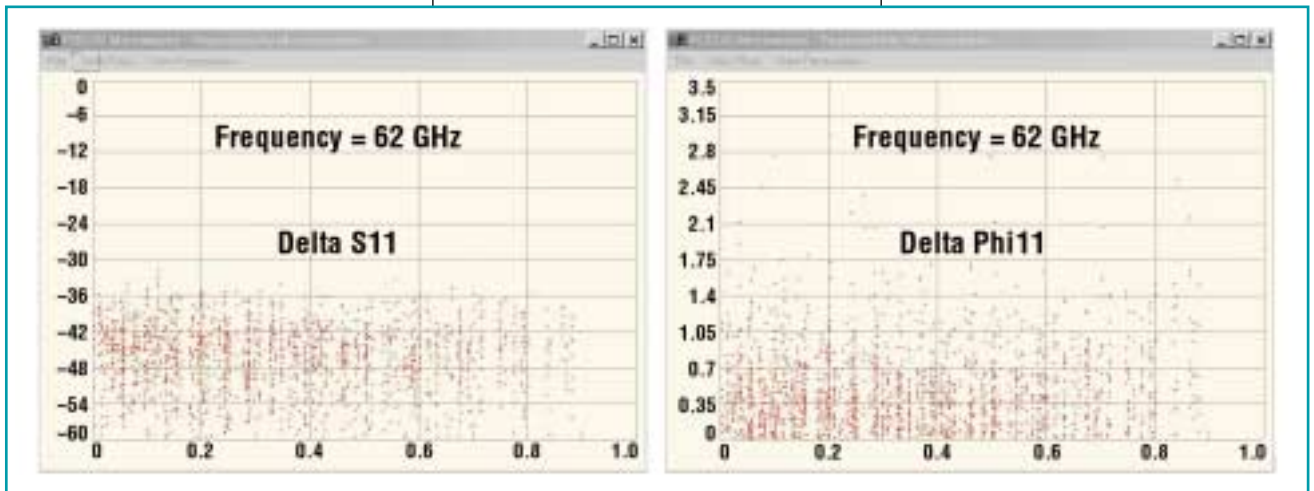
The biharmonic combination tuners are available for testing from S to K



2. The measured S_{11} forward reflection for the CCMT-6510 programmable tuner shows excellent performance at marker frequencies from 9.5 to 65 GHz.

band. The tuners contain multiple probes or tuning slugs to control the impedance not only at the fundamental frequency, but also at the second- and third-harmonic frequencies. The probes are sliding resonant circuits connected in parallel to a low-loss transmission line. Depending upon the Class of bias (A, B, C, etc.), harmonics may have some effect on the behavior of a DUT. A biharmonic combination tuner allows independent impedance tuning at all three frequencies, allowing characterization as a function of three different impedance states.

For example, short circuits at second- and third-harmonic frequencies with the right phase at the output of a transistor in saturation can improve its gain and power-added efficiency (PAE). In addition, a short circuit at the second- and third-harmonic frequencies with the right phase at the input of a transistor can improve the device's linearity. Harmonic tuning has the maximum effect



3. The repeatability of the CCMT-6510's impedance points is shown here for measurements of ΔS_{11} (left) and $\Delta \phi_{11}$ (right).



4. This cover-off view of the 1804-bH tuner shows the resonator assemblies and stepper motor used to control a wide range of impedances at the fundamental, second-harmonic, and third-harmonic frequencies.



5. The measured S_{11} performance of the 1804-bH biharmonic combo tuner shows the low-loss performance of the instrument.

when the DUT is in saturation and generating high levels of harmonics. A device's PAE can be increased by as much as 10 to 35 percent with load harmonic tuning, while linearity can be improved by as much as 3 to 8 dB with source harmonic tuning.

The effects of harmonic tuning depend on the type of transistor, the power-saturation level, the frequency, and the bias conditions. Because of these variables, it is almost impossible to create an accurate nonlinear device model to describe the harmonic behavior of a transistor, and harmonic load-pull testing is required to understand a device's behavior under a specific set of conditions.

The biharmonic tuners are able to generate a high reflection factor (between 0.95 and 0.99) at both harmonic frequencies over a 360-deg. phase tuning range. As with the millimeter-wave tuner, the biharmonic tuners are calibrated on an automatic VNA. At each position of the fundamental set of resonators, all user-defined impedances of the harmonic resonators are calibrated. After this, second-order polynomial algorithms interpolate between the calibrated points to provide phase errors of typically as low as 0.1 to 0.6 deg. and amplitude errors between -40 and -60 dB.

Model 2608-bH is an example of the new biharmonic tuner line. It covers a fun-

damental/harmonic range of 8 to 26.5 GHz, with a nominal fundamental frequency of 8 GHz, second-harmonic frequency of 16 GHz, and third-harmonic frequency of 24 GHz. Model 1804-bH has a fundamental/harmonic frequency range of 4 to 18 GHz. With a nominal fundamental frequency of 5.25 GHz, the second-harmonic frequency is 10.5 GHz and the third-harmonic frequency is 15.75 GHz. The multiple-resonator, stepper-motor-driven tuner (Fig. 4) can be controlled or programmed by means of a PC program. Harmonic load-pull software controls the tuners for independent tuning at fundamental and harmonic frequencies.

In a measure of frequency response (S_{11} forward reflection), the 1804-bH shows levels at are down by -0.43 dB or better at the second- and third-harmonic frequencies from a nominal -dB reference level (Fig. 5). The independent tuning control of the 1804-bH is apparent from a linear polar plot at the fundamental and harmonic frequencies (Fig. 6).

The electromechanical biharmonic tuners are compact and sufficiently light in weight for use in on-wafer harmonic load-pull test setups, with installation close to the wafer under test. In addition to the frequencies noted, the two models above can be tuned to other frequencies by replacing the harmonic resonators. Focus Microwaves, Inc., 1603 St. Regis, Dollard-des-Ormeaux, Quebec, Canada H9B 3H7; (514) 683-4554, FAX: (514) 684-8581, e-mail: info@focus-microwaves.com, Internet: www.focus-microwaves.com.

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6. This linear polar plot of the 2608-bH combo tuner demonstrates the precise and independent tuning control over the impedances at the harmonic frequencies.