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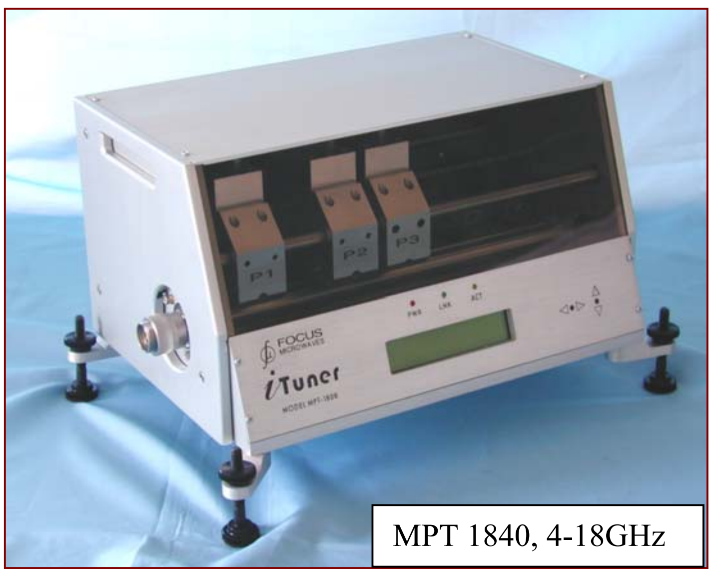
***Product Note 79***

# MPT, a universal Multi-Purpose Tuner*

## Introduction

Electro-mechanical microwave tuners are, for several reasons, the preferred solution for in-fixture and on-wafer load pull testing; they provide the highest VSWR (up to 200:1), the highest power handling (up to 400W CW) and resolution (several million tunable points at any frequency), tuning capability to any impedance (due to interpolated tuning), low-pass behavior (because they use a 50Ω transmission airline as default media) and comprehensive harmonic tuning using, preferably, harmonic rejection tuners, or frequency discriminators (triplexers) [1].

Up to now electromechanical slide screw tuners can be built either as ultra wideband (using two probes of different widths), high VSWR (using a prematching stage) or as harmonic rejection tuners, but not all at the same time. Especially disturbing are wideband tuners, when used in load pull testing of highly compressed transistors without separate tuning capability of the harmonics. In this case the effect of uncontrollably dangling harmonic impedances generates non-quantifiable and non-correctable systematic measurement errors, which falsify the basic form of the load pull contours [2].



MPT 1840, 4-18GHz

In order to avoid this phenomenon rather complex harmonic load pull setups have been proposed and used [3], [4]. Some of those setups use frequency triplexers and three tuners [3] and others two tuners, one wideband and one harmonic rejection tuner [4], per DUT side.

In this note we present a new type of electromechanical tuner, the Multi-Purpose Tuner (MPT), which, using three cascaded and independent wideband probes, allows all needs for tuners to be satisfied by a single unit:

This tuner can be used as

- Harmonic Tuner (fo, 2fo, 3fo), operational over a wide frequency range without hardware interventions (resonator or triplexer changes)
- High VSWR (Prematching) tuner
- Ultra wideband tuner
- Ultra stable tuner for on-wafer applications.

The concept and mode of operation of this new tuner type is described in this note.

**Patent pending, May 24$^{th}$ 2004*

# A Multi-Purpose Three-Probe Tuner

Slide screw tuners use a metallic probe, coupled capacitively to the central conductor of a slotted airline (slabline), in order to create a variable reflection factor. By inserting the probe into the slabline we increase the amplitude of the reflection factor and by moving it horizontally we change its phase. A half-wavelength travel along the slabline allows for a 360° control of the phase. Any impedance within the maximum tuning range ($VSWR_{max}$) of the tuner can thus be created. Typical values of $VSWR_{max}$ vary between 12:1 and 30:1 for single-probe tuners ($\Gamma$=0.846 to 0.935). Dual probe tuners, if configured properly (prematching) may create VSWR up to 200:1 ($\Gamma$=0.99) at C band. Figure 2 demonstrates the tuning mechanism and trajectory from point **a** to point **b** using a single-probe slide-screw tuner.

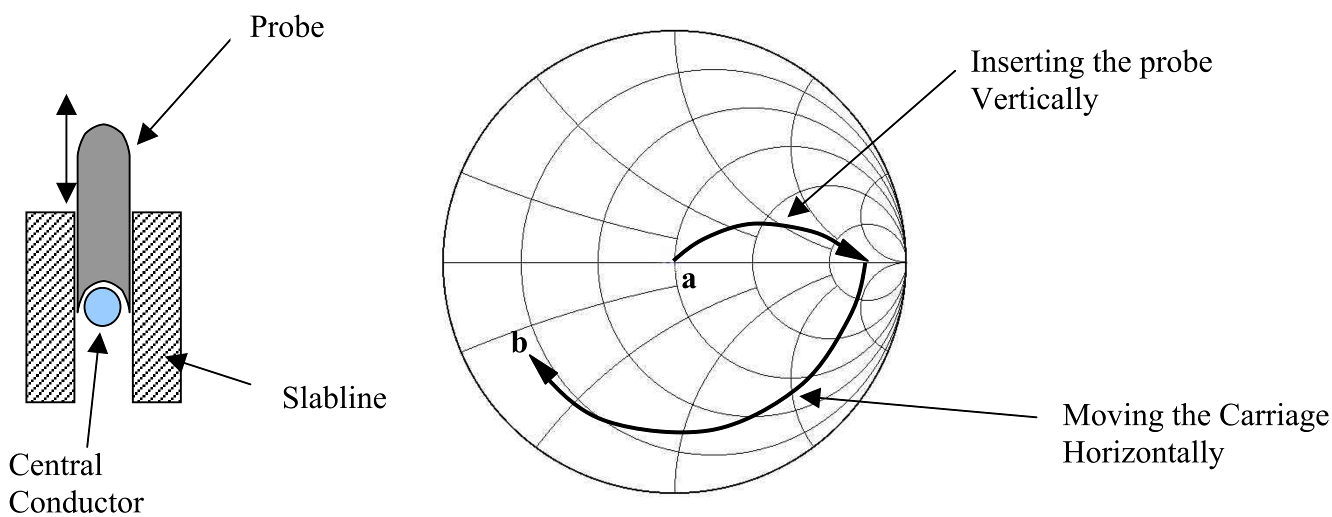



Figure 2: Cross section and tuning mechanism of slide-screw tuner

There are other methods allowing an arbitrary reflection factor to be generated. One of them uses 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 concepts work best when the electrical distance between individual reflection factors is 120°.
This is shown in figure 3: Assuming each one of three independent probes (slugs) P1, P2, P3 are positioned at 120° from each-other and their amplitude is changed independently, we can easily see that 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).
Therefore, varying <u>only the amplitude,</u> which means changing only the vertical position of the probes P1, P2 and P3, we can tune to any point on the Smith Chart, within the tuning range of the probes.
A major disadvantage of existing multi-stub tuners, with fixed distance between the stubs, is that the optimum distance of 120° is only valid for one frequency. This obviously limits the coverage on the Smith Chart at other frequencies (see figures 8, 9, 10). Another disadvantage is that the shorted stubs of traditional multi-stub tuners act either as capacitors or inductors, depending on the frequency, and thus change the basic tuning behaviour.

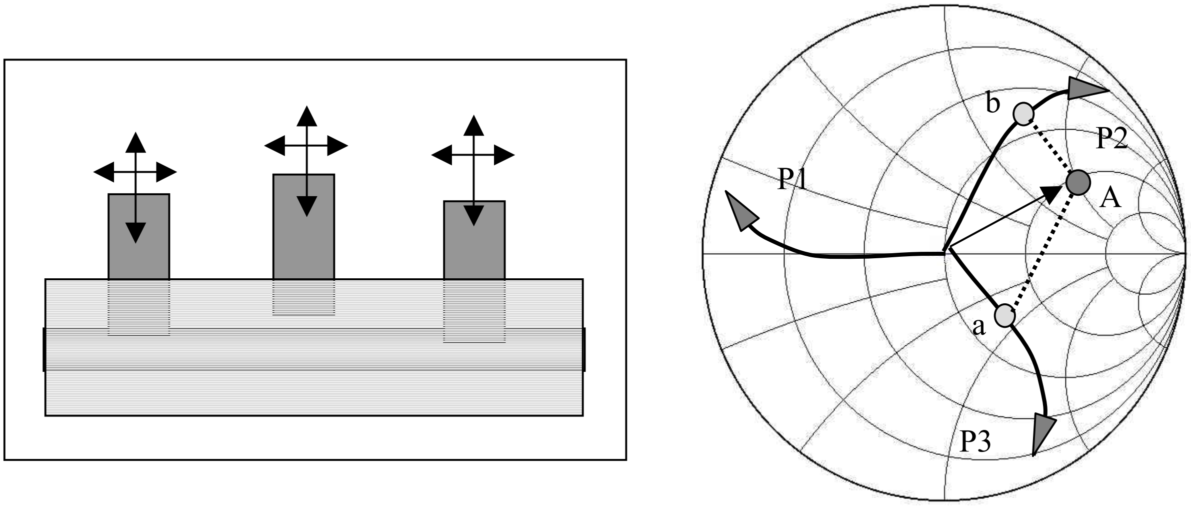



Figure 3: Tuning mechanism of Multi-Probe Tuner. The probes are identical as in the slide screw tuner

On the other hand, the new tuner concept, described here, allows free positioning of each probe horizontally and thus selecting the optimum phase between probes at every frequency.

Also, a Multi-Probe tuner can be manufactured using existing technology: it requires a minimum of three independent carriages and probes (slugs) of the same design as used in traditional slide screw tuners. This is mainly what makes this new design attractive.

The only complication, concerning existing Focus tuner technology, is the need for three independent horizontal drives, because Focus tuners use a lead screw, centred on the mobile carriage. Using three smaller size axes centred in the carriage has solved this problem. Figure 4 shows a frontal cross section of the basic concept of the Multi-Probe Tuner and the picture on page 1 shows the actual instrument.

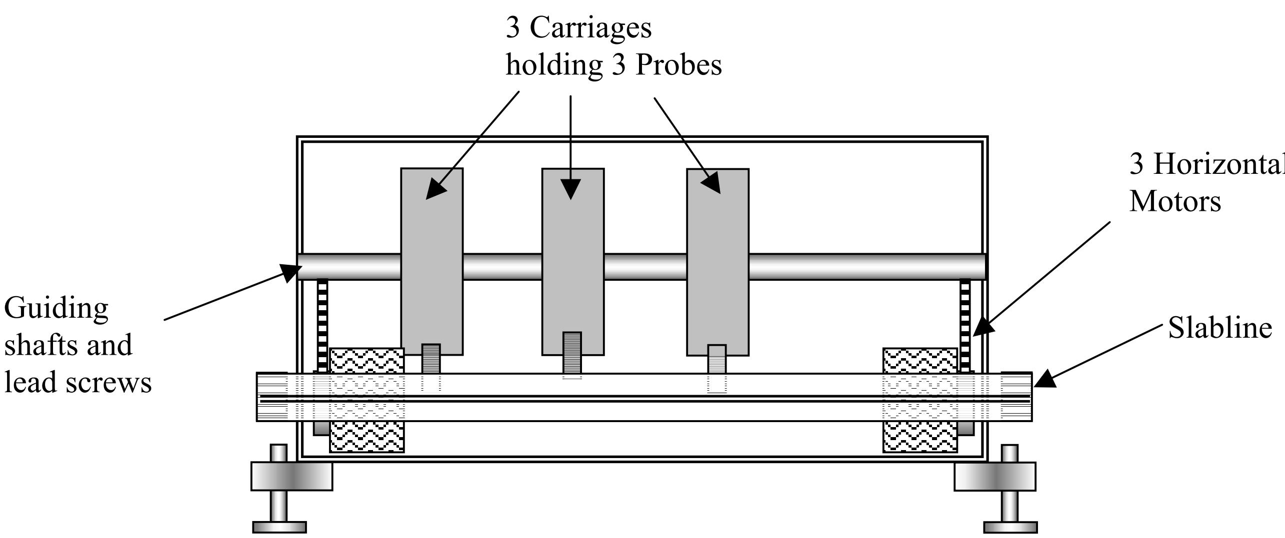



Figure 4: Schematic cross section of the Three-Probe Tuner (see picture on page 1)

# Calibrating the MPT for Harmonic Tuning

MPT is calibrated using a pre-calibrated VNA. VNA calibration is a crucial operation that has to be carried out previously, using TRL techniques, and verified meticulously.
MPT calibration can be carried through either by directly connecting it to the VNA or "in-situ". In-situ means that several other components of the setup remain connected with the tuner and fixture de-embedding algorithms are used to extract the tuner parameters from the overall s-parameter measurements on the VNA. In-situ techniques are more delicate to execute, but provide better accuracy due to fewer disconnections; they are recommended for measurements above 10 GHz.

The MPT has three independent cascaded tuning sections. The total combined calibration points, if each section were calibrated at 455 points, is $455^3$ = 94,196,375 per harmonic frequency. Of course it is impossible to calibrate such an instrument in a traditional fashion, even using very fast computers and VNAs.

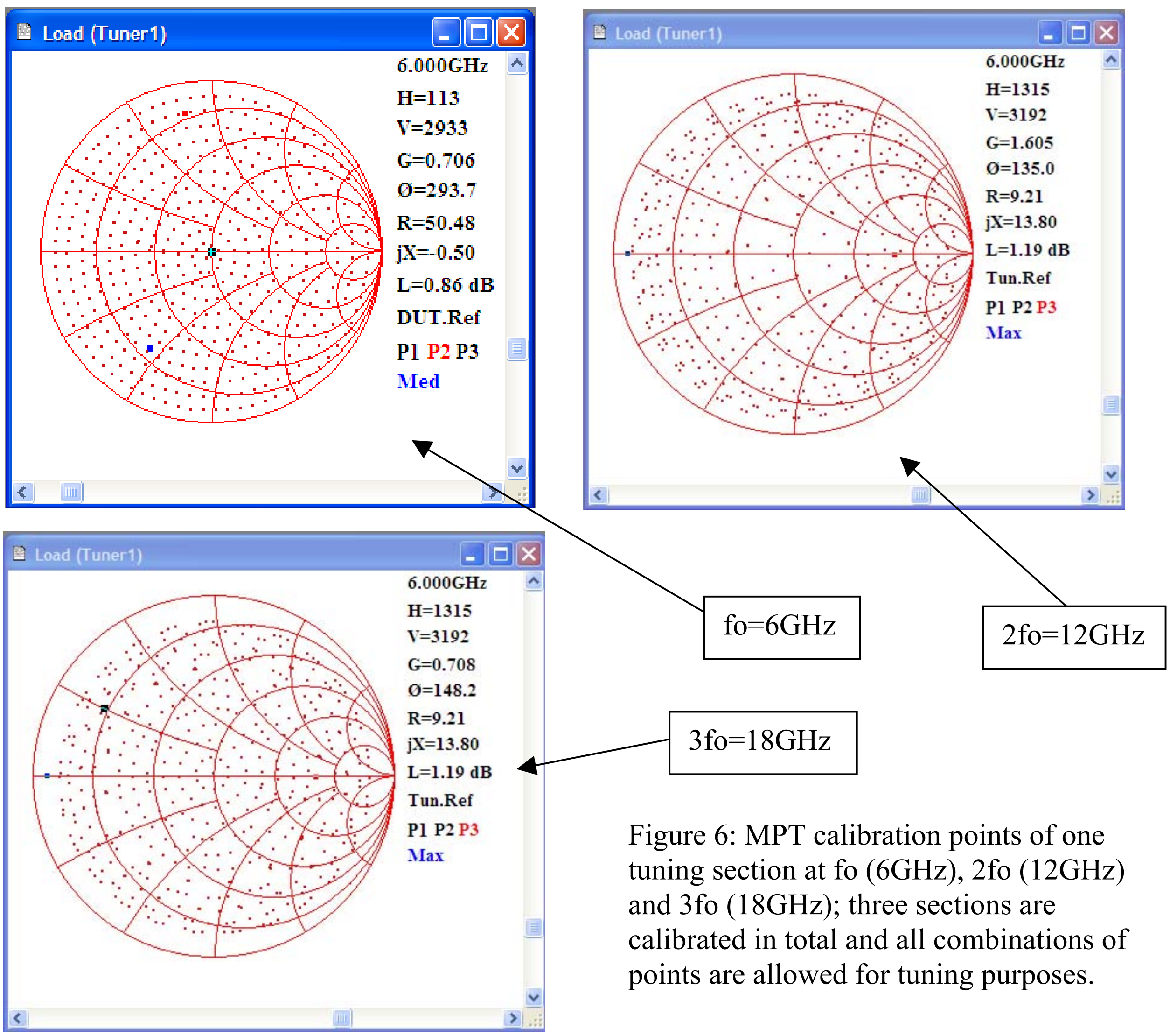



Figure 6: MPT calibration points of one tuning section at fo (6GHz), 2fo (12GHz) and 3fo (18GHz); three sections are calibrated in total and all combinations of points are allowed for tuning purposes.

Focus' MPT software uses a calibration algorithm, which allows generating all 94 million possible

combinations of points per set of harmonic frequencies (fo, 2fo and 3fo) in less than 30 minutes; due to second order interpolation, available in Focus software, even more impedance states, limited only by the mechanical resolution of the stepper motors and translation gears, can be synthesized.
The full calibration of MPT, including calibration points for three tuning sections and a set of harmonic frequencies (fo, 2fo and 3fo) is saved in a tuner calibration file of a typical size of 60 to 120 kilobytes.
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.

## Tuning using the MPT

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

- Single probe or ultra-wideband tuner, if two probes are initialized and one probe used at a time (figure 6),
- Pre-matching tuner (figure 7), if one probe is initialized and two probes used [4],
- Vibration-Free and Harmonic tuner, when all three probes are inserted into the slabline (figures 8-11).

In this last case there are two possibilities:

1. The whole Smith Chart or selected parts of it can be attained using vertical movement of the probes only (figures 8-10). Figure 8 shows the distribution of calibrated points when the horizontal distance between the three probes is selected such as to spread the points best over the entire Smith Chart (typically 120°). Figures 9 and 10 show calibration point distribution when the horizontal distance between probes is chosen in order to focus in a certain area of the Smith Chart. All points shown in figures 8-10 can be synthesized without horizontal tuner movement, which also means vibration-free operation.
2. If horizontal and vertical movement of all three probes is used, then several millions of impedance states are available. This means it is practically certain that not only any impedance at fo, but also any impedance at 2fo and 3fo can be synthesized

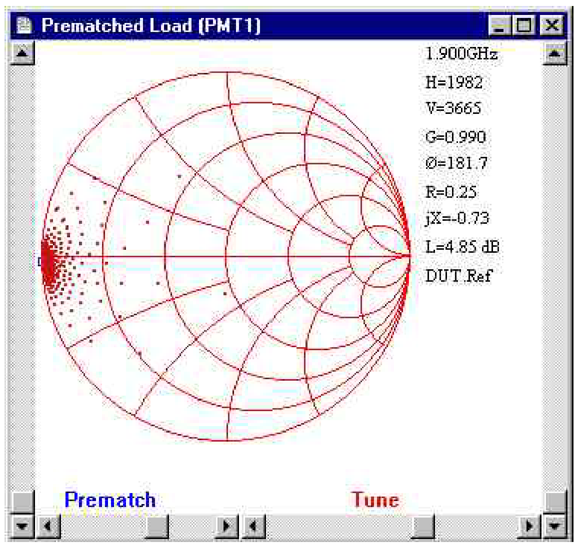



Figure 7: Using the MPT as Prematching Tuner (two probes active, one initialized)

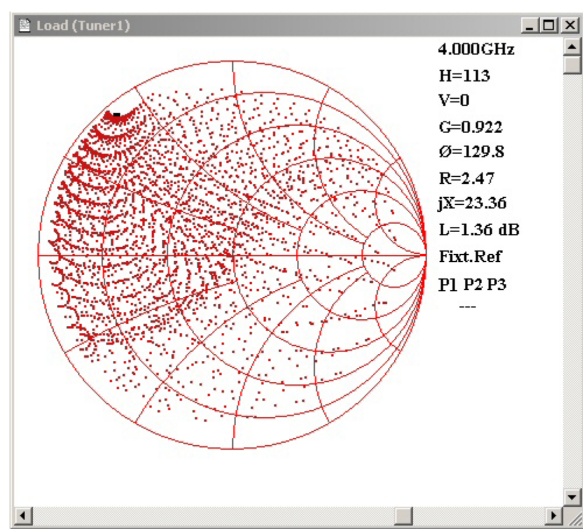
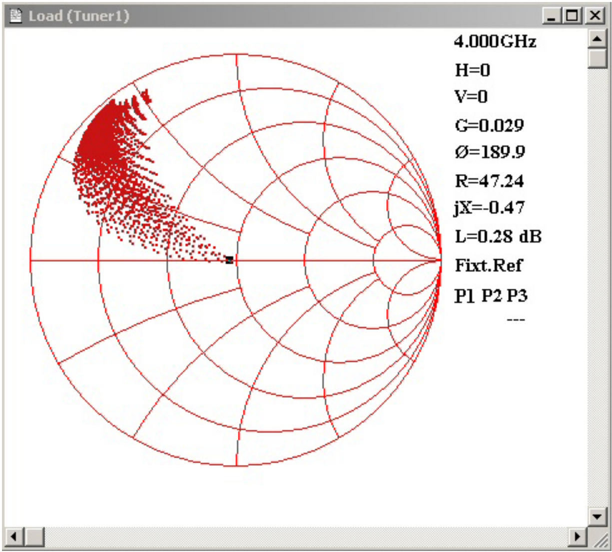
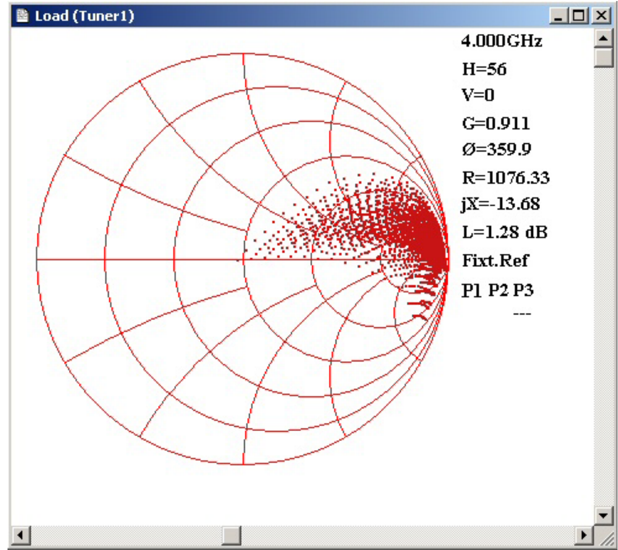



Figure 8: Tuning using the MPT and vertical probe movement only: distance between probes selected for best Smith Chart coverage




Figures 9, 10: Focusing high-density calibration points in certain areas of the Smith Chart by changing the horizontal distance between probes (vertical movement only)

simultaneously for certain probe positions.

Depending on the probes used (high or low frequency) this is true for the whole Smith Chart or a major part of it. In order to tune to a set of harmonic impedances simultaneously, or, what is a practical case of harmonic load pull, tune the impedance at one frequency and keep the other two constant. The calibration data are pre-configured and saved on the hard-disk in an attempt to make the search among millions of tuner positions for the appropriate solution time effective.

All above tuning patterns are accessible from within WinPower, the main load pull measurement application. In particular full load pull at the fundamental frequency can be carried through without moving any of the three probes horizontally and thus eliminating any cause of vibration.

## Harmonic tuning of amplitude and phase, using the MPT...

As already mentioned the large amount of tuning points at all harmonic frequencies offers the possibility of simultaneous harmonic tuning of individual impedances at fo, 2fo and 3fo. The technique used consists in searching within the large amount of calibrated points for the appropriate sets of probe positions, for which the impedances at three harmonic frequencies are as requested by the user.

Because of the huge amount of calibrated points (if we calibrate each section at 200 points we get 8,000,000 calibrated points and if we calibrate each section at 400 points we get 64,000,000 points and so on…) it is statistically certain that several tuner positions will generate harmonic

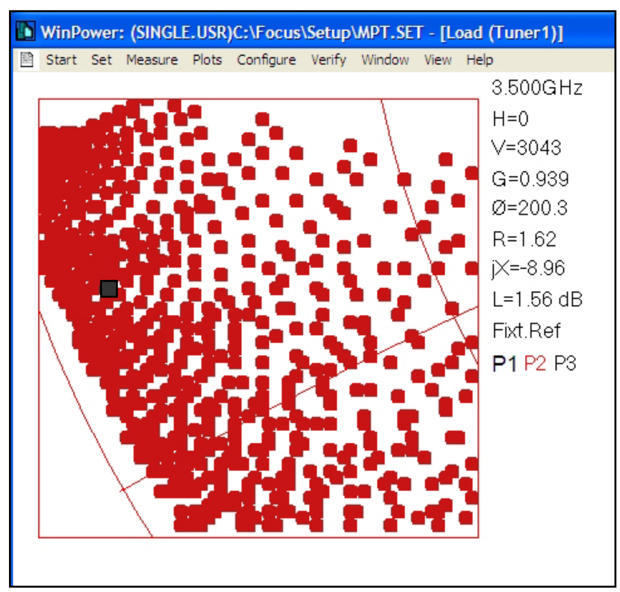



Figure 11: Tuning in a high-density area of the Smith Chart. Red spots=calibrated points, black spot=tuned position, using vertical movement only.

impedances satisfying certain tuning conditions. Under "tuning conditions" we define the acceptable tolerance, in terms of reflection factor units, between the target and the attained reflection factors at the three harmonic frequencies. The smaller the "tuning tolerance" is, the higher the tuning resolution must be and the longer the "tuning search" algorithm gets. Appropriate file segmentation and fast computers (>2.4GHz and at least 1GB RAM are required) allow fine harmonic tuning in a matter of seconds. Depending on the RF probes used, of course, it is possible that harmonic tuning is not always possible in every corner of the Smith Chart; this may happen if the effective bandwidth of the probes does not cover simultaneously fo to 3fo. The size and frequency range of the probes must therefore be carefully chosen. It is obvious that harmonic tuning is, after all, a matter of appropriate hardware and not simply a software issue.

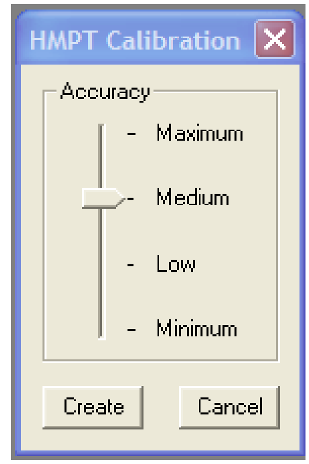


Figure 12: Accuracy options for harmonic tuning

Figure 12 shows the dialog, which allows the user to generate the search files needed for different harmonic tuning accuracies of the MPT tuner. 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… Highest accuracy requires maximum amount of storage and processing time. Once the data created it can be used for harmonic tuning.

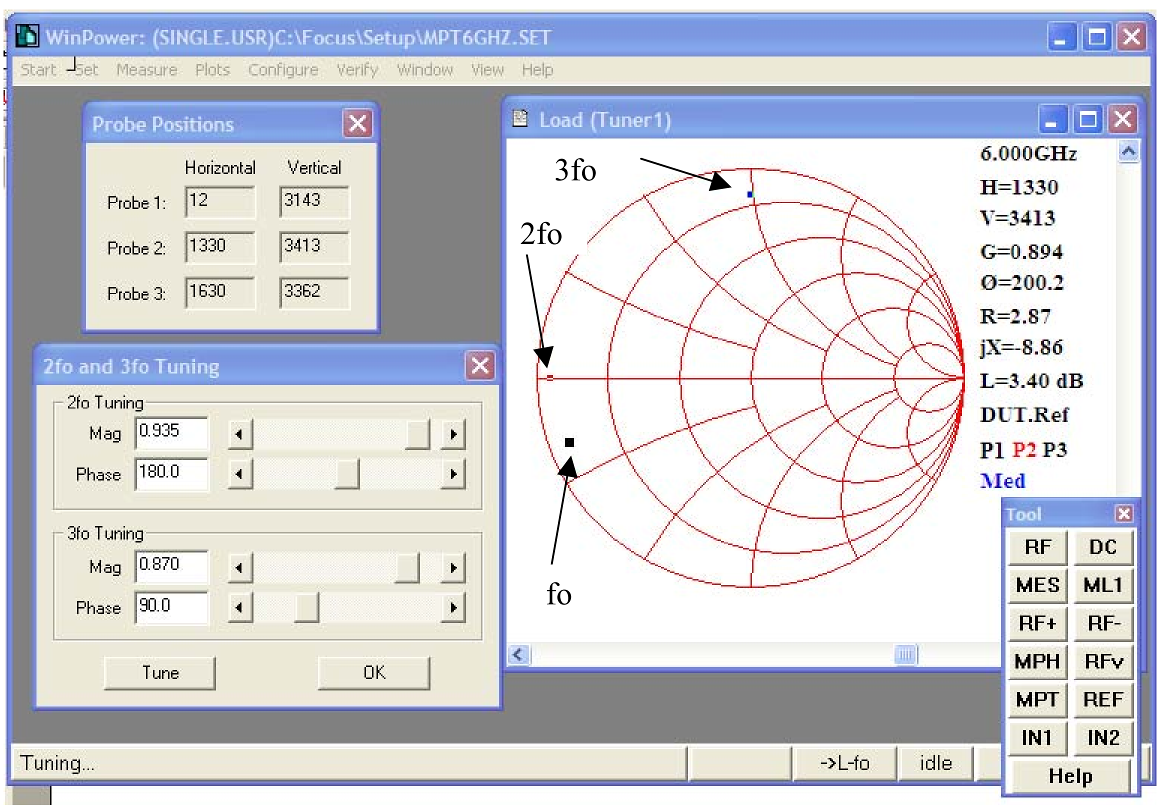


Figure 13: Operation screen of WinPower allowing simultaneous and independent fundamental and harmonic tuning (fo=6GHz, 2fo=12GHz, 3fo=18GHz)

## Vibrations of MPT

MPT's do not have any tilting (or long term movement) problem when used in "vertical mode" only. Since, in this case, the probes move only vertically, the centre of gravity is immobile during the entire cycle of a load pull operation. The only possible cause of vibration is therefore the vertical stepper motors (short term vibrations). This has been tested using non-contacting Hall effect sensors and a dual channel storage oscilloscope. Figure 14 shows typical short-term vibrations of standard single-carriage electromechanical tuners. This typical data has been measured both on Focus and Maury ATS tuners.

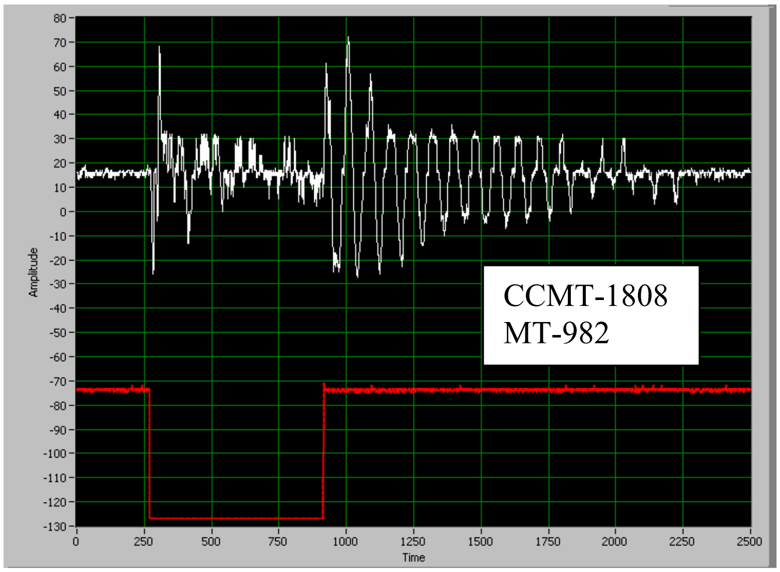



Figure 14: Short-term vibrations of standard slide screw tuner (CCMT-1808), in horizontal move mode

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 = 100µm). This type of behaviour has been measured on all electromechanical tuners of this type on the market. In particular a model MT-982 of Maury Microwave Corp. has been tested under the same conditions and the results are practically the same.

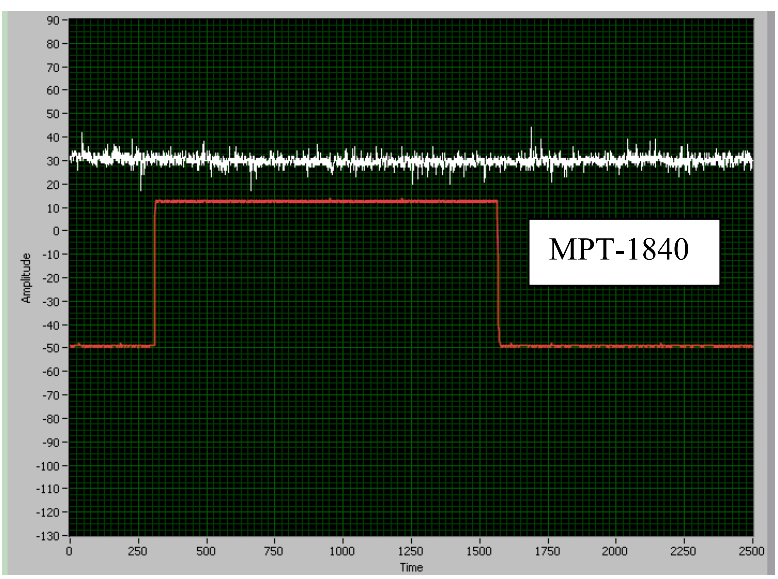



Figure 15: Short-term vibrations of the Multi-Probe tuner (MPT-1840), in vertical move mode

When an MPT is triggered in the vertical-move-only mode, there is no measurable vibration (upper trace in figure 15). This is not surprising: Since only the vertical motors move, and their impact on the overall tuner stability is negligible, because they do not rotate and translate any important mass. As previously explained only the movement of the tuner carriage creates instability and vibration. This movement is absent in vertical-mode MPTs, which fully explains their vibration-free behaviour.

# Conclusion

Triple-probe Multi-Purpose Tuners (MPT) represents one important step in the evolution of electromechanical tuners. For the price of a slightly more complex control mechanics and electronics, a completely new horizon of applications becomes accessible using different operation modes of the same instrument, such as:

- Wideband Harmonic tuning of amplitude and phase
- Pre-matching operation for very high VSWR
- Vibration-free on-wafer load pull and noise measurements
- Extremely wideband operation, using small and large RF probes simultaneously

In addition, the employment of the new, microprocessor based, control electronics (TCP/IP or iTuner) allows users to develop their applications themselves using LabView™, Visual Basic™, Agilent Vee™ etc…

## Literature

[1] http://www.focus-microwaves.com/FAQs/FAQ_Links/ETS vs. EMT.pdf

[2] Application Note 56, Focus Microwaves, "Harmonic Effects in Load Pull using Wideband Tuners".

[3] http://www.focus-microwaves.com/News/NewsLinks/What not to forget to ask when selecting a Harmonic Load Pull System.1.pdf

[4] Product Note 52, Focus Microwaves, "Prematching Tuners for High VSWR Load Pull Testing".

[5] Application Note 42, Focus Microwaves, "Using Stub Tuners and Slide Screw Tuners".

[6] ATN Microwave Inc., "A Load Pull System with Harmonic Tuning", Microwave Journal, March 1996.