FOCUS MICROWAVES GROUP

# Harmonic Low Frequency Tuner (HLFT)

## Product Note #85

Dr. Christos Tsironis


This Product Note presents the Harmonic Low Frequency Tuner (HLFT) technology, covering a frequency range from 5 to 150MHz.

# Summary

MHz range programmable tuners (model family LFT, figure 1) are made by Focus Microwaves since 2006 (US patents 7,646,267 - 7,646,268 - 8,629,742 - 8,497,745). LFT are available in Octave and Octave+ bands from 5 MHz and up to 150 MHz. They use rotary air capacitors and optimized lengths of semi-rigid coaxial cable for maximum Smith chart coverage and instantaneous frequency bandwidth. Calibration on VNA lasts 2-3 minutes per frequency. Proprietary tuning algorithms allow homogenous coverage of the Smith chart, equivalent to slotted airline based slide screw tuners, even though by their nature the LFT create irregular tuning patterns (compare Figures 4 and 5) with tuning repeatability >55dB and tuning accuracy >40dB.
The latest development of the low frequency tuners is two frequency harmonic tuning: Fo and 2Fo can be tuned independently. This new technology opens the hitherto impossible considered task of accurate and predictable ("Click and Tune") harmonic MHz range tuning.

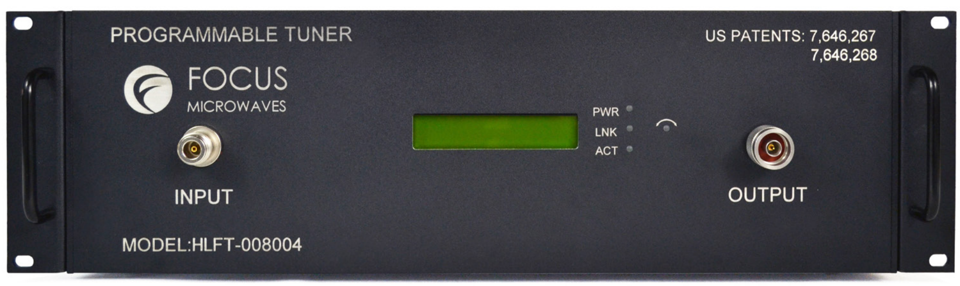


Figure 1: 19" rack mounted low frequency tuner, model LFT-008004 (40-80MHz)

# Product Description


Figure 2: Inside view of a 4 section LFT

The LFT housing comprises the tuning sections, stepper motors, on-board processor, motor control electronics and LAN communication interface.
Calibration data are retrieved from the VNA and saved in the control computer to be used for actual impedance synthesis. Each capacitor, when rotated, creates a perfect arc on the Smith chart (Figure 3).
The angle between the arcs changes with frequency. Proprietary optimization software determines the lengths of cable sections between capacitors for maximum reflection factor and frequency coverage.

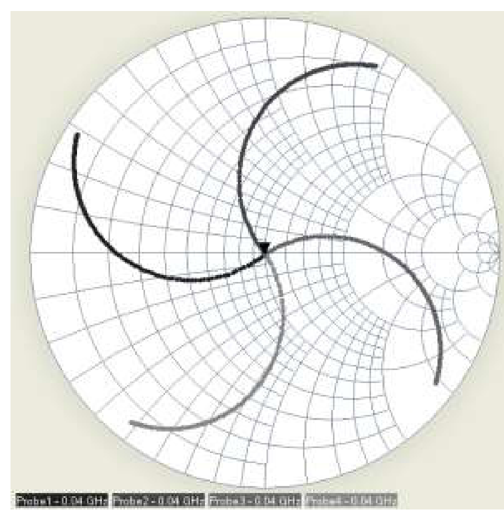

Figure 3: Reflection factor created by individual capacitors

# LFT Calibration

A typical LFT tuning pattern based on permutations of all calibrated points is shown in figure 4; as expected the calibration points do not generate equally distributed pattern over the entire Smith chart. This irregular point distribution is not optimum for load pull testing, since the data will be irregularly distributed and, if the optimum is not inside a high density tunable area the accuracy and contouring algorithm may suffer.

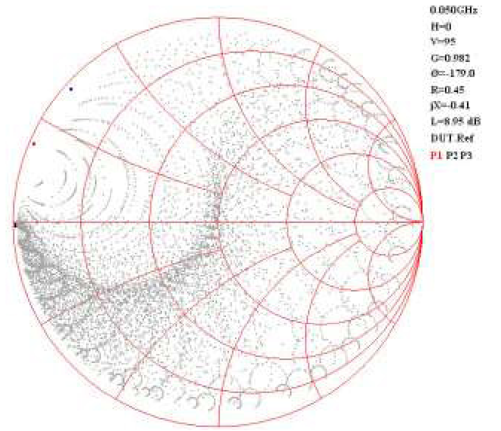


Figure 4: LFT Calibrated points (F=50MHz)

# LFT Tuning

Tuning algorithms developed for multiprobe harmonic tuners (MPT series), however, applied to LFT tuners, allow de-skewing of the calibration points and generating extremely regular tuning patterns, fully equivalent to patterns generated by traditional slide screw tuners (Figure 5).
The tuning pattern of Figure 5 is generated using the calibration data with the pattern distribution as shown in Figure 4.

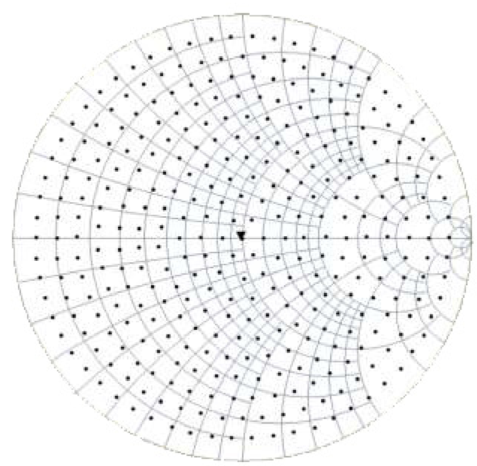

Figure 5: LFT tuned points (F=50MHz)

# Repeatability and Tuning Accuracy

Repeatability is the difference between reflection factors measured after the tuner returns to a previous state. Typically the calibrated points are measured in two sessions (a) and (b) and compared. The possible differences are due to mechanical tuner errors, connect-disconnect operations, cable instability or VNA drift. Even if the mechanics of the setup are carefully preserved, earlier studies have shown that the VNA's are not always drift-less.
Figure 6 shows the repeatability **$\Delta S11=10\log|S11.a - S11.b|^2$** of the LFT calibration at 50MHz.

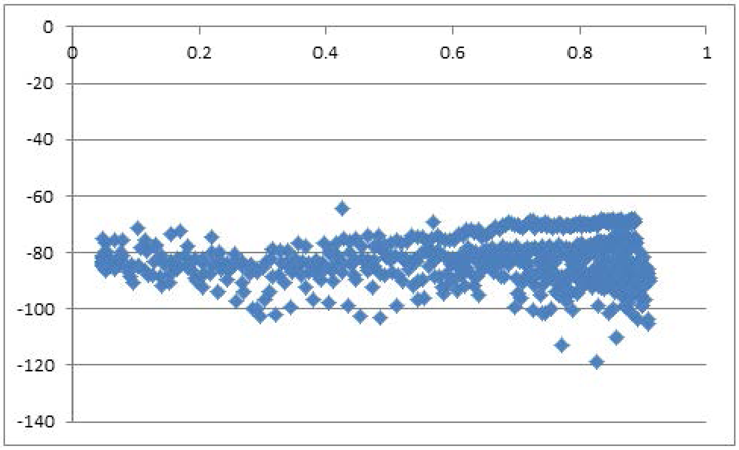


Figure 6: LFT repeatability at 50MHz

Tuning accuracy is the difference between a calculated "target" reflection factor **S11.c** and the corresponding measured **S11.m**. Tuning accuracy cannot exceed repeatability, since it includes interpolation and approximations. Instead "tuning" generates concentric circles up to **|S11|≈0.9**.

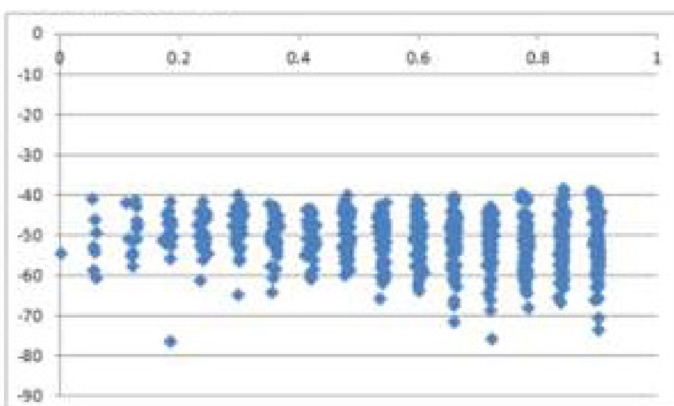


Figure 7: LFT tuning accuracy at 50MHz

# Harmonic Tuning

Harmonic tuning is naturally achieved using frequency selective (resonant) networks. Focus has employed this technique in the PHT (Programmable Harmonic Tuner) since 1999 (US patent 6,297,649). There are two shortcomings to that: 1. Limited bandwidth (5-8%) and 2.Tuning range limited to |Γ(2Fo, 3Fo)| > 0.9.

In 2004 Focus introduced and, since 2006 uses the MPT (Multi-Purpose Tuner) harmonic tuning technology, employing multiple, independent wideband tuning probes, which offer billions of tuning state permutations, allowing to tune any harmonic frequency at any Γ inside the frequency coverage of the probes and the tuning range from 0 up to |Γ| > 0.9.

Each MPT probe is calibrate at a minimum of 1000 states (10 vertical and 100 horizontal positions) leading to at least 109 tuning permutations. Instead a 6 section LFT yields between $10^6$ (10 capacitor steps) and $64*10^6$ (20 capacitor steps) tuning states, or between 15 and 1000 times less permutations. Consequently harmonic LFT tuning will, a priori, not cover as much of the Smith chart as MPT harmonic tuning, neither can one expect the same tuning resolution and accuracy. Figure 8 shows Fo (40MHz) and 2Fo (80MHz) tuning of LFT-008004 (40-80MHz).

The table summarizes all permutations of a set of Γ(Fo) target reflection factors with |S11(Fo)|=0.7 and phase steps of $90^0$ and all associated permutations and tuning errors of |S11(2Fo)|=0.85 and the same phase steps.

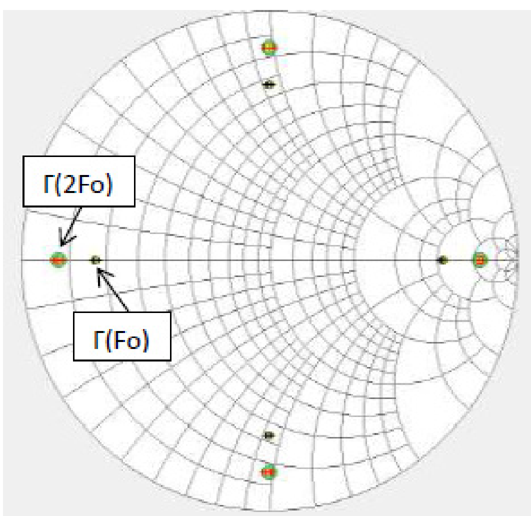


Figure 8: LFT harmonic tuning

| F0 Hit | 2F0 Hit | F0 Error | 2F0 Error |
|---|---|---|---|
| 0.7,0 | 0.85,90 | -38.19 | -30.58 |
| 0.7,0 | 0.85,-180 | -36.42 | -33.11 |
| 0.7,0 | 0.85,-90 | -36.28 | -32.14 |
| 0.7,90 | 0.85,0 | -35.15 | -31.84 |
| 0.7,90 | 0.85,90 | -36.47 | -32.16 |
| 0.7,90 | 0.85,-180 | -35.06 | -31.9 |
| 0.7,90 | 0.85,-90 | -36.57 | -36.35 |
| 0.7,-180 | 0.85,0 | -36.04 | -36.3 |
| 0.7,-180 | 0.85,90 | -36.98 | -37.31 |
| 0.7,-180 | 0.85,-180 | -42.03 | -30.58 |
| 0.7,-180 | 0.85,-90 | -38.25 | -33.13 |
| 0.7,-90 | 0.85,0 | -39.03 | -32.59 |
| 0.7,-90 | 0.85,90 | -38.05 | -32.24 |
| 0.7,-90 | 0.85,-180 | -35.71 | -30.31 |
| 0.7,-90 | 0.85,-90 | -35.14 | -33.18 |

## Conclusions

- Harmonic, low frequency (5-150MHz range) tuning is possible.
- Harmonic LFT (HLFT) tuners are available in Octave and Octave+ frequency range
- Typical frequency ranges are:

| Tuner Model | Fo Tuning | Fo&2Fo Tuning |
|---|---|---|
| HLFT-0010005 | 4.5-11 MHz | $4.5 \leq Fo \leq 5.5$ MHz |
| HLFT-002001 | 9-22 MHz | $9 \leq Fo \leq 11$ MHz |
| HLFT-004002 | 18-44 MHz | $18 \leq Fo \leq 22$ MHz |
| HLFT-0080032 | 30-88 MHz | $30 \leq Fo \leq 44$ MHz |
| HLFT-011004 | 36-120 MHz | $36 \leq Fo \leq 60$ MHz |
| HLFT-015007 | 63-165 MHz | $63 \leq Fo \leq 82$ MHz |

## References


1 US patent 7,646,268 Low frequency electro-mechanical impedance tuner.

2 US patent 7,646,267 Low frequency harmonic load pull tuner and method.

3 US patent 8,497,745 VHF harmonic impedance tuner.

4 US patent 8,629,742 VHF harmonic impedance tuner.

5 US patent 8,912,861 Mechanically controlled variable capacitors for impedance tuners.

6 US patent 9,344,061 Low frequency coaxial capacitors and tuners.