1603 St. Regis D.D.O., Quebec H9B 3H7, Canada
Tel 514-684-4554 Fax 514-684-8581
E-mail: info@ focus-microwaves.com
Website: http://www.focus-microwaves.com

Product note 90

Kilo-Watt Range Tuners

Summary

Impedance tuners use a slotted airline (slabline) and metallic (reflective) probes. The slabline has two vertical sidewalls and a round center conductor. The probes (slugs) have a concave bottom matching the radius of the center conductor (CC). At high VSWR (>10:1) the probes approach the center conductor within a few dozens of micro-meters (1 µm=10^{-6} m, 1 mil = 25.4 µm).

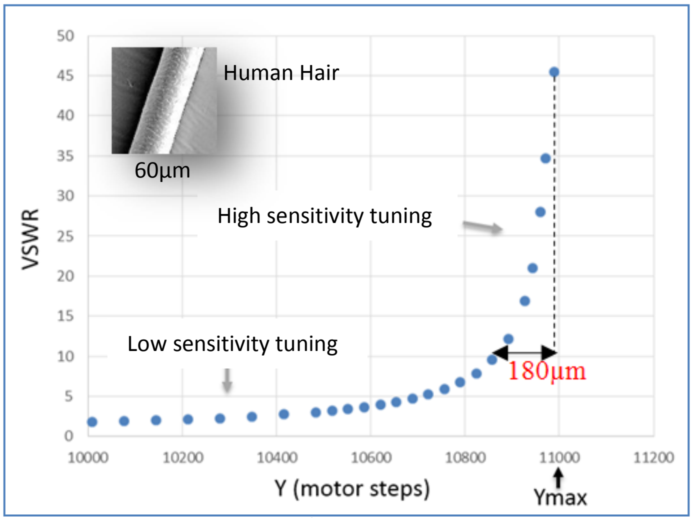

Figure 1

During operation, the probe travels at constant distance to the CC over at least one half of a wave-length (150 mm at 1GHz, 15 mm at 10 GHz). The diameter of the center conductors decreases with increasing frequency (12.5mm up to 1 GHz, 3mm up to 18GHz, 1mm up to 50GHz).

The total length of the CC must exceed λ/2 because of the tuner mechanics. Typical “slenderness factors” (SF=Length/Diameter) of CC, especially for 3 probe harmonic tuners (MPT), are between 150 and 250. Mechanically, values over 100 are considered unstable.

The Road to kW Tuners

RF power handling of slide screw tuners is limited by two basic phenomena:

1. Electric field breakdown (sparking or Corona discharge)
2. Thermal (expansion of center conductor and connector limitations).

The tuner areas where the problems occur are:

1. Connectors
2. Area below the probes
3. Center conductors

Focus Microwaves has addressed all limitations using mechanical and electrical solutions as follows:

1. The center conductors are protected from thermal expansion and mechanically supported.
2. The (coaxial) connectors are modified for using high temperature beads.
3. The probes have been redesigned and dielectrically protected.

These measures allow manufacturing high power tuners able to handle up to several hundreds of Watts in CW operation and several kilo Watts RF power in pulsed mode.

We have developed a formula allowing the estimation of the maximum electric field as a function of frequency, VSWR and tuner loss: E_{max} = F (freq, VSWR, Loss) and compared the result with High Frequency Simulator (HFSS) as follows:

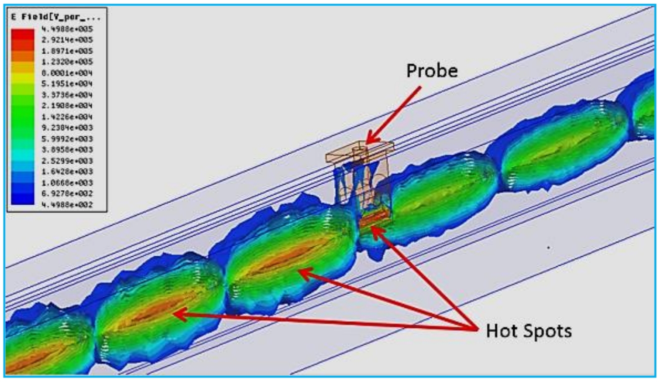

Figure 2 –HFSS Simulation

Frequency = 3GHz, VSWR=10:1, Tuner 0.2-3GHz; Corona Limit ≈ 3kV/cm

Method / CW Power	1000W	2000W	3000W
HFSS (kV/cm)	0.39	0.55	0.68
Focus Method 1 (kV/cm)	0.39	0.55	0.68
Focus Method 2 (kV/cm)	0.56	0.79	0.96
Focus Method 3 (kV/cm)	1.25	1.77	2.17

Table I

None of the above calculation methods is reliable enough to predict exactly the electric field breakdown in tuners. For the simple reason that the mechanics is not static (the tuners have moving parts) and the dimensions dealt with are minuscule. Minor dust particles, movement, vibration or connector over-torque will change the tuner geometry in unpredictable way, in addition to normal thermal expansion effects.

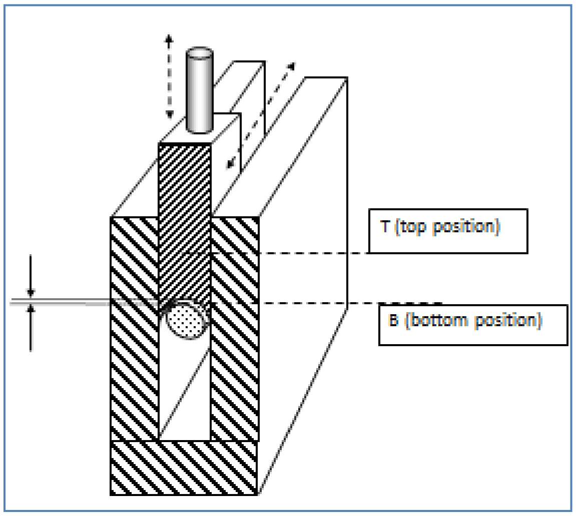

Figure 3

Never-the-less Table I indicates that, under perfect circumstances, Corona should not occur, and, if it happens the reasons are elsewhere.

The breakdown phenomena limiting the maximum power handled by tuners are caused by a combination of (a) high electric field, which is created by the injected RF power and (b) heat, which is created by dissipated RF and DC power. Dissipated power increases with tuner loss, i.e. center conductor resistivity, frequency and VSWR and electric field increases with injected power. Thermal effects cause deformation of the center conductor and therefore risk reducing the already small gap between probe and center conductor, therefore creating electric fields beyond the ideal case. This phenomenon has been observed repeatedly and may reduce the maximum tuner power to below 100 Watts.

It is simplistic to calculate pulsed RF power times the pulse rate and use as the equivalent CW power, because, whereas CW power may deform the center conductor and reduce the gap between the center conductor and the bottom of the probe, but still not reach electric field breakdown, the equivalent peak power times the pulse rate, causing a similar deformation (gap) may cause breakdown, because the peak electric field is, now, much higher.

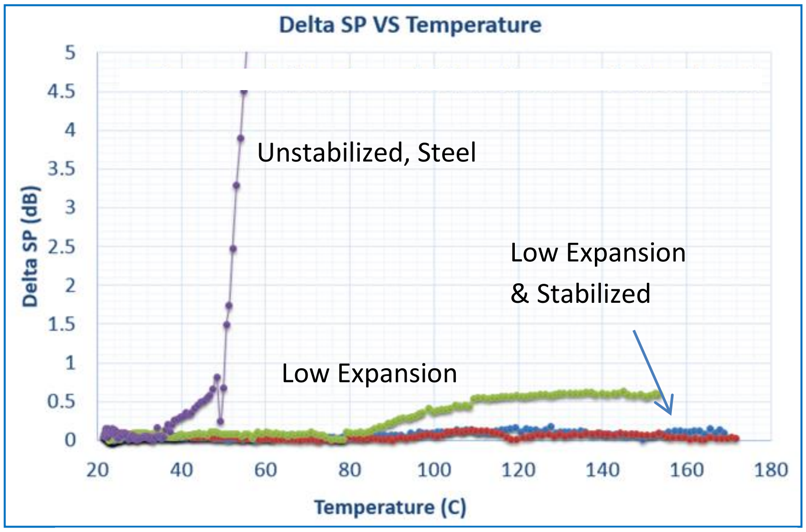

Figure 4: Material and mechanics of center conductor

As shown from figure 4, the stabilization of the center conductor and the material used affect the RF performance critically. Center conductor temperatures up to 170^{o}C are not uncommon. A simple phenomenon, caused by thermal expansion, is easily underestimated: Assuming a metallic rod of length L, when prohibited from expanding by $\Delta L \approx 10^{-6} * L$, and knowing that steel expands thermally by 12-14ppm/^{o}C, one can easily estimate that not allowing center conductors to expand will lead to catastrophic failure. As an example: a 200 mm long center conductor, if heated by 40^{o}C (from 20^{o}C to 60^{o}C) will expand by $\delta L \approx 96 \mu m$; if this sounds affordable (in view of figure 1) the reality, though, is that, at the center of the slabline this center conductor will "buckle" (deviate sidewise) by H≈4.4 millimeter, obviously causing a catastrophic short circuit, even at low VSWR (figure 6).

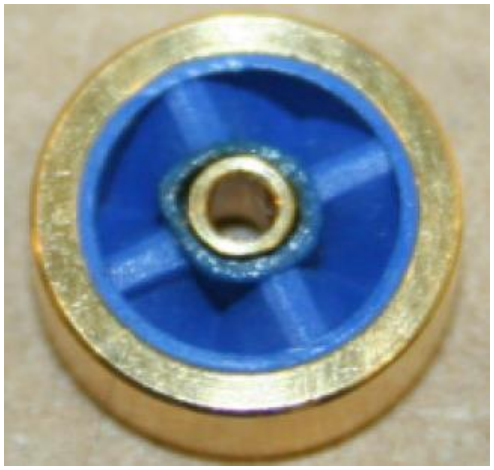

Figure 5

Another limitation is coaxial connectors. For two reasons

(a) If the DC contact between center conductors of the adjacent adapters is not perfect, which is typical in SMA and low grade adapters, but also in 7mm (APC-7), because of their hermaphrodite design; and

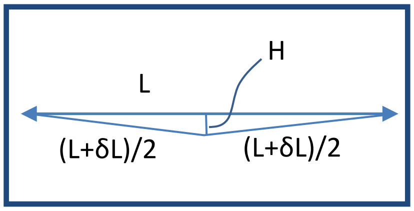

Figure 6

(b) Because of inadequate dielectric material used in the center conductor holding beads. Figure 5 shows a melted bead from an APC-7 adapter submitted to ~100 Watt RF power at high VSWR.
Electric field simulations and optimizations have led to improved probe designs, which allow reducing the maximum electric field, at very high VSWR and RF power from a critical 3kV/cm to a safe 2kV/cm, at negligible loss of VSWR, all other conditions being equal. Therefore, the probes (slugs) have been modified from the original “boxy” design, in order to transition and reduce electric field deformation and associated “antenna” effects.

As a result, our high-power tuners can handle very high power, up to several Kilo Watts, as is shown in table I.

Examples of kW tuners are CCMT-975-UHP (Ultra High Power) and CCMT-303-UHP:

- Frequency range: 7.5-9.5GHz/ 0.3-3GHz
- VSWR: >10:1
- Power handling: DC+CW: 500W; Peak (1%): 5,000W
- Connectors: Precision N, 7/16.
- Cooling: Forced air
- Size: 8.6” (L), 7.8” (W), 6.4” (H) /
  29.5” (L), 9.1” (W), 10.6” (H)
- Weight: 10 lbs/ 60 lbs

CCMT-975-UHP

CCMT-303-UHP