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Product Note 52

Prematching Tuners for Very High VSWR and Power Load Pull Measurements

A new family of programmable tuners, model PMT-xxyy, utilize the tuning capability of two independent tuning sections and prove to be a major breakthrough in very high VSWR testing by providing simultaneously high power handling, bandwidth, calibration accuracy and versatility for testing various types of power transistors. VSWR up to 100:1 (Z≈0.4Ω) combined with 2-3 octave bandwidth, 360° target tuning area and 50 to 150 Watt RF power handling are standard performance, depending only on connector type and frequency range.

Introduction

Load Pull testing of high power transistors in the PCS and cellular frequency range (0.85 – 3 GHz) require accurate tuning capability around 1 Ω output impedance or less. RF Power handling capability of the tuners beyond 50 Watts at very high VSWR is meanwhile a "must".

The traditional approach to respond to these requirements is to use low characteristic impedance (like 10 Ω or 20 Ω) λ/4 long microstrip transformers on the test fixture, which allow to effectively tune around the 1Ω or less impedance range. There are though three major inconveniences of this type of solution:

1. Limited bandwidth of less than 10%
2. Fixed tuning direction (typically, but not always 180°).
3. Fixed transforming ratio

This means that for every new transistor and frequency new transformers must be designed, manufactured, characterized and assembled. Premathing probes used for low impedance testing on-wafer have the same disadvantages as long as they are narrow band (like the probes of Cascade Microtech [1]). Wideband transforming probes (GGB Industries [2]) have the disadvantage of targeting only the 180° area of the Smith Chart (Z ≈0Ω).

In view of these limitations, new tuning instruments with <u>high VSWR capability and bandwidth and adjustable target tuning range</u> were required.

Prematching Tuners as presented here, are these new devices (figure 1).

Figure 1: High Power Prematching Tuner, model PMT-1818-N (1.8-18 GHz with N connectors)

Principle of Operation

“Prematching” is the process of generating a total reflection in two steps: The first step brings the device impedance from a very low level to a medium level and the second step brings it to 50Ω. This can be done “on-chip”, using lumped elements like capacitors and bonding inductors or on microstrip using low characteristic impedance λ/4 transformers. Wideband prematching is possible using either more than one step transformers or tapered transmission line sections where the characteristic impedance change happens gradually. In this case bandwidth is gained at the price of size (tapers are long).
At a single frequency prematching consists of adding two reflection factor vectors at the right phase to generate a larger one. Prematching tuners use this technique [(*)]

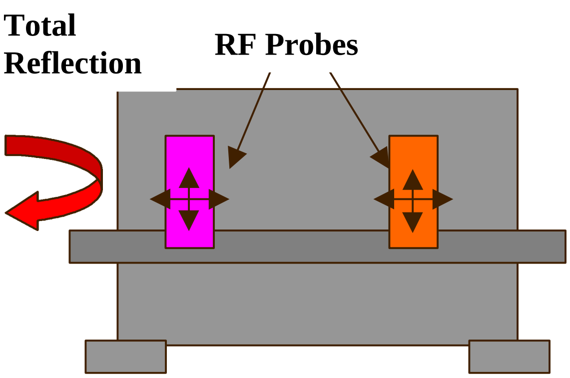

Figure 2: Principle of prematching tuners

The first probe generates a reflection vector which is added to the reflection of the second probe.
The combination of both generates a total reflection factor which reaches 1.0 at the reference plane of the first probe. Losses in the transmission line between the connector of the tuner and the first probe limit this total reflection to values between 0.98 and 0.95 or VSWR between 100:1 and 40:1.

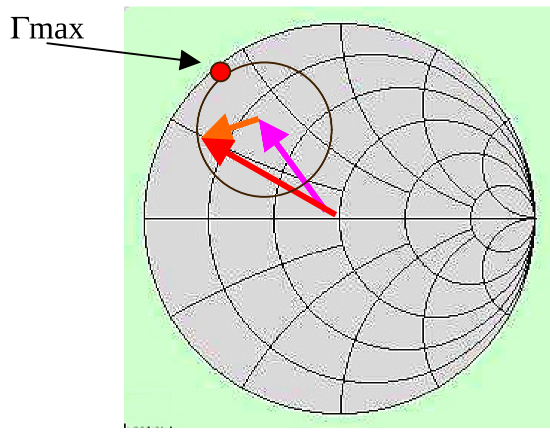

Figure 3: Vector presentation of Prematching.

The advantages of this technique lay at hand:

1. Γmax reaches almost 1
2. Φmax can be shifted through probe 1
3. Each probe does not need to generate excessive VSWR
4. Any frequency can be tuned
5. When the tuner is initialized the system has 50Ω impedance (=no parasitic oscillations)

Item 3 provides two further benefits

6. Power Handling capability at very high VSWR increases due to less risk for corona discharges between the RF probe and the central conductor
7. Calibration accuracy improves due to the lower Γ max of each probe.

There are, though potential inconveniences: Because the system includes in reality two independent tuners, calibration time of the combination of both of them simultaneously might drive calibration time too high for

(*) patent pending

practical considerations: If each tuner is calibrated at 400 impedance positions per frequency then the combination should be calibrated at 400 x 400 = 160,000 points per frequency. At an average of 10 minutes per tuner per frequency this means 3 days per frequency. This would be unacceptable. Focus Microwaves has developed a new tuner calibration technique (*) which allows the complete tuner to be calibrated in a maximum of 20 minutes per frequency, for all 160,000 impedances. In addition Focus software allows interpolation between calibration points, which drives the impedance multiplexing capability of the new tuners into the hundreds of millions.

<u>In conclusion</u> the PMT tuners using Focus' new calibration technique and interpolation routines represent a "continuous tuning device" with fine tuning resolution equivalent to manual tuners.

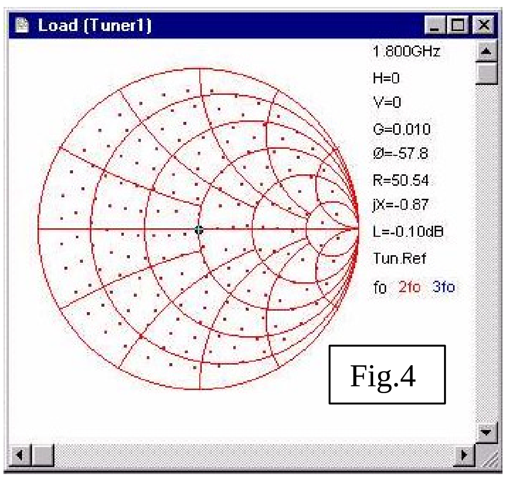

Fig.4

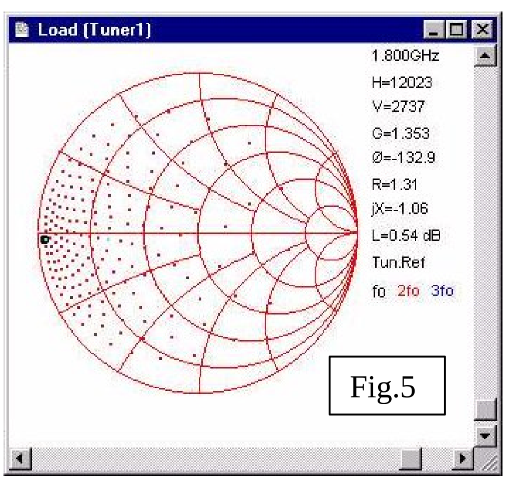

Fig.5

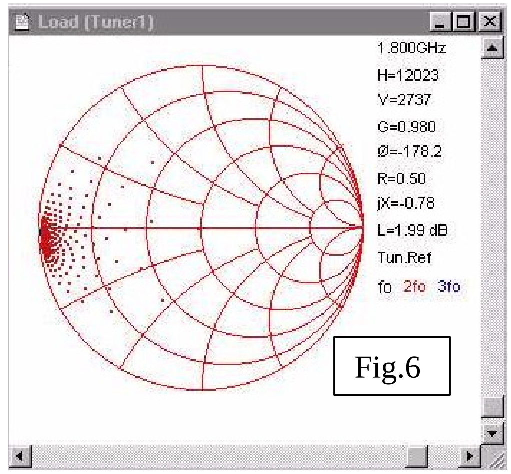

Fig.6

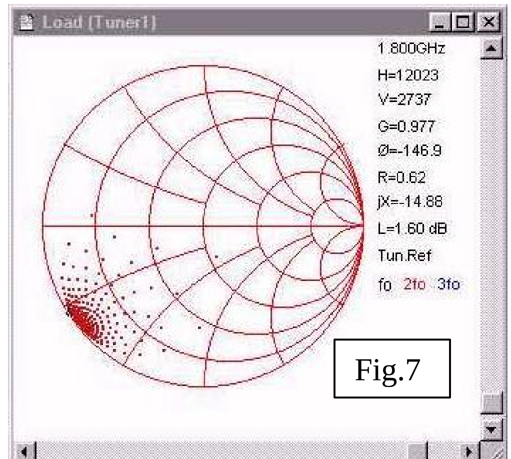

Fig.7

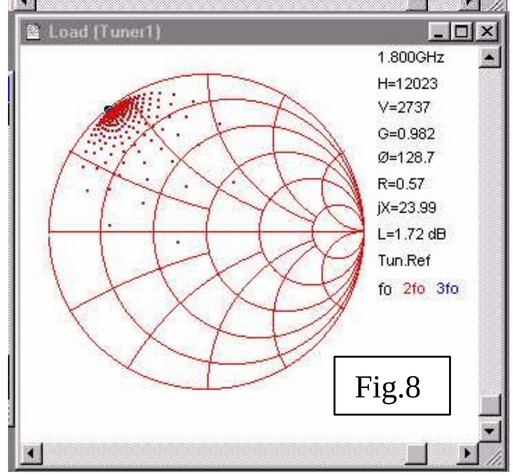

Fig.8

Figures 4 to 6 show how PMT tuners focus into a particular area of the Smith Chart by adjusting the characteristic impedance of the prematching section.

Figures 6 to 8 show how PMT tuners select the phase of the target tuning area even at maximum VSWR.

Tuning Accuracy

A major advantage of Prematching Tuners is that they can be calibrated and tuned more accurately to extremely high reflection factors, up to Γ=0.987 (VSWR=150:1). This is possible since each section is tuned to $\Gamma_{max} \approx 0.85$, whereas the cascaded sections generate very high reflection factors.
The accuracy test results in tables I, II and III show that strong Prematching rather improves tuning accuracy. The tables show the Impedance tuned to [in Ω] and the corresponding reflection factor. The error term Δ(Γ) is defined as:

$$\Delta(\Gamma) = 20 \bullet \log |S11.meas - S11.calc|$$

R[Ω]	jX	|Γ|	Φ	Δ(Γ)[dB]
Area 1: Tuning around 50Ω				
51.625	3.4658	0.038	62.9	-49.82
60.250	8.9712	0.123	36.5	-43.68
43.625	-0.5923	0.068	185.7	-52.92
68.762	16.124	0.206	32.9	-35.63
53.425	21.129	0.203	69.2	-42.21
36.161	7.3822	0.181	147.0	-49.50
43.501	-12.378	0.148	249.8	-43.69
……………………….				
Area 2: Tuning around 5Ω				
8.998	-49.433	0.834	270.3	-34.68
7.384	-33.943	0.817	249.1	-63.96
5.836	-21.668	0.821	227.3	-38.54
5.530	-11.494	0.810	206.2	-44.94
5.403	-2.2951	0.805	185.3	-37.07
5.165	6.6575	0.816	164.7	-47.89
5.660	15.7333	0.813	144.7	-47.46
6.769	25.4610	0.806	125.4	-43.56
8.3450	36.7926	0.806	106.3	-40.23

Table I: Tuning accuracy <u>without</u> Prematching.

<u>Area 1</u> corresponds to positions of the tuning section around 50Ω, whereas <u>Area 2</u> corresponds to positions around the edge of the Smith Chart.

R[Ω]	jX	|Γ|	Φ	Δ(Γ)[dB]
Area 1: Tuning around 2.5Ω				
2.5832	0.1040	0.902	179.8	-41.28
3.0218	0.1003	0.886	179.8	-40.94
2.2070	0.1084	0.915	179.8	-41.75
3.9554	0.3192	0.853	179.3	-32.07
3.0889	0.7485	0.884	178.3	-41.84
2.0462	0.5574	0.921	178.7	-41.06
2.0128	-0.3123	0.923	180.7	-42.29
3.2723	-1.0936	0.877	182.5	-42.60
2.0484	-0.8165	0.921	181.9	-36.86
………………….				
Area 2: Tuning around 0.65Ω				
0.728	-1.7964	0.971	184.1	-37.73
0.654	-1.2212	0.974	182.8	-34.88
0.630	-0.7550	0.975	181.7	-36.78
0.596	-0.3369	0.976	180.8	-33.79
0.601	0.0463	0.976	179.9	-36.90
0.613	0.4272	0.976	179.0	-38.14
0.622	0.8344	0.975	178.1	-39.40
0.673	1.2873	0.973	177.1	-38.98
0.774	1.8240	0.970	175.8	-39.42

Table II: Tuning accuracy with <u>medium</u> Prematching

R[Ω]	jX	|Γ|	Φ	Δ(Γ)[dB]
Area 1: Tuning around 1Ω				
0.986	0.0918	0.961	179.8	-47.26
0.996	0.2147	0.961	179.5	-49.35
0.949	-0.0245	0.963	180.1	-53.10
0.977	0.3455	0.962	179.2	-45.05
0.845	0.2406	0.967	179.5	-50.32
0.798	-0.0107	0.969	180.0	-47.06
1.093	-0.1666	0.957	180.4	-47.32
1.359	0.4402	0.947	179.0	-55.03
………………				
Area 2: Tuning around 0.4Ω				
0.414	-0.1211	0.984	180.3	-47.43
0.409	-0.0106	0.984	180.0	-54.03
0.408	0.0954	0.984	179.8	-51.13
0.406	0.2044	0.984	179.5	-55.49
0.407	0.3217	0.984	179.3	-45.48
0.418	0.4574	0.983	179.0	-51.18
0.428	0.6284	0.983	178.6	-45.02
0.453	0.8637	0.982	178.0	-51.74

Table III: Tuning accuracy with <u>strong</u> Prematching