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

Application Note 22

Peak Search Algorithms of CCMT Software

Introduction

Automatic search for the maximum (minimum) of a multi-parameter target function $y=f(x_1, x_2,..)$ is a typical mathematical task for which there are many solutions. Experience shows, however that finding the optimum becomes increasingly difficult and time consuming with increasing number of parameters x_i and the appearance of local minima (or maxima).
In those cases different search algorithms may be used alternatively, such as gradient and random methods, because it happens that the optimum found is a function of the starting conditions.
Searching the maximum output power of a transistor using a load pull tuner is, mathematically, not very complicated, as we only have two parameters *Re(Z)* and *Im(Z)*. Assuming that source impedance is optimally set then search for maximum power is simple, as long as the transistor is not hard driven into compression.
In the case of compression things become more complex for two reasons:
1- the function $P_{out}(Z)$ flattens out around the maximum point
2- the effect of harmonic loading (the uncontrollable impedances at harmonic frequencies) becomes visible.
In this case we need a more sophisticated search algorithm.

Bearing in mind that in real operation the search algorithm has to converge fast and that all data taken are attributed measurement errors further restricts the possible algorithms.

This note describes the peak search algorithms used in the WinPower load pull software for medium and high power operation.

Description of CCMT Peak Search algorithms

An efficient mathematical method in order to determine the maximum (minimum) of a target function $y=f(x_1, x_2, x_3...)$ is called after *Powell*. It consists of orthogonal search, i.e. after all parameters x_i are set to initial (starting) values, one parameter is modified at a time until the target function y passes through a relative maximum. Then the next variable is being changed until a second maximum occurs and so on.
If the target function has one maximum in the permitted search area of values *xi* and if it has a smooth dependence without local maxima then this algorithm converges very fast. This is normally the case with the output power of a transistor as a function of the complex load.
It however, the target function has a more complex dependence on one or more variables and the possibility of local maxima exists then the result will, unavoidably, depend on the staffing (initial) conditions given to the algorithm.

Our basic search algorithm for the maximum output power $P_{out}(\Gamma_L)$ of the transistors therefore consists of two steps:
1- Change the phase of the load (Angular Search...) until a first maximum appears
2- Change the amplitude of the load (Radial Search...) until a second maximum occurs. Within the accuracy of the tuners and the measurement this second maximum is considered the final one.

The WinPower load pull software presents the following Peak Search capabilities to the User:

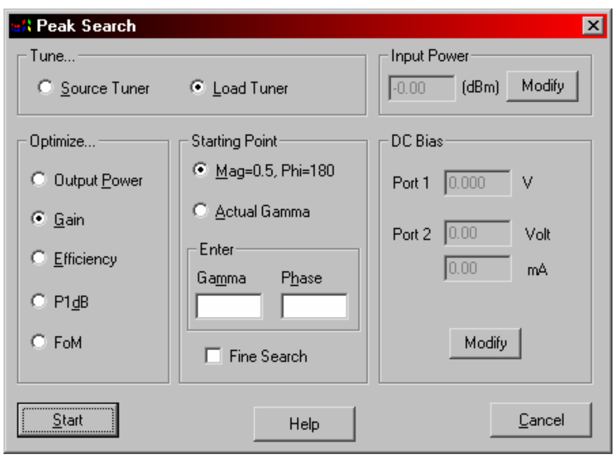


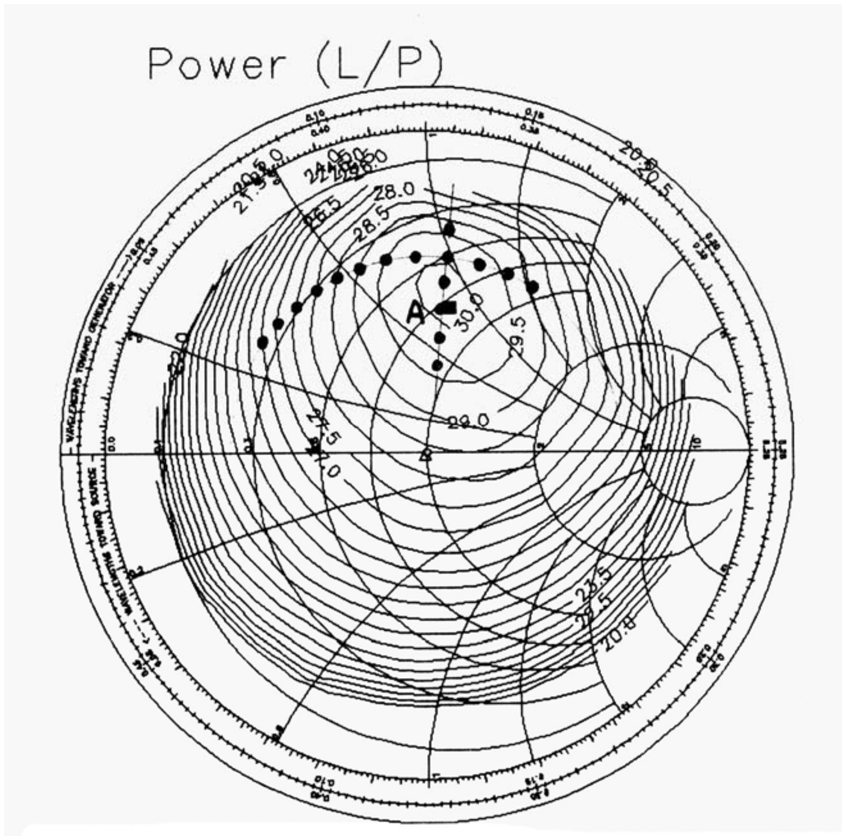
Figure 1 : The Peak Search dialog box.

The Peak Search dialog box allows selecting which tuner has to be tuned and for what parameter the routine has to search a maximum.
Only the most frequently used parameters could be selected, but the *Figure of Merit (FoM)* parameter allows the User to perform Peak Search on virtually any parameter by configuring this *FoM*.

The bias point and input power can also be adjusted from this dialog box.

As we will see later, the starting point plays on the accuracy of the results. WinPower allows to choose three options, Γ*=0.5 <180º*, *Actual Gamma* or User's defined gamma.

Another important option that can be choose here is *Fine Search* ; we will see the interest of this later.



Freq=1 GHz P_{Max}=3O.1 at 36.9 + j43.5 Ohm

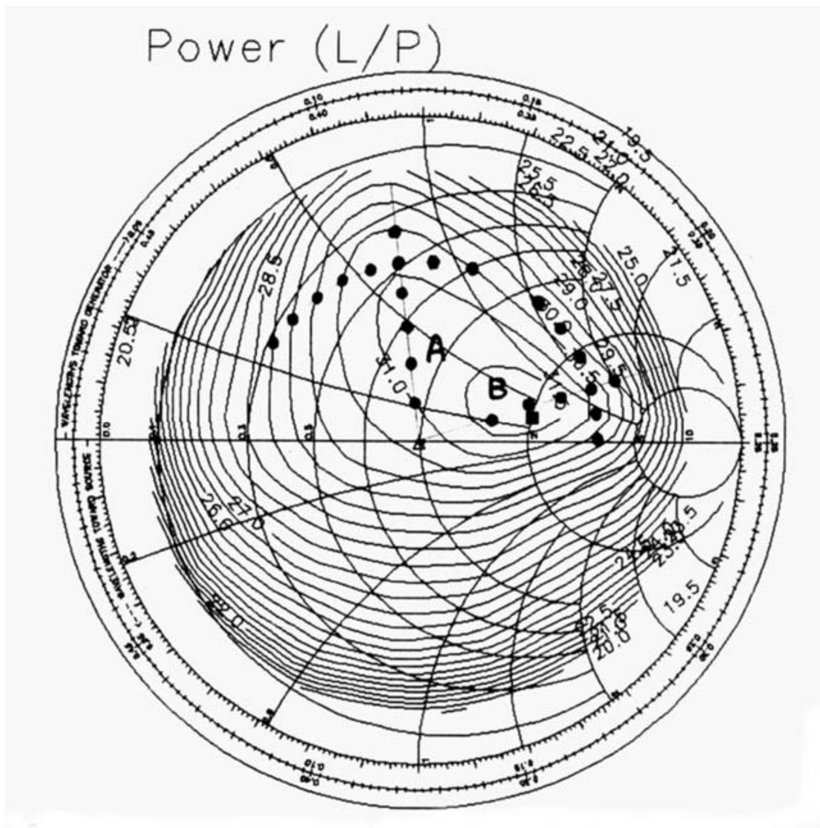
Figure 2: Low Power: Peak Search Algorithm finds ONE solution: A

The problem with this algorithm occurs when the transistor is operating in compression. Then the $P_{out}(\Gamma_L)$ behavior flattens up considerably at the top and makes the search for a maximum much more tedious for a number of reasons:

1- The final maximum is not on the same radius as the first one (small signal case).
2- Because of the flat $P_{out}(\Gamma_L)$ behavior, minor perturbations of the power readings may affect the direction of the search.
3- Harmonic loading becomes important and cannot be controlled by the tuners.

A typical set of contours of a compressed transistor is shown in figure 3.

This set of contours, drawn with a step of 0.5dB between each other shows that minor measurement errors will affect the final result. These errors may be coming either from instrument readings, tuner calibration or repeatability or harmonic loading and must be considered normal measurement uncertainty. In this case the system will find many solutions for Γ at practically the same output power.



Freq=1 GHz, P_{Max}=31.8 at 102.9 +j19.3 Ω

Figure 3: High Power: Peak Search Algorithm finds more than one solution:A,B

The search algorithm must be such that even in this case those errors do not alternate the final result. We evaluated a number of alternatives that might lead to a solution, the conditions being:

1- User can define how accurate he wants to be.
2- Time needed is an increasing function of this accuracy.

There is one generic solution to this problem, which we have adopted:

The User can define an area for a *Fine Search* and the number of impedance points he wants to consider. After this the Search routine generates a square pattern around the actual maximum and systematically scans all impedances within this pattern. There is no limitation to the size or density of the points. All points are considered.

The default area is 0.2xo.2 in size and includes 25 impedance points, but there is no limitation either to the size of the area or the number of points selected by the User. Increasing the size of the square decreases the density of points and increasing the number of points increases the resolution of the search and the search time.

Figure 4 shows such a *Fine Search* pattern :

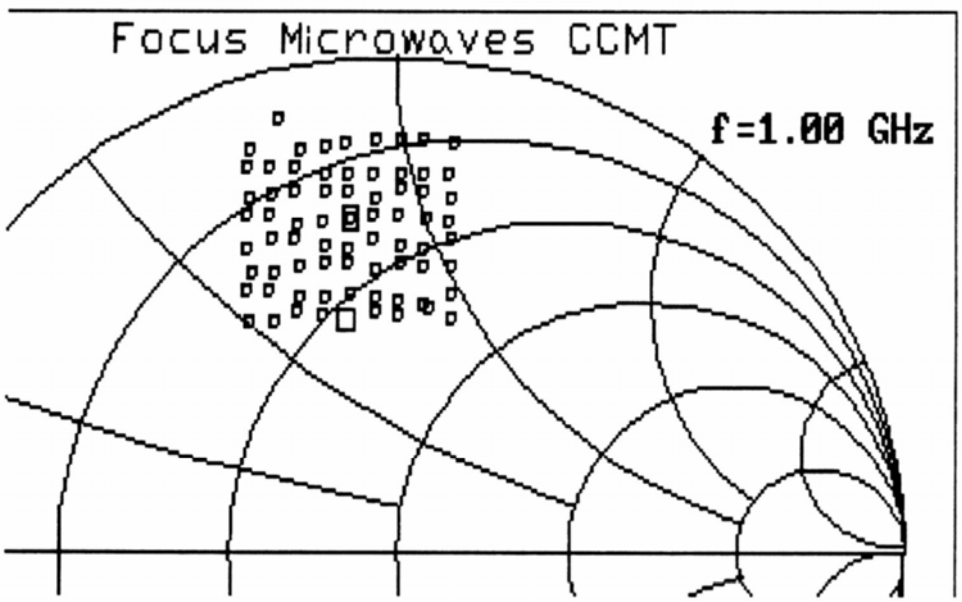


Figure 4: Automatically generated *Fine Search* pattern

The tuner tunes automatically to all shown points and retains in memory the maximum power and corresponding *Γ*, which are then saved as the final optimum tuning conditions.

The following tables summarize the effect of starting point for different input power

Pin = 5.9 dBm (No Compression)

Starting Point	Result (no Fine Search)	Result (Fine Search)	Pout (dBm)
0.750 ∠80.0°	0.764 ∠76.6°	0.782 ∠73.6°	20.36
0.500 ∠0°	0.723 ∠82.2°	0.773 ∠77.9°	20.36
0.500 ∠180°	0.725 ∠81.8°	0.782 ∠75.8°	20.33
0.700 ∠45°	0.768 ∠78.0°	0.772∠76.8°	20.34
0.300 ∠180°	0.746 ∠81.8°	0.766 ∠78.1°	20.32

Pin = 15.9 dBm (1 dB Compression)

Starting Point	Result	Result (Fine)	Pout (dBm)
0.750 ∠80.0°	0.576 ∠88.1°	0.564 ∠83.8°	29.11
0.500 ∠0°	0.560 ∠84.5°	0.576 ∠82.8°	29.10
0.500 ∠180°	0.576 ∠84.1°	0.568 ∠81.9°	29.10
0.700 ∠45°	0.577 ∠89.4°	0.571 ∠83.3°	29.08
0.300 ∠180°	0.566 ∠76.0°	0.572 ∠84.6°	29.03

Pin = 25.9 dBm (>5 dB Compression)

Starting Point	Result	Result (Fine)	Pout (dBm)
0.750 ∠80°	0.362 ∠94.8°	0.370 ∠67.9°	31.49
0.500 ∠0°	0.268 ∠14.7°	0.364 ∠65.2°	31.66
0.500 ∠180°	0.367 ∠91.7°	0.359 ∠66.0°	31.50
0.700 ∠45°	0.371 ∠100.8°	0.354 ∠63.7°	31.44
0.300 ∠0°	0.275 ∠27.2°	0.381 ∠66.7°	31.70

Table 1: Effect of Starting Point on Peak Search at different input power levels.

It is clear that *Fine Search* improves the *Peak Search* accuracy in the case of strong compression.

Effect of Source Matching

Source matching affects not only the overall gain of the devices but also the optimum load impedance.
The CCMT system can only match one side of the DUT at a time. The question arises how many times one has to match input and output alternatively until the device is matched on both sides.

We have studied this question on different types of transistors. The higher the feedback capacitance *Cgd* (or *Ccb*) the more sensitive is output matching in regard with input matching.

We found, however that 2 iterations are in general sufficient to find a stable condition:

Step 1; Input matching $\Gamma=\Gamma_{s0}$ (Output at $\Gamma_L=0$).

Step 2: Output Matching $\Gamma = \Gamma_L$

Step 3: Input matching (2nd iteration) $\Gamma=\Gamma_{s1}$

If we try to match the output again in normal cases it does not change compared to $\Gamma_{L.}$

Table 2 demonstrates this effect on a practical example (1 GHz):

Action	Γ Source	Γ Load	Pout [dBm]
Source Matching	0.874 ∠178.5°	0	25.71
Load Matching	" " "	0.560 ∠86.0°	29.14
2nd Source Matching	0.883 ∠175.1°	" " "	29.47
2nd Load Matching (not required)	" " "	0.562 ∠86.7°	29.50

Table 2: Procedure for simultaneous Source/Load Matching

It is obvious that the second Load side matching iteration does not improve the output power and does not generate different load impedance, it can thus be omitted.

Conclusion

This note describes the different Peak Search routines available in the CCMT software. The simple peak search consisting of one angular and one radial search cycles provides consistent results for low power operation of transistors.

At high compression conditions a *Fine Search* algorithm executes a search on a User defined (automatically generated) pattern and improves the, otherwise, scaterred results. Source and Load matching are related. A straightforward solution to the "simultaneous matching" problem consists of a "Source-Load-Source" matching sequence, which then delivers a final result.

Related Topics

[1] Technical Note 1-92: "Design of a Power Amplifier stage using “µW-PADS”, Focus Microwaves, April 1992

[2] Application Note 8: “Basics on Load Pull and Noise Measurements”, Focus Microwaves, June 1994

[3] Product Note 12: “Software Packages for the CCMT system”, Focus Microwaves, January 1994