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Product Note 56

WinPADS, a Power Amplifier Design Software using Load Pull Contours

WinPADS is a two stage power amplifier design software package that employs fast and accurate circuit analysis and optimization techniques for which it only requires measured load pull data of power transistors. The data and design targets may include Pout, IMD, PAE, ACPR and more.

Background

Nonlinear models are commonly used today for designing power amplifiers. This approach bears problems: the models are not accurate enough for high compression conditions, in particular concerning critical characteristics like Intermod and ACPR or PAE. Nonlinear transistor models are generated using combinations of small signal S-parameters, DC measurements (under preferably pulsed bias conditions to compensate for self-heating effects), capacitance over voltage curves (C(V)) and optimization programms for curve fitting. Some nonlinear models provide analytic functions as approximations for certain device operation range and some work with measurement listings. Except of their limited accuracy nonlinear models are also cumbersome to deduct and, in most cases, users depend on either transistor manufacturers or software vendors to provide appropriate models. This is not always an acceptable alternative, since the users have no control over the test conditions (frequency, bias, power, signal form, etc..) under which the models have been deduced, and, in several cases, this information is not complete. So, designing high power amplifiers using exclusively nonlinear transistor models boards sometimes to a guessing game. For some of those reasons serious designers require hard measured load pull data as realistic support instead of simply manipulating numbers in models and experience ineffective "iterations".
Such data are generated by any FOCUS load pull system. WinPADS uses this data directly in the design and optimization of power amplifiers.

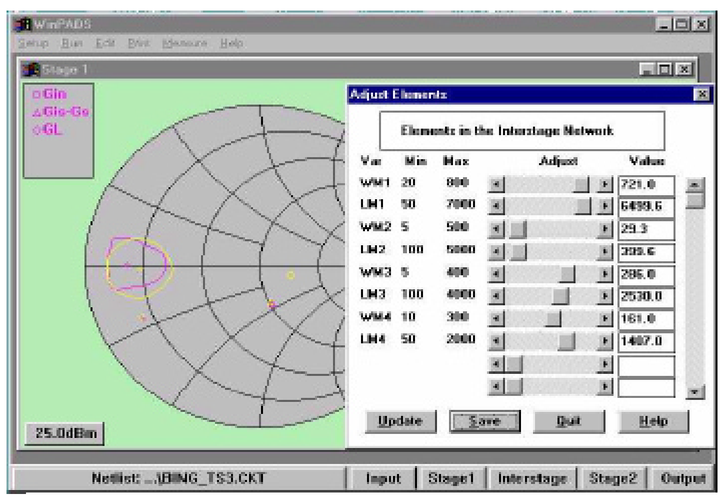

Figure 1: WinPADS main menu with Interactive Manual Tuning (IMT) dialogue and power contours at the output of stage 1

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Programm Description

WinPADS is a Windows® application based on the DOS programm µW-PADS (see Appendix), a single stage power amplifier design software, first launched by Focus in 1992. The philosophy of the operation is the same, but WinPADS can handle a two stage amplifier design, has a more powerful user interface and includes a multitude of new features and accessories which increase design productivity and facilitate the operation and data processing.

In principle WinPADS, as well as µW-PADS, use load pull data to describe a power transistor in an amplifier circuit as a "load dependent power generator" i.e. for each load presented by the matching networks to the output of the transistor, WinPADS computes the associated output power (or PAE, IMD, ACPR etc..) using measured data and fast proprietary interpolation routines.
The network parameters are modified within user defined limits and optimized using simplex and gradient optimizers in order to minimize an Error Function, which can cover a large frequency band and include a combination of output and matching parameters. A handy "Interactive Manual Tuning (IMT)" routine operates both on reflection factor (Smith Chart) as well as on output parameter (Cartesian frequency plots) display and allows fast conversion to the target and overcoming local minima of the error function.
WinPADS can be used to design single and two stage amplifiers. The two options are distinguished by the circuit description in the net-list (.CKT) file (see Appendix).
WinPADS includes a "scaling factor" feature which allows the determination of the most appropriate transistor to be used as a second stage; this feature also helps defining the test conditions and input power levels of the second stage device, in order to make both stages match into an operating two stage amplifier.
No knowledge of the transistor's nonlinear behaviour, other than its load pull data and, optionally a set of S-parameters (in .S2P format) are required for "first pass" accurate amplifier designs.
WinPADS can also handle harmonic impedance data. This data must be included in a separate harmonic impedance file (format .HRM) and is displayed on the Smith Chart as a comparison of measured and calculated data points.

The **Error Function** (figure 3) to be optimized may include Output Power, Efficiency, Intermod, ACPR (CDMA) and any other measured parameter.

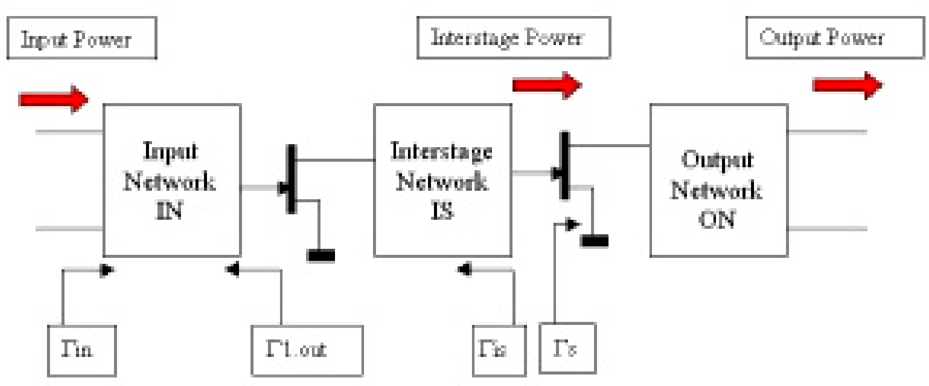


Figure 2: Principle of operation of WinPADS; the source reflection factors Γ1.out and Γis must be the same as during the measurement for the load pull contours to be valid.

The universality of accurately measured data that can be optimized for design when included in the Error Function is a key element of the utility and advantages of this method, as compared to nonlinear modelling, which is mostly restricted to output power and possibly, but not accurately, PAE and IMD, whereas other parameters cannot really be modelled.

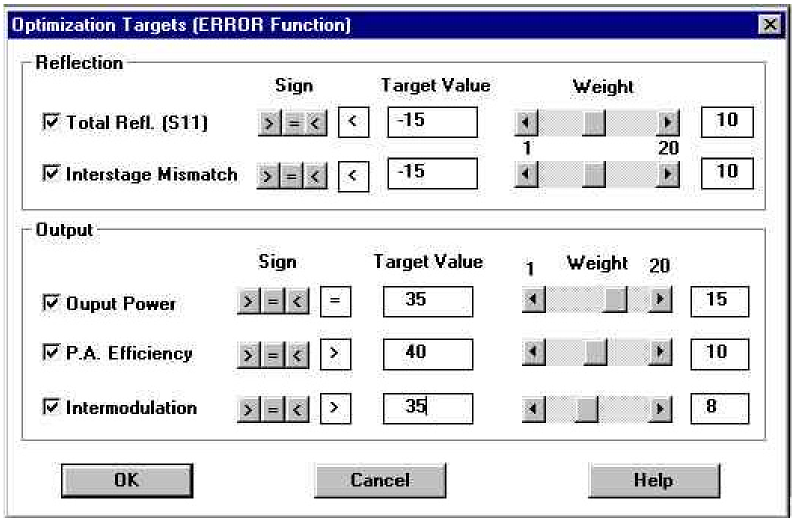


Figure 3: Dialogue used to define the Error Function.

WinPADS is also not particularly related to any type of transistor or other and can be used for any kind of transistor, like FET, MOSFET, LDMOS or Bipolar.

WinPADS describes transistors in the form of a generalized function

Output Parameter = Function (Γ_{Load})

Associated conditions, such as input power and source impedance must be considered and respected in the design process. This is a very important feature of WinPADS: it reproduces exactly the measurement conditions and guarantees thus the validity of the data used in the design.

Optimization Targets and Error Function (figs. 2, 3)

There are three basic optimization targets:

1. **$|\Gamma_{in}| = 0$**
2. **$|\Gamma_{is}-\Gamma_s| = 0$**
3. **P_{out} = Target (or PAE, IMD, ACPR etc..)**

$|\Gamma_{in}| = 0$ ensures that the amplifier is input matched. This is a normal operation condition for power amplifiers. In the case of WinPADS, however, this condition is more important, because it guarantees that the source impedance conditions for the load pull data are going to be the same for the measurement and the final amplifier, or the load pull contours will contain valid data.

Assuming the Input Network "IN" does not include any important lossy components inside the frequency range of interest, the condition $|\Gamma_{in}|=0$ means that the transistor too will be matched at the source ($\Gamma_{dut}=\Gamma_s^*$).
This condition is considered "satisfied" when $|\Gamma_{in}|$ corresponds to a return loss of more than 10 to 15 dB. This is also a typical condition at which load pull measurements are carried out.

$|\Gamma_{is} - \Gamma_s| = 0$ ensures the same for the interface between the two transistors.
This condition means that the second stage transistor will see at the output of the first stage the same impedances it was seeing when it was tested. If the second transistor was tested under input matching conditions then Γ_{is} (i.e. the output reflection factor of the first stage) will match the input of the second stage, which is also a desirable condition for maximum power transfer.

However, it is not mandatory to operate this way. We can also test the second stage under different source impedance conditions (for instance 50 Ω) and design the interstage network such as to synthesize these conditions. In this case there is no assumption as to the interstage network being allowed to include lossy elements or not. Again this condition is considered "satisfied" when $|\Gamma_{is} - \Gamma_s|$ is smaller than 0.2 to 0.3 (≈ -15 dB).

Parameter = Target = constant.
This optimization condition is the main part of the Error Function and may include a combination of several amplifier parameters. The error function (EF) is calculated as follows:

$$\mathbf{EF = W_1 \bullet |\Gamma_{in}| + W_2 \bullet |\Gamma_{is} - \Gamma_s| + TARGET}$$

where

$$\mathbf{TARGET = W_3 \bullet Pout + W_4 \bullet PAE + W_5 \bullet IMD + W_6 \bullet ACPR\ldots}$$

The user can define all weight factors W_1 to W_6 thus <u>including several measured parameters to the final performance of the amplifier.</u>
In most cases one parameter is the most important and it is best to start optimizing with this one. Then as the design is close to completion additional parameters and conditions can be added to improve the final design.

Optimization Procedure

The optimization procedure of WinPADS is quite particular: As a matter of fact, because the impedance conditions change during the optimization, the load pull data used in the design are not valid at the beginning and during the optimization. When conditions 1. And 2. Above are not satisfied the data in the computer memory are unrealistic. This does not matter, however, since, when the optimization terminates and all three conditions are satisfied then the load pull data will be valid, because all test conditions are met. In other words, the

intermediate results being wrong we can still expect the final data to be accurate (see Appendix for data obtained on a specific amplifier).

Optimization should be as much as possible done using the Interactive Manual Tuning (IMT) dialogues for each network separately (see figure 1). The input network will mostly affect the input matching whereas the interstage and output network will affect the interstage and output data correspondingly. Our experience shows that IMT is very efficient.
Final optimizations can be carried out using the built-in optimizers (TAUROS and SIMPLEX, figure 4).

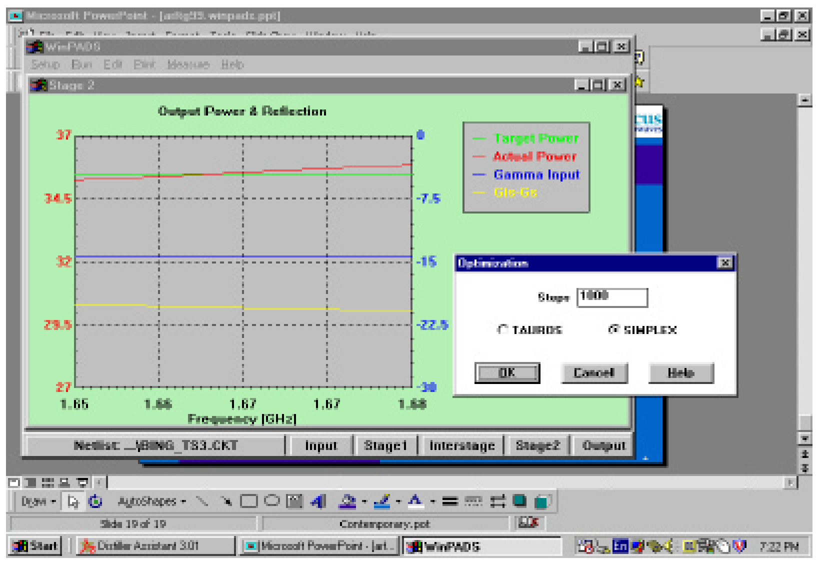


Figure 4: WinPADS automatic optimization routines and Cartesian output plots

Load Pull Data Measurement

The input stage is measured the traditional way, i.e. with Pin = constant. The measurement can be done using any load pull system, in particular a Focus system (figure 5). Data from other systems can be converted to WinPADS compatible data sets, since the software accepts standard ASCII files.

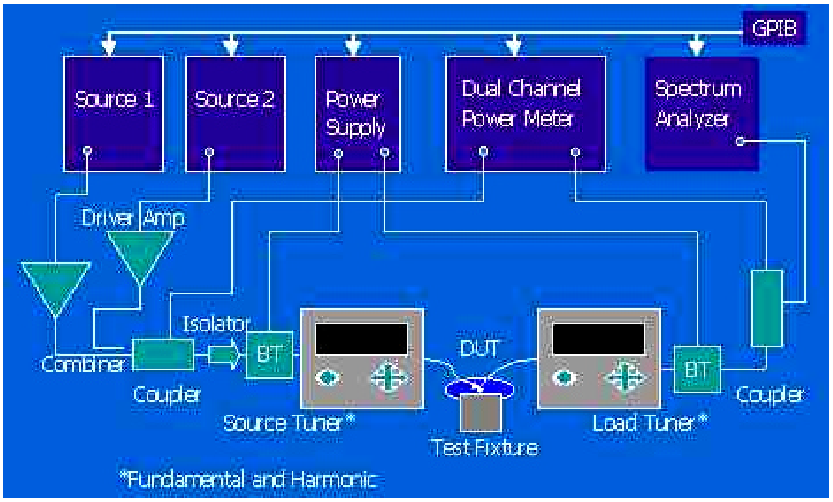


Figure 5: A typical Focus Load Pull setup

The second stage is more delicate to characterize: the reason is that the input power to this stage changes when the optimizer modifies the input and interstage networks. It is not predictable at the time of the load pull measurement which impedance at the output of stage 1 will be necessary in order to match this stage to stage 2. Therefore we cannot predict how much power will be delivered from stage 1 to stage 2, in other words we do not know in advance the input power of stage 2 at the time of the test and the load pull data must be available for a complete range of input powers. The most adequate way to handle this situation

all possible input power conditions, in order to be able to pick the right input power conditions.

We use two types of load pull testing and corresponding data files:

1. Files wit P_{in}=constant (.LPD files)
2. Files with Compression=constant (.LPC files).

The .LPD files are standard load pull data files, measured under Pin=constant conditions. They include information on source impedance at the fundamental and harmonic frequencies and columns of measured parameters as a function of load impedance (figure 6).

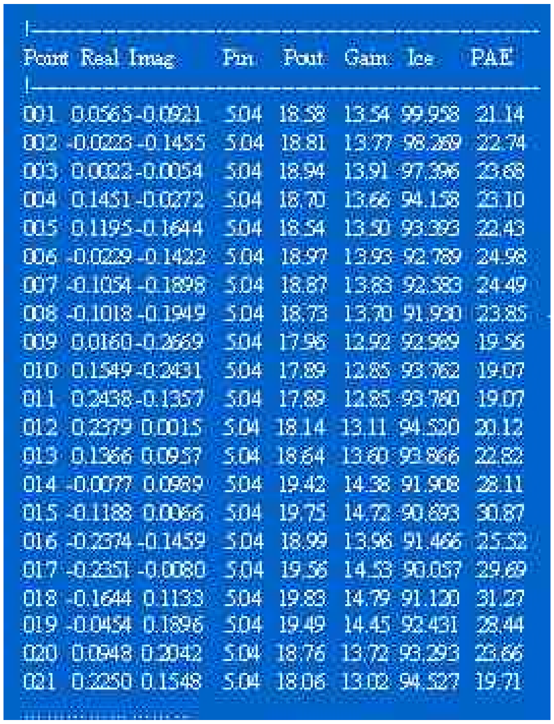
is to characterize the transistor for stage 2 under

The .LPC files are measured under variable (swept) input power conditions. During the measurement the tuner is moved to an impedance and the input power is increased by a user defined step until a pre-defined gain compression (typically 2 to 4 dB) is reached; the data for all input powers are saved (figure 7); this provides for data columns including all measured parameters for all input powers regrouped for the same load pull impedance.

During circuit optimization of the Interstage network the output power of stage 1 changes and so does the input power into stage 2. WinPADS interpolation routines scan the .LPC file (of stage 2) and extract the corresponding data for each computed Pin (this is in general different for each frequency), interpolate and compute the output power from stage 2 (or PAE, IMD etc..).

```
|-----------------------------------------------
Point  Real Imag  Pin Pout Gain Ids PAE
|-----------------------------------------------
# 001  -0.1035  0.0348
   8.58    18.65    10.07  331.504    3.99
   9.56    19.61    10.04  328.149    5.03
  10.56    20.57    10.01  323.598    6.37
  11.57    21.53     9.96  318.362    8.05
  12.61    22.47     9.86  312.202   10.17
  13.55    23.30     9.75  305.735   12.52
  14.57    24.14     9.57  297.518   15.57
  15.61    24.87     9.26  287.578   18.86
  16.63    25.46     8.83  276.454   22.15
  17.06    25.65     8.59  272.426   23.31
# 002  -0.0092  0.0579
   8.57    18.20     9.63  329.967    3.58
   9.57    19.15     9.58  326.374    4.50
  10.57    20.12     9.55  321.563    5.70
  11.58    21.06     9.49  315.908    7.20
  12.60    21.99     9.40  309.344    9.08
  13.56    22.81     9.25  302.271   11.17
  14.58    23.63     9.05  293.350   13.81
  15.61    24.32     8.71  282.466   16.61
  16.64    24.87     8.23  270.805   19.31
  16.78    24.93     8.15  269.462   19.62
# 003  -0.0895 -0.0676
   8.56    18.62    10.05  333.240    3.95
   9.57    19.58    10.01  330.118    4.97
  10.56    20.55     9.99  325.935    6.28
```

Figure 6: .LPD data file (Input Stage)



Point	Real	Imag	Pin	Pout	Gain	Ice	PAE
001	0.0565	-0.0921	5.04	18.58	13.54	99.958	21.14
002	-0.0223	-0.1455	5.04	18.81	13.77	98.269	22.74
003	0.0022	-0.0054	5.04	18.94	13.91	97.396	23.68
004	0.1451	-0.0272	5.04	18.70	13.66	94.158	23.10
005	0.1195	-0.1644	5.04	18.54	13.50	93.393	22.43
006	-0.0229	-0.1422	5.04	18.97	13.93	92.789	24.98
007	-0.1054	-0.1898	5.04	18.87	13.83	92.583	24.49
008	-0.1018	-0.1949	5.04	18.73	13.70	91.930	23.85
009	0.0160	-0.2669	5.04	17.96	12.92	92.989	19.56
010	0.1549	-0.2431	5.04	17.89	12.85	93.762	19.07
011	0.2438	-0.1357	5.04	17.89	12.85	93.760	19.07
012	0.2379	0.0015	5.04	18.14	13.11	94.520	20.12
013	0.1366	0.0957	5.04	18.64	13.60	93.866	22.82
014	-0.0077	0.0989	5.04	19.42	14.38	91.908	28.11
015	-0.1188	0.0066	5.04	19.75	14.72	90.893	30.87
016	-0.2374	-0.1459	5.04	18.99	13.96	91.466	25.52
017	-0.2351	-0.0080	5.04	19.56	14.53	90.057	29.69
018	-0.1644	0.1133	5.04	19.83	14.79	91.120	31.27
019	-0.0454	0.1896	5.04	19.49	14.45	92.431	28.44
020	0.0948	0.2042	5.04	18.76	13.72	93.293	23.66
021	0.2250	0.1548	5.04	18.06	13.02	94.527	19.71

Figure 7: .LPC data file (Output Stage).

A WinPADS specific element library has been created and is accessible from OrCAD (figure 8). The user can put together the physical layout of his circuit and connect twoports electrically. He can also enter
component values in the corresponding OrCAD dialogues and prepare for an optimization, based on the available technological sizes and other limitations.
Once the circuit description is terminated a translator programm converts the circuit layout into a WinPADS compatible circuit file (.CKT file, see Appendix for a concrete example of a single stage amplifier). This file can be edited and default plot settings and limits can be modified using any ASCII editor, that can be configured to work as a default editor from within the WinPADS menus.

Since all data are stored in RAM and because of the optimized interpolation routines this procedure is very fast when a Pentium 233 MHz or higher is used.

WinPADS Schematic Capture

WinPADS schematic capture uses OrCAD®, a popular and commonly available layout software package which creates .DSN files and NetList describing the layout working area.

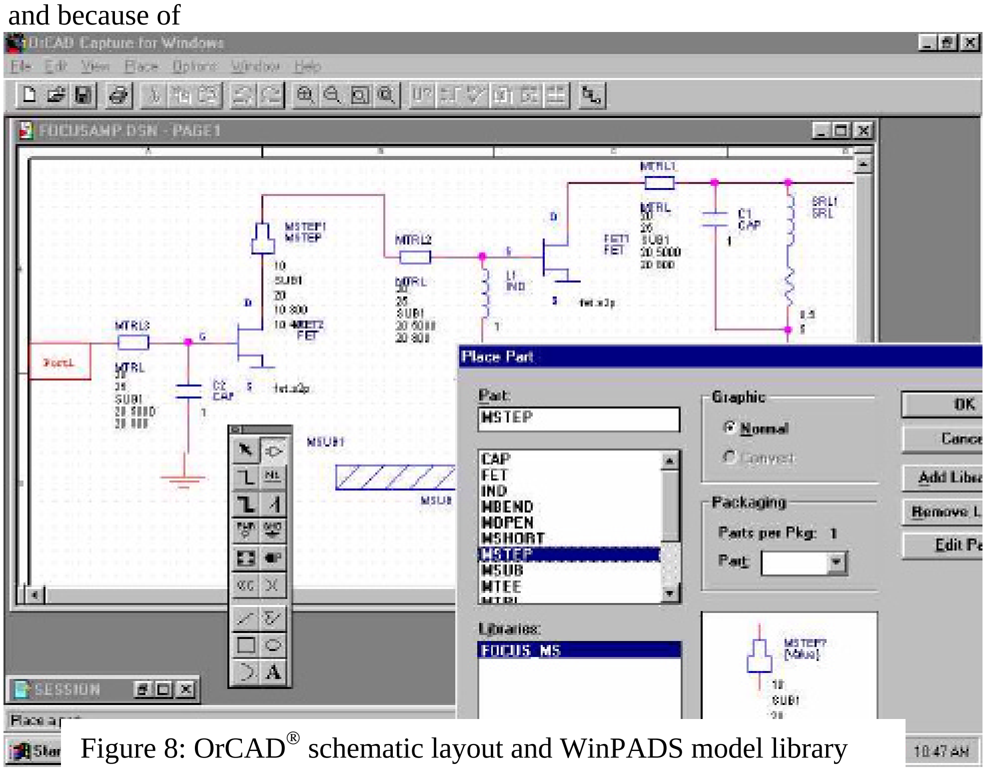


Figure 8: OrCAD® schematic layout and WinPADS model library

Model Library

WinPADS model library includes the following lumped and distributed components:

- CAP = lumped capacitor
- IND = lumped inductor
- RES = lumped resistance
- FET = S2P FET file
- MSUB = Definition of Microstrip Substrate
- MSTRIP = Microstrip line
- MTEE = Microstrip Tee Junction
- MSTEP = Microstrip Step between two widths
- MBEND = Microstrip Bend
- MOPEN = Microstrip Open Circuit
- MSHORT = Microstrip Short
- MTRL = Microstrip Transmission Line
- SRC = Serial RC Circuit
- SRL = Serial RL Circuit
- SRLC = Serial RLC Circuit

Using the components of this library the majority of amplifier circuits can be described.

Appendix: Design Example

Please ask for Technical Note 1-92:

“Design a Power Amplifier Stage using μW-PADS”