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Product Note 34

LSM, Large Signal S-Parameter Module

LSM is a microwave test module that measures transistor ***large signal "S"-parameters***. It is used with a Network Analyzer either as a stand-alone unit or as an accessory to a passive load pull system. LSM includes a twoport-Reflectometer, a Driver Amplifier, a Switch Matrix and complete Calibration, Measurement and Graphics software in Windows®. Used with a load pull system, LSM acquires large signal "S"-parameters ***under matched source and load conditions.***

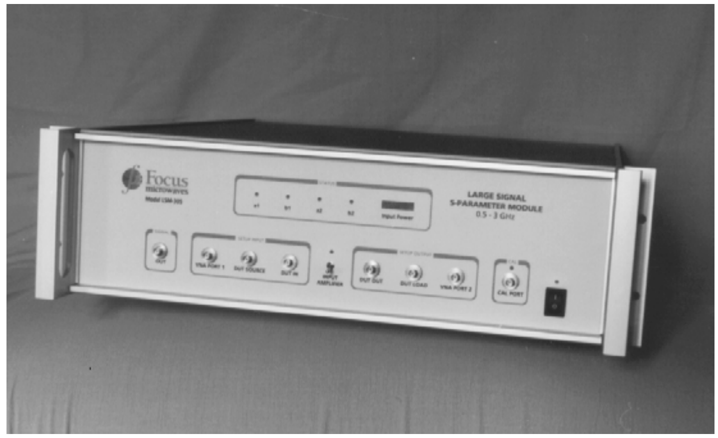
Introduction

LSM (figure 1) has been developed as a component to Focus' Active Load Pull System (ALPS) [1]. It includes a twoport Reflectometer and a set of electronic RF switches that permit to sample and measure injected and reflected power waves of a transistor in a test fixture or on-wafer. LSM is connected to a Vector Network Analyzer using two RF cables. It is compatible with all commercial network analyzers of Hewlett-Packard® and Wiltron® (_). The power injected into the transistor may come from the network analyzer itself or from an external, synchronized, synthesizer. LSM can amplify and electronically control the input power level. System control is provided by an IBM®-PC using an internal parallel bus and Windows® software. This software permits calibration of the system and generation of .S2P ASCII files. These files contain the *nonlinear "S"-parameters*. LSM's software has also the capability of generating cartesian or polar plots of the measured "S"-parameters.

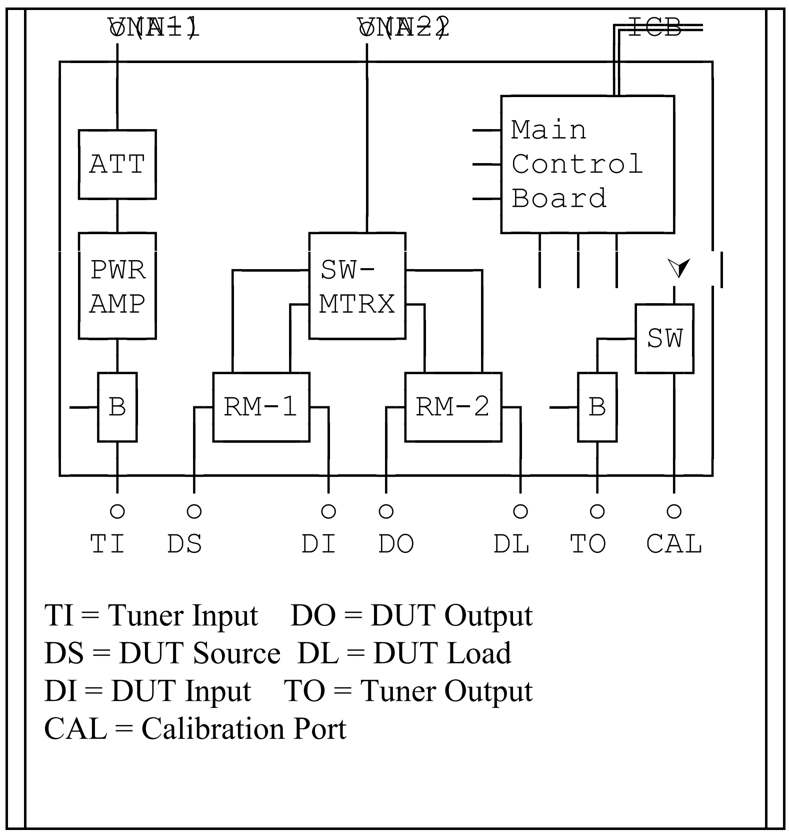
We are using the term "S"-parameters in double quotes, since we are dealing with special quantities, which describe the DUT twoport like S-parameters, but they are measured, in general, under non-50Ω source and load conditions. *These parameters depend on those conditions as they depend on the level of the power injected into the device.*

(_) HP-8510, 8720, 8753, 8753D, Wiltron 360, 37000

System Description



LSM model 305 operates from 500 MHz to 3 GHz and beyond. LSM's frequency limitation is caused by the directivity of the couplers and the isolation and insertion loss of the electronic switches used. The concept of LSM is valid for any frequency and the calibration and measurement techniques used can be extended to much higher frequencies, at least 26 GHz.
LSM is built into a 19" box compatible with instrumentation racks (figure 1).

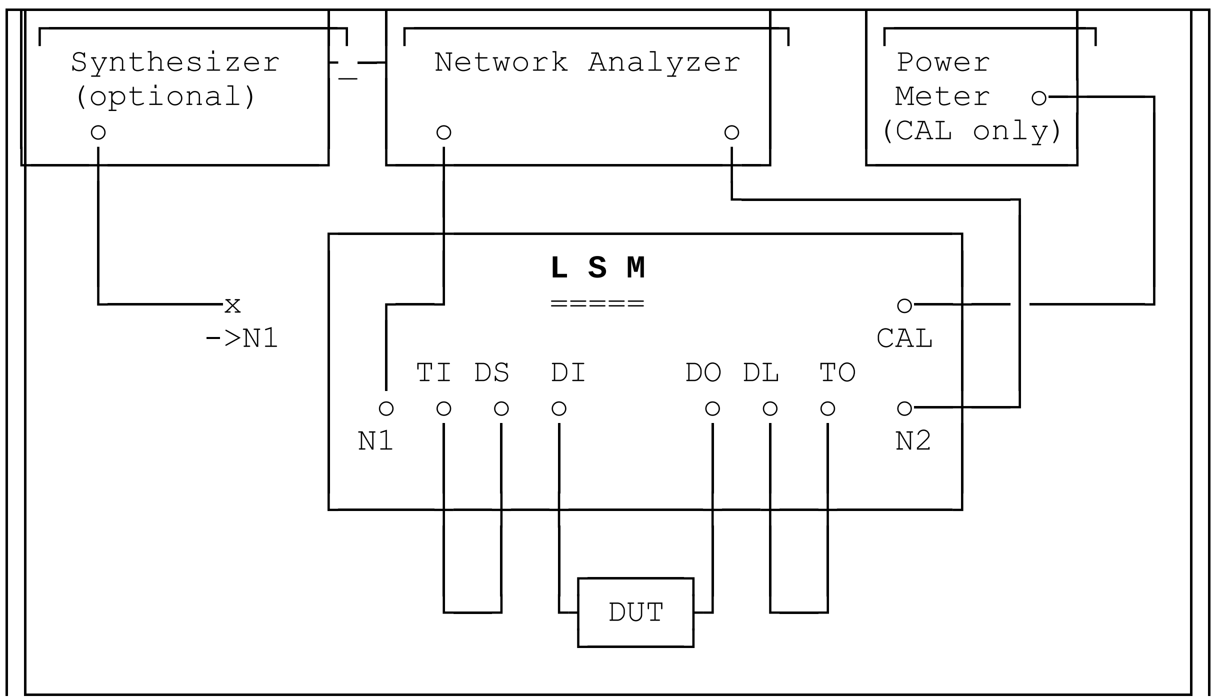


LSM's core component is a twoport Reflectometer with full compatibility towards all existing network analyzers and additional power measurement capability (figure 2).
It includes two directional couplers (RM-1 and RM-2) and a fast electronically controlled switch matrix (SW-MTRX). It also includes a power amplifier (PWR AMP), an electronic attenuator (ATT) and two bias tees (B).

The signal received from the output of the DUT (port DO, figures 2 and 3) can be routed through an output tuner (port DL). The mechanical switch SW can connect to a 50Ω load or the CAL port, used for true power calibration.
During tests an external bridge has to be connected between ports TI and DS as well between DL and TO.
If LSM is used as part of a load pull system those bridges are replaced by the input and output tuners (figure 4).
LSM is remotely controlled by an IBM®-PC computer via internal control bus (ICB). The PC

simultaneously controls the network analyzer via GPIB and retrieves measured data. The network analyzer is used as fast detector and, normally, signal source.
LSM can be calibrated at DUT reference plane using TRL and ***measures all four S-parameters of the DUT at any input power, within the linearity of the system***.
A ***true power*** calibration at the CAL port using a power meter permits the measurement of the absolute values of the two incident and the two reflected power waves at the ports of the DUT.

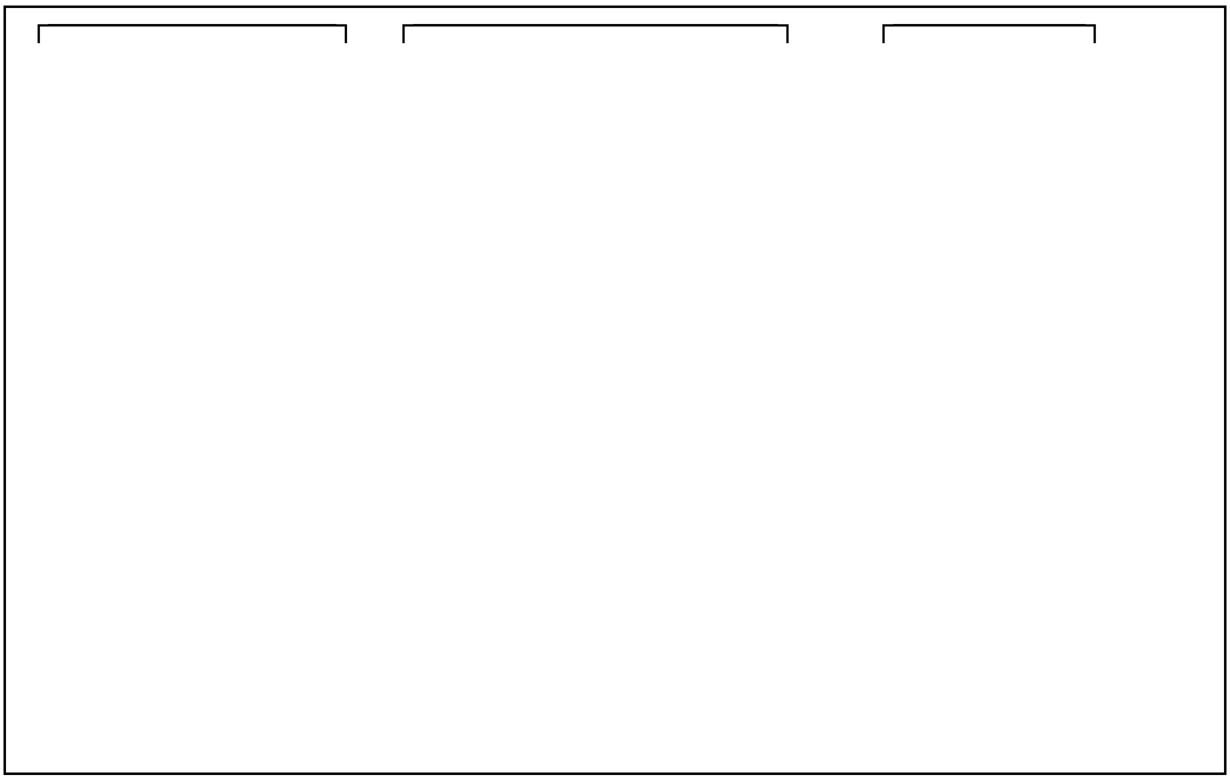
An external synthesizer (figure 3) can be used as a signal source in order to measure S_{22} of the DUT at harmonic frequencies. In this case the synthesizer's output is connected at port N1 (called also VNA-1 in figure 2) instead of the network analyzer. The synthesizer is tuned to the



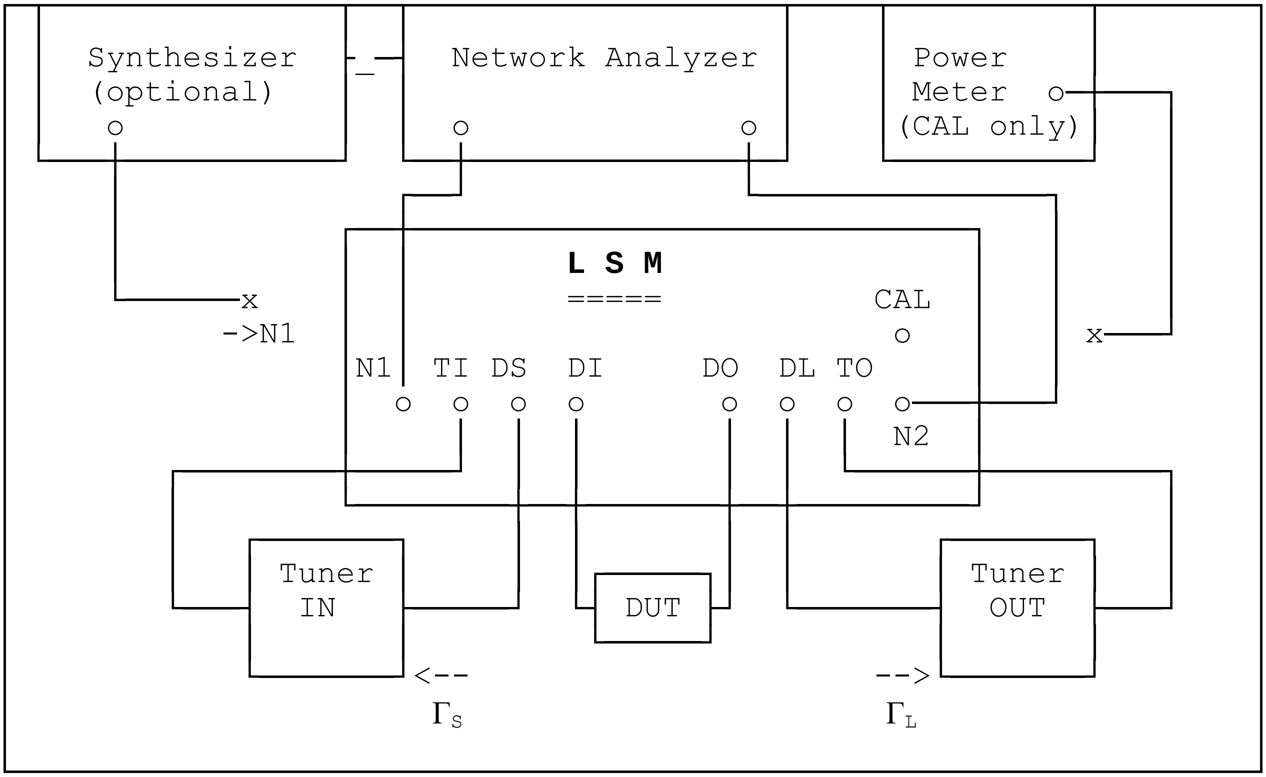
fundamental frequency. The network analyzer, who's port 1 is now idle, can be tuned to measure the injected and reflected waves at the DUT's output port at the harmonic frequencies. This new quantity would be the "harmonic S_{22} " or $S_{22}h$. Another quantity that can be measured is the harmonic output power wave $a_2\,(n\bullet f_0)$ as a function of the fundamental input power wave $a_1\,(f_0)$. This can be used to define the "harmonic conversion gain" $S_{21}h(n) = a_2(n\bullet f_0) / a_1(f_0)$.

If LSM is used together with a passive load pull system (figure 4) this permits to perform large signal "S"-parameter measurements under variable load and source impedance conditions. Most significant, in this case, are the measurements where the transistor is simultaneously matched at each frequency. Since, however, the tuners of the passive system cannot present to the transistor the required impedances at all frequencies simultaneously, this measurement has to be made in CW mode, frequency by frequency. A special routine tunes the network analyzer to a given

frequency and then both tuners are tuned in order to match input and output of the transistor, after that a twoport S-parameter measurement is performed and the system is tuned to the next frequency.
The fact that both ***incident and reflected waves*** are measured allows to compute the real ***power added efficiency*** of the transistor tested under all source impedance conditions. This is not the case with passive load pull systems which do not use LSM. Those systems do not use a calibrated Reflectometer and can measure power added efficiency only under matched source conditions



[2].



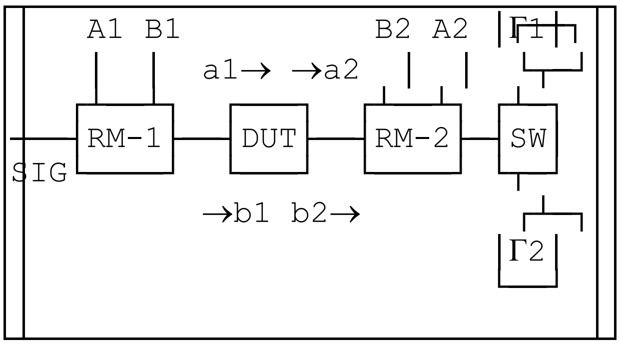
The shortcoming of this configuration is, however, that losses in the directional couplers and the cables from and to the LSM ports DS and DL reduce the reflection factor available for matching the DUT.

"S"-Parameter Measurements using LSM

LSM is a ***calibrated twoport Reflectometer***. This permits to measure full twoport S-parameters of active and passive twoports, such as attenuators, test fixtures, transistors, cables, couplers and isolators.
There are two possibilities for measuring twoport S-parameters:

1) Inject the source signal at the input and output port of the DUT and measure injected and reflected power waves. This requires the RF signal to be internally switched from port 1 to port 2.

2) Measure injected and reflected power waves at input and output port of the DUT under two different values of the load impedance Γ_L ,for instance Γ_1 and Γ_2.



The second technique is better suitable to LSM, since we have simple control of the load conditions by switching between the CAL port and the DUT Load port (fig. 5).

$$B1 = S11 \bullet A1 + S12 \bullet A2 \qquad \Gamma=\Gamma_1 \quad (1)$$
$$B2 = S21 \bullet A1 + S22 \bullet A2 \qquad (2)$$

$$B1' = S11 \bullet A1' + S12 \bullet A2' \qquad \Gamma=\Gamma_2 \quad (3)$$
$$B2' = S21 \bullet A1' + S22 \bullet A2' \qquad (4)$$

Combining these four equations we obtain the S-parameters at Reflectometer reference plane (waves A1, B1, A2, B2) as described in [3]:

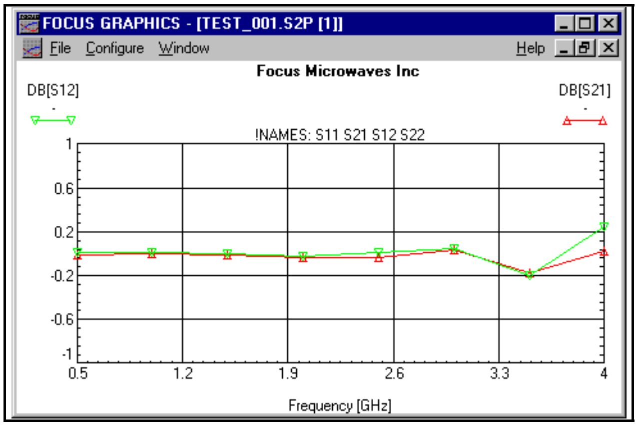
$$S11 = \frac{B1/A2 - B1'/A2'}{DEN} \ (5), \quad S12 = \frac{B1/A1 - B1'/A1'}{DEN} \ (6), \quad S21 = \frac{B2/A2 - B2'/A2'}{DEN} \ (7)$$

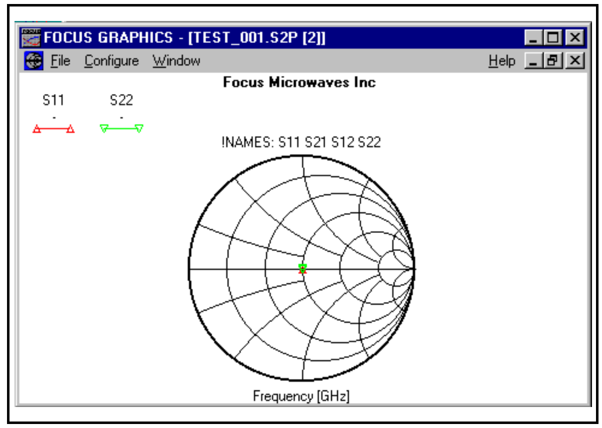
$$S22 = \frac{B2/A1 - B2'/A1'}{DEN} \ (8), \quad \text{whereas } DEN = A2/A1 - A2'/A1' \ (9).$$

Using the error terms determined by the TRL calibration of the system [1] these S-parameters can be corrected back to the DUT reference plane (waves a1, b1, a2, b2).

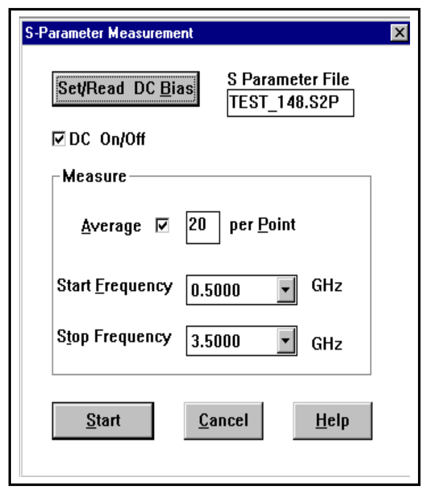
The choice of Γ_1 and Γ_2 is not trivial, however, since the device may oscillate under certain load impedance conditions. This may happen either at a given load impedance or *during the switching between two states*. During switching, large reflection factors (open circuit) may occur for a very short period of time, enough to trigger an oscillation, which is then sustained after the new load impedance has settled. LSM software provides a solution for this particular problem, by allowing the User to switch off the bias of the transistor during the impedance switching period of time. The result of this measurement is meaningful if the behaviour of the DUT does not change significantly between the two load conditions Γ_1 and Γ_2. If it changes then the result will be an average value between the two states.

The RF bandwidth of the components used in LSM-305 permit large and small signal S-parameter measurements in a frequency range wider than actually specified, though with somehow limited accuracy. **The accuracy of the LSM calibration** is verified by measuring the S-parameters of a THRU Line (figures 6,7).



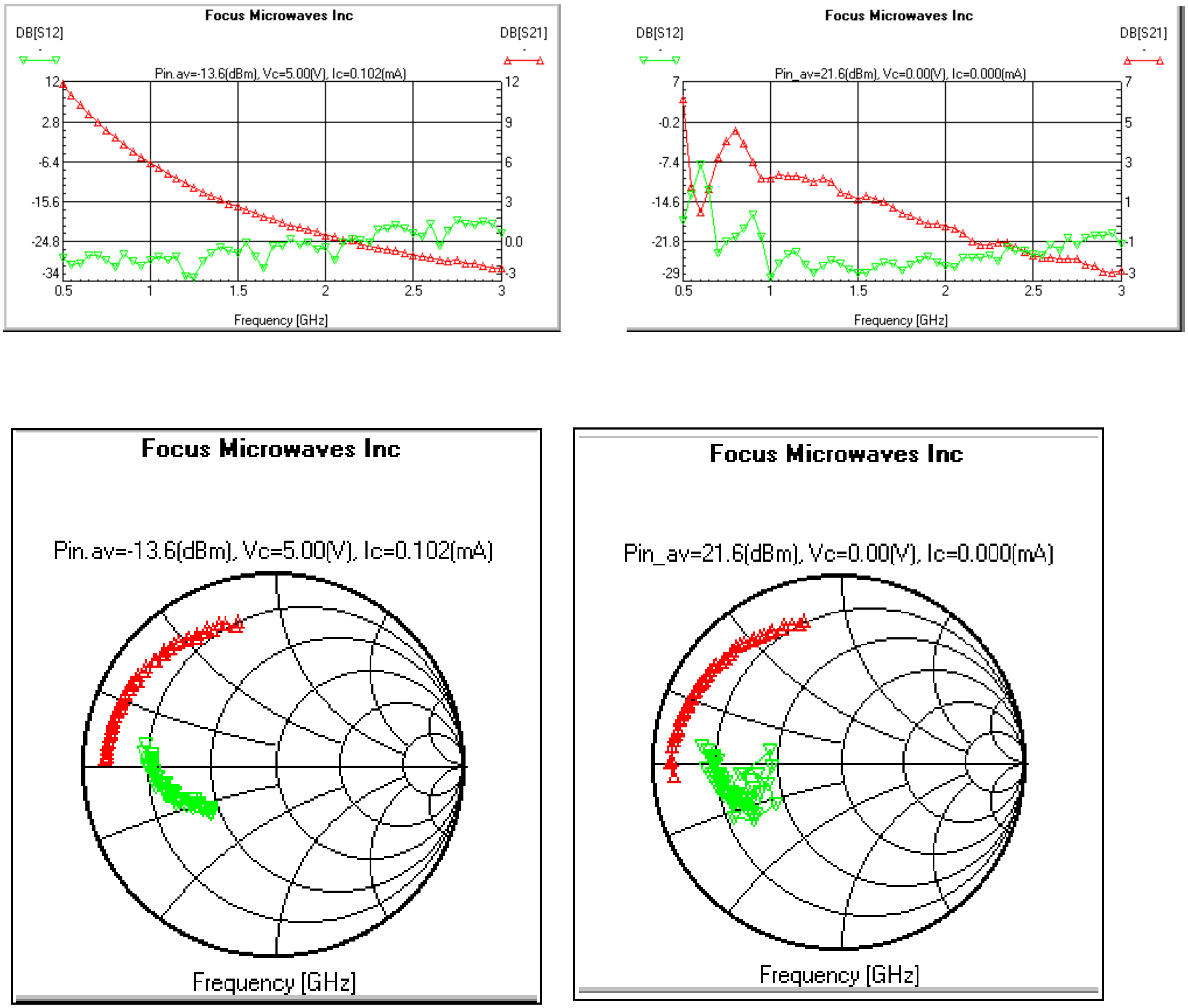


LSM Software and Measurements



LSM software is written in C++ programming language as a Windows® application.
It includes a number of menus that permit to Configure the system, Calibrate and Measure S-Parameters and DC-Parameters (IV-curves and Bias Setting). It also permits to invoke the ***Display*** utility which generates Cartesian, Polar and Smith Chart plots.

S-parameter measurements are initiated by a dialogue that allows to set all required conditions (figure 8). This includes start, stop frequency and frequency step, as well as input power at which the measurements will take place. Averaging factor can also be selected.
A useful feature is the "**Bias On/Off**" option, which, if activated, turns the DC bias off just before it switches to the second load impedance state in order to minimize the risk for transition oscillations.

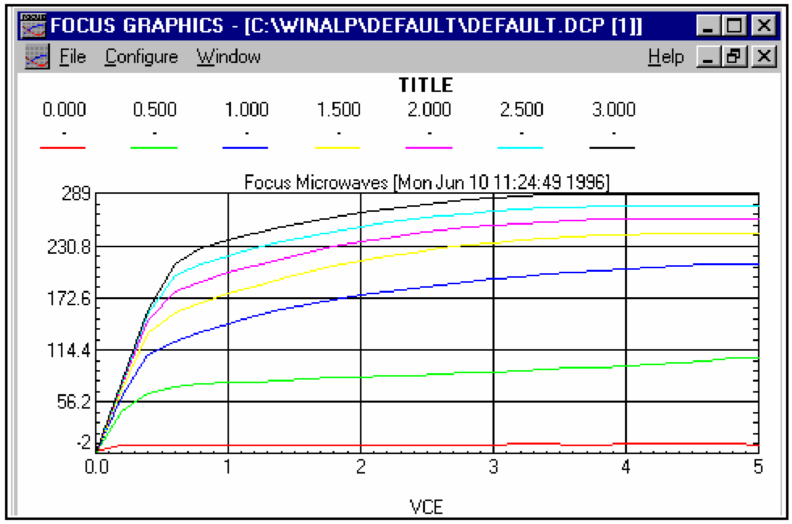


Figures 9-12: S-parameters of a bipolar transistor measured at Pin=-13.6dBm (left) and 21.6dBm (right).

The data above are shown in order to demonstrate the capability of the system. The dip in S21 at 600 MHz, associated with the scattering of S22 may be due to an oscillation at some, non-detected frequency (|S22| is <1 at all measured frequencies).

DC-parameters and IV-curves are measured automatically by LSM software and plotted using the Display utility.
A corresponding Dialogue (figure 14) permits to bias the device either manually or automatically. A set of IV curves measured using LSM software is shown in figure 13.

After DC parameters have been measured the IV curves of figure 13 can be displayed in a window and help select the parameters of the biasing dialogue (figure 14).

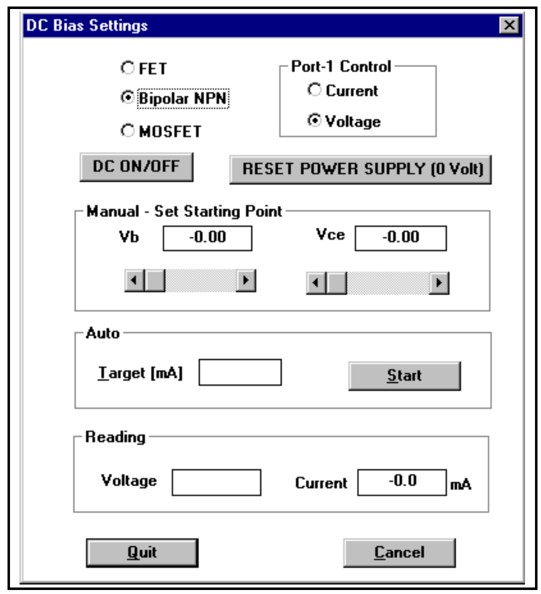


LSM Capabilities

- Frequency range 0.5 - 3 GHz
- Input Power 30 dBm, higher optional
- Inp. Power Control 40 dB
- Bias 30V, 500mA higher optional
- Passive Tuner Control Optional

Measurement

- S-Parameter Yes
- DC-Parameter Yes
- Harmonics Optional



References

[1] "ALPS, Active Load Pull System...", Product Note 33, Focus Microwaves, April 1996.
[2] "Efficiency Measurements using the CCMT", Application Note 9, Focus Microwaves, July 1996, to be published.
[3] "Verifying High Power Base Station Amplifiers", Hewlett-Packard Seminar, May 1996.