Agilent Technologies

Advanced Design System 2001

Oscillator DesignGuide

August 2001

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Oscillator DesignGuide

1 Oscillator QuickStart Guide

2 Oscillator DesignGuide Reference

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Chapter 1: Oscillator QuickStart Guide

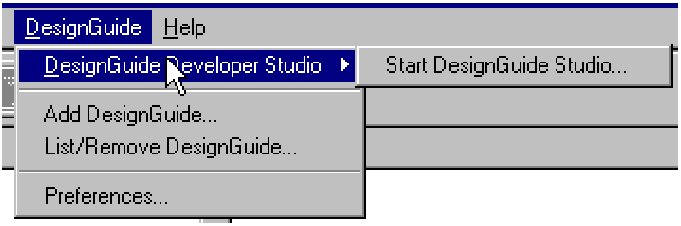
The Oscillator QuickStart Guide serves as a simple introduction to using the Oscillator DesignGuide. For more detailed reference information, refer to Chapter 2, Oscillator DesignGuide Reference.

The DesignGuide is applicable to any oscillator, but is especially useful for RF Board and Microwave applications. It is designed to help both experts and novices to create designs of various complexity.

Note This manual is written describing and showing access through the cascading menu preference. If you are running the program through the selection dialog box method, the appearance and interface will be slightly different.

Using DesignGuides

All DesignGuides can be accessed in the Schematic or Layout window through either cascading menus or dialog boxes. You can configure your preferred method in the Advanced Design System Main window. Select the *DesignGuide* menu.



The commands in this menu are as follows:

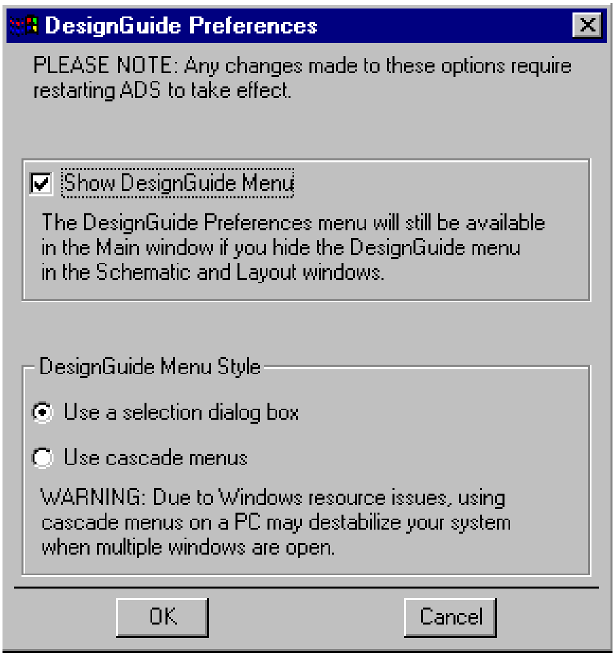
DesignGuide Developer Studio > **Start DesignGuide Studio** is only available on this menu if you have installed the DesignGuide Developer Studio. It launches the initial Developer Studio dialog box.

Add DesignGuide brings up a directory browser in which you can add a DesignGuide to your installation. This is primarily intended for use with DesignGuides that are custom-built through the Developer Studio.

List/Remove DesignGuide brings up a list of your installed DesignGuides. Select any that you would like to uninstall and choose the *Remove* button.

Preferences brings up a dialog box that allows you to:

- Disable the DesignGuide menu commands (all except Preferences) in the Main window by unchecking this box. In the Schematic and Layout windows, the complete DesignGuide menu and all of its commands will be removed if this box is unchecked.
- Select your preferred interface method (cascading menus vs. dialog boxes).



PLEASE NOTE: Any changes made to these options require restarting ADS to take effect.

☑ Show DesignGuide Menu

The DesignGuide Preferences menu will still be available in the Main window if you hide the DesignGuide menu in the Schematic and Layout windows.

DesignGuide Menu Style

● Use a selection dialog box

○ Use cascade menus

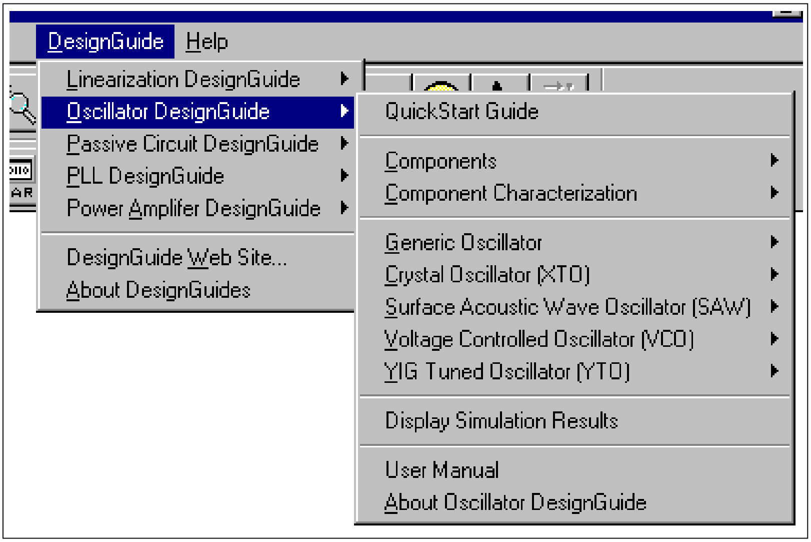
WARNING: Due to Windows resource issues, using cascade menus on a PC may destabilize your system when multiple windows are open.

Close and restart the program for your preference changes to take effect.

Note On PC systems, Windows resource issues might limit the use of cascading menus. When multiple windows are open, your system could become destabilized. Thus the dialog box menu style might be best for these situations.

Basic Procedures

Access the Oscillator DesignGuide from the ADS Schematic window. Select *Design Guide* > *Oscillator Design Guide*, as shown here. All features of the Design Guide are available from the Oscillator DesignGuide menu.



The Guide contains the following:

- Five oscillator circuits (Generic Oscillator, XTO, SAW, VCO, and YTO), containing ready-to-use typical oscillator structures for fixed frequency (XTO, SAW) and tunable (VCO, YTO) oscillators in various frequency ranges
- Component library (Components), providing useful building blocks for oscillator design
- Selection of circuits that simulate their behavior (Component Characterization), providing simulations that characterize 1-ports and 2-ports.

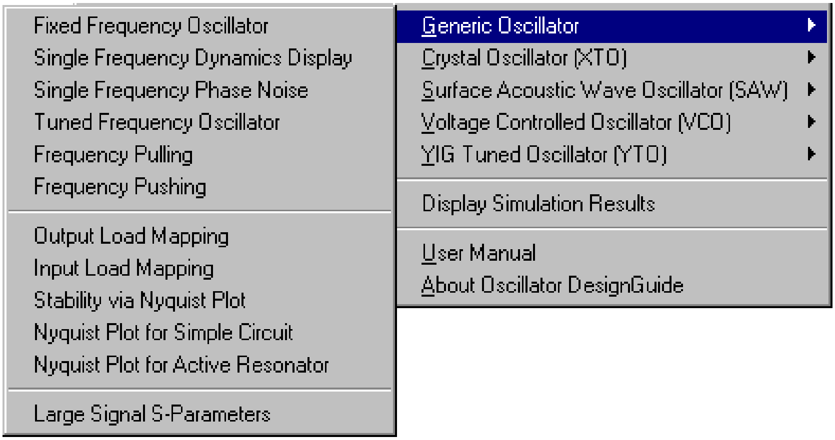
Note Selection of a component brings a component into a design. All other selections (oscillators and component characterization) bring a circuit and simulation into a design (replacing a previous design).

Component Sub-menu Structure

The Components menu contains a small custom library of resonators and devices, which can help in either modifying an existing oscillator or assembling a new one. They include: device DC and S-parameter characteristics and resonator and filter S-parameter and impedance/admittance characteristics

Oscillator Sub-menu Structure

Select *DesignGuide> Oscillator DesignGuide > Generic Oscillator* and explore the entries in the cascading menu, as shown here.



Each Oscillator design is divided into two groups. large-signal measurements and linear/nonlinear design tools.

Easy-to-use large-signal measurements (for *push-button* nonlinear analysis), contain simulations of the following:

- Single-frequency oscillations
- Phase noise
- Tuned oscillations
- Frequency pulling
- Frequency pushing

This group is recommended as starting point for both an expert and a novice user. For the expert, it provides an overview of tool capabilities. For the novice user, it provides a working oscillator together with simulations of its typical characteristics. You can choose either the Generic Oscillator or one of the examples (XTO, SAW, VCO, YTO) to start close to the desired application.

Linear and nonlinear design tools include Output Load Mapping, Input Load Mapping, Stability via Nyquist Plot, Nyquist Plot for Simple Circuit, Nyquist Plot for Active Resonator, and Large Signal S-Parameters.

These tools are intended as an aide in designing an oscillator from scratch and in gaining insight into an existing oscillator. The full choice of tools is contained in the Generic Oscillator. The examples use only those tools that are useful in their particular case. The full set of tools include the following:

- Load mapping for load-to-resonator
- Resonator-to-load
- Nyquist stability criterion for varying Zo
- Two additional examples (only in Generic Oscillator), explaining the role of Zo.

For nonlinear designs, large-signal S-parameters are defined and applied to oscillator power and frequency prediction.

Design Flow Example

Following is a simple design flow example for a fixed frequency oscillator.

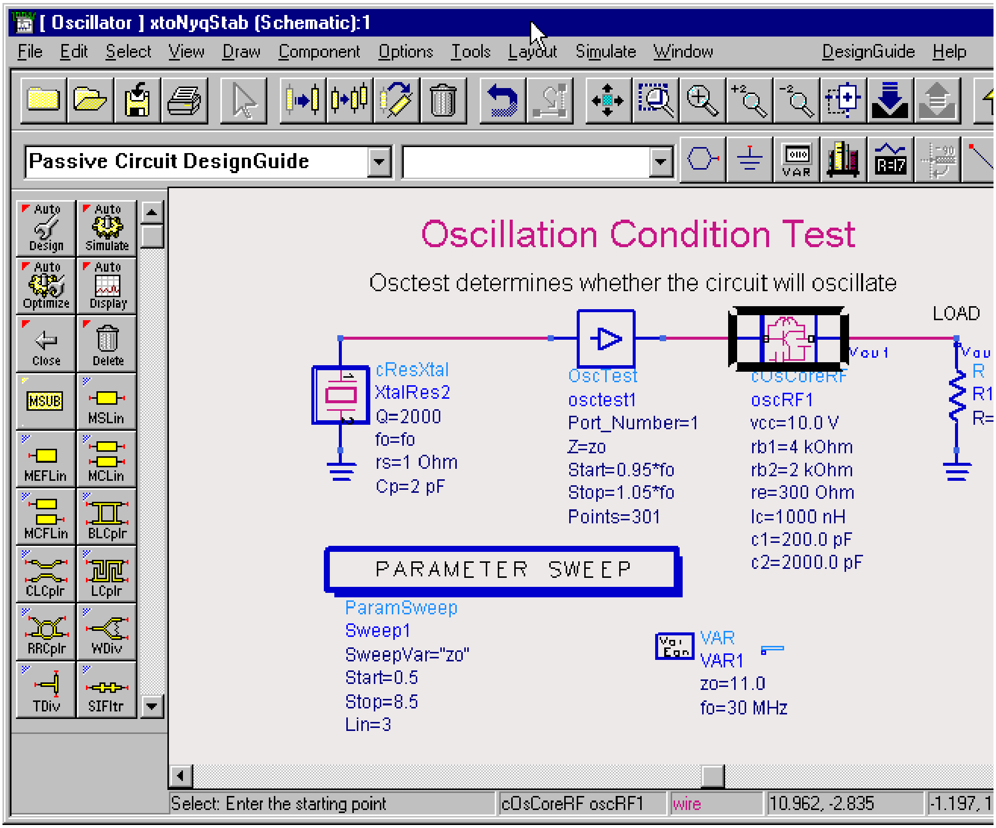
Preliminary Steps

1. Open ADS.
2. Open a new or existing project.
3. Open a new Schematic window.
4. Select **DesignGuide** > **Oscillator DesignGuide**.
5. Select **Crystal Oscillator (XTO)** > **Stability via Nyquist Plot**.

Important Preliminary Decisions

The schematic hides the following important choices:

- Device (a BJT)
- Biasing circuit
- Feedback scheme (Colpitts used in OsCore)
- Biasing point, which is shown in the OsCore subcircuit (which you can see from the Schematic window by clicking the **OsCore** component in the design, then pressing the down-arrow from the Main menu). The schematic is shown in the following illustration.



Oscillation Condition Test

Osctest determines whether the circuit will oscillate

cResXtal
XtalRes2
Q=2000
fo=fo
rs=1 Ohm
Cp=2 pF

OscTest
osctest1
Port_Number=1
Z=zo
Start=0.95*fo
Stop=1.05*fo
Points=301

cOsCoreRF
oscRF1
vcc=10.0 V
rb1=4 kOhm
rb2=2 kOhm
re=300 Ohm
lc=1000 nH
c1=200.0 pF
c2=2000.0 pF

R
R1
R=

ParamSweep
Sweep1
SweepVar="zo"
Start=0.5
Stop=8.5
Lin=3

VAR
VAR1
zo=11.0
fo=30 MHz

Select: Enter the starting point | cOsCoreRF oscRF1 | wire | 10.962, -2.835 | -1.197, 1

Moreover, the 30 MHz resonance frequency is assumed and the 20-ohm load resistance that models the actual load seen through a buffer amplifier and a matching circuit. At this point, you might want to modify the resonator and the OsCore (or replace them by your own circuit).

The modified circuit can be saved as a new design. We want the S11 trace shown on the polar plot in the data display window to encircle the point *1+j*0*. If this does not happen, the circuit must be modified. In that case, the menu selections *Output Load Mapping* and *Input Load Mapping* will help in determining the circuit and the load matching. Refer to the Oscillator DesignGuide reference manual for details. From the ADS Schematic window, select *DesignGuide* > *Oscillator DesignGuide* > *User Manual*.

Oscillator Performance

The following menu selections determine the oscillator performance:

- Fixed Frequency Oscillator
- Single Frequency Phase Noise
- Frequency Pulling
- Frequency Pushing

They determine the oscillation frequency and power, phase and amplitude noise, and circuit elements that contribute most to noise.

You can find frequency variations with load and bias. Modify (or replace) the subcircuits (the resonator, the OsCore, and the load resistance).

Chapter 2: Oscillator DesignGuide Reference

This manuals provides reference information on the use of the Oscillator DesignGuide.

Oscillator Design Guide Structure

The Oscillator DesignGuide is integrated into Agilent EEsof's Advanced Design System environment, working as a smart library and interactive handbook for the creation of useful designs. It allows you to quickly design oscillators, interactively characterize their components, and receive in-depth insight into their operation. It is easily modifiable to user-defined configurations. The first release of this DesignGuide focuses on RF printed circuit boards and microwave oscillations.

In addition to the requirements of the ADS software, the Oscillator DesignGuide requires approximately 30 MBytes of additional storage space.

Note This manual assumes that you are familiar with all of the basic ADS program operations. For additional information, refer to the ADS *User's Guide*.

The Oscillator DesignGuide contains templates that can be used in the ADS software environment. It consists of a generic oscillator example, four additional examples, and a library of components and component characterization tools.

To assist both expert and novice oscillator developers in creating designs of various complexity, each example design is divided into three groups:

- Quick and simple push-button nonlinear oscillator measurements
- Easy-to-use design tools for small- and large-signal designs
- Customized library of components and component characterization tools

To access these groups, select *DesignGuide* > *Oscillator DesignGuide* from the ADS Schematic window, then select the appropriate examples and tools.

Push-Button Nonlinear Measurements

The push-button nonlinear measurements are recommended as a starting point for both expert and novice users creating large-signal designs. For the expert, these measurements provide an overview of tool capabilities. For the novice user, they provide a working oscillator together with simulations of its typical characteristics of nonlinear designs. The full set of available large-signal measurements in the Generic Oscillator example are described in Table 2-1. Subsets of these measurements appear in the other four examples. Refer to the section "Additional Examples" on page 2-26.

Descriptions of Push-Button Measurements

Table 2-1 provides descriptions of the available push-button large-signal measurements, as well as the associated filenames for schematics and data displays.

Table 2-1. Push-Button Large-Signal Measurements

Measurement	Schematic Filename	Data Display Filename	Description
Fixed Frequency Oscillator	FixedFreqOsc.dsn	FixedFreqOsc.dds	Oscport simulation. Display shows Spectrum and waveforms for the output and resonator voltages, plus supplied DC power and the output power.
Single Frequency Dynamics Display	n/a	LargeSignalDynamics.dds	Only a display. Combines periodic waveforms from FixedFreqOsc.dsn with DC characteristics from czBJTCurveTracer.dsn.
Single Frequency Phase Noise	PhaseNoise.dsn	PhaseNoise.dds	n/a
Tuned Frequency Oscillator	FreqTune.dsn	FreqTune.dds	n/a
Frequency Pulling	FreqPull.dsn	FreqPull.dds	n/a
Frequency Pushing	FreqPush.dsn	FreqPush.dds	n/a

Linear and Nonlinear Design Tools

The linear and nonlinear design tools are intended to facilitate you in designing an oscillator from scratch and in gaining insight into an existing oscillator. The full selection of tools is contained in the Generic Oscillator example. Other examples use only those tools that are useful in their particular case.

Descriptions of Design Tools

Table 2-2 provides descriptions of the available design tools.

Table 2-2. Design Tools

Measurement	Schematic Filename	Data Display Filename	Description
Output Load Mapping	MapLoad.dsn	MapLoad.dds	Mapping of passive loads onto resonator interface plane
Input Load Mapping	MapInput.dsn	MapInput.dds	Mapping of passive loads from resonator interface plane to output plane
Stability via Nyquist Plot	NyqStab.dsn	NyqStab.dds	Tests whether the circuit will oscillate (using OscTest to plot Nyquist loop)
Nyquist Plot for Simple Circuit	NyqPlot.dsn	NyqPlot.dds	Simple example that explains effect of zo in OscTest use
NyqPlot for Active Resonator	NyqPlotA.dsn	NyqPlotA.dds	Simple example that further explains intricacies of Nyquist plots and the use of OscTest
LSSpar (nonlinear tool)	LSSpar.dsn	LSSpar.dds	Image of Kurokawa Plots, their justification (describing function method), and definition of large signal S-parameters. Tools for easy selection of Kurokawa Plots (presented in KurPlot1)

Components and Component Characterization Tools

The items in the Components and Component Characterization libraries contain a small custom library of resonators and devices, which can help in either modifying an existing oscillator or assembling a new one. They include device DC and S-parameter characteristics, as well as resonator and filter S-parameter and impedance/admittance characteristics.

Table 2-3 through Table 2-5 provide schematic filenames and brief descriptions for each component. Table 2-6 provides schematic filenames and brief descriptions for each component characterization tool.

Available Components

Table 2-3 provides schematic filenames and descriptions for the available active device components.

Table 2-3. Available Active Device Components

Component Description	Schematic Filename	Description
Biased BJT	cBJTBiased.dsn	Common Emitter BJT with a standard (1-voltage source) biasing circuit
Biased RF BJT	cBJTRFBiased.dsn	The RF version of BJT used in Crystal Oscillator
Biased MESFET	cFETBiased.dsn	n/a
Varactor Diode	cVar.dsn	Varactor diode model, included for convenience. Within this DesignGuide, it always appears with the reverse-biasing circuit (see next table entry).
Biased Varactor Diode	cbVar.dsn	Reversed-biasing varactor

Table 2-4 provides schematic filenames and descriptions for the available subcircuit components.

Table 2-4. Available Subcircuit Components

Component Description	Schematic Filename	Description
Buffer Amplifier (microwave)	cAmpBuff.dsn	A simple amplifier with capacitive feedback used in frequency pull and push simulations, used above 2GHz (for lower frequencies, see below). You are encouraged to replace it by your own amplifier and matching circuit.
Buffer Amplifier (1 - 2 MHz)	cAmpBuffS.dsn	Buffer amplifier with reactive components adjusted for 1GHz to 2GHz range, used in SAW oscillator
Buffer Amplifier (10 - 100 MHz)	cAmpBuffX.dsn	Buffer amplifier with reactive components adjusted for 10MHz to 100MHz range, used in crystal oscillator
Oscillator Core	cOsCore.dsn	Colpitts structure with a BJT with standard bias
RF Oscillator Core	cOsCoreRF.dsn	Oscillator Core adapted to MHz frequency ranger
Fixed VSWR Complex Load	cLoadEqs.dsn	Load determined through VSWR and phase of the reflection coefficient

Table 2-5 provides schematic filenames and descriptions for the available resonator components.

Table 2-5. Available Resonator Components

Component Description	Schematic Filename	Description
Crystal Resonator	cResXtal.dsn	Straightforward resonator model
SAW Resonator	cResSAW.dsn	Straightforward resonator model
YIG Resonator	cResYIG.dsn	Straightforward resonator model
Parallel Resonator	cResP.dsn	Straightforward resonator model
Series Resonator	cResS.dsn	Straightforward resonator model

Available Component Characterization Tools

Table 2-6 provides schematic and data display filenames and descriptions for the component characterization tools.

Table 2-6. Available Component Characterization Tools

Tool Description	Schematic Filename	Data Display Filename	Description
S-parameters for 1-port	cz1PortSp.dsn	cz1PortSp.dds	S-parameter simulation of a 1-port
S-parameters for 2-port	cz2PortSp.dsn	cz2PortSp.dds	S-parameter simulation of a 2-port. Uses the Buffer Amplifier
BJT Curve Tracer	czBJTCurveTracer.dsn	czBJTCurveTracer.dds	DC Curves for a common emitter BJT, they can be observed independently or combined with periodic waveforms in LargeSignal-Dynamics.dds
RF BJT Curve Tracer	czBJTRFCurveTracer.dsn	czBJTRFCurveTracer.dds	The RF version of BJT used in Crystal Oscillator
FET Curve Tracer	cFETBiased.dsn czFETCurveTracer.dsn	czFETCurveTracer.dds	n/a
S-parameters for Biased BJT	czBJTSp.dsn	czBJTSp.dds	S-parameter simulation of biased BJT
Capacitance and Admittance of Biased Varactor	czbVarSp.dsn	czbVarSp.dds	S-parameter simulation of the reversed biased varactor. Displays admittance values and capacitance versus the biasing voltage
S-parameters for Parallel Resonator	czResPSp.dsn	czResPSp.dds	n/a

Table 2-6. Available Component Characterization Tools (continued)

Tool Description	Schematic Filename	Data Display Filename	Description
S-parameters for Series Resonator	czResSSp.dsn	czResSSp.dds	n/a
S-parameters for Generic Resonator	czResScvSp.dsn	czResScvSp.dds	The resonator contains a series resonator with parallel capacitance.
S-parameters for Crystal Resonator	czResXtalSp.dsn	czResXtalSp.dds	n/a
S-parameters for SAW Resonator	czResSAWSp.dsn	czResSAWSp.dds	n/a
S-parameters for YIG Resonator	czResYIGSp.dsn	czResYIGSp.dds	n/a

Generic Oscillator Example

The oscillator circuit for the Generic Oscillator example is set up as follows:

- Resonator
- Oscillator active part (OscCore)
- Lload, which can include buffering amplifier and matching circuits

The tools consists of three parts, as explained in the section, "Oscillator Design Guide Structure" on page 2-1.

For simplicity, we show the buffering amplifier in two designs only and don't include the matching circuits. The generic resonator is presented here by a series resonant circuit shunted by a capacitance, which can model either a tuning capacitance, or the effect of packaging.

The OsCore is the Colpitts structure, which was introduced soon after the invention of triode (called audion at the time). It is still widely used. It uses a capacitive RF transformer to provide feedback. The transformer capacitors together with the inductor determine the oscillation frequency $f = 1/sqrt(L \times C1 \times C2/(C1+C2))$.

The Load models impedance, as seen by the OsCore component. Typically, this is the input impedance of the buffering amplifier(s) (including matching circuits) and the actual load.

Oscillator Simulation

The oscillator designs included in this DesignGuide provide easy access to observing the nonlinear behavior of an oscillator. The circuit design for the generic example is shown in Figure 2-1. It includes fixed load, a clearly visible active circuit, and the tunable resonator separated by the OscPort component.

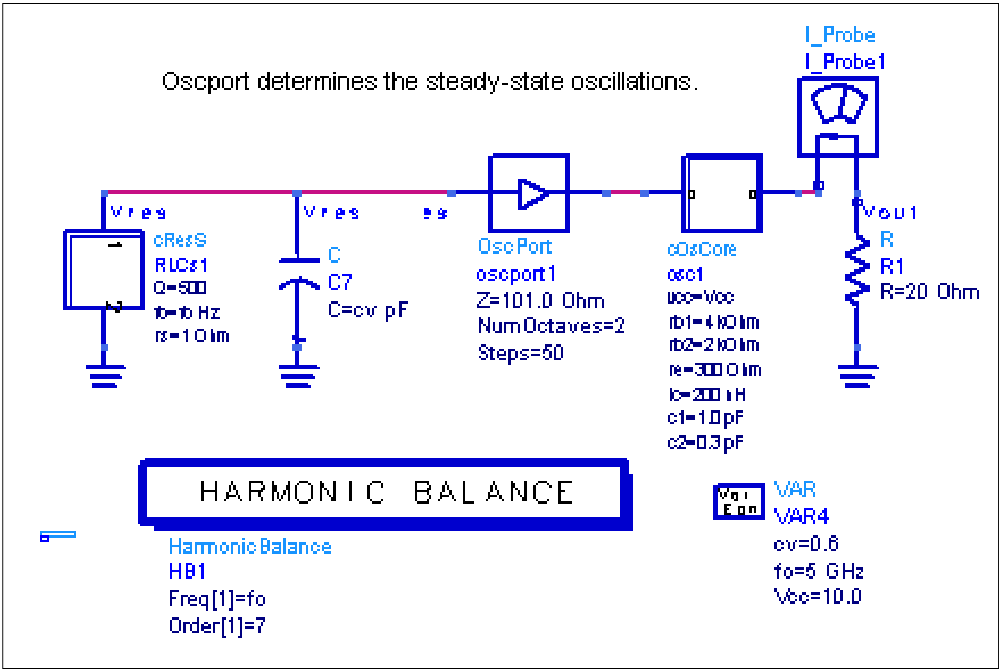
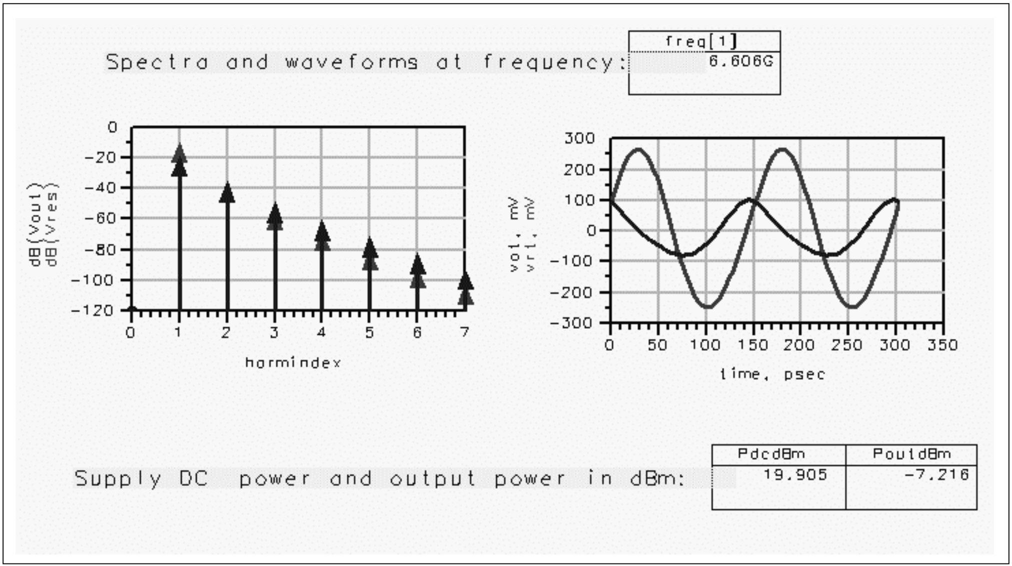


Figure 2-1. Structure of Oscillator Circuit

Single-Frequency Oscillations

The results of single-frequency oscillations in Figure 2-2 show output and resonator voltages. They also provide oscillations frequency, power harmonic content, the corresponding time-domain waveform, and the values of DC power and RF output power.



Spectra and waveforms at frequency:

freq[1]
6.606G

Supply DC power and output power in dBm:

PdcdBm	PoutdBm
19.905	-7.216

Figure 2-2. Results of Single-Frequency Oscillations

Dynamics of Single-Frequency Oscillations

The graph in Figure 2-3 shows waveforms of Collector-Emitter voltage and the collector current of the OsCore BJT superimposed on BJT's DC characteristics.

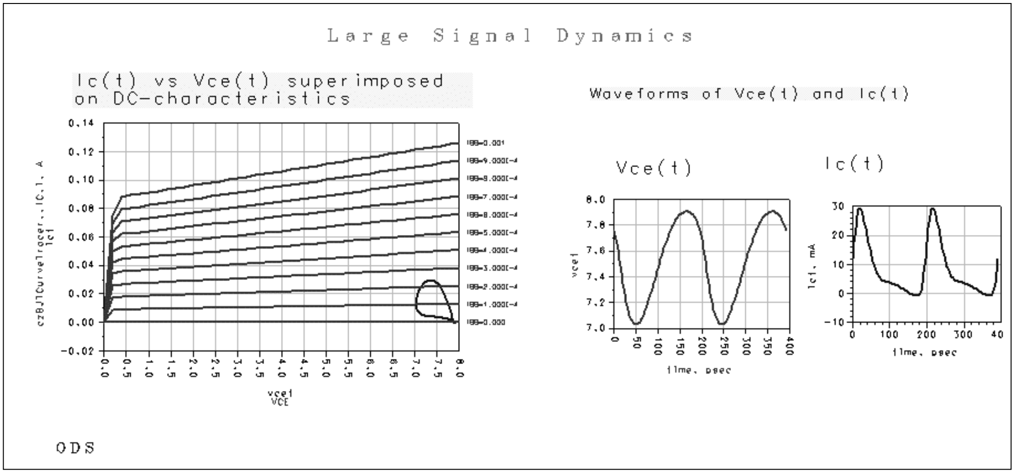
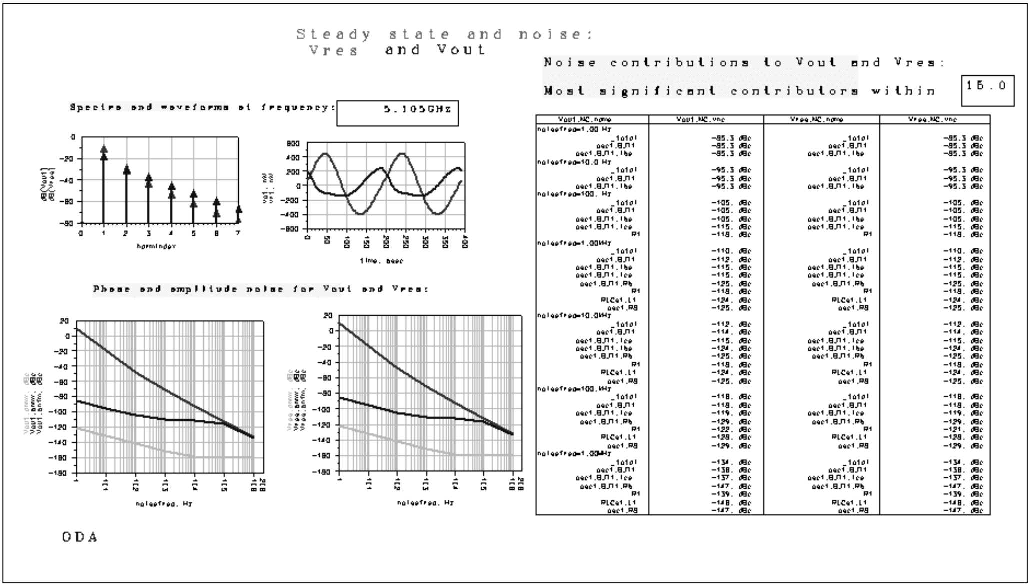


Figure 2-3. Dynamics of Single-Frequency Oscillation

Single-Frequency Oscillations with Noise

The graph in Figure 2-4 shows single-frequency results with the noise characteristics of Vout and Vres. It also lists the components that affect the noise the most. You can specify the range after which small contributors to noise will be neglected. In this example, the range is set to 15 dB.



Noise contributions to Vout and Vres:

Most significant contributors within 15.0

Vout.NC.name	Vout.NC.vnc	Vres.NC.name	Vres.NC.vnc
noisefreq=1.00 Hz			
_total	-85.3 dBc	_total	-85.3 dBc
osc1.BJT1	-85.3 dBc	osc1.BJT1	-85.3 dBc
osc1.BJT1.Ibe	-85.3 dBc	osc1.BJT1.Ibe	-85.3 dBc
noisefreq=10.0 Hz			
_total	-95.3 dBc	_total	-95.3 dBc
osc1.BJT1	-95.3 dBc	osc1.BJT1	-95.3 dBc
osc1.BJT1.Ibe	-95.3 dBc	osc1.BJT1.Ibe	-95.3 dBc
noisefreq=100. Hz			
_total	-105. dBc	_total	-105. dBc
osc1.BJT1	-105. dBc	osc1.BJT1	-105. dBc
osc1.BJT1.Ibe	-105. dBc	osc1.BJT1.Ibe	-105. dBc
osc1.BJT1.Ice	-115. dBc	osc1.BJT1.Ice	-115. dBc
R1	-118. dBc	R1	-118. dBc
noisefreq=1.00kHz			
_total	-110. dBc	_total	-110. dBc
osc1.BJT1	-112. dBc	osc1.BJT1	-112. dBc
osc1.BJT1.Ibe	-115. dBc	osc1.BJT1.Ibe	-115. dBc
osc1.BJT1.Ice	-115. dBc	osc1.BJT1.Ice	-115. dBc
osc1.BJT1.Rb	-125. dBc	osc1.BJT1.Rb	-125. dBc
R1	-118. dBc	R1	-118. dBc
RLCs1.L1	-124. dBc	RLCs1.L1	-124. dBc
osc1.R9	-125. dBc	osc1.R9	-125. dBc
noisefreq=10.0kHz			
_total	-112. dBc	_total	-112. dBc
osc1.BJT1	-114. dBc	osc1.BJT1	-114. dBc
osc1.BJT1.Ice	-115. dBc	osc1.BJT1.Ice	-115. dBc
osc1.BJT1.Ibe	-124. dBc	osc1.BJT1.Ibe	-124. dBc
osc1.BJT1.Rb	-125. dBc	osc1.BJT1.Rb	-125. dBc
R1	-118. dBc	R1	-118. dBc
RLCs1.L1	-124. dBc	RLCs1.L1	-124. dBc
osc1.R9	-125. dBc	osc1.R9	-125. dBc
noisefreq=100.kHz			
_total	-118. dBc	_total	-118. dBc
osc1.BJT1	-118. dBc	osc1.BJT1	-118. dBc
osc1.BJT1.Ice	-119. dBc	osc1.BJT1.Ice	-119. dBc
osc1.BJT1.Rb	-129. dBc	osc1.BJT1.Rb	-129. dBc
R1	-122. dBc	R1	-121. dBc
RLCs1.L1	-128. dBc	RLCs1.L1	-128. dBc
osc1.R9	-129. dBc	osc1.R9	-129. dBc
noisefreq=1.00MHz			
_total	-134. dBc	_total	-134. dBc
osc1.BJT1	-138. dBc	osc1.BJT1	-138. dBc
osc1.BJT1.Ice	-137. dBc	osc1.BJT1.Ice	-137. dBc
osc1.BJT1.Rb	-147. dBc	osc1.BJT1.Rb	-147. dBc
R1	-139. dBc	R1	-139. dBc
RLCs1.L1	-148. dBc	RLCs1.L1	-148. dBc
osc1.R9	-147. dBc	osc1.R9	-147. dBc

Figure 2-4. Single-Frequency Oscillations with Noise

Frequency Pulling

Figure 2-5 shows results after the original circuit is modified for frequency pull. Changes include the varying load and a simple buffer amplifier, which was added to make pulling values realistic. The load is specified in terms of VSWR. You can determine the best variation. The graph shows that frequency variation for varying phase of the load. VSWR is fixed, with its value shown above the plot. By moving the marker on the VSWR selection plot, you can obtain the results for other VSWR values. The corresponding load characteristic and the corresponding value of Vout fundamental are shown in the lower plots. The equation with pulling value will be added.

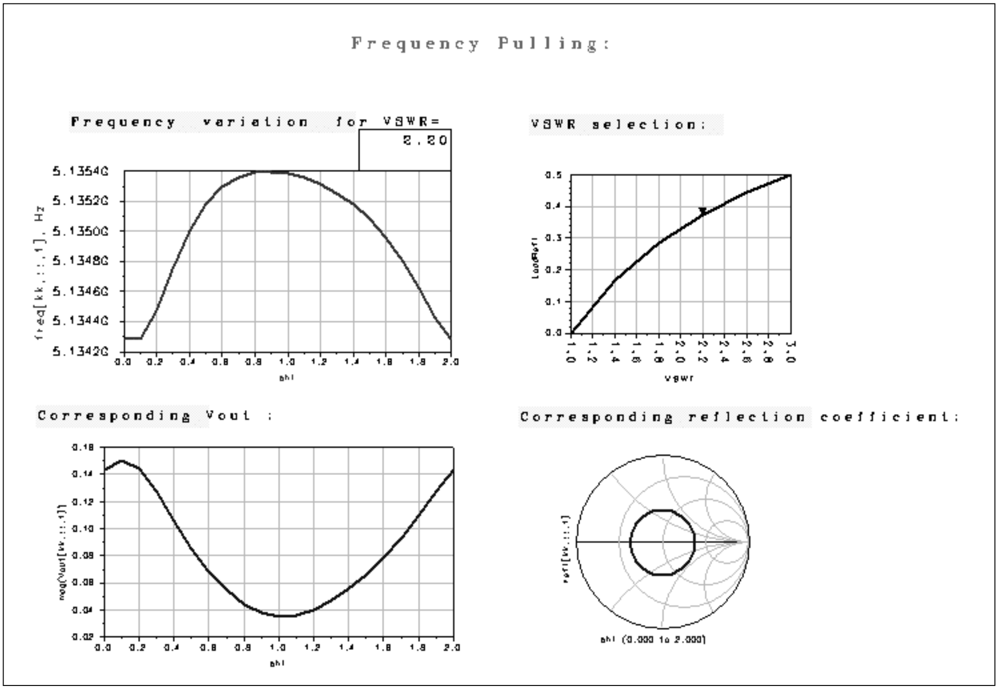


Figure 2-5. Results with Circuit Modified for Frequency Pulling

Frequency Pushing

Figure 2-6 shows results after the frequency pull circuit is modified for frequency push, with fixed load (*vswr=1*, *phi =0*) and varying bias on oscillator's transistor Vcc. The display presents frequency variation with Vcc.

For Vcc=8V, the circuit does not oscillate, which results in the error message. Nevertheless, the sweep is performed, showing oscillations for higher bias. Two markers on the plot allow us to zoom in at the frequency plot. The plot to the right is determined by markers position. The corresponding value of Vout fundamental is shown in the lower plot.

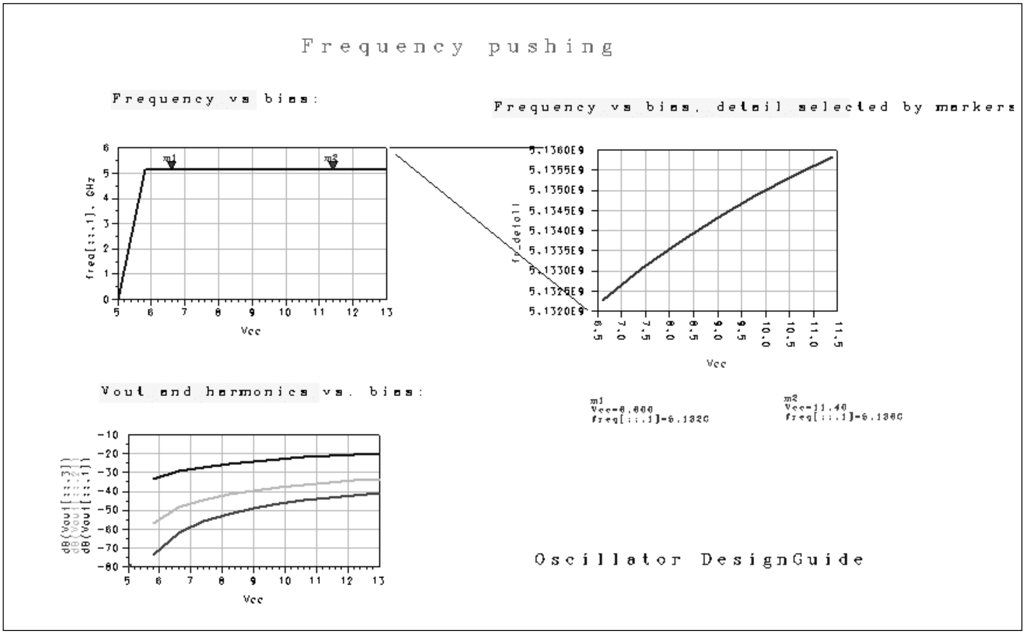


Figure 2-6. Results with Circuit Modified for Frequency Pushing

Tuned Oscillations

Figure 2-7 shows the resonator voltage and its harmonics. It provides the tuning characteristics of sweeps vs. capacitance vs. frequency.

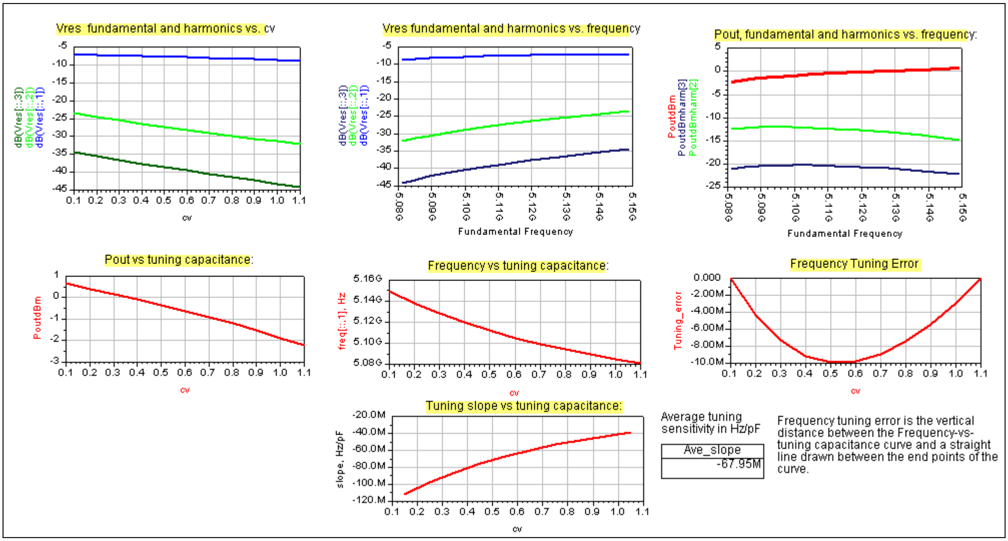


Figure 2-7. Resonator Voltage and Harmonics

Linear Design Tools

The designs used for linear applications provide tools to investigate oscillations conditions. They belong to two groups, as follows:

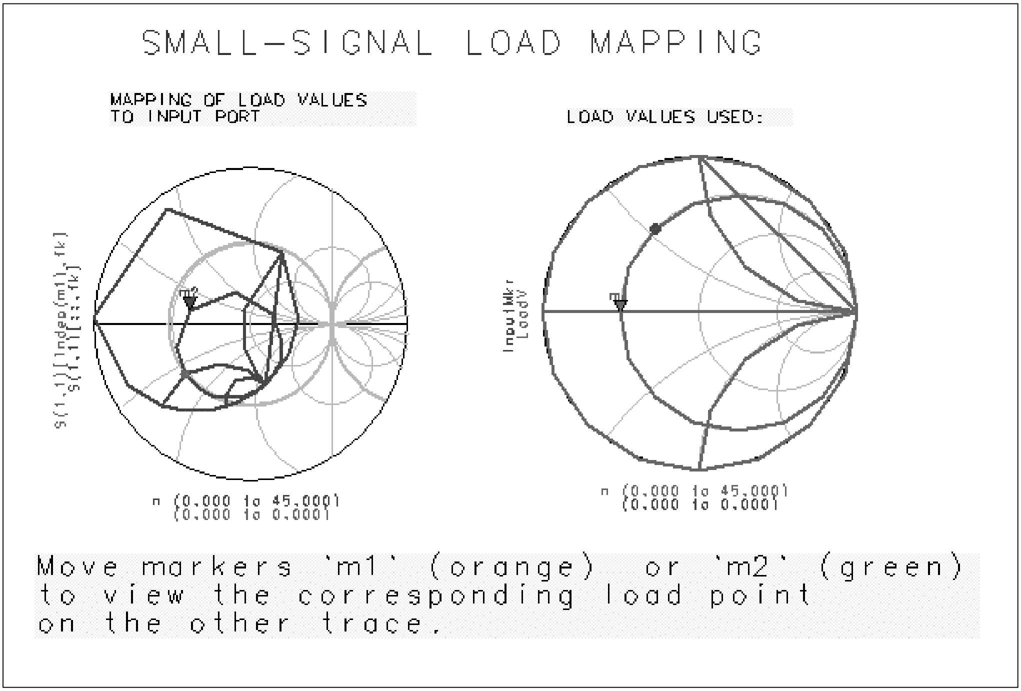
- Necessary oscillation conditions
- Check for Nyquist stability criterion, using the linearized version of the OscPort component, called OscTest.

Load-to-Resonator Mapping

Load-to-resonator mapping is represented by the design *MapLoad.dsn* and the graph *MapLoad.dds*. The design consists of the oscillator circuit without the resonator. The buffer and load are replaced by varying load. The load values correspond to main traces on a Smith chart (shown in the *loadmap.dds* display). You can specify the number of samples per trace and the radius of the small circle. On the resonator side, the circuit is terminated by an S-parameter port. S-parameter analysis is performed over frequency band determined that you specify so that the mapping can be analyzed at various frequencies.

The purpose of the analysis is to observe how the different values of the load will be detected by the resonator. The values that map outside the unit circle are of particular interest. These are the values that will provide negative resistance facing the resonator, so that the necessary oscillations conditions will be satisfied

The graph *MapLoad.dds*, as shown in Figure 2-8, represents load values and their image in the resonator plane. Color-coded markers facilitate orientation. The marker on the bottom plot selects frequency at which the mapping is performed.



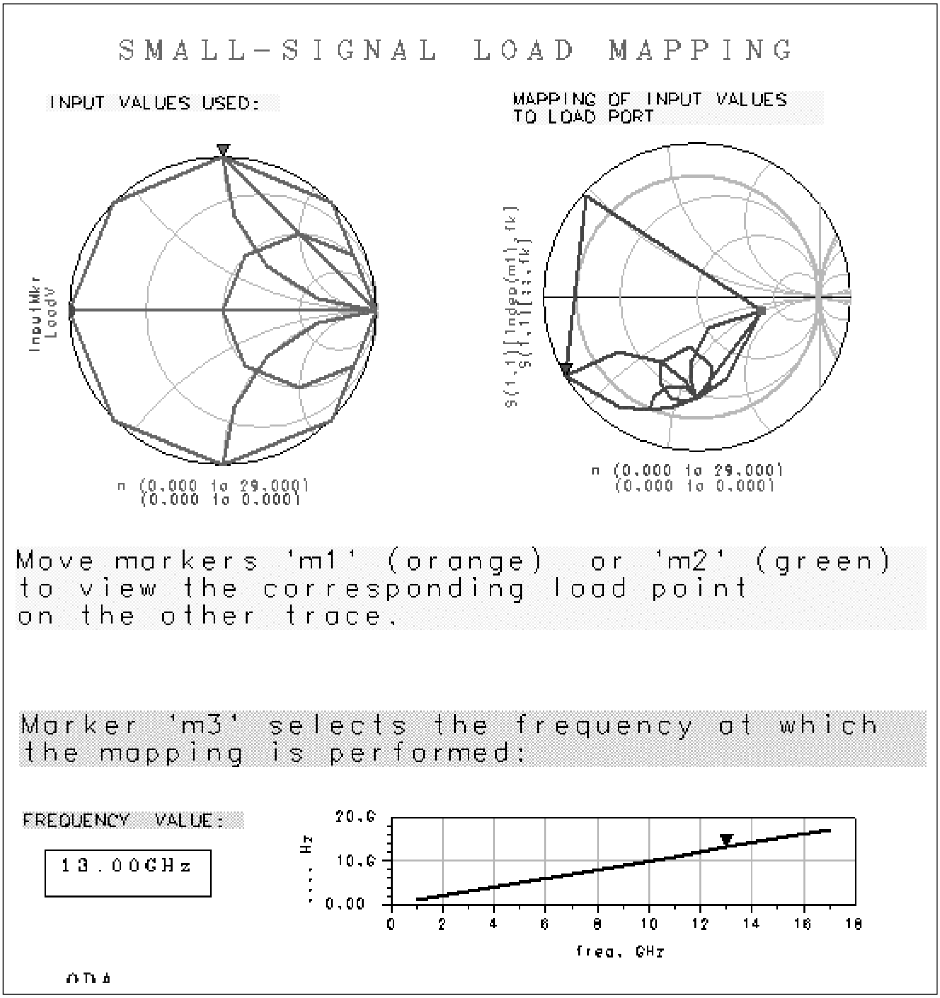
Move markers 'm1' (orange) or 'm2' (green) to view the corresponding load point on the other trace.

Figure 2-8. Load Values and Their Image in Resonator Plane

Resonator-to-Load Mapping

Resonator-to-load mapping is represented by the design *MapInput.dsn* and the graph *MapInput.dds*, as shown in Figure 2-9. The design is dual to load-to-resonator mapping, and it determines the image of the resonator at the buffer amplifier input.

Consequently, it is useful in designing of the amplifier matching circuit. A special case restricted to a unit circle input gave rise to the method of stability circles (see Reference 1 in the section "Bibliography" on page 2-28).



SMALL-SIGNAL LOAD MAPPING

INPUT VALUES USED:

MAPPING OF INPUT VALUES TO LOAD PORT

Move markers 'm1' (orange) or 'm2' (green) to view the corresponding load point on the other trace.

Marker 'm3' selects the frequency at which the mapping is performed:

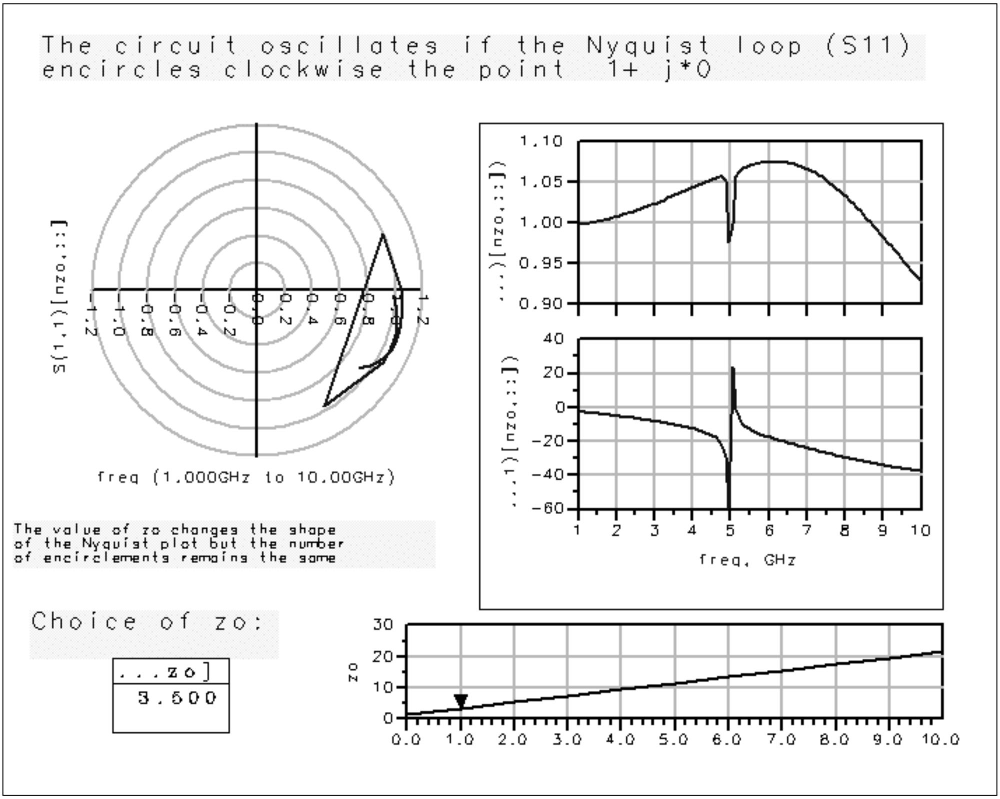
FREQUENCY VALUE:

13.00GHz

Figure 2-9. Resonator-to-Load Mapping

Stability Via Nyquist Plots

The design Nyquist Stab shows the use of the OscTest component. The results shown for different choices of the OscTest characteristic impedance Zo illustrate the importance of the Nyquist plot. Zo is swept from 1.5ohm to 21.5 ohm in 10 steps. The plots clearly show that it is the encirclement of *1+j0* that matters (as we know from the Nyquist theorem) and not the value of S11 at the crossing of the real axis. The justification of this statement is illustrated by two simple designs (NyqStab, NyqStabA) described in the next section.



The circuit oscillates if the Nyquist loop (S11) encircles clockwise the point 1+ j*0

The value of zo changes the shape of the Nyqist plot but the number of encirclements remains the same

Choice of zo:

...zo] 3.500

Figure 2-10. Resonator-to-Load Mapping

Theory of Stability vs. Nyquist Plots

There is a widespread belief [3,7,9,10,11,12,13,14,15] that the stability of oscillators can be determined by a particular criterion. When the phase of the transfer function is zero and the magnitude (at the same frequency) is larger than one, the system is unstable. The circuit shown in the criterion is usually presented as two equations:

$$arg(Sn) = -arg(Sr), \qquad |Sn\ Sr| > 1$$

Consider a simplest possible linearized oscillator, as shown in Figure 2-11. The circuit has the resonator's resistance $rr=1/G = 100.0$ ohm and the active (linearized) resistance $ra = 1/g'(Vo) = -5.0$ ohm and is obviously unstable.

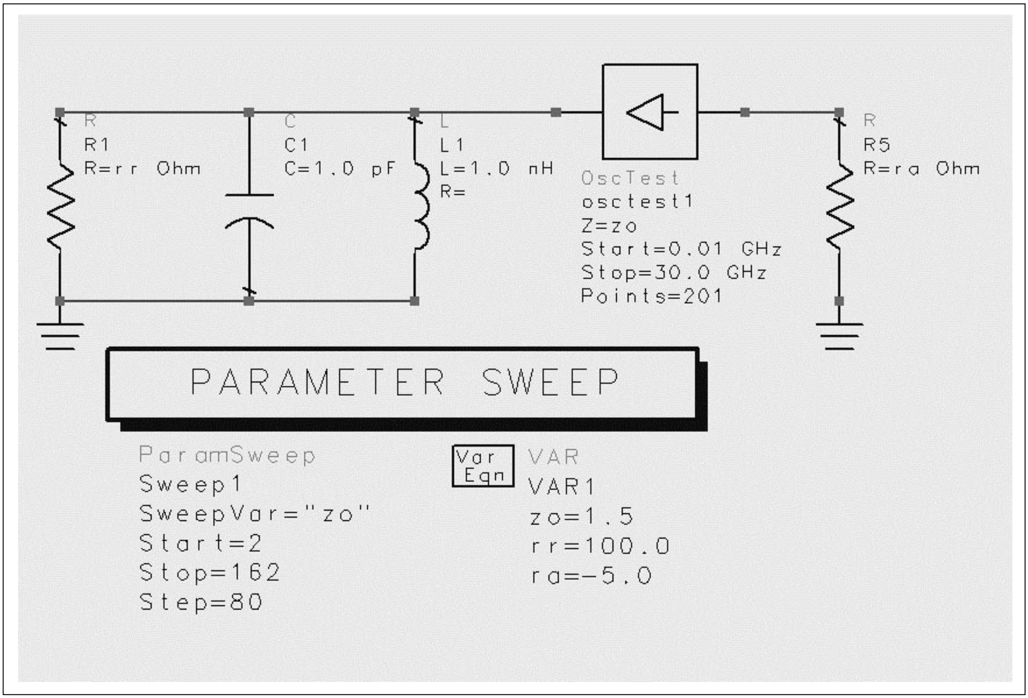
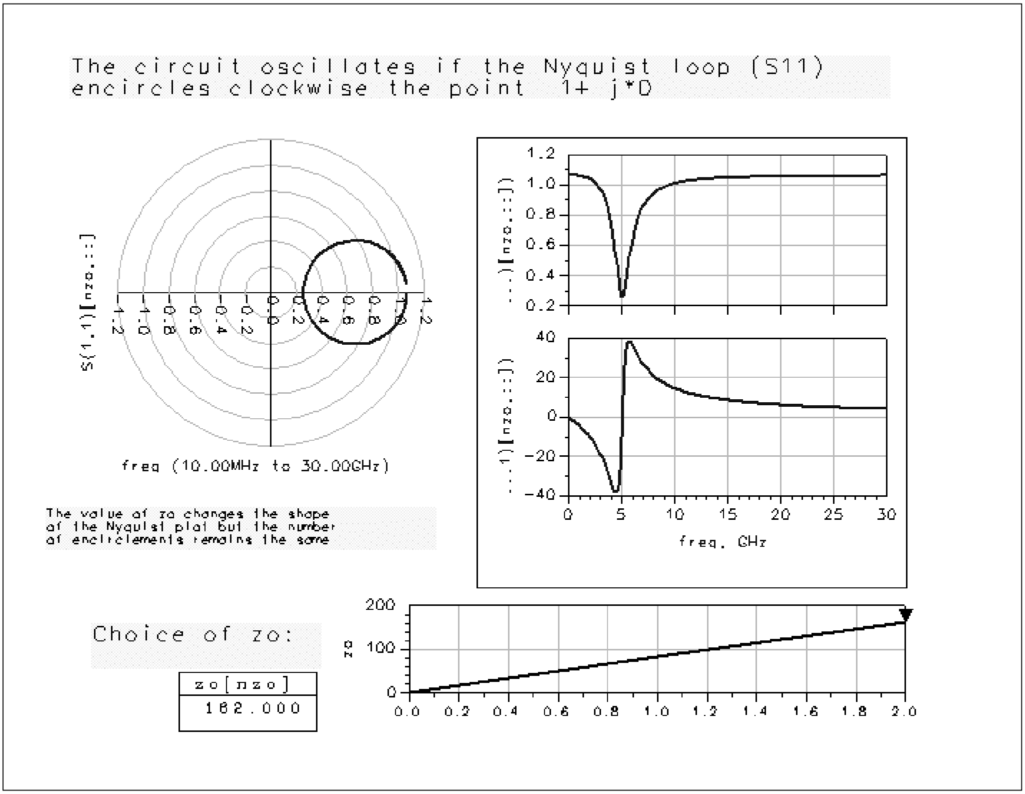


Figure 2-11. Stability Via Nyquist Plots

The Nyquist plots and equation were checked for different values of the characteristic impedance Zo. The system stability depends on the position of poles of the transfer function $Sr(s)Sn(s)$. If the function possesses poles in the right half plane, the system is unstable. It follows from the Nyquist criterion that the presence of poles in the right-half plane and the system instability can be determined by the encirclements of point $1+j0$ by the osctest generated contour $S11 = Sr(jw)Sn(jw)$.

The Nyquist plots obtained for $Zo = 2.0, 82.0, 162.0$ ohm are shown in Figure 2-12.



The circuit oscillates if the Nyquist loop (S11) encircles clockwise the point 1+ j*0

The value of zo changes the shape of the Nyquist plot but the number of encirclements remains the same

Choice of zo:

zo[nzo]
162.000

Figure 2-12. Nyquist Plot for Simple Linearized Oscillator

The three values of Zo are chosen so that we get respectively:

$Zo < |ra| < rr, \quad |ra| < Zo < rr$

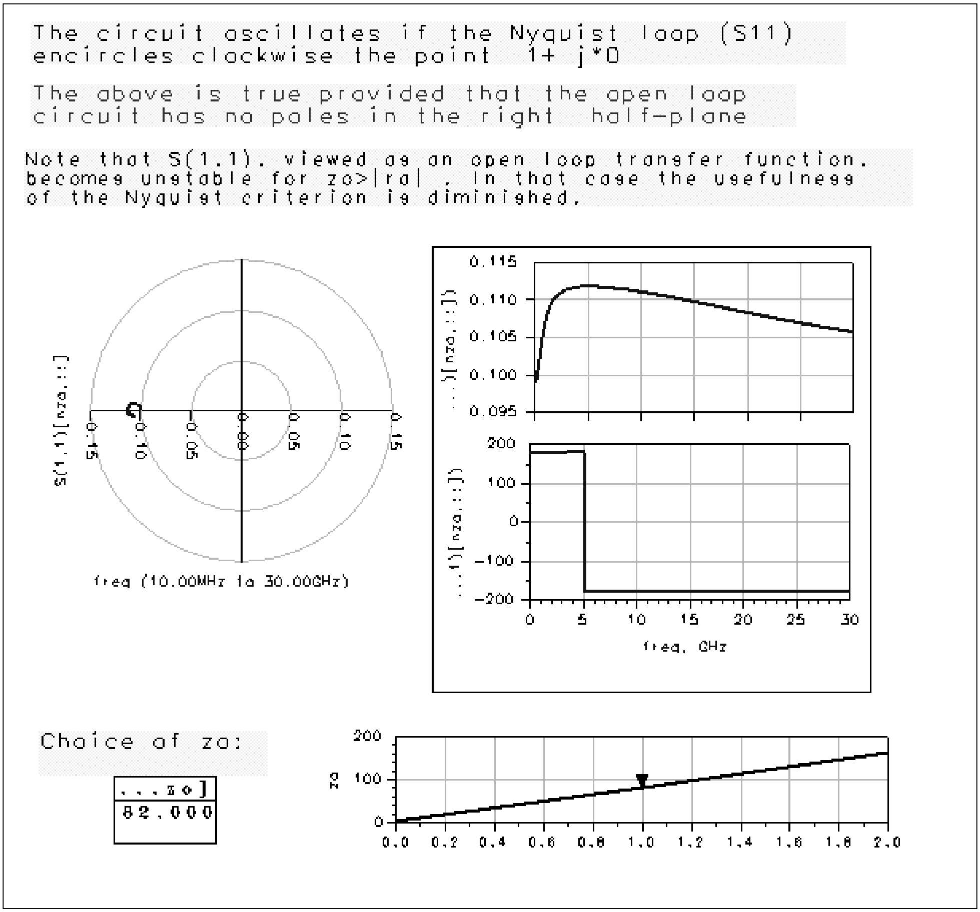
and

$|ra| < rr < Zo$

The circuit is obviously unstable. Consequently, the Nyquist loop, shown in the plots on the left in Figure 2-13, encircles the *point 1+j0* for every value of Zo. However, if we turn to the magnitude-phase plots (shown to the right), then the circuit instability will be hard to deduce. Finally the intuitive condition *(1) (SnSr >1 for arg(SnSr) = 0)* obviously fails for *Zo = 82.0 and Zo=162.0* ohm.

The *SrSn* contours clearly show that it is the encirclement of *1+j0* that matters (as we know from Nyquist theorem) and not the value of *SnSr* at the crossing of the real axis.

The Nyquist criterion is most useful when the open loop system is stable. In that case, the stability of the feedback system is determined by the closing of the feedback loop. Figure 2-13 shows a variation of our original circuit.



The circuit oscillates if the Nyquist loop (S11) encircles clockwise the point 1+ j*0

The above is true provided that the open loop circuit has no poles in the right half-plane

Note that S(1,1), viewed as an open loop transfer function, becomes unstable for zo>|ra| . In that case the usefulness of the Nyquist criterion is diminished.

Choice of zo:

...zo]
82.000

Figure 2-13. Nyquist Plot for Simple Circuit

In the circuit shown, the resistances were interchanged, resulting in an active resonator, for which adding the 100 ohms in parallel (i.e. loop closing) does not change its instability. Obviously, in this system, the Nyquist loop does not encircle the $1+j0$. This is because the open loop transfer function $Yn\ Zr = (s/rrC)/(s^2 + s/raC + 1/LC)$ has two poles in the right half plane and loop closing does not add any new poles.

Therefore the position of the OscTest probe (which automatically computes $SrSn$ in the simulator) should be carefully chosen. It should be placed between the resonator and the active circuit so that the open-loop system is stable.

The plots of S11 for $Zo = 2.0,82.0,162.0$ need to be considered.For $Zo = 82.0$, 162.0 the Nyquist loop does not encircle $1+j0$, as expected. However, for $Zo=2.0$ it does, which seems contrary to the fact that the resonator circuit is active. The explanation for this is that the open loop S-parameter transfer function:

$$Sr(s) = (Zr - Zo)/(Zr + Zo) = -(s^2 + s((1/ra)-(1/Zo))/C+1/LC)/(s^2 + s((1/ra)+(1/Zo))/C+1/LC)$$

has all poles in the left hand plane for $Zo < |ra|$. Only closing the loop makes the system unstable.

Using Nonlinear Design Tools

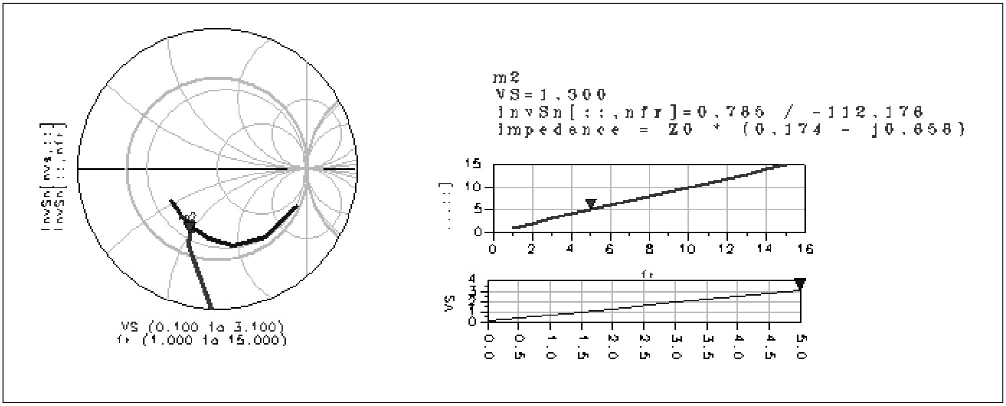


Figure 2-14. Large-Signal S-Parameter Design

In the steady-state, because of intrinsically nonlinear behavior of oscillators, signals are no longer sinusoidal. Consequently, the concepts of impedance and S-parameters are not obvious. However, in high-Q circuits, in which signals are represented by their fundamental components, there is a natural way to define the large-signal impedance, or large-signal S-parameters. In this section, we define the large signal S-parameters and demonstrate that the equations

$$\arg(Sn) = -\arg(Sr)$$
$$|Sn\ Sr| = 1$$

determine amplitude and phase of oscillations.

The steady state periodic oscillations can be represented by their Fourier series:

$v(t) = \sum |v_n| \cos(n\omega t + \varphi_n)$ $i(t) = \sum |i_n| \cos(n\omega t + \psi_n)$

For a high-Q resonator the higher harmonics are negligibly small and voltage and current can be approximated by:

$v(t) \approx |V| \cos(\omega t + \varphi)$

$i(t) \approx |I| \cos(\omega t + \psi)$

where

$V = |V| \exp(j\varphi)$, *and* $I = |I| \exp(j\psi)$

denote the fundamental components of voltage and current.

Thus the signals are represented by their complex amplitudes V and I, for which we define the large-signal incident and reflected waves:

$a = (V + Zo \times I)/(2\sqrt{Zo})$, $b = (V - Zo \times I)/(2\sqrt{Zo})$

On the resonator side, we have $a = Sr\ b$, with $b = b(a)$ on the active circuit side. These two relationships provide us with the steady-state equations $a = Sr\ b(a)$. After defining the large signal S-parameter: $Sn = b(a)/a$ the steady state equation can be represented as $a = Sr\ Sn\ a$, which leads to: $1 = Sr\ Sn$, which is equivalent to the equations..

Additional Examples

Following are examples in addition to the primary example, as described in the section, "Generic Oscillator Example" on page 2-8.

The design and display filenames for these examples follow the generic oscillator naming convention with 3-letter prefixes attached to the generic names, as follows:

- xxxgenericoscillator name.dsn
- xxxgenericoscillator name.dds

where xxx stands for one of: saw, vco, xto, or yto.

For example, VCO Large Signal S-Parameters have the filenames *vcoLSSpar.dsn* and *vcoLSSpar.dds*.

Crystal Oscillator (XTO)

These oscillators are notable for their high frequency stability and low cost. Typical structure is that of a Colpitts oscillator with quartz crystal resonator introduced into feedback path. Mechanical vibrations of the crystal stabilize the oscillations frequency. Vibration frequency is sensitive to temperature. Therefore, temperature compensation circuits are often used to improve frequency stability. Crystal resonators are typically used in the range up to 100 MHz (to a few hundreds of MHz if resonating on overtones).

SAW Resonator Oscillator (SAW)

Principle of operation is similar to that of crystal oscillator with the quartz resonator replaced by a Surface Acoustic Wave oscillator. SAW resonators are used in frequency range up to 2 GHz.

Voltage Controlled Oscillator (VCO)

In any of the preceding structures, frequency tuning can be provided by adding a varactor diode to the resonator. The varactor diode serves as a voltage controlled capacitor. It has very fast tuning speed (GHz/nsec) and low Q. Consequently, the varactor can be used with LC elements to provide wide tuning (with poor frequency stability) or with a crystal, SAW or DRO resonator for narrow tuning with better frequency stability.

At microwave frequencies, the device capacitances become significant, resulting in a different (often simpler) circuit. The operation principles, remain the same.

YIG Tuned Oscillator (YTO)

For a very wide band (that can reach decade) tuning with high frequency stability and for frequency range of 1 GHz to 50 GHz. YIG (Yttrium-Iron-Garnett) resonators are used. The YIG sphere behaves like a resonator with 1000-to-8000 unloaded Q resulting in very good frequency stability. The resonator are tunable over wide bandwidth with excellent linearity (~0.05%). For fine tuning (for phase-lock), or frequency modulation an FM coil can be added.

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