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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 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 Studio Documentation > Developer Studio Documentation is only available on this menu if you have installed the DesignGuide Developer Studio. It brings up the DesignGuide Developer Studio documentation. Another way to access the Developer Studio documentation is by selecting Help > Topics and Index > DesignGuides > DesignGuide Developer Studio (from any ADS program window).

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).

![DesignGuide Preferences dialog box]

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

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.
Accessing the Documentation

To access the documentation for the DesignGuide, select either of the following:

- DesignGuide > Oscillator > Oscillator DesignGuide Documentation (from ADS Schematic window)
- Help > Topics and Index > DesignGuides > Oscillator (from any ADS program window)
Basic Procedures


The Guide contains the following:

- Nine oscillator circuits (Generic Oscillator, Clapp Oscillator, Hartley Oscillator, Modified Clapp Oscillator, Modified Colpitts 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.

```
Fixed Frequency Oscillator
Single Frequency Dynamic Display
Single Frequency Phase Noise
Tuned Frequency Oscillator
Frequency Pulling
Frequency Pushing

Output Load Mapping
Input Load Mapping
Stability via Nyquist Plot
Nyquist Plot for Simple Circuit
Nyquist Plot for Active Resonator
Large Signal S-Parameters
```

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, Clapp Oscillator, Hartley Oscillator, Modified Clapp Oscillator, Modified Colpitts Oscillator, or one of the examples (XTO, SAW, VCO, YTO) to start a 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.
Tools Sub-menu Structure

These utilities provide added functionality to this DesignGuide. A brief description is provided for each. For more information select the help button located in each utility.

Transistor Bias Utility

The Transistor Bias Utility provides SmartComponents and automated-assistants for the design and simulation of common resistive and active transistor bias networks. The automated capabilities can determine the transistor DC parameters, design an appropriate network to achieve a given bias point, and simulate and display the achieved performance. All SmartComponents can be modified when selected. You simply select a SmartComponent and with little effort redesign or verify their performance.
Smith Chart Utility

This DesignGuide Utility provides full smith chart capabilities, synthesis of matching networks, allowing impedance matching and plotting of constant Gain/Q/VSWR/Noise circles. This guide assumes you have installed the associated DesignGuide with appropriate licensing codewords.

Impedance Matching Utility

The Impedance Matching Utility performs the synthesis of lumped and distributed impedance matching networks based on provided specifications. The Utility features automatic simulation, sensitivity analysis, and display setup to enable simple and efficient component verification.
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.
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.
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 Design Guide

Reference

This manual provides reference information on the use of the Oscillator Design Guide.

Oscillator Design Guide Structure

The Oscillator Design Guide 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 Design Guide focuses on RF printed circuit boards and microwave oscillations.

In addition to the requirements of the ADS software, the Oscillator Design Guide 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 Schematic Capture and Layout manual.

The Oscillator Design Guide contains templates that can be used in the ADS software environment. It consists of generic colpitts, clapp, modified colpitts, modified clapp, and hartley oscillator design 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 Design Guide 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 other examples. Refer to the section “Additional Examples” on page 2-41.

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>
<thead>
<tr>
<th>Measurement</th>
<th>Schematic Filenames</th>
<th>Data Display Filename</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fixed Frequency Oscillator</td>
<td>FixedFreqOsc.dsn</td>
<td>FixedFreqOsc.dds</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>ClappFixedFreqOsc.dsn</td>
<td>ClappFixedFreqOsc.dds</td>
</tr>
<tr>
<td></td>
<td>HartleyFixedFreqOsc.dsn</td>
<td>HartleyFixedFreqOsc.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedClappFixedFreqOsc.dsn</td>
<td>ModifiedClappFixedFreqOsc.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedColpittsFixedFreqOsc.dsn</td>
<td>ModifiedColpittsFixedFreqOsc.dds</td>
</tr>
<tr>
<td>Single Frequency Dynamics Display</td>
<td>n/a</td>
<td>LargeSignalDynamics.dds</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td>Only a display. Combines periodic waveforms from FixedFreqOsc.dsn with DC characteristics from czBJTCurveTracer.dsn.</td>
<td></td>
</tr>
<tr>
<td>Single Frequency Phase Noise</td>
<td>PhaseNoise.dsn</td>
<td>PhaseNoise.dds</td>
</tr>
<tr>
<td></td>
<td>ClappPhaseNoise.dsn</td>
<td>ClappPhaseNoise.dds</td>
</tr>
<tr>
<td></td>
<td>HartleyPhaseNoise.dsn</td>
<td>HartleyPhaseNoise.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedClappPhaseNoise.dsn</td>
<td>ModifiedClappPhaseNoise.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedColpittsPhaseNoise.dsn</td>
<td>ModifiedColpittsPhaseNoise.dds</td>
</tr>
</tbody>
</table>
Table 2-1. Push-Button Large-Signal Measurements

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Schematic Filenames</th>
<th>Data Display Filename</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tuned Frequency</td>
<td>FreqTune.dsn</td>
<td>FreqTune.dds</td>
</tr>
<tr>
<td>Oscillator</td>
<td>ClappFreqTune.dsn</td>
<td>ClappFreqTune.dds</td>
</tr>
<tr>
<td></td>
<td>HartleyFreqTune.dsn</td>
<td>HartleyFreqTune.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedClappFreqTune.dsn</td>
<td>ModifiedClappFreqTune.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedColpittsFreqTune.dsn</td>
<td>ModifiedColpittsFreqTune.dds</td>
</tr>
<tr>
<td>Frequency Pulling</td>
<td>FreqPull.dsn</td>
<td>FreqPull.dds</td>
</tr>
<tr>
<td></td>
<td>ClappFreqPull.dsn</td>
<td>ClappFreqPull.dds</td>
</tr>
<tr>
<td></td>
<td>HartleyFreqPull.dsn</td>
<td>HartleyFreqPull.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedClappFreqPull.dsn</td>
<td>ModifiedClappFreqPull.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedColpittsFreqPull.dsn</td>
<td>ModifiedColpittsFreqPull.dds</td>
</tr>
<tr>
<td>Frequency Pushing</td>
<td>FreqPush.dsn</td>
<td>FreqPush.dds</td>
</tr>
<tr>
<td></td>
<td>ClappFreqPush.dsn</td>
<td>ClappFreqPush.dds</td>
</tr>
<tr>
<td></td>
<td>HartleyFreqPush.dsn</td>
<td>HartleyFreqPush.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedClappFreqPush.dsn</td>
<td>ModifiedClappFreqPush.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedColpittsFreqPush.dsn</td>
<td>ModifiedColpittsFreqPush.dds</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Measurement</th>
<th>Schematic Filename</th>
<th>Data Display Filename</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output Load Mapping</strong></td>
<td><strong>Description:</strong> Mapping of passive loads onto resonator interface plane</td>
<td><strong>MapLoad.dsn</strong>&lt;br&gt;<strong>ClappMapLoad.dsn</strong>&lt;br&gt;<strong>HartleyMapLoad.dsn</strong>&lt;br&gt;<strong>ModifiedClappMapLoad.dsn</strong>&lt;br&gt;<strong>ModifiedColpittsMapLoad.dsn</strong></td>
</tr>
<tr>
<td><strong>Input Load Mapping</strong></td>
<td><strong>Description:</strong> Mapping of passive loads from resonator interface plane to output plane</td>
<td><strong>MapInput.dsn</strong>&lt;br&gt;<strong>ClappMapInput.dsn</strong>&lt;br&gt;<strong>HartleyMapInput.dsn</strong>&lt;br&gt;<strong>ModifiedClappMapInput.dsn</strong>&lt;br&gt;<strong>ModifiedColpittsMapInput.dsn</strong></td>
</tr>
<tr>
<td><strong>Stability via Nyquist Plot</strong></td>
<td><strong>Description:</strong> Tests whether the circuit will oscillate (using OscTest to plot Nyquist loop)</td>
<td><strong>NyqStab.dsn</strong>&lt;br&gt;<strong>ClappNyqStab.dsn</strong>&lt;br&gt;<strong>HartleyNyqStab.dsn</strong>&lt;br&gt;<strong>ModifiedClappNyqStab.dsn</strong>&lt;br&gt;<strong>ModifiedColpittsNyqStab.dsn</strong></td>
</tr>
<tr>
<td><strong>Nyquist Plot for Simple Circuit</strong></td>
<td><strong>Description:</strong> Simple example that explains effect of zo in OscTest use</td>
<td><strong>NyqPlot.dsn</strong></td>
</tr>
</tbody>
</table>
### Table 2-2. Design Tools

<table>
<thead>
<tr>
<th>Measurement</th>
<th>Schematic Filename</th>
<th>Data Display Filename</th>
</tr>
</thead>
<tbody>
<tr>
<td>NyqPlot for Active Resonator</td>
<td>NyqPlotA.dsn</td>
<td>NyqPlotA.dds</td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple example that further explains intricacies of Nyquist plots and the use of OscTest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LSSpar (nonlinear tool)</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Description:</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>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)</td>
<td>LSSpar.dsn</td>
<td>LSSpar.dds</td>
</tr>
<tr>
<td></td>
<td>ClappLSSpar.dsn</td>
<td>ClappLSSpar.dds</td>
</tr>
<tr>
<td></td>
<td>HartleyLSSpar.dsn</td>
<td>HartleyLSSpar.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedClappLSSpar.dsn</td>
<td>ModifiedClappLSSpar.dds</td>
</tr>
<tr>
<td></td>
<td>ModifiedColpittsLSSpar.dsn</td>
<td>ModifiedColpittsLSSpar.dds</td>
</tr>
</tbody>
</table>
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>
<thead>
<tr>
<th>Component Description</th>
<th>Schematic Filename</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biased BJT</td>
<td>cBJTBiased.dsn</td>
<td>Common Emitter BJT with a standard (1-voltage source) biasing circuit</td>
</tr>
<tr>
<td>Biased RF BJT</td>
<td>cBJTRFBiased.dsn</td>
<td>The RF version of BJT used in Crystal Oscillator</td>
</tr>
<tr>
<td>Biased MESFET</td>
<td>cFETBiased.dsn</td>
<td>n/a</td>
</tr>
<tr>
<td>Varactor Diode</td>
<td>cVar.dsn</td>
<td>Varactor diode model, included for convenience. Within this DesignGuide, it always appears with the reverse-biasing circuit (see next table entry).</td>
</tr>
<tr>
<td>Biased Varactor Diode</td>
<td>cbVar.dsn</td>
<td>Reversed-biasing varactor</td>
</tr>
</tbody>
</table>
Table 2-4 provides schematic filenames and descriptions for the available subcircuit components.

### Table 2-4. Available Subcircuit Components

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Schematic Filename</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Buffer Amplifier (microwave)</td>
<td>cAmpBuff.dsn</td>
<td>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.</td>
</tr>
<tr>
<td>Buffer Amplifier (1 - 2 MHz)</td>
<td>cAmpBuffS.dsn</td>
<td>Buffer amplifier with reactive components adjusted for 1GHz to 2GHz range, used in SAW oscillator</td>
</tr>
<tr>
<td>Buffer Amplifier (10 - 100 MHz)</td>
<td>cAmpBuffX.dsn</td>
<td>Buffer amplifier with reactive components adjusted for 10MHz to 100MHz range, used in crystal oscillator</td>
</tr>
<tr>
<td>Oscillator Core</td>
<td>cOsCore.dsn</td>
<td>Colpitts structure with a BJT with standard bias</td>
</tr>
<tr>
<td>RF Oscillator Core</td>
<td>cOsCoreRF.dsn</td>
<td>Oscillator Core adapted to MHz frequency range</td>
</tr>
<tr>
<td>Clapp Oscillator Core</td>
<td>cClappCore.dsn</td>
<td>Bipolar Clapp Oscillator covering a frequency range of 0.5 to 15GHz. (Other frequencies are possible by modifying component values.)</td>
</tr>
<tr>
<td>Hartley Oscillator Core</td>
<td>cHartleyCore.dsn</td>
<td>Bipolar Hartley Oscillator covering a frequency range of 1 to 1000MHz. (Other frequencies are possible by modifying component values.)</td>
</tr>
<tr>
<td>Modified Clapp Oscillator Core</td>
<td>cModifiedClappCore</td>
<td>Bipolar Modified Clapp Oscillator covering a frequency range of 0.7 to 7.2GHz. (Other frequencies are possible by modifying component values.)</td>
</tr>
<tr>
<td>Modified Colpitts Oscillator Core</td>
<td>cModifiedCopittsCore</td>
<td>Bipolar Colpitts Oscillator covering a frequency range of 0.8 to 6.5GHz. (Other frequencies are possible by modifying component values.)</td>
</tr>
<tr>
<td>Fixed VSWR Complex Load</td>
<td>cLoadEqs.dsn</td>
<td>Load determined through VSWR and phase of the reflection coefficient</td>
</tr>
</tbody>
</table>
Oscillator Core Circuits

Figure 2-1 shows the cClappCore.dsn oscillator core schematic symbol.

The cClappCore.dsn oscillator operates from 0.5 to 15GHz using the existing component values in the Clapp oscillator sub-circuit. Resonator tank components $C_t$ and $L_t$ are automatically calculated with approximations referenced to 1GHz and displayed on some display pages. The Ground or Series Resonator port is either connected directly to ground or connected to ground through a series resonator. The Variable Capacitance Tuning Port is used for VCO design by coupling a varactor diode across the tank capacitor $C_t$. Coupling is accomplished by capacitor $C_{cpl}$. Larger
values of \( C_{cpl} \) yield tighter coupling and wider tuning range for a given amount of tuning capacitance variation. The OscPort1 and OscPort2 ports are either connected directly together or connected through a series resonator. You can connect the OscPort test probe between these two ports for harmonic balance oscillator simulations. The Output Port is used for oscillator signal output. The variable \( C_{tune} \) sets the oscillator at the desired oscillation frequency when the capacitance across the Variable Capacitance Tuning Port is equal to the \( C_{tune} \) set value. Figure 2-2 is an example of the Clapp Oscillator subcircuit.

Figure 2-2. Bipolar Clapp Oscillator Subcircuit

Increase capacitors \( C_1 \) and \( C_2 \) for lower frequency oscillator circuits. Adjust resonator frequency offset (currently 390E6) to recenter oscillator frequency.
Figure 2-3 shows the cHartleyCore.dsn oscillator core schematic symbol. This oscillator operates from 1 to 1000MHz using the existing component values in the Hartley oscillator sub-circuit. The resonator tank component $C_t$ is scaled from 500MHz with an approximation and displayed on some display pages. You can connect the Ground or Series Resonator to the port directly to ground, or it can be connected to ground through a series resonator. The Variable Capacitance Tuning Port is used for VCO design by coupling a varactor diode across the tank capacitor $C_t$. Coupling is accomplished by capacitor $C_{cpl}$. Larger values of $C_{cpl}$ yield tighter coupling and wider tuning range for a given amount of tuning capacitance variation. The OscPort1 and OscPort2 ports are either connected directly together or connected.
through a series resonator. For harmonic balance oscillator simulations, connect the OscPort test probe between these two ports. The Output Port is used for oscillator signal output. The variable Ctune sets the oscillator at the desired oscillation frequency when the capacitance across the Variable Capacitance Tuning Port is equal to the Ctune set value. Figure 2-4 shows the Hartley Oscillator subcircuit.

Figure 2-4. Bipolar Hartley Oscillator Subcircuit

Increase inductors L1 and L2 for lower frequency oscillator circuits. Adjust resonator capacitor Ct reference value (currently 21.3pF) to recenter oscillator frequency.
Figure 2-5. Bipolar Modified Clapp Oscillator Schematic Symbol

Figure 2-5 shows the cModifiedClappCore.dsn oscillator core schematic symbol. The cModifiedClappCore.dsn oscillator operates from 0.7 to 7.2GHz using the existing component values in the Modified Clapp oscillator sub-circuit. Resonator tank components $C_t$ and $L_t$ are automatically calculated with approximations referenced to 1GHz and displayed on some display pages. The Ground or Series Resonator port can be connected directly to ground or connected to ground through a series resonator. The Variable Capacitance Tuning Port is used for VCO design by coupling a varactor diode across the tank capacitor $C_t$. Coupling is accomplished by capacitor $C_{cpl}$. Larger values of $C_{cpl}$ yield tighter coupling and wider tuning range for a given amount of tuning capacitance variation. The OscPort1 and OscPort2 ports are either connected directly together or connected through a series resonator. You can connect the OscPort test probe between these two ports for harmonic balance oscillator.
simulations. The Output Port is used for oscillator signal output. Variable Ctune sets the oscillator at the desired oscillation frequency when the capacitance across the Variable Capacitance Tuning Port is equal to the Ctune set value. Figure 2-6 shows the Modified Clapp Oscillator subcircuit.

Figure 2-6. Bipolar Modified Clapp Oscillator Subcircuit

Increase capacitors C1 and C2 for lower frequency oscillator circuits. Adjust resonator frequency offset (currently 290E6) to recenter oscillator frequency.
Figure 2-7. Bipolar Modified Colpitts Oscillator Schematic Symbol

Figure 2-7 shows the `cModifiedColpittsCore` dsn oscillator core schematic symbol. This oscillator operates from 0.8 to 6.5GHz using the existing component values in the Modified Colpitts oscillator sub-circuit. Resonator tank inductor $L_t$ is automatically calculated with an approximation and displayed on some display pages. The Ground or Series Resonator port can be connected directly to ground or connected to ground through a series resonator. The Variable Capacitance Tuning Port is used for VCO design by coupling a varactor diode across the tank inductor $L_t$. Coupling is accomplished by capacitor $C_{cpl}$. Larger values of $C_{cpl}$ yield tighter coupling and wider tuning range for a given amount of tuning capacitance variation.

```
cModifiedColpittsCore
ModifiedColpittsBipolarCore1
fosc=1GHz
C1=3.3pF
C2=3.9pF
Ccouple=.01fF
Cvar=.01fF
Vcc=5V
R1=3kOhm
R2=6.8kOhm
Re=510Ohm
```
The OscPort1 and OscPort2 ports are either connected directly together or connected through a series resonator. Connect the OscPort test probe between these two ports for harmonic balance oscillator simulations. The Output Port is used for oscillator signal output. The variable Ctune sets the oscillator at the desired oscillation frequency when the capacitance across the Variable Capacitance Tuning Port is equal to the Ctune set value. Figure 2-8 is the Modified Colpitts Oscillator subcircuit.

Figure 2-8. Bipolar Modified Colpitts Oscillator Subcircuit

Increase scaled 10nH inductance reference value for lower frequency oscillator circuits. Tank inductance Lt is scaled from 1GHz using an approximation. Increasing C1 and C2 capacitors yields a lower frequency oscillator as well.
Table 2-5 provides schematic filenames and descriptions for the available resonator components.

Table 2-5. Available Resonator Components

<table>
<thead>
<tr>
<th>Component Description</th>
<th>Schematic Filename</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crystal Resonator</td>
<td>cResXtal.dsn</td>
<td>Straightforward resonator model</td>
</tr>
<tr>
<td>SAW Resonator</td>
<td>cResSAW.dsn</td>
<td>Straightforward resonator model</td>
</tr>
<tr>
<td>YIG Resonator</td>
<td>cResYIG.dsn</td>
<td>Straightforward resonator model</td>
</tr>
<tr>
<td>Parallel Resonator</td>
<td>cResP.dsn</td>
<td>Straightforward resonator model</td>
</tr>
<tr>
<td>Series Resonator</td>
<td>cResS.dsn</td>
<td>Straightforward resonator model</td>
</tr>
</tbody>
</table>

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

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

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

- Resonator
- Oscillator active part (OscCore)
- \( L_{load} \), 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

\[
\frac{1}{\sqrt{L \times C_1 \times C_2 / (C_1+C_2)}}.
\]

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 2-9. It includes fixed load, a clearly visible active circuit, and the tunable resonator separated by the OscPort component.

![Figure 2-9. Structure of Oscillator Circuit](image)
Single-Frequency Oscillations

The results of single-frequency oscillations in Figure 2-10 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.

Figure 2-10. Results of Single-Frequency Oscillations
Dynamics of Single-Frequency Oscillations

The graph in Figure 2-11 shows waveforms of Collector-Emitter voltage and the collector current of the OsCore BJT superimposed on BJT’s DC characteristics.

Figure 2-11. Dynamics of Single-Frequency Oscillation
Single-Frequency Oscillations with Noise

The graph in Figure 2-12 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.

Figure 2-12. Single-Frequency Oscillations with Noise
Frequency Pulling

Figure 2-13 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 2-13. Results with Circuit Modified for Frequency Pulling
**Frequency Pushing**

Figure 2-14 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.

![Frequency pushing](image)

Figure 2-14. Results with Circuit Modified for Frequency Pushing
Tuned Oscillations

Figure 2-15 shows the resonator voltage and its harmonics. It provides the tuning characteristics of sweeps vs. capacitance vs. frequency.

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 2-16, 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.

**Figure 2-16. 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 2-17. 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 2-43).

**Figure 2-17. Resonator-to-Load Mapping**

*Illustration showing small-signal load mapping with input values and 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:** 13.000MHz

---

2-28 Generic Oscillator Example
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.

Figure 2-18. 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:

\[
\text{arg}(S_n) = - \text{arg}(S_r), \quad |S_n S_r| > 1
\]

Consider a simplest possible linearized oscillator, as shown in Figure 2-19. The circuit has the resonator's resistance \( r_r = 1/G = 100.0 \) ohm and the active (linearized) resistance \( r_a = 1/g'(V_0) = -5.0 \) ohm and is obviously unstable.

![Figure 2-19. Stability Via Nyquist Plots](image)

The Nyquist plots and equation were checked for different values of the characteristic impedance \( Z_0 \). The system stability depends on the position of poles of the transfer function \( S_r(s)S_n(s) \). 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 oscetest generated contour $S11 = Sr(jw)Sn(jw)$.

The Nyquist plots obtained for $Zo = 2.0, 82.0, 162.0$ ohm are shown in Figure 2-20.

The circuit oscillates if the Nyquist loop $(S11)$ encircles clockwise the point $1 + j0$.

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 2-21, 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 2-21 shows a variation of our original circuit.

The circuit oscillates if the Nyquist loop encircles clockwise the point 1+j0. 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 $zo > r1$. In that case the usefulness of the Nyquist criterion is diminished.

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 \( S_r S_n \) 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 \( S_{11} \) for \( Z_0 = 2.0, 82.0, 162.0 \) need to be considered. For \( Z_0 = 82.0, 162.0 \) the Nyquist loop does not encircle \( 1+j0 \), as expected. However, for \( Z_0 = 2.0 \) 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:

\[
S_r(s) = \frac{(Z_r - Z_0)}{(Z_r + Z_0)} = \frac{-(s^2+s((1/ra)-(1/Zo)) \cdot C+\frac{1}{L} \cdot C)}{(s^2+s((1/ra)+(1/Zo)) \cdot C+\frac{1}{L} \cdot C)}
\]

has all poles in the left hand plane for \( Z_0 < |ra| \). Only closing the loop makes the system unstable.

**Using Nonlinear Design Tools**

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

\[
\begin{align*}
\arg(S_n) &= -\arg(S_r) \\
|S_n S_r| &= 1
\end{align*}
\]

determine amplitude and phase of oscillations.
The steady state periodic oscillations can be represented by their Fourier series:
\[ v(t) = \sum |v_n| \cos(n\omega t + \phi_n) \quad i(t) = \sum |i_n| \cos(n\omega t + \psi_n) \]

For a high-Q resonator the higher harmonics are negligibly small and voltage and current can be approximated by:
\[ v(t) \approx |V| \cos(\omega t + \phi) \]
\[ i(t) \approx |I| \cos(\omega t + \psi) \]

where
\[ V = |V| \exp(j\phi), \text{ and } I = |I| \exp(j\psi) \]

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:
\[ a = \frac{V + Z_0 I}{2 \sqrt{Z_0}}, \quad b = \frac{V - Z_0 I}{2 \sqrt{Z_0}} \]

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: \( S_n = b(a)/a \) the steady state equation can be represented as \( a = Sr S_n a \), which leads to: \( 1 = Sr S_n \), which is equivalent to the equations.

**Solving Harmonic Balance Convergence Problems**

Harmonic balance simulation in Advanced Design System is an excellent way to analyze many oscillators in the frequency domain. Occasionally, you might have an oscillator that converges in a time-domain simulation, but the harmonic balance oscillator algorithm is unable to find the solution. There are two techniques in ADS for solving those oscillators:

- Analyzing the large-signal loop gain in harmonic balance to find the point of oscillation and using that as an initial guess for the full harmonic balance oscillator analysis
- Using a transient analysis to produce an initial guess for harmonic balance oscillator analysis.

In the DesignGuide > Oscillator menu, select Solving Harmonic Balance Conversion Problems for several useful design examples.
For more information on these techniques, refer to the ADS Circuit Simulation manual, in the section “Simulation Techniques for Recalcitrant Oscillators, in Chapter 9, “Harmonic Balance for Oscillator simulations.

**Oscillator Core Examples**

Oscillator Cores (cClappCore, cHartleyCore, cModifiedClappCore, and cModifiedColpittsCore) are compatible with simulation and measurement setups outlined by the Generic Oscillator Example. These core oscillator circuits are configured for low resistance loads. (50ohm is used for these four oscillator cores, although other load values are possible.) The design and display filenames for these examples follow a naming convention that indicates oscillator type and simulation setup as follows:

- OscillatorTypeSimulationType.dsn
- OscillatorTypeSimulationType.dds

where:

OscillatorType indicates one of the following topologies: Clapp, Hartley, Modified Clapp, or Modified Colpitts.

SimulationType provides one of the following simulation set-ups or measurements: FixedFreqOsc, FreqPull, FreqPush, FreqTune, LSSpar, MapInput, MapOutput, NyqStab, or Phase Noise.

For example, the simulation that determines oscillator frequency of a Clapp oscillator has the design filename ClappFixedFreqOsc.dsn and a data display filename ClappFixedFreqOsc.dds. This simulation predicts oscillation frequency, output power, and calculates tank components $L_t$ and $C_t$. The accompanying data display presents these results.
The cClappCore circuit is used to illustrate available simulation setups offered in the design guide.

**Figure 2-23. Oscillator Core Circuit Simulation Connections**

Figure 2-23 shows the Clapp oscillator harmonic balance simulation ClappFixedFreqOsc.dsn that determines oscillation frequency, output power and tank component values at 1GHz. The OscPort probe is shown connected between the active device and tank resonator. Resonator tank components $L_t$ and $C_t$ are computed and shown on the companion data display page.
Oscillator Core Series Resonator Connection Alternatives

Oscillator core circuits (cClappCore, cHartleyCore, cModifiedClappCore, and cModifiedColpittsCore) are compatible with series resonators in two ways.

Figure 2-24. Series Resonator Connection Between Tank and Active Circuit

The first possibility shown by Figure 2-24 connects the series resonator between the tank circuit and active device. If resonator losses are low, the series resonator can also be connected between the bipolar base terminal and ground as shown in Figure 2-25.
Figure 2-25. Series Resonator Connection Transistor Base and Ground
Simulation Warnings

Several simulation setups connect portions of the tank circuit to ground reference. Performing the simulation issues warnings that indicate some components are short-circuited. These warnings are expected and should cause no concern. Figure 2-26 shows a load pull of the Clapp oscillator circuit. Notice that components \( L_t \), \( C_t \), and \( C_{cpl} \) are connected to ground and are not part of the actual simulation in this example. Short-circuited component warnings are issued for LSSpar, MapInput, and MapOutput simulations.

![Figure 2-26. Example Simulation that Issues Warnings](image-url)
Additional Examples

Following are examples in addition to the primary example, as described in the section, “Generic Oscillator Example” on page 2-18.

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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