VCO Fundamentals

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Overview

• Functional Block Concept
• Oscillator Review
• Basic Performance Metrics
• Methods of Tuning
• Advanced Performance Metrics
• Conclusion
Overview

• Functional Block Concept
  – Applications
  – Specifications
• Oscillator Review
• Basic Performance Metrics
• Methods of Tuning
• Advanced Performance Metrics
• Conclusion
Functional Block Concept

- Input control voltage $V_{\text{TUNE}}$ determines frequency of output waveform
Applications: RF System

- Downconvert band of interest to IF
- VCO: Electrically tunable selection
Applications: Digital System

- Clock synthesis (frequency multiplication)

# Specifications

## VOLTAGE CONTROLLED OSCILLATORS 50 Ω

12.5 MHz to 3 GHz

<table>
<thead>
<tr>
<th>MODEL PREFIX</th>
<th>FREQUENCY (MHz)</th>
<th>POWER OUTPUT (dBm)</th>
<th>TUNE VOLTAGE (V)</th>
<th>PHASE NOISE (dBc/Hz) SSB@ offset frequencies: Typ.</th>
<th>PULLING (MHz pk-pk @12 dB)</th>
<th>PUSHING (MHz/V)</th>
<th>TUNING SENSITIVITY (MHz/V)</th>
<th>HARMONICS (dBc)</th>
<th>3dB MOD. BANDWIDTH (kHz)</th>
<th>POWER SUPPLY</th>
<th>VOLTAGE (V)</th>
<th>CURRENT (mA)</th>
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<td>JCOS-175LN</td>
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<td>JTOS 300</td>
<td>150-280</td>
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<td>1.0</td>
<td>30-40</td>
<td>-26-20</td>
<td>12.0-20</td>
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</table>
Overview

• Functional Block Concept
• Oscillator Review
  – Frequency Control
  – Amplitude Control
  – Types of Oscillators
• Basic Performance Metrics
• Methods of Tuning
• Advanced Performance Metrics
• Conclusion
Oscillator Review

• Types of Oscillators
  – Multivibrator
  – Ring
  – Resonant
  – Feedback

• Basic Factors in Oscillator Design
  – Frequency
  – Amplitude / Output Power
  – Startup
Multivibrator

- Conceptual multivibrator oscillator
  - Also called astable or relaxation oscillator
- One energy storage element
Example: Multivibrator

- Frequency: Controlled by charging current $I_{REF}$, $C$, $V_{REF}$ thresholds
- Amplitude: Controlled by thresholds, logic swing
- Startup: Guaranteed; no stable state
Ring Oscillator

- Frequency: Controlled by gate delay
- Amplitude: Controlled by logic swing
- Startup: Guaranteed; no stable state
Resonant Oscillator

• Concept: Natural oscillation frequency of resonance
• Energy flows back and forth between two storage modes

\[ f_{osc} = \frac{1}{2\pi\sqrt{LC}} \]
Resonant Oscillator (Ideal)

- Example: swing (ideal)
- Energy storage modes: potential, kinetic
- Frequency: Controlled by length of pendulum
- Amplitude: Controlled by initial position
- Startup: Needs initial condition energy input
Resonant Oscillator (Real)

- Problem: Loss of energy due to friction
- Turns “organized” energy (potential, kinetic) into “disorganized” thermal energy (frictional heating)
- Amplitude decays toward zero
- Requires energy input to maintain amplitude
- Amplitude controlled by “supervision”
LC Resonant Oscillator (Ideal)

- Energy storage modes: Magnetic field (L current), Electric field (C voltage)
- Frequency: Controlled by LC
- Amplitude: Controlled by initial condition
- Startup: Needs initial energy input (initial condition)
LC Resonant Oscillator (Real)

- Problem: Loss of energy due to nonideal L, C
  - Model as resistor $R_{LOSS}$; $Q$ of resonator
- $E$, $M$ field energy lost to resistor heating
- Amplitude decays toward zero
LC Resonant Oscillator (Real)

- Problem: Loss of energy due to nonideal L, C
- Requires energy input to maintain amplitude
- Synthesize “negative resistance”
- Cancel $R_{LOSS}$ with $-R_{NEG}$
Negative Resistance

- Use active device to synthesize V-I characteristic that “looks like” \(-R_{\text{NEG}}\)
- Example: amplifier with positive feedback
- Feeds energy into resonator to counteract losses in \(R_{\text{LOSS}}\)
Feedback Oscillator: Wien Bridge

- Forward gain $A=3$
- Feedback network with transfer function $\beta(f)$
- At $f_{osc}$, $|\beta|=1/3$ and $\angle \beta =0$
- Thought experiment: break loop, inject sine wave, look at signal returned around feedback loop
$A\beta = 1$

- “Just right” waveform is self sustaining
$A\beta = 0.99$

- "Not enough" waveform decays to zero
$A\beta = 1.01$

- “Too much” waveform grows exponentially

![Circuit Diagram and Waveforms](Image)
Feedback oscillator

- Stable amplitude condition: $A\beta = 1$ EXACTLY
- Frequency determined by feedback network $A\beta = 1$ condition
- Need supervisory circuit to monitor amplitude
- Startup: random noise; supervisory circuit begins with $A\beta > 1$
Resonant Oscillator (Real)

- Stable amplitude condition: \( |R_{\text{NEG}}| = R_{\text{LOSS}} \) EXACTLY
- Frequency determined by LC network
- Startup: random noise; begin with \( |R_{\text{NEG}}| > R_{\text{LOSS}} \)
- Amplitude grows; soft clip gives average \( |R_{\text{NEG}}| = R_{\text{LOSS}} \)
Clapp oscillator

\[ f_{osc} = \frac{1}{2\pi \sqrt{LC_{eq}}} \]
\[ C_{eq} = \left( \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} \right) \]

- \( L, C1-C2-C3 \) set oscillation frequency \( f_{osc} \)
Clapp oscillator

- Circuit configuration
- Equivalent circuit

MiniCircuits AN95-007, “Understanding Oscillator Concepts”
Clapp oscillator

- Frequency: Determined by L, C1, C2, C3
- Amplitude: Grows until limited by $g_m$ soft clipping
- Startup: Choose C1, C2 feedback for $|R_{NEG}| > R_{LOSS}$

\[ Z_{eq} = \frac{1}{j\omega C_1} + \frac{1}{j\omega C_2} - \frac{g_m}{\omega^2 C_1 C_2} \]
Oscillator Summary

- Typical performance of oscillator architectures:

```
BETTER PHASE NOISE

FEEDBACK
MULTIVIBRATOR
RING

FREQUENCY $f_{osc}$

kHz MHz GHz
```
Overview

• Functional Block Concept
• Oscillator Review
• Basic Performance Metrics
  – Frequency Range
  – Tuning Range
• Methods of Tuning
• Advanced Performance Metrics
• Conclusion
## Basic Performance Metrics

**VOLTAGE CONTROLLED OSCILLATORS** 50 Ω

12.5 MHz to 3 GHz

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<thead>
<tr>
<th>MODEL PREFIX</th>
<th>FREQUENCY (MHz)</th>
<th>POWER OUTPUT (dBm)</th>
<th>TUNE VOLTAGE (V)</th>
<th>PHASE NOISE (dBc/Hz) SSB @ offset frequencies:</th>
<th>PULLING (MHz) pk-pk @12 dBm</th>
<th>PUSHING (MHz/V)</th>
<th>TUNING SENSITIVITY (MHz/V)</th>
<th>HARMONICS (dBc)</th>
<th>3dB MOD. BANDWIDTH (kHz)</th>
<th>POWER SUPPLY</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Min.</td>
<td>Max.</td>
<td>Typ.</td>
<td>Min.</td>
<td>Max.</td>
<td>1 kHz</td>
<td>10 kHz</td>
<td>100 kHz</td>
<td>1 MHz</td>
<td></td>
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<td>JCOS-175LN</td>
<td>125</td>
<td>175</td>
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<td>1.0</td>
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<td>3.7</td>
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<td>-119</td>
<td>-132</td>
<td>-151</td>
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<tr>
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<td>1.0</td>
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<td>-112</td>
<td>-112</td>
<td>-171</td>
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<td>-112</td>
<td>-132</td>
<td>-151</td>
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<td>1114</td>
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<td>20.0</td>
<td>9.5</td>
<td>8.5</td>
<td>-88</td>
<td>-110</td>
<td>-130</td>
<td>-150</td>
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</table>

**LINEAR TUNING** Wideband

| JTOS 25      | 12.5 | 25   | 1.5  | 1.0  | 1.1  | 3.8 | 8.5 | 10.8 | 12.7 | 14.7 | Typ. | 0.03 | 0.03 | 2.0 | 4.0 | 26 | 13 | 190 | 12.0 | 20 |
| JTOS 50      | 25   | 47   | 1.5  | 1.0  | 1.6  | 8.5 | 8.5 | 10.8 | 12.7 | 14.7 | Typ. | 0.06 | 0.04 | 2.0 | 4.0 | 26 | 13 | 190 | 12.0 | 25 |
| JTOS 75      | 37.5 | 75   | 1.5  | 1.0  | 1.6  | 8.5 | 8.5 | 10.8 | 12.7 | 14.7 | Typ. | 0.15 | 0.11 | 2.8 | 4.0 | 27 | 20 | 126 | 12.0 | 20 |
| JTOS-100     | 50   | 100  | 1.5  | 1.0  | 1.6  | 8.5 | 8.5 | 10.8 | 12.7 | 14.7 | Typ. | 0.6  | 0.2  | 3.7-1.8 | 25 | 20 | 100 | 12.0 | 13 |
| JTOS-150     | 75   | 150  | 1.5  | 1.0  | 1.6  | 2.5 | 7.9 | 10.8 | 12.7 | 14.7 | Typ. | 0.8  | 0.3  | 5.8-6.7 | 23 | 1/ | 112 | 12.0 | 20 |
| JTOS-200     | 100  | 200  | 1.5  | 1.0  | 1.6  | 9.3 | 9.3 | 10.8 | 12.7 | 14.7 | Typ. | 1.0  | 0.2  | 4.0 | 4.0 | 23 | 25 | 110 | 12.0 | 20 |
| JTOS-300     | 150  | 280  | 1.5  | 1.0  | 1.6  | 2.5 | 7.9 | 10.8 | 12.7 | 14.7 | Typ. | 1.0  | 0.2  | 4.0 | 4.0 | 23 | 25 | 110 | 12.0 | 20 |
| JTOS-400     | 200  | 380  | 1.5  | 1.0  | 1.6  | 2.5 | 7.9 | 10.8 | 12.7 | 14.7 | Typ. | 1.4  | 0.4  | 10.5 | 17.1 | 25 | 20 | 150 | 12.0 | 20 |
| JTOS-535     | 300  | 525  | 1.5  | 1.0  | 1.6  | 2.5 | 7.9 | 10.8 | 12.7 | 14.7 | Typ. | 2.0  | 0.5  | 10-24 | -28 | -20 | 115 | 12.0 | 20 |
| JTOS-765     | 400  | 765  | 1.5  | 1.0  | 1.6  | 2.5 | 7.9 | 10.8 | 12.7 | 14.7 | Typ. | 2.0  | 0.5  | 20-30 | -28 | -20 | 115 | 12.0 | 20 |
| JTOS-840LNW  | 500  | 840  | 1.5  | 1.0  | 1.6  | 2.5 | 7.9 | 10.8 | 12.7 | 14.7 | Typ. | 4.0  | 1.5  | 18-60 | -28 | -20 | 115 | 12.0 | 20 |
| JTOS-1000W   | 500  | 1000 | 1.5  | 1.0  | 1.6  | 2.5 | 7.9 | 10.8 | 12.7 | 14.7 | Typ. | 5.0  | 1.0  | 30-40 | -28 | -20 | 115 | 12.0 | 20 |
Basic Performance Metrics

Surface Mount
Voltage Controlled Oscillator

JTOS-1000W+

Wide Band 500 to 1000 MHz

Features
- wide frequency range, 500 to 1000 MHz typ.
- 3 dB modulation bandwidth 100 kHz typ.
- octave, linear tuning
- low phase noise, -134 dBc/Hz at 1 MHz offset, typ.
- excellent harmonic suppression, -26 dBc typ.
- aqueous washable

Applications
- test instruments-signal generators
- wideband frequency synthesizers
- agile communications systems
- catv distribution and set-top converters
- cellular up and down converters
- digital cordless phones

Electrical Specifications

<table>
<thead>
<tr>
<th>FREQUENCY (MHz)</th>
<th>POWER OUTPUT (dBm)</th>
<th>TUNING VOLTAGE (V)</th>
<th>PHASE NOISE (dBc/Hz) SSB at offset frequencies: Typ.</th>
<th>PULLING pk-pk @ 12 dB (MHz)</th>
<th>PUSHING (MHz/V)</th>
<th>TUNING SENSITIVITY (MHz/V)</th>
<th>HARMONICS (dBc)</th>
<th>3 dB MODULATION BANDWIDTH (MHz)</th>
<th>DC OPERATING POWER</th>
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<td>500</td>
<td>1000</td>
<td>47.0</td>
<td>1.0</td>
<td>18</td>
<td>-73</td>
<td>-94</td>
<td>-114</td>
<td>-134</td>
<td>5.0</td>
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</table>
Basic Performance Metrics

- Supply: DC operating power
- Output
  - Sine: output power dBm into 50Ω
  - Square: compatible logic
- Frequency Range
- Tuning Voltage Range
Frequency Range

- Output frequency over tuning voltage range
- Caution: Temperature sensitivity
Overview

• Functional Block Concept
• Oscillator Review
• Basic Performance Metrics
• **Methods of Tuning**
• Advanced Performance Metrics
• Conclusion
VCOs / Methods of Tuning

- Require electrical control of some parameter determining frequency:
  - Multivibrator
    - Charge / discharge current
  - Ring Oscillator
    - Gate delay
  - Resonant
    - Voltage control of capacitance in LC (varactor)
Example: Tuning Multivibrator

- Frequency: Controlled by $I_{REF}$, $C$, $V_{REF}$ thresholds
- Use linear transconductance $G_M$ to develop $I_{REF}$ from $V_{TUNE}$
  
  + Very linear $V_{TUNE} - f_{OSC}$ characteristic
  - But: poor phase noise; $f_{OSC}$ limited to MHz range

\[ f_{OSC} = \frac{I_{REF}}{4CV_{REF}} \]

\[ I_{REF} = G_M V_{TUNE} \]

\[ f_{OSC} = \left( \frac{G_M}{4CV_{REF}} \right) V_{TUNE} \]
Tuning LC Resonator: Varactor

- Q-V characteristic of pn junction
- Use reverse bias diode for C in resonator

\[ Q = \frac{dQ}{dV_R} \]

\[ C_j = \frac{C_j^0}{\left(1 + \frac{V_R}{V_{bi}}\right)^m} \]
Example: Clapp oscillator

\[ f_{osc} = \frac{1}{2\pi\sqrt{LC_{TUNE}}} \sqrt{1 + \frac{C_{TUNE}}{C_1} + \frac{C_{TUNE}}{C_2}} \]
Overview

- Functional Block Concept
- Oscillator Review
- Basic Performance Metrics
- Methods of Tuning
- Advanced Performance Metrics
  - Tuning Sensitivity
  - Phase Noise
  - Supply Pushing
  - Load Pulling
- Conclusion
## Advanced Performance Metrics

### Voltage Controlled Oscillators

**12.5 MHz to 3 GHz**

### Linear Tuning vs. Wideband

<table>
<thead>
<tr>
<th>Model Prefix</th>
<th>Frequency (MHz)</th>
<th>Power Output (dBm)</th>
<th>Tune Voltage (V)</th>
<th>Phase Noise (dBc/Hz) SSB@ offset frequencies:</th>
<th>Pulling (MHz/V)</th>
<th>Pushing (MHz/V)</th>
<th>Tuning Sensitivity (MHz/V)</th>
<th>Harmonics (dBc)</th>
<th>3dB Mod. Bandwidth (kHz)</th>
<th>Power Supply</th>
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<td>125-175</td>
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<td>1.0</td>
<td>-96 - 112 - 138 - 150</td>
<td>0.05</td>
<td>0.05</td>
<td>2.5</td>
<td>-25 - 20</td>
<td>2900</td>
<td>12.0 (20)</td>
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<td>0.0</td>
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<td>0.4</td>
<td>0.4</td>
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<td>24 - 20</td>
<td>2000</td>
<td>10.0 (25)</td>
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<td>13 - 20</td>
<td>2000</td>
<td>8.0 (25)</td>
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<td>15 - 20</td>
<td>2000</td>
<td>8.0 (25)</td>
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<td>127-25</td>
<td>16.0</td>
<td>1.0</td>
<td>-96 - 112 - 138 - 150</td>
<td>0.05</td>
<td>0.05</td>
<td>2.5</td>
<td>-25 - 20</td>
<td>2900</td>
<td>12.0 (20)</td>
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<tr>
<td>JTO5-50</td>
<td>25-47</td>
<td>16.0</td>
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<td>-90 - 112 - 139 - 150</td>
<td>0.4</td>
<td>0.4</td>
<td>6.0</td>
<td>24 - 20</td>
<td>2000</td>
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<tr>
<td>JTO5-75</td>
<td>37.5-75</td>
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<td>-86 - 110 - 130 - 150</td>
<td>4.5</td>
<td>0.3</td>
<td>8.0</td>
<td>13 - 20</td>
<td>2000</td>
<td>8.0 (25)</td>
</tr>
<tr>
<td>JTO5-100</td>
<td>50-100</td>
<td>16.0</td>
<td>1.0</td>
<td>-76 - 110 - 130 - 150</td>
<td>10/9-114</td>
<td>0.5</td>
<td>4.5</td>
<td>15 - 20</td>
<td>2000</td>
<td>8.0 (25)</td>
</tr>
<tr>
<td>JTO5-150</td>
<td>75-150</td>
<td>16.0</td>
<td>1.0</td>
<td>-96 - 112 - 138 - 150</td>
<td>0.05</td>
<td>0.05</td>
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<td>-25 - 20</td>
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<td>12.0 (20)</td>
</tr>
<tr>
<td>JTO5-200</td>
<td>100-200</td>
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<td>1.0</td>
<td>-90 - 112 - 139 - 150</td>
<td>0.4</td>
<td>0.4</td>
<td>6.0</td>
<td>24 - 20</td>
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<td>10.0 (25)</td>
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<tr>
<td>JTO5-300</td>
<td>150-300</td>
<td>16.0</td>
<td>1.0</td>
<td>-86 - 110 - 130 - 150</td>
<td>4.5</td>
<td>0.3</td>
<td>8.0</td>
<td>13 - 20</td>
<td>2000</td>
<td>8.0 (25)</td>
</tr>
<tr>
<td>JTO5-400</td>
<td>200-400</td>
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<td>1.0</td>
<td>-76 - 110 - 130 - 150</td>
<td>10/9-114</td>
<td>0.5</td>
<td>4.5</td>
<td>15 - 20</td>
<td>2000</td>
<td>8.0 (25)</td>
</tr>
<tr>
<td>JTO5-505</td>
<td>300-505</td>
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<td>1.0</td>
<td>-86 - 110 - 130 - 150</td>
<td>10/9-114</td>
<td>0.5</td>
<td>4.5</td>
<td>15 - 20</td>
<td>2000</td>
<td>8.0 (25)</td>
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<tr>
<td>JTO5-850W</td>
<td>405-850</td>
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<td>0.05</td>
<td>2.5</td>
<td>-25 - 20</td>
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<td>12.0 (20)</td>
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<tr>
<td>JTO5-1000W</td>
<td>500-1000</td>
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<td>1.0</td>
<td>-76 - 110 - 130 - 150</td>
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<td>0.05</td>
<td>2.5</td>
<td>-25 - 20</td>
<td>2900</td>
<td>12.0 (20)</td>
</tr>
</tbody>
</table>
Tuning Sensitivity

Surface Mount
Voltage Controlled Oscillator

JTOS-1000W+

Wide Band 500 to 1000 MHz

Features
- Wide frequency range, 500 to 1000 MHz typ.
- 3 dB modulation bandwidth 100 kHz typ.
- Octave, linear tuning
- Low phase noise, -134 dBc/Hz at 1 MHz offset, typ.
- Excellent harmonic suppression, -26 dBc typ.
- Aqueous washable

Applications
- Test instruments-signal generators
- Wideband frequency synthesizers
- Agile communications systems
- CATV distribution and set-top converters
- Cellular up and down converters
- Digital cordless phones

Electrical Specifications

<table>
<thead>
<tr>
<th>FREQUENCY (MHz)</th>
<th>POWER OUTPUT (dBm)</th>
<th>TUNING VOLTAGE (V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>1000</td>
<td>+7.0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PHASE NOISE (dBc/Hz) SSB at offset frequencies: Typ.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 kHz</td>
</tr>
<tr>
<td>-73</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>PULLING pk-pk @ 12 dBc (MHz)</th>
<th>PUSHER (MHz/MV)</th>
<th>TUNING SENSITIVITY (MHz/V)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typ.</td>
<td>Typ.</td>
<td>Typ.</td>
</tr>
<tr>
<td>5.0</td>
<td>1.0</td>
<td>30-40</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>HARMONICS (dBc)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typ.</td>
</tr>
<tr>
<td>-26</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>3 dB MODULATION BANDWIDTH (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Typ.</td>
</tr>
<tr>
<td>0.1</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DC OPERATING POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vcc (Volts)</td>
</tr>
<tr>
<td>12</td>
</tr>
</tbody>
</table>

CASE STYLE: BK377
PRICE: $21.95 ea. QTY (5-49)

RoHS Compliant
The + Suffix identifies RoHS Compliance. See our web site for RoHS Compliance methodologies and qualifications.
Frequency Range

- Change in slope [MHz/V] over tuning voltage range
Why do you care?

- PLL: Tuning sensitivity $K_O$ affects control parameters
- Loop bandwidth $\omega_L$ (may not be critical)
- Stability (critical!)

\[
K_d (\theta_i - \theta_o) \quad \frac{1 + s \tau_Z}{s \tau_I} \quad \frac{K_O}{s} 
\]

$\omega_L \approx \frac{K_d K_O \tau_Z}{\tau_I}$

Fig. 3.5. Phaselock loop as a control system.
Varactor Tuning

\[
C_j = \frac{C_{j0}}{(1 + \frac{V_{TUNE}}{V_{bi}})^m}
\]

\[
f_{osc} = \frac{1}{2\pi\sqrt{LC}}
\]

\[
f_{osc} \approx \frac{1}{2\pi\sqrt{LC_j0}} \left(\frac{V_{TUNE}}{V_{bi}}\right)^{m/2}
\]

\[m = 1/2\]

- Disadvantages of abrupt junction C-V characteristic (m=1/2)
  - Smaller tuning range
  - Inherently nonlinear \( V_{TUNE} - f_{osc} \) characteristic
Hyperabrupt Junction Varactor

\[ C_j = \frac{C_{j0}}{\left(1 + \frac{V_{\text{TUNE}}}{V_{\text{bi}}}ight)^m} \]

\[ f_{\text{osc}} = \frac{1}{2\pi\sqrt{L/C}} \]

\[ f_{\text{osc}} \approx \frac{1}{2\pi\sqrt{L/C_{j0}}} \left(\frac{V_{\text{TUNE}}}{V_{\text{bi}}}ight)^{m/2} \quad m = 1/2 \]

\[ m \to 2 \]

- Hyperabrupt junction C-V characteristic (m ≈ 2)
  + Larger tuning range; more linear \( V_{\text{TUNE}} - f_{\text{osc}} \)
  - Disadvantage: Lower Q in resonator
Phase Noise

Surface Mount
Voltage Controlled Oscillator  JTOS-1000W+

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<th>PHASE NOISE (dBc/Hz)</th>
<th>HARMONICS (dBc)</th>
<th>3 dB MODULATION BANDWIDTH (MHz)</th>
<th>DC OPERATING POWER</th>
</tr>
</thead>
<tbody>
<tr>
<td>500</td>
<td>-10.0</td>
<td>-7.0</td>
<td>-5.0</td>
<td>-73</td>
<td>-94</td>
<td>-114</td>
</tr>
</tbody>
</table>
Phase Noise

- Power spectrum “close in” to carrier
**Phase Noise: RF System**

- Mixers convolve LO spectrum with RF
- Phase noise “blurs” IF spectrum
Phase Noise: Digital System

- Time domain jitter on synthesized output clock
- Decreases timing margin for system using clock
Shape of Phase Noise Spectrum

- LC filters noise into narrow band near fundamental
- High Q resonator preferred to minimize noise
Phase Noise: Intuitive view

- Phase Noise: Sine wave + white noise
- Filter: limit
- Result: 59
Phase Noise: Intuitive view

ADD WIDEBAND NOISE

NARROWBAND FILTER

HARD LIMITER

TIME DOMAIN

FREQUENCY DOMAIN

PHASE NOISE

AMPLITUDE NOISE

f

f

Mini-Circuits®
Phase Noise Description

- Symmetric; look at single sided representation
- Normalized to carrier: dBC
- At different offset frequencies from carrier
- White frequency noise: phase noise with -20dB/decade slope
- Other noise processes change slope; 1/f noise gives -30dB/decade
Phase Noise Specification

Surface Mount Voltage Controlled Oscillator

<table>
<thead>
<tr>
<th>Offset Frequency (kHz)</th>
<th>PHASE NOISE (dBC/Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>-73</td>
</tr>
<tr>
<td>10</td>
<td>-94</td>
</tr>
<tr>
<td>100</td>
<td>-114</td>
</tr>
<tr>
<td>1 MHz</td>
<td>-134</td>
</tr>
</tbody>
</table>

$S_\phi(f) \sim \frac{1}{f^2}$
Sources of Phase Noise

White noise in $V_{\text{TUNE}}$ signal path

Thermal noise: Losses in resonator, series R of varactor

Noise of active devices
Supply / Load Sensitivity

- Ideally tuning voltage is the only way to change output frequency
  - In reality other factors involved
  - Mechanism depends on specifics of circuit
- Power supply dependence: Supply Pushing
- Impedance mismatch at output: Load Pulling
Supply Pushing

- Change in $f_{osc}$ due to change in supply voltage
- Clapp oscillator: supply affects transistor bias condition, internal signal amplitudes
Load Pulling

- Change in $f_{osc}$ due to impedance mismatch at output
- Clapp oscillator; reflection couples through transistor parasitic to LC resonator
Overview

• Functional Block Concept
• Oscillator Review
• Basic Performance Metrics
• Methods of Tuning
• Advanced Performance Metrics
• Conclusion
Summary: VCO Fundamentals

• First order behavior
  – Tuning voltage $V_{TUNE}$ controls output frequency
  – Specify by min/max range of $f_{OSC}$, $V_{TUNE}$

• Performance limitations
  – Linearity of tuning characteristic
  – Spectral purity: phase noise, harmonics
  – Supply, load dependence

• Different VCO architectures trade frequency range, tuning linearity, phase noise performance
Questions?

Thank you to our presenter John McNeill and our sponsor Mini-Circuits