Design Tips of OP Amplifier and TINA Simulation Tool
運算放大器設計小技巧 + TINA教學

Ting Ye
Field Application Engineer
Agenda

• Op Amp in Over Current Protection Circuit
  – Output swing limitation
  – Input ESD steering diodes

• Improve Thermal Performance Op Amp Circuit
  – Power Dissipation Calculation
  – Thermal Impedance and Junction Temperature
  – Consider Protection Response Time, Signal Latency, Spike Signal Rise Time

• Amplifier Major Parameters in Current Sensing Application
  – High Side Current Sensing Circuit Specifications
  – $R_{\text{shunt}}$ Calculation
  – Offset Voltage and Drift
  – Slew Rate and Bandwidth
  – CMRR AC

• TINA Tutorial
Op Amp in Over Current Protection Circuit (OCP)
Op Amp for OCP - Vout_swing Limitation

Reference Design of Output Short-Circuit Protection for TPS61088 10A Boost Converter (PMP9779)

- I’ve got an extra, not used channel of LM324 or TL074.
- Can I use it as the OCP comparator?
• Problem: When set the load current within the normal operating range, the OCP circuit is **false triggered**, Q1 is off and no path for current to flow.

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**Figure 1. Block Diagram of PMP9779**
Problems and Why

A. Root cause:
   Op Amp output swing limitation. Output swing range from -40°C to +85°C with R\text{load} \geq 2k-ohm is VEE + 5V and VCC -5V.

B. Output swing shrinks with load current increase. In Figure 6, with 2k-ohm load at TA 25°C, output swing is +/-11.75V. 0.6k-ohm load shows VOM of +/-10V.

![Figure 1. Block Diagram of PMP9779](image)

![Image of circuit diagram](image)

**6.10 Electrical Characteristics: TL071C, TL072C, TL074C**

- **VCC = ±15 V (unless otherwise noted)**

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS (1) (2)</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td>V\text{in}</td>
<td>V\text{cc} = 0</td>
<td>3</td>
<td>10</td>
<td>13</td>
<td>mV</td>
</tr>
<tr>
<td>+ Temperature</td>
<td>R\text{in} = 50 Ω</td>
<td>18</td>
<td></td>
<td></td>
<td>μV/°C</td>
</tr>
<tr>
<td>V\text{O (2)}</td>
<td>V\text{O} = 0</td>
<td>5</td>
<td>100</td>
<td>10</td>
<td>pA</td>
</tr>
<tr>
<td>I\text{O (2)}</td>
<td>V\text{O} = 0</td>
<td>65</td>
<td>200</td>
<td>7</td>
<td>nA</td>
</tr>
<tr>
<td>Common-mode</td>
<td>R\text{L} = 10 kΩ</td>
<td>±11</td>
<td>12</td>
<td>±13.5</td>
<td>V</td>
</tr>
<tr>
<td>Maximum peak output</td>
<td>R\text{L} = 20 kΩ</td>
<td>±12</td>
<td></td>
<td>±10</td>
<td>V</td>
</tr>
<tr>
<td>Voltage swing</td>
<td>R\text{L} = 2 kΩ</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Graph of VOM vs Load Resistance](image)

*Figure 6. Maximum Peak Output Voltage vs Load Resistance*
TI Precision Labs – Op Amps: Input and Output Limitations

Op Amp for OCP– Input Clamping Diode

- Problems: Op Amp IC has high failure rate and is damaged after turning on power for a while.

- Root cause: Input clamping diode is conducting and could be damaged without external current limiting resistor.
TI Precision Labs – Op Amps: Electrical Overstress (EOS)

Improve Thermal Performance of Wide Voltage/ Dual Supply Op Amp
+/-15V Op Amp Gain of 10 Circuit
Power Dissipation Calculation

Non-inverting amplifier power dissipation for specific $V_{OUT}$

\[ I_{RL} = \frac{V_{OUT}}{R_L} \quad (134) \] \text{Current through load resistor}

\[ I_{FB} = \frac{V_{OUT}}{R_c + R_g} \quad (135) \] \text{Current through feedback network}

\[ P_L = \left( |I_{RL}| + |I_{FB}| \right) \left( |V_{sup}| - |V_{OUT}| \right) \quad (136) \] \text{Power dissipated inside op amp from load current.}

\[ V_{sup} = V_{pos} \text{ if the amplifier is sourcing.} \]
\[ V_{sup} = V_{neg} \text{ if the amplifier is sinking.} \]

\[ P_Q = (V_{pos} - V_{neg}) \cdot I_Q \quad (137) \] \text{Total power from quiescent current}

\[ P_T = P_L + P_Q \quad (138) \] \text{Total power dissipated inside the op amp}

Non-inverting amplifier maximum power dissipation
Junction Temperature Calculation

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS (1) (2)</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
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</thead>
<tbody>
<tr>
<td>lcc (Supply current)</td>
<td>V_o = 0; no load</td>
<td>1.4</td>
<td>2.5</td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td></td>
<td>T_a = 25°C</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

SPICE-based Simulator
http://www.ti.com/tool/TINA-TI
Reduce Heat, Reduce Power, Decrease Output Current
Reduce Heat, Reduce Power, Decrease Current Consumption

**Electrical Characteristics (continued)**

For $V_0 = (V^+) - (V^-) = 4.5$ V to 40 V ($\pm2.25$ V to $\pm20$ V) at $T_A = 25^\circ$C, $R_L = 10$ kΩ connected to $V_S / 2$, $V_{CM} = V_S / 2$, and $V_{OUT} = V_S / 2$, unless otherwise noted.

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>TEST CONDITIONS</th>
<th>MIN</th>
<th>TYP</th>
<th>MAX</th>
<th>UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>OUTPUT</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Voltage output swing from rail</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Positive rail headroom</td>
<td>$V_S = 40$ V, $R_L = $ no load</td>
<td>3</td>
<td></td>
<td></td>
<td>mV</td>
</tr>
<tr>
<td></td>
<td>$V_S = 40$ V, $R_L = 10$ kΩ</td>
<td>50</td>
<td>75</td>
<td></td>
<td></td>
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<tr>
<td></td>
<td>$V_S = 40$ V, $R_L = 2$ kΩ</td>
<td>250</td>
<td>350</td>
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<td></td>
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<tr>
<td>Negative rail headroom</td>
<td>$V_S = 4.5$ V, $R_L = $ no load</td>
<td>1</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_S = 4.5$ V, $R_L = 10$ kΩ</td>
<td>20</td>
<td>30</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>$V_S = 4.5$ V, $R_L = 2$ kΩ</td>
<td>40</td>
<td>75</td>
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<td></td>
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<tr>
<td>$I_{SC}$</td>
<td>Short-circuit current</td>
<td>±60</td>
<td></td>
<td></td>
<td>mA</td>
</tr>
<tr>
<td>$C_{LOAD}$</td>
<td>Capacitive load drive</td>
<td>See Typical Characteristics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$Z_D$</td>
<td>Open-loop output impedance</td>
<td>$f = 1$ MHz, $I_D = 0$ A</td>
<td>300</td>
<td></td>
<td>Ω</td>
</tr>
<tr>
<td><strong>POWER SUPPLY</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>$I_Q$</td>
<td>Quiescent current per amplifier</td>
<td>$I_Q = 0$ A</td>
<td>150</td>
<td>175</td>
<td>μA</td>
</tr>
</tbody>
</table>

Van der Waals
## What else needs to be considered?
**SR, BW, Spike Signal Capture**

<table>
<thead>
<tr>
<th>TL07x Circuit</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SR</strong></td>
<td>1.256 V/us</td>
</tr>
<tr>
<td><strong>F</strong></td>
<td>1.00E+04 Hz</td>
</tr>
<tr>
<td><strong>Vout</strong></td>
<td>20 V</td>
</tr>
<tr>
<td><strong>TL07x 13V/us</strong></td>
<td></td>
</tr>
<tr>
<td><strong>TLV930x 3V/us</strong></td>
<td></td>
</tr>
<tr>
<td><strong>Topology</strong></td>
<td>Non-inverting</td>
</tr>
<tr>
<td><strong>R1</strong></td>
<td>1.00E+04 ohm</td>
</tr>
<tr>
<td><strong>R2</strong></td>
<td>9.00E+04 ohm</td>
</tr>
<tr>
<td><strong>Noise Gain</strong></td>
<td>10</td>
</tr>
<tr>
<td><strong>TL07x Unity Gain Bandwidth</strong></td>
<td>3.00E+06 Hz</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>0.3 MHz</td>
</tr>
<tr>
<td><strong>0.35 = TR x BW</strong></td>
<td></td>
</tr>
<tr>
<td><strong>BW</strong></td>
<td>0.3 MHz</td>
</tr>
<tr>
<td><strong>Signal Rise Time (able to capture)</strong></td>
<td>1.16666667 us</td>
</tr>
<tr>
<td><strong>TLV930x Unity Gain Bandwidth</strong></td>
<td>1.00E+06 Hz</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>0.1 MHz</td>
</tr>
<tr>
<td><strong>Signal Rise Time (able to capture)</strong></td>
<td>3.5 us</td>
</tr>
</tbody>
</table>
Op Amp Selection Tips

• Considering circuit function and important specs of it:
  • Process sine wave/ care synchronization => Small signal latency => GBW
  • Use as OCP/ OVP protection function => Large signal response time => Slew Rate
  • Light load current monitoring/precision current sensing

Accuracy: Offset, drift, PSRR, CMRR, noise, potential external noise etc.
  – AC-coupling cap may be required; differential cap may degrade performance since forming low impedance path for interference
  – Surrounding circuits are noisy => EMIRR may help to suppress high frequency noise hence improving accuracy
  – Power sources are from DC-DC with switching noise => High PSRR and wide bandwidth may be needed
High Side Current Sensing Considerations
High Side and Low Side Current Sensing

High side current sensing:
- HV op amp, potential higher cost
- Able to detect load short circuit/leakage

Low side current sensing:
- LV op amp, potential lower cost
- Ground Noise, Inaccuracy at light load
- Not able to detect load short circuit/leakage

High Side Current Sensing Example
High Side Current Sensing Circuit Specifications

Design Goals

<table>
<thead>
<tr>
<th>Input</th>
<th>Overcurrent Conditions</th>
<th>Output</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{\text{load Min}}$</td>
<td>$I_{\text{load Max}}$</td>
<td>$I_{\text{OC_TH}}$</td>
<td>$V_{\text{out_OC}}$</td>
</tr>
<tr>
<td>1.5A</td>
<td>40A</td>
<td>35A</td>
<td>2.8V</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$I_{\text{Release_TH}}$</td>
<td>$V_{\text{out_release}}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>32A</td>
<td>2.61V</td>
</tr>
</tbody>
</table>

Light Load Accuracy @1.5A +/-10%

OCP response time 10us

Input signal max frequency sine 10kHz

Analog Engineer's Circuit: Amplifiers
High Side Current Sensing and OCP
INA381 Current Shut Monitor Overview

1 Features
- Common-Mode Input Range: −0.2 V to 26 V
- High Accuracy Amplifier:
  - Offset Voltage, \( V_{CM} \) = 12 V: 500 \( \mu \)V (Maximum)
  - Offset Voltage, \( V_{CM} \) = 0 V: 150 \( \mu \)V (Maximum)
  - Offset Voltage Drift: 1 \( \mu \)V/°C (Maximum)
  - Gain Error: 1% (Maximum)
  - Gain Error Drift: 20 ppm/°C (Maximum)
- Available Amplifier Gains:
  - INA381A1: 20 V/V
  - INA381A2: 50 V/V
  - INA381A3: 100 V/V
  - INA381A4: 200 V/V
- Comparator Specifications:
  - Hysteresis: 50 mV
  - Response Time: 500 ns
  - Alert Threshold Set Through External Reference Voltage
- Open-Drain Comparator Output With Latching Mode
- Package: WSON-8 (2 mm × 2 mm)

訊號經過放大器後，SNR增加，再連接到比較器輸入。

运算放大器 + 比较器
Rshunt Calculation: Highest SNR

\[ V_{out\_max} = I_{max} \times R_{shunt} \times \text{Gain} \]

\[ R_{shunt} = \frac{V_{out\_max}}{\text{Gain} \times I_{max}} = \frac{V_S - 0.02V}{\text{Gain} \times I_{max}} = \frac{3.3V - 0.02V}{20V/V \times 40A} = 0.0041\Omega \]

\[ R_{standard\_shunt} = 4m\Omega \text{ (standard 1\% value)} \]

Considering power loss:

12V x 40A = 480W
480W x 0.1\% = 0.48W
0.48W = I^2R
R = 0.48/1600 = 0.3m-ohm
System Specs and INA381 Parameter Offset Voltage and Drift

Light Load Accuracy @1.5A +/-10%:

\[ \text{Vsense} = I_{\text{min}} \times R_{\text{sense}} \]
\[ \text{Vsense} = 1.5A \times 4\text{m-ohm} \]
\[ \text{Vsense} = 6\text{mV} \]
Allowable Error = 6m-ohm x +/-10% = +/-600uV

Drift calculation
Max ambient temperature 45C
\[ \text{Vos_Drift} = 1\mu V/\text{C} \times (\text{delta T}) \]
\[ = 1\mu V/\text{C} \times (45 - 25) \]
\[ = 20\mu V \]
System Specs and INA381 Parameter
Slew Rate and Bandwidth

<table>
<thead>
<tr>
<th>Input</th>
<th>Overcurrent Conditions</th>
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</tr>
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<tbody>
<tr>
<td>(I_{load\ Min})</td>
<td>(I_{load\ Max})</td>
<td>(I_{OC\ TH})</td>
<td>(I_{Release\ TH})</td>
</tr>
<tr>
<td>1.5A</td>
<td>40A</td>
<td>35A</td>
<td>32A</td>
</tr>
</tbody>
</table>

Slew Rate Requirement:

\[
V_{out\_35A} = I_{OC\_TH} \times R_{\text{standard shunt}} \times \text{gain}
\]

\[
= 35A \times 4\Omega \times 20V/V = 2.8V
\]

OCP response time
10us

Slew Rate

\[
= \frac{V_{out\_max}}{\text{time}}
\]

\[
= \frac{2.8V}{10\mu s} = 0.28V/\mu s
\]

Fin max
10kHz

---

Analog Engineer’s Circuit: Amplifiers
High Side Current Sensing and OCP

25
High Side Current Sensing Circuit Specifications

Design Goals

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<td>$I_{\text{Release_TH}}$</td>
</tr>
<tr>
<td>1.5A</td>
<td>40A</td>
<td>35A</td>
<td>32A</td>
</tr>
</tbody>
</table>

- **Light Load Accuracy**
  - @1.5A +/-10%
  - Allowable Error:
    - $4\text{m-ohm} \times 1.5\text{A} \times +/-10\% = +/-600\mu\text{V}$
    - $0.25\text{m-ohm} \times 1.5\text{A} \times +/-10\% = +/-37.5\mu\text{V}$

- **OCP response time**
  - 10us

- **Input Signal max frequency sine**
  - 10kHz
  - Slew Rate (SR)
    - Full power Bandwidth
    - $SR = 2 \times \pi \times F \times V_{pp}$
    - $SR = 2 \times 3.14 \times 10\text{kHz} \times 2.8$
    - $SR = 0.176\text{V/\mu s}$

- **Slew Rate**
  - $SR = \frac{\sqrt{2} \times V_{pp}}{10\text{us}}$
  - $SR = \frac{2.8}{10\text{us}} = 0.28\text{V/\mu s}$
Current Sensing Error Sources

Op Amp Input Offset Voltage (Vos) Correlated:
- Vos at Room Temperature 25°C
- Vos Drift
- Vos_CMRR_DC
- Vos_CMRR_AC
- Noise
  - Extrinsic Noise
  - Intrinsic Noise

Shunt Resistor Tolerance
Trace Resistance
VCM 12V Ripple and FFT

12V supply AC coupling mode
System Specs and INA381 Parameter

CMRR AC

- A1 CMRR is ~55dB@1MHz at 25-C.
- It has 1.78mV/V attenuation capability to the common mode noise.
- VOS_CMRR_AC = 13mV x 1.78mV = 23.14μV
To see more circuit detail analysis:

**Transimpedance amplifier circuit**

### Design Goals

<table>
<thead>
<tr>
<th>Input</th>
<th>Output</th>
<th>BW</th>
<th>Supply</th>
</tr>
</thead>
<tbody>
<tr>
<td>$I_{in}$</td>
<td>$I_{out}$</td>
<td>$V_{in}$</td>
<td>$V_{out}$</td>
</tr>
<tr>
<td>0A</td>
<td>50μA</td>
<td>0V</td>
<td>5V</td>
</tr>
</tbody>
</table>

### Design Description

The transimpedance op amp circuit configuration converts an input current source into an output voltage. The current to voltage gain is based on the feedback resistance. The circuit is able to maintain a constant voltage bias across the input source as the input current changes which benefits many sensors.

### Design Notes

1. Use a JFET or CMOS input op amp with low bias current to reduce DC errors.
2. A bias voltage can be added to the non-inverting input to set the output voltage for 0-A input currents.
3. Operate within the linear output voltage swing (see $A_v$ specification) to minimize non-linearity errors.
類比工程師 電路設計指導手冊

Introduction to TINA-TI Simulations
OPA189 Circuit
TINA-TI Editor/Tool Bar

- 地
- DC电源
- Function Gen
- 點選物件
- 连線
- Single-ended probe (V)
- Differential-probe (V)
- Current probe (I)
DC, Transient, and AC Simulation
Performing Analysis with TINA-TI

**Case Study:** OPA189 Circuit from TINA Reference Design

- Running DC Analysis
- Running AC Analysis
- Running Transient Analysis
Simulate OPA189 with a 1 uF load

OPA189 TINA-TI Reference Design based on Green-Williams-Lis Pspice simulation model
TINA Model 模擬參數

14MHz, MUX-friendly, low-noise, zero-drift, RRO, CMOS precision operational amplifier

OPA189(ACTIVE)

Description & parametrics | Technical documents | Design & development | Order now | Quality & packaging | Support

Models | Design kits & evaluation modules | TI Designs & reference designs | Software | Development tools | TI design

Models (3)

<table>
<thead>
<tr>
<th>Title</th>
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<td>OPA189 PSpice Model (Rev. C)</td>
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<td>ZIP</td>
<td>27 Feb 2019</td>
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<tr>
<td>OPA189 TINA-TI Reference Design (Rev. C)</td>
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<td>27 Feb 2019</td>
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</table>

TINA-TI Reference Design

- OPA189 Precision, Lowest-Noise 36-V, Zero-Drift, 14-MHz MUX-Friendly, Rail-to-Rail Output, Operational Amplifiers datasheet (Rev. E)

** Released by: Online Design Tools, Texas Instruments Inc.**
- Part: OPA189
- Date: 04FEB2019
- Model Type: Generic (suitable for all analysis types)
- EVM Order Number: N/A
- EVM Users Guide: N/A
- Datasheet: SBO5830D DECEMBER 2017/REVISED DECEMBER 2018
- Created with Green-Williams-Liao Op Amp Macro-model Architecture

- Model Version: Final 1.0

- OPEN-LOOP GAIN AND PHASE VS. FREQUENCY WITH RL, CL EFFECTS (A01)
- UNITY GAIN BANDWIDTH (GBW)
- INPUT COMMON-MODE REJECTION RATIO VS. FREQUENCY (CMRR)
- POWER SUPPLY REJECTION RATIO VS. FREQUENCY (PSRR)
- DIFFERENTIAL INPUT IMPEDANCE (Zid)
- COMMON-MODE INPUT IMPEDANCE (Zic)
- OPEN-LOOP OUTPUT IMPEDANCE VS. FREQUENCY (Zo)
- OUTPUT CURRENT THROUGH THE SUPPLY (Iout)
- INPUT VOLTAGE NOISE DENSITY VS. FREQUENCY (en)
- INPUT CURRENT NOISE DENSITY VS. FREQUENCY (in)
- OUTPUT VOLTAGE SWING vs. OUTPUT CURRENT (Vo)
- SHORT-CIRCUIT OUTPUT CURRENT (Isc)
- QUIESCENT CURRENT (Iq)
- SETTLING TIME VS. CAPACITIVE LOAD (ts)
- Slew Rate (SR)
- SMALL SIGNAL OVERTONE VS. CAPACITIVE LOAD
- LARGE SIGNAL RESPONSE
- OVERLOAD RECOVERY TIME (t0)
- INPUT BIAS CURRENT (Ib)
- INPUT OFFSET CURRENT (Ios)
- INPUT OFFSET VOLTAGE (Vos)
- INPUT OFFSET VOLTAGE VS. TEMPERATURE (Vos Drift)
- INPUT COMMON-MODE VOLTAGE RANGE (Vcm)
- INPUT OFFSET VOLTAGE VS. INPUT COMMON-MODE VOLTAGE (Vos vs. Vcm)
- INPUT/OUTPUT ESD CELLS (ESDin, ESDout)
建議電路完成後先Run DC節點分析。
DC Nodal Analysis
Transient Analysis
AC Analysis

With 1uF cap load

W/o 1uF cap load
Parameter-stepping
Parameter-stepping – Transient Analysis
Parameter-stepping – AC Analysis
TINA Tips
Supply Noise and Decoupling Cap

PSRR at high frequency:
assume 10mVpp ripple:
40dB => 10mV/V => 0.1mV (Vos_PSRR)
20dB => 100mV/V = 1mV
10dB => 316mV/V => 3.16mV
Put Real Capacitor in TINA

How to Choose a TPS7B67xx-Q1 Output Capacitor

Input and Output Capacitor Selection

Figure 4. Capacitor Impedance Characteristics

\[ f = \frac{1}{2 \pi \sqrt{LC}} \]
\[ L = \frac{1}{\sqrt{2 \pi f C}} \]

\[
\begin{align*}
\text{Frequency (Hz)} & = 4.60 \times 10^5 \\
C & = 4.70 \times 10^{-5} \text{ F} \\
L & = 2.549571 \text{ nH}
\end{align*}
\]
Function Generator

Time 1ms, voltage 1V
Error – Irregular Circuit

This error message means that TINA could not solve the circuit equations, probably due to an irregular (contradictory) feature of the circuit.

A simple example of an irregular circuit is a circuit containing a shorted voltage source or an open current source. These circuits have a topology that contradicts the definition of the parts, resulting in unsolvable equations (system of linear equations with a zero determinant).
Error – Convergence Problem
TINA-TI Training Videos
Right-Click the desired line and select *Open Hyperlink.*

- Introduction to TINA-TI
- Using the TINA-TI simulator – ERC and Analysis types
- Configuring Sources in TINA-TI simulator
- TINA-TI Waveform Viewer, Part 1
- TINA-TI Waveform Viewer, Part 2
- Sweeping parameters in TINA-TI simulator
- Noise, Fourier analysis and Signal Chain content in TINA-TI
- Power product simulation in TINA-TI simulator
- Importing SPICE models into TINA-TI
- Tips and Tricks for TINA-TI simulator
- How to use the Controlled Source Wizard in the TINA-TI simulator
- Using WEBENCH® simulation export to create files for TINA-TI simulator
- https://training.ti.com/tina-ti-video-training-series
The document contains a section titled "1.10 Tips and Tricks for TINA-TI(TM) simulator". It features a screenshot of the TINA-TI simulator interface, with a section on TPS54331 Transient Model (TPS54331EVM-232). The notes include:

- To Run, select Analysis -> Transient
- Plot for Vin=15V and Iout=3A is shown.
- Zoomed plot of steady state for above conditions also shown.
- The model has been encrypted.
Summary

• Op Amp in Over Current Protection Circuit
  – Output swing limitation
  – Input ESD steering diodes

• Improve Thermal Performance Op Amp Circuit
  – Power Dissipation Calculation
  – Thermal Impedance and Junction Temperature
  – Consider Protection Response Time, Signal Latency, Spike Signal Rise Time

• Amplifier Major Parameters in Current Sensing Application
  – High Side Current Sensing Circuit Specifications
  – $R_{shunt}$ Calculation
  – Offset Voltage and Drift
  – Slew Rate and Bandwidth
  – CMRR AC

• TINA Tutorial
Thank you.