Impedance measurement solution
抗阻測量解決方案

August 2021
Andrew Wang
Agenda

• LCR Meter Front-End - TIDA-060029:
  – LCR Meter Analog Front-End Reference Design

• Discrete Impedance Spectroscopy Design

• Resistive Impedance measurement
High Speed Amplifiers for LCR meter

**Key OPAMP Care Abouts / Key Parts**

Used in a composite loop to measure impedance of the DUT using the ABB architecture.

- **FET-Input amplifier for current-to-voltage conversion and DUT voltage measurements**
  - OPA810 offers extremely high input impedance at low power consumption

- **High current output drive for driving low impedance DUT**

- **Fully protected for sturdy design**
  - The BUF634A is fully protected by an internal current limit in its output stage and by thermal shutdown, making the device rugged and enabling the customer to use without any other discrete protection circuitry.

**Key End Equipments**

- LCR Meter
- Impedance Analyzers
- Electrochemical analysis
- Semiconductor Manufacturing

**Applications: Output Driver in a Composite Loop**

**Useful Reference Designs and Collateral**

- **SBOA496**: Application brief- Optimizing LCR Meter and Impedance Analyzer Front-End Design for Accurate Impedance Measurements

- **TIDA-060029**: LCR Meter Analog Front-End Reference Design
LCR Meter Front-End

[Graphical diagram of LCR Meter Front-End]
What is an Impedance Analyzer/LCR Meter?

• LCR meters and Impedance Analyzers, as the name suggests, are used to measure unknown values of passive components – Inductance, Capacitance or Resistance in lab settings

• Both are fundamentally similar, except that:
  • Impedance Analyzer = LCR Meter + Multi-Frequency Measurement
Design Challenge/Problem statement

- Circuit stability across types and values (from 1Ω to 10MΩ) of unknown DUT impedance, typically a problem with capacitive DUTs.
- High-frequency (up to 1MHz) impedance measurement.
- Single-point DUT Voltage/Current measurement.
- Ability to measure small value impedance. (even 1Ω)
- ADC based digitization and impedance measurement.
TIDA-060029 Reference Design

- Inherently Stable Signal Chain
- No Tuning Requirements
- Auto-Balance Technique provides good accuracy over wide range of impedance

Table 1-2. Key System Specifications

<table>
<thead>
<tr>
<th>PARAMETER</th>
<th>SPECIFICATIONS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resistance Range</td>
<td>1 Ω to 10 MΩ</td>
</tr>
<tr>
<td>Capacitance Range</td>
<td>1.76 pF to 1.59 mF</td>
</tr>
<tr>
<td>Inductance Range</td>
<td>2.59 μH to 1432 H</td>
</tr>
<tr>
<td>Frequencies of Operation</td>
<td>100 Hz, 1 kHz, 10 kHz, 100 kHz</td>
</tr>
<tr>
<td>R_G – R_F Settings</td>
<td>100Ω, 5 kΩ, 100 kΩ</td>
</tr>
<tr>
<td>Best % Accuracy</td>
<td>0.1%</td>
</tr>
<tr>
<td>Power Supply</td>
<td>+/- 12 V</td>
</tr>
</tbody>
</table>

https://www.ti.com/tool/TIDA-060029
Principle of Operation:

• Measure Voltage & Current through an unknown impedance, to give:

\[ Z \angle \theta = \frac{V_X \angle \theta_V}{I_X \angle \theta_I} \]

– Where \( V_X \angle \theta_V \) and \( I_X \angle \theta_I \) are the DUT voltage and current, respectively.

• Auto-Balancing Method of impedance measurement:

\[ \frac{V_X}{Z_X} = I_X = \frac{V_o}{R_F} \]
\[ \frac{V_o}{V_X} = \frac{R_F}{Z_X} \]
Foundation:

Inductive and Capacitive Reactance

\[ X_L = 2\pi fL = \omega L \]
\[ \omega: \text{Angular frequency (}= 2\pi f) \]

\[ X_C = \frac{1}{2\pi fC} = \frac{1}{\omega C} \]

(a) Inductive vector on impedance plane

(b) Capacitive vector on impedance plane

\[ Q = \text{quality factor} = \frac{X_L}{R} = \frac{-X_C}{R} = \tan \theta \]
\[ D = \text{dissipation factor} = \frac{1}{Q} = \tan \delta \]

Reference:
http://www.pinsyun.com.tw/
Foundation:

Capacitor:
I leads V by 90°

Inductor:
I lags V by 90°
Foundation:

X versus Test Signal Frequency

Reference:
http://www.pinsyun.com.tw/
What Differentiates this Subsystem Solution?

• Auto balancing impedance measurement systems deliver high accuracy over a wide measurement range without any turning requirements
  – Measures wide range of components (L, C, R) with impedance values ranging from 1 Ω to 10 MΩ
  – Tested at 100 Hz, 1 kHz, 10 kHz, 100 kHz
  – Impedance accuracy of 0.1 %

• Inherent Stability in the signal chain

• Low cost, small form factor solution with high accuracy.
## Impedance Measurement Methods

<table>
<thead>
<tr>
<th>METHOD</th>
<th>ADVANTAGES</th>
<th>DISADVANTAGES</th>
<th>APPLICABLE FREQUENCY RANGE</th>
<th>COMMON APPLICATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bridge method</td>
<td>• High Accuracy</td>
<td>• Manual balancing needed</td>
<td>DC to 300 MHz</td>
<td>Standard Lab</td>
</tr>
<tr>
<td></td>
<td>• Wide frequency range with different types of bridges</td>
<td>• Narrow frequency coverage with single bridge</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Resonant method</td>
<td>• Good Q measurement accuracy up to high Q</td>
<td>• Tuning required</td>
<td>10 kHz to 70 MHz</td>
<td>High Q device measurement</td>
</tr>
<tr>
<td></td>
<td>• Wide frequency coverage</td>
<td>• Low impedance measurement accuracy</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>• Good accuracy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Network analysis method</td>
<td>• Wide frequency coverage</td>
<td>• Narrow impedance measurement range</td>
<td>5 Hz to above</td>
<td>RF component measurement</td>
</tr>
<tr>
<td></td>
<td>• Good accuracy</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Auto balancing method</td>
<td>• Good accuracy over wide range of impedances</td>
<td>• High frequency ranges are not available</td>
<td>20 Hz to 120 MHz</td>
<td>Generic component measurement</td>
</tr>
<tr>
<td>(Method used in this design)</td>
<td>• Grounded device measurement</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Impedance Measurement Methods

Frequency vs. Measurement Techniques

- Auto Balancing Bridge
- Resonant
- I-V
- RF I-V
- Network Analysis

Frequency (Hz)
# Measurement Range

<table>
<thead>
<tr>
<th>PARAMETERS</th>
<th>( R_G = R_F ) SETTING</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100 ( \Omega )</td>
</tr>
<tr>
<td>Frequency (Hz)</td>
<td>Component</td>
</tr>
<tr>
<td>100</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
<tr>
<td>1 k</td>
<td>R</td>
</tr>
<tr>
<td></td>
<td>L</td>
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<td></td>
<td>C</td>
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<tr>
<td>10 k</td>
<td>R</td>
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<td>C</td>
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<td>100 k</td>
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<tr>
<td></td>
<td>L</td>
</tr>
<tr>
<td></td>
<td>C</td>
</tr>
</tbody>
</table>
LC to Z table

Reference:
Chroma LCR 11025 manual
Impedance Analyzers & LCR Meters
Analog Front-End using Amplifiers

Design Challenges Solved!

- Circuit stability across types and values (from 1 Ω to 10MΩ) of unknown DUT impedance, typically a problem with capacitive DUTs
  - Multi-feedback TIA compensation using high-speed VFAs
  - High-frequency (upto 1MHz) impedance measurement
- Small ~pA bias current FET-input amplifier used as TIA for DUT current-measurement
- Single-point DUT Voltage/Current measurement
  - Large Aol of high-speed amplifiers ensures virtual ground at inverting input of TIA
  - Ability to measure small value impedance (even 1 Ω)
- High-lout (upto 250mA) buffer easily drives small-impedance DUTs and multi-feedback transimpedance resistors
- ADC based digitization and impedance measurement
  - High-speed FDAs available to drive SAR ADC Inputs!

Key Devices for easy LCR meter design:

- **OPA810**: 70MHz, 27V, low-power, RRIO FET-input amplifier used as voltage buffer and TIA
- **BUF634A**: 210MHz, 250mA output, unity-gain buffer for large I_{DUT} drive
- **THS4561**: Low-power, 60 MHz, 12V, Single-Ended/Fully-Differential SAR ADC Input Driver
Optimizing Accuracy on LCR Meter Front-End

1. Using multiple feedback resistor paths
   - Single value for $R_F$ is not enough to provide wide range of measurement
   - Series switches, for both $R_F$ & $R_G$, will allow for multiple measurement ranges

2. Adding series resistor $R_G$ increases systems phase stability
   - Series resistor introduces pole to cancel out zero in the circuit

3. Using High Z input amplifiers for large value measurements
   - Input amplifiers with ~pA range bias currents
Measuring Without Node A2

- Front-End can be configured to work with Single-ended ADCs.
- Inverting node of A2 is not measured due to virtual ground concept.
- In reality small voltage will appear at the inverting node.
  - Voltage inversely proportional to AOL of A2.
- The higher the AOL of the amp, the smaller the error.
Measuring With Node A2

- Nullifies error introduced by voltage at inverting node of A2.
- Configuration requires differential ADC for measurements.
- Can allow for higher accuracy, but with high enough AOL from A2 the accuracy can be similar enough.
Phase Stability of Measurement Circuit

• Typical measurement circuit and the corresponding Bode plot
• Zero frequency \( f_Z \) depends on unknown capacitance \( C_X \)
• Loop gain has rate of closure of 40 dB/dec
Phase Stability of TIDA-060029 Circuit

- Presence of series resistor ($R_G$) introduces pole
- Pole cancels out the zero, restoring phase stability
- Loop gain rate of closure 20 dB/dec
Large Z value measurements

• High accuracy measurements should be buffered with high Z input amplifiers. (Shown in figure)
• If open loop gain (AOL) is large enough, amplifier measuring inverting node can be removed.
• General rule-of-thumb is to ensure A1 has >60 dB AOL at the highest frequency of interest for high accuracy measurements.
Hero Devices for TIDA-060029

• **OPA810/8210 (single/dual)**
  – 70MHz, 27V, low-power, RRIO FET-Input amplifier used as *voltage buffer and TIA*
  – Low input bias current of 2 pA.
    • Great for high impedance measurements.
  – Open loop gain of 120 dB and GBW of 70 MHz.
    • High AOL reduces error in measurements.
  – High voltage supply range ±13.5 V.
    • High voltage operation provides optimal distortion performance.

• **BUF634A**
  – 210MHz, 250mA output, unity-gain buffer *for large* \( I_{OUT} \) *drive.*
  – High output current capability up to 250 mA.
Impedance Measurement Procedure

• One-time calibration procedure that consists of 4 different calibration measurements. Done for all frequencies of operation (100Hz, 1kHz, 10kHz, and 100kHz)

• Purpose is to fine calibrated values of $R_F$ for all resistor settings at each frequency of operation.

1. Impedance Cal
2. Short Cal
3. 100k Setting Cal
4. Open Cal
Impedance Cal

• Only for 100 Ω and 5 kΩ settings.
• A known 500 Ω ($R_{\text{CAL}}$) is used as $Z_X$.
• Measure the exact value of $R_F$ using the equation shown.
  – $V_{\text{IN}} = V_X$ as shown in the figure.
• 500 Ω is used for best calibration accuracy.
• The accuracy of $R_{\text{CAL}}$ will affect the calibration accuracy.
• The calibrated values below are now identified:
  – $R_F = 500 \, \Omega$
  – $R_F = 5 \, \text{k}\Omega$

$$V_O = \left(-\frac{R_F}{500}\right) \times V_{\text{IN}}$$
Short Cal

- $Z_X$ is shorted and the ratio between $V_O$ and $V_{IN}$ is measured.
- $V_{IN}$ is the voltage across $R_G + Z_X$.
- Only needed to calibrate $R_F = R_G = 100k$
- Ratio is classified as $G_{CAL}$

$$G_{CAL} = \frac{V_O}{V_{IN}}$$
100k Setting Cal

- Set $R_G = 100 \, \text{k}\Omega$ and short ZX. $R_F$ is the calibrated value of 5 kΩ from previous step.
- Measuring the Gain, $G_1$, the calibrated of $R_G = 100 \, \text{k}\Omega$ can now be found.
- Once the calibrated value of $R_G = 100 \, \text{k}\Omega$ is found, the \textit{calibrated value of $R_F = 100 \, \text{k}\Omega$} can now be identified using $G_{\text{CAL}}$ from “Short Cal”.
- All calibrated values of $R_F$ have been obtained.

\[
G_1 = -\frac{R_F}{R_G}
\]
Open Cal

• \( Z_X \) is kept open (\( Z_{\text{OPEN}} \))

• \( G_{\text{OPEN}} \) is given by:

\[
G_{\text{OPEN}} = - \frac{R_F}{Z_{\text{OPEN}}}
\]

• Significance of this calibration is mainly for higher frequencies when the parasitic capacitance in parallel with \( Z_X \) is large enough to affect the measurement significantly.

\[
Z_X = Z_0 \ || \ Z_X' \\
Z_X' = \frac{Z_0 - Z_X}{Z_0 \times Z_X}
\]

\( Z_x \): Effective impedance formed by the parallel combination of an actual unknown impedance
\( Z_0 \): Open circuit Impedance)
\( Z_x' \): Actual value of the unknown impedance
Data Acquisition and Processing

\[ \omega_r = \omega_L \]

Low Pass Filter

\[ \frac{1}{2} V_{\text{sig}} \cos(\theta_{\text{sig}} - \theta_{\text{ref}}) \]

DC Signal!

Reference:
Optimizing LCR Meter Appnote

- Optimizing LCR Meter and Impedance Analyzer Front-End Design for Accurate Impedance Measurements

Introduction
LCR meters and impedance analyzers are used to measure unknown values of passive components like resistors, capacitors, inductors, or a combination of these elements. These lab equipment are similar, except that an impedance analyzer allows measurements at different test frequencies. The auto-balancing (ABB) method, compared to the other architectures, offers good measurement accuracy over a wide range of values of impedance, and is discussed in this technical report.

Auto-Balancing Method
Figure 1 shows a representative schematic of an analog front-end using the ABB method. Z_{OUT} is the unknown impedance (device under test or DUT) and R_{f} is a known feedback resistance in this circuit. A known voltage V_{IN} is forced at input to the signal chain. For a voltage V_{OUT} across Z_{OUT} and a current I_{OUT} flowing through it,

\[ Z_{OUT} \cdot I_{OUT} = V_{IN} \cdot R_{f} \]

(1)

Amplifier A1 is used as an inverting amplifier, whose output voltage is given as,

\[ V_{O} = -\frac{V_{IN} \cdot R_{f}}{R} \]

(2)

Figure 1. Representative Schematic of an LCR Meter Analog Front-End Using ABB Method

Design Challenges
A few things need careful consideration when designing an LCR meter analog front-end circuit using the ABB method:

1. A single value of R_{f} will not suffice for measuring a wide range of values of Z_{OUT}. To increase the measurement range and sensitivity of the LCR meter multiple feedback resistors (R_{f} = 1.3) are switched into the circuit through series switches (SW1, SW2), shown in Figure 2.

2. A large value of R_{f} forms a zero in the noise-gain transfer function causing 40 dB/decade roll-off and potential instability. Use of a capacitor C_{S} in parallel with the large R_{f}, shown in Figure 1, introduces a pole to cancel this zero and restores phase margin; but it is difficult to find a single value of C_{S} for stability with all values of capacitive Z_{OUT}. This problem is solved using series resistors.
Comparison to Keysight E4980A LCR meter

- For testing, an input of $3.6 \text{ V}_{\text{PP}}$ was used and results were measured with a board utilizing the THS4551 and ADS9224R.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>RG = RF Setting</th>
<th>Component</th>
<th>$100 \Omega$ (Error(%))</th>
<th>$5 \Omega$ (Error(%))</th>
<th>$100 \Omega$ (Error(%))</th>
</tr>
</thead>
<tbody>
<tr>
<td>frequency</td>
<td></td>
<td></td>
<td>1 Ω – 900 Ω</td>
<td>0.74</td>
<td>0.11</td>
</tr>
<tr>
<td>100</td>
<td>R</td>
<td></td>
<td>1.99 mH – 2.38 H</td>
<td>1.18</td>
<td>72.9 H – 1432 H</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>1.05 μF – 1.59 μF</td>
<td>3</td>
<td>1.76 nF – 34.7 nF</td>
</tr>
<tr>
<td></td>
<td></td>
<td>C</td>
<td>31.78 nF – 1.11 μF</td>
<td>0.62</td>
<td>0.36</td>
</tr>
<tr>
<td>1k</td>
<td>R</td>
<td></td>
<td>1.0 Ω – 900 Ω</td>
<td>0.12</td>
<td>0.56</td>
</tr>
<tr>
<td></td>
<td></td>
<td>L</td>
<td>1.99 mH – 2.38 H</td>
<td>0.47</td>
<td>7.29 H – 143.2 H</td>
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<td></td>
<td></td>
<td>C</td>
<td>1.05 μF – 1.59 μF</td>
<td>0.12</td>
<td>176 pF – 3.47 nF</td>
</tr>
<tr>
<td>10k</td>
<td>R</td>
<td></td>
<td>1.0 Ω – 900 Ω</td>
<td>0.12</td>
<td>2.49</td>
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<tr>
<td></td>
<td></td>
<td>L</td>
<td>25.9 μH – 23.8 mH</td>
<td>0.57</td>
<td>729 mH – 14.3 H</td>
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<tr>
<td></td>
<td></td>
<td>C</td>
<td>10.6 nF – 15.9 µF</td>
<td>0.94</td>
<td>17.6 pF – 347 pF</td>
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<td>100k</td>
<td>R</td>
<td></td>
<td>1.0 Ω – 900 Ω</td>
<td>0.12</td>
<td>14</td>
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<tr>
<td></td>
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<td>L</td>
<td>2.99 μH – 2.38 mH</td>
<td>0.71</td>
<td>72 mH – 1.43 H</td>
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<td></td>
<td></td>
<td>C</td>
<td>1.05 nF – 1.59 μF</td>
<td>1.17</td>
<td>1.76 pF – 34.7 nF</td>
</tr>
</tbody>
</table>
Example of measurement accuracy
Using the OPA3S328

- Using the OPA3S328 in the design can simplify the design.
- Dual high precision op-amps and 6 integrated switches in a 2 x 2 mm DSBGA package.
- High GBW of 40 MHz.
- High AOL of 122 dB.
OPA3S328 integrates red circled components into one device!
**OPA3S328 5.5V TIA with integrated switches (40 MHz)**

High precision, low power, high speed, RRIO log amp replacement

### Features

- **Gain bandwidth:** 40 MHz
- **Slew Rate:** 25 V/µs
- **Bias current:** 10 pA (@ 25°C, max)
- **Voltage noise:** 6.2 nV/√Hz at 1KHz
- **Voltage offset:** 25 µV (@ 25°C, max)
- **Offset voltage drift:** 1.5 µV/°C (max)
- **CMRR:** 114 dB (typ)
- **Low supply current:** 4 mA (typ/ch)
- **Wide Supply Range:** 2.7V to 5.5V

### Benefits

- **Integrated low-resistance switches** provides selectable gain and reduces system size
- **Wide bandwidth** maximizes dynamic range current measurements for optical power monitors and communications equipment
- **Low input bias** enables high precision photodiode current measurements
- **Rail-to-rail** capability enables measurements near the supply and ground, and improves the SNR of the design

### Packages

**OPA3S328:** (3.5 x 3.5 mm WSON-20)

### Applications

- Optical Power Monitors
- Test and Measurement Equipment
- Photodiode Monitoring
- Communications
- Wide dynamic range current measurements

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**Texas Instruments**

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![Diagram of OPA3S328 5.5V TIA with integrated switches](image-url)
**OPA810** Single Channel FET-Input RRIO 27 V, Low Power Amplifier

### Features
- Single Channel, High Voltage, FET Input, Rail-to-rail input/output amp
- \( +4.75V \) to \( +27V \) Single Supply Operation
- \( I_q: \) 3.7 mA trimmed supply current
- **Bandwidth:** 140 MHz (\( G = 1V/V \))
- **Input Voltage Noise:** 6.3 nV/√Hz \((f > 500kHz)\)
- **HD2/3:** -101/-101dBc @ 2Vpp, 1MHz
- +/-2.5μV/°C Typical Offset Drift, 0.55mV max offset
- -40°C to 125°C Operating Temperature

### Benefits
- Ideal for transimpedance circuits, current sensing, test & measurement and general signal buffering from sources with high/unknown impedance
- Very low power for hand-held/portable systems
- High bandwidth and slew rate to offer low distortion at high speed >1MHz and large signal swing ~20Vpp
- Low flat band and 1/f noise for best signal integrity and SNR in high performance systems
- Wide supply voltage range, rail to rail input/output for best system flexibility
- Current limit to protect device against fault conditions

### Applications
- High Speed Photodiode TIA
- Current Sensing
- T&M – oscilloscopes, current probes, power analyzers, etc.
- Multi-channel sensor interface

### Packages & Body Size
- **Packages**  |  **Body Size** |
- 5-pin SOT-23 | 1.6 mm x 2.9 mm |
- 5-pin SC70  | 2.0 mm x 1.25 mm |
- 8-pin SOIC  | 3.91 mm x 4.9 mm |

### Tools & Resources
- Device Product Overview: [LINK](#)
- Device Evaluation Board (EVM): [LINK](#)
- Support: [LINK](#)

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**OPA810 as High voltage, Hi-Z Buffer Stage**

- [Charge Bucket Filter](#)
- THS45xx
- ADC

Vin \[+\] \[-\]
\[+V_{CC}\] \[-V_{EE}\]
\[+\] \[\] \[\] \[\] \[\]
\[-\] \[\] \[\] \[\] \[\]
\[+V_{CC}\] \[-V_{EE}\]
\[+\] \[\] \[\] \[\] \[\]
\[-\] \[\] \[\] \[\] \[\]
OPA2810 Dual FET-Input RRIO 27 V, Low Power Amplifier

**Features**
- Dual Channel, High Voltage, FET Input, Rail-to-rail input/output amp
- +4.75V to +27V Single Supply Operation
- $I_q$: 3.6 mA trimmed supply current
- **Bandwidth**: 105 MHz (G = 1V/V)
- **Input Voltage Noise**: 6 nV/√Hz (f > 500kHz)
- **HD2/3**: -99/-104dBc @ 2Vpp, 1MHz
- +/-2μV/°C Typical Offset Drift, 1.5mV max offset
- -40°C to 125°C Operating Temperature

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- Current limit to protect device against fault conditions

**Tools & Resources**
- Device Product Overview: [LINK](#)
- Device Evaluation Board (EVM): [LINK](#)
- Support: [LINK](#)
### Features
- Adjustable Small Signal Bandwidth: 35 - 210 MHz
- Slew Rate: 3750 V/µsec
- High output drive capability: 250 mA
- Low quiescent current with 35MHz BW: 1.5mA, 210MHz: 8.5mA
- Wide supply range from +/-2.25V to +/-18V
- Low 3.4 nV/√Hz Output noise in high-BW mode
- Fast settling performance to 0.1% (20V step): 90ns
- Package: SOIC-8, 3X3 SON, SOIC-8 with power pad

### Applications
- Radar and Sonar Drivers
- Low power servo drivers
- Closed-loop current buffer
- Test Equipment/ATE Pin Driver
- Audio headphone driver
- DAC reference drive
- Line drivers and multiplexing

### Benefits
- Supply Voltage Flexibility for variety of applications
- Excellent for high speed open loop applications Adaptable for application needs
- High output current drive for capacitive loads and line drivers
- Flexibility to choose lower power & bandwidth vs. higher power & bandwidth
- Internal current limit and thermal shutdown protection
- Very low output impedance, thus capable of driving high cap values

**BUF634DRB** Sampling NOW and SOIC-8 power pad option to be available soon!
Discrete Impedance Spectroscopy Design
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• LCR meters and Impedance Analyzers, as the name suggests, are used to measure unknown values of passive components – Inductance, Capacitance or Resistance in lab settings

• Both are fundamentally similar, except that:
  • Impedance Analyzer = LCR Meter + Multi-Frequency Measurement

• A DAC is used to generate a signal of set amplitude and frequency. The response of the sample to this signal is then gained up precision amplifiers and read by a precision ADC. Digital computations are then performed to filter and determine the impedance of the sample at each tested frequency.
What Impedance Spectroscopy can do?

Reference:
Electrochemical Impedance Spectroscopy for Online Battery Monitoring - Power Electronics Control (IEEE)
What Differentiates This Subsystem Solution

• Better performance in the market.
  – High resolution (<0.1° phase resolution) and SNR (70 dB @ 100KHz) across impedance range.
  – Wider excitation voltage range (<1 mV – 5 V+)
  – Suitable for voltage sensitive applications that can be damaged at higher voltages.
  – Wider excitation frequency (0.1 Hz to 100 KHz)

• Flexibility and configurability allows for optimized design.
  – Multi-Sourcing available, less risk for EOL.
  – Configurable discrete components for specific design requirements.
Phase Shift Simulations

Calibration = 100kOhm

- Phase Shift at 10kHz = -0.91°
- Phase Shift at 100kHz = -8.88°

Sample = 100kOhm + 1pF

- Phase Shift at 10kHz = -0.92°
- Phase Shift at 100kHz = -8.96°
- Phase difference at 10kHz = (-0.91°) - (-0.92°) = .01°
- Phase difference at 100kHz = (-8.88°) - (-8.96°) = .08°
### Phase Shift Simulations

**Sample = 100kOhm + 2pF**

- Phase Shift at 10kHz = -0.93°
- Phase Shift at 100kHz = -9.04°

**Sample = 100kOhm + 3pF**

- Phase Shift at 10kHz = -0.93°
- Phase Shift at 100kHz = -9.12°
- Phase difference at 10kHz = (-0.93°) - (-0.93°) = 0.00°
- Phase difference at 100kHz = (-9.04°) - (-9.12°) = 0.08°
Impedance Range Simulations

- Sample Impedance = 10k, Phase Shift at 100kHz = 7.63°
- Sample Impedance = 10k + 1pF, Phase Shift at 100kHz = 7.67°
- Vout p-p = 1.227V

- Sample Impedance = 100k, Phase Shift at 100kHz = 8.88°
- Sample Impedance = 100k + 1pF, Phase Shift at 100kHz = 8.96°
- Vout p-p = 2.22V

- Sample Impedance = 1M, Phase Shift at 100kHz = 9.13°
- Sample Impedance = 1M + 1pF, Phase Shift at 100kHz = 9.21°
- Vout p-p = 2.42V
Signal to Noise Ratio

SNR @ Sample Excitation = 106.16dB @ 100kHz

SNR @ output = 70.30dB @ 100kHz
Simulation Models

• Simulation models for both single-ended and differential models exist in ADS7057 product page. Under “Design tools & simulation”

![Single-Ended ->](image1)

![<- Differential](image2)
Impedance Measurement: (OPA3S328 + DAC80508+ ADS131E08)

LCD/OLED Shorting bar tester leakage test:
• Design challenge is the dynamic range to accurately measure the resistance starting from short, 0 Ohm to 1MOhm.
• Discrete sub system solution (OPA3S328 + DAC80508 + ADS131E08) offers low cost, small solution size and achieve high accuracy.
OPA3S328 Schematic
What Differentiates this Subsystem Solution

• Reasonable good accuracy performance in a dense and low cost offering.
• Higher measurement accuracy.
  – Reduced # of switches in the OPA3S328 amplifier architecture reducing parasitic current draw.
• Simplified design allows for competitive size density.
  – Does not require additional external components for additional range.
  – Only common power rails needed (1.8 V – 5 V). No need for uncommon 15 V supplies.
  – Scalable for multi-channel applications.
Calculated and Measured Resistance

Using Ohm’s law, our measured resistance \( R_m \) would be

\[
R_m = \frac{V_{rm}(x)}{A_{rm}(x)}
\]

where \( A_{rm}(x) = \frac{V_{rm}}{R_m} = \frac{V_o - V_{rm}}{R_f} \)

Re-writing the gain equation, our calculated resistance \( R_{cal} \) would be

\[
R_{cal} = \frac{V_{setup} \cdot R_f}{V_o - V_{setup}}
\]

\[
V_{rm} = V_{setup}
\]

\[
A_{rm(x)} = \frac{V_o - V_{rm}}{R_f}
\]

*Feedback of 1k Ω used*
Measuring Error

To find the error, our equation would be:

\[
\text{Error (ppm)} = \frac{R_{\text{cal}} - R_{m}}{R_{m}} \times 1 \text{ million}
\]
Simulations in TINA-TI

From our simulations, we found feedback resistors 1k, 8.5k and 17.5k gave us great range (500 Ω to 1M Ω) while measuring the unknown resistance accurately.
## Lowest Possible Error

### Rf = 1k Ω

Range: 200 Ω to 3k Ω

<table>
<thead>
<tr>
<th>Resistor (Ω)</th>
<th>V_set (V)</th>
<th>Error (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200</td>
<td>0.69899</td>
<td>0.01441</td>
</tr>
<tr>
<td>300</td>
<td>0.80146</td>
<td>0.00969</td>
</tr>
<tr>
<td>690</td>
<td>1.2</td>
<td>0.00749</td>
</tr>
<tr>
<td>880</td>
<td>1.39</td>
<td>0.00524</td>
</tr>
<tr>
<td>1.07k</td>
<td>1.58</td>
<td>0.00508</td>
</tr>
<tr>
<td>1.45k</td>
<td>1.96</td>
<td>0.00387</td>
</tr>
<tr>
<td>1.64k</td>
<td>2.15</td>
<td>0.00315</td>
</tr>
<tr>
<td>2.21k</td>
<td>2.73</td>
<td>0.00314</td>
</tr>
<tr>
<td>2.59k</td>
<td>3.11</td>
<td>0.00247</td>
</tr>
<tr>
<td>3k</td>
<td>3.51</td>
<td>0.00287</td>
</tr>
</tbody>
</table>

Vsetup = 0.001007*Rm + 0.502

### Rf = 8.5k Ω

Range: 2.21k Ω to 300k Ω

<table>
<thead>
<tr>
<th>Resistor (Ω)</th>
<th>V_set (V)</th>
<th>Error (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2.21k</td>
<td>0.101</td>
<td>0.90443</td>
</tr>
<tr>
<td>15.46k</td>
<td>0.29871</td>
<td>0.14157</td>
</tr>
<tr>
<td>28.71k</td>
<td>0.49632</td>
<td>0.20687</td>
</tr>
<tr>
<td>55.22k</td>
<td>0.89962</td>
<td>0.10364</td>
</tr>
<tr>
<td>94.97k</td>
<td>1.51</td>
<td>0.04246</td>
</tr>
<tr>
<td>121.48k</td>
<td>1.91</td>
<td>0.05005</td>
</tr>
<tr>
<td>161.24k</td>
<td>2.52</td>
<td>0.02416</td>
</tr>
<tr>
<td>187.74k</td>
<td>2.93</td>
<td>0.02808</td>
</tr>
<tr>
<td>214.24k</td>
<td>3.33</td>
<td>0.00422</td>
</tr>
<tr>
<td>300k</td>
<td>4.66</td>
<td>0.01421</td>
</tr>
</tbody>
</table>

Vsetup = 1.528e-5*Rm + 0.05748

### Rf = 17.5k Ω

Range: 200k Ω to 1.1M Ω

<table>
<thead>
<tr>
<th>Resistor (Ω)</th>
<th>V_set (V)</th>
<th>Error (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>200k</td>
<td>0.73893</td>
<td>0.21781</td>
</tr>
<tr>
<td>254k</td>
<td>0.93874</td>
<td>0.04845</td>
</tr>
<tr>
<td>336.89k</td>
<td>1.24</td>
<td>0.09149</td>
</tr>
<tr>
<td>419.78k</td>
<td>1.53</td>
<td>0.09097</td>
</tr>
<tr>
<td>502.67k</td>
<td>1.84</td>
<td>0.0567</td>
</tr>
<tr>
<td>585.56k</td>
<td>2.14</td>
<td>0.03323</td>
</tr>
<tr>
<td>668.44k</td>
<td>2.44</td>
<td>0.05447</td>
</tr>
<tr>
<td>834.22k</td>
<td>3.06</td>
<td>0.0256</td>
</tr>
<tr>
<td>917.11k</td>
<td>3.37</td>
<td>0.02989</td>
</tr>
<tr>
<td>1.1M</td>
<td>4.06</td>
<td>0.03201</td>
</tr>
</tbody>
</table>

Vsetup = 3.675e-6*Rm - 0.005343
Graph (Error vs Resistance)

Error vs Resistance
Rf = 1k

Error vs Resistance
Rf = 8.5k

Error vs Resistance
Rf = 17.5k
Shorted Simulation

With all of the switches turned on, we can calculate $R_m$ from $1 \, \Omega$ to $200 \, \Omega$

Using probes $V_{rm}$, $V_o$ and $A_{rm}$, our new feedback resistance would be

$$R_f = \frac{V_o - V_{rm}}{A_{rm}}$$

Giving us a resistance of $R_f = 871.180915 \, \Omega$
Graph (Error vs Resistance)

Error vs Resistance
Rf = 871.18

- Error (ppm) vs Resistance (Ω) graph
- The graph shows a decreasing trend in error with increasing resistance.
- The resistance value Rf = 871.18 is indicated on the graph.
Thank you!
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