

# 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.  $Z_{DUT}$  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  $V_{DUT}$  across  $Z_{DUT}$  and a current  $I_{DUT}$  flowing through it,

$$Z_{DUT} \angle \theta_Z = \frac{V_{DUT} \angle \theta_V}{I_{DUT} \angle \theta_I} \quad (1)$$

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

$$V_O = -R_F I_{DUT} \quad (2)$$

$$\Rightarrow I_{DUT} = \frac{-V_O}{R_F} \quad (3)$$

From (1) and (3), the unknown impedance  $Z_{DUT}$  is given by,

$$Z_{DUT} = \frac{V_{DUT}}{\left(\frac{-V_O}{R_F}\right)} \quad (4)$$

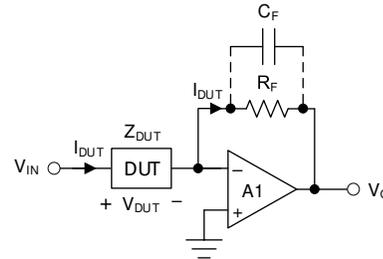
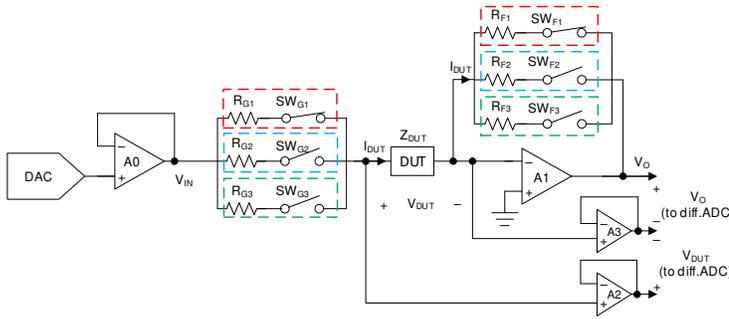


Figure 1. Representative Schematic of an LCR Meter Analog Front-End Using ABB Method

## 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  $Z_{DUT}$ . To increase the measurement range and sensitivity of the LCR meter multiple feedback resistors ( $R_{F1,2,3}$ ) are switched into the circuit through series switches ( $SW_{F1,2,3}$ ), shown in Figure 2.
2. A large value of  $R_F$  forms a zero in the noise-gain transfer function causing 40 dB/decade rate-of-closure and potential instability. Use of a capacitor  $C_F$  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  $C_F$  for stability with all values of capacitive  $Z_{DUT}$ . This problem is solved using series resistors  $R_{G1,2,3}$  with  $Z_{DUT}$ , as Figure 2 shows. Use of  $R_G$  introduces a pole in noise-gain, cancelling the zero and restoring phase for a stable circuit. Multiple values of  $R_G$  (equal to corresponding  $R_{F1,2,3}$ ) with corresponding series switches ( $SW_{G1,2,3}$ ) need to be used. The same  $R_F$  and  $R_G$  pairs (marked with the same color in Figure 2) are switched in every time for the required measurement range to ensure stable operation.
3. For high accuracy measurements with large value DUTs,  $V_{DUT}$  and  $I_{DUT}$  should be buffered with high-Z input amplifiers (A2 and A3 here, CMOS or FET-input amplifiers with  $\approx$ pA range bias currents).



**Figure 2. Modified Circuit for High-Frequency Measurements Needing More Amplifiers and Differential ADCs**

Amplifier A3 can be eliminated for a simplified analog front-end design; however, to maintain measurement accuracy, amplifier A1 should have a large enough open-loop gain (AOL), and hence a gain-bandwidth product at the highest measurement frequency of interest. With a large AOL at the test frequency, a virtual ground is maintained at A1’s inverting input.

Eliminating A3 allows for single-point ground-referenced measurements with need for smaller number of amplifier channels and single-ended ADCs. A general rule-of-thumb is to ensure that A1 has >60-dB AOL at the highest frequency of interest for high accuracy measurements. For higher test frequencies, two-point measurements for  $V_{DUT}$  and  $I_{DUT}$  are needed to calculate  $Z_{DUT}$  with high-accuracy, which requires more amplifiers (A3 in Figure 2) and differential input ADCs.

**Conclusion**

The TIDA-060029 reference design describes this LCR meter analog front-end and the associated challenges in detail. An analog front-end with impedance measurements accurate to 0.1% is implemented in this reference design. Impedance values in the range 1 Ω to 10 MΩ can be measured at frequencies from 100 Hz to 100 kHz. Table 1 lists Texas Instruments amplifiers suitable for use in an LCR meter design:

**Table 1. Recommended Amplifiers for LCR Meter Design**

Device	Architecture	GBW	Quiescent Current	Noise	Function
OPA810	FET-input, voltage-feedback	70 MHz	3.7 mA	6.3 nV/rtHz	Unity-gain buffer for $V_{DUT}$ and $I_{DUT}$ measurements
OPA656	FET-input, voltage-feedback	230 MHz	14 mA	7 nV/rtHz	High-frequency $V_{DUT}$ and $I_{DUT}$ measurements
THS4551	Low-power fully differential amplifier	135 MHz	1.37 mA	3.3 nV/rtHz	ADC input driver for differential $V_{DUT}$ and $I_{DUT}$ measurements
BUF634A	High $I_{OUT}$ buffer	210 MHz	8.5 mA	3.4 nV/rtHz	High $I_{OUT}$ buffer for driving small-value DUT with $V_{IN}$

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