Application Brief

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,

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

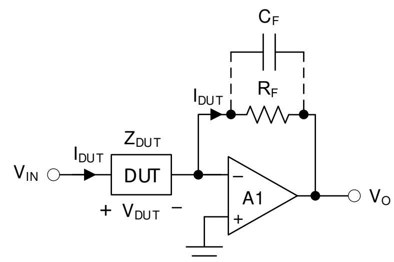

Figure 1. Representative Schematic of an LCR Meter Analog Front-End Using ABB Method

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 ≈pA range bias currents).

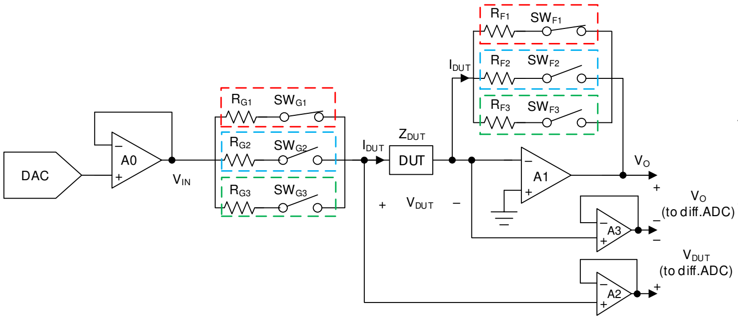

Figure 2. Modified Circuit for High-Frequency Measurements Needing More Amplifiers and Differential ADCs

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}