Supplemental Material: BIA Device Description

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Abstract. This document contains details on the design, construction, and functionality of the BIA device described in "Bioelectrical Impedance Analysis as a laboratory activity: at the interface of physics and the body." The complete circuit diagram of the device is given as well as the equations for V_{phase} and V_{mag}.

Introduction

The BIA device is based on the AD8302 Gain and Phase Detector, which can be used to find the impedance and phase of an RC circuit[1] and has already been shown to work in a BIA device.[2] The principle components of the BIA device are: a function generator, a Howland Current Pump, a differential amplifier and the AD8302 gain and phase detector (Fig 1).

As shown in Fig. 1, four electrodes are needed for BIA: two electrodes to carry current and two to measure the potential across the body. Tetrapolar voltage probes minimize the effect of the skin-electrode impedance on the measurement of the body's deep tissue impedance.[3]

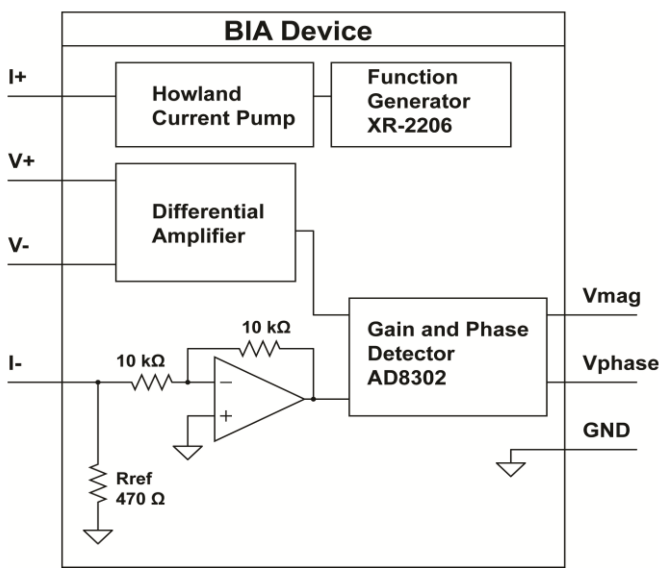

Fig. 1. Block diagram of the educational BIA device.

The AC signal is generated using an XR-2206 function generator (Fig 2).[4] The amplitude of the AC signal is 470 mV and is set by the resistor R3. The frequency is given by $1/(R2 \cdot C)$ where R2 is the resistance between TR1 and –Vcc and C is the capacitance between TC1 and TC2. R2 is determined by a 12 way rotary switch connected to a series of resistors. Two capacitors (C1 and C2), which are selected by a switch, are used to set the frequency range. This gives the device a high and low frequency range. As part of the activity, students use an inexpensive frequency counter to measure the frequency settings of the device. [5]

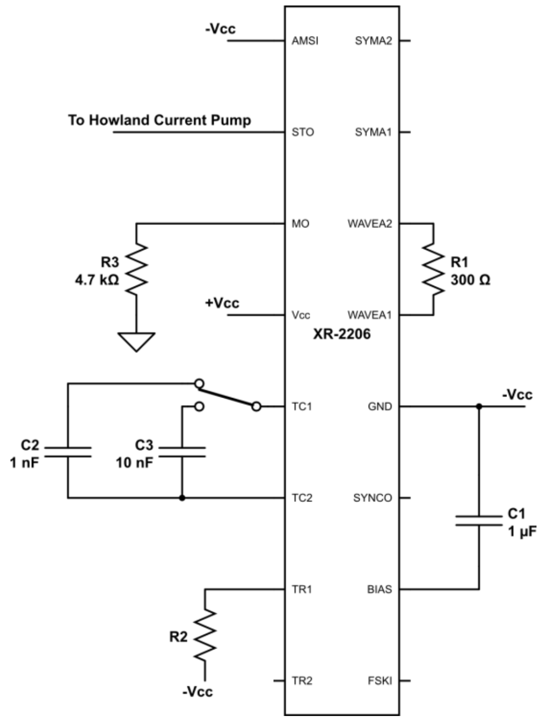

Fig. 2. XR-2206 function generator

The signal from the function generator is passed to the Howland Current Pump (Fig. 3). The purpose of the current pump is to maintain a constant current amplitude regardless of the load.[6] The educational BIA device outputs a constant current amplitude of 100 µA, which is set by both the magnitude of the voltage from the function generator and R7 according to the formula[6]

$$I = \frac{V_{in}}{R7}\,. \qquad (1)$$

This current is less than the maximum current considered safe for BIA devices 800 µA.[7] The current pump is constructed using a TLC074 quad op amp.[8] It is important to note that the resistors in Fig. 3 must be closely matched.[6] 1% resistors were used in the educational BIA device.

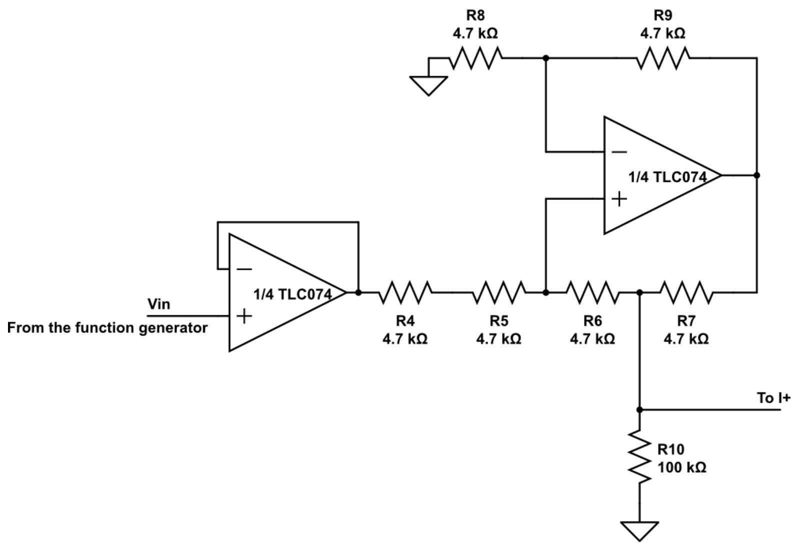

Fig. 3. Howland Current Pump

The differential amplifier is used to find the potential across the deep body impedance (Fig. 4). The amplifier is a standard design[9] and like the current pump is also created using TLC074 op amps. The fourth op amp on the TLC074 was used to make the inverting amplifier with unity gain connected to the reference resistor (Fig. 1). It was necessary to use an amplifier as a buffer going from the potential across the reference resistor to the gain and phase detector.

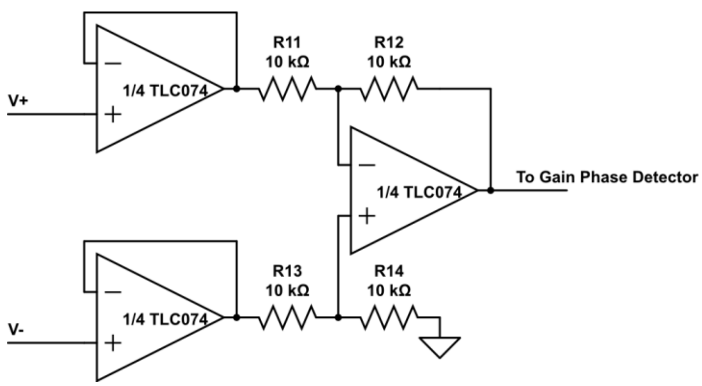

Fig. 4. Differential Amplifier

The AD8302 Gain and Phase Detector takes two sinusoidal signals as inputs and outputs two DC potentials, V_{phase} and V_{mag}. V_{phase} is proportional to the phase shift $\Delta\varphi$ between the inputs. V_{mag} is proportional to the logarithm of the ratio of the connected impedance, Z, and the reference resistance, R_{ref} [Eq. (2)].

$$V_{mag} = 0.61\,V \cdot \log\left(\frac{Z}{R_{ref}}\right) + 0.94\,V, \quad V_{phase} = -0.011\,V \cdot \Delta\varphi + 1.888\,V \qquad (2)$$

The resistors R15-18 are voltage dividers which lower the amplitude of the input signals to be within the prescribed limits of the AD8302. The capacitors C6 and C7 set the high pass corner frequency of the device. (See Ref. 1 for more information on calculating corner frequency.) Using 10 μF capacitors, the corner frequency is set to 20 Hz. In actuality, the AD8302 is not able to accurately measure signals at frequencies this low.[1,2] Therefore, for measurements below 5 kHz, traditional undergraduate differential voltage probes are used to calculate impedance and gain.[10]

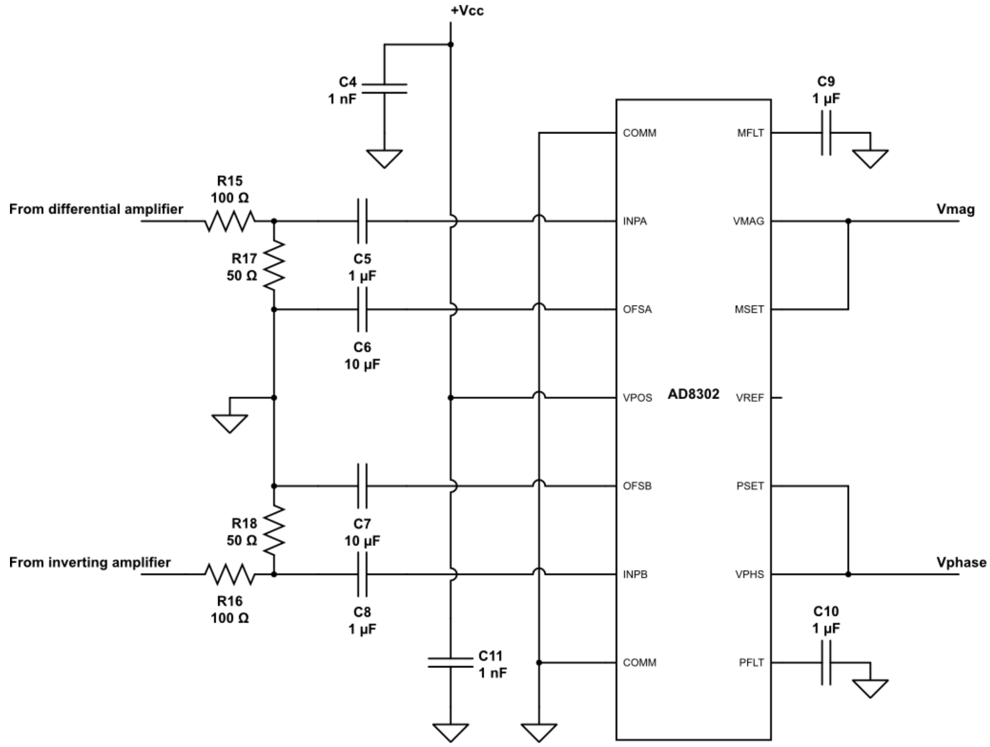

Fig. 5. AD8302 Gain Phase Detector

References

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