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EBI100C ELECTRICAL BIOIMPEDANCE AMPLIFIER

See also
Application Note #AH-196
Cardiac Output Measurement
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and
Applications (Appendix) in the "Acq*Knowledge* Software Guide"

The EBI100C records the parameters associated with cardiac output measurements, thoracic impedance changes as a function of respiration or any kind of biological impedance monitoring.

The EBI100C incorporates a precision high frequency current source, which injects a very small (400 µA) current through the measurement tissue volume defined by the placement of a set of current source electrodes. A separate set of monitoring electrodes then measures the voltage developed across the tissue volume. Because the current is constant, the voltage measured is proportional to the characteristics of the biological impedance of the tissue volume.

The EBI100C simultaneously measures impedance **magnitude** and **phase**. Impedance can be recorded at four different measurement frequencies, from 12.5 kHz to 100 kHz; cardiac output measurements are usually performed at a measurement frequency of 50 kHz.

For operation, the EBI100C connects to four unshielded electrode leads terminating in 1.5 mm female Touchproof sockets. The EBI100C is typically used with EL500 paired disposable electrodes, but can function with spot or ring electrodes, reusable electrodes, or needle electrodes.

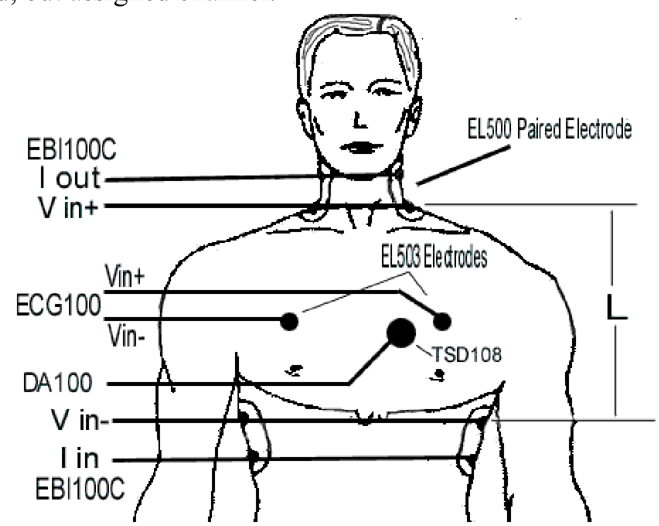
The **CH SELECT** switch has four bank settings, which assign EBI100C output (i.e., Magnitude or Phase) channels as follows:

Bank	Magnitude (MAG)	Phase (PHS)
1	Channel 1	Channel 9
2	Channel 2	Channel 10
3	Channel 3	Channel 11
4	Channel 4	Channel 12

If the particular EBI100C output is not used, the respective assigned channel cannot be used for another module's output; users should simply not record on the unwanted, but assigned channel.

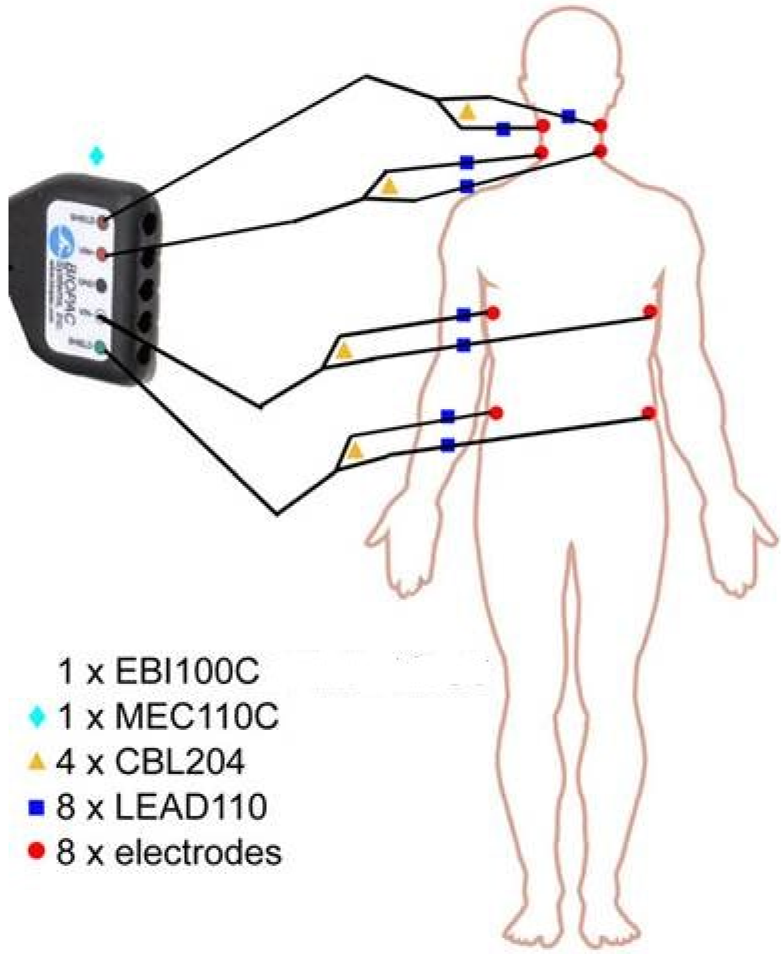
Typical Configuration for Cardiac Output Measurements

For injecting current and averaging voltage at four paired-electrode sites (required for **cardiac output measurements**), use four CBL204 1.5 mm Touchproof "Y" electrode lead adapters and eight LEAD110 electrode leads with each EBI100C.



When using EBI100C with MEC110C Module Extension Cable:

Connect the four CBL204 1.5 mm Touchproof "Y" lead adapters to the following color inputs on the MEC110C. I OUT = brown (Shield), VIN+ = red, VIN- = white, I IN = green (Shield). (The black GND port on the MEC110C is normally not used in this application.) The diagram below shows the eight LEAD110 electrode positions for impedance cardiography or cardiac output.



NOTE: The EBI100C measures bioimpedance in terms of both magnitude and phase as a function of frequency (12.5, 25, 50, and 100 kHz). The choice of interfacing cables will impact both magnitude and phase readings. The impacts will be larger as the frequency of the source current increases. To obtain accurate measures at any frequency, calibrate the measurement for magnitude and phase after the interface cabling infrastructure is stabilized. (See EBI100C Calibration steps on page 4.)

Grounding

When using the EBI100C amplifier with other biopotential amplifiers attached to the same subject, it's not necessary to attach the ground lead from the biopotential amplifier(s) to the subject. The subject is already appropriately referenced to the subject via the attachment to the EBI100C. If a biopotential ground is attached to the subject, then currents sourced from the EBI100C will be split to the biopotential amplifier ground lead, potentially resulting in measurement errors.

Derivative Polarity – EBI100C vs. NICO100C

The EBI100C does not include an internal, hardware-based, derivative function for the Z (impedance magnitude) channel. An Acq*Knowledge* calculation channel can be used to determine dZ(t)/dt, if required. Channel scaling can be employed to specify the dZ(t)/dt polarity desired.

The NICO100C module incorporates an internal, hardware-based, derivative function, which outputs dZ(t)/dt simultaneously with Z (impedance magnitude). This internal derivative function also inverts the polarity of the dZ(t)/dt signal so that it displays a positive-going peak, coincident with negative slopes indicated in Z, as per academic research convention.

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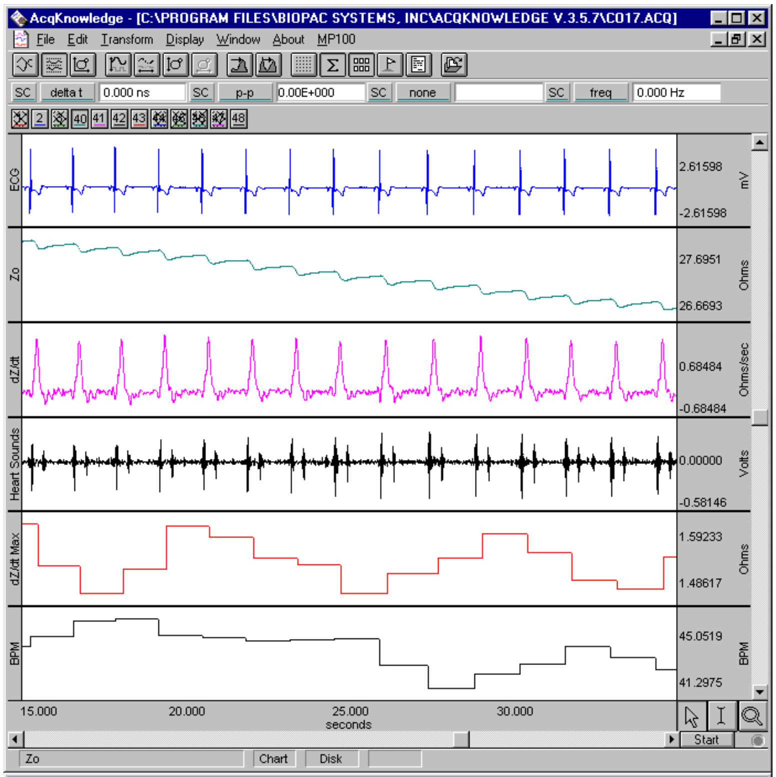
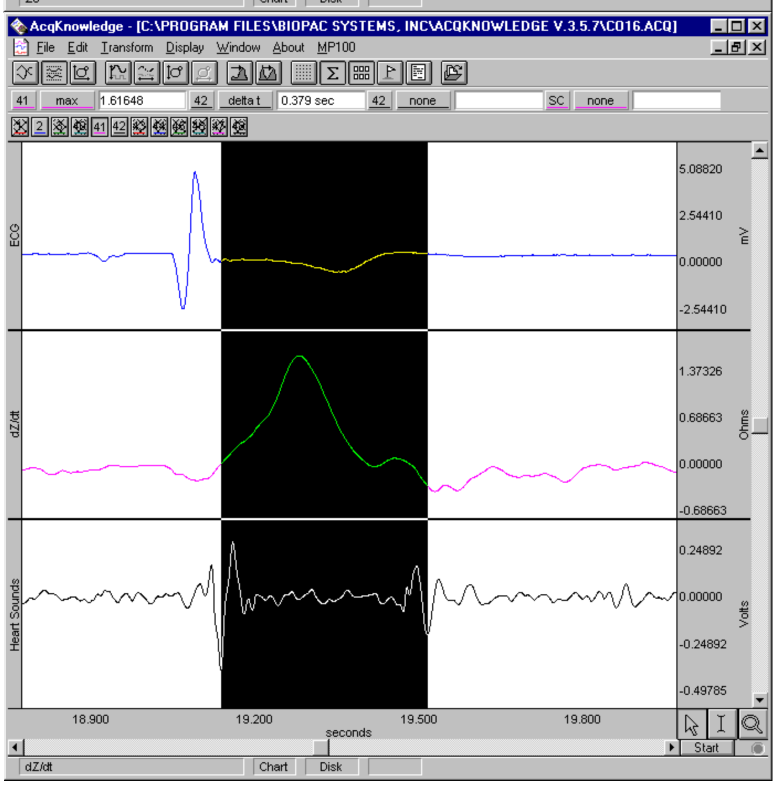
Sample Data



Note that dZ(t)/dt maximum is determined on a cycle-by-cycle basis from the raw dZ(t)/dt waveform.

Similarly, the heart rate in BPM is derived from the raw ECG waveform in Channel 1.



This graph illustrates the procedure for measuring Left Ventricular Ejection Time (T).

The Acq*Knowledge* cursor was swept to bridge from peak to peak in the filtered (40-60 Hz) Heart Sounds channel.

The Delta T (0.379 seconds) indicates the time from aortic valve opening to closing.

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Applications

Cardiac Output

Cardiac Output can be determined noninvasively by employing electrical bioimpedance measurement techniques. Electrical bioimpedance is simply the characteristic impedance of a volume of tissue and fluid. In the case of Cardiac Output measures, the relevant tissue includes the heart and the immediate surrounding volume of the thorax, and the relevant fluid is blood. The electrical impedance of the thorax can be thought of as composed of two impedance types:

1. **Zo** (the base impedance) corresponds to non-time varying tissues, such as muscle, bone and fat.
2. **dZ(t)/dt** is the magnitude of the largest impedance change during systole (Ω /sec).

BIOPAC Application Note #AH-196 Cardiac Output Measurements, implements the following equation, but other equations/modifications can be incorporated:

$$SV = r \cdot (L^2/Zo^2) \cdot T \cdot dZ(t)/dt$$

Where: SV = Stroke volume (ml)

r = Resistivity of blood (Ω · cm)

L = Length between inner band electrodes (cm)

Water Content Measurement and Adiposity

This is an area of active research and so specific methods of performing total body water (TBW) measurements using BIA may change. The following formula is sometimes used:

$$TBW = A * (H**2/R) + C$$

Where: A = a proportionality constant specific for a given subject population
H = subject's height
R = resistance obtained by single-frequency BIA (usually 50 kHz)
C = a constant

It may also be possible to obtain additional specificity in TBW measurements by performing BIA at multiple frequencies.

Frequency Response Plots

The 0.05 Hz lower frequency response setting is a single pole roll-off filter.

See also: Sample frequency response plots, 10 Hz LP, 100 Hz LP

EBI100C Calibration

The EBI100C can be calibrated using external loads. BIOPAC factory calibration is performed with 20, 200 and 900 Ohm loads. The EBI100C can measure from zero phase to 90 degree phase at the limits. Measurements of zero phase (using resistors) may not mean the output voltage of the phase signal is exactly zero. The user will need to scale the output voltage to 0 degrees phase when calibrating. Typically, a couple of tenths of volts are possible to obtain (at zero phase), depending on frequency of excitation.

For Cardiac Output Measurements

1. Set the EBI100C to a Frequency of 50 kHz and a Magnitude Gain range of 5 ohms/volt.
2. Introduce a 20 ohm resistor between the I Out / Vin+ combination terminal to the I In / Vin- combination terminal.
3. Press the Cal1 button…
4. Introduce a 40 ohm resistor between the I Out / Vin+ combination terminal to the I In / Vin- combination terminal.
5. Press the Cal2 button…

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EBI100C SPECIFICATIONS

Number of Channels:	2 – Magnitude (MAG) and Phase (PHS)
Operational Frequencies:	12.5, 25, 50, 100 kHz
Current Output:	400µA (rms)—constant sinusoidal current
Outputs:	MAG of Impedance (0-1000 Ω)*
	PHS of Impedance (0-90°)*
Output Range:	±10 V (analog)
Maximum Over-Voltage for Differential Input: ±25 V	
Operational Resistance:	The resistance range is 10 Ohms to 1,000 ohms; the minimum operational resistance is around 10 Ohms. A delta of 0.1 ohms is quite simple to measure with the correct EBI100C settings (assuming the data acquisition system used provides sufficient resolution.)
MAG Gain Range:	100, 20, 5, 1 Ω/volt
MAG LP Filter:	10 Hz, 100 Hz
MAG HP Filter:	DC, 0.05 Hz
MAG Sensitivity:	0.0015 Ω rms @ 10 Hz bandwidth
PHS Gain:	90°/10 volts
PHS LP Filter:	100 Hz
PHS HP Filter:	DC coupled
PHS Sensitivity:	0.0025 degrees @ 10 Hz bandwidth
CMIV – referenced to	
Amplifier ground:	±10 V
Mains ground:	±1500 VDC
Signal Source:	Electrodes (four electrode leads required)
Weight:	370 grams
Dimensions:	4 cm (wide) x 11 cm (deep) x 19 cm (high)
Input Connectors:	Five 1.5 mm male Touchproof sockets (Input, Vin+, Ground, Vin-, Output)

*The EBI100C and NICO100C amplifiers are specifically designed to measure complex impedances that have a magnitude between 10 Ω and 1000 Ω and phases between 0° and 90° degrees; they are not designed to measure any arbitrary impedance.

*Since these amplifiers require at least some small leakage path of DC current from I+ to I-, 89.9° degrees is the maximum measurement; they can't measure exactly to 90°.

Note—If a series capacitor is placed in the measurement circuit, then a large valued parallel resistor (10 K-100 K) should be placed across the capacitor to permit a small DC current to flow.

Possible EBI100C Lead Configurations

Setup Type	Amplifier	MEC	Lead	Adapter	Electrode
Simulated Equipotential *Absolute measures*	EBI100**D** *optimal*		LEAD132		4 x EL500
	EBI100**D** *optimal*	MEC104D	LEAD132		4 x EL500
	EBI100**D**		LEAD131		4 x EL503
	EBI100**D**	MEC104D	LEAD131		4 x EL503
	EBI100C *optimal*	1 x MEC110C	8 x LEAD110	4 x CBL204	4 x EL500
	EBI100C		8 x LEAD110A	4 x CBL204	4 x EL500
Fully Equipotential *Absolute measures* Uses ICG strip conductor, circumferential, cardiographic electrode tape (ICG Tape)	EBI100C *optimal*	1 x MEC110C	4 x LEAD140		ICG Tape
Non-Equipotential *Relative measures* Suitable for establishing timing relationships between waves	EBI100**D**		LEAD131		2 x EL500
	EBI100**D**	MEC104D	LEAD131		2 x EL500
	EBI100C	1 x MEC110C	4 x LEAD110		2 x EL500
	EBI100C		4 x LEAD110A		2 x EL500

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Usage Statement

Bioimpedance methods to perform stroke volume and cardiac output measurements via application of electrodes on the neck and torso are considered by BIOPAC to be research and educational tools. Historically, there have been numerous research efforts to measure stroke volumes and cardiac outputs using bioimpedance techniques. The performance of these systems is subject to evolving algorithms. New bioimpedance methods, such as TransRadial Electrical bioimpedance Velocimetry (TREV) are examples that show new promise in this area. Additionally, machine learning strategies are beginning to accommodate the variabilities of bioimpedance methods due to electrode type, placement, body position, movement artifacts, and electrical signal filtering. Research is ongoing as bioimpedance techniques offer profound non-invasive advantages compared to thermodilution and similar "gold-standard" historical methods for measuring stroke volume and cardiac output. BIOPAC is committed to continue to offer educational and research solutions for the application of bioimpedance methods to measure cardiovascular parameters despite the present "state of the art" showing these measures to be generally more useful for determining relative changes versus absolute values.