TI HealthTech

Engineering components for life.

AFE4300: Analog Front End for Body Composition / Weigh Scales

Fitness

Texas Instruments

Introduction

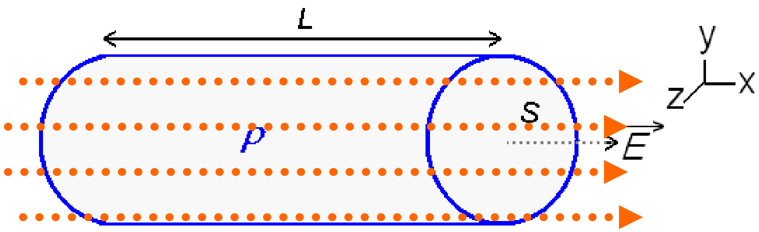
- Purpose
  - To introduce TI's AFE4300 for body composition / weigh scale applications
- Objectives
  - To discuss AFE4300's features and benefits
- Content
  - Bio-Impedance measurement & its applications
  - Body Composition Measurements
    - Parameters
    - Methods
    - Estimators
    - Sensors
    - Instrumentation
  - AFE4300 : Integrated AFE for Body composition measurements
  - Evaluation Module and wireless demo

What is Bio-Impedance Measurement?

- Measurement of passive electrical properties of biological materials.
- Non-invasive, non destructive technique
- High sensitivity, low specificity
- Low cost

Electrical impedance of Biological Materials

- **Intrinsic material properties + geometrical factors**



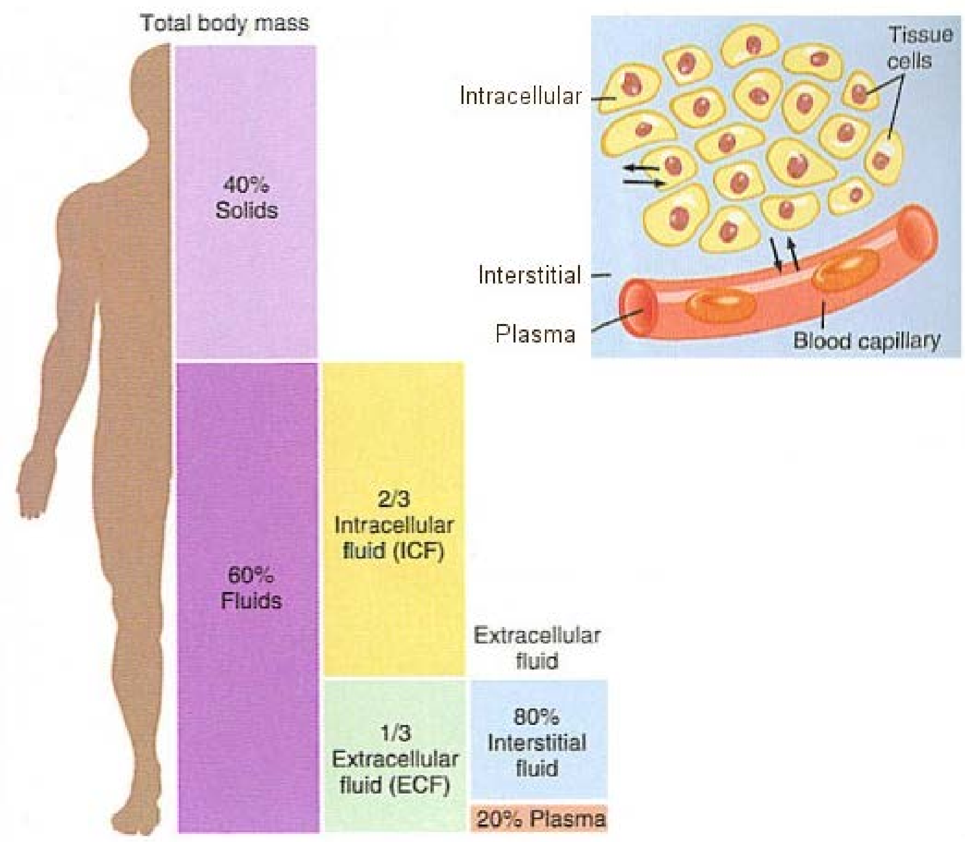
$$Z = \rho^* \cdot \frac{L}{S} = \frac{1}{\sigma + j\omega\varepsilon} \cdot \frac{L}{S}$$

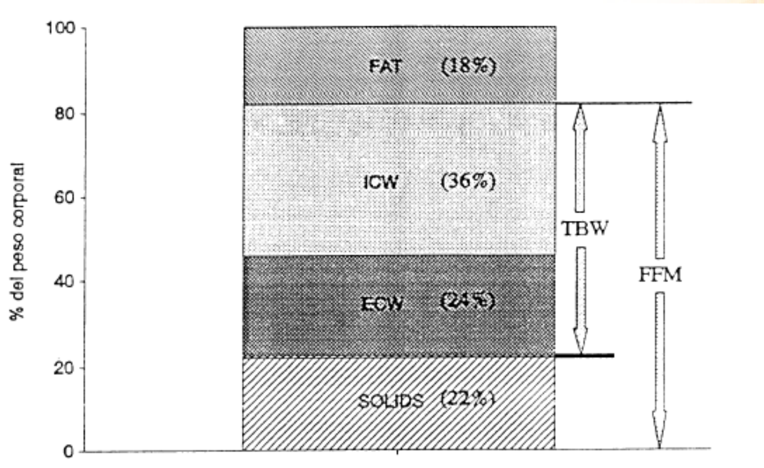
- **We can detect macroscopic changes due to**
  - Dimensions (volume changes)
  - Composition (cell type, size, density, homogeneity)
  - Fluids (accumulation, shift)

Applications for Bio-Impedance Analysis

- Detection of volume changes (Respiration with Impedance pneumography, apnea detection)
- Tissue characterization (Ischemia detection : lack of oxygen)
- Cell culture monitoring
- Electrical Impedance Tomography
- Measurement of body composition

Measurement of Body Composition





TBW Total Body Water

ICW Intracellular Water

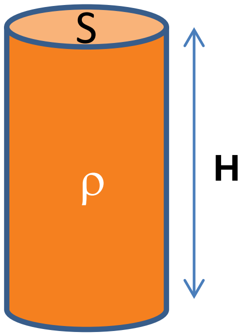
ECW Extracellular Water

FFM Fat-Free Mass

FM Fat Mass

Body composition characterization by impedance measurement

- Basic approach



$$R = \rho \frac{H}{S}$$

$$V = \mathrm{H} \cdot \mathrm{S}$$

$$V = \rho \frac{H^2}{R}$$

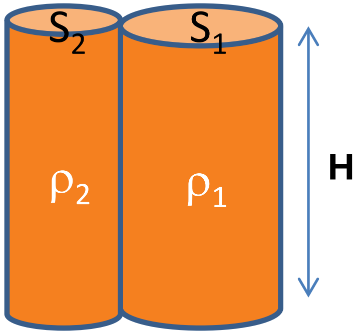
Conducting volume: TBW

- Given a hydration coefficient of 73%, FFM = TBW/0.73
- The body is not a cylinder and is not homogeneous:

$$TBW = k_1 \frac{H^2}{R} + k_2 \qquad TBW = k_1 \frac{H^2}{R} + k_2 W + k_3$$

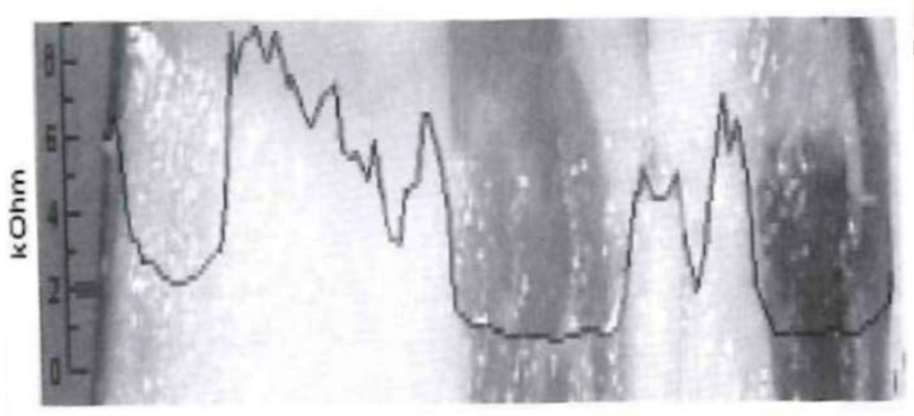
Body composition characterization by impedance measurement .. cont

- **The fat has much lower conductivity than the other tissues: double compartment model**



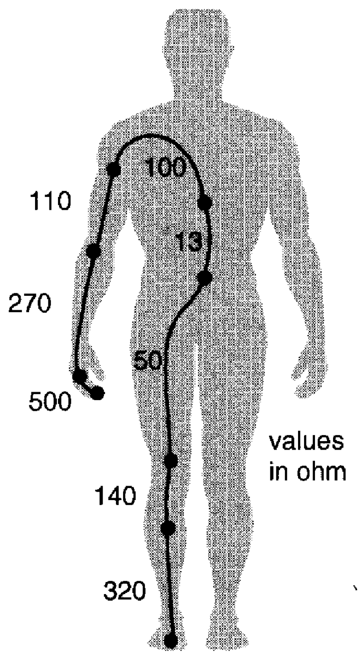
$$R = R_1 || R_2 \approx R_1$$

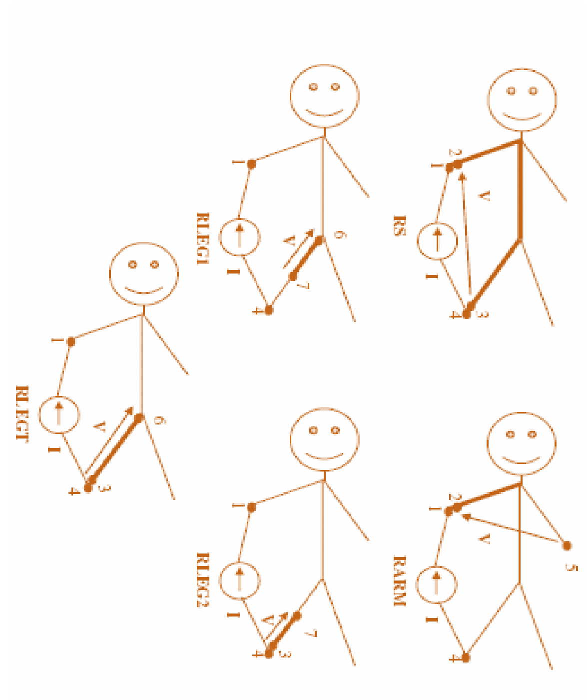
FM = W - FFM



BCM Measurement methods

- **Segmental impedance analysis**





Hand to Hand, Foot to Foot,
Hand to Foot measurements

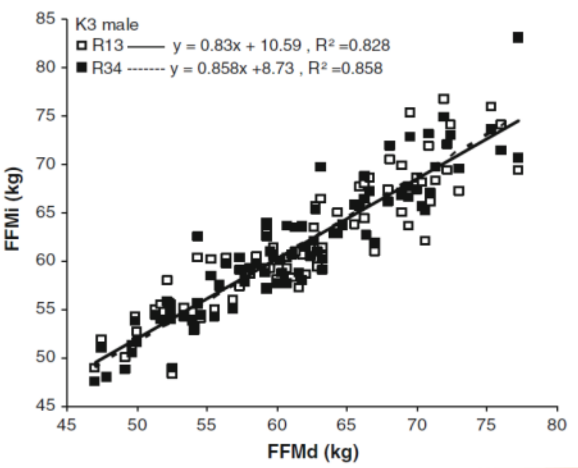
Measurement of Body Composition

- Basic measurement approaches and estimators are enough for normally hydrated subjects
- They give large errors in subjects with fluid and electrolyte abnormalities (dialysis, pregnant, children, elderly, …)

- High-end medical devices need more accurate measurement methods and estimators
- Several low-end home scales provide advanced estimators

Advanced Estimators

Boy fat-free-mass (FFM) is generally calculated by a linear regression of height, weight, and age, which is determined by comparison with dual X-ray absorptiometry (DXA) or Deuterium dilution or densitometry (under water weighing)



Determination of FFM

$$FFM = a_1 H^2 / R + b_1 W + c_1 \left(Age \right) + C_{t1}$$

or

$$FFM = a_2 H^2 / R + b_2 W + c_2 \left(Age \right) + d_2 X + C_{t2}$$

Determination of FM

$$FM = W - FFM$$

X reactance

a, b, c, d coefficients

Ct constant

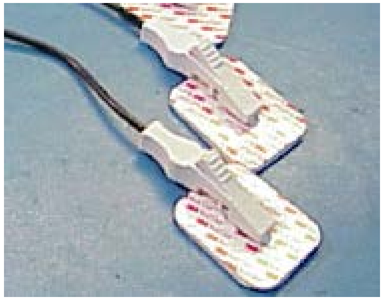
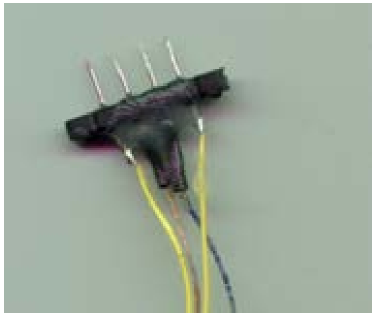
Advanced Estimators – Published Equations

Table 1 Bioelectrical impedance analysis equation reported in the literature since 1990 for fat-free mass (FFM) classified according to subject category (adult, elderly, overweight) and standard error of the estimate (SEE).

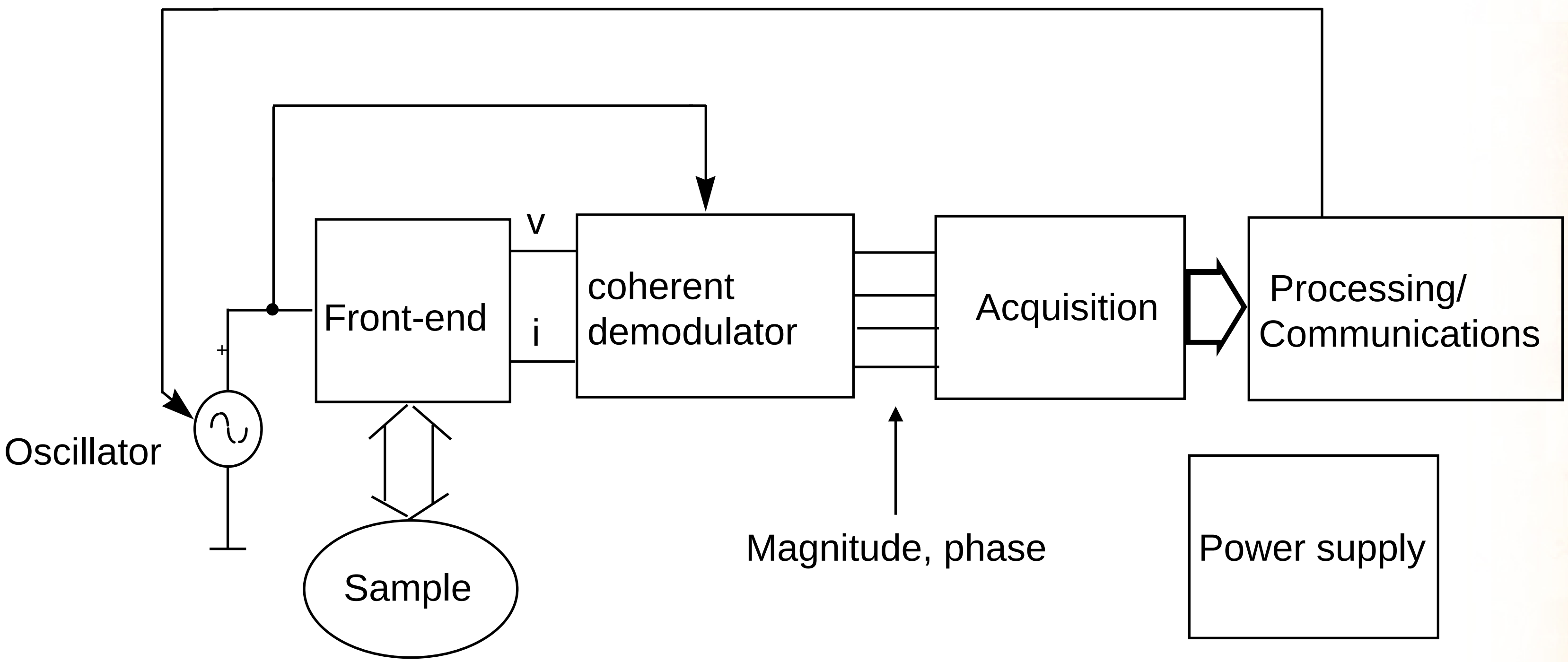
Population	Source	*n*	Criterion measure	Equation	r^2	SEE*	BIA instrument
Adults							
Healthy subjects, 18–94 yr	Kyle et al.[74]	343	DXA	$-4.104 + 0.518\,Ht^2/R_{50} + 0.231$ weight $+0.130\,Xc + 4.229$ sex	0.97	1.8	Xitron
Healthy adults, 18–29 yr	Lohman[75]	153	Densitometry[85,†]	Women $= 5.49 + 0.476\,Ht^2/R_{50}$ $+0.295$ weight	NR	2.1	Valhalla
Healthy adults, 30–49 yr	Lohman[75]	122	Densitometry[85,†]	Women $= 11.59 + 0.493\,Ht^2/R_{50}$ $+0.141$ weight	NR	2.5	Valhalla
Healthy, ethnic divers	Kotler et al. SF parallel[58]	126	DXA	Women $= +0.07 + 0.88\,(Ht^{1.97}/Z_{50}^{0.49})$ $(1.0/22.22) + 0.081$ weight	0.71	6.56% (≈2.6)	RJL-101
Healthy subjects, >16 yr	Deurenberg et al.[76]	661	Multi-C,[87] densitometry[86,‡]	$-12.44 + 0.34\,Ht^2/R_{50} + 0.1534$ height $+0.273$ weight $- 0.127$ age $+ 4.56$ sex	0.93	2.6	RJL-101
Healthy subjects, 12–71 yr	Boulier et al.[6]	202	Densitometry	$6.37 + 0.64$ weight $+ 0.40\,Ht^2/Z_{1\,MHz} - 0.16$ age -2.71 sex (men $= 1$, women $= 2$)	0.92	2.6	IMP BO-1
Women 18–60 yr	Stolarczyk et al.[77]	95	Multi-C[§]	$20.05 - 0.04904\,R_{50} + 0.001254\,Ht^2$ $+0.1555$ weight $+ 0.1417\,Xc - 0.0833$ age	0.75	2.6	Valhalla
Healthy adults, 50–70 yr	Lohman[75]	72	Densitometry[85,†]	Women $= 6.34 + 0.474\,Ht^2/R_{50} + 0.180$ weight	NR	2.8	Valhalla
Healthy adults, 18–29 yr	Lohman[75]	153	Densitometry[85,†]	Men $= 5.32 + 0.485\,Ht^2/R_{50} + 0.338$ weight	NR	2.9	Valhalla
Healthy subjects, 12–94 yr	Sun et al.[70]	1095	Multi-C	Women: $-9.529 + 0.696\,Ht^2/R_{50}$ $+0.168$ weight $+ 0.016\,R_{50}$	0.83	2.9*	
Healthy, ethnic divers	Kotler et al. SF parallel[58]	206	DXA	Men $= +0.49 + 0.50\,(Ht^{1.48}/Z_{50}^{0.55})$ $(1.0/1.21) + 0.42$ weight	0.92	5.45% (≈3.2)	RJL-101
Healthy adults, 30–49 yr	Lohman[75]	111	Densitometry[85,†]	Men $= 4.51 + 0.549\,Ht^2/R_{50}$ $+0.163$ weight $+ 0.092\,Xc$	NR	3.2	Valhalla
Healthy subjects, 35–65 yr	Heitmann[78]	139	Multi-C,[88] ^3H_2O, TBK	$-14.94 + 0.279\,Ht^2/R_{50} + 0.181$ weight $+0.231$ height $+ 0.064$ (sex weight) $- 0.077$ age	0.90	3.6	RJL-103
Healthy adults, 50–70 yr	Lohman[75]	74	Densitometry[85,†]	Men $= -11.41 + 0.600\,Ht^2/R_{50}$ $+0.186$ weight $+ 0.226\,Xc$	NR	3.6	Valhalla
Healthy subjects, 12–94 yr	Sun et al.[70]	734	4 compart	Men : $-10.678 + 0.652\,Ht^2/R_{50}$ $+0.262$ weight $+ 0.015\,R$	0.90	3.9*	RJL-101

BCM Instrumentation: Sensors

- Electrodes: Interface between the measurement system and the biological material
  - Electrochemical electrodes Ag-AgCl (body applications)
  - Capacitive coupling metallic surface-tissue (samples, home applications)


BCM Instrumentation: Block Diagram



AFE4300

Weight Scale / Body Composition Analog Front End

Features

Weigh Scale

- Supports four bridge inputs
  - 1.7V, 20mA LDO single output with enable/disable (50ms switching time).
  - Voltage tied to ADC reference (ratio-metric).
- IA amplifier internal feedback resistors trimmed to +/-5%.
- Gain setting through single external resistor.
- 58nVrms input referred noise from 0.1Hz to 2Hz
- 6b, +/-6.5uA offset correction DAC.

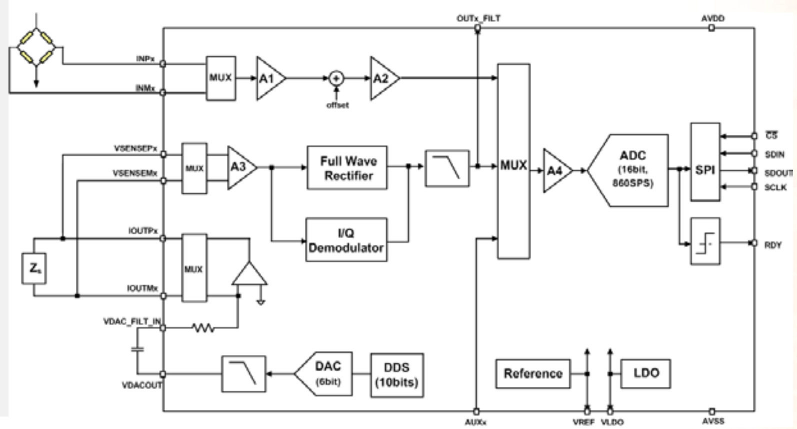
Body Composition

- Supports three tetra-polar impedance measurements
- Supports complex impedance measurement
  - 6b, 1MSPS sine wave generation DAC with integrated pattern memory (DDS).
  - 100KHz 2nd order low pass filter.
  - 375uArms +/-20%1 source.
  - 0.1Ω measurement rms noise in 2Hz BW
  - Supply current: 400uA (without output current).
- Supports SFBIA, MFBIA,
- 16-Bit, 860SPS, ADC multiplexing between
- 2V to 3.6V supply and Low Power

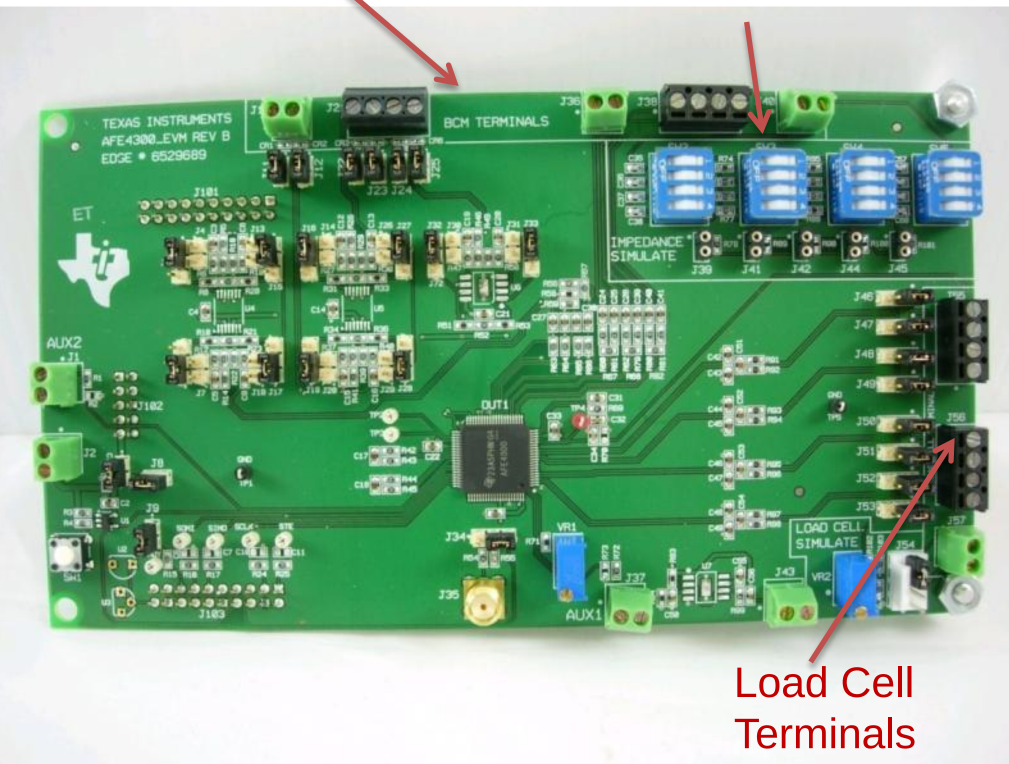
Samples: Now
EVM: Now
Production: Released

Benefits

- Easy way to add BMI to weigh scale end equipment
  - faster customer time to market
  - design without in-house expertise
- Improved accuracy vs Discrete solutions
- Segmental BIA for better body part specific measurements
- Eliminates electrode impedance related inaccuracies
- Low power enhances battery lifetime

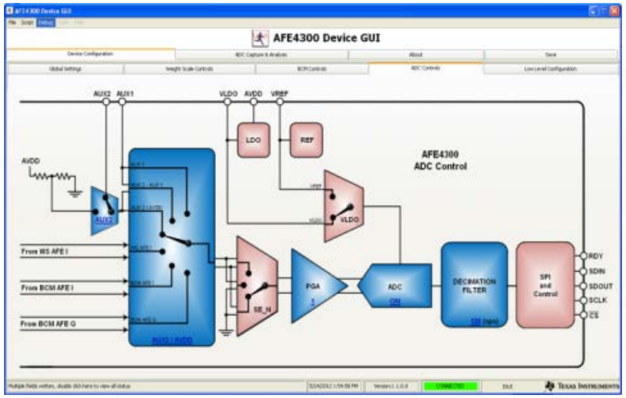


Body Composition Eval Module

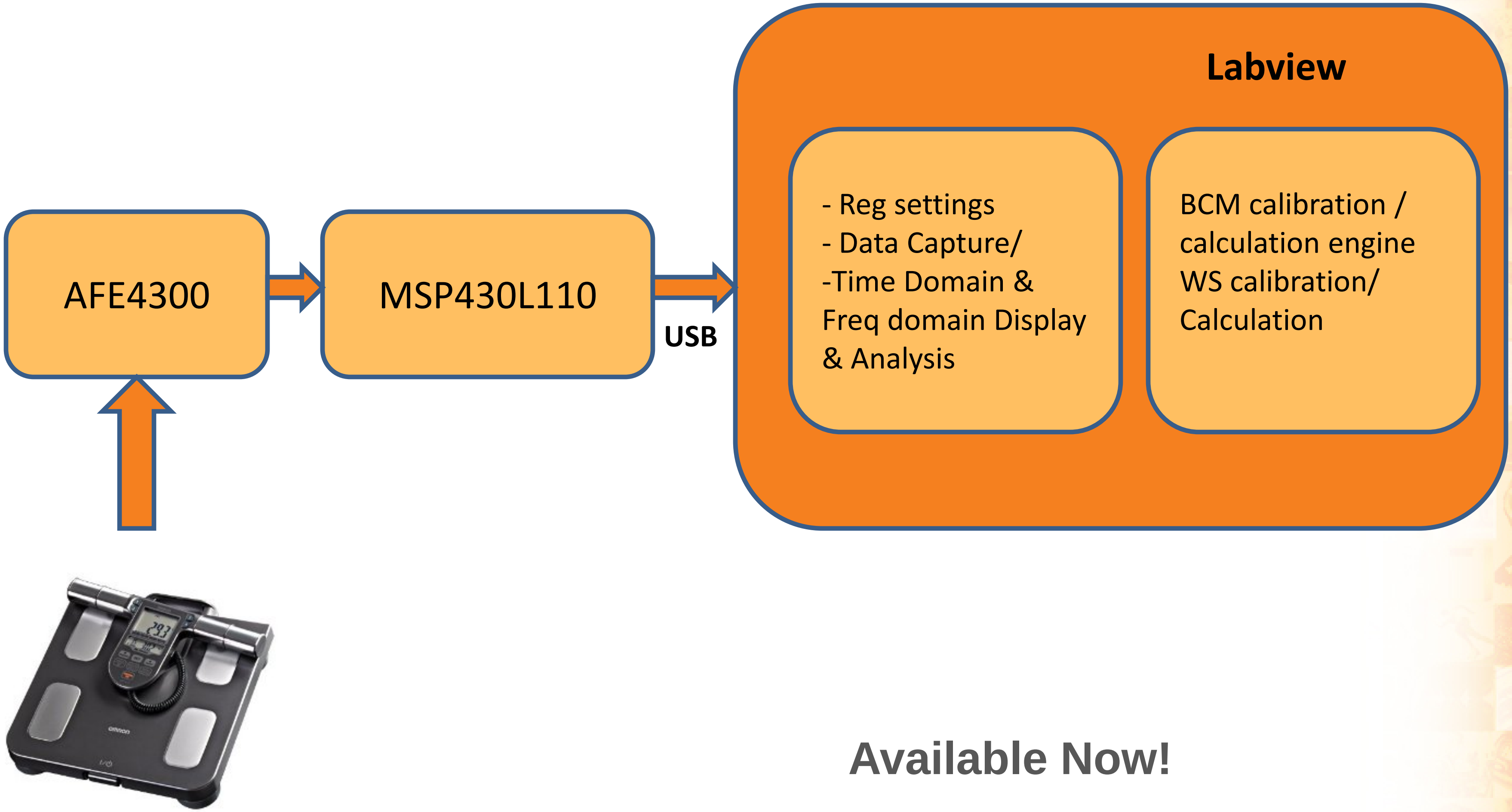


AFE4300EVM-PDK

- Fully functional development Kit
- Support for three tetra-polar impedance measurements
- On-board load cell simulation block
- On-board impedance simulation block
- USB based power and PC application connectivity
- Built-in analysis tools including a virtual oscilloscope, histogram, and FFT on the PC application.



Evaluation Module

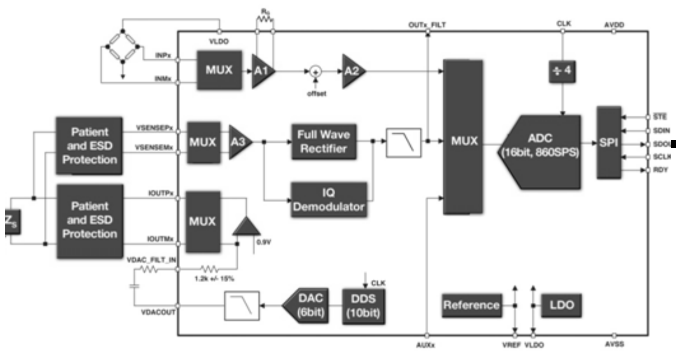


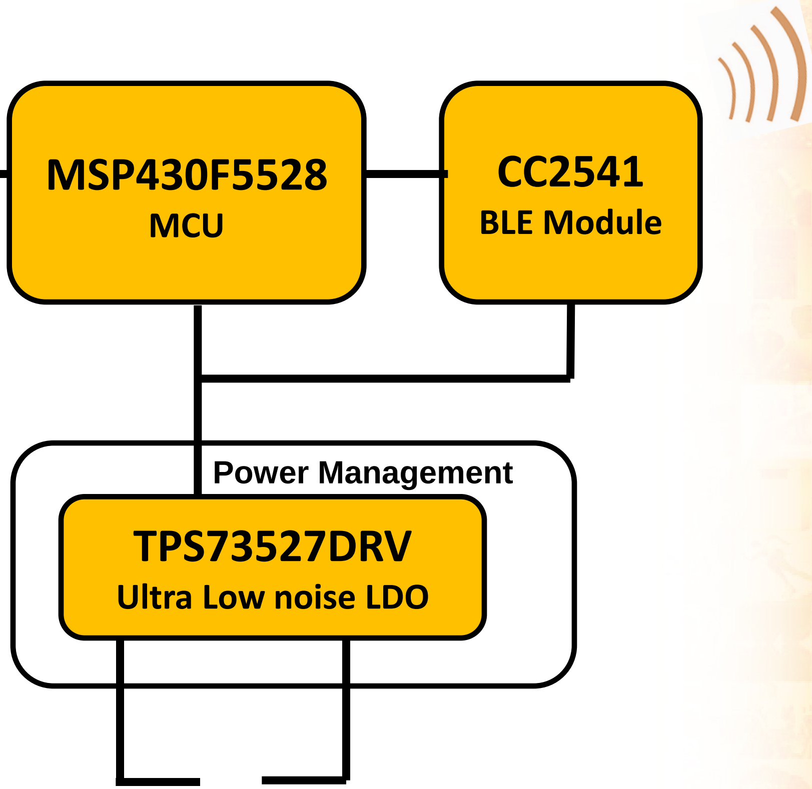
Available Now!

Health Hub: Body Composition

Hand to Hand or
Foot to Foot

AFE4300





Summary

- The AFE4430 is a complete analog front end solution for body composition and weigh scale applications
- Features and Benefits include
  - Complete front end solution = faster time to market
  - Multi-channel and Tetra-polar measurement options = increased accuracy
  - Low power = longer battery
- To learn more or order samples or evaluation module please visit www.ti.com/product/AFE4300