Bioheat Dissipation of an Implantable Brain-Computer Interface

by Jorge Herrera Morales

24.10.2018

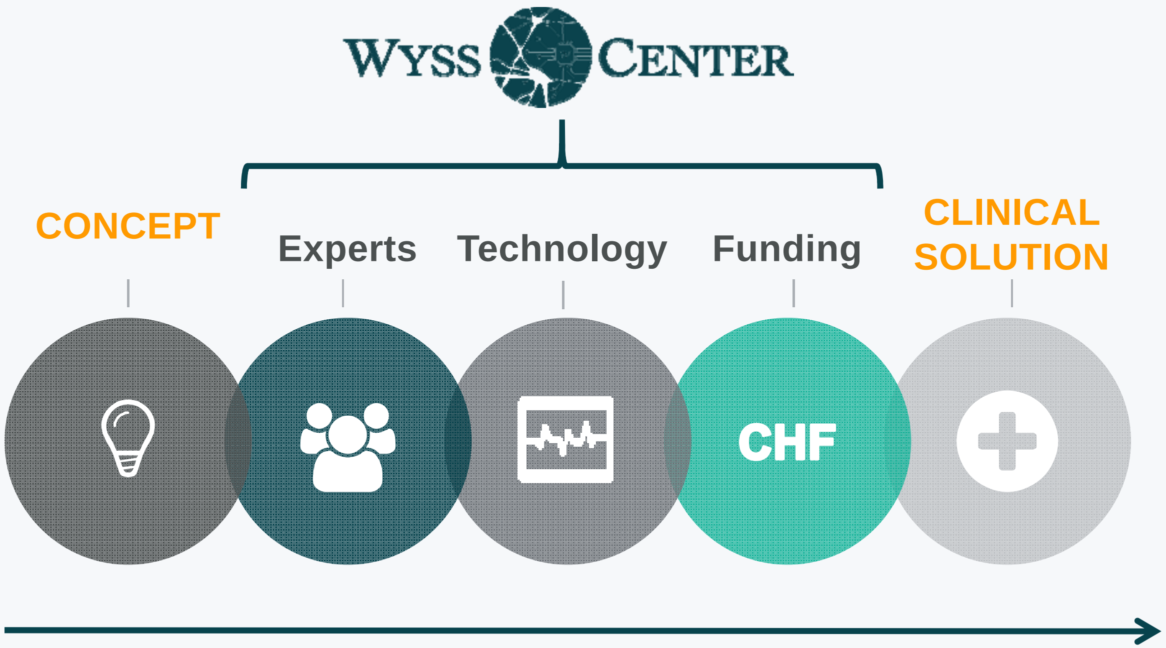
About us

Independent translational organization

Not-for-profit

Based at Campus Biotech, Geneva

Accelerating neurotechnology for human benefit



"Read" the brain

Why?

- Information not available anywhere else
- Access at the source
- Information not any longer transmitted

When?

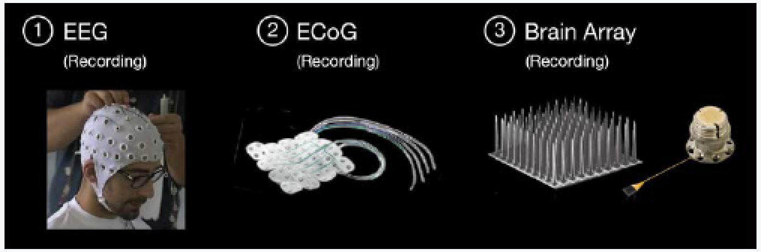
- Once
- From time to time
- Frequently
- Constantly, in real time

Where?

- Outside the head
- Under the scalp
- On the cortex
- In the cortex
- Deep in the brain

How?

- Tissue interface
- Pick the signals
- Transfer the signals
- Decode



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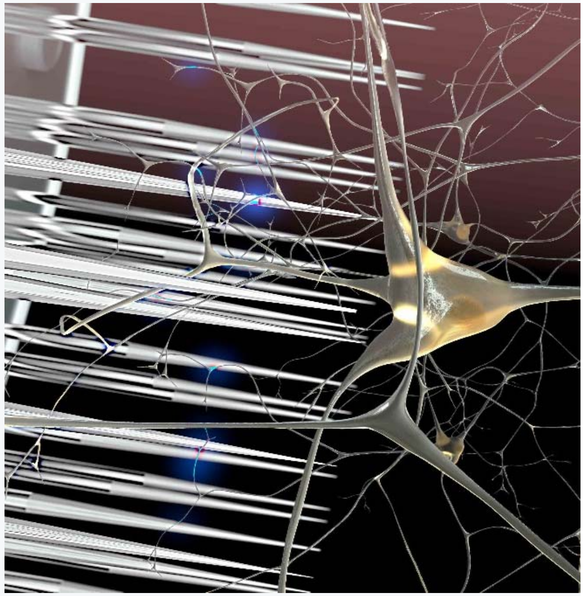
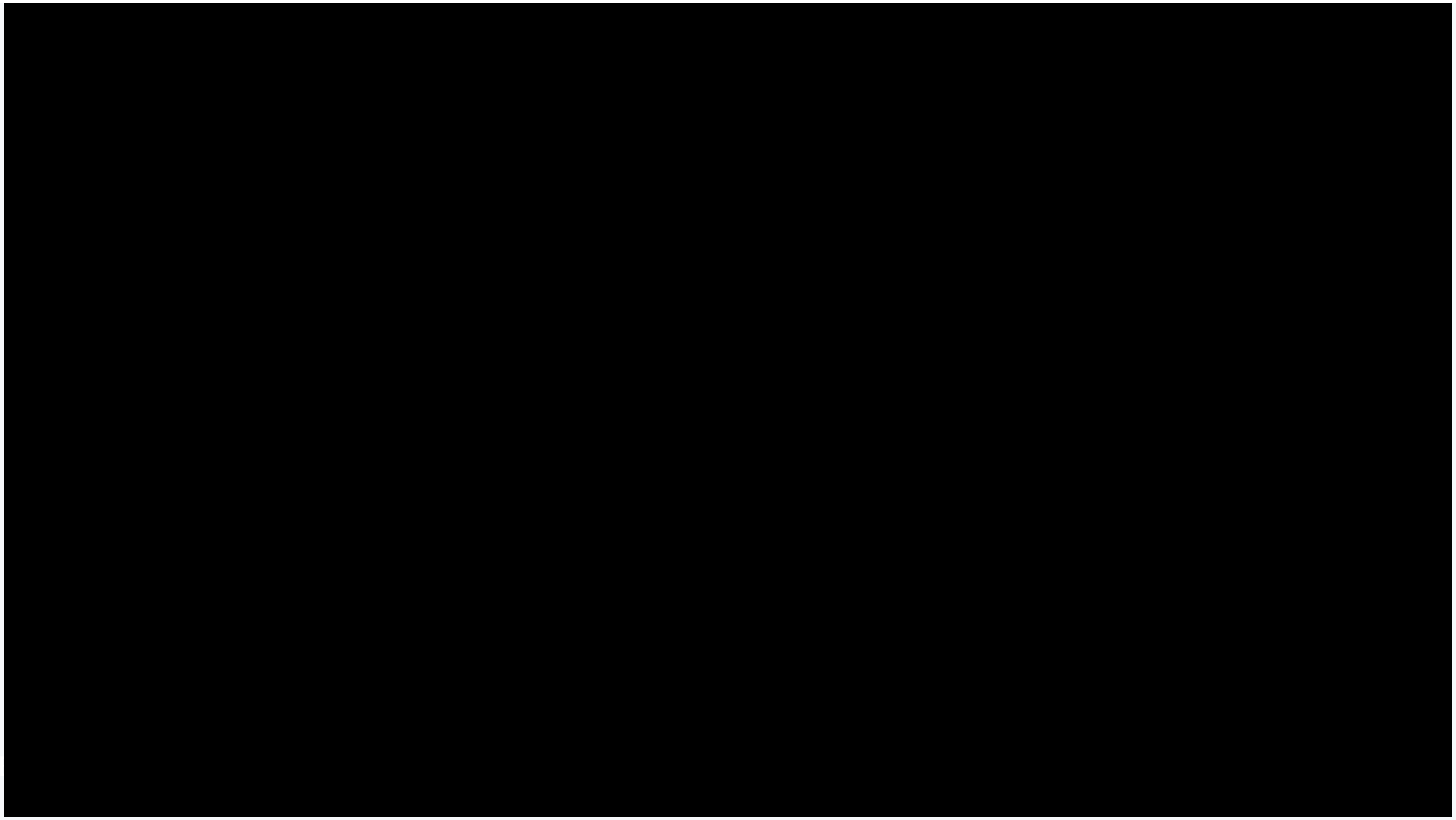
Brain Computer Interface (BCI)

Listen to the crowd



Listen to individuals

WYSS CENTER **Why do we need to go implantable?**



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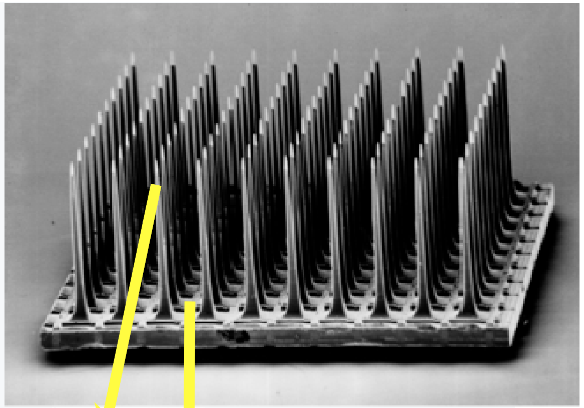
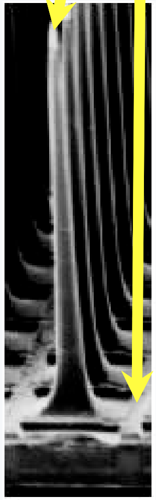
Where we want to go

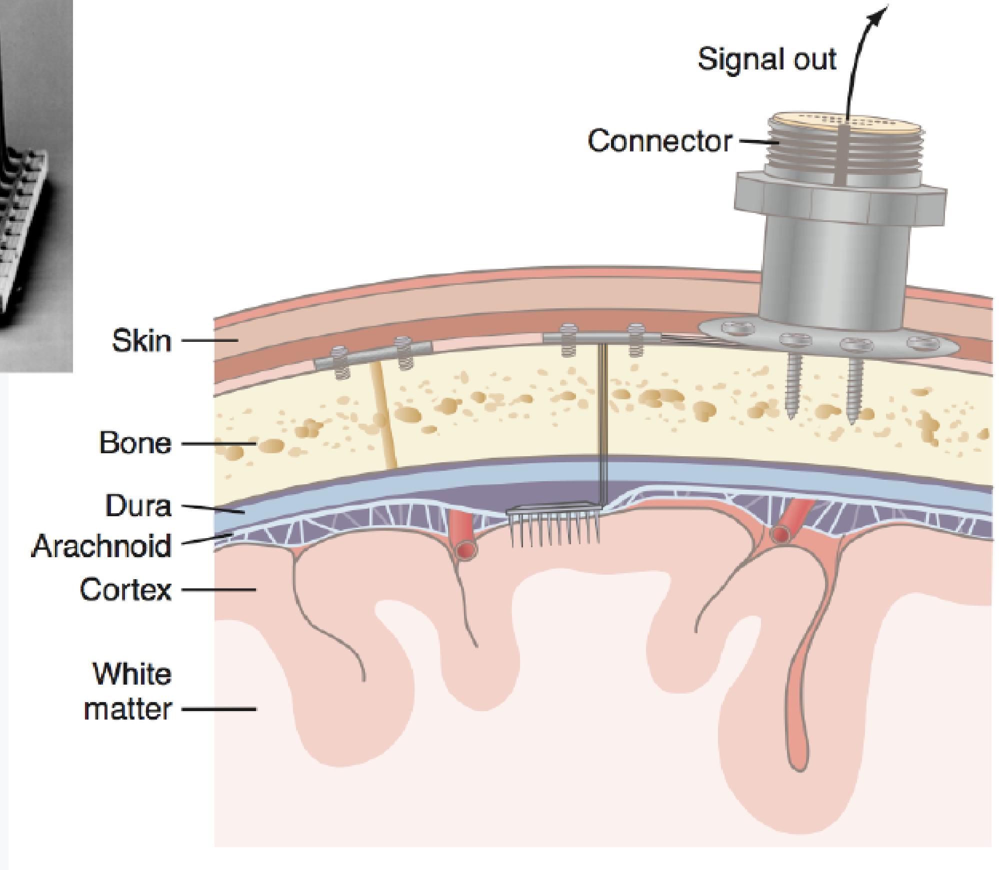

The Lancet 2017

Sensor:
100
Microelectrodes
Array 4 x4 mm

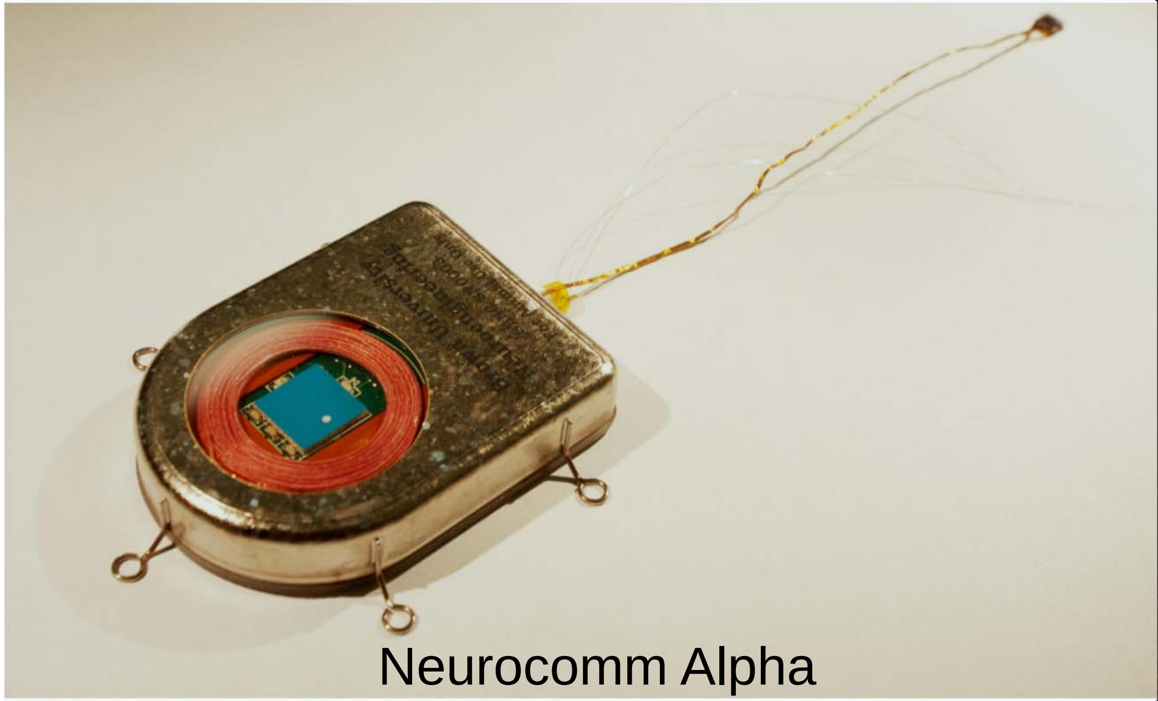


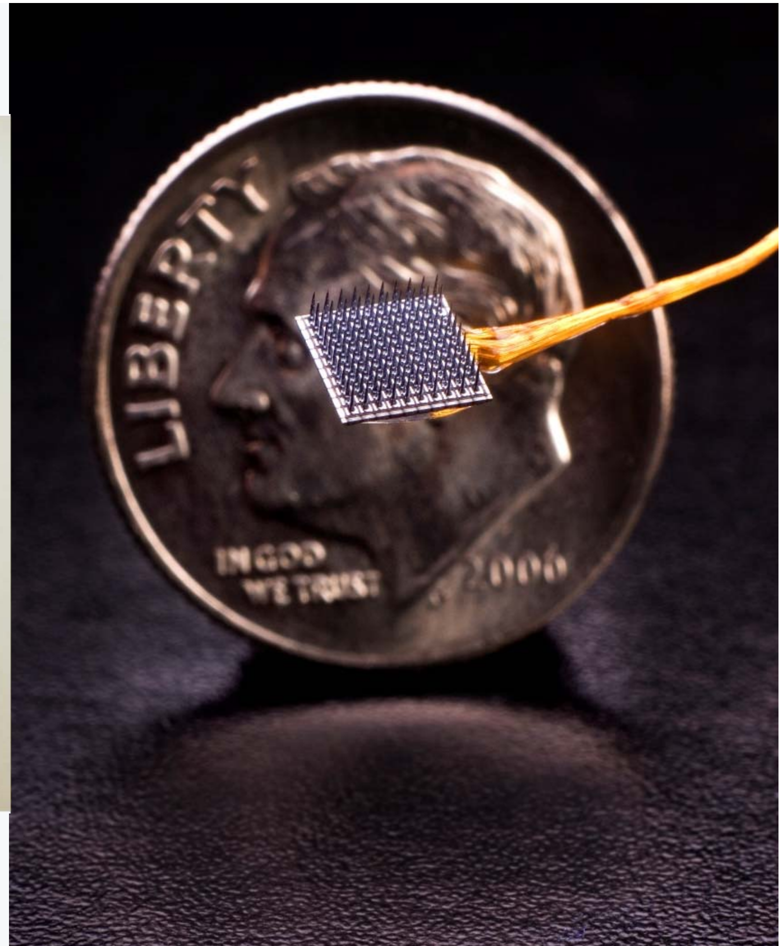


R. Normann Utah
J.P. Donoghue Brown
Cyberkinetics
Blackrock Microsystems
‘neuroport’

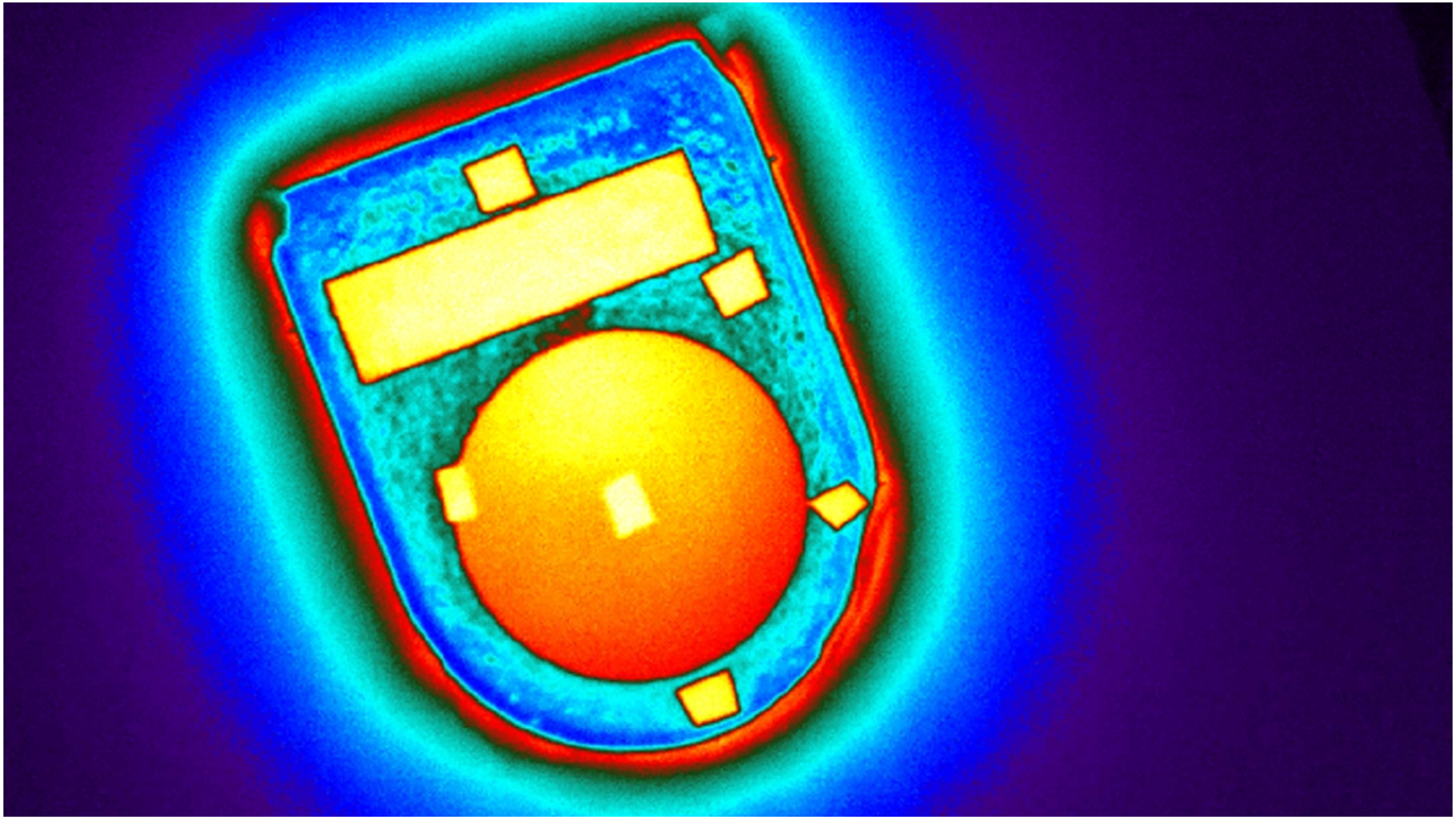


Wired Intracortical BCI


Neurocomm Alpha



Wireless Intracortical BCI



Bioheat dissipation limited to +2°C

INTERNATIONAL STANDARD

ISO 14708-1

Second edition
2014-08-15

Implants for surgery — Active implantable medical devices —

Part 1:
General requirements for safety, marking and for information to be provided by the manufacturer

Clause 17.1
Protection from harm to the patient caused by heat

In the absence of external influence, **no outer surface** of an implantable part of the active implantable medical device not intended to supply heat to the patient **shall be greater than 2 °C above the normal surrounding body temperature of 37 °C when implanted**, and when the active implantable medical device is in normal operation or in any single component failure (see 19.3).

NOTE: Examples of external influences include exposure to MRI, electrosurgery, external defibrillation, ultrasound and electromagnetic fields.

Compliance is checked by inspection of a design analysis provided by the manufacturer, **supported by the manufacturer's calculations and data from test studies**, as appropriate.

Methods

COMSOL Multiphysics 5.3 with Heat Transfer Module and LiveLink for SOLIDWORKS were used to solve the Bioheat Transfer equation [1] to obtain the temperature distribution of tissue in contact with our wireless BCI :

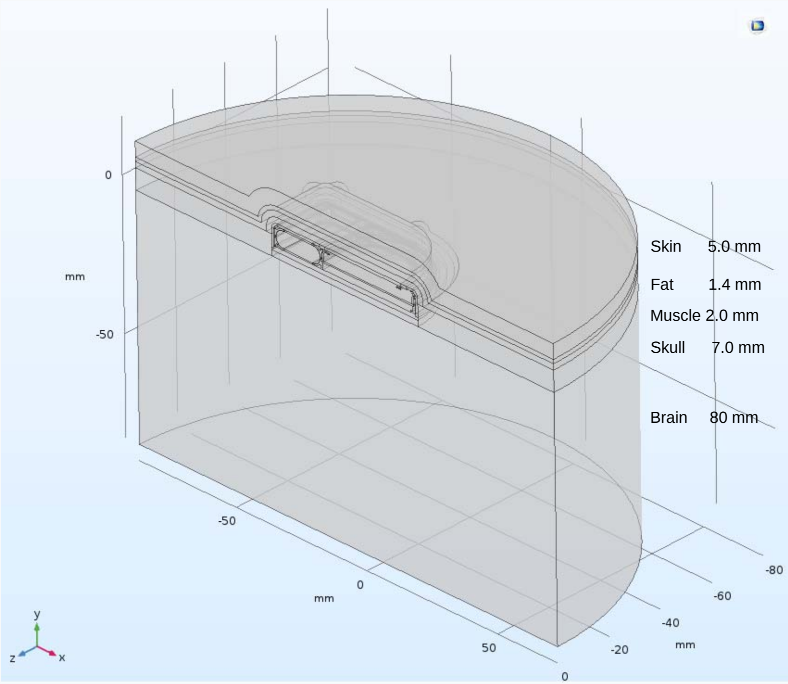
$$\underbrace{C\rho\frac{\partial T}{\partial t}}_{\substack{\text{Thermal}\\\text{Elevation}}} = \underbrace{\nabla\cdot(K\nabla T)}_{\substack{\text{Thermal Spatial}\\\text{Diffusion}}} + \underbrace{A_0}_{\substack{\text{Tissue}\\\text{Metabolism}}} - \underbrace{B_0(T-T_B)}_{\substack{\text{Blood Perfusion}\\\text{Coefficient}}} + \underbrace{\rho\text{SAR} + P^{\text{Density}}_{\text{Electronics}}}_{\text{External Heat Sources}} \left[\frac{W}{m^3}\right]$$

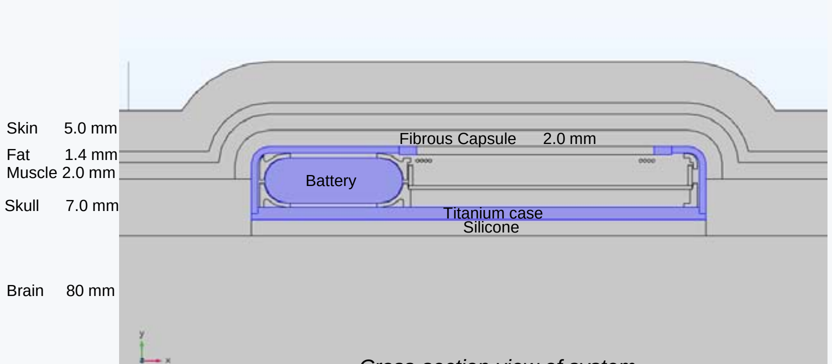
This model includes heat conduction, convection through blood flow, metabolic heat generation in the tissue, and heat generation by eddy currents. Tissues were assumed to be homogeneous and isotropic. Blood's specific heat of 3840 J/kg/K and density of 1060 kg/m^3 were used with the following values :

Tissue	Thickness (mm)	Blood perfusion rate (1/s)	Metabolic rate (W/m^3)	Heat capacity C_p (J/kg/K)	Density (kg/m^3)	Conductivity (W/m/K)
Skin, Fib. capsule	5.0 , 2.0	2.57 E-3	1000	3500	1010	0.420
Fat	1.4	2.3 E-3	180	2500	920	0.250
Muscle	2.0	7.21 E-4	690	3600	1040	0.498
Skull	7.0	4.0 E-5	0	1300	1810	0.300
Brain	80	9.32 E-3	10000	3600	1043	0.503

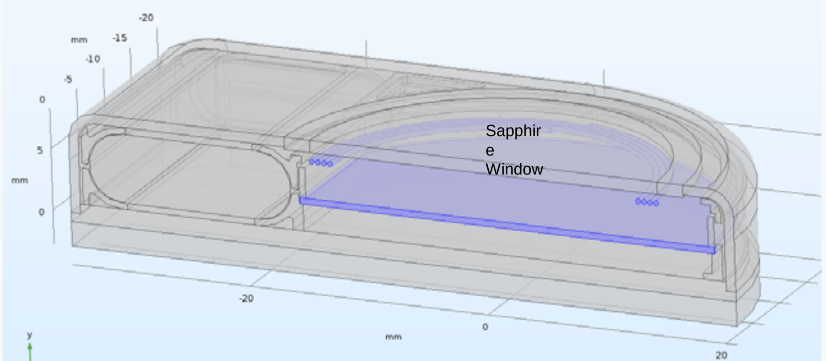
Table 1: Bioheat equation parameters of the head main tissues [2]

Geometry & Materials





Cross-section view of system



Induction coil and copper shield

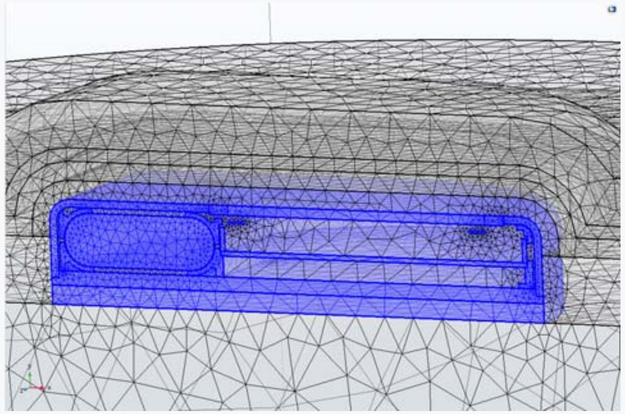
Model details

Physics

Type	Heat Transfer in Solids (ht)
Initial Temperature	310.15 K
Thermal properties	From material

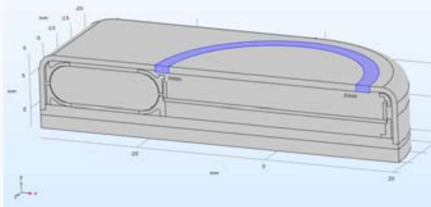
Mesh

Size	Component-dependent
Sequence type	User-controlled mesh
Number of elements	246344
Average elem. quality	0.6001



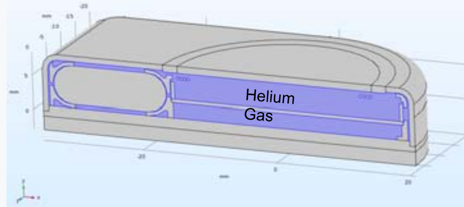
Heat Source

Location	Around window
Power	range(0.3,0.1,1.4) W



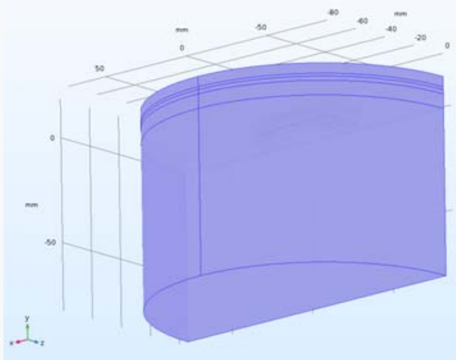
Fluid

Equivalent conductivity for convection
Horizontal cavity heated from below



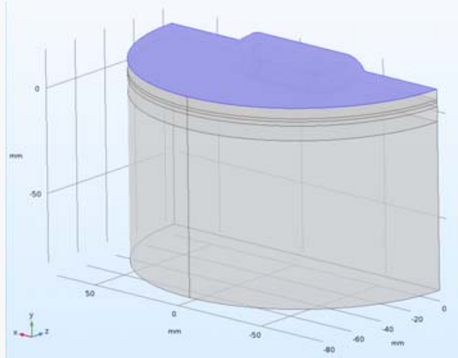
Temperature

Location	Edges of system
System size	80 mm
Value	310.15 K



Heat Flux

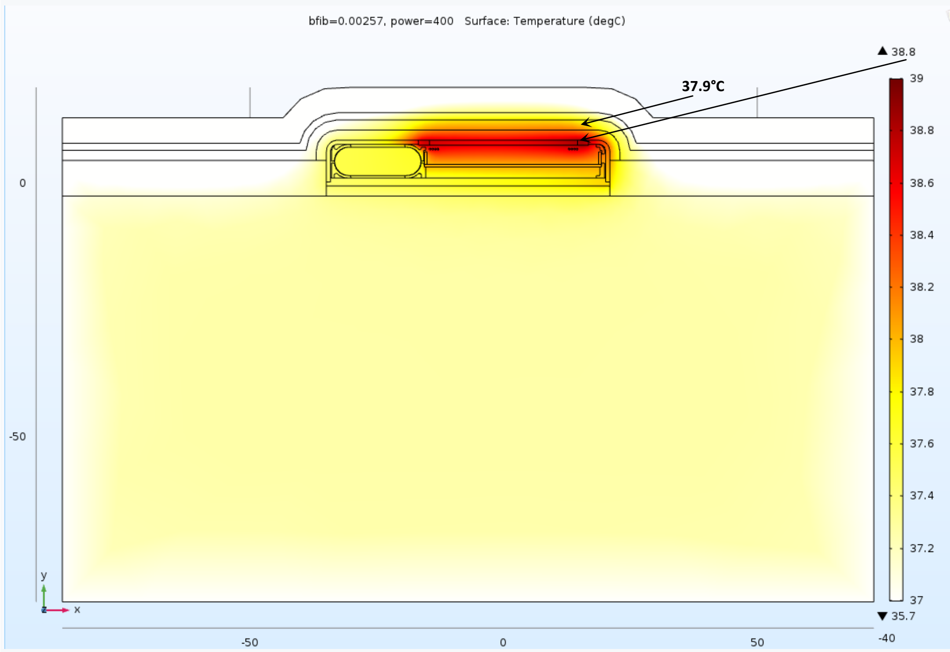
Type	Convective heat flux
Heat Transfer Coeff.	5 $W/m^2/K$
Location	Upper Skin surface



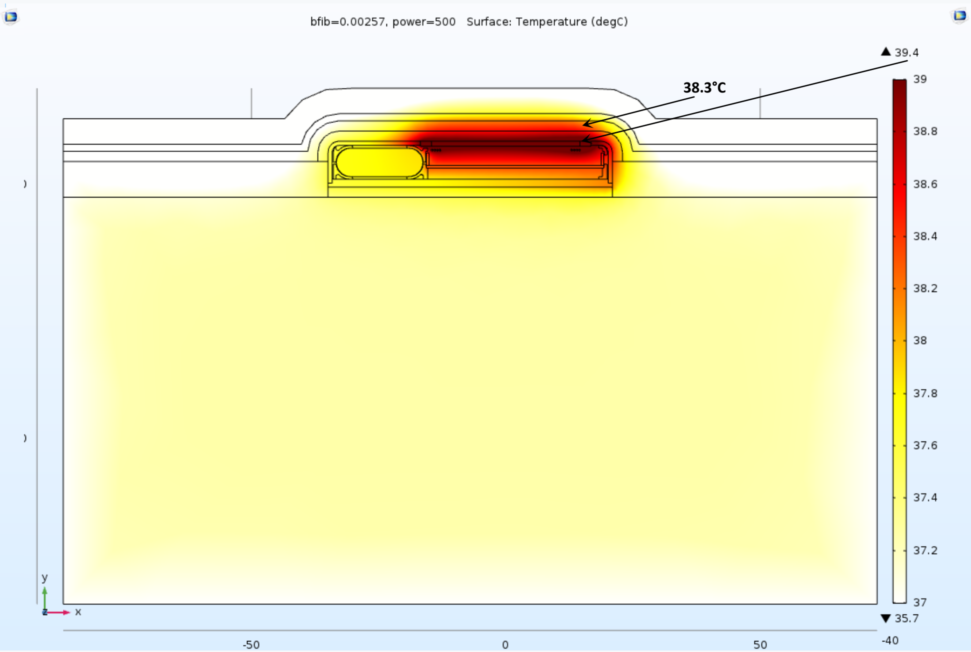
Worst-scenario results

No angiogenesis occurs (ex. Prutchi2013) so Fibrous capsule blood perfusion rate = $2.57 * 10^{-3}\ s^{-1}$

- Temperature applied on tissues with **400 mW** of heat



- Temperature applied on tissues with **500 mW** of heat

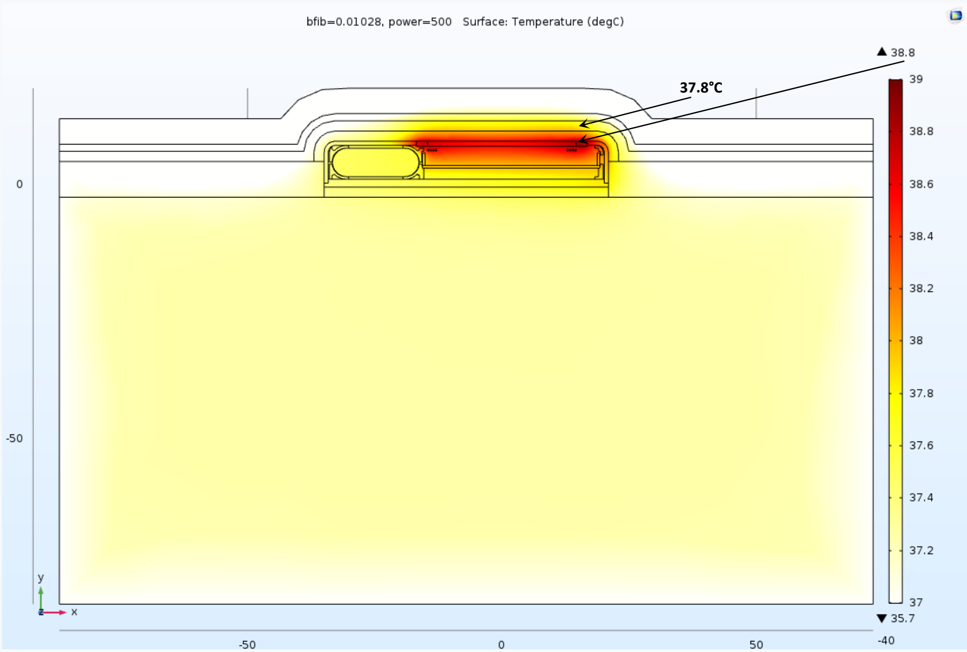


Bioheat dissipation per surface area = 6.1 mW/cm²/°C

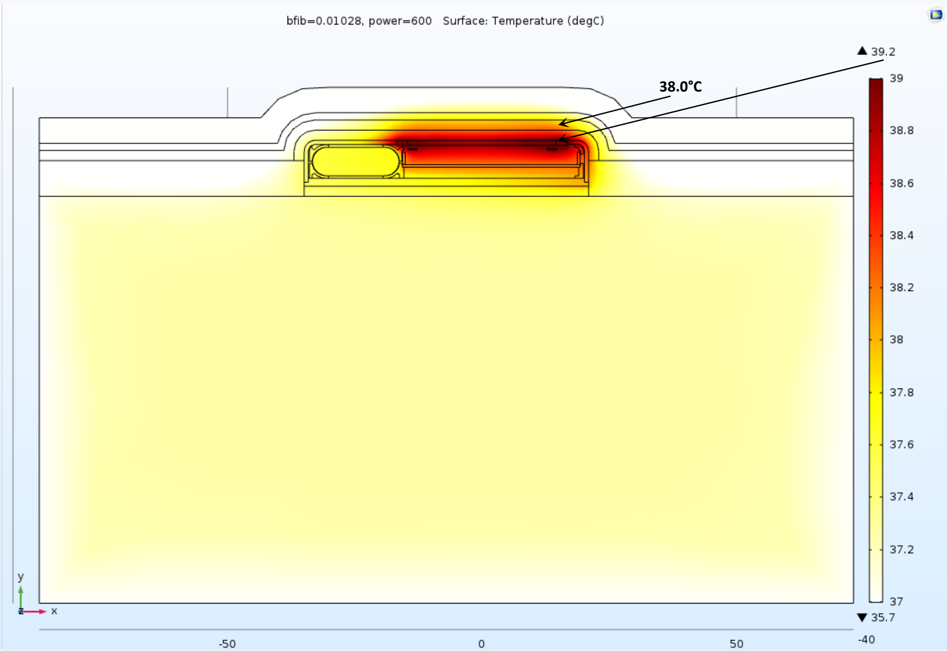
Best-scenario results

Angiogenesis increases Fibrous capsule blood perfusion rate by 400% (ex. Davies1994) to $10.28 * 10^{-3}$ s^{-1}

- Temperature applied on tissues with **500 mW** of heat



- Temperature applied on tissues with **600 mW** of heat



Bioheat dissipation per surface area = 7.8 mW/cm²/°C

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References

[1] P. Wolf, Indwelling Neural Implants: Strategies for Contending with the In Vivo Environment, W. M. Reichert, Ed. Boca Raton: CRC Press/Taylor & Francis, 2008.

[2] G. Lazzi et al., Thermal Effects of Bio-Implants. IEEE Eng. Med. Biol. Mag 2005, 24, 75–81. 16248120.

[3] D. Borton et al., M. Yin, J. Aceros, and A. Nurmikko, Journal of Neural Engineering 2013, vol. 10, no. 2, p. 026010.

[4] D. Prutchi, Analysis of Temperature Increase at the Device/Tissue Interface for Implantable Medical Devices Dissipating Endogenous Heat, Impulse Dynamics, 2013.

[5] C. R. Davies et al., Adaptation of Tissue to a Chronic Heat Load, ASAIO Journal 1994, 40(3) : M514–17.

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The Wyss Center

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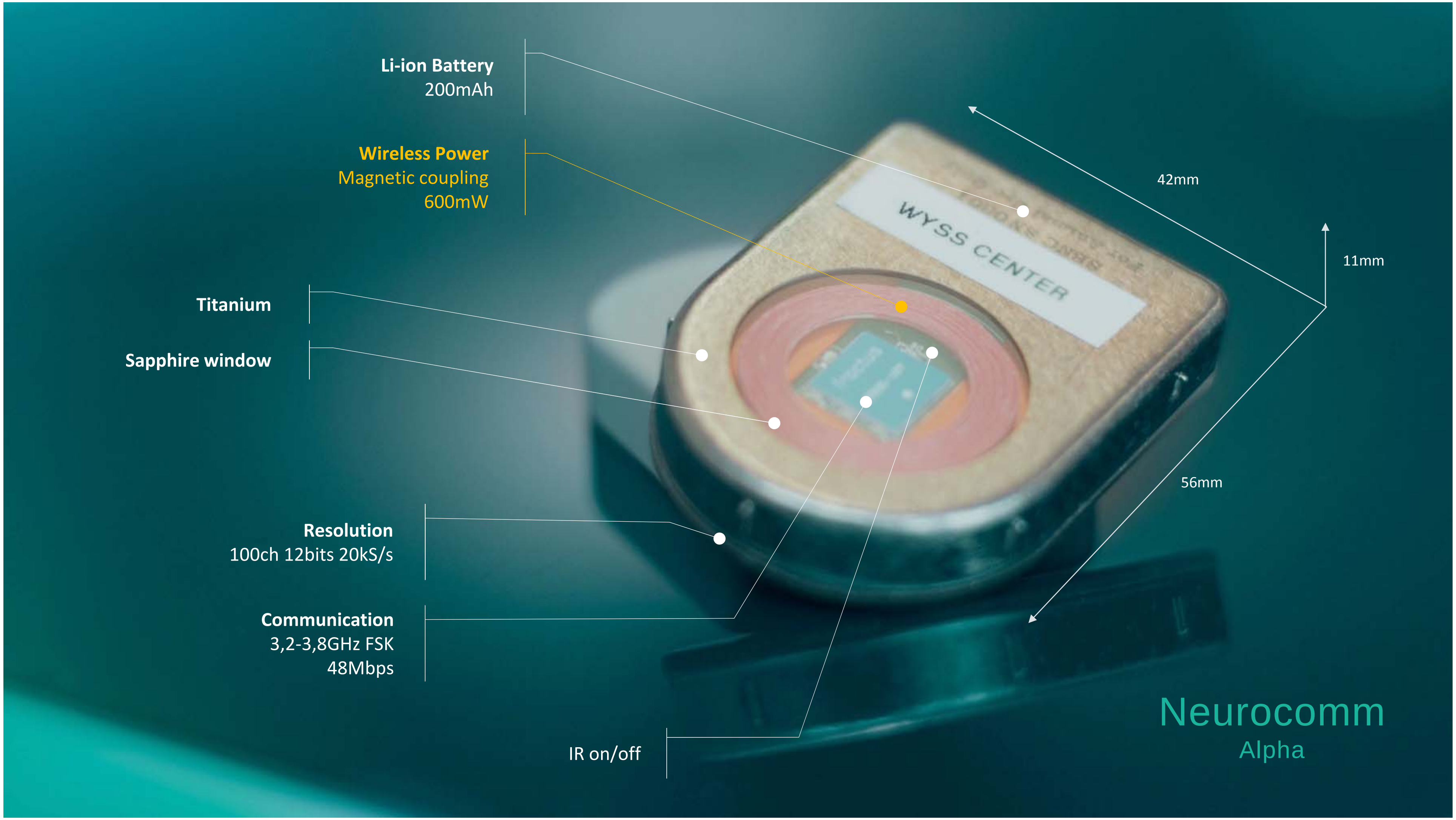
Li-ion Battery
200mAh
Wireless Power
Magnetic coupling
600mW
Titanium
Sapphire window
Resolution
100ch 12bits 20kS/s
Communication
3,2-3,8GHz FSK
48Mbps
IR on/off
42mm
11mm
56mm
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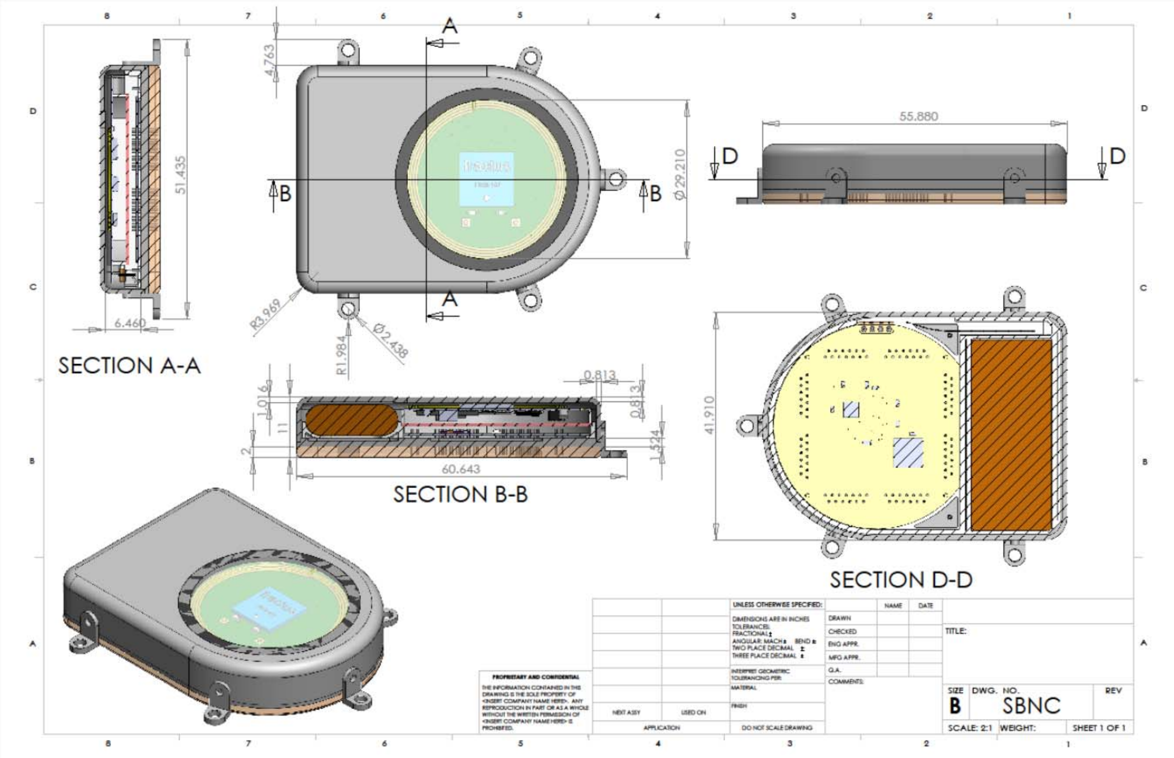
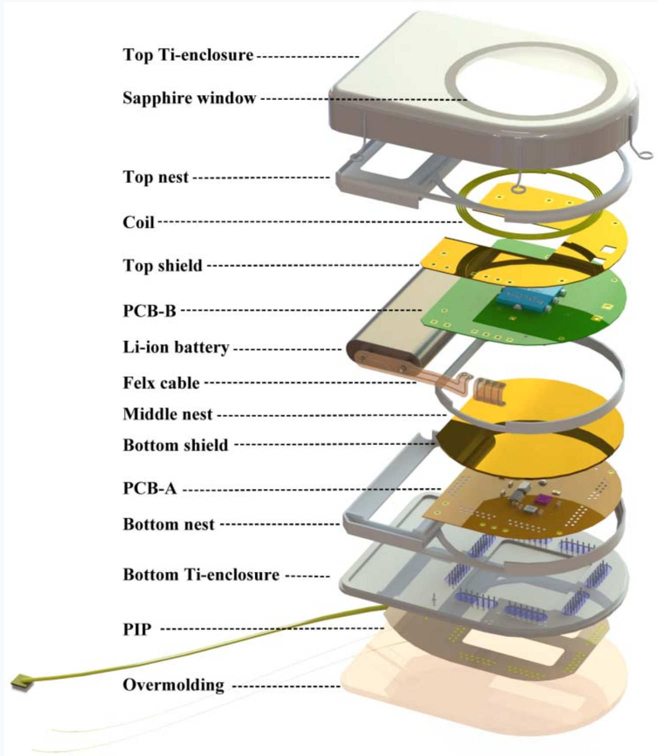
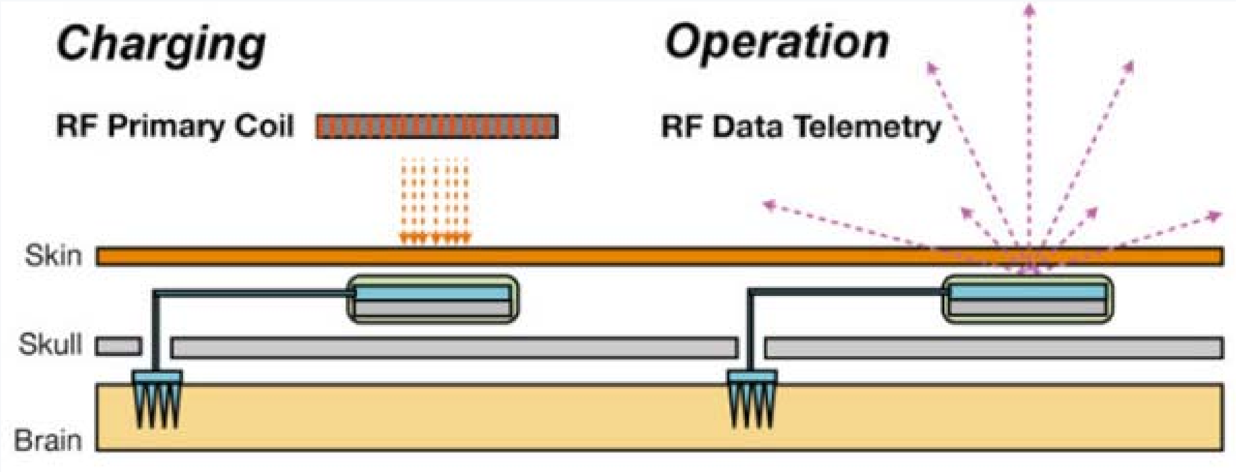
Neurocomm
Alpha


SECTION A-A
SECTION B-B
SECTION D-D
51.435
6.460
4.763
Ø29.210
R3.969
R1.984
Ø2.438
55.880
0.813
1.016
1.524
60.643
41.910
UNLESS OTHERWISE SPECIFIED:
PROPRIETARY AND CONFIDENTIAL
TITLE:
SIZE
B
DWG. NO.
SBNC
REV
SCALE: 2:1
WEIGHT:
SHEET 1 OF 1


Top Ti-enclosure
Sapphire window
Top nest
Coil
Top shield
PCB-B
Li-ion battery
Felx cable
Middle nest
Bottom shield
PCB-A
Bottom nest
Bottom Ti-enclosure
PIP
Overmolding

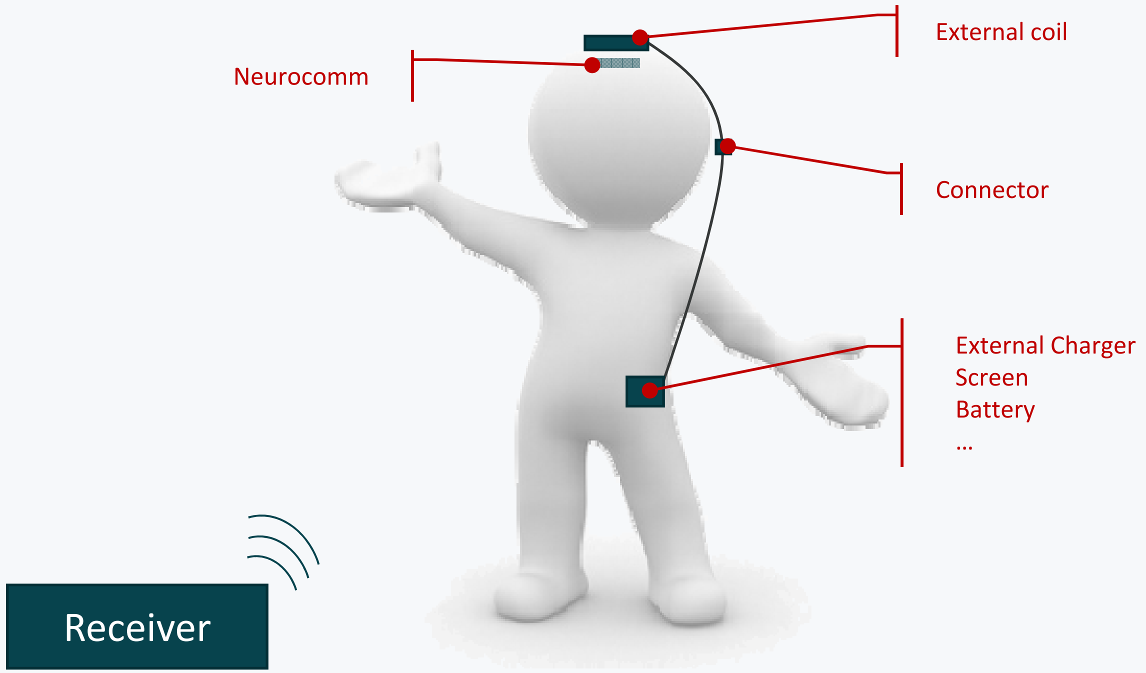
Heating problem in wireless BCI Neurocomm Alpha



cf. D Borton *JNE 10 (2013) 026010*

- Wireless Power Transfer (WPT) efficiency is 30%
- As charging the 200mAh battery at 1C requires 0.6W, up to 1.4W of heat are generated by eddy currents in the titanium can during WPT
- Temperature of any device surface must be less than 39°C (std. ISO 14708-1:2014)

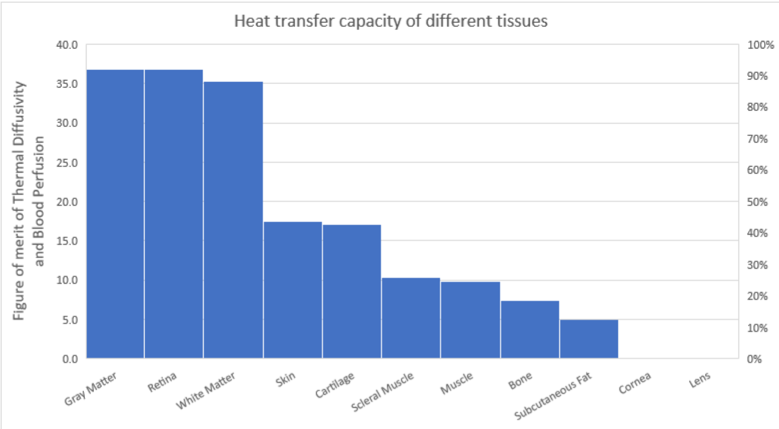
Wireless Power Transfert



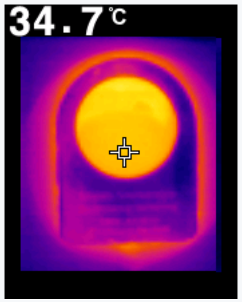
Heat transfer capacity of different tissues

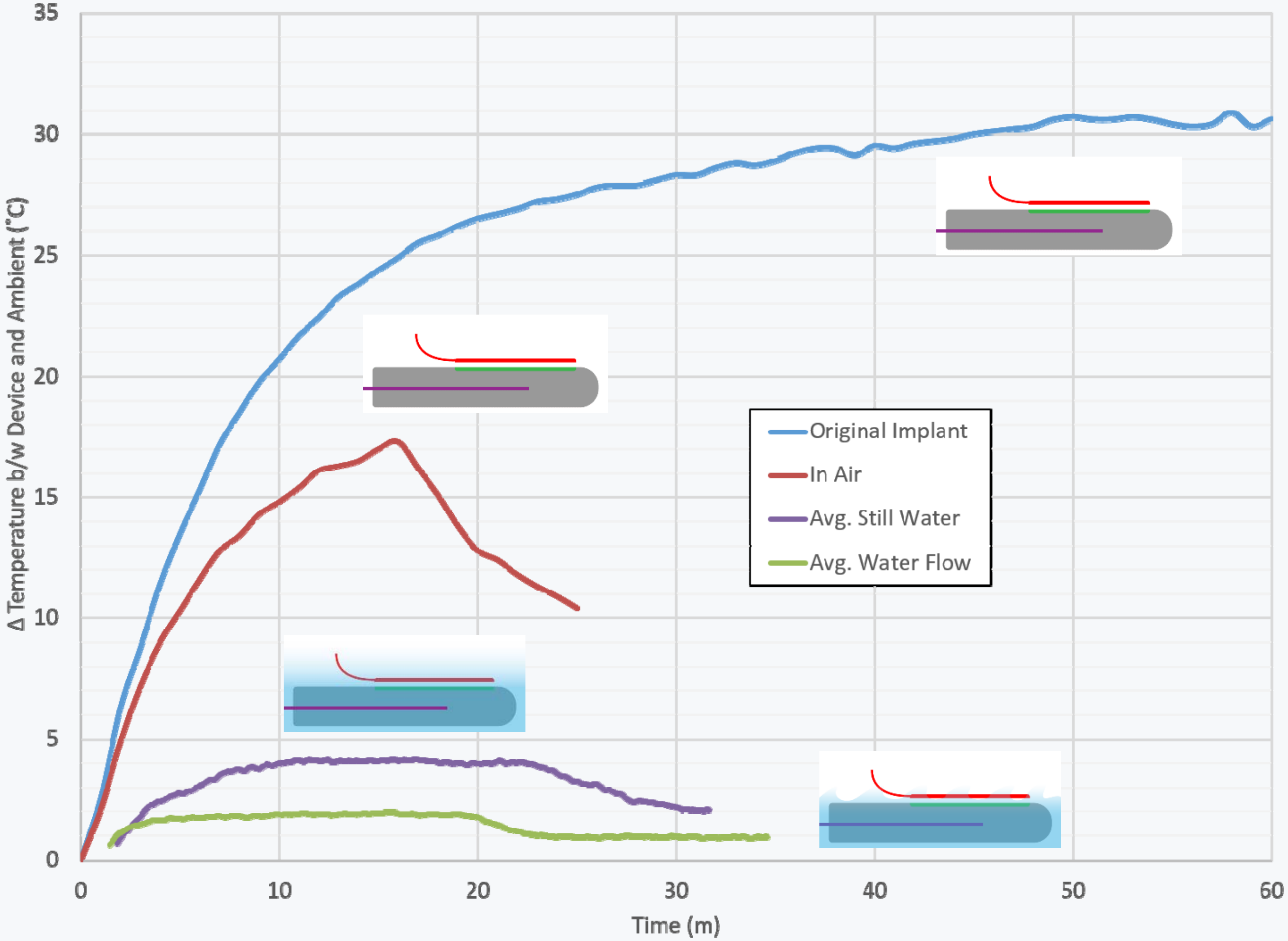
Source: G. Lazzi, Thermal Effects of Bio-Implants. IEEE Eng. Med. Biol. Mag 2005, 24, 75–81. 16248120

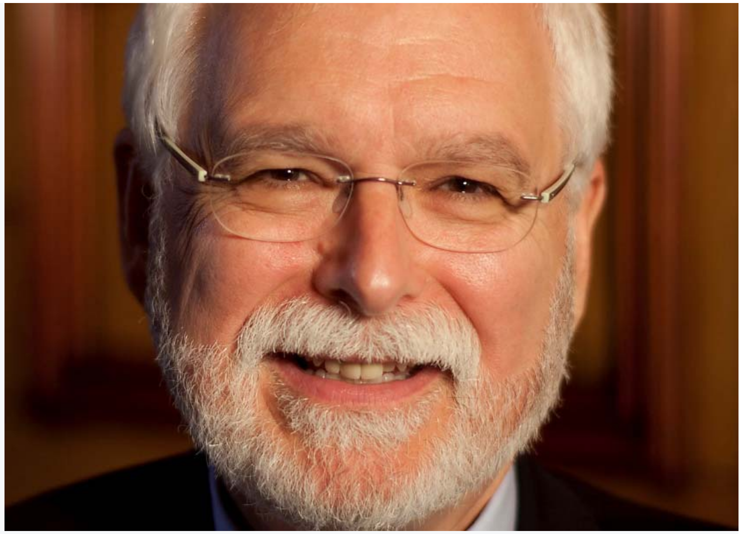
Tissue	Relative Permitivity εr	Conductivity σ (S/m)	Density ρ (kg/m3)	Specific Heat C (J/(kg K))	Conductivity K (J/(m s K)	Blood Perfusion B (J/(m3 s K))	Metabolic Rate A0 (J/(m3 s))	Diffusivity α (m2/s)	Blood Perfusion B' (s-1)	Figure of merit (αB')^0.5 (um/s)
Muscle	826	0.5476	1,040	3,600	0.498	2,700	690	1.33E-07	7.21E-04	9.8
Bone	106	0.0285	1,810	1,300	0.3	1,000	0	1.27E-07	4.25E-04	7.4
Cartilage	815.5	0.2776	1,100	3,400	0.45	9,100	1,000	1.20E-07	2.43E-03	17.1
Skin	858	0.0371	1,010	3,500	0.42	9,100	1,000	1.19E-07	2.57E-03	17.5
Subcutaneous Fat	22.95	0.0255	920	2,500	0.25	520	180	1.09E-07	2.26E-04	5.0
Gray Matter	656.5	0.1807	1,039	3,680	0.565	35,000	10,000	1.48E-07	9.15E-03	36.8
White Matter	340.6	0.1118	1,043	3,600	0.503	35,000	10,000	1.34E-07	9.32E-03	35.3
Scleral Muscle	826	0.5476	1,040	3,430	0.498	2,700	690	1.40E-07	7.57E-04	10.3
Cornea	1,429	0.7438	1,076	4,178	0.58	0	0	1.29E-07	0.00E+00	0.0
Lens	829.7	0.417	1,100	3,000	0.4	0	0	1.21E-07	0.00E+00	0.0
Retina	1,145	0.6889	1,039	3,680	0.565	35,000	10,000	1.48E-07	9.15E-03	36.8

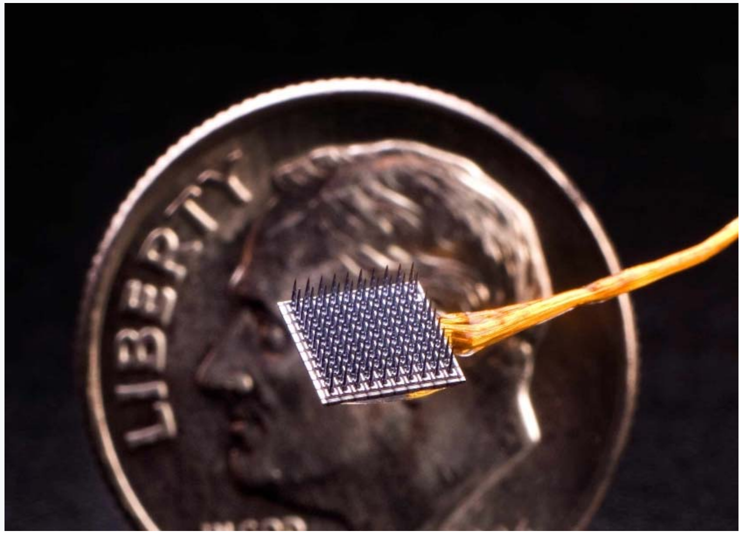


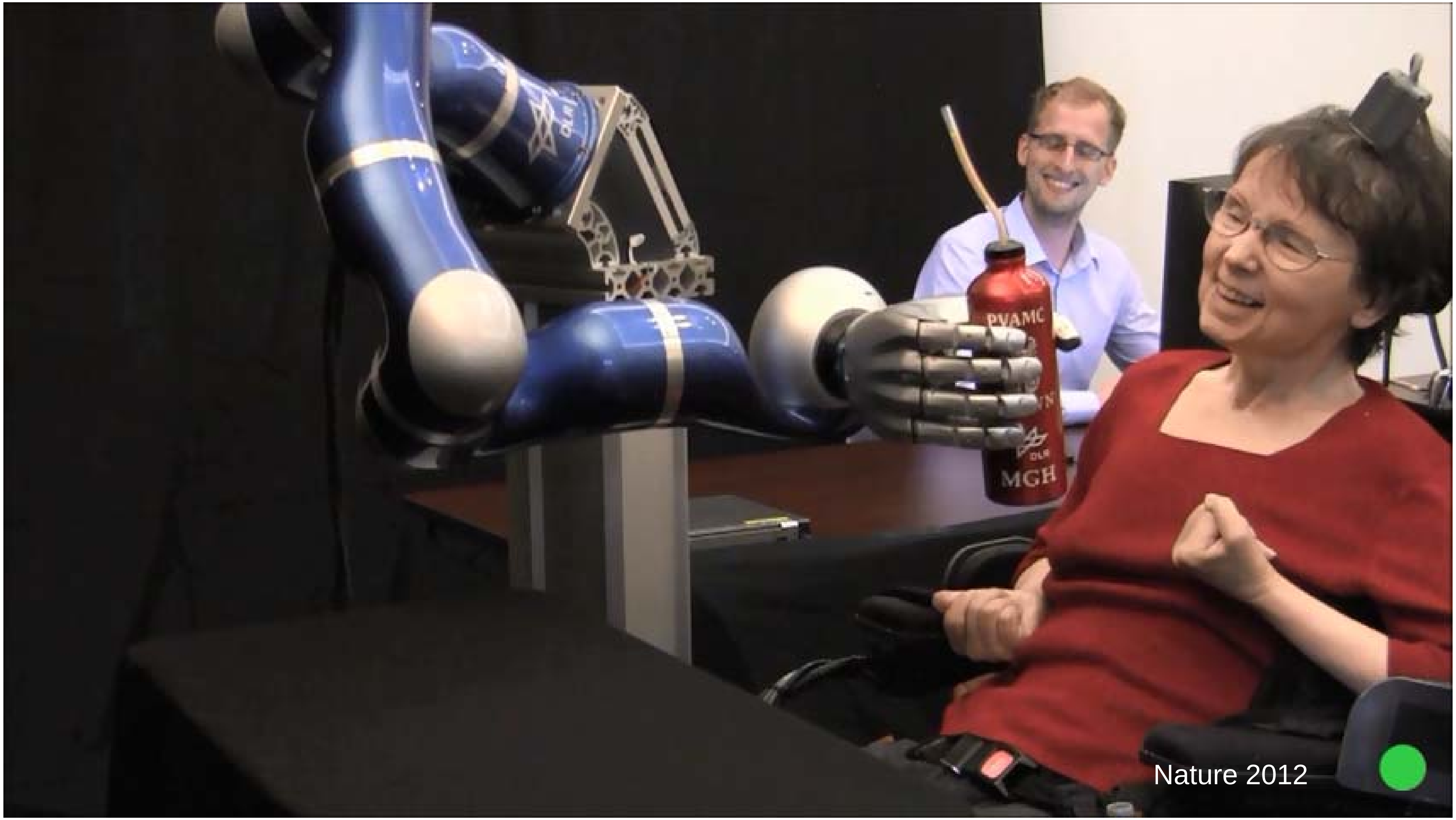
Experimental Data on Thermal Profile Overview








LIBERTY



Nature 2012

Accelerating neurotechnology for human benefit

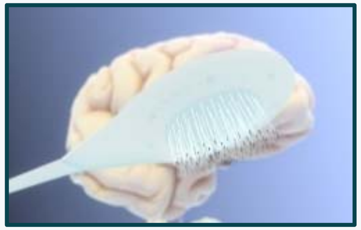
Stroke therapy

Movement & communication restoration

Epilepsy Tinnitus Dyslexia

Vision diagnostics

Advanced technology components



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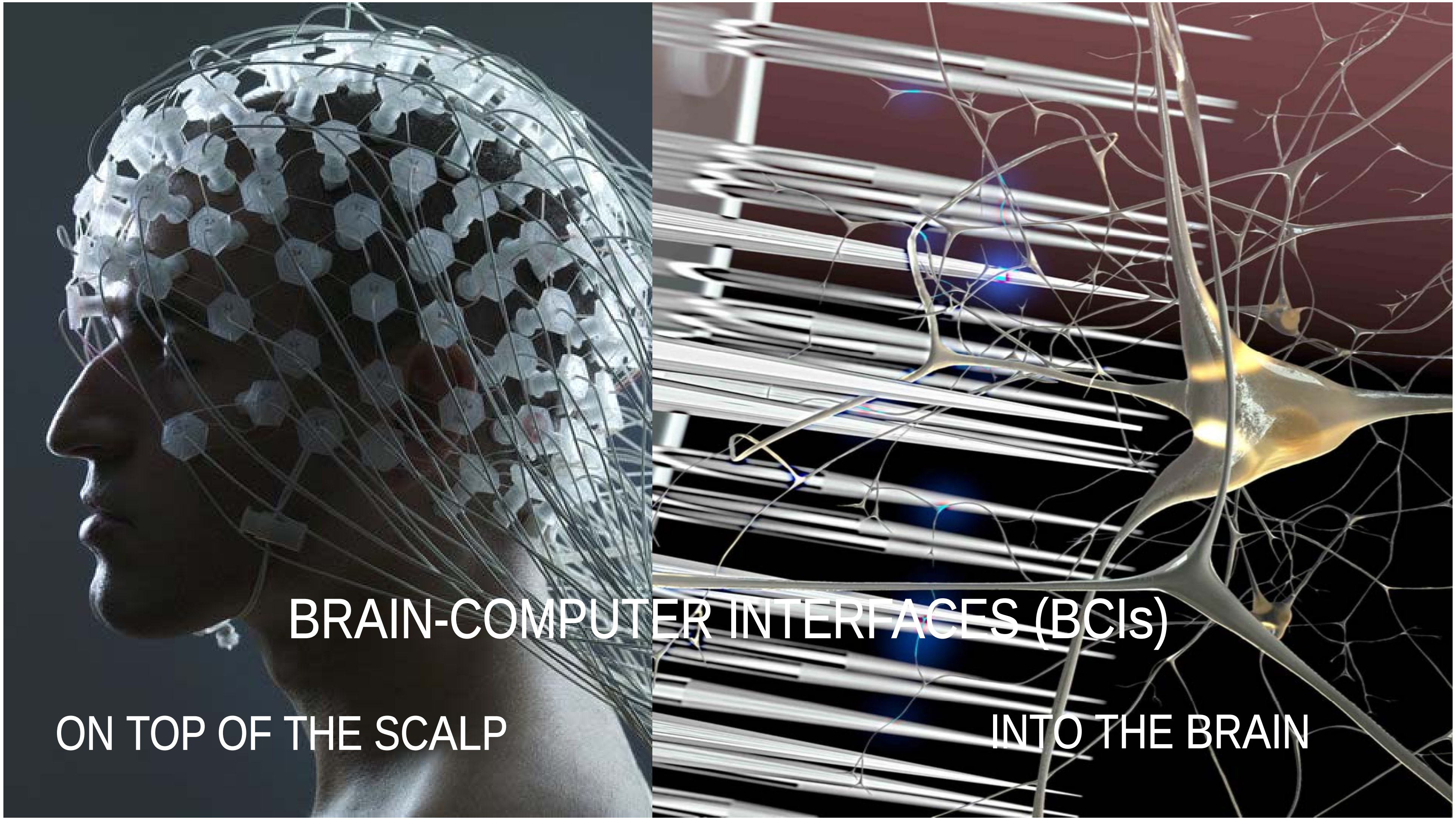
BRAIN-COMPUTER INTERFACES (BCIs)
ON TOP OF THE SCALP
INTO THE BRAIN