Circuits and Systems for Wireless Body Area Networks (WBAN)

Fernando Rangel de Sousa

JULY/2015

Outline

- WBAN Review
- WBAN Research at UFSC
  - HBC Channel characterization
  - RF-powered temperature sensor
  - Wireless power transmission to miniaturized implants
  - Energy harvesting
  - ISFET for pH and glicose measurement
  - Flexible sensors
- Concluding remarks

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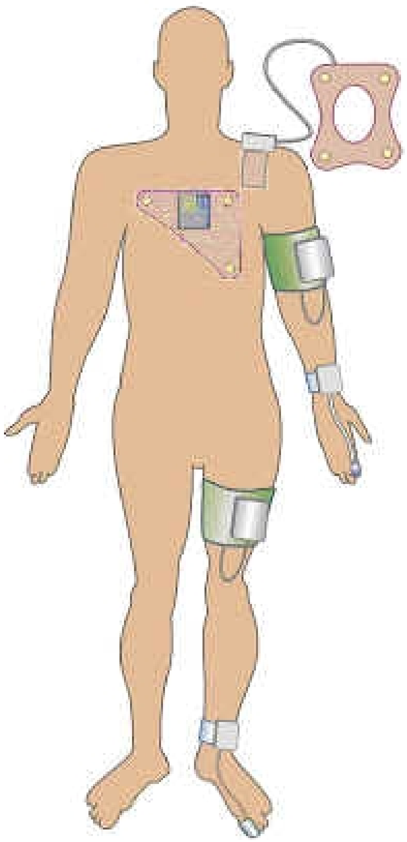
Why do we need a Body Sensor Network ?

- The ideal place to monitor different vital signals, to perform electrical stimulation or to inject therapeutic drugs does not happen at the same point.
- Lifes can saved if the diagnostic of a disease can be obtained in real time, while the patient executes daily tasks.
- A WBAN must:
  - provide communication links in/on the body or around it.
  - Allow the communication between sensors, actuators and processing of energy and information.



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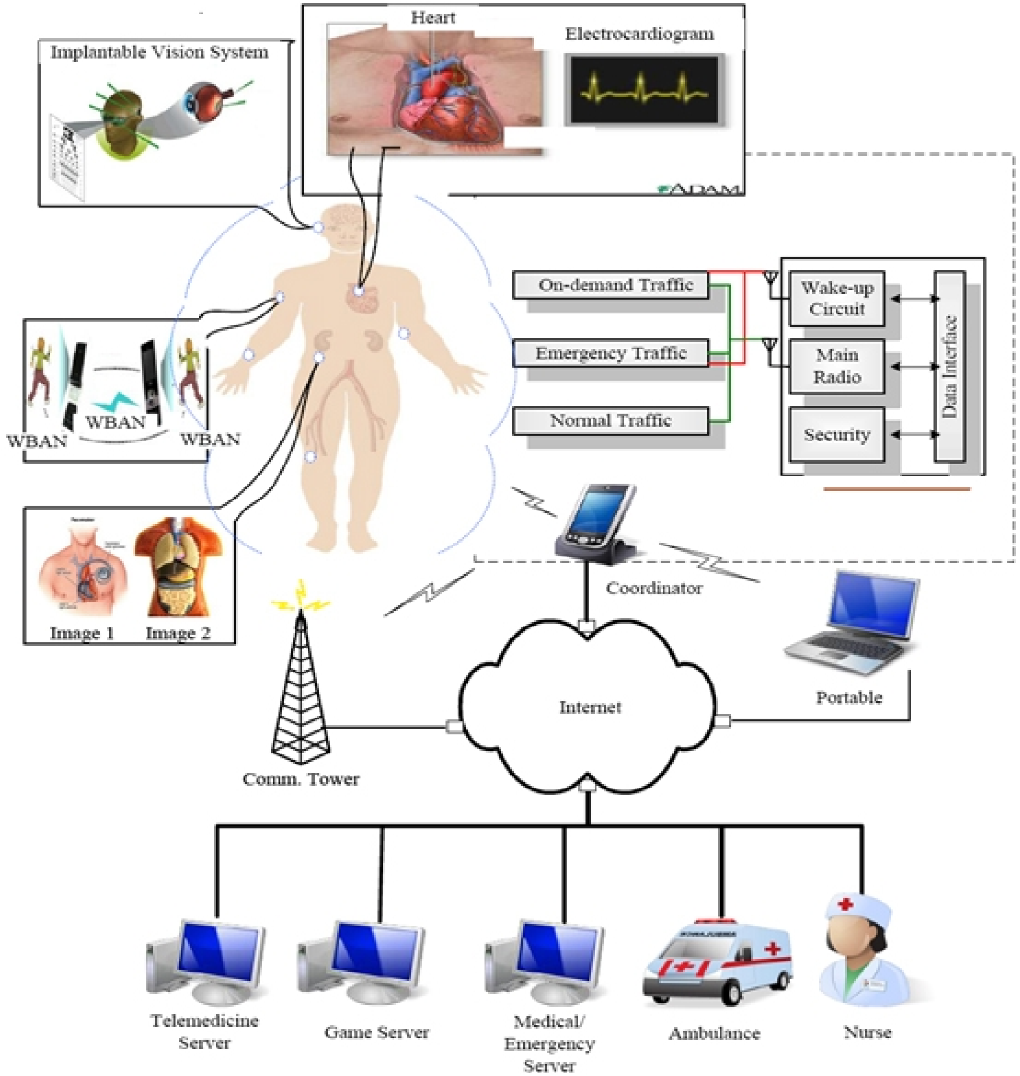
A typical WBAN scenario



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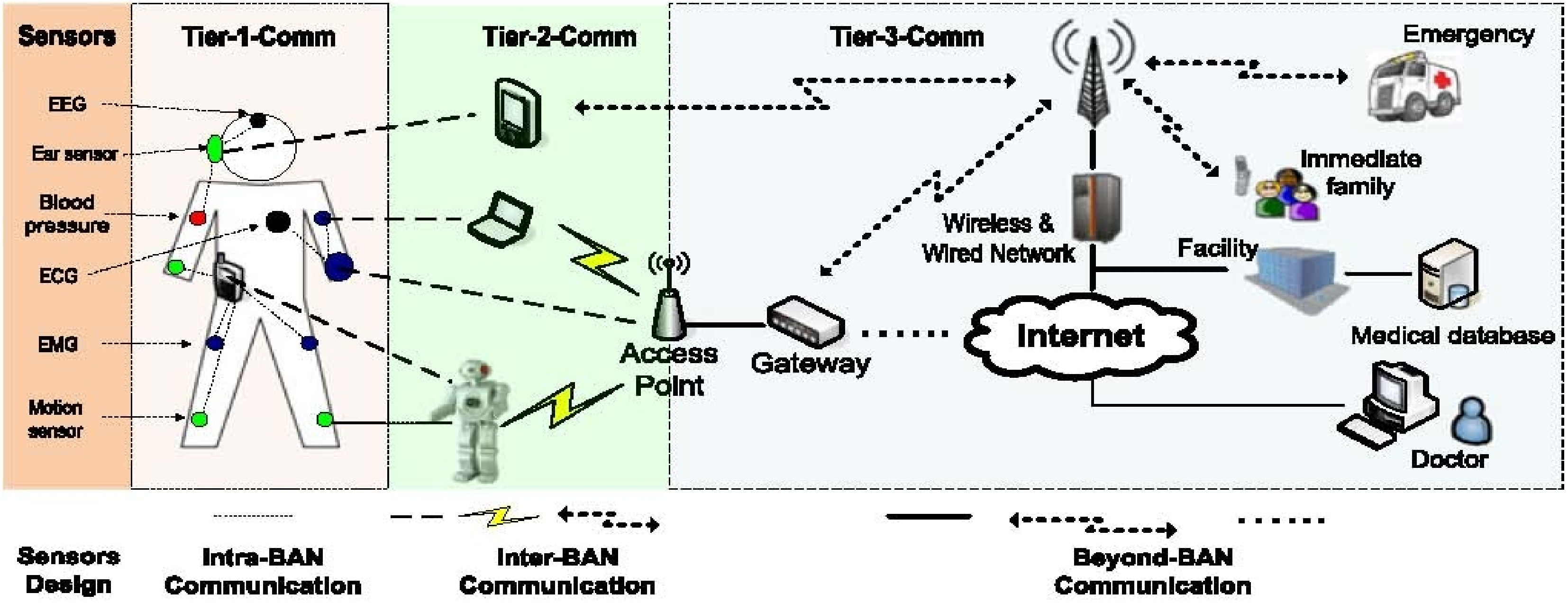
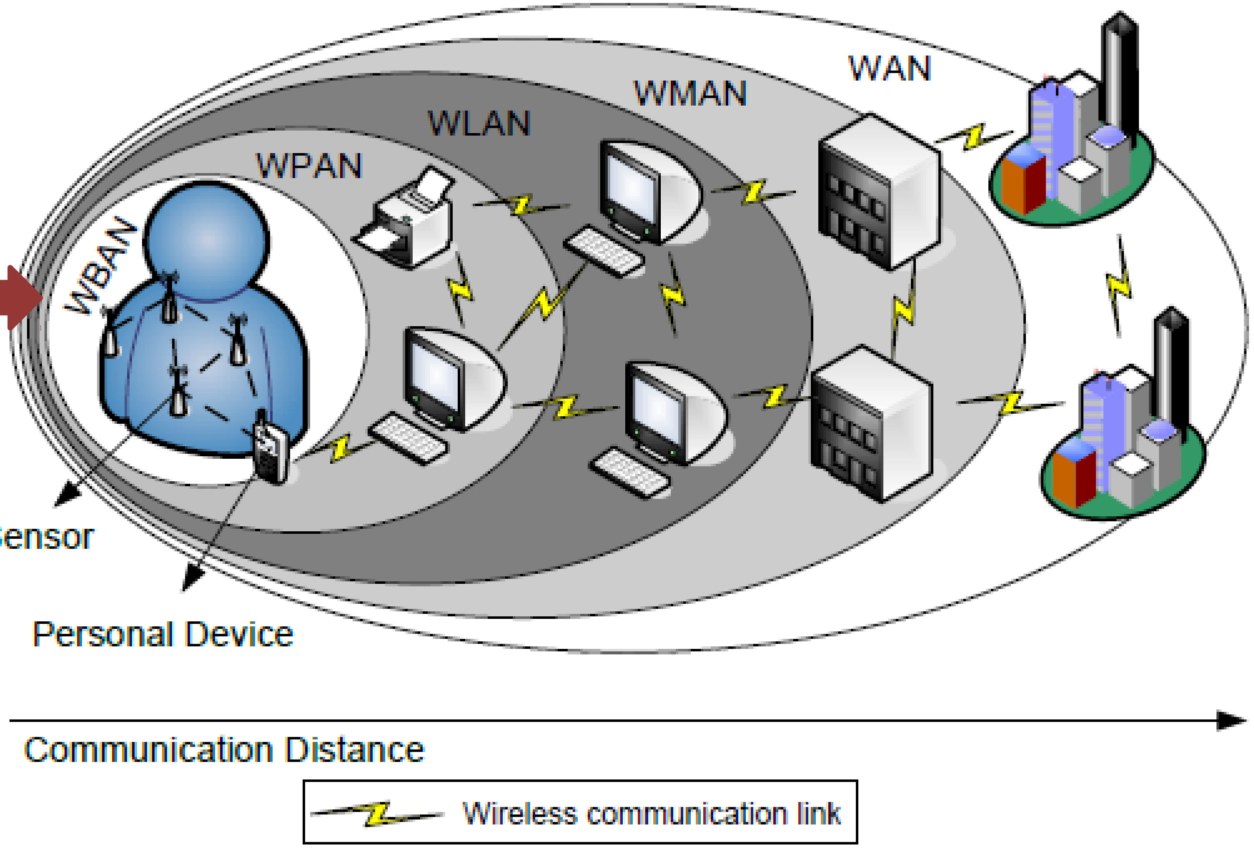
Intra and Inter WBAN

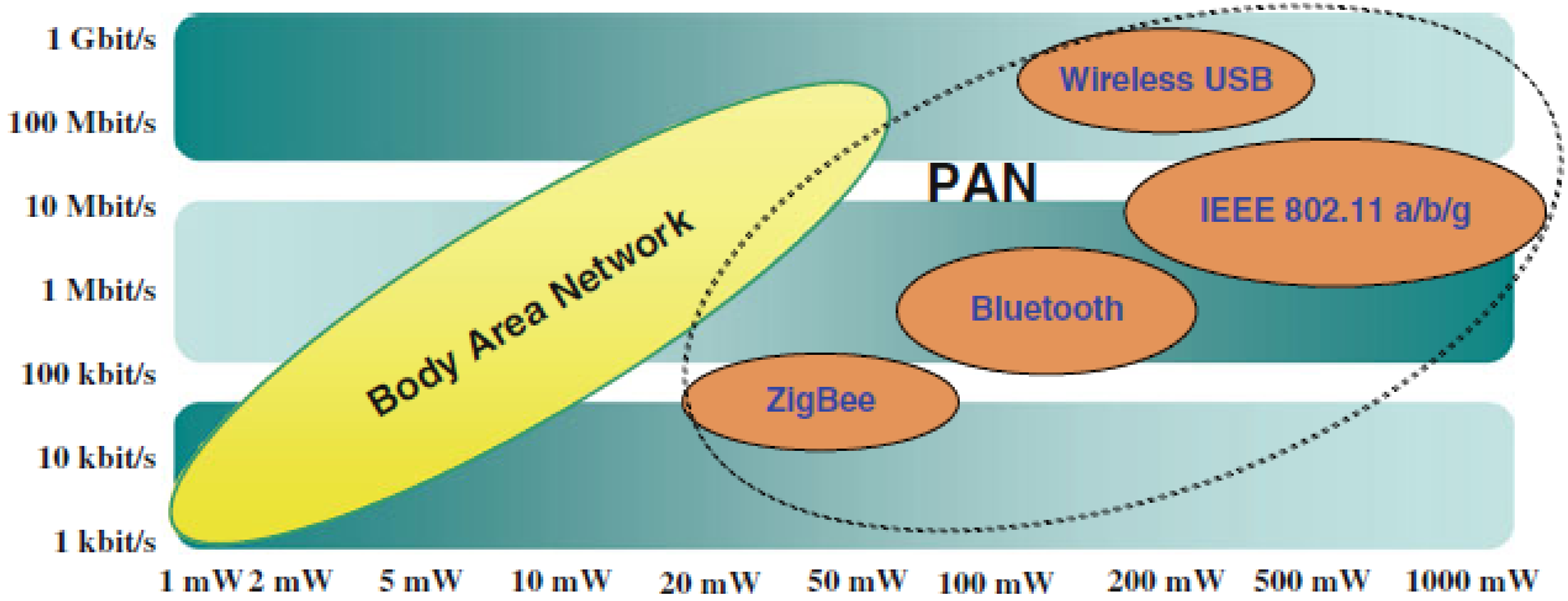


Wireless Communication standards (IEEE 802)

IEEE 802.15.6



WBAN tradeoffs



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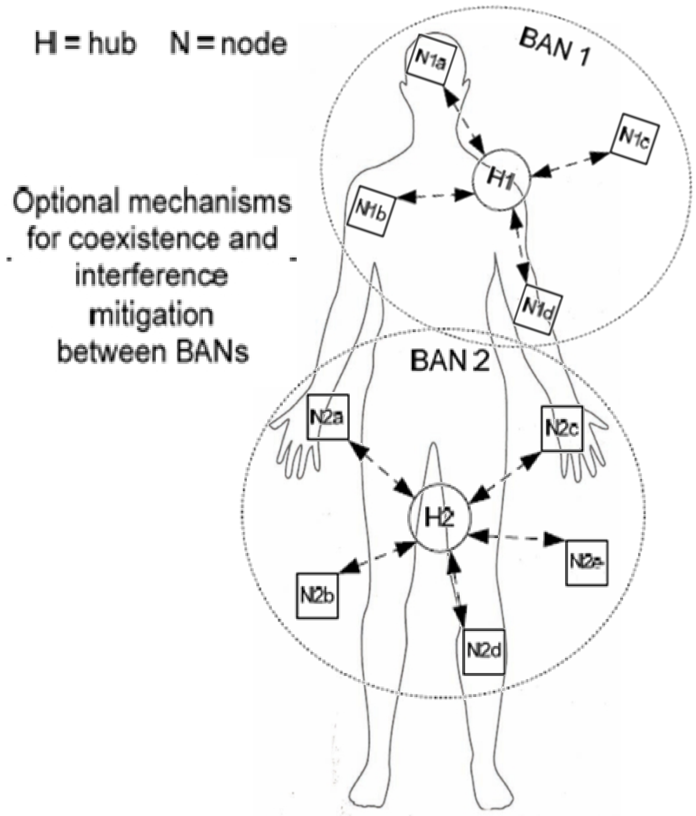
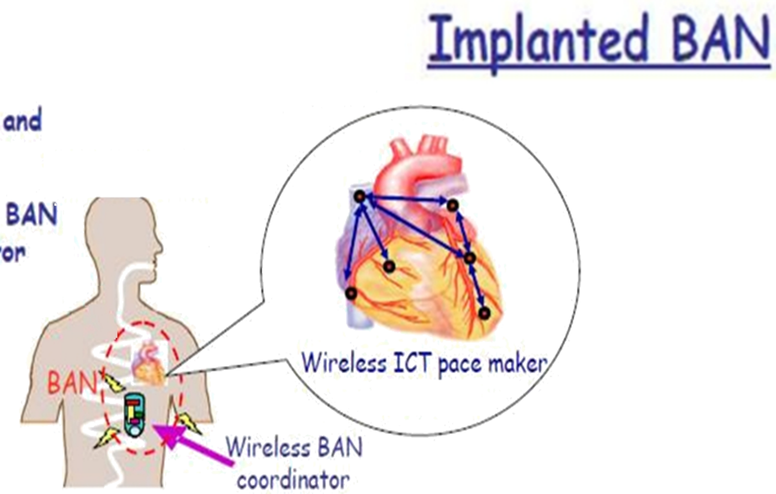
WBAN deployment





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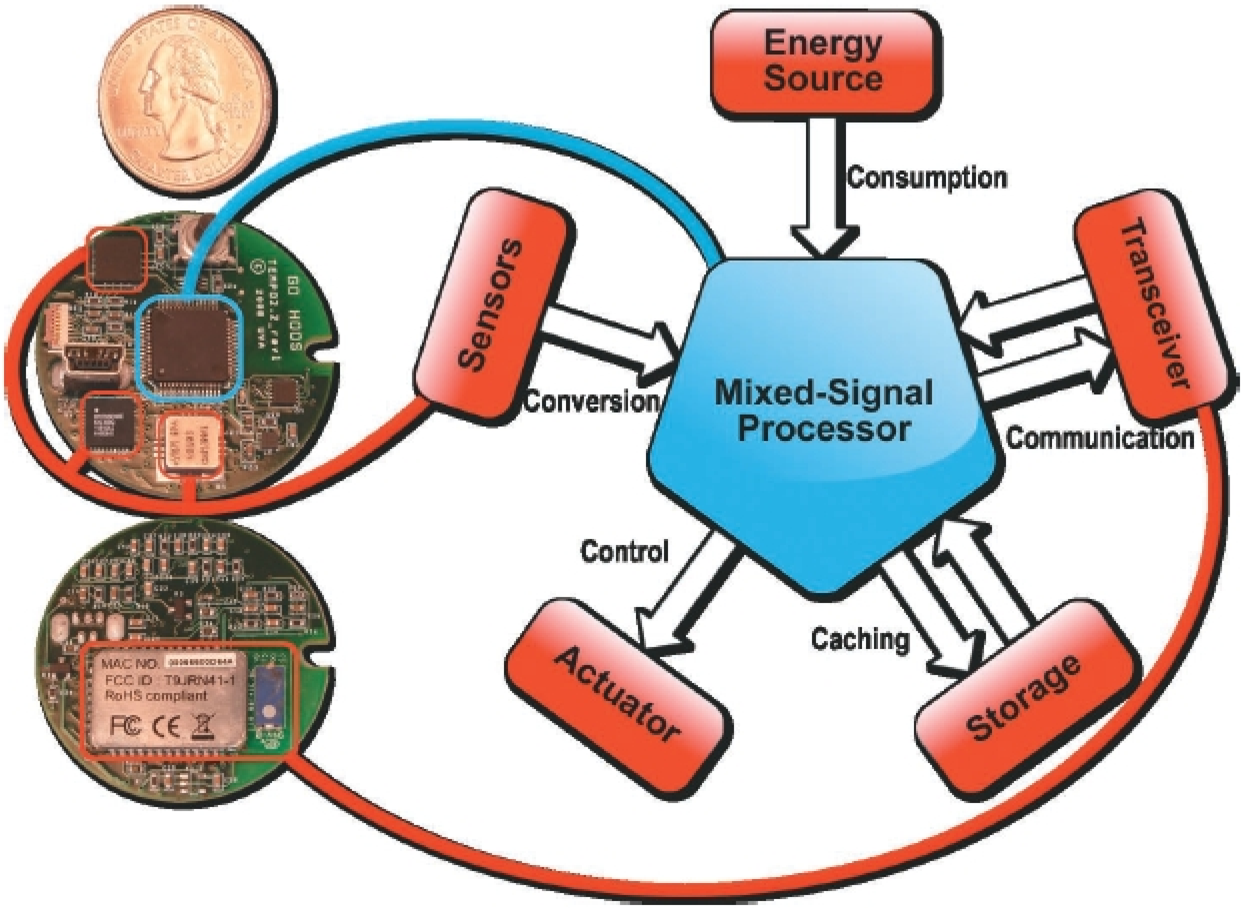
WBAN sensor node



BODY AREA SENSOR NETWORKS: CHALLENGES AND OPPORTUNITIES

Mark A. Hanson, Harry C. Powell Jr., Adam T. Barth, Kyle Ringgenberg, Benton H. Calhoun, James H. Aylor, and John Lach, *University of Virginia*

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WBAN applications and requirements

Application	Target data rate	No. of nodes	Topology	Setup time	P2P latency	BER	Duty cycle	Desired battery lifetime
Deep brain stimulation	1 Mb/s	2	P2P	< 3 s	< 250 ms	$< 10^{-3}$	< 50%	>3 years
Hearing aid	200 kb/s	3	Star	< 3 s	< 250 ms	$< 10^{-10}$	< 10%	>40 hours
Capsule endoscope	1 Mb/s	2	P2P	< 3 s	< 250 ms	$< 10^{-10}$	< 50%	>24 hours
Drug dosage	< 1 kb/s	2	P2P	< 3 s	< 250 ms	$< 10^{-10}$	< 1%	>24 hours
ECG	72 kb/s (500 Hz sample, 12-bit ADC, 12 channels)	< 6	Star	< 3 s	< 250 ms	$< 10^{-10}$	< 10%	>1 week
EEG	86.4 kb/s (300 Hz sample, 12-bit ADC, 24 channels)	< 6	Star	< 3 s	< 250 ms	$< 10^{-10}$	< 10%	>1 week
EMG	1.536 Mb/s (8 kHz sample, 16-bit ADC, 12 channels)	< 6	Star	< 3 s	< 250 ms	$< 10^{-10}$	< 10%	>1 week
O2/CO2/BP/temp/respiration/glucose monitoring, accelerometer	< 10 kb/s	< 12	Star	< 3 s	< 250 ms	$< 10^{-10}$	< 1%	>1 week
Audio	1 Mb/s	3	Star	< 3 s	< 100 ms	$< 10^{-5}$	< 50%	>24 hours
Video/med imaging	< 10 Mb/s	2	P2P	< 3 s	< 100 ms	$< 10^{-3}$	< 50%	>12 hours

Table 1. *Technical requirements of selected BAN applications [1].*

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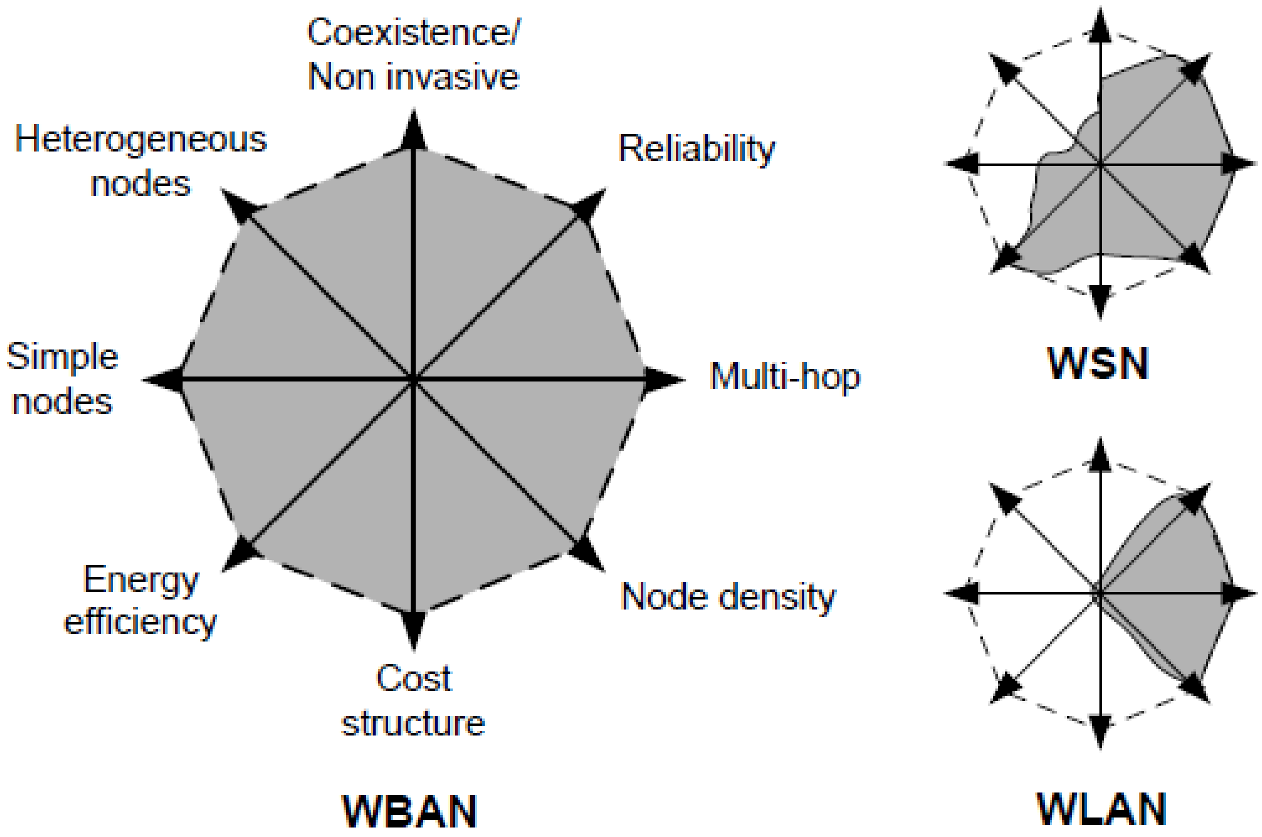
COMPLEXITY OF A WBAN



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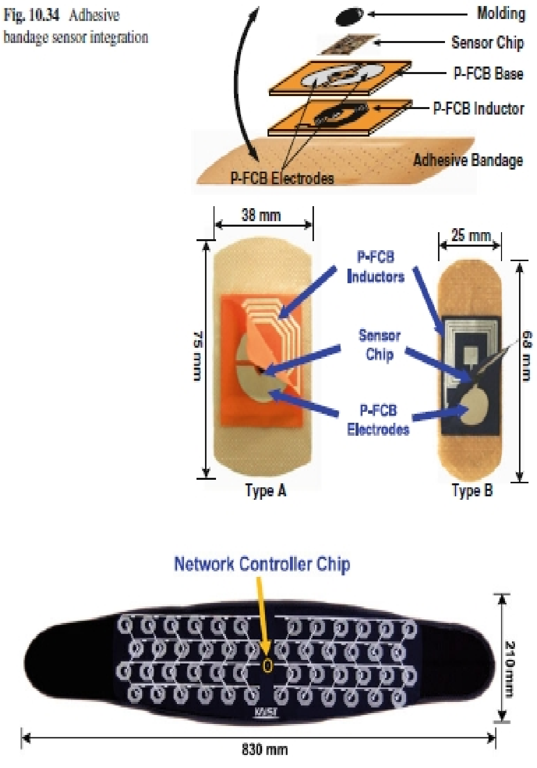
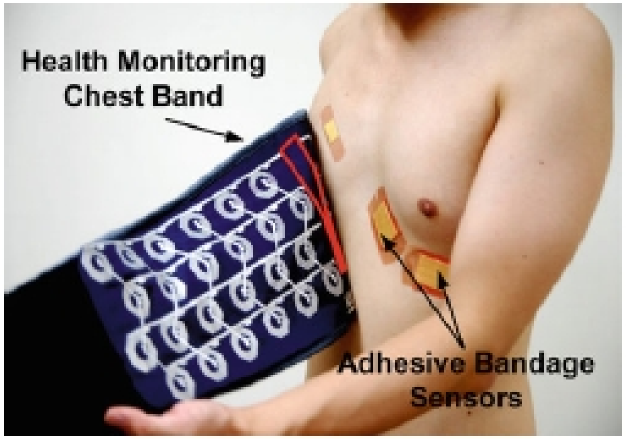
POWERING WBAN NODES

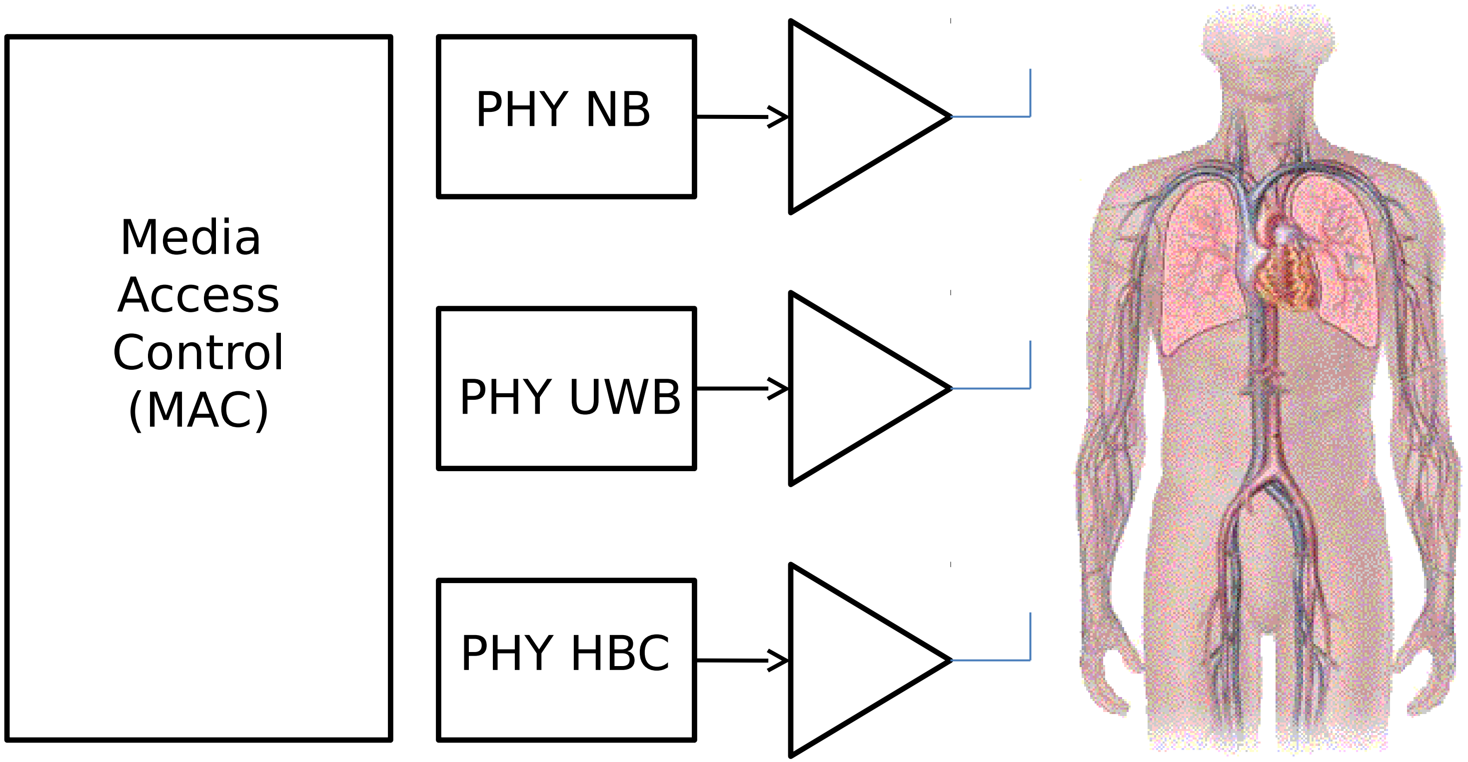
Fig. 10.34 Adhesive bandage sensor integration



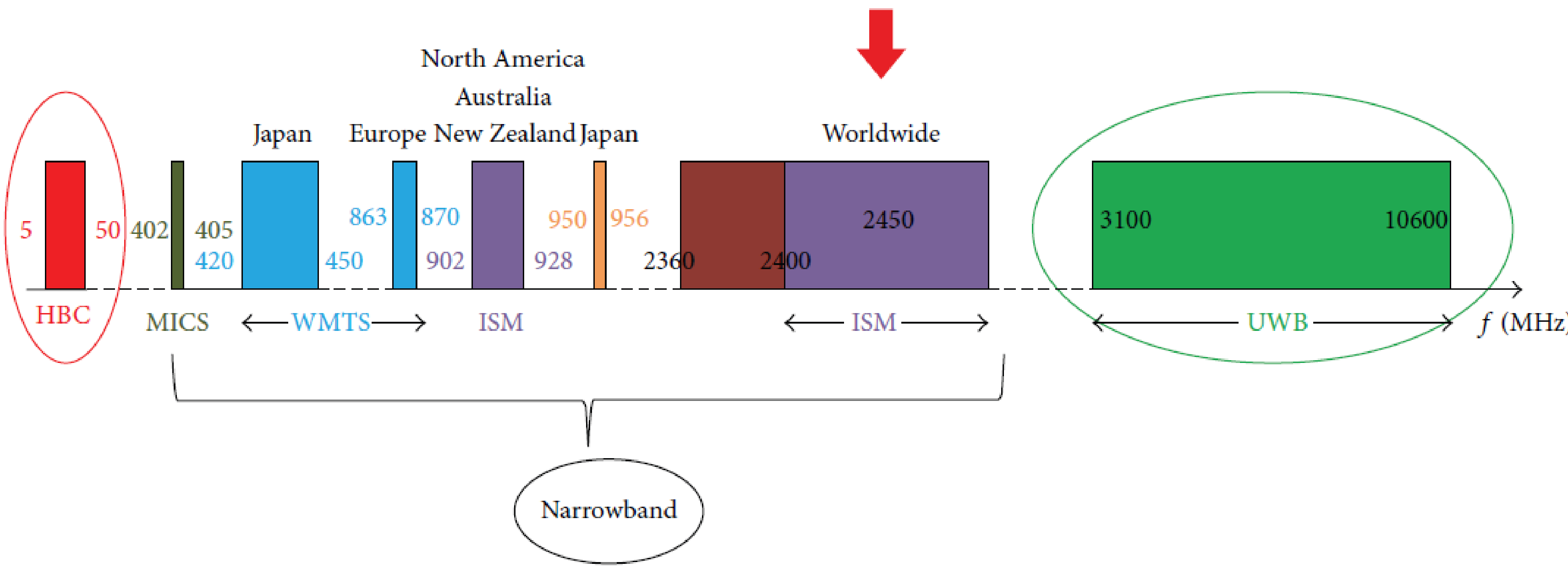


IEEE 802.15.6 standard

- 1 MAC e 3 PHYs



IEEE 802.15.6 frequencies



A Review of IEEE 802.15.6 MAC, PHY, and Security Specifications

Sana Ullah,[1,2] Manar Mohaisen,[3] and Mohammed A. Alnuem[1,2]

International Journal of Distributed Sensor Networks

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WBAN Challenges

REQUIREMENTS FOR WIDESPREAD ADOPTION

Widespread BASN adoption and diffusion will depend on a host of factors that involve both consumers and manufacturers. User-oriented requirements include the following:

- *Value.* Perceived value can depend on many factors, such as assessment ability, but overall, the BASN must improve its user's quality of life.
- *Safety.* Wearable and implanted sensors will need to be biocompatible and unobtrusive to prevent harm to the user. Safety-critical applications must have fault-tolerant operation.
- *Security.* Unauthorized access or manipulation of system function could have severe consequences. Security measures such as user authentication will prevent such consequences.
- *Privacy.* BASNs will be entrusted with potentially sensitive information about people. Protecting user privacy will require both technical and nontechnical solutions. BASN packaging will need to be inconspicuous to avoid drawing attention to medical conditions. Encryption will be necessary to protect sensitive data, and encryption mechanisms will need to be resource-aware.
- *Compatibility.* BASN nodes need to interoperate with other BASN nodes, existing inter-BASN networks, and even with electronic health record systems. This will require standardization of communication protocols and data storage formats.
- *Ease of use.* Wearable BASN nodes will need to be small, unobtrusive, ergonomic, easy to put on, few in number, and even stylish. On-body and off-body user interfaces will need intuitive controls and presentation of information.

Beyond user concerns, BASN manufacturers will face imposing and expensive regulatory processes (FCC certification and FDA approval, for example) to get products to market. Once developed, BASN systems will likely involve a complex web of stakeholders (users, emergency services, caregivers, physicians, researchers, and so on). Each stakeholder will provide value to and derive value from BASN systems. Such dynamics create complex relationships that raise ownership and liability issues. Who will pay for BASN systems? Who will own BASN data? How will access to data and information be granted? Who is liable for damages involving BASN systems? These questions must be answered to protect all stakeholder interests and to promote BASN systems' widespread adoption and diffusion.

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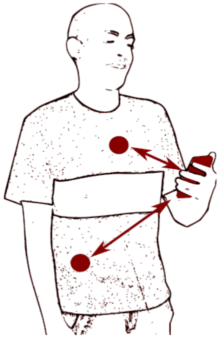
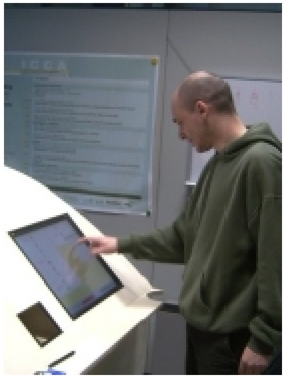
Human Body Communication

- 1995: Zimmerman proposes HBC concept [1].
- Electrostatic coupling of signals to the body using electrodes.
- Suitable in the 0.1 -100MHz range.
- Low interference, high security, low power and better spectral efficiency.
- Application in wearables and implantable circuits for BANs related to health-care, entertainment, identification, etc.





[1] Zimmerman, T. G., "Personal Area Networks: Near-field intra-body communication," M.S. Thesis, MIT Media Laboratory, Cambridge, MA, Sept. 1995

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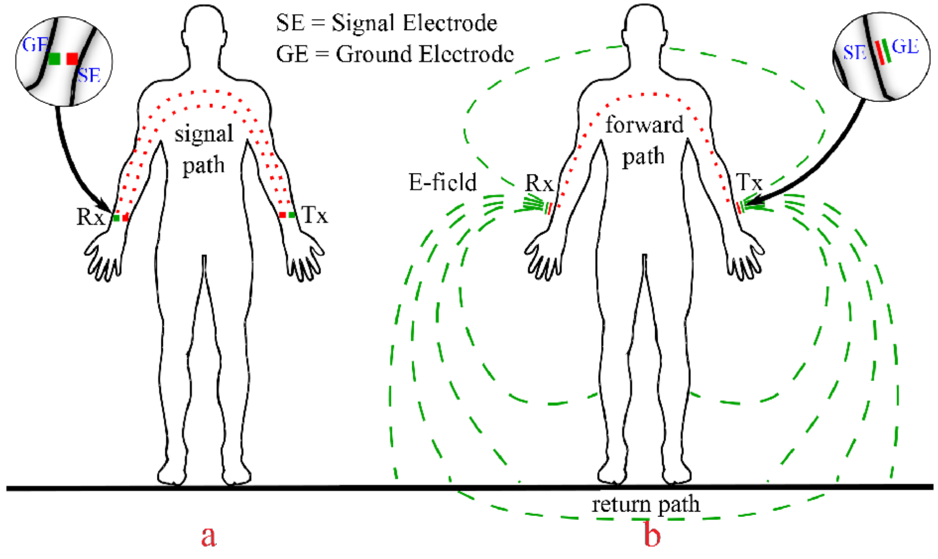
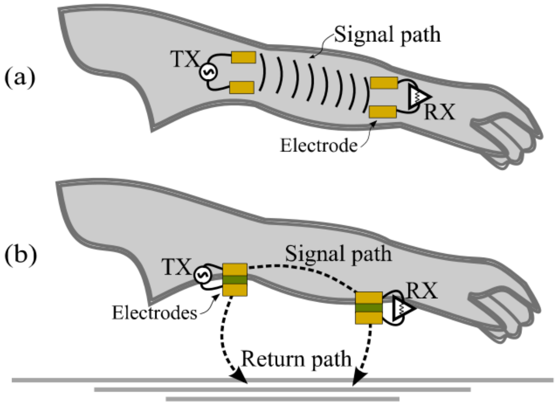
HBC coupling methods

- Electric field coupling: galvanic (a) and capacitive (b).
- Focus on capacitive HBC





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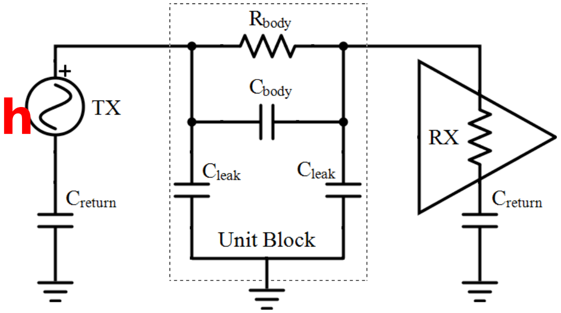
HBC channel measurements

- Objective: design an ultra low-power integrated transceiver for HBC applications
- IEEE 802.15.6 standard is very flexible. There are no requirements for hardware.
- Published results on the HBC channel are very divergent.
- We started by doing measurements and trying to correlate than with proposed models.

Channel path compact model.



[2] R. Xu; H. Zhu; J. Yuan, "Electric-Field Intrabody Communication Channel Modeling With Finite-Element Method," Biomedical Engineering, IEEE Transactions on, March 2011.

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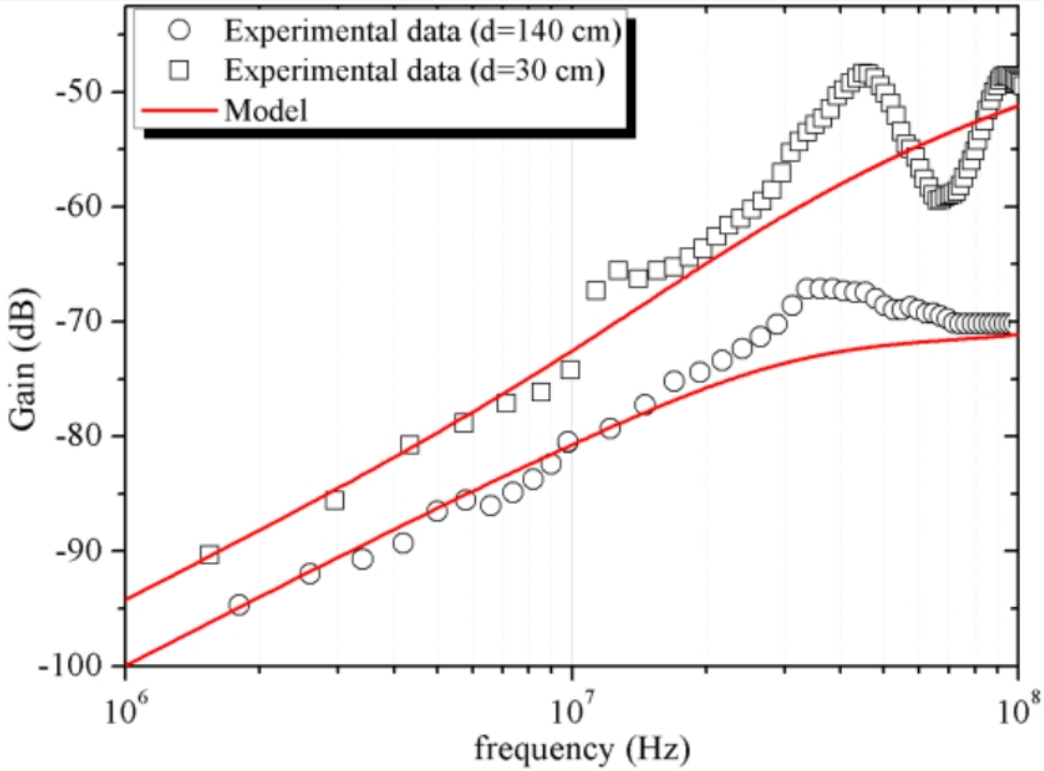
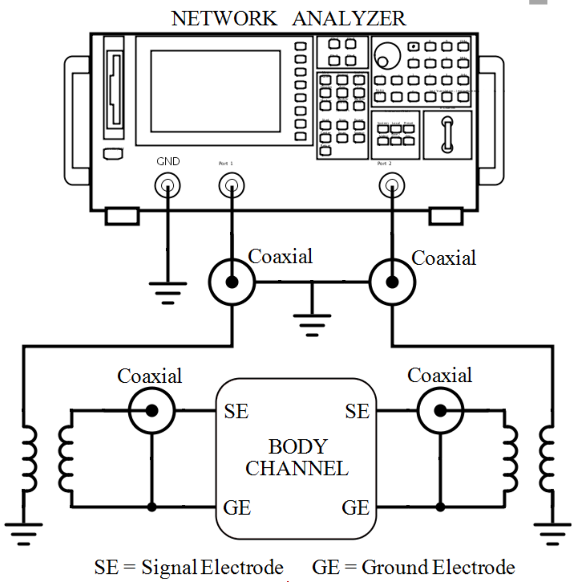
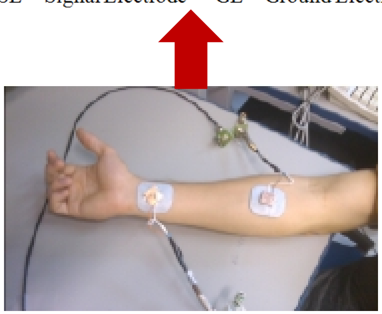
HBC channel







Calibration Procedure to Remove the Balun Effects on HBC Channel Measurements

G.A. Álvarez-Botero, *Member, IEEE*, M. D. Pereira, *Member, IEEE*, F. R. de Sousa, *Senior Member, IEEE*,

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Objective

- Design a batteryless temperature sensor for human body temperature measurement
- Motivation:
  - Fast diagnostic of anomalous situations
  - Cost reduction in hospitals

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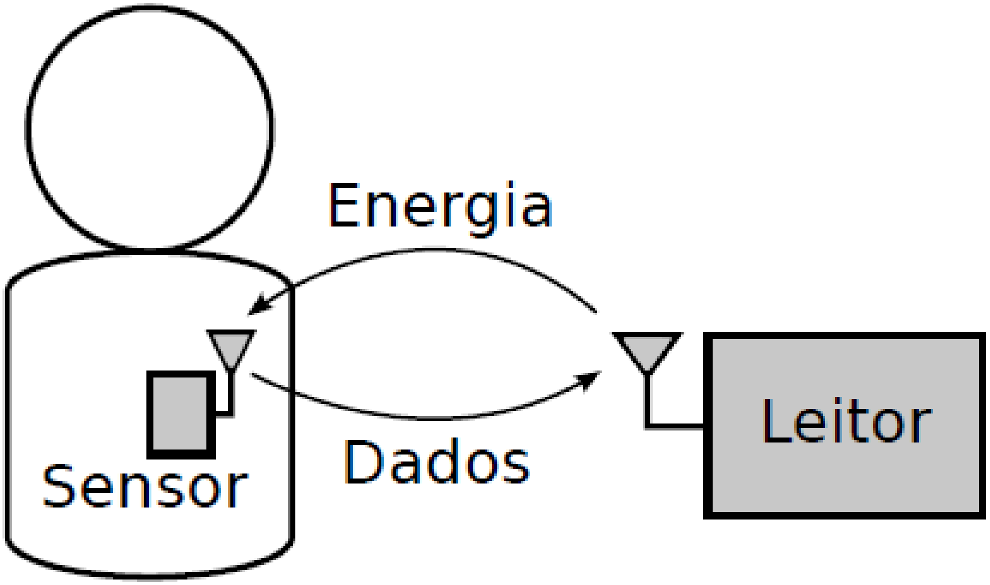
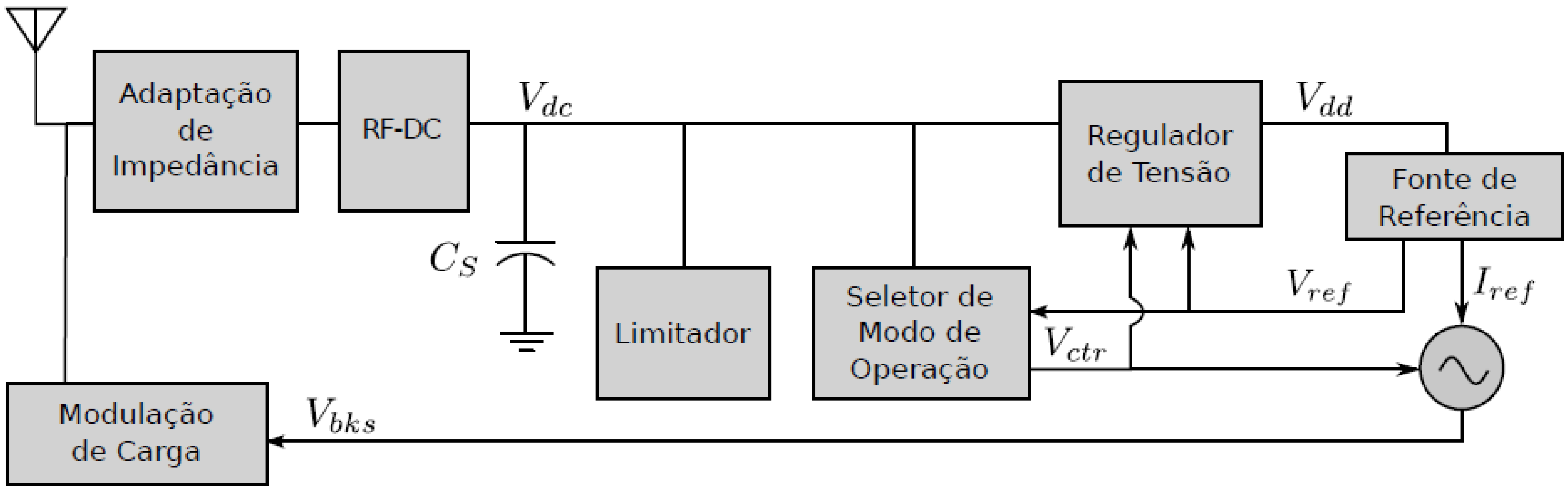
Solution adopted

- RF-powered CMOS sensor



System architecture



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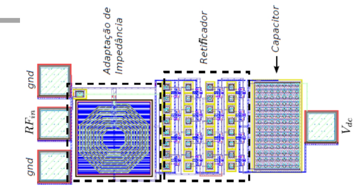
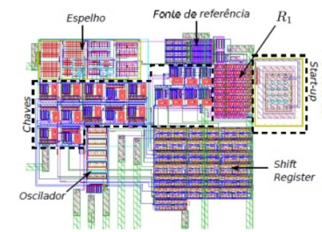
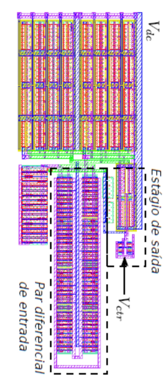
Circuit designed

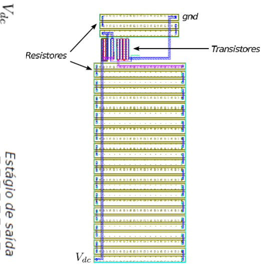
Referência	[1]	[2]	[3]	[4]	[5]	Este trabalho
Tecnologia (nm)	250	130	130	130	180	130
Frequência (MHz)	450	900	900	868	910	900
Área (mm^2)	1,2	-	0,95	3,96	1,2	0,34
Cons. *standby* (μW)	5	6	-	$\approx$ 0,11	-	4,9
Cons. ativo (μW)	1500	9	7,9	-	7	8,5
Eficiência RF-DC (%)	-	30	7,6	35	-	10
$P_{av,min}$ (dBm)	−12,5	−12	−10,3	-	−5	−10

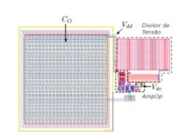
[1] KOCER, F.; FLYNN, M. *An rf-powered, wireless cmos temperature sensor.* **Sensors Journal, IEEE**, 2006.
[2] YEAGER, D. et al. *A 9 μA, Addressable Gen2 Sensor Tag for Bio-signal Acquisition.* **Solid-State Circuits, IEEE Journal of**, 2010.
[3] REINISCH, H. et al. *A multifrequency passive sensing tag with on-chip temperature sensor and off-chip sensor interface using epc hf and uhf rfid technology.* **Solid-State Circuits, IEEE Journal of**, 2011.
[4] VAZ, A. et al. *Full passive uhf tag with a temperature sensor suitable for human body temperature monitoring.* **Circuits and Systems II: Express Briefs, IEEE Transactions on**, 2010.
[5] QIAN, J. et al. *A passive UHF tag for RFID-based train axle temperature measurement system.* In: **Custom Integrated Circuits Conference (CICC), 2011 IEEE**, 2011.

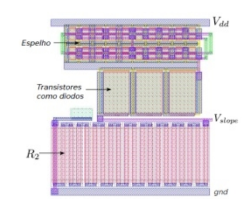












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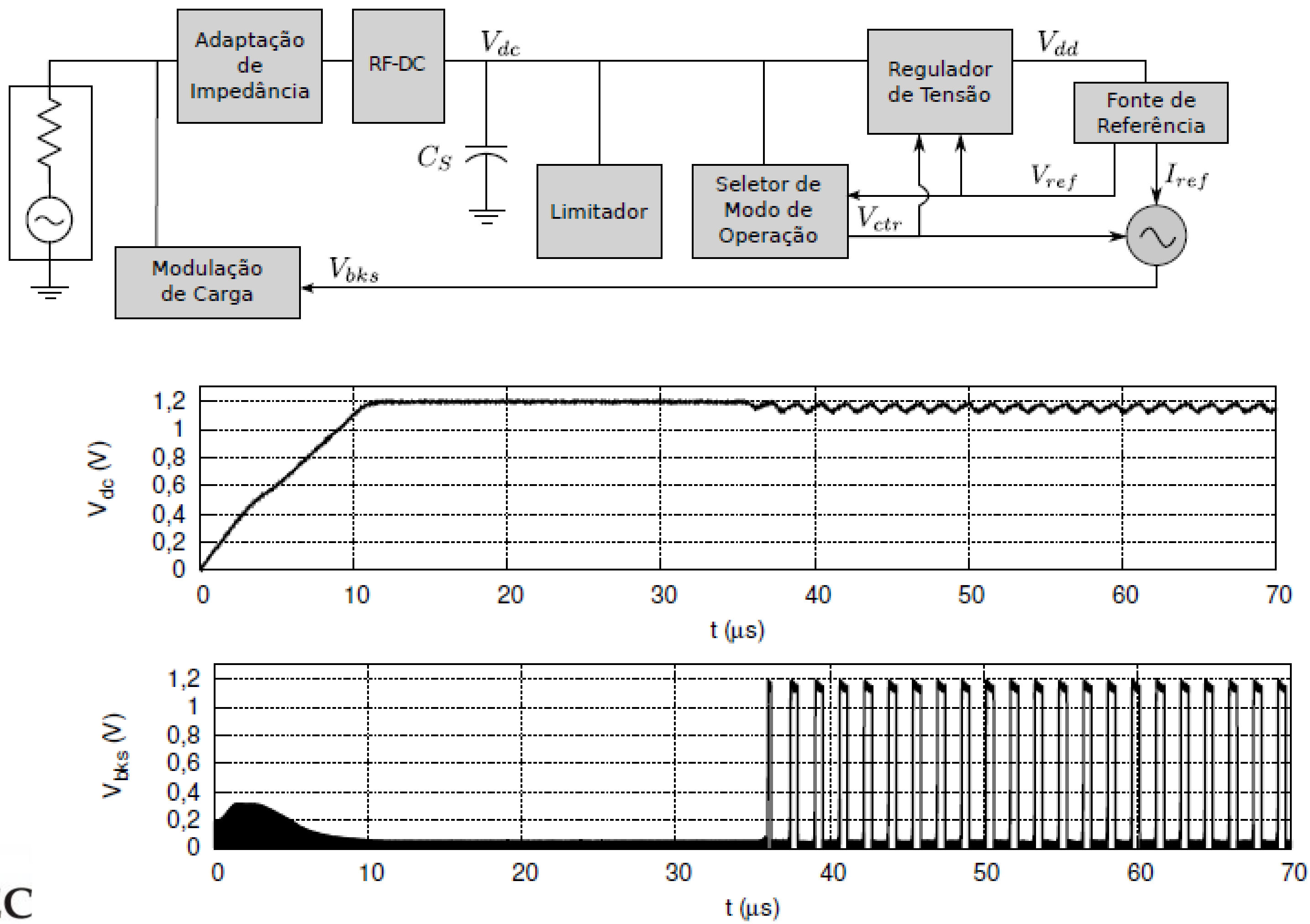
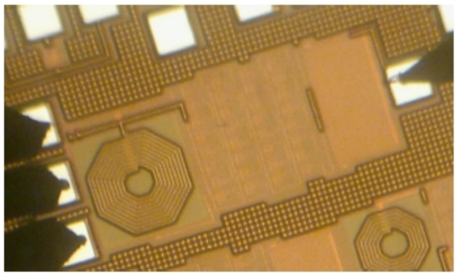
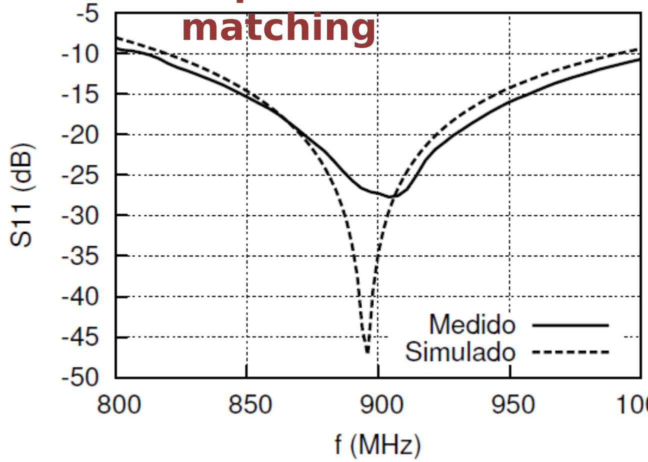
System operation



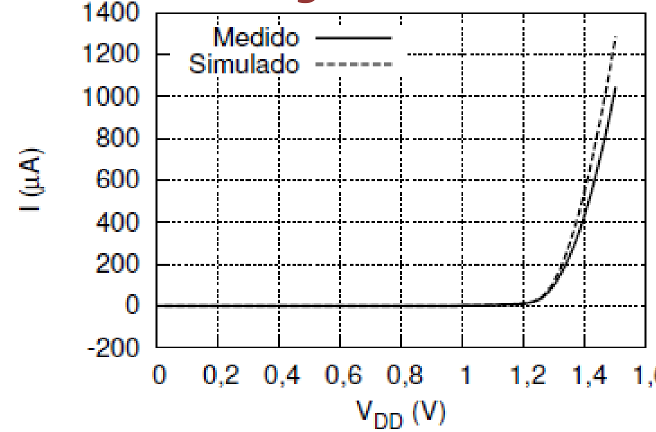
Results

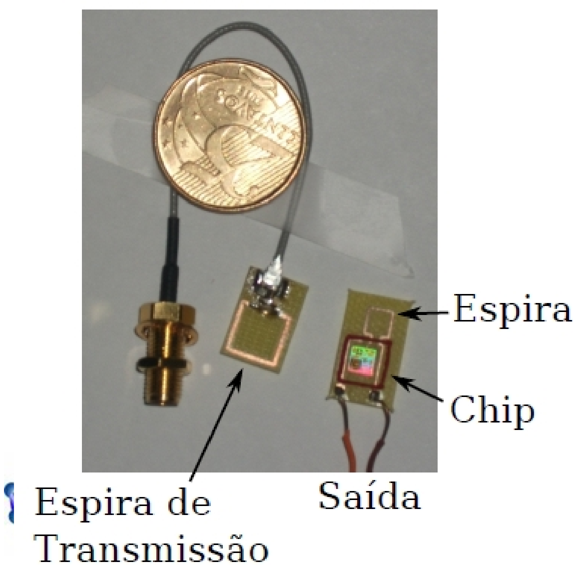


Impedance matching

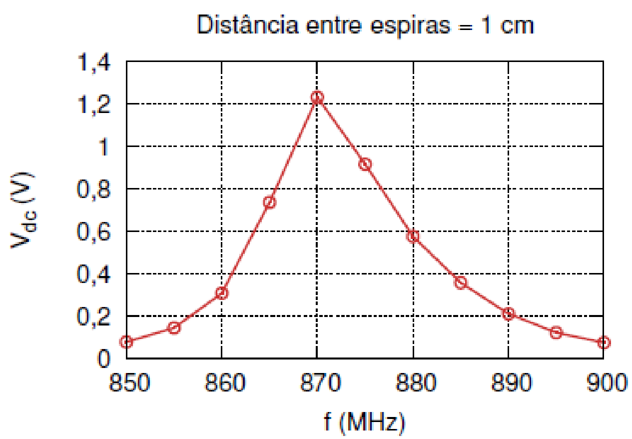


Voltage limiter

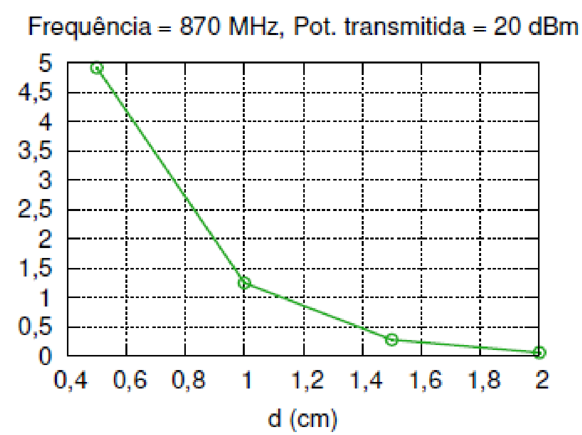




RF-DC response



RF-DC X distance



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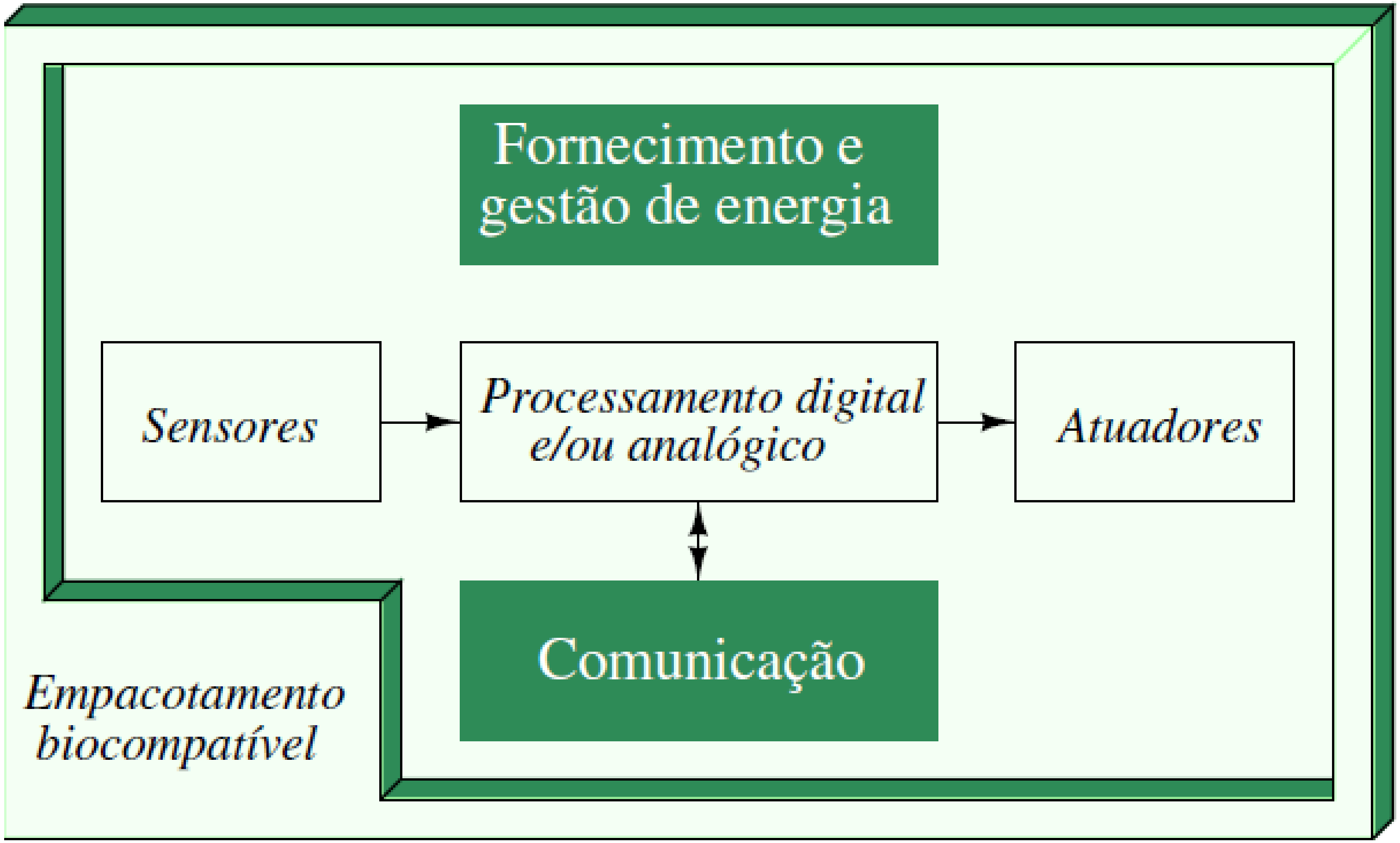
Typical architecture of na implanted system



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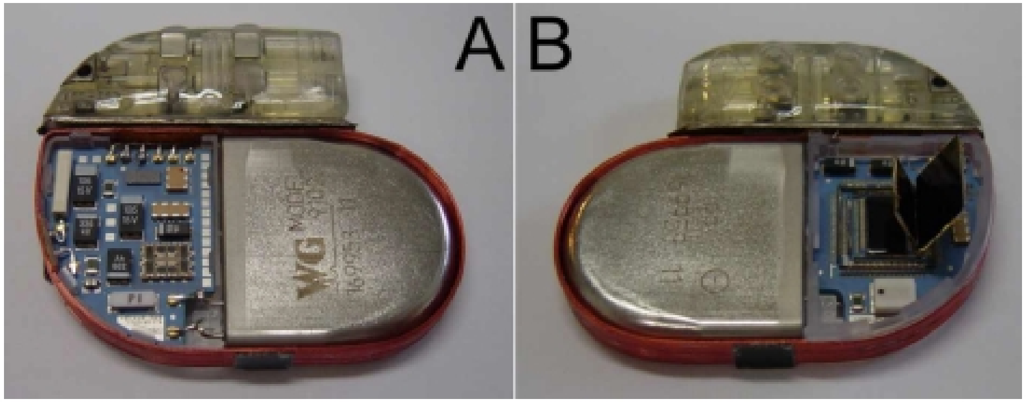
Powering the implant

Baterias:



Outras formas de energia:

- Luz, gradiente de temperatura, vibrações mecânicas
- Campo elétrico
- Campo magnético (acoplamentos indutivos)

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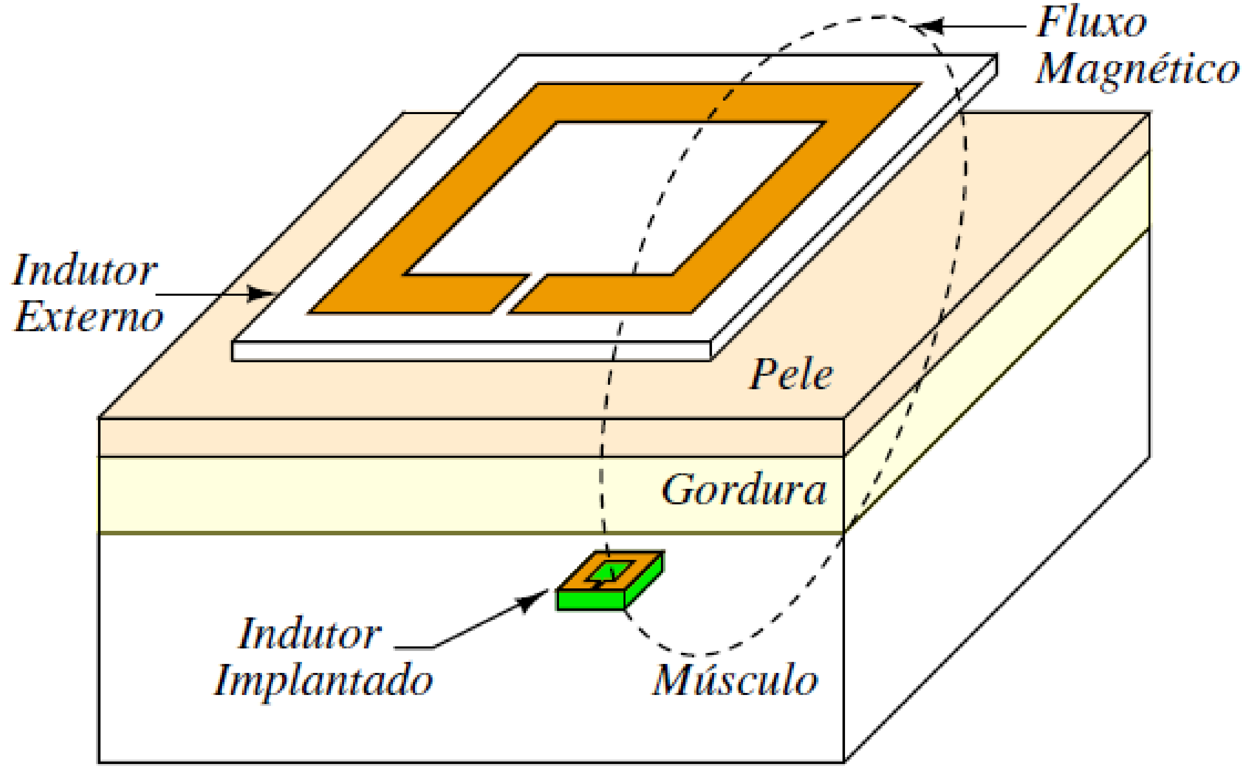
Magnetic coupling



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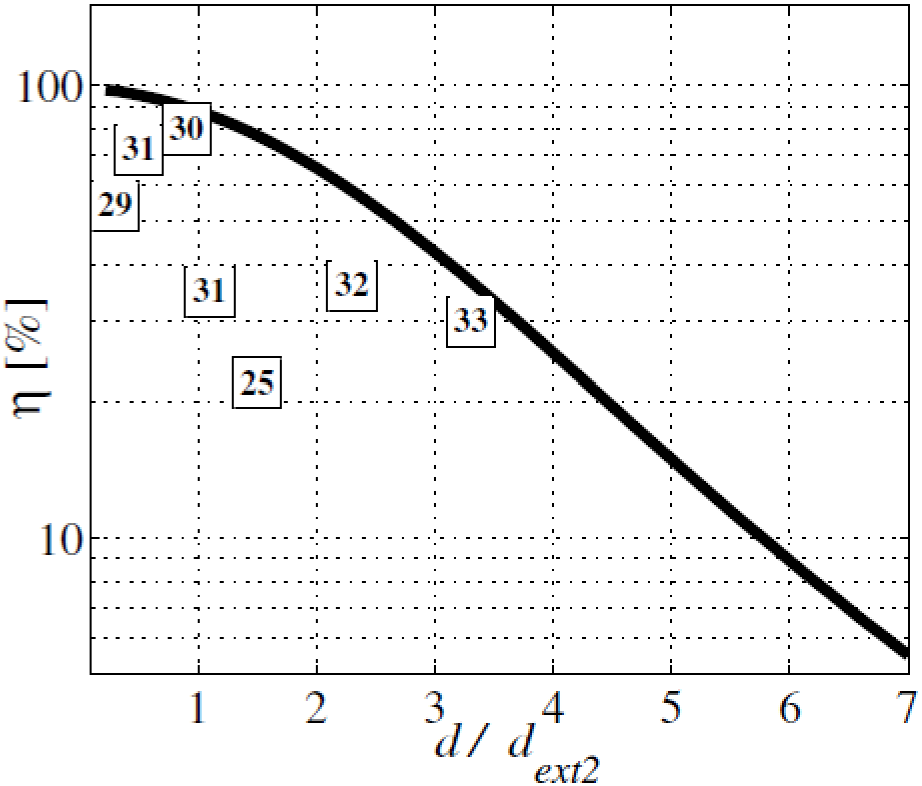
Efficiency of recent published works



[25] R.R. Harrison, "Designing Efficient Inductive Power Links for Implantable Devices,"2007.

[29] M. Baker *et al*, "Feedback Analysis and Design of RF Power Links for Low-Power Bionic Systems,"2007.

[30] A. RamRakhyani *et al*, "Design and Optimization of Resonance-Based Efficient Wireless Power Delivery Systems for Biomedical Implants,"2011.

[31] G. Yilmaz *et al*, "An efficient wireless power link for implanted biomedical devices via resonant inductive coupling,"2012.

[32] R. Jegadeesan *et al*, "Topology Selection and Efficiency Improvement of Inductive Power Links,"2012.

[33] F. Cabrera and F. Rangel, "Optimal Design of Energy Efficient Inductive Links for Powering Implanted Devices,"2014.

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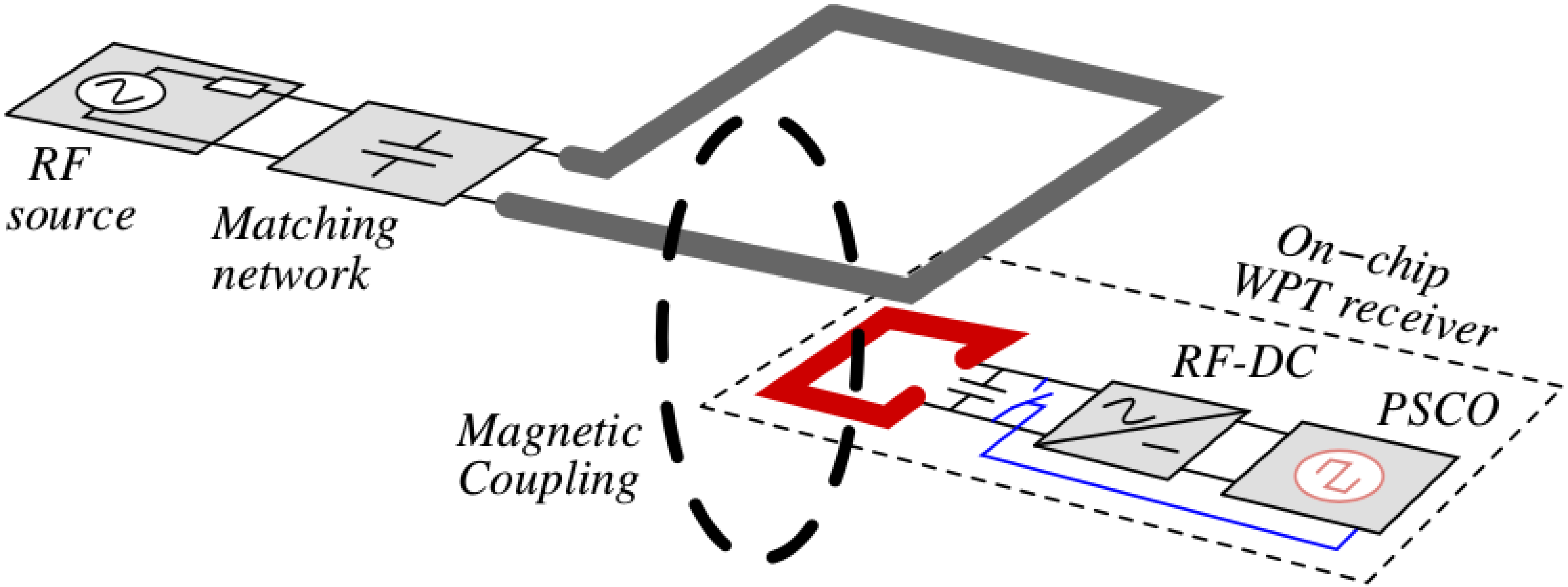
Integrated transponder



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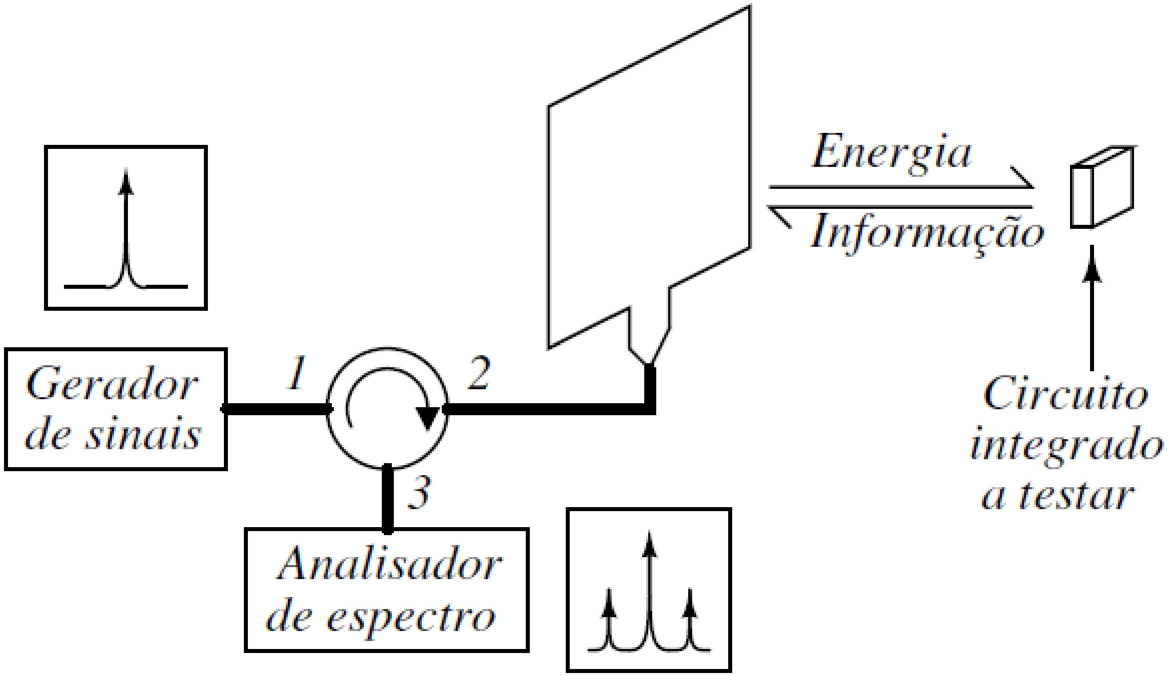
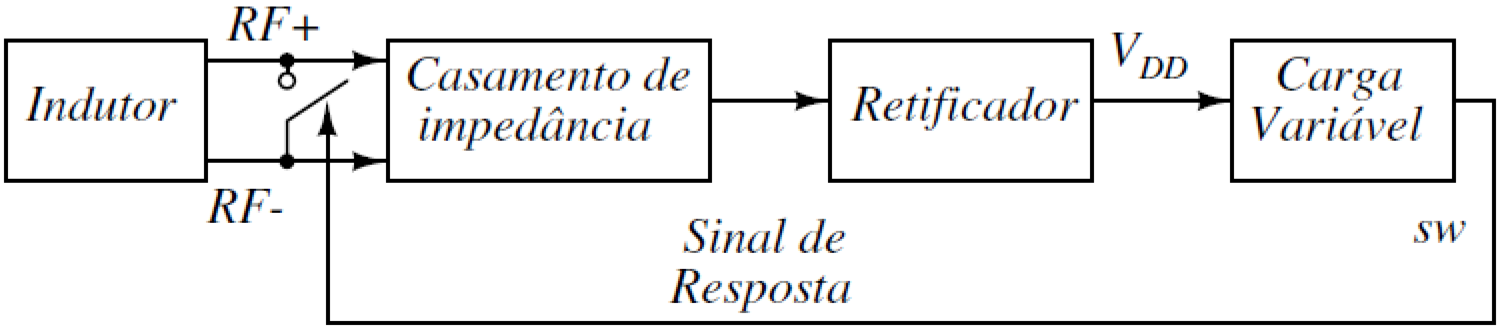
Testing of the Integrate transponder

- Wireless testing



IC architecture



$$\frac{1}{\eta_T} = \frac{1}{\eta_{RT}} \left[\frac{1}{k^2} \frac{1}{Q_1} \frac{1}{Q_2} (p + 2 + \frac{1}{p}) + p + 1 \right]. \qquad (1)$$

- $\frac{1}{k^2}\frac{1}{Q_1}$ é considerado como um parâmetro de entrada.
- Acoplamento fraco.
- Otimizar os valores de Q_2, p e η_{RT}.

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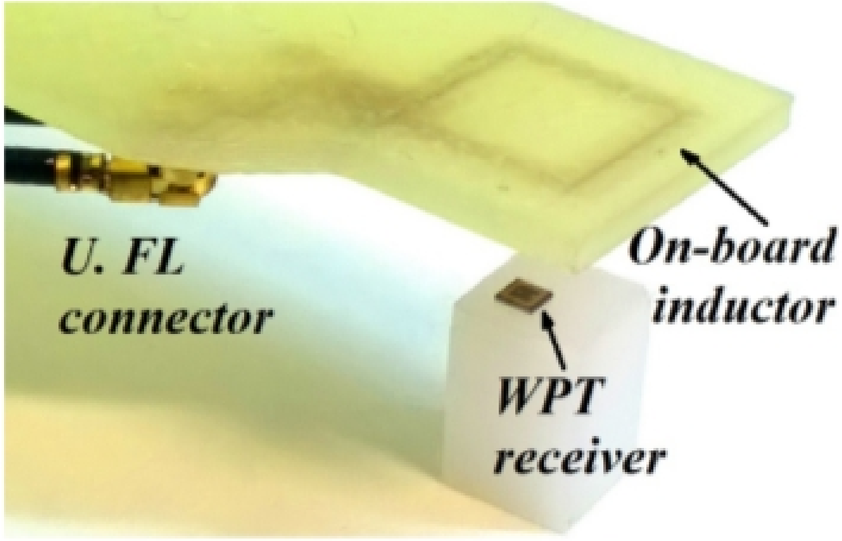
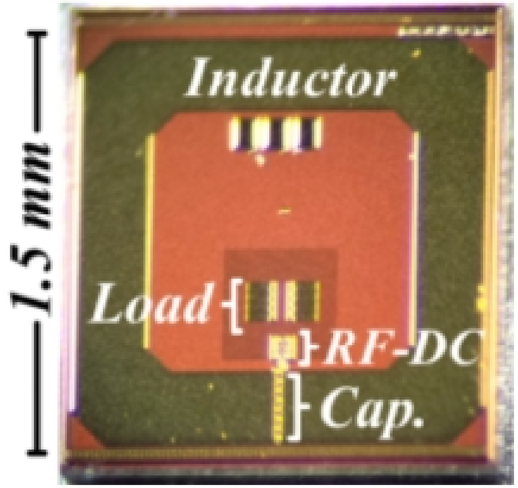
Layout



(a) Photography.



(b) Receiver detail.

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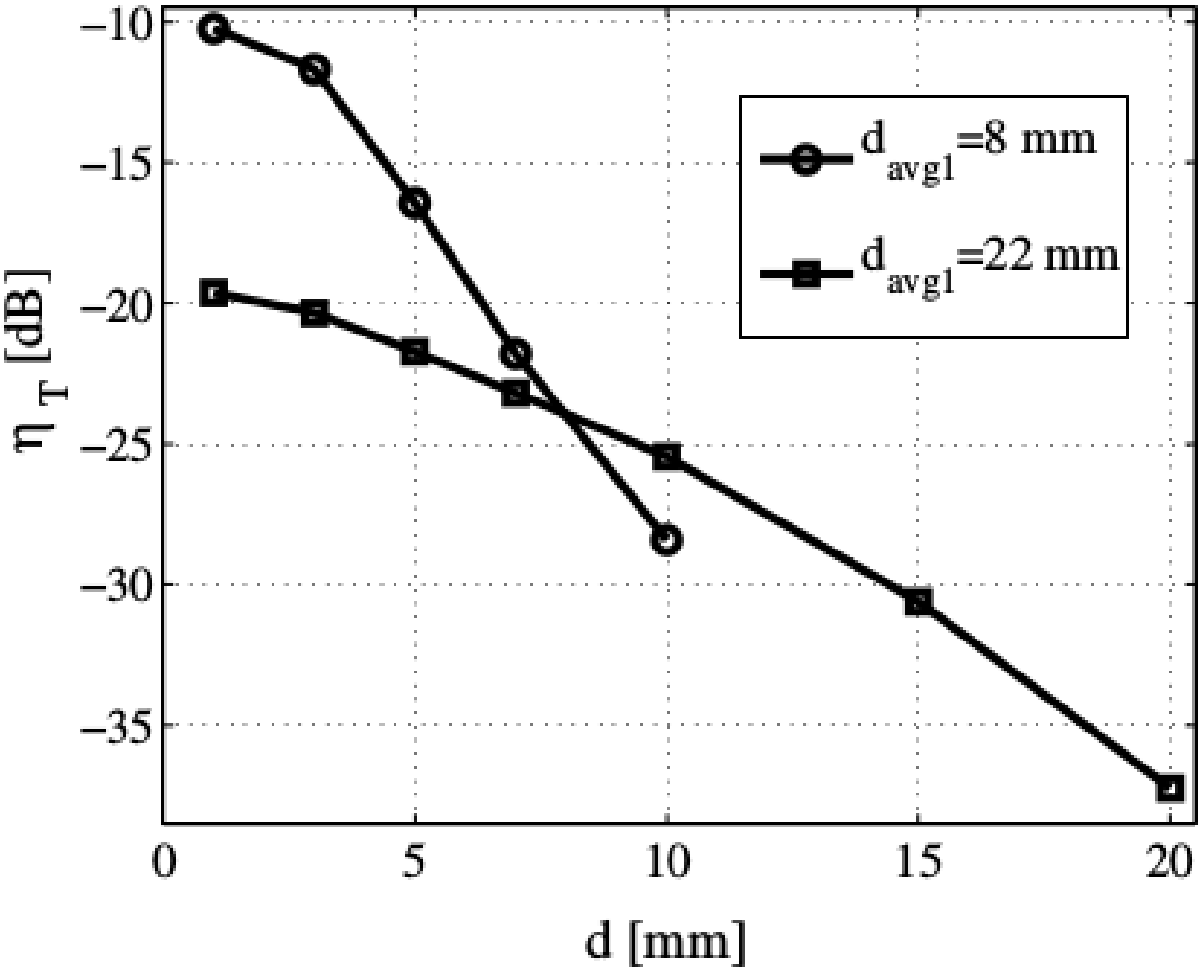
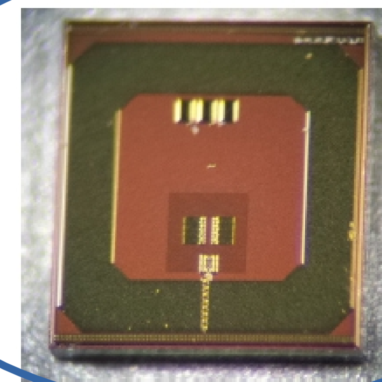
Results



Future



$12\ cm^3$

$0{,}75\ cm^3$

$0{,}0007\ cm^3$

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Outline

- WBAN Review
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  - HBC Channel characterization
  - RF-powered temperature sensor
  - Wireless power transmission to miniaturized implants
  - Energy harvesting
  - ISFET for pH and glicose measurement
  - Flexible sensors
- Concluding remarks

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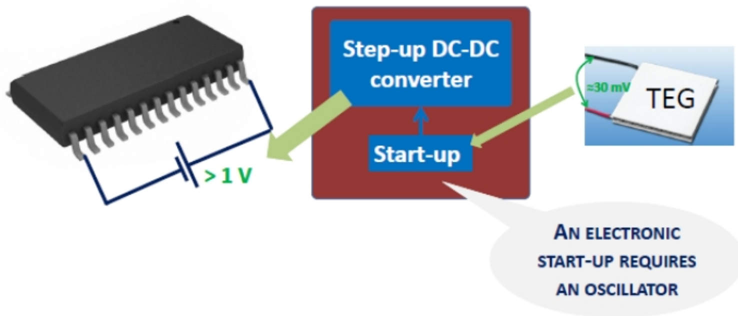
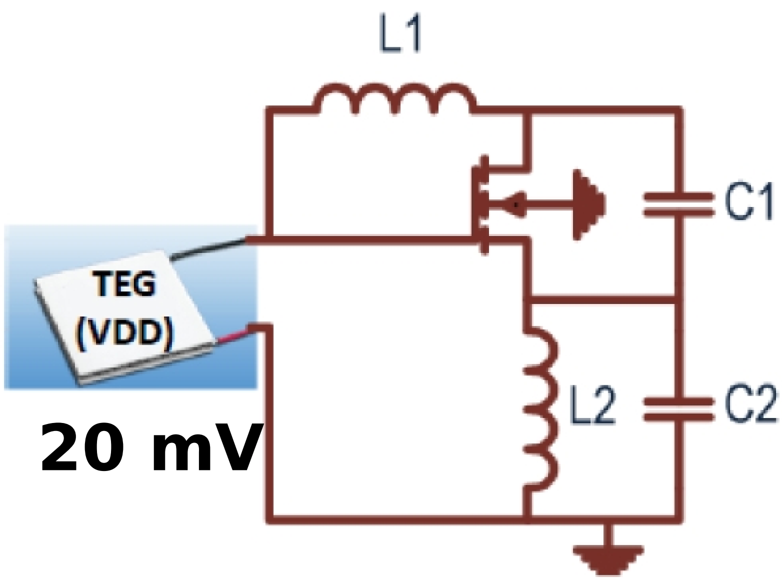
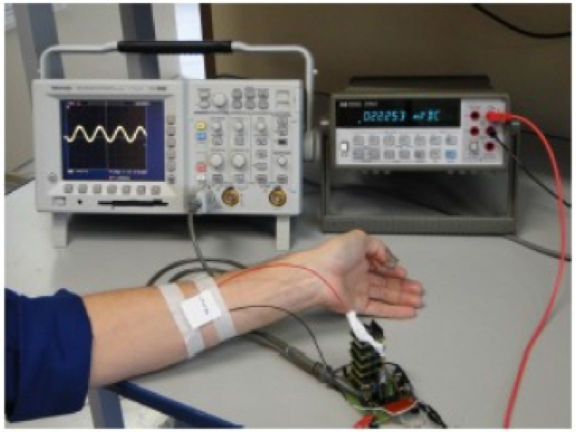
Thermoelectric energy harvesting







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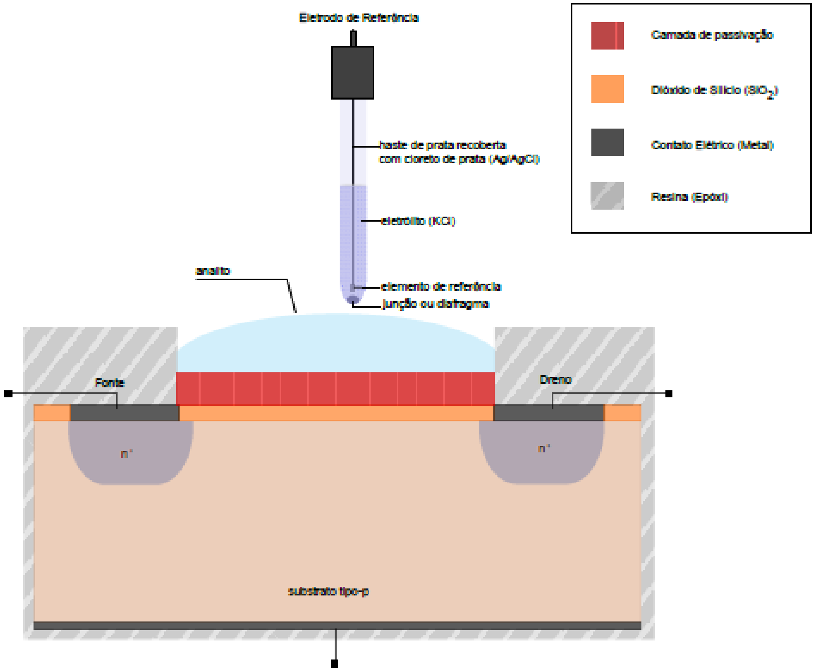
ISFET sensor

- Partnership with CCS/UNICAMP



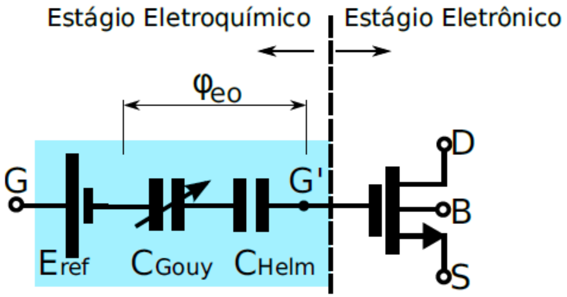
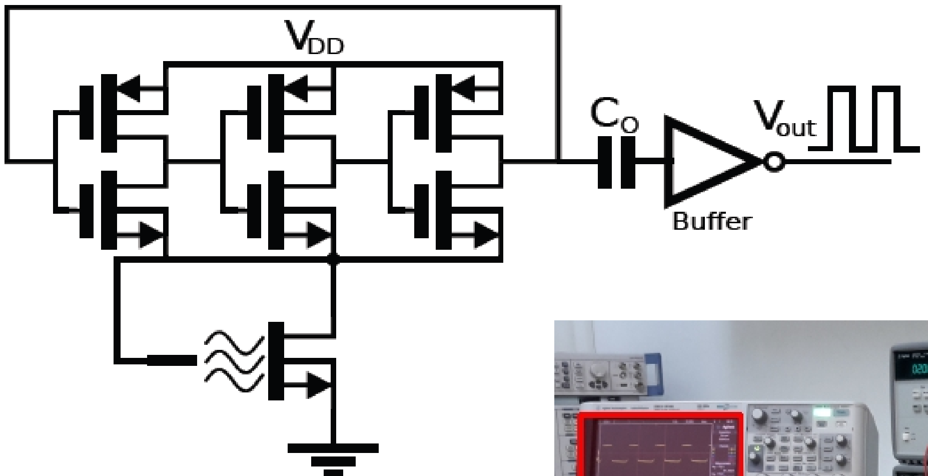
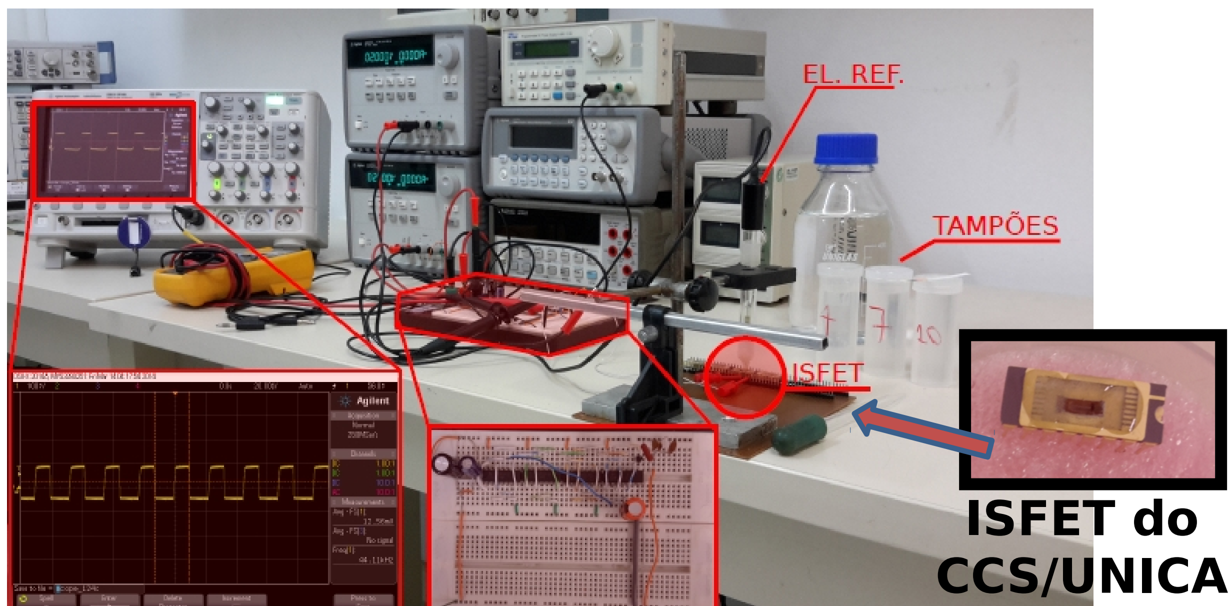


Figura 3: Macro-modelo do ISFET

PH controlled oscillator – PHCO





ISFET do CCS/UNICAMP

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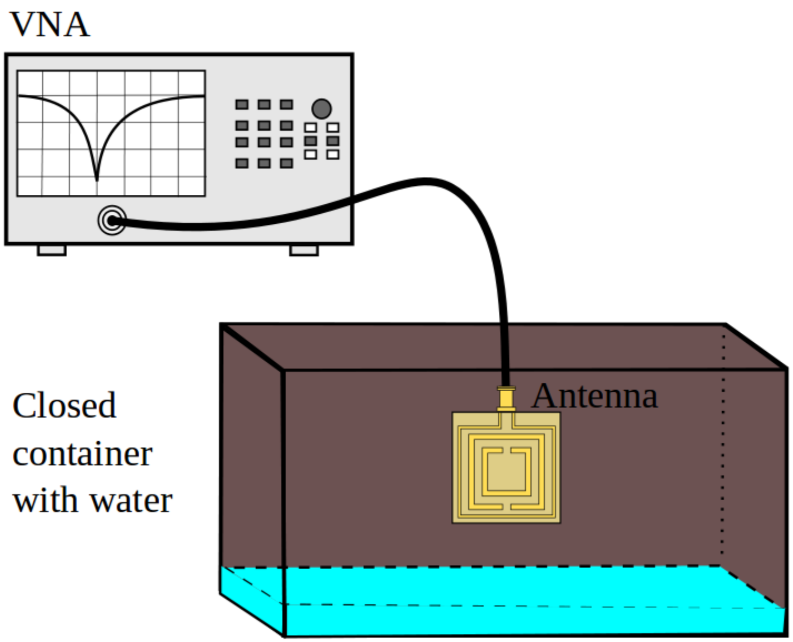
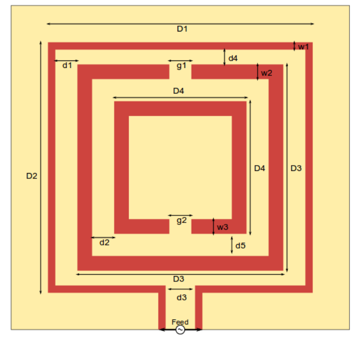
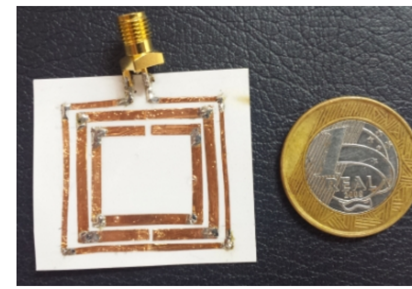
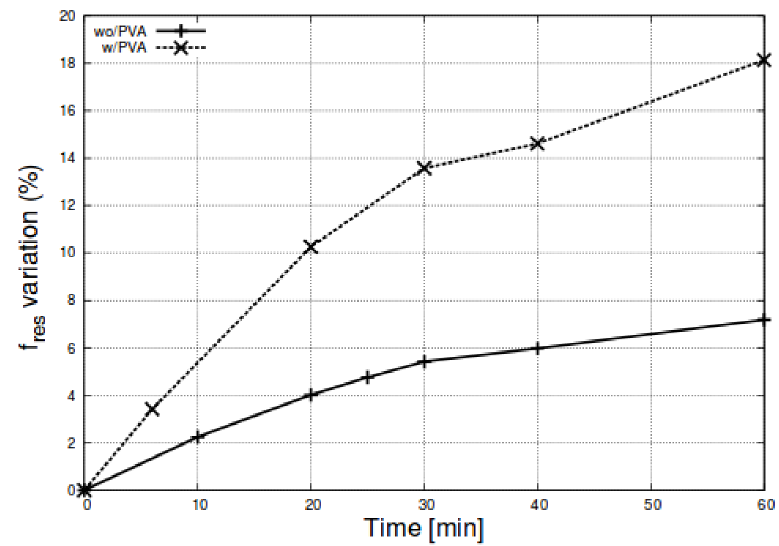
Passive wireless sensing TAG









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Concluding remarks

- WBAN applications offer the opportunity to innovate in several domains
- Contributions are required in all levels: devices, circuits, systems, BUSINESS
- Difficulties with ethic committees
- Regulation delay the market entrance

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People behind these works

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Thanks

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- More in :
  - http://rfic.ufsc.br