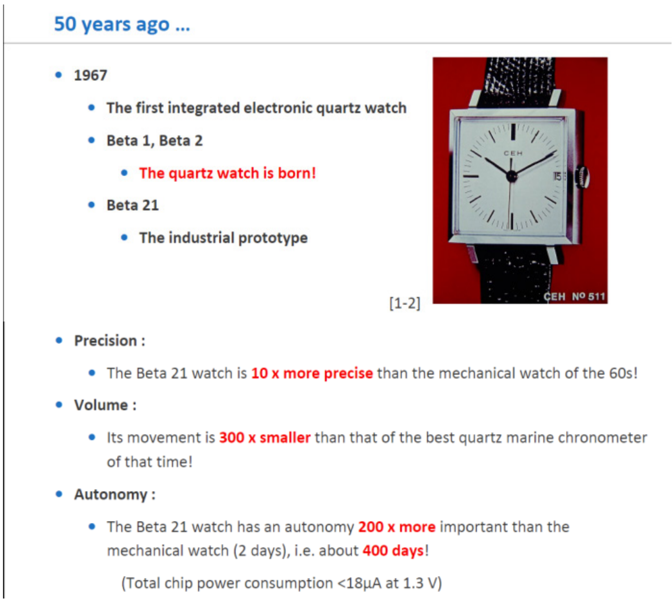
Ultra-Low Power, Sub-threshold Design - From Watch Microelectronics to IoT Integrated Circuits

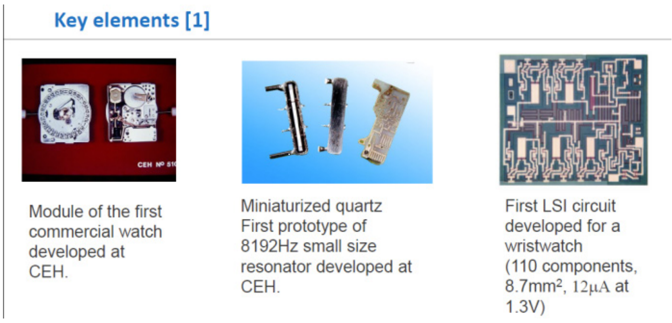
Dragan Manić

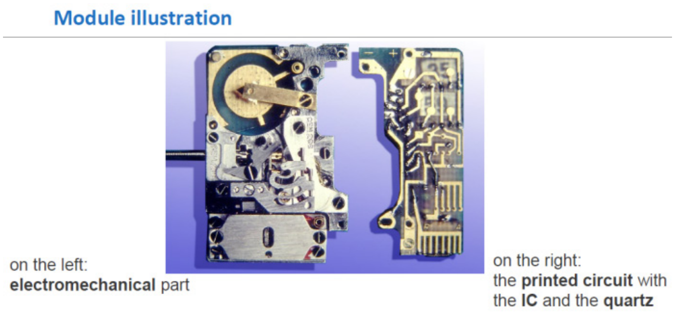
Abstract—**In the era of battery operated devices, in particular booming wearables and Internet-of-Things (IoT) objects, ultra-low energy consumption is becoming the most important challenge in the electronic design. Supply-voltage scaling is an efficient way to reduce energy by lowering the operating voltage. The reported Minimum Energy Point (MEP), in i.e. modern CMOS 65nm, can be as low as 0.35V. To achieve such low voltage operation, sub-threshold circuit design needs to be considered. Swiss watch microelectronics was exploring this approach since 1970. An overview of the principles and challenges of today's sub-threshold design will be given in this paper. The paper depicts also the 50 years of the Swiss "Quest for the Holy Grail" in ultra low-power wearable electronics, started with the world's first electronic quartz wrist watch BETA1 (1967) developed by the Centre Electronique Horloger (CEH) in Neuchâtel, toward autonomous, batteryless IoT objects of tomorrow.**

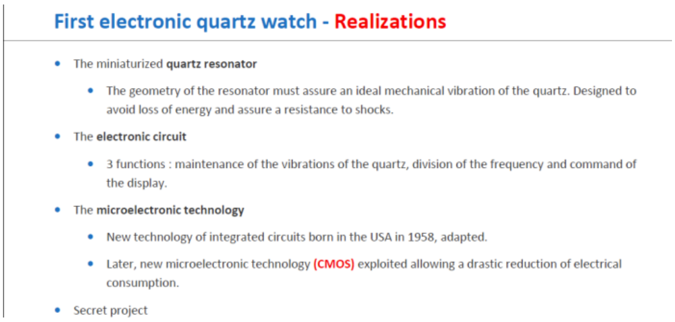
Index Terms—**Sub-threshold design; Watch microelectronics; Integrated circuits; IoT**

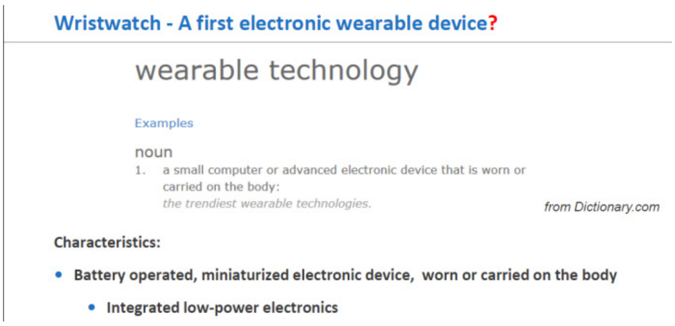
I. The First Electronic Quartz Watch











Dragan Manić is with Centre Suisse d'Electronique et de Microtechnique (CSEM), Rue Jaquet-Droz 1, CH-2002 Neuchâtel, Switzerland E-mail: Dragan.Manic@csem.ch

Proceedings of 4th International Conference on Electrical, Electronics and Computing Engineering, IcETRAN 2017, Kladovo, Serbia, June 05-08, ISBN 978-86-7466-692-0

The CEH prototype [2]

CEH (since 1962) -> CSEM (since 1984)

Centre Electronique Horloger (CEH)

Centre Suisse d'Electronique et de Microtechnique (CSEM)

II. From battery-light to battery-less

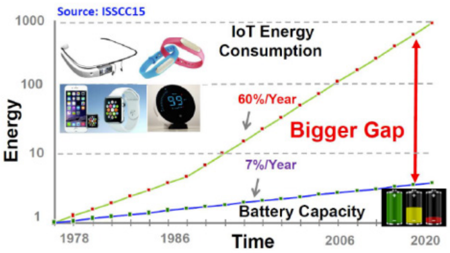
And today?

50 years later …

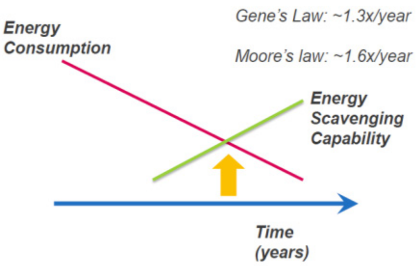
Power and miniaturization challenge remains!

… from battery-light to battery-less

Power challenge for Internet of Things (IoT)



CSEM Vision : From wireless to batteryless

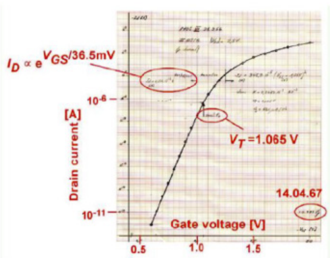


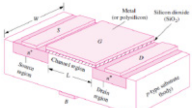
Ultra-low energy consumption

- becoming the most important challenge in the electronic design
- supply-voltage scaling (an efficient way to reduce energy)
  - extreme low supply operation – below MOS threshold voltage
    - **-> "sub-threshold"/"week inversion" circuit design techniques!**
- **Swiss watch microelectronics was exploring this approach since the end of '60s**
- **hundred of millions of week inversion ICs been produced for watch applications**

III. Sub-threshold design

Pioneering weak inversion for analog CMOS [1]





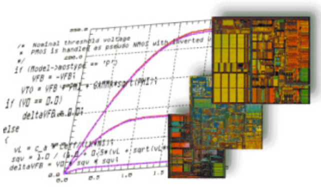
- **First measurement of a MOS transistor at very low current (1967, by Eric Vittoz)**
  - **Sub-threshold voltage experiments**

EKV Model (Low Power MOSFET Model) [3]

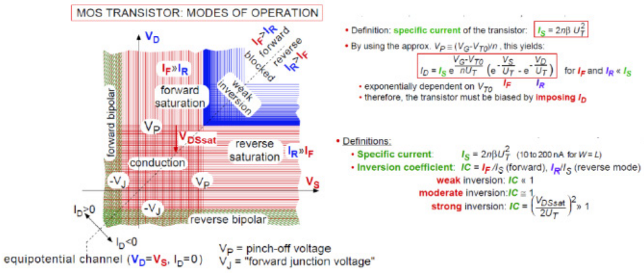
- **Advanced MOSFET model for low-voltage low-current circuit design**
- As supply voltage of circuits decreases to reduce power consumption
  - analog designs require a more physical, accurate and continuous compact MOS model.

=> Enz-Krummenacher-Vittoz (EKV) model

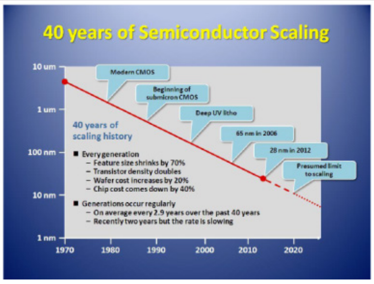
(http://ekv.epfl.ch/)

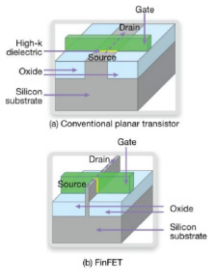


Modeling [3]

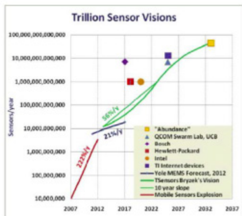


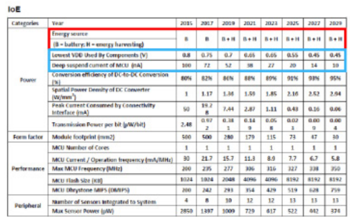
CMOS technology scaling





CMOS supply voltage scaling: Challenge to operate at 0.4V!



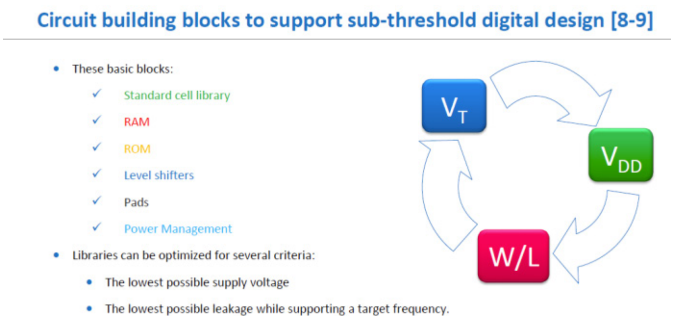


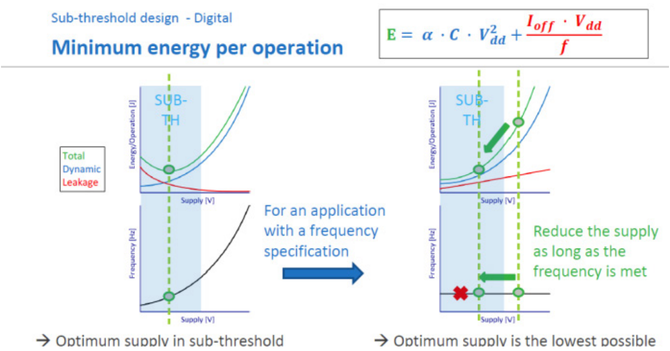
Opportunity:
Sensors will populate the world of IoT

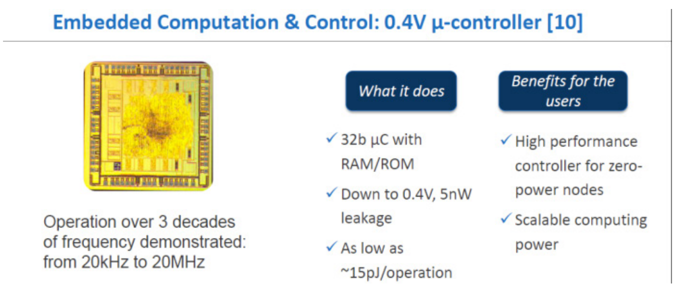
Source: 2015 ITRS "IoE" roadmap [4]

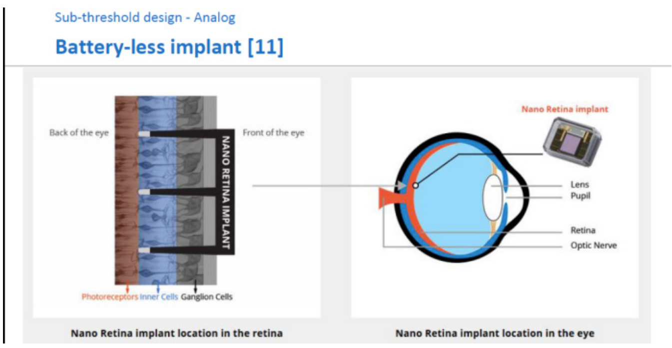
Design considerations in week inversion [5-7]

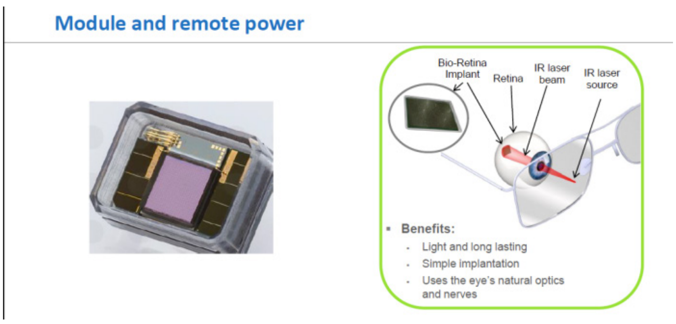
- Exponential I-V characteristics in week inversion
  - **PVT variations** – Not only an issue for analog!
    - Small variation on process (i.e. Vt)
      - exponential variation on the bias current
    - Temperature effects
  - **Matching**
    - Current matching degraded
    - Voltage matching improved

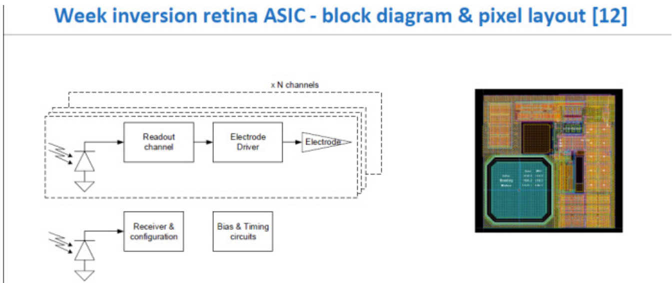


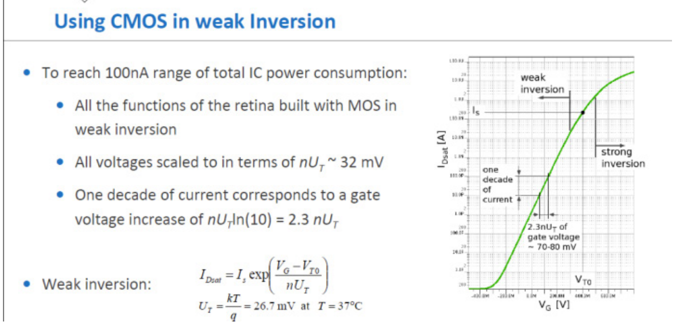






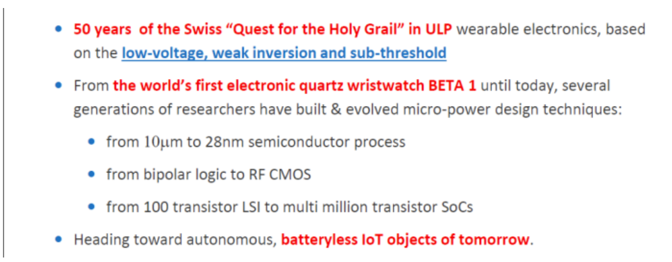






IV. ULP IoT CONNECTIVITY

V. CONCLUSION



REFERENCES

[1] E. Vittoz, "The Electronic Watch and Low-Power Circuits", *in IEEE Solid-State Circuits Newsletter* · pp. 7-23, February 2008.

[2] C. Piguet, "The First Quartz Electronic Watch", PATMOS 2002, Sevilla, Spain, 2002.

[3] C.Enz, F.Krummenacherand E.Vittoz, "An analytical MOS transistor model valid in all regions of operation and dedicated to low-voltage and

low-current applications", *Analog Integrated Circuits and Signal Processing*, vol.8, pp.83-114, 1995.
[4] ITRS –International Technology Roadmap For Semiconductors 2.0, 2015 Edition, Executive Summary.
[5] E. Vittoz, "Micropowertechniques", in *Design of VLSI Circuits for Telecommunication and Signal Processing*, edited by J.Francaand Y. Tsividis, Prentice Hall, 1994.
[6] A. Tajalli, Y. Leblebici, "Extreme Low-Power Mixed Signal IC Design: Subthreshold Source-Coupled Circuits", Springer, 2010.
[7] “Sub-Threshold Design -A Revolutionary Approach to Eliminating Power”, White Paper, ambiqmicro.com, Issued in May 2014.
[8] M. Pons, J.-L. Nagel, D. Séverac, M. Morgan, D. Sigg, P.-F. Rüedi, C. Piguet, “Ultra Low-Power Standard Cell Design using Planar Bulk CMOS in Subthreshold Operation”, PATMOS 2013.
[9] M. Pons Solé, T.-C. Le, C. Arm, D. Séverac, S. Emery, C. Piguet, “Design and on-Silicon Characterization of a 6T SRAM Memory Operating at Subthreshold Voltage”, CSEM Scientific & Technical Report 2015.
[10] J.-L. Nagel, M. Pons Solé, T.-C. Le, C. Arm, D. Séverac, S. Emery, “Sub-threshold Latch-based icyflex2 32-bit Processor with Wide Supply Range Operation”, CSEM Scientific & Technical Report 2016.
[11] http://www.nano-retina.com/technology/
[12] R. Gefen, C. Enz, D. Manic “Ultra-small, easy to implant, artificial retina combining nanotechnologies and ultra low power microelectronics”, Vision Artificielle, Lausanne, Switzerland, 2012.