Asleep Yet Aware, Awake on Declare Virginia Efficient Near-zero Ultra-low-power System

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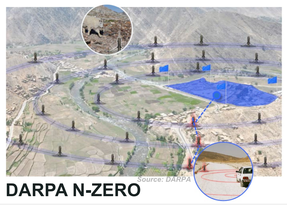
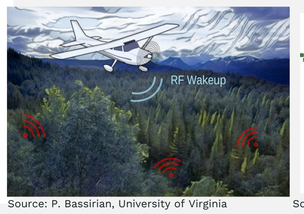
Driving Applications: Near Zero Power RF and Sensor Operations (N-ZERO)

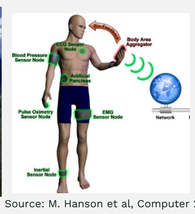
Overview of Event Driven Sensor Nodes



DARPA N-ZERO

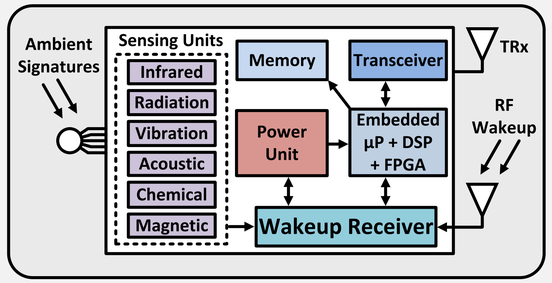


Source: P. Bassirian, University of Virginia



Source: M. Hanson et al, Computer 2009

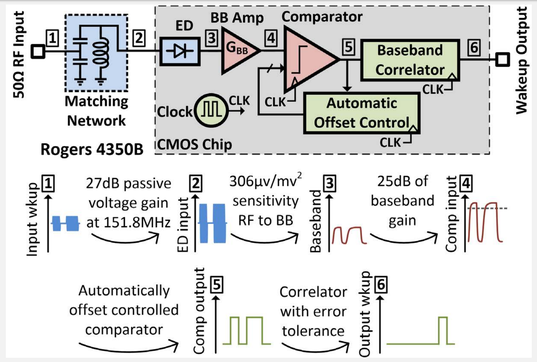
Source: Kim Komenich / The Chronicle



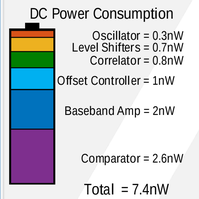
System Opportunities:
Large Scale Fields of Sensor Nodes that can last for years on a small coin-cell battery
Ongoing Needs:
Sensitivity, High RF Freq., Self-Calibration, Node Selectivity, Efficient Low Power Transmitter

Virginia Efficient Near-zero Ultra-low-power System (VENUS) Concept

System Design

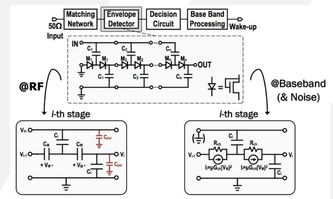


Envelope detector first architecture utilizes passive voltage gain followed by an envelope detector. Low frequency baseband amplification can achieve noise limited, not voltage limited operation, and ultra low power digital correlation rejects false positives while maintaining sensitivity. Automatic offset calibration maintains functionality in the presence of process and temperature variation and external interferes. [1]



Passive Envelope Detector

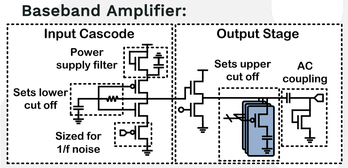
Opportunities: Create very sensitive, passive detection by trading off sensitivity, speed and input impedance at frequencies where low power RF amplification is not attainable. RF frequencies detectable at a GHz or more [2].



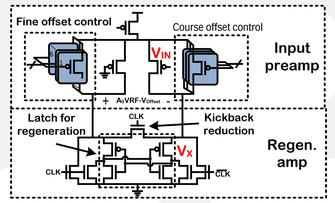
Ultra-Low Power Active Circuits

Opportunities: Enables detection of mV level baseband signals while consuming just a few nW of power. Increase reliability and error correct for imperfect RF and mixed signal circuits and provide selectivity between signals [1,3].

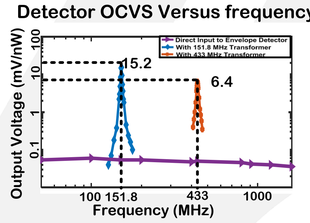
Baseband Amplifier:



Comparator

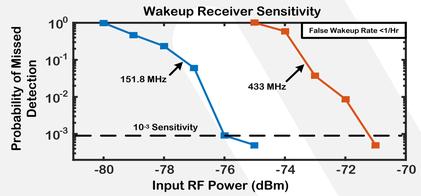


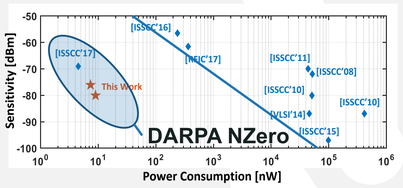
Detector OCVS Versus frequency

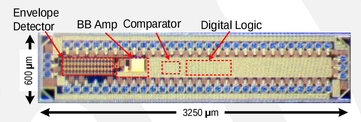


System Performance

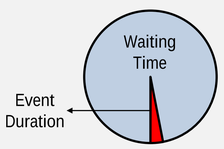
- ✓ DC Power: <10 nW
- ✓ Sensitivity: -76 dBm
- ✓ Signal Energy: <30pJ
- ✓ Prob. Of Detect.: >99%
- ✓ False Alarm Rate: <1/hour
- ✓ Signal Detection: <2mS





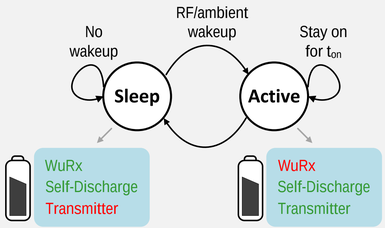


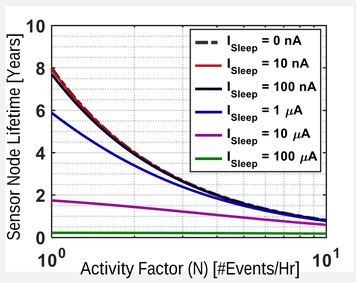
How Low is Low Enough Power?



$$T_{bat} = \frac{Q_{bat}}{Nt_{on}I_{on} + (1 - Nt_{on})I_{sleep} + I_{leakage}}$$

195 mAh; WuRx and other Sleep Power; 10 sec; 1 mA; Self-Discharge





For event driven sensor nodes with low activity factors, WuRx power can dominate battery lifetime.

The self discharge of a battery is about 10nW. Assuming that a sensor node turns on for approximately 10 seconds to take a measurement and transmit the data back, and uses 1mA DC current draw during active mode, it becomes critical to keep all a sleep mode power including the WuRx below 100nA and even 10nA for activity factors less than once per hour [2].

Similarly, receiver sensitivity is of fundamental performance as it enables sensors to be activated at larger distances.

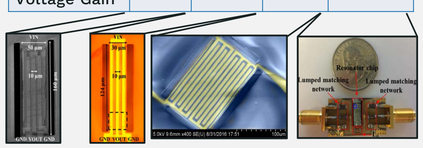
Through the N-Zero program, critical metrics such of power consumption and receiver sensitivity are improved by greater than 1 and 2 orders of magnitude respectively.

Acoustic MEMS Devices

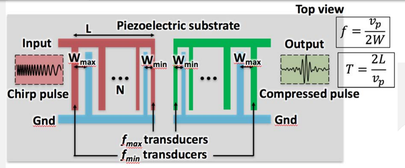
Opportunities: Very high quality factors enable transformations to very large impedances found within ultra low power systems.

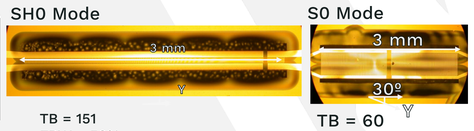
Acoustic RF Filters and Impedance Transformers

Transformer	2-Port AlN	2-Port AlN	2-Port LN	1-port AlN + lumped
Frequency (MHz)	358	506	260	447
Open Circuit Voltage Gain	16.0	7.3	35	27



Lithium Niobate Chip Compressors

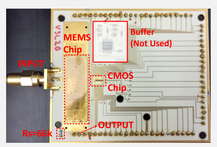


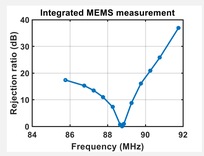


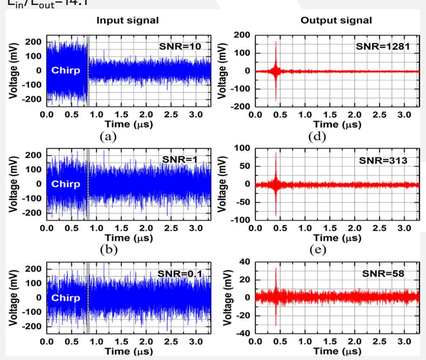
TB = 151
FBW = 50%
L_{in}/L_{out}=14.1

TB = 60
FBW = 50%

Lithium Niobate - CMOS Integration

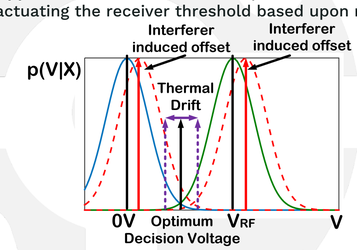


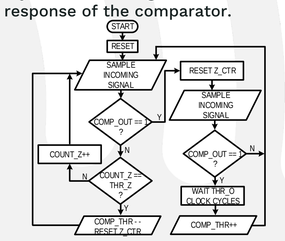




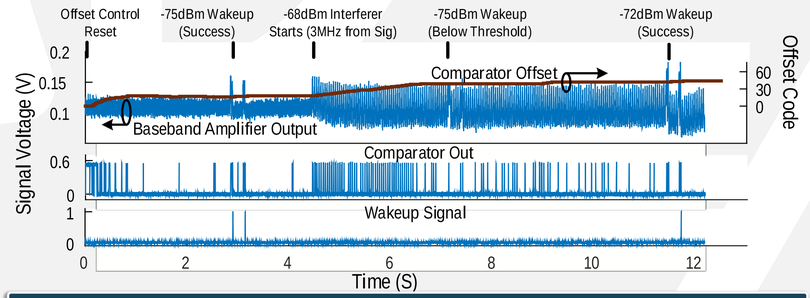
Interference and Process Variation Rejection

Opportunities: Enable robust performance in a variety of electromagnetic environments by actuating the receiver threshold based upon measured response of the comparator.





Fully-Integrated Automatic Offset Control Demonstration



References

[1] J. Moody et al., "A -76dBm 7.4nW Wakeup Radio with Automatic Offset Compensation," *ISSCC*, Feb. 2018.
[2] P. Bassirian, et al., "Analysis of Quadratic Dickson Based Envelope Detectors for IoE Sensor Node Applications," *IEEE IMS*, pp. 215-218, June 2017.
[3] H. Jiang et al., "A 4.5nW Wake-Up Radio with −69dBm Sensitivity," *ISSCC*, pp. 416-417, Feb. 2017.
[4] T. Manzaneque, et al., "Lithium Niobate Chirp Compressors for RF front ends of IoT Devices," in JMEMS, vol. 26, no. 6, pp. 1204-1215, Dec. 2017.
[5] T. Manzaneque, et al., , "An SH0 Lithium Niobate Trans-impedance Chirp Compressor with High Voltage Gain", in 2018 IEEE MEMS, pp. 783-786

The material is based upon work supported by the Defense Advanced Research Projects Agency (DARPA). The views, opinions and/or findings expressed are those of the author and should not be interpreted as representing the official views or policies of the Department of Defense or the U.S. Government.

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