WISP

Wireless Identification and Sensing Platform

Presenter: Ian Clester

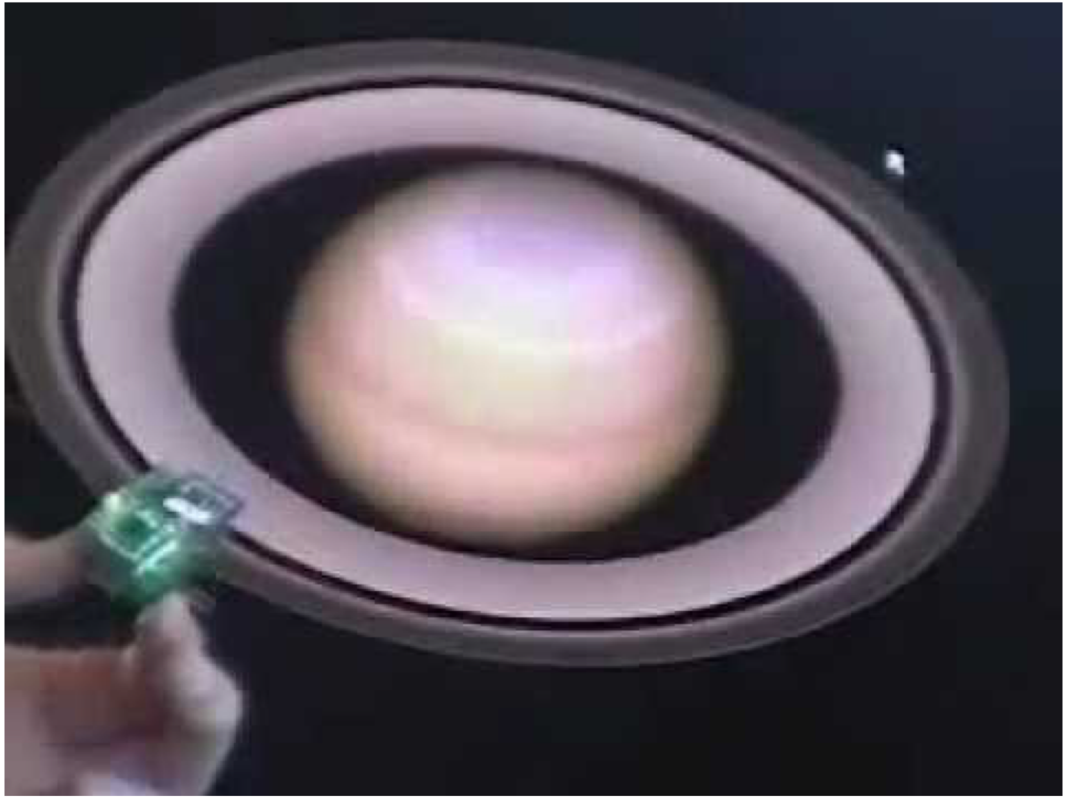
Motivation

"This core technology enables a new class of wireless battery-free devices with communication, sensing, computation, and data storage capabilities. Unconstrained by batteries, these devices have the potential to operate for years if not decades."

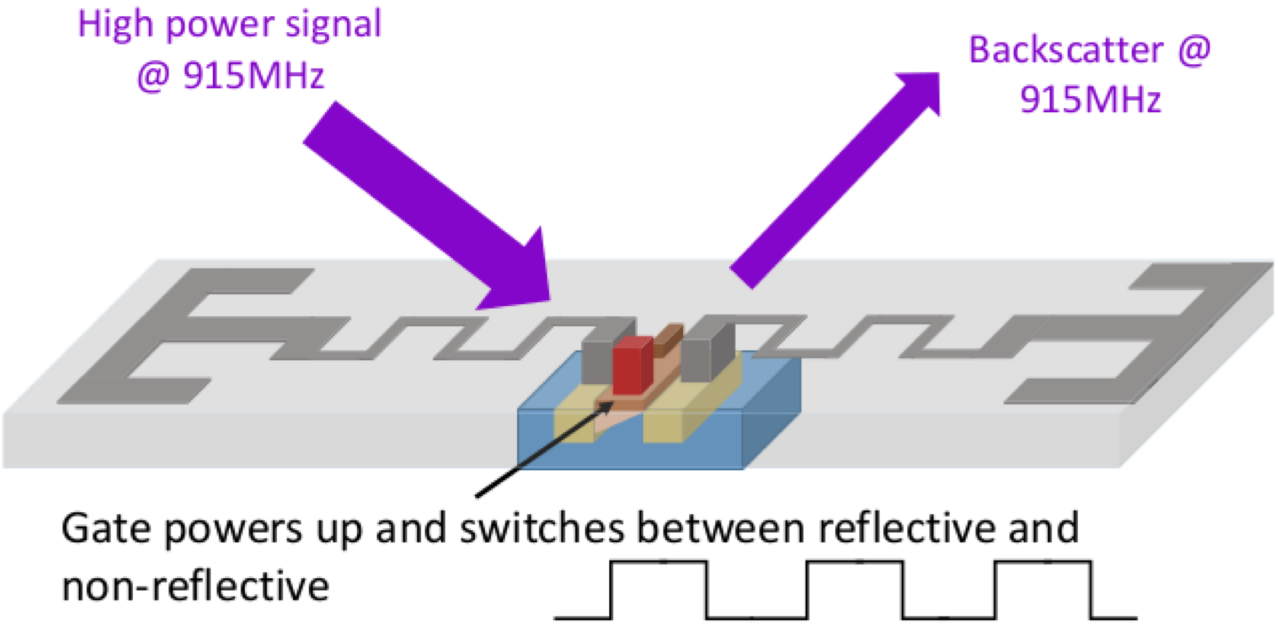
- Applications: anywhere you would want to use a sensor and preferably NOT have to deal with power!
- Ex: any kind of long-term monitoring - structural, medical, product.
- Also, anywhere you'd like a little bit of computational power without dealing with power.

Motivation

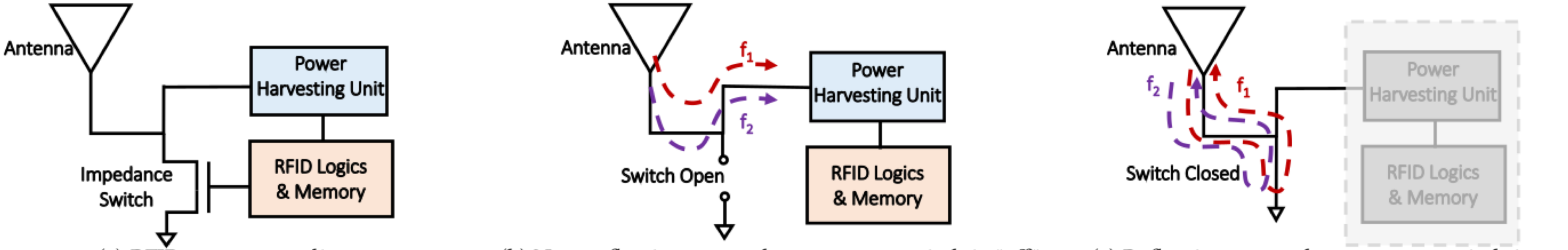
https://www.youtube.com/watch?v=SKQ3wkAqA_8



Background: RFID & Backscatter



Background: RFID & Backscatter



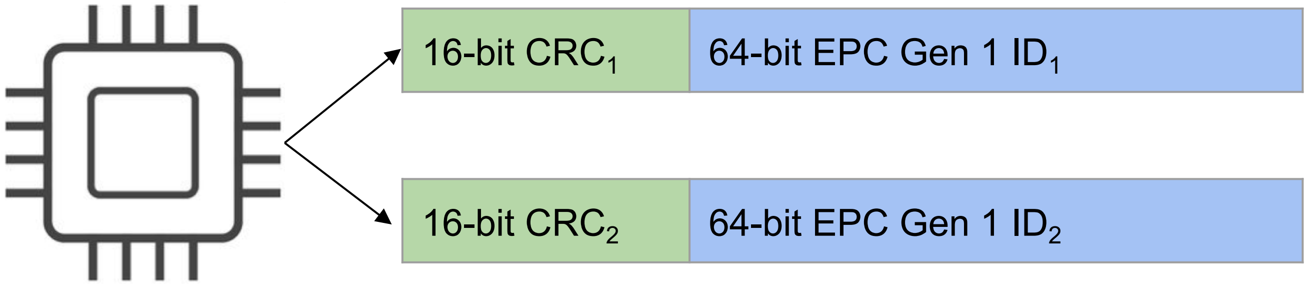
(a) RFID tag system diagram (b) Non-reflective state when antenna switch is "off" (c) Reflective state when antenna switch is on

Background: EPC Class 1 Gen 1

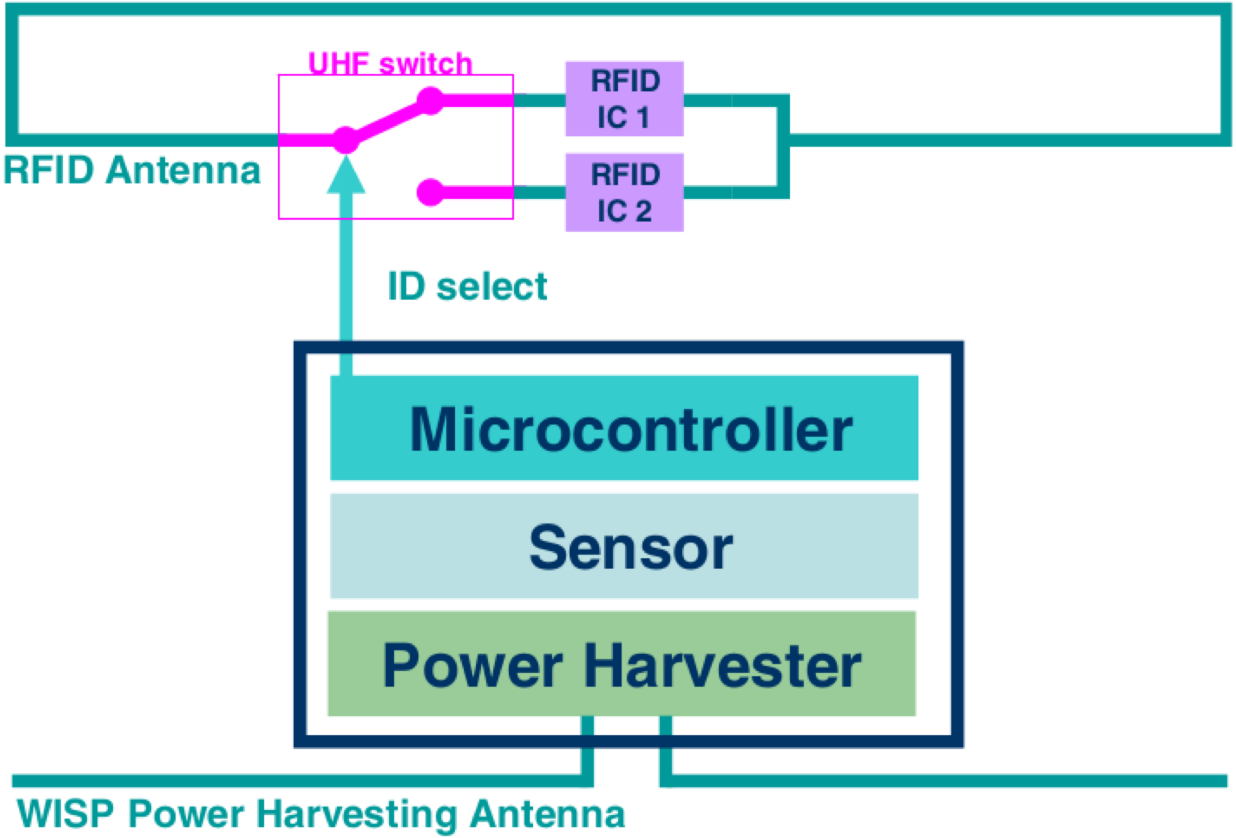
- Intended as RF-enabled alternative to bar codes.
- Protocol for communication between RFID readers and RFID tags.

16-bit CRC	64-bit EPC Gen 1 ID

Initial approaches: α-WISP and π-WISP



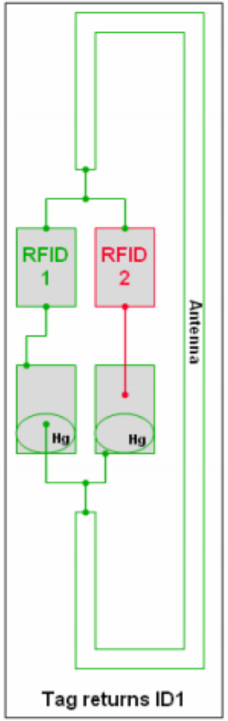
1-bit of freedom



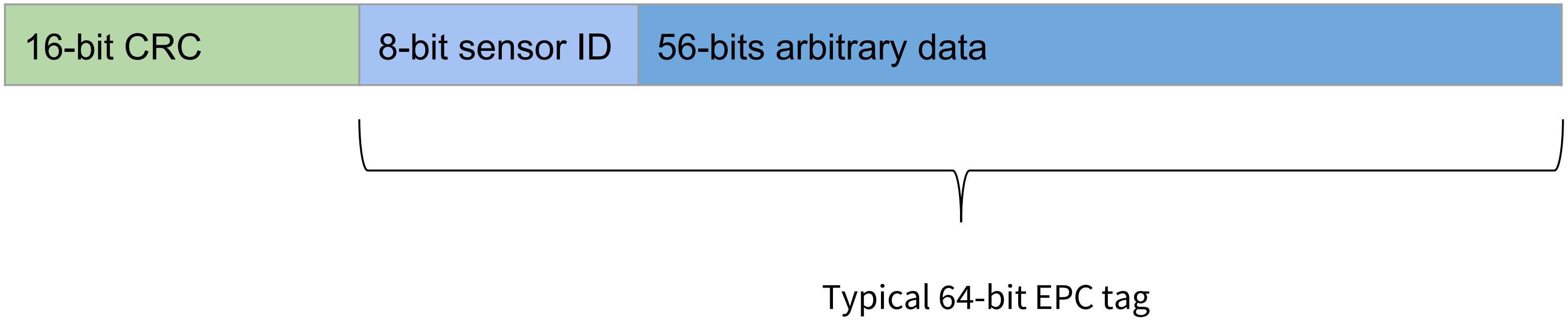
From “ID Modulation: Embedding Sensor Data in an RFID Timeseries”, J. Smith et al

Initial approaches: α-WISP and π-WISP

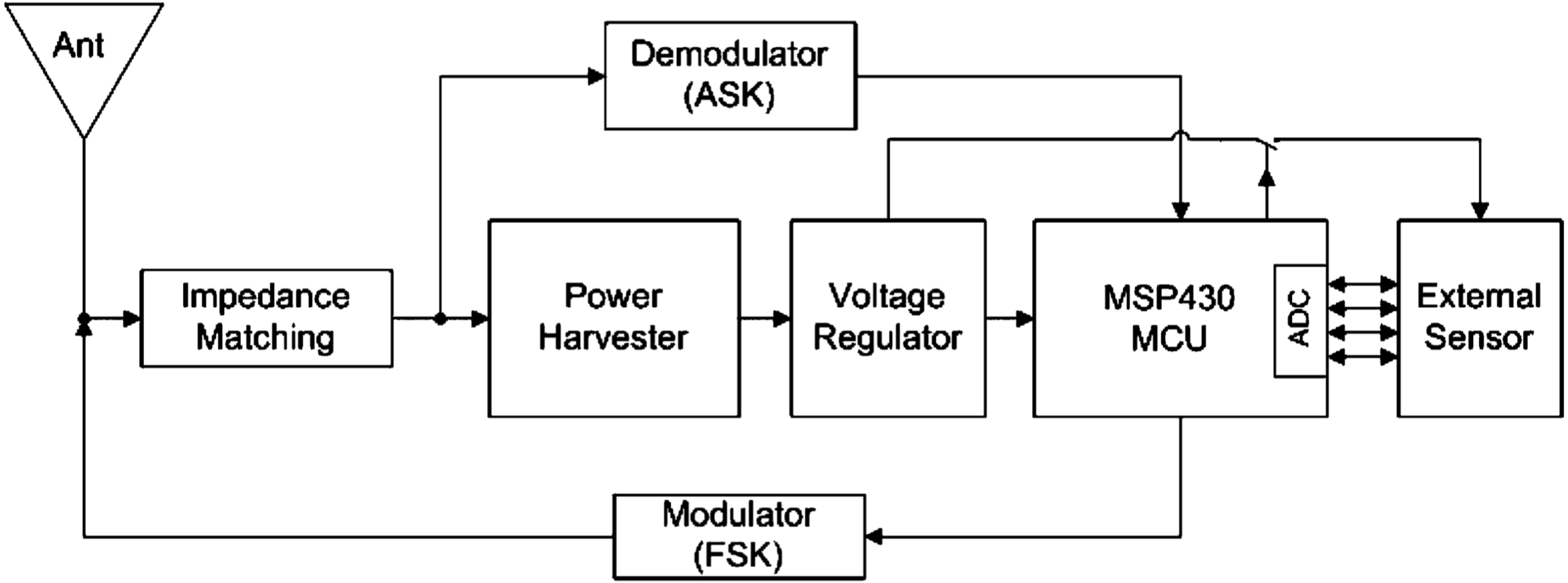
https://www.youtube.com/watch?v=mRc3peXsR8o



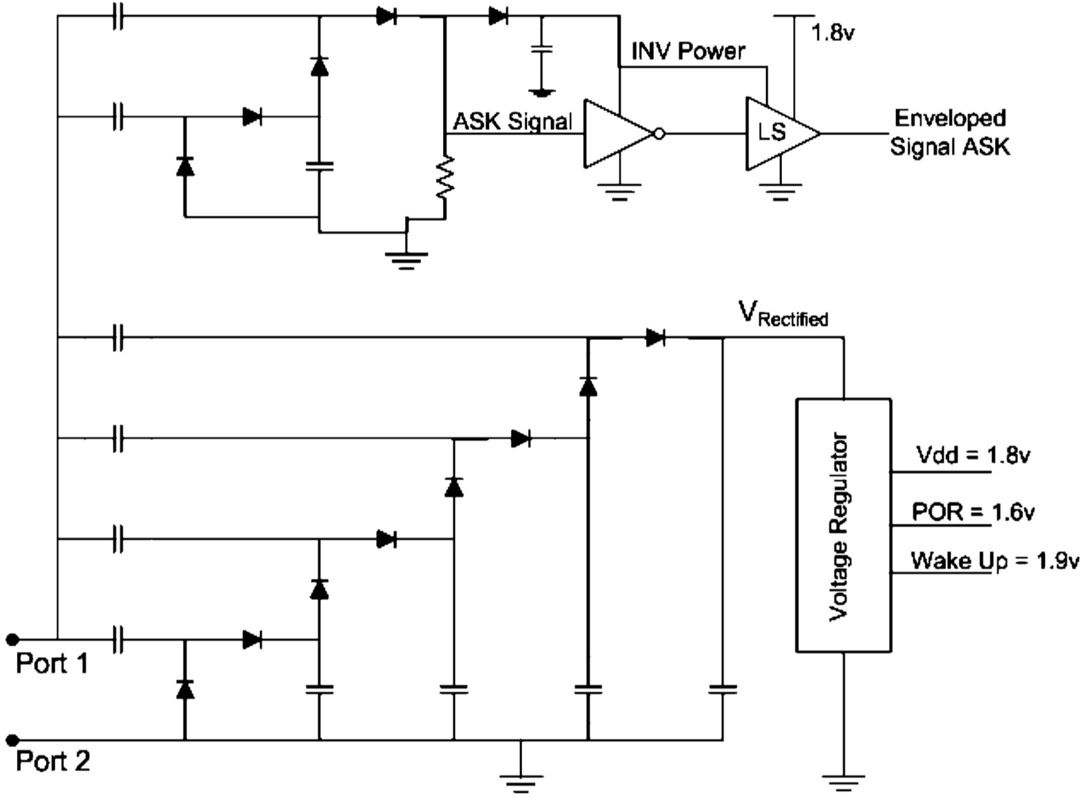
Main idea: ID as data transfer



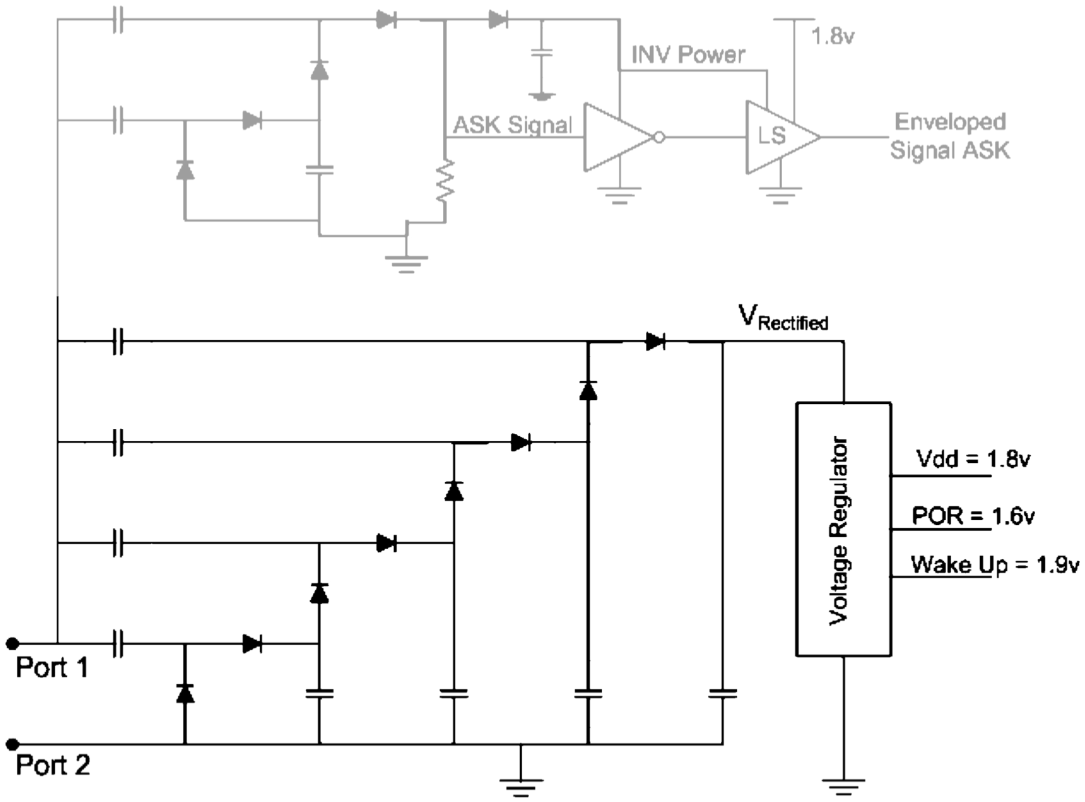
Implementation Overview



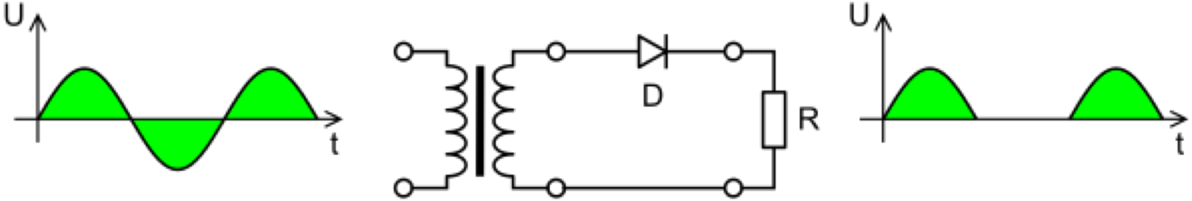
Hardware

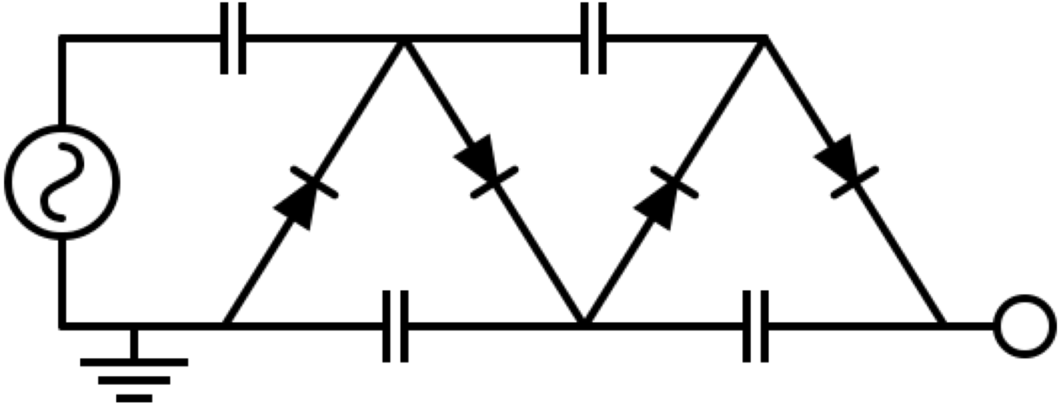

1.8v
INV Power
ASK Signal
LS
Enveloped
Signal ASK
$V_{Rectified}$
Voltage Regulator
Vdd = 1.8v
POR = 1.6v
Wake Up = 1.9v
Port 1
Port 2

Hardware: Power Harvester

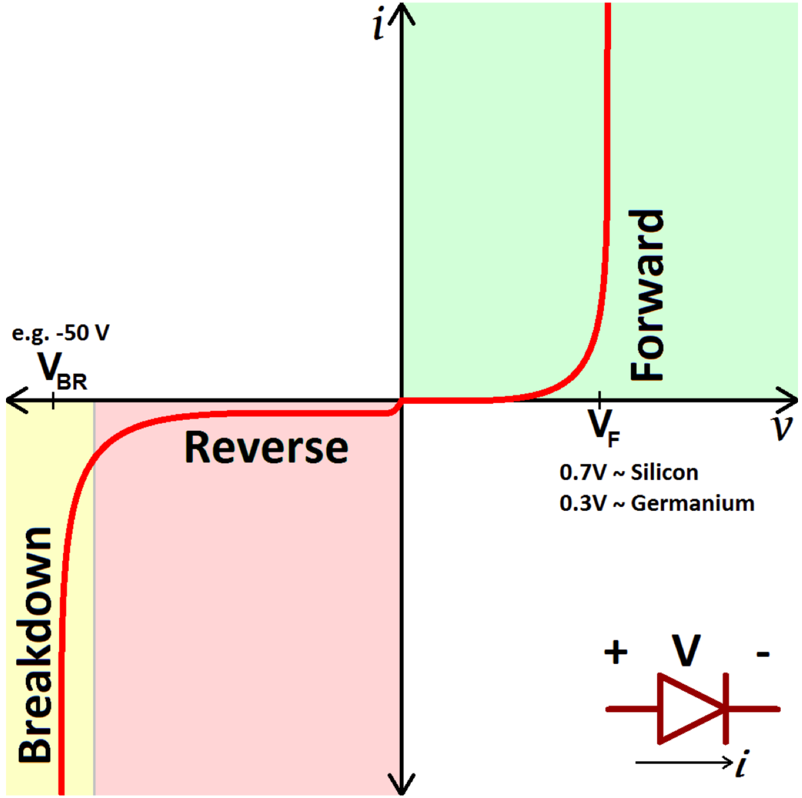


Aside: Voltage Rectification



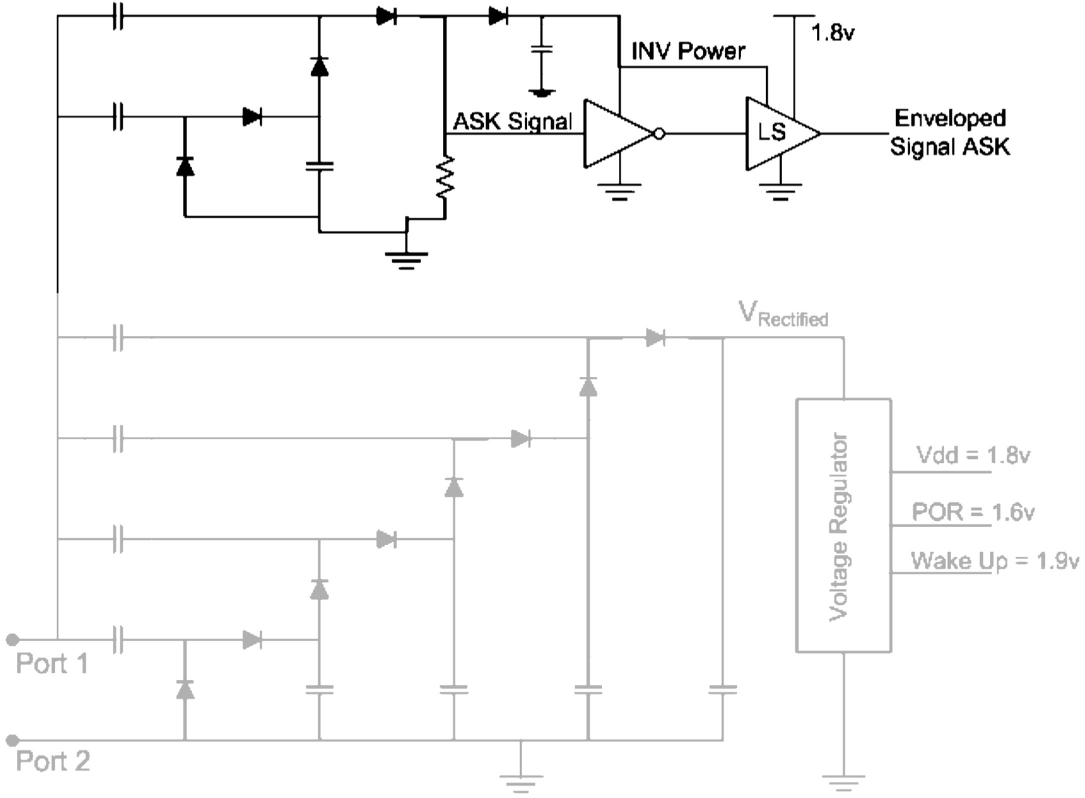


Diodes

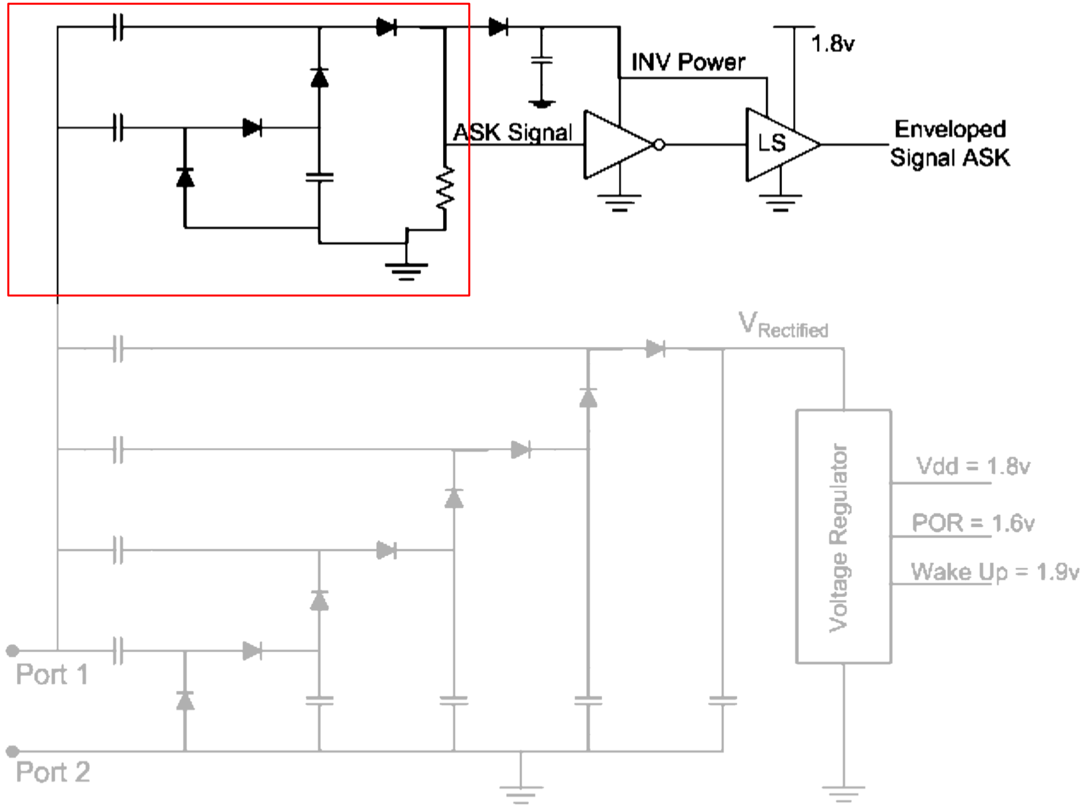


i
e.g. -50 V
V BR
Forward
Reverse
Breakdown
V F
v
0.7V ~ Silicon
0.3V ~ Germanium
+ V -
i

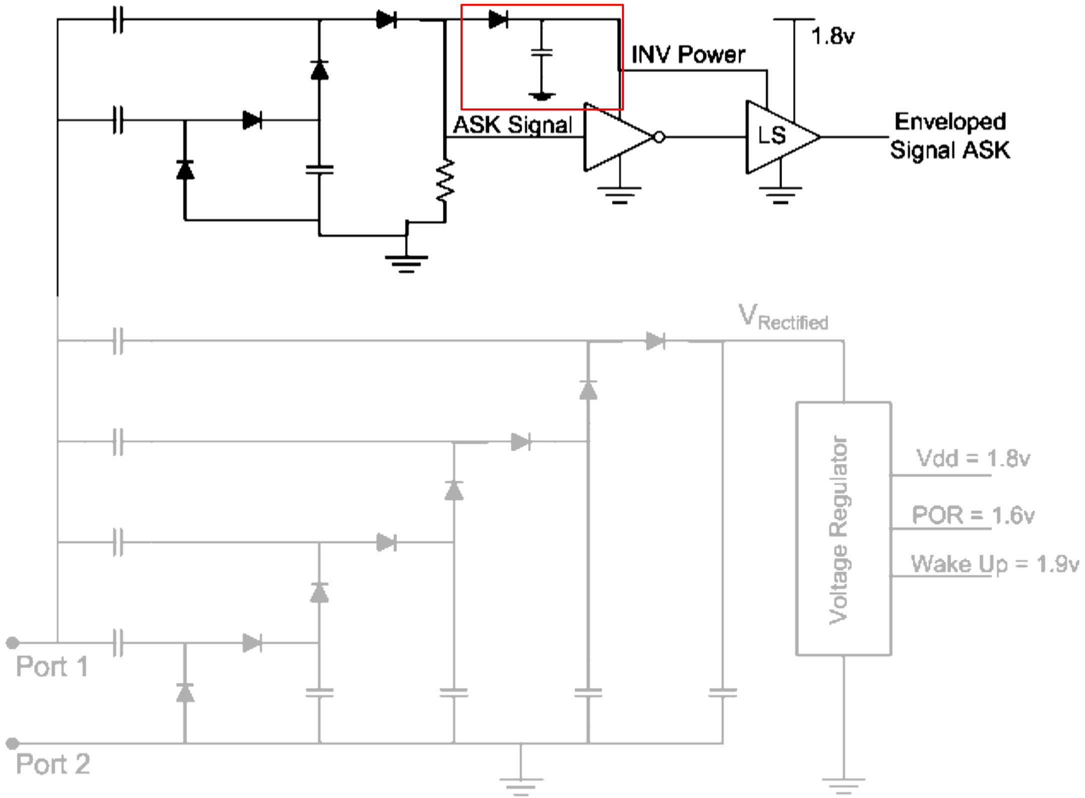
Hardware: Demodulator



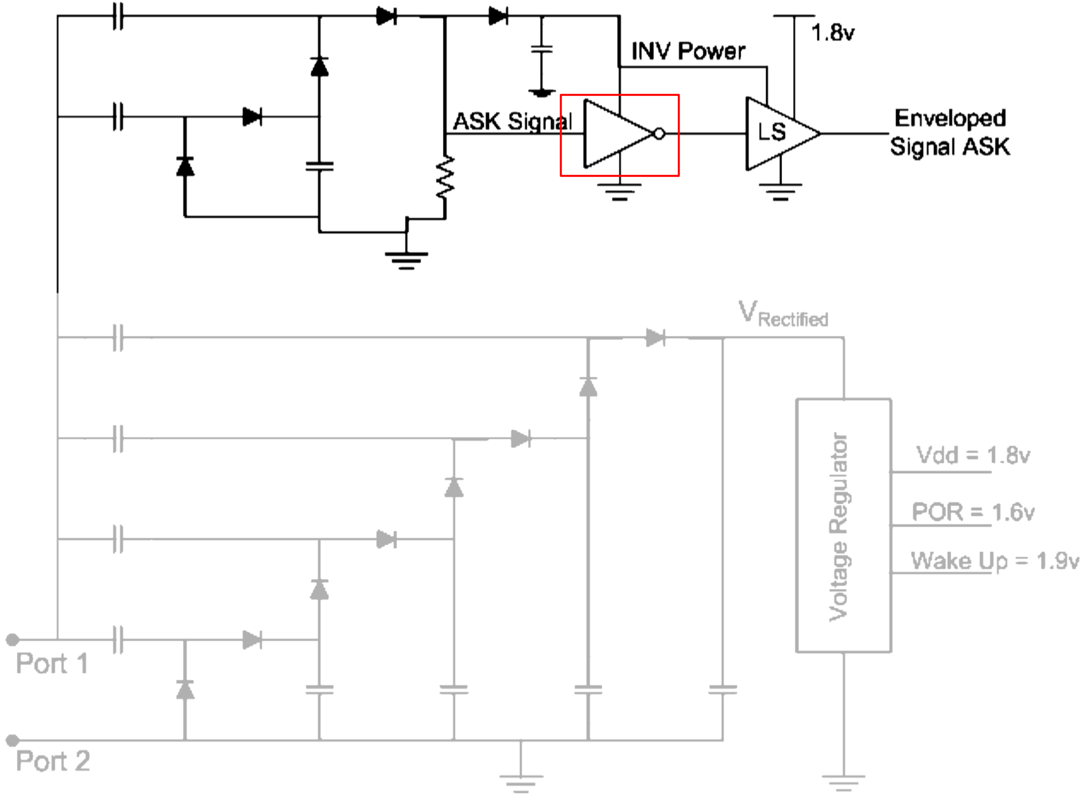
Hardware: Demodulator



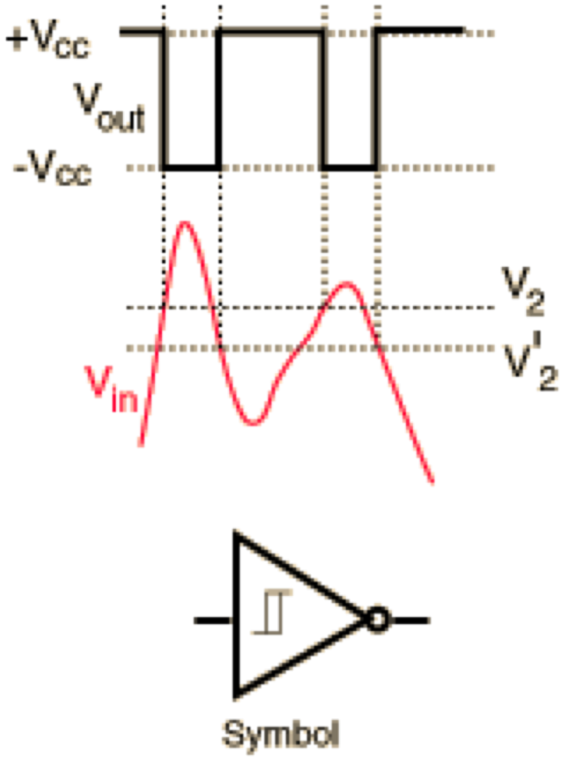
Hardware: Demodulator



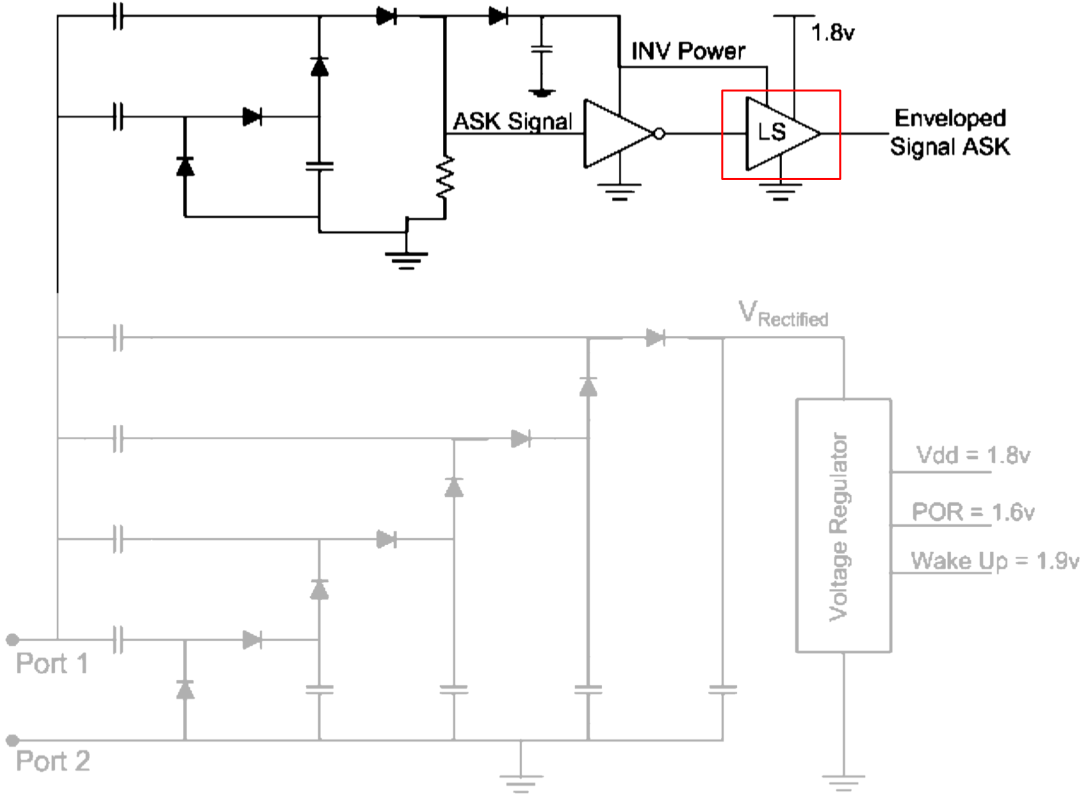
Hardware: Demodulator



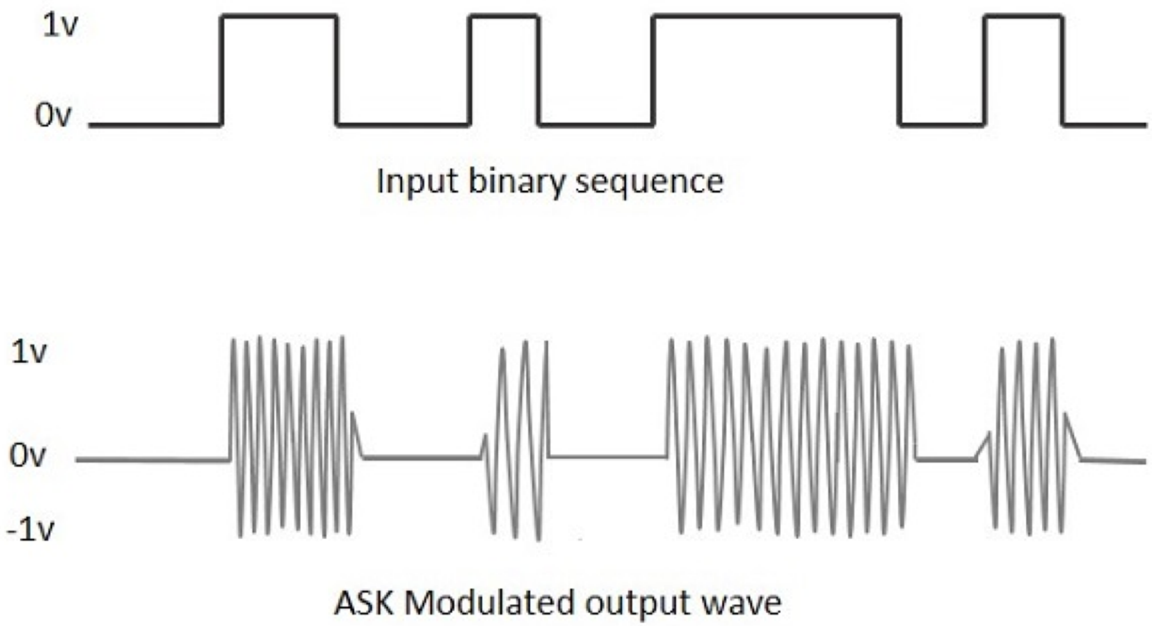
Schmitt Trigger



Hardware: Demodulator



ASK: Amplitude-Shift Keying



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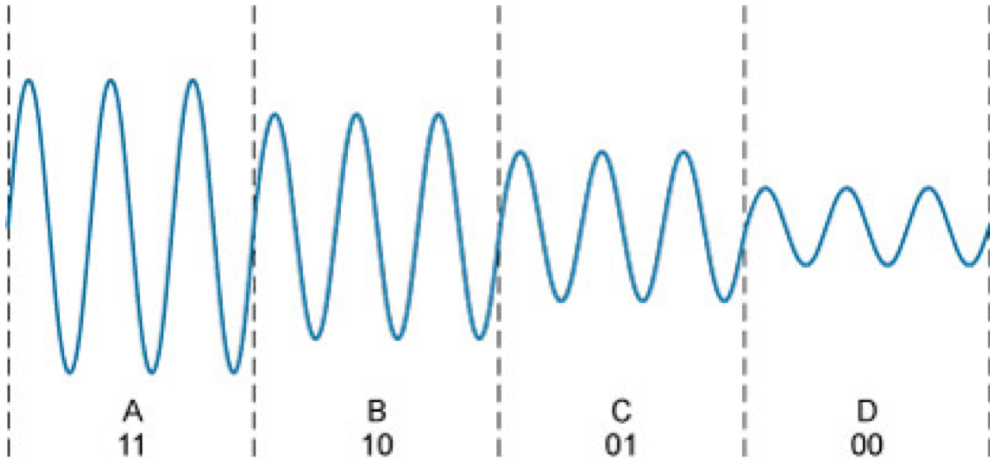
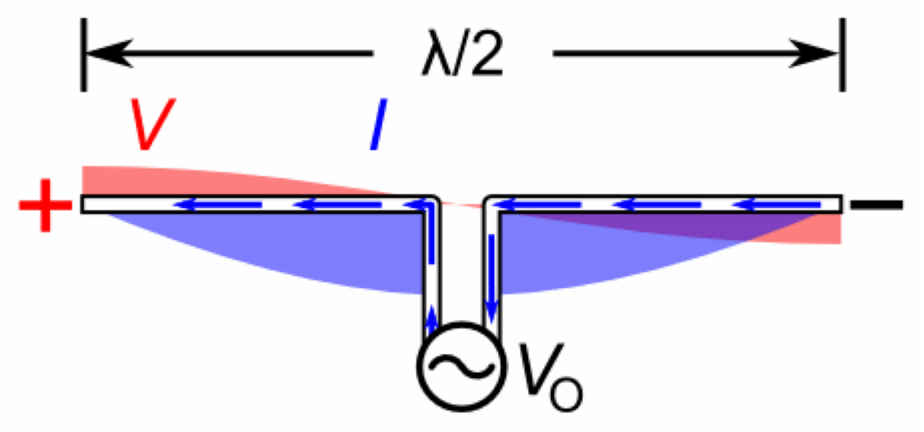
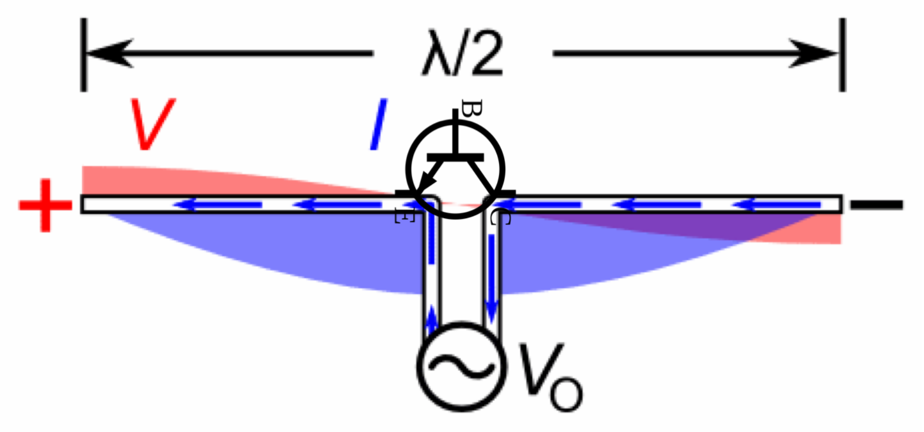


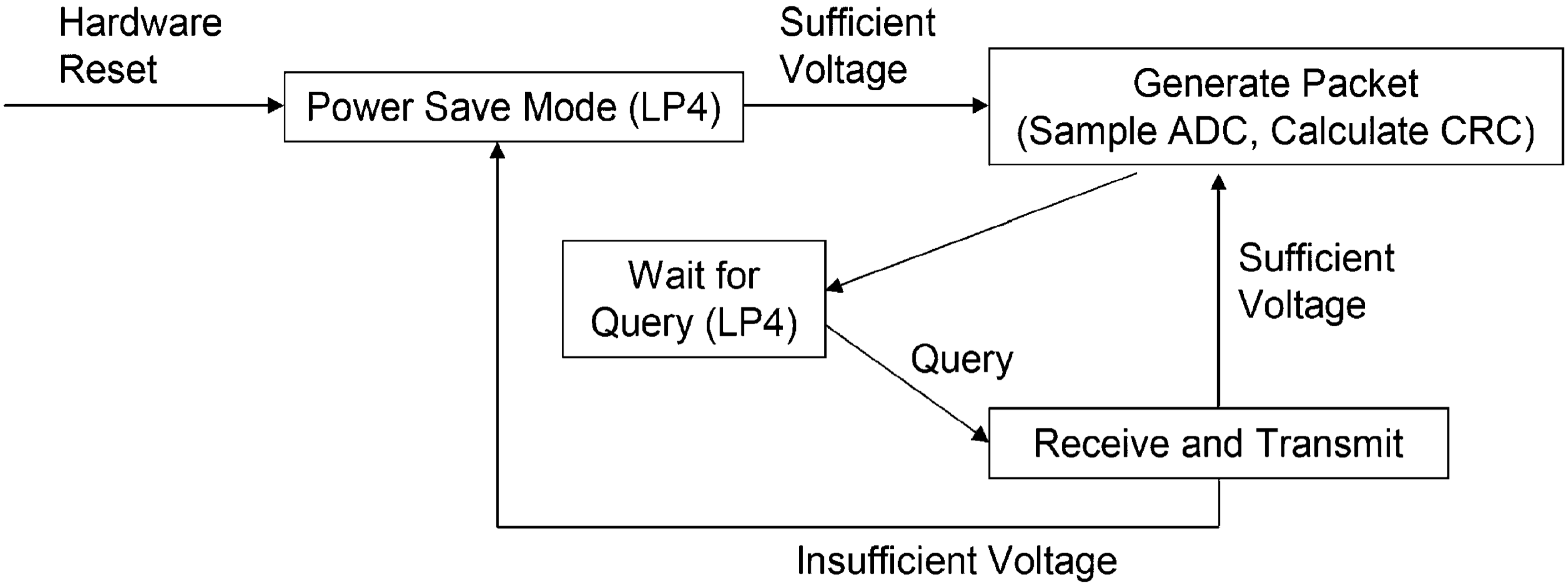
Hardware: Modulation



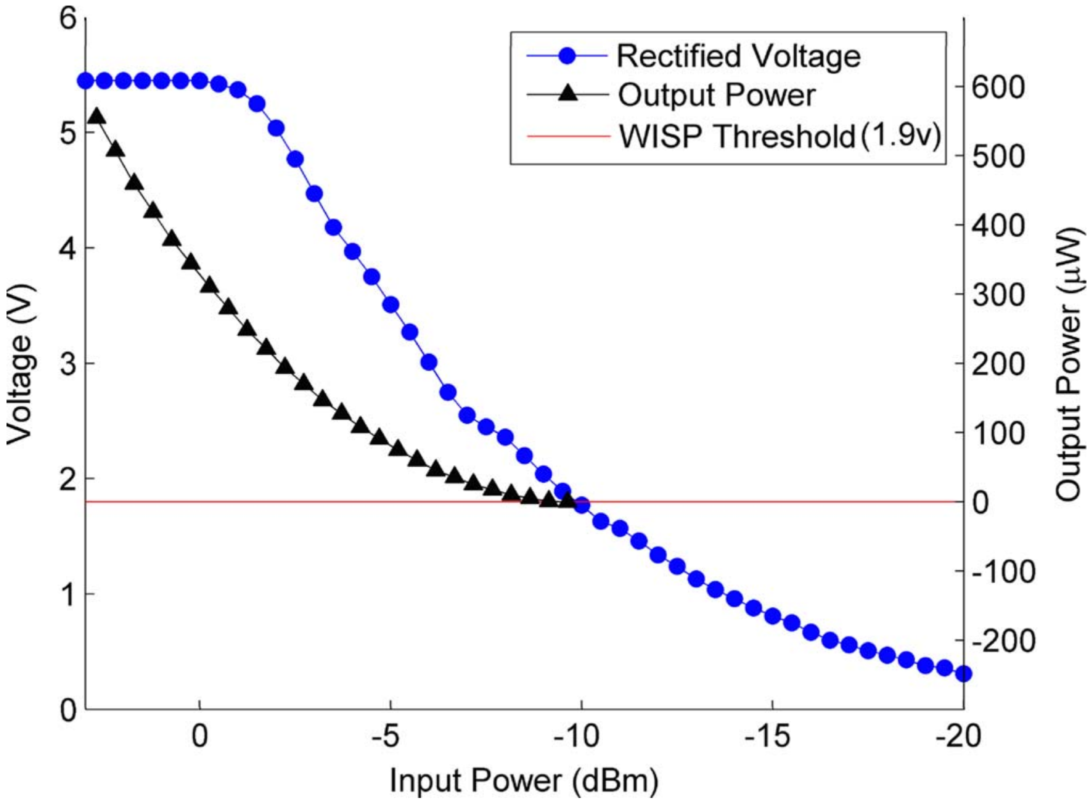
Hardware: Modulation



Software: Operational Cycle



Power Budget



Power Budget

$$P_R = P_T - 20\log\left(\frac{4\pi d}{\lambda}\right) + G_T + G_R - L_P$$

- P_T = 1 W = 30 dBm
- G_T = 6 dBi (regulatory limit)
- G_R = 2 dBi (dipole antenna)
- λ = 0.33m (915 MHz)
- L_P = 3 dB

Power Budget

- MSP430: Family of low-power microcontrollers from Texas Instruments
- MSP430F1232: 16-bit Ultra-Low-Power Microcontroller
  - 8kB Flash, 256B RAM
  - 10 bit ADC (200 ksps), 1 USART
- Power consumption per TI:
  - 0.1 µA in off-mode (RAM retention)
  - 0.7 µA in standby mode
  - 200 µA in active mode (1 MHz, 2.2 V)
- Per WISP authors, 470 µA at 3 MHz, 1.8 V, or 600 µA at 4 MHz.

Power Budget

$$\frac{P_{\text{out}}}{P_{\text{active}}} = \frac{T_{\text{on}}}{T_{\text{on}} + T_{\text{sleep}}} = \text{Duty cycle}$$

1.8 V * 600 µA = 1.08 mW

Output power available at 0 dBm input is 310 µW (from previous figure).

310 µW / 1.08 mW = about 28% (apparent typo in paper; 1.12 mW → 27%)

Energy Consumption

$$\frac{P_{\text{out}}}{P_{\text{active}}} = \frac{T_{\text{on}}}{T_{\text{on}} + T_{\text{sleep}}} = \text{Duty cycle}$$

1.8 V * 600 µA = 1.08 mW

Query time is 2ms. 2 ms * 1.08 mW = 2.16 µJ.

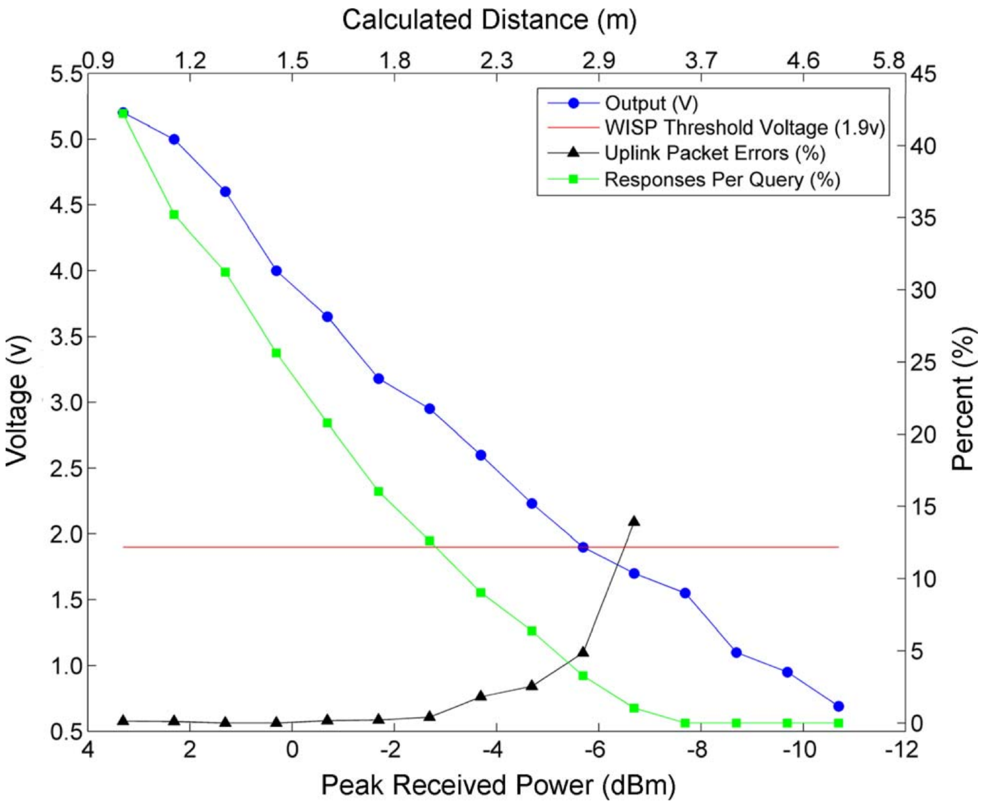
Energy in capacitor is C V^2/ 2. For C = 10 µF, baseline energy is 10 µF * $(1.8 V)^2$ / 2 = 16.2 µJ

C V^2 / 2 = 16.2 µJ + 2.16 µJ ⇒ V = 1.916, in order to complete the query.

Power Budget

$$V_{dd}(I_S + I_W)T \leq \frac{1}{2}C\left(V_{\mathrm{rec}}^2 - V_{dd}^2\right)$$

Evaluation



Calculated Distance (m)
0.9
1.2
1.5
1.8
2.3
2.9
3.7
4.6
5.8
Output (V)
WISP Threshold Voltage (1.9v)
Uplink Packet Errors (%)
Responses Per Query (%)
Voltage (v)
5.5
5.0
4.5
4.0
3.5
3.0
2.5
2.0
1.5
1.0
0.5
Percent (%)
45
40
35
30
25
20
15
10
5
0
4
2
0
-2
-4
-6
-8
-10
-12
Peak Received Power (dBm)

Epilogue

- Moo (UMass)
- EPC Generation 2
- WISP 5 - FM0 encoding
- Further developments in low-power MCUs
- NFC-WISP
- “WISP Challenge”

RFID Internals

- “Black box”: RFID state machine
  - Lots of development time goes into this
  - Most WISP users should not need to touch this
  - Protocol hackers will want to understand this

this Happy WISP Developer ignores the contents of the black box

Learning from the WISP 4.1

- Non-modular
- 1500-line mixed C and ASM file...
- Unclear how to extend/add functionality
- **Seemingly simple tasks took lots of development time**
- WISP 5 addresses these issues!

A very incomplete listing...

Of projects done by WISP Challenge recipients:

Elliptic Curve Cryptography on the WISP UHF RFID Tag, Christian Pendl, Markus Pelnar, and Michael Hutter; 7th Workshop on RFID Security (RFIDsec 2011); Amherst, Massachusetts, USA, June 26-28, 2011

Wireless Strain Measurement for Structural Testing and Health Monitoring of Carbon Fiber Composite, Federico Gasco, Paolo Feraboli, Jeff Braun, Joshua Smith, Patrick Stickler, and Luciano DeOto; Journal of Composites: Part A, May 14, 2011

Concealable, Low-Cost Paper-Printed Antennas for WISP-based RFIDs, Mauro Marroncelli, Daniele Trinchero, Vasileios Lakafosis, and Manos M. Tentzeris. 2011 IEEE International Conference on RFID. April 12-24

A Software Radio-based UHF RFID Reader for PHY/MAC Experimentation, Michael Buettner and David Wetherall. 2011 IEEE International Conference on RFID. April 12-24

Photovoltaic Enhanced UHF RFID Tag Antennas for Dual Purpose Energy Harvesting, Alanson Sample, Jeff Braun, Aaron Parks, and Joshua Smith. 2011 IEEE International Conference on RFID. April 12-24

Dewdrop: An Energy-Aware Runtime for Computational RFID, Michael Buettner, Ben Greenstein and David Wetherall. NSDI, March 2011.

Mementos: System support for long-running computation on RFID-scale devices, Benjamin Ransford, Jacob Sorber, and Kevin Fu. In Proceedings of the 16th Architectural Support for Programming Languages and Operating Systems (ASPLOS 2011), Newport Beach, CA, March 2011

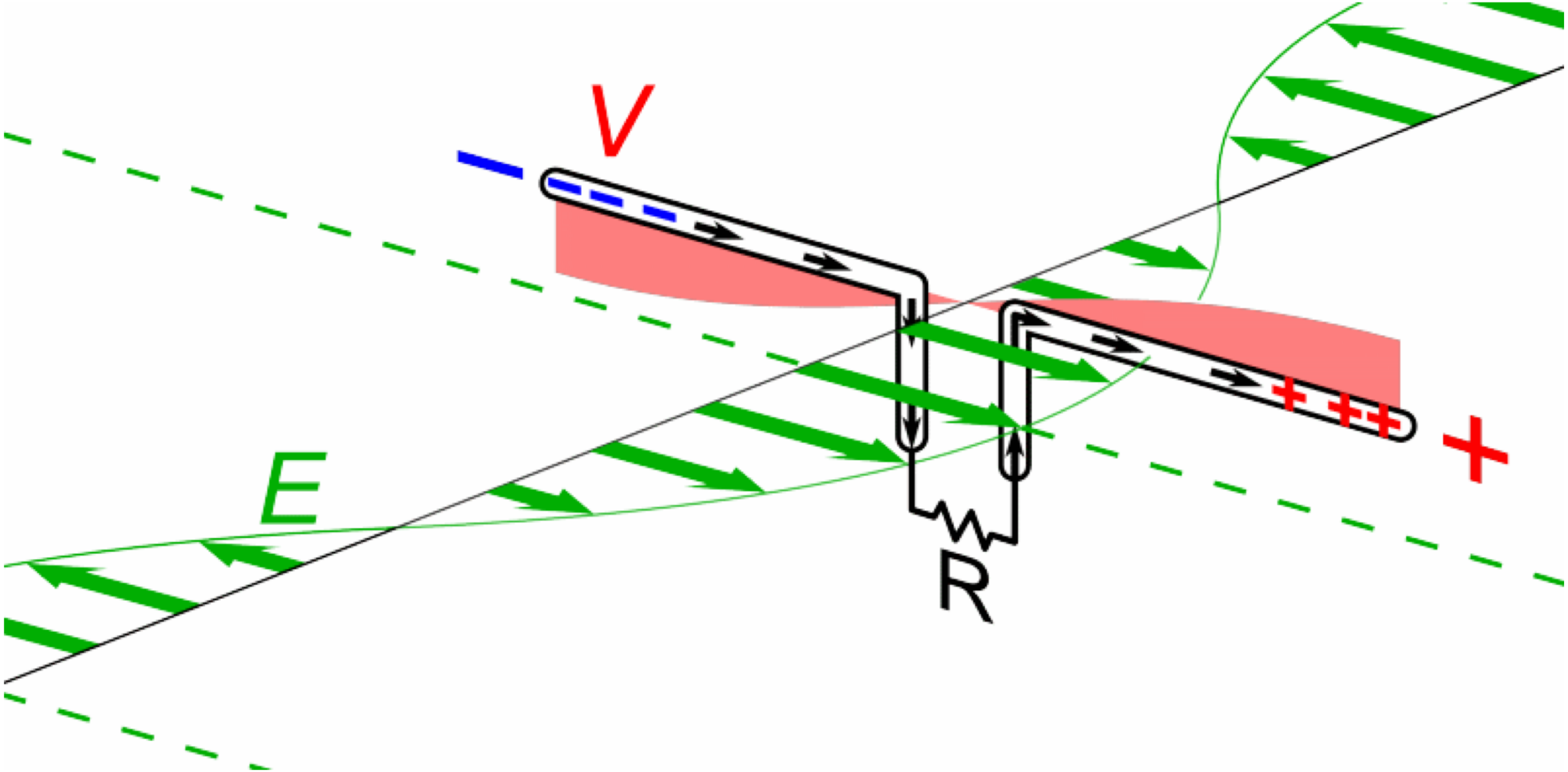
Exploiting Half-Wits: Smarter Storage for Low-Power Devices, Mastooreh Salajegheh, Yue Wang, Kevin Fu, Anxiao (Andrew) Jiang, Erik Learned-Miller. In Proceedings of the 9th USENIX Conference on File and Storage Technologies (FAST 2011), San Jose, CA, February 2011.

See wisp.wikispaces.com/Publications for more

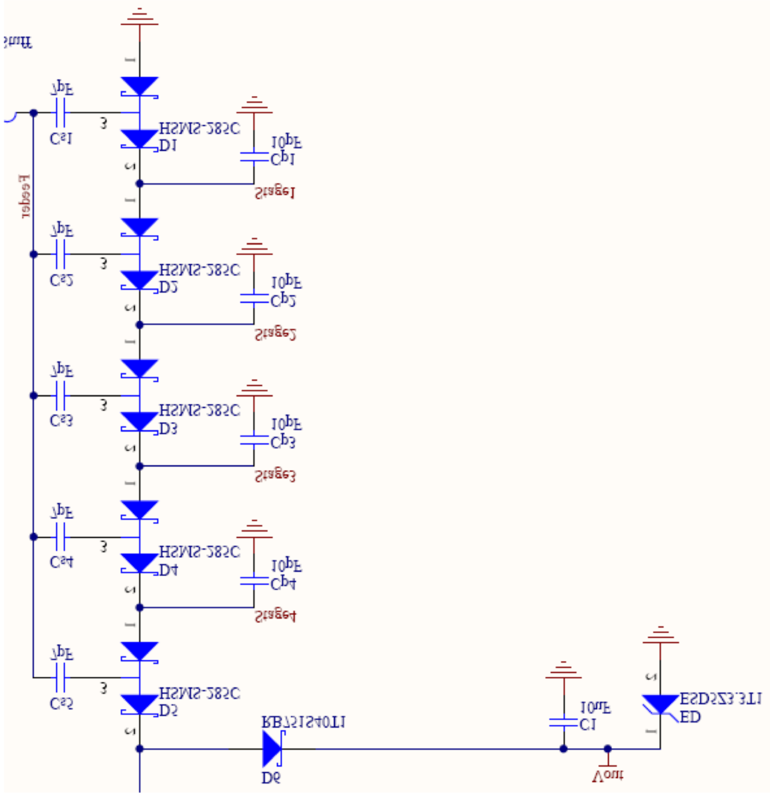
Bonus Video

https://www.youtube.com/watch?v=laTsFCMM7kA

Dipole antenna

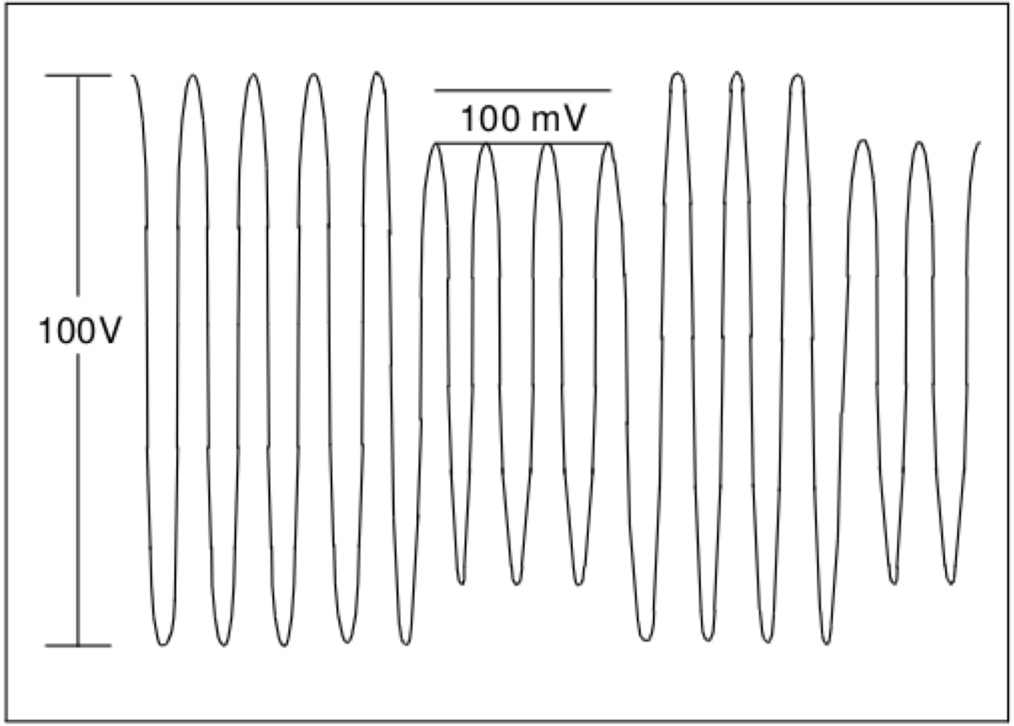


Moo

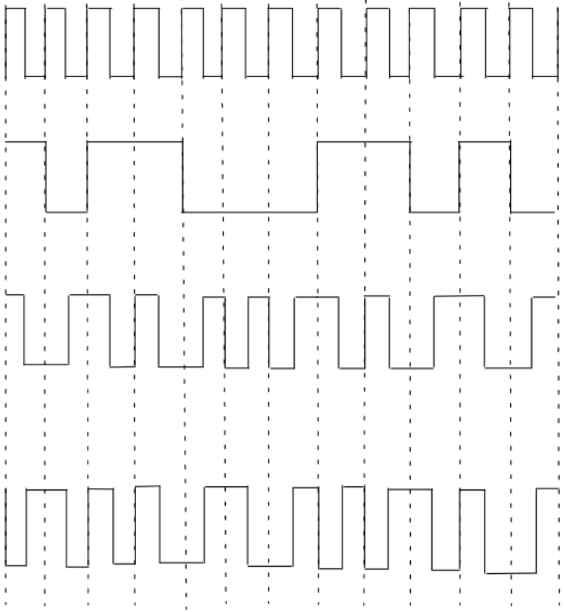


Feeder
7pF
Cs1
Cs2
Cs3
Cs4
Cs5
HSMS-285C
D1
D2
D3
D4
D5
10pF
Cp1
Cp2
Cp3
Cp4
Stage1
Stage2
Stage3
Stage4
D6
10uF
C1
Vout
ED

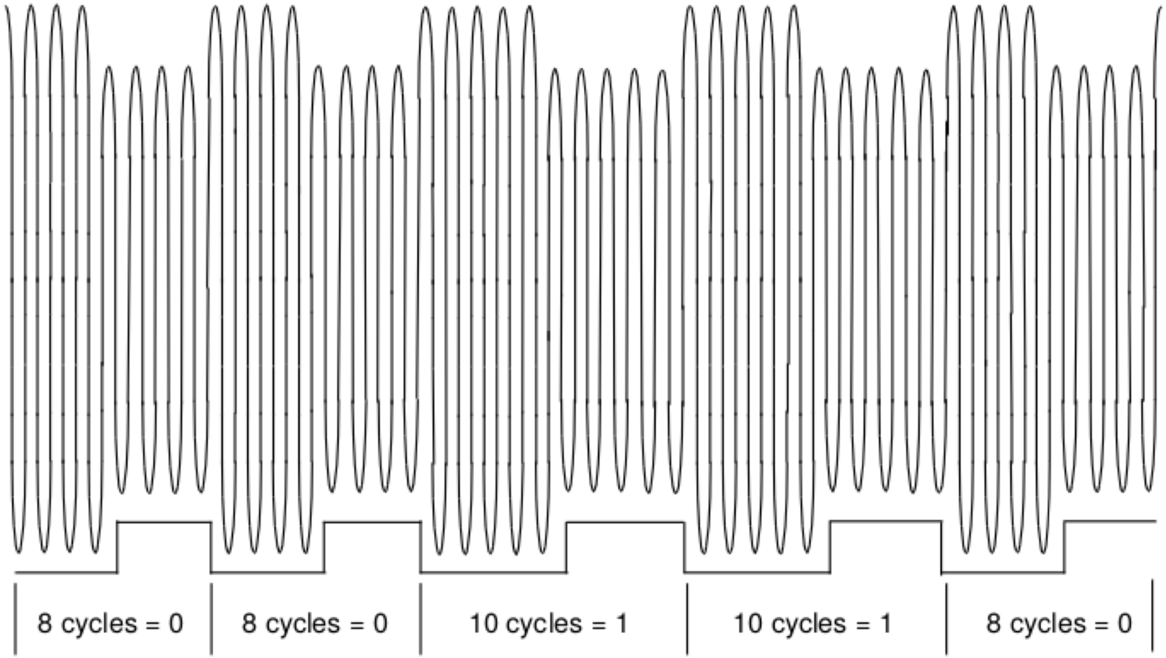
ASK



SIGNAL	WAVEFORM	DESCRIPTION
Data	1 0 1 1 0 0 0 1 1 0 1 0	Digital Data
Bit Rate CLK		Clock Signal
NRZ L (Direct)		Non-Return to Zero - Level '1' is represented by logic high level. '0' is represented by logic low level.
Biphase L (Manchester)		Biphase - Level (Split Phase) A level change occurs at middle of every bit clock period. '1' is represented by a high to low level change at midclock. '0' is represented by a low to high level change at midclock.
Differential Biphase S		Differential Biphase - Space A level change occurs at middle of every bit clock period. '1' is represented by a change in level at start of clock. '0' is represented by no change in level at start of clock.



FSK on ASK



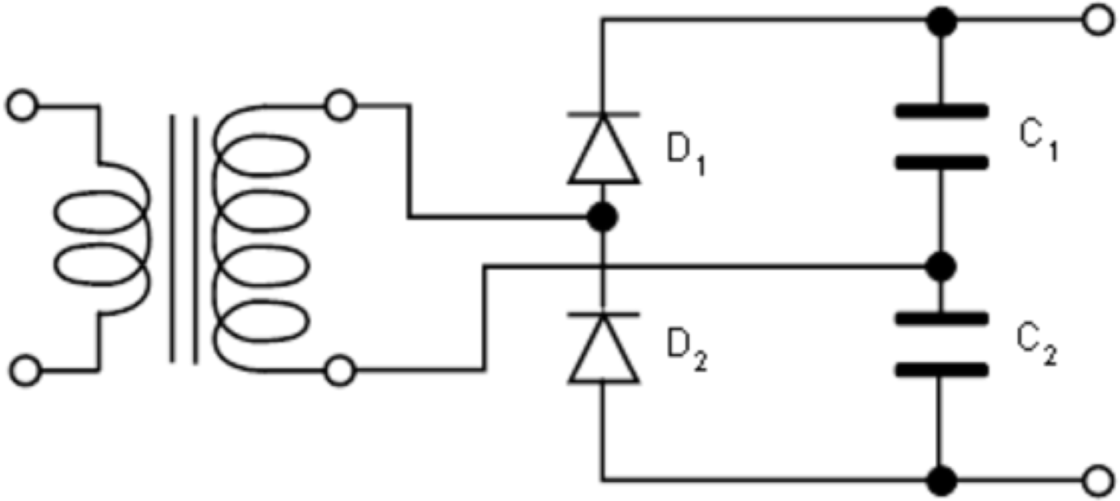
NFC-WISP 1

https://www.youtube.com/watch?v=YVdQx6ZjGuo

NFC-WISP 2

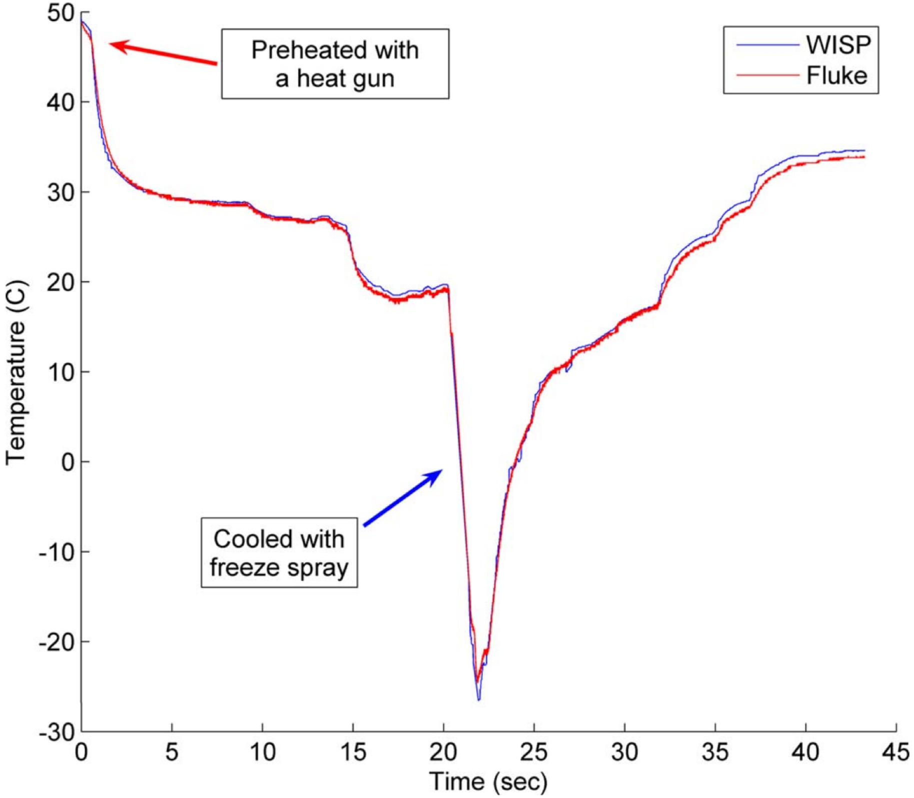
https://www.youtube.com/watch?v=xI2xMxhkhQ0

Transformer-based rectifier

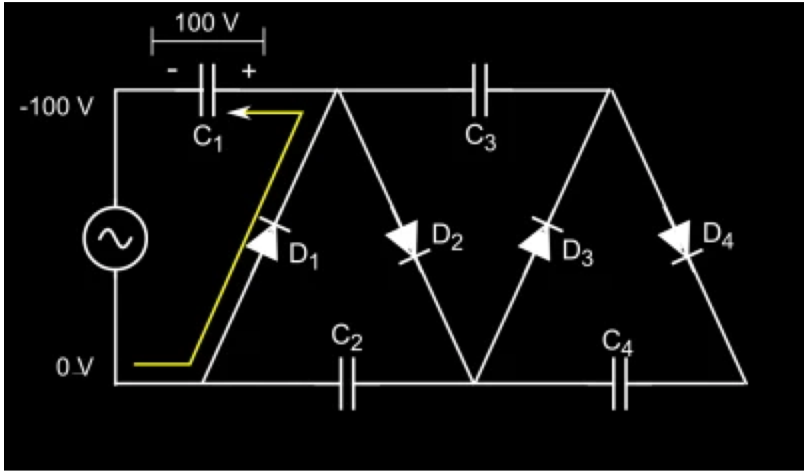


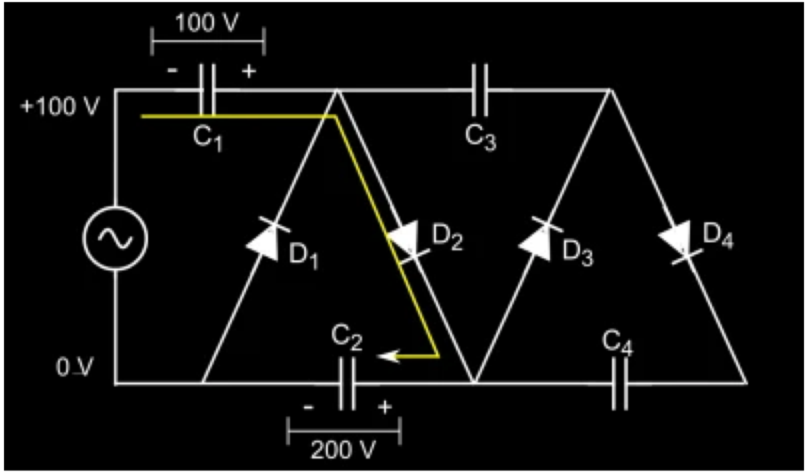
Power Budget

$$P_{\text{in}} = P_{\text{loss}} \equiv V_{\text{rectified}} \times I_{\text{loss}}$$

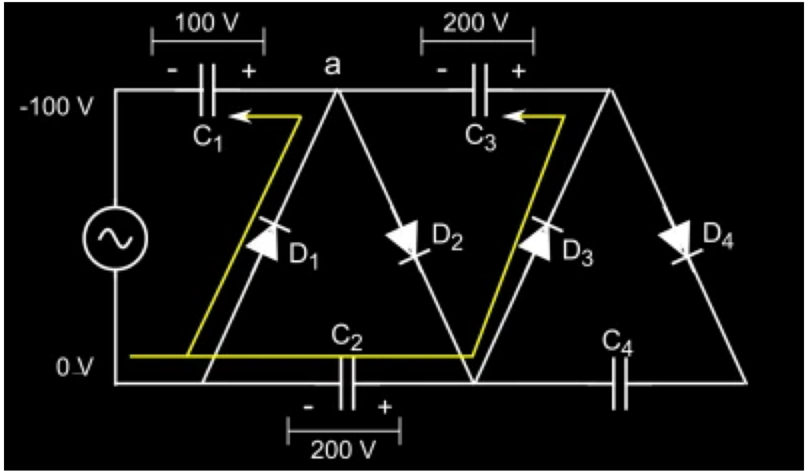


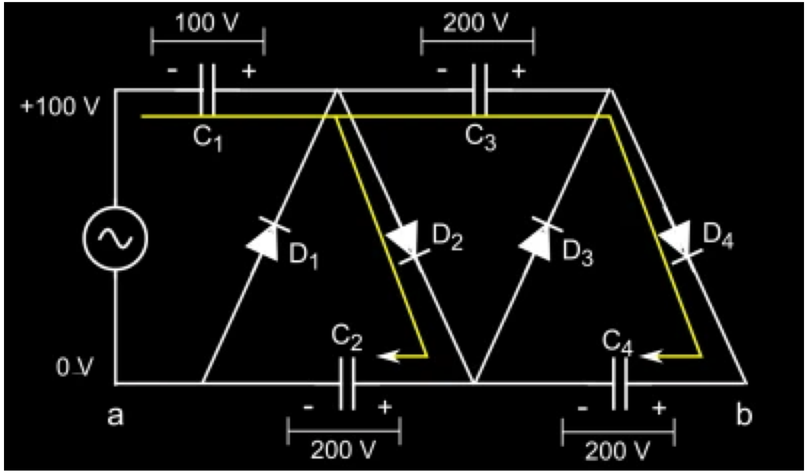
Preheated with
a heat gun
Cooled with
freeze spray
WISP
Fluke
Temperature (C)
Time (sec)
50
40
30
20
10
0
-10
-20
-30
0
5
10
15
20
25
30
35
40
45


100 V
-
+
-100 V
C1
C3
D1
D2
D3
D4
C2
C4
0 V



100 V
-
+
+100 V
C1
C3
D1
D2
D3
D4
C2
C4
0 V
-
+
200 V


100 V
200 V
a
-100 V
C_1
C_3
D_1
D_2
D_3
D_4
C_2
C_4
0 V
200 V



100 V
200 V
+100 V
C1
C3
D1
D2
D3
D4
C2
C4
0 V
a
b
200 V
200 V

Image Sources

- WISP paper
- RFind paper
- Wikipedia
- https://www.tutorialspoint.com/digital_communication/digital_communication_amplitude_shift_keying.htm
- https://www.open.edu/openlearn/science-maths-technology/exploring-communications-technology/content-section-1.4
- Passive RFID Basics - Peter Sorrells
- http://hyperphysics.phy-astr.gsu.edu/hbase/Electronic/schmitt.html
- https://hackaday.com/2017/03/22/how-does-a-voltage-multiplier-work/
- https://learn.sparkfun.com/tutorials/diodes/real-diode-characteristics