Backscatter and Ambient Communication

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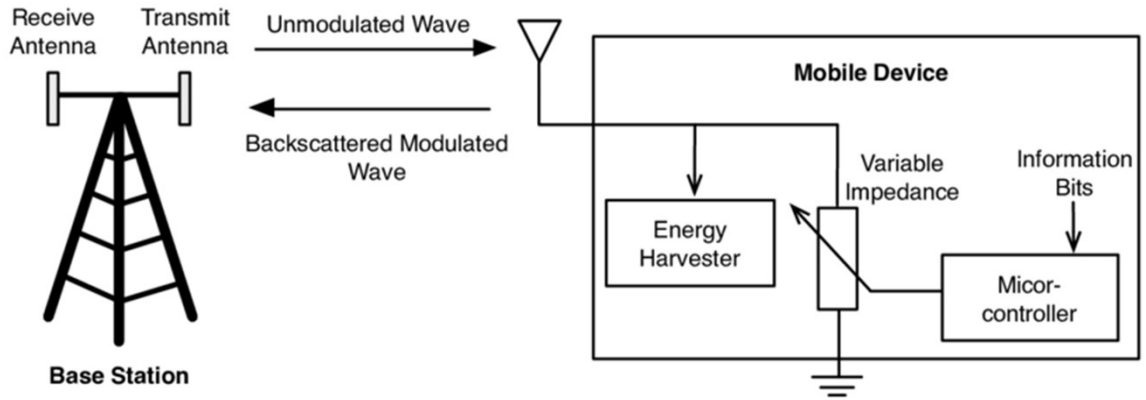
Overall Concept

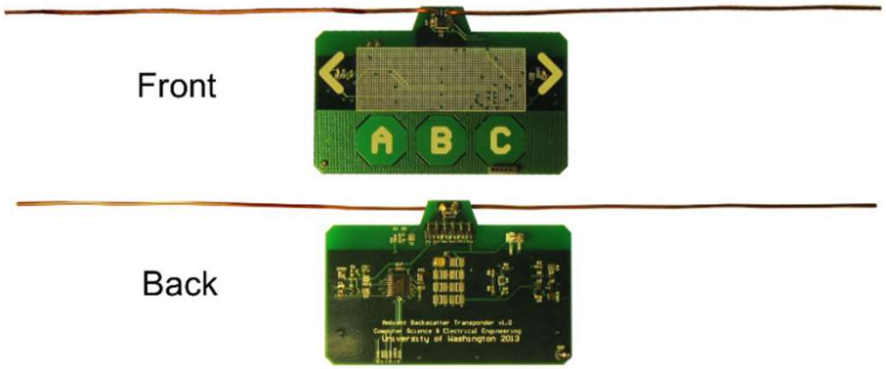
- Backscatter is when signals reflected
  - Can be modulated through different impendences, other effects
- Can be used to transmit data (eg RFID)
- Ambient Backscatter would use existing signals (no base station)
- Extremely low power communication
- “Smart Dust”

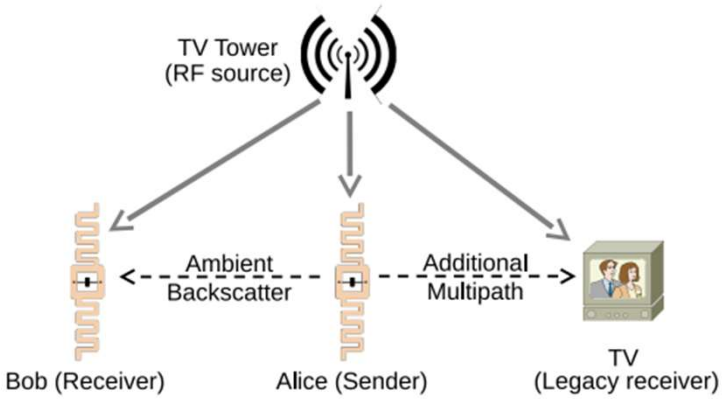


Ambient Backscatter: Wireless Communication Out of Thin Air

Overview

- Small tags that are powered by ambient signals
- Communicate using those ambient signals
- Device to device communication
  - 1kbps at 2.5ft indoors, 1.5ft outdoors
- No additional infrastructure required



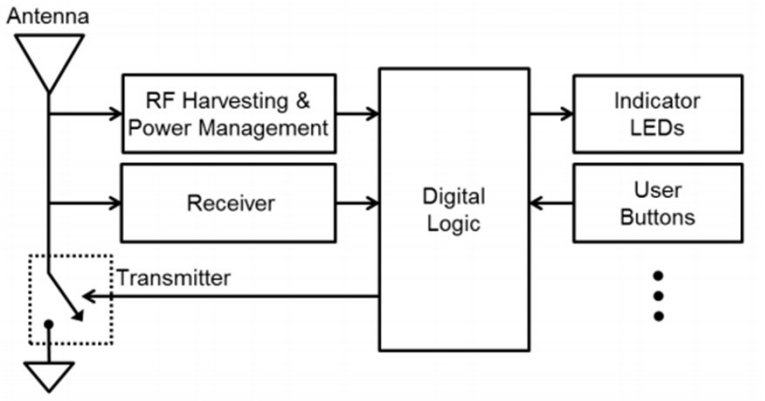


Fundamentals

- No central controller or arbiter
- Very low power available, very basic signal modulation
- Avoid interference to existing devices
- Rely on random and uncontrolled signals
- Tens to hundreds of microwatts from these signals

Ambient Backscatter Transmission

- Transmits by varying antenna impedance
  - Reflects different amount of the signal
  - Changes multipathing that can be detected if looking for it
- TV transmission standards are resistant to multipathing effects



Ambient Backscatter Reception

- Receive data encoded on top of already fast changing signals
- Backscatter information is at a lower rate than ambient signals
  - Can average to recover signal
  - Avoids more power hungry ADCs and computation

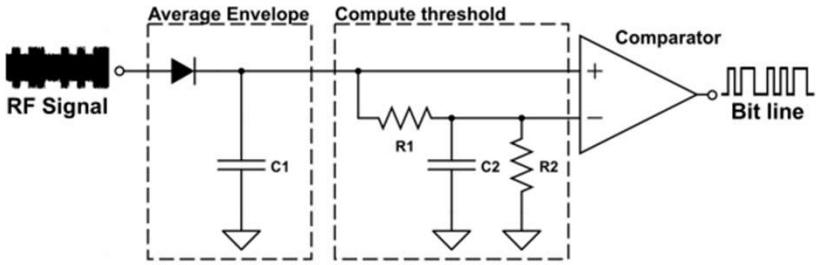
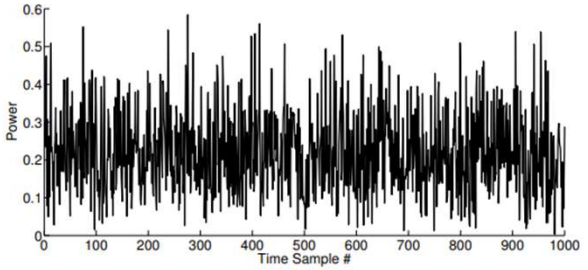
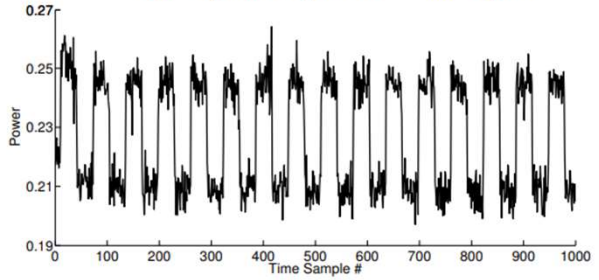


Table 1—Power Consumption of Analog Components

	Tx	Rx
Ambient Backscatter	$0.25\mu W$	$0.54\mu W$
Traditional Backscatter (WISP [33])	$2.32\mu W$	$18\mu W$



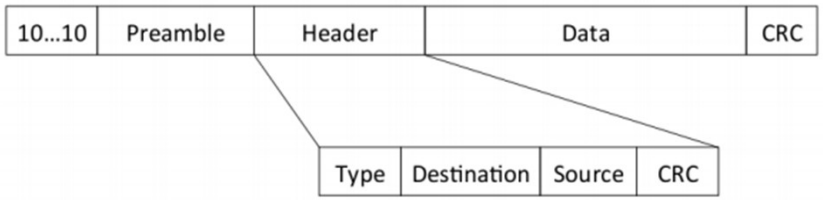
(a) Original TV plus Backscatter signal



(b) Signal After Averaging

Arbitration

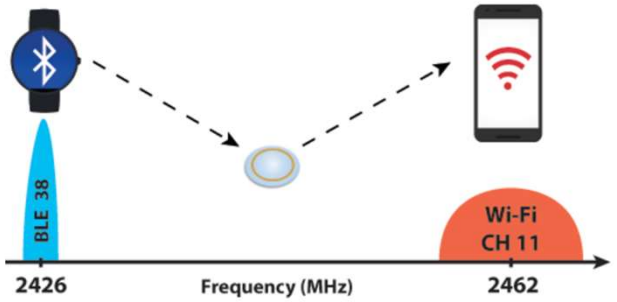
- Carrier sense
  - FM0 (manchester) encoding to simplify hardware detection
  - Comparator to wake microcontroller only on bit transitions
- Preamble to wake listener hardware
- Acknowledgement on successful reception
- Packet detection
  - Averaging received logic level
  - Active transmission, due to encoding, will be even



Inter-Technology Backscatter: Towards Internet Connectivity for Implanted Devices

Overview

- Achieves backscatter communications without the need for wireless infrastructure to excite the backscatter device
  - Enables self-sufficient systems where consumer devices can power backscatter to other consumer devices
  - Demonstrate using Bluetooth to power a 802.11b transmitter

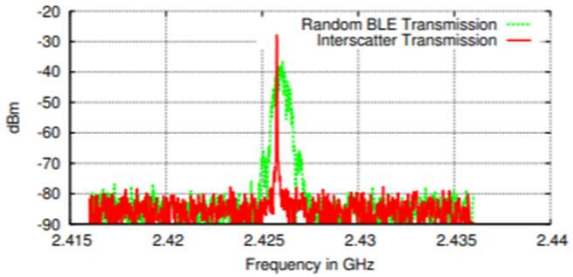


Power Souce

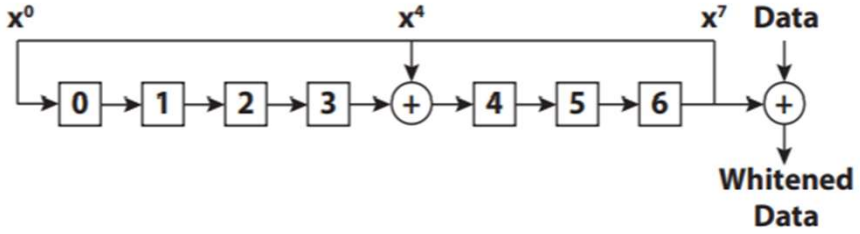
- Power for these devices is severely limited
- While they did not produce their own IC, the researchers showed a 65nm process would produce a chip consuming only 28uW
    - This is well within the capability of power harvesting far-field RF, though this paper did not demonstrate it

Backscatter Source

- To produce a new 802.11p waveform from the low power device, a backscatter waveform is first created from the Bluetooth device
- To provide an easy source to modulate, a clean tone is desired
- The researchers showed that they can reverse the physical encoding process (data whitening, primarily) to send single tones from commodity bluetooth transceivers

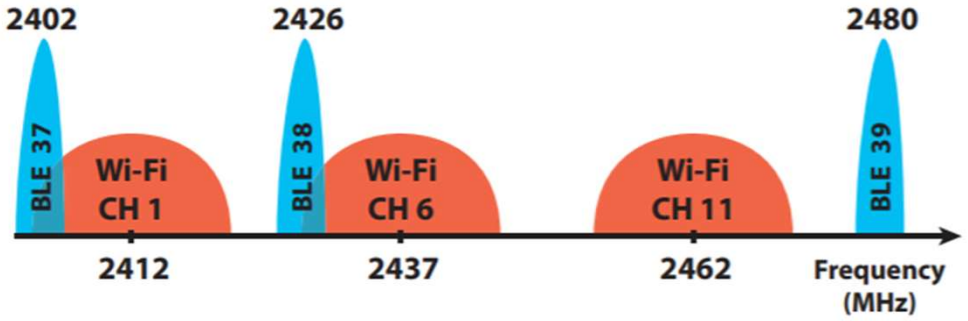


(b) Galaxy S5 Smartphone



802.11b Modulation

- Using the Bluetooth tone as a source, the backscatter device can then reflect energy using its antenna and backscatter circuit to produce a new waveform
- Certain WiFi channels are adjacent to Bluetooth advertisement channels, providing an opportunity to create transmissions on a single side of the bluetooth tone



802.11b Modulation

- By modulating the impedance of the device's antenna, this new waveform can be created
- Multiplication by a complex waveform leads to a shift in frequency without opposing mirror

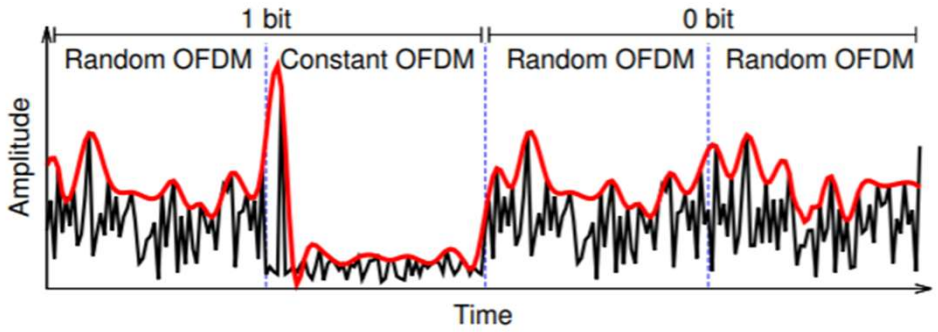
$$e^{j2\pi\Delta ft} = \cos(2\pi\Delta ft) + j\sin(2\pi\Delta ft)$$

- By selecting four options for Zc and approximating a cos/sin wave with the corresponding square wave, they were able to successfully modulate up the 802.11b signal

$$S_{out} = \frac{Z_a - Z_c}{Z_a + Z_c} S_{in}$$

Reverse Communication

- To communicate to the backscatter device, the researchers need to have an AM waveform (for power restrictions)
- Able to transform a 802.11g transmitter into a low-bitrate AM transmitter by using every two OFDM slots to signify one bit
    - Key insight: constant signal in frequency becomes impulse in time



Demonstrations

- Showed ranges of 2 meters on large implanted devices and several feet on contact-lens size antennas
- Cranial implant put 1/16” below the surface of a “0.75in thick pork chop” to simulate gray matter
- Mbps datarates possible
  - Limitation is computation power

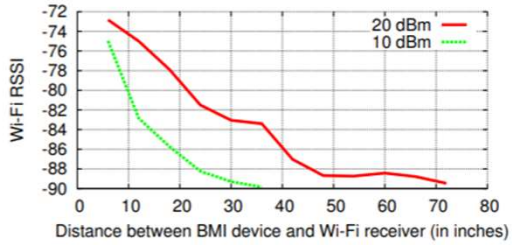
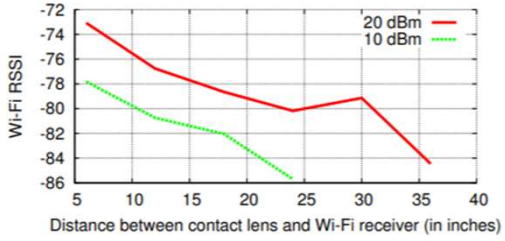


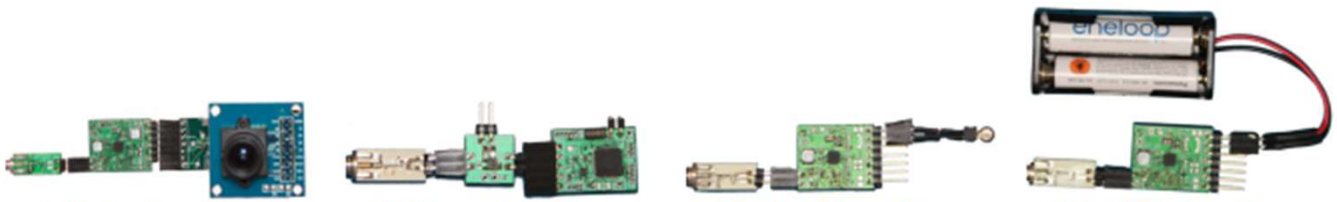
Figure 16—RSSI with implantable neural recording antenna.



Powering the Next Billion Devices with Wi-Fi

Overview

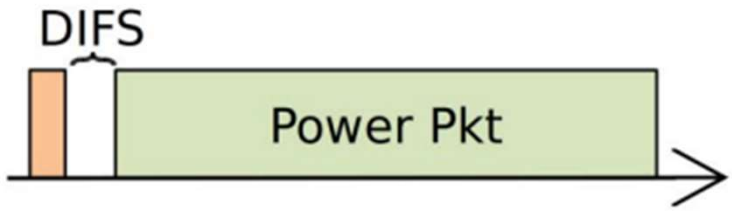
- Use Wi-Fi to transmit power to devices
- Maximize transmitted power
- Minimize data throughput degradation



(a) Battery Free Camera (b) Temperature Sensor (c) Li-Ion Battery Charger (d) NiMH Battery Charger

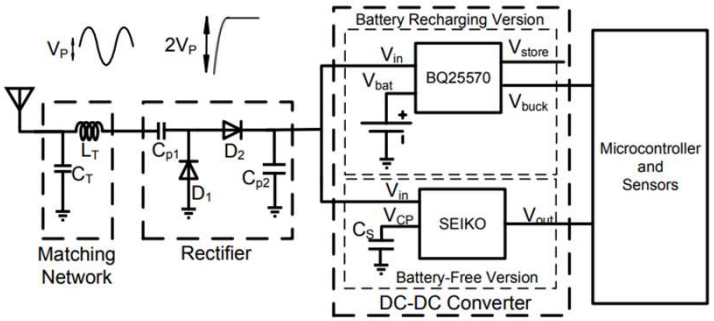
Maximizing Transmitted Power

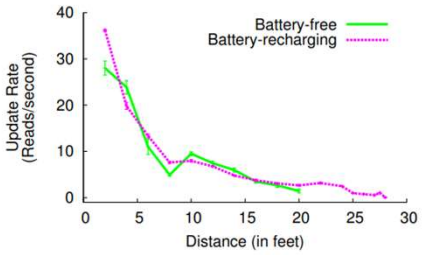
- Transmit “Power Packets” of garbage data at the highest bit rates
  - When there are not many frames to transmit, send them on the three non-overlapping channels
- Allow power packets to collide if there are multiple access points
- Can modulate power packet rates if the sensor requirements are known



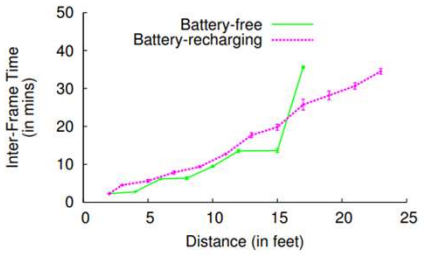
Maximizing Received Power

- Match impedance to absorb as much energy as possible
- Boost converter to reach more useful voltages
- Delivers ~10mW at 5-7cm



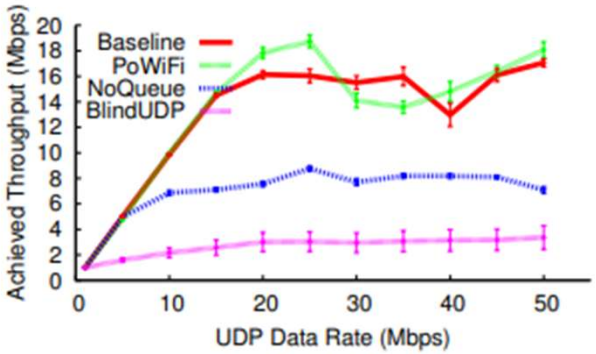


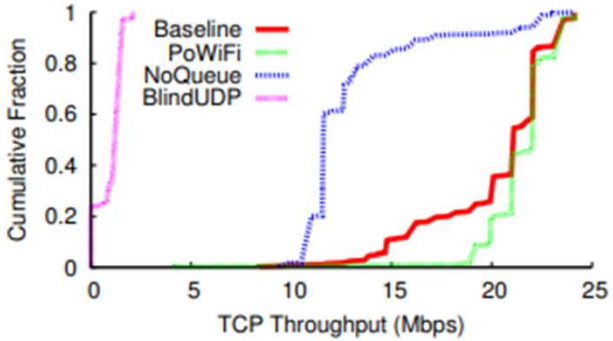
(a) Temperature Sensor

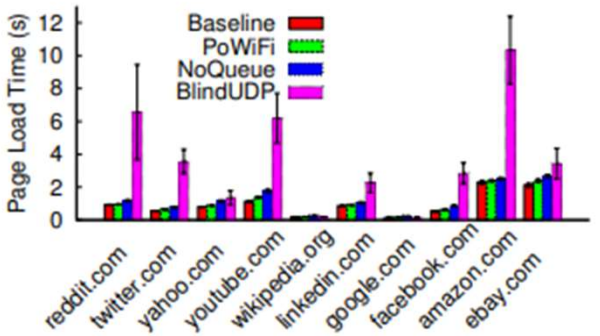


(b) Camera

Impact on Existing Traffic







Summary

Power Overview

- Specialized receiver to rectify and store power
  - Charge to some threshold, activate, charge again
- Modified base station to broadcast more power
- No wired infrastructure requirement

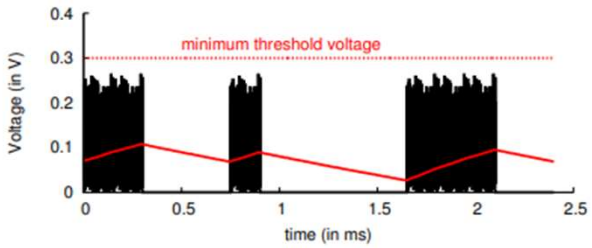
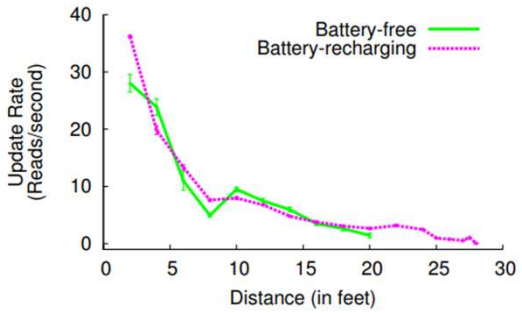


Figure 1—Key challenge with Wi-Fi power delivery. While the harvester can gather power during Wi-Fi transmissions, the power leaks during silent periods, limiting Wi-Fi's ability to meet the minimum voltage requirements of the hardware.



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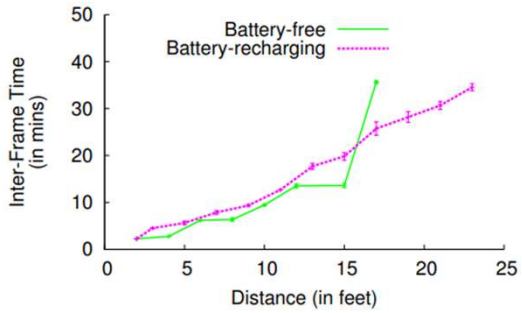


(b) Camera

Ambient Backscatter

- Variable reflection
  - Vary impedance to ambient signals
  - Modulate multipathing
  - Most receivers ignore it
  - Simple analog detector circuit

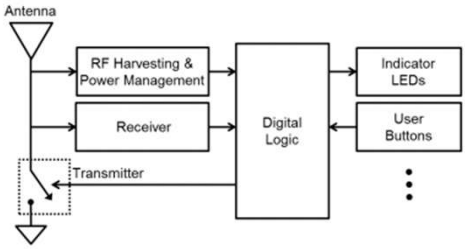
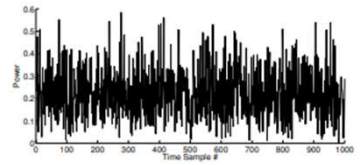
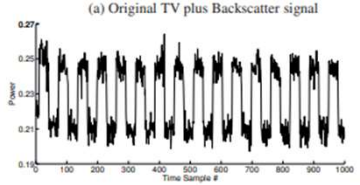


Figure 3—Block diagram of an ambient backscattering device. The transmitter, receiver, and the harvester are all connected to a single antenna and use the same RF signals. The transmitter and receiver communicate by backscattering the ambient signals. The harvester collects energy from the ambient signals and uses it to provide the small amount of power required for communication and to operate the sensors and the digital logic unit.



(a) Original TV plus Backscatter signal



(b) Signal After Averaging

Figure 5—Comparison of backscattered signal received both with (*b*) and without (*a*) averaging.

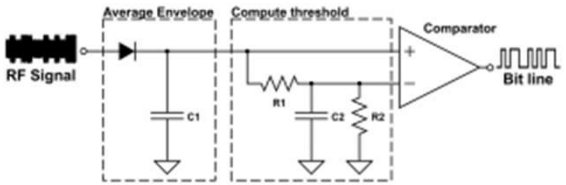


Figure 6—Circuit Diagram for the Demodulator: The demodulator has two stages: an envelope detection and averaging stage that produces an average envelope of the signal, and a compute-threshold stage that compares the averaged signal with a threshold value computed by taking a longer-term average of the signal.

Transmitting with Backscatter

- Inter-Technology Backscatter
  - Backscatter bluetooth to get other protocols
    - Utilize waveform to generate other consumer protocol
  - Hack one physical layer to transmit like another
    - Low-bitrate AM from OFDM

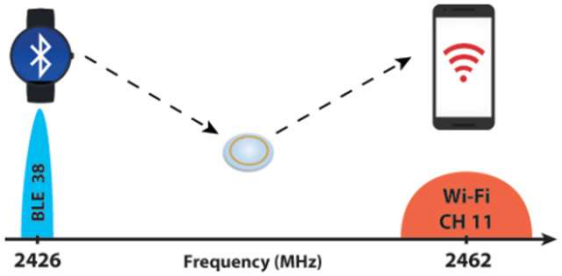


Figure 1—Interscatter Communication. The backscatter device (e.g., contact lens) reflects transmissions from a Bluetooth device (e.g., smart watch) to generate standards-compatible Wi-Fi signals that are decodable on a Wi-Fi device (e.g., smartphone).

Conclusion

- Backscatter enables completely unpowered devices
  - Harvest power from existing installations if device is very low power

Sources

https://homes.cs.washington.edu/~gshyam/Papers/amb.pdf

https://dl.acm.org/doi/10.1145/2716281.2836089

https://homes.cs.washington.edu/~gshyam/Papers/interscatter.pdf