DYP DPU

Dr. D. Y. Patil Institute of Technology

LoRa

# RF Technology

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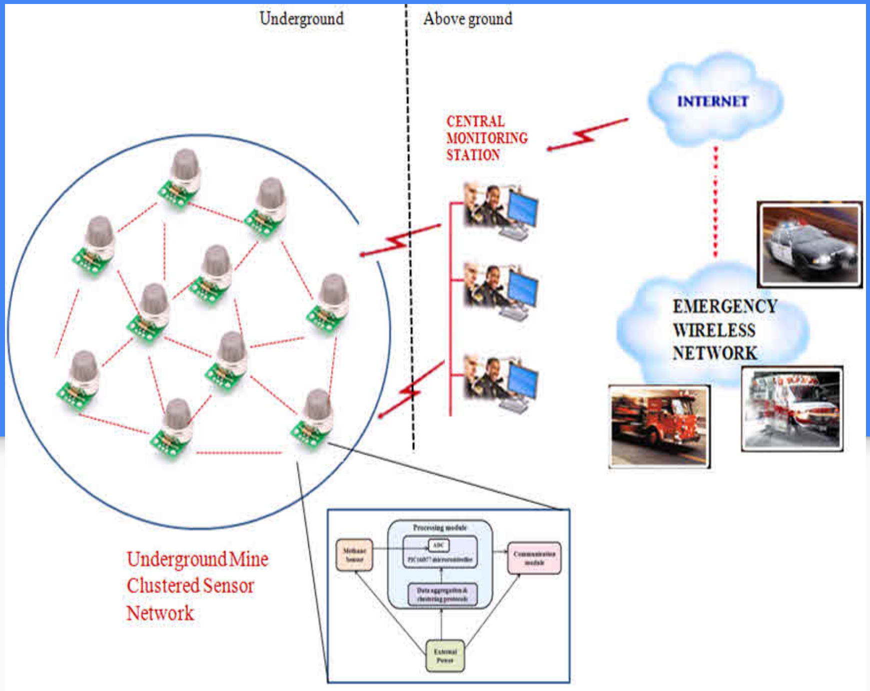
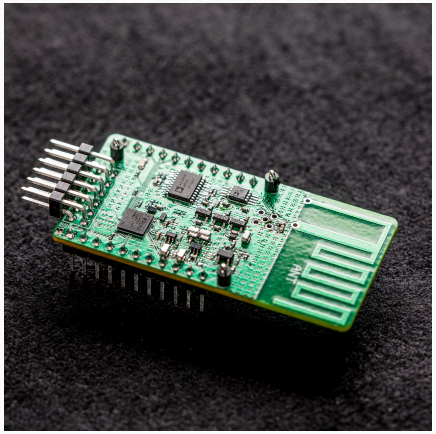
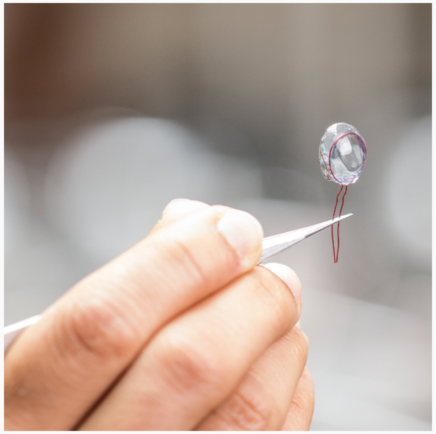
# Motivation: Ubiquitous Connectivity

- Implementing communication between billions of devices
- Requirements
  - Reliable and long range communication
  - Low power
  - Inexpensive to manufacture
- Issues
  - No existing technology combines all three factors
  - E.g., backscattering is low power and cheap, but short ranged
- Solution
  - LoRa

# Applications




- Smart cities
- Precision agriculture
- Whole-home and office sensing
- Body-mounted medical sensing


Images courtesy of longrange.cs.washington.edu

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Results
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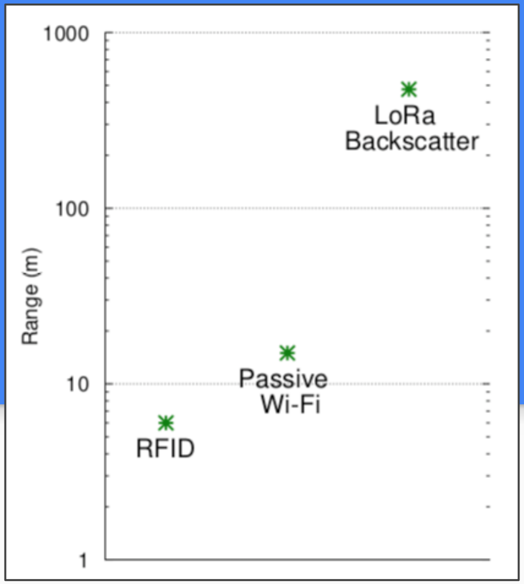
# Why LoRa ?




**Advantages:**

- **Low power consumption** (three orders of magnitude lower than radios; not significantly better than other backscatter modes)
- **High operating range** (100s of meters compared to tens for other backscatter modes)
- **Low cost and size** (primarily digital construction materials)

**Alternatives Explored:**

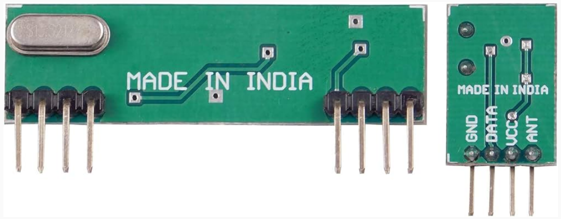
Radios

- Wi-Fi
- BLE
- ZigBee
- SigFox

Backscatter

- RFID
- Passive Wi-Fi

# RF Module

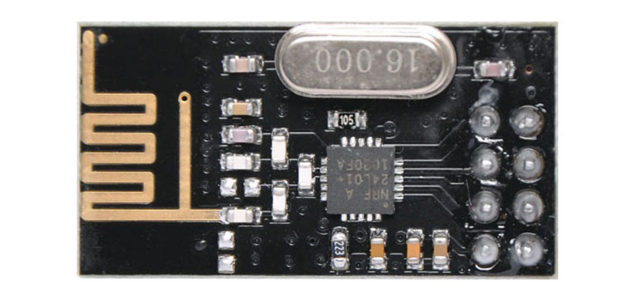



1. Low Power Consumption.
2. Easy For RF-based Application.
3. Complete Radio Transmitter.
4. Transmit Range Up To 50m.
5. CMOS / TTL Input.

## RF zigbee Module

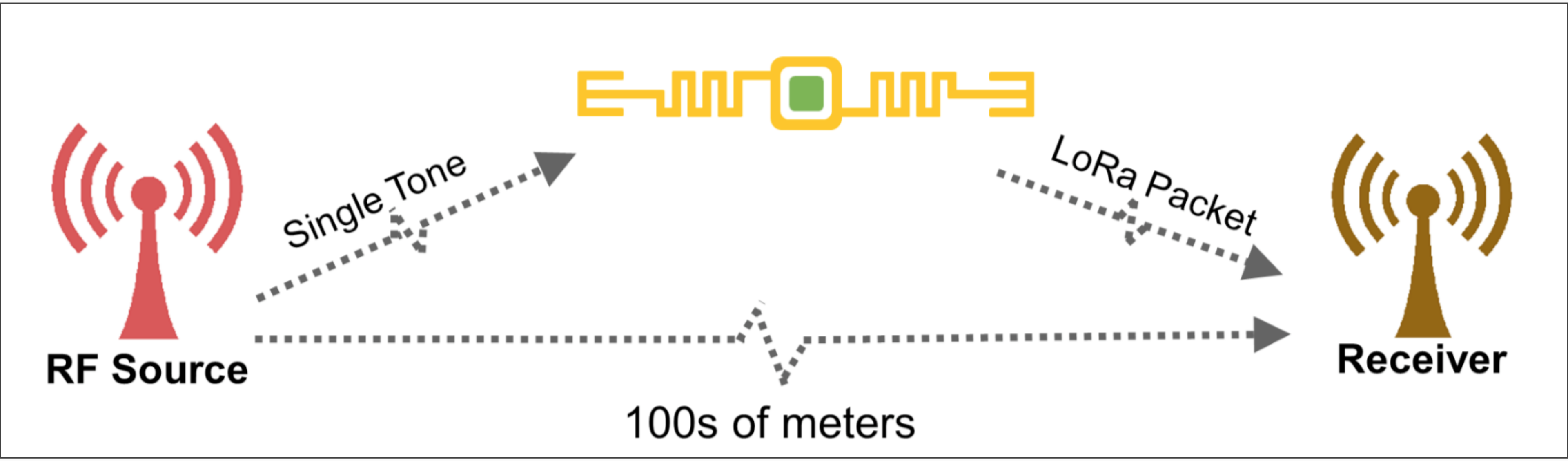

1. Integrated, Wire Antenna
2. Interoperable other ZigBee-compliant devices
3. 15 general-purpose I/O lines
4. Industry-leading sleep current of sub 1 μA
5. Transmit Range Up To 1km.

## RF NRF Module



1. Voltage: 3-3.6V (recommended 3.3V).
2. Maximum output power: +20dBm.
3. Power-down mode current: 4.2uA.
4. Operating Range: 1Km
5. Receive Mode Current(peak): 45mA
6. It uses 2.4GHz global open ISM band.

# Why LoRa ?

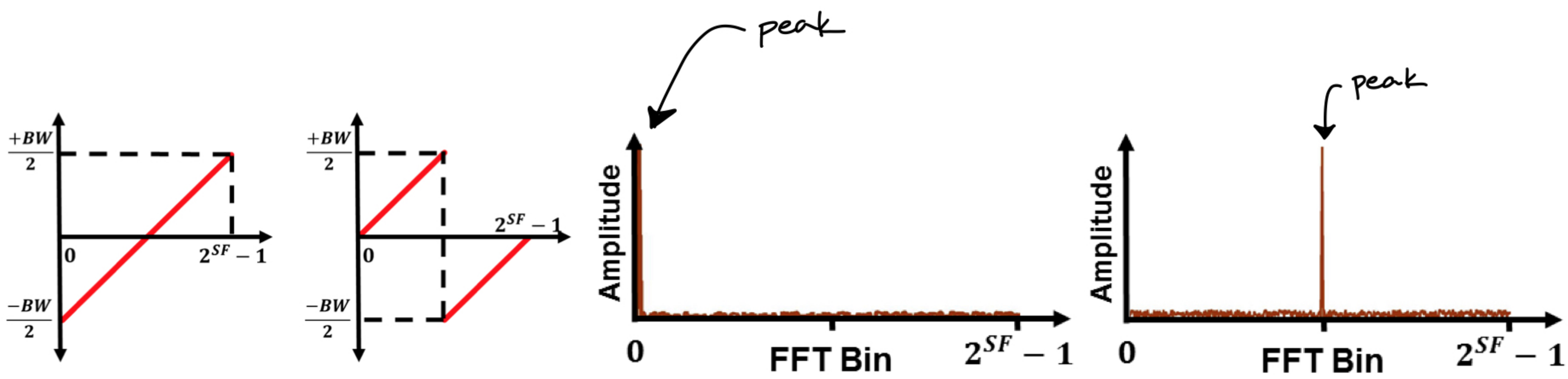


# LoRa Architecture

- The LoRa wireless uses a chirp-spread spectrum (CSS) modulation with options for different Spreading Factors (SF) and bandwidth to optimize the modulation to meet the range and data requirements.
- LoRa uses ISM bands 433MHz, 868MHz or 915MHz depending on jurisdiction with the band divided up into channels.
- LoRa network consists of several elements. Most of the modern LoRa IoT LAN technologies use mesh network architecture.
    - **LoRa Nodes/ End points**
    - **LoRa Gateways**
    - **Network servers**
    - **Application server**

# Synthesizing CSS with Backscatter

Recall: **Chirp spread spectrum** (CSS) encodes data as cyclic time shifts of the baseline "chirp," which appear as frequency shifts after an FFT.




(a) Symbol 1 (b) Symbol 2 (c) FFT output 1 (d) FFT output 2

# Synthesizing CSS with Backscatter

Recall: **Chirp spread spectrum** (CSS) encodes data as cyclic time shifts of the baseline "chirp," which appear as frequency shifts after an FFT.

- Bit rate: **BW/($2^{SF}$)·SF** (BW = bandwidth; SF = spreading

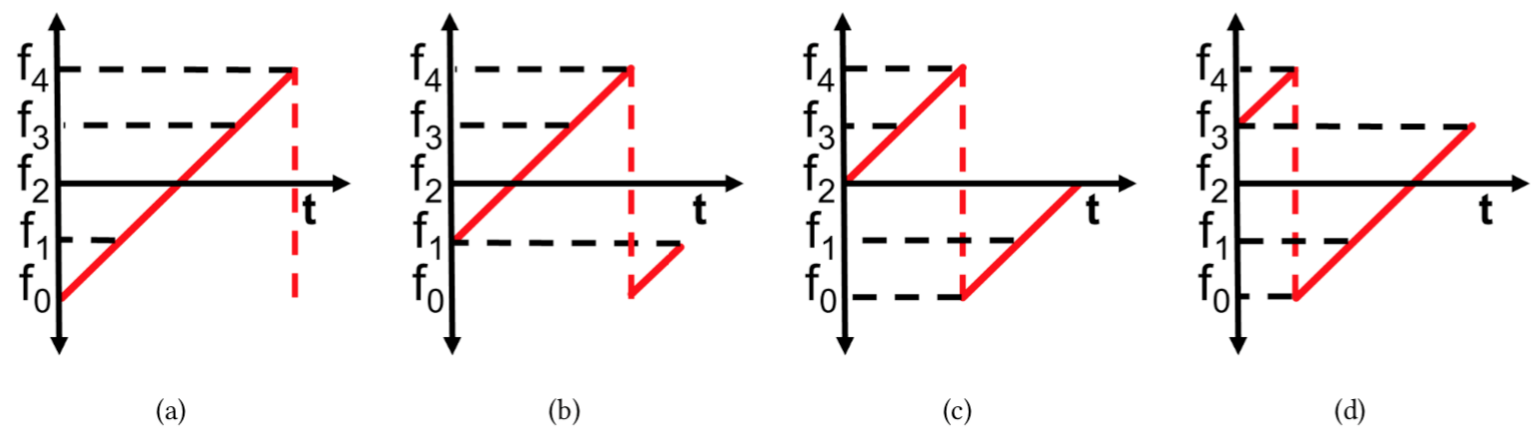


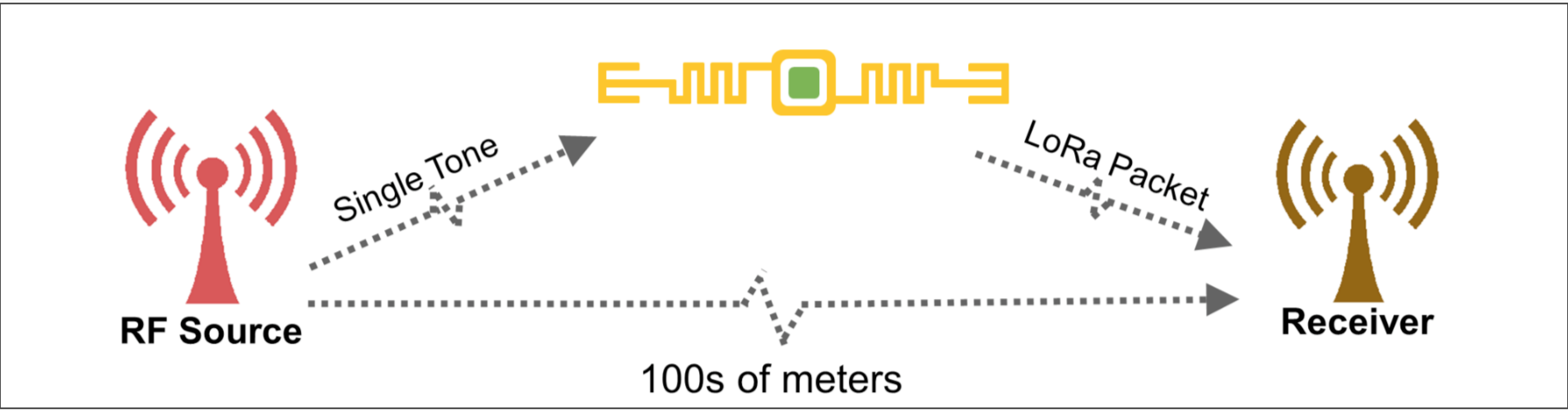

Fig. 6. Four CSS symbols when spreading factor is 2.

# Backscatter Harmonic Cancellation

- Issues in signal approximation with square waves
  - Creates mirror copies at third and fifth harmonics
  - Prior systems ignored these signals (out-of-band)
  - Noisy for LoRa due to high sensitivity
- Solution
  - Use different signal than a square wave
  - Square waves have two voltage levels → high frequency components
  - Multilevel signal to better approximate sinusoid
  - Designed such that third and fifth harmonics are cancelled

# Reverse-Engineering LoRa Packet Structure

- Challenge: physical layer specification for LoRa is proprietary
- Solution:
  - Reverse-engineer LoRa physical layer using Semtech patents
  - Analyze transmissions from LoRa chipsets on a Universal Software Radio Peripheral (USRP)



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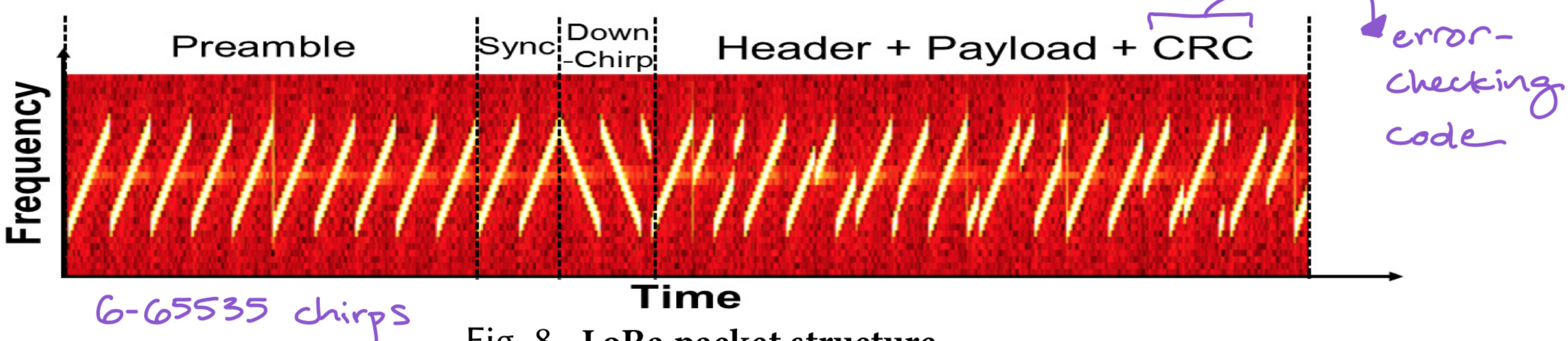


Fig. 8. **LoRa packet structure.**

# Setting LoRa Parameters

- LoRa bit rate determined by 3 factors:
  - chirp bandwidth
  - spreading factor
  - error correction coding rate
- BW and SF set in advance, known by transmitter & receiver
- High sensitivity: phase of chirps must change continuously with time and have same value at each end of chirp
  - At each frequency, increase phase by $2\pi/SF$
- To comply with FCC, frequency-hop the single-tone chirp transmitter
  - Backscatter device continues to be offset by $\Delta f$

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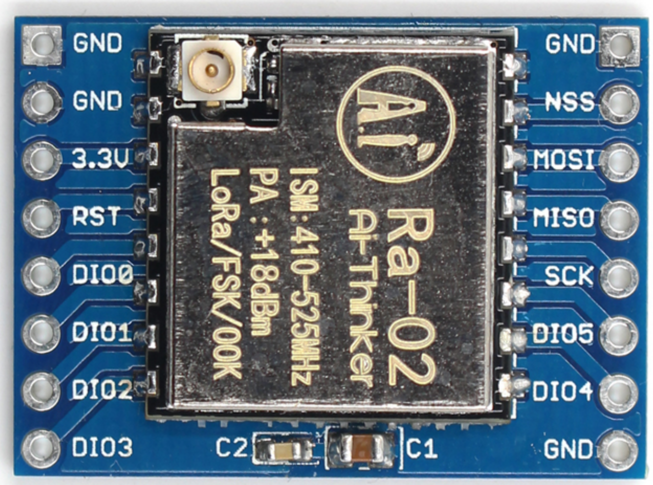
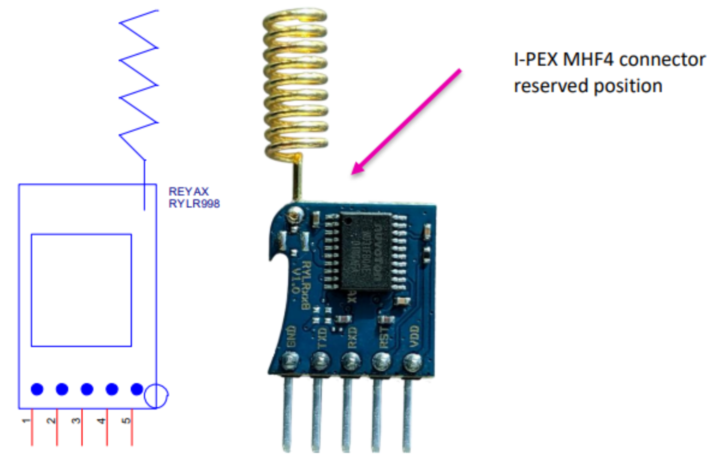
# Hardware Implementation

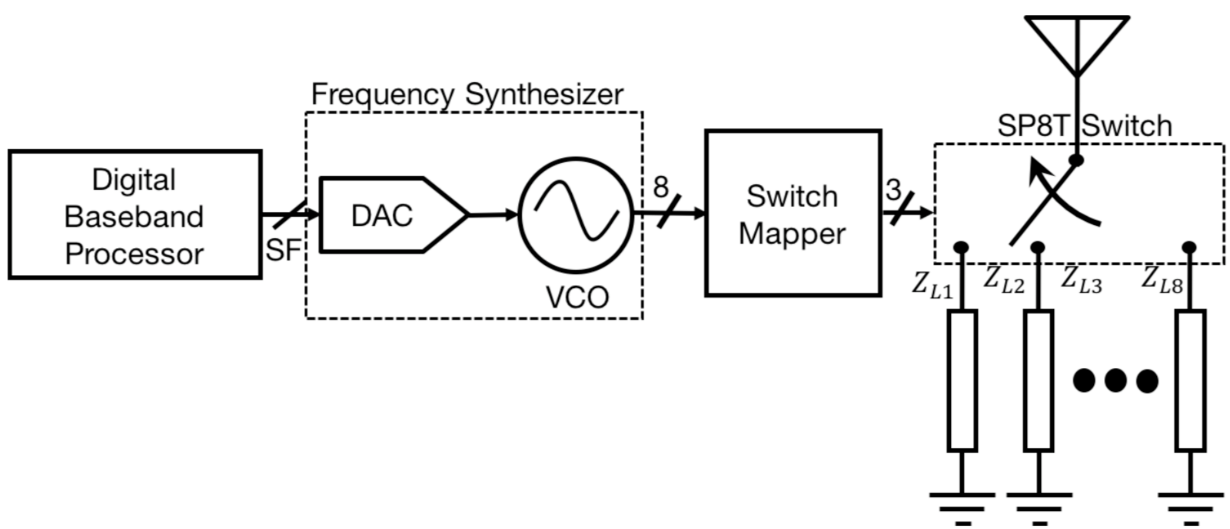



| Pin | Name | I/O | Condition |
|---|---|---|---|
| 1 | VDD | I | Power Supply |
| 2 | NRST | I | RESET(Active Low) 100KΩ Internal pull up, Pull down at least 100ms |
| 3 | RXD | I | UART Data Input |
| 4 | TXD | O | UART Data Output |
| 5 | GND | - | Ground |

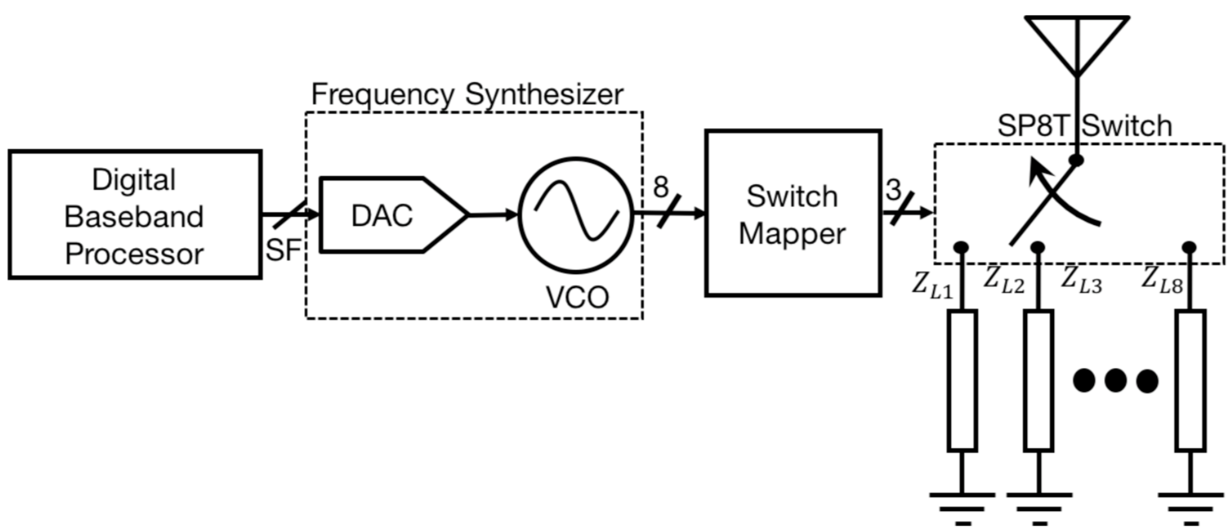
# Hardware Implementation

- **Digital Baseband Processor** sends the spreading factor (SF) to the **DAC** to be converted to an analog voltage
- The **DAC**'s output controls the oscillation speed of the **VCO**
- **VCO**'s output is mapped to used to select appropriate impedance



# Hardware Implementation

- VCO can only output positive frequencies, while negative frequencies are needed as well
- This can be achieved by selecting impedances to produce complex values to match the exponential signal output



# Hardware Implementation

- Designed custom IC to minimize costs
- Consists of three main components
- Baseband Processor
  - Creates LoRa packet using SF, BW, and code rate
  - Sends packet data to Frequency Synthesizer to create the CSS signal
  - Uses 1.25$\mu$W to make packet with SF=12, BW=3.25kHz, and an (8, 4) Hamming code

# Hardware Implementation

- Uses an **extremely** small amount of power
  - Other systems use complex analog components
  - Backscatter systems use switches to modulate reflections
- Costs **extremely** cheap
  - IC costs proportional to size of chip
  - Active radio devices like for Wi-Fi, LoRa, BLE have about $10mm^2$ die area used for RF components
  - Backscatter systems like RFID use about $0.15mm^2$ of die area
  - This LoRa backscatter system uses $<0.01mm^2$ of die area
    - Switches use space efficient resistors and capacitors
    - Metal in metal capacitors made on metal layers on top of MOS structures

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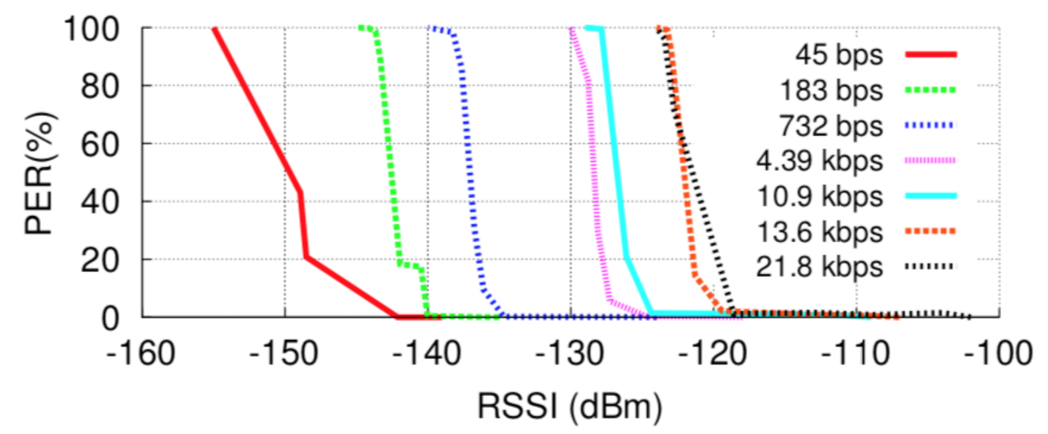
# Results Overview

- Receiver Characterization
- Operational Range
- Wide-Area Applications
  - Whole-Home and Office Sensing
- RF-Challenged Applications
  - Smart Contact Lens
  - Flexible Epidermal Patch Sensor

# Receiver Characterization



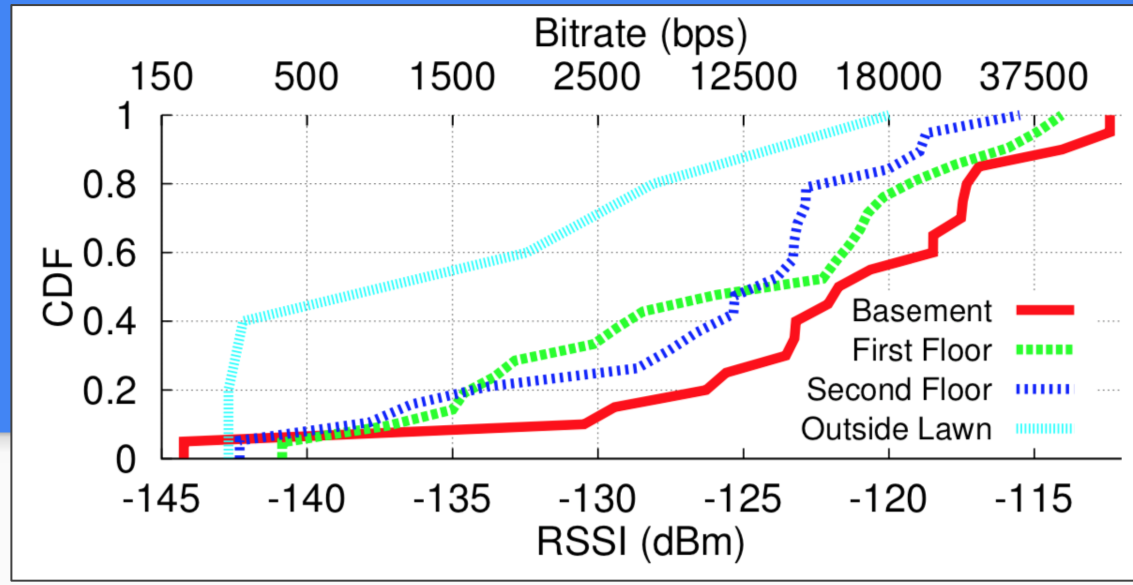

(a) **Receiver Characterization.** PER as a function of RSSI values reported by the receiver for different data rates.

- Wired setup (avoid multipath complications)
- Semtech SX1276 chipsets are both CSS transmitter and receiver
- Conclusion: sensitivity is inversely proportional to the data rate of the packet
    - Below -142 dBm, receiver cannot correctly decode packets
    - RSSI values reported by chipset do not correspond to actual power level of received packet, but proportional

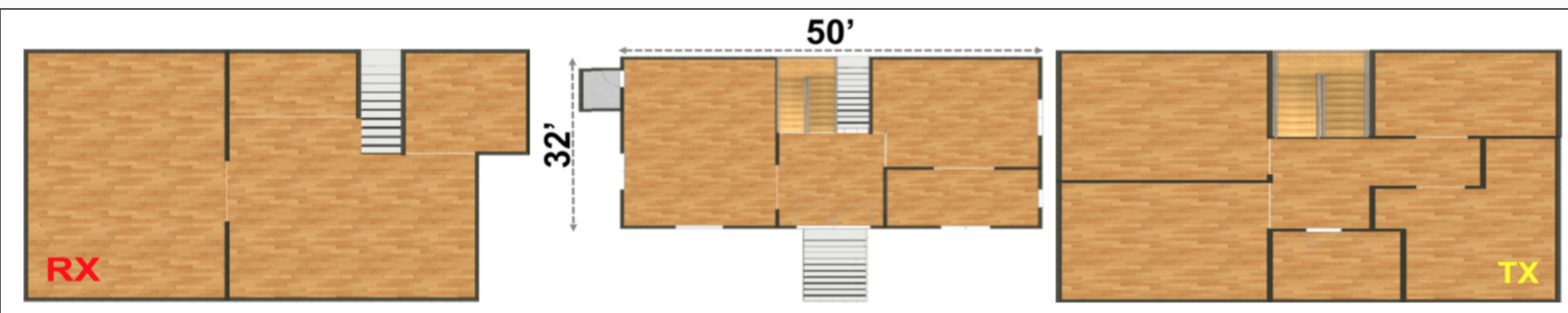
# Operational Range

- Setup
  - SX1276 LoRa development kit with power amplifier as RF source
  - Transmitting 30 dBm signals in 6 dBi patch antenna at 915 MHz
  - Backscatter device to transmit LoRa packets at offset 3 MHz, SF=12, BW=31.25 kHz, (8,4) hamming code (3-byte payload, 2-byte CRC)
- Two deployment scenarios

# Applications: Whole-Home Sensing

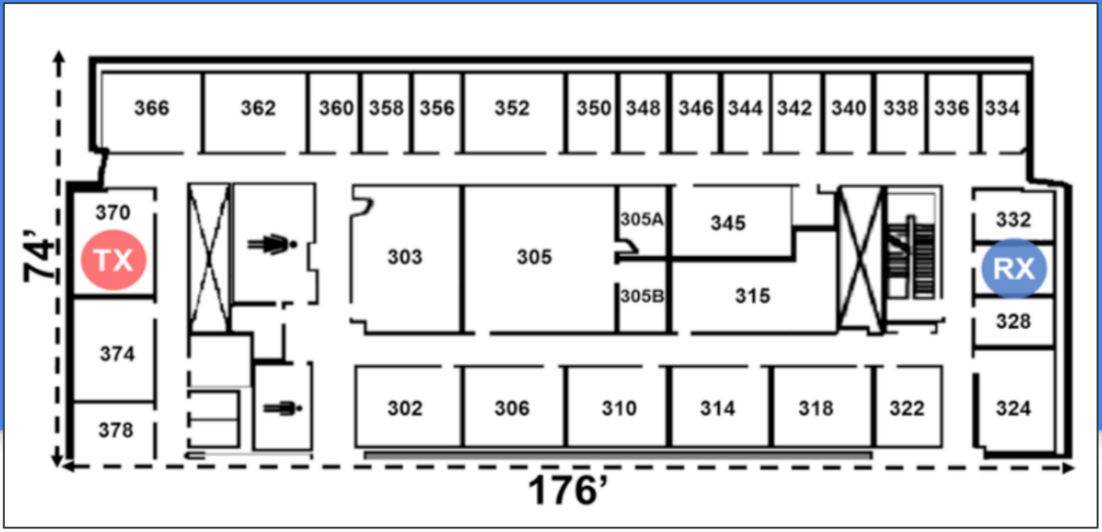



- Previously: limited range and coverage preclude whole-home sensing
- LoRa backscattering deployment: 4,800 ft² three-story house ($\Delta f$ = 1 MHz)
- Backscattering device moved through house in 6x6-ft. grid
- Conclusion: coverage is equivalent to typical wireless coverage; sufficient for smarthome IoT devices

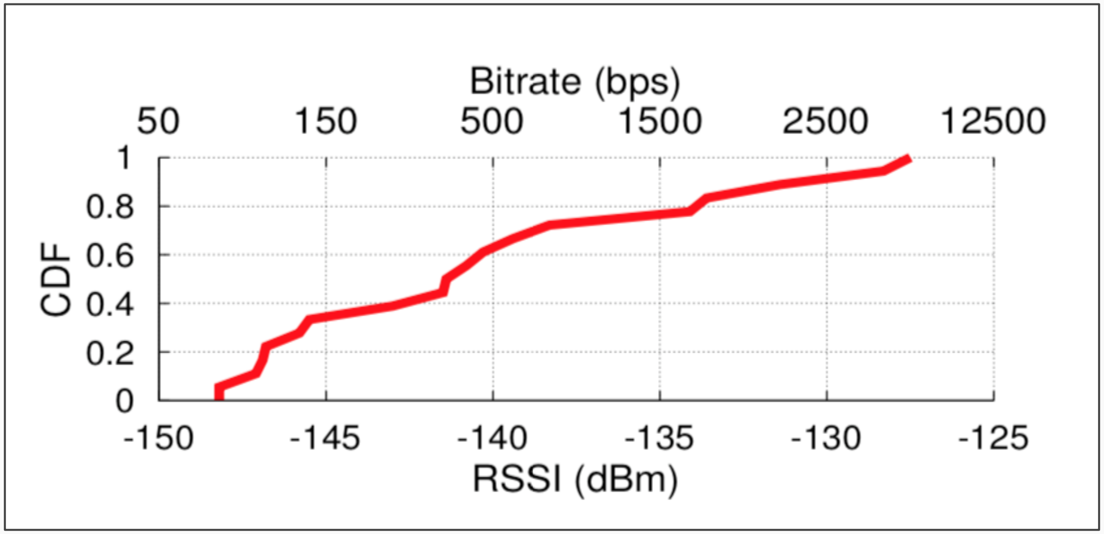



(a) Basement (b) First Floor (c) Second Floor

# Applications: Office Sensing



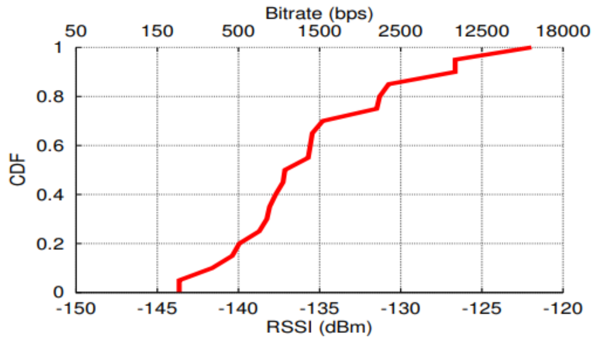

- LoRa backscattering deployment: 13,024 ft$^2$ office with 41 rooms ($\Delta f = 3$ MHz)
- Backscattering device moved through office in 26x26-ft. grid; source and receiver have sheet-rock, metal, insulation, and offices between them




- Conclusion: able to achieve wide-area backscatter coverage in significant multi-path environments

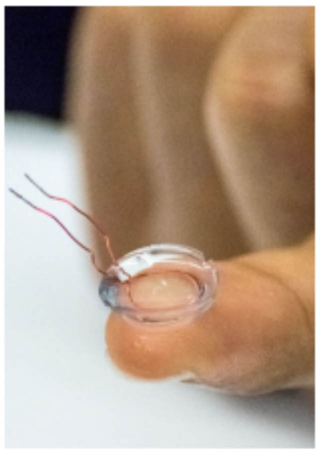
# Applications:
# Precision Agriculture

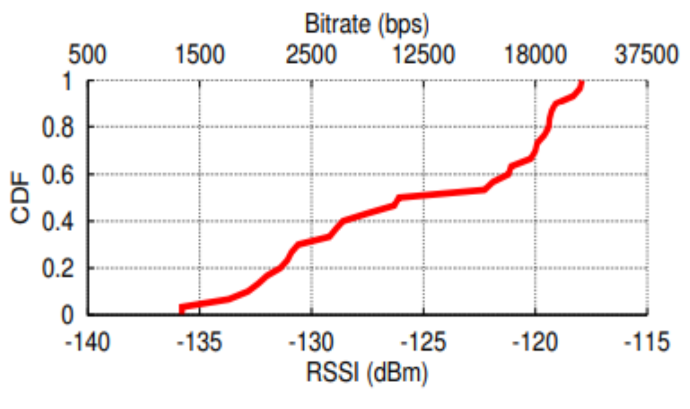

- Deployed on one-acre (~43560 $ft^2$) farm
- RF source and receiver on opposite sides
- Farm divided into 45ft x 45ft grids
- Backscatter device w/ 1MHz offset placed at ground level, between plants and bushes




- RSSI measured across 20 locations at center of the grids
- Median RSSI = -137 dBm, minimum RSSI = -143 dBm
- Conclusion: reliable backscatter communication across a one-acre farm with only one transmitter and receiver

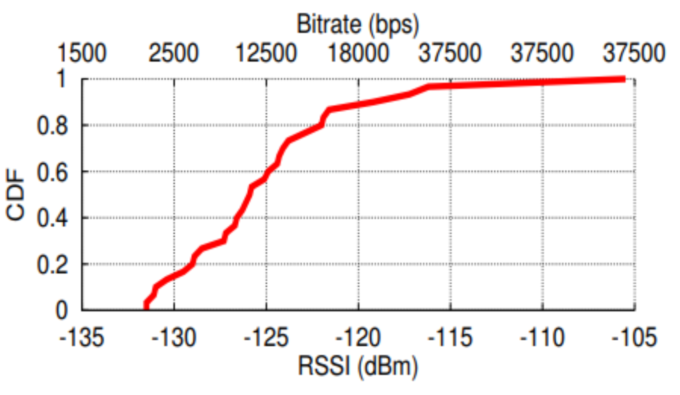
# Applications: Smart Contact Lens






- Can measure various health indicators (glucose, sodium, cholesterol) in tears
- IC not currently possible to place in lens
- 1 cm diameter loop of 30 AWG wire between two contact lenses
- Deployed in 104ft x 32ft atrium with RF source and receiver at opposite ends of the room
- Driven by FPGA PoC and sends LoRa packets at 1MHz offset
- RSSI measured at center of 12ft x 10ft grids in the room
- Conclusion: smart contact lens **can** communicate via CSS backscatter at farther distances than prior approaches

# Applications: Epidermal Patch Sensor




- Measure temperature, sweat, ECG, and other vitals in real time
- Sticker RFID antenna (Alien's Squiggle inlay) connected to FPGA PoC driver
- Utilize cheap RFID tags with LoRa backscatter system to create cheap patch sensors
- RF transmitter and receiver at opposite ends of 3,328 ft² atrium
- Measuring RSSI of 1MHz offset backscatter signals just as the lens
- Conclusion: patch sensor provides reliable connectivity with RSSI greater than -132 dBm

# Conclusion

- LoRa backscatter is the first wireless system that operates at km distances while consuming less than 10 $\mu W$
- Inexpensive, flexible form factor connectivity solutions which can be integrated into everyday objects
- Feasible for wide-area deployment: whole-home coverage, precision agriculture, long-range medical implants, and more

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# References

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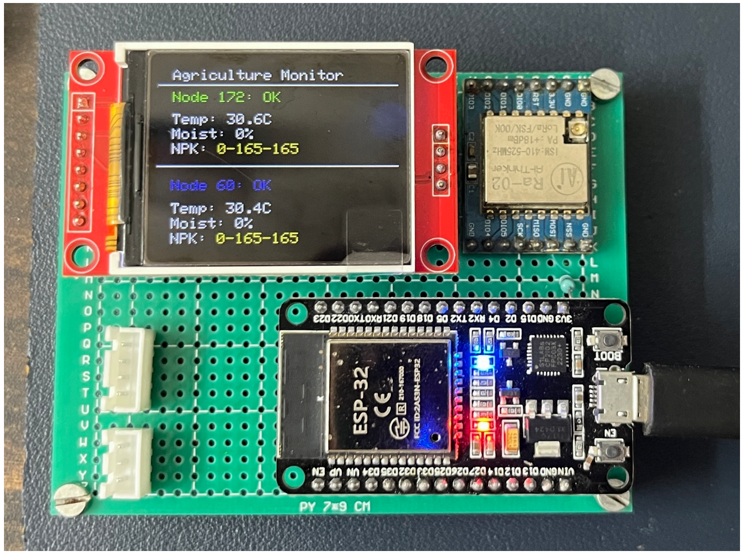
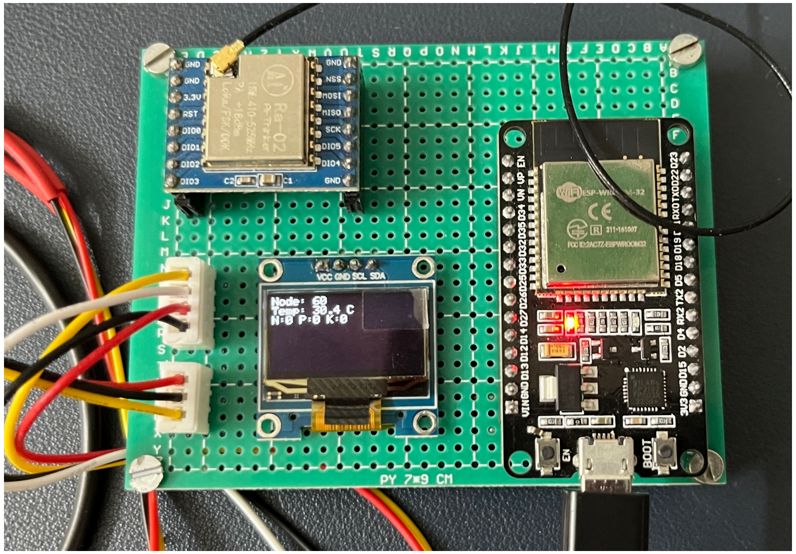
# Questions?

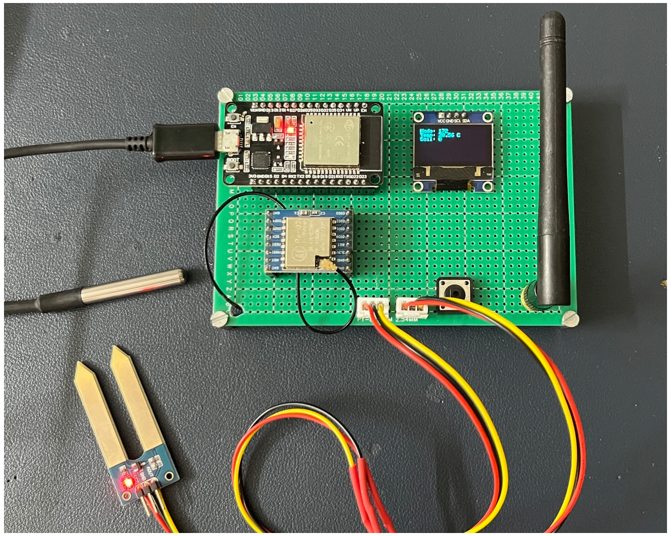
**Receiver**




**NODE 1**




**NODE 2**



https://github.com/PrateekSinghRajput/Post-Graduate-Project-Details-2025