

Sisyphus

Redefining Low Power for LoRa Receiver

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*Sisyphus is a character from ancient Greek mythology who kept pushing a boulder up a mountain and finally found special meaning in meaningless things



LoRa – a key cog to enable the ubiquitously connected world 😊

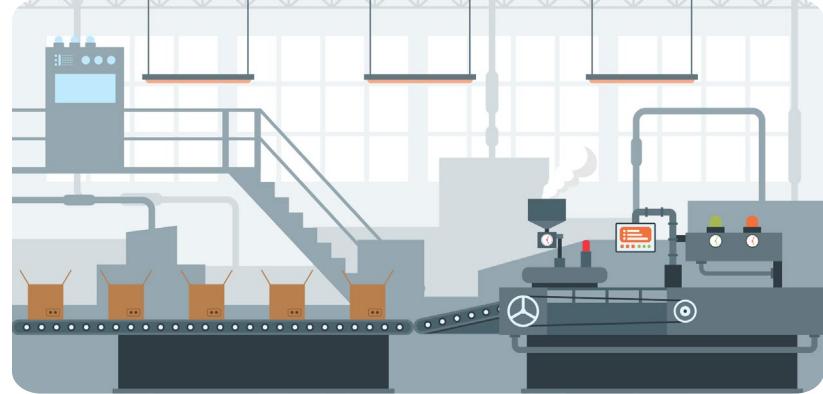
The LoRa and LoRaWAN IoT market will reach **US\$ 5.7 billion** in 2024, expected to surge at a CAGR of **35.6%** from 2024 to 2034 [1].



Precision Agriculture



Smart City



Industrial IoT

Long-range

Low-power

Anti-interference

[1] <https://www.futuremarketinsights.com/reports/lora-and-lorawan-iot-market>

 LoRa – always low power? 🤔



LoRa – always low power?

Empirical testing reveals that:



- **Class A and B** -- extremely low duty-cycle



~ 1500 mAh



~ 225 mAh

battery life > 5 years 😊

- **Class C** -- usually have to be utility-powered

If powered by battery?

only ~hours to days 😰





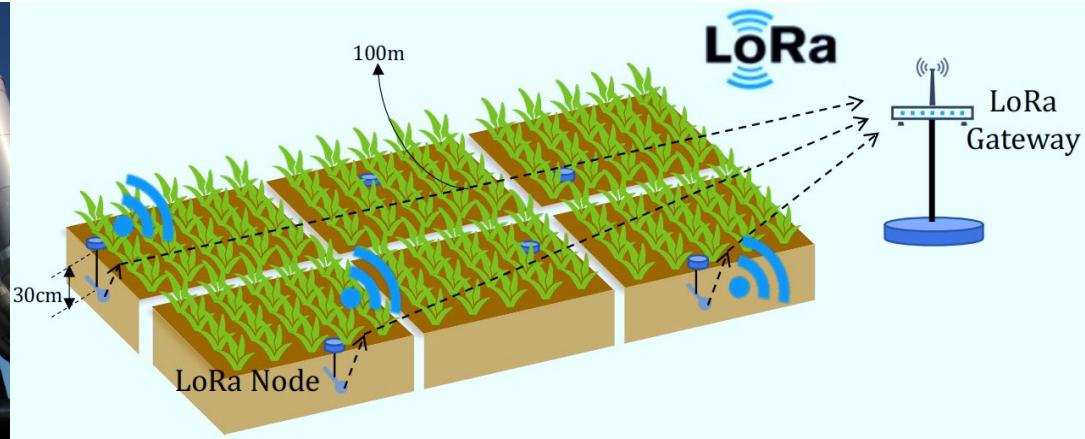
LoRa – always low power?



Forest fire-alarm



Toxic materials monitoring



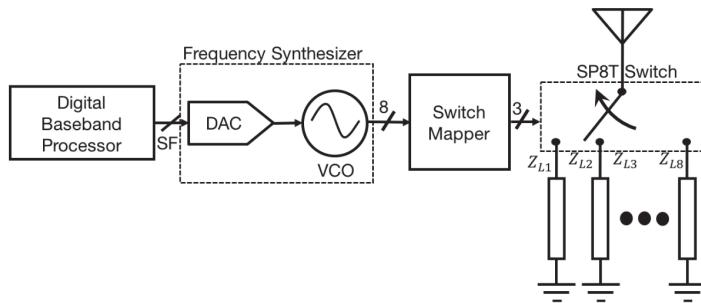
Sensor-less sensing in the wild

Necessitate **long-term** and **around-the-clock** operation !

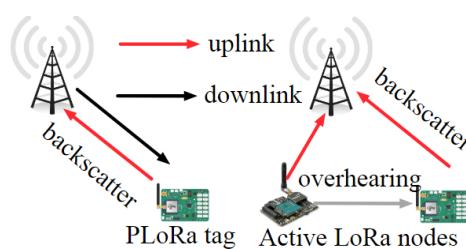
Utility power is not always **available**



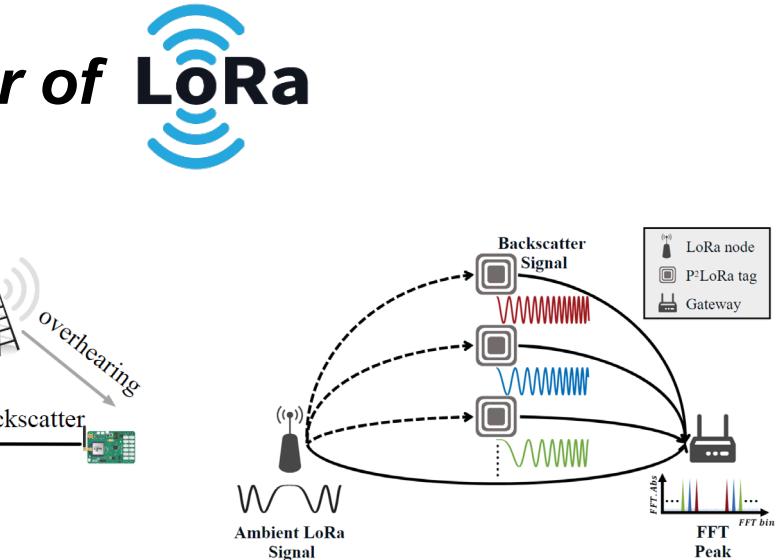
Reducing the runtime power of LoRa



LoRa Backscatter
[UbiComp '17]



PLoRa
[SIGCOMM '18]



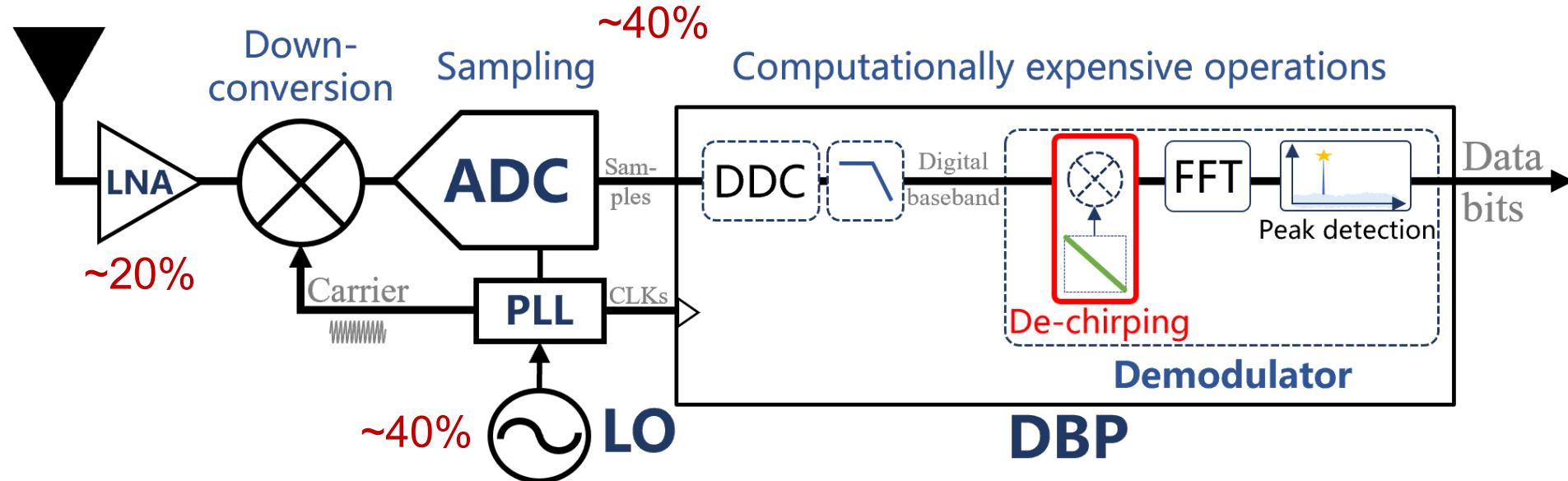
P²LoRa
[MobiCom '21]

LoRa-based backscatter systems reduce the power of
uplink LoRa transmission by $100\mu\text{W}$ -level

The **downlink** now becomes the power-saving bottleneck!



LoRa Primer 1 – legacy LoRa receiver



Superheterodyne architecture requires bulky components
consuming intensive power 😰

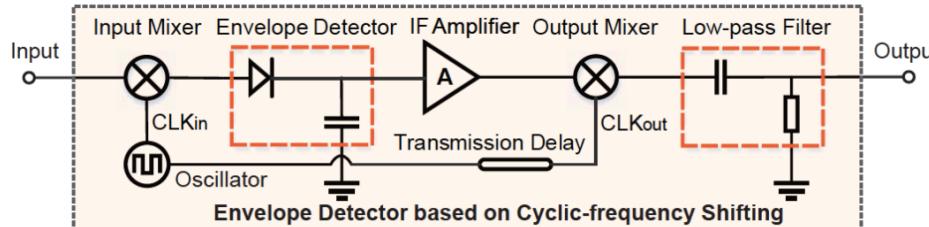
Addressing the downlink runtime power issue of LoRa



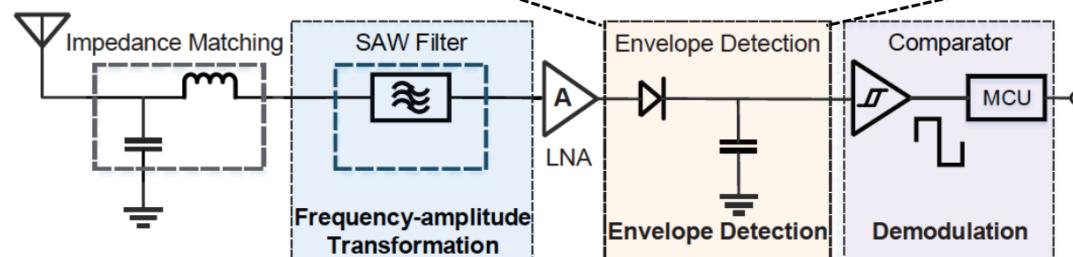
Existing work: Saiyan^[1] – passive non-coherent demodulation

(Improve demodulation sensitivity)

Super Saiyan



Vanilla Saiyan
(Demodulate LoRa signals)



No de-chirping



Puzzling power consumption

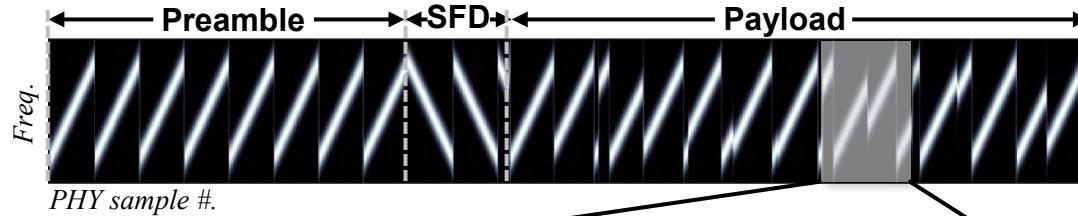
[1] Saiyan: Design and implementation of a low-power demodulator for {LoRa} backscatter systems. In 19th USENIX Symposium on Networked Systems Design and Implementation (NSDI 22) (pp. 437-451).



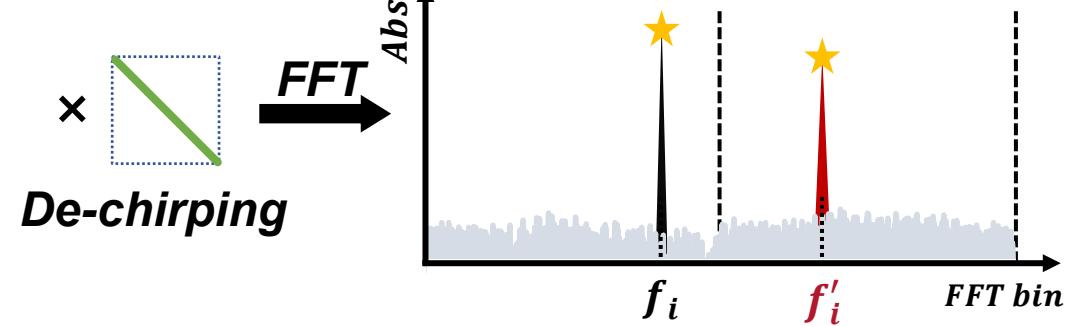
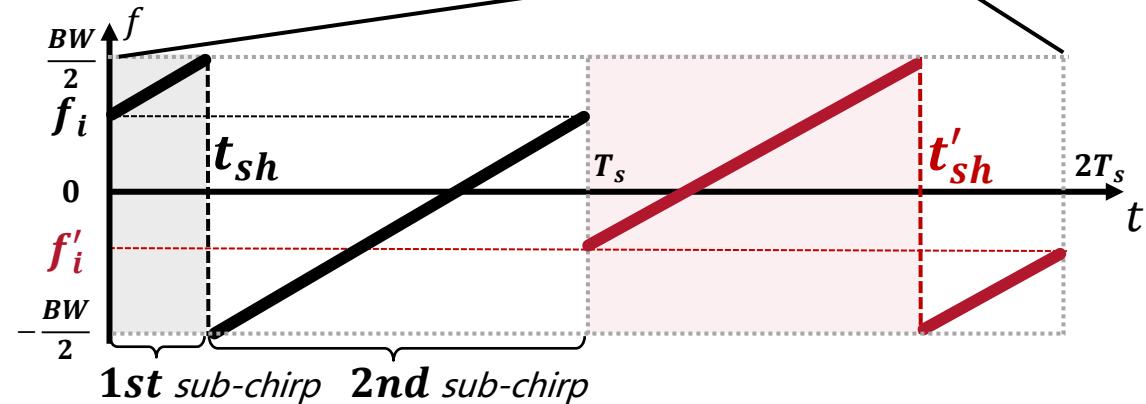
**LoRa – Can it low-power 🤔
while retaining de-chirping?**



LoRa Primer 2 – chirp spread spectrum (CSS) technology



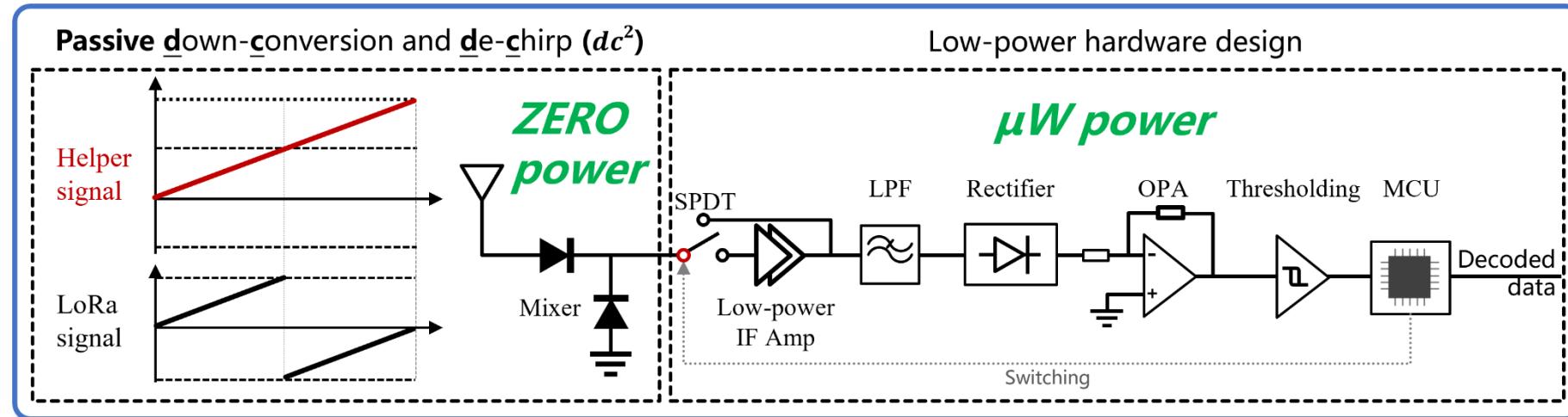
LoRa packet



Observation: an ' f_i ' corresponds to a specific ' t_{sh} ' due to the inherent chirp **geometric feature**

$$t_i^0 = \frac{BW - f_i^0}{k} = \frac{2^{SF} - i_0}{BW}.$$

Sisyphus addresses the downlink LoRa power issue while retaining de-chirping ability

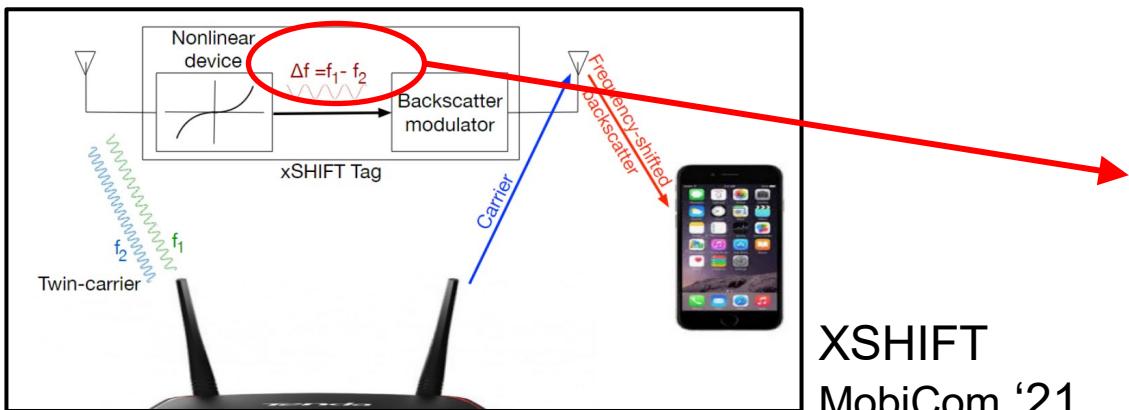
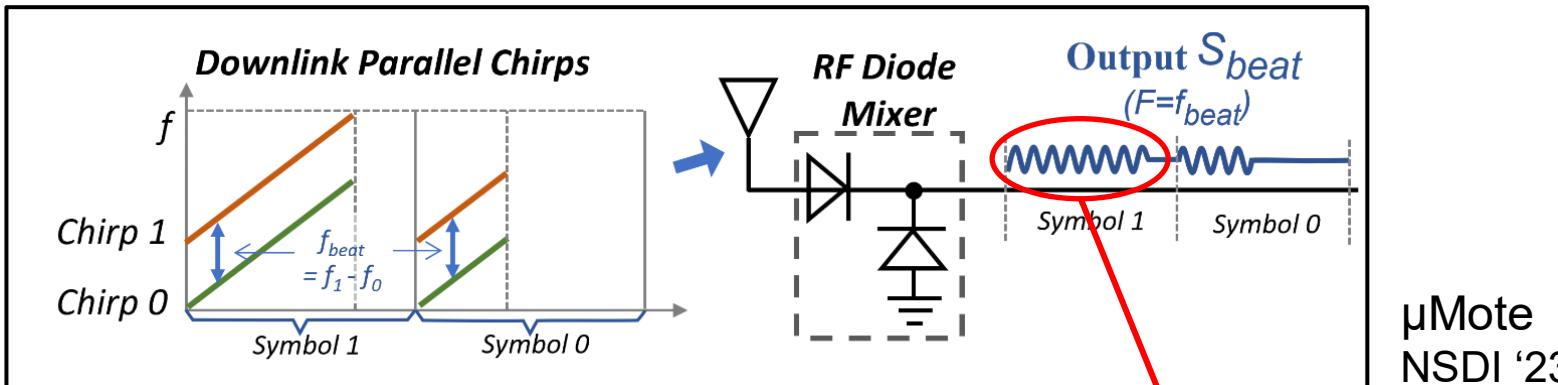


Insight: time localization LoRa demodulation

- ✓ Passive dc^2
- ✓ Low-power demodulator hardware
- ✓ Compatible with COTS LoRa

Problem:

Passive one-shot down-conversion and de-chirping (dc^2) while reserving the time-frequency feature for LoRa demodulation

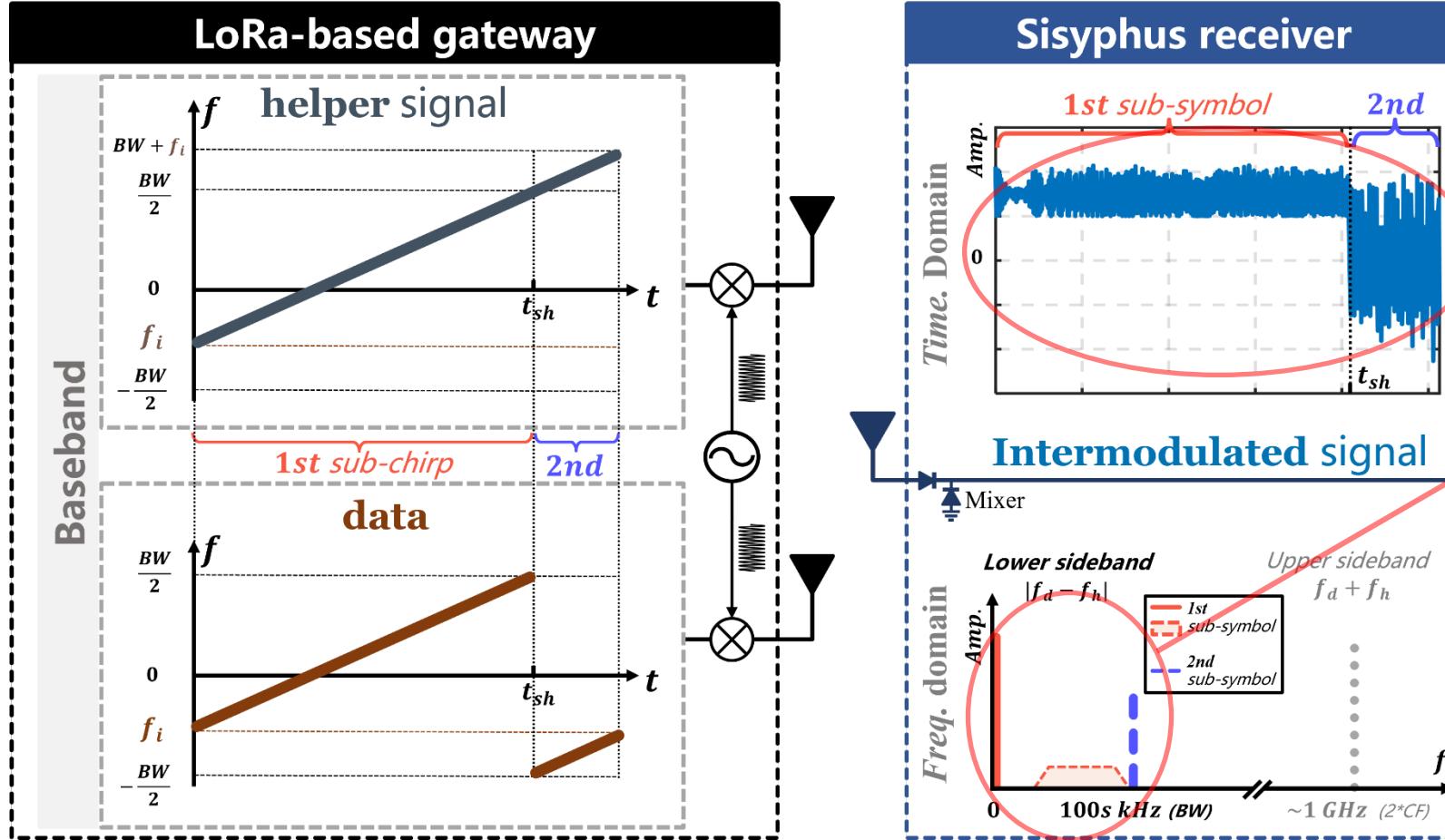


Single-tone
Destroy the demodulation feature

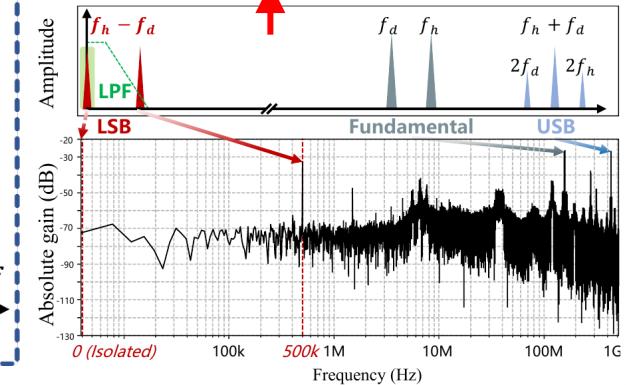


Solution:

Collaborative helper signal waveform design

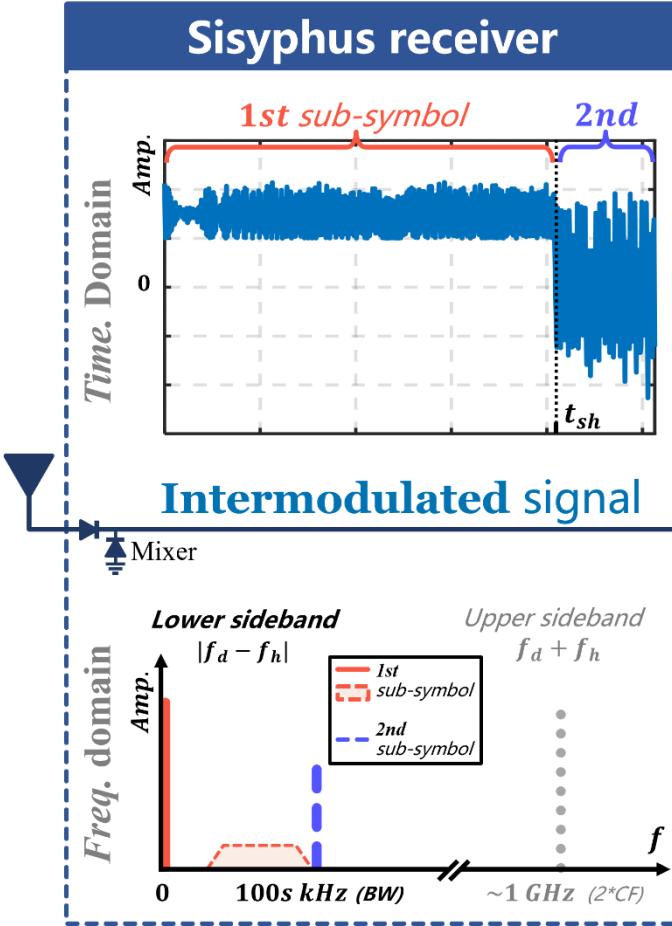


Feature reserved!

One-shot dc²!

Problem:

How to demodulate post- dc^2 signals with negligible power consumption



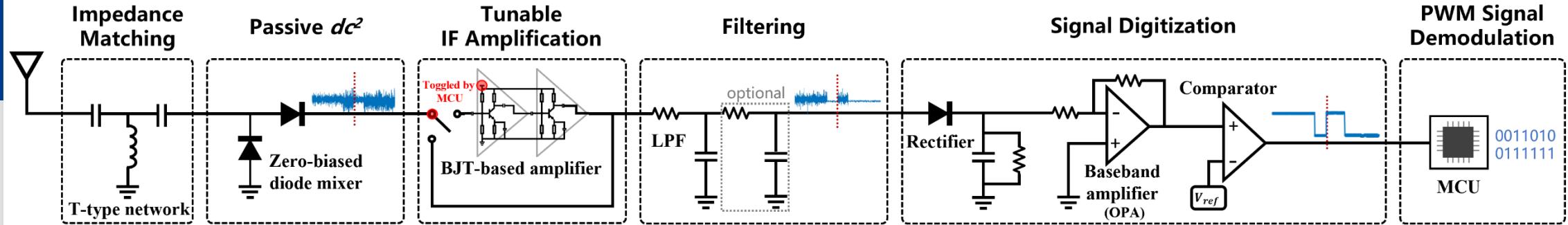
Through digital signal processing? 🤔
(e.g., wavelet transform, Kalman filter and etc.)



**Power-consuming
and defeat our original purpose**

Solution:

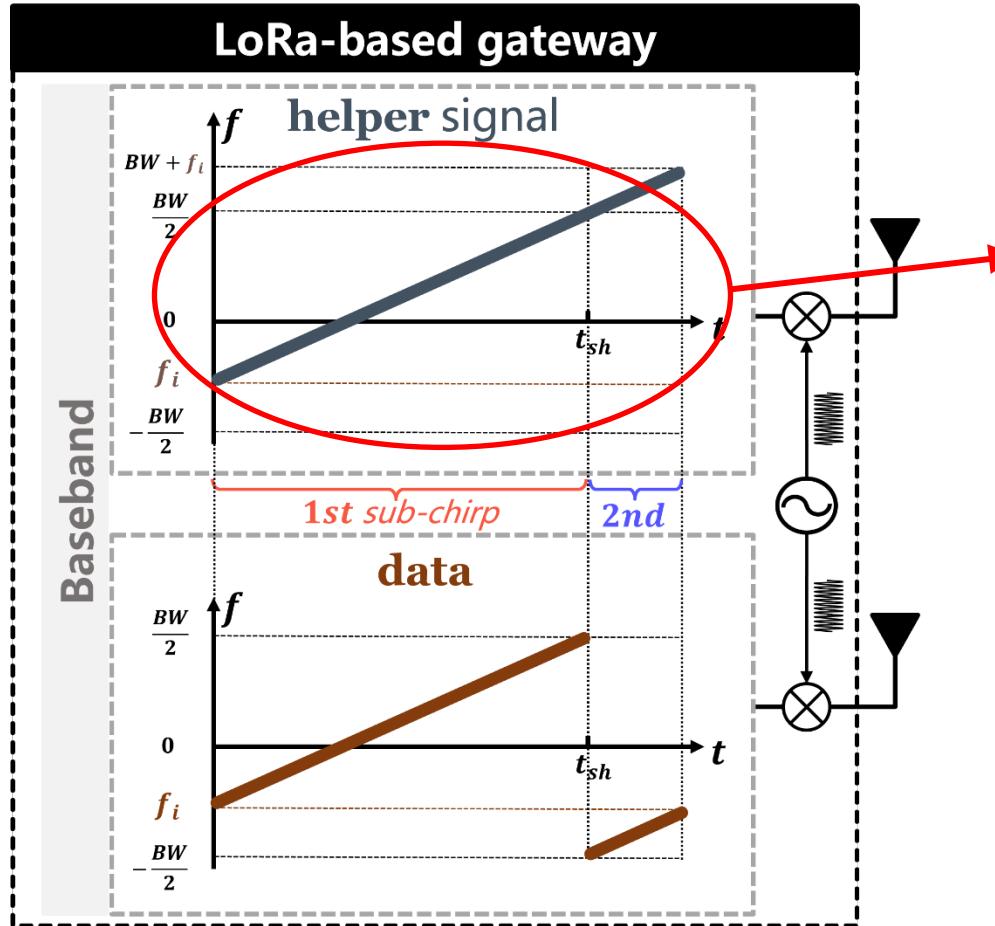
Analog-digital hybrid demodulation



- ✓ **Feature transformation** based on passive RC filter
- ✓ **Digitization** based on passive rectifier and low-power comparator
- ✓ **Data bit extraction** based on low-load PWM signal duty-cycle calculation

Problem:

Backward compatible with COTS LoRa



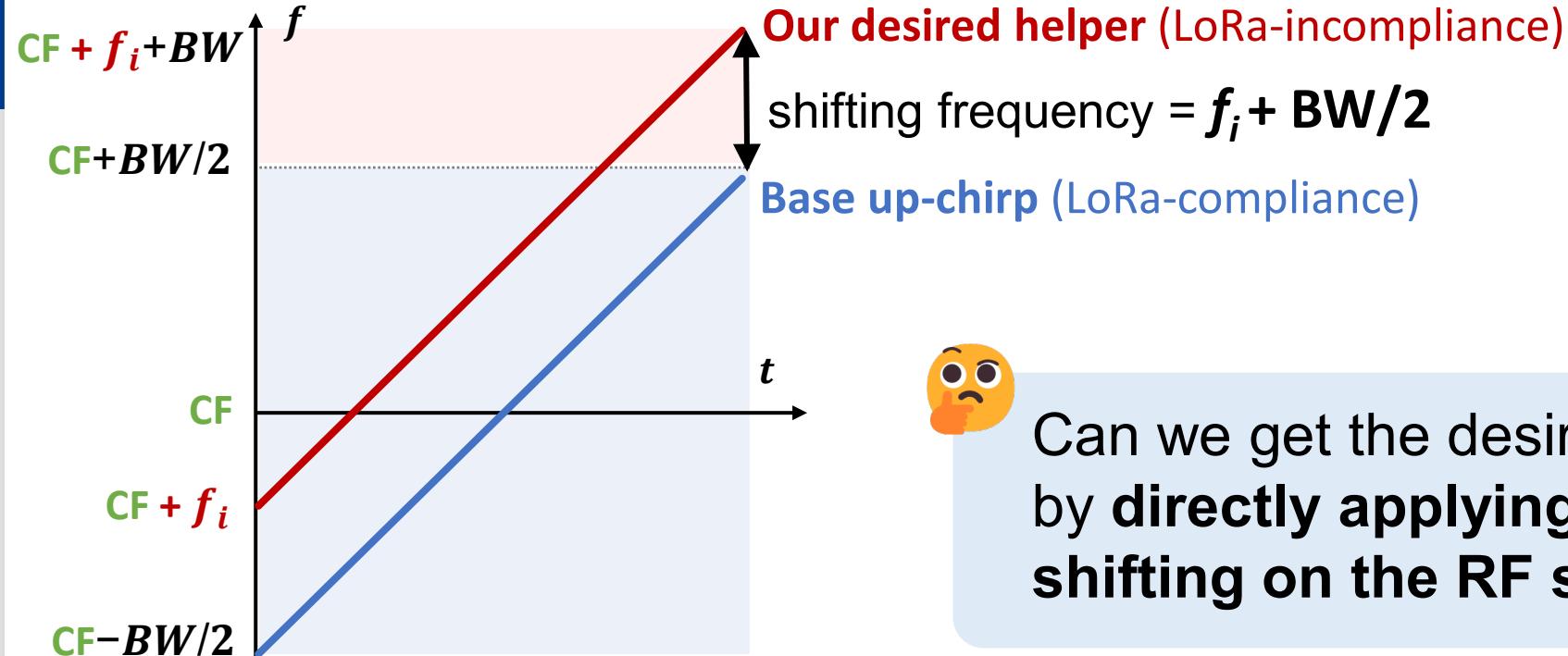
Not compliant with
LoRa baseband specification!



Can we still emit helper signal
using COTS LoRa transceiver?

Insight 1:

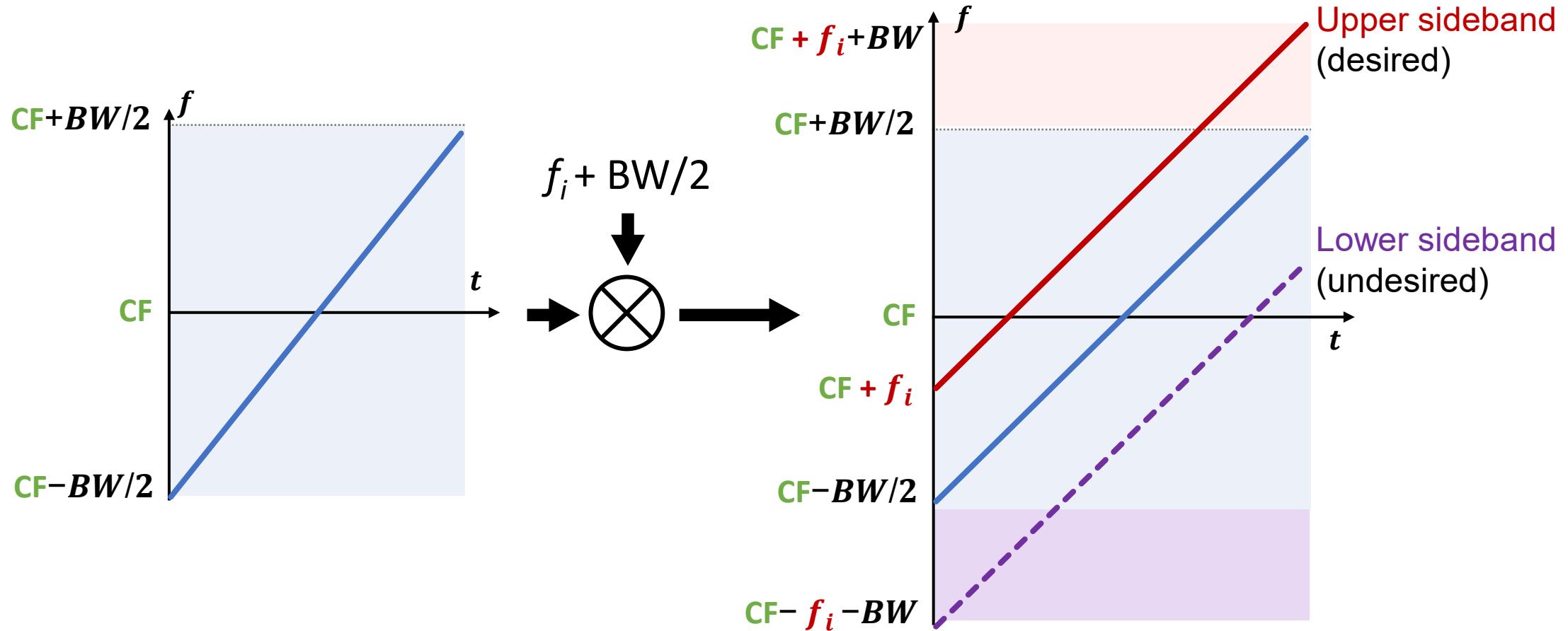
Signal frequency over-the-air = baseband freq. + carrier freq. (CF)



Can we get the desired helper signal by directly applying a frequency shifting on the RF signal?

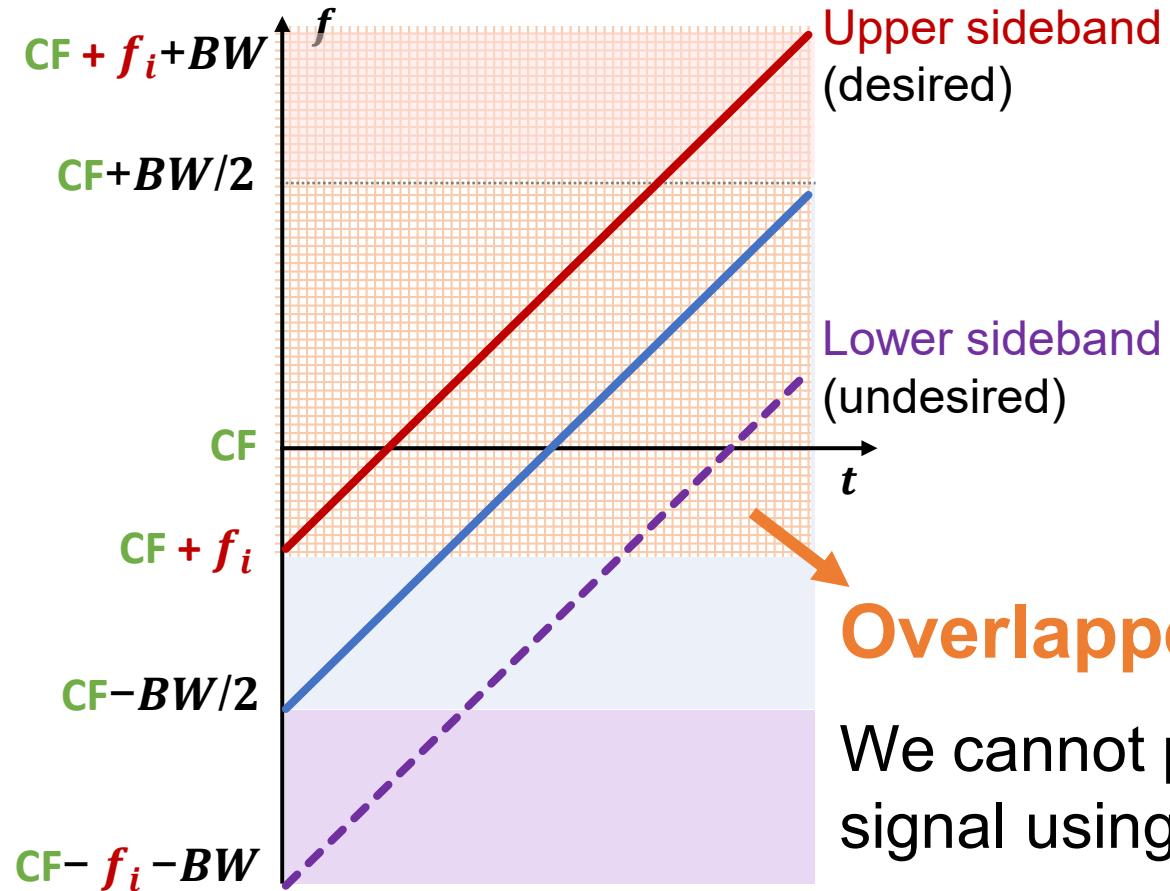
Problem:

Double sideband overlapping



Problem:

Double sideband overlapping



We cannot pick-up the desired signal using high pass filter



Observation:

The CF of COTS LoRa module can be customized via register

4.1.4. Frequency Settings

Recalling that the frequency step is given by:

(P36 in the datasheet of SX127X chip)

$$F_{STEP} = \frac{F_{XOSC}}{2^{19}}$$

In order to set LO frequency values following registers are available.

F_{RF} is a 24-bit register which defines carrier frequency. The carrier frequency relates to the register contents by following formula:

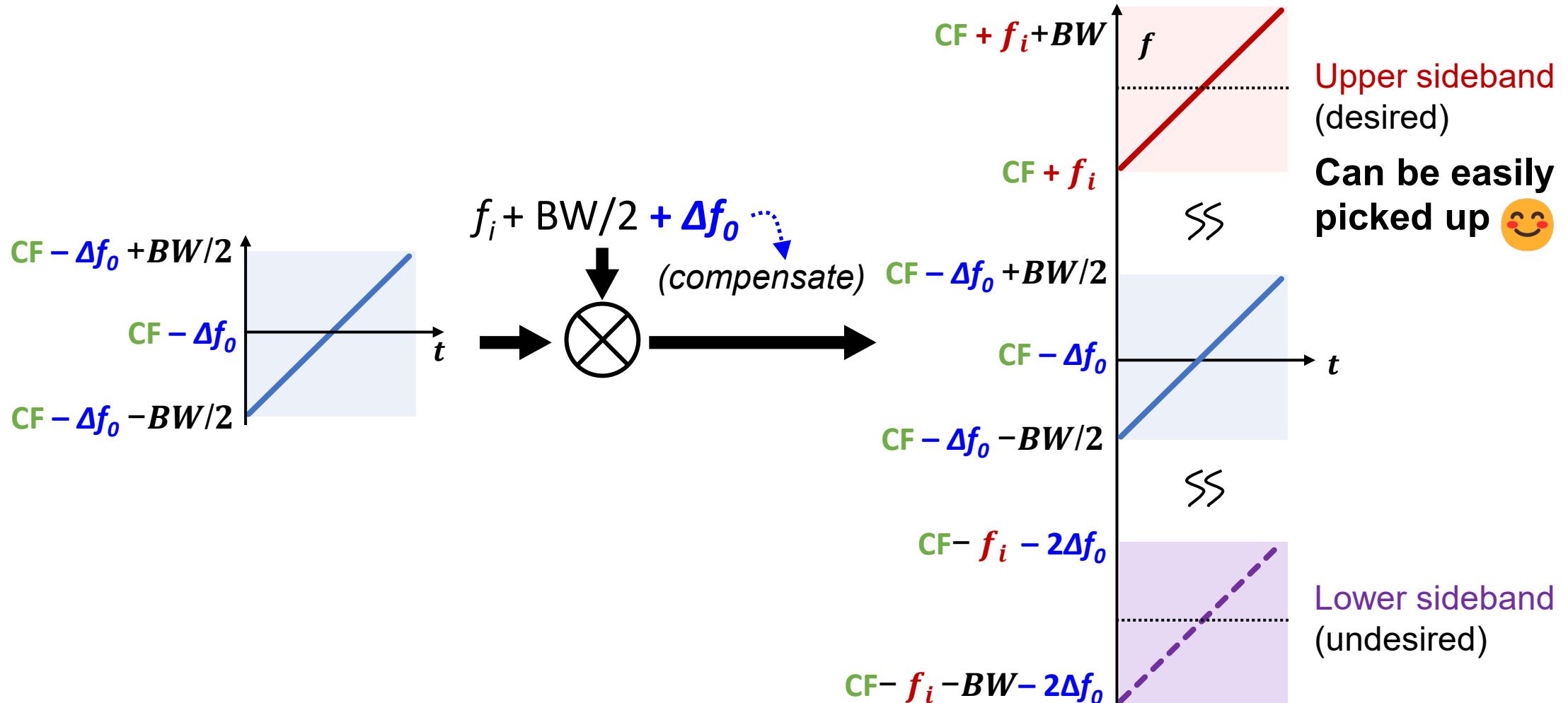
$$F_{RF} = F_{STEP} \times Frf(23,0)$$

Solution:

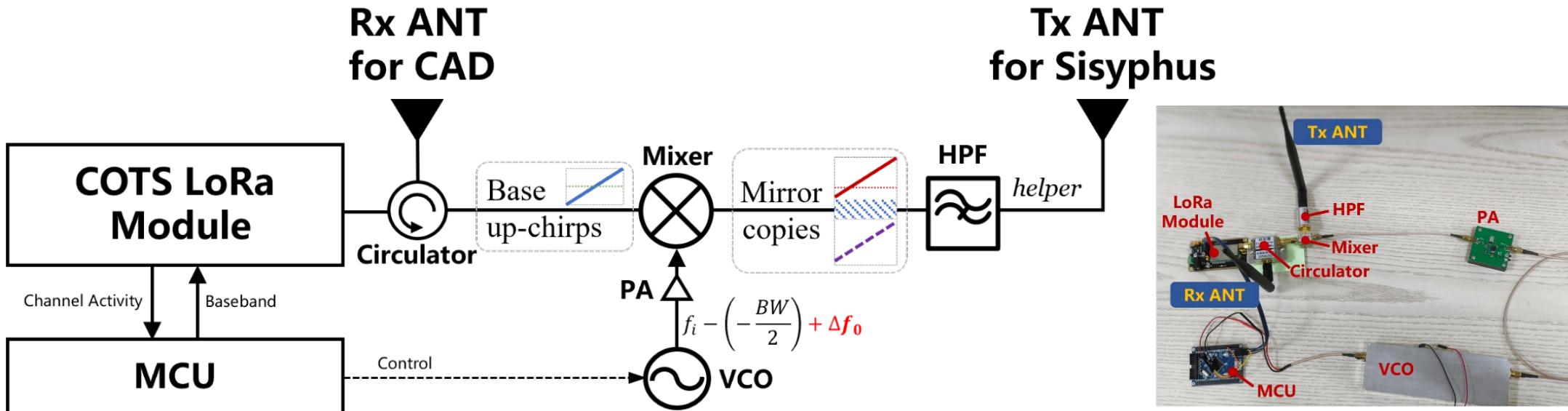
Modify CF and compensate its variation in the shifting frequency 

Solution:

Modify CF and compensate its variation in the shifting frequency

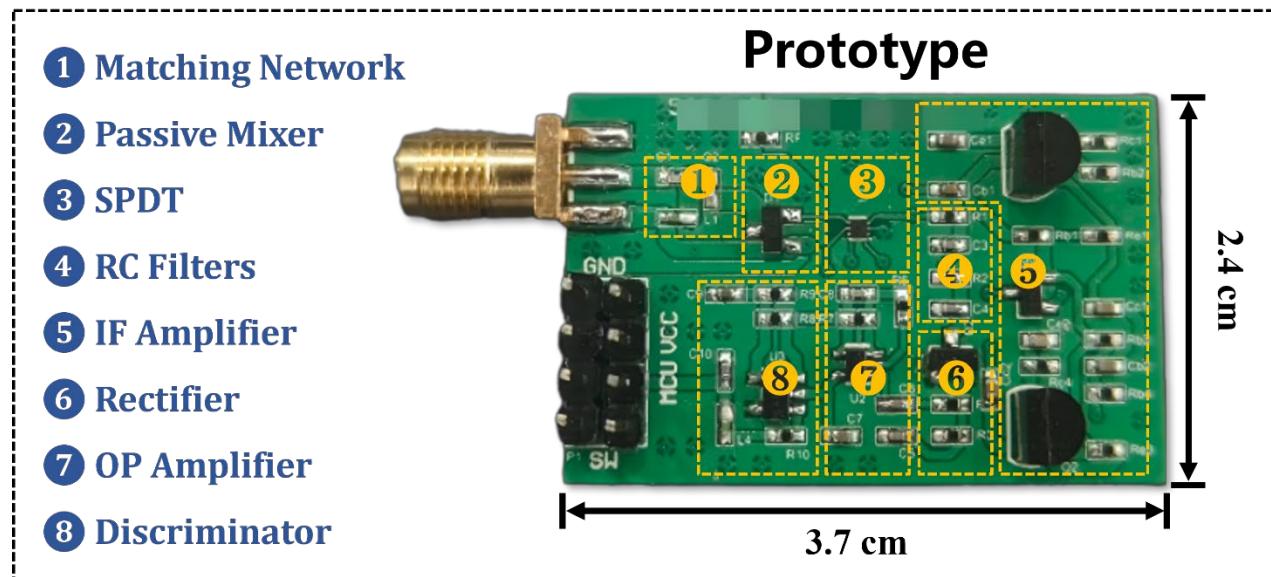
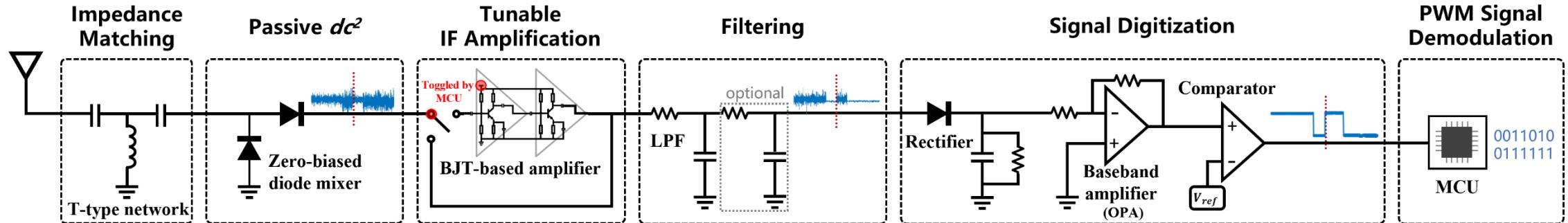


Hardware design of helper emitter

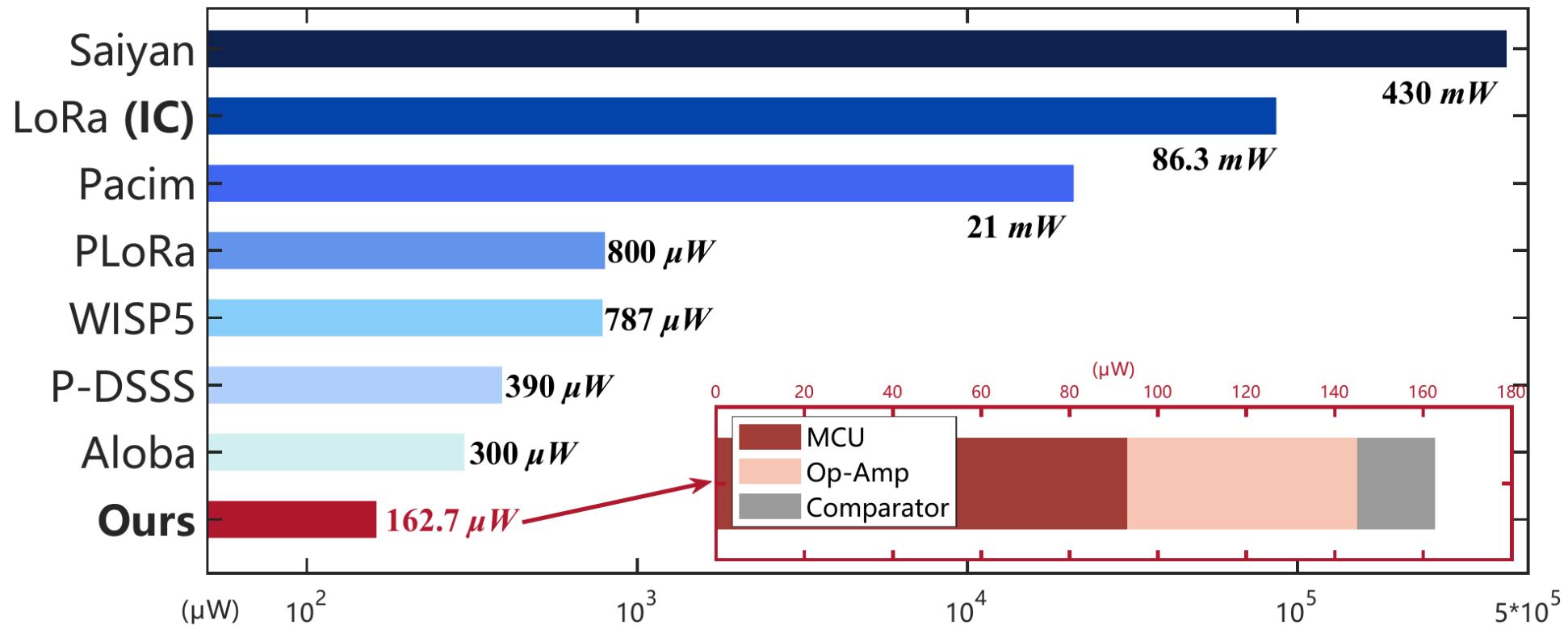


- ✓ Rx ANT is employed for avoiding collision with non-Sisyphus link based on CSMA
- ✓ Synchronization with data signal transmitter is detailed in our paper...

Implementation

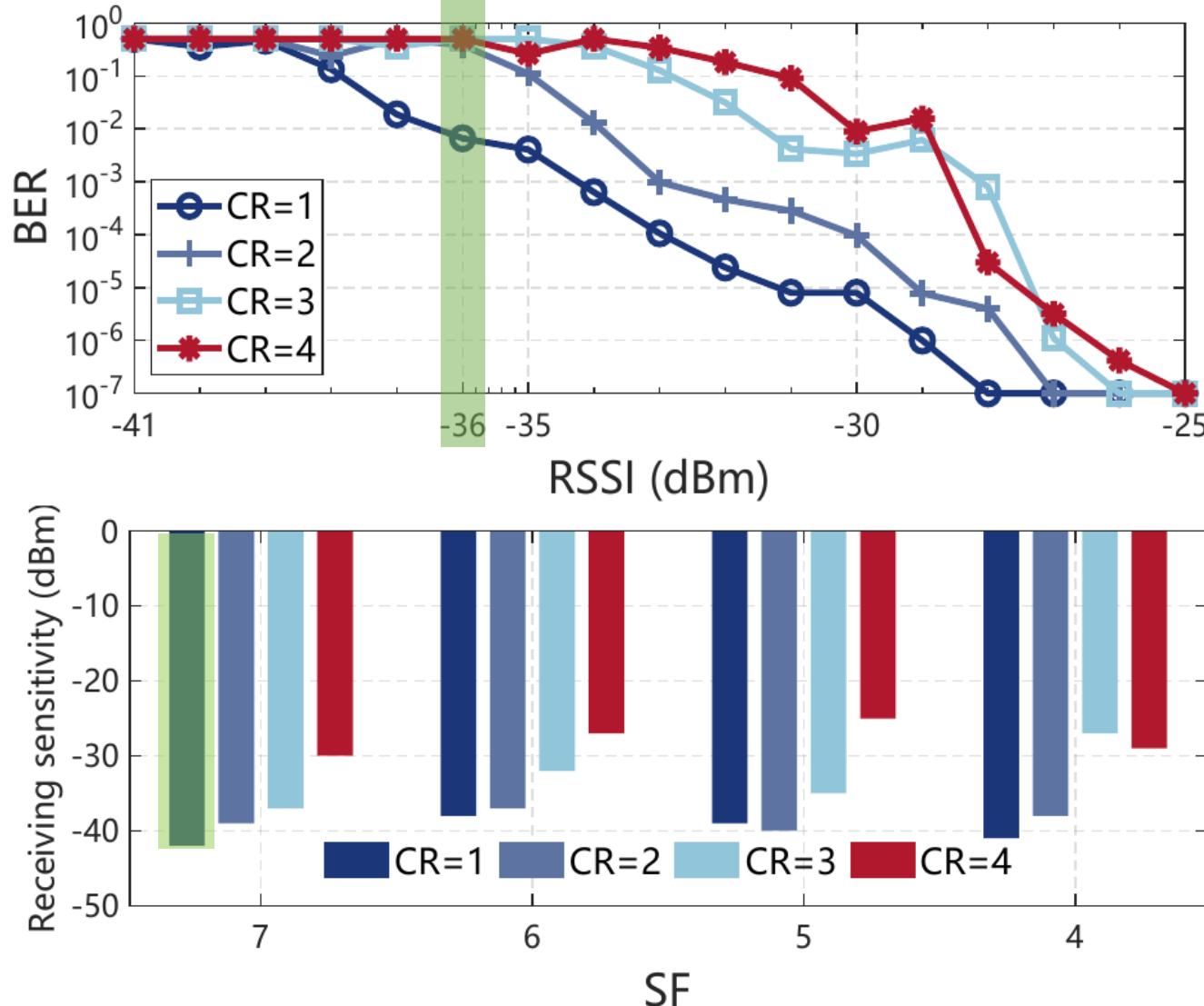


- 37mm × 24mm 4-layer FR4 PCB
- 2 versions:
 - Sisyphus+: IF amplifier ON
 - Sisyphus: IF amplifier OFF



- ✓ **530×** reduction compared to IC-based legacy LoRa receiver
- ✓ **4.9×**, **1.8×**, **129×** reduction compared to demodulation-disable LoRa-based backscatter systems' downlink
- ✓ Power of IF amplifier: **286 μW**

Evaluation > receiving sensitivity



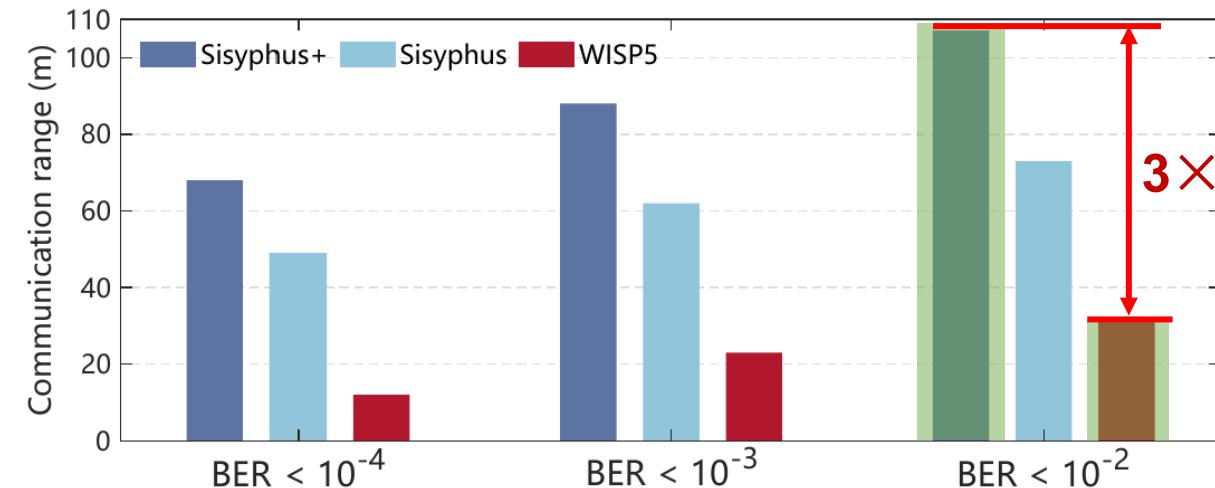
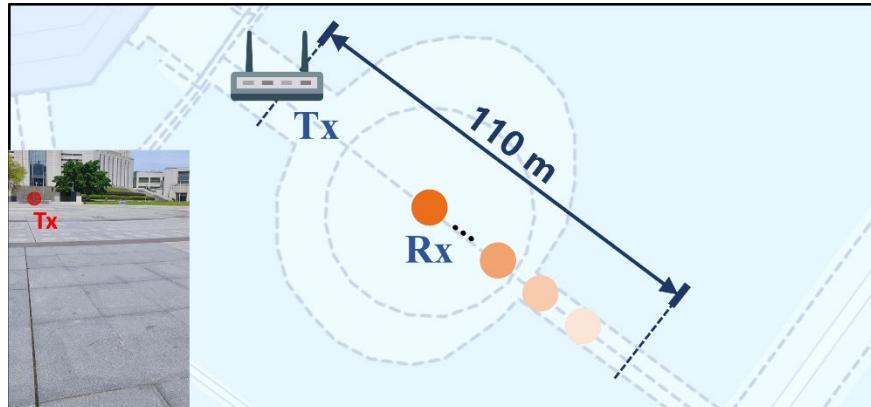
Sisyphus

Sensitivity: **-36dBm**

6dB gain
with IF amplifier ON

Experimental setup:

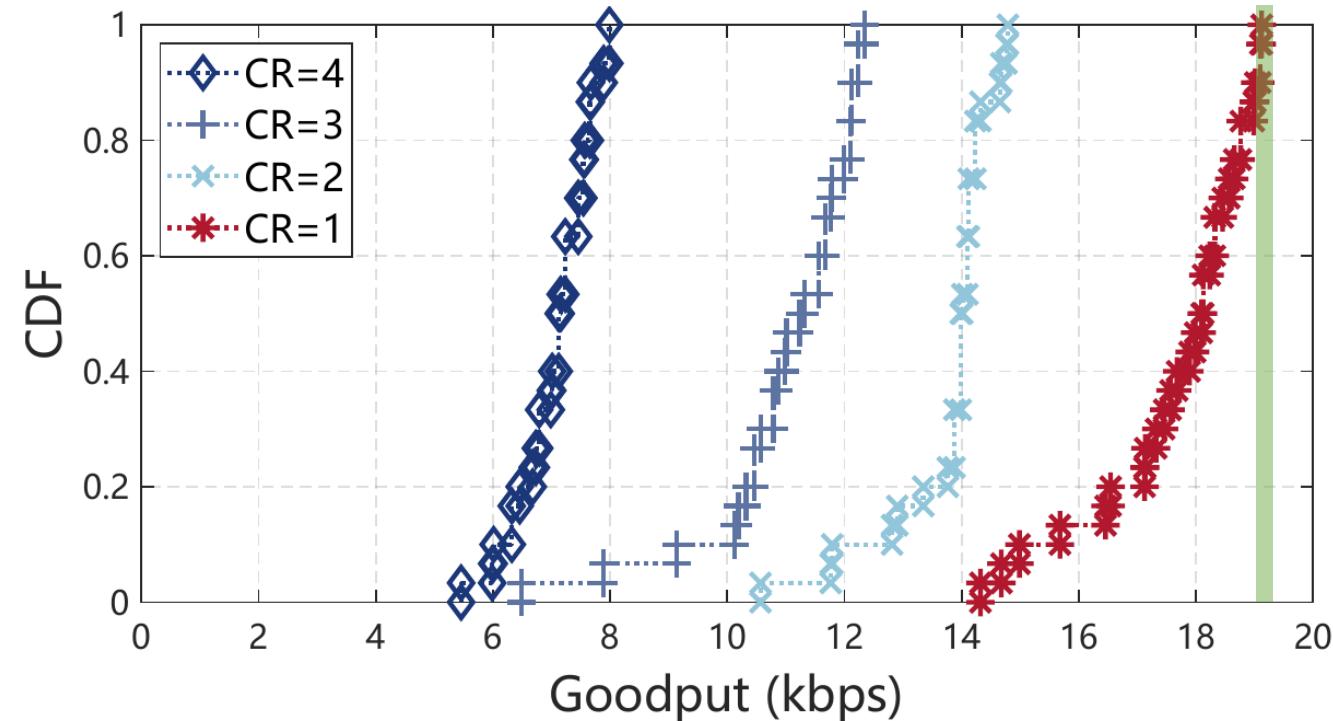
- Transmission power: 20dBm;
- LOS Tx antenna gain: 6dBi, Rx antenna gain:3dBi.



3× improvement range
compared to ED-based receiver

Goodput

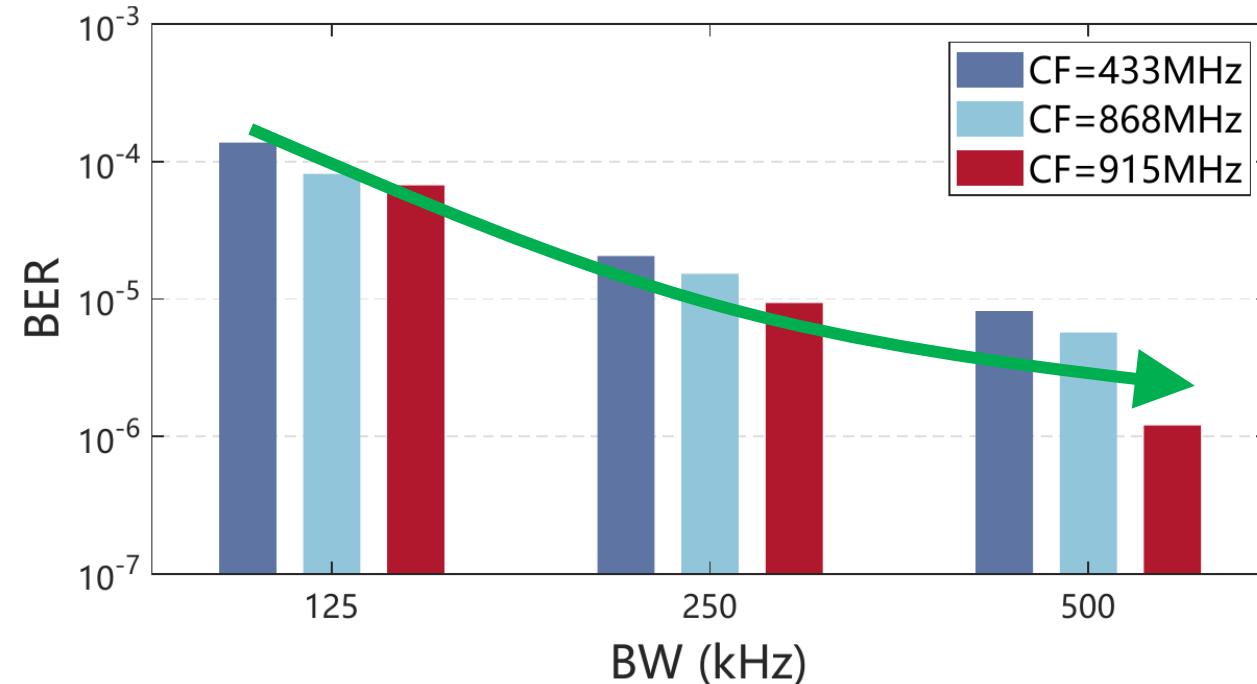
Indicating the BER in different time and locations



Comparative goodput with legacy receiver

Why?

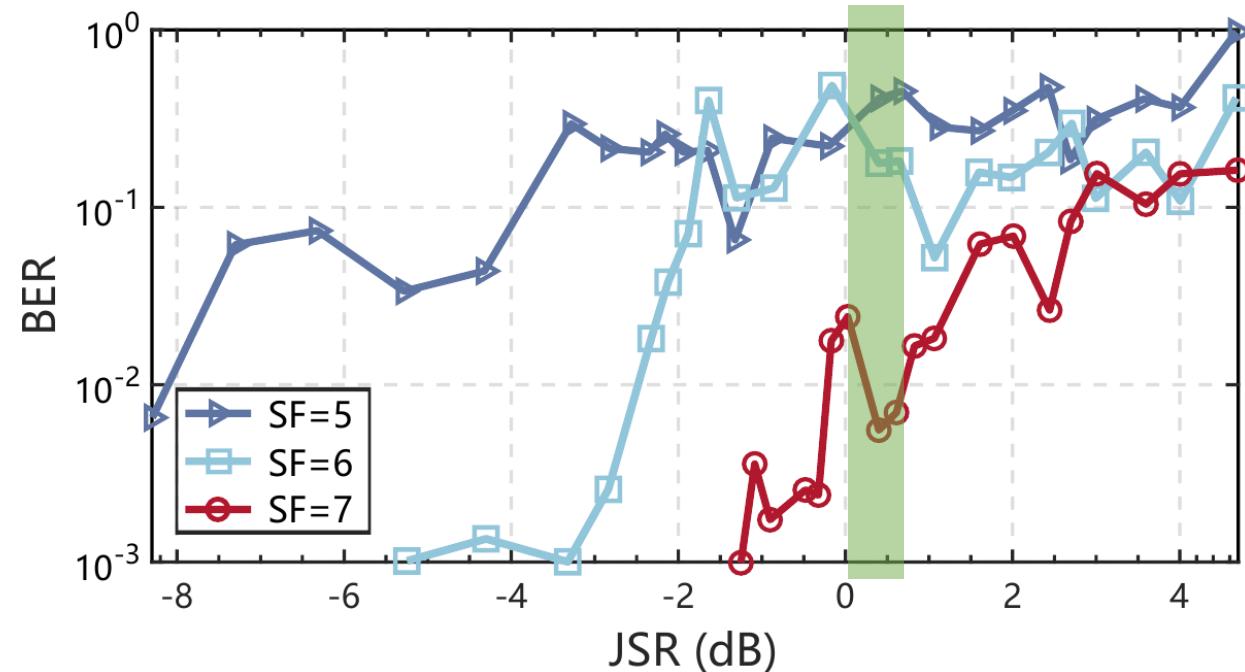
More BW, more distinguishable sub-symbols;
And CF will impact the conversion loss of diode in our circuit.



BW↑ and CF↑, performance↑

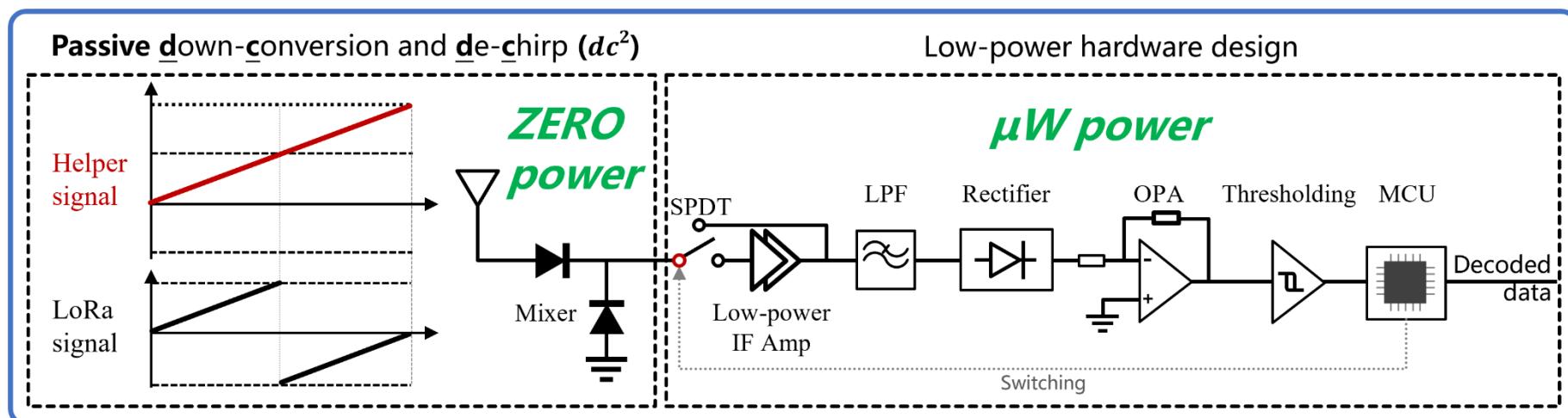
Setup:

Send helper+data along with in-band jamming signals within an RF cable



**Sisyphus can achieve accurate communication
with 0.8dB JSR**

- ✓ The low-power promise of LoRa can only be delivered in Class A and B, in other words, **LoRa is NOT always low power!**
- ✓ Sisyphus enables the first **ultra-low-power LoRa receiver design with de-chirping ability**
- ✓ Sisyphus can be **compatible with legacy LoRa**





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Thanks for your attention! 😊

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Q&A