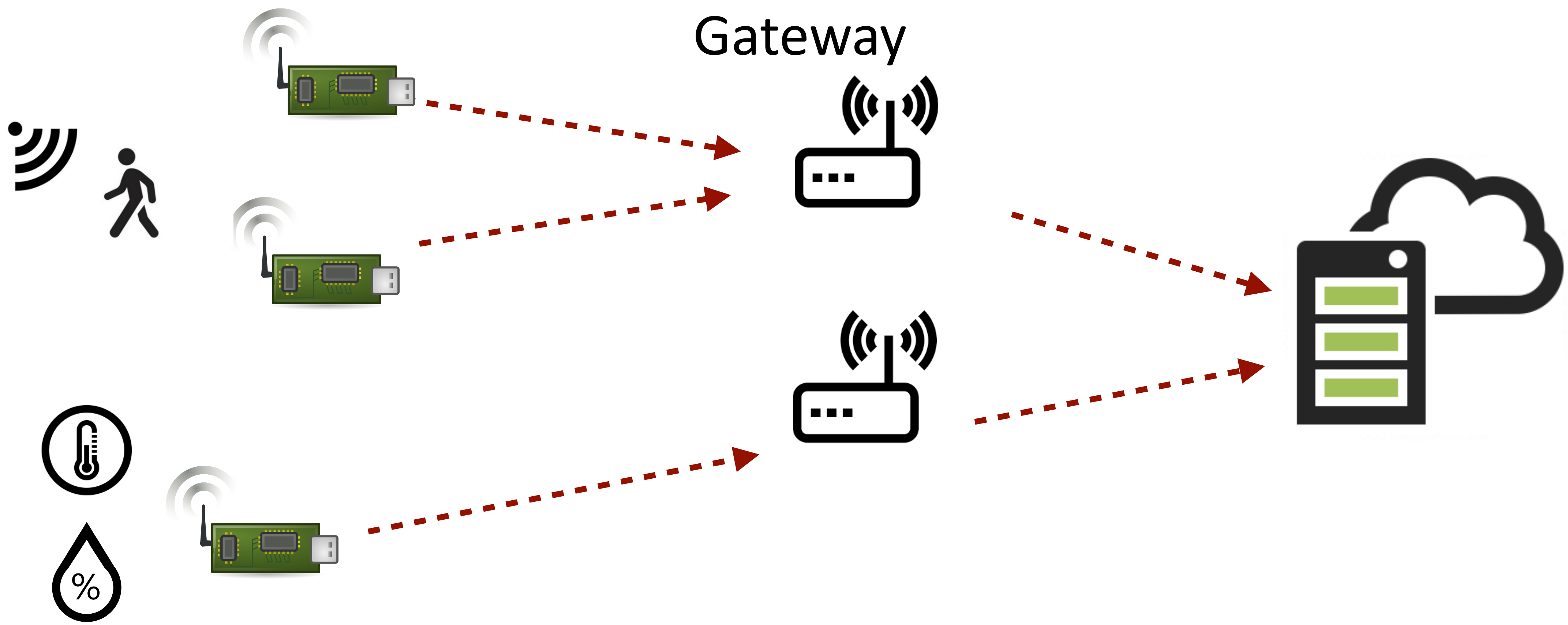
Polymorphic Radios: A new design paradigm for ultra-low power communication

Mohammad Rostami, Jeremy Gummeson, Ali Kiaghadi, Deepak Ganesan, *University of Massachusetts Amherst*

Why do we need a new low-power radio?

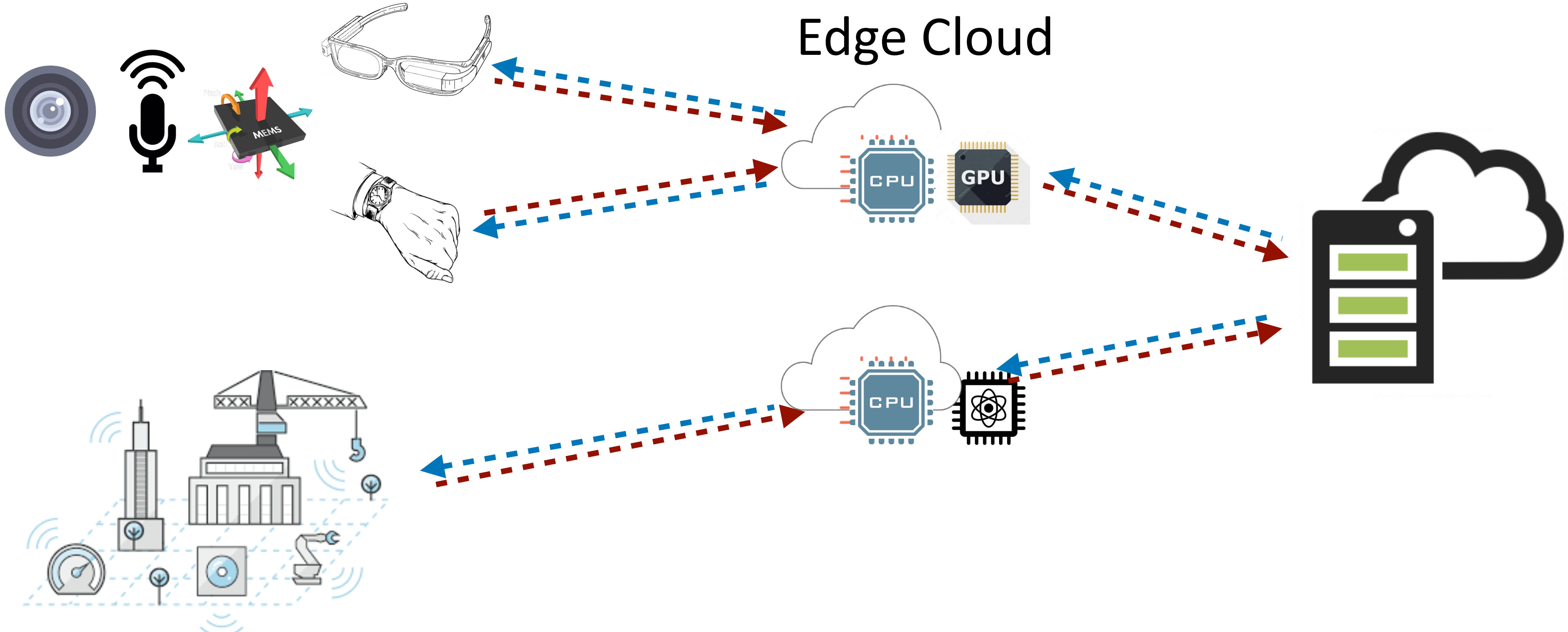
Evolving communication needs



Connectivity
(circa 1995)

Streaming
(circa 2015)

Evolving communication needs



Connectivity
(circa 1995)

→

Streaming
(circa 2015)

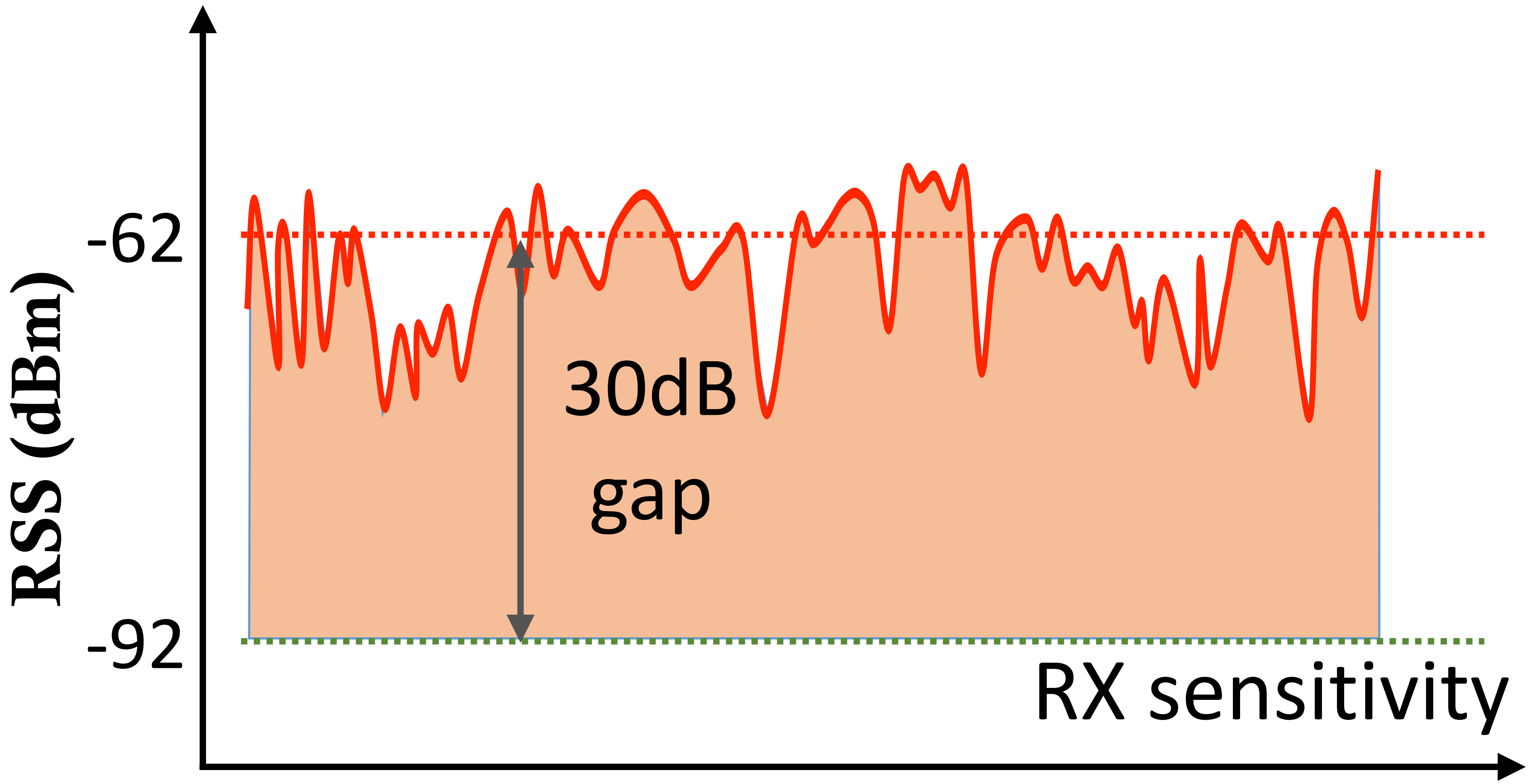
What about radio power consumption?

Challenge: Low-power radios optimized for sporadic rather than streaming communication.

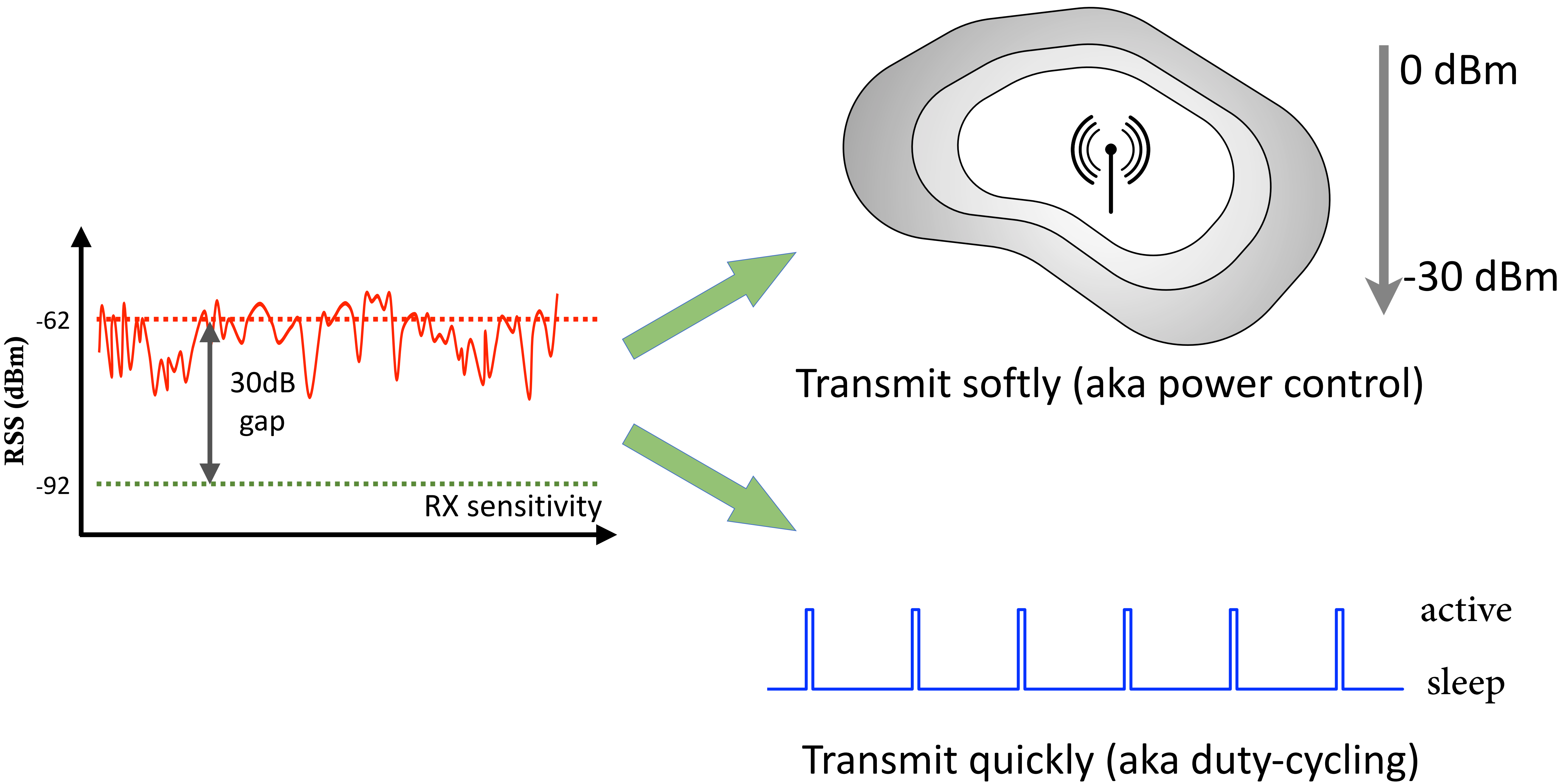
What about radio power consumption?

Goal: Design a low-power streaming radio that provides low-latency connectivity and is reliable under dynamics.

How can we optimize a streaming radio?



How do radios leverage the gap?



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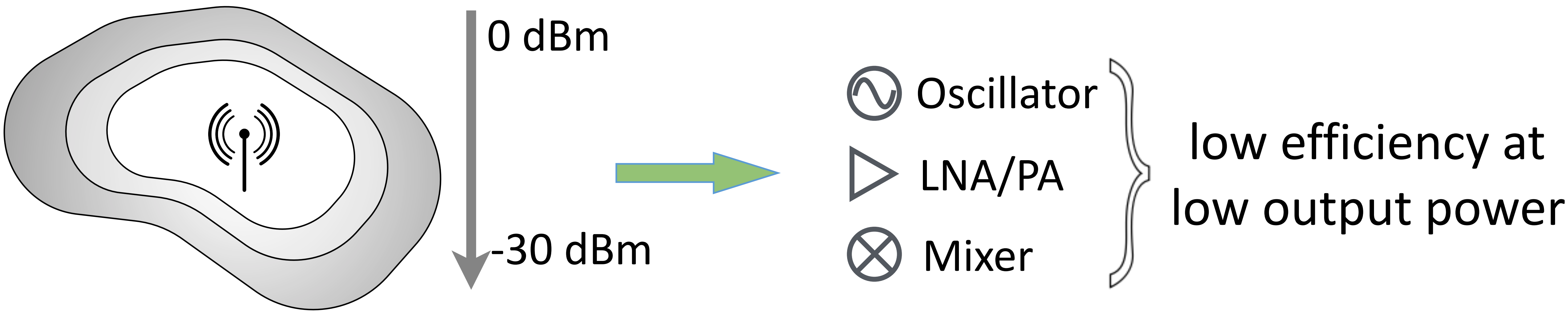

Transmit softly (aka power control)

Transmit quickly (aka duty-cycling)

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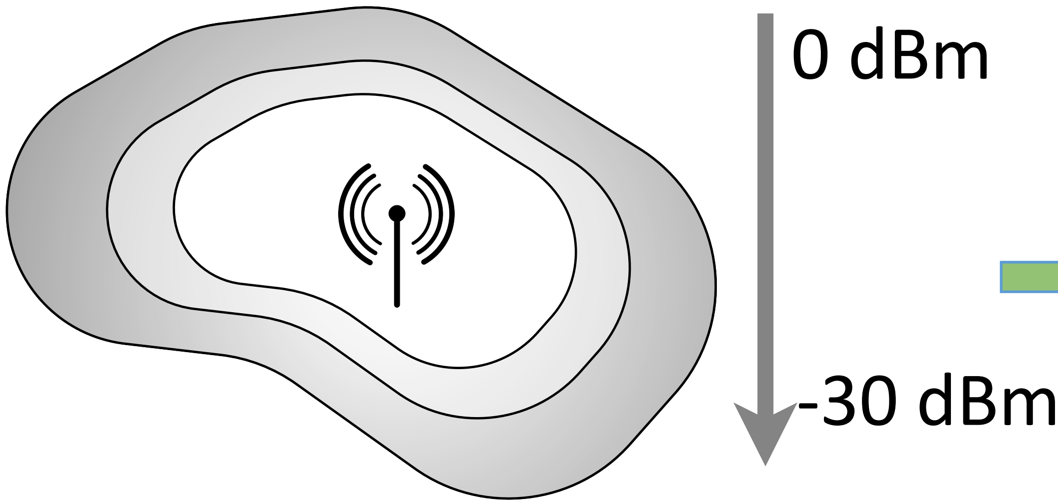

Transmit softly (aka power control)

State-of-art low-power active radio (Nordic nRF5):

- 16mW @ 0dBm
- 8mW @ -40dBm

Transmit quickly (aka duty-cycling)

How do radios leverage the gap?

State-of-art BLE (Nordic nRF5):

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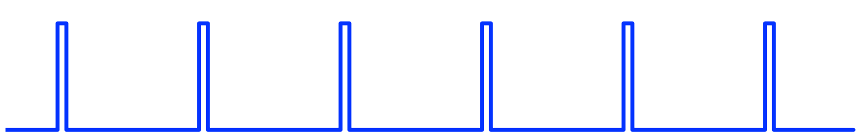

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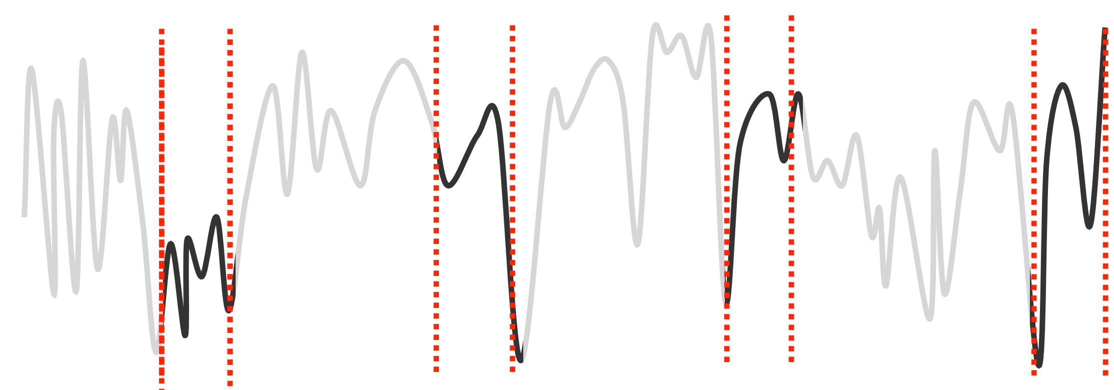

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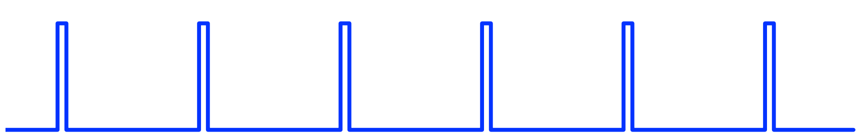

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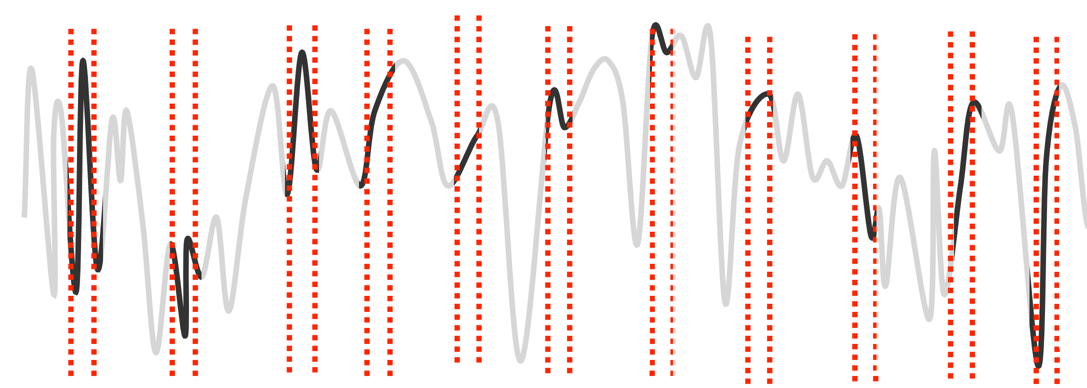
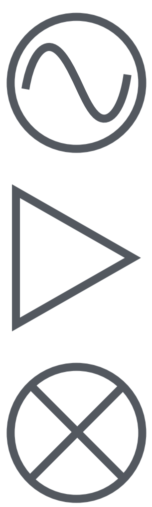


- Faster ⇒ higher on-off overhead
- Shorter ⇒ less channel visibility

Can we use passive radios?

Active Radios

Bluetooth® LoRa™ ZigBee®

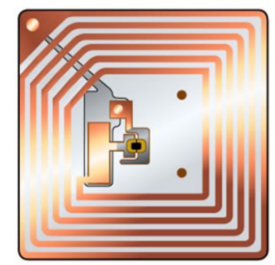


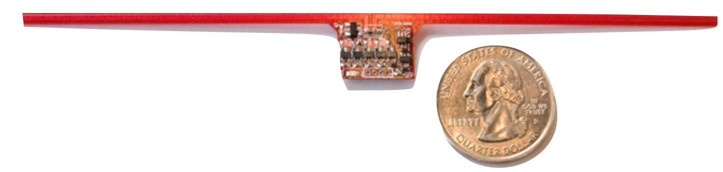
Oscillator

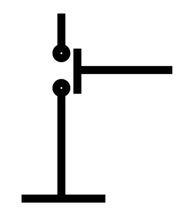
LNA/PA

Mixer

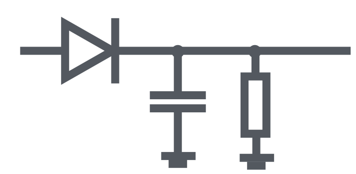
Passive Radios







Backscatter TX

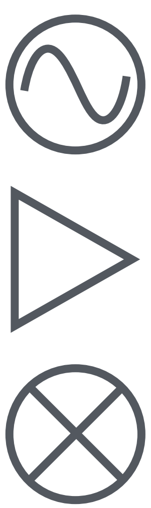


Envelope Detector RX

Can we use passive radios?

Active Radios

Bluetooth LoRa ZigBee



Oscillator

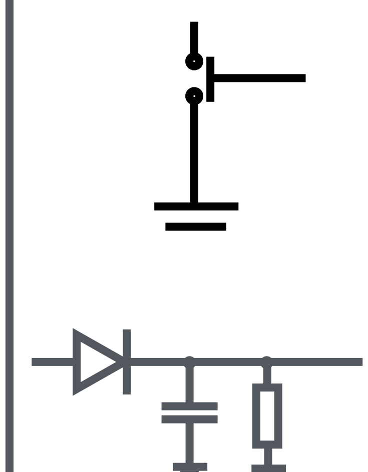
LNA/PA

Mixer

power efficiency →

← reliability

Passive Radios

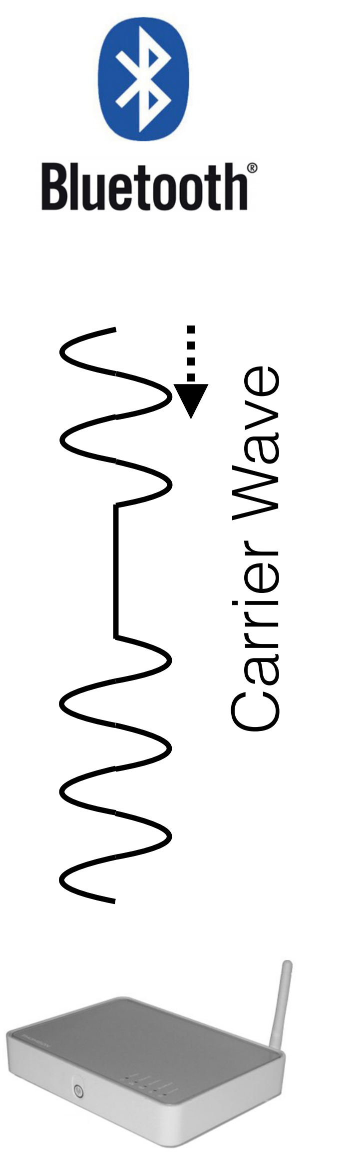


Backscatter TX

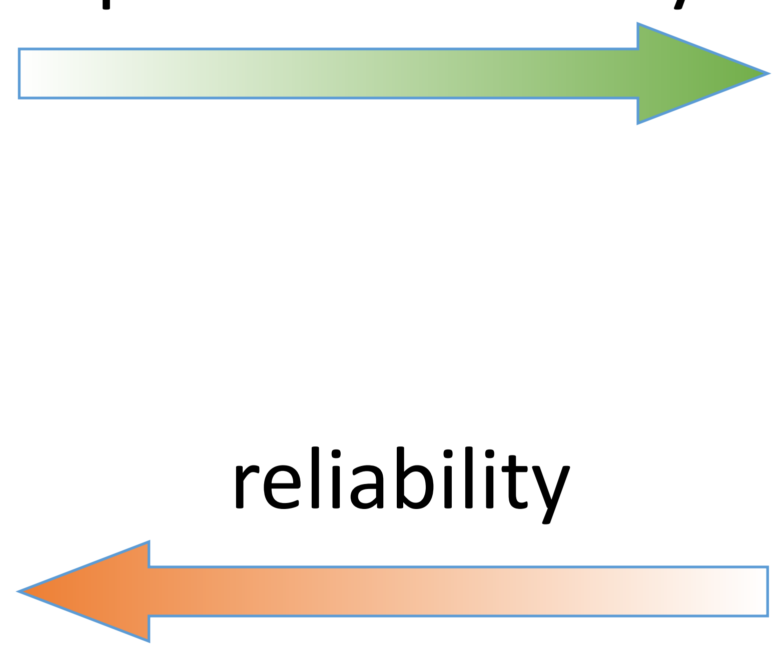
Envelope Detector RX

How about passive radios?

Active Radios



$$P_r \propto \frac{1}{d^2}$$



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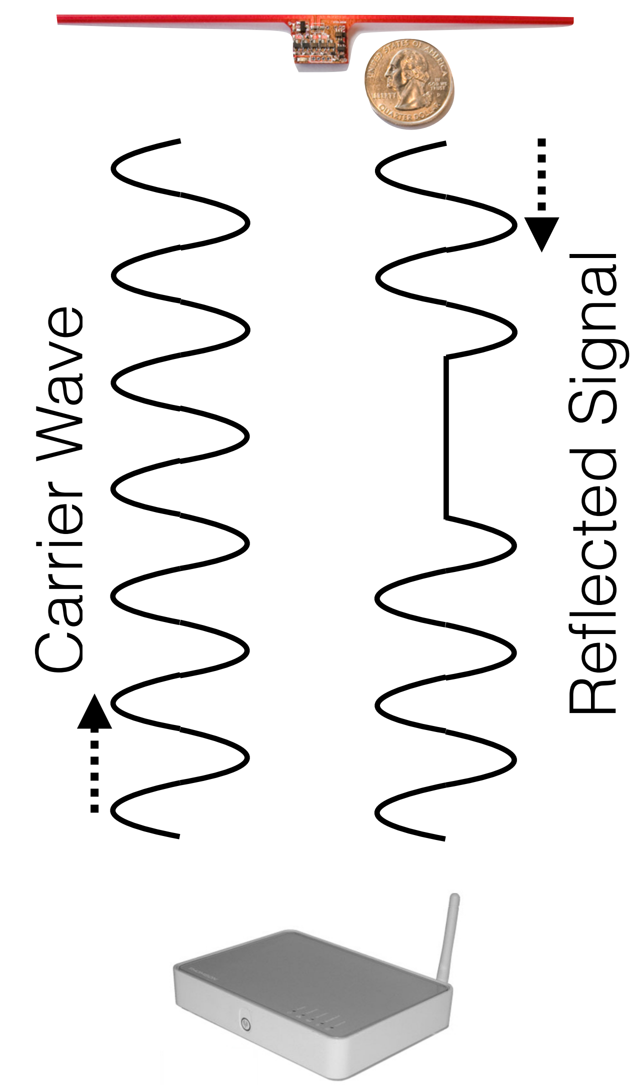
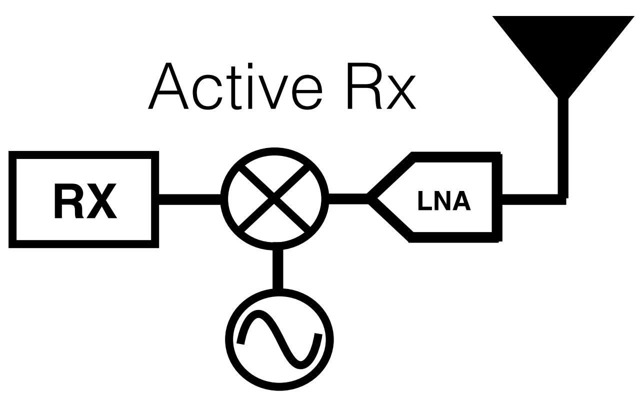


$$P_r \propto \frac{1}{d^4}$$

How about passive radios?

Active Radios

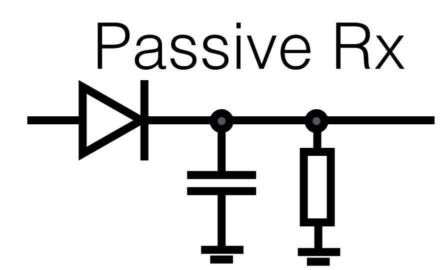


Sensitivity = -92dBm

power efficiency

reliability

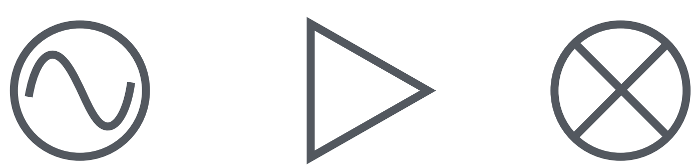
Passive Radios



Sensitivity = -50dBm

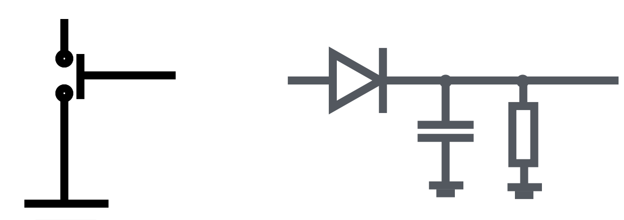
Key Challenge

Active RF



reliable but inefficient

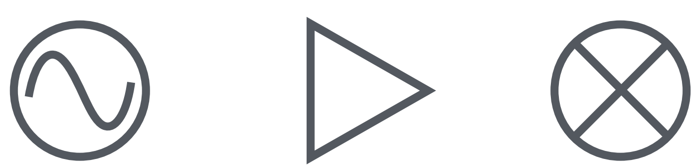
Passive RF



efficient but unreliable

Key Challenge

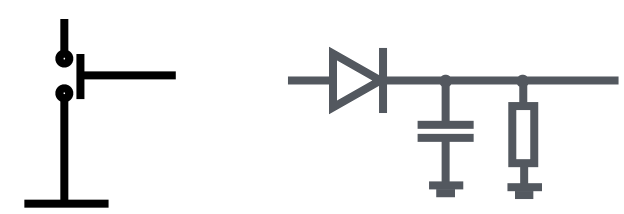
<u>Active RF</u>



reliable ~~but inefficient~~

+

<u>Passive RF</u>

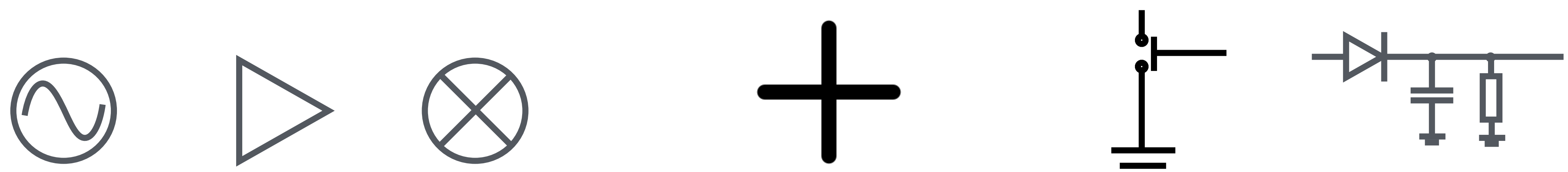


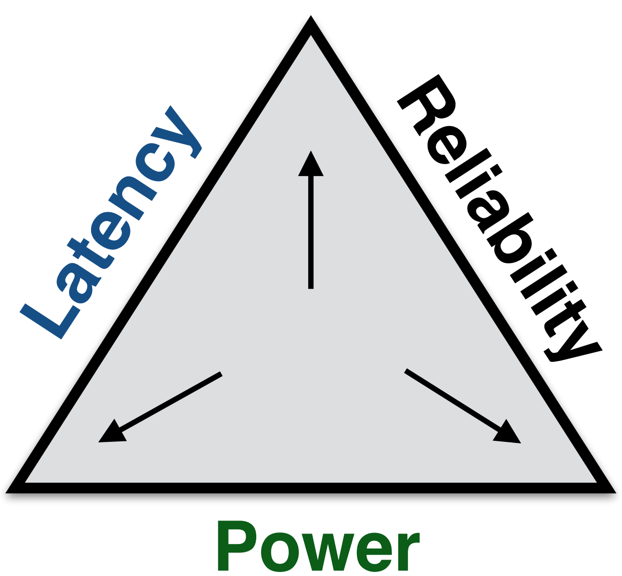
efficient ~~but unreliable~~

Polymorphic Radios

Active RF

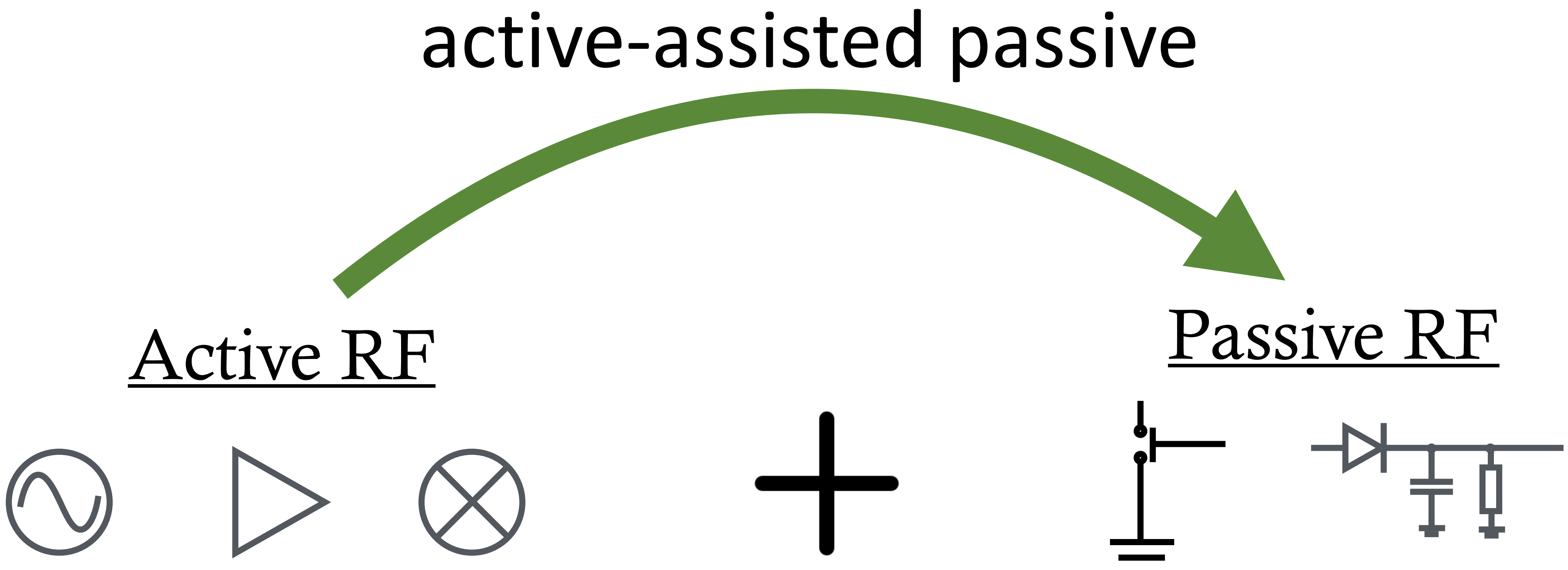
Passive RF



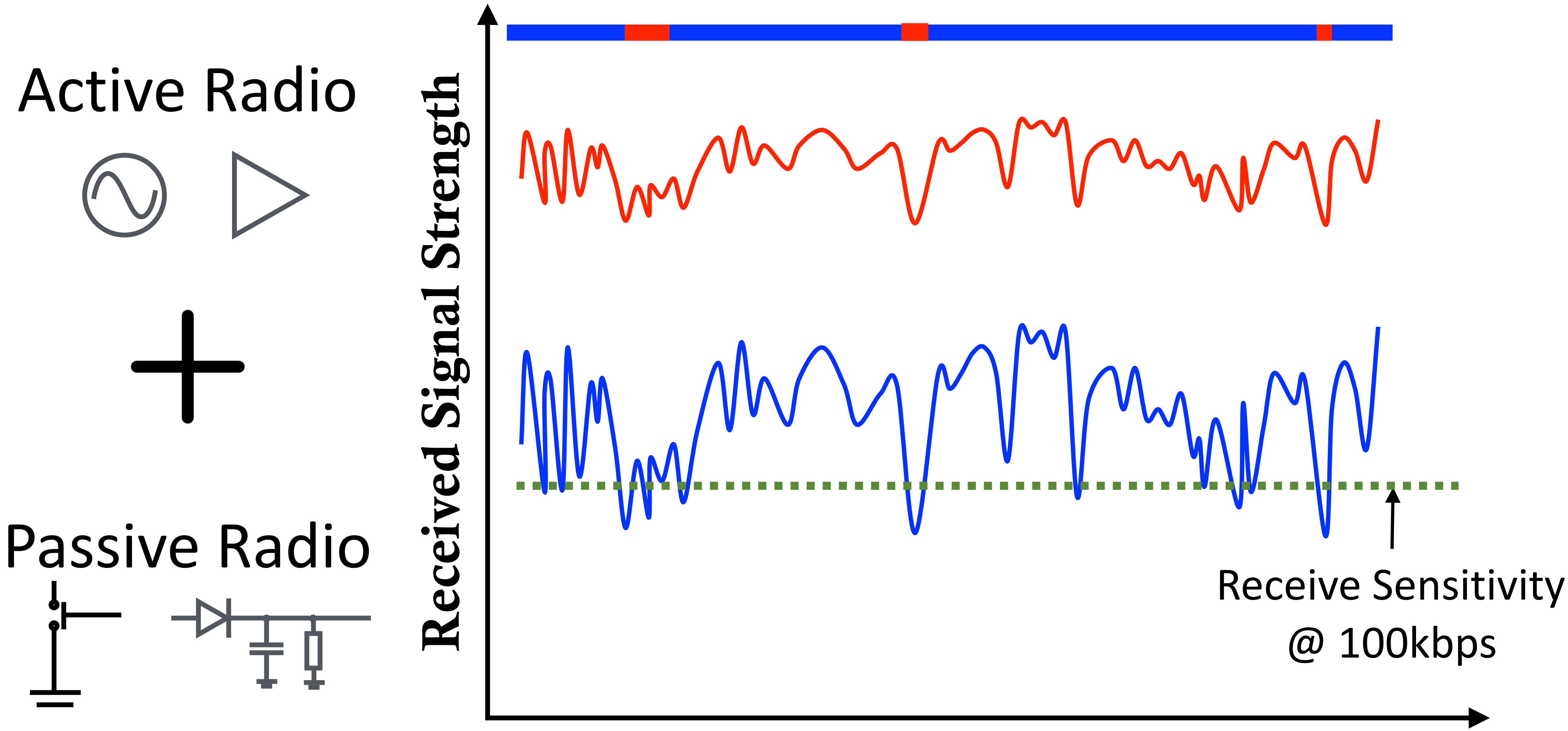


Polymorphic radios: Combine active and passive building blocks to design low-power streaming radios.

Two modes of operation



Mode 1: Active-assisted Backscatter



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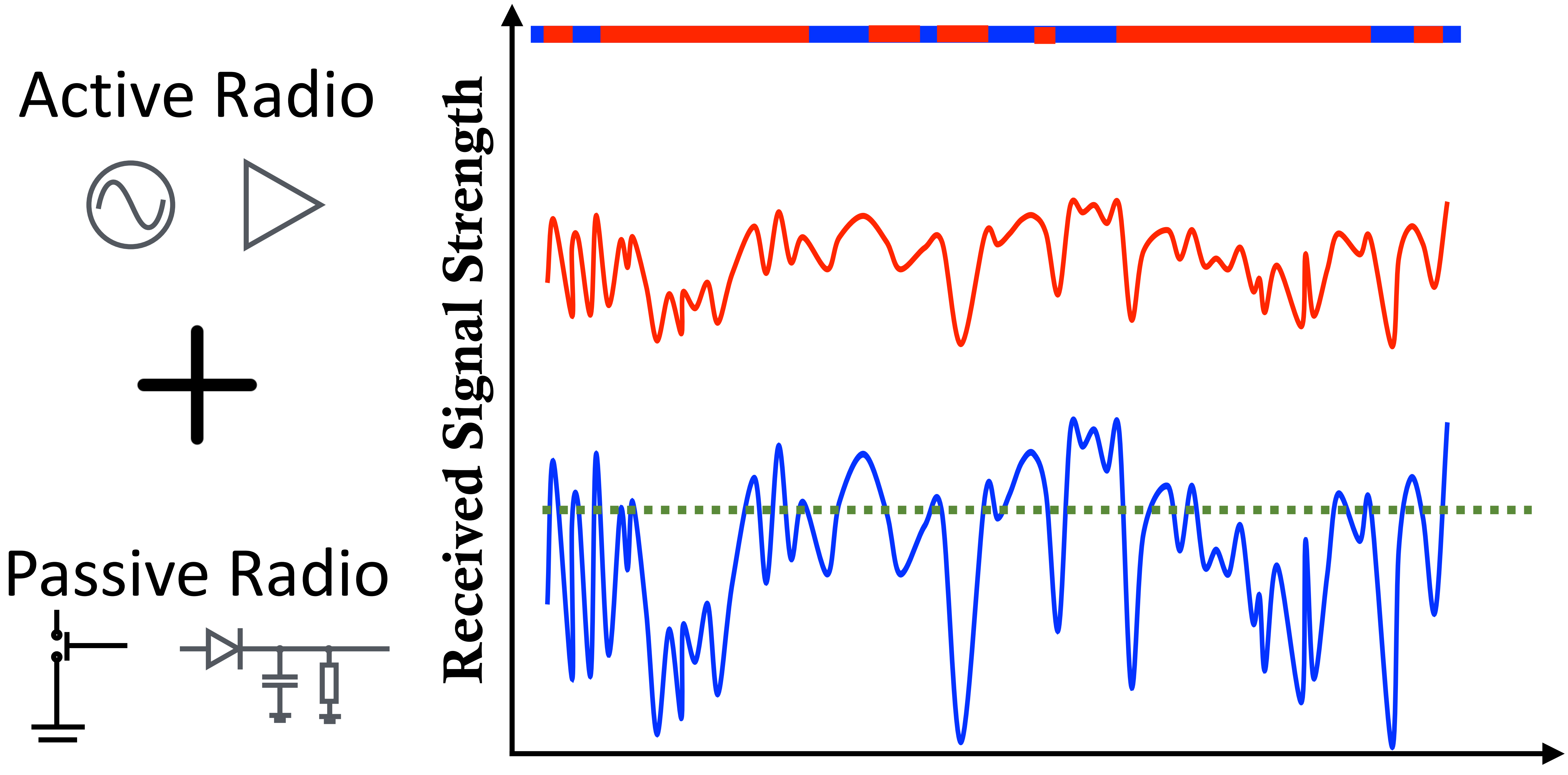

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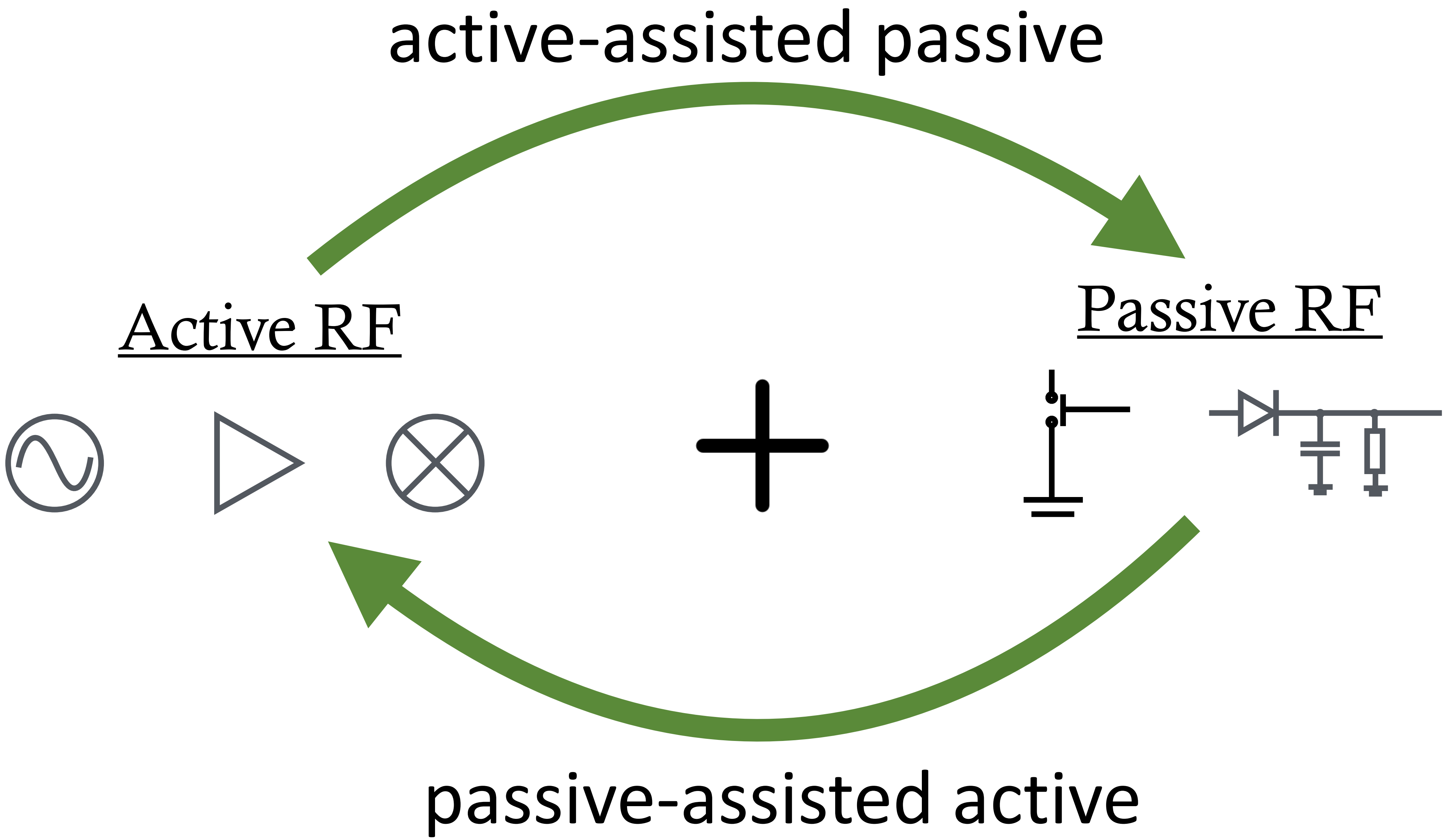
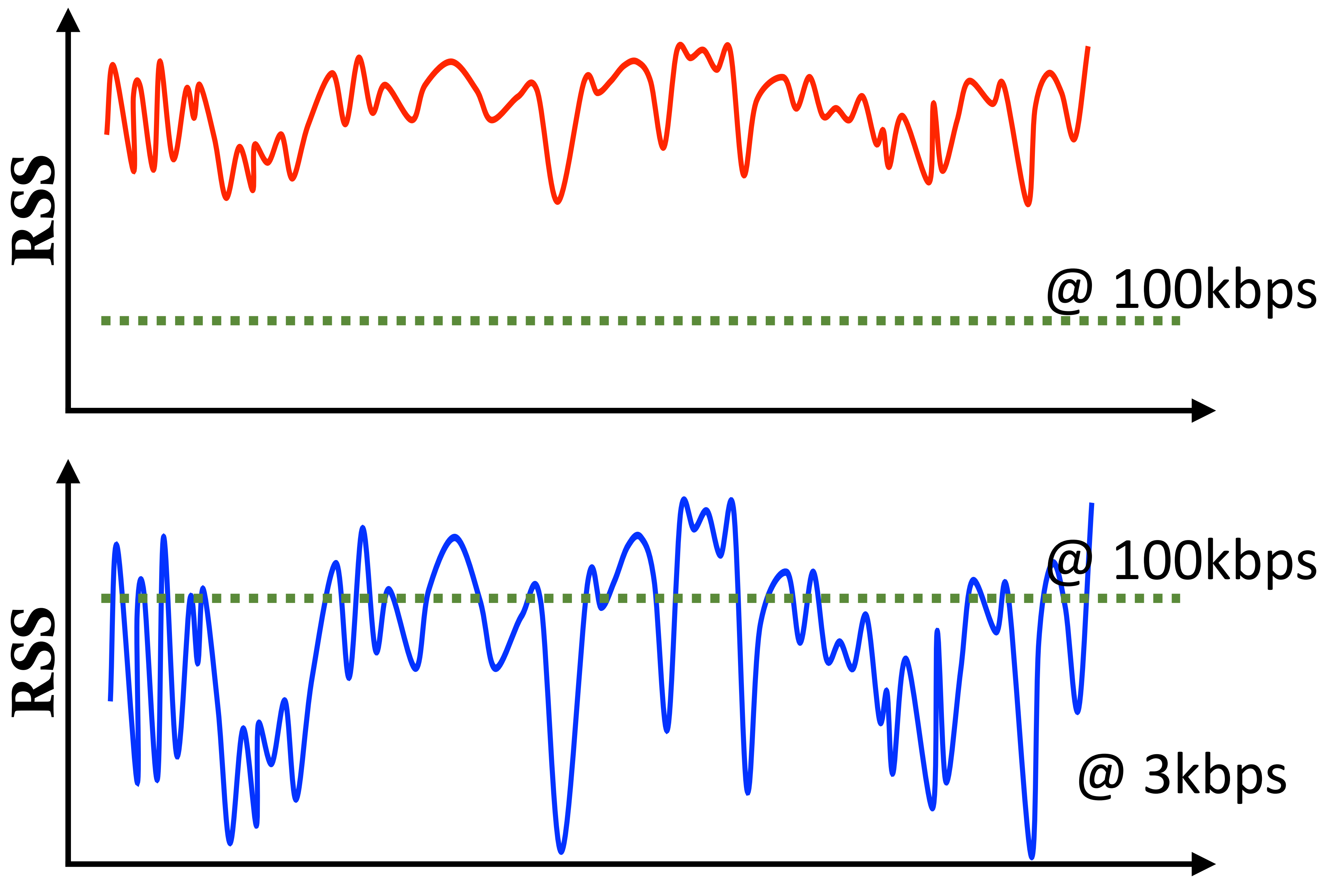


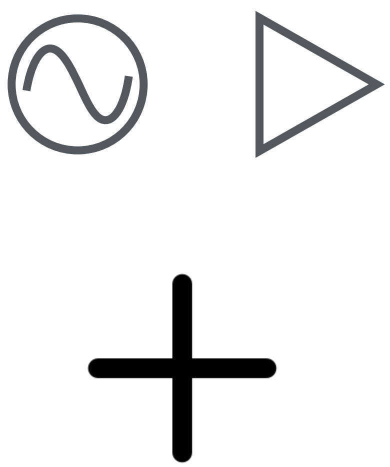
Mode 2: Backscatter-assisted Active



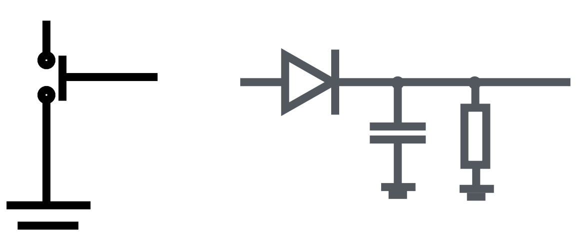
Rx sensitivity depends on energy-per-bit

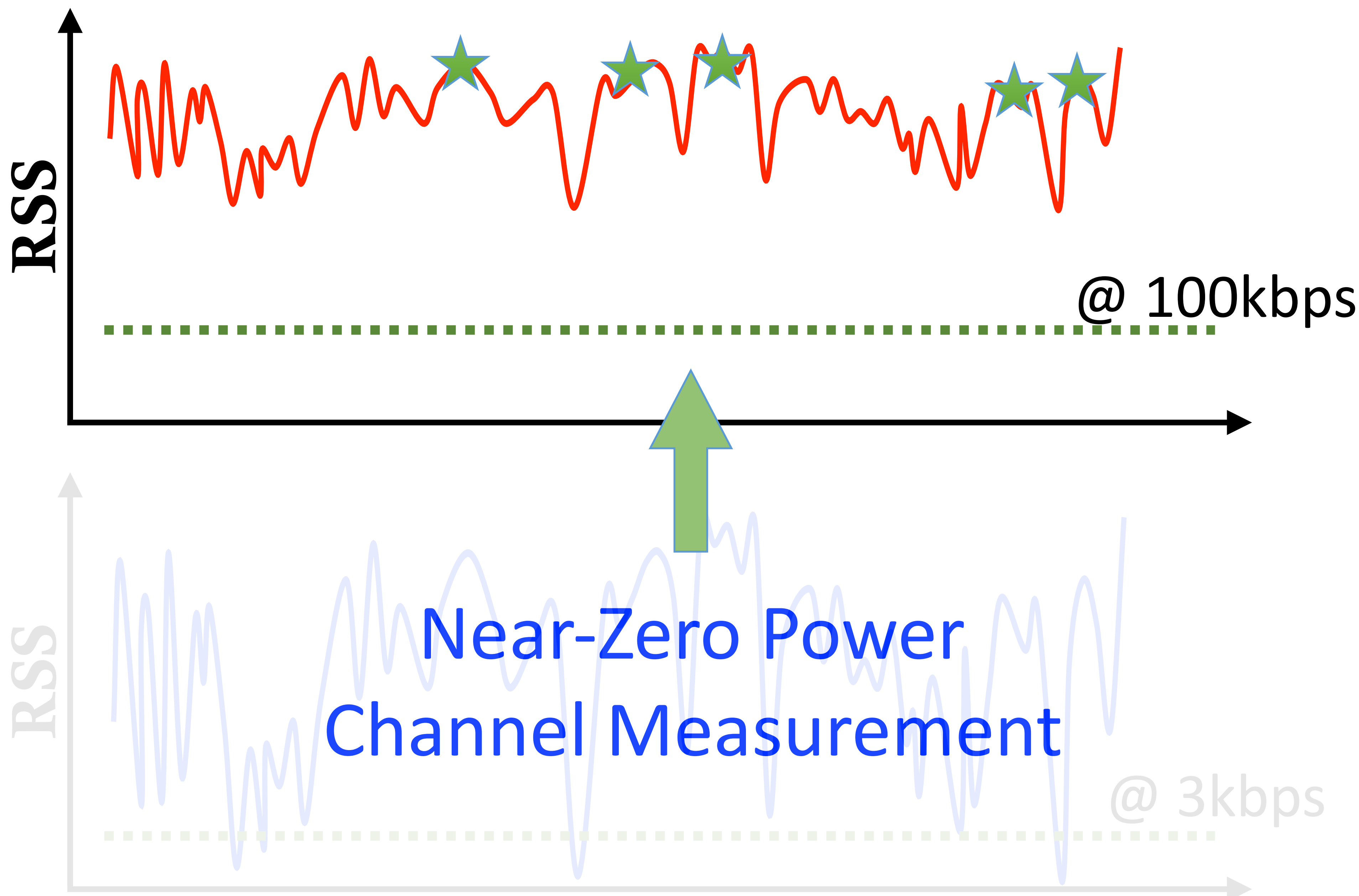
Mode 2: Backscatter-assisted Active

Active Radio



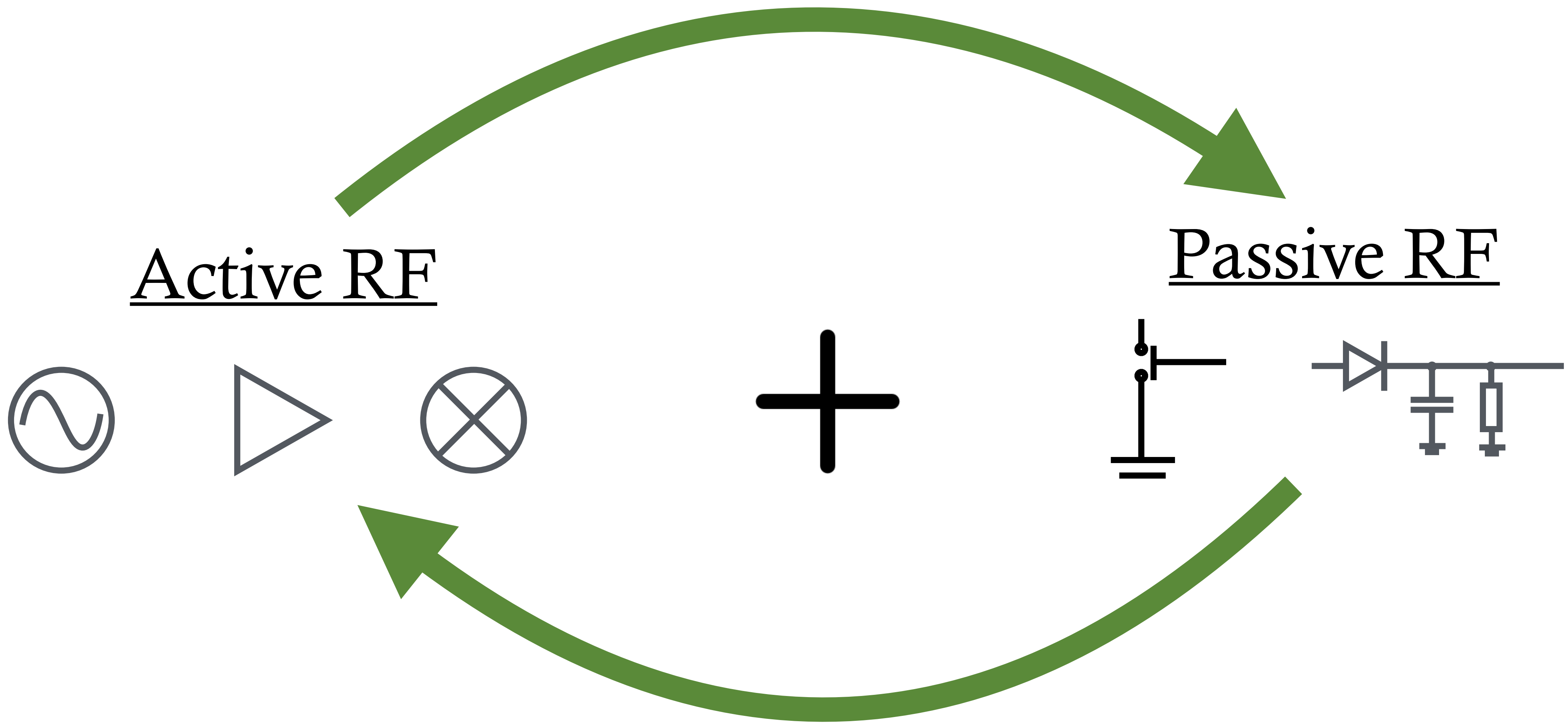
Passive Radio





Polymorphic radio in a nutshell

When passive works well, use active sparingly for reliability

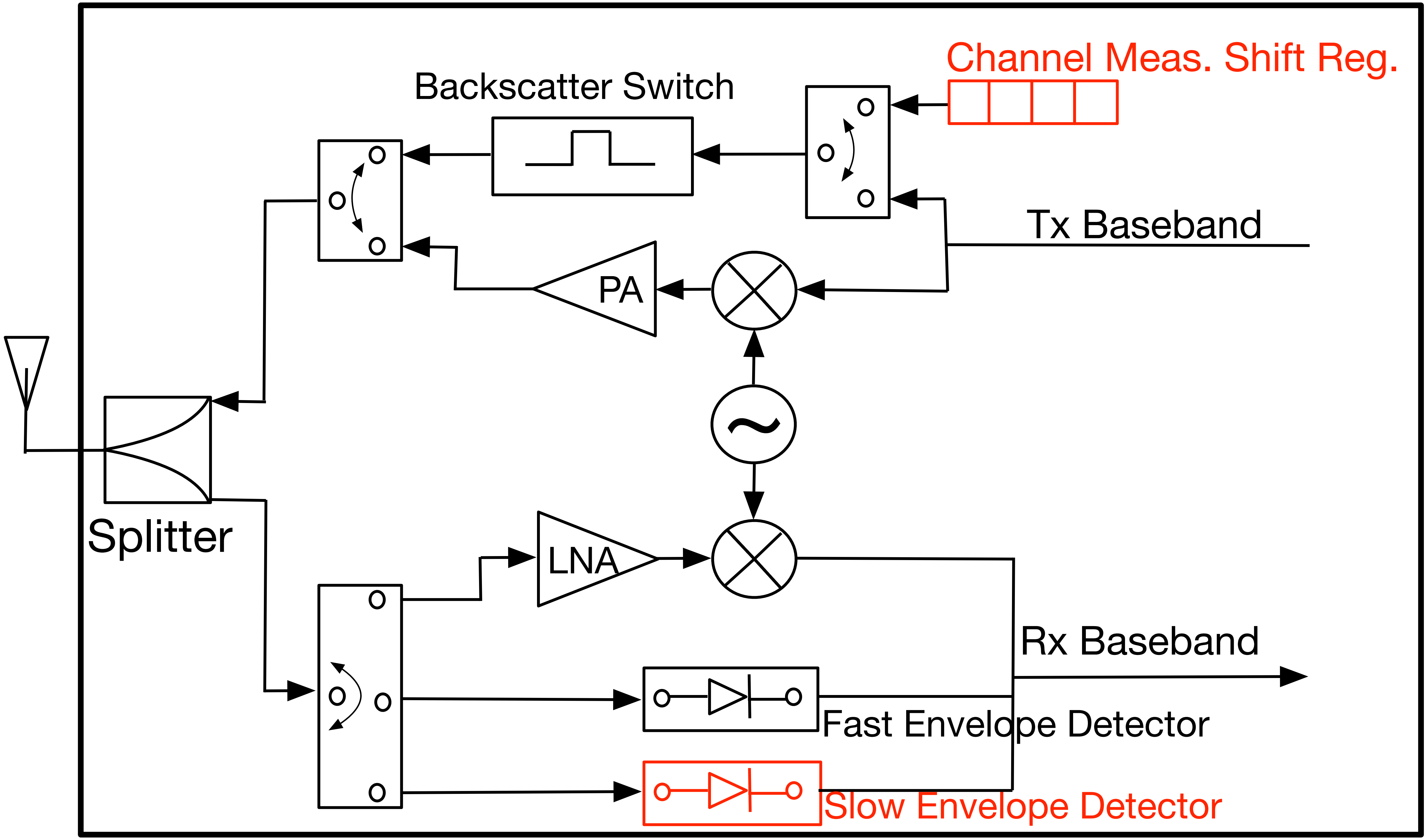


When passive works poorly, use to monitor channel and optimize active duty-cycling.

Roadmap: Network Stack

- Application → Streaming Video/Audio
- MAC → Radio Selection/Switching
- PHY → Polymorphic Radio HW

Hardware Overview



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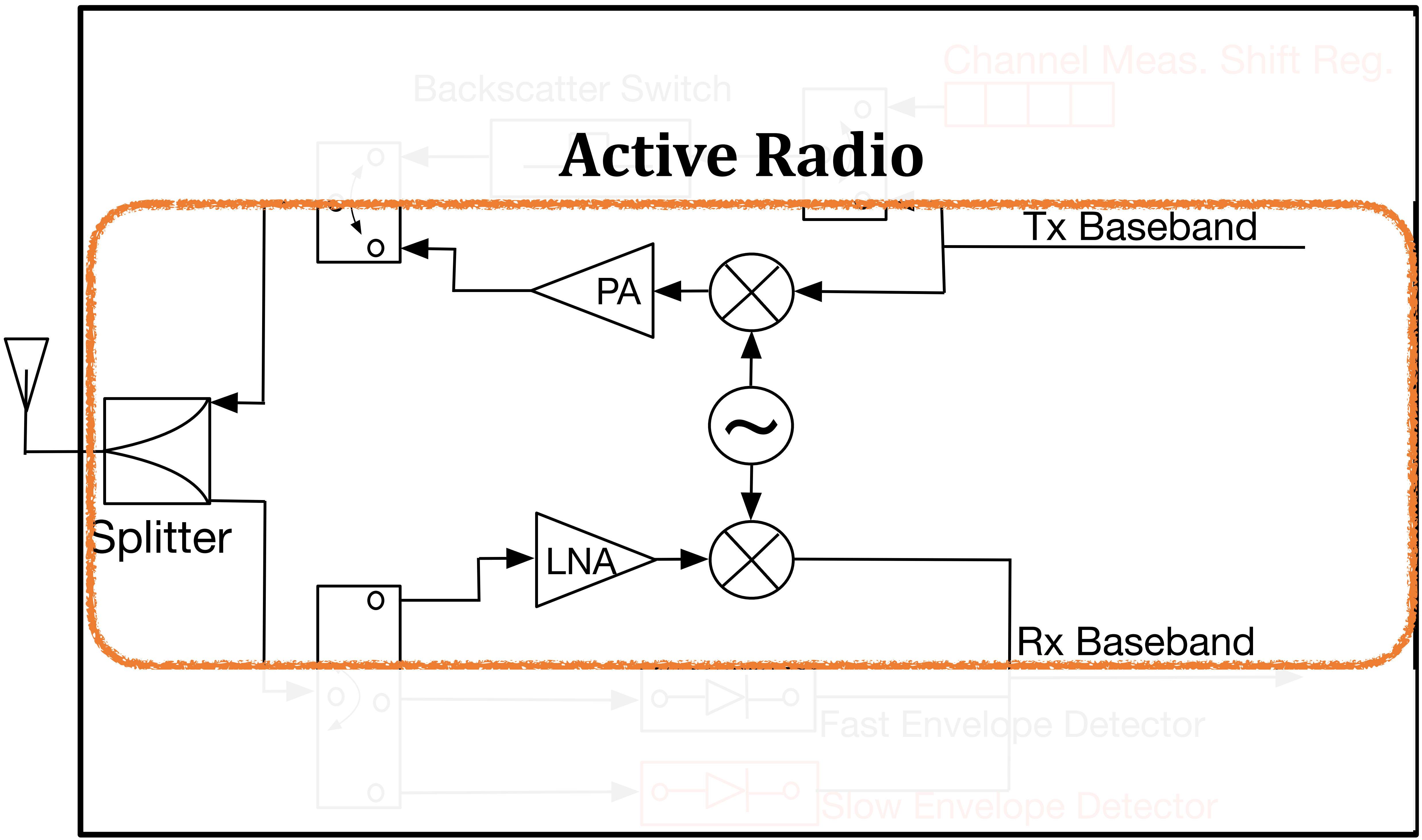

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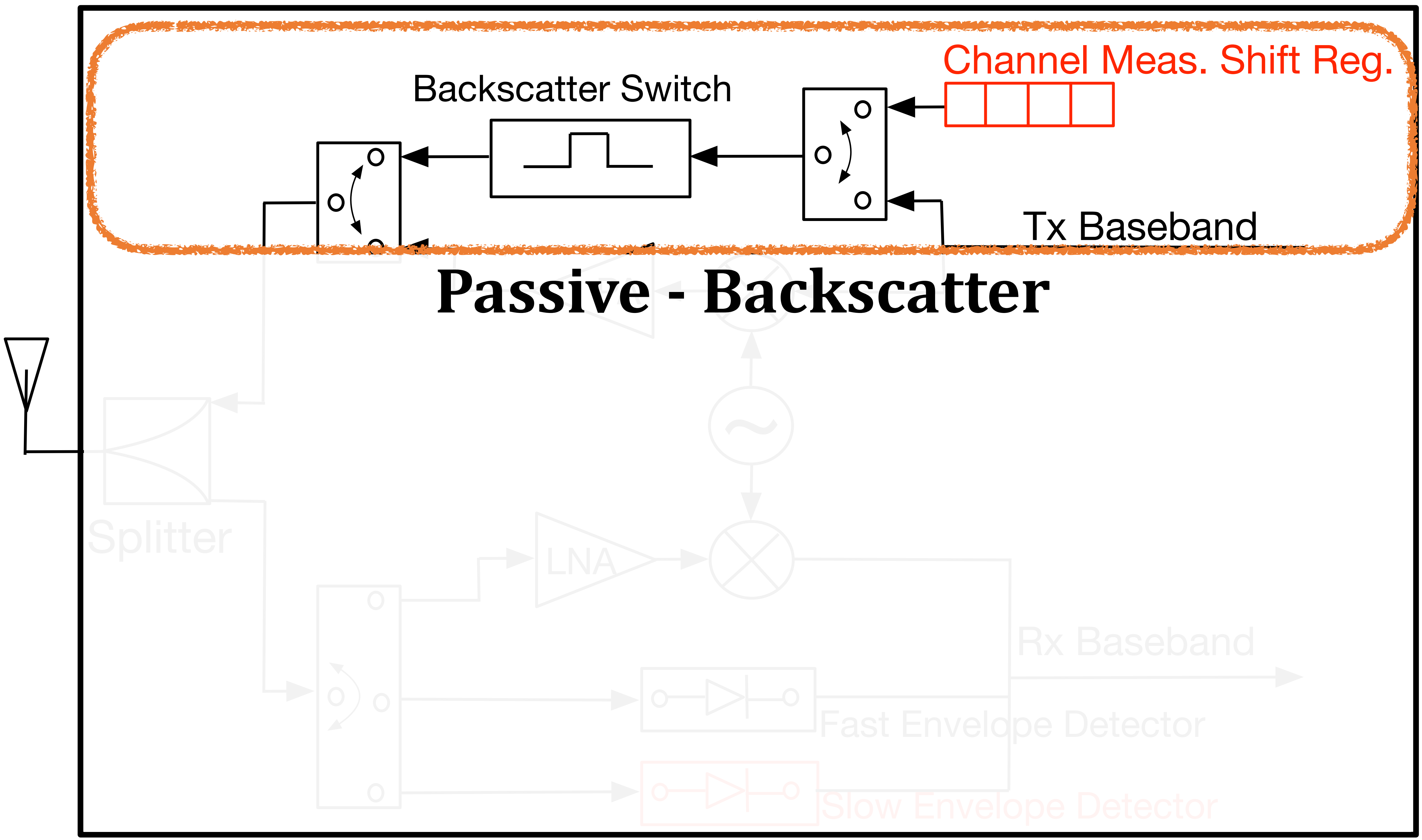

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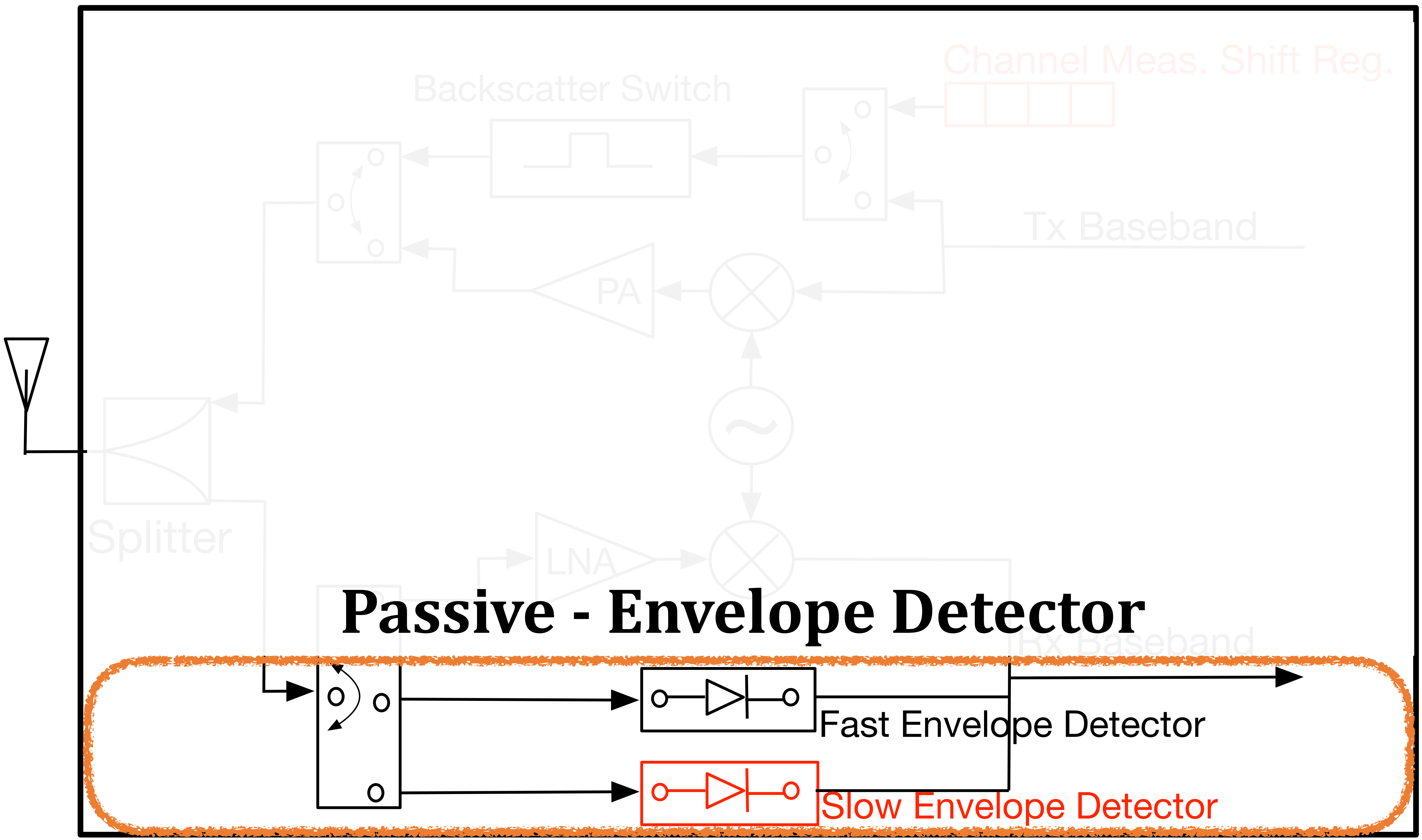
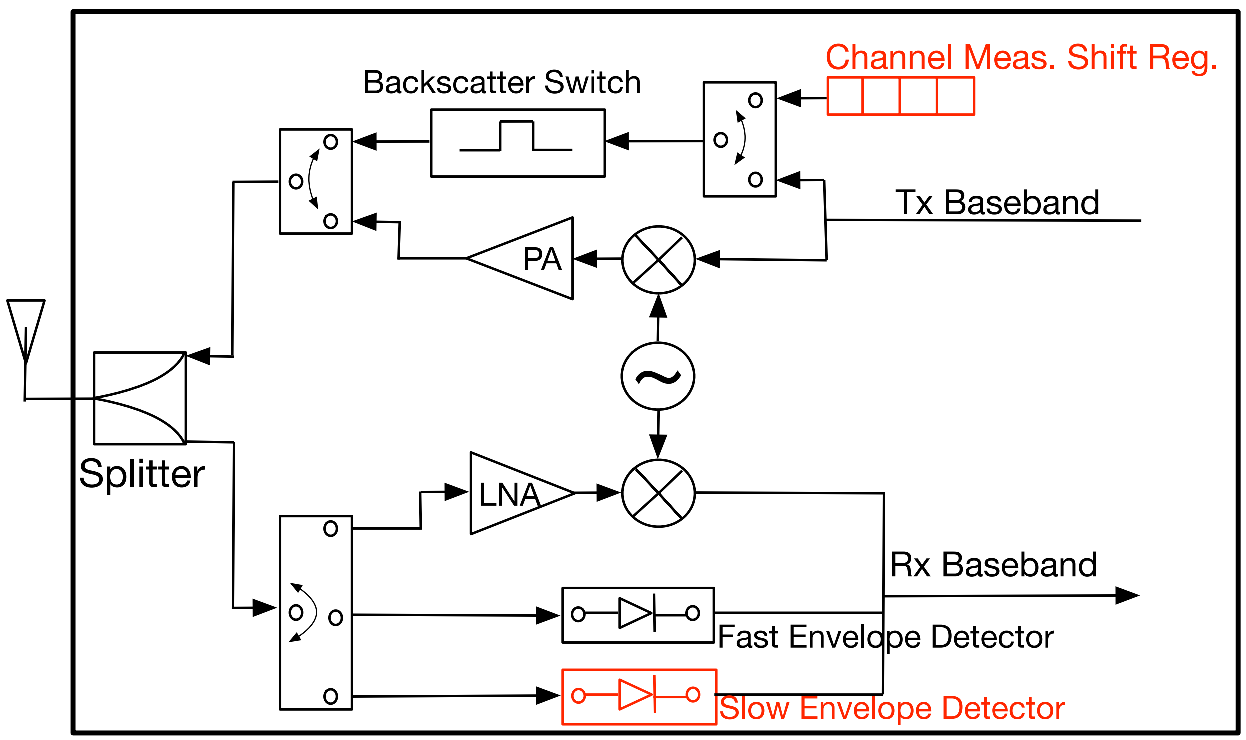
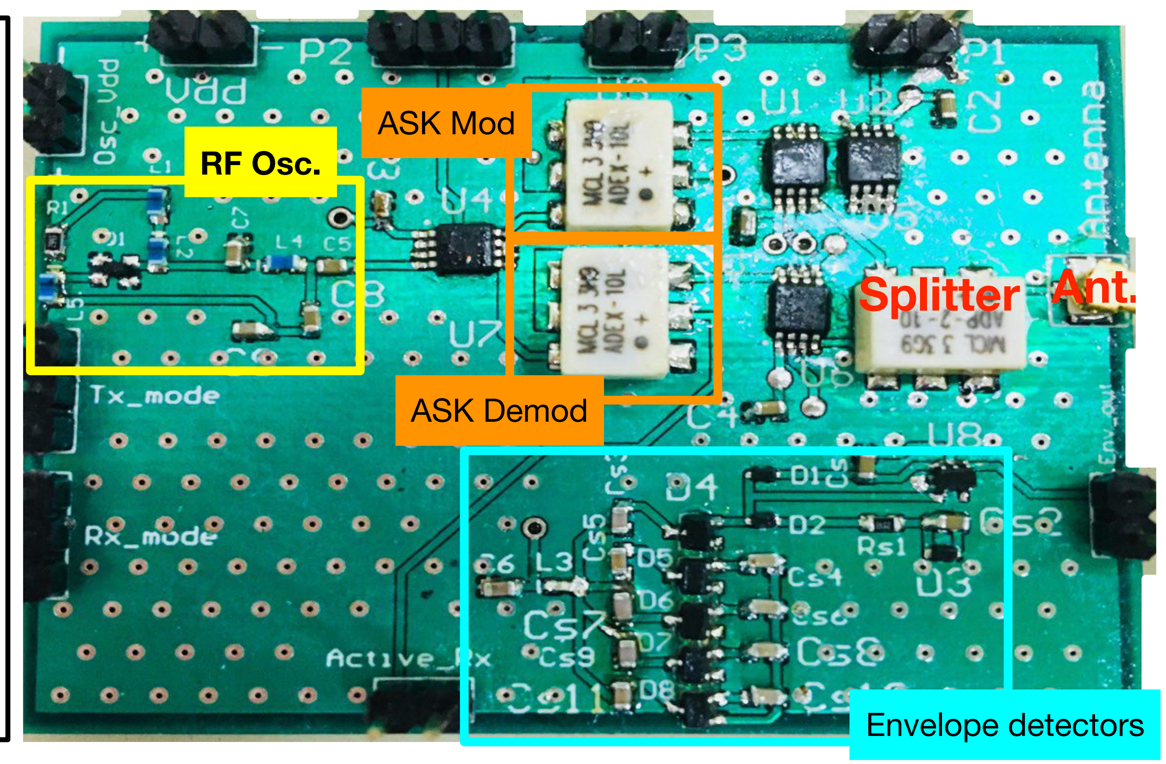


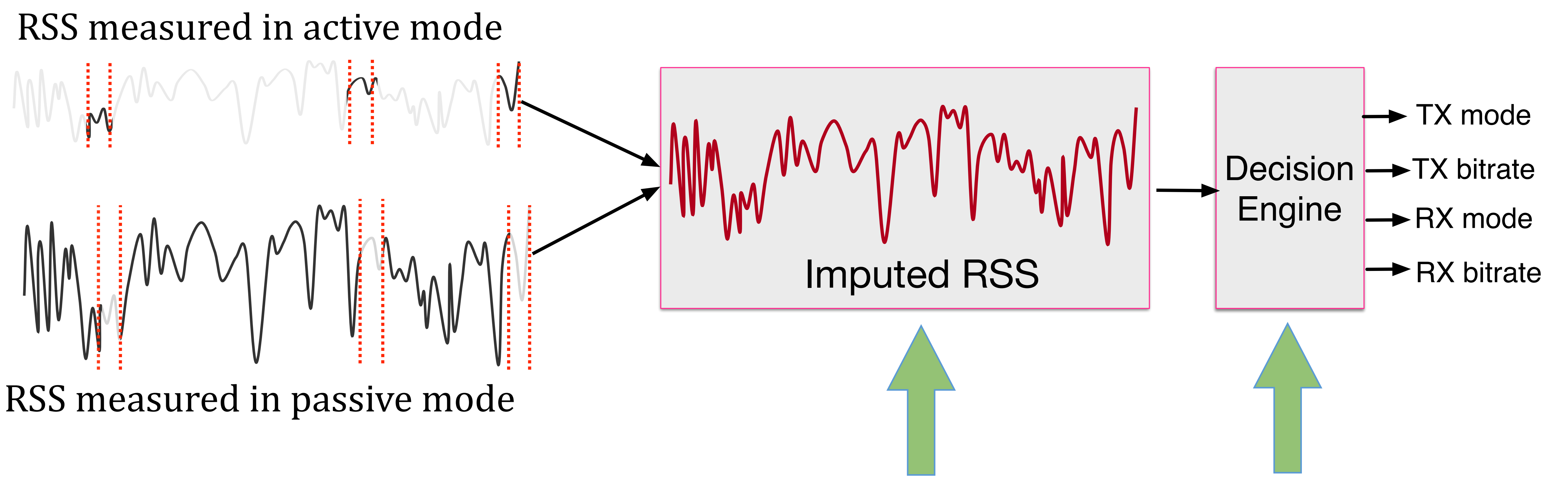
Hardware Benchmarks



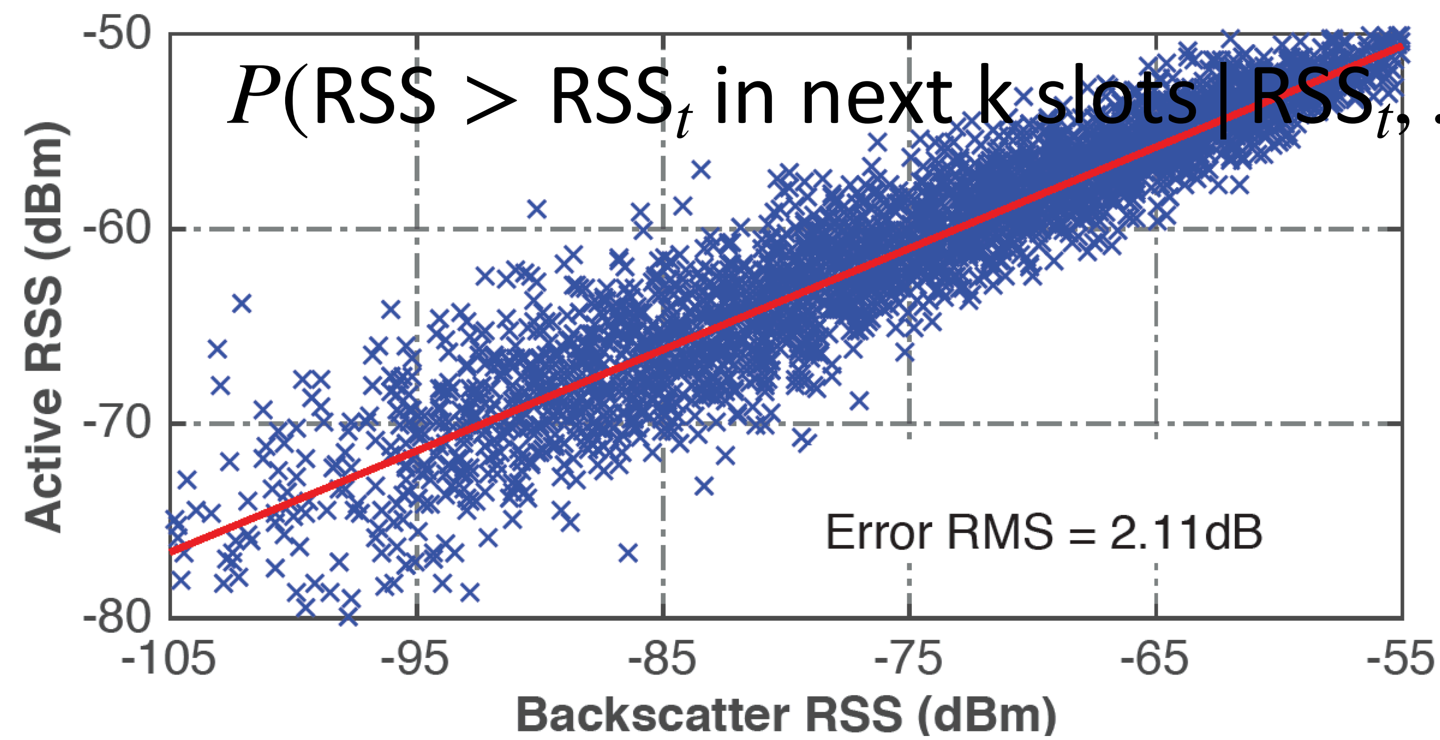


Mode Switching - Latency	30µs
Active Mode	5.2mW @ 1.1dBm, 900MHz
Backscatter Mode	10µW (measurement) 50µW (data)

MAC - Decision Engine

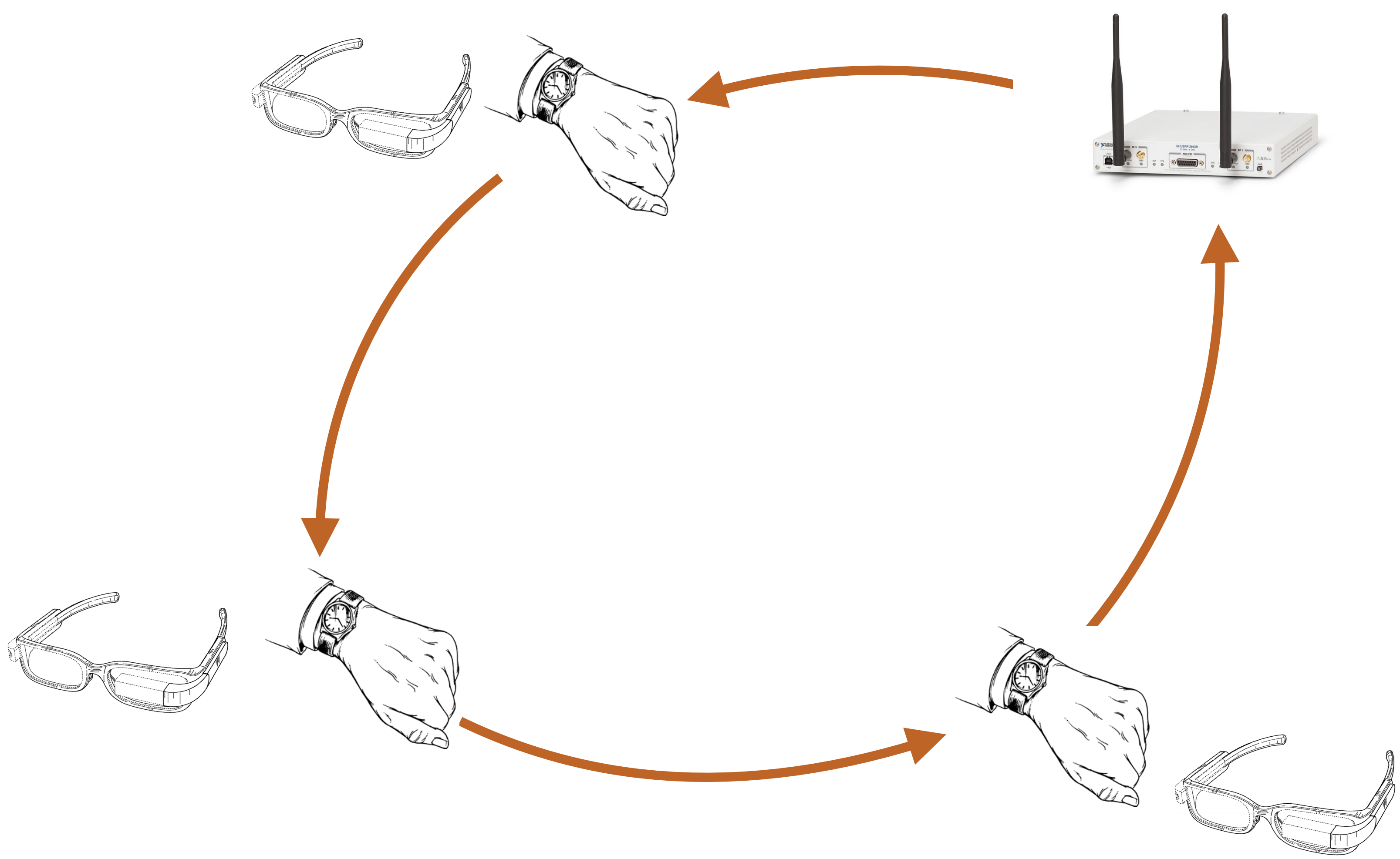


$$P(\text{RSS} > \text{RSS}_t \text{ in next k slots} \mid \text{RSS}_t, \ldots, \text{RSS}_{t-10})$$

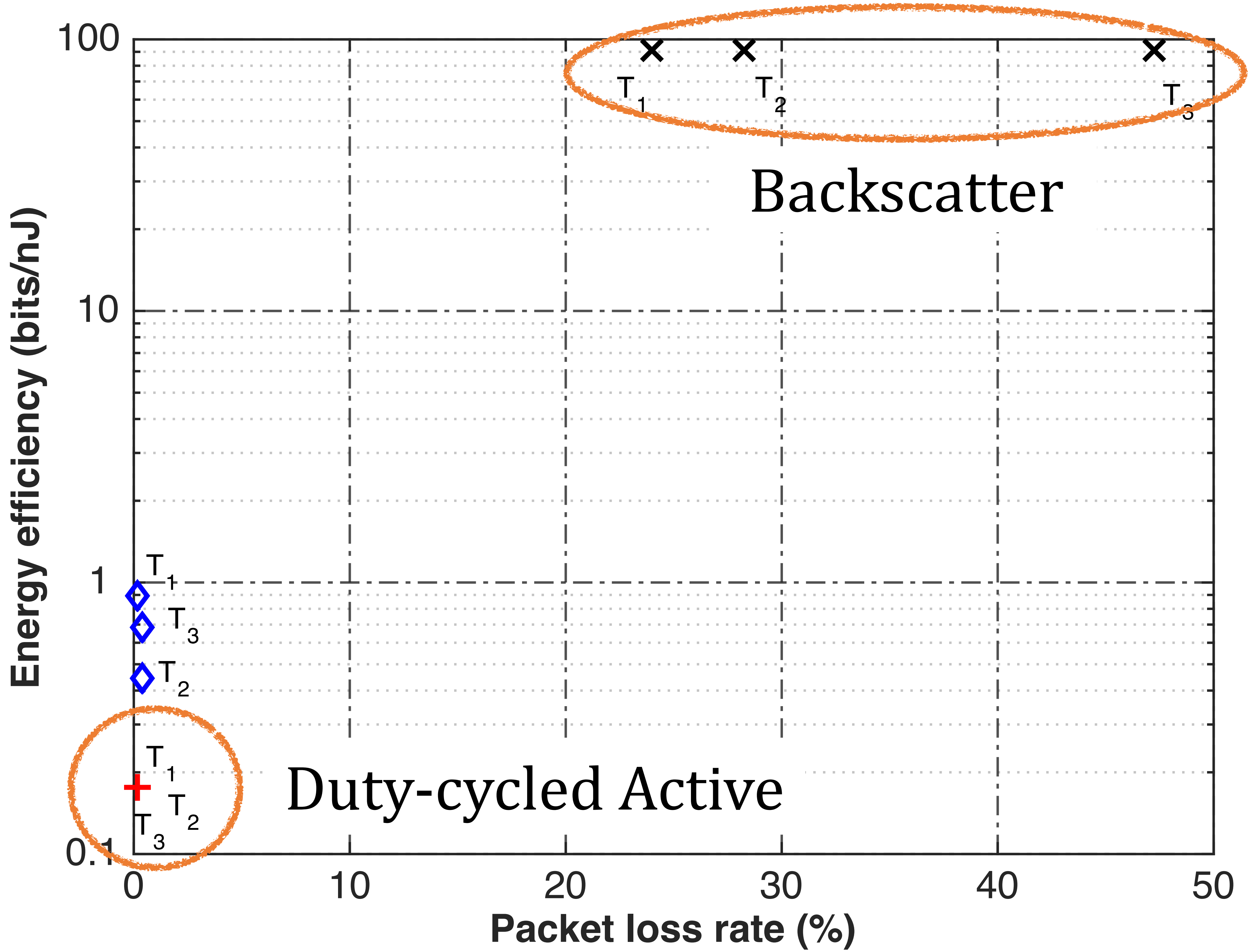


MAC Evaluation - Datasets

Wrist IMU	Streaming IMU data @ 100 samples/sec from a Smartwatch
Lapel Audio	Streaming audio @ 4kHz sampling rate from a Lapel accessory (dialog)
Eyeglass camera	Streaming video @ 30fps from low power camera on an eyeglass



Energy-efficiency vs. Reliability



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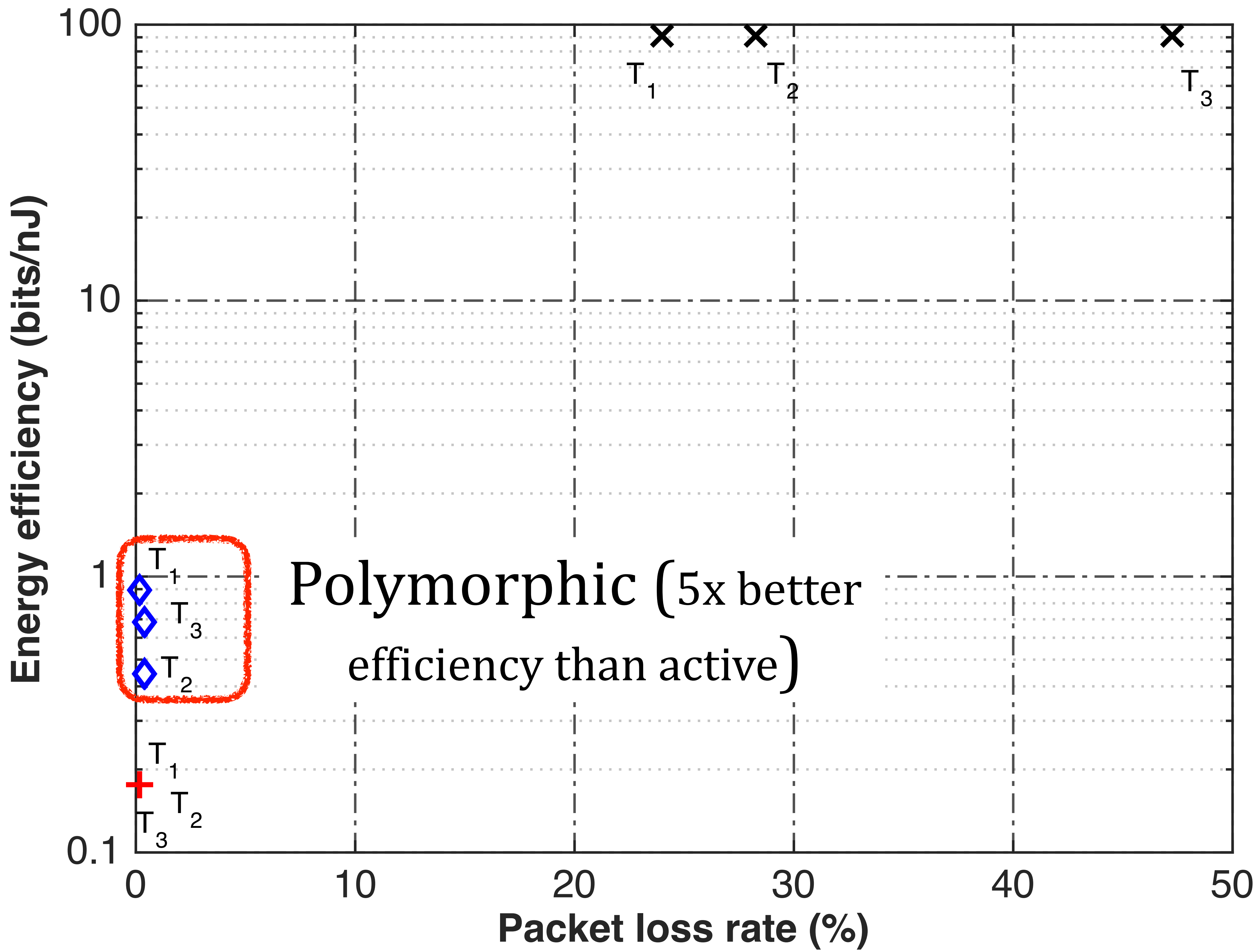
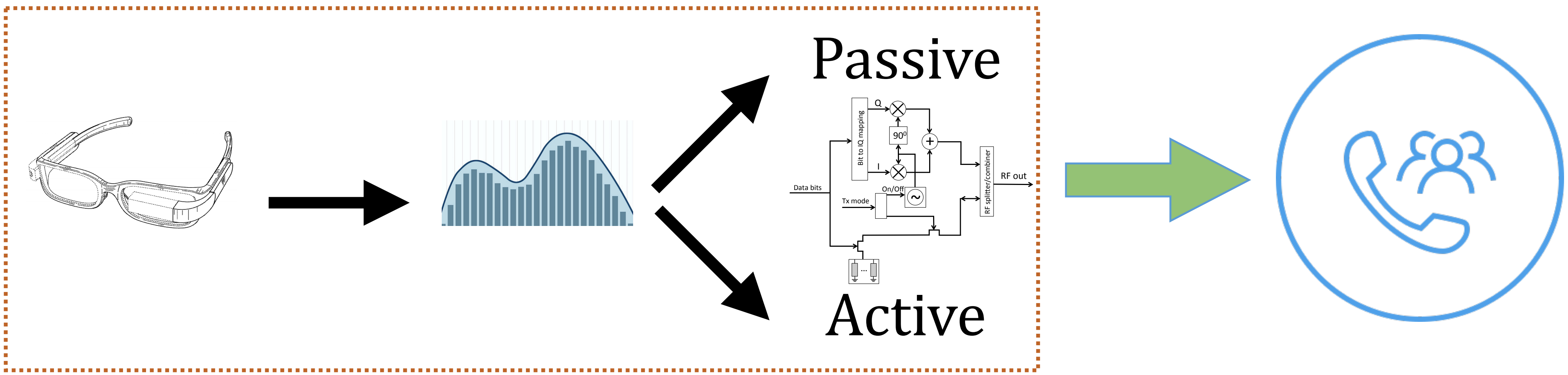
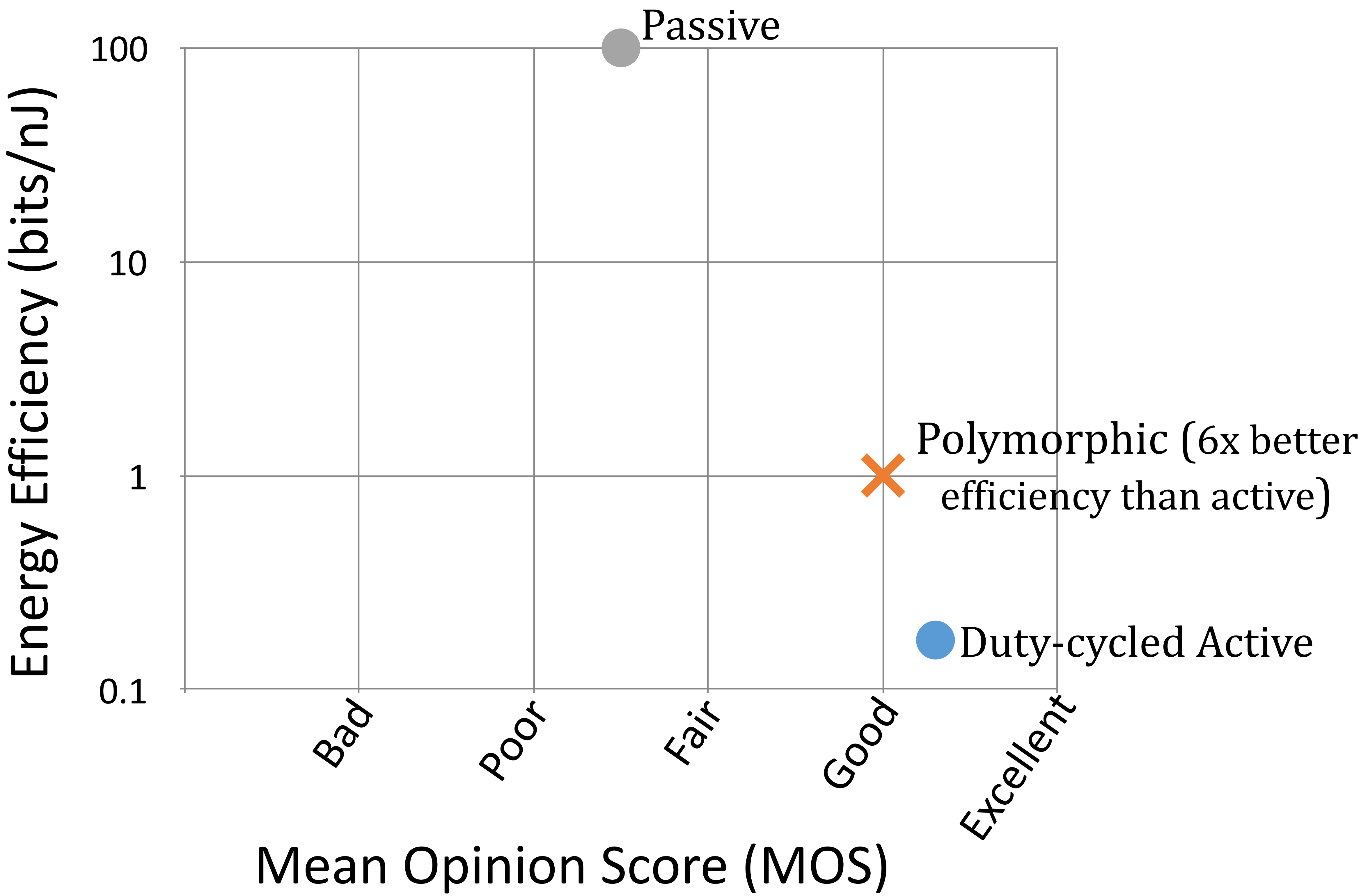


Application: Audio Streaming

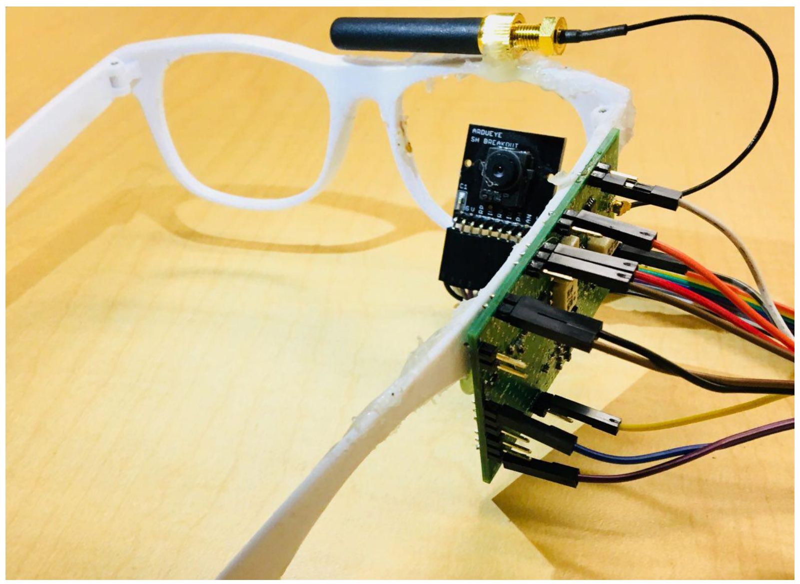


Goal: Demonstrate low-power yet high quality audio streaming using a polymorphic radio

Application: Audio Streaming

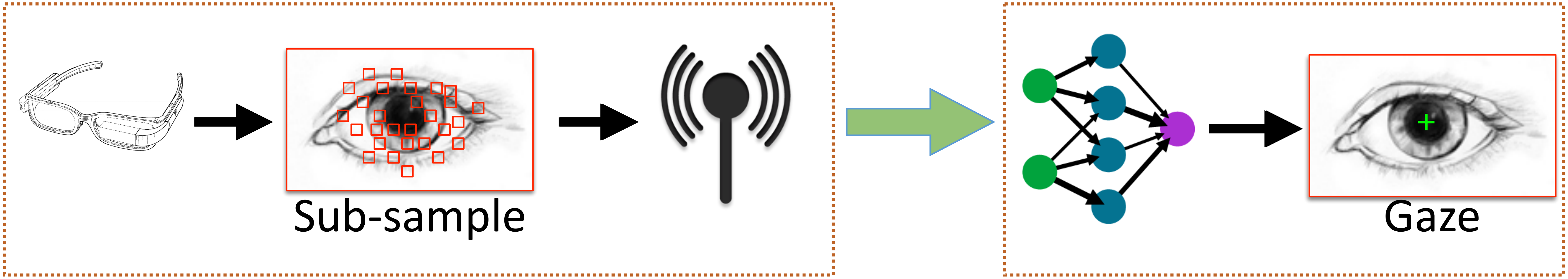


Application: Video Streaming



Goal: Demonstrate tradeoff between sensing cost and communication cost using a polymorphic radio

Application: Video Streaming



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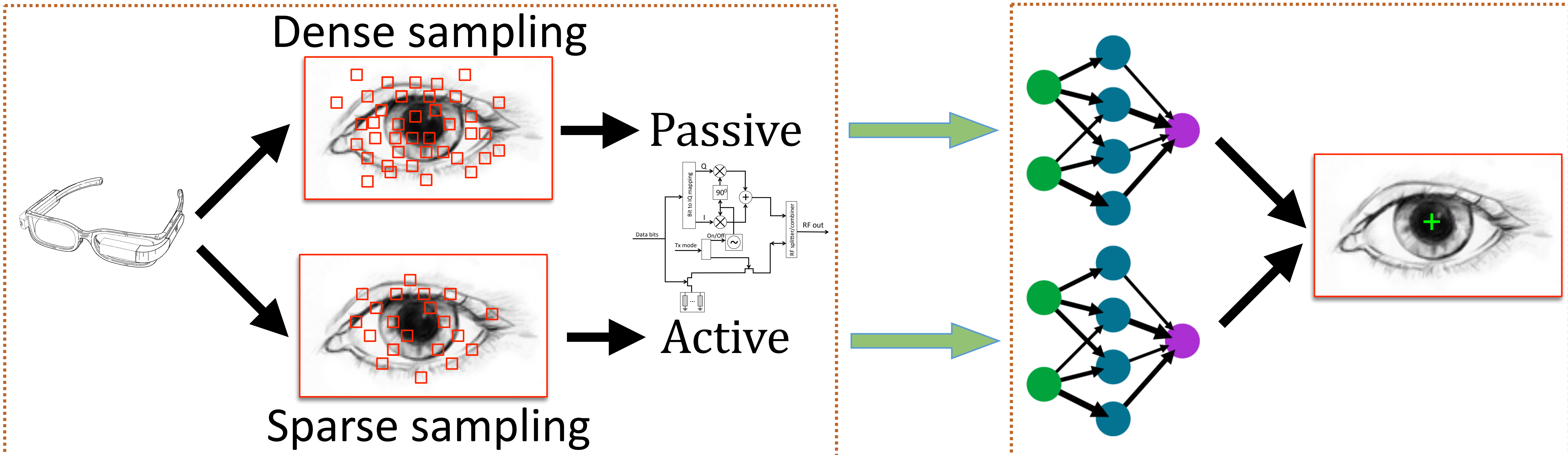
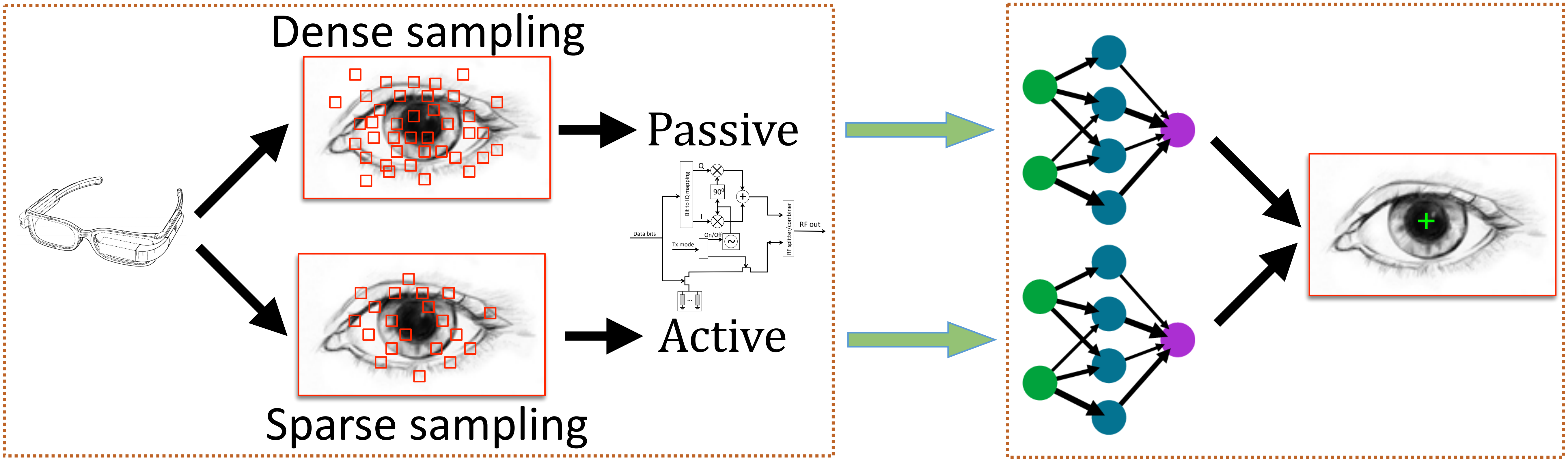
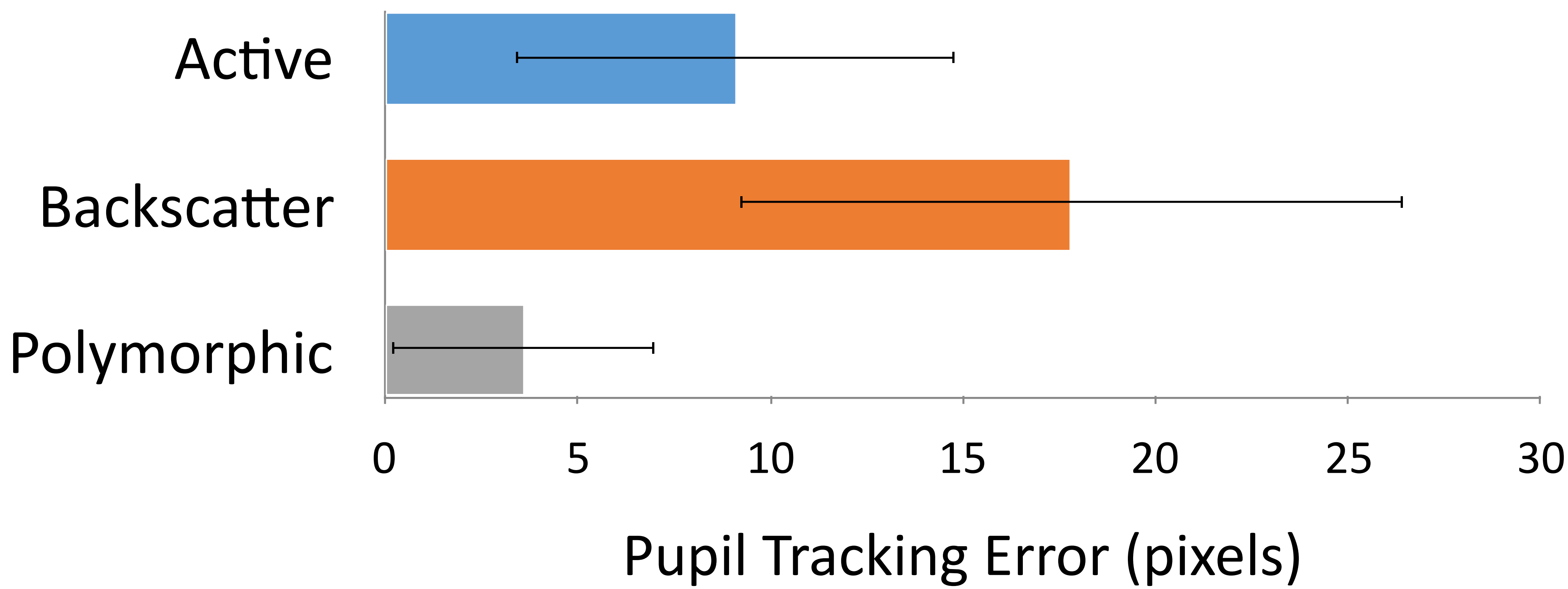


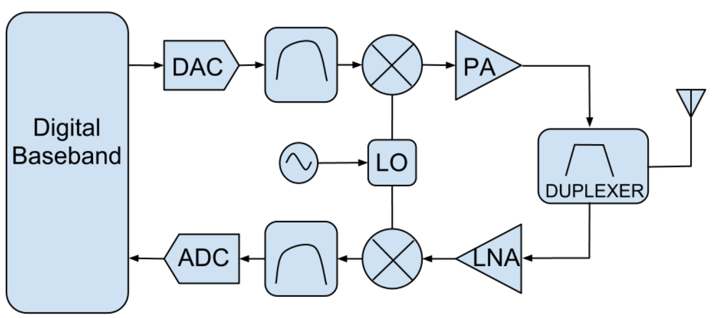
Passive radio has low cost, hence more energy is available for sampling, and vice-versa for active radio

Application: Video Streaming



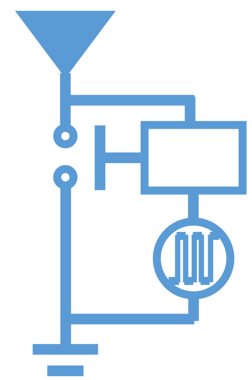


Conclusions

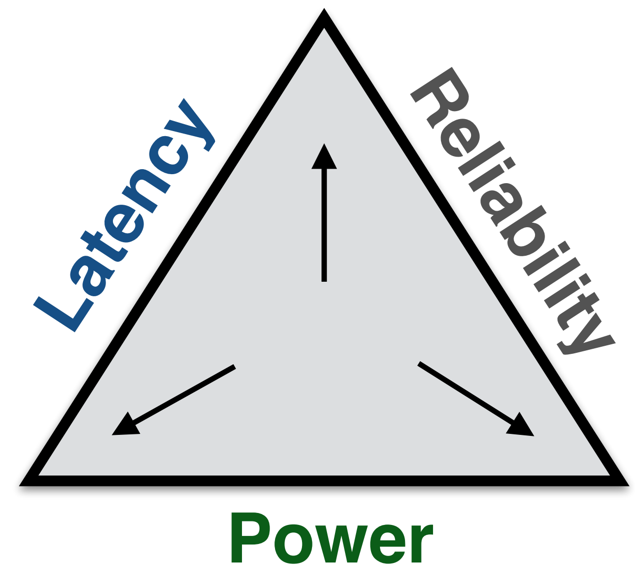


Active radio

+



Backscatter radio



Combining active and passive architectures allows us to design low-power streaming radios.