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Time for Change: How Clocks Break UWB Secure Ranging

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Why Secure Ranging matters

Passive Keyless Entry And Start (PKES)

Contactless Payments

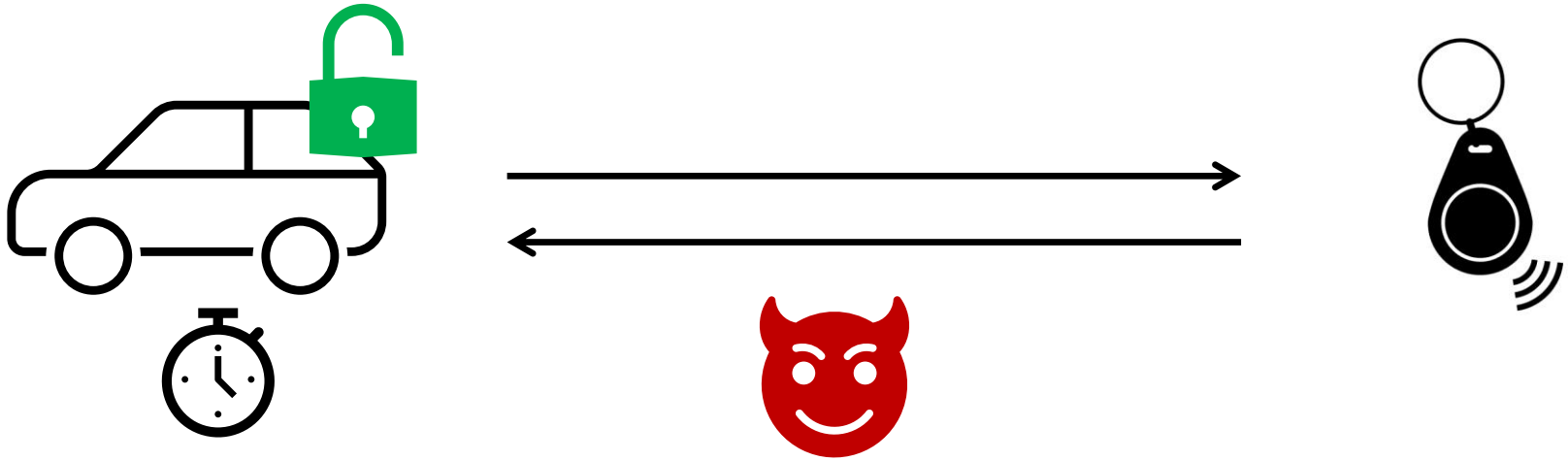
Generic Access Control

Attacks on the physical layer: distance reduction and distance enlargement

- Distance reductions to bypass authorization or access control
- Distance enlargements out of scope

Using UWB for Secure Ranging

UWB's bandwidth allows to measure the time of flight (ToF) of a signal precisely:



- High sensitivity to clock errors: $1\,ns \Rightarrow 30cm$
- Threat model: wireless channel under attacker control

Our Contribution

We identify device clocks as a new attack vector.

Mix-Down:

- Affects the current (and future?) UWB standard
- Targets the Single-Sided Two-Way Ranging (SS-TWR) mode

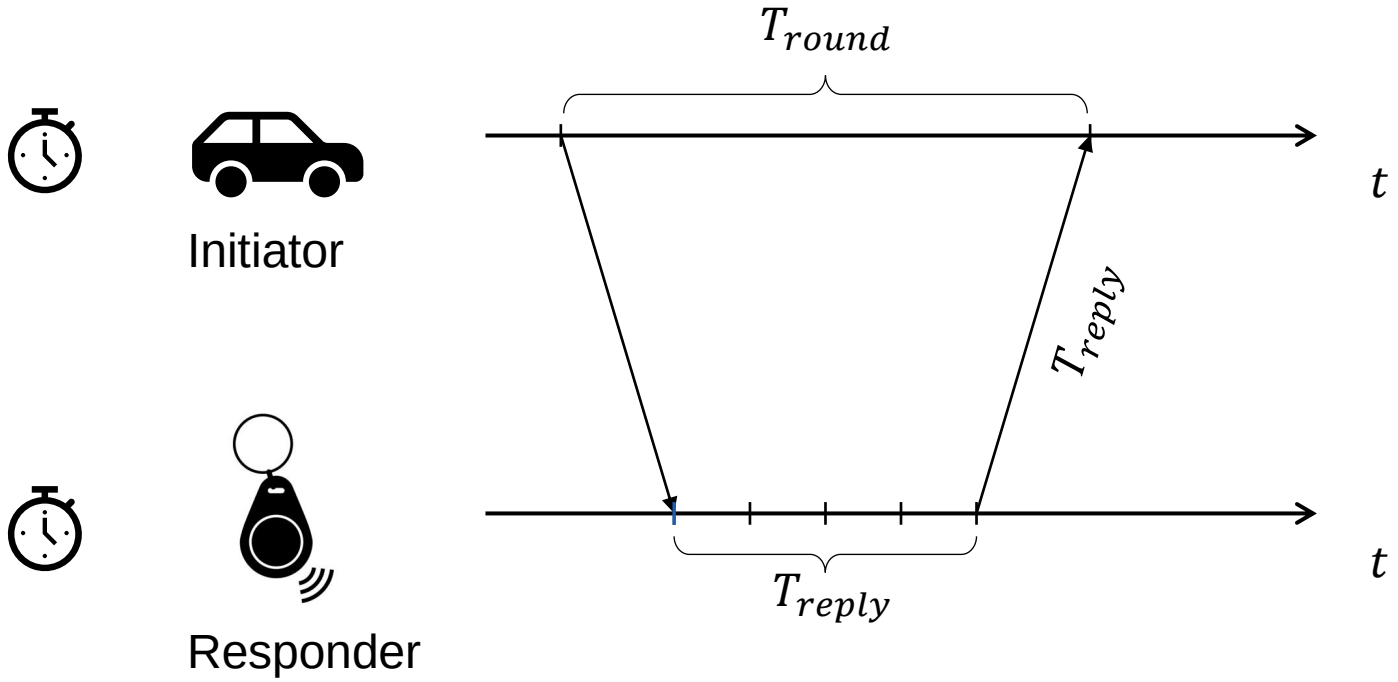
→ *We analyze and demonstrate the attack against off-the-shelf UWB chips*

Stretch-and-Advance:

- Affects the future UWB standard (IEEE 802.15.4ab)
- Attack is conceptual, vulnerable hardware does not exist (yet)

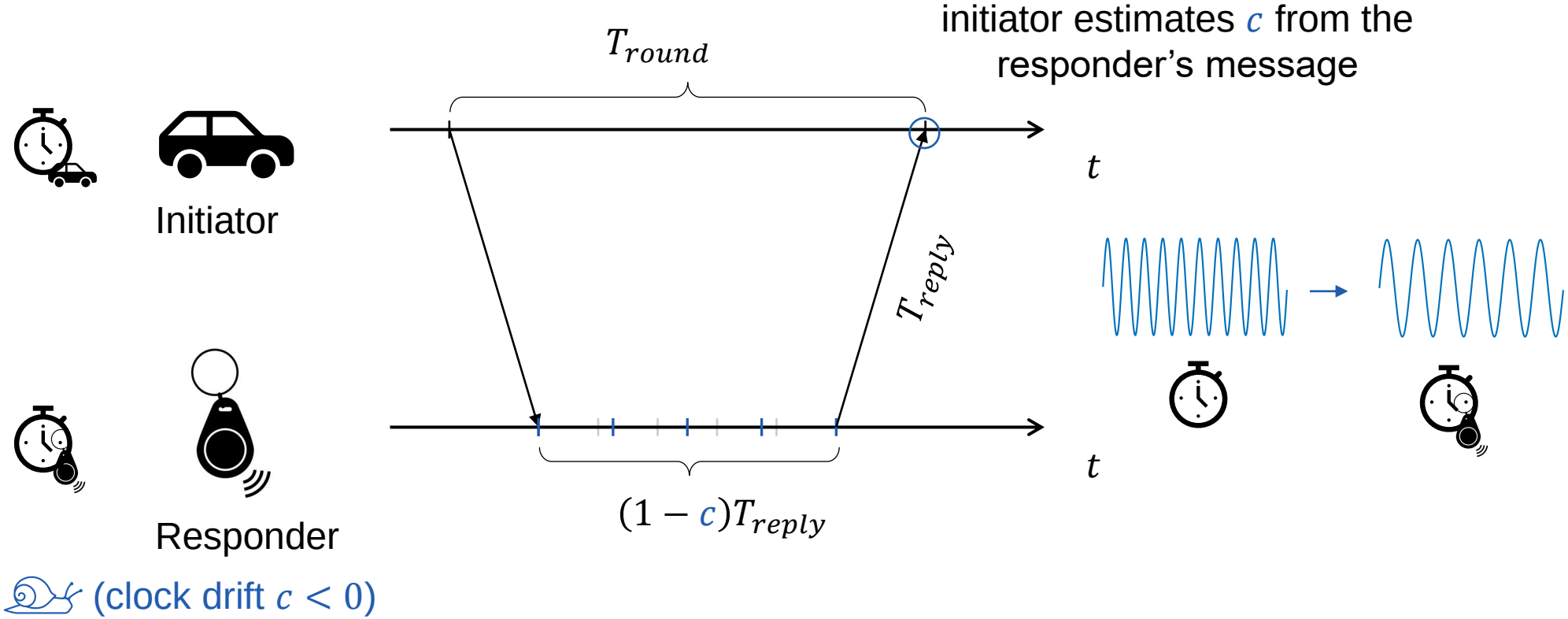
→ *We provide an extensive analysis of the attack and propose a countermeasure*

Single-Sided Two-Way Ranging in 802.15.4z



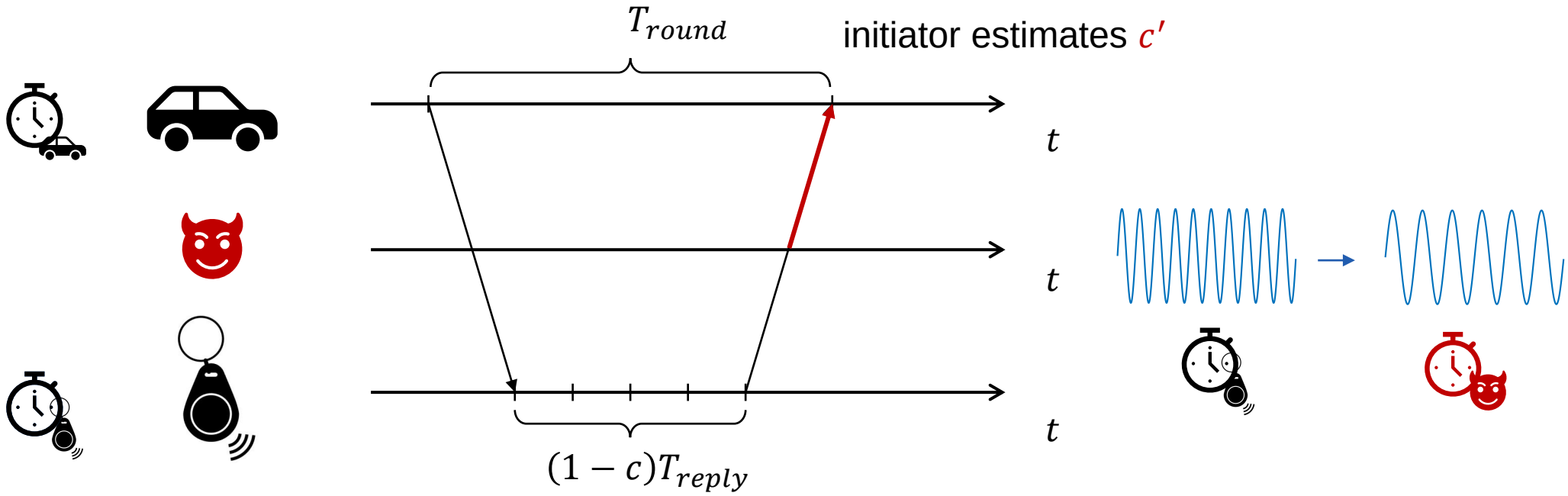
$$T_{ToF} = \frac{1}{2}\left(T_{round} - T_{reply}\right)$$

Single-Sided Two-Way Ranging in 802.15.4z



$$T_{ToF} = \frac{1}{2}\left(T_{round} - (1 - c)T_{reply}\right)$$

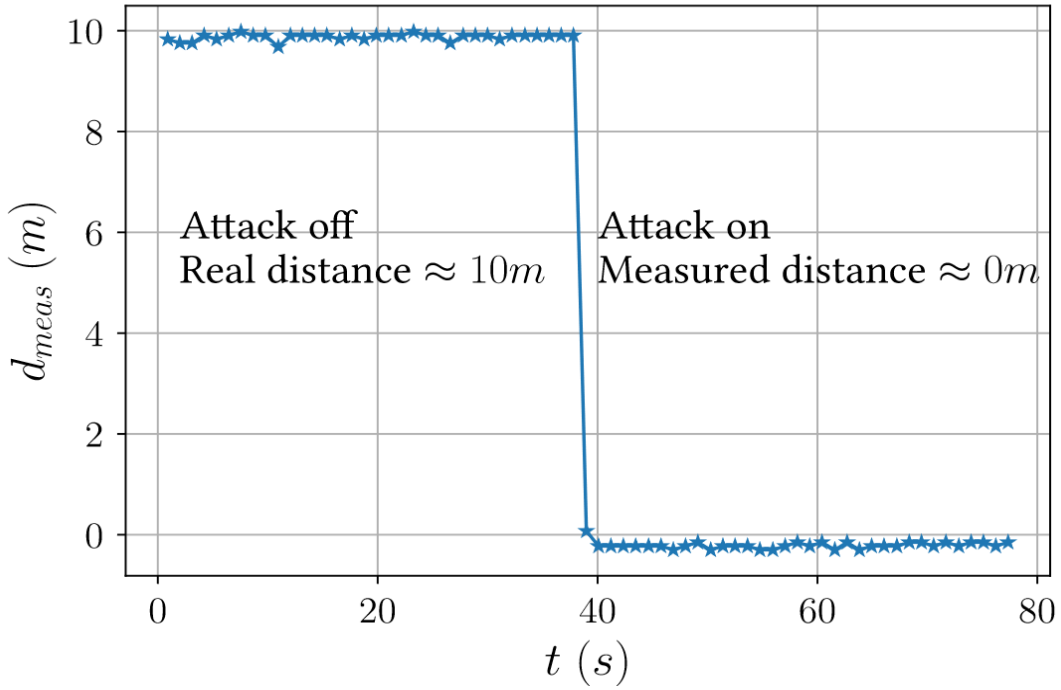
The Mix-Down Attack



$$T_{ToF} = \frac{1}{2}\left(T_{round} - (1-c)T_{reply}\right)$$

Results
(Figure 4)

We conducted the attack against two off-the-shelf UWB chips (Qorvo DWM3000EVB):



- Attack results in immediate, reliable distance reductions.
- Reductions can be controlled by gradually changing the clock drift.

Summary Mix-Down

Impact: Mix-Down only affects Single-Sided Two-Way Ranging (SS-TWR).

- Most (security-sensitive) applications use Double-Sided Two-Way Ranging.
- But: The upcoming standard IEEE 802.15.4ab seems to use SS-TWR as a default.

Countermeasures: No silver bullet in sight.

- The carrier frequency cannot be cryptographically protected
- Clocks drift naturally, e.g., due to changes in temperature
- Exchanging clock drift estimations? attacker can manipulate clock speeds in both directions

Alternative: Double-Sided Two-Way Ranging (but beware of Stretch-and-Advance!)

Takeaway

Mix-Down:

- Exploiting the clock drift compensation in SS-TWR
- Message content *not* changed
- Success rate: up to 100%
- Reductions depend on UWB chip's response time (e.g. $2ms \Rightarrow 12m$)
- No straightforward countermeasure

Stretch-and-Advance:

- Conceptual attack against the upcoming standard
- Affects SS-TWR and DS-TWR
- Reductions in the order of $100m$
- Analysis and countermeasure discussed in the paper

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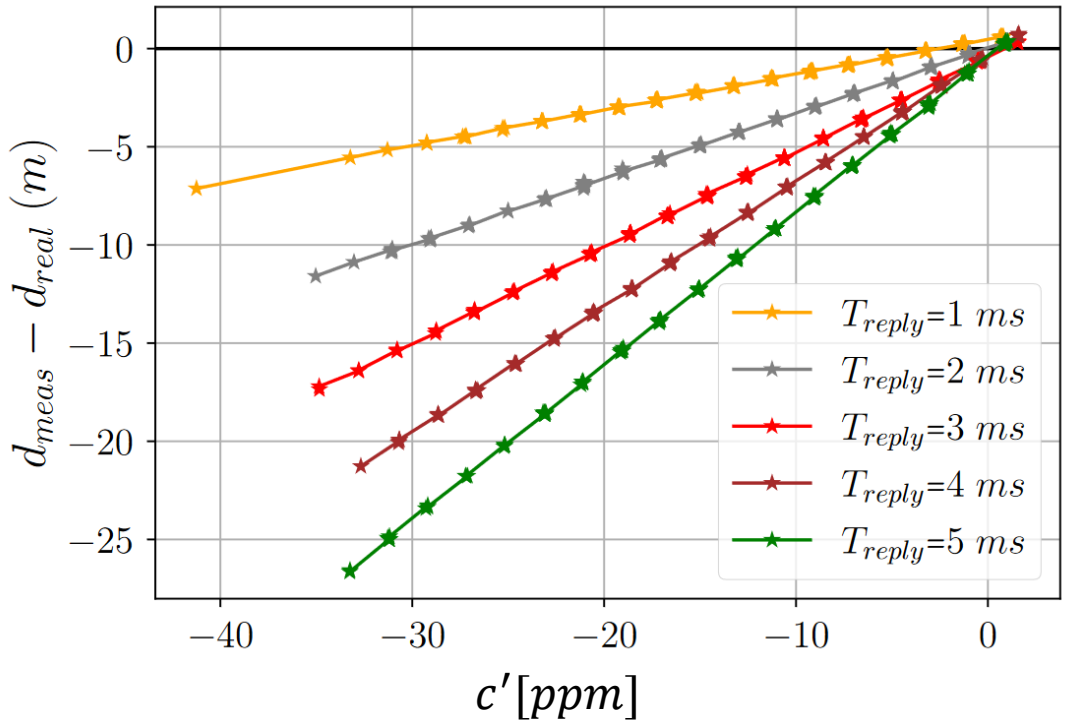
APPENDIX

Image sources:

- BMW Keyfob: https://www.autox.com/quattroruote/bmw-ix-ev-road-test-110419/
- Keyfob icon: https://www.istockphoto.com/de/vektor/nfc-schl%C3%BCsselanh%C3%A4nger-silhouettensymbol-gm1352049152-427589349?phrase=key+fob+icon
- Contactless payments: https://n26.com/en-eu/contactless-card
- Access control: https://cie-group.com/how-to-av/videos-and-blogs/bluetooth-ble-access-control
- Chip icon: https://www.flaticon.com/free-icon/chip_2818291

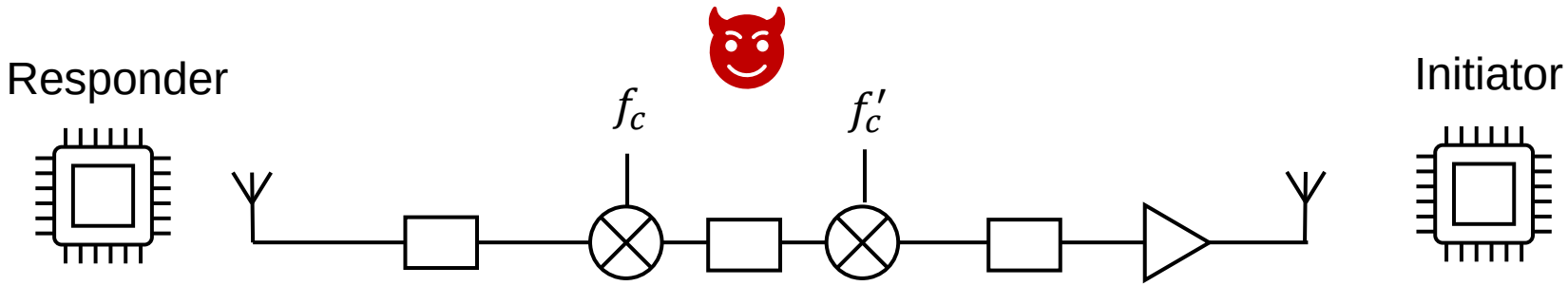
Results
(Figure 5, simplified)

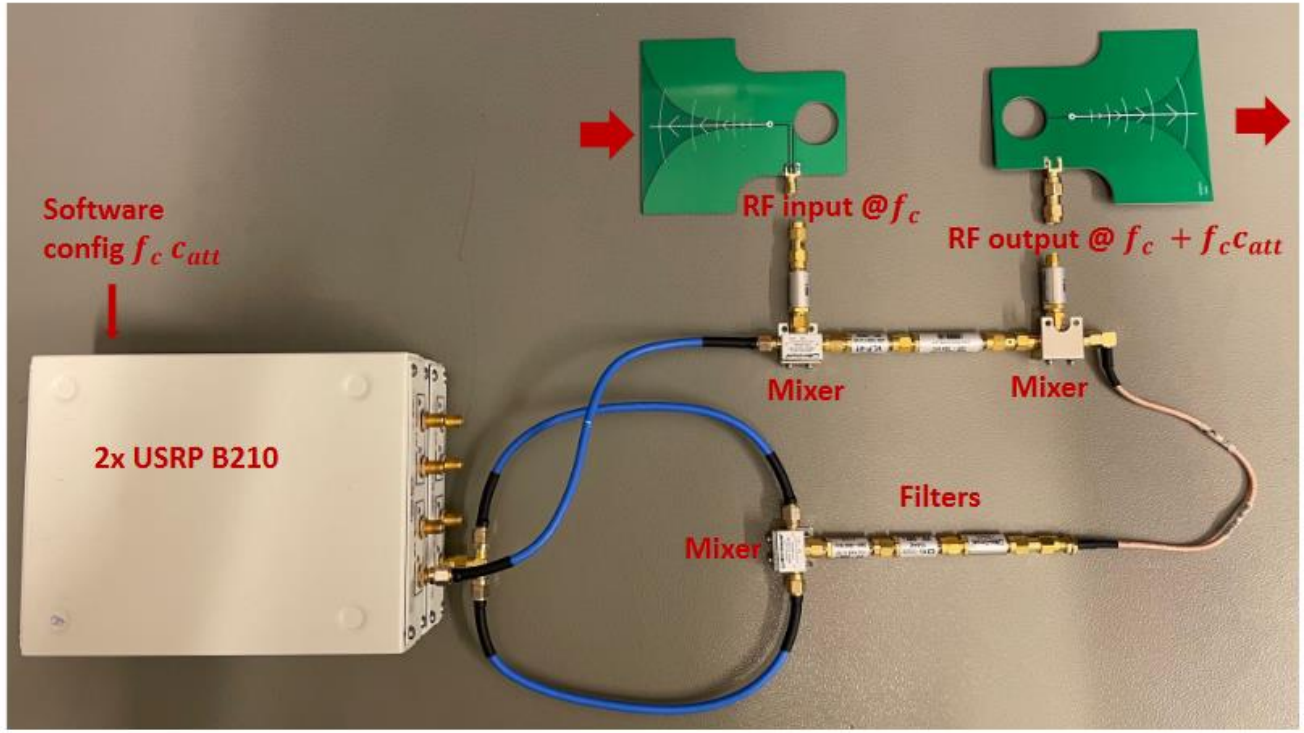


The distance reductions depend linearly on

- the clock drift c' caused by the attacker and
- the reply/processing time of the responder.

Setup


Responder
f_c
f_c'
Initiator


Software config f_c c_{att}
RF input @ f_c
RF output @ $f_c + f_c c_{att}$
Mixer
Mixer
2x USRP B210
Filters
Mixer

A Glimpse into Stretch-and-Advance

The upcoming UWB standard IEEE 802.15.4ab introduces Multi-Millisecond Ranging

- Length of ranging frames changes from $\approx 100\mu s$ to dozens of ms.
- Successful reception of such frames requires compensation of clock errors
- With specialized hardware, an attacker could
  - *stretch* the genuine ranging message in time and
  - *advance* parts of it (send it earlier)
- Exploitability and reduction limits depend on implementation
- These effects are negligible in 802.15.4z because the messages are too short.