Terrorist Fraud resistant nanosecond-scale Distance Bounding

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Terrorist fraud resilient distance Bounding with Analog components

Work in progress.

Joint work with
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Outline

- Types of relay attack
- Distance bounding
  - Swiss Knife
- Analog hardware
  - challenge reflection
  - channel selection
  - limitations
- New scheme
  - modified analog circuit
  - adapted Swiss Knife

Why distance bounding?

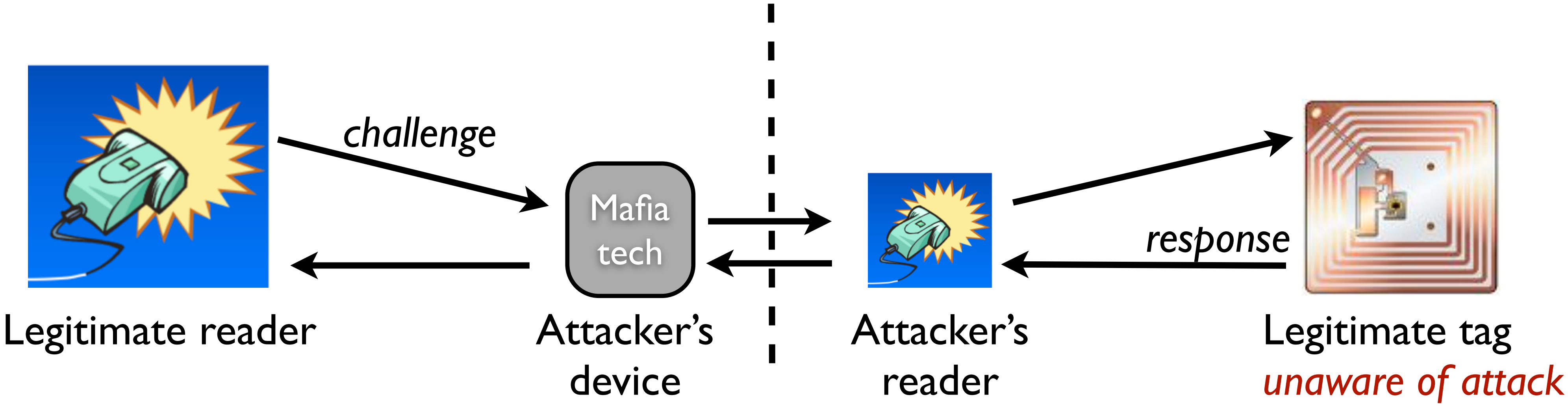
Authentication alone may not be sufficient

- physical access to buildings etc.
  - watch out for relay attack

Two main types of attack

- *Mafia Fraud*
- *Terrorist Fraud*

Relay attacks: Mafia Fraud

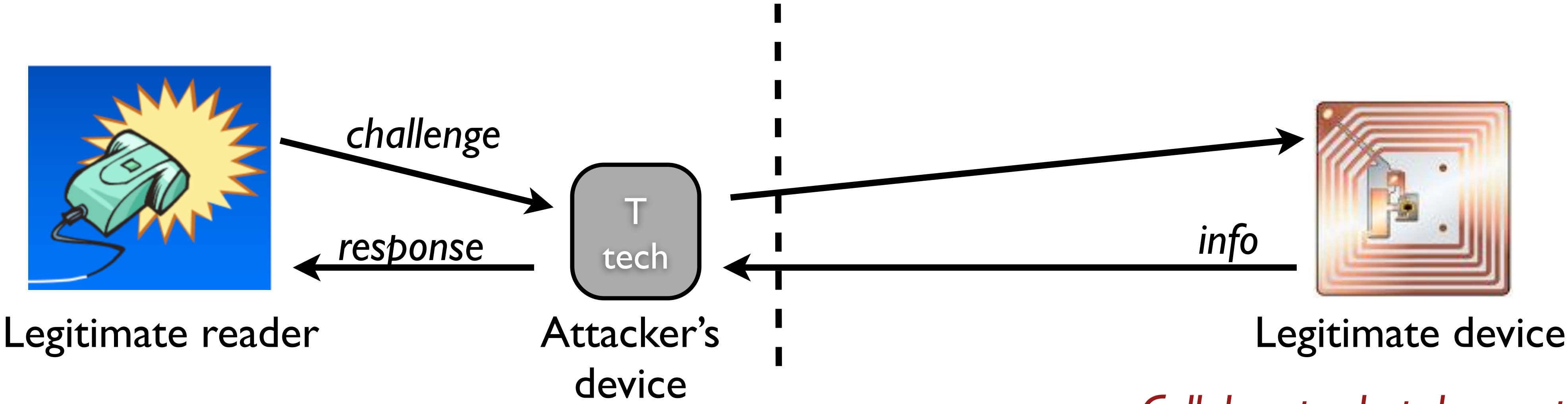


Authentication without distance checking

- *Correct response*
- *from legitimate tag*
- *... but attacker gets access!*

Famous urban myth: Mig-in-the-middle attack

Relay attacks: Terrorist Fraud



Collaborates but does not reveal long-term secrets

More powerful than Mafia fraud:

- *legit device does not have to be tricked*
- *device can provide more info than just response*

Countermeasures

What to do against relay attacks?

- Ask the prover where he is
  - but he could be lying
- Signal strength
  - can be spoofed
- Measure the distance to the prover
  - “distance bounding”
  - nothing travels faster than light $c = 2.99792458 \cdot 10^8$ m/s
  - infer distance from traveling time of signal

300 meters per microsecond

Distance bounding

Demand response within time t_{max}

- travel time to distance x_{max} and back
- allow some "slack" time for computations
- dist. measurement & demonstration of knowledge at the same time

$$t_{\max} = 2\frac{x_{\max}}{c} + t_{\text{slack}}$$

$$x_{\text{spoofable}} = \tfrac{1}{2}c\,t_{\max} = x_{\max} + \tfrac{1}{2}c\,t_{\text{slack}}$$

has to be very small

Distance bounding: practical problems

t_{slack} must be very small

- no (heavy) computations
  - addition lasts too long
  - *but still cryptographic challenge-response protocol !*
- delays inside prover device become problematic
  - missed cycles, bus speed, etc
- no error correction
  - live with transmission errors

Solving the practical problems

- no (heavy) computations
  - split protocol into slow and quick phase
  - prover creates LUT in slow crypto phase
  - verifier: unpredictable selection from LUT in quick phase
- delays inside prover
  - LUT sitting right "next to" emitter
- no error correction
  - decide afterwards if there were transmission errors

Swiss Knife protocol (Kim et al. 2008)

<u>Reader</u> has DB {ID, x} | <u>Tag</u> (ID, x)

Random N_A;
random d (Hamm.weight m)

$\xrightarrow{N_A,\, d}$

Random N_B

$\xleftarrow{N_B}$

$Z^0 = f_x(C_B, N_B)$; $Z^1 = Z^0 \oplus x$;
For $i = 1$ to m { j = index of next 1 in d;
$R^0_i = Z^0_j$; $R^1_i = Z^1_j$ }

Rapid bit exchange

For $i = 1$ to m

Random bit c_i ; start clock $\xrightarrow{c_i'}$

$$r_i = \begin{cases} R^0_i & \text{if } c_i' = 0 \\ R^1_i & \text{if } c_i' = 1 \end{cases}$$

Stop clock; store Δt_i $\xleftarrow{r_i}$

$t_B = f_x(c_1', \ldots, c_m', \mathrm{ID}, N_A, N_B)$

$\xleftarrow{t_B,\, c_1',\, \ldots,\, c_m'}$

Find matching (ID, x) in DB;
compute R^0, R^1;
$\mathrm{err}_c = \#\{i: c_i' \neq c_i\}$;
$\mathrm{err}_r = \#\{i: c_i' = c_i \wedge r_i \neq R^{c_i}_i\}$;
$\mathrm{err}_t = \#\{i: c_i' = c_i \wedge \Delta t_i > \Delta t_{\max}\}$;
if $\mathrm{err}_c + \mathrm{err}_r + \mathrm{err}_t \geq T$ reject;
$t_A = f_x(N_B)$

$\xrightarrow{t_A}$

Check t_A

Still too slow!

State of the art hardware:

- analog → digital conversion: 50 ns
- all conversion steps together: 170 ns (26 meters)

Only analog processing is fast enough!

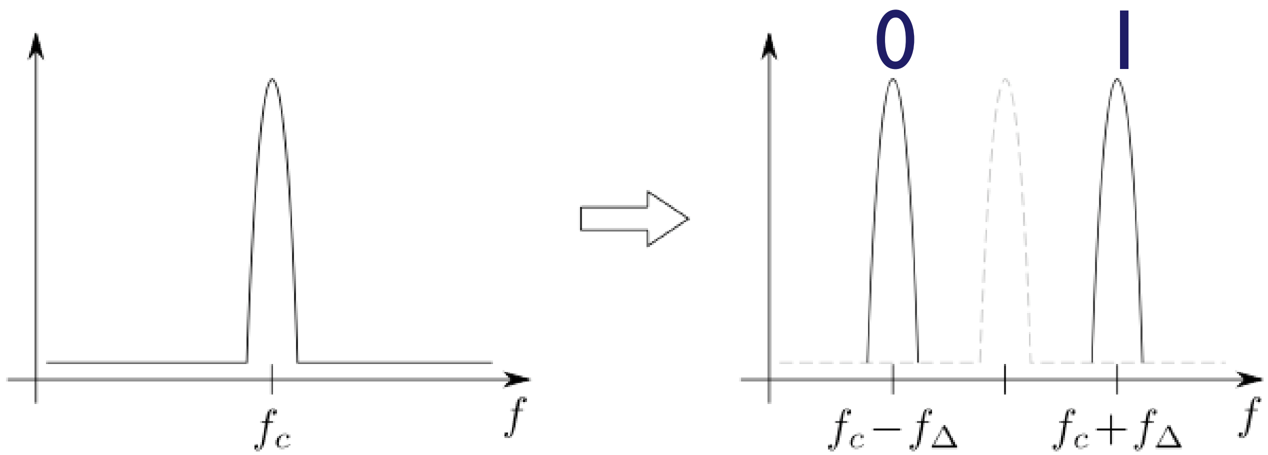
Analog challenge-response

Rasmussen & Čapkun 2010

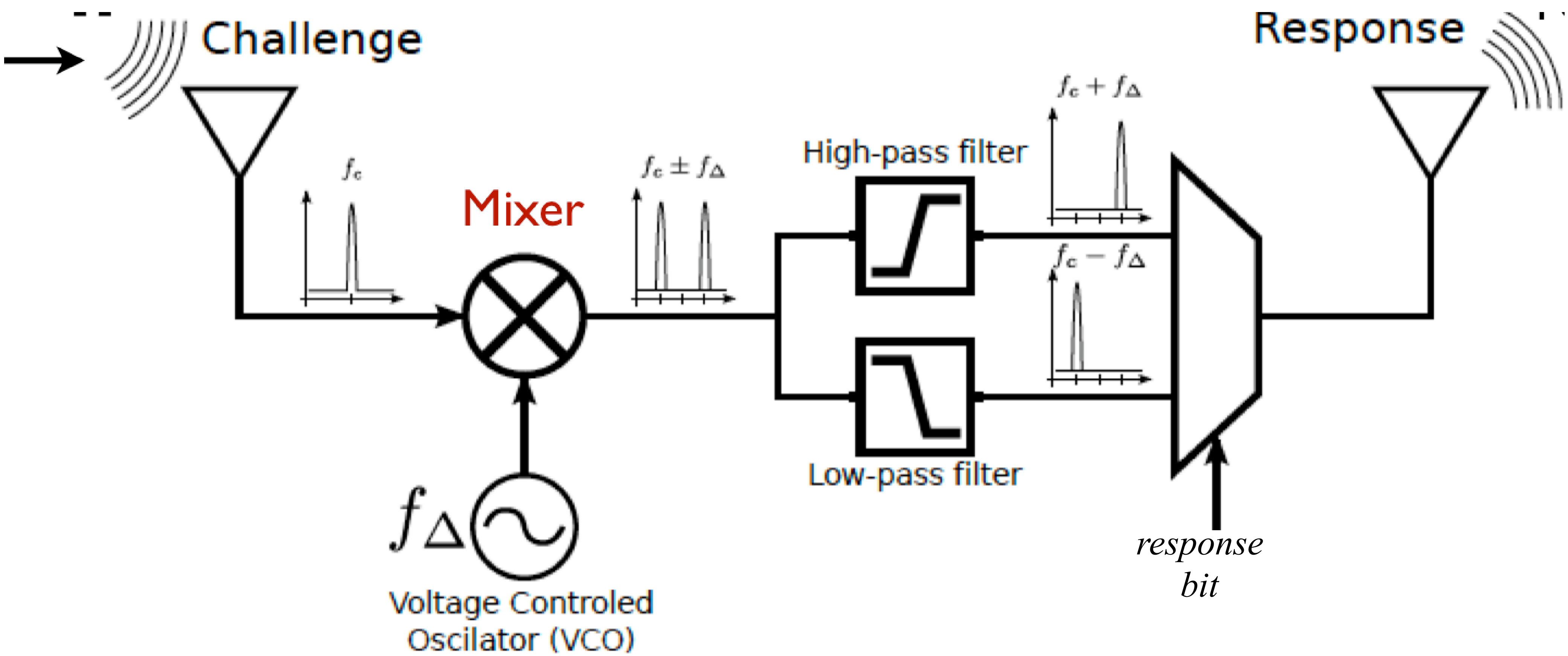
- Brands-Chaum with analog response.
- **CRCS**: *Challenge Reflection with Channel Selection.*

Challenge: unpredictable signal c(t) at frequency f_c

Response: reflection of c(t) at shifted frequency



Challenge Reflection with Channel Selection



< 1 nanosecond !

Security of Rasmussen-Čapkun

- [Same as Brands-Chaum]
- Secure against Mafia Fraud
- NOT against Terrorist Fraud
  - need AD conversion for challenge interpretation

Swiss Knife

Rapid bit exchange

For $i = 1$ to m

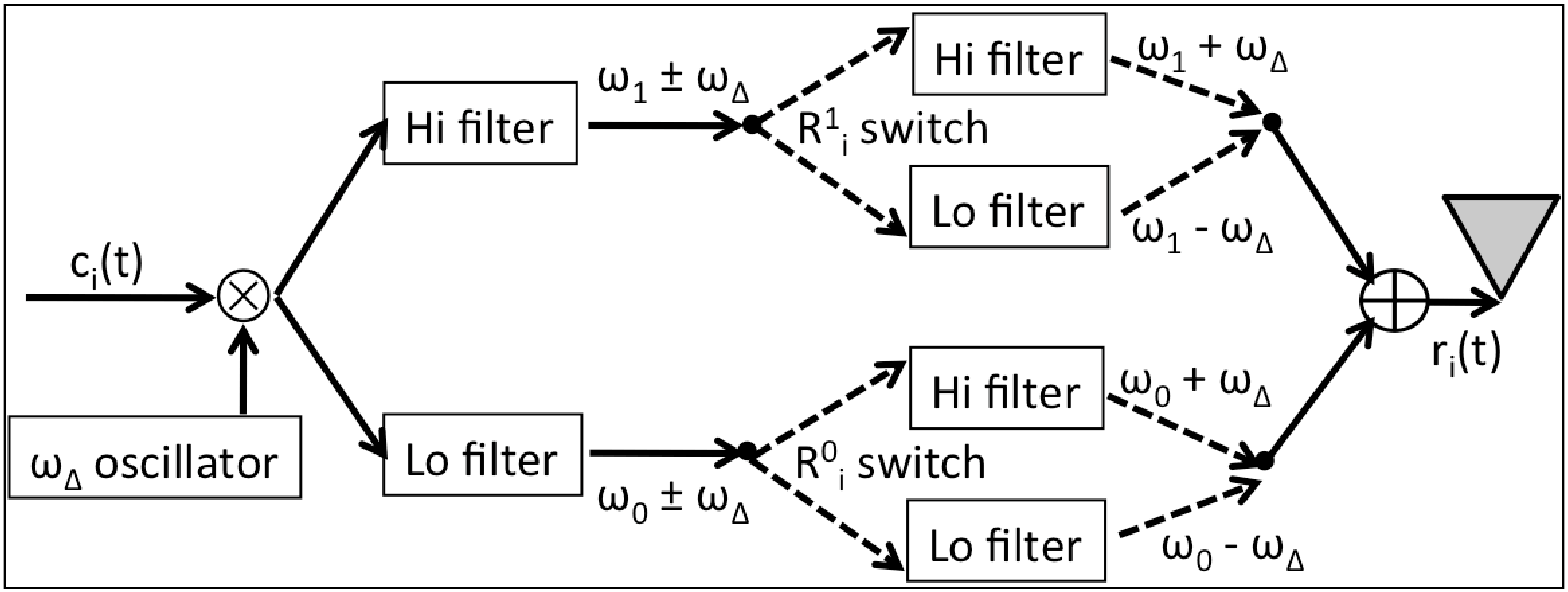
Random bit c_i ; start clock $\xrightarrow{c_i'}$ $r_i = \begin{cases} R^0_i & \text{if } c_i' = 0 \\ R^1_i & \text{if } c_i' = 1 \end{cases}$

Stop clock; store Δt_i $\xleftarrow[r_i]{}$

Generalized CRCS

Doing the register choice with <u>analog</u> hardware

- Challenge $c(t)$ at freq ω_0 or ω_1.
- Two CRCS circuits in parallel.



Danger: malicious verifier may read out both registers.

Protocol adaptation

- Problem: readout of *both* registers
  - attacker learns the secret
  - detection takes time
  - need to respond immediately
- Solution: masking
  - commit to random mask
  - do rapid part with masked registers
  - if no cheating, then open commitment

Verifier has DB {ID, x}

Prover (ID, x)

Random N_A;
random d (Hamm.weight m)

$\xrightarrow{N_A,\, d}$

Random M^0, M^1, N_B; $F = f_x(M^0, M^1)$

$Z^0 = f_x(C_B, N_B)$; $Z^1 = Z^0 \oplus x$;

For i = 1 to m { j = index of next 1 in d;
$R^0{}_i = Z^0{}_j$; $R^1{}_i = Z^1{}_j$ }

$T^0 = R^0 \oplus M^0$; $T^1 = R^1 \oplus M^1$

$\xleftarrow{F,\, N_B}$

Rapid bit exchange using CRCS

For i = 1 to m

Random bit b_i;
Random signal $c_i(t)$
at freq. ω_{bi}

$\xrightarrow{c_i(t)}$

Circuit reflects signal at freq. $\omega_{bi} + (2\, T^{bi}{}_i - 1)\, \omega_\Delta$

Slow interpretation of b'_i.

$\xleftarrow{r_i(t)}$

Record $r_i(t)$ and delays Δt_i

Proceed only if no cheating detected;
$t_B = f_x(b_1', \ldots, b_m', \text{ID}, M^0, M^1, N_A, N_B)$

$\xleftarrow{t_B,\, b_1',\, \ldots,\, b_m'}$ M^0, M^1

Find matching (ID, x) in DB;
Check if $F = f_x(M^0, M^1)$;
Compute T^0, T^1;
$\text{err}_b = \#\{i: b_i' \neq b_i\}$;
$\text{err}_f = \#\{i: b_i' = b_i \wedge r_i$ has wrong freq.$\}$;
$\text{err}_r = \#\{i: b_i' = b_i \wedge r_i$ differs too much from $c_i\}$;
$\text{err}_t = \#\{i: b_i' = b_i \wedge \Delta t_i > \Delta t_{max}\}$;
Reject if $\text{err}_b + \text{err}_f + \text{err}_r + \text{err}_t$ too large;
$t_A = f_x(N_B)$ $\xrightarrow{t_A}$ Check t_A

Summary

- Distance bounding: absurd timing requirements
- Analog challenge-response, CRCS
  - secure against Mafia Fraud, but not Terrorist Fraud
- Generalized CRCS and extra masking step
  - ➡ nanosecond-scale responses
  - ➡ security against Terrorist Fraud
  - not restricted to Swiss Knife
- Embarrassingly trivial-looking