650.445: Practical Cryptographic Systems

Side Channel Attacks

Instructor: Matthew Green

Housekeeping:

- A2 tonight
- Grades for A1 back

Current Events

by Michael Mimoso Follow @mike_mimoso September 19, 2016 , 4:03 pm

Current Events

CVE-2016-6309 (OpenSSL advisory) [Critical severity] 26th September 2016:

> This issue only affects OpenSSL 1.1.0a, released on 22nd September 2016. The patch applied to address CVE-2016-6307 resulted in an issue where if a message larger than approx 16k is received then the underlying buffer to store the incoming message is reallocated and moved. Unfortunately a dangling pointer to the old location is left which results in an attempt to write to the previously freed location. This is likely to result in a crash, however it could potentially lead to execution of arbitrary code. Reported by Robert Święcki (Google Security Team).
>
> - Fixed in OpenSSL 1.1.0b (Affected 1.1.0a)

CVE-2016-7052 (OpenSSL advisory) [Moderate severity] 26th September 2016:

> This issue only affects OpenSSL 1.0.2i, released on 22nd September 2016. A bug fix which included a CRL sanity check was added to OpenSSL 1.1.0 but was omitted from OpenSSL 1.0.2i. As a result any attempt to use CRLs in OpenSSL 1.0.2i will crash with a null pointer exception. Reported by Bruce Stephens and Thomas Jakobi.
>
> - Fixed in OpenSSL 1.0.2j (Affected 1.0.2i)

Current Events

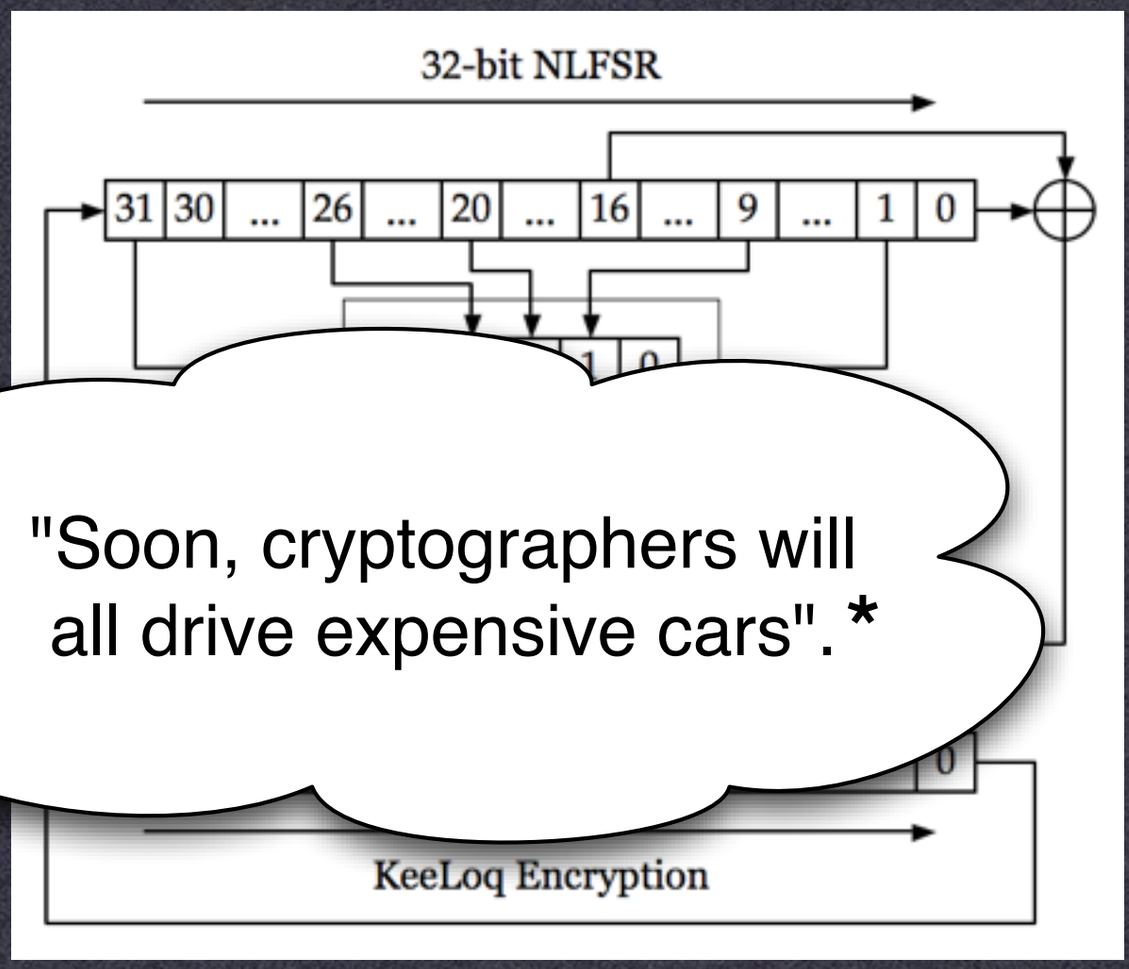
MOZILLA REDUCES THREAT OF EXPORT-GRADE CRYPTO TO FIREFOX

by Michael Mimoso Follow @mike_mimoso October 3, 2016 , 8:45 am

Logjam was one of several downgrade attacks discovered in the last 18 months that could theoretically allow a resourced attacker to take advantage of lingering export-grade cryptography to read and modify data over a supposedly secure connection.

KeeLoq

- Designed by Kuhn & Smit
  - Block cipher: 64-bit key, 32-bit block
  - 528 rounds
  - Mostly used for door opening
  - Direct attacks*:
    A. 2^{16} data & 2^{51} operation
    B. 2^{32} data & 2^{27} operations
    C. Indesteege et al.:
    (65 min to get data,
    218 CPU days to process)



"Soon, cryptographers will all drive expensive cars".*

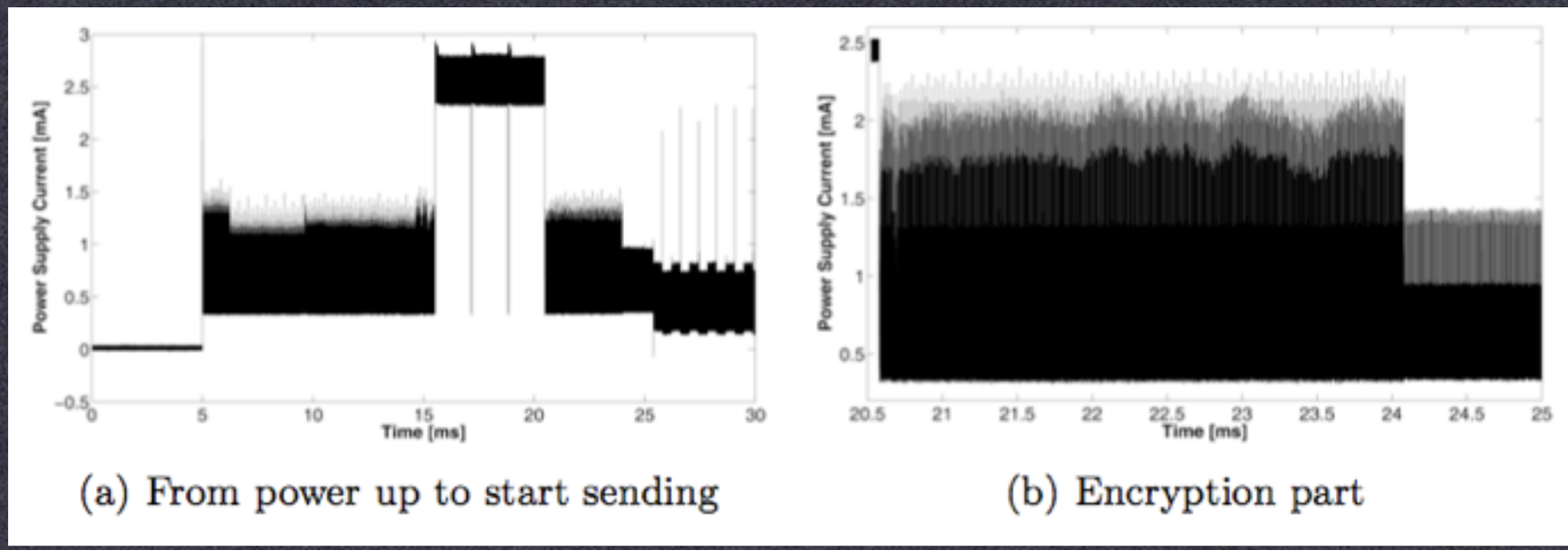
Public domain image from Wikipedia
* Source: Indesteege et al.: http://www.cosic.esat.kuleuven.be/keeloq/keeloq-slides.pdf

KeeLoq

- Newer attack, CRYPTO 2008
  - Requires physical access to device
  - Recovers secret key after 10-60 reads
  - How?

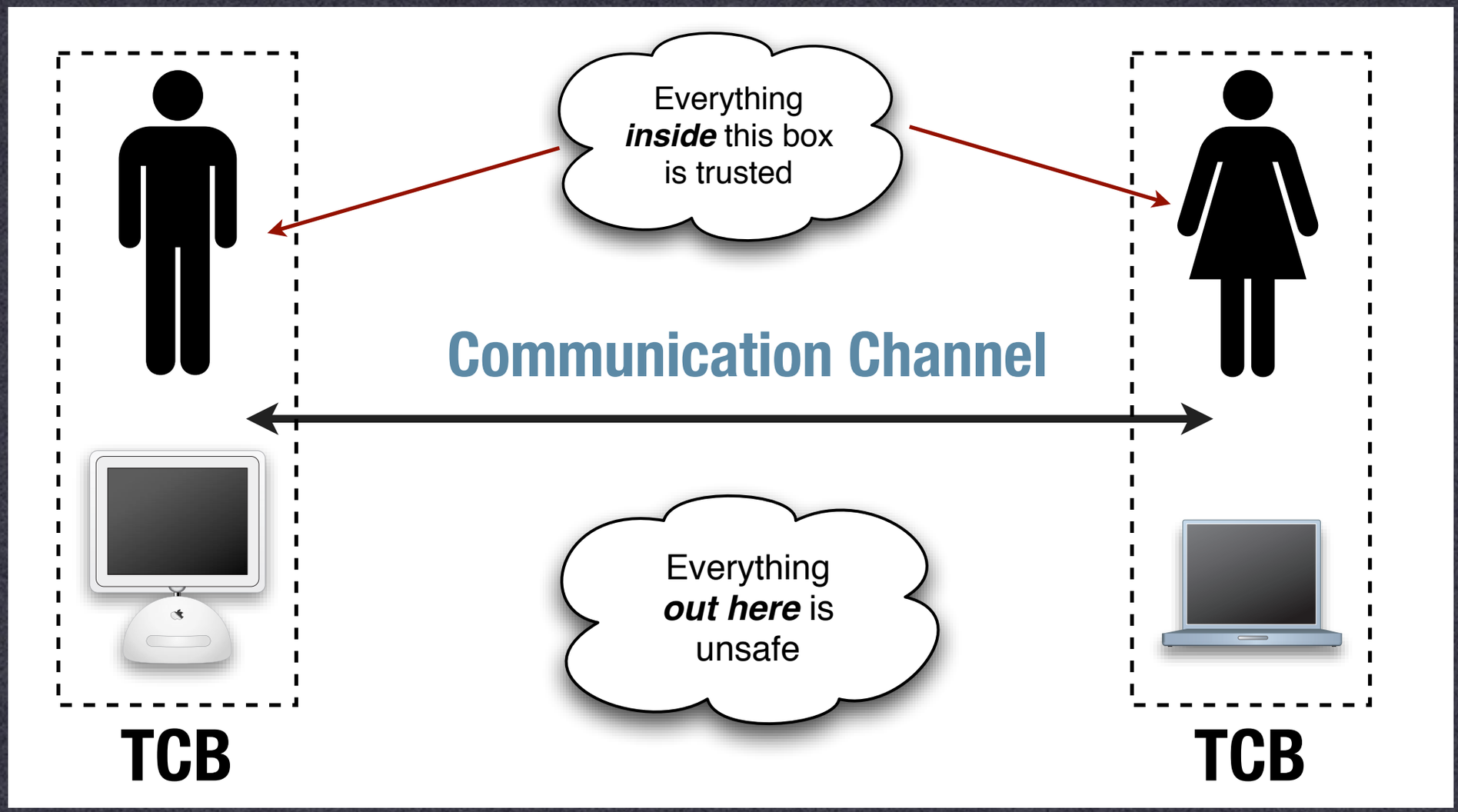
KeyLoq

- CRYPTO 2008
  - Doesn't directly attack the cipher
  - Instead, measures how the cipher works in operation.
- In this case, use power consumption

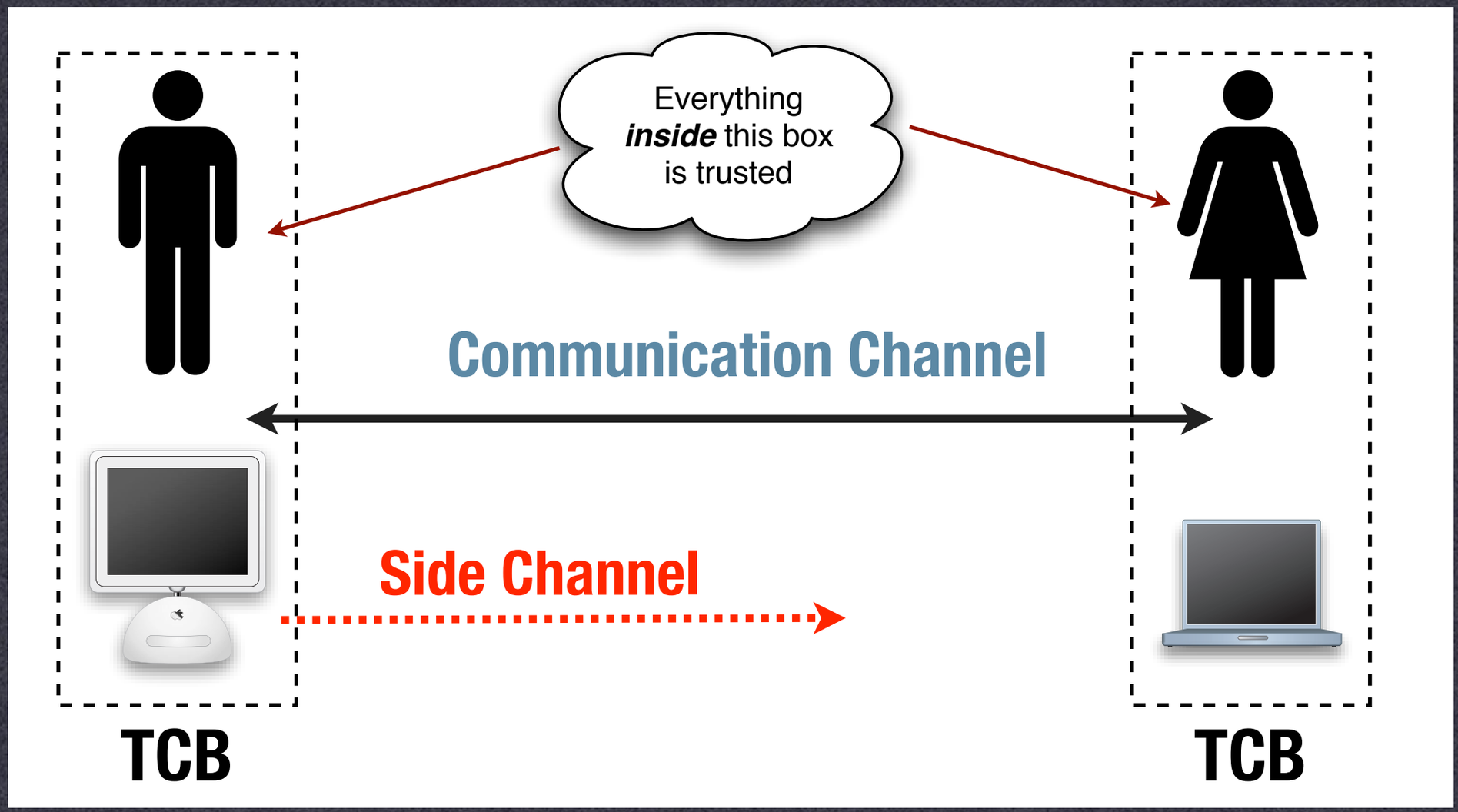


Source: Eisenbarth et al., On the Power of Power Analysis in the Real World: A Complete Break of the KeeLoq Code Hopping Scheme

Review

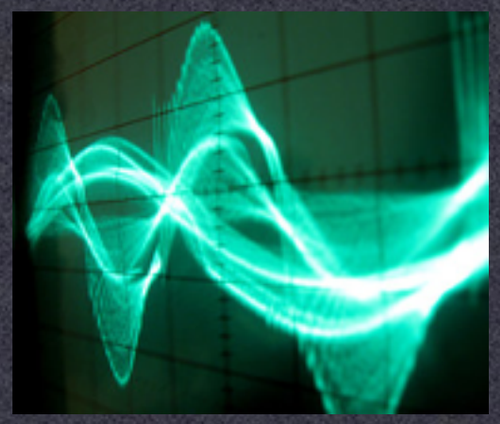

Everything
inside this box
is trusted
Communication Channel
Everything
out here is
unsafe
TCB
TCB

Side Channels



Side Channels

- Some history:
  - 1943: Bell engineer detects power spikes from encrypting teletype
  - 1960s: US monitors EM emissions from foreign cipher equipment
  - 1980s: USSR places eavesdropping device inside IBM Selectric typewriters

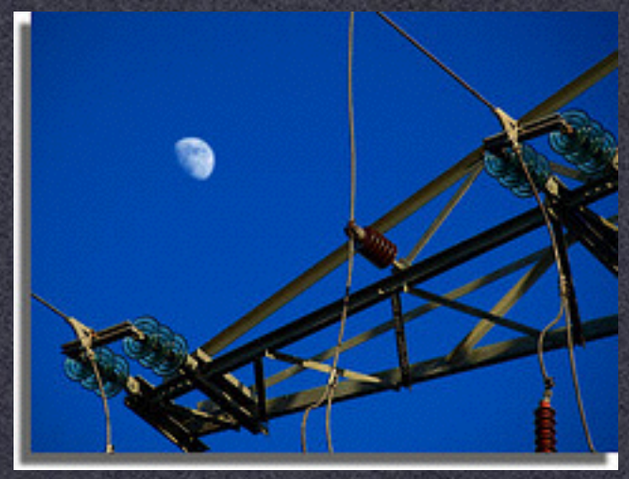


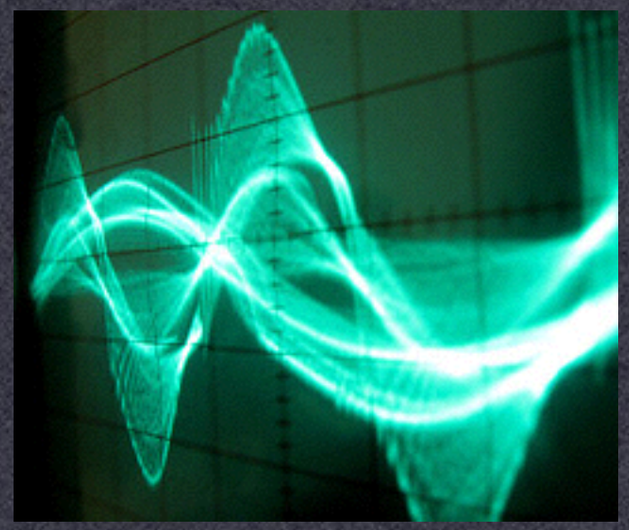
Side Channels

- Some history:
  - 1990s: Paul Kocher demonstrates timing attacks, power analysis attacks against RSA, Elgamal

Common Examples

- Timing
- Power Consumption
- RF Emissions
- Audio





RSA Cryptosystem

$N = p \cdot q$

$e \cdot d \equiv 1 \; mod \; (p-1)(q-1)$

Encryption

$$c = m^e \; mod \; N$$

Decryption

$$m = c^d \; mod \; N$$

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Decryption

$$m = c^d \; mod \; N$$

$$m = \underbrace{c * c * c * \cdots * c}_{\text{d times}} \; mod \; N$$

Modular Exponentiation

$$m = c^d \ mod \ N$$

$$d = 10101010011101010110010010001001$$

```
modpow(c, d, N) {

    result = 1;

    for (i = 1 to |d|) {
        if (the ith bit of d is 1) {
            result = (result * c) mod N;
        }

        c = c² mod N;
    }

    return result;
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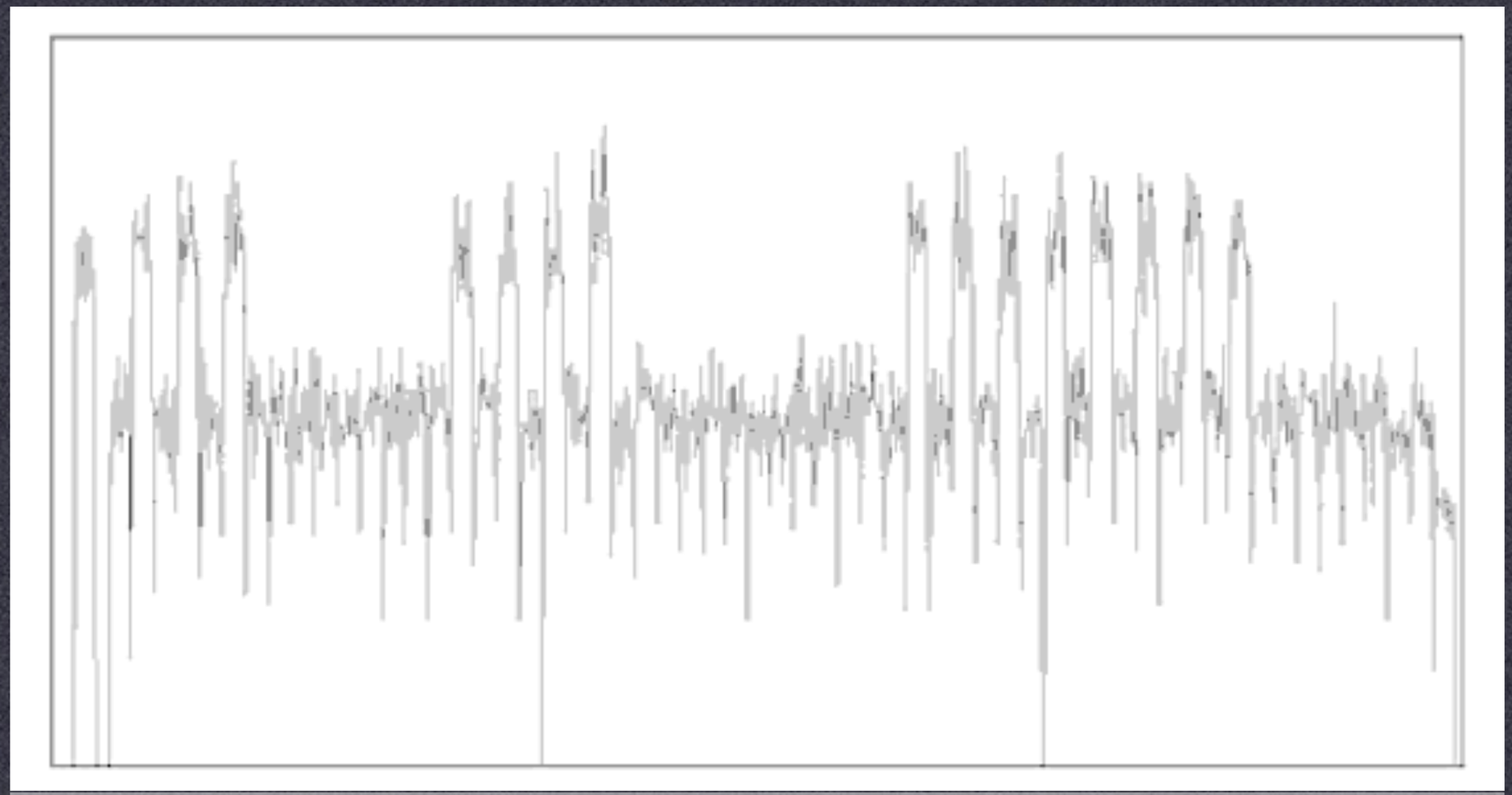
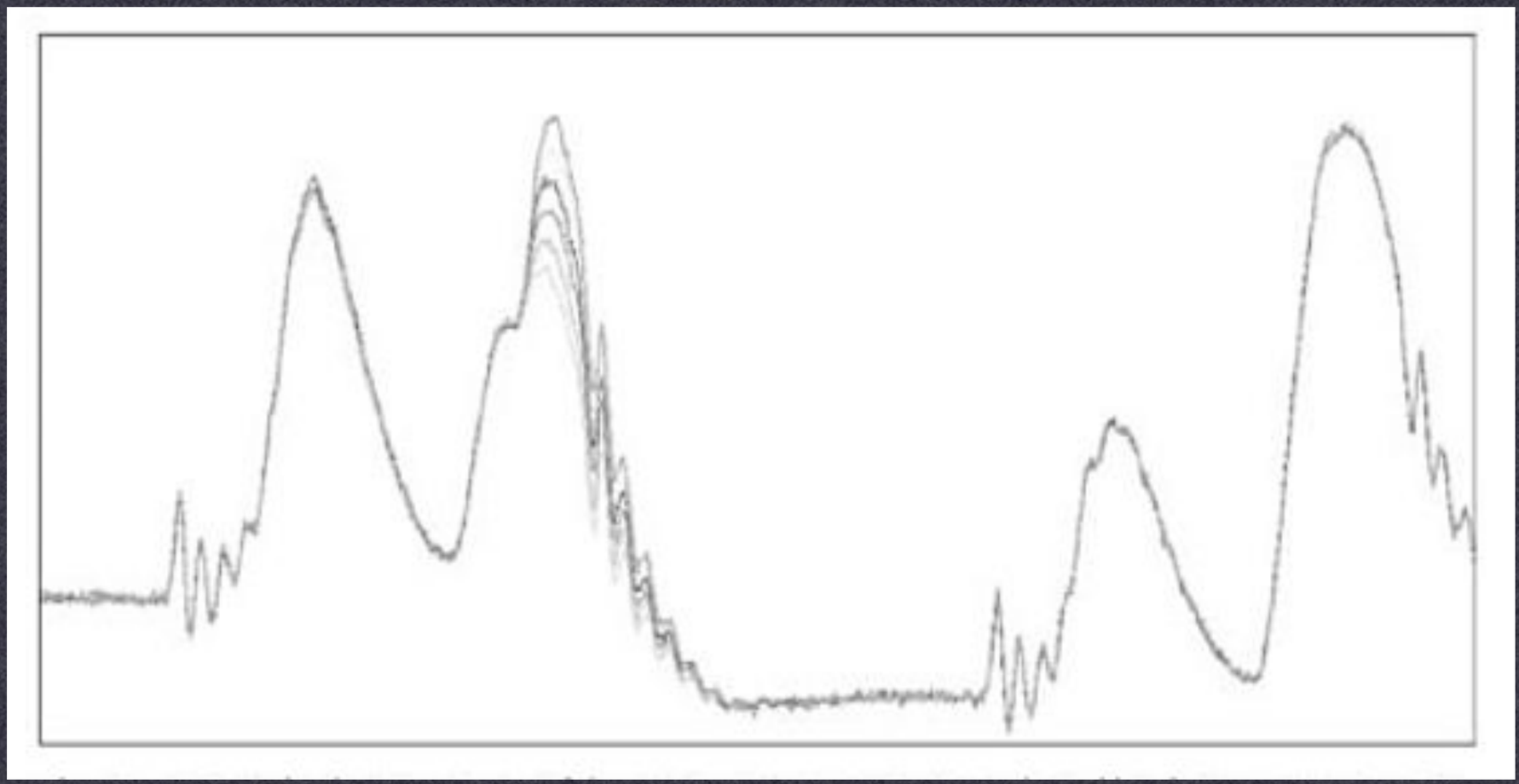
Expensive Operation

Simple Power Analysis



Source: Bidgoli, Handbook of Information Security

Differential Power Analysis



Source: Bidgoli, Handbook of Information Security

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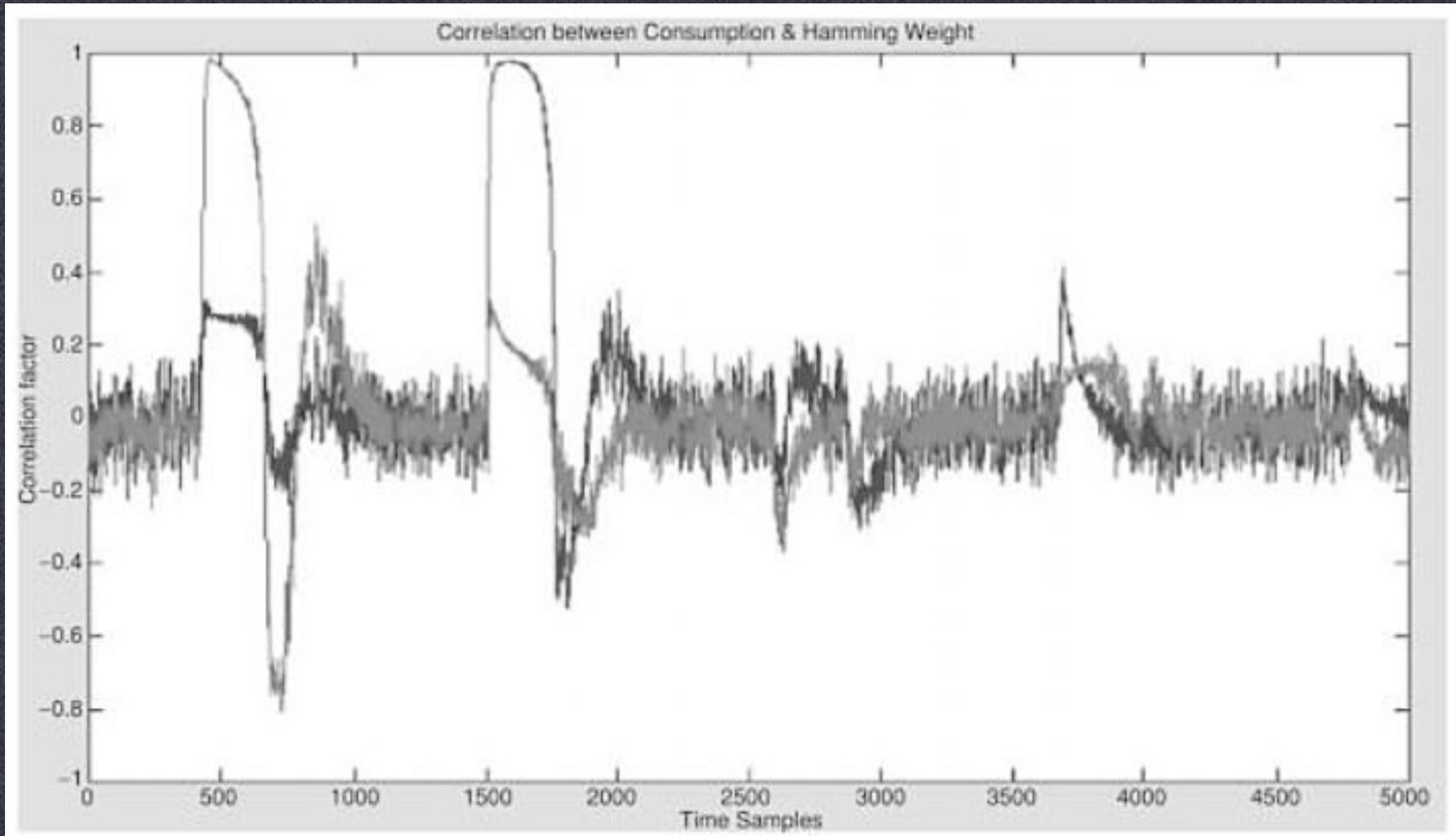

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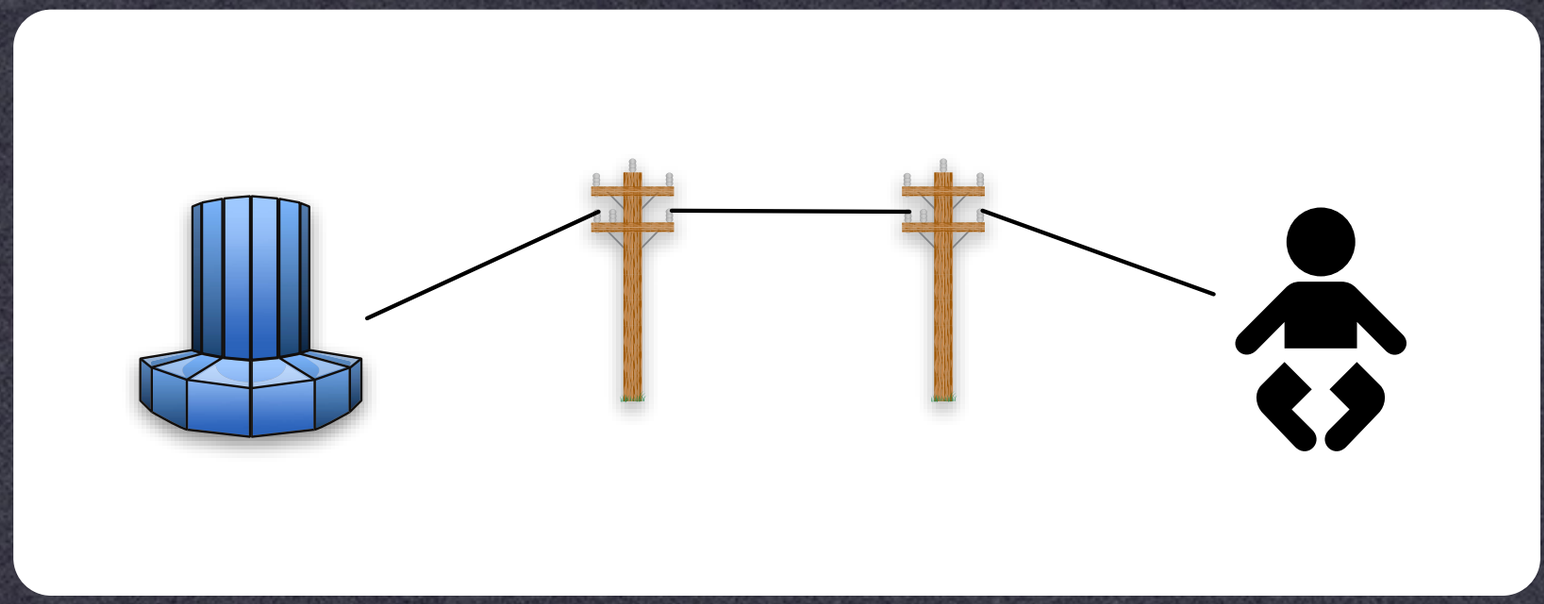
Expensive Operation

Kocher's Timing Attack

- Assume that for some values of (a * b), multiplication takes unusually long
- Given the first b bits, compute intermediate value
  "result" up to that point
- If the next bit of d = 1, then calc is (result * c)
- If this is expected to be slow,
  but response is fast then the next bit of d != 1

Remote Timing Attacks

- Boneh & Brumley
  - Remote attack on RSA-CRT as implemented in OpenSSL
  - Optimization, uses knowledge of p,q



Solutions

- Quantization:
  - All operations take the same time
  - Hard to do without sacrificing performance
- Blinding:
  - Prevents attacker from selecting ciphertext (that is processed with the secret key)

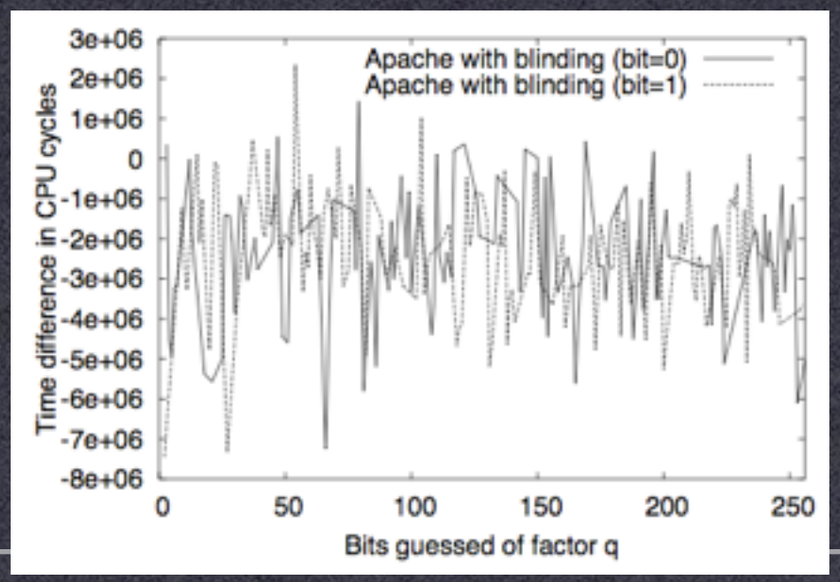
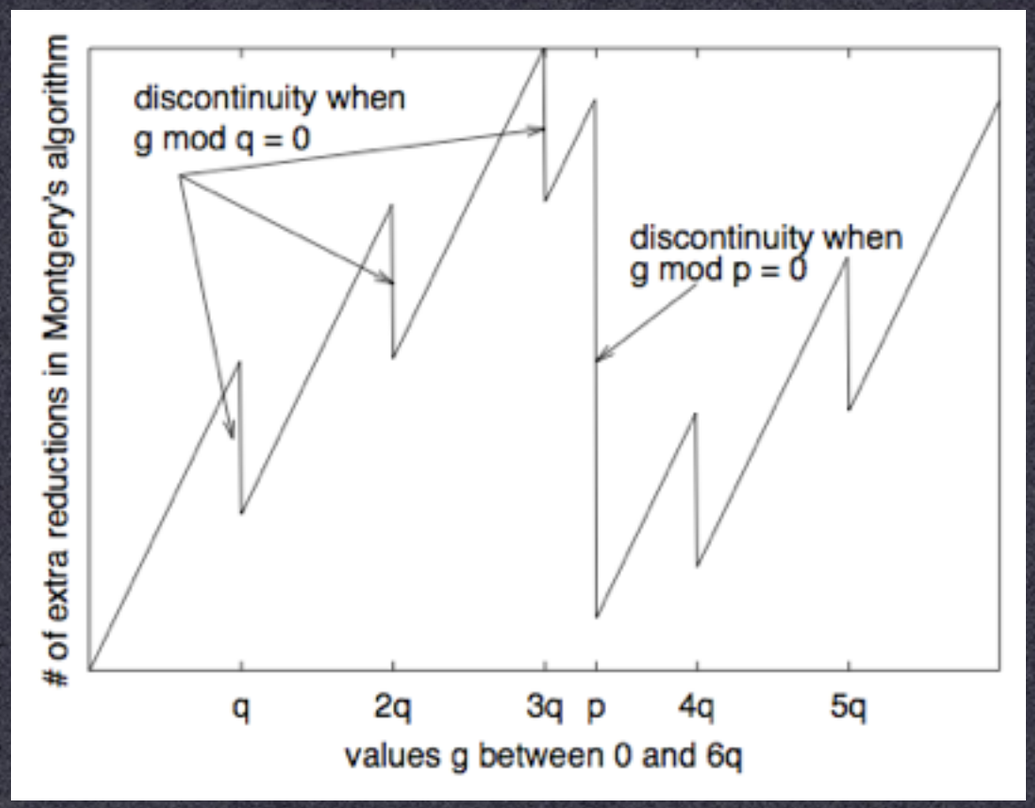
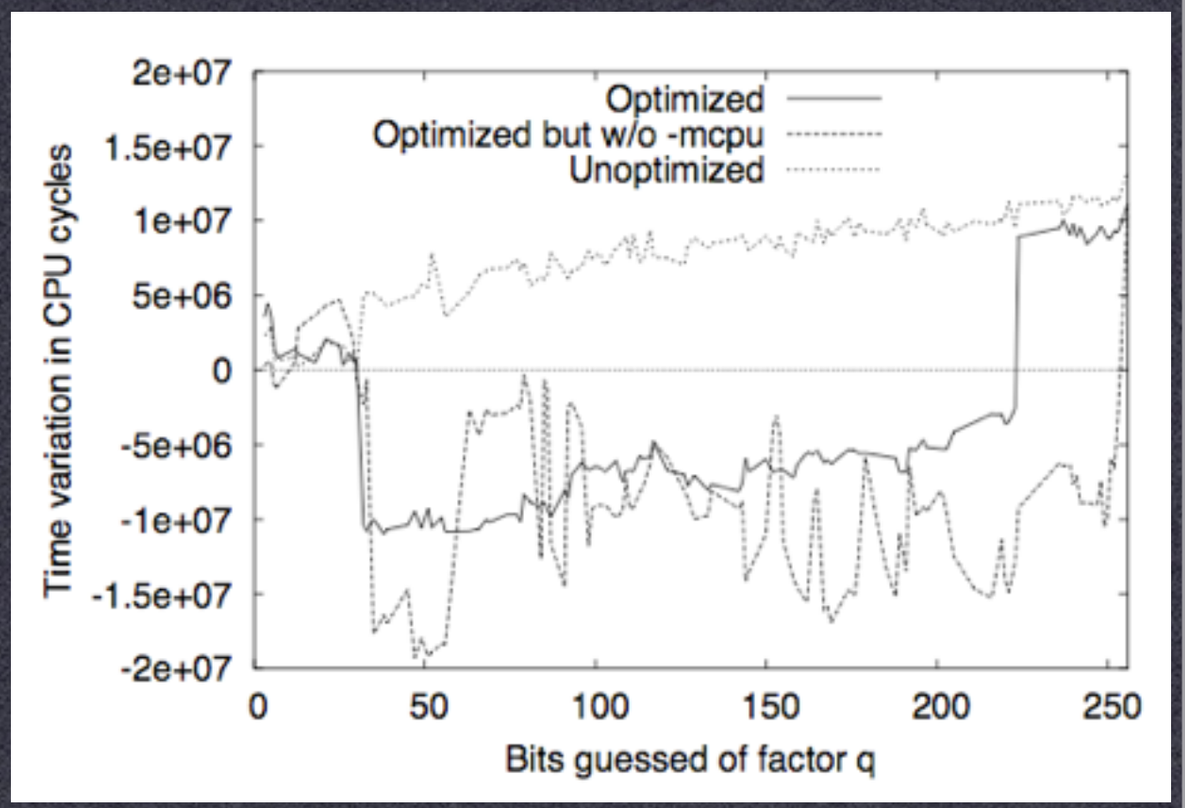


Image Source: Boneh, Brumley: Remote Timing Attacks are Practical

Remote Timing Attacks

- **Boneh & Brumley**
  - **By repeating the timing measurements, they were able to extract a secret key after several million samples**





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Windowed Exponentiation

$$m = c^d \ mod \ N$$

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- Handles the input in larger “chunks”
  - Fixed or variable sized
  - Can speed up by pre-computing some values

-e.g., c^2, c^3, ..., c^16

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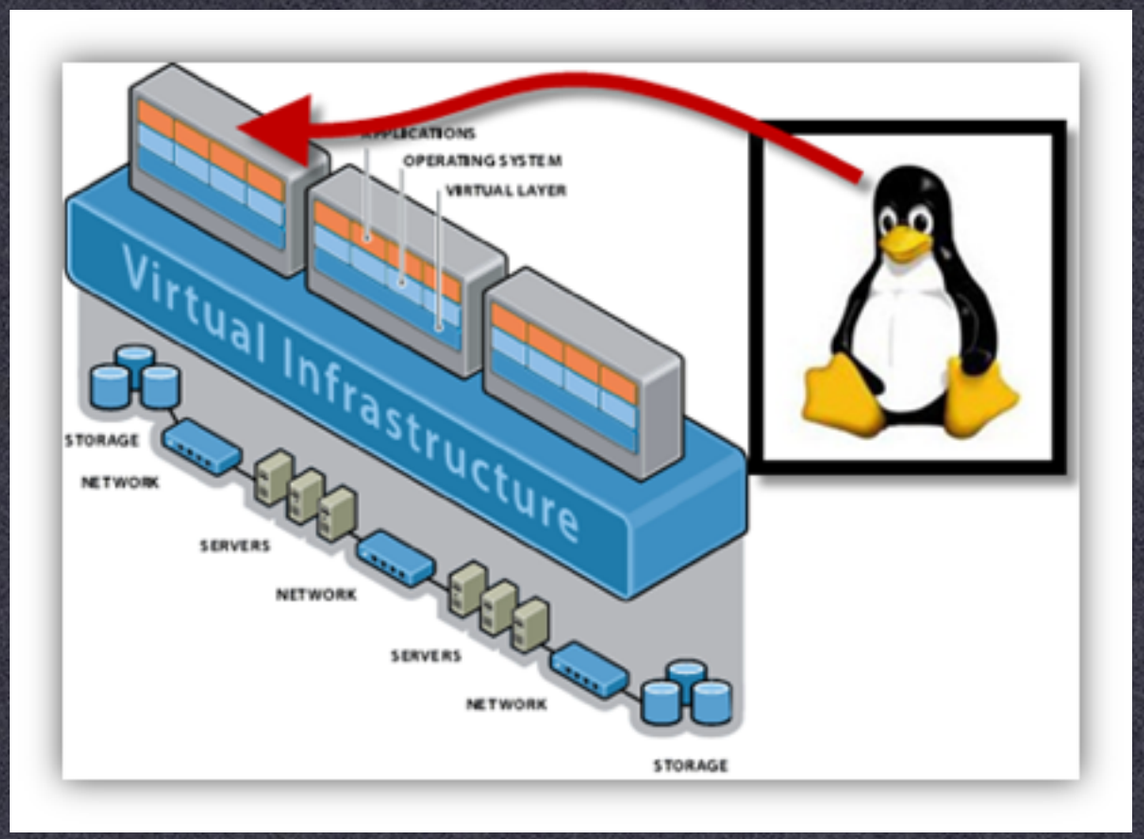
Cache Timing Attacks

- Observation
  - When we use pre-computed tables, this implies a memory access
  - This takes time
  - Unless the data is cached!

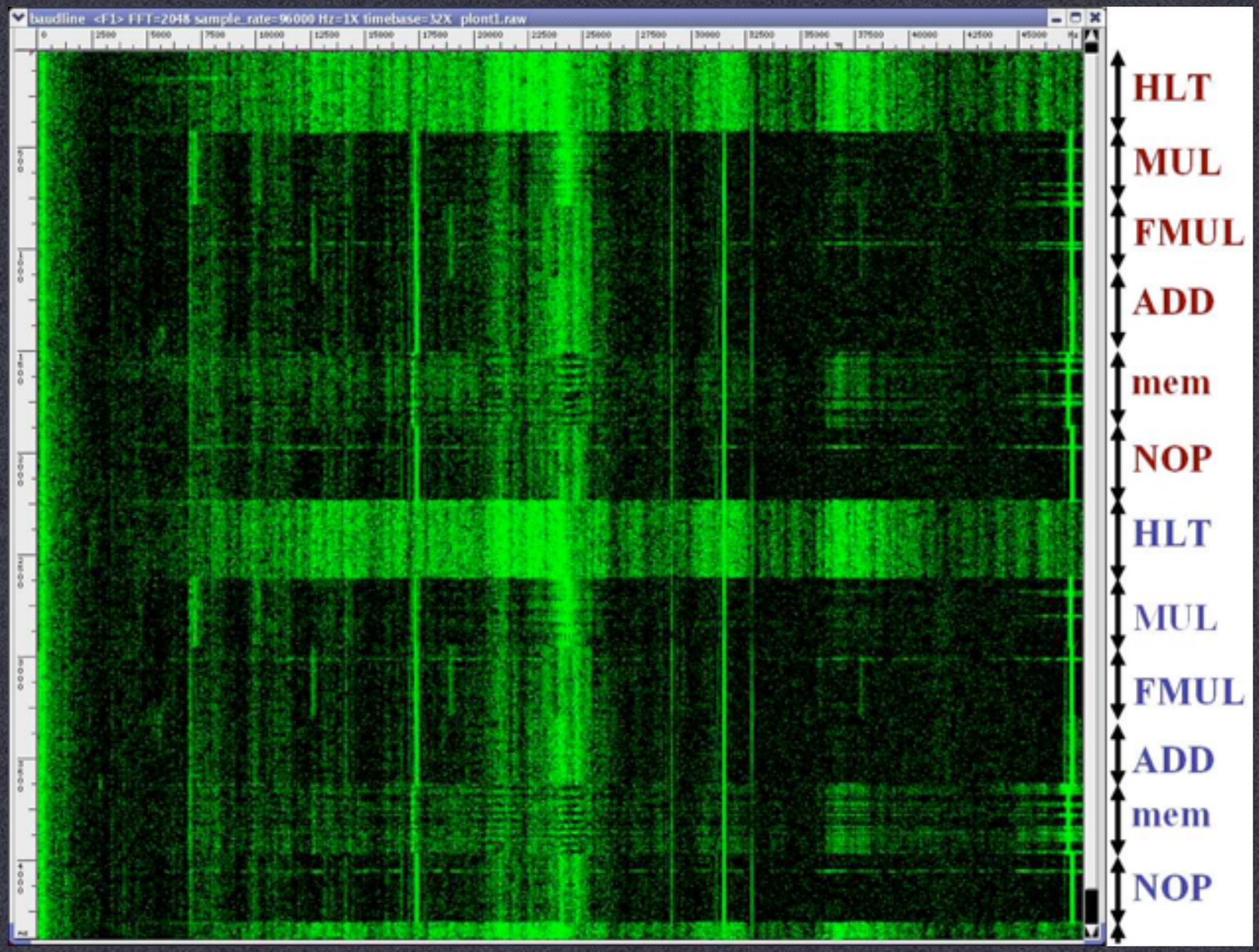


Hypervisor attacks

- **Observation**
  - **This applies to code too!**

SquareMult(x, e, N):
  let $e_n, \ldots, e_1$ be the bits of e
$y \leftarrow 1$
for $i = n$ down to 1 {
  $y \leftarrow$ Square(y) (S)
  $y \leftarrow$ ModReduce(y, N) (R)
  if $e_i = 1$ then {
    $y \leftarrow$ Mult(y, x) (M)
    $y \leftarrow$ ModReduce(y, N) (R)
  }
}
return y

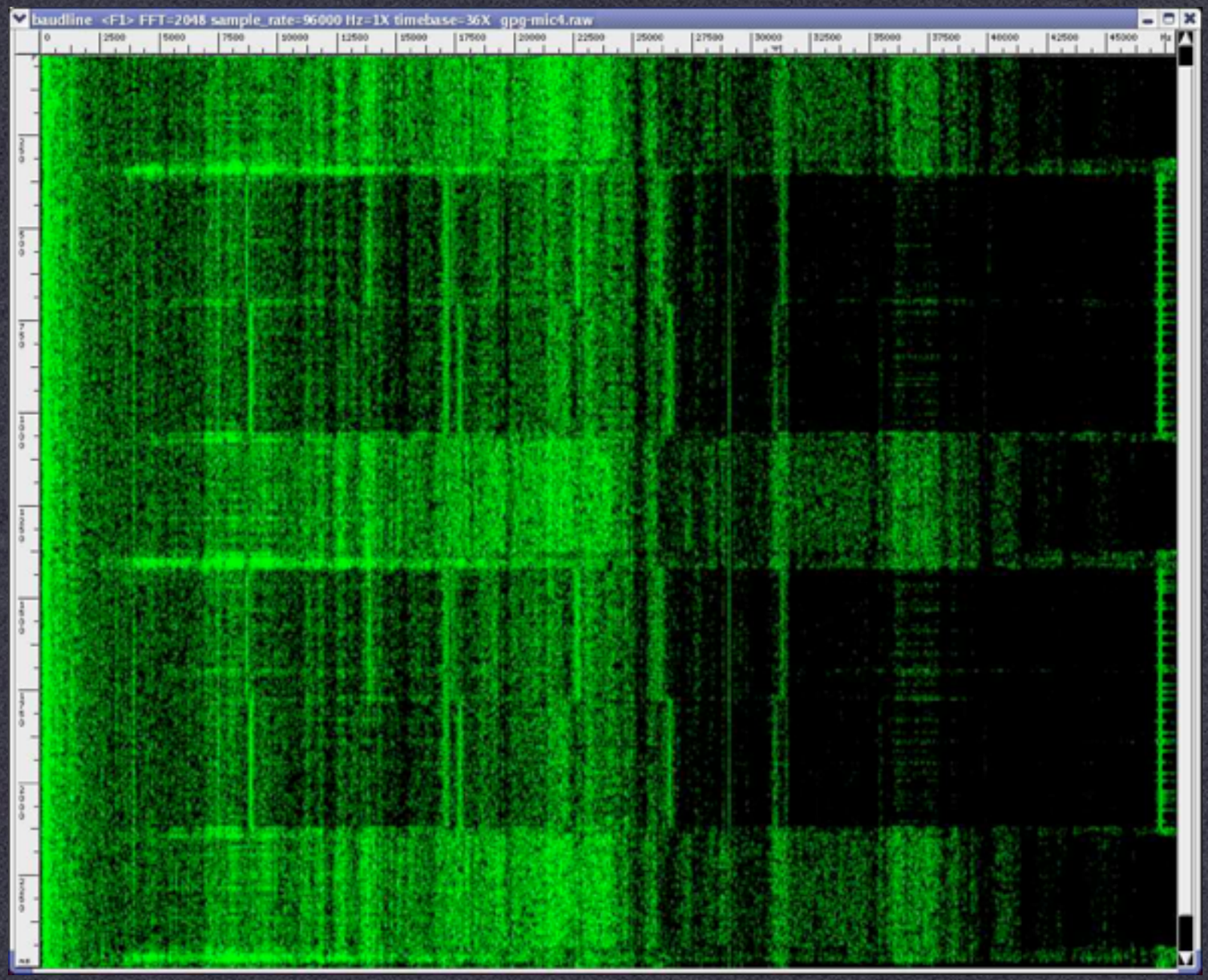
Acoustic Side Channels



Source: Tromer, Acoustic Cryptanalysis: http://people.csail.mit.edu/tromer/acoustic/

Acoustic Side-Channels

GPG RSA-CRT signature #1:



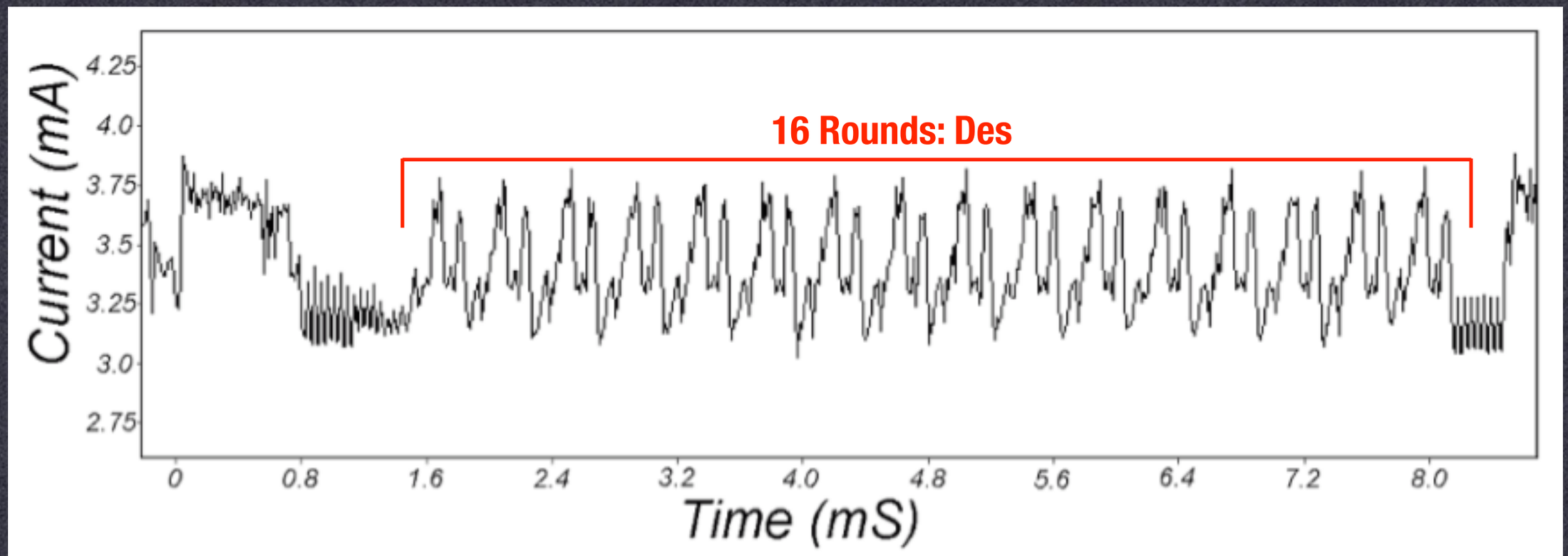
mod q

mod p

(repeated)

Source: Tromer, Acoustic Cryptanalysis: http://people.csail.mit.edu/tromer/acoustic/

Reverse Engineering



Source: Kocher et al. 1999

Back to KeyLoq

- **KeyLoq attack has an unhappy coda:**
  - **Turns out that all keys for a given manufacturer are derived from the same MK**

$$k = pad(ID, seed) \oplus MK$$

  - **Key derivation function based on XOR :(**
  - **By observing 2 interactions between key/car we can derive the MK and thus steal any car**