Chip card sidelight on lightweight crypto

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Contents

Warning

- Sorry but this talk mainly tells facts that occurred in France…
- A similar story, with actors in Germany, could (should) also be told

1. Back to 1985

Why 1985 ? (1)

- Because 1985 is a key year for massive deployment of chip cards in France
- In two sectors (mainly): public telephony and banking
- In two forms: memory card (*without* microprocessor) and smart card (*with* microprocessor)
- More precisely…

Why 1985 ? (2)

- This is the year when prepaid phone memory cards were massively *deployed* in France by

(famous) pyjama-style

Why 1985 ? (3)

- This is also the year when French banks *decided* to move to smart cards

Massively deployed some years later

Why 1985 ? (4)

- This talk is only about phone cards (memory cards)
- Thanks to their microprocessor, bank cards did not need lightweight crypto
  - DES was on the point to be implemented in smart cards
  - In the mean-time, “medium-weight” proprietary algorithms were used (Telepass 1, Telepass2)

Public phones (1)

- In 1985, telephone is (prominently) fixed and analogic
- Mobile telephones exist but are not portable, are expensive and don't work everywhere
- In France, Radiocom 2000 program (first cellular network) will start in 1986 and the handsets are priced at more than 4 000 €

Public phones (2)

- To call outdoor requires phones in streets (booths) and public places (airports, stations…)

Téléphone public

Public phones (3)

- In France public phones long worked with coins…
- then specific tokens…

- … then coins again!

- Not practical (collecting money) and dangerous (vandalism, theft)
- The idea of using cards instead of coins emerges in the late 70's

Public phones (4)

- Several card technologies are tested: magnetic, holographic, thermo-magnetic…

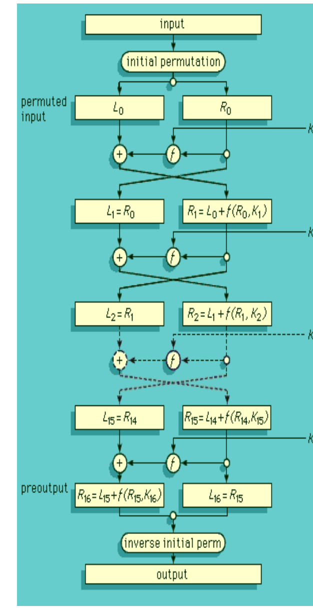
- Finally PTT selects the “invented here” chip card

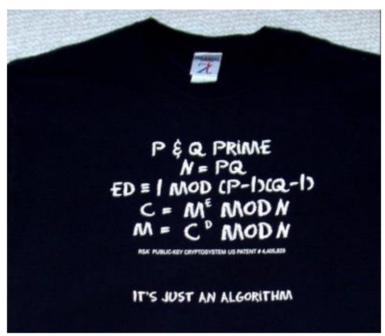
Public phones (5)

- 1993 (France)
  - 173 000 public phones in the streets : 123 000 with “télécartes”
  - 100 millions “télécartes” sold this year
- 1997 (France)
  - 1 billion of “télécartes” sold from the beginning but…
  - … first year the sales decrease
- 2002 (world)
  - 1.3 billion of prepaid cards sold this year but…
  - … first year the sales decrease

Cryptology (1)

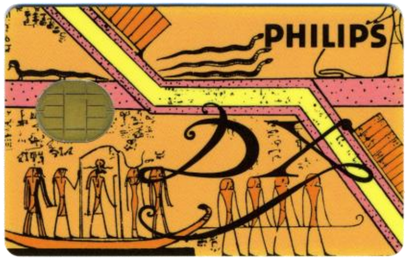
- In 1985, DES and RSA undisputed crypto-stars
  - DES: the glory (widely deployed)
  - RSA: towards the glory (implemented in French bank cards a as a static signature for card authentication)





Cryptology (2)

- Suitability for smart cards
  - DES: soon (1986)
  - RSA: later
- Suitability for memory cards
  - DES: never
  - RSA: never never never



Cryptology (3)

- Still (officially) unknown or uninvented
  - Differential cryptanalysis
  - Linear cryptanalysis
  - Attacks against modes of operation
  - Side-channel attacks
  - Alternatives to DES: FEAL, IDEA, RCx…. AES

- Lightweight crypto starts (nearly) from scratch

2. Prepaid phone cards

Background (1)

- Goal: replace true money by virtual call units
  - A unit allows a local call during a little less than 1 minute
- Dilemma: where is the balance ? Who updates it ?
- Two main approaches
  - on-line approach
  - off-line approach

Background (2)

- *On-line approach:* virtual units are at operator's side
- User buys a "number"
  - written on a plastic card or stored in a memory card
  - equivalent to *n* units
  - built with (cryptographic) redundancy
- User provides this number to the phone and makes a call
- Operator progressively updates the balance

Background (3)

- *Off-line approach:* virtual units are at card's side
- User buys a card
  - "containing" *n* units
  - storing a (cryptographic) certificate
- User inserts the card in the phone and makes a call
- Public phone progressively updates the balance *inside the card*

Background (4)

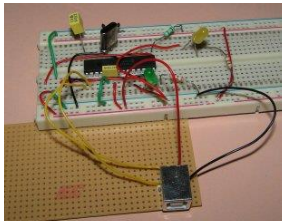
- *On-line* vs *off-line* approach
- *On-line*
  - pro: fake units cannot be forged
  - con: many simultaneous connections
- *Off-line*
  - pro: a few simultaneous connections
  - con: fake units could be forged
- In the mid-80's, off-line solution is preferred
- Nowadays, on-line solution is preferred

Background (5)

- *<u>Forging vs cloning</u>*
- *Forging*
  - the enemy can forge a fake cardsfrom scratch
  - he can choose any serial number → untraceable
- *Cloning*
  - the enemy can only clone (= duplicate) a genuine card
  - he must choose the same serial number → traceable
- Forging is easier to prevent

Background (6)

- ***Emulating***
- *Not emulating*
  - the fake card is physically and functionally indistinguishable from a genuine card
- *Emulating*
  - the fake "card" is functionally indistinguishable from a genuine card (not physically, it can be a bulky electronic device)
- Emulating is less discreet but sufficient for a fraud (not for a mass fraud)



T1G (1)

- *T1G* = “Télécarte de première génération”

- Disposable → must be very cheap
- Designed in the early 80’s
- 1984: first T1G
- 1985: deployment
- 1998: end of production
- Much later: end of acceptability

T1G (2)

- Memory card
  - no PIN
  - no computation capabilities
- N-MOS technology
- EPROM memory (256 bits)
  - unary counting
- Synchronous protocol
- 50 or 120 units

T1G (3)

- EPROM contents
  - *I* (permanent public data, including card identifier)
  - *D* (variable data, including balance)
- To prevent from forging, the permanent data *I* are “signed” by a (static) 16-bit MAC, *not computed* by the card, called certificate
- The certificate does not prevent from cloning

T1G (4)

- Frauds on T1G are reported in the late 80’s
- Some of them (not all) are clone-based
  →Need for a challenge-response protocol
- T2G (“Télécarte de seconde génération”) will include a “fonction anti-clone” (FAC, roughly a MAC)
- Works starts in 1989
  - ends in 1994 for “télécartes”
  - continues for other applications

T2G (1)

- *T2G* = “Télécarte de seconde génération”

- *Still* disposable→ must *still* be very cheap
- Designed in the late 80’s
- 1993: first T2G
- 1994: deployment (in France and abroad)
- 2013: end of acceptability

  (2015: end of acceptability of T3G, next and last generation)

T2G (2)

- Memory card
  - light computation capabilities
- C-MOS technology
- E2PROM memory (340 bits)
  - binary counting
- Synchronous protocol
- 50 or 120 units

T2G (3)

- E2PROM contents
  - *I* (permanent public data, including card identifier)
  - *D* (variable data, including the balance)
  - *S* (secret key)
- To prevent from cloning, the data *I* and *D* are "signed" along with a challenge *X,* by a (dynamic) MAC, *computed* by the card
- This protocol is repeatedly executed during the phone call
- Typical sizes: 64 bits for each parameter

T2G (4)

X

Y = FAC (I, D, S, X)

....

X’

Y’ = FAC (I, D’, S, X’)

T2G (5)

- <u>General requirements</u>

  1) The chip must remain cheap

     → design the FAC with only **500 GE** !!!

     (*GE = logic Gate Equivalent*)

  2) The transaction time must be short

     → the number of rounds/iterations is "limited"

- Several versions of FAC have been designed

FAC (1)

- Technical requirement 1: The protocol is synchronous

  → E2PROM is read sequentially (bit by bit)

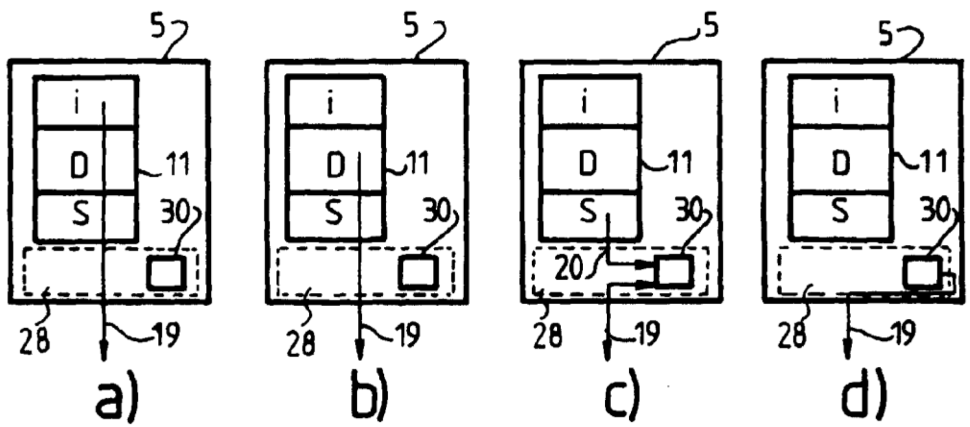


FIG.6

FAC (2)

- Technical requirement 2: The number of GE is… 500 !

  → ROM (≈ 6 GE/bit) and RAM (≈ 4 GE/bit) are very limited

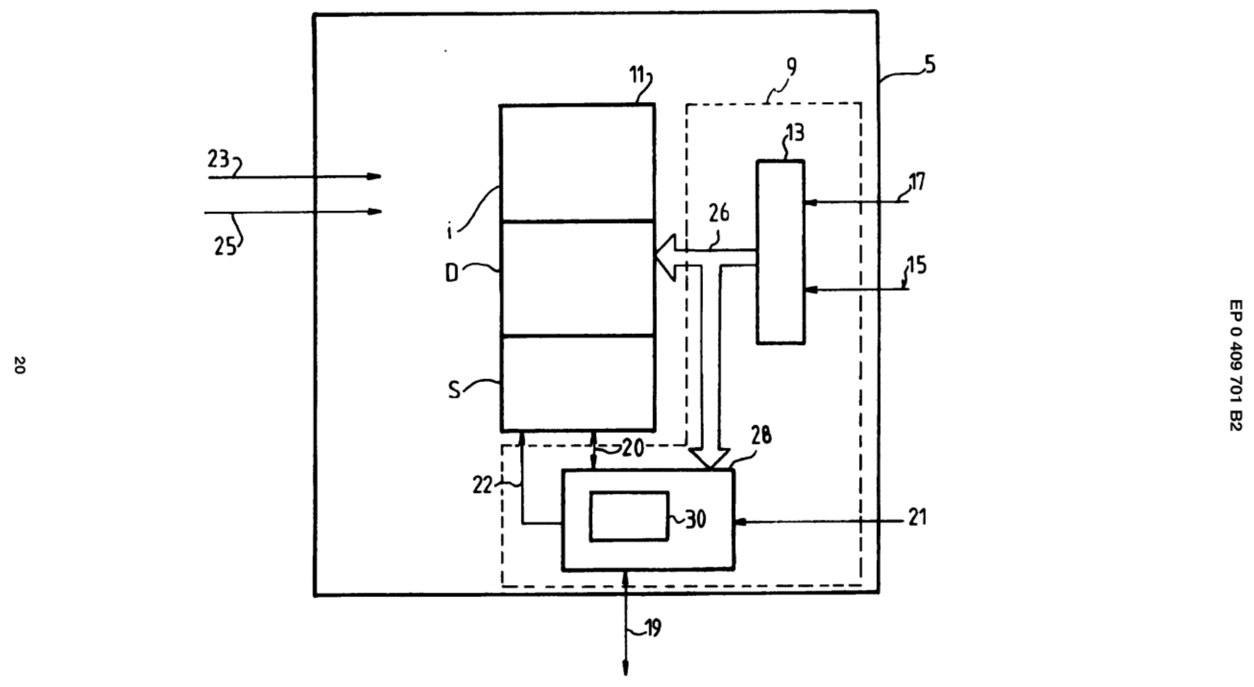


FIG 2

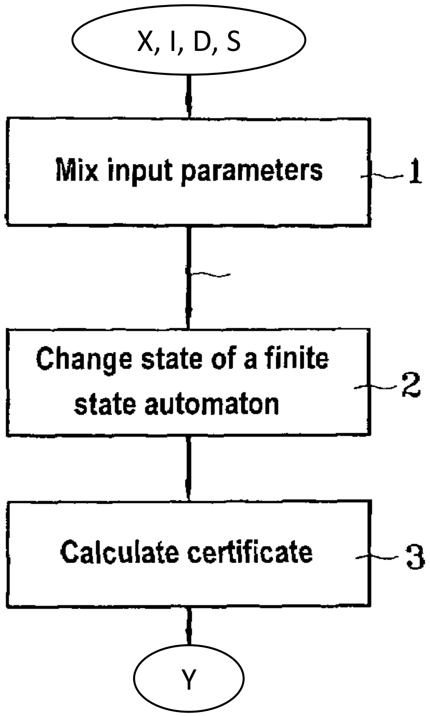
FAC (3)

- Technical requirement 3: Clock frequency is low (typically 847 kHz)

→ E2PROM can be scanned only a few times

FAC (4)

- <u>Overall process</u>

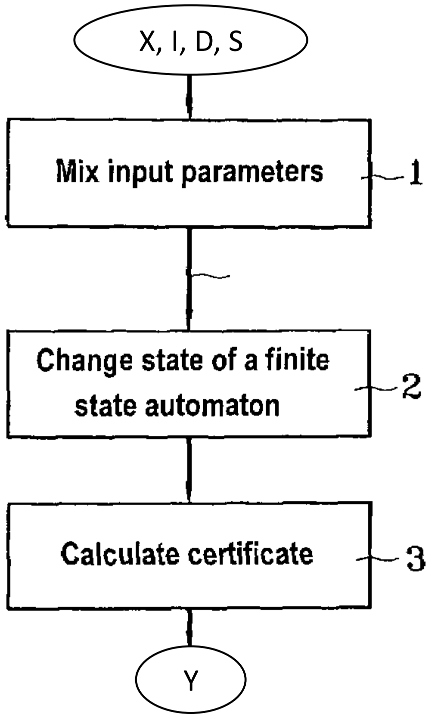


FAC (5)

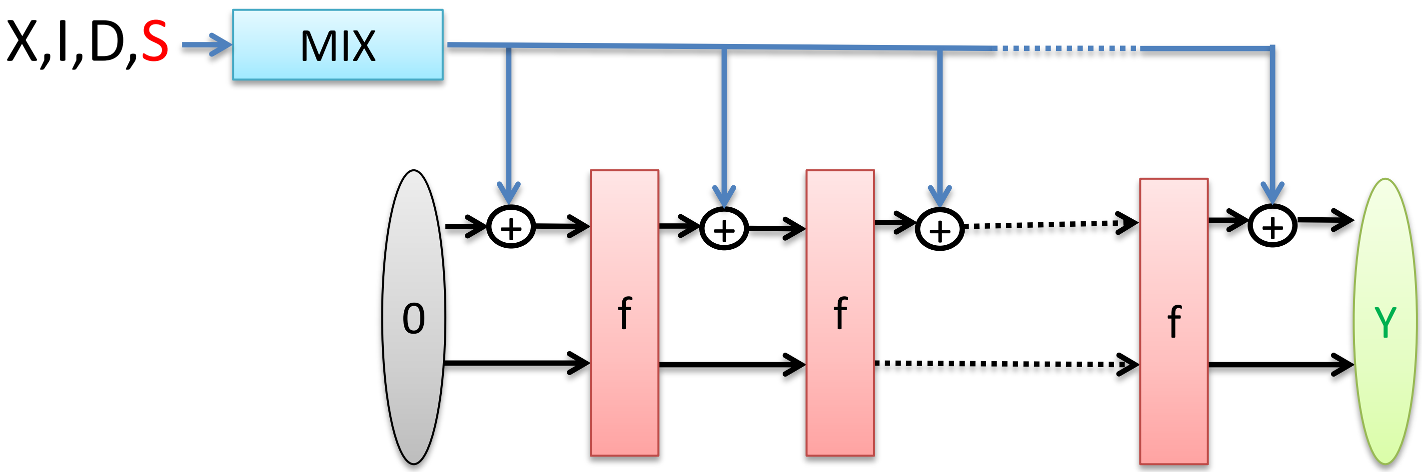
- Back to the 500 GE requirement

→ trade-off to find between:

- Complexity of *Mix* function
- State length
- Complexity of *Change state* function



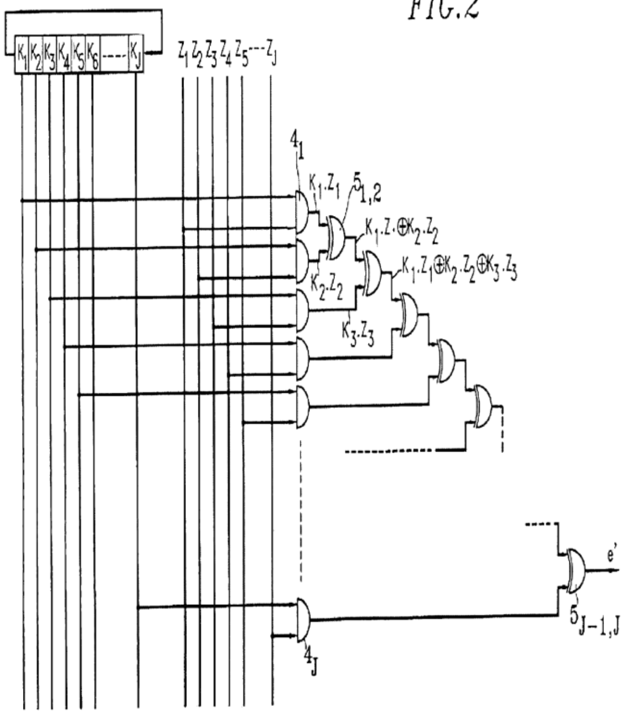
FAC (6)



FAC (7)

- *Mix* function
- A linear function of inputs
- Main ingredients:
  - inputs entered several times
  - sometimes after (easy-to-wire) permutation of bits
  - (easy-to-wire) LFSR

FIG.2



FAC (8)

- State length (*b bits*)
- Recall: RAM bit ≈ 6 GE
- Depending on version, $b = 4m$ ($1 \leq m \leq 8$)
- Result Y is (part of) last state

FAC (9)

- *Change state* function
- A non-linear *b*-bit permutation
- Main ingredient: 4-bit S-box
  - State bit *r0* is XOR-ed with the output bit of Mix function
  - Other state bits are unchanged
- Up to four S-box, completed with rotations (of quartets)

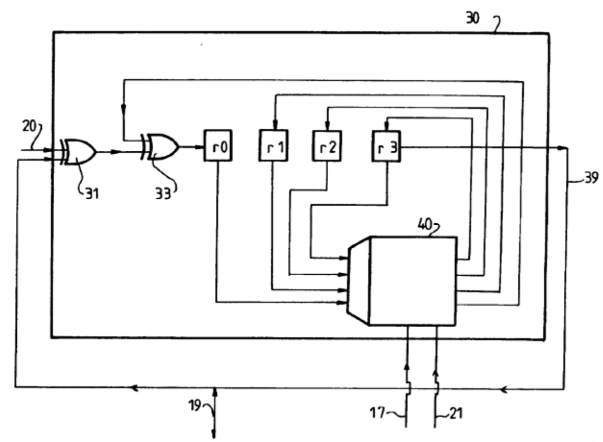
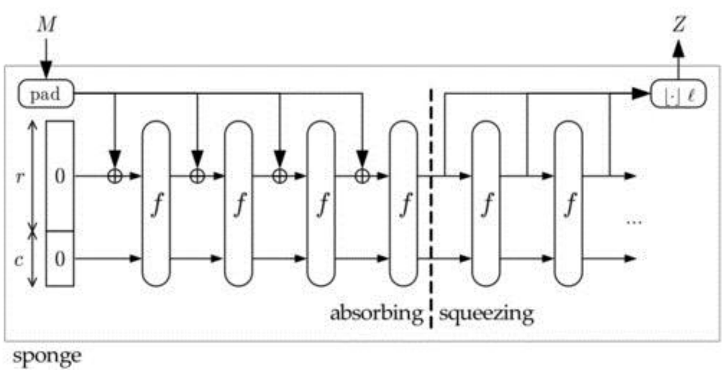


FIG.5

Looking back 25 years after (1)

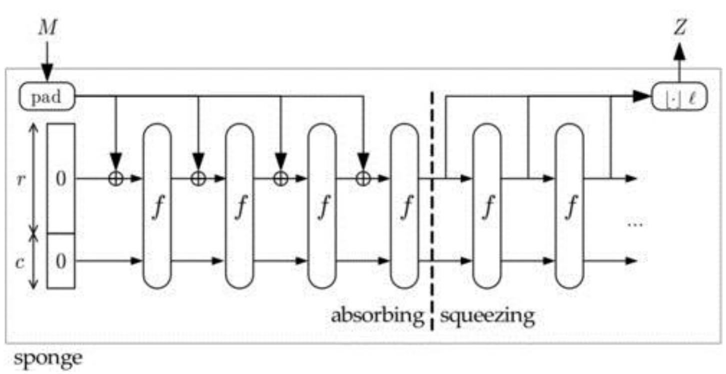
- Overall process

- Partly similar to the "absorbing phase" of a binary sponge – function:
  - All inputs are concatenated
  - Phase 1 output bit is XOR-ed with the state
  - Then the state enters a permutation



Looking back 25 years after (2)

- <u>Overall process</u>
- But it differs in that:
  - state is much smaller but…
  - … the inputs are mixed in a “complex” not only padded

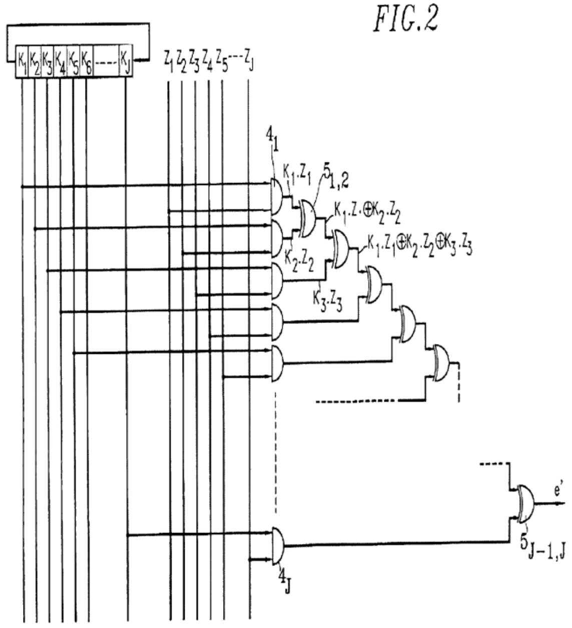


Looking back 25 years after (3)

- <u>*Mix* function</u>

- Evolution similar to the one of "message schedule" process in MDx-SHAx family:
  - inputs processed several times
  - sometimes after (easy-to-wire) bit-permutations
  - linear recurrences

FIG.2



Looking back 25 years after (4)

- *Change state* function
- 4-bit S-boxes happen to be a "natural" choice in lightweight crypto

(see e.g. *Present*)

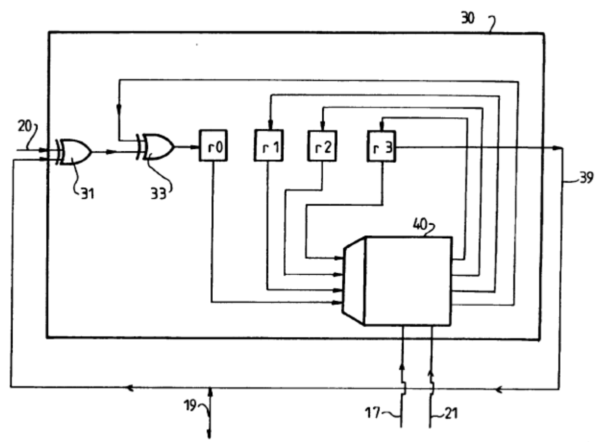


FIG.5

Conclusion

- Lightweight crypto was made necessary as soon as 1989 because:
  - mobile phones did not exist
  - money in public phones was undesirable
  - on-line architecture was not yet technically possible
  - prepaid chip phone cards had to be very cheap

- Lightweight crypto became a recognized research area 10-15 years later, with emergence of RFID

Credits

- Jean-Claude Paillès, David Arditti, Henri Gilbert, Jacques Burger