Chapter 12

Hash Algorithms

Hash Algorithms

- see similarities in the evolution of hash functions & block ciphers
  - increasing power of brute-force attacks
  - leading to evolution in algorithms
  - from DES to AES in block ciphers
  - from MD4 & MD5 to SHA-1 & RIPEMD-160 in hash algorithms
- likewise tend to use common iterative structure as do block ciphers

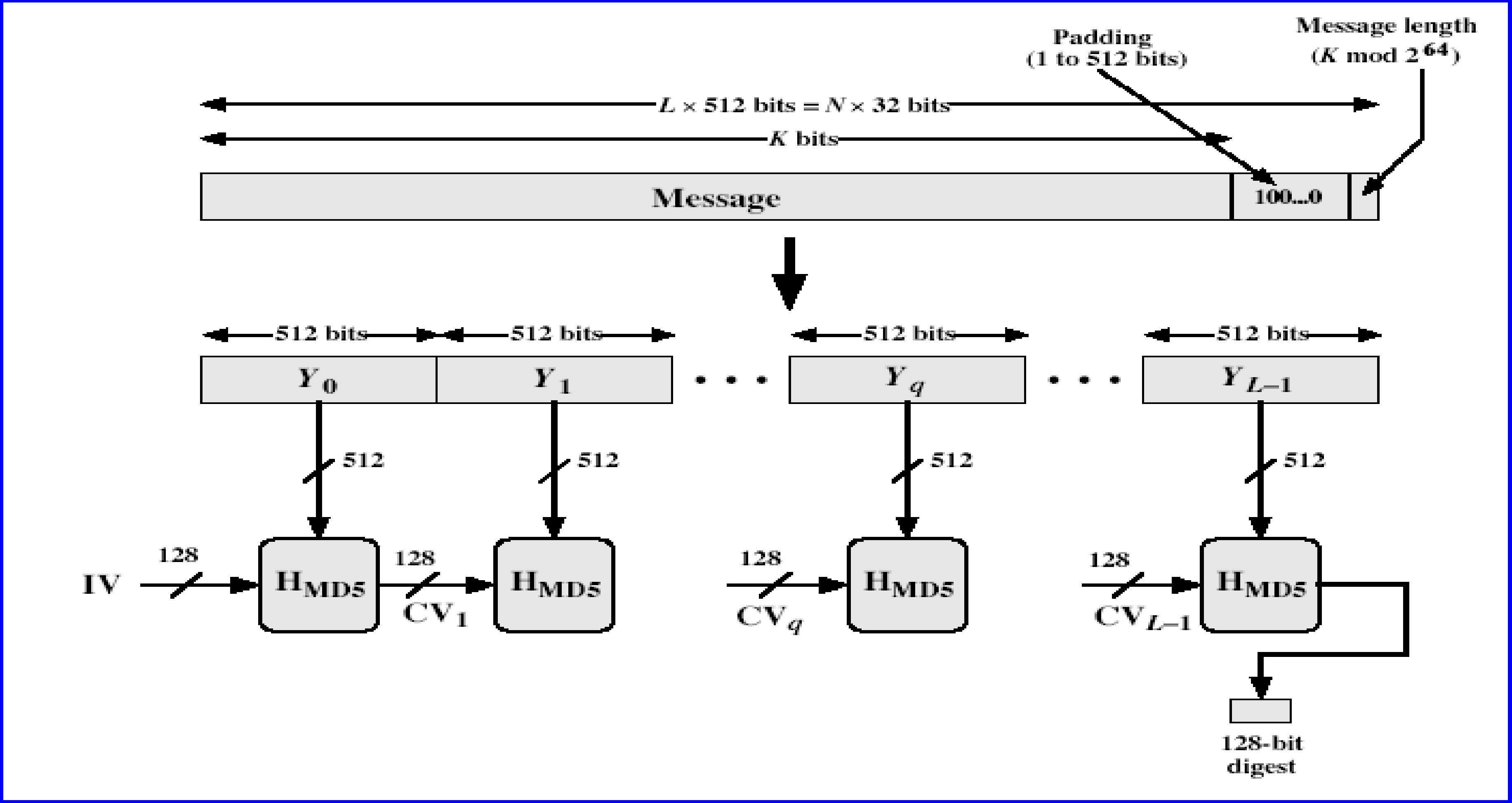
MD5

- designed by Ronald Rivest (the R in RSA)
- latest in a series of MD2, MD4
- produces a 128-bit hash value
- until recently was the most widely used hash algorithm
  - in recent times have both brute-force & cryptanalytic concerns
- specified as Internet standard RFC1321

MD5 Overview

1. pad message so its length is 448 mod 512
2. append a 64-bit length value to message
3. initialise 4-word (128-bit) MD buffer (A,B,C,D)
4. process message in 16-word (512-bit) blocks:
   - using 4 rounds of 16 bit operations on message block & buffer
   - add output to buffer input to form new buffer value
5. output hash value is the final buffer value

MD5 Overview



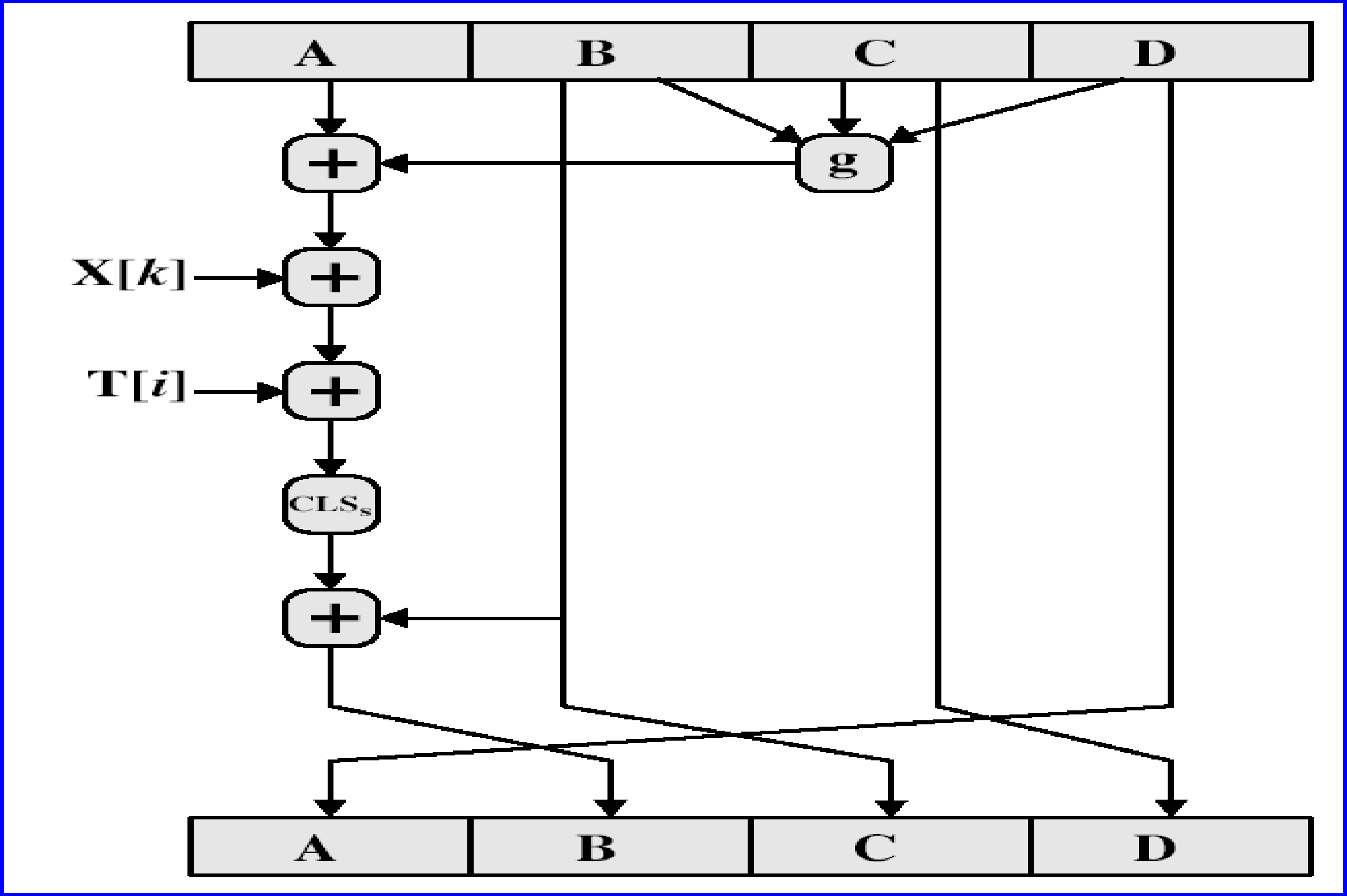
MD5 Compression Function

- each round has 16 steps of the form:

```
a = b+((a+g(b,c,d)+X[k]+T[i])<<<s)
```

- a,b,c,d refer to the 4 words of the buffer, but used in varying permutations
  - note this updates 1 word only of the buffer
  - after 16 steps each word is updated 4 times
- where g(b,c,d) is a different nonlinear function in each round (F,G,H,I)
- T[i] is a constant value derived from sin

MD5 Compression Function



MD4

- precursor to MD5
- also produces a 128-bit hash of message
- has 3 rounds of 16 steps vs 4 in MD5
- design goals:
  - collision resistant (hard to find collisions)
  - direct security (no dependence on "hard" problems)
  - fast, simple, compact
  - favours little-endian systems (eg PCs)

Strength of MD5

- MD5 hash is dependent on all message bits
- Rivest claims security is good as can be
- known attacks are:
  - Berson 92 attacked any 1 round using differential cryptanalysis (but can’t extend)
  - Boer & Bosselaers 93 found a pseudo collision (again unable to extend)
  - Dobbertin 96 created collisions on MD compression function (but initial constants prevent exploit)
- conclusion is that MD5 looks vulnerable soon

Secure Hash Algorithm (SHA-1)

- SHA was designed by NIST & NSA in 1993, revised 1995 as SHA-1
- US standard for use with DSA signature scheme
  - standard is FIPS 180-1 1995, also Internet RFC3174
  - nb. the algorithm is SHA, the standard is SHS
- produces 160-bit hash values
- now the generally preferred hash algorithm
- based on design of MD4 with key differences

SHA Overview

1. pad message so its length is 448 mod 512
2. append a 64-bit length value to message
3. initialise 5-word (160-bit) buffer (A,B,C,D,E) to (67452301,efcdab89,98badcfe,10325476,c3d2e1f0)
4. process message in 16-word (512-bit) chunks:
   - expand 16 words into 80 words by mixing & shifting
   - use 4 rounds of 20 bit operations on message block & buffer
   - add output to input to form new buffer value
5. output hash value is the final buffer value

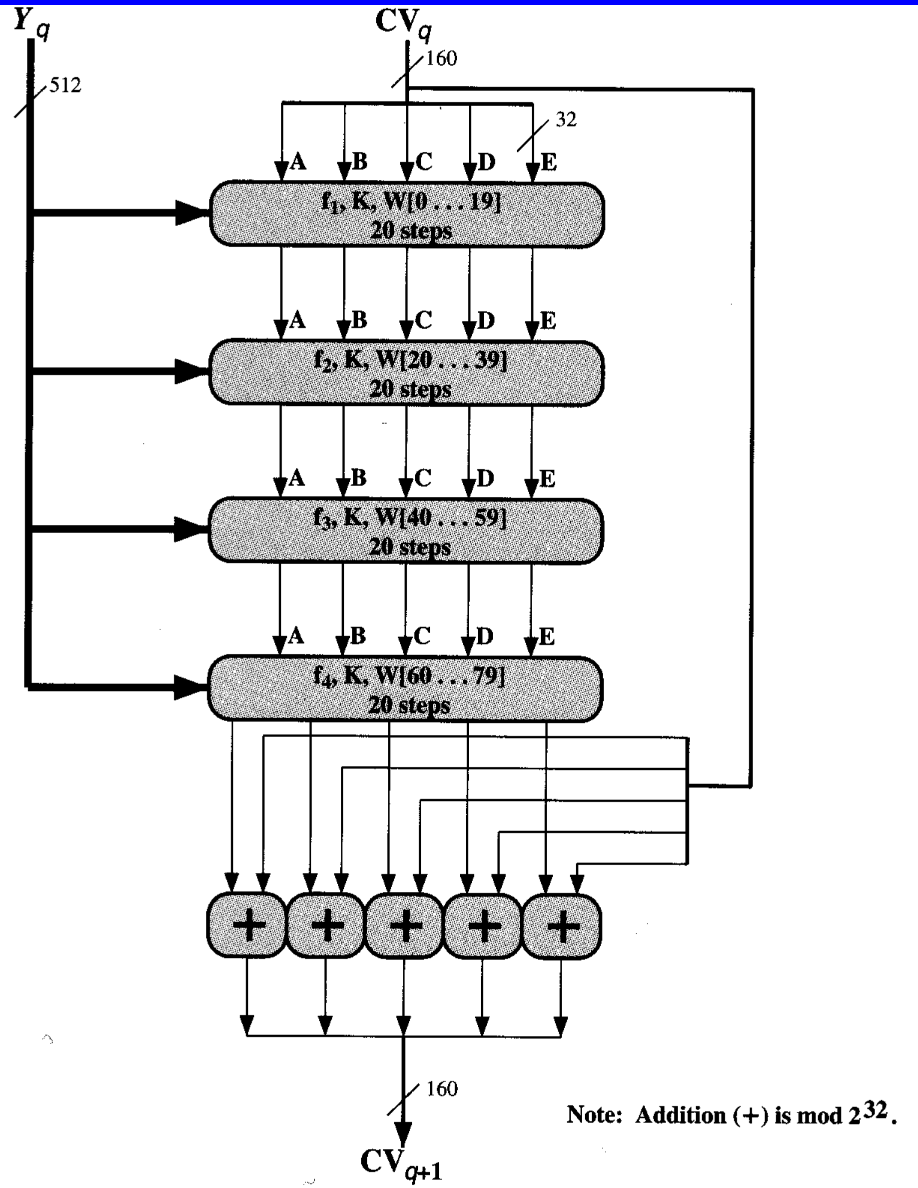


Figure 12.5 SHA-1 Processing of a Single 512-bit Block (SHA-1 compression function)

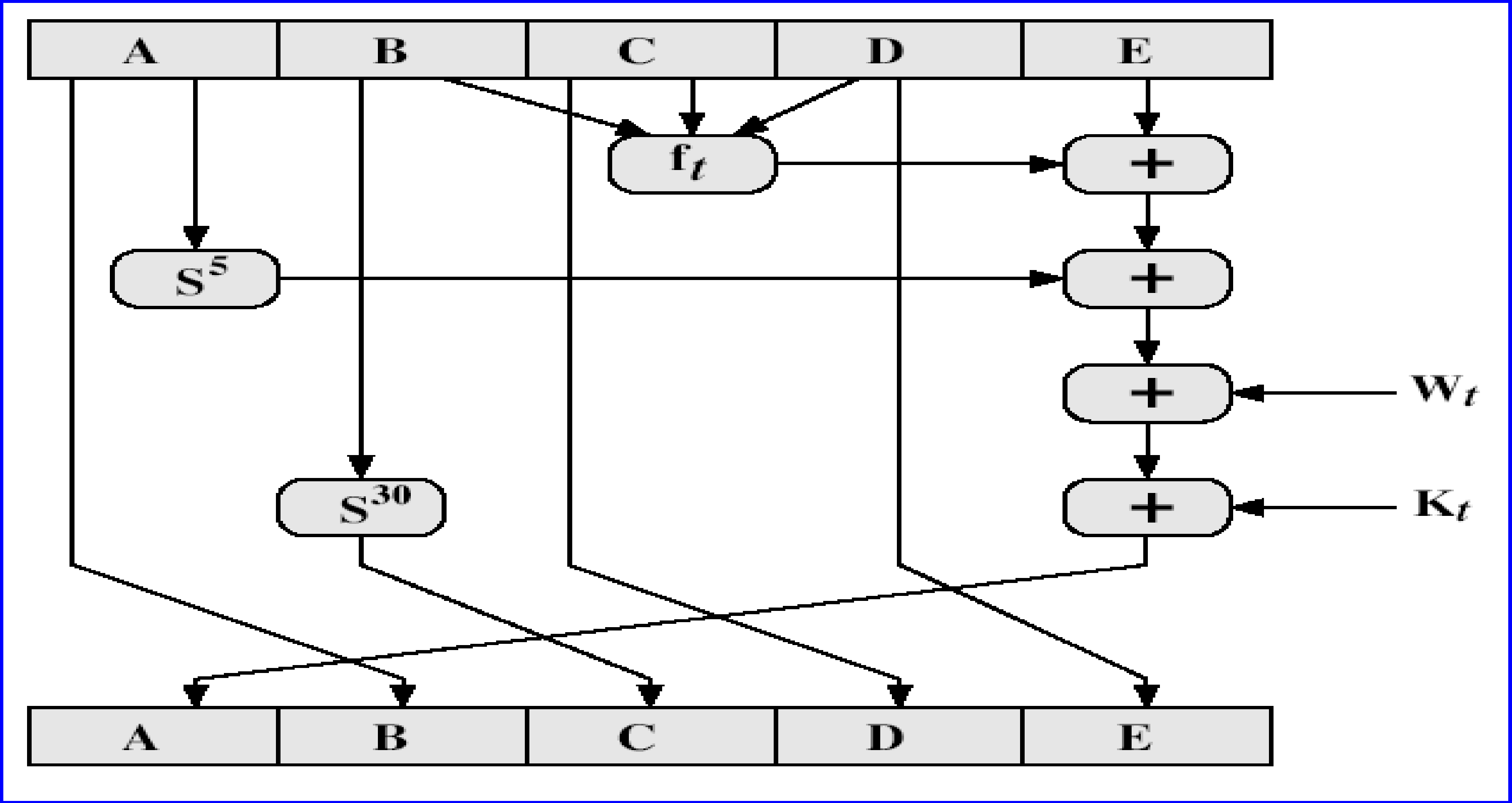
SHA-1 Compression Function

- each round has 20 steps which replaces the 5 buffer words thus:

  (A,B,C,D,E) <-
  (E+f(t,B,C,D)+(A<<5)+W_t+K_t),A,(B<<30),C,D)

- a,b,c,d refer to the 4 words of the buffer
- t is the step number
- f(t,B,C,D) is nonlinear function for round
- W_t is derived from the message block
- K_t is a constant value derived from sin

SHA-1 Compression Function



SHA-1 versus MD5

- brute force attack is harder (160 vs 128 bits for MD5)
- not vulnerable to any known attacks (compared to MD4/5)
- a little slower than MD5 (80 vs 64 steps)
- both designed as simple and compact
- optimised for big endian CPU's (vs MD5 which is optimised for little endian CPU’s)

Revised Secure Hash Standard

- NIST have issued a revision FIPS 180-2
- adds 3 additional hash algorithms
- SHA-256, SHA-384, SHA-512
- designed for compatibility with increased security provided by the AES cipher
- structure & detail is similar to SHA-1
- hence analysis should be similar

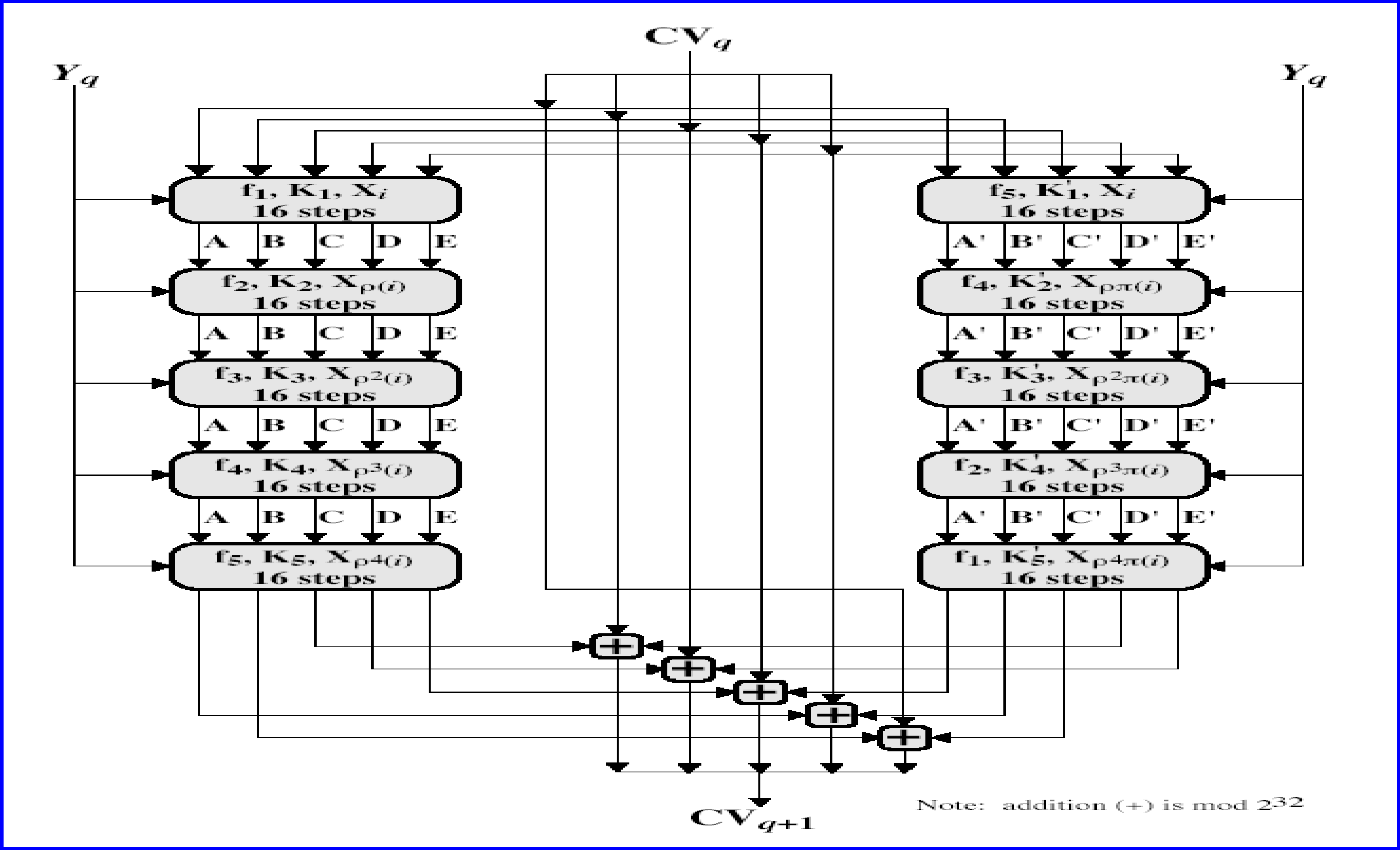
RIPEMD-160

- RIPEMD-160 was developed in Europe as part of RIPE project in 96
- by researchers involved in attacks on MD4/5
- initial proposal strengthen following analysis to become RIPEMD-160
- somewhat similar to MD5/SHA
- uses 2 parallel lines of 5 rounds of 16 steps
- creates a 160-bit hash value
- slower, but probably more secure, than SHA

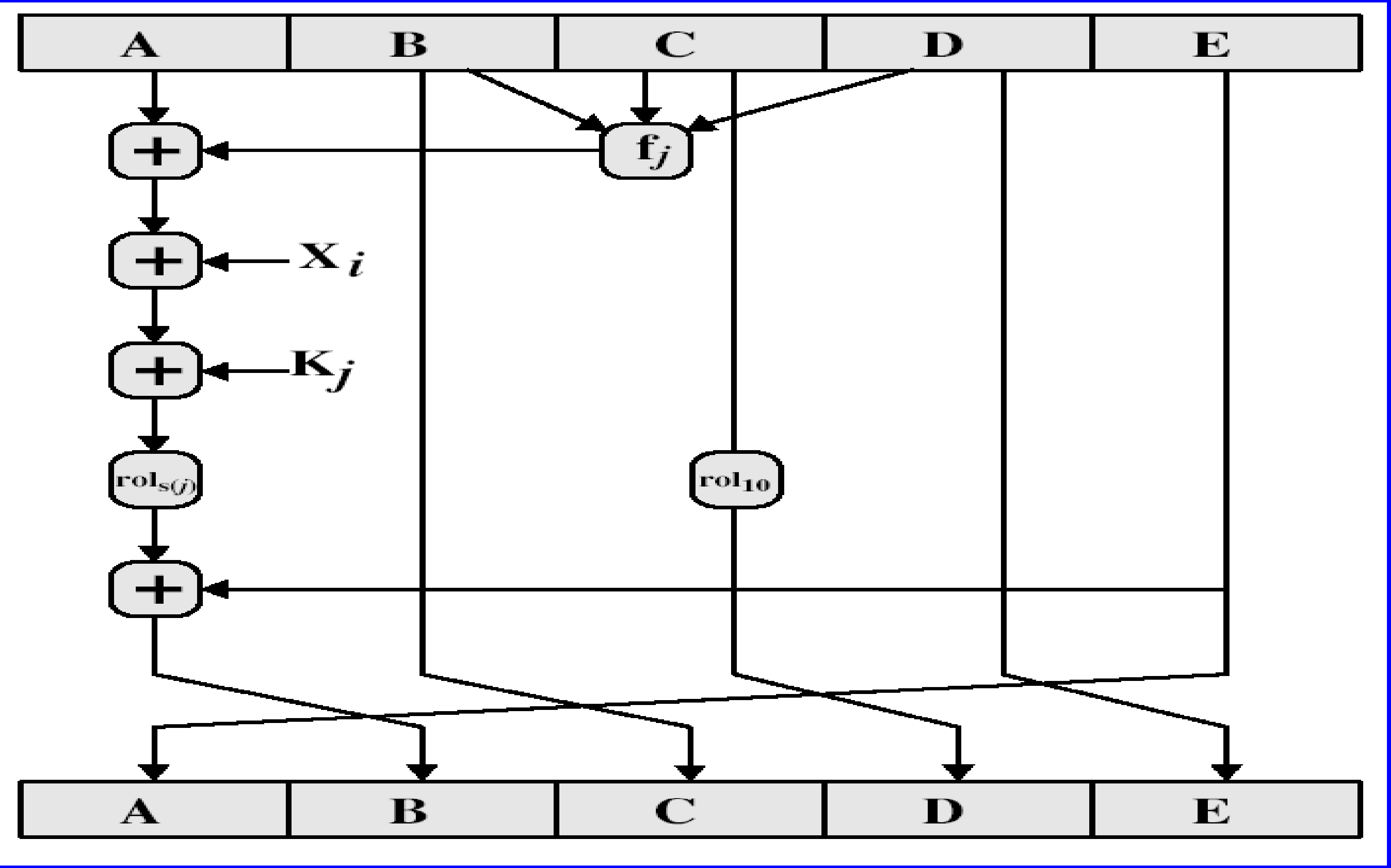
RIPEMD-160 Overview

1. pad message so its length is 448 mod 512
2. append a 64-bit length value to message
3. initialise 5-word (160-bit) buffer (A,B,C,D,E) to (67452301,efcdab89,98badcfe,10325476,c3d2e1f0)
4. process message in 16-word (512-bit) chunks:
   - use 10 rounds of 16 bit operations on message block & buffer – in 2 parallel lines of 5
   - add output to input to form new buffer value
5. output hash value is the final buffer value

RIPEMD-160 Round



RIPEMD-160 Compression Function



RIPEMD-160 Design Criteria

- use 2 parallel lines of 5 rounds for increased complexity
- for simplicity the 2 lines are very similar
- step operation very close to MD5
- permutation varies parts of message used
- circular shifts designed for best results

RIPEMD-160 versus MD5 & SHA-1

- brute force attack harder (160 like SHA-1 vs 128 bits for MD5)
- not vulnerable to known attacks, like SHA-1 though stronger (compared to MD4/5)
- slower than MD5 (more steps)
- all designed as simple and compact
- SHA-1 optimised for big endian CPU's vs RIPEMD-160 & MD5 optimised for little endian CPU's

Keyed Hash Functions as MACs

- have desire to create a MAC using a hash function rather than a block cipher
  - because hash functions are generally faster
  - not limited by export controls unlike block ciphers
- hash includes a key along with the message
- original proposal:

```
KeyedHash = Hash(Key|Message)
```

  - some weaknesses were found with this
- eventually led to development of HMAC

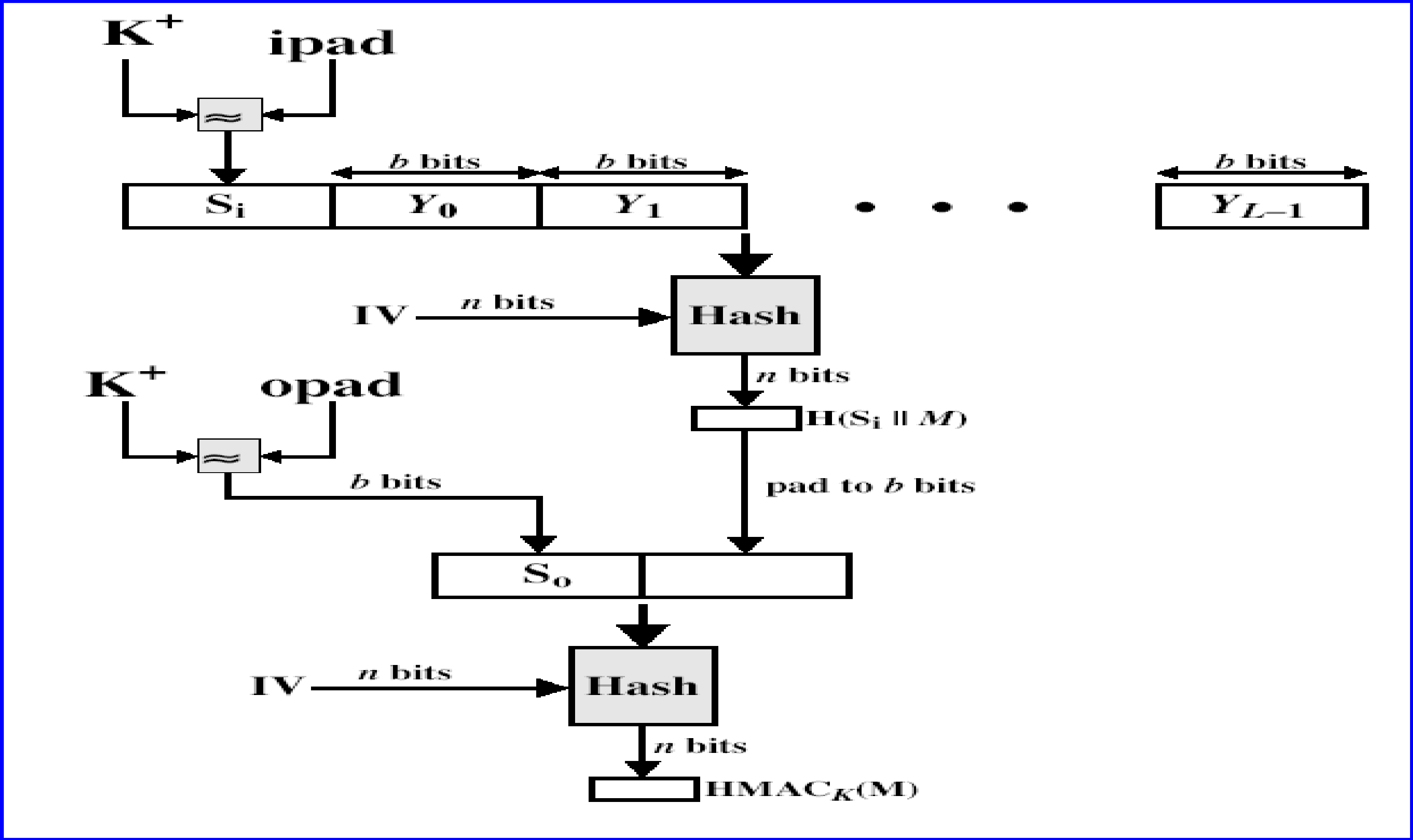
HMAC

- specified as Internet standard RFC2104
- uses hash function on the message:

$$HMAC_K = Hash[(K^+ \text{ XOR } opad) \,||\, Hash[(K^+ \text{ XOR } ipad)||M)]]$$

- where K^+ is the key padded out to size
- and opad, ipad are specified padding constants
- overhead is just 3 more hash calculations than the message needs alone
- any of MD5, SHA-1, RIPEMD-160 can be used

HMAC Overview



HMAC Security

- know that the security of HMAC relates to that of the underlying hash algorithm
- attacking HMAC requires either:
  - brute force attack on key used
  - birthday attack (but since keyed would need to observe a very large number of messages)
- choose hash function used based on speed verses security constraints

Summary

- have considered:
  - some current hash algorithms:
    - MD5, SHA-1, RIPEMD-160
  - HMAC authentication using a hash function