Advanced Encryption Standard (AES)

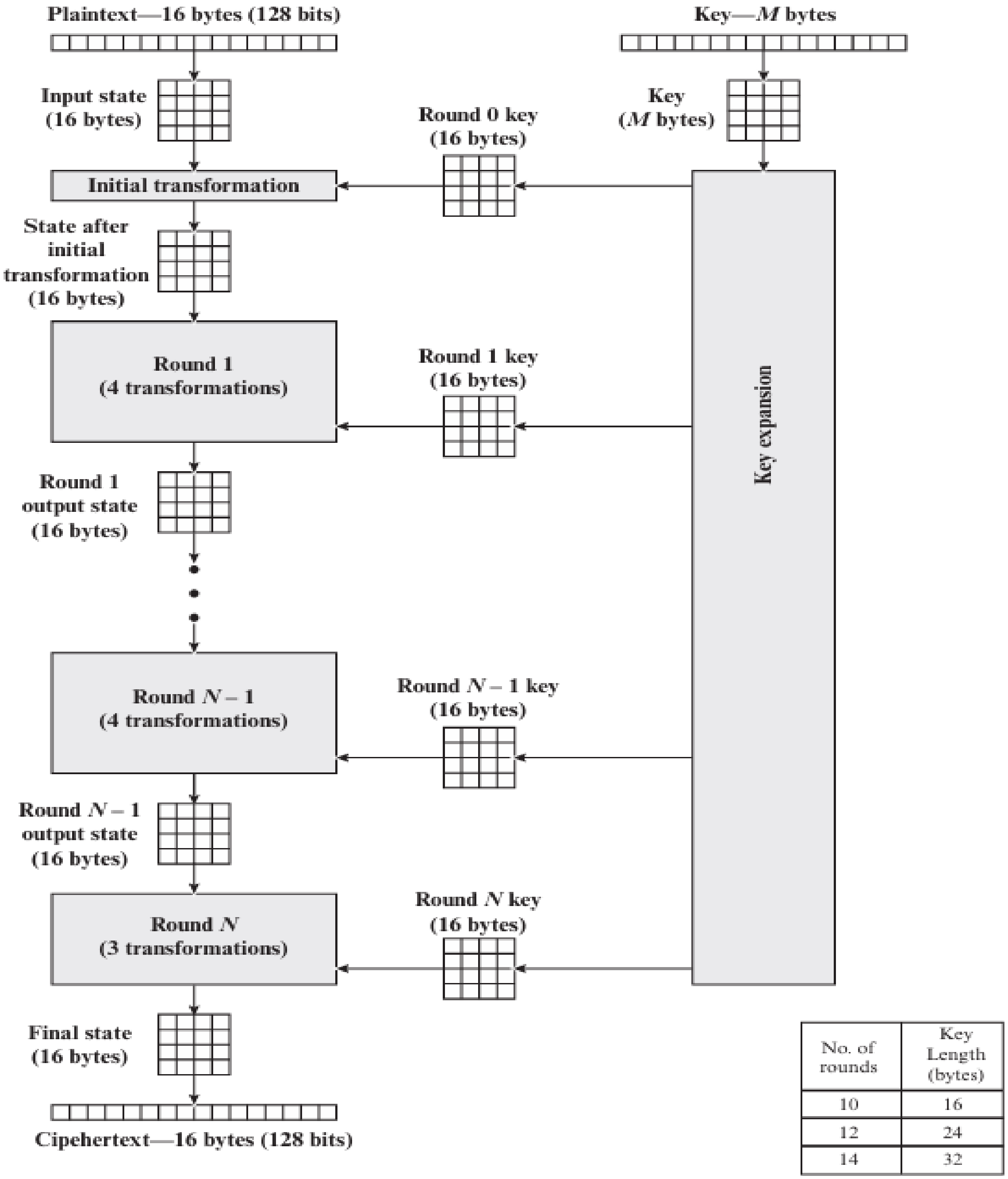
AES is a Block Cipher.

The key size can be 128/192/256 bits.(16/24/32 bytes)

Plain text block size:128 bits/16 bytes.

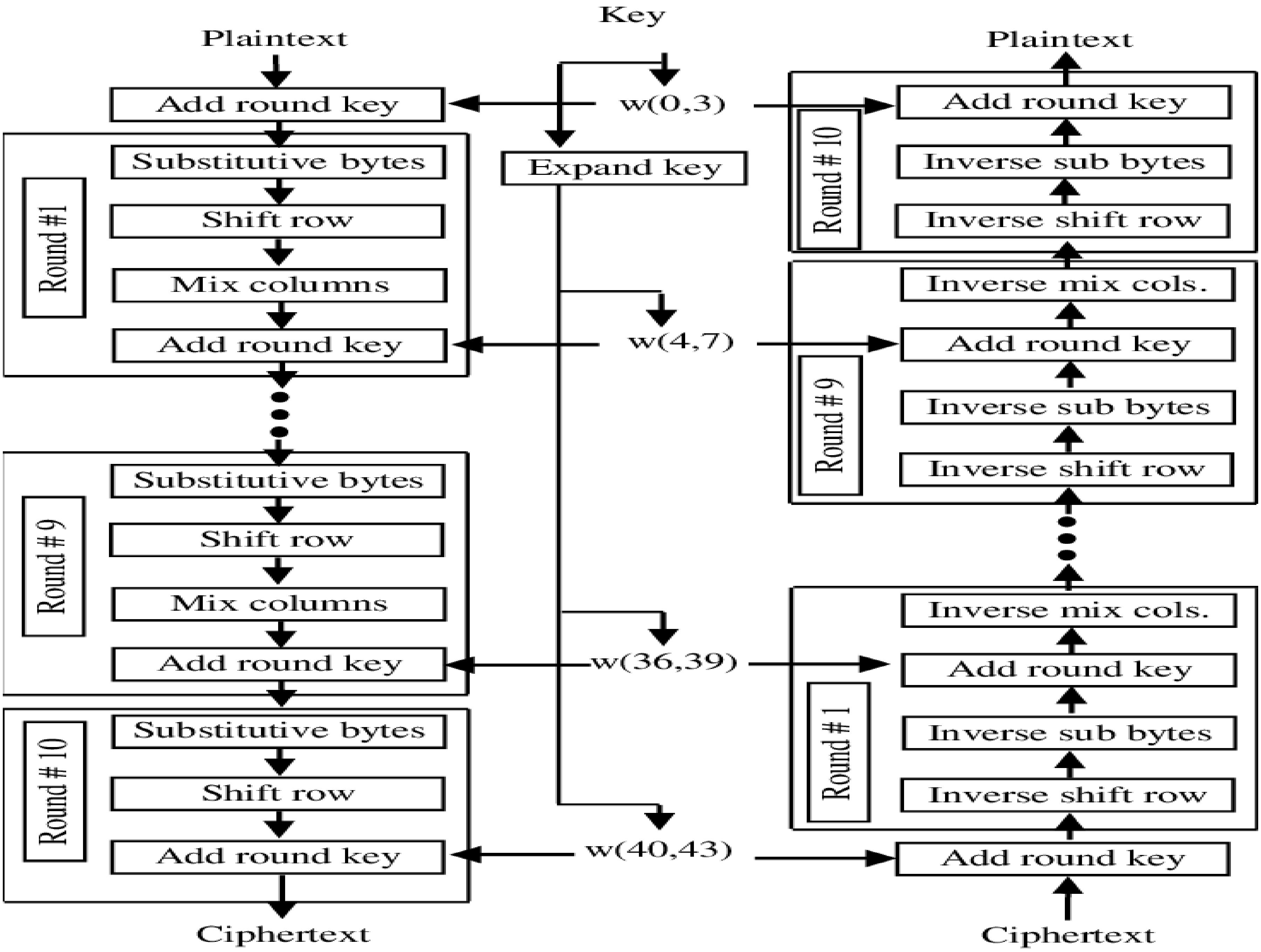
The number of rounds depends on the key length as follows :

- 128-bit key – 10 rounds
- 192-bit key – 12 rounds
- 256-bit key – 14 rounds

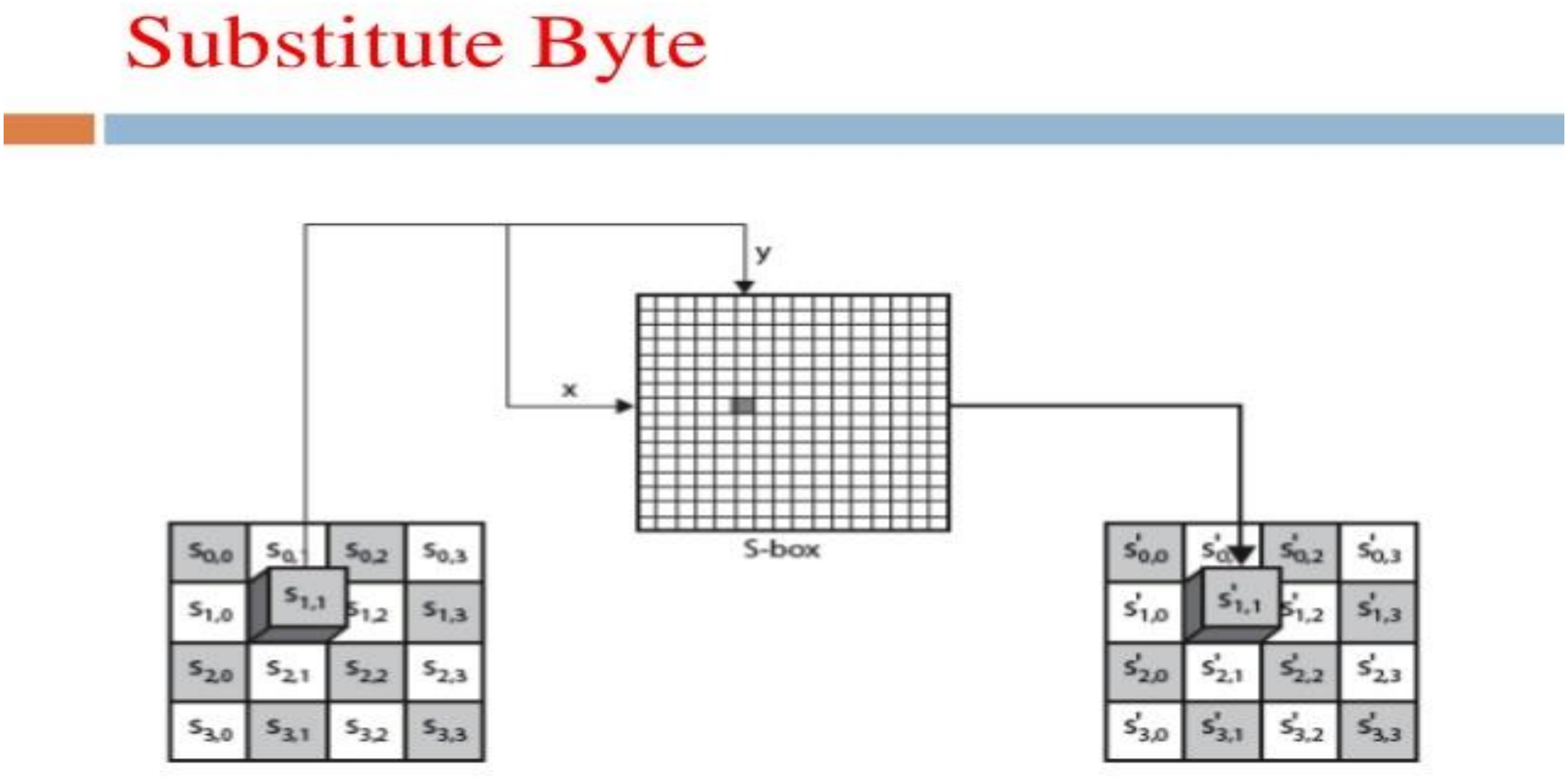

Plaintext—16 bytes (128 bits)
Key—M bytes
Input state (16 bytes)
Key (M bytes)
Round 0 key (16 bytes)
Initial transformation
State after initial transformation (16 bytes)
Round 1 (4 transformations)
Round 1 key (16 bytes)
Key expansion
Round 1 output state (16 bytes)
Round N – 1 (4 transformations)
Round N – 1 key (16 bytes)
Round N – 1 output state (16 bytes)
Round N (3 transformations)
Round N key (16 bytes)
Final state (16 bytes)
Cipehertext—16 bytes (128 bits)

No. of rounds	Key Length (bytes)
10	16
12	24
14	32

Figure 6.1 AES Encryption Process


Key
Plaintext
Add round key
w(0,3)
Expand key
Round #1
Substitutive bytes
Shift row
Mix columns
Add round key
w(4,7)
Round # 9
Substitutive bytes
Shift row
Mix columns
Add round key
w(36,39)
Round # 10
Substitutive bytes
Shift row
Add round key
w(40,43)
Ciphertext
Plaintext
Round # 10
Add round key
Inverse sub bytes
Inverse shift row
Round # 9
Inverse mix cols.
Add round key
Inverse sub bytes
Inverse shift row
Round # 1
Inverse mix cols.
Add round key
Inverse sub bytes
Inverse shift row
Add round key
Ciphertext

Substitute byte transformation

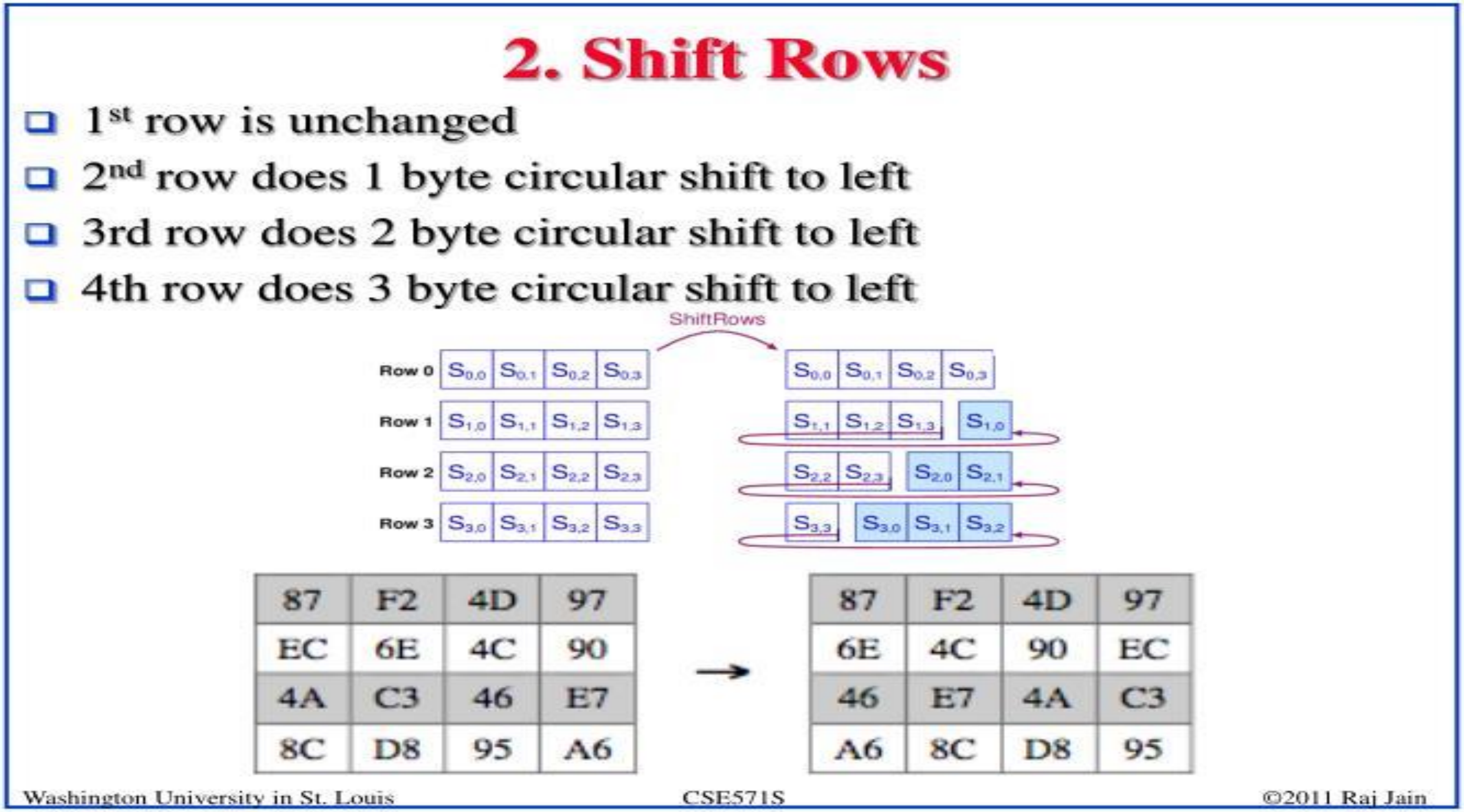


Substitute Byte

$s_{0,0}$	$s_{0,1}$	$s_{0,2}$	$s_{0,3}$
$s_{1,0}$	$s_{1,1}$	$s_{1,2}$	$s_{1,3}$
$s_{2,0}$	$s_{2,1}$	$s_{2,2}$	$s_{2,3}$
$s_{3,0}$	$s_{3,1}$	$s_{3,2}$	$s_{3,3}$

$s'_{0,0}$	$s'_{0,1}$	$s'_{0,2}$	$s'_{0,3}$
$s'_{1,0}$	$s'_{1,1}$	$s'_{1,2}$	$s'_{1,3}$
$s'_{2,0}$	$s'_{2,1}$	$s'_{2,2}$	$s'_{2,3}$
$s'_{3,0}$	$s'_{3,1}$	$s'_{3,2}$	$s'_{3,3}$

Shift Row



2. Shift Rows

- 1st row is unchanged
- 2nd row does 1 byte circular shift to left
- 3rd row does 2 byte circular shift to left
- 4th row does 3 byte circular shift to left

ShiftRows

Row 0	$S_{0,0}$	$S_{0,1}$	$S_{0,2}$	$S_{0,3}$
Row 1	$S_{1,0}$	$S_{1,1}$	$S_{1,2}$	$S_{1,3}$
Row 2	$S_{2,0}$	$S_{2,1}$	$S_{2,2}$	$S_{2,3}$
Row 3	$S_{3,0}$	$S_{3,1}$	$S_{3,2}$	$S_{3,3}$

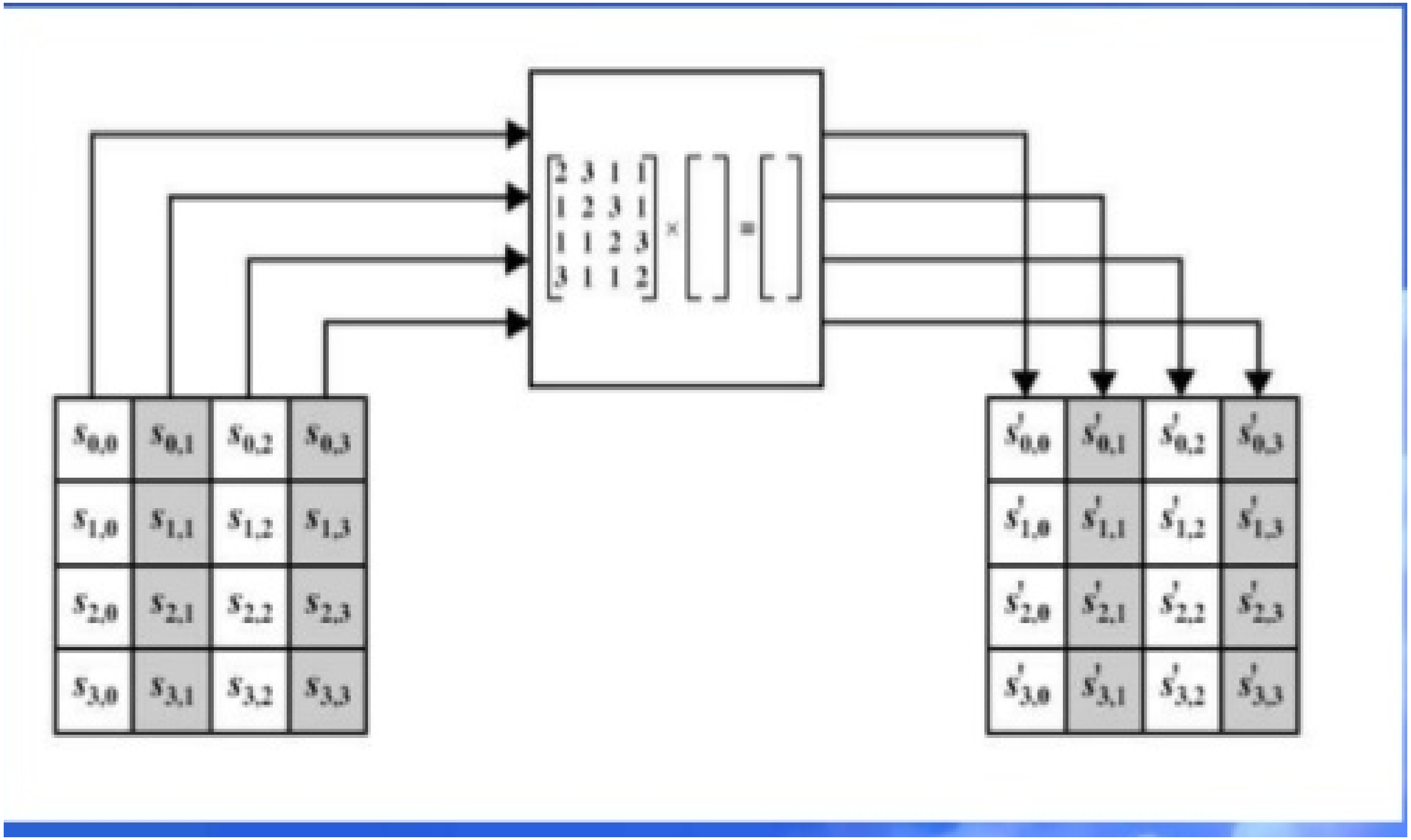
$S_{0,0}$	$S_{0,1}$	$S_{0,2}$	$S_{0,3}$
$S_{1,1}$	$S_{1,2}$	$S_{1,3}$	$S_{1,0}$
$S_{2,2}$	$S_{2,3}$	$S_{2,0}$	$S_{2,1}$
$S_{3,3}$	$S_{3,0}$	$S_{3,1}$	$S_{3,2}$

87	F2	4D	97
EC	6E	4C	90
4A	C3	46	E7
8C	D8	95	A6

→

87	F2	4D	97
6E	4C	90	EC
46	E7	4A	C3
A6	8C	D8	95

Mix columns

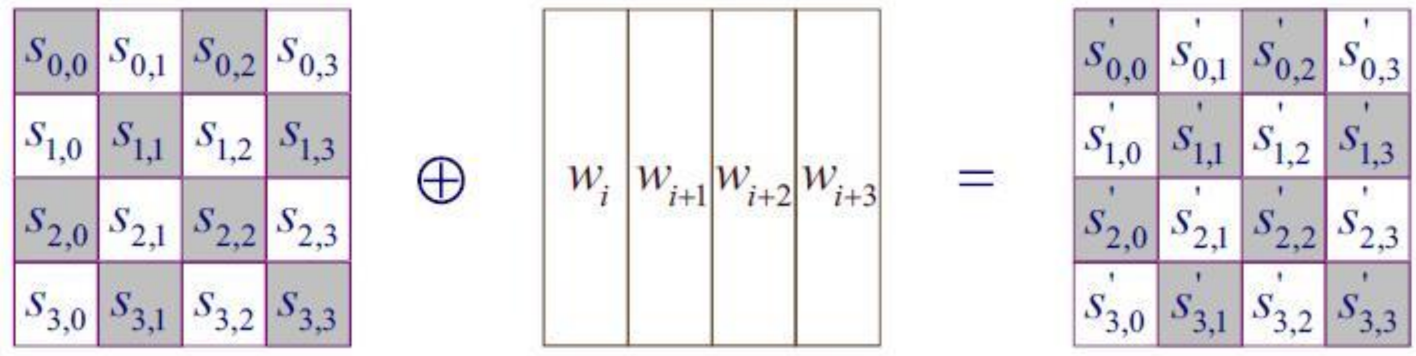


$$\begin{bmatrix} 2 & 3 & 1 & 1 \\ 1 & 2 & 3 & 1 \\ 1 & 1 & 2 & 3 \\ 3 & 1 & 1 & 2 \end{bmatrix} \times \begin{bmatrix} \quad \end{bmatrix} = \begin{bmatrix} \quad \end{bmatrix}$$

$s_{0,0}$	$s_{0,1}$	$s_{0,2}$	$s_{0,3}$
$s_{1,0}$	$s_{1,1}$	$s_{1,2}$	$s_{1,3}$
$s_{2,0}$	$s_{2,1}$	$s_{2,2}$	$s_{2,3}$
$s_{3,0}$	$s_{3,1}$	$s_{3,2}$	$s_{3,3}$

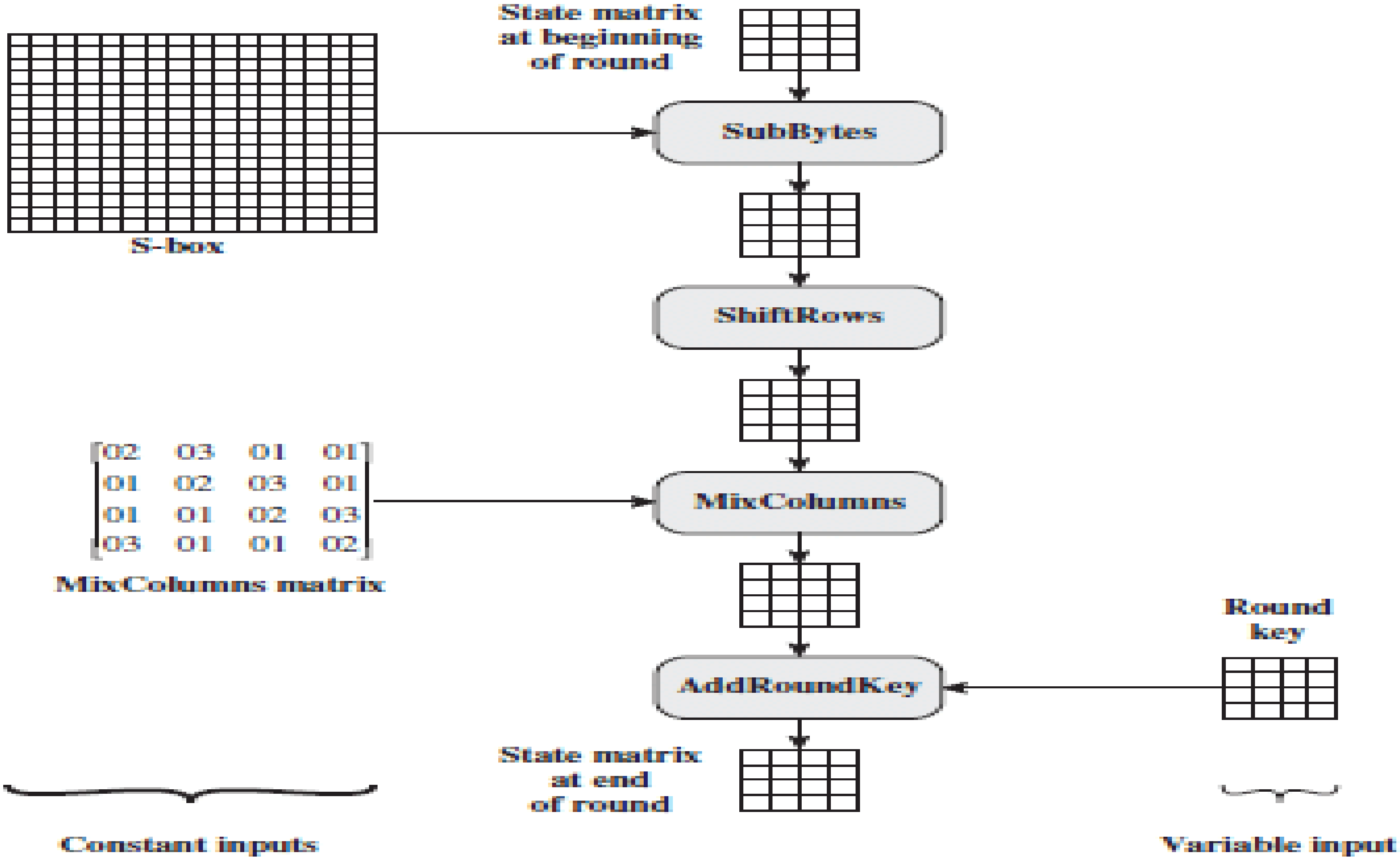
$s'_{0,0}$	$s'_{0,1}$	$s'_{0,2}$	$s'_{0,3}$
$s'_{1,0}$	$s'_{1,1}$	$s'_{1,2}$	$s'_{1,3}$
$s'_{2,0}$	$s'_{2,1}$	$s'_{2,2}$	$s'_{2,3}$
$s'_{3,0}$	$s'_{3,1}$	$s'_{3,2}$	$s'_{3,3}$

Add Round Key

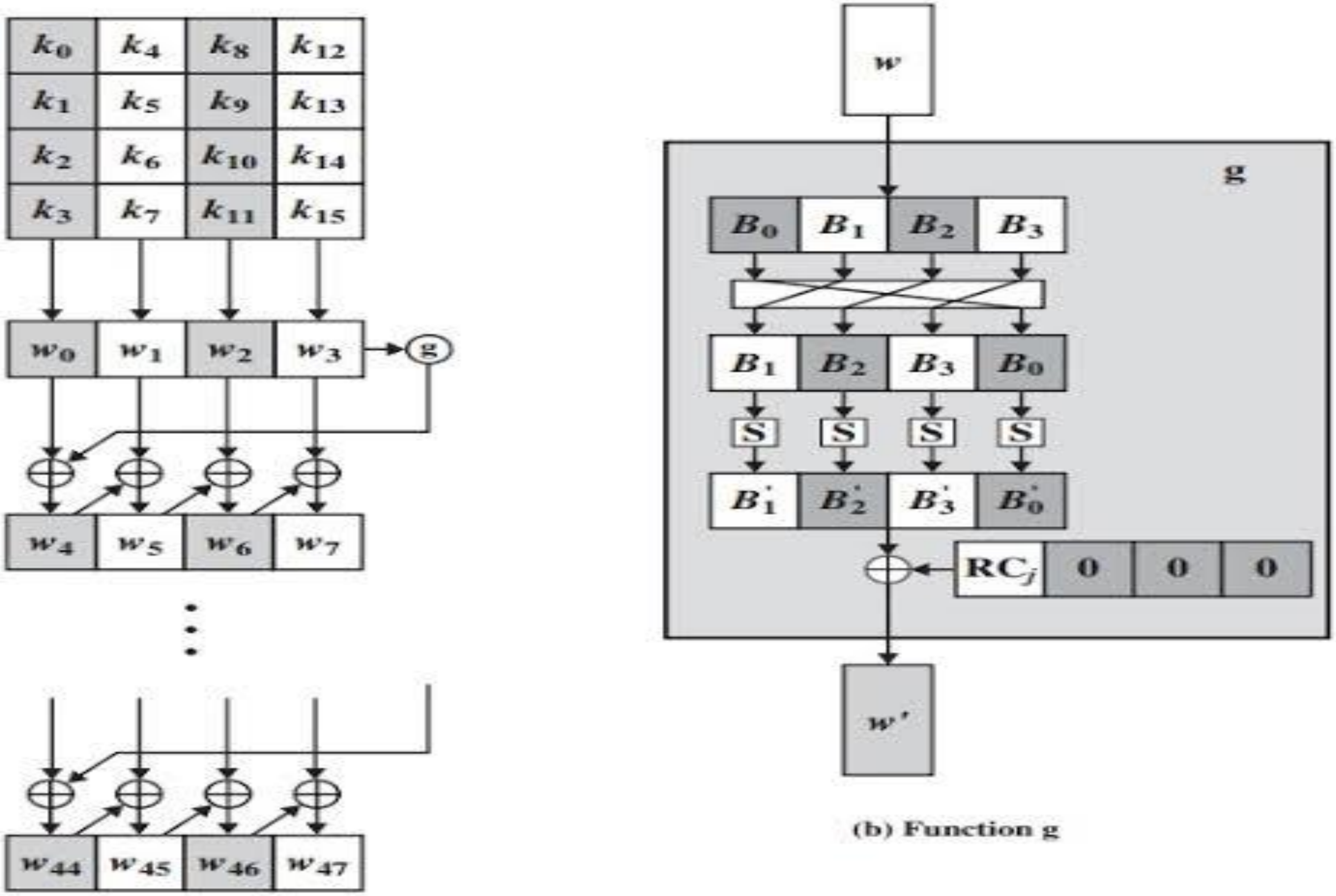


$$\begin{array}{|c|c|c|c|} \hline s_{0,0} & s_{0,1} & s_{0,2} & s_{0,3} \\ \hline s_{1,0} & s_{1,1} & s_{1,2} & s_{1,3} \\ \hline s_{2,0} & s_{2,1} & s_{2,2} & s_{2,3} \\ \hline s_{3,0} & s_{3,1} & s_{3,2} & s_{3,3} \\ \hline \end{array} \oplus \begin{array}{|c|c|c|c|} \hline w_i & w_{i+1} & w_{i+2} & w_{i+3} \\ \hline \end{array} = \begin{array}{|c|c|c|c|} \hline s'_{0,0} & s'_{0,1} & s'_{0,2} & s'_{0,3} \\ \hline s'_{1,0} & s'_{1,1} & s'_{1,2} & s'_{1,3} \\ \hline s'_{2,0} & s'_{2,1} & s'_{2,2} & s'_{2,3} \\ \hline s'_{3,0} & s'_{3,1} & s'_{3,2} & s'_{3,3} \\ \hline \end{array}$$

Inputs for single AES Rounds



AES KEY Expansion



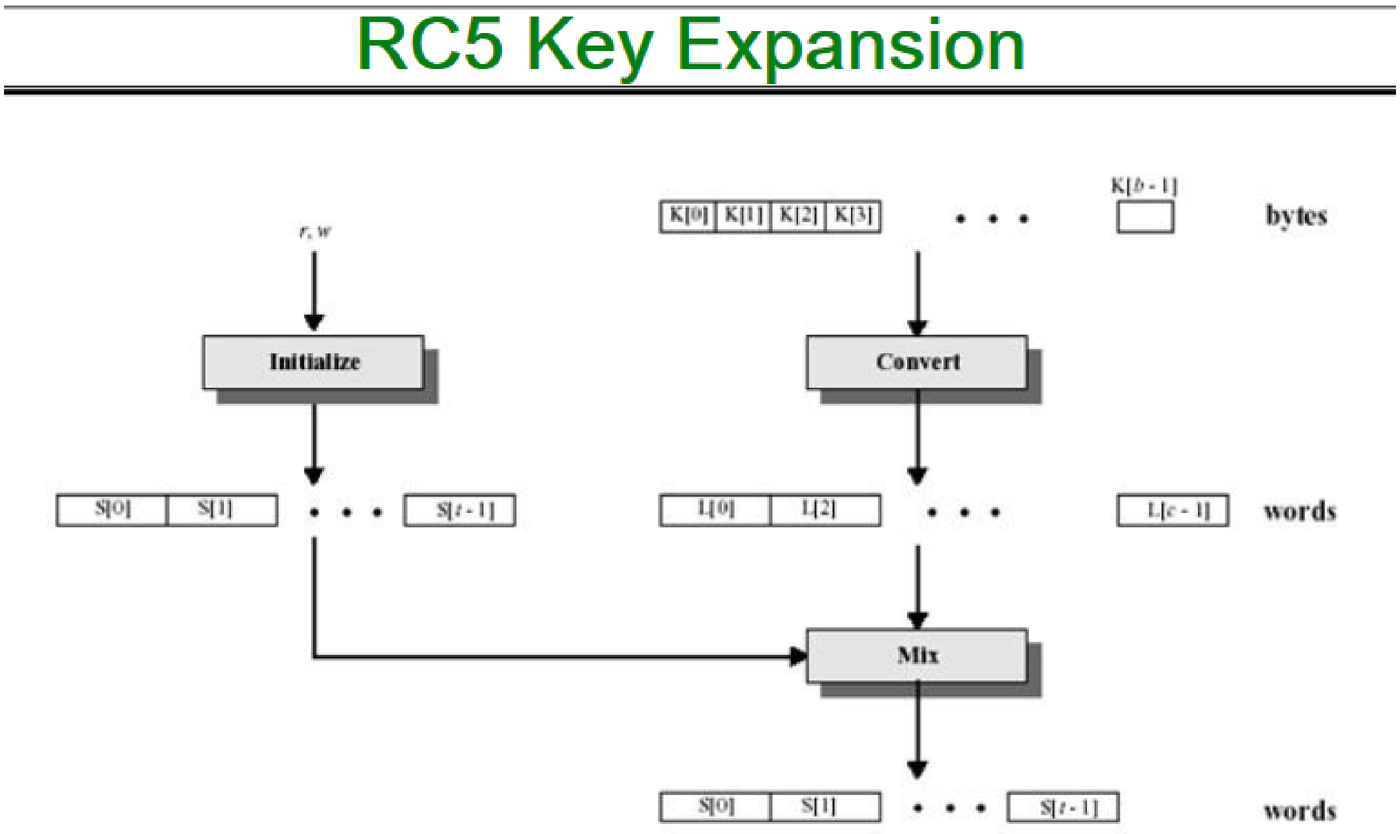
k_0 k_4 k_8 k_{12}
k_1 k_5 k_9 k_{13}
k_2 k_6 k_{10} k_{14}
k_3 k_7 k_{11} k_{15}
w_0 w_1 w_2 w_3
g
w_4 w_5 w_6 w_7
w_{44} w_{45} w_{46} w_{47}
w
g
B_0 B_1 B_2 B_3
B_1 B_2 B_3 B_0
S S S S
B'_1 B'_2 B'_3 B'_0
RC_j 0 0 0
w'

(b) Function g

(a) Overall algorithm

Figure 5.9 AES Key Expansion

RC5



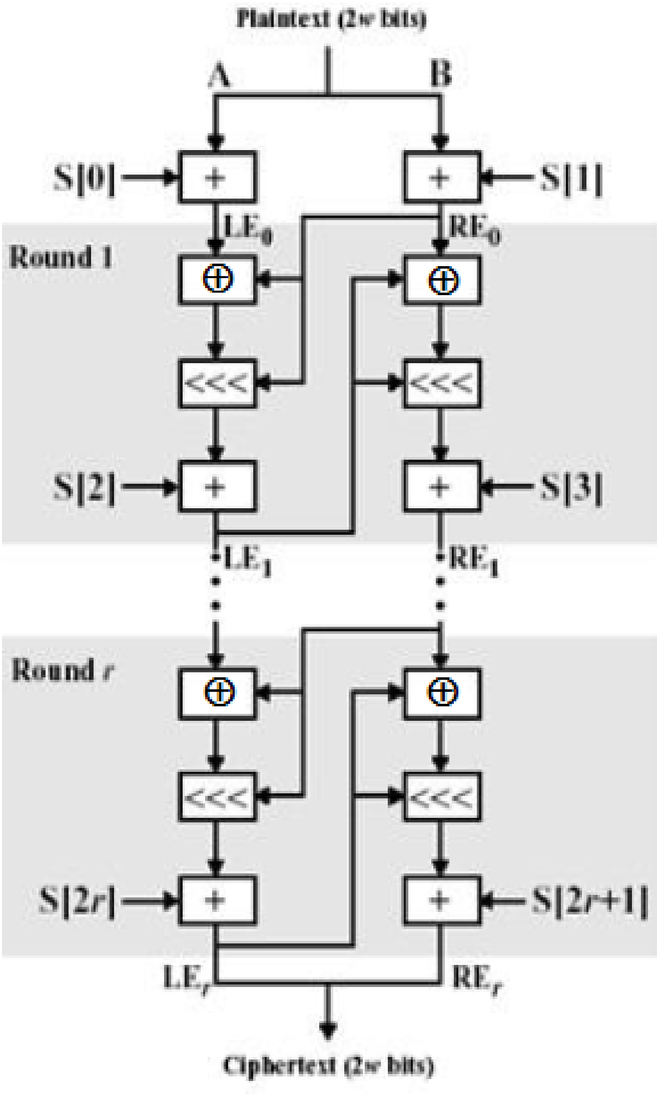
RC5 Key Expansion

RC5 Encryption

- RC5 uses 3 primitive operations
  - Addition, Subtraction (of words): modulo 2^w
  - Bitwise XOR
  - Left, right circular rotation

- Encryption

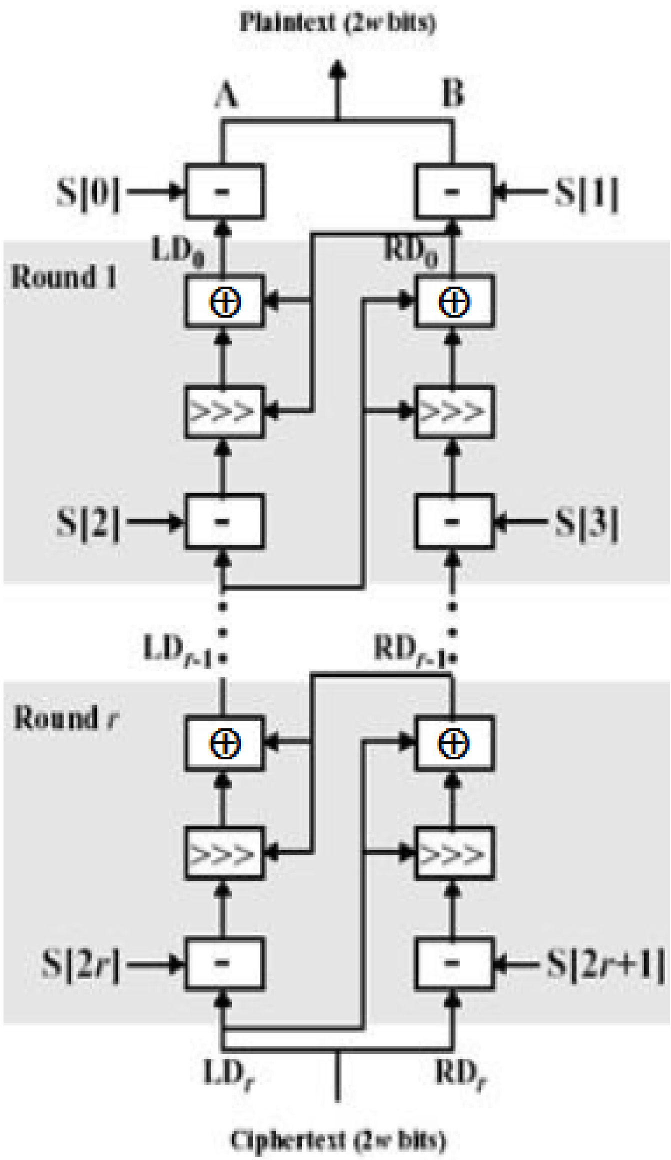
```
$LE_0 = A + S[0]$;
$RE_0 = B + S[1]$;
for i = 1 to $r$ do
    $LE_i = ((LE_{i-1} \oplus RE_{i-1}) <<< RE_{i-1}) + S[2i]$;
    $RE_i = ((RE_{i-1} \oplus LE_i) <<< LE_i) + S[2i+1]$;
```



(a) Encryption

RC5 Decryption

```
for i = $r$ downto 1 do
    $RD_{i-1} = ((RD_i - S[2i+1] >>> LD_i) \oplus LD_i)$ ;
    $LD_{i-1} = ((LD_i - S[2i] >>> Rd_{i-1}) \oplus RD_{i-1})$ ;
$B = RD_0 - S[1]$;
$A = LD_0 - S[0]$;
```



(b) Decryption