Computer Security
Lecture 5

Simplified Advanced Encryption Standard

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Simplified Advanced Encryption Standard

- Simplified AES (S-AES) was developed by Professor Edward Schaefer of Santa Clara University in 2003

- its purpose is educational, since its key and block size are very small 16bits
- it is possible for students to encrypt or decrypt a block doing all operations by hand
- it easier for students to understand the structure AES

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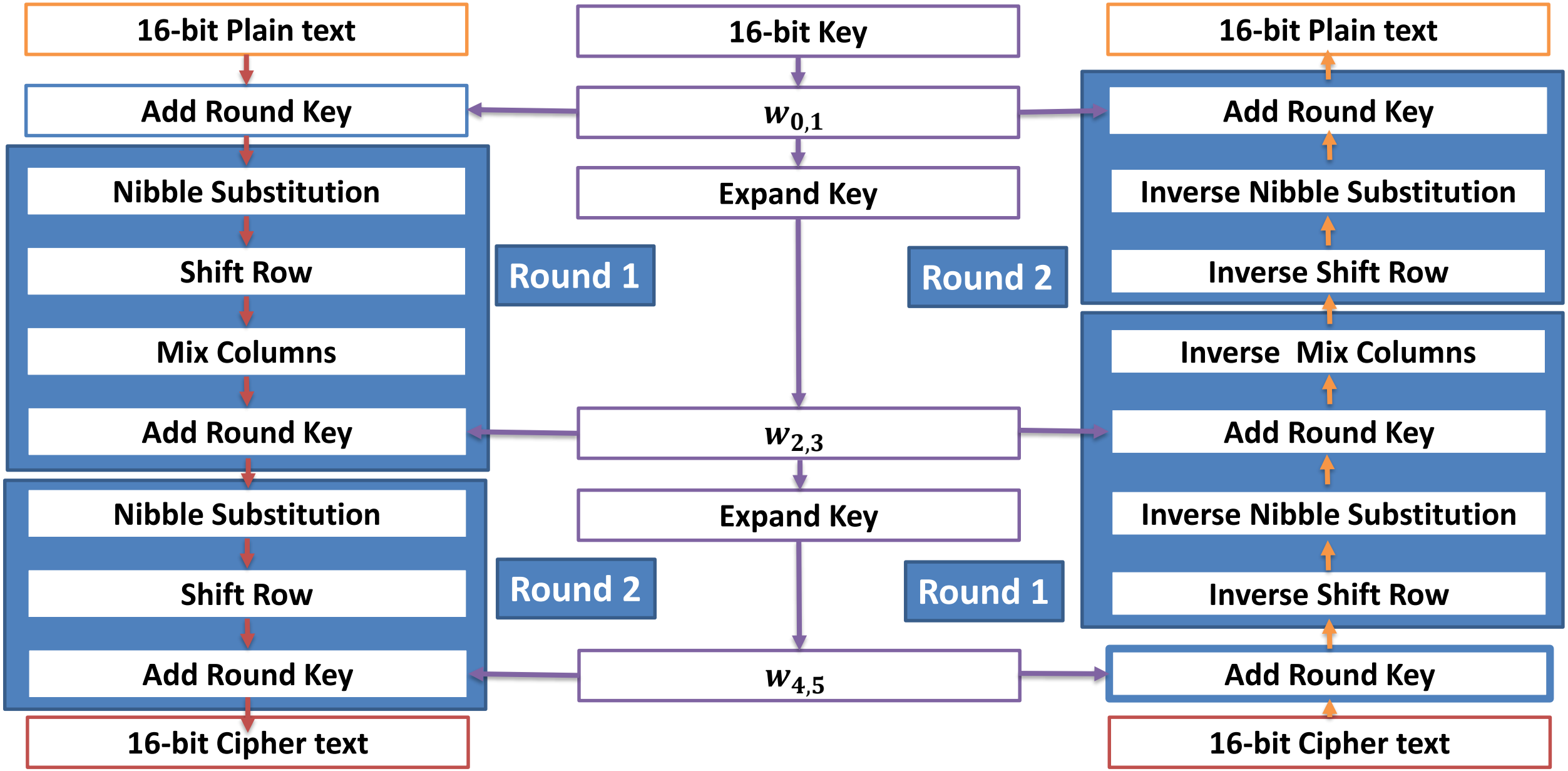
S-AES Encryption and Decryption



S-AES Encryption Example

- 16-bit Plaintext, P= D7 28

  =1101 0111 0010 1000

- 16-bit Key, K= 4A F5

  =0100 1010 1111 0101

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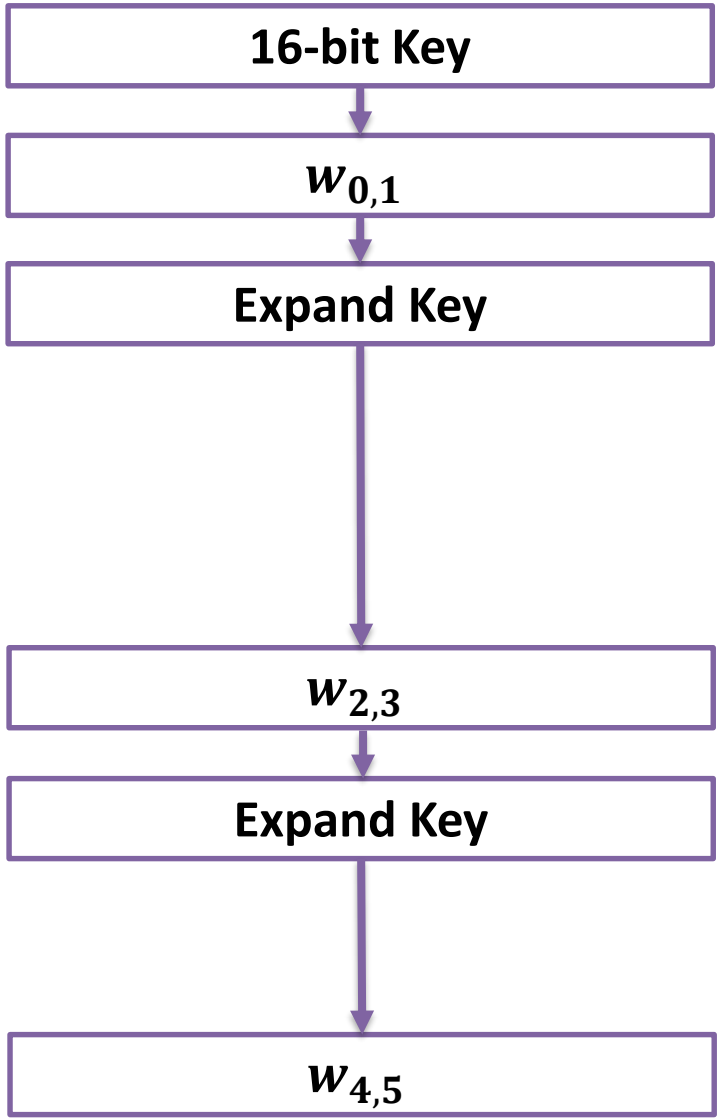
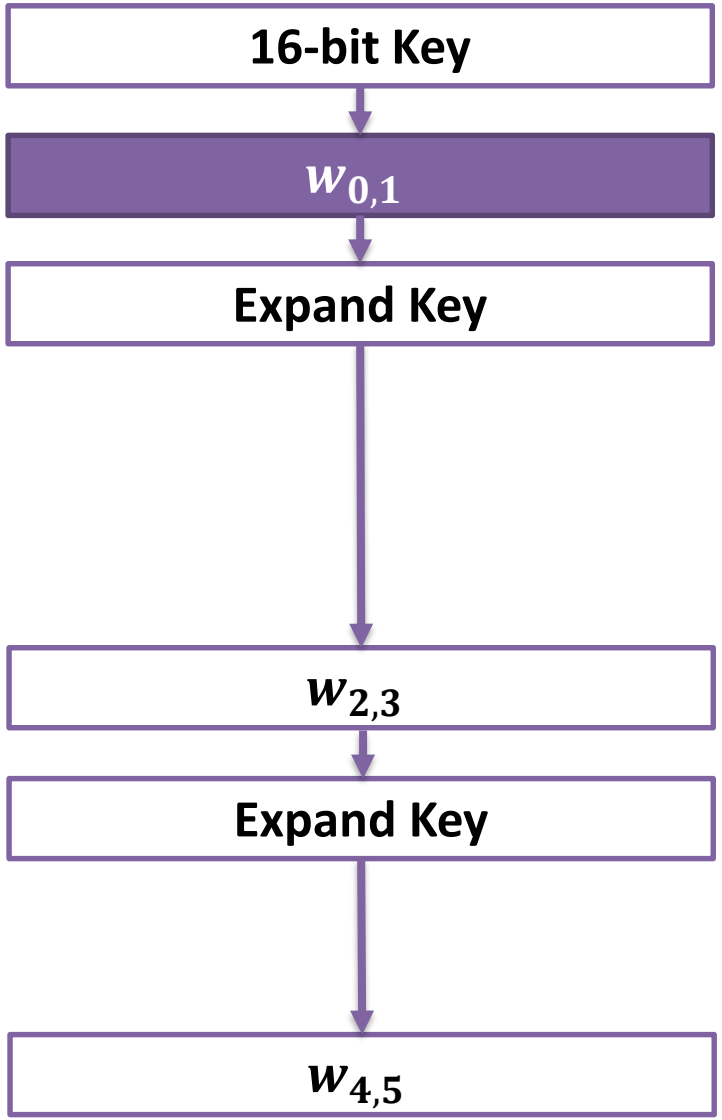
S-AES Key Generation



S-AES Key Generation



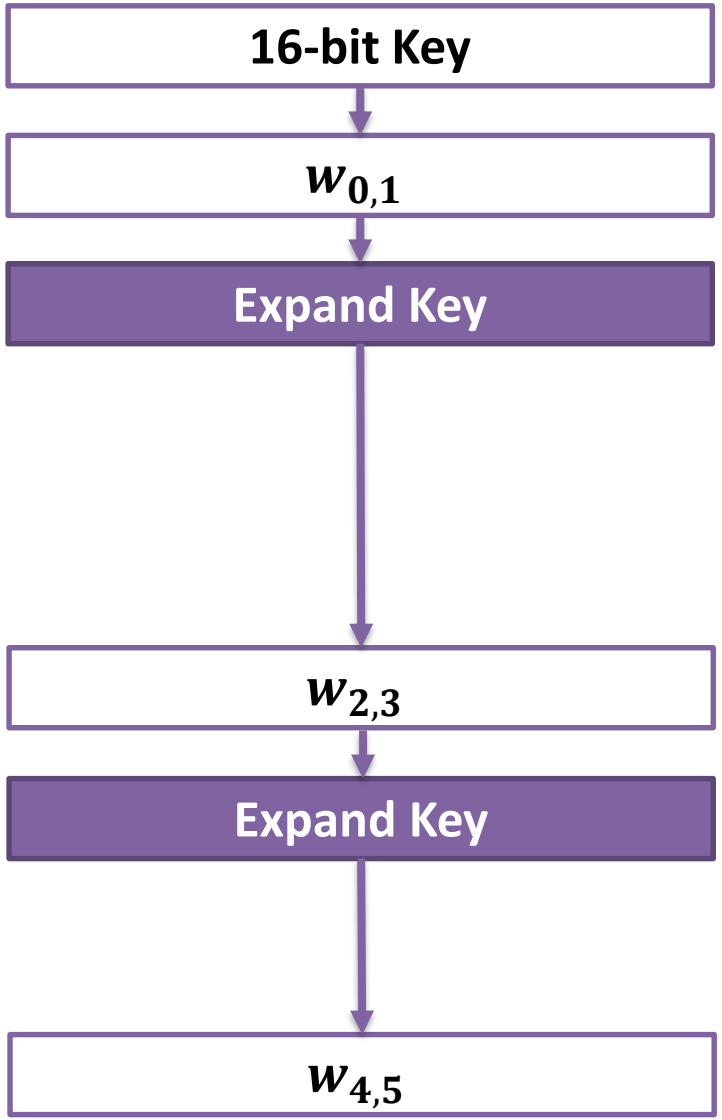
S-AES Key Generation

- K= 4A F5

  = 0100 1010 1111 0101

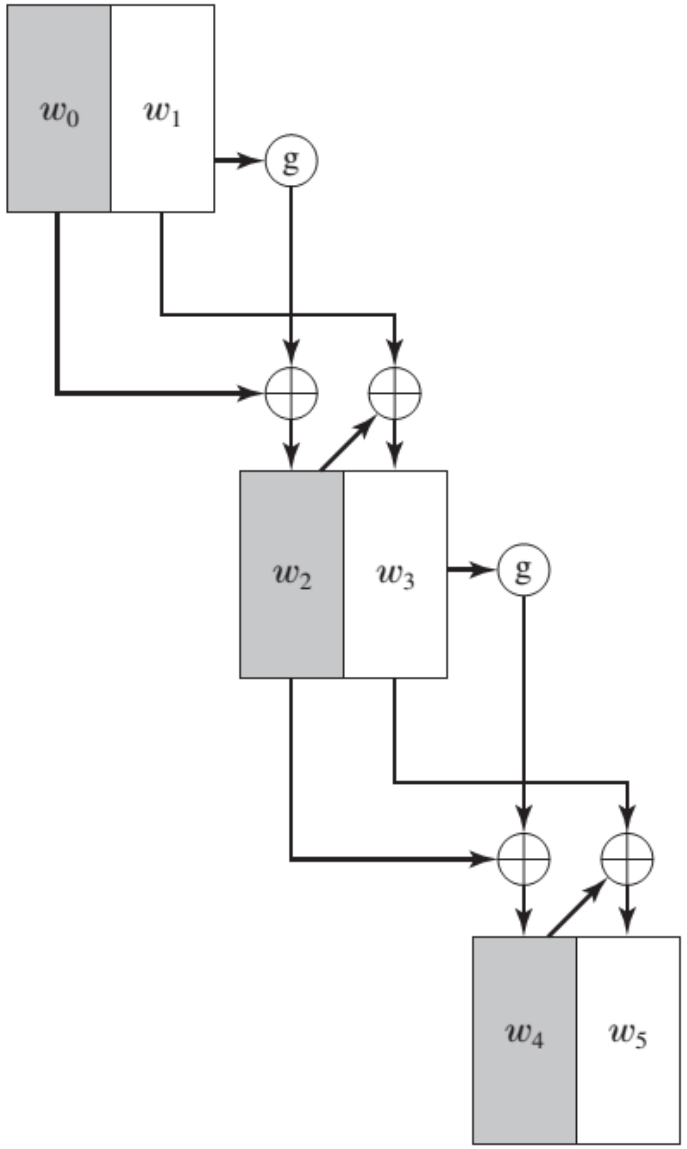
- The input key, K, is split into 2 words, w0 and w1:
- w0 = 0100 1010
- w1 = 1111 0101

S-AES Key Generation



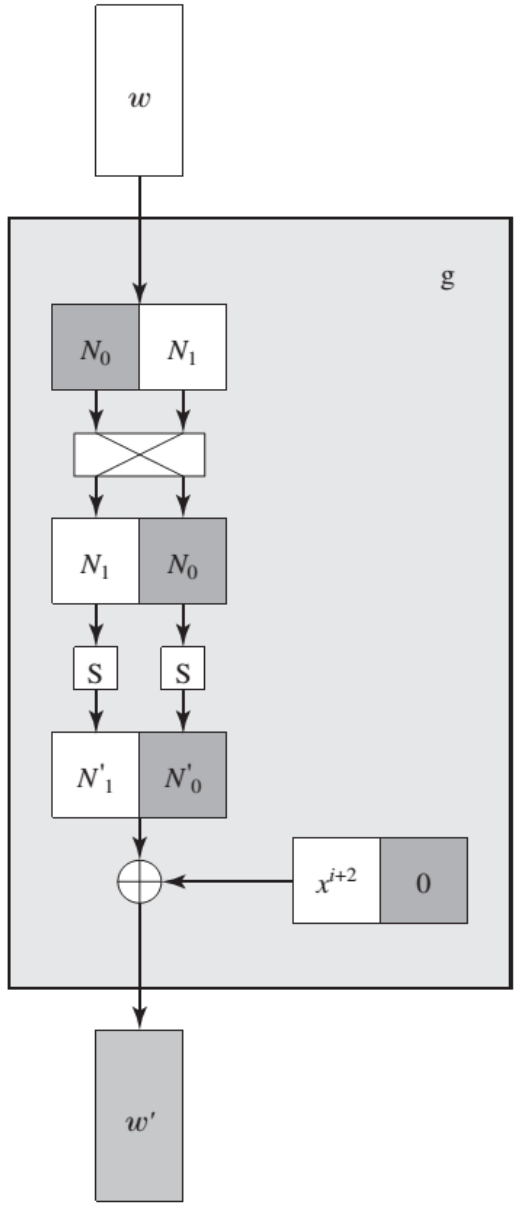
S-AES Key Generation

- S-AES Key Expansion

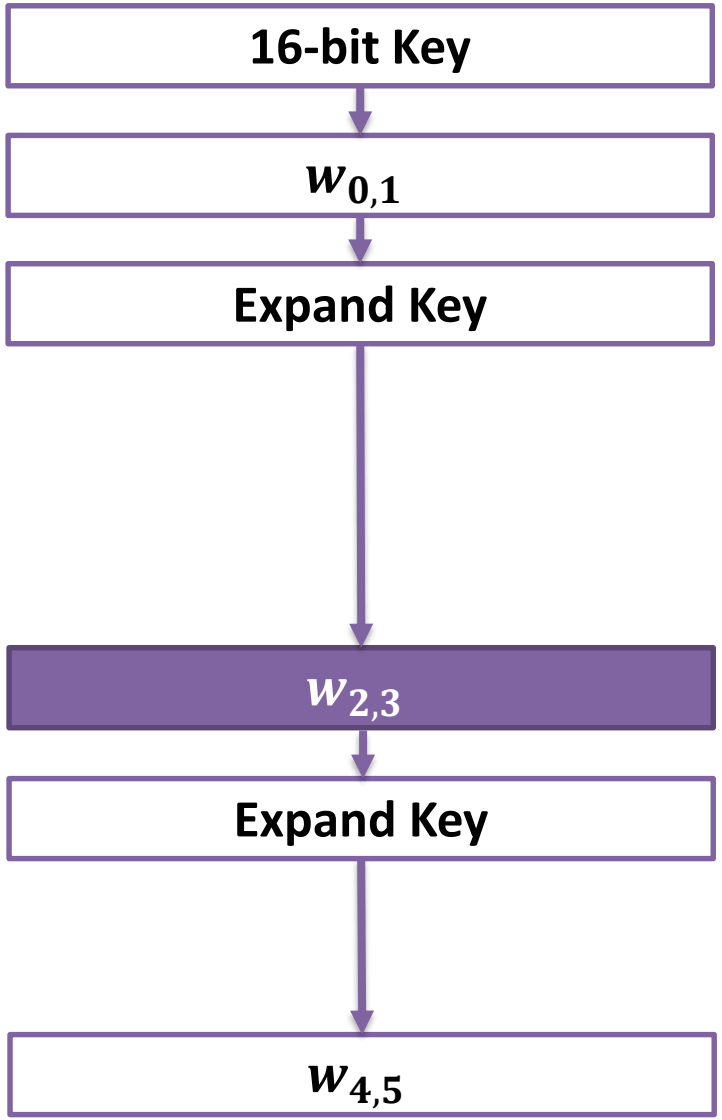


S-AES Key Generation

- Function g



S-AES Key Generation



S-AES Key Generation

- w0 = 0100 1010, w1 = 1111 0101
- w2 = w0 ⊕ Rcon(1) ⊕ SubNib(RotNib(w1))
- **RotNib**() is "rotate the nibbles", which is equivalent to swapping the nibbles , **Rcon** is a round constant
- **SubNib**() is "apply S-Box substitution on nibbles using encryption S-Box"
- RotNib(w1) = 0101 1111
- SubNib(0101 1111) = 0001 0111
- Rcon(1) = 10000000

S-Box

		j			
		00	**01**	**10**	**11**
i	**00**	9	4	A	B
	01	D	1	8	5
	10	6	2	0	3
	11	C	E	F	7

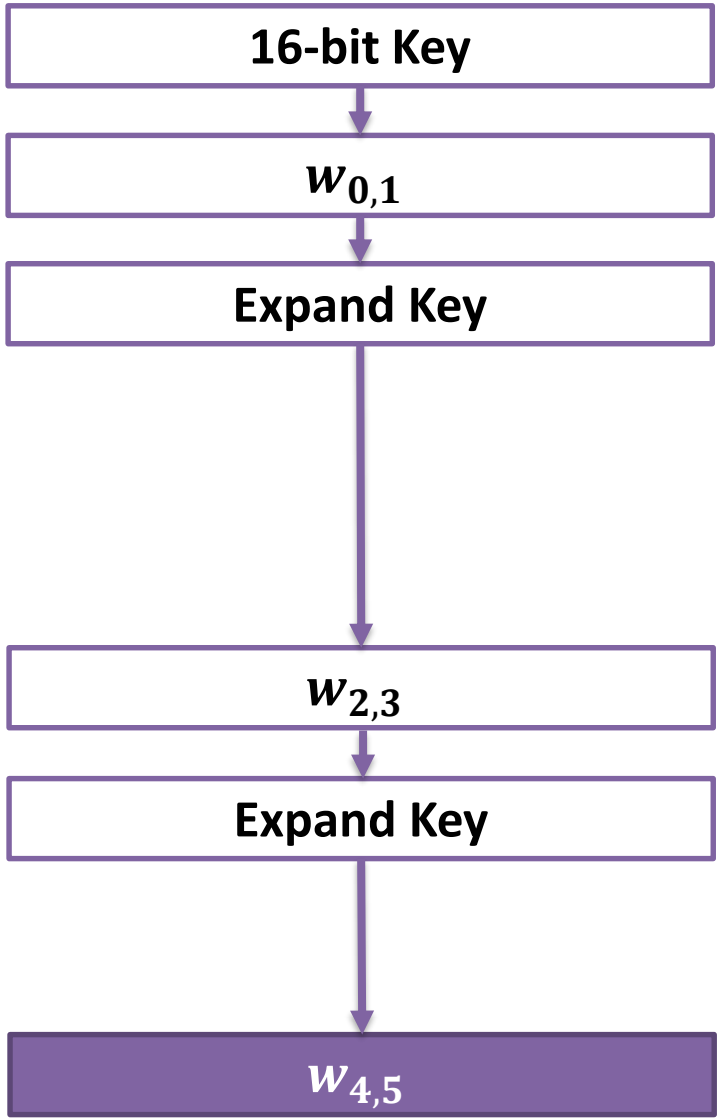
S-AES Key Generation

- w0 = 0100 1010, w1 = 1111 0101
- w2 = w0 ⊕ Rcon(1) ⊕ SubNib(RotNib(w1))

  = 0100 1010 ⊕ 1000 0000 ⊕ 0001 0111

  = 0100 1010 ⊕ 1001 0111=1101 1101
- w2 =1101 1101
- w3 = w2 ⊕ w1 = 1101 1101 ⊕ 1111 0101= 0010 1000
- w3 = 0010 1000

S-AES Key Generation



S-AES Key Generation

- w2 = 1101 1101, w3 = 0010 1000
- w4 = w2 ⊕ Rcon(2) ⊕ SubNib(RotNib(w3))

  = 1101 1101 ⊕ 0011 0000 ⊕ SubNib(1000 0010)

  = 1110 1101 ⊕ 0011 0000 ⊕ 0110 1010

  = 1110 1101 ⊕ 0101 1010

  = 1011 0111
- w5 = w4 ⊕ w3

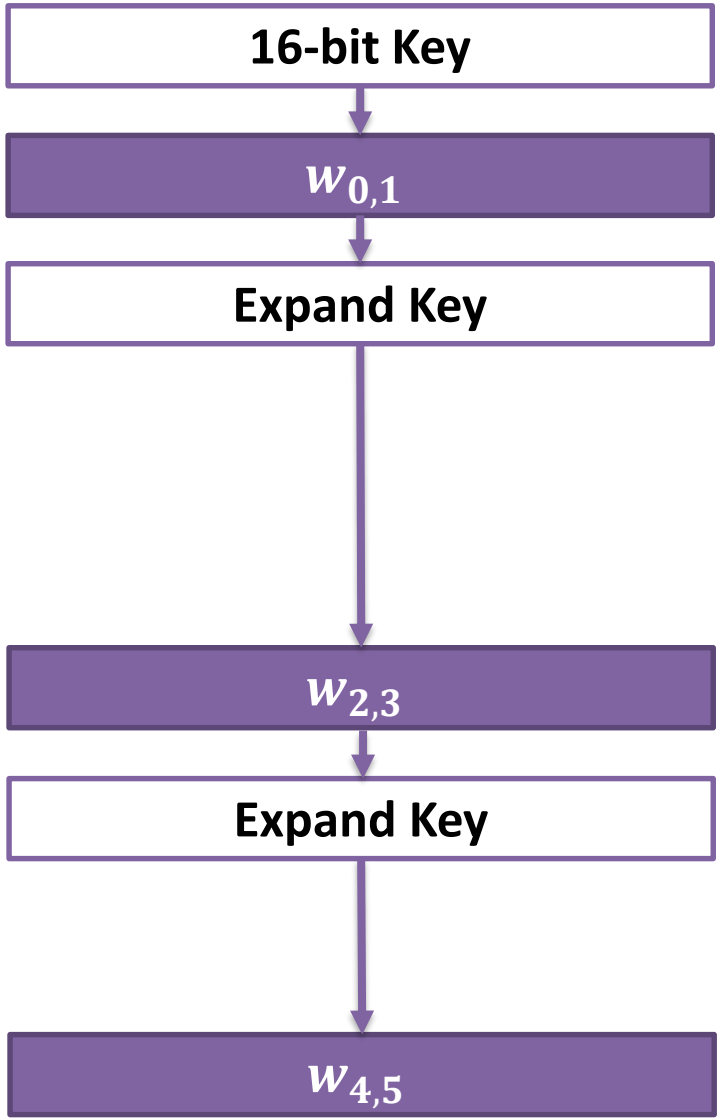
  =1011 0111 ⊕ 0010 1000

  =1001 1111

S-Box

		j			
		00	**01**	**10**	**11**
i	**00**	9	4	A	B
	01	D	1	8	5
	10	6	2	0	3
	11	C	E	F	7

S-AES Key Generation



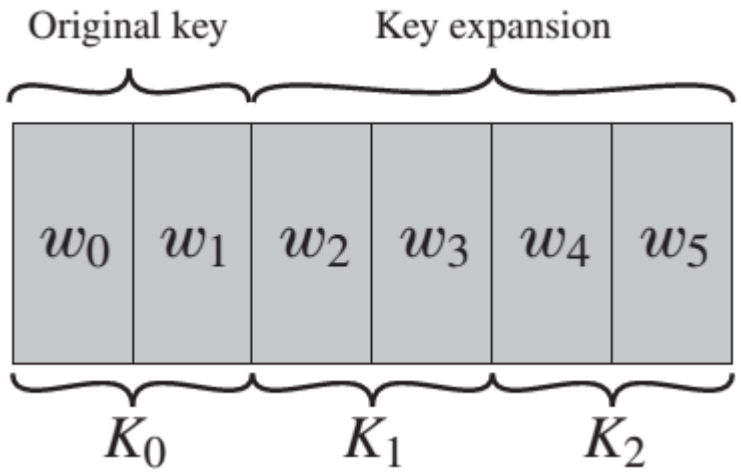
S-AES Key Generation

- Key
- Key0 = w0w1

  = 0100 1010 1111 0101
- Key1 = w2w3

  = 1101 1101 0010 1000
- Key2 = w4w5

  = 1011 0111 1001 1111



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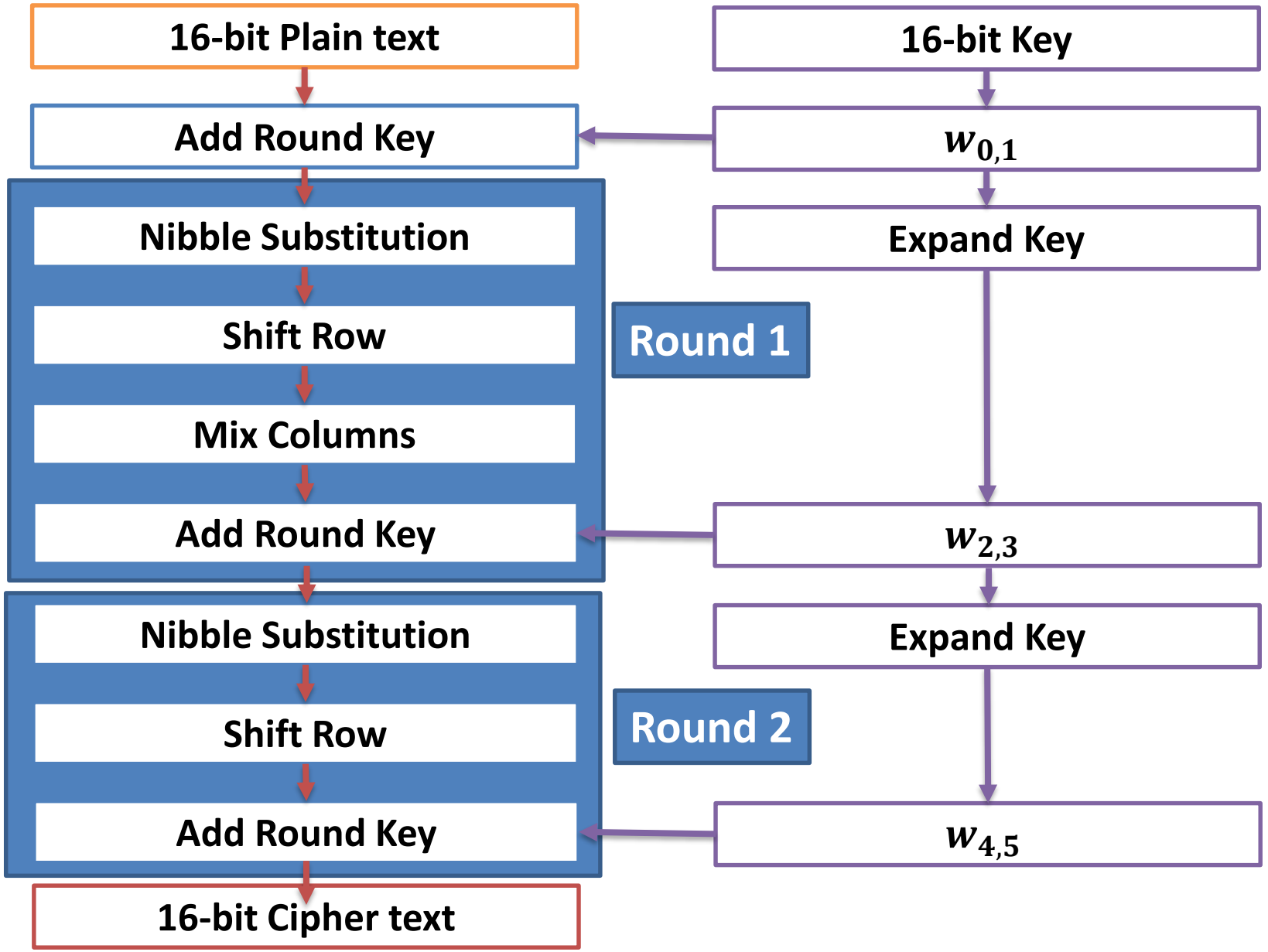
S-AES Encryption



S-AES Encryption

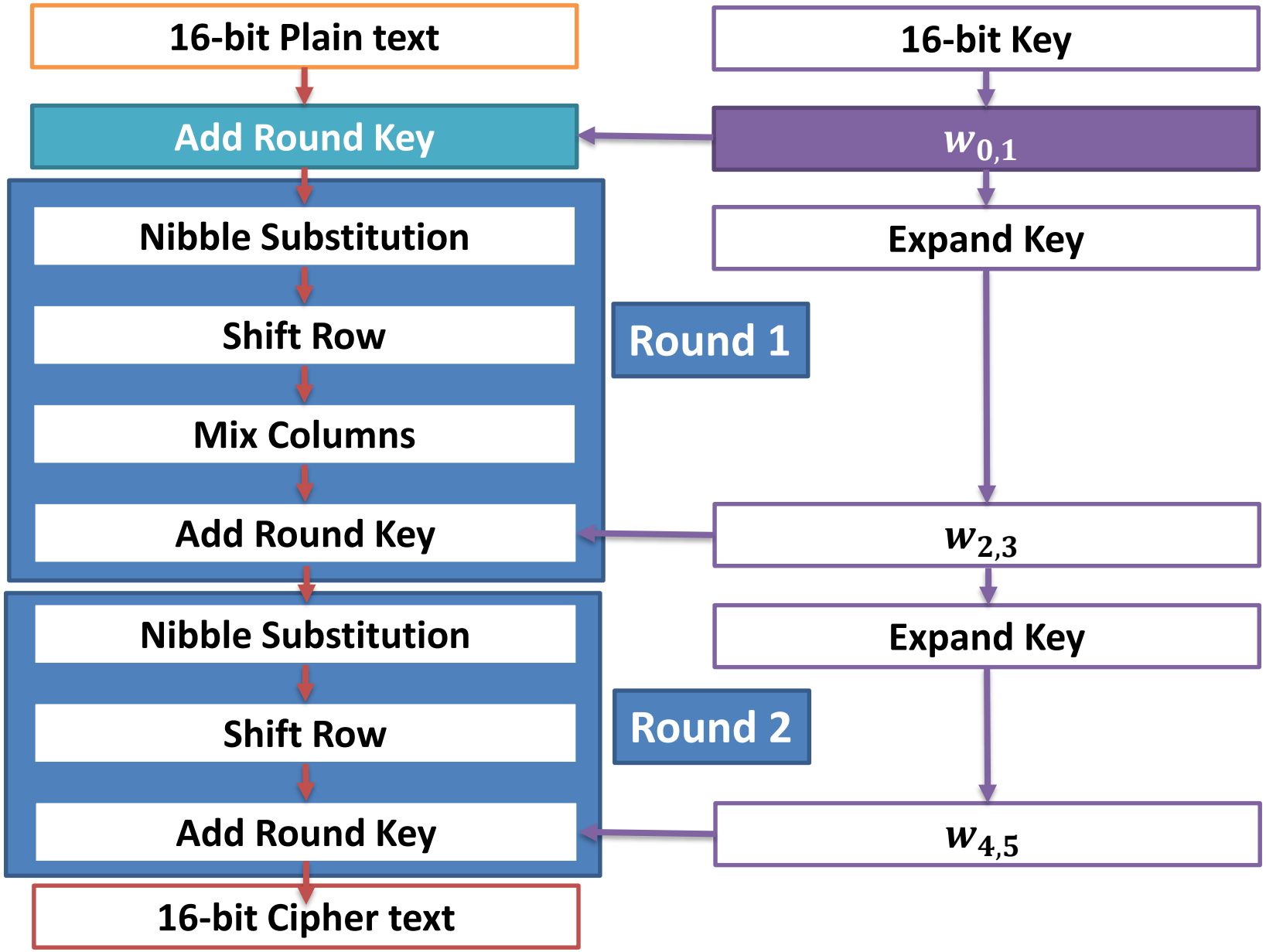
- Assume: P= 1101 0111 0010 1000
- Key0 = w0w1

  = 0100 1010 1111 0101
- Key1 = w2w3

  = 1101 1101 0010 1000
- Key2 = w4w5

  = 1000 0111 1010 1111

S-AES Encryption



S-AES Encryption

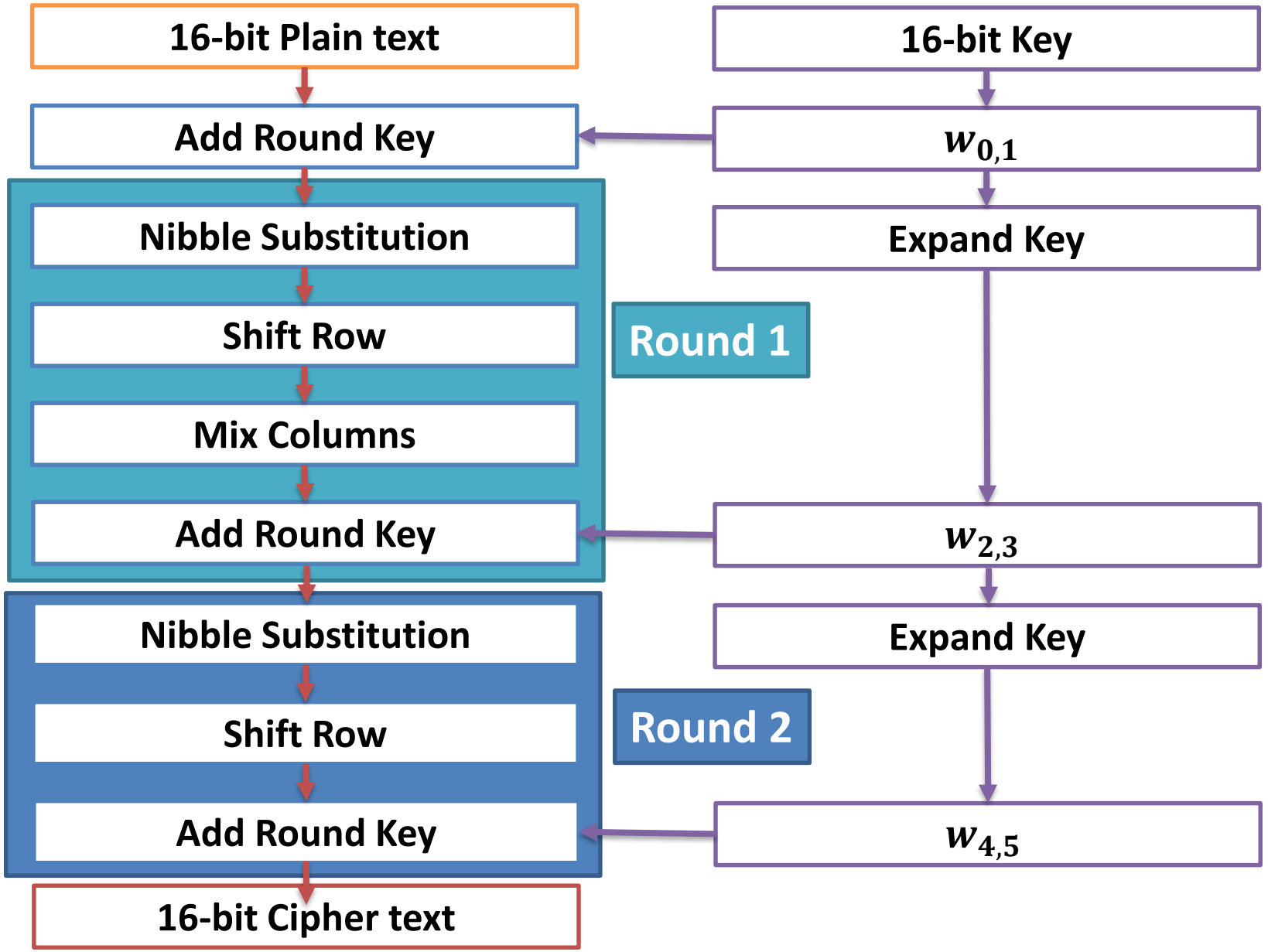
- Round 0
- P= 1101 0111 0010 1000
- Key0 = 0100 1010 1111 0101
- R0= P $\oplus$ Key0

  = 1101 0111 0010 1000 $\oplus$

  0100 1010 1111 0101

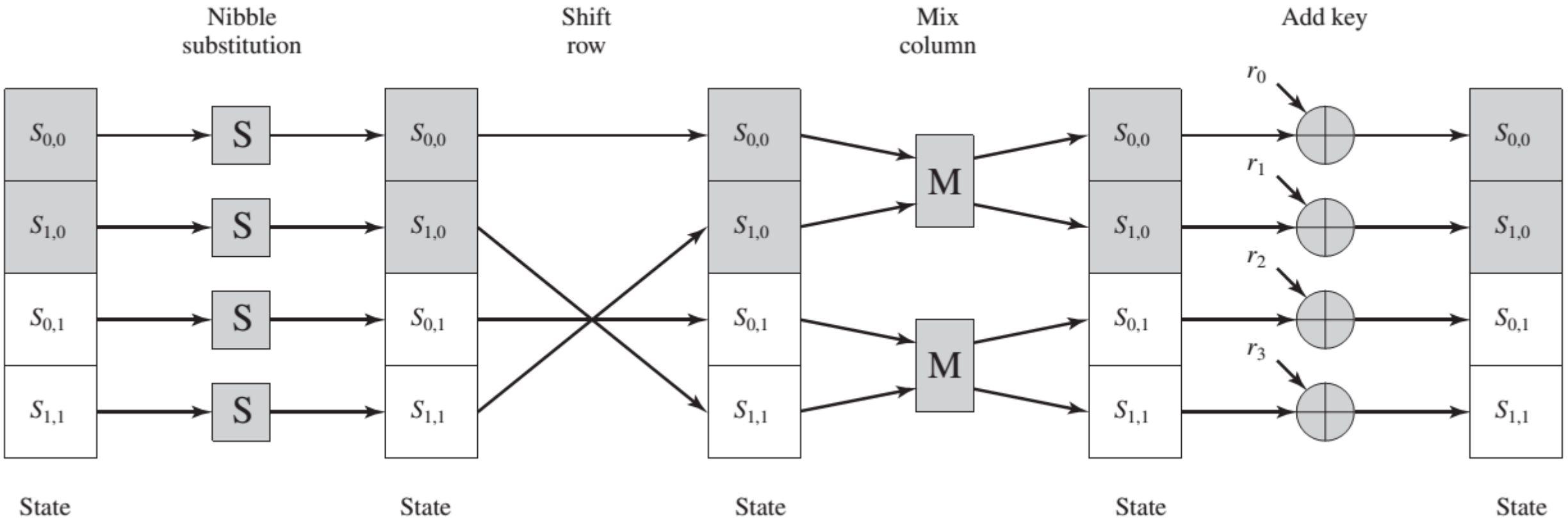
  = 1001 1101 1101 1101

S-AES Encryption



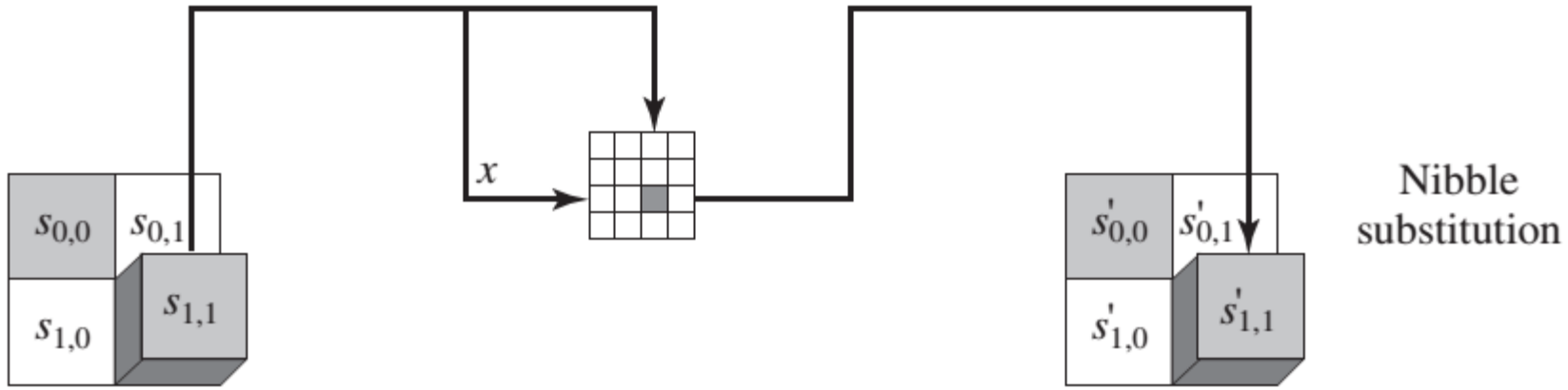
S-AES Encryption

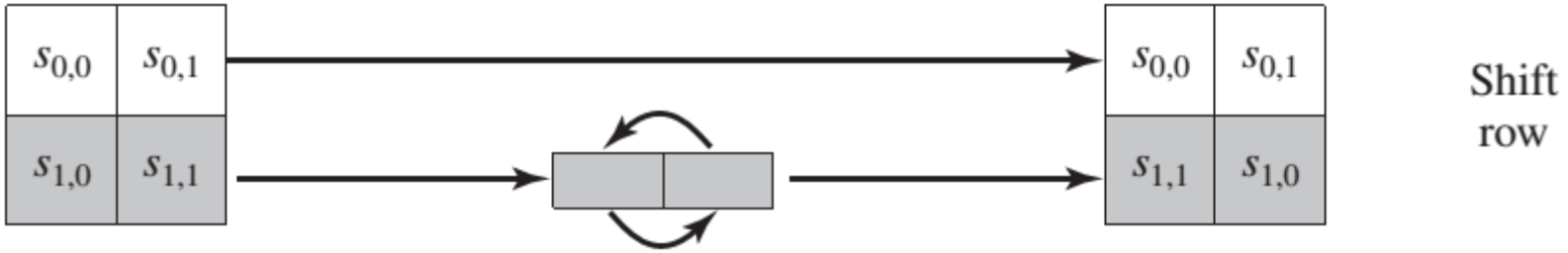
❑ S-AES Encryption Round



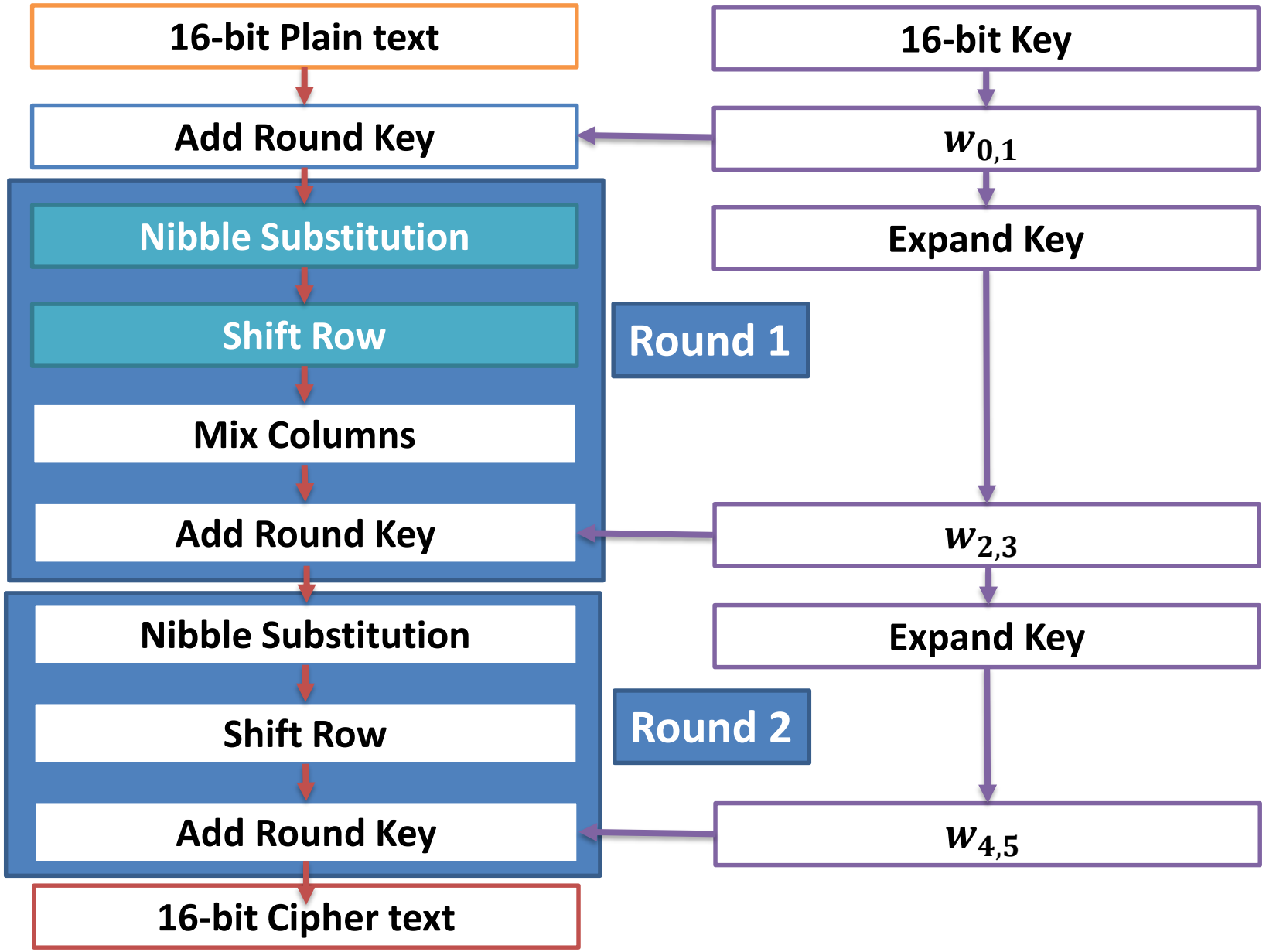
S-AES Encryption

❑ S-AES Transformation (Substitution and Shift row)





S-AES Encryption



S-AES Encryption

- Round 1

1) Nibble Substitution :

- SubNib(1001 1101 1101 1101)= 0010 1110 1110 1110

2) Shift Row:

- Swap 2nd nibble and 4th nibble
- ShRow(0010 1110 1110 1110)

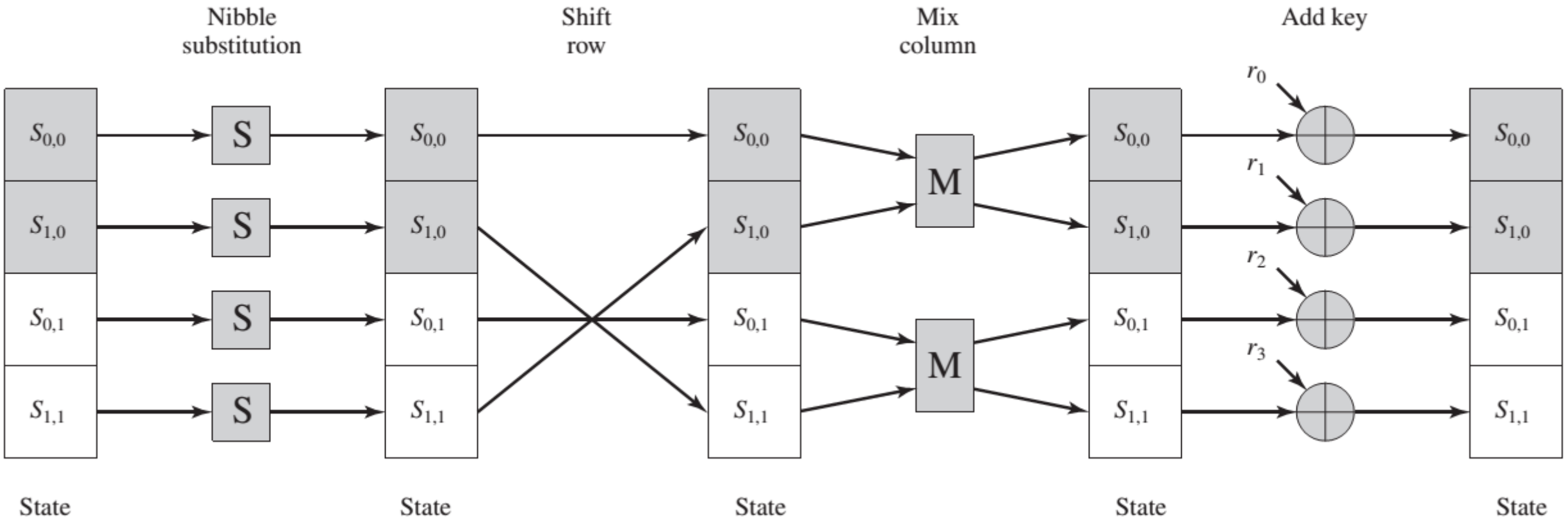
  = 0010 1110 1110 1110

S-Box

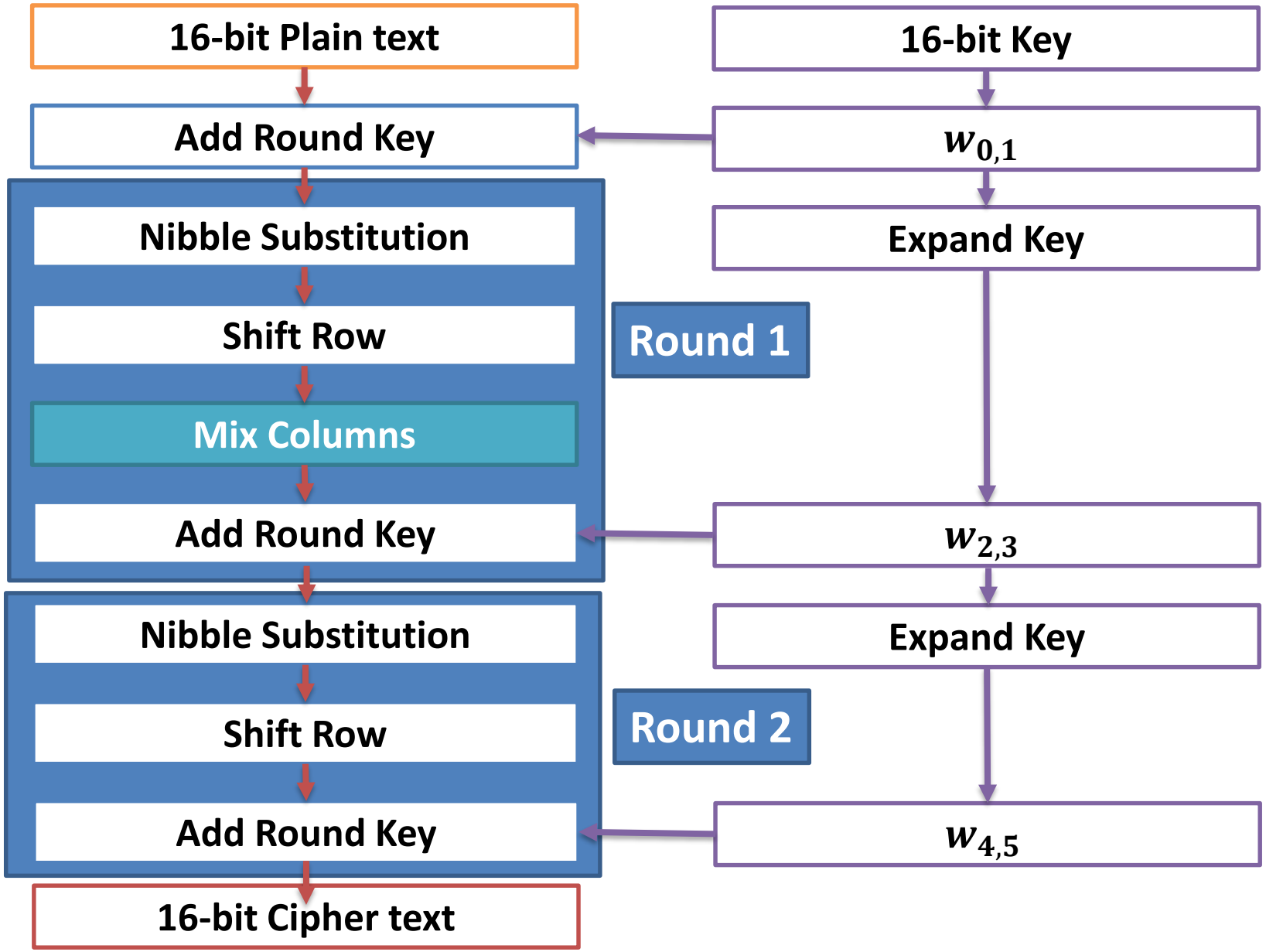
		j			
		00	**01**	**10**	**11**
i	**00**	9	4	A	B
	01	D	1	8	5
	10	6	2	0	3
	11	C	E	F	7

Key Generation

❑ S-AES Encryption Round

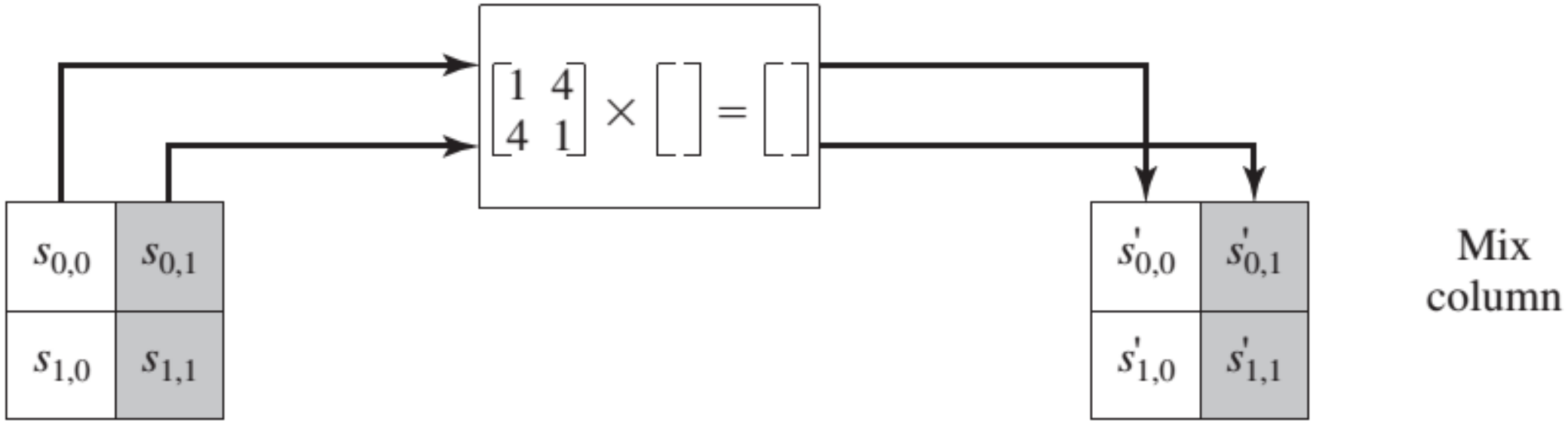


S-AES Encryption



S-AES Encryption

❑ S-AES Transformation (Mix Column)



S-AES Encryption

- Mix Column Table

*	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
2	2	4	6	8	A	C	E	3	1	7	5	B	9	F	D
4	4	8	C	3	7	B	F	6	2	E	A	5	1	D	9
9	9	1	8	2	B	3	A	4	D	5	C	6	F	7	E

S-AES Encryption

- Round 1

3) Mix Columns:

*	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
2	2	4	6	8	A	C	E	3	1	7	5	B	9	F	D
4	4	8	C	3	7	B	F	6	2	E	A	5	1	D	9
9	9	1	8	2	B	3	A	4	D	5	C	6	F	7	E

- MixCol (0010 1110 1110 1110) $= \begin{pmatrix} 0010 & 1110 \\ 1110 & 1110 \end{pmatrix} * \begin{pmatrix} 1 & 4 \\ 4 & 1 \end{pmatrix} =$

- $= \begin{pmatrix} 2 & E \\ E & E \end{pmatrix} * \begin{pmatrix} 1 & 4 \\ 4 & 1 \end{pmatrix} = \begin{pmatrix} (2*1 \oplus E*4) & (E*1 \oplus E*4) \\ (2*4 \oplus E*1) & (E*4 \oplus E*1) \end{pmatrix}$

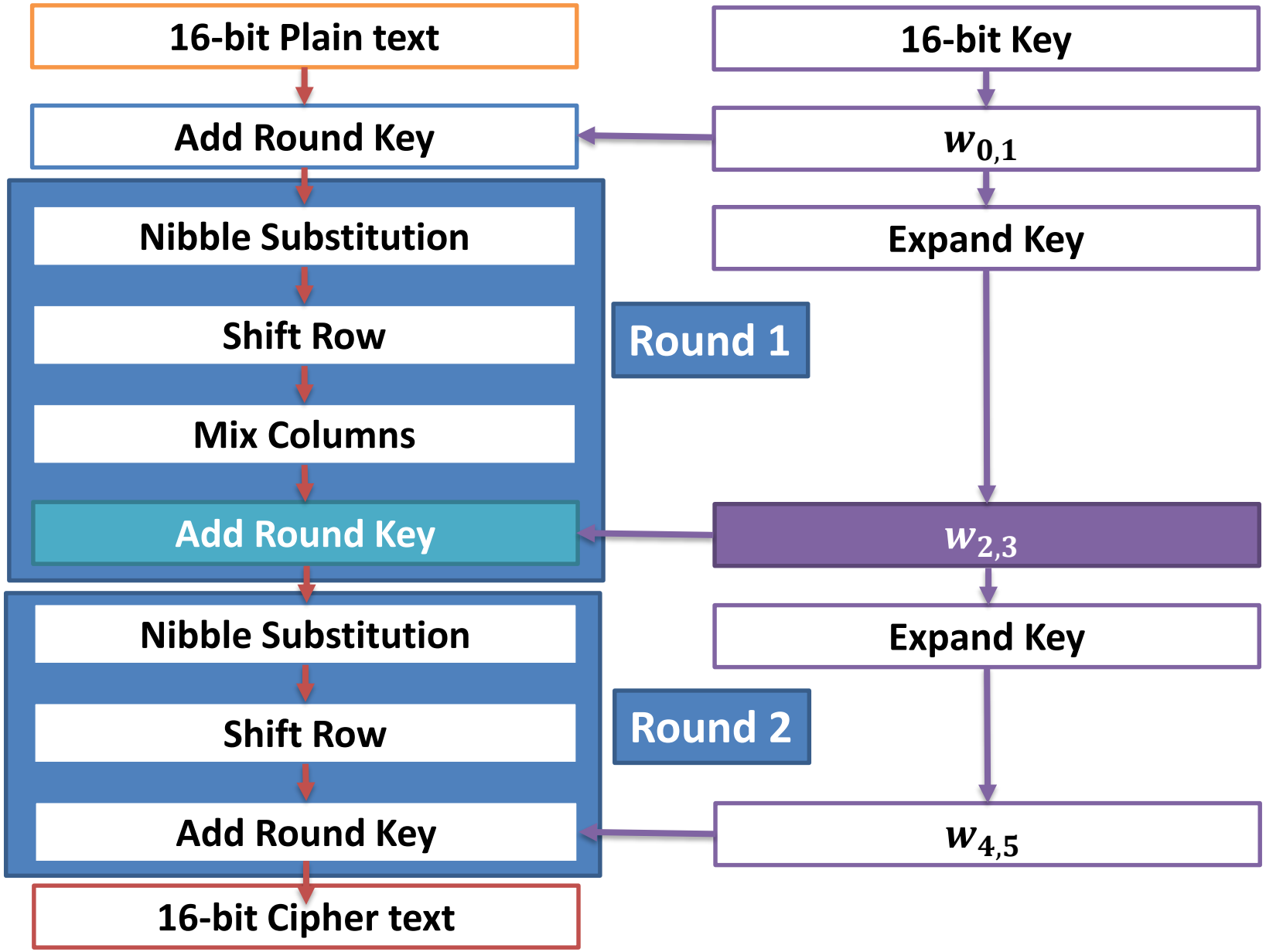
S-AES Encryption

- $= \begin{pmatrix} (2 \oplus D) & (E \oplus D) \\ (8 \oplus E) & (D \oplus E) \end{pmatrix} = \begin{pmatrix} (0010 \oplus 1101) & (1110 \oplus 1101) \\ (1000 \oplus 1110) & (1101 \oplus 1110) \end{pmatrix}$

- $\begin{pmatrix} (0010 \oplus 1101) & (1110 \oplus 1101) \\ (1000 \oplus 1110) & (1101 \oplus 1110) \end{pmatrix} = \begin{pmatrix} 1111 & 0011 \\ 0110 & 0011 \end{pmatrix}$

$= 1111\ 0110\ 0011\ 0011$

S-AES Encryption



S-AES Encryption

- Round 1

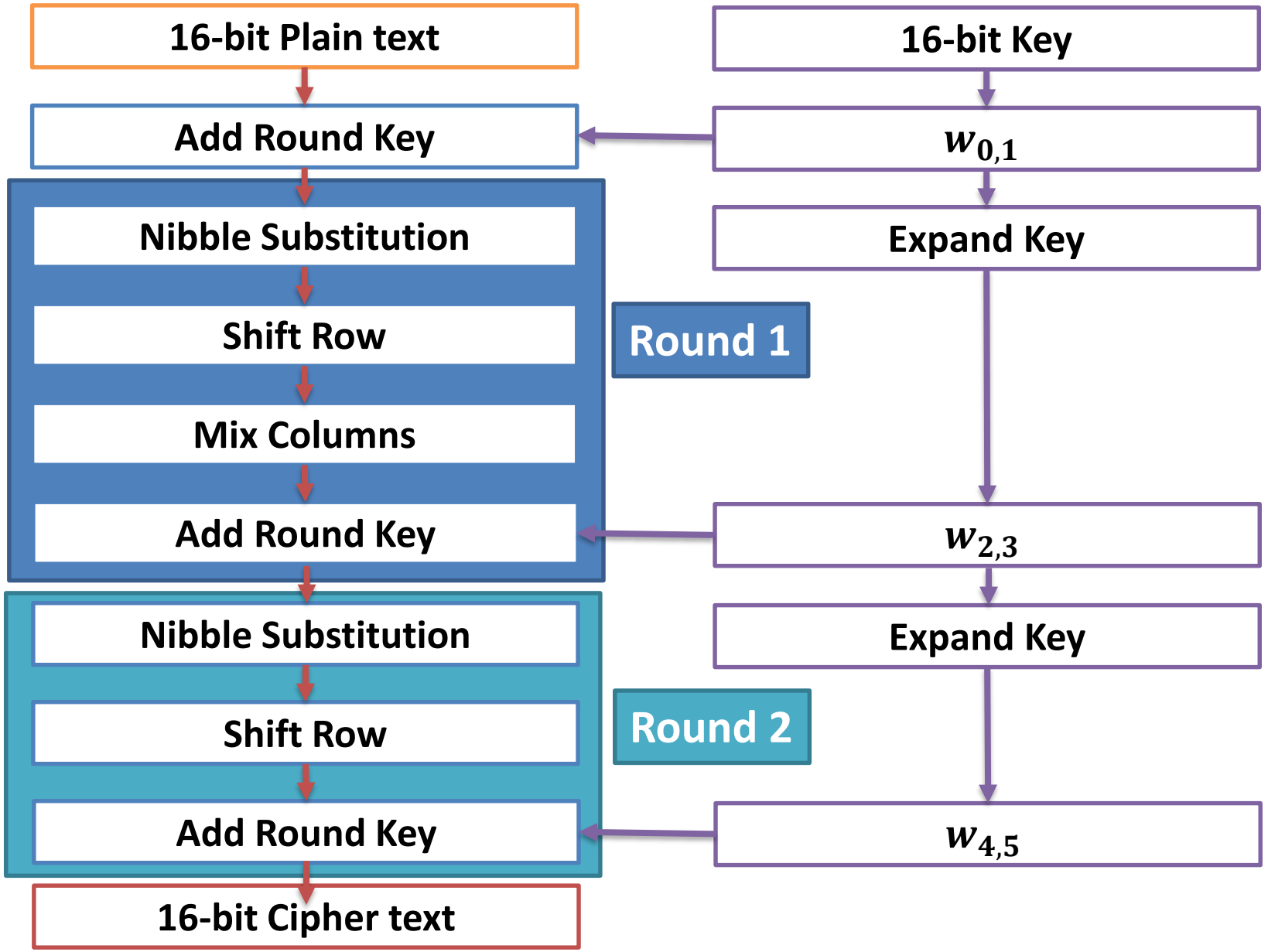
4) Add round Key1

- Key1 = 1101 1101 0010 1000
- R1= Key1 $\oplus$ MixCol(ShRow(SubNib(R0)))

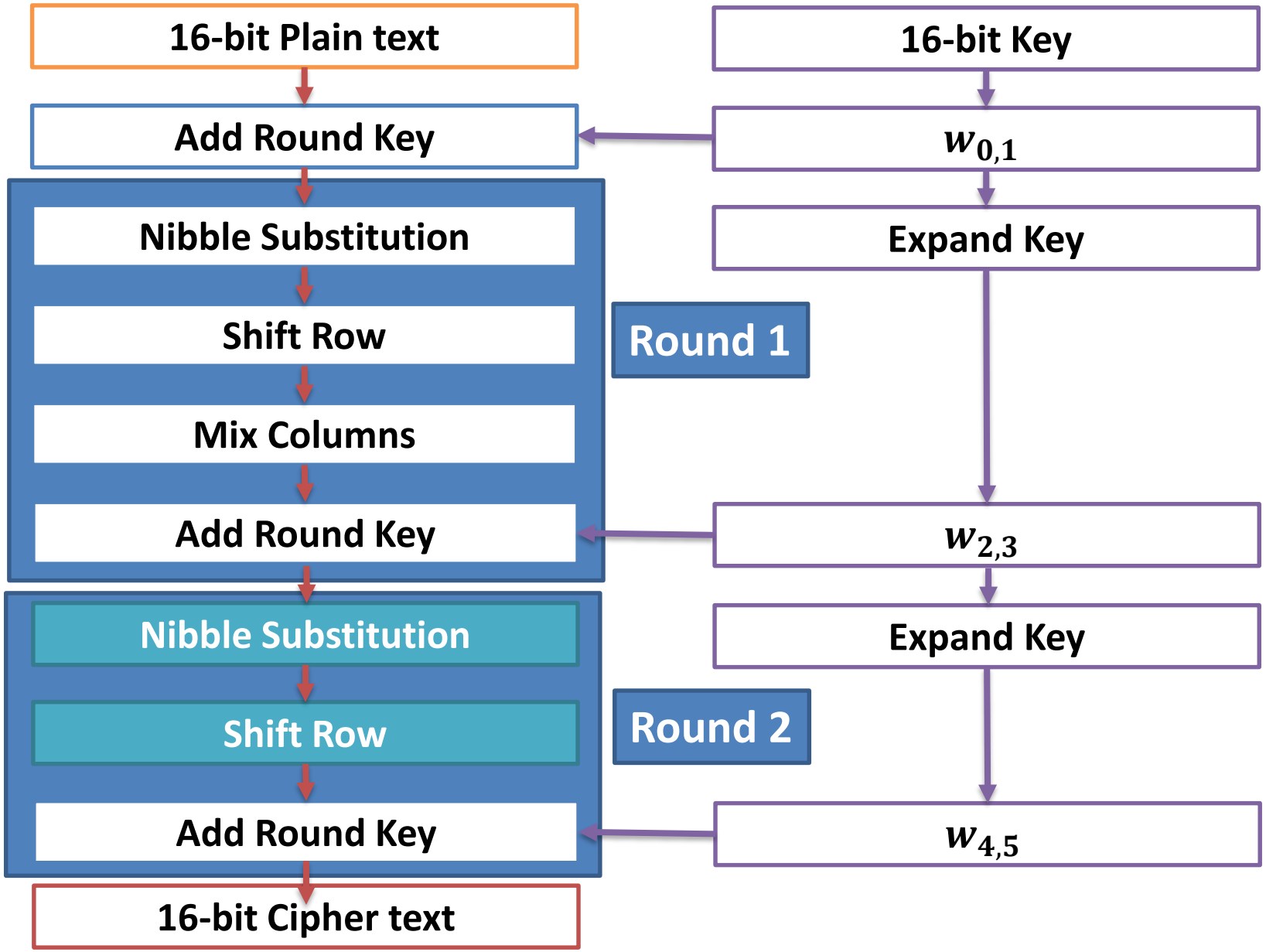
= 1101 1101 0010 1000 $\oplus$ 1111 0110 0011 0011

= 0010 1011 0001 1011

S-AES Encryption

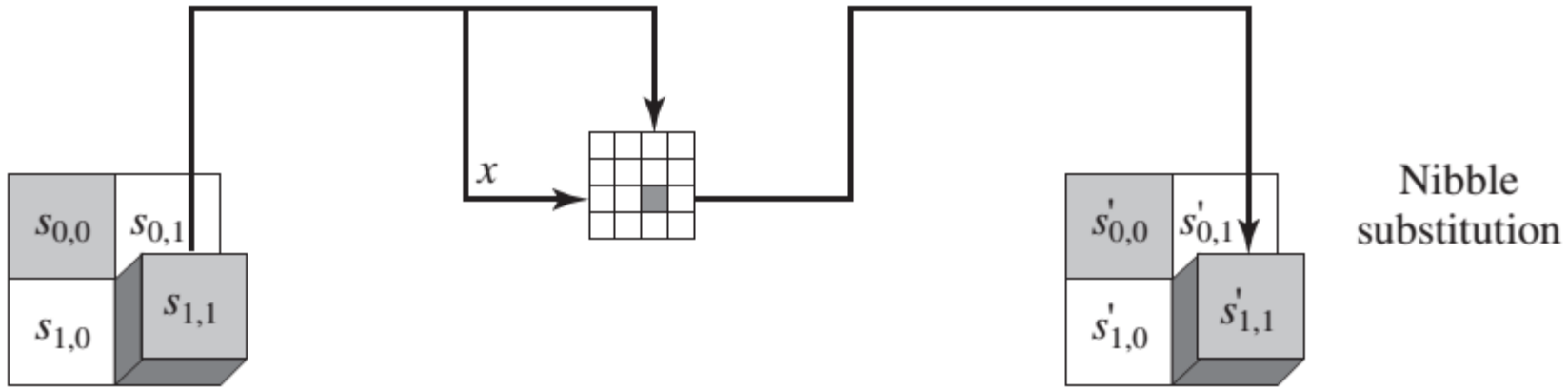


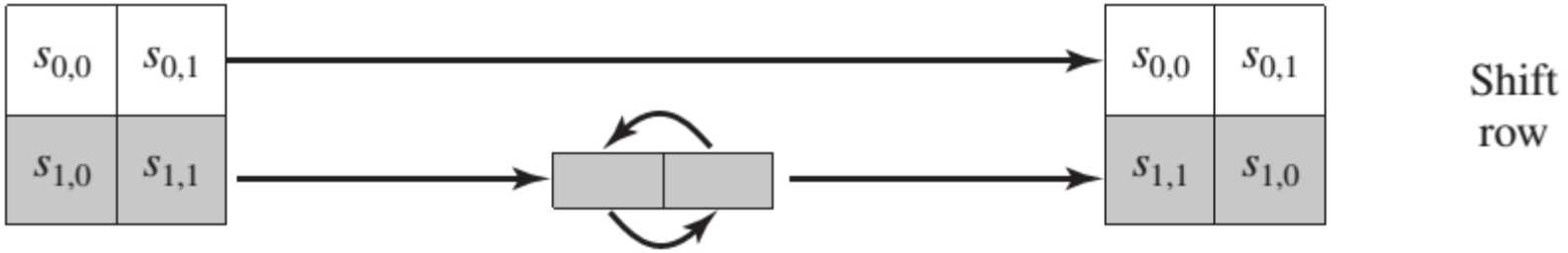
S-AES Encryption



S-AES Encryption

❑ S-AES Transformation (Substitution and Shift row)





S-AES Encryption

- Round 2

1) Nibble Substitution :

- SubNib(0010 1011 0001 1011)= 1010 0011 0100 0011

2) Shift Row:

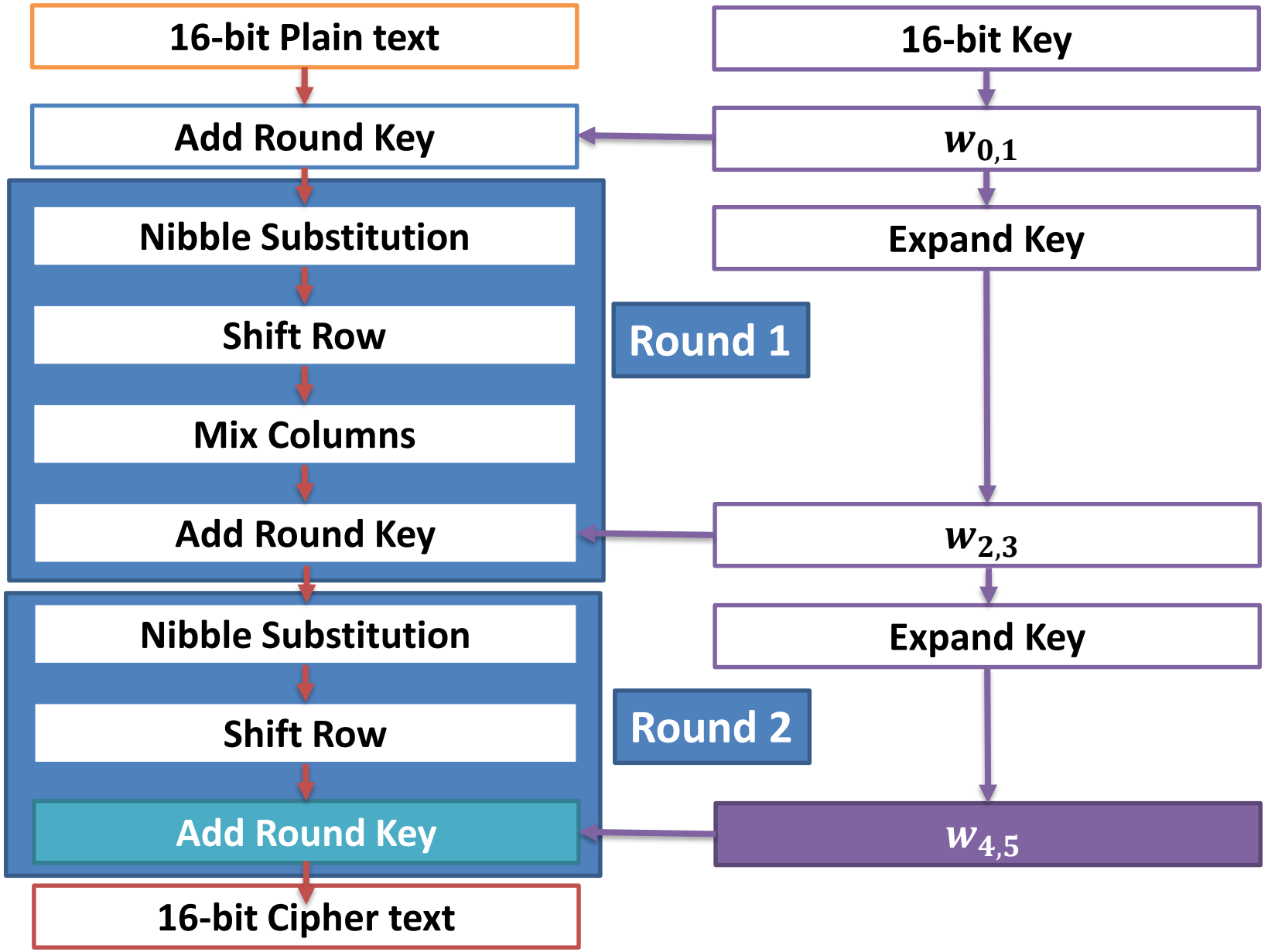
- Swap 2nd nibble and 4th nibble
- ShRow(1010 0011 0100 0011)

  = 1010 0011 0100 0011

S-Box

		j			
		00	**01**	**10**	**11**
i	**00**	9	4	A	B
	01	D	1	8	5
	10	6	2	0	3
	11	C	E	F	7

S-AES Encryption



S-AES Encryption

- Round 2

4) Add round Key2

- Key2 = 1000 0111 1010 1111
- R2= Key2 $\oplus$ ShRow(SubNib(R1))

= 1101 1101 0010 1000 $\oplus$ 1010 0011 0100 0011

= 0010 0100 1110 1100

Ciphertext = 0010 0100 1110 1100

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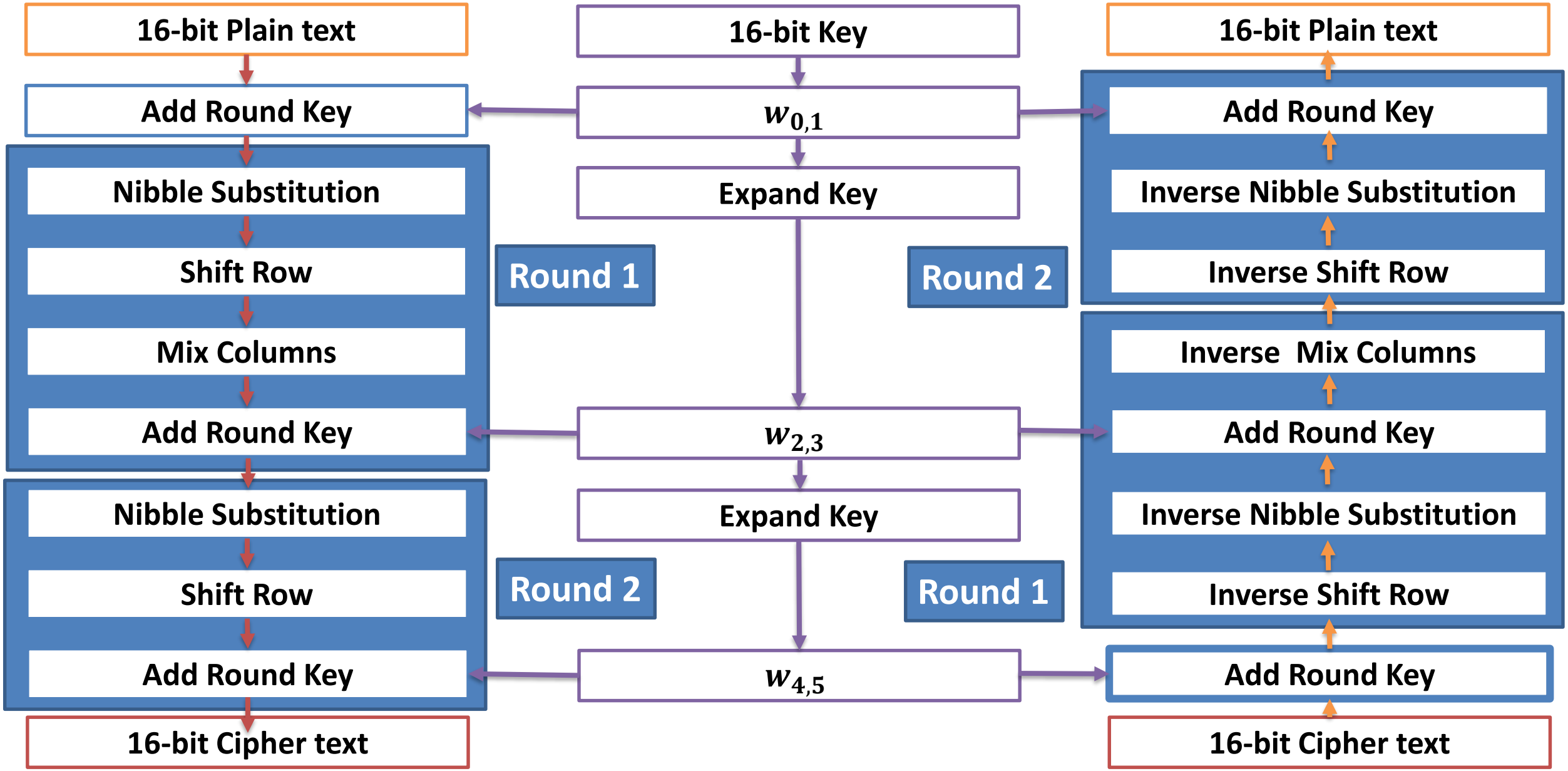
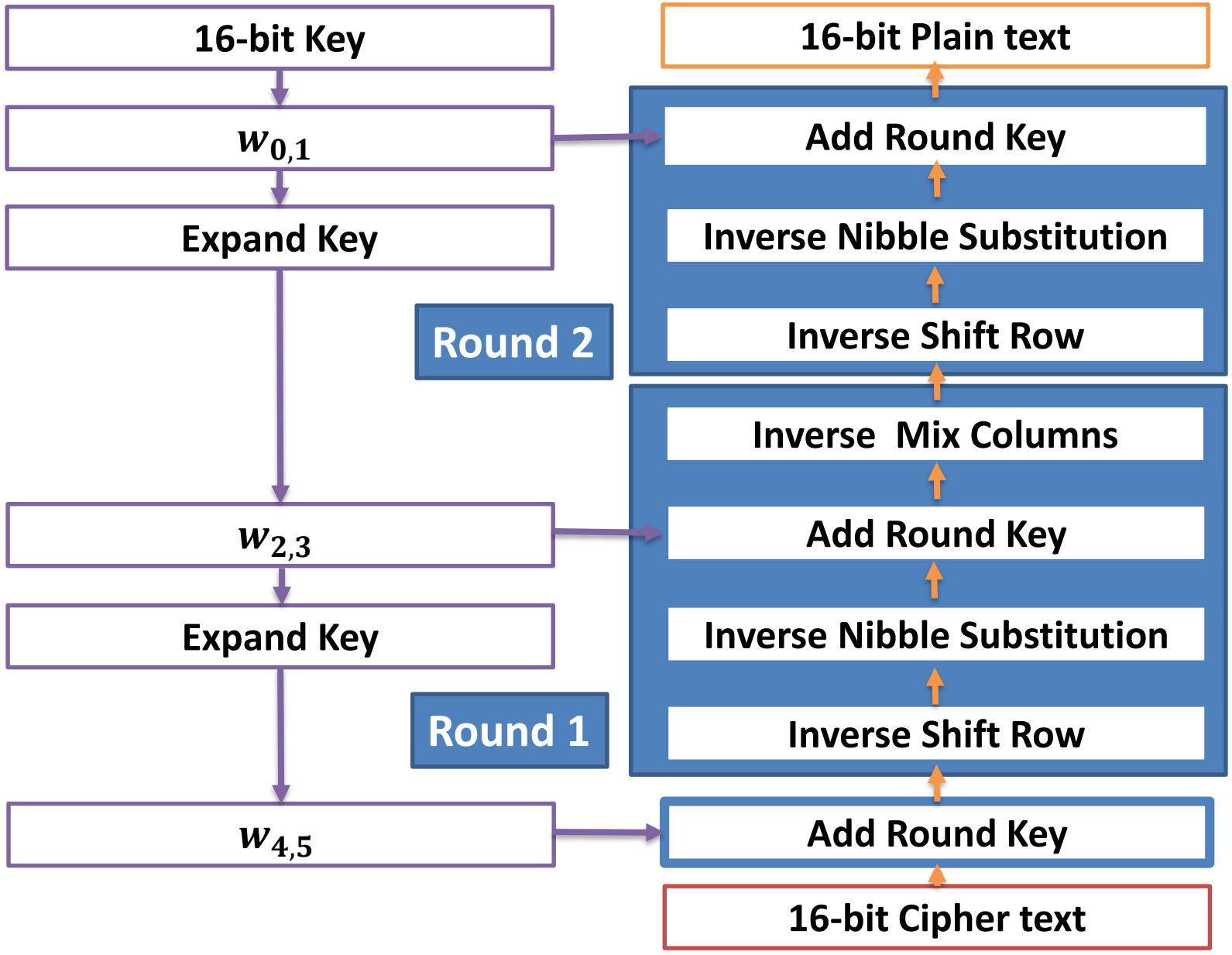
S-AES Encryption and Decryption



S-AES Decryption



S-AES Decryption

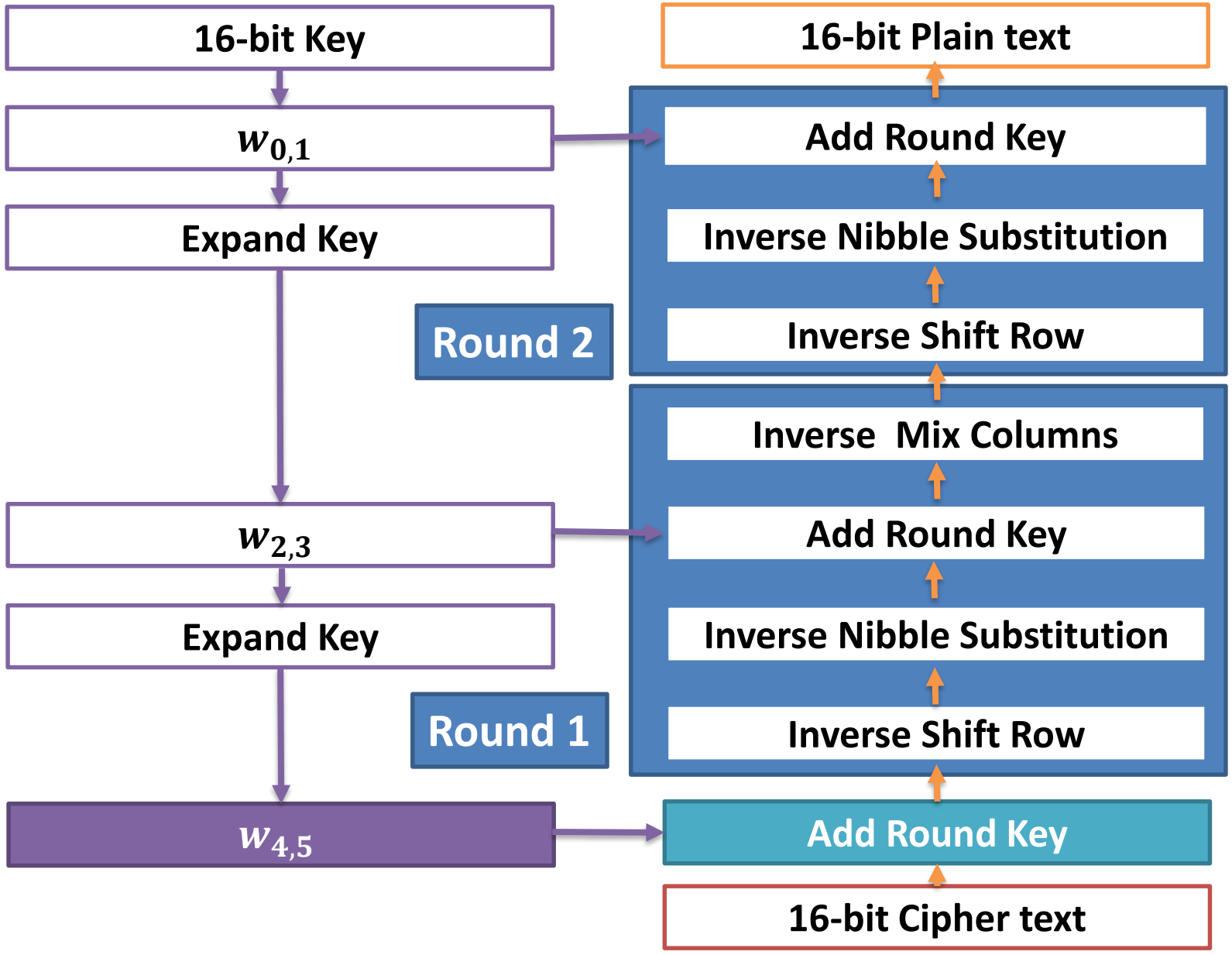
- Assume: C= 0010 0100 1110 1100
- Key0 = w0w1

  = 0100 1010 1111 0101
- Key1 = w2w3

  = 1101 1101 0010 1000
- Key2 = w4w5

  = 1000 0111 1010 1111

S-AES Decryption



S-AES Decryption

- Key2 = w4w5

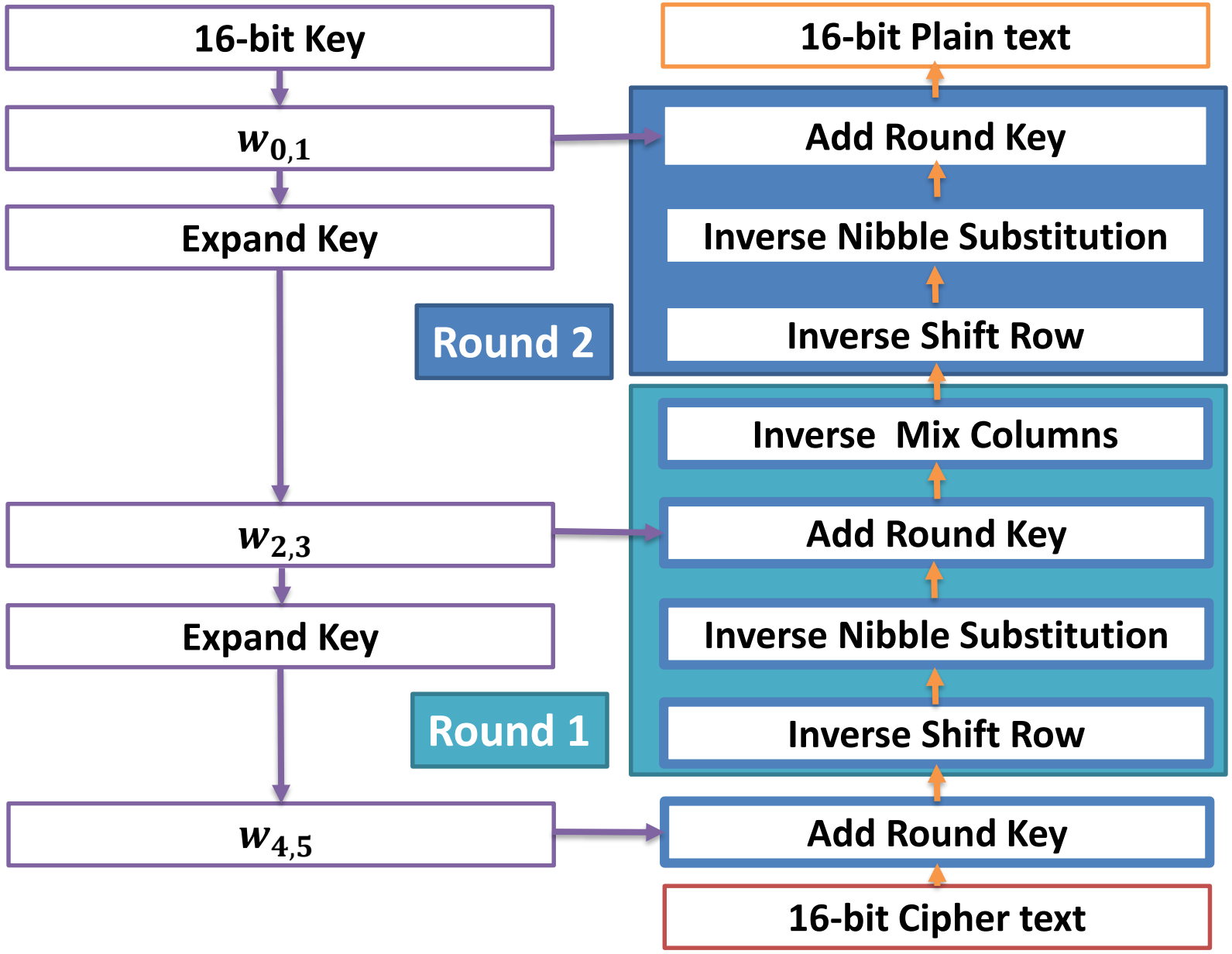
  = 1000 0111 1010 1111

- C= 0010 0100 1110 1100

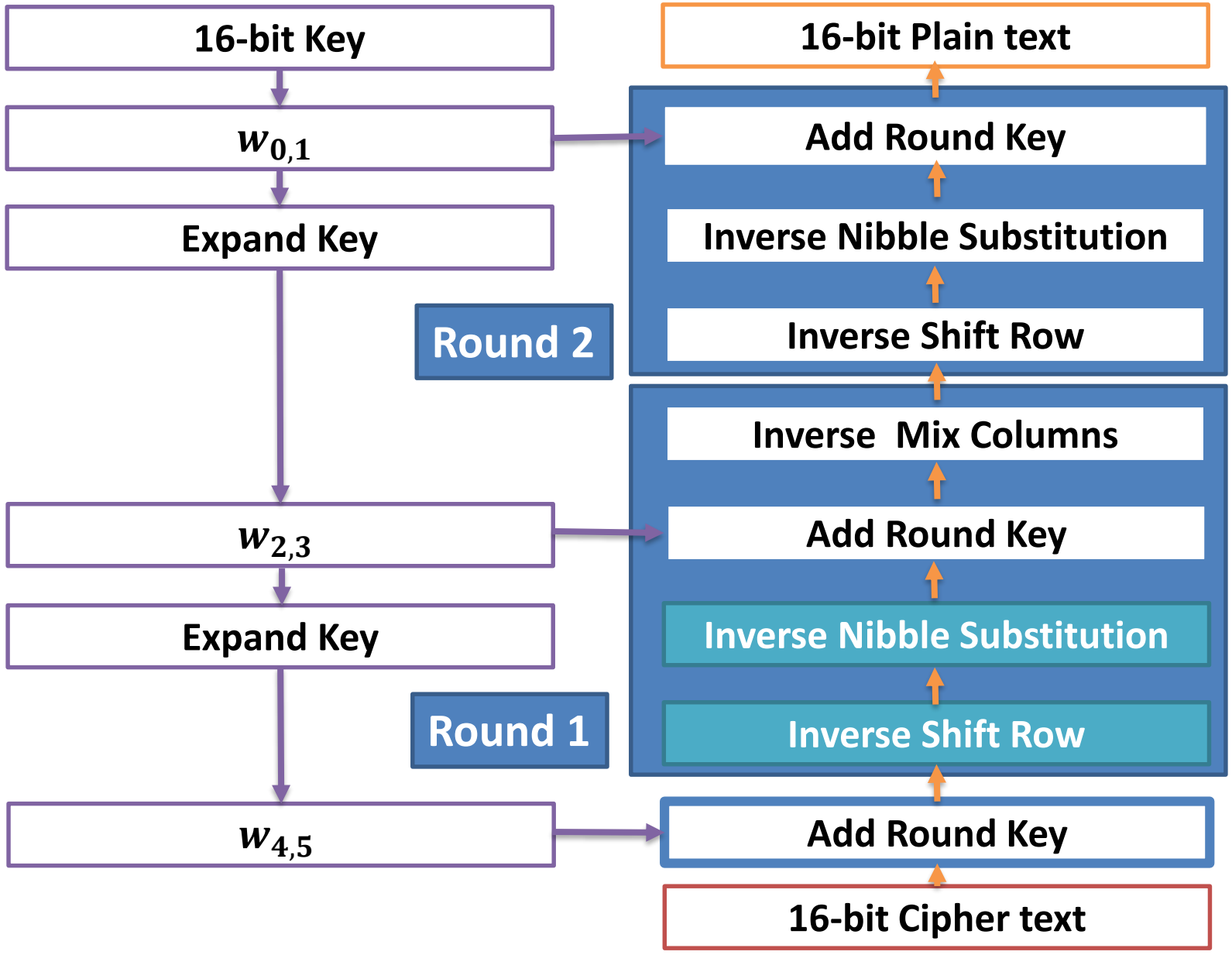
- R0= C $\oplus$ Key2 = 0010 0100 1110 1100 $\oplus$ 1000 0111 1010 1111

- =1010 0011 0100 0011

S-AES Decryption



S-AES Decryption



- Round 1

1) Inverse Shift Row

- IShRow(R0)=IShRow(1010 0011 0100 0011)=

  = 1010 0011 0100 0011

2) Inverse Nibble Sub

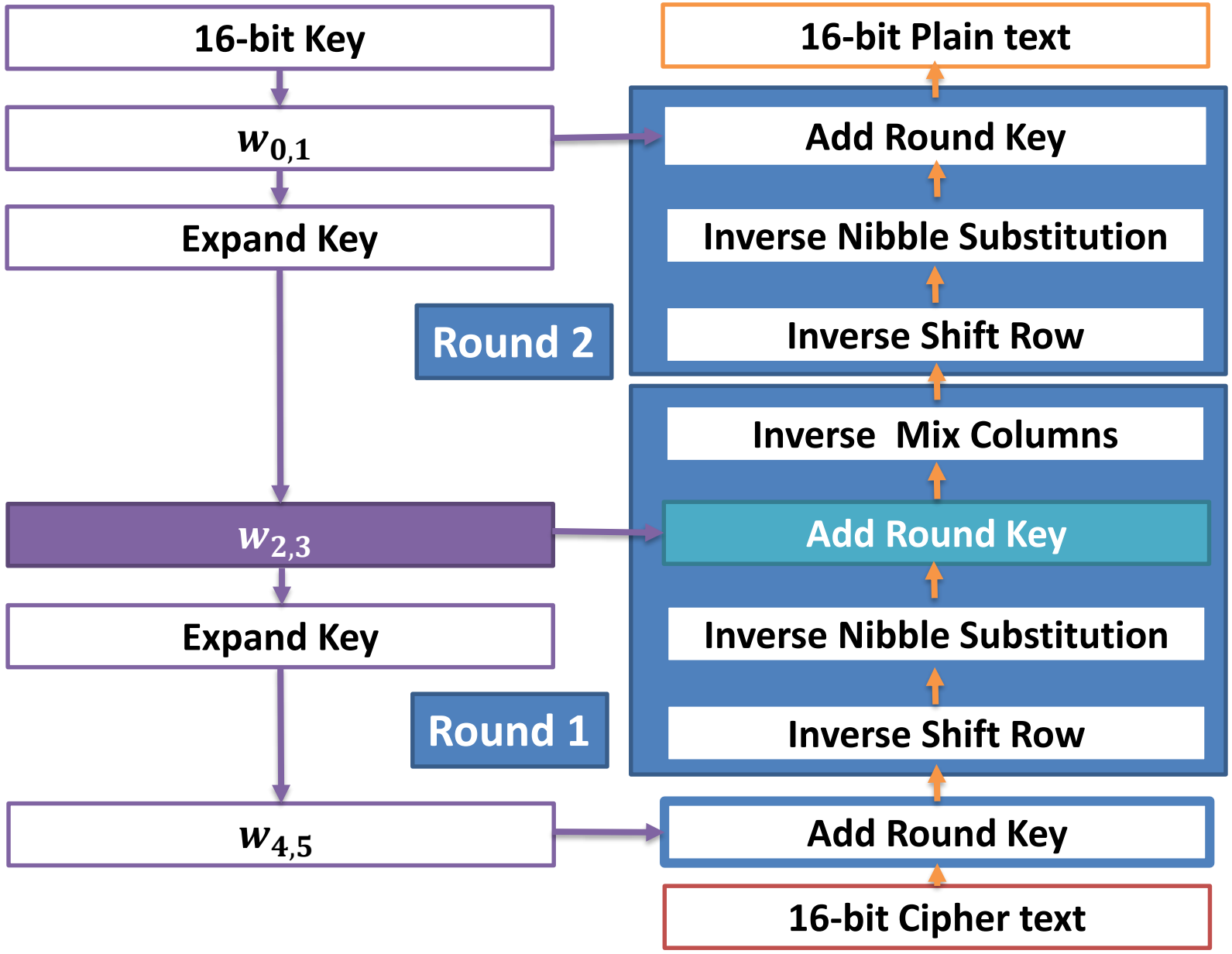
- ISubNib(1010 0011 0100 0011)=

  = 0010 1011 0001 1011

Inv S-Box

		j			
		00	**01**	**10**	**11**
i	**00**	A	5	9	B
	01	1	7	8	F
	10	6	0	2	3
	11	C	4	D	E

S-AES Decryption



S-AES Decryption

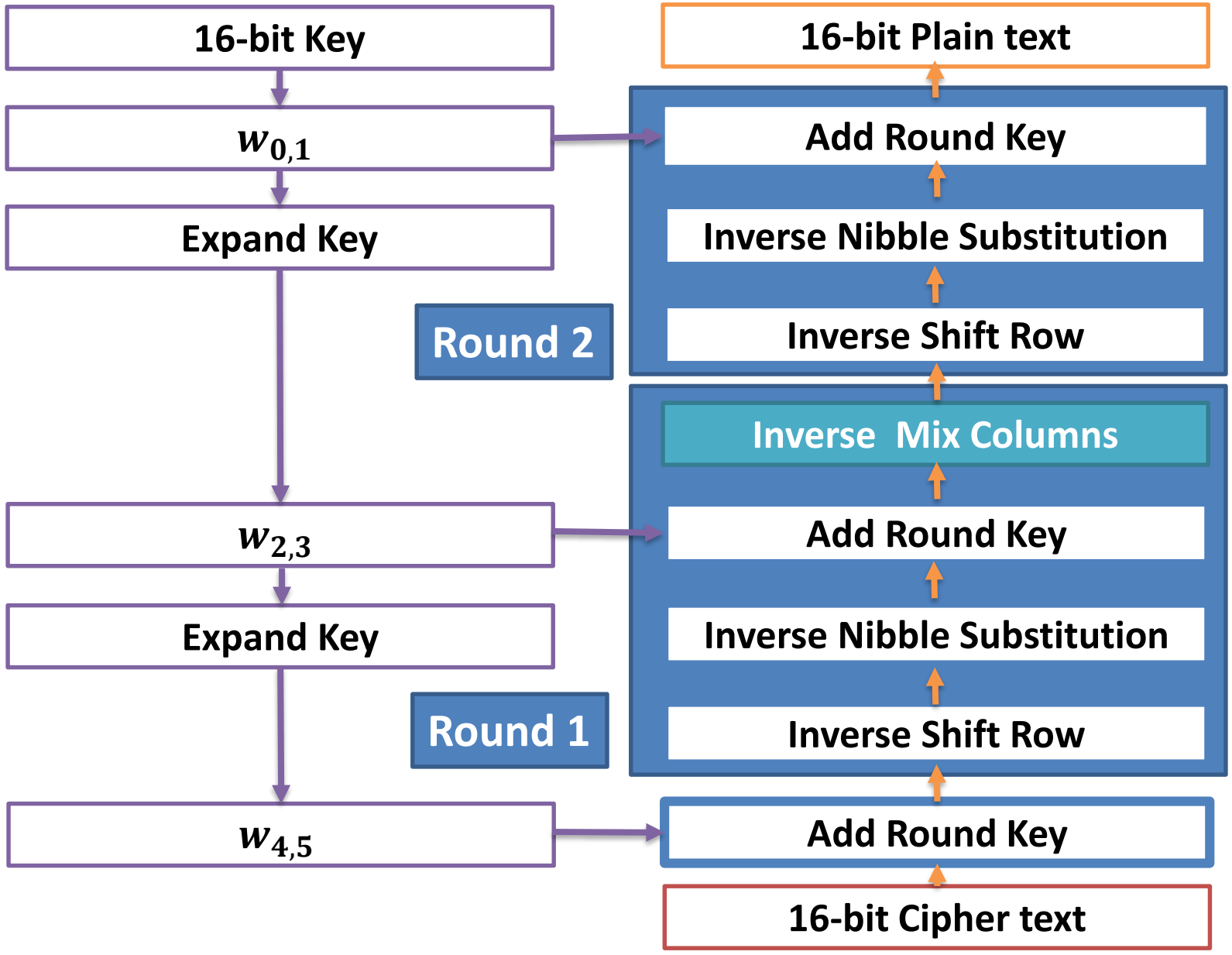
3) Add Round 1 Key

- 0010 1011 0001 1011 $\oplus$ Key1

  = 0010 1011 0001 1011 $\oplus$ 1101 1101 0010 1000

  =1111 0110 0011 0011

S-AES Decryption



S-AES Encryption

- Round 1

4) Inverse Mix Columns :

- MixCol (1111 0110 0011 0011) = $\begin{pmatrix} 1111 & 0011 \\ 0110 & 0011 \end{pmatrix} * \begin{pmatrix} 9 & 2 \\ 2 & 9 \end{pmatrix} =$
- $= \begin{pmatrix} F & 3 \\ 6 & 3 \end{pmatrix} * \begin{pmatrix} 9 & 2 \\ 2 & 9 \end{pmatrix} = \begin{pmatrix} (F*9 \oplus 6*2) & (3*9 \oplus 3*2) \\ (F*2 \oplus 6*9) & (3*2 \oplus 3*9) \end{pmatrix}$
- $= \begin{pmatrix} (E \oplus C) & (8 \oplus 6) \\ (D \oplus 3) & (6 \oplus 8) \end{pmatrix}$
- $= \begin{pmatrix} (1110 \oplus 1100) & (1000 \oplus 0110) \\ (1101 \oplus 0011) & (0110 \oplus 1000) \end{pmatrix}$

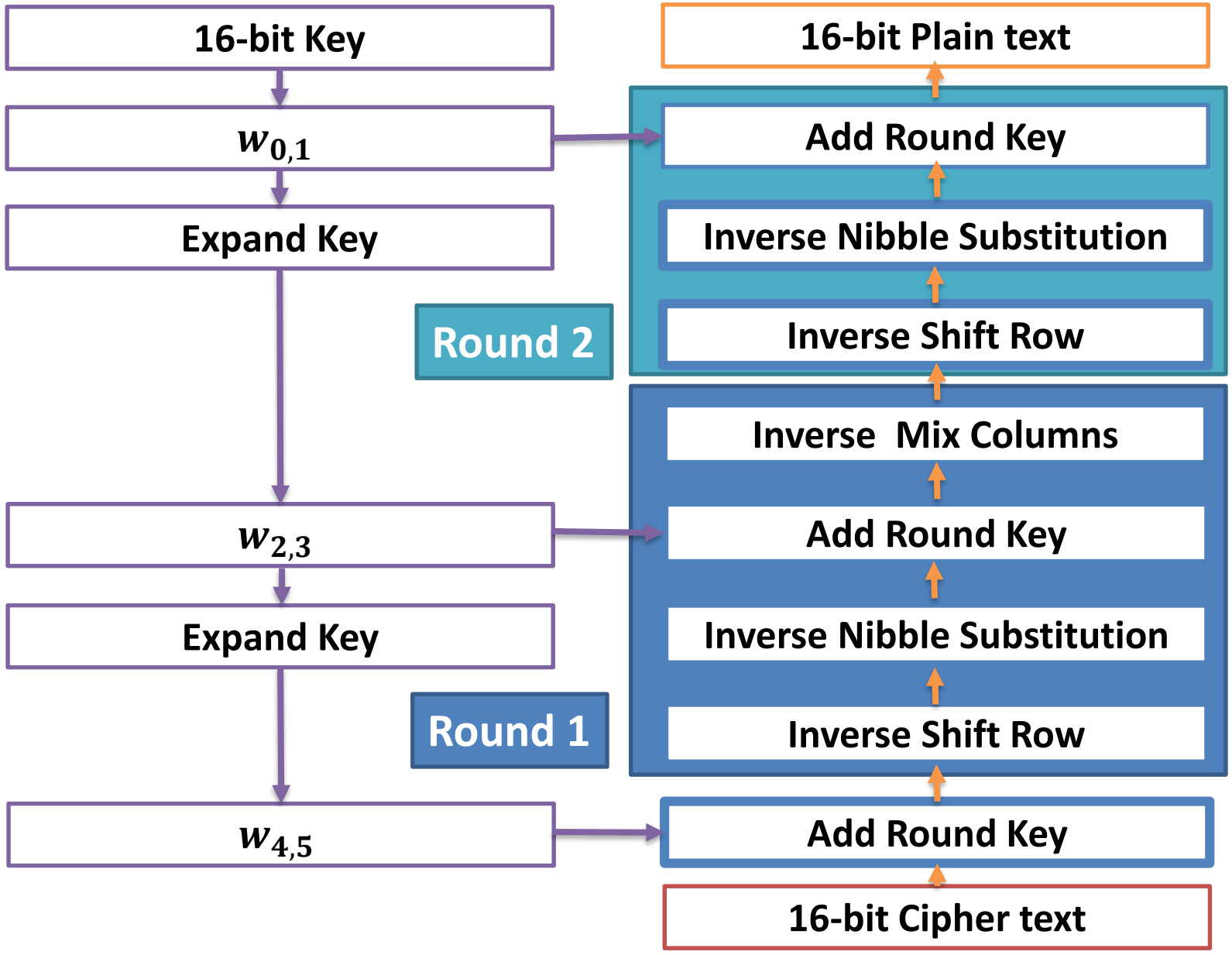
*	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
2	2	4	6	8	A	C	E	3	1	7	5	B	9	F	D
4	4	8	C	3	7	B	F	6	2	E	A	5	1	D	9
9	9	1	8	2	B	3	A	4	D	5	C	6	F	7	E

S-AES Encryption

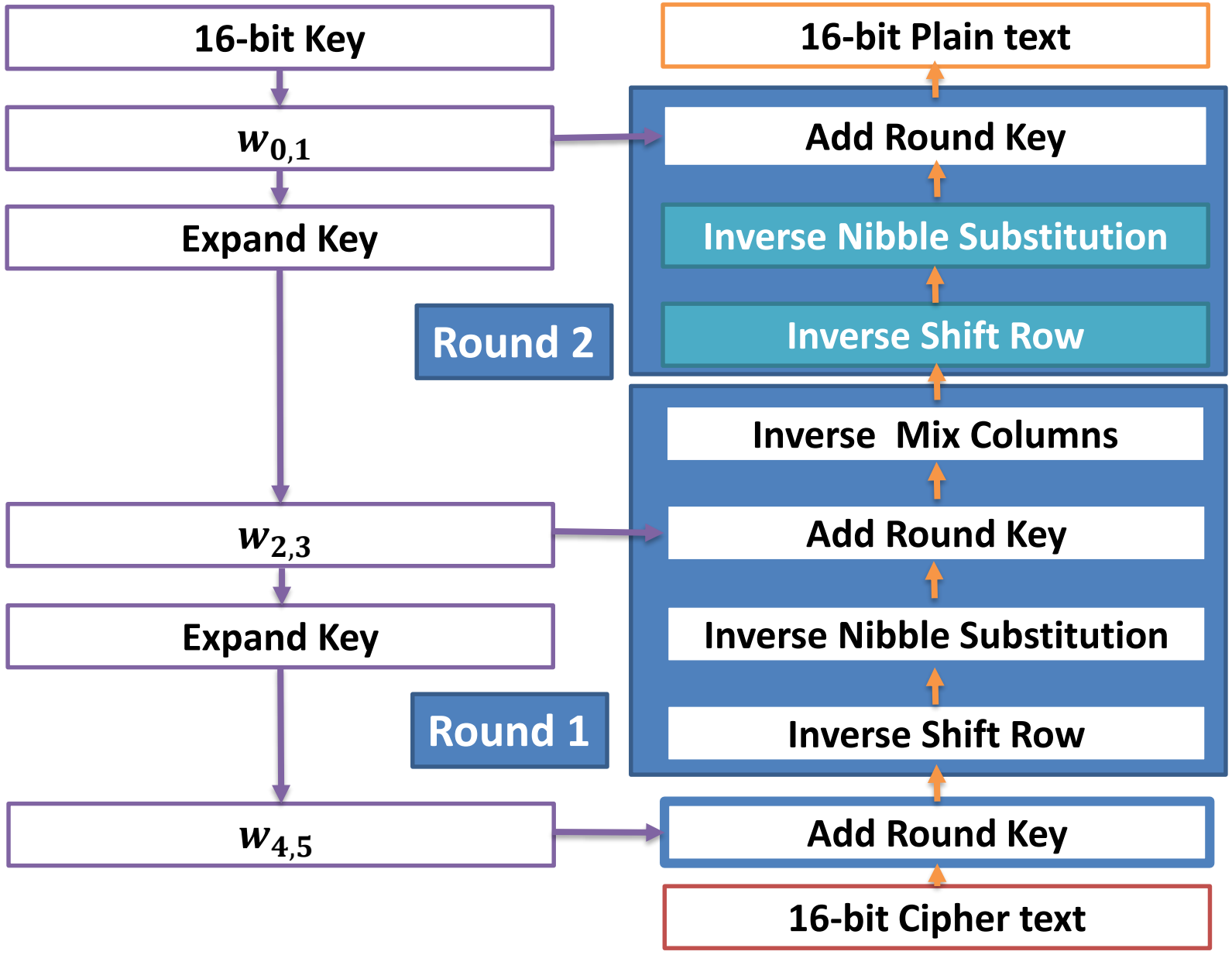
- $\begin{pmatrix} (1110 \oplus 1100) & (1000 \oplus 0110) \\ (1101 \oplus 0011) & (0110 \oplus 1000) \end{pmatrix} = \begin{pmatrix} 0010 & 1110 \\ 1110 & 1110 \end{pmatrix}$

R1 = 0010 1110 1110 1110

S-AES Decryption



S-AES Decryption



- Round 2

1) Inverse Shift Row

- IShRow(R1)=IShRow(0010 1110 1110 1110)=

  = 0010 1110 1110 1110

2) Inverse Nibble Sub

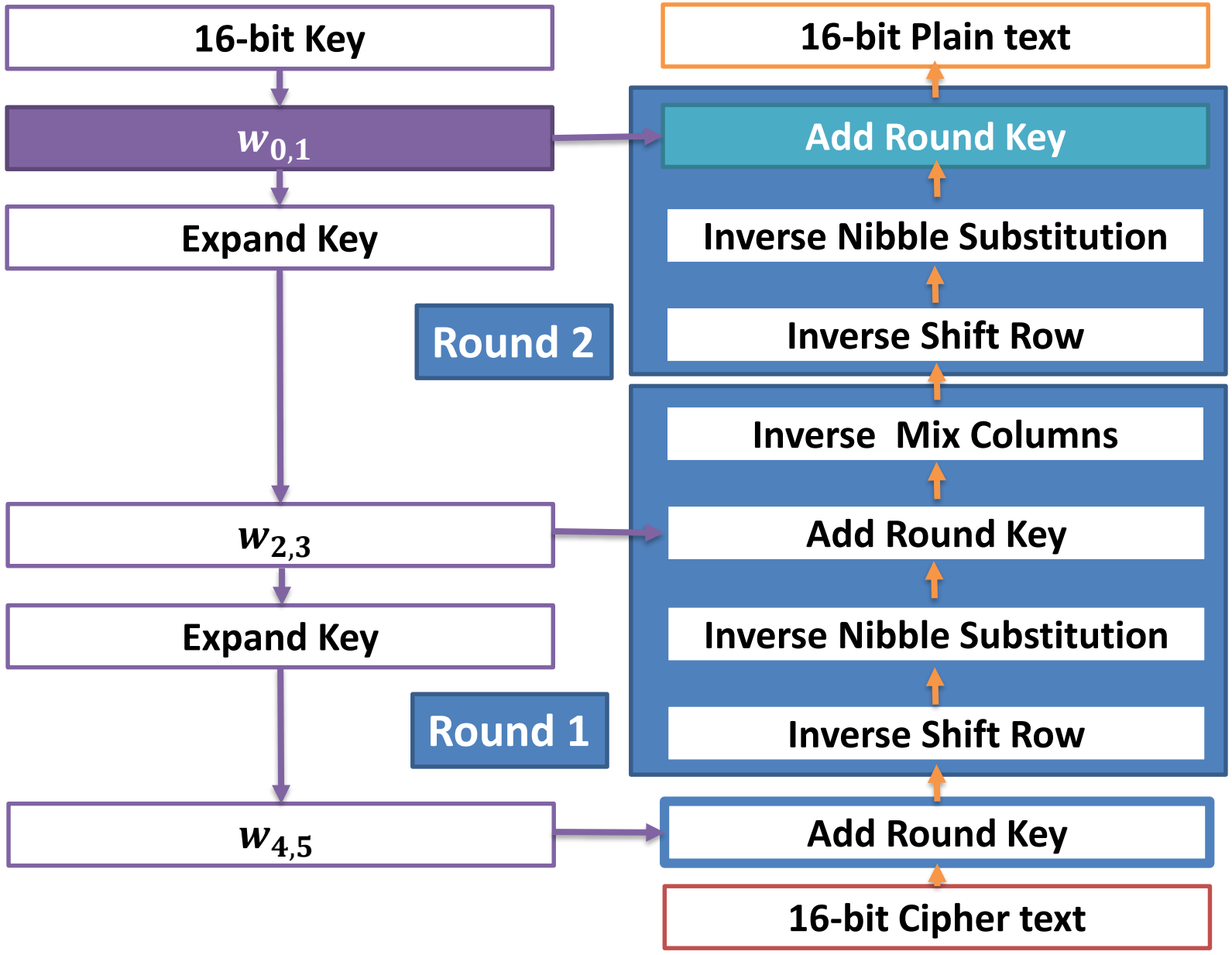
- ISubNib(0010 1110 1110 1110)=

  = 1001 1101 1101 1101

Inv S-Box

		j			
		00	**01**	**10**	**11**
i	**00**	A	5	9	B
	01	1	7	8	F
	10	6	0	2	3
	11	C	4	D	E

S-AES Decryption



S-AES Decryption

3) Add Round 2 Key

- R2= 1001 1101 1101 1101 $\oplus$ Key0

  = 1001 1101 1101 1101 $\oplus$ 0100 1010 1111 0101

  =1101 0111 0010 1000

Plaintext = 1101 0111 0010 1000 = D7 28

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THANKS FOR YOUR TIME