SNS COLLEGE OF ENGINEERING
Kurumbapalayam(Po), Coimbatore – 641 107
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DEPARTMENT OF INFORMATION TECHNOLOGY

Course Code and Name : 19IT602– CRYPTOGRAPHY AND CYBER SECURITY

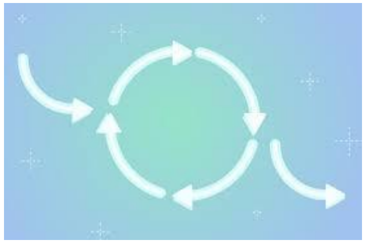
III YEAR / VI SEMESTER

Unit 2: SYMMETRIC KEY CRYPTOGRAPHY

Topic : Advanced Encryption Standard

Advanced Encryption Standard - AES

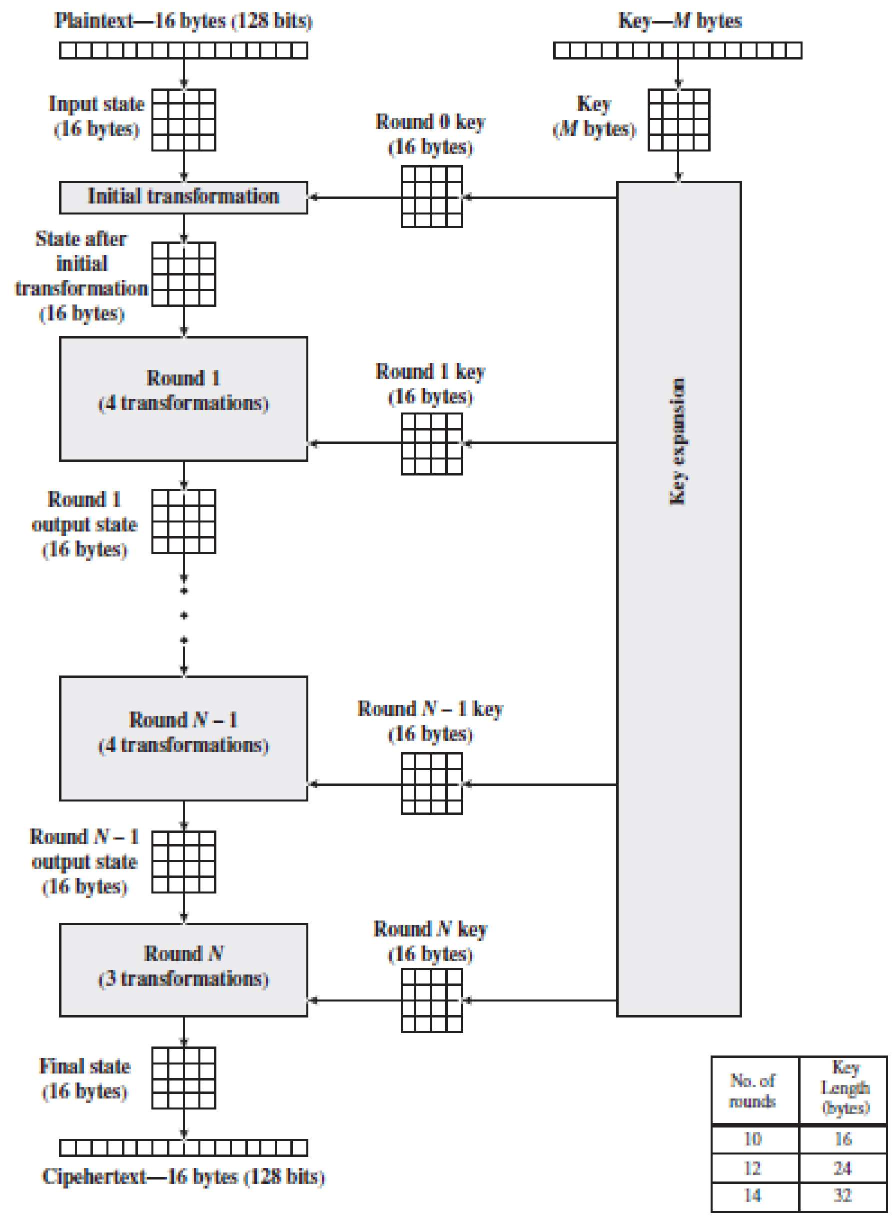
- designed by Rijmen-Daemen in Belgium
- has 128/192/256 bit keys, 128 bit data
- an **iterative** rather than **feistel** cipher
  - treats data in 4 groups of 4 bytes
  - operates an entire block in every round
- designed to be:
  - resistant against known attacks
  - speed and code compactness on many CPUs
  - design simplicity



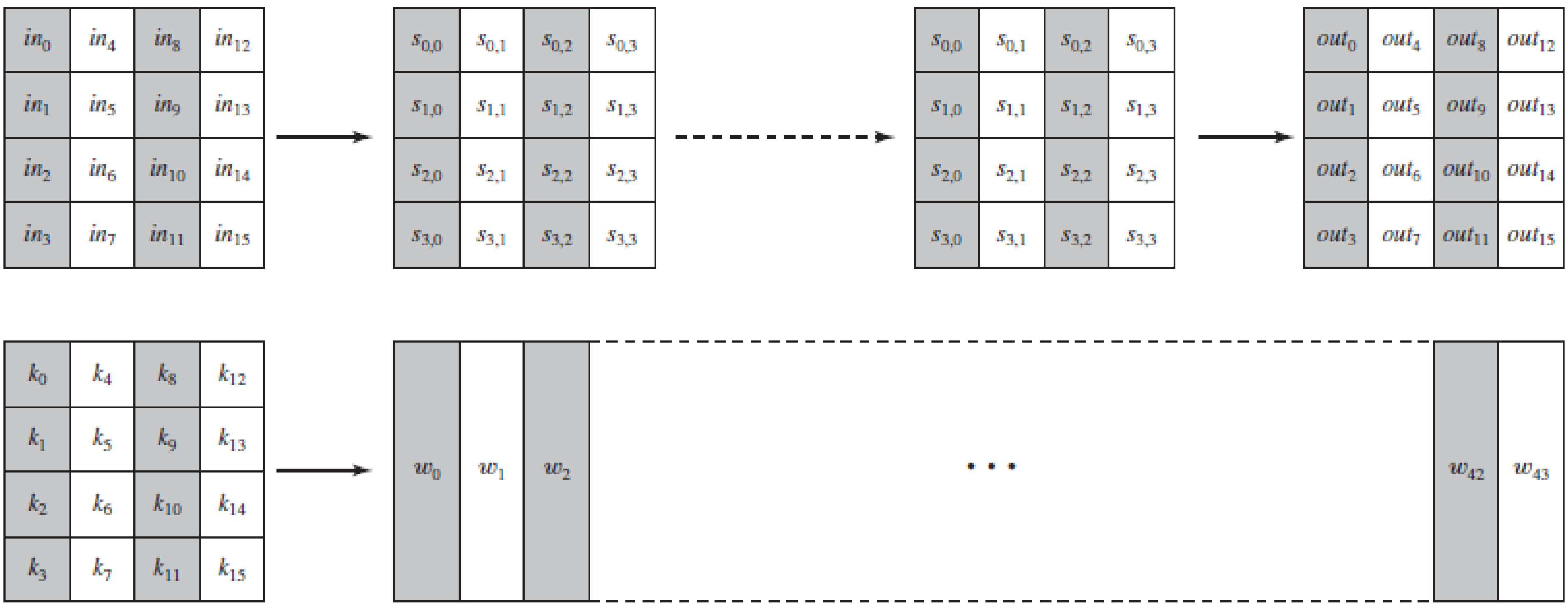
AES Encryption

- State Arrays
  - 4 x 4 Matrix
- Key
  - 44 Words

Key Size (words/bytes/bits)	4/16/128	6/24/192	8/32/256
Plaintext Block Size (words/bytes/bits)	4/16/128	4/16/128	4/16/128
Number of Rounds	10	12	14
Round Key Size (words/bytes/bits)	4/16/128	4/16/128	4/16/128
Expanded Key Size (words/bytes)	44/176	52/208	60/240

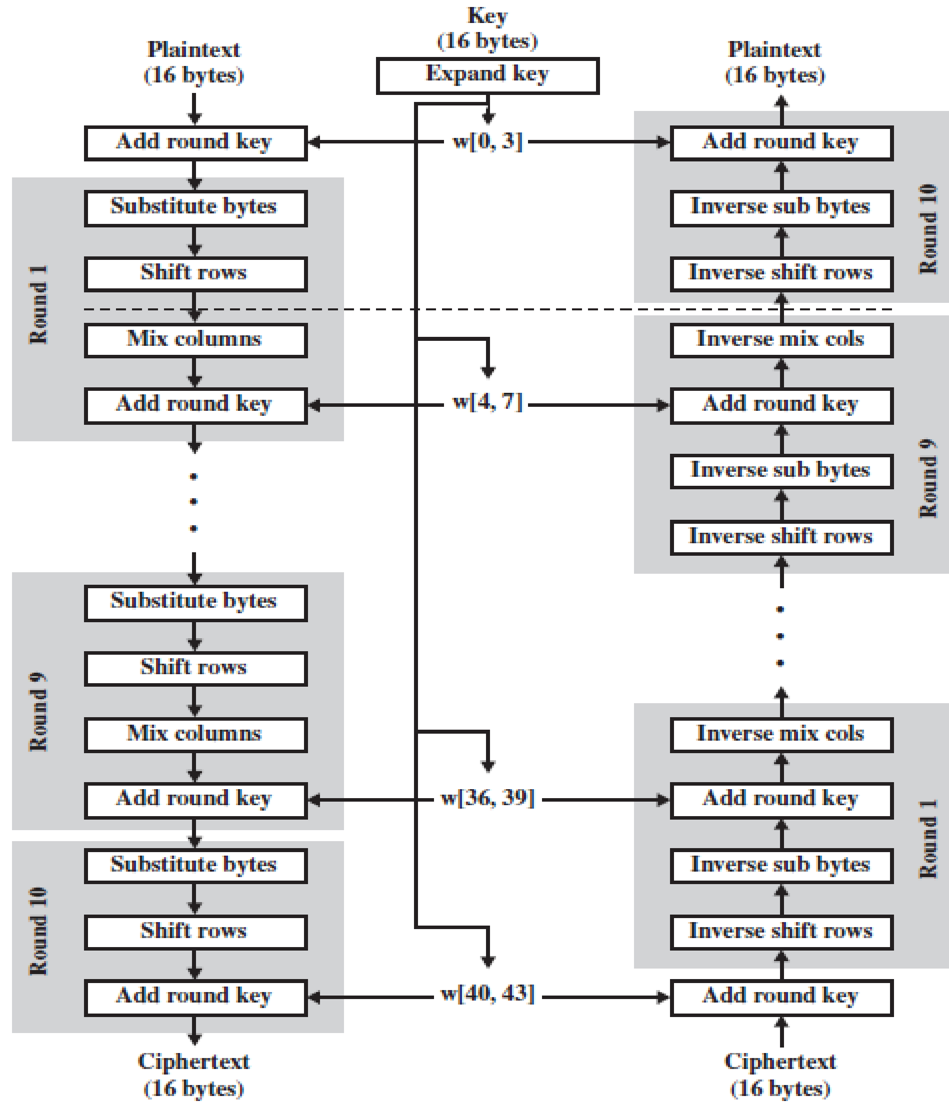


Input(in), State array (s), Output (out), Key(k) and Expanded Key(w)



AES Structure

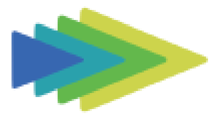
- Key – is expanded into array of 44 32-bit words
- 4 Stages
- Simple Structure
  - Encryption and Decryption – Add round key followed by 9 rounds –all 4 stages except 9th round – 3 stages
- Starts with AddRoundkey – uses key
- Efficient and highly secure – XOR, confusion, Diffusion
- Easily Reversible
- Decryption is not the same as encryption



AES Transformation Function

Stages of AES

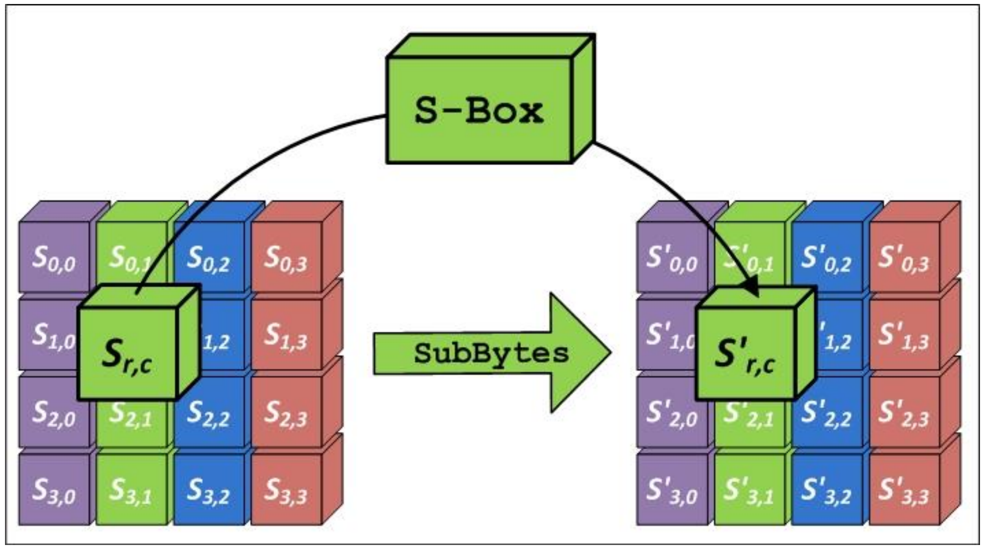
- Substitute bytes
  - Uses an S-box to perform a byte-by-byte substitution of the block
- ShiftRows
  - A simple permutation



- MixColumns

  - A substitution that makes use of arithmetic over
- AddRoundKey
  - A simple bitwise XOR of the current block with a portion of the expanded key

Substitute Bytes Transformation



EA	04	65	85
83	45	5D	96
5C	33	98	B0
F0	2D	AD	C5

→

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

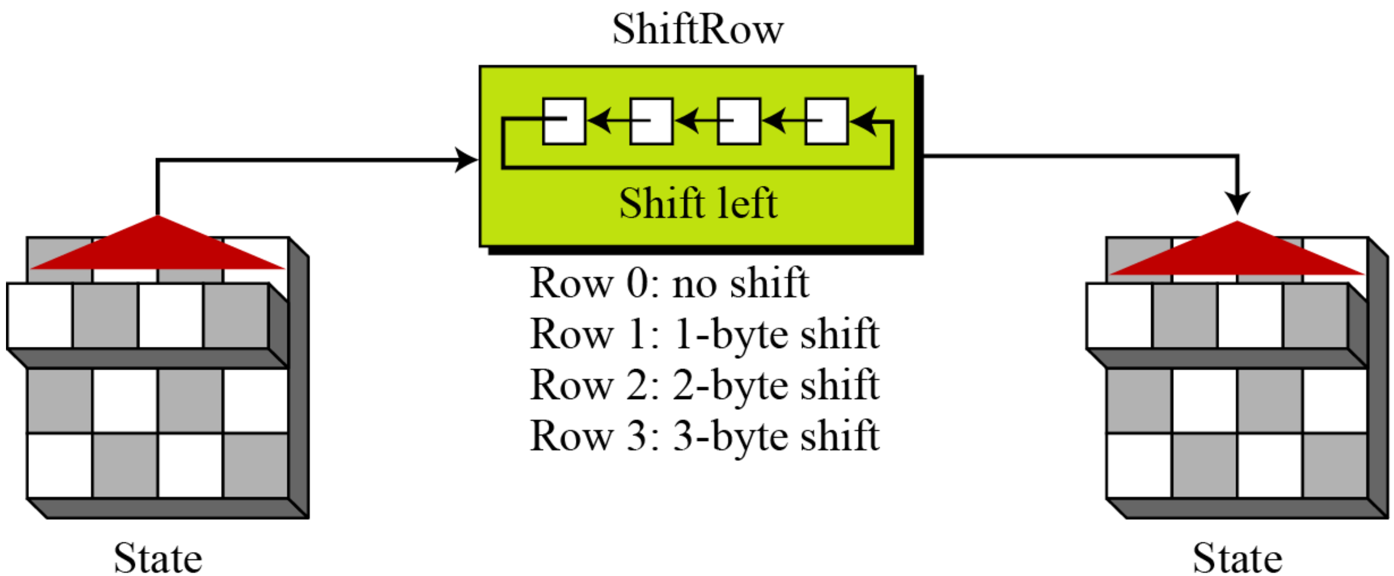
S-Box

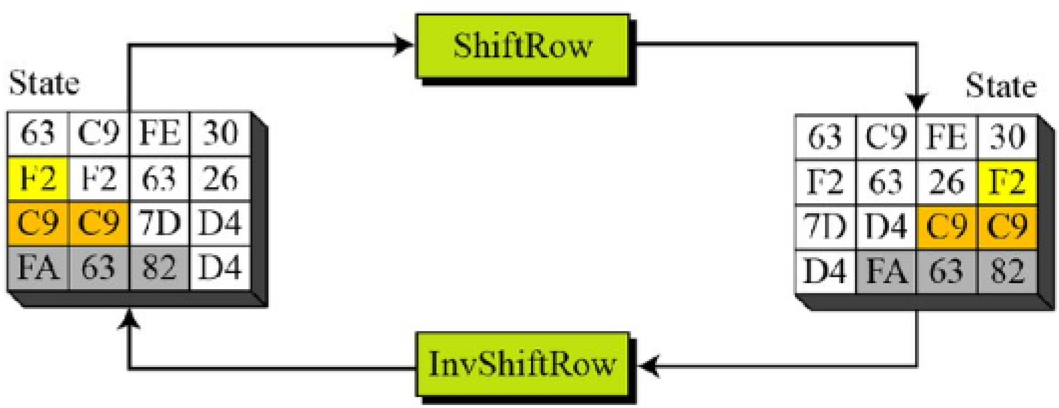
	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	63	7C	77	7B	F2	6B	6F	C5	30	01	67	2B	FE	D7	AB	76
1	CA	82	C9	7D	FA	59	47	F0	AD	D4	A2	AF	9C	A4	72	C0
2	B7	FD	93	26	36	3F	F7	CC	34	A5	E5	F1	71	D8	31	15
3	04	C7	23	C3	18	96	05	9A	07	12	80	E2	EB	27	B2	75
4	09	83	2C	1A	1B	6E	5A	A0	52	3B	D6	B3	29	E3	2F	84
5	53	D1	00	ED	20	FC	B1	5B	6A	CB	BE	39	4A	4C	58	CF
6	D0	EF	AA	FB	43	4D	33	85	45	F9	02	7F	50	3C	9F	A8
7	51	A3	40	8F	92	9D	38	F5	BC	B6	DA	21	10	FF	F3	D2
8	CD	0C	13	EC	5F	97	44	17	C4	A7	7E	3D	64	5D	19	73
9	60	81	4F	DC	22	2A	90	88	46	EE	B8	14	DE	5E	0B	DB
A	E0	32	3A	0A	49	06	24	5C	C2	D3	AC	62	91	95	E4	79
B	E7	C8	37	6D	8D	D5	4E	A9	6C	56	F4	EA	65	7A	AE	08
C	BA	78	25	2E	1C	A6	B4	C6	E8	DD	74	1F	4B	BD	8B	8A
D	70	3E	B5	66	48	03	F6	0E	61	35	57	B9	86	C1	1D	9E
E	E1	F8	98	11	69	D9	8E	94	9B	1E	87	E9	CE	55	28	DF
F	8C	A1	89	0D	BF	E6	42	68	41	99	2D	0F	B0	54	BB	16

Inverse S-Box

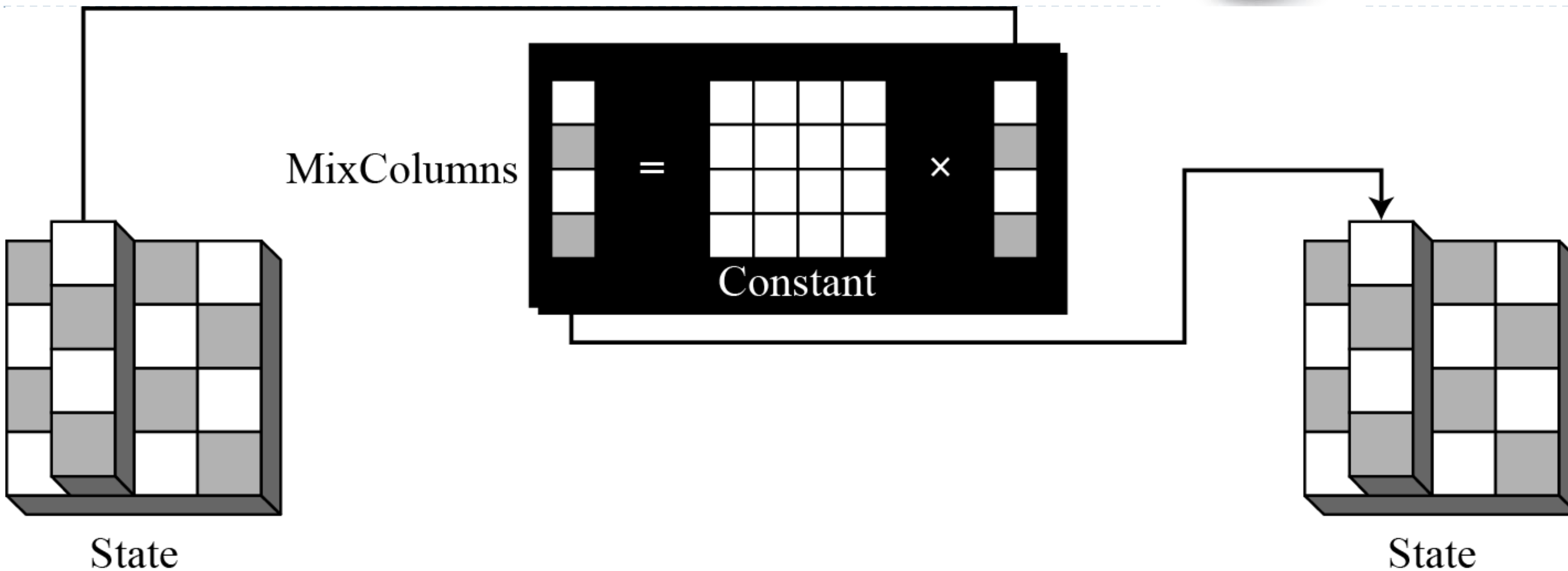
		y															
		0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
x	0	52	09	6a	d5	30	36	a5	38	bf	40	a3	9e	81	f3	d7	fb
	1	7c	e3	39	82	9b	2f	ff	87	34	8e	43	44	c4	de	e9	cb
	2	54	7b	94	32	a6	c2	23	3d	ee	4c	95	0b	42	fa	c3	4e
	3	08	2e	a1	66	28	d9	24	b2	76	5b	a2	49	6d	8b	d1	25
	4	72	f8	f6	64	86	68	98	16	d4	a4	5c	cc	5d	65	b6	92
	5	6c	70	48	50	fd	ed	b9	da	5e	15	46	57	a7	8d	9d	84
	6	90	d8	ab	00	8c	bc	d3	0a	f7	e4	58	05	b8	b3	45	06
	7	d0	2c	1e	8f	ca	3f	0f	02	c1	af	bd	03	01	13	8a	6b
	8	3a	91	11	41	4f	67	dc	ea	97	f2	cf	ce	f0	b4	e6	73
	9	96	ac	74	22	e7	ad	35	85	e2	f9	37	e8	1c	75	df	6e
	a	47	f1	1a	71	1d	29	c5	89	6f	b7	62	0e	aa	18	be	1b
	b	fc	56	3e	4b	c6	d2	79	20	9a	db	c0	fe	78	cd	5a	f4
	c	1f	dd	a8	33	88	07	c7	31	b1	12	10	59	27	80	ec	5f
	d	60	51	7f	a9	19	b5	4a	0d	2d	e5	7a	9f	93	c9	9c	ef
	e	a0	e0	3b	4d	ae	2a	f5	b0	c8	eb	bb	3c	83	53	99	61
	f	17	2b	04	7e	ba	77	d6	26	e1	69	14	63	55	21	0c	7d

ShiftRows Transformation





MixColumns Transformation



$$C = \begin{bmatrix} 02 & 03 & 01 & 01 \\ 01 & 02 & 03 & 01 \\ 01 & 01 & 02 & 03 \\ 03 & 01 & 01 & 02 \end{bmatrix} \xleftrightarrow{\text{Inverse}} C^{-1} = \begin{bmatrix} 0E & 0B & 0D & 09 \\ 09 & 0E & 0B & 0D \\ 0D & 09 & 0E & 0B \\ 0B & 0D & 09 & 0E \end{bmatrix}$$

87	F2	4D	97		47	40	A3	4C
6E	4C	90	EC		37	D4	70	9F
46	E7	4A	C3	→	94	E4	3A	42
A6	8C	D8	95		ED	A5	A6	BC

$$
\begin{aligned}
(\{02\}\bullet\{87\}) &\oplus (\{03\}\bullet\{6E\}) \oplus \{46\} \oplus \{A6\} = \{47\} \\
\{87\} &\oplus (\{02\}\bullet\{6E\}) \oplus (\{03\}\bullet\{46\}) \oplus \{A6\} = \{37\} \\
\{87\} &\oplus \{6E\} \oplus (\{02\}\bullet\{46\}) \oplus (\{03\}\bullet\{A6\}) = \{94\} \\
(\{03\}\bullet\{87\}) &\oplus \{6E\} \oplus \{46\} \oplus (\{02\}\bullet\{A6\}) = \{ED\}
\end{aligned}
$$

$$
x \times f(x) = \begin{cases} (b_6 b_5 b_4 b_3 b_2 b_1 b_0 0) & \text{if } b_7 = 0 \\ (b_6 b_5 b_4 b_3 b_2 b_1 b_0 0) \oplus (00011011) & \text{if } b_7 = 1 \end{cases}
$$

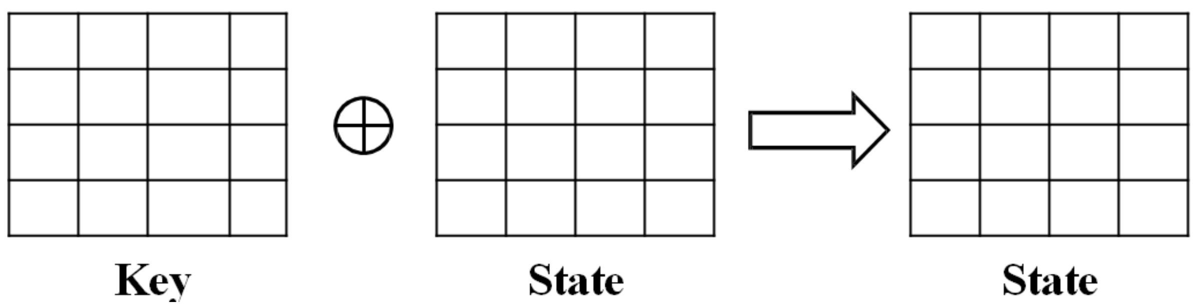
$$\{02\}\bullet\{87\} = (0000\ 1110) \oplus (0001\ 1011) = (0001\ 0101)$$

$$\{03\}\bullet\{6E\} = \{6E\} \oplus (\{02\}\bullet\{6E\}) = (0110\ 1110) \oplus (1101\ 1100) = (1011\ 0010).$$

$$
\begin{aligned}
\{02\}\bullet\{87\} &= 0001\ 0101 \\
\{03\}\bullet\{6E\} &= 1011\ 0010 \\
\{46\} &= 0100\ 0110 \\
\{A6\} &= \underline{1010\ 0110} \\
& \ 0100\ 0111 = \{47\}
\end{aligned}
$$

AddRoundKey Transformation

- **AddRoundKey(State, Key):**



47	40	A3	4C
37	D4	70	9F
94	E4	3A	42
ED	A5	A6	BC

⊕

AC	19	28	57
77	FA	D1	5C
66	DC	29	00
F3	21	41	6A

=

EB	59	8B	1B
40	2E	A1	C3
F2	38	13	42
1E	84	E7	D6

Thank You