Modes
ECB
CBC
CFB
OFB
CTR
Feedback
XTS-AES

COMP412 Computer Security

Lec 04
Block Cipher Operation

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2021/2022

Modes
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Modes of Operation

Electronic Code Book

Cipher Block Chaining Mode

Cipher Feedback Mode

Output Feedback Mode

Counter Mode

Feedback Characteristics of Modes

XTS-AES

Modes of Operation

- Block cipher: operates on fixed length b-bit **input** to produce b-bit **ciphertext**
- What about encrypting plaintext longer than b bits?
  - Break plaintext into b-bit blocks (padding if necessary) and apply cipher on each block
- Security issues arise: different modes of operation have been developed

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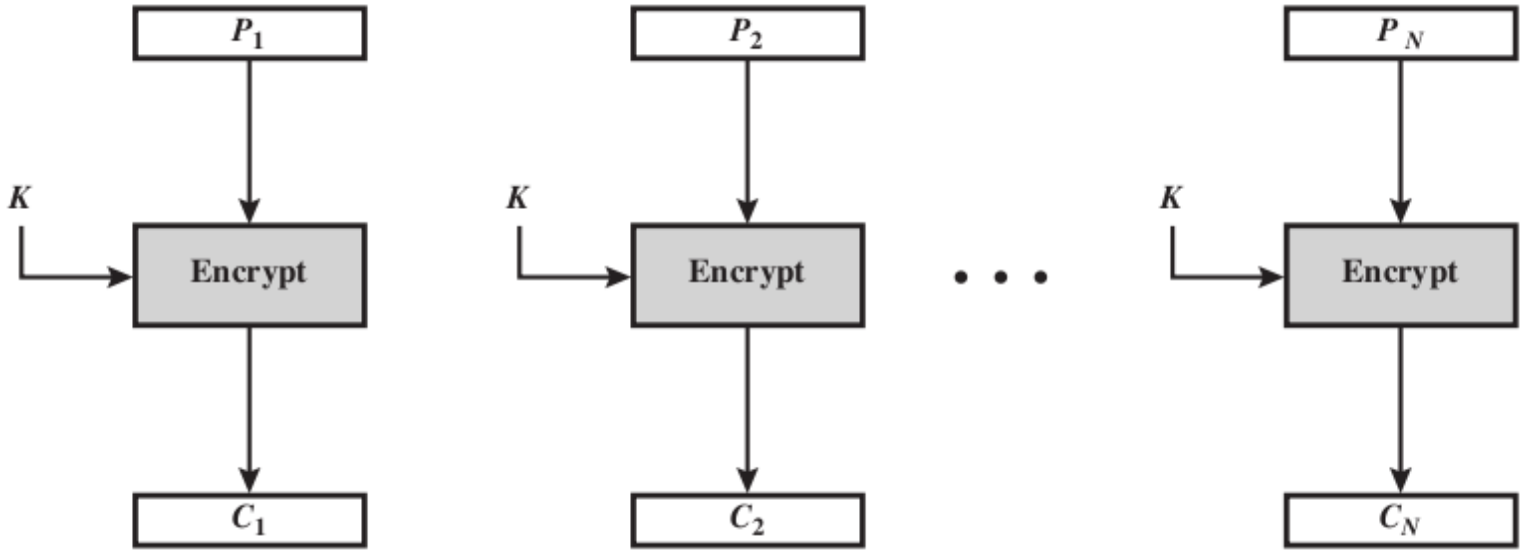
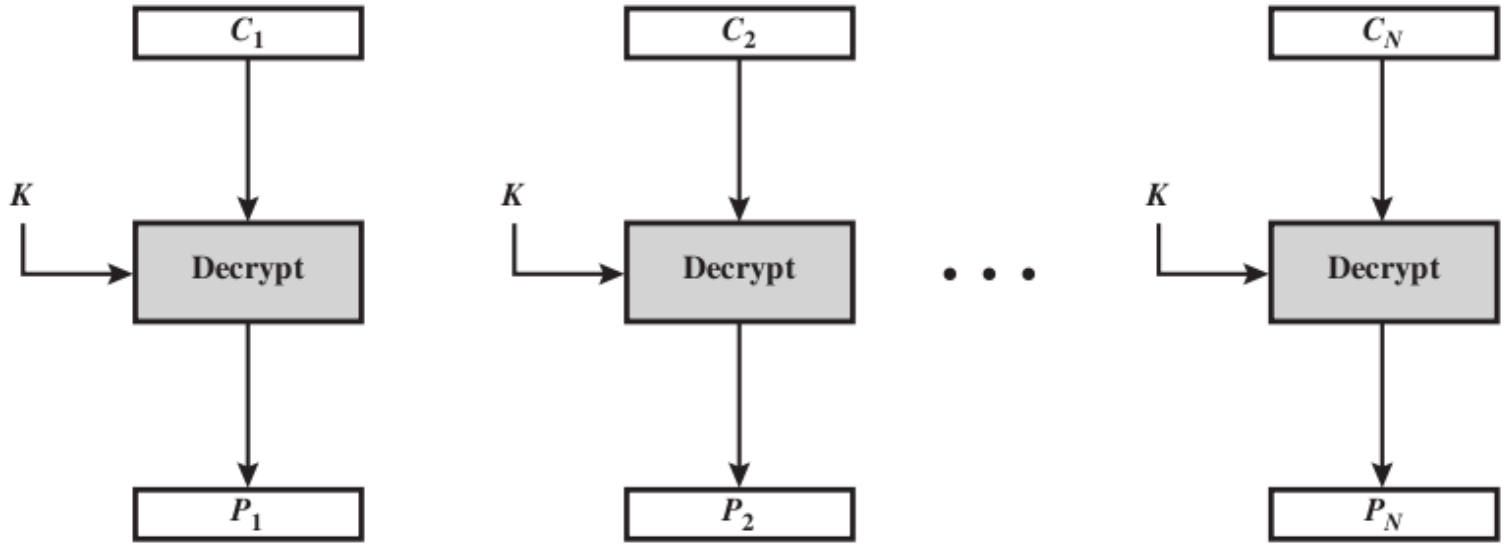
Electronic Code Book (ECB) Encryption



- Each block: 64 bits
- Same key in each block
- Independently

Electronic Code Book (ECB) Decryption



Summary

- Each block of 64 plaintext bits is encoded independently using same key
- Typical applications: secure transmission of single values (e.g. encryption key)
- Problem: with long message, repetition in plaintext may cause repetition in ciphertext

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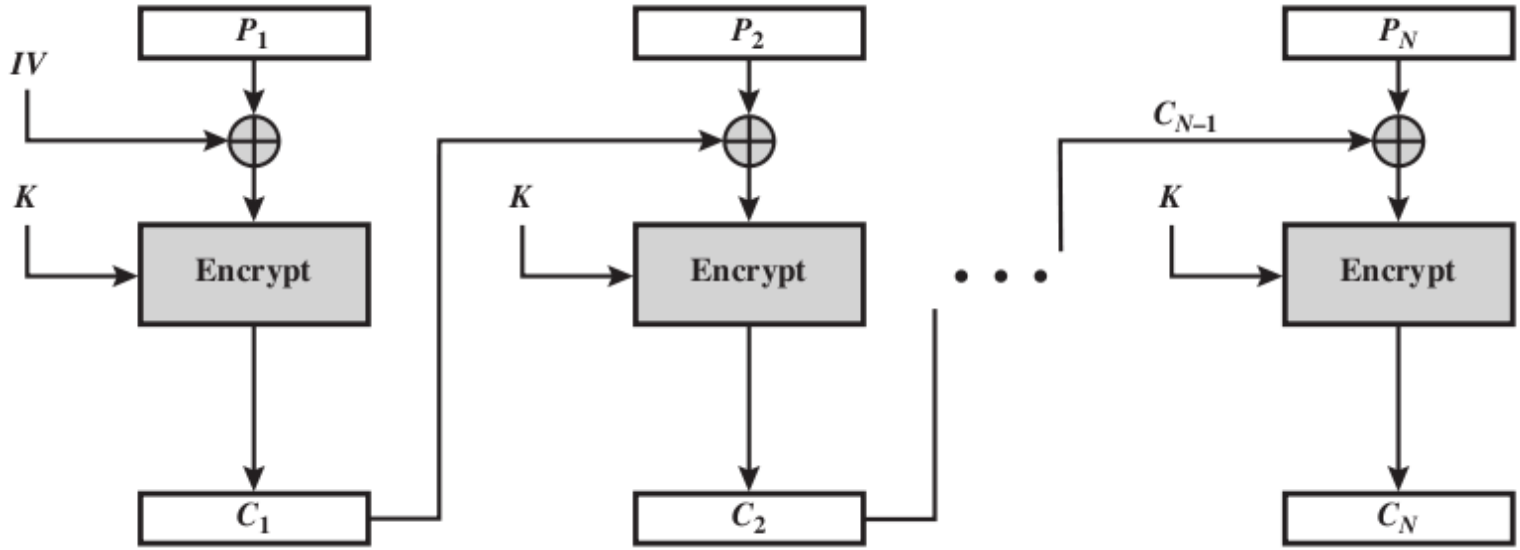
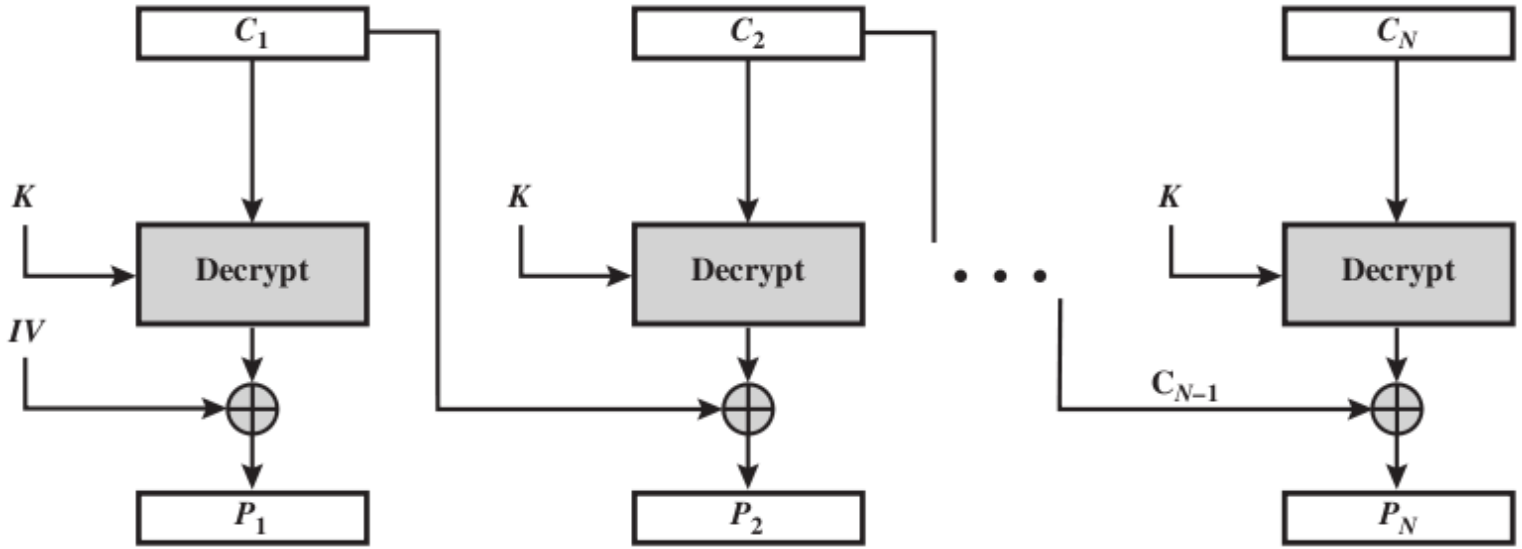
Cipher Block Chaining Mode (CBC) Encryption



- Each block: 64 bits
- Same key in each block
- Initialization Vector (IV) necessarily
- IV XORed P_1, Ci XORed P_{i+1}

Question: *How to avoid the repetition in ciphertext for repetition in plaintext?*

Cipher Block Chaining Mode (CBC) Decryption



CBC Summary

- Input to encryption algorithm is XOR of next 64-bits plaintext and preceding 64-bits ciphertext
- Typical applications: General-purpose block-oriented transmission; authentication
- Initialisation Vector (IV) must be known by sender/receiver, but secret from attacker
  - In particular, it must be impossible to predict the IV for any given plaintext;
  - For maximum security, IV should be protected against unauthorized changes.
    - E.g., send the IV using ECB encryption.

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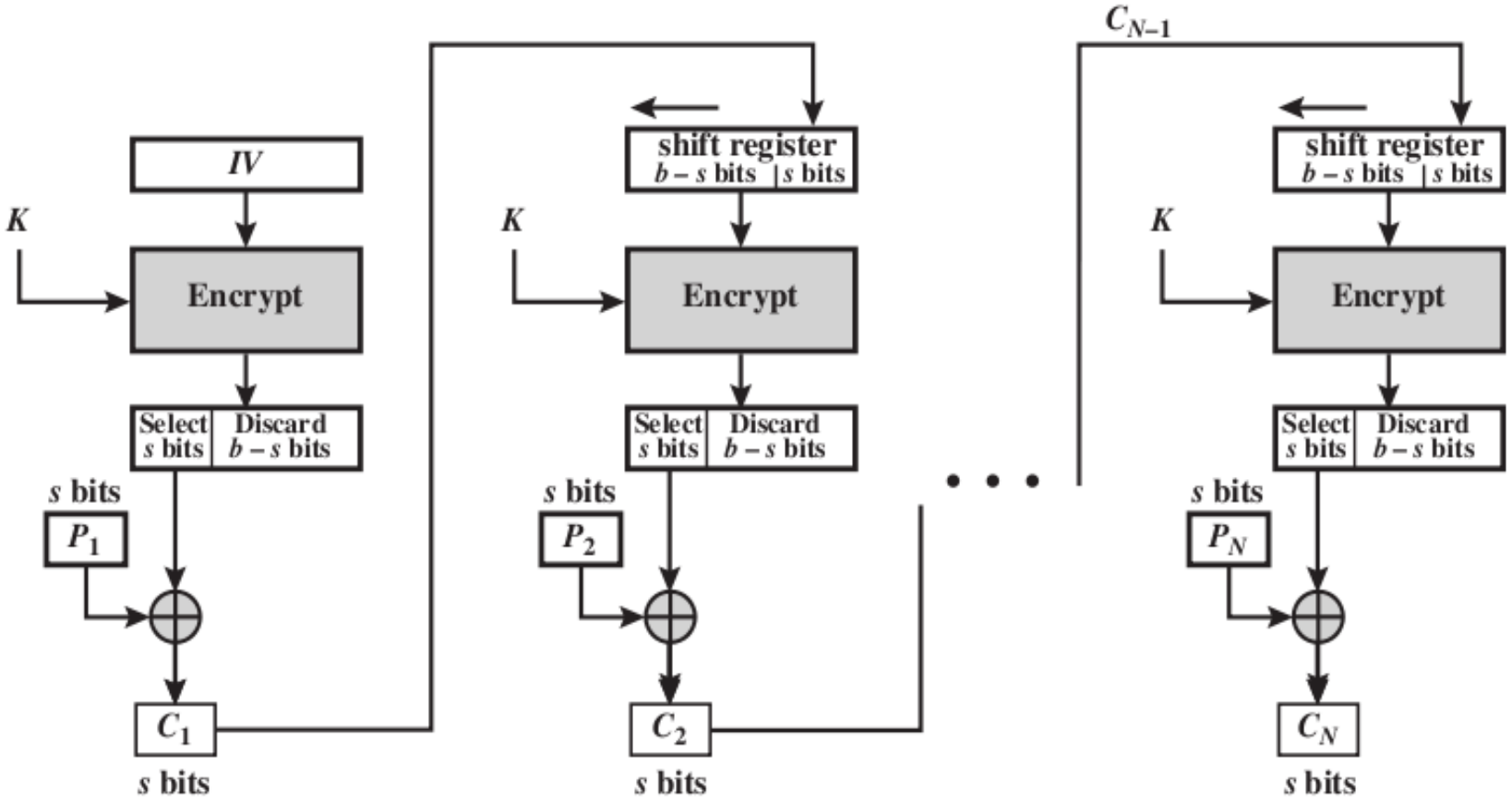
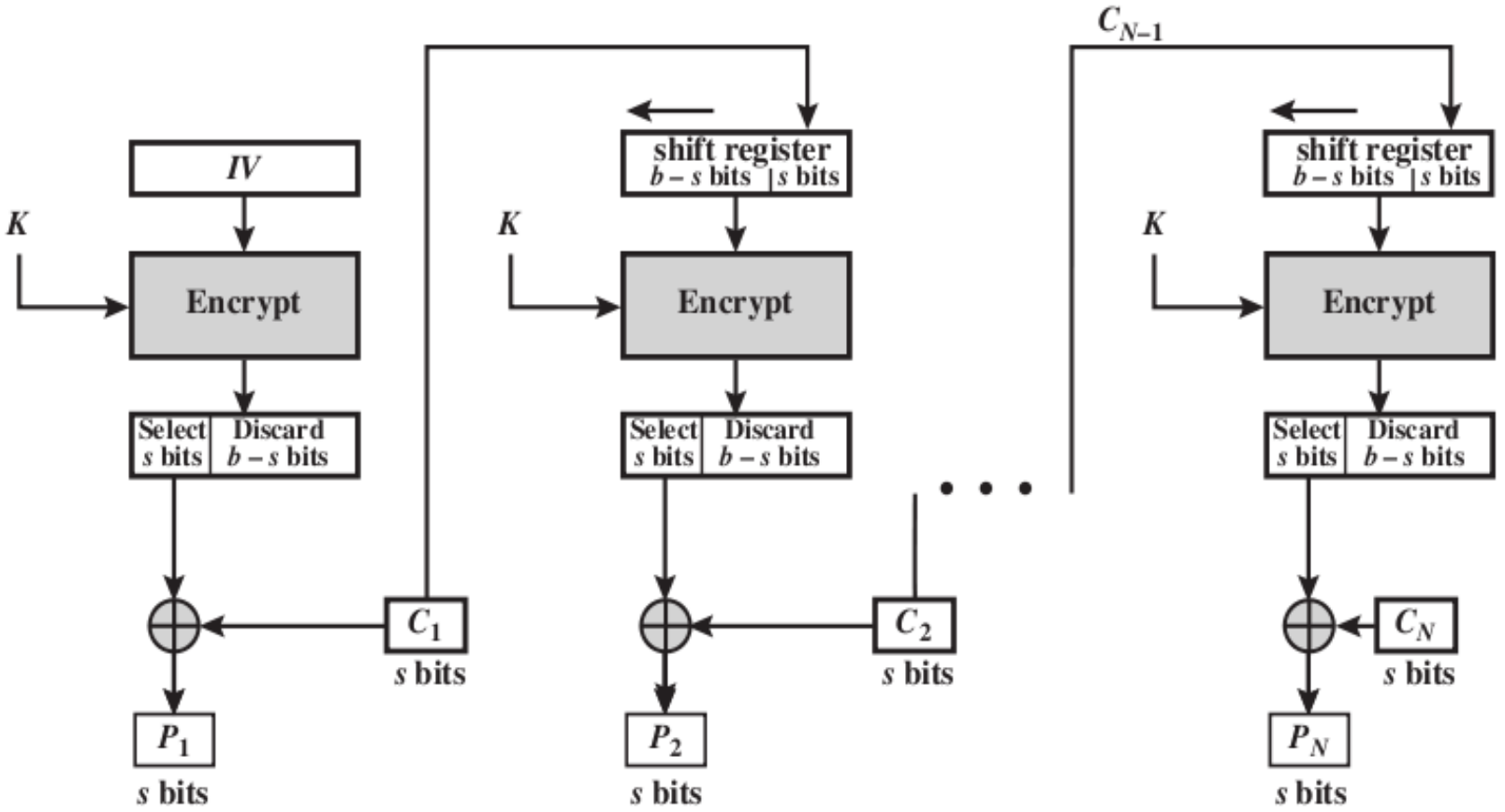
Cipher Feedback Mode (CFB) Encryption



- Totally: ***b*** bits
- Each time process ***s*** bits
- Shift register applied each time
- Initialization Vector (IV) necessarily

Cipher Feedback Mode (CFB) Decryption



CFB Summary

- Converts **block cipher** into **stream cipher**
  - No need to pad message to integral number of blocks
  - Operate in real-time: each character encrypted and transmitted immediately
- Input processed s bits at a time
- **Preceding ciphertext** used as input to cipher to produce pseudo-random output
- XOR **output** with **plaintext** to produce ciphertext
- Typical applications: General-purpose stream-oriented transmission; authentication

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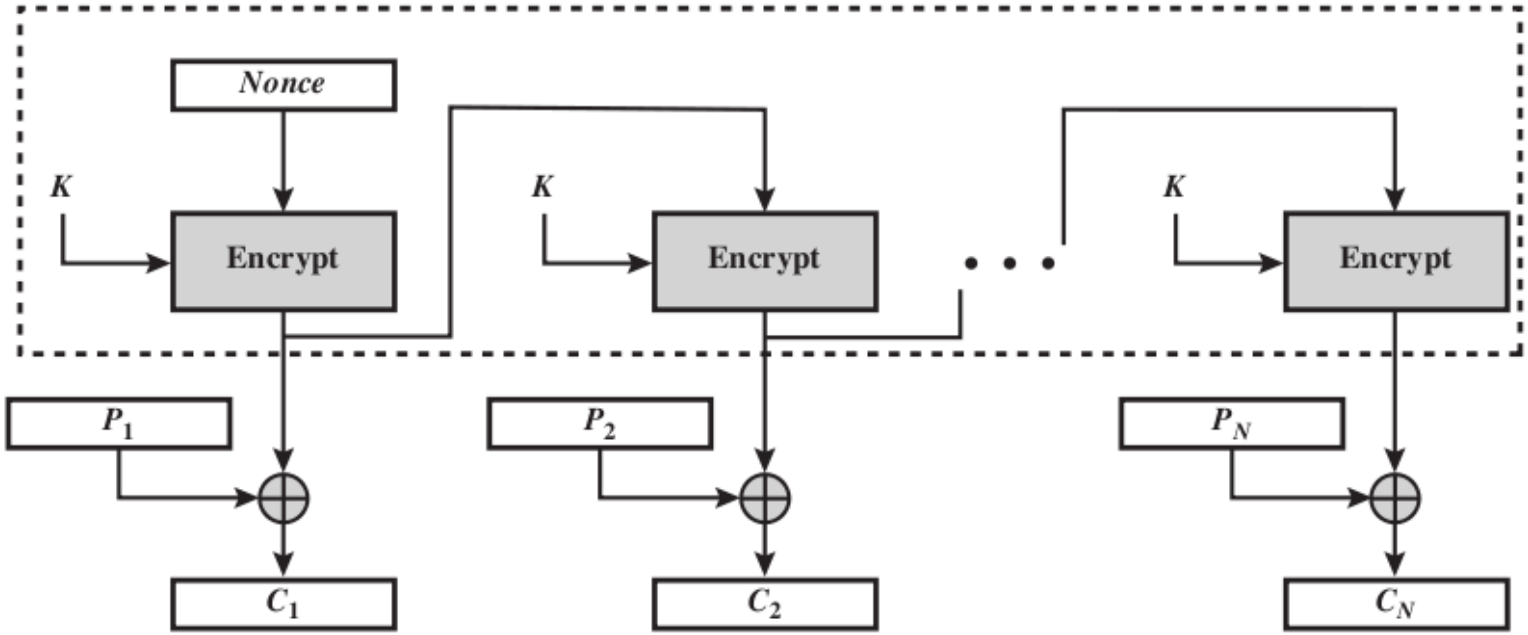
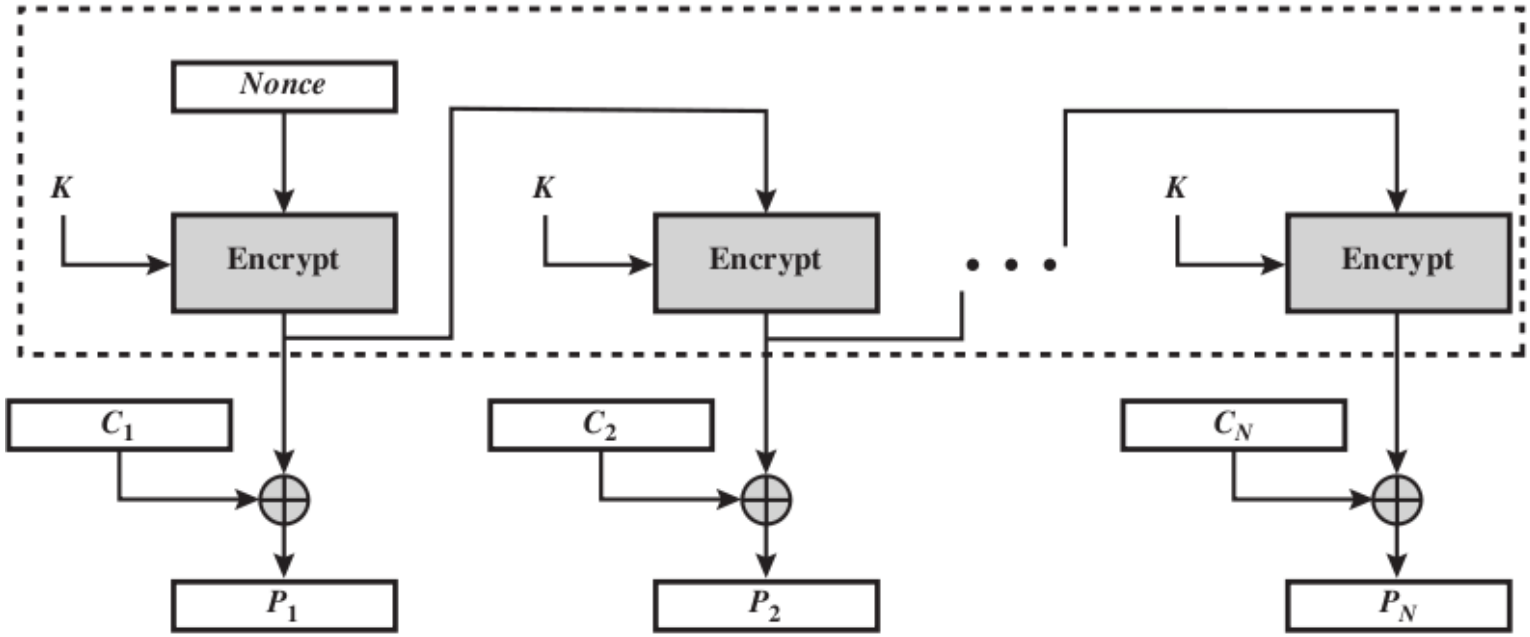
Output Feedback Mode (OFB) Encryption



- Initialization Vector (IV) necessarily
  - IV must be a nonce,
  - must be unique to each execution of the encryption operation
  - Because each encryption output depends only on the key and the IV.

Output Feedback Mode (OFB) Decryption



OFB Summary

- Converts **block cipher** into **stream cipher**
  - OFB has structure of a typical stream cipher;
  - Distinction from the stream cipher is OFB encrypts a full block at a time; while many stream ciphers encrypt one byte at a time.
- Similar to CFB, except input to encryption algorithm is **preceding encryption output**
- Typical applications: stream-oriented transmission over noisy channels (e.g. satellite communications)
- Advantage compared to CFB: bit errors do not propagate
- Disadvantage: more vulnerable to message stream modification attack

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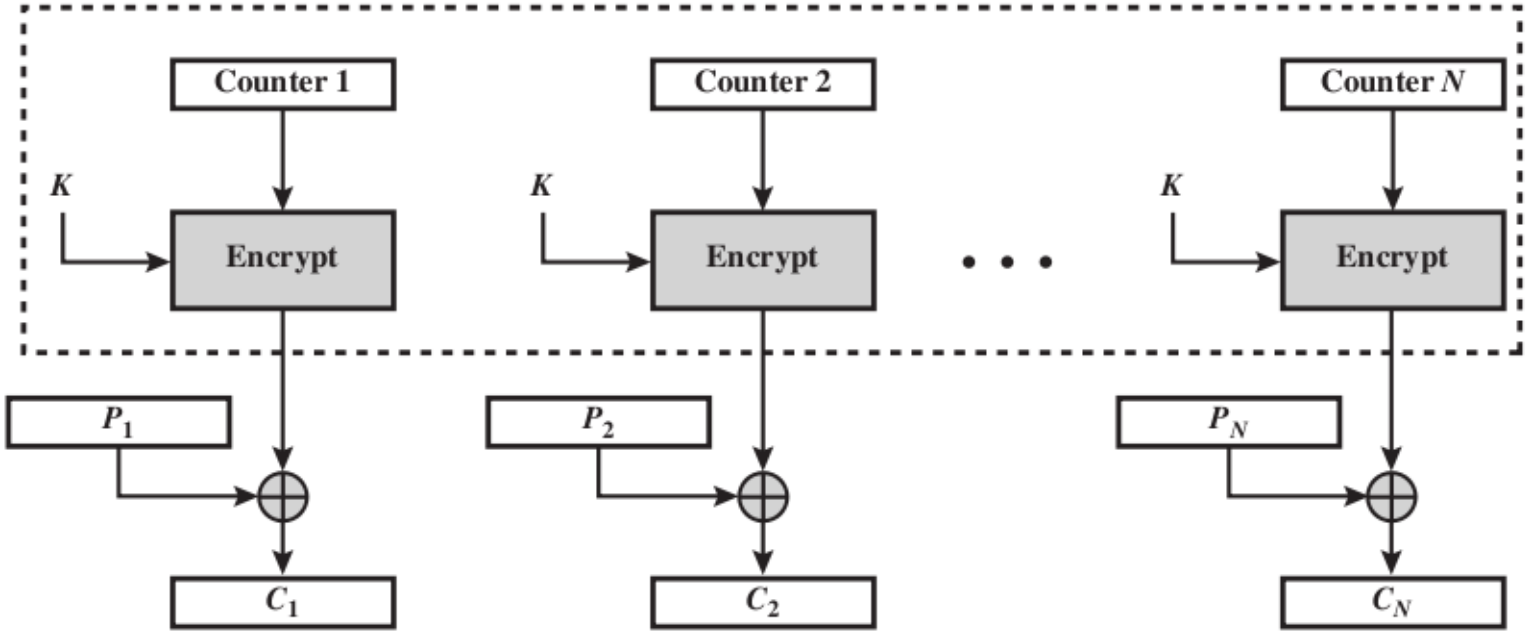
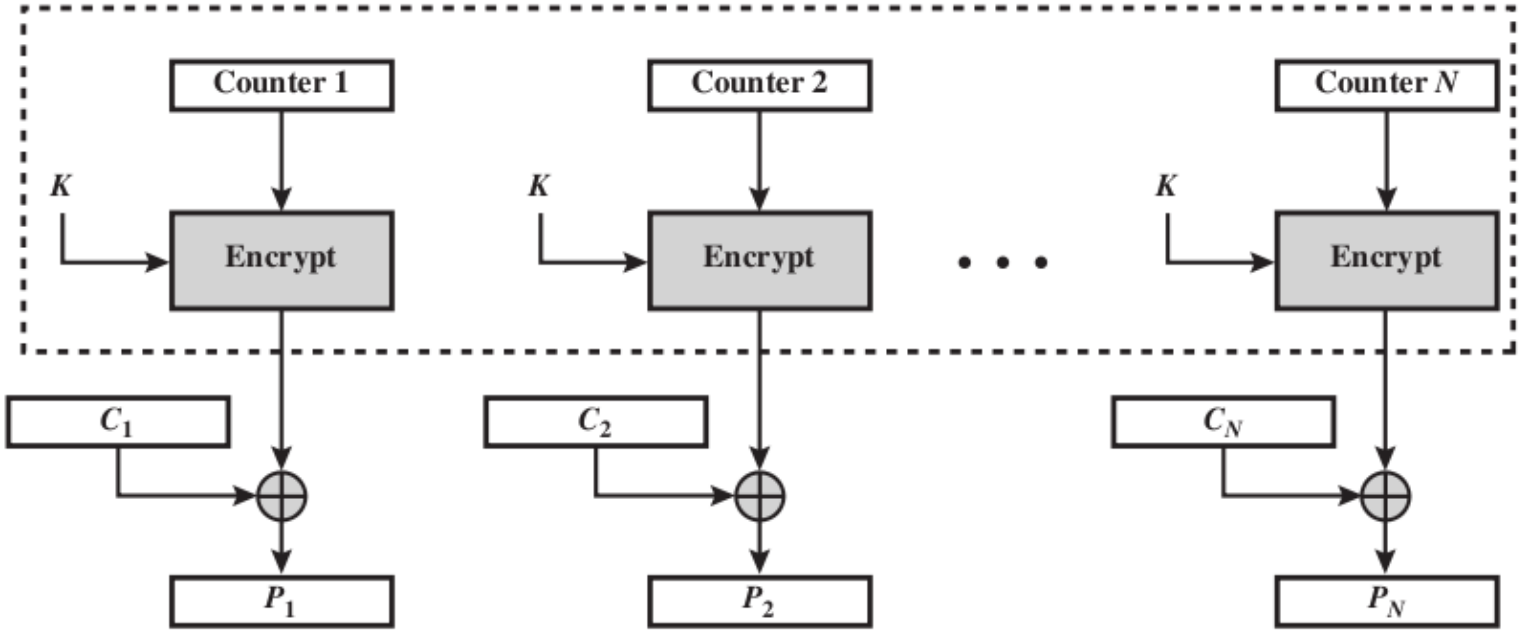
Counter Mode (CTR) Encryption



- Initial Counter value must be a **nonce**
- All the counter values across all the messages should be **unique**.
- Same key in each block

Counter Mode (CTR) Decryption



CTR Summary

- Converts **block cipher** into **stream cipher**
- Each block of plaintext XORed with encrypted counter
- Typical applications: General-purpose block-oriented transmission; useful for high speed requirements
- Efficient hardware and software implementations
- Simple and secure

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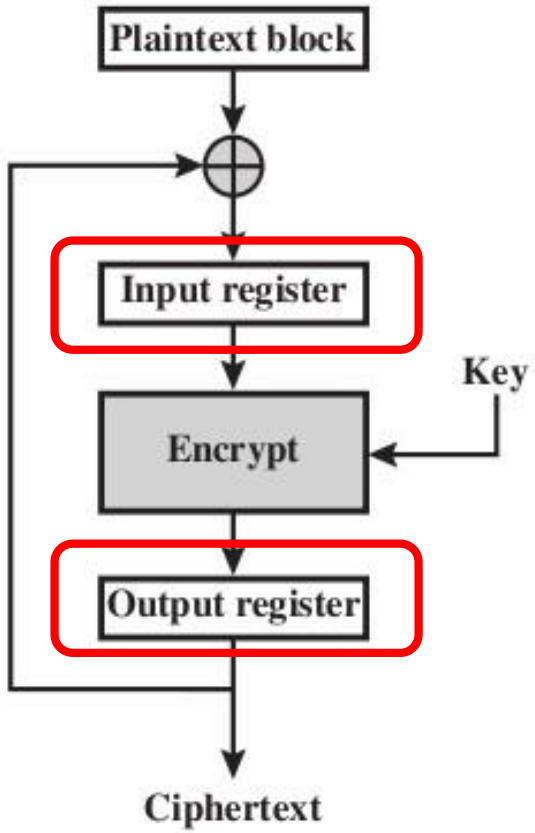
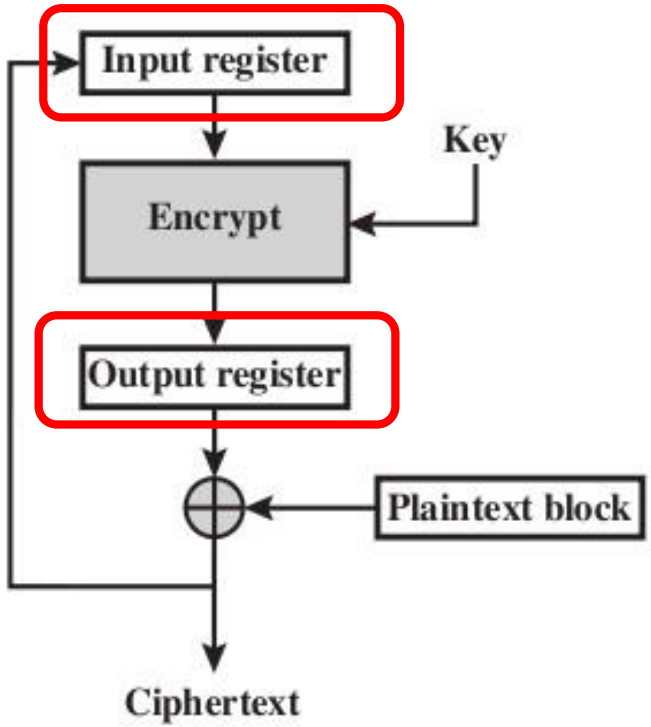
Feedback: CBC and CFB

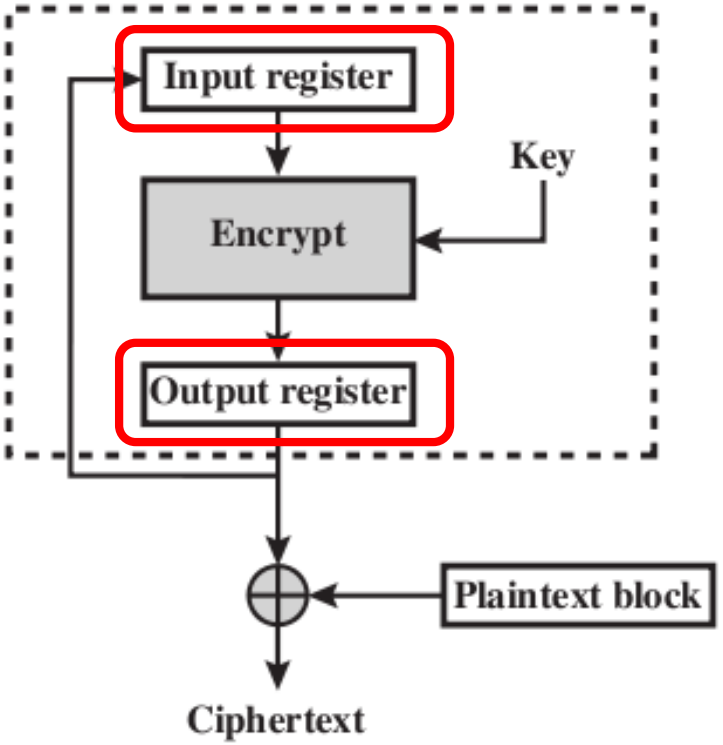


(a) Cipher block chaining (CBC) mode

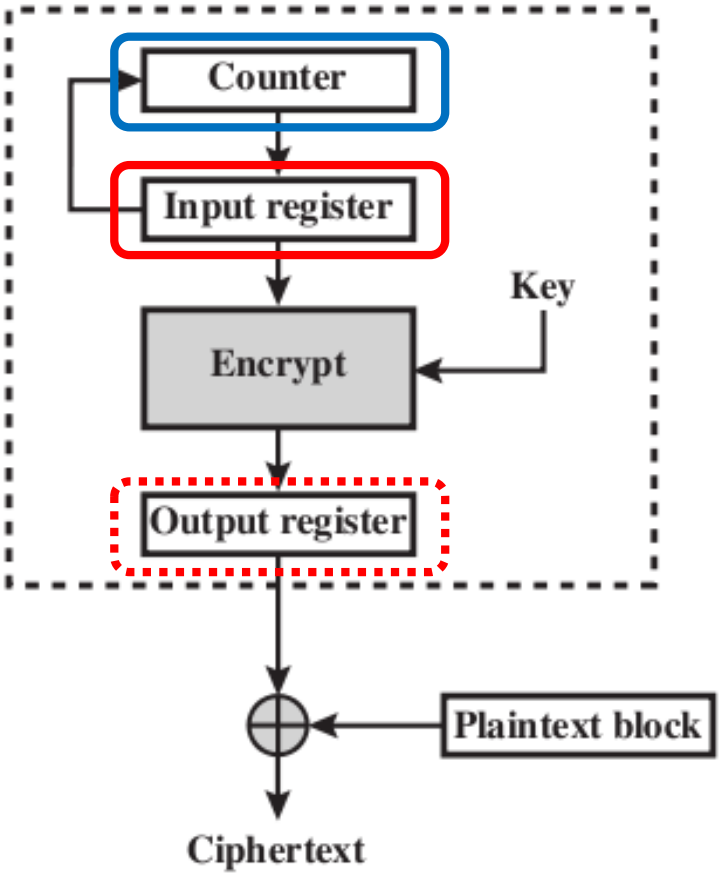


(b) Cipher feedback (CFB) mode

Feedback: OFB and CTR



(c) Output feedback (OFB) mode



(d) Counter (CTR) mode

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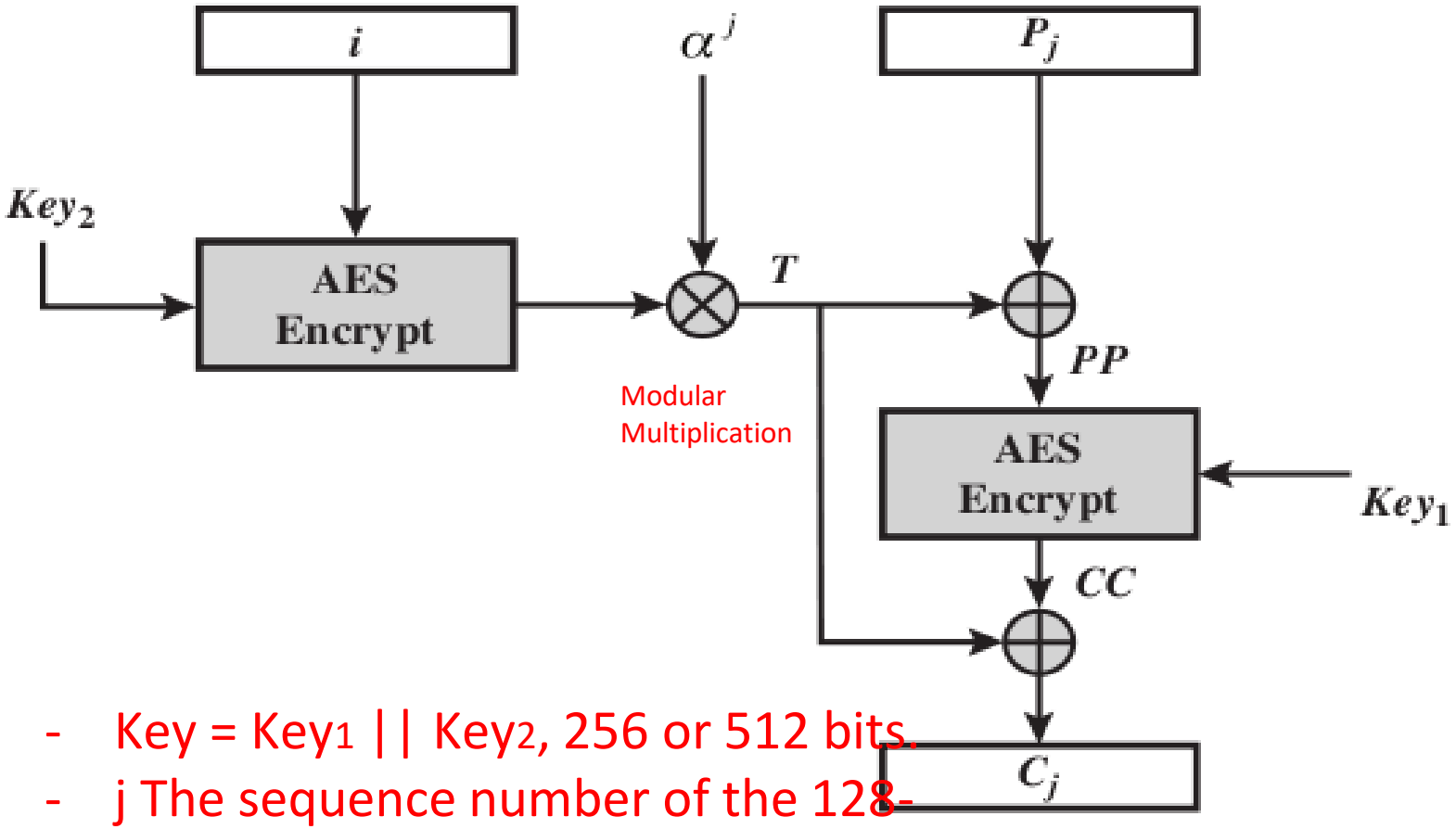
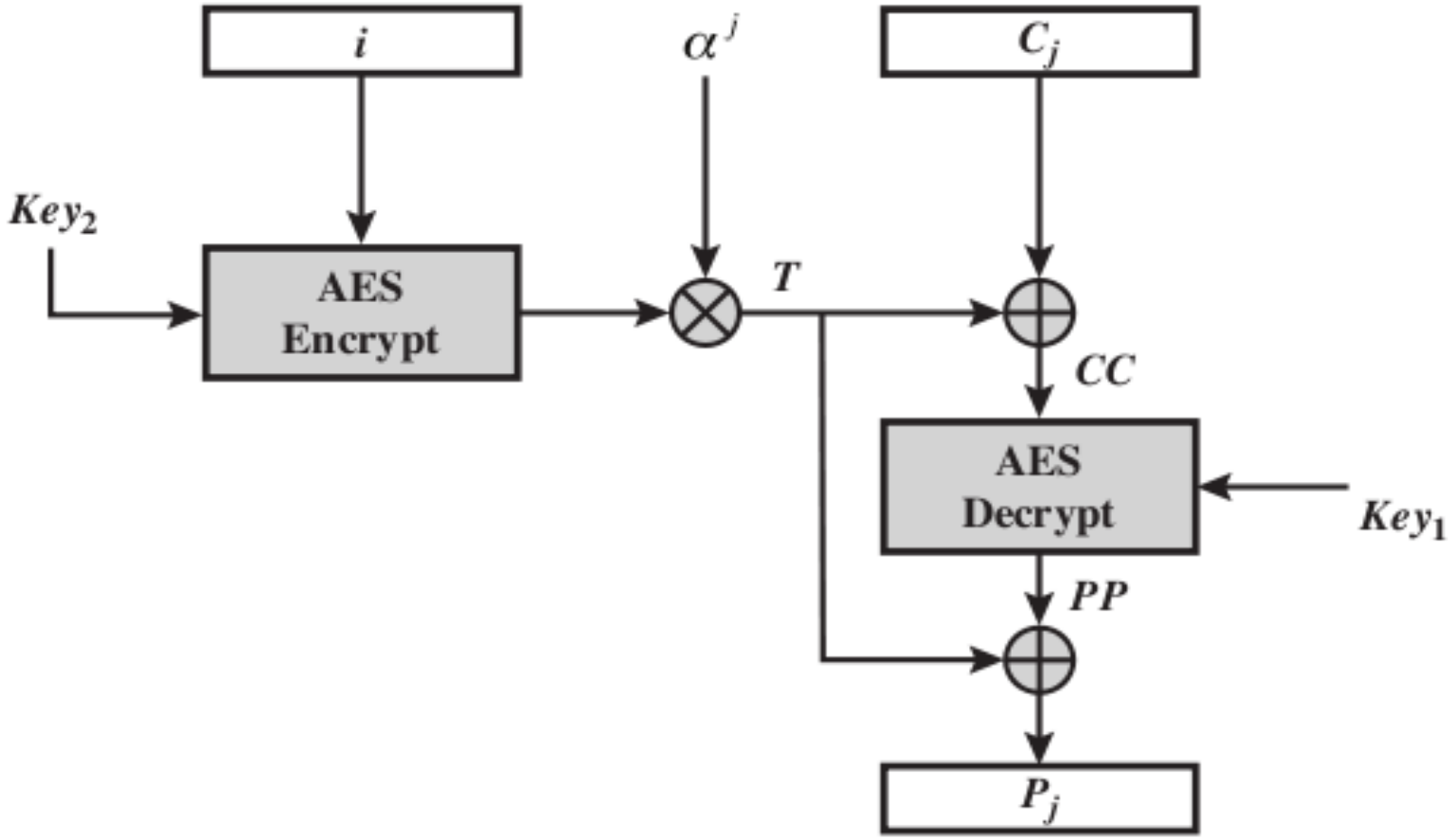
XTS-AES Encryption of Single Block



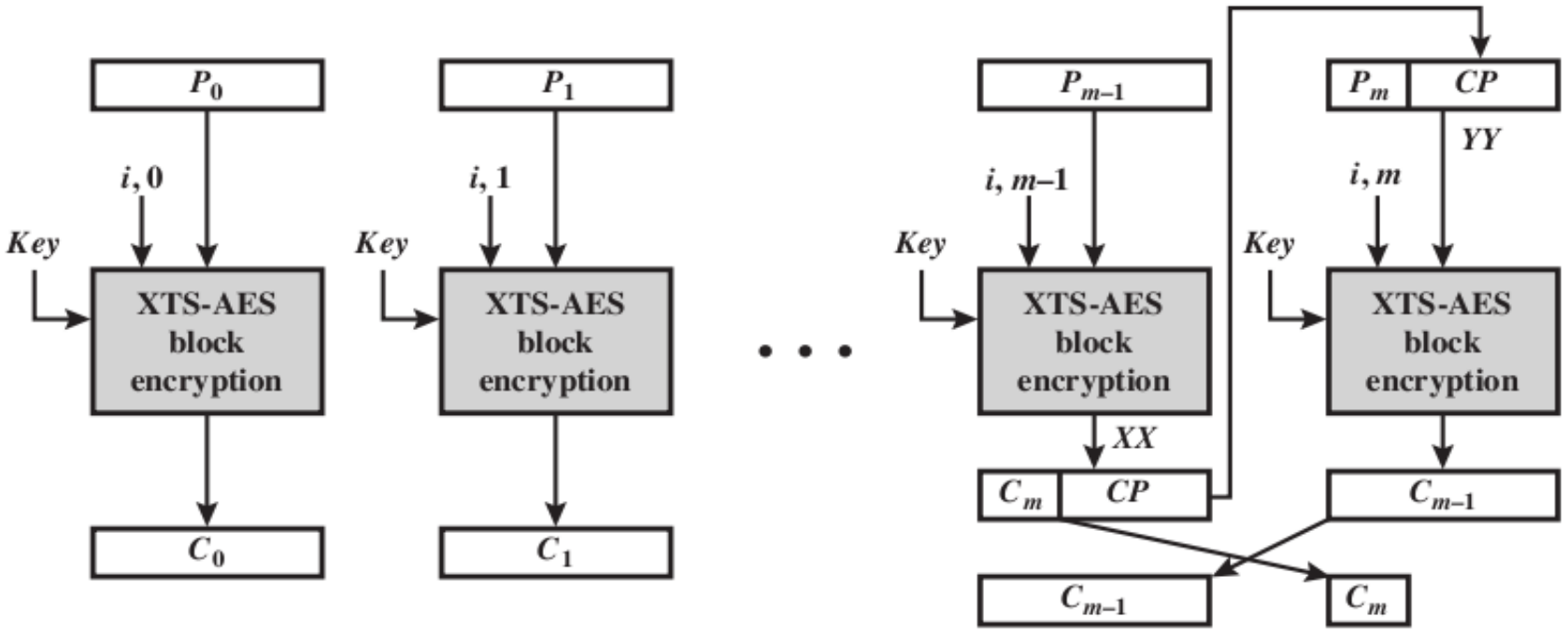
- Key = Key_1 || Key_2, 256 or 512 bits.
- j The sequence number of the 128-bit block.
- P_j The jth block of plaintext
- i The value of the 128-bit tweak; a nonnegative integer.

XTS-AES Decryption of Single Block

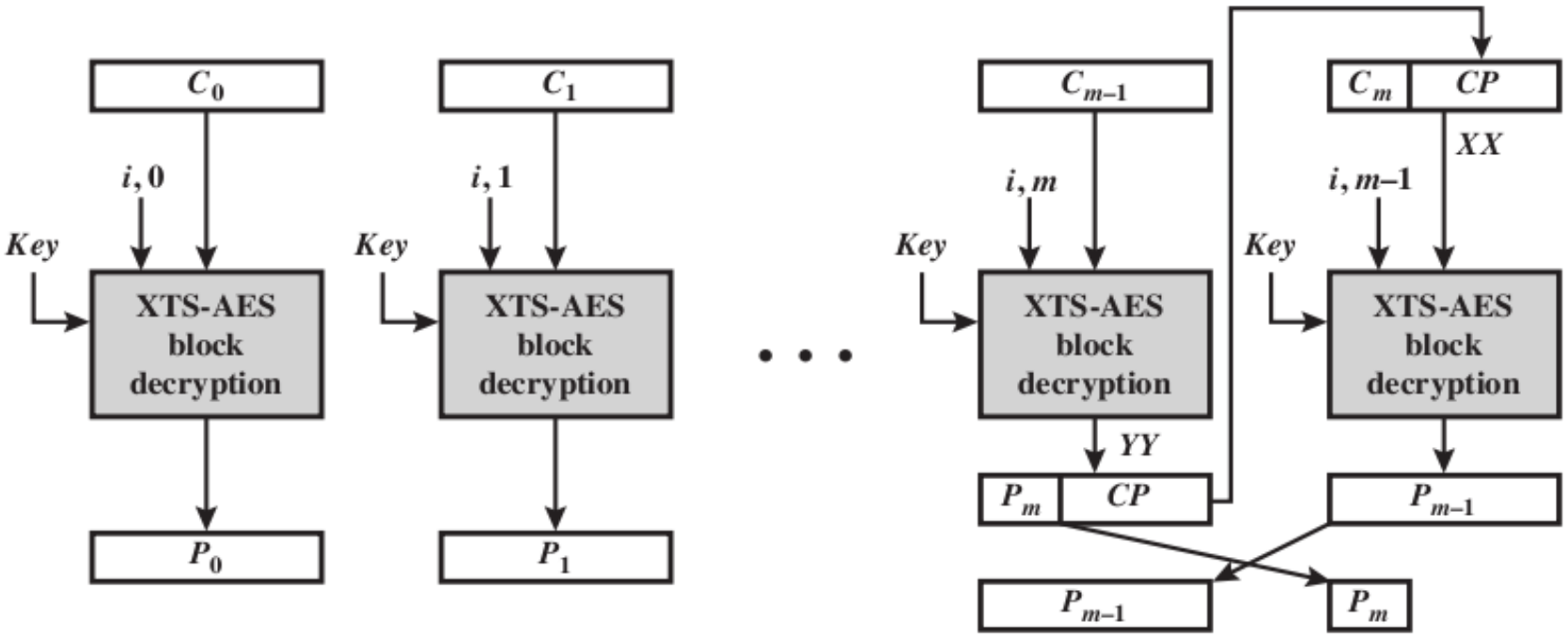


Prove: Decrypted P = Plaintext P?

XTS-AES Encryption



XTS-AES Decryption



Encryption for Stored Data

- XTS-AES designed for encrypting stored data (as opposed to transmitted data)

- The P1619 standard was designed to specify the requirement for encrypting stored data.

  "data at rest" differ somewhat from those for transmitted data.

Storage Encryption Requirements

- The **ciphertext** is freely available for an attacker.
- The data layout is not changed on the storage medium and in transit. The encrypted data must be the same size as the plaintext data.
- **Data** are assessed in fixed sized blocks, independently from each other.
- Encryption is performed in 16-byte blocks, independently from other blocks.
- There are no other metadata used, except the location of the data blocks within the whole data set.
- The same plaintext is encrypted to different ciphertexts at different locations, but always to the same ciphertext when written to the same location again.
- A standard conformant device can be constructed for decryption of data encrypted by another standard conformant device.