“Introduction to Block Ciphers“

Seminar
“Block Cipher Cryptanalysis“
Summer 2011

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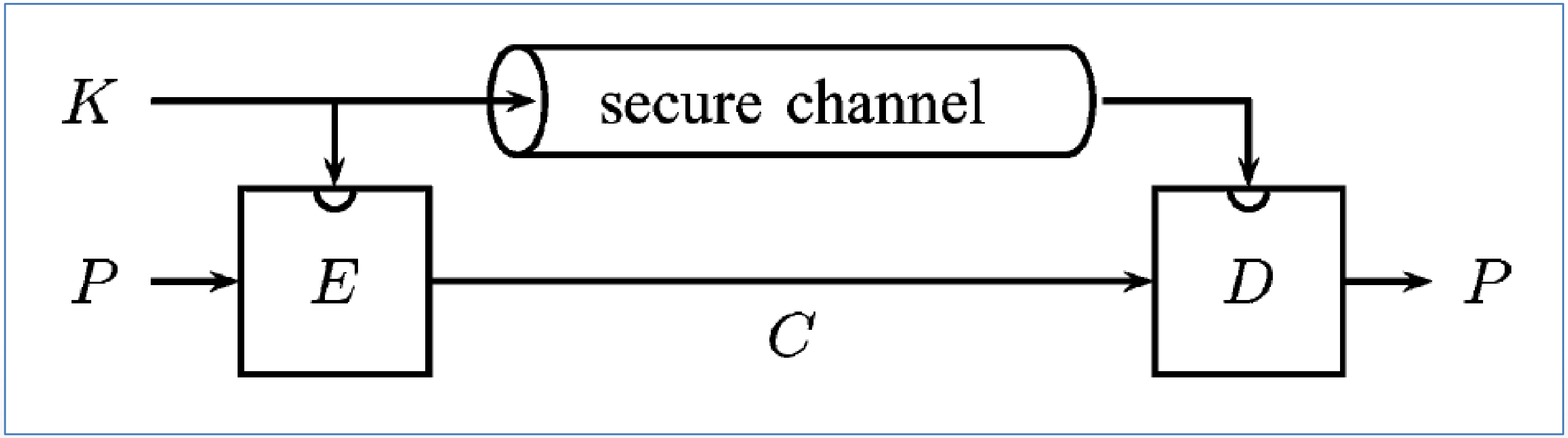
18.04.2011

Agenda

- Block Cipher
- Stream Cipher
- Modes of Operation
  - Electronic Code Book (ECB)
  - Cipher Block Chaining (CBC)
  - Output Feedback Mode (OFB)
  - Cipher Feedback Mode (CFB)
  - Counter Mode (CTR)
- Summery
- Conclusion

Block Cipher

- Symmetric key cipher



Symmetric encryption [can06]

- Operates on fixed-length groups of bits (block)
- Typical block size: 64 bit or 128 bit

Anatomy of a Block Cipher

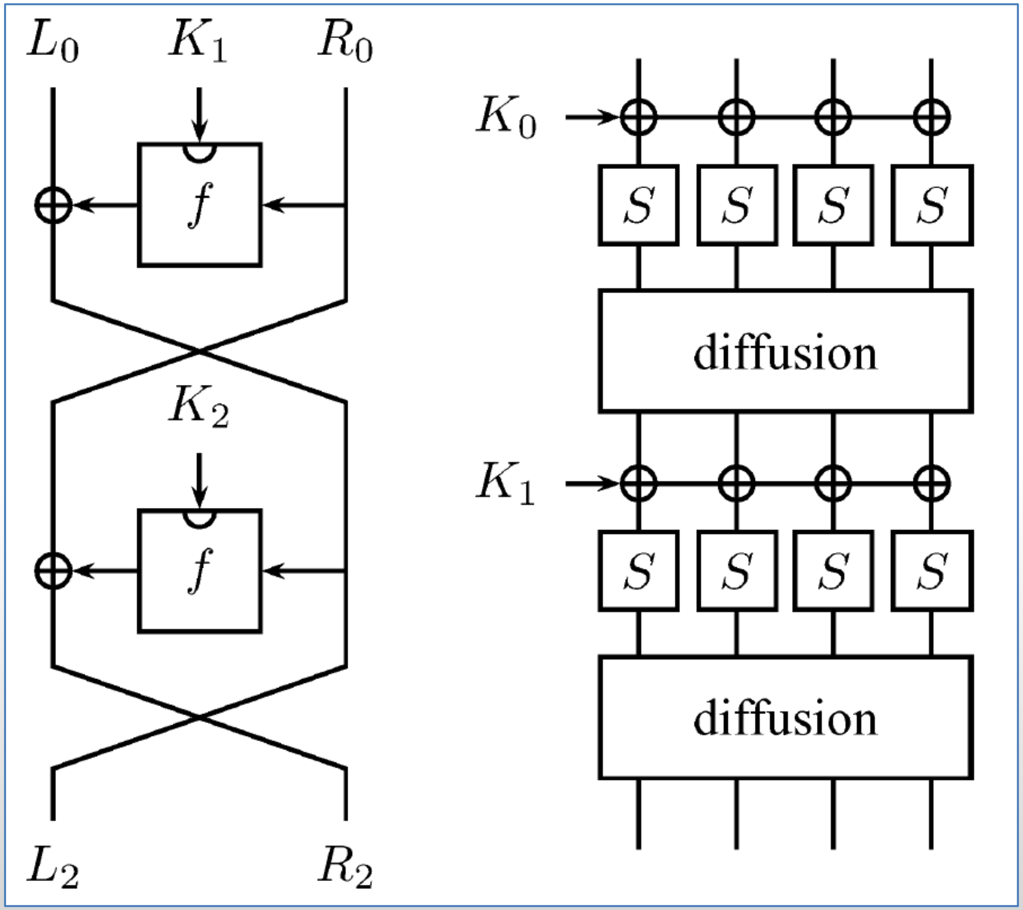
General approach of most block cipher designs:

- Round function
  - Repeated several times (rounds)
    - First round takes n-bit plaintext as input
    - Last round outputs n-bit cipher text
    - Each round depends on a roundkey
      - Derived from k-bit secret key (key schedule)
  - Has to be bijective

Two Examples

1. Feistel ciphers
2. SP Networks

Feistel Cipher vs. SP Network



Feistel cipher and SP network [can06]

Feistel Cipher

Examples of Block Ciphers using a Feistel structure:

- DES
  - Published 1977
  - Designed by IBM
- Blowfish
  - Published 1992
  - Designed by Bruce Schneier
- RC5
  - Published 1994
  - Designed by Ron Rivest

SP Network

Examples of Block Ciphers using a SP Network structure:

- AES (Rijndael)
  - Published 1998
  - Designed by Vincent Rijmen and Joan Daemen
- CAST-128
  - Published 1996
  - Designed by Carlisle Adams and Stafford Tavares
- IDEA
  - Published 1991
  - Designed by Xuejia Lai and James Massey

Overview

- Block Cipher ✓
- Stream Cipher ←
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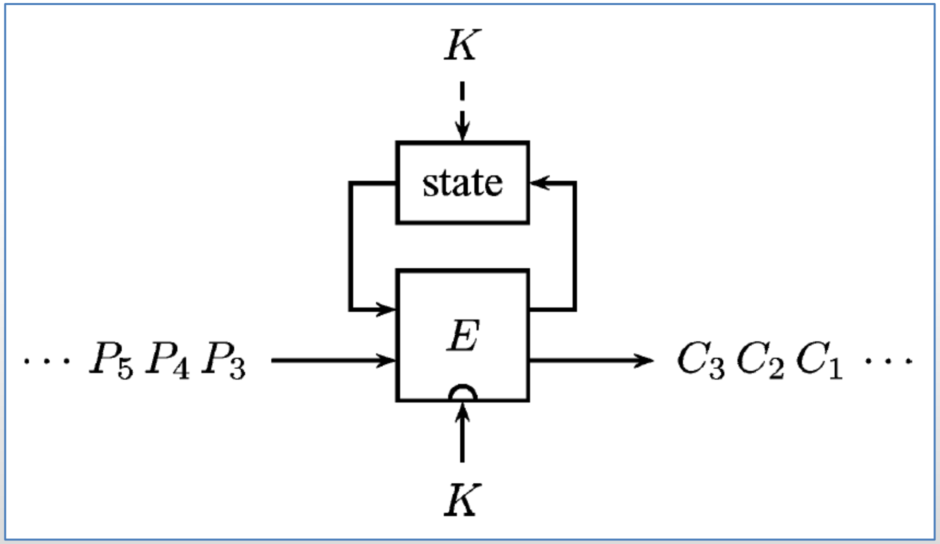
Stream Cipher

- Symmetric key cipher
- Input is a continuous stream of plaintext
- Single bit will be encrypted one by one



Stream encryption [can06]

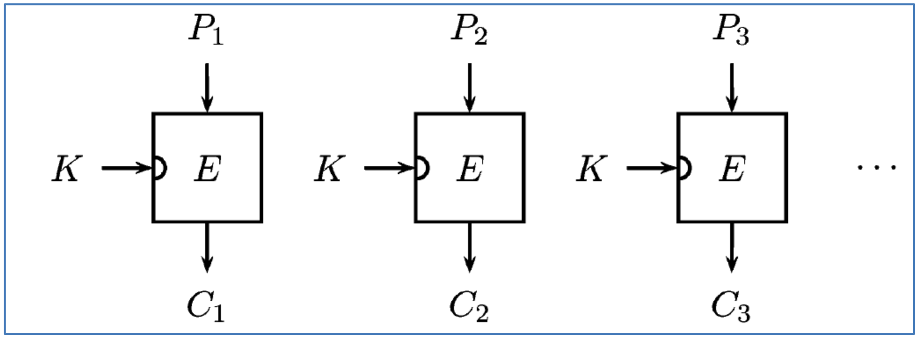
Stream Cipher

Examples:

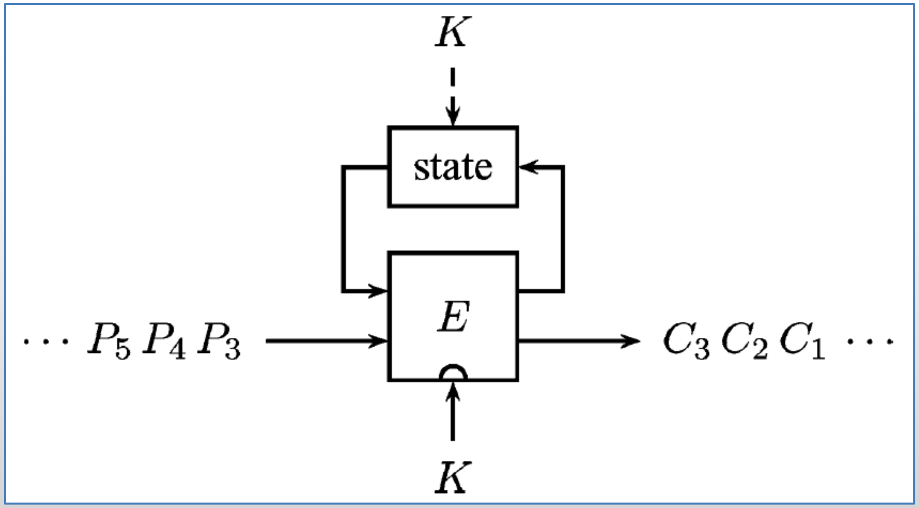
- One Time Pad
  - 1917
- A5/1
  - Developed 1987
  - Used in the GSM standard

Stream encryption [can06]

Block Cipher vs. Stream Cipher



Block encryption (ECB) [can06]



Stream encryption [can06]

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Modes of Operation

- Defines a way how to encrypt arbitrary-length messages using a block cipher
  - Devide message into blocks – encrypt each of them independently
- Last block has to be extended to match block size
  - Padding
- Some modes need an additional input value
  - Initialisation vector

Padding

- Various padding schemes
  - Zero Padding

    … | 1100 0110 1001 0101 1011 0101 **0000 0000** |

    … | 1A 45 AE 56 9B DD 5D FF | 26 14 FC FC **00 00 00 00** |

  - Ansi X.923

    … | 1A 45 AE 56 9B DD 5D FF | 26 14 FC FC **00 00 00 04** |

  - ISO 11026

    … | 1A 45 AE 56 9B DD 5D FF | 26 14 FC FC **81 A6 23 04** |

Padding

- Good padding scheme
  - Generate random bits/bytes
  - End of message is clear
- Choice of padding scheme affects the security

Initialization Vector

- Fixed-size input value
- Requires to be random or pseudorandom
- A good initialization vector should be
  - Unique
  - Unpredictable

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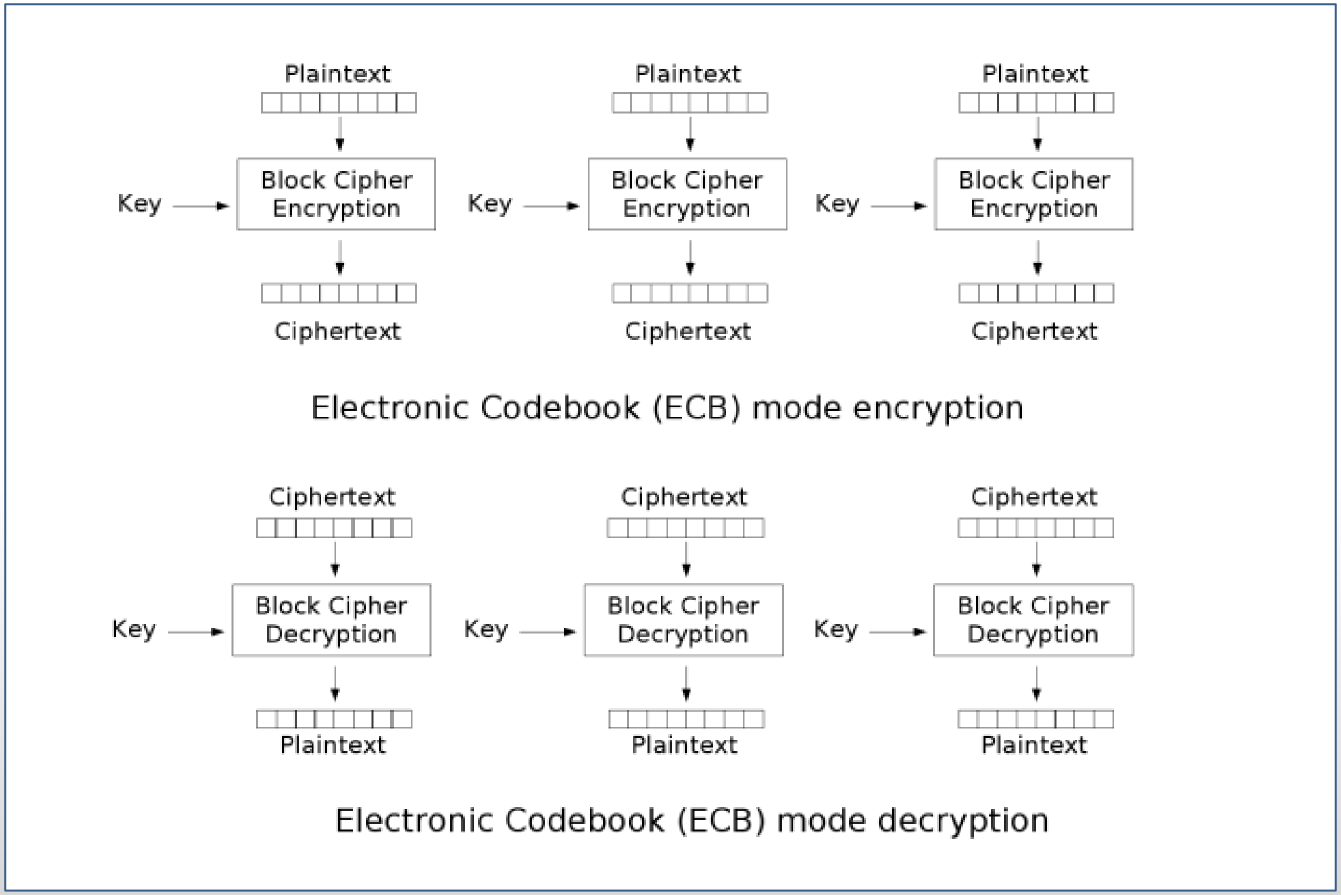
Electronic Code Book (ECB)



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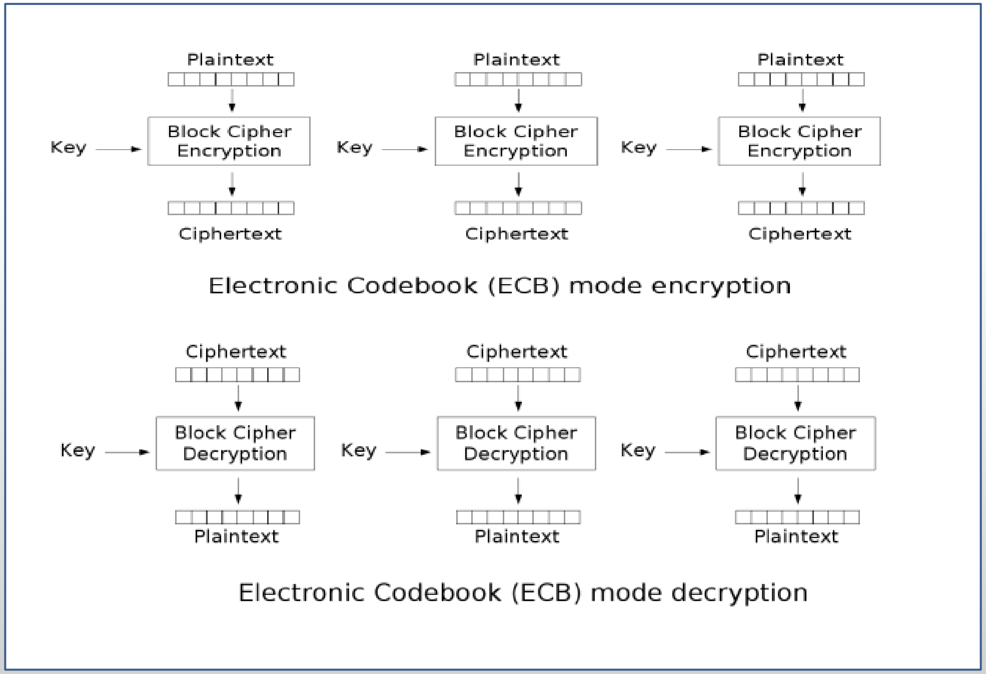
Electronic Code Book (ECB)

- Advantages
  - En-/decryption of each block could be parallelized

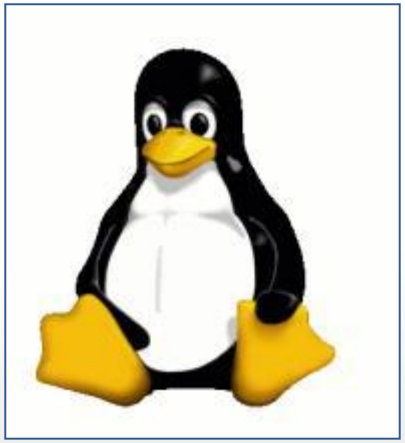


Electronic Codebook (ECB) mode encryption

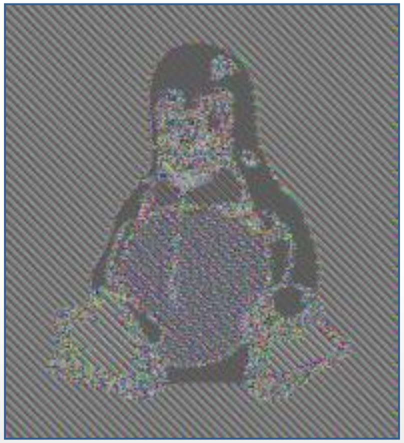
Electronic Codebook (ECB) mode decryption

- Disadvantages
  - Two blocks with identical plaintext produces identical ciphertext
  - Bit error in one block affect the whole block
  - Plaintext patterns are still visible after encryption

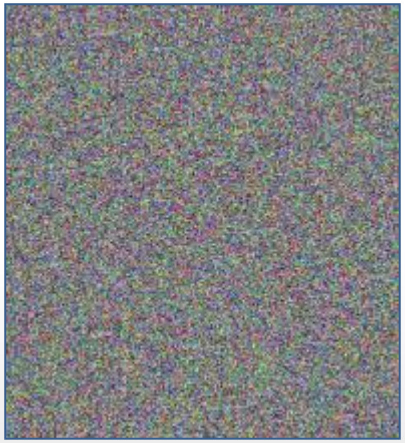
Electronic Code Book (ECB)



Original



ECB-Mode encryption



Other mode encryption

Electronic Code Book (ECB)

Summary

- Most naive mode of operation
- En-/decryption of a block does not depend on the successor or predecessor
- Not suitable for encryption of messages bigger than one block

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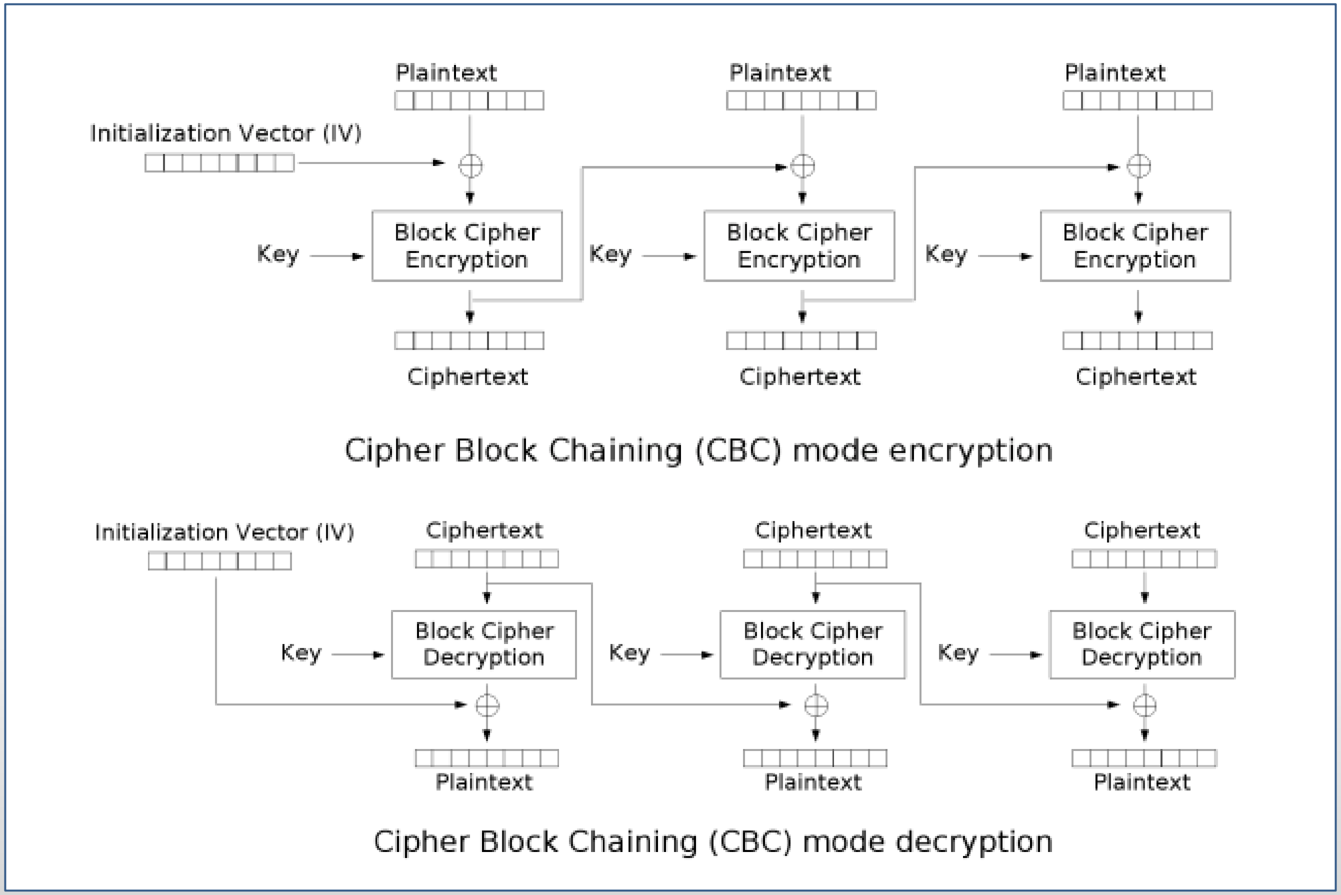
Cipher Block Chaining (CBC)



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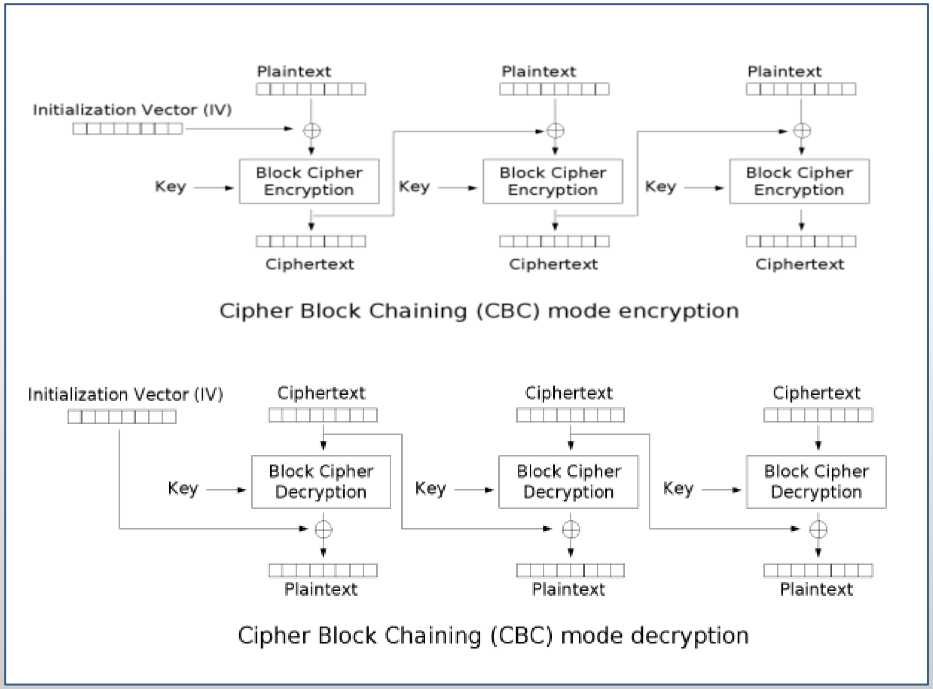
Cipher Block Chaining (CBC)

- Advantages
  - Decryption could be parallelized
  - Different initialization vectors
    - Different ciphertext
  - Plaintext patterns are blurred

- Disadvantages
  - Encryption has to be done sequential
  - Bit error in one block effects two blocks



Cipher Block Chaining (CBC)

Summary

- CBC-Mode was invented to eliminate the disadvantages of the ECB-Mode
    - Equal messages produce different cipher text by using different initialization vectors
- Encryption of a plaintext block depends on this block and its predecessor

Overview

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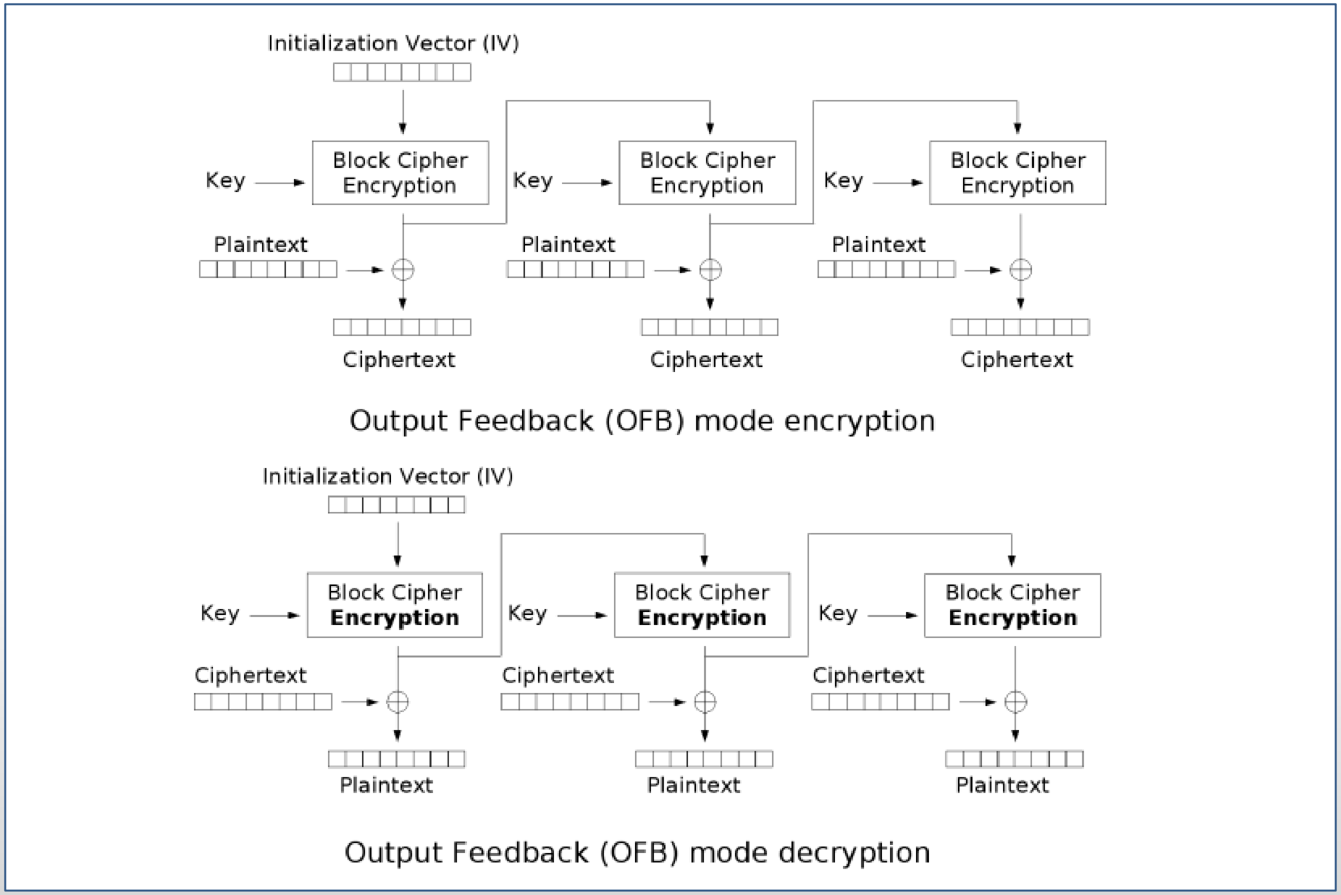
Output Feedback Mode (OFB)



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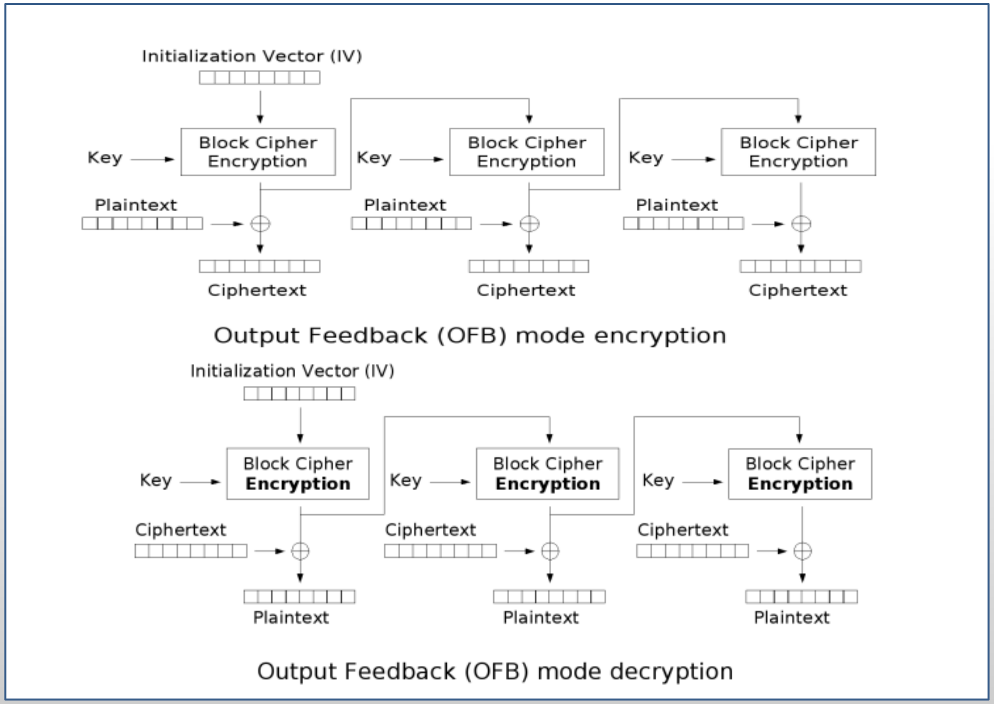
Output Feedback Mode (OFB)

- Advantages
  - Keystream can be pre-computed
  - No padding
  - Bit error only affect one bit


Initialization Vector (IV)
Key
Block Cipher Encryption
Plaintext
Ciphertext
Output Feedback (OFB) mode encryption
Initialization Vector (IV)
Key
Block Cipher Encryption
Ciphertext
Plaintext
Output Feedback (OFB) mode decryption

- Disadvantages
  - Keystream computation cannot be parallelized
  - Reusing of key an initialization vector is dangerous
  - Bit-flipping attacks are easy

Output Feedback Mode (OFB)

Summary

- Combines a block cipher with a stream cipher
- Needs an initialization vector
- Uses same function for encryption and decryption
  - Makes it possible to choose the faster function
  - Makes it possible to use one-way-functions
- Pre-calculation possible

Overview

- Block Cipher ✓
- Stream Cipher ✓
- Modes of Operation
  - Electronic Code Book (ECB) ✓
  - Cipher Block Chaining (CBC) ✓
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  - Cipher Feedback Mode (CFB) ←
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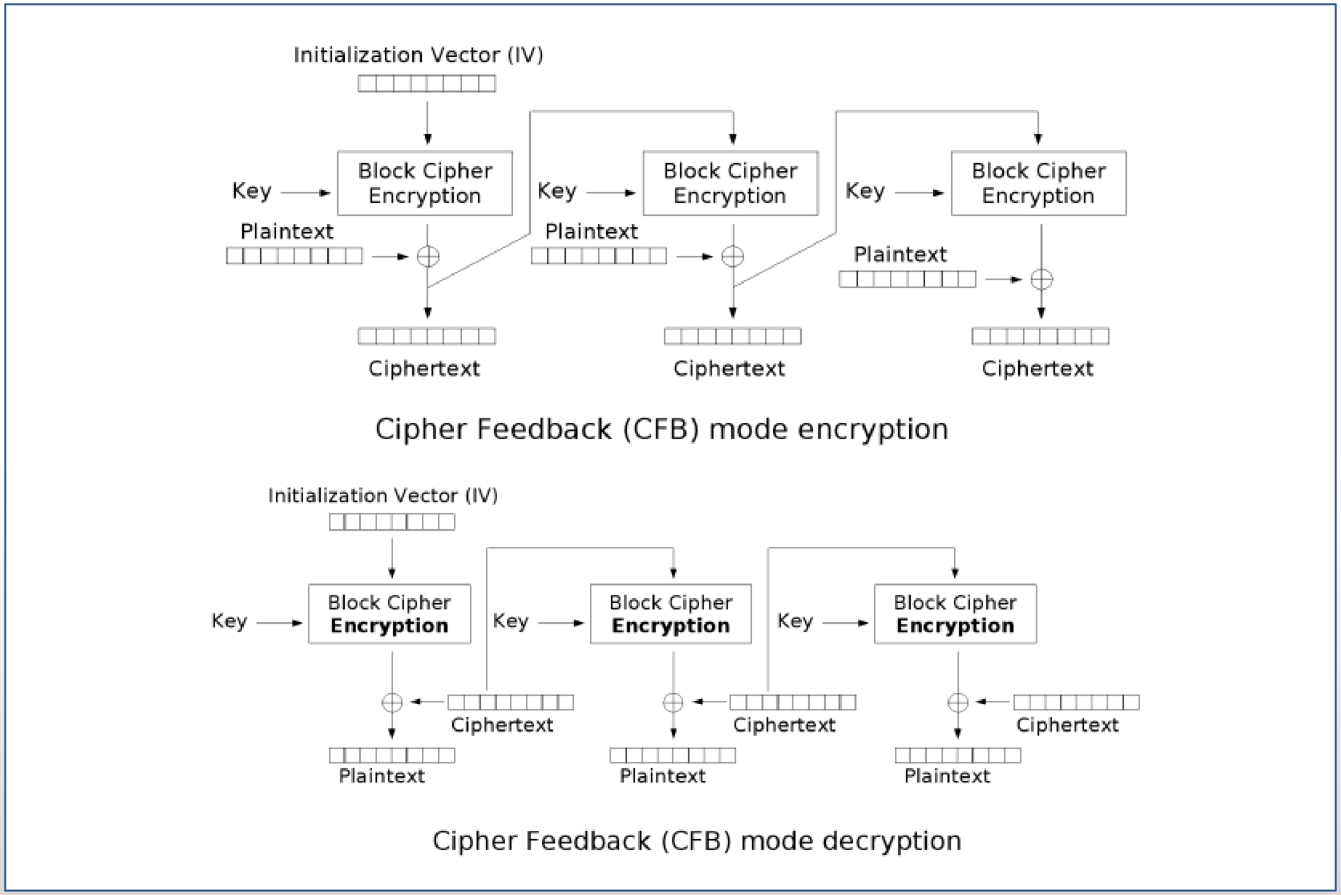
Cipher Feedback Mode (CFB)

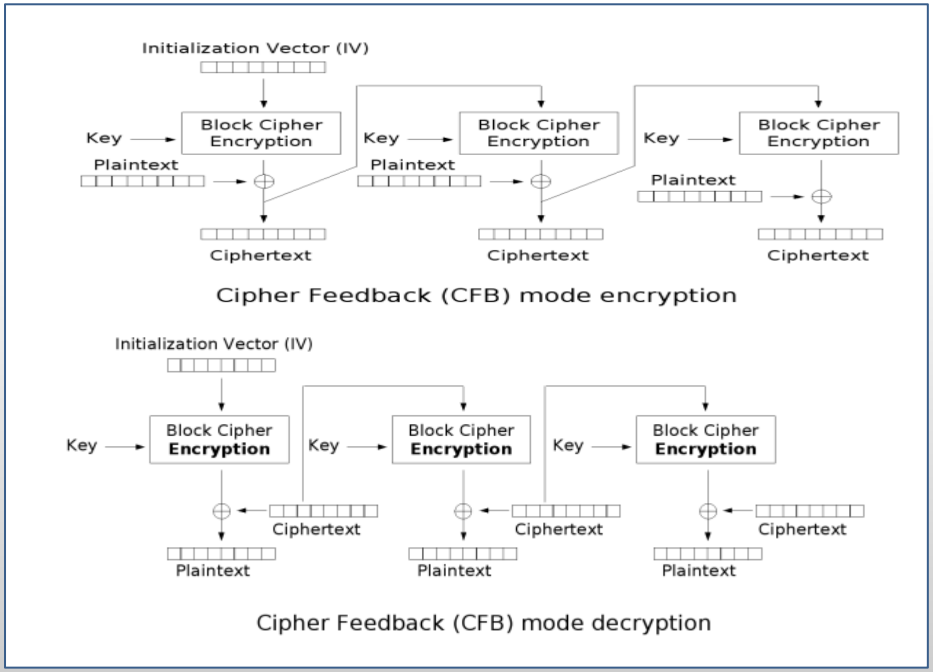

Initialization Vector (IV)
Key
Block Cipher Encryption
Plaintext
Ciphertext
Cipher Feedback (CFB) mode encryption
Initialization Vector (IV)
Key
Block Cipher Encryption
Ciphertext
Plaintext
Cipher Feedback (CFB) mode decryption

Pictures from Wikimedia Commons

Cipher Feedback Mode (CFB)

- Advantages
  - No padding
  - Bit error only affects one bit
  - Decryption can be parallelized

- Disadvantages
  - Bit-flipping attacks are easy
  - Encryption cannot be parallelized
  - No pre-computation of the keystream



Cipher Feedback Mode (CFB)

Summary

- Similar to OFB-Mode
- Combines a block cipher with a stream cipher
- Needs an initialization vector
- Uses same function for encryption an decryption
    - Makes it possible to choose the faster function
    - Makes it possible to use one-way-functions
- Encryption of a plaintext block depends on its predecessors

Overview

- Block Cipher ✓
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- Modes of Operation
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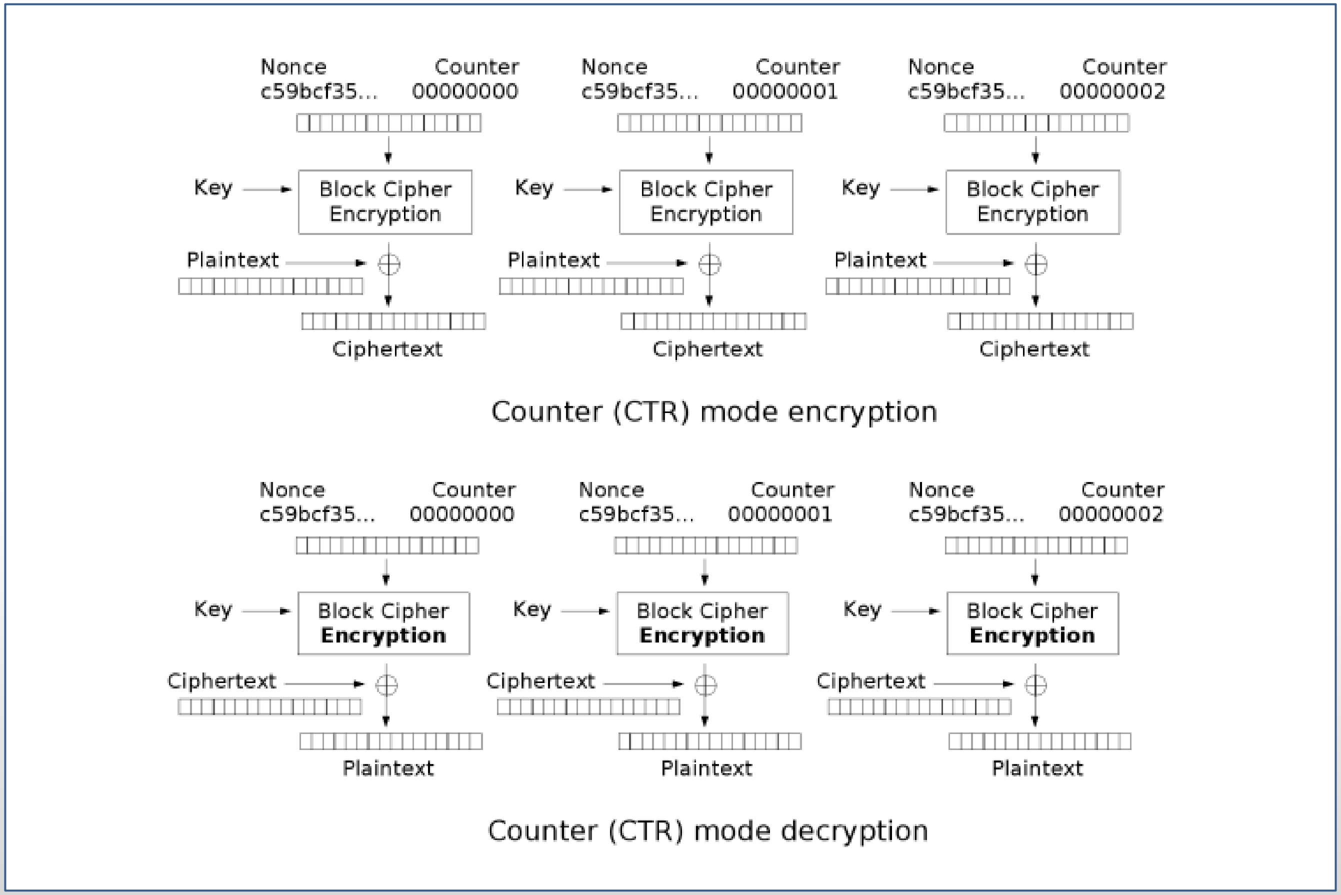
Counter Mode (CTR)



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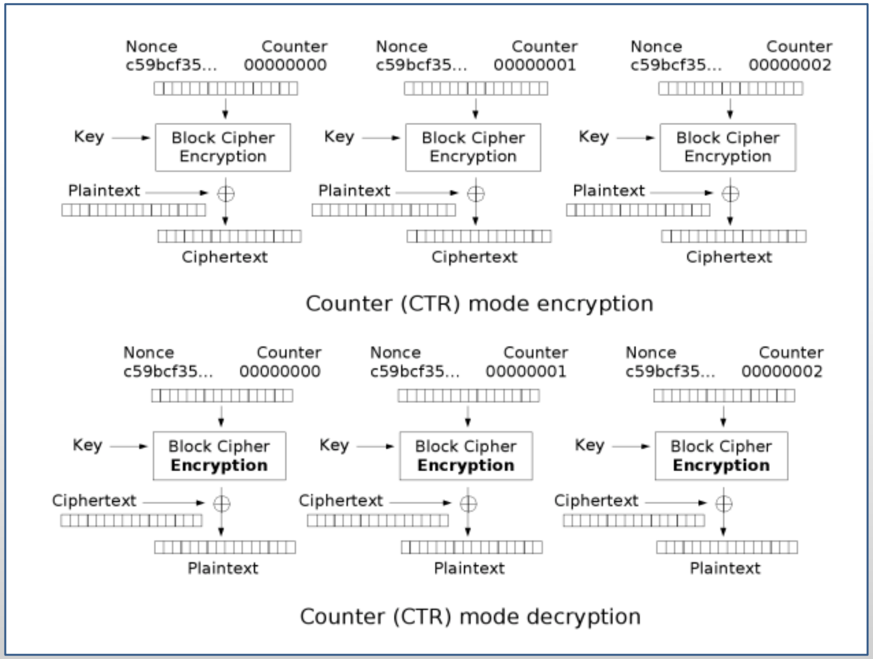
Counter Mode (CTR)

- Advantages
  - En-/decryption of each block could be parallelized
  - No padding
  - Keystream can be pre-computed
    - Can be done in parallel

- Disadvantages
  - Bit-flipping attacks are easy
  - Reusing of key and nonce/counter is dangerous



Counter Mode (CTR)

Summary

- Combines a block cipher with a stream cipher
- Just as in the ECB mode en-/decryption of a block does not depend on the successor or predecessor

Overview

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Summary

Now, we should all be able to give a short answer to these questions:

- What is a block cipher?
- What are the differences between a block cipher and a stream cipher?
- For what do we need Modes of operation?

Summary

And we all know 5 modes of operation:

- Electronic Code Book (ECB)
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Overview

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- Summery ✓
- Conclusion ←

Conclusion

Security of a block cipher always depends on:

- Choice of the cipher itself
- Choice of mode of operation
- Choice of padding scheme
- Choice of initialization vector

References

- [kat08] J. Katz and Y. Lindell – Introduction to Modern Cryptography, Chapman & Hall/CRC, 2008
- [wob01] Reinhard Wobst – Abenteuer Kryptologie, Addison-Wesley, 2001
- [can06] Christophe de Canniere, Alex Biryukov and Bart Preneel – „An Introduction of Block Cipher Cryptanalysis“, Proceedings of the IEEE, 02.2006

Thank you!

Questions?