UNIVERSITI TEKNOLOGI MALAYSIA

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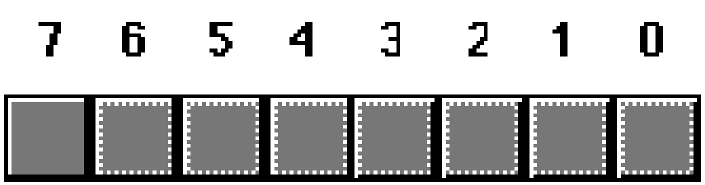
# SCSR1013 DIGITAL LOGIC

# MODULE 2: DATA ORGANIZATION (CODES)

FACULTY OF COMPUTING

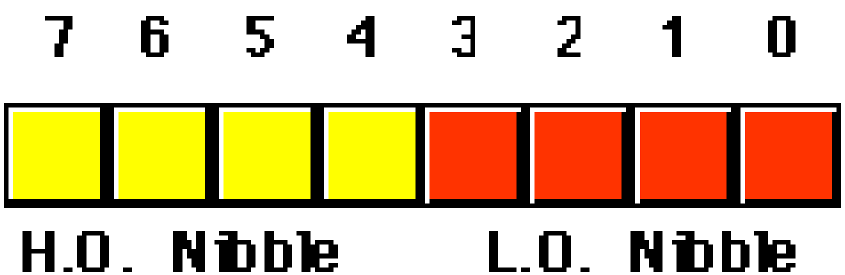
# Data Organization

- A value may take an arbitrary number of bits.
- Common collections are single bits
  - smallest "unit" of data on a binary computer is a single bit
  - groups of four bits called nibbles
  - groups of eight bits called bytes
  - groups of 16 bits called words
- The bits in a byte are normally numbered from zero to seven.



- Bit 0 is the low order bit (rightmost) or least significant bit (LSB) bit 7 is the high order bit (leftmost) or most significant bit (MSB) of the byte.
  Note 1 byte also contains exactly 2 nibbles:

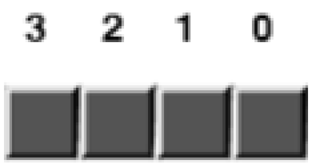
MSB




LSB

# Nibbles

- 4 bits

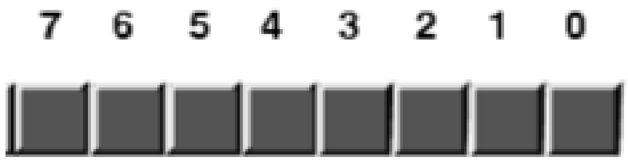



- **Major uses**:
  - BCD (Binary Coded Decimal)
  - Hexadecimal numbers

Example: 0111, 1011 and 1111.

$7_{16}$, $B_{16}$, $F_{16}$

# Bytes

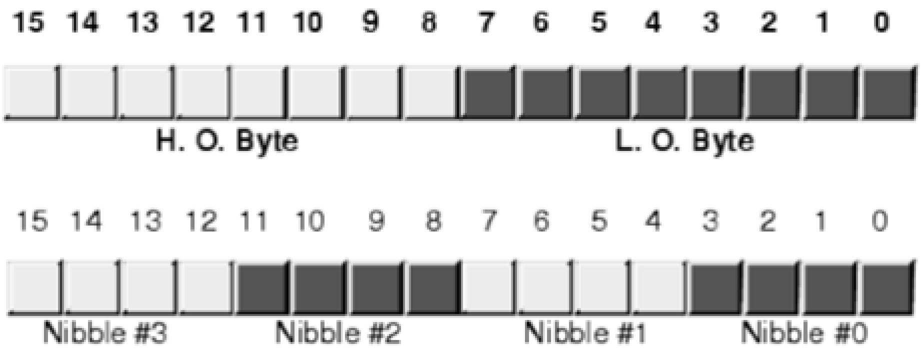



- 8 bits
- Total values: $2^8 = 256$

- **Major uses**:
  - Numeric values (0 … $2^8$-1 = 0 … 255)
  - Signed numbers: (-128 to +127)

# Word

- 16 bits = 2 bytes
- Bit 0 to 15
- **Total values**:
  - $2^{16} = 65,536$




- **Major uses of word**:
  - signed integer (-32,768 … +32,767)
  - unsigned integer (0 … $2^{16}$-1) = 0 … 65,535)
  - UNICODE characters

# What are codes?

- Code is a representation of information generated by following a certain rules.
- In general, we need code because:
  - Code is unique
  - Codes are easy to process
  - Code is easy to represent
  - Codes enable communication in place where ordinary spoken or written language is difficult or impossible, eg Morse Code
- Due to this, code can simplify the process (such as manipulation and arithmetic operations) of the information in the digital system.

**We will learn:**

i. BCD codes
ii. Gray Codes
iii. ASCII codes
iv. Parity codes/bit

# Binary Coded Decimal (BCD)

- BCD is a way to express each of the decimal digits with a binary code.
- There are only 10 code groups in the BCD system, one for every digit (0000 – 1001)

| Decimal | BCD | Decimal | BCD |
|---|---|---|---|
| 0 | 0000 | 5 | 0101 |
| 1 | 0001 | 6 | 0110 |
| 2 | 0010 | 7 | 0111 |
| 3 | 0011 | 8 | 1000 |
| 4 | 0100 | 9 | 1001 |

Invalid codes are 1010, 1011, 1100, 1101, 1110, 1111

Example 1: Convert 3245 to BCD

3 2 4 5

3245 = 0011 0010 0100 0101

Example 2: Convert 7848 to BCD

7 8 4 8

7848 = 0111 1000 0100 1000

# Gray Codes

Electromechanical switches


- Designed to prevent false output from electromechanical switches.
- Are widely used to facilitate error correction in digital communications such as digital terrestrial television and some cable TV systems.
- In modern digital communications, Gray codes play an important role in error correction.
- It is arranged so that every transition from one value to the next value involves only one bit change.
- Sometimes referred to as reflected binary, because the first eight values compare with those of the last 8 values, but in reverse order.

# Gray codes

| Decimal | Binary | Gray Code |
|---|---|---|
| 0 | 0 0 0 0 | 0 0 0 0 |
| 1 | 0 0 0 1 | 0 0 0 1 |
| 2 | 0 0 1 0 | 0 0 1 1 |
| 3 | 0 0 1 1 | 0 0 1 0 |
| 4 | 0 1 0 0 | 0 1 1 0 |
| 5 | 0 1 0 1 | 0 1 1 1 |
| 6 | 0 1 1 0 | 0 1 0 1 |
| 7 | 0 1 1 1 | 0 1 0 0 |
| 8 | 1 0 0 0 | 1 1 0 0 |
| 9 | 1 0 0 1 | 1 1 0 1 |
| 10 | 1 0 1 0 | 1 1 1 1 |
| 11 | 1 0 1 1 | 1 1 1 0 |
| 12 | 1 1 0 0 | 1 0 1 0 |
| 13 | 1 1 0 1 | 1 0 1 1 |
| 14 | 1 1 1 0 | 1 0 0 1 |
| 15 | 1 1 1 1 | 1 0 0 0 |
| 16 | 1 0 0 0 0 | 0 0 0 0 |

# Gray Code Conversion

- Binary to Gray Code
  1. Record the MSB as it is
  2. Add the MSB to the next bit of binary, record the sum and neglect carry.
  3. Repeat the process

# Example:

Convert 10011010 to its equivalent gray code value

| $b_7$ | $b_6$ | $b_5$ | $b_4$ | $b_3$ | $b_2$ | $b_1$ | $b_0$ |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |

(Maintain MSB)

(Discard carries)

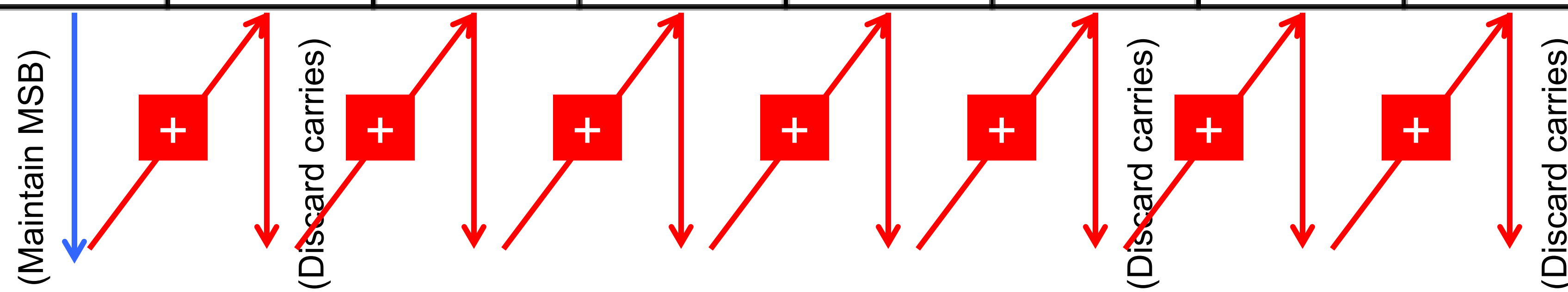
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| $g_7$ | $g_6$ | $g_5$ | $g_4$ | $g_3$ | $g_2$ | $g_1$ | $g_0$ |

- Gray Code to Binary
  1. Record the MSB as it is
  2. Add the MSB to the next bit of Gray code, record the sum and neglect carry.
  3. Repeat the process

# Example:

Convert the Gray code 11010111 to binary.

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 |
| $g_7$ | $g_6$ | $g_5$ | $g_4$ | $g_3$ | $g_2$ | $g_1$ | $g_0$ |




| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 1 | 1 | 0 | 1 | 0 |
| $b_7$ | $b_6$ | $b_5$ | $b_4$ | $b_3$ | $b_2$ | $b_1$ | $b_0$ |

# Parity Code

- Parity bit used for bit error detection
  - Even parity – total number of 1s even
  - Odd parity – total number of 1s odd
- Parity bit is append to the code at the leftmost position (MSB) .

A parity bit is a bit that is added to ensure that the number of bits with value of 1's in a given set of bits is always even or odd. Parity bits are used as the simplest error detecting code.

## Examples:

1 1 0 1 0 0 1 1 1

Even Parity bit

0 1 0 1 0 0 1 1 1

Odd Parity bit

| Number 1s | Even Parity | Odd Parity |
|---|---|---|
| Even | 0 | 1 |
| Odd | 1 | 0 |

(Remember these basic rule)

| 7 bits of data (number of 1s) | 8 bits including parity | |
|---|---|---|
| | even | odd |
| 0000000 (0) | 00000000 | 10000000 |
| 1010001 (3) | 11010001 | 01010001 |
| 1101001 (4) | 01101001 | 11101001 |
| 1111111 (7) | 11111111 | 01111111 |

Parity bit

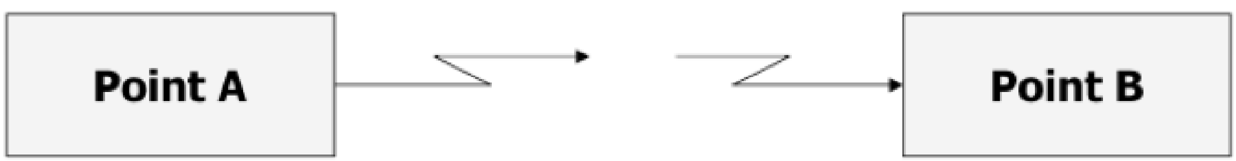
Resource: *http://en.wikipedia.org/wiki/Parity_bit*

- Example: Calculate the parity bit for the codes below.

| Code | Number of 1s | Even/Odd | Even Parity | Odd Parity |
|---|---|---|---|---|
| 110010 | 3 | Odd | **1** 110010 | **0** 110010 |
| 101110 | 4 | Even | **0** 101110 | **1** 101110 |
| 101000 | 2 | Even | **0** 101000 | **1** 101000 |
| 110111 | 5 | Odd | **1** 110111 | **0** 110111 |
| 111111 | 6 | Even | 0 111111 | 1 111111 |
| 100000 | 1 | Odd | 1 100000 | 0 100000 |

# Error Detection by Parity Checking

- Assume that data = 0101
- It uses even parity.
- Therefore the appended parity bit is 0.
- The data with parity bit: 0 0101
- The data is transmitted.
- The data is received as 00001 → odd no. of 1, not even!!




Data: 0 0101
(even parity)

Data: 0 0001
(even parity)
but does not conform
to even parity

# American Standard Code for Information Interchange (ASCII)

- It has 128 characters and symbols represented in 7-bit binary code
- Example :
- A = $1000001_2$
- a = $1100001_2$
- A parity bit is added so that the total number of bits is 8 → a byte.

# ASCII TABLE

| Decimal | Hex | Char | Decimal | Hex | Char | Decimal | Hex | Char | Decimal | Hex | Char |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 0 | [NULL] | 32 | 20 | [SPACE] | 64 | 40 | @ | 96 | 60 | ` |
| 1 | 1 | [START OF HEADING] | 33 | 21 | ! | 65 | 41 | A | 97 | 61 | a |
| 2 | 2 | [START OF TEXT] | 34 | 22 | " | 66 | 42 | B | 98 | 62 | b |
| 3 | 3 | [END OF TEXT] | 35 | 23 | # | 67 | 43 | C | 99 | 63 | c |
| 4 | 4 | [END OF TRANSMISSION] | 36 | 24 | $ | 68 | 44 | D | 100 | 64 | d |
| 5 | 5 | [ENQUIRY] | 37 | 25 | % | 69 | 45 | E | 101 | 65 | e |
| 6 | 6 | [ACKNOWLEDGE] | 38 | 26 | & | 70 | 46 | F | 102 | 66 | f |
| 7 | 7 | [BELL] | 39 | 27 | ' | 71 | 47 | G | 103 | 67 | g |
| 8 | 8 | [BACKSPACE] | 40 | 28 | ( | 72 | 48 | H | 104 | 68 | h |
| 9 | 9 | [HORIZONTAL TAB] | 41 | 29 | ) | 73 | 49 | I | 105 | 69 | i |
| 10 | A | [LINE FEED] | 42 | 2A | * | 74 | 4A | J | 106 | 6A | j |
| 11 | B | [VERTICAL TAB] | 43 | 2B | + | 75 | 4B | K | 107 | 6B | k |
| 12 | C | [FORM FEED] | 44 | 2C | , | 76 | 4C | L | 108 | 6C | l |
| 13 | D | [CARRIAGE RETURN] | 45 | 2D | - | 77 | 4D | M | 109 | 6D | m |
| 14 | E | [SHIFT OUT] | 46 | 2E | . | 78 | 4E | N | 110 | 6E | n |
| 15 | F | [SHIFT IN] | 47 | 2F | / | 79 | 4F | O | 111 | 6F | o |
| 16 | 10 | [DATA LINK ESCAPE] | 48 | 30 | 0 | 80 | 50 | P | 112 | 70 | p |
| 17 | 11 | [DEVICE CONTROL 1] | 49 | 31 | 1 | 81 | 51 | Q | 113 | 71 | q |
| 18 | 12 | [DEVICE CONTROL 2] | 50 | 32 | 2 | 82 | 52 | R | 114 | 72 | r |
| 19 | 13 | [DEVICE CONTROL 3] | 51 | 33 | 3 | 83 | 53 | S | 115 | 73 | s |
| 20 | 14 | [DEVICE CONTROL 4] | 52 | 34 | 4 | 84 | 54 | T | 116 | 74 | t |
| 21 | 15 | [NEGATIVE ACKNOWLEDGE] | 53 | 35 | 5 | 85 | 55 | U | 117 | 75 | u |
| 22 | 16 | [SYNCHRONOUS IDLE] | 54 | 36 | 6 | 86 | 56 | V | 118 | 76 | v |
| 23 | 17 | [END OF TRANS. BLOCK] | 55 | 37 | 7 | 87 | 57 | W | 119 | 77 | w |
| 24 | 18 | [CANCEL] | 56 | 38 | 8 | 88 | 58 | X | 120 | 78 | x |
| 25 | 19 | [END OF MEDIUM] | 57 | 39 | 9 | 89 | 59 | Y | 121 | 79 | y |
| 26 | 1A | [SUBSTITUTE] | 58 | 3A | : | 90 | 5A | Z | 122 | 7A | z |
| 27 | 1B | [ESCAPE] | 59 | 3B | ; | 91 | 5B | [ | 123 | 7B | { |
| 28 | 1C | [FILE SEPARATOR] | 60 | 3C | < | 92 | 5C | \ | 124 | 7C | \| |
| 29 | 1D | [GROUP SEPARATOR] | 61 | 3D | = | 93 | 5D | ] | 125 | 7D | } |
| 30 | 1E | [RECORD SEPARATOR] | 62 | 3E | > | 94 | 5E | ^ | 126 | 7E | ~ |
| 31 | 1F | [UNIT SEPARATOR] | 63 | 3F | ? | 95 | 5F | _ | 127 | 7F | [DEL] |

| Decimal | Hex | ASCII | Decimal | Hex | ASCII | Decimal | Hex | ASCII | Decimal | Hex | ASCII |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 0 | 00 | NUL | 32 | 20 | (blank) | 64 | 40 | @ | 96 | 60 | ` |
| 1 | 01 | SOH | 33 | 21 | ! | 65 | 41 | A | 97 | 61 | a |
| 2 | 02 | STX | 34 | 22 | " | 66 | 42 | B | 98 | 62 | b |
| 3 | 03 | ETX | 35 | 23 | # | 67 | 43 | C | 99 | 63 | c |
| 4 | 04 | EOT | 36 | 24 | $ | 68 | 44 | D | 100 | 64 | d |
| 5 | 05 | ENQ | 37 | 25 | % | 69 | 45 | E | 101 | 65 | e |
| 6 | 06 | ACK | 38 | 26 | & | 70 | 46 | F | 102 | 66 | f |
| 7 | 07 | BEL | 39 | 27 | ' | 71 | 47 | G | 103 | 67 | g |
| 8 | 08 | BS | 40 | 28 | ( | 72 | 48 | H | 104 | 68 | h |
| 9 | 09 | HT | 41 | 29 | ) | 73 | 49 | I | 105 | 69 | i |
| 10 | 0A | LF | 42 | 2A | * | 74 | 4A | J | 106 | 6A | j |
| 11 | 0B | VT | 43 | 2B | + | 75 | 4B | K | 107 | 6B | k |
| 12 | 0C | FF | 44 | 2C | , | 76 | 4C | L | 108 | 6C | l |
| 13 | 0D | CR | 45 | 2D | - | 77 | 4D | M | 109 | 6D | m |
| 14 | 0E | SO | 46 | 2E | . | 78 | 4E | N | 110 | 6E | n |
| 15 | 0F | SI | 47 | 2F | / | 79 | 4F | O | 111 | 6F | o |
| 16 | 10 | DLE | 48 | 30 | 0 | 80 | 50 | P | 112 | 70 | p |
| 17 | 11 | DC1 | 49 | 31 | 1 | 81 | 51 | Q | 113 | 71 | q |
| 18 | 12 | DC2 | 50 | 32 | 2 | 82 | 52 | R | 114 | 72 | r |
| 19 | 13 | DC3 | 51 | 33 | 3 | 83 | 53 | S | 115 | 73 | s |
| 20 | 14 | DC4 | 52 | 34 | 4 | 84 | 54 | T | 116 | 74 | t |
| 21 | 15 | NAK | 53 | 35 | 5 | 85 | 55 | U | 117 | 75 | u |
| 22 | 16 | SYN | 54 | 36 | 6 | 86 | 56 | V | 118 | 76 | v |
| 23 | 17 | ETB | 55 | 37 | 7 | 87 | 57 | W | 119 | 77 | w |
| 24 | 18 | CAN | 56 | 38 | 8 | 88 | 58 | X | 120 | 78 | x |
| 25 | 19 | EM | 57 | 39 | 9 | 89 | 59 | Y | 121 | 79 | y |
| 26 | 1A | SUB | 58 | 3A | : | 90 | 5A | Z | 122 | 7A | z |
| 27 | 1B | ESC | 59 | 3B | ; | 91 | 5B | [ | 123 | 7B | { |
| 28 | 1C | FS | 60 | 3C | < | 92 | 5C | \ | 124 | 7C | \| |
| 29 | 1D | GS | 61 | 3D | = | 93 | 5D | ] | 125 | 7D | } |
| 30 | 1E | RS | 62 | 3E | > | 94 | 5E | ^ | 126 | 7E | ~ |
| 31 | 1F | US | 63 | 3F | ? | 95 | 5F | _ | 127 | 7F | (delete) |

*Resource: http://www.s4a.us/support/cimco_faq.htm*

# ASCII codes – More compact table

7-bits binary$_2$ ASCII code

**Examples:**

$B_7b_6b_5$ $b_4b_3b_2b_1$

110 1101

is represent as **'m'**

| Bits | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $b_7$ $b_6$ $b_5$ | | | | | 0 0 0 | 0 0 1 | 0 1 0 | 0 1 1 | 1 0 0 | 1 0 1 | 1 1 0 | 1 1 1 |
| $b_4$ ↓ | $b_3$ ↓ | $b_2$ ↓ | $b_1$ ↓ | Column → Row ↓ | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 |
| 0 | 0 | 0 | 0 | 0 | NUL | DLE | SP | 0 | @ | P | ` | p |
| 0 | 0 | 0 | 1 | 1 | SOH | DC1 | ! | 1 | A | Q | a | q |
| 0 | 0 | 1 | 0 | 2 | STX | DC2 | " | 2 | B | R | b | r |
| 0 | 0 | 1 | 1 | 3 | ETX | DC3 | # | 3 | C | S | c | s |
| 0 | 1 | 0 | 0 | 4 | EOT | DC4 | $ | 4 | D | T | d | t |
| 0 | 1 | 0 | 1 | 5 | ENQ | NAK | % | 5 | E | U | e | u |
| 0 | 1 | 1 | 0 | 6 | ACK | SYN | & | 6 | F | V | f | v |
| 0 | 1 | 1 | 1 | 7 | BEL | ETB | ' | 7 | G | W | g | w |
| 1 | 0 | 0 | 0 | 8 | BS | CAN | ( | 8 | H | X | h | x |
| 1 | 0 | 0 | 1 | 9 | HT | EM | ) | 9 | I | Y | i | y |
| 1 | 0 | 1 | 0 | 10 | LF | SUB | * | : | J | Z | j | z |
| 1 | 0 | 1 | 1 | 11 | VT | ESC | + | ; | K | [ | k | { |
| 1 | 1 | 0 | 0 | 12 | FF | FC | , | < | L | \ | l | \| |
| 1 | 1 | 0 | 1 | 13 | CR | GS | - | = | M | ] | **m** | } |
| 1 | 1 | 1 | 0 | 14 | SO | RS | . | > | N | ^ | n | ~ |
| 1 | 1 | 1 | 1 | 15 | SI | US | / | ? | O | _ | o | DEL |

*Resource: http://en.wikipedia.org/wiki/File:ASCII_Code_Chart-Quick_ref_card.png*

## Exercise 2b.2:

Convert the string SCR1013 to its ASCII hexadecimal value.

SCR1013 = 53 43 52 31 30 31 33

By using even parity coding, calculate the parity bit and insert this bit at the MSB position. Recalculate the ASCII value in its hexadecimal representation.

Extra

## Exercise 2b.3:

Given a string (character) UTM1435.

a) Convert the string to its ASCII hexadecimal value.

b) Calculate the odd parity bit and insert as MSB.

a) Recalculate the ASCII value in hexadecimal.

| Number 1s | Even Parity | Odd Parity |
|---|---|---|
| Even | 0 | 1 |
| Odd | 1 | 0 |

Extra

| Character (ASCII) | ASCII (Hex) | Binary | Odd parity bit + Binary | New ASCII (Hex) |
|---|---|---|---|---|
| U | | | | |
| T | | | | |
| M | | | | |
| 1 | | | | |
| 4 | | | | |
| 3 | | | | |
| 5 | | | | |
| h | | | | |