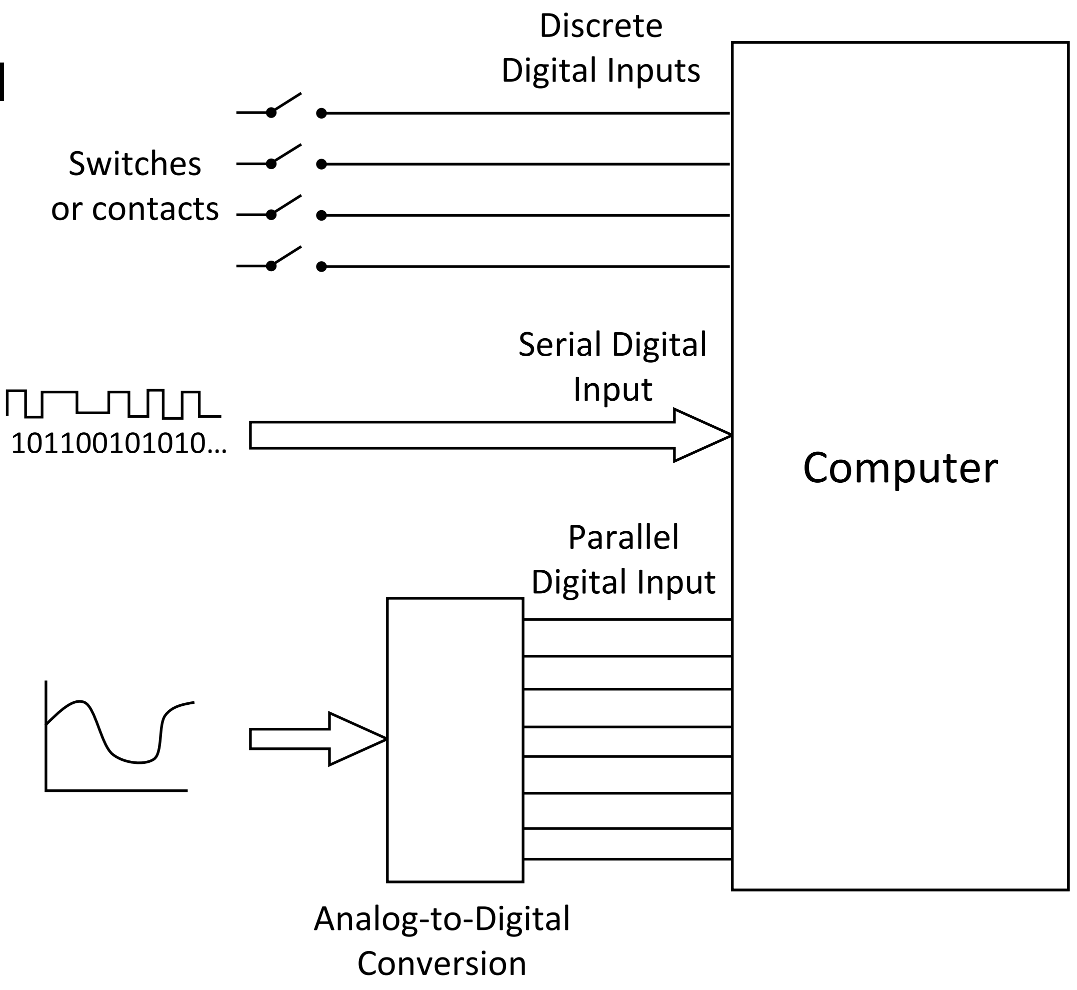
시스템 프로그래밍을 위한 C언어

- Hardware Memory Allocation to Access On-Chip Hardware via Memory Mapped I/O

현대자동차 입문교육
박대진 교수

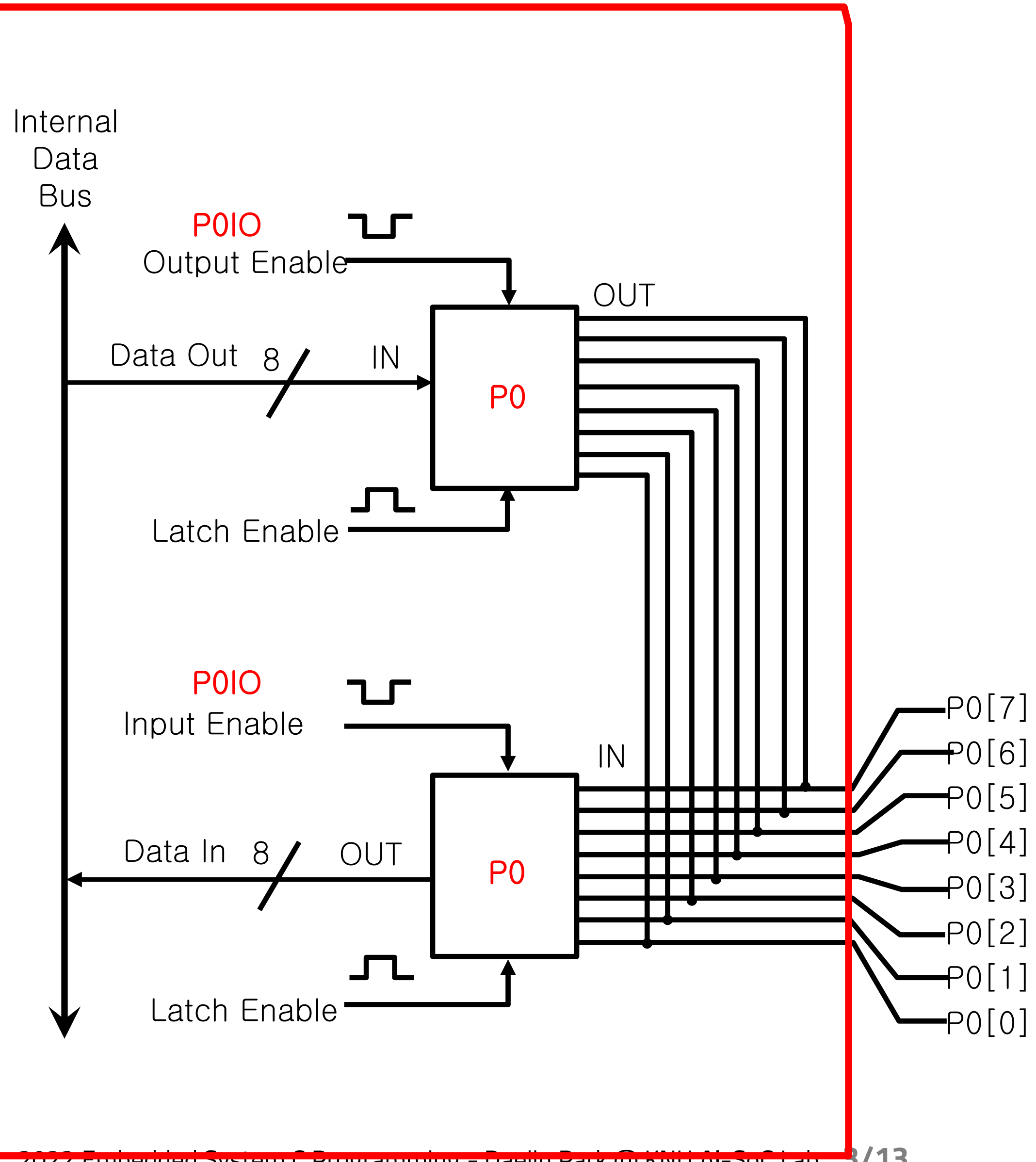
Real World Interfacing by using MCU

- Analog or Digital
- Bit or Bus



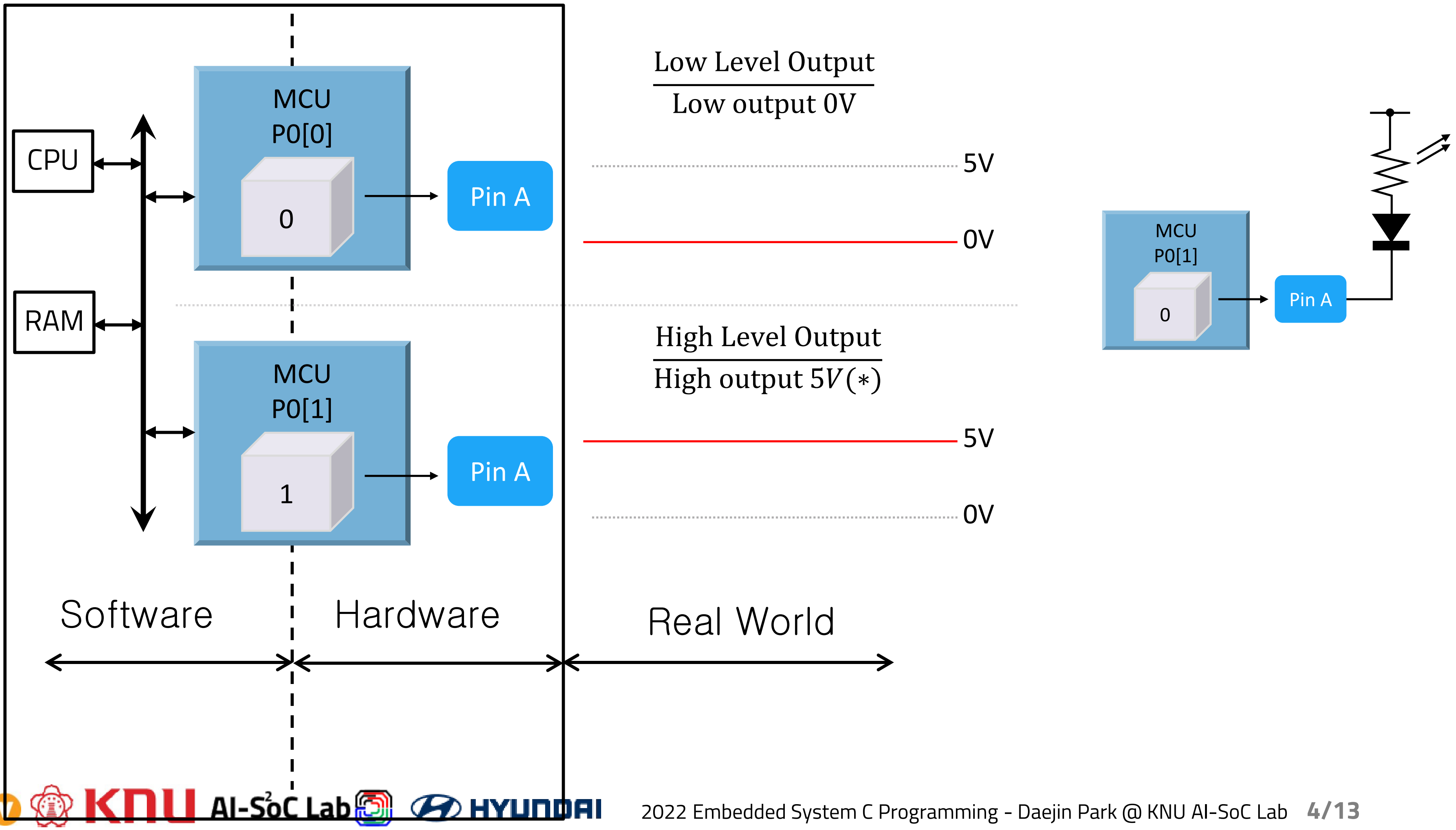
GPIO and Internal Bus

- General Purpose Input/Output
  - Interface Between Internal Bus and Outside world
  - Time-multiplexed Data Path (Input, output)
  - GPIO Port is mapped to registers in Memory Map



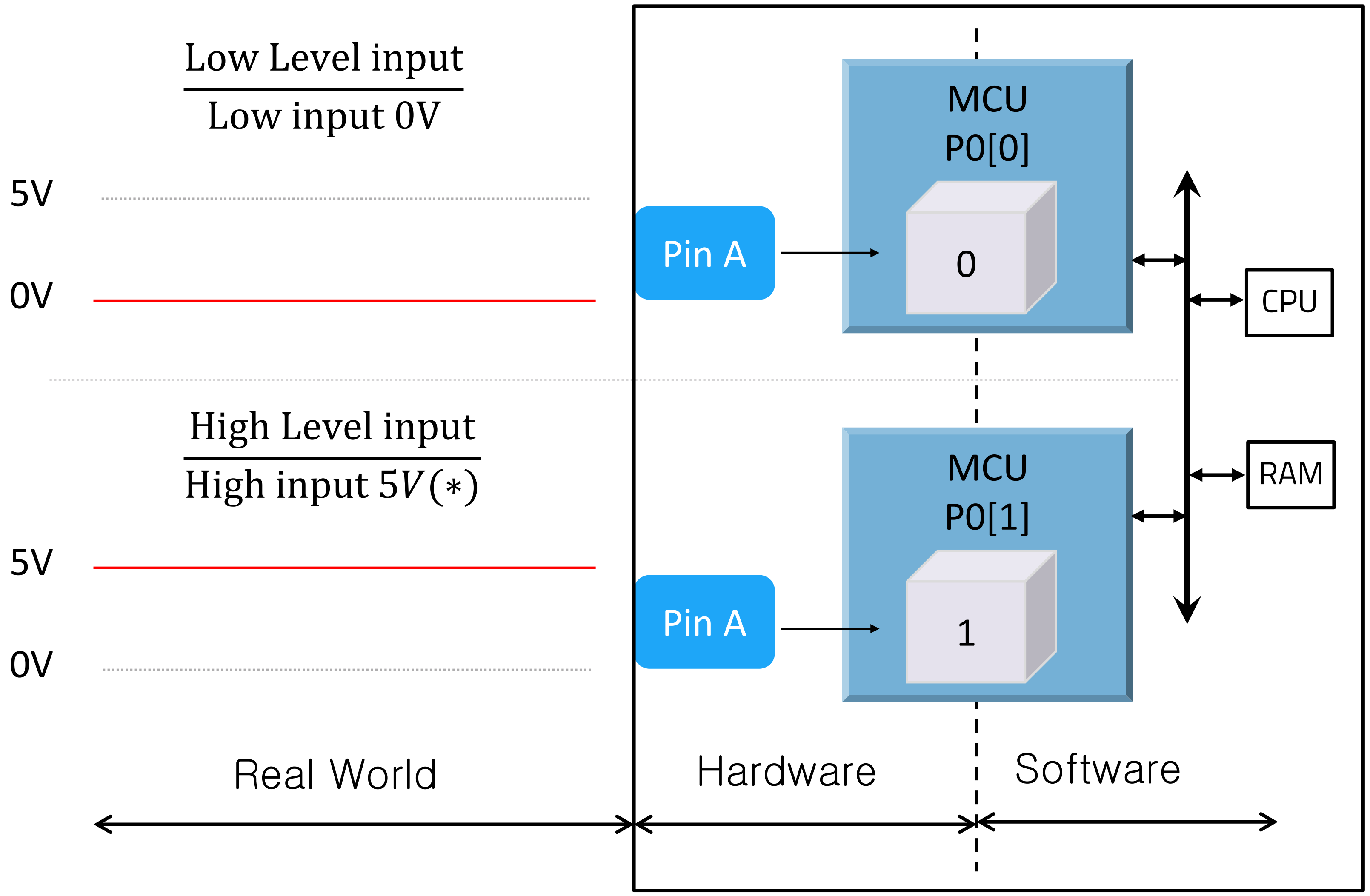
Interfacing via PORT Register on Memory Map : Write Mode

- Write value on Register → Control the output voltage



Interfacing via PORT Register on Memory Map: Read Mode

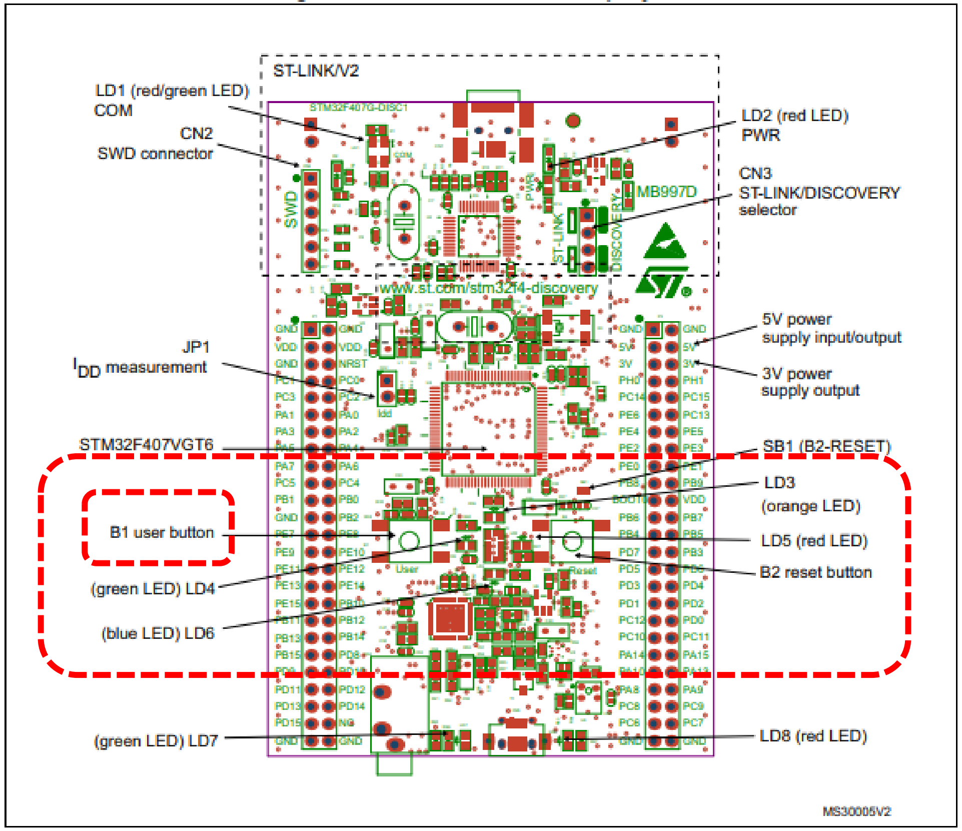
- Reading Register Value → Can Identify the input voltage

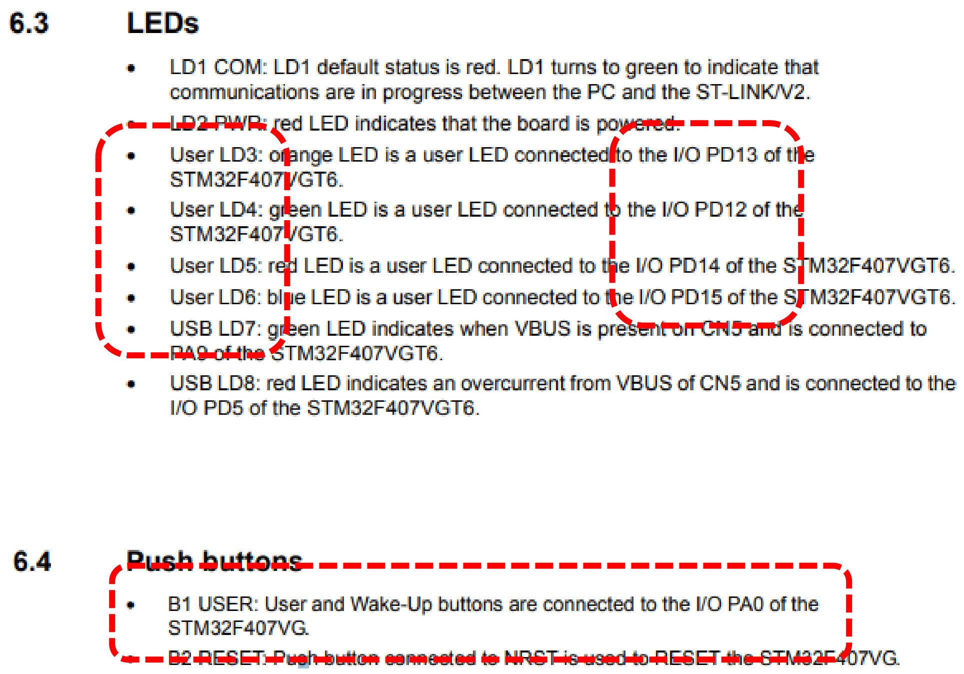


코드 설명 – GPIO 설정

- 보드의 LED, 버튼을 사용하기 위한 하드웨어 회로 파악
  - 4개 LED : LD3 ~ 6 는 PD12 ~ 15에 연결되어 있음 (PD, **Port D**)
  - 버튼 B1은 PA0에 연결되어 있음 (PA, **Port A**)

Figure 3. STM32F4DISCOVERY top layout





6.3 LEDs

- LD1 COM: LD1 default status is red. LD1 turns to green to indicate that communications are in progress between the PC and the ST-LINK/V2.
- LD2 PWR: red LED indicates that the board is powered.
- User LD3: orange LED is a user LED connected to the I/O PD13 of the STM32F407VGT6.
- User LD4: green LED is a user LED connected to the I/O PD12 of the STM32F407VGT6.
- User LD5: red LED is a user LED connected to the I/O PD14 of the STM32F407VGT6.
- User LD6: blue LED is a user LED connected to the I/O PD15 of the STM32F407VGT6.
- USB LD7: green LED indicates when VBUS is present on CN5 and is connected to PA9 of the STM32F407VGT6.
- USB LD8: red LED indicates an overcurrent from VBUS of CN5 and is connected to the I/O PD5 of the STM32F407VGT6.

6.4 Push buttons

- B1 USER: User and Wake-Up buttons are connected to the I/O PA0 of the STM32F407VG.
- B2 RESET: Push button connected to NRST is used to RESET the STM32F407VG.

코드 설명 – GPIO 설정

- GPIO Port A, Port D를 사용하기 위한 GPIO 레지스터 설정

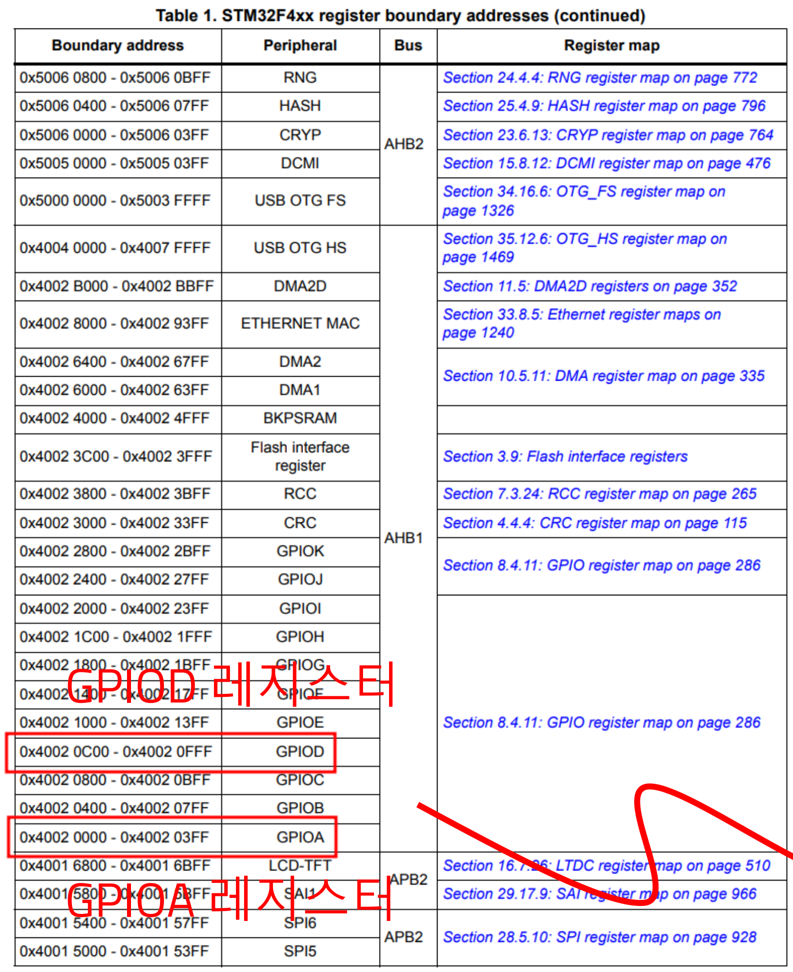
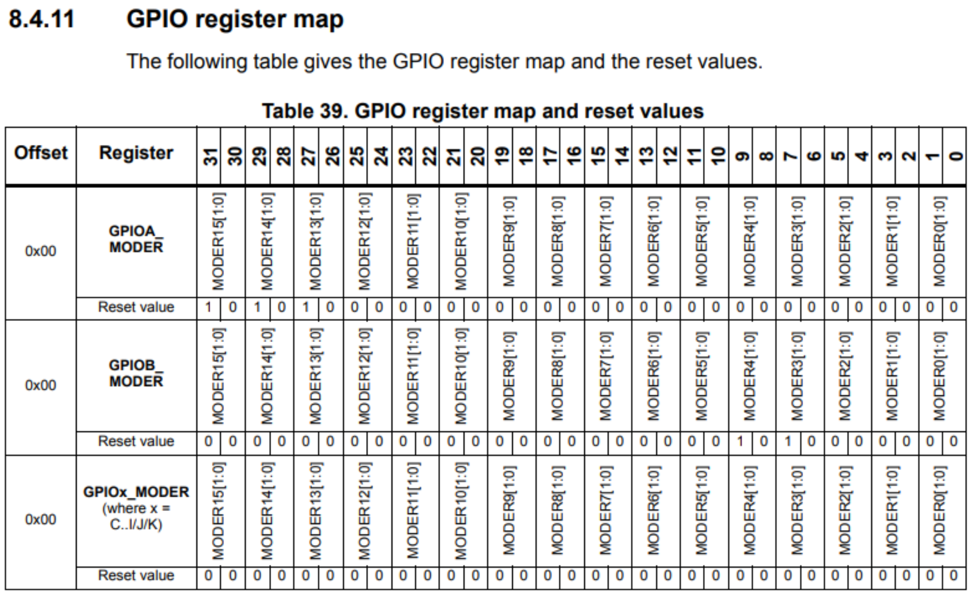


Table 1. STM32F4xx register boundary addresses (continued)

Boundary address	Peripheral	Bus	Register map
0x5006 0800 - 0x5006 0BFF	RNG	AHB2	Section 24.4.4: RNG register map on page 772
0x5006 0400 - 0x5006 07FF	HASH		Section 25.4.9: HASH register map on page 796
0x5006 0000 - 0x5006 03FF	CRYP		Section 23.6.13: CRYP register map on page 764
0x5005 0000 - 0x5005 03FF	DCMI		Section 15.8.12: DCMI register map on page 476
0x5000 0000 - 0x5003 FFFF	USB OTG FS		Section 34.16.6: OTG_FS register map on page 1326
0x4004 0000 - 0x4007 FFFF	USB OTG HS	AHB1	Section 35.12.6: OTG_HS register map on page 1469
0x4002 B000 - 0x4002 BBFF	DMA2D		Section 11.5: DMA2D registers on page 352
0x4002 8000 - 0x4002 93FF	ETHERNET MAC		Section 33.8.5: Ethernet register maps on page 1240
0x4002 6400 - 0x4002 67FF	DMA2		Section 10.5.11: DMA register map on page 335
0x4002 6000 - 0x4002 63FF	DMA1		
0x4002 4000 - 0x4002 4FFF	BKPSRAM		
0x4002 3C00 - 0x4002 3FFF	Flash interface register		Section 3.9: Flash interface registers
0x4002 3800 - 0x4002 3BFF	RCC		Section 7.3.24: RCC register map on page 265
0x4002 3000 - 0x4002 33FF	CRC		Section 4.4.4: CRC register map on page 115
0x4002 2800 - 0x4002 2BFF	GPIOK		Section 8.4.11: GPIO register map on page 286
0x4002 2400 - 0x4002 27FF	GPIOJ		
0x4002 2000 - 0x4002 23FF	GPIOI		Section 8.4.11: GPIO register map on page 286
0x4002 1C00 - 0x4002 1FFF	GPIOH		
0x4002 1800 - 0x4002 1BFF	GPIOG		
0x4002 1400 - 0x4002 17FF	GPIOF		
0x4002 1000 - 0x4002 13FF	GPIOE		
0x4002 0C00 - 0x4002 0FFF	GPIOD		
0x4002 0800 - 0x4002 0BFF	GPIOC		
0x4002 0400 - 0x4002 07FF	GPIOB		
0x4002 0000 - 0x4002 03FF	GPIOA		
0x4001 6800 - 0x4001 6BFF	LCD-TFT	APB2	Section 16.7.26: LTDC register map on page 510
0x4001 5800 - 0x4001 5BFF	SAI1		Section 29.17.9: SAI register map on page 966
0x4001 5400 - 0x4001 57FF	SPI6	APB2	Section 28.5.10: SPI register map on page 928
0x4001 5000 - 0x4001 53FF	SPI5		

GPIOD 레지스터

GPIOA 레지스터



8.4.11 GPIO register map

The following table gives the GPIO register map and the reset values.

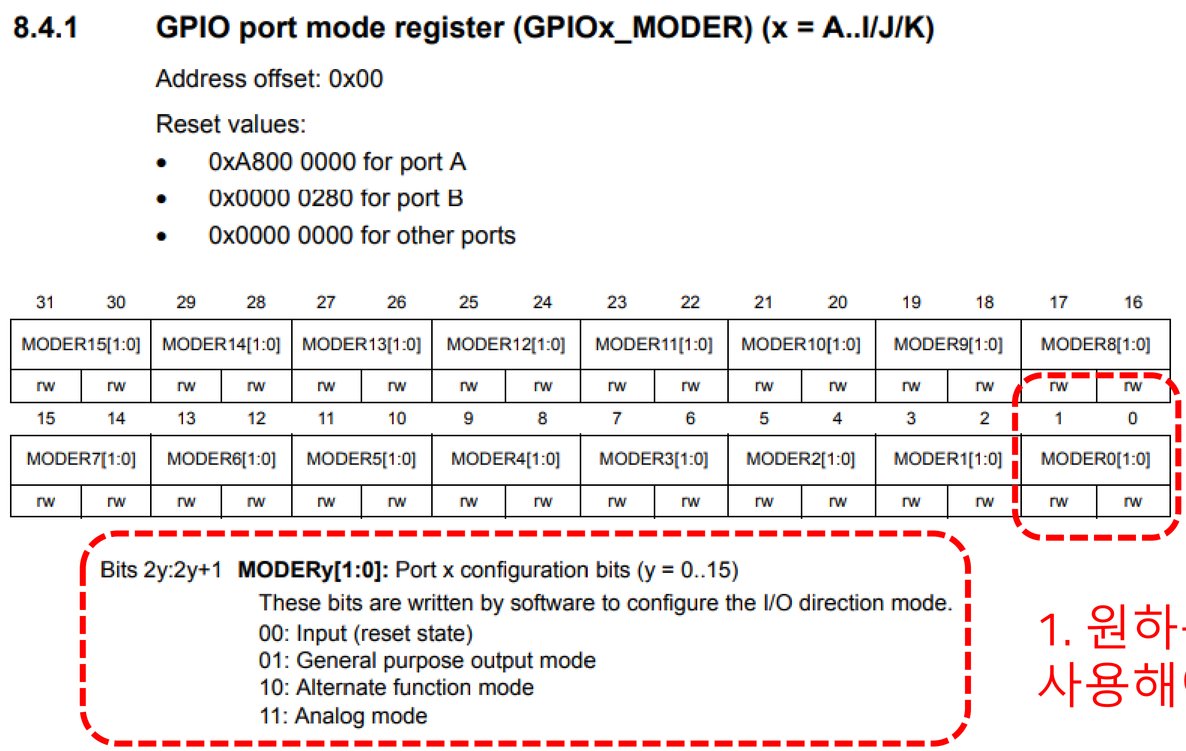
Table 39. GPIO register map and reset values

Offset	Register	31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	6	5	4	3	2	1	0
0x00	GPIOA_MODER	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
	Reset value	1	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
0x00	GPIOB_MODER	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0
0x00	GPIOx_MODER (where x = C..I/J/K)	MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]		MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
	Reset value	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

전체 레지스터 map에서 base address를 찾아 GPIO 모듈의 세부 레지스터 map으로 이동

코드 설명 – GPIO 설정

- 레지스터 설정 값을 결정하기 위한 스펙 문서 이해
  - GPIO의 여러 레지스터 중, 1개의 예시



8.4.1 GPIO port mode register (GPIOx_MODER) (x = A..I/J/K)

Address offset: 0x00

Reset values:

- 0xA800 0000 for port A
- 0x0000 0280 for port B
- 0x0000 0000 for other ports

31	30	29	28	27	26	25	24	23	22	21	20	19	18	17	16
MODER15[1:0]		MODER14[1:0]		MODER13[1:0]		MODER12[1:0]		MODER11[1:0]		MODER10[1:0]		MODER9[1:0]		MODER8[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw
15	**14**	**13**	**12**	**11**	**10**	**9**	**8**	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**
MODER7[1:0]		MODER6[1:0]		MODER5[1:0]		MODER4[1:0]		MODER3[1:0]		MODER2[1:0]		MODER1[1:0]		MODER0[1:0]	
rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw	rw

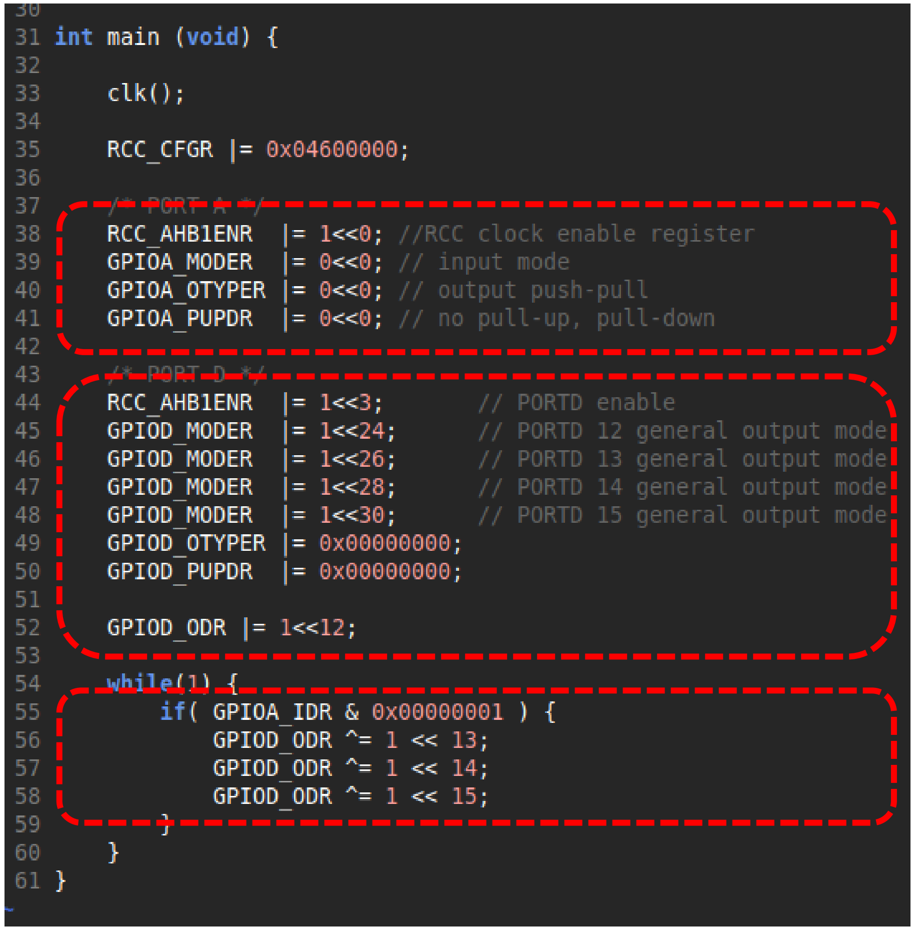
Bits 2y:2y+1 **MODERy[1:0]:** Port x configuration bits (y = 0..15)
These bits are written by software to configure the I/O direction mode.
00: Input (reset state)
01: General purpose output mode
10: Alternate function mode
11: Analog mode

2. 사용하려는 component를 위해서 전체 레지스터 중, 어디에 write해야 하는지 파악

1. 원하는 동작을 위해서 어떤 값을 사용해야 하는지 파악

코드 설명 – GPIO 설정

- GPIO 레지스터를 설정하는 코드



```c
int main (void) {

    clk();

    RCC_CFGR |= 0x04600000;

    /* PORT A */
    RCC_AHB1ENR  |= 1<<0; //RCC clock enable register
    GPIOA_MODER  |= 0<<0; // input mode
    GPIOA_OTYPER |= 0<<0; // output push-pull
    GPIOA_PUPDR  |= 0<<0; // no pull-up, pull-down

    /* PORT D */
    RCC_AHB1ENR  |= 1<<3;       // PORTD enable
    GPIOD_MODER  |= 1<<24;      // PORTD 12 general output mode
    GPIOD_MODER  |= 1<<26;      // PORTD 13 general output mode
    GPIOD_MODER  |= 1<<28;      // PORTD 14 general output mode
    GPIOD_MODER  |= 1<<30;      // PORTD 15 general output mode
    GPIOD_OTYPER |= 0x00000000;
    GPIOD_PUPDR  |= 0x00000000;

    GPIOD_ODR |= 1<<12;

    while(1) {
        if( GPIOA_IDR & 0x00000001 ) {
            GPIOD_ODR ^= 1 << 13;
            GPIOD_ODR ^= 1 << 14;
            GPIOD_ODR ^= 1 << 15;
        }
    }
}
```

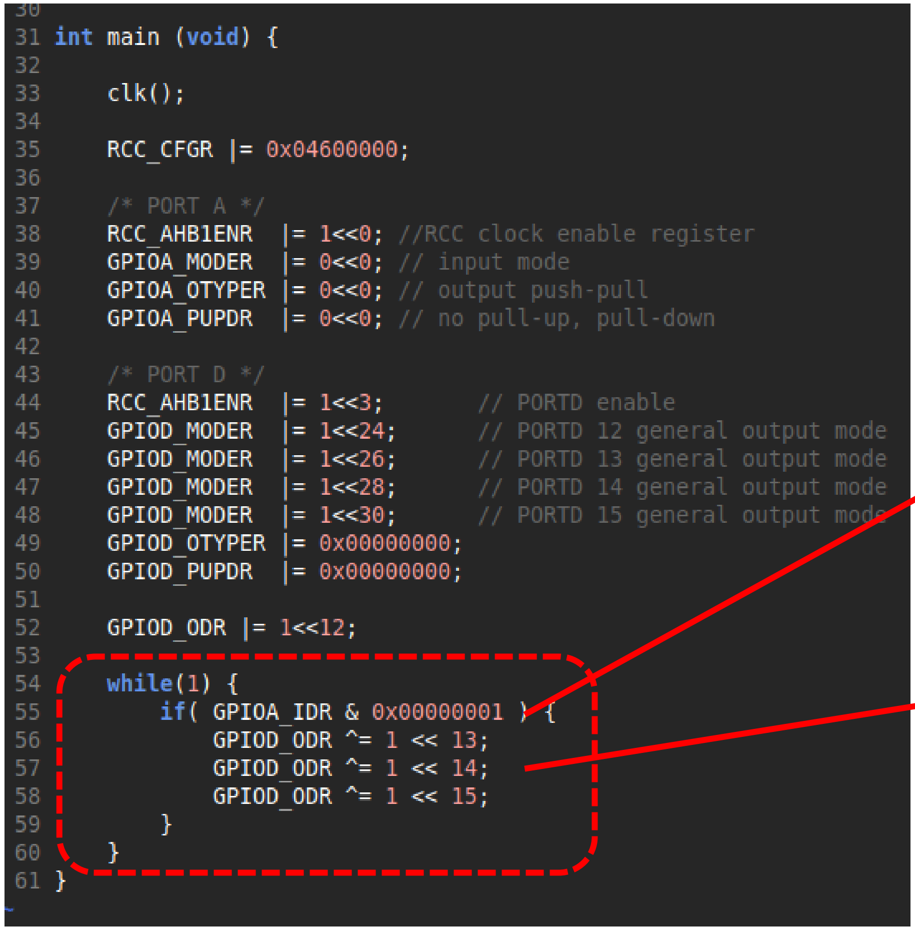
PA0 (Port A의 pin 0)을
입력으로 사용하기 위한 설정
- Port A 모듈에 clock 인가
- 핀 입출력 방향 설정

PD12~15 (Port D의 pin 12~15)을 입력으로
사용하기 위한 설정
- Port D 모듈에 clock 인가
- 핀 입출력 방향 설정

출력 핀에 원하는 값 인가

코드 설명 – 전체 동작

- 버튼으로 입력되는 값에 따라 LED toggle 여부를 결정



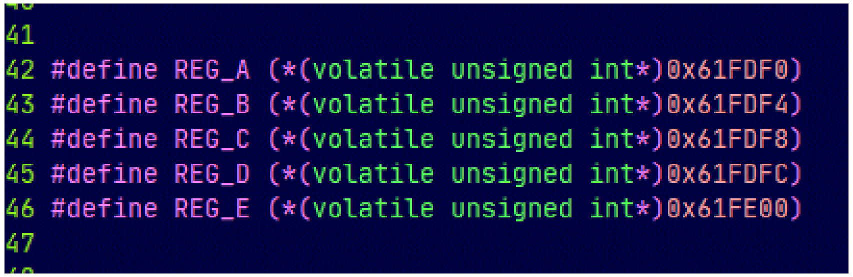
```c
int main (void) {

    clk();

    RCC_CFGR |= 0x04600000;

    /* PORT A */
    RCC_AHB1ENR  |= 1<<0; //RCC clock enable register
    GPIOA_MODER  |= 0<<0; // input mode
    GPIOA_OTYPER |= 0<<0; // output push-pull
    GPIOA_PUPDR  |= 0<<0; // no pull-up, pull-down

    /* PORT D */
    RCC_AHB1ENR  |= 1<<3;       // PORTD enable
    GPIOD_MODER  |= 1<<24;      // PORTD 12 general output mode
    GPIOD_MODER  |= 1<<26;      // PORTD 13 general output mode
    GPIOD_MODER  |= 1<<28;      // PORTD 14 general output mode
    GPIOD_MODER  |= 1<<30;      // PORTD 15 general output mode
    GPIOD_OTYPER |= 0x00000000;
    GPIOD_PUPDR  |= 0x00000000;

    GPIOD_ODR |= 1<<12;

    while(1) {
        if( GPIOA_IDR & 0x00000001 ) {
            GPIOD_ODR ^= 1 << 13;
            GPIOD_ODR ^= 1 << 14;
            GPIOD_ODR ^= 1 << 15;
        }
    }
}
```

버튼으로 입력되는 값이 1이라면,

3개의 LED (PD13, PD14, PD15)의 상태를 toggle
- on되어 있으면 off
- off되어 있으면 on

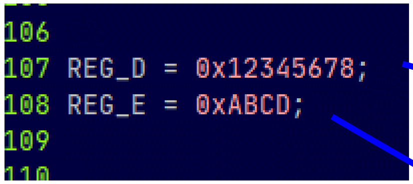
여러가지 SFR 접근 방법

Memory Mapped된 하드웨어 영역의 특정 주소를 define



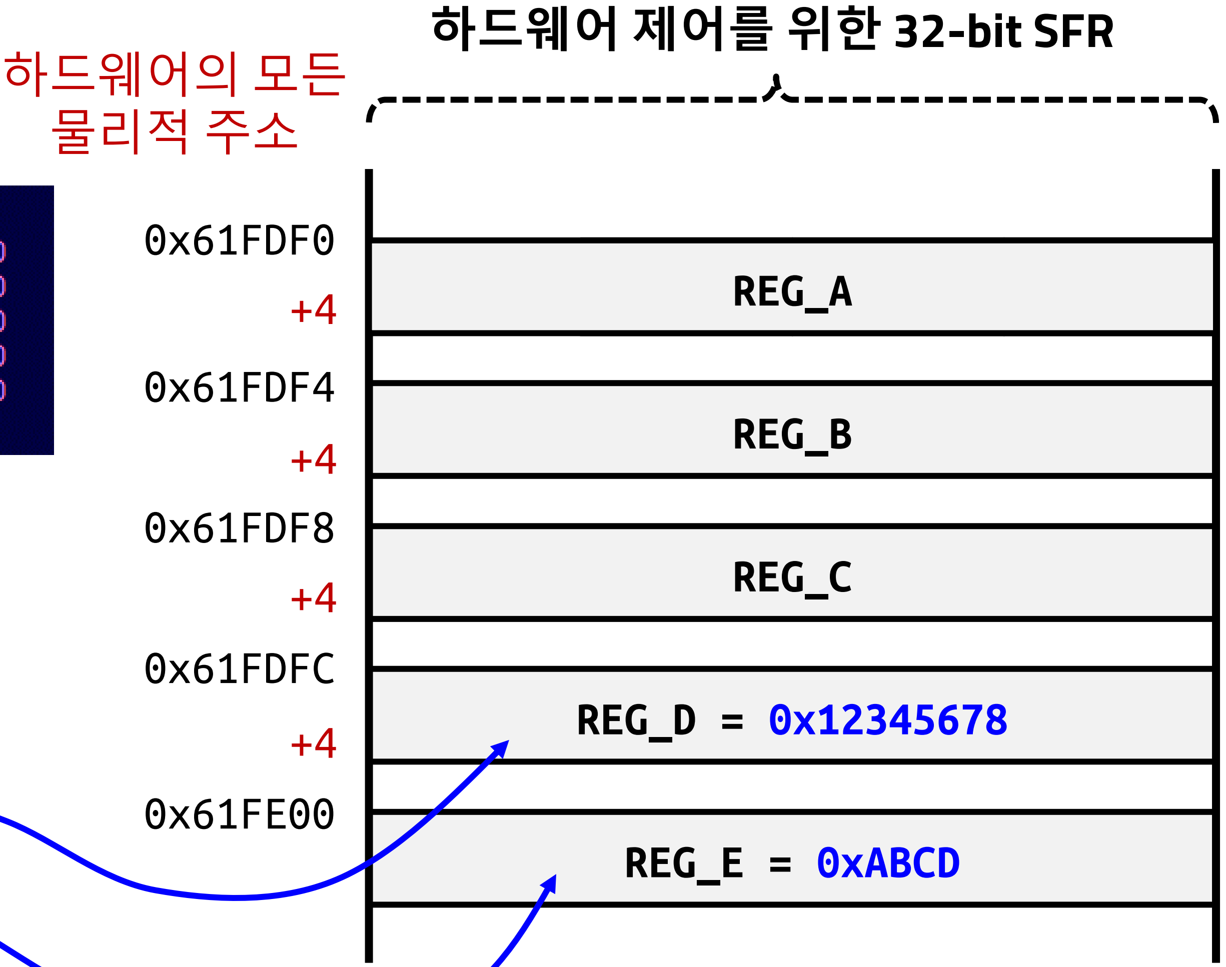
```c
#define REG_A (*(volatile unsigned int*)0x61FDF0)
#define REG_B (*(volatile unsigned int*)0x61FDF4)
#define REG_C (*(volatile unsigned int*)0x61FDF8)
#define REG_D (*(volatile unsigned int*)0x61FDFC)
#define REG_E (*(volatile unsigned int*)0x61FE00)
```

특정 SFR의 주소에 직접적으로 접근



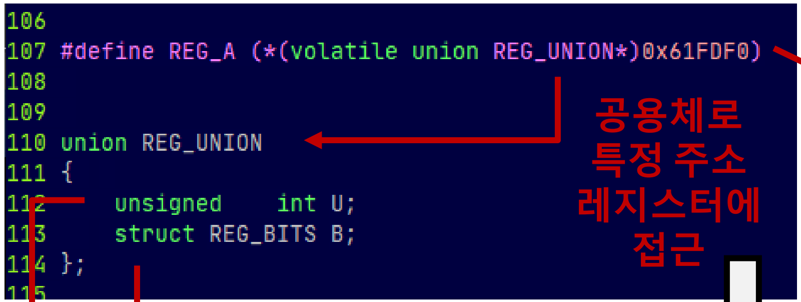
```c
REG_D = 0x12345678;
REG_E = 0xABCD;
```

하드웨어에 값 할당



여러가지 SFR 접근 방법

공용체를 이용한 SFR의 필드 별 접근



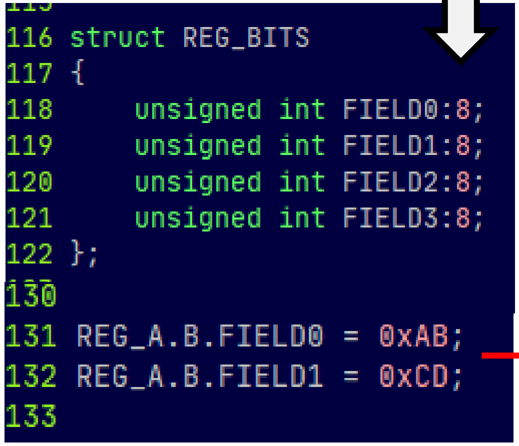
```
#define REG_A (*(volatile union REG_UNION*)0x61FDF0)


union REG_UNION
{
    unsigned    int U;
    struct REG_BITS B;
};
```

공용체로 특정 주소 레지스터에 접근

REG_A 레지스터의 물리적 주소

0x61FDF0

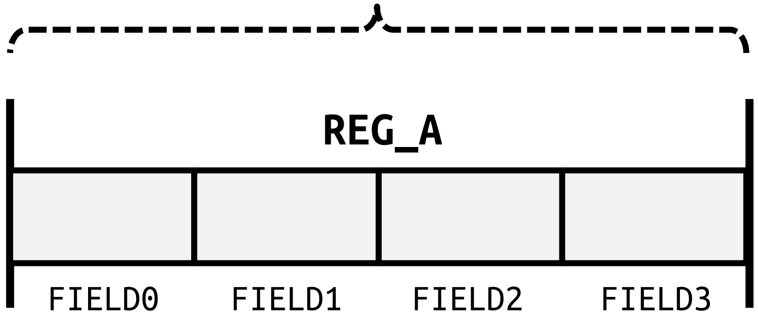
공용체 B 변수



```
struct REG_BITS
{
    unsigned int FIELD0:8;
    unsigned int FIELD1:8;
    unsigned int FIELD2:8;
    unsigned int FIELD3:8;
};

REG_A.B.FIELD0 = 0xAB;
REG_A.B.FIELD1 = 0xCD;
```

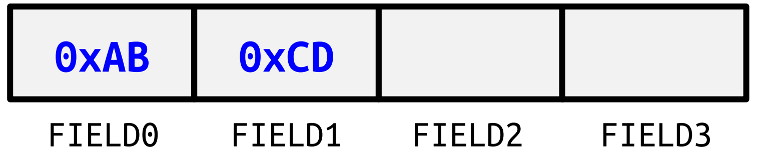
레지스터의 필드에 따로 접근 가능

하드웨어 제어를 위한 32-bit SFR

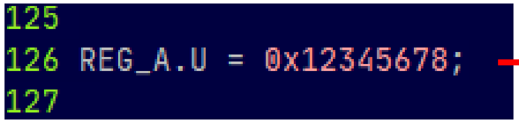


4개의 8-bit 필드들로 구성된 **REG_A** 레지스터

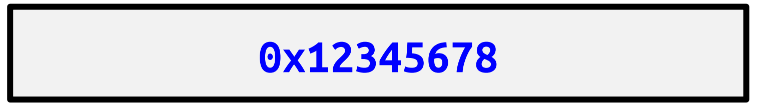
레지스터의 특정 필드에만 값 할당



공용체 U 변수



```
REG_A.U = 0x12345678;
```



unsigned int → 32-bit 크기

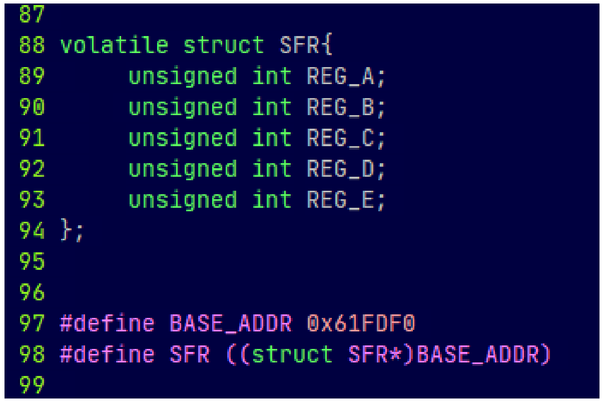
레지스터 전체 영역에 값 할당

REG_A

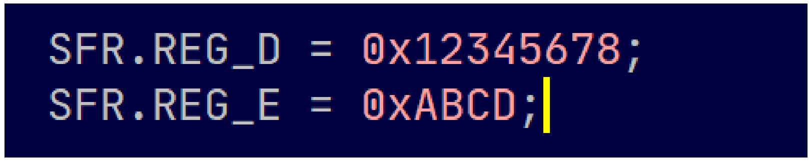
여러가지 SFR 접근 방법

Memory Mapped된 하드웨어 영역을 구조체로 정의

unsigned int → 32-bit 크기



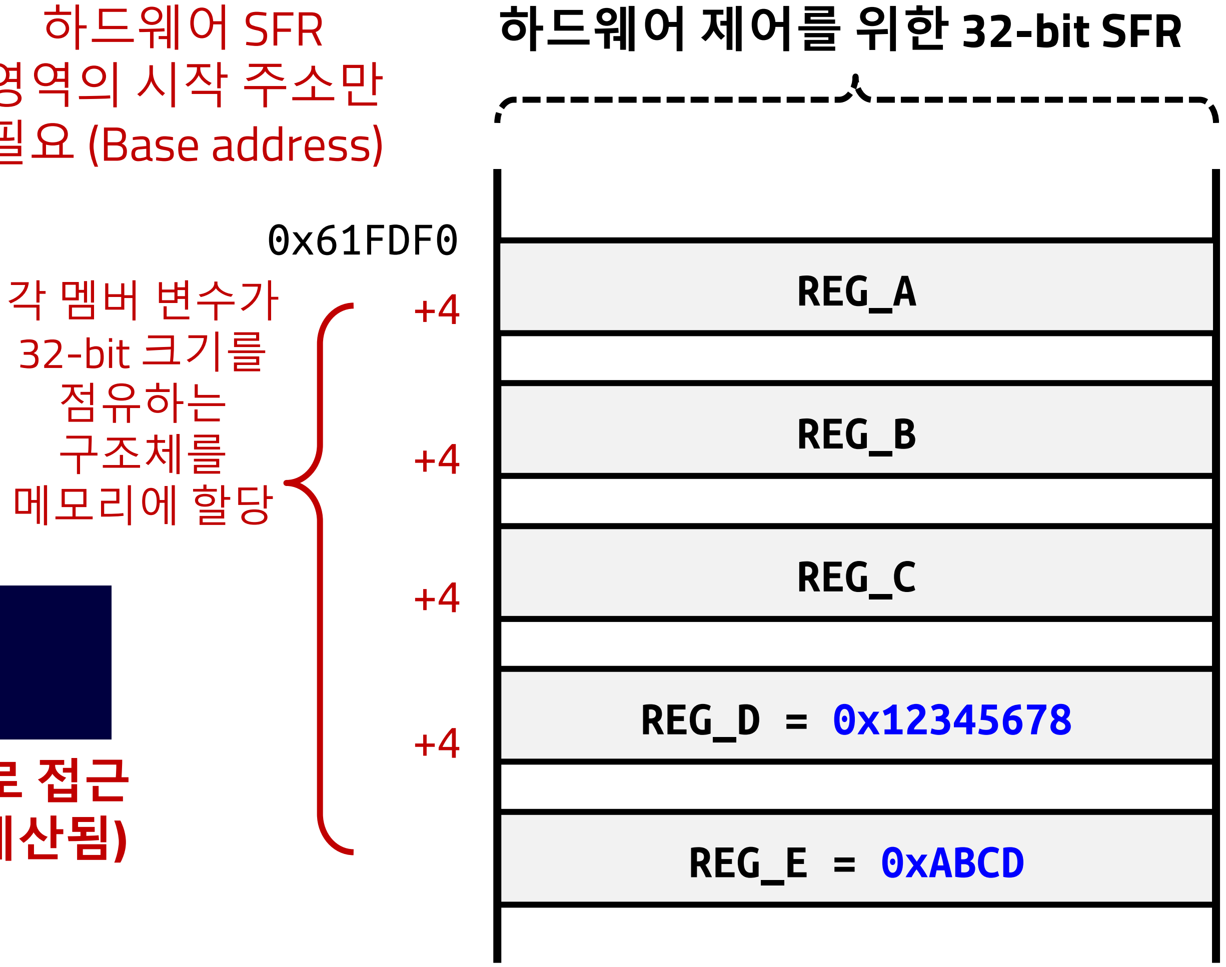
```
volatile struct SFR{
      unsigned int REG_A;
      unsigned int REG_B;
      unsigned int REG_C;
      unsigned int REG_D;
      unsigned int REG_E;
};


#define BASE_ADDR 0x61FDF0
#define SFR ((struct SFR*)BASE_ADDR)

```



```
SFR.REG_D = 0x12345678;
SFR.REG_E = 0xABCD;
```

구조체 시작주소로부터 상대 거리로 접근
(맴버 변수 접근시 자동으로 주소 계산됨)

하드웨어 SFR
영역의 시작 주소만
필요 (Base address)


하드웨어 제어를 위한 32-bit SFR
0x61FDF0
각 멤버 변수가
32-bit 크기를
점유하는
구조체를
메모리에 할당
+4
+4
+4
+4
REG_A
REG_B
REG_C
REG_D = 0x12345678
REG_E = 0xABCD