Notes for ECE 36200 - Microprocessor Systems and Interfacing

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These are lecture notes for spring 2024 ECE 36200 at Purdue as taught by Professor Younghyun Kim. Modify, use, and distribute as you please.

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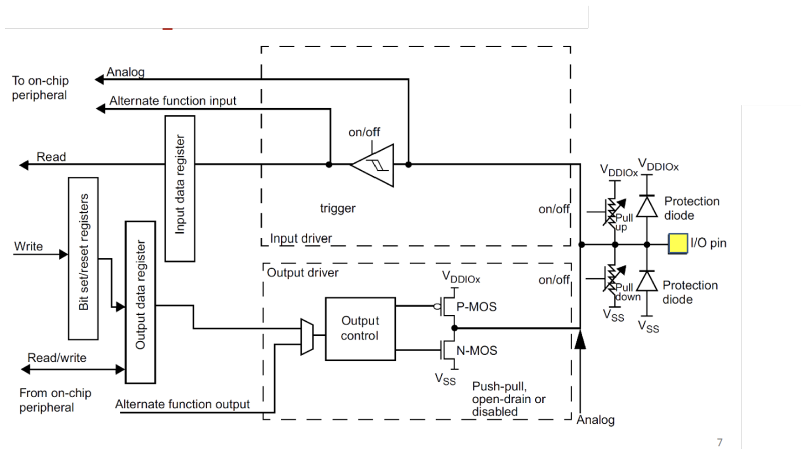
GPIO

The idea behind a GPIO pin is the fact that it can do basically anything, due to which it is called General Purpose.
The structure of a GPIO pin is the following:



This circuit can be broken down into two parts - Output control and Input Control.

Output Control

Output Control, can be written to by bit set/reset registers, or by read/write operations.
Bit set/reset registers are registers within the microcontroller that connect to specific pins on the board. When the program writes to these registers, depending on which operation was executed, it will make the Output Data Register output a high or low bit (set and reset respectively).
On the other hand, read/write operations directly write in the bit they want written to the pin, without the use of BSRRs.
Once one of these operations is executed, the ODR sends connects to a multiplexer, which, in turn, connects to the output control. This will, in fact act as an inverter, as it will output a 0 if the input is 1, and output a 1 if the input is 0.
The output control connects to a pair of transistors which can be set to two modes aside from disabled - push-pull and open-drain.
When the output control is set to push-pull, it is connected to two transistors in an inverting setup. This allows it to flip the previously inverted values once again, thus allowing the output to be what was written in to the pin.
When the output is open-drain, the PMOS transistor is left floating, while the NMOS transistor is connected to a pull-up resistor. So, when

the output control writes a 0, the NMOS remains open, and is pulled up by the resistor. Otherwise, the NMOS closes and connects the output to ground.

The output is then set to the values defined by the previous section.

The speed at which the output value changes is known as slew rate, that is:

$$Slew_{Rate} = \max(\frac{\Delta V}{\Delta t})$$

Input Control

Input Control consists of a pull-up or pull-down resistor, and a Schmitt Trigger. The pull-up or pull-down resistor prevents the value being read from the IO pin from ever floating. The user must decide which of the two resistors they wish to enable.
The Schmitt Trigger acts as a buffer. It's purpose is to minimize the fluctuations of the input pin, as well as forcing the value to be a high or a low (like a comparator). It has two voltage values, which we can call V_{high} and V_{low}. When the input to the diode is greater than V_{high}, it toggles from low to high. When it is lower than V_{low}, it toggles from high to low. If this were not present, if the voltage were to fluctuate a lot around the toggle value, the voltage would keep on toggling between high and low, which would not be ideal.

Things to consider

A buffer, like the Schmitt Trigger, needs to have well defined inputs, that is, they should not be floating. To do this, there must be pull-up or pull-down resistors connected to the inputs, of values lower than the internal resistance of the buffer itself. Whether it is pull-up or pull-down is defined by what the input of the buffer is connected to by default. If it is connected to ground by default, then it needs a pull-up resistor, otherwise, it needs a pull-down resistor.
High resistance means slow adjustments of voltage, and are thus considered weak pull up or down resistors.

GPIO control

The functionality of GPIO pins is defined by writing different values to the GPIO control registers.
Note: to write something to a single bit in a register, we use "|=" for high, and "!(&=)" for low.

Interrupts

Interrupts are called by the peripherals when a predefined even occurs, this can be a timer overflowing, or a pin receiving data, among others.

There are three main parameters on interrupts: ISR, EN, Pri.

- ISR: Index of the routine, the lower the value, the higher the priority of the interrupt.
- EN: marks whether the interrupt is enabled, if it is not, it cannot be raised, and should thus not be considered.
- Pri: It is another method of indicating priority, and can override the priorities defined by the ISR.

Now that we know all these, we can understand how these behave. Let us say that the program is running in main and an interrupt is called. It will be marked as pending. The program will check if the priority of the pending interrupt is higher than the current running program (if it is main, then it will always be higher). If it is, the current state will be saved, and the program will execute the interrupt. This process is constantly executed, so, if higher priority interrupts are called during an interrupt, it will save once again, and address that interrupt again. If the interrupt being called is of lower priority than what is running at the given moment, it is marked as pending. When the interrupt finishes running, it will head to the interrupt with the highest priority that is pending. Once all the pending interrupts are addressed, the program returns to main.

Timers

Timers allow the microcontroller to execute things periodically.
Every clock cycle the program checks whether the value stored in the hardware counter is 0. If not, the value stored is decrease by 1, otherwise, it copies the reload value into the counter and raises an interrupt if enabled.
So, the interrupt is called every $(reload_{value} + 1) * clock_{period}$.
There also exist more general timers, which have an additional parameter, the prescaler, which changes the equation to:

$$reload_{value} = \frac{interrupt_{interval}}{clock_{period} * (prescaler + 1)}$$

as opposed to the equation for the system timer:

$$reload_{value} = \frac{interrupt_{interval}}{clock_{period}} - 1$$

DMA

DMA optimizes data copying/data movement. Normal copying requires the peripheral to write the data to the CPU, and then the CPU writes the data to the destination.

On the other hand DMA directly copies the data to the destination, without ever interacting with the CPU.
There are two kinds of DMA:

- Flow-Through: Connects to the DMA controller, and is then sent over. This is slower than fly-by, however, it simplifies the wiring. Used as long as the requirements for speed are not too stringent. It is also more convenient for cases where the destination and origin registers are of different sizes.
- Fly-By: Connects all the wires directly, making the space utilization worse, but speeding up the transfer speed considerably. Useful when read and write operations are executed in the same cycle.

DAC

If we base

$$DAC_{output} = V_{ref} \times \frac{Digital_{Value}}{2^N}$$

With default N = 12.
Digital Value is:

$$\sum_{i=0}^{N-1} 2^i \times DAC_{bit}[i]$$