Computer Labs: The i8254 Timer/Counter

2º MIEIC

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Lab 2: The PC's Timer/Counter - Part I

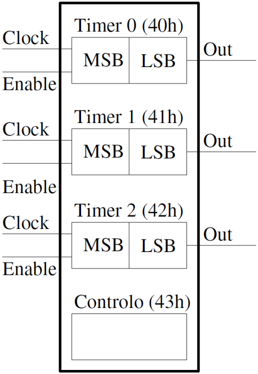
- Write a set of functions:

```
int timer_test_read_config(uint8_t timer,
                           enum timer_status_field field)
int timer_test_time_base(uint8_t timer, uint32_t freq)
```

  that require programming the PC's Timer/Counter
- These functions are at a high level for pedagogical reasons
  - The idea is that you design the lower level functions (with the final project in mind)
  - In this lab we have also defined the lower level functions
- What's new?
  - Program an I/O controller: the PC's timer counter (i8254)
  - Use interrupts (Part II)

The i8254

- It is a programmable timer/counter
  - Each PC has a functionally equivalent circuit, nowadays it is integrated in the so-called south-bridge
  - Allows to measure time in a precise way, independently of the processor speed



- It has 3 16-bit counters, each of which
  - May count either in binary or BCD
  - Has 6 counting modes
    - The counting mode determines how the `Out` pin changes with the value of the timer/counter

i8254 Counting Modes (4 of 6)

Mode 0 Interrupt on terminal count – for counting events

- `OUT` goes high and remains high when count reaches 0

Mode 1 Hardware retriggerable one-shot

- `OUT` goes low and remains low until count reaches 0, the counter is reloaded on a rising edge of the `ENABLE` input

Mode 2 Rate Generator (divide-by-N counter)

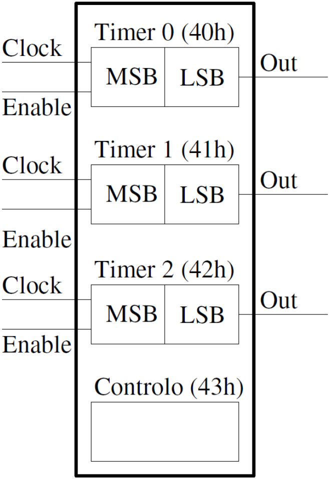
- `OUT` goes low for one clock cycle when count reaches 0, the counter is reloaded with its initial count afterwards, and ...

Mode 3 Square Wave Generator – for Lab 2

- Similar to mode 2, except for the duty-cycle: `OUT` will be high for half of the cycle and low for the remaining half of the cycle

Note In all modes, the counters perform a down count from a programmable initial counting value

i8254 Block Diagram



- Three independent 16-bit counters
  - Ports 40h, 41h and 42h
  - MSB and LSB addressable separately
  - Independent counting modes
  - Independent initial counting values
- An 8 bit-control register
  - Port `43h`
  - Programming of each counter independently

i8254 Control Word

- Used to program the timers, one at a time
- The control word must be written to the Control Register (`0x43`)
- The initial counting value must be written on the timer's port (one of `0x40, 0x41, 0x42`)
  - If programming the initial value of a single byte, the other byte will be initialized to 0

Bit	Value	Function
7,6		**Counter selection**
	00	0
	01	1
	10	2
5,4		**Counter Initialization**
	01	LSB
	10	MSB
	11	LSB followed by MSB
3,2,1		**Counting Mode**
	000	0
	001	1
	x10	2
	x11	3
	100	4
	101	5
0		**BCD**
	0	Binary (16 bits)
	1	BCD (4 digits)

i8254 Control Word: Example

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7,6		**Counter selection**
	00	0
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5,4		**Counter Initialization**
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3,2,1		**Counting Mode**
	000	0
	001	1
	x10	2
	x11	3
	100	4
	101	5
0		**BCD**
	0	Binary (16 bits)
	1	BCD (4 digits)

Example

- Timer 2 in mode 3
- Binary counting
- Initial counting value: 1234 = 0x04D2

Control Register: `10110110`

- "**NOTE:** Don't care bits (X) should be 0 to insure compatibility with future Intel products."

Timer2 LSB `0xD2`

Timer2 MSB `0x04`

How to assemble the control word?

How to assemble the control word?

Use bitwise operations

Use the macros defined in i8254.h

i8254: Read-Back Command

The command

- Allows to retrieve
  - the programmed configuration
  - and/or the current counting value

  of one or more timers
  - The bars over COUNT and STATUS means that these bits are active in 0
- Written to the Control Register (`0x43`)

Read-Back Command Format

Bit	Value	Function
7,6		**Read-Back Command**
	11	
5		$\overline{\text{COUNT}}$
	0	Read counter value
4		$\overline{\text{STATUS}}$
	0	Read programmed mode
3		**Select Timer 2**
	1	Yes
2		**Select Timer 1**
	1	Yes
1		**Select Timer 0**
	1	Yes
0		**Reserved**

Reading of the status/count

- The configuration (status) is read from the timer's data register
  - The 6 LSBs match those of the Control Word

Read-Back Status Format

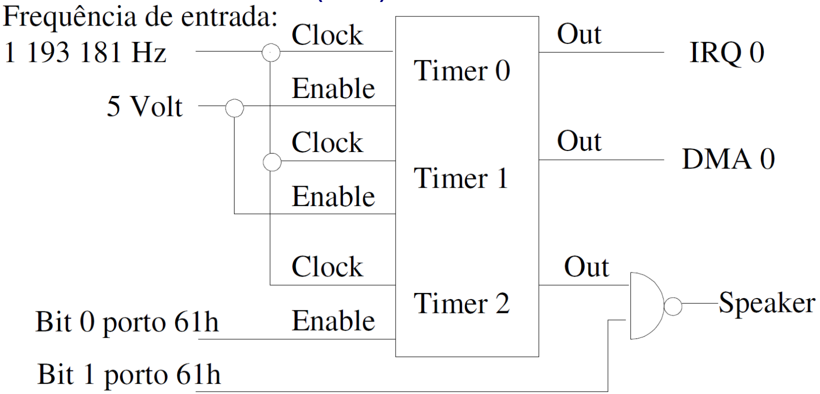
Bit	Value	Function
7		**Output**
6		**Null Count**
5,4		**Counter Initialization**
3,2,1		**Programmed Mode**
0		**BCD**

How to parse the the status word?

Use bitwise operations

Use the macros defined in i8254.h

i8254: Use in the PC (1/2)



- Timer 0 is used to provide a time base.
- Timer 1 is used for DRAM refresh
  - Via DMA channel 0

  (Not sure this is still true.)
- Timer 2 is used for tone generation

i8254: Use in the PC (2/2)

- The i8254 is mapped in the I/0 address space:

```
Timer 0:           0x40
Timer 1:           0x41
Timer 2:           0x42
Control Register:  0x43
```

- Need to use `IN/OUT` assembly instructions
  - Minix 3 provides the `SYS_DEVIO` kernel call for doing I/O

```
#include <minix/syslib.h>

int sys_inb(int port, u32_t *byte);
int sys_outb(int port, u32_t byte);
```

  - **Note** that the second argument of `sys_inb()` must be the address of a 32-bit unsigned integer variable.
  - **Hint** (must) implement

```
util_sys_inb(int port, u8_t *byte)
```

    - This is a wrapper to `sys_inb()`
    - You can use it thereafter instead of `sys_inb()`
- Need to write to the control register before accessing any of the timers
  - Both to program (control word) a timer, or to read its configuration (read-back command)

Minix 3 and Timer 0

- At start up, Minix 3 programs Timer 0 to generate a square wave with a fixed frequency
  - Timer 0 will generate an interrupt at a fixed rate:
    - Its output is connected to `IRQ0`
- Minix 3 uses these interrupts to measure time
  - The interrupt handler increments a global variable on every interrupt
  - The value of this variable increments at a fixed, known, rate
- Minix 3 uses this variable mainly for:
  - Keeping track of the date/time
  - Implementing SW timers

Lab 2: Part 1 - Reading Timer Configuration (1/2)

What to do? Read timer configuration in Minix

```
int timer_test_read_config(uint8_t timer,
                              enum timer_status_field field)
```

1. Write read-back command to read input timer configuration:
   - Make sure 2 MSBs are both 1
   - Select only the status (not the counting value)
     - Remember, these are active low, i.e.when the bit value is 0
2. Read the timer port
3. Parse the configuration read
4. Call the function `timer_print_config()` that **we provide you**

How to design it? Try to develop an API that can be used in the project.

```
int timer_get_conf(uint8_t timer, uint8_t *st);
int timer_display_conf(uint8_t timer, uint8_t st,
                           enum timer_status_field status);
```

Lab 2: Part 1 - Reading Timer Configuration (2/2)

Stuff we provide you

```
int timer_print_config(uint8_t timer,
                       enum timer_status_field field,
                       union timer_status_field_val val);
enum timer_status_field  {
    tsf_all,       // configuration in hexadecimal
    tsf_initial,   // timer initialization mode
    tsf_mode,      // timer counting mode
    tsf_base       // timer counting base
};
enum timer_init {
    INVAL_val,
    LSB_only,
    MSB_only,
    MSB_after_LSB
};
union timer_status_field_val {
    uint8_t          byte;        // status, in hexadecimal
    enum timer_init in_mode;      // initialization mode
    uint8_t          count_mode;  // counting mode: 0, 1, ..., 5
    bool             bcd;         // true, if counting in BCD
};
```

C Enumerated Types

- This is a user-defined type that can take one of a finite number of values

```
enum timer_status_field  {
    tsf_all,       // configuration in hexadecimal
    tsf_iniital,   // timer initialization mode
    tsf_mode,      // timer counting mode
    tsf_base       // timer counting base
};
enum timer_status_field info = base;
```

  - The C compiler represents each possible value of an enumerated type by an integer value. By default:
    - The first value is represented with 0
    - Any other value, is one more than the previous value
  - However, it is possible to assign to an enumerated value an integer value different from the default (e.g. `all = 255;`)
  - The names of the members of an enumerated type have global scope
    - To avoid collisions we use the `tsf_` prefix
- The use of enumerated types makes the code more readable

C Unions

- Syntatically, a union data type appears like a struct:

```
union timer_status_field_val {
    uint8_t          byte;       // status, in hexadecimal
    enum timer_init in_mode;     // initialization mode
    uint8_t          count_mode; // counting mode: 0, 1, ...,
    bool             bcd;        // true, if counting in BCD
};
```

  - Access to the members of a union is via the dot operator

- However, semantically, there is a big difference:

  Union contains space to store **any** of its members, but **not all** of its members simultaneously

  - The name **union** stems from the fact that a variable of this type can take values of **any** of the types of its members

  Struct contains space to store **all** of its members simultaneously

In `timer_print_config()` we are using it to reduce the number of arguments passed

- But need another argument the kind of information passed

Lab 2: Part 1 - Setting the Time-Base (1/2)

What to do? Before the LCF, change the rate at which a Timer 0 generates interrupts.

- With the LCF, changed to allow specifying the timer, and thus fully test the more general `timer_set_frequency()` (see below)

```
int timer_test_time_base(uint8_t timer, uint32_t freq)
```

1. Write control word to configure Timer 0:
   - **Do not change 4 least-significant bits**
     - Mode (3)
     - BCD/Binary counting

     You need to read the Timer 0 configuration first.
   - Preferably, LSB followed by MSB
2. Load Timer 0 with the value of the divisor to generate the frequency corresponding to the desired rate
   - Depends on the previous step
   - Remember that the frequency of the `Clock` input of all timers is 1 193 181 Hz

Lab 2: Part 1 - Setting the Time-Base (2/2)

How to design it? Try to develop an API that can be used in the project.

```
int timer_set_frequency(uint8_t timer, uint32_t freq);
```

How do we know it works? Use the `date` command.

Minix 3 programs Timer 0 to generate interrupts at a fixed rate (60 Hz) at boot-time and assumes that rate is not changed thereafter

- By programming a different rate, Minix 3 will measure time incorrectly. E.g. with a 30 Hz rate ...
- Or, even better, use the test code provided.

Lab 2: Grading Criteria

SVN (5%) Whether or not your code is in the right place (under `lab2/`, of the repository's root)

- Also, evidence of incremental development approach

Execution (80%) Including automatic code grading.

Code (15%)

return values of function/kernel calls must be checked

global variables only if you cannot do what you want, or if they can be considered fields/members of an object (if using object oriented design)

symbolic constants i.e. use `#define`

modularity both at the level of functions and **at the level of files**

Self-evaluation **Must submit** it by filling a Google Form (check the handout)

IMPORTANT Please follow exactly the instructions, otherwise you may be penalized

Further Reading

- Lab 2 Handout
- i8254 Data-sheet