Lecture7: ATMega 2650 Datasheet and 16 bit timer

Vikram Iyer

Adapted from material by Blake Hannaford

Monday	Tuesday	Wednesday	Thursday	Friday
15 9:30-11:30 OH (Deeksha) ECE 345 11:30-13:30 OH (Alex) ECE 345	16 13:00-15:00 OH (Zach) ECE 345	17 9:30-11:30 OH (Deeksha) ECE 345 12:00-13:00 Remote OH (Vikram) Zoom	18 10:00-12:00 OH (Zach) ECE 345 12:30-14:30 OH (Alex) ECE 345 23:59 Lab 1 due	19 12:30-14:20 Lecture MOR 230 *Lecture 7: ATMega 2560 Datasheet and Timers* 14:00-15:00 OH (Vikram) ECE 345
22 9:30-11:30 OH (Deeksha) ECE 345 11:30-13:30 OH (Alex) ECE 345	23 13:00-15:00 OH (Zach) ECE 345	24 9:30-11:30 OH (Deeksha) ECE 345 12:30-14:20 Lecture MOR 230 *Lecture 8: Reading Analog Data and Intro to Interrupts* 14:00-15:00 OH (Vikram) ECE 345	25 10:00-12:00 OH (Zach) ECE 345 12:30-14:30 OH (Alex) ECE 345 23:59 C Programming 2 due	26 12:30-14:20 Lecture MOR 230 *Lecture 9: Tasks, Threads, Scheduling I, Interrupts* 14:00-15:00 OH (Vikram) ECE 345
29 9:30-11:30 OH (Deeksha) ECE 345 11:30-13:30 OH (Alex) ECE 345	30 13:00-15:00 OH (Zach) ECE 345	01 9:30-11:30 OH (Deeksha) ECE 345 12:30-14:20 Lecture MOR 230 *Lecture 10: Scheduling II* 14:00-15:00 OH (Vikram) ECE 345	02 10:00-12:00 OH (Zach) ECE 345 12:30-14:30 OH (Alex) ECE 345 23:59 Lab 2 due	03 12:30-14:20 Lecture MOR 230 *Lecture 11: Scheduling III and Lab 3 Intro* 14:00-15:00 OH (Vikram) ECE 345

May

Monday	Tuesday	Wednesday	Thursday	Friday
06 9:30-11:30 OH (Deeksha) ECE 345 11:30-13:30 OH (Alex) ECE 345	07 13:00-15:00 OH (Zach) ECE 345	08 9:30-11:30 OH (Deeksha) ECE 345 12:30-14:20 Lecture MOR 230 *Lecture 12: Midterm Review* 14:00-15:00 OH (Vikram) ECE 345	09 10:00-12:00 OH (Zach) ECE 345 12:30-14:30 OH (Alex) ECE 345	10 12:30-14:00 Midterm

Structures (structs) in C

Structs are a way to group several related variables into one place. Each variable in the structure is known as a **member** of the structure. Unlike an array, a structure can contain many different data types (int, float, char, etc.).

```
struct MyStructure {   // Structure declaration
  int myNum;           // Member (int variable)
  char myLetter;       // Member (char variable)
}; // End the structure with a semicolon
```

```
s1.myNum = 13;
// Print values
printf("My number: %d\n", s1.myNum);
```

Assignments

- Programming assignment 2
  - Bit manipulation, more pointer practice, intro to structs
  - Tried to incorporate feedback from assignment 1 and fix bugs
  - Meant to be fairly straightforward, more practice in C

- Lab 2
  - Longer than Lab 1, get started early
  - After today we'll have covered material for Part 1 and 2
  - Material will be in next couple of lectures

Last time

- MPU6050 demo
  - What is an IMU and how does it work?
  - Reading datasheets
  - Demo of reading and writing registers to control sensor

Plan for today

- Walk through ATMega datasheet
  - Point out where to look for documentation in lab 2
- Details of 16 bit timer counter

Plan for today

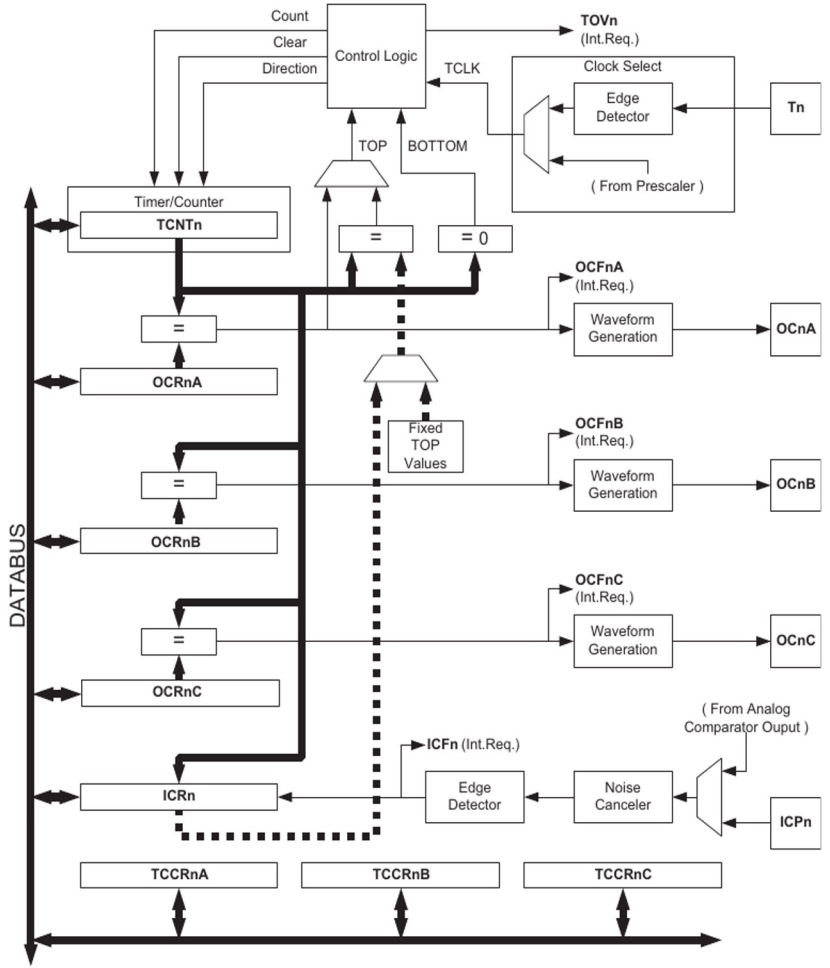
- Walk through ATMega datasheet
  - Point out where to look for documentation in lab 2
- Details of 16 bit timer counter

ATMega2650 Datasheet

16-bit Timer/Counter

Block Diagram

Figure 17-1. 16-bit Timer/Counter Block Diagram[1]



16-bit Timer/Counter

Block Diagram

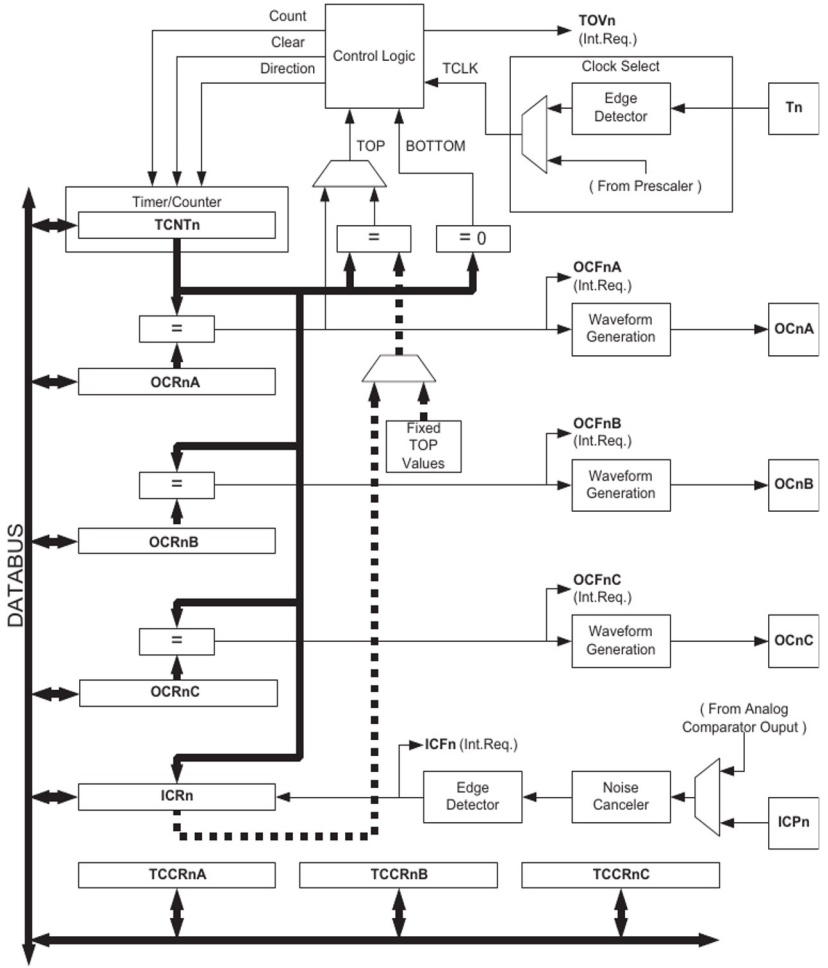
Key terms:

“**TOP**” -- user programable

“**MAX**” -- 0xFFFF (65535)

“**BOTTOM**” -- 0x0000

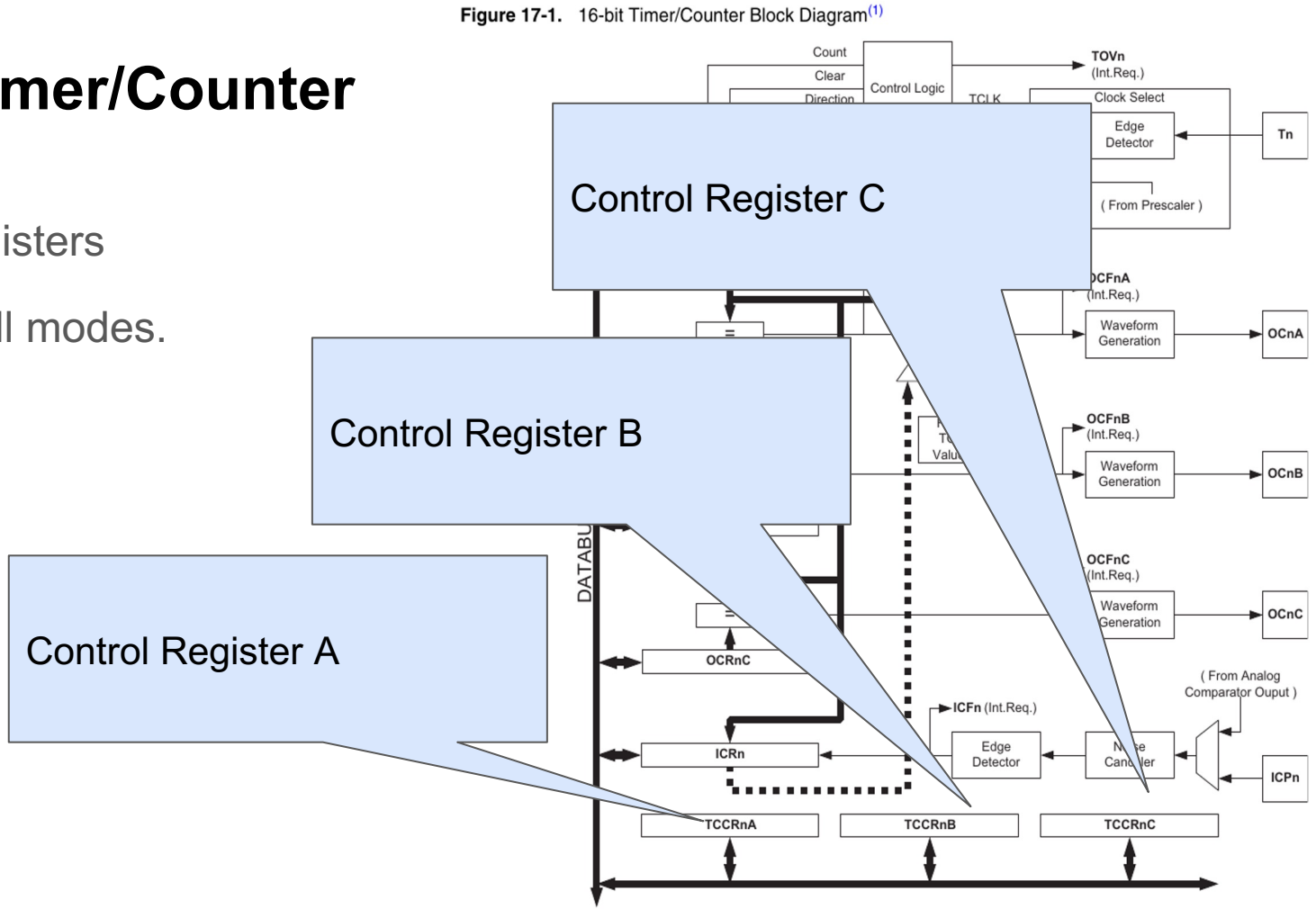
Figure 17-1. 16-bit Timer/Counter Block Diagram[1]



16-bit Timer/Counter

Control Registers

Configure all modes.



16-bit Timer/Counter

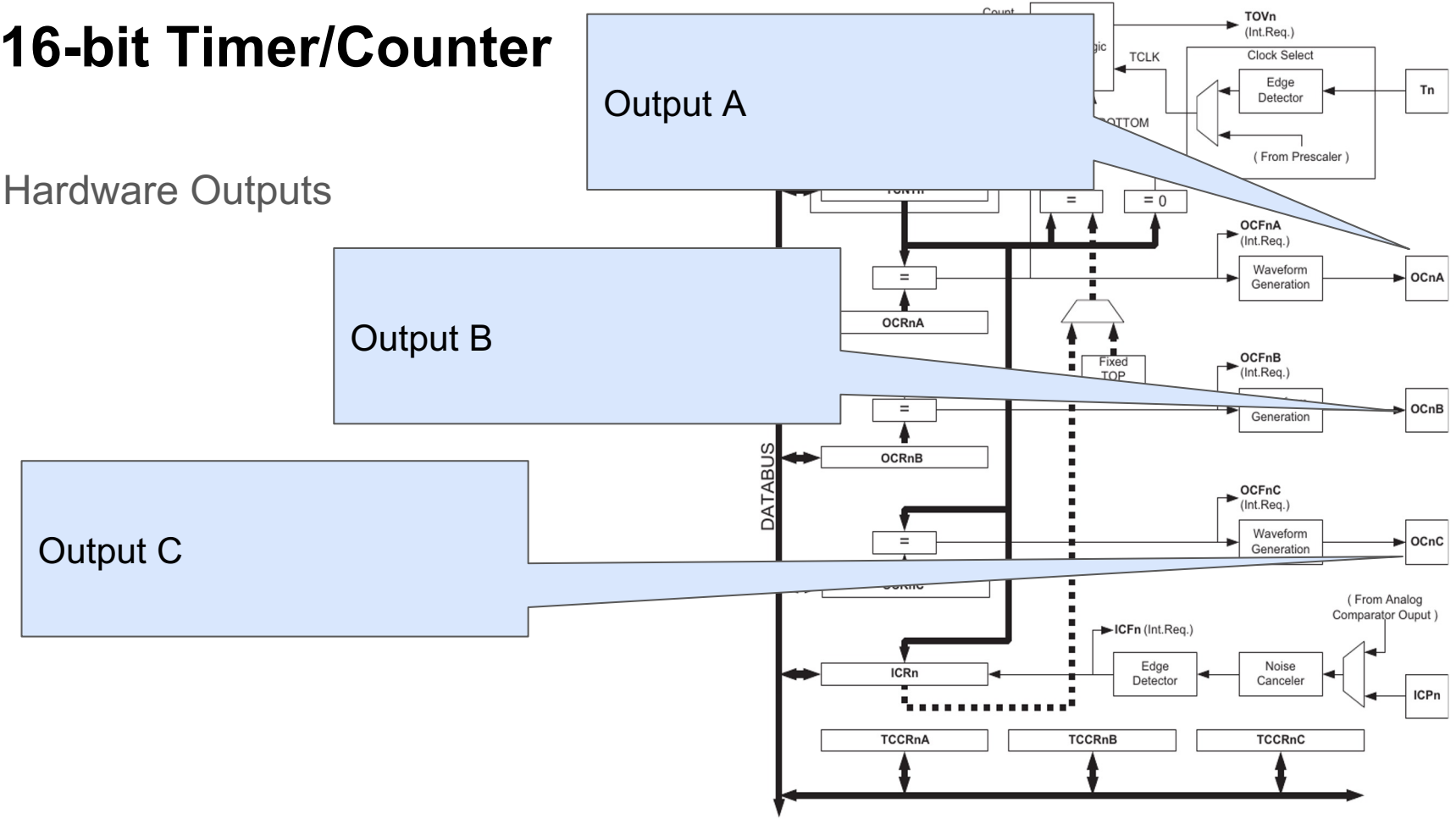
Hardware Outputs

Output A

Output B

Output C

Figure 17-1. 16-bit Timer/Counter Block Diagram(1)



16-bit Timer/Counter

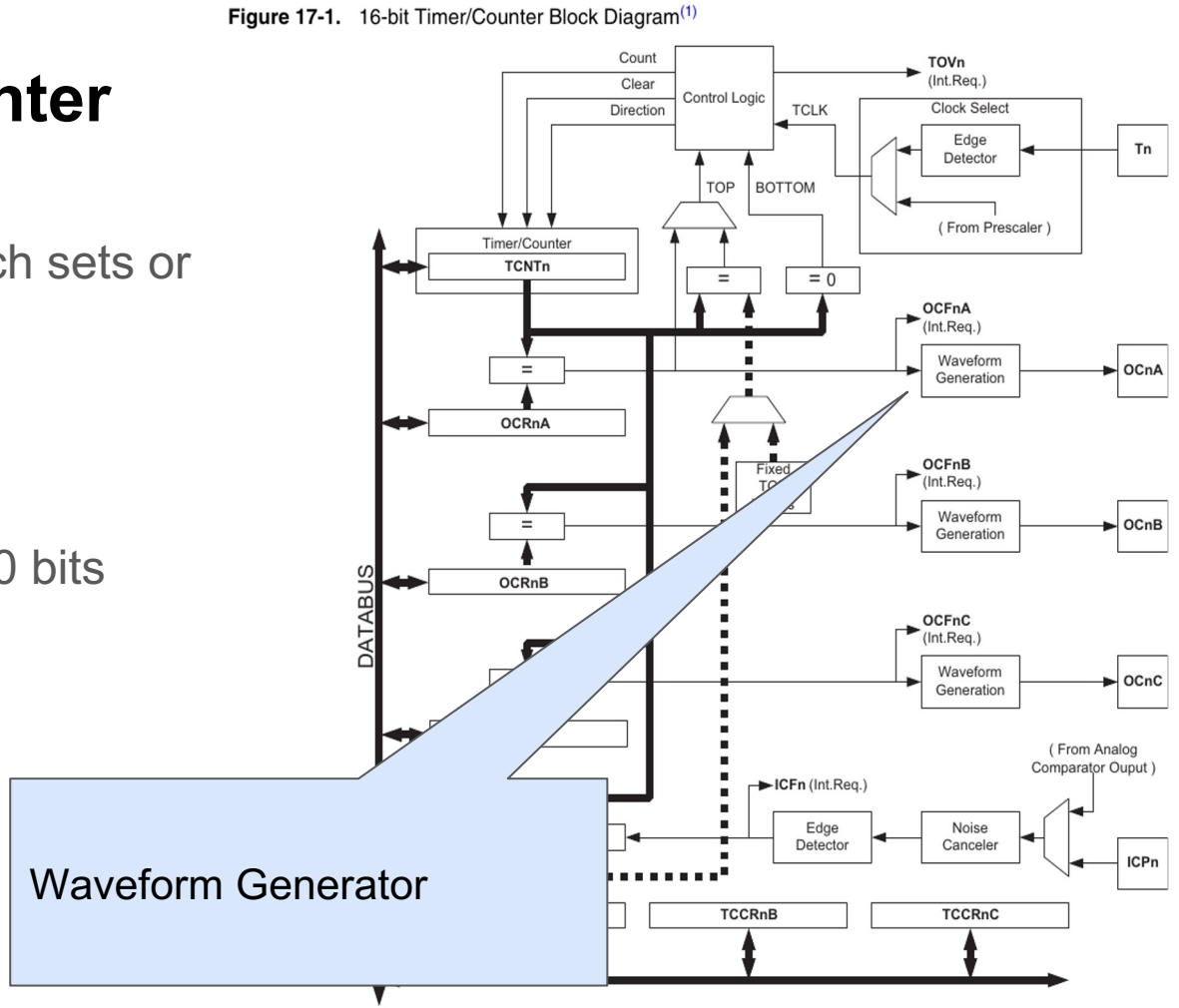
Combinatorial circuit which sets or clears the output pin.

Inputs:

- Match
- WGMn3:0 COMnx1:0 bits
- TOP, BOTTOM

Actions:

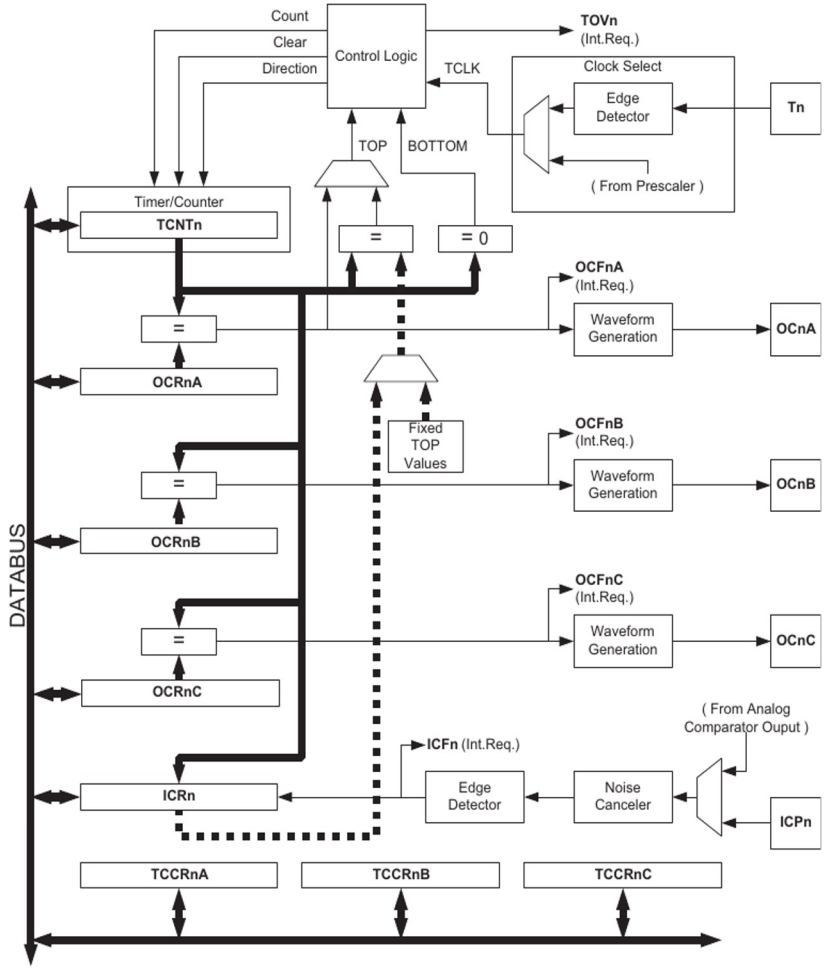
- Set, Clear, Toggle



16-bit Timer/Counter

Block Diagram

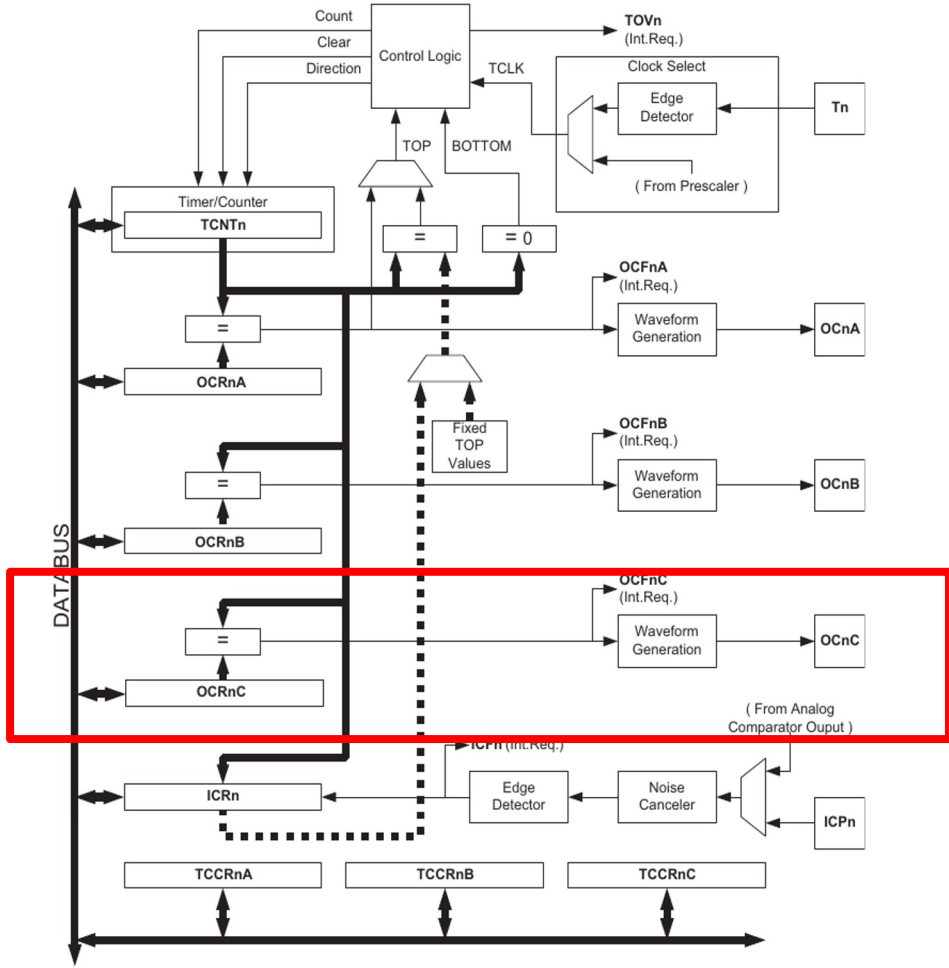
Figure 17-1. 16-bit Timer/Counter Block Diagram[1]



16-bit Timer/Counter

Block Diagram

Figure 17-1. 16-bit Timer/Counter Block Diagram[1]

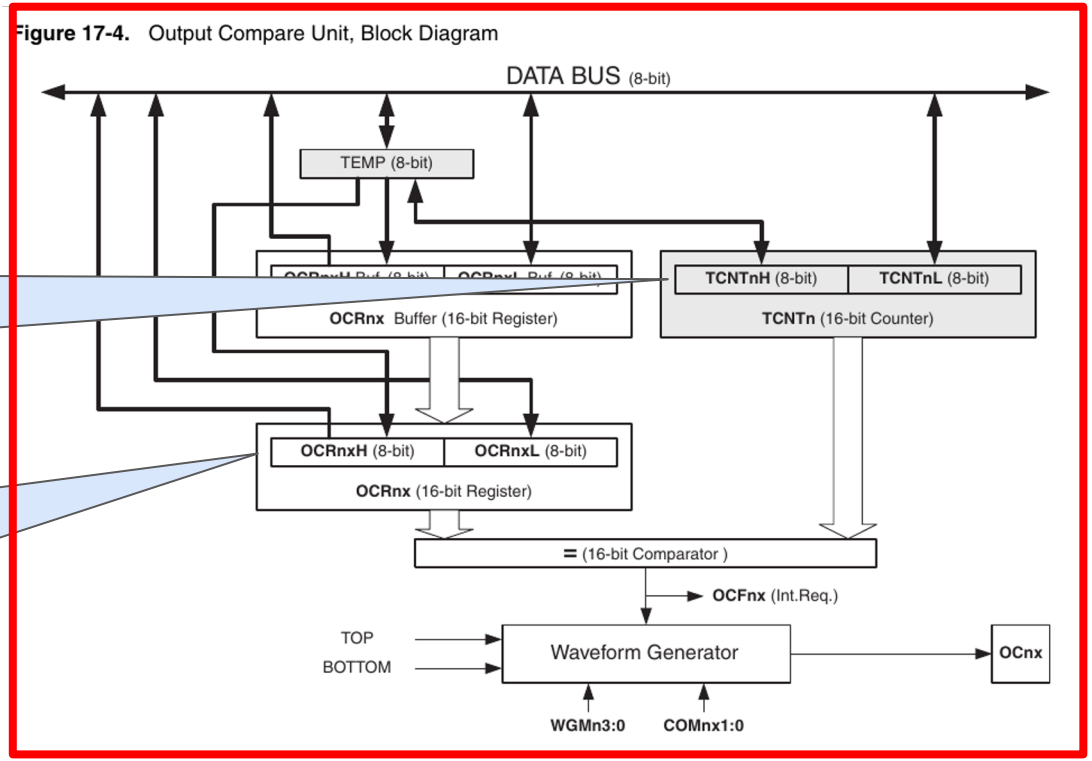


Output Compare Unit

Expanded Block Diagram

Current Counter Value

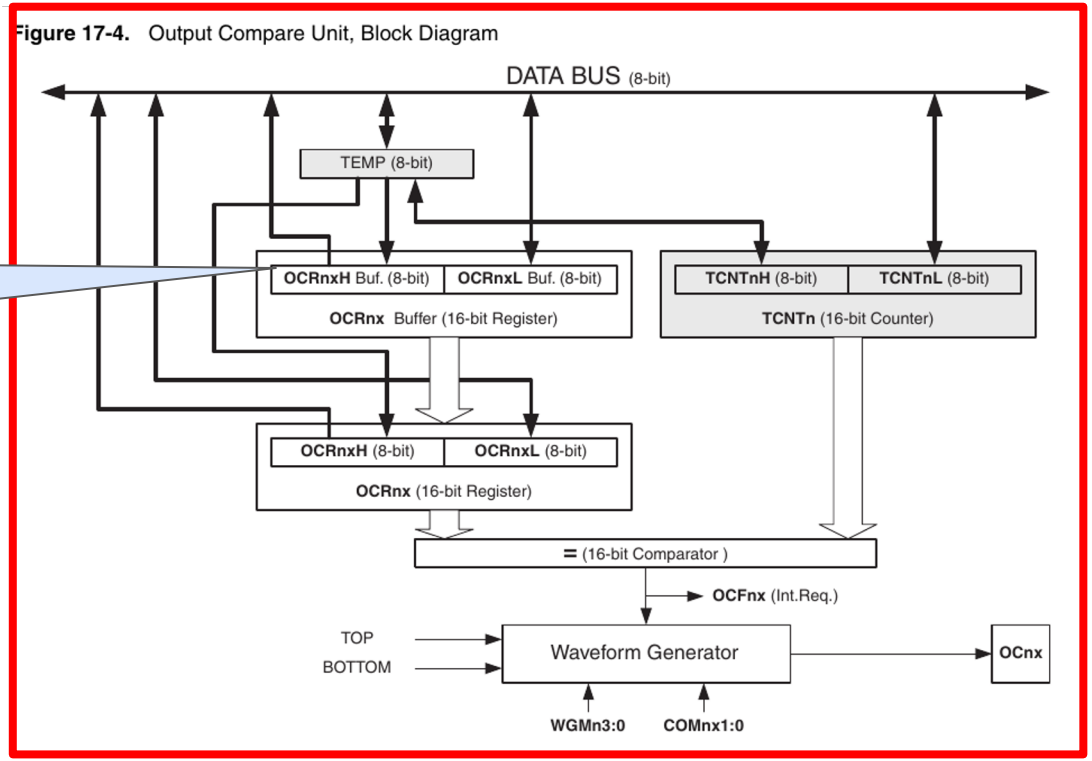
Compare Value



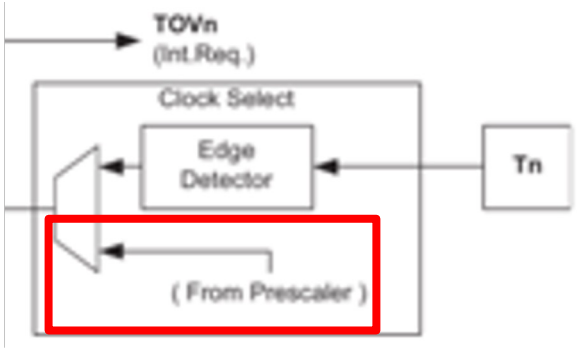
Output Compare Unit

Expanded Block Diagram

Local Counter Reset Value



Clock and Pre-scaler



Internal clock = 16MHz (Period = 62.5ns)

- Can also count external events
- Can divide the clock by 1, 8, 64, 256, or 1024

	A	B	C	D	E	F	G	H	I
1				16-bit			8-bit		
2		**Freq (Hz)**	**Period (msec)**	**Max Time (sec)**	**Min Freq (Hz)**	**Max Freq (Hz)**	**Max Time (sec)**	**Min Freq (Hz)**	**Max Freq (Hz)**
3	**prescale**	16,000,000	0.0000625	0.0041	488.3	8,000,000.00	0.00002	125000.0	8,000,000.00
4	**8**	2,000,000	0.0005	0.0328	61.0	1,000,000.00	0.00013	15625.0	1,000,000.00
5	**64**	250,000	0.004	0.2621	7.6	125,000.00	0.00102	1953.1	125,000.00
6	**256**	62,500	0.016	1.0486	1.9	31,250.00	0.00410	488.3	31,250.00
7	**1024**	15,625	0.064	4.1943	0.5	7,812.50	0.01638	122.1	7,812.50
8									

Assuming Toggle Mode

16-bit Timer MODES

Table 17-2. Waveform Generation Mode Bit Description(1)

Mode	WGMn3	WGMn2 (CTCn)	WGMn1 (PWMn1)	WGMn0 (PWMn0)	Timer/Counter Mode of Operation	TOP	Update of OCRnx at	TOVn Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCRnA	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICRn	BOTTOM	BOTTOM
9	1	0	0	1	PWM,Phase and Frequency Correct	OCRnA	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICRn	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCRnA	TOP	BOTTOM
12	1	1	0	0	CTC	ICRn	Immediate	MAX
13	1	1	0	1	(Reserved)	–	–	–
14	1	1	1	0	Fast PWM	ICRn	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCRnA	BOTTOM	TOP

Note: 1. The CTCn and PWMn1:0 bit definition names are obsolete. Use the WGMn2:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

For detailed timing information refer to "Timer/Counter Timing Diagrams" on page 152.

16-bit Timer MODES

"Normal"

Count up to 0xFFFF (MAX)

Table 17-2. Waveform Generation Mode Bit Description(1)

Mode	WGMn3	WGMn2 (CTCn)	WGMn1 (PWMn1)	WGMn0 (PWMn0)	Timer/Counter Mode of Operation	TOP	Update of OCRnx at	TOVn Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCRnA	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICRn	BOTTOM	BOTTOM
9	1	0	0	1	PWM,Phase and Frequency Correct	OCRnA	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICRn	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCRnA	TOP	BOTTOM
12	1	1	0	0	CTC	ICRn	Immediate	MAX
13	1	1	0	1	(Reserved)	–	–	–
14	1	1	1	0	Fast PWM	ICRn	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCRnA	BOTTOM	TOP

Note: 1. The CTCn and PWMn1:0 bit definition names are obsolete. Use the WGMn2:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

For detailed timing information refer to "Timer/Counter Timing Diagrams" on page 152.

16-bit Timer MODES

CTC (Clear Timer on Compare Match)

Table 17-2. Waveform Generation Mode Bit Description(1)

Mode	WGMn3	WGMn2 (CTCn)	WGMn1 (PWMn1)	WGMn0 (PWMn0)	Timer/Counter Mode of Operation	TOP	Update of OCRnx at	TOVn Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCRnA	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICRn	BOTTOM	BOTTOM
9	1	0	0	1	PWM,Phase and Frequency Correct	OCRnA	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICRn	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCRnA	TOP	BOTTOM
12	1	1	0	0	CTC	ICRn	Immediate	MAX
13	1	1	0	1	(Reserved)	–	–	–
14	1	1	1	0	Fast PWM	ICRn	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCRnA	BOTTOM	TOP

Note: 1. The CTCn and PWMn1:0 bit definition names are obsolete. Use the WGMn2:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

For detailed timing information refer to "Timer/Counter Timing Diagrams" on page 152.

16-bit Timer MODES

CTC (Clear Timer on Compare Match)

Count up to OCRnA (user value)

Set, Clear, or Toggle Output on match (COMnA1:0)

Table 17-2. Waveform Generation Mode Bit Description(1)

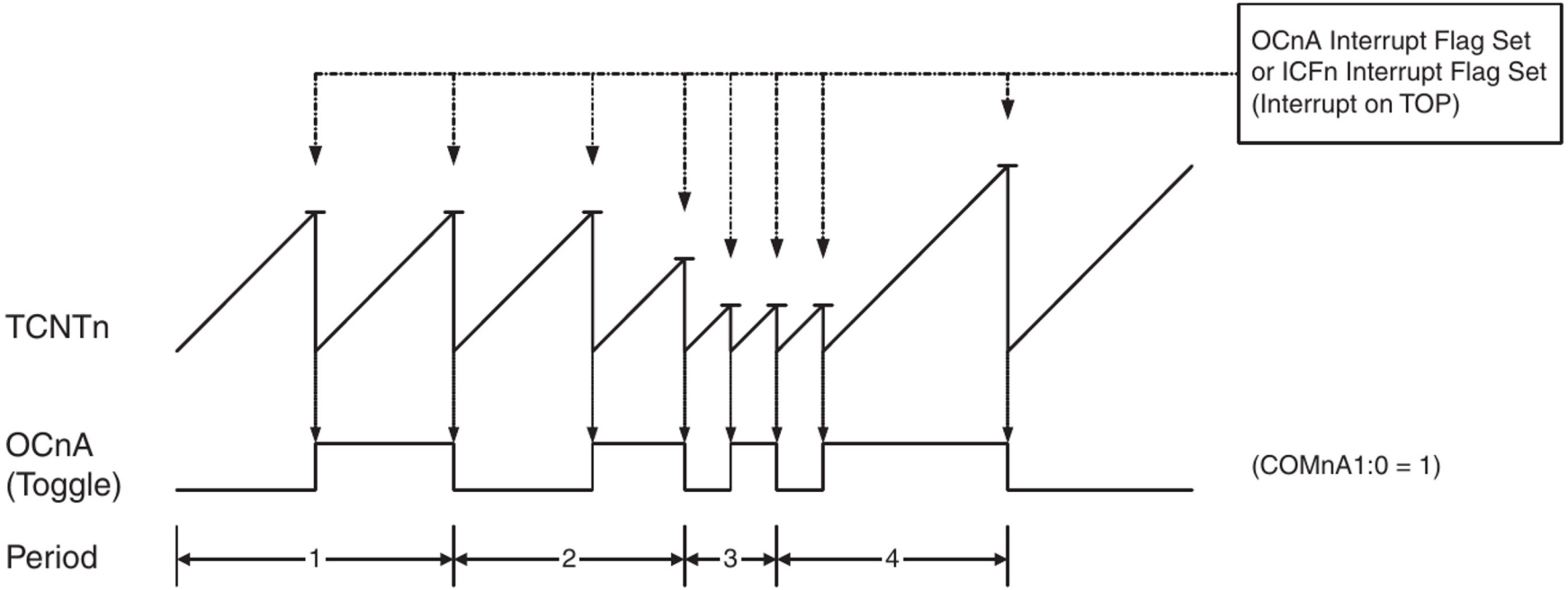
Mode	WGMn3	WGMn2 (CTCn)	WGMn1 (PWMn1)	WGMn0 (PWMn0)	Timer/Counter Mode of Operation	TOP	Update of OCRnx at	TOVn Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCRnA	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICRn	BOTTOM	BOTTOM
9	1	0	0	1	PWM,Phase and Frequency Correct	OCRnA	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICRn	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCRnA	TOP	BOTTOM
12	1	1	0	0	CTC	ICRn	Immediate	MAX
13	1	1	0	1	(Reserved)	–	–	–
14	1	1	1	0	Fast PWM	ICRn	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCRnA	BOTTOM	TOP

Note: 1. The CTCn and PWMn1:0 bit definition names are obsolete. Use the WGMn2:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

For detailed timing information refer to "Timer/Counter Timing Diagrams" on page 152.

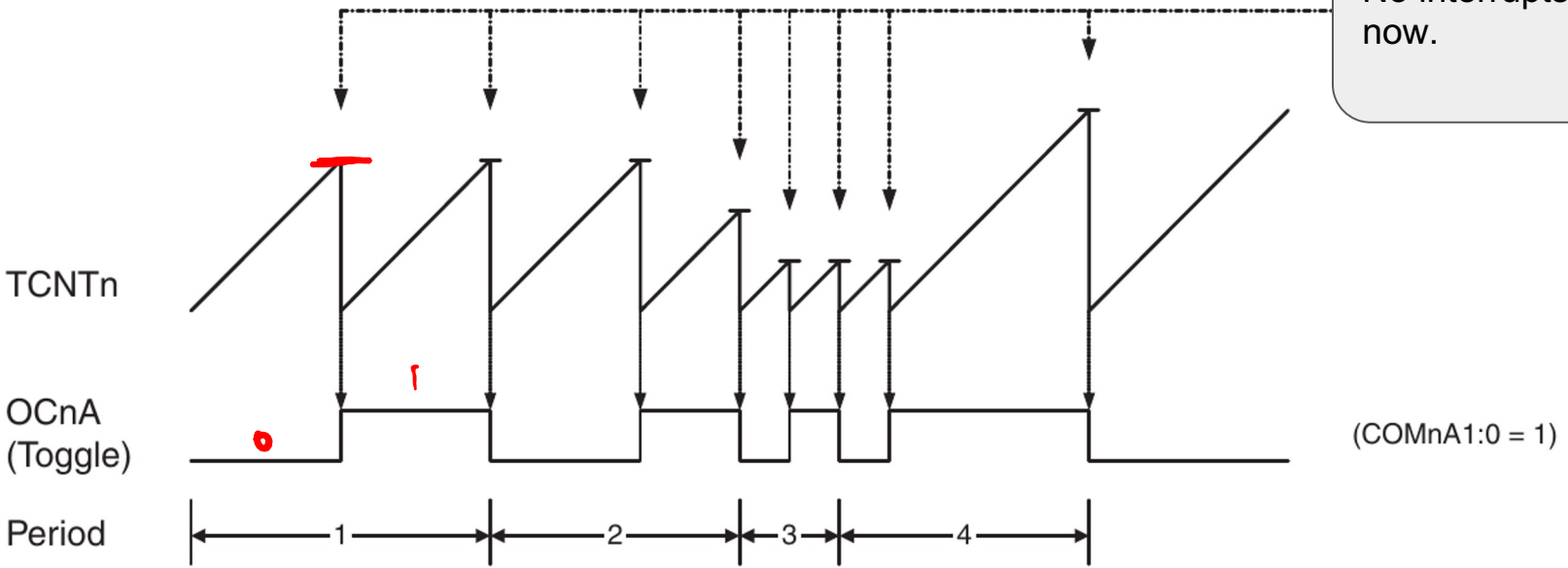
CTC Mode

Figure 17-6. CTC Mode, Timing Diagram



CTC Mode

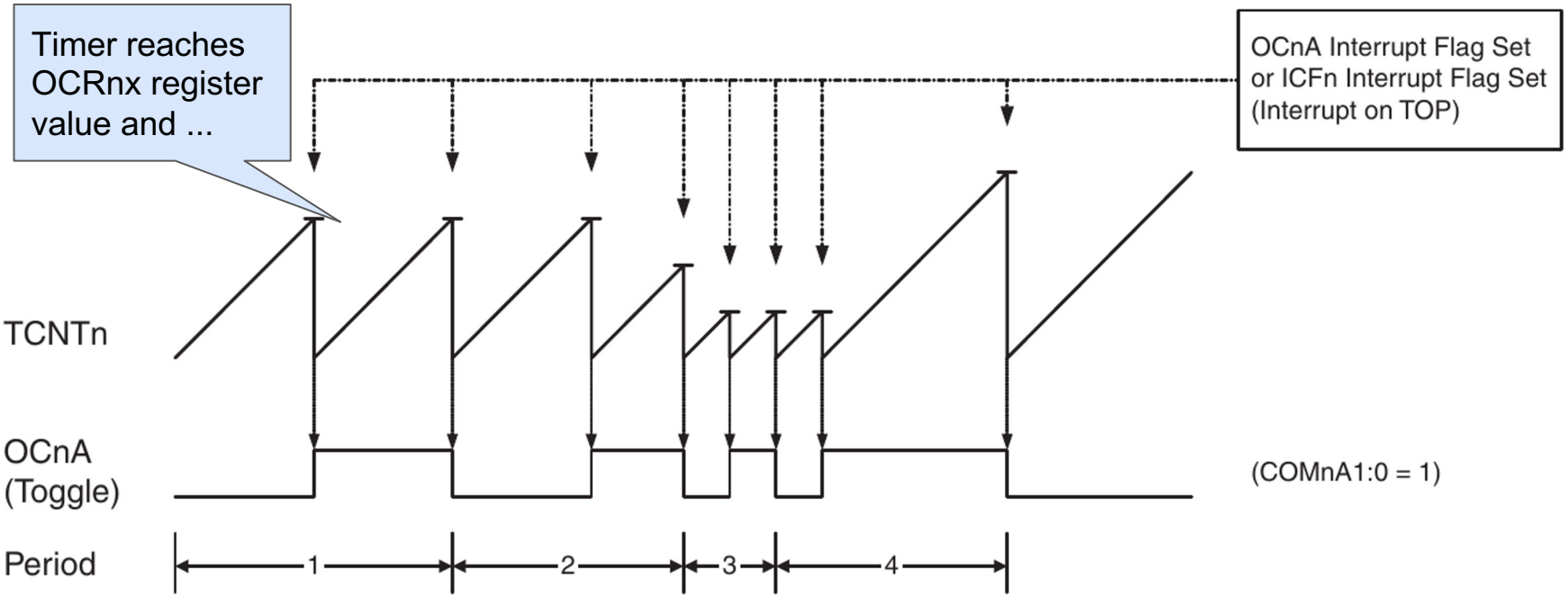
Figure 17-6. CTC Mode, Timing Diagram



No interrupts for now.

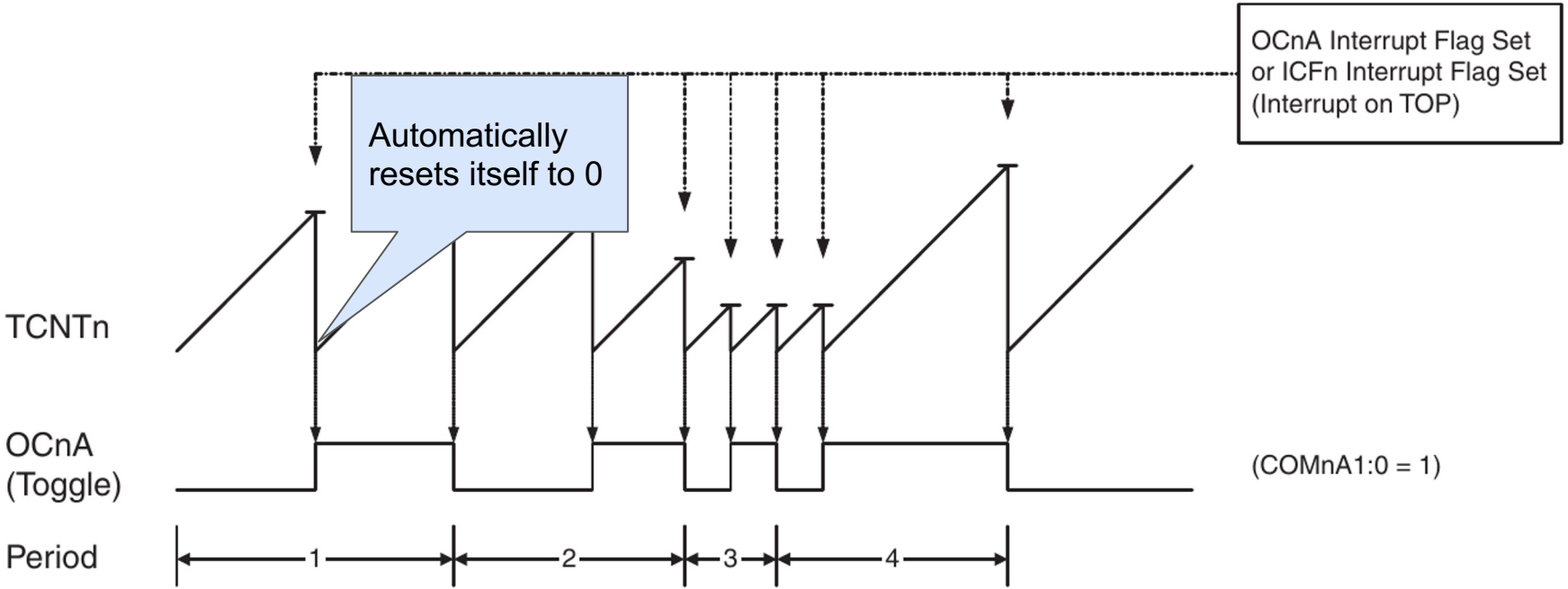
CTC Mode

Figure 17-6. CTC Mode, Timing Diagram



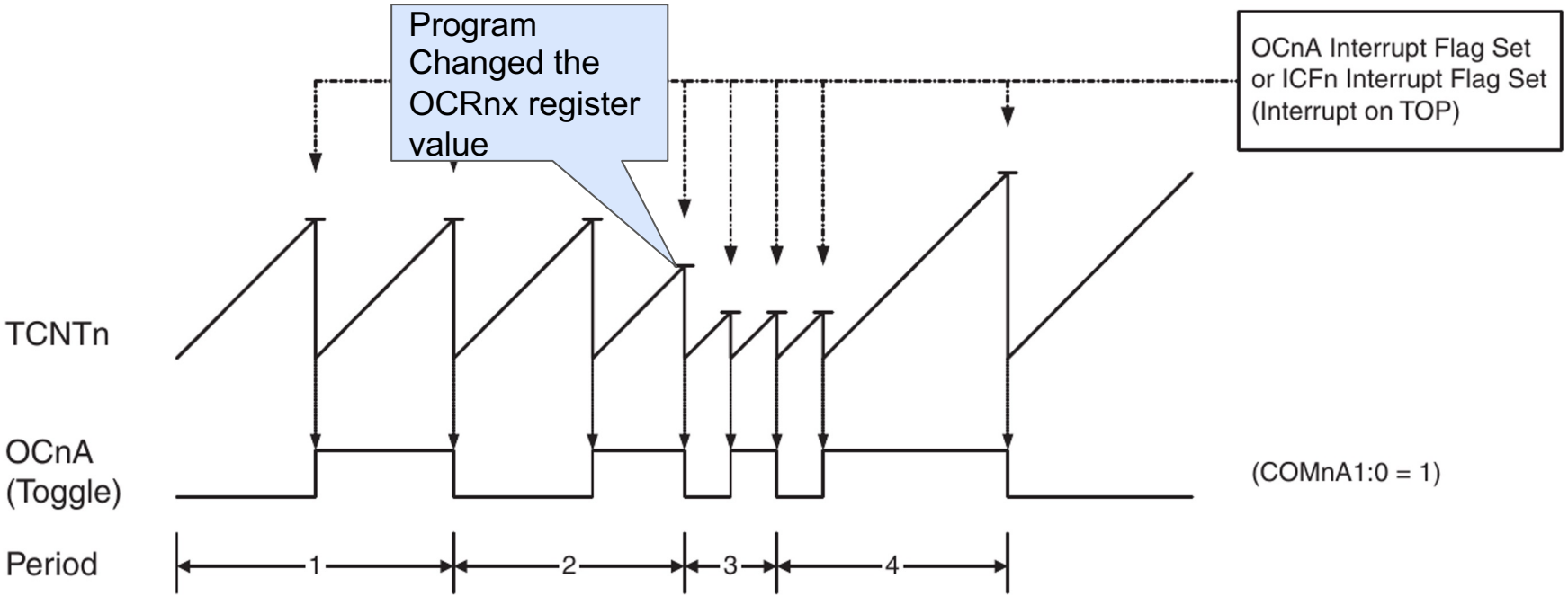
CTC Mode

Figure 17-6. CTC Mode, Timing Diagram



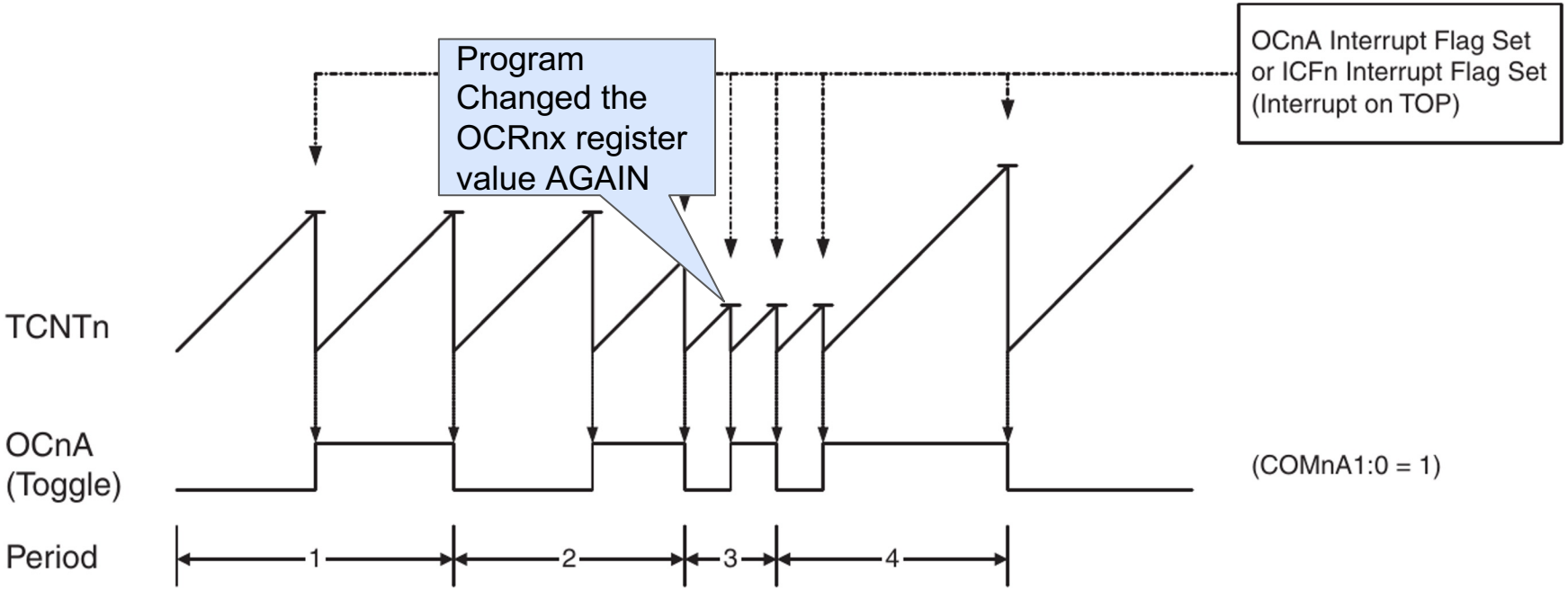
CTC Mode

Figure 17-6. CTC Mode, Timing Diagram



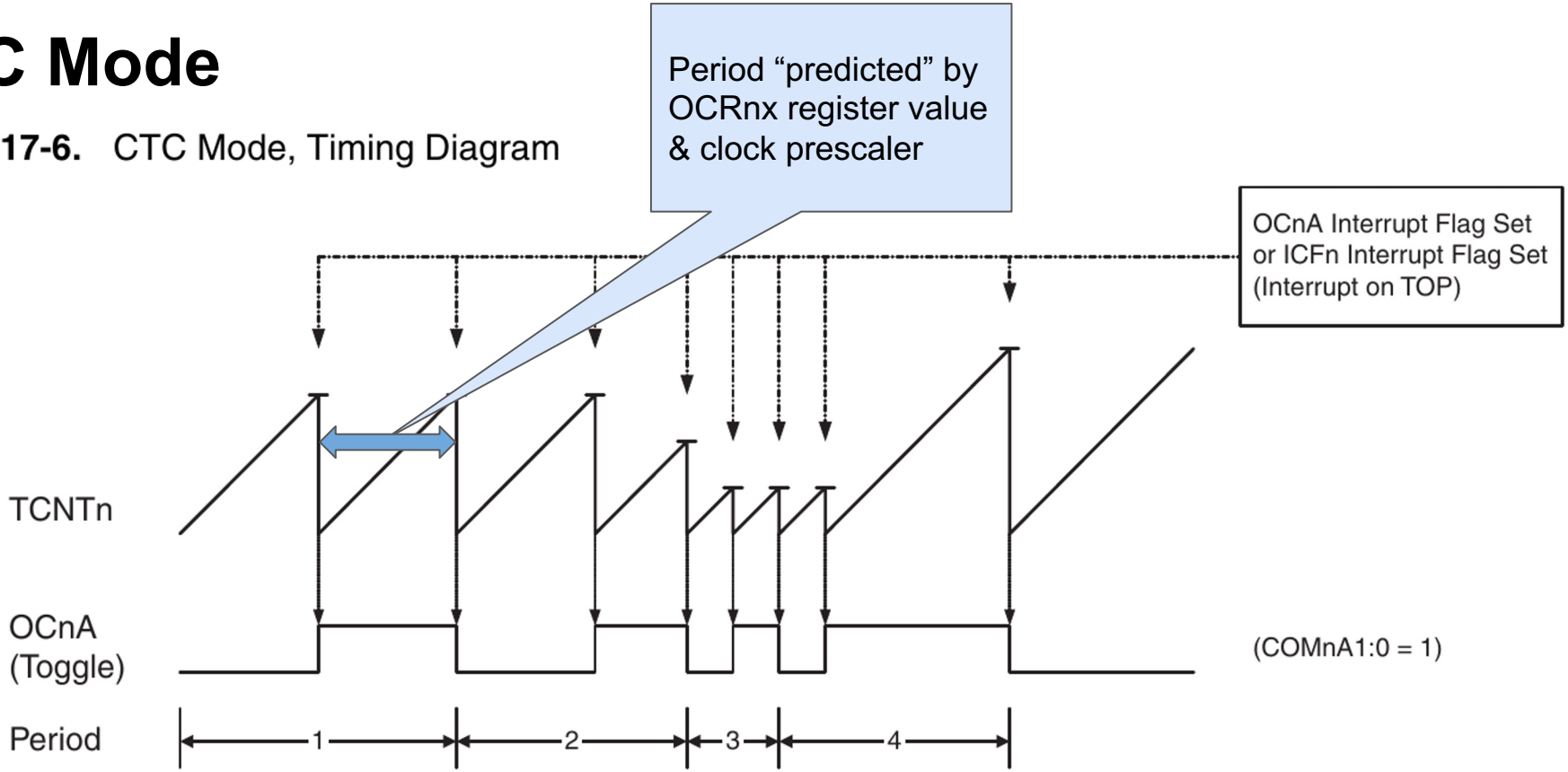
CTC Mode

Figure 17-6. CTC Mode, Timing Diagram



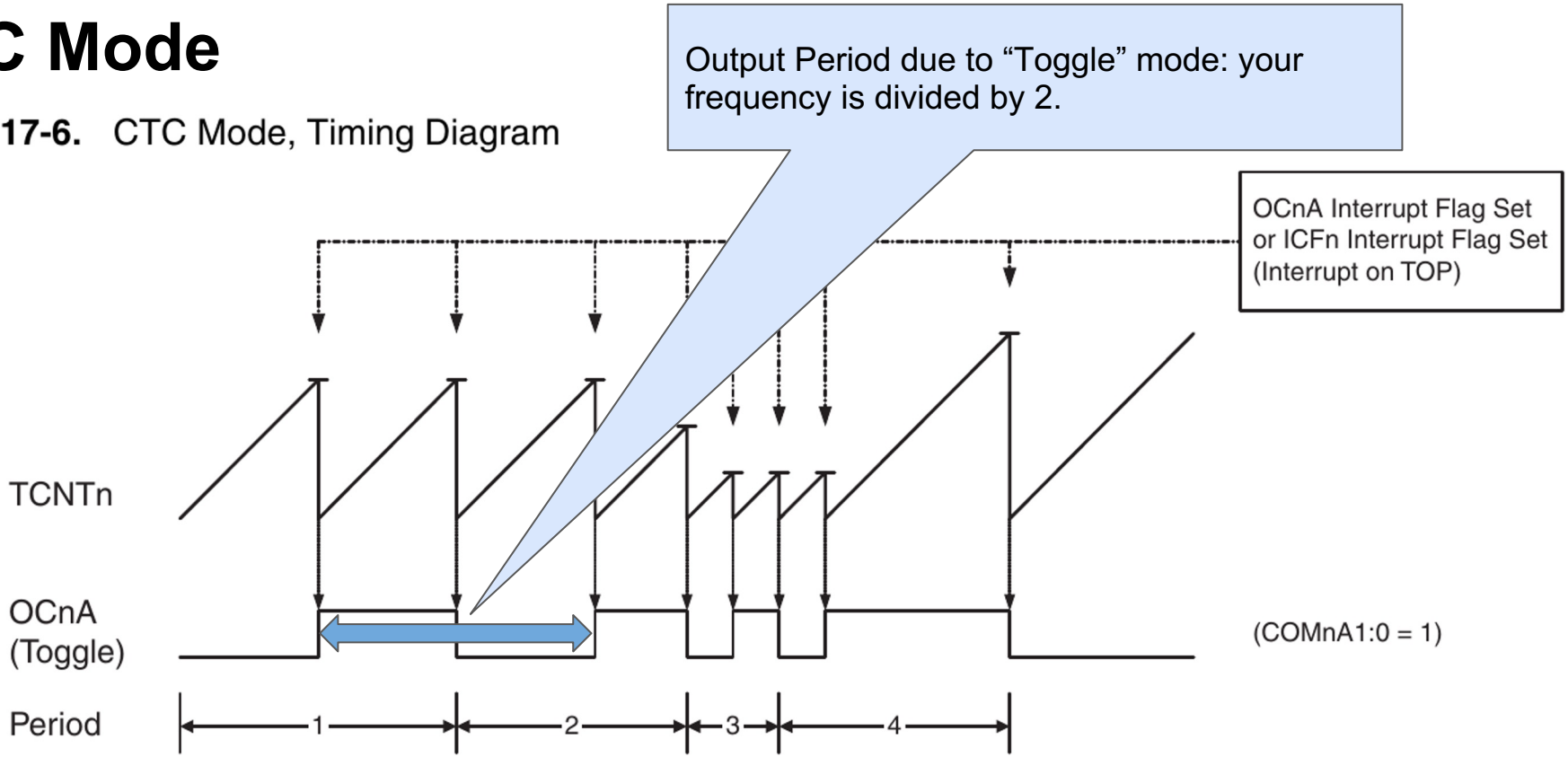
CTC Mode

Figure 17-6. CTC Mode, Timing Diagram



CTC Mode

Figure 17-6. CTC Mode, Timing Diagram



16-bit Timer MODES

"Fast PWM"

Count up to ICRn/OCRnA (MAX), reset to 0x000

Clear output at compare match

Table 17-2. Waveform Generation Mode Bit Description(1)

Mode	WGMn3	WGMn2 (CTCn)	WGMn1 (PWMn1)	WGMn0 (PWMn0)	Timer/Counter Mode of Operation	TOP	Update of OCRnx at	TOVn Flag Set on
0	0	0	0	0	Normal	0xFFFF	Immediate	MAX
1	0	0	0	1	PWM, Phase Correct, 8-bit	0x00FF	TOP	BOTTOM
2	0	0	1	0	PWM, Phase Correct, 9-bit	0x01FF	TOP	BOTTOM
3	0	0	1	1	PWM, Phase Correct, 10-bit	0x03FF	TOP	BOTTOM
4	0	1	0	0	CTC	OCRnA	Immediate	MAX
5	0	1	0	1	Fast PWM, 8-bit	0x00FF	BOTTOM	TOP
6	0	1	1	0	Fast PWM, 9-bit	0x01FF	BOTTOM	TOP
7	0	1	1	1	Fast PWM, 10-bit	0x03FF	BOTTOM	TOP
8	1	0	0	0	PWM, Phase and Frequency Correct	ICRn	BOTTOM	BOTTOM
9	1	0	0	1	PWM,Phase and Frequency Correct	OCRnA	BOTTOM	BOTTOM
10	1	0	1	0	PWM, Phase Correct	ICRn	TOP	BOTTOM
11	1	0	1	1	PWM, Phase Correct	OCRnA	TOP	BOTTOM
12	1	1	0	0	CTC	ICRn	Immediate	MAX
13	1	1	0	1	(Reserved)	–	–	–
14	1	1	1	0	Fast PWM	ICRn	BOTTOM	TOP
15	1	1	1	1	Fast PWM	OCRnA	BOTTOM	TOP

Note: 1. The CTCn and PWMn1:0 bit definition names are obsolete. Use the WGMn2:0 definitions. However, the functionality and location of these bits are compatible with previous versions of the timer.

For detailed timing information refer to "Timer/Counter Timing Diagrams" on page 152.

Duty Cycle (PWM) Control

- PWM = Pulse Width Modulation
- Switch on and off “quickly”
- “Quickly” means faster than process can react.
- Effective output is time average of on-off signal.
- For this application replace “5V” with power for any device.

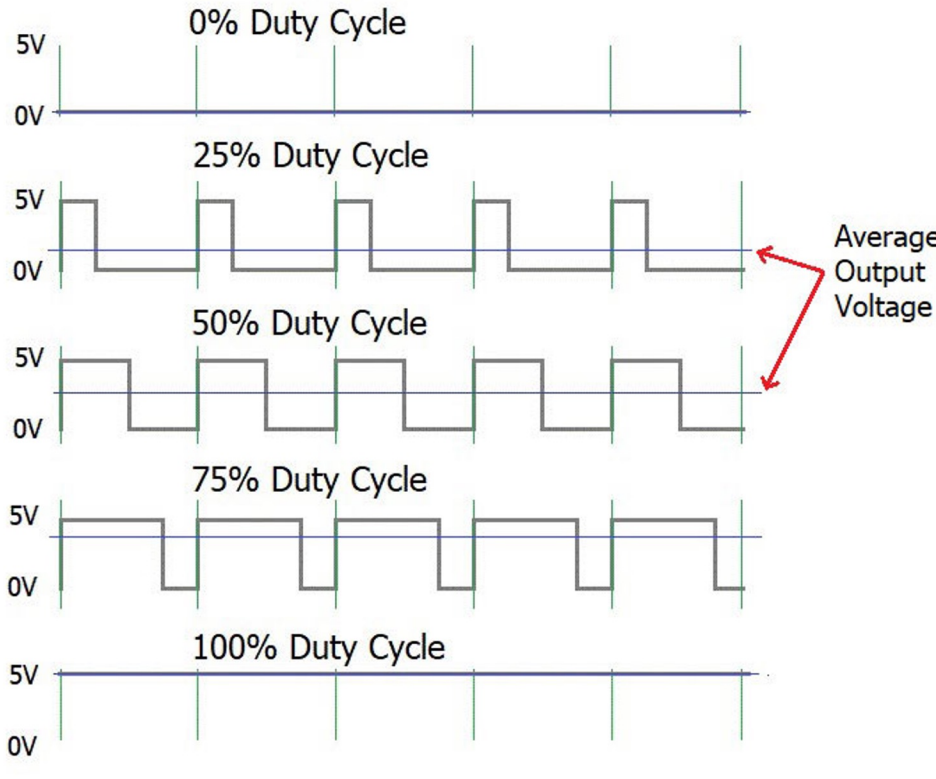


Figure 17-7. Fast PWM Mode, Timing Diagram

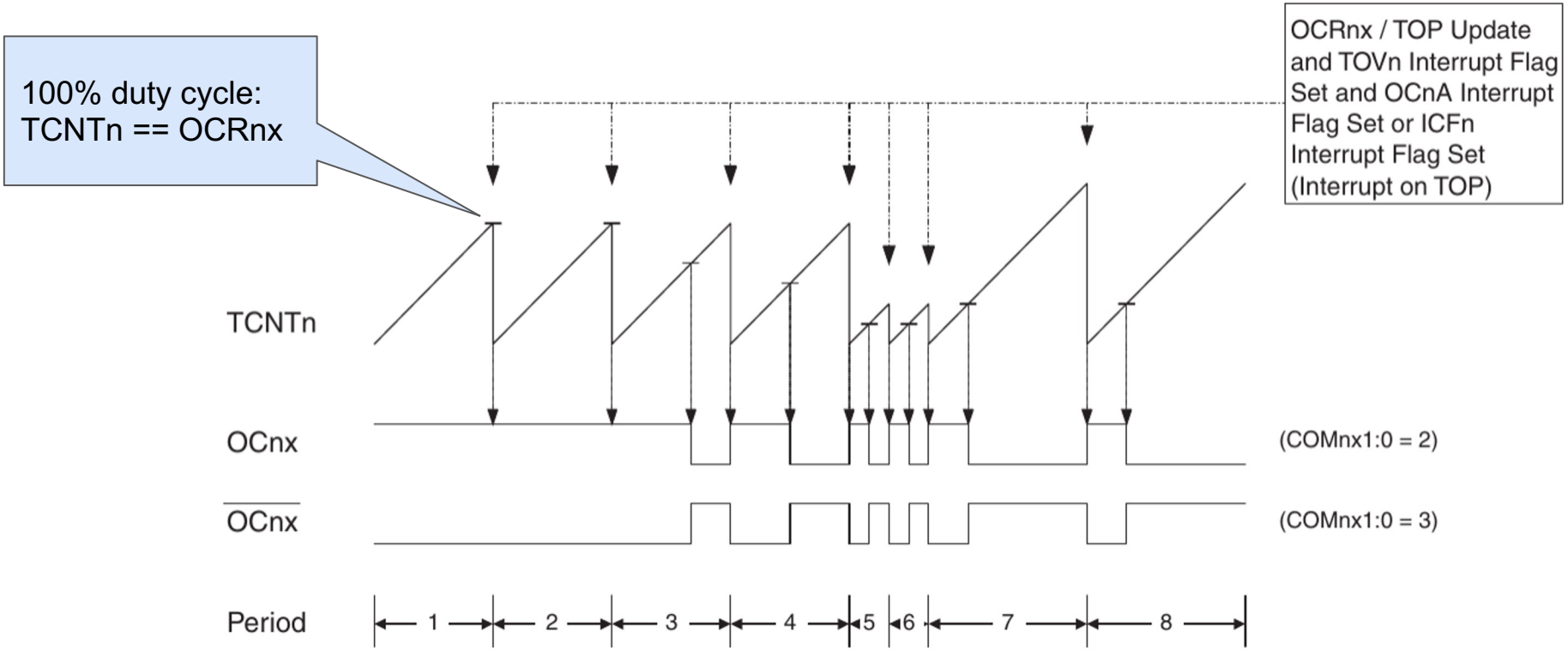


Figure 17-7. Fast PWM Mode, Timing Diagram

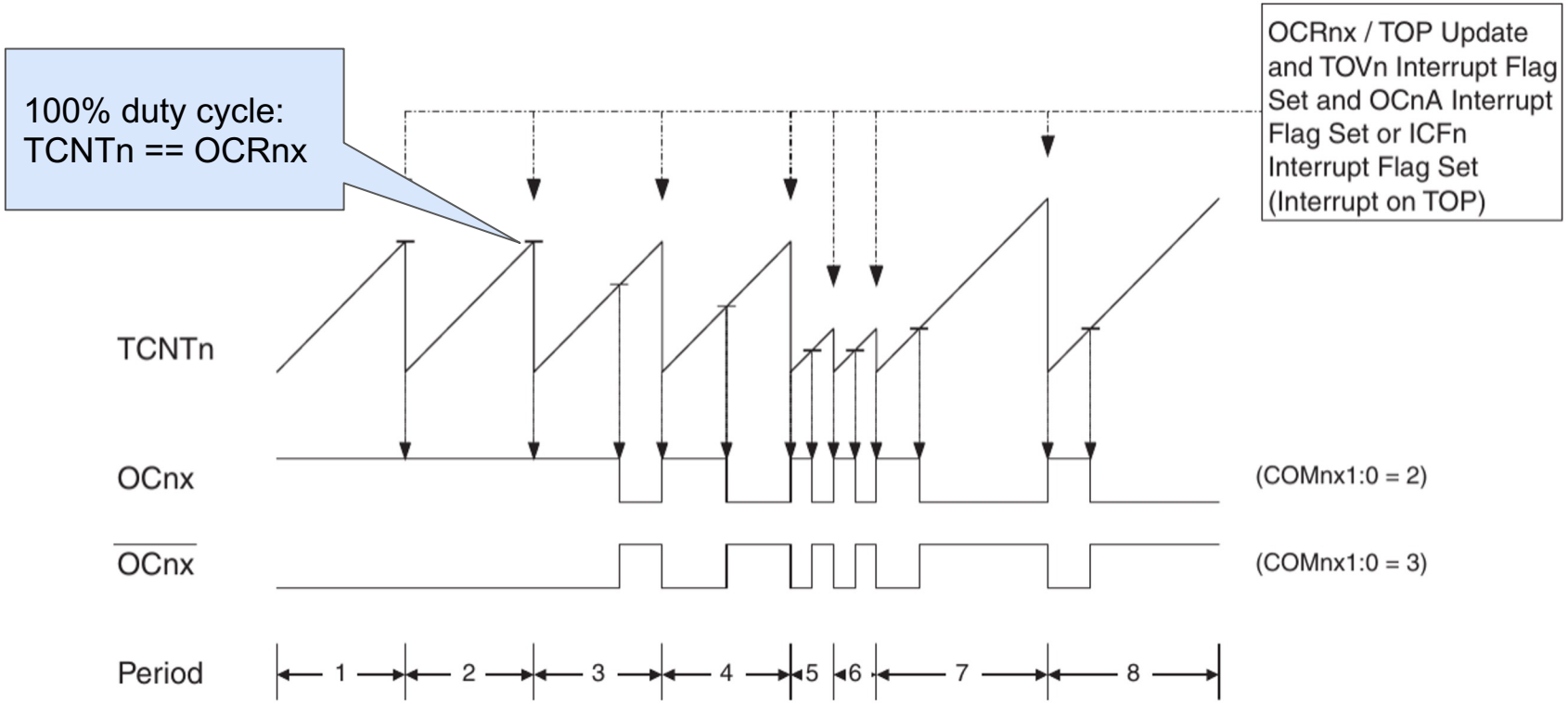


Figure 17-7. Fast PWM Mode, Timing Diagram

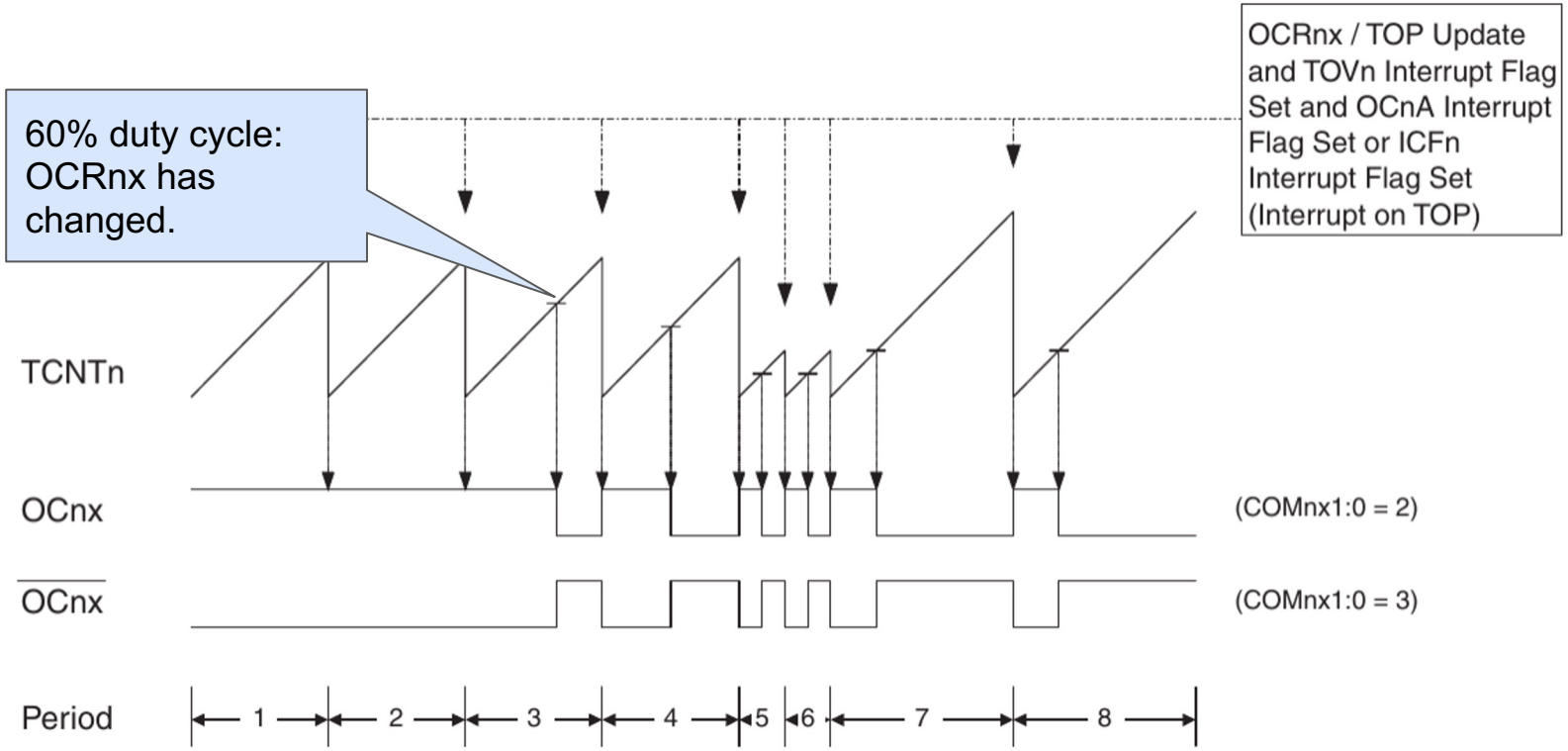


Figure 17-7. Fast PWM Mode, Timing Diagram

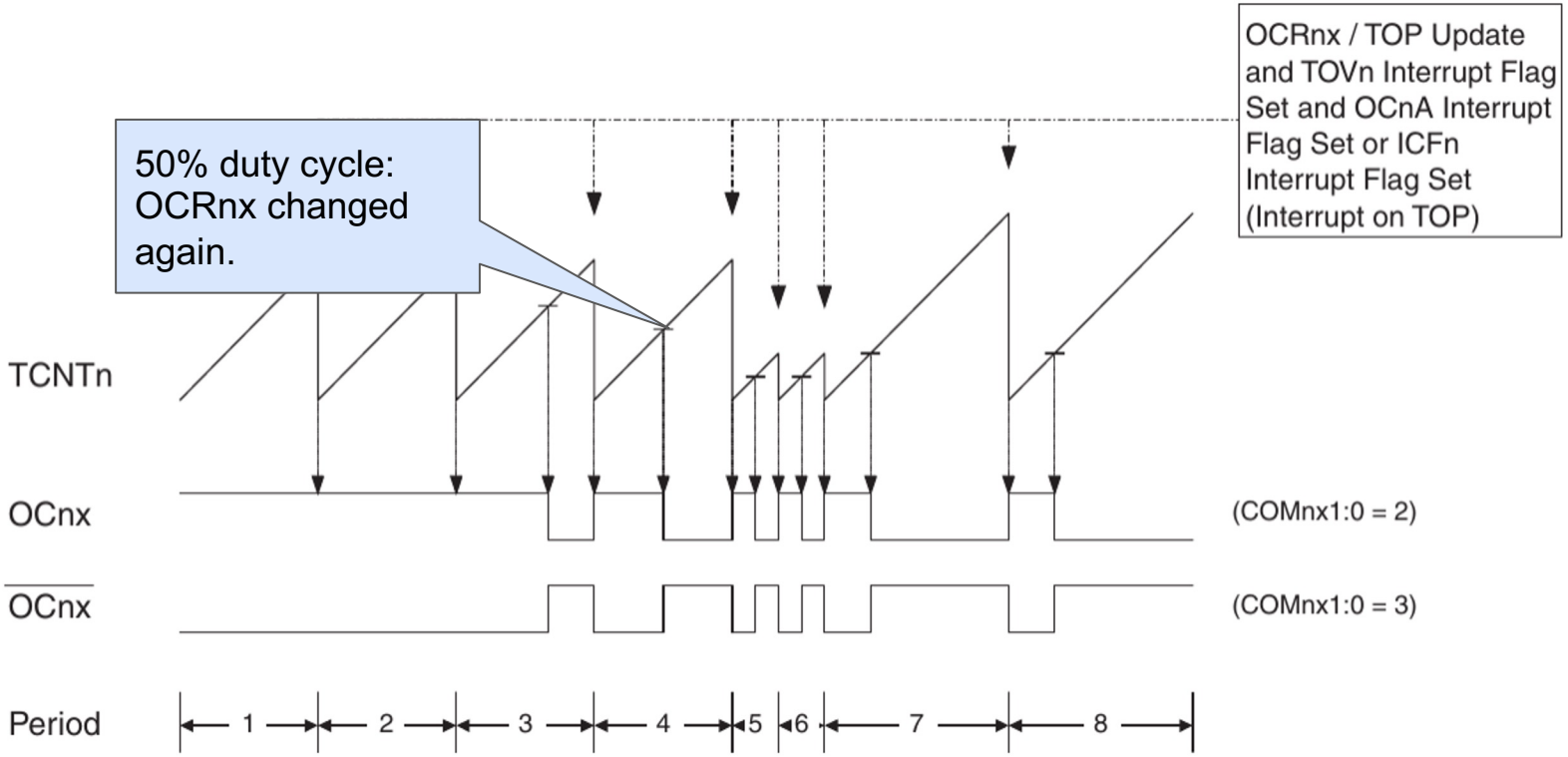
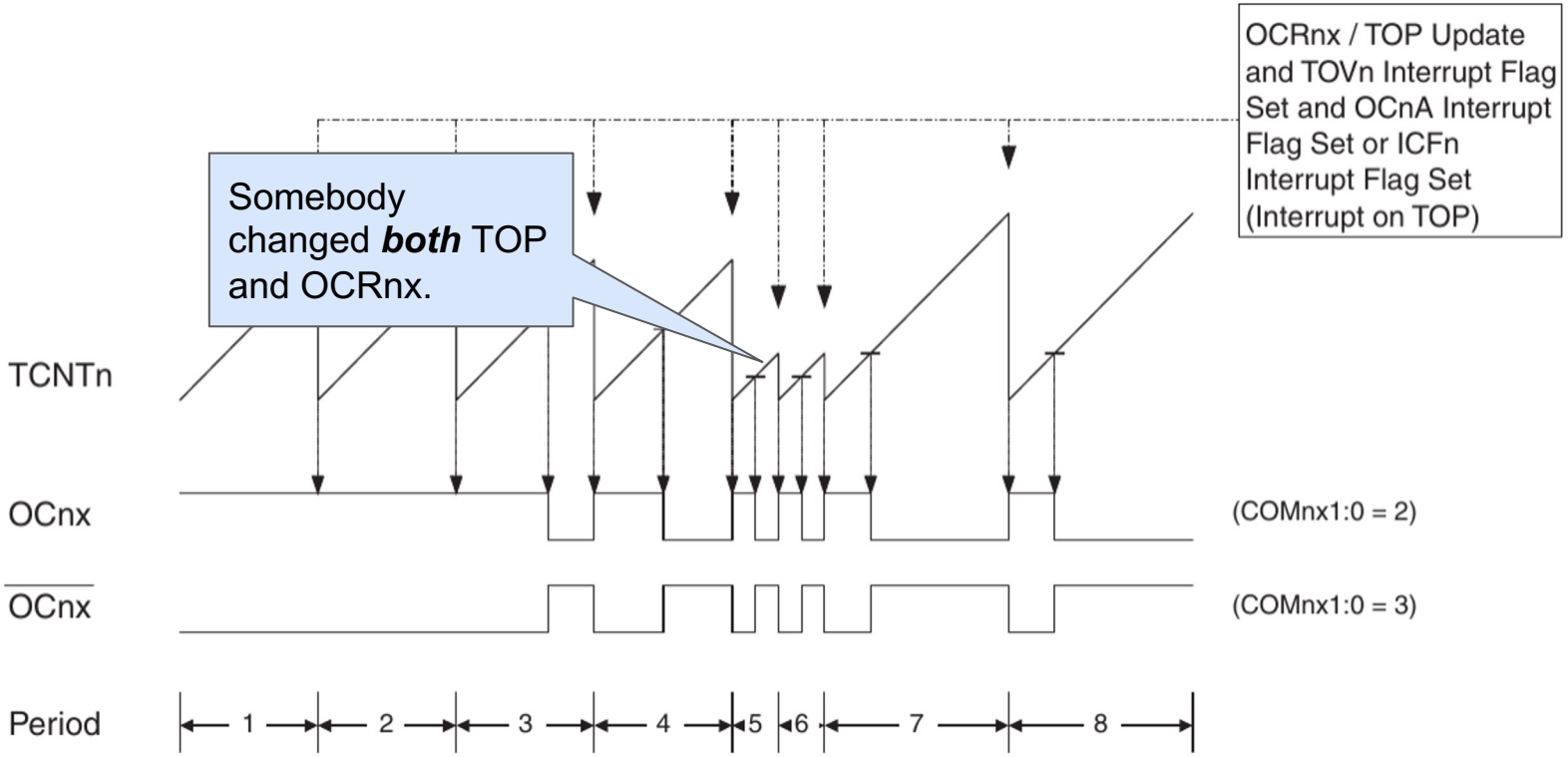


Figure 17-7. Fast PWM Mode, Timing Diagram



16-bit Timer/Counter

Programming Steps: Setup

1) Enable Timer (Arduino automatically does it already)

   (write zero to a **Power Reduction Register** bit. "1" turns Timer/Counter off) (p55,56)

1) Figure out what clock frequency (prescaler *setting*) you want to use.
2) Select a Mode using the 3 control registers (TCCRnA, TCCRnB,TCCRnC)
3) set/clear Waveform Generation Mode bits:
   WGMn0 --- WGMn3 (two different registers)
   a) **TCCRnA**: Compare Mode and partial WG Modes
   b) **TCCRnB**: partial WG Modes and Clock/Prescaler select.
   c) "n" is your counter number.
4) Set your ISR and enable interrupts. (**LATER**)

Thinking about timers as software

Here's a way to think about timers for those more comfortable with software, it's basically a for loop counter. We also have a conditional to perform an action and break out of the loop. For example in CTC mode, counting up to `output_compare` triggers an action (e.g. toggling a pin). Note that this whole thing is wrapped in a big `while(1)` loop because the counter resets to zero and then starts over.

```
1  while(1){
2      int output_compare = 26; // some number we want to count up to
3      int timer_counter = 0;
4
5      // This assumes we're using an 8 bit timer
6      for(timer_counter = 0; timer_counter < 256; timer_counter++) {
7          if(timer_counter == output_compare){
8              // We counted up to the number we set, now we do something
9              toggle_pin(); // or other action based on your registers
10             break; // Example: in CTC mode we stop counting now and start ove
11         }
12     }
13 }
```

16-bit Timer/Counter

Programming Steps: Setup

5) Figure out the compare count you need and set it in **OCRnA**
6) Enable or disable timer hardware output with **DDRx** (data direction register for the output pin).