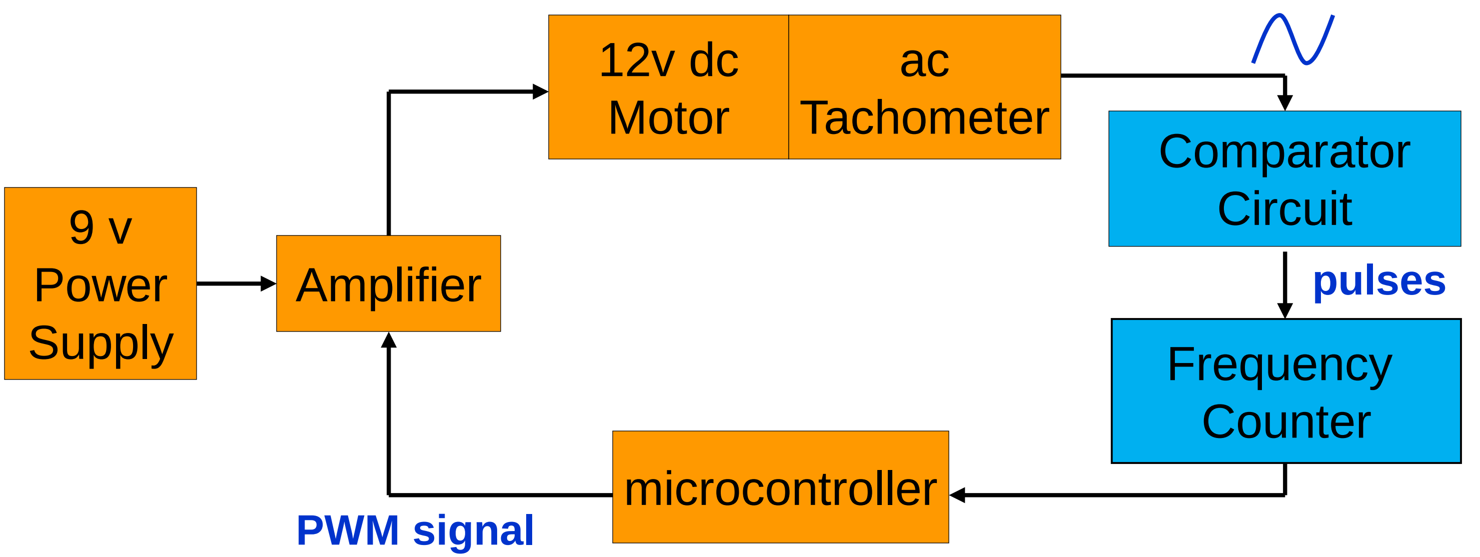
Lab 9. Speed Control of a D.C. motor

Sensing Motor Speed

(Tachometer Frequency Method)

Motor Speed Control Project

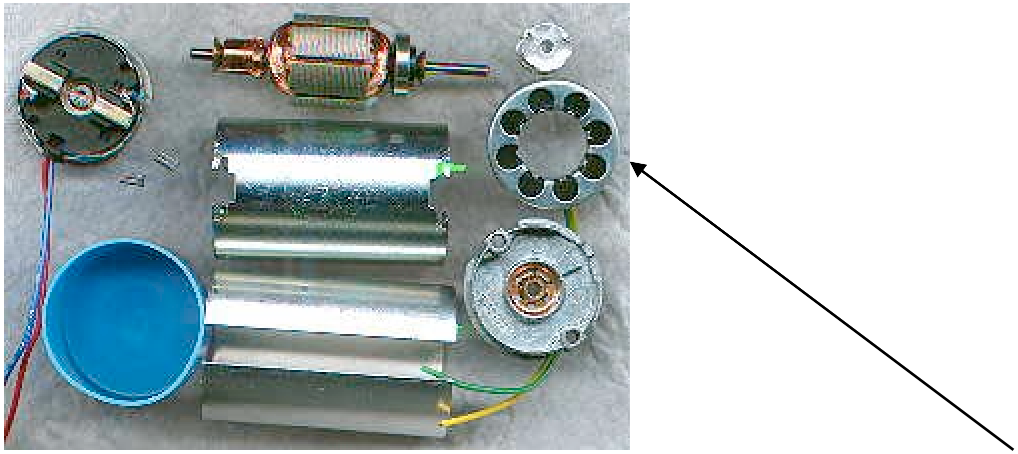
1. Generate PWM waveform
2. Amplify the waveform to drive the motor
3. **Measure motor speed**
4. Measure motor parameters
5. Control speed with a computer algorithm



Tachometer circuits

- Electrical signal carries speed information (revolutions per unit time) in amplitude and/or frequency
  - Optical encoder: disk on motor shaft alternately blocks and passes light to a sensor
  - Variable reluctance tachometer: gear teeth pass a magnetic pickup
  - Pickup coil/generator: voltage induced on separate winding in the motor

Pickup coil (Buehler motor)



- Voltage induced in separate coil at one end of rotor
- Both frequency and amplitude of the generated signal are proportional to motor speed

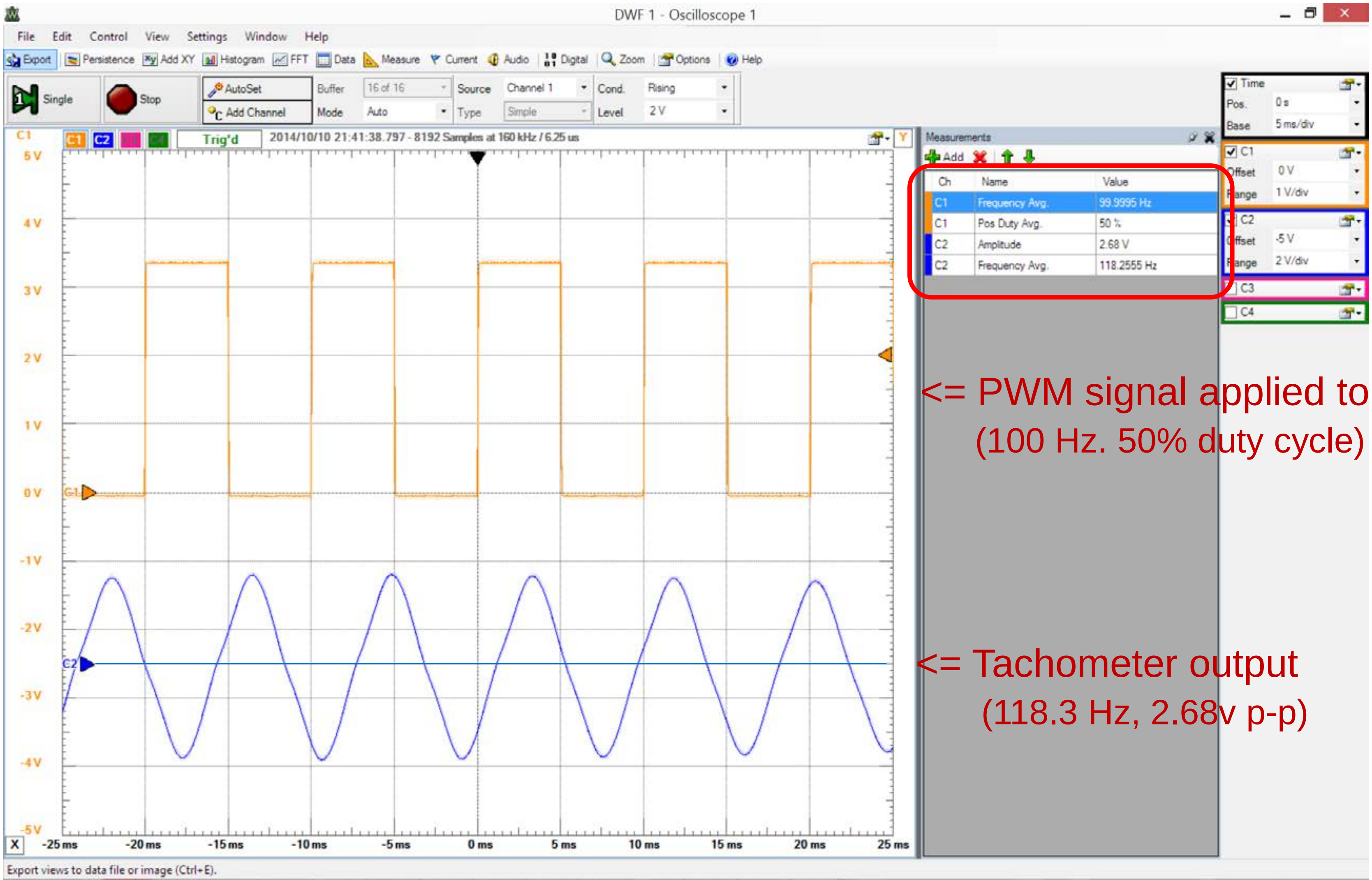
$$v_{tach}(t) = K\omega \sin(\omega t)$$

ω = rotational speed

K is a constant (depends on windings and geometry)

DC offset = 0v

Tachometer output



<= PWM signal applied to motor (100 Hz. 50% duty cycle)

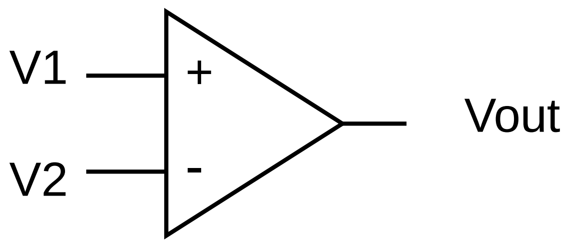
<= Tachometer output (118.3 Hz, 2.68v p-p)

Frequency measurement methods

1. Convert frequency to an analog voltage, and then to digital form
   - frequency-to-voltage converter IC
   - digitize voltage level with A/D converter
2. Count # signal periods per unit of time
   - frequency = # periods / time
   - count periods with programmable timer/counter
   - *useful for higher frequencies*
3. Measure one signal period (T)
   - frequency = 1 / T
   - measure period with programmable timer
   - *useful for lower frequencies*

Methods 2 & 3: signal conditioning

- Convert tachometer output to a digital waveform
  - Tachometer output signal: sinusoid with 0 V dc offset
    - Amplitude ranges from 0 V to well over 12 V peak (Measure in lab for min and max speeds)
  - Desired form: square wave, oscillating between 0 and 3 V
- Convert with an analog "comparator"



  - Vout = 0 V *(logic 0)* for V1 < V2
  - Vout = 3 V *(logic 1)* for V1 > V2

LM111/LM211/LM311 voltage comparator

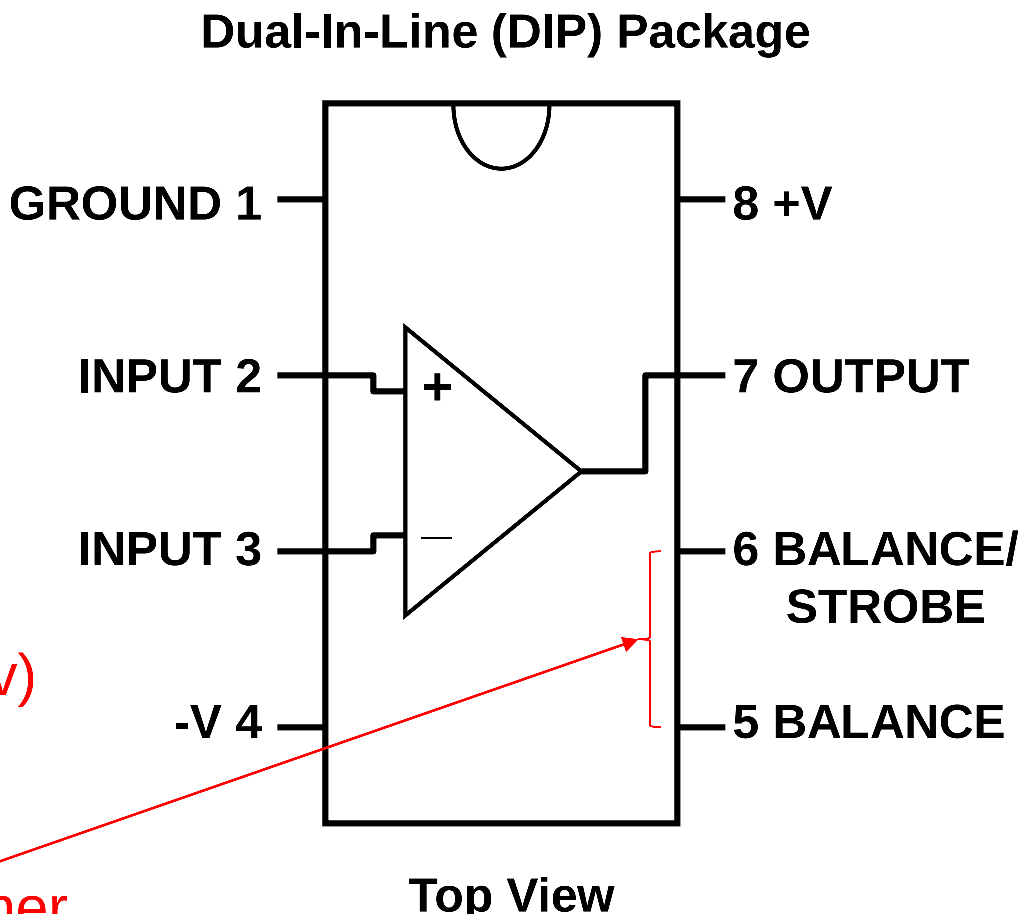
- Nearly identical, except for temperature range
  - LM111 [-55^{o}C…+125^{o}C] (military grade)
  - LM211 [-25^{o}C…+85^{o}C] (industrial grade)
  - LM311 [0^{o}C…+70^{o}C] (commercial grade)
- Power supply range = ±5 V to ±15 V
- Input voltage range = ±30 V
- Output drives loads between ground and positive supply value
  - **Pull-up resistor needed** from output to positive supply
- Output balancing and strobe capability

LM111 / LM211 / LM311 Package

Pin# Function (lab values)

1. Ground (0 V)
2. V1 input
3. V2 input
4. -V supply (-9 V)
5. Balance**
6. Balance/strobe**
7. Vout (*open collector*)
   (pull-up resistor to +3v)
8. +V supply (+9 V)

**short pins 5-6 together



Comparator signal & reference voltages (V1 and V2)

- Goal: V1 > V2 approximately half of each period, to produce square wave at Vout
- Option 1
  - V1 = ac signal
  - V2 = dc offset of the ac signal
    - V2 = signal with sinusoid removed by a low pass filter
    - OR, apply a constant voltage to V2 ≈ dc offset
- Option 2
  - V1 = ac signal with dc offset removed by high pass filter
  - V2 = ground (0v)

Buehler motor tachometer signal offset ≈ 0v.
Which option would be more efficient?

Design & verify comparator circuit

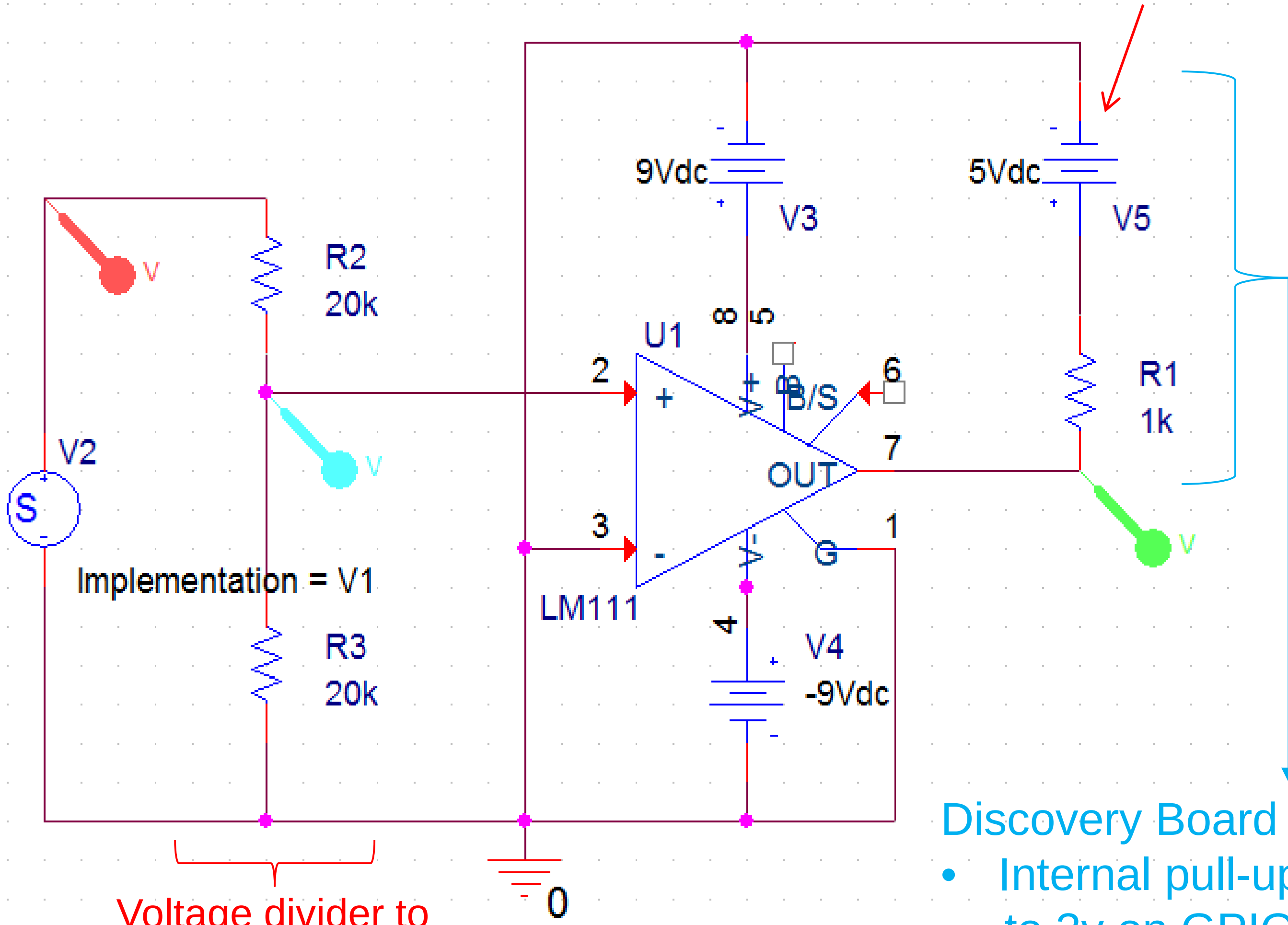
- Model in PSPICE or Multisim
- LM311 comparator (or LM211 or LM111), resistors, DC voltages, etc. found in libraries
- Use a VSTIM (voltage stimulus) generator to model the optical encoder
- Simulate to verify square wave output over the range of optical encoder signal frequencies and amplitudes, corresponding to “useful” motor speeds
  - Use voltage probes to examine signals
  - Measure expected frequencies in lab for min/max speeds
- Implement circuit and compare actual operation to simulation of the modeled circuit

Example model

5v was used here.
3v should be used.

VSTIM from library "sourcestim"

**R,C from "analog" lib.
LM111 from "eval" lib.
VDC from "source" lib.
AGND from "port" lib.**

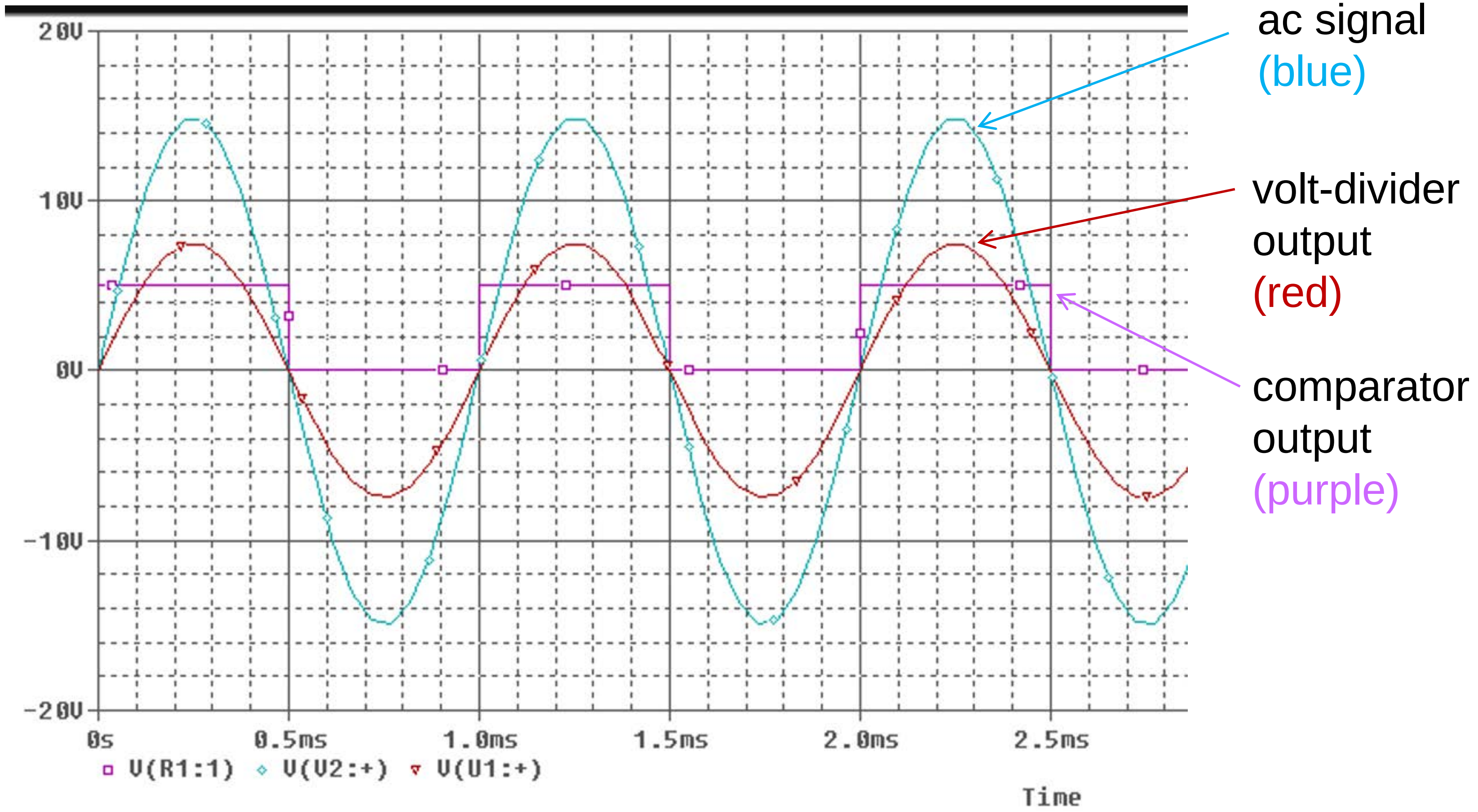


Voltage divider to reduce amplitude

Discovery Board

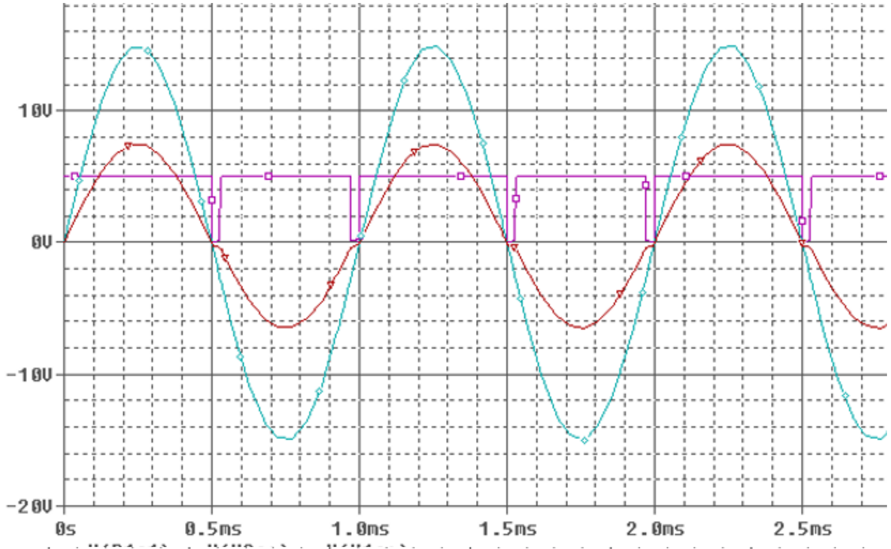
- Internal pull-up to 3v on GPIO?
- 3v output pin?

Simulation

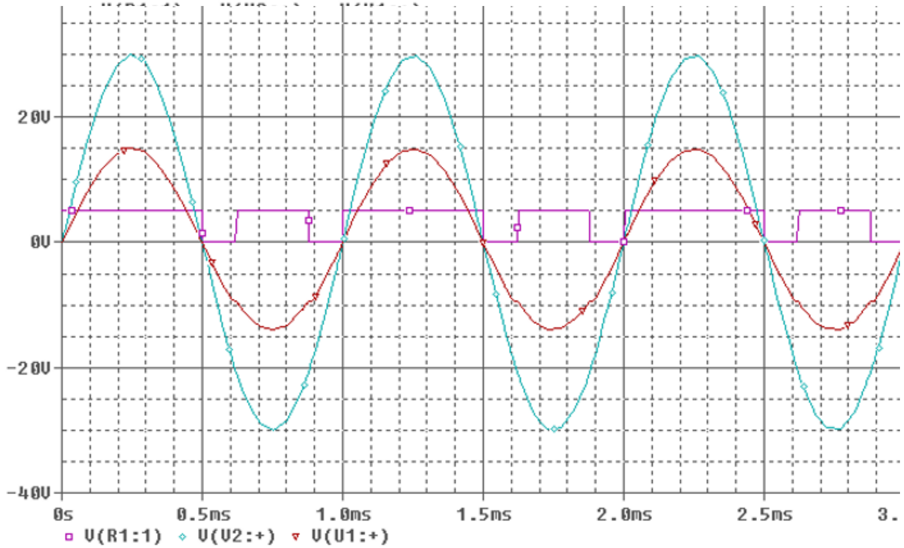


20V
10V
0V
-10V
-20V
0s
0.5ms
1.0ms
1.5ms
2.0ms
2.5ms
V(R1:1)
V(V2:+)
V(U1:+)
Time
ac signal (blue)
volt-divider output (red)
comparator output (purple)

Simulation – undesirable results



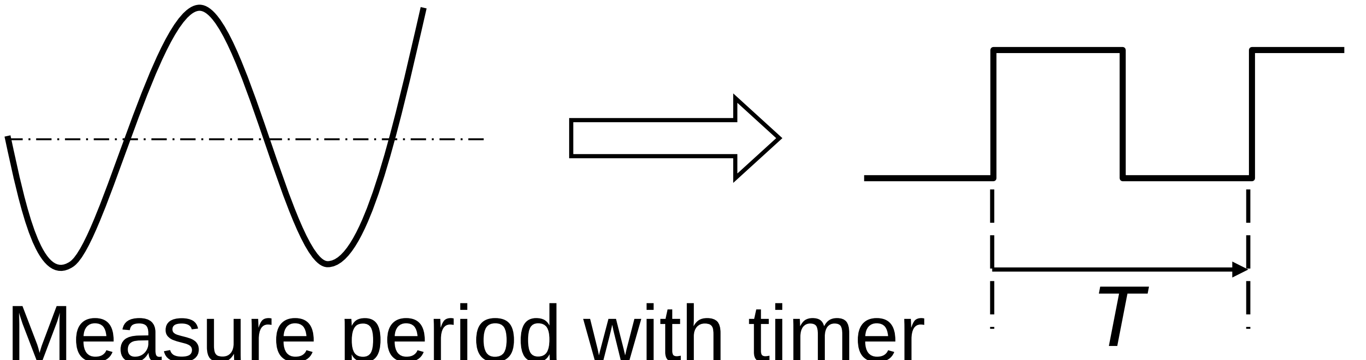
Ground instead of negative supply on pin -V



Input voltage range exceeds +V/-V supplies

Signal conditioning review

- Convert ac signal to digital signal



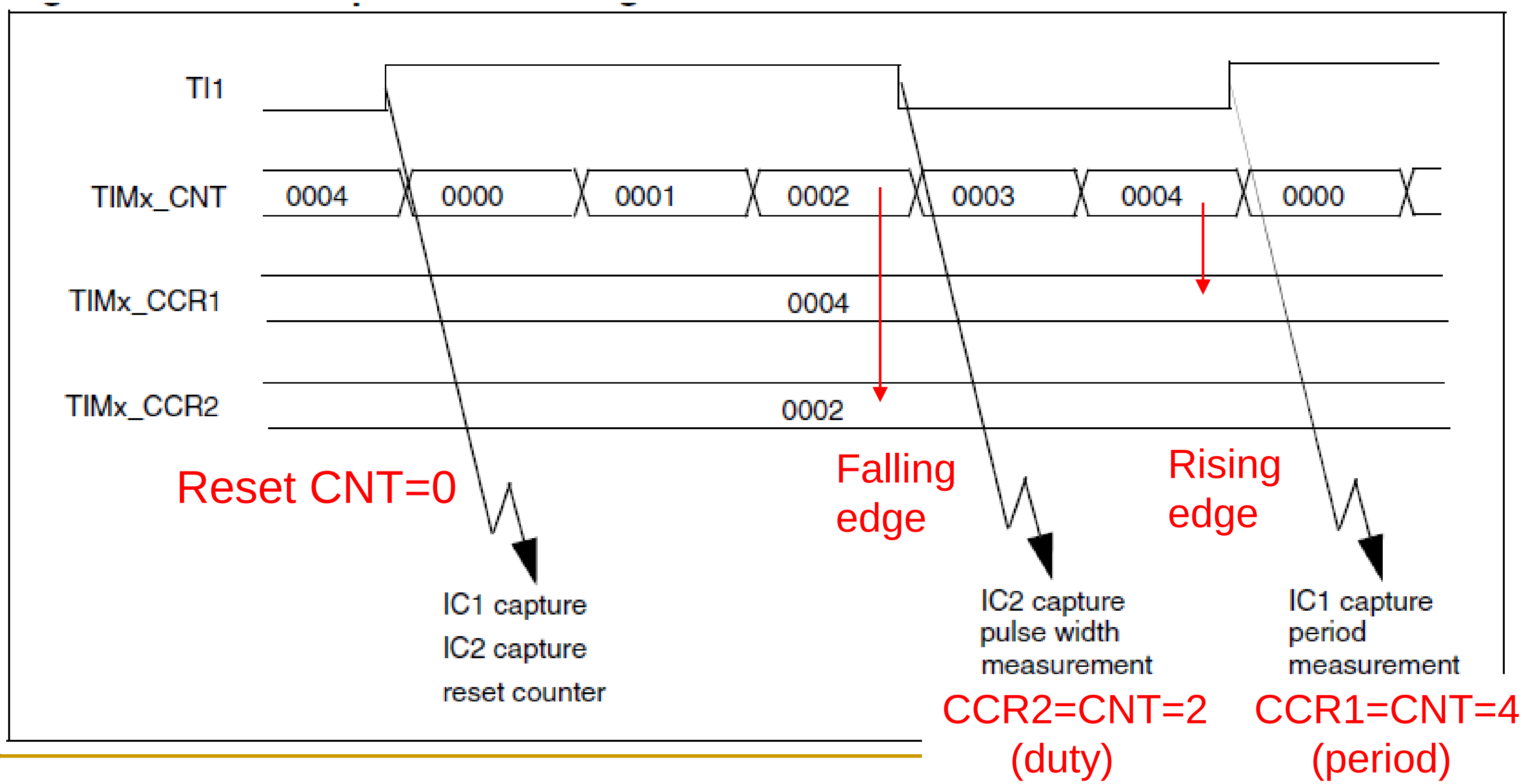
- Measure period with timer
- Design challenges:
  - ac signal exceeds comparator voltage ratings
    - reduce with voltage divider?
  - ac signal may be noisy
    - may cause "false" transitions
    - introduce hysteresis or filter?

STM32 timer "input capture" mode

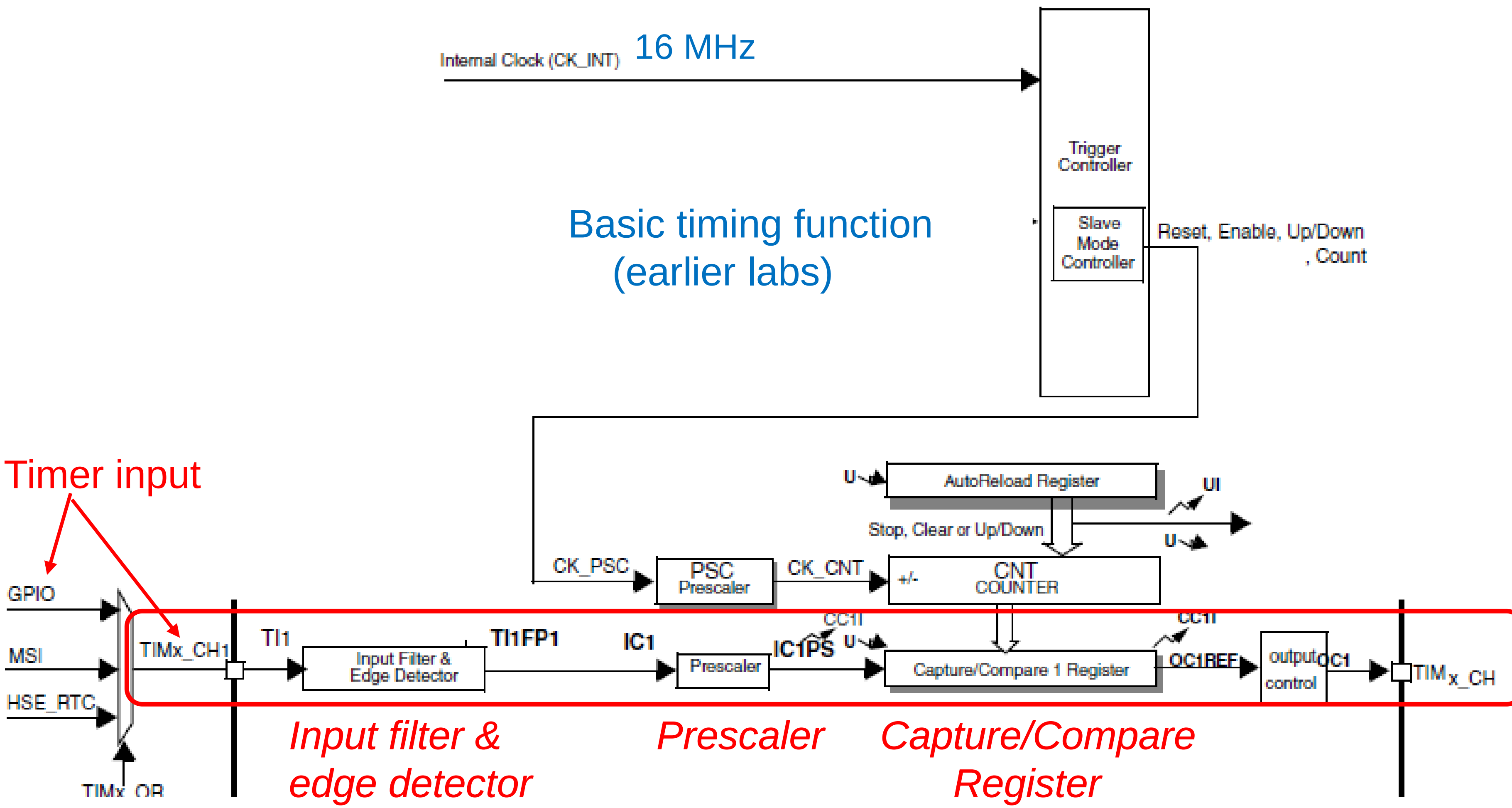
TIMx_CCRy latches TIMx_CNT value when transition detected on input TIMx_CHy

- CCxIF flag sets, and interrupt generated if enabled (CCxIE=1)
- Detected signal edge is programmable (rising, falling, both)

Example: Use two channels to measure PWM duty & period via opposite edges



General-purpose timers TIM10/TIM11



Capture/Compare Channel 1 Input/Output = TIMx_CH1

(other timers have additional channels)

Input capture mode

- **Input pin: TIMx_CHy** (ex. TIM11_CH1, accessible at pin PA7)
  - Connect a GPIO pin to timer input TIMx_CHy
    - Select *alternate function* mode for the pin in MODER
    - Select TIMx_CHy as the alt. function input in TIMx->AFR[0]

      Example: Pin PA7 => TIM11_CH1

      Pin PA6 => TIM10_CH1

- **TIMx_CCRy** = TIMx capture/compare register, channel y
  - Use TIM11->CCR1 (only one channel in TIM10 and TIM11)
  - Could also use TIM10, but it is generating the PWM signal to drive the motor.
  - **TIMx_CNT** value captured in **TIMx_CCRy** at time of event on input TIMx_CHy
    - Captures time (count) at which the event occurred
    - Use to measure time between events, tachometer signal periods, etc.

- **TIMx_CNT** operates as discussed previously
  - Trigger update event and reset to 0 when CNT = ARR (up-counter)
  - For best results:
    - Reset TIMx->CNT to 0 after each capture event (captured CNT = desired period)
    - Set TIMx->ARR to a value greater than expected period (prevent update event)

Configure the GPIO alternate function

- Refer to User Manual to determine which GPIO pin is able to connect to TIMx_CHy

  Example: TIM11_CH1 connects to PA7

- In MODER, configure the GPIO pin as AF mode
- In the GPIO AF register, select TIMx_Chy
- Configure GPIO PUPDR register if pull-up or pull-down desired**
  - This should match the edge detection setting (rise or fall)
  - For example, use pull-up if detecting rising edge

  ** Recall that the LM311 comparator requires a pull-up resistor between its output and +3 V.

Timer configuration

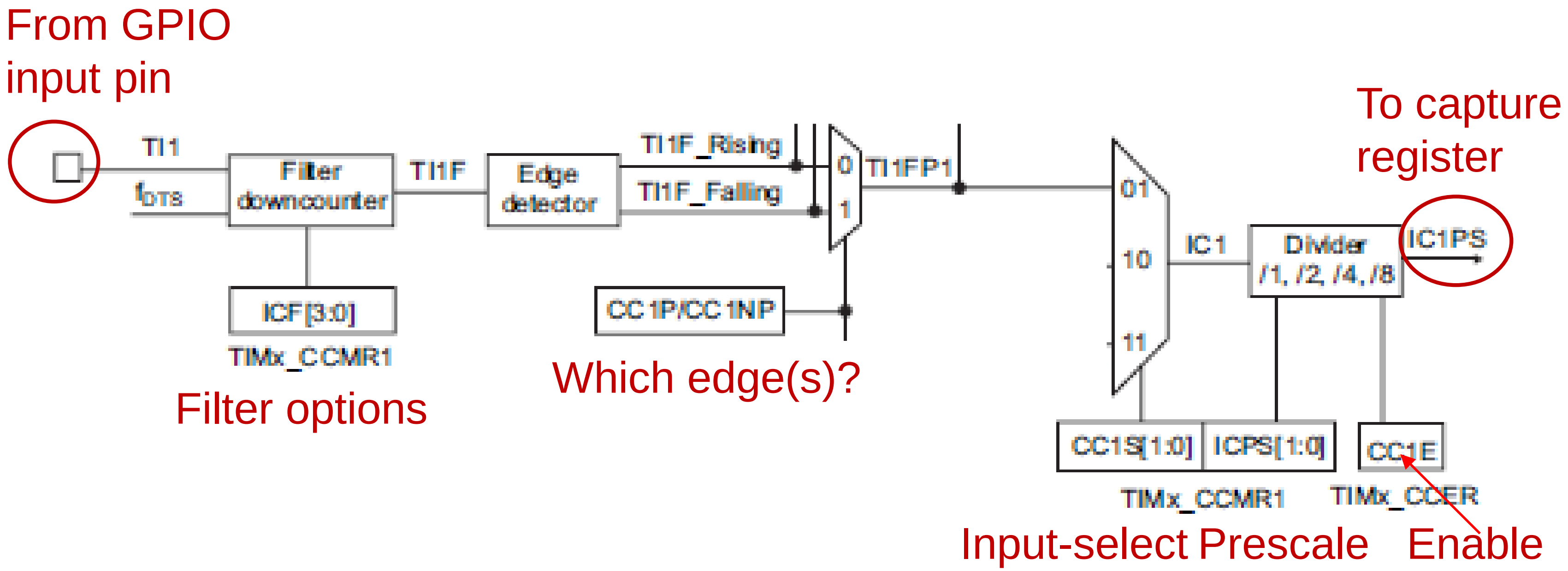
Basic timer setup same as previously discussed

- **TIMx_CNT**: 16-bit counter
  - Set to 0 at start of period, so captured value = period
- **TIMx_ARR**: auto-reload value
  - Set to value > max period to prevent update event before capture
- **TIMx_PSC**: prescale value
  - Prescale the clock, if necessary, to measure larger periods
- **TIMx_CR1**: control register 1
  - CEN=1 to enable counter
- **TIMx_SR**: status register ; **TIMx_DIEN**: interrupt enables
  - CC1IF sets on capture event for channel 1
  - Interrupt when CC1IF sets, if CC1IE=1
  - UIF sets on update event (TIMx_CNT overflow), interrupt if UIE=1

Capture/Compare Channel Inputs

Input stage includes digital filter, edge detection, multiplexing and prescaler

- **Filter**: sample input signal after an event to ensure it's not "noise"
- **Edge detector**: detect rising edge, falling edge, or both
- **Divider/prescale**: capture every event (typical), or every 2^{nd}, 4^{th} or 8^{th} event
- Configure in **Capture/Compare Mode Register** (CCMRx) and **Capture/Compare Enable Register** (CCER)



Capture/compare mode register 1
(Input capture mode)

TIMx_CCMR1 (reset value = all 0’s)

CC1S = Input mode =>

7	6	5	4	3	2	1	0
OC1CE	OC1M[2:0]			OC1PE	OC1FE	CC1S[1:0]	
IC1F[3:0]				IC1PSC[1:0]			
rw	rw	rw	rw	rw	rw	rw	rw

Input Capture 1 Filter

Sampling frequency for TI1 input, plus
Length of digital filter applied to TI1
(see next slide)

Input Capture 1 Prescaler

00: capture on **every event**
01: capture on every 2^{nd} event
10: capture on every 4^{th} event
11: capture on every 8^{th} event

Capture/Compare 1 Select

00 = output
01 = input: IC1 = TI1
10 = input: IC1 = TI2
11 = input: IC1 = TRC

Suggestion:
First try default
IC1F/IC1PSC
settings

- Bits 15-8 configure Channel 2 (same order)
- CCMR2 configures Channels 3/4

Input Capture Filter

- IC1F (Input Capture 1 Filter) selects sampling frequency and #samples (N) needed to validate a transition on the input.
- **Example:** If IC1F = 0001, and set to capture rising edge,
  - When rising edge detected, sample the channel twice with F_{CK_INT}.
  - If both samples are high then the capture is validated. Otherwise, no event.

IC1F		IC1F	
0000:	No filter, sampling is done at f_{DTS}	1000:	$f_{SAMPLING}=f_{DTS}/8$, N=6
0001:	$f_{SAMPLING}=f_{CK\_INT}$, N=2	1001:	$f_{SAMPLING}=f_{DTS}/8$, N=8
0010:	$f_{SAMPLING}=f_{CK\_INT}$, N=4	1010:	$f_{SAMPLING}=f_{DTS}/16$, N=5
0011:	$f_{SAMPLING}=f_{CK\_INT}$, N=8	1011:	$f_{SAMPLING}=f_{DTS}/16$, N=6
0100:	$f_{SAMPLING}=f_{DTS}/2$, N=6	1100:	$f_{SAMPLING}=f_{DTS}/16$, N=8
0101:	$f_{SAMPLING}=f_{DTS}/2$, N=8	1101:	$f_{SAMPLING}=f_{DTS}/32$, N=5
0110:	$f_{SAMPLING}=f_{DTS}/4$, N=6	1110:	$f_{SAMPLING}=f_{DTS}/32$, N=6
0111:	$f_{SAMPLING}=f_{DTS}/4$, N=8	1111:	$f_{SAMPLING}=f_{DTS}/32$, N=8

f_{DTS} = Dead Time and Sampling clock = 1/2/4 f_{CK_INT} (select in TIMx->CR1)

Capture/compare enable register (Input capture mode)

TIMx_CCER (reset value = all 0's)

3	2	1	0
CC1NP	Res.	CC1P	CC1E
rw		rw	rw

CC4: bits 15-12
CC3: bits 11-8
CC2: bits 7-4
(same order as CC1)

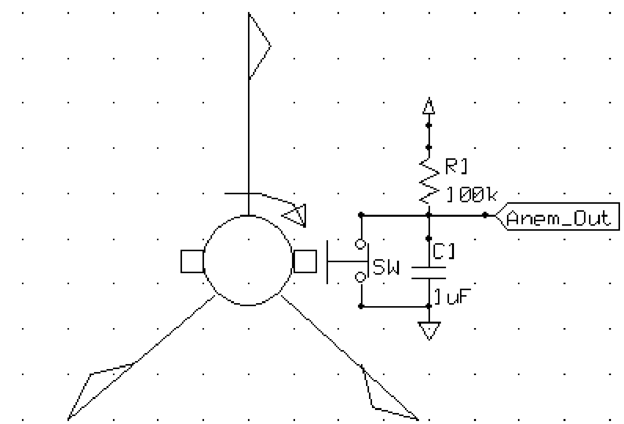
CC1 Polarity:
CC1NP/CC1P select capture trigger:
- 00: **rising** edge of input
- 01: **falling** edge of input
- 11: **both** edges of input

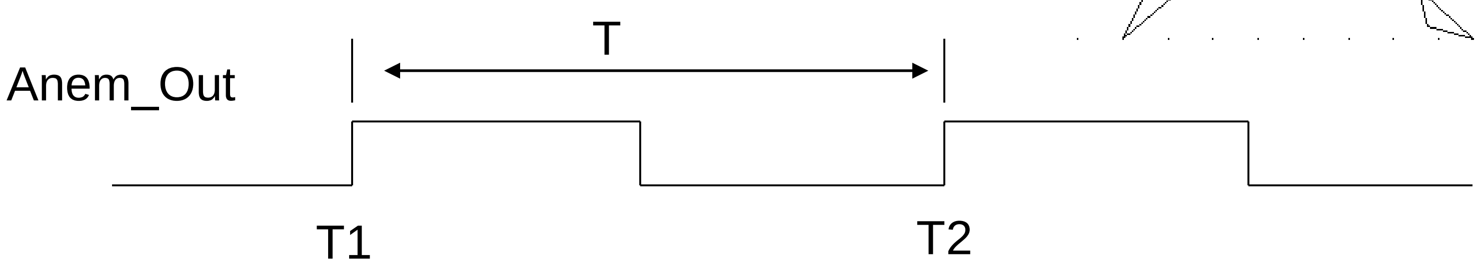
CC1 Enable:
- **1 = Capture enabled**
- 0 = Capture disabled

Must enable capture and select capture trigger

Example: Wind Speed Indicator (Anemometer)

- Rotational speed (and pulse frequency) proportional to wind velocity
- Two measurement options:
  - Frequency (best for high speeds)
  - Width (best for low speeds)
- Can solve for wind velocity v
- How can we use the Timer for this?
  - Use Input Capture Mode to measure period T of input signal





Input Capture Mode for Anemometer

- Operation (repeat continuously):
  - First capture - on rising edge (C_{rising_1})
    - Clear counter, start new counting
  - Second Capture - on rising edge (C_{rising_2})
    - Read capture value, save for wind speed calculation
    - Clear counter, start new counting

- Solve the wind speed

$$V_{wind} = K \div (C_{rising\_2} - C_{rising\_1}) \times Freq\_cnt$$

- Or, if count reset to 0 on each rising edge:

$$V_{wind} = K \div (C_{rising\_2}) \times Freq\_cnt$$

Set up for Anemometer measurement

- Apply ***Anem_Out*** signal to pin PD15
  - TIM4_CH4 is an alternate function for PD15 (from data sheet)
  - Configure PD15 as alternate function in GPIOD->MODER
  - Select alternate function TIM4_CH4 for PD15 in GPIOD->AFRH
- Configure **TIM4_PSC** and **TIM4_ARR** for TIM4 counting period
  - Best if counting period > time to be measured (avoid overflow interrupt)
  - Reset **TIM4_CNT** to 0 after each capture
- **TIM4_CCMR2** Capture/Compare mode register 2 (Channel 4)
  - Set CC4S to map IC4 to TI4
  - Set IC4F, IC4PSC to defaults (no filter or prescale)
- **TIM4_CCER** Capture/compare enable register
  - Set CC4E to select “input” mode
  - Set CC4N:CC4P = 00 to select rising-edge (01 for falling edge)
- **TIMx_DIER** DMA/interrupt enable register
  - Set CC4IE to enable interrupt on input capture event *(to read captured value)*
- **TIM4_CR1** Control register: Set CEN to enable the counter
- **TIM4_SR** Status register: CC1IF indicates input event occurred *(clear by software)*
- **TIM4_CCR4** Capture/Compare register: captured value of TIM4_CNT
- **TIM4 Interrupt handler**:
  - Read TIM4_CCR4 to get period, reset TIM4_CNT, reset CC1IF, calculate wind speed.

Lab Procedure

- Simulate comparator circuit in PSPICE to verify circuit & values
  - Verify that a square wave (0 to 3 V) is produced
- Re-verify motor speed controller from Lab 8
  - **Components can be damaged with incorrect connections/operation!**
  - **Triple-check power/ground connections!**
- Incorporate comparator into your circuit
  - Verify comparator inputs & square wave output on o'scope
- Modify software to measure square wave period
- Measure **ac tachometer signal period*** for each of the 11 keypad-selected settings (11th setting is stopped)
- Plot:
  - Signal period* vs. measured motor speed
  - Signal period* vs. PWM signal duty cycle

*Measured by the µC via input capture