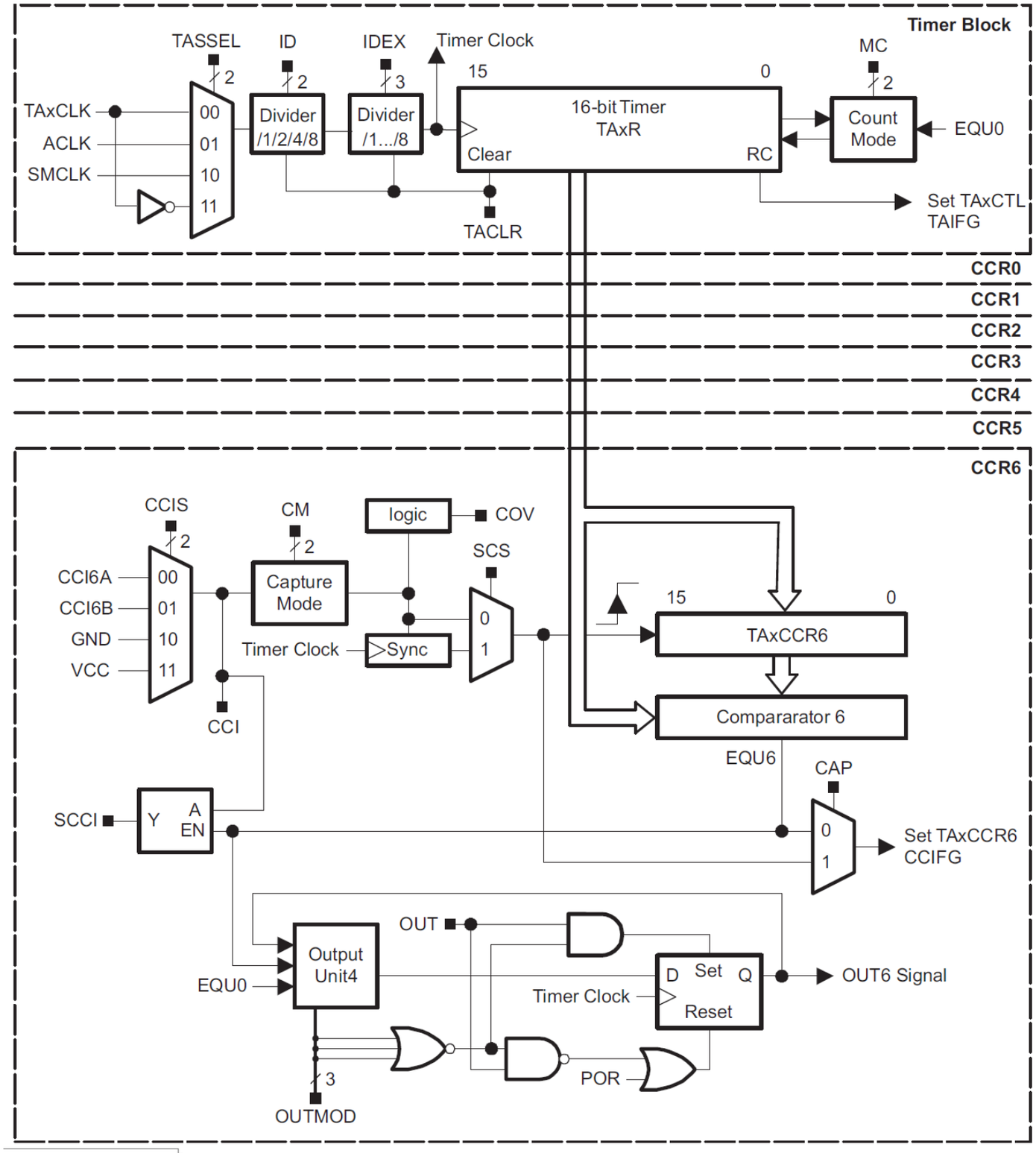
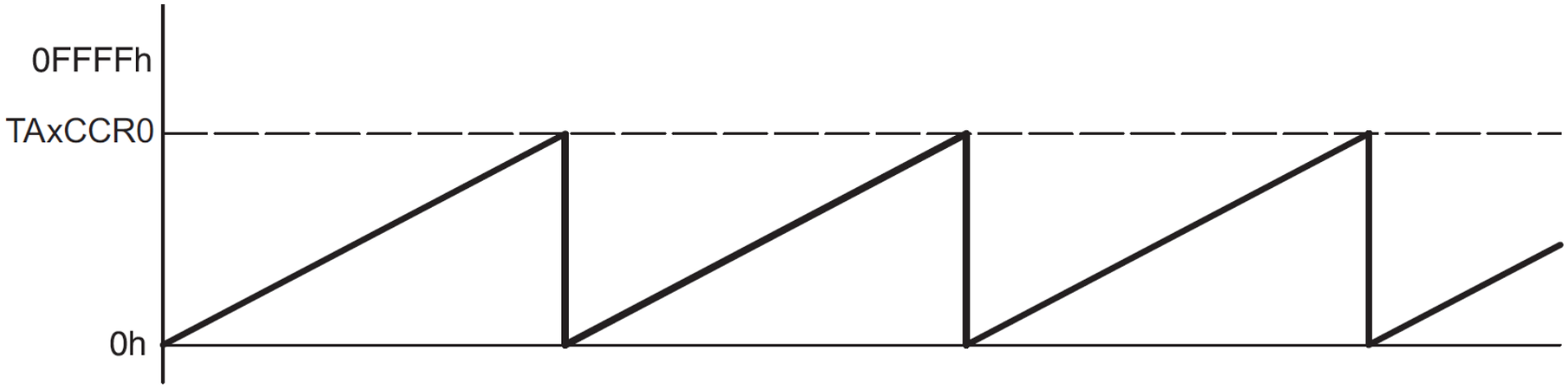
Timer Basics

- 16-bit Counter
  - Clock source selector
  - Dividers
  - Counter Register
  - Count Mode (up, down, up/down)
- Capture/Compare Unit
  - Capture Register
  - Compare Register
  - Capture/Compare Inputs – Interrupt
  - Output Unit

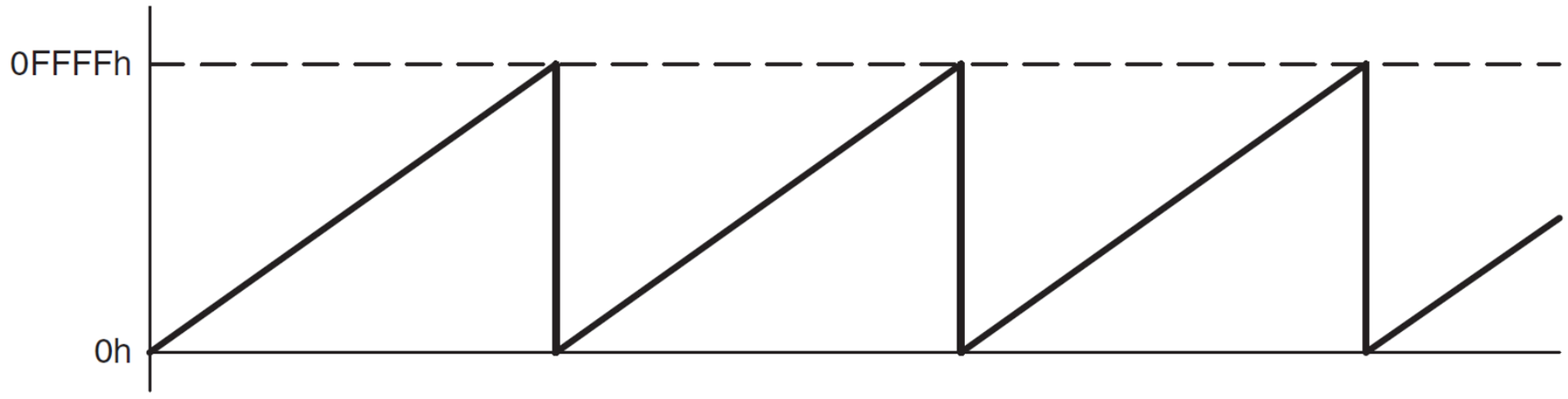


Timer counting modes

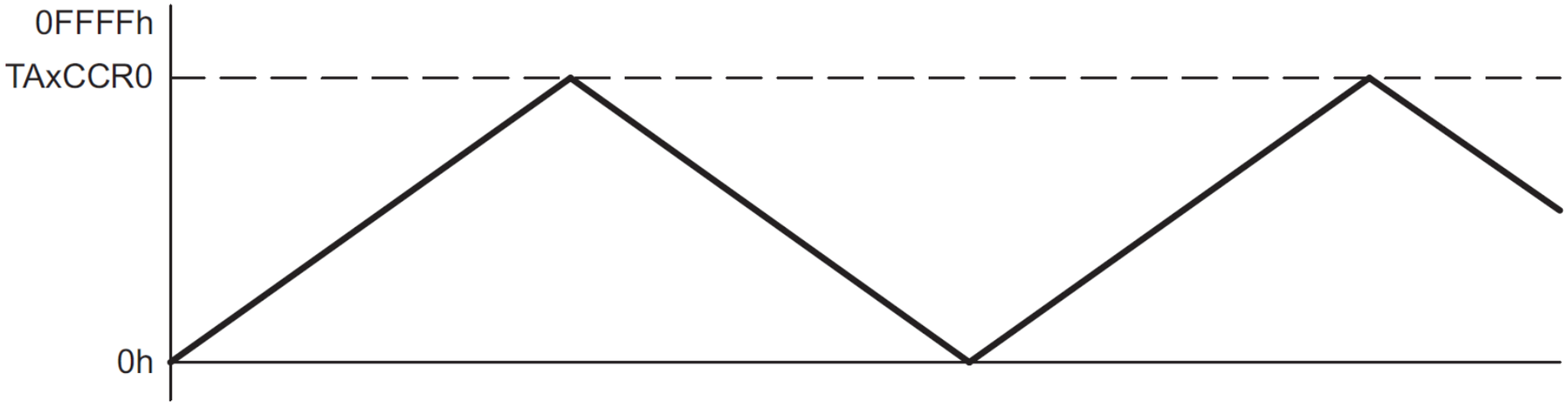
Up mode



Continuous mode



Up/Down mode



Capture, Compare, PWM

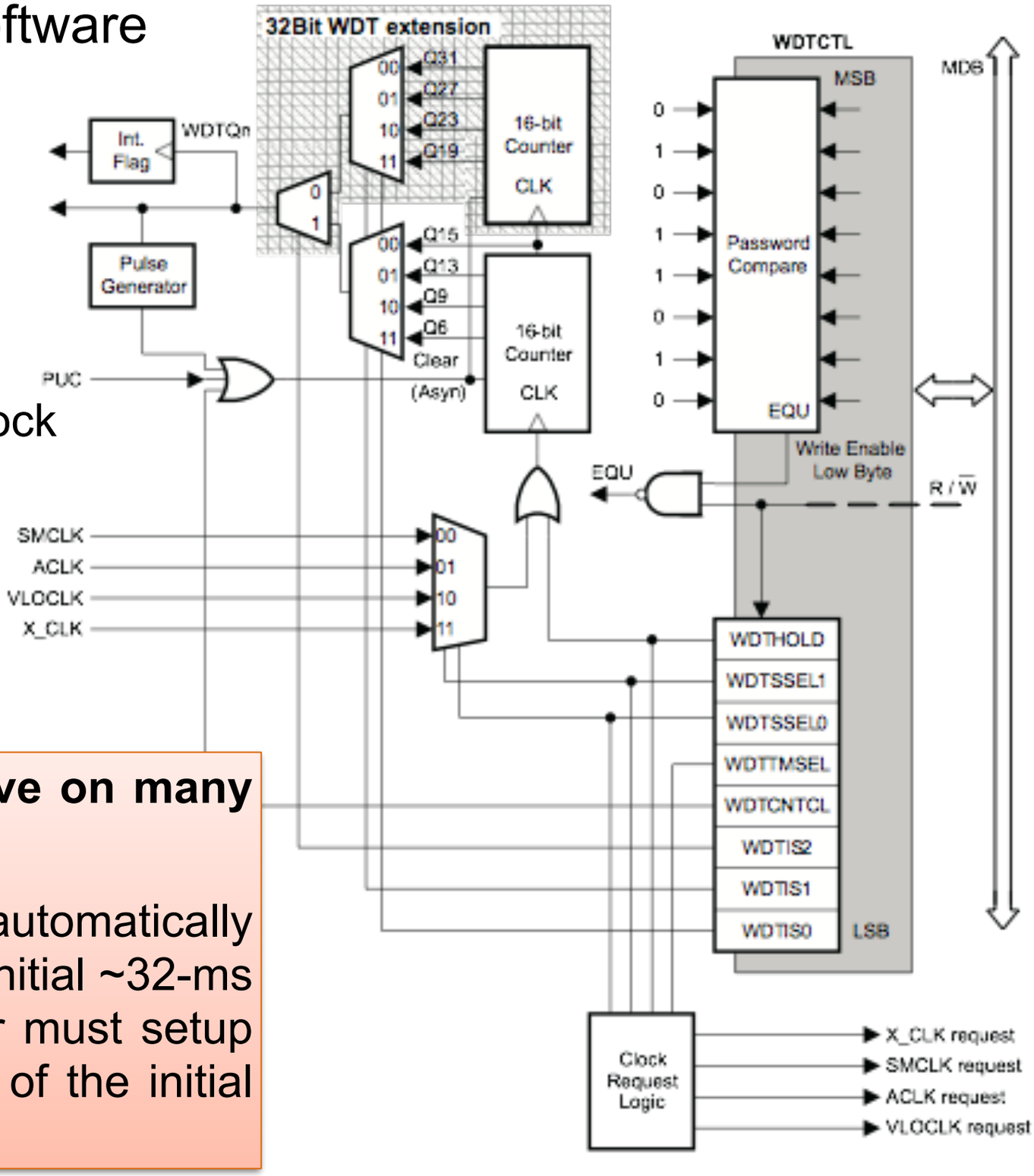
- Input Capture Mode: Save time when a specific event occurs and signal interrupt

- Output Compare Mode: Generate interrupt when counter reaches a specific value
  - Can set/reset/toggle a GPIO when counter reaches a specific value

- Output/ Pulse Width Modulated (PWM): Special case of Output Compare Mode
  - Set I/O when reaching a specific counter value
  - Clear I/O when reaching LOAD value
  - Usually used in continuous mode

Watchdog Timers (WDT)

- 32-bit counter not accessible by software
- Two modes: watchdog or interval
- Selectable, fail-safe clock source
- WDTCTL reg controls operation
  - 3 LSBs set the interval
  - WDTHOLD stops the WDT
  - WDTSSEL1 and WDTSSEL0 select clock
  - WDTCNTCL clears the WDT
  - WDTTMSEL sets the mode
- Password protected
  - Wrong password causes system reset

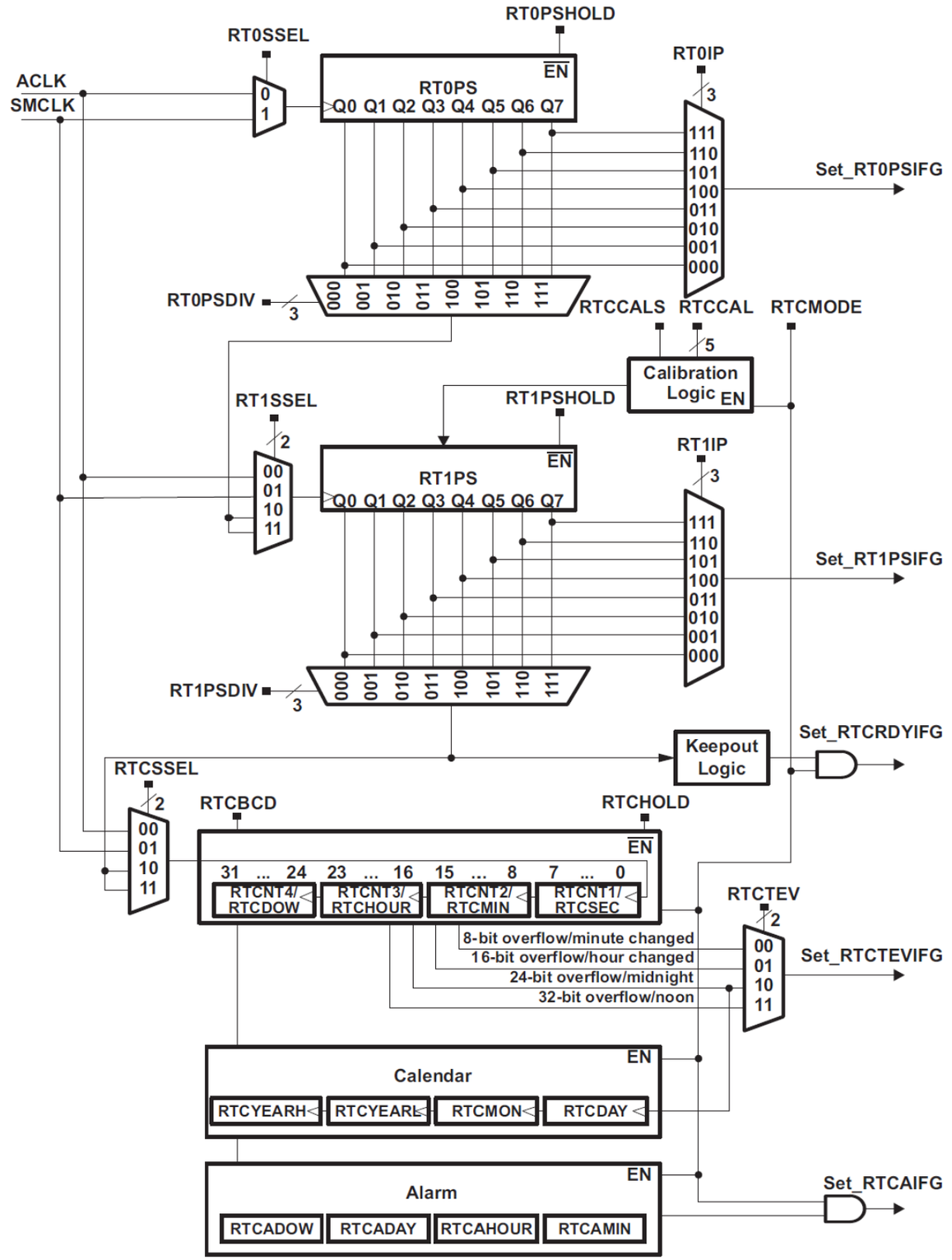


NOTE: Watchdog timer powers up active on many MCUs.

After a PUC, the WDT_A module is automatically configured in the watchdog mode with an initial ~32-ms reset interval using the SMCLK. The user must setup or halt the WDT_A prior to the expiration of the initial reset interval.

Real Time Clock (RTC)

- Calendar mode or counter mode
- Provides seconds, minutes, hours, day of week, day of month, month, and year in real-time clock with calendar function
- Interrupt capability
- Programmable alarms in real-time clock mode

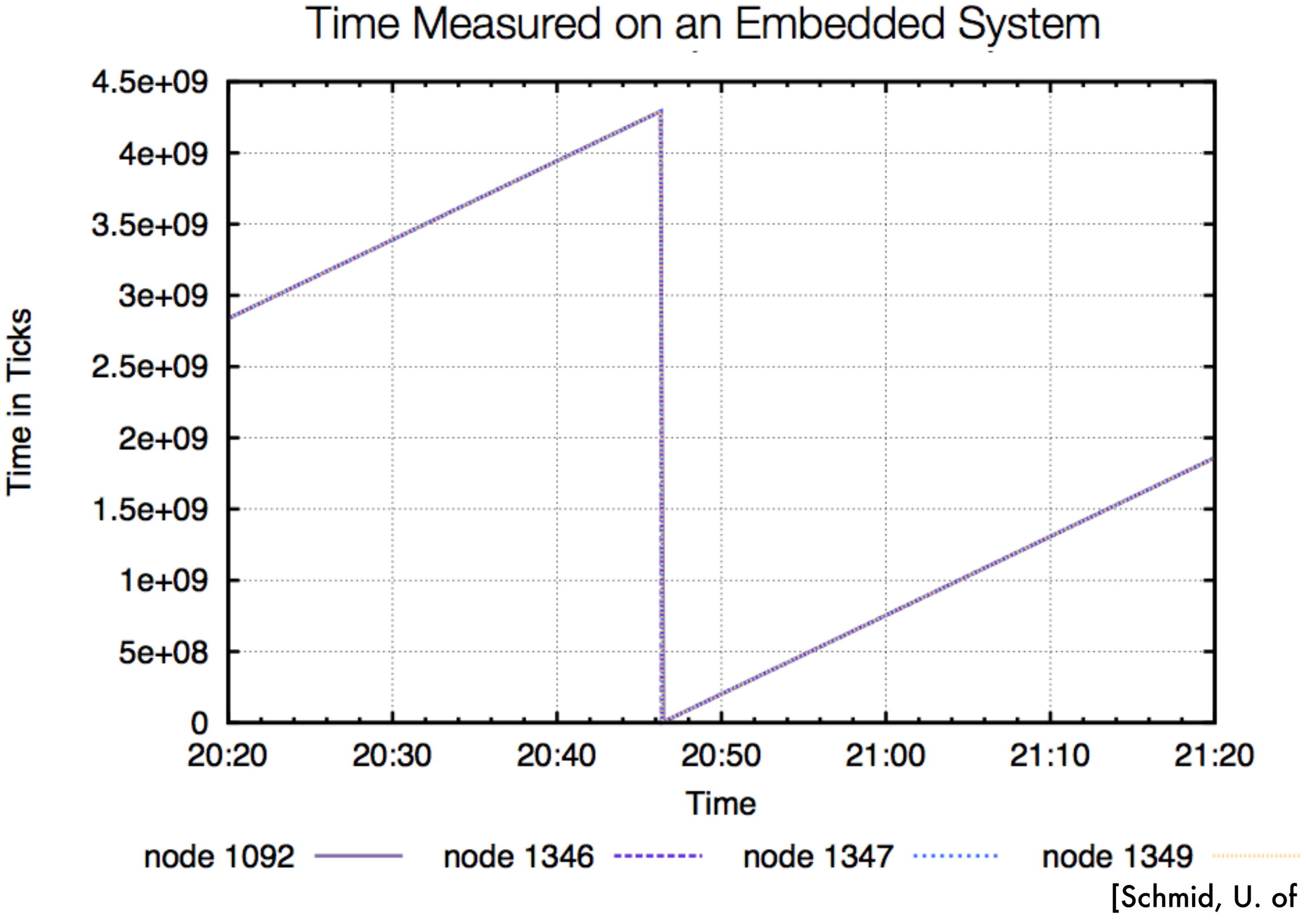


External RTC modules

- Complete modules that often provide a calendar function
- Example:
  - Maxim DS3231: Extremely Accurate I²C-Integrated RTC/TCXO/Crystal
- Accuracy
  - ±2ppm from 0°C to +40°C
  - ±3.5ppm from -40°C to +85°C
- Battery backup input for continuous timekeeping
- Low power consumption (< 3.5 uA while outputting 32 kHz clock)
- Real-Time Clock
  - Counts Seconds, Minutes, Hours, Day, Date, Month, and Year
  - Leap year compensation valid up to 2100
- Two time-of-day alarms
- Fast (400 kHz) I²C Interface
- 3.3V Operation
- Digital Temp Sensor Output: ±3°C Accuracy
- Register for Aging Trim

Clock Accuracy and Stability

Example: Four 32-bit, 32 kHz clocks



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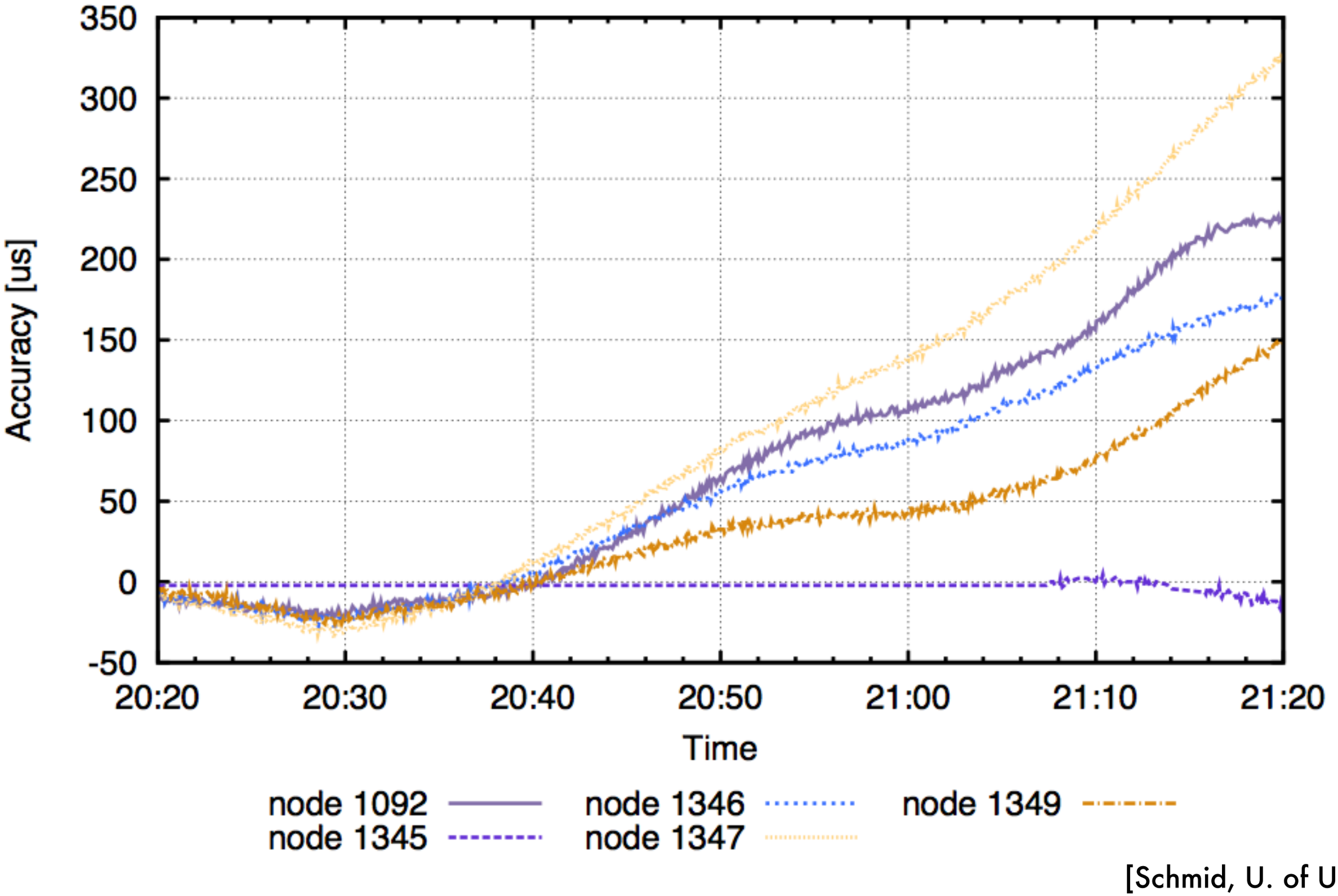
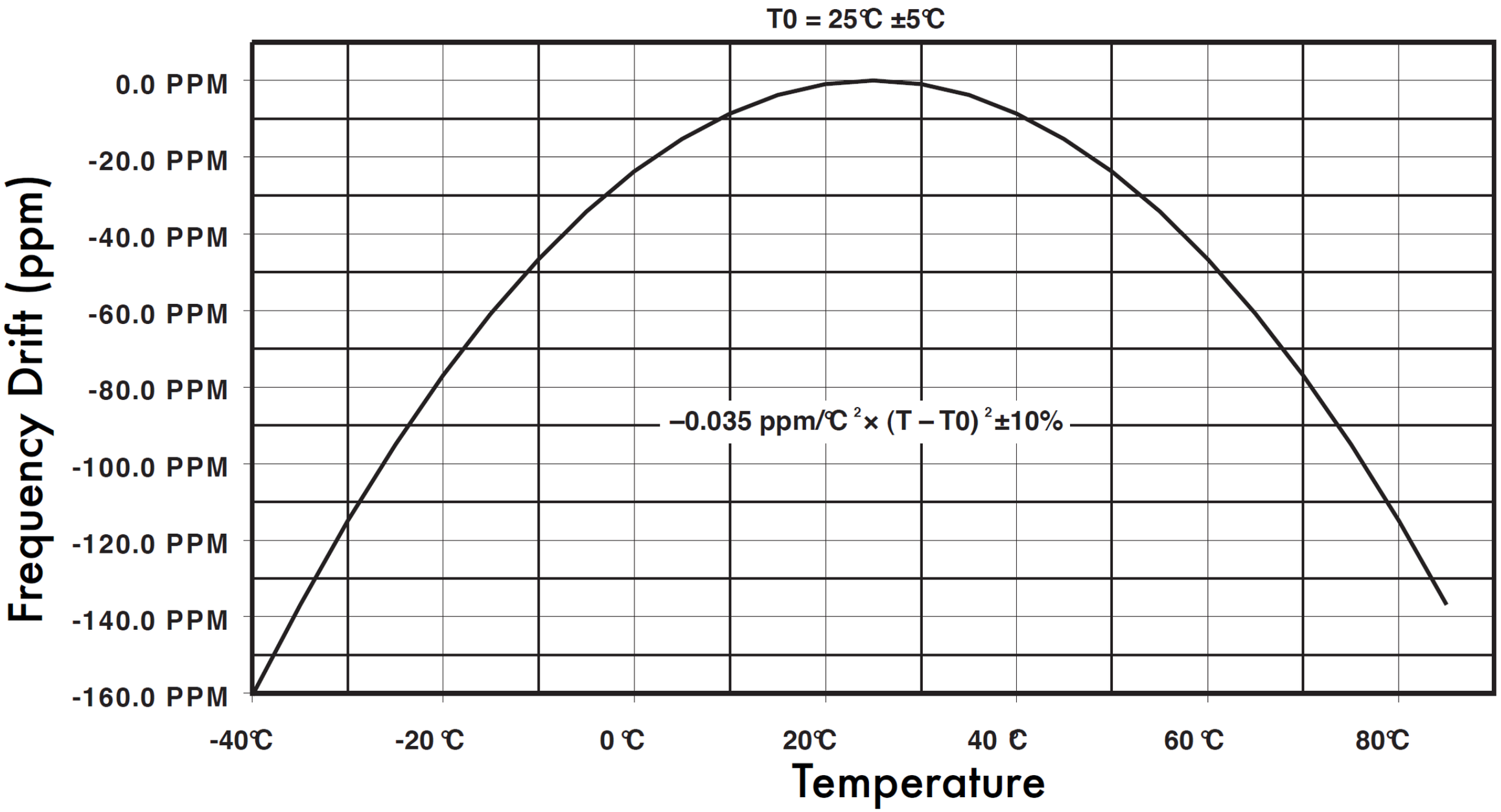
Example: Time Accuracy



[Schmid, U. of Utah]

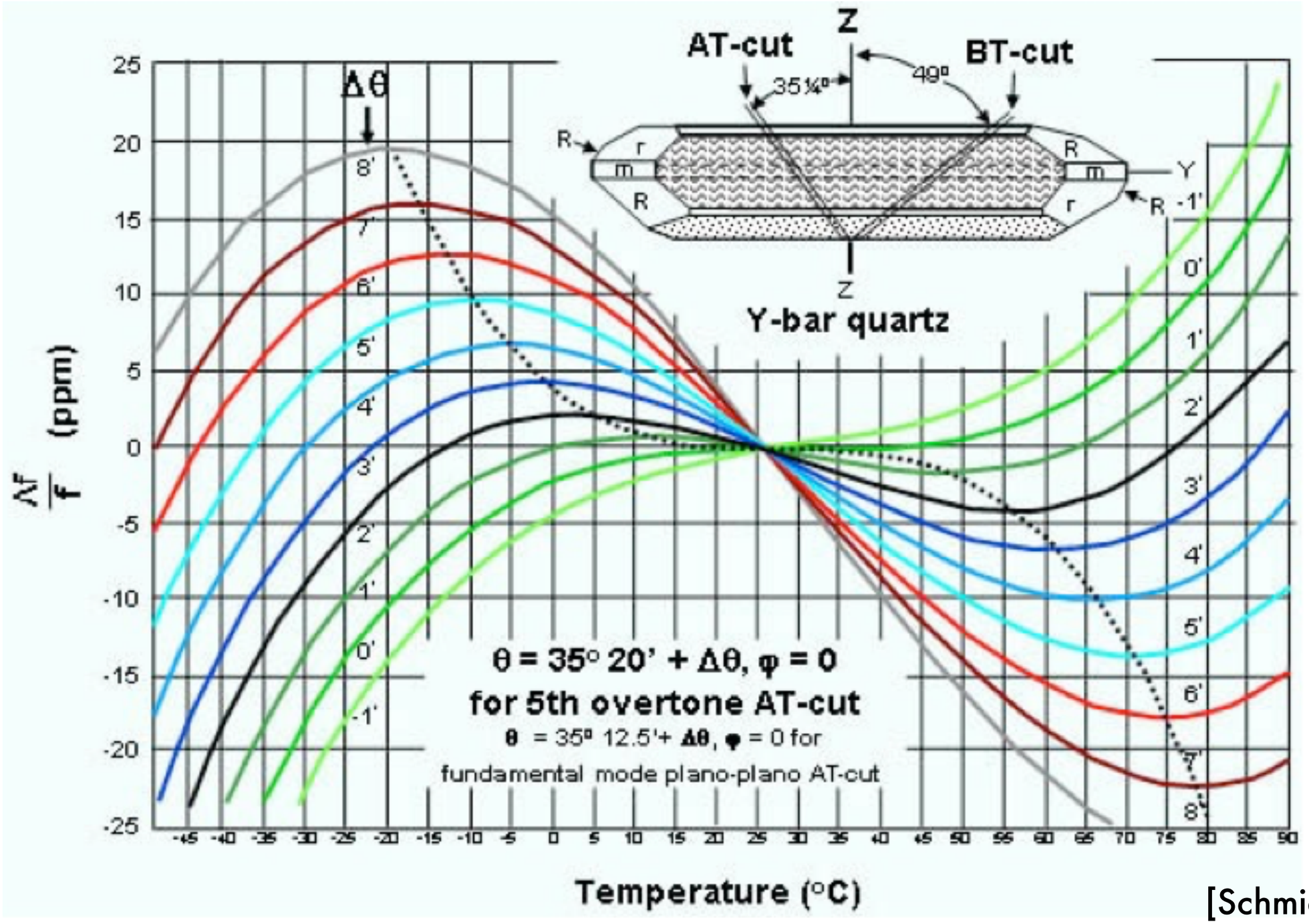
Tuning Fork Temp. Dependence

- Most common 32 KHz clock source
- Quadratic curve with zero ppm set at room temperature



Temp. Dependence of AT Cut

- Most common clock source > 400 KHz
- Cubic curve with parameters highly dependent on angle of cut



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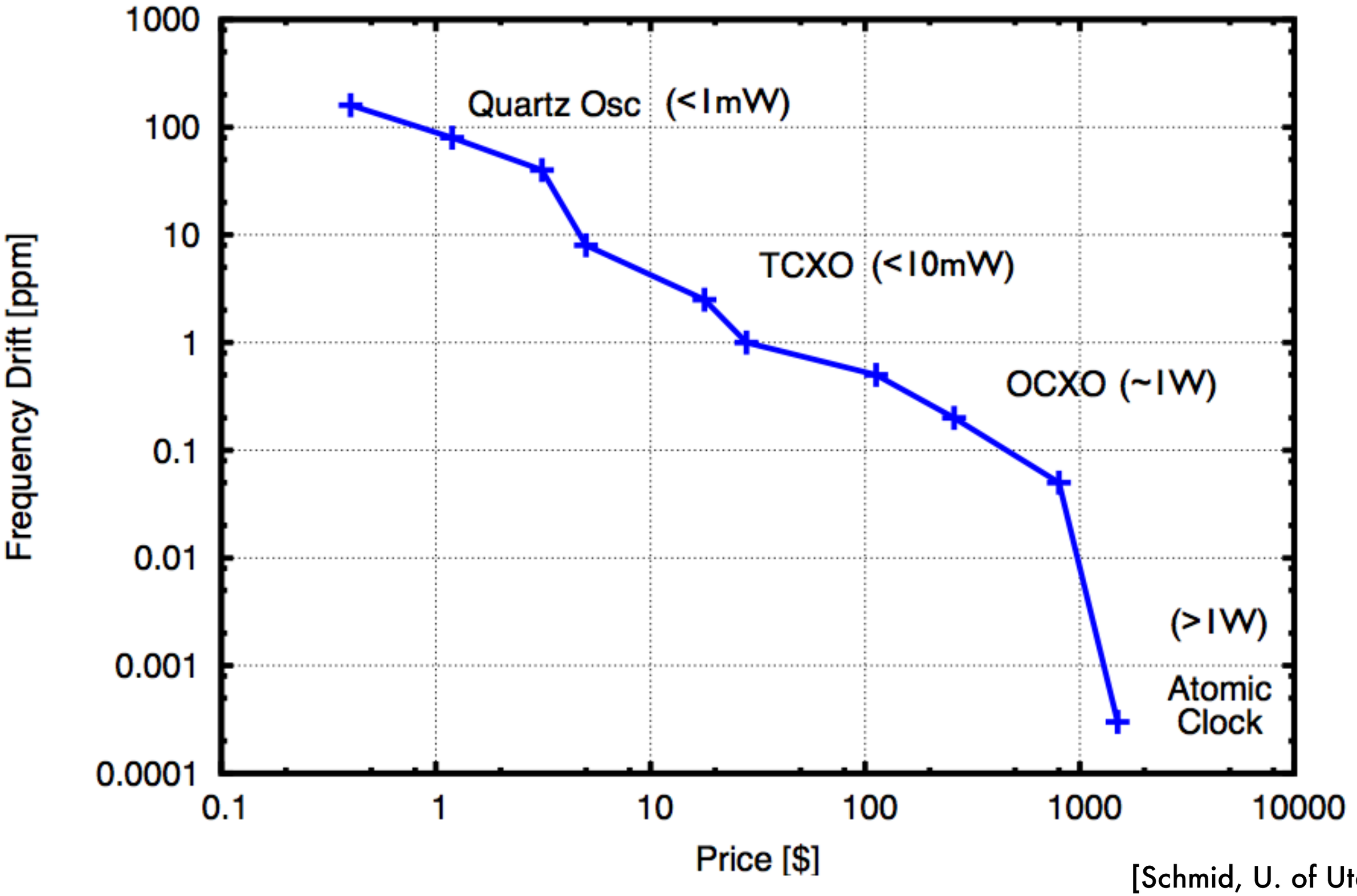
Frequency Drift vs. Cost



[Schmid, U. of Utah]

Did You Know?

- The most basic unit of time for humans is the second
  - 1s = Time a Cesium atom needs for 9,192,631,770 state transitions at 0°K
- Many other measurements are defined from the second
  - "The length of the path travelled by light in vacuum during a time interval of 1/299,792,458 of a second (17th CGP, 1983, Resolution 1)"
- World's most accurate clock (quantum clock) can keep time to an accuracy of within ±1 second in 3.7 billion years
  - NIST-F1 (Cesium fountain atomic clock) is the official time standard of the USA and keeps time to an accuracy of within ±1 second in 60 million years
- International Time Standard: UTC (Coordinated Universal Time)
  - UTC is based on the International Atomic Time (TAI) with leap seconds added
  - TAI is a weighted average of over 200 atomic clocks (mostly Cesium) in 70 national labs worldwide
  - UTC is exactly 36 seconds behind TAI as of 2017

Quick Review of Interrupts

- Program flow usually proceeds predictably, barring two exceptions that can happen at unpredictable times
  - Interrupts
  - Resets
- What is an interrupt?
  - A notification that something has happened that the MCU must attend to (usually quickly)
  - There can be many sources of interrupts in MCUs

- What happens when an interrupt occurs?
  - Processor stops what it is doing, executes an interrupt service routine (ISR), and then returns to what it was doing when the ISR has been completed

- The MCU must first know where the ISR code is located in memory to execute it. How does it know this?
  - It uses the interrupt vector (or vectors)
  - Can have a single vector for all interrupts or one vector per interrupt

Key Interrupt Issues

- Vectored Interrupts
- Interrupt Priority
- Maskable vs. Non-Maskable Interrupts
- What information is stored when interrupts occur?
- Nesting of Interrupts (use with care!)

Exception number	Exception type	Priority	Descriptions
1	Reset	-3 (Highest)	Reset
2	NMI	-2	Non-Maskable Interrupt
3	HardFault	-1	Fault handling exception
4–10	Reserved	NA	–
11	SVCall	Programmable	Supervisor call via SVC instruction
12–13	Reserved	NA	–
14	PendSV	Programmable	Pendable request for system service
15	SysTick	Programmable	System Tick Timer
16	Interrupt #0	Programmable	External Interrupt #0
17	Interrupt #1	Programmable	External Interrupt #1
…	…	…	…
47	Interrupt #31	Programmable	External Interrupt #31