Time / Frequency References

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Outline

- Time / frequency references
- Specifications
- Circuit solutions

Time / Frequency References

1. Time information
   – Continuously-on clock
   – Extremely low power
2. Frequency reference for communication
   – Carrier frequency for transmitter/receiver
   – Relatively high frequency
3. System clock for DSP/mixed-signal blocks
   – Clock-gated (only enabled at events)

Specifications

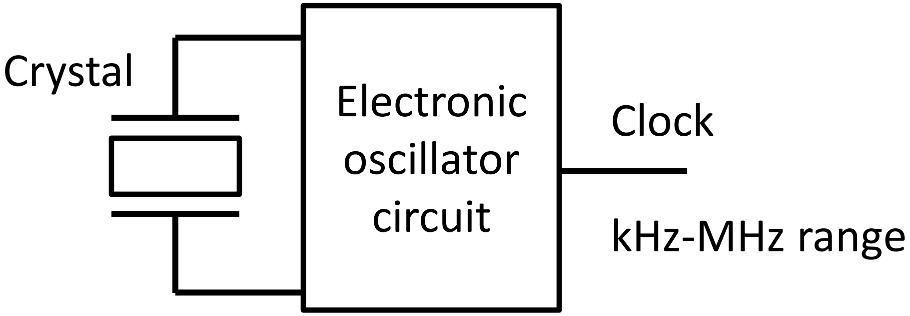
- Frequency of operation
- Power consumption
- Absolute precision (sample-sample variation)
- Voltage and temperature stability (ppm)
- Phase noise
- Start-up time (if not always-on)
- …

Circuit Solutions

- Frequency references
  - Using external resonator
    - Crystal oscillator
    - FBAR/SAW/BAW oscillator
    - MEMS oscillator
  - Using on-chip solution
    - LC oscillator
    - Ring oscillator
- Frequency synthesis
    - Frequency multiplier
    - PLL/DLL

Crystal Oscillator (XO)

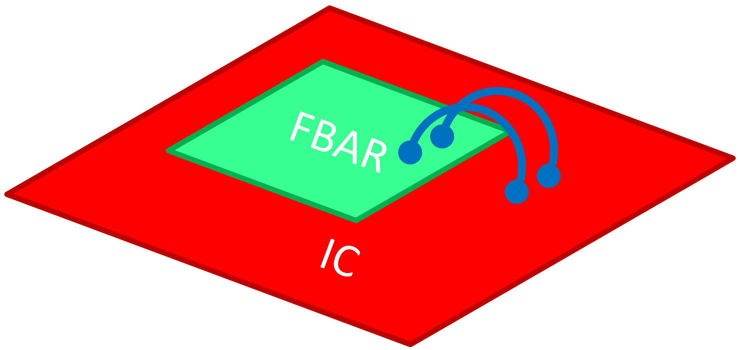
Crystal



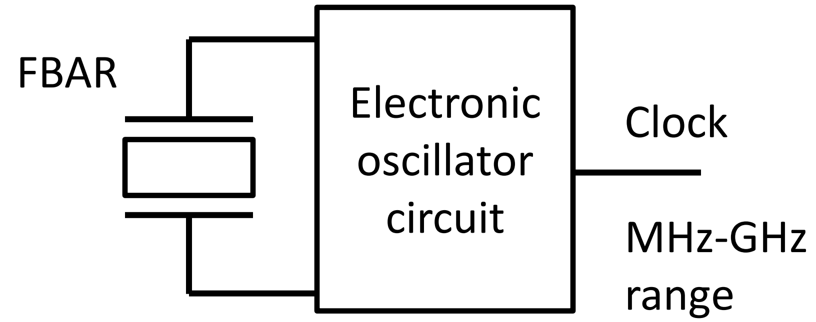
- Accurate; stable over voltage and temperature
- Relatively bulky crystal
- Examples
  - [1]: Crystal: 32kHz, 1.5mm^3, 30ppm
  - [2]: XO circuit: 2-28nW, 32kHz, 50ppm variation

[1] http://www.euroquartz.co.uk/Portals/0/eq158.pdf [2] K.-J. Hsiao, ISSCC 2014

FBAR/SAW/BAW Oscillator



FBAR on top of IC [3]
22uW at 2GHz



- FBAR = thin-Film Bulk Acoustic Resonator
- SAW/BAW = Surface/Bulk Acoustic Wave
  - Small form factor
  - Usually at high-frequency (>100MHz)

[3] Nelson, RFIC 2011

MEMS Oscillator

- MEMS = Micro Electro Mechanical System

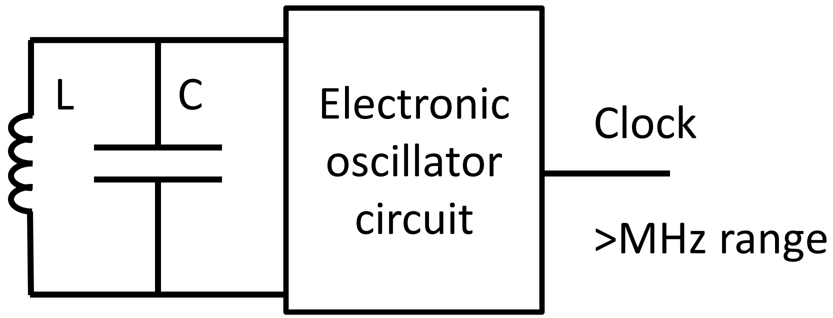
MEMS device packaged with oscillator circuit [4]
1uW at 32kHz, 10ppm variation, 1.2mm^2 with package

- Smaller than crystal oscillator
- High accuracy and stability
- Higher power (due to stand-alone comp.?)
- Special (MEMS) technology

[4] http://www.sitime.com/products/datasheets/sit1532/SiT1532-datasheet.pdf

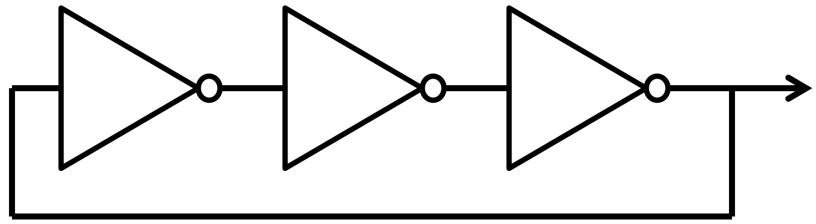
LC Oscillator

$$f_{osc} = \frac{1}{2\pi\sqrt{LC}}$$



- Circuit (including L, C) can be integrated on-chip
  - On-chip LC: limited to small L, C → High frequency
  - Off-chip LC: larger L, C → Lower frequency possible

Ring Oscillator



- Transistors-only solution
  - No external components
  - Usually no large passives (like L, C)
- Fundamentally sensitive to VT and not precise
- Example:
  - [5]: RC oscillator; 190nW; 32kHz; 2000ppm

[5] D. Griffith, ISSCC 2014

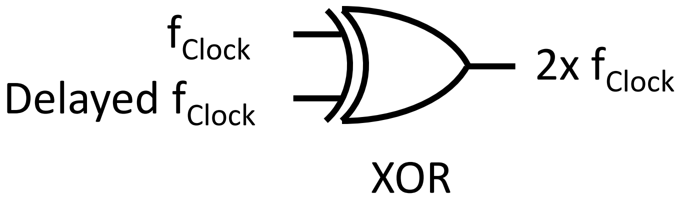
Summary Frequency References

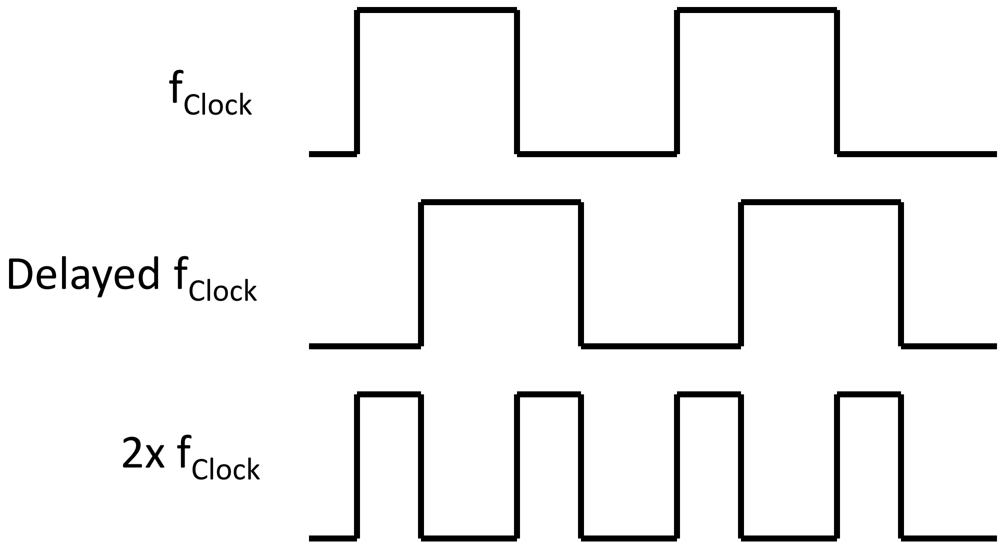
Type	Advantages	Disadvantages
Crystal	Stable over VT; low power (50ppm, 2nW, 32kHz)	External crystal; large size ($1.5mm^3$ for 32kHz)
FBAR/SAW/BAW	Small size, could be placed on top of chip	Only at high frequency (>100MHz), consuming too much power (>>uW)
MEMS	Small size, could be placed on top of chip (10ppm, 1uW, 32kHz)	Special technology needed
LC oscillator	On-chip or Off-chip LC	On-chip only at high freq. (>MHz)
Ring oscillator	Small size, on-chip	Not precise; not stable over VT (~2000ppm, 190nW, 32kHz)

- Crystal has excellent performance but is a bit bulky and not on-chip
- MEMS has excellent performance but consumes more power
- LC can be integrated on-chip, but only for high frequencies
- Ring oscillator can be small & on-chip but has limited performance

Frequency Multiplier

- Circuit that can generate harmonics of the reference → Multiplies reference frequency
- Example: XOR gate with clock/delayed clock





PLL/DLL

- PLL/DLL can generate a range of output frequencies based on a single ref. frequency
- Flexible freq. generation but complex circuit
- Could be duty-cycled (event-driven) if start-up time is fast enough
- Example:
  - [6]: PLL, 19uW at 20MHz output frequency, using 150kHz reference frequency

[6] G. Meuleman, ISCAS 2014