Timing Methods

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The Walk Effect

- **Resolution**: the smallest time interval that can be measured with accuracy.
- **Walk**: caused by variations in amplitude and/or risetime of the incoming signals.
  - This dependence on the amplitude or rise-time causes the logic signal to *walk about*.
  - To minimize walk a number of different triggering or time-pickoff methods have been developed.
  - A second source of walk is the finite amount of charge necessary to trigger the discriminator.

Timing Jitter

- A time variation dependent on the amplitude of the fluctuations due to noise and statistical fluctuations
  - faster the rise time the better the time jitter.

Time-Pickoff Methods

Leading Edge Triggering (LE)

- The logic signal is generated at the moment the analog pulse crosses the threshold.
- Walk can be reduced by restricting the amplitude range and using as low a threshold as electronic noise will permit.
  - 1 to 1.2 amplitude range => 0.4 ns resolution.
  - 1 to 10 amplitude range => 10 ns resolution.

Fast Zero-Crossing Triggering

- Pulse is transformed into a bipolar pulse and a trigger made on the zero-crossing point.
- Signals are required to be of constant shape and risetime.
  - 1 to 1.2 amplitude range => 0.4 ns resolution.
  - 1 to 10 amplitude range => 0.6 ns resolution.

Time-Pickoff Methods continued

Constant Fraction Triggering (CFT)

- The logic signal is generated at a constant fraction of the peak height to produce an essentially walk-free time signal.
- CFT technique:
  - split incoming pulse into 2 parts, with one part delayed by a time equal to the time it takes for the pulse to rise from the constant fraction level to the pulse peak,
  - the other part is inverted and attenuated by a factor k,
  - the 2 are then summed to produce a bipolar pulse,
  - the point at which the signals cancel (zero-crossing point) is then at a constant fraction k of the original signal height.
- A constant risetime is required for the method to work.
  - 1 to 100 amplitude range => 20 ps resolution.

Time-Pickoff Methods continued

Amplitude and Risetime Compensation Triggering (ARC)

- This is a variant of CFT that does not require a constant risetime.
- ARC technique:
  - In the true CFT method, τ_d must be long enough to allow the undelayed signal to reach its peak.
  - In the ARC method, τ_d is made smaller than the risetime so that the summed signal crosses before the signal maximum is reached.
  - The zero-crossing time thus depends only on the early portion of the signal where differences between pulse shapes are at a minimum.

Analog Timing Methods

The Start-Stop time-to-Amplitude Converter

- Relate time interval between two events to quantity of charge discharged by a capacitor during this period.

Time Overlap TAC's

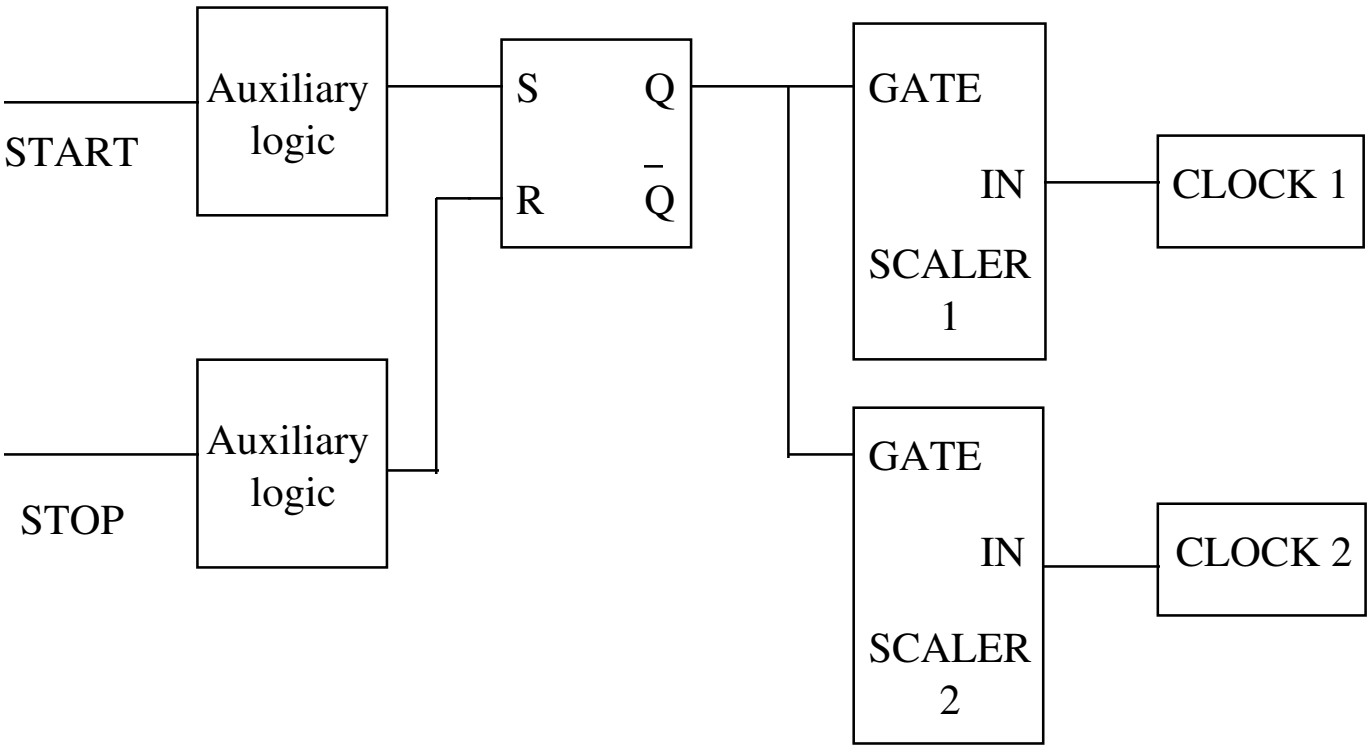
- Overlap between two wide START and STOP pulses is measured and the difference is taken.
- The method is restricted to pulses smaller than the pulse width.
- The method does not distinguish between which pulse arrives first.

Digital Timing Methods

The Time-to-Digital Converter (TDC)

- Best resolution achieved by digitize a TDC using an ADC.
- Direct method uses counting techniques & stable oscillators.
  - Use START signal to gate scaler which counts a constant frequency oscillator (or clock). Gate scaler off with STOP signal to yield a number proportional to the time interval between pulses.
  - Possible that START and STOP signal arrive at same time. This is remedied by using a second *watchdog* timer which is triggered by each CLEAR and reset by each START.
  - The resolution of the counting TDC depends on the frequency of the clock used.
  - For a given frequency this resolution can be doubled by using two clocks synchronized on opposite phases.

Oppositely Synchronized Clocks

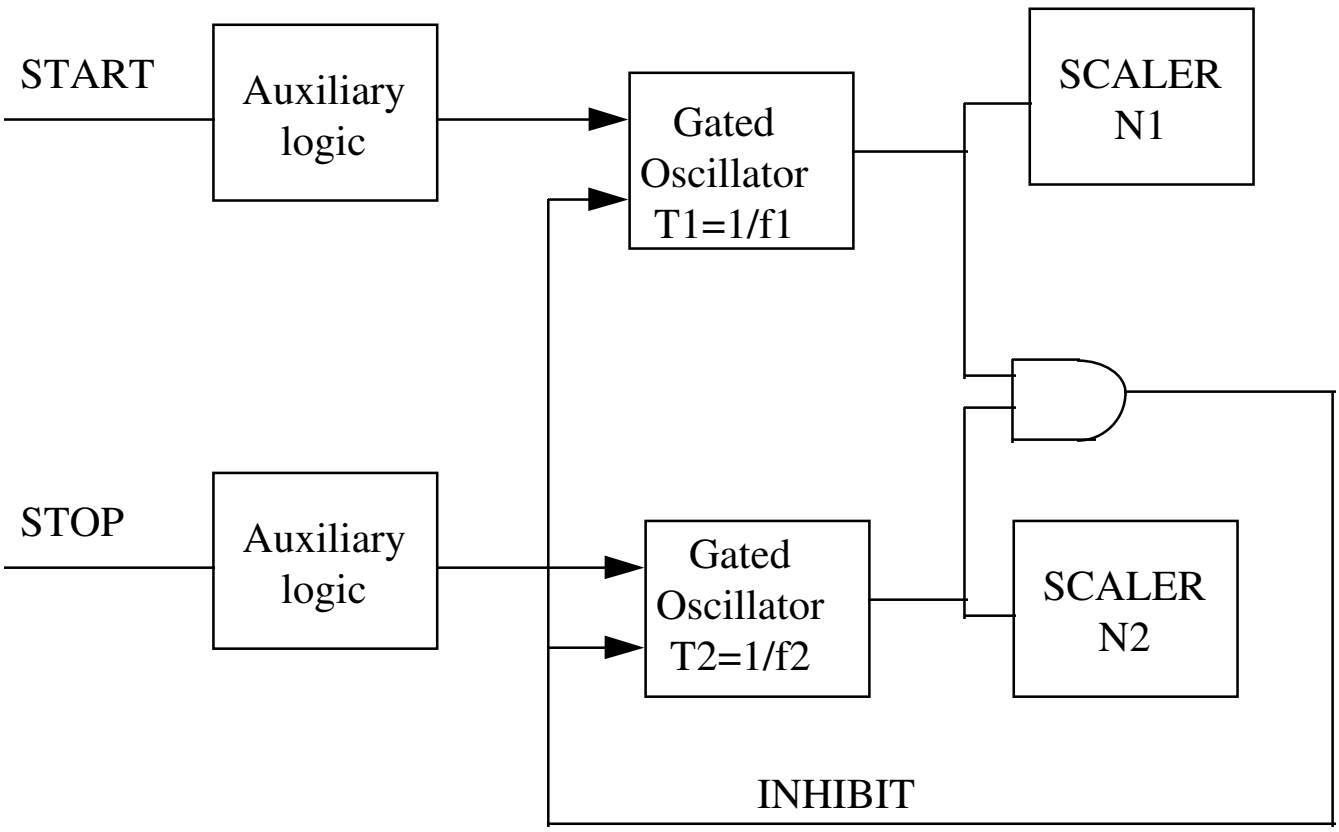


Digital Timing Methods Continued

The Vernier TDC

- Two oscillators of slightly different frequencies f_1 and f_2 are used.
  - START gates on first clock while second remains off.
  - STOP gates second clock on and continues oscillating along with first clock until the two are in phase.

The Vernier TDC



Digital Timing Methods Continued

Calibrating the Timing System

- Must calibrate time scale, and measure system linearity and resolution.

Time Scale Calibration

- Calibrate with single source to drive both the START and STOP channels.
- Delay the STOP.
- Difference between peaks produced by different delays gives calibration of time scale.

Time Resolution

- The width of each peak serves also as a measure of the time resolution.

Linearity

- Clock is applied to START channel while random source gates on STOP.
- Time intervals are thus produced randomly.
- The degree of uniformity provides a measure of the differential linearity.
- The integral linearity can be obtained by plotting the integral counts versus channel number.