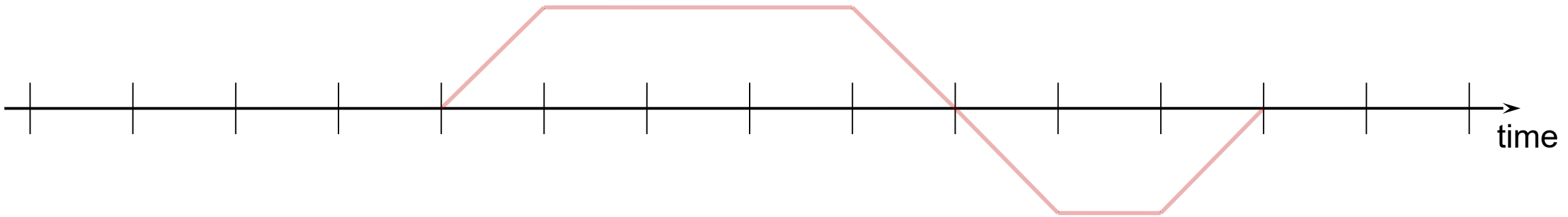
# *Pulseq*

# Time and Shape Specification

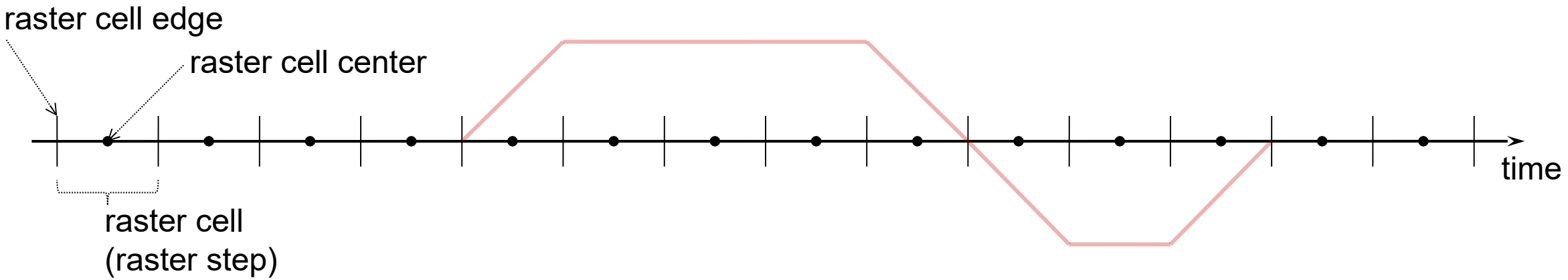
(including v1.5.0 updates)

# Shapes and Raster Times in *Pulseq*




- Specification needed for achieving precise control of gradient and RF waveforms (was missing prior to 1.4.0)
- Pulseq defines four types of raster times
  - adcRasterTime, rfRasterTime, gradRasterTime, blockDurationRaster
- Raster ‘thinking’ is probably one of the most demanding concepts in the practical pulse sequence programming
- Important concepts: **raster cells, edges and centers**

# Definitions

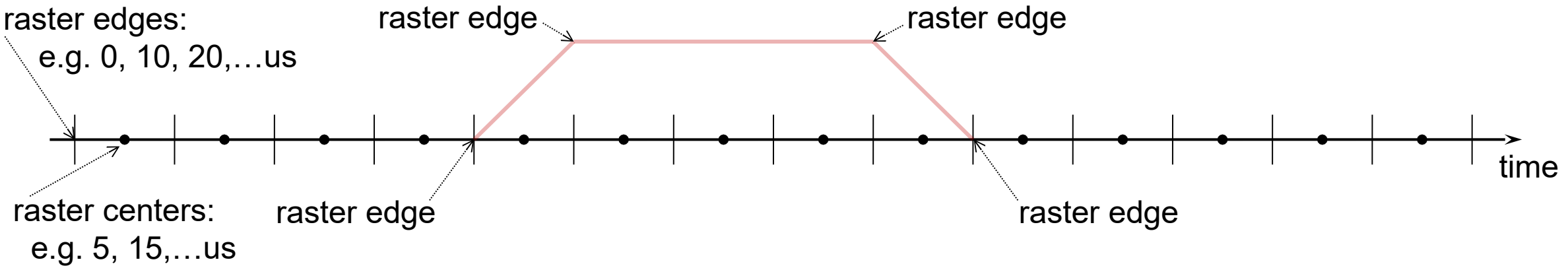



- The continuous and uninterrupted time axes is split in discrete time intervals, ***raster cells***, each of the equal duration of ***raster step***
- Each raster cell begins with the ***raster edge***
- The center of each raster cell is termed ***raster center***

# Shapes in *Pulseq*

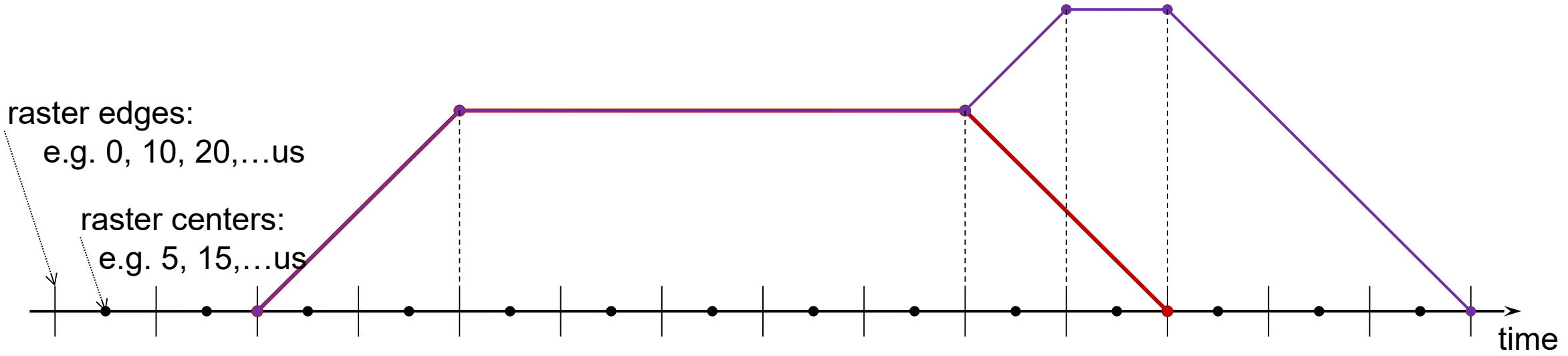
- Objects stored in [Shapes] are 1D vectors
  - Complex-valued shapes (e.g. for RF): two vectors (amplitude & phase)
- Two types of time representation (three since v1.5.0):
  - Shapes with explicit time vectors (time_shape_id >=1 provided)
    - Sampling points are (typically) on raster edges, but this is not a requirement
  - Shapes with a regular sampling
    - No time_shape_id provided (time_shape_id=0)
    - Sampling time points are ALWAYS at raster cell centers
    - Time vector can be restored based on the corresponding raster step as
      ( [1:N] - 0.5 ) * raster_step  % Matlab notation
  - Updated in v1.5.0: regular sampling with oversampling
    - Marked by time_shape_id = -1
    - Sampling time points alternate between the cell centers and cell edges with the sampling period being exactly 0.5 of default dwell time
    - The shape starts and ends at the cell centers; first and last points are not included into the shape vector

# Conventional Trapezoid Gradient



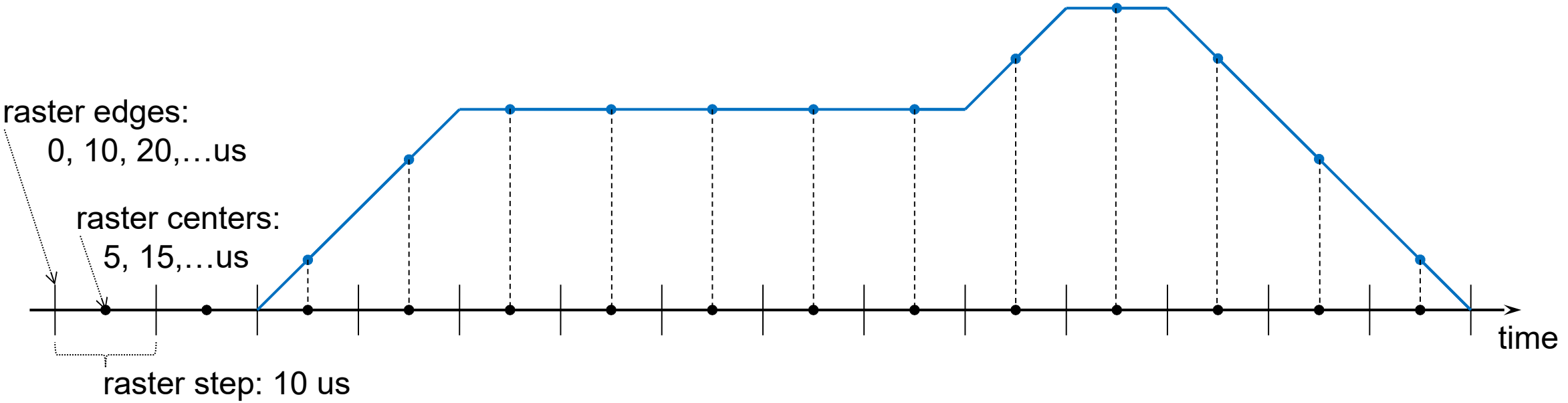

- Conventional gradients begin and end on gradient raster edges
- All timing elements of trapezoids need to be multiple of gradientRasterTime
- Beginning and end of the gradient flat top are both aligned to gradient raster edges
- The value of gradRasterTime (raster step) on Siemens is 10 us

# Extended Trapezoid Gradient



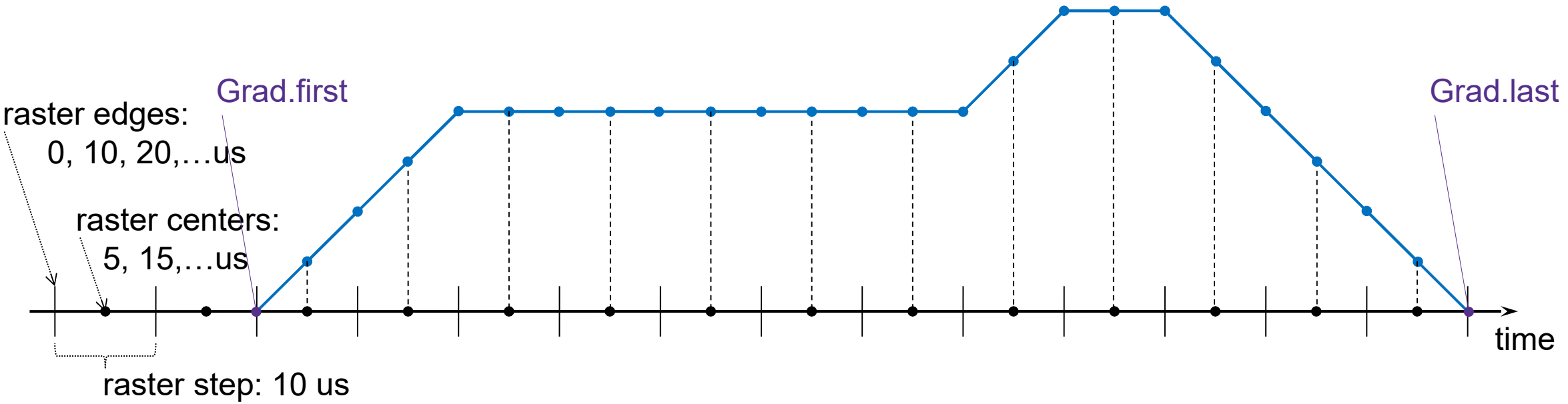

- Conventional trapezoid has it vertices on raster edges
- Extended trapezoid is a generalization of a conventional trapezoid
- Arbitrary number of vertices, all aligned on raster edges
  - Implemented by providing time_shape_id with the “Grad” object
- Extended trapezoids may start/end at non-zero amplitude(s)
  - Vertices with non-zero amplitude must touch block boundary (to connect to neighbors)

# Gradient with a Regularly-Sampled Shape




- Sampled (a.k.a. arbitrary) gradients: samples on raster centers
  - Gradient raster is 10 us on Siemens
  - Note raster differences to conventional and extended trapezoids!
- Implemented by setting time_shape_id to 0 with the “Grad” object
- As for extended trapezoids: non-zero start/end values are allowed

# Gradient with an Oversampled Shape



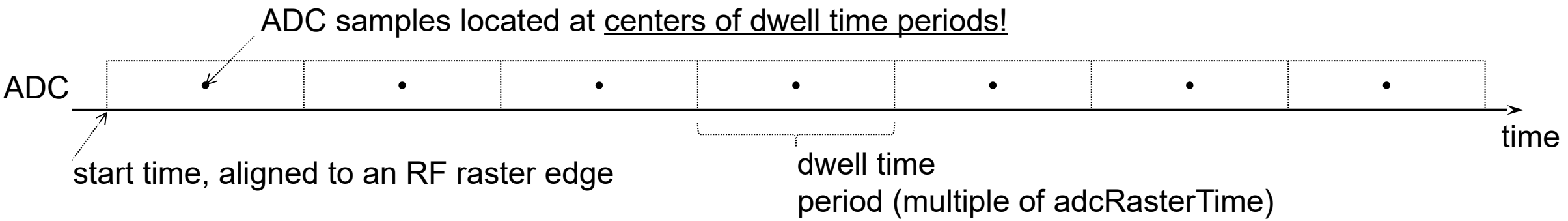

- Sampled (a.k.a. arbitrary) gradients: samples on raster centers
  - Gradient raster is 10 us on Siemens
  - Note raster differences to conventional and extended trapezoids!
- Implemented by setting time_shape_id to -1 in the “Grad” object
- First and last values are not stored as a part of the shape, but only in the “Grad” object

# RF Raster Times

- RF objects can be either regularly sampled or defined by vertices
  - mr.makeSincPulse() defines a regularly sampled pulse
  - mr.makeBlockPulse() uses a shape with two points: (0,1) and (dur,1)
- The majority of shaped RF pulses are regularly sampled
  - Dwell time for regularly-sampled pulses: multiple of rfRasterTime
- Raster alignment rules:
  - The beginning of an RF object must be aligned to the RF raster edge
  - Sampling points of RF pulses are aligned to the centers of the dwell time periods
- rfRasterTime on Siemens: 1us

# ADC Raster Times

- Special rules for the ADC (mixing RF and ADC raster times)
  - ADC start time must be aligned to rfRasterTime
  - ADC dwell time: multiple of adcRasterTime
- adcRaster time is 100ns on Siemens
- Sampling is assumed to happen instantly at the **centers** of the dwell time periods



# Block Duration Raster

- blockDurationRaster is the atomic time step defining the duration of all blocks in a Pulseq sequence
  - All blocks have duration integer-multiple of blockDurationRaster

- All blocks begin and end at edges of the block raster
- Edges of all types of rasters coincide at the beginning of the block
  - rfRasterTime and gradRasterTime must be integer-multiples of blockDurationRaster or vise versa