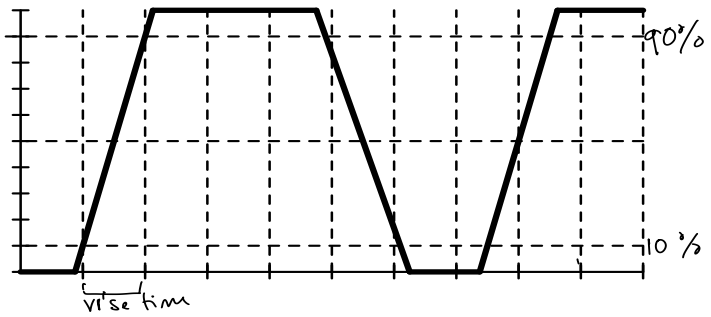
## Timing Analysis

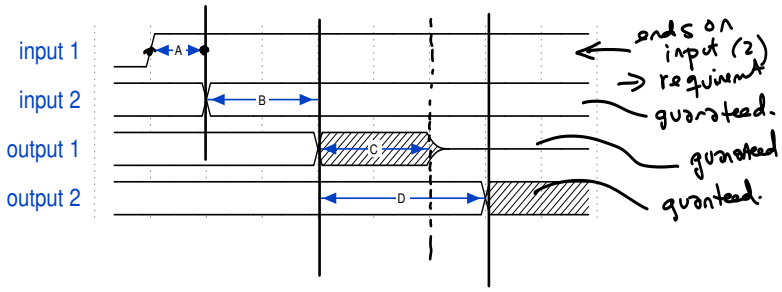
**Exercise 1**:




rise time = 1 div = 20ns.
period = 6.5 div x 20ns/div = 130ns.
+ve pulse width = 4 div. · 20ns/div = 80ns
(low for 2.5 · 20) = $\frac{50\text{ns}}{130\text{ns}} \simeq 38.4\%$

The diagram above shows an oscilloscope screen capture that includes one period of an *active-low* digital waveform. The scale on the horizontal axis is 20 ns per division. What are: the rise time, period, positive pulse width and duty cycle?

## Exercise 2:




Label the specifications A through D as requirements or guaranteed responses. Which specifications are measured to a signal being in a high-impedance state? Which are measured from a rising edge only? From either?

**Exercise 3**: Is $t_{PD}$ a requirement or a guaranteed response?

measured to an output ⇒ guaranteed response

**Exercise 4**: Is $t_{SU}$ a requirement or a guaranteed response? How about $t_H$?

$t_{SU}$ → measured from D to ↓ clock
⇒ requirement

$t_H$ → measured from ↓ clock to D
⇒ requirement.

**Exercise 5**:

$$t_{SU}\text{ (avail)} = T_{clock} - t_{CO}\text{ (max)} - t_{PD}\text{ (max)}$$

Which of the specifications in the formula above decrease the available setup time as they increase? Which increase it?

$T_{clock}$ increases ($t_{su}$ avail)

$T_{co}$ & $t_{PD}$ decrease $t_{su}$ (avail)

**Exercise 6**: For a particular circuit $f_{clock}$ is 50 MHz, $t_{CO}$ is 2 ns (maximum), the worst-case (maximum) $t_{PD}$ in a circuit is 15 ns and the minimum setup time requirement is 5 ns. What is the setup time slack? Will this circuit operate reliably? If not, what it the maximum clock frequency at which it will?

$$t_{SU}\text{ (avail)} = T_{clock} - t_{CO}\text{ (max)} - t_{PD}\text{ (max)}$$

$$\text{slack} = t_{SU}\text{ (available)} - t_{SU}\text{ (required)}$$

$$T_{clock} = \frac{1}{50\times10^6} = \frac{1000}{50\times10^9} = 20\times10^{-9} = 20\text{ns}$$

$t_{su}$ (avail) $= 20 - 2 - 15 = 3$ ns.

$t_{su}$ (reqd) $= 5$ ns.

slack $= 3 - 5 = -2$ — negative slack → possible metastable (unreliable) behaviour

for slack $= 0$ need $t_{su}$ (avail) $= 5$ ns.

$$5 = T_{clock} - 2 - 15$$

$$T_{clock} = 5 + 2 + 15 = 22\text{ns}$$

$$f_{clock} = \frac{1}{T_{clock}} = \frac{1}{22\times10^{-9}} \approx 45.5\text{ MHz}$$

**Exercise 7**: What is the maximum clock frequency for a counter using flip-flops with 200 ps setup times, 50 ps clock-to-output delays and adder logic that has a 250 ps propagation delay?

$t_{su}$ (reqd) $= 200$ ps

$t_{co} = 50$ ps

$t_{PD} = 250$ ps

$$t_{su}\text{ (avail)} = t_{su}\text{ (reqd)} = 200 = T_{clock} - t_{co} - t_{PD}$$

$$= T_{clock} - 50 - 250$$

$$T_{clock} = 200 + 50 + 250 = 500\text{ps}$$

$$f_{clock} = 2\text{ GHz}.$$