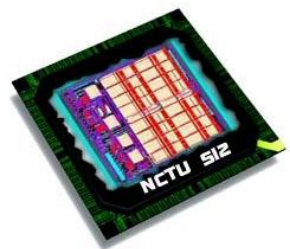


STATIC TIMING ANALYSIS

NYCU-EE IC LAB FALL 2023

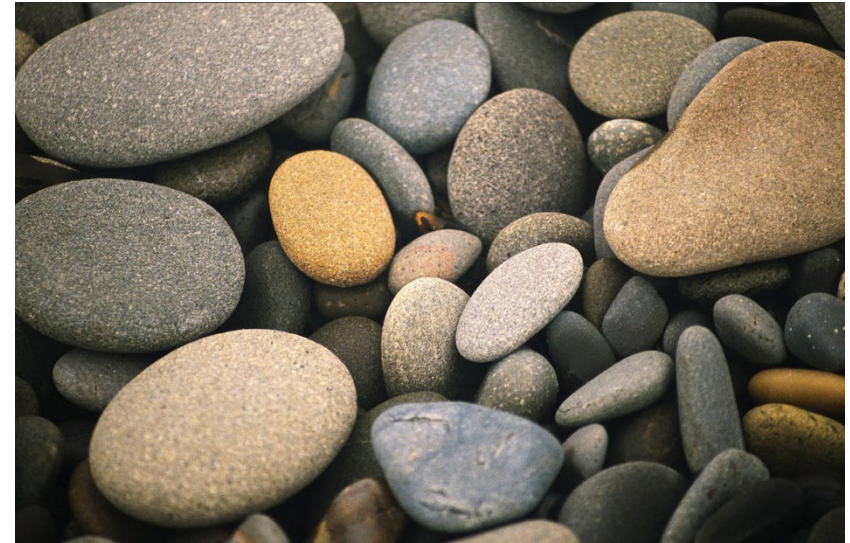
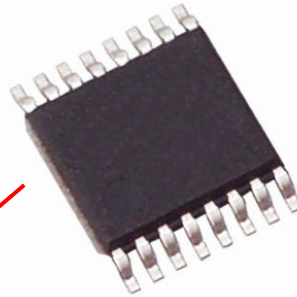


Lecturer: Ting-Yu Chang

- ✓ **Timing analysis is integral part of ASIC/VLSI design flow. Anything else can be compromised but not timing!**

Timing correct !

Timing error !



Outline

✓ **Timing Analysis Considering Clk Latency**

- STA vs DTA
- CLK latency
- CLK uncertainty

✓ **Multicycle Path Specification**

- Specify Multicycle Path
- Single clock system
- Multiple clocks system

✓ **Clock Domain Crossing (CDC)**

✓ **Appendix**



✓ **Timing Analysis Considering Clk Latency**

- STA vs DTA
- CLK latency
- CLK uncertainty

✓ **Multicycle Path Specification**

- Specify Multicycle Path
- Single clock system
- Multiple clocks system

✓ **Clock Domain Crossing (CDC)**

✓ **Appendix**



STA vs DTA

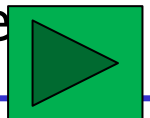
✓ STA(Static Timing Analysis)

- Verify the timing of a digital design based on a **statistic** method without requiring a simulation of the full circuit
- STA is a **complete** and **exhaustive** verification of all timing checks of a design because it **analyzes every timing paths in design according to constraints.**
- check that if there is any violation on setup/hold time in the timing path, glitches, critical path and clock skew.
- STA aims at different corner to analysis, so the analysis time is faster than DTA.

✓ DTA (Dynamic Timing Analysis)

- Quality(Coverage) of the Dynamic Timing Analysis (DTA) increases with the increase of **input test vectors.**
- The growing size of test vectors increase simulation time, especially in post-sim, but can verify the functionality at the same time

Review setup/hold time



Clock Latency

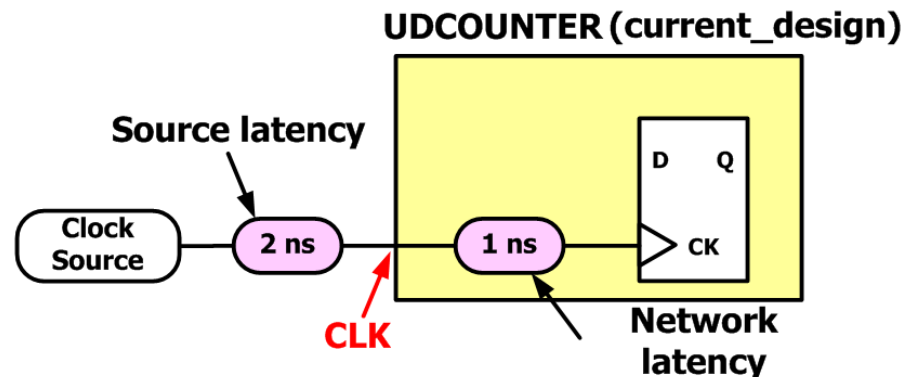
✓ Two types of clock latency

– Clock source latency

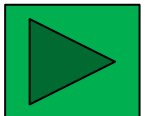
- Clock source latency is the delay from the **clock source** to the **clock definition point(CLK)**.
- Source latency could represent either on-chip or off-chip latency.

– Clock network latency

- from the **clock definition point(CLK)** to the **clock pin of a flip-flop**.



Appendix

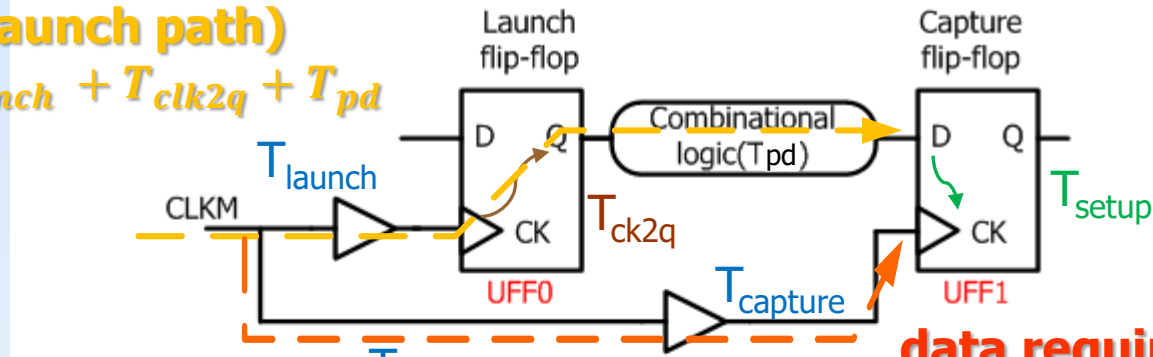


Setup time issue

data arrival time

(Launch path)

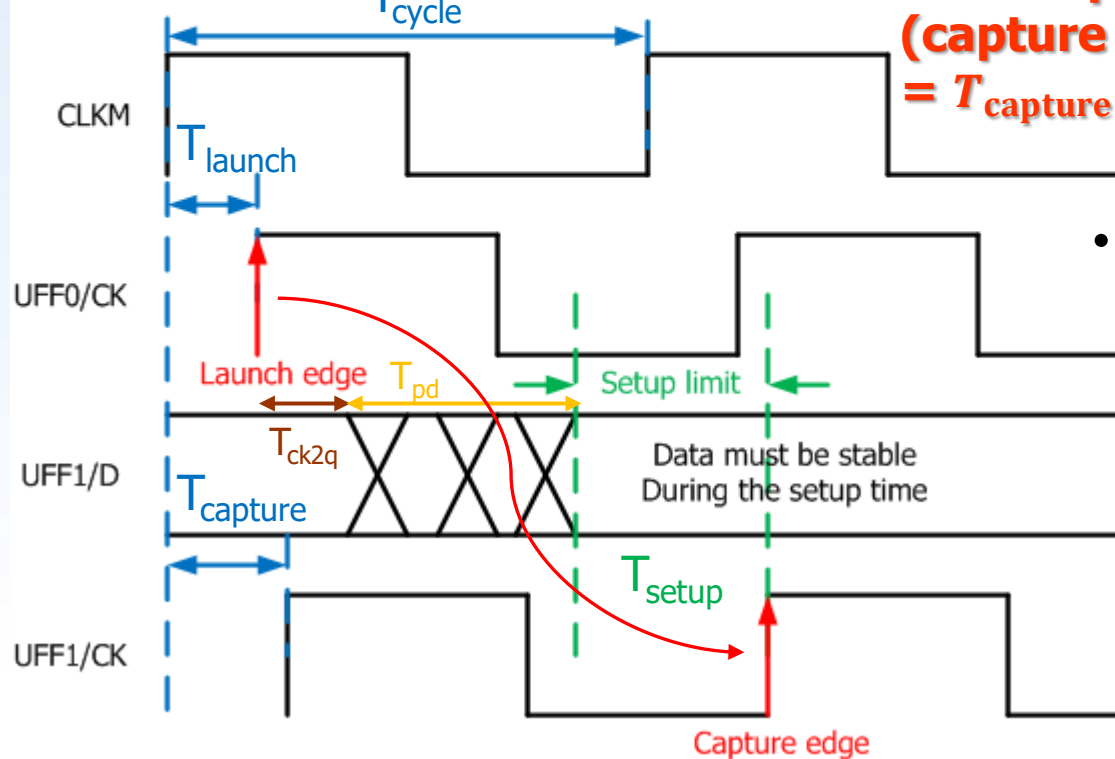
$$= T_{\text{launch}} + T_{\text{clk2q}} + T_{\text{pd}}$$



data arrival time <
data required time

**data required time
(capture path)**

$$= T_{\text{capture}} + T_{\text{cycle}} - T_{\text{setup}}$$



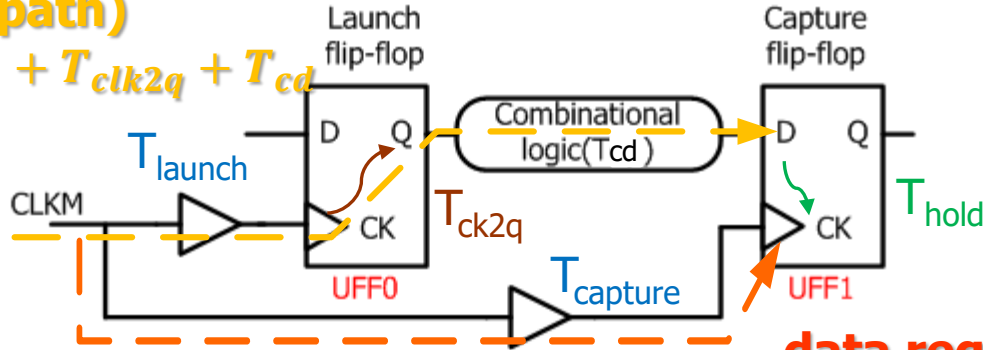
- Setup check ensures that data can arrive at a flip-flop within the given clock period.



Hold time issue

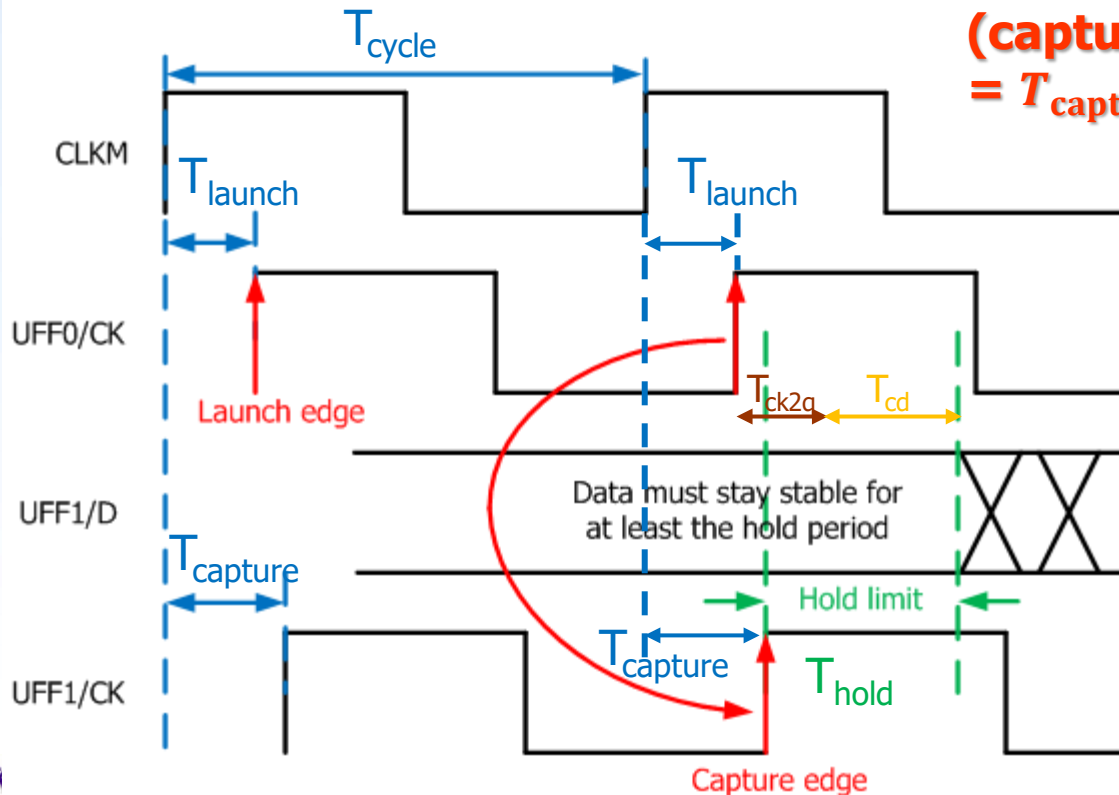
**data arrival time
(Launch path)**

$$= T_{\text{launch}} + T_{\text{clk}2q} + T_{\text{cd}}$$



**data arrival time >
data required time**

**data required time
(capture path)**
 $= T_{\text{capture}} + T_{\text{hold}}$



- Hold check ensures that data is held for at least a minimum time so that there is no unexpected pass-through of data through a flip-flop.

Clock Latency(cont.)

✓ Example

```
dc_shell>current_design UDCOUNTER
```

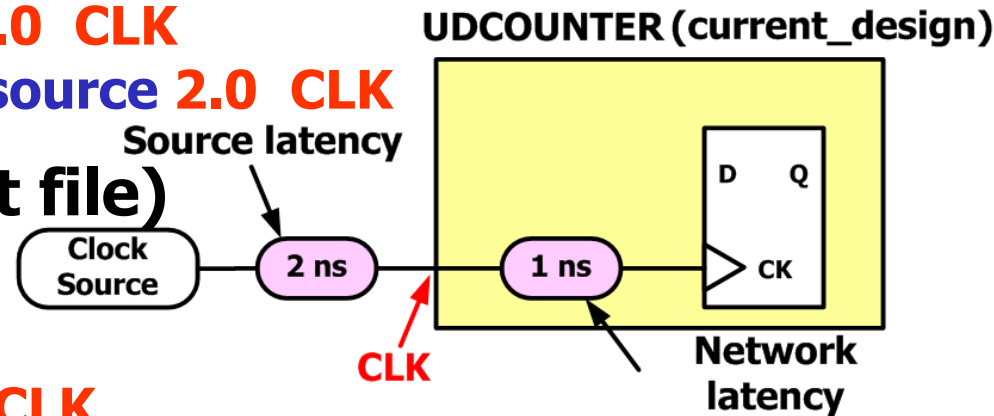
```
dc_shell>set_clock_latency 1.0 CLK
```

```
dc_shell>set_clock_latency -source 2.0 CLK
```

✓ .sdc file (design constraint file)

✓ Check clock latency

```
dc_shell>report_clock -skew CLK
```



Report : clock_skew

Design : UDCOUNTER

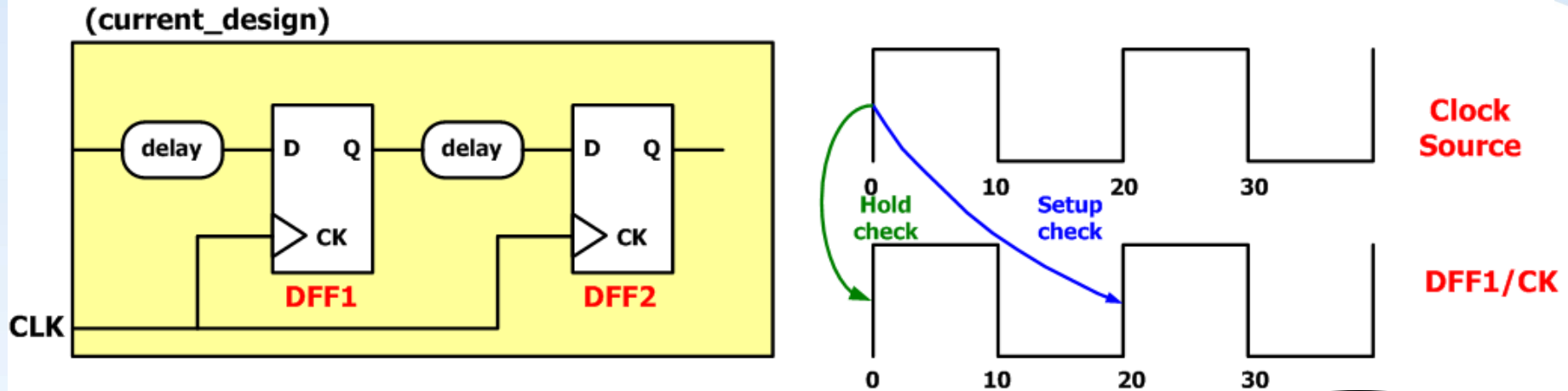
Object	Rise Delay	Fall Delay	Min Rise Delay	Min fall Delay	Uncertainty Plus	Minus
CLK	1.0	1.0	1.0	1.0	-	-

Object	Max Source Latency				Min Source Latency			
	Early Rise	Early Fall	Late Rise	Late Fall	Early Rise	Early Fall	Late Rise	Late Fall
CLK	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0

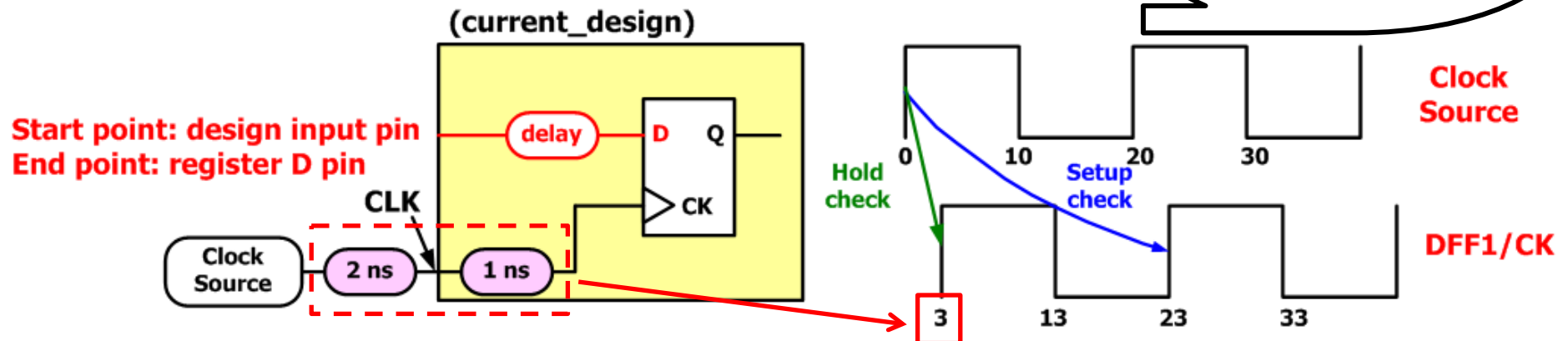


Clock Latency (cont.)

- **Timing checks for ideal case**



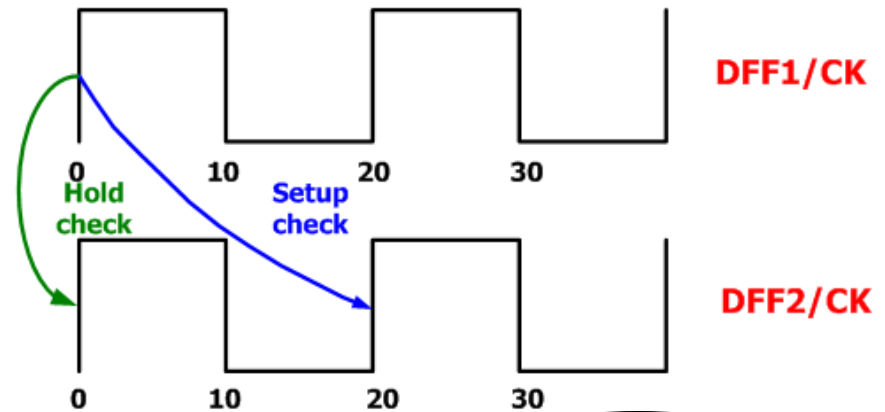
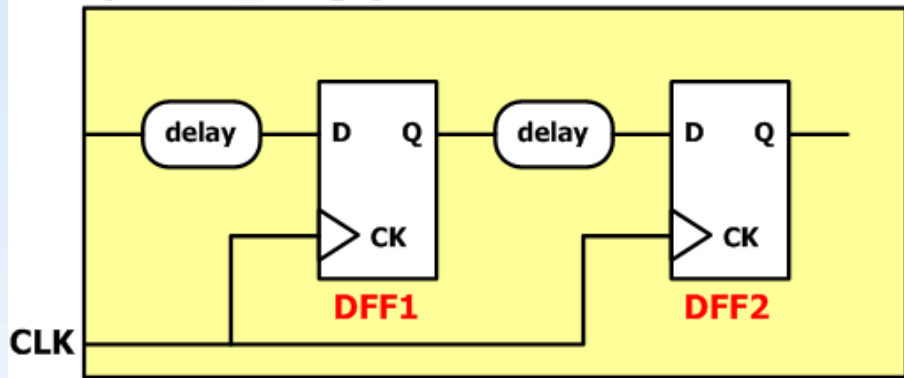
- **Timing checks with clock network latency**



Clock Latency_(cont.)

– Timing checks for ideal case

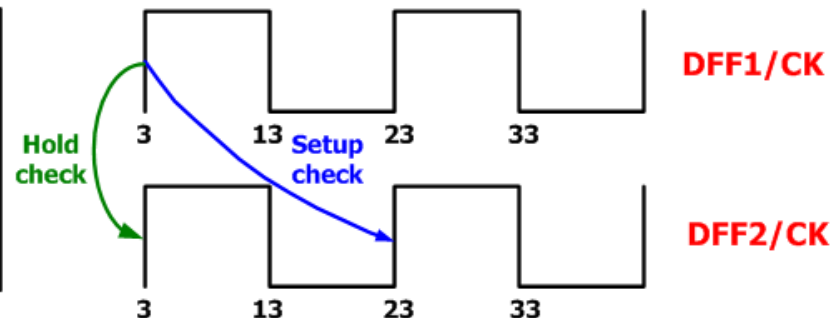
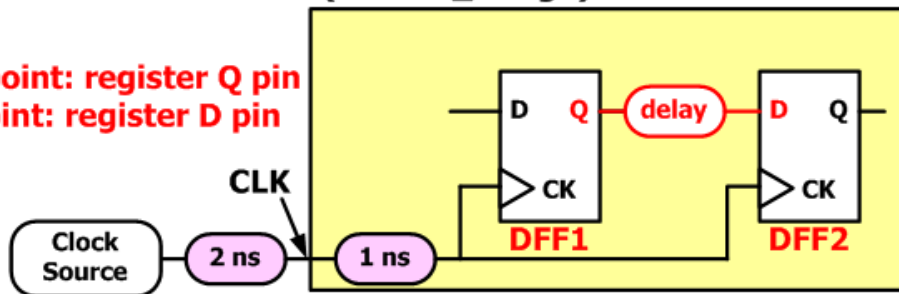
(current_design)



– Timing checks with clock network latency

(current_design)

Start point: register Q pin
End point: register D pin



Setup time check same
Hold time check same

Clock Latency_(cont.)

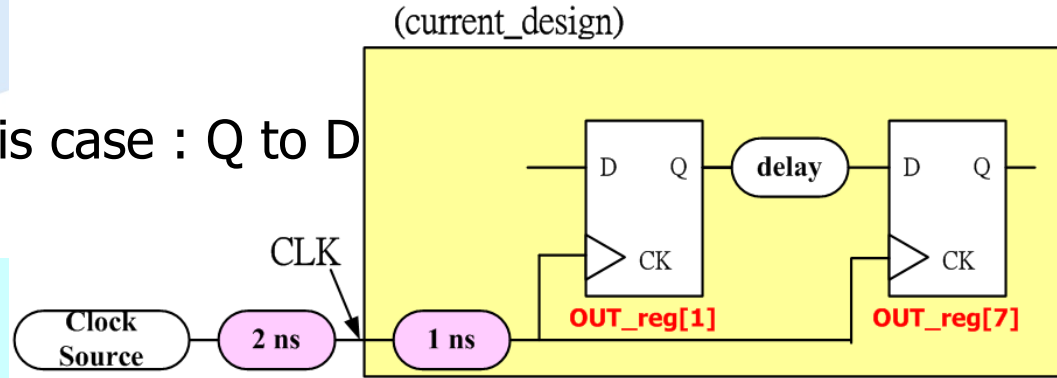
✓ Example

- Setup timing report for this case : Q to D

dc_shell>report_timing

```
*****
Report : timing -path full -delay max -max_paths 1
Design : UDCOUNTER
*****
```

Point	Incr	Path
clock CLK (rise edge)	0.00	0.00
clock network delay (ideal)	3.00	3.00
OUT_reg[1]/CK (EDFFX1)	0.00	3.00 r
OUT_reg[1]/Q (EDFFX1)	0.36	3.36 f
add_70/A[1] (UDCOUNTER_DW01_add_8_0)	0.00	3.36 f
...(ignored)		
U274/Y (DLY4X1)	1.10	12.63 f
OUT_reg[7]/D (EDFFX1)	0.00	12.63 f
data arrival time		12.63
clock CLK (rise edge)	20.00	20.00
clock network delay (ideal)	3.00	23.00
OUT_reg[7]/CK (EDFFX1)	0.00	23.00 r
library setup time	-0.89	22.11
data required time		22.11
data required time		22.11
data arrival time		-12.63
slack (MET)		9.48



Clock network delay
= source latency + network latency
= 2.0 + 1.0 = 3.0

critical path of setup time check

- start point : register Q pin
- end point : register D pin

dc_shell> report_timing -max_paths 5



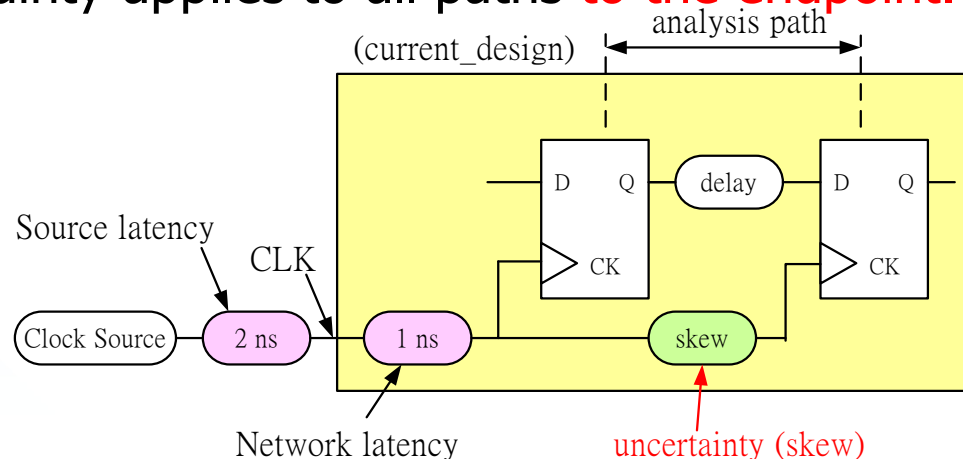
Set Clock Uncertainty

✓ Clock uncertainty (clock skew)

- This constraint can be used to model various factors that can influence the effective clock period.
- These factors may come from clock jitter and any other factors that one may want to include for timing analysis.
- Leave some **timing margin** for **APR routing** imperfection.

✓ Clock skew of **single** clock network

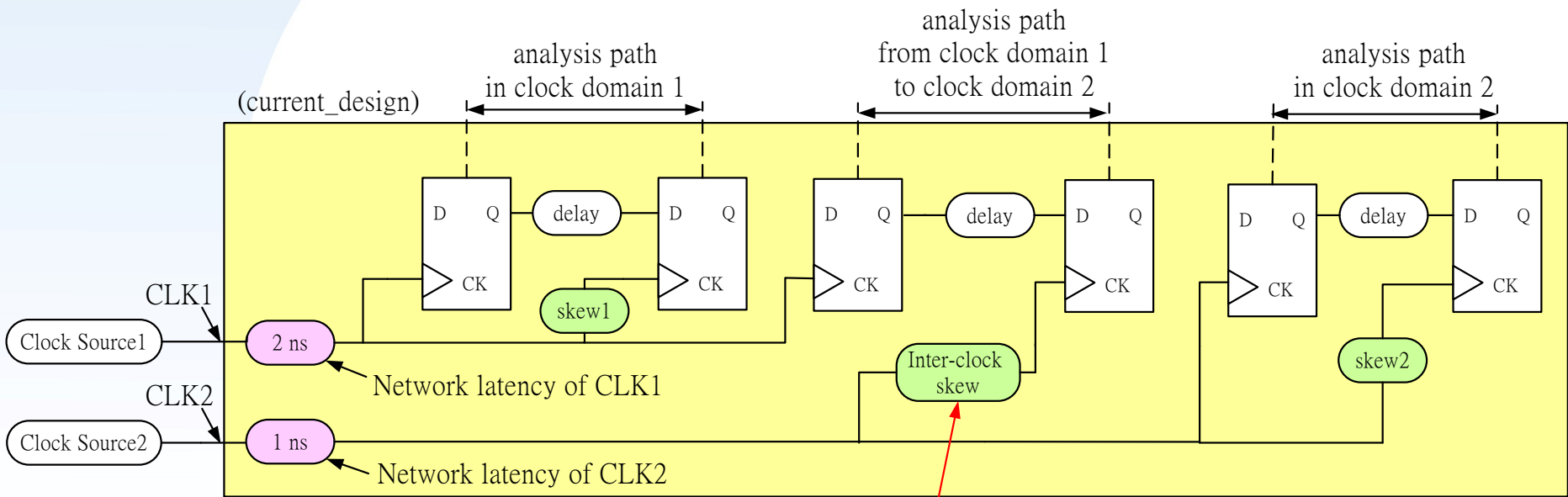
- **Simple uncertainty** means the setup uncertainty and hold uncertainty applies to all paths **to the endpoint**.



Set Clock Uncertainty_(cont.)

✓ Inter-clock skew of **multiple** clock networks

- **Inter-clock uncertainty** means the setup uncertainty and hold uncertainty applies to all paths **from start point of clock domain1 to the endpoint of clock domain2**
- skew1 and skew2 are simple uncertainty of clock domain1 and clock domain 2



Inter-clock uncertainty
(if not defined, it will be skew2)

Set Clock Uncertainty_(cont.)

✓ Setting simple clock uncertainty

```
set_clock_uncertainty [-setup] [-hold] value {object_list}
```

✓ Setting inter-clock uncertainty

```
set_clock_uncertainty [-from from_clock] [-to to_clock] [-rise] [-fall] [-setup] [-hold]  
value
```

— Options

arguments	Usage	Default
[-setup]	If specified, uncertainty is applied only for setup check	Both setup and hold checks
[-hold]	If specified, uncertainty is applied only for hold check	Both setup and hold check
[-from from_clock]	Specifies the source clock for inter-clock uncertainty	
[-to to_clock]	Specifies the destination clock for inter-clock uncertainty	
[-rise]	Specifies uncertainty applied to the rising edge of destination clock	Both
[-fall]	Specifies uncertainty applied to the falling edge of destination clock	Both



Set Clock Uncertainty_(cont.)

✓ Example:

```
module MULTICLOCK
(
  // Output Port
  OUT,
  // Input Port
  CLK1, CLK2, IN1, IN2
);

output OUT;
input CLK1;
input CLK2;
input IN1;
input IN2;

reg temp1, temp2, OUT;
wire CLK1, CLK2, data;

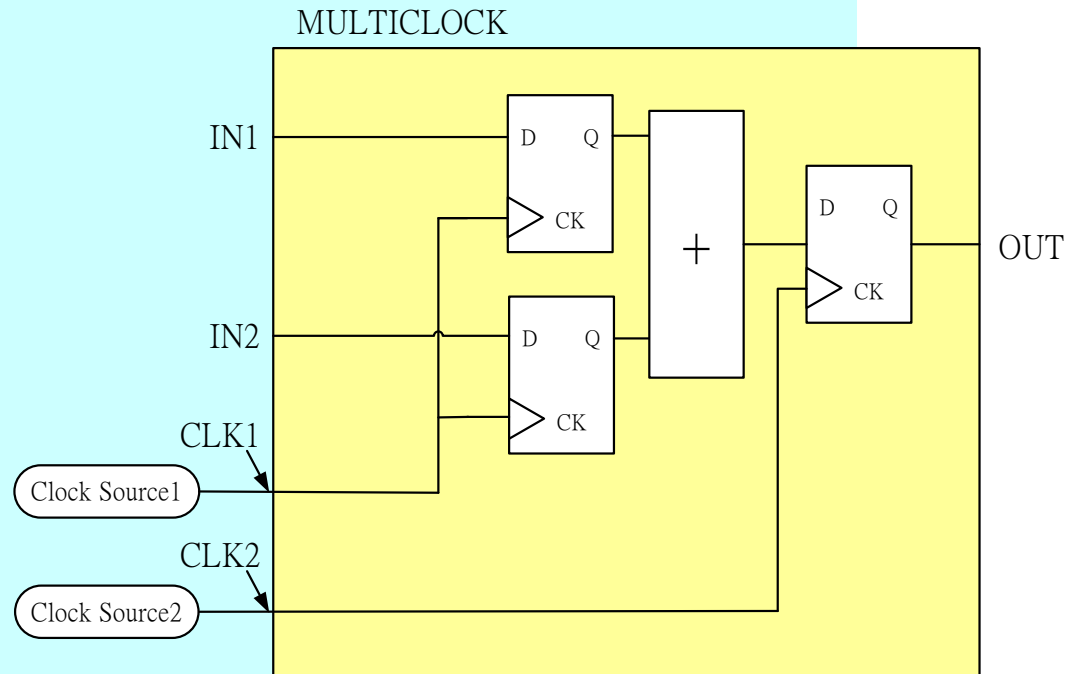
assign data = temp1 + temp2;

always @(posedge CLK1)
  temp1 <= IN1;

always @(posedge CLK1)
  temp2 <= IN2;

always @(posedge CLK2)
  OUT <= data;

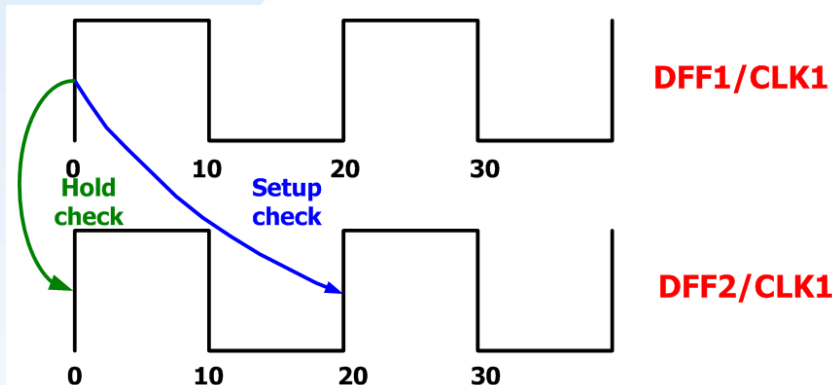
endmodule
```



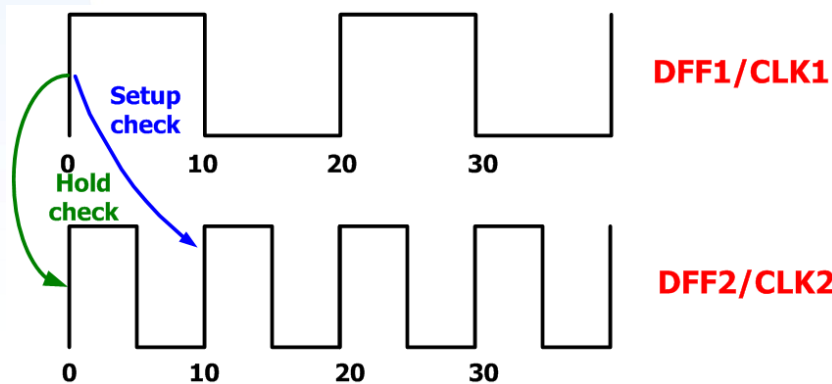
Set Clock Uncertainty_(cont.)

```
dc_shell>create_clock -period 20 CLK1
```

```
dc_shell>create_clock -period 10 CLK2
```



setup and hold check
in clock domain 1



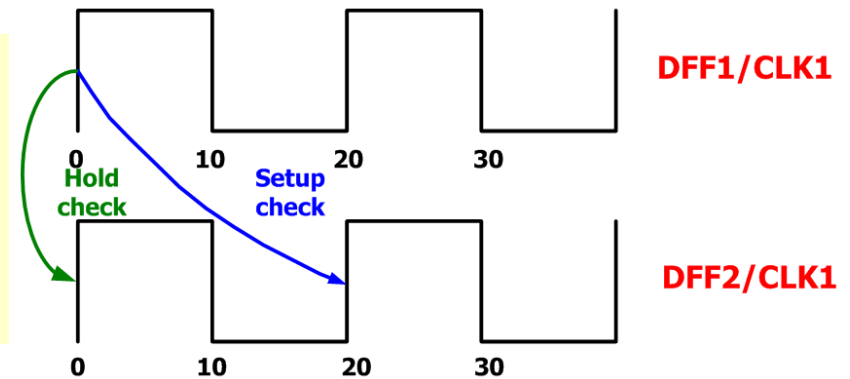
setup and hold check
from clock domain 1
to clock domain 2



Set Clock Uncertainty(cont.)

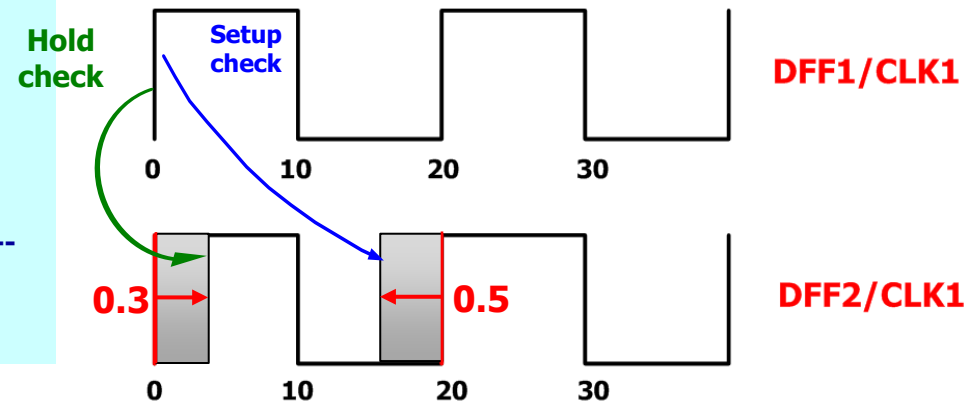
- During timing analysis, clock uncertainty will **tighten up** the timing constraints.
- **Plus** uncertainty is for **hold time** check.
- **Minus** uncertainty is for **setup time** check.

```
set_clock_uncertainty -setup 0.5 CLK1
set_clock_uncertainty -hold 0.3 CLK1
set_clock_uncertainty -setup 0.6 CLK2
set_clock_uncertainty -hold 0.4 CLK2
report_clock -skew
```



```
*****
Report : clock_skew
Design : MULTICLOCK
*****
```

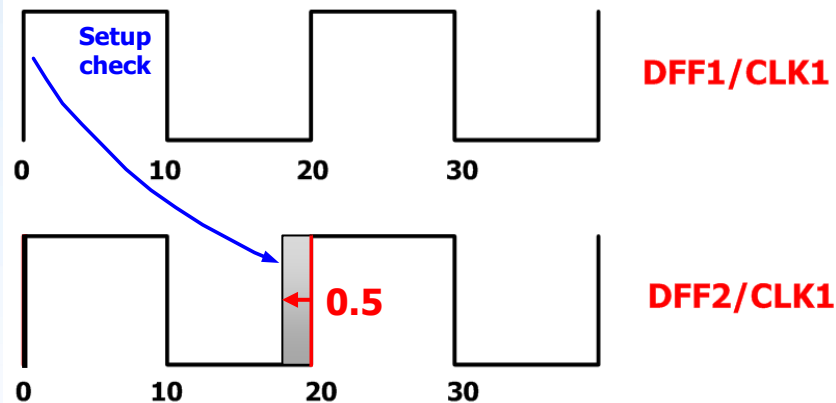
Object	Rise Delay	Fall Delay	Min Rise Delay	Min fall Delay	Uncertainty Plus	Minus
CLK1	-	-	-	-	0.30	0.50
CLK2	-	-	-	-	0.40	0.60



Set Clock Uncertainty_(cont.)

- Timing report (setup time check)

```
dc_shell>compile
dc_shell>report_timing
```



Minus uncertainty 0.5 of CLK1 for setup time check

Report : timing -path full -delay max -max_paths 1

Design : MULTICLOCK

Path Group: CLK1

Clock domain : CLK1

Path Type: max

Point	Incr	Path

clock (input port clock) (rise edge)	0.00	0.00
input external delay	0.00	0.00 f
IN1 (in)	0.00	0.00 f
U8/Y (DLY4X1)	1.03	1.03 f
TEMP1_reg/D (DFFX1)	0.00	1.03 f
data arrival time		1.03

clock CLK1 (rise edge)	20.00	20.00
clock network delay (ideal)	0.00	20.00
clock uncertainty	-0.50	19.50
TEMP1_reg/CK (DFFX1)	0.00	19.50 r
library setup time	-0.33	19.17
data required time		19.17

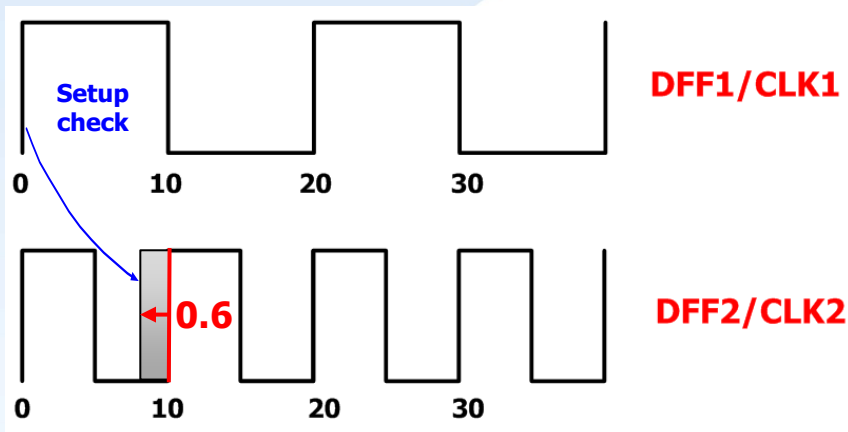
data required time		19.17
data arrival time		-1.03

slack (MET)		18.13



Set Clock Uncertainty_(cont.)

- Timing report (setup time check)



Because **inter-clock uncertainty is not defined**, here compiler uses **uncertainty of CLK2 automatically**.

Clock domain : from CLK1 to CLK2

(cont.)

Path Group: CLK2

Path Type: max

Point	Incr	Path
clock CLK1 (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
TEMP2_reg/CK (DFFX1)	0.00	0.00 r
TEMP2_reg/Q (DFFX1)	0.41	0.41 r
U5/Y (XOR2XL)	0.40	0.81 f
U4/Y (DLY4X1)	1.09	1.90 f
OUT_reg/D (DFFX1)	0.00	1.90 f
data arrival time		1.90
clock CLK2 (rise edge)	10.00	10.00
clock network delay (ideal)	0.00	10.00
clock uncertainty	-0.60	9.40
OUT_reg/CK (DFFX1)	0.00	9.40 r
library setup time	-0.33	9.07
data required time		9.07
data required time		9.07

```
set_clock_uncertainty -setup 0.5 CLK1
set_clock_uncertainty -hold 0.3 CLK1
set_clock_uncertainty -setup 0.6 CLK2
set_clock_uncertainty -hold 0.4 CLK2
report_clock -skew
```



Set Clock Uncertainty_(cont.)

- Timing report (setup time check)
- Add inter-clock uncertainty and re-compile

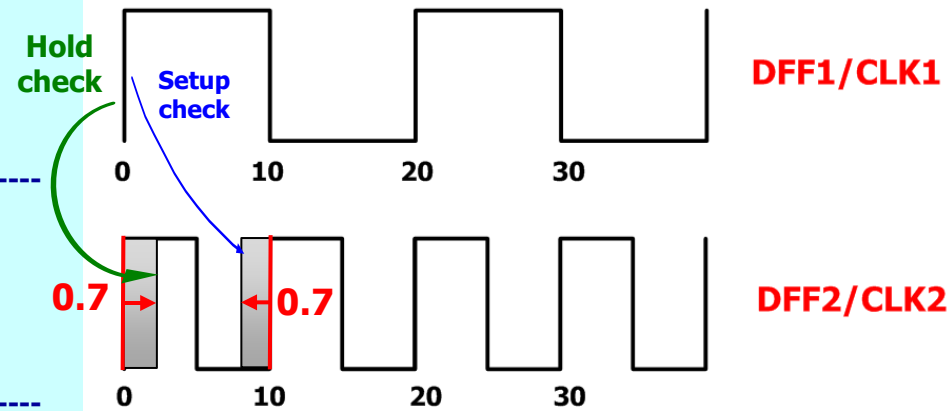
```
dc_shell>set_clock_uncertainty -from CLK1 -to CLK2 0.7
dc_shell>report_clock -skew
```

Report : clock_skew

Design : MULTICLOCK

Object	Rise Delay	Fall Delay	Min Rise Delay	Min fall Delay	Uncertainty	
					Plus	Minus
CLK1	-	-	-	-	0.30	0.50
CLK2	-	-	-	-	0.40	0.60

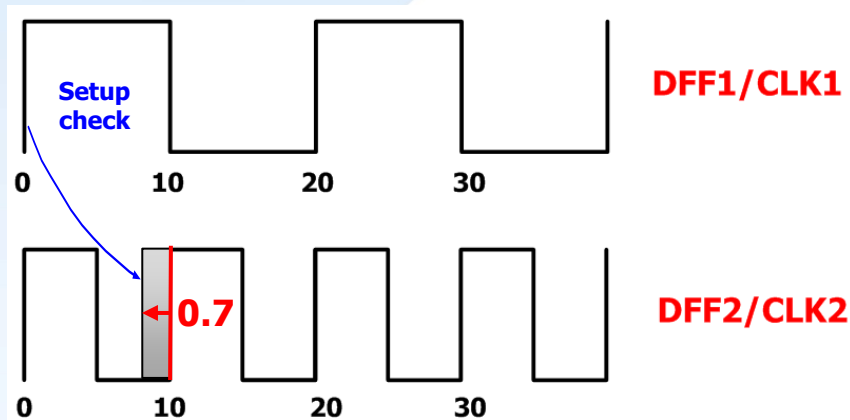
From Clock	To Clock	Hold Uncertainty		Setup Uncertainty	
		Rise	Fall	Rise	Fall
CLK1	CLK2	0.70	0.70	0.70	0.70



Set Clock Uncertainty_(cont.)

- Timing report (setup time check)

```
dc_shell>compile
dc_shell>report_timing
```



Because inter-clock uncertainty is **specified**, here compiler **uses inter-clock uncertainty**

**Clock domain :
from CLK1 to CLK2**

Path Group: CLK2		
Path Type: max		
Point	Incr	Path

--		
clock CLK1 (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
TEMP2_reg/CK (DFFX1)	0.00	0.00 r
TEMP2_reg/Q (DFFX1)	0.41	0.41 r
U13/Y (XOR2XL)	0.40	0.81 f
U12/Y (DLY4X1)	1.09	1.90 f
OUT_reg/D (DFFX1)	0.00	1.90 f
data arrival time		1.90

clock CLK2 (rise edge)	10.00	10.00
clock network delay (ideal)	0.00	10.00
inter-clock uncertainty	-0.70	9.30
OUT_reg/CK (DFFX1)	0.00	9.30 r
library setup time	-0.33	8.97
data required time		8.97

--		
data required time		8.97
data arrival time		-1.90

--		
slack (MET)		7.07



Summary timing check behavior

✓ Positive edge trigger circuit timing check

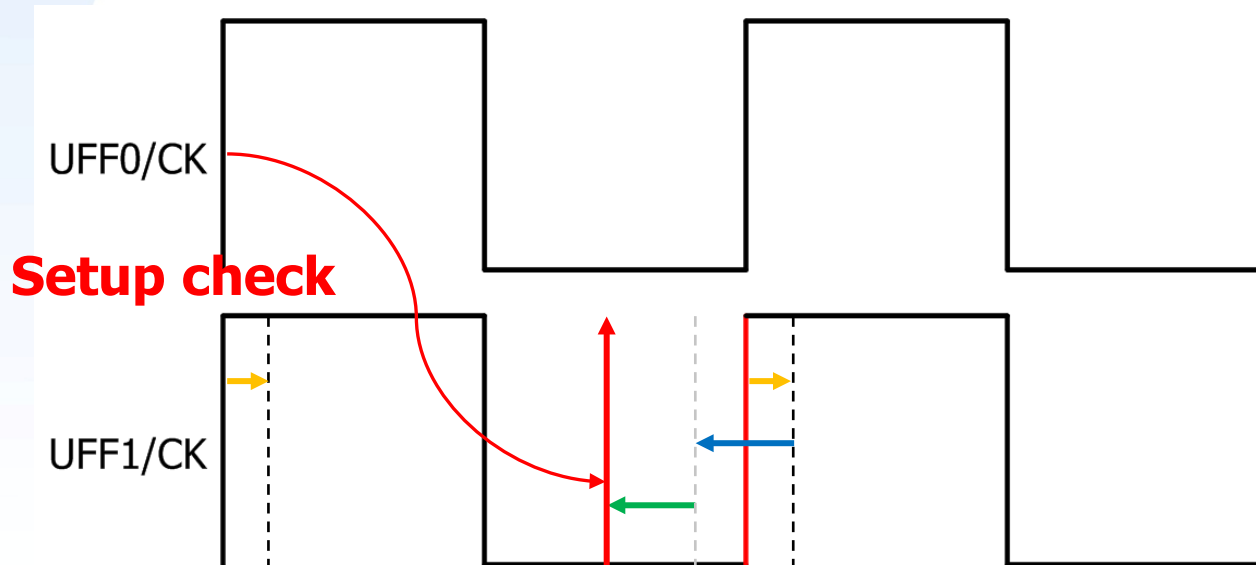
– Setup check (different module)

• check_edge : **ideal_clock_rise_edge**

+ **rise_delay**(source latency+network latency)

– **setup_uncertainty**(minus uncertainty)

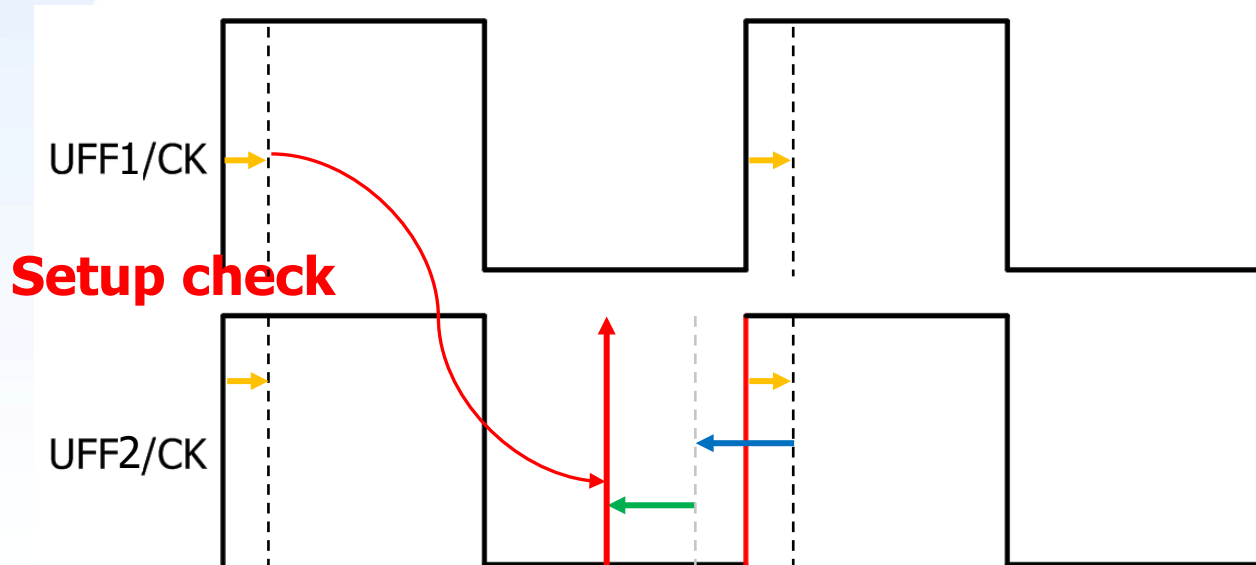
– **T_{setup}**(library setup time)



Summary timing check behavior

✓ Positive edge trigger circuit timing check

- Setup check (same module)
 - check_edge : **ideal_clock_rise_edge**
+ rise_delay(source latency+network latency)
– setup_uncertainty(minus uncertainty)
– T_{setup} (library setup time)

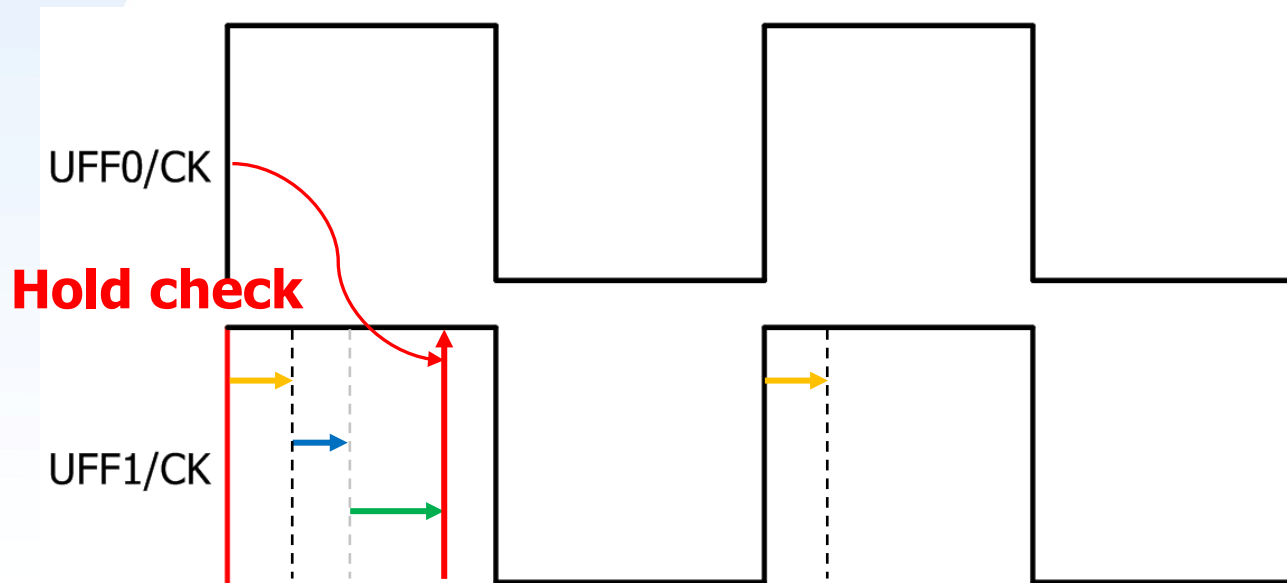


Summary timing check behavior

✓ Positive edge trigger circuit timing check

– Hold check (different module)

- check_edge : **ideal_clock_rise_edge**
 - + rise_delay(source latency+network latency)
 - + hold_uncertainty(plus uncertainty)
 - + T_{hold} (library hold time)

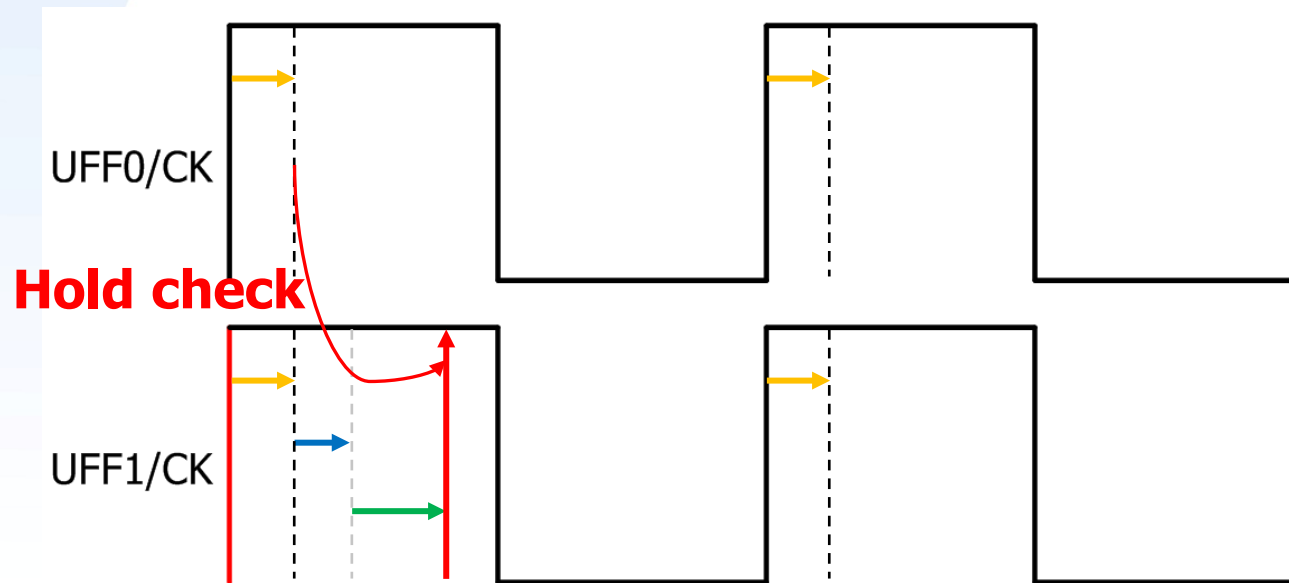


Summary timing check behavior

✓ Positive edge trigger circuit timing check

— Hold check (same module)

- check_edge : **ideal_clock_rise_edge**
 - + rise_delay(source latency+network latency)
 - + hold_uncertainty(plus uncertainty)
 - + T_{hold} (library hold time)



✓ **Timing Analysis Considering Clk Latency**

- STA vs DTA
- CLK latency
- CLK uncertainty

✓ **Multicycle Path Specification**

- Specify Multicycle Path
- Single clock system
- Multiple clocks system

✓ **Clock Domain Crossing (CDC)**

✓ **Appendix**



✓ Timing Analysis Considering Clk Latency

- STA vs DTA
- CLK latency
- CLK uncertainty

✓ Multicycle Path Specification

- Specify Multicycle Path
- Single clock system
- Multiple clocks system

✓ Clock Domain Crossing (CDC)

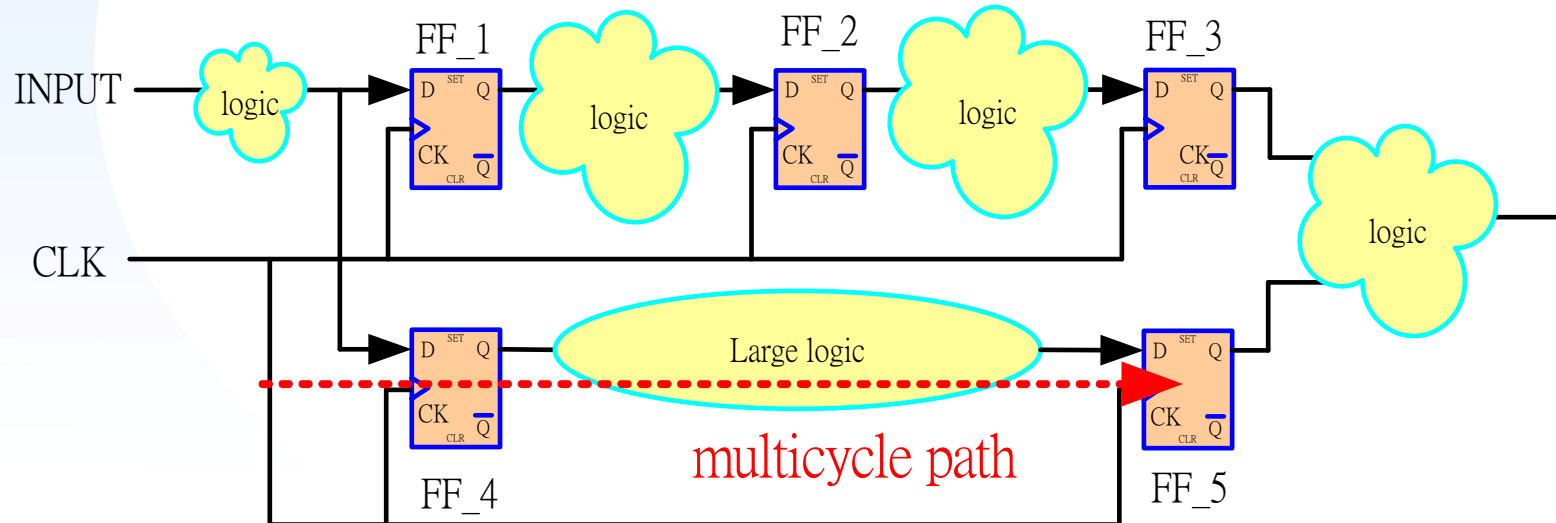
✓ Appendix



Multicycle Path

✓ A multicycle path

- A timing path which is not expected to propagate a signal in one cycle.
- Normally, all paths are constrained for single-cycle timing. Multicycle paths are exceptions to the default single-cycle timing.
- Set multicycle paths to direct compiler to allow multiple clock cycles for data to propagate along a path.



Specify Multicycle Path

✓ Set multicycle path

```
set_multicycle_path path_multiplier –from $start_point –to  
$end_point [-setup] [-hold][-start][-end]
```

✓ Option definition:

- path_multiplier: Specify the number of cycles
- \$start_point: Specifies start points (clocks, ports, pins, or cells) of multicycle path
- \$end_point: Specifies through points (ports, pins, or leaf cells) of multicycle path
- -setup: Used for setup time calculation(default)
- -hold: Used for hold time calculation
- -start (clock launch edge)(Hold check default): Indicate the multicycle information is relative to the start clock
- -end (clock capture edge)(Setup check default): Indicate the multicycle information is relative to the end clock



✓ Timing Analysis Considering Clk Latency

- STA vs DTA
- CLK latency
- CLK uncertainty

✓ Multicycle Path Specification

- Specify Multicycle Path
- Single clock system
- Multiple clocks system

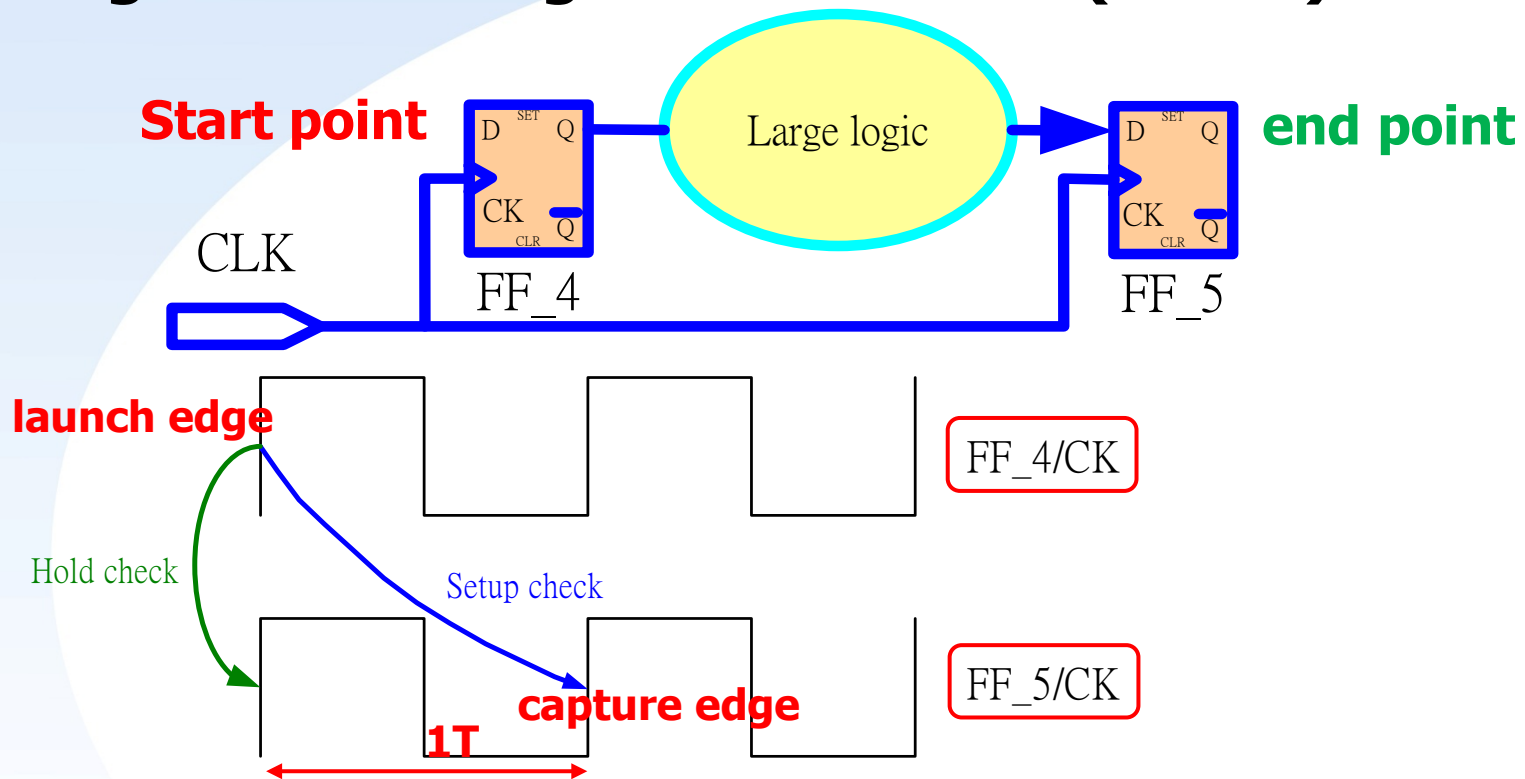
✓ Clock Domain Crossing (CDC)

✓ Appendix



Multicycle Path of Single Clock Domain

✓ Timing check in single clock domain(Initial)



Equivalent(default setting, don't need to write):

`set_multicycle_path` **1** –from **FF_4/CK** –to **FF_5/D**

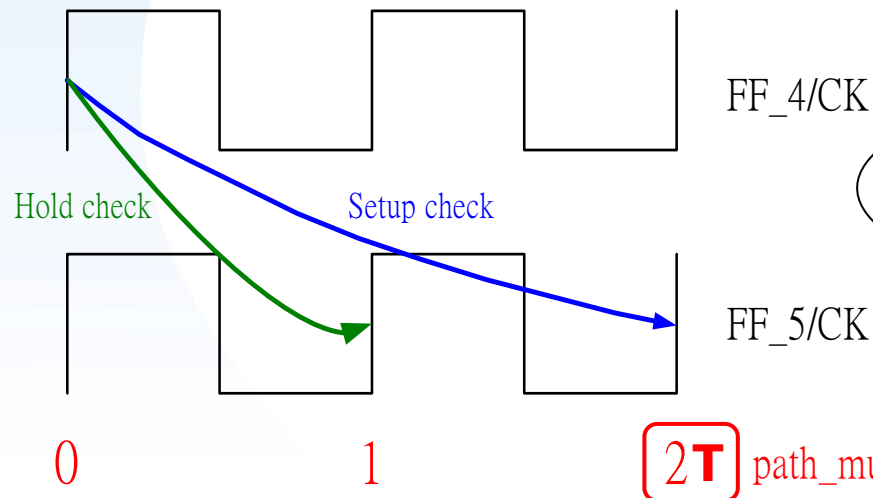
`set_multicycle_path` **0** –hold –from **FF_4/CK** –to **FF_5/D**

Multicycle Path of Single Clock Domain_(cont.)

- ✓ Specify multiple path for **setup** time check
 - Hold time check edge will be changed too!!

`set_multicycle_path 2` –from FF_4/CK –to FF_5/D

`set_multicycle_path 0` –hold -end –from FF_4/CK –to FF_5/D



Setup time check looser

Hold time check tighter

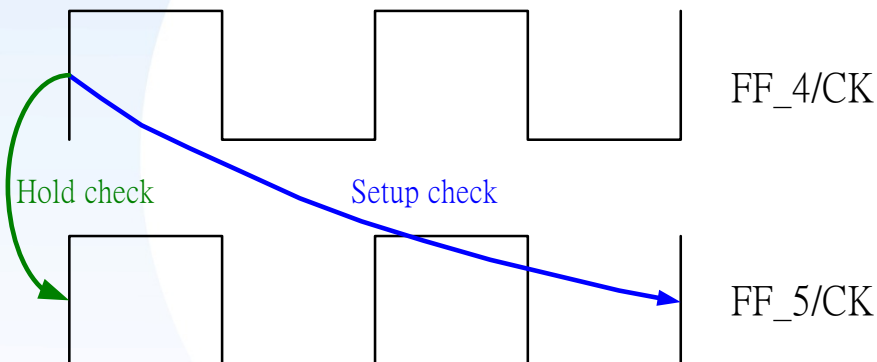
Multicycle Path of Single Clock Domain_(cont.)

- ✓ Specify multiple path for **hold** time check

```
set_multicycle_path 2 -from FF_4/CK -to FF_5/D
```

```
set_multicycle_path 1 -hold -end -from FF_4/CK -to FF_5/D
```

- Timing check edge is what we desire!



Setup time check looser

Hold time check same

0

1

2T

path_multiplier for -setup

1T

0

-1

path_multiplier for -hold



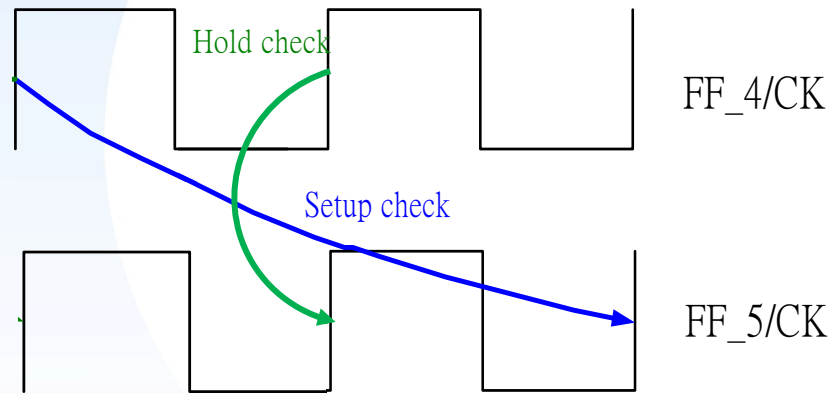
Multicycle Path of Single Clock Domain_(cont.)

- ✓ Specify multiple path for **hold** time check

```
set_multicycle_path 2 -from FF_4/CK -to FF_5/D
```

```
set_multicycle_path 1 -hold -from FF_4/CK -to FF_5/D
```

- Timing check edge is what we desire!



Setup time check looser

Hold time check same

0 1 2 path_multiplier for -setup

0 1 2 path_multiplier for -hold



✓ Timing Analysis Considering Clk Latency

- STA vs DTA
- CLK latency
- CLK uncertainty

✓ Multicycle Path Specification

- Specify Multicycle Path
- Single clock system
- Multiple clocks system

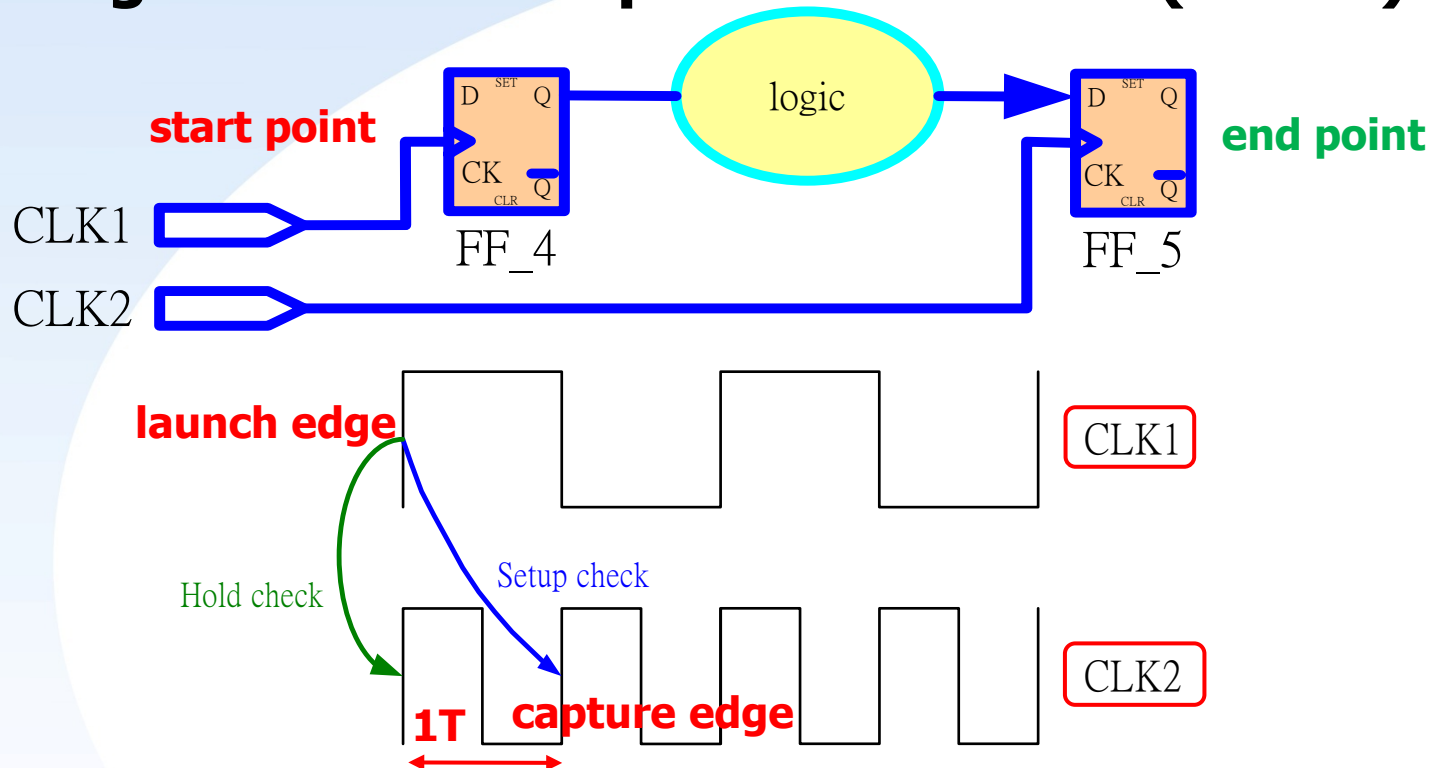
✓ Clock Domain Crossing (CDC)

✓ Appendix



Multicycle Path of Multiple Clock Domain

✓ Timing check in multiple clock domain(Initial)



Equivalent:

set_multicycle_path **1** -end -from CLK1 -to CLK2

set_multicycle_path **0** -hold -start -from CLK1 -to CLK2

Multicycle Path of Multiple Clock Domain_(cont.)

✓ Specify multiple path

`set_multicycle_path` **2** -from CLK1 -to CLK2

– Hold time check edge will be changed too!!

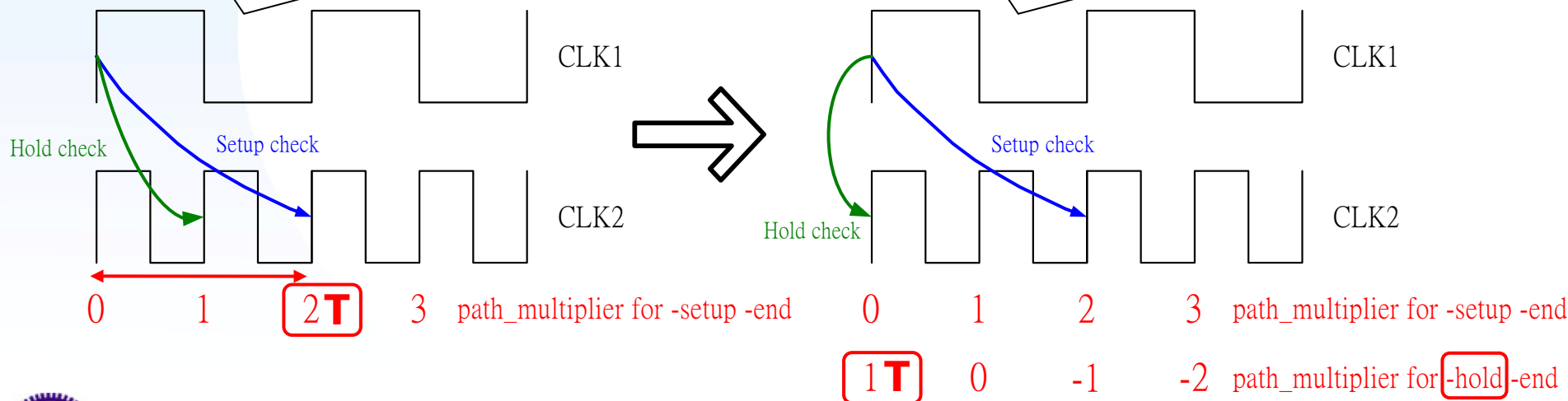
`set_multicycle_path` **1** -hold -end -from CLK1 -to CLK2

Setup time check **looser**

Hold time check **tighter**

Setup time check **looser**

Hold time check **same**



Multicycle Path of Multiple Clock Domain_(cont.)

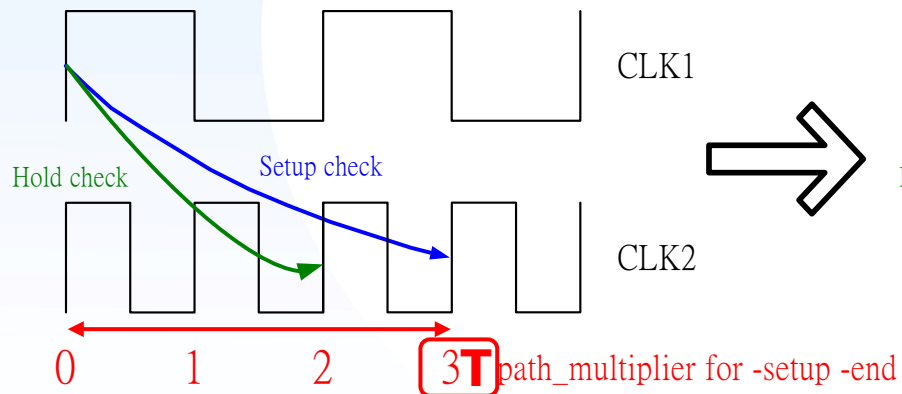
✓ Specify multiple path(Different combinations)

set_multicycle_path **3** -from CLK1 -to CLK2

set_multicycle_path **1** -hold -end -from CLK1 -to CLK2

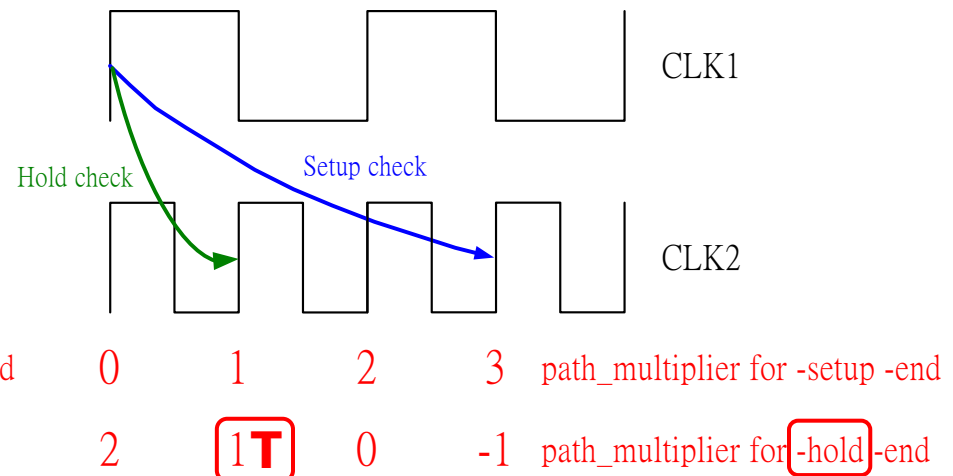
Setup time check **looser**

Hold time check **tighter**



Setup time check **looser**

Hold time check **tighter**



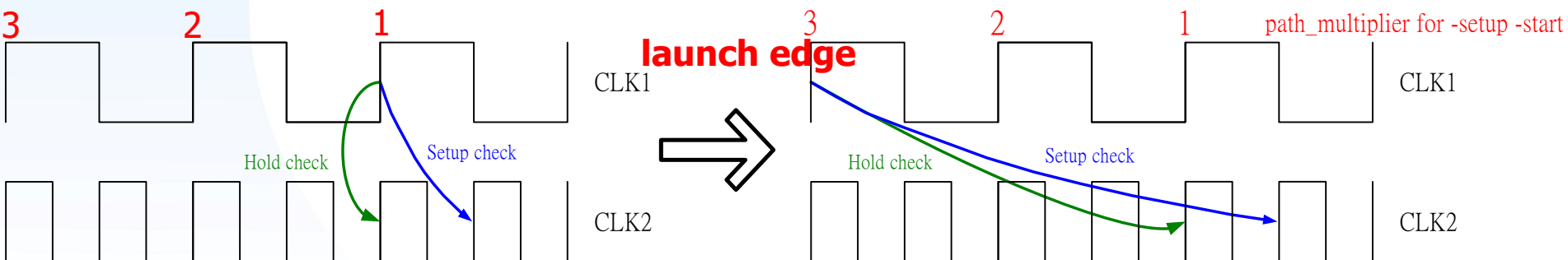
Multicycle Path of Multiple Clocks Domain_(cont.)

- ✓ Specify multiple path for setup time check **relative to start point**

set_multicycle_path **3** -start -from CLK1 -to CLK2

Setup time check **looser**

Hold time check **tighter**

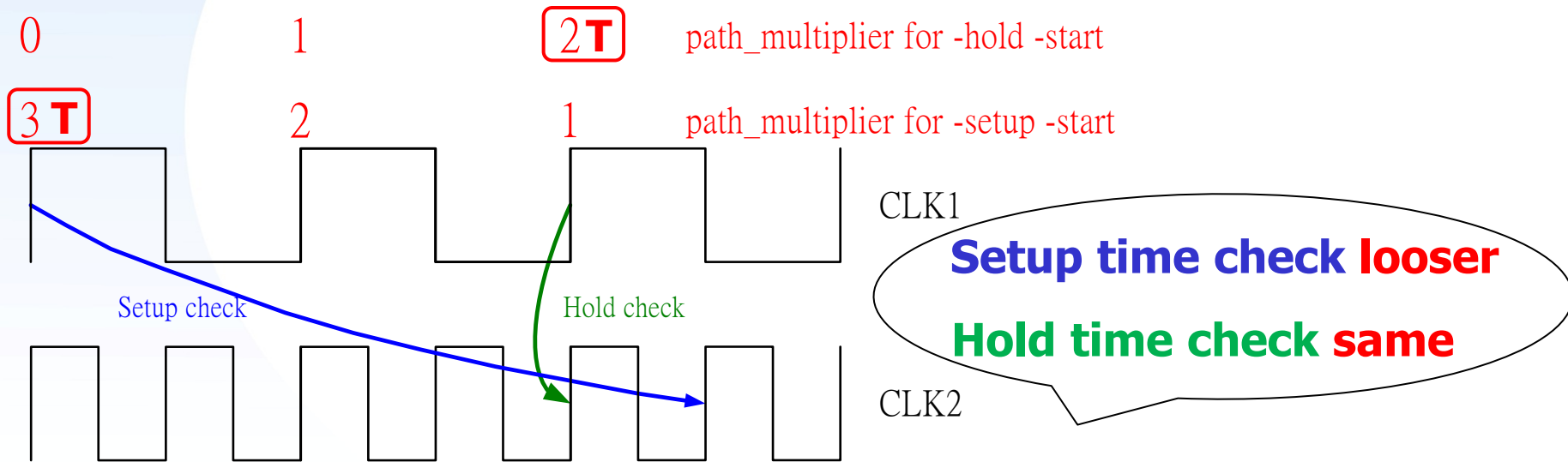


Multicycle Path of Multiple Clock Domain_(cont.)

- ✓ Specify multiple path for hold time check **relative to start point**

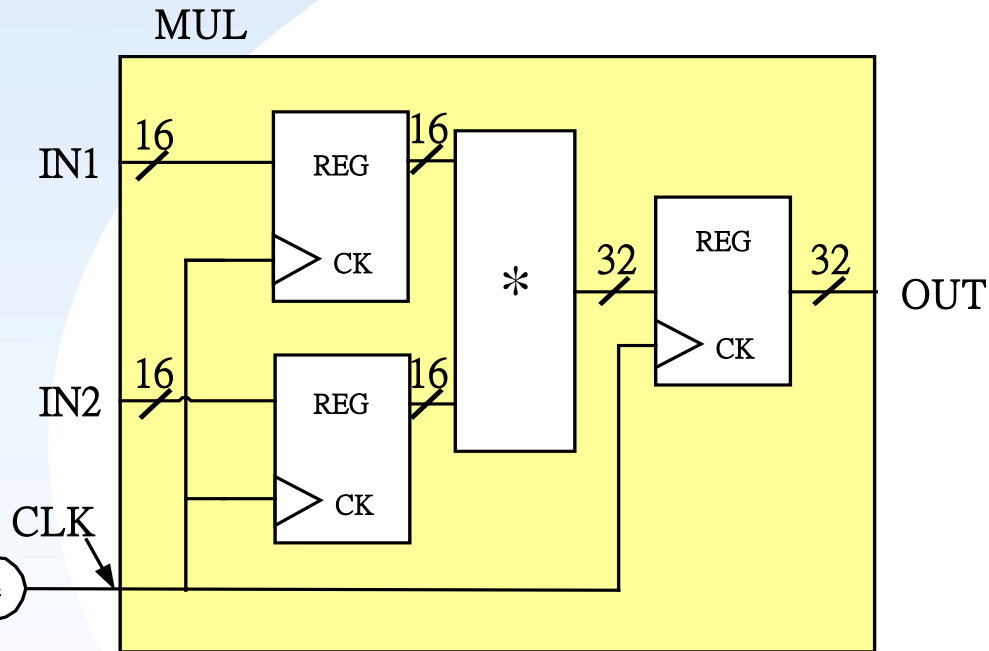
```
set_multicycle_path 3 -start -from CLK1 -to CLK2
```

```
set_multicycle_path 2 -hold -start -from CLK1 -to CLK2
```



Example: Multicycle Path of Single Clock Domain

e.g.1



```
module MUL
(
    // Output Port
    OUT,
    // Input Port
    IN1, IN2, CLK
);

output reg[31:0] OUT;
input  [15:0] IN1, IN2;
input          CLK;

reg [15:0] IN1_R, IN2_R;

always @(posedge CLK)
    IN1_R <= IN1;

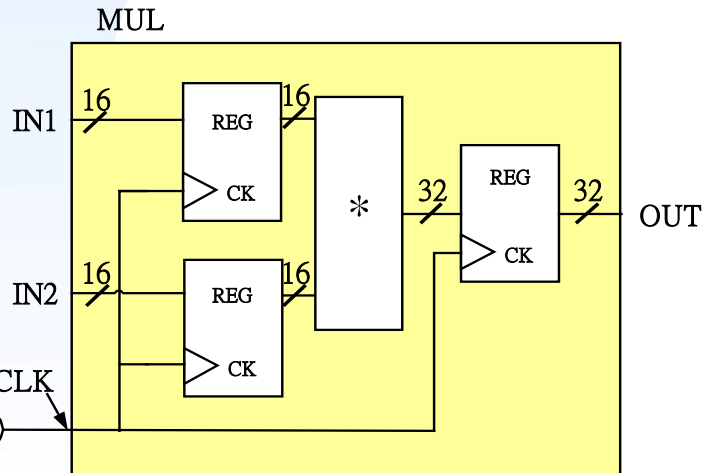
always @(posedge CLK)
    IN2_R <= IN2;

always @(posedge CLK)
    OUT <= IN1_R*IN2_R;

endmodule
```

Example: Multicycle Path of Single Clock Domain

```
dc_shell>create_clock -period 4 CLK
dc_shell>compile
dc_shell>report_timing
```



Report : timing -path full -delay max
-max_paths 1

Design : MUL

Point	Incr	Path
clock CLK (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
IN1_R_reg[14]/CK (DFFHQX4)	0.00	0.00 r
IN1_R_reg[14]/Q (DFFHQX4)	0.30	0.30 r
U14/Y (BUFX20)	0.18	0.48 r
mult_21/A[14]		
(MUL_DW02_mult_16_16_0)	0.00	0.48 r
... (ignored)		
mult_21/PRODUCT[28]		
(MUL_DW02_mult_16_16_0)	0.00	4.91 r
OUT_reg[28]/D (DFFXL)	0.00	4.91 r
data arrival time		4.91
clock CLK (rise edge)	4.00	4.00
clock network delay (ideal)	0.00	4.00
OUT_reg[28]/CK (DFFXL)	0.00	4.00 r
library setup time	-0.10	3.90
data required time		3.90
data required time		3.90
data arrival time		-4.91
slack (VIOLATED)		-1.00

Timing Violation!!!



Example: Multicycle Path of Single Clock Domain

```
dc_shell>set_multicycle_path 2 -from [get_cells IN1_R_reg[*]] -to [get_cells OUT_reg[*]]
dc_shell>set_multicycle_path 2 -from [get_cells IN2_R_reg[*]] -to [get_cells OUT_reg[*]]
dc_shell>set_multicycle_path 1 -hold -end -from [get_cells IN1_R_reg[*]] -to [get_cells OUT_reg[*]]
dc_shell>set_multicycle_path 1 -hold -end -from [get_cells IN2_R_reg[*]] -to [get_cells OUT_reg[*]]
dc_shell>report_timing_requirements
```

Report : timing_requirements -attributes

Design : MUL

Description	Setup	Hold
TIMING EXCEPTION	cycles=2	cycles=1(end)

-from { IN1_R_reg[0]\

.....
IN1_R_reg[15]}\

-to { OUT_reg[0]\

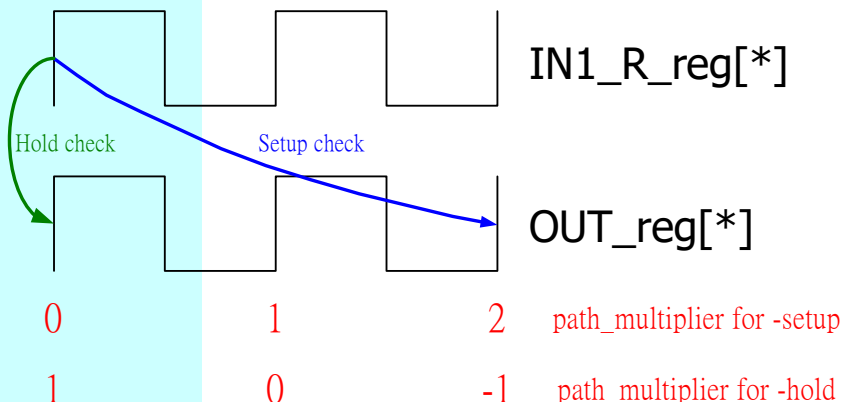
.....
OUT_reg[31] }

-from { IN2_R_reg[0]\

.....
IN2_R_reg[15]}\

-to { OUT_reg[0]\

.....
OUT_reg[31] }



Example: Multicycle Path of Single Clock Domain

Report : timing -path full -delay **max**
-max_paths 1

Setup time

Design : MUL

Point	Incr	Path

clock CLK (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
IN1_R_reg[13]/CK (DFFX1)	0.00	0.00 r
IN1_R_reg[13]/Q (DFFX1)	1.27	1.27 r
mult_21/A[13]		
(MUL_DW02_mult_16_16_0)	0.00	1.27 r
.....(ignored)		
mult_21/PRODUCT[28]		
(MUL_DW02_mult_16_16_0)	0.00	7.56 f
OUT_reg[28]/D (DFFX1)	0.00	7.56 f
data arrival time		7.56

clock CLK (rise edge)	8.00	8.00 2T
clock network delay (ideal)	0.00	8.00
OUT_reg[28]/CK (DFFX1)	0.00	8.00 r
library setup time	-0.33	7.67
data required time		7.67

data required time		7.67
data arrival time		-7.56

slack (MET)		0.11

dc_shell>compile

dc_shell>report_timing

dc_shell>report_timing -delay min

Report : timing -path full -delay **min**
-max_paths 1

Hold time

Design : MUL

Point	Incr	Path

clock (input port clock) (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
input external delay	0.00	0.00 r
IN1[0] (in)	0.00	0.00 r
IN1_R_reg[0]/D (DFFX1)	0.00	0.00 r
data arrival time		0.00

clock CLK (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
IN1_R_reg[0]/CK (DFFX1)	0.00	0.00 r
library hold time	-0.03	-0.03
data required time		-0.03

data required time		-0.03
data arrival time		0.00

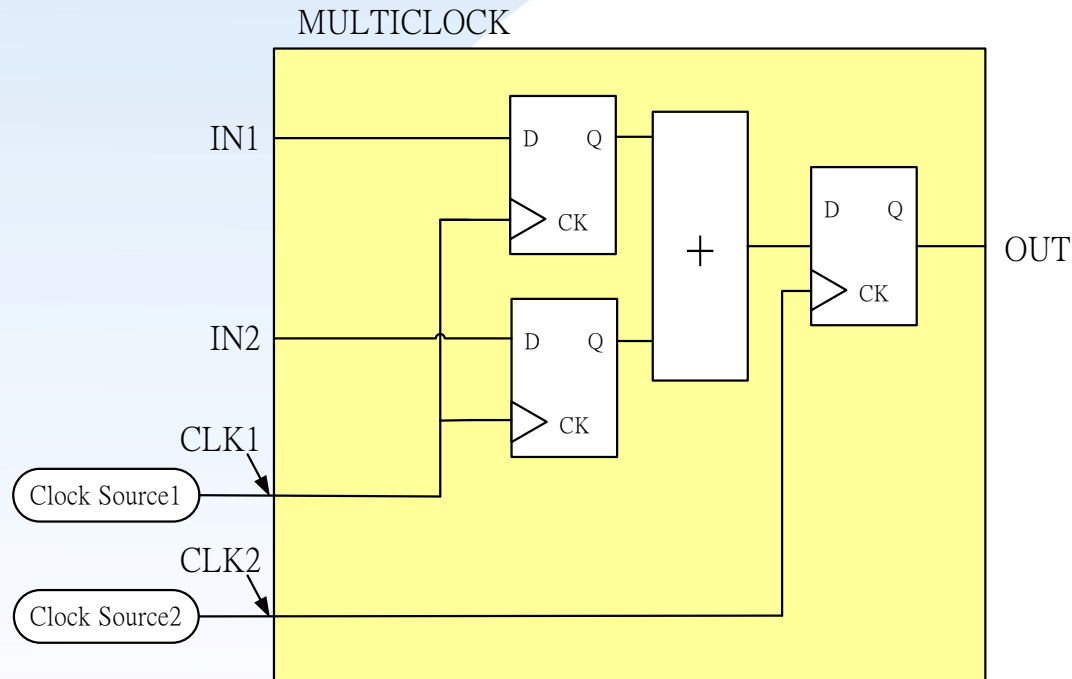
slack (MET)		0.03

**Timing
Met !!!**



Example: Multicycle Path of Multiple Clock Domain

e.g.2



```
module MULTICLOCK  
(  
    // Output Port  
    OUT,  
    // Input Port  
    CLK1, CLK2, IN1, IN2  
);
```

```
output reg OUT;  
input CLK1, CLK2;  
input IN1, IN2;
```

```
reg temp1, temp2;
```

```
assign data = temp1 + temp2;
```

```
always @(posedge CLK1)  
    temp1 <= IN1;
```

```
always @(posedge CLK1)  
    temp2 <= IN2;
```

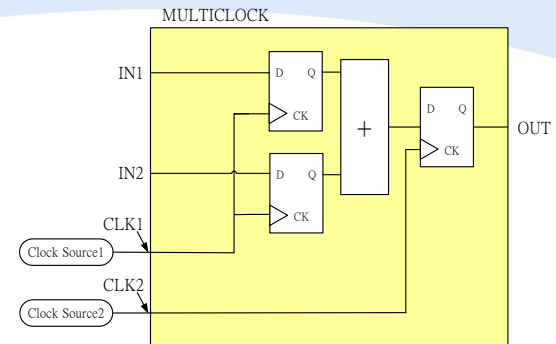
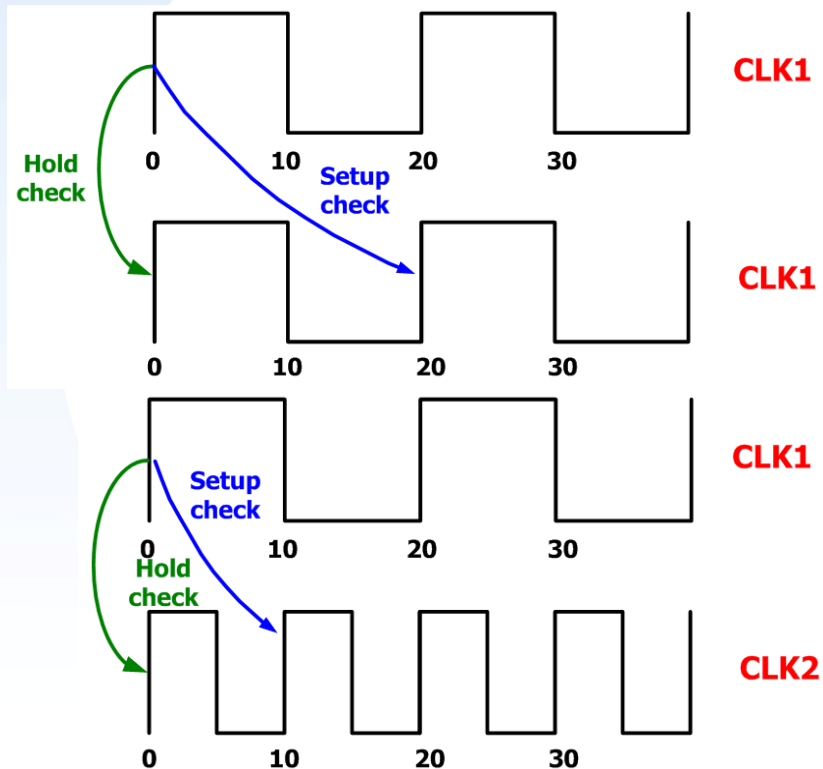
```
always @(posedge CLK2)  
    OUT <= data;
```

```
endmodule
```



Example: Multicycle Path of Multiple Clock Domain

```
dc_shell>create_clock -period 20 CLK1  
dc_shell>create_clock -period 10 CLK2
```



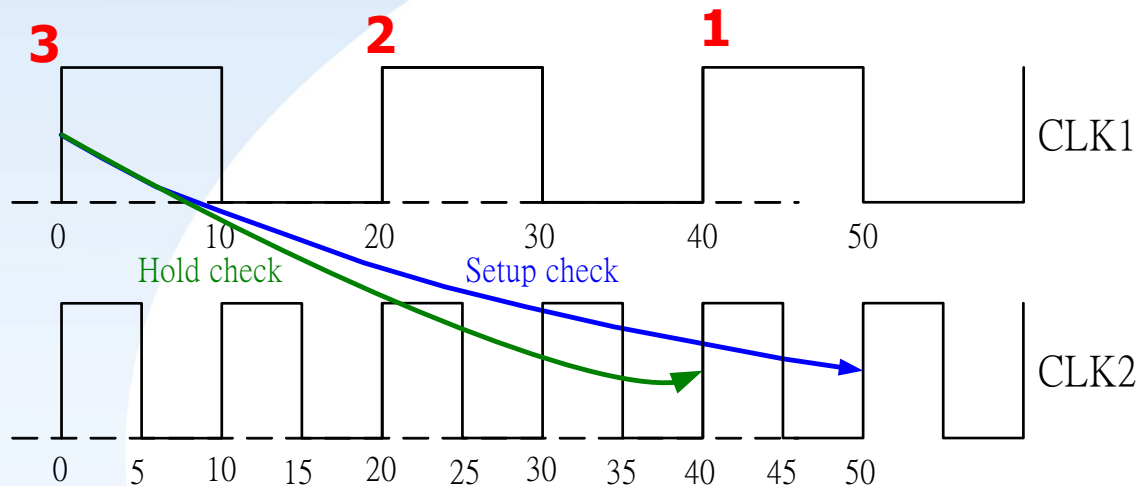
setup and hold check
in clock domain 1

setup and hold check
from clock domain 1
to clock domain 2



Example: Multicycle Path of Multiple Clock Domain (Hold Time violation version)

```
dc_shell>set_multicycle_path 3 -start -from CLK1 -to CLK2
dc_shell>report_timing_requirements
```



```
*****
Report : timing_requirements
-attributes
Design : MULTICLOCK
*****
```

Description

Setup

Hold

TIMING EXCEPTION

cycles=3(start)

cycles=0

-from CLK1\
-to CLK2



Example: Multicycle Path of Multiple Clock Domain (Hold Time violation version)

dc_shell>compile

dc_shell>report_timing

dc_shell>report_timing -delay min

Try to satisfy hold time check by insert many delay cells

Path Group: CLK2

Path Type: max

Point	Incr	Path
clock CLK1 (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
TEMP2_reg/CK (DFFX4)	0.00	0.00 r
TEMP2_reg/Q (DFFX4)	0.28	0.28 r
U48/Y (XOR2XL)	0.41	0.69 r
.....(ignored)		
U5/Y (INVXL)	0.21	49.77 f
U4/Y (CLKIN VX8)	0.08	49.85 r
OUT_reg/D (DFFX4)	0.00	49.85 r
data arrival time		49.85
clock CLK2 (rise edge)	50.00	50.00
clock network delay (ideal)	0.00	50.00
OUT_reg/CK (DFFX4)	0.00	50.00 r
library setup time	-0.14	49.86
data required time		49.86
data required time		49.86
data arrival time		-49.85
slack (MET)		0.01

Path Group: CLK2

Path Type: min

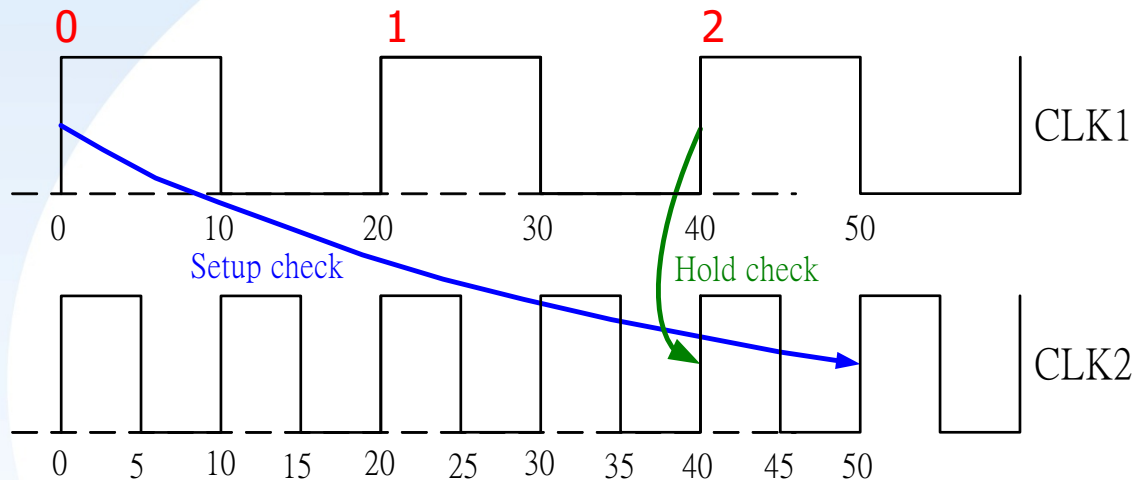
Point	Incr	Path
clock CLK1 (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
TEMP1_reg/CK (DFFX4)	0.00	0.00 r
TEMP1_reg/Q (DFFX4)	0.10	0.10 f
U48/Y (XOR2XL)	0.10	0.20 f
U47/Y (DLY4X1)	0.46	0.65 f
U46/Y (DLY4X1)	0.47	1.12 f
U45/Y (DLY4X1)	0.47	1.59 f
.....(ignored)		
U6/Y (DLY4X1)	0.47	19.90 f
U5/Y (INVXL)	0.15	20.05 r
U4/Y (CLKIN VX8)	0.03	20.08 f
OUT_reg/D (DFFX4)	0.00	20.08 f
data arrival time		20.08
clock CLK2 (rise edge)	40.00	40.00
clock network delay (ideal)	0.00	40.00
OUT_reg/CK (DFFX4)	0.00	40.00 r
library hold time	-0.04	39.96
data required time		39.96
data required time		39.96
data arrival time		-20.08
slack (VIOLATED)		-19.88

Timing Violation!!!



Example: Multicycle Path of Multiple Clock Domain (Correct version)

```
dc_shell>set_multicycle_path 3 --start --from CLK1 --to CLK2
dc_shell>set_multicycle_path 2 --hold --start --from CLK1 --to CLK2
dc_shell>report_timing_requirements
```



```
*****
Report : timing_requirements
-attributes
Design : MULTICLOCK
*****
```

Description	Setup	Hold
TIMING EXCEPTION	cycles=3(start)	cycles=2
-from CLK1\ -to CLK2		



Example: Multicycle Path of Multiple Clock Domain (Correct version)

```
dc_shell>compile
```

```
dc_shell>report_timing
```

```
dc_shell>report_timing -delay min
```

Path Group: CLK2

Path Type: **max**

Point	Incr	Path

clock CLK1 (rise edge)	0.00	0.00
clock network delay (ideal)	0.00	0.00
TEMP1_reg/CK (DFFX1)	0.00	0.00 r
TEMP1_reg/Q (DFFX1)	0.44	0.44 r
U49/Y (XOR2X1)	0.29	0.73 f
OUT_reg/D (DFFX1)	0.00	0.73 f
data arrival time		0.73

clock CLK2 (rise edge)	50.00	50.00
clock network delay (ideal)	0.00	50.00
OUT_reg/CK (DFFX1)	0.00	50.00 r
library setup time	-0.31	49.69
data required time		49.69

data required time		49.69
data arrival time		-0.73

slack (MET)		48.95

Path Group: CLK2

Path Type: **min**

Point	Incr	Path

clock CLK1 (rise edge)	40.00	40.00
clock network delay (ideal)	0.00	40.00
TEMP2_reg/CK (DFFX1)	0.00	40.00 r
TEMP2_reg/Q (DFFX1)	0.14	40.14 f
U49/Y (XOR2X1)	0.08	40.22 r
OUT_reg/D (DFFX1)	0.00	40.22 r
data arrival time		40.22

clock CLK2 (rise edge)	40.00	40.00
clock network delay (ideal)	0.00	40.00
OUT_reg/CK (DFFX1)	0.00	40.00 r
library hold time	-0.03	39.97
data required time		39.97

data required time		39.97
data arrival time		-40.22

slack (MET)		0.25

Timing
Met !!!



✓ Timing Analysis Considering Clk Latency

- STA vs DTA
- CLK latency
- CLK uncertainty

✓ Multicycle Path Specification

- Specify Multicycle Path
- Single clock system
- Multiple clocks system

✓ Clock Domain Crossing (CDC)

✓ Appendix



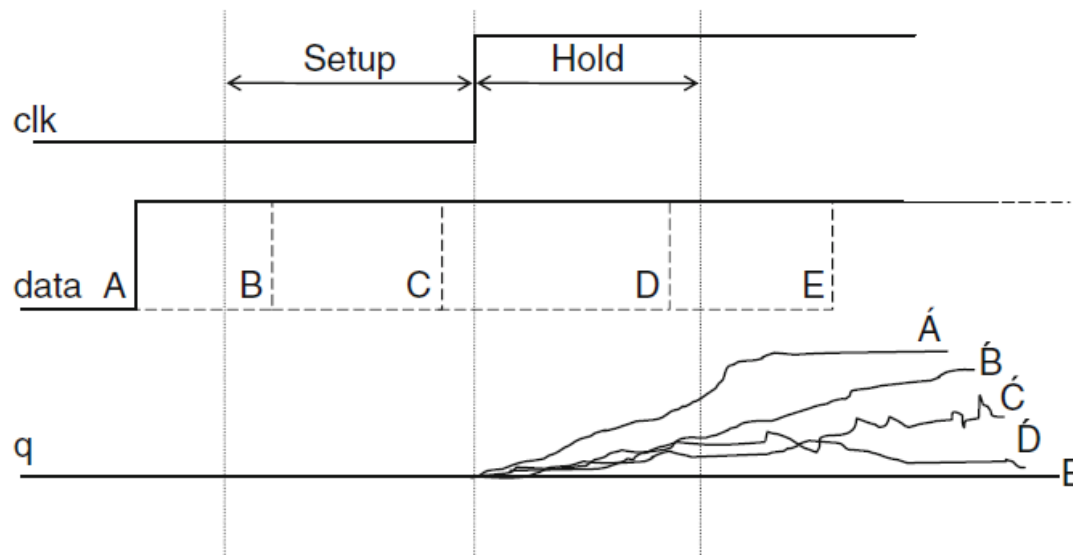
Clock Domain Crossing (CDC)

- ✓ Because different blocks require different clock period, some blocks need long clock period to operate, but others only do simple work. If we all use long clock period, it will cause the performance to be poor. So that's why we need to use clock domain crossing .



Metastability

- ✓ The unstable status due to non-ideal data transition is called metastability.
- ✓ To avoid this phenomenon, we have to ensure no data transition during setup/hold timing check.
- ✓ However, CDC designs will inevitably face this problem.



CDC solution

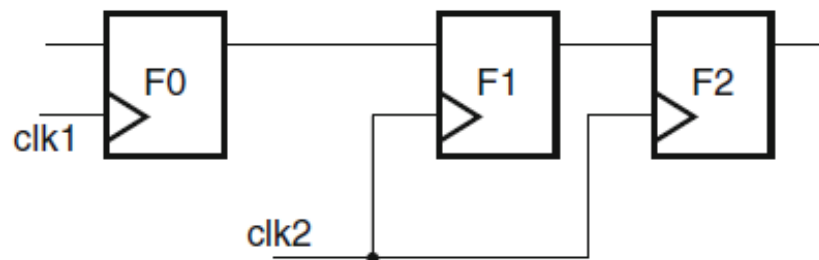
- ✓ There are lots of solutions for CDC designs, here we would only introduce an easy one.
- ✓ Double Flop(2-FF) Synchronizer
 - Flag
 - Handshake
 - FIFO(First In First Out)



CDC solution

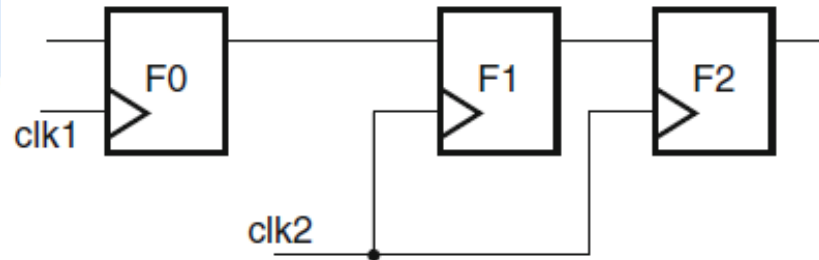
✓ Double Flop(2-FF) Synchronizer

- F1 samples the asynchronous input signal into the destination clock domain, probably a meta-stable value.
- any meta-stability on the F1 output signal to decay. With a full clk2 cycle to permit
- clock into F2, which we expect to be a stable and valid signal. Then the signal is sampled by the same.
- Often used in 1-bit flag transmission.

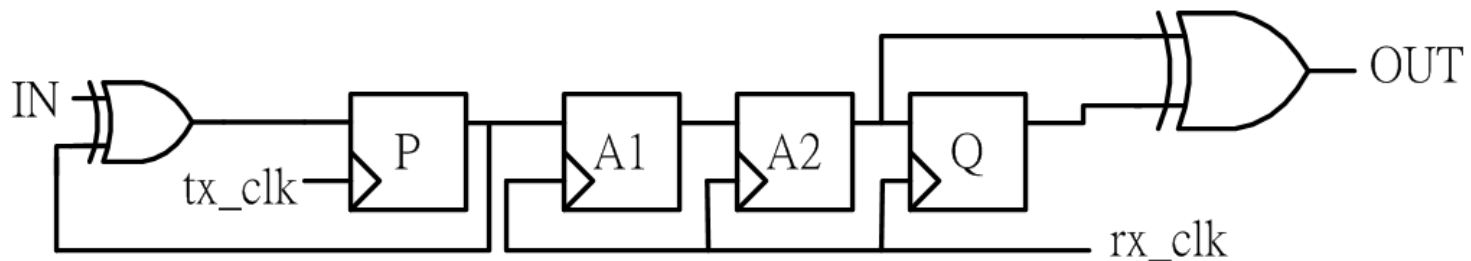


CDC solution – Flag

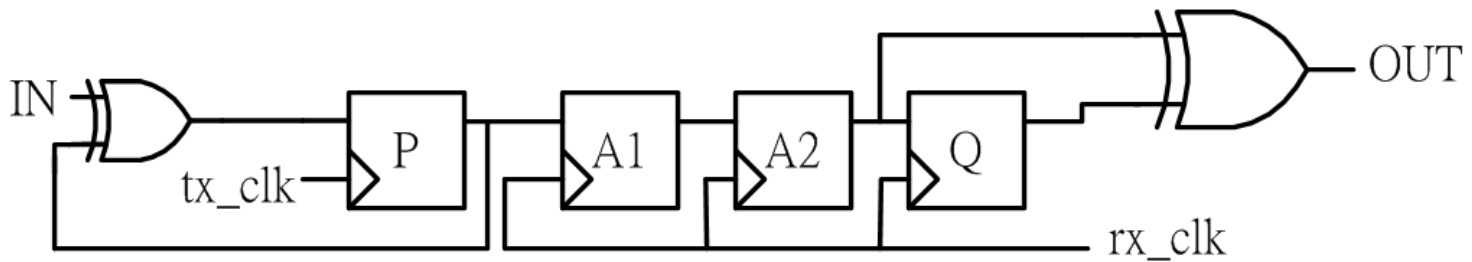
- ✓ Double Flop(2-FF) Synchronizer



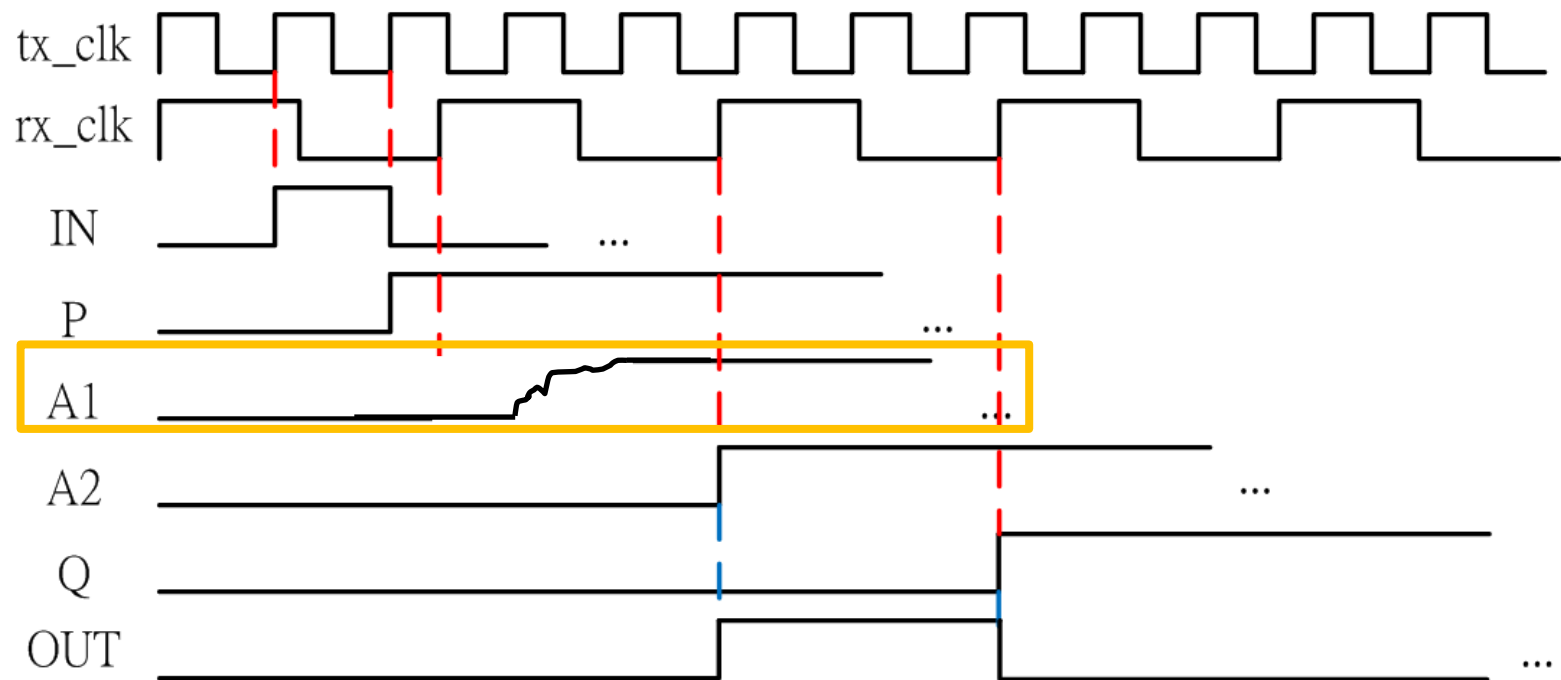
- ✓ Double Flop(2-FF) Synchronizer + XOR (PULSE)



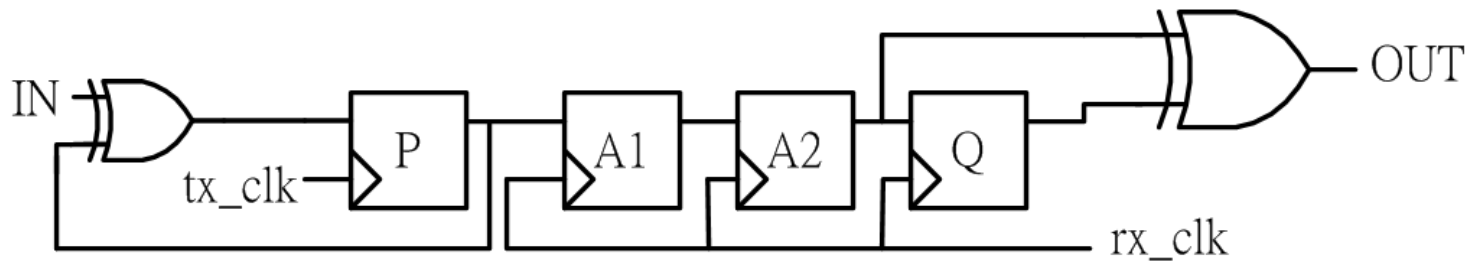
Example



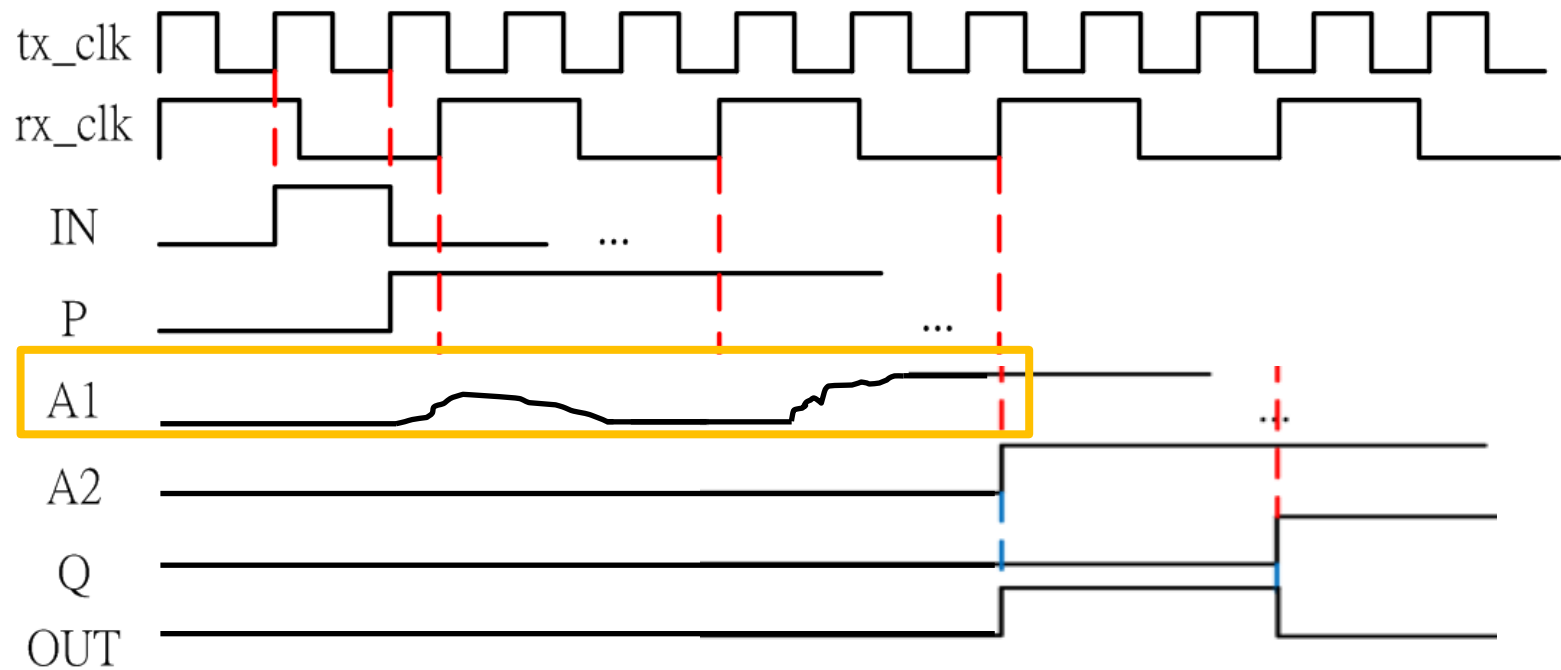
fast to slow



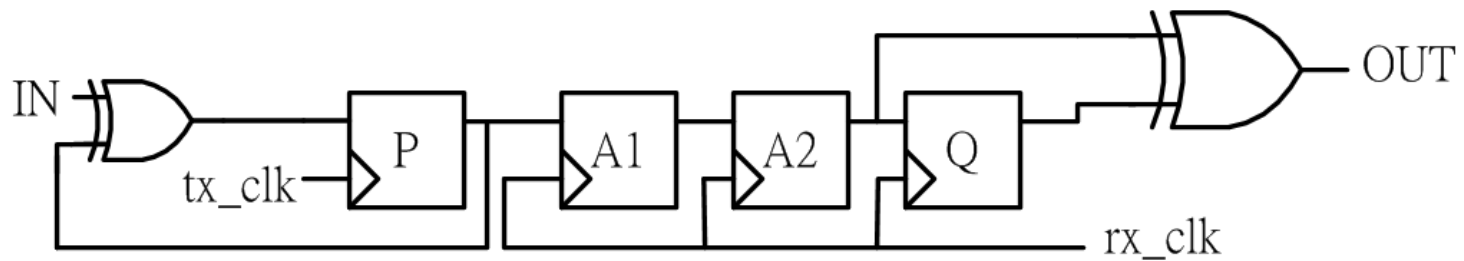
Example



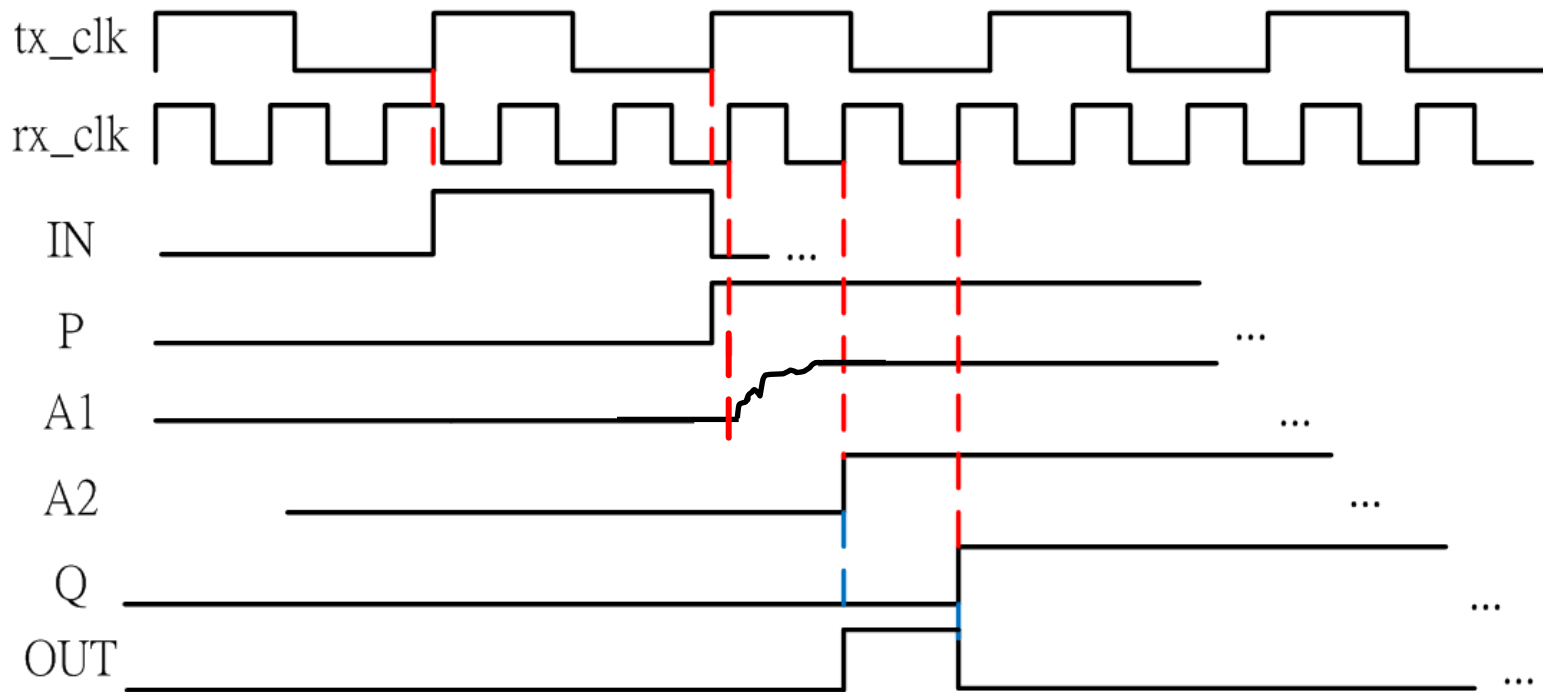
fast to slow



Example

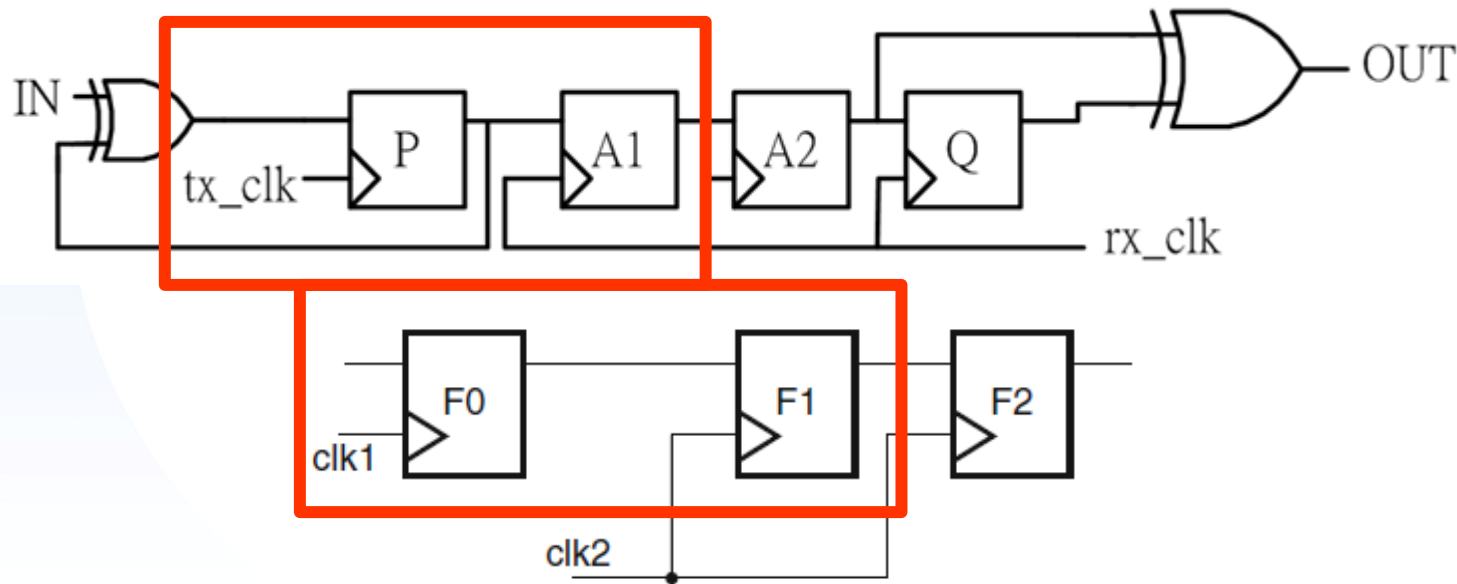


slow to fast



Specify False Path

- ✓ **Remove timing constraints from particular path**
 - Timing checks of false path will be disabled. Therefore, use this command carefully
- ✓ **dc_shell>set_false_path –from FF_A/CK –to FF_D/D**



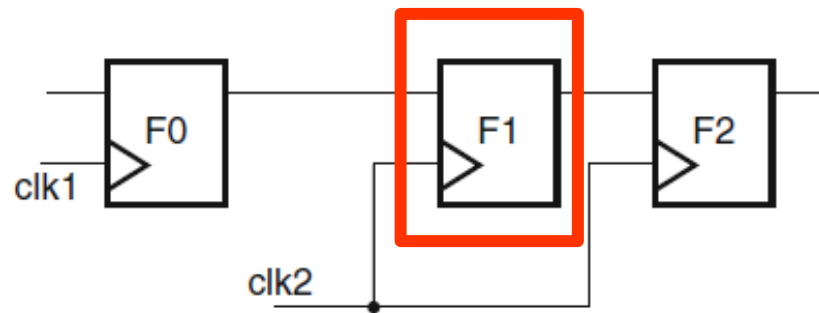
Specify Clock Group

- ✓ **Remove timing constraints of cross clock domain path**
 - Timing checks of cross clock group domain path will be disabled. Therefore, use this command carefully
 - Make sure synchronizers are used correctly for all cross-domain pairs
- ✓ **dc_shell>set_clock_groups -name group1 -asynchronous -group {clk1} -group {clk2} -group {clk3}**



set_annotated_check

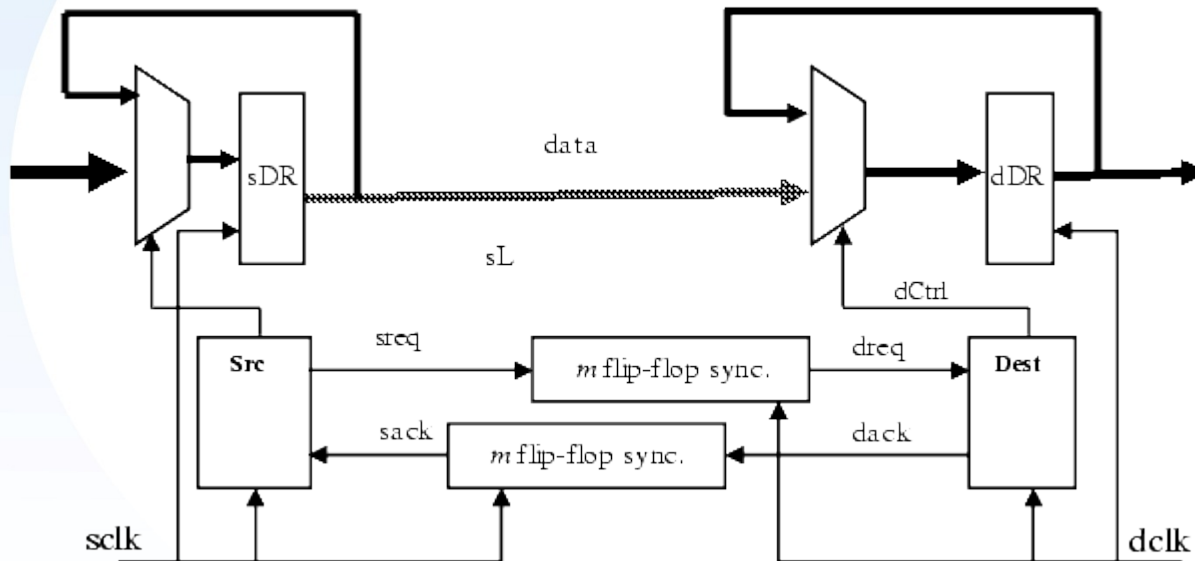
- ✓ Using PrimeTime tool rewrite the sdf file to ignore some timing checks.
- ✓ `pt_shell>set_annotated_check -0 -setup -from F1/CK -to F1/D -clock rise`
- ✓ `pt_shell>set_annotated_check -0 -hold -from F1/CK -to F1/D -clock rise`



CDC solution - Handshake

✓ Handshake Synchronizers.

- Synchronize a single-bit request into the destination clock domain and wait for a synchronized version of the acknowledge to come back.
- Time uncertainty and high latency.
- Data stability and protocol check



CDC solution - FIFO

- ✓ Dual Clock FIFO synchronizers (Asynchronous FIFO)
- Data is written into a dual-port RAM block from the source clock domain and the RAM is read in the destination clock domain.
- Gray-coded read and write pointers are passed into the alternate clock domain to generate full and empty status flags.
- High throughput but difficult hardware.

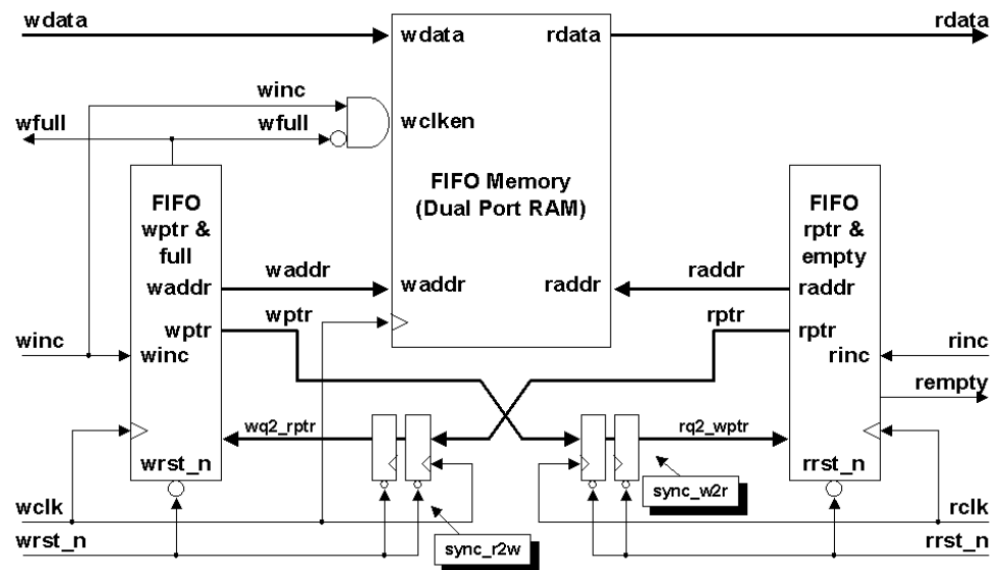


Figure 5 - FIFO1 partitioning with synchronized pointer comparison

Reference: Simulation and Synthesis Techniques for Asynchronous FIFO Design

CDC solution - FIFO

- ✓ Dual Clock FIFO synchronizers (Asynchronous FIFO)
 - Data is written into a dual-port RAM block from the source clock domain and the RAM is read in the destination clock domain.
 - Gray-coded read and write pointers are passed into the alternate clock domain to generate full and empty status flags.
 - High throughput but difficult hardware.

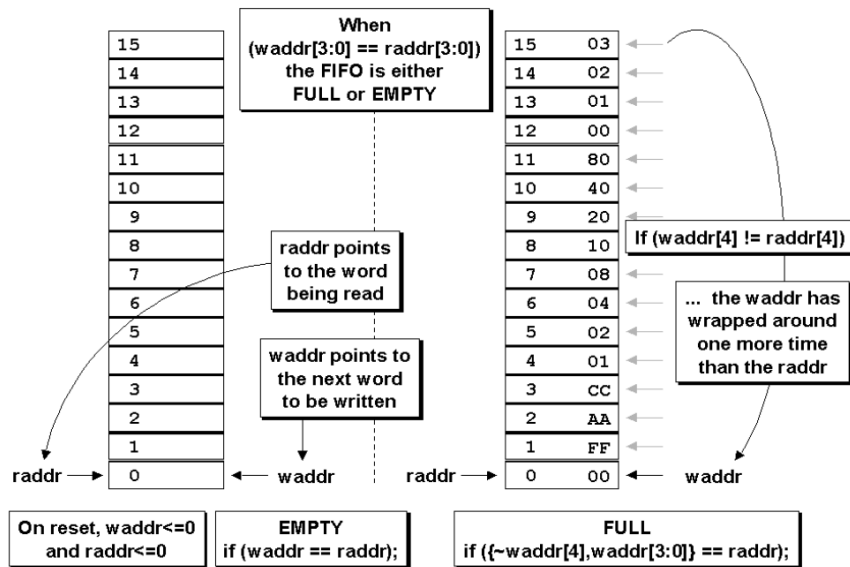


Figure 1 - FIFO full and empty conditions

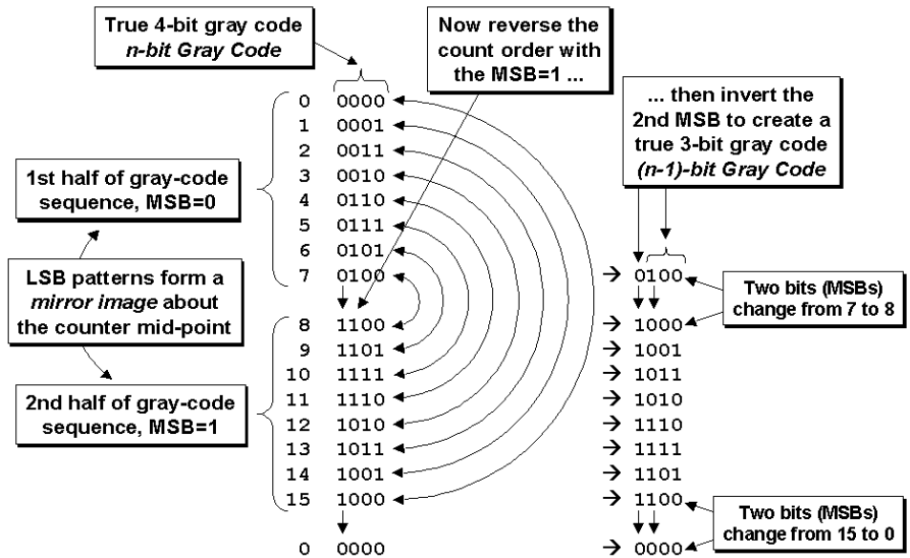


Figure 2 - n -bit Gray code converted to an $(n-1)$ -bit Gray code

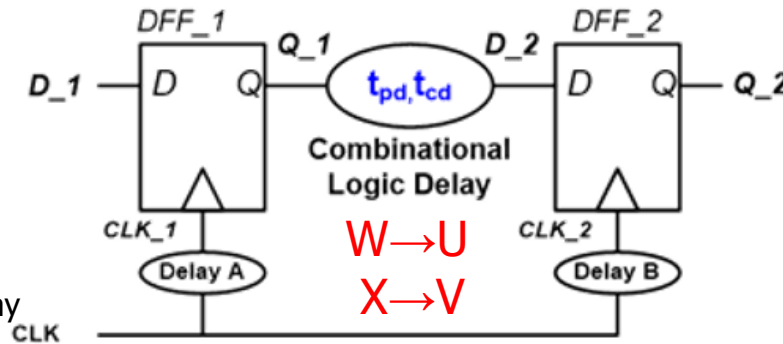
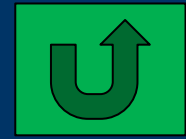
Reference: Simulation and Synthesis Techniques for Asynchronous FIFO Design

Reference

- ✓ More detail please refer “Principles of VLSI RTL Design A Practical Guide”
- ✓ More detail please refer “Static Timing Analysis for Nanometer Design”

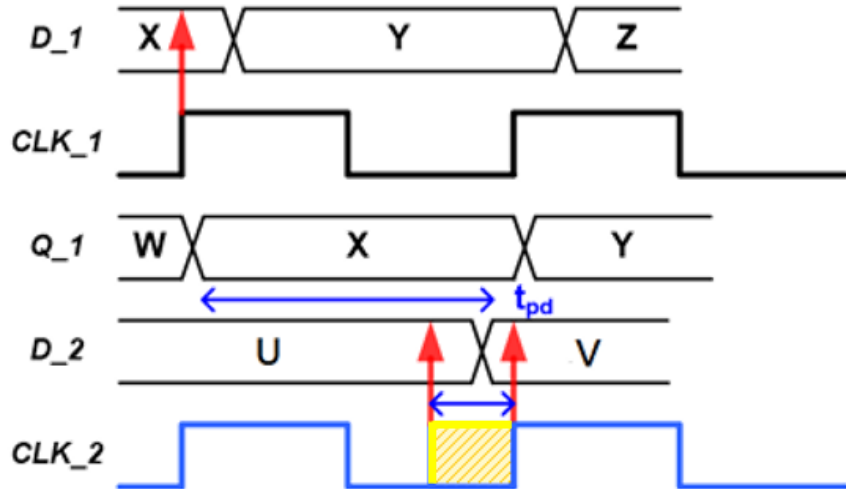


Appendix-Timing Check



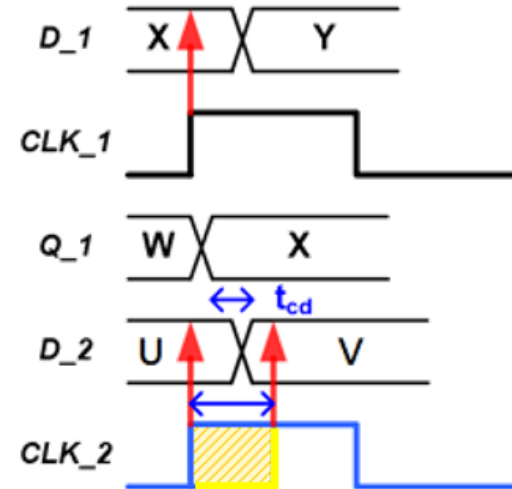
Setup time determines **max** value of t_{pd}

Hold time determines **min** value of t_{cd}



Setup Time Check

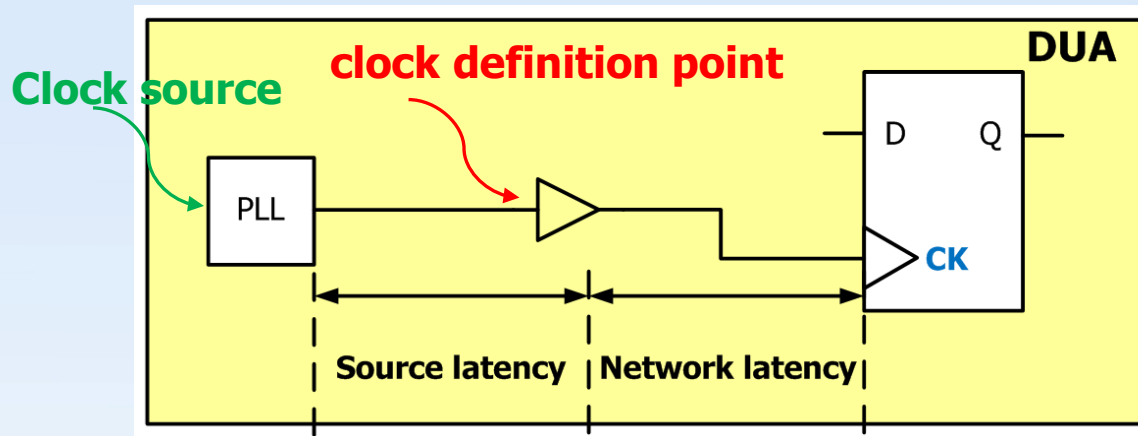
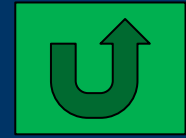
$$T_{cycle} \geq T_{pd} + T_{setup}$$



Hold Time Check

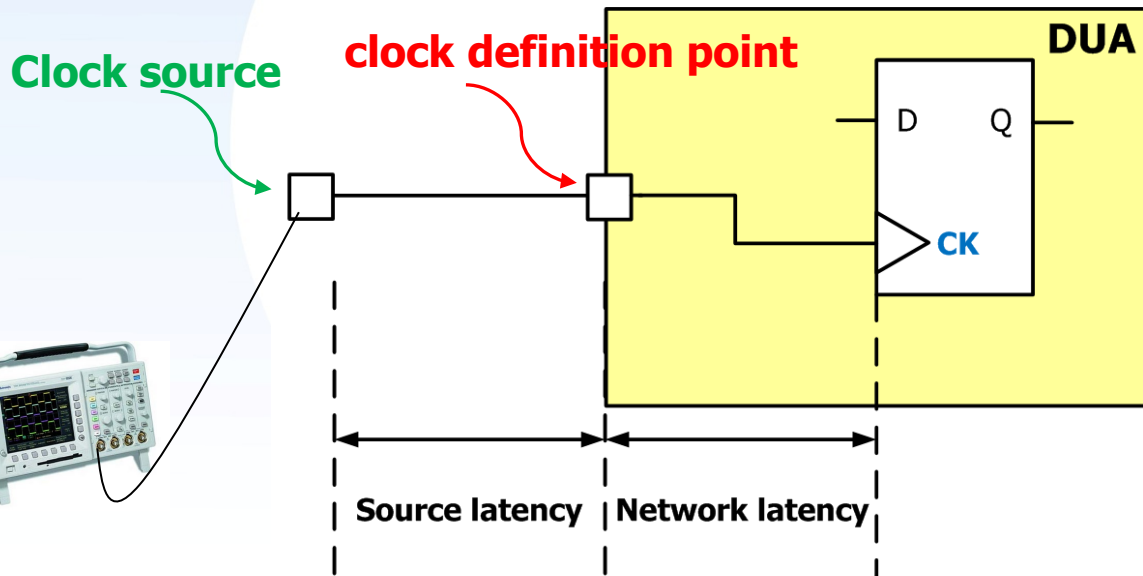
$$T_{cd} \geq T_{hold}$$

Appendix-Clock Latency



p.s. DUA(Design under analysis)

- On-chip clock source



- Off-chip clock source