04: Buses II

Engr 315: Hardware / Software Codesign

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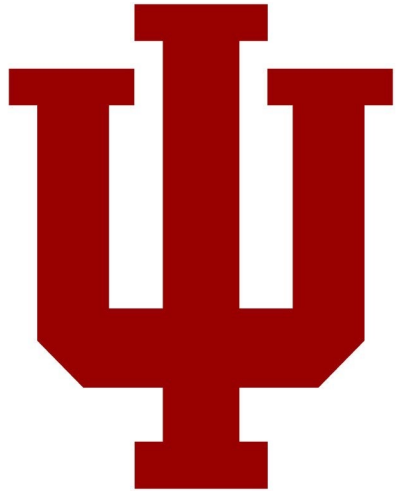
Indiana University



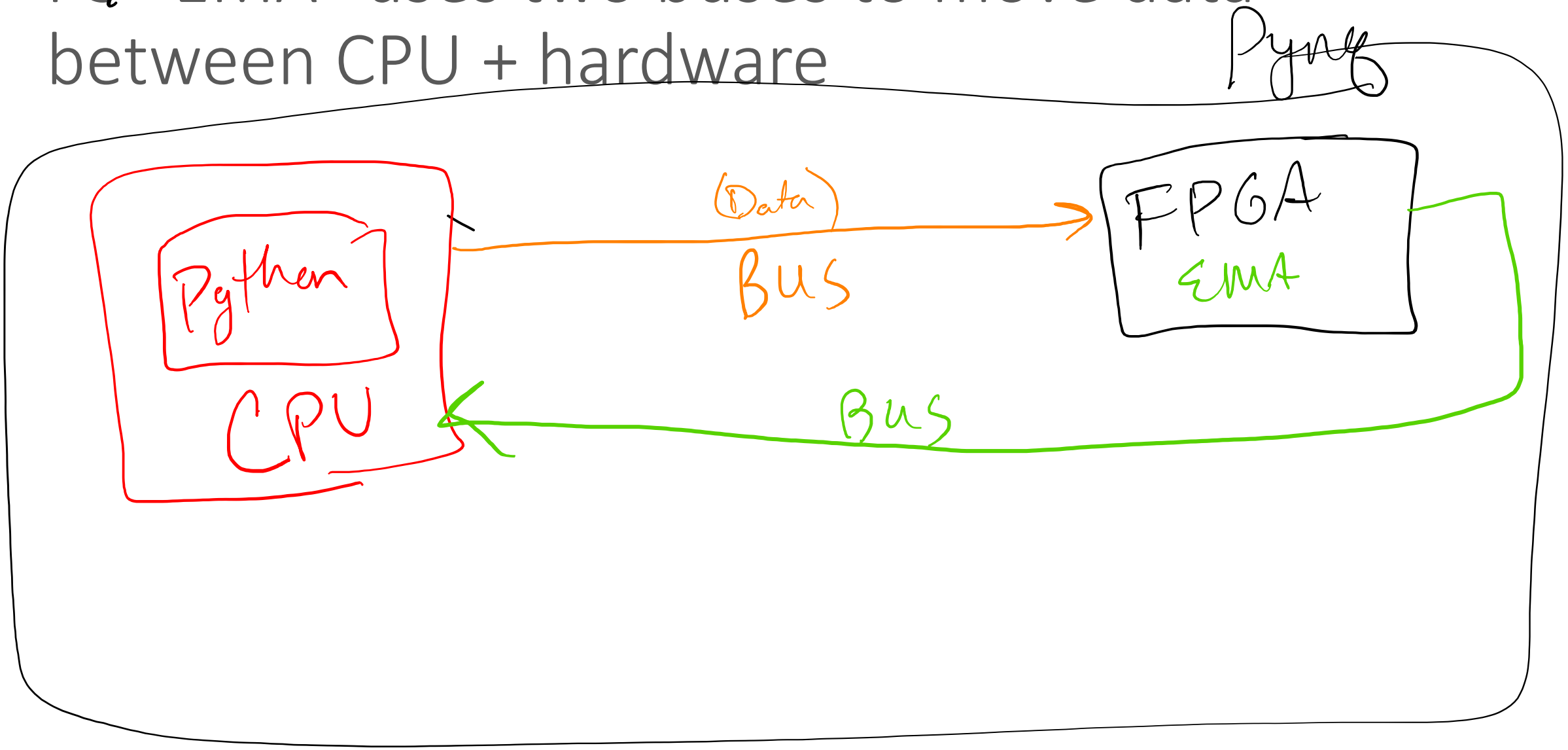
Announcements

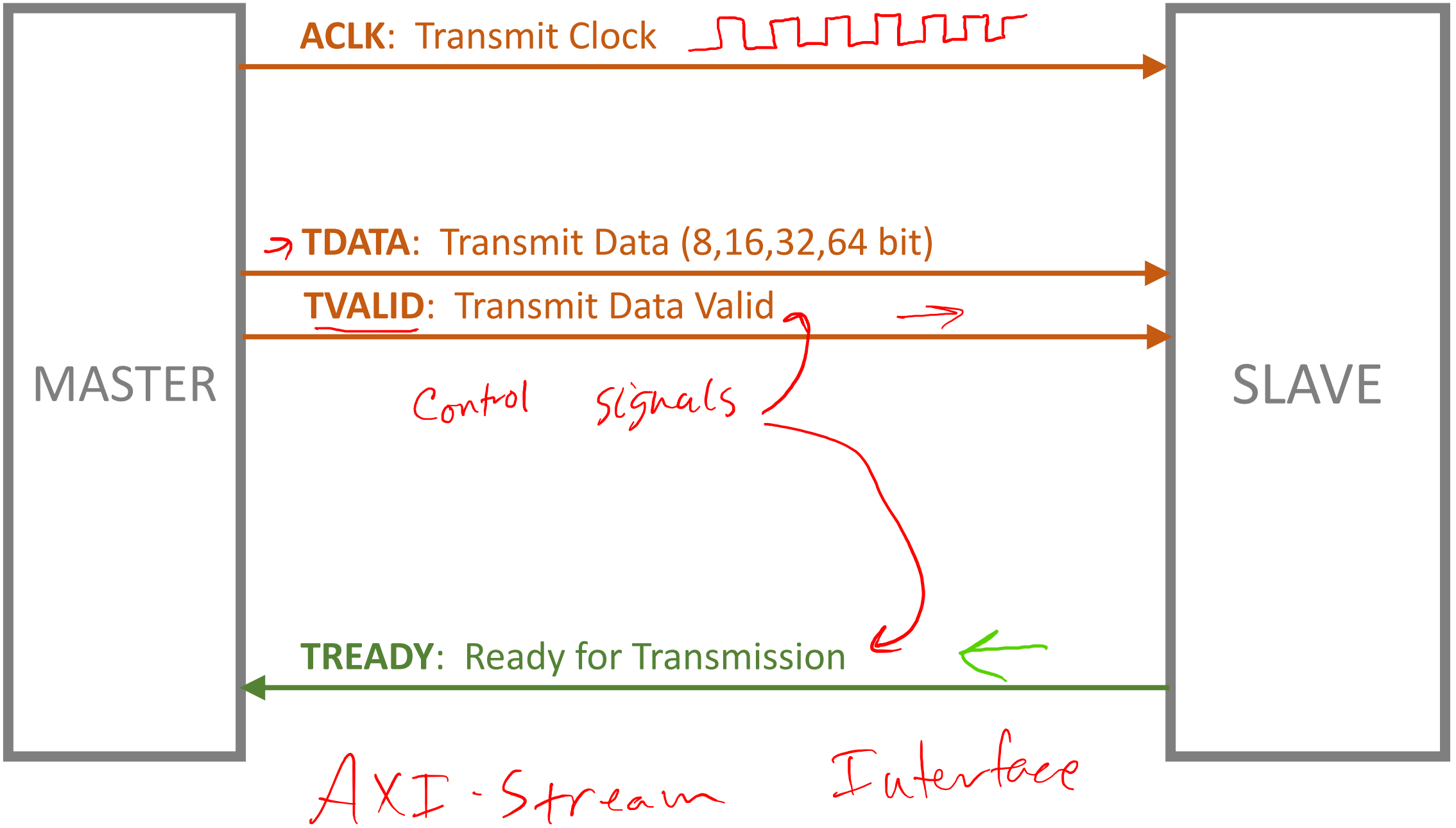
- P2 is live
  - Going to need a Pynq.
- P3 is live.

Bus terminology

- A "transaction" occurs between an "*initiator*" and "*target*"
- Any device capable of being an initiator is said to be a "*bus master*"
  - In many cases there is only one bus master (*single master* vs. *multi-master*).
- A device that can only be a target is said to be a "slave device".

P2 "EMA" uses two buses to move data between CPU + hardware




MASTER
SLAVE
ACLK: Transmit Clock
TDATA: Transmit Data (8,16,32,64 bit)
TVALID: Transmit Data Valid
Control signals
TREADY: Ready for Transmission
AXI-Stream Interface

Data (TDATA) is only transferred when

TVALID is **1.**

This indicates the **MASTER** is trying to transmit new data.

TREADY is **1.**

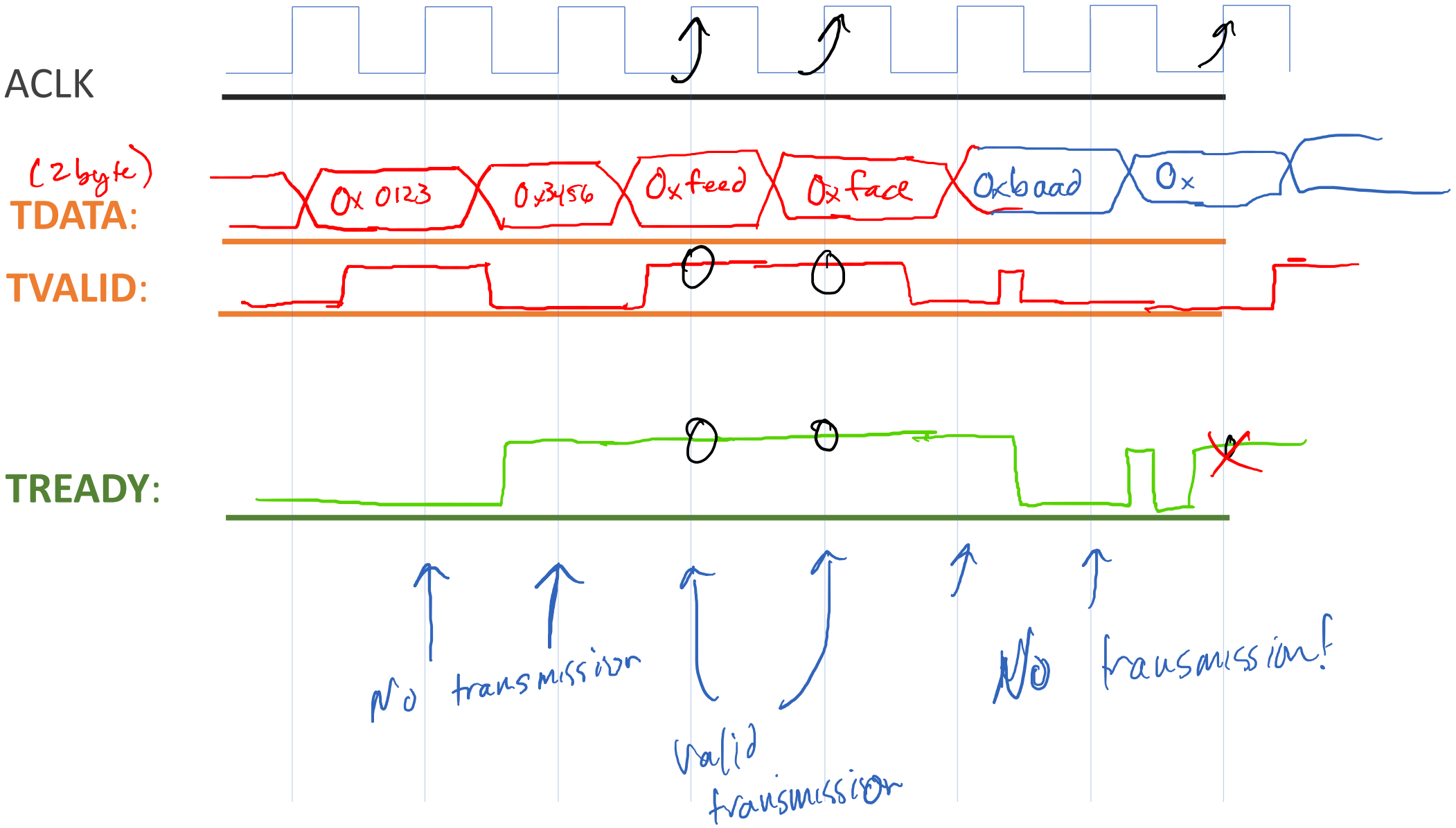
This indicates the **SLAVE** is ready to receive the data.

If either **TVALID** or **TREADY** are 0, **no data is transmitted**.

If **TVALID** and **TREADY** are 1, **TDATA** is transmitted

at the positive edge of ACLK

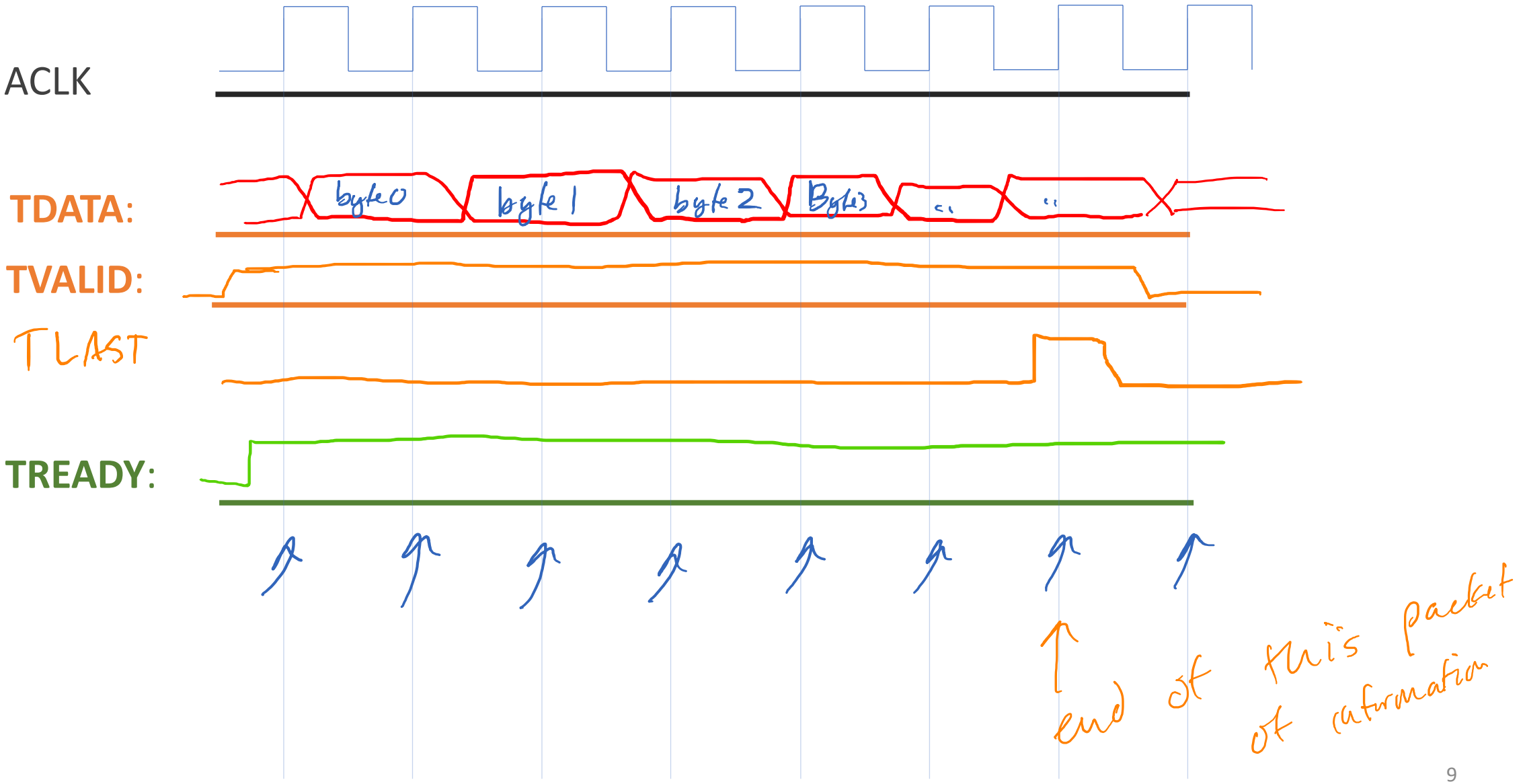
Transferring data on a AXI4-Stream Bus.

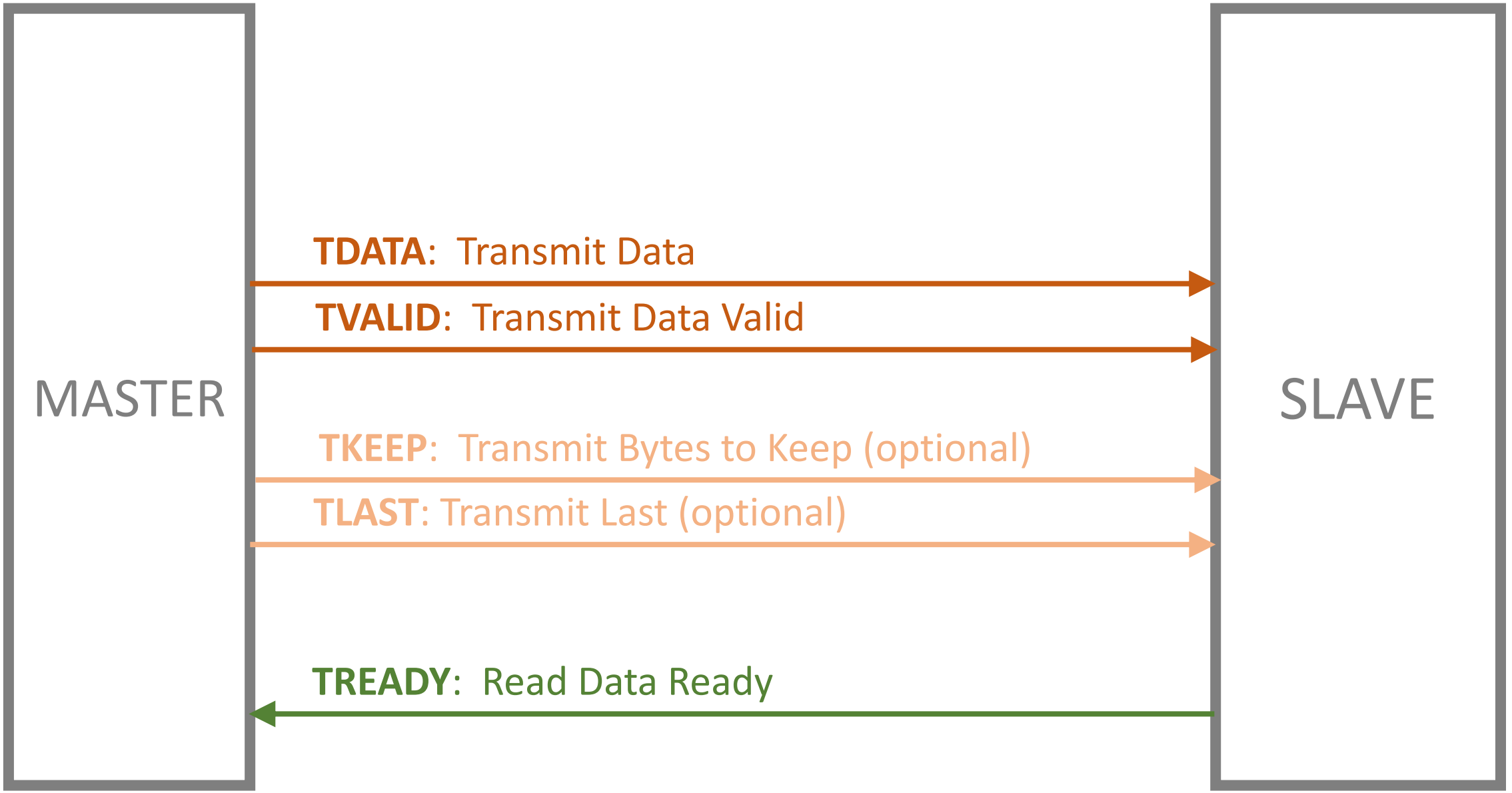


TLAST

- Special signal to indicate a group or “burst” of transmissions is complete.
- “Indicates the boundary of a packet”

Transferring data on a AXI4-Stream Bus.




MASTER
SLAVE
TDATA: Transmit Data
TVALID: Transmit Data Valid
TKEEP: Transmit Bytes to Keep (optional)
TLAST: Transmit Last (optional)
TREADY: Read Data Ready

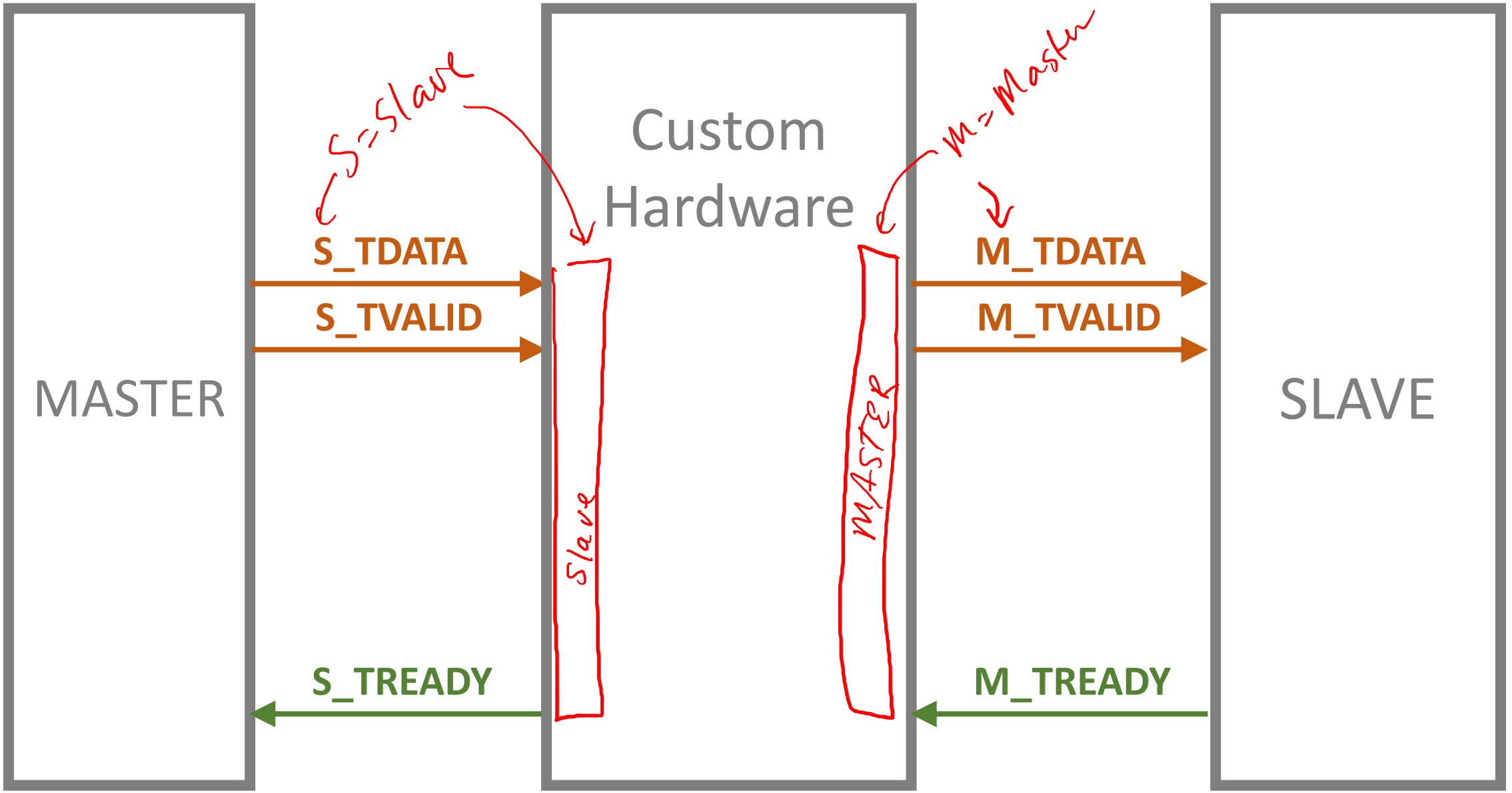
TKEEP

- What if TDATA is 32-bits (4 bytes) wide, and I want to send 6 bytes?

- **TKEEP** let's me specify which bytes to "keep".

- **TKEEP** ==1111 -> Keep all 4 bytes (32-bits)
- **TKEEP** ==1100 -> Keep first 2 bytes (16-bit)
- **TKEEP** ==1000 -> Keep first byte (8-bit)

Transferring data on a AXI4-Stream Bus.

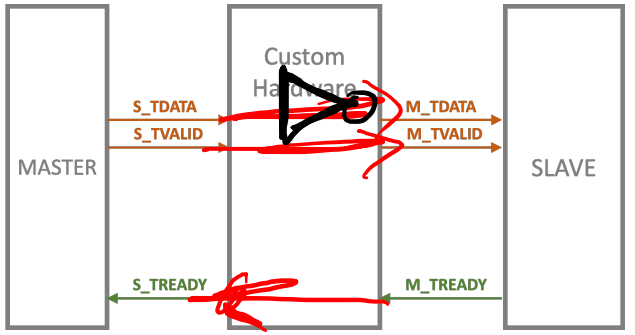

MASTER
Custom Hardware
SLAVE
S=Slave
M=Master
S_TDATA
S_TVALID
S_TREADY
M_TDATA
M_TVALID
M_TREADY
Slave
MASTER

Let's build a custom block that does nothing!

```
module custom_hw (
        input           ACLK,
        input           ARESET,
        input [31:0]    S_TDATA,
        input           S_TVALID,
        output          S_TREADY,
        output [31:0]   M_TDATA,
        output          M_TVALID,
        input           M_TREADY
);

assign M_TDATA = S_TDATA;
assign M_TVALID = S_TVALID;
assign S_TREADY = M_TREADY;

endmodule
```



Let’s build a custom block that does nothing!

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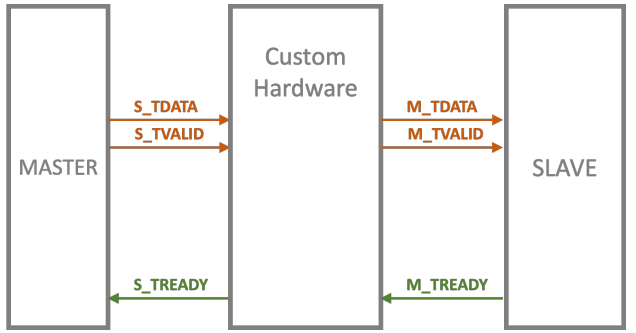
        input          ACLK,
        input          ARESET,
        input [31:0]   S_TDATA,
        input          S_TVALID,
        output         S_TREADY,
        output [31:0]  M_TDATA,
        output         M_TVALID,
        input          M_TREADY
);

assign M_TDATA = S_TDATA;
assign M_TVALID = S_TVALID;
assign S_TREADY = M_TREADY;

endmodule
```

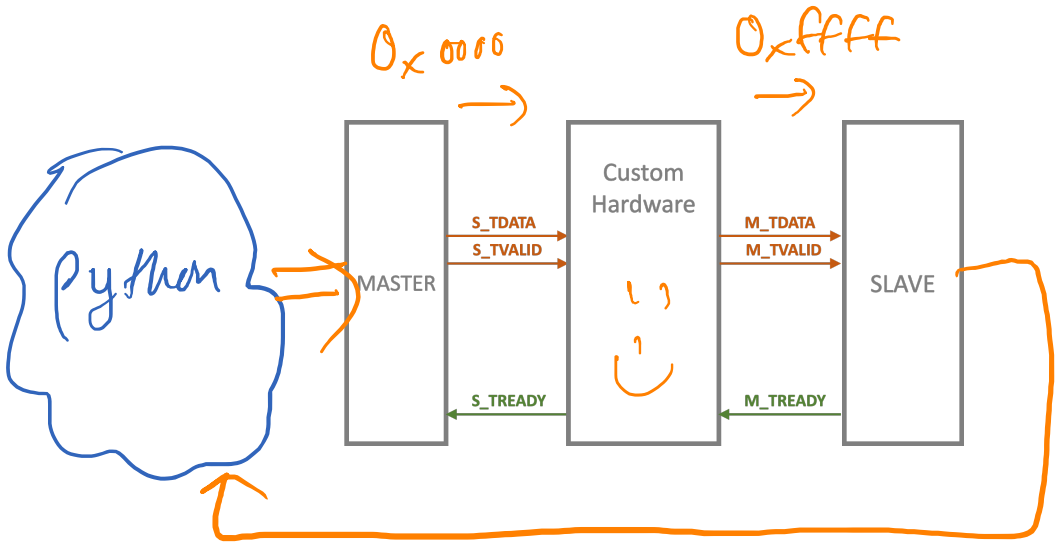


How would I flip all the bits of TDATA?

```
module custom_hw (
        input           ACLK,
        input           ARESET,
        input [31:0]    S_TDATA,
        input           S_TVALID,
        output          S_TREADY,
        output [31:0]   M_TDATA,
        output          M_TVALID,
        input           M_TREADY
);

assign M_TDATA = S_TDATA;
assign M_TVALID = S_TVALID;
assign S_TREADY = M_TREADY;

endmodule
```

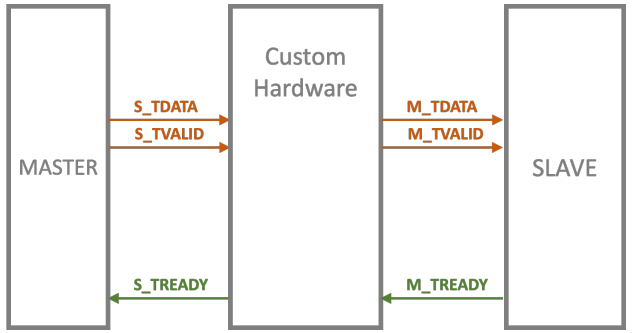


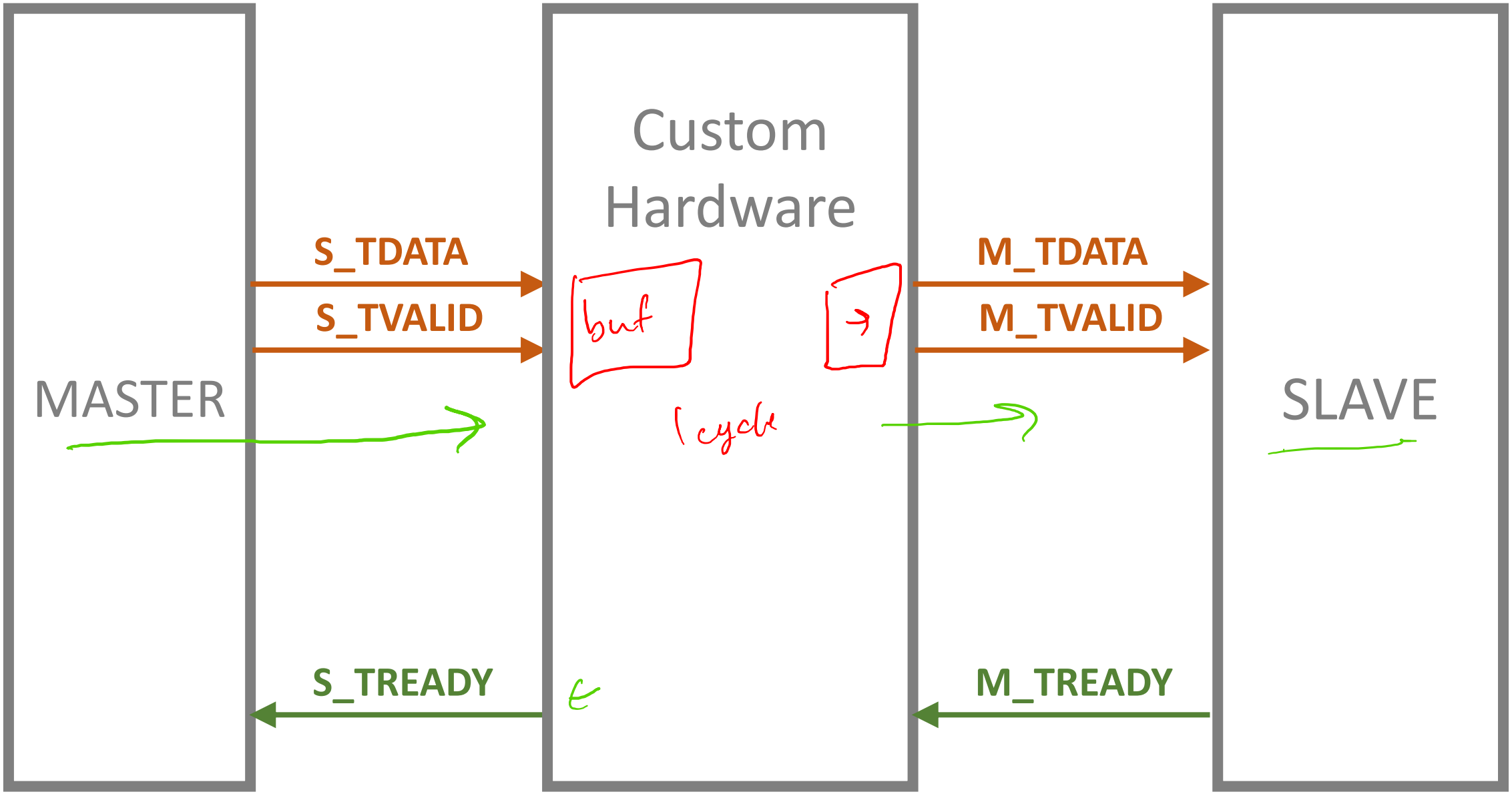
How would I flip all the bits of TDATA?

```
module custom_hw (
        input          ACLK,
        input          ARESET,
        input [31:0]   S_TDATA,
        input          S_TVALID,
        output         S_TREADY,
        output [31:0]  M_TDATA,
        output         M_TVALID,
        input          M_TREADY
);

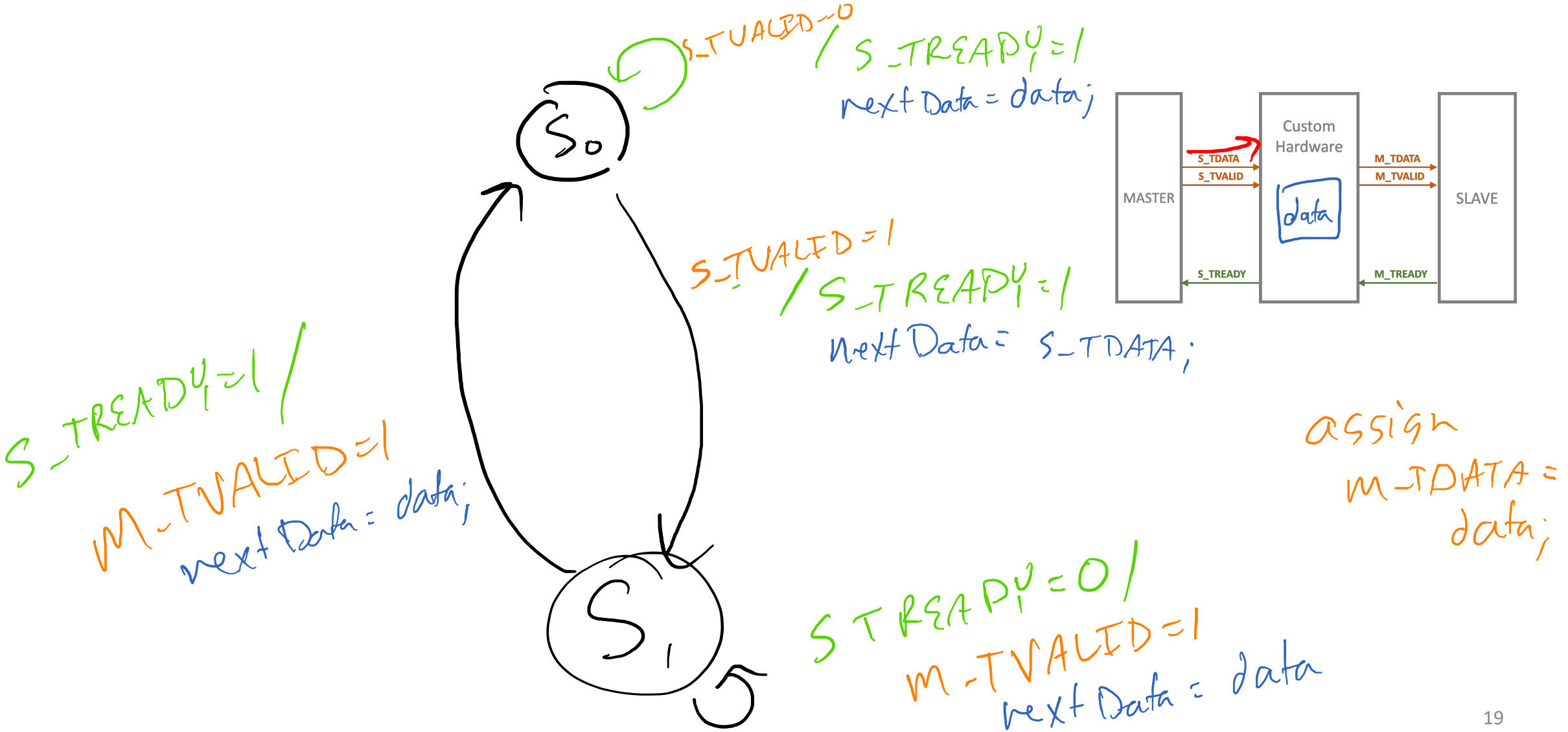
assign M_TDATA = ~S_TDATA;
assign M_TVALID = S_TVALID;
assign S_TREADY = M_TREADY;

endmodule
```

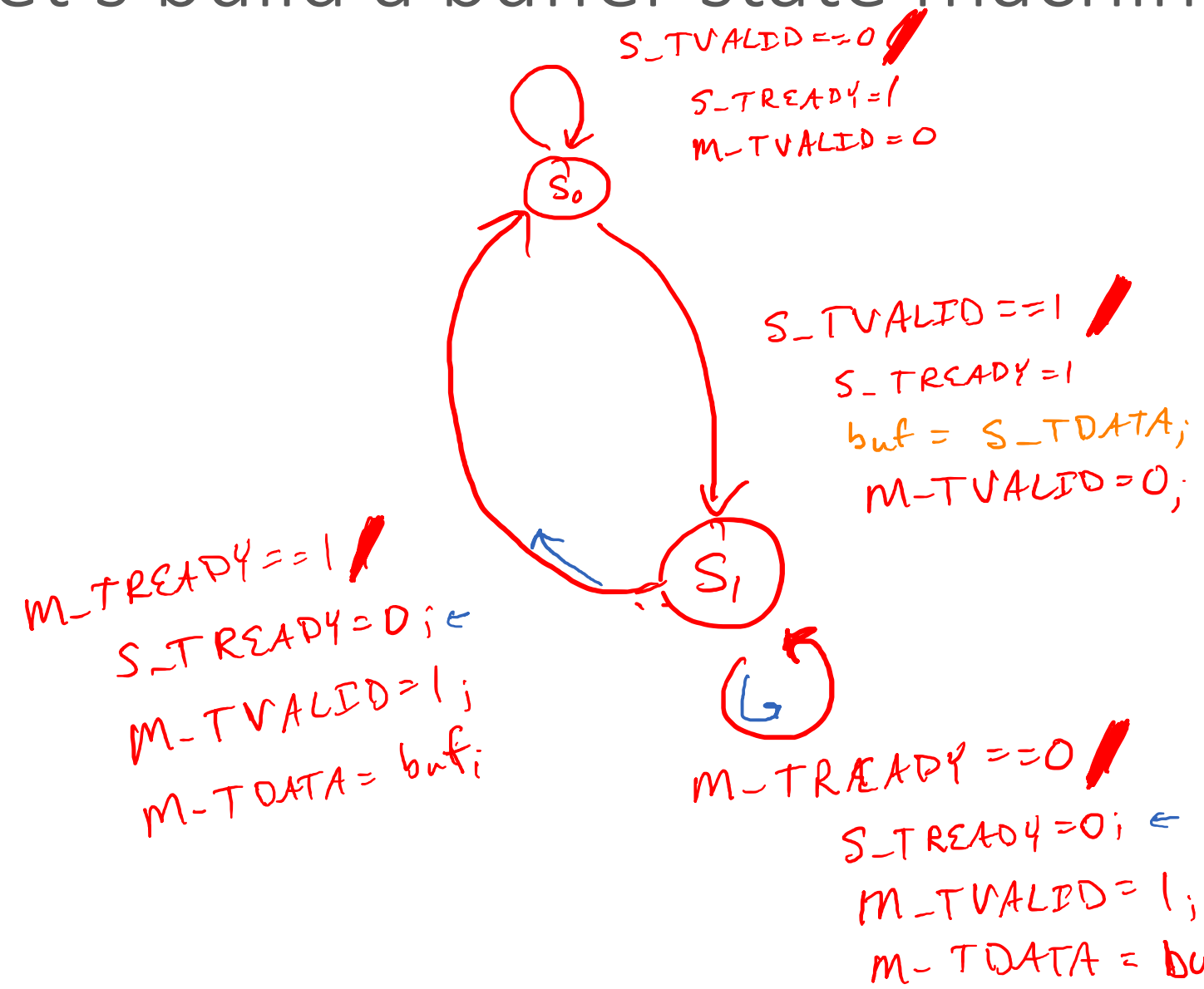


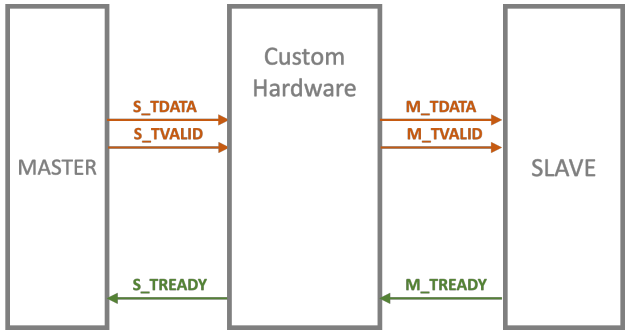

Custom
Hardware
MASTER
SLAVE
S_TDATA
S_TVALID
S_TREADY
M_TDATA
M_TVALID
M_TREADY
buf
1 cycle

Let's build a buffer state machine.



Let's build a buffer state machine.



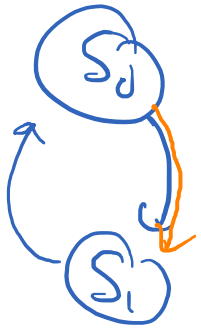


Let's build a buffer state machine.

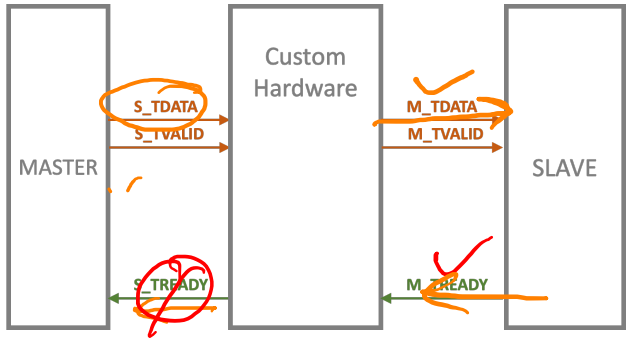
```
module custom_hw_buf (
        input             ACLK,
        input             ARESET,
        input [31:0]      S_TDATA,
        input             S_TVALID,
        output            S_TREADY,
        output [31:0]     M_TDATA,
        output            M_TVALID,
        input             M_TREADY
);
```

reg [31:0] buf, nextbuf;

enum { S_0, S_1 } state, nextState;



buf

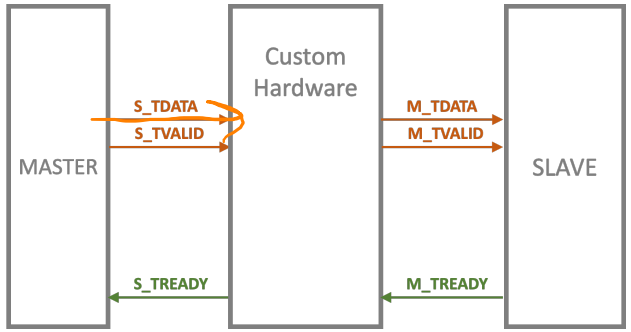



```
always_ff (@posedge ACLK) begin
    if (ARESET) begin
        state <= S0;
        buf <= 32'h0;
    end else begin
        state <= nextState;
        buf <= nextbuf;
    end
end
```

```
always_comb begin
    M_TDATA = buf
    M_TVALID = 1'h0;
    S_TREADY = 1'h1;
    nextState = state;
    nextbuf = buf;
    case (state)
        S0: if (S_TVALID) begin
                nextbuf = S_TDATA;
                nextState = S1;
            end
        S1: S_TREADY = 0;
            M_TVALID = 1;
            if (M_TREADY)
                nextState = S0
```

endmodule

Let’s build a buffer state machine.




```
module custom_hw_buf (
        input           ACLK,
        input           ARESET,
        input [31:0]    S_TDATA,
        input           S_TVALID,
        output          S_TREADY,
        output [31:0]   M_TDATA,
        output          M_TVALID,
        input           M_TREADY
);

enum {S0, S1} state, nextState;
reg [31:0] nextVal;

always_ff @(posedge ACLK) begin
    if (ARESET)begin
        state <= S0;
        M_TDATA <= 32’h0
    end else begin
        state <= nextState;
        M_TDATA <= nextVal;
    end
end
```

```
always_comb begin
    S_TREADY = ‘h1;
    M_TVALID = ‘h0;
    nextState = state;
    nextVal = M_TDATA;
    case(state)
        S0:  begin
            if (S_TVALID) begin
                nextState = S1;
                nextVal = S_TDATA;
            end
        end
        S1: begin
            S_TREADY = ‘h0;
            M_TVALID = ‘h1;
            if (M_TREADY) begin
                nextState = S0;
        end
    endcase
end

endmodule
```

Vivado Demo

Next Time

- Memory-Mapped I/O
- Memory-Mapped Buses

References

- Zynq Book, Chapter 19 “AXI Interfacing”
- Practical Introduction to Hardware/Software Codesign
  - Chapter 10
- AMBA AXI Protocol v1.0
  - http://mazsola.iit.uni-miskolc.hu/~drdani/docs_arm/AMBAaxi.pdf
- https://lauri.võsandi.com/hdl/zynq/axi-stream.html

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