AVIONICS INTEGRATION TESTBENCH

TEAM AI-26

AeroSim

Aero Sim

CONTENT

1. Our Team
2. The Client
3. The Problem
4. The Solution
5. Why AeroSim?
6. Requirements
7. Design Details
8. Demo
9. Test Plan

Team AI-26

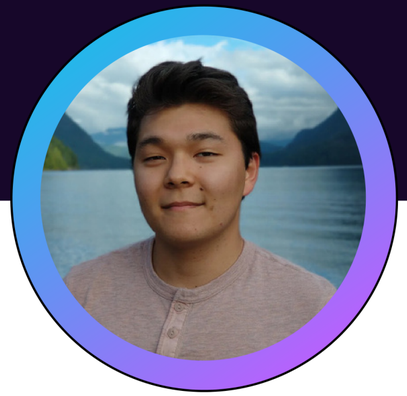
Anthony. Patric. Andrew. Isabelle. Nursultan.
Long ago, the 5 friends lived in harmony. Then everything changed when Capstone started...

Anthony Wang
His Majesty King of GUI Frontend

Patric McDonald
Holy Guardian of the GUI Backend

Andrew Hanlon
Firmware Wizard

Isabelle André
Lord of the FPGA



Nursultan Tugolbaev
Sultan of the PCB

KF AEROSPACE

Image: KF Aerospace

The Client

KF Aerospace performs maintenance, repair, overhaul, and other services for commercial aircraft at 4 facilities across Canada.

KF AEROSPACE

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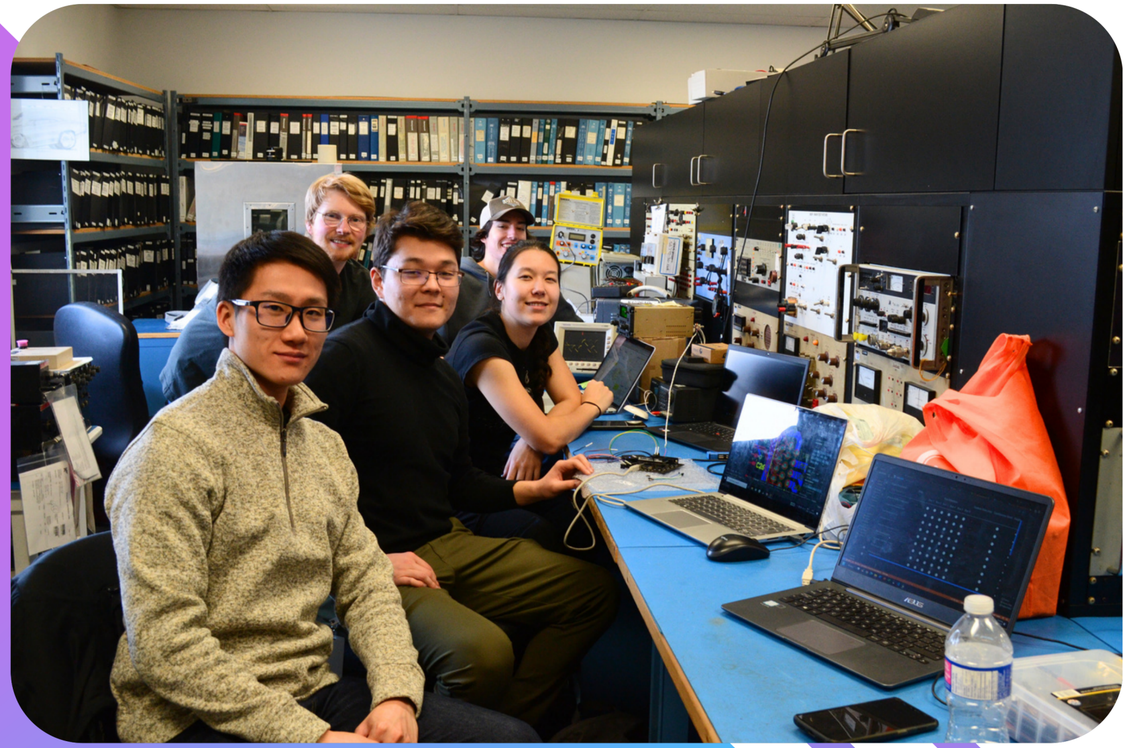
KF Aerospace performs maintenance, repair, overhaul, and other services for commercial aircraft at 4 facilities across Canada.

They have a significant engineering operation supporting the hangar-floor technical staff.

KF AEROSPACE



The Client

KF Aerospace performs maintenance, repair, overhaul, and other services for commercial aircraft at 4 facilities across Canada.

They have a significant engineering operation supporting the hangar-floor technical staff.

Many of their projects are retrofits or modifications to the avionics installed on in-service aircraft.

The Problem

High priority for KF Aero!

The Problem

Average Avionics Engineer Tasks

25% Avionics Testing

10% Avionics Installation

Overhauling 65%

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Overhauling 65%

5 Days

on an aircraft to validate avionics equipment

The Problem

Average Avionics Engineer Tasks

25% Avionics Testing

10% Avionics Installation

Overhauling 65%

5 Days

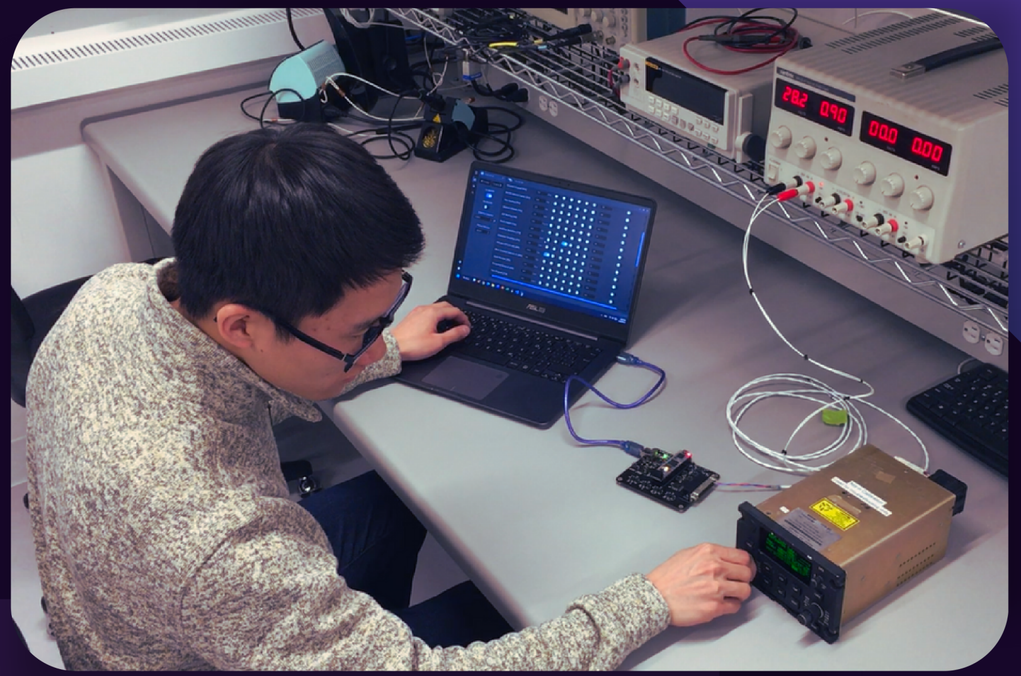
on an aircraft to validate avionics equipment

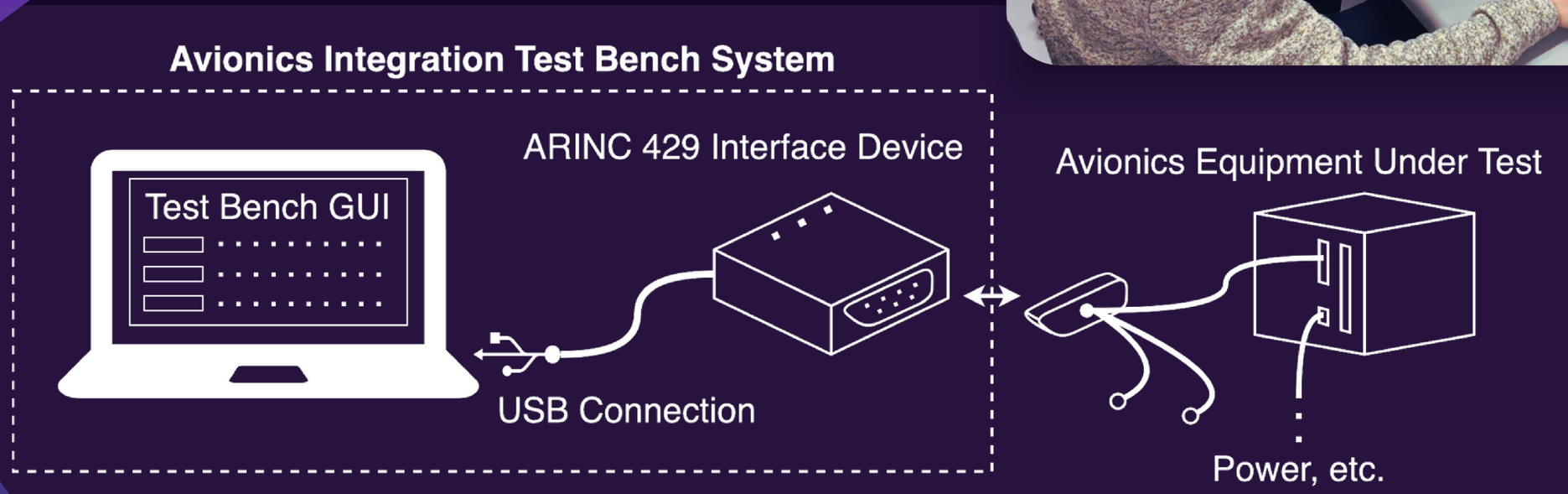
1+ Weeks

to fix incorrect equipment integration

The Solution

AeroSim

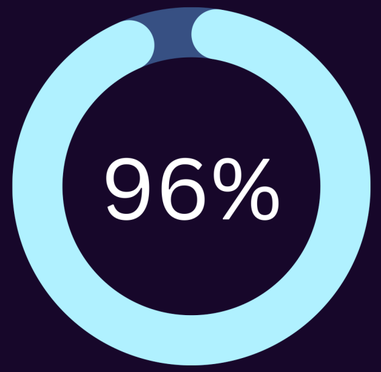




Why AeroSim?

Images: Astronics and TechSAT

Why AeroSim?



cheaper than similar off-the-shelf options

Why AeroSim?

cheaper than similar off-the-shelf options

Full ownership and flexibility

Why AeroSim?

96%

cheaper than similar off-the-shelf options

Full ownership and flexibility

Savings

$10,000

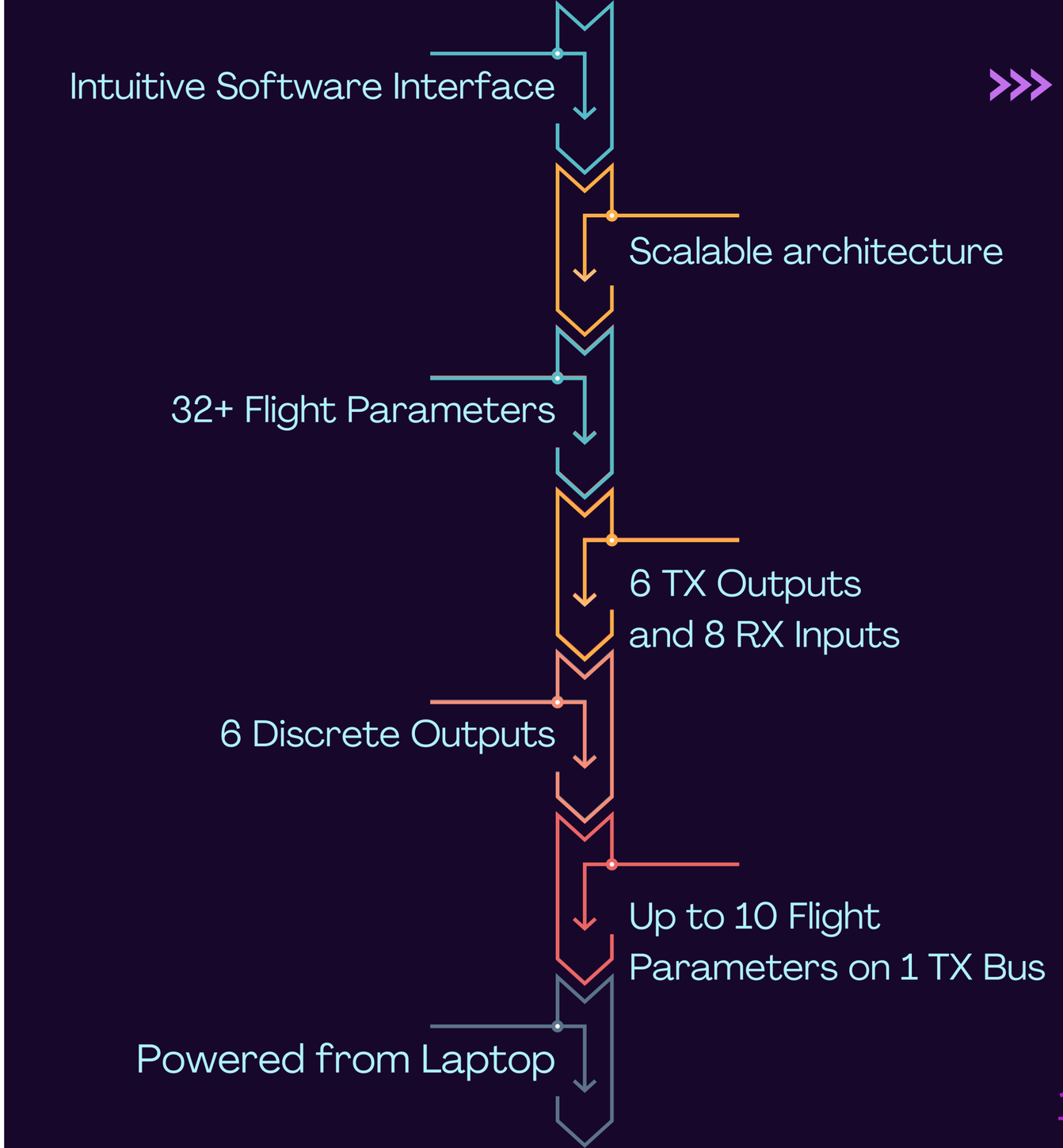
8 hours

Reported savings of **8 person-hours** per maintenance project and up to **$10,000**

Requirements

Functional	Non-functional
ARINC 429 Data Protocol	Flexibility *for future extensions*
TX & RX *2-12 Buses each*	Cost Effectiveness
32 specific flight parameters	Component Commonality
Benchtop use-oriented	User friendly *for aerospace engineers*

AeroSim Features



What is ARINC 429?

ARINC 429 is a communication protocol that aircraft electronics use to exchange flight data.

ARINC 429 Word Format

Data ID

Standard **labels** designate **flight parameter types**.
Eg. Label *203* (octal) translates to *Pressure Altitude*

What is ARINC 429?

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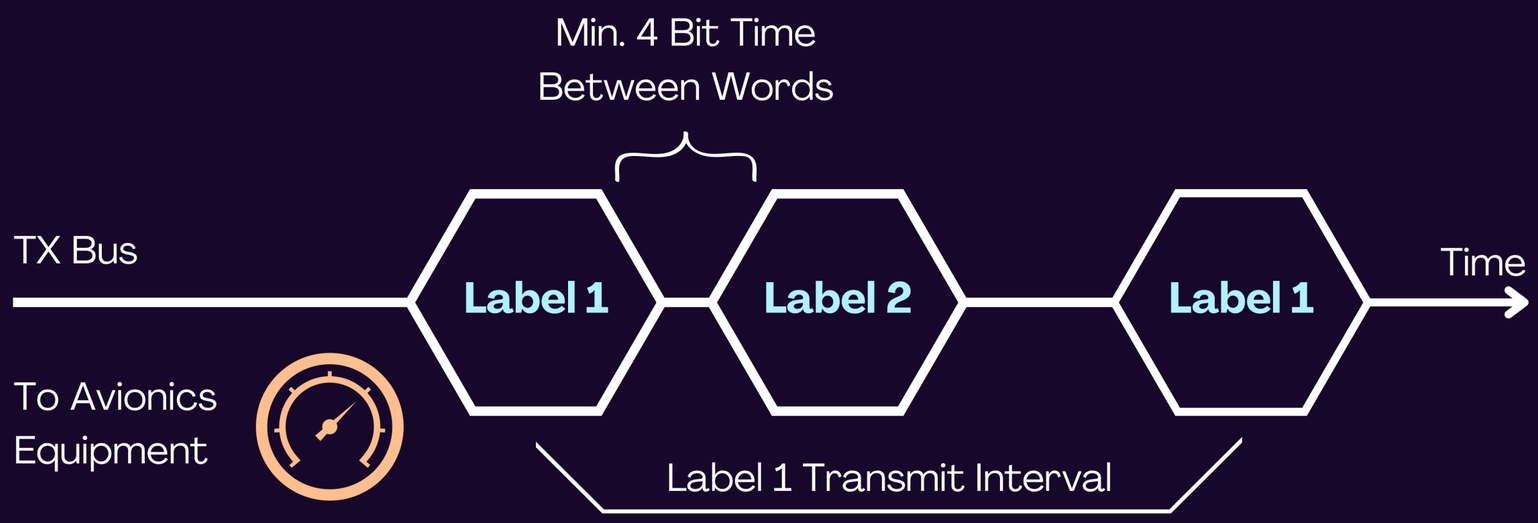
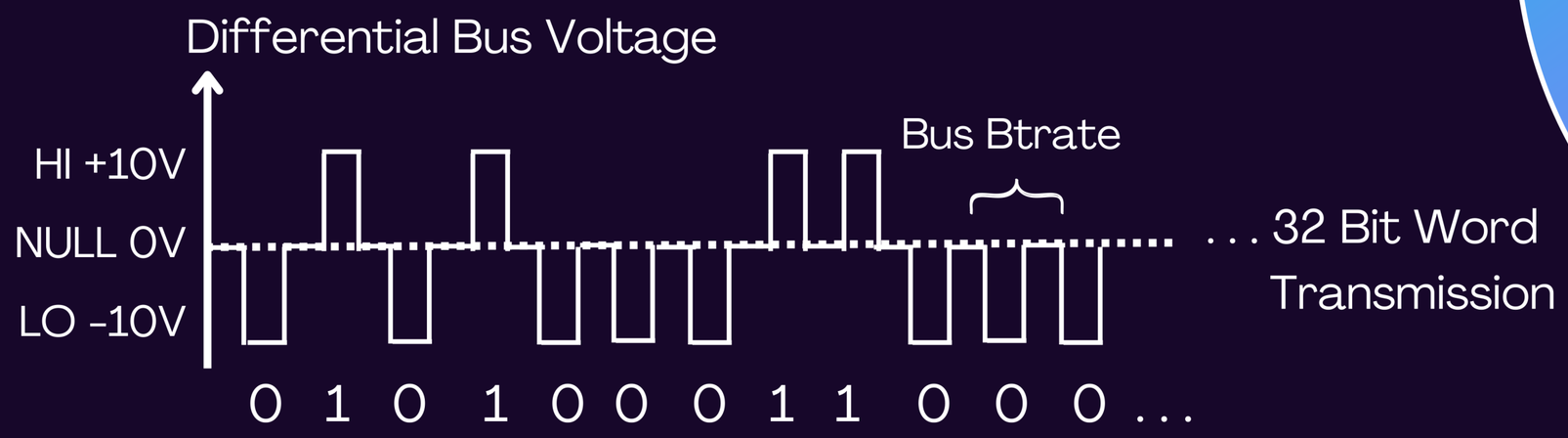


Word Transmission

ARINC 429 words are **continuously transmitted** to avionics equipment at the **rate** defined by the standard for a specific label

What is ARINC 429?

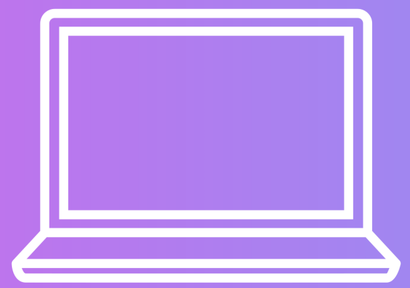
ARINC 429 is a communication protocol that aircraft electronics use to exchange flight data.



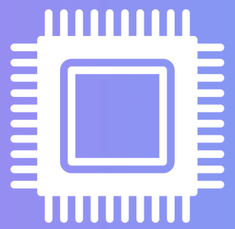
ARINC 429 Bus

0 and 1 bit pulses are transmitted on a **differential pair of buses** at a fixed bit rate.

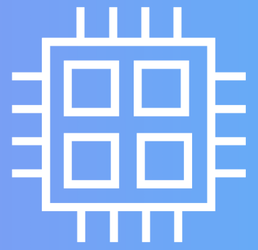
System Overview



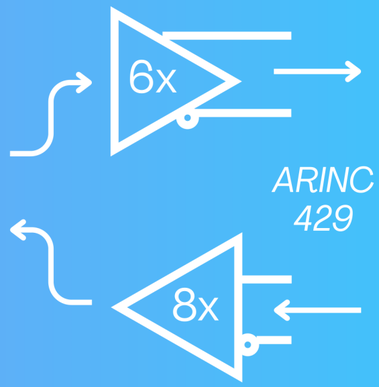
GUI (User Input)



STM32 MCU



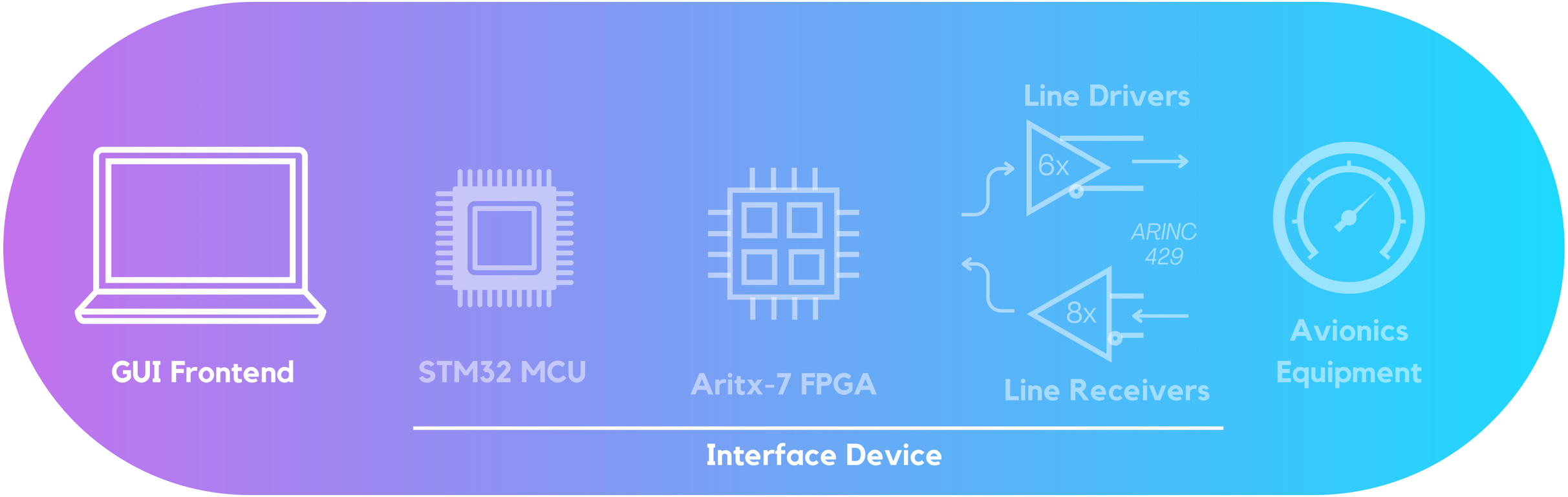
Aritx-7 FPGA



Avionics
Equipment

Interface Device

System Overview



GUI Design Considerations

- Intuitive to use
- Easily configurable
- Scalable for future updates
- Meets flight parameter and discrete output requirements

Scalable Architecture

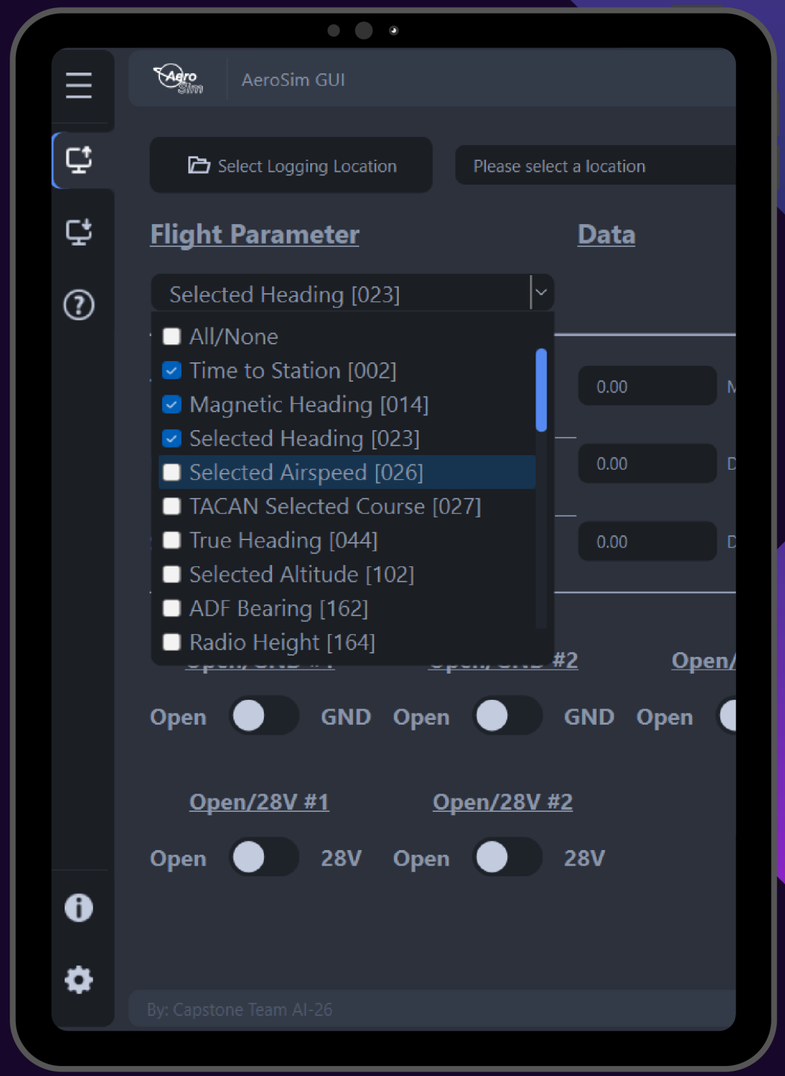
Additional flight parameters can be added by quickly copying data from the ARINC 429 standard into a configuration file

```
{
    "Altitude (1013.25 mb) [203]":
    {
        "label": "203",
        "encoding": "BNR",
        "units": "Feet",
        "min_range": 0,
        "max_range": 131072,
        "sig_bits": 17,
        "resolution": 1.0,
        "tx_period": 50
    },

    "Computed Airspeed [206]":
    {
        "label": "206",
        "encoding": "BNR",
        "units": "Knots",
        "min_range": 0,
        "max_range": 1024,
        "sig_bits": 14,
        "resolution": 0.0625,
        "tx_period": 100
    },
```

Parameter Filter

- Text search and check-box functionality
- Leads to less cluttered screen
- Specially requested feature



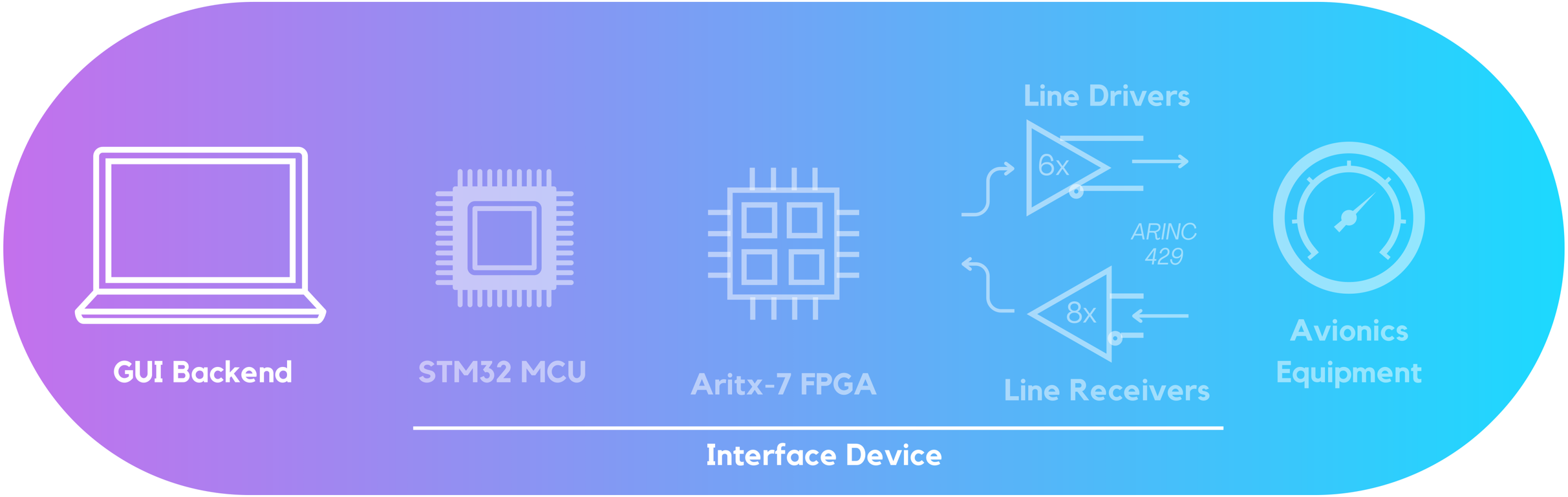
GUI Preview

TX Menu

RX Menu

Port & Bitrate Settings

System Overview

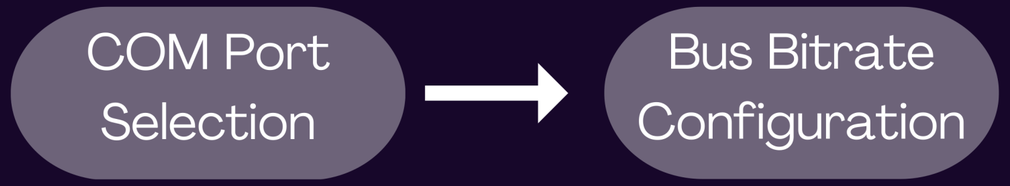


AEROSIM

TX User Input Logic

COM Port Selection

TX User Input Logic



AEROSIM

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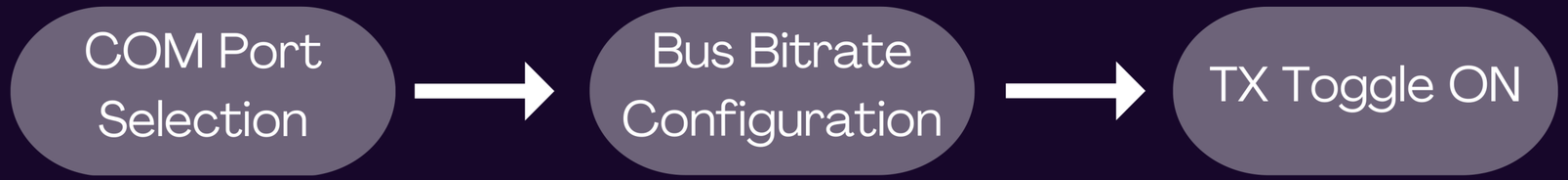

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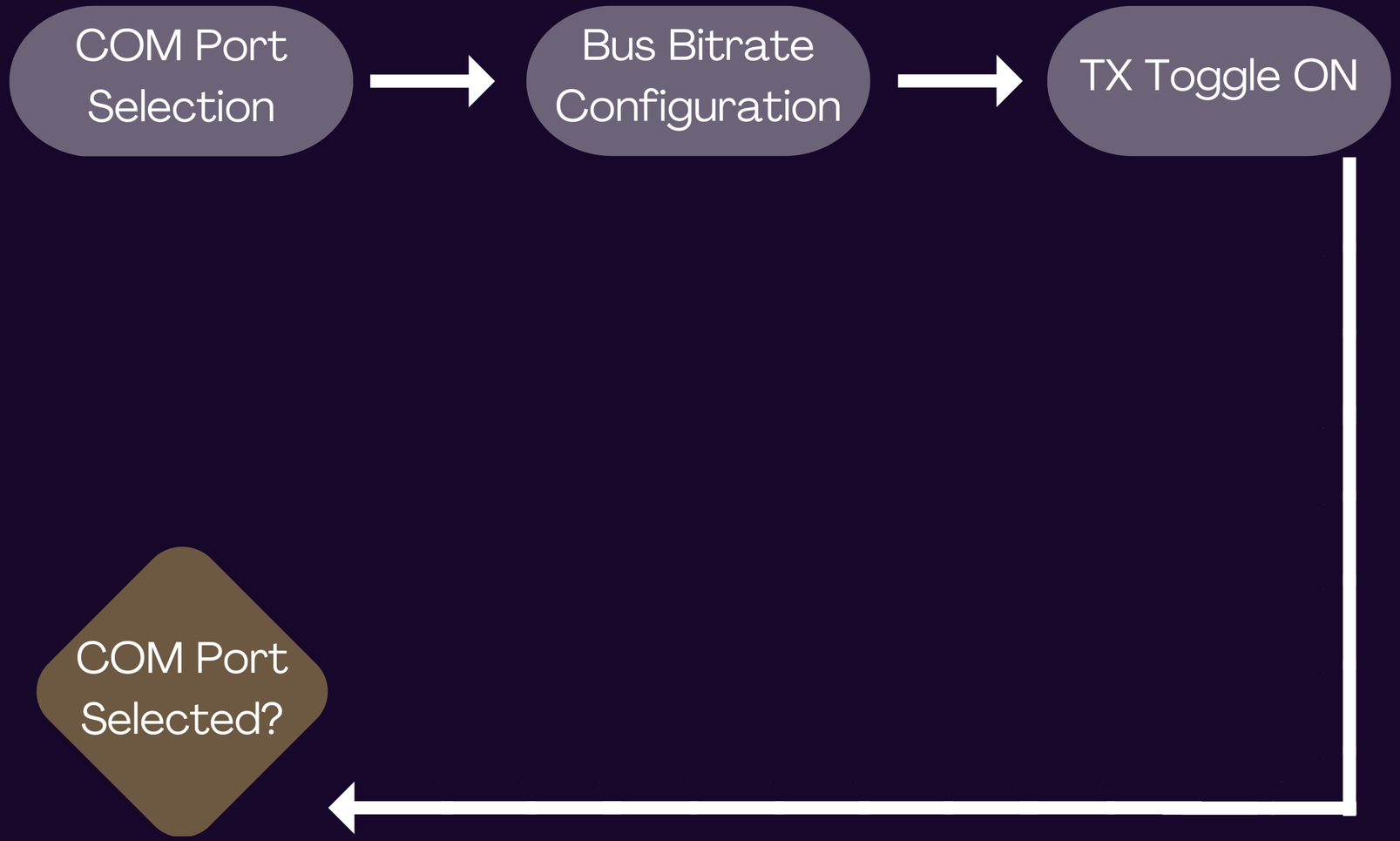

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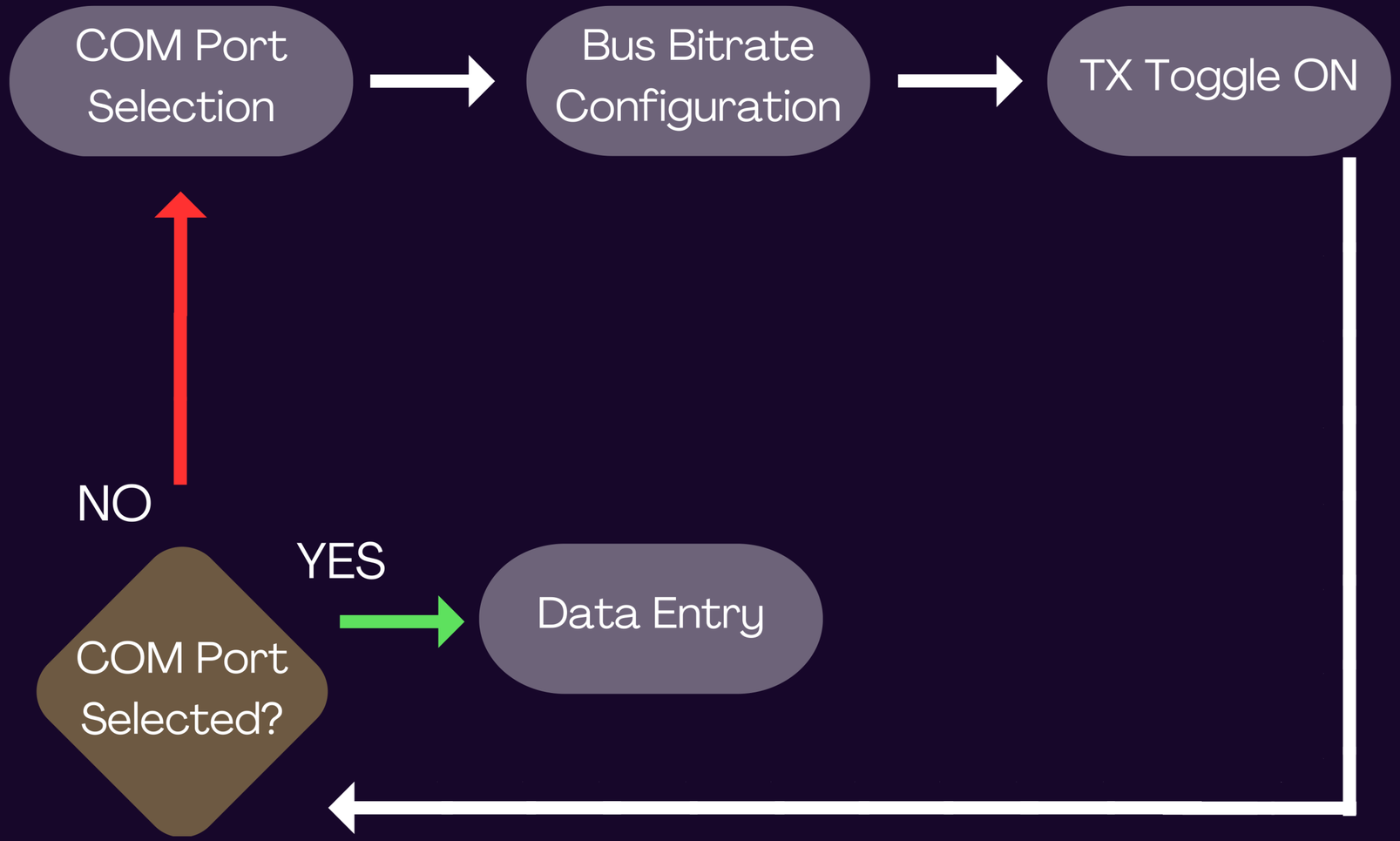

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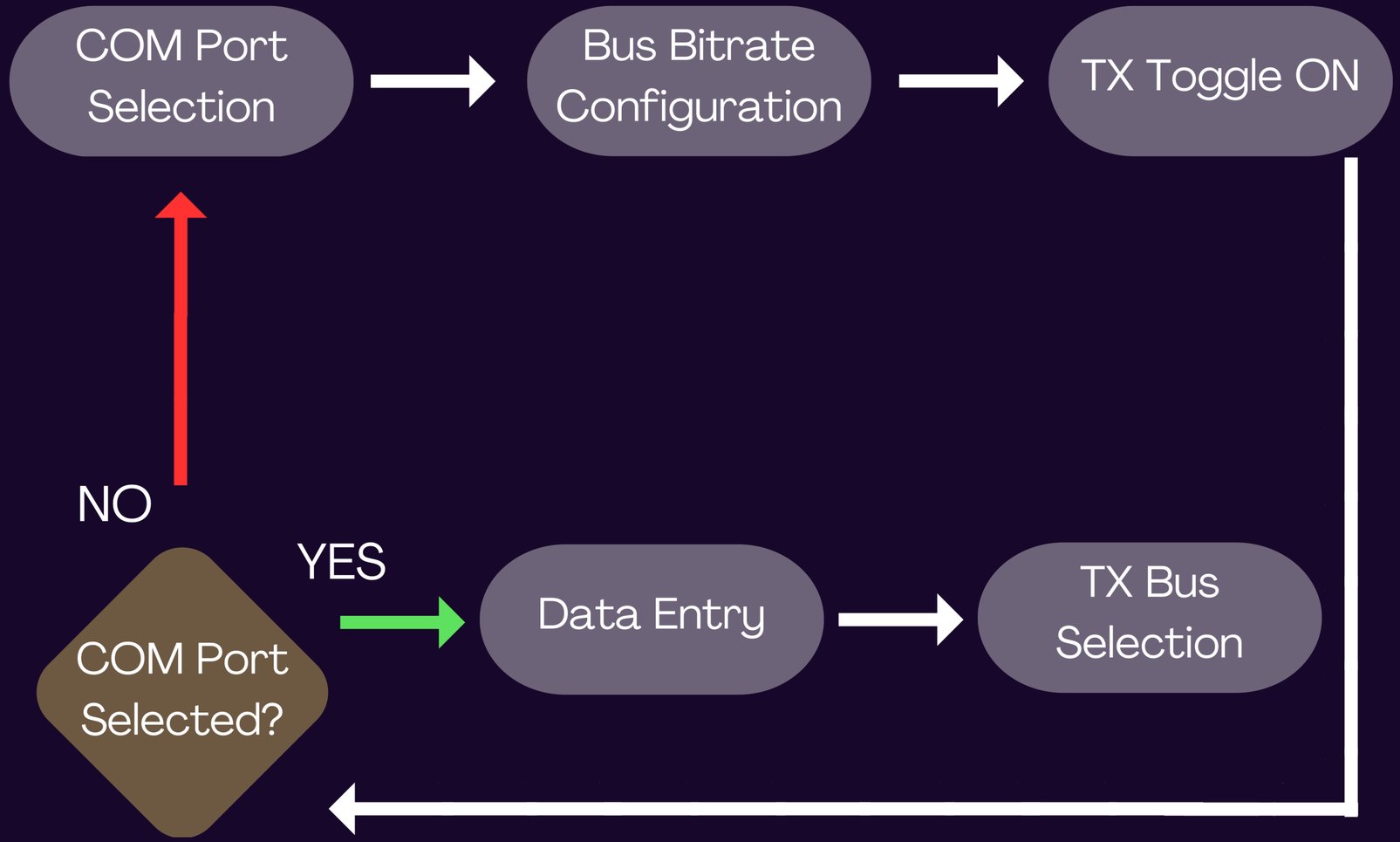

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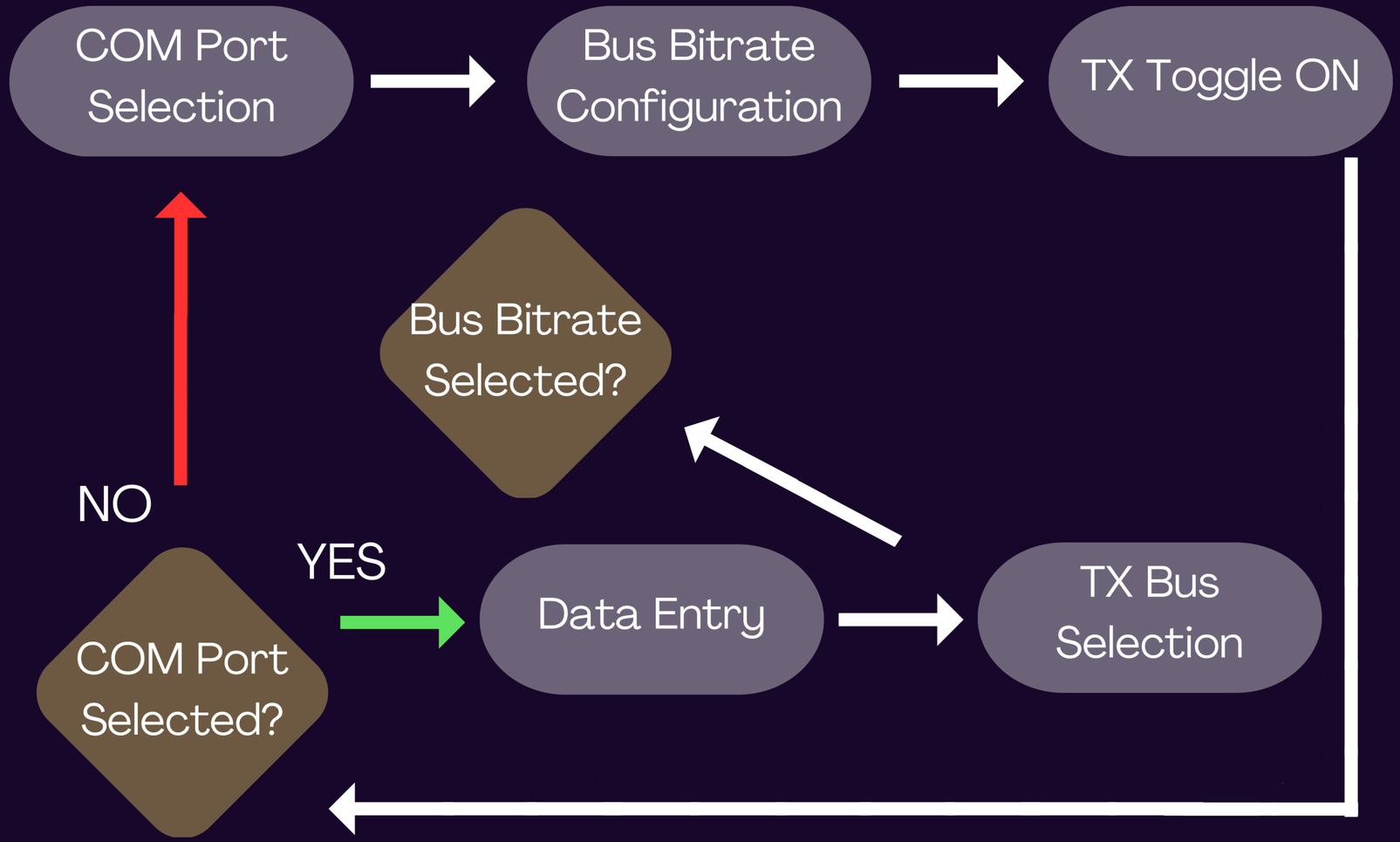

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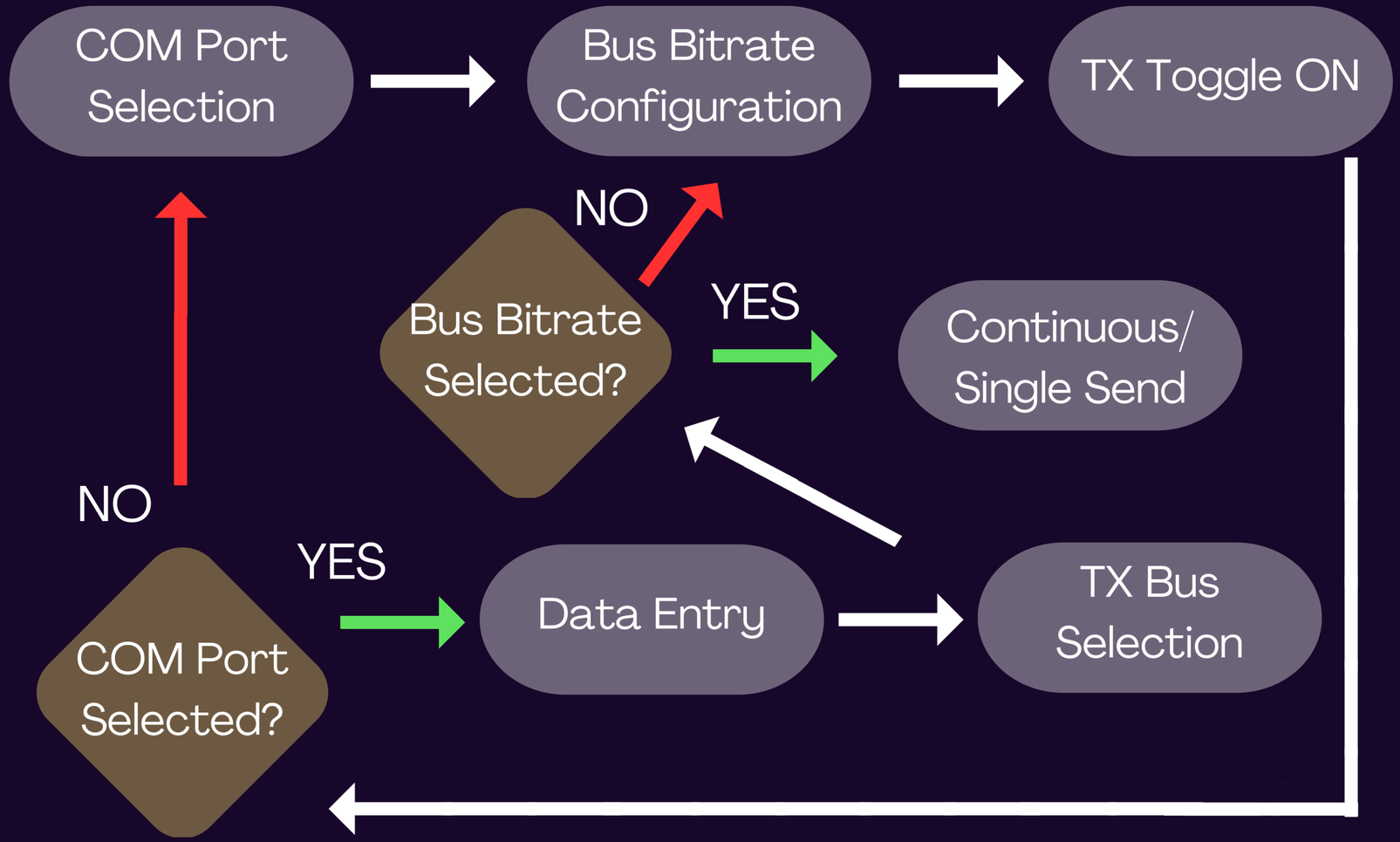

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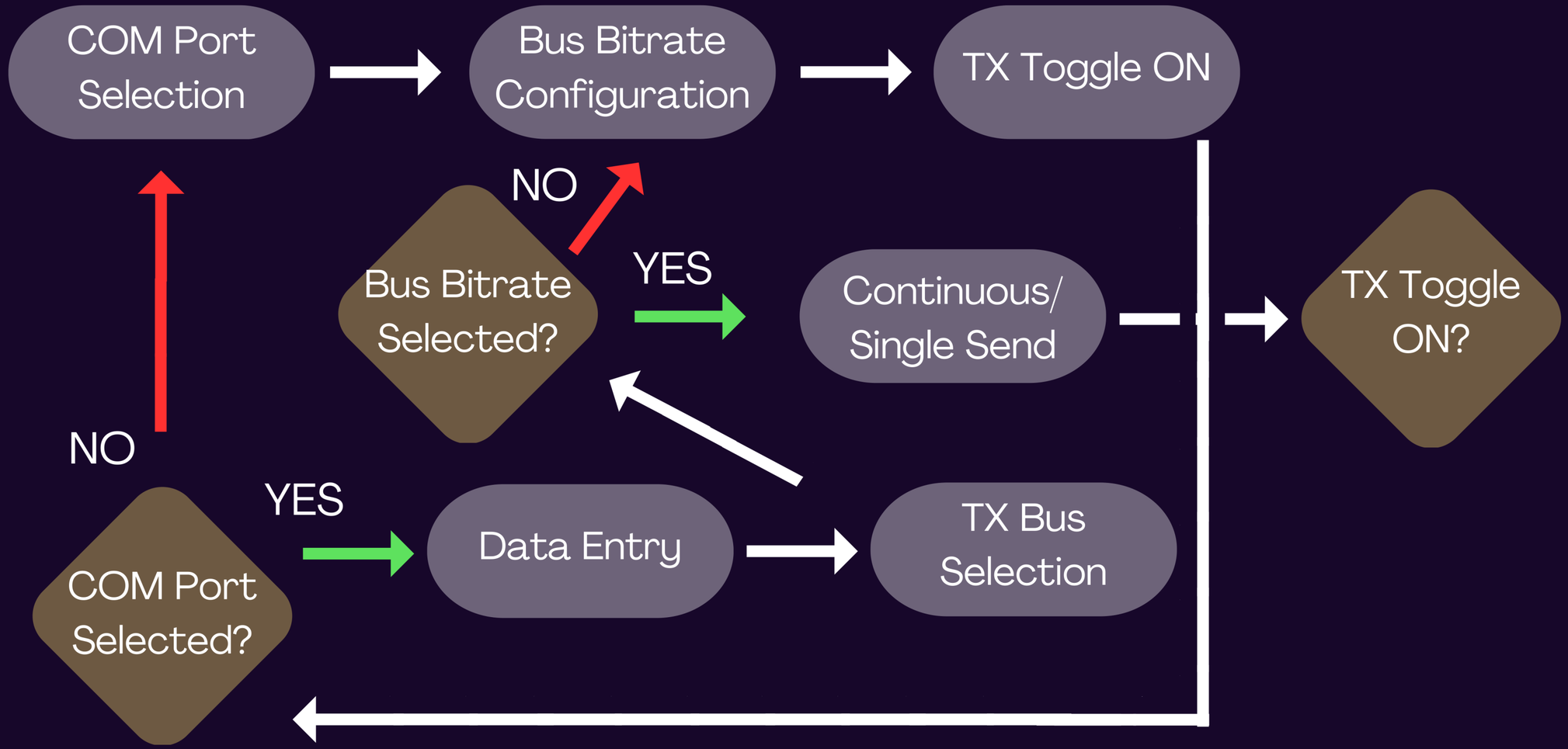

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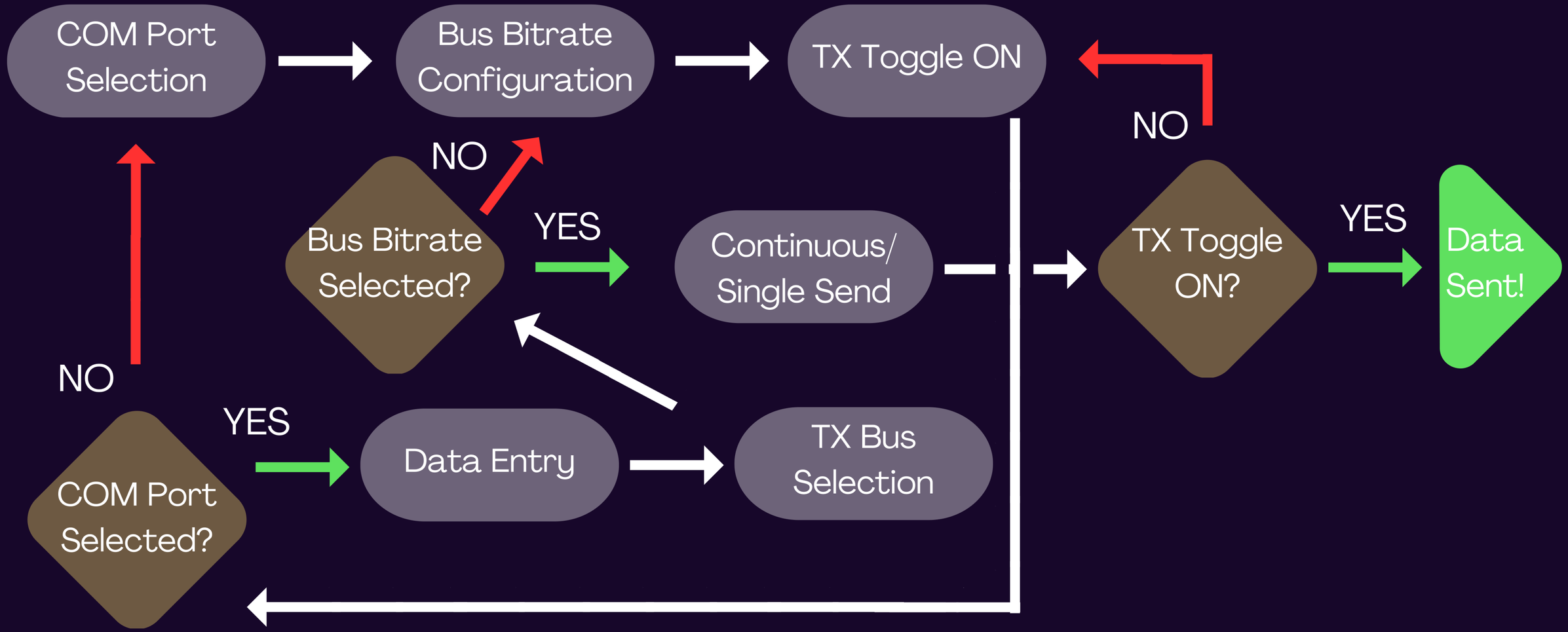
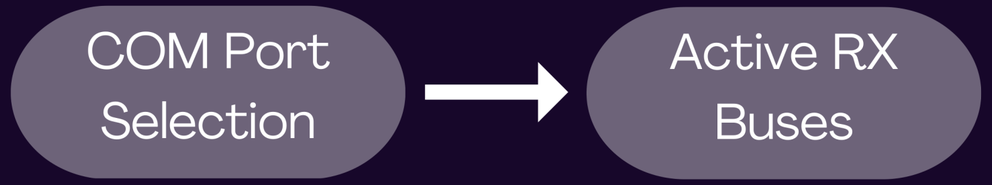


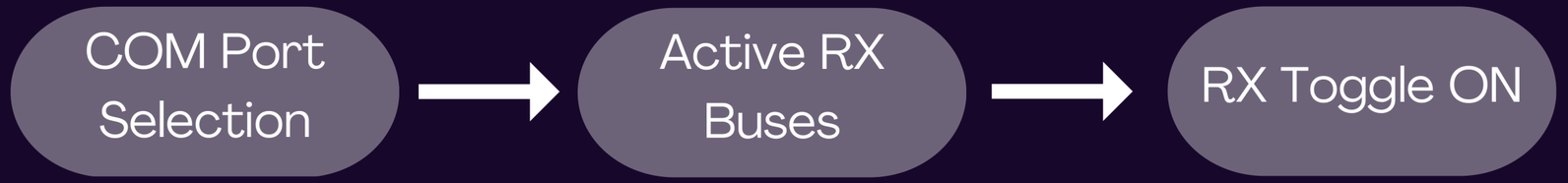
RX User Input Logic

COM Port Selection

RX User Input Logic



RX User Input Logic



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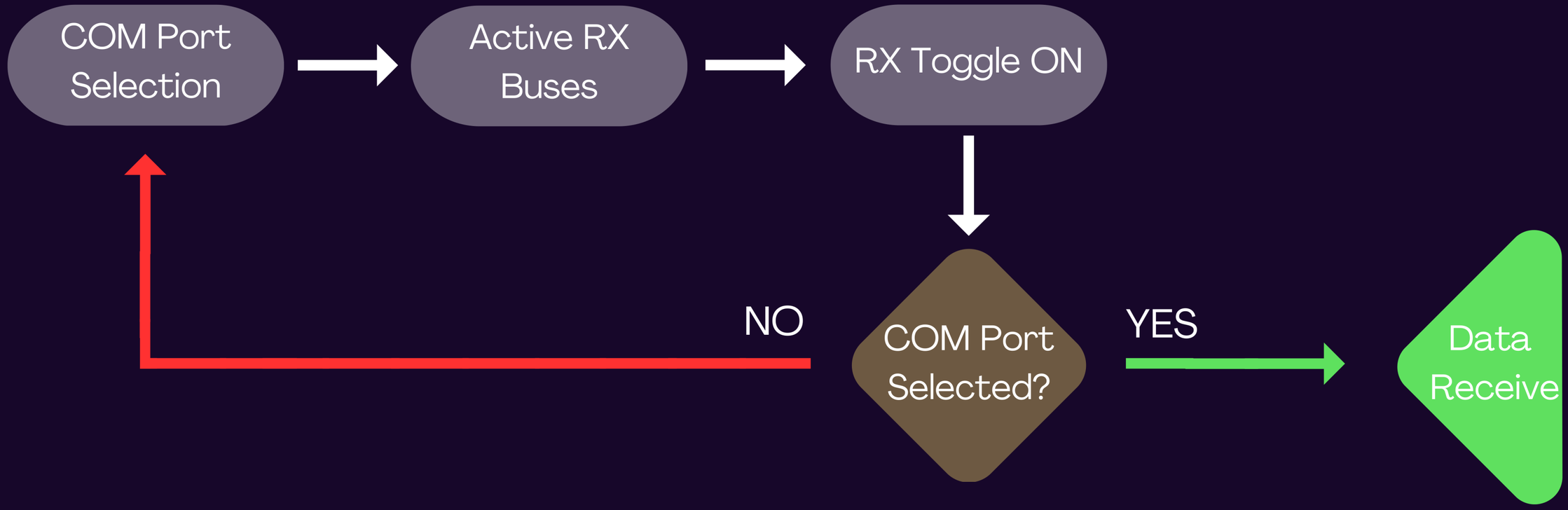

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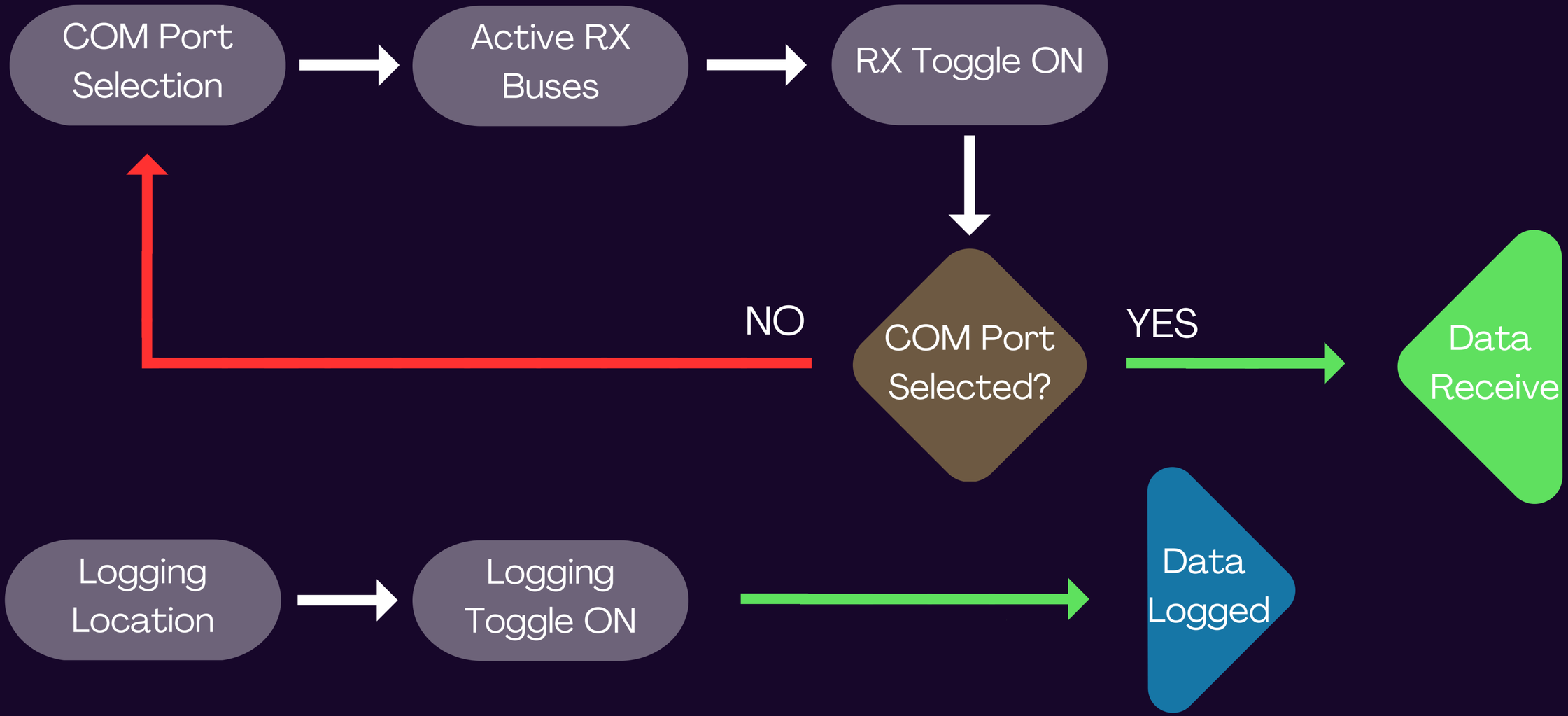
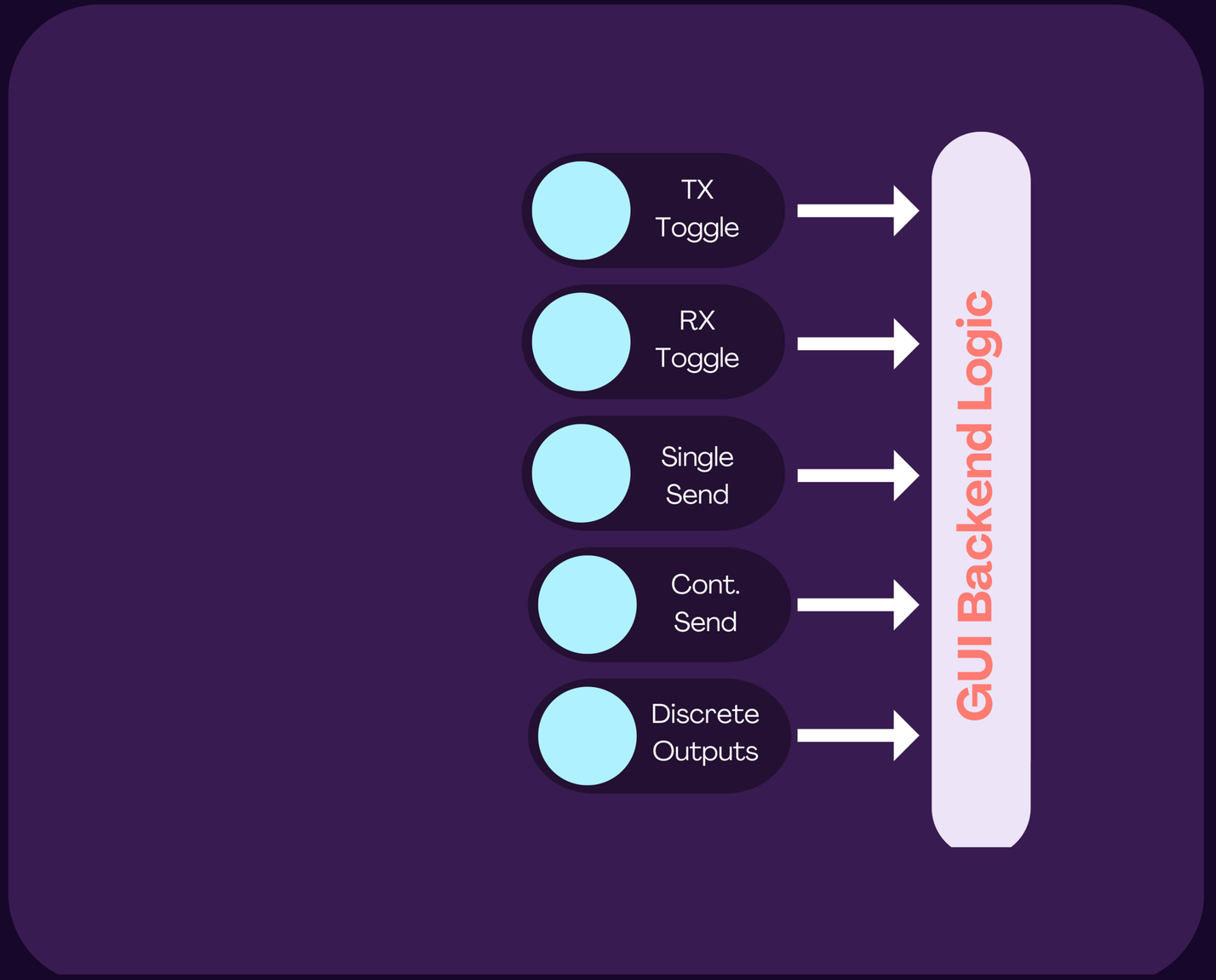


GUI Message Sequencing



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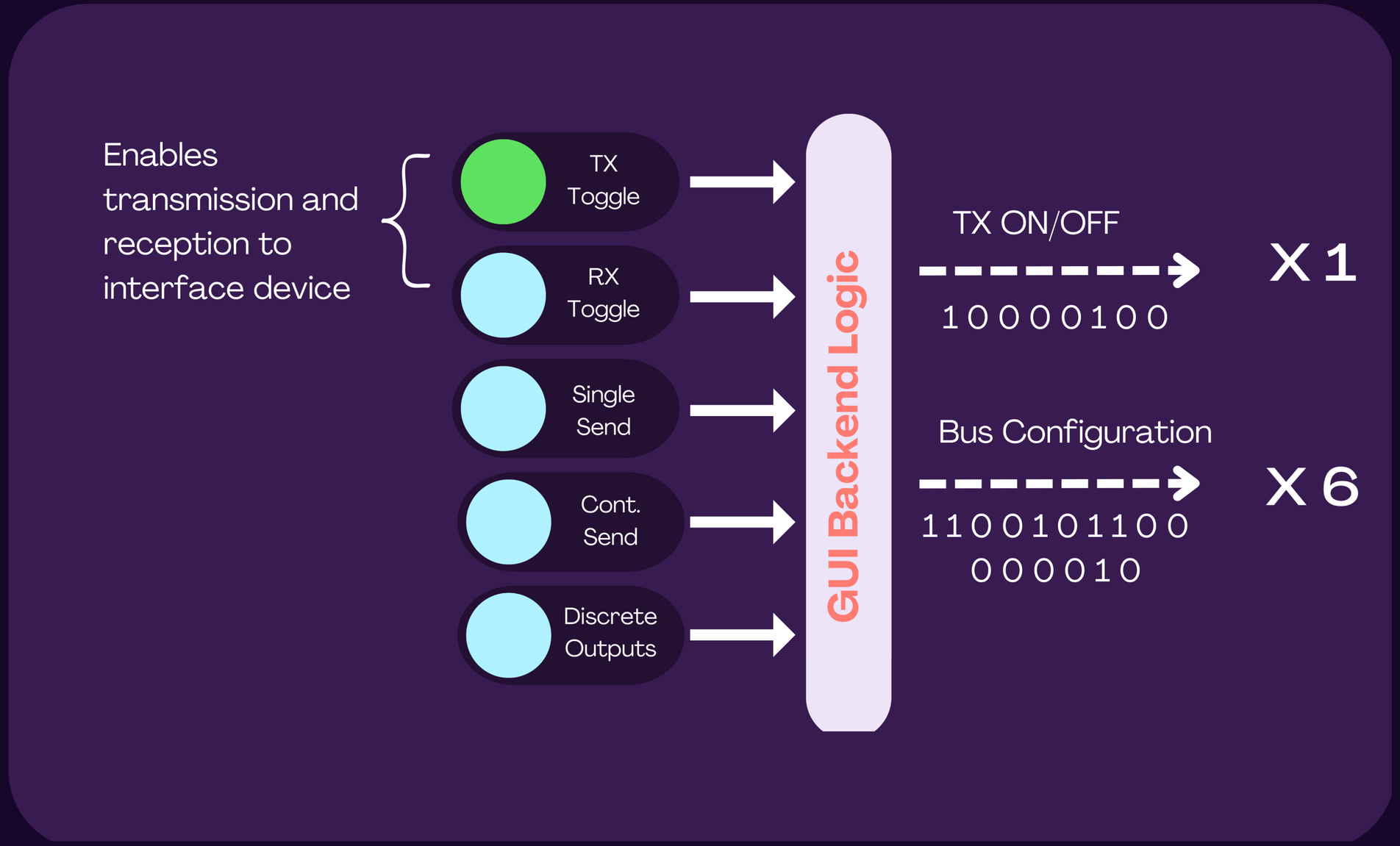

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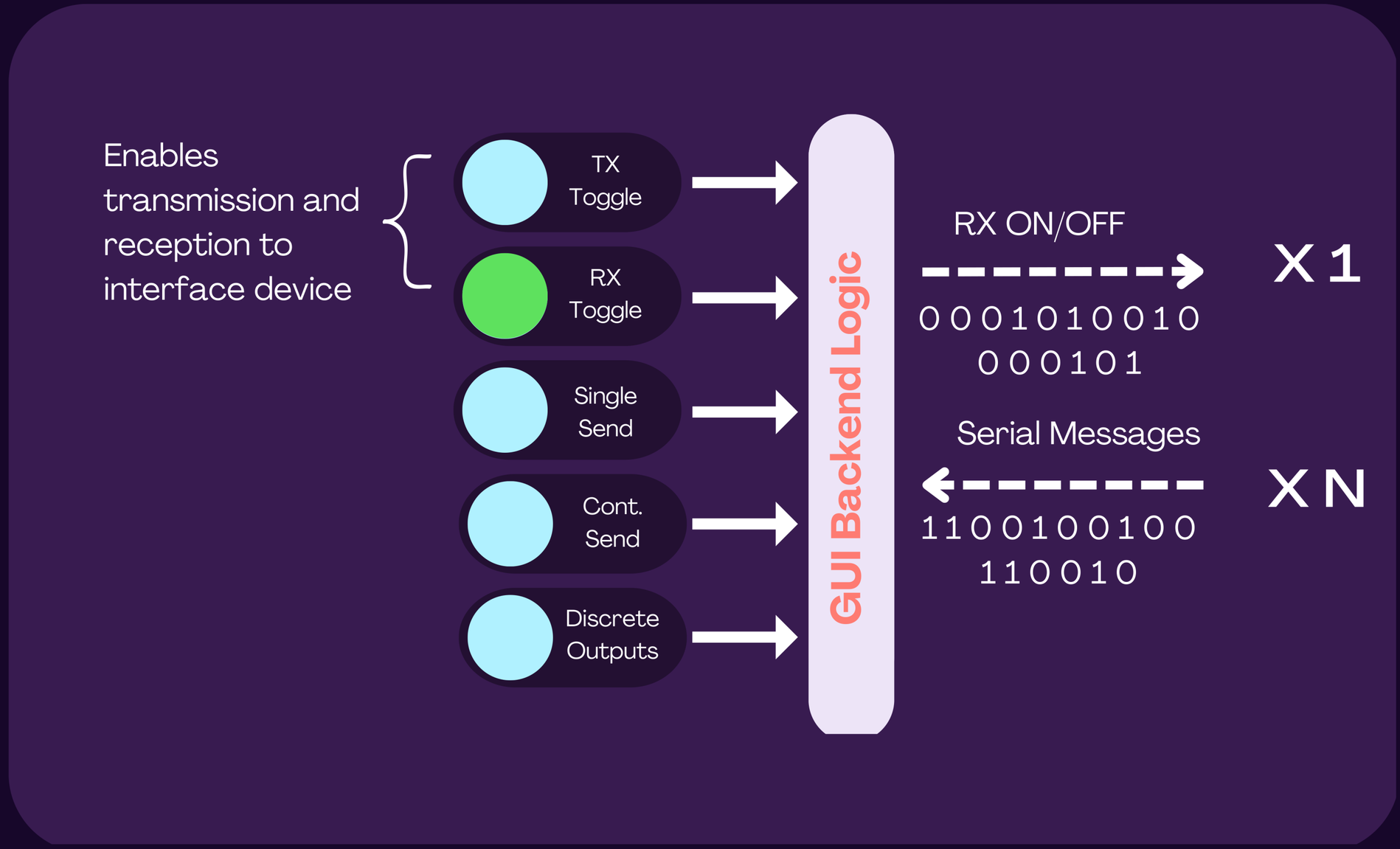

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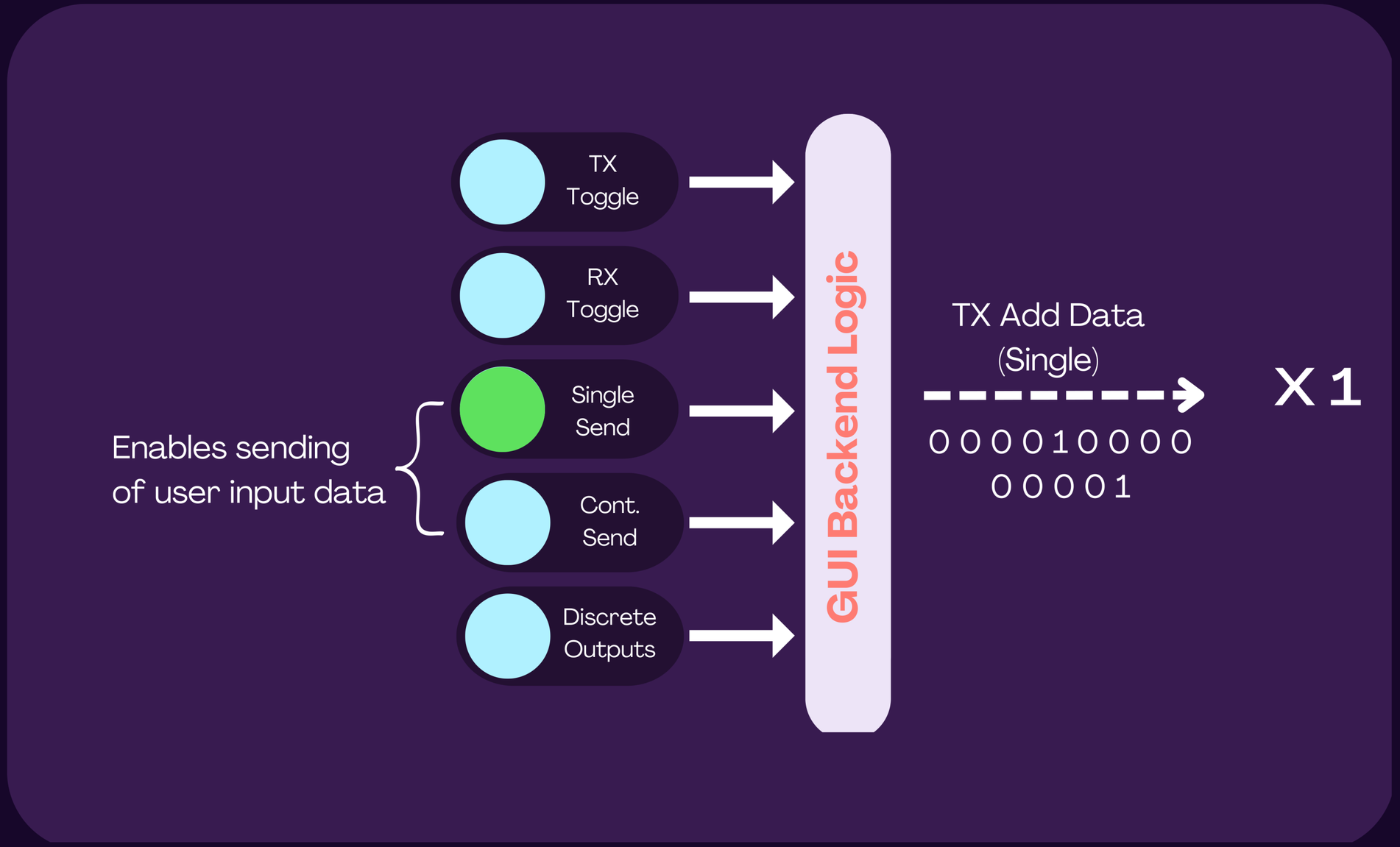

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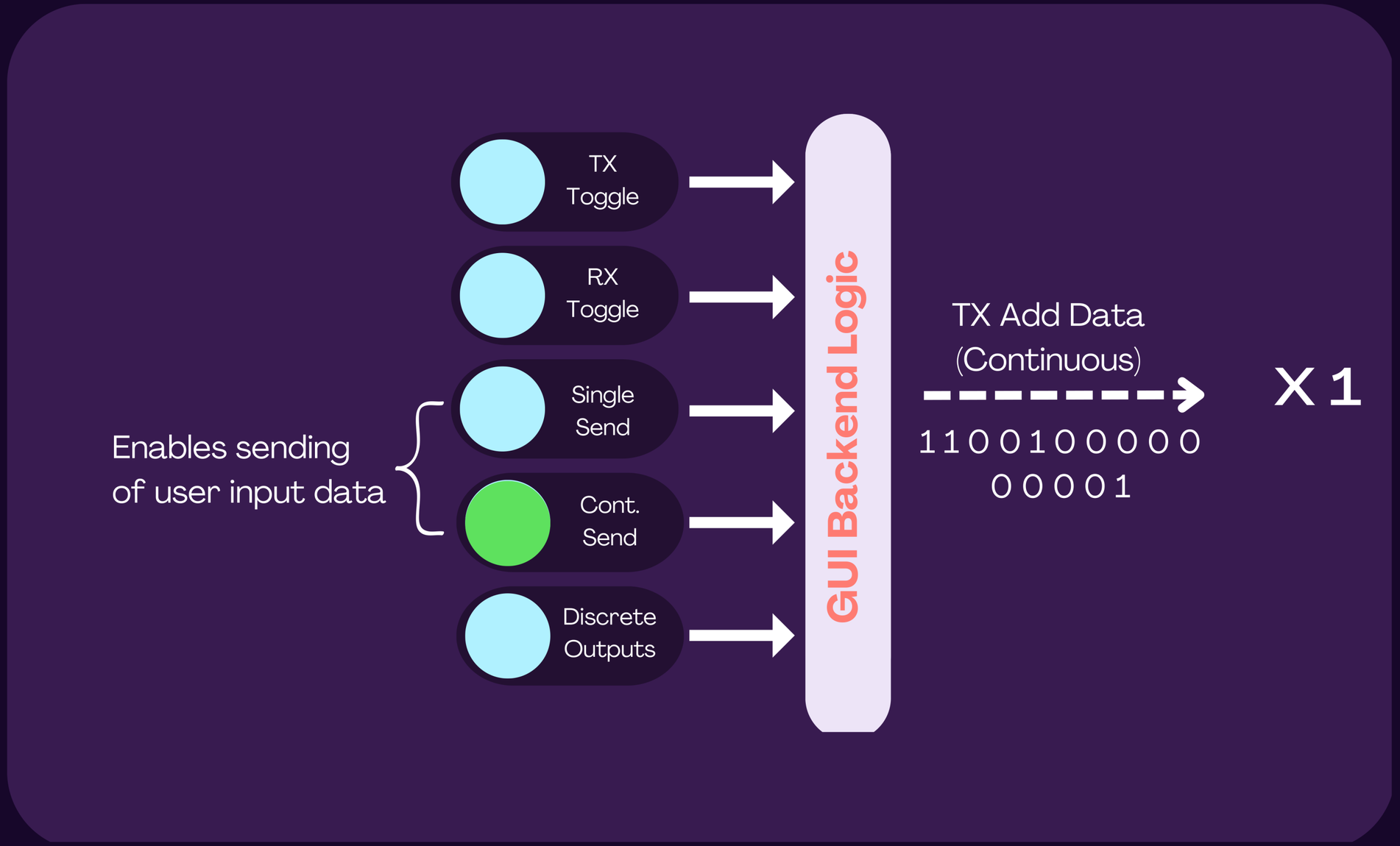

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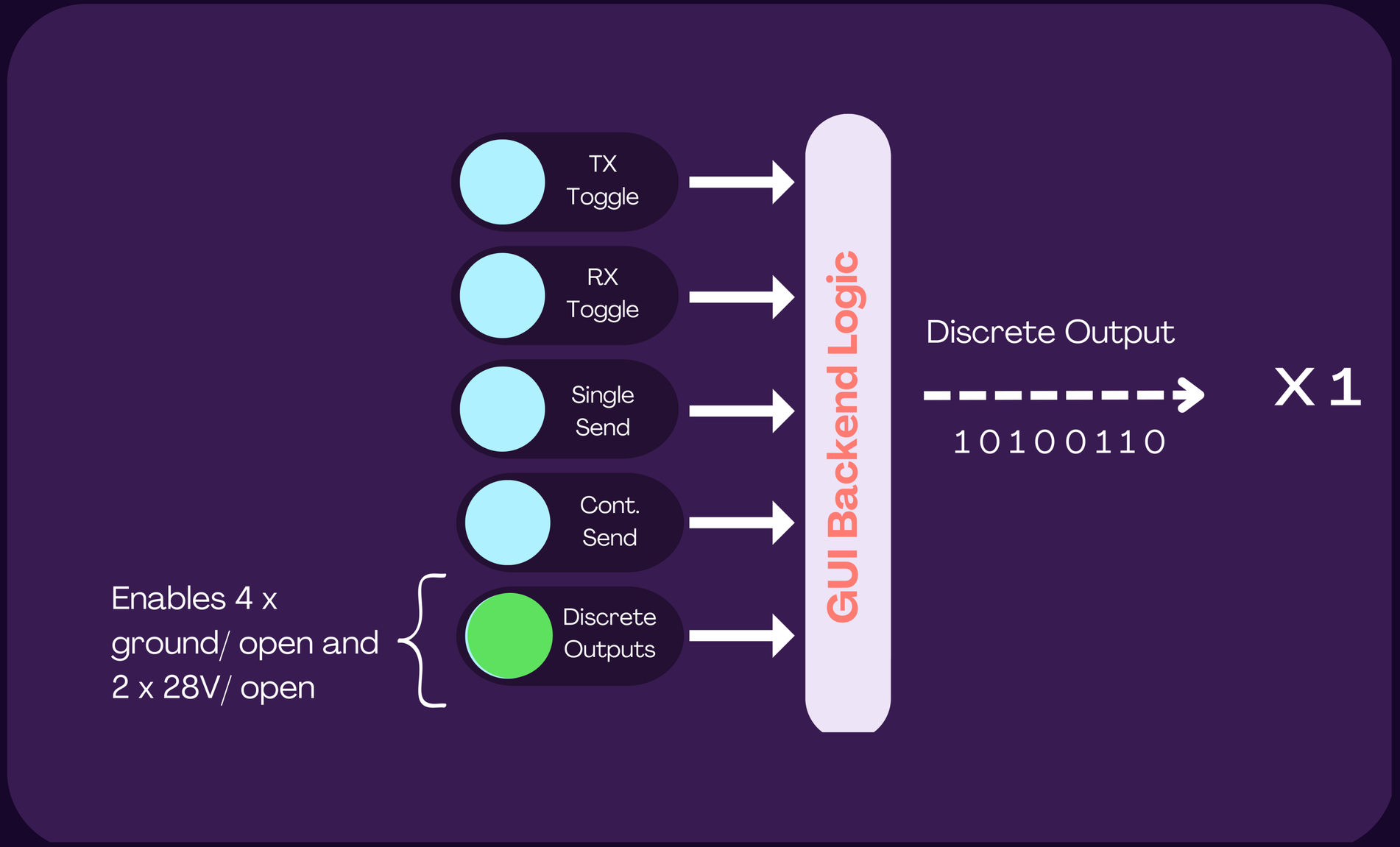
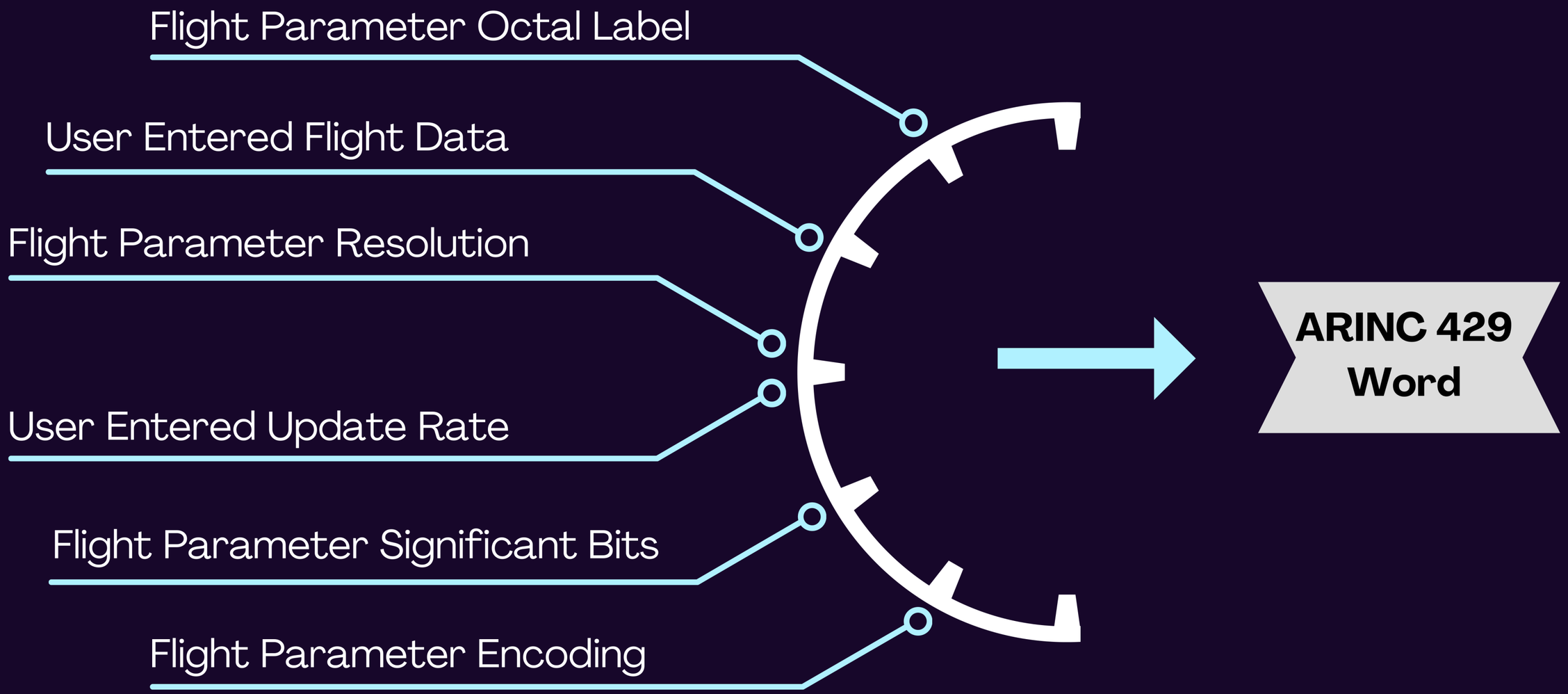


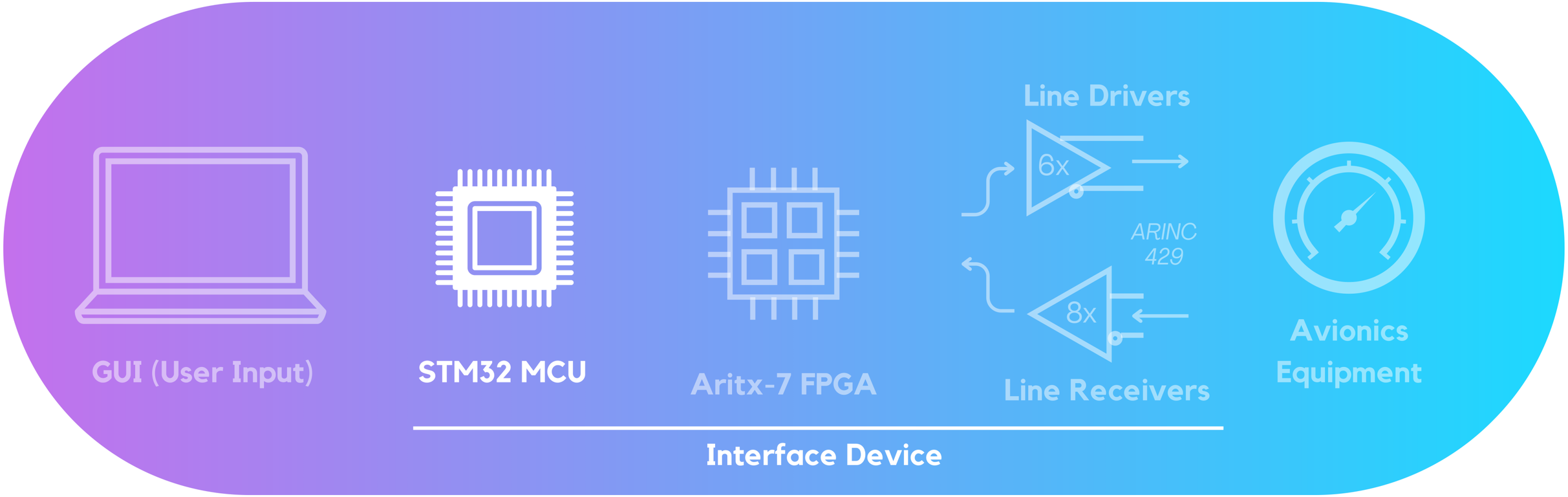
Design Consideration

Encoding/Decoding of ARINC 429 Words

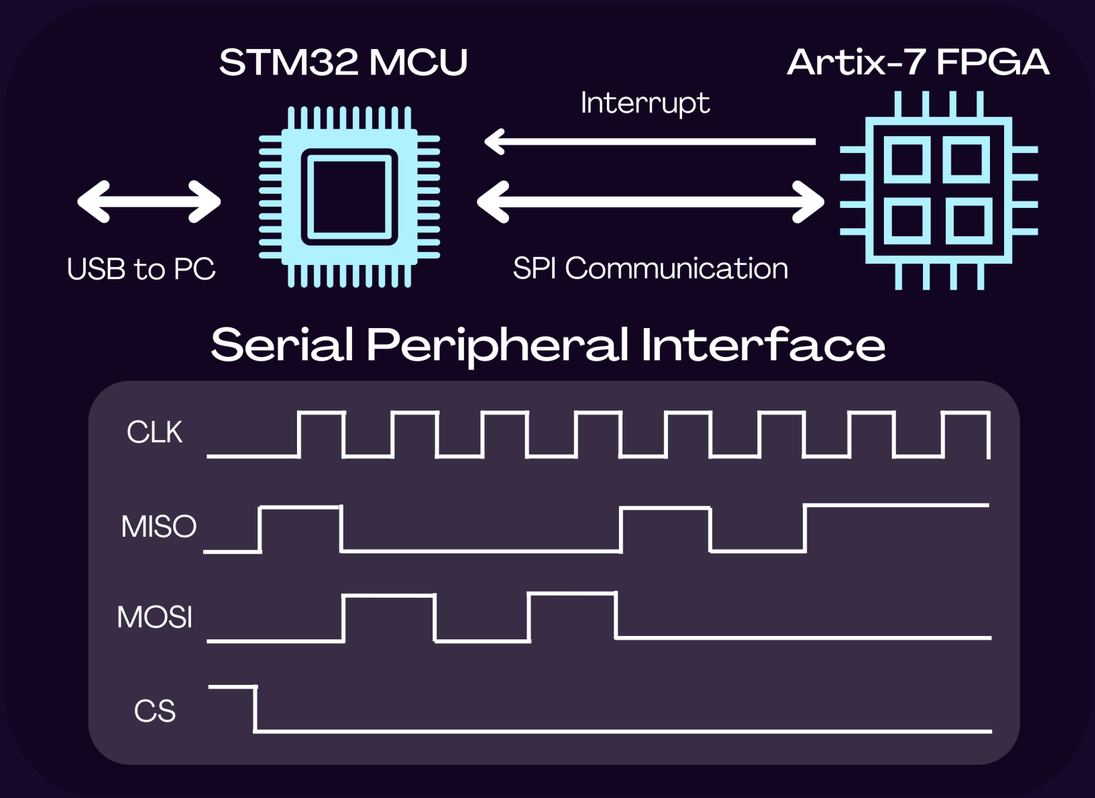
PyARINC 429


Flight Parameter Octal Label
User Entered Flight Data
Flight Parameter Resolution
User Entered Update Rate
Flight Parameter Significant Bits
Flight Parameter Encoding
ARINC 429 Word

System Overview



Microcontroller (MCU)



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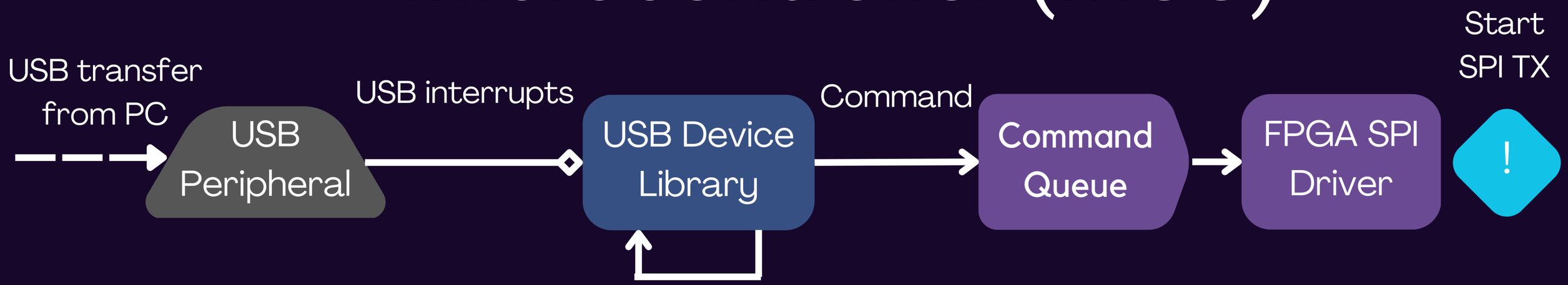

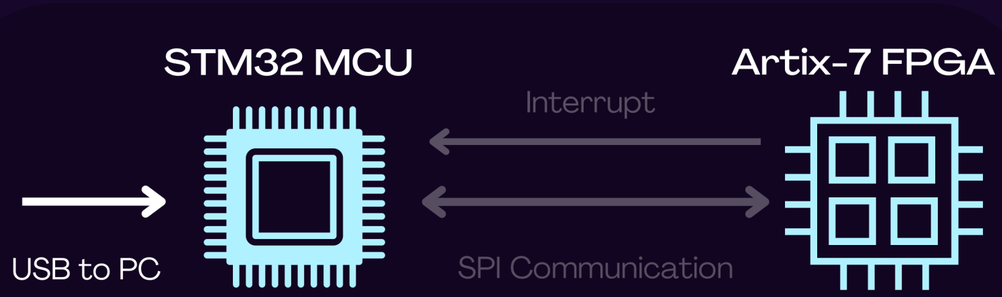

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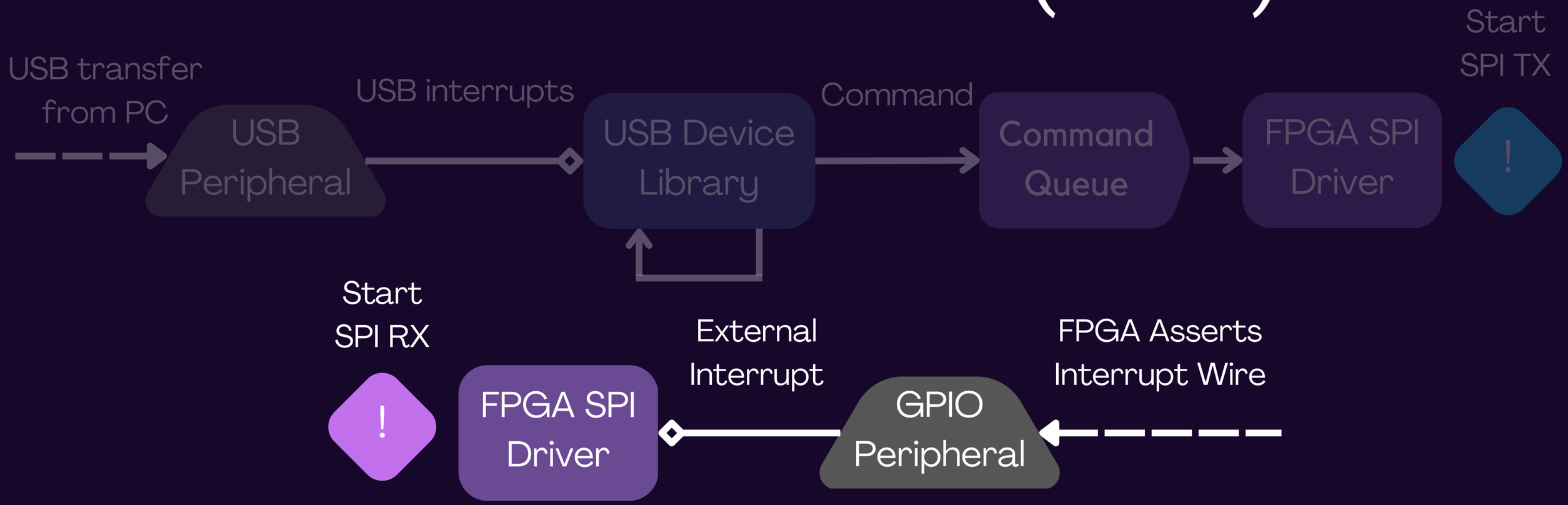

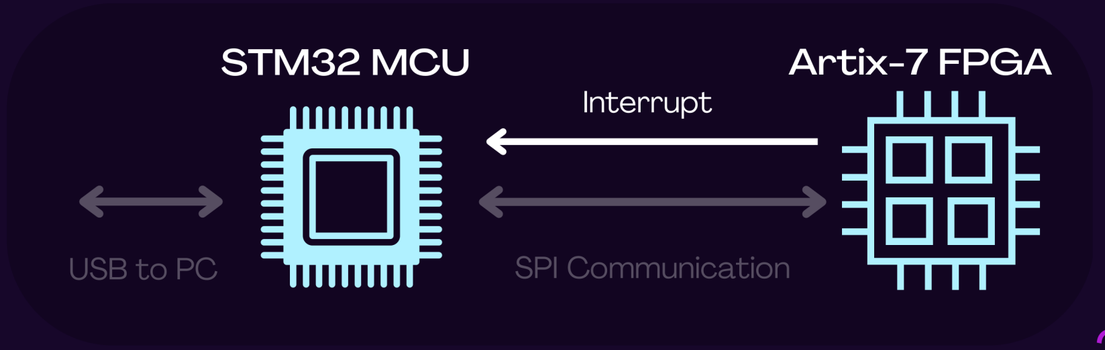

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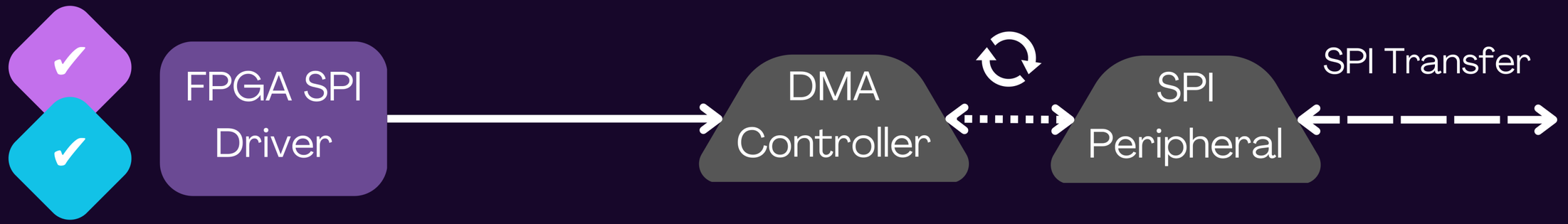

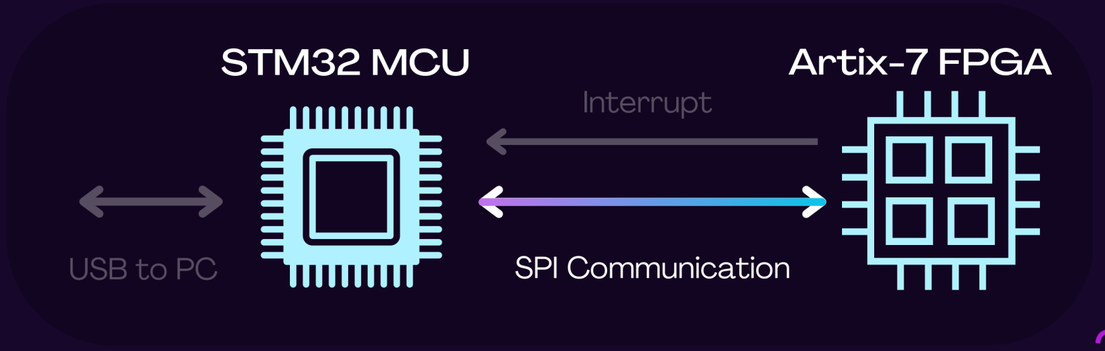

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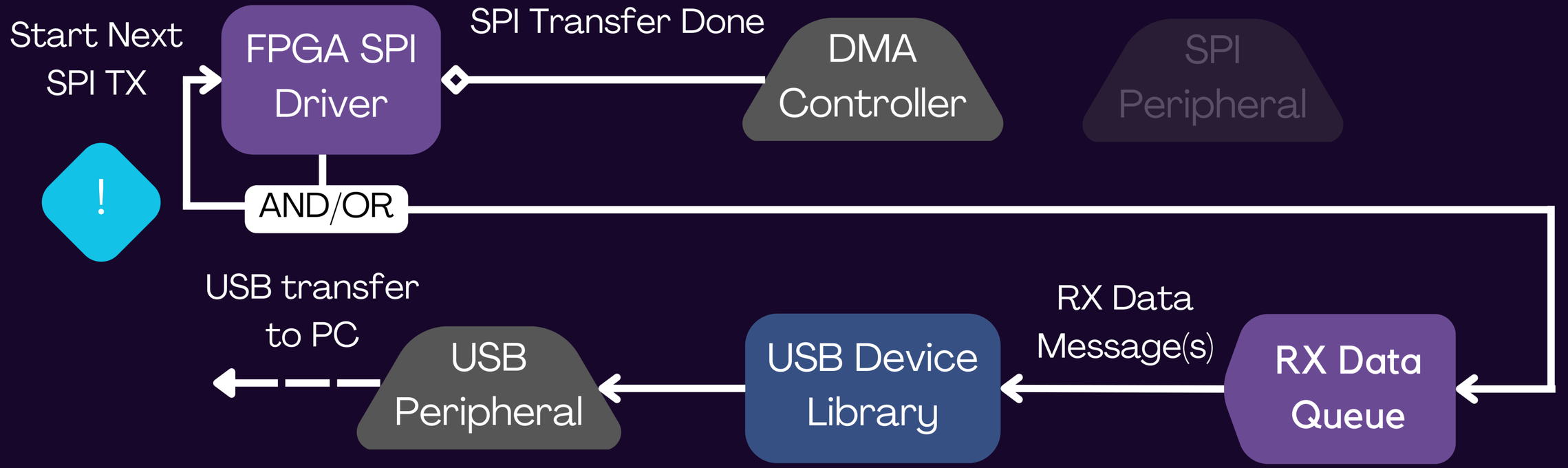
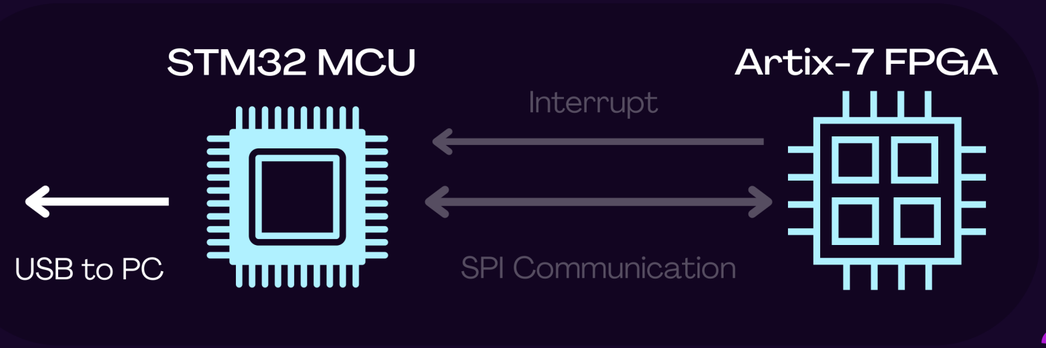
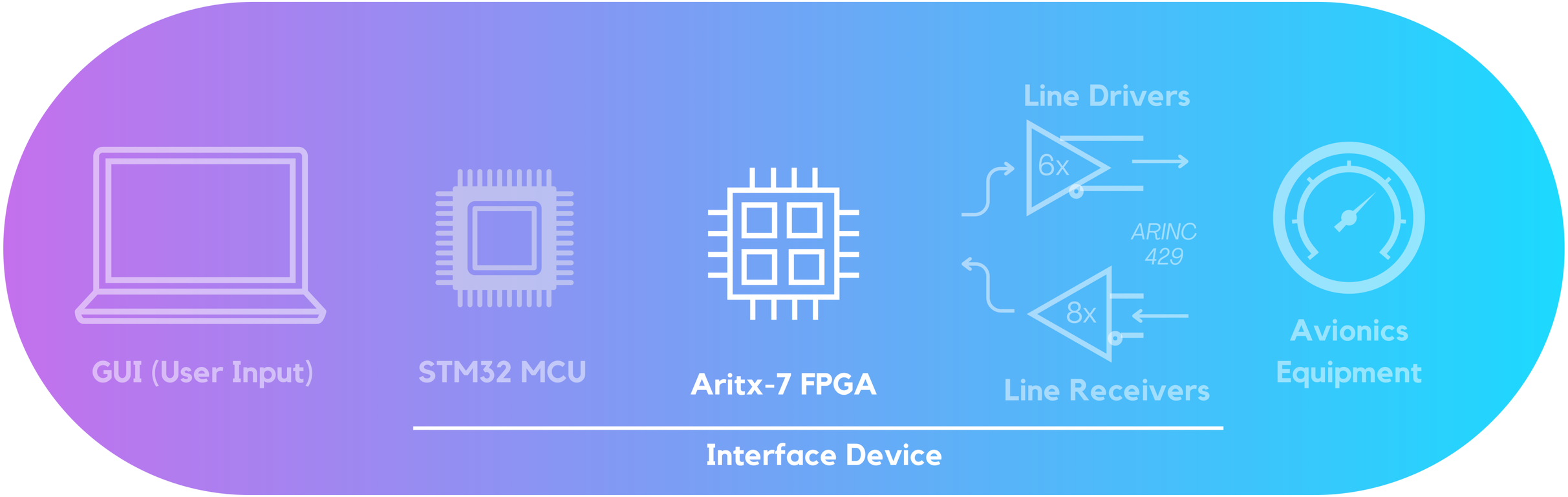


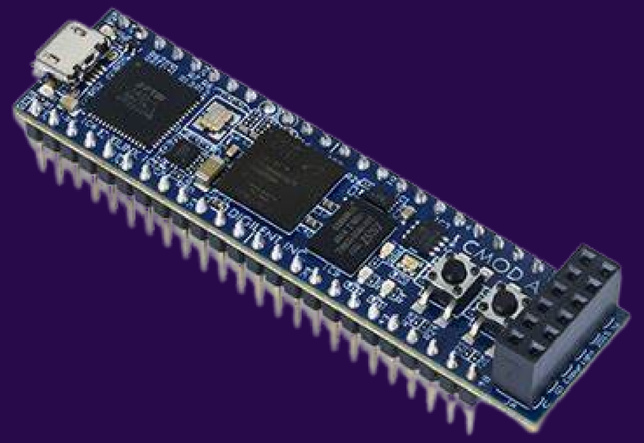


System Overview



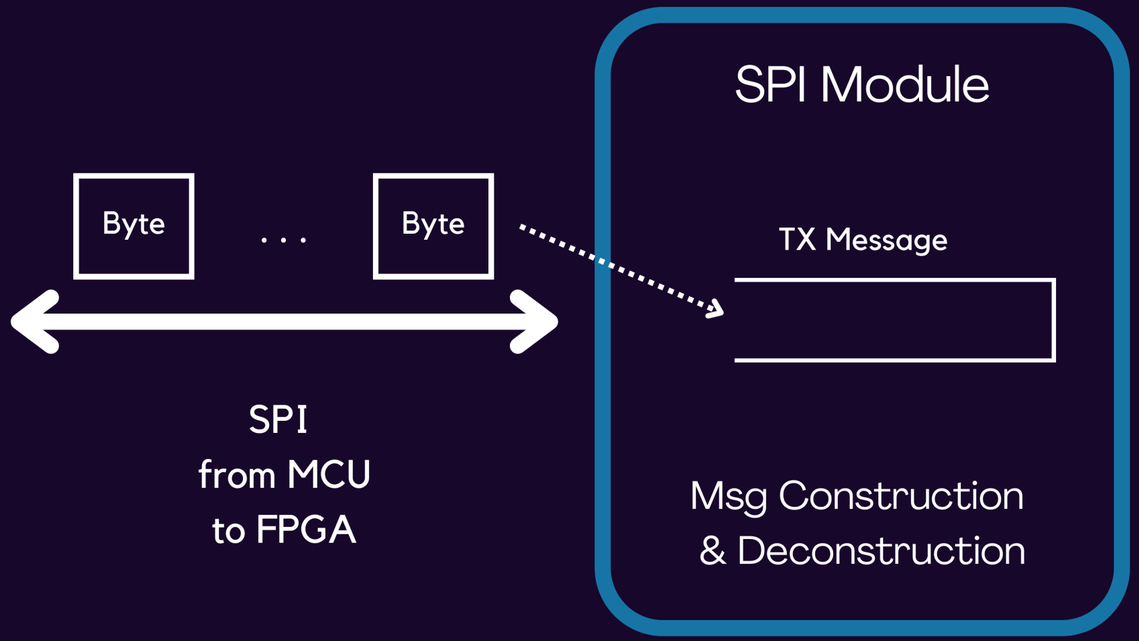
FPGA

- Message processing and bit timing of all TX and RX message transmission to and from avionics equipment
- Controls 6 TX Buses and 8 RX Buses

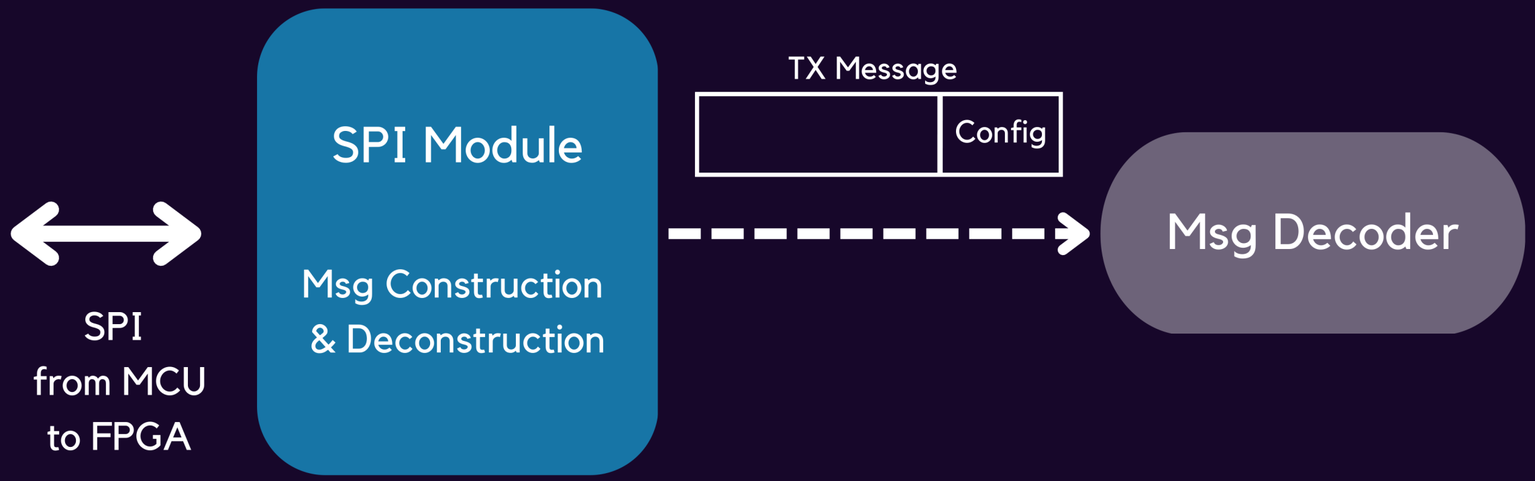


Cmod A7-35T Board with
Artix-7 FPGA

MCU Message to FPGA



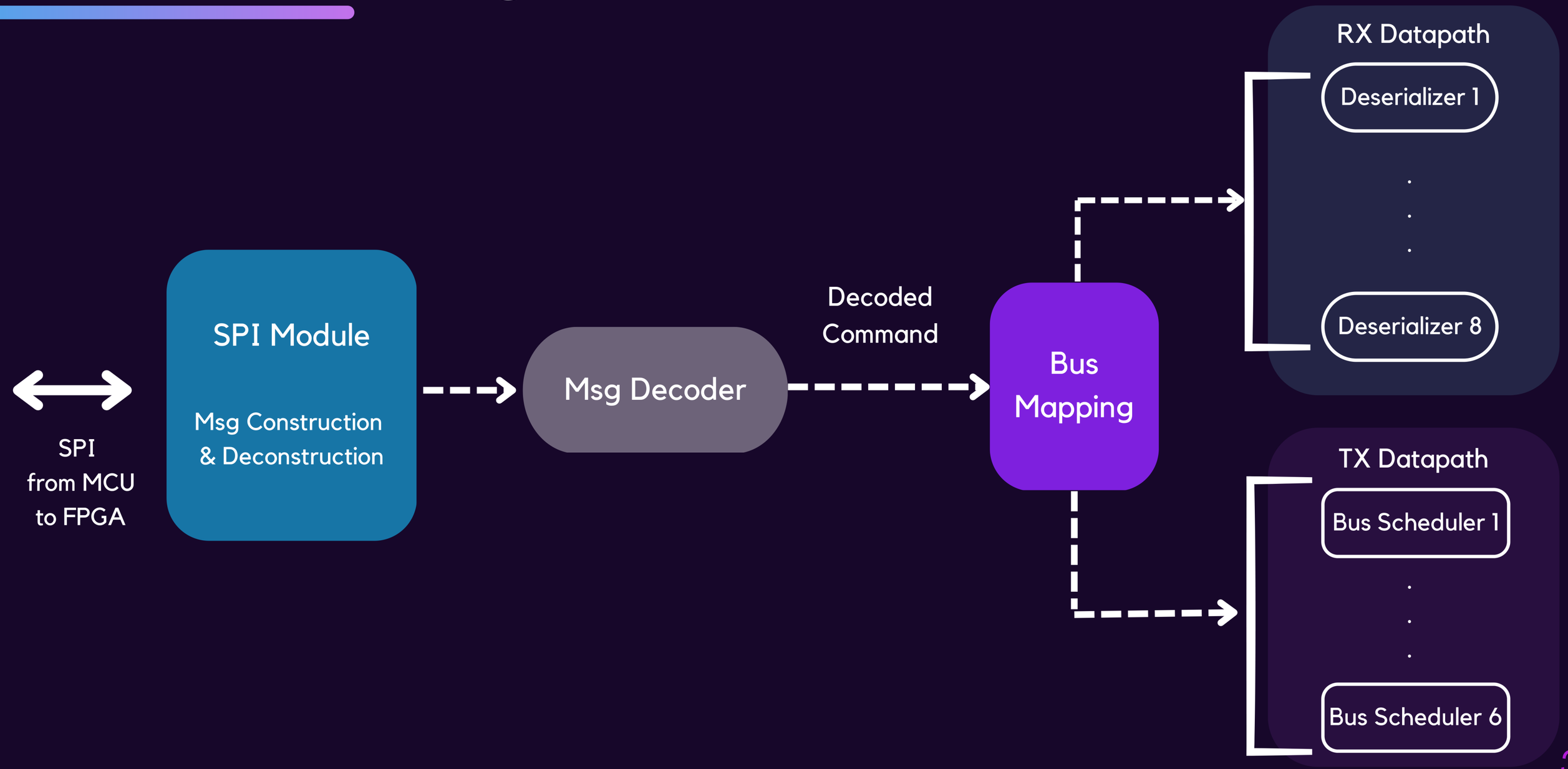
MCU Message to FPGA



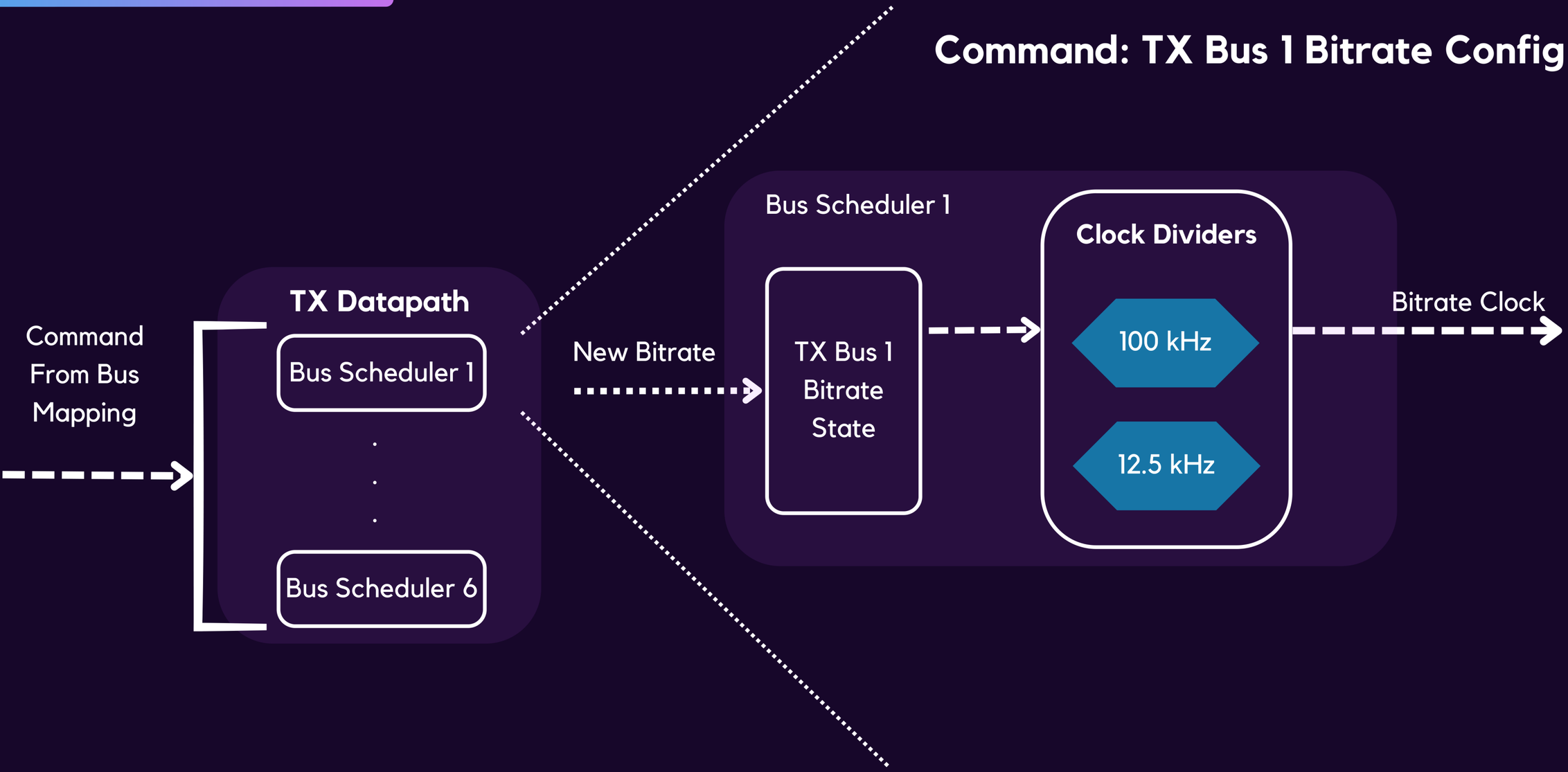
Commands

- Turn a TX Bus ON & set bitrate?
- Turn a TX Bus OFF?
- Turn an RX Bus ON?
- Turn an RX Bus OFF?
- Send ARINC 429 data on a TX Bus at a Transmit Interval?
- Stop sending ARINC 429 data to a TX Bus?

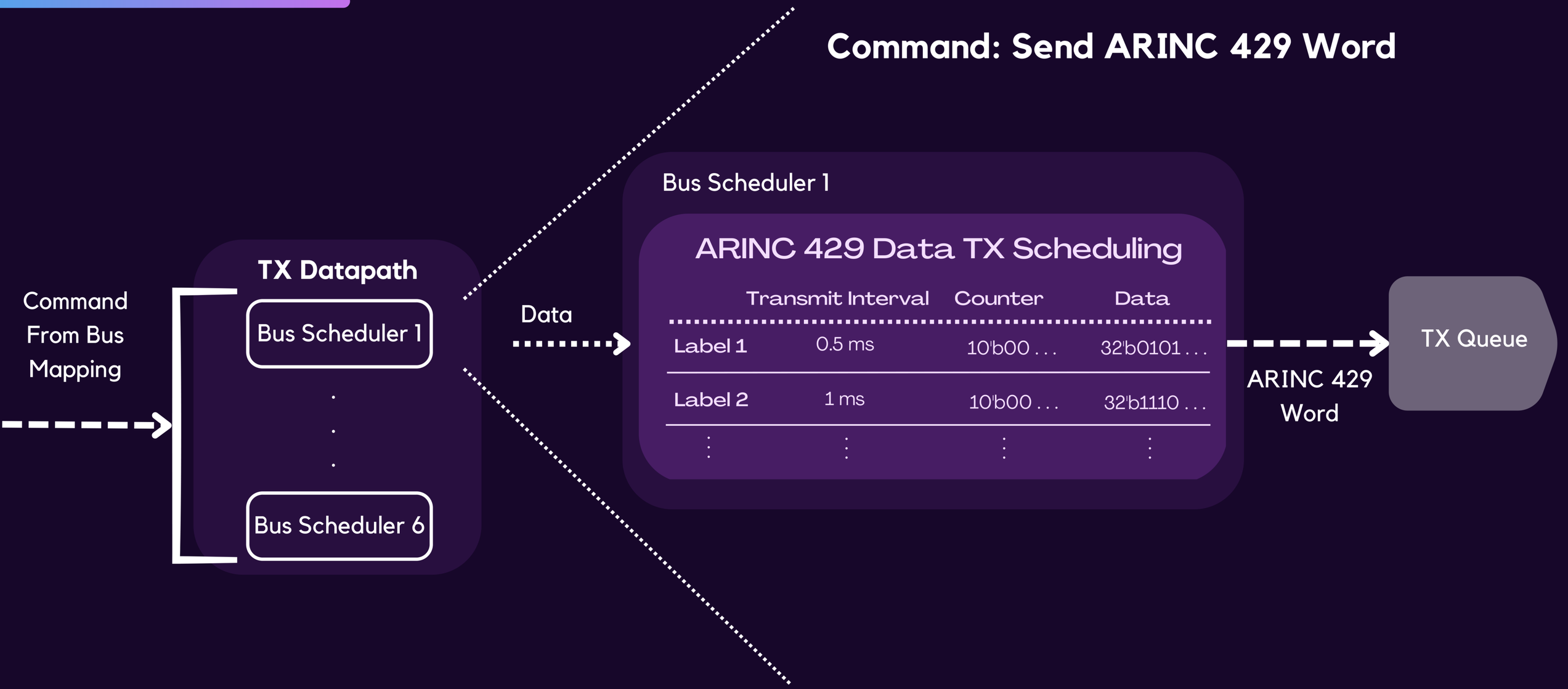
MCU Message to FPGA



TX Bus Scheduling

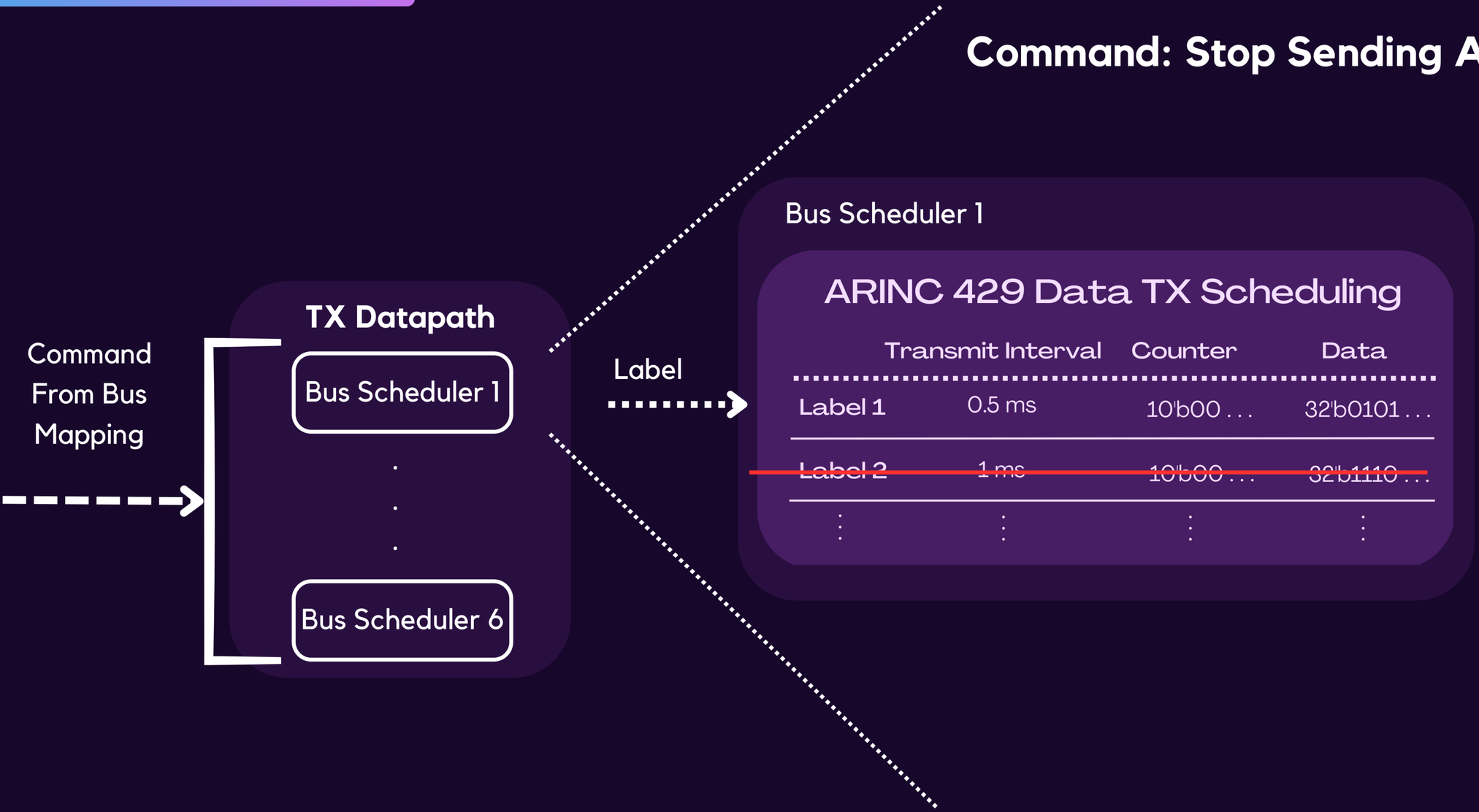


TX Bus Scheduling

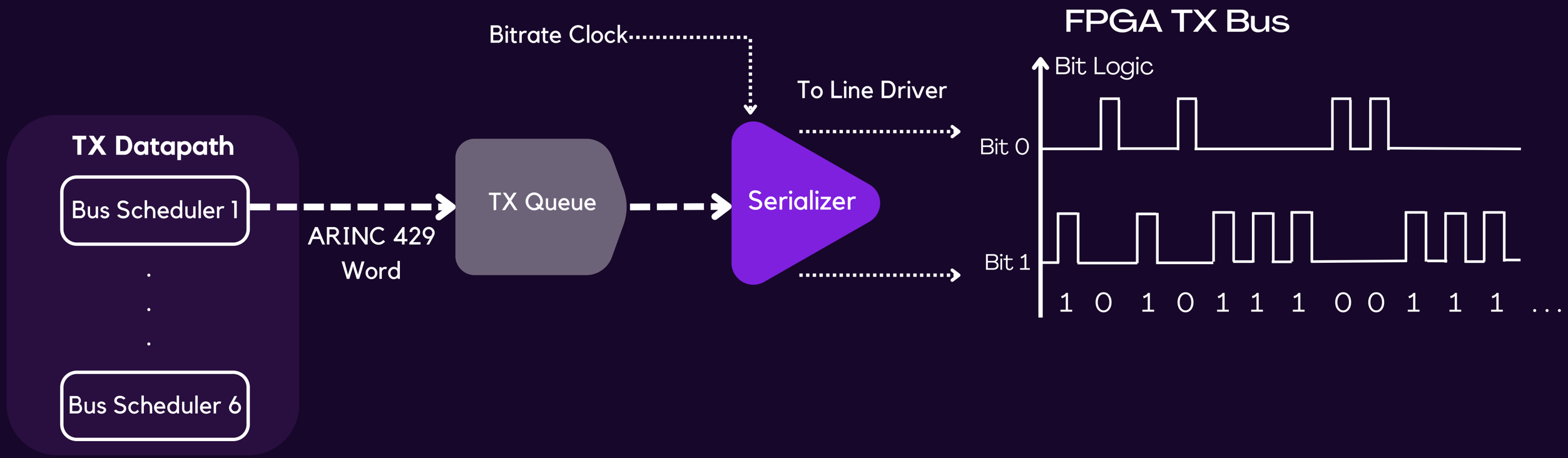


TX Bus Scheduling

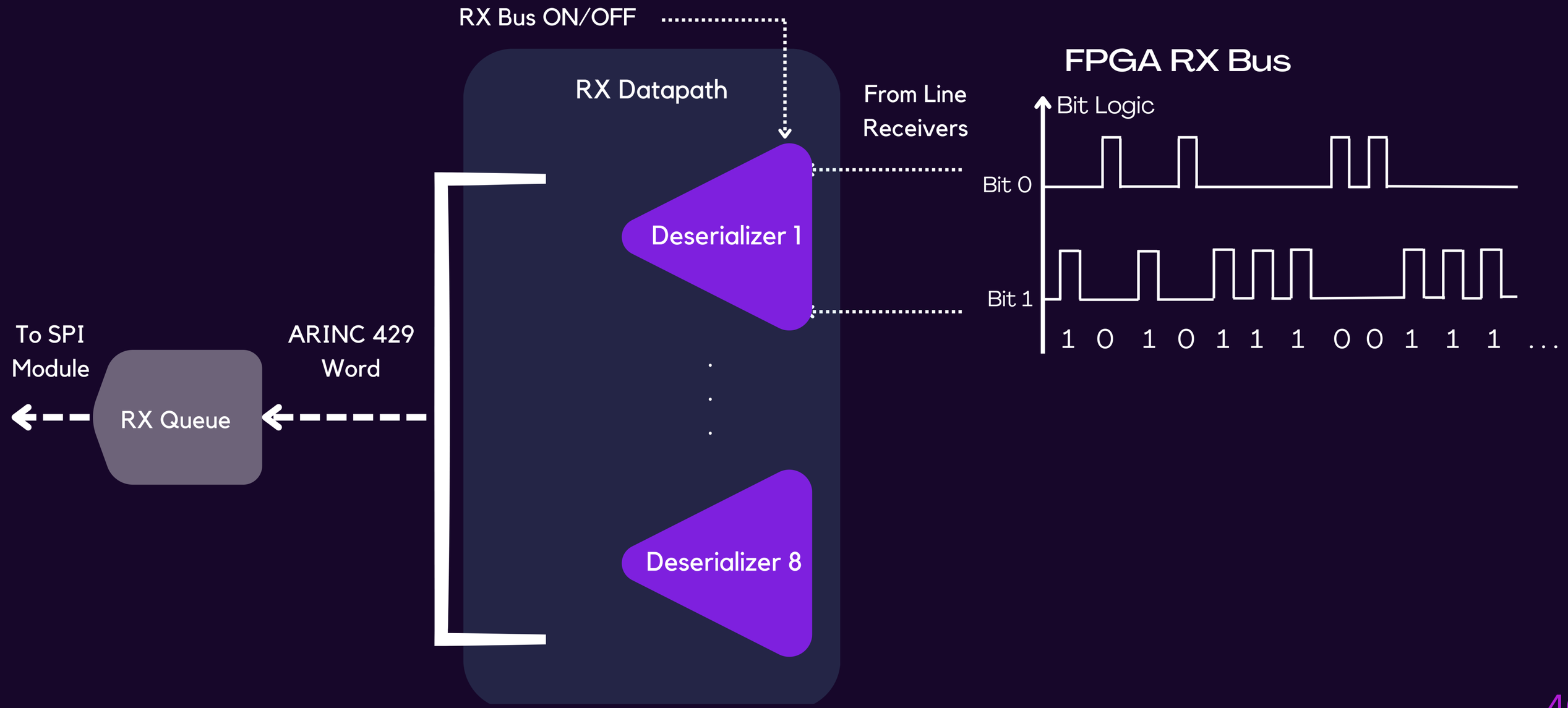
Command: Stop Sending ARINC 429 Word



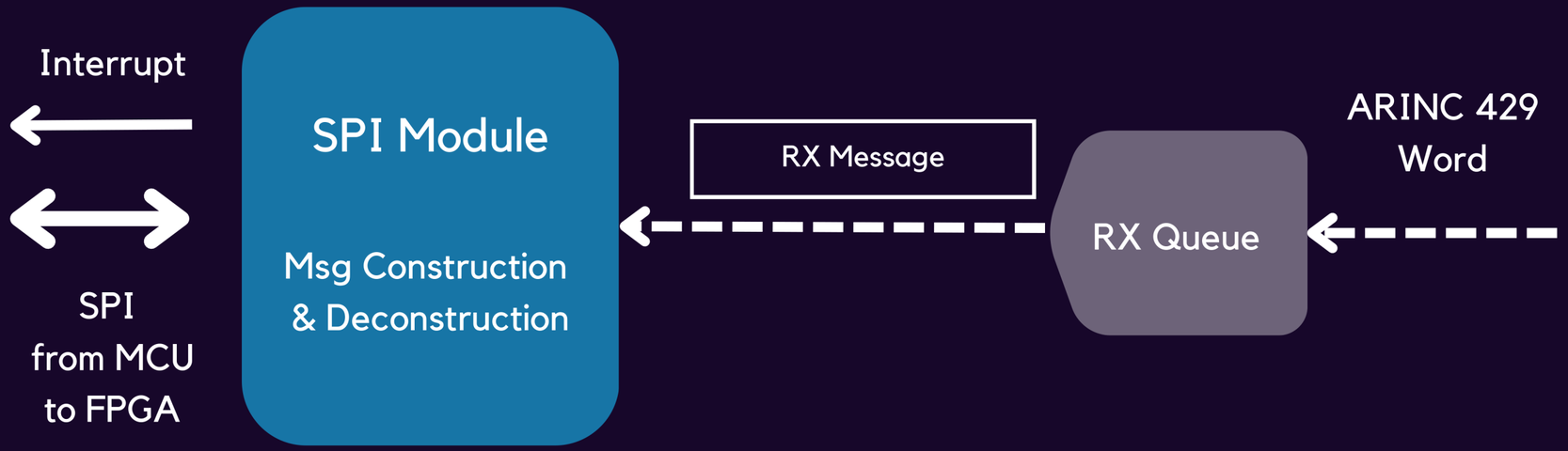
FPGA Data Output



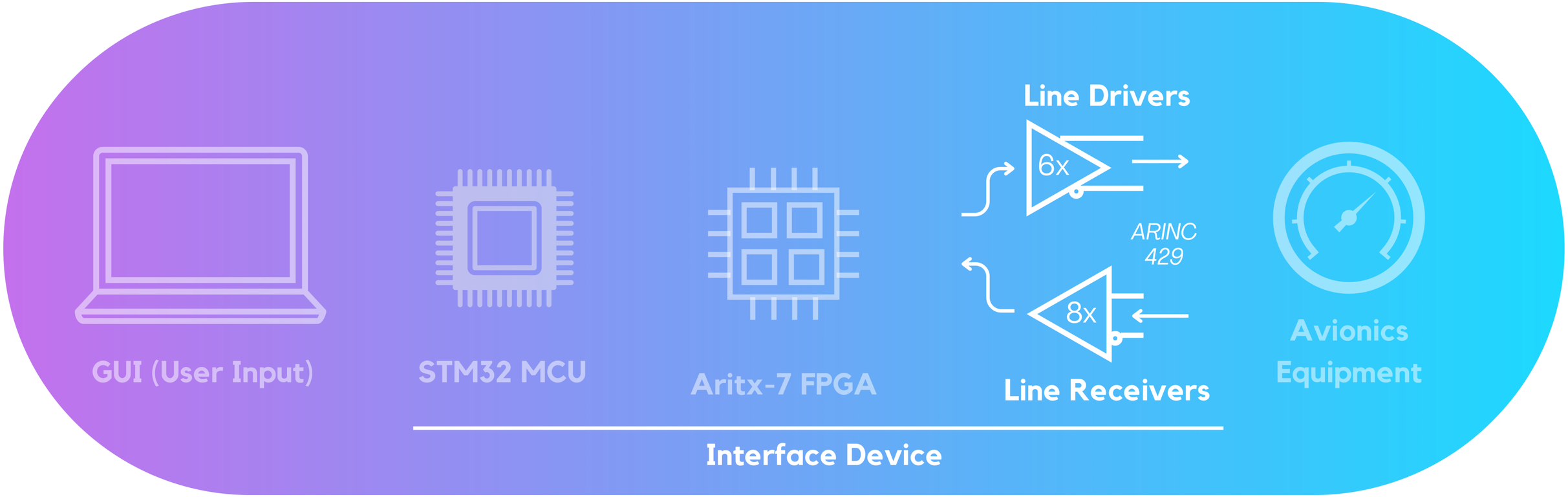
FPGA Data Input



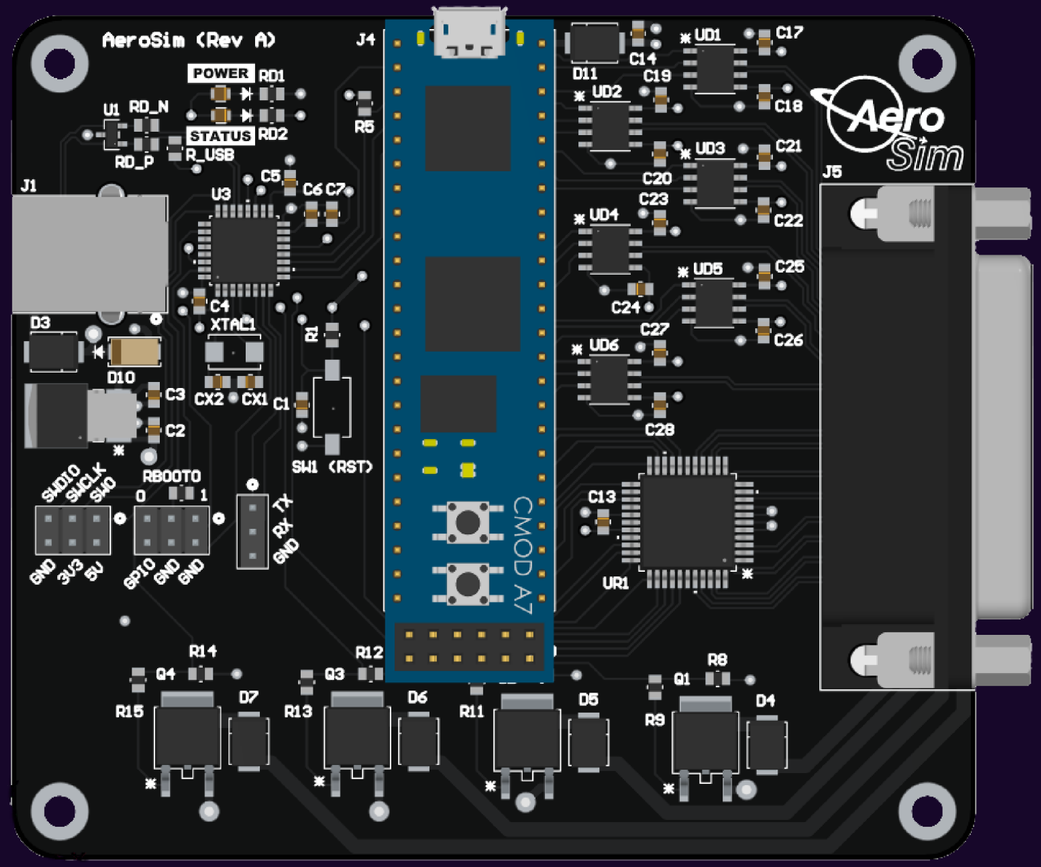
MCU Message to FPGA



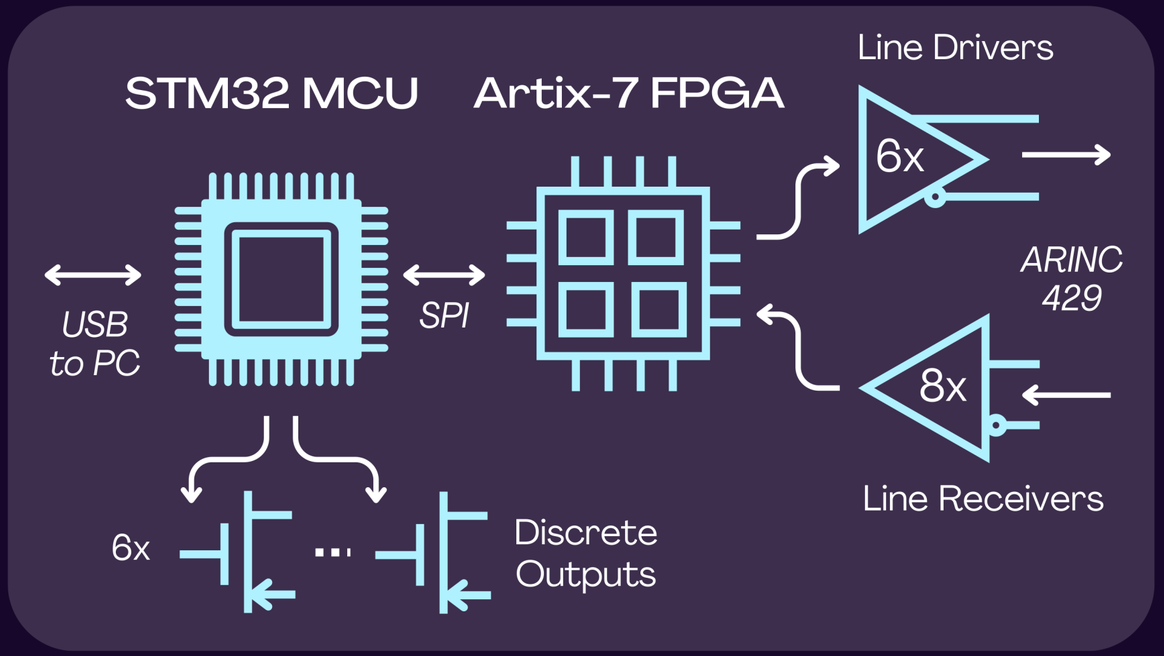
System Overview



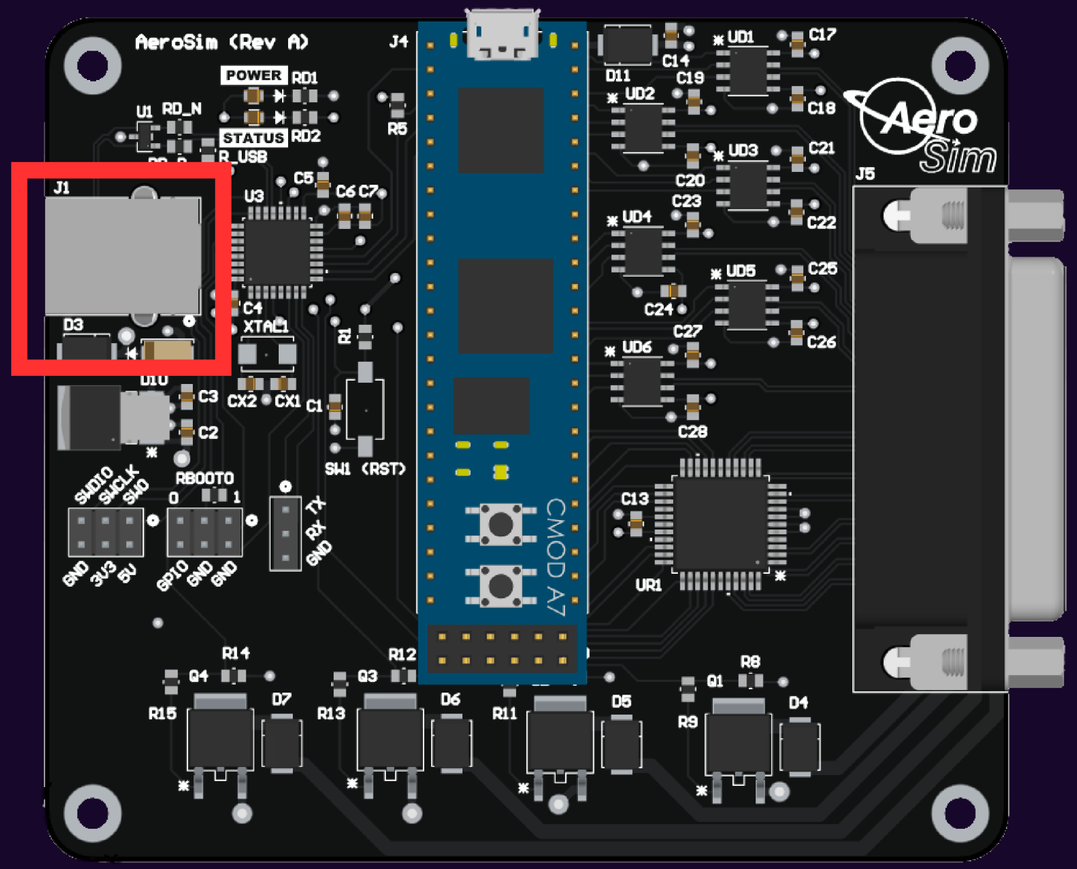
Custom Circuit (PCB)

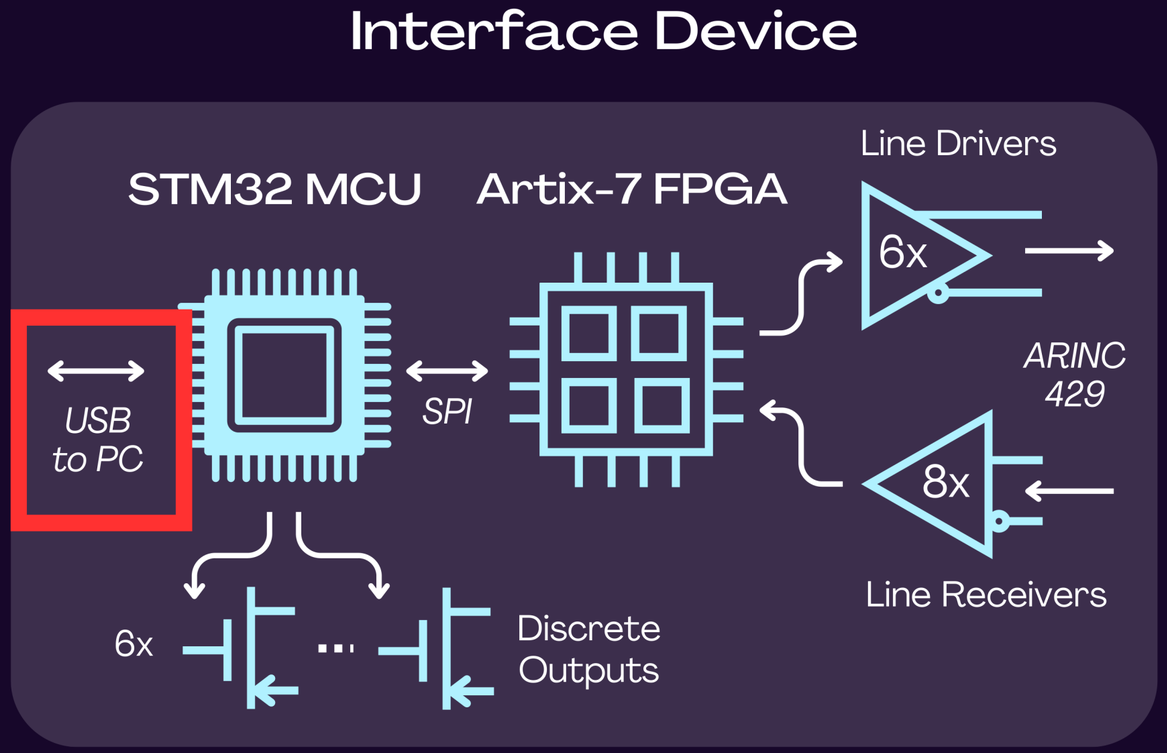


Interface Device

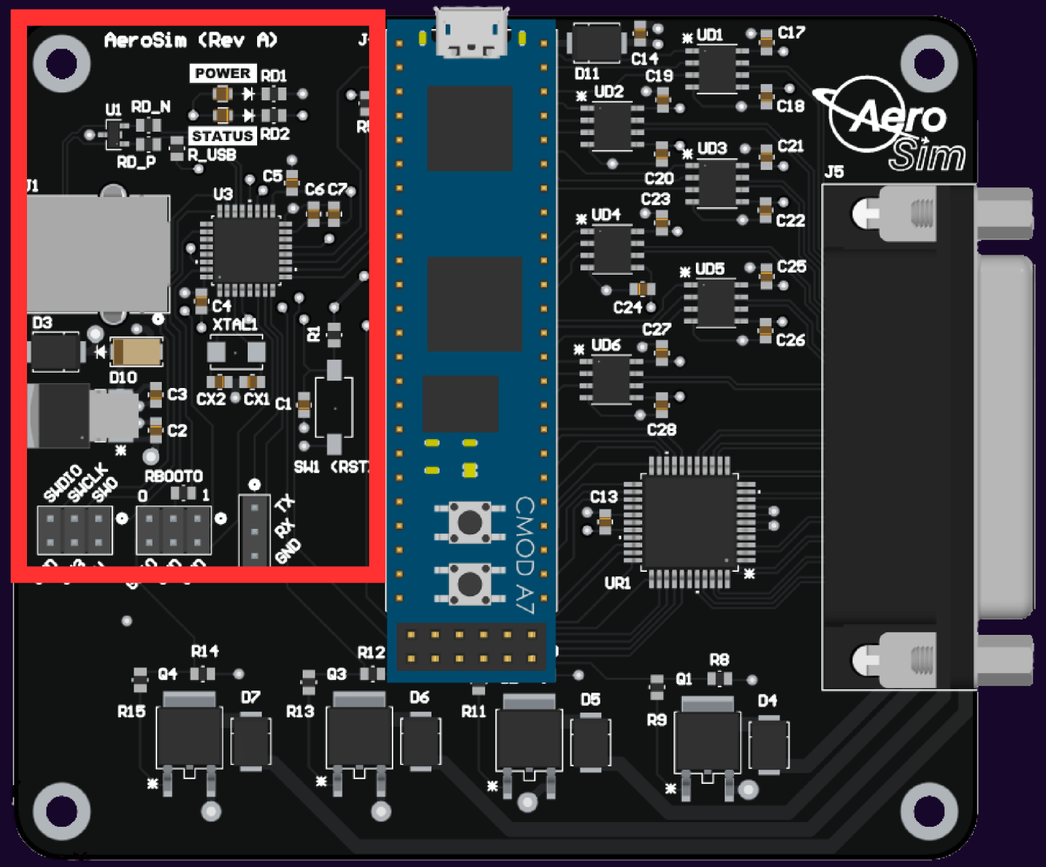


Custom Circuit (PCB)

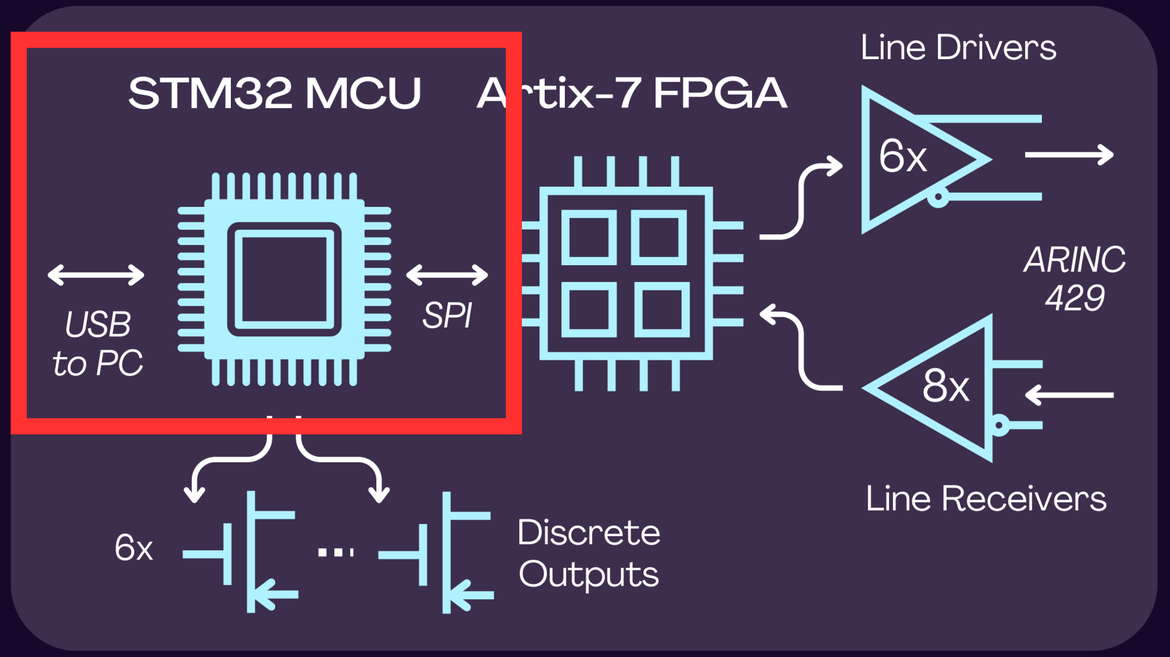




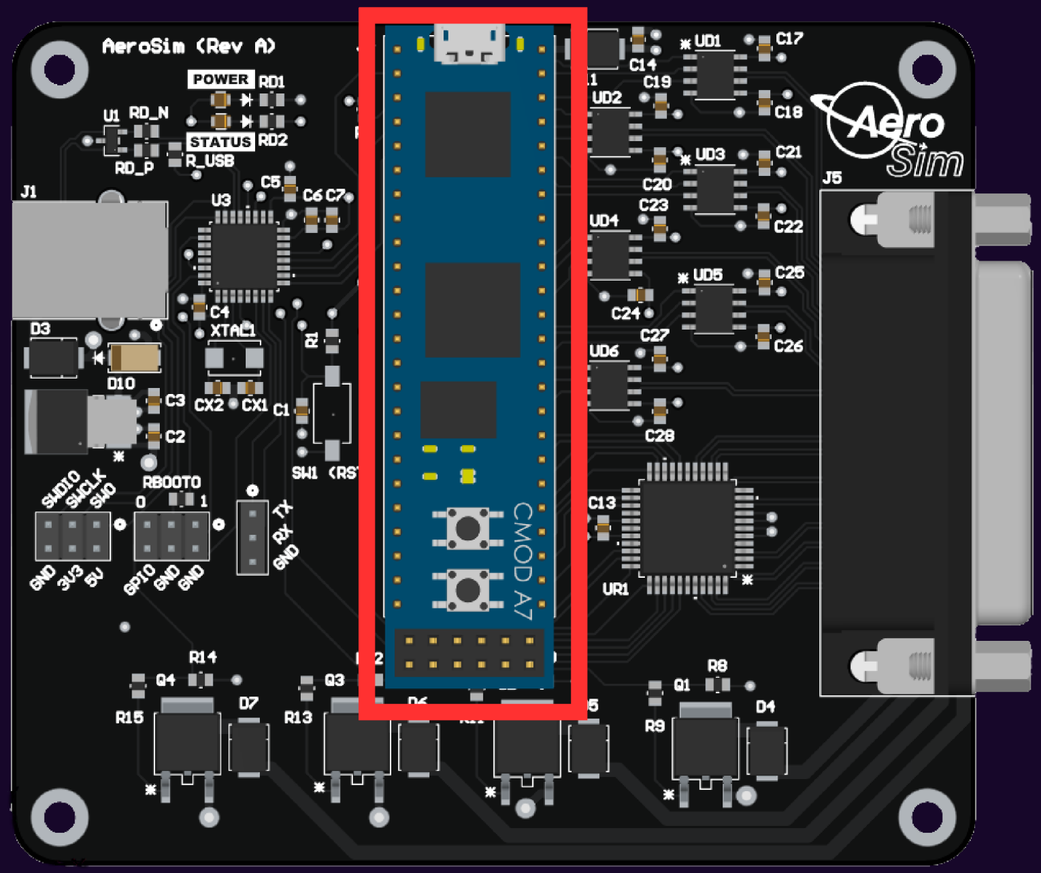
Custom Circuit (PCB)

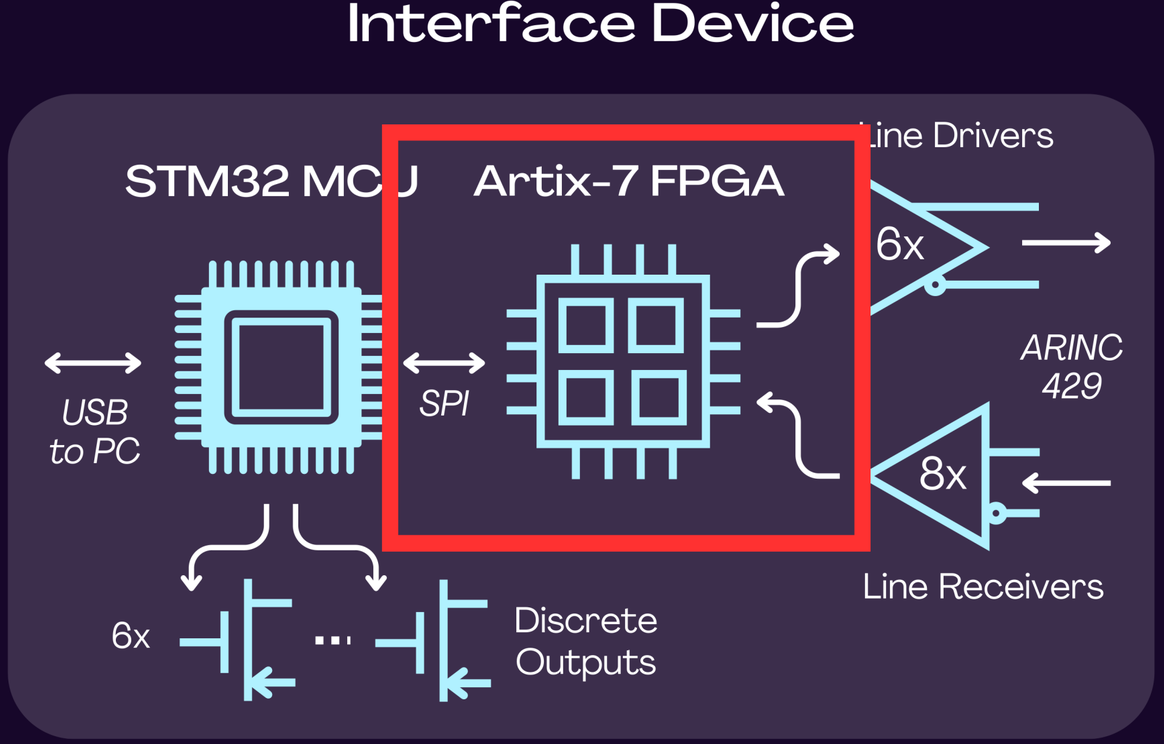


Interface Device

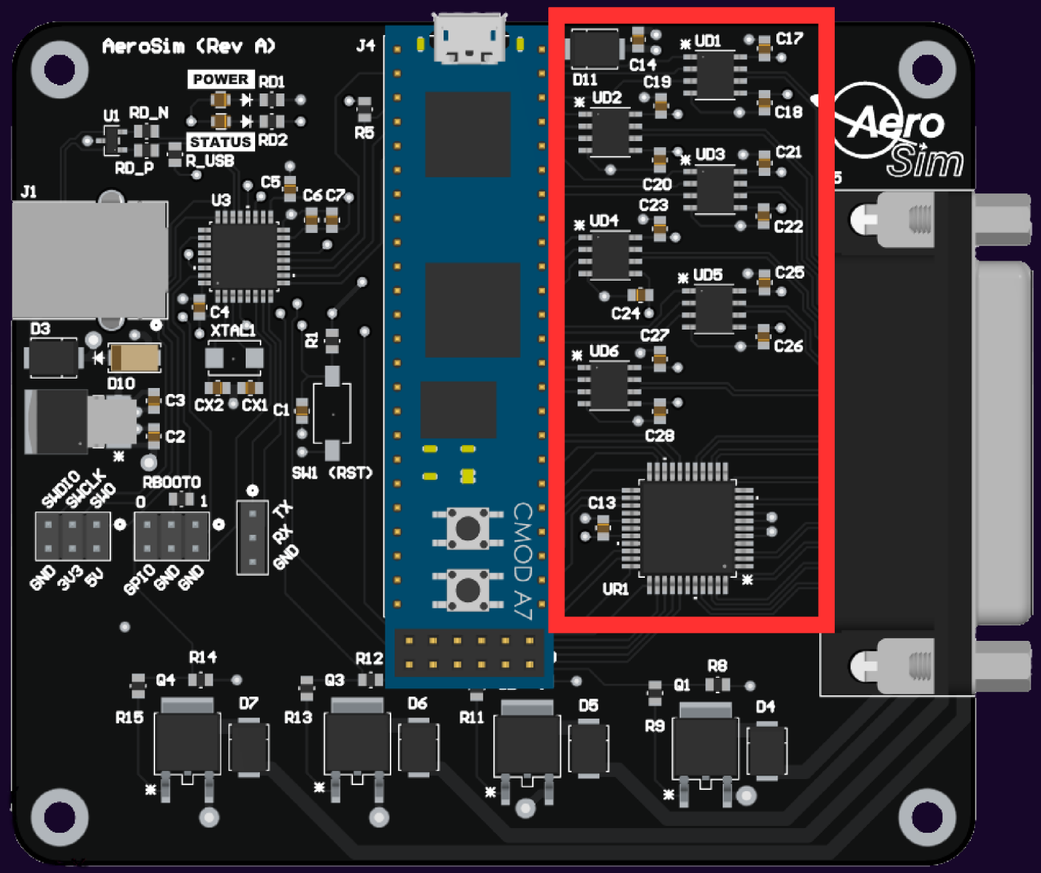


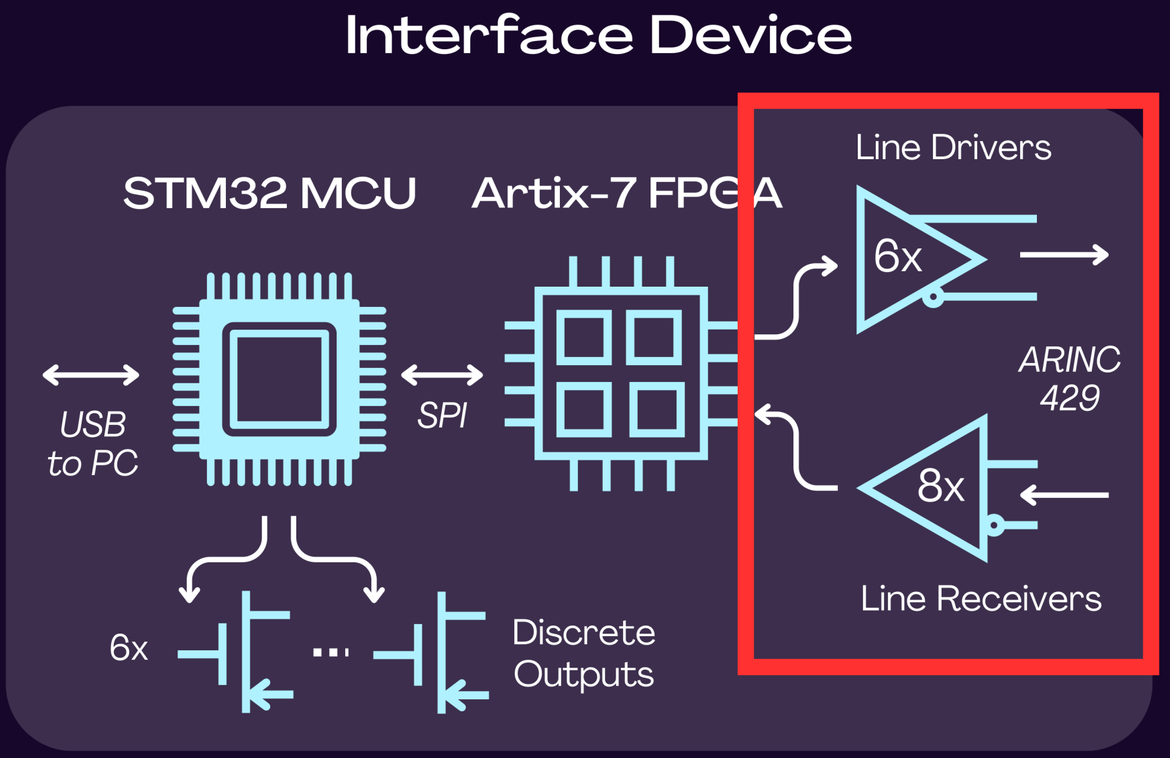
Custom Circuit (PCB)



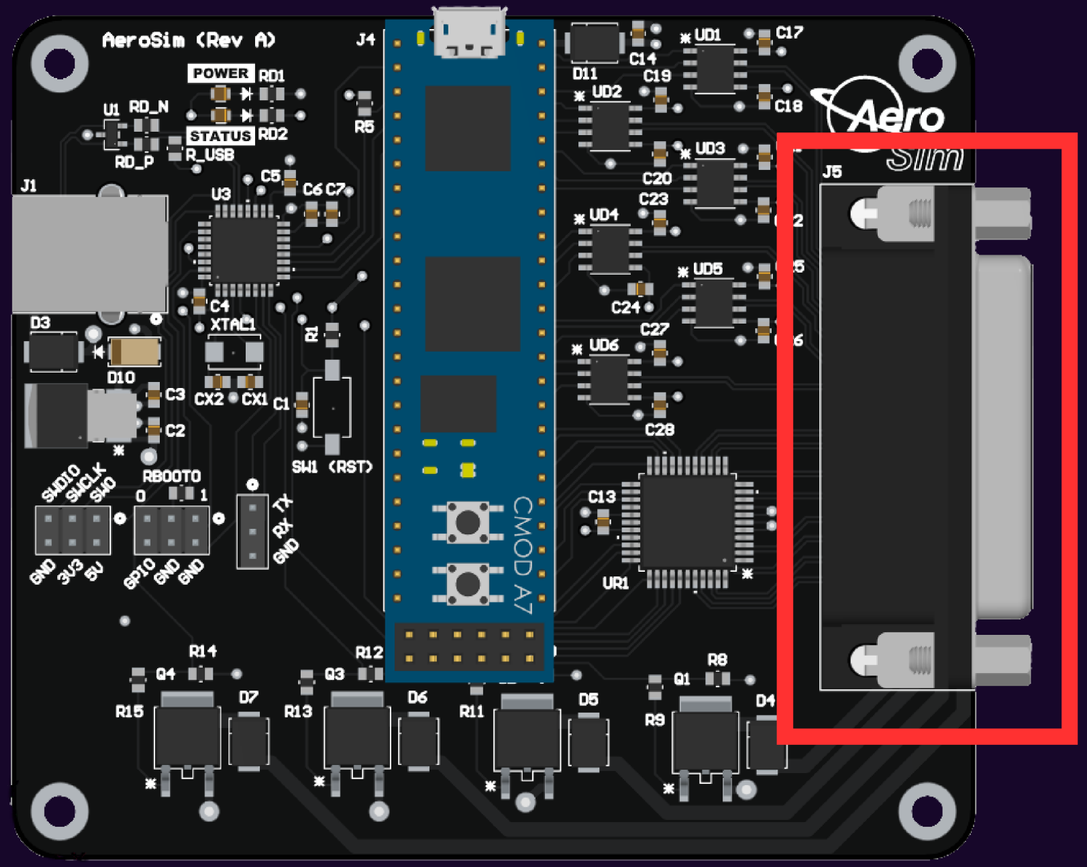


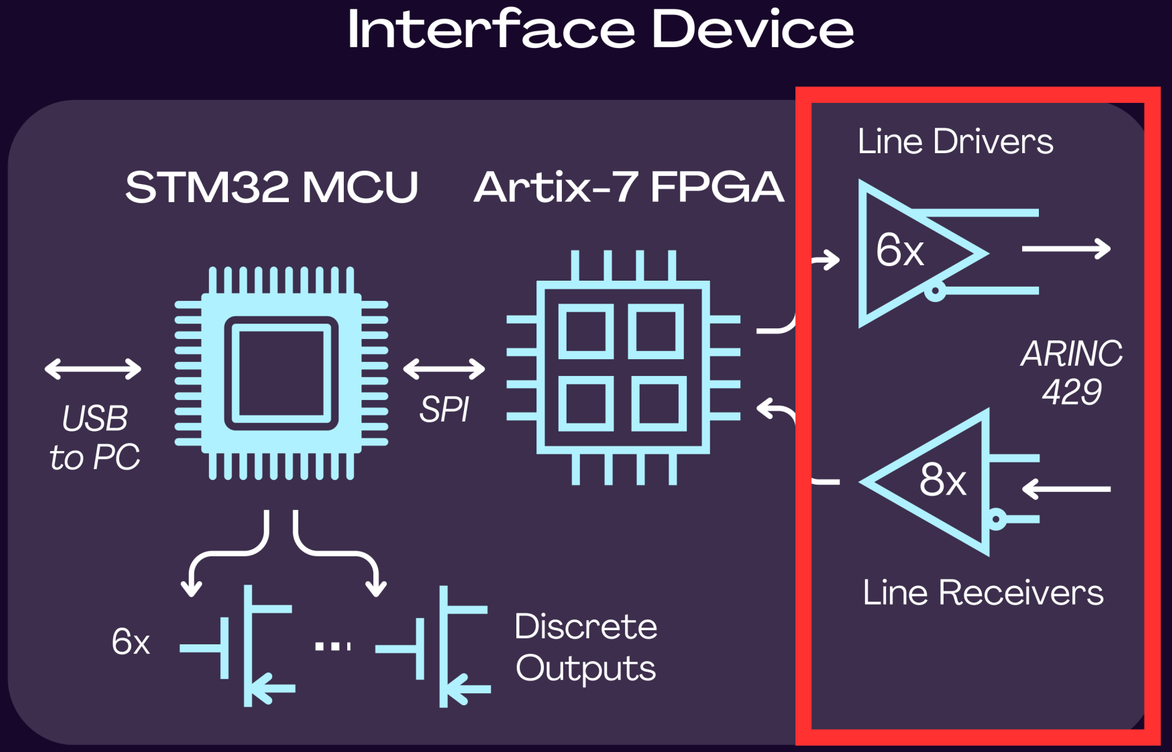
Custom Circuit (PCB)



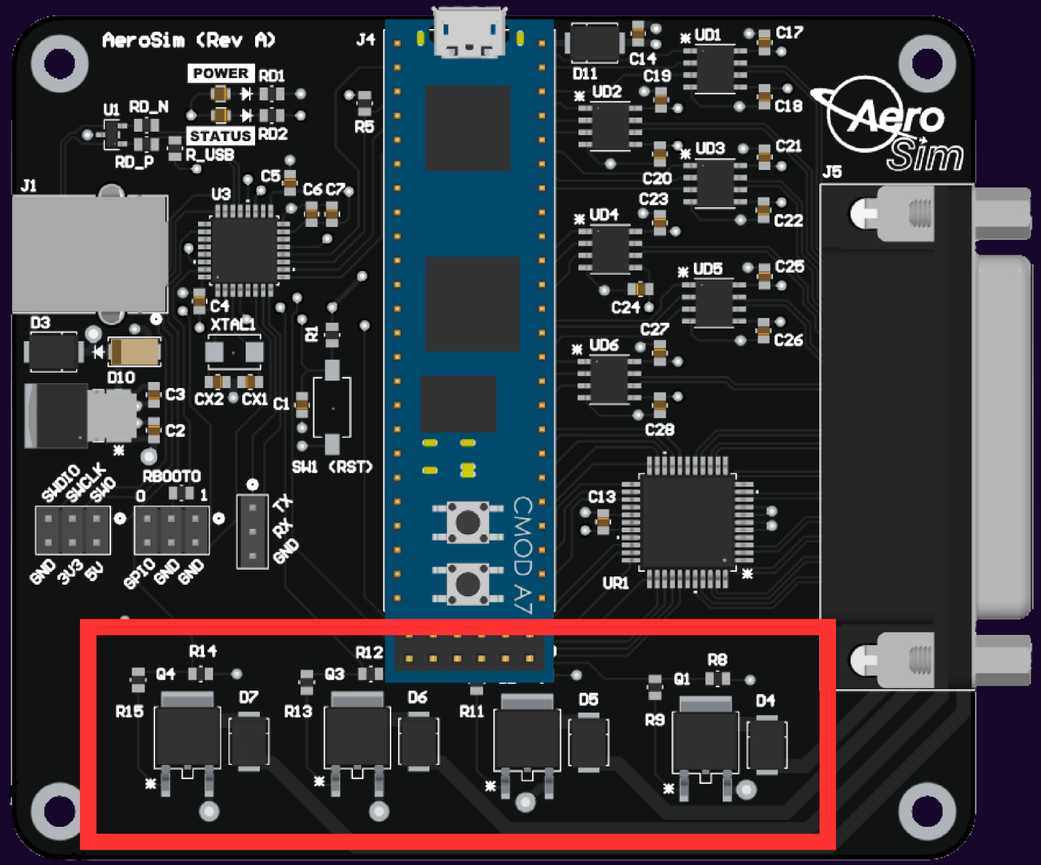


Custom Circuit (PCB)

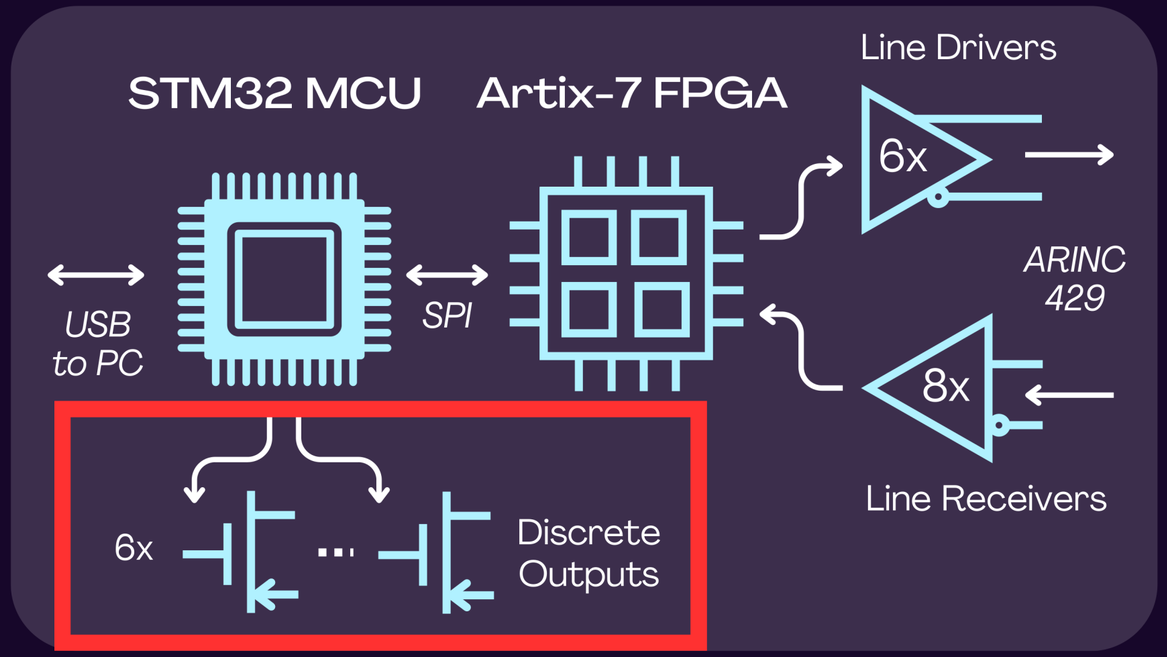




Custom Circuit (PCB)



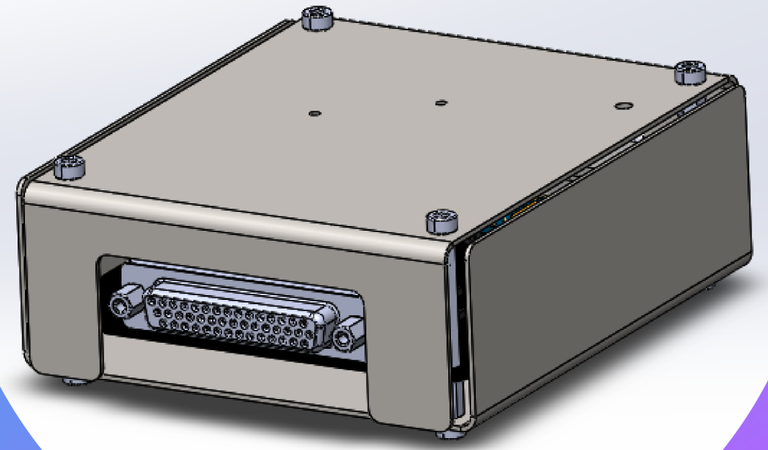
Interface Device



OUTPUTS GROUND OR 28V

Enclosure

A sheet metal enclosure, manufactured by KF Aerospace.



Product Demo

SAMPLE FLIGHT PARAMETER TX PROMPT

“Transmit a 1900 ft Altitude Flight Parameter on TX Bus 1 at 100 kbps”

“Transmit a 1900 ft Altitude Flight Parameter on Bus 1 at 100 kbps”

1. Select **COM Port** and Toggle **TX ON**

“Transmit a 1900 ft Altitude Flight Parameter on Bus 1 at 100 kbps”

1. Select COM Port and Toggle TX ON

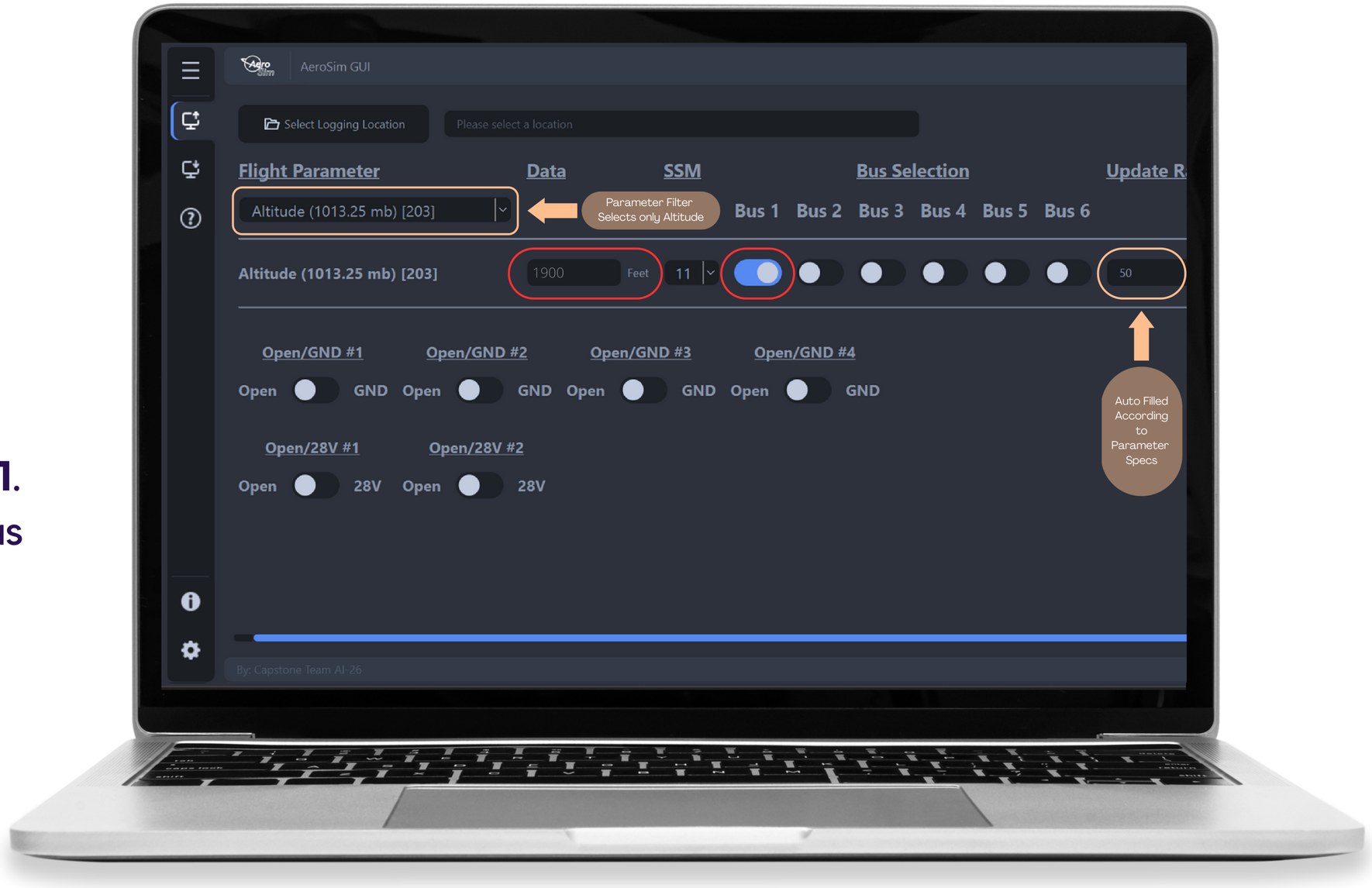
2. Select a Bitrate of **100kbps** for **Bus 1**

“Transmit a 1900 ft Altitude Flight Parameter on Bus 1 at 100 kbps”

1. Select COM Port and Toggle TX ON

2. Toggle TX Bus 1 and select Bitrate 100kbps

3. Enter **1900 ft** in the Altitude Flight Parameter Data field, Toggle **TX Bus 1**. Set **SSM** & **Update Rate** as desired.



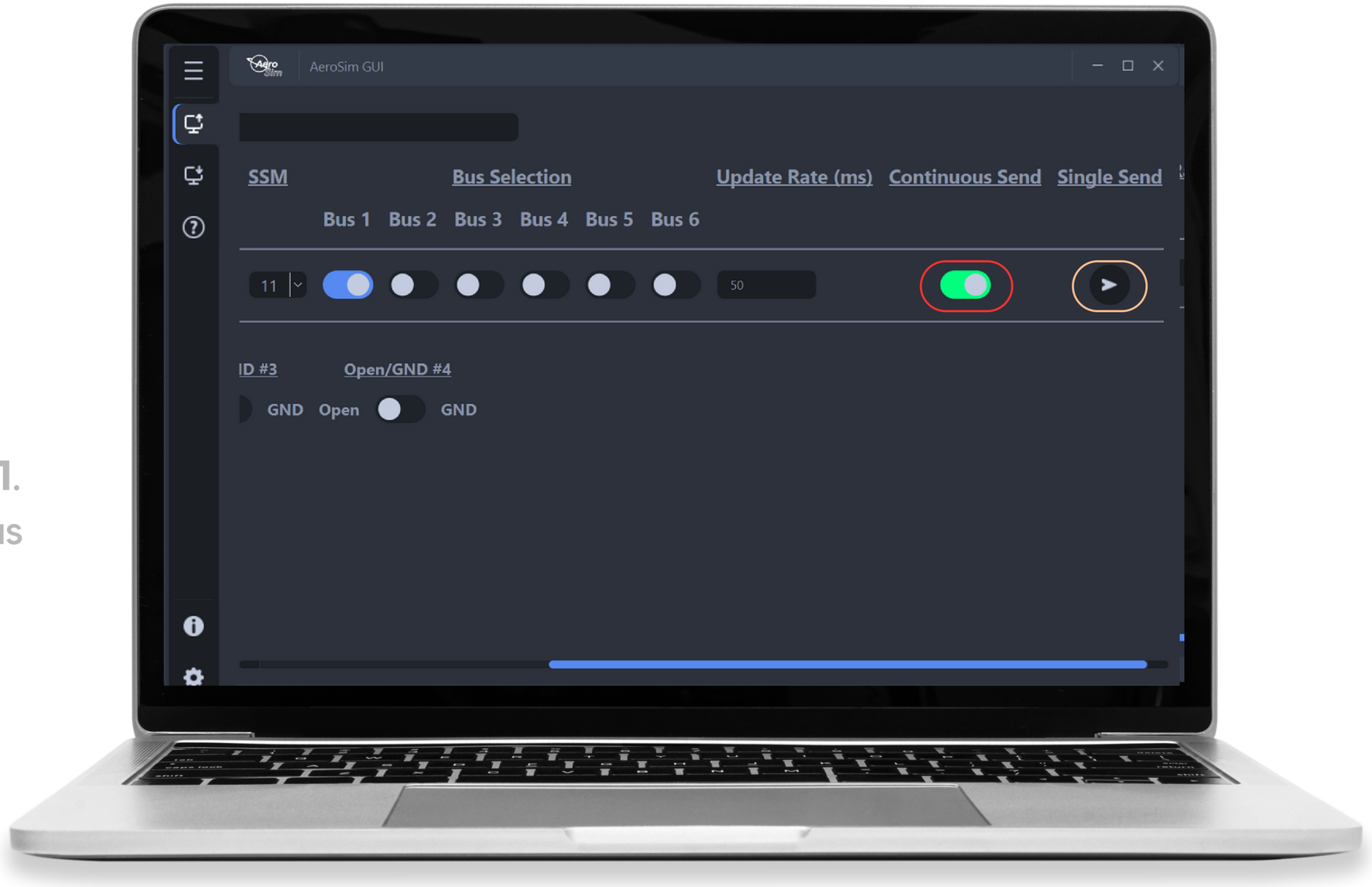
“Transmit a 1900 ft Altitude Flight Parameter on Bus 1 at 100 kbps”

1. Select COM Port and Toggle TX ON

2. Toggle TX Bus 1 and select Bitrate 100kbps

3. Enter **1900 ft** in the Altitude Flight Parameter Data field, Toggle **TX Bus 1**. Set **SSM** & **Update Rate** as desired.

4. Toggle **Continuous Send** for continuous data transmission (at FPGA level) or **Single Send** to send data once



GUI Messages Sent By Serial

GUI Backend Logic

TX ON/OFF

TX Enable	Pad	Config
1'b	3'b	4'b

X 1

GUI Messages Sent By Serial

GUI Backend Logic

TX ON/OFF

TX Enable	Pad	Config
1'b	3'b	4'b

X 1

Bus Configuration

Bitrate	Enable	TX Port	Pad	Config
1'b	1'b	6'b	4'b	4'b

X 6

GUI Messages Sent By Serial

GUI Backend Logic

TX ON/OFF

TX Enable	Pad	Config
1'b	3'b	4'b

X 1

Bus Configuration

Bitrate	Enable	TX Port	Pad	Config
1'b	1'b	6'b	4'b	4'b

X 6

Serial to MCU

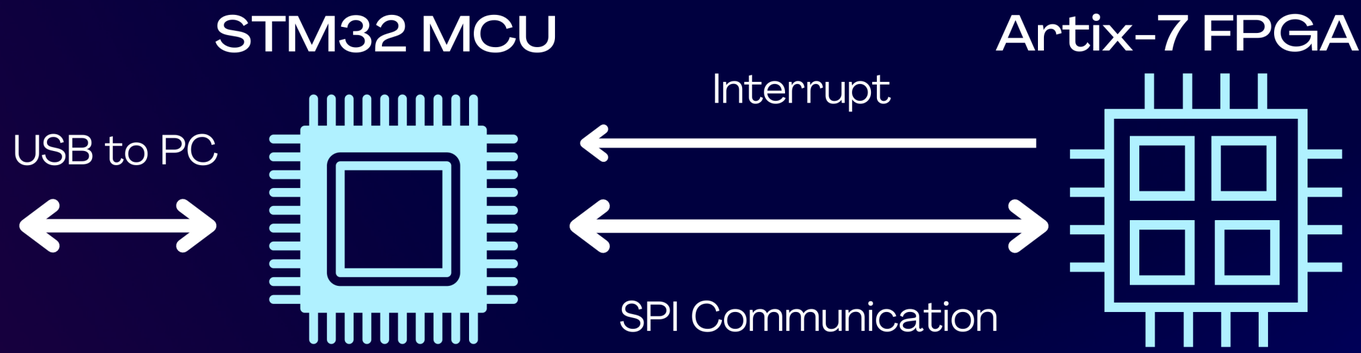
TX Add Data

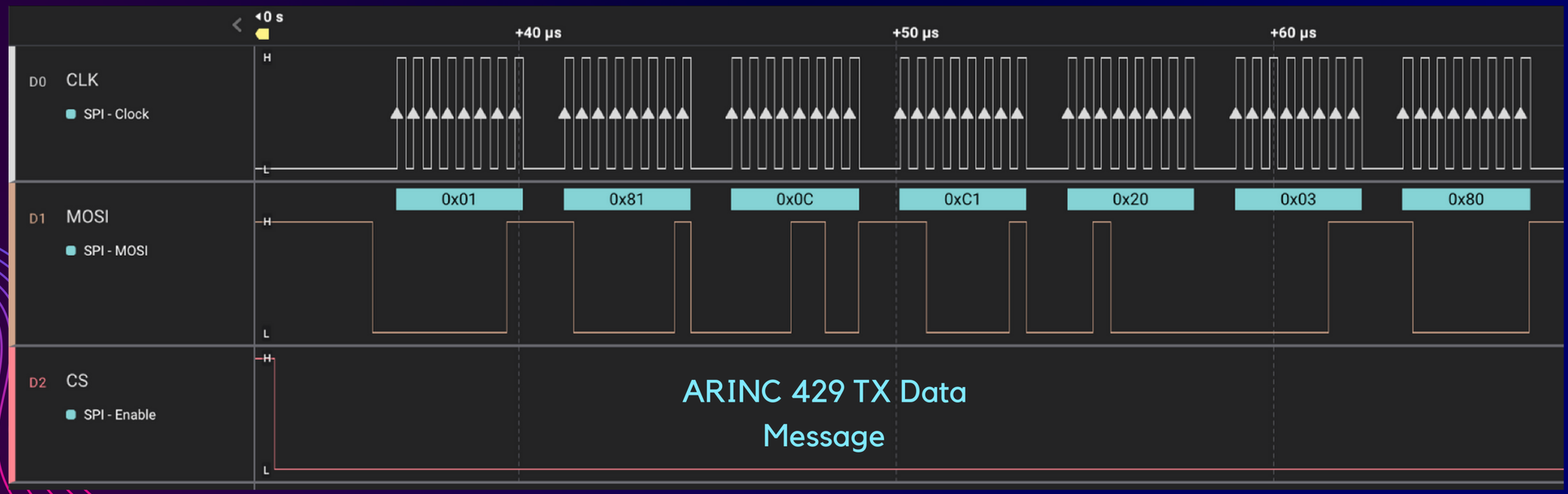
ARINC 429 Word	Transmit Interval	TX Bus	Pad	Config
32'b	10'b	6'b	4'b	4'b

X 1

AEROSIM

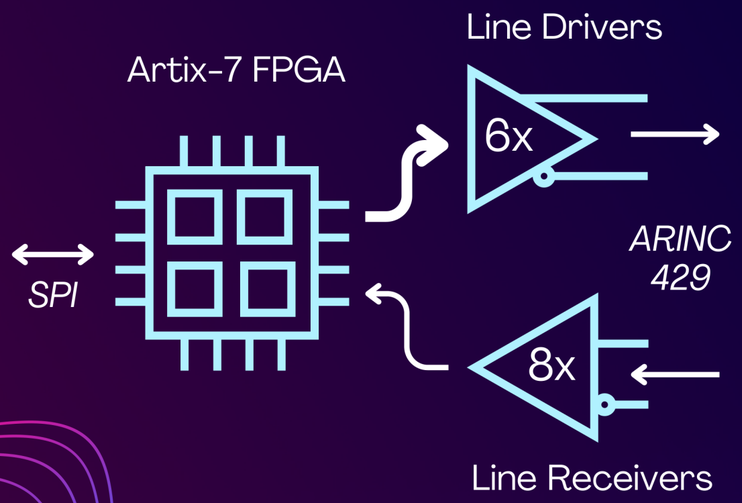
MCU SPI Ouptut to FPGA

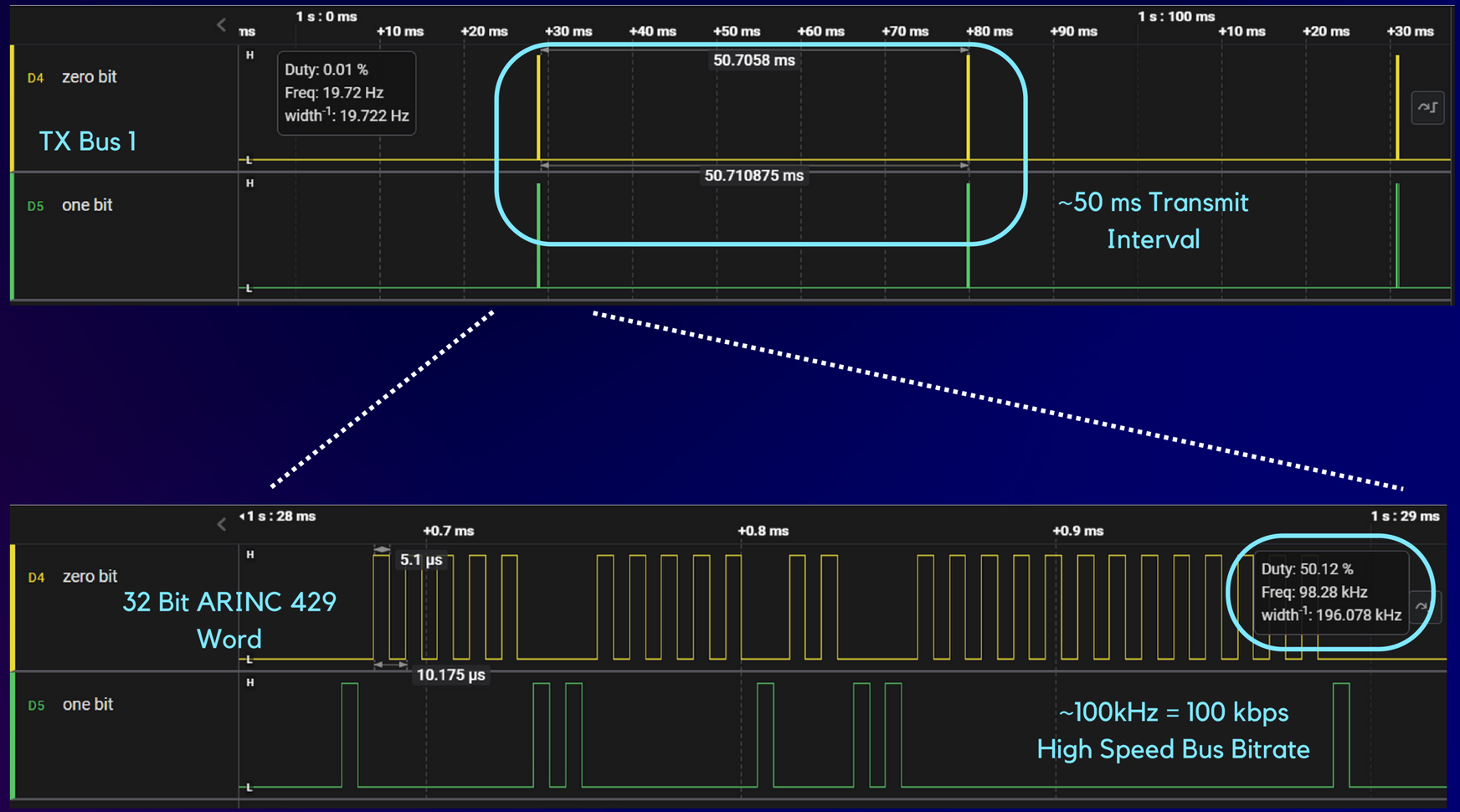




AEROSIM

FPGA Output to Line Driver





Avionics Equipment: GPS Module

*Provided by KF Aerospace

Altitude Parameter will display 1900ft, and update in real-time

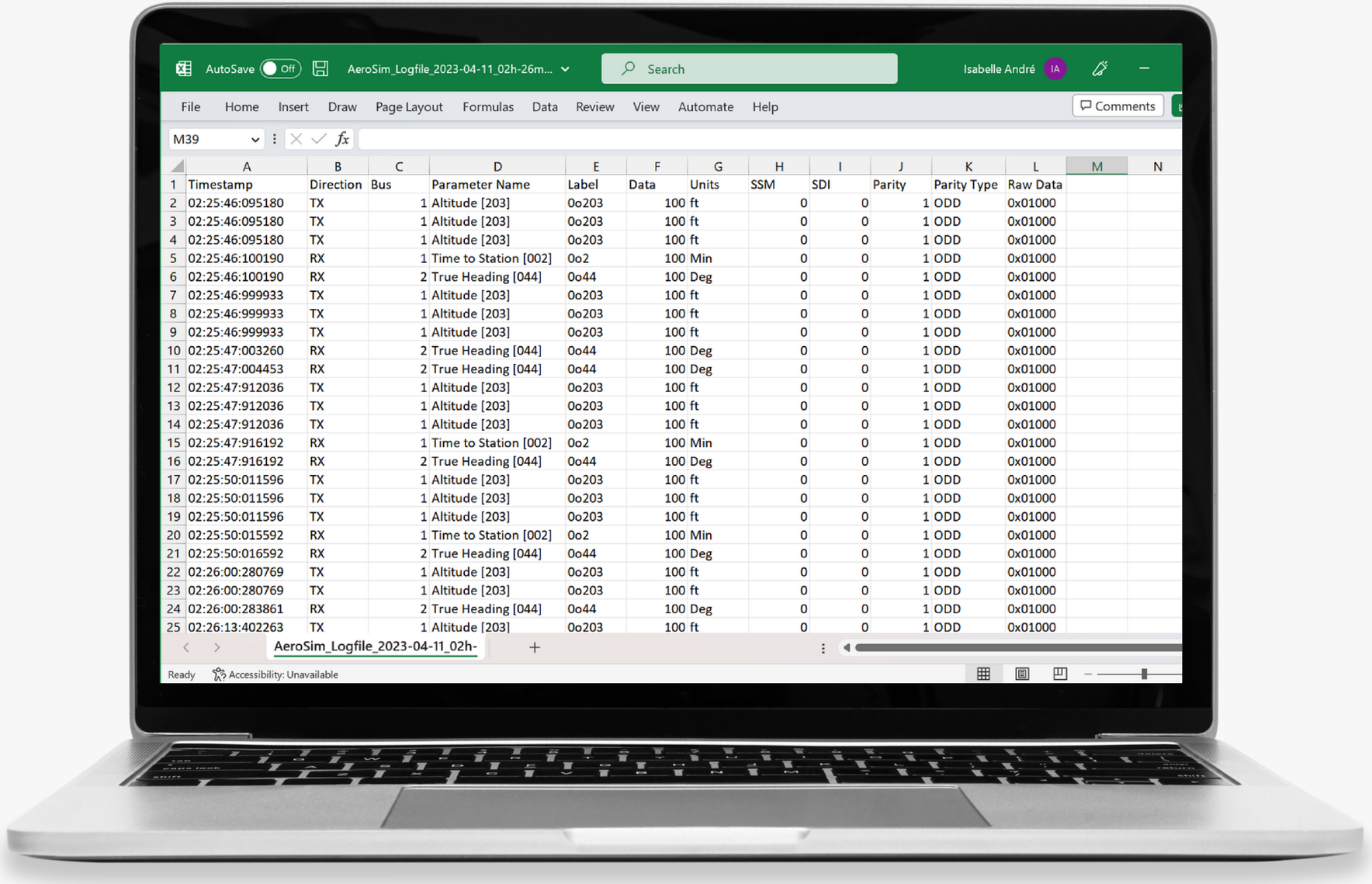
Product Demo

LOGGING RX DATA FROM AVIONICS EQUIPMENT

Send Altitude 2500ft at 100kbps on TX Bus 1,3,6, and display and log RX data from RX Bus 1 & 2 in a CSV file”

*For the sake of time, will not be demonstrated

Sample Generated Log File with RX ON and Logging ON



	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Timestamp	Direction	Bus	Parameter Name	Label	Data	Units	SSM	SDI	Parity	Parity Type	Raw Data		
2	02:25:46:095180	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
3	02:25:46:095180	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
4	02:25:46:095180	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
5	02:25:46:100190	RX	1	Time to Station [002]	0o2	100	Min	0	0	1	ODD	0x01000		
6	02:25:46:100190	RX	2	True Heading [044]	0o44	100	Deg	0	0	1	ODD	0x01000		
7	02:25:46:999933	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
8	02:25:46:999933	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
9	02:25:46:999933	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
10	02:25:47:003260	RX	2	True Heading [044]	0o44	100	Deg	0	0	1	ODD	0x01000		
11	02:25:47:004453	RX	2	True Heading [044]	0o44	100	Deg	0	0	1	ODD	0x01000		
12	02:25:47:912036	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
13	02:25:47:912036	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
14	02:25:47:912036	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
15	02:25:47:916192	RX	1	Time to Station [002]	0o2	100	Min	0	0	1	ODD	0x01000		
16	02:25:47:916192	RX	2	True Heading [044]	0o44	100	Deg	0	0	1	ODD	0x01000		
17	02:25:50:011596	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
18	02:25:50:011596	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
19	02:25:50:011596	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
20	02:25:50:015592	RX	1	Time to Station [002]	0o2	100	Min	0	0	1	ODD	0x01000		
21	02:25:50:016592	RX	2	True Heading [044]	0o44	100	Deg	0	0	1	ODD	0x01000		
22	02:26:00:280769	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
23	02:26:00:280769	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		
24	02:26:00:283861	RX	2	True Heading [044]	0o44	100	Deg	0	0	1	ODD	0x01000		
25	02:26:13:402263	TX	1	Altitude [203]	0o203	100	ft	0	0	1	ODD	0x01000		

Verification & Validation Test Plans

1. Basic GUI Functionality
2. Software Backend Message Transmission
3. Serial Communication
4. SPI Communication
5. FPGA Logic and Outputs
6. Discrete Outputs
7. Load and Stress Testing
8. End-to-End System

Limitations

- Max 10 Flight Parameters on 1 TX bus at once
- No user feedback of faulty ARINC words received
- RX ARINC 429 input rate from avionics equipment

AEROSIM

Client Impact

Reduced Test Time and Aircraft Downtime

Monetary Savings

Full Ownership and Flexibility

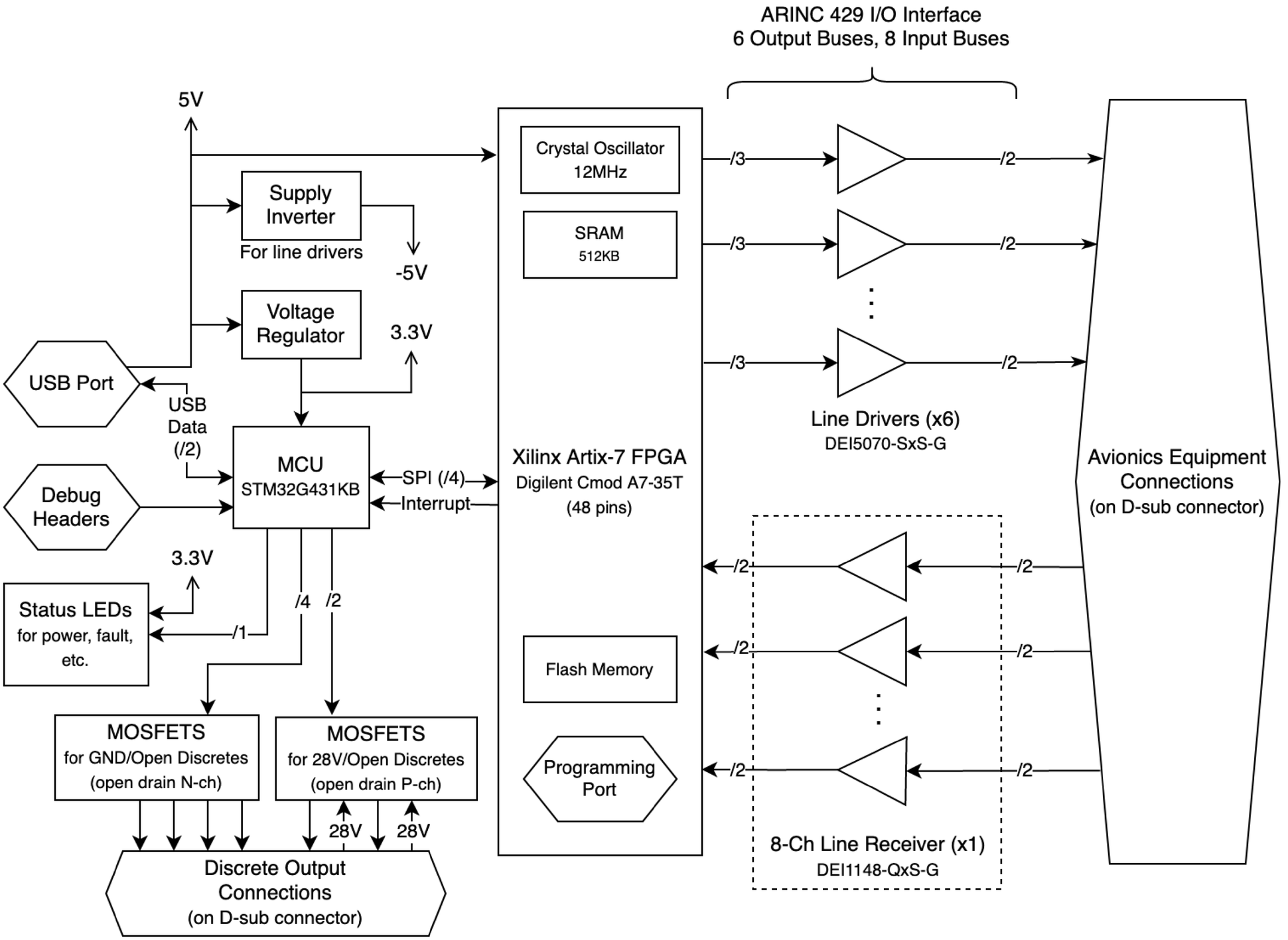
QUESTIONS?

Avionics Integration Test Bench

Team AI-26

UBC ELEC 491 Capstone 2022-23

AeroSim


ARINC 429 I/O Interface
6 Output Buses, 8 Input Buses
5V
Supply Inverter
For line drivers
-5V
Voltage Regulator
3.3V
USB Port
USB Data (/2)
MCU
STM32G431KB
SPI (/4)
Interrupt
Debug Headers
3.3V
Status LEDs
for power, fault, etc.
/1
/4
/2
MOSFETS
for GND/Open Discretes
(open drain N-ch)
MOSFETS
for 28V/Open Discretes
(open drain P-ch)
28V
28V
Discrete Output Connections
(on D-sub connector)
Crystal Oscillator
12MHz
SRAM
512KB
Xilinx Artix-7 FPGA
Digilent Cmod A7-35T
(48 pins)
Flash Memory
Programming Port
/3
/2
Line Drivers (x6)
DEI5070-SxS-G
8-Ch Line Receiver (x1)
DEI1148-QxS-G
Avionics Equipment Connections
(on D-sub connector)

TX ON/OFF

	MSB		LSB
Field Size	1 bit	3 bits	4 bits
Field	**TX Enable**	**Pad**	**Config**

RX ON/OFF

	MSB			LSB
Field Size	8 bits	1 bit	3 bits	4 bits
Field	**RX Port**	**RX Enable**	**Pad**	**Config**

Discrete Output

	MSB		LSB
Field Size	1 bit	3 bits	4 bits
Field	**Discrete Enable**	**Discrete Port**	**Config**

TX Bus Bitrate

	MSB				LSB
Field Size	1 bit	1 bit	6 bits	4 bits	4 bits
Field	**Bitrate**	**Enable**	**TX Port**	**Pad**	**Config**

TX Add Data

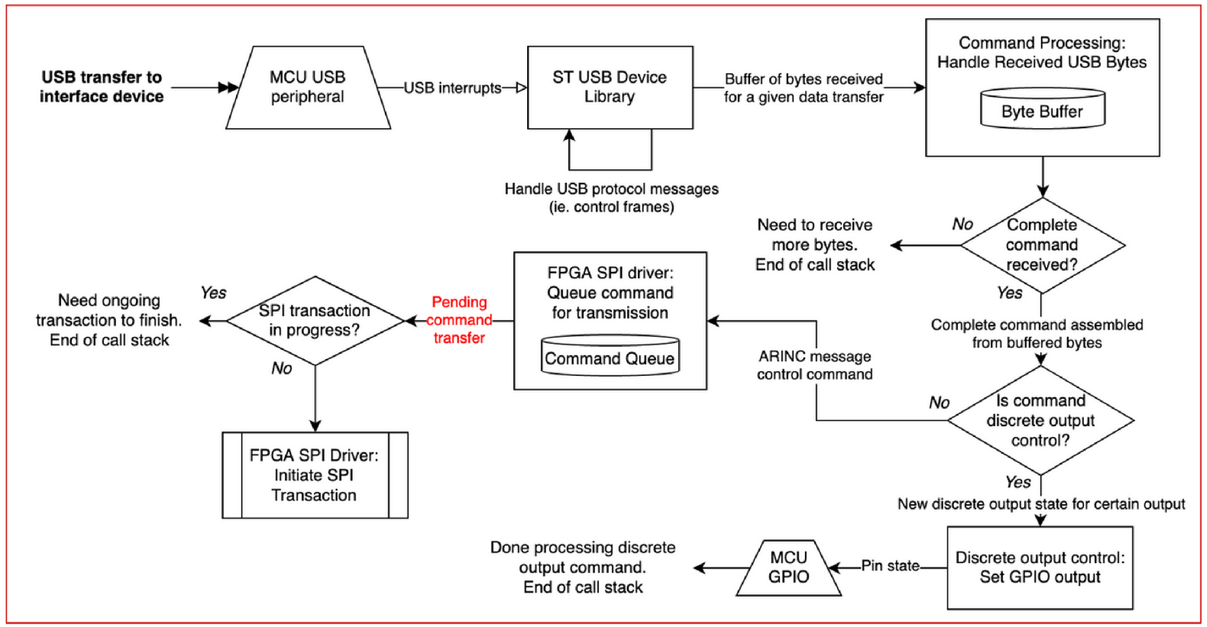
	MSB				LSB
Field Size	32 bits	10 bits	6 bits	4 bits	4 bits
Field	**ARINC Word**	**Transmit Interval**	**TX Port**	**Pad**	**Config**

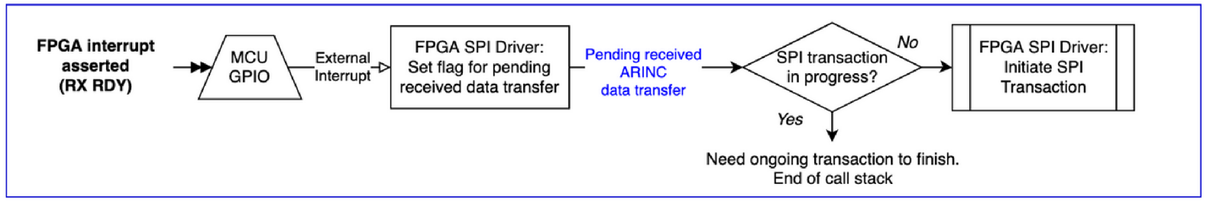
TX Remove Data

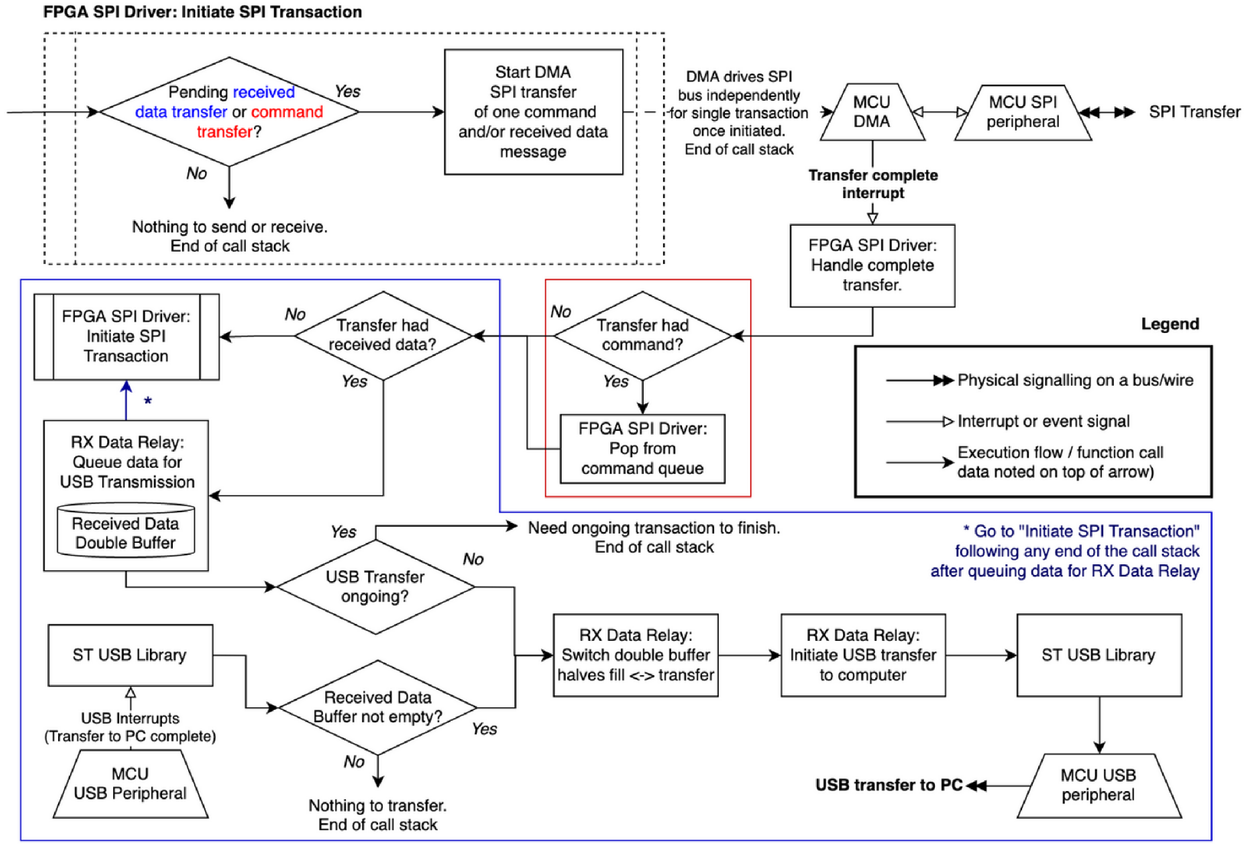
	MSB					LSB
Field Size	8 bits		2 bits	6 bits	4 bits	4 bits
Field	LSB	**Label**	MSB	**Pad**	**TX Port**	**Pad**	**Config**

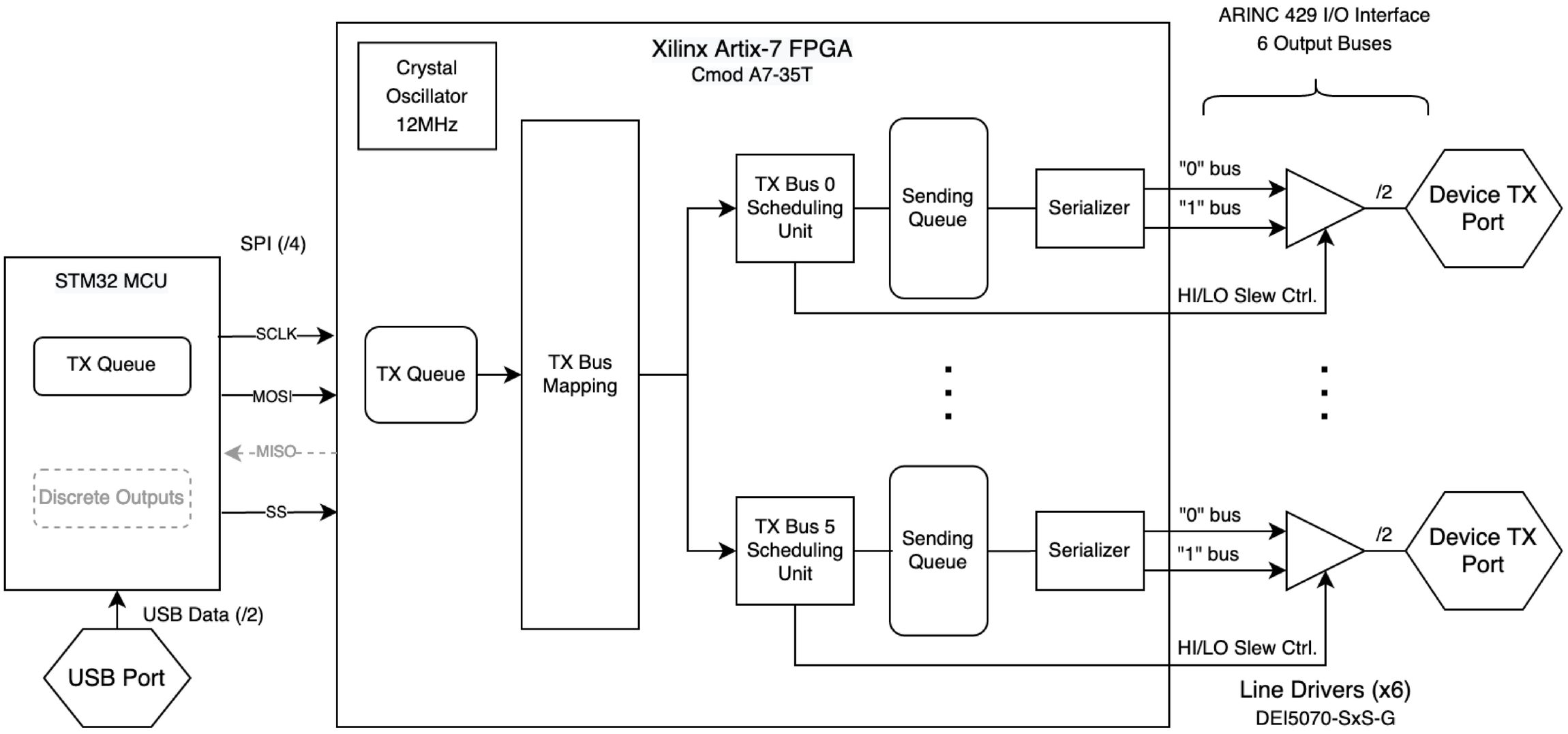
RX Data

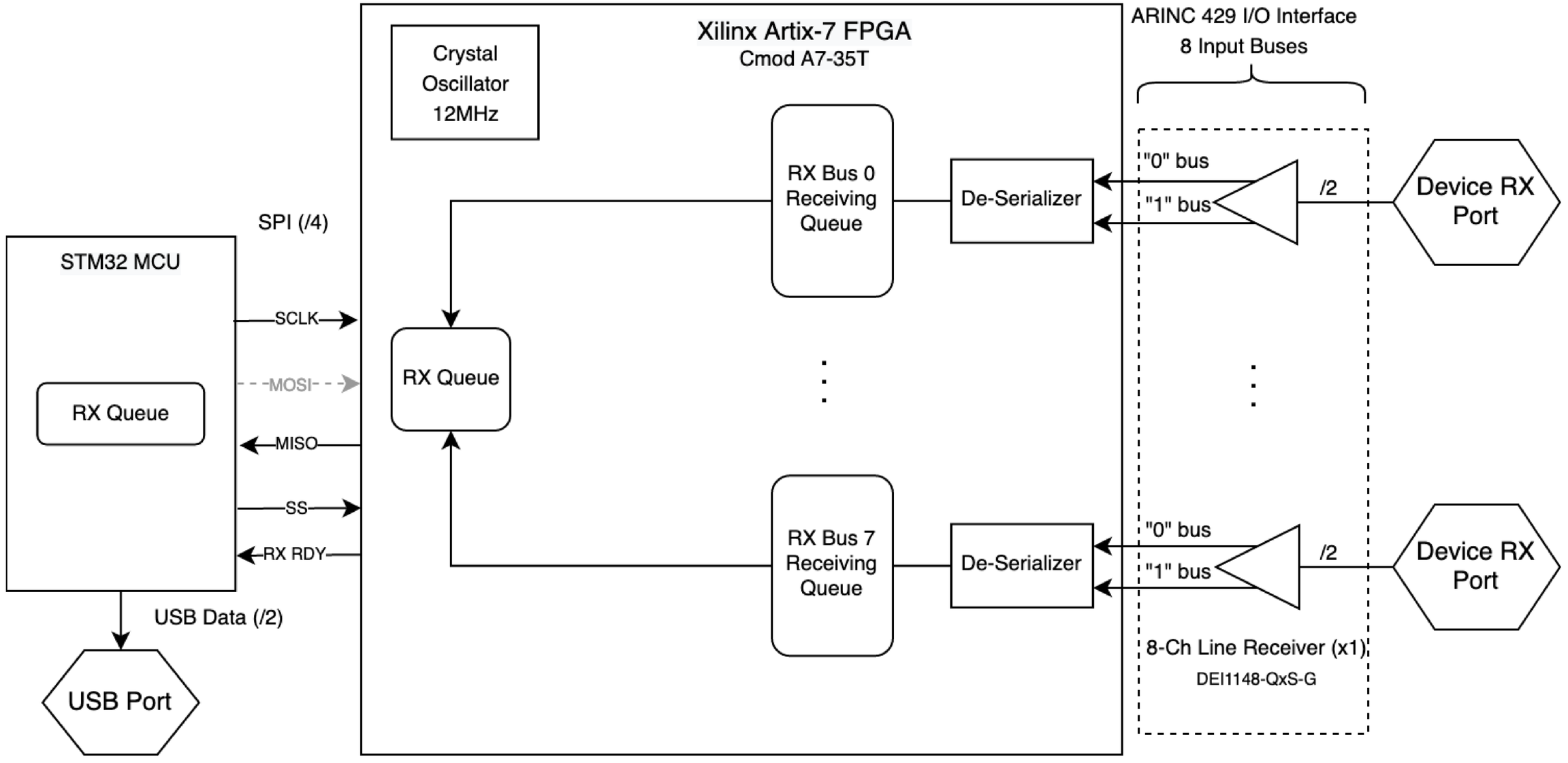
	MSB			LSB
Field Size	32 bits	5 bits	3 bits
Field	**Data**	**Pad**	**RX Port**


USB transfer to interface device
MCU USB peripheral
USB interrupts
ST USB Device Library
Handle USB protocol messages (ie. control frames)
Buffer of bytes received for a given data transfer
Command Processing: Handle Received USB Bytes
Byte Buffer
Complete command received?
No
Need to receive more bytes. End of call stack
Yes
Complete command assembled from buffered bytes
Is command discrete output control?
No
ARINC message control command
Yes
New discrete output state for certain output
Discrete output control: Set GPIO output
Pin state
MCU GPIO
Done processing discrete output command. End of call stack
FPGA SPI driver: Queue command for transmission
Command Queue
Pending command transfer
SPI transaction in progress?
Yes
Need ongoing transaction to finish. End of call stack
No
FPGA SPI Driver: Initiate SPI Transaction

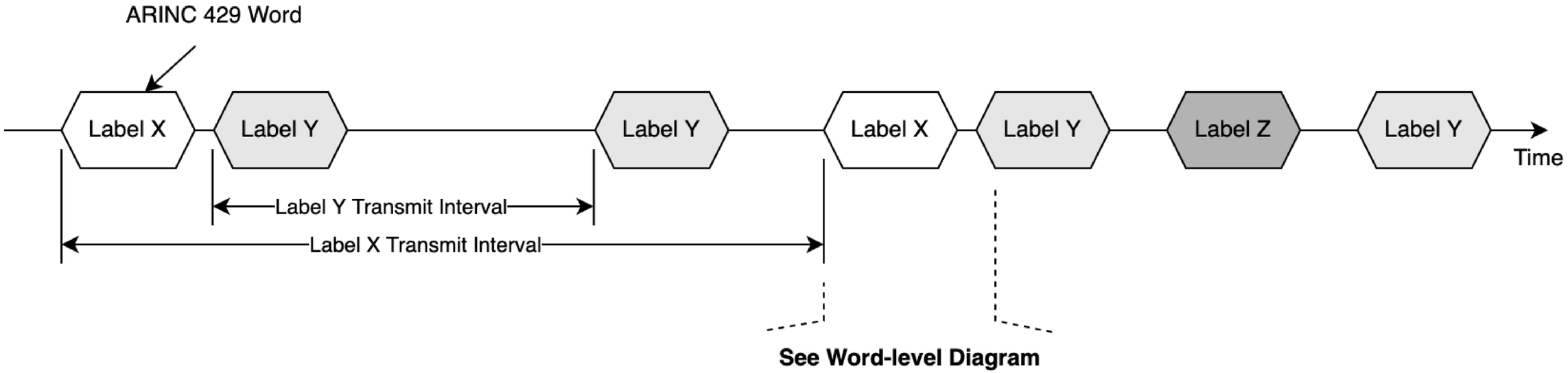

FPGA interrupt asserted (RX RDY)
MCU GPIO
External Interrupt
FPGA SPI Driver: Set flag for pending received data transfer
Pending received ARINC data transfer
SPI transaction in progress?
No
Yes
Need ongoing transaction to finish. End of call stack
FPGA SPI Driver: Initiate SPI Transaction


FPGA SPI Driver: Initiate SPI Transaction
Pending received data transfer or command transfer?
Yes
No
Nothing to send or receive. End of call stack
Start DMA SPI transfer of one command and/or received data message
DMA drives SPI bus independently for single transaction once initiated. End of call stack
MCU DMA
MCU SPI peripheral
SPI Transfer
Transfer complete interrupt
FPGA SPI Driver: Handle complete transfer.
Transfer had command?
No
Yes
FPGA SPI Driver: Pop from command queue
Transfer had received data?
No
Yes
FPGA SPI Driver: Initiate SPI Transaction
*
RX Data Relay: Queue data for USB Transmission
Received Data Double Buffer
Legend
Physical signalling on a bus/wire
Interrupt or event signal
Execution flow / function call data noted on top of arrow)
Yes
No
Need ongoing transaction to finish. End of call stack
USB Transfer ongoing?
* Go to "Initiate SPI Transaction" following any end of the call stack after queuing data for RX Data Relay
ST USB Library
USB Interrupts (Transfer to PC complete)
MCU USB Peripheral
Received Data Buffer not empty?
Yes
No
Nothing to transfer. End of call stack
RX Data Relay: Switch double buffer halves fill <-> transfer
RX Data Relay: Initiate USB transfer to computer
ST USB Library
MCU USB peripheral
USB transfer to PC

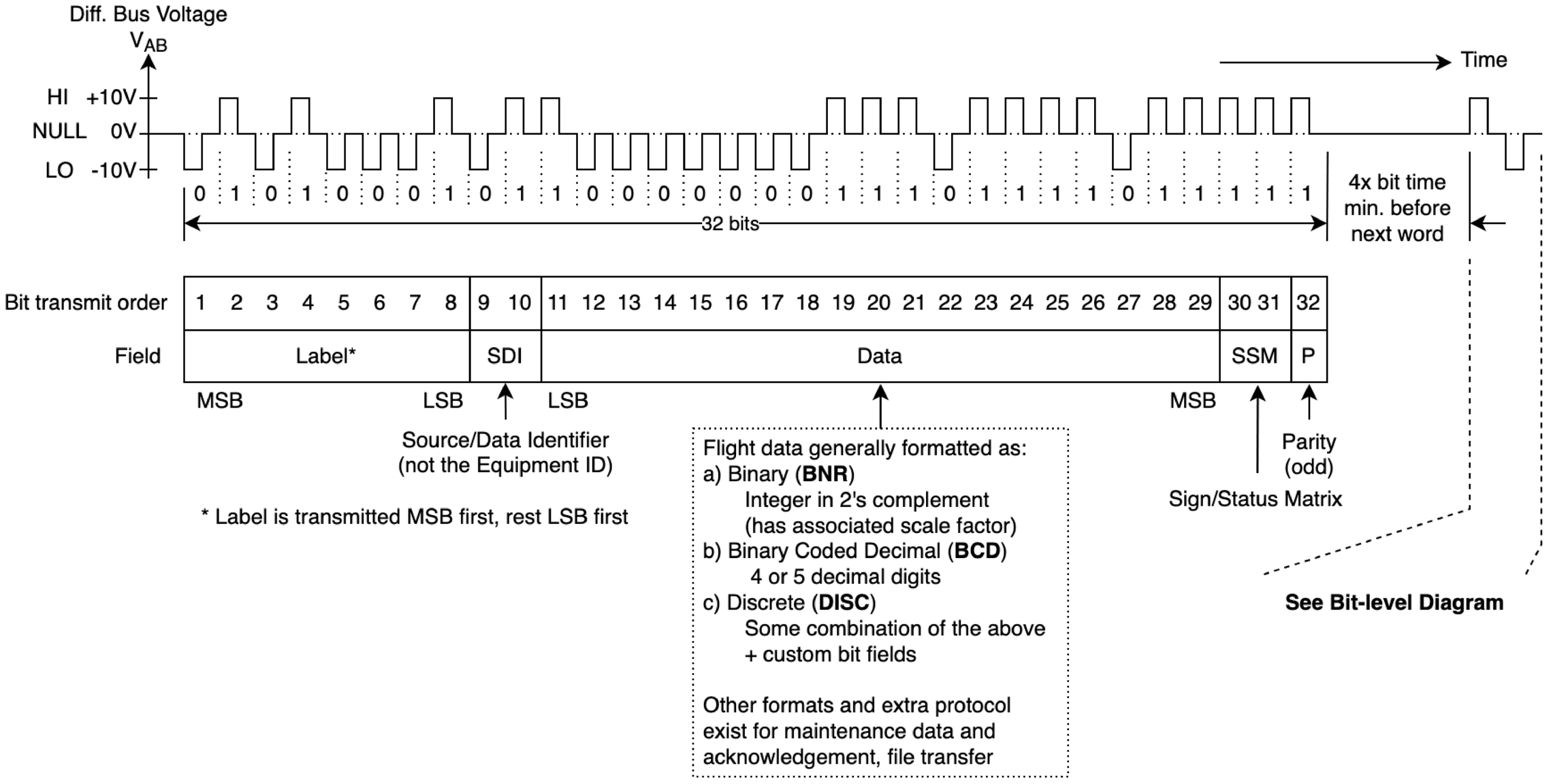

ARINC 429 I/O Interface
6 Output Buses
Xilinx Artix-7 FPGA
Cmod A7-35T
Crystal Oscillator 12MHz
STM32 MCU
SPI (/4)
TX Queue
SCLK
MOSI
MISO
SS
Discrete Outputs
USB Data (/2)
USB Port
TX Queue
TX Bus Mapping
TX Bus 0 Scheduling Unit
Sending Queue
Serializer
TX Bus 5 Scheduling Unit
Sending Queue
Serializer
"0" bus
"1" bus
/2
Device TX Port
HI/LO Slew Ctrl.
"0" bus
"1" bus
/2
Device TX Port
HI/LO Slew Ctrl.
Line Drivers (x6)
DEI5070-SxS-G


Xilinx Artix-7 FPGA
Cmod A7-35T
Crystal Oscillator 12MHz
ARINC 429 I/O Interface
8 Input Buses
RX Bus 0 Receiving Queue
De-Serializer
"0" bus
"1" bus
/2
Device RX Port
SPI (/4)
STM32 MCU
SCLK
MOSI
MISO
SS
RX RDY
RX Queue
RX Queue
RX Bus 7 Receiving Queue
De-Serializer
"0" bus
"1" bus
/2
Device RX Port
USB Data (/2)
USB Port
8-Ch Line Receiver (x1)
DEI1148-QxS-G

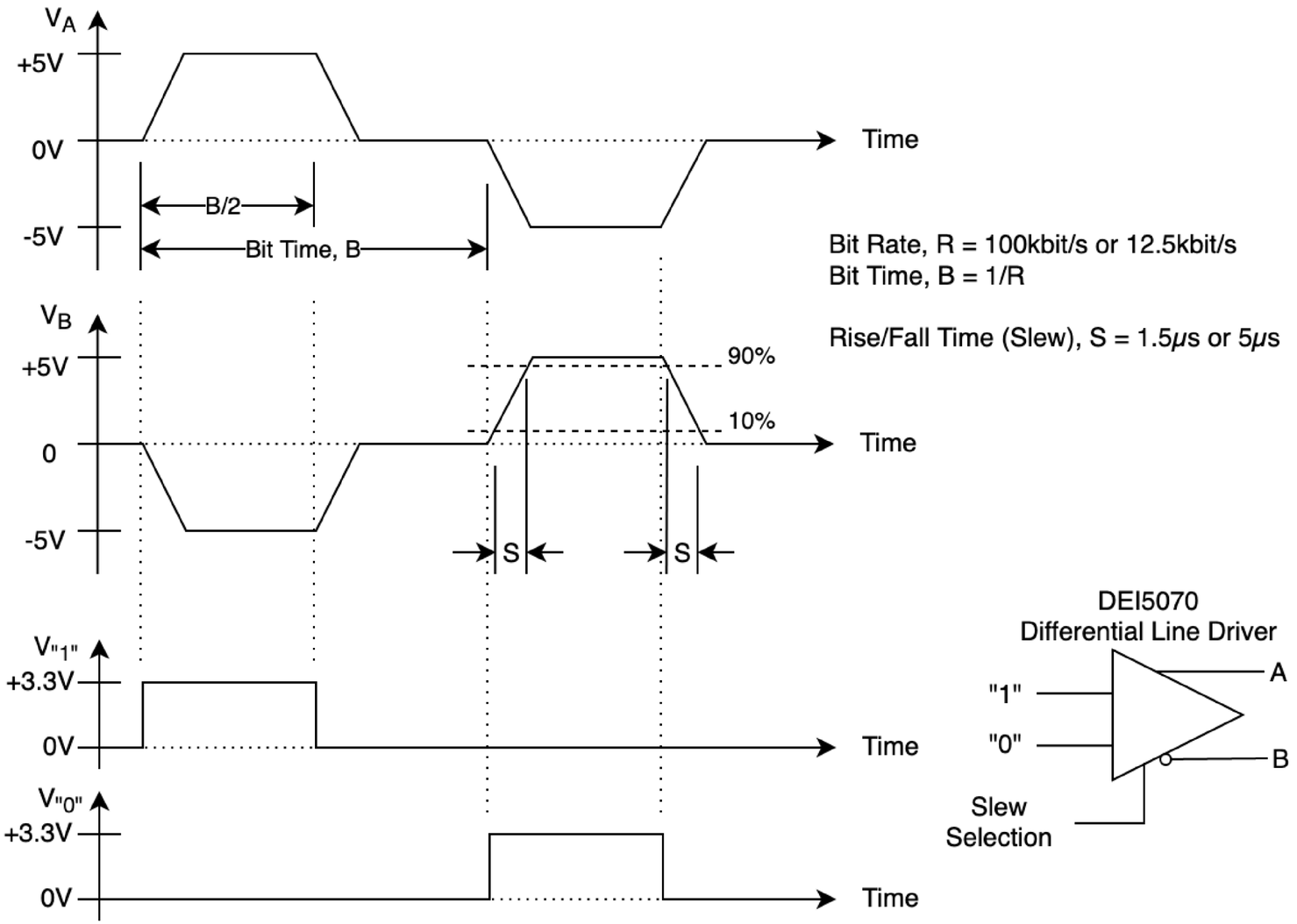
Bus Level:
- ARINC words have a label field that indicates what information is contained in the word
- ARINC 429 specifies a "transmit interval" required for each label
- Any combination of different labels associated with the same equipment ID can be transmitted on one bus



Word Level:
- A word is 32 bits long
- ARINC 429 defines the format of the data contained in a word per label

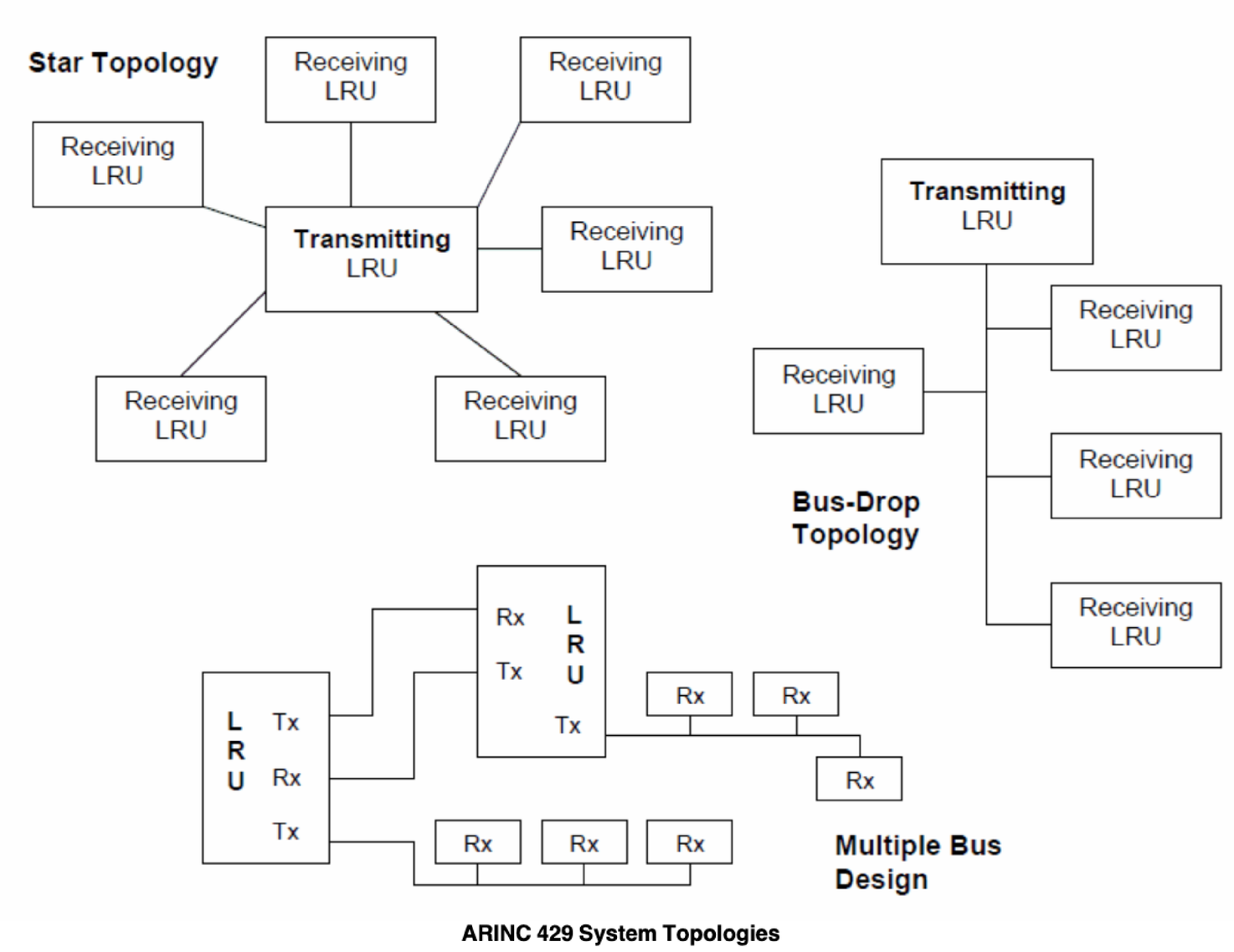


Bit Level:



Bit Rate, R = 100kbit/s or 12.5kbit/s
Bit Time, B = 1/R

Rise/Fall Time (Slew), S = 1.5μs or 5μs



ARINC 429 System Topologies

Image: Avionics Interface Technologies