APEC® 2006

Seminar 01

Digital Power System Management

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Westminster, Colorado

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Seminar Overview

- What (Basics)
  – Understand The Goal
  – Data Flow And Storage
  – What Is A Protocol?
- Data Communication Buses For Digital Power Management
- What (Details)
  – Numerical Formats
  – Commands, Commands And More Commands
  – Fault Management & Status Reporting

Digital Control Vs. Power Management

Digital Control

- Cycle-By-Cycle Control Of The Switches
- Real Or Near Real Time

Digital Power Management

- Configuration
- Control
- Monitoring
- Not Real Time

This Seminar Is About Digital Power Management; It Is Not About Digital Control

Why Digital?

Function Is Cheaper
In Digital Than In Analog

Function Can't Be Done
In Analog

Why Digital Right Now?

Because The Digital Technology Needed For Power Management Has Become Very Inexpensive

State Of Digital Power Management

- Digital Power Management Is Not New
  - Telecomm Power Systems Described At Intelec 1982
  - Used In The Computer Industry Since 1980s
- Several Proprietary Solutions
- Some Standardization Efforts, e.g. PMBus™
- Little Or No University Research
- Drivers For Adoption
  - Intermediate Bus Architecture
  - Data Center Management Needs
- Some Industry Offerings From IC Companies

Power Management Functions

- Configure
  - Set Output Voltage
  - Set Fault Thresholds & Responses
  - Set Turn-On And Turn-Off Timing
- Control
  - On/Off
  - Adjust Output
- Monitor
  - Operation Condition (OK/Fault)
  - Parametric Information
  - Inventory Information

Advantages Of Digital Power Management

- Reduced Parts Count
- Reduced Board Area
- Flexibility Through Programmability
  - ECO By GUI, Not ECO By Soldering Iron
  - Example: Margin Testing Much Simpler
- Calibration At Manufacturing Test
- Inventory Information Available
- Insensitivity To Environment
- Better Noise Immunity

Digital Vs. Analog Summary

Analog Power Management

- Good For Simple, Low Function Systems
  - Example: Resistor Programming Of Output Voltage OK For Many Applications
- Inflexible
- Not Attractive When Host System Wants A Lot Of Information About Power

Digital Power Management

- Flexibility
  - In The Lab
  - In The Factory
  - In the Field
- Excels When Host System Wants Lots Of Information About The Power System
- Speeds Power System Development

What Are You Going To Do With It?

- Development Laboratory
  - Tweaking, Tuning, Adjusting
  - Testing (Margins, Schmoo, Regulation, Fault Mgt)
- Factory Floor
  - Device Configuration
  - Converter And System Test
- In The Field
  - Active Monitoring And Control
  - Fault Monitoring And Reporting
  - Fault Prediction

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Computer Based
Graphical User Interface

Test Equipment
Programming

System Maintenance
Processor Firmware

Know What You Need

- Physical Scope
  - On-Board Power System?
  - Shelf Or Sub-Rack System?
  - Rack Or Frame System?
  - Multiple Rack Or Frame System?
  - Facility Wide System?
- What Type Of Units To Be Controlled
  - Point-Of-Load Converters
  - Standard DC-DC Converters
  - AC-DC Power Supplies
  - Other Equipment (e.g. Fans, Heaters)?

Know What You Need - Functions

Configure What?

- Output Voltage
- Fault Thresholds And Responses
- Turn-On And Turn-Off Behavior
- Digital Control Loop Parameters
- Inventory Information
- Switching Frequency
- Interleaving For Parallel Operation

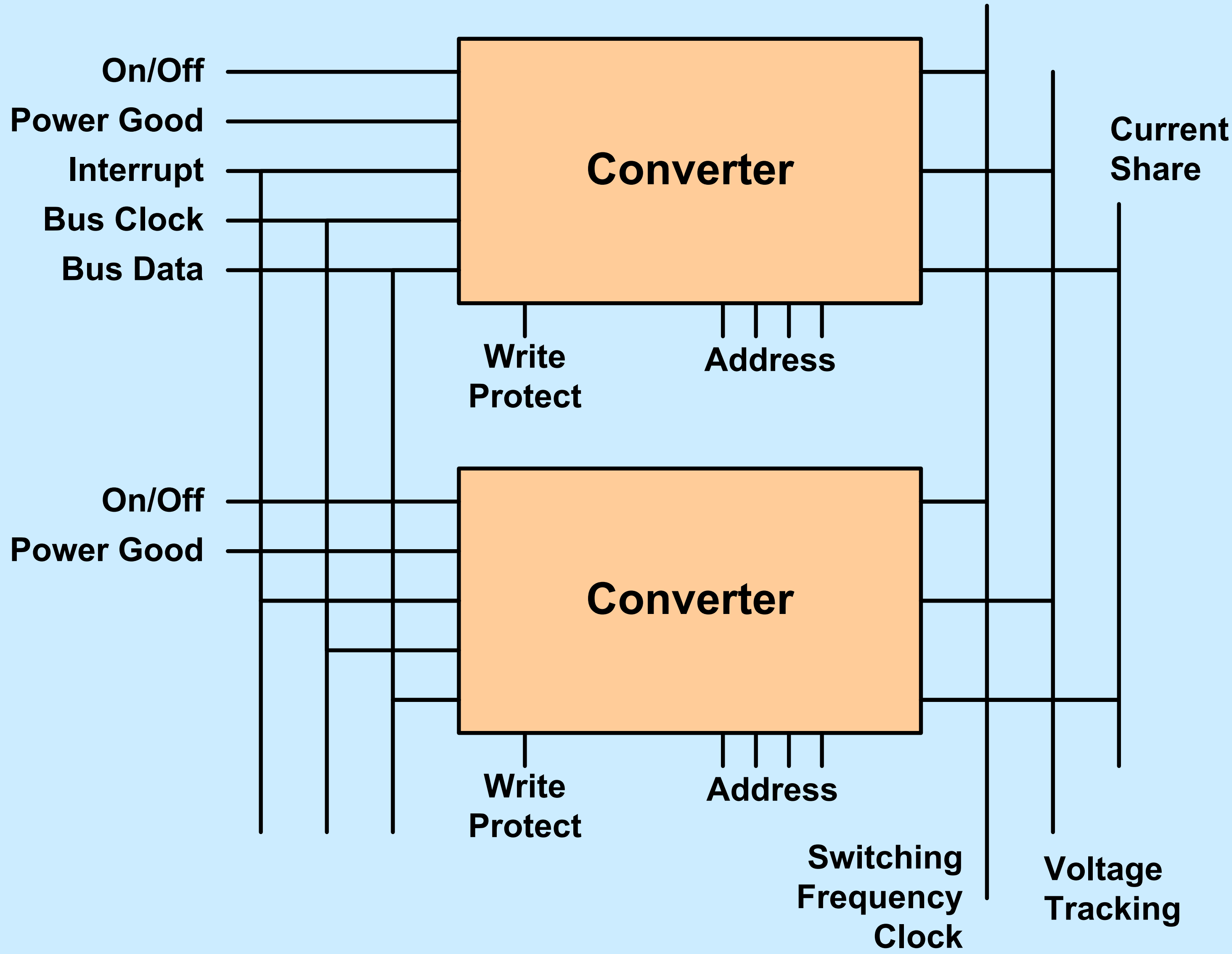
Control What?

- On/Off
- "Turn It Up" And "Turn It Down"

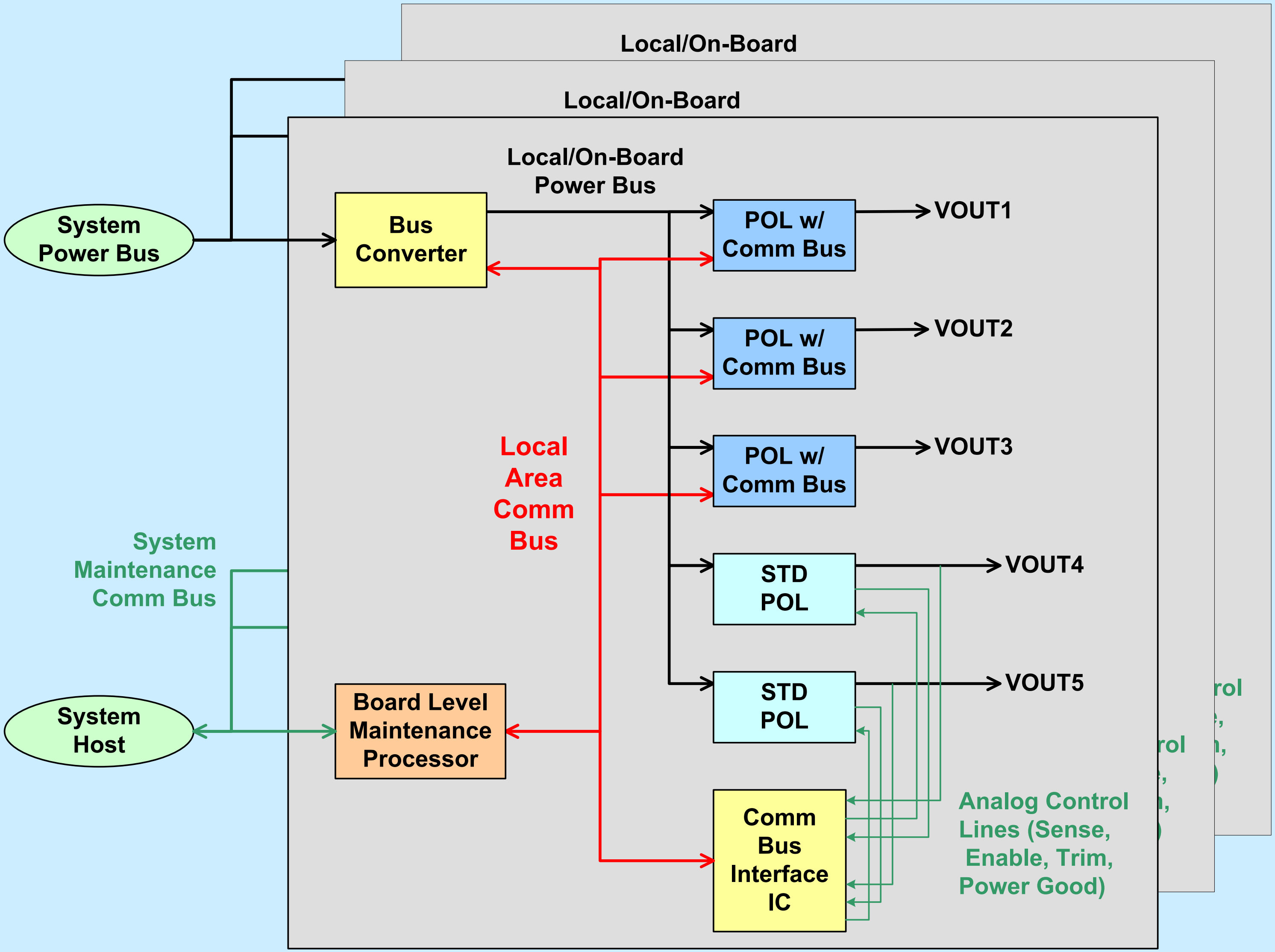
Monitor What?

- "One Green LED"
- Detailed Status Information
  - Binary Or Parametric?
- Who Uses The Information, When, And For What?
- Inventory Information

Data Types And Data Flow



Data Types And Data Flow (cont'd)



Power System Management Implementation

- Discrete
  - Separate Digital Power Management And Controller Components
  - Advantage: Flexibility, Parts Availability
  - Disadvantage: Cost, Size
- Integrated Solutions
  - Everything On One IC
  - Advantage: Size, Maybe Cost
  - Disadvantage: Limited Parts Availability, Functionality Limited

Definition: Protocol

- Protocol Has Two Basic Parts
- Transport:
  How Do Bits Get From Here To There?
- Language:
  What Do The Bits Mean?

- Error Checking
  - How Do We Know That The Right Bits Were Received?

Fundamental Communication Requirements

- Low Cost, Low Cost & Low Cost
  – Component - Low Cost
  – Development - Low Cost
- Robust
  – Carry Data Without Corruption Or Interruption In The Presence Of Noise
  – Does Not Pass the Burden To The Host
- Must Support Time Critical Communication
  – Address The Need For Alarms And Alerts
  – Address The Need For Fast Host Intervention

Two Ways To Transfer Data

- Read/Write Like
  - Entire Transmit And/Or Receive In One Transaction
    - Each Transaction Controlled By One Master
  - Like Reading From Or Writing To A Memory Location
  - Examples: I^2C, SMBus
- Message Based
  - Example Of Reading Output Voltage
    - Host To Device: “Device 3, This Is The Host, Send Me A Reading Of Your Output Voltage” [End Of Message]
    - Device To Host: “Host, This Is Device 3, My Output Voltage Is 3.317 V” [End Of Message]
  - Examples: IPMI, Ethernet

Transport

- Lots Of Ways To Move Bits
- Dedicated Signal Lines
  - Good For Transmitting A Single, Time Critical Piece Of Information
- Buses
  - Serial/Parallel/Hybrid
  - Many Standard Buses For All Types Of Applications
  - Few Support Time Critical Operation
  - Few Are Inherently Fault Tolerant

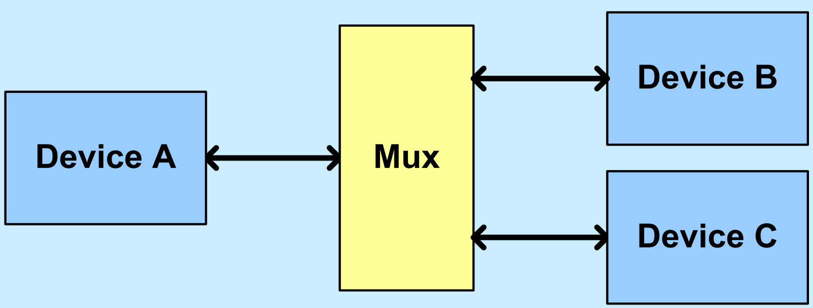
Transport Decision Factors

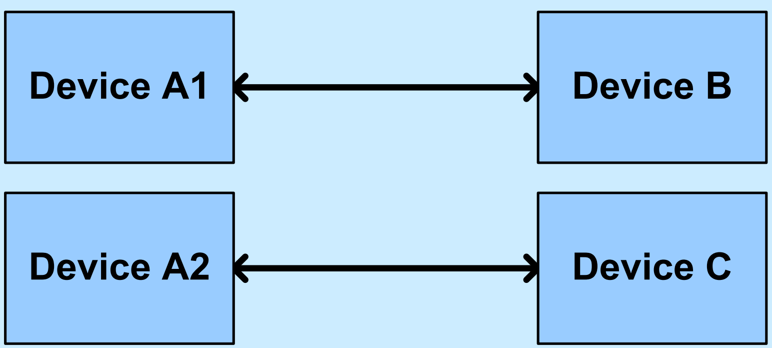
- Signaling Speed
  - Data Bandwidth
  - Response Time
- Signaling Distance
- Electrical Isolation Needed Or Not
- Electrical Noise Immunity
- Need For Hot Swap
- Board Space Allowed (Number Of Lines)
- Need For Fault Tolerance
- Maximum Number Of Units On The Bus
- Cost

Dedicated Signal Lines

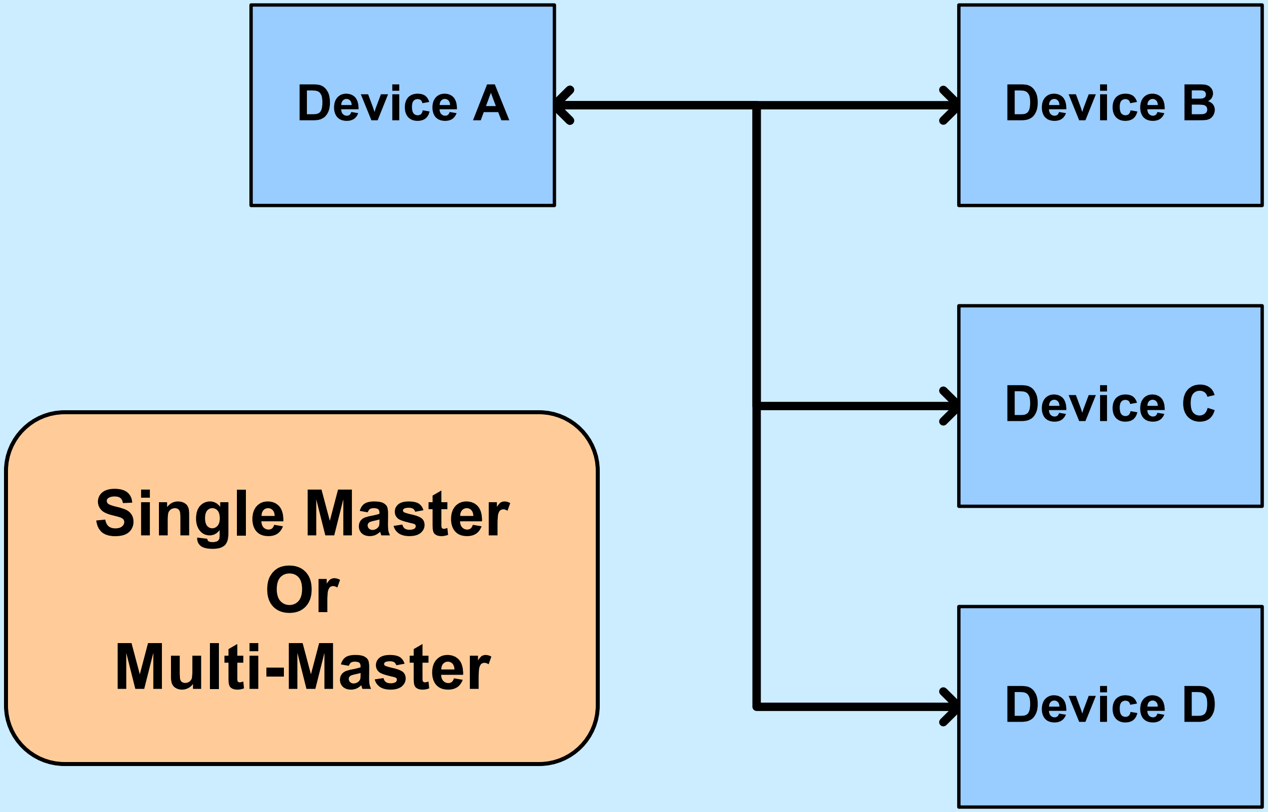
- Speed: Nothing Beats A Dedicated Signal Line
- On/Off Control
  - Fast Shut-Down
  - Synchronized Turn-On And Turn-Off
- Interrupt Signals
- Time Critical Faults
  - Overvoltage
  - Power Fail Warning
- Module Present
- Write Protect

Data Communication Characteristics: Connectivity: Point-to-Point





Data Communication Characteristics:
Connectivity: Multi-Drop



Data Communication Characteristics: Directing Communication On Multi-Drop Bus

- Chip/Device Select Lines
  - Simple Implementation
  - Lots Of Wires And Board Space
- Addressing
  - Minimizes Wiring
  - Adds Complexity To Devices
  - How Does A Device Get Its Address?
    - Over A Communication Link
    - Hardwired Pins
  - Fixed Versus Soft Addresses
  - Allowable Addresses
  - Assuring Unique Addresses
  - Address Can Indicate Physical Location Or Function

Data Communication Characteristics: Programmable Addresses

- Generally Requires Each Unit To Have A Totally Unique Identifier
  - Often Burned Into An IC
  - Moderate Cost – Programmed During IC Test
  - Requires Single Point Of Control Of Addresses
- Requires A Search And Identify Process
  - Host Must Obtain The Unique Identifiers For Every Device On the Bus
  - Unique Identifier Could Be The Address, Or The Host Can Assign An Address
- No Correlation Between Address And Physical Location

Data Communication Characteristics: Hardwired Addressing

- Pins Are Used To Set Address
- Binary Input Is Typical
  - Requires Many Pins For Full Address Space
  - Address May Be Partitioned Into A Type And A Local Physical Address
    - Limited Physical Address => Fewer Pins
    - This Requires A Bureaucracy To Manage Type Codes
- Multi-State Or Multi-Value Pins Saves Pin Count
  - Tri-State Input
  - Resistor Value Programming

Data Communication Characteristics: Transmission Initiation

- Who Can Initiate Data Transmission?
- Single Master System
  - Only One Designated Unit
  - Simplifies Programming
- Multi-Master System
  - More Than One Unit Can Initiate
  - More Complex Programming
    In Any Unit Capable Of Being A Master
- Redundant Master System

Data Communication Characteristics: Bus Contention

- Bus Contention In Multi-Drop Buses Is Unavoidable For Multi-Master Implementations
- Lossless, Bitwise Arbitration Common For Simultaneous Attempts To Transmit
- Adding Priority To Messages (Like CAN Bus) Does Not Prevent Delayed Messages
  - If Bus Is Busy, Even High Priority Messages Have To Wait Until The Bus Is Clear
  - Continuous Stream Of Higher Priority Messages Can Indefinitely Delay A Lower Priority Message

Data Communication Characteristics: Speed And Timing

- Megabits Per Second Is Not The Whole Story
- Packet Overhead Reduces Effective Bit Rate
  - Especially Problematic With Message Based Protocols
- How Fast Can Data Get From Sender To Receiver?
  - Over Communication Bus, Not Fast Enough For Most Time Critical Events

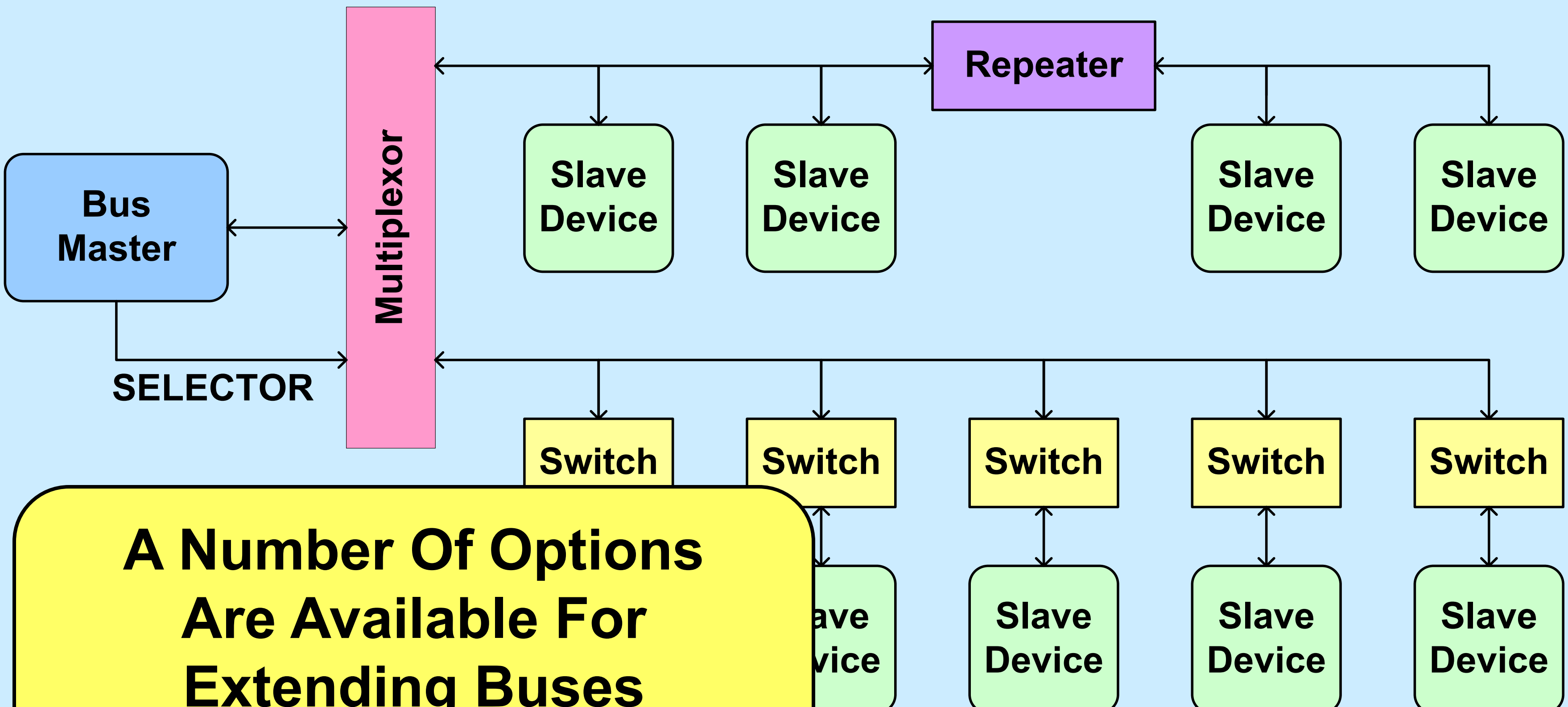
Data Communication Characteristics: Real Time Data

- Time Critical Information Of Two Types
  - Events
  - Parametric
- Fault Events Can Be Catastrophic And Must Be Transmitted With Minimum Delay
- Parametric Data Requires Data Rates Of Tens Of Megabits Per Second
- Recommendation
  - Events: Dedicated Signal Lines
  - Parametric: Dedicated, Customized Buses

Data Communication Characteristics: Range And Number Of Devices

- Range
  - Often Capacitance Limited
  - Short Range, Open Drain Drivers = Low Cost
  - Longer Range Requires More Robust Drivers
- Number Of Devices
  - Like Range, Often Load Limited
  - May Be Address Limited
  - Generally Not A Problem

Data Communication Characteristics: Range And Number Of Devices



A Number Of Options Are Available For Extending Buses And Number Of Devices

Data Communication Characteristics: Clock

- Synchronous
  - Clock Signal Sent With Data
  - Receiving Devices Do Not Need An Oscillator
  - Range Limited
- Asynchronous
  - No Clock Signal Sent With Data
  - Each Device Needs Its Own Oscillator
    - Accuracy Determined By Length Of Transmitted Data
  - Can Loose Sync On Long Strings Of Ones Or Zeroes
    - Bit Stuffing
    - Fancy Coding

Data Communication Characteristics: Single Ended Or Differential Signaling

- Single Ended Signaling
  - One Wire For Data
  - Lower Cost, Less Complicated
  - More Susceptible To Noise Then Differential
- Differential Signaling
  - Two Wires For Data
    - Opposite Polarity Signals On Each
  - More Immune To Noise
  - More Immune To Ground Voltage Differences
  - Higher Cost

Data Communication Characteristics: Transmission Control

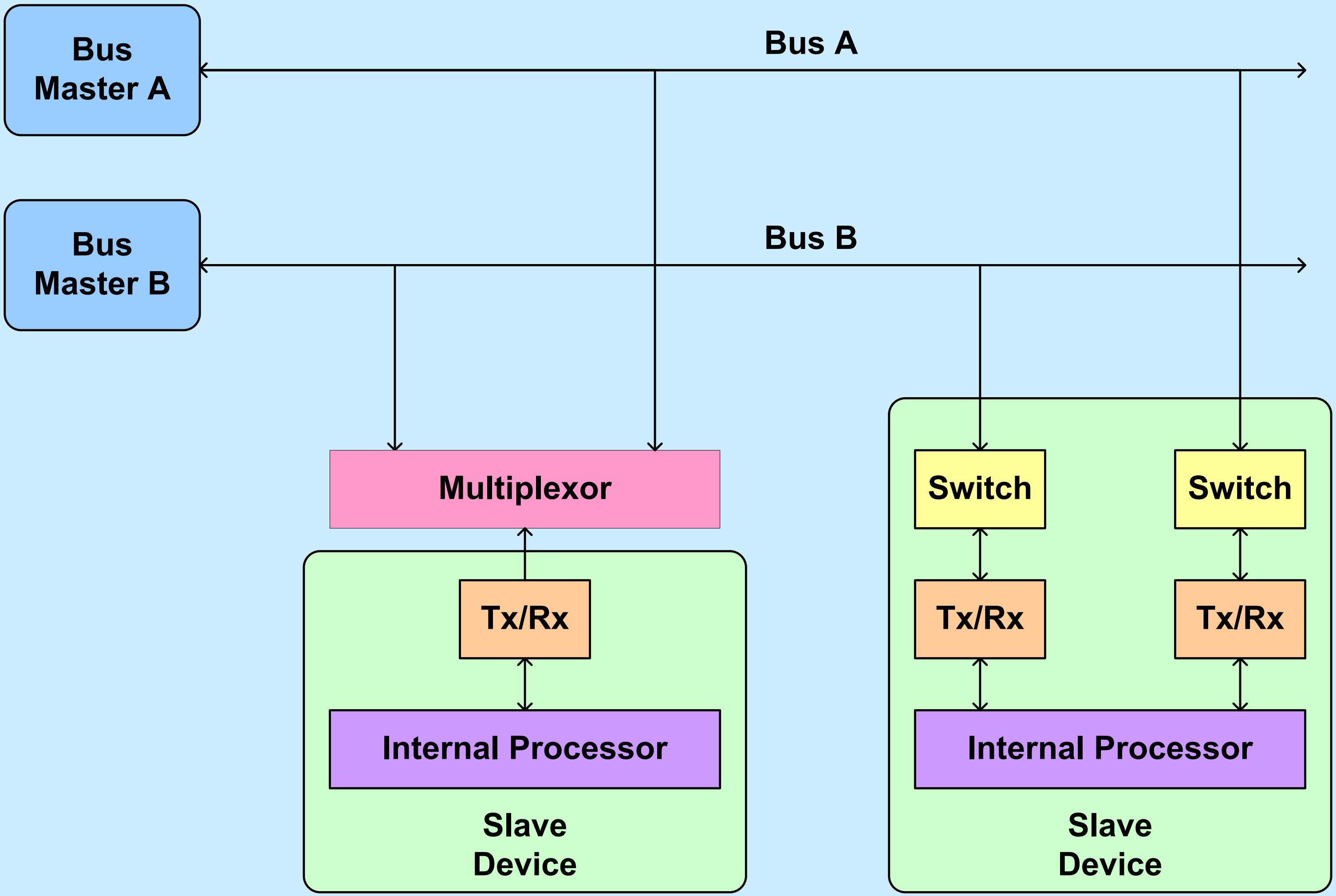
- Devices Must Know When:
  - Bus Is Available For Sending
  - Devices Are Ready To Receive
  - Bus Events Are Starting And Stopping
    - Packets, Bytes
- Transmission Control Issues
  - Device Is Busy And Cannot Be Interrupted To Respond To Another Request
  - Device Cannot Accept Data At Current Rate
  - Device's Buffer Is Full
  - Bus Is Busy And Device Must Wait

I²C And SMBus Transmission Control

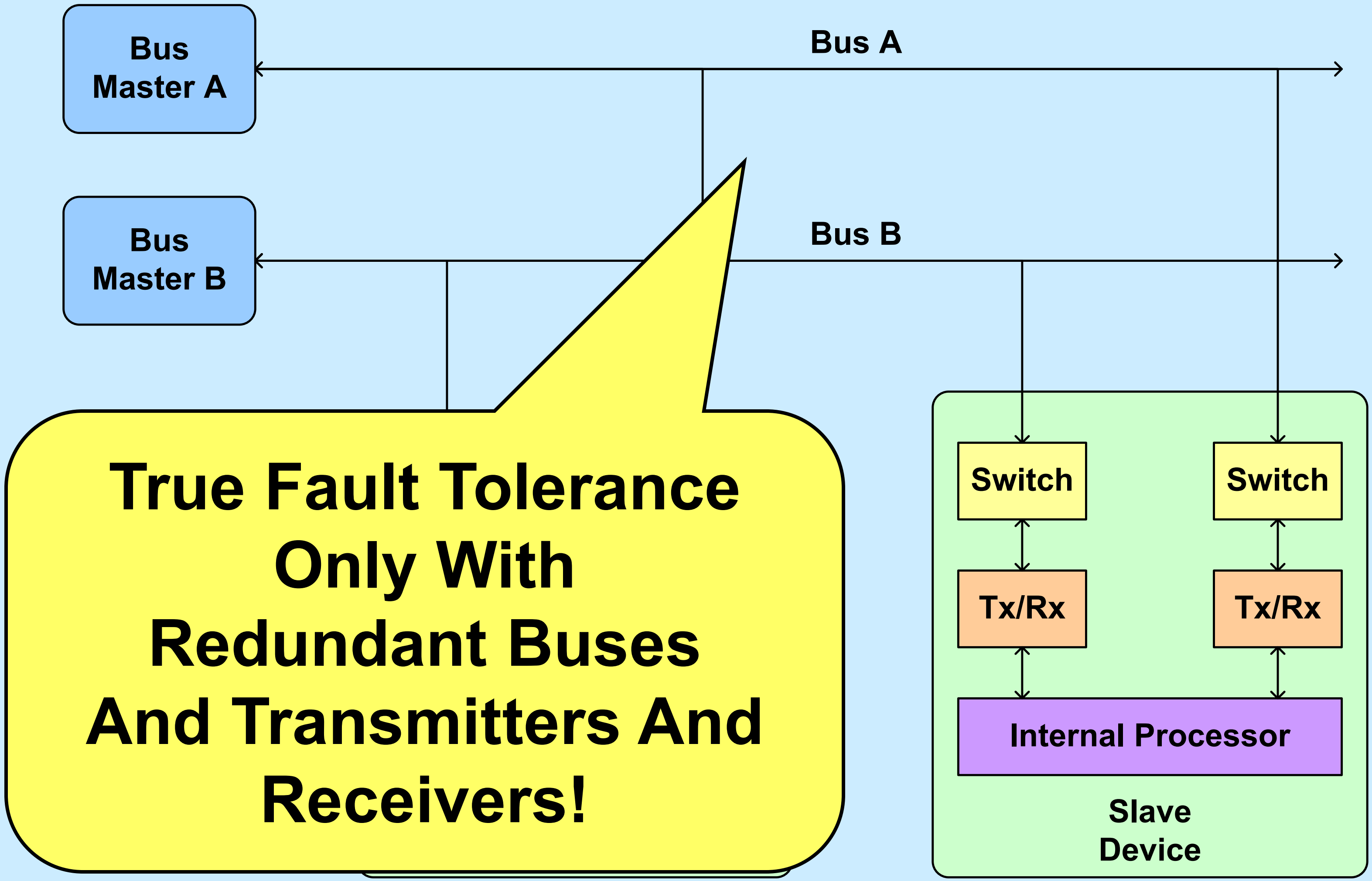
	Address Byte									Data Byte									
S	7	6	5	4	3	2	1	0	A	7	6	5	4	3	2	1	0	A	P

- **S** — Start Condition From Bus Master
- **A** — Acknowledge Condition From Receiver
- **P** — Stop Condition From Bus Master
- **0** — Bit 0 Is Read/Write#
  1 = Read, 0 = Write

Data Communication Characteristics: Fault Tolerance



Data Communication Characteristics: Fault Tolerance



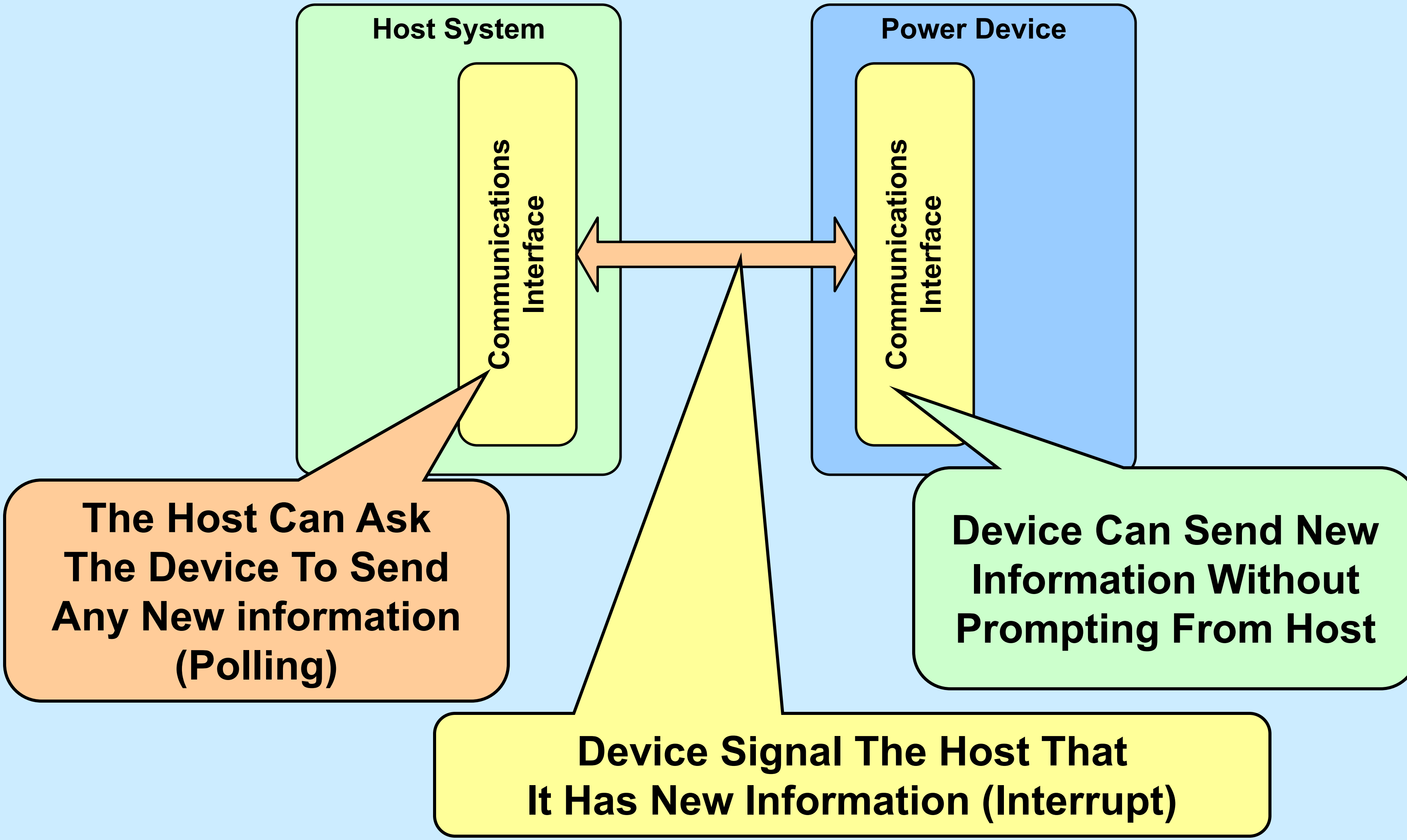
Data Communication Characteristics: Hot Swap

- Hot Swap Issues
  - Removal And Insertion Without Disruption
  - How Does System Know If A Unit Has Been Added Or Removed?
- Most Buses Support Hot Swap Fairly Well
- Implementation Issues
  - Making Ground Connection “Last Break & First Make”
  - Preventing Unpowered Devices From Shorting Bus During Insertion Or Removal
  - MODULE_PRESENT Signal To Assist Detection

Data Communication Characteristics: IP Issues

- Standard: De Facto vs. De Jure
- Who Controls?
  - An Organization
  - Single Company
  - No One
- Organization Ownership Preferred
  - Adopter's Agreements
  - Compliance Assurance
- Royalty Free Or Not?

Data Communication Characteristics: How Does The Host Get Information?



Data Communication Characteristics: Polling And Interrupts

- Multi-Master Messaging – Not Recommended
- Polling
  - Simple To Implement
  - Allows Detection Of Failed Or Removed Devices
  - Consumes A Lot Of Host Resources
  - Possible Delay Time = Refresh Rate
- Alert Or Interrupt Driven
  - More Complicated Code
  - Reduces Burden On Host
  - Quick Notification Of Events
- Good Choice: Blend Polling And Interrupt Driven

Data Communication Characteristics: Communication Implementation

- Software Emulation Using GPIO
  - Possible To Do
  - A Source Of Many, Many Headaches
  - Timing Is Very Difficult Even For “Slow” Buses
- Integrated Solutions
  - Many Low Cost Microcontrollers Have Bus Interfaces Built In
  - Must Have For Complex Buses Like CAN Bus And Ethernet

Recommendation By Bus Type
RS-232 & RS-485

RS-232

- Advantages
  - Common Peripheral
  - Simple
  - Relatively Low Cost
- Disadvantages
  - Point-To-Point
  - Oscillator
  - Speed
- Recommended
  - Simple Point-To-Point With Logic Level Interface

RS-485

- Advantages
  - Differential Signaling
  - Long Distance Communication
- Disadvantages
  - Additional Cost Of $1.00 to $1.50 In High Volume
  - All Protocol In Software
- Recommended
  - Longer Range Communication Such As Rack-To-Rack

Recommendation By Bus Type
I²C And SMBus

I²C

- Advantages
  - Common Peripheral
  - Simple
  - Very Low Cost
- Disadvantages
  - Noise Sensitivity
  - Bus Capacitance Limitation
- Recommended
  - SMBus Is Better Choice In Almost Any Case

SMBus

- Advantages
  - Low Cost Like I²C
  - More Robust Than I²C
  - Additional Features
- Disadvantages
  - Bus Capacitance Limitation
- Recommended
  - On-Board And Shelf-Level Communication

Recommendation By Bus Type
SPI Bus And Dallas 1-Wire

SPI Bus

- Advantages
  - Simple
  - Chip Select Lines Eliminate Addressing Concerns
  - Good Speed (1 MHz)
- Disadvantages
  - No Standard
  - Chip Select Lines
- Recommended
  - Local Interconnect Of A Couple Of Peripherals

Dallas 1-Wire

- Advantages
  - 1-Wire
  - Unique ID In Every Device
  - Low Power
- Disadvantages
  - Noise Sensitivity
  - Proprietary
  - Cost
- Recommended
  - Only To Accommodate Legacy Situations

Recommendation By Bus Type
CAN Bus & LIN Bus

CAN Bus

- Advantages
  - Differential Signaling
  - Noise Immunity
  - Fault Tolerance
- Disadvantages
  - Cost
  - Requires Integrated Peripheral
- Recommended
  - Longer Range Communication Such As Rack-To-Rack And Beyond

LIN Bus

- Advantages
  - Single Wire
  - Reasonable Noise Immunity
- Disadvantages
  - Cost
  - Slow Speed
  - Complexity
- Recommended
  - Not Recommended (Use SMBus Or CAN Bus/ RS-485 Instead)

Recommendation By Bus Type
USB & Ethernet

USB

- Advantages
  - Well Supported
  - Hot Swap Friendly
- Disadvantages
  - Requires Hub To Initiate All Communication
  - Relatively Complex Software And Hardware
- Recommended
  - PC To Power System Interface For Service

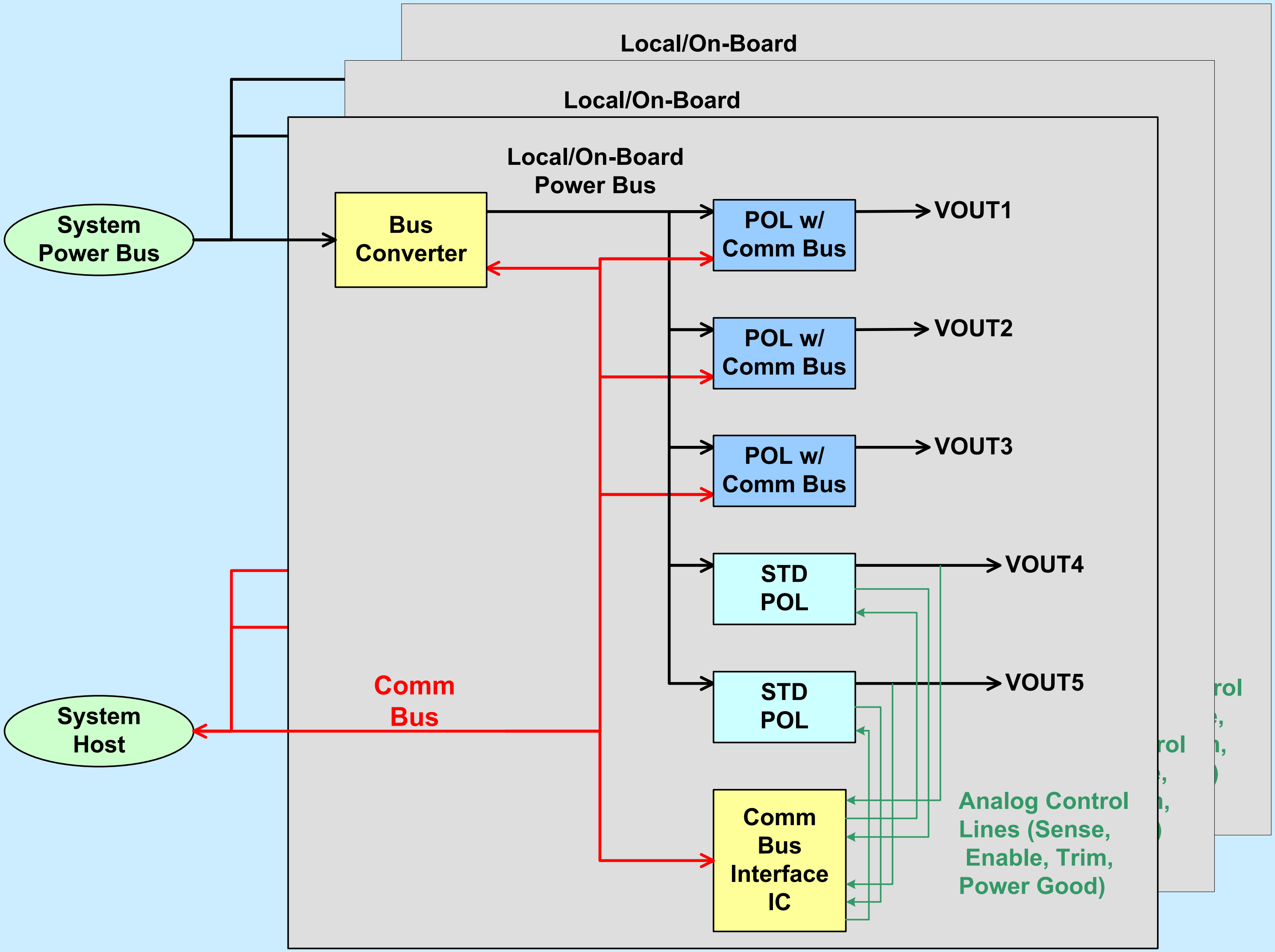
Ethernet

- Advantages
  - Long Haul Capability
  - Internet Friendly
- Disadvantages
  - Cost And Complexity
  - Very Large Packets
  - Software Support
- Recommended
  - Interface To An Embedded Web Server In A Power System Manager

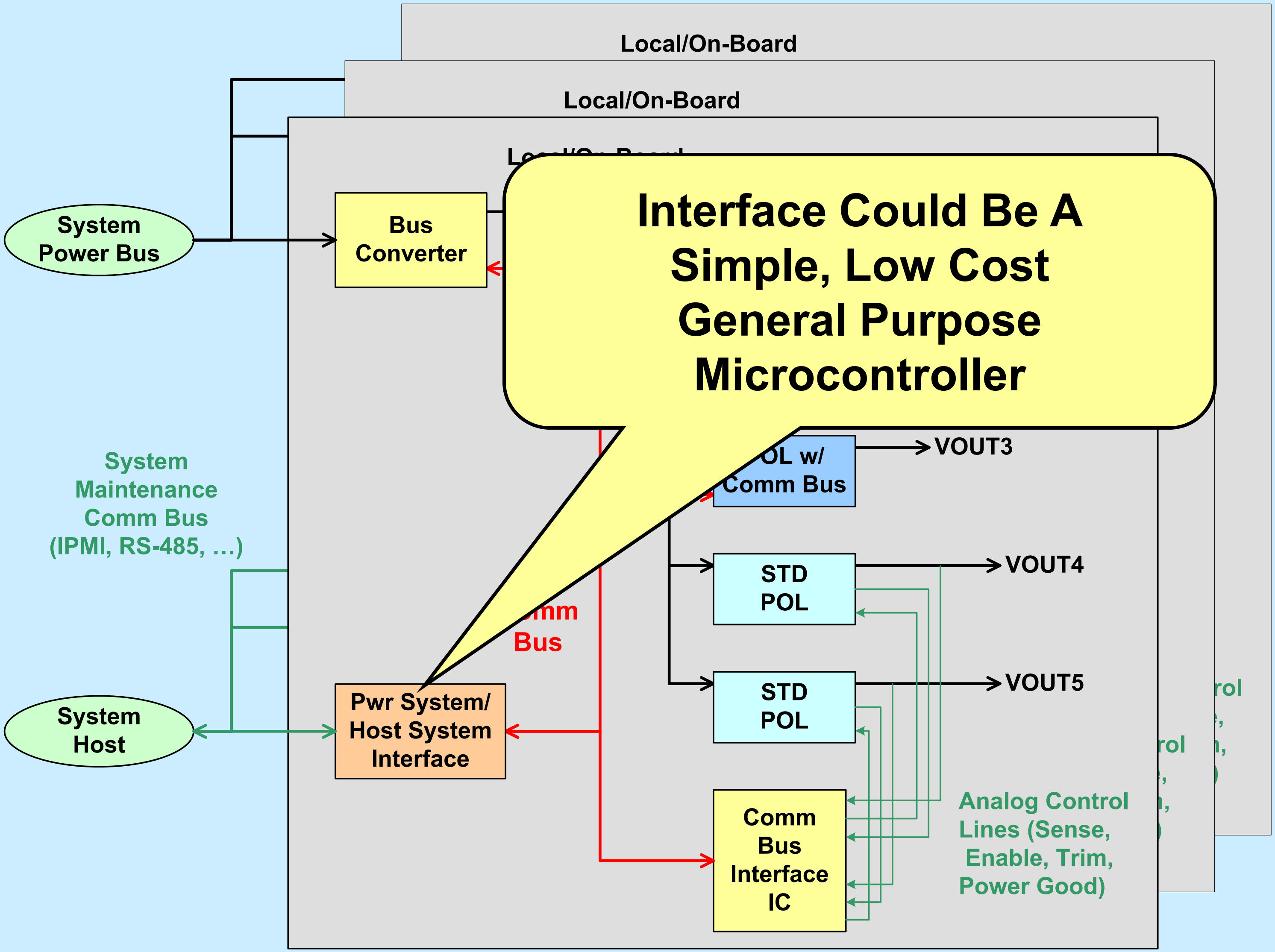
Recommended Transport Buses

Application	Recommended Bus
On-Board	I^2C Bus Or SMBus
Shelf Level/ Board-To-Board	
Rack Level/ Shelf-To-Shelf	RS-485
Rack-To-Rack	
Facility Or Campus Wide	Ethernet

System Level Power Management Bus



Bridging Local And System Buses



Communication Bus Summary

- No One “Right” Bus For All Power Communications
  - The Scope and Benefits Extend To Beyond The Local Area
  - Several Well Established Buses To Choose From
- Know Your Application And Its Requirements
- Be Knowledgeable About Your Choices
- Choose The “Right Tool For The Job”
- Be Smart In Your System Design
  - Imitate Successful Designs
  - Understand The Constraints Before You Start Your Design
- **Follow The Specification!**

Existing Protocols
IPMI – Intelligent Platform Management Interface

- Development Driven By Intel
- Intended For System Management
- Message Based Protocol
- Base Specification Is 590 Pages!
- Requires Licensing
- Web Site: http://www.intel.com/design/servers/ipmi/

Can Be Used For Power System
But Very Complicated

Existing Protocols
PowerWise™

- National Semiconductor And ARM
- Open Standard, Royalty Free Licensing
- Aimed At Portable Devices (Cell Phones, PDAs)
- Limited Functionality
  - Voltage Adjustment To Minimize Energy Consumption
- Web Site: www.pwistandard.org

Good For What It Does
But Quite Limited In Scope And Function

Existing Protocols
Smart Battery System

- Aimed At Managing Battery Packs In Portable Equipment
  - Such As Laptop Computers
- Created The System Management Bus (SMBus) Specification
  - Very Similar To Philips I^2C Bus
- Web site: http://www.sbs-forum.org/

Good For What It Does
But Quite Limited In Scope And Function

Existing Protocols
Power Supply Monitoring Interface (PSMI)

- Developed By SSI Forum, i.e. Intel
- System Interface To AC-DC Power Supplies
- Defines Contents Of Specific Register Addresses
- SMBus For Transport
- PSMI Capabilities
  - Thermal Management, Power Monitoring, Control, Status, Diagnostics, Power Supply Capability Records
- http://ssiforum.org/specifications.aspx

Limited In Scope And Function
Strongly Oriented To Intel Based Computers

Existing Protocols
Power Management Bus (PMBus™)

- General Purpose Protocol For Power System Management
- Open Standard, Non-Proprietary, Royalty Free
- Transport
  - SMBus
  - Hardwire CONTROL Signal
  - Optional Signals
- Command Language Based
  - Comprehensive
- Web Site: www.pmbus.org

Widespread Support

Very Flexible

Existing Protocols
Proprietary Solutions

- Most Major System OEMs Have At Least One Power System Management Protocol
- Some Power Supply Companies Have Their Own Power System Management Protocol

Key Decisions

Use An Existing Standard Or Write Your Own?

If Existing, Open Or Proprietary?

Data Communication Errors

- General Rule: Sender Must Be Able To Know If The Data Was Received Without Corruption
- Three General Types Of Errors
  – Protocol Errors
  – Data Corruption
  – Invalid Data Errors
- Protocol Errors
  – Too Many Or Too Few Bytes
  – Too Many Or Too Few Bits
  – Start/Stop Not Recognized

Data Communication Errors

- Data Corruption
  - Bit Values Changed In Transmission
  - Potentially Catastrophic!
  - Detection And Even Corrections Means Available
- Invalid Data Errors
  - Data Sent Is Received Without Corruption
  - Invalid Commands Or Invalid Data
  - What To Do?
    - Execute With Closest Value?
    - Or Reject And Not Do Anything?

Responding To Data Communication Errors

- How Does Host Know That There Was A Problem With The Data Transmission?
- Generally Critical That The Host Knows That There Was A Problem
  - Only The Simplest Systems Do Not Require Error Detection
- The Choice Is Between Burdening The Host Or Burdening The Device

Responding To Data Communication Errors Method 1: Receiving Device Validation

- Receiving Device Validates Each Packet
  - Implies Some Form Of Error Detection And Possibly Error Correction
- Device Rejects A Transmission With An Error
- Device Notifies Host That Packet Was Bad
- Allows Execution On Reception
  - As Opposed To Separate Load And Execute Commands

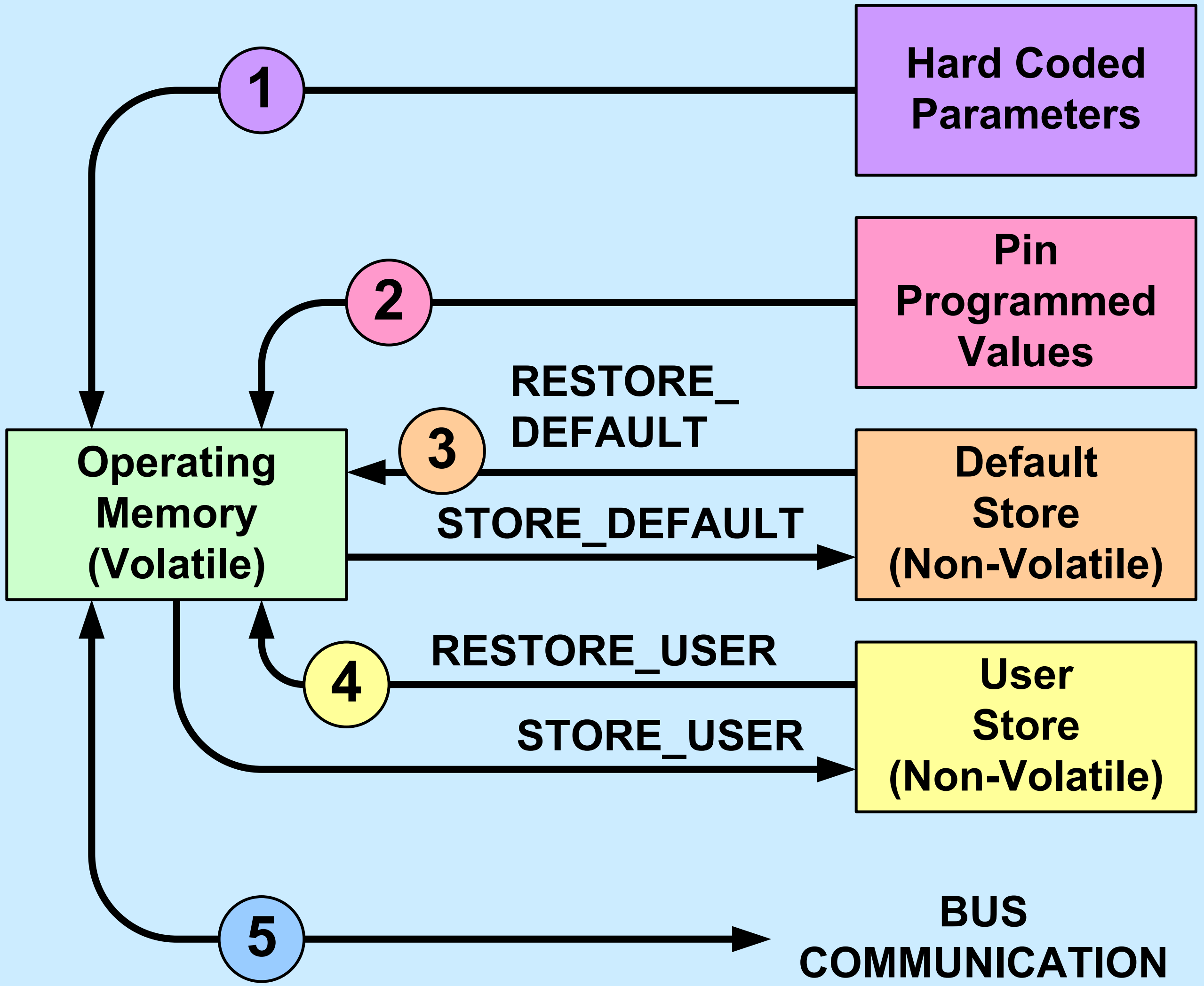
Responding To Data Communication Errors Method 2: Host Validates

- Host Transmits
- Devices Receives Data, Stores It, And Does Not Act On It
- Host Then Reads Back Data And Compares With The Transmitted Value
- If Data Matches, The Device Is Instructed To Execute The Command
- If Data Does Not Match, Host Starts Transmission Process Again

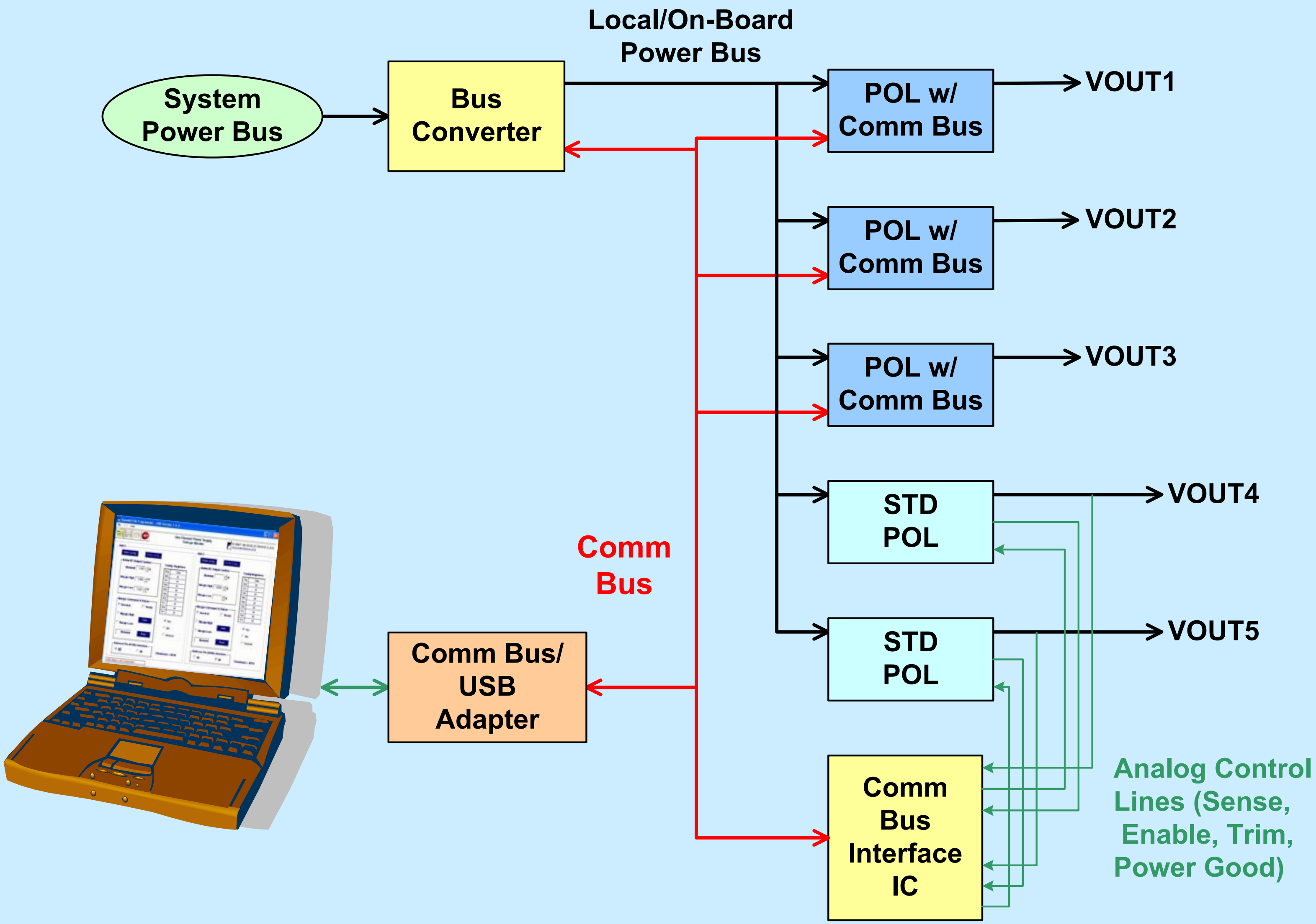
Data Communication Errors
Invalid Data Errors

- What If Host Sends A Value That For The Receiving Device:
  - An Unknown Command Or Value
  - A Value Out Of Range
- Possible Responses
  - Recommended To Declare A Fault
  - If A Command, Should Be Ignored
  - If Data, Two Choices:
    - Ignore
    - Use Nearest Valid Value

Communication Buses Are Not The Only Way To Program A Device



Don’t Forget The User Interface!



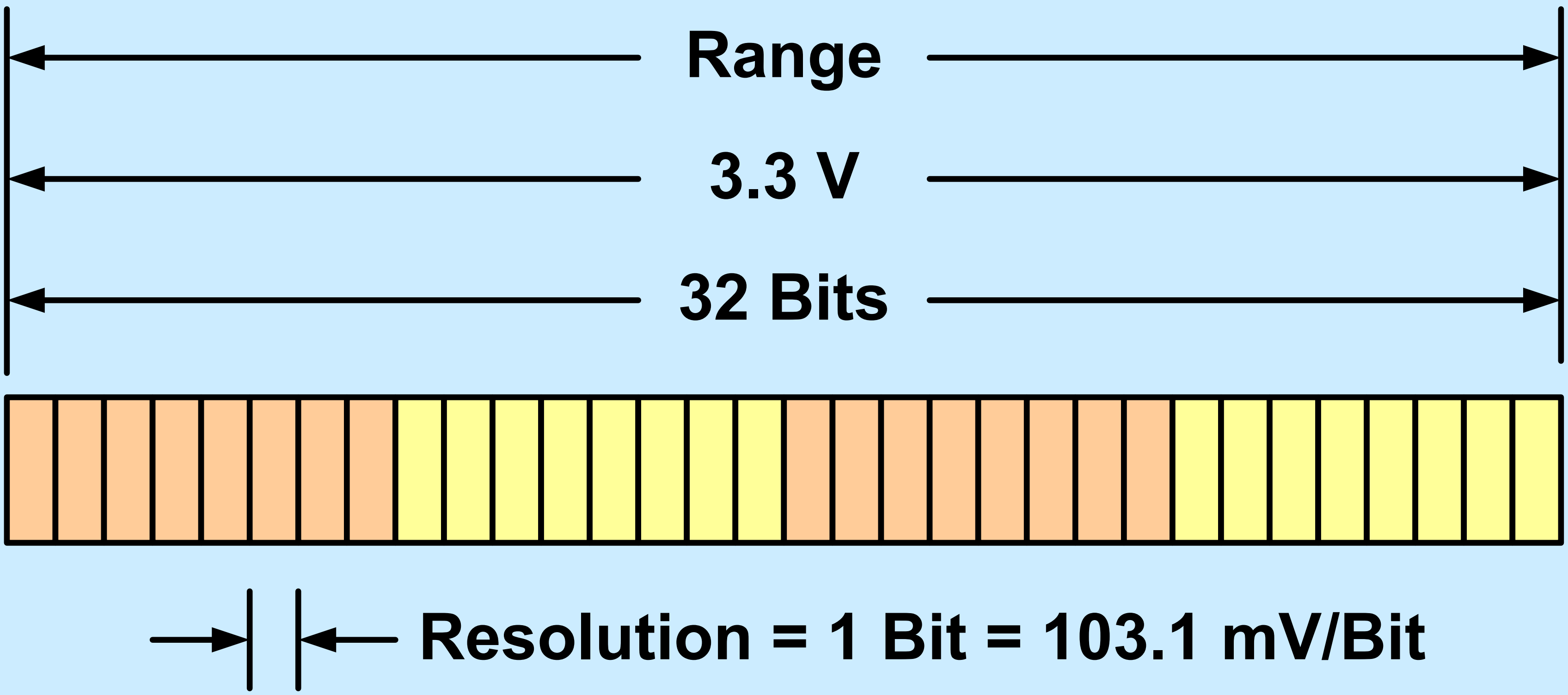
Data Integrity & Security: Protecting Against Unwanted Changes

- Always A Challenge For Programmable Devices
- Protect Against:
  - Misdirected Transmissions
  - Accidental Change
  - Malicious Intent
- Hardware Protection
  - Write Protect Pin
- Software Protection
  - Passwords: Very Difficult To Manage
  - Different Areas Of Memory May Need Different Access Control: Program Memory Versus Configuration

Typical Range And Resolution Requirements

Application	Range (V)		Resolution (Per LSB)	Number Of Bits
	Minimum	Maximum		
Microprocessor Power	0.5	1.8	1 mV, 6.25 mV, 12.5 mV, etc.	5 – 8
Low Voltage Logic	0	2.5	5 – 25 mV	7 – 9
General Logic	0	5.0	20 – 50 mV	7 – 8
On-Board Power Bus, Linear, +12 V Loads	0	18	50 – 100 mV	8 – 9
System Power Bus	0	60	100 mV	10
Telecomm Power Bus	36	60	10 – 20 mV	10 – 11
AC Input Voltage	0	300	1 V	8 – 9
Bulk Storage Capacitor Voltage	0	500	1 V	8 – 9
Temperature	–55	150	0.1 – 2 °C	8 – 10

Range, Resolution And Accuracy



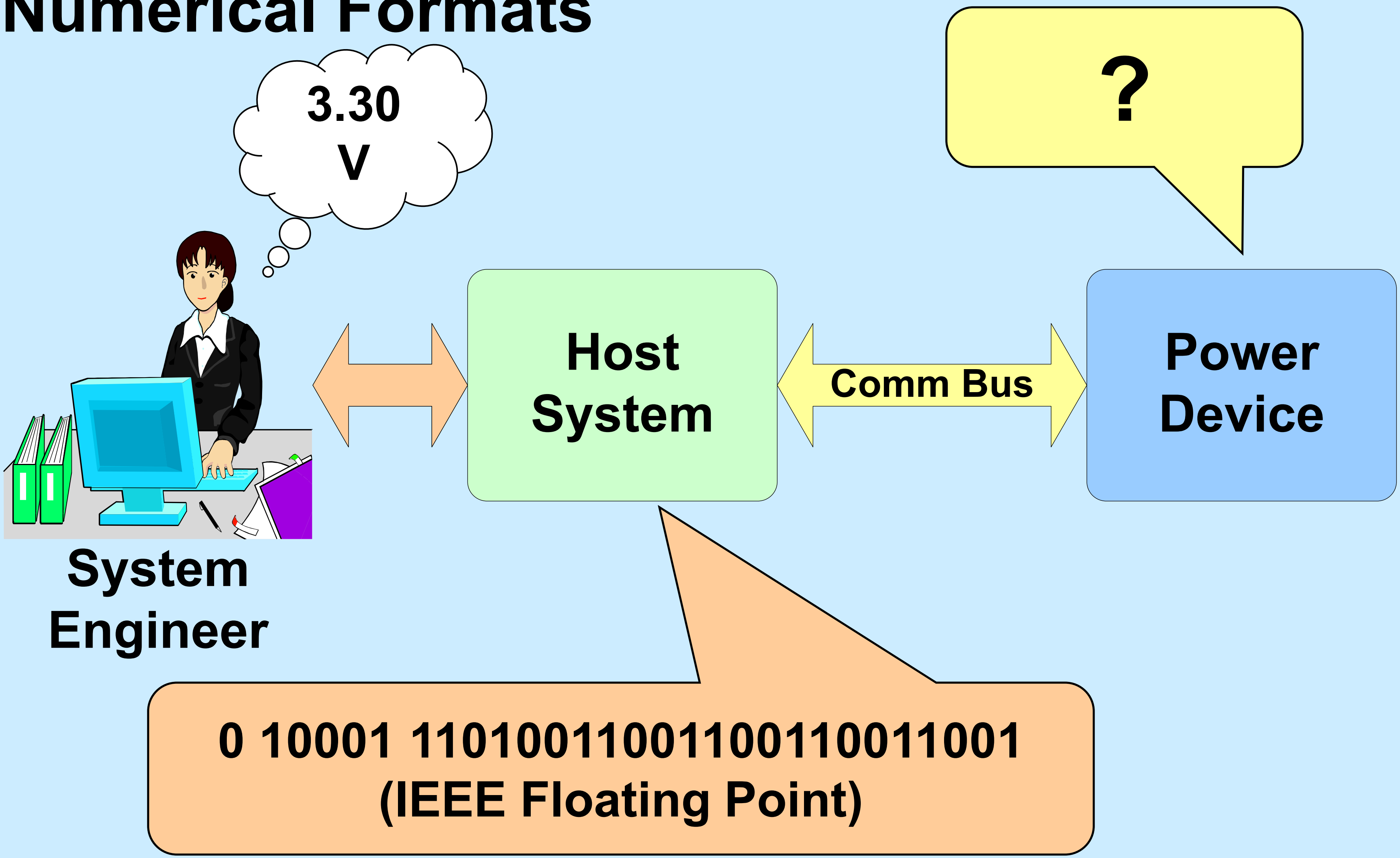
Resolution ≠ Accuracy

Resolution Versus Number Of Bits

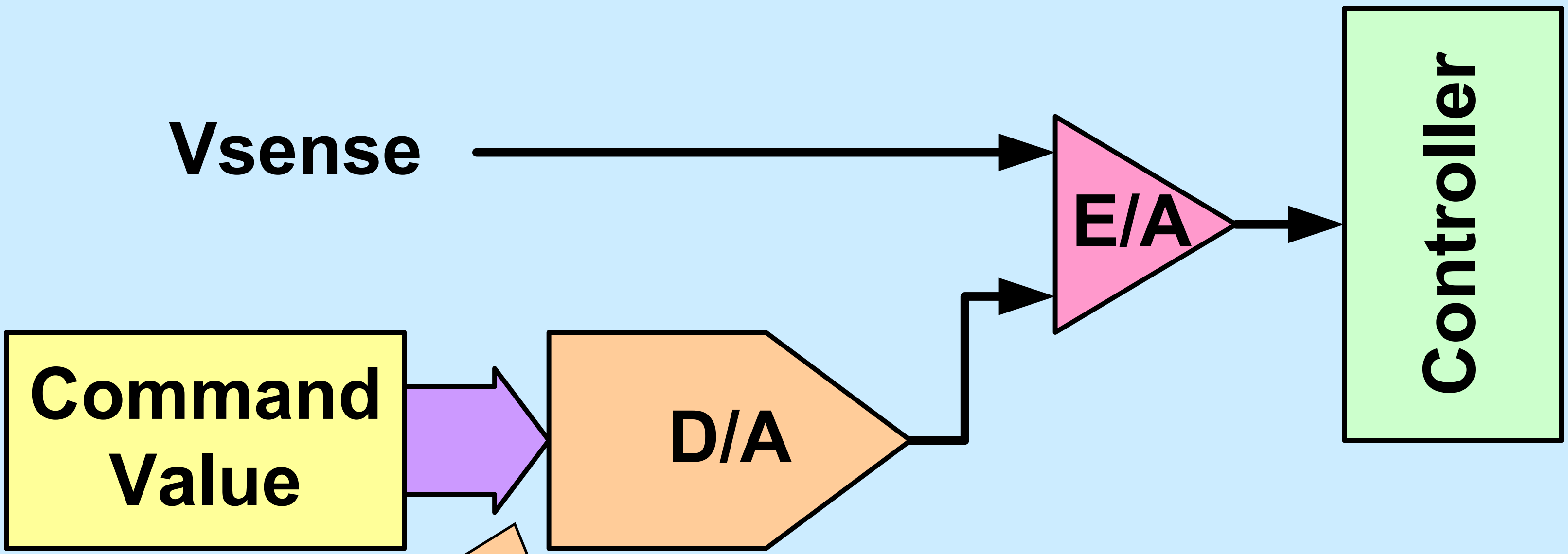
- Value = Value Of LSB x Number Of Bits
- Need To Balance Range And Resolution
- Ranges With Offset Waste A Lot Of Bits

Bits	# LSBs	Resolution (%)
6	64	1.5625%
8	256	0.3906%
10	1024	0.0977%
12	4096	0.0244%
14	16384	0.0061%
16	65536	0.0015%

Numerical Formats

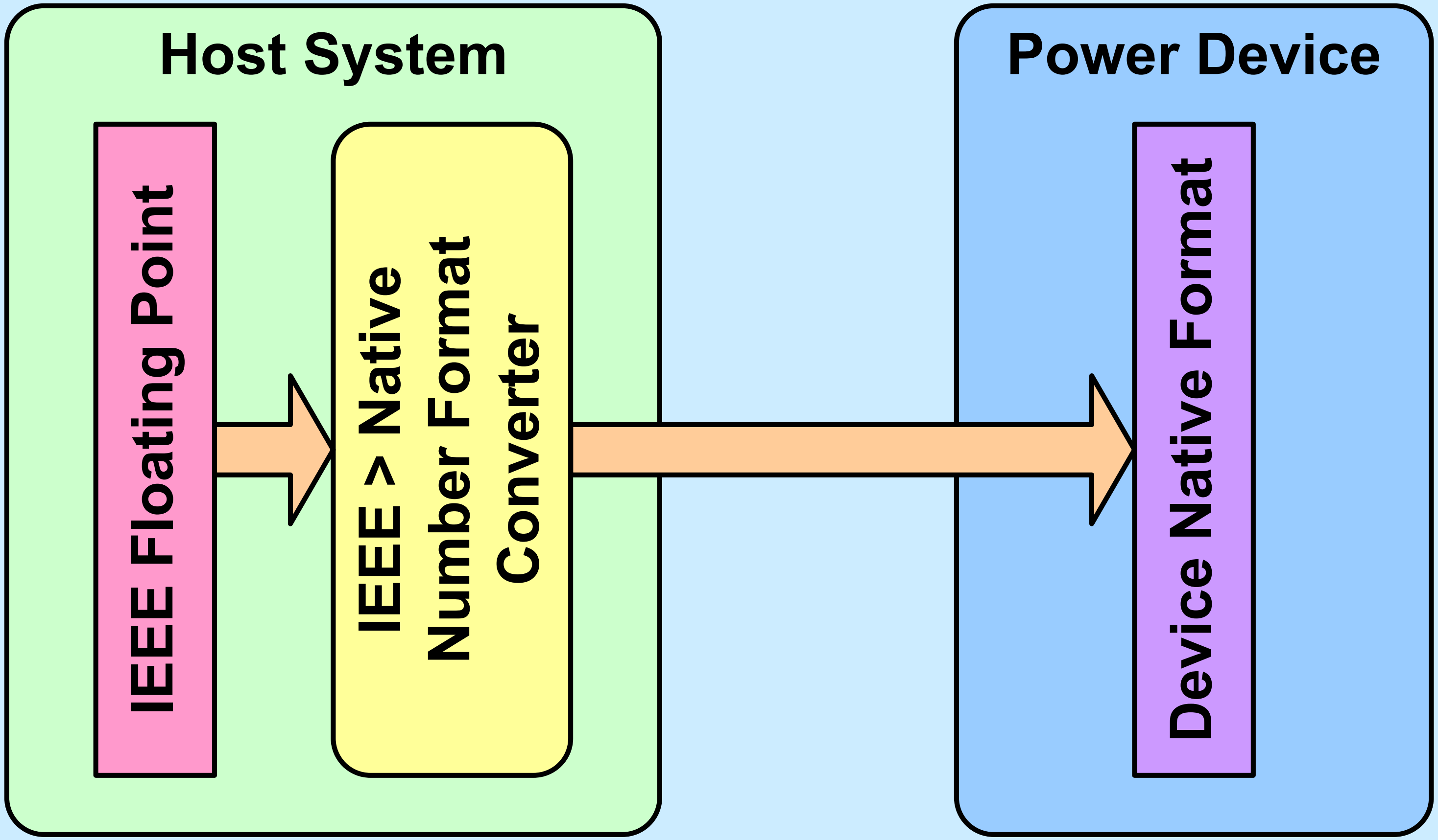


Typical Digital Setpoint Control

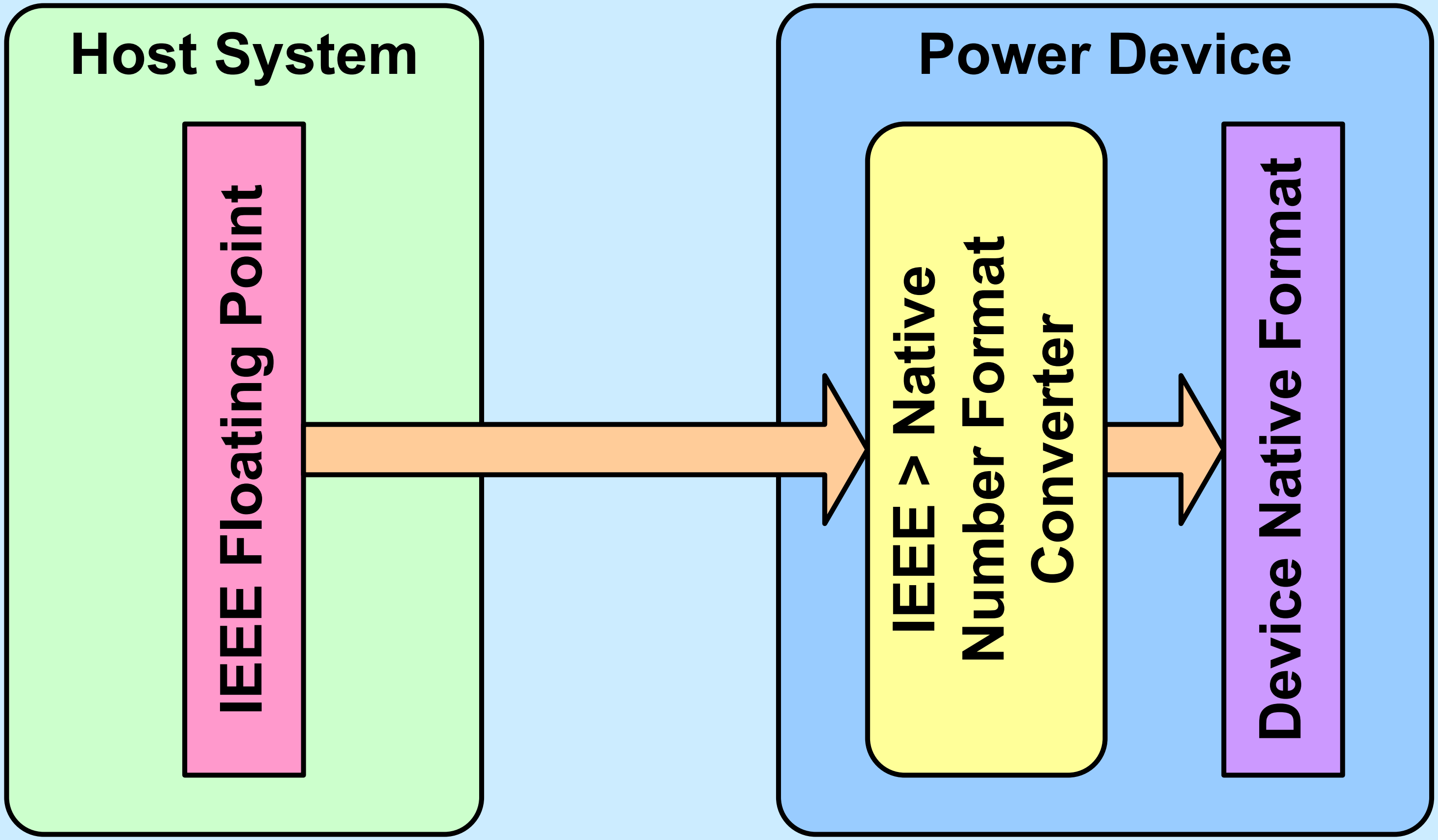


D/A Converters Generally
Do Not Accept IEEE Floating Point!
Input Needs To Be Positive Binary Integer

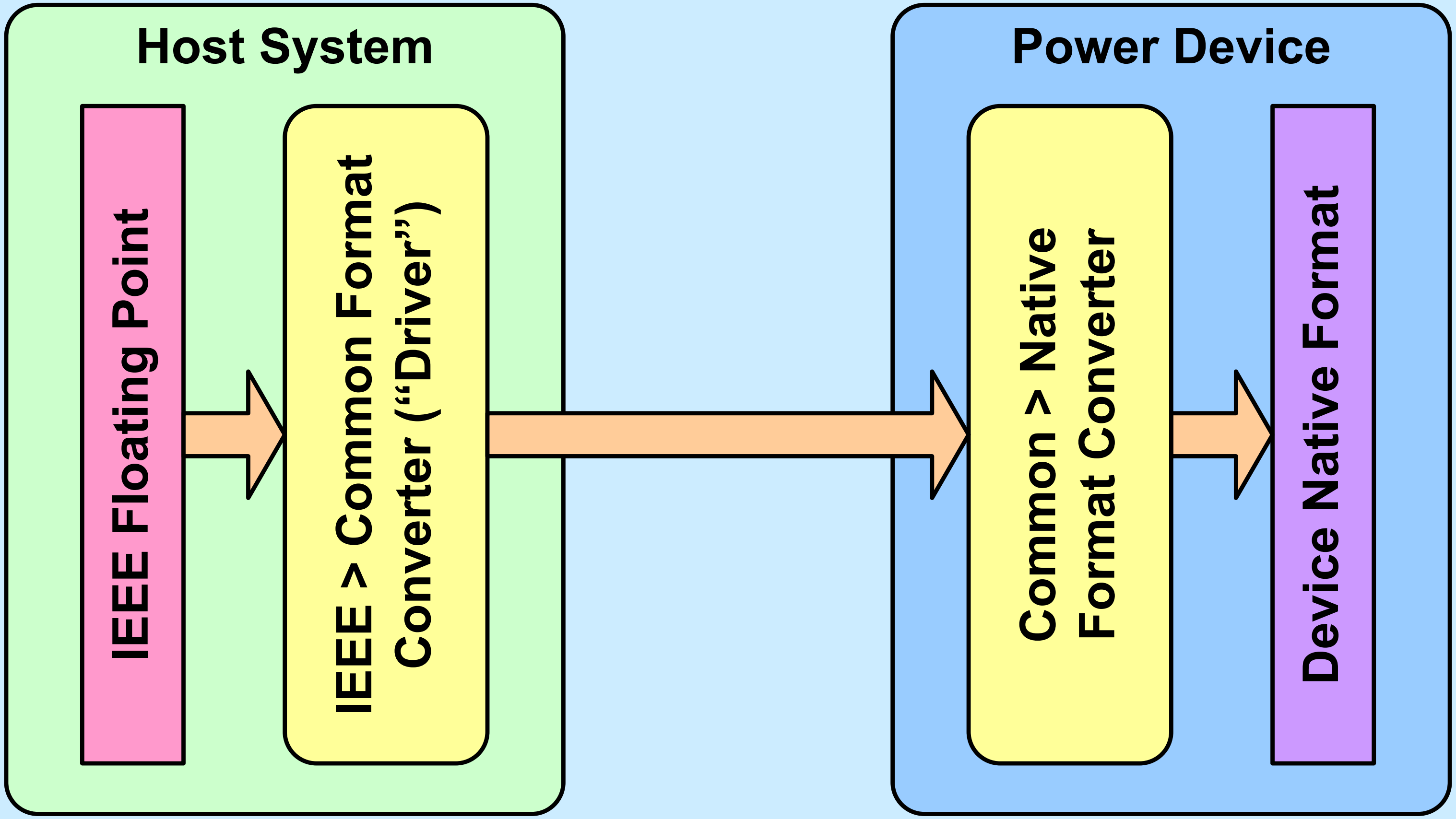
Choice 1: Burden The Host



Choice 2: Burden The Device

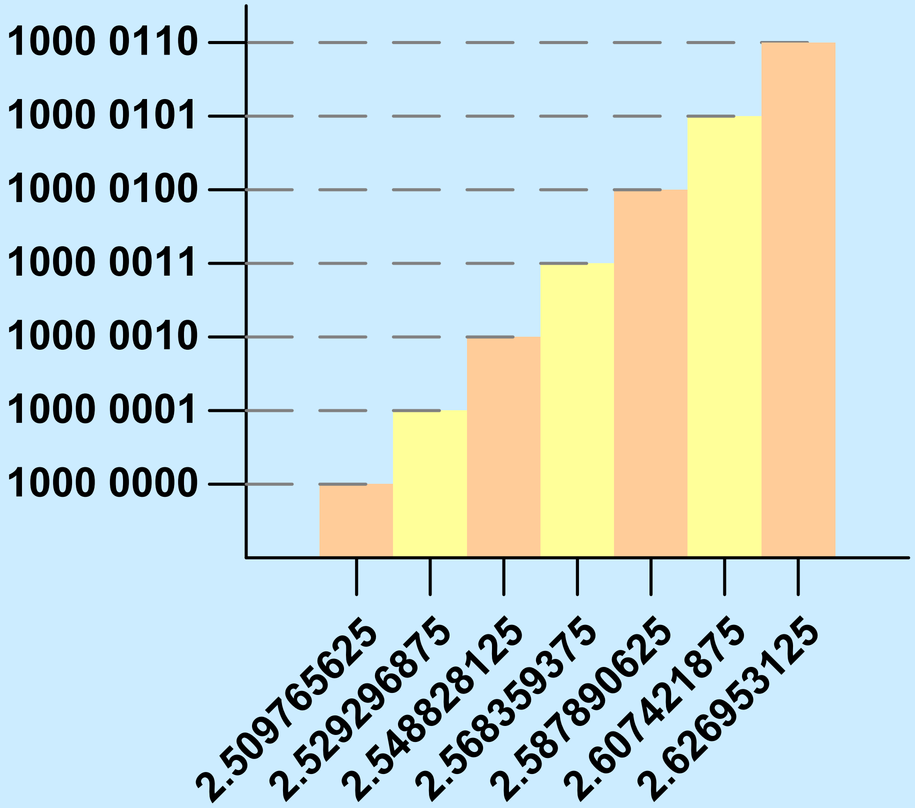


Choice 3: Lightly Burden Both



Sending Native Format

- How Does The Host Know The Relationship Between Its Format And The Device's Native Format?
  - Pre-Loaded In The Host
  - Retrieved From The Device Itself
- Relationship Is Typically A Linear Mapping

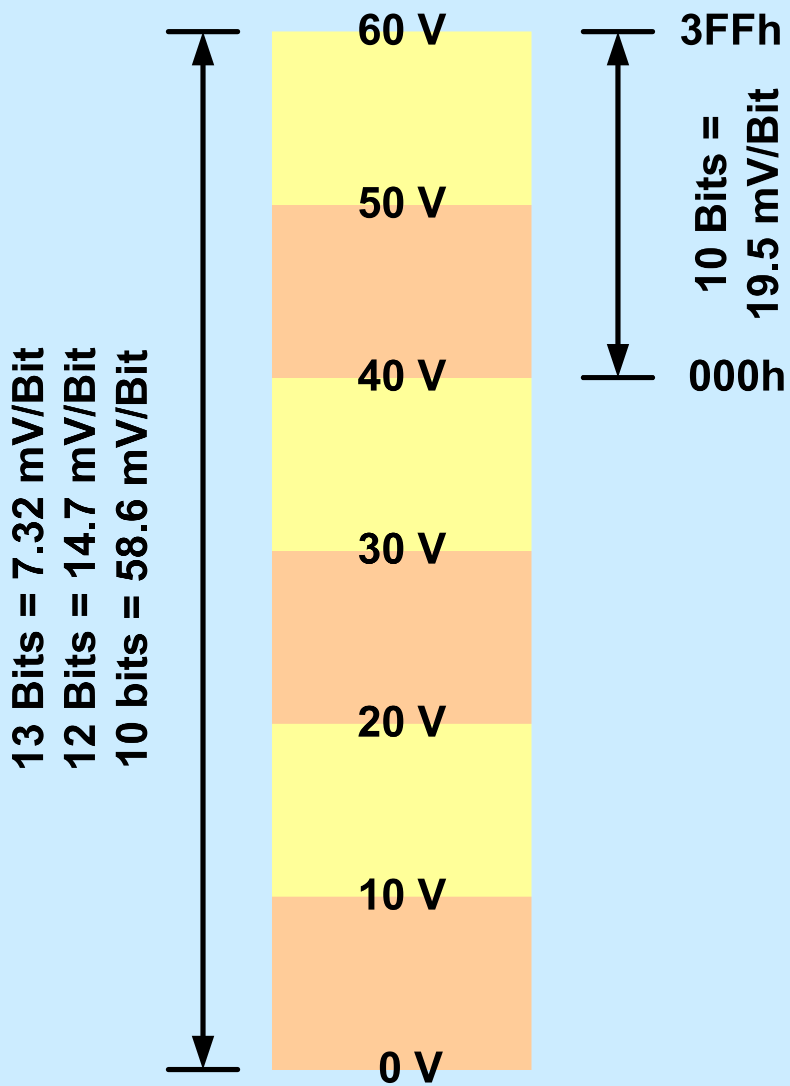


Converting To Native Format

- Two Choices
  - Memory Intensive
  - Compute Intensive
- Memory Intensive = Lookup Table
  - Conversion From Host Format To Power Device Native Format Then Becomes A Search
  - Tables Offer Non-Linear Or Discontinuous Mapping
- Compute Intensive = Use An Equation
  - $Y = m*X + b$ (Two Coefficients)
  - Scaling Factor Also Useful

Large Offset => Use An Equation

- Telecomm Rectifier:
  Vout = 40 Vdc To 60 Vdc
- Need 10-20 mV
  Resolution => 12-13 Bits
  - Economical Is 10 Bits
- What If Only 40–60 V Is Communicated?
  - 10 Bits => 19.5 mV/Bit



Example: PMBus™ Direct Mode

- The Direct Mode Uses An Equation As Follows:

$$Y = (mX + b) \bullet 10^{R}$$

- Where:
  - *Y* Is The Value Transmitted To Or Received From The PMBus Device (16 Bits, Signed)
  - *X* Is The “Human” Value To Be Encoded
  - *m* Is The Scaling Coefficient (16 Bits, Signed)
  - *b* Is The Offset Coefficient (16 Bits, Signed)
  - *R* Is The Scaling Coefficient (8 Bits, Signed)

Direct Mode: *m*, *b* And *R*

- *m*, *b* And *R* Are Known As The Coefficients
- They Are Supplied By The PMBus Device Manufacturer
- Preferred:
  Coefficients Stored In The Device And Retrieved By The Host With The COEFFICIENTS Command
- Alternative:
  Coefficients Are Provided In The Product Literature (Data Sheet, Application Note)

Calculating The Coefficients

- Problem
  - 3 Unknowns (*m*, *b*, *R*)
  - 2 Constraints
- The Two Constraints
  - X_{min} => Y_{min} And X_{max} => Y_{max}
- Solution Procedure:
  See “Using And Understanding PMBus Data Formats” – Thursday Morning, Paper 23.4

Calculating The Coefficients: Example

- Chosen Solution
  - m: 731
  - b: –32151
  - R: –1
- Double Check Calculation

$$
\begin{aligned}
Y_{\min} &= (mX_{\min} + b) \bullet 10^{R} \\
&= (731 \bullet 44 - 32{,}151) \bullet 10^{-1} \\
&= 1.3 \neq 0
\end{aligned}
$$

$$
\begin{aligned}
Y_{\max} &= (mX_{\max} + b) \bullet 10^{R} \\
&= (731 \bullet 58 - 32{,}151) \bullet 10^{-1} \\
&= 1024.7 \neq 1023
\end{aligned}
$$

Note The Rounding And Quantizaton Errors!

What To Do About Errors?

- Choices
  - Live With It
  - Adjust The Slope (m)
  - Adjust the Offset (b)
  - Adjust Both
  - Adjust X_{max} And X_{min}
- See Paper 23.4 For Detailed Discussion

Lesson:
You Must Pay Attention To Errors Introduced By Discrete Arithmetic!

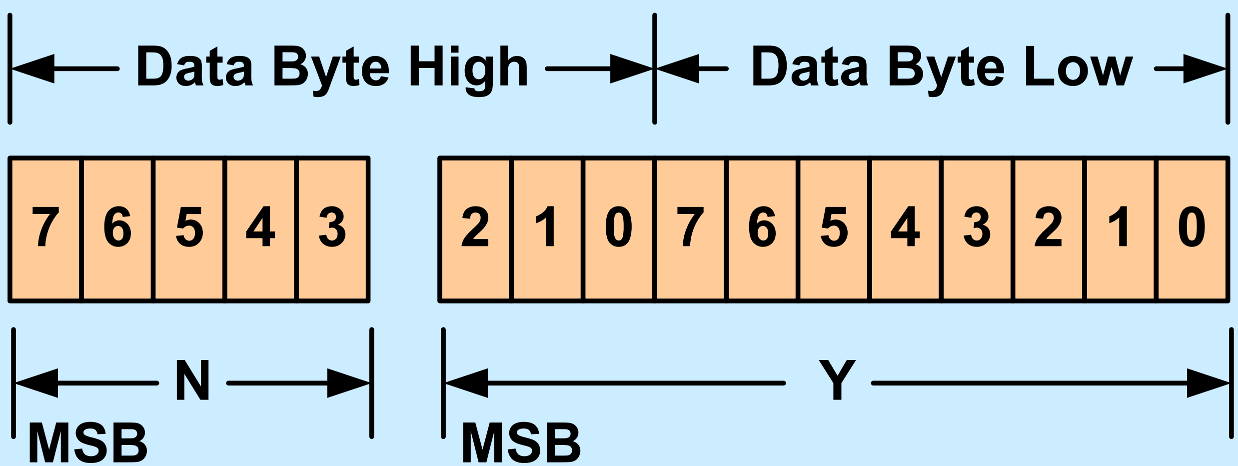
Defining A Common Format

- For General Purpose Power Applications, Need:
  - Good Resolution: At Least 10 Bits
  - Wide Range: Micro-Units To Mega-Units
- PMBus Solution
  - Simplified Floating Point Notation
  - Two Data Bytes
  - 11 Bit Signed Mantissa
  - 5 Bit Signed Exponent

PMBus General Purpose Common Format

- $X = Y \cdot 2^{-N}$
- Wide Range Of Values Possible
  - Maximum Positive: $1023 \times 2^{15} = +33.52 \times 10^{6}$
  - Minimum Value: $\pm 1 \times 2^{-16} = \pm 15.26 \times 10^{-6}$
  - Maximum Negative: $-1024 \times 2^{15} = -33.55 \times 10^{6}$

General Purpose (10 Bit) Literal Format



Language

- Language For Power System Management Has Two Basic Parts
- Command
  - The “Verb” – Action Device Is To Take
  - Example: Set The Output Voltage
- Data
  - Information Needed To Carry Out The Command
  - Example: The New Output Voltage Value
- May Be Other, Related Elements
  - Examples: Block Counts, Checksums

A Good Rule

- Everything The Host Can Write, The Host Must Be Able To Read
- Conversion To Local, Native Format Can Cause Problems
  - Suppose Host Sends A Value Using The General Purpose 11+5 Format
  - Device Then Converts To An Internal 10 Bit Value That Is The Input To A D/A Converter
  - If The Host Reads The Value, What Is Returned?
    - Original 11+5 Format Value?
    - Or Nearest 11+5 Value To Internal 10 Bit Value?
    - What If Values Do Not Match?

On/Off Control

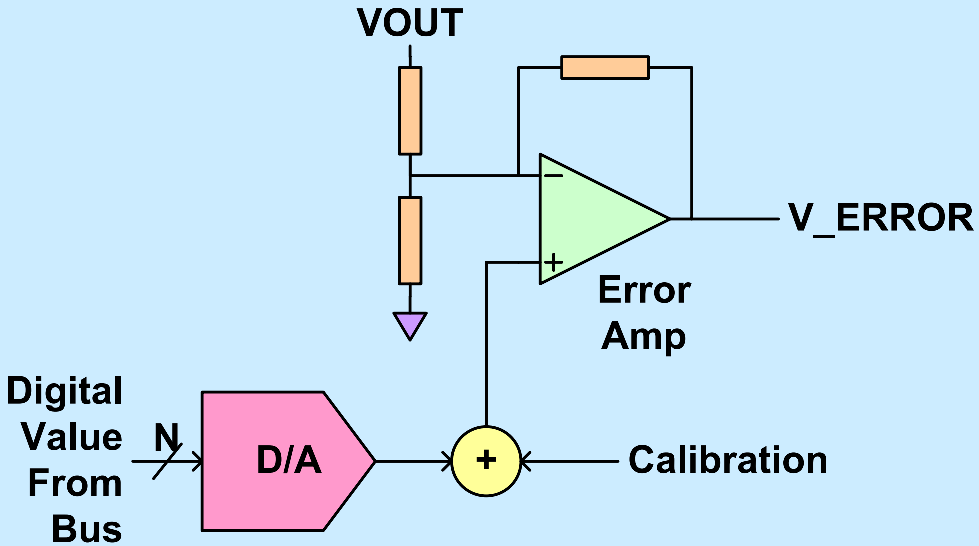
- Typically Two Control Handles
  - Hardwired On/Off Pin
  - Bus Command
- Polarity Of On/Off Pin?

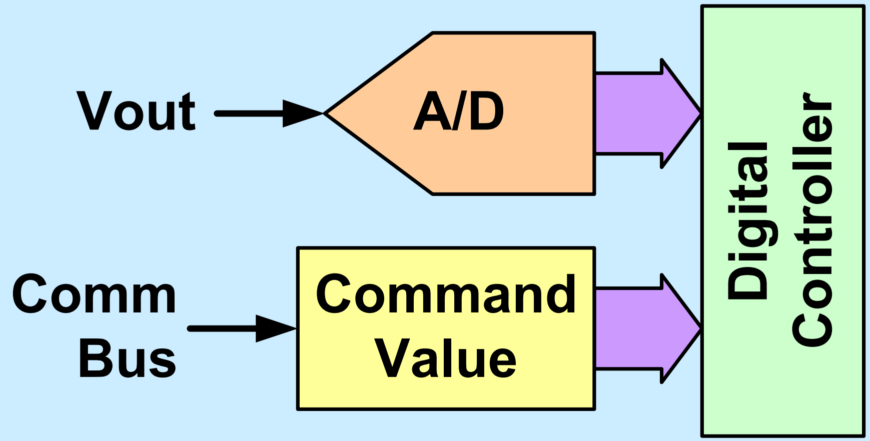
On/Off Pin	Bus Command
Ignore	Ignore
	Respond
Respond	Ignore
	Respond

"Always On"

Commanding The Output Voltage

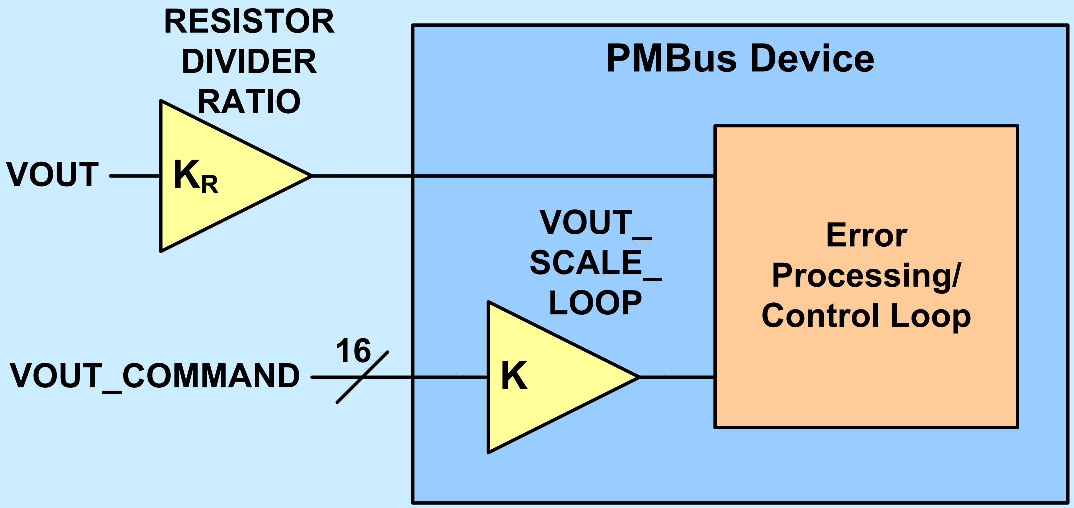
- In Many Cases, Commands Are Not Directly For The Output Voltage
- What Really Gets Commanded Is The Reference Voltage
- Need A Way To This As Easy As Possible For The User





Voltage Loop Scale Factors

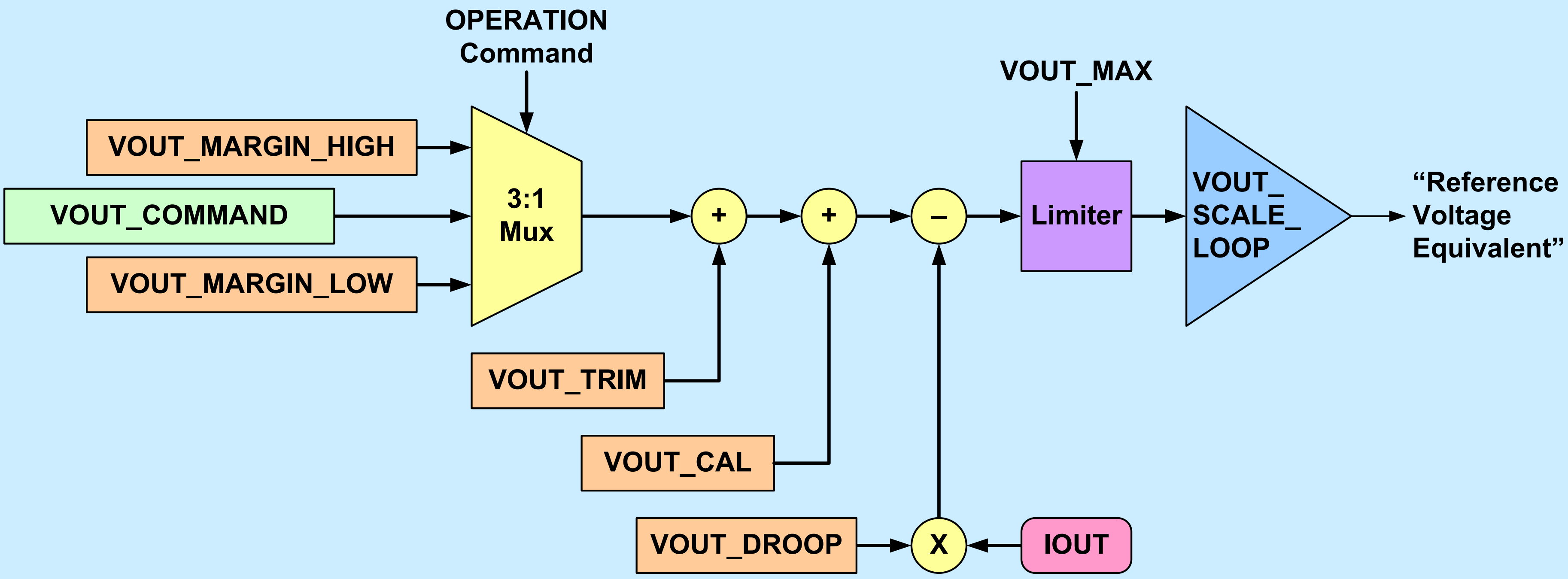
- Adding Scale Factors Into The Configuration Allows The User To Think In Terms Of The Actual Output Voltage
- Voltage Scale Factor Is Essentially The Ratio Of The Resistor Divider Used To Sense The Output Voltage



Margining

- Margining Outputs Is Important For System Development And Verification
  - Not Often Used Once System Is Deployed
- Several Ways To Command Voltage For Margining
  - Command New Value Directly (Simplest)
  - Use Pre-Set Values Like PMBus
  - Command Just The Offset Voltage
    - From Current Or Original Value?
  - Command The Percentage Change
    - Very Ugly Arithmetic In A Simple Device
    - Multiply An 8 Bit Number By 0.95d?

Commanding Output Voltage: Example From PMBus



Commanding And Reporting Current

- Range And Resolution As Needed
- Often Need Current Scale Factor To Adjust For Varying Sense Resistance
- Synchronous Rectifiers May Need To Measure Negative (Sink) Current
  - This May Challenge Range And Resolution
- Current Sense Calibration
  - Both Gain And Offset Errors Are Often Important
  - Temperature Compensation Can Be Important In Some Applications (Like VRMs)

Application: Digital Current Share

- Unit-To-Unit Digital Current Share Is Possible
  - Can Be Done In Real Time
- Host Based Is Simpler
  - Not Real Time
  - No Extra Hardware In The Units
- Host Based Digital Current Share Process
  - Host Collects Output Current From Paralleled Units
  - Host Computes Output Voltage Adjustments
  - Host Sends Trim Commands To The Units
  - Repeats As Necessary

Commanding And Reporting Temperature

- Temperature Fault Thresholds
  - Usually Only Positive Values
  - 1 °C/Bit Often Sufficient
  - One Byte Often Sufficient (0 °C To 255 °C)
- Reporting Temperatures
  - Application Dependent
  - Outdoor And Military Applications Require A Wide Range From As Low As –60 °C To +150 °C
  - One Byte Not Sufficient (–128 °C To +127 °C)
- Challenge And Choice
  - Same For Both Commands And Reports?

Commanding And Reporting Fans

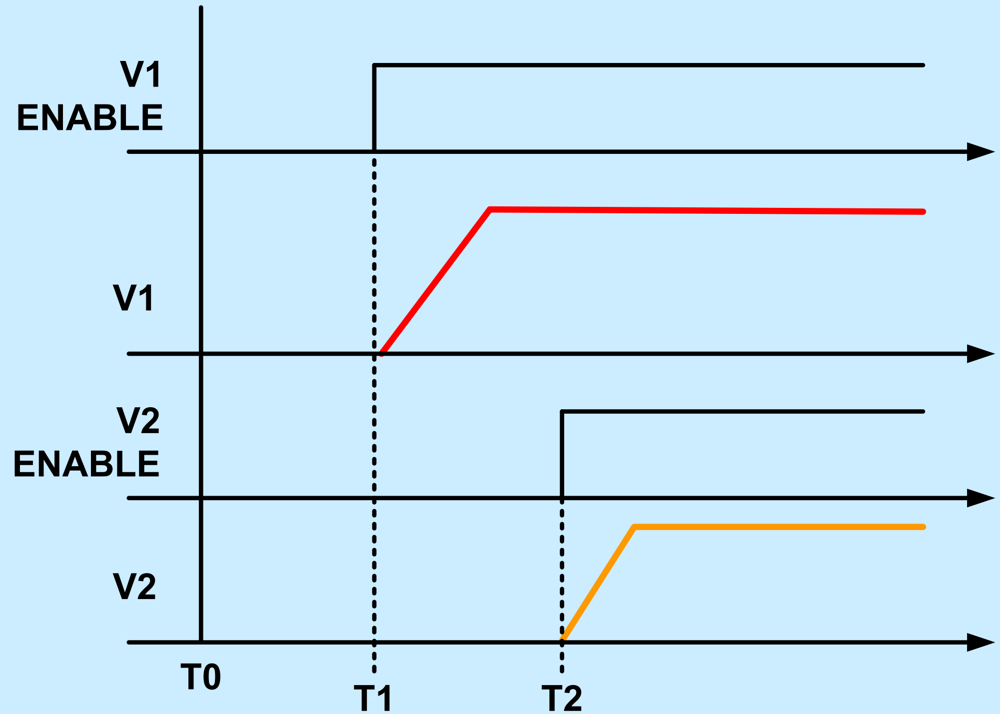
- Fans Are Not Straightforward
- Commanding Fan Operation – Three Choices
  - Fan Voltage
  - Fan Speed
  - PWM
- Reporting Fan Speed
  - Fan Tachometers Put Out Various Number Of Pulses Per Revolution
  - This Needs To Be Known Before Speed Can Be Reported => Configuration File?

Other Possible Configuration Parameters

- Digital Loop Control Parameters
- Switching Frequency
- Maximum Duty Cycle
- Equivalent Output Voltage Droop Resistance For Passive Current Sharing
- Slew Rate When Changing Output Voltage
- Turn-On Delay And Rise Time Or Slew Rate
  - Also Turn Off Parameters

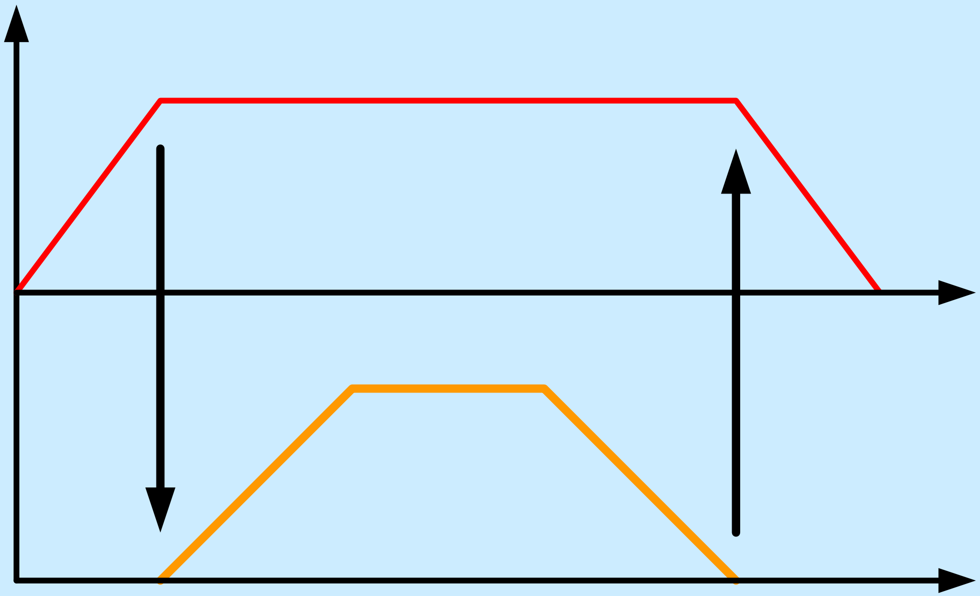
Sequencing – Open Loop Host Driven

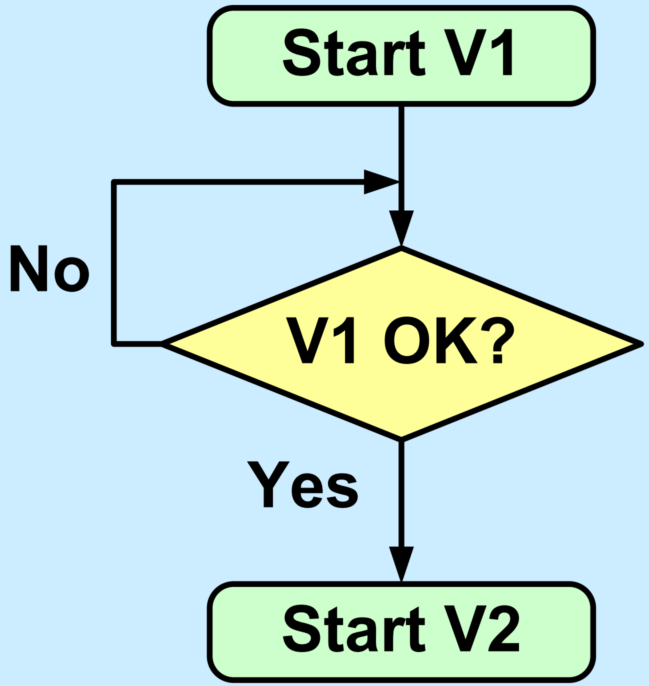
- Host System Sends Turn On (Or Turn Off) Commands At Pre-Programmed Times
- Burdens Host To Get A Simpler Device
- No Monitoring During Power Up Can Allow Sequencing Errors To Cause Problems



Sequencing: Event Driven

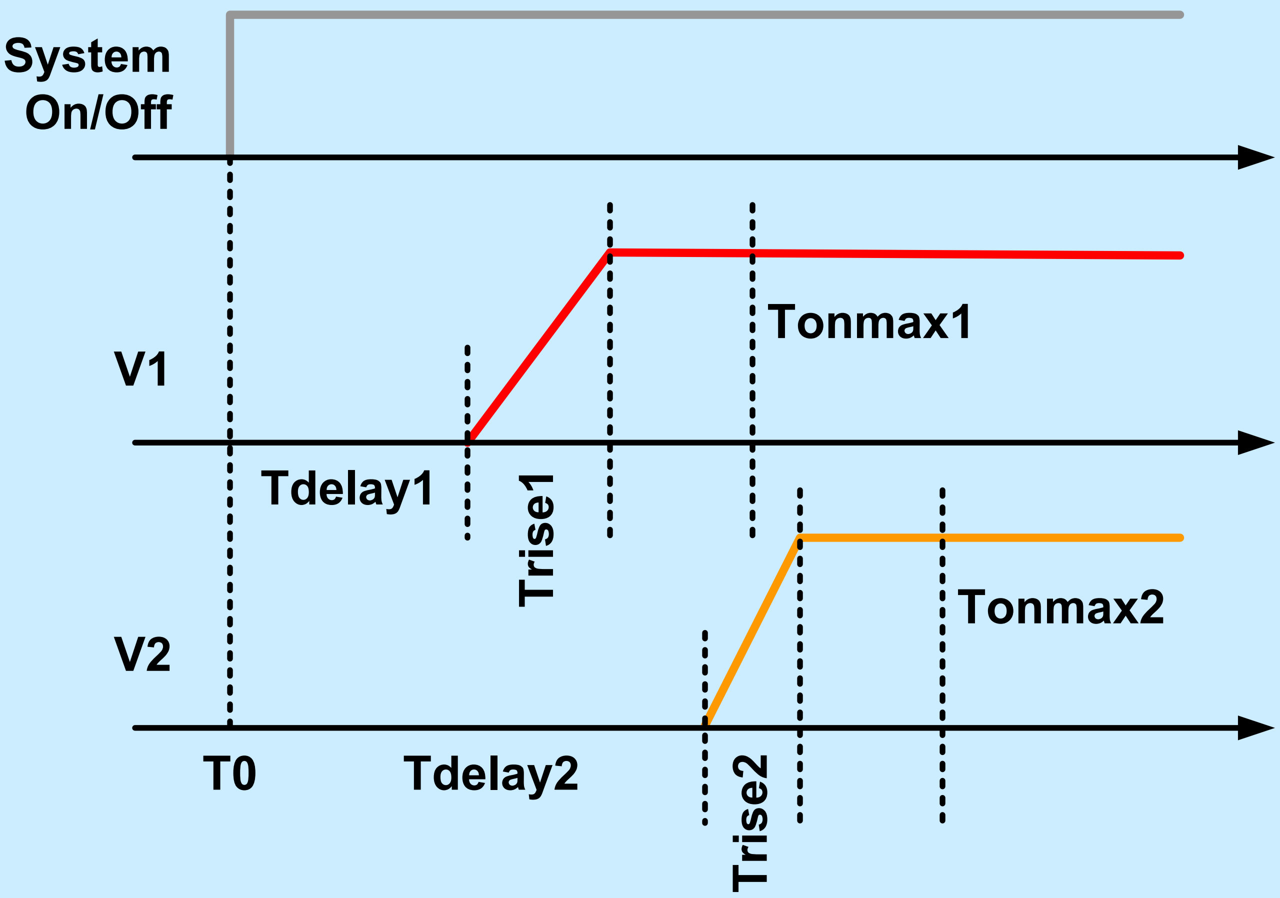
- Event Driven Sequencing Is Closed Loop Host Driven Sequencing
- Burdens Host, Simple Device
- Better Control Of Start Up



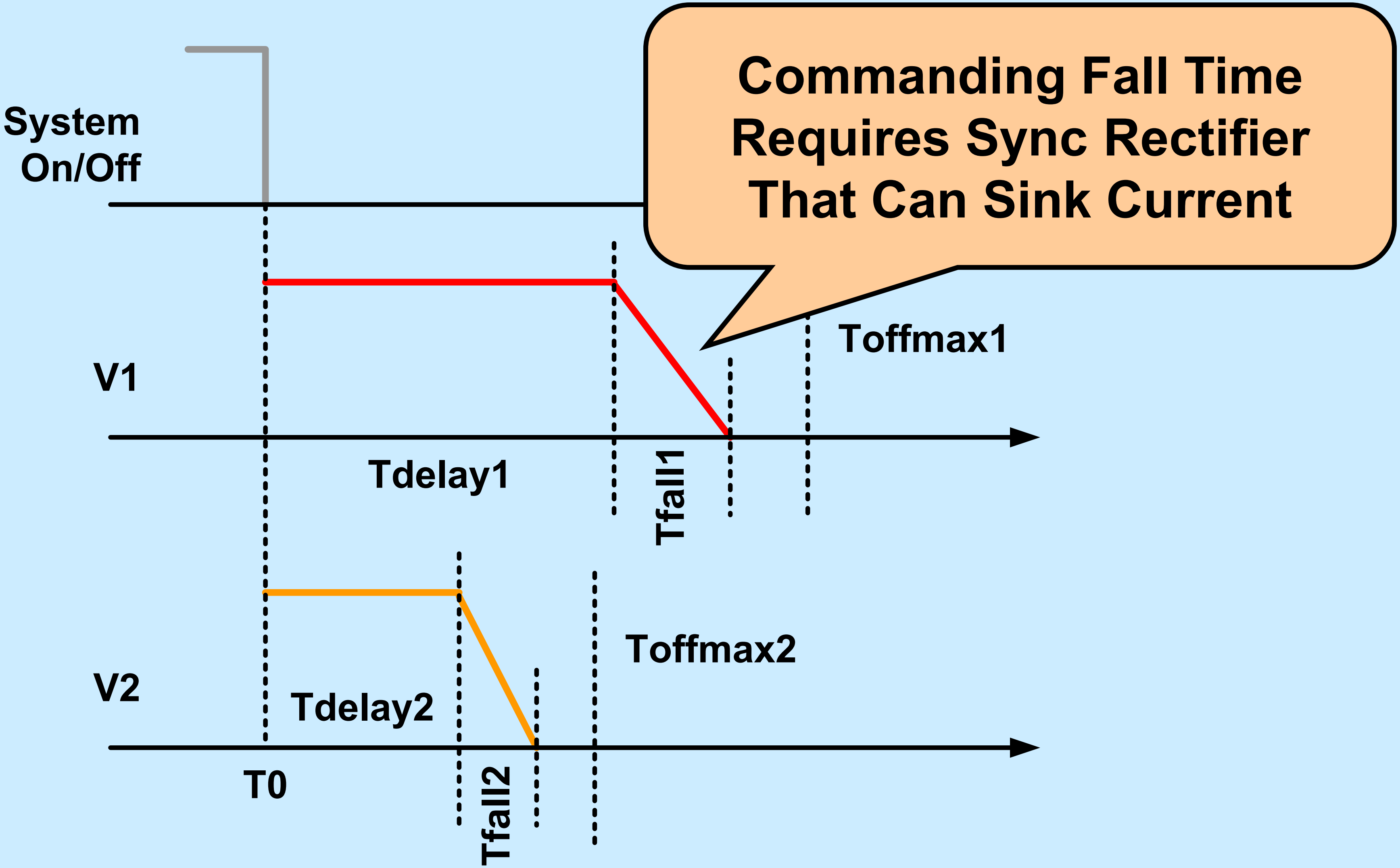


Sequencing: Time Driven

- Time Driven Sequencing Is Open Loop
- Power System Manager Not Required
- Delays And Rise Times Programmed Into Units



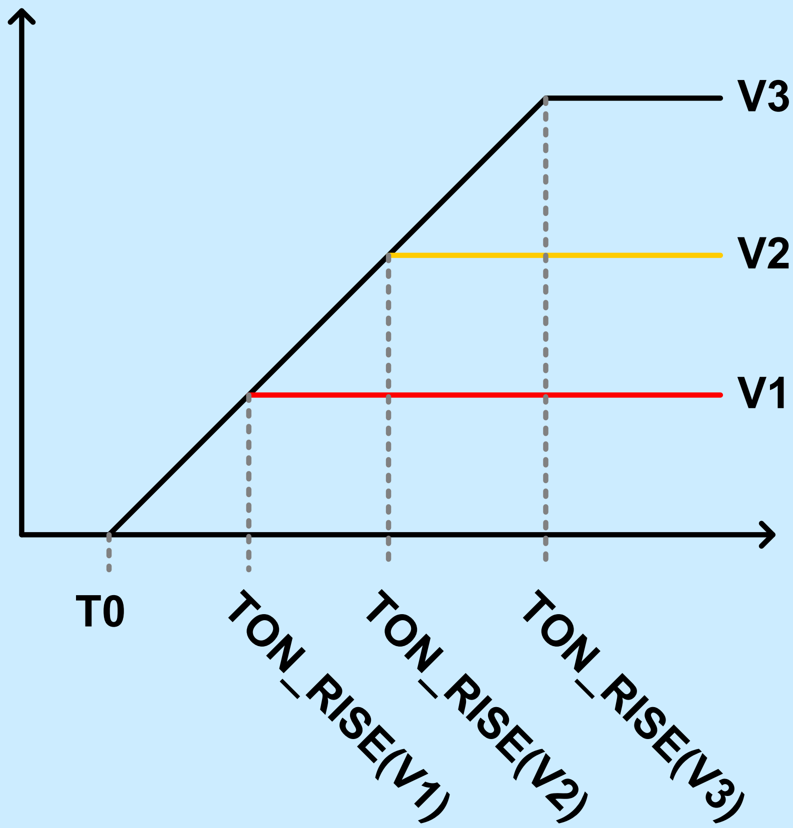
Sequencing: Time Driven



Sequencing: Time Driven

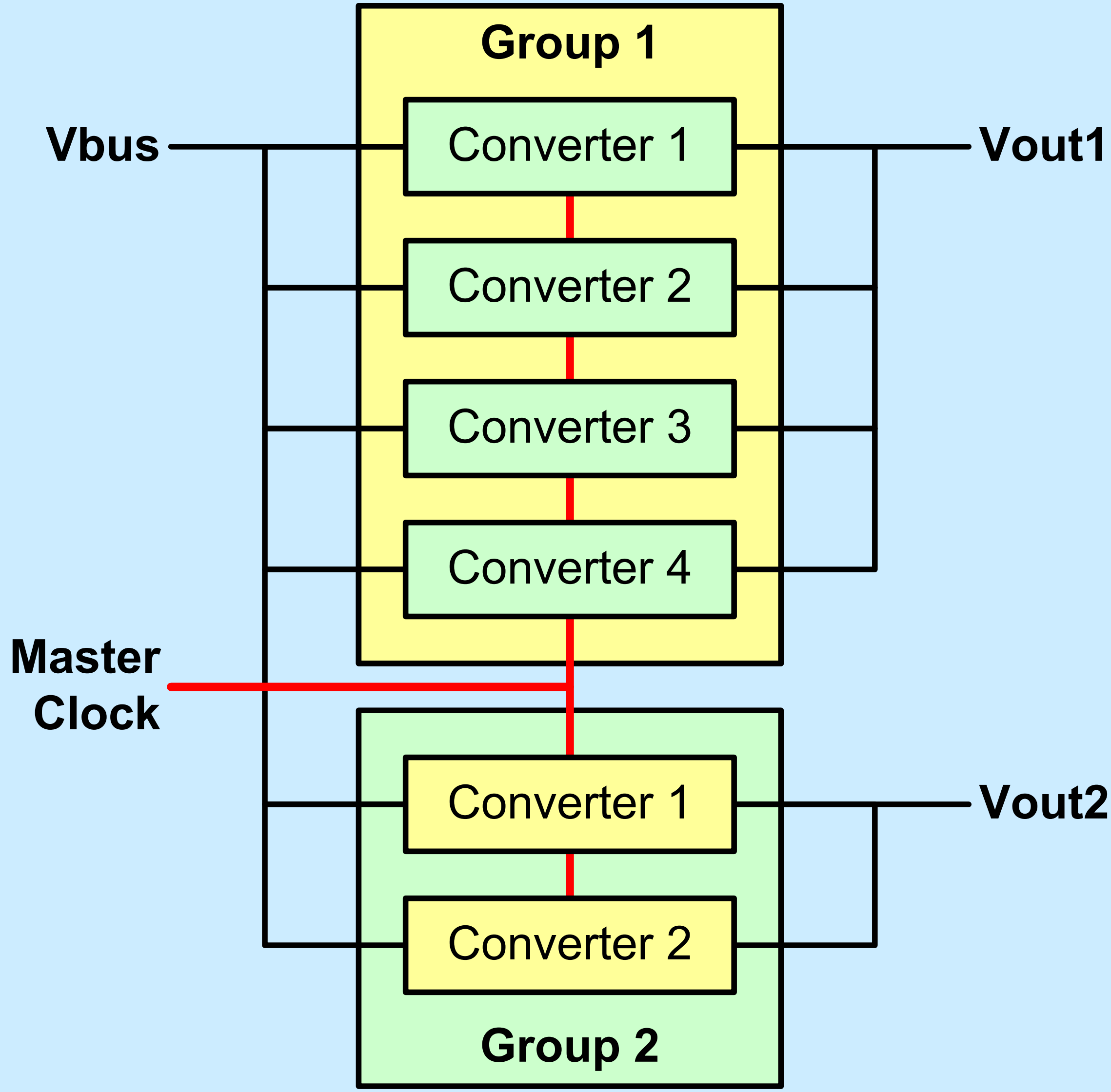
- Coincident Sequencing Can Be Achieved With Time Driven Method
- Turn On Times And Output Voltages Are Simply Related

$$\frac{V3}{TON\_RISE(V3)} = \frac{V2}{TON\_RISE(V2)} = \frac{V1}{TON\_RISE(V1)}$$



Interleaving

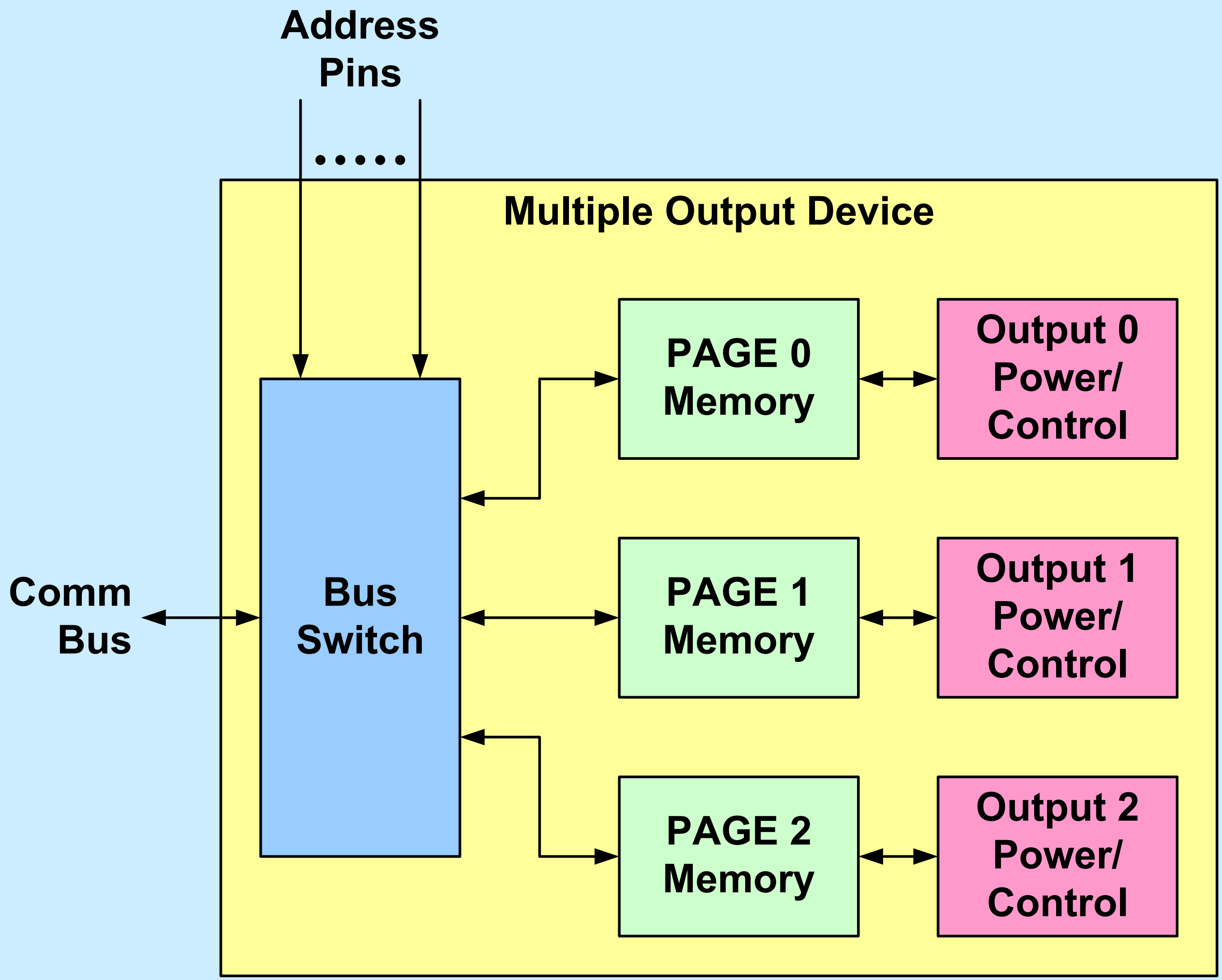
- Command
  – Group ID
  – Number Of Members In Group
  – Firing Order
- Also Need A Synchronizing Master Clock



Multiple Output Units

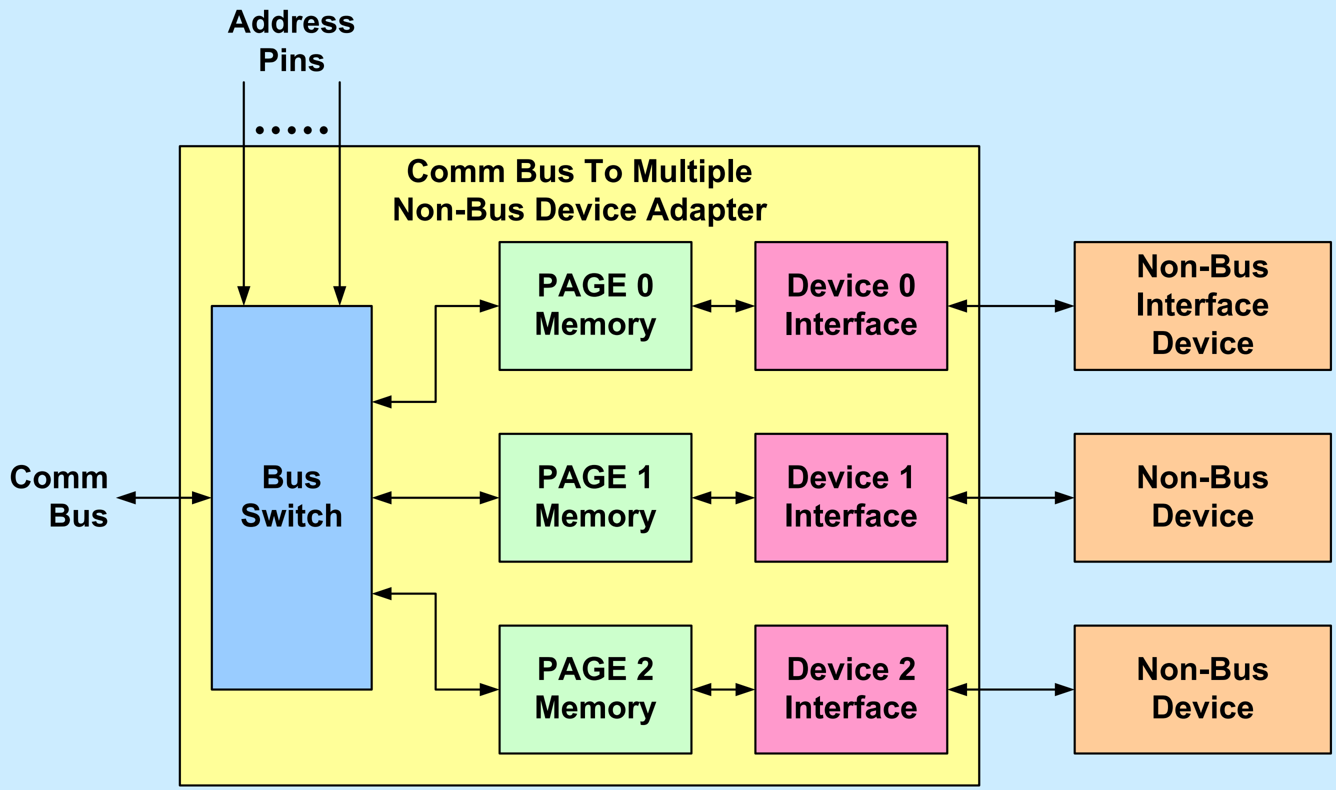
- One Address Per Output
- Paging
  - One Address Per Physical Unit
  - One Page Per Output
  - Pages Contain All The Settings Of Each Output
- Paging Process
  - Set Page For Output Of Interest
  - Send Commands
    - Configure, Control, Read Status

Multiple Outputs - Paging



Paging Also Useful:

- For Units With Multiple Operating Modes
- To Connect Multiple Non-Bus Interface Devices To One Communications Bus



Group Commands

- Often Useful To Send Commands To Multiple Units At One Time
- Broadcast Addresses
  - Universal Address To Which Every Device Responds
  - Only Useful For Write Operations
- Load And Execute
  - Load Multiple Devices With Commands
  - Send Execute Command By Broadcast
- Multiple Addresses In One Packet
  - Quite Possible With I^2C And SMBus

Inventory Information

Possible Users

- IC Maker
- IC User
- Module User
- End Customer

Typical Information

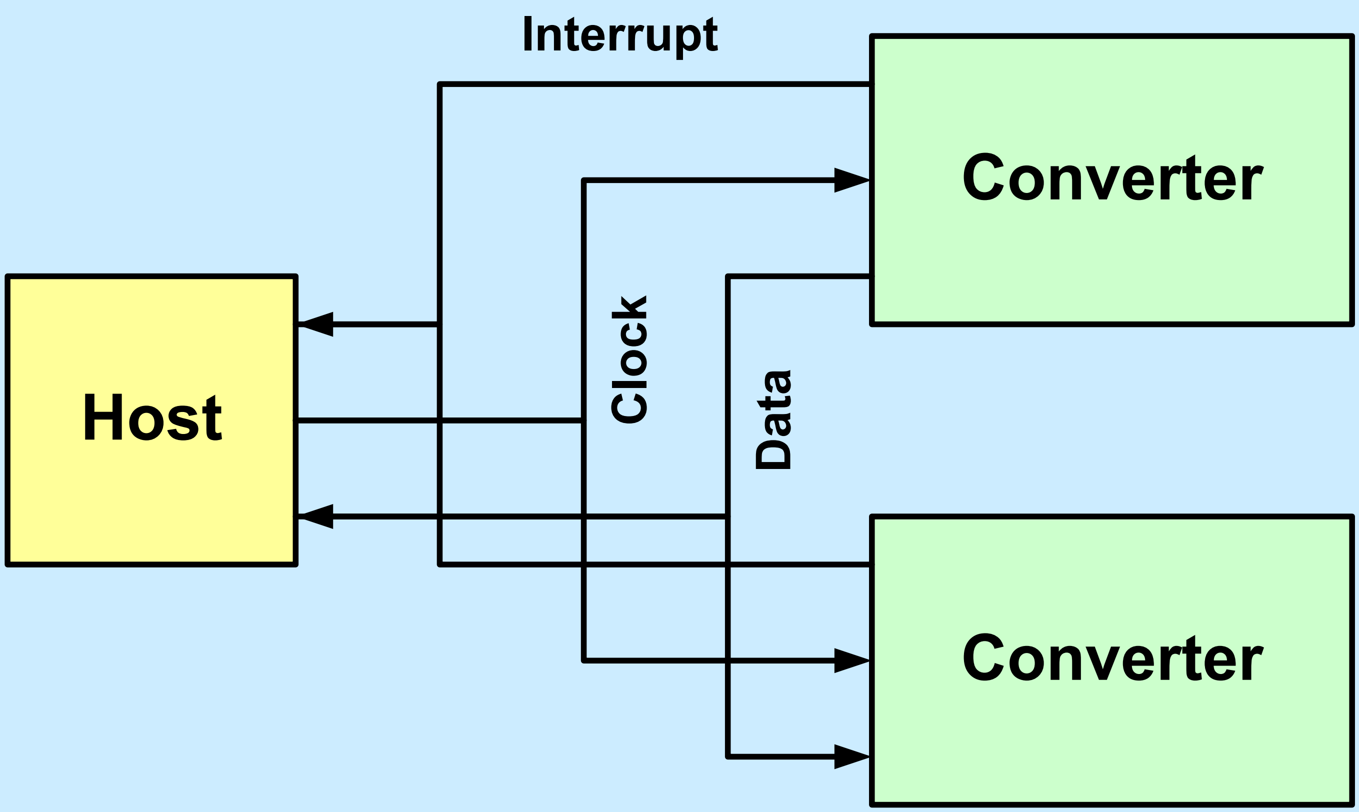
- Manufacturer ID
- Mfr Model Number
- Mfr Serial Number
- Date Of Manufacture
- Revision Level
- Manufacturing Location
- Date Of Install

Be Careful!
Inventory Information Can Use
A Lot Of Memory

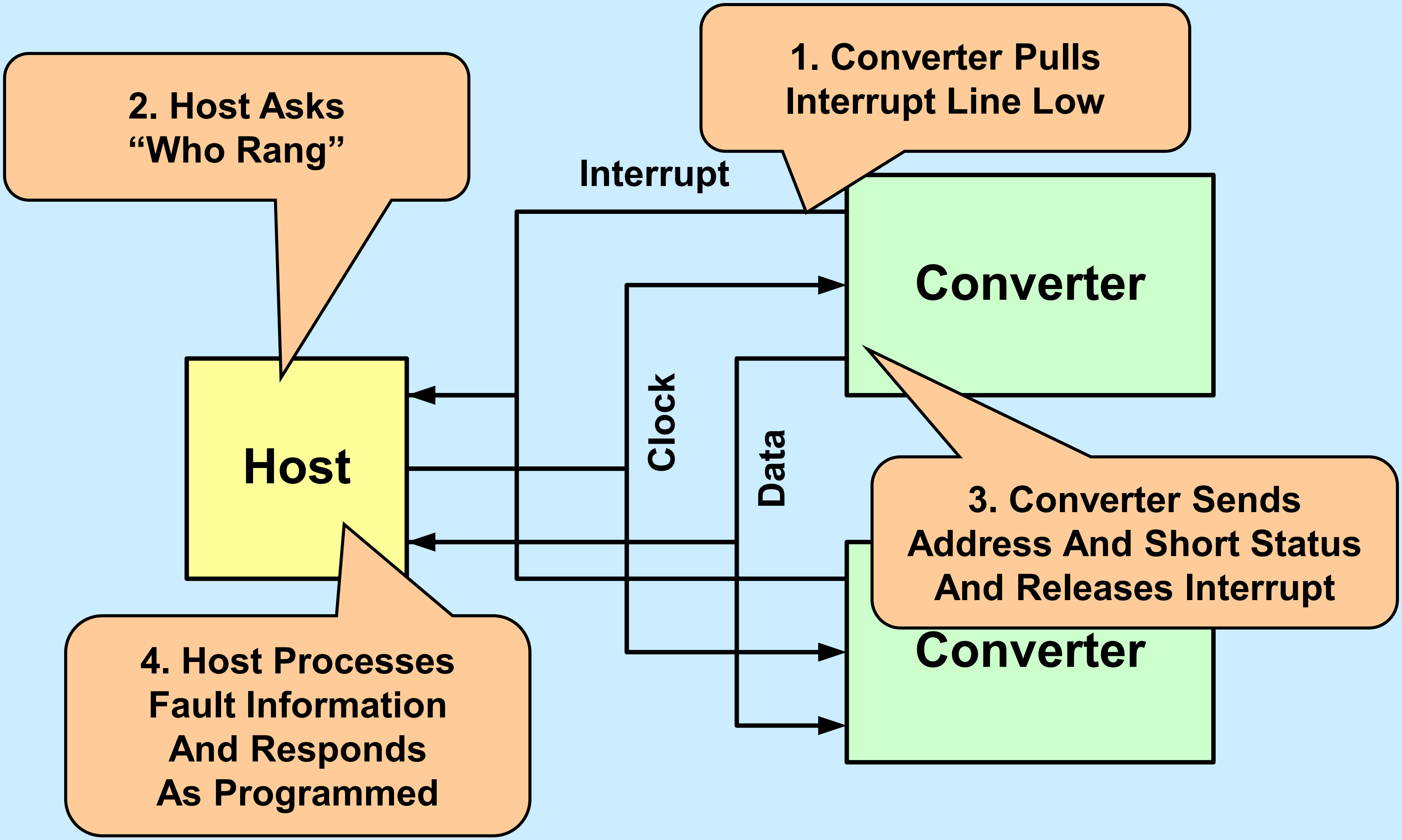
Fault Monitoring: Notifying The Host

- How Does The Host System Know There Is A Fault?
- Host Continuously Polls The Power System
  - Least Complex Power Converter
  - Response Time Can Be Poor
  - Consumes A Lot Of Resources In The Host
- Bus Message
  - Power Device Sends A Message To The Host
  - Multiple Master Bus Complicates Everything
  - Avoids Need For A Separate Interrupt Signal Line

Fault Monitoring: Interrupt Driven



Fault Monitoring: Interrupt Driven



Fault & Status Monitoring

- Where Is Fault Data Stored?
  - In The Device
    - Volatile
    - Non-Volatile
  - In The Host Or Other External Memory
- How Is Data Extracted
  - Especially In A Repair Depot!
- How Much Data Is Kept?
  - Is This Information Ever Going To Be Used By Anyone?
  - Timestamps? Don’t Want Real Time Clock In Most Power Devices – Too Expensive

More Fault & Status Monitoring

Sticky Fault And Status Data Or Not?

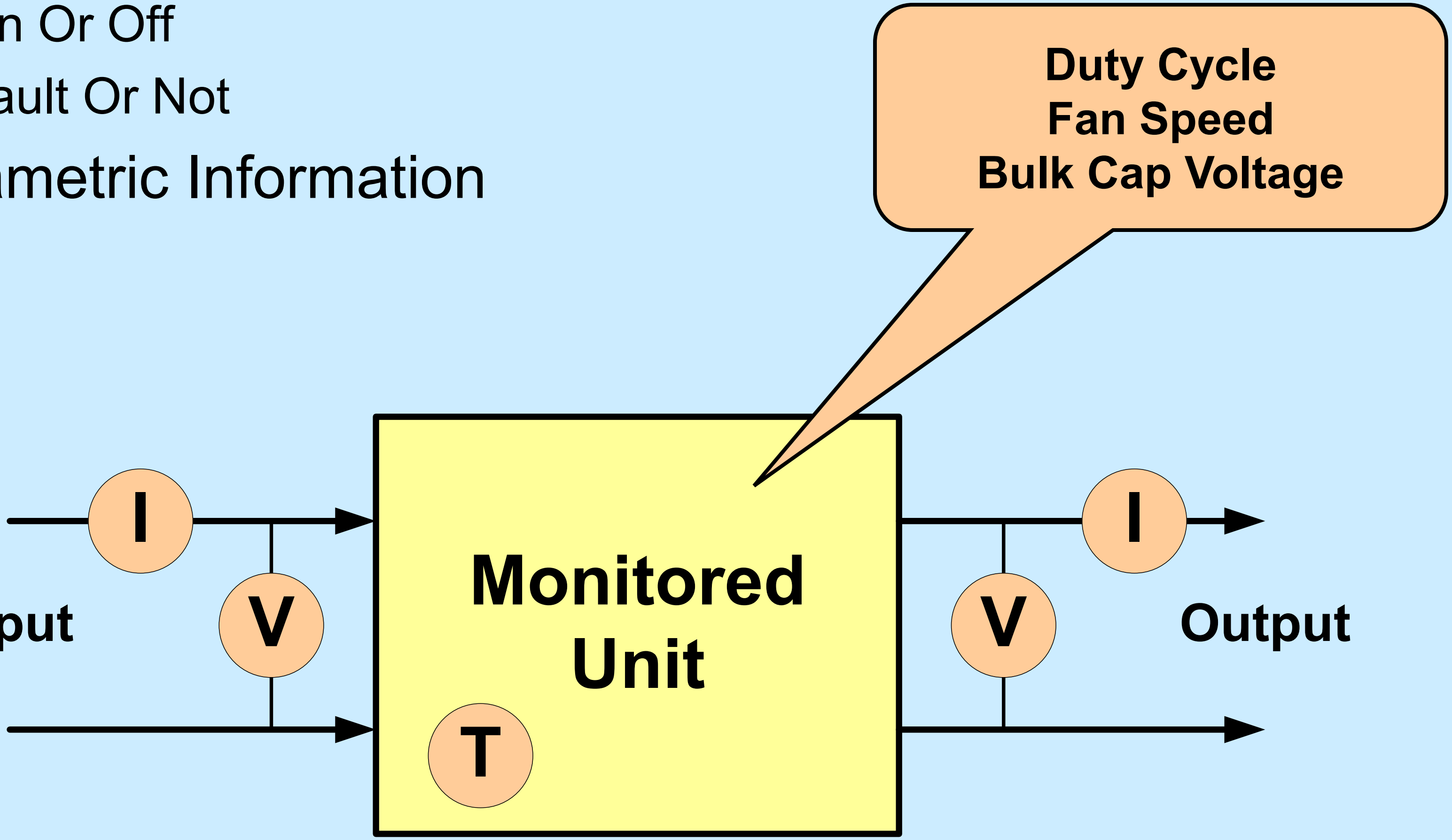
- Do Status Bits Indicating A Fault Or Warning Remain Set When Condition Corrects Itself?
  – Example: Overtemperature Warning
- Consider This Scenario
  – Host Uses Interrupt Line To Notify Host Of Fault
  – Host Is Busy, Does Not Query Devices Right Away
  – Fault Clears Itself And Device Clears The Fault Flag
  – Host Queries The Device But Does Not See A Fault Indicated
- This Can Be A Nightmare For Field Service – The Customer – And You!

More Fault & Status Monitoring
When To Clear The Status In The Device?

- Clear On Send (Or Read)?
  – Fault Still Present After Status Sent Can Cause Repeated Interrupts To Host
- Clear On Command To Clear
  – Need To Manage New Faults And When To Notify The Host Of A Change
  – Two Registers Needed
    - One Keeps What The Host Knows About
    - The Other Reflects Current Status

Status Monitoring

- Binary Information
  - On Or Off
  - Fault Or Not
- Parametric Information



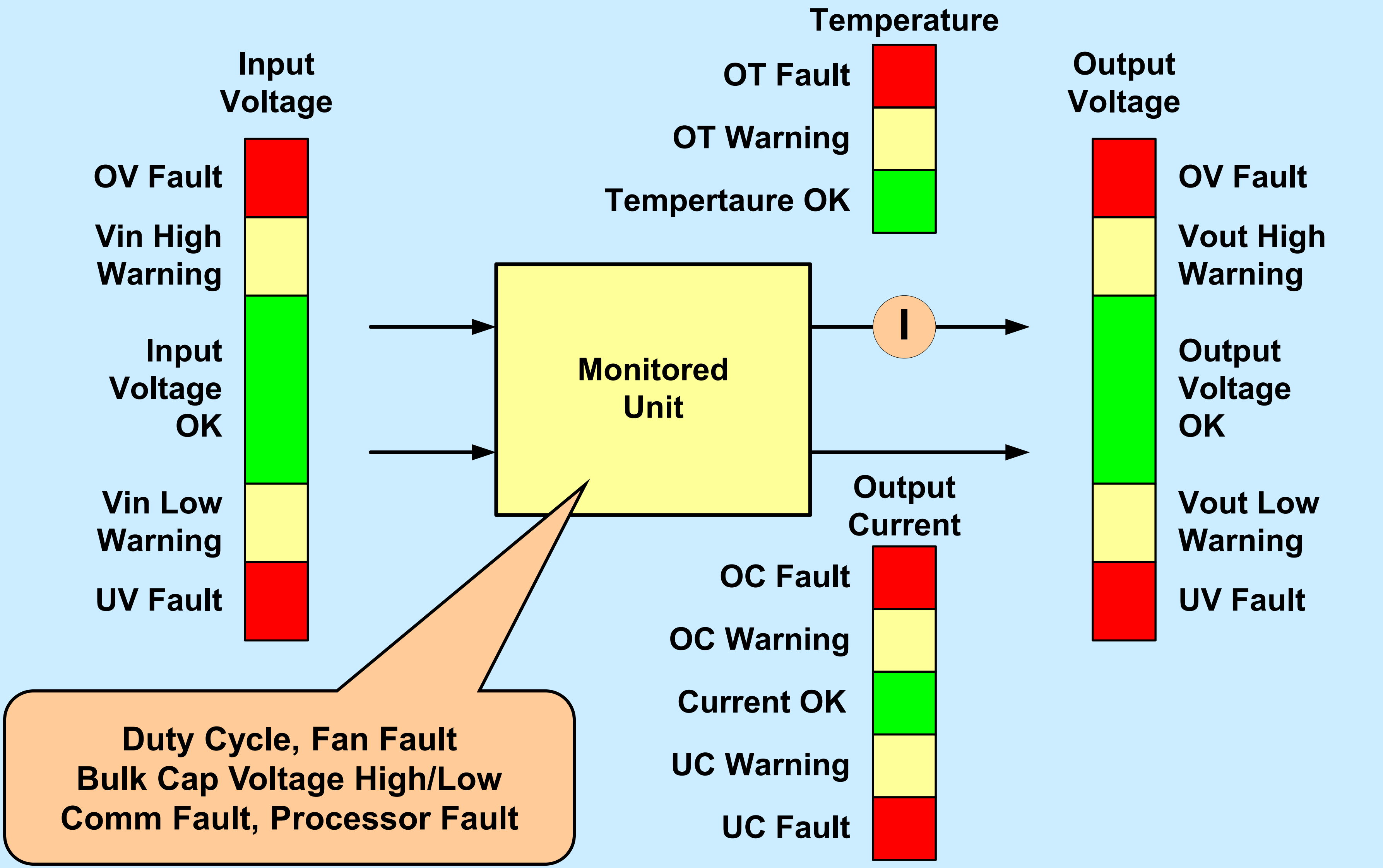
Status Monitoring Issues

- Accuracy Limitations
  - A Power Supply Is Not A Laboratory Instrument!
  - Input Power With ±5% Accuracy Is Not Reasonable
- Calculated Values Can Be Problematic
  - Example: VRM Output Power
  - Rapid Variation Of Current And Voltage Require Simultaneous Measurement For Accurate Result
- Data Packet Size Choice
  - Read Individual Parameters And Fault Status
  - Read “All At Once” In A Large Block

Status Monitoring
Reading Parametric Information

- Two Choices
- Take A Reading When Commanded
  - OK For Message Based Systems
  - Too Slow For Most Read/Write Data Transfer Systems
- Send A Value Already In Memory
  - How Is Age Of Data Controlled?

Fault Monitoring

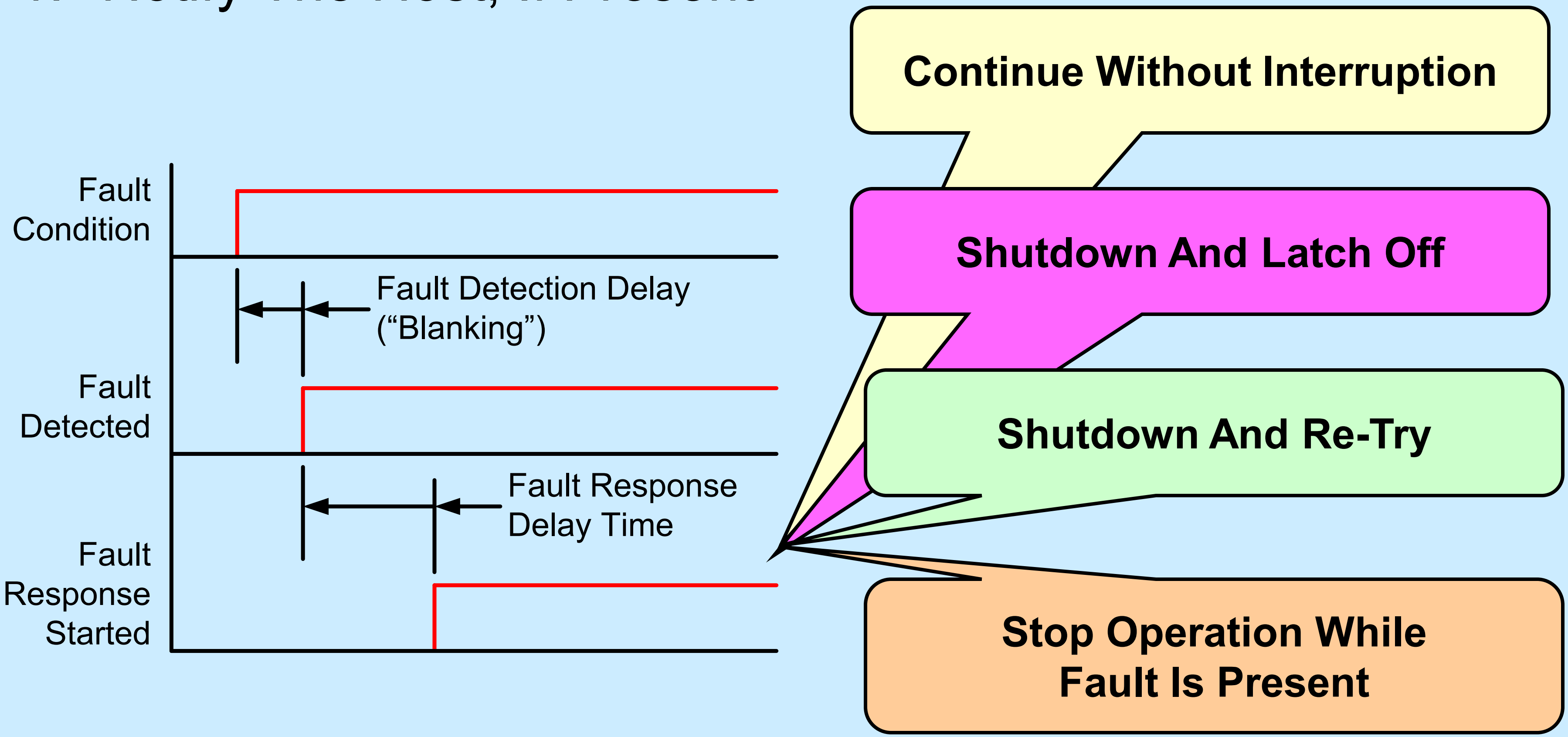


Fault Types And Response

- Warnings
  - Set Corresponding Status Bit(s)
  - Host Is Notified
  - The Device Keeps Operating
  - Threshold Value Programmed
    - Hysteresis May Also Be Programmed
- Faults
  - Set Corresponding Status Bit(s)
  - Host Is Notified
  - The Device Takes Some Action
  - Threshold Value Programmed
  - Fault Response Programmed

Fault Response Programming

1. Notify The Host, If Present



Fault Response Programming

- Delay Times
  - How Long To Suppress Fault Detection
  - How Long Of A Delay Before Starting Fault Response
  - How Long Between Retries
- Overcurrent Faults
  - Continue Or Shut Down After Delay Options Generally Means Constant Current Limiting
  - Option To Add Shutdown If Output Voltage Falls Below A Certain Value For A Given Period
- Undercurrent Fault
  - Stop Synchronous Rectification

Fault Response Programming
What Information Available To The Host?

- Two Possibilities
  - Status Bits
  - Values Captured At Time Of Fault
- Returning Values Sounds Good – But Make Sure The Information Has Value
  - If Fault Limits Are Programmed, Then Value That Initiates The Fault Are Already Known
  - Power Supplies Don't Make Good Data Loggers
- Make Sure Status Bits Are Useful
  - Easy To Have A Bit For Every Possible Condition Which Can Unnecessarily Increase Cost And Complexity

Summary

- Lots Of Choices – All Driven By Details
- There Is No Free Lunch;
  Lots Of "Pay Me Now Or Pay Me Later"
- No One Communications Bus Or Protocol
  Is Right For All Applications
- Understanding Your Needs Is Key
  To Making The Best Choice

Digital Power System Management Is Here To Stay