TekShare

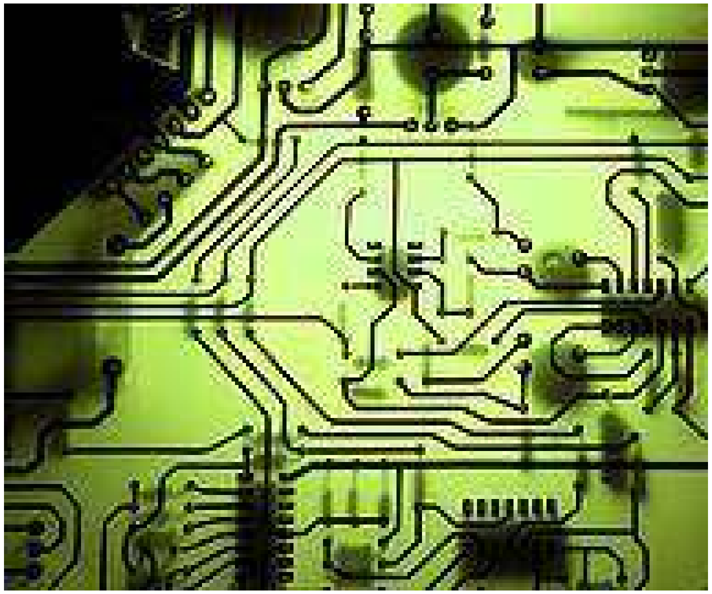
Serial Bus Decode Made Easy Webinar

CARL WONG

EVENT NUMBER: **980 0648 0374**

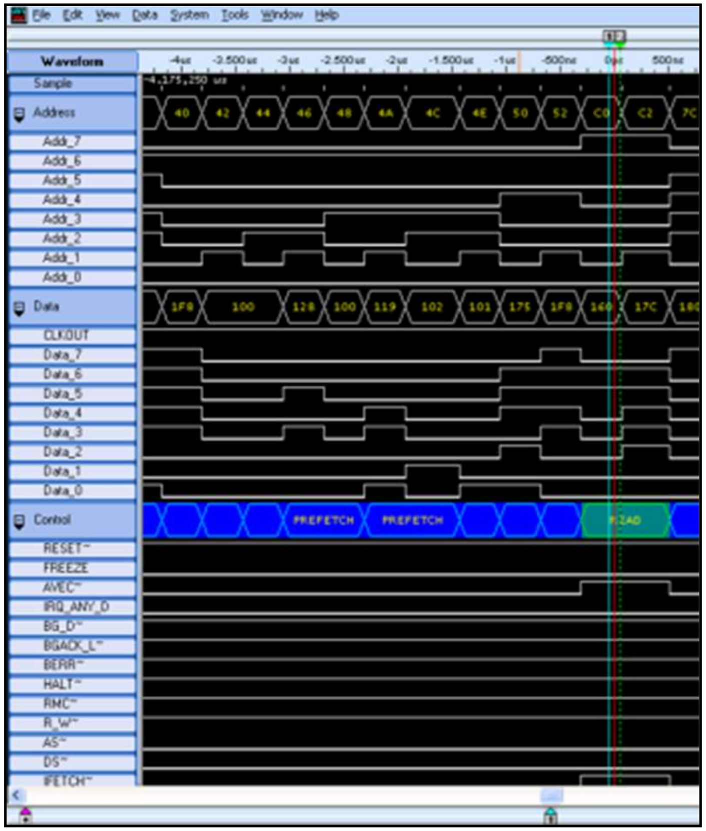
Agenda

- Introduction
- Serial Data Buses
  - I^2C
  - SPI
  - USB
  - Ethernet
  - RS-232
- Troubleshooting Your Device
- Summary



Transition from Parallel to Serial Buses

- Traditional way to connect digital devices used parallel buses
- Advantages
  - Simple point-to-point connections
  - All signals are transmitted in parallel
- Disadvantages
  - Occupies a lot of circuit board space
  - All connections must be the same length
  - Many connections limit reliability
  - Connectors may be very large
  - SSN and crosstalk (NEXT & FEXT) issues.
- With serial buses, these disadvantages are minimized



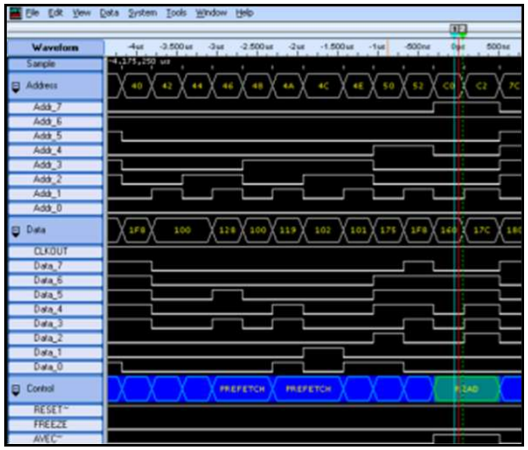
Design Implications of Serial Communication

- Product Design
  - Integrated into many processors, ASICs, and FPGAs
  - Easier signal routing
  - Less space, less weight, less power
  - Higher manufacturing yields and reliability
  - ***Improves circuit board designs, lowers cost and reduces form factor***

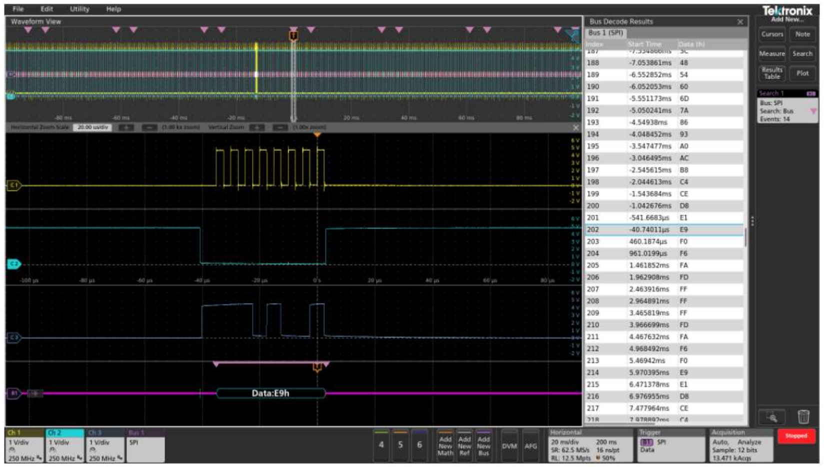
- System Design
  - SPI and I^{2}C buses enable connection of many ICs without external components.
  - CAN enables connection of sub-assemblies in automotive applications, and industrial controls in factory automation applications.
  - ***Simplifies designs of complex systems***.

Debug Challenges of Serial Data

- Parallel Buses
  - Each line has its own signal path
  - Clock is generally a separate line
  - Easy to decode
  - State and Pattern triggering and decoding are straightforward with a logic analyzer or mixed signal oscilloscope



- Serial Buses
  - Signals are spread over time
  - Clock is sometimes embedded
  - Decode is tedious
  - Must decode first to trigger on packet
  - Analysis solutions available on some oscilloscopes



Bus Decode Results

Bus 1 (SPI)

Index	Start Time	Data (h)
187	-7.554866ms	5C
188	-7.053861ms	48
189	-6.552852ms	54
190	-6.052053ms	60
191	-5.551173ms	6D
192	-5.050241ms	7A
193	-4.54938ms	86
194	-4.048452ms	93
195	-3.547477ms	A0
196	-3.046495ms	AC
197	-2.545615ms	B8
198	-2.044613ms	C4
199	-1.543684ms	CE
200	-1.042676ms	D8
201	-541.6683µs	E1
202	-40.74011µs	E9
203	460.1874µs	F0
204	961.0199µs	F6
205	1.461852ms	FA
206	1.962908ms	FD
207	2.463916ms	FF
208	2.964891ms	FF
209	3.465819ms	FF
210	3.966699ms	FD
211	4.467632ms	FA
212	4.968492ms	F6
213	5.46942ms	F0
214	5.970395ms	E9
215	6.471378ms	E1
216	6.976955ms	D8
217	7.477964ms	CE
218	7.978892ms	C4

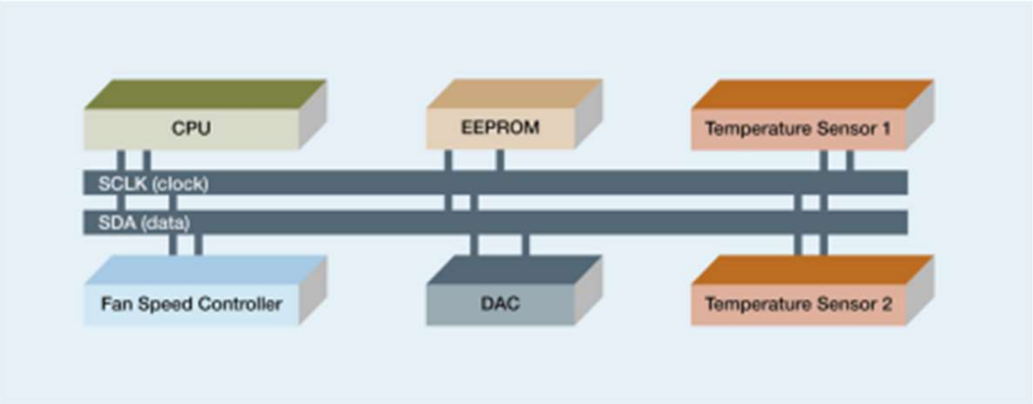
Serial data complicates bus troubleshooting

Serial Bus Review

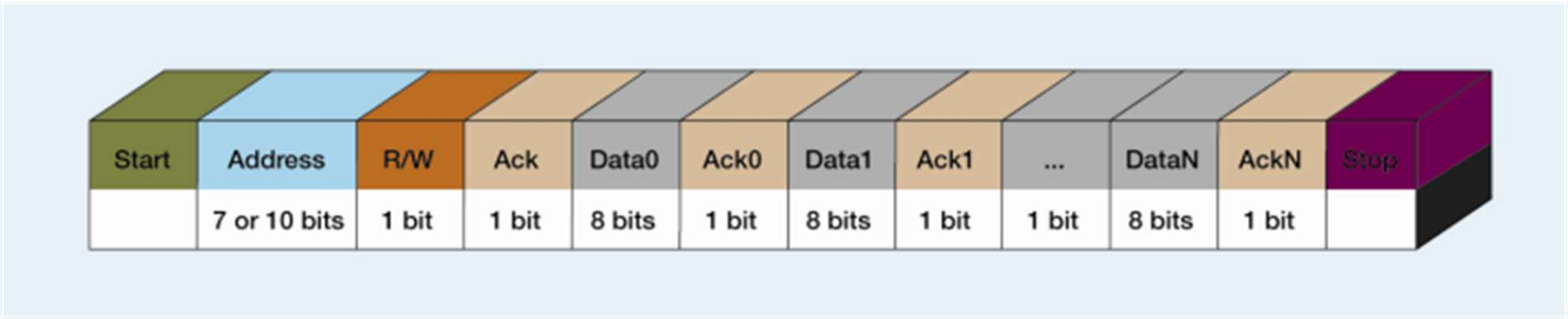
- I2C
- SPI
- USB
- Ethernet
- RS-232
- CAN
- MIL-STD-1553
- Audio

I^{2}C (Inter-Integrated Circuit)

- Used for chip-to-chip communication between microcontrollers and A/Ds, D/As, FPGAs, sensors, etc.
- Uses two single-ended, bi-directional signals: clock and data
- Any I^{2}C device can be attached to the bus
- Multiple masters and slaves on the bus
- Data rates:
  - Standard Mode (100 kbps)
  - Fast Mode (400 kbps)
  - High Speed Mode (3.4 Mbps)



I^{2}C Message Structure



Start	Address	R/W	Ack	Data0	Ack0	Data1	Ack1	...	DataN	AckN	Stop
	7 or 10 bits	1 bit	1 bit	8 bits	1 bit	8 bits	1 bit	1 bit	8 bits	1 bit	

- Start: Indicates the device is taking control of the bus and a message will follow
- Address: 7-bit or 10-bit number representing the slave device address to read or write with MSB first.
- R/W: Read(0), write(1).
- Data: Integer number of bytes read from or written to the device with MSB first.
- Acknowledge: 1-bit from the slave device acknowledging the master's actions
- Stop: Indicating the message is complete and the master has released the bus

SPI (System Peripheral Interface)

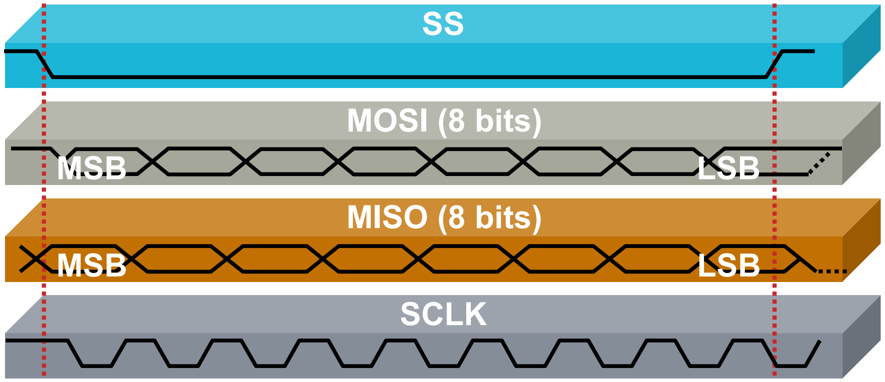
- Used primarily to communicate between microcontrollers and their immediate peripheral devices
- Typical configuration has four signals: SCLK, MOSI, MISO, SS
  - Data is simultaneously transmitted and received
  - SS line used to specify slave device
  - Each unique device on bus has its own SS signal from master
- Multiple bus configurations are allowed
  - Network can use 2-, 3-, or 4-wire bus topology
- Data rates up to 10 Mbps

SS – enables slave device to accept data

MOSI – data from the master to a slave

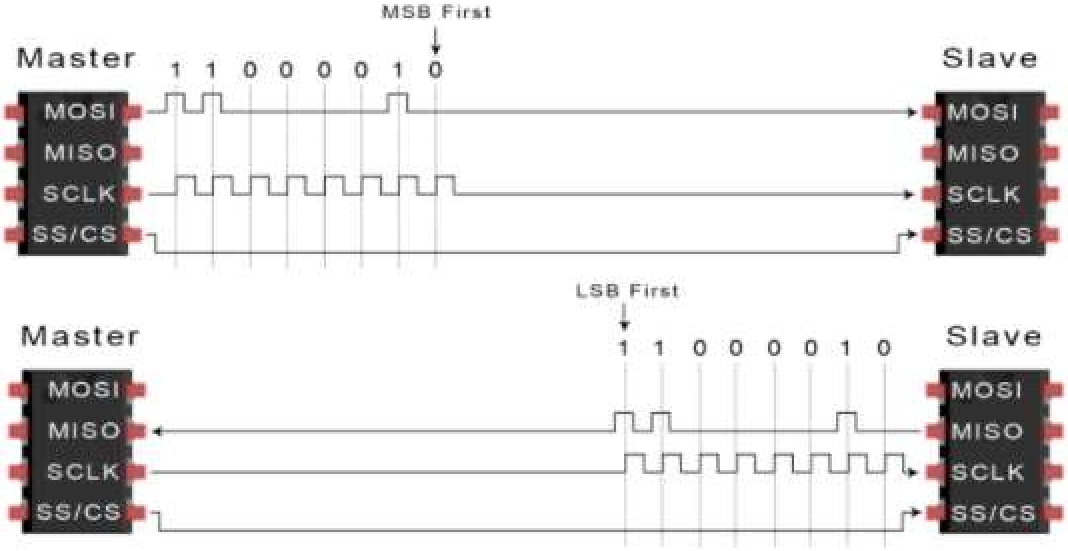
MISO – data from a slave to the master

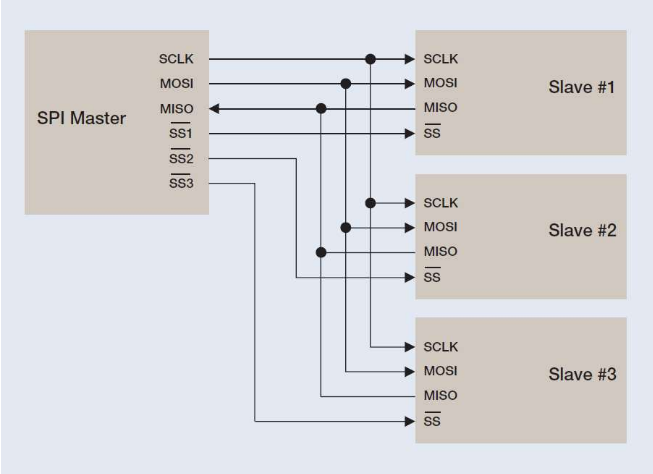
SCLK – serial clock driven by Master

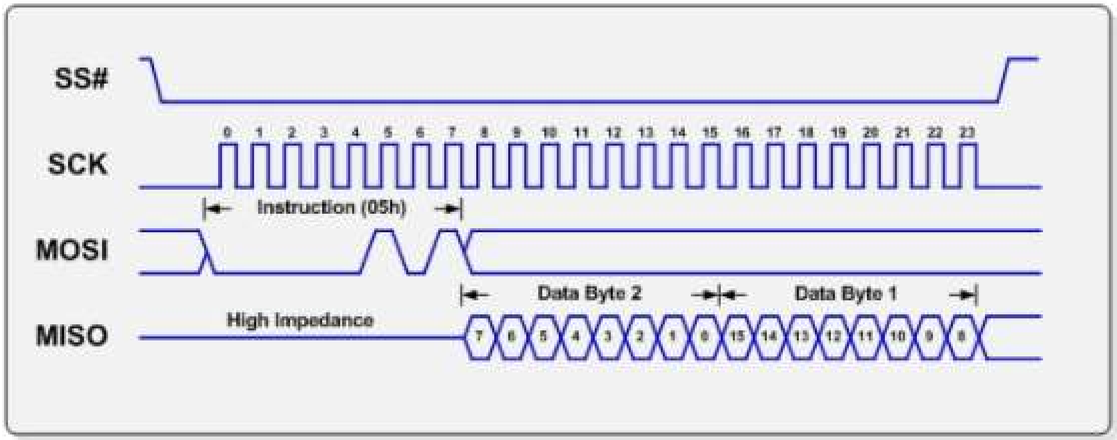


SPI (Serial Peripheral Interface)

- Step of SPI data transmission







SS – enables slave device to accept data

MOSI – data from the master to a slave

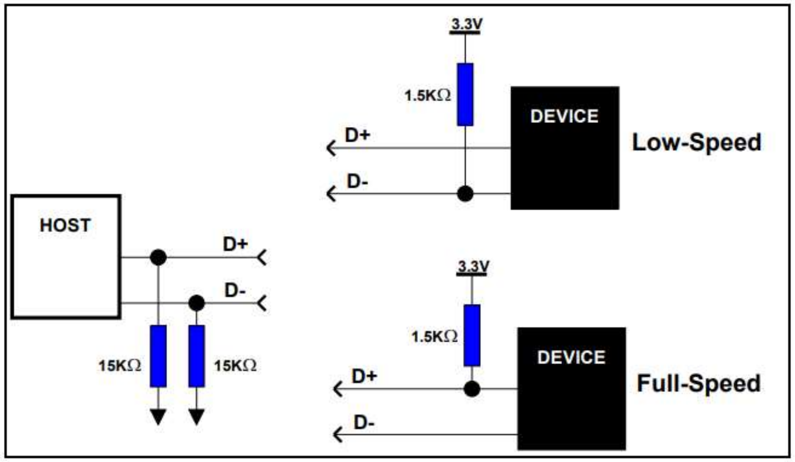
MISO – data from a slave to the master

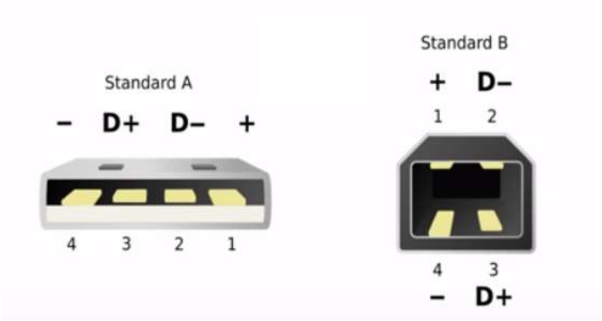
SCLK – serial clock driven by Master

USB (Universal Serial Bus)

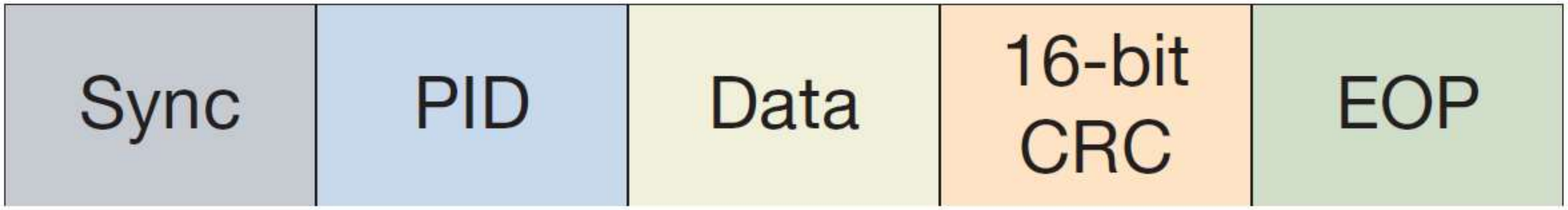
- Used for system-to-system communication between subsystems, peripherals and other devices

- Data rates:
  - Low Speed (1.5 Mbps)
  - Full Speed (12 Mbps)
  - High Speed (480 Mbps)
  - Super Speed (5 Gbps)
  - Super Speed+ (10 Gbps)





USB 2.0 Data Packet Structure

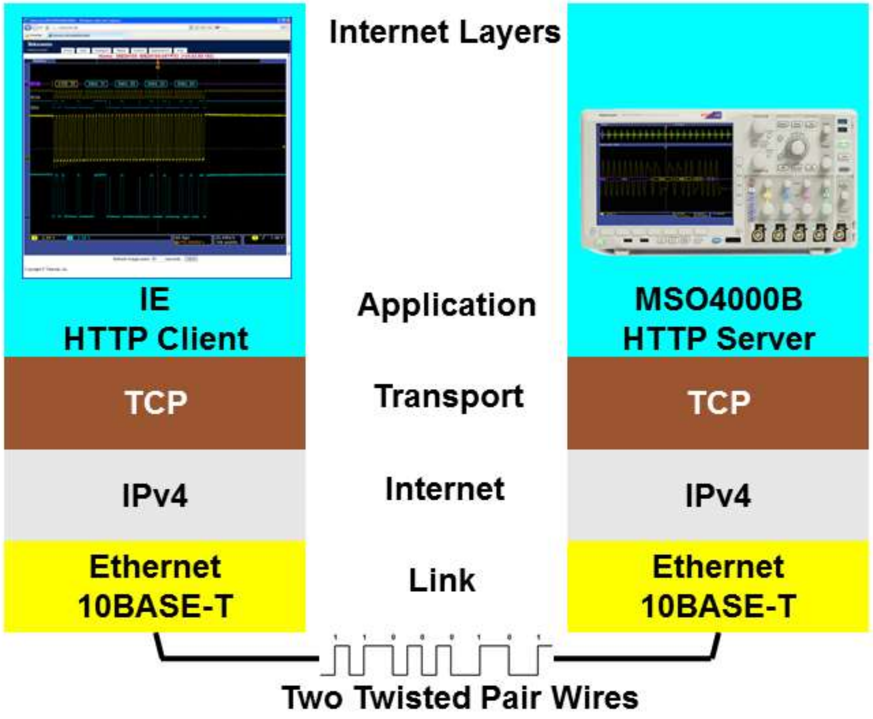


Sync	PID	Data	16-bit CRC	EOP

- Sync: The sync field is 8 bits long at low and full speed or 32 bits long for high speed and is used to synchronize the clock of the receiver with that of the transmitter. The last two bits indicate where the PID fields starts.
- Packet Identifier (PID): Identifies the type of packet being sent (DATA0, DATA1), TOKEN. DATA, Handshake, Special. 4bits and another 4bits are complemented and repeated.
- Data: Maximum data payload of 8, 1023, and 1024 bytes for low, full and high speed devices respectively
- Cyclic Redundancy Check (CRC): 16-bit code used for error-detection
- End of Packet: Indicates the packet is complete

Ethernet

- Used for system-to-system communication between subsystems, peripherals and other devices within a local area network (LAN).
- Uses unshielded twisted-pair cabling (UTP)
- Data rates:
  - 10BASE-T(10 Mbps)
  - 100BASE-T (100 Mbps)
  - 1000BASE-T (1000 Mbps)
  - 10GBASE-T (10 Gbps)



Internet Layers

IE
HTTP Client

Application

MSO4000B
HTTP Server

TCP

Transport

TCP

IPv4

Internet

IPv4

Ethernet
10BASE-T

Link

Ethernet
10BASE-T

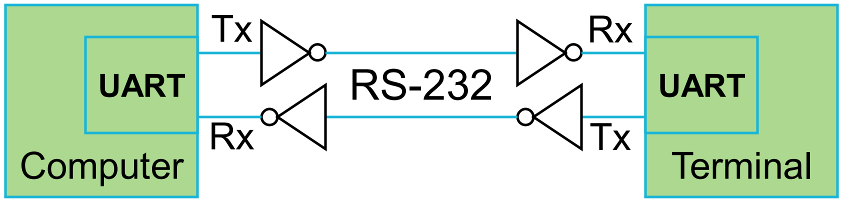
Two Twisted Pair Wires

Ethernet Frame Format

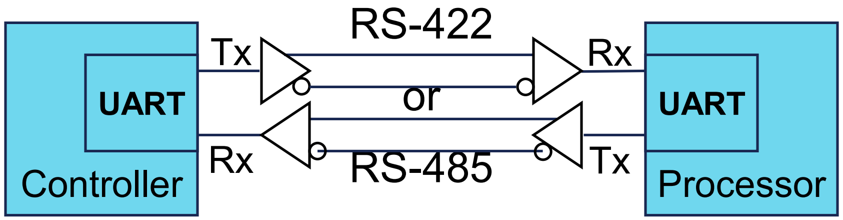
Header Offset in Bytes	Field Name	Field Length in Bytes
0 - 6	Preamble (PRE)	7
7	Start-of-frame Delimiter (SFD)	1
8 - 13	Destination Address (DA)	6
14 - 19	Source Address (SA)	6
20 - 21	Length/Type	2
22 - 67 to 1521	Data + Pad	46-1500
At end of data	Frame check sequence (FCS)	4

RS-232/422/485/UART

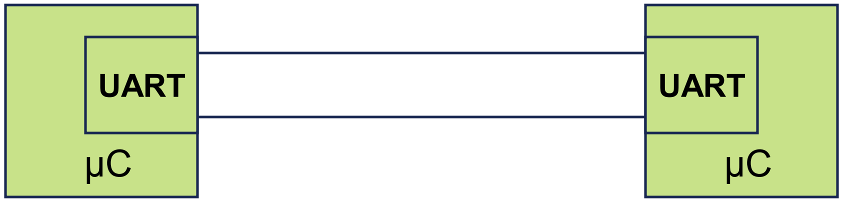
- Point-to-point communication at slow speeds over short distances
- Two single-ended signals provide point-to-point, full-duplex communication
- Standard does not specify character encoding, data framing, or protocols
- Transmission systems:
  - Managed by Universal Asynchronous Receiver/Transmitters (UARTs)
  - Pre-determined bit rate
  - RS-232 is an inverting, single-ended high-voltage interface
  - RS-422 or RS-485 are differential interfaces
  - Or ICs can be connected directly



RS-232 Application Example

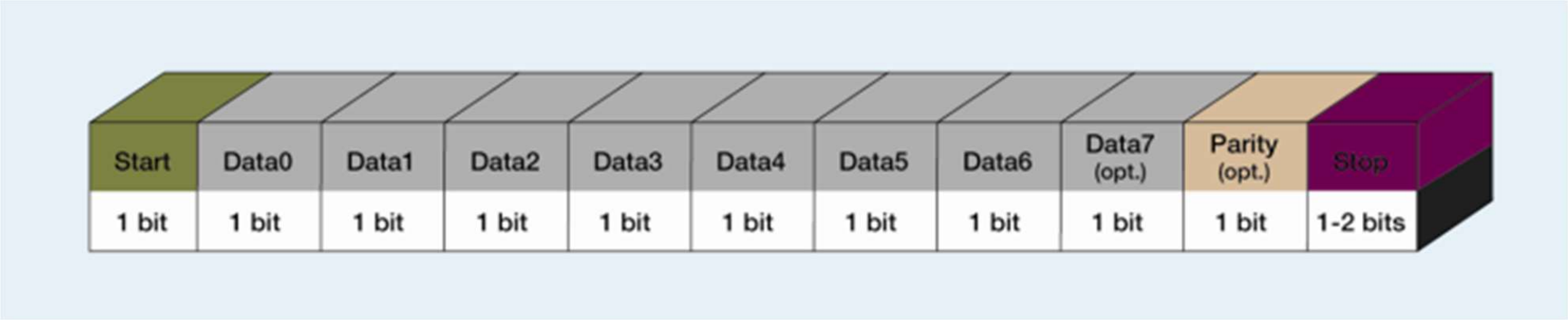


Audio and Video Application Example



Embedded Communication Application Example

RS-232 Byte Structure



Start	Data0	Data1	Data2	Data3	Data4	Data5	Data6	Data7 (opt.)	Parity (opt.)	Stop
1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1 bit	1-2 bits

- Each character begins with a Start bit, a logic “0”
- Character is comprised of 7 or 8 data bits
- Optional Parity bit is next
- Terminated in 1, 1.5, or 2 stop bits

POLL QUESTION 1

Which of the following serial buses do you commonly dealt with?

a. Embedded Design (I2C, SPI)

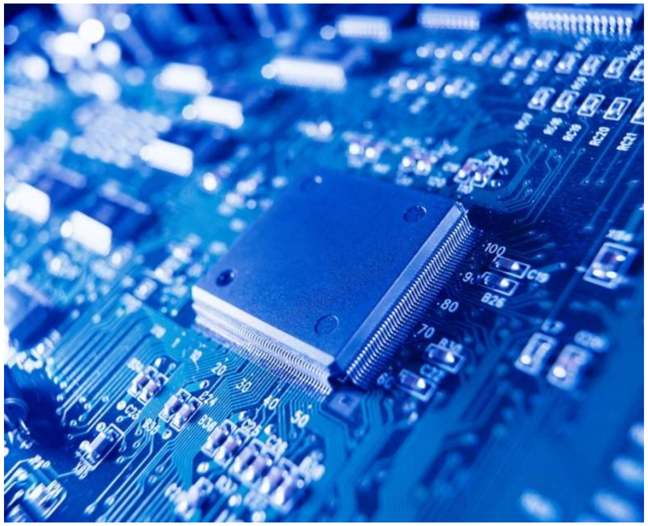
b. Automotive (CAN, LIN, FlexRay, Ethernet)

c. USB

d. Others… Please name it..

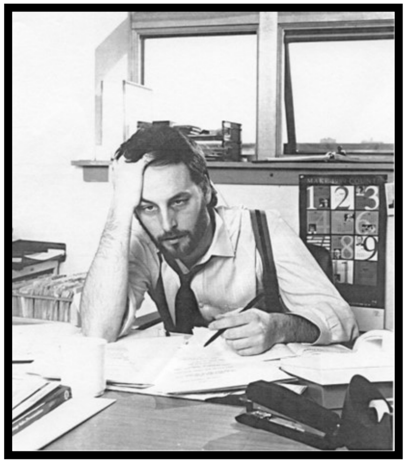
Troubleshooting Your Device

- **Decode of Serial Data**
- Capture and Search for Specific Messages
- Characterize System Timing
- Trace Data Flow Through a Network
- In-Depth Analysis of Network Performance



Decode of Serial Data

- ***Hardware Engineers:*** verify connections and adequate signal integrity for the bus to transmit data.
  - Monitor waveforms and decoded bus data values



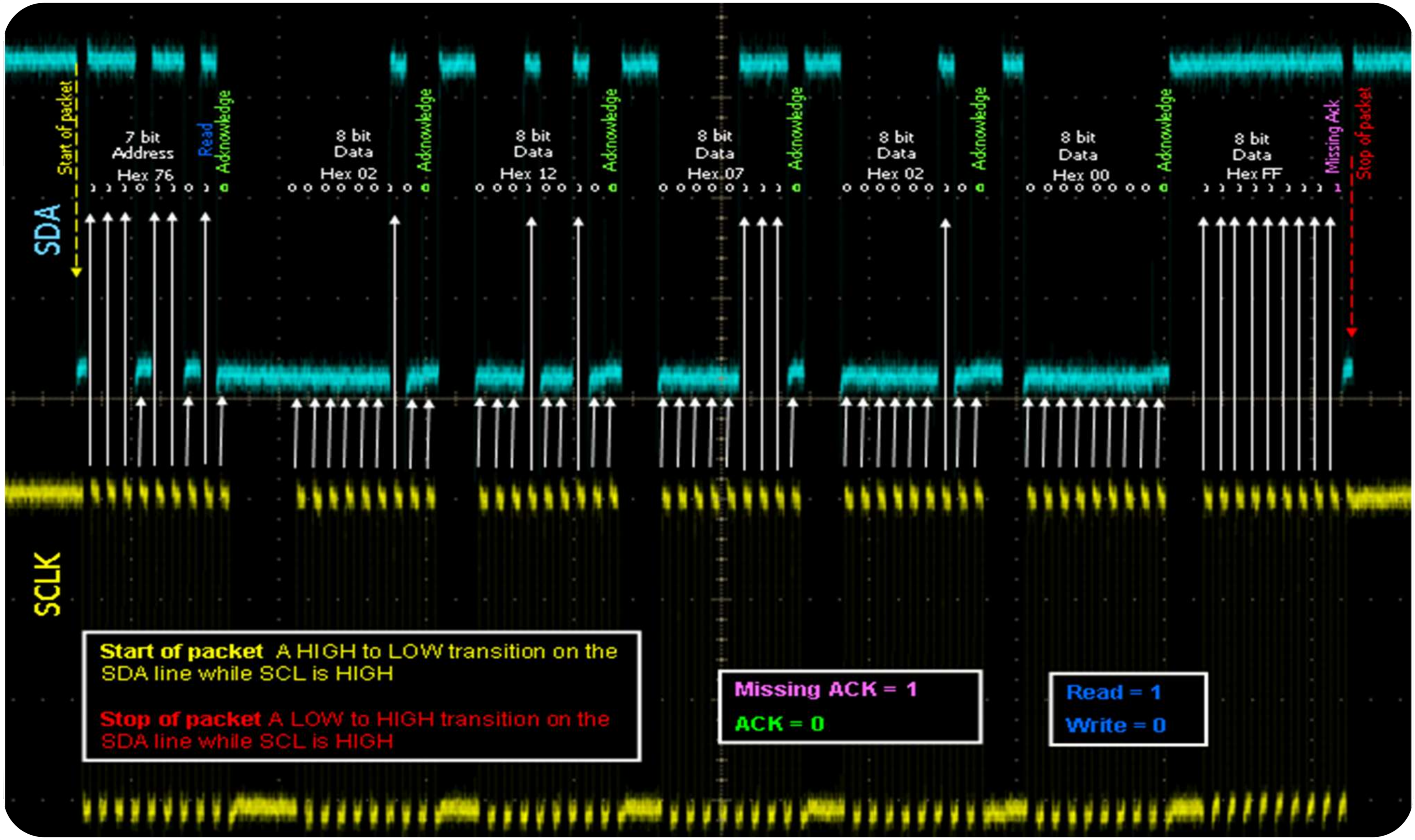
- ***Software/Firmware Engineers:*** verify bus messages are being sent as expected.
  - Waveform displays are not the preferred format.

- ***System Engineers:*** verify system components are working together as designed.
  - Again, waveform displays are not the preferred format.

Bus waveforms can be manually decoded…

But it is tedious and error-prone.

Example - I^{2}C Manual Decoding



Start of packet A HIGH to LOW transition on the SDA line while SCL is HIGH

Stop of packet A LOW to HIGH transition on the SDA line while SCL is HIGH

Missing ACK = 1

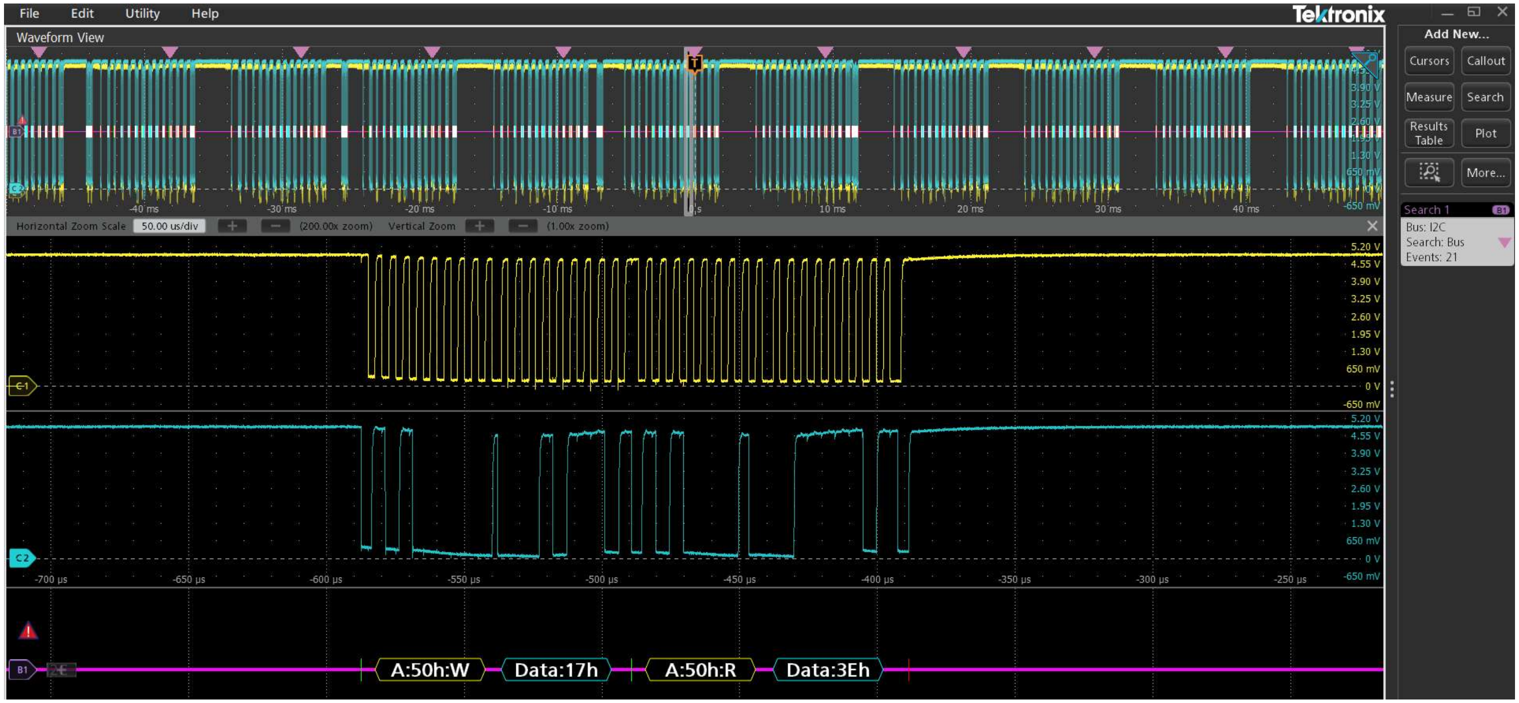
ACK = 0

Read = 1

Write = 0

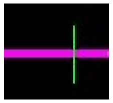
Automated Decode with Tektronix’ Oscilloscopes

Tektronix MSO4 Series Automated Decode

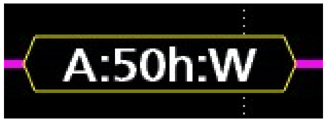


Horizontal Zoom Scale 50.00 us/div (200.00x zoom) Vertical Zoom (1.00x zoom)

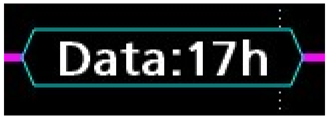
Bus: I2C
Search: Bus
Events: 21



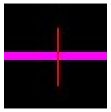
Start



Address
[W] for Write, [R] for Read
Displayed in hex or binary



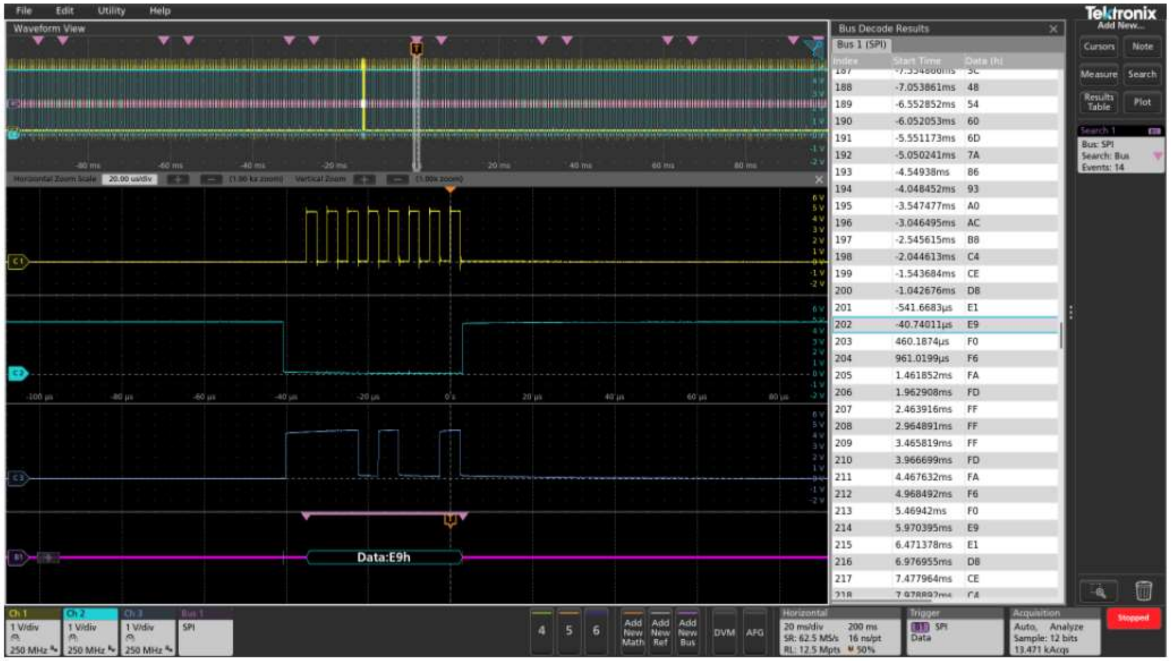
Data
Displayed in hex or binary



Stop

Event Table for Viewing Bus Traffic

- Shows decoded message content with time stamps
- View bus traffic in tabular format
- Compare with software listings
- Easy timing measurements



Bus Decode Results

Bus 1 (SPI)

Index	Start Time	Data (h)
187	[illegible]	5C
188	-7.053861ms	48
189	-6.552852ms	54
190	-6.052053ms	60
191	-5.551173ms	6D
192	-5.050241ms	7A
193	-4.54938ms	86
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215	6.471378ms	E1
216	6.976955ms	D8
217	7.477964ms	CE
218	7.978892ms	C4

Bus: SPI
Search: Bus
Events: 14

Ch 1 1 V/div 250 MHz · Ch 2 1 V/div 250 MHz · Ch 3 1 V/div 250 MHz · Bus 1 SPI

Horizontal: 20 ms/div 200 ms · SR: 62.5 MS/s 16 ns/pt · RL: 12.5 Mpts 50%

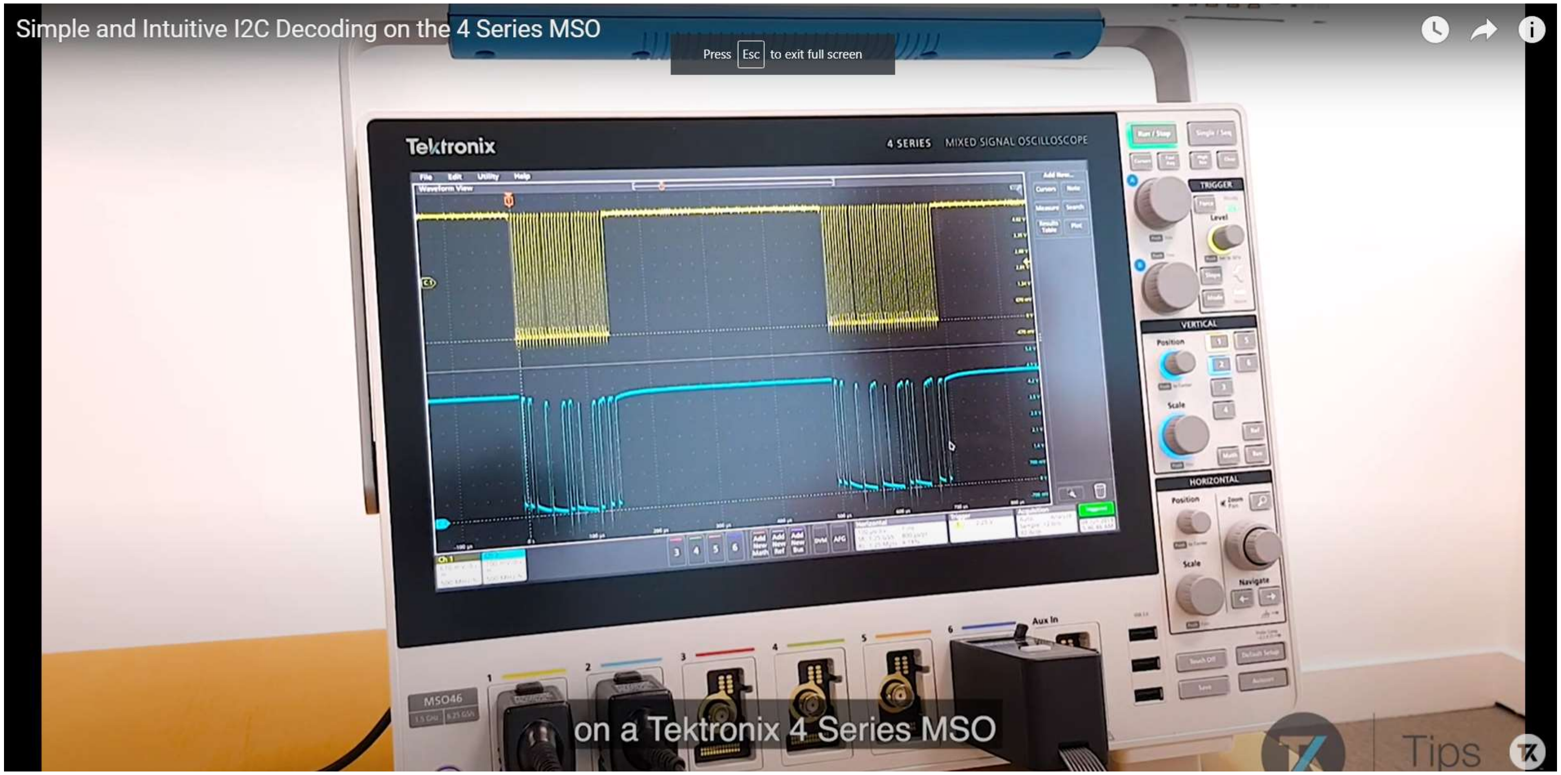
Trigger: B1 SPI Data

Acquisition: Auto, Analyze · Sample: 12 bits · 13.471 kAcqs

Tektronix MSO4 Series Event Table

Simple and Intuitive I2C Decoding on the 4 Series MSO

https://www.youtube.com/watch?v=ByksjkE6wUE&t=24s



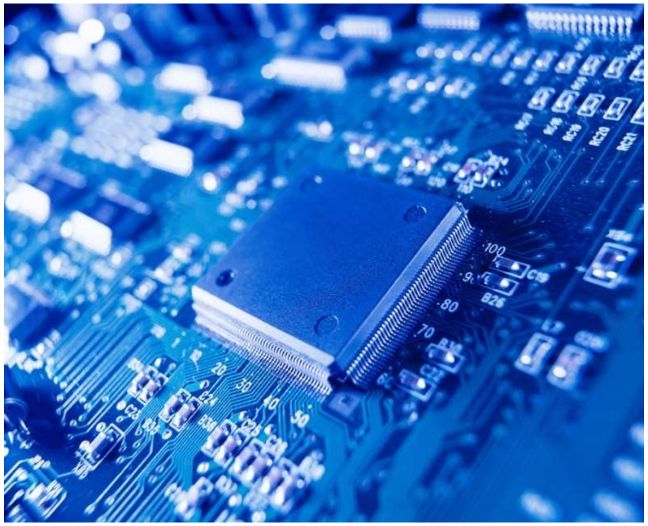
Simple and Intuitive I2C Decoding on the 4 Series MSO

Press Esc to exit full screen

on a Tektronix 4 Series MSO

Troubleshooting Your Device

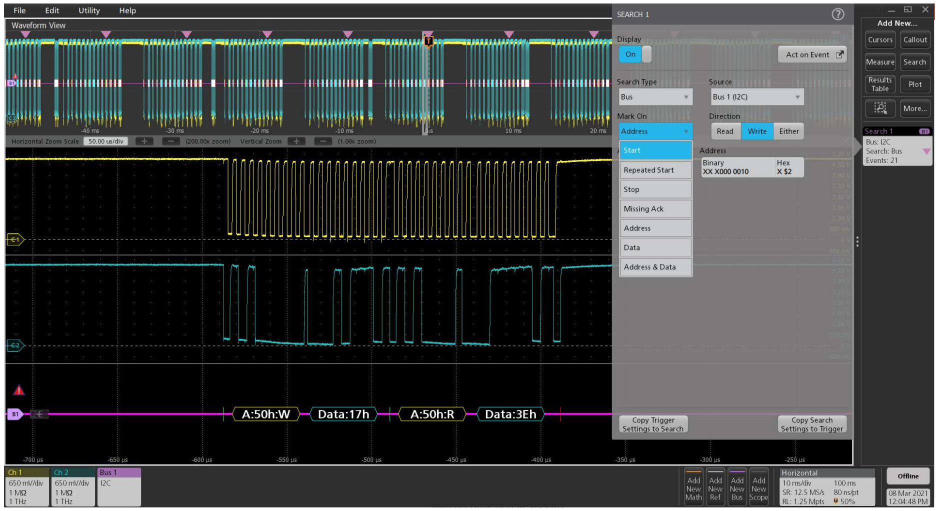
- Decode of Serial Data
- **Capture and Search for Specific Messages**
- Characterize System Timing
- Trace Data Flow Through a Network
- In-Depth Analysis of Network Performance



Capture a Specific Message

- Even if you can easily decode messages, the message of interest probably wasn't captured
- Need to specify messages to ***capture***:
  - In the language of the serial bus standard
  - On all critical elements of the serial message
  - With full or partial specification
- Tektronix' oscilloscopes offer serial data triggers

I2C Trigger on MSO4 Series



SEARCH 1

Display: On

Search Type: Bus

Source: Bus 1 (I2C)

Mark On: Address

Direction: Write

Address: Binary XX X000 0010 Hex X $2

Search 1
Bus: I2C
Search: Bus
Events: 21

Ch 1: 650 mV/div, 1 MΩ, 1 THz

Ch 2: 650 mV/div, 1 MΩ, 1 THz

Bus 1: I2C

Horizontal: 10 ms/div, 100 ms, SR: 12.5 MS/s, 80 ns/pt, RL: 1.25 Mpts, 50%

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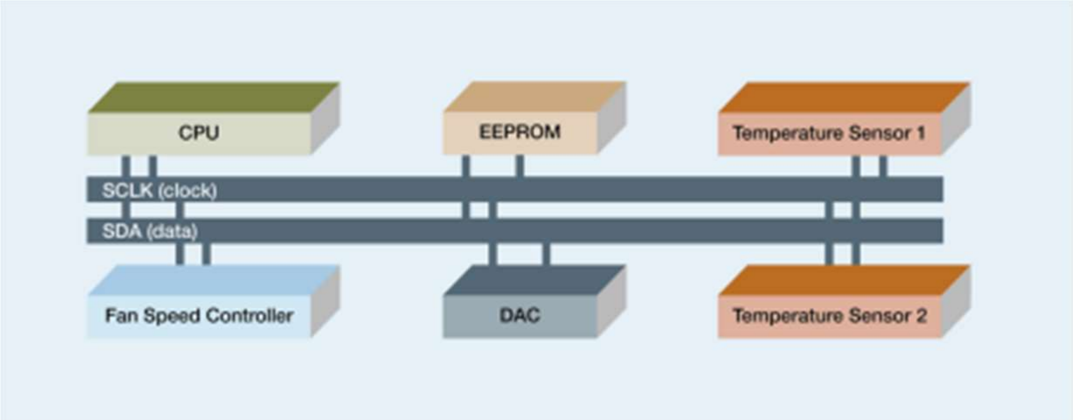
An Example: Faulty Thermal Management System

- The product is overheating and shutting off.

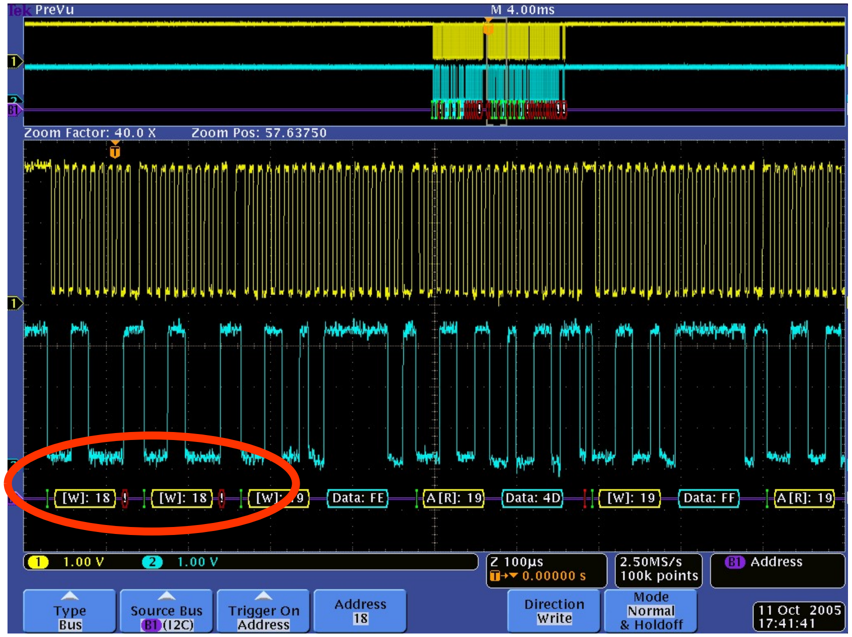
- Microprocessor-controlled thermal management system should sense the product’s internal temperature and adjust the fan speed.
  - All of the circuits appear to have the correct power applied.
  - The processor is running and appears to be communicating with the sensors and the fan control module.
  - The software team is sure that the software is running as designed.

- Yet, the product is getting hot and the fan is not turning on.



Trigger on Packet Content

- Trigger on address 18 (sensor).
- Software tries to communicate with the sensor – twice!
- No response.
- Moves to the next address, as designed.
- Upon close inspection of the board, a cold solder joint was found on the fan controller IC.



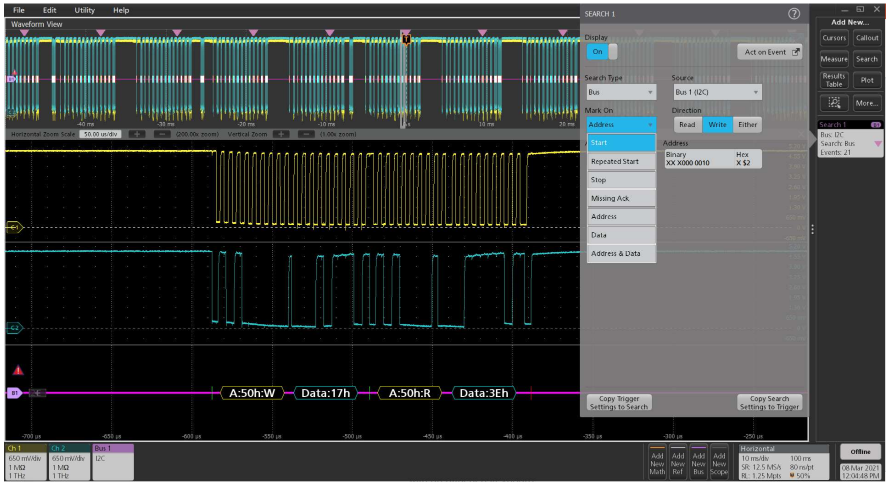
Search for a Specific Message

- Even if you capture the message of interest, now you have to find it!

- Need to specify messages to ***search*** for:
  - In the language of the serial bus standard
  - On all critical elements of the serial message
  - With full or partial specification
  - Same conditions as needed for ***capture***

- Tektronix' oscilloscopes provide automatic search and mark capabilities

Search & Mark Function on MSO4 Series


SEARCH 1

Display: On

Search Type: Bus

Source: Bus 1 (I2C)

Mark On: Address

Direction: Write

Address: Binary XX X000 0010, Hex X $2

Search 1: Bus: I2C, Search: Bus, Events: 21

Troubleshooting Your Device

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- Trace Data Flow Through a Network
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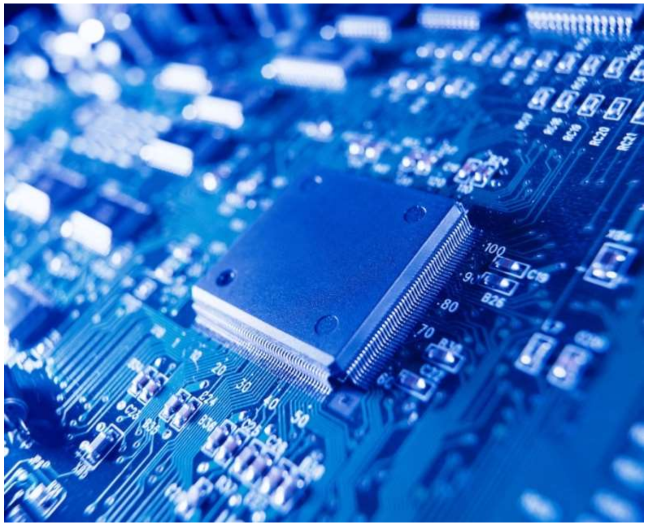
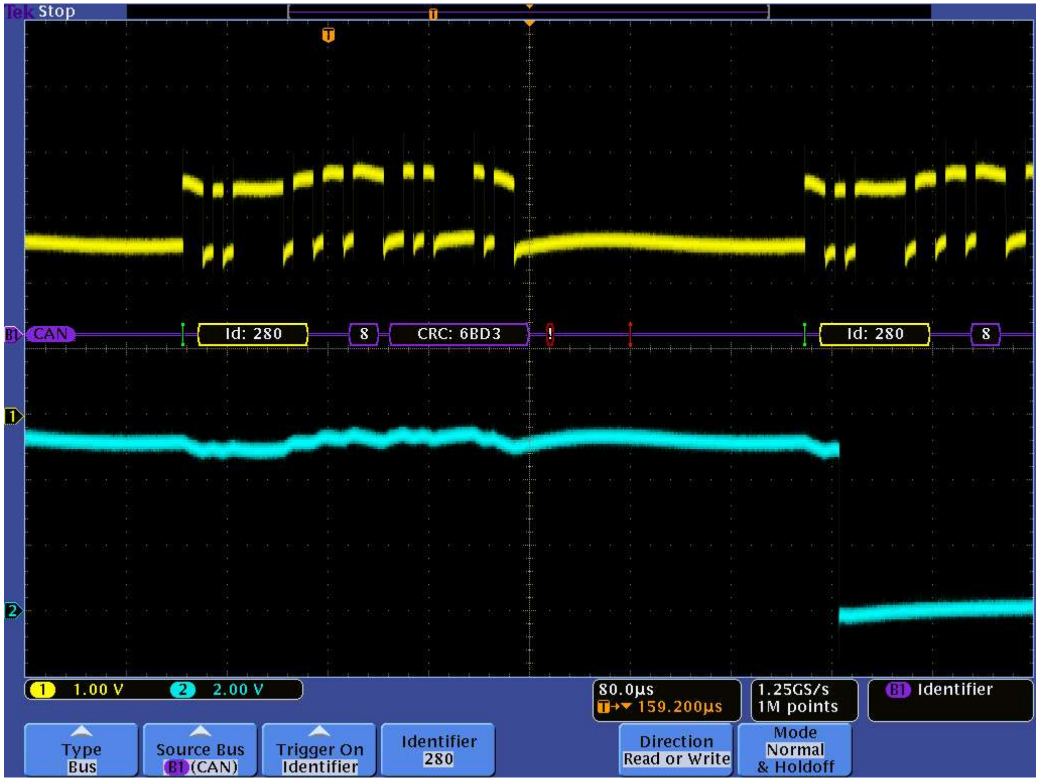


Characterize System Timing

- Characterize timing between bus messages and system operation
    - Requires waveform displays time-correlated with decoded messages
- Characterize timing differences which occur when adding a new network node to an existing network
- Automotive application example:
    - Measure worst-case time from crash sensor output to airbag activation
    - Measure variations in timing of airbag activation with varying levels of CAN bus traffic

Characterizing System Timing with Tektronix' Oscilloscopes

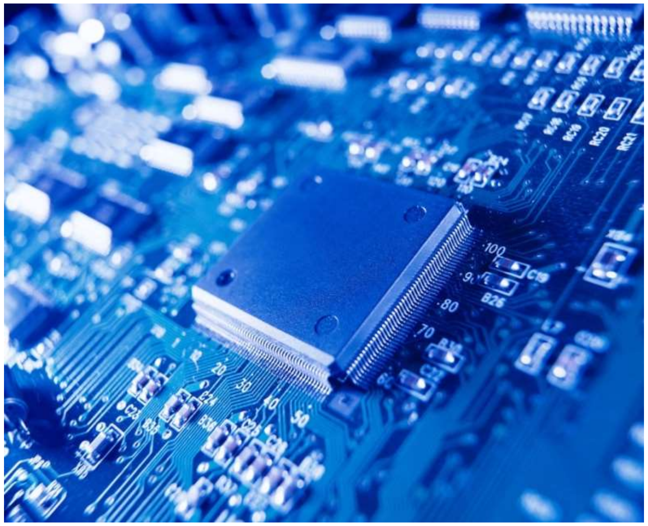
- Tektronix' oscilloscopes provide integrated tools for characterizing timing between bus messages and system operation:
  - Time-correlated waveform displays and decoded bus messages
  - Intensity-graded infinite persistence displays to show variations in timing



Tektronix MDO4000C Series

Troubleshooting Your Device

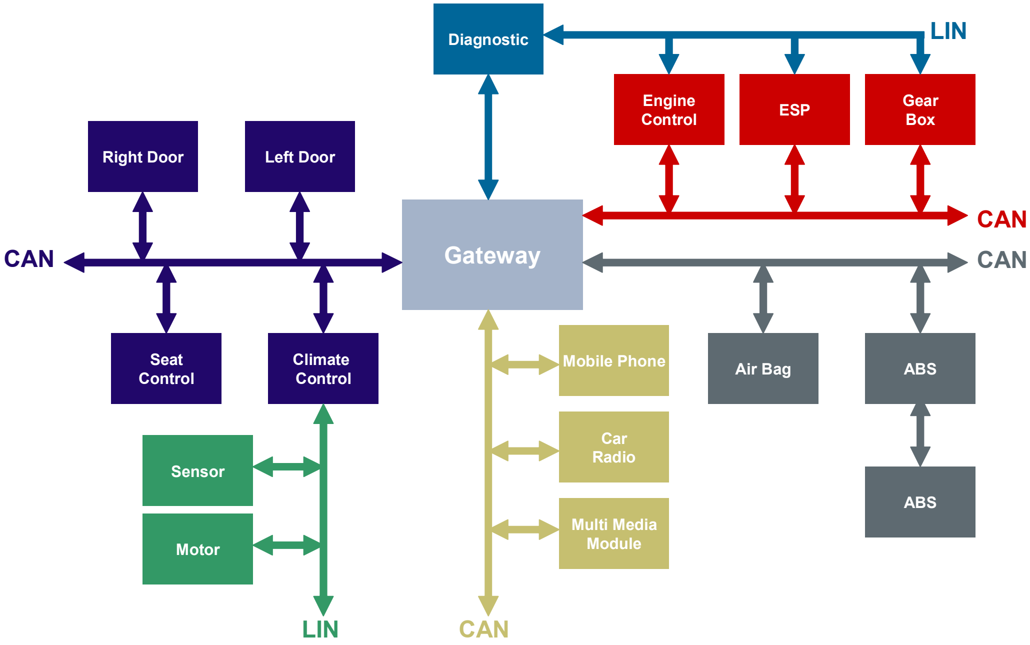
- Decode of Serial Data
- Capture and Search for Specific Messages
- Characterize System Timing
- **Trace Data Flow Through a Network**
- In-Depth Analysis of Network Performance



Trace Data Flow Through a Network

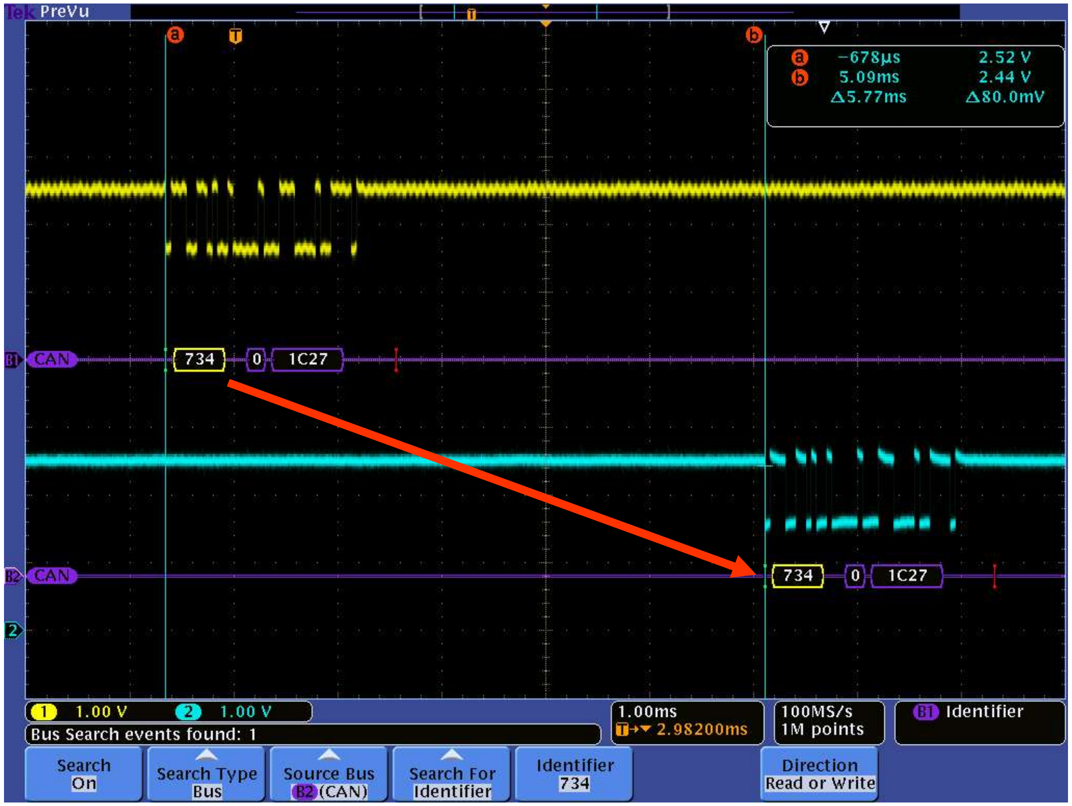
- Trace serial data flow between nodes through a network
  - Simultaneously display messages at transmitter and receiver to verify continuity and propagation delays

- Trace serial data flow between network segments separated by a gateway
  - Simultaneously display messages from multiple buses, at different speeds, or even different bus standards



Tracing Data Flow with Tektronix’ Oscilloscopes

- Tektronix’ oscilloscopes simultaneously display messages at different points in the network
  - Verify continuity and propagation delays on up to 3 buses
  - Validate network gateway operation by decoding different bus speeds & protocols



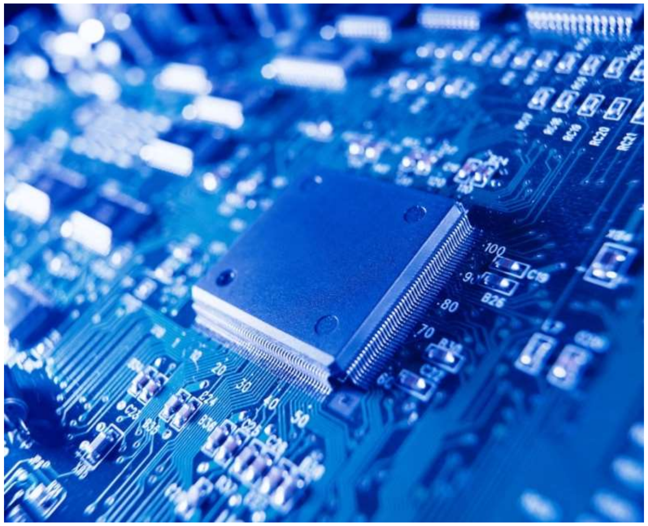
```
a  −678µs     2.52 V
b   5.09ms    2.44 V
   Δ5.77ms   Δ80.0mV
```

```
1  1.00 V   2  1.00 V
Bus Search events found: 1
1.00ms   T→▾ 2.98200ms
100MS/s   1M points
B1 Identifier
```

Tektronix MDO4000C Series

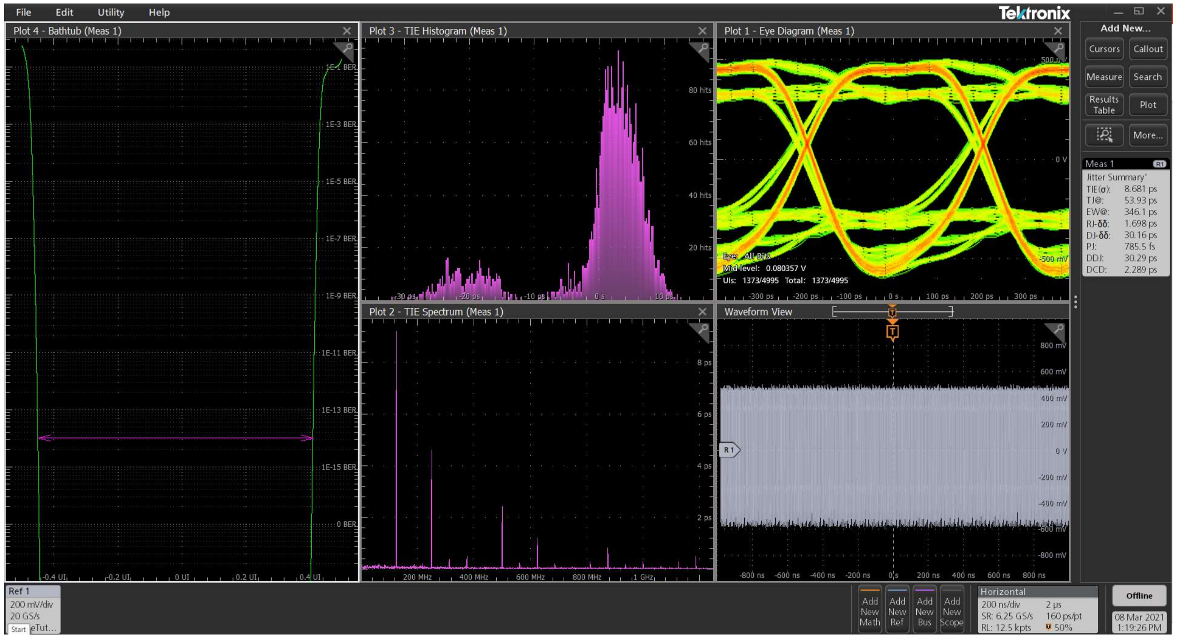
Troubleshooting Your Device

- Decode of Serial Data
- Capture and Search for Specific Messages
- Characterize System Timing
- Trace Data Flow Through a Network
- **In-Depth Analysis of Network Performance**



Eye Diagram Analysis with Tektronix' Oscilloscopes

- Quickly locate noise caused by jitter, amplitude aberrations, spikes and glitches
  - Eye diagram shows changes in amplitude and jitter in the CAN bus signal
  - Measure amplitude and jitter with cursors



Eye: All Bits
Mid-level: 0.080357 V
UIs: 1373/4995 Total: 1373/4995

```
Meas 1                R1
Jitter Summary'
TIE(σ):     8.681 ps
TJ@:        53.93 ps
EW@:        346.1 ps
RJ-δδ:      1.698 ps
DJ-δδ:      30.16 ps
PJ:         785.5 fs
DDJ:        30.29 ps
DCD:        2.289 ps
```

```
Ref 1
200 mV/div
20 GS/s
eTut...
```

```
Horizontal
200 ns/div       2 µs
SR: 6.25 GS/s    160 ps/pt
RL: 12.5 kpts    50%
```

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Jitter Analysis with MSO5 Series

Debug Serial Buses with the 5 Series MSO

THE LARGEST DISPLAY. THE MOST CHANNELS. THE GREATEST EXPERIENCE

Five Industry Firsts

1. Reconfigurable scope inputs (FlexChannel^{TM} inputs)
2. 4, 6, and 8 channel product family
3. 15.6” HD (1,920 x 1,080) display with capacitive touch
4. User interface actually designed for touch
5. Optional Windows 10 operating system

4 Series MSO

EXTREME VISIBILITY, VERSATILITY, AND USABILITY FOR ANY BENCH

Bandwidths from 200 MHz to 1.5 GHz
4 or 6 FlexChannel inputs

- 13.3” High Definition (1920 x 1080) capacitive touch display
- Award-winning intuitive user interface
- Up to 6 FlexChannel inputs
- 12-bit A/Ds behind all channels
- Serial bus decode, trigger and search
- Optional built-in arbitrary / function generator
- Fully upgradeable

POLL QUESTION 2

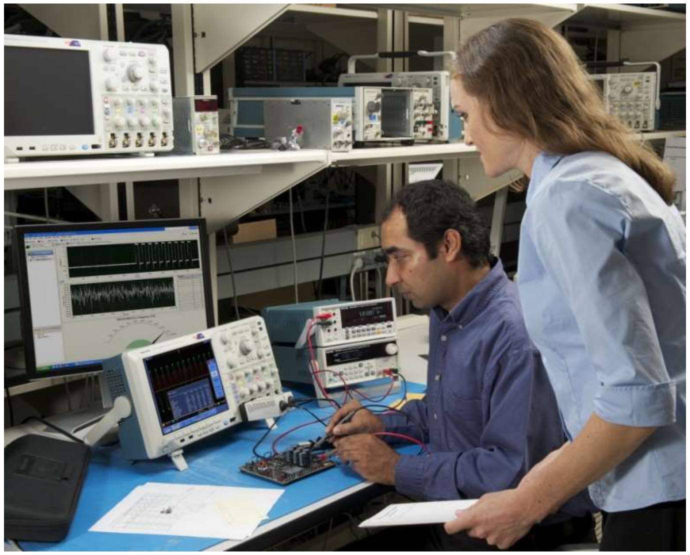
In your experience, which equipment do you prefer to use for serial bus decoding and analysis?

a. Oscilloscope with Protocol Decoding capability

b. Standalone Protocol Analyzer

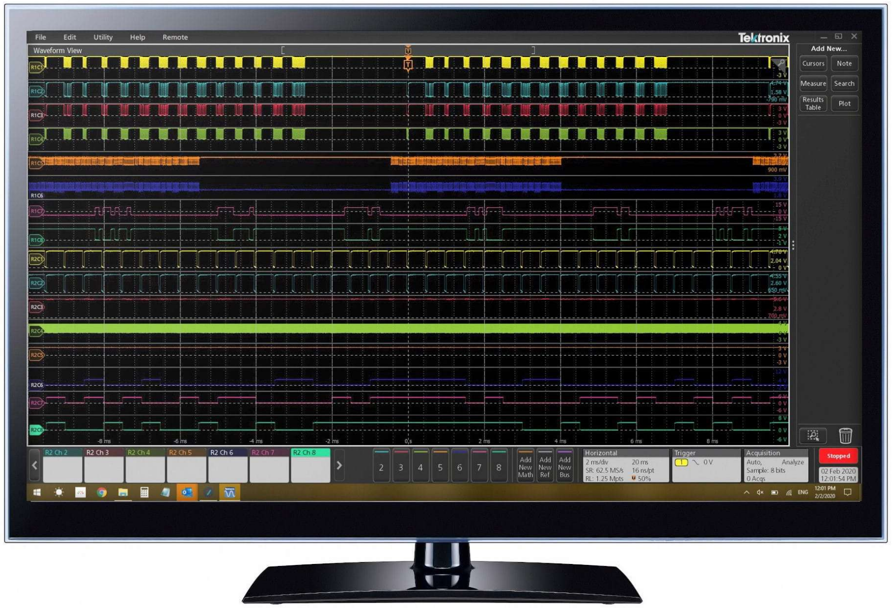
Summary

- Serial buses are pervasive, creating a unique set of measurement and analysis needs
- Making measurements needs to be easier, faster, and more accurate
- Requires an oscilloscope with triggering, decoding, and analysis tools for serial protocols



Tektronix' MSO oscilloscopes offer automated decode, trigger, search and analysis for serial buses

DEMO: TekScope PC Analysis Software



Horizontal
2 ms/div 20 ms
SR: 62.5 MS/s 16 ns/pt
RL: 1.25 Mpts 50%

Trigger
1 0 V

Acquisition
Auto, Analyze
Sample: 8 bits
0 Acqs

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- Offline Analysis
  - ✓ Any Tektronix scope
  - ✓ Most Keysight scope
  - ✓ Most LeCroy scope

- Online / Remote Scope Analysis
  - ✓ 4 / 5 / 6 Series MSO
  - ✓ 5 Series Low Profile
  - ✓ 6 Series Low Profile

- Serial Bus Decoding
- Base version is free

More info:
https://scope.tekcloud.com/#/