# What is MIL-STD-1553?

- MIL-STD-1553 is a military standard that specifies the requirements for a digital command/response time division multiplex data bus for integration of aircraft subsystems.

- MIL-STD-1553B defines the term Time Division Multiplexing (TDM) as "the transmission of information from several signal sources through one communications system with different signal samples staggered in time to form a composite pulse train."

- *Review of MIL-STD-1553 Specification*

| | |
|---|---|
| WHY? | What need does it fill |
| WHAT? | What does the spec say |
| HOW? | How is it implemented |

# MIL-STD-1553 Highlights

- The 1553 Standard contains several sections and describes the method of communication, the data bus requirements and the electrical interface requirements for subsystems connected to the data bus.
- MIL-STD-1553B defines the term Time Division Multiplexing (TDM) as "the transmission of information from several signal sources through one communications system with different signal samples staggered in time to form a composite pulse train."
- MIL-STD-1553 IS A STANDARD, NOT A SPECIFICATION.
- The functional elements of 1553 consist of the data bus and terminals. The Standard defines the data bus to be a single path between the bus controller and all remote terminals.
- This includes the twisted, shielded pair cable, terminators and couplers. Most systems today
- The ***bus controller*** is the master device and there is only one terminal operating as bus controller at any one point in time.

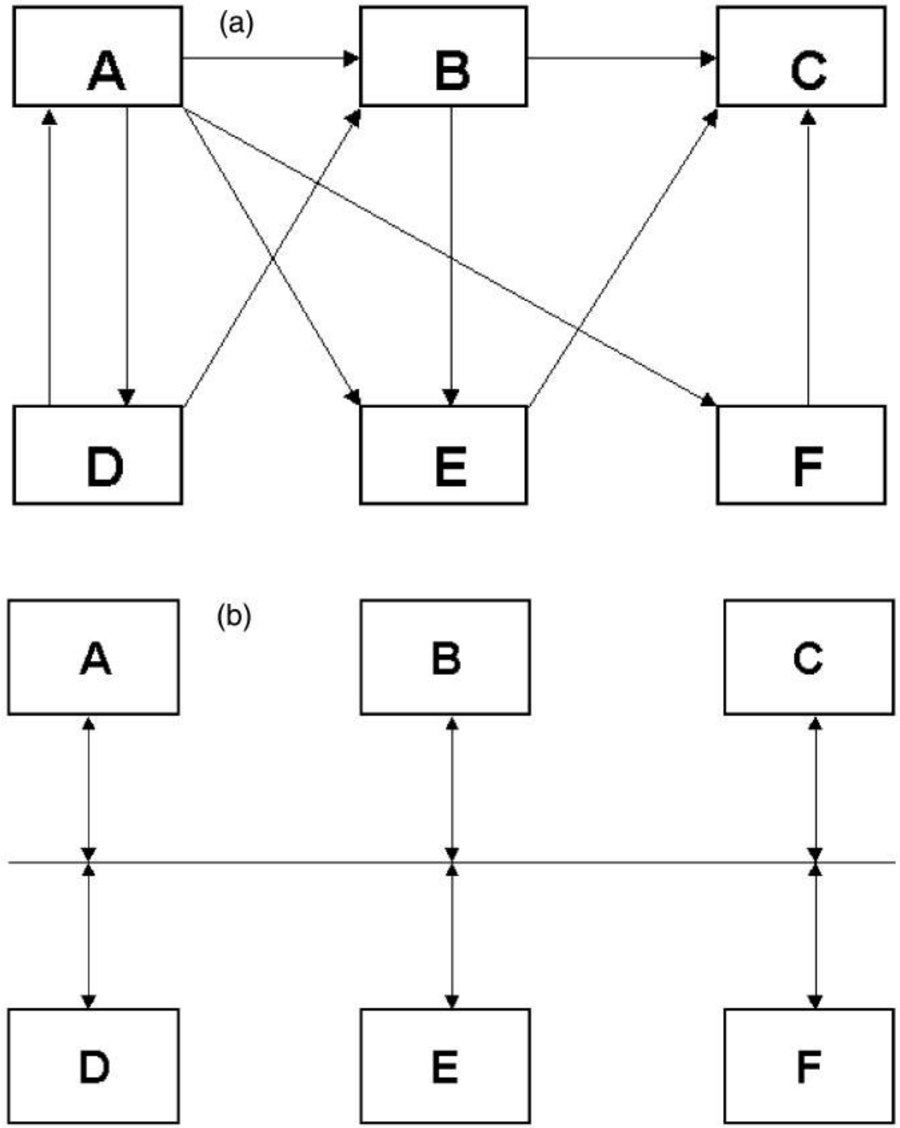

(a)
A
B
C
D
E
F
(b)
A
B
C
D
E
F

**TABLE 1.1** Summary of the 1553 Data Bus Characteristics

| | |
|---|---|
| Data Rate | 1 MHz |
| Word Length | 20 bits |
| Data Bits per Word | 16 bits |
| Message Length | Maximum of 32 data words |
| Transmission Technique | Half-Duplex |
| Operation | Asynchronous |
| Encoding | Manchester II Bi-phase |
| Protocol | Command-Response |
| Bus Control | Single or Multiple |
| Message Formats | Controller-to-Terminal (BC-RT) |
| | Terminal-to-Controller (RT-BC) |
| | Terminal-to-Terminal (RT-RT) |
| | Broadcast |
| | System Control |
| Number of Remote Terminals | Maximum of 31 |
| Terminal Types | Remote Terminal (RT) |
| | Bus Controller (BC) |
| | Bus Monitor (BM) |
| Transmission Media | Twisted Shielded Pair Cable |
| Coupling | Transformer or Direct |

## 1553 Communication

- 1553 communication uses three word types: command, status and data. All words are 20 bits long.

Bits Used

- Word Sync------3 bits
- Information-----16 bits and
- Parity-----------1 bit

## Data Integrity and System Reliability

- MIL-STD-1553 provides a high degree of data integrity by specifying word and message validation requirements.
- These include checks for parity, proper Manchester encoding, bit count, word count and proper timing.

## Testing 1553

When working with MIL-STD-1553 there are a number of phases of testing that should be considered:

- development testing,
- validation testing,
- system integration/simulation.

## 1553 Applications

- The 1553 data bus is the most commonly used military data bus today.
- It is used in systems where data integrity and system reliability are critical.
- It is heavily used in aircraft avionics and stores and in ships, submarines and ground vehicles such as tanks.

- The data bus is also being used in space in numerous satellites and the Space Station and in some commercial applications such as reactors, subway cars and oil drilling.

# TERMS

- Avionics Bus
- Remote Terminal
- Bus Controller
- Bus Monitor
- Source
- Sink
- Data Coupler
- Dual Redundant
- Minor Frame
- Major Frame
- Message

# Examples of Clients

| | |
|---|---|
| Altimeter …… | Active Device |
| Display …… | Passive Device |
| Black Box …… | Passive Device |
| Flight Computer …… | Active and Passive |

# First Generation
# Analog Devices

| **One Device** | **One Display** |
| --- | --- |
| Altimeter | Gauge |
| Speedometer | Gauge |
| Compass | |

# Second Generation

# ARINC-429

**<u>One Device</u>**

Altimeter

Engine


**<u>Multiple Sink</u>**

Display

Auto Pilot

Flight Recorder

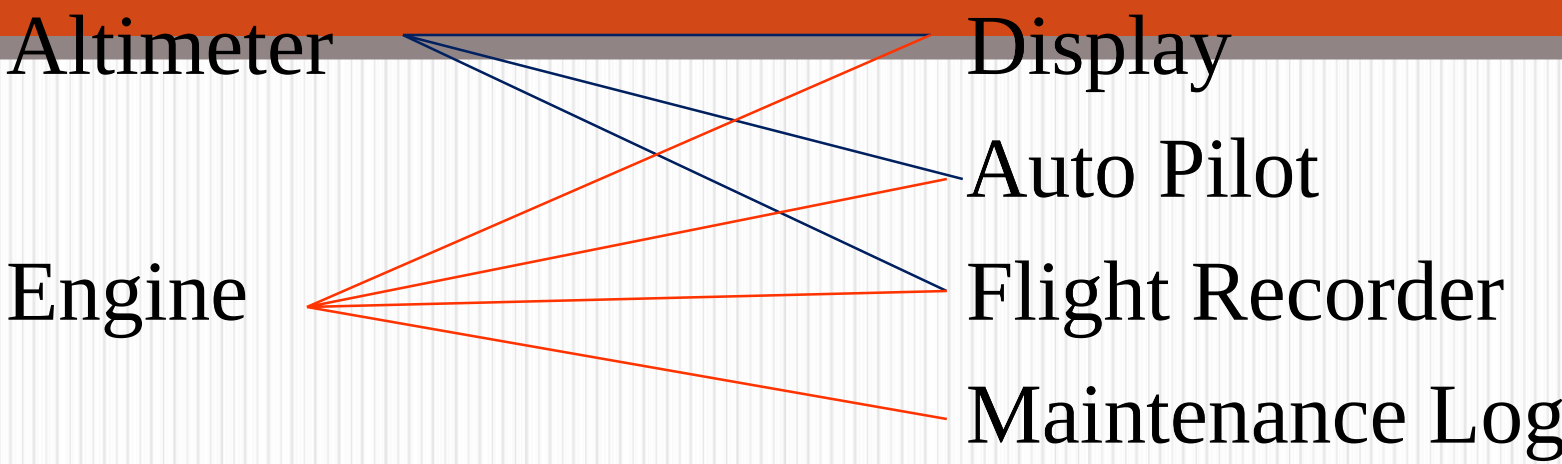
Display

Auto Pilot

Flight Recorder

Maintenance Log

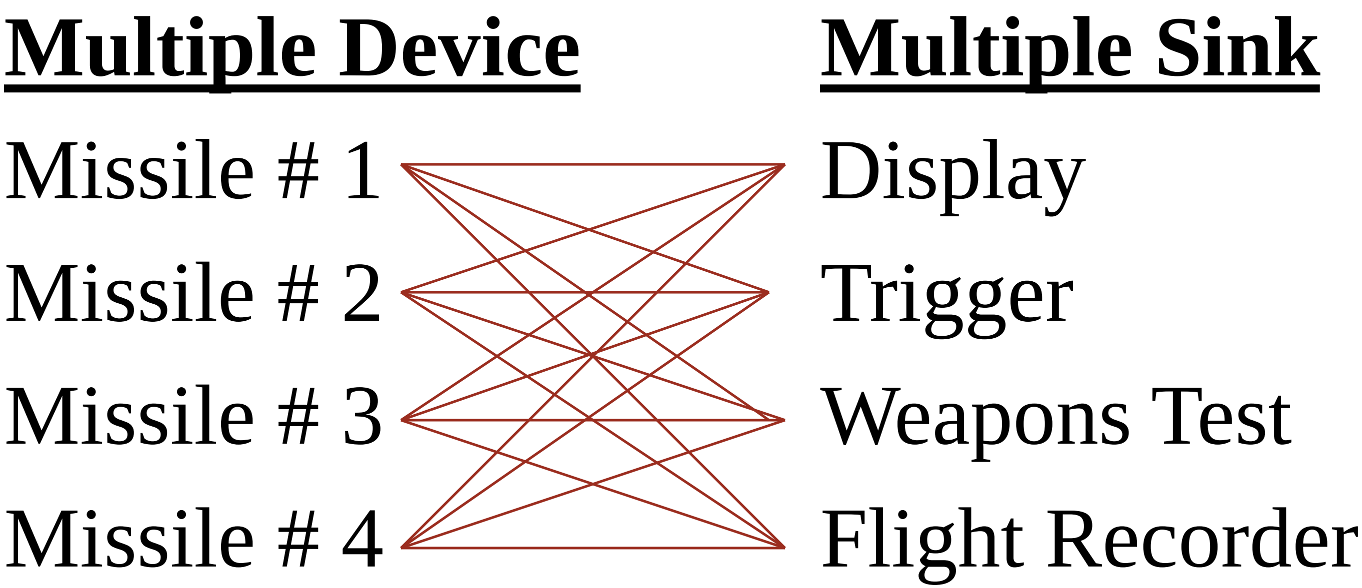
# Wiring Diagram



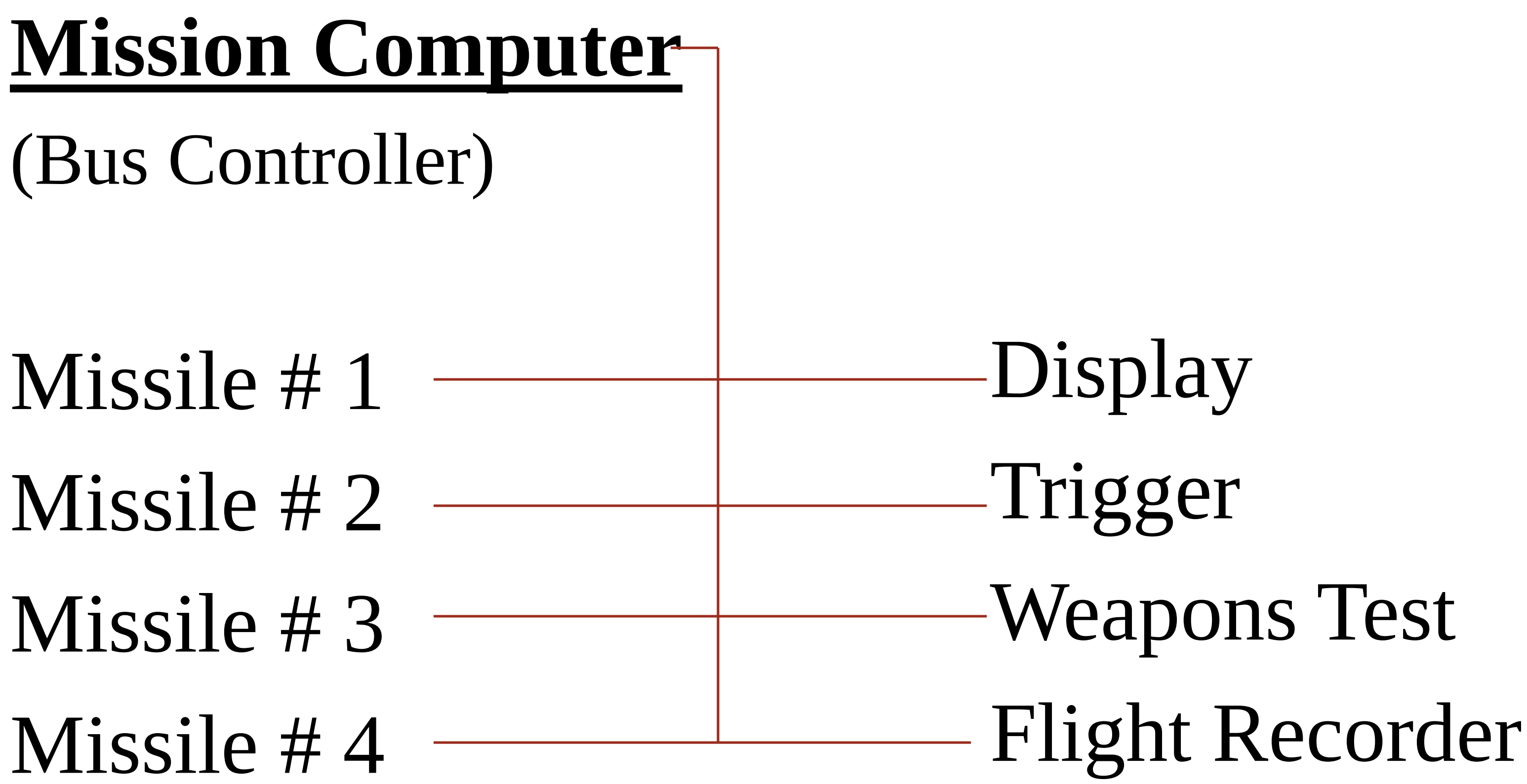
# Military Applications

| **Multiple Device** | **Multiple Sink** |
| --- | --- |
| Missile # 1 | Display |
| Missile # 2 | Trigger |
| Missile # 3 | Weapons Test |
| Missile # 4 | Flight Recorder |

# Military Application
# ARINC-429 Wiring



# Military Applications
# MIL-STD-1553 Wiring



# 1553 Advantages

- Low Weight
- Easy Bus Installation
- Easy to Add RT's

# Bus Controller

- Determines Order of Transmission
- Is Source or Sink for almost all Data
- Can check for bus errors

## 1553 Problem

Cable Cut = Crash

Inefficiency

- Serial Transmission
- Xmt to / from BC
- BC Overhead

BC Lost = Crash

## Solution

Dual Redundant Bus

- 1 Mhz speed vs. 100 Khz for 429
- Minor Frames

Backup BC

# Goals of MIL-STD-1553

- Communication between <= 32 Boxes
- Low Data Requirement <= 32 Words

- High Reliability
  - Ability to detect communication errors
  - Ability to retry on error

# Mindset of MIL-STD Design

- Military Approach
  - 1 Commander in Control
  - All others speak when spoken to
  - Commander speaks to one at a time or to all together (Broadcast)

# 1553 Message

- All Communication is by Message
- All Messages are Initiated by the BC
- All Messages begin with a Command Word

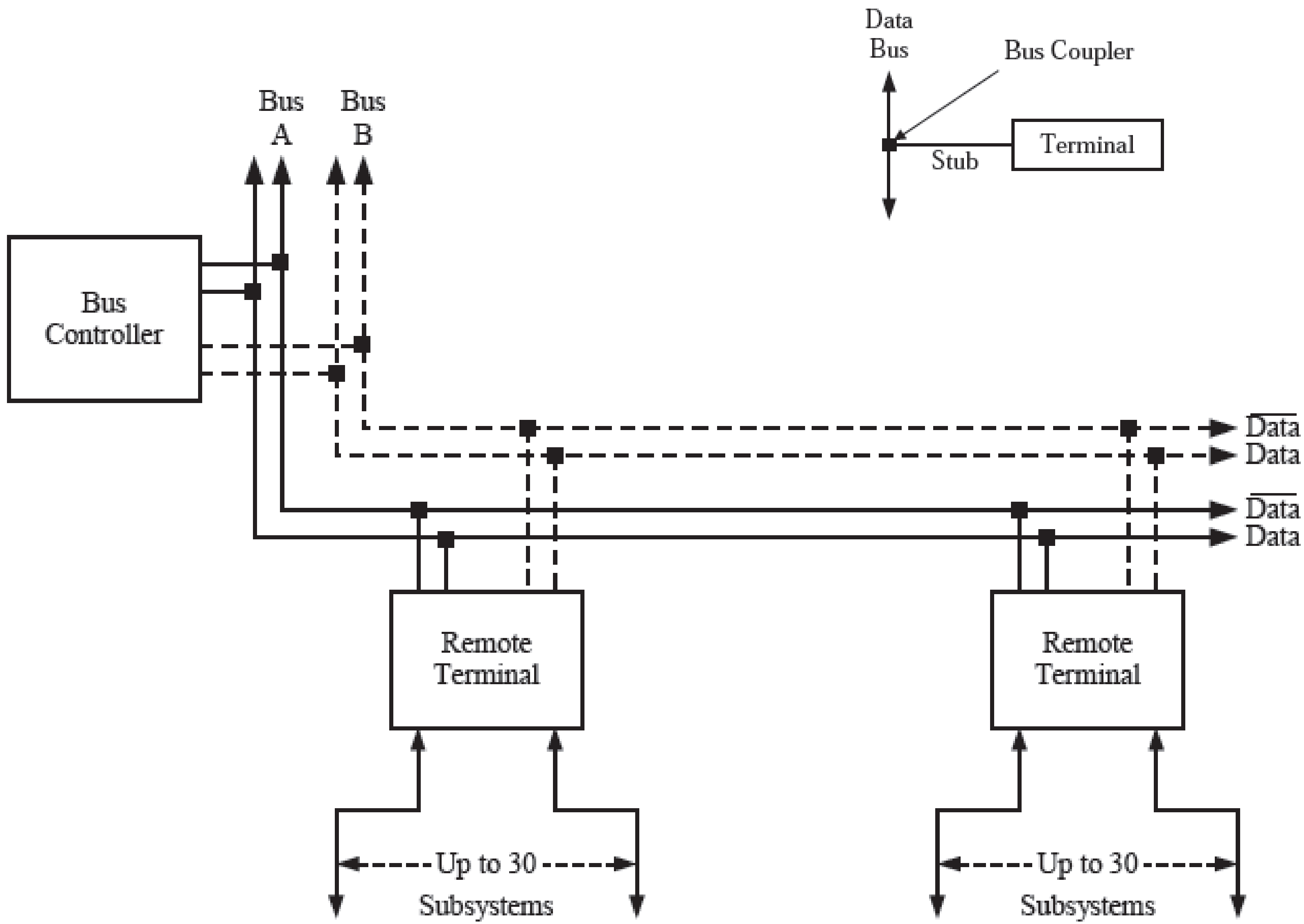
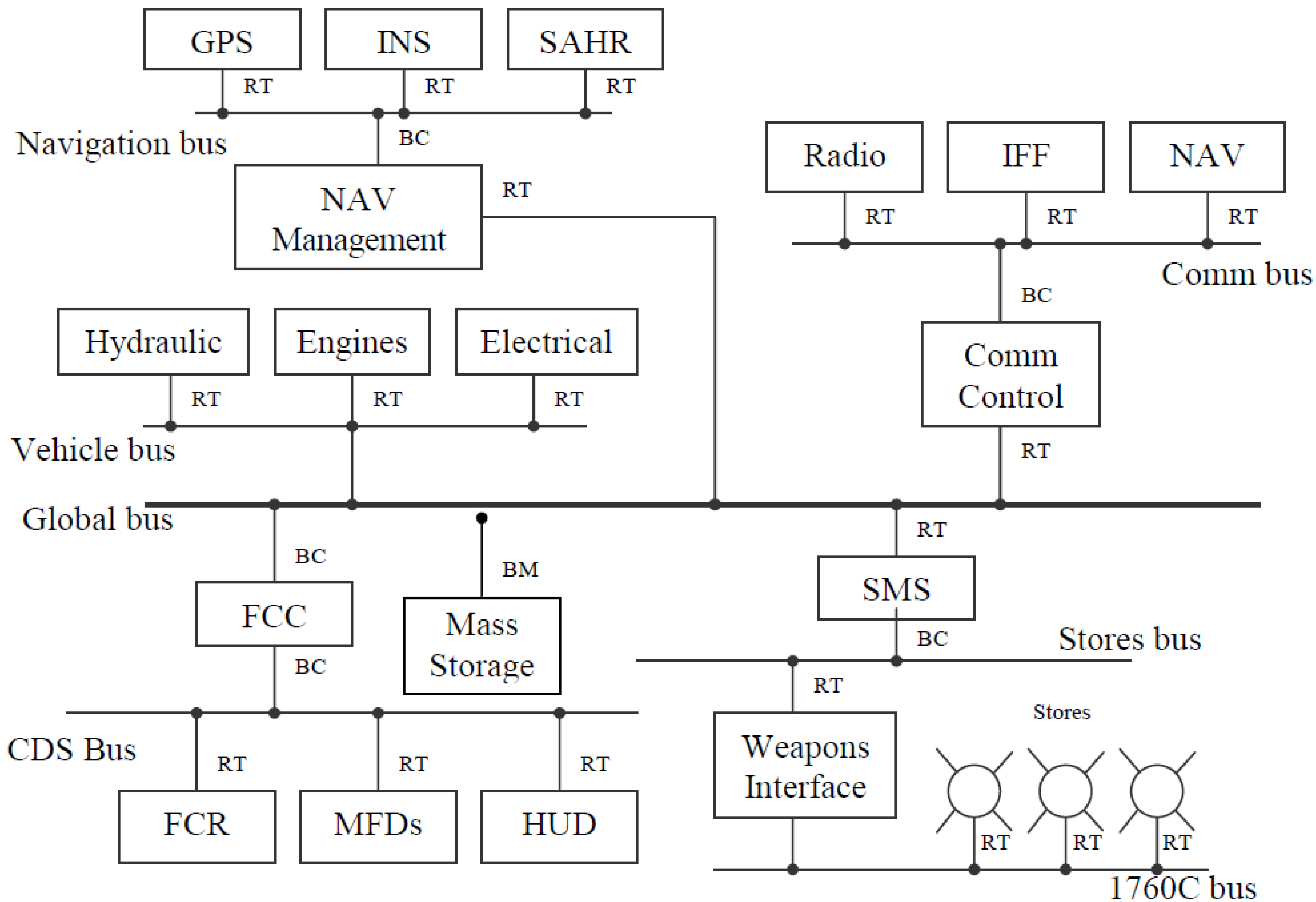



**Figure 12.10** MIL-STD-1553B data bus



GPS
INS
SAHR
RT
RT
RT
Navigation bus
BC
NAV Management
RT
Radio
IFF
NAV
RT
RT
RT
Comm bus
BC
Comm Control
RT
Hydraulic
Engines
Electrical
RT
RT
RT
Vehicle bus
Global bus
BC
BM
RT
FCC
Mass Storage
SMS
BC
BC
Stores bus
RT
CDS Bus
RT
RT
RT
FCR
MFDs
HUD
Weapons Interface
Stores
RT
RT
RT
1760C bus

# Bus Controller

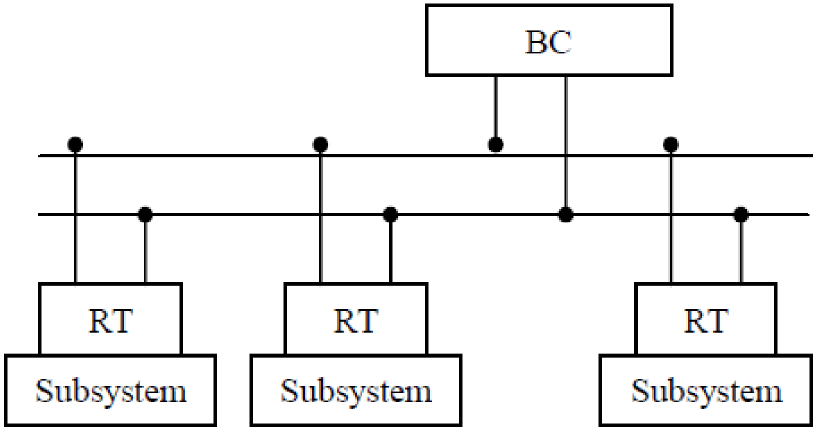



Figure 3-10.1 – Possible Redundancy

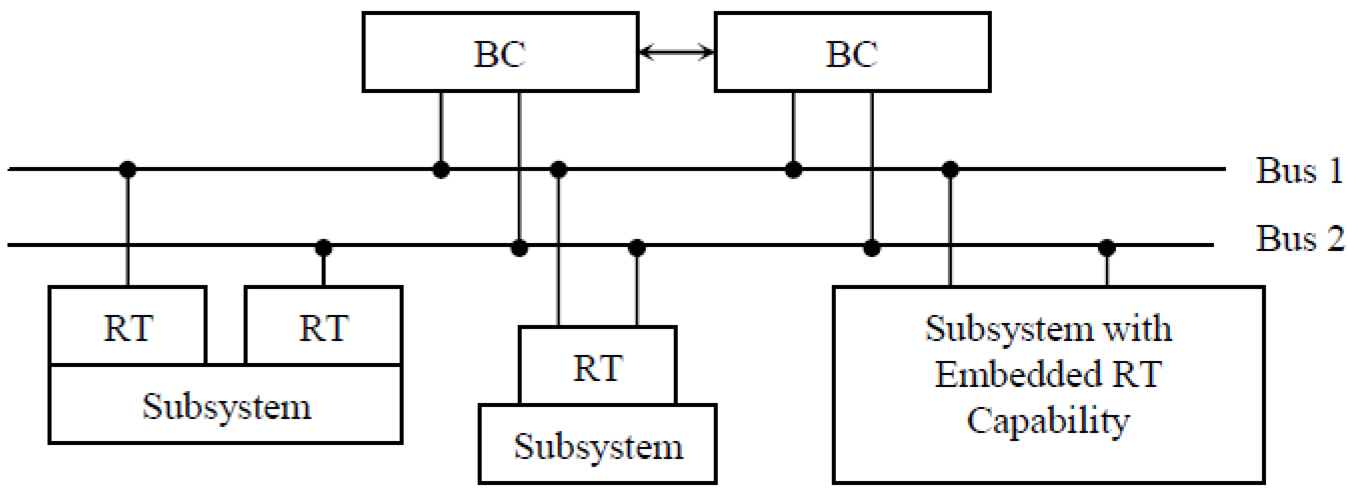
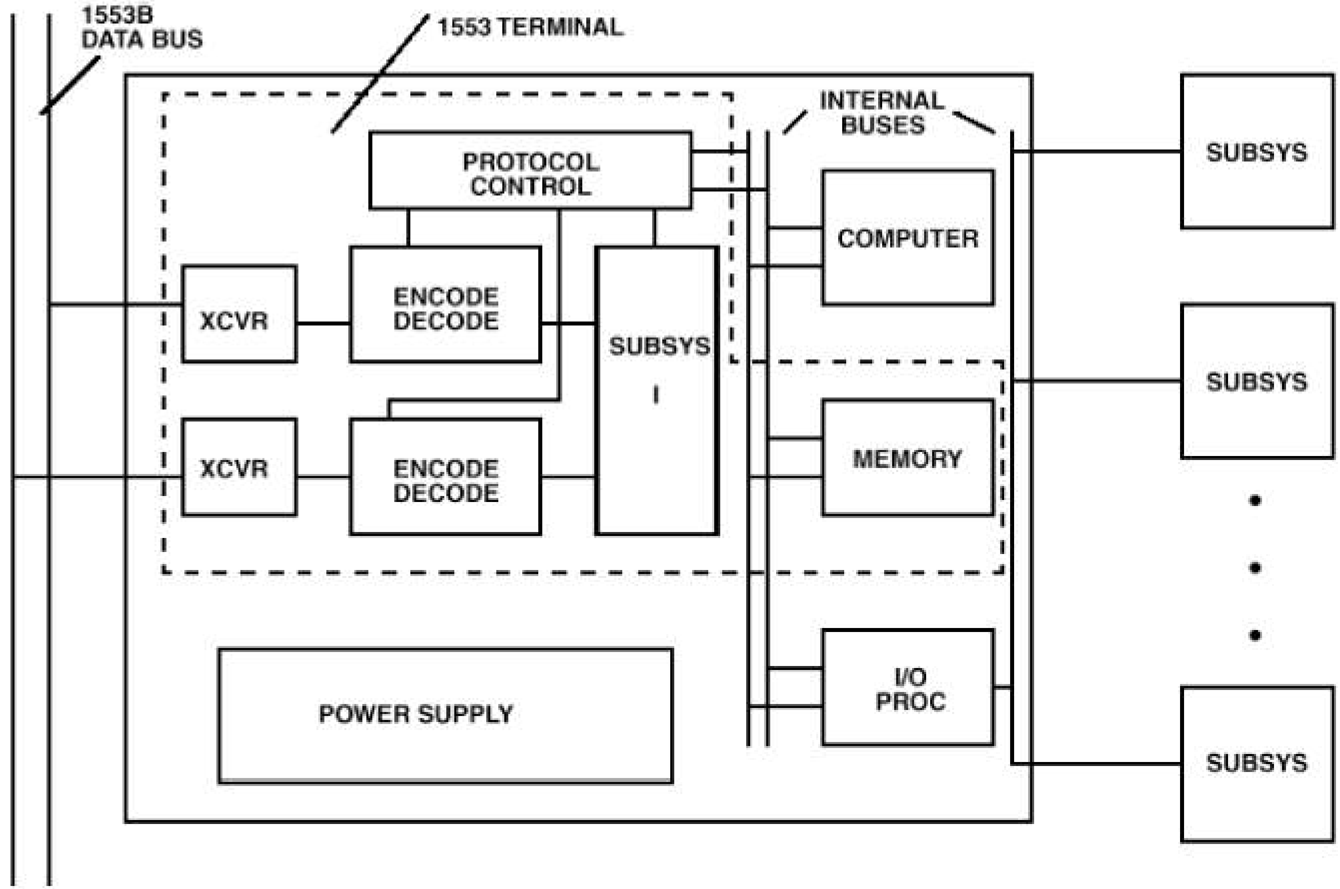



Figure 3-10.2 – Possible Redundancy



1553B
DATA BUS
1553 TERMINAL
INTERNAL
BUSES
PROTOCOL
CONTROL
XCVR
ENCODE
DECODE
SUBSYS
I
XCVR
ENCODE
DECODE
COMPUTER
MEMORY
I/O
PROC
POWER SUPPLY
SUBSYS
SUBSYS
SUBSYS

**TABLE 1.3** Terminal Electrical Characteristics

| Requirement | Transformer Coupled | Direct Coupled | Condition |
|---|---|---|---|
| | Input Characteristics | | |
| Input Level | 0.86–14.0 V | 1.2–20.0 V | p–p, l–l |
| No Response | 0.0–0.2 V | 0.0–0.28 V | p–p, l–l |
| Zero Crossing Stability | ±150.0 nsec | ±150.0 nsec | |
| Rise/Fall Times | 0 nsec | 0 nsec | Sine Wave |
| Noise Rejection | 140.0 mV WGN[a] | 200.0 mV WGN | BER 1[b] per $10^7$ |
| Common Mode Rejection | ±10.0 V peak | ±10.0 V peak | line-gnd, DC-2.0 MHz |
| Input Impedance | 1000 ohms | 2000 ohms | 75 kHz–1 MHz |
| | Output Characteristics | | |
| Output Level | 18.0–27.0 V | 6.0–9.0 V | p–p, l–l |
| Zero Crossing Stability | 25.0 nsec | 25.0 nsec | |
| Rise/Fall Times | 100–300 nsec | 100–300 nsec | 10%–90% |
| Maximum Distortion | ±900.0 mV | ±300.0 mV | peak, l–l |
| Maximum Output Noise | 14.0 mV | 5.0 mV | rms, l–l |
| Maximum Residual Voltage | ±250.0 mV | ±90.0 mV | peak, l–l |

[a] WGN = White Gaussian Noise.
[b] BER = Bit Error Rate.

# Message Types

- Bus Controller to RT
- Bus Controller to All RT's (Broadcast)
- RT to Bus Controller
- Housekeeping messages (Mode Codes)
- RT to RT Commands

# Message Format

- Messages Begin With A Command Word
- Data may flow to/from BC from/to RT
- RT's return a Status Word

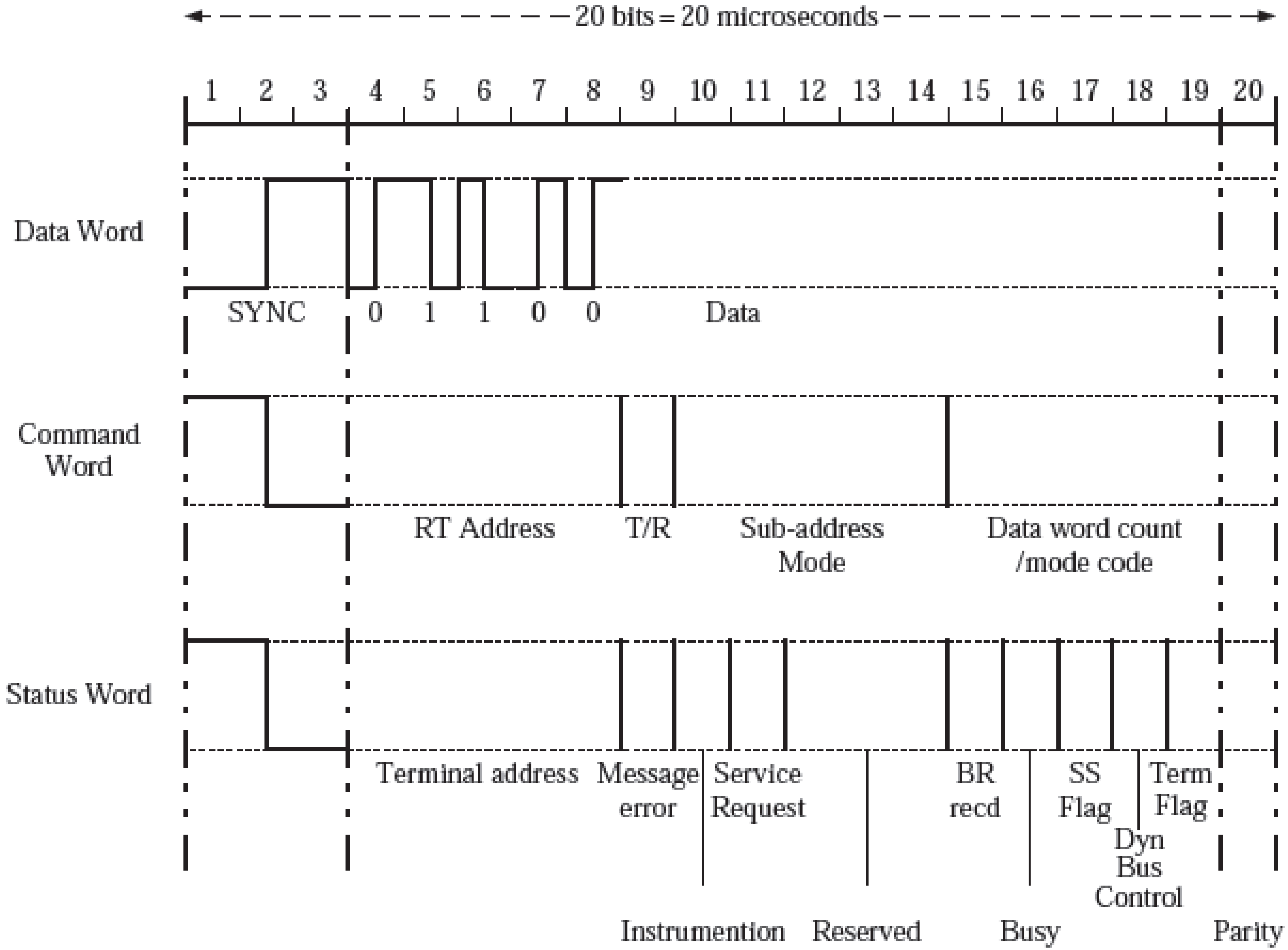



**Figure 12.11** MIL-STD-1553B data bus word formats

# Command Word

| 5 Bits | | 1 Bit | 5 Bits | | 5 Bits | |
|---|---|---|---|---|---|---|
| 15 | 11 | 10 | 9 | 5 | 4 | 0 |
| RT Address | | T/R Bit | Subaddress | | Word Count | |

# Command Fields

- RT Address
  - Address range is 0 - 31
  - Some Systems use Address 31 as Broadcast
- T/R Bit
  - If T/R = 1, RT Transmits Data
  - If T/R = 0, RT Receives Data

# Command Fields

- RT Subaddress
  - Additional Routing for Complex RT's
  - May Correspond to Subsystems
  - Subaddress 0 is for Mode Codes
  - Subaddress 31 is MIL-STD-1553B Mode Code

# Command Fields

- Word Count
  - Range is 1 to 32 (field value 0 = 32 words)
- For Mode Codes this is Mode Code Type
  - There are 16 Mode Codes with No Data
  - There are 16 Mode Codes with 1 word of Data

Table 3-I – Assigned Mode Codes

| T/R Bit | Mode Code | Function | Associated Data Word | Broadcast Command Allowed |
|---|---|---|---|---|
| 1 | 00000 | Dynamic Bus Control | N | N |
| 1 | 00001 | Synchronize | N | Y |
| 1 | 00010 | Transmit Status Word | N | N |
| 1 | 00011 | Initiate Self Test | N | Y |
| 1 | 00100 | Transmitter Shutdown | N | Y |
| 1 | 00101 | Override Transmitter | N | Y |
| 1 | 00110 | Inhibit Terminal Flag Bit | N | Y |
| 1 | 00111 | Override Inhibit Terminal Flag Bit | N | Y |
| 1 | 01000 | Reset RT | N | Y |
| 1 | 01001 | Reserved | N | TBD |
| | ↓ | ↓ | ↓ | ↓ |
| 1 | 01111 | Reserved | N | TBD |
| 1 | 10000 | Transmit Vector Word | Y | N |
| 0 | 10001 | Synchronize | Y | Y |
| 1 | 10010 | Transmit Last Command | Y | N |
| 1 | 10011 | Transmit BIT Word | Y | N |
| 0 | 10100 | Selected Transmitter | Y | Y |
| 0 | 10101 | Override Selected Transmitter | Y | Y |
| 1 or 0 | 10110 | Reserved | Y | TBD |
| | ↓ | ↓ | ↓ | ↓ |
| 1 or 0 | 11111 | Reserved | Y | TBD |

# Status Word

| Bit # | Description |
|---|---|
| 15-11 | RT Address |
| 10 | Message Error |
| 8 | Service Request |
| 4 | Broadcast Received |
| 3 | Busy |

# Status Bit Fields

- RT Address
  - Lets BC Know Correct RT is Responding
  - Usually The Only Field Set
- Message Error
  - Indicates a Communications Error

# Status Bit Fields

- Service Request (SRQ)
  - Indicates another Subaddress has info ready
  - Used with Get Vector Mode Command
- Broadcast Received
  - Set in response to the message following a broadcast command
- Busy
  - When RT can't respond - discouraged by spec

# Message Sequence

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Receive Command | Data Word | Data Word | . . . | Data Word | * | Status Word | • | Next Command |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| Transmit Command | * | Status Word | Data Word | Data Word | . . . | Data Word | • | Next Command |

# RT to RT Command

| | | | | | | |
|---|---|---|---|---|---|---|
| **Receive** Command | **Transmit** Command | **Tx Status Word** | **Data Word** | **Data Word** | **Rx Status Word** | Next Command |

# Mode Commands

**Mode Command** * **Status Word** • Next Command

**Mode Command** * **Status Word** **Data Word** • Next Command

**Mode Command** **Data Word** * **Status Word** • Next Command

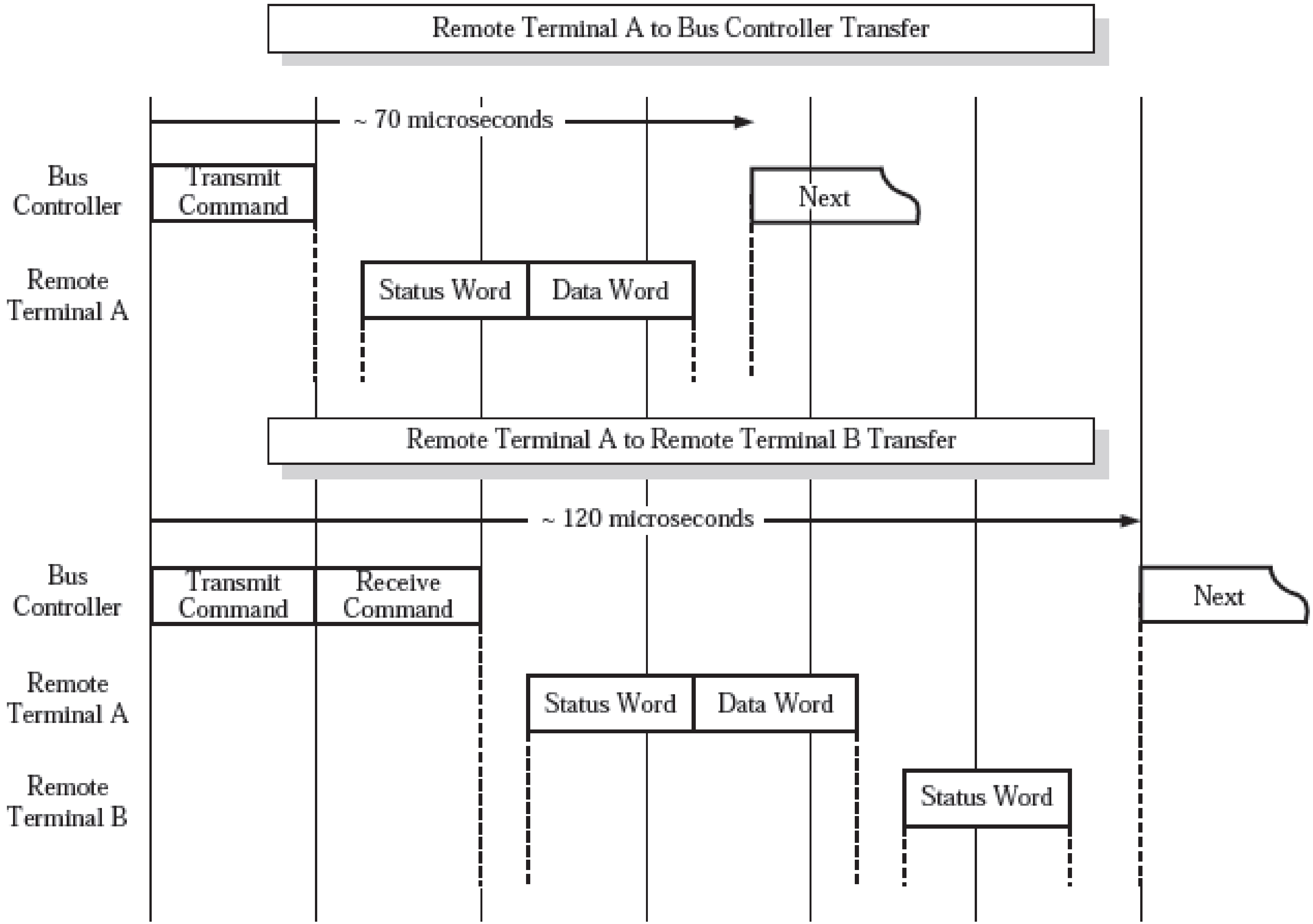



**Figure 12.12** MIL-STD-1553B typical data transactions

- Implementation Issues
  - Timing
  - Major / Minor Frames
  - Implementation Examples

# Timing Issues

- Intermessage Gap Time
- Response Time
- Major Frame
- Minor Frame

# Intermessage Gap Time

- Time Between Messages
  - At Least 4 usec Mid Sync to Mid Parity
  - No Maximum in Specification

# Response Time

- Time Until RT Sends A Status Word
  - MIL-STD-1553A Maximum = 7 usec
  - MIL-STD-1553B Maximum = 12 usec

# Major Frame

- A Major Frame is the set of all messages in a single cycle
- Typical Cycle is 20 to 80 milliseconds
- Some messages may appear more than once in a single Major Frame

# Minor Frames

- Some Messages Are High Priority
- We can alter frequency of specific messages

| | | | |
|---|---|---|---|
| **10 Mill** | **10 Mill** | **10 Mill** | **10 Mill** |
| **ABC** | **AB** | **A** | **AB** |

# Example: Missile Test

- Does Pilot Wish To Perform a Test
- Instruct Missile to Execute Self Test
- Get Results Of Self Test
- Display Results On HUD

# RT's in Test

- SelfTest Button on Console RT2
- Missile RT3
- Heads Up Display (HUD) RT4

# Message Frame

| | | |
|---|---|---|
| RT2 | → BC | Button to BC |
| BC | → RT3 | BC to Missile |
| RT3 | → BC | Missile to BC |
| BC | → RT4 | BC to HUD |

# Example: Synchronize RT's

- Synchronize Time Tags for All Terminals
- Check If Terminal Received the Command

# Set & Check Synch

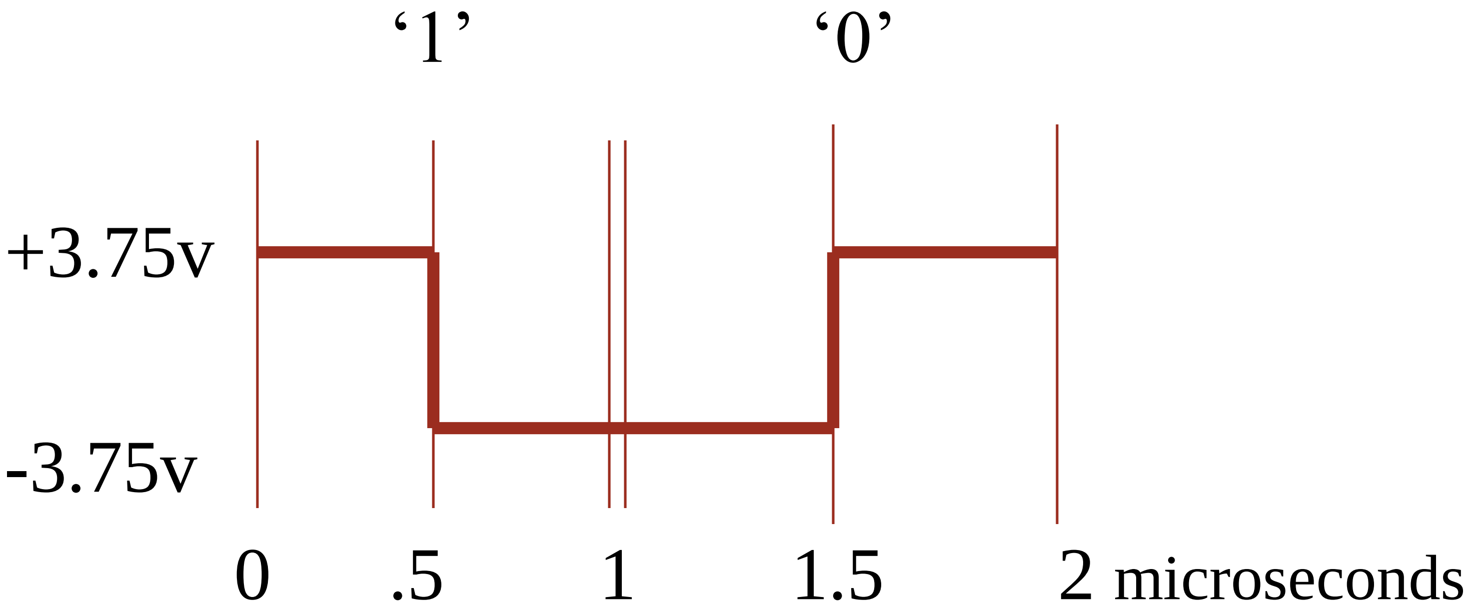
| | |
|---|---|
| BC → Broadcast | Synchronize Mode Command |
| BC → RT1 | Last Command Mode |
| BC → RT2 | Last Command Mode |

- Hardware Issues
  - Manchester 2 coding
  - Differential Signals
  - Bus Termination

# Manchester Properties

- Signal moves between +3.75v and -3.75v
- Signal always crosses 0v at mid bit
  - Direction of cross determines bit value
- Data Bits are 1 microsecond
  - mid bit after .5 microseconds
- Sync is 3 microseconds
  - mid sync after 1.5 microseconds

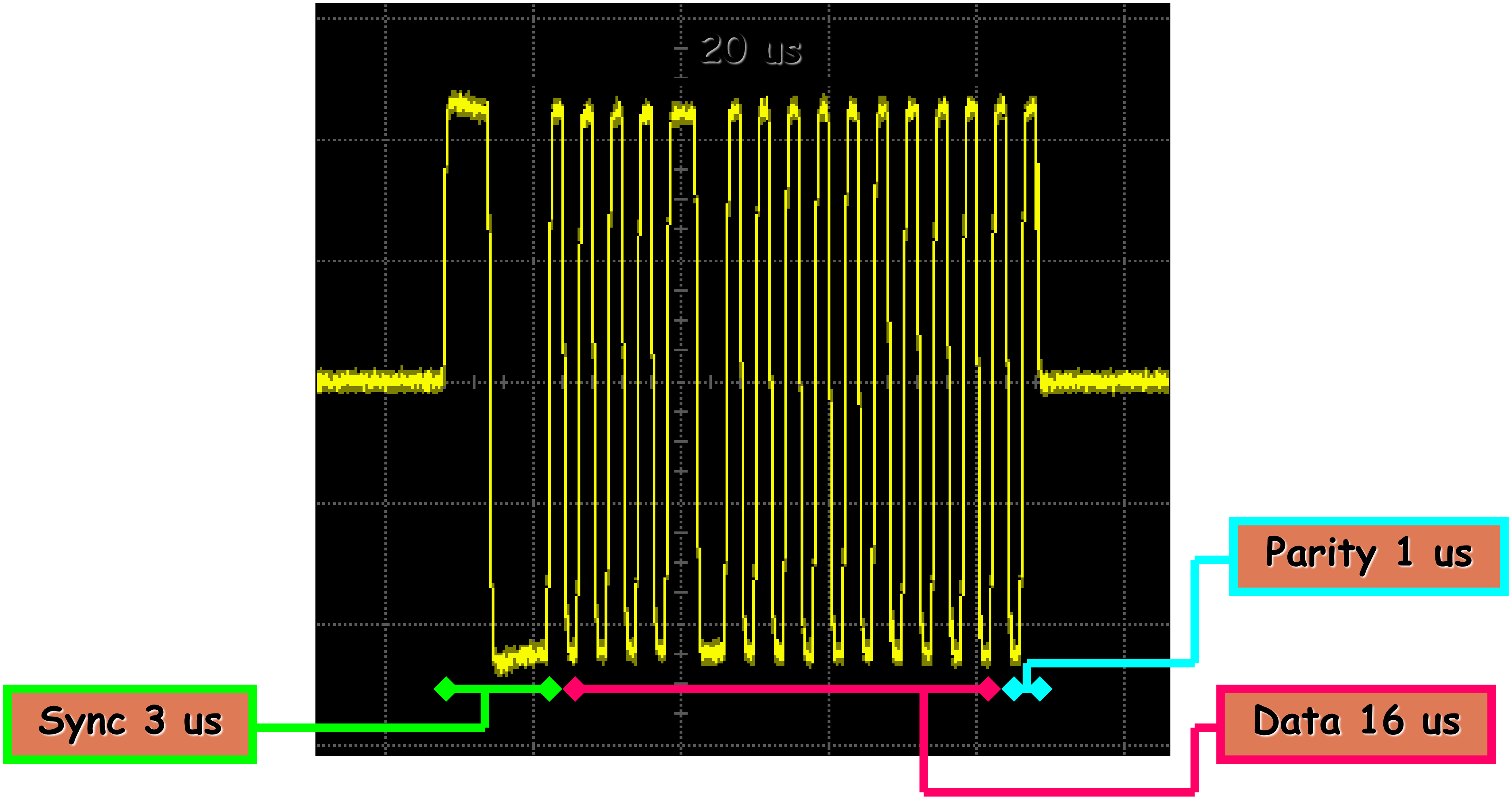
# Manchester 2 Coding



# Oscilloscope View

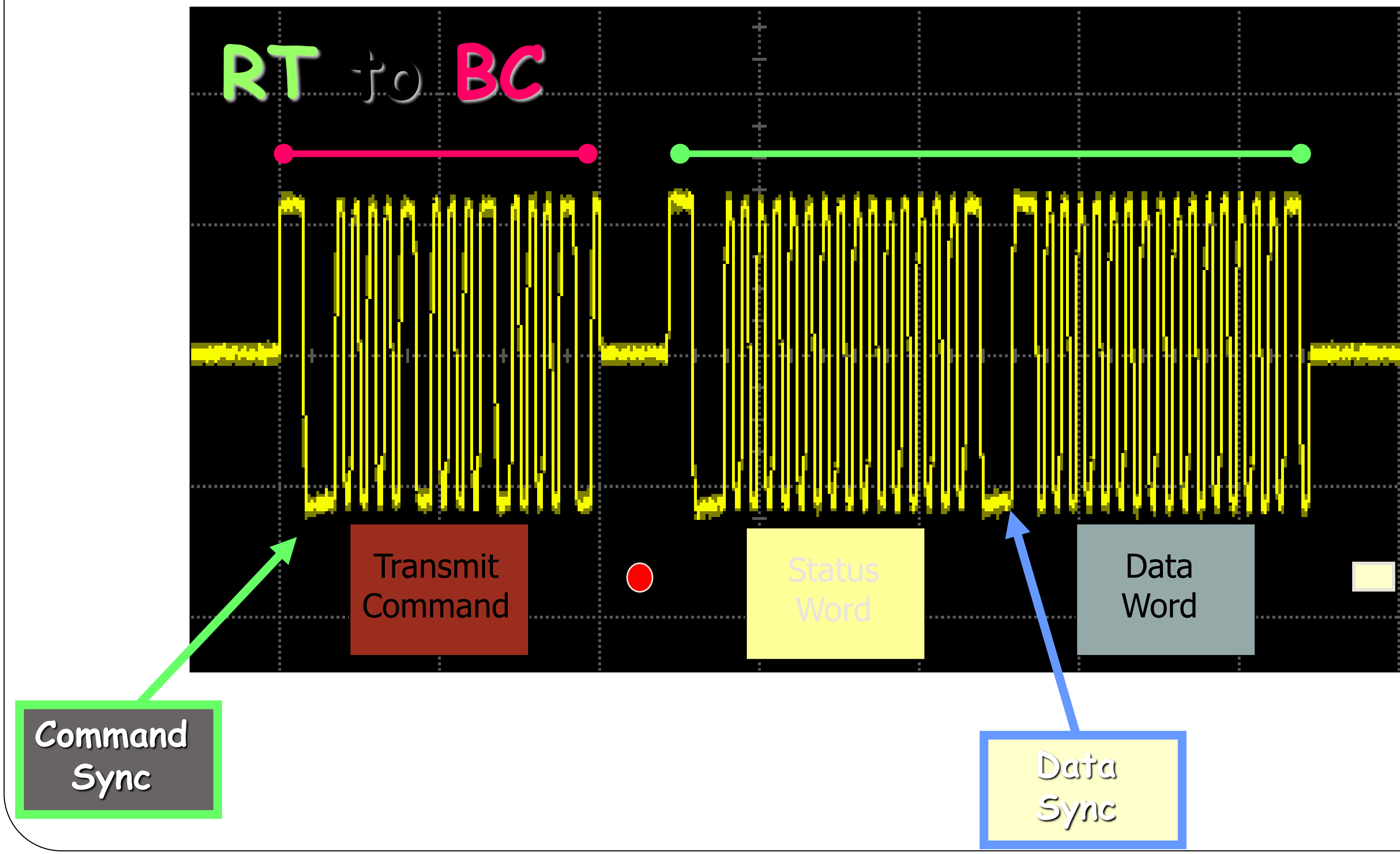
- Like preceding chart but less square
- Original spec has Trapezoidal signal
- MacAir introduced Sinusoidal signal
  - Fewer harmonics
  - Cleaner signal (less noise)

# Oscilloscope View - 1553 word



# Oscilloscope View 1553 message

- Response Time
- Intermessage Gap time



# Differential Signals

- 1553 Bus is actually 2 wires
- The first is Manchester described above
- The second is the complement of the first
- During Bus Quiet both lines are 0 volts

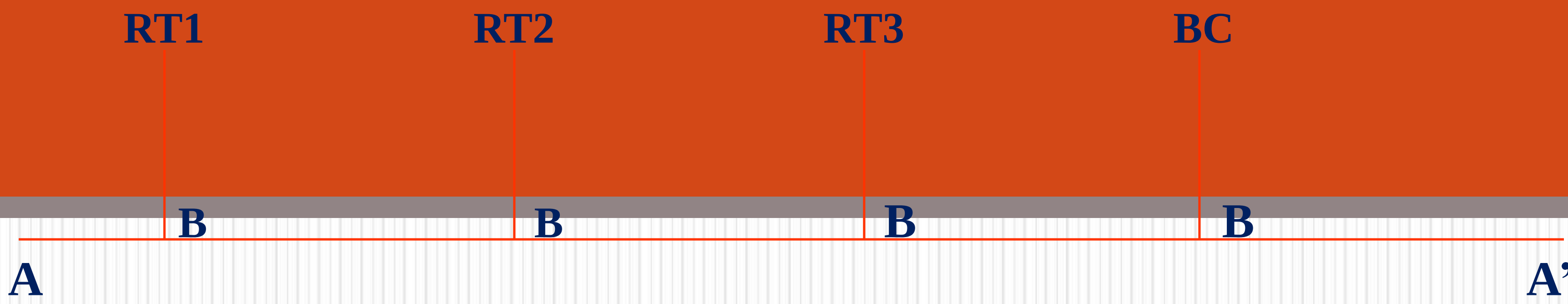
# Advantages

- Less Dependent On Ground
- Less Susceptible To Spikes

# Bus Termination

- Hi frequency signals are sensitive to reflection
- At the end of the Bus the signal can't continue and tries to "Bounce Back"
- This is caused by Lo Resistance wire meeting Hi Resistance air

# 1553 Topology




- Point A, A’ and B represent junctions
- We put Terminators on A and A’ to make the bus appear infinitely long
- This prevents signal reflection

# Coupling

- ‘B’ Junctions Represent BC’s RT’s and BM’s Connection To The Bus
- Two Methods Are Permitted By The Spec
  - Direct Coupling
  - Transformer Coupling

# Direct Coupling

- Simple Point To Point Connection
- Maximum Stub Length Is 1 Foot (30cm)

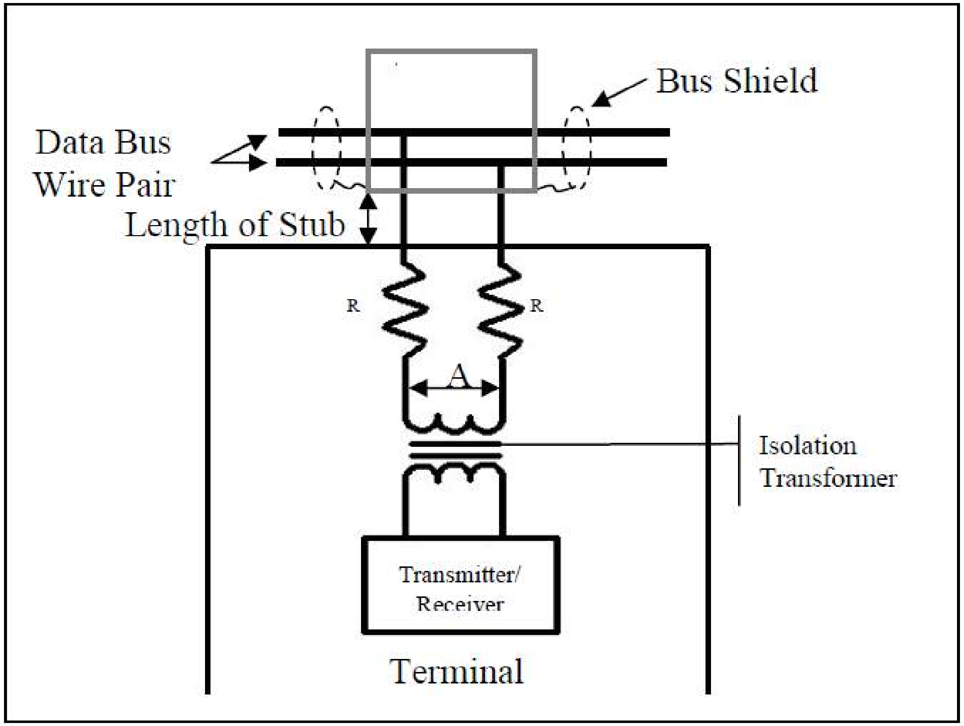



**Figure 3-10 – Data Base Interface Using Direct Coupling**

# Transformer Coupling

- Uses An Isolation Stub Coupler
- Filters out DC and Noise
- Prevents all Reflections
- May Be Used For Up To 20 Foot (6 m) Stubs

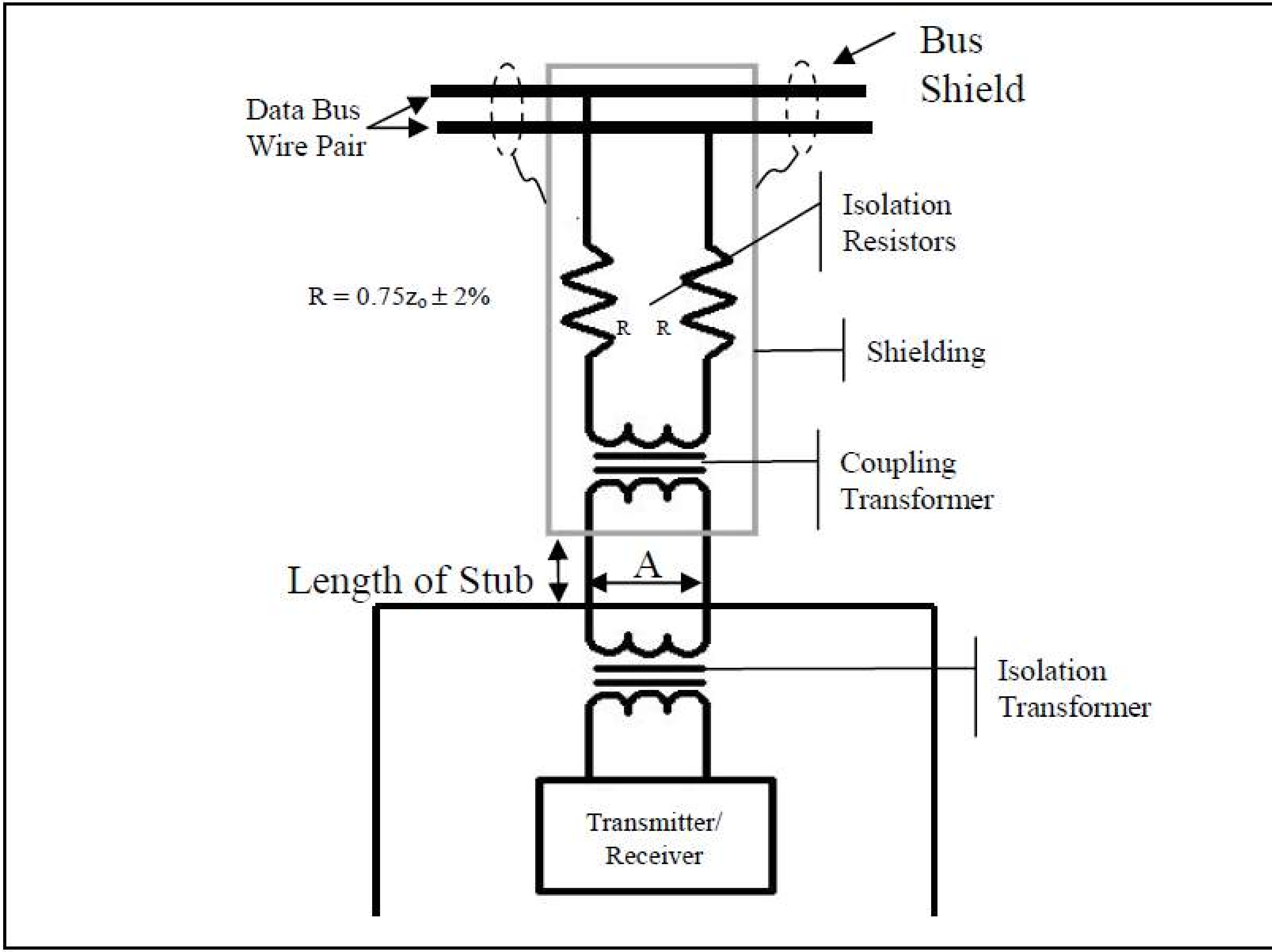
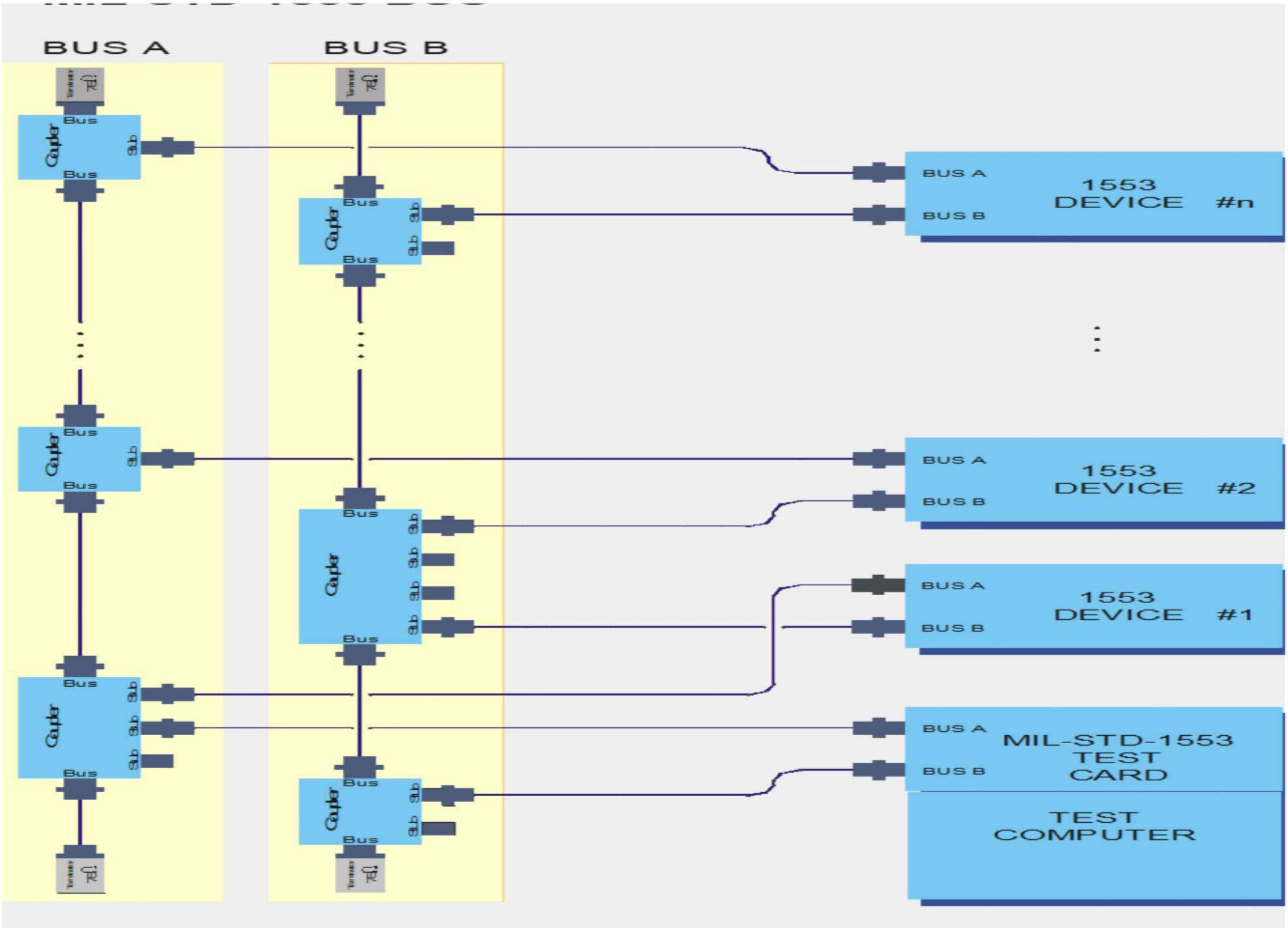



**Figure 3-9 – Data Bus Interface Using Transformer Coupling**

# The US Air Force Prohibits Direct Coupling on Aircraft

- Direct Coupling is convenient when:
  - Used in a lab
  - Connecting Two Boxes Directly


BUS A
BUS B
Bus
Coupler
Stub
BUS A
BUS B
1553
DEVICE #n
1553
DEVICE #2
1553
DEVICE #1
MIL-STD-1553
TEST
CARD
TEST
COMPUTER

| | |
|---|---|
| Cable Type | Twisted Shielded Pair |
| Capacitance | 30 pF/ft $_{max}$ |
| Cable Impedance | 70-85 Ω at 1 MHz |
| Cable Attenuation | 1.5 dB per 100 ft at 1 MHz $_{max}$ |
| Twist Ratio | 4 per foot $_{min}$ |
| Shield Coverage | 75% $_{min}$ |
| Cable Termination | Cable Impedance ± 2% |

1553B Cable Characteristics

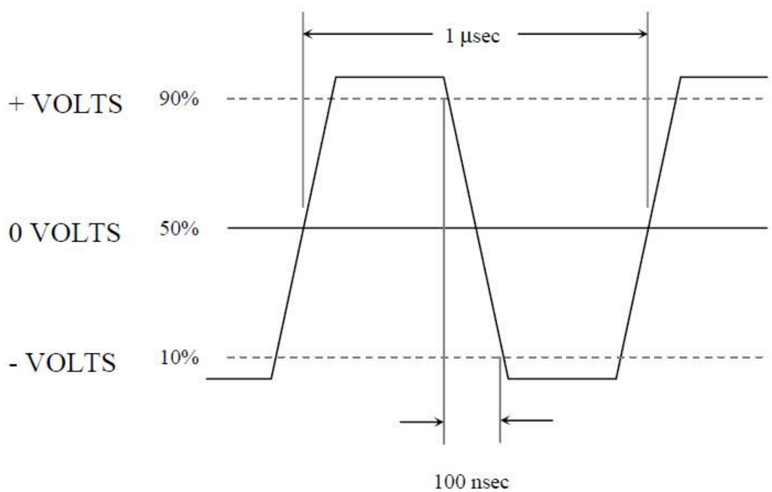
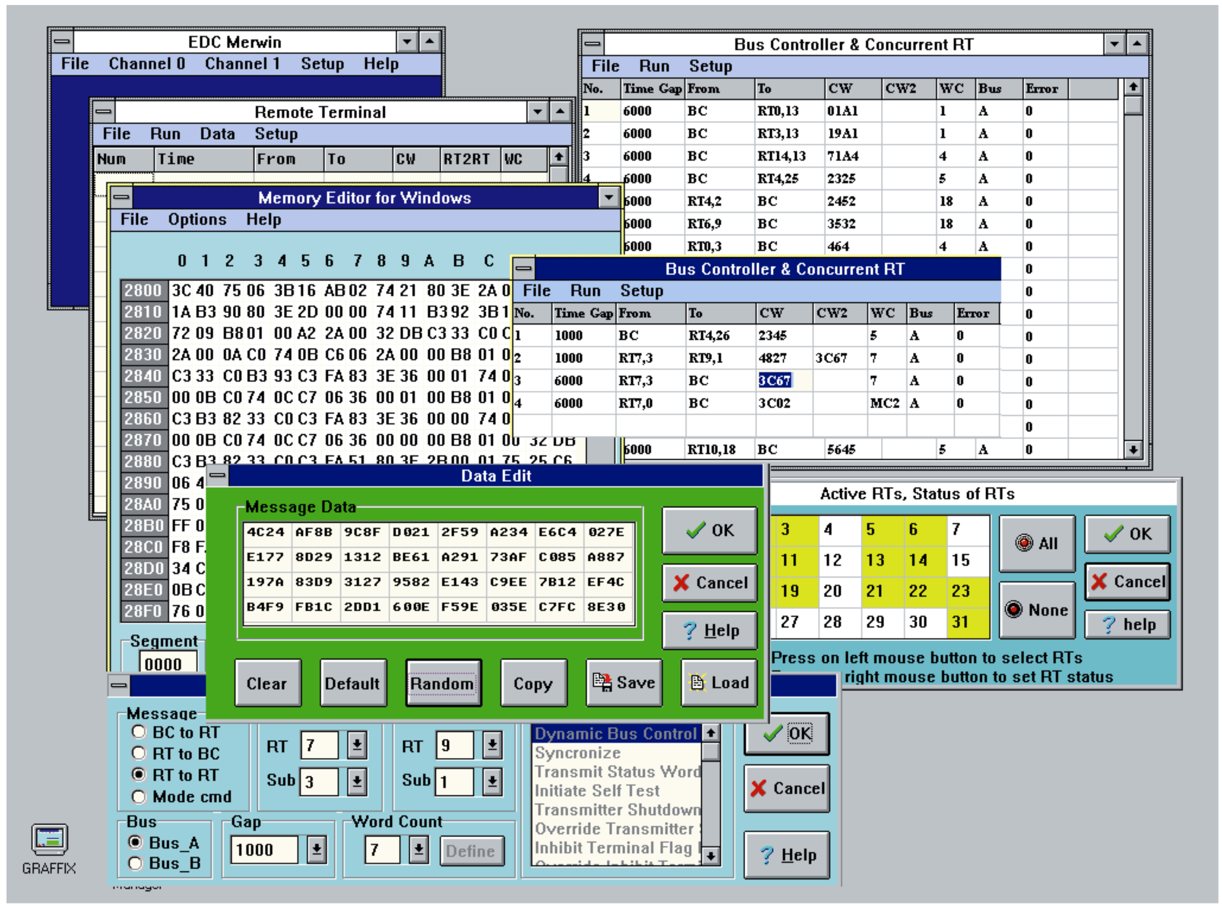



Figure 3-13 – Output Waveform

# Software

- Software Applications

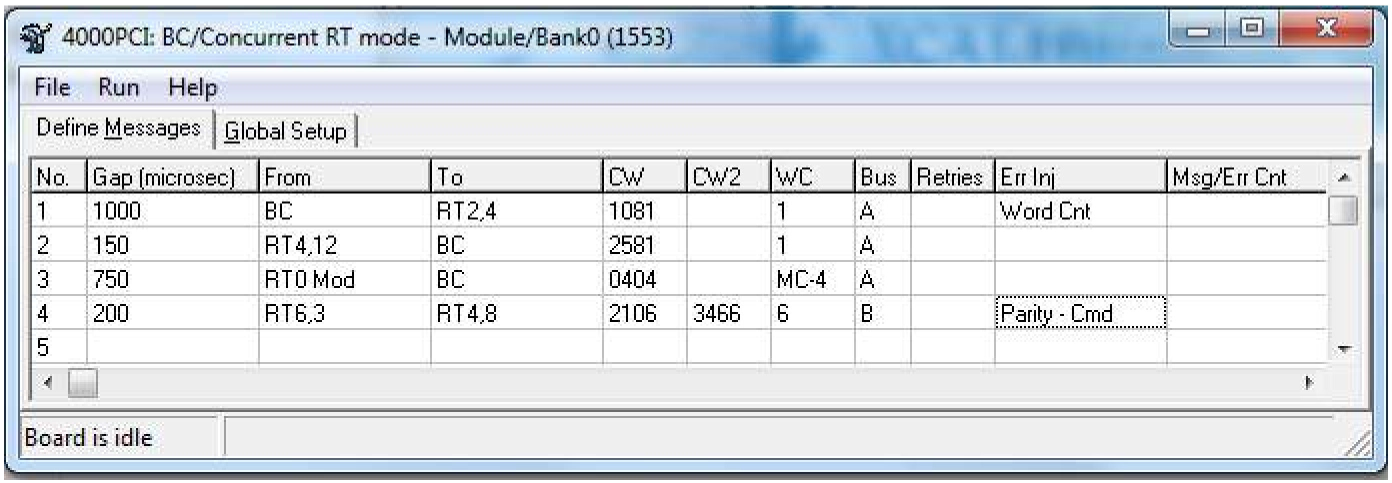


- Systems Integration
- RT Development
- Problem Isolation
- Post Flight Analysis

# Systems Integration

- Run multiple RT's in Lab
  - Some RT's may be ready some not
  - Simulate Bus Controller and some RT's
  - Simulate Bus timing and errors
  - Monitor responses for timing, quality and correctness

# RT Development




| No. | Gap (microsec) | From | To | CW | CW2 | WC | Bus | Retries | Err Inj | Msg/Err Cnt |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1000 | BC | RT2,4 | 1081 | | 1 | A | | Word Cnt | |
| 2 | 150 | RT4,12 | BC | 2581 | | 1 | A | | | |
| 3 | 750 | RT0 Mod | BC | 0404 | | MC-4 | A | | | |
| 4 | 200 | RT6,3 | RT4,8 | 2106 | 3466 | 6 | B | | Parity - Cmd | |
| 5 | | | | | | | | | | |

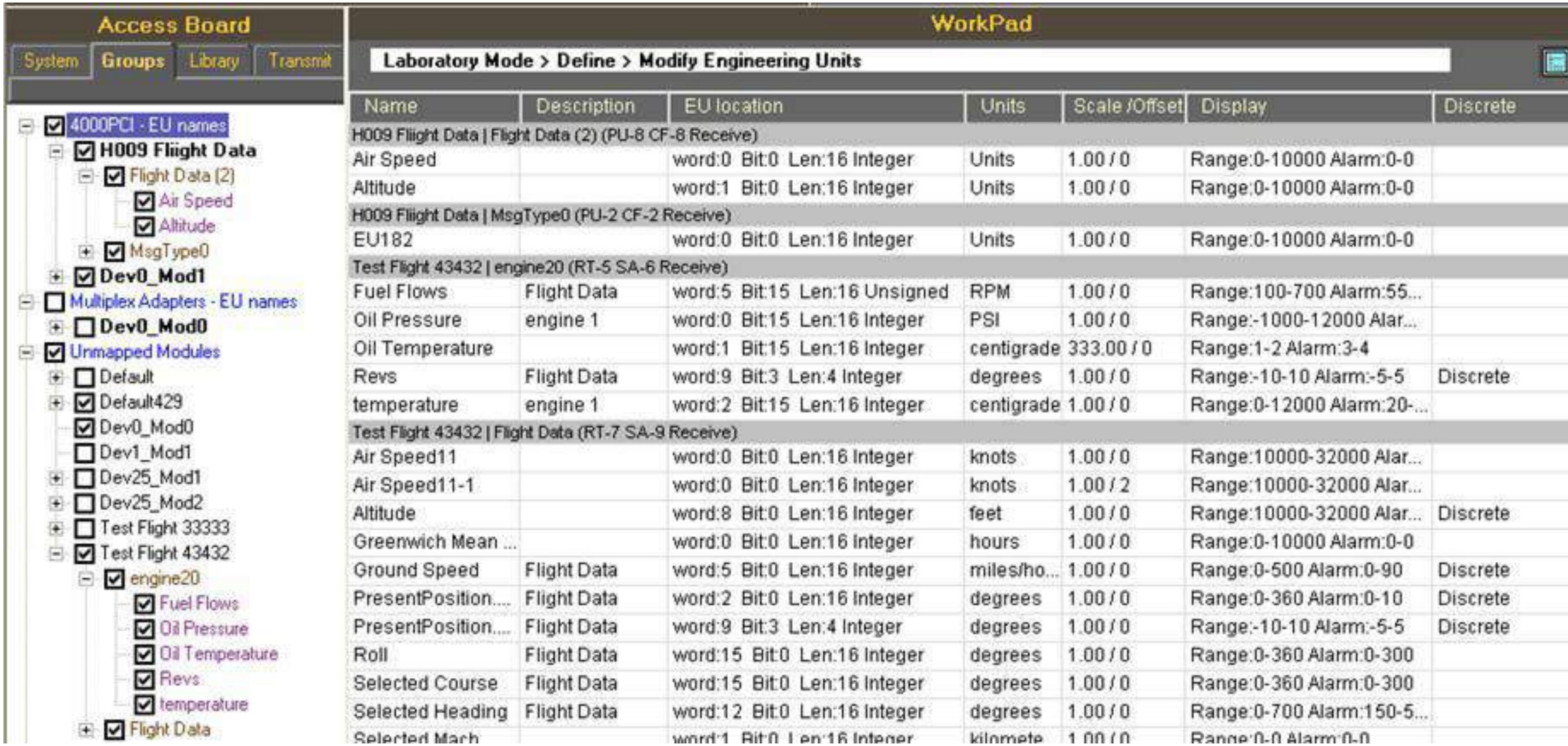
- Simulate BC for single message response
- Simulate other RT for RT to RT commands
- Inject errors to check response
- Alter intermessage timing for stress testing

# Problem Isolation

- Reconstruct Bus activity in lab
  - Selectively simulate RT's
  - Match bus timing taken from in flight record
- Perform regression testing

# Post Flight Analysis

- Analyze flight data for:
  - Health analysis – error statistics
  - Throughput analysis
  - Engineering data patterns
  - Indirect data analysis i.e., data comprised of other units, e.g., acceleration = speed Δ / time
  - Correlations between different data elements, e.g. temperature relative to altitude




| Name | Description | EU location | Units | Scale /Offset | Display | Discrete |
|---|---|---|---|---|---|---|
| H009 Fliight Data \| Flight Data (2) (PU-8 CF-8 Receive) | | | | | | |
| Air Speed | | word:0 Bit:0 Len:16 Integer | Units | 1.00 / 0 | Range:0-10000 Alarm:0-0 | |
| Altitude | | word:1 Bit:0 Len:16 Integer | Units | 1.00 / 0 | Range:0-10000 Alarm:0-0 | |
| H009 Fliight Data \| MsgType0 (PU-2 CF-2 Receive) | | | | | | |
| EU182 | | word:0 Bit:0 Len:16 Integer | Units | 1.00 / 0 | Range:0-10000 Alarm:0-0 | |
| Test Flight 43432 \| engine20 (RT-5 SA-6 Receive) | | | | | | |
| Fuel Flows | Flight Data | word:5 Bit:15 Len:16 Unsigned | RPM | 1.00 / 0 | Range:100-700 Alarm:55... | |
| Oil Pressure | engine 1 | word:0 Bit:15 Len:16 Integer | PSI | 1.00 / 0 | Range:-1000-12000 Alar... | |
| Oil Temperature | | word:1 Bit:15 Len:16 Integer | centigrade | 333.00 / 0 | Range:1-2 Alarm:3-4 | |
| Revs | Flight Data | word:9 Bit:3 Len:4 Integer | degrees | 1.00 / 0 | Range:-10-10 Alarm:-5-5 | Discrete |
| temperature | engine 1 | word:2 Bit:15 Len:16 Integer | centigrade | 1.00 / 0 | Range:0-12000 Alarm:20-... | |
| Test Flight 43432 \| Flight Data (RT-7 SA-9 Receive) | | | | | | |
| Air Speed11 | | word:0 Bit:0 Len:16 Integer | knots | 1.00 / 0 | Range:10000-32000 Alar... | |
| Air Speed11-1 | | word:0 Bit:0 Len:16 Integer | knots | 1.00 / 2 | Range:10000-32000 Alar... | |
| Altitude | | word:8 Bit:0 Len:16 Integer | feet | 1.00 / 0 | Range:10000-32000 Alar... | Discrete |
| Greenwich Mean ... | | word:0 Bit:0 Len:16 Integer | hours | 1.00 / 0 | Range:0-10000 Alarm:0-0 | |
| Ground Speed | Flight Data | word:5 Bit:0 Len:16 Integer | miles/ho... | 1.00 / 0 | Range:0-500 Alarm:0-90 | Discrete |
| PresentPosition.... | Flight Data | word:2 Bit:0 Len:16 Integer | degrees | 1.00 / 0 | Range:0-360 Alarm:0-10 | Discrete |
| PresentPosition.... | Flight Data | word:9 Bit:3 Len:4 Integer | degrees | 1.00 / 0 | Range:-10-10 Alarm:-5-5 | Discrete |
| Roll | Flight Data | word:15 Bit:0 Len:16 Integer | degrees | 1.00 / 0 | Range:0-360 Alarm:0-300 | |
| Selected Course | Flight Data | word:15 Bit:0 Len:16 Integer | degrees | 1.00 / 0 | Range:0-360 Alarm:0-300 | |
| Selected Heading | Flight Data | word:12 Bit:0 Len:16 Integer | degrees | 1.00 / 0 | Range:0-700 Alarm:150-5... | |
| Selected Mach | | word:1 Bit:0 Len:16 Integer | kilomete | 1.00 / 0 | Range:0-0 Alarm:0-0 | |