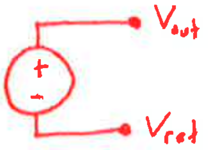
AEM 617

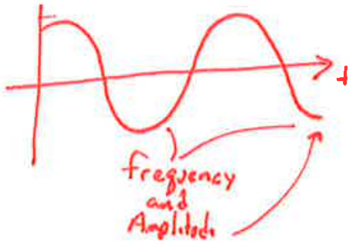
Bus

Electrical Refresher



Voltage Source (DC)
[V]

Voltage Source (AC)
[V]



Ground (Reference)

Resistor
[Ω] ohm

$V = iR$
Amp
Resistance

Switch

Variable Resistor
"Potentiometer"

Capacitor
[F] farad

$$\frac{dV}{dt} = \frac{I}{C}$$

stores energy in an electric field

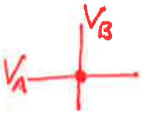
$$E = \frac{1}{2} C V^2$$

Inductor
[H] Henry

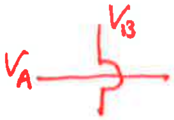
$$V = L \frac{dI}{dt}$$

stores energy in a magnetic field

$$E = \frac{1}{2} L I^2$$

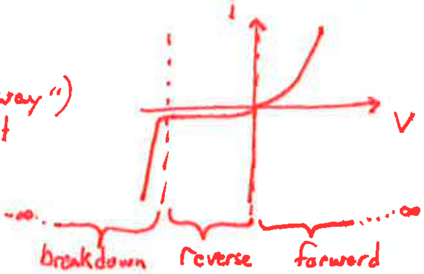


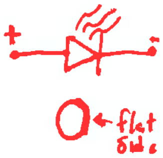
Connected wires
$V_A = V_B$



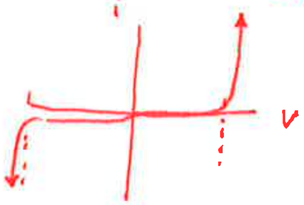
Not connected
$V_A \neq V_B$

Diode ("one way") almost





LED



Volt = Amp Ω

$$\text{Watt} = \frac{\text{Volt}^2}{\Omega}$$

Haitz's Law: (Similar to Moores law)

Amount of light increases by 20 every decade

Cost per unit of light falls by 10 every decade

Q: What is the current and power?

$$V=IR \Rightarrow I = \frac{V}{R} = \frac{12^V}{1000\Omega} = 0.012^A$$

Power is $V \cdot A = P^{[watt]}$

$$P = V\cdot \cancel{A} = (IR)I = I^2R = (0.012^2)(1000\Omega)$$

$$V\cdot I = V\cdot\frac{V}{R} = \frac{V^2}{R} = \frac{12^2\,\cancel{V^2}}{1000\cancel{\Omega}}\Big|\frac{\cancel{\Omega}\,W}{\cancel{V^2}} = 0.144^W$$

Q: What is the current and power in an A.C. circuit?

$$V = IR = |V|e^{i(\omega t+\phi)}$$

Solve for I

$$I = \frac{V}{R} = \frac{|V|e^{i(\omega t+\phi)}}{R}$$

$$= I_0 e^{i(\omega t+\overset{\uparrow}{\phi})}$$

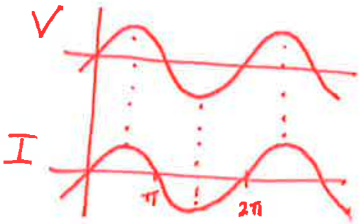
No change in phase.

this is just sines and cosines

The current is also a sine + cosine with the same phase. ∅

Impedance (Think resistance at a phase)

• Resistor $\underset{\substack{\uparrow\\ \text{impedance}}}{Z} = \underset{\substack{\uparrow\\ \text{resistance}}}{R} = Re^{i0} = R$ since $e^0 = 1$



• Inductor

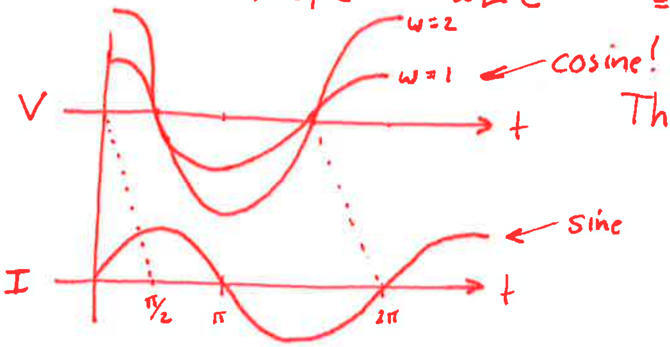
$$Z = \underset{\substack{\uparrow\\ \sqrt{-1}}}{j}\,\underset{\substack{\uparrow\\ \text{freq}}}{\omega}\,\underset{\substack{\nwarrow\\ \text{Inductance Value [H]}}}{L}$$

$$= \omega L \underbrace{e^{i\pi/2}}_{\text{phase!!}}$$

from Complex #s geometry, multiplying by $i=\sqrt{-1}$ rotates in the polar axis by 90°

$$i = e^{i\pi/2}$$

$$V = IR = IZ = |I_0|e^{i(\omega t)}\omega L e^{i\pi/2} = |I_0|\,\omega L\, e^{i(\omega t+\pi/2)}$$



The output voltage {leads / is ahead of} current.

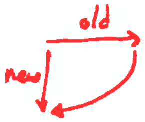
ELI The ICE man

$\uparrow$ voltage $\uparrow$ inductor $\nwarrow$ current

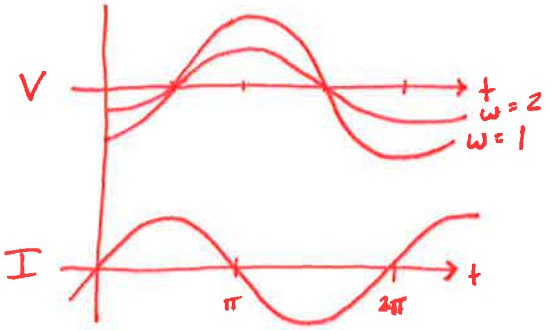
- Capacitor ⊣⊢

$$Z = \frac{1}{j\omega C} = \frac{j}{j}\frac{1}{j\omega C} = \frac{j}{-1}\frac{1}{\omega C} = -j\frac{1}{\omega C} = \frac{1}{\omega C}e^{-i\pi/2}$$

$$= \frac{1}{\omega C}\underbrace{e^{-i\pi/2}}_{\text{phase}}$$



$$V = IR = |I_0|e^{i(\omega t)}\frac{1}{\omega C}e^{-i\pi/2} = |I_0|e^{i(\omega t - \pi/2)}$$



The output voltage lags current

"charging a battery"

ELI the ICE man

current cap voltage

Kirchhoffs laws

1) Sum of currents at a node is zero (i.e. electron conservation!)

2) Sum of voltages around any loop is zero (i.e. conservative field)

Q:

What is the current i_0?

K1: $i_0 - i_2 - i_1 = 0 \Rightarrow i_0 = i_1 + i_2$

K2: loop through resistors ↻ $V_2 - V_1 = 0 \Rightarrow V_2 = V_1$

Also $i_1 = \frac{V_1}{R_1} = \frac{V_2}{R_1}$ and $i_2 = \frac{V_2}{R_2}$.

Thus,

$$i_0 = \frac{V_0}{R_0} = i_1 + i_2 = \frac{V_2}{R_1} + \frac{V_2}{R_2}$$

But $V_0 = V_1 = V_2$

$$\frac{1}{R_0} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_2}{R_1R_2} + \frac{R_1}{R_1R_2} = \frac{R_1 + R_2}{R_1R_2}$$

In series

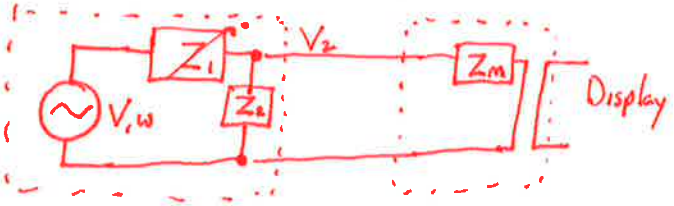
$R_s \equiv$ equiv resist $= R_1 + R_2$

In parallel

$R_0 \equiv$ equiv Resistance $= \frac{R_1R_2}{R_1 + R_2}$

Voltmeter (VOM : Volt, ohm, meter) and Oscilloscopes

Usually advertised with a high impedance. Why?



In normal operation (not VOMing it), $|V_0|e^{i(\omega t+\emptyset)} = |I_0|e^{i(\omega t)}(\cancelto{\cdot}{Z_1}+Z_2)$

$$V_2 = |I_0|e^{i(\omega t)} Z_2$$

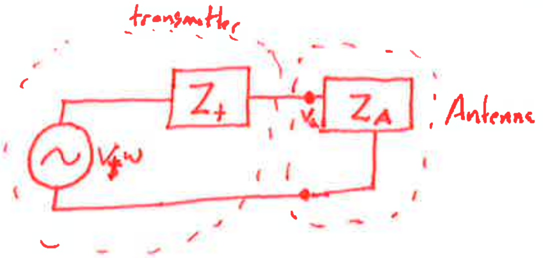
But when we add the VOM,

$$V_2 = |I_0|e^{i\omega t}\frac{(Z_2 \cdot Z_m)}{Z_2+Z_m} \xrightarrow[\lim_{Z_m\to\infty}]{} |I_0|e^{i\omega t}\cancelto{1}{\frac{Z_m}{Z_m}} Z_2 = |I_0|e^{i\omega t}Z_2$$

However, if the VOM has too low of $Z_m \approx Z_2$

$$V_2 = |I_0|e^{i\omega t}\left(\frac{Z_2^2}{2Z_2}\right) = I_0 e^{i\omega t}\frac{Z_2}{2} \neq$$

Antennas



We want to maximize Power!

$$(x+iy)^* = (x-iy)$$

$$P = \frac{1}{2}\mathrm{Re}(V_a I_a^*) \quad \text{with} \quad V_A = V_t\frac{Z_A}{Z_A+Z_t}$$

$$I_A = \frac{V_t}{Z_A+Z_t} = \frac{V_t}{R_A+jX_A+R_t+jX_t}$$

$$= \frac{1}{2}\mathrm{Re}\left(V_t\frac{Z_A}{Z_A+Z_t}\,\frac{V_t}{R_A+R_t-j(X_A+X_t)}\right)$$

$$= \frac{1}{2}\frac{V_t^2}{|Z_A+Z_t|^2}$$

We want $Z_A + Z_t$ to be small, thus $X_A = X_t^*$
so the imaginary part goes to zero

$$\boxed{P = \frac{V_t^2}{8R_t}}$$

Your antenna must be tuned!!

Source: ECE692, Yan

ARINC 429

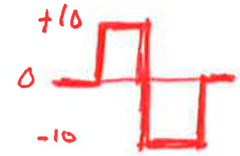
ARINC ≡ Aeronautical Radio Incorporated

Low cost digital communications, one direction (simplex)

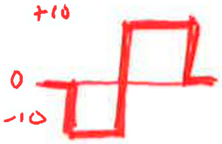
100 Kbps . 1977 standard twisted pair wire 20 devices

$12\,^{5}$ Kbps 32 bit "words"

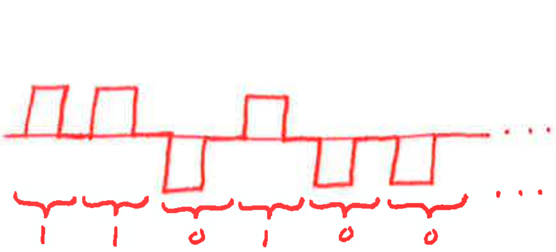
Bit modulation RZ ≡ return to zero Requires ± Voltages!



= 1 = high to low



= 0 = low to high



Timing: At 100 kbps = f the period is $\frac{1}{f} = \tau = \frac{1}{100 \times 10^3}$ = 0.00001 s = 10µs

=>

The pulse must rise / fall within 1.5 ± 0.5 µs meaning that the bandwidth must be on the order of 1 MHz or so.

Data BCD ≡ binary coded decimal = each digit is coded by a binary sequence

10 values = 2^{bits} => bits = 4 $2^4 = 16$ (wastes bits)

8	4	2	1	
0	0	0	0	= 0
0	0	0	1	= 1
0	0	1	0	= 2
⋮				
1	0	0	1	= 9

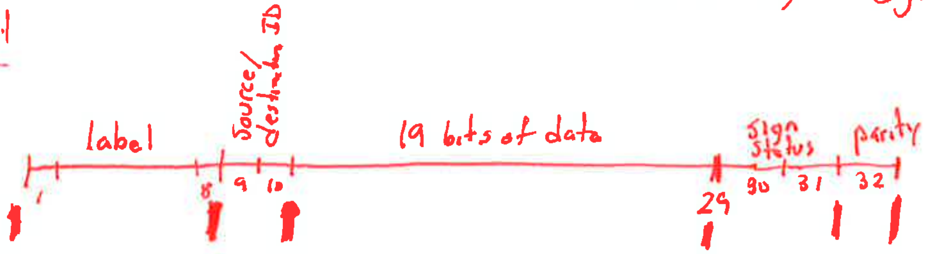
$\text{BCD}(\underbrace{0011}_{3}\ \underbrace{0001}_{1}\ \underbrace{0100}_{4}\ \underbrace{0001}_{1}\ \underbrace{0101}_{5})$

BNR = binary data

Label 8 bit source label

Specifies the device (and the data format) eg. 01001011 = airspeed sensor
10000011 = distance to VOR
⋮ ⋮

Data Format



North, East, Up, Right = 0 0
South, West, Down, Left = 1 1
No data = 0 1
Test = 1 0

MIL STD 1553B

Military Standard, linear, duplex (2 way)

1 Mbps, 1973 standard, 32 devices (including controller)

20 bit words, 16 bits of data per word

Manchester encoding: See previous notes

 low to high = 0  high to low = 1

Devices: Up to 32 devices = 2^5

BC: Bus Controller
RT: Remote Terminal

Operation

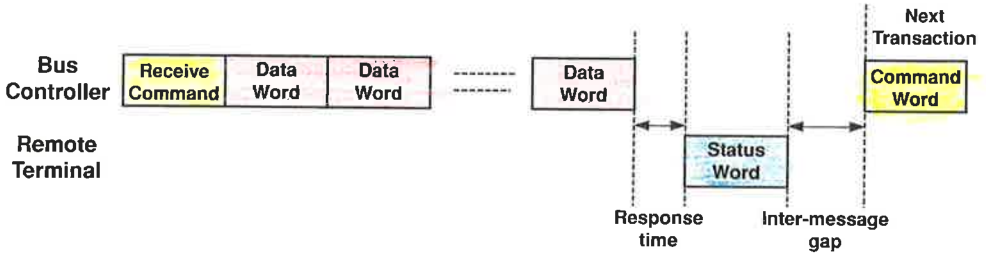
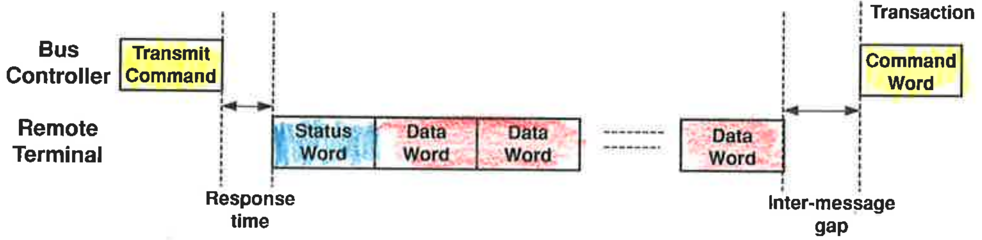
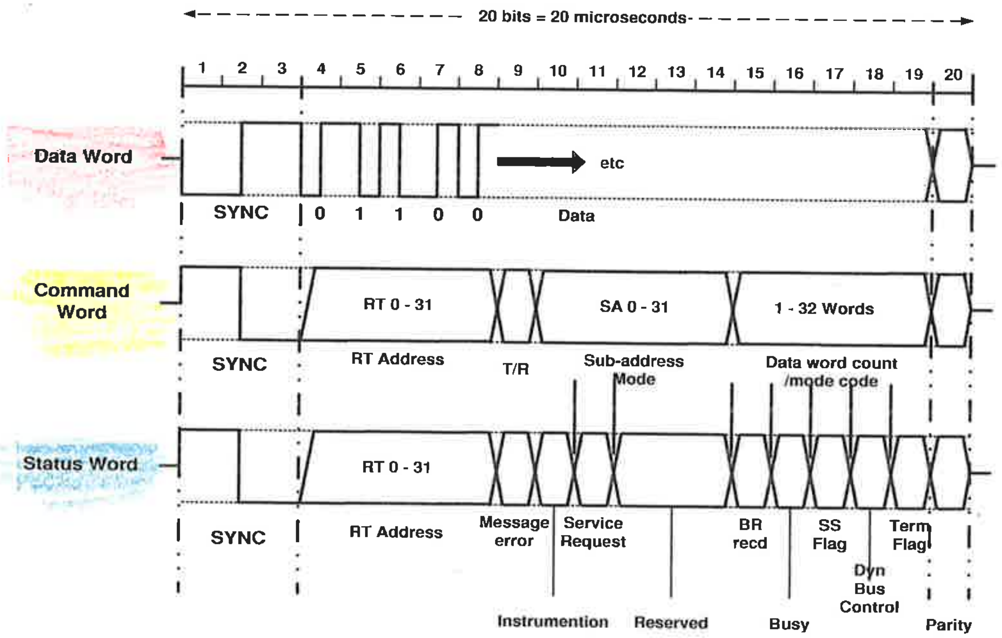


Figure 3.15 BC to RT transaction protocol



Word Formats



- SYNC pulse before every word
- BC determines length/# of words up to 32 = 2^5

Figure 3.14 MIL-STD-1553B word formats

Source Civil Avionics Systems, Moir + Seabridge

Address

5 bit = 32 devices

Command Word

- RT address bits 4-8 = 5 bits
- T/R transmit or receive
- Mode bits 10-14 = 5 bits

TABLE 33.4 Mode Code

T/R	Mode Code	Function	Data Word	Broadcast
1	00000	Dynamic bus control	No	No
1	00001	Synchronize	No	Yes
1	00010	Transmit SW	No	No
1	00011	Initiate self-test	No	Yes
1	00100	Transmitter shutdown	No	Yes
1	00101	Override transmitter shutdown	No	Yes
1	00110	Inhibit terminal flag bit	No	Yes
1	00111	Override inhibit terminal flag bit	No	Yes
1	01000	Reset	No	Yes
1	01001	Reserved	No	TBD
1	•	•	No	•
1	•	•	No	•
1	01111	Reserved	No	TBD
1	10000	Transmit vector word	Yes	No
0	10001	Synchronize	Yes	Yes
1	10010	Transmit last CW	Yes	No
1	10011	Transmit BIT word	Yes	No
0	10100	Selected transmitter shutdown	Yes	Yes
0	10101	Override selected transmitter shutdown	Yes	Yes
1/0	10110	Reserved	Yes	TBD
	•	•	Yes	•
	•	•	Yes	•
1/0	11111	Reserved	Yes	TBD

Status Word

"Transmitted by an RT in response to a valid message" Digital Avionics Handbook, Spitzer

- Address
- Message Error ? "1"
- Instrumentation
- Service Request

} Inform the BC of the RT status.

ARINC 629

Civil Standard, Linear, Distributed (no BC)
20 bit Manchester, 2 Mbps, 128 devices

Limited use to Boeing 777 and Airbus A330, A340

Interesting way to prevent collisions and ensure priority

SG = synchronization gap timer
triggers when bus is quiet.

TG = Terminal gap timer
higher priority devices get <u>shorter</u> TG times
If a device wants to send data, it starts at the end of its TG.

M = Message

TI = Terminal Interval
Timeout once a terminal sends a message to ensure other devices have time to send

No collisions!

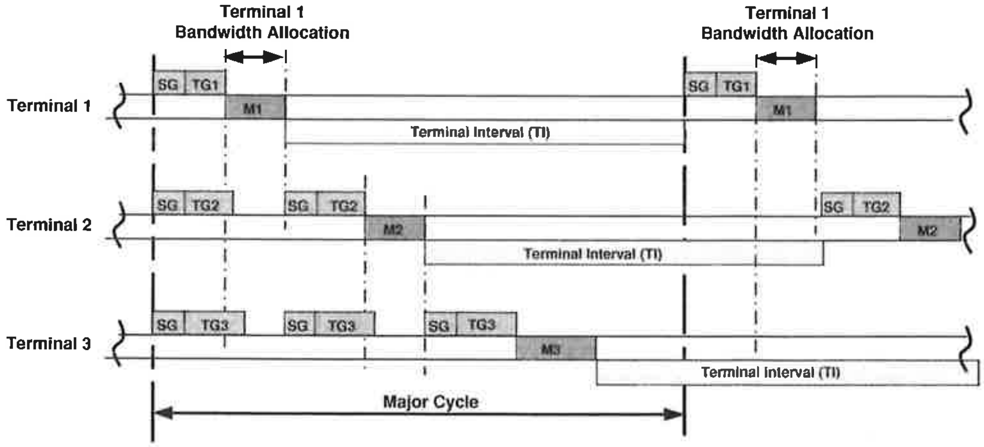


Figure 3.20 ARINC 629 message protocol

ARINC 664

Q: What is the most widely used bus in the world?
A: Ethernet

Why not use this techology for aircraft? ARINC 664

Ethernet, full duplex, 100 Mbps, large message lengths, 6 byte address = $2^{48} \approx$ 300 trillion

- Data Format

	Preamble	Synch start	Destination Address	Source Address	Length	Data	Check
Bytes	7	1	6	6	2	46-1500	3

Source: CAS

Addresses

6 byte = 48 bit $\qquad 2^{48} \approx 281,474,976,710,656$

One bus for all devices is possible.

Length

2 bytes = 16 bit = 65536

Data

From 46 to 1500 bytes (368 bits to 12000 bits) High Efficiency Low Overhead

Check

Verify message integrity CRC

- problems
  - Special deterministic behavior (different from regular TCP/IP over ethernet)
  - Isolation (malicious passenger vs flight control system)

This is the state-of-the-art on Boeing and Airbus products

CAN Bus

Low cost automotive data bus, 1980s, twisted pair

1Mbps, up to 8 byte message, priority system

Message

Synch data length

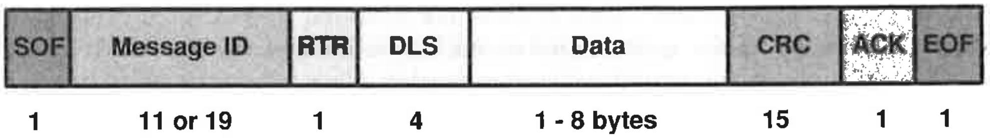
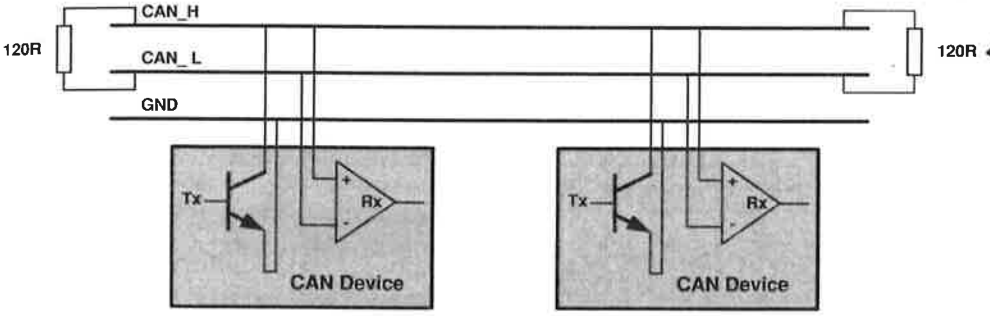


Figure 3.37 CANbus message format (simplified)

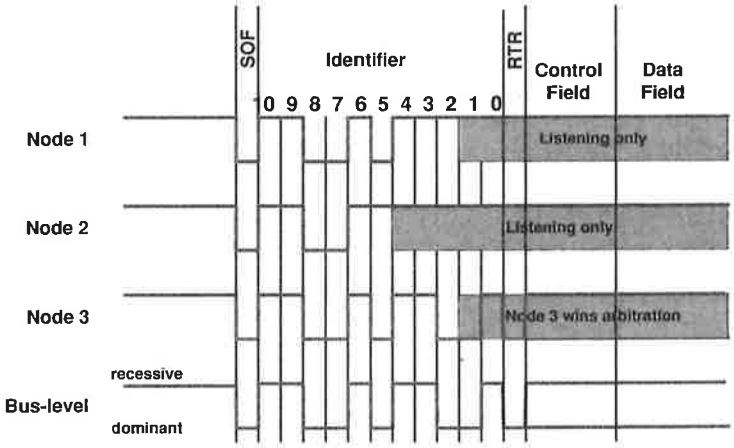
Topology



120 ohm resistor simple!

Figure 3.36 CANbus topology

Priority



- At bit 5, nodes 1 and 3 send a dominant identifier bit, node 2 sends a recessive bit but reads back a dominant bit. Node 2 loses the bus.
- At bit 2 node 1 loses arbitration against node 3.
- Node 3 wins. Nodes 1 and 2 send their message after node 3 has finished.

Figure 3.38 CANbus message prioritisation

Table 3.1 Data bus network comparisons

Attribute	MIL-STD-1553B	ARINC 429	ARINC A664-P7	CANbus
Max. message length (data element)	32 × 16-bit words	18-bit word	1518 bytes (1 byte = 8 bits)	8 bytes
Max. bit rate	1 Mbps	100 kbps	10/100 Mbps	1 Mbps
Topology	Linear Single source, single sync (unicast)	Linear Single source, multisync (multicast)	Star Single source, multisync (multicast)	Linear Single source, multisync (multicast)
Communication type	Bidirectional Half-duplex	Unidirectional	Bidirectional Full-duplex	Bidirectional Half-duplex
Media access (protocol)	Command/response	Direct	CSMA/CD plus extensions	CSMA/CD
Max. bus length	100 m (6 m stub)	65 m	<100 m	40 m
Latency	Immediate	Small	Depends on network load	Depends on message priority
Jitter	Small	Small	Depends on network load	Depends on message priority
Error containment	Parity bit	Parity bit	Cyclic redundancy check	Extensive cyclic redundancy check
Error handling	Extensive retry capability	Ignored by receivers	Shut-off erroneous nodes	Immediate retry
Redundancy	Dual redundant	Simplex	Dual redundant	Simplex
Physical layer	Shielded twisted pair	Shielded twisted pair	Shielded twisted (quadrax/2× twinax) or optical fibre	Shielded twisted pair or optical fibre
Price per chipset	$1000	$30–$200	$250–$700	$1–$2