CAN Primer

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Version 2.0

Agenda:

- What exactly is CAN ?
- Identifiers – what they are.
- What does the data look like ?
- What the CAN wires look like.
- Example CAN circuits.
- Arbitration – who gets priority.
- Errors and how to detect them !
- Some Tips and Hints….

Myths about CAN:

- Is not only for automotive applications !
- Can be found everywhere.
- Automation is one (CANopen, DeviceNet)
- Is easy to implement…no mystery anymore
- …unless you use some tricky protocols.
- You can “roll your own” for simplicity.
- Can gateway to USB, Ethernet, RS232 and other networks to form larger systems.

Why Use CAN ?

- Electrically robust with built-in error and arbitration features. These are automatic !
- Differential pair reduces EMI in/out.
- Many controllers and parts available.
- Plenty of software and hardware tools.
- Really, really easy to add another node.
- Hard work is done by the CAN controller.
- Many chips have implemented CAN.
- Largest CAN network in world is believed to be the Vancouver Olympic sign.

What exactly is CAN ?

- CAN – Controller Area Network
  The Bosch CAN spec includes:
- Some of the physical layer (wires).
- Message frame description.
- Attributes – Peer-to-Peer network.
- Arbitration scheme - multiple messages.
- Some error detection and handling.

The CAN spec does not include:

- Any high level addressing modes.
- Any message descriptions or groupings.
- Diagnostics or messages streams.
- Any acknowledgement a message reached its intended target.
- Bus Speed: see ISO 11898-2, J2284.
- The physical link – you can use anything.
- People often include these items. Shouldn't !

CAN Speeds

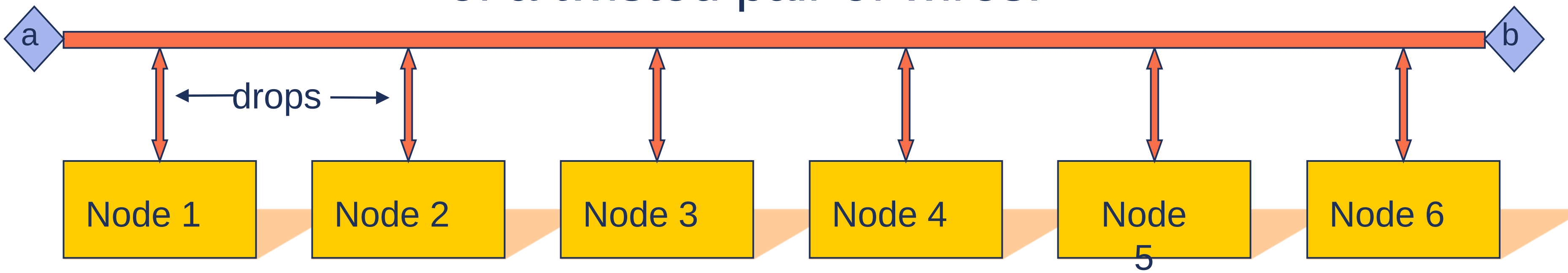
- Is specified from ~10 Kbps to 1Mbps.
- Can’t change speed dynamically…ever !
- 125, 250 & 500 Kbps common.
- Longer cable runs means slower frequency.
- 1 Mbps a bit hard to manage in a real system.

High Points of the CAN Bus

- Uses a Differential twisted pair of wires.
- The highest priority message gets thru.
- Uses non-destructive arbitration.
- The priority of message is its identifier.
- 0 has the highest priority. Always.
- No Master or Slave – Peer to Peer.
- All nodes see all messages on network.
- …except their own…..

Construction of a CAN Network

The main CAN backbone and drops are comprised of a twisted pair of wires.

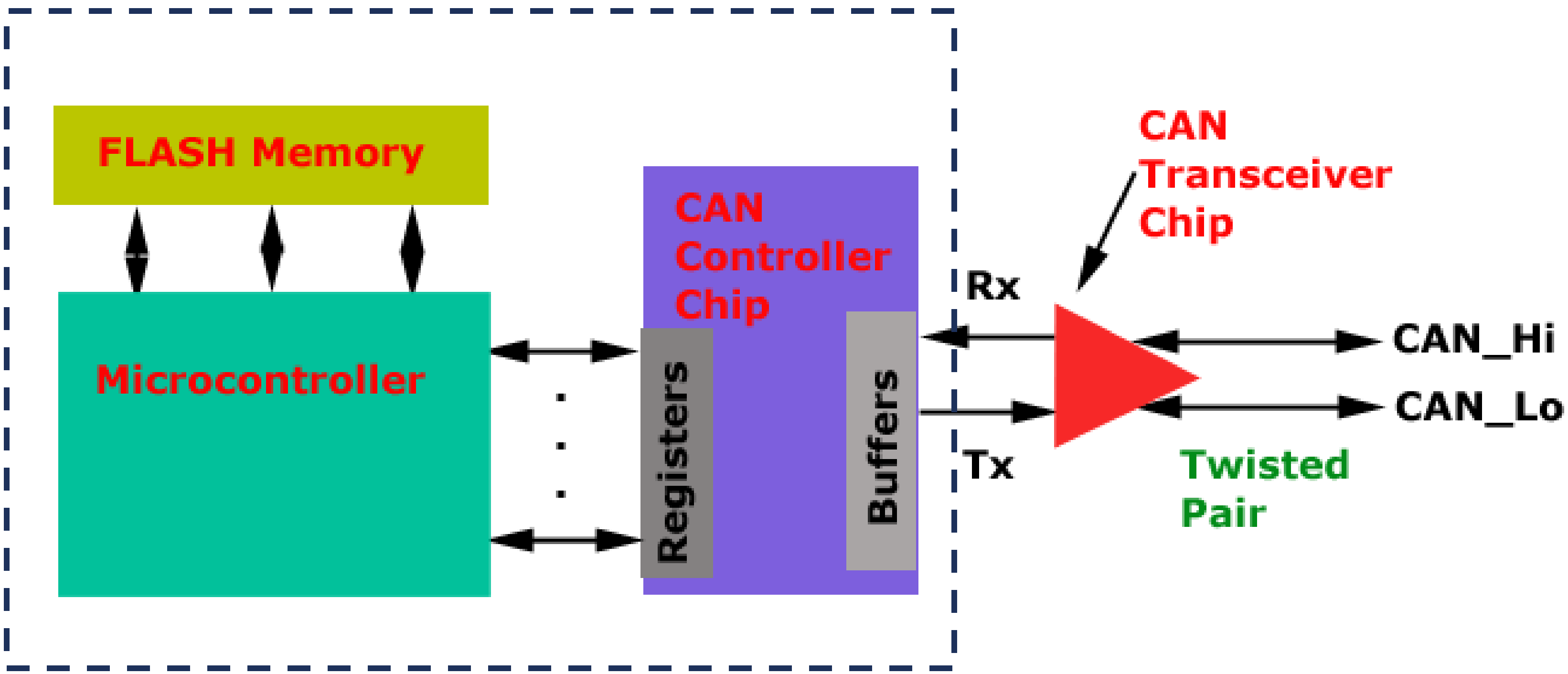


a,b = 120 Ω ½ watt termination resistors.

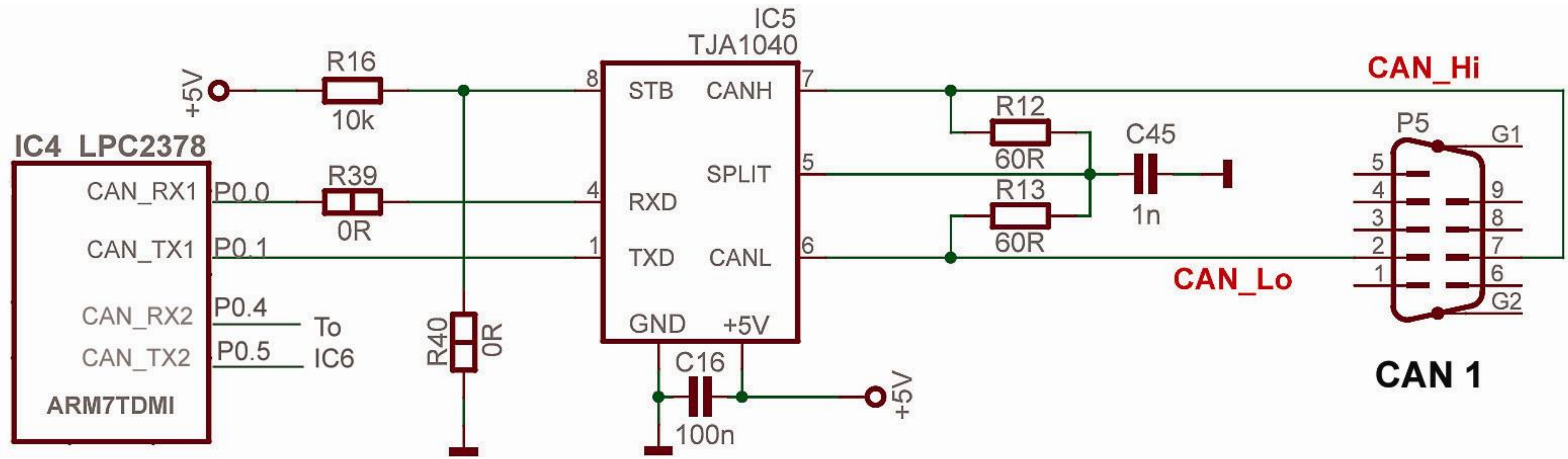
Drops use the same twisted pair of wires as the backbone.

Example CAN Node

Typical microcontroller

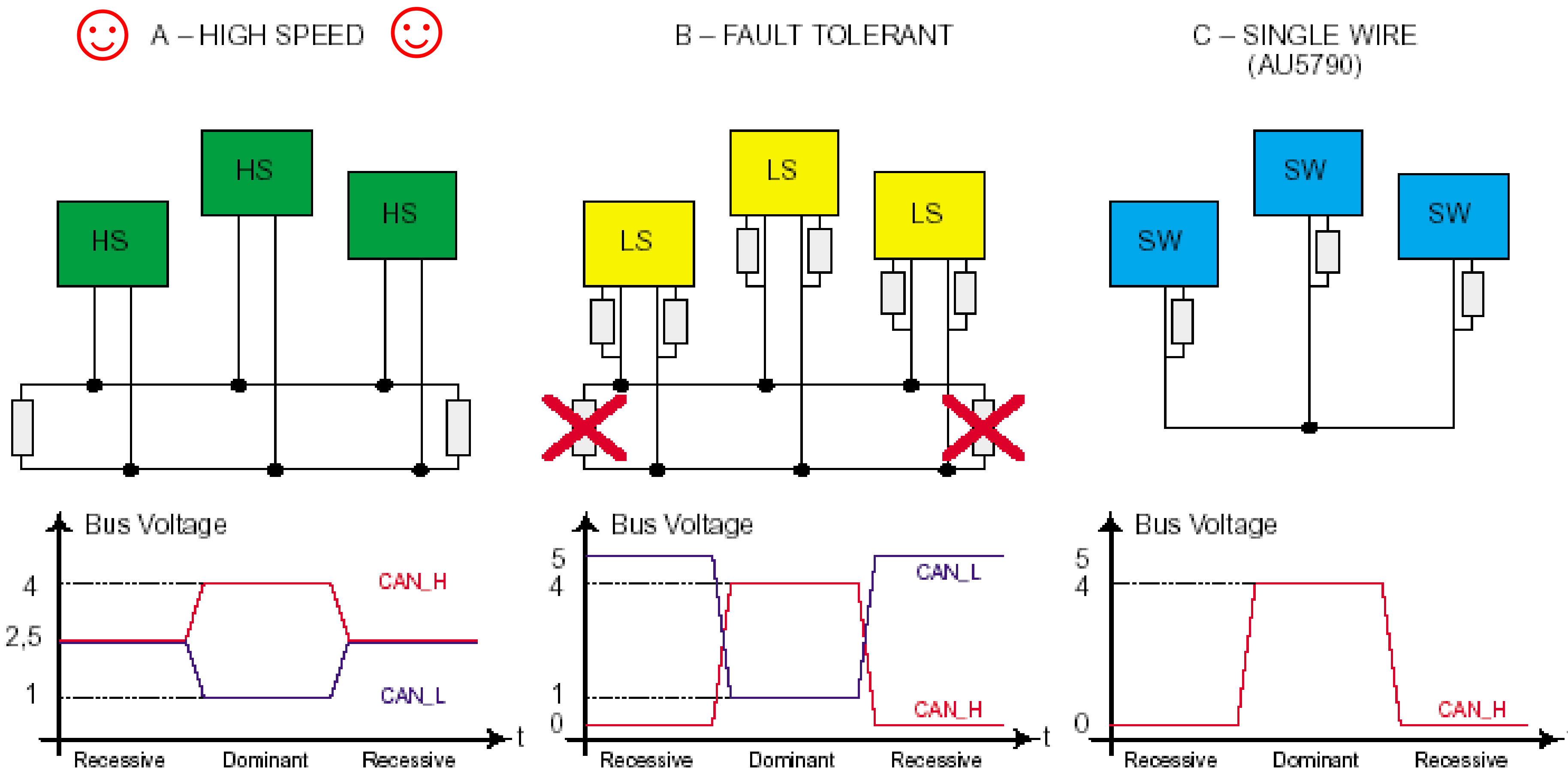


A real CAN circuit:



- R12, R13 & C45 create "Split Termination" for extra noise immunity instead of one 120 ohm.
- Note: A Common Mode Choke can be used.
- TIP: Use USB cable to power Keil boards.

Three Flavours of CAN



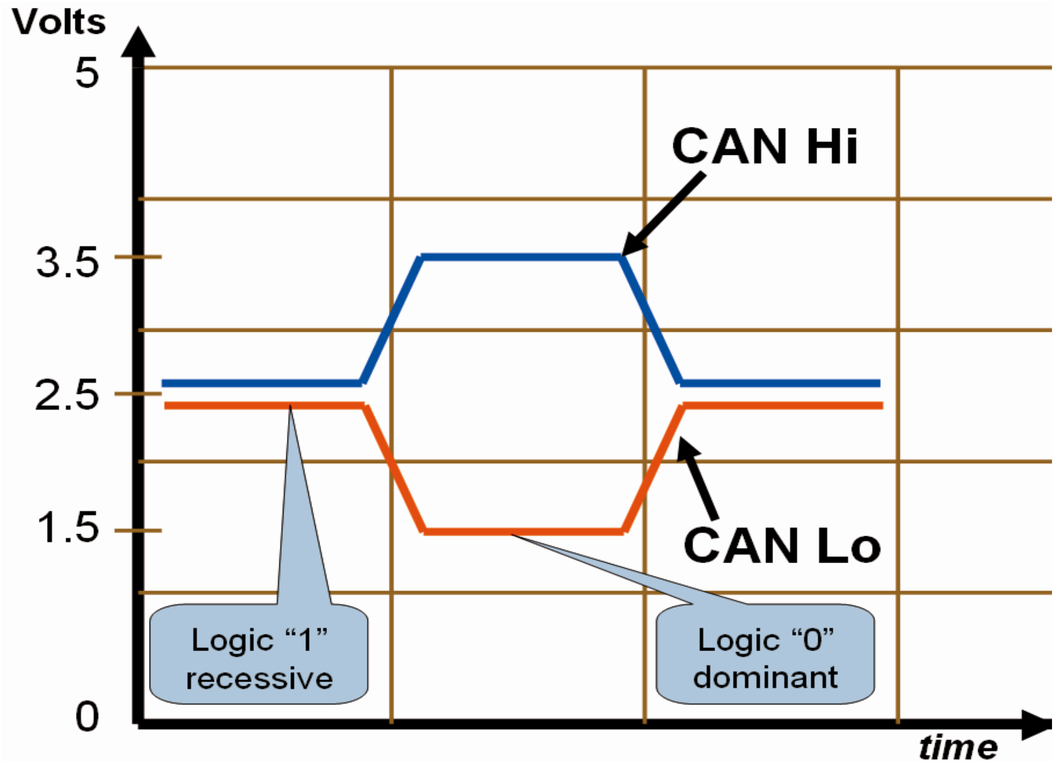
The difference between these three is the CAN transceiver and normally the speed.

Differential Twisted Pair

- CAN transceiver converts single-ended Tx to a differential pair output.
- ALSO – takes differential pair and converts back to Rx.
- Node sees in and out at same time.
- Interference coming in & out cancels out.
- Twisted pair and receiver ccts does this.

Recessive and Dominant Bits

- Recessive is 2.5 volts CAN Hi and Lo.
  Difference is 2.5 – 2.5 = 0 volts.   Call this a “1”
- Dominant is CAN_Hi 3.5v CAN_Lo 1.5v.
  Difference is 3.5 – 1.5 = 2.0 volts.   Call this a “0”

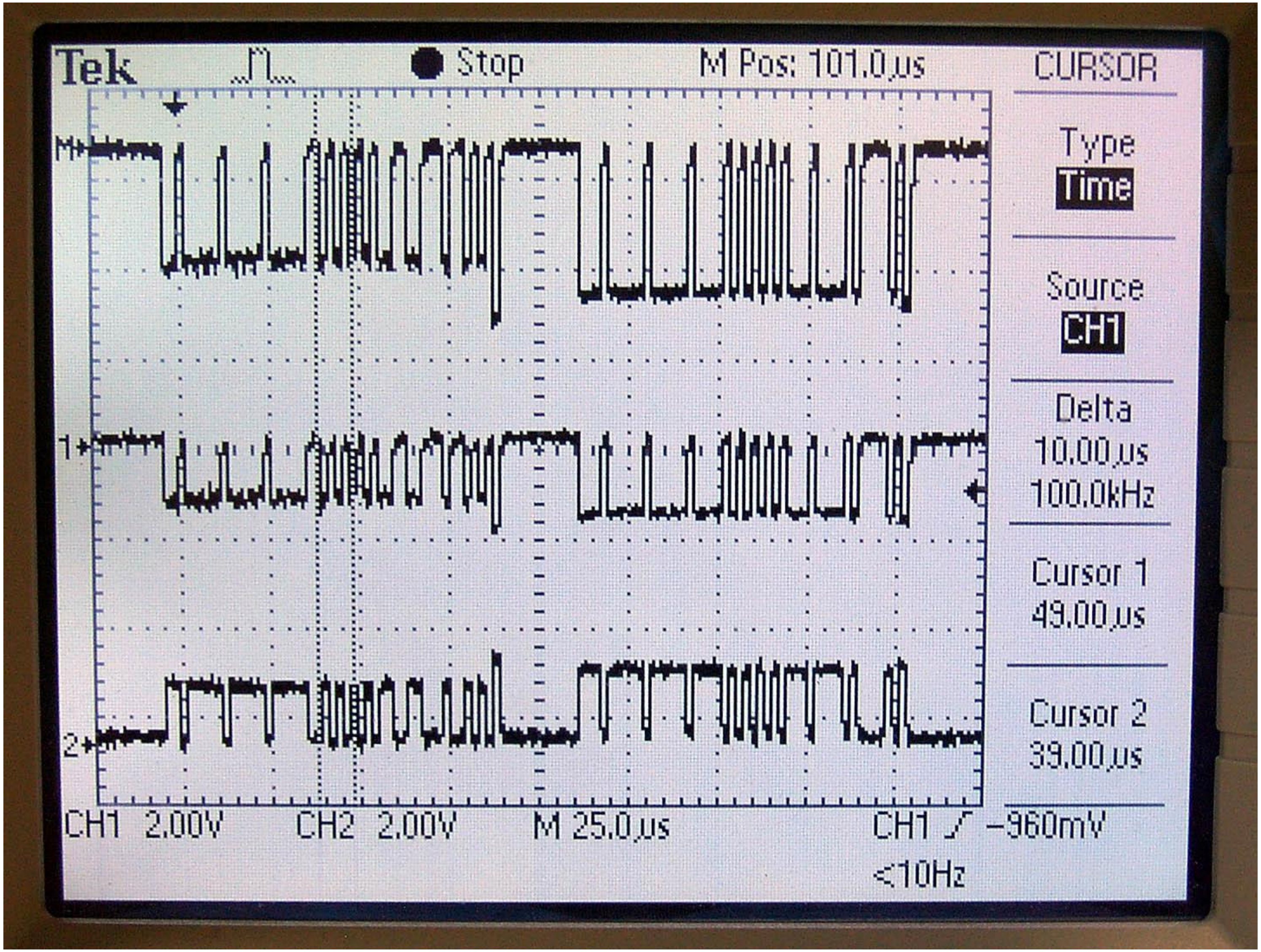


The important voltage is the difference between CAN Hi and Lo and not to ground.

Recessive and Dominant Bits

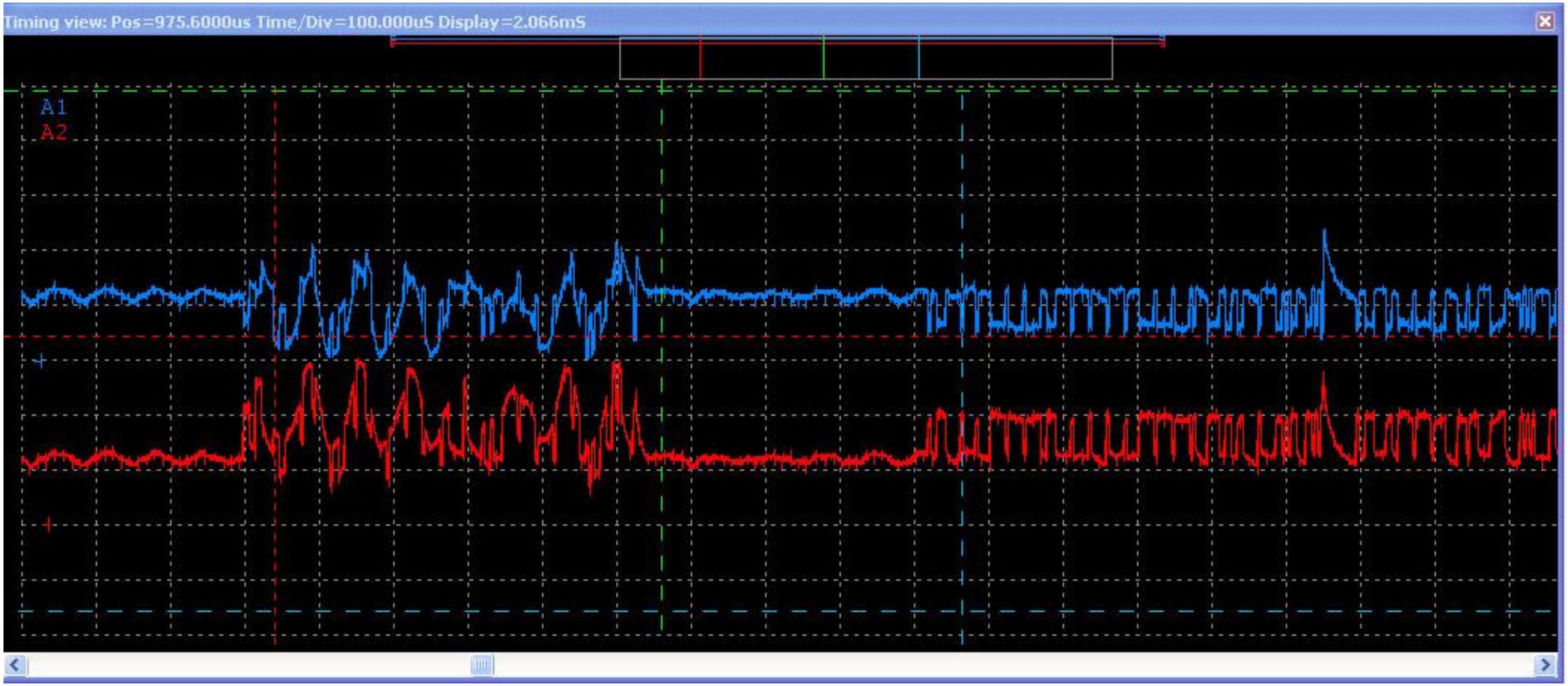
- Any node can pull Hi and Lo apart on the bus.
- No node can force Recessive.
- This means an idle bus has zero volts Hi & Lo and about 2.5 volts to ground.
- This is how arbitration works.
- A bus can sit idle for a hundred years and every node will see the first message sent.
- The clocks in CAN need to be good ones.

The Differential Signals



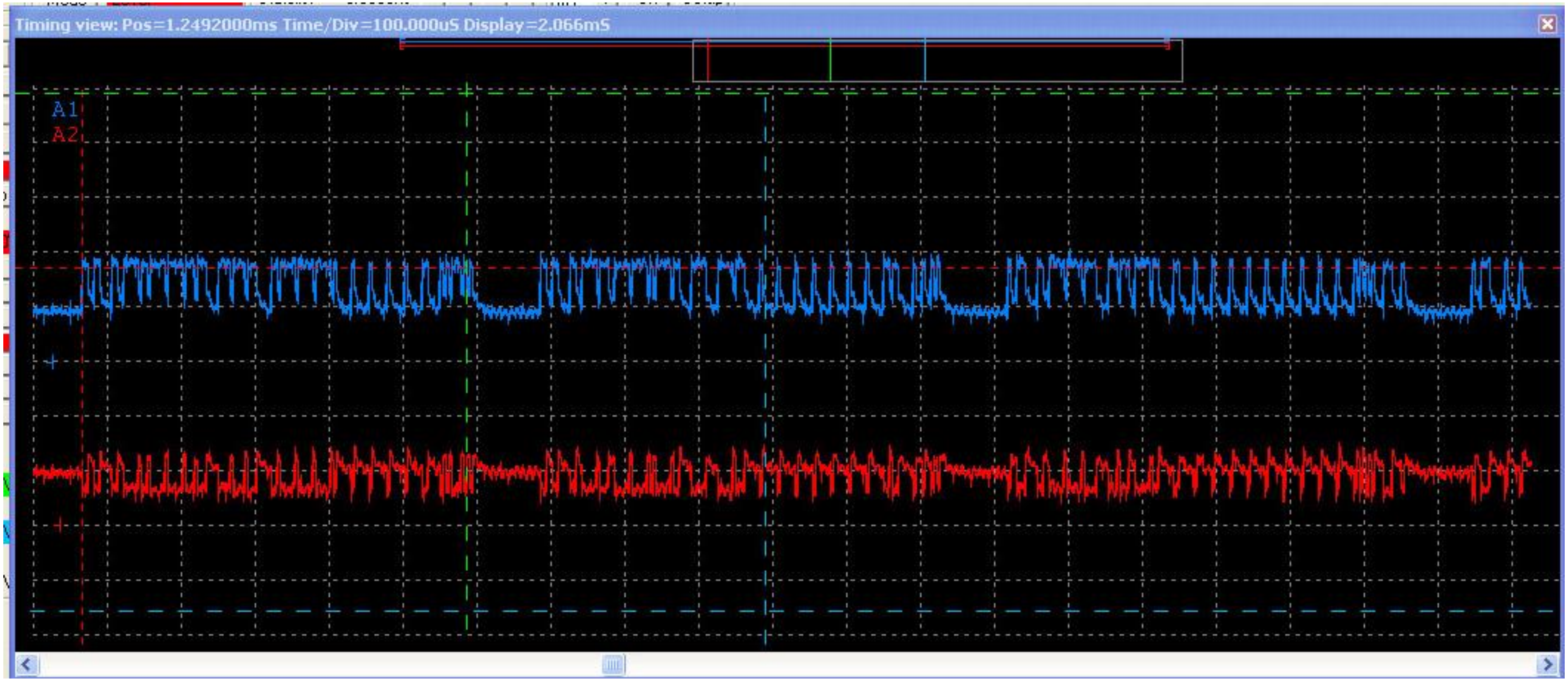
Bottom signals are algebraically subtracted to result in the top signal:

A problem !!



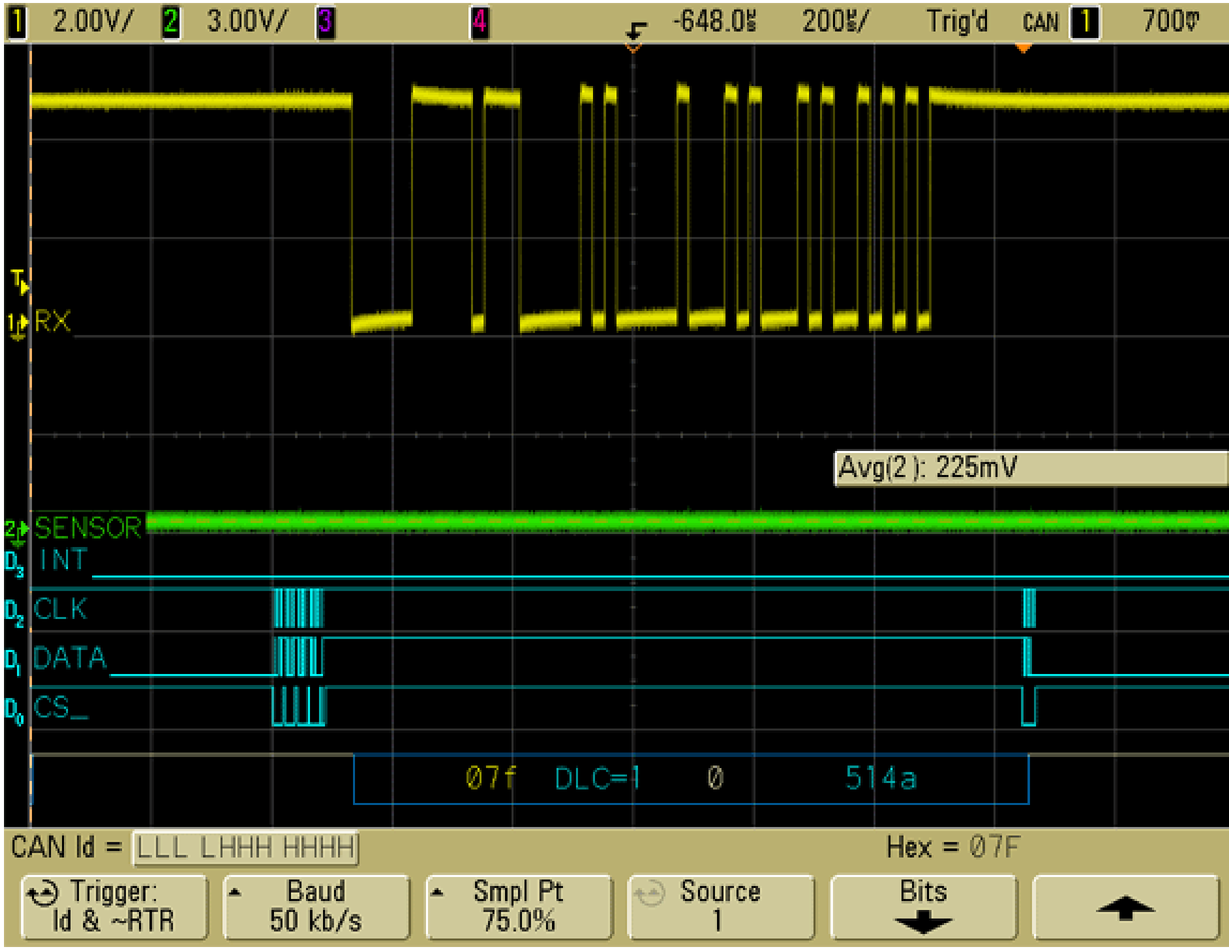
Timing view: Pos=975.6000us Time/Div=100.000uS Display=2.066mS
A1
A2

Older system works OK !



Bit Stuffing

- Nodes need an active clock to stay in sync.
- Must come from the bus transitions.
- If no change for 5 bit times – will add a bit.
- CAN frame is actually lengthened by this.
- CAN controllers add & remove stuffed bits.
- Invisible to the programmer.
- Only an oscilloscope will show this...and here is where a problem can surface !



Differential CAN signal

Rain sensor output

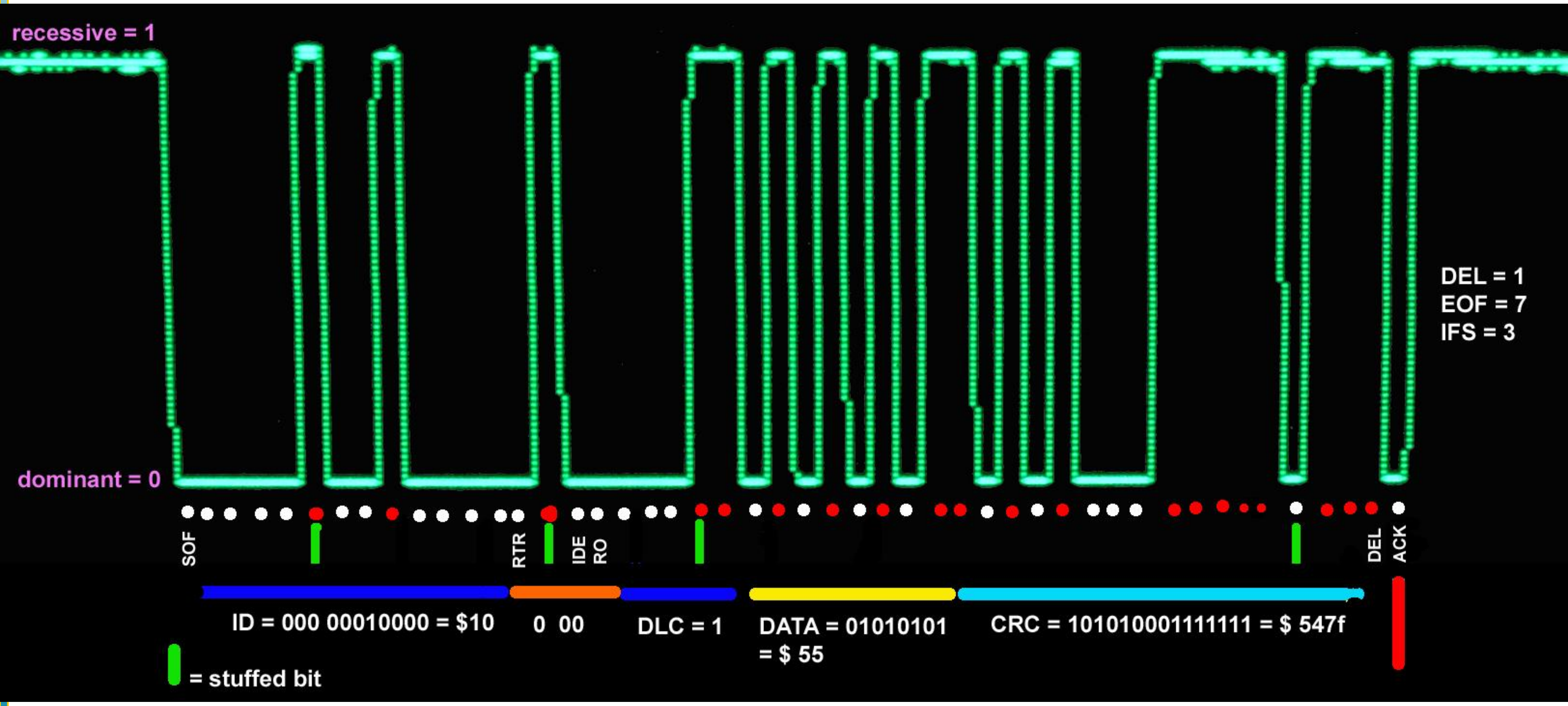
SPI signals in ECU

CAN decode

Bit stuffing makes the frame look like it has jitter !

It does not….but it can be confusing.

A CAN Frame Decoded:



Data Link: the frame.

- CAN is a serial bus. 1 or 2 wires. (SW-CAN)
- **CAN 2.0 A** Standard

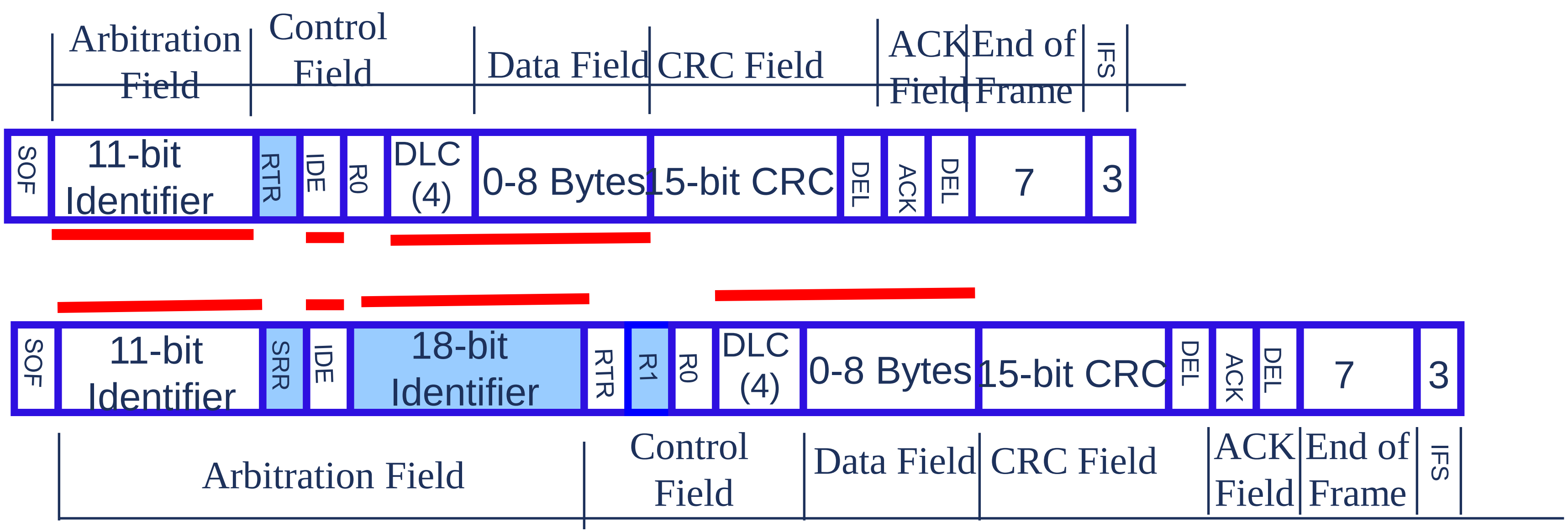
  11 bit identifiers – 2,048 ID's. 0 – 7FF
- **CAN 2.0 B** Extended

  29 bit identifiers – 536 million ID's.
  - 0 – 1FFF FFFF
- Both 11 and 29 bit can be used on the bus.
- CAN controllers can easily sort them out.

A little more…

- 0 to 8 bytes of data per CAN frame.
- This can be changed dynamically.
- Bus length to 40 meters @ 1 Mbps,
  1 meter drops. Slower = longer.
- Two 120 termination resistors needed at each end of the bus. (measure 60 ohms)

Standard and Extended CAN Frames



Designers need only fill in the RED lines !

Extended Frame: SRR=1, IDE=1

SOF - Start of Frame
SRR - Substitute Remote Request
IDE - Identifier Extension
RTR - Remote Transmission Request
R0 - Reserved bit

R1 - Reserved bit
DLC - Data Length Code
CRC - Cyclic Redundancy Check
DEL - Delimiter
ACK - Acknowledgement bit

CAN Programming Model

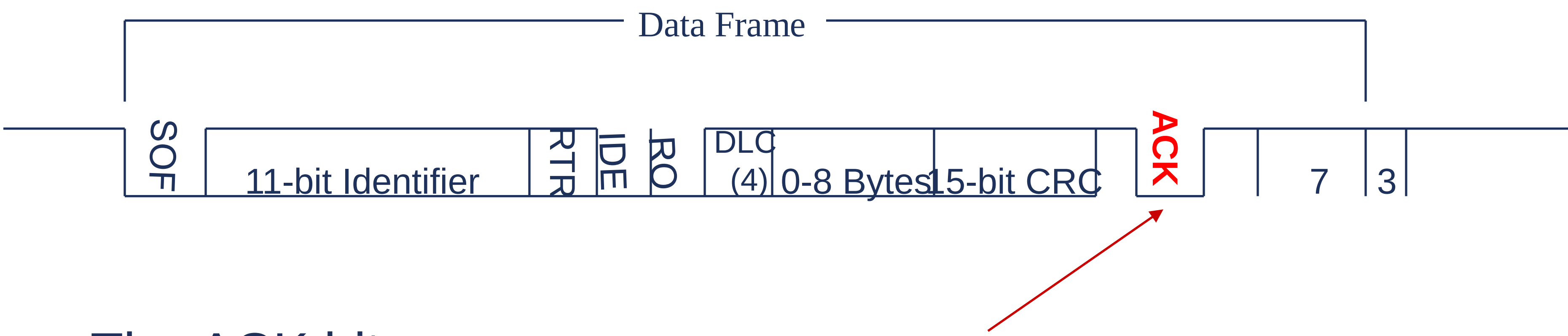
* IDE 1 bit — *Is the frame 11 or 29 bits long ?*

IDE = 0	11 bit ID
IDE = 1	29 bit ID

* DLC 4 bit — *How many data bytes are there ?* DLC = 0 thru 8

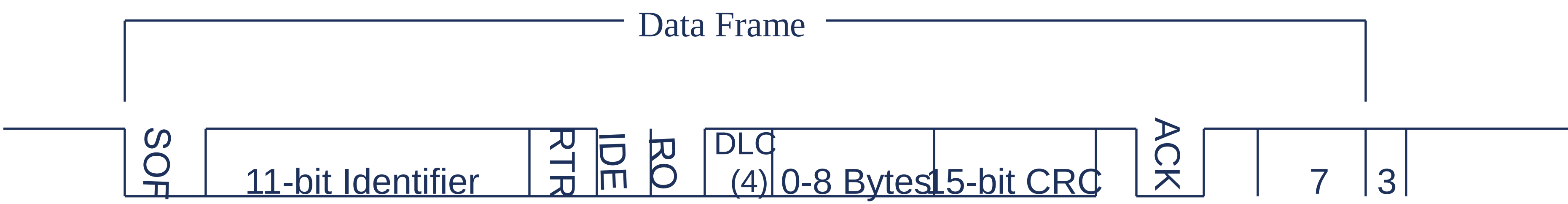
Data bytes: 0, 1, 2, 3, 4, 5, 6 ,7 or 8 bytes (0 to 64 bits)

Acknowledge: Newbie mistake # 1.



- The ACK bit.
- Sender sets this Recessive.
- Someone has to assert this to dominant.
- Else: sender re-transmits again forever.
- So – need at least one other CAN node.
- Is merely 2 µsec wide @ 500 Kbps.

A bug turned into a feature…..



- If bus gets trashed after sender finishes…
- But before others think is over…
- Bus fault occurs and message retransmitted.
- **SO: don’t increment or toggle a value !**
- If you want a variable to be 64 – say it in full.

Priority Levels

- Message with highest priority gets thru.
- Lowest Identifier has priority.
- 000 beats 001, 123 beats 256. Always.
- Arbitration evaluated in real-time.
- Uses Recessive and Dominant bits.
- A node can (and must!) see itself and others on the bus in real time.
- Note: a node can’t see its own ID and data.

Arbitration Notes:

- Illegal to have same identifier at same time.
- Possible a node will never get priority.
- CAN is not deterministic. TTCAN is though.
- Note: if 11 and 29 bit same identifier at the same time – 11 bit wins arbitration.
- i.e. 11010101010 & (wins because IDE = 0)
  11010101010101100101001101000

What can you put into the ID ?

- Anything at all ! CAN does not specify.
- IDs will get on bus according to priority.
- Your System Designer will not agree !
- **Normally:** addresses of modules or devices.
- Or tasks….Request or Response
- Acknowledge (don’t confuse with ACK)
- ID values are carefully selected for filtering.

What can put into Data ?

- Anything at all ! CAN does not specify.
- Will not be prioritized by CAN controller.
- Your System Designer will not agree !
- **Normally:** Services, Modes, data (signals).
- Data transfers etc.
- Multi-byte data control bytes. i.e. # bytes sent
- Number of data bytes can be changed.

Diagnostics and Standard Traffic

- **Standard Mode:** ordinary data from ordinary vehicle operation.
  - Nodes are operating normally.
- **Diagnostic Mode:** Nodes are put into a special mode for queries by a scantool.
  - Is problem or inquiry related.
- Diagnostics handle “Limp Home Mode”
- Not CAN spec – higher layers

Polled and Periodic Messages

- **Periodic Messages:** messages broadcast continually on the bus at certain rate.
- **Polled Messages:** messages provided due to a query by a node or diagnostic tool.
- Are created by high level – not CAN.
- Such as J1939 and proprietary systems.

Real CAN traffic on a 500 Kbps car.

000:000	**0B2**	**00 48 00 48 00 00**
004:510	2D2	00
008:240	025	00 A2 00 00 00 00 00 CF
010:240	**0B0**	**00 48 00 48 00 00**
011:810	**2C4**	**00 00 00 20 00 80 21 8F**
012:260	**0B2**	**00 48 00 48 00 00**
014:360	223	00 00 00 00 00 00 00 2D
016:420	224	00 00 00 00 00 00 00 00
020:510	025	00 A2 00 00 00 00 00 CF
021:030	2C1	08 05 83 28 06 EC 00 75
022:500	**0B0**	**00 48 00 48 00 00**
024:540	**0B2**	**00 48 00 48 00 00**
029:220	2D0	00 00 08 00 10 00 00 F2
032:770	025	00 A2 00 00 00 00 00 CF
034:770	**0B0**	**00 48 00 48 00 00**
035:370	**2C4**	**00 00 00 20 00 80 21 8F**
036:260	2D2	00
036:840	**0B2**	**00 48 00 48 00 00**

Real J1939 Traffic

Scrolling Monitor - Configuration = brose.her

Line No	TimeStam...	Channel	Frame Id	Header Details	Frame Acronym	Protocol	Data	Rx/Tx
3171	00:07:28...	CH#B	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3172	00:07:28...	CH#A	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3173	00:07:28...	CH#B	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3174	00:07:28...	CH#A	0CF00400	P/T = 3 : PGN = 00F004 : Src Addr = 00	EEC1_00F004	J1939	FE 7D 7D 00 00 00 FF FF	Rx
3175	00:07:28...	CH#B	0CF00400	P/T = 3 : PGN = 00F004 : Src Addr = 00	EEC1_00F004	J1939	FE 7D 7D 00 00 00 FF FF	Rx
3176	00:07:28...	CH#A	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3177	00:07:28...	CH#B	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3178	00:07:28...	CH#A	18FEF000	P/T = 6 : PGN = 00FEF0 : Src Addr = 00	PTO_00FEF0	J1939	FF FF FF 00 00 F0 CC FF	Rx
3179	00:07:28...	CH#B	18FEF000	P/T = 6 : PGN = 00FEF0 : Src Addr = 00	PTO_00FEF0	J1939	FF FF FF 00 00 F0 CC FF	Rx
3180	00:07:28...	CH#A	18F0000F	P/T = 6 : PGN = 00F000 : Src Addr = 0F	18F0000F	J1939	C0 7D FF FF 0F FF FF FF	Rx
3181	00:07:28...	CH#B	18F0000F	P/T = 6 : PGN = 00F000 : Src Addr = 0F	18F0000F	J1939	C0 7D FF FF 0F FF FF FF	Rx
3182	00:07:28...	CH#A	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3183	00:07:28...	CH#B	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3184	00:07:28...	CH#A	0CF00400	P/T = 3 : PGN = 00F004 : Src Addr = 00	EEC1_00F004	J1939	FE 7D 7D 00 00 00 FF FF	Rx
3185	00:07:28...	CH#B	0CF00400	P/T = 3 : PGN = 00F004 : Src Addr = 00	EEC1_00F004	J1939	FE 7D 7D 00 00 00 FF FF	Rx
3186	00:07:28...	CH#A	0CF00300	P/T = 3 : PGN = 00F003 : Src Addr = 00	EEC2_00F003	J1939	F1 00 00 FF FF FF FF FF	Rx
3187	00:07:28...	CH#B	0CF00300	P/T = 3 : PGN = 00F003 : Src Addr = 00	EEC2_00F003	J1939	F1 00 00 FF FF FF FF FF	Rx
3188	00:07:28...	CH#A	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3189	00:07:28...	CH#B	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3190	00:07:28...	CH#A	18FEF100	P/T = 6 : PGN = 00FEF1 : Src Addr = 00	CCVS_00FEF1	J1939	FF 00 00 00 00 60 00 C0	Rx
3191	00:07:28...	CH#B	18FEF100	P/T = 6 : PGN = 00FEF1 : Src Addr = 00	CCVS_00FEF1	J1939	FF 00 00 00 00 60 00 C0	Rx
3192	00:07:28...	CH#A	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx
3193	00:07:28...	CH#B	0CF00203	P/T = 3 : PGN = 00F002 : Src Addr = 03	0CF00203	J1939	CC 00 00 FF F0 FF FF FF	Rx

CAN Summary

- This gives a basic understanding of CAN.
- From here you can go to:

  High level protocols connect to CAN

  J1939, CANopen, MilCAN, J2284, …

Now: a bit about tools….and then errors and some handy hints…

Tools

- Design, development and maintenance.
- Hardware and software.
- Cheap, average and high cost.
- Vastly different capabilities.
- Designed to save you time and money.
- Low cost tools are alluring but….

Cheap Tools

- Costs you time and money and worse….
- Adverse to critical Time-To-Market.
- Awkward, hard to use, hard to setup.
- Limited info provided – no trigger or filters.
- Some interesting tests might not happen.
- Time is better to use for testing product.

Network Tools –

Bus Analyzers and CAN Oscilloscopes

- Development of network and diagnostics
- Sits on a bus and monitor.
- Can send and receive messages on bus.
- Save messages, trigger, filter, respond.

CAN Faults

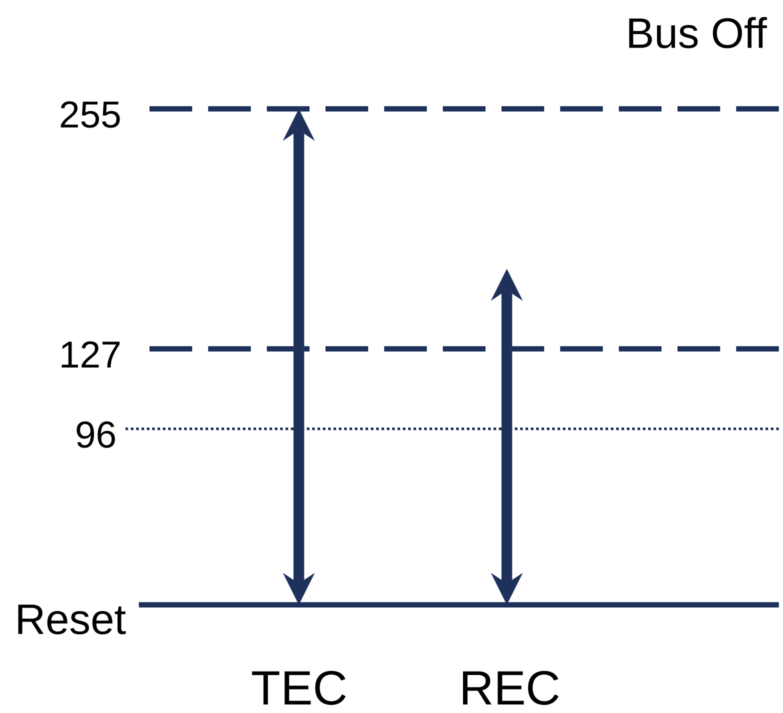
- Regular dual-wire CAN redundancy:
- One CAN open or shorted to ground.
  - Note: ground must be connected for open.
- But not to each other or both to ground.
- Ground can be open.
- or a ground loop can exist.

Error Frames

- Any node see something wrong on the bus.
- Makes bus dominant.
- All nodes knows this is an error frame.
- Sender stops transmitting.
- Increments its Transmit Error Counter by 8.
- If TEC < FF, resends message else busoff.
- Others increment their Receive Error Counters.
- Note: only a node can boot itself off the bus.

Error Counters

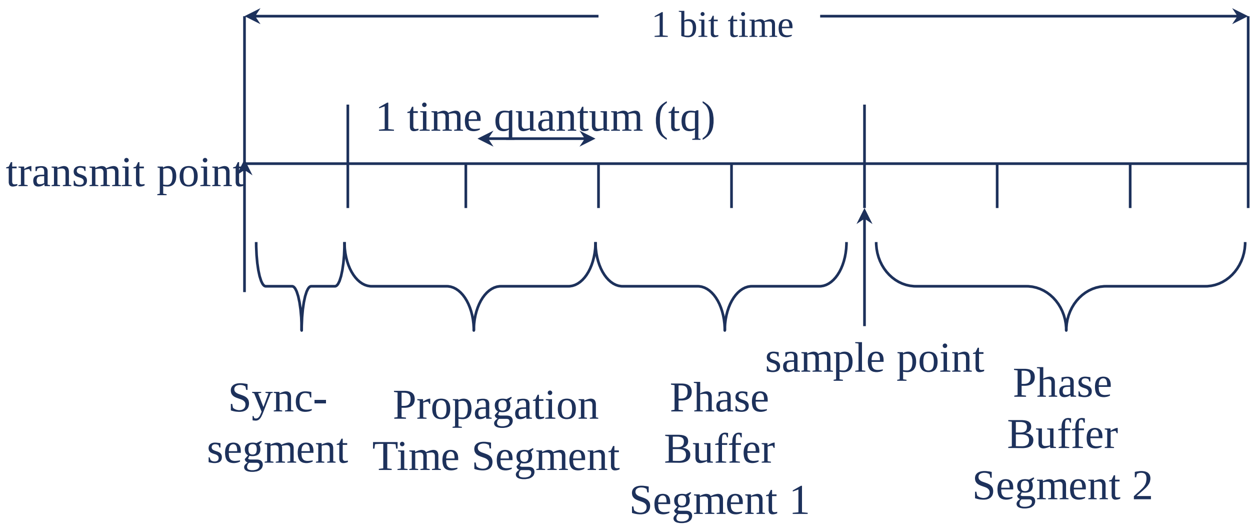
- Two 8 bit counters in CAN controller.
- Counts the errors.
- Inc. & decrement.
- Up by 8, down by 1
- Can read as an indication of bus health.
- Busoff return: RESET or 128 good messages :its what you say.



Note: 96 is considered a significant error level

CAN Bit Timing

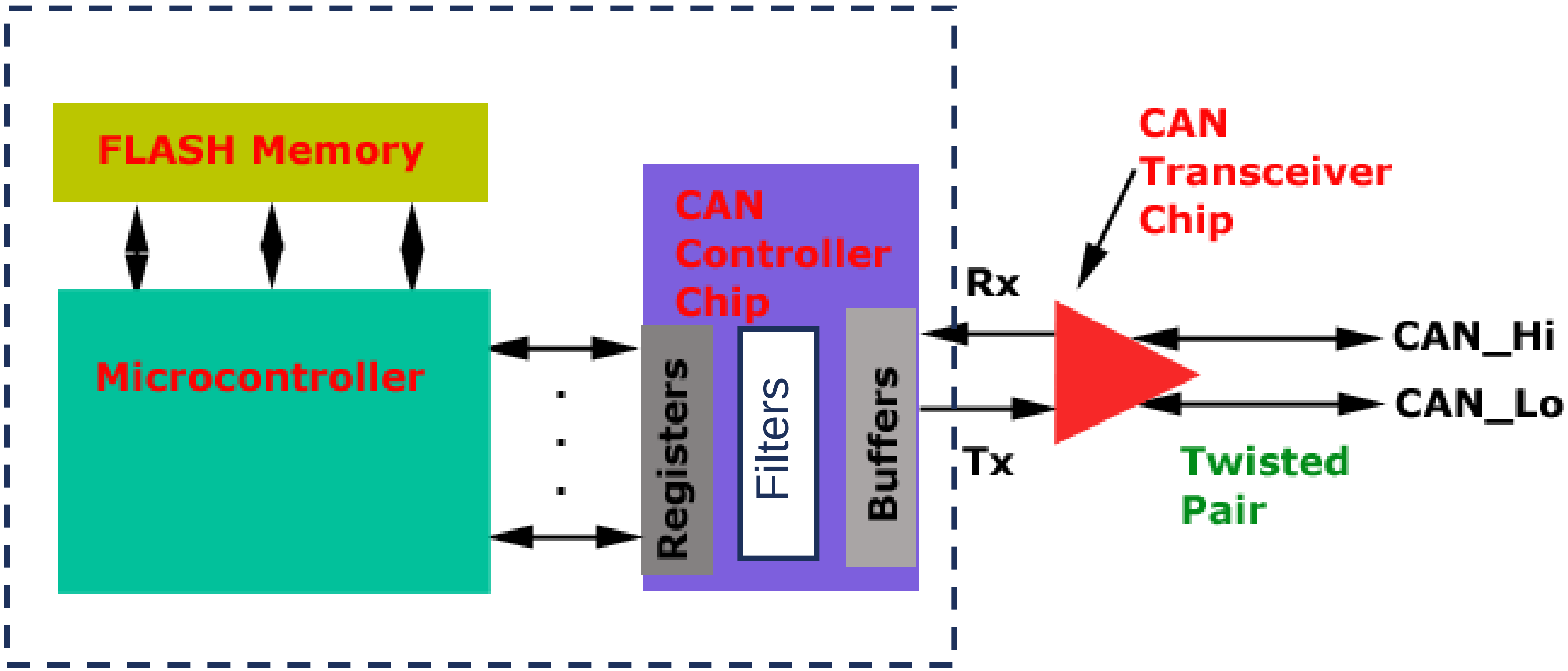
- Each bit consists of a # of time quantum (tq).
- TQs added and subtracted as clock syncs.
- Tqs are set by designer in CAN controller chip.
- See your datasheet for help.



CAN Filters

- Allow only selected messages through !
- On ID and sometimes 1st byte of data.
- This is why IDs are carefully chosen.

Typical microcontroller



CAN Statistics

- Periodic Auto bus rates about 6 – 7 %
- GM periodic about 15 % @ 500 Kbps.
- Getting higher and higher.
- Design in some slack for expansion.

Tips & Hints

- 2 nodes: never send the same message.
  - Get a bus error or both think successful.
- Use same # data bytes all the time.
  - Software is much simpler to debug and maintain.
- Never change the bus speed !
- Beware of short bursts of high bus traffic.
- Read TEC & REC to view state of your bus
- If use a protocol – implement all of it !
- Through data on the floor but take care of it.

more Tips & Hints

- Don’t mix one protocol with another
  - J1939 and CANopen will crash…maybe…
- Use defaults – don’t do anything “elegant”
  - You don’t want to be the first to find that bug !
- Use timeouts – don’t hang until RESET.
- Don’t make timeouts too tight – sloppy is better.
- Select IDs with care for easy filtering.
- Don’t fudge the bus. Fix it.

And a few more….

- Design in some “elbow room”.
- Reserve some IDs for expansion/bug fixes.
- Take care of “Reserved Bits”.
- Remember protocols are designed by committees. Investigate odd things.
- Watch out for the simple things…..

The End…*for now*…

- See www.keil.com/can
  …and look for my CAN Primer.
- Versions for Luminary, NXP and ST.
- ISO 11898-1,-2-3-4 defines CAN further.
- Testing CAN Physical layers:
  www.dgtech.com/pdfs/techpapers/CIA_article.pdf