

CAN

What is CAN ?

It is a serial, multi-master, message broadcast system developed by Bosch. It's considered asynchronous as each node can send any time on the bus. Its speed varies between 20Kbit/s to 1Mbit/s.

CAN in the OSI model (ISO11898)

- Physical layer
 - CAN Transceiver (bus line, electrical specs, connections)
 - Bit timing
 - Bit encoding
 - Synchronization
- Data link layer
 - CAN Controller (includes physical signaling)
 - Medium Access Control
 - Arbitration
 - ACK
 - Error D/C
 - Signal
 - Fault confinement (self check for distinguishing short disturbances from permanent failures on the bus)
 - Logic Link Control
 - Message filtering
 - Overload notification
 - Recovery management

CAN Bus signals

- If MCU does not support CAN by having a CAN Trcv, it only needs the CAN controller which outputs TX & RX at TTL levels to the CAN Trcv, which then transforms the data into CANH & CANL.
 - CAN operates on differential signals using CANH and CANL lines.
 - CANH, L are always opposite in state.
 - Logic Low (0) -> $CANH - CANL > 0.9v$ (Dominant state)
 - Logic High (1) -> $CANH - CANL < 0.5v$ (Recessive state)
 - $0.5v < CANH - CANL < 0.9v$ -> **Undefined**
 - The idle state of the bus is dominant state (Logic low)
-

CAN basic concepts

- Any connected node to the network can receive the message if it is interested in it (message filtering)
 - The identifier describes the meaning of the data not destination
 - The identifier defines static priority.
 - Bus access conflict is resolved by bitwise arbitration using the identifier.
 - ex.:
 - Sender 1: 1100
 - Sender 2: 1110
- Bus content: 1 1 0 0 -> sender 1 wins the bus access

- CAN uses bit stuffing after 5 consecutive bits of identical value (either 0 or 1)
 - CAN uses CRC to check for data corruption
-

CAN Frames

Standard Frame (high priority than ex)

Uses 11 bit identifier

Extended frame

Uses 29 bit identifier

Types

Data frame

- Contains actual data from transmitter to receiver

Remote frame

- Exactly like data frame but without data.
- Transmitted by a node which requests transmission of the data from another node (Uses the same identifier)
 - Example:
 - Node 3 wants temperature data, sends remote frame with ID = 5
 - Node 2 is the one responsible for temperature data, it sees a request on the bus with ID = 5 (it filters ID 5 messages)
 - Node 2 sends temperature data on the bus in a data frame using ID = 5

Error frame

- Sent by any node which detects a bus error.

- Used for signaling other nodes if bus error occurs.

Overload frame

- Used to provide extra delay between data or remote frames for slow receivers.

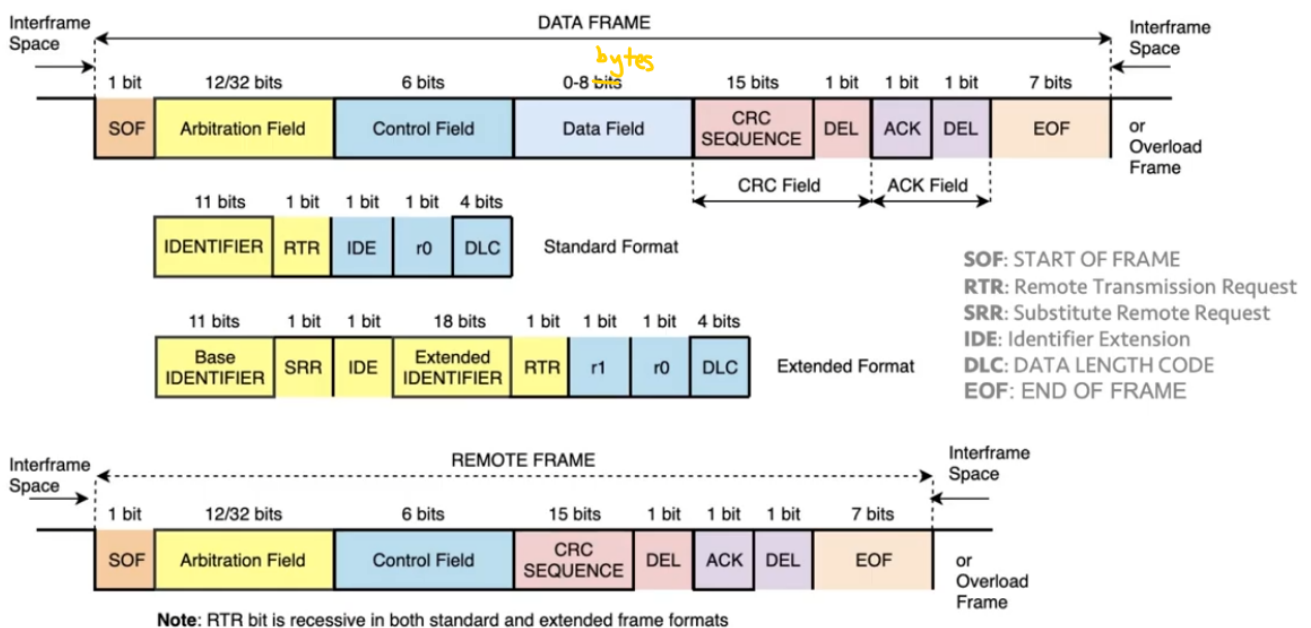
*Note: For data & remote frames, each frame must be separated by an **interframe space** except if the preceeding frames are overload or error frames*

Example:

IFS | Data frame | IFS | Remote frame | IFS | Data frame (has error) | Error frame

CAN Frame format

Data frame

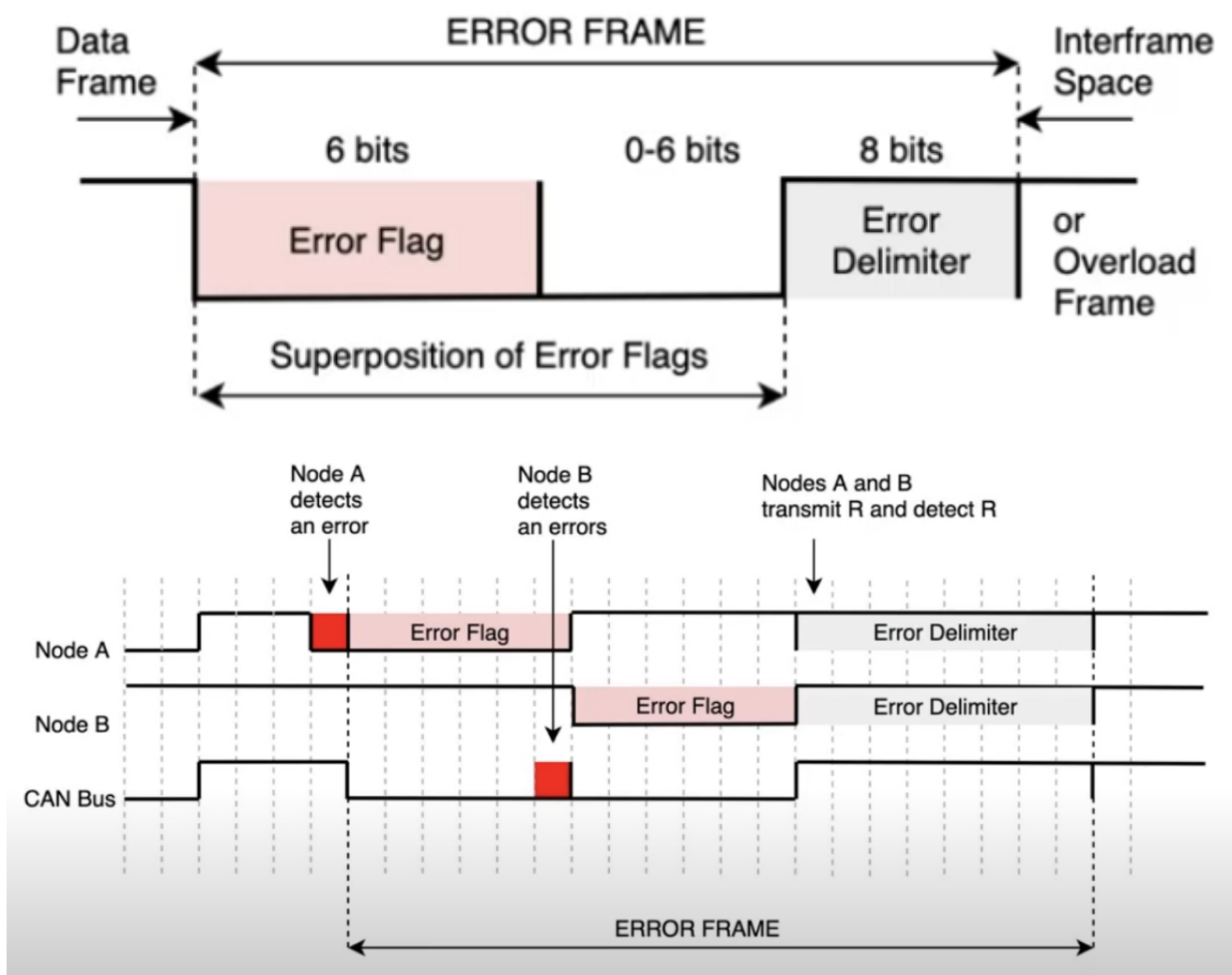


Source: CAN Specification Version 2.0, 1991, Robert Bosch GmbH

- RTR
 - 0 Frame is not remote frame
 - 1 Frame is remote frame
- RTR is useful if both nodes are sending data (one is remote and one is data with same ID), the data frame wins bus arbitration and data is sent successfully.

- SRR
 - Always '1' (recessive)
 - Makes extended frame format lower priority since RTR is 0 if it is data frame, so standard frame wins bus arbitration.
- IDE
 - 0 Frame is standard frame
 - 1 Frame is extended frame
- IDE is useful if two nodes are sending remote(std) ext(data), IDE will be 0 in std frame, so std format will have higher priority and wins bus arbitration.
- rX bits are reserved bits
- DEL is a de-limiter bit

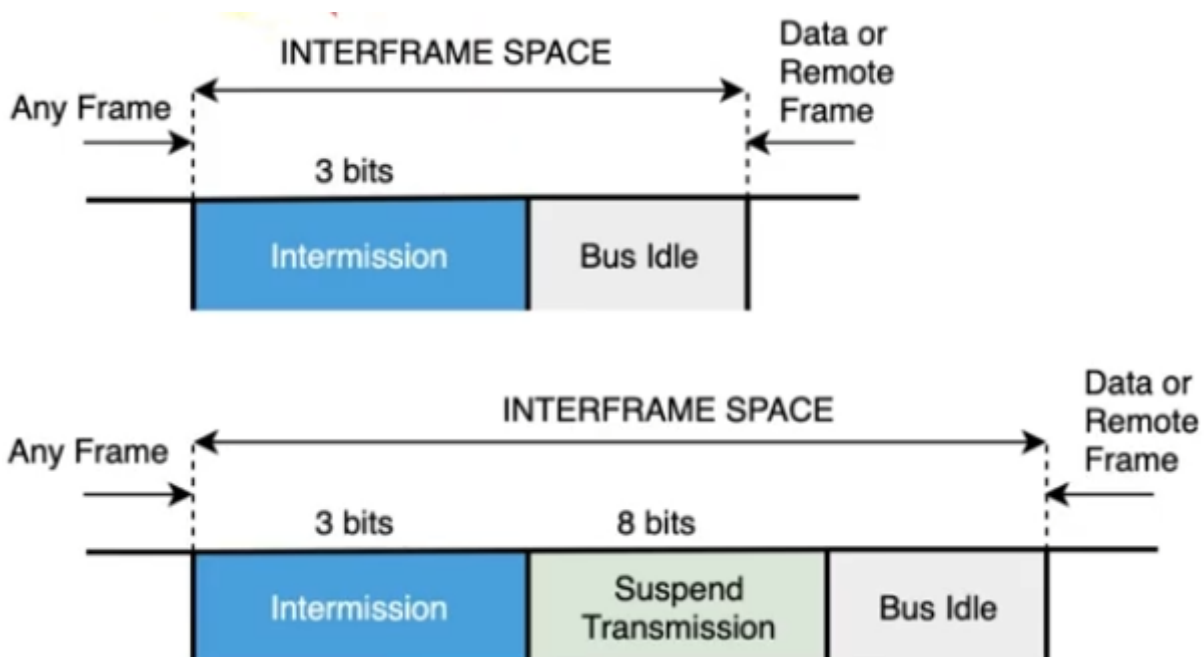
Error frame



- Node A detected by monitoring its own bus signals.

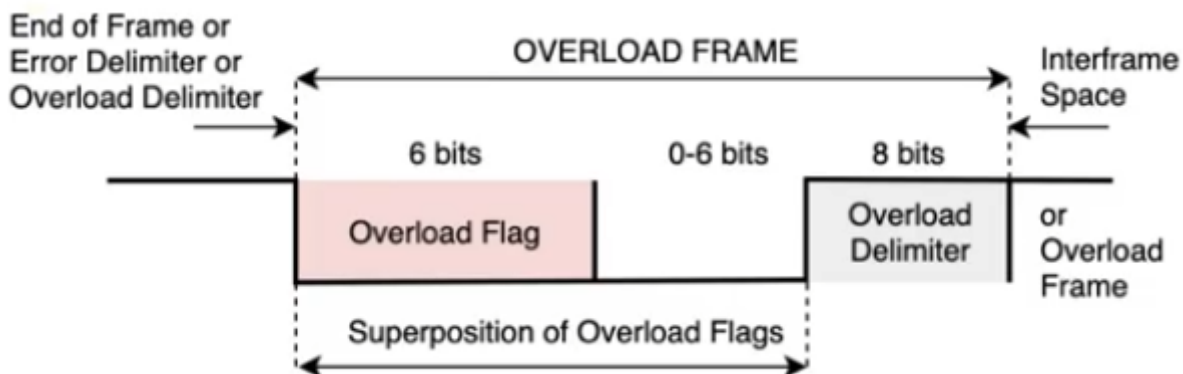
- Node B detected the error by detecting bit stuffing violation CAUSED by Node A.
- Error frame is based on violating the bit-stuffing condition by sending 6 consecutive dominant bits, so other nodes will detect that an error has occurred on the bus.

Interframe space



- Any node which wants to start/continue data transmission, it must detect that the bus is idle after the 3 intermission bits.
- Overload frame (dominant) is sent immediately after the data or remote frame, even before the intermission bits.

Overload frame



Must be started on the first bit time of expected intermission bit.
Otherwise, it cannot be sent.

Example:

Data frame | Overload frame

-----| Expected bit 1 of Intermission bits

- If 3rd bit ITM is dominant (0), it is interpreted as SOF bit for a new frame. It is transmitted in 3 cases:
 1. Internal conditions of receiver which requires delay of incoming data/remote frames.
 2. Detection of a dominant bit at the first & second bit of intermission
 3. If a CAN node samples a dominant bit at the last (8th) bit of an error delimiter or overload delimiter.

Error types

- Bit error
 - Bit value monitored is different from the actual bit that is sent (except during arbitration or ACK slot)
- Stuff error
 - Detecting 6 consecutive equal bit level in a message field (CRC delimiter, ACK, EOF)
 - Error & overload frames are not stuffed.
- CRC error
 - Receiver calculates CRC and result is not the same as received CRC sequence.
- Form error
 - Occurs when one or more illegal bits are found in fixed form bit field
 - For a receiver, a dominant bit in the EOF is not a form error
- Acknowledgement error
 - Detected when a transmitter does not monitor a dominant bit during ACK slot.

Fault confinement

Unit states

- Error active: Node can participate normally in bus communication and sends an active error flag when error is detected.
- Error passive: Node can participate normally in bus communication, but when an error has been detected, only a passive error flag is sent. (does not affect the bus if nodes are sending while the node is sending an error flag because it is a recessive flag). This node will also wait suspend transmission before initiating further transmission.
- Bus Off: Not allowed to participate on the bus.

Error counts

- Receive error count (*REC*)
 - (+) 1
 - Receiver detects error
 - (+) 8
 - Receiver detects error during sending of active error/overload flag
 - ex. 0001 <--- Detecting 1 during sending dominant 0, so it must be an internal error in the receiver circuits.
 - Receiver detects a dominant bit as the first bit after sending an error flag (even though it should detect recessive bits (1's))
 - Dominant bits are detected after an error/overload flag.
 - ex. Error flag: 0 0 0 0 0 0 1 1 1 1 1 1 x
 - Sending 6 dominant & 7 recessive
 - x must be recessive also, so if it is dominant, an error occurred
 - (-) 1
 - Receiver received a message without error (up to ACK slot) successfully and sending the ACK successfully

Notes

- If REC is already 0 and decremented, it stays 0
- If REC is 127 and incremented, it gets set to a value between 119 & 127.

- Transmit error count (*TEC*)
 - (+) 8
 - When a transmitter sends an error flag
 - Transmitter detects a bit error while sending an active error/overload flag.
 - ex. 0001 <--- Detecting 1 during sending dominant 0, so it must be an internal error in the transmitter circuits.
 - When many dominant bits are detected after error/overload flag.
 - (-) 1
 - Frame transmission was successful and getting ACK.
-

Node states & error counts

Error active

- $TEC < 128$ and $REC < 128$
- Good transmitter and receiver

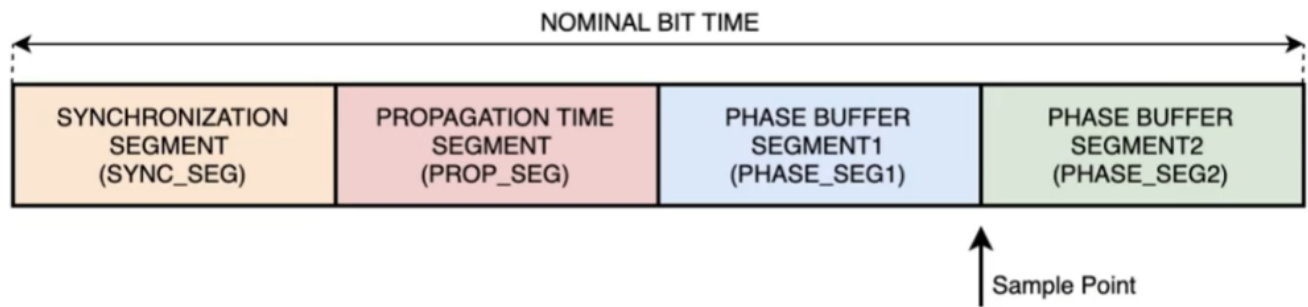
Error passive

- $TEC > 127$ or $REC > 127$
- Bad transmitter or bad receiver

Bus off

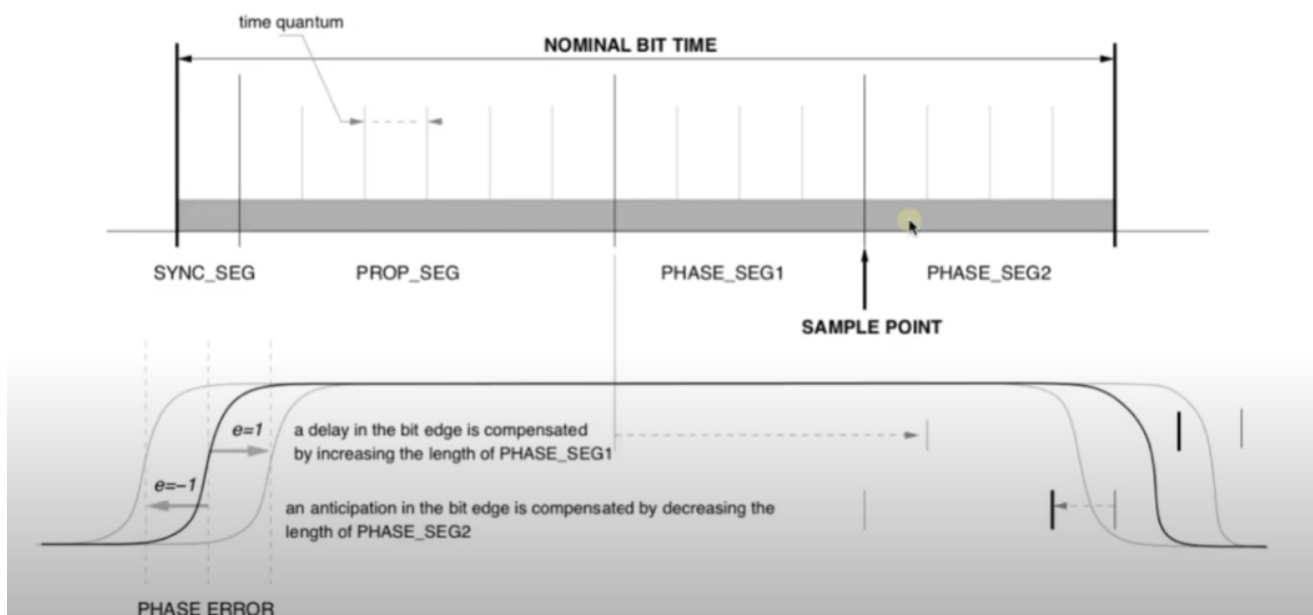
- $TEC \geq 256$
- Very bad transmitter
- Bus off can become error active after the node monitors 128 occurrences of 11 consecutive recessive bits.
- A bus with *one node*, it will transmit without acknowledgment, then it will become error passive not bus off (can happen in case of powered off devices or plug & play devices)

Bit timing requirements



$$Nominal\ Bit\ Time = \frac{1}{Bit\ Rate}$$

- **SYNC_SEG** Used to synchronize the various nodes on the bus, the edge is expected to lie within this segment
- **PROP_SEG** Used to compensate for physical delay times within the network
- **PHASE_SEG1,2** Used to compensate for edge phase buffers (helps in correct sampling)



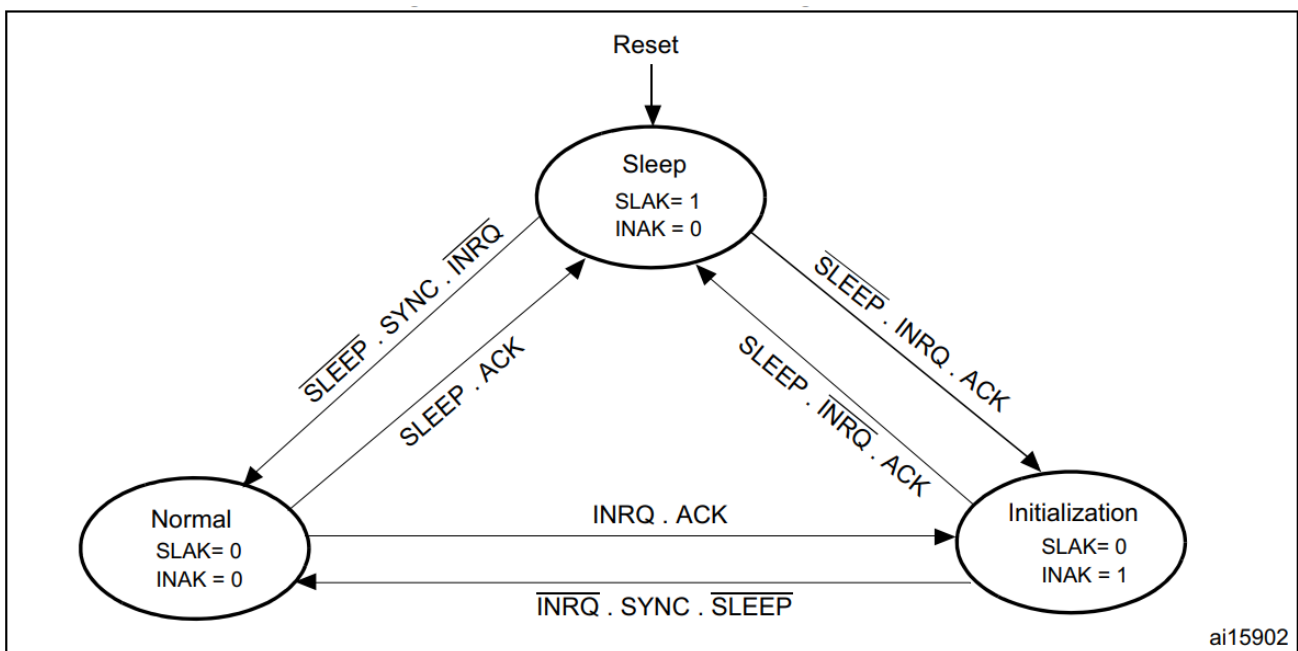
- Time quantum must be an integer
- SYNC_SEG can only be +/- 1
- If a delay in a bit edge increases, we increase the length of PHASE_SEG1 to shift the **sample point right**.
- If a bit edge arrives before we expect it, then we should decrease PHASE_SEG2 to shift the **sample point left**.

CAN in STM

Features

- Supports version 2.0 A(standard) & B(extended)
- Transmission
 - 3 Transmit mailboxes
 - Transmit priority
 - Time stamp on SOF transmission
- Reception
 - Two receive FIFOs with 3 stages
 - Filtration of messages

Modes



1. ACK = The wait state during which hardware confirms a request by setting the INAK or SLAK bits in the CAN_MSR register
2. SYNC = The state during which bxCAN waits until the CAN bus is idle, meaning 11 consecutive recessive bits have been monitored on CANRX

Sleep

SLAK = 1
INAK = 0

Entered by: Setting SLEEP in MCR
Exited by : Clearing SLEEP in MCR

- When the HW is reset, the CAN is in sleep mode
- When in sleep mode, the internal pull-up resistor is activated
- This mode can be entered from any mode by setting the SLEEP bit in the MCR register
- In this mode, the CAN clock is stopped but mailboxes are accessible
- Exiting sleep mode to normal mode requires clearing the SLEEP bit.

Normal

SLAK = 0
INAK = 0
Entered by: Clearing INRQ in MCR
Exited by : Setting SLEEP/INRQ in MCR

- Entering this mode requires clearing the INRQ bit in MCR register
- When the CAN has synchronized with the bus successfully, it clears INAK bit in the MSR register
- If a filter is used, we must ensure that it is configured before the filter is active (FACTx = 0)

Initialization

SLAK = 0
INRQ = 1
Entered by: Setting INRQ in MCR
Exited by : To sleep: Setting SLEEP in MCR
To normal: Clearing INRQ
in MCR

- Must enter this mode to set up bit timing parameters
- Software enters this mode by setting the INRQ bit in the MCR register.

- Message reception is stopped
- CANTX output is recessive (1)

Notes:

1. From mode X to mode Y: Set the bit of mode Y
2. From mode X to normal: Clear the bit of mode Y
3. To initialize filter banks, we must set FINIT bit

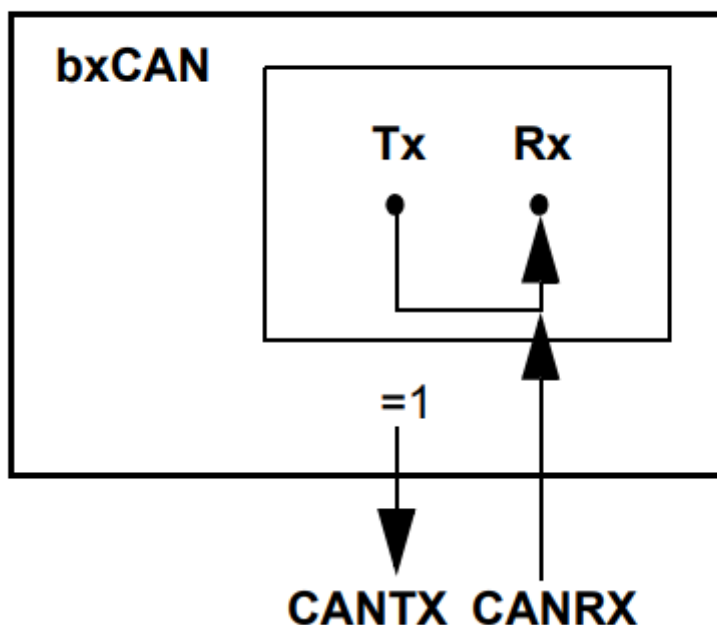
bxCAN bus modes

Test mode

- This mode must be entered before selecting one of the 3 testing modes (silent, loopback, silent & loopback)
- Entered by setting SILM & LBKM bits in BTR register
- Must set this bits while in initialization mode

Silent mode

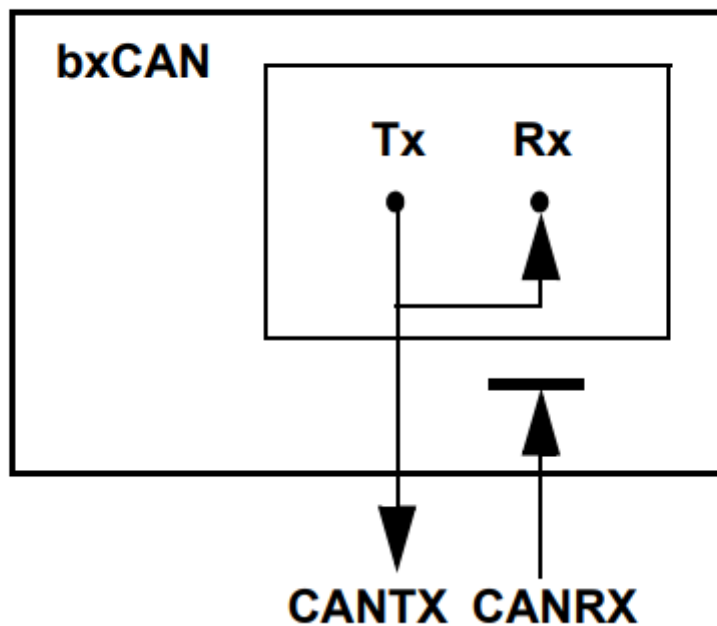
Figure 225. bxCAN in silent mode



- This mode allows the CAN to listen to all messages on the bus, but not participate in it.
- In this mode, CANTX is in recessive state.
- If the node has to send a dominant bit (ACK, overload, error), it routes this bit internally to the CANRX and does not actually send it on the bus.

Loopback mode

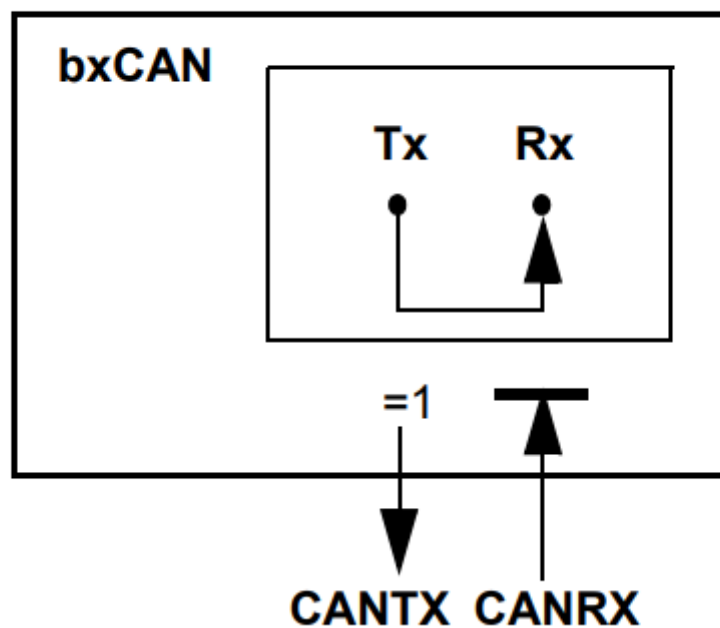
Figure 226. bxCAN in loop back mode



- In this mode, sent messages are sent on the bus from CANTX and routed to CANRX as received messages.
- The node cannot receive any messages on the bus, just the ones it transmits.
- CANRX pin value does not contain the message sent by the node
- To monitor messages in this mode, monitor CANTX
- This mode ignores ACK errors

Loopback silent mode

Figure 227. bxCAN in combined mode



- In this mode, the node does not affect the CAN bus, so its CANTX output is always recessive (1)
- Any sent message from the node is routed internally to the CANRX as a received message

bxCAN filter

If a node is connected on a network, it's usually interested in certain messages on the bus. STM implements HW filtration which filters messages according to the filter configuration without intervention from software which saves time and CPU. Therefore, SRAM will not contain any new messages that did not pass through the filter.

Identifier filtration technique

Mask mode

In this mode, a mask is provided which is used to check for certain bits only on the identifier, this allows us to allow a range of identifiers to be filtered.

Identifier list mode

Identifier list mode is basically a finite list of identifiers which **MUST** match with incoming ID's, if they don't match exactly, the message is discarded.

Filter bank & scale

Definitions:

- Bank: A bank is basically a filter which is composed of ID's or masks. Each filter bank has 2 32-bit registers which can be in 2 modes:
 - Mask mode: R1 for ID, R2 for mask
 - Identifier mode: R1 & R2 for ID
- Scale: It is the size of the bank, there are single 32 bit and double 16 bit scales, just offers more filtering per the same bank to be used.
 - 32 bit: Checks for RTR, IDE, STDID, EXTID completely (**all bits** of ID's can be checked).
 - 16 bit: Checks for RTR, IDE, all of STDID, **only 3 bits of EXTID**

In STM32F10x, there are 2 CAN interfaces (CAN1, CAN2), CAN1 is master while CAN2 is a slave. For each interface, we can assign a number of banks for the interface to use to match ID's. In devices which only have one interface,

this configuration is irrelevant, and the interface will use all banks. Maximum number of banks in STM32F10x are **28**.

How to use the filter to match ID's?

Usually, it is better to configure **ONLY** the banks that we wish to use at a time and leave the rest as inactive.

Step 1

To configure filter registers, we must enter filter initialization mode by **setting** *FINIT* bit in FMR register before modifying filter registers.

Step 2

For devices with more than 1 CAN interface

Assign n number of filters for CAN1, ($maxbanks - n$) for CAN2 by writing ($max_banks - n$) into *_CAN2SB* in **CAN_FMR** register.

Step 3

Choose the filter scale for the selected bank by setting the *FSCx* bit in **CAN_FS1R** register.

- 0: Dual 16 bit configuration
- 1: Single 32 bit configuration

For devices with 1 CAN interface, there are only 14 banks so, only 0-13 FSCx bits can be used

Step 4

Choose which FIFO to assign the filter bank activated to by writing to *FFAx* bit in **CAN_FFA1R** register.

- 0: Filter bank is assigned to FIFO0
- 1: Filter bank is assigned to FIFO1

Step 5

Choose filter mode for the selected bank by configuring its corresponding *FBMx* bit in **CAN_FMR** register

- 0: Identifier mask for FR1 & FR2
 - FR1 = Identifier
 - FR2 = Mask
- 1: Identifier list for FR1 & FR2
 - FR1 = Identifier #1
 - FR2 = Identifier #2

Step 6

FACTx must be cleared in *CANFAXR* register & *_FINIT* bit must be set in **CAN_FMR** register

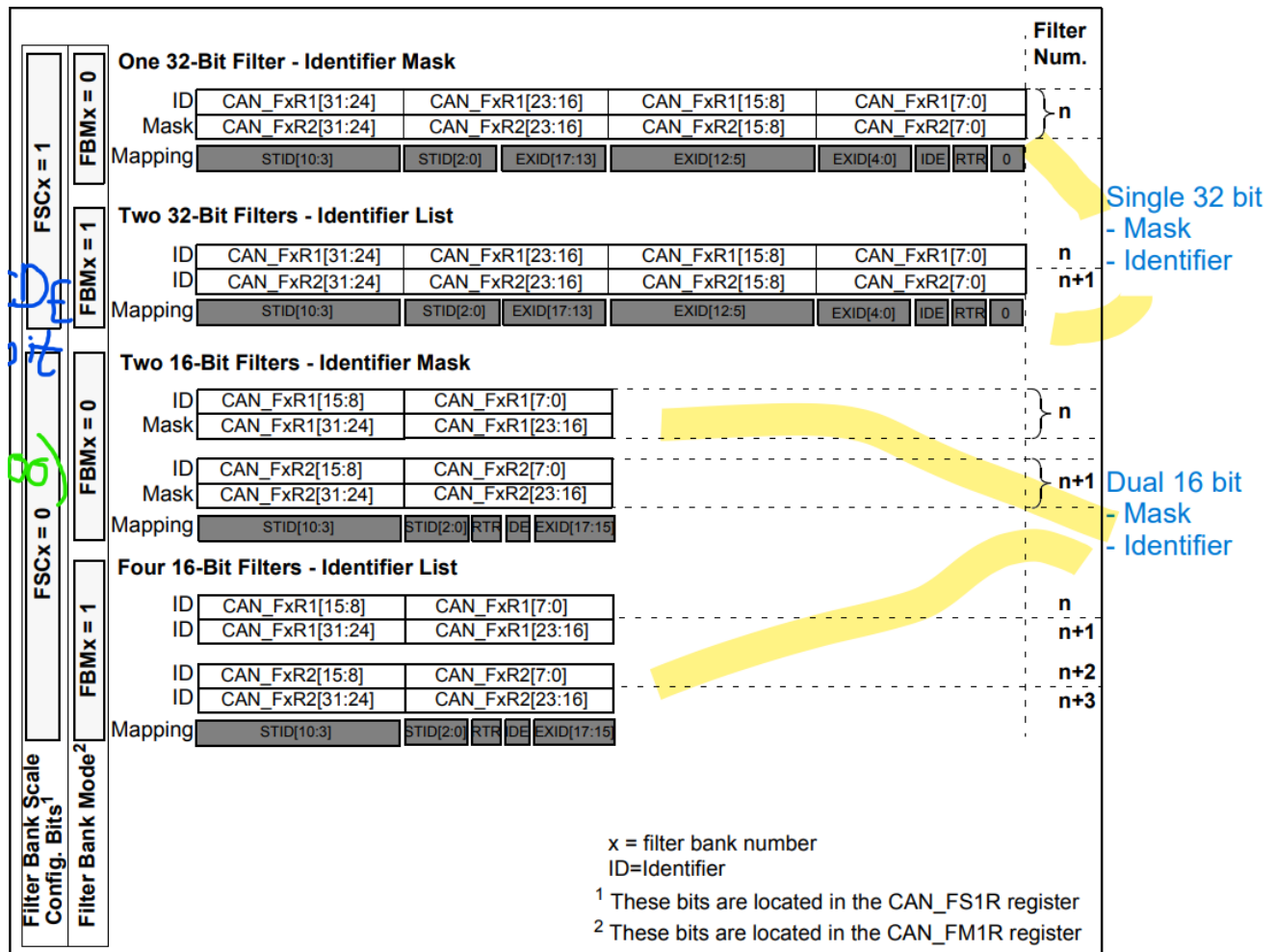
Assign FR1 & FR2 registers to mask values or identifier list values

- In mask mode, all bits that are 1 need to match the ID filter
- In list mode, all bits must match

Step 7

Activate the filter by setting the corresponding *FACTx* bit in **CAN_FA1R** register.

Inserting the right values in FR1 & FR2



32-bit scale

ID	CAN_FxR1[31:24]	CAN_FxR1[23:16]	CAN_FxR1[15:8]	CAN_FxR1[7:0]				
Mask	CAN_FxR2[31:24]	CAN_FxR2[23:16]	CAN_FxR2[15:8]	CAN_FxR2[7:0]				
Mapping	STID[10:3]	STID[2:0]	EXID[17:13]	EXID[12:5]	EXID[4:0]	IDE	RTR	0

Two 32-Bit Filters - Identifier List

ID	CAN_FxR1[31:24]	CAN_FxR1[23:16]	CAN_FxR1[15:8]	CAN_FxR1[7:0]				
ID	CAN_FxR2[31:24]	CAN_FxR2[23:16]	CAN_FxR2[15:8]	CAN_FxR2[7:0]				
Mapping	STID[10:3]	STID[2:0]	EXID[17:13]	EXID[12:5]	EXID[4:0]	IDE	RTR	0

Standard Identifier (11bit)

Assuming the Identifier and mask we need are 11 bits:

```
u32 std_id      = 0b0000_0000_1010_1010;
u32 std_mask    = 0b0000_0111_1001_1100;
/* Match for bits 2,3,4,7,8,9,10 only in std_id */
// If we cared about RTR bit we should set FR1Low and FR2Low to
0b10
FR1Low = 0;
FR2Low = 0;
/* Shifting by 5 because the mapping of the standard identifier
starts at bit 5 till the end*/
FR1High = (std_id << 5);
FR2High = (std_mask << 5);
```

Extended Identifier (29bit-> 11 bit stdID & 18 bit EXTID)

Assuming that STDID is 11 bit only and EXTID is 18 bits only

```
/*                                end of std id      | */
u32 std_id      = 0b0000_0000_0000_0000_0000_0001_1010_1010;
u32 ext_id      = 0b0000_0000_0000_0011_1011_0011_1010_1010;
/*                                ^
| end of ext id
*/
u32 std_mask    = 0b0000_0000_0000_0001_1100_0111_0000_1100;
u32 ext_mask    = 0b0000_0000_0000_0001_0000_0000_0110_1011;
```

```

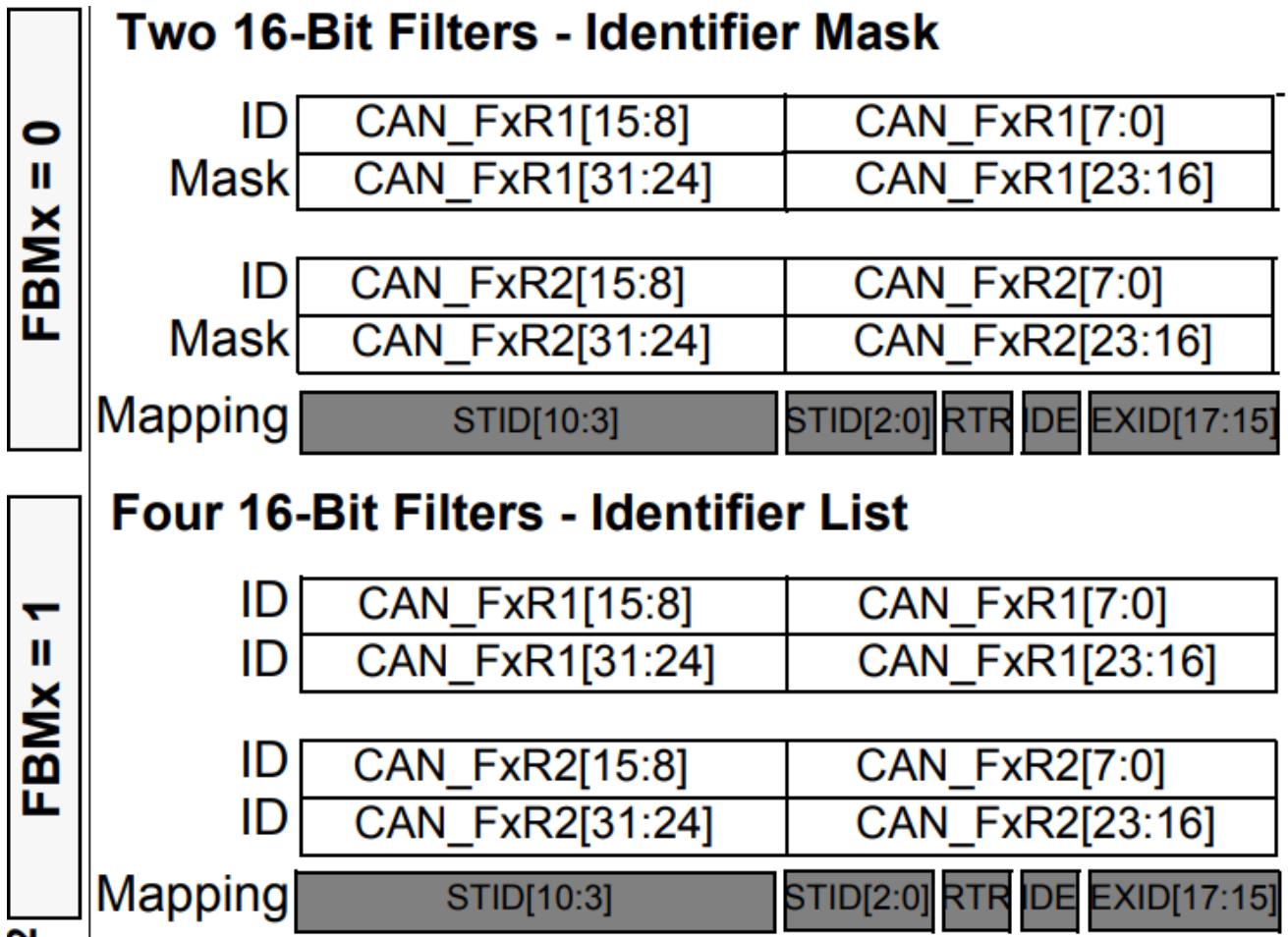
ext_mask&= (0x1FFFFFFF);/* Ensure it is 29 bits*/
ext_id& = (0x1FFFFFFF);

std_mask&= (0x7FF);      /* Ensure it is 11 bits*/
std_id&= (0x7FF);

/* FRx Low -> Responsible for RTR, IDE & EXTID[0:12]
   FRx High-> Responsible for EXTID[13:17], STDID[0:10]
   In the case of IDE, we must OR with 0b10 in FRx Low because
   extended
   frame will have IDE = 1
*/
/* &0x1FFF-> Because we only need the first 13 bits of ext_id*/
FR1Low = ( (ext_id&0x1FFF) << 3 ) | (0b10);
FR2Low = ( (ext_mask&0x1FFF) << 3 ) | (0b10);
/* ext_id>>13 -> we just need the bits from 13:17
   std_id<<5 -> we need to make space for the ext id since std id
   starts at idx 5 in FRxHigh
*/
FR1High = (ext_id>>13) | (std_id<<5);
FR2High = (ext_mask>>13) | (std_mask<<5);

```

16-bit scale



This mode is a little simpler and only filters extended ID's partially.

Standard Identifier (11bit)

Assuming the Identifier and mask we need are 11 bits:

```
u32 std_id      = 0b0000_0000_1010_1010;
u32 std_mask    = 0b0000_0111_1001_1100;
/* Match for bits 2,3,4,7,8,9,10 only in std_id */
// If we cared about RTR bit we should set FR1Low and FR2Low to
0b10000
FR1Low = std_id << 5;
FR2Low = std_mask << 5;
/* Shifting by 3 because the mapping of remaining std identifier
starts from idx 3 until the end*/
FR1High = (std_id >> 3);
FR2High = (std_mask >> 3);
```

Extended Identifier (29bit-> 11 bit stdID & 18 bit EXTID)

Assuming that STDID is 11 bit only and EXTID is 18 bits only

```
/*                                end of std id      | */
u32 std_id      = 0b0000_0000_0000_0000_0000_0001_1010_1010;
u32 ext_id      = 0b0000_0000_0000_0011_1011_0011_1010_1010;
/*                                ^

| end of ext id
*/
u32 std_mask    = 0b0000_0000_0000_0001_1100_0111_0000_1100;
u32 ext_mask    = 0b0000_0000_0000_0001_0000_0000_0110_1011;

ext_mask&= (0x1FFFFFFF); /* Ensure it is 29 bits*/
ext_id&   = (0x1FFFFFFF);

std_mask&= (0x7FF);      /* Ensure it is 11 bits*/
std_id&   = (0x7FF);

/* FRx Low -> Responsible for RTR, IDE & EXTID[15:17], STDID[0:2]
   FRx High-> Responsible for STDID[3:10]
   In the case of IDE, we must OR with 0b1000 in FRx Low because
   extended frame will have IDE = 1
*/
/*
   ext_id >> 15 -> We want the last 3 bits of ext_id at the
   beginning
   std_id << 5 -> we want the first 3 bits at position 5
*/
FR1Low = (ext_id >> 15) | (std_id << 5);
FR2Low = (ext_mask >> 15) | (std_mask << 5);
/*
   std_id >> 3 -> We want to insert std id starting from bit 3
   in FRxHigh
*/
FR1High = (std_id >> 3);
FR2High = (std_mask >> 3);
```
