Usage of CAN and CAN FD for high-definition headlight systems

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In the past few years, there has been a remarkable development in the vehicle front lighting field. Intelligent systems for automatic adjustment of light distribution to particular road and weather conditions have entered the Front Lighting ECUs. After an introduction of Full-LED headlights in the mid-range cars, the next step has to be done.
The aim of increasing the safety for drives by night leads to adaptive high beam systems with an automatic dim out of other traffic participants to avoid dazzling them. In connection with a front camera, it is possible to either switch the high beams automatically on to low or to switch off individually the potential glaring segments of a multiple beam headlight system. With an increasing number of such light sources and segments the communication bus load increases as well.
This paper focuses on the option of transmitting data to high-definition headlight systems using the nowadays implemented CAN bus and coming CAN FD bus. Some examples and limits are presented and discussed.

Introduction

Today’s E/E Architecture is mainly based on several CAN buses connected by a gateway to transfer selected messages between them. The same applies to the intelligent front-lighting bus. The headlamp ECUs may either be connected to one or separated CAN buses, being supplied with data by one or more ECUs.
In the last few years, Adaptive Frontlighting Systems (AFS) have become a common Advanced Driver Assistance System (ADAS). This functionality results from processing sensor information like image (IP), velocity, yaw rate and pitch angle in the light master ECUs. Afterwards, the calculated settings are
transferred via CAN bus to the headlamp ECUs to set up dynamically the lighting range and light distribution by driving the headlamp motors (Figure 1).
With the introduction of multiple beam headlight systems, so called Matrix Headlights, the car manufacturers face growing requirements on the used CAN bus depending on the number of LED pixels and the desired grey level depth.
Since CAN is a well-known and economical communication standard in the car industry, there is an aim to keep it as long as possible. CAN FD is seen as the legitimate successor of CAN and will very likely replace highly stressed CAN buses.
The term “high-definition” isn’t yet well defined in the headlight field. Assuming a high-definition headlamp with more than 1,000 pixels, application of CAN FD needs to be analyzed.

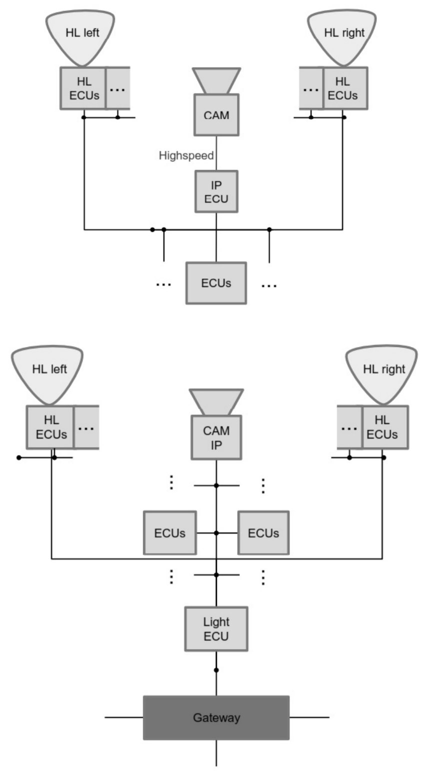

Figure 1: Examples of today’s frontlight E/E-architecture

Basics of bit rate estimation for CAN

In the most cases of application the maximum bit rate of a CAN bus is 500 kbit/s. By experience, a CAN bus may have a worst-case bus load of about 50 % to ensure a low error rate of transmission and to satisfy the cyclic times of less prioritized messages.

It is possible to read out from a CAN communication matrix the transmitted messages, their data field length, send type and cycle time. This information allows to estimate the bit rate of a CAN bus.

$$Bitsum = (SOF + Arb + Ctrl + Data + CRC) \bullet Stuff + ACK + EOF + IFS$$

$$Stuff = \begin{cases} 1.0 \; without \; Stuff - Bits \\ 1.2 \; with \; Stuff - Bits \end{cases}$$

$$Busload = \frac{Bitsum \bullet \frac{1}{Cycletime}}{Bitrate \bullet 1000} \bullet 100\%$$

[Bitsum] = bit *[Cycletime] = s*
[Bitrate] = kbit/s

The messages are usually transmitted with a specific constant cycle time tc1. In cases of a value change, a part of these messages may switch over to a faster cycle time tc2. As a consequence, the bus load increases, which leads to a necessary distinction between a best and worst case scenario. The best case forms the base load of the considered CAN bus, in the worst case the bus load may not exceed 50 %. In both scenarios, bit stuffing needs to be regarded as either non-existent or fully set increasing the bit number by up to 20 %.

Basics of bit rate estimation for CAN FD

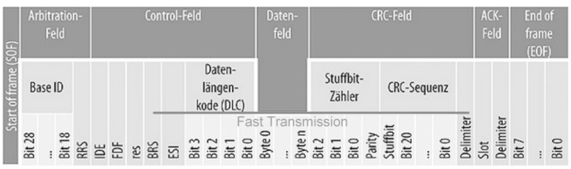

Figure 2: CAN FD frame [1]

For higher bit rates than CAN, in CAN FD there were implemented two basic changes, a longer data field of up to 64 Bytes and a higher allowed bit rate of the data field ('data rate'). The frame parts are transmitted with 0.5 or 1 Mbit/s ('arbitration rate'). Data rate goes up to 8 Mbit/s. Therefore, the frame needs to be separated into slow and fast bits to calculate the average bit rate and the desired bus load (Figure 2). For the bus load estimation, stuff bits need to be regarded again. CRC field of an ISO CAN FD frame has static stuff bits, which do not depend on the bit sequence [2].

Additionally, Intermission Frame Space (IFS) of minimum 3 bits needs to be regarded in the calculation as well.

$$Bitsum = (SOF + Arb + Ctrl + Data) \bullet Stuff + CRC + ACK + EOF + IFS$$

$$Stuff = \begin{cases} 1.0 \; without \; Stuff - Bits \\ 1.2 \; with \; Stuff - Bits \end{cases}$$

$$Avg \; Bitrate \; CANFD = \frac{Bitsum}{\frac{Slow\_Bits}{Arb\_Rate} + \frac{Fast\_Bits}{Data\_Rate}}$$

$$Busload = \frac{Bitsum \bullet \frac{1}{Cycletime}}{Avg \; Bitrate \; CANFD \bullet 1000} \bullet 100\%$$

[Bitsum] = bit *[Cycletime] = s*
[Bitrate] = kbit/s

Bit rate for a pixelwise control of headlamp ECUs

To begin with, the regarded headlamp shall be assumed to have 90 pixels and 6-bit grey level depth for each LED. Pixels one to 45 are parts of the low beam light distribution and are always on, the rest are part of the high beam and are to be adaptively driven. This means, there is a need of nine CAN-messages per headlamp to control the pixels built of data frames with a length of eight Bytes. As a consequence, there are ten 6-bit-signals in each CAN-message. Figure 3 shows the matrix segments of a possible headlamp with 30 by 3 LEDs.

Both headlamps are connected to one front-lighting CAN. Its data rate is assumed to be 500 kbit/s. There are messages which are received and processed by both left and right headlamps. These messages mostly carry some status information. They make up about 10 % of the bus load. Furthermore, there are some messages with detected object information, which make up about 5 %. The other messages are exclusively for the left or right headlamp.

Table 1 shows results of a simulated CAN bus load including all mentioned messages for headlamp like beam height, range control and status with object information.

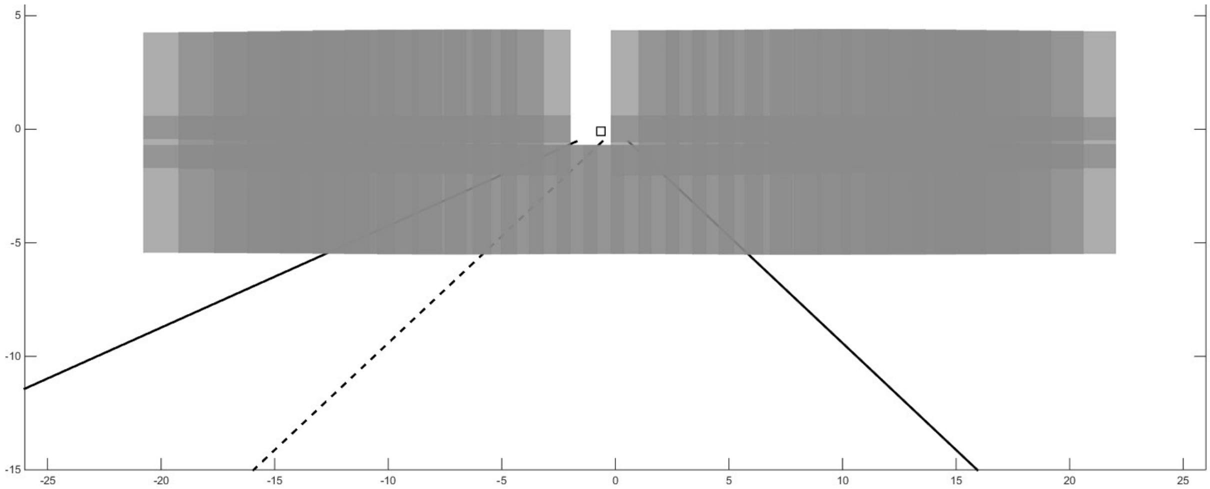

Figure 3: Matrix light distribution with 30x3 pixels and a cut-out traffic participant

Worst case condition describes a situation with a switch of "on change" cycle send time t_{c1} of specific messages like pixel information for high beam to their maximum cycle time t_{c2} = 40 ms.

Table 1: Overview of bus load rates

90 pixels, 6 bit	CAN 500 kbit/s	CAN FD 2 Mbit/s	CAN FD 8 Mbit/s
best case/ no bit stuffing	30.83 %	10.98 %	4.62 %
best case/ with stuffing	36.37 %	12.96 %	5.45 %
worst case/ no bit stuffing	38.33 %	15.03 %	6.49 %
worst case/ bit stuffing	**45.22 %**	17.72 %	7.64 %

Regarding the CAN bus load in the worst case with bit stuffing, the front-lighting CAN bus appears to be already almost full assuming the mentioned maximum bus load of 50%. So, the number of pixels can't be increased anymore using CAN.

For calculation of maximum number of pixels using CAN FD, the worst case with bit stuffing can be seen as the upper allowed limit of the bus load. Eight CAN FD messages are to be reserved for status and object information and other basic headlamp functions. For a transmission of 90 pixels over a 2 Mbit- respectively 8 Mbit-CAN FD bus, as expected, the bus load is significantly lower. The remaining bus bandwidth is available for transmission of additional pixel information.

$$\left\lfloor 64\,Byte \cdot \frac{8\,bit/Byte}{6Bit} \right\rfloor$$

Assuming a 64-Byte data frame of a CAN FD message for highest average data rate, 85 pixel values having a 6-Bit grey level can be transmitted in each CAN FD message. Table 2 shows the simulated results for an arbitration bit rate of 500 kbit/s and different data bit rates between 2 and 8 Mbit/s.

Table 2: Achievable number of pixels per headlamp using CAN FD

Bus Load <50%	CAN FD 2 Mbit/s	CAN FD 5 Mbit/s	CAN-FD 8 Mbit/s
Number of Pixels/HL	~1500	~3500	~4700

The number of controllable pixels per headlamp can be strongly increased using a CAN FD bus instead of the common CAN. Today's CAN FD transmitters are mainly able to perform a data rate of 2 Mbit/s, which makes it possible to drive more than 1500 pixels in each headlamp using only one CAN-FD bus for both. A possible matrix of 1545 pixels with aspect ratio of about 9.5:2 can be seen in Figure 4.

Considered Road Space Situation Present driver assistance front cameras provide a resolution of up to 1280 x 960 pixels with a horizontal field of view of about 50°, and vertically 40°. That implies a resolution of 0.04° per pixel. Specific image processing algorithms are able to detect objects like traffic participants and traffic signs in the road space, and to determine their position including the distance.

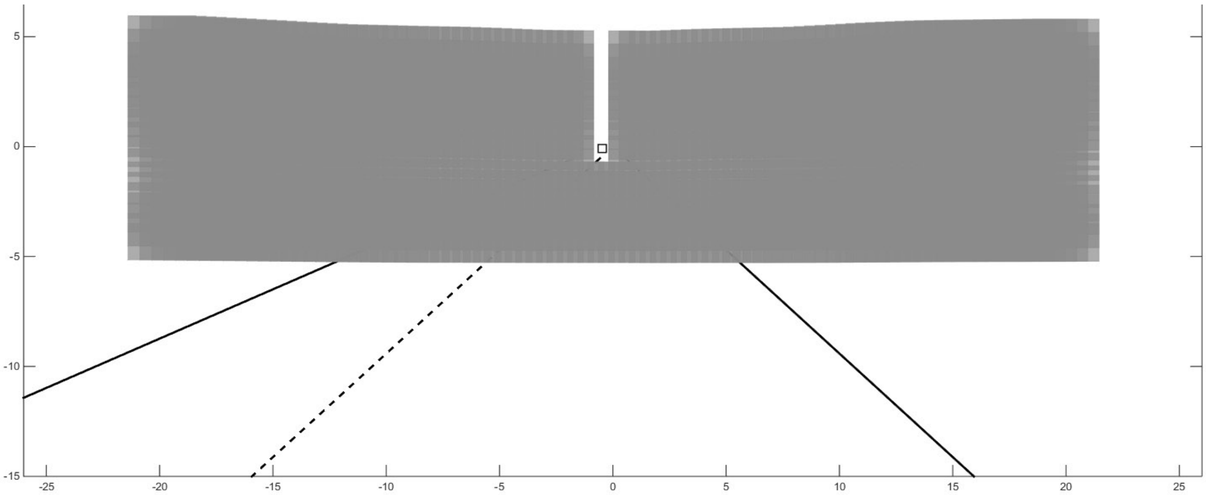

Figure 4: Matrix light distribution with 86x18 pixels and a cut-out traffic participant

Knowing the exact position of the camera and the headlamps, object positions of interest are transformed from the camera coordinate system into the coordinate system of the left respectively right headlamp. That needs to be done to avoid the parallax effect (Figure 5). A point in the road space is seen from different points of view (camera and headlamp) at different angles. The smaller the distance to a detected object, the greater the role of the parallax effect.

Since the matrix beam angles of each headlamp-pixel are known, the system is able to switch on, switch off or just dim the corresponding pixel of each headlamp. This is done by a CAN message sent by an image processing ECU and received by headlamp ECUs. Cameras are able to output new object data with a cycle time of about 40 ms (25 Hz), which is also the maximum “on change” cycle time t_{c2}.

The use of multiple beam headlight systems is especially attractive on roads outside of a city, with speed limits up to 100 kmh. It is not uncommon for road situations with oncoming vehicles to have a relative speed of up to 200 km/h.

The simulated road course is straight. The vehicle of the camera perspective moves in the middle of its lane, the oncoming vehicle however may have a transverse movement on its lane.

A headlamp has at least two basic light distributions, the low and high beams. In accordance with the ECE regulation 112 [4] for the right-hand traffic, the left part of the low beam close to the kink of the cut-off line has to be set up with an inclination of 1 % (-0.57°) to avoid dazzling of oncoming traffic participants.

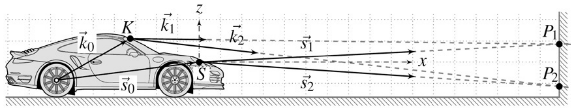

Figure 5: Example of parallax [3]

Now, the difference between the two introduced 30 by 3 and 86 by 18 pixel matrices shall be shown by an example regarding pixel states of the left headlamp. The starting conditions are a distance of 300 m between both vehicles, 200 km/h relative speed and 1.9 m object width. Figure 6 shows the number of changed pixels from on to off and vice versa. The number increases the closer the object is, which also leads to a higher bus load accordingly. The number of all switched off pixels can be seen in Figure 7. Its growth in the higher resolution matrix is more regular with smaller steps in respect with the complete number of pixels.

Since the resolution is limited, it is unlikely to cut out a specific object exactly. There will always be an “overhead” angle, the part of the light distribution around an object itself. The range of that angle can be decreased by about a factor of two using the higher resolution matrix (Figure 8).

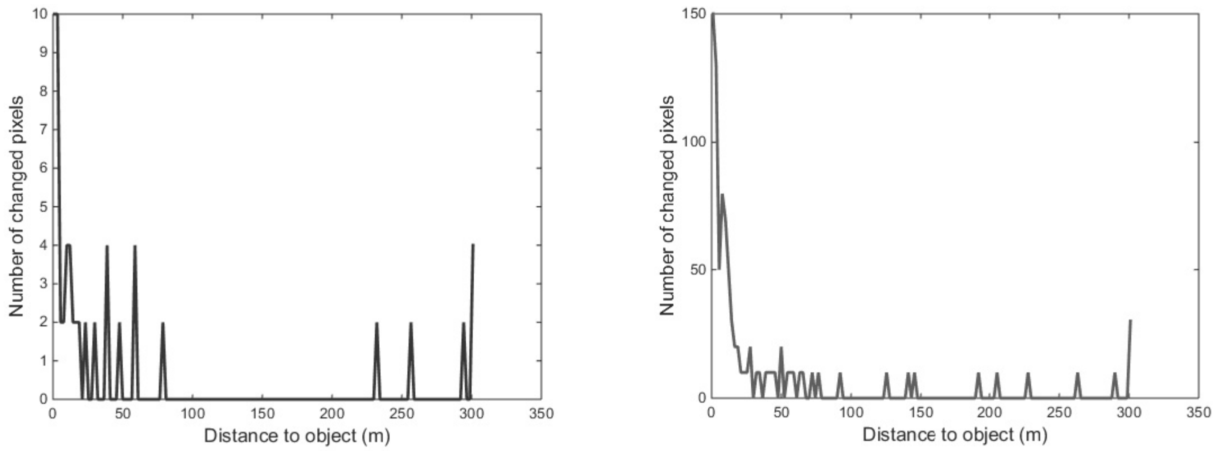

Figure 6: Number of changed pixels per step: left: 30 by 3, right: 86 by 18

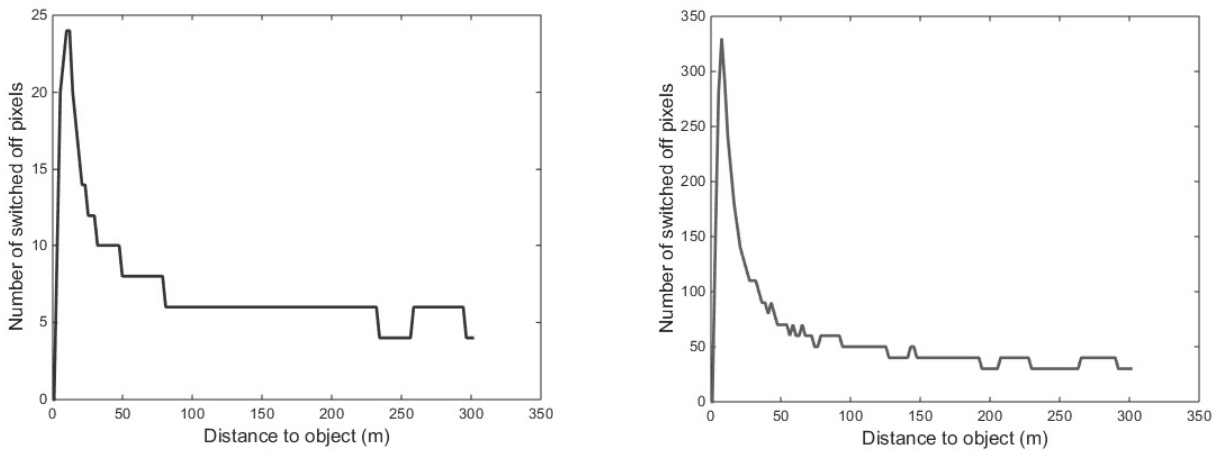

Figure 7: Number of switched off pixels: left: 30 by 3, right: 86 by 18

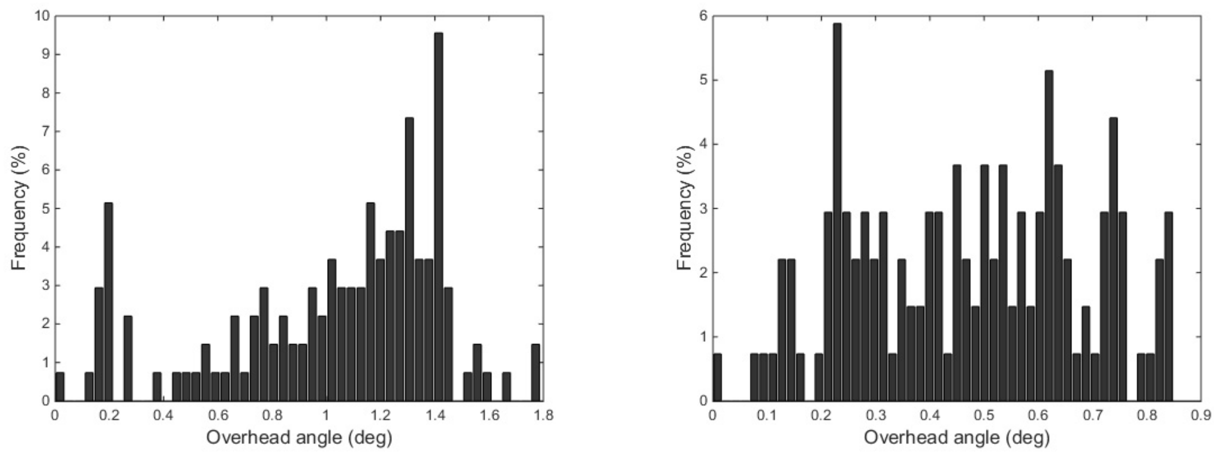

Figure 8: Frequency of overhead angles: left: 30 by 3, right: 86 by 18

Alternative control of headlamp pixels

The calculated maximum number of pixels using CAN FD bus is still far away from a high-definition headlight system. A possible option for controlling a highdefinition headlamp is to transfer object information to the headlamp itself [5].

Here, two different coordinate systems can be used, the one of the camera and the coordinate systems of each headlamp. The advantage of the camera coordinate system is a reduced bus load since both headlamps get the same object information including its distance to avoid parallax error. Following, both the left and the right headlamps need to transform the object coordinates in their own coordinate system. This is a computationally intensive task and is certainly the disadvantage of the camera coordinate system transmission. In both cases the headlamp ECUs have to assign the existing angles to their matrix pixels.

Regarding a usual aspect ratio of today's headlamp light distribution, a highdefinition headlamp might have a matrix of 1024x256 pixels. A pixelwise control of such a matrix with over 250,000 pixels is possible neither by CAN nor by CAN-FD. Assuming maximum 16 detected objects on the road, data transmission of objects in the camera coordinate system can be estimated by using 1 CAN message per object. Additionally, up to 2 messages need to be reserved to have a possibility to modulate and to switch between different light distributions, which need to be saved in the headlamp ECUs. As a consequence, memory of the ECUs needs to be increased.

Nevertheless, the regarded approach can be realized by existing CAN E/E-architectures since the data rate does not turn out to be higher.

Conclusion

After an introduction into front lighting E/E-architecture and basics of headlight control, the paper describes a best and worst case bit rate estimation for a CAN message depending on bit stuffing and cycle time. Then, bit rate estimation for CAN FD is introduced with an intermediate step of average bit rate regarding different arbitration and data rates.

The paper presents a headlamp of 90 pixels, which can be pixelwise controlled using a CAN bus. Its bus load is estimated. As a comparison, a change from CAN to CAN FD with different data rates is examined. The bus load can be strongly decreased, which allows a higher number of pixels per headlamp. This maximum number is estimated for 2, 5 and 8 Mbit/s CAN FD with the result of up to 4700 pixels per headlamp being connected to one 8 Mbit CAN FD bus.

Two headlamps with different resolutions are compared in a specific road space situation. An oncoming vehicle is to be glared out. Pixel states and overhead angles are compared. The overhead can be strongly reduced allowing a more exact glare out.
For pixel numbers over 4700, another approach of headlamp control needs to be introduced for continuous use of CAN buses. Object information in headlamp or camera coordinate system are transmitted to the headlamp. The controlled pixels are calculated by the headlamp ECUs. This approach requires a higher computational power, more memory and increases the costs and complexity of headlamp ECUs.

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