Switch, minibridge and multiplexer for optical and electrical mixed Controller Area Networks (CAN)

Stephan Rohr, Henry Thasler and Herbert Kabza

A reliable communication of electrical fieldbus systems in EMI critical environments requires to precisely keep the specifications of the physical layer. Within R&D it is useful to change the topology of the connected nodes by demand and therefor fast. It is a key technology to use rapid prototyping systems to save development resources. Changes in the fieldbus topology should therefor prevent the developer of wasting time by arising communication problems. One solution for this problem could be the use of optical CAN networks. Unfortunately all components have to be prepared to be used in optical CAN networks. If only several nodes disturb the network communication by EMI problems electrical and optical mixed networks could provide a faster and cheaper solution. This paper focuses on optical and electrical mixed topologies for the CAN network. Changing the physical layer from an electrical to an optical layer means changing the topology from a bus to a star. A hub or switch becomes necessary and the support of point-2-point connections which could lead to a wire length amplification. To minimize the amount of wires a Switch, a Minibridge and a Multiplexer are proposed in this paper. The Switch supports point-2-point connections for optical nodes as well as an electrical uplink. The Minibridge connects electrical sub-segments to optical segments and supports bitwise arbitration. With the Minibridge and the Switch electrical and optical mixed bus-star-bus-topologies can be created for wire length reduction and easy connection of only electrical nodes to an optical network. The Multiplexer is necessary to merge different optical nodes to one optical network link which also leads to a wire length reduction. All proposed components support bitwise arbitration and are fully compatible to the CAN specification which is necessary for supporting electrical and optical mixed network topologies.

1 Introduction

The CAN bus is a differential two-wire bus system. Nodes are connected with short wires through a transceiver chip to the network. In environments with strong electromagnetic induction the transmission of a CAN message can be distorted or the CAN message can be completely destroyed. To allow a reliable communication special care has to be spent on the termination and shielding of electrical networks. Another possibility is to change the electrical medium by an optical one.

With the changeover to an optical medium only point-2-point connections are possible and a network star topology must be provided [1], [2]. In this paper a switch, a minibridge and a multiplexer are introduced which allow multiple network topologies and electrical and optical mixed networks.

The switch can act as a simple star coupler with error detection which means it behaves like a hub. With the use of arbitration groups and the message switch matrix functionality the switch can connect several independent CAN busses which means it acts like a network switch. Arbitration groups and switch-matrix functionality is explained in the section switch.

The minibridge is used to connect electrical and optical sub-segments supporting bitwise arbitration throughout the optical and electrical medium. Bitwise arbitration must be provided through the whole network including optical and electrical segments to keep the CAN specification.

The multiplexer connects several optical nodes to one uplink to reduce the length of optical segments. Additional logic is necessary to prevent nodes which are connected to the multiplexer of error faults caused by other nodes which are connected to the same multiplexer.

The following chapters explain the network components in detail and the network topologies which are supported by these network components. Concluding measurements verify the delay time which is introduced into the network and prove their use also at high bus speeds up to 1,000 kBit/s.

2 Switch

The switch supports a point-2-point connection of 16 optical ports as well as one electrical CAN interface [5], [7]. Fig. 1 shows a picture of the switch which uses an Altera Cyclone FPGA and TOSLINK connectors at the optical side [6].

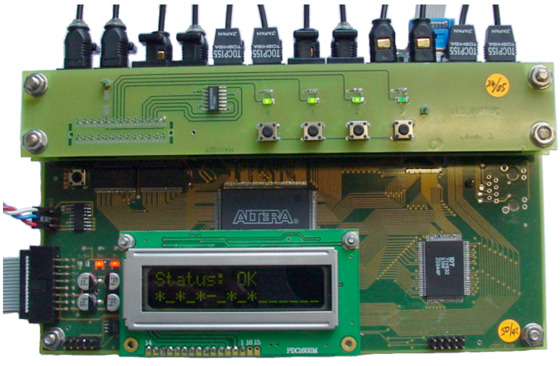

Figure 1: Picture of the developed switch

The optical interface of the hub provides recessive or dominant bit states to allow non-destructive arbitration. During arbitration the receive and send bits are compared and a decision is made if arbitration is lost due to a low priority or not. As a result a dominant bit which is sent by another node must arrive within this bit time. Only then it is possible to detect if arbitration is lost and the sender has to be cut off. Additional logic of the switch ensures that dominant bit states are always distributed to all electrical and optical interfaces. This is supervised by a Real-time error detection algorithm and common bitwise arbitration of all connected ports (optical and electrical) as well as supervision for errors which are not part of the CAN specification. This may be a connection or disconnection of a node, errors due to broken POFs or a node with non-specified errors. The belonging port is then disconnected permanently.

The internal structure of the switch is shown in fig. 2.

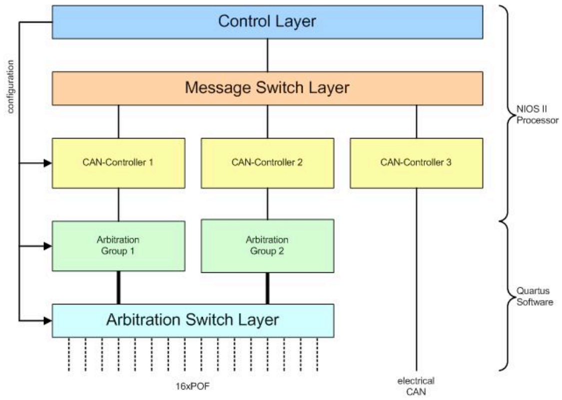

Figure 2: Internal structure of switch

The switch has a control layer which can be configured by a separate GUI (see fig. 3). This control layer controls the configuration of each CAN controller as well as the configuration of the arbitration groups and the arbitration switch layer. An arbitration group can be compared with collision domains in Ethernet technology. Bitwise arbitration is supported by the arbitration switch layer, the arbitration groups and the CAN controllers. All other features cannot support bitwise arbitration.

The arbitration switch layer consists of a free-programmable matrix to route physical optical ports to one of the arbitration groups. This allows the user to define groups of CAN networks which have common arbitration. Every group has its own CAN controller which is connected via the message switch layer to the other CAN controllers. The message switch layer supports message exchange between the CAN controllers in a predefined manner.

Every group has its own configuration settings.

If messages are exchanged between the CAN controllers through the switch layer there is no common arbitration possible.

They behave like separate CAN networks. So if nodes with a high amount of CAN messages between each other are placed in the same arbitration groups the bus load of each arbitration group can be remarkably reduced.

The configuration of the switch and especially the switch matrix is shown in fig. 3 and fig. 4. The GUI of fig. 3 allows individual settings of every arbitration group and CAN controllers. The exchange of messages between the CAN controllers is configured by setting the destination group, the source group and a mask which behaves in the same manner as the acceptance filter configuration of standard CAN controllers. Up to 8 different switch matrix entries are supported.

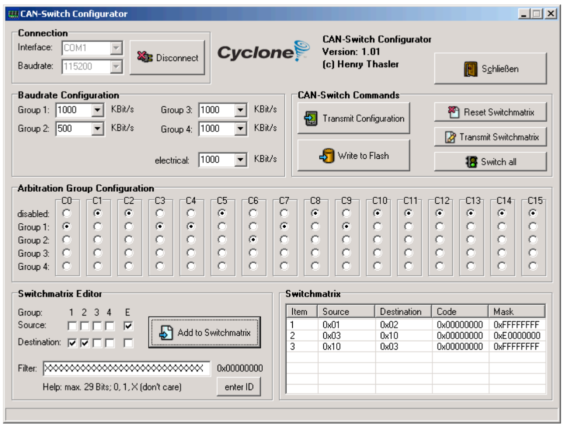

Figure 3: User interface for switch configuration

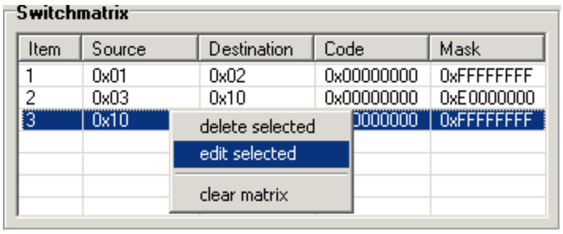

Figure 4: Detail of Switchmatrix configuration

3 Minibridge

The so called minibridge provides two interfaces which is an electrical and an optical one. Fig. 5 shows the minibridge which consists of the electrical transceiver chip and the optical transmit and receive connectors. Both devices are connected via a CPLD which ensures bitwise arbitration and data integrity as well as port supervision for non-specified errors.

If there is a microcontroller (active interface) connected to the optical side of the minibridge it behaves like a state-of-the-art optical interface. But if there is an electrical interface connected to the electrical side a special behavior is necessary to provide an optical interface which behaves like an active interface.

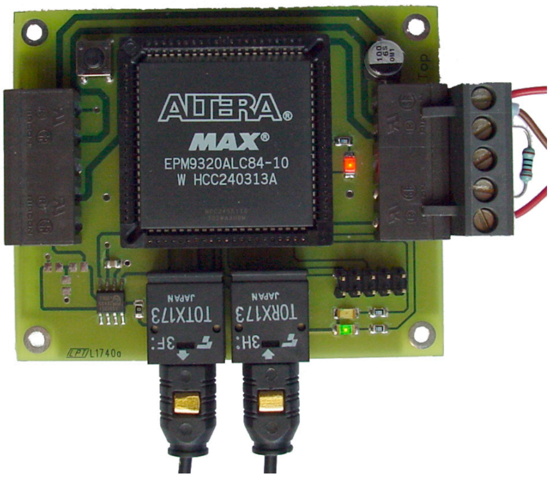

Figure 5: Picture of minibridge in EPLD technology

The proposed minibridge connects its optical side to the switch (passive interface) which leads to an important difference because a dominant bit at the switch's optical in-port results in a dominant bit at all of its out-ports. Unfortunately the electrical CAN interface echoes the bit state to the optical side. With no further logic this behavior would result in a permanent dominant bit state of the whole CAN network and therefore a permanent network fault [3], [4].

Fig. 6 shows the state machine of the minibridge which ensures correct translation of dominant and recessive bit states.

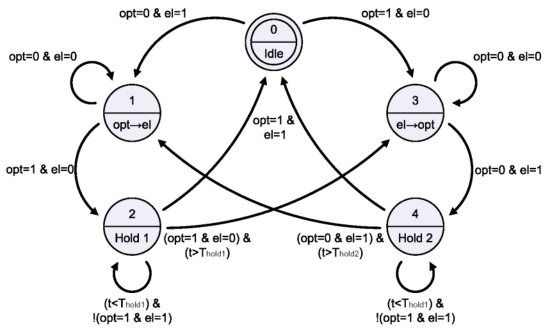

Figure 6: State machine of the minibridge

If there is no dominant bit state the minibridge is in idle mode. Due to the fast CPLD technology the minibridge is able to detect whether a bit state changes on its optical or electrical connector. So if there is a change to a dominant bit e.g. at its optical side the state machine change its state and transmits the bit from the optical to the electrical side. A better understanding is given by fig. 7 and 8. An electrical node is connected to the minibridge and the optical side of the minibridge is connected to the switch. Fig. 7 shows the arbitration process in detail where the switch is winner. After the transmission of the 6^{th} bit the minibridge changes its state and transmits recessive bits to the switch during the message transmission from the switch to the electrical node. TORX is the signal of the optical receiver. TOTX is the signal of the optical transmitter. RxD and TxD are the receive and transmit signals of the electrical node.

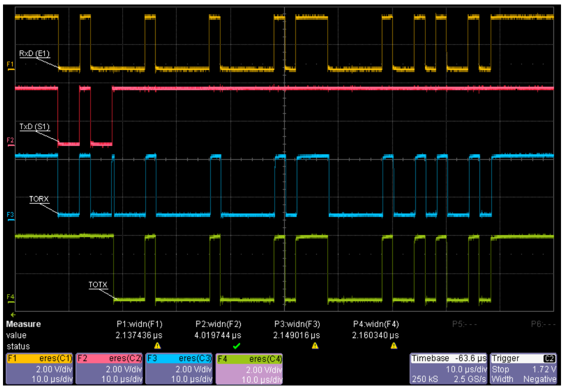

Figure 7: Arbitration Process through Minibridge

The same arbitration process of Fig. 8 shows Fig. 8 including the whole CAN message for a better understanding.

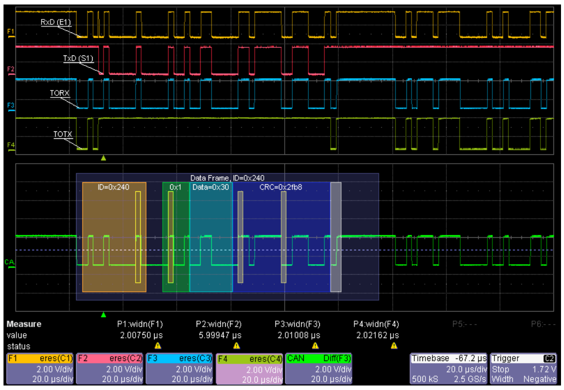

Figure 8: Arbitration process and whole CAN message

The minibridge is useful to connect only electrical nodes to optical ports of the switch and allows easy network topologies which are shown in section Network Topologies.

4 Multiplexer

The multiplexer uses a complex programmable logic device (Altera EPM570 MAX II family) which consists of the multiplexer's combinatorial logic. A logic unit exists of a flip-flop and a 4-bit lookup table (LUT). The use of the lookup table allows to create almost every combinatorial logic without using AND or OR gates. This allows to predefine the exact signal delay times. The multiplexer uses a quartz with a frequency of 50 MHz. Fig. 9 shows a picture of the proposed multiplexer in glass fiber technology [7]. The dimension of the PCB is 80x100 mm. It has one optical uplink and three optical connection ports as well as an electrical interface.

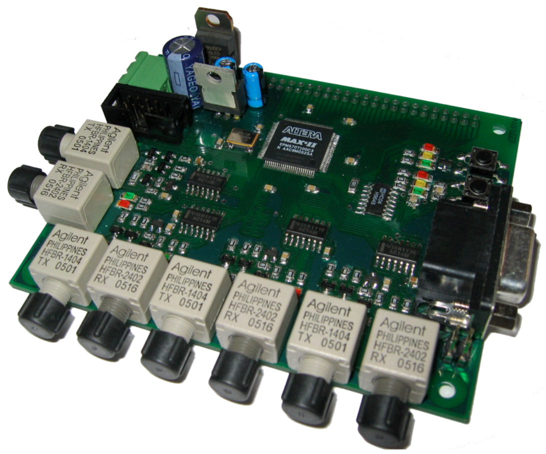

Figure 9: Picture of multiplexer in fiber glass technology

The main differences between the multiplexer and the switch are with the error handling. Received data at the uplink port is transmitted to the three optical CAN ports under two conditions:

- There is no pending reset at the multiplexer (otherwise the nodes which are connected to the optical ports of the multiplexer would increase their error counters)
- The port to which the data is to be transmitted has no error detected (if there is no identification of this condition the optical port which has an error would be included in the arbitration process and therefor disturb the arbitration process of the other connected nodes).

5 Network topologies

The introduction of switch, minibridge and multiplexer supports following network topologies:

- Bus with branch lines. Optical branch lines within an existing electrical CAN network (fig. 10). Even for long branch lines bus termination problems are avoided. A low-cost solution is the use of an pure optical node with a minibridge [1].

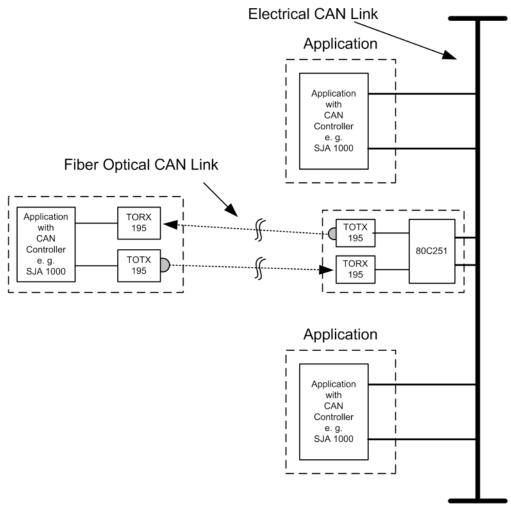

Figure 10: Optical branch line

- If the electrical uplink port of the switch is deactivated, an optical star topology with only optical nodes is supported. Switching off the electrical uplink minimizes the total delay time and allows high speed CAN (see fig. 11).

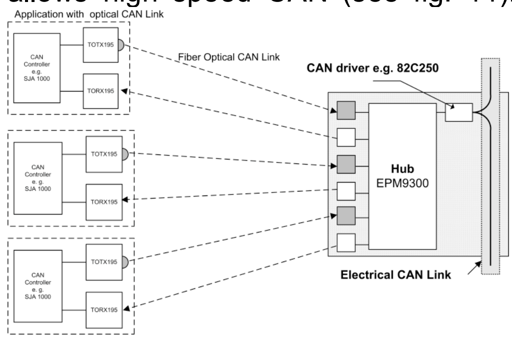

Figure 11: Optical star topology

- An electrical and optical mixed network with an electrical bus and an optical star as sub-segment is provided by the switch with activated electrical uplink. Multiple switches can be introduced if the overall delay time is not exceeded. Fig. 12 shows the mixed network topology.

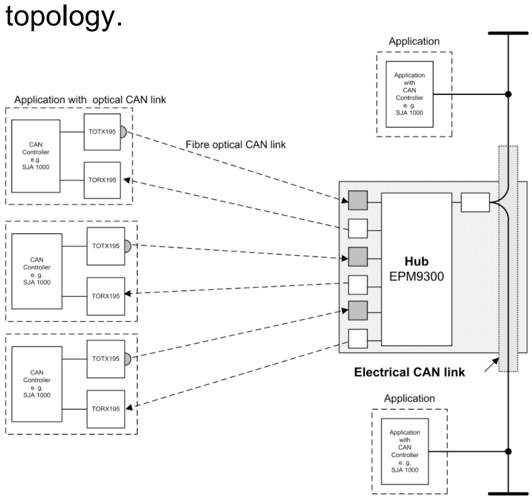

Figure 7: Optical and electrical mixed bus-star topology

- The use of the minibridge allows also electrical sub-segments which can be connected to an optical port of the switch. Bus-star-bus topologies can be supported if the electrical uplink is used additionally. The topology is shown in fig. 13.

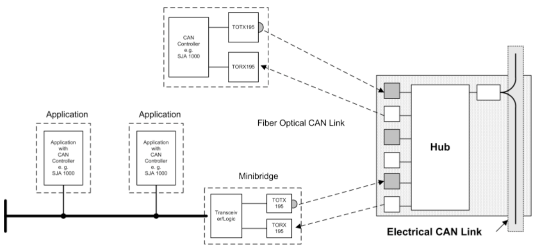

Figure 13: Electrical bus connected to an optical port of the switch via minibridge

- If the multiplexer is used several nodes which are placed locally together can be connected to the switch via a common optical medium. This minimizes the wire length. Fig. 14 shows the star-star topology.

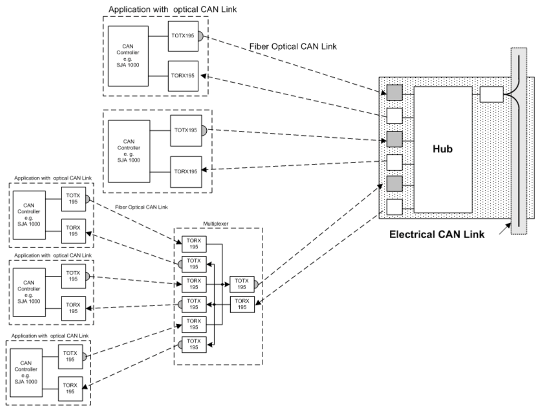

Figure 14: Optical star-star topology

All types of network topologies can be mixed with respect to the maximum delay time.

6 Measurements

For long time tests the switch has been operating for about 48 hours. During this time it transmitted 720 million frames at a bus speed of 1 Mbit/s without any errors. With 4,150 frames per second at 1 Mbit/s it is equal to a bus load of 24 %. However environmental tests have to be made to prove the functionality also in harsh environments.

For stress tests the number of frames has been increased up to 5,120 frames per second (31 % bus load). Overall about 400 million frames have been transmitted and 800 million frames have been received within 23 hours. However if the bus load is increased up to 8,000 frames per second (50 % bus load) the software of the switch reaches its capacity. Receiving frames is still possible but the transmission fails due to internal buffer overflows and frames are lost. The transmission capacity depends on following properties:

- Mode of switch (switch messages to all ports or only to selected ports)
- Size of frames
- Standard or extended frames
- Composition of arbitration groups

Increasing the transmission capacity is also possible if the software algorithms are optimized or the processor speed is increased. However, most applications should work with the current switch performance.

7 Summary

Employing optical connections between CAN nodes ensures reliable CAN communication even under high level EMI conditions with a minimum of modifications of the existing electrical CAN network. Using star topologies it is possible to reach unfavorably positioned nodes without exceeding the maximum cable length. The electrical uplink of the switch allows to incorporate an existing electrical CAN network and expand it by optical sub-segments. For connection of single CAN nodes into existing electrical CAN networks the minibridge can be used, thereby avoiding electrical branch lines. If optical nodes should be connected to one optical port of the switch a multiplexer can be used to form optical sub-segments. Bitwise arbitration is supported by all components and meets the CAN specification. Due to the use of programmable logic devices the delay times of the components could be decreased to a minimum. However the delay time which is introduced into the network by the optical transmitters is a multiple of the delay time of the logic devices. Therefor for further improvements the delay time of the transmitters has to be decreased.

This paper shows that the introduction of optical components could simplify the use of CAN networks in EMI critical environments and therefor accelerate the development process of nodes which are exposed to high EMI.

Reference

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