iCC 1994

1st international CAN Conference

in Mainz (Germany)

Sponsored by

Allen Bradley
National Semiconductor
Philips Semiconductors

Organized by

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A Global Time System for CAN Networks

CAN is known as a protocol for high performance and high reliable serial communication links between electronic control units in the field of automotive and industrial control applications. A new method of real-time support in the network allows to enhance the dynamic behaviour of the overall system as well as the diagnostic capability. With the µPD72005, NEC has developed a CAN controller, which allows to establish a global time system among the loosely coupled nodes of the network.

The characteristic behaviour and performance of modern industrial control systems is more and more determined by high sophisticated electronics. Micro controller based control units have taken control over electric motors, hydraulic valves and pneumatic pistons. The introduction of electronically controlled subsystems like positioning systems, speed, pressure or temperature control systems have improved the functionality and reliability of industrial machines and plants remarkably.
In the past the design of electronic controllers was mainly focused on subsystems, i.e. to improve the performance of isolated functions. Of cause, limitations for an overall control strategy appeared since physical couplings among the various subsystems could only be considered as far as they were measurable from the local electronic control units (ECU's). Moreover, controller activities of ECU's in the neighbourhood often appeared physically as disturbances for a control unit even though they all contributed to the same control action of the overall system. It is obvoius, that much better results could be achieved, if the ECU's know in advance, what actions other control units will take.

Thus a consequent next step was, to integrate the previously isolated functions into a general control strategy for the overall system. One possible approach is to centralise the functions of the various ECU's into one central controller unit. But often geometrical, conceptual, or logistic reasons do not allow to follow this idea. The other approach is to establish a system of distributed intelligence, i.e. to stay with a multitude of ECU's , which communicate with each other to build up the overall system control. Obviously this approach raises the strong demand for communication links between the various ECU's.
Today highly integrated microelectronics allow to realise these communication links based on a network structure similar to computer networks. Of cause, reliability and real time performance are two of the mayor requirement for a network in distributed feedback control systems.

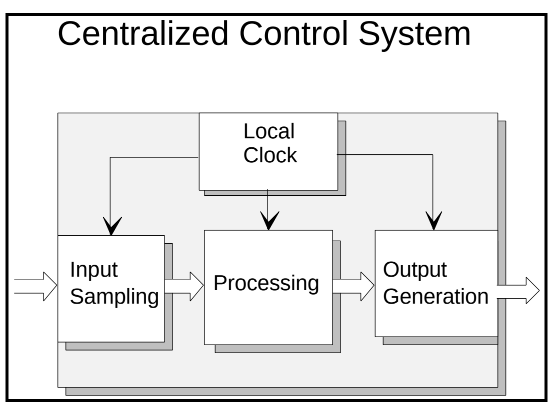

Fig 1: A digital control system in a central unit is synchronised by the local clock system

In the automotive area as well as the industrial field, CAN [1] has developed as a standard protocol for high speed serial communication links between real time oriented control units. Especially the short latency times for message transfers in the multi-master system and the sophisticated error detection and error confinement features make this protocol best suited for this type of applications.

The benefit of a global time base in a CAN network

The integration of the various distributed control functions into one overall controller by means of a serial communication network results in a loosely coupled decentralised control system. In contrast to a central control unit, see Fig. 1, such a system has no central clock supply to co-ordinate the distributed processes, like sampling, algorithm calculation and output processing, which have to be performed precisely in time by the different nodes. Of cause, each single unit has a local time base derived from the crystal of the ECU, which co-ordinates all local processing within the control units. However, as soon as processes are distributed among various ECU´s, as shown in Fig. 2, there is no longer a common time base, which could be used to co-ordinate the different tasks.

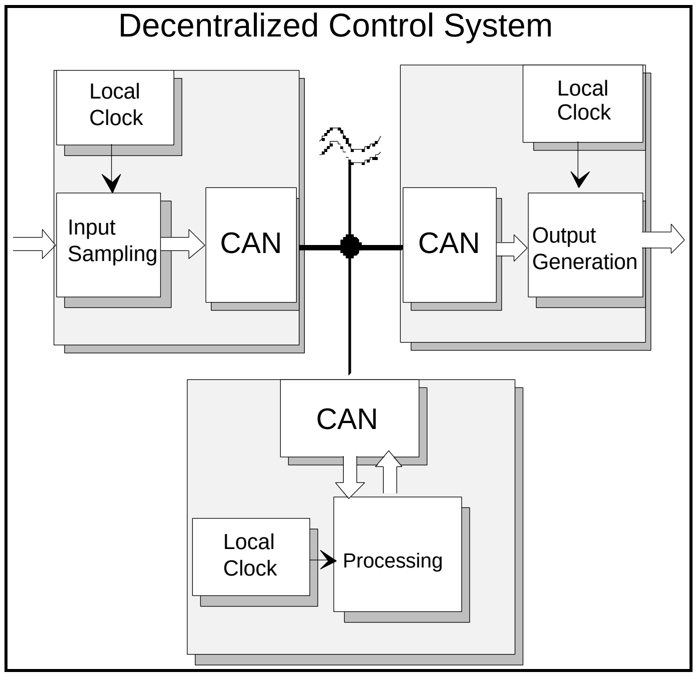

Fig 2: A loosely coupled distributed control system has no common time base for synchronisation

As a further consequence, the different nodes of the network are not able to communicate about time related values like delays, sampling times and trigger points. For example, a node, which broadcasts a speed or position measurement of a piston via the CAN network, is not able to add the respective sampling time of the measurement, which could be utilised by other receiving nodes.

Another example occurs, in case that a node requests simultaneous actions from several other nodes at a certain point in time. Here two different methods could be applied.

Following the first method, the requesting node would announces, what kind of action should be performed by the other nodes. After that, a message would be used as a trigger event to determine the point in time, when the actions have to be performed.

A second method could be, that the request for an action is again given in advance but it already contains the information, at what point in time this action should be performed. In this case, no trigger message is required to define the starting point of the action.

The first method can only be applied under the following two conditions

- the trigger message is received by the different nodes simultaneously

and

- the requesting node can assure the reception of the trigger message with sufficient precision at the desired point in time.

The first condition is already satisfied by the fact, that CAN is a broadcast communication network, in which a message can be received simultaneously by an arbitrary number of nodes. The second condition, i.e. to assure the reception of a message at a desired point in time, is a more difficult task for the system designer. On the one hand, the message could loose arbitration in case, that it does not have highest priority in the network. On the other hand, unpredictable delays in the transmission of a message can occur due to disturbances etc., i.e. in case, that a node detects an error during transmission. Especially the second reason makes it rather impossible to assure the reception of a trigger message at a desired point in time.

The second method is based on the existence of a common time base among the nodes of the CAN network, which has to be build up with sufficient precision. Assuming , that such a common time base could be established, this method does not raise the difficulties described for the first method. Here the request for an action including the necessary timing information could be transmitted early enough to avoid any problems caused by transmission delays due to disturbances on the network.

How to establish a global time base in a CAN network?

Generally a global time base can be set up in two different ways. Either the different nodes adjust their local time bases according to a pre defined master clock in the system or the local time bases remain unchanged but the nodes calculate the relation between their local time base and one or more selected reference time bases by means of a transformation equation.
In this article the second method is described.

The following steps could be used to build up the global time base using transformation equations:

- From time to time all nodes of the CAN network capture their local time base counters. The capture operation is performed simultaneously at all nodes at the reception of a synchronisation message.

- One or possibly more pre defined nodes broadcast their capture values (time messurements) to all other nodes as reference values.

- Each node updates its transformation equation(s) between their local time and the reference time(s). In case, that more than one node take part as reference nodes, the global time base could be selected from the reference time bases according some criteria like most stable relation to the majority of local times for example.

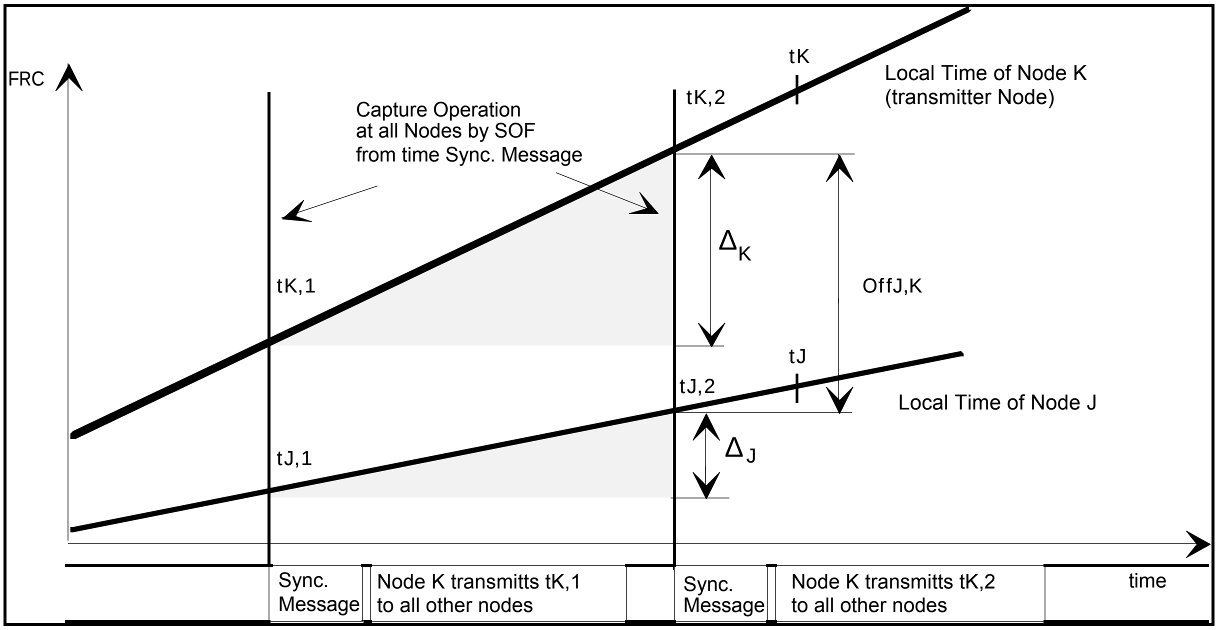

Fig 3: **How to determine the relations of the different time bases**

Assuming, that the time bases follow a linear equation, then the transformation equation can be calculated completely after two capture operations have been performed. With the first capture operation, the offset between the time bases can be calculated; after the second one the slope and offset relation is determined. All further capture operations are used to update the calculated transformation coefficients.
Fig. 3 shows the operation for the case, that the time base of node K is used as reference time and node J calculates its transformation equation. Fig. 4 then shows the equations to be calculated for a transformation of local time into global time and vice versa.

$$t_K = \Delta_{K,J}(t_J - t_{J,2}) + Off_{K,J} \quad \text{Transformation from Node J into Node K}$$

$$t_J = \Delta_{J,K}(t_K - t_{K,2}) + Off_{J,K} \quad \text{Transformation from Node K into Node J}$$

$$\text{with} \quad \Delta_{K,J} = \frac{1}{\Delta_{J,K}} = \frac{\Delta_K}{\Delta_J} = \frac{(t_{K,2} - t_{K,1})}{(t_{J,2} - t_{J,1})}, \qquad Off_{K,J} = -Off_{J,K} = (t_{K,2} - t_{J,2})$$

Fig 4: **The transformation equations between different time bases.**

As already mentioned, it is not of great importance, at which points in time the capture operations at the nodes are performed but that they are taken simultaneously, i.e. at the same point in time, by all nodes. Thus it is no problem, when synchronisation messages are delayed due to bus disturbances or other messages having higher priority for arbitration. It only has to be assured, that all nodes take their capture value at the reception of the same message and at a characteristic point of the message frame, which guarantees most simultaneous recognition at the different nodes.

The application of the global time system with the µPD72005 CAN controller

The µPD72005 CAN controller [2] supports the above mentioned synchronisation operation by a special synchronisation output called SOF as depicted in Fig. 5. This output is connected to a capture register at the local time base counter of the ECU. The output SOF of the µPD72005 has to be enabled by the CPU. Then a trigger signal is generated, whenever the CAN controller recognises a **S**TART **O**F **F**RAME on the bus line. With the successful reception of the defined synchronisation message the signal is automatically disabled again, i.e. no more trigger is generated at the SOF output (see Fig. 6). The CPU can then take the captured value to calculate the transformation equation.

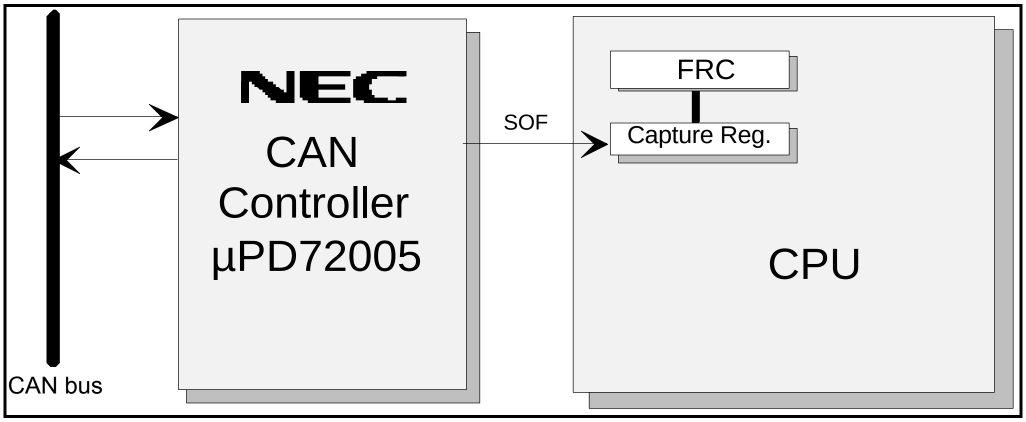

Fig. 5: Application of µPD72005 for global time base support

The proceeding, as described above, guarantees the best possible precision with respect to simultaneousity of the capture operation by using the START OF FRAME recognition. The automatic disable function of the trigger output then assures, that the last capture operation is definitely taken from the start of frame of the valid synchronisation message and not possibly at any other message or SOF recognition caused by a bus disturbance.

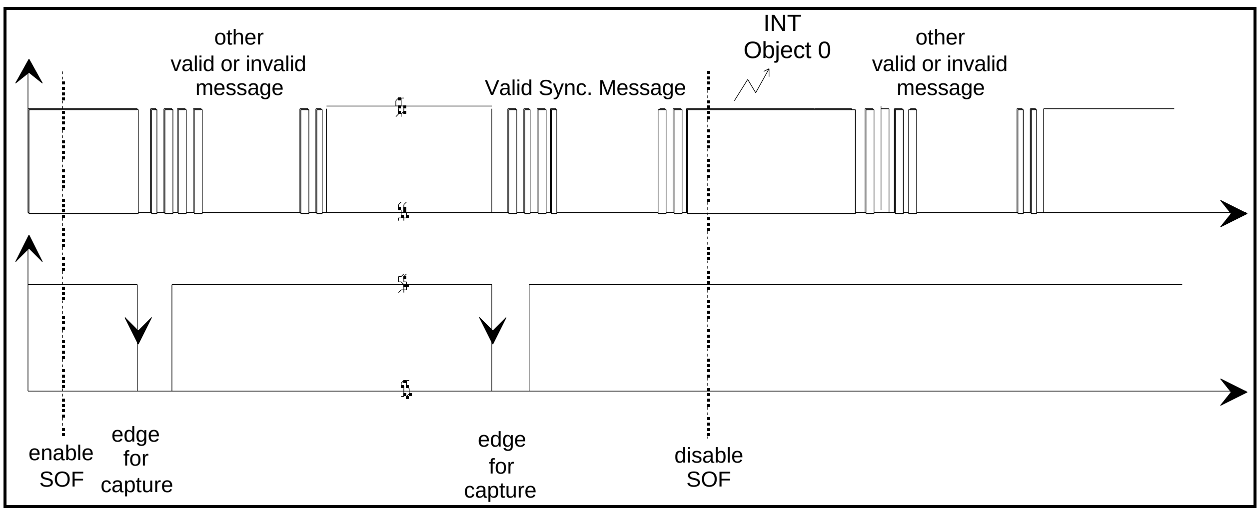

Fig. 6: The principals of SOF trigger generation

Herewith all the advanced CAN protocol mechanisms are used to support the proper capture operation at all nodes to establish the global time base within the network.

The µPD72005 is a so called FULL CAN controller, which autonomously (automatically) handles the reception and transmission of messages. The messages are presented via a dual ported memory area of 160 bytes in which up to 28 communication objects can be defined (see Fig. 7).
At the µPD72005 the a.m. synchronisation message is implicitly defined as the message residing in the first communication object.

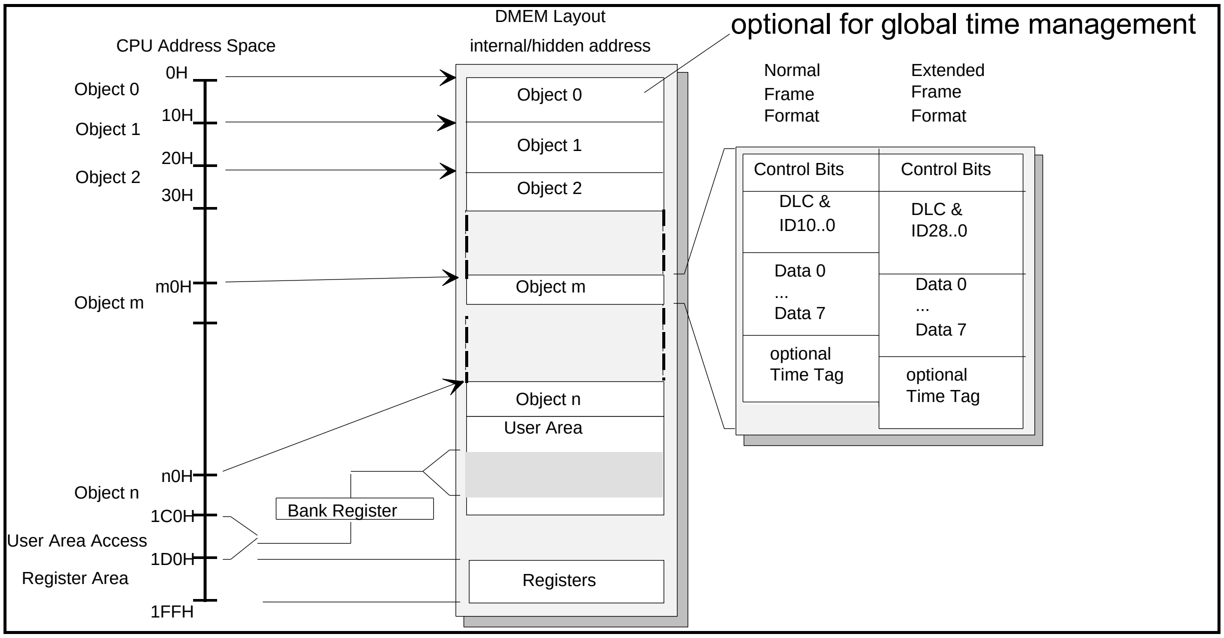

Fig 7: The layout of the internal DMEM at the µPD72005

Beside the global time base support, the µPD72005 provides some other extraordinary features for a convenient and high performing serial data communication, as there are:

- Standard/Extended Frame Format
  (support of the BOSCH Specification 2.0 Part A and B).
- Time Tag Support
  (optionally a time tag can be added to the message, which identifies the time of reception).
- Dynamic Object Management
  (communication objects can be redefined on-line, i.e. other objects remain under communication).
- Group Message Objects
  (two of the 28 objects can be defined for a whole range of identifiers, i.e. many messages can be received via these objects - BCAN function).
- Advanced Error Detection and Diagnosis Functions
  (single protocol error signalling like Bit-, Stuff-, CRC- and ACK-errors etc.).
  (a trace buffer allows to check the communication path)
  (a special configuration error bit signals possible network configuration conflicts)

Summary

With the µPD72005 CAN controller it is possible to establish a global time base among the different nodes of the network without any additional hardware. The required overhead with respect to software and CPU load can almost be neglected compared to the benefit such a global time base offers. On the one hand external and internal events, that are distributed over the different ECU´s of the total system can be determined precisely with respect to their timing relation only by means of the already existing CAN network. On the other hand the diagnostic capability of the total system is remarkably increased due to the fact, that the different subsystems can supervise the proper function of their local time bases.

<u>Literature:</u>

[1] CAN Specification 2.0 Part A and B
Robert Bosch GmbH

[2] Data Sheet µPD72005 CAN Controller
NEC Electronics (Europe) GmbH