DEMONSTRATIONAL SYSTEM FOR TRAINING IN FlexRay COMMUNICATION

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Abstract − This work deals with an educational system for the teaching of standard FlexRay (FR). The FR is a new communication standard intended to be used in cars in the near future. It is primarily intended for communication among so-called x-by-wire systems. Many fundamental and advanced features of FR standard, as well as basic kinds of x-by-wire systems, can be demonstrated by this educational system. The largest benefit is in an illustrative presentation of the FR synchronization mechanism (SM) in operation, as well as of its robustness. The SM is probably the most important FR process, and provides synchronization among time bases in a FR network. The educational system allows the disturbance of the time bases by modification of clock frequency. External generators are used for this purpose. The changes in SM behaviour can be observed as a result of time base disturbing. The most interesting observation is to what degree the SM is able to cope with this clock frequency fluctuation. No similar FR educational systems have previously been equipped with a possibility like this.

Keywords: FlexRay, x-by-wire-systems

1. INTRODUCTION

Commonly used communication buses in today's cars are CAN (*Communication Area Network*) and LIN (*Local Interconnected Network*). Both of these serve to provide data transmission between measuring points (sensors) and the control unit. The time schedule on the bus tends to be fully utilized at the present time. In other words, there is not enough space for future applications. In 1999, the consortium FlexRay developed a new automotive communication standard, also entitled FlexRay [1] and [2]. This standard is intended to be used in cars in the near future. The maximal baud rate is 10 Mbps. This is ten times more than CAN supports. Another main reason for implementing this new standard is because of its totally different Media Access Control (MAC). Standard CAN is based on CSMA/CR (*Carrier Sense Multiple Access with Collision Resolution*). This is a similar approach to that used by Ethernet. Communication protocols based on this kind of MAC cannot be used for real-time controlling at all because of collision, which can be dangerous [3]. On the other hand, standard FlexRay uses TDMA (*Time Division Multiple Access*) which makes it suitable for many applications including real-time.

Examples of these real-time applications in cars are so-called x-by-wire systems [4]. These systems will replace some mechanical parts in cars. The excluded parts are then replaced by electronic systems that are more flexible, safer and easier to maintain. As an example, the information related to the angle of the steering wheel will be transferred by means of wires only. There will not be any mechanical link between the steering wheel and the wheels. This system is called steer-by-wire. Another similar application is brake-by-wire or drive-by-wire. The idea of using x-by-wire systems in cars is taken from aircraft where similar systems have been working reliably with communication protocol TTP/C (*Timed Triggered Communication Protocol*) [5] for many years.

This article deals with the educational system consisting of ten FR nodes. This system provides a suitable tool for training in FlexRay technology. Many interesting features of FlexRay standard can be demonstrated by this system, including the following:

I. Demonstration of basic FlexRay features
    a. Physical layer parameters
    b. FlexRay frame format
    c. Data coding and decoding

II. Advanced study of some FlexRay processes
    a. Wake-up mechanism
    b. Start-up procedure
    c. SM of time base

III. Reliability and robustness test
    a. Behaviour in case of one FlexRay communication channel resection
    b. Behaviour in case of a time base frequency fluctuation

TDMA and some potential frequency discrepancies among time bases cause FlexRay to be quite complex. The correction of time base frequency fluctuation is a task for the complex synchronization process [6] implemented in every communication controller. The process is very important for the correct running of the FlexRay network, and so it is necessary to test it. For this purpose, it is necessary to have access to a time base, and also the ability to change it. No other FlexRay educational system has previously included this possibility. However, our training system has been

designed to have the ability to make time bases influenceable. Each node allows the disconnection of the internal time-base and uses external generators as a source of time. The time generated in this way can be changed according to requirements. For example, the frequency of a time base can be swept. This is the great contribution of our system allowing influence of the frequency of time base in order to test the SM behaviour.

2. DEMONSTRATIONAL SYSTEM DESCRIPTION

The demonstrational system for training in FlexRay communication was designed as a panel containing ten FR nodes. One node comprises the motherboard based on processor STR710 with core ARM7 and FR board consisting of FR controller MFR4310 and two FR drivers TJA1080. The physical connection between these nodes is provided by an active star. The block diagram is shown in fig.1. In fact there are two active stars in the network because FR standard supports two independent channels. The real system is possible to see in fig. 2. There is also some logical connection in the network given by time slot because of TDMA:
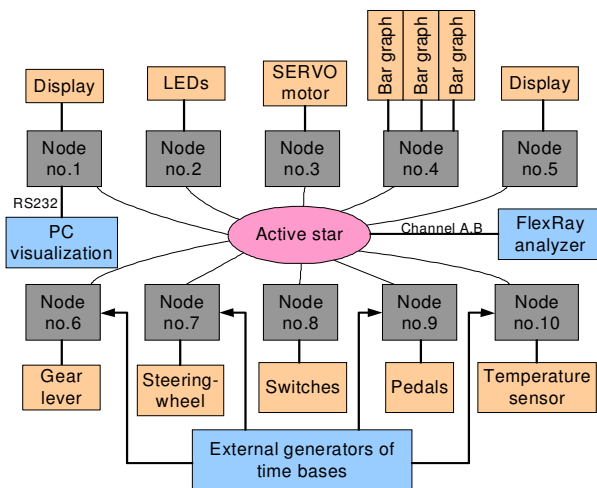

Fig.1. The block diagram of FlexRay demonstrational system

- **Time slot no. 1** – transmission between steering wheel (node no. 7) and servo motor (node no. 3). The value related to the steering wheel angle is transported by means of this slot.

- **Time slot no**. 2 – transmission between pedals (node no. 9) and bar graphs (node no. 4). The three values related to the positions of three pedals are transported by means of this slot.

- **Time slot no**. 3 – transmission between gear lever (node no. 6) and segment display (node no. 1). The value related to the chosen level of gear lever is transported by means of this slot.

- **Time slot no**. 4 – transmission between temperature sensor (node no. 10) and display (node

no. 5). The value related to the temperature in the area is transported by means of this slot.

- **Time slot no**. 5 - transmission between switches (node no. 8) and LEDs (node no. 2.). The value related to the state of switches is transported by means of this slot.

In addition, all information in time slots 1–5 is received by node no.1. This node transforms the data to the RS232 protocol and transmits it to the PC. There is a visualization application running in the PC.

The demonstrational system also contains a few measuring devices:

The oscilloscope is able to capture the signal from the bus and construe it according to FlexRay standard. The device allows a broad range of trigger conditions related to standard. In this way the actions running on the bus can be studied in detail.

Generators serve as an external source of the node's time base. They are applicable for testing of SM.
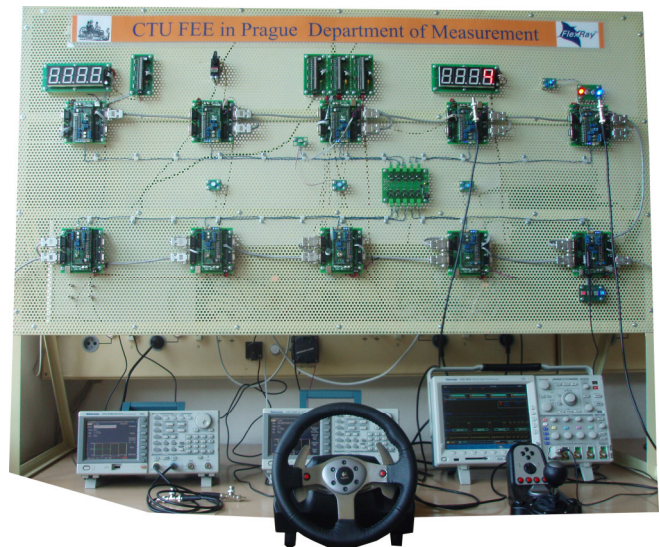

Fig.2. The real view of FlexRay demonstrational system

3. DEMONSTRATIONAL SYSTEM CAPABILITY

Wake-up observation

Wake-up procedure is used for waking up the FlexRay network from sleeping mode. Sleeping mode is a special state when consumption is minimal. There are ten nodes and one of them can be woken up by the external wake-up event. The node woken in this way begins to send so-called wake-up symbols (WUS) to the bus. These symbols are received by means of FR bus drivers in every other node in the network. The driver is able to receive it even if the driver is in sleeping mode. It is one of the functions of drivers to switch on the power source for the rest of the node (processor, FR controller and so on) after receiving WUS. This process is described in detail in [1]. The demonstrational system allows the observation of WUSs in

connection with switching on power sources. The WUS structure can be displayed and compared with standard.

Start-up observation

Start-up procedure comes after successful wake-up. At least two nodes with so-called cold-start status are necessary for this process. Their main task is time schedule determination because of TDMA. This activity is performed by means of start-up frames.

First of all, an election of cold-start leader has to be executed by means of CAS (*Collision Avoidance Symbol*). The elected leader initiates the communication by transmitting start-up frames according to its time schedule. In this way the time schedule is defined on the communication bus and the rest of the network is allowed to join to the time schedule in correct time slots.

The start-up procedure is a quite complex process and it is described in detail in [1]. The demonstrational system allows observation of the whole start-up procedure step-by-step:

i. Start-up leader election by way of CAS transmitting.
ii. The establishment of communication between cold-start nodes by means of start-up frames.
iii. The non cold-start nodes joining.

Data observation

It is possible to catch data related to the steering wheel, three pedals, gear lever and so on in the relevant slot by using suitable trigger conditions. This observation is also suitable for FR frame structure study including data coding and decoding.

Modification of time base frequency

Each node has its own clock for time schedule generation because of TDMA. Due to some influences such as crystal ageing or temperature variation there are some discrepancies between time base frequencies. Without correction the network would not be able to work at all. For this reason the SM must be implemented in every communication controller.

First of all, some necessary basic terms relating to timing in FR network must be explained:

a. Micro-tick (µT)
The Micro-tick is the smallest time unit derived directly from period of clock signal.

b. Macro-tick (MT)
The Macro-tick is a larger time unit consisting of integer number of µT.

c. Communication cycle
Communication on a FR bus is performed in repetitive cycles. One cycle consists of two main parts. The first of these contains time slots assigned to appropriate nodes. The second is an idle segment where correction of frequency fluctuation is partially applied. Each cycle consist of integer number of MT, which must be the same in each node.

The SM measures time deviations between the assumed and actual time of synchronization frames' arrival from the other nodes in appropriate time slots. The rate and offset correction value is computed using these deviations. On the basis of these correction values, the nodes are brought to have a similar view of global time even if there are some frequency differences among nodes.

The rate correction value is a number of µT evenly distributed over each cycle. This distribution is performed in such a way that nominal number of µT per MT in evenly chosen MT is modified by 1 µT.

The offset correction value is a number of µT added at the end of each odd communication cycle.

Both correction values can be positive or negative, thus the cycle can be lengthened or shortened. It depends on whether the time base in the node is slower or faster than the time bases in the rest of the network.

More detailed information related to SM can be found in [1] and [6].

Each of our FR nodes is fitted with a connector for connecting a generator as an external time base. This fact allows changes to the frequency of the time base according to requirements:

- The frequency can be swept by deterministic signal or noise
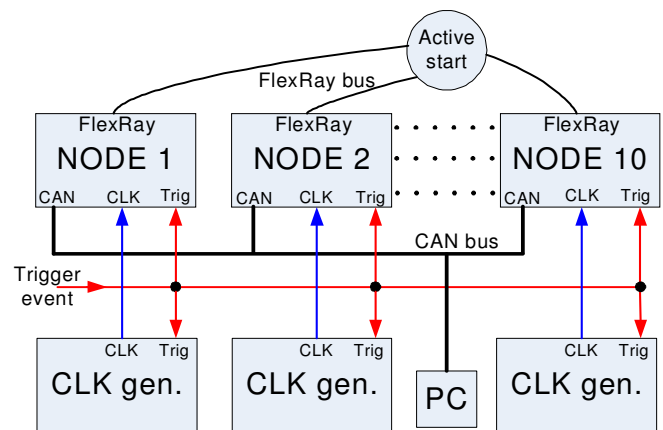- Nominal value of frequency can be shifted by an offset

Fig.3. System for measuring time deviations and correction parameters

Fig.3 shows a block diagram of a system allowing measurement of the time deviations and correction parameters in each node. Immediately after a trigger event occurring, the clock generator starts to change the frequency of individual time bases in a defined way. In addition, on the basis of the trigger signal, each node begins to store time deviations and calculated correction parameters acquired directly from the FR controller. This storing can be provided with an adjustable pre-trigger and is performed once every communication cycle.

In addition to the FR interface, the nodes are also fitted with CAN bus. By means of the CAN, the measured values can be transmitted to a PC for subsequent data processing. A diagram representing the rate and offset correction values as well as time deviations in dependence on communication cycle can be displayed for each FR node. This possibility of observing SM functioning versus time base disturbing is a great contribution in this work. No similar FR educational system has been equipped with a feature like this until now.

Channel resection

The FR standard supports data transmission by force of two independent channels. One channel is redundant and serves in communication in the case of the other channel failing. Behaviour as a reaction on channels resection can be observed. The system is able to cope with one missing channel. After elimination of one of the channels, communication continues by means of the second channel without any interruption in data transmission. The channel resection can be made by disconnection of an appropriate connector.

4. SOME PRACTICAL RESULTS

Data observation

As an example there is a part of the FR frame in fig. 4 where the data related to steering-wheel angle are captured. First waveform (A) represents a situation where the steering wheel is in the extreme right position, and the second (B) shows extreme left position. Fig. 5 depicts the headers of previous frames. They differ in cycle number because they were taken in dissimilar communication cycles.
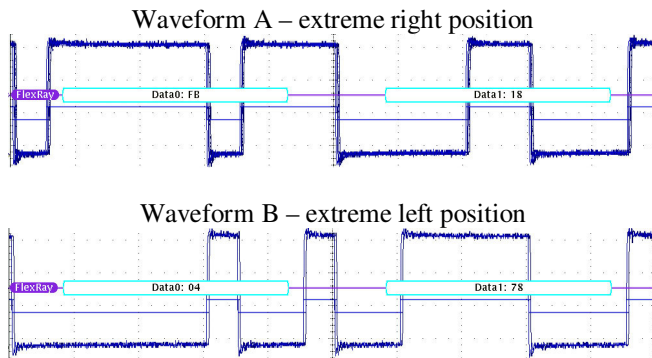
Waveform A – extreme right position

Waveform B – extreme left position

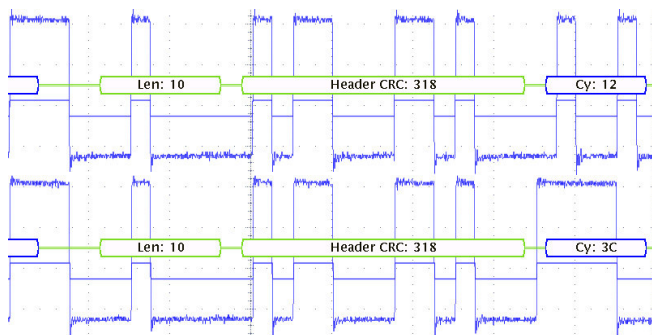Fig.4. Captured data related to steering-wheel angle

Fig.5. Headers of frames

Start-up observation

Fig.6 shows a successful start-up procedure. There is one CAS symbol followed by start-up frames transmitted by a cold-start node in every communication cycle in the appropriate time slot.

On the other hand, fig.7 represents an unsuccessful start-up process. In this case the other cold-start node is not able to join to the communication for some reason. The figure depicts waveform consisting of repetitive group containing CAS symbol and set of start-up frames from the leader. In other words the leader constantly repeated attempts to join with other cold-start nodes, but always unsuccessfully.
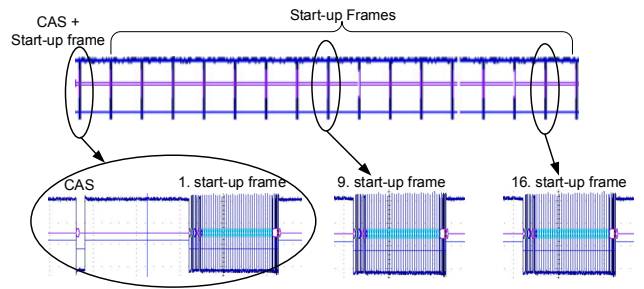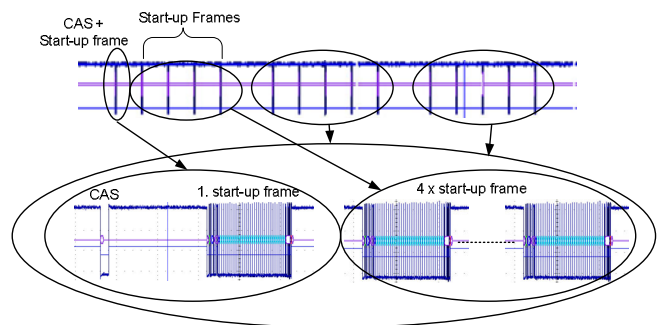

Fig.6. Successful start-up procedure

Fig.7. Unsuccessful start-up procedure

Modification of time base frequency

By modification of time base frequency the behaviour of SM can be shown. This is the most interesting observation in this work. For this purpose a case study has been made on the FR network consisting of 10 nodes. Each node in the network has been set with time parameters according to Tab.1.

Tab.1. Used time parameters

Duration of one μT	25 ns
Nominal number of μT per 1 MT	40 μT/MT
Length of communication cycle	5 000 MT (5 ms)
Number of μT per 1 bit	4 μT/bit (10Mbit/s)

The nodes had constant clock frequency (nominal value 40 MHz) given by its internal crystal oscillator with the exception of node no. 4. This node had a clock source provided by an external generator allowing sweep frequency by a modulation signal. In this study the period of all sweeps

is supposed to be quite long. It covers hundreds of communication cycles. The study focuses on following cases of sweeping:

I. Sweeping by sinus

The clock frequency of node no. 4 has been set to 40 MHz and being swept by sinus shape with the amplitude equal to 100 kHz (f_{min} = 39.9 MHz, f_{max} = 40.1 MHz) with the period 200 communication cycles. This situation is shown in fig. 9 depicting the dependency of frequency deviation (Δf) on communication cycle number (CN). All measurement has been performed within a range of 500 communication cycles. Dependency of correction parameters computed in node no. 4 on CN is depicted in fig. 10, 11, 12. Fig. 10 represents rate correction parameter (RC in μT) and fig. 11 shows offset correction parameter (OC in μT). A detail of OC in CN range 220 - 320 can be seen in fig. 12.

II. Linear sweeping

In this case a linear shape has been used for sweeping the clock frequency in node no. 4 with nominal value 40 MHz. In the same way as in the previous case, the frequency deviation has been set to 100 kHz (see fig. 13) and dependency of correction parameters (RC, OC) in μT on CN has been measured (see fig. 14, 15, 16).

In a simplified view, both of the previous cases show RC to be directly proportional to the frequency deviation function, and envelope of OC to be directly proportional to first derivation of frequency deviation function.

III. Multiple sweeping by sinus

In contrast to the first case, in this case the frequency sweeping by sinus has taken place in two nodes (node no. 4 and no. 5). In addition, the frequency in node no. 5 had twice value of node no. 4. Deviations (Δt in μT) between the presumed and actual arrival time of sync frames coming from node no. 5 have been measured by node no. 4. These deviations in μT are depicted in fig. 8 as a dependency on CN. The figure shows these deviations to be influenced by the superposition of two sinus signals used for frequency sweeping in node no. 4 and no. 5.
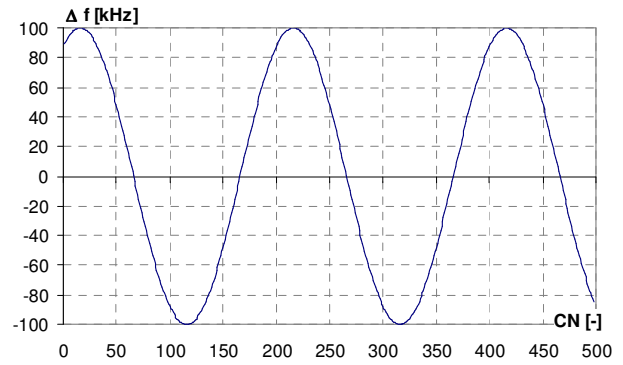

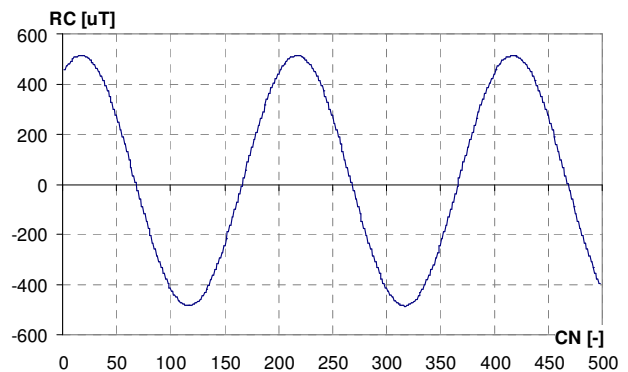Fig.9. Sinusoidal modulation signal for node no.4

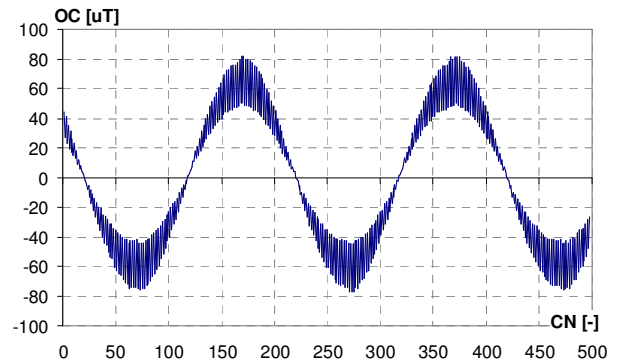Fig.10. Rate correction parameter computed in node no.4

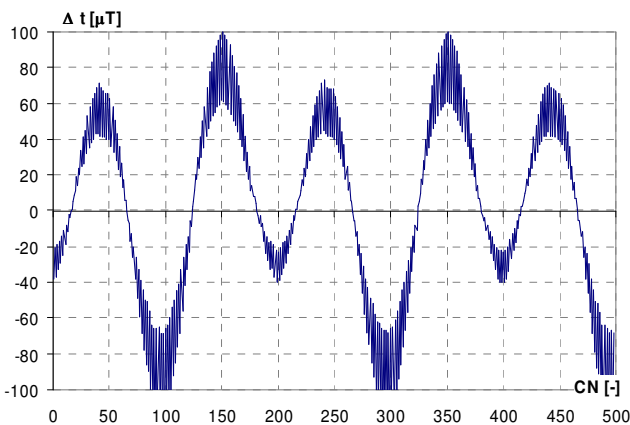Fig.11. Offset correction parameter computed in node no.4

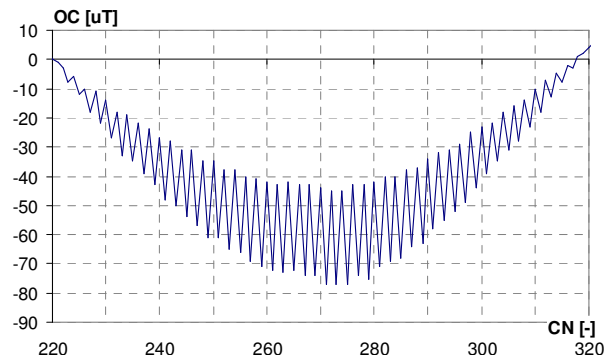Fig.8. Time deviations between node no. 4 and node no. 5

Fig.12. A detail of offset correction parameter
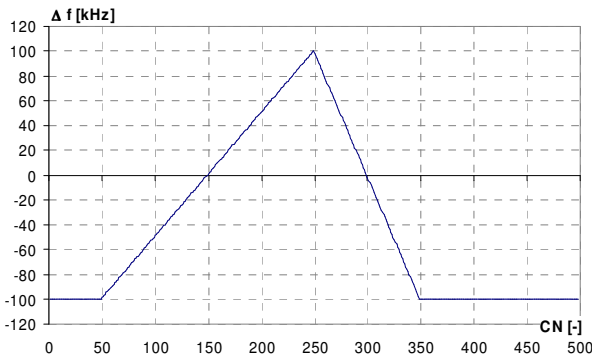
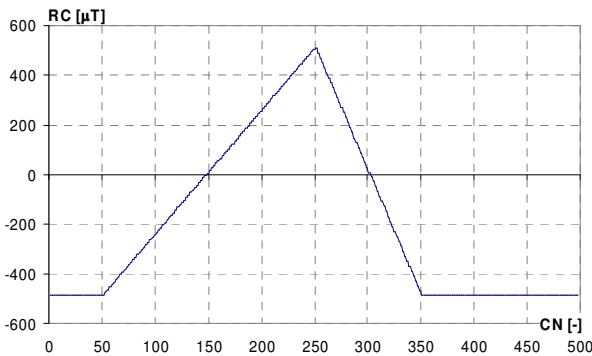Fig.13. Linear modulation signal for node no.4

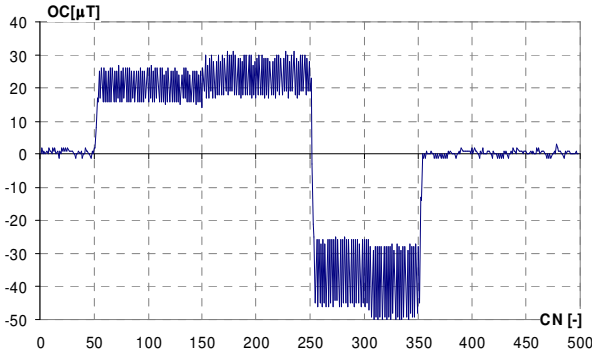Fig.14. Rate correction parameter computed in node no.4

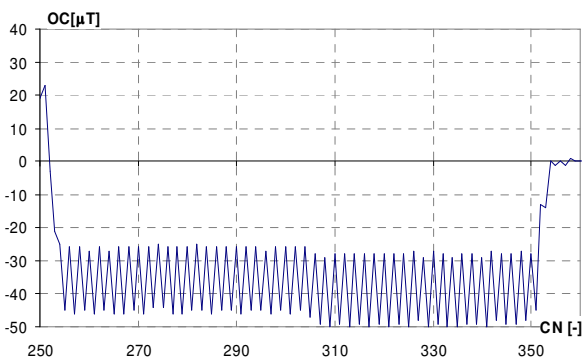Fig.15. Offset correction parameter computed in node no.4

Fig.16. A detail of offset correction parameter

FUTURE RESEARCH

A mathematical model of SM has been created. It is expected to be published in the near future. Future research will then verify the model with the aid of the practical results in this article. If the verification proves the model to be credible enough, the model will be used for studying the behaviour of SM mechanism under conditions where some parts of SM fail to work correctly.

CONCLUSION

This educational system for training in FR technology has been developed to be suitable for demonstrating fundamental and advanced FR features. The great benefit is in the possibility to influence the frequency of the time base in each node. In this way the robustness of SM can be tested. The behaviour of SM in connection with time base disturbing can be observed and the dependence of synchronization correction values on the communication cycle can be displayed. No previous similar FR educational system has supported the ability to demonstrate the FR SM, as well as other FR features, in such a clear way.

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