

# MEASUREMENT SYSTEM WITH FIBER OPTIC INTERFACE

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*Abstract: The measurement system destined for "blind" dynamic error correction has been presented in the paper. The system consists of double analog channel which measure the same input signal. The structure of the measurement system and the DSP algorithm guarantees in theory that there will be no dynamic error. The single fiber-optic cable has been used for data transmission to a distant DSP equipment. The fiber-optic guarantees very good insulation. The structures of transmitter and receiver have been described. A few methods of data modulation have been discussed with respect to the data rate of the transmission. The third channel with a separate A/D converter but without a conditioning circuit has been used as a reference channel for evaluation of the correction quality. Some aspects of technological applications have been mentioned.*

*Keywords: Fiber-optic, Data transmission, Dynamic error correction*

## 1 INTRODUCTION

Tasks concerning reactive power compensation, and precise measuring of the electrical power consumption or evaluation of the electrical power quality require measurement system of very good features. The measurement results obtained from the single channel circuit are often to be sent to a distant place in very noisy industrial environment. This channel should be galvanic insulated. The hardware of this system and fiber-optic interface have been presented in the paper.

Fiber optic coupling and transmission of the digital data is very convenient in this case, unlike the analog signal transmission and analog insulation circuits. The analog signal ought to be converted to the digital representation as close the source of it as possible to avoid the influence of the electromagnetic noise on the input signal. This minimizes the dynamic error involved by analog transmission equipment. The digital result of measurement ought to be transmitted to a distant controller of the system instead of transmission of the analog signal.

An instrumentation amplifier or other conditioning circuits are the only source of a considerable dynamic error. A method used for "blind" correction of this error has been proposed [1].

## 2 STRUCTURE OF THE SYSTEM

The structure of the laboratory equipment destined for verification of this method has been presented in Fig. 1. It consists of the transmitter, single fiber optic cable and a distant DSP equipment with receiver. The transmitter contains a double measurement channel and a single reference channel. The examined measurement channel consists of two analog transducers described by transfer functions  $g_1$ ,  $g_2$  and gains  $k_1$ ,  $k_2$ , two 12-bit A/D converters and a distant DSP system [2]. The maximum sampling frequency  $f_s=1/T_s$  of 100 kHz has been assumed. Both analog channels measure the same signal  $x(t)$ . Their output signals  $x_1(t)$  and  $x_2(t)$  are synchronically converted to the digital representations  $xd_1(n \cdot T_s)$  and  $xd_2(n \cdot T_s)$  at sampling moments  $n \cdot T_s$ . The A/D conversion results have to be transmitted to the remote digital core of the system using a single fiber optic channel. The DSP algorithm identifies dynamic features of the analog input circuits (e.g. time constants  $T_1$  and  $T_2$ ). Afterwards the correction is calculated using simple FIR filter and added to the registered signal of the first channel  $xd_1(n \cdot T_s)$  in real time. Theoretically, the algorithm returns the instantaneous value of the measured signal at sampling moments  $y_1(n \cdot T_s)=x(n \cdot T_s)$  without dynamic error.

The third measurement channel has been added as a reference channel to the former structure for laboratory testing of the correction algorithm only. During tests the simple inertial objects of the first order of time constants  $T_1$  and  $T_2$  have been used as transducers of the first and the second channel. They have unity gain for DC signal. The measured signal  $x(t)$  has been directly connected to the input of the A/D converter of the third channel. It samples the input signal synchronously with both A/D

converters of the examined structure. The reference channel contains no conditioning circuit. So it measures the  $x(t)$  signal without dynamic error. The digital result  $x_r(n \cdot T_s)$  of the third A/D is attached to the output data of the first and second channel. Standard signals of sinusoidal or triangle shape have been used during laboratory test as an input signal  $x(t)$ . The difference  $\varepsilon(n \cdot T_s)$  (1) between a corrected calculated output signal  $y_1(n \cdot T_s)$  and a reference signal registered at sampling moments  $x_r(n \cdot T_s)$  are used for evaluation of the criteria of the „blind” correction quality.

$$\varepsilon(n \cdot T_s) = y_1(n \cdot T_s) - x_r(n \cdot T_s) \quad (1)$$

The remote receiver is used for the demodulation of the incoming serial data and fitting them to the parallel DSP bus.

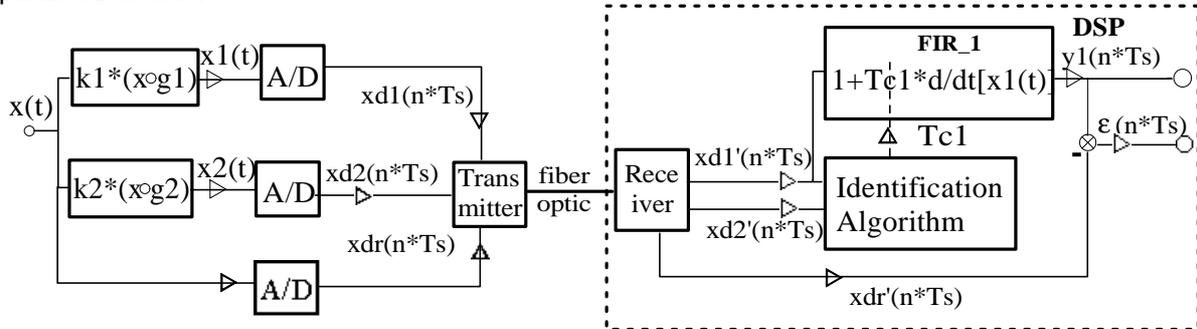


Figure 1. Equipment structure for verification of the "blind" correction algorithm

The measurement system may be used for monitoring the three phase voltage as well. In this case the third conditioning circuit is necessary. Each analog channel measures the separate voltage of the electrical engineering circuit (e.g. star connection). The dynamic errors caused by conditioning circuits are not corrected with the help of the „blind algorithm” in this case.

### 3 RATE OF DATA TRANSMISSION VERSUS METHOD OF MODULATION

Each sampling operations produces  $L=36$  bits as a measurement result. 24 bits are the output of two channels of the examined circuit. They are the input data for the correction algorithm. Additional 12 bits are the output result of the reference channel. This information should be transferred to the distant DSP processor using a single fiber optic cable. This information is long, therefore a self-synchronizing code should be used. The Manchester RZ (Return to Zero), Coherent Frequency Shift Keying (FSK) or Pulse Width Modulation (PWM) have been taken under consideration. The asynchronous Start-Stop technique might be used to transmit these data under condition that the long data are divided into  $K$  short  $M$ -bit words ( $L=K \cdot M$ ). Besides "0" and "1" the third logical state of the digital fiber optic connection is necessary to indicate the beginning of the new measurement result transmission. The "Silence" in the fiber optic is very useful for this purpose. The "S" abbreviation for "Silence" denotes stable "0" or "1" with neither rising nor falling slope of the signal during the time period longer than the duration of the assumed period of time. The "Silence" acts as a stop bit therefore for Manchester and SFK the determined Start bit is required as a preamble.

For Manchester modulation, two periods  $\Phi$  of the transmitter clock have to be used for transmission of a single bit of information. Four periods  $\Phi$  have to be added as "S" and two periods  $\Phi$  for a Start bit. The total number  $J$  (2) of transmitter clock periods is used for transmitting of the whole  $L$ -bit data word.

$$J = 2 \cdot L + 4 + 2 \quad (2)$$

For  $L=36$   $J$  takes value 78.

The same result is valid for FSK technique modulation for data transmission.

The PWM technique requires 3 periods  $\Phi$  for transmission the single bit but it needs no special Start bit. The Silence has to have at least 4 periods  $\Phi$ . The total number  $J$  (3) of periods  $\Phi$  is used for transmitting the whole  $L$ -bit data word.

$$J = 3 \cdot L + 4 \quad (3)$$

For the  $L=36$   $J$  takes value 112.

The great advantage of the Start-Stop method is that the transmission of a single data bit requires only one period  $\Phi$ . The Start bit and Stop bit have to be added to the each transmitted  $M$ -bit word. The duration of the silence has to be longer than frame of the single  $M$ -bit word. The total number  $J$  (4) of periods  $\Phi$  is used for transmitting the whole  $L$ -bit data word.

$$J = L/M \cdot (M+2) + M + 3 \quad (4)$$

The Table 1 presents the total number  $J$  of the period  $\Phi$  with respect to the number of data bits  $M$  of the transmitted frame, effective minimum sampling period  $T_{smin}$  and sampling frequency  $f_{smax}$  for

L=36. The maximum rate of a very convenient fiber optic set (by Hewlet-Packard) [5] is 5Mbits/s for NRZ code. The minimum transmitter clock period  $\Phi$  takes value 200 ns.

**Table 1.** Sampling frequency vs. number of bits M of the frame

M	J	T <sub>smin</sub> [μs]	f <sub>smax</sub> [kHz]
36	77	15.4	64.9
18	61	12.2	81.9
12	57	11.4	87.7
9	56	11.2	89.2
6	57	11.4	87.7
4	61	12.2	81.9
3	66	13.2	75.5
2	77	15.4	64.9
1	122	24.4	40.9

The Start-Stop technique with a 9-bit data frame is the most efficient method with respect to the data transfer rate but the maximum sampling frequency is still lower than the maximum assumed value of 100 kHz. The total time of transmission of the single measurement result takes 11.4 μs.

The maximum data transfer rate might be increased but with slightly worse synchronization. The successive complete A/D conversion results (denoted by number P>1) of N analog channels are linked sequentially in a defined order to set one Macro-Block. The "Silence" points to the beginning of the followed Macro - Block. The complete duration of the last A/D result of the previous Macro\_Block, "Silence" and the

first A/D result of the successive Macro-Block has to be shorter than or equal two sampling periods. If the duration of it is longer the sampling frequency might be disturbed. The L-bit data output of the single measurement ought to be also divided into short M-bit parts. The total number of bits J (5) must be lower than 100 for L=36, N = 3, f<sub>s</sub> = 100 kHz, 12-bit A/D converter and  $\Phi=200$  ns.

$$J = L/M * (M+2M) + 3 + L/M * (M+2) \leq 2 T_s / \Phi = 100 \tag{5}$$

**Table 2.** J vs. M for J=36

M	J
6	105
9	100
12	99
18	101

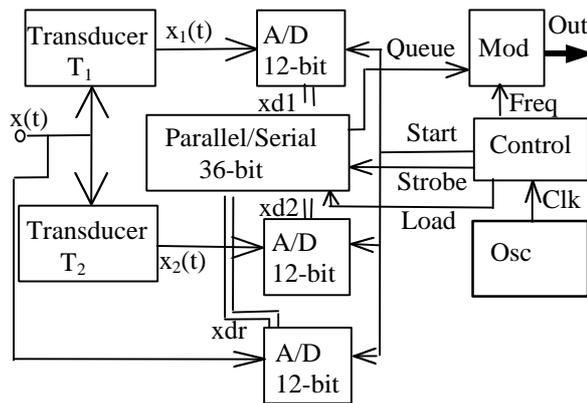
Table 2 presents the value of J vs. M for the considered case. The solutions of the formula (5) are M=9 or M=12. The data transmission may be considered as "hard real time" for these M and maximum sampling frequency f<sub>s</sub>=100 kHz.

The Start -Stop technique with MacroBlock gathering of data modulation is the most efficient for this measurement system although realisation of it is slightly complicated. For this solution the special FIFO memory of the transmitter is not needed.

#### 4 TRANSMITTER

The transmitter works in a stand alone broadcasting mode. This method of data transmission is resistant to the signal propagation delay and does not yield synchronization problems caused by different length of the cable connections. The delay compensation circuit is not needed. Digital data are sent throughout the single fiber-optic cable one by one. The modulator MOD controls the LED.

The Structure of the transmitter is presented in figure 2. Two A/D converters sample the output signals x<sub>1</sub>(t), x<sub>2</sub>(t) of analog transducers with maximum frequency up to 100 kHz. After that two 12-bit results xd1 and xd2 are transferred to the 36-bit Parallel/Serial shift register. Then this information is modulated and sent in a serial manner Out to the distant Receiver as an output signal. The Start-Stop asynchronous technique has been used for synchronisation the transmission of the whole word. The Start signal initiates the A/D conversion. The Load and Strobe signals perform the parallel load of the shift register. When the Load is inactive the contents of the register is shifted out Queue by the Strobe. The 12-bit A/D conversion result xdr of the reference channel is loaded to the register synchronously with xd1 and xd2.



**Figure 2.** Structure of the transmitter

## 5 RECEIVER

Figure 3 presents the structure of the receiver. It consists of the light detector Det which converts the information from light to the TTL standard. The slope detector SI\_D points to each rising or falling slope of the incoming signal. The control circuit Ctr\_R measures the duration of the silence as a time interval between successive slopes of the incoming signal. When the duration of the silence fits the assumed value, the Ctr\_R begins shifting of the incoming signal Dat into the Serial/Parallel register. The control circuit supervises the frame of the incoming signal. It links K successive frames into one L-bit A/D conversion result of each single sampling. This long word is formatted to the size which fits the data lines of the DSP System BUS.

Control circuit Ctr\_R generates the Irq\* signal when the appropriate L/M number of a stop bit occurs and the L-bit result is completed. The control circuit may neglect NN number of activations due to the number determined by the algorithm. The increase of the NN number slows down the effective sampling frequency if needed. Due to the Irq\* signal the processor is informed that the new measuring result is ready for reading. The reading operation must not disturb the serial shifting of the incoming data into the shift register. On the other hand, reading operation needs stable information in the shift register. „On the fly” reading of the shift register has been used to fulfil these contradictory requirements. The control circuit supervises also the result reading procedure. If the overrun error occurs the warning flag is set. If a frame error is detected or duration of the Silence is out of order the another warning flag is activated. The standard bus interfacing technique has been applied.

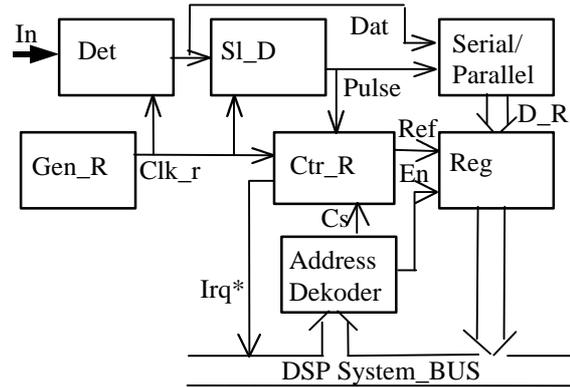


Figure 3. Structure of the receiver

## 6 TECHNICAL REALISATION

This system has been made and verified. Three MAX120 [3] chips have been used for digitization of the analog signals. Most of the digital circuits of a transmitter and receiver have been made using ispLSI LATTICE chips [4]. The TTL technique is not useful for this purpose. The BUS buffers, integrated clocks and transmitter LED driver have been applied as separate digital chips.

The standard low cost fiber optic transmitter and receiver of the Hewlett-Packard X4XX series [3] have been used for the long distance (up to 3 km) data digital transmission with the rate up to 5 Mbit/s.

For a laboratory purpose the transmitter is supplied by a rechargeable battery. For industrial applications special supply circuits (e.g. photovoltaic) are needed.

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