Integrated Digital Control

Test Report

SYTRL400

October 2006

IDC 2000 PLC Modem Characterization

Introduction

The aim of the communication test is to study the reliability of the Power Line Communication (PLC) using the modem embedded in the IDC2000 by using the transceivers in the wall control and the ballast reference designs of Systel's Lighting Evaluation Kit. The aim of the present test is to find the minimum permissible signal level at the receiver input as a function of the interfering noise at the required Bit Error Rate (BER). The test therefore consists of three parts:

- determination of the PLC receiver sensitivity without line noise influence
- determination of BER for the Ballast receiver depending on the lamps' light level and power consumption
- determination of BER as a function of on-line noise level

The receiver's absolute sensitivity may be defined as a minimal signal level, which supplies communication with an admissible BER - error probability. A main factor that increases the BER is the spurious internal noise of the end-product power circuit in which the receiver is implemented. This internal noise is mainly a result of the power switching elements of the product (auxiliary power supplies, PFC, DC/AC stage, etc.) in general and the ballast and wall control board of the evaluation kit in particular. This switching phenomenon may jam a communication signal and even reject it, and as is well known, it depends on the power switching strength and especially the design of the power and controller circuit, the board layout, disposition of the components, etc.

Background

1. Input Signal Measurement

Taking into account a rather low level of internal noise, as was achieved in the design of the evaluation kit boards, the expected minimal signal level would be low (in the 2-10mV range). This would complicate accurate measurements because of the influence of outside interfering noise. On the other hand, the transmitter output signal typically has a relatively high level: 1V or 2V; thus we must apply a variable attenuator in the test set up to achieve the required input signal values. This provides a side benefit: avoidance of noise influence and an increase in measurement accuracy. We can measure a high-level output signal, which is a thousand fold higher than the noise level, and then divide the result by the attenuator's coefficient. The noise influence would be negligible in this case.

Figure 1 illustrates the above statement. The oscilloscope screenshot shows the measured results V = 1.868 V rms of the transmitter output signal (channel 4) and the same signal after the attenuator with an attenuation of 46.5 dB – V = 10.39 mV rms (channel 3).

According to our calculation, we should have a signal of 8.8 mV after the attenuator. Thus, we get a measurement error of about 1.4 dB.

Taking into account that an S/N variation of only 1 dB changes the BER by almost one order of magnitude, therefore, the error of 1.4 dB in the signal measurement is inadmissible in our tests.

Therefore, a precision attenuator with acceptable accuracy is deployed in this case. The Attenuator and Mixer used in the tests were additionally calibrated to define their setup tolerance.

In the test the LeCroy Digital Oscilloscope Waverunner-2 was used in the voltage rms measuring mode to record the transmitter output signal. The "Tx enable" signal was used for synchronizing. This allows measurement of one transmitted data packet rms voltage.

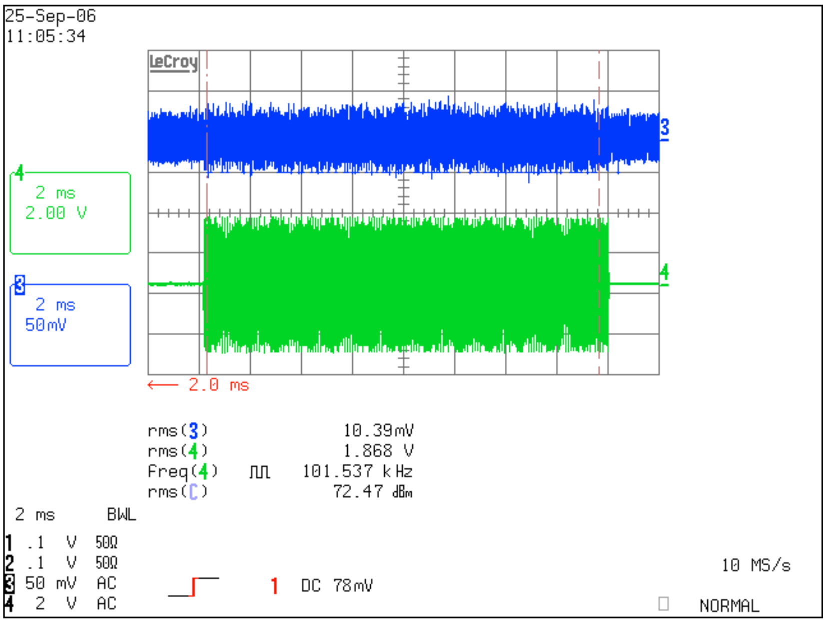

Figure 1

2. Noise Level Measurement

BER measurements require an external tunable noise source such as Random-Noise Generator Type 1390-B (RNG).

As opposed to signal measurements, the noise measurements must be performed directly at the receiver input. All additional external noises will be measured together with noise generated from RNG in this case, and will not influence the overall accuracy of measurements.

The noise level should be measured in the signal frequency band (that is 91 – 116 kHz). The LeCroy Waverunner-2 in FFT averaging mode was used for these measurements.. The results in dBm were converted to voltage rm units

3. BER Measurement

Bit Error Rate is the relation between the number of incorrectly received bits and the total number of transmitted bits. It calculates the probability of errors in the communication channel. Hence, the BER measuring procedure consists of multiple transitions of random data, comparison with received data, detection, and counting incorrectly received bits, and the final calculation of BER. This procedure is repeated for several S/N ratios. The random noise from RNG is added to the receiver input signal in the Analog Mixer.

It is important to note that the expected BER lays in the $10^{-2} – 10^{-6}$ range, therefore the required number of transmitted bits must be in the $10^{4} – 10^{8}$ range in order to achieve acceptable accuracy. It is obvious that manual BER tests require too much time and in the case of BER 10^{-6} it is impractical. Systel designed the PLC Modem BER Test program for the BER test in order to automate it.

This PLC Modem BER Test program controls a transmitter and receiver via RS 232 communication ports. It performs the following functions:

- creates data to be transmitted over PLC communications
- transfers data packets to the transmitter over RS 232 port (COM 1)
- reads received data from the receiver over RS 232 port (COM 2)
- compares received data with transmitted data
- detects and classifies errors according to their multiplicity
- counts the error number of every class and total error number
- calculates BER
- calculates Command Error Rate (CER)
- displays calculation results
- creates report files

CER explanation: The IDC2000 PLC modem includes an error correction mechanism, which allows repairing one error and detecting two errors in a 16-bit code packet. Thus, such a class of errors is not fatal for communication. However, more than two errors per 16-bit packet cause undetectable distortion of transmitted data or commands. Hence, only such a class of errors has to be taken into account in CER calculations.

The PLC Modem BER Test program allows measurements of BER up to 10^{-8} in 15-20 hours.

The BER measurement requires special configuration of the receiver's IDC2000. In this configuration the IDC2000 does not execute commands which it receives from PLC input, in order to avoid an accidental interpretation of received random data packets as a command and its unwanted execution.

The error correction needs to be disabled as well; otherwise, the most probable 1-bit errors would be corrected and packets with 2-bit errors would be interpreted as not received packets. In spite of the fact that the receiver works with error correction in real situations and 1-bit errors do not influence its reliability, the information regarding the probability of 1-bit errors is very important in this test because it allows further calculation of the probability of errors of higher multiplicity. The probability of such classes of errors (more than two errors per 16-bit data packet) is very low and experimental determination of them requires too much time even when using the PLC Modem BER Test program.

4. BER versus Light Level Test

This test is performed in the same way as the previous test, but without injecting the additional noise from RNG. The PLC input is connected to the power line (switch is in “Line” position). The BER is measured for different input signal voltages and different lamp light levels controlled by the ballast evaluation board being tested. The lamp light level is controlled using the PC Light Controller program included in the evaluation kit before running the PLC Modem BER Test program.

Based on the measurement results we can determine the minimal permissible signal levels for the required BER in full range of lamp light levels.

Test Setup

Tests were carried out for ballast and wall control unit evaluation kit boards.

1. Equipment

Table 1lists the equipment used and functions tested.

Table 1

Equipment	Function	Implementation	Accuracy
LeCroy Waverunner-2	Measurement of: 1 Signal level 2 Noise level	All tests	
General Radio Co. Random Noise Generator 1390-B	Adjustable noise source	BER vs S/N test	
Attenuator PE7036-2	Signal attenuation in 0-80 bB range with 0.5 dB step	All tests	setup tolerance ±0.01dB*
Analog Mixer	Signal with noise mixing	BER vs. S/N test	transfer constant K= – 10 ± 0.02 dB*
Mains Transformer	Galvanic isolation of test boards from the mains	All tests	
Variac	Setup the supply voltage: 120 or 220 V	All tests	
Power Strip	Test boards connections to supply voltage	All tests	
Personal computer	Test management	All tests	

*Remarks: * measured before test performance*

2. Software

Software used and its functions are listed in Table 2

Table 2

Name	Function	Implementation
PLC Modem BER Test V. 03.03	BER test control	All tests
PC Light Controller V 14.01	Lamps light level control	BER vs light level test

Test Setup Block Diagram

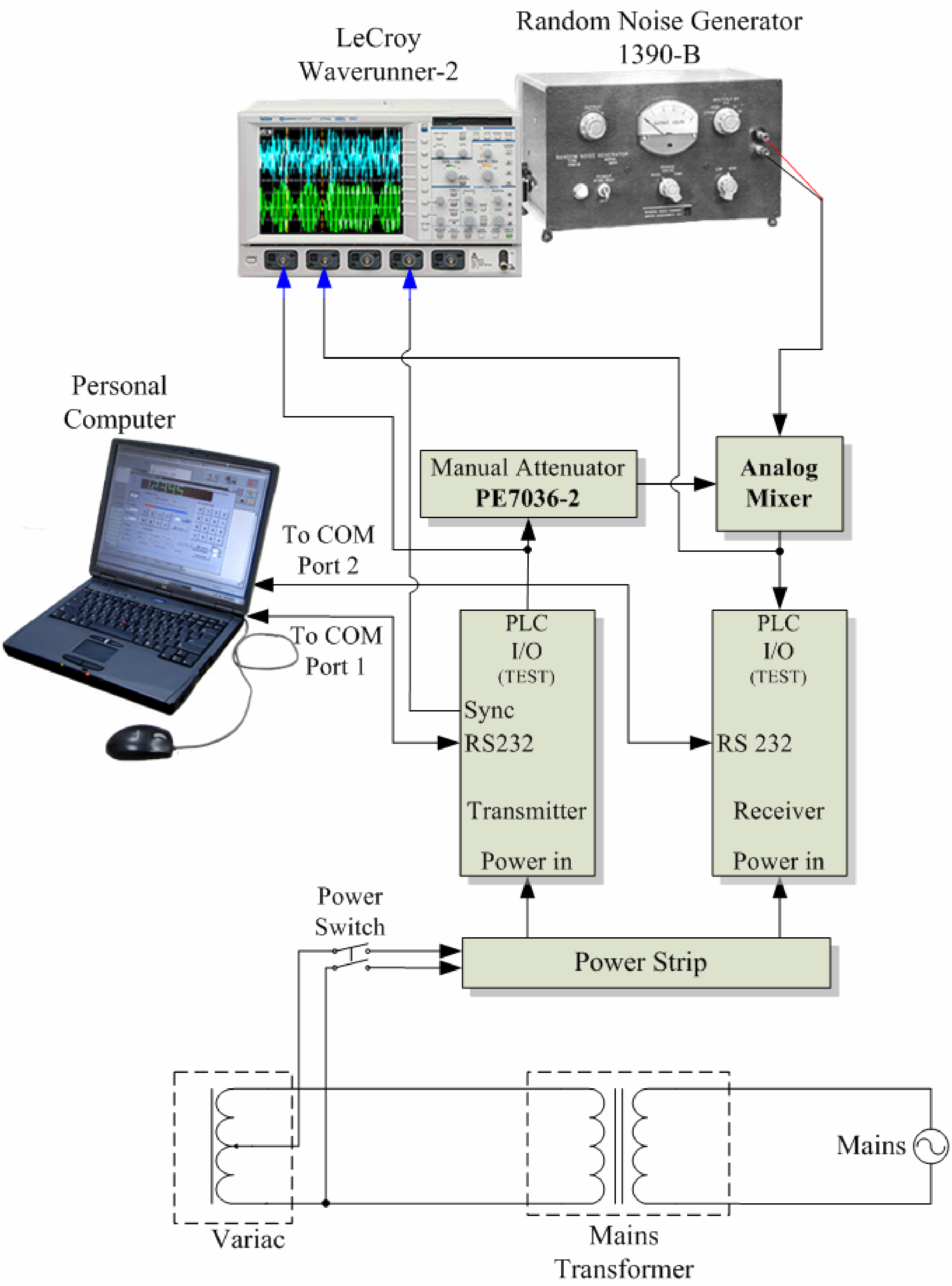

Figure 2

Figure 2 depicts the generalized block diagram for all tests. Here one can see the complete test setup and all connections needed to perform every test. The noise generator and mixer are used only in BER vs. S/N test, and may be excluded from other test setups.

The sensitivity and BER vs. S/N tests should be carried out in the following two circumstances:

- wall control board operates as transmitter, and the ballast as receiver;
- ballast board operates as transmitter and the wall control board as receiver.

Naturally, only the ballast board may be the receiver in the BER vs. Light Level test.

Both boards are connected to the supply voltage through the Mains Transformer and the Variac Autotransformer. The Mains Transformer provides galvanic isolation of the test boards and all test equipment from the mains. The Variac Autotransformer allows the supply voltage to be adjusted to the required level. This allows to study the supply voltage influence on the communication parameters.

The Personal Computer manages tests. It is connected to the test boards over RS 232 communication.

The manual attenuator adjusts the signal level to the required value. The analog mixer adds the noise from the RNG to the signal and creates a required S/N ratio.

The RNG produces the noise signal. The noise level is set up by its output attenuator and fine tuning handle.

The LeCroy scope provides all required measurements.

The first scope channel is connected to the transmitter output and measures voltage rms of transmitted data packets. The scope is synchronized by the transmitter's "Tx enable" signal (pin GPIO_C0 of IDC Module on the transmitter board) and the first channel is set to rms voltage measuring mode. Cursors are placed at the start and the end of the transmitting packet. The resulting measurement is indicated on the screen (see Figure 1).

The second scope channel is connected to the receiver input. It provides the noise measurements. Internal channel "A" measures the FFT of signal in the second scope channel, and internal channel "C" provides an averaging of the FFT from channel "A". Cursors "start frequency" and "finish frequency" are placed at 91 and 116 kHz respectively, i.e. at the coverage of the PLC signal frequency band. The PLC signal spectrum is shown in Figure 3. One can see that harmonics, which carry most of the energy, lay between these frequencies. The measurement results are output on the screen as rms of all points of the average spectrum curve between cursors (see Figure 4).

The result can be recalculated to noise voltage in millivolts by the following formula:

$$V_{noise} = 10^3 * \sqrt{10^{(P/10)} * 50 * 10^{-3} * N_P}$$

Where: V_{noise} – noise level (mV rms);
P – rms of noise power from start and stop frequency (dBm);
N_P – point number between start and finish frequency.

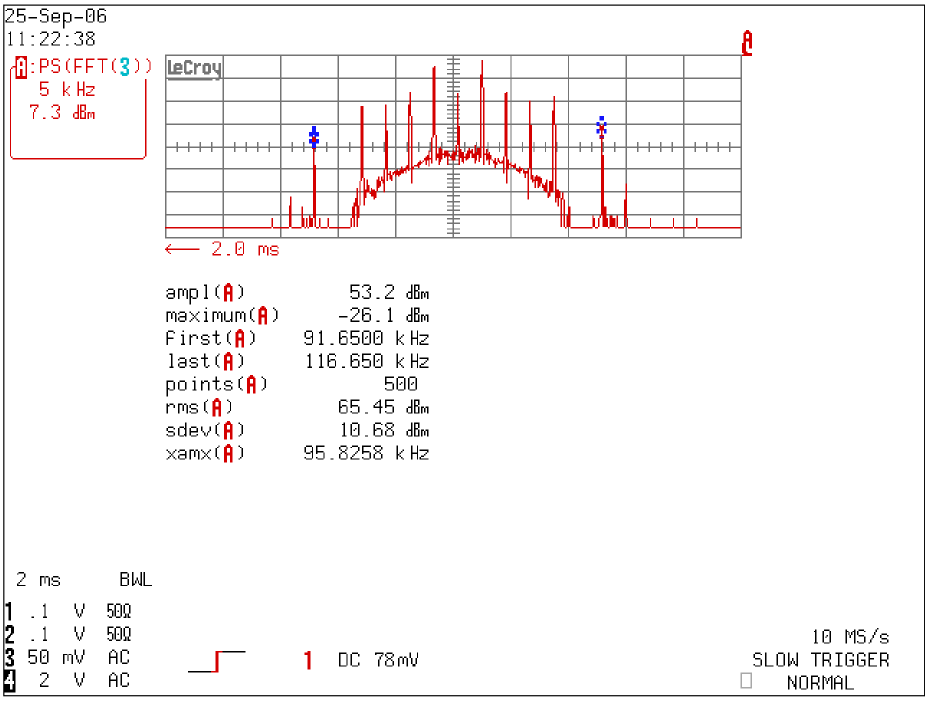

Figure 3

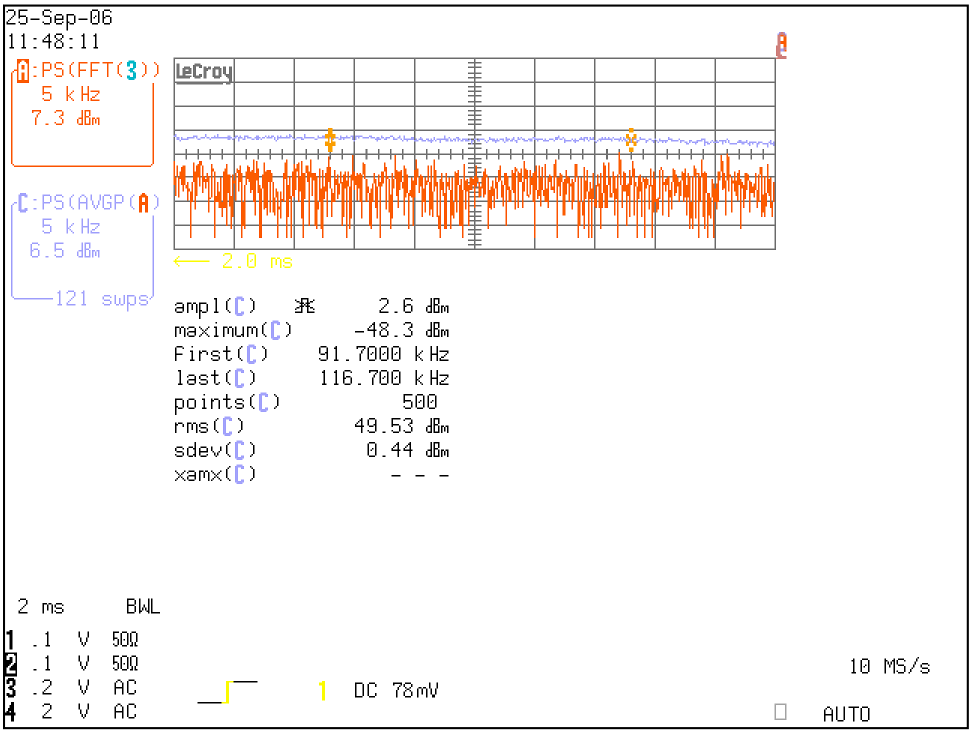

Figure 4

Test Results

1. PLC Receiver Sensitivity Test Results

The measurement results for the Ballast and Wall Control are presented in Tables 3 and 4 respectively.

- Vin is the voltage rms at the receiver input
- Transmitted bits is a total number of bits transmitted during the test
- Transmitted packets is a total number of 32-bit data packets transmitted during the test.
- Error class shows the number of groups of erroneous bits inside a 16-bit packet. There are two such packets in every 32-bit data packet.
- Total Er. Bits is a total number of erroneous bits during the test.
- BER is the relation Transmitted bits / Total Er. Bits.
- CER is the command rate.

Table 3

Vin (mV)		2.5	3.14	3.7	4.3	5
Transmitted bits		1548288	1701152	1132960	1463968	18732832
Transmitted packets		48384	53161	35405	45749	585401
Error Class	1	12074	5374	893	181	106
	2	822	142	8	3	0
	3	38	4	0	0	0
	4	0	0	0	0	0
Total Er. Bits		12074	5374	893	181	106
BER		7.8E-03	3.2E-03	7.9E-04	1.2E-04	5.6E-06
CER		7.9E-04	7.5E-05	0.0E+00	0.0E+00	0.0E+00

Table 4

Vin (mV)		2.4	3.1	3.8	4.4	5.1
Transmitted bits		1498304	1720256	1201888	1503488	18732832
Transmitted packets		46822	53758	37559	46984	585401
Error class	1	10074	4991	991	181	106
	2	792	201	8	3	0
	3	41	5	1	0	0
	4	0	0	0	0	0
Total Er. Bits		10074	4991	991	181	106
BER		6.7E-03	2.9E-03	8.2E-04	1.2E-04	5.7E-06
CER		8.8E-04	9.3E-05	2.7E-05	0.0E+00	0.0E+00

Figure 5 depicts a graph based on the results from the above tables.

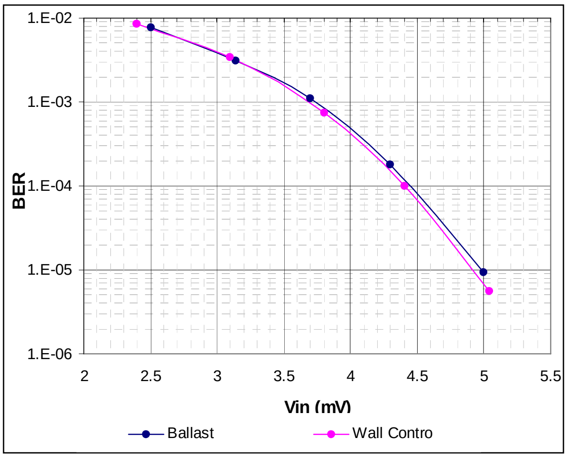

Figure 5

Based upon the test results it is possible to define the receiver sensitivity. Taking into account that for a signal higher than 4 mV a probability of three errors per 16-bit packet becomes negligible, we can define the sensitivity of both receivers to be about 4-5 mV.

2. BER vs. S/N Test Results

The measurement results for Ballast and Wall Control are given in Tables 5 and 6 respectively.

- Vin is the voltage rms at the receiver input
- N – scope data in db
- Points – the number of points between cursors
- N (mV) is the calculated noise level in mV rms
- S/N – signal to noise ratio
- Transmitted bits is the total number of bits transmitted during the test
- Transmitted packets is the total number of 32-bit data packets transmitted during the test
- Error class shows the number of groups of erroneous bits inside a 16-bit packet. There are two such packets in every 32-bit data packet. Classes of errors more than four per 16-bit block are not shown in the tables, because there were no such errors during tests.
- Total Er. Bits is a total number of erroneous bits during the test
- BER is the relation Transmitted bits / Total Er. Bits
- CER is the command rate

Table 5

Vin (mV)		18.1	19.17	21.51	24.13	27.08	30.38
N (dBm)		49.95	49.94	49.6	49.96	50	49.99
Points		501	501	501	501	501	501
N (mV)		15.92	15.94	15.94	15.90	15.83	15.85
S/N dB (dB)		1.1	1.6	2.6	3.6	4.7	5.7
Transmitted bits		745792	310528	383520	825760	1407323	14718208
Transmitted packets		23306	9704	11985	25805	43979	459944
Error class*	1	5721	1516	724	406	160	475
	2	341	59	3	2	0	0
	3	21	1	0	0	0	0
	4	0	0	0	0	0	0
Total Er. Bits		6466	1637	730	410	160	475
BER		8.7E-03	5.3E-03	1.9E-03	5.0E-04	1.1E-04	1.9E-05
CER		9.0E-04	1.0E-04	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Test time (h)		0.4	0.2	0.2	0.4	0.7	7.7

Table 6

Vin (mV)		16.22	18.2	22.91	25.43	28.85
N (dBm)		50.72	50.77	50.88	50.76	50.77
Points		502	502	502	502	502
N (mV)		14.6	14.5	14.3	14.5	14.5
S/N (dB)		0.9	2.0	4.2	4.9	6.0
Transmitted bits		1538908	1701152	1132960	1463968	17632832
Transmitted packets		48119	53161	36254720	45843	551255
Error class*	1	12351	5621	293	135	226
	2	945	156	6	3	1
	3	45	4	0	0	0
	4	0	0	0	0	0
Total Er. Bits		14376	5945	305	141	228
BER		9.34E-03	3.49E-03	2.69E-04	9.63E-05	1.29E-05
CER		9.4E-04	7.5E-05	0.0E+00	0.0E+00	0.0E+00
Test time (h)		0.8	0.9	0.6	0.8	9.2

Figure 6 depicts a graph based on the results from the above tables.

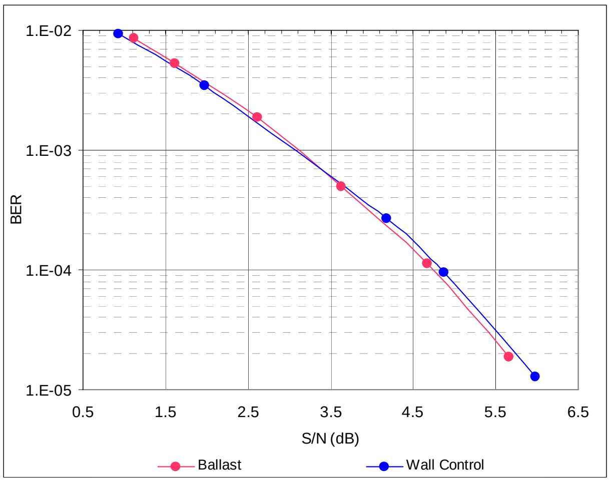

Figure 6

4. BER versus Light Level Test

This test is performed only for the ballast board. The additional PLC transformer winding is connected to the power line in order to emulate real conditions.

The test was performed for the signal level of 8 mV in order to obtain an acceptable BER which does not require a long measurement time. This level was found experimentally before testing. Yhr test results are given in Table 7.

Table 7

Light Level %	5	10	20	30	40	51	61	73	86	100
BER	5.9E-04	1.2E-03	1.8E-03	7.1E-03	1.2E-02	5.1E-02	2.2E-02	1.1E-03	1.2E-03	1.6E-03

Figure 7 depicts a graph of BER vs. light level based on test results.

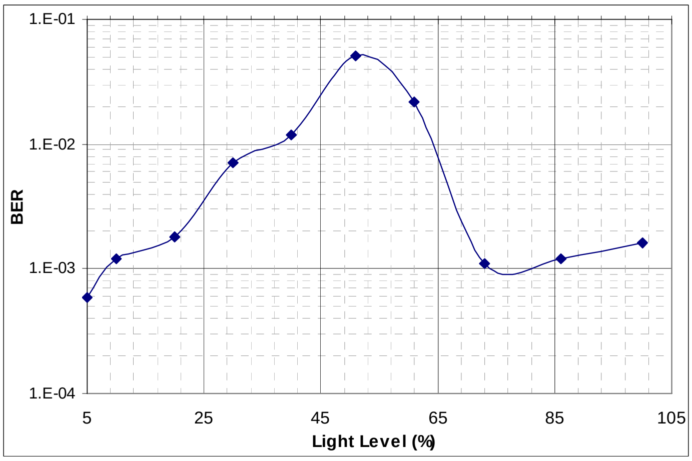

Figure 7

Test Results Analysis and Conclusion

The BER measurement results estimate PLC communication reliability and define a boundary condition for the required reliability. Reliable results are obtained only for 1-bit error probability. The measurement of other classes of errors is not reliable enough due to lack of sufficient statistics to supply an acceptable level of accuracy. However, it is possible to calculate the probability of these classes of errors based on the results received and using Bernoulli trials (2).

$$p(\nu_n = k) = C_n^k p^k (1-p)^{n-k} \qquad (2)$$

where: $p = BER$ – probability of 1-bit error;
$n = 16$ – bits number of error correction code block;
$k = 1 \dots 16$ – error multiplicity.

This should define the probability of all classes of errors. Tables 8 and 9 shows calculation results for Ballast and Wall Control boards respectively.

Table 8

BER		8.7E-03	5.3E-03	1.9E-03	5.0E-04	1.1E-04	1.9E-05
S/N		1.1	1.6	2.6	3.6	4.7	5.7
Error class	1	1.2E-01	7.8E-02	3.0E-02	7.9E-03	1.8E-03	3.0E-04
	2	8.0E-03	3.1E-03	4.2E-04	2.9E-05	1.5E-06	4.2E-08
	3	3.3E-04	7.7E-05	3.8E-06	6.8E-08	8.2E-10	3.7E-12
	4	9.3E-06	1.3E-06	2.3E-08	1.1E-10	3.0E-13	2.2E-16
	5	1.9E-07	1.7E-08	1.1E-10	1.3E-13	8.3E-17	9.9E-21
	6	3.1E-09	1.6E-10	3.7E-13	1.2E-16	1.7E-20	3.4E-25
	7	3.9E-11	1.2E-12	1.0E-15	8.5E-20	2.8E-24	9.1E-30
	8	3.8E-13	7.4E-15	2.2E-18	4.7E-23	3.6E-28	1.9E-34
	9	3.0E-15	3.5E-17	3.7E-21	2.1E-26	3.6E-32	3.2E-39
	10	1.8E-17	1.3E-19	4.9E-24	7.3E-30	2.9E-36	4.2E-44
	11	8.7E-20	3.7E-22	5.1E-27	2.0E-33	1.8E-40	4.2E-49
	12	3.2E-22	8.2E-25	4.1E-30	4.1E-37	8.5E-45	3.3E-54
	13	8.5E-25	1.3E-27	2.4E-33	6.2E-41	3.0E-49	1.9E-59
	14	1.6E-27	1.5E-30	9.8E-37	6.6E-45	7.2E-54	7.6E-65
	15	1.9E-30	1.1E-33	2.5E-40	4.4E-49	1.1E-58	1.9E-70

Table 9

BER		9.3E-03	3.5E-03	2.7E-04	9.6E-05	1.3E-05
S/N		0.9	2.0	4.2	4.9	6.0
Error class	1	1.3E-01	5.3E-02	4.3E-03	1.5E-03	2.1E-04
	2	9.2E-03	1.4E-03	8.7E-06	1.1E-06	2.0E-08
	3	4.0E-04	2.3E-05	1.1E-08	5.0E-10	1.2E-12
	4	1.2E-05	2.6E-07	9.5E-12	1.6E-13	5.1E-17
	5	2.8E-07	2.2E-09	6.2E-15	3.6E-17	1.6E-21
	6	4.8E-09	1.4E-11	3.0E-18	6.4E-21	3.7E-26
	7	6.5E-11	7.1E-14	1.2E-21	8.8E-25	6.9E-31
	8	6.9E-13	2.8E-16	3.5E-25	9.5E-29	1.0E-35
	9	5.8E-15	8.7E-19	8.5E-29	8.2E-33	1.2E-40
	10	3.8E-17	2.1E-21	1.6E-32	5.5E-37	1.0E-45
	11	2.0E-19	4.1E-24	2.3E-36	2.9E-41	7.4E-51
	12	7.7E-22	6.0E-27	2.6E-40	1.2E-45	4.0E-56
	13	2.2E-24	6.4E-30	2.2E-44	3.4E-50	1.6E-61
	14	4.5E-27	4.8E-33	1.3E-48	7.1E-55	4.4E-67
	15	5.7E-30	2.3E-36	4.5E-53	9.1E-60	7.6E-73

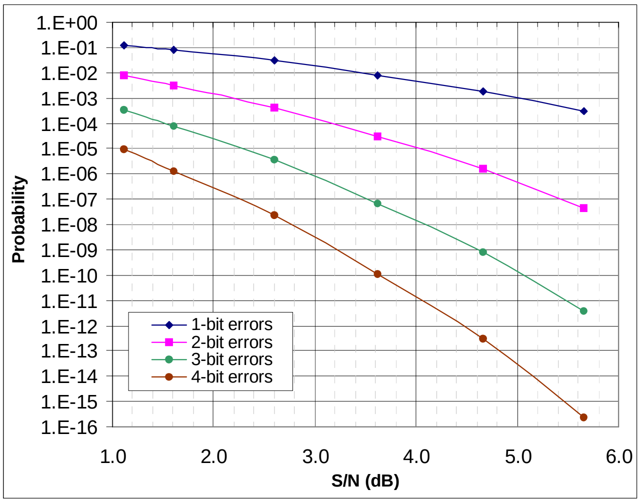

Figure 8

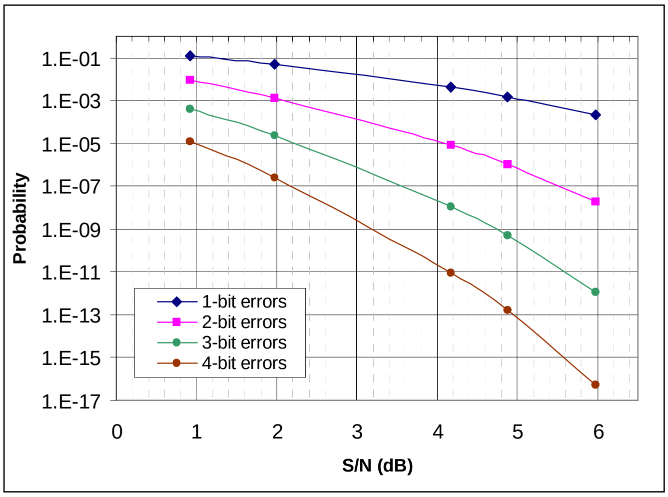

Figure 9

Figures 8 and 9 depict graphs, built on calculation results for the Ballast and Wall Control boards respectively. Only the probability of one, two, three, and four erroneous bits in a sixteen bit packet is shown on the graphs because the probability of other classes of errors is negligible. The performed tests confirm this fact very well.

One can see from the results, that even after S/N of about 4 dB the probability of non detectable errors (more than two erroneous bits in a sixteen bit packet) decreases to the value of about 10^{-8}, and after 6 dB it is negligible altogether (about 10^{-12}). The detectable double bit errors would happen no more often than in one of 10^{8} transmitted packets. However, should such a distorted data packet or command be classified as erroneous, the receiver will not send an acknowledgement and the transmitter will repeat this message. The error correction decoder corrects all single bit errors. Hence, these classes of errors may be ignored, despite the fact that their probability is rather high. Such reliability of communication may be considered as acceptable.

The results of the sensitivity test show that the receiver is able to work with input signal level of about 5 mV and supply the same reliability of communications as in case of S/N of 6 dB. In other words, we may conclude, that internal noise of both boards is less than 1.5 – 2 mV.

However, the results of BER vs. Light Level tests show that the Ballast board injects additional noise at light levels of 10 – 90%, which worsen its BER. The BER at light level of 40 – 50% corresponds to S/N of about 1 – 0.8 dB. This means that the noise level in the receiver frequency band is near to 8 mV. Hence, it is necessary to increase the minimal input signal level in order to achieve the required Ballast noise immunity, up to 16 mV.

Finally, we can define the sensitivity of

- Wall control board – 5 mV
- Ballast board – 17 mV (in the worst case scenario – 50% of light level).

The typical noise level in a power line at frequencies of 100 – 300 kHz is about 10 – 12 mV. Therefore, in order to supply S/N of 6 dB, the input signal should be about:

- 40 mV for the Ballast board
- 10 mV for the Wall Control board

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