Low-voltage power line broadband carrier communication signal detection based on eigenvalue analysis

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Abstract. In this paper, the eigenvalue analysis of the channel characteristics of low-voltage power lines is carried out, and the characteristics of impedance, signal attenuation and noise interference are studied. Based on the characteristics of China's power grid and the on-site measurement of power lines in residential communities and metalworking internships, the noise sources and corresponding noise characteristics of low-voltage power line networks are analyzed. Aiming at the characteristics of signal attenuation and interference on low-voltage power lines, which are complex, random, and time-varying, and difficult to describe with more accurate analytical or mathematical models, several anti-interference measures to improve communication quality are proposed: Data packet reorganization Adding a wave blocker, multipath receiving technology, spread spectrum communication technology, and adopting a standardized communication protocol, and applying it to engineering experiments, the practice proves that the measures used are feasible and effective.

1. Introduction
In a complex large communication network, the communication process consists of a series of communication nodes relaying each other. The performance of direct communication (point-to-point communication) of two adjacent nodes directly determines the communication performance of the entire communication network. Therefore, it is necessary to test and evaluate the performance of peer-to-peer communication. The performance of point-to-point communication is mainly reflected in the system error rate and system transmission rate. The bit error rate plays an important role in the communication system. Usually, the bit error rate can be obtained through theoretical simulation or through field test or laboratory test. The bit error rate can be used to analyze the communication performance of the system under the current channel environment, and provide reliable measurement indicators for system performance comparison and system improvement design.

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The paper analyses the channel characteristics of low-voltage power lines based on the field measurement results of power lines in a residential area and metalworking internship, and proposes corresponding anti-interference measures that can be taken when designing a carrier communication system. Due to the complete variety of electrical signals in the residential building, the high-power electrical facilities in the factory workshop are also relatively complete, so the selected measurement objects are considered representative.

2. Problems in power carrier transmission channels

2.1. Channel noise
This noise is the largest source of interference on the low voltage power line. There are many sources, such as narrow-band noise from power line standing waves, resonance and short- and medium-wave broadcasts; periodic noise from power-frequency synchronization of switching devices, motors and thyristors, and TV screens or computer screens. Periodic noise such as radiation and asynchronous to the power frequency. Impulse noise is also the main influence of the carrier communication system, mainly caused by lightning, sudden switch of electrical appliances, short circuit of power line, etc. It has the characteristics of large energy and concentration, wide frequency band, short duration, random appearance, etc. The carrier signal transmission has a great influence, which makes the bit error rate of the signal increase during transmission, and causes the receiver to correct the signal correctly, and may also cause self-interference of the receiver, which seriously affects the normal operation of the system [1].

Impulse noise is mainly composed of periodic impulse noise and non-synchronous impulse noise synchronized with the grid frequency. Non-synchronous impulse noise plays a leading role. It has strong randomness, concentrated energy, and wide spectrum. It is often short-time, high-energy pulse interference. Or pulse interference group, is the most difficult problem of PLC system, such as the disconnection of electrical switches, lightning strikes and so on. A lot of research and measurement must be done to find the time-frequency characteristics of the impulse noise. The pulse model of the impulse noise class is shown in Figure 2.
The parameters $t_{w,i}$, $A_i$ and $t_{a,i}$ of pulse $i$ are random variables. Zimmermann used statistical methods to approximate the research and measurement. The measurement results show that 90% of the pulse amplitude is 100-200 mV, and only about 1% of the pulse width exceeds 500 μs. 90% of the pulse interval is below 200 ms. Pulses with a pulse interval of more than 200 ms have an exponential distribution of intervals.

### 2.2. Signal attenuation

Due to the non-uniform distribution of the low voltage power lines, the impedance of the power lines is small and the impedance varies with signal frequency and time, the attenuation of the carrier signal is very severe. The attenuation of the low-voltage power carrier signal is usually relatively large, and can reach more than 20 dB, and the attenuation of the signal is also related to the transmission distance and the frequency of the signal: in general, the farther the transmission distance of the signal is, the higher the frequency of the signal is. The attenuation of the signal is also greater. Signal attenuation is difficult to accurately measure and establish a correct digital model. It is not easy to express with a simple numerical formula. It can only be calculated by statistical methods, which brings certain difficulties to system design [2]. Multiple measurements by Zimmermann M and Dostert K show that multipath reflection is the main cause of signal attenuation in the PLC channel. Considering the variation of input impedance and the influence of multipath effect, combined with weight, attenuation and delay, the expression of PLC channel model is as follows:

$$ H(f) = \sum_{i=1}^{N} g_i e^{-(\alpha_0 + \alpha_1 f^k) t_i} e^{-2j\pi ft_i} $$

Where $g_i$ is the weighting factor associated with the reflection and transmission coefficients on path $i$. The more transitions and reflections on a path, the smaller the weighting factor; $e^{-(\alpha_0 + \alpha_1 f^k) t_i}$ is
the attenuation caused by the power line, $k$ is the relevant parameter of the power line (such as the characteristic impedance and Propagation constant, etc.), the attenuation factor $\alpha$ is proportional to the length $l$ of the path and the $f$ frequency; $\tau_i$ is the propagation delay on the multipath path $i$ of the same signal, which is related to the propagation distance and velocity.

2.3. Multipath effect

Multipath effect is a kind of unique interference in digital communication, which refers to the phenomenon of mutual interference caused by signal delay when signals arrive at their destination through different paths. The equipment connected to the low-voltage power network has a large number and a variety of characteristics, and the impedance of the entire network is always in a dynamic state, which inevitably causes many power-consuming equipment to work in an impedance mismatch state. Since the signal experiences different times on each different path, a multipath effect occurs at the receiving point, and the delay of the signal interferes with the useful signal. This interference is negligible when the delay of the multipath signal is short; however, if the delay of the signal is long, very severe intermember interference (ISI) is generated for the wanted signal.

3. System design

3.1. Physical layer structure

At the transmitting end of the broadband carrier communication module, the MAC layer separately processes the frame control data and the payload data, and the generated protocol data unit is sent to the physical layer. The frame control data completes Turbo coding, channel interleaving and diversity copying, and the payload data is whitened, Turbo coded, channel interleaved and ROBO interleaved. After being input into the constellation mapping module, the output complex signal is serially converted and sent to the IFFT module. Converting to a time domain signal, then adding a cyclic prefix, and performing windowing processing, finally generating a physical layer burst frame into the analog front end, which is called a protocol packet data unit PPDU.

![Physical structure](image-url)

**Figure 3. Physical structure**

The frame control information and payload data from the MAC layer are processed by whitening, Turbo coding, interleaving, etc., and then sent to serial-to-serial conversion and constellation mapping. The output complex signal is mapped to subcarriers according to a prescribed rule to form 1,024. After the IFFT transform, the frequency domain data is inserted into the cyclic prefix and windowed to form an OFDM symbol, as shown in FIG. The cyclic prefix consists of a roll-off interval and a guard interval. The various processing modules required to generate the preamble sequence symbols, control symbols, and payload data symbols for the transmitting end are described in more detail below.
3.2. Physical layer module function and algorithm implementation

3.2.1. Whitening. When a sequence of length 0 or length 1 appears in a digital signal sequence, it is easy to lose the synchronization information of the signal and cause a wrong code. Whitening is a kind of statistical feature that does not increase data redundancy, disturbs the signal, changes the digital signal, and makes it similar to white. A signal coding technique for noise statistical characteristics [3]. The whitening sequence is generated by the linear shift register based on the m-sequence generator using the following formula (3):

\[ S(x) = x^{10} + x^{3} + 1 \]  

Each initial value of the shift register is 1, and each time one data is input, the shift register is shifted to the left by one bit, and the operation process can be illustrated by FIG.

3.2.2. Turbo encoder. A turbo encoder consists of a component encoder, an interleaver, a puncturing device, and a multiplexer. The Turbo coding in this paper adopts a quadratic iterative structure, taking the end state corresponding to the end of the first iteration as the initial state of the second iteration, and inputting the data for the second iteration coding. After two rounds of encoded output data, it has better error correction performance than the classic one-round coded output. At the same time, in order to reduce the redundancy caused by the coding, the verification information bit output by the encoder is punctured and deleted [4]. The encoding process of each submodule is described in detail below. The component encoders BMQ1 and BMQ2 use an 8-state encoder, and the first two bits of the input data stream are respectively mapped to u1 and u2, and are similarly encoded and encoded by two bits. In one encoding, each pair of bits corresponds to output one. Check Digit. The interleaving parameters are shown in Table 1.

| Physical block number of bytes | N value | M value | Double bit interleaves length L |
|--------------------------------|---------|---------|---------------------------------|
| 16                             | 8       | 8       | 64                             |
| 136                            | 34      | 16      | 544                            |
| 520                            | 40      | 52      | 2080                           |

The address mapping of Turbo interleave is defined as the following formula (4):

\[ A(x) = \text{mod}((S(\text{mod}(x,N)+1)-(\text{fix}((x)/N)) \times N+L),L) \]  

4. System test

4.1. Isolation and shielding

Broadband carrier testing requires isolation of power lines between shielded boxes to avoid interference from nodes in each analog station. The shielded box design and the power supply filter isolation used can reach 70 dB over the wideband carrier frequency range. All the boxes share the same power source, and the broadband carrier device is used to measure that the power lines between the two shielding boxes are completely unable to communicate, and the requirements for complete isolation of the power lines can be achieved. After filtering, the carrier conduction signal is greatly attenuated, close to the noise floor, and the filtering effect is good [5-6]. The power line carrier conduction signal curve is shown in Figure 4.
Since the broadband carrier signal has a frequency of 2~12 MHz, the spatial radiation cannot be ignored. Especially when the broadband carrier devices are too close together, they can communicate with each other through space radiation without physical connection, so the test system needs to be completely isolated. Shielding the space radiation signal between the cabinets. The shielding effectiveness of the low-frequency shielding box can reach 70 dB, which can completely shield the space radiation between the shielding boxes, isolate the communication interference between different carrier communication units, and provide a pure conduction and radiation test environment. The completely isolated platform and the infinity open space enable the controllable and controllable communication path through isolation and shielding to ensure accurate, consistent and repeatable test data [7].

4.2. Signal Matrix

The signal matrix is used for routing relay test and communication networking test in interoperability test, and adjusts the attenuation value of the signal matrix attenuator. The routing topology diagram of the actual communication unit can be obtained through the transparent transceiver unit and the query master node. In the actual test, the verification result of the broadband carrier communication unit of a certain company is as follows: the routing information table is queried by software, and the path relationship diagram of each node is drawn. When all the attenuator values are adjusted to 0, the stars of all the child nodes at the same level can be obtained. The topology map is exactly the same as the plan design. Set the 90dB attenuation at the interval node to form a tree topology. Modify the attenuation value of the adjacent nodes to set up as a multi-network topology, satisfying the tree network topology and the multi-network coordination test topology environment. The broadband carrier communication unit tree topology is shown in Figure 5 [8].
Figure 5. Broadband carrier communication unit tree topology

5. Conclusion
This paper focuses on the research of broadband carrier standard signal generation. With reference to the relevant standards of a power grid company, the system physical layer modular structure and signal generation process are designed according to the system's functions, parameters and design goals. At high speed FPGA/ADC/ The DAC hardware platform completes the function modules such as Turbo coding, interleaving, OFDM modulation, windowing and frame shaping, and introduces the technical details of the main module implementation in detail, and realizes the function of the physical layer transmitting end of low-voltage power line broadband carrier communication. At the same time, the paper introduces the hardware design method and key technology of the broadband carrier communication test system in detail, analyzes and studies the design difficulties, and verifies the feasibility of the scheme through practical application test, and meets the specification requirements of broadband carrier detection technology. The paper lays a solid foundation for the generation of broadband carrier standard signals, and provides a prerequisite for independent and objective detection of broadband carrier communication.

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