Performance Optimization Of Micro-Power Wireless Transmission Based On Hardware Test

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Abstract. Wireless communication system is more unstable than wired transmission due to the influence of transmission media. However, the micro-power transmission technology applied in the power system, the hardware parameter is more susceptible to various factors, resulting in unstable communication performance. By testing the RF parameter of transmitting and receiving signals of communication products in the laboratory, it can guide to optimize the hardware circuit and improve the communication performance of wireless transmission of micro-power, which has important reference value for hardware design.

1. Introduction
Wireless communication is a way of communication that uses the characteristics of electromagnetic wave signals that can be propagated in free space to exchange information. It has many advantages, such as flexible use, small capital investment, not limited by physical environment, and suitable for mobile use environment. In recent decades, communication technologies have developed rapidly, and all kinds of wireless communication technologies have also been updated iteratively, and they are developing towards the direction of faster transmission rate, higher spectrum utilization rate and higher energy conversion efficiency. With the application of more advanced modulation methods, the requirement for signal quality is also becoming higher and higher, including the power intensity of transmitted signal, modulation accuracy, receiver sensitivity and other indicators. [1-6].

In the application of power system, due to the large number of terminal users in the power industry and the complex use environment, the power management requires more and more data collection and transmission, and it is more and more difficult. At present, the new intelligent instrument represented by intelligent electricity meter has been vigorously promoted, among which the micro-power wireless technology used can quickly send the management command to the electricity information acquisition terminal, and feed back the corresponding information to the management center. Compared with wired transmission, it is an important means to overcome the complex electromagnetic interference in the power grid environment and the influence of the change of power grid structure. [7-12].

The definition of micro-power wireless communication technology is very wide. In general, as long as the communication is transmitted by radio signals and the transmitting power is controlled within a small range, it can be called micro-power wireless communication. Its application in power system has the following significant characteristics: 1. Relative to wired transmission, its transmission power is usually below 100mW (20dBm). It has the characteristics of low power consumption, and has significant advantages in radiation interference, heat dissipation, centralized miniaturization and other...
aspects. 2. The working frequency band is in the special frequency band of 470MHz-486 MHz. The use of this frequency band requires authorization from relevant departments, which can greatly reduce the situation of interference. 3. Adopt GFSK modulation mode, namely Gaussian frequency shift keying. This is a kind of modulation mode used earlier in information transmission. Its main characteristics are easy to realize, good anti-interference and anti-attenuation performance, and it is widely used in medium and low rate transmission. Moreover, due to the high receiving sensitivity determined by working bandwidth and modulation mode, it can reach above -100dBm, which is especially suitable for industrial remote control and remote meter reading industry. [13-16]

2. The design of the hardware in the system

2.1 Transmission circuit

The function of the transmitting part of the RF circuit is to raise the IQ signal generated by the baseband part, after one or two or even more up-conversion, to the RF signal frequency suitable for wireless transmission. It is then amplified by power amplifiers to increase the signal strength for long-distance transmission. In the actual device product, it will include clock crystal oscillator, phase locked loop, and more levels of middle and high frequency filter functional modules[13-16]. The principle block diagram of the transmitting circuit is shown in Figure 1.

![FIG. 1- Principle block diagram of transmitting circuit](image1)

2.2 Receiving circuit

The principle block diagram of the receiving circuit is shown in Figure 2 below. Firstly, the weak radio signals received from the air are converted into radio frequency electrical signals, which are connected to the Radio Frequency receiving circuit. Then, the signal intensity is amplified to the magnitude suitable for the mixer through a primary or secondary amplifier circuit. The mixer circuit then reduces the RF signal to the intermediate frequency signal, and divides it into two IQ channels for amplification respectively. After digital-analog conversion, the digital signal enters baseband circuit. In the actual circuit, the number of drive amplification and mixing will be increased or decreased according to the performance requirements.

![FIG. 2 Schematic diagram of receiving circuit](image2)
2.3 Transceiver circuits in actual products

In practical products, most components of the transceiver circuit are encapsulated in a radio frequency chip based on signal strength and industrial division of labor. This is conducive to the miniaturization of products, and performance can be more guaranteed. In a product, the RF and baseband parts of the micropower transceiver circuit, as well as the control function unit, are encapsulated in a chip device. The specific internal structure is shown in Figure 3 below.

![Block diagram of internal function of micropower transceiver chip](image_url)

FIG. 3 Block diagram of internal function of micropower transceiver chip

Its external pin can be classified into four categories: control and communication interface, power supply pin, clock pin, and RF input and output pin. The following introduction focuses on the performance of RF indicators, namely the input and output signals of TX and RXP and RXN. Through the measurement and analysis of its radio frequency index, to judge the communication performance, so as to further improve the product performance.

3. RF performance

3.1 Operating frequency and frequency deviation

According to the provisions in Sections 10.1.1 and 10.1.7 of DL/T 698. 44 -- 2014 Power Information Acquisition and Management System -- Part 4-4: Communication Protocol-Micropower Wireless Communication Protocol, the communication channel is defined in the frequency band 471MHz ~ 486MHz. A total of 33 channel groups are defined, each of which has two channels. Channel group is divided into two types: channel group No.0 is used for network maintenance (network channel group); Channel groups 1 to 32 are a category for applications such as meter reading (working channel groups).

In the laboratory, control the DUT (Device Under Test) to transmit in a certain channel, and then measure the emitted signal working frequency on the spectrometer. To protect the measuring instrument, a fixed attenuator may be added to control the signal strength. The test environment is shown in Figure 4.

![Connection diagram of transmitting signal frequency test](image_url)

FIG. 4 Connection diagram of transmitting signal frequency test
According to the relevant standards of the State Grid, the working frequency band range is 471.5MHz to 485.7MHz, with each channel spaced at 200K, a total of 64.

It can be seen that in the networking mode, each device needs to work within the agreed frequency range in accordance with a certain transceiver frequency and a certain working bandwidth. If the range is beyond this, the communication cannot be established and cannot work.

Combined with the practical circuit, the main consideration is the stability of the local oscillator signal used in the up-conversion mixer, as well as the performance of AFC Loop composed of PFD, Loop Filter, VCO, and divider[17]. According to the requirements in the State Grid DLT 698. 44-2014 standard, an error of 20ppm is allowed. The test frequency points are randomly measured according to the uniform distribution of the whole frequency band, and the test can be traversed through the whole channel if possible. During the test, the transmitting channel is controlled to work at a certain frequency point, then the RF interface is connected to the spectrometer, reasonable parameters of the spectrometer are set, and the actual emitted RF signal frequency is read out. The error value is converted into PPM to determine whether meet the State Grid standard, test standard and sample test results are shown in Table 1 below.

| channel number | channel group number | carrier frequency | carrier Frequency Offset | PPM | limit                  | result |
|----------------|----------------------|-------------------|--------------------------|-----|------------------------|--------|
| 0              | 1                    | 471.5 MHz         |                          | 4.2 ppm | -20 ppm ≤ E ≤ 20 ppm | Pass   |
| 0              | 32                   | 477.9 MHz         |                          | 2.1 ppm | -20 ppm ≤ E ≤ 20 ppm | Pass   |
| 1              | 1                    | 479.3 MHz         |                          | 2.1 ppm | -20 ppm ≤ E ≤ 20 ppm | Pass   |
| 1              | 1                    | 479.3 MHz         |                          | 2.1 ppm | -20 ppm ≤ E ≤ 20 ppm | Pass   |

Due to the index deviation of the device, if the frequency deviation is out of range, it needs to be corrected by calibration. The hardware designer will neutralize the discretization of device indicators by randomly sampling several or dozens of products in a batch of communication module products and taking the average value as the standard value, which will be written into the register inside the chip. In the future, the compensation value will be automatically transferred to the chip to ensure the accuracy of transmission frequency.

3.2 Maximum and minimum transmitted power

A significant characteristic of wireless communication is that the signal strength decreases exponentially with the increase of the space radiation distance. Specifically, the mathematical formula is as follows: Loss of free space =36.7+20|gd (km) + 20|gF (Mhz) - Gt-GR. Gt is the gain of transmitting antenna and Gr is the gain of receiving antenna[18].

It can be seen that transmission power is a key index in wireless communication. If the transmitting power is not enough, the signal strength sent to the receiver is not enough to demodulate normally. If the delivery signal is too large, the signal strength sent to the receiver will be too large, which will saturate the receiver signal and make it impossible to demodulate normally. According to the standards of state grid related protocols, the antenna radiated power (E. R. P) shall not be greater than 50 milliwatts (17dBm). At the same time, the minimum transmitting power should be less than -5dBm, and the power range should be satisfied in the whole working frequency band, and the error should be within 1dB. Test power points can be sampled at several fixed points or traversed all the way. Test standards and sample test results are shown in Table 2 below.
Table 2 Test values of transmitting signal power

| carrier frequency | set output power | real output | <1db |
|-------------------|------------------|-------------|------|
| 471.5MHz-485.7MHz | >17              | 19          | /    |
|                   | 16               | 15.6        | Y    |
|                   | 10               | 9.8         | Y    |
|                   | 4                | 4           | Y    |
|                   | -2               | -1.9        | Y    |
|                   | <-5              | -6.2        | Y    |

3.3 Stray radiation

Stray radiation is one of the important indexes to measure the performance of transmitter. It mainly considers the linearity performance of the transmitter. With the wide application of wireless communication technology, wireless spectrum resources are becoming more and more scarce. Each user is required to work only within their own agreed frequency range, beyond which other devices will be disturbed, known as noise. Both the electric power industry and the National Radio Commission have set guidelines for stray radiation. Taking the transmitting frequency point at 471.5MHz as an example, the test requirements and test results of a certain project are shown in Table 3:

Table 3 Measurement values of stray radiation of emitted signals

| frequency range       | limit     | stray test results |
|-----------------------|-----------|--------------------|
|                       |           | frequency (MHz)    | Power (dBm) |
| 30.0 MHz-48.5 MHz     | -36dBm    | 36.15625           | -78.3       |
| 48.5 MHz-72.5 MHz     | -54dBm    | 72.31875           | -70.62      |
| 72.5 MHz-76.0 MHz     | -36dBm    | 75.378125          | -93.06      |
| 76.0MHz-108.0MHz      | -54dBm    | 103.825            | -73.08      |
| 108.0MHz-167.0MHz     | -36dBm    | 162.725            | -61.39      |
| 167.0MHz-223.0MHz     | -54dBm    | 180.79375          | -71.76      |
| 223.0MHz-470.0MHz     | -36dBm    | 435.30625          | -52.71      |
| 470.0MHz-471.0MHz     | -54dBm    | 470.989375         | -42.52      |
| 471.0MHz-472.0MHz     | /         | /                  | /           |
| 472.0 MHz-566 MHz     | -54dBm    | 472                | -43.93      |
| 566.0 MHz-606MHz      | -36dBm    | 579.968            | -59.12      |
It can be seen that in the test results, there is an overshoot point near the operating frequency band. This is caused by the poor performance of the filter in the transmitting circuit, which makes the signal power outside the frequency range fail to decay rapidly, resulting in the out-of-band power exceeding the standard and interference. In addition, the second and third harmonic frequencies of the transmission frequency often exceed the standard, which is caused by the nonlinearity of the amplifier, so it is necessary to optimize the index by debugging the matching circuit of the power amplifier.

### 3.4 Receiving sensitivity

The receiving sensitivity is the most important index to consider the performance of the receiver. Poor sensitivity will directly lead to short transmission distance and unstable communication performance. Therefore, this index is the key concern item in the hardware test item. According to theoretical analysis, the formula of receiving sensitivity is: 

$$S_{in} = -174 + NF + 10\log B + 10\log SNR$$  

(NF: noise factor, B: signal bandwidth, SNR: demodulation signal-to-noise ratio) [19]; When the operating bandwidth and SNR demodulation threshold are fixed, the hardware circuit part can do is to reduce the NF coefficient of the receiving link. It includes the matching circuit of the receiving path to reduce the insertion loss through debugging, and the selection of low insertion loss and low noise factor devices in two directions. In the micropower technology, B is the working bandwidth of 200K, SNR is the demodulation threshold, and the sensitivity $S_{in} = 174 + NF + 10\log B + SNR = -174 + NF + 53 + 6 = -115 + NF$, and the unit is dBm. According to the requirements of DL/T 698.44 -- 2014 Power Information Acquisition and Management System -- Part 4-4: Communication Protocol -- Micropower Wireless Communication Protocol, the minimum signal energy that the receiver can demodulated reliably shall be less than -106dBm when the receiver’s bit error rate is less than 1%. In the actual product performance can achieve about -112dBm. The specific sensitivity testing environment is set up as shown in Figure 5 below.

![Connection diagram of sensitivity test](image)

**FIG. 5 Connection diagram of sensitivity test**

The sensitivity test results of an item are shown in Table 4

| channel number | channel group number | carrier frequency | receive sensitivity (dBm) | ≤-106dBm |
|----------------|----------------------|-------------------|---------------------------|----------|
| 0              | 1                    | 471.5MHz          | -112                      | Y        |
| 0              | 16                   | 474.5MHz          | -112.5                    | Y        |

*Table 4 Wireless micropower product sensitivity test value*
If this item fails, what the hardware circuit needs to do is to match and debug the circuit between the antenna port and the receiving port of the chip on the network partition, so as to achieve the optimal insertion loss and reflection coefficient between the two ends.

3.5 Receiving anti-interference suppression

When the receiver is working, in addition to receiving useful signals within the working channel range, it will inevitably receive interference signals outside the channel range.

These interference signals will reduce the sensitivity of the receiver and affect the transmission distance of wireless communication. This index is also stipulated in DL/T 698.44 -- 2014 Electric energy Information Acquisition and Management System -- Part 4-4: Communication Protocol -- Micro Power Wireless Communication Protocol. The suppression value of adjacent frequency interference signal is not less than 24dB. Test mode for adjacent channel interference source using PBRS9 number. Increase the output power of the signal source used for sensitivity test by 3dB(-103dBm), change the output power of the adjacent signal source until the received bit error rate is ≥0.1%, and calculate the difference between the output power of the two signal sources.

The anti-interference test environment is set up as shown in Figure 6:

![Figure 6. Receive anti-interference test connection diagram](image)

| Channel Frequency          | Test Value under Modulation | Limit   |
|----------------------------|----------------------------|---------|
| Adjacent channel frequency=471.5MHz | -28                        | -25dBC  |
| Useful channel frequency=471.7MHz | /                          |         |
| Adjacent channel frequency=471.9MHz | -30                        | 25dBC   |
| Adjacent channel frequency=485.3MHz | -29                        | 25dBC   |
| Useful channel frequency=485.5MHz | /                          |         |
| Adjacent channel frequency=485.7MHz | -30                        | 25dBC   |

The test standards and measured results are shown in Table 5 above.

Because the frequency of the jamming signal and the frequency of the working channel are very close, the filter on the hardware cannot distinguish the two. So, if this term doesn't pass, it will be optimized by software. [20]

3.6 The power consumption of the current

A good communication system, in addition to excellent RF performance indicators, also needs to have low power consumption current. The relatively small power consumption current represents the high
energy conversion efficiency of the system, which can save the consumed energy, and is also very beneficial to the life of the device and the heat dissipation of the equipment. This is not a mandatory requirement as an industry standard, nor is it restricted in the regulations of State Grid. However, as an important index to evaluate the performance of communication equipment, it is also a test item that needs to be paid attention to in hardware testing.

During the test, you need to pay attention to the current in transmit mode, receive mode, and standby mode. Among them, the transmission mode should be divided into different power levels, while the standby mode should clarify the functional units in the circuit to retain work. Such ability has contrast and reference value. Because the hardware design of each manufacturer is quite different, the measured current value result will also be quite different. It is not listed here.

In addition, hardware performance indicators including phase noise, spectrum templates, modulation frequency deviation, ESD and other items can represent the performance level of hardware circuits. It won't introduce it here.

4. Application instance

When the baseband circuit part and the frequency conversion circuit part are encapsulated in the chip, the design of the chip periphery will be equally important and will directly determine the communication performance. Take the hardware peripheral circuit of a product as an example:

![Peripheral circuit diagram of micropower transceiver chip](image)

In the transmitting path, the chip encapsulates the baseband, up-conversion, power amplifier, filter and other devices in the chip. The output is directly the high-power RF signal, but impedance matching is still needed to connect the peripheral 50Ω devices. On the receiving path, the chip encapsulates baseband, down-conversion, low-noise amplifier, filter and other devices in the chip. The differential input is beneficial to anti-interference and improve the signal accuracy. The periphery uses the Barron circuit, converts the difference into a single end signal, and connects with the peripheral 50Ω devices. The transceiver time division duplex approach determines the need to use a single pole double throw switch to switch the transceiver signal. The RF switch and antenna connector need to be matched to overcome the impedance mismatch caused by wiring on the circuit board.

In the hardware debugging stage, the micropower transceiver chip will be welded to the test board by making the test board, and then the peripheral design will match the device to simulate the working circuit of the actual communication module product. In the test board test stage, the network analyzer, high-precision power supply, oscilloscope and other instruments to debug the peripheral circuit. If necessary, register parameters inside the chip can be adjusted based on the observation and measurement data to control the chip output index. So as to achieve the performance requirements of the whole machine.

5. Conclusion

Under the background of the vigorous promotion of intelligent power consumption by the state, the construction of the China Power Internet of Things is further deepened, and new businesses and applications such as orderly charging, intelligent energy use, and integration of business and distribution are emerging in the power grid market. Under the guidance of the new demand, the technology of narrowband micropower wireless communication also develops rapidly. Micropower
technology has broad market prospects and great development potential in distribution automation, electricity information acquisition, intelligent energy use, distributed power supply, etc. By testing and debugging the hardware of micro-power wireless communication equipment, the wired and wireless signal performance indexes can meet the transmission demand. In this paper, the main rf test items of the equipment hardware are described, and the test standards and industry level are also introduced. It has certain reference value for hardware design of micro-power wireless transmission equipment in power industry.

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