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Research on Electromagnetic Environment Characteristic Acquisition System for Industrial Chips

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Abstract: With the system interconnection and intelligence of application scenario equipment, the electromagnetic environment of chips is becoming more and more complex. Problems such as communication interruption and data loss caused by electromagnetic interference often occur. The electromagnetic reliability of chips has become an important index to measure their availability. In order to effectively detect the electromagnetic reliability of industrial chips applied to specific scenarios, it is necessary to measure and analyze the electromagnetic characteristics of the application scenarios, as the boundary conditions of the electromagnetic protection simulation analysis and design of the chip, and to develop Electromagnetic Compatibility (EMC) test items, test limits and test methods suitable for carrying out tests and monitoring on chips. The paper presents an acquisition system, which can complete the collection of transient electromagnetic interference, steady electromagnetic field, temperature, humidity and near-field data. The transient interference measurement frequency range is 300 kHz–500 MHz, with a rising edge of 1.5 ns; the steady-state electromagnetic field measurement frequency ranges from 100 Hz to 3 GHz. By collecting the electromagnetic environmental characteristics of chips and analyzing situations in which chips are prone to interference, protective measures can be implemented.

Keywords: electromagnetic characteristics; industrial chips; acquisition system; near-field scan

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1. Introduction

Many achievements have been made in environmental parameter acquisition systems. For the collection of systems' electromagnetic environmental characteristics, domestic and foreign scholars have carried out a lot of research [1–4]. B Peng et al. designed an acquisition system for transient electromagnetic method (TEM) receivers using FPGAs to improve signal acquisition accuracy [2]. XP Yuan et al. proposed an acquisition and playback method for complex electromagnetic environments, which has practical value [5]. C Zhang et al. produced a temperature and humidity probe using a fiber optic sensor with high accuracy [6]. For research into electromagnetic characteristic acquisition systems, domestic and foreign scholars mostly use a combination of software and hardware [7,8]. LabVIEW 2021 has been widely used in the development of acquisition systems as a graphical programming environment [9,10]. Z Zhao et al. developed a real-time data acquisition system for the automotive industry based on LabVIEW, which can adjust the state of a vehicle and improve the real-time performance of data processing [11].

Before a power chip is put into use, the radiated emission of the chip needs to be collected to verify whether it meets the standards, and various reliability tests must be performed to ensure that the chip will not affect other chips or malfunction due to environmental interference. This test needs to refer to the electromagnetic interference level of the environment. The radiated emission of the chip belongs to the near field, and the electromagnetic interference of the application environment belongs to the far field. Currently, in the power field, people only focus on far-field acquisition and ignore the necessity of near-field acquisition. However, antennas are too large to fit into compact spaces. The acquisition system proposed in this article can complete near-field and far-field acquisition, more comprehensively evaluate the performance of chips, indirectly improve the reliability of chips, and save costs. By obtaining near-field data through miniaturized near-field probes and then performing far-field transformation, more comprehensive environmental electromagnetic characteristics can be obtained.

The electromagnetic characteristic acquisition system for industrial chips is utilized to gather, record, and process a diverse range of data pertaining to the actual operational environment of electronic equipment. This system provides essential data support for the subsequent replication of the electronic equipment's working environment within a laboratory setting, thereby facilitating the completion of comprehensive performance testing in said laboratory. The execution sequence of LabVIEW is determined by the way the data flows, rather than the order in which the lines of code appear, so that flow charts can be designed to execute multiple programs simultaneously. In man–machine interface design, the required control and data display objects can be selected from the control template. With the aid of the LabVIEW development environment, a range of instruments including an oscilloscope, spectrum analyzer, near-field probe, low-frequency probe, electromagnetic radiation frequency selector, and pulse-signal probe are uniformly deployed via an upper computer to comprehensively collect and process various data in the environment. After conducting comprehensive testing, the system is capable of accurately measuring and efficiently storing data related to temperature, humidity, low-frequency electromagnetic radiation, high-frequency electromagnetic radiation, and pulse radiation. Furthermore, it can effectively reproduce saved data in order to fulfill all test requirements.

The paper is organized as follows: Section 2 introduces the hardware composition of the acquisition system in detail. Section 3 presents a brief introduction to the software design of the acquisition system. Section 4 describes how to calibrate the acquisition system and its application. Finally, Section 5 concludes on the results and points to future enhancements.

2. Hardware Composition

When testing the performance of electronic equipment in the laboratory, in order to make the test results as close as possible to the actual working results of the electronic equipment, the laboratory testing environment should be as consistent as possible with the actual working environment of the electronic equipment. Based on the requirements of electronic equipment performance measurement, this paper studies an electromagnetic characteristic acquisition system for power-industry chips. The application environment of industrial chips includes not only the steady-state electromagnetic environment in the form of power-frequency electric fields and magnetic fields, but also transient electromagnetic interference caused by corona discharge, partial discharge, switching operation, lightning, static electricity, etc. As shown in Figure 1, external electromagnetic interference is coupled into the chip through cables and ports. Secondly, near-field coupling will occur between chips. These electromagnetic interferences can have a serious impact on the chip and even damage it. It is necessary to collect and quantify external and internal electromagnetic interference to analyze their impact on the chip.

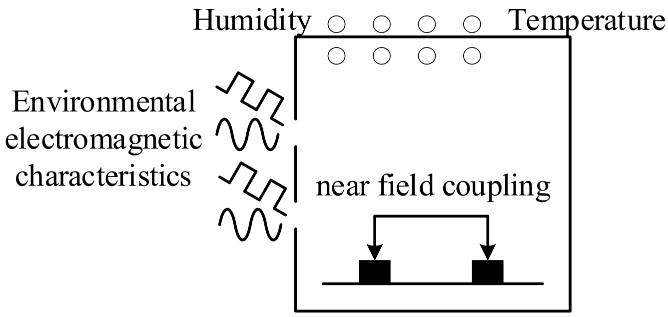


Figure 1. Industrial chip electromagnetic environment characteristics.

The electromagnetic characteristic acquisition system for industrial chips is developed and designed based on LabVIEW, which can be divided into a temperature and humidity measurement module, a low-frequency electromagnetic characteristic measurement module, a high-frequency electromagnetic characteristic measurement module, a near-field electromagnetic characteristic measurement module, and a pulse-signal measurement module. The low-frequency, the high-frequency, and pulse electromagnetic characteristic measurement modules constitute the application environment electromagnetic measurement module. The upper computer is capable of performing comprehensive scheduling for each module, as well as data acquisition, storage, and processing. Figure 2 shows the block diagram of the hardware composition principle.

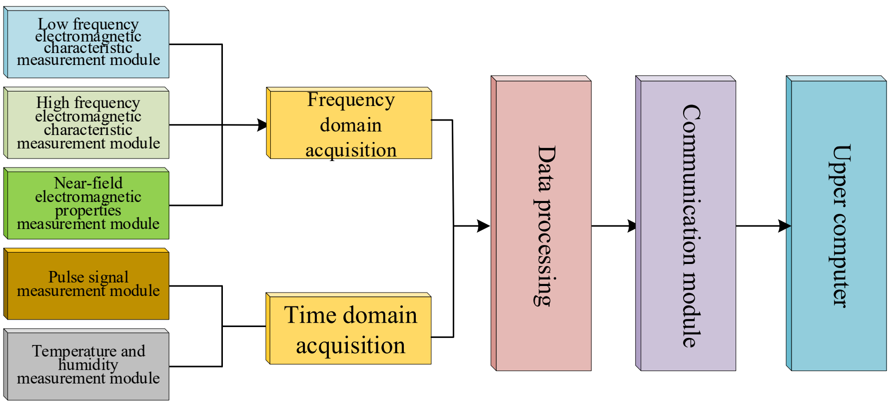


Figure 2. Hardware composition block diagram.

2.1. Temperature and Humidity Measurement Module

The electromagnetic characteristic acquisition system for industrial chips employs the HMP7 relative humidity and temperature probe to measure the temperature and humidity in the testing environment. The probe has the ability to measure relative humidity ranging from 0% to 100%, as well as temperatures between −70 °C and +18 °C. This makes it suitable for accurately monitoring temperature and humidity levels in a wide variety of electronic equipment operating environments. As shown in Figure 3, the EPHV5 transmitter is utilized to convert the measured relative humidity and temperature data from the probe, which is then connected to an upper computer for the complete display and storage of said data.

Figure 3. Relative humidity and temperature probe and Modbus RTU transmitter.

2.2. Application Environment Electromagnetic Measurement Module

Transient disturbances and transient overvoltages generated by primary equipment such as isolation switches and circuit breakers in power systems have a frequency spectrum ranging from approximately 0.1 to 200 MHz. Each pulse has a rise time of about 5 ns and a duration of about 50 ns. According to measurements of the radiated field of typical fast transient pulse groups in substations with voltages above 110 kV, conducted by CIGRE, the maximum transient electric field strength can reach several tens of kilovolts per meter. For the measurement of pulse electric fields, the pulse signal measurement module utilizes the JZHM-500-50 optical fiber pulse probe, as shown in Figure 4, which is capable of measuring pulse signals with a pulse width in the microsecond range, a rising edge of 3 nanoseconds, and a maximum amplitude of the test electric field reaching 50 kV/m [12]. Through the analysis of electromagnetic signal characteristics generated by high-voltage equipment, strong transient and high-field-strength signal acquisition is conducted, achieving the effective measurement of electromagnetic pulse signals with rising edges in nanoseconds and amplitudes at the kilovolts per meter level.

Figure 4. Pulsed electric-field probe and photoelectric converter.

The EHP-50F low-frequency electromagnetic radiation analyzer is used to measure the low-frequency electromagnetic characteristics of the environment. The low-frequency electromagnetic radiation analyzer can measure electromagnetic signals up to 400 kHz, maximum electric field strength of 100 kV/m, and maximum magnetic induction intensity of 10 mT, which meets the measurement needs [13]. EHP50-F cannot accurately measure electric fields exceeding 100 kV/m and magnetic induction intensity exceeding 10 mT.

The SRM-3006 electromagnetic radiation frequency analyzer is a receiver connected to a three-axis electric-field probe to measure high-frequency electromagnetic characteristics. The measurement range of the electromagnetic radiation frequency selection analyzer is 9 kHz to 6 GHz [14]. Equipped with a three-axis antenna, the analyzer can complete the three-dimensional omnidirectional measurement of the electromagnetic field and can be connected to the upper computer through the optical fiber interface or USB interface for remote control.

All the above devices transmit signals through optical fibers to prevent each transmission link from external interference and coupling between links. Finally, it is connected to the host computer through the optical fiber to the serial port and communicates based on the RS232 protocol. Before each measurement, the equipment is calibrated, and the calibration factors are saved in the system. During measurement, the system will read the calibration factor to correct the data to ensure the accuracy of the measurement.

2.3. Near-Field Electromagnetic Characteristics Measurement Modul

The near-field test is widely used as an important means to test the electromagnetic characteristics of electronic equipment [15]. As shown in Figure 5, electric-field probes and magnetic-field probes are used to measure the electric field and magnetic field characteristics of electronic equipment, respectively. The near-field electromagnetic characteristic measurement module consists of a near-field testing electric-field probe, a near-field testing magnetic-field probe, and a spectrum analyzer.

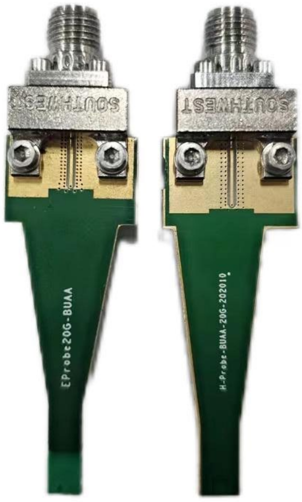


Figure 5. Near-field electric- and magnetic-field probes.

The structure of the near-field electric-field probe is evolved from the coaxial line, and the type of near-field coupling is capacitive coupling. During the testing process of the device under testing by the near-field electric-field probe, the current on the surface of the device under testing generates a time-varying electric field between the device under testing and the probe, which forms an induced current on the surface of the metal conductor through capacitive coupling. This current magnitude can be obtained from Equation (1), where $I(t)$ is the induced current, A is the system constant, C_d is the coupling capacitance between the electric-field probe and the device under testing, and $E(t)$ is the time-varying electric field between the device under testing and the probe.

$$I(t) = A \cdot C_d \cdot \frac{dE(t)}{dt} \tag{1}$$

The near-field magnetic probe is developed from the closed-metal-ring antenna, and its testing principle is Faraday's law of electromagnetic induction. During the testing process of the equipment by the near-field magnetic probe, the time-varying magnetic field on the surface of the device under testing forms an effective magnetic flux in the closed metal ring of the near-field magnetic probe and then forms an induced current. The electromotive force in the near-field magnetic probe consists of two parts, and the magnitude of the electromotive force can be obtained by Equation (2).

$$\oint \boldsymbol{E} \cdot d\boldsymbol{l} = -\frac{d}{dt}\int_S \boldsymbol{B} \cdot d\boldsymbol{S} + \oint_C \boldsymbol{B} \times \boldsymbol{v} \cdot d\boldsymbol{l} \tag{2}$$

The first term on the right side of the equation represents the induced electromotive force generated by the time-varying magnetic field on the magnetic-field probe. The second term on the right side of the equation represents the induced electromotive force caused by the relative motion of the magnetic-field probe in the magnetic field generated by the device under testing. In order to ensure the accuracy of the magnetic field test results, the first electromotive force should be increased as much as possible, and the second electromotive force should be avoided.

3. Software Design

The software of electromagnetic signature acquisition system for industrial chips is designed by LabVIEW. The overall view of the electromagnetic signature acquisition system for industrial chips is shown in Figure 6, and the corresponding modules can be selected for testing according to the measured requirements.

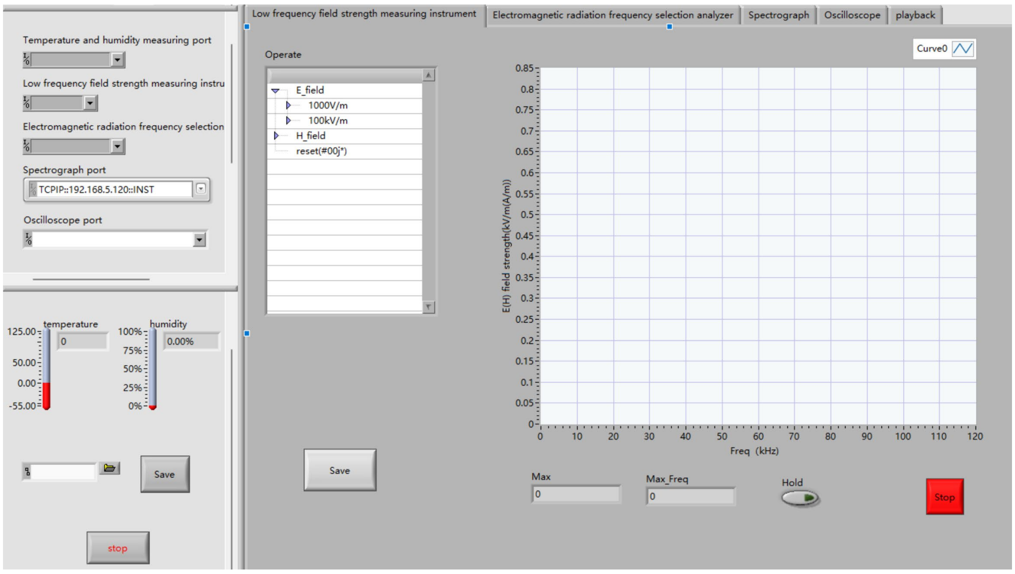


Figure 6. Overall view of the electromagnetic feature acquisition system for industrial chips.

In the upper left corner of Figure 6 is the serial port configuration interface. This acquisition system contains multiple receivers, corresponding to different serial ports. Multi-channel simultaneous acquisition is realized through multiple serial ports [16]. Changes in temperature and humidity can be observed in real time in the lower left corner. The right side of Figure 6 shows the control and display interfaces of different receivers. Through this interface, you can modify the measurement parameters, display the waveform or spectrum in real time, and save the data. Finally, historical data can be viewed in the data playback interface.

3.1. Temperature and Humidity Probe Control Module

The upper computer controls the probe to collect the relative humidity and temperature of the environment through the transmitter. The relative humidity and temperature probe measurement data are transmitted to the transmitter, and the transmitter processes the original data, converts the corresponding measurement value, and converts the analog signal into a digital signal for transmission to the upper computer for display and storage. The upper computer and the transmitter are connected in series through RS-485, following the Modbus communication protocol. The upper computer converts the 32 bit hexadecimal number transmitted by the transmitter into a decimal number and displays it in real time.

3.2. Application Environment Electromagnetic Measurement Device Control Module

During the test, the pulse electric-field probe is calibrated by the calibration pulse electric-field measuring system. The pulse signal measured by the probe is first converted into an optical signal, which is transmitted through the optical fiber for a long distance and then converted back to the electrical signal by the photoelectric converter, and finally transmitted to the oscilloscope for display. The pulse electric-field data are obtained by a remote-control oscilloscope. The upper computer can control the channel, time base, and recording length of the oscilloscope according to the measurement requirements. The measurement signal can be saved through the save function, and the save format is "tdms".

According to the electric-field intensity, magnetic induction intensity, and the frequency and amplitude of the electromagnetic signal to be measured in the upper computer, the corresponding measurement command is selected to control the low-frequency electromagnetic radiation analyzer for the corresponding acquisition and measurement. After receiving instructions from the upper computer, the low-frequency electromagnetic radiation analyzer will return data containing the electric- or magnetic-field values of the tested frequency band. The raw data returned by the low-frequency electromagnetic radiometer are a large-endian hexadecimal number of 870 bytes, and each set of numbers starts with FFFF. After receiving the FFFF command, the upper computer will store the data in the queue. After receiving the next FFFF, it will determine whether the queue contains 870 bytes and output the queue elements if the elements in the queue meet the requirements. The raw data need to be multiplied by the coefficient of the response according to the selected frequency band and the test-field amplitude to obtain the field value result of the corresponding frequency. The hold function can temporarily stop the measurement of the probe, and the save function can save the test results in a tdms file.

The upper computer is used to control the center frequency, reference level, bandwidth, and resolution of the electromagnetic radiation frequency selector to complete the electromagnetic performance test of the corresponding frequency band. The length of the data returned by the electromagnetic radiation frequency selection analyzer is different for the different width of the set frequency band, and each group of data is marked by "0;"as the stop character. The original data returned by the electromagnetic radiation frequency selection analyzer also need to be transformed into the actual measured field value after being processed and displayed in the upper computer. The measurement results can be saved in a tdms file with the save function.

3.3. Near-Field Electromagnetic Probe Control Module

The near-field electric-field probe and near-field magnetic-field probe are selected for the electromagnetic characteristic acquisition system of power chips. The test frequency is 9 kHz to 20 GHz, and the spatial resolution is 1 mm, which meets the measurement bandwidth requirements. Both the electric-field probe and the magnetic-field probe are connected to the spectrum analyzer and are controlled accordingly through the upper computer.

The probe first transmits the measured field value information to the spectrum instrument and then transmits the AD conversion through the spectrum instrument to the upper computer. The upper computer can control the starting frequency, termination frequency, reference level, scanning mode of the spectrum analyzer, and value of the peak point or fixed frequency point to record. The measurement signal can be saved through the save function, and the save format is tdms.

4. Calibration and Application of Electromagnetic Signature Acquisition System

4.1. Calibration of Electromagnetic Signature Acquisition System

To verify the performance of each module of the electromagnetic signature acquisition system for industrial chips, it is necessary to use a double-cone antenna, TEM chamber, pulse signal generator, spectrum analyzer, oscilloscope, and other equipment. The temperature and humidity probe controlled by the upper computer is used to measure the ambient temperature and relative humidity. The results are consistent with the actual results and verify that the temperature and humidity measurement module work properly.

A TEM signal of 0.1~400 kHz is generated in the TEM cell, as shown Figure 7, and the low-frequency electromagnetic radiation analyzer is used to measure the signal. The height of the TEM cell is 3 m, which can generate a standard electric field with a frequency range of DC-3GHz. Table 1 shows that the test deviation does not exceed 3 dB. The results are basically consistent with the actual results and verify that the low-frequency electromagnetic characteristic measurement module works properly.

Figure 7. TEM cell.

Table 1. The low-frequency electromagnetic radiation analyzer test calibration results.

Frequency (kHz)	Cell Input Voltage U (V)	Standard Field E (V/m)	Indicated Value E (V/m)	Deviation δ (dB)
0.1	15.06	20.1	23.28	1.3
0.2	15.04	20.0	23.44	1.4
0.4	15.06	20.0	23.58	1.4
2	15.09	20.0	23.43	1.4
10	15.05	20.1	23.62	1.4
70	15.02	20.0	21.42	0.6
400	15.05	20.0	20.97	0.4

The double-cone antenna generates a 27 MHz~3 GHz electric field in the semi-anechoic chamber. As shown in Figure 8, the three-axis electric-field probe to be tested is facing the biconical antenna. The electromagnetic radiation frequency selection analyzer, the receiver of the three-axis electric-field probe, and the upper computer are placed outside the semi-anechoic chamber. Table 2 shows that the test deviation does not exceed 3 dB. The results are basically consistent with the actual results and verify that the high-frequency electromagnetic characteristic measurement module works normally.

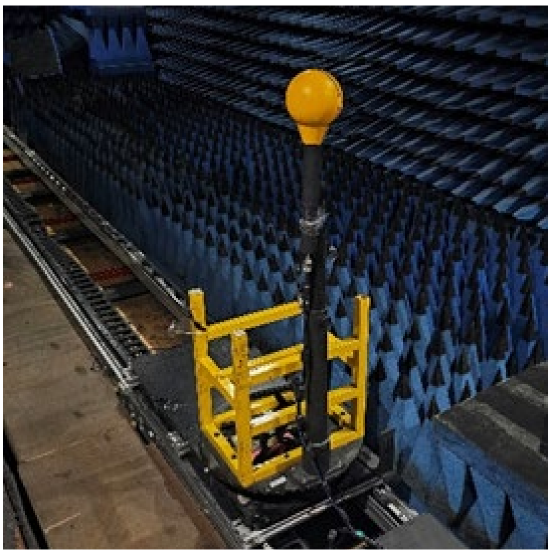


Figure 8. The electromagnetic radiation frequency selection analyzer test diagram.

Table 2. The electromagnetic radiation frequency selection analyzer test calibration results.

Frequency (MHz)	Input P (dBm)	Standard Field E (V/m)	Indicated Value E (V/m)	Deviation δ (dB)
27	22.60	19.9	21.22	0.5
40	22.58	19.9	21.51	0.7
60	22.59	19.9	20.85	0.4
80	22.58	19.9	20.50	0.2
100	22.58	19.9	21.51	0.7
200	22.58	19.9	20.83	0.4
400	22.54	19.9	17.41	−1.2
800	44.51	20.1	15.23	−2.4
1000	41.24	20.2	17.69	−1.2
2450	28.65	20.1	16.24	−1.9
3000	27.98	20.1	38.16	2.9

The pulse signal generator is used to generate the pulse signal, the pulse electric-field probe is connected with the oscilloscope, and the upper computer is used to control the oscilloscope to display and measure the signal results detected by the pulse electric-field probe. Figure 9 shows that the measured pulse front is about 1.29 ns, which meets the measurement requirements of pulse interference in the industrial field.

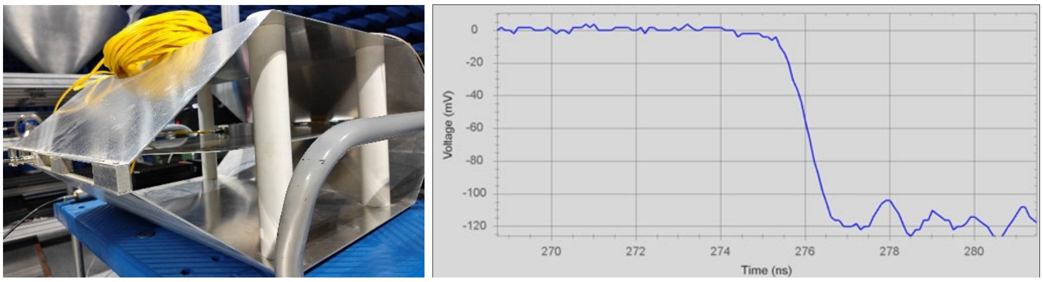


Figure 9. Transient electromagnetic signal test diagram and results.

As shown in Figure 10, the test board generates a signal with a frequency of 24 MHz, and the near-field probe is connected to the spectrum analyzer. The upper computer controls the spectrum analyzer to display and measure the signal results detected by the near-field probe. The results are consistent with the actual results and verify that the near-field electromagnetic characteristic measurement module works normally.

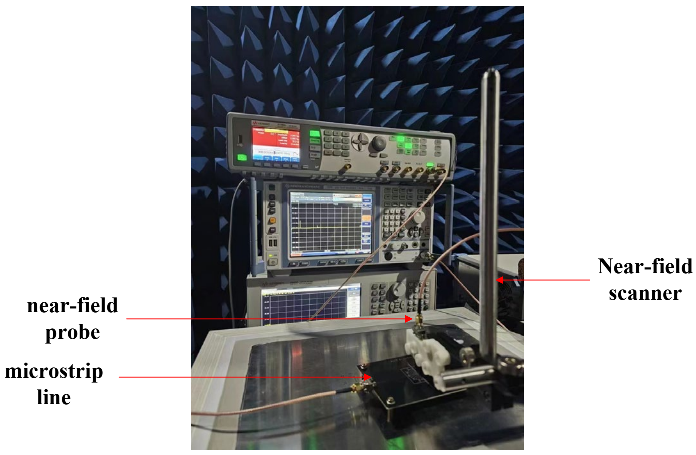


Figure 10. Near-field scanning diagram.

The electromagnetic signature acquisition system for industrial chips proposed in this paper has a wide measurement frequency range and a large dynamic range and can be applied to electric power, rail transit, and other industrial scenarios.

4.2. Application of Electromagnetic Signature Acquisition System

In Section 4.1, it is verified that the functions of the electromagnetic signature acquisition system continue to operate normally. Taking a high-voltage charging pile as an example, we collect its electromagnetic environment characteristics to provide data support for analyzing the reliability of the chip inside the high-voltage charging pile. Two probes in different frequency bands are used to cover the measurement range of 0.1 kHz to 3 GHz, as shown in Figure 11.

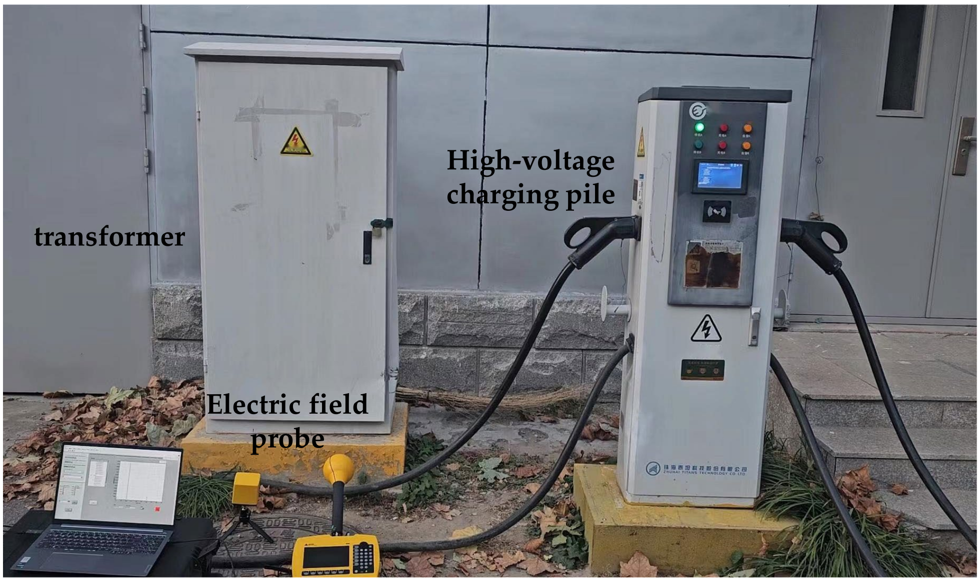


Figure 11. High-voltage charging pile field test diagram.

In the above acquisition process, what is collected is the discrete sampling value $x(nT)$ of the electromagnetic signal $x(t)$ in the environment. The discrete Fourier transform (DFT) needs to be used to obtain the spectrum, as shown in Equation (3).

$$X(k) = \sum_{n=0}^{N-1} x(n) W_N^{kn}, k = 0, 1, \ldots, N-1, W_N = e^{-j\frac{2\pi}{N}} \quad (3)$$

The fast Fourier transform (FFT) algorithm exploits the symmetry and periodicity of W_N, decomposing N-point DFT into N/2 two-point DFT. FFT is a fast operation method of DFT, which reduces the operation requirements and improves the operation speed. The electric-field intensity spectrum results collected by the high-voltage charging pile are shown in Figure 12. The probe can simultaneously measure the field strength in the x, y, and z directions, and the results in the graph are the combined field strengths from these three directions.

According to market regulations, during the charging process of high-voltage charging piles, the single-phase voltage fluctuation range is $\pm 15\%$. Voltage fluctuations will cause charging piles to radiate electromagnetic fields with higher frequencies and wider spectra. Figure 12 shows that the electric field strength radiated from the high-voltage charging pile can reach 17 mV/m at about 950 MHz. Therefore, chips used in charging piles must pay special attention to the anti-interference ability at the 950 MHz frequency point. In large power distribution stations and power swap stations, a probe location distribution strategy needs to be developed. In this demonstration example, there is no requirement for the position of the probe.

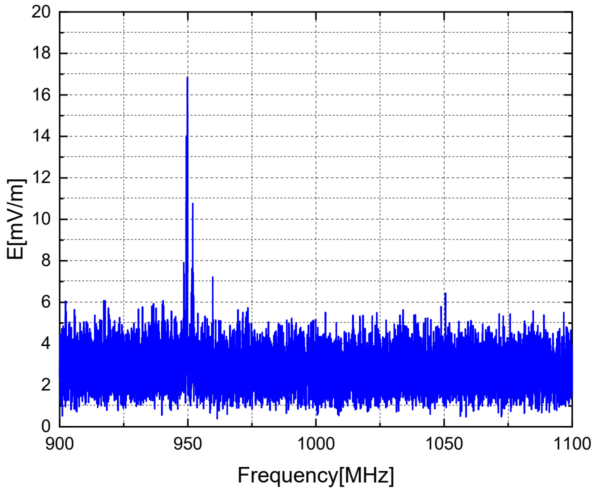
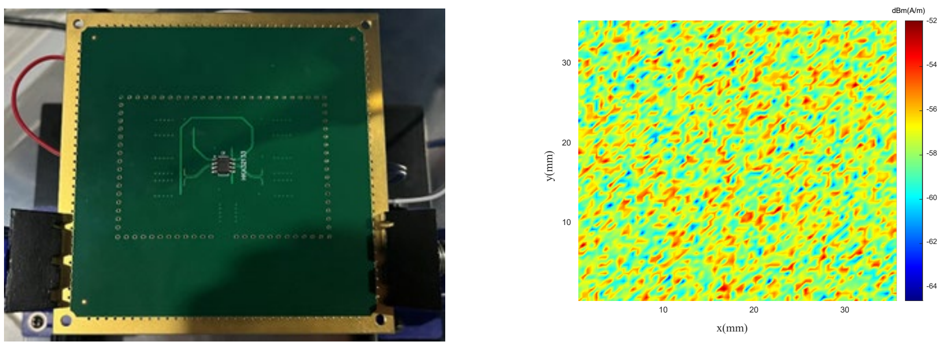


Figure 12. Electric field strength diagram of high-voltage charging pile.

Chip near-field acquisition requires a scanner to accurately control the movement of the near-field probe. Figure 13a shows the test board of the HKA32133 chip, which is used to observe the near-field conditions of the chip when it is working normally. The scanning area and the grid with the chip as the center are divided, where the scanning area is 35 mm × 35 mm and the grid area is 1 mm × 1 mm. The scanner is used to move the near-field probe to 0.5 mm above the chip, and then, it is moved within the scanning area in 1 mm steps. The upper computer controls the spectrum analyzer to display and measure the signal results detected by the near-field probe. Figure 13b shows the field strength distribution at 0.5 mm above the chip, and the radiation of this chip is relatively low. The result is also helpful for locating interference sources and provides a reference for subsequent circuit rectification.



(**a**) (**b**)

Figure 13. Near-field acquisition: (**a**) HKA32133 test board; (**b**) field strength distribution.

5. Conclusions

The collection system proposed in this paper can be used to measure the complex electromagnetic environments in industrial chip application scenarios, extract electromagnetic characteristic parameters, and analyze the electromagnetic environment characteristics of and variations in chips under multi-factor conditions. The acquisition system has a low rising edge and can measure the transient interference accurately. The wide range of steady-state measurement covers low-power-frequency signals, which provides real and effective data support for subsequent industrial chip reliability analysis. The verification results are in good agreement with the design expectations. The electromagnetic signature acquisition system for industrial chips can collect many characteristics of the environment in which the chip is located, which is comprehensive and innovative, and can provide original data acquisition for the construction of the environment required for chip performance testing in the laboratory to meet the needs of chip testing. A further improvement to the acquisition system could be the use of wireless data transmission to prevent data from being interfered with by the external environment.

Author Contributions: Y.C., F.L. and J.G. provided research objects and financial support; F.Z. designed and set up the acquisition system, completed the system test and verified and wrote the paper. Z.Y. was responsible for the review and revision of the paper. All authors have read and agreed to the published version of the manuscript.

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Data Availability Statement: Data are contained within the article.

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