A self-check method used in complex electromagnetic pulse measuring system

FABAO YAN
School of Geosciences and InfoPhysics
Central South University
Lushan South Road No. 932, Changsha, Hunan Province
CHINA
Hunan Key Laboratory of Non-ferrous Resources and Geological Hazard Detection
Lushan South Road No. 932, Changsha, Hunan Province
CHINA
JIANXIN LIU
School of Geosciences and InfoPhysics
Central South University
Lushan South Road No. 932, Changsha, Hunan Province
CHINA
Hunan Key Laboratory of Non-ferrous Resources and Geological Hazard Detection
Lushan South Road No. 932, Changsha, Hunan Province
CHINA
CHUANGHUA CAO
School of Geosciences and InfoPhysics
Central South University
Lushan South Road No. 932, Changsha, Hunan Province
CHINA
Hunan Key Laboratory of Non-ferrous Resources and Geological Hazard Detection
Lushan South Road No. 932, Changsha, Hunan Province
CHINA
YANRUI SU
Institute of Optics and Electronics
Chinese Academy of Sciences
Guangdian Road No.1, Chengdu, Sichuan Province
CHINA
ljx6666@126.com, hjc-8555@hotmail.com

Abstract: -In order to meet the self-check requirements of the non-standard complex electromagnetic measuring system in the using process, we put forward a self-check scheme with low power consumption, high precision and being simple to design, starting with the analysis of self-check signal characteristics, through research and comparison with several existing self-check mechanisms. We designed a set of implementation circuit based on the scheme and did simulation to the circuit. The simulation results show that a range of 20uV~2V self-check pulse signal ,whose frequency range lies between 1Hz and 100kHz, can be produced through selector switch. The frequency of the signal steadies at 1%, and phase stability is less than 1.5% through repeating test, as well as the amplitude error can be optimized to less than 1%. Stable harmonic component of the signal can be used to get wider bandwidth channel response for the measurement system. The experimental results show that actual power consumption of self-check model is less than 0.3W, and performance indicators are consistent to simulation results, while the amplitude is in the range of 20uv to 2V and frequency ranges from 1Hz to 100, 000Hz. And the scheme achieves success in applying for a monitoring system. The self-check model has the advantages of convenient operation, low cost and easy to design, so it can make up for the defect of other self-check modes effectively.

Key-Words: -Complex environment; Electromagnetic pulse; Data acquisition; Self-check signal; Low power consumption; CPLD; Analog switch

1 Introduction

In order to ensure the complete function and stable performance of the measuring system of some electromagnetic or power devices, the self-check procedures on the devices must be executed before using[1]. The traditional electromagnetic signal measuring systems commonly need to be input into the signals of generators to test its own function. As for the high-precision electromagnetic measuring systems, the high-accuracy signal generators will be helpful, such as the vector signal generator. And when it comes to the electromagnetic measuring systems with low demands, the signals generated by themselves can be applied for self-check, such as oscilloscope can generate 5V or 3.3V square waves for artificial self-check[2][3]. At present, the above self-check methods are with defects of inconvenient use, high price, low accuracy and insufficient bandwidth[4].

With the development of technology, in view of some complex electromagnetic environments, especially for the high-precision signal acquisition, it requires that the measuring systems should be with high precision and the resolution of the signals can reach the sub microvolt level. The methods that have mentioned are no longer to meet the requirements of function and performance indicators, especially under the circumstances of limiting the weight and volume in aviation and aerospace industries[5]. We proposed a high-precision, low-cost and convenient-use self-check method and circuit, which takes self-check of the non-standard electromagnetic pulse measuring system under complex environments as the research object. And simulation, testing and use were done for the practical circuit at last.

2 Self-check principle

Non-standard electromagnetic pulse measuring systems under complex environments, which are designed according to the actual environments and needs, are mainly used to measure parameters of the frequency and amplitude of the electromagnetic field. The self-check signals are required to be with high-precision, accurate frequency, as well as the consistent phase[3].

In the measuring system, we usually suppose $h(t)$ as the system response model, $f(t)$ as the input signals to be measured, $y(t)$ as the output signals. In the frequency domain, their relations can be expressed as:

$$H(j\omega) = \frac{Y(j\omega)}{F(j\omega)} \qquad (1)$$

If subdivide the self-check signals into different frequency bands, then we can get the corresponding response $H(j\omega)$ of the relevant frequency domains. The model parameters can be used to calibrate the measuring system. Do inverse transformation on Eq.(1) to obtain the real acquisition signals $f(t)$ at the actual use and realize the self-check function.

In order to get the accurate self-check frequency and phase, set $f(t)$ as self-check signal expression, which carries rich harmonic frequency square waves:

$$f(t) = A\Gamma(\omega t + \varphi) + n(t) \qquad (2)$$

Where A stands for self-check signal amplitude of the measuring system, Γ represents the function generated by square waves, ω is the angular frequency, φ is the initial phase, while $n(t)$ illustrates the noise. A 、 ω 、 φ are the key parameters to the self-check signals. The accuracy of A decides whether the measuring system can effectively reflect the measured electromagnetic signal information or not. The parameter ω reflects the response of the system on the frequency. The parameter φ shows whether all the testing channels are synchronous or not. The parameter $n(t)$ stands for the noise generated in the process of producing the self-check signals, which determines the quality and the repetitive degree of the self-check signals.

Therefore, in order to meet a variety of restrict requirements, frequency source with stable output, generators with precise signal amplitude and small channel noises generated by self-check signals are demanded, which requires to use as few devices as possible to satisfy the design of self-check system to reach the purpose of introducing as few noises as possible into the measuring system, under the circumstance of each parameter is qualified.

As is shown in Figure 1, in non-standard complex electromagnetic pulse measuring system, we designed a self-check signal module controlled by measurement and the process. The function of the module mainly consists of self-check power supply, signal control, self-check signal generation and self-check signal conditioning. The module is used to complete the self-check signal input with high precision and accurate frequency. In addition, input an analog selective switch between the sensor input and the signal conditioning module to complete the measuring conversion between the self-check signals and the signals that the sensor produces.

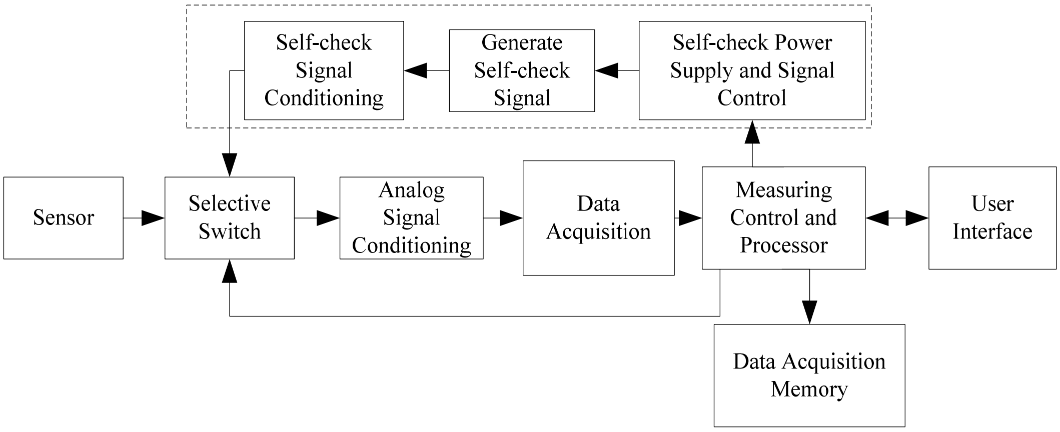

Fig.1 Principle of self-correction

The voltage peak of the self-check signal that we designed ranges from volt level to the millivolt level and even to the microvolt. So the self-check signal has a relative high precision and its frequency measurement generally reach dozens of Hz to hundreds of kHz, which is a wide frequency span. And sometimes in order to obtain the transfer function response of non-standard complex electromagnetic pulse measuring channel, harmonic measurement can be adopted.

3 Self-check model

Figure 2 shows the self-check model, which consists of the high-precision voltage reference circuit, SPDT(single-pole double throw) switch circuit, precise resistance attenuation selective circuit, signal of low-noise operational amplifier conditioning circuit, CPLD or FPGA and GPS. When self-check is required, the measuring control and processor control module switches off the sensor signal input and turns to select self-check signal input instead, i.e. the signal that has passed through high-precision resistance attenuation selective circuit is input into the non-standard complex electromagnetic pulse measuring system. GPLD/FPGA controls the switches of the power sources to supply the whole self-check module. In the mean time, it gets the precise synchronization and clock signal by receiving relative GPS signal[6]. Voltage converted by the power source is input into the voltage reference circuit to obtain a low-noise, low-temperature-drift stable voltage output. One pole of SPDT switch is connected to the ground, while another pole is input into the high-precision voltage reference circuit output. CPLD/FPGA controls the SPDT switch and the square wave output signals can be achieved with required frequency. After the attenuation of the precise resistance attenuation selective circuit and the conditioning of the low-noise operational amplifier conditioning circuit, a stable self-check signal source with high precision, accurate frequency and low output resistance is formed.

In order to make self-check signal frequency precise and all self-check signal phase consistent, the PPS signal and the 10MHz stable clock signal produced by GPS are very important. The rising edge of the PPS signal is used to trigger and do frequency division to the 10MHz clock signal to get the signal source with consistent phase and accurate frequency.

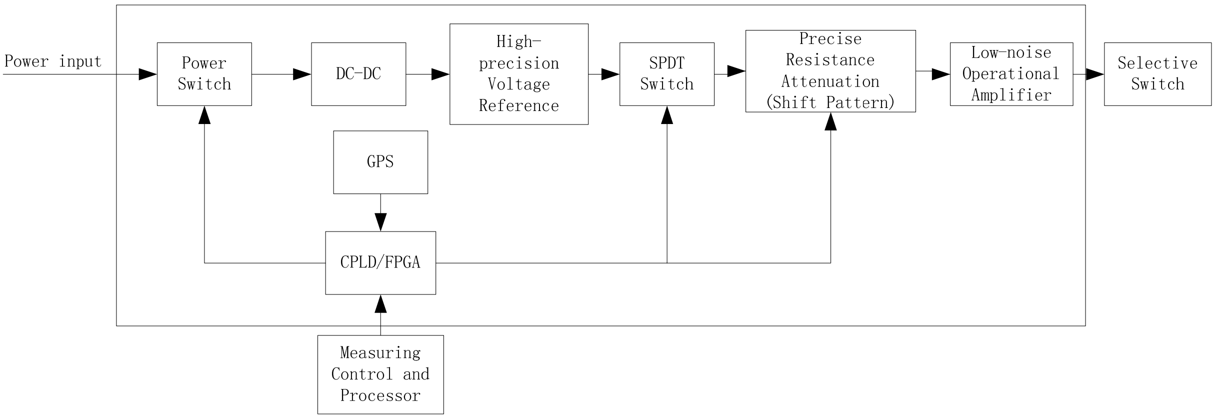

Fig.2 Model of self-correction

In Figure 2, self-check signal amplitude A is provided by the high-precision voltage reference, so the selection of voltage reference will directly influence the amplitude parameter index. The frequency ω is guaranteed by the clock signal provided by GPS, and CPLD/FPGA guarantees the phase coherence parameter φ . The noise of self-check signal generating system will be a sum of high-precision voltage reference, SPDT switch, precise resistance attenuation (Shift Pattern), and low-noise amplifier and selective switch modules. In the design process, the noises of high-precision voltage reference module and precise resistance attenuation module are within an allowable range, which can be ignored. The noises of switch and low-noise operational amplifier are the main consideration, so the voltage noise parameters of operational amplifiers should be as small as possible when we choose chips, and SPDT switches and selective switches should be with as small as possible parasitic capacitances, and good consistent on-resistances. In the design of the PCB, attention should be paid to reduce the parasitic capacitances and inductance, which can be used to reduce the high-frequency harmonic attenuation.

4 Simulation and experimental verification

Different components could be selected as Figure 2 during the designing, and the circuit diagram is shown in Figure 3. After omitting some conventional design like power source switches and Power converter, we select the high-precision and low-power voltage reference chip ADR5040 as the reference of the high-precision voltage. Generate a 2.048V voltage reference by the chip ADR5040, then access S1 feet of SPDT switch ADG819, and S2 feet is connected to the ground. The control pin of ADG819 is connected to the CPLD chip MachXO2-640-100 produced by Lattice company, and the control pin input signal belongs to square wave with 50% duty cycle, whose frequency is 1~100000Hz, which makes the output frequency of SPDT switch same with the input frequency of the control pin, while the output peak is 2.048V. By the attenuation array composed of analogue switch ADG1604 to select a proper attenuation factor, then the signal is sent to the amplifying buffer composed of low-noise operational amplifier ADA489801 after the attenuation. Here the values of R3, R4 are for enlargement factor setting. In the simulation, R3 is dangling and R4=10 Ω , which constitute a direct follower circuit. The capacitor C is for out-band filtering, which filters out the unwanted high-frequency signal. At last, the signal goes through self-check and signal selecting switch, which is composed of ADG819, to do a selection between regular test or self-check.

In order to ensure the consistency of the phase, using the timing principle, the 10MHz signal generated by GPS is ready, then do frequency division by 10MHz clock signal which is triggered through rising edge when next PPS signal arrive. At the same time, switch on all of the switching signal, and start to collect signals. So each phase error of the collected signal will be a sum of PPS error and 10MHz clock signal jitter error. Therefore, this way ensures consistency of self-check signal phases, as well as the stability of self-check signal frequency.

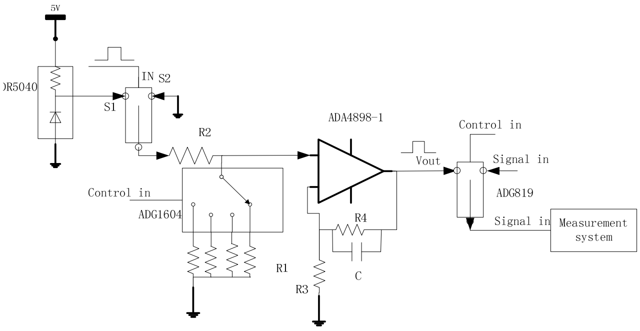

Fig.3 Simulation and the experiment circuit

Frequency selected in the simulations and experiments were 1Hz, 10Hz, 1000 Hz, 10000 Hz, 50000 Hz and 100000 Hz respectively, and attenuation factor selected were 1, 0.01, 0.001, 0.0001 and 0.00001. As shown in Figure 4, it there are waveform graphs obtained in simulation when the attenuation coefficients are 1 and 0.00001 respectively at the frequency of 100000Hz. This circuit mainly considers the bandwidth problem when the it is works at high frequency, so if the normal operation at 100000Hz can guaranteed, the bandwidth range circuit normal function and performance can be guaranteed. From the simulation diagram, we can know that shows that the frequency and phase is completely consistent, and the amplitude fluctuates about 2%,which meet the self-check testing requirements. By the way, we can see from the figure that the square wave waveforms are with good integrity, rising and falling edge is steep, and there are no overshoots and resonances, which means the harmonic can be used to do the tests.

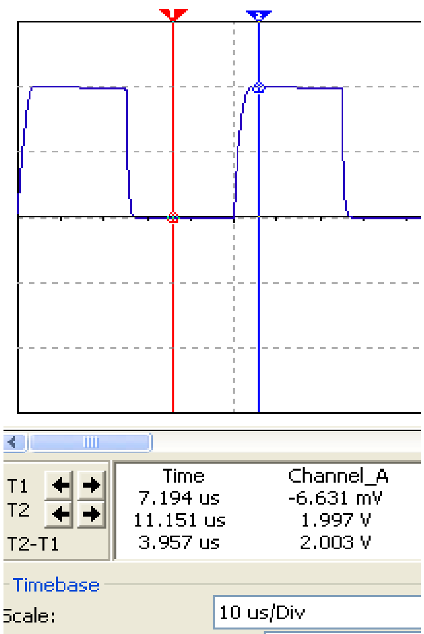

Fig.4 (a)The attenuation coefficient of 1

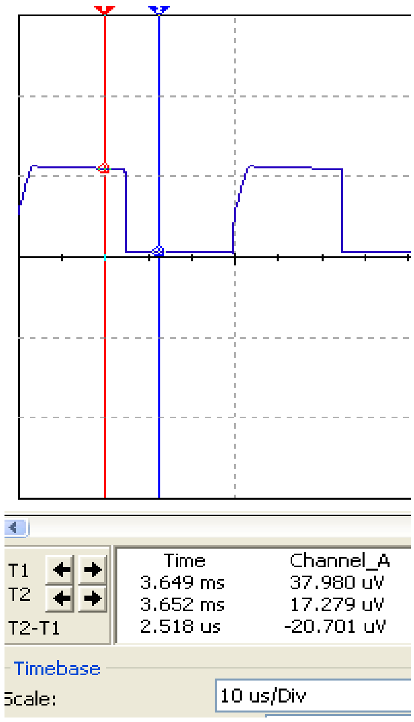

Fig.4 (b) The attenuation coefficient of 0.00001
Fig.4 Simulation results of 100000Hz

Table 1 shows the 10 times average values of frequencies, phases, amplitudes tested by oscilloscope, frequency meter, high-precision digital millivoltmeter, and 24bit or higher digit signal acquisition instrument under the effectively shielded environment. We can see from Table 1 that , the error is large when the attenuation coefficient is 0.00001, and the response parameters of the rest attenuation coefficients are satisfied for the system requirement. Because of the resistance errors, circuit internal noises and external coupling noises, signal amplitude is about 20uV parameter error which is slightly large, when the attenuation coefficient is 0.00001. In the project, the average values are usually regarded as effective value, which self-check can also effectively detect the circuit response of the electromagnetic pulse measuring system. After many times average, the phase errors are all within 150ns, and when the frequency is 100000Hz, the phase stability is the worst, which is 1.5%. Although the frequency meter itself also carries with error, according to the tested frequency value and the characteristics of the 10MHz signal that generated by self-check signal of the GPS clock source as shown in the Table 1, we can know that the frequency stability error is surely less than 1%. After the switch self-check module testing, the power consumption increased is 0.3W.

Table 1 Results of experiments

f/(Hz)	attenuation coefficient /(V)					frequency test /(Hz)	phase error /(%)
	1	0.01	0.001	0.0001	0.00001		
1	1.989	0.01987	0.001988	0.000198	0.000017	1	0.000003
10	1.995	0.01997	0.001996	0.000201	0.000018	10	0.00001
1000	1.994	0.01998	0.001998	0.000203	0.000019	1000	0.0012
50000	2.001	0.02010	0.002011	0.000202	0.000024	50000	0.5
100000	2.032	0.02023	0.002033	0.000206	0.000023	100000	1.2

We can see from Table 1, the indexes of the experimental results are much better than those of the ordinary signal generators, especially for the small signals, which cannot be generated by lots of signal sources. And compared with the high- precision signal sources, frequency stability index and phase consistency index are relatively higher.

5 Conclusion

Self-check techniques and methods on existing non-standard complex environmental electromagnetic pulse measuring system were studied. Based on the principle of non-standard complex environmental electromagnetic pulse measuring system, a model that self-check signal can be generated at any time were put forward and established. Self-check signal generating circuit is composed of high-precision voltage references, analog switches and low-noise operational amplifiers, which is selected basing on the self-check model. Theoretical analysis and simulation have been done to the circuit, and the GPS and CPLD are used to compose the clock and phase preserving circuit to complete a high-performance and low-power self-check circuit, which can be applied to the non-standard complex environmental electromagnetic pulse measuring system. The frequency range of the self-check circuit can be 1~100000Hz, and amplitude range can be 20uV ~2V. And the repeated measuring frequency stability, phase consistency and amplitude stability are all less than1.5%, which is superior to the conventional self-check signal sources obviously and can surpasses current high-precision signal generators on many performance indexes. This circuit has been successfully used in a monitoring system of a research institute for real-time self-check. In the project, anti-interference and noise reduction ability of the self-check model can be enhanced by using differential mode. And the circuit can be applied in multi-channel electromagnetic pulse measuring system or some high-power laser measuring system.

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