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Research on Measurement System of High-Frequency Parameters for Line Traps

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Abstract

The composing of high frequency line trap of power system is briefly introduced, A new method based on improved voltage meter method is presented, which can measure the frequency-impedance characteristic of the line trap of power system. A new testing arithmetic is presented based on the correlation principle, Cross-correlation functions of the two measured signals are directly computed and some properties about correlation and sine function are adopted to separate the useful signals from the part noises, so the measurement accuracy is improved, A group of practical formulas for calculating the impedance and resistive component is summarized, the MATLAB simulation of the arithmetic is presented. Using DSP chip TMS320LF2407 and A/D chip THS12082 as the core of the measurement system, its software and hardware are designed. Analyze the Given K-type broadband tuning traps which has typical parameters. Experimental results and theoretical analysis demonstrate the measurement system can obtain a precision of better than 1 %and has a good ability of anti-jamming.

Keywords: *line trap, arithmetic, correlation principle, DSP, Measurement system*

1. Introduction

High-frequency traps and coupling filter, line tuner and power lines constitute a power line carrier channel. Power line carrier (PLC) communication is still the important means of communication of the power system, which used in production scheduling、 high-frequency protection [1-3] and administrative contact, especially the high-frequency protection, which is still used as the main protection widely in power system. Line traps consists of strong current coil which can flow through power frequency current, the tuning elements and the lightning arrester which can protect the tuning elements. Figure 1 is the case of using in power system. According to the different blocking frequency, it can be divided into single-frequency traps, double-frequency traps and the Given K-type filter of broadening traps etc [5-6].

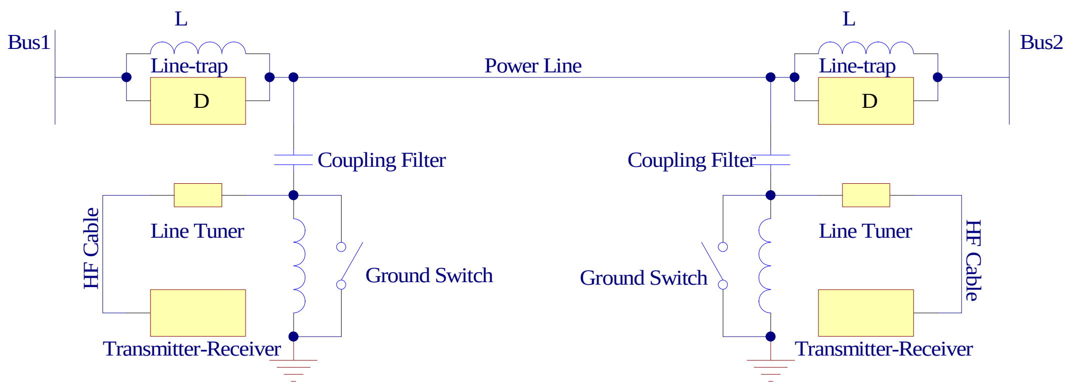

Figure 1. Power line carrier system constitution

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According to the provisions of the national standard of china GB / T7330-1998, the traps must be measured in blocking impedance and the frequency characteristics of resistive component in the period of installation and annual inspection. High-frequency traps worked in strong power frequency current, also may be affected by bad weather, so will cause the phenomenon of the breakdown、 discharge、 and burn out of its internal component, so it's important to test the performance parameters of high-frequency traps on a regular basis. This article strive to achieve a breakthrough in the anti-interference ability and accuracy, using the correlation detection principle combined with DSP technology, and to measure the frequency blocking characteristic of high frequency line trap of power system precisely, and using DSP processor's built-in timer which export stable square wave signal including rich harmonic instead of oscillator as the signal source, and it can also cover the entire measurement band, and it can make the system structure more simple and easier to debug. Experimental results demonstrate the system can obtain a precision of better than 1%.

2. Test Principle and Algorithm of Line Traps Characteristics

2.1. Test Principle of Line Traps Characteristics

In a Given K-type broadband tuning traps with typical parameters to analyze, Figure 2 is a circuit diagram which use improved voltmeter method to measure high-frequency parameter measurement. Among them, L_1, C_1, L_2, C_2, R_1 form traps, R_2 is the external resistor, f is the oscillator.

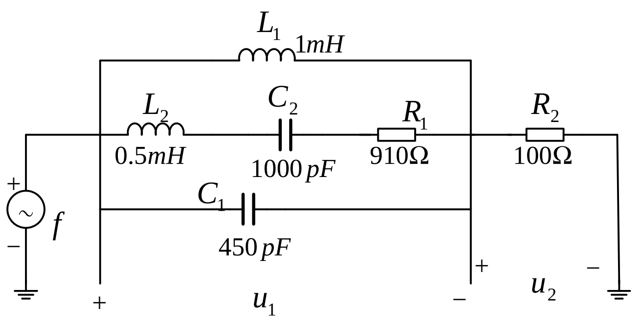

Figure 2. Measuring circuit of high-frequency parameters for line traps

$Z_b = \frac{U_1}{U_2} R_2$, $R_b = Z_b \cos(\varphi_1 - \varphi_2)$. Among them, U_1、U_2 is the amplitude of u_1、u_2 respectively, φ_1、φ_2 is the initial phase of u_1、u_2 respectively, R_b is the resistance component, Z_b is the impedance component.

2.2. Correlation Detection Principle

Let $x(t)$ be a cycle square wave signal accompanied by noise, which can be expressed as:

$$x(t) = u(t) + e(t) = \sum_{k=1}^{\infty} A_k \sin(k\omega_0 t + \varphi_k) + e(t)$$

Among them, $u(t)$ is standard square wave signal which has zero mean, and can be decomposed into base band ω_0's total number of all harmonic, $e(t)$ is the white Gaussian noise which has zero mean.

To avoid spectrum aliasing, signal should be filtered turn into band-limited signal which satisfy the Nyquist theorem.

Use synchronous sampling to avoid spectral leakage, suppose that sample N_s time per cycle, the resulting sequence is:

$$x(n) = u(n) + e(n) = \sum_{i=1}^{M} A_i \sin(2\pi i n / N_s + \varphi_i) + e(n)$$

Introducing the reference sine sequence whose frequency is K times than square-wave serie:

$$y_k(n) = B_k \sin(2\pi k n / N_s)$$

Using the orthogonality of the harmonics, can obtain correlation function between all the harmonics and the signals to be detected:

$$R_{xy_k}(m) = \lim_{N\to\infty} \frac{1}{N} \sum_{n=0}^{N=1} \{B_k \sin[2\pi k(n+m)/N_s] \times [\sum_{i=1}^{M} A_i \sin(2\pi i n / N_s + \varphi_i) + e(n)]\}$$

$$= \frac{A_k B_k}{2} \cos(2\pi k m / N_s - \varphi_k) + R_{ey_k}(m)$$

As the reference sequence $y_k(n)$ and random noise sequence $e(n)$ uncorrelated, so $R_{ey_k}(m) = 0$, then:

$$R_{xy_k}(m) = \frac{A_k B_k}{2} \cos(2\pi k m / N_s - \varphi_k),\ R_{xy_k}(0) = \frac{A_k B_k}{2} \cos\varphi_k$$

Introducing the orthogonal sequence with $y_k(n)$:

$$z_k(n) = B_k \cos(2\pi k n / N_s)$$

The same reason, it can obtain:

$$R_{xz_k}(0) = \frac{A_k B_k}{2} \sin\varphi_k$$

There are:

$$A_k \cos\varphi_k = 2R_{xy_k}(0)/B_k,\ A_k \sin\varphi_k = 2R_{xz_k}(0)/B_k$$

The harmonic can use vector expressed as:

$$\boldsymbol{U}_k = A_k \cos\varphi_k + \mathrm{j} A_k \sin\varphi_k = 2R_{xy_k}(0)/B_k + \mathrm{j}2R_{xz_k}(0)/B_k$$

From the above analysis, using the strong correlation between reference signal and the signals to be tested, independence and uncorrelated property between reference signal and random noise, it can reduce or even eliminate the effect of noise on the measurement results, the measurement error of correlation detection method primarily depends on the capacity of the sample and sampling accuracy.

2.3. The Test Algorithms of Line Traps Characteristics

Using the relevant law [7-8], because of the similar circumstances of each harmonic, and all the harmonics follow the principle of superposition after the response of linear systems, only consider the situation of fundamental wave.

Figure 2, assuming that $u_1 = U_1 \sin(\omega_0 t + \varphi_1)$, $u_2 = U_2 \sin(\omega_0 t + \varphi_2)$

After sampling, the sequence of numbers as follows:

$u_1(n) = U_1 \sin(2\pi n / N_s + \varphi_1)$, $u_2(n) = U_2 \sin(2\pi n / N_s + \varphi_2)$, the detector signal is two same-frequency orthogonal signal, orthogonal sine function sequence as follows respectively:

$e_1(n) = U_0 \sin(2\pi n / N_s)$, $e_2(n) = U_0 \cos(2\pi n / N_s)$

According to the relevant law [9] - [10], it can obtain:

$$U_1 = \frac{2\sqrt{R^2_{u_1e_1}(0) + R^2_{u_1e_2}(0)}}{U_0}, U_2 = \frac{2\sqrt{R^2_{u_2e_1}(0) + R^2_{u_2e_2}(0)}}{U_0}$$

$$U_1 \cos\varphi_1 = \frac{2R^2_{u_1e_1}(0)}{U_0}, \quad U_1 \sin\varphi_1 = \frac{2R^2_{u_1e_2}(0)}{U_0}$$

$$U_2 \cos\varphi_2 = \frac{2R^2_{u_2e_1}(0)}{U_0}, \quad U_2 \sin\varphi_2 = \frac{2R^2_{u_2e_2}(0)}{U_0}$$

$$z_b = 100\frac{U_1}{U_2} = 100\sqrt{\frac{R^2_{u_1e_1}(0) + R^2_{u_1e_2}(0)}{R^2_{u_2e_1}(0) + R^2_{u_2e_2}(0)}}$$

$$\cos(\varphi_1 - \varphi_2) = \frac{\mathbf{U_1} \bullet \mathbf{U_2}}{U_1U_2} = \frac{U_1\cos\varphi_1 U_2\cos\varphi_2 + U_1\sin\varphi_1 U_2\sin\varphi_2}{U_1U_2}$$

$$= \frac{R^2_{u_1e_1}(0)R^2_{u_2e_1}(0) + R^2_{u_1e_2}(0)R^2_{u_2e_2}(0)}{\sqrt{R^2_{u_1e_1}(0) + R^2_{u_1e_2}(0)}\sqrt{R^2_{u_2e_1}(0) + R^2_{u_2e_2}(0)}}$$

$$R_b = \mathrm{Z}_b \cos(\varphi_1 - \varphi_2) = 100\frac{R^2_{u_1e_1}(0)R^2_{u_2e_1}(0) + R^2_{u_1e_2}(0)R^2_{u_2e_2}(0)}{\sqrt{R^2_{u_2e_1}(0) + R^2_{u_2e_2}(0)}}$$

As the analysis, we can know that the resistance which connect with traps have a great effect on accuracy of measurement, so the high precision, small temperature coefficient of the standard non-inductive resistor should be used, or use standard resistance to correct.

2.4. The MATLAB Simulation of the Test Algorithms of Line Traps Characteristics

Simulation of the circuit for Figure 2 Using MATLAB [9-11], the simulation results are shown in Figure 3 and Figure 4.

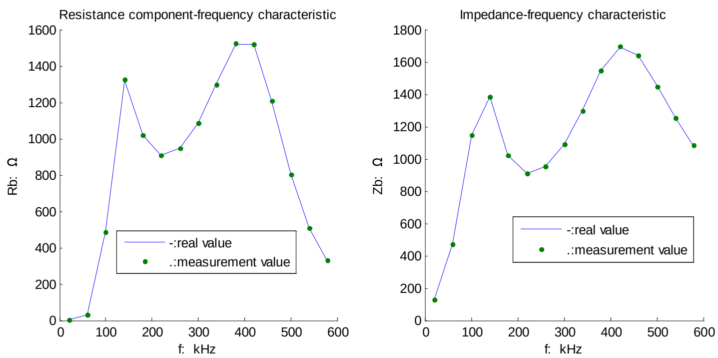

Figure 3. Frequency blocking characteristic while SNR=40dB

3. High-Frequency Parametric Measurement System Hardware Design of Line Traps

3.1. Measuring System Constitution

The measuring system consists of power, microprocessor, random access memory (RAM), control logic, anti-aliasing filters, A/D converter、keyboard and LCD display. Figure 5 is the structure of measurement system, Figure 6 is the schematic diagram of measurement system.

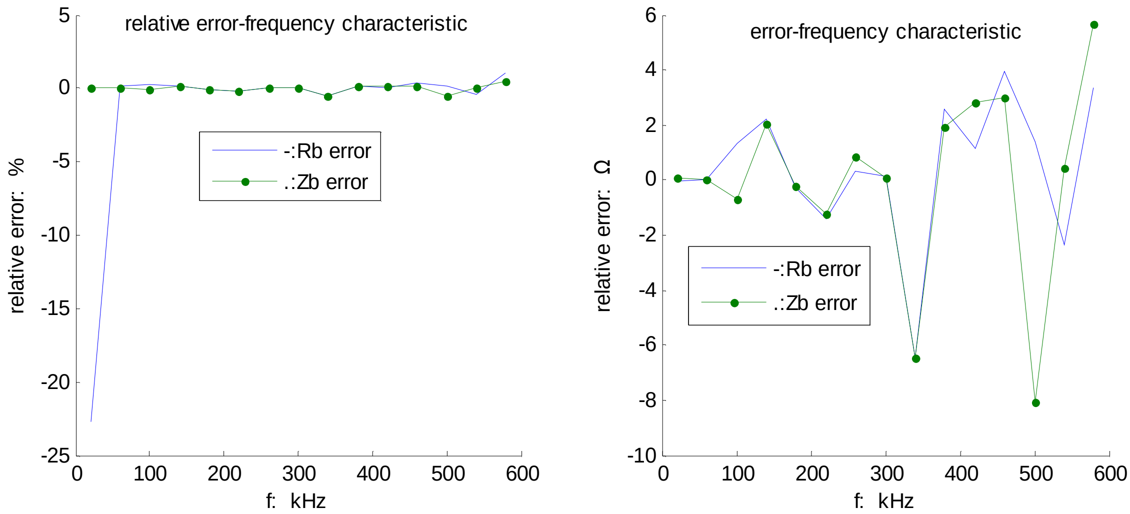

Figure 4. Error-frequency characteristic while SNR=40dB

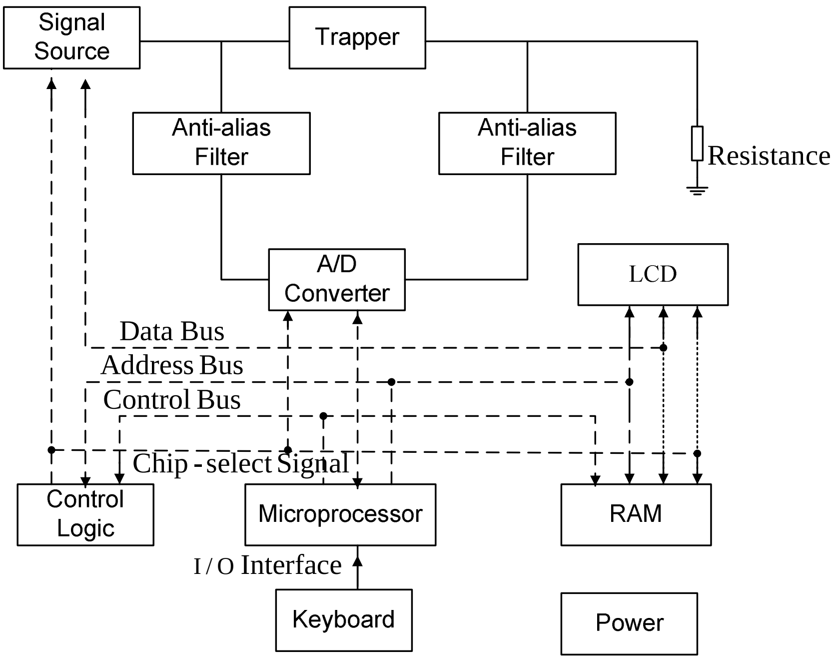

Figure 5.Measuring system constitution

In Figure 6, U1 is the digital signal processor, DSP）, U2 is the random access memory, U3 is the 6th-order low-pass filter which consists of operational amplifier and resistive and capacitive components, U4 is the dual operational amplifier, U5 is the A/D converter,U6 is the PLD, U7 is the LCD display modules, U8 is the keyboard.

3.2. The PSPICE simulation of the analog part of Measuring system

The analog part consists of timer, output filter, trap, preamplifier. Figure 7 is simulation circuit schematic of the analog part based pspice. Figure 8 is the simulation results of Impedance-frequency characteristic in the range of 40kHz to 500kHz. The maximum error is less than 0.1%.

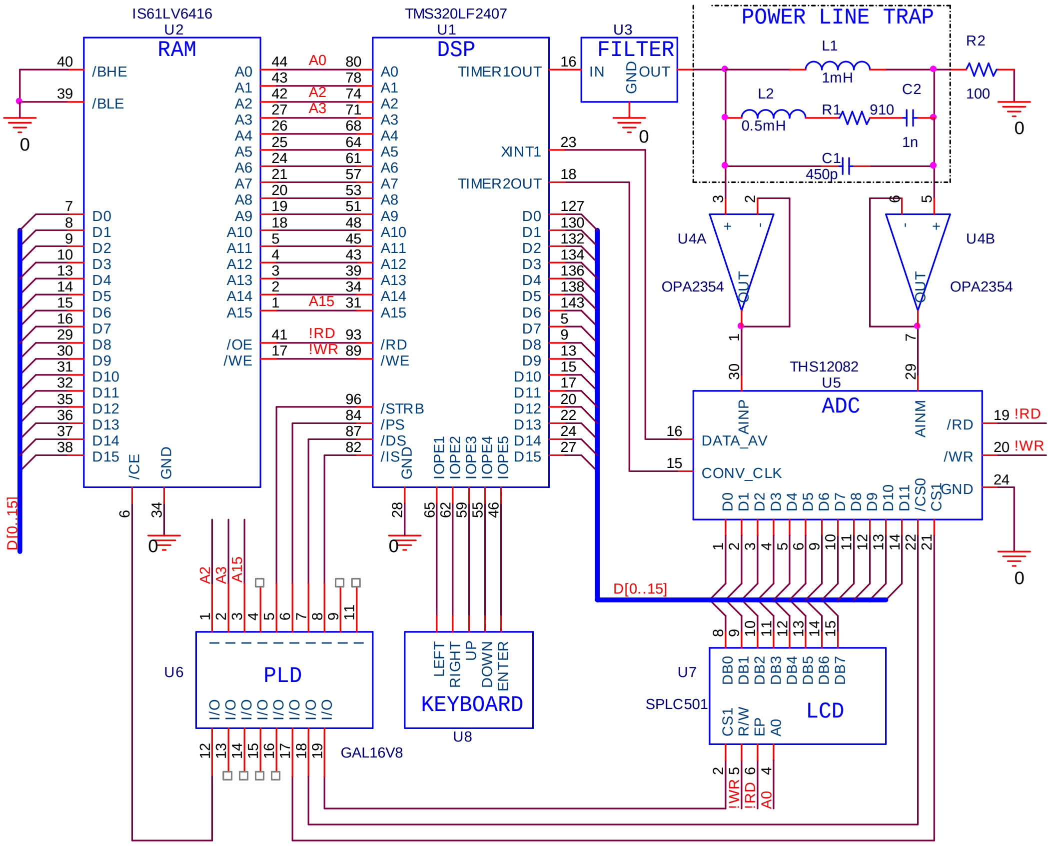

Figure 6. Schematic diagram of measurement system

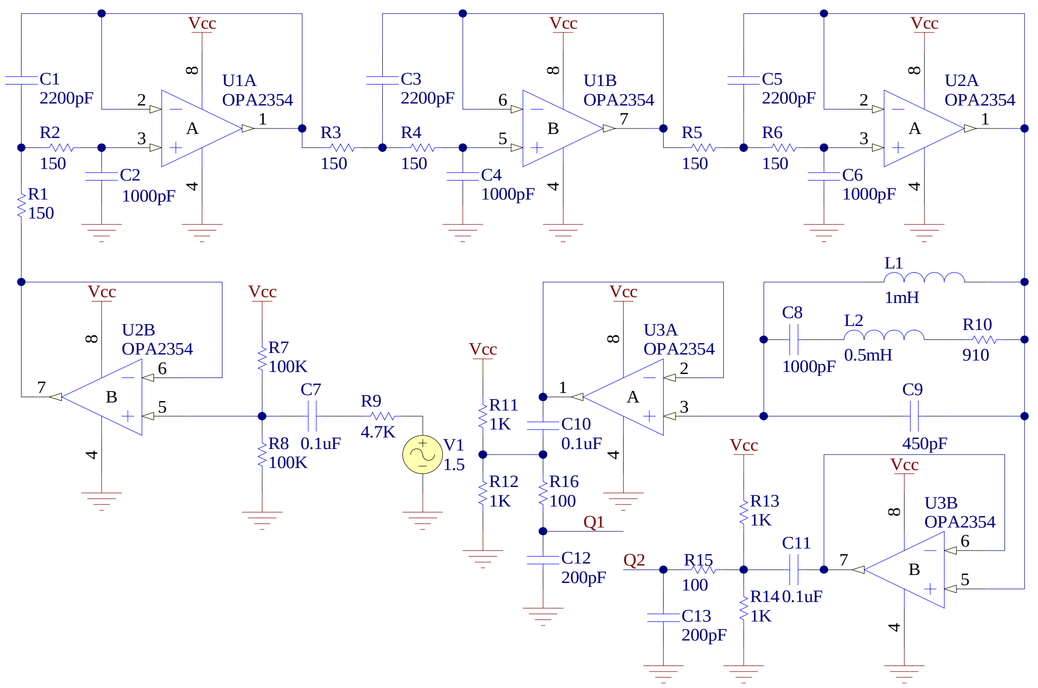

Figure 7. Simulation circuit schematic of the analog part

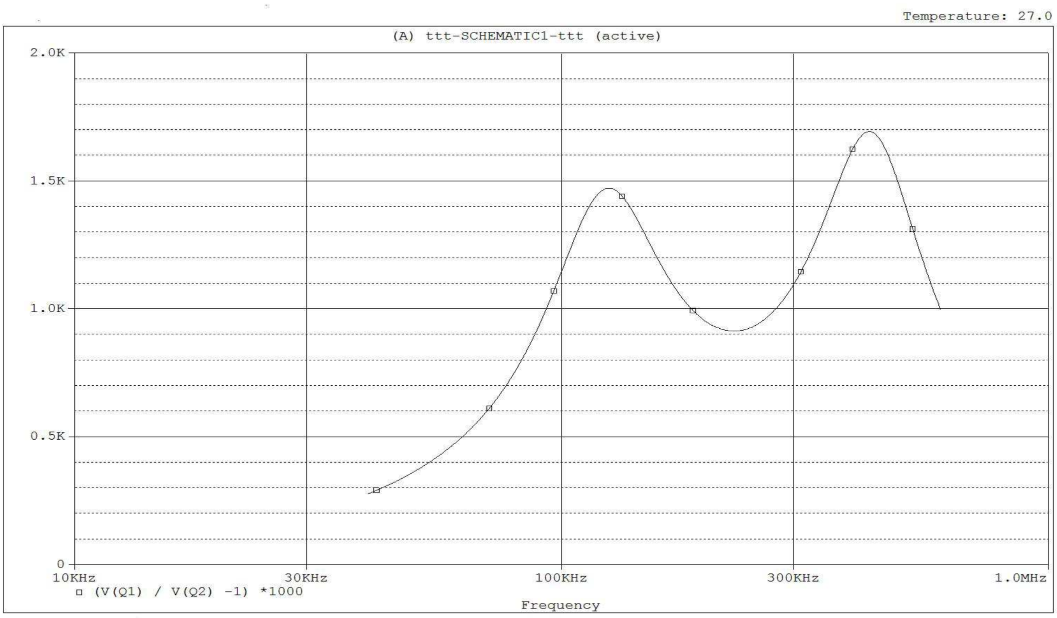

Figure 8. Impedance-frequency characteristic

4. High-Frequency Parametric Measurement System Software Design of Line Traps

The main program consists of four modules: the initialization module, the keyboard scanning module, the data processing module and the results display module. Figure 9 is the software flow chart.

5. Experimental Results

To test the circuit in Figure 2, and the component measured parameters is: R=909Ω, C_1=419.5pF, C_2=1032pF, L_1=1.006mH, L_2=0.4905mH.The compare of experimental results and calculation results are listed in Table 1.

Table 1. Experimental results

f(kHz)	R_b Calculated value(Ω)	R_b Measured value(Ω)	$dR/R\%$	Z_b Calculated value(Ω)	Z_b Measured value(Ω)	$dZ/Z\%$
80	140.7	139.7	0.7107	752.0	752.6	0.0798
120	1086.6	1084.5	0.1933	1410.4	1409.3	0.0780
160	1131.8	1132.1	0.0265	1142.3	1142.6	0.0262
200	929.9	928.9	0.1070	932.6	931.7	0.0965
240	903.9	904.5	0.0664	911.5	912.3	0.0878
280	988.4	985.2	0.3237	1002.1	999.2	0.2794
320	1166.1	1165.1	0.0857	1177.3	1176.9	0.0339
360	1418.4	1417.6	0.0564	1418.9	1418.1	0.0563
400	1641.1	1640.5	0.0366	1669.7	1669.4	0.0179
440	1602.5	1599.5	0.1872	1799.8	1796.2	0.0200
480	1244.9	1241.4	0.2811	1722.8	1718.7	0.2380

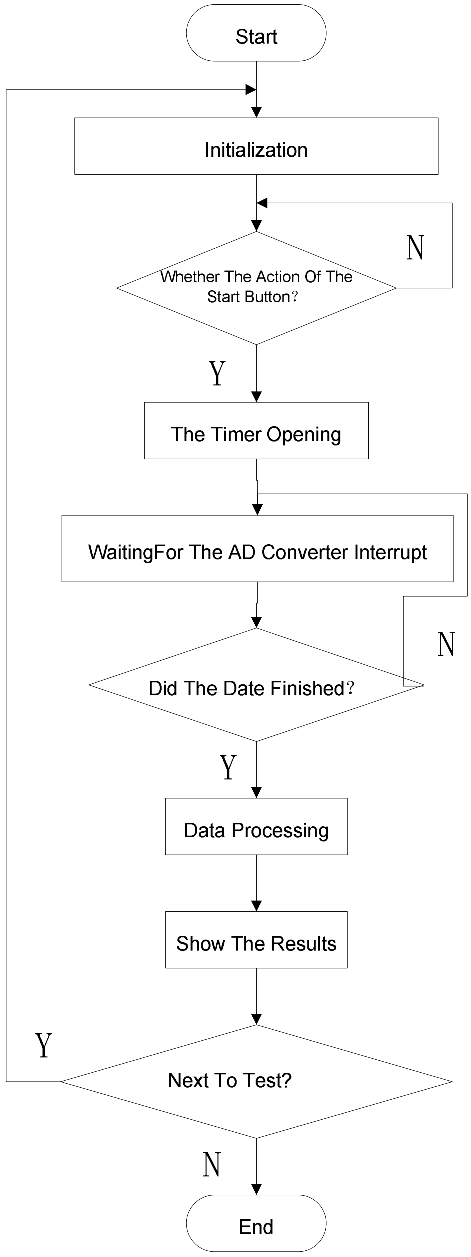

Figure 9. Flow chart of main program

6. Conclusion

In practice, the measurement of traps always has low measurement accuracy and weak anti-jamming capability. This paper presents an improved voltage meter for the test of blocking characteristics of power high-frequency traps. Using correlation method to provide the test algorithms of trap characteristics, the algorithm make a cross-correlation operation between the two measured signals directly, and using correlation and the related nature of the sine function, make some noise components separated from the useful signal efficiently, and obtain an accurate measurement result, and summarize a set of formula concerning trap impedance and resistance component, at the same time it gives MATLAB simulation of the test algorithms of trap characteristics. It gives this system’s circuit design and software implementation based on DSP hardware. Analyze the Given K-type broadband tuning traps which has typical parameters. According to experimental results and calculation results, the measurement system of the high-frequency parameters of trap can obtain a precision of better than 1%. It is fast and has a good ability of anti-jamming, moreover it has small volume, light weight, low power consumption, and it provides convenience to the site maintenance and large-scale testing of equipment. In a word, it has a good prospect.

Acknowledgements

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