Implementation and Performance Analysis of Small Scale Integrated Circuit Test System Based On PMU

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ABSTRACT

A design method of small integrated circuit test system based on precise measurement unit is presented in this paper, and the small power range is verified in detail. The test system the voltage/current clamp technique, comparison of technology, power expansion constant current source and voltage source and four quadrant drive technology, the combination of technology, to the device under test (DUT) applied to precisely and accurately measure the DUT value of the incentive, incentive in the response of the system at the same time. With high power capacity expansion to meet the various needs of the test circuit. The four channel system with integrated instrument amplifier circuit, combining extension circuit and PC control interface to accomplish the design of embedded controller, power, solve the nA current cannot be accurately measured, by optimizing the compensation circuit design, improve the testing speed of circuit. The analysis results show that the performance of the system, integrated circuit test system in the design of high precision, stable and reliable excitation and fast response speed, cost saving compared to 2/3 hardware design of similar products, to meet the integrated circuit DC parameter test requirements.

INTRODUCTION

With the integrated circuit integration continues to improve, the difficulty of integrated circuit testing continues to increase. At present, mainly rely on the integrated circuit ATE (Automatic Test Equipment) to complete the integrated circuit test. ATE test principle is through the device under test (Device under Test) to impose excitation and collection of response signals, and DUT technical manual parameters to compare, to determine whether the DUT qualified [1]. The integrated circuit tester is mainly used in the wafer test (mid-test) and finished product testing (measured), the article in the integrated circuit test system for the measurement of DC parameters in the design. From the development of semiconductor technology, chip testing technology behind the chip manufacturing rate, high-performance test equipment is expensive, greatly improving the cost of circuit testing [2]. In order to reduce the cost of IC testing, this paper presents a new circuit test system design scheme to meet the requirements of small micro integrated circuit test users for test accuracy and test speed.

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ANALOG INTEGRATED CIRCUIT TESTER OVERALL STRUCTURE

Analog integrated circuit tester mainly by the embedded controller, bus interface circuit, PAB board, MAB board and DUT adapter board composition, the system as shown in Figure 1.

This paper mainly introduces the design principle, performance analysis and power expansion and realization of the DC parameter test board (PAB) of the integrated circuit tester.

PAB CIRCUIT WORKS AND STRUCTURE OF THE COMPOSITION

When designing the DC parameters of the analog integrated circuit, it is necessary to provide constant current source and constant voltage source excitation to the DUT, and to accurately measure the response value of the DUT. The PMU unit can complete the DUT excitation and response measurement. Voltage source / current source, clamp circuit and measurement circuit is the main part of the PAB board, taking into account the test system accuracy and cost requirements, the choice of ADI's integrated PMU external power expansion circuit design. The PMU includes a voltage source, a current source, a Compare circuit, a Clamp circuit, a Measure circuit, and a Compensate circuit. Part of the small range of test high precision, but the power is limited, the need to increase the power expansion circuit to meet the requirements of a variety of circuit testing.

Figure 1. The overall architecture of the analog integrated circuit tester.
Voltage/current source to the DUT to apply constant current source/constant voltage source excitation, while the power supply for the DUT, in order to meet the needs of integrated circuit test for high power, high-power operational amplifier and follower to form a negative feedback circuit, the output stable high current/large voltage. The comparison circuit mainly completes the comparison between the excitation response value and the design value in the parameter manual, and outputs the pass/fail. The clamping circuit includes circuit clamps and voltage clamps that are primarily designed to prevent large losses due to operational errors and the introduction of capacitive loads, large voltage damage to the tester and damage to the DUT. Measurement circuit to complete the DUT response signal detection, the use of four-wire Kelvin connection DUT can improve the measurement accuracy. The compensation circuit is mainly to prevent the circuit from self-excitation and shock. The operating mode of the PAB board is designed using a four quadrant technique. Each PMU has an applied voltage measurement current (FVMI), an applied current measurement voltage (FIMV), an applied current measurement current (FIMI), a voltage measurement voltage (FVMV), an applied voltage (FV), applied current (FI), measured voltage (MV), measured current (MI) eight operating modes. Figure 2 shows the circuit structure of the PAB board, using the embedded controller to complete the PMU control and range switching to improve the flexibility of circuit testing.

PAB BOARD HARDWARE CIRCUIT DESIGN AND IMPLEMENTATION

Voltage Source and Current Source

In order to meet the needs of integrated circuit high-power test, while taking into account the small range of test accuracy, the current range greater than 2mA for a separate design, less than 2mA current range using PMU internal range, which reduces the PMU heating power, but also improve the test System accuracy. According to the schematic diagram of the PAB board, the low power voltage/current source is provided by the high-precision op amp A1. The sampling resistor and the current detection operational amplifier A3 and A4 constitute the current source feedback back,
the op amp A1 and the voltage detection op amp A5 and A6 constitute the constant
Power supply feedback loop; high-power voltage source/current source by the high-
precision op amp A1, A2 and high-power op amp A9 together to complete the
sampling resistor, high-power current instrumentation amplifier, current detection op
amp A3 and A4 constitute high-power constant current Source feedback circuit,
operational amplifier A1, A2, A9, high-power voltage instrumentation amplifier and
voltage detection amplifier A5 and A6 constitute a high-power constant voltage source
feedback circuit, through the analog switch to complete the current source and voltage
source switching.

Constant pressure source and constant current source to achieve the principle of
basically the same, the following high-power constant voltage source design and
implementation as an example to introduce.

The conversion value of the applied DAC is added to the negative feedback value,
and the positive input of the operational amplifier A1 is applied with high accuracy,
and the stable output of the high voltage and the high current is completed together
with the operational amplifier A2 and the high power amplifier A9. Among them, the
compensation circuit design will be described later. Power buffer circuit shown in
Figure 3. High-power op amp A9 (OPA541) to do the same proportion of
amplification feedback, magnification of +7 times.

According to the principle of opener virtual short break, op amp magnification is
+7 times, R1, R2 meet [6]:

\[
\frac{R_1 + R_2}{R_1} = 7
\]

Sampling resistor and high-precision op amp (LF411) to form the voltage to
follow the instrumentation amplifier, the output voltage is fed back to the input
through the divider resistor to achieve voltage stable output[5], the voltage detection
instrument amplification circuit shown in Figure 4.

In order to meet the voltage output range and voltage detection range to match,
design R3 = R7, R2 = R6, R1 = R5, R4 = R8. The amplification factor K of the circuit
satisfies the following relationship[4][6]:

\[
K = \frac{V_{out}}{V_{in1} - V_{in2}} = \frac{R_1}{R_6} \times \frac{R_7 + R_8 + R_5}{R_4}
\]

As can be seen from equation (2), the magnification K is set by the resistance
value. The output voltage range of the PMU is limited to ±10V. To improve the
voltage measurement accuracy, and the output of the PMU match, the output voltage
is divided into 4V, 8V, 20V and 40V fourth gear, the corresponding voltage
amplification factor are: 2.5, 1.25, 0.5 and 0.25.

Constant current source design principle and constant voltage source similar to the
sampling resistor to the current sampling, and voltage detection op amp composed of
negative feedback circuit. Taking into account the detection of precision, current
measurement circuit current feedback voltage range is set to ±2V, the current sense
amplifier magnification should be +5, the current range can be switched through the
relay switching resistor to achieve. For example, the resistance of the sampling resistor
RS = 2 Ω, according to Ohm’s law, the current range should be selected 1A.
**Compensation Circuit**

The design of the integrated circuit test system, the use of operational amplifier (internal compensation) and load devices (external compensation) were compensated, through the programmable way to switch the different capacitors. Compensation circuit in the integrated circuit test has two main functions: the system in the test range of large capacitive load to maintain the stability of the circuit; internal "integrator" to limit the loop conversion speed, increase the loop DC gain, To minimize the loop error voltage.

The compensation circuit only works on the voltage mode, the greater the compensation capacitance, the easier the circuit to stabilize, but will lengthen the entire loop setup time. The use of on-resistance less than 50 $\Omega$ analog switch and multiplexer to switch the different capacitance values to complete the compensation. When switching to current mode, the external compensation is automatically disconnected. According to the experimental data, the reference value of the compensation capacitor selection is shown in Table 1.

Note: CDUT measured load capacitance value; Cin internal compensation capacitor value; Cout outside the external compensation capacitor value.

**Clamp Circuit**

Clamp circuit is mainly to prevent the loop voltage or current value suddenly rises, protect the DUT and tester. The system is designed with two clamping modes, one by high-voltage op amp, as shown in Figure 3, by adjusting the size of the Rlim to change the clamping range; the other is through the PMU loop clamp, Figure 5 Shown as the principle of clamp circuit, clamp circuit through two high-precision op amp to achieve high and low clamp settings, compare the amount of feedback is set within the high and low clamp range, if within the range, the clamp circuit If the feedback value exceeds the clamp range, the clamp diode turns on, and the input voltage of the op amp A2 becomes the clamp voltage set value. The voltage outside the clamp range is consumed by the resistor R2, and the op amp A1 is output, The clamp circuit starts to function.

| \( C_{\text{DUT}} \) | \( C_{\text{in}} \) | \( C_{\text{out}} \) |
|-----------------|-----------------|-----------------|
| \( \leq 1\text{nF} \) | 100pF | 220pF |
| \( \leq 10\text{nF} \) | 100pF | 1nF |
| \( \leq 100\text{nF} \) | \( C_{\text{DUT}}/100 \) | \( C_{\text{DUT}}/10 \) |

**TABLE 1. COMPENSATION CAPACITOR SELECTION REFERENCE.**

![Figure 3. Power snubber circuit.](image)
Other

Using the 16-bit analog-to-digital converter AD7686 as the ADC conversion circuit, the four PMU measurement output connected in parallel with the ADC, through the analog switch to switch the measurement output loop open and close, simplifying the circuit design, but also meet the need for data conversion in the system, while reducing the hardware cost of the system.

In order to reduce the impact of the relay resistance on the sampling resistor, in the current/voltage sampling circuit using four-wire Kelvin connection. Similarly, from the point of view of improving the test accuracy, the application line (FORCE) and the measurement line (SENSE) of the DUT are separated by Kelvin's connection.

In the test found that the load off the case of switching current stalls, this time equivalent to the infinite load, access to load after a long time to achieve the stability of the loop. Select the default load in parallel at both ends of the DUT, when the load is off, the switching relay will be the default load access circuit, can effectively reduce the loop again stable time.

TEST PERFORMANCE ANALYSIS

In order to test the accuracy of the current stalls, the use of precision 0.1% of the metal film resistors for sampling. As the test workload is relatively large, the following precision of the voltage source for detailed testing. When the operating mode is FV (applied voltage), the accuracy of the application of the voltage source is detected by the precision multimeter; the current measurement accuracy when the operating mode is FVMI (applied voltage measurement current); the voltage measurement when the operating mode is FVMV (voltage applied voltage) Accuracy.

When the system works in the application of voltage mode, the system set to apply the voltage value of +5 V as an example, through the precision multimeter and other spacing to collect 100 points, the data show that the system output voltage maximum of 5.006791V, the minimum 5.004120V, The average is 5.005291V, the application accuracy of 0.09% or so, Figure 6 shows the voltage source +5 V when the system output.

System operating mode for the application of voltage measurement current (FVMI) mode, the choice of resistance of 10K \( \Omega \) metal film resistors as DUT, the
voltage source output -5V ~ +5 V DC voltage, step length of 10mV, Figure 7 for the system measured. The current value is converted by ADC. It can be concluded from Fig. 7 that the measurement accuracy of the current is less than 0.3%.

When the system operating mode is the voltage measurement voltage (FVMV) mode, the voltage source output -10V ~ +10 V DC voltage, step length of 10mV, Figure 8 is the result of ADC conversion. It can be seen from Figure 8, the system output is linear, the voltage measurement accuracy of less than 0.5%.

In the same way can be measured when the system works in the application of current (FI) mode, the system output 1uA current, after ADC conversion results shown in Figure 9, according to the measurement results, before the software correction, current source application and measurement Accuracy less than 0.3%.

![Multimeter measured voltage value](image)

Figure 6. Voltage source output + 5V when the fluctuations.

![After ADC conversion of the current value](image)

Figure 7. FVMI mode current measurement accuracy.

![After ADC conversion voltage value](image)

Figure 8. FVMV mode voltage measurement accuracy.
Compared with the theoretical calculation, the accuracy of the current source can be controlled at 0.05% compared with the theoretical value. The absolute error value is linearly distributed compared with the theoretical value after sampling and sampling by ADC. Current accuracy of less than 0.4%, the same method to get the voltage accuracy of less than 0.3%, to meet the requirements of integrated circuit testing.

A lot of experiments and tests show that by optimizing the compensation circuit can effectively improve the stability of the system to solve the power frequency interference, high frequency signal and the problems caused by bad components. In addition, the capacitive load at both ends of the parallel compensation capacitor can also play a role in maintaining the stability of the circuit.

CONCLUSION

Circuit test results show that the system works in a small range, high precision, fast. In addition, the system has a power expansion unit, the test circuit can be more wide, you can flexibly apply to the measured parts of the voltage source excitation or current source excitation, from the optimization of circuit structure and improve the compensation circuit in two ways to improve the system test accuracy, and The system is running more stable and reliable, to meet the industrial test requirements. The design of the product compared to existing products can reduce the 2/3 of the hardware design costs, to meet the requirements of small micro-circuit testing business.

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