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Analysis of Non-Vibration of EP9302 RTC Oscillator

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Abstract. The paper analyzes the problem of the non-vibration of the RTC oscillator of the ARM9 microprocessor EP9302. It points out the main causes of the problem and the matters that need attention in the circuit design. It also gives an example of a solution to solve such problems. The program has been tested in the environment with high temperature and low temperature. The results show that the ratio of the RTC circuit that does not vibrate at -10 degrees Celsius is reduced from greater than one percent to four out of ten thousand, which can be used by the relevant design and application personnel of EP9302.

1. Introduction

The EP9302 is a high-performance ARM920T core microprocessor from Cirrus Logic ^[1]. Its highly integrated structure and advanced performance design make it suitable for a wide range of consumer electronics and industrial control applications. This chip was used in the digital voice terminal product that the author participated in design process. A customer once reported that a large percentage of non-starting problems emerged for a batch of products when the temperature is below zero in the winter, and the proportion can be more than 20%. After comparison and verification, the preliminary judgment is that the RTC circuit is not oscillated due to the poor performance of the 32.768KHz quartz crystal. However, after replacing the quartz crystal of well-known manufacturers with good performance, the product that does not start still accounted for more than 1%. According to the data, the manufacturer has published an erratum that mentions that the real-time clock (RTC) circuit in the EP93xx device is susceptible to on-chip noise, which causes it to generate inaccurate clock counts and may cause the IC to enter an incorrect state when power-on. The solution is to input a clean square wave signal from the outside of the RTCXTALI pin, that is, to use an external clock oscillator or a dedicated RTC chip instead of the internal circuit ^[2]. If the solution is related to the aforementioned product non-launching issues, it is likely to involve recalls of a large number of products and redesign of hardware circuits. Unlike other ARM microprocessors, the EP93XX family of microprocessors uses the RTC clock as the system boot clock. If the RTC circuit does not vibrate, the system will not start. In order to find out the nature of the problem and find a reasonable solution to the problem, the paper intends to analyze the problem of the RTC oscillator of EP9302.

2. RTC oscillator circuit principle

The RTC oscillator of EP9302 is mainly composed of 32.768KHz quartz crystal, which is oscillated by the piezoelectric effect of quartz crystal. Quartz crystal oscillator is made of quartz crystal with very small power loss through precise cutting, grinding, electroplating and welding of lead wire. If an alternating voltage is applied between the quartz crystal plates, mechanical deformation vibration occurs, and at the same time, the mechanical deformation vibration generates an alternating electric field. When the frequency of the applied alternating voltage is equal to the natural frequency of the



wafer, the amplitude of the mechanical vibration will increase sharply. This phenomenon is called Piezoelectric Resonance. Since the chemical properties of the quartz crystal are very stable, the thermal expansion coefficient is very small, and the oscillation frequency is also very high. It is stable and can be very precise by controlling the geometry, so its resonant frequency is also very accurate.

2.1 Characteristics and model of quartz crystal

Quartz crystal oscillator is a piezoelectric device that can convert electrical energy and mechanical energy into each other. The energy transition occurs at the resonance frequency point. It can be represented by the following model:

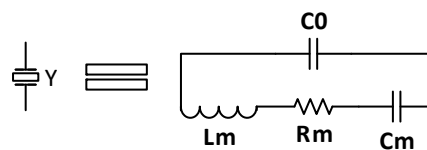


Figure 1. Quartz crystal model

In Figure 1:

C0: The electrostatic capacitance which value is generally only related to the size of the crystal.

Lm: Dynamic equivalent inductance, representing the inertia of the mechanical vibration of the crystal.

Cm: Dynamic equivalent capacitance, representing the elasticity of the crystal.

Rm: Dynamic equivalent resistance, representing the loss of the circuit.

In electrical engineering, this network has two resonance points, which are distinguished by the frequency. The lower frequency is series resonance, and the higher frequency is parallel resonance. Due to the characteristics of the crystal itself, the distance between the two frequencies is quite close. In this extremely narrow frequency range, the crystal oscillator is equivalent to an inductor, as long as the crystal oscillator is connected in parallel with a suitable capacitor, it will form a parallel resonant circuit. The parallel resonant circuit is added to a negative feedback circuit to form a sine wave oscillating circuit. Since the crystal oscillator is equivalent to a narrow frequency range of the inductor, even if the parameters of other components vary greatly, the frequency of the oscillator will not be changed dramatically.

2.2 Typical crystal oscillator circuit schematic

Figure 2 shows a typical CMOS inverter oscillator circuit, also known as a Pierce oscillator, which features low power consumption, low cost, and good stability. The circuit works like this:

Rf: The feedback resistor of the CMOS inverter allows the inverter to operate in the linear region, so that it gains the same effect as the amplifier. Normally, the value of Rf is chosen to be between 1MΩ and 10MΩ. As Rf increases, the gain of the inverter increases, making the oscillator to start faster and maintain oscillation at lower supply voltages.

Rd: It isolates the output of the inverter from the crystal and prevents parasitic high-frequency oscillations in order to obtain a good waveform. It also reduces the power consumption of the oscillator circuit. The optimum value for Rd depends on the operating frequency and the stability required. For the 32.768KHz crystal oscillator, the common problem is that it does not vibrate, not that it overdrives, so Rd can be set as 0.

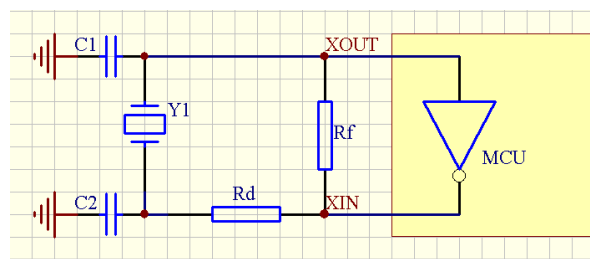


Figure 2. Schematic diagram of a typical crystal oscillator circuit

C1 and C2: Parallel combination constitutes C_p , $C_p = (C1 \cdot C2) / (C1 + C2)$. C1 and C2 are usually taken equal, then $C_p = C1/2$, and the optimum value of C_p determines the quality and frequency stability of the crystal oscillator.

Typically, the quartz crystal manufacturer's data sheet will give the crystal's load capacitance (CL). $CL = C_p + C_s$, C_s is the equivalent stray capacitance caused by parasitic effects such as PCB wiring and connections (on X_IN and X_OUT pins), which generally takes 2pF~6pF.

For example, in the data sheet of 32.768KHz crystal of KDS, Japan, CL is 12.5pF. Assuming $C_s = 3\text{pF}$, and C_p is 9.5pF by the above formula, then $C1 = C2$ is 19pF, and the nominal value $C1 = C2$ is generally acceptable as 20pF.

2.3 Factors affecting the oscillation of the crystal oscillator circuit

The Pierce oscillator is a closed-loop system consisting of an amplifier and a feedback network. To start the oscillation, the Barkhausen condition must be satisfied. That is, the closed-loop gain should be greater than 1, and the total phase shift should be 360 degrees. When designing the Pierce oscillator, the quartz crystal appears purely inductive at resonance and produces a 180-degree phase shift, along with a 180-degree phase shift of the inverter, with a total phase shift of 360 degrees. In addition, the closed loop gain is much larger than 1, so the crystal oscillator circuit is oscillated.

2.3.1 Gain margin The most important parameter that determines whether the oscillator can start properly is the gain margin. The expression is as follows:

$$\text{Gainmargin} = g_m / g_{m\text{crit}}$$

In the equation:

g_m is the transconductance of the inverter, and its unit is mA/V (for high frequency cases) or $\mu\text{A/V}$ (for low frequency cases, for example 32 kHz).

The value of $g_{m\text{crit}}$ (g_m critical) depends on the parameters of the crystal itself. Assuming $CL1 = CL2$ and assuming that the CL value of the crystal is the same as that given by the manufacturer, the $g_{m\text{crit}}$ expression is as follows: where ESR is the equivalent series resistance of the crystal.

$$g_{m\text{crit}} = 4 \times \text{ESR} \times (2\pi F)^2 \times (C_0 + C_L)^2 \quad \dots\dots\dots (1)$$

The inverter transconductance (g_m) must satisfy: $g_m > g_{m\text{crit}}$. In this case, the oscillation condition of the start-up is satisfied. To ensure reliable start-up, the minimum value of the gain margin is generally set to 5.

Since the internal inverter of the microprocessor is designed and fixed, the g_m parameter is basically fixed, so choosing the right external device becomes the most important task, and the choice of quartz crystal is especially important. From the calculation formula of $g_{m\text{crit}}$, it is known that selecting a crystal with a smaller ESR and a smaller load capacitance to process CL will reduce $g_{m\text{crit}}$, and it is easier to satisfy the oscillation condition of the start-up.

2.3.2 Quartz crystal selection There are two types of 32KHz crystals commonly found on the market: 6pF and 12.5pF. The crystal must meet the recommended capacitive characteristics when selected. The 12.5pF is chosen for EP9302's RTC circuit, which is the most commonly used one. Due to the low power design, many manufacturers' ICs are currently designed to use 6pF crystals. The power consumption of a 12.5pF crystal oscillator is twice as large as the 6pF crystal, but the 6pF crystal cost is much higher than 12.5pF. If the specifications are misused, it will undoubtedly cause the RTC oscillator to work unstable or not vibrate.

Another important parameter of quartz crystal is the equivalent series resistance ESR and the static capacitance C_0 . For example, the 32KHz crystal parameters of 2*6 specifications of Zhankete Electronics Technology Co., Ltd. are: $\text{ESR} \leq 35\text{K}\Omega$, $C_0 = 1.8\text{pF}$, $CL = 12.5\text{pF}$, and 3*8 specifications 32KHz crystal of Zhankete $\text{ESR} \leq 25\text{K}\Omega$, $C_0 = 1.8\text{pF}$, $CL = 12.5\text{pF}$; the latter ESR is much smaller, if you do not need to consider the volume limit, the 3*8 specification is easier to start.

2.3.3 Selection of peripheral devices The selection of peripheral devices is also an important factor, such as the bias resistor R_f , the inverter inv1 should be operated in the linear amplification region, so that the inverter has a large gain and oscillates at a certain frequency.

See in Section 2.2 for the calculation of external load capacitance.

The external resistance R_d is calculated as 0 for a 32 kHz crystal; if it is not 0, it is included in the ESR value of the crystal.

2.3.4 PCB design requirements Generally, the RTC (32.768KHz quartz crystal) oscillators are low-power design. In order to ensure normal oscillation during the application, the position of the oscillator should be as close as possible to the MCU, and the connection should be the shortest. At the same time, due to the high input impedance of the oscillator, it is very sensitive to glitch, which results in faster clock operation. The best precaution is to add shielding to the oscillator circuit.

The crystal oscillation circuit itself is easily interfered by the outside world, and it is also the source of interference. Therefore, in the process of layout and wiring, some principles must be grasped, including: the oscillation circuit components should be as close as possible to the IC, and the oscillation circuit should be far away from other high-speed clock signals, and the oscillating circuit should be far away from the antenna and other vulnerable areas; the crystal is best placed on the ground pad, and the metal casing of the crystal is preferably grounded; the length of the clock signal trace should be as short as possible, the line width should be as large as possible, and the distance from other traces should be as large as possible. The inner layer can be removed and surrounded by the ground line; the external stray capacitance and inductance should be controlled within a range as small as possible to avoid the crystal oscillator from entering an abnormal working mode or causing abnormal oscillation. Also the crystal oscillator circuit should be avoided from passing through other circuits. In actual wiring, the ground plane can be used for signal isolation and noise reduction. A ring of wires around the crystal and the trace forms a guard ring to shield interference. Directly laying under the guard ring helps isolate the crystal from noise from other PCB layers. Pay attention that the ground plane is close to the crystal but only under the crystal, instead of spreading the ground plane over the entire PCB, also, a tantalum capacitor can be connected on each pair of VDD and GND ports to smooth out the noise.

3. Comparative analysis of RTC circuits

3.1 Typical RTC circuit of EP9302

Figure 3 shows the typical RTC circuit of the EP9302.

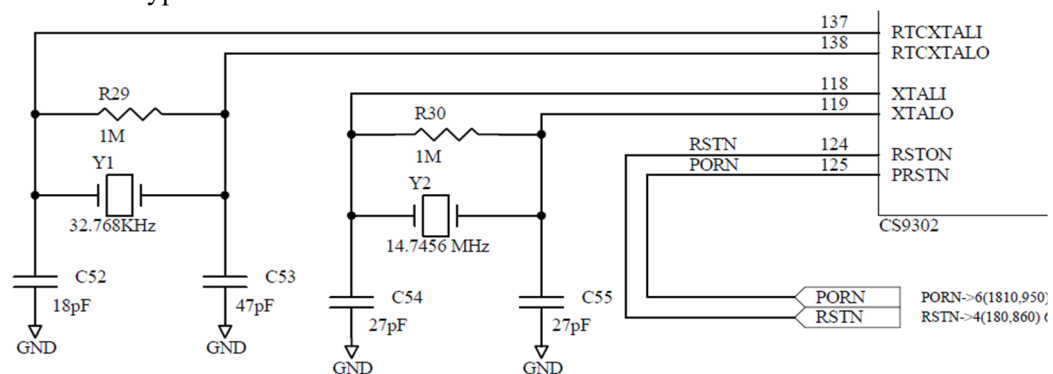


Figure 3. RTC typical circuit of EP9302 [1]

As can be seen from the figure 3, the equivalent load capacitance of the crystal oscillator Y1 is:

$$CL = (C52 * C53) / (C52 + C53) = 13.015 \text{ pF}$$

It is close to the selected crystal load capacitance of 12.5pF. The difference between the two capacitors is to speed up the start-up time.

Considering the influence of distributed capacitance, the actual capacitor selected during product design is 20pF, 27pF, and its equivalent load capacitance is:

$$CL = (20 \times 27) / (20 + 27) = 11.49 \text{ pF}$$

A small capacitance makes it easier to start, and the distributed capacitance of the PCB layout is closer to the load capacitance of the crystal 12.5pF.

3.2 RTC oscillator test circuit

According to the above analysis on the principle of RTC oscillator, the author believes that the RTC oscillator of EP9302 does not vibrate mainly because the crystal oscillator is not properly selected and the value of the external device is not suitable. For this reason, it is proposed to reselect the crystal oscillator and increase R35. The value is 2.2MΩ. In order to verify, the author designed a test circuit, the circuit schematic is as follows:

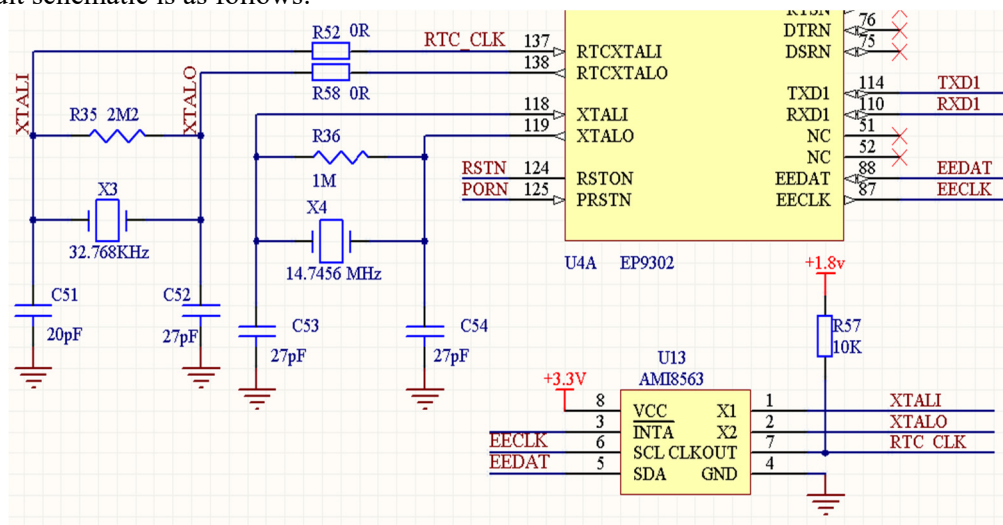


Figure 4. RTC oscillator test circuit

This circuit combines the use of an internal RTC circuit with an external clock circuit to facilitate selection of connections for testing. Among them, X3 is always connected, and the DT-26 crystal oscillator of KDS and the 2*6 crystal oscillator of Zhankete are used for comparison test.

When using the internal RTC circuit, R52 and R58 are soldered with 0Ω resistors, U13 and R57 are not soldered, and R35 is 2.2MΩ.

When using an external clock circuit, R52, R58, R35, C52 are not soldered, C51 is changed to 4.7pF, and U13 and R57 are soldered. The circuit is mainly composed of U13. U13 is the RTC/calendar integrated circuit AMI8563 produced by Yaxin Microelectronics Co., Ltd. It is fully compatible with PCF8563. Its 1st and 2nd pins are connected with 32.768KHz crystal oscillator. Since the internal pins of the chip have integrated crystal oscillated load capacitance, and the typical value is 20pF, C52 does not need to be connected. C51 is used for frequency compensation, and adjusted according to the frequency deviation. U13's pin7 CLKOUT is a programmable square wave signal output. It is an open-drain output pin. The default output frequency is 32768Hz square wave signal, which is used as the input clock of EP9302. In order to match the pin7 level to the 1.8V of the EP9302, the pin7 is connected to +1.8V using a pull-up resistor R57.

3.3 Test plan design

The purpose of the test was to evaluate the effect of internal and external clock circuits on the normal startup success rate of the product when using different external devices at a low temperature of -10 degrees to obtain the final solution. The test equipment includes high and low temperature test chambers, 20 voice terminals, network and network switch, the test computer, the controllable power box and the test software include "controllable power box test program" and "terminal login test program". The

temperature of the high and low temperature test chamber is set as -10°C , It is required to maintain the set temperature for 1 hour and reach the temperature balance before the test. The device connection topology is shown in Figure 5.

20 voice terminals are connected to the network switch by network cable, and each terminal is set with an IP address by using the terminal configuration program. The terminal and the network switch are placed in the high and low temperature test box, and the test computer is also connected to the switch by the network cable, thus forming a star network. The power adapter of the voice terminal is connected to the "equipment output" power socket of the controllable power box, the serial port control line of the controllable power box is connected to the serial port of the test computer. Start "the controllable power box test program" on the test computer. If you click the "Device On" button on the control power box test program window, the corresponding control power box "device output" power socket outputs 220V power supply, so the terminal is powered on. Otherwise, if you click the "Device Off" button on the test program window, the corresponding "Device Output" power outlet power output is cut off, and the terminal is powered off.

The specific test method is: running the "terminal login test program" on the terminal test computer. If the terminal is not logged in and is not normally started, the login test tool will automatically record the number of terminals that are not logged in each time for analysis.

In order to do the automatic test, the software tool "button wizard" which can simulate the mouse operation is used, and "the terminal login test program" and "the controllable power box test program" are operated according to the following test strategies, and the loop execution is performed:

Switch to the power box test program → click button "device power on" → delay 50 seconds → switch to the landing test program → click button "online detection" → delay 10 seconds → Switch to the power box test program → click button "device power off" → delay 60 seconds.

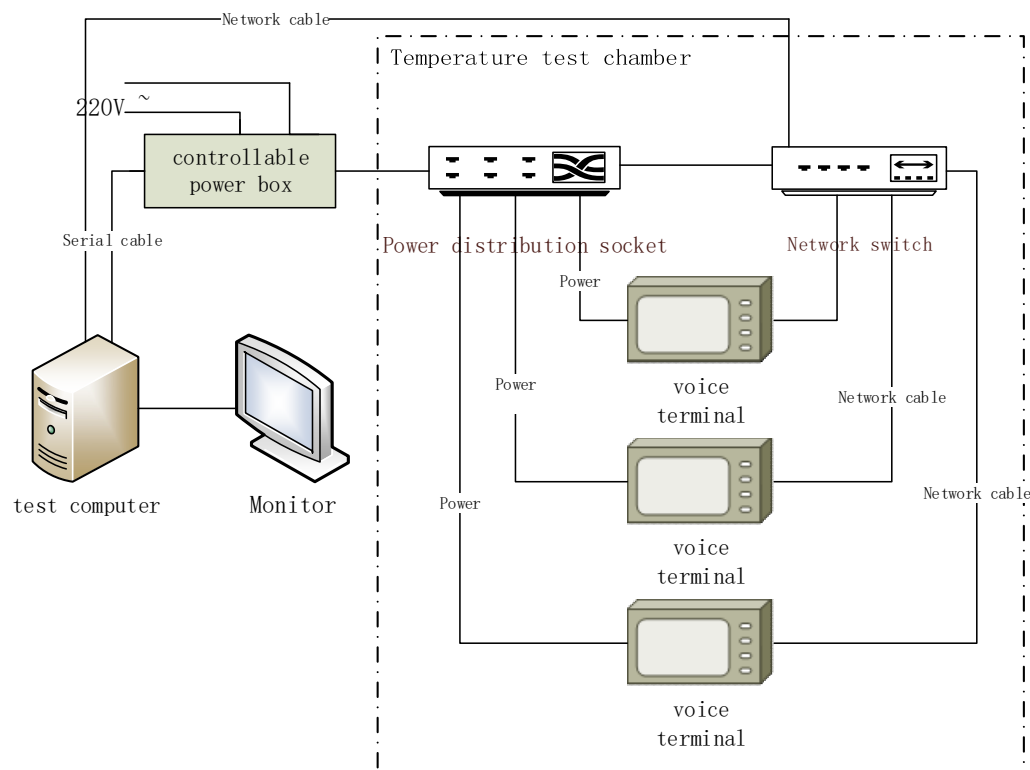


Figure 5. Test device connection topology

3.4 Test results and analysis

The terminal startup failure test data is shown in Table 1.

Table 1. Terminal start failure test data.

Test content	Unsuccessful start-up	No login times	Test conditions
R35= 1M, original quartz crystal	32.5%	13	-10°C, 2 rounds
R35= 1M, use Zhankete quartz crystal	0.42%	3	-10°C, 354 rounds
R35= 2.2M, original quartz crystal	9%	9	-10°C, 5 rounds
R35= 2.2M, use KDS quartz crystal	2.3%	56	-10°C, 122 rounds
R35= 2.2M, use Zhankete quartz crystal	0.04%	2	-10°C, 249 rounds
Add an external clock to use the Zhankete quartz crystal	0.033%	2	-10°C, 304 rounds
R35= 2.2M, use Zhankete quartz crystal, high temperature test (45°C)	0	0	45°C, 142 rounds

Note: The test used 20 voice terminals, all of the same batch and the same hardware version.

It can be seen from the data in Table 1 that the effect of crystal performance on the start-up is the most important one. When the R35 is 2.2M at -10°C, the unsuccessful rate of starting with KDS crystal is 2.3%. If the Zhankete crystal is used, the startup failure rate is reduced to 0.04%. This is very close to the data of 0.033% using the external clock circuit, and the test unsuccessful rate is 0 when tested at a high temperature of 45°C, indicating that the high temperature does not affect the start-up. It can be seen that under the condition of -10°C, the value of R35 is 2.2M, and the usage of Zhankete crystal can meet the requirement, which is less than 0.05% of the product's failure rate of starting the product. This is also implemented as the final solution.

4. Conclusion

Through the principle analysis and actual test verification, the low temperature non-starting problem of the terminal products is mainly caused by the selection of the crystal oscillator and the inappropriate value of the peripheral feedback resistor, which has nothing to do with the problems mentioned in the RTC circuit errata released by the manufacturer about EP9302. The test results show that if the circuit design is followed by some precautions, the internal RTC circuit of the EP9302 can work normally without using an external clock circuit, which has practical significance for simplifying the design and reducing the cost. In addition, for IC design and application personnel, the design details of the RTC circuit, various factors involved need to be highly concerned, and full attention needs to be paid to RTC. This will avoid major product quality accidents caused by clock circuit failure.

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