HT46R47 AC Zero Crossing Detection

D/N : HA0157E

Description

This application note shows a simple method for measuring parameters such as AC power zero, power frequency and the regarding phase angle. It allows direct connection of the AC power line to the Holtek MCU I/O port using only two resistors. The AC power line can be hundreds of volts with different frequencies (50/60Hz). It is mainly applied in products measuring and controlling AC power parameters and is especially widely used in household appliances. The typical applications are for power on-off timing control (such as motor control, lighting control and heater control etc), electric power, power factor regulation and phase line control etc.

The following note uses the HT46R47 as an example. The method described is used to design an AC power operating frequency detection demo board.

Operation Principle

One of the application circuit characteristics is to note that there is a protection circuit attached to each of the Holtek MCU I/O pins. This is created by using two protection diodes connected to each MCU I/O pin. One is connected to VDD and the other to VSS as figure 3 shows. This circuit structure can protect the I/O pin from surge voltages or HF-noise EOS damage. By directly connecting a high voltage signal to the I/O pin via one or two current-limiting resistors, a Zero Crossing Detector input circuit can be created. This circuit can be used to measure certain AC power parameters such as zero crossing, line frequency and phase angle etc. This method can be used in product applications such household appliances. This application note uses this principle to design a demo board to detect the AC power frequency.
Schematic Block Diagram and Designation

The most important section is the design of the Zero Crossing Detection circuit. For this circuit special attention must be given to the following issues:

- Main power circuit design
- Zero crossing detector current-limiting resistor value
- LED output circuit design

Schematic Diagram

This schematic diagram includes the EMI filter circuit - optional but nearly always used in household appliances - resistor-capacitor power circuit, zero crossing detection circuit and the LED output circuit etc as shown in figure 1.
Power Circuit

The HT46R47 power supply is supplied by a capacitor dropper circuit. The circuit consists of R7, C5, D1, D6, C1 and C4, as figure 2 shows. The designed total input current in this application note must be greater than the maximum output current for the application. The maximum output current can be calculated by the following formula:

\[
I_{in} > I_{out} = \frac{V_{RMS}}{X_{C5} + R_7} - \frac{1}{2}\left(\frac{V_{RMS} - V_{VIDO}}{X_{C5} + R_7}\right) = \frac{1}{2}\left(\frac{1}{2\pi C_5 + R_7}\right)
\]  

(1)

Here,

\( V_{RMS} \) refers to the AC sinewave power RMS voltage

\( V_{RMS/2} \) refers to a half of \( V_{RMS} \). Hence, the output capacitor C5 operates at half waveform

\( V_{VIDO} \) refers to the regulated voltage

\( X_{C5} \) refers to the C5 impedance which is reactive

As formula (1) shows, for the output voltage to be maintained, the output current \( I_{out} \) must be less than or equal to (under ideal conditions) the input current \( I_{in} \). The input current \( I_{in} \) value is determined by the resistor R7 and the capacitor C5. Attention must be paid to the maximum output current passing through the capacitor C5 when calculating the output current \( I_{out} \).

Here, when the input voltage is 230V AC/50Hz, the maximum output current \( I_{out} \) is:

\[
I_{out} = \frac{230 - 5.1}{2\left(\frac{1}{2\pi \times 50 \times 1 \times 10^{-6}} + 51 + 51\right)} = 34.21mA
\]
Note that in the above equation the capacitance impedance is reactive and therefore is 90 degrees out of phase with the resistor voltage. The equation is however a good enough approximation for this application’s purposes.

When the input voltage is 110V AC/60Hz, the maximum output current $I_{out}$ is:

$$I_{out} = \frac{110 - 5.1}{2\pi \times 60 \times 1 \times 10^{-6} + 51 + 51} \approx 19.03 mA$$

Note: In the actual measurement, the maximum output current is 31mA (@230V AC/50Hz, C5=1000nF). In general, the actual maximum output current will be less than the calculated value. Additionally, when calculating the maximum output current, maintain an allowance of about 20%.

Figure 2  Power Circuit
Zero Crossing Detection

To synchronise with every operating period, the MCU needs to have a zero crossing signal. This takes the form of a Zero Crossing Detector circuit. The zero crossing detection circuit consists of two external current-limiting resistors R1 and R2, an equivalent value capacitor (typical value: 5~10pF) and two internal amplitude-limiting diodes. Fig 3 shows the equivalent circuit.

![Zero Crossing Detector Circuit](image)

**Figure 3  Zero Crossing Detector Circuit**

For each HT46R47 I/O pin, there is always a maximum input current \( I_{j\_\text{max}} (I_{\text{peak}}) \). The typical value is 400 mA. During design, the input current \( I_j \) must be less than the maximum input current \( I_{j\_\text{max}} (I_{\text{peak}}) \). It can be calculated using the following formula:

\[
I_j = \frac{V_{\text{RMS}}}{R_1 + R_2} < I_{j\_\text{max}} = 400\mu A
\]

(2)

When \( V_{\text{RMS}} = 230V, R1 = R2 = 2M \) ohms, the input current is:

\[
I_j = \frac{230}{2*10^6 + 2*10^6} = 57.5\mu A < 400\mu A
\]
When the input AC power is 230V AC/50Hz, the related Zero Crossing Detector circuit waveform is shown in figure 4 (without load) and in figure 5 (with load). Here, CH1 is connected to the test point, TP2, while CH2 is connected to TP1. As figure 6 shows, when the input signal level on the PA5 pin is greater than 0.7VDD=0.7×5V=3.5V then this will be seen as a high logic level. For these values refer to the DC electrical characteristics in the datasheet. At this time, the zero crossing point of the input signal will be delayed by 240s. The zero crossing point delay time can be changed according to the two current-limiting resistors R1 and R2 values. Therefore, the appropriate delay time will not affect the measuring accuracy of the AC power frequency. It is recommended that the zero crossing point current-limiting resistor value should be selected within a range of 4MΩ~5MΩ to ensure a zero crossing input current of Ij < I_{peak} (400μA) but with no waveform deformation.

Figure 4  Zero Crossing Detector Circuit Actual Waveform (without load)
Figure 5  Zero Crossing Detector Circuit Actual Waveform (with load)

Figure 6  Zero Crossing Detector Circuit Actual Waveform (rise time)
Note: when the input is 230V, the maximum voltage that both ends of the current-limiting resistor must withstand is about 325V. Hence, for fear of an overly high voltage damaging the resistor, the required resistance is normally made up from two series resistors. For example, for the 1206 SMD (Surface Mount Device) type resistors, its maximum voltage is about 200V. Therefore these types would need to use two resistors connected in series.

LED Output Circuit

In this demo board, the output circuit consists of two current-limiting resistors and two LEDs, respectively controlled by the HT46R47 I/O pin, as figure 7 shows. Hence, the output current is mainly provided for the two LEDs to illustrate whether the AC power frequency is 50Hz or 60Hz. During design, the maximum output current I_{out} should ensure that the LEDs’ illuminate normally.

Figure 7  LEDs Output Circuit
PCB Integrated Layout Diagram

The figure 8 shows the designed PCB layout diagram. Some tips should be noted for the PCB layout:

- The trace between MCU VDD and VSS should be parallel
- The reset circuit signal and oscillator circuit signal trace should be as short as possible
- The signals connected to the MCU should be shielded by a GND signal

Figure 8  PCB Integrated Diagram

Figure 9 shows the final demo board view.

Figure 9  Demo Board View
Software Flowchart

This example program is written in assembly language. It includes several subroutines, the external interrupt subroutine generated by the PA5 pin input, the internal timer overflow interrupt subroutine, special purpose Data memory initialization subroutine and general purpose data memory initialization subroutine etc. Figure 10 shows the main software flowchart.
The external interrupt subroutine generated by the PA5 pin falling edge input is handled in INT_ISR, as flowchart 11 shows. In the HT46R47 configuration options, the PA5 pin must be setup to have no pull-high resistor. When it detects the first zero crossing signal when executing the program, it enters the interrupt subroutine. Then enable the timer and start to count the variable in phase_position. If it enters the interrupt subroutine for the second time, it stops counting and records the count value. The AC power operating frequency is calculated by comparing the counting value, after which the appropriate LED can be illuminated. For example, if the defined interval upon entering the interrupt is 125us and the count value measured is 158, then the AC power operating frequency is 50.63Hz, calculated using the following formula:

\[
f_{AC\_line} = \frac{1}{158 \times 125\mu s} = 50.63Hz
\]

Here, figure 12 shows, the timer interrupt subroutine TMR_ISR flowchart.
Conclusion

- The MCU integrated protection diodes are used for ESD protection.
- To directly connect the AC line to an MCU I/O pin, the MCU I/O pin maximum current value and over voltage issues caused by the AC LINE surge voltages or high frequency noise should be considered.
- In general, the series resistor between AC LINE and MCU I/O must be greater than 1M/100V to protect the MCU I/O.
- The maximum current into the HT46R47 input pin I/O should meet the requirement of $I_{\text{peak}} \leq 400\text{A}$. An external Zero Crossing Detector current-limiting resistor value should be selected to have a range of $4\Omega \sim 5\Omega$.
- It is recommended to solve the problem by software and hardware for better EMC countermeasure. Add an EMI filter as figure 1 shows and reset the flags as figure 10 shows.