Detailed Explanation of the Circuit Principle of DSO183 Oscilloscope

1. The principle of an oscilloscope

Briefly explaining the principle of an oscilloscope, as the name suggests, the function of an oscilloscope is to display the waveform of an electrical signal. If you were to design one, how would you implement this function?

First, a waveform is the trajectory of an electrical signal changing over time. An electrical signal is a certain electrical parameter, usually voltage or current. If we use the horizontal axis to represent time and the vertical axis to represent the magnitude of the signal and draw the trajectory of the signal changing over time on a plane, then we get the waveform of the signal. An oscilloscope uses electronic means to draw the waveform of the signal on the screen.

To achieve this, we only need to design a circuit that continuously measures the signal magnitude, records the results, and then plots these measurements sequentially on the screen. This simple idea is the implementation principle of digital storage oscilloscopes.

2. Overall Circuit Structure

How to design an oscilloscope circuit?

Signals are generally continuously changing analog quantities. In order to measure and record signals, we first think of using an analog-to-digital converter (ADC) to convert analog quantities into digital quantities, so that they can be stored in memory.

To display the saved signal, we can use a microcontroller to read the saved signal using software and then draw it onto the screen as required.

Because the signals to be observed vary in size, while the range of signals that an analog-to-digital converter (ADC) can convert is limited, and the signal often needs to be increased or decreased during observation, we need to add a signal adjustment circuit before the signal is input to the ADC to change the signal magnitude to suit the range of the ADC and the observation requirements.

Finally, all of these circuits require a power supply to operate, so a power supply must also be added.

In summary, the circuit of an oscilloscope can be composed of several parts as shown in Figure 1.

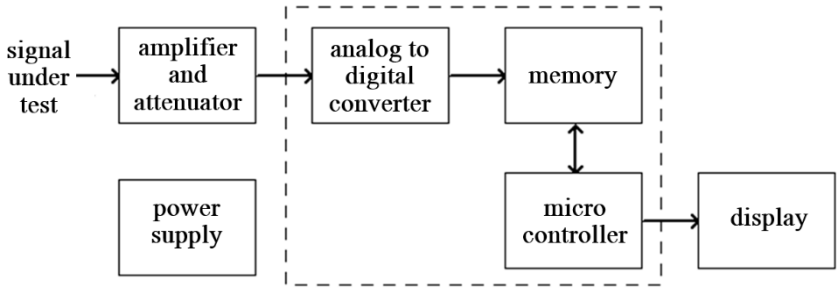

Fig. 1

The analog-to-digital converter (ADC) and memory in the DSO183 oscilloscope are included in the microcontroller (the dashed box in Figure 1), so these parts are not visible on the circuit. In addition to the basic circuits mentioned above, the DSO183 also has some auxiliary circuits, which will be described in detail below.

3. Microcontroller circuit

The microcontroller circuit is shown in Figure 2. Its core is the microcontroller U1, model STM32F103C8, a 32-bit microcontroller manufactured by STMicroelectronics. It has 64K bytes of program memory, 20K bytes of SRAM, two ADC converters with a speed of 1Msps, as well as timers, communication interfaces and other modules. Its operating clock can reach 72MHz, making it a powerful microcontroller.

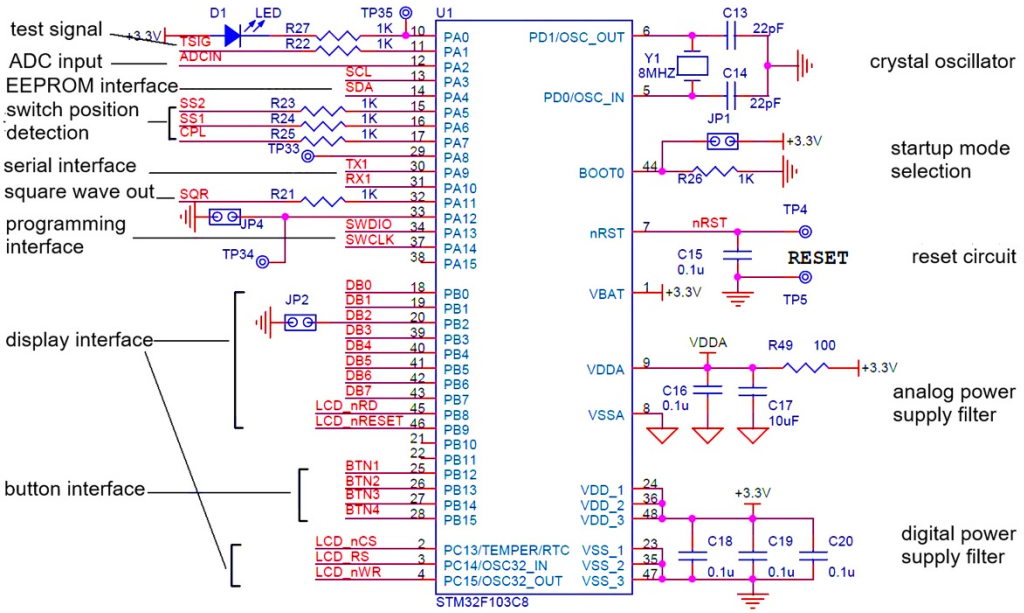

Fig. 2

1) Understanding the connection relationships

First, let's understand the circuit connections. The microcontroller is the center of the entire oscilloscope, and the operation of each part of the circuit is closely related to it. Therefore, we must first understand how the microcontroller is connected to other circuits.

The main connections are as follows:

- **Display interface:** includes 8 data lines (DBO-DB7) and 5 control lines (LCD nWR, LCD nRD, LCD RS, LCD nCS and LCD nRESET).
- **Button interface:** includes 4 wires (BTN1-BTN4), which are connected to the 4 buttons respectively.
- **Analog channel switch position detection interface**: includes three lines (CPL, SS1, SS2), each connected to the coupling switch, sensitivity switch 1, and sensitivity switch 2 of the analog channel circuit.
- **ADC input**: has only one line, connected to the output of the analog channel.>
- **EEPROM interface**: includes two lines (SCL and SDA) connected to the electrically erasable programmable read-only memory chip U5.
- **Serial communication interface**: consists of two lines (TX1 and RX1), which are connected to ports J9 and J11 via resistors R30 and R31.
- **Programming interface**: consists of two lines (SWDIO and SWCLK) connected to programming port J8.
- **Test signal output:** has one line (TSIG), connected to the test signal output port J7.
- **Square wave signal output:** line (SQR) connected to the square wave signal output port J6.

2) Other relevant circuits of the microcontroller

Below are other circuits related to the operation of the microcontroller:

- **Crystal oscillator**: consists of crystal Y1 and capacitors C13 and C14, and is integrated with the internal circuitry of the microcontroller, it forms a crystal oscillator to generate the clock signal required for the internal operation of the microcontroller itself.
- **Reset circuit**: consists of C15, TP4, and TP5. When TP4 and TP5 are shorted, it will reset the microcontroller. The machine resets and restarts; the function of C15 is to improve anti-interference capability.
- **Analog power supply filter:** consists of C16, C17 and R49. The +3.3V power supply passes through this filter and then used as the power supply VDDA for the analog section inside the microcontroller.
- **Digital power supply filter**: consists of C18, C19, and C20. Their function is to reduce interference in the power supply of the digital part of the microcontroller, making the microcontroller work more stably.

- **Boot mode selection** consists of R26 and JP1 and JP2, which can select the boot mode of the microcontroller. There: are two modes. Under normal circumstances, JP1 and JP2 are disconnected, and the microcontroller will enter the normal working program after power-on or reset. If JP1 and JP2 are

shorted, the microcontroller will enter another internal program (called the Bootloader) after power-on or reset, at which time the microcontroller can be programmed.

4. Display circuit

The DSO183 uses a 2.4-inch TFT color LCD display with a resolution of 320x240. The display circuit is shown in Figure 3.

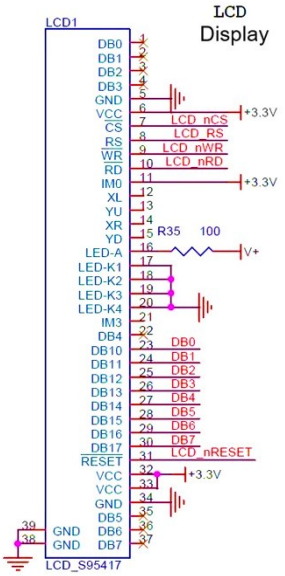

Fig. 3

The display screen has a total of 37 pins, of which DB0-DB7 and DB10-DB17 are 16-bit data lines, and CS, RS, WR, RD and RESET are control lines. The microcontroller mainly uses these lines to control the operation of the display screen and transmit the content to be displayed. In the DSO183, only 8 data lines DB10-DB17 are used; DB0-DB7 are not used.

LED-A and LED-K1 – LED-K4 are the four backlight diode pins of the LCD. LED-A is the common anode of these diodes, and LED-K1 – LED-K4 are the cathodes of the four LEDs respectively. Resistor R35 is the current-limiting resistor for the backlight diodes. When the power is turned on, the power supply passes through R35 to supply power to these diodes, and the backlight lights up.

VCC is the power supply pin for the display screen, and GND is the ground pin.

IM0 and IM3 are used to select the operating mode of the display.

XL, YU, XR, and YD are pins reserved for touchscreens and are not used in the DSO183.

5. Button circuit

The button circuit is relatively simple, as shown in Figure 4. Buttons BTN1-BTN4 are directly connected to pins PB12-PB15 of the microcontroller. Each of these pins has an internal pull-up resistor connected to the microcontroller's power supply VDD (+3.3V). When the button is not pressed, these pins are at a high level. When the button is pressed, it shorts the corresponding pin to ground, pulling it low. During operation, the microcontroller continuously monitors the potential of the button pins. Once a low level is detected, it knows a button has been pressed and executes the operation corresponding to the pressed button.

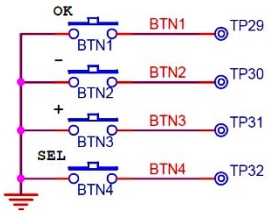

Fig. 4

6. EEPROM circuit

EEPROM is an electrically erasable and rewritable read-only memory. Its characteristic is that the data will not be lost even if the power is turned off after it is stored. Here, it is used to save the operating parameters of the oscilloscope and also to prevent program piracy.

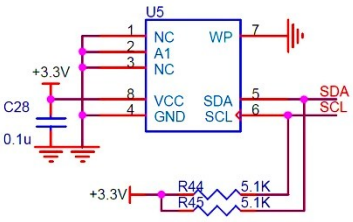

Fig. 5

Figure 5 shows the EEPROM circuit, which is connected to the microcontroller via two lines (SDA and SCL). These two lines operate according to a protocol called I2C. Bya manipulating these two lines, data can be stored in or read out of the EEPROM.

7. Analog Channel circuit

The analog channel circuit is shown in Figure 6. Its main function is to amplify or attenuate the signal to suit the observation requirements. We will analyse it step by step from input to output below.

1) Coupling circuit

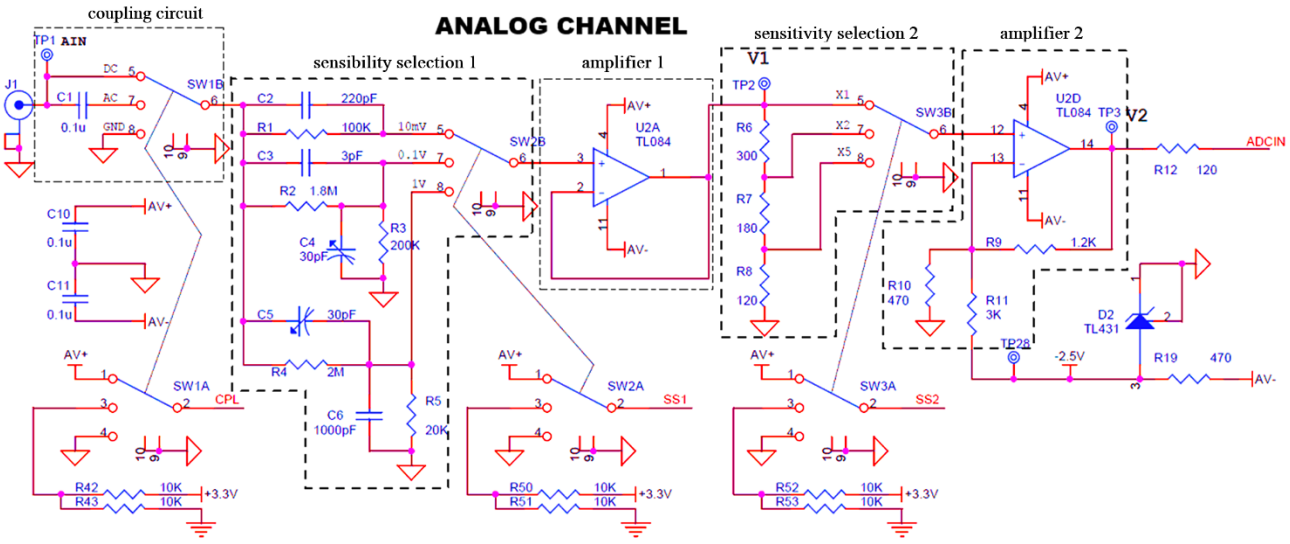

Fig. 6

After the signal is input from port J1, it first passes through the coupling circuit. The coupling circuit of the DSO183 consists of C1 and the toggle switch SW1B.

Here, "coupling" means allowing a signal to pass through in a certain way. Specifically, this circuit can choose whether the signal passes through directly or through a capacitor. The former is called DC coupling, denoted by DC, and the latter is called AC coupling, denoted by AC.

This selection is achieved by toggle switch SW1B. As can be seen from the circuit diagram, when SW1B is switched to the DC position, the signal passes directly. When SW1B is switched to the AC position, the signal passes through capacitor C1. Since the capacitor isolates DC, only AC signals can pass through at this time, hence the name AC coupling.

As can be seen from the circuit diagram, the toggle switch SW1B has another grounded position, marked GND. When SW1B is in this position, the oscilloscope input is grounded. This position is set because sometimes we need the oscilloscope input to be 0V to determine the waveform baseline. Simply switching the coupling switch to the GND position, the oscilloscope input becomes 0V.

So, why are coupling circuits necessary? Or, what are the practical uses of coupling circuits?

The function of the coupling circuit can be illustrated with a common example: in practice, signals are often a superposition of DC and AC signals. If we only want to see the AC signal, we can simply switch the coupling switch to the AC coupling position. At this time, the DC component of the signal is blocked, and only the AC component can pass through. The screen will then only display the AC component. This function is especially important when the DC component is large and the AC component is small. Without this function, the AC component would not be able to be displayed on the screen because the DC component is too large.

2) Sensitivity selection circuit 1

After passing through the coupling circuit, the signal arrives at the first-stage sensitivity selection circuit. This stage circuit consists of resistors R1-R5, capacitors C2-C6, and toggle switch SW2B. Its function is to adjust the signal magnitude.

How is this adjustment effect achieved?

According to the circuit diagram, the toggle switch SW2B has three positions, each corresponding to a voltage divider:

- In the 1st position, switch set to the 10mV position, signal is input to the non-inverting input of op-amp U2A through R1/C2. There is no voltage division; the signal passes directly, which can be considered as a voltage division ratio of 1.
- In the 2nd position, switch set to 0.1V, the signal passes through the voltage divider formed by R2/C3 and R3/C4 before going to the non-inverting input of op-amp U2A. The voltage division ratio of this circuit is

R3/(R2 + R3) = 200K/(1.8M + 200K) = 1/10, meaning that the signal will be attenuated by a factor of 10 in this position.

- In the 3rd position, with the switch set to 1V, the signal passes through a voltage divider composed of R4/C5 and R5/C6 before going to the non-inverting input of op-amp U2A. The voltage division ratio of this circuit is R5/(R4 + R5) = 20K/(2M+20K) ≈ 0.0099 ≈ 1/100, meaning that at this level, the signal will be attenuated by 100.

As we can see, we can change the signal magnitude simply by toggling the SW2B switch and change it by a factor of 10.

3) Amplifier 1 (U2A)

The first-stage amplifier consists of U2A, which is actually a follower, or in other words, a voltage amplifier with a gain of 1.

A voltage amplification factor is 1, meaning no amplification, so what's the purpose?

The main function of this op-amp here isn't amplification, but to provide high input impedance. We know that op-amps is forming a non-inverting amplifier have a very high input impedance. This feature is utilized here because there is no need to amplify the voltage. Therefore, the inverting input terminal of the op-amp is directly connected to the output to make the voltage amplification factor 1.

Some students might ask, why is a high input impedance needed here?

When you observe a signal with an oscilloscope, the oscilloscope's input is connected in parallel with the circuit under test. Therefore, the oscilloscope will inevitably draw some current from the circuit. If the oscilloscope's input impedance is low, it will draw more current; if the oscilloscope's input impedance is high, it will draw less current. To minimize the impact on the circuit under test, we naturally want the drawn current to be as low as possible. Therefore, we want the oscilloscope's input to have a high impedance. However, not too high, as it presents practical difficulties. Typically, the input impedance of an oscilloscope is around 1MΩ.

4) Sensitivity selection circuit 2

After passing through the first-stage amplifier, the signal enters the second-stage sensitivity selection circuit, which consists of resistors R6, R7, R8 and toggle switch SW3B.

As can be seen from the circuit diagram, this stage of sensitivity selection is also a voltage divider circuit composed of resistors, and different voltage division ratios are selected by switch SW3B.

- When SW3B is in position X1, the output of U2A is directly transmitted to the input of U2D without attenuation, and the voltage divider ratio is 1.
- When SW3B is in position X2, the output of U2A is divided and then transmitted to the input of U2D. The voltage division ratio is (R7+R8)/(R6 + R7 + R8) = (180+120)/(300 + 180 +120) = 1/2.
- When SW3B is in the X5 position, the output of U2A is divided and then transmitted to the input of U2D. The voltage division ratio is R8/(R6+R7+R8) = 120/(300+180+120) = 1/5.

Why add another sensitivity setting?

This is mainly because the sensitivity adjustment is too coarse if there is only the first level, which is inconvenient to use. With this level combined with the first level, the overall sensitivity can be varied in multiples of 1-2-5 between 10mV/division and 5V/division, meeting practical requirements.

5) Amplifier 2 (U2D)

After the second stage of sensitivity selection, we arrive at the second stage amplifier, which is also the final stage amplifier of the analog channel.

It consists of U2D and R9, R10, and R11.

There are two requirements for this amplifier stage: first, to provide the main amplification of the analog channel; and second, to achieve level shifting.

Let's address the second point first: why perform a level shift and by how much?

The input voltage range of the ADC microcontroller is between 0V and VDDA while the signal input to the non-inverting input of a U2D is based on 0V and can be positive or negative. If this signal is directly sent to the ADC, the negative signal will fall outside the ADC's range, which is obviously unacceptable. To solve this problem, the

entire signal must be "raised," shifting the signal level in the positive direction so that it falls within the ADC's input range.

To achieve a positive level shift, we can apply a fixed negative voltage to the inverting input of the U2D. Based on the characteristics of the op-amp inverting amplifier, the op-amp will output a positive voltage. The magnitude of the output positive voltage can be determined by selecting the negative voltage and the value of the relevant resistors.

In the DSO183, D2 and R19 are used to generate the required fixed negative voltage. D2 is a high-precision Zener diode that produces a negative voltage of -2.5V. This negative voltage is applied to the inverting input of U2D through R11, and the positive voltage generated at the output of U2D is:

$$- (R9/R11)(-2.5V) = -(1.2K/3K)(-2,5V) = 1V$$

Because the signal input from the non-inverting input is amplified by U2D and then superimposed on this 1V voltage the signal level was shifted upwards by 1V, so that any originally negative signal, as long as it wasn't lower than -1V, would fall within the ADC's range and could be effectively converted.

Now let's go back to the first point: how does U2D amplify signals?

Because the signal is applied to the non-inverting input of U2D, U2D is a non-inverting amplifier for the signal, and its amplification factor is:

$$1+R9/(R10//R11) = 1 + R9(R10 + R11)/(R10*R11) = 3.95$$

The required amplification factor for the analog channel of the DSO183 oscilloscope is 4. 3.95 is very close, with an error of only about 1%, which is acceptable.

6) Switch position detection circuit

The analog channel has three toggle switches, SW1, SW2, and SW3. The microcontroller needs to know the positions of these switches to correctly display and process the waveforms. Therefore, there needs to be a way for the microcontroller to detect the positions of these switches.

These three toggle switches are all double-pole triple-throw switches. The two poles operate synchronously, so one pole can be used to detect the position of the other. As shown in Figure 6, the pole marked B performs the circuit function, and the pole marked A is used for position detection.

The detection uses a voltage measurement method. Taking SW1 as an example, when the switch is in the AV+ position, the voltage at the CPL node is AV+, which is about 4V. When the switch is in the middle position, the voltage at the CPL node is approximately 1.65V, which is the voltage of +3.3V divided by R42 and. When the switch is in the ground position, the voltage at the CPL node is 0V. The CPL node is connected to the microcontroller through R25. The microcontroller can determine the position of the SW1 switch by measuring the voltage at the CPL node.

Similarly, by measuring the voltages of nodes SS1 and SS2, the microcontroller can determine the voltages of nodes SS1 and SS2, and thus the positions of nodes SW2 and SW3.

8. Power circuit

The power supply circuit is shown in Figure 7. It is divided into digital power supply and analog power supply. The digital power supply mainly powers the digital circuits of DSO183, which mainly include microcontroller, LCD and memory. The analog power supply powers the analog circuits, which mainly include analog channels, as well as sine wave and the triangle wave generators.

The digital power supply circuit consists of U3 and C21 and C22. U3 is a low-dropout three-terminal regulator. After the power supply V+ is input from J2, U3 outputs a stable +3.3V voltage to power U1, LCD, and U5. The function of C21 and C22 is to filter and reduce interference and fluctuations.

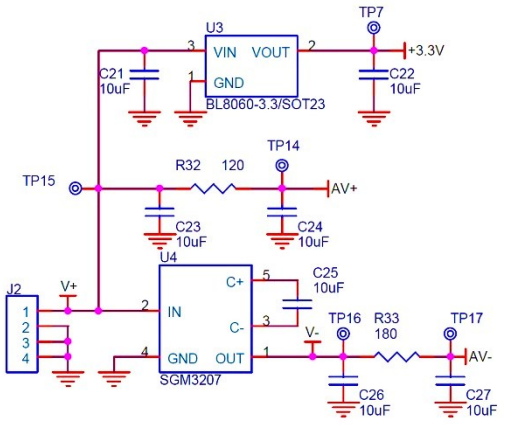

Fig. 7

Analog power supplies are divided into positive (AV+) and negative (AV-) power supplies.

The positive power supply circuit is relatively simple. V+ passes through the filter circuit composed of R32, C23, and C24, and becomes AV+ to power the analog circuit. The negative power supply is slightly more complex because the input is only positive V+. It first needs to go through a converter to generate a negative power supply. U4, C25, and C26 are such a converter. It generates a negative voltage V-. V- then passes through the filter composed of R33 and C27 and became AV- to power the analog circuit.

9. Sine Wave Generator

As shown in Figure 8, the sine wave generating circuit is a Wien bridge oscillator circuit. R13, R14, C7, and C8 form the frequency selection network, and U2C, R15, and POT1 form a non-inverting amplifier.

The frequency selection network determines the frequency of the sine wave. When R13 = R14 = R, C7 = C8 = C the sine wave frequency is:

$$F = 1/(6.28*R*C)$$

Substituting R = 16K and C = 0.01uF, the calculated frequency F is approximately 995Hz.

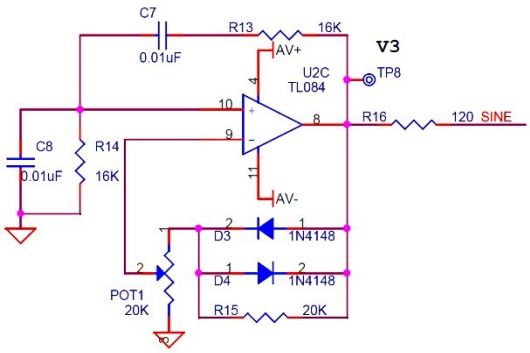

Fig. 8

The ratio of R15 to POT1 determines the amplification factor of the non-inverting amplifier. If the amplification factor is too large, the output waveform will be distorted; if the amplification factor is too small, it will cause no oscillation. POT1 is an adjustable resistor. Adjusting POT1 will provide the appropriate amplification. The function of diodes D3 and D4 is to stabilize the amplitude of the oscillation. Here, the nonlinearity of the diodes is used to automatically adjust the amplification factor within a certain range to stabilize the oscillation.

The generated sine wave is output to the sine wave port J3 through the protection resistor R16.

10. Triangular Wave Generator

The triangular wave generating circuit is shown in Figure 9. It consists of two main parts: a clamping circuit composed of C12, R20, and DN1, and an integrator composed of U2B, R17, C9, and R46.

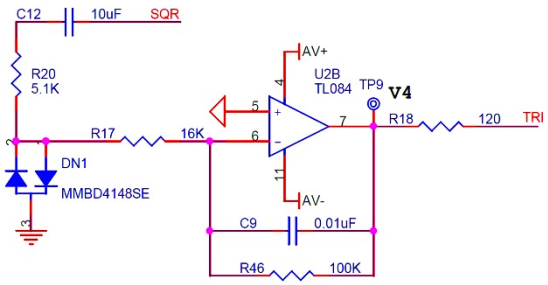

Fig. 9

The function of the clamping circuit is to generate square wave of approximately 0.7V. The original square wave is generated by the microcontroller and output from pin PA11. This square wave has a low level of 0V and a high level of 3.3V, meaning the amplitude is 3.3V. After C12 filters out the DC component, it becomes a square wave with a low level of -1.65V and a high level of 1.65V, after clamping through R20 and DN1, the amplitude is limited to approximately -0.7V to +0.7V.

This square wave signal is applied to the input of the integrator composed of R17, C9 and U2B. After integration a triangular wave is formed at the output of U2B. This triangular wave is connected to the output of the triangular wave J4 through the protection resistor R18.

The function of resistor R46 is to stabilize the DC level of the integrator output.

Revision Hystory

Version	Date	Summary
v01	2025.09.26	first draft
v01b	2026.03.30	English translation by D. Benvenuti