Frontiers in Power and Energy Systems (2024)
Clausius Scientific Press, Canada

DOI: 10.23977/fpes.2024.030104
ISSN 2516-2926 Vol. 3 Num. 1

Design of transmitter for mine NMR water finder

Henggong Yue, Zhenzhou Li, Zekun Shi, Duo Xu, Tianyi Zhang, Yimin Liu, Junwei Liu

Mengda Power Generation Electricity Co.,Ltd, Ordos, China

Keywords: NMR water finding, low voltage, fast consumption, inverter

Abstract: As far as the current technology is concerned, the only geophysical method that can directly find water is NMR. The technology has been developed for decades, and the technical level is relatively developed, and as a new technology, it is also a new field in water search. In this paper, the application of NMR water finder transmitter in underground is studied. This paper first describes the development at home and abroad, and then introduces the principle of Larmor frequency and its role in nuclear magnetic resonance water finder transmitter, and then puts forward the overall design scheme. According to the electrical requirements of underground safety operation, the bad underground environment is considered, the hardware of the system is designed, and the function and selection of each device are analyzed. In this paper, the following key technologies are used: the generation of Larmor frequency adopts bipolar PWM signal inverter, serial-connected diode module and capacitor to realize the rapid energy absorption and release after the coil sends the signal, and the voltage is controlled at 160V within the safe voltage range under the mine, which improves the safety level of underground work.

1. Introduction

In many underground operations in China, mine water disaster is a serious threat to the safety of workers. Due to the extremely complicated geological conditions in China, water inrush accident in mine often occurs, which not only threatens the normal work and operation of mine, but also poses a great threat to the life and property safety of underground workers.

Mine water mainly comes from rain precipitation and underground water. The underground water mainly includes aquifer, fault fissure water and goaf water, which may penetrate into the mine from soil and rock cracks. When the water flowing into the mine exceeds the designed drainage capacity of the mine, the mine will be flooded, causing casualties and huge losses [4][5]. How to control the mine water disaster is an important link in the safe production of the mine, and mine water disaster has been the second major disaster. Therefore, it is of great significance for mining to conduct hydrogeological research, improve the safety of mine and protect the safety of underground personnel by controlling water disasters. [3]

2. Status quo

In 1962, Varian, R.H., applied for a patent on MRS, but due to the scientific immaturity of the time, the experimental prototype was not realized. In 1978, the former Soviet Union began further scientific research on the basis of the original, and in 1981 developed a prototype that could detect groundwater, and successfully developed the world's first NMR water finder. A mathematical model of positive MRS and negative inversion, computer processing and interpretation programs and hydrogeological interpretation methods was established based on comparative tests at the Central Asian Hydrological Station and other areas, while experiments around the world confirmed that MRS technology is the only geophysical method in the world that can directly search for water. The French Geographic Survey (BRGM) purchased the patent. In 1999, NMR depth detection was 150 meters, but it could not meet a variety of complex environment requirements, and the requirements of NMR detectors for the environment were still very high [1][2].

In 1956, Chinese scientists conducted an NMR water search experiment, but due to the immaturity of science and technology, they did not receive NMR signals. However, the program used in the experiment is correct. In 1997, China University of Geosciences introduced NUMIS system, which promoted the development of MRS Technology in China, and in 2002, Jilin University developed a prototype NMR water finder at its own expense [3][4]. The water finder prototype successfully found the NMR signal, which was basically matched the known data. Although it was only 10m deep, but it was also a major breakthrough on MRS Technology in our country. In 2006, it received state funding. In 2007, the depth was successfully reached 100m. In 2008, the error between new prototype and the French NUMISPIUS is small, and reached the international leading level in the same year.

3. The overall scheme design of the transmitter of nuclear magnetic resonance water finder

The transmitter system is controlled by MCU STM32 and the peripheral circuit is linked through JTAG interface. The principle of the transmitter is shown in Figure 1.

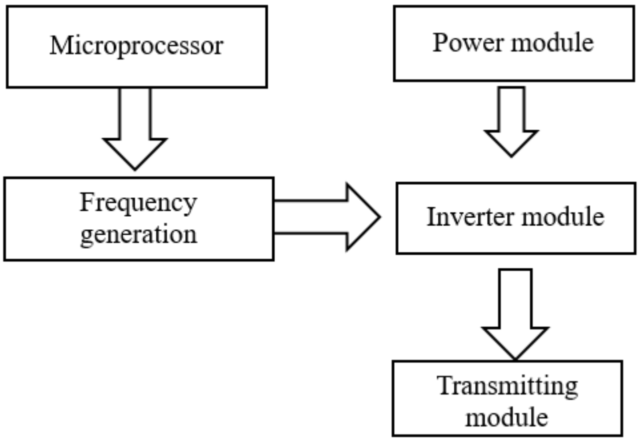

Figure 1: Circuit diagram

3.1 Hardware

(1) The power source is mainly supplied by 220V AC, and then converted from AC/DC to DC voltage. 24V DC is generated by LM7824 chip, and 3.3V DC is generated by LM317 chip, wherein 160V DC voltage is directly connected to the circuit.

(2) The frequency is mainly generated by the square wave signal with 50% Larmor frequency duty cycle, which is controlled by the initial phase, mainly by the 48-bit STM32F101C6T6 chip. The signal is directly output by the MCU, which makes the transmission frequency of the NMR water detector transmitter more accurate.

(3) The inverter is realized through the H-bridge circuit to complete the transformation of DC to high-power AC square wave signal.

(4) Through LC series resonance, we could achieve the emission pull mole frequency.

4. Hardware circuit design

4.1 Driver circuit design

In this paper, I2110 of American IR company is used as the driving circuit chip. It is a common driver, it has the advantages of optocoupler isolation and electromagnetic isolation (small size, fast speed). Due to the adoption of HVIC and latch-lock anti-interference CMOS manufacturing process, with independent low and high-end input channels, so it is easy to use and strong functionality, which is in line with the needs of use[6].

Figure 2 shows the IGBT driver circuit designed by using IR2110. (Figure 3). It is composed of two units, each of which drives the two switching tubes of the H-bridge drive circuit, namely, the U11 driver chip drives Q11 and Q14, and the U12 driver chip drives Q12 and Q13. The U11 and U12 are powered by two 24V AC/DC conversion circuits respectively, where the power supply of the U11 and U12 is connected to two capacitors, and the two capacitors are in common ground. According to the IR2110 chip introduction and user manual, the selection of IGBT tubes should be tubes that can withstand 220V voltage and can pass through 300A current.

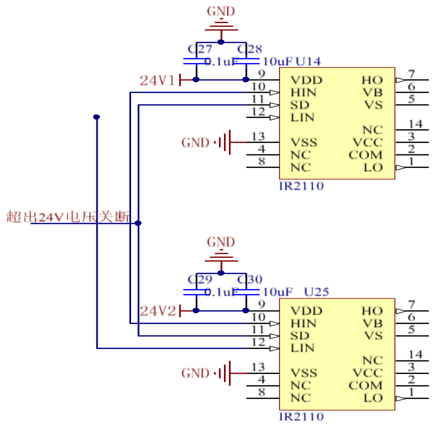

Figure 2: Drive circuit diagram

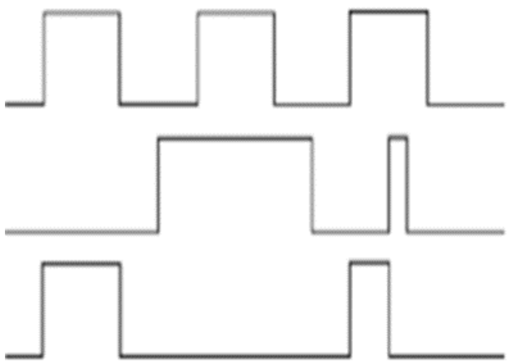

Figure 3: IR2110 input and output timing diagram

Before driving the circuit, it is necessary to add a reverse proportion to make the output voltage stable and the front and rear impedance matched.

4.2 Frequency circuit design

This part is composed of single chip microcomputer, trigger circuit and drive circuit, etc. Its working process: the single chip microcomputer (STM32F101C6T6) outputs the frequency, and starts the drive circuit through the trigger circuit to achieve the generation of the Larmor frequency.

The single chip microcomputer mainly generates square wave signal with Larmor frequency. The clock output end of STM32F101C6T6 is supplied by an active crystal oscillator. Due to the characteristics of the H-bridge inverter circuit, it can maximize the depth and accuracy of water search. The duty cycle ratio of PWM square wave signal output here is 50%. Our transmission frequency is (1-3KHz). According to the equation:

$$f_{out} = 12/f_c$$

In the equation, f_c is the frequency range of the clock source, and STM32F101C6T6 can be calculated. If the frequency is (1-3KHz), the active crystal oscillator should be selected as 4KHz and 12KHz. Pin 5 (crystal oscillator input), pin 6 (crystal oscillator output), pin 3 (crystal oscillator input) and pin 4 (crystal oscillator output) are respectively connected to the 4Khz crystal oscillator and 12KHz crystal oscillator. Since the nuclear magnetic resonance water search needs to be in a high-power situation to generate Larmor frequency, so the machine will not have a low power or hibernation state when running. Here the 10 pin (waking up the MCU, let the MCU into the normal working state) is not connected. The 7 pin (asynchronous reset) is connected to a reset circuit, using a general 10UF capacitor and 4.7K resistor and set up a switch. When the switch is pressed, the machine is reset. In the operation, the setting of Larmor frequency can be determined by the keyboard input MCU, the maximum bit machine, amd it does not need to start through serial port (SPI) communication, so pin 20 (determining the state of the chip after the reset) and pin 21 (determining the state of the chip after the reset) are connected to a resistor after the grounding program starts from flash. (See Figure 4)

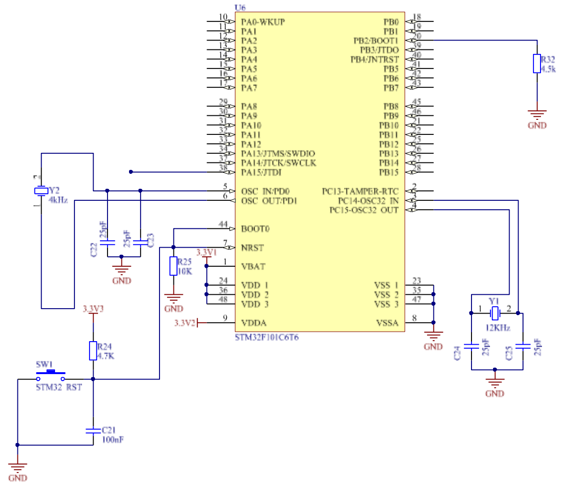

Figure 4: Frequency generation part of the circuit diagram

4.3 Buffer circuit design

In order to use a typical turn-off voltage waveform of the discharge blocking buffer circuit (Figure 5), Figure 6 shows the working principle of the buffer circuit. During the IGBT turn-on period, the capacitor is charged to the DC voltage V_{CC}. When the IGBT is turned off, the stray inductance distributed in the DC loop of the inverter causes the voltage V_{CE} on the collector and emitter to rise rapidly beyond the voltage on the buffer capacitor. The buffer diode is forward-biased, and the buffer circuit starts to work. The buffer capacitor absorbs the energy on the stray inductance, reduces the amplitude of V_{CE} rise. The first peak voltage is caused by the reverse recovery of the stray inductance of the buffer circuit and the buffer diode. Non-inductive components and fast diodes can be used to reduce the peak voltage. After the first peak voltage, the buffer capacitor begins to charge and V_{CE} rises again. At this time, the voltage and current on the buffer circuit meet Equation (1) and Equation (2) respectively, where C is the buffer capacitance value, I_0 is the current flowing through the IGBT at the turn-off time. L_B is the stray inductance of the DC loop, T_{off} is the turn-off time. And the voltage on the buffer capacitor rises to the second peak when the turn-off process is over. The capacitor then starts discharging through the buffer resistor and the voltage returns to V_{CC} in preparation for the next shutdown. [5][7][8]

$$V_{CE} = V_{CC} + \frac{1}{C}\int_0^{T_{off}} i(t)dt \tag{1}$$

$$i(t) = I_0 \cos\left(t/\sqrt{L_B C}\right) \ldots. \tag{2}$$

As can be seen from Equation (1) and Equation (2), in order to reduce the peak value of the second peak voltage on the IGBT during the shutdown process, it is necessary to increase the buffer capacitance value. However, a large capacitance value will increase the average current flowing through the diode during the shutdown process, which will increase the cost, so the higher the capacitance is, the better it is. It will be described as follows [5][9][10].

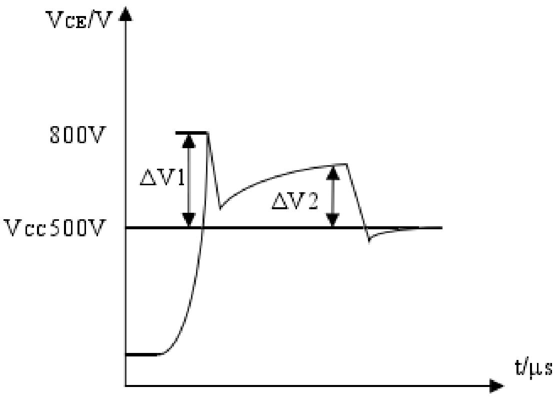

Figure 5: Typical turn-off waveform of an IGBT with buffer circuit

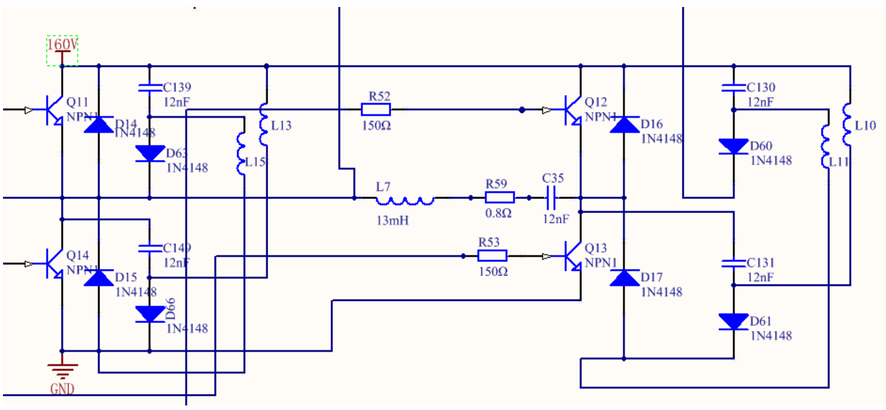

Figure 6: Schematic diagram of the H-bridge with buffer circuit

4.4 Fast absorption circuit design

The capacitor C2 is connected in parallel with the output end of the IGBT, and there are positive and negative parallel diode modules in series, grounding the NMR detector to transmit and receive the same coil, which requires a fast switching switch between the transmitting and receiving loops, which is achieved by using a vacuum high-voltage relay, so as not to affect the reception of nuclear magnetic signals. At the same time, when IGBT outputs signals of Larmor frequency, the loop resonates in series. At this time, capacitor C2 and diode module will not affect the loop operation, because the diode on-resistance is very small and can be ignored. Capacitor C2 is equivalent to cut-off circuit at this time, and the loop is in a free oscillation state when IGBT has no output signal. The coil and capacitor C1 and C2 are resonated in parallel, and the resonant frequency is $\frac{1}{2\pi\sqrt{LC}}$, where $C = \frac{C_1C_2}{C_1+C_2}$, so that it is far away from the Larmor frequency, which will not interfere with the nuclear magnetic resonance phenomenon, and achieve the purpose of fast shutdown. While the diode tube pressure drop is certain. At this time, the current in the loop will become smaller and smaller, so the equivalent resistance of the diode will become larger and larger, which will consume more energy in the loop and speed up the switching speed of the loop. When the voltage at both ends of the diode is less than 1V, the diode will automatically shut down and cut off the connection between the coil and the transmission circuit. The coil itself is connected to the input end of the receiver amplifier, and the parallel capacitor resonates with the coil. Thus, the magnetic resonance signal induced in the coil is received to the maximum extent, and the fast switching absorption function is well realized in the process cycle [5][6][7]. (See Figure 7)

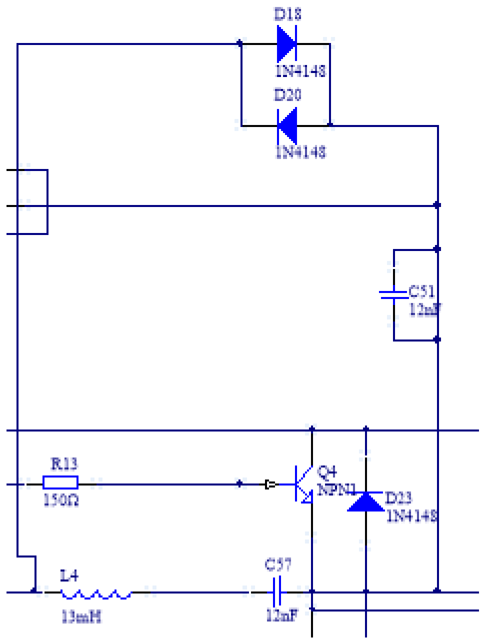

Figure 7: Fast absorbing circuit

4.5 Power source design

As for the design of the power source, considering the impact of too high voltage on the safety of the mine, we adopted a new type of transmitting coil to achieve the purpose, while reducing the voltage, in which the +160V voltage is achieved by the chip FANC7554 and AC/DC conversion circuit, in order to make the power supply have more power. This is achieved by charging the electrolytic capacitor. For the underground environment, the use of multiple DC power supplies will affect the operation of the transmitter. So we will use 220V AC power through AC/DC conversion to achieve that purpose. In order to ensure the efficient and smooth DC output, the filter capacitor is used. The design of the power supply here is mainly composed of 220v AC power supply, FAN7554 chip, LM317 chip, LM2596S-5.0 chip, LM7824 and LM7812 chip.

When the power supply is in normal operation, the whole process is controlled by the STM32 chip, which generates +160V, +24V, +12V, +5V and +3.3V DC respectively through these chips and circuits. Among them, +160V DC is a high-power power supply, which is used to stimulate the puller frequency, and +24V DC is mainly used to power the IR2110 chip for H-bridge trigger. +12V power supplies overvoltage protection circuit, +5V DC is mainly used for display module power supply, +3.3V DC is used for STM32 chip.

5. Circuit simulation by designing

The expected goal can be achieved through simulation. See Figure 8.

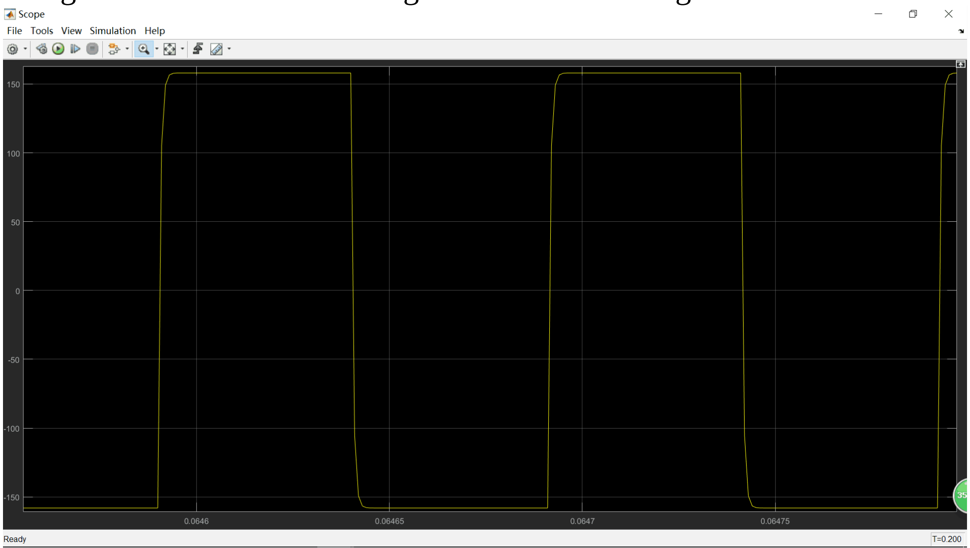

Figure 8: Simulation of the output waveform

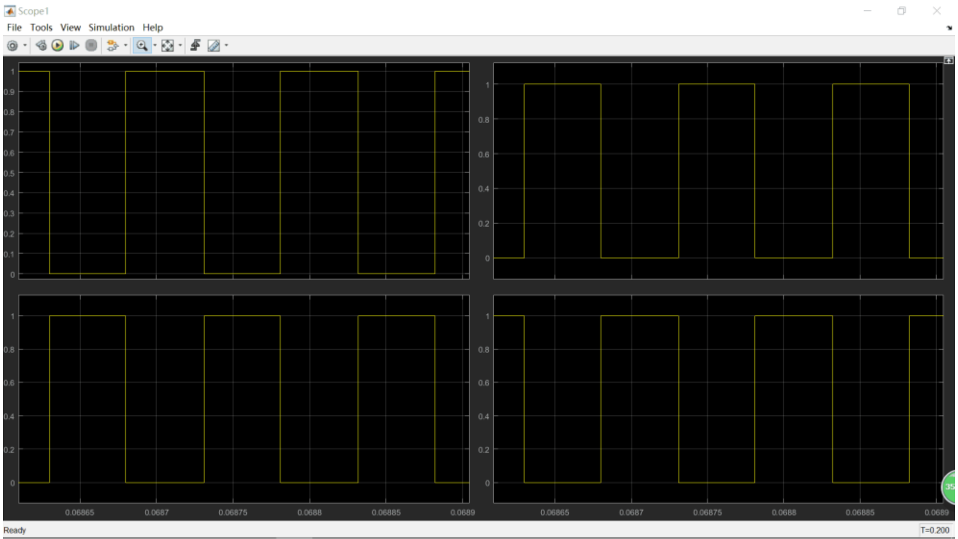

Figure 9: Signal waveform of four IGBT tubes

As shown in Figure 8 and Figure 9, signals with a duty cycle of 50% can be output to achieve the maximum detection depth of the Larmor frequency.

6. Conclusion

This paper completes the overall design of the transmitter of the mine NMR water finder, uses the key technology and overcomes the design difficulties, and completes the simulation. With the deep understanding of Larmor frequency, the high power signal is transmitted by low voltage, which ensures the safety of underground work. Moreover, the output of PWM50% duty cycle and the signal of in-phase transmission are realized by single chip microcomputer. The typical LC series resonant circuit is adopted in the transmission, which makes the energy utilization more effective and improves the safety of the circuit through the protection of overvoltage.

References

[1] Shi Wenlong. Development of prototype principle of full wave receiving system for nuclear magnetic resonance groundwater detection. Jilin University, 2014.

[2] Wang Longqin. Research on mine flood emergency rescue management system based on GIS. Guizhou University, 2015.

[3] Zhang Xiaohua. Development of prototype of nuclear magnetic resonance water finder. Jilin University, 2006.

[4] Li Tianchao. Research and design of experimental prototype of nuclear magnetic resonance water finder. China University of Geosciences (Beijing), 2008.

[5] Jiang Yanqiu. Development of transmitter for ground nuclear magnetic resonance water finder. Jilin University, 2006.

[6] Ding Zhuyu. Research on automatic temperature control system of pepper drying room based on fuzzy PID. Southwest University, 2014.

[7] Ayachit, U. The Para View Guide: A Parallel Visualization Application. Kitware, Inc., 2015.

[8] Legchenko A, Beauce A, Guillen A, Valla P and Bernard J. Natural variations in the magnetic resonance signal used in NMR groundwater prospecting from the surface. European Journal of Environmental and Engineering Geophysics, 1997, 2:173-190.

[9] Jin, J. M. The finite element method in electromagnetics. 3rd ed.: Wiley-IEEE Press, 2014.

[10] Shen Yimin, Hironori KAJI, Fumitaka Horii. An Exact Solution of a Mas Fid in Two-Site Exchange Problem. Chinese Journal of Magnetic Resonance, 1999, 16 (6): 485-493.