Time Delay Module Design, Simulation and Synthesis Based on FPGA for Dielectric Dispersion Logging

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Abstract— A few years ago, a kind of dielectric scanning imaging logging instrument emerged in the foreign markets. That instrument scanned the earth at different frequency electromagnetic wave. It can measure the dielectric constant at different frequencies of the layer. There is not any similar instrument developed at home. Xi'an Shiyou University has launched a project to develop a comparable instrument. This paper introduces the basic principle of dielectric dispersion logging. A general layout is given for the dielectric dispersion logging. The time delay module is simulated and synthesized based on FPGA. This laid the foundation for the development of comparable instruments gradually.

1. INTRODUCTION

Dielectric logging is known for a group of logging method by using the rock dielectric constant to distinguish between different strata. It is currently the most potential one of the logging technologies. It uses a transmitting coil and two receiving coils. The coil center is in the well shaft. A transmitting antenna transmits electromagnetic (EM) wave to the layer. Because of the influence of EM wave propagation, there is phase change and amplitude attenuation in the propagation process. It leads to a difference in the signals' phase and amplitude of the two coils. The two receiving antennae can be used to received the layer's EM wave phase difference and amplitude ratio. The phase difference and amplitude ratio are functions of the layer's resistivity and dielectric constant. It can be used to inversely calculate the layer's resistivity and dielectric constant.

The relevant research of dielectric logging is started from the former Soviet Union. In 1966, a new kind of method of high-frequency logging was proposed in the former Soviet Union. Its principle is putting two receiving coils nearby the transmitting one, and detecting the EM wave's phase difference between the two receiving coils. When the detection frequency is nearly tens of MHz, the phase difference mainly depends on the rock dielectric constant. Thus far, the Soviet Union completed the relevant theoretical research, manufactured a prototype, and tested the prototype in the well smoothly. As a result, high-frequency logging is used in the production [1–3]. In America, the most well-known instrument is Schlumberger's Electromagnetic Wave Propagation Tool. Its operation frequency is 1.1 GHz [4]. In 2010, high frequency dielectric logging tool with 1 GHz frequency that developed by Halliburton is put into commercial application [5].

In China, many institutes have developed this technique. Nowadays dielectric logging tools have been successfully put into markets [6]. Their function is equivalent to Schlumberger's instrument.

All the above is about the dielectric logging technology of a single frequency. The dielectric dispersion logging technology is to emit different frequencies of EM waves into the stratum. Different frequencies mean different dielectric constant. According to the analysis result of the scanning information, it can reverse the stratum's structure.

In 2010, Schlumberger released the dielectric dispersion logging instrument. The instrument can measure the stratum's water saturation and rock structure [7]. Field test results show that it provides a new method to find oil and gas. But its current price in China is extremely expensive. Xi'an Shiyou University has launched a project to develop dielectric dispersion logging equipment. As an early work, the authors have carried on the corresponding research. This paper introduces the basic principle of dielectric dispersion logging and its framework design, and the time delay module has been simulated and synthesized based on FPGA.

2. TIME DELAY DIFFERENCE OF DIELECTRIC LOGGING

If emit EM wave into the stratum, the stratum's EM parameters will be reflected in the amplitude and phase of EM waves, such as the stratum's dielectric constant, resistivity and magnetic conductivity. Generally speaking, there exist great differences of the dielectric constant among oil, water, and rock matrix. For example, at normal temperature the relative dielectric constant of water is about 80, while the oil's is about 2.0–2.4, and the rock matrix' is about 3–9. Thus far, in some logging circumstances it has great advantages to using dielectric constant parameter instead of resistivity parameters.

The dielectric constant of strata can usually be expressed in a complex form as below: $\varepsilon = \varepsilon' - j\varepsilon''$, where, the real part $\varepsilon' = t_{p1}/\mu_{0=}\alpha/(\omega^2\mu_0)$, the imaginary part $\varepsilon'' = 2\alpha t_{p1}/(\omega\mu_0)$, t_{p1} is EM wave's propagation time delay per meter, μ_0 is the magnetic permeability of vacuum, α is EM wave's propagation attenuation coefficient per meter, ω is the EM wave's angular frequency, j is the imaginary unit. Usually the so-called dielectric constant refers to the real part, while the imaginary part comes from the EM wave's attenuation when propagating in the medium. The imaginary part is not zero means that the medium absorbs the EM energy and converts it into heat. Since ω and μ_0 are known, the complex dielectric constant ε can be reached as long as t_{p1} and α are measured.

Usually dual-frequency technique is used to detect dielectric constant. Then reverse the stratum information. The so-called "dual frequency" is to change the detection depth by using two different working frequencies, such as Western Atlas's dual-frequency dielectric logging instrument. The deep detector uses 47 MHz operating frequency, and the shallow detector uses 200 MHz operating frequency.

And Schlumberger's dielectric dispersion logging instrument can use EM wave to scan the stratum with a band from 1 MHz–1 GHz. It can depict the dielectric constant of the entire frequency band. For us, our approach is selecting 4 frequency points to detect the dielectric constant in the 1 MHz–1 GHz frequency range. It is enough.

As shown in Figure 1, it is the principle of the dielectric dispersion logging instrument designed by the authors.

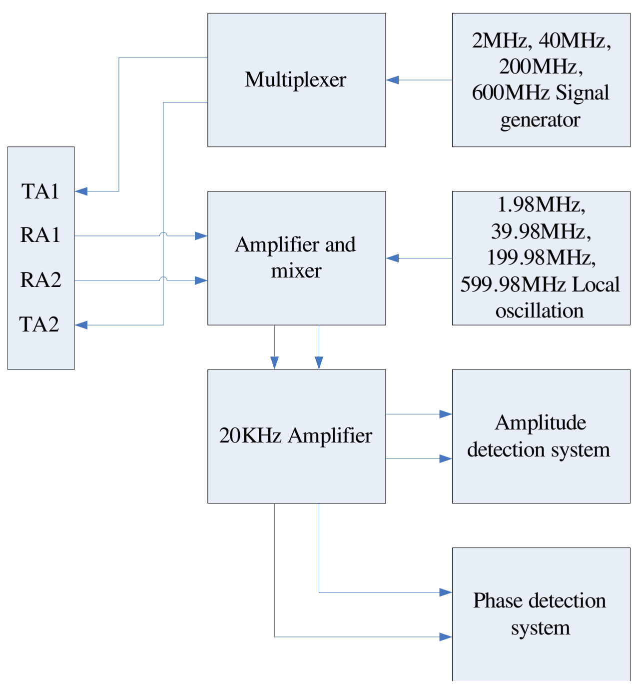

Figure 1: Principle of the dielectric dispersion logging instrument.

In Figure 1, there are 2 transmitting antennas TA1 and TA2, and 2 receiving antennas RA1 and RA2. The signal source can respectively emit 4 EM waves of different frequency: 2 MHz, 40 MHz, 200 MHz and 600 MHz. It uses double transceiver working mode. This paper mainly studies the module of time delay. Assuming that the frequency of the emitting signal $S(t)$ is $\omega = 600$ MHz, then the output of receiver RA1 is $R_1(t) = A_1 \sin(\omega t + \varphi_1)$, the output of receiver RA2 is $R_2(t) = A_2 \sin(\omega t + \varphi_2)$. The frequency of the local oscillation signal $S_L(t) = A_L \sin(\omega_L t + \varphi_L)$ is $\omega_L = 599.98$ MHz. The local oscillation signal mixes with the output of the first receiver, and the result is $M_1(t) = S_L(t) * R_1(t) = A_L \sin(\omega_L t + \varphi_L) * A_1 \sin(\omega t + \varphi_1)$. Passing through the low-pass filter, filtering out the sum frequency term, taking into account the transmission coefficient of the filter K_1, we arrive at the difference frequency term as below: $M_1(t) = 0.5{*}K_1 A_L A_1 \cos[(\omega-\omega_L)t+\varphi_1\varphi_L]$. Similarly, the output of the second mixer is $M_2(t) = 0.5 * K_2 A_L A_2 \cos[(\omega - \omega_L)t + \varphi_2\varphi_L]$. Suppose that $K_1 = K_2$, therefore the time delay difference of the two mixer's output can be calculated as

$\Delta\varphi = (\varphi_2 - \varphi_L) - (\varphi_1 - \varphi_L) = \varphi_2 - \varphi_1$. Accordingly, it provides a reference for the inversion of the dielectric constant.

3. SIMULATION AND SYNTHESIS BASED ON FPGA

As to the time delay module, the authors write source codes based on the Verilog HDL. The time delay module is simulated by Modelsim software. As shown in Figure 2, it is the simulation result. In Figure 2, clk is the system clock, and CP is the input signal. CP consists of CP1 and CP2. CP1 and CP2 are differential frequency signals. When the rising edge of CP1 comes, it generates a rising edge at the output Qout; when the rising edge of CP2 comes, it generates a falling edge at the output Qout. The high level width of Qout is the time delay difference of CP1 and CP2.

Using the clock signal clk to count in the time of high level of Qout, we can know the length of time delay difference.

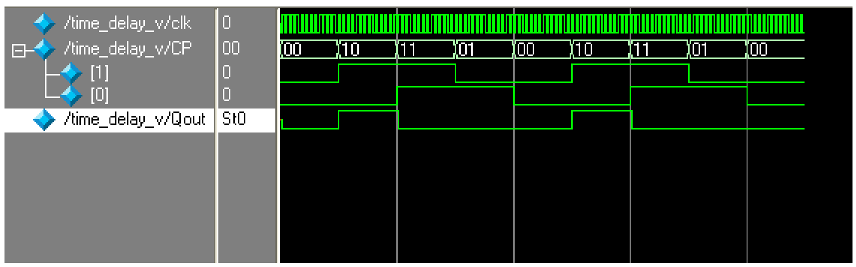

Figure 2: Simulation result of the time delay module.

As shown in Figure 3, it is the hardware synthesis result of this module. The hardware synthesis is based on Synplify software. The hardware structure of the system is very simple. It mainly consists of a multiplexer and a D flip-flop. The output of the multiplexer is used as the input of the D flip-flop. The CP signal is used to control the multiplexer. The synchronous clock clk is used to control the D flip-flop.

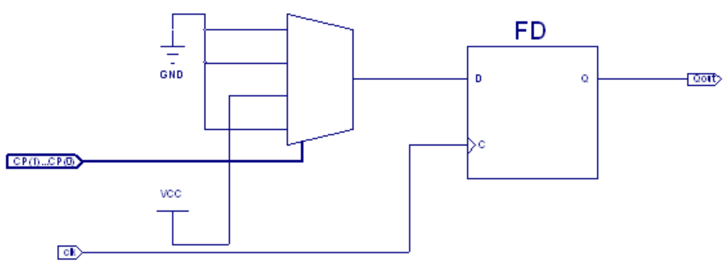

Figure 3: Synthesis result of the time delay module.

4. DISCUSSION

The dielectric dispersion logging technology is reviewed in this paper. The principle of the dielectric dispersion logging is introduced. The authors establish a model on how to extract the time delay signal. Software simulation and hardware synthesis are carried on this model. The simulation results accord with the theoretical expectations. The next step goes to study the amplitude attenuation module.

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