Application of Four-Channel Broadband Transmitter in Coal Mine

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Abstract. For the situation of water bursting and gas security in coal mine, a wireless transmitter system was designed to survey the water, gas and other geological structures in the coal seam. The Four-channel broadband transmitter is to generate multiplexed high-frequency pulse signal from the FPGA, through power amplifiers respectively, and the high frequency signals are fed via antennas into the ground, then completing the launch function. The results showed that application of Four-channel broadband transmitter technology is achievable, and the antenna act as the most important part of transmitter is also tested by HFSS simulation and network analyzer, the testing result is better. Studies suggest that the design of transmitter can be applied to the advanced detection of coal seam, which has played a leading role for the application of wireless detection technology in the promotion.

Keywords: Transmitter · FPGA · Four-channel · Antenna

1 Introduction

With the rapid development of wireless communication technique, the wireless detection technology has been more and more widespread used in the mining filed. Especially during the process of mining, the advanced detection of the conditions of coal seam can reduce the water inrush accident and gas leak [1–3]. The wireless detection technology use a transmitter to send signals during the antennas. Then the structure, type and distribution of underground media is deduced according to the difference between the various medias' electrical parameters and the receiver signals.

In this paper, we design a transmitter, which can be used in the wireless detection technology for coal mining. The Shape structure, types and distribution of the underground medium can be detected by using the technique of multi-frequency &Four-channel. It has important practical significance for learning the surrounding of coal seam ahead of time and reducing coal mining accident [11]. Considering the problem of the signal stability and multiple frequency, a FPGA development board is used to generate signals. The presented system of transmitter can not only meet the requirement of advanced detecting coal seams, but also be applied in other fields.

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2 The System Structure

The transmitter is made up of three main parts, the signal generator, the power amplifier and the antenna. Firstly a FPGA Cyclone IV is used to generate Four-channel high frequency pulsed signals. Then the signals are power amplified by a RF Power Transistor. A quarter-wave patch antenna is applied to transmit the signals output by the power amplifiers. Figure 1 shows the structure of a kind of wideband transmitter with four-channels.

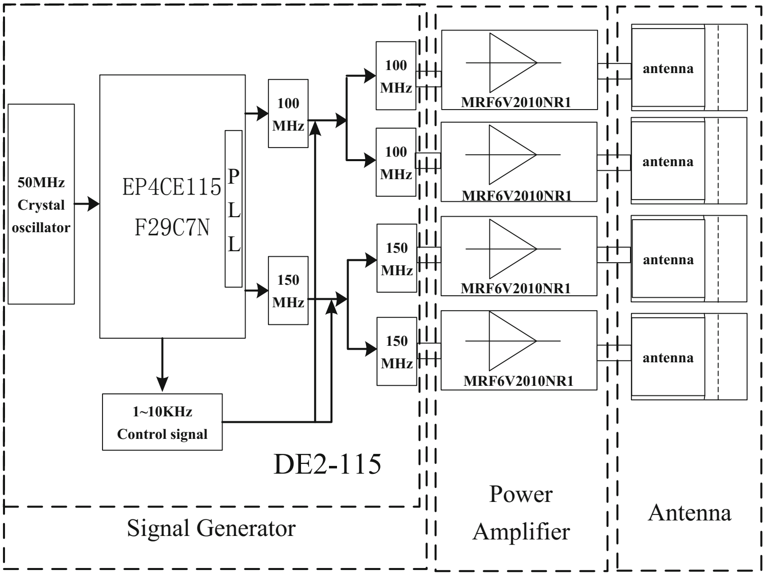

Fig. 1. Structure diagram of Four-channel broadband transmitter

2.1 The Signal Generator

The transmitter will firstly generate wideband pulse signal, and the range of signal frequency is from 50 MHz to 200 MHz. Taking advantage of avalanche transistors, the nanosecond pulse generator has been frequently-used. Though it can generate signals with large amplitude, the circuit design and adjustment process are complex. To get more stable and smart pulse signals, a FPGA development board, the present popular tool, is used as the signal generator. Figure 2 shows the main structure the generator. The multiple-frequencies signal and output control signal can be produced simultaneously. And the delayed signal, coded by Verilog Language, is used to control the signal generated.

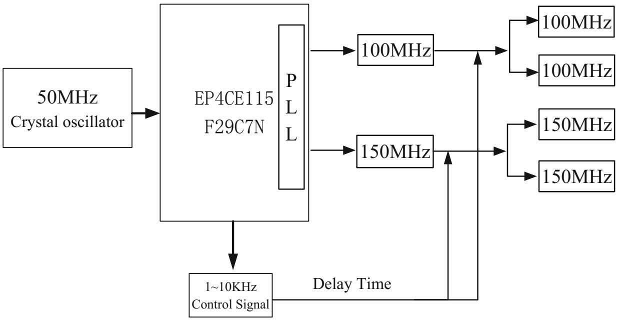

Fig. 2. Signal generator

2.2 The Power Amplifier

Due to the power is too small, the signal outgoing signal of the FPGA development board can not be sent out directly. A power amplifier is needed to improve the signal power. According to the power and frequency of the output of the signal generator, the MRF6V2010NR1 Field Effect Transistor developed by Freescale combined with a peripheral circuit is designed in Fig. 3 as the power amplifier (Table 1).

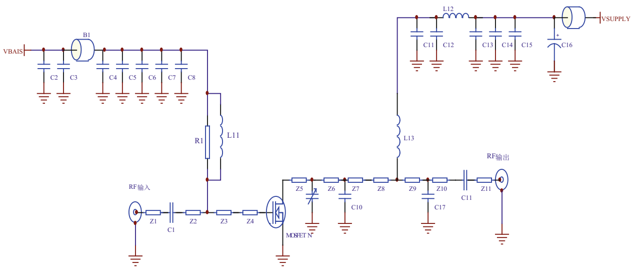

Fig. 3. The application circuit of MRF6V2010NR1

Table 1. The parameters of RF power amplifier MRF6V2010NR1

Parameters	Value
Working frequency range	10 ~ 450 MHz
Input power	7–15 dBm
Output power	30–40 dBm
Power gain	18 ~ 22 dB
Noise figure	4 dB
Three-order intercept point	40.5 dBm

2.3 Antenna

The function of the antenna is to convert electromagnetic energy into electromagnetic field, and the electromagnetic field in the space is converted to electromagnetic energy to receive electromagnetic wave, which is the transmission and sending electromagnetic energy of the conductive element [9]. As the most important component of the transmitter, the performance of the antenna can play a decisive role in the correct realization of the whole system. The design requirements of the transmission frequency in 50 MHz ~ 200 MHz, microstrip patch antenna is not only able to meet the frequency requirements, but also to compare with the general antenna, with a light weight, small size and easy to achieve, and so on. Therefore, the design of microstrip patch antenna, through its continuous optimization to achieve system functions.

The following is the central frequency of 150 MHz patch antenna design process:

(a) Theoretical calculation of the various parameters of the patch.

The design uses 1/4 wavelength microstrip patch antenna, Fig. 4 is the principle of 1/4 wavelength patch antenna:

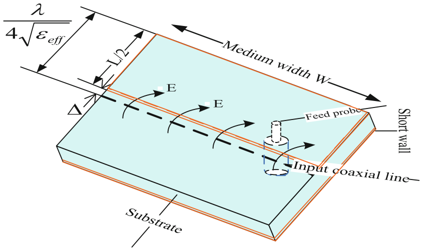

Fig. 4. Theory of quarter-wavelength patch antenna

A virtual short circuit is formed on the surface of the middle of the two radiation edge when the patch antenna is working at the lowest die. So the patch can be used in half of the short circuit to produce the antenna [5]. Then the E surface direction map is stretched to a single gap. The resonance length is about 1/4 of the wavelength in the medium of the substrate. Using the patch width W for the effective dielectric constant $\varepsilon_{有效}$ of the microstrip line and the equivalent radiation width ΔL are used to calculate the resonance length L of the 1/4 wavelength patch.

$$\frac{L}{2} = \frac{\lambda}{4\sqrt{\varepsilon_e}} - \Delta L \tag{1}$$

The patch width, effective dielectric constant and the equivalent radiation width are calculated as follows:

$$W = \frac{c}{2f_o}\left(\frac{\varepsilon_r + 1}{2}\right)^{-\frac{1}{2}} \tag{2}$$

$$\varepsilon_{有效} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}(1 + 12\frac{h}{W})^{-\frac{1}{2}} \tag{3}$$

$$\Delta L = 0.412\frac{(\varepsilon_e + 0.3)(W/h + 0.264)}{(\varepsilon_e - 0.258)(W/h + 0.8)}h \tag{4}$$

At the same time, a series of probes or etched with the patch between the hole to achieve short circuit. The transmission line model of the antenna increases the inductance component. The equivalent extra length Δl can be obtained from a parallel plate model, which is equivalent to a uniform spacing of the probes. The distance of the probe center is S. Radius is r, and the wavelength of the medium is $\lambda_d = \lambda_0/\sqrt{\varepsilon_r}$, which is calculated by the reduction of the length of the patch:

$$\Delta l = \frac{S}{2\pi}\left[\ln\frac{S}{2\pi r} - \left(\frac{2\pi r}{S}\right)^2 + 0.601\left(\frac{S}{\lambda_d}\right)^2\right] \tag{5}$$

As for the feed position, the formula (6) gives an approximate feed position from the side of the short circuit.

$$x = \frac{L}{\pi}\sin^{-1}\sqrt{\frac{\mathrm{R}_i}{\mathrm{R_e}}} \tag{6}$$

Because of the $R_e = \frac{1}{2G}$, so the radiation conductance of the single edge is:

$$G = \frac{\pi W}{\eta\lambda_0}\left[1 - \frac{(KH)^2}{24}\right] \tag{7}$$

With the movement of the feed position, the resonant frequency will be slightly deviated (Table 2).

Table 2. 150 MHz center frequency of the quarter-wavelength antenna parameters

Parameters	Value
Effective dielectric constant ε_e	4.071
Length L/2	178.955 mm
Width W	140 mm
Thickness h	7 mm
Equivalent radiation width ΔL	3.221 mm
Single edge radiation conductance G	0.562 mS
Feed coordinate x	37.33 mm

(b) Model simulation.

The patch antenna is simulated by ADS software of Agilent company.

(c) Material selection

For the patch antenna, dielectric material is FR4, selecting patch for the copper, choosing a thick copper for wire probe.

(d) Making antenna

The antenna production process is complex, using AB glue to paste and press, looking for the feed point and joining the coaxial line, making the antenna finally.

(e) Theoretical and practical comparison

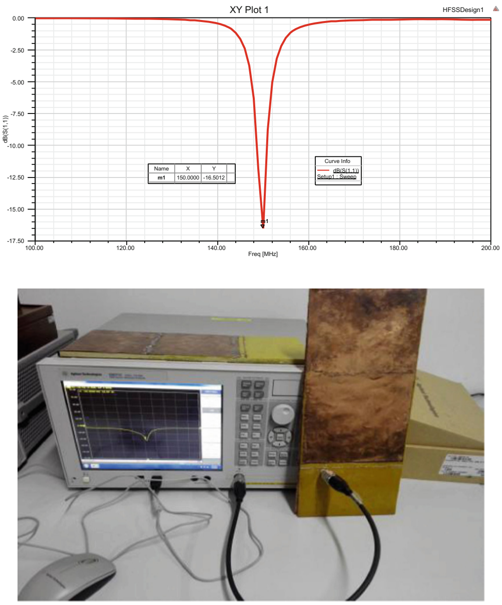

Fig. 5. Comparison chart of simulation and physical results

HFSS simulation software is used to simulate the model, and the simulation results are compared with the simulation results of the network analyzer, as shown in Fig. 5.

Figure 5 shows that there is a litter error between the antenna and the theoretical analysis of the actual production, but the error range is small, so it is necessary to test and optimize the actual production of the antenna, so that its performance is the best.

Figure 6 is the simulation results of the antenna in the 50 MHz $\sim$ 200 MHz frequency gain by HFSS simulation software. The analysis shows that the total gain effect is remarkable, and it is consistent with the broadband characteristic.

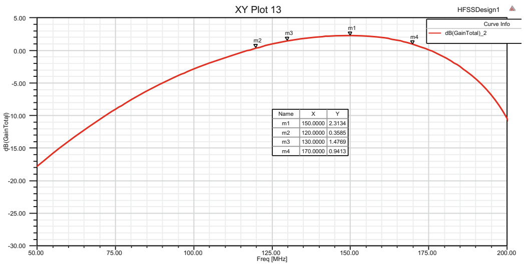

Fig. 6. Gain Total of 100 MHz ~ 200 MHz

3 Conclusions

This article describes the overall design of the Four-channel broadband transmitter, In particular, this paper has completed the design of the antenna portion, which plays a crucial role in the performance of the entire transmitter. The results show that Four-channel broadband transmitter can achieve the basic requirements for the coal seam detection, and reach the designed requirements. The author believes that the wireless detection technology has a great advantage in the coal seam detection. Four-channel, multi-frequency point selection, it can increase the capacity of the coal seam detection, In addition, the design and implementation of the band broadband antenna can improve detection the coal seam depth. It will not only be able to determine the thickness of the seam, but also to achieve the coal seam geological structure detection, This reduces the occurrence of water inrush, methane gas and other accidents in the coal mining process. The study result suggests that the designed transmitter can be used in the coal seam leading exploration, It promotes the application of wireless advanced detection technology.

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