An Active E-field Sensor Based on Laser Diode for EMP Measurement

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Abstract

A kind of active E-field sensor based on Laser diode and fiber-optic link for EMP measurement is designed and fabricated. The sensor uses an asymptotic conical antenna to sense the incoming E-field. And the derivative signal of the antenna is processed by an active integrator based on high speed operational amplifier. A DFB-LD (Distributed feedback laser) is employed to convert the electrical signal to optical signal. The test results show that this kind of sensor can be used to detect nanosecond electromagnetic pulse.

1. Introduction

In High-Power Electromagnetics research field it is unavoidable to measure electromagnetic pulse (EMP) signals which rise-time can be several nanoseconds. So sensors for such transient pulse signal detection must have high bandwidth to capture the nanoseconds signals. One kind of E-field sensor for the nanosecond fast transient pulse is designed and fabricated in this paper.

D-dot antenna is a kind of broadband E-field antenna first proposed by Carl E. Baum[4]. Generally speaking the work bandwidth of D-dot antenna can be several GHz. So ACD (asymptotic conical antenna) is selected as the receiving antenna of the E-field sensor. But the ACD's output signal is the derivative of the E-field. Generally there are two ways to get the original signal. One way is processing the antenna's output signal through a passive integrator[6]. Another way is integrating the digital signal by software on computer. While in this paper an active integral circuit is proposed to get the original signal. An electro-optical converting circuit is also integrated in the sensor. So the signal can be transmitted by fiber which can reduce the interference by the electromagnetic environment be possible.

2. Sensor design

2.1 General configuration

The sensor for the electromagnetic pulse is composed of three parts: the asymptotic conical antenna, the active integrator and the electro-optical converting circuit. The configuration diagram of the sensor is shown in Fig.1. Monopole ACD is chosen as the receive antenna. The monopole antenna needs a relatively large metal plane to get a mirror image antenna. So the height of the monopole antenna must less than one-eighth of the shield shell's side length. The height of the antenna is also constrained by the upper limit of the sensor's operating frequency. A kind of active integral circuit is proposed to process the ACD's output signal. An electro-optical converting circuit is designed to convert the electrical signal to optical signal and sensor's measurement signal is transmitted by fiber. The whole circuit is battery powered and shielded in an aluminum case. The sensor shape is shown in Fig.2.

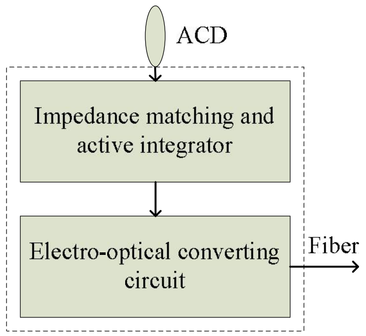

Fig.1 Configuration diagram

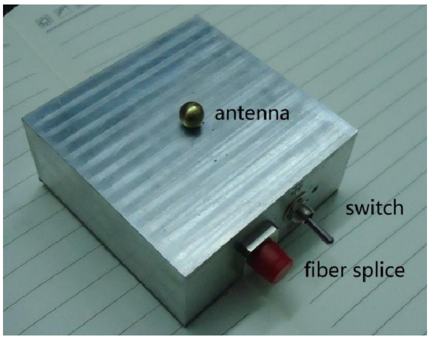

Fig.2 Sensor shape

2.2 Design of the ACD

The asymptotic conical is designed based on equivalent charge method which is described in detail by G. D. Sower[5]. The antenna geometry is determined by equipotential surfaces of a particular static charge distribution. Through this method various important electromagnetic parameters of the antenna such as the equivalent capacitance and equivalent area can be calculated accurately.

For a conical half-angle θ of the antenna we can have the monopole antenna characteristic impedance *Zc* by

$$Z_c = 60\ln\left[\cot\left(\frac{\theta}{2}\right)\right] \tag{1}$$

If we choose the antenna characteristic impedance to be 50 Ohm the conical half-angle will be 47°. For any given conical half-angle and the height of the antenna *h* the height of the line charge z_0 can be determined by

$$\ln\left[\cot\left(\frac{\theta}{2}\right)^2\right] = \ln\left(\frac{h^2}{h^2 - z_0^2}\right) + \frac{2z_0^2}{h^2 - z_0^2} \tag{2}$$

Then the equivalent capacitance of the antenna is given by

$$C_{eq} = \frac{4\varepsilon_0 \pi z_0}{\ln\left[\cot\left(\frac{\theta}{2}\right)\right]} \tag{3}$$

And the equivalent area of the antenna is given by

$$A_{eq} = \frac{3\pi z_0^2}{\ln\left[\cot\left(\frac{\theta}{2}\right)\right]} \tag{4}$$

The equivalent Norton circuit of the antenna is shown in Fig.3. The transfer function of the antenna is given by

$$\frac{V(s)}{E(s)} = \frac{s\varepsilon_0 A_{eq} R}{1 + sRC} \tag{5}$$

So the cutoff frequency of the antenna can be calculated by $\omega_0 = 1/\left(RC_{eq}\right)$. On the lower frequency of ω_0, the output signal of the antenna is the derivative of the electrical field. If the height of the antenna chosen to be 10 millimeter the cutoff frequency of the antenna can be as high as 24 GHz. Actually this theoretical upper frequency limit couldn't achieve. Because the antenna's conical structure will be deformed at the vertex. The junction between the antenna and the integrating circuit can also introduce impedance discontinuity.

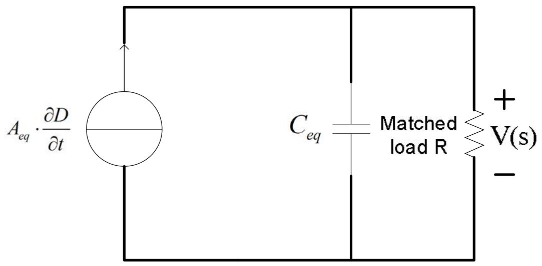

Fig.3 Equivalent Norton circuit of the antenna

2.3 Active integrator and electro-optical converting circuit

An illustration of the sensor's circuit schematic is given in Fig.4. The active integrator is composed of an operational amplifier, an integrating capacitor C_I and a resistor *R*. It is important to select the high speed operational amplifier to make sure the integrator have good high frequency response. The experiment shows that parasitic inductance of the integrating capacitor can distort the signal significantly. So in this paper high frequency microwave capacitor is chosen to be the integrating capacitor. In order to restrain the drifting of the operational amplifier's output a feedback resistor parallel with the integrating capacitor is needed. The corresponding time constant $\tau=RC_I$ must be more than 10 times of the pulse width of the measured signals.

In order to use fiber as the transmission media the electrical signal is converted to optical signal by a DFB laser. The laser needs a bias current to work in linear range and the inductor L is needed to block the driving signal which is modulated on the laser through coupling capacitor C_{couple}.

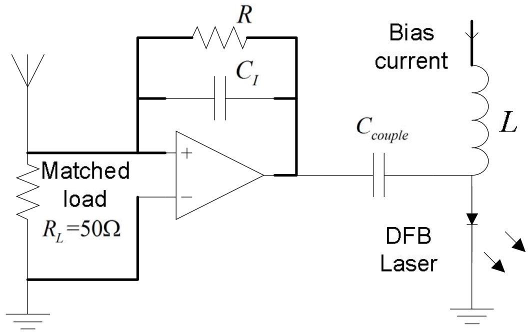

Fig.4 Principle circuit of sensor

3. Sensor performance

The calibration system is shown in Fig.5. The pulse generator is used to generate square pulses with 50ns pulse width. Uniform plane electromagnetic wave is produced by the TEM cell. And the sensor is placed in the middle position of the TEM cell to measure the pulsed E-filed.

Fig.6 shows the measuring result of the sensor. Solid line represents the voltage signal generated by the pulse generator and dotted line represents the measuring signal of the sensor. The 10~90 rise time of the solid line is about 1 ns and the 10~90 rise time of the received signal is about 3 ns. There is a time delay between the two signals because the fiber between the sensor and receiver is much longer than the coaxial cable connecting the TEM cell and the oscilloscope.

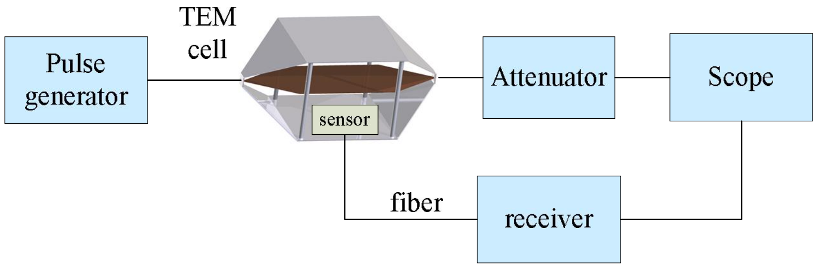

Fig.5 Calibration system

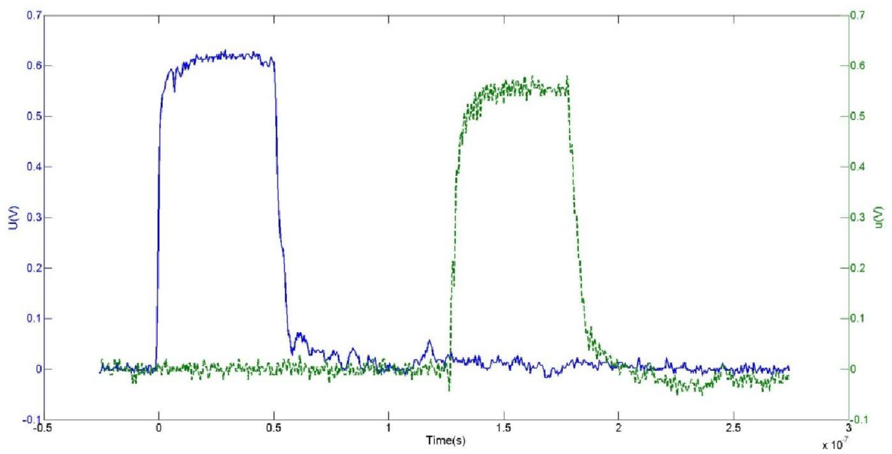

Fig.6 Test waveform

4. Conclusion

In order to detect the EMP of nanosecond rise-time, a E-field sensor with D-dot antenna and active integrator has been designed and fabricated. The experiment result shows that the sensor can capture transient pulse with fast rise-time of several nanoseconds.

In the future the sensor can be improved by optimizing the structure of the junction between the antenna and the integrator which can introduce impedance discontinuity. And the impact of the parasitic parameter can be decreased by optimizing the PCB design of the circuit and selecting circuit components with better high frequency performance.

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