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Nanosecond Pulser Based on Serial Connection of Avalanche Transistors

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***Abstract*—Generation and measure of nanosecond pulse with large amplitude are difficult problems in the field of exploration. The principle of avalanche transistor is analysised and four-stage serial connection of avalanche transistors is designed. Experimental results show that across the 50Ω load the amplitude of the output pulse can reach 666V and half-width is 3.4 nanosecond. Repeat frequency of the pulse can reach 10KHz. Time-domain waveforms of the pulse and the measure data are shown in the paper. The pulser and the RL-loaded bowtie antenna get matched. The pulser can be fabricated easily and works well. It can be used in UWB Ground Penetrating Radar to improve its validity.**

Keywords-electronic technology; nanosecond pulse; avalanche transistor; serial connection

I. INTRODUCTION

In the field of exploration,the nanosecond pulse with high power is desired as in [1]. Avalanche transistors are adopted as the key component to achieve nanosecond pulse in most ultra wide band (UWB) radar systems. The pulser is currently based on the avalanche transistor in a Marx bank circuit. This structure can realize that capacitors are charged in parallel connection and discharged in series. It does not require high working voltage and can generate highe pulse power. But all avalanche transistors are hardly simultaneously triggered when the number of avalanche transistors is too large as in [2~8]. Serial connection can insure that each avalanche transistor discharge simultaneously and high working voltage can reduce fall time of the pulse further. High voltage power supply specially designed for avalanche transistor can be easily found now as in [9]. In this paper, four-stage serial connection of avalanche transistor is designed according to the avalanche current. A simple RC-divider is designed to match the probe for measuring the pulse. The pulser and the RL-loaded (resistive and inductive loaded) bowtie antenna as in [10] get matched.

II. DIAGRAM OF THE PULSER

Diagram of pulser is shown in Fig 1. High voltage power provides working voltage for the avalanche transistor circuit. Its output voltage is adjustable from 0 to 3000V. Differential circuit works as the input of the trigger signal,which controls repetition frequence of the pulse. Serial connection circuit is based on simple avalanche transistor circuit and each avalanche transistor works in zero-voltage mode except the trigger stage. Four-stage serial connection of avalanche transistors is designed in the whole and nanosecond pulse with large amplitude can be obtained across the standard load.

III. PRINCIPLE OF AVALANCHE TRANSISTOR

A. Avalanche theory of transistor

When collector junction of transistor(NPN) is under reverse high voltage,electric field intensity in the space charge area of collector junction is much larger than low voltage application. Carriers entering collector junction are accelerated and get much energy. They collide with crystal lattice and then generate more and more carriers,which induce the current to increase rapidly. This is called avalanche phenomena.

B. Simple circuit of avalanche transistor

Fig.2 shows the simple circuit of avalanche transistor as in [11]. Avalanche equations can be obtained as

$$\left.\begin{aligned} & i = i_R + i_A \\ & U_{CE} = V_{CC} - i_R R \\ & U_{CE} = U_C(0) - \frac{1}{C}\int_0^{t_A} i_A dt - i_A R_L \end{aligned}\right\} \quad (1)$$

where i is the current flowing into avalanche transistor; i_R is the current flowing into static resistor R; i_A is the current flowing into avalanche capacitor; $U_C(0)$ is the initial voltage over the capacitor; R is the static resistor; R_L is the dynamic resistor; C is the avalanche capacitor; t_A is avalanche duration. From (1) avalanche dynamic load line can be obtained as

$$U_{CE} = U_C(0) - \frac{1}{C}\int_0^{t_A}\left[i + \frac{U_{CE} - V_{CC}}{R}\right]dt - \left[i + \frac{U_{CE} - V_{CC}}{R}\right]R_L \quad (2)$$

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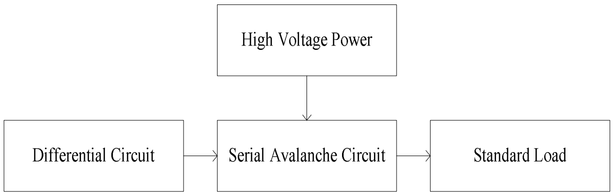

Figure 1. Diagram of pulser

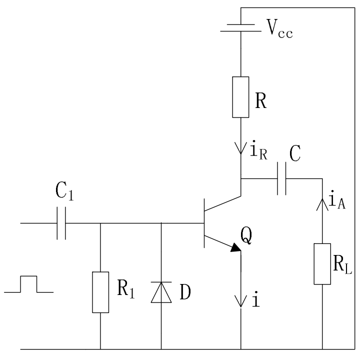

Figure 2. Basic avalanche transistor circuit

IV. EXPERIMENTAL CIRCUIT AND RESULTS

A. Selection of avalanche transistor

The circuit employed Motorola 2N3035 n-p-n bipolar junction transistors (BJTs). Its breakdown voltage is about 350V when it works at zero-voltage mode. Avalanche second breakdown in the transistors can be seen in the transistor tracer. Rising time is less than 2 ns. All these can insure that the number of serial stage is small and the pulse could be sharp enough. In the experiment the important aspect to note is that even the avalanche transistors of same type their breakdown parameter may not be the same. Practical measure is the only method to confirm the breakdown parameter of the avalanche transistor.

B. Experimental circuit

Fig.3 shows a four-stage serial connection avalanche circuit used in this work. Experimental results show that when the serial stage is more than 4 the amplitude of pulse can not increase correspondingly. This is because the avalanche current reachs maximum. Q_1~Q_4 are avalanche transistors. In order to enhance the breakdown voltage of the avalanche transistor base-emitter junction is short which is called zero-voltage mode. In the quiescent condition,all the avalanche transistors are biased beyond their avalanche breakdown voltage or little below the voltage. When the trigger pulse is applied to the base of the trigger transistor, avalanche pulse can be obtained across the standard load.C_1 is the discharge capacitor; R_1 limits the current flowing out from the supply power. C_2 and R_2 form the differential circuit. R_L is the standard load. D_1 is the diode eliminating high reverse voltage. In the experiment another important aspect to note is that when the supply voltage is too high the avalanche transistors fall into self-excitation avalanche. The repetition frequency is not controlled by the trigger signal which should be avoided. Supply voltage and the trigger signal must be considered as a whole. The supply voltage is adjusted at 1380V at last.

C. RC-divider

The narrow pulse is processed with attenuation before measuring. Considering the probe of Tek P6139A a RC-divider is designed and used in measuring the pulse. Fig.4 shows the divider, where C_1=C_2=C_p=8pf，R_1=R_2=R_p=10M ohm. C_p and R_p are equivalent impedance of the probe. The divider is tested by both DC and AC signal. The attenuation ratio is 3:1.

D. Test results

The test instrumentation is oscillograph of Tek754C Its bandwidth is 500MHz.The measure results are shown as followed. Fig.5 shows time-domain waveform of the pulse and Fig.6 shows the spectrum of the pusle signal. In the standard load path there is not the DC tailing. Both the fall time and rise time of the pulse can meet the requirement.This means that the spectrum of the pulse signal can match the UWB antenna. Under the same condition pulse waveforms are measured 10 times and Tab.1 gives the measure data. The dithering of waveform is less than 3%. From the data it can be concluded that the stability of the pulse is satisfiable.

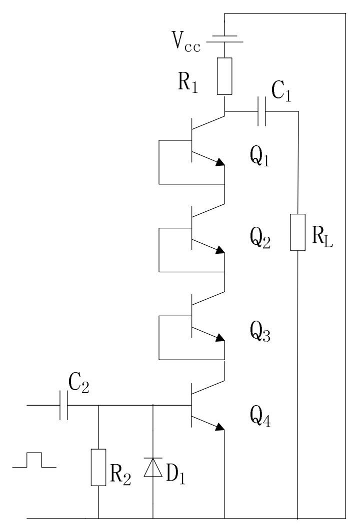

Figure 3. Circuit of pulser

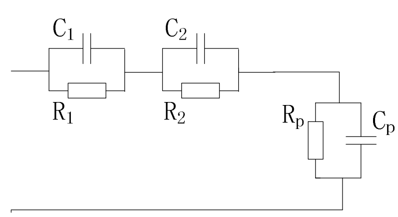

Figure 4. Resistance-capacitance divider

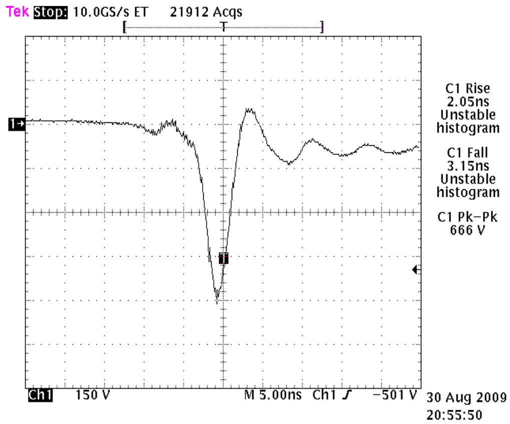

Figure 5. Output waveform of pulser

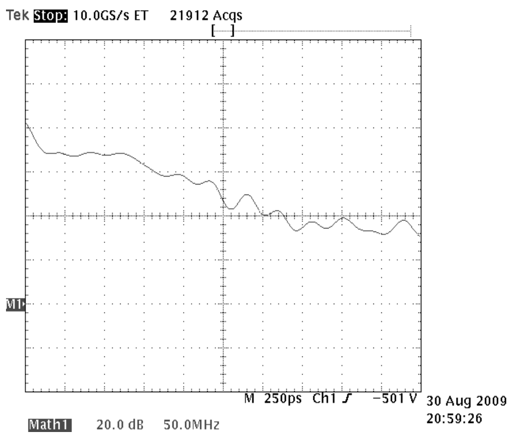

Figure 6. FFT of the output waveform

TABLE I. MEASURE DATA

Times	V_{p-p}(V)	Half-width(ns)
1	666	3.2
2	629	3.4
3	644	3.5
4	656	3.4
5	605	3.4
6	661	3.2
7	632	3.5
8	599	3.7
9	642	3.3
10	653	3.4
Dithering	2.8%	2.9%

The pulser and the RL-loaded bowtie antenna are connected with coaxial-cable and a wideband balun. The central frequency of the antenna is 100MHz. The transmitting antenna and the receiving antenna are placed vertically face to face. Time domain waveform between the feeding points of receiving antennas is measured and shown in Fig.7. The receiving waveform is the direct wave of the transmission pulse. There is no tailing basically in the receiving waveform which indicates that the pulser and the antenna get matched. Experiment is not carried out in darkroom and there are some reflection waves from antenna themselves and walls.

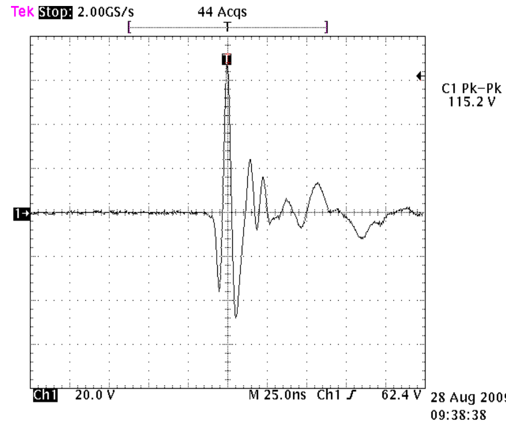

Figure 7. Waveform of receiving antenna

V. CONCLUSION

In this paper,the principle of avalanche transistor is analysised and four-stage serial connection of avalanche transistor circuit is designed according to the avalanche current of the transistor. The amplitude of output pulse can reach 666V and the half-width is 3.4 nanosecond. Repeat frequency of the pulser can reach 10KHz. Stability of the pulse waveform can meet requirement. Measure waveform shows that the pulser and the RL-loaded bowtie antenna get matched. The pulser can be fabricated easily and works well. It can be used in UWB Ground Penetrating Radar （GPR） system to improve its validity especially when GPR is used in tunnel geology forecast.

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