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A High-power Bipolar Sub-Nanosecond Pulser Based on Power Synthesis Method

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Abstract

Compared with the monopolar pulser, the bipolar pulser is more suitable to be the excitation pulser of the ultra-wideband radiation system for its less content in low frequency range. In this paper, a high-power bipolar sub-nanosecond pulser based on the avalanche transistor is developed through the power synthesis method, whose principle is combining two monopolar pulses with different polarity together. Experimental results show the designed bipolar pulser has a 1.8-kV peak-to-peak amplitude, 94-ps rise time and 400-kHz maximum PRF.

1. Introduction

Bipolar sub-nanosecond pulse has been widely used in many fields, e.g., ultra-wideband (UWB) radiation, biological electromagnetics, the impulse radar and so on [1-3]. Compared with the monopolar pulse, the bipolar pulse has much less low-frequency components. Therefore, the bipolar pulser has a higher radiation efficiency to be the excitation pulser over the monopolar pulse, because the UWB antennas often have poor low-frequency radiation characteristics. What's more, the use of the bipolar pulse could avoid low-frequency reflection problem caused by the monopolar excitation pulse, which goes against the stability of the pulser.

Approaches of producing sub-nanosecond has been studied in recent years. M. Gundersen et al. [2] developed a bipolar pulser based on the shorted transmission line method. The shorted transmission line with a certain characteristic impendence and length is connected with the main path line in parallel. When the monopolar pulse is fed, one part of the pulse flows to the load directly and the other enters the transmission line and reflects from the shorted end with inverted shape and then the inverted pulse will return to the load. As a result, a bipolar pulse is obtained in the load. However, the addition of the shorted impendence line will inevitably lead to the impendence mismatch problem, which is harmful to the stability of pulser, especially in the high-power output mode. X. Li [4] designed a differential circuit module after the monopolar pulser so that the monopolar pulse is altered into the bipolar pulse. But the output parameters (rise time, amplitude) of the bipolar pulse will deteriorate seriously due to the non-ideal devices. In this paper, a sub-nanosecond bipolar pulser based on the power synthesis method is developed. Its principle is to combine two monopolar pulses with different polarity together in a certain time sequence. In theory, this method could avoid the adverse effects of the above-mentioned two methods on the pulser. However, although the theory of the bipolar pulser based on this technical method is very mature, there is little research on the sub-nanosecond bipolar pulser based on the power synthesis method. Therefore, this paper aims to develop a high-power sub-nanosecond bipolar pulser with this method.

2. Design of the bipolar pulser

To achieve a high-power bipolar pulser, the monopolar pulser with high-power and high-time base stability output pulse is required. The transistorized pulser has been studied in recent decades for its advantages of fast rise time, high power, high pulse repetition frequency (PRF), high stability and so on [5]-[11]. Marx circuit is always adopted in the avalanche transistor-based pulser to achieve a high-amplitude output pulse. Its principle is the parallel charging of the charging capacitance followed by serial connection of the stages when the switch devices are closed. Some measures are taken to improve the output parameters of the transistorized pulser as below.

The structure of the ferrite bead and the isolation resistor connected in series is applied to isolate the pulse forming path and the ground or the power supply as shown in Fig. 1. Compared with the conventional Marx circuit that only uses the isolation resistor, the use of the ferrite bead improves the circuit isolation in the high-frequency range without influencing the charging speed of the charging capacitance, which helps to improve the amplitude of the output pulse. Heat accumulation of the avalanche transistor is a great limit for the output power of the pulser. Therefore, the avalanche transistor-charging capacitance parallel structure is applied to improve the power capacity of the pulser. And, the pulser is immersed in fluorinert liquid, which could transform from liquid phase to gas phase when heated, and thus a lot of heat can be taken away. As a result, the PRF of the pulse is largely enhanced. In addition, the conventional triggering mode, i.e., the base triggering mode is replaced by the collector voltage ramp triggering mode to improve the time base stability.

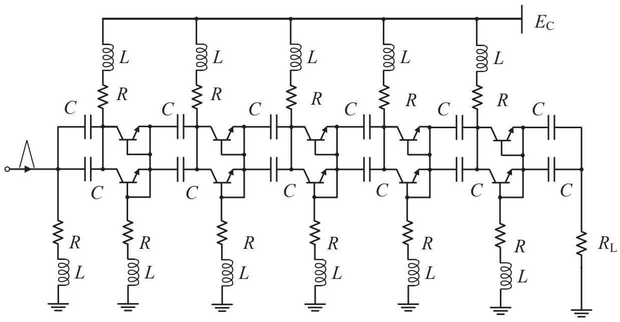


Fig 1. Optimized Max circuit based on the avalanche transistor

Based on the development of the monopolar pulser, the bipolar pulser is designed. The schematic diagram of the bipolar pulser is shown in Fig. 2. The output pulse of the trigger pulse is divided into two identical pulses by a power divider as the trigger pulses of the two monopolar pulsers respectively. The relative time delay of the positive pulse and the negative pulse could be adjusted by changing the lengths of the trigger lines, i.e., T1 and T2. Then, the output pulses of the positive and the negative pulsers are combined together by a power combiner. Both the power divider and the power combiner we use have the frequency bands ranging 10 MHz to more than 3 GHz, which could cover the spectrum of the output pulse in our case basically.

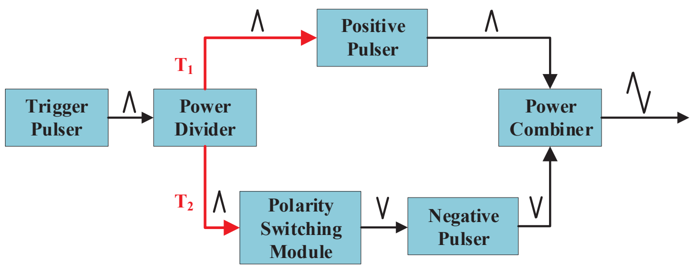


Fig 2. The diagram of the bipolar pulser.

It must be noted that the negative pulser is triggered by the negative signal. Therefore, the polarity of the positive trigger pulse must be changed after it passing through the power divider, which could be achieved by a polarity switching module. Since the trigger pulse affects greatly on the time base stability of the pulser, the polarity switching module is required to have as little effect as possible on the pulse parameters.

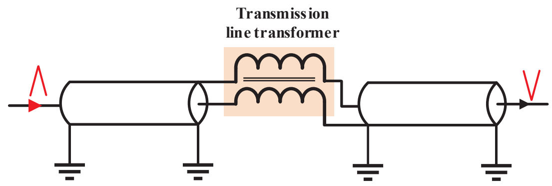
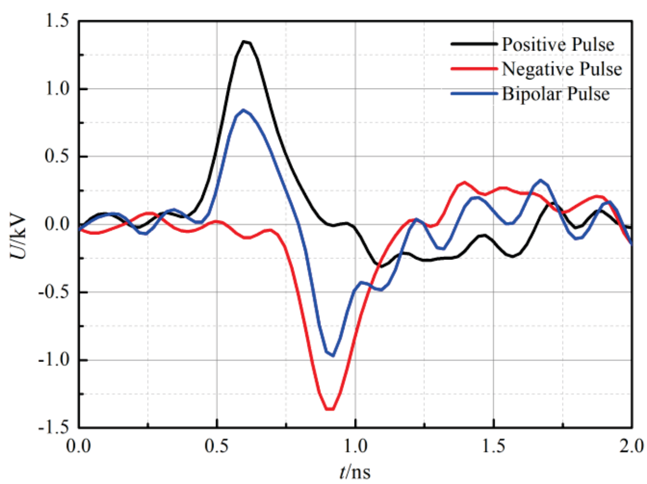


Fig 3. The schematic diagram of the polarity switching module.

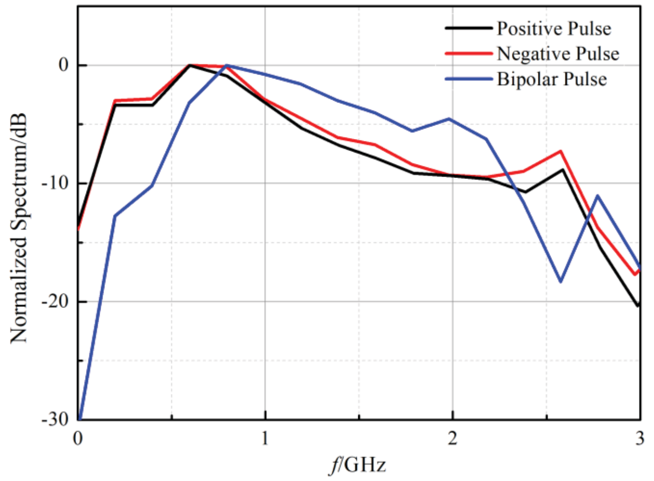
The core component of the polarity switching module is the transmission line transformer. The transmission line transformer is the product which combines the transmission line and the transformer. At low frequencies, the transmission line transformer works as a transformer, and the electromagnetic energy is transmitted through the electromagnetic coupling between the two coils. However, at high frequencies, it works as a transmission line, and the electromagnetic energy is transmitted in the medium between the two coils. Therefore, the frequency band of the transmission line is quite wide, even to the order of GHz. The transmission line transformer from the MINI CIRCUITS is used in this paper with the frequency band of 4.5 MHz~3 GHz [12]. The schematic diagram of the polarity switching module is shown in Fig. 3, where the outgoing line corresponding to the left core line of the transmission line transformer is connected to the ground line of the right transmission line, whereas the outgoing line corresponding to the left ground line is connected to the core line of the right transmission line. As a result, the pulse polarity is to be reversed.

3. Measurements of the bipolar pulser

In this section, the designed pulser is measured by the LeCroy Wave Runner 8404M with an analog bandwidth of 4 GHz. The output waveforms of the positive pulser and the negative pulser are shown in Fig. 4 (a), the positive pulse has a 1.35-kV amplitude, 138-ps rise time, and 194-ps fall time. And the negative pulse has the amplitude of 1.36 kV, rise time of 130 ps, fall time of 180 ps and pulse width of 390 ps, which is similar to the positive pulse.



(a)



(b)

Fig 4. The output waveforms of the monopolar and bipolar pulsers (a) in time domain. (b) in frequency domain

According to the experimental results, the pulse jitter of the positive monopolar pulser is 22 ps and the relative pulse jitter of the two pulsers is 18 ps. The pulse drift characteristics of the pulsers are illustrated in Fig .5. The pulse drift increases with the increase of PRF. It has a maximum value of 47 ps/ min at the PRF of 400 kHz. The relative pulse drift of the two pulsers is smaller than the corresponding pulse drift. At the PRF of 400 kHz, the relative pulse drift is 46 ps/min, which is almost 1/10 of the pulse width of 411 ps. Hence, the two pulsers can achieve a good match in time base.

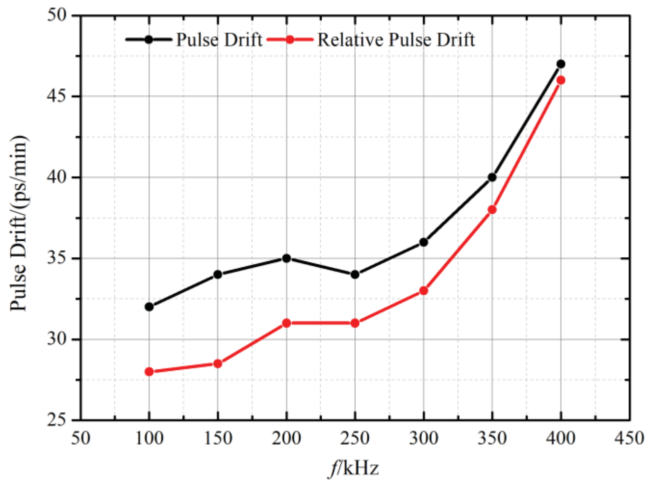


Fig 5. The pulse drift and the relative pulse drift of the monopolar pulser.

Finally, the synthesis bipolar pulse is obtained as the blue curve in Fig. 4(a). The positive peak of the bipolar pulse is 0.84 kV, the negative peak value is -0.97 kV and thus its peak-to-peak amplitude is about 1.8 kV. Its rise time is 94 ps and the 10% pulse width is 714 ns. After calculation, the efficiency of the power synthesis is more than 90 %. In Fig. 4(b), the -10 dB frequency band of the bipolar pulse is between 0.40 GHz and 2.32 GHz. However, the positive pulse and the negative pulse have almost the same frequency band of 0.07 GHz to 2.26 GHz. Compared to the monopolar pulse, the bipolar pulse has more high-frequency components and much fewer low-frequency components, which is more favorable to antenna radiation. What’s more, the bipolar pulser could work stably at the PRF of 400 kHz with the pulse peak-to-peak amplitude of 1.67 kV for more than 1 min, as shown in Fig. 6.

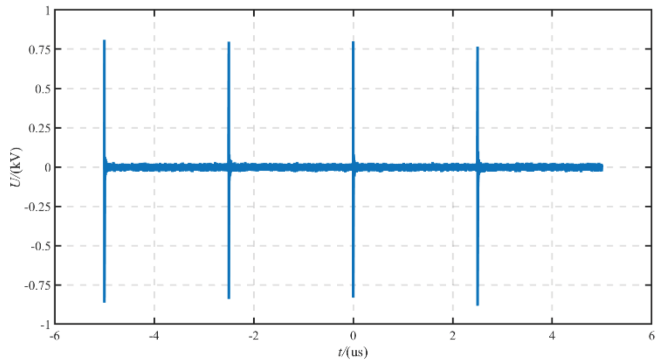


Fig 6. The bipolar pulse with the PRF of 400 kHz.

4. Conclusion

In this paper, a high-power sub-nanosecond bipolar pulser based on the power synthesis method is developed. Firstly, some improvement measures are taken to enhance the output power and time-base stability of the monopolar pulser base on the avalanche transistor. Then the circuit topology of bipolar pulser is designed. According to the experimental results, the bipolar pulse has the peak-to-peak amplitude of 1.8 kV, the rise time of 94 ps and the maximum PRF of 400 kHz.

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