1000-V, 300-ps pulse-generation circuit using silicon avalanche devices

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A Marx configured avalanche transistor string and a pulse rise-time peaking diode are used to generate pulses of > 1000 V into a 50-Ω load with rise times of less than 300 ps. The trigger delay of this circuit is about 7–10 ns, with jitter < 100 ps. This circuit has been used to generate pulses at a repetition rate up to 5 kHz.

INTRODUCTION

There are many applications for fast rise-time (subnanosecond) high-voltage (kilovolt) electrical pulses in instrumentation for fast transient measurements. Some typical applications are the sweeping of CRT streak cameras, the gating of microchannel plates and Pockels cells, and the triggering of scopes and transient recorders. We have designed a circuit that uses avalanche transistors and pulse sharpening diodes to produce a 0.8–1.2-kV pulse with < 300-ps rise time into a 50-Ω load.

The key component of this circuit is a diode having a particular structure that results in a pulse sharpening behavior when driven into reverse breakdown by a linearly rising input voltage pulse. These diodes were first described by Grekhov *et al.* in the Soviet Union.[1] We believe that this is the first description of this pulse sharpening behavior reported in the United States.

The next section presents a discussion of the overall circuit followed by a section on the details of operation of the diodes. The last two sections present experimental results and concluding remarks.

I. PULSE-GENERATION CIRCUIT

The Marx generator described here is a circuit used to generate a 1.5-kV pulse with a rise time of about 3 ns from several low-voltage switching devices. The leading edge of this pulse is then sharpened to a rise time of 300 ps by the diode. The circuit in Fig. 1 operates by charging up several capacitors in parallel and then discharging them in series. When the first transistor in the string is triggered, the second transistor in the string sees two times its breakdown voltage. This fast voltage step causes the second transistor to switch into avalanche second breakdown. This effect ripples up the series string until the circuit is completed to the load. The output voltage ideally will equal the number of stages in series times the capacitor bank voltage. The actual output voltage is somewhat less due to the finite voltage drop across each of the series avalanche transistors.

In this implementation of the Marx generator, eight transistors are used in series. Two of these eight-transistor sections are put in parallel to increase the output voltage and reduce the current flowing in each section. The first transistor in each section of the eight-transistor stack is triggerable from a TTL source. The typical breakdown voltage for the 2N5551 transistors used here is 375 V. The 400-V power supply is connected across the transistors through 1 MΩ of resistance in order to limit the standby current to less than 50 μA for any reasonable variation in transistor characteristics. We find that this small bias current also reduces the delay time and jitter. The pulse width is limited to < 10 ns, because we have found that these transistors tend to burn out in a short period of time (< 1000 pulses) if wider pulses are used.

The output pulse of the Marx generator is applied to the diode board through a 5-ns length of RG58 50-Ω cable. The purpose of the series diode is to sharpen the leading edge of the pulse. To determine the effect of biasing the diode, it is capacitively coupled to the Marx generator and a reverse bias is applied to it. The use of a shunt diode to sharpen the trailing edge of the pulse is also being investigated.

II. PULSE-SHARPENING DIODES

Grekhov *et al.*[1] have reported observing a delayed breakdown in silicon P + N − N + diodes, which results in pulses with <200-ps rise time. We have found that high-

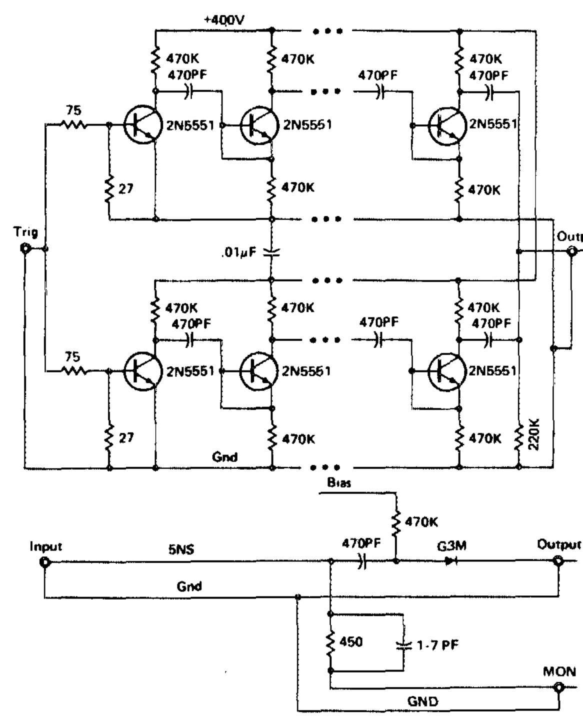

FIG. 1. Schematic diagram of the Marx generator and diode sharpener.

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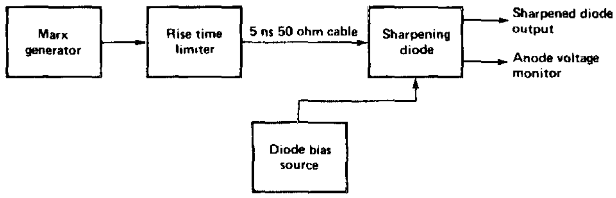

FIG. 2. Block diagram of the sharpening diode test setup.

voltage diodes, such as the General Instruments G3M have a physical structure very similar to that described by Grekhov *et al.*[1] and have observed similar delayed breakdown behavior. Figure 2 is a block diagram of a typical test circuit, consisting of a pulse generator with filters in the output to reduce the pulse rise time as desired, a 50-Ω transmission line to the diode, and a 50-Ω load. A compensated voltage divider is used to measure the voltage applied to the diode. Figure 3 is an oscilloscope photograph showing the delayed breakdown and resulting fast rise-time pulse into a 50-Ω load. We have found, as reported by Grekhov *et al.*,[1] that the jitter of this fast switching mechanism is very low, making these diodes ideal for use in low jitter pulse-generation circuits.

III. EXPERIMENTAL RESULTS

The rise time of the incident pulse seems to have little effect on the fast switching behavior of the diode but does have significant effect on the prepulse. The prepulse is attributed to displacement current as the diode's capacitance is charged by the incident pulse. Since the current is proportional to dv/dt, faster rise-time incident pulses result in larger prepulses. Figure 4 shows plots of several output waveforms corresponding to input pulses with differing rise times. We have tried to achieve an incident pulse rise time of ~ 3 ns as a tradeoff between trigger delay and magnitude of the prepulse. Other applications may require different incident pulse rise times. We have found that the fast breakdown effect occurs for incident pulse rise times as slow as 7 ns, at which point the output amplitude starts to fall off.

There is some indication that the current that can be handled by one of these diodes without significant degradation of useful life is related to the physical size (area) of the

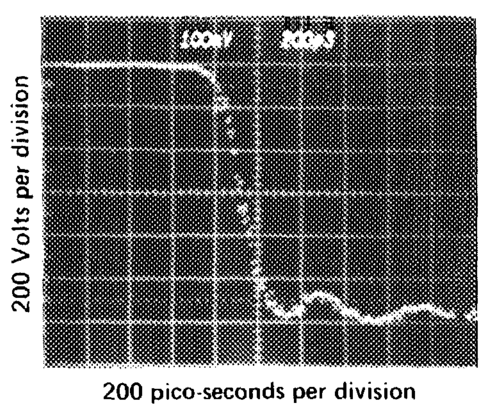

FIG. 3. Output of the pulse sharpening diode into a 50-Ω load.

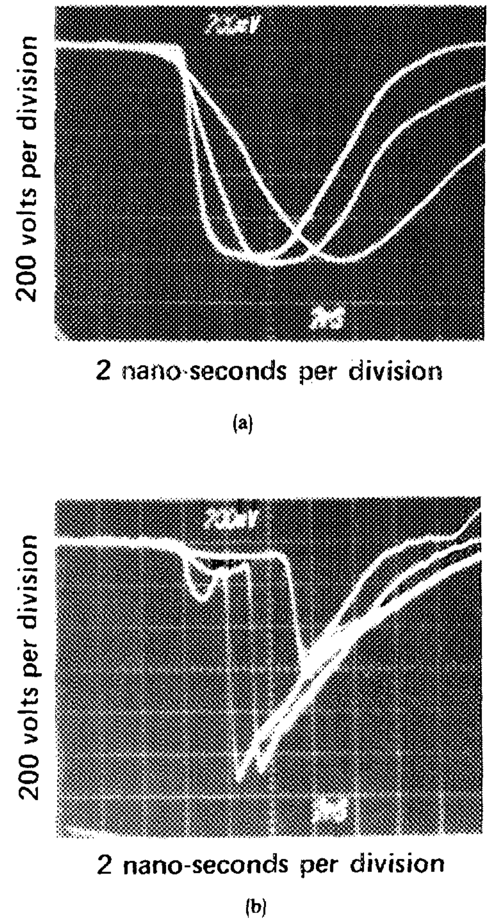

FIG. 4. (a) Incident pulses of various rise times; (b) corresponding sharpened output pulses.

device. We have found that diodes rated at 1 A forward current (1.2 mm diameter) tend to burn out rather quickly (1000 pulses) when generating 1000-V pulses into a 50-Ω load (20 A peak), whereas somewhat larger diodes rated at 3 A (2 mm diameter) last indefinitely under the same conditions. There appear to be two important parameters that influence the safe operating range of these devices. They are the amplitude and the width of the incident pulse. We are currently gathering data on the lifetime of the diodes while varying these parameters.

Grekhov *et al.*[2] have found a significant change in the delay time to trigger this fast breakdown (several nanoseconds) as the dc bias voltage on the diode is changed. We do not see such a large change in delay time. Figure 5 is an

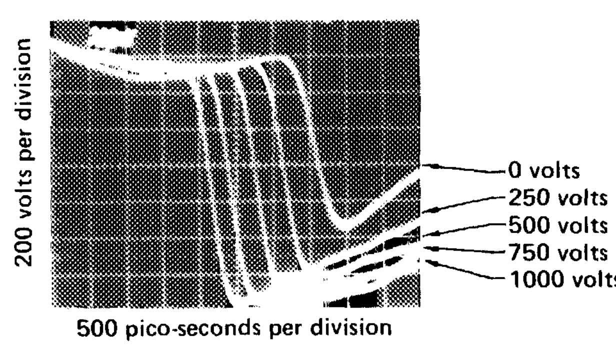

FIG. 5. Output of the sharpening diode for various reverse bias voltages.

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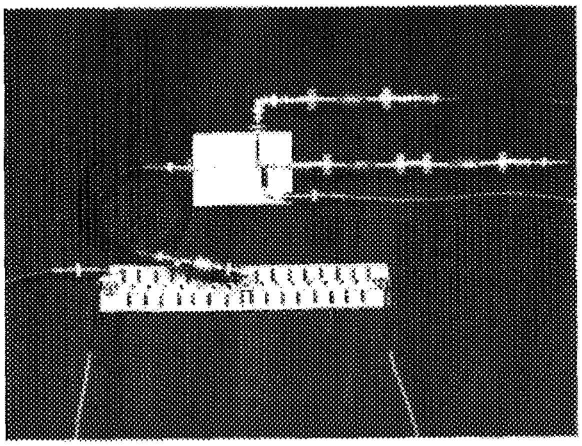

FIG. 6. (Top) Sharpening diode circuit board; (bottom) avalanche transistor Marx generator circuit board.

oscilloscope photograph of the results we have obtained using a reverse bias of 0–1000 V. We have also found that the application of reverse bias will decrease the amount of prepulse capacitively coupled to the output and increase the amplitude of the sharpened pulse.

IV. CIRCUIT CONSTRUCTION

Figure 6 is a photograph of the complete circuit, consisting of the avalanche transistor Marx pulse generator on the bottom and the diode board on the top. The Marx circuit is constructed on double-sided printed circuit board with the top layer being the ground plane. Wide, low inductance pads are provided for all high-current connections. The circuit uses low-cost 1000-V ceramic disk capacitors for the bank. Sockets are provided for 2N5551 avalanche transistor replacement in the event of transistor failure (none has failed as of this writing). The 470-kΩ charge circuit resistors are 1/2 W to provide a high-voltage breakdown rating. Output connection is made via a 50-Ω BNC connector. High voltage is supplied to the Marx board through an SHV connector.

The diode board is also constructed on double-sided PC board with the bottom layer being the ground plane. Strip line elements of 50 Ω are used for all fast parts of the circuit. A high-frequency chip capacitor is used on this board due to the subnanosecond rise times. A 1-W 470 kΩ resistor is used to supply bias to the series diode to provide enough voltage standoff. Pulse input is by means of a BNC connector. A GR connector is used for connection to the load. High-voltage bias is supplied to this board through an SHV connector.

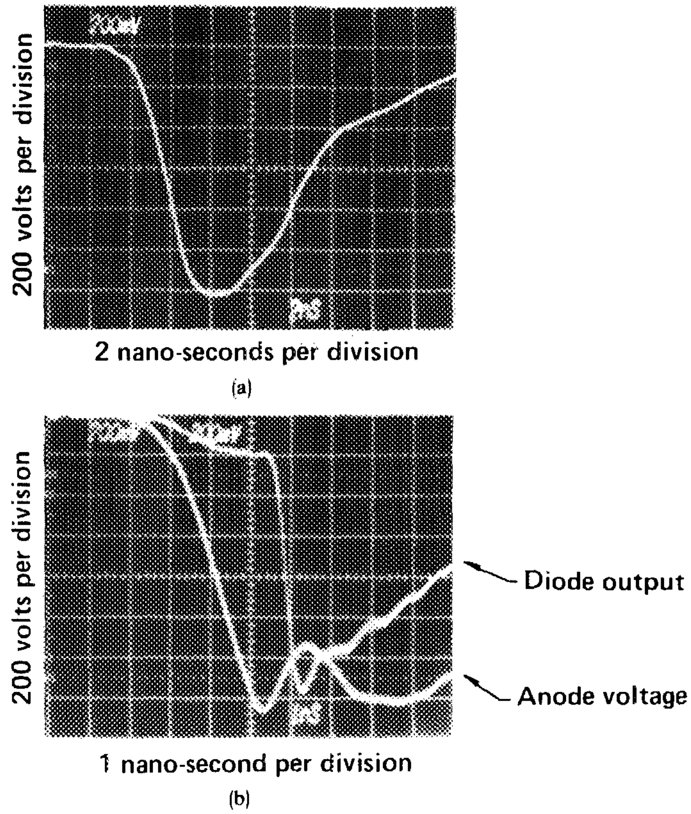

FIG. 7. (a) Output of the Marx generator into a 50-Ω load; (b) diode output and anode voltage monitor output into a 50-Ω load.

Typical output waveforms are shown in Fig. 7. The incident pulse generated by the Marx circuit [Fig 7(a)], when applied to the diode, results in the final 1200-V, 300-ps risetime pulse. Figure 7(b) shows the relationship between the diode anode voltage and the sharpened output pulse.

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[1] I. V. Grekhov *et al.*, Electron. Lett. **17**, 422 (1981).
[2] I. V. Grekhov *et al.*, Prib. Tekh. Eksp. **4**, 135 (1981).

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