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DESIGN NOTE

A transistorized Marx bank circuit providing sub-nanosecond high-voltage pulses

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Abstract. An improved version of a Marx bank circuit has been developed using 2N5551/2N5550 transistors as switching elements in avalanche mode which provides a negative pulse of about 4 kV amplitude and ⩽1 ns rise time. The circuit has about 14 ns delay and ⩽1 ns jitter.

Fast rise time (sub-nanosecond) and high-voltage (about 1 kV) electrical pulses are required in many applications, such as gating of MCP [1], Pockel cells [2] and sweeping of photoelectrons in a streak camera [3]. Various kinds of circuits are available, which use different kinds of switching elements. Various Marx bank circuits [2, 4–8] are used to provide such fast high-voltage pulses. Some transistors operating in avalanche mode have proved to be a reliable and stable switching element for the Marx bank circuits [2, 4–8]. The fastest Marx bank circuit reported so far [2, 8] has provided a rise time of 1.5–2 ns.

We report here a modified version of a Marx bank circuit [2], which can provide a voltage pulse of about 4 kV amplitude with a rise time of ⩽1 ns.

On the basis of the data available concerning transistors operating in avalanche mode, 2N5551/2N5550 transistors were chosen to make this circuit. The two transistors have very similar characteristics, except for a somewhat smaller breakdown voltage in the latter. These transistors were tested carefully, using a circuit reported earlier [2]. Only those transistors were selected that had similar breakdown voltage (about 300 V for 2N5551), similar and smaller rise time (about 1.5 ns), and small delay and jitter. It was found that most of the transistors selected had their h_{Fe} around 120. However, the correlation between h_{Fe} value and avalanche mode operation of transistors is not yet known.

A Marx bank circuit (Figure 1) was developed which has a circuit similar to that reported earlier [2] (four stages) except for the number of stages, which is five in our case, with a modified wiring and triggering scheme. This circuit provided a pulse of about 4 kV amplitude with ⩽1 ns rise time. It consists of stacks of three avalanche transistors (2N5551/2N5550) in series as a switching element at each stage. The improvement in the rise time (⩽1 ns) seems to be due to a decrease in the effective junction capacitance of the stacks of transistors when connected in series combination, whereas a single transistor shows a rise time of about 1.5 ns. However, we could not succeed in improving the rise time by increasing the current passing through the transistors. The number of stages in the Marx bank circuit can be reduced by increasing the number of transistors in the stack, which required a higher voltage for biasing the circuit. Triggering the first transistor of the first stage breaks down all three transistors (of the first stage) and subsequently the remaining stages of the circuit. This circuit was triggered through a wide band transmission line pulse transformer (⩽1 ns response time), which consists of a 50 Ω impedence coaxial cable wrapped (5 turns) on a small ferrite core. Here the shield of the cable acted as a primary of the transformer, whereas the central conductor acted as a secondary. A 24 V amplitude pulse with 1.5 ns rise time was used to trigger the circuit, whereas only 4 V are sufficient for this purpose. This improves the trigger jitter in the circuit. The trigger pulse was sharpenned using a 20 pF capacitor and a 50 Ω resistance at the output of the transmission line pulse transformer in differentiation mode, because a small pulse width effectively protects the base–emitter junction of the transistor being triggered, which enhances the life time of the circuit.

A carefully designed printed circuit board was used together with proper soldering to reduce extra inductance. A ceramic disc capacitor of 1000 pF at 3 kV, obtained from MULCO (India), was used in this circuit with a roughly 900 V power supply connected across the transistor through 1–50 MΩ of resistance, which limits the stand-by current and reduces delay and jitter

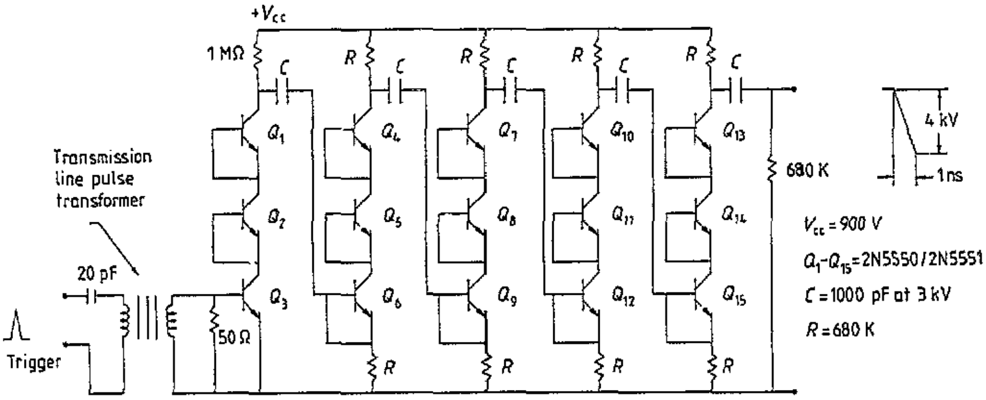

Figure 1. Diagram of a Marx bank circuit.

in the circuit. Owing to higher current flowing in the circuit during breakdown, the current crowding at the base–emitter junction was diverted by shorting the base and emitter of the circuit [6], which diverts a portion of the current flowing through the emitter. However, no significant change was observed in the result or in operation of the circuit even on shorting the base and emitter through 51 Ω resistance. A roughly 4 kV pulse was obtained with a roughly 3 kV (10–90%) linear portion having a rise time better than 1 ns (figure 2) when measured on a Tektronix Model 7834 oscilloscope with a vertical plug-in model 7A19 device (400 MHz combined bandwidth). The pulse showed a rise time of about 800 ps when measured on a Tektronix Model 7104 with a vertical plug-in Model 7A29 device (1 GHz bandwidth). A six-stage circuit was also tested. This could provide a 4.5 kV pulse, which is the fastest high-voltage pulse obtained using any known transistorized Marx bank circuit. However, our attempt to increase the voltage beyond 4.5 kV failed because we could not succeed in making circuits of more than six stages using 2N5551 transistors, nor of more than five stages using 2N5550 transistors, due to frequent failure of the transistors. This failure seems to be due to the limitation in current-carrying capacity of these transistors. According to theory, the output pulse amplitude should be equal to the number of stages times the capacitor bank charging voltage. However, a smaller voltage (about 4 kV instead of 4.5 kV) was obtained in the case of a five-stage circuit due to the finite drop across the transistors. A time $\tau = RC = 10^{-3}$ S ($R = 1$ MΩ and $C =$ 1000 pF) taken by the capacitor bank in charging decides the maximum operating frequency of the circuit, which was tested satisfactorily up to 1 kHz. A small decrease in the amplitude of the output pulse was noted, with an increase in operating frequency of the circuit, which may be due to partial discharge of the capacitor bank. However, any decrease in C increases the operating frequency limit of the circuit, but again with a decrease in amplitude of the output pulse. The breakdown delay of the circuit was measured as about 14 ns, whereas the jitter was measured ($\leqslant 1$ ns) after proper shielding of the circuit, otherwise a jitter of >1 ns was seen.

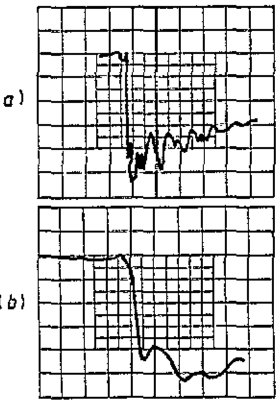

Figure 2. *Electrical pulse obtained from a Marx bank circuit* and recorded on a Tektronix model 7834 oscilloscope with a vertical plug-in model 7A19 device (500 MHz combined band width). (*a*) Horizontal axis 10 ns per small division, vertical axis 400 V per small division. (*b*) Horizontal axis 1 ns per small division, vertical axis 400 V per small division.

This circuit was used in an optical and X-ray picosecond streak camera [9] to sweep the photo-electrons on the phosphor screen. The camera was operated satisfactorily with a time jitter of about 1 ns, which indicates that even a Marx circuit can be used successfully for operating a picosecond streak camera where the time for full screen deflection is $\geqslant 5$ ns.

In conclusion, we have developed a Marx bank circuit that provides about 4 kV amplitude pulse with $\leqslant 1$ ns rise time. This circuit requires a low-voltage biasing power supply (about 900 V) for its operation. It was also found that transistors having h_{Fe} values around 120 are best for this circuit.

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