Bipolar nanosecond pulse electric field generator using open circuit transmission line technique and avalanche transistors for nanosecond electroporation

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Abstract

The SUMCASTEC project aims to isolate and neutralise brain cancer stem-like cells (CSC) using electromagnetic stimulation.

A bipolar nanosecond pulse electric field generator based on slow charging and fast discharging of an open circuit co-axial transmission line through a stack of avalanche transistors, which operate as a fast switching element, is demonstrated. This low-cost circuit design produces well defined symmetrical 'flat-topped' nanosecond pulse electric fields with rise and fall times of less than 2 ns. The bipolar pulse width, repletion rate and amplitude of the pulses are determined by various elements of the circuit. Initial results indicate that the circuit can generate well defined nanosecond pulse to support nanosecond electroporation and other biomedical applications of nanosecond pulse electric field in a cost-effective manner.

Presented Work

A transmission line and a fast switching element can be used as a technique of generating square symmetrical pulses. By charging an open circuit co-axial transmission line to a voltage level V_{CC}, through a high impedance resistor, R_C, and then discharging the line into a resistive load, R_L, through a fast switching element, provides a means of producing a rectangular pulse with a pulse width twice the associated delay time, T, of the transmission line on R_L. The fast switching element determines the rise time of the rectangular pulse on R_L, whilst the transmission line determines the pulse duration (or width), of 2T, and the fall time of the incident pulse. This is a simple and affordable technique.

The pulse amplitude and shape (pulse reflection) at the load depends on characteristic impedance of the transmission line, Z_0 and the load, R_L, relationship. An ideal pulse with zero reflection, is obtained when $R_L = Z_0$, and its associated pulse amplitude would be $V_L = V_{CC}/2$.

An avalanche transistor is utilized as the switching element, with literature indicating that avalanche transistors can be used as a switching element to provide sub nanosecond rise times, as low as 300 ps. The downfall is that a single FMMT417 avalanche transistors can only operate between voltage of 100 V to 320 V, thus limiting the amplitude of the incident pulse at the load, as the V_{CC} cannot exceed the transistor collectoremitter breakdown voltage, V_{CES}. However, staking multiple avalanche transistor in series overcomes this and results in a proportionally higher pulse amplitude at the load. With every additional transistors tack the amplitude at the load can increase by $V_{CES}/2$. The repletion rate of the incident pulse on R_L is determined by the repletion rate of the triggering signal onto the lowest staked transistors base.

Utilizing the current flow within the circuit, a monopolar positive or negative pulse can be produced across a load depending on the position of the load within the circuit. Placing a R_L in series with the emitter of the lowest avalanche transistor to ground a positive nanosecond pulse electric field is observed on the load.
Whilst placing a load R_L in series with the outer conductor of the transmission line to ground a negative nanosecond pulse electric field is observed.
Bipolar pulses are generated identical to the monopolar designs, where the charged line is dischargedthrough stacked avalanche transistors, except that there are two separate loads in the circuit. One in series with the emitter of the lowest avalanche transistor to ground and another placed in series with the outer conductor of the transmission line to ground.
Depending on the reference point within the circuit we measure three potential difference or pulses is generated simultaneously. A positive pulse is produced at the reference point of the emitter of the lowest avalanche transistor to ground, and a negative pulse is produced at the reference point between outer conductor of the transmission line to ground. Both pulses have identical pulse width, rise times and repletion where their amplitude is the same if the impedance of both loads at the two reference points are have the same. The third pulse is the voltage difference between the emitter of the lowest avalanche transistor to the outer conductor of the transmission line. The amplitude of the pulse observed here has the accumulated amplitude of both the negative and positive pulse.
The parameters of the bipolar pulses are determined by the same circuit element as the monopolar pulses.
There pulse width is twice the associated delay time of the transmission line. The repletion rate of the incident pulses is determined by the repletion rate of the triggering signal onto the lowest staked transistors base. The extend of the amplitude of the pulses is increase with the more avalanche transistors stacked. The pulse amplitude and shape (reflection) at the loads depends on relationship between characteristic impedance of the transmission line, and the total load impedance of the circuit. The total load impedance is the combine impedance of the load between the emitter of the lowest avalanche transistor to ground and the load between
the outer conductor of the transmission line to ground.

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