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CIRCUIT ARRANGEMENT FOR CHARGING AND DISCHARGING
MULTISTAGE PULSE GENERATORS
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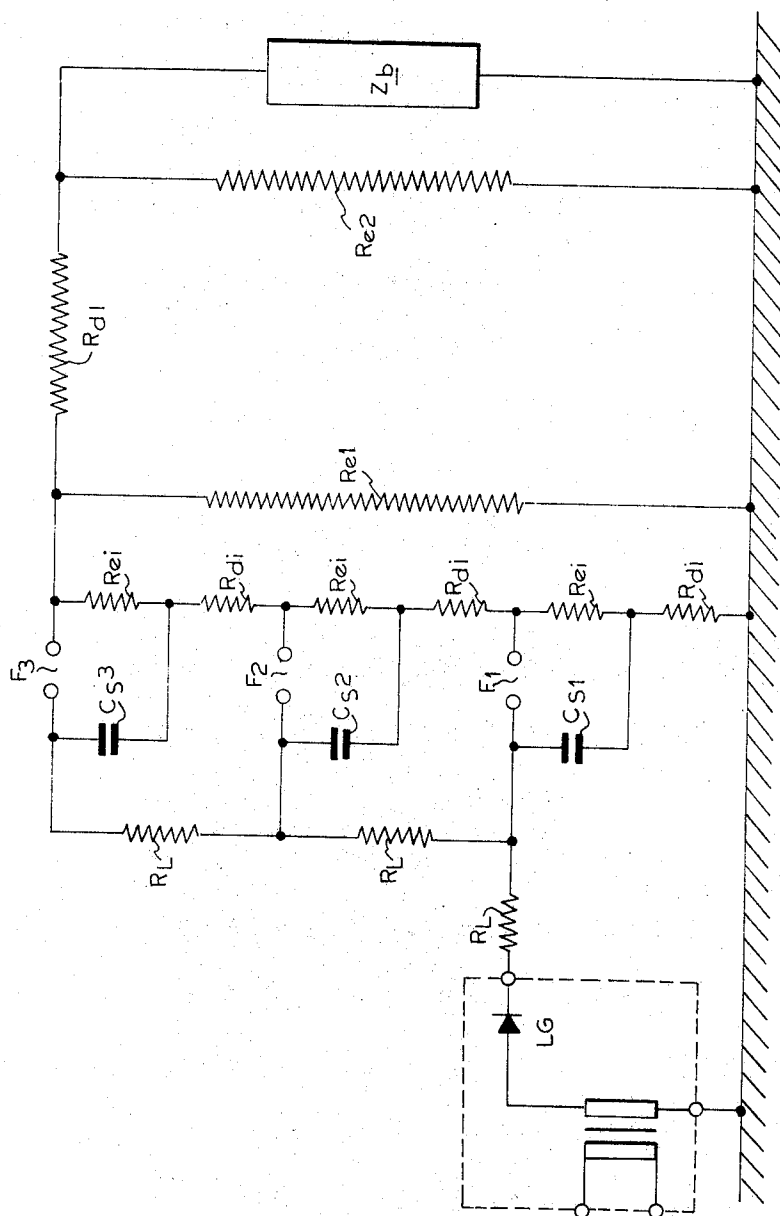


FIG. 1

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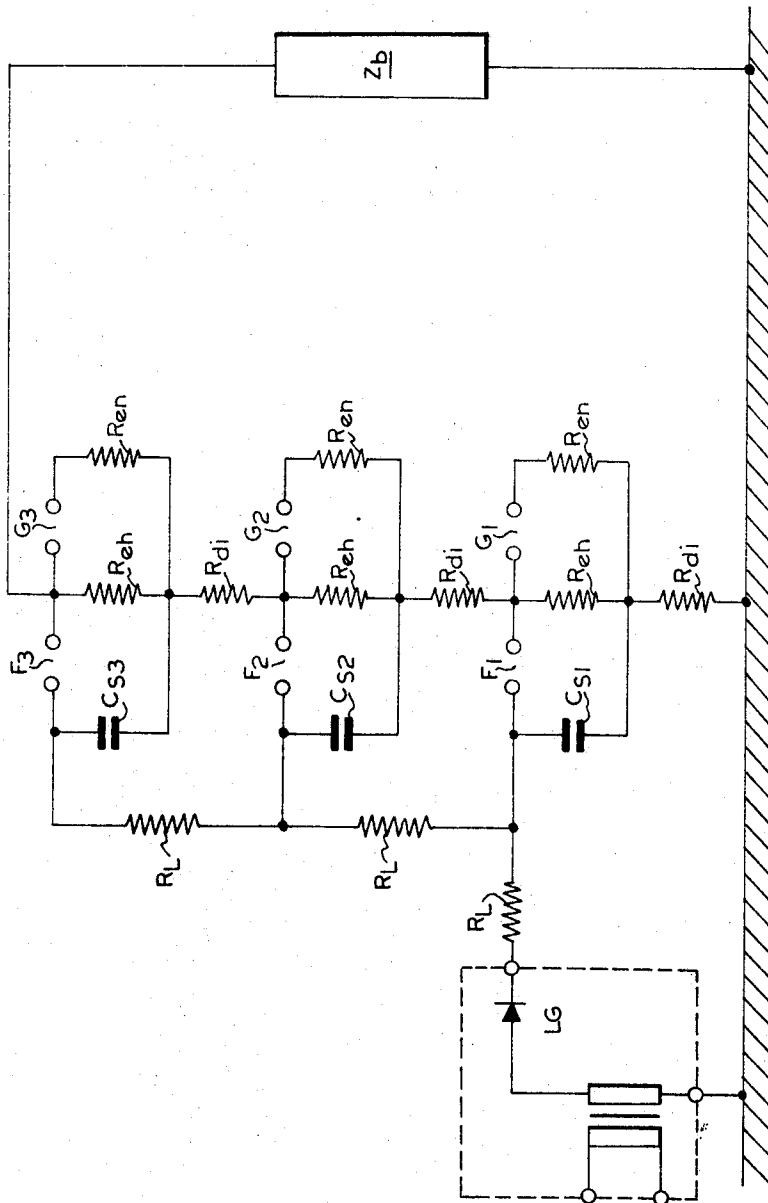


FIG. 2

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CIRCUIT ARRANGEMENT FOR CHARGING AND DISCHARGING MULTISTAGE PULSE GENERATORS

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8 Claims

ABSTRACT OF THE DISCLOSURE

A multistage pulse generator wherein a plurality of capacitors are charged-up in parallel via resistors and are discharged in series via spark gaps which may be ball or rod elements. The discharge circuit resistor of each stage consists of two parallel branches. The first branch is formed by a high-value resistor and the second branch is formed by the series combination of a low-value resistor and an auxiliary discharge device.

The invention relates to multistage pulse generators of the type in which capacitors are charged in parallel via resistors and discharged in series via spark gaps, to give a high voltage pulse.

High voltage pulses are normally produced by means of the Marx multiple circuit. In this circuit a number n of identical capacitors are charged in parallel via resistors and then connected in series by the ignition of spark gaps, to produce a pulse whose peak value is approximately n -times the charging voltage.

In the design of a Marx pulse voltage generator, the following characteristics must be considered:

(A) The load factor of the generator should be as large as possible. The load factor μ of an n -stage generator is:

$$\mu = \frac{\text{peak value of the pulse voltage}}{n \times \text{stage-charge voltage}}$$

FIGURES 4a and 4b in the VDE-publication 0450/XI.39 depict two basic arrangements with reference to the load factor.

(B) The satisfactory ignition of the spark gaps must be guaranteed. It should be possible to ignite the spark gaps far below their static response voltage with the aid of an ignition device arranged at the first stage. The further below their static response voltage the spark gaps can be ignited, the smaller becomes the probability of misignition of the spark gaps.

(C) The physical construction of the generator should be as compact as possible. In this context, it is particularly necessary to consider the damping resistance which is provided to control the form of the leading edge of the pulse. This resistance should if possible be distributed over the individual stages in the generator. An individual damping resistor provided outside the actual multiplication circuit, and subjected to the full voltage, is disadvantageous both from an electrical as well as from a mechanical point of view. Electrically there is the danger of series flashovers, in particular during the production of so-called switching voltages. Mechanically the suspension of a resistor having a length of some metres, provides a number of difficulties.

(D) The generator should be able to produce both short voltage pulses approximately of the form $1.2/50 \mu\text{s}$. in the sense of the CEI-publication 60, as well as so-called switching voltages approximately of the form $200/3000 \mu\text{s}$. The conversion work required for change-

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over from one type of operation to the other should be as little as possible.

None of the previously mentioned arrangements of multiplication circuits can fulfil all of these requirements simultaneously, so that it has only been possible to satisfy at most three conditions, and some compromise has had to be made with regard to the remaining condition or conditions.

One object of the present invention is to provide an arrangement which can be designed to satisfy all four above-mentioned requirements simultaneously.

The invention consists in a multistage pulse generator, in which a plurality of capacitors are charged-up in parallel via resistors, and are discharged in series via spark gaps, and in which the discharge circuit resistor of each stage consists of two parallel branches, a first branch being formed by a high-value resistor, and a second branch being formed by the series combination of a low-value resistor and an auxiliary discharge device.

The invention will now be described with reference to the accompanying drawings, in which:

FIGURE 1 is an example of a conventional 3-stage multiplication circuit; and

FIGURE 2 is a schematic circuit diagram of an exemplary embodiment of the present invention.

In FIGURE 1,

C_{s1} to C_{s3} are the pulse capacitors,

F_1 to F_3 are the spark gaps,

R_L are the charge resistors,

R_{d1} are the damping resistors distributed over the individual stages,

R_{e1} are the discharge resistors distributed over the individual stages,

LG is the charge rectifier,

Z_b is the impedance of the output circuit, for example, that of a component being tested.

These are the elements of the actual multiplication circuit. In addition, to this, there are the ancillary external resistors:

R_{e1} and R_{e2} which may be provided to determine the trailing edge of the standardised pulse wave, in cases where the discharge resistors R_{e1} are not sufficient for this; and

R_{d1} which may be provided to determine the front of the voltage wave applied to a sample to be tested in cases where the damping resistors R_{d1} are not sufficient for this.

Consideration will now be given to possible resistance combinations which may be employed, to fulfil at least some of the above described requirements that a properly functioning multiplication circuit should satisfy, and to indicate that they always strongly contradict at least one requirement.

First combination:

$$R_{e1} = R_{e2} = \infty$$

$$R_{d1} = 0$$

$$R_{e1} \ll R_L$$

The requirements A and C are satisfied by this resistance combination, but the requirements B and D are not fulfilled. When a generator having this circuit is to produce a pulse having a trailing edge half-value time of $50 \mu\text{s}$. or $5 \mu\text{s}$., in particular in generators with a high performance the discharge resistors R_{e1} are comparatively low in value. As known low-value discharge resistances result in bad ignition properties of the spark gaps. These can be reliably ignited with the aid of a triggering device, only just below their static response voltage.

Second combination:

- $R_L = R_{e1}$ (high-value)
- R_{e1} = determined by the required trailing edge of half-value time
- $R_{e2} = \infty$
- $R_{d1} = 0$

The requirements B and C are satisfied by this resistor combination, but the requirements A and D are not fulfilled. The arrangement of the resistors corresponds to the circuit VDE 0450/XI.39 view 4a, which as known, exhibits a bad load factor, in particular at small load capacitances.

Third combination:

- $R_L = R_{e1}$ (high value)
- $R_{d1} = 0$
- R_{d1} = a few hundred ohms
- R_{e1} = determined by the required half-value time

The requirements A and B are satisfied by this resistance combination, but the requirements C and D are not fulfilled. The electrical behaviour of this circuit is good. The disadvantage of this arrangement consists in the fact that the resistors R_{d1} and R_{e1} are situated outside the actual multiplication circuit. In generators for producing pulse voltages of the order of magnitude of several million volts these resistors are several metres long. The mechanical attachment, insulated for several million volts, in particular of the resistor R_{d1} which is generally arranged horizontally, provides a difficult technical problem.

The present invention is based on the recognition that after ignition of the first spark gap the automatic ignition of the remaining spark gaps can be effected more reliably if larger value discharge resistors R_{e1} are employed. The ideal discharge resistance should exhibit a high resistance, at least as long as the spark gap of the stage has not yet ignited and the desired multiplication has not yet taken place. After ignition of the spark gap, the resistance value of the appropriate discharge resistor should drop, to the extent which is required for reaching that trailing edge half-value time of the voltage wave required by the relevant standard.

In a generator constructed in accordance with the invention, the high resistance value which is first operative and its subsequent dropping to a low-ohmic value is obtained by an arrangement which is characterised in that the discharge resistor of each stage consists of two parallel branches where the one branch is formed by a high-value resistor, and the other branch by the series combination of a low-value resistor with an auxiliary discharge region.

The mode of operation of this arrangement will now be explained with reference to the exemplary embodiment of a 3-stage system depicted in FIGURE 2, which corresponds to FIGURE 1 as far as the charging circuit is concerned, but each stage now has a discharge circuit having two branches in parallel, one branch containing a high-value resistor R_{eh} , and the other branch containing a low-value resistor R_{en} , in series with an auxiliary discharge device.

All pulse capacitors C_s are charged with the aid of the rectifier LG to the voltage U. The response voltages U_{ZF} of the spark gaps F_1 and F_2 and F_3 are the same, but larger than the charge voltage U. At the spark gaps F_1 , F_2 and F_3 the charge voltage U is obtained, whilst at the discharge regions G_1 , G_2 and G_3 no voltage occurs. A test object is depicted by an impedance Zb in a similar manner to FIGURE 1.

With the aid of a triggering device (Trigatron) the spark gap F_1 is ignited, whereupon the charge voltage U appears across the resistor R_{eh} of the first stage and thus also at the discharge region G_1 . The ignition characteristic of the discharge region G_1 can be selected in such a way that it responds at the voltage U, after approximately 10^{-7} to 10^{-8} seconds. If G_1 responds, then C_{s1} is dis-

charged within the standard time (50 μs . or 5 μs .) to the voltage $U/2$.

As known, after ignition of F_1 , a transient voltage appears across the discharge resistor of the second stage after the ignition of the first stage, in such multistage generators, and this is true in the present case. The level and the characteristic in time are determined as known by the ohmic value of the resistor R_{eh} , as well as by the magnitude of the stray capacities operative in the circuit. The said transient voltage also occurs across the discharge region G_2 , as long as this is not yet ignited. Moreover, the transient voltage superimposes itself upon the D.C. voltage operative at the spark gap F_2 to increase the voltage operative at F_2 above the static response voltage U_z .

The ignition characteristic of the discharge region G_2 is selected in such a way that the transient voltage occurring before the ignition of F_2 does not lead to ignition of G_2 . The voltage U occurring after the ignition of F_2 at G_2 is, however, larger than the response voltage of G_2 . The discharge region G_2 is thus ignited approximately 10^{-7} to 10^{-8} seconds after ignition of F_2 . The ignition process of the third spark gap F_3 and of the discharge region G_3 are then effected automatically by a similar process.

With the aid of the discharge regions G, which ignite in delayed fashion after the ignition of the associated spark gaps F, it is thus possible to positively effect the series connection of the charged-up pulse capacitors C_s at individual voltages far below the static response voltage of the spark gaps. Only after the series connection has been automatically effected by the high-value resistors R_{eh} , are the discharge regions G ignited to connect the low-value discharge resistors R_{en} in each stage.

The discharge regions G can be formed by ball-electrode spark gaps whose sparking distances are made slightly smaller than those of the spark gaps F. Alternatively, the discharge regions G can be formed by an electrode arrangement having a very inhomogeneous field distribution, for instance by tube spark gaps. The response delay inherent in inhomogeneous field arrangements with rapid voltage demands, supports the delay in ignition of the discharge regions G desired in the present case with respect to the time of ignition of the appropriate spark gaps F.

To provide the simple changeover properties of the multiplication circuit mentioned above under point D, for the changeover from the wave 1.2/50 to the switching voltage 200/300 μs , or vice versa, in all arrangements known to date it has been necessary to provide means for changing both sets of damping resistors and discharge resistors of the multiplication circuit, or at least to provide them with appropriate short-circuit connections. In contrast to this, with the present invention the changeover of the discharge resistors can be rapidly effected if the high-value resistors R_{eh} are designed to effectively discharge the pulse capacitors C_s to give a trailing edge half-value time required for the switching voltage, of for instance 3000 μs . The discharge regions G can then be set in such a way that they definitely do not ignite during the production of switching voltages.

The resulting discharge circuits obtained by the parallel connection of the high-value resistor R_{eh} and the low-value resistor R_{en} , are then dimensioned in such a way that both resistors together discharge the pulse capacitors to give a trailing edge half-value time of, for instance, 50 μs . The discharge regions G are then adjusted in such a way that for the production of a trailing edge half-value time of 50 μs they respond as described above, shortly after the ignition of the appropriate spark gaps.

The present arrangement, which is characterised by two parallel branches of the discharge circuit employing one branch alone for producing a trailing edge of approximately 3000 μs , and both together for producing a trailing edge half-value time of approximately 50 μs , thus

offers the advantage that for the changeover to different trailing edge half-value times only the setting of the discharge regions G need be changed.

A generator constructed in accordance with the invention can thus meet all the requirements set out above.

adA: The load factor of the new circuit is good. It corresponds to the basic arrangement depicted in view 4b of the VDE-publication 0450/XI.39.

adB: The spark gaps can be ignited far below their static response voltage with the aid of an igniting device arranged at the first stage. This property is due to the high-value discharge resistor R_{eh} operative alone during the igniting process.

adC: The generator circuit can be constructed in a very compact fashion, since all pulse circuit elements can be accommodated within the actual multiplication circuit. Standard voltage waves at a simultaneously high load factor in the multiplication circuit and simultaneous satisfactory igniting of the spark gaps can be ensured without the use of ancillary external pulse circuit elements R_{e1} , R_{e2} and R_{d1} , depicted in FIGURE 1.

Ad D: A generator designed in accordance with the new circuit can be designed to produce voltage pulses with short trailing edges (for instance 50 μs) or so-called switching voltages having long flanks (for instance 3000 μs), without the alteration of discharge resistors. The conversion required for changeover from the one voltage form to the other is limited to the adjustment of the discharge regions G, for instance with the aid of a motor drive, so that they either definitely *do* respond in order to produce a short trailing edge half-value time, or that they definitely *do not* respond in order to produce a long trailing edge half-value time.

What I claim as my invention and desire to secure by Letters Patent of the United States is:

1. A multistage pulse generator comprising a plurality of stages of capacitors, a first series of circuits for said capacitors each having a resistor for charging up said capacitors in parallel, a second series of circuits each having a spark gap in series therein for discharging said capacitors; the discharge circuit of each of said second series of circuits comprising two parallel branches, the first of said branches having a high value resistor and the second of said branches comprising a series combination of a low value resistor and an auxiliary discharge device.

2. A generator as claimed in claim 1 wherein said auxiliary discharge device is a ball-electrode spark gap.

3. A generator as claimed in claim 1, wherein said auxiliary discharge device is a rod-electrode spark gap.

4. A generator as claimed in claim 1 wherein said discharge circuit during discharge of said capacitors in the

trailing edge half-value time corresponding to the switching voltage, of preferably approximately 3000 μs , contains said high-value resistor, while during discharge of said capacitors with short trailing edge half-value times of preferably 5 to 50 μs it contains both said high-value resistor and said low-value resistor.

5. A generator as claimed in claim 1 wherein means are provided for changing the ignition characteristic of said auxiliary discharge device from a setting at which each device ignites when the associated spark gap in its stage has been ignited, to a second setting at which it does not ignite when the associated spark gap has been ignited.

6. A generator as claimed in claim 5 wherein said discharge circuit is such that said second setting is employed during discharge of said capacitors and therefore said discharge circuit consists only of said first branch to give a trailing edge half-value time corresponding to a switching voltage approximately of 3000 μs , and said first setting is employed during discharge of said capacitors to give a short trailing edge half-value time, of 5 to 50 μs , when both said first branch and said second branch are included.

7. A generator as claimed in claim 1 wherein means are provided for delaying the ignition of said auxiliary discharge device after the ignition of the associated spark gap.

8. A generator as claimed in claim 7 wherein means are provided for adjusting said delaying means from a value of a few nanoseconds up to a value of a few seconds.

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