My invention relates to pulse generating systems, particularly to such systems employing spark gaps as switching mechanism, and the object of the invention is to provide improved systems of this character which produce pulses at a relatively high rate and operate at a high charging voltage, and which supply a large value of instantaneous power with a high order of timing precision of sparking of the switch means proper.

In pulse generating systems for supplying instantaneous high power at a rapid rate which have been proposed and used heretofore in an extended range of applications, difficulties have been encountered in obtaining pulses of the required power and repetition rate and at the same time with the desired timing accuracy.

In accordance with my present invention these disadvantages are overcome by the provision of a pulse generating apparatus in which a charged capacitor storage element is connected to a load by a spark gap arrangement for assembly providing two spark gaps in series, and in which a predetermined initial apportionment of the voltages across the two gaps is changed or disturbed at the desired triggering instant thereby to cause breakdown of the spark gaps and to initiate the discharge through the load, of a pulse from the storage element.

In one embodiment of my invention an alternating current source is arranged to charge the storage element at each cycle through a rectifier, and during the interval at each cycle when the voltage of the alternating current source is reversed the spark gap switch means is triggered thereby initiating the discharge of the storage element through the load. The capacitive storage element is preferably of such character as to produce a discharge pulse of substantially rectangular wave form and for this purpose may comprise a section of a suitable transmission line.

In this embodiment of the invention the initial apportionment of the voltages is disturbed or changed to initiate the discharge by reducing to a substantial degree, preferably close to zero, the potential initially impressed on one of the conductive electrode members which provide the two spark gaps. The reducing of the potential is accomplished by pulsing positive the control electrode of a space discharge device normally in cutoff condition connected to the spark gap electrode member, the conduction periods of the space discharge device being synchronized, through timing means which may comprise a multivibrator and a primary or initial timing device connected thereto with the frequency of the alternating current source which charges the storage element. Instead of the alternating current source a direct current source may be employed to charge the capacitive storage element and in this case the timing means above mentioned may be utilized to control the positive pulsing of the space discharge device control electrode.

In another embodiment of the invention the predetermined initial apportionment of the voltages across the two gaps is changed or disturbed not by reducing close to zero the potential initially impressed on one of the electrode members but by impressing a voltage pulse thereon, preferably from an inductance arranged to be charged periodically from a space discharge device having a pulse timing means associated therewith which may include a multivibrator.

The novel features which are considered to be characteristic of my invention are set forth with particularity in the appended claims. My invention itself, however, both as to its organization and method of operation together with further objects and advantages thereof may best be understood by reference to the following description taken in connection with the accompanying drawings wherein Fig. 1 is a diagrammatic representation of a pulse generating system, powered from an alternating current source, in which my invention has been embodied; Fig. 2 is a detailed illustration of a spark gap switching assembly in accordance with my invention: Fig. 3 illustrates a voltage pulse produced in accordance with my invention; Figs. 4 and 4a illustrate systems similar to that of Fig. 1 but powered from a direct current source: and Fig. 5 illustrates a modification of the embodiments shown in Figs. 1 and 4.

In Fig. 1 the numeral 1 designates a capacitive element adapted to be charged periodically from an alternating current source through a transformer 2, a rectifier 3 and an inductance 4 shunted by a resistor 5, and to be discharged during the reverse period of the current source through a load element such as a resistor 6, across which may be connected a desired output or utilization circuit. For example, the pulses from the resistor 6 may be supplied to radio apparatus or the like employed to transmit high-power signals, rapidly repeated and accurately timed and of short duration. For illustrative purposes the utilization circuit is shown herein as including a magnetron upon the anode-cathode circuit of which the pulses from resistor 6 are impressed and which is connected to an antenna to transmit therefrom rapidly repeated short-duration pulses of intense microwave radiation utilized, for example, in the detection of distant objects.

The capacitive storage element 1 is constituted preferably by a section of transmission line of such character that the discharge therefrom approximates a rectangular wave form. In Fig. 1 the transmission line section comprises a plurality of condensers 8, preferably at least five in number, connected in parallel, with one side of each connected to a common lead 9 and with the
other sides of adjacent condensers connected by inductances \( I \). The operation of the element \( I \) in forming a square pulse will be understood if this element is looked upon as an approximation to a uniform transmission line having uniformly distributed inductance and capacity of total amounts \( L \) and \( C \) respectively. It is well known that if such a line, open at the far end, is charged to a potential \( V \) and then discharged through a resistance

\[ R = \sqrt{L/C} \]

ea square pulse is generated at the resistance having the voltage value

\[ V \]

current value

\[ \frac{V}{2h} \]

and duration

\[ 2\sqrt{L/C} \]

To discharge the storage element \( I \) through the load \( S \), in accordance with the present invention a switching means is provided comprising a plurality of spark gap members or conductive electrode members in the present embodiment three in number, \( 11, 12, \) and \( 13 \), providing two spark gaps \( 14 \) and \( 15 \) in series with the storage element \( I \) and the load \( S \). The constructional features of the switching means comprising spark gap members \( 11 \) to \( 13 \) will be explained in detail hereafter in connection with Fig. 2. The voltages initially impressed across the spark gaps \( 14 \) and \( 15 \) are preferably equally apportioned as by resistors \( 16 \) and \( 17 \) connected respectively between member \( 17 \) connected to the capacitor element \( I \) and the intermediate member \( 12 \), and between the intermediate member \( 12 \) and member \( 13 \) connected to the load \( S \). A capacitor \( 18 \) for balancing the distributed capacity of member \( 12 \) is shown connected between members \( 17 \) and \( 12 \) but is not always necessary.

The numeral \( 19 \) designates a space discharge device, normally in cutoff condition, the anode \( 20 \) of which is connected to the intermediate spark gap member \( 12 \), and the cathode \( 21 \) of which is connected to ground through a bypass condenser \( 32 \). To cause space discharge device \( 19 \) to become periodically conducting, thereby to reduce periodically close to zero the potential of spark gap member \( 12 \), a means is provided to impress a positive pulse upon the control electrode \( 23 \) of the latter space discharge device. Any suitable means may be utilized for this purpose. Preferably, however, an inductance \( 24 \) shunted by a damping resistor \( 25 \) and included in the anode circuit of a space discharge device \( 26 \), normally in cutoff condition, is provided which is connected through a condenser \( 27 \) to the control electrode \( 23 \) of discharge device \( 19 \) to supply the positive pulse thereto. A relatively large leak resistance \( 28 \) is connected between the control electrode \( 23 \) and cathode \( 21 \) of a space discharge device \( 19 \) to suppress to a sufficient extent a positive reversal of the potential impressed thereon. To facilitate the supplying of the pulse from inductance \( 24 \) to the control electrode \( 23 \) of device \( 19 \) and to maintain synchronization of this pulse and the frequency of the above-mentioned alternating current source, a space discharge device \( 29 \) of the gas filled type, arranged to operate in a usual sweep circuit, or saw tooth wave generating circuit, is preferably employed in connection with a multivibrator \( 31 \). Potentials are supplied to the control electrode \( 32 \) of device \( 29 \) through a transformer \( 33 \) to initiate periodic operation of the discharge device \( 29 \) and thereby to cause negative potentials in synchronism with the frequency of the alternating current source to be impressed upon an input electrode of the multivibrator.

By adjusting the cathode bias of gas filled device \( 29 \) the pulse phase relative to the voltage from the alternating current source may be regulated over nearly a full 180 degrees.

The pulse rate of the multivibrator is thus synchronized, by connection to circuit \( 30 \), with the predetermined frequency, and the output circuit of the multivibrator is in turn connected through a capacitor \( 34 \) and resistor \( 35 \) to the control electrode \( 36 \) of space discharge device \( 26 \) to impress short pulses at this frequency upon the latter electrode.

Danger of overloading of the anode circuit of device \( 26 \) which is likely to occur unless the current passing interval, or interval during which current is traversing inductance \( 24 \), is maintained at a small fraction of the total time period of each pulse is avoided, since current passed during intervals of the required short duration in device \( 26 \) are obtained corresponding to the short pulses readily obtainable from the multivibrator and impressed upon the control electrode \( 36 \).

Any conventional means other than as above described for maintaining synchronization of the pulse from inductance \( 24 \) and the frequency of the alternating current source may be employed.

In the operation of the system illustrated in Fig. 1, the transformer \( 2 \) charges the capacitive element or transmission line section \( 3 \) opening a cycle through rectifier \( 3 \) and inductance \( 4 \). After charging is complete and during the interval when the voltage of transformer \( 1 \) is reversed, the switching means constituted by the spark gap members or spark electrode members \( 11 \) to \( 13 \) is triggered, thus applying to the load \( 6 \) one-half of the voltage of transmission line \( I \) in the form of a wave approximating a square wave.

A suitable air blast directed through the spark gaps \( 14 \) and \( 15 \) removes the ionization products resulting from the discharge thereby reestablishes control or reopening of the circuit at the spark gaps after each sparking period.

Referring to Fig. 2, in the spark gap switching means illustrated in detail therein, the spark gap or electrode members \( 11, 12, \) and \( 13 \) are mounted in spaced relation on a frame \( 37 \). One of the electrode members, \( 11 \), upon which the highest potential is impressed, is supported on the frame by a terminal member \( 38 \) which may be rigidly fixed thereto. The intermediate electrode member \( 12 \) is supported by a terminal member \( 39 \) fastened to a block or sliding member \( 40 \) of suitable form movable laterally with respect to the frame to adjust the position of member \( 12 \) with respect to member \( 11 \). The third electrode member \( 13 \) is supported by a terminal member \( 41 \) movable laterally in the frame to adjust the position of member \( 13 \) with respect to member \( 12 \). The main bodies \( 42 \) and \( 43 \) and \( 44 \) of the spark gap members \( 11 \) to \( 13 \) are formed of a suitable electrically conducting material to which tungsten can be soldered. The members \( 42 \) and \( 44 \) are roughly elliptical in cross sectional outline, tapering at an angle of approximately five degrees from near the axis of the spark gaps toward the opposite ends in order to reduce the tendency to formation
of sparks not in the line of the axis of the gaps and 6.

In the high potential member 42 and the inter- 
mediate member 43 are formed air ducts which, 
when the bodies are of solid metal, may com- 
prise holes 45 and 46 extending from the center 
the distance to one end of the bodies, and holes 47 and 48 at 
right angles to the holes 45 and 46 and extending 
from the inner ends thereof to an outer face of the 
body. To conduct an air blast through the 
air ducts, the terminal members 38 and 39 are 
preferably tubular and are in connection respec- 
tively with the holes 45 and 46.

Electrodes 49 and 50 having preferably the form 
of rounded rods connected respectively in- 
teriorly of members 41 and 12, extend respec- 
tively through holes 47 and 48 and project there- 
from a short distance, electrode 49 being directed 
toward member 12 and electrode 50 toward mem- 
ber 13.

On the faces of members 12 and 13 toward 
which electrodes 49 and 50 respectively extend 
are soldered or otherwise secured tungsten plates 
or bosses 51 and 52. A suitable means (not 
shown) is provided for producing a blast of air 
or other suitable gas through the air ducts and 
in the spark gaps 45 and 18. Instead of being 
formed from a solid block as shown in Fig. 2, the 
main spark gap bodies 42 to 44 may be spun or 
pressed from sheet material, and to prevent un- 
dered or outlaw sparks from their surfaces 
caused of rusting, the surfaces may be plated 
with gold or silver, for example.

In a practical application of the invention con- 
structed and operated as described in connection 
with Figs. 1 and 2, the charging circuit was pow- 
ered from a 406 cycle alternating current source. 
The charging voltage from transformer 2 was 
65 kilovolts, 54 kilovolts being applied to the load 4. 
Substantially instantaneous power of 4.6 meg- 
awatts was delivered from the transmission line 
I, which had a capacitance of 2300 micromicro- 
farads and an impedance of 233 ohms. The 
curve of the discharged pulse applied to the non-induc- 
tive load constituted by the resistance 6 had the 
form, approximating a rectangular wave, shown 
in Fig. 3, the pulse lasting approximately only 
1.1 microsecond with a precision of sparking 
proper of a fraction of 10⁻¹ second. The space 
discharge device 28 included in the gas trigger 
circuit, was of the type RK65; space discharge 
device 26, included in the pulse amplifier circuit, 
of the GL13 type; and space discharge device 28, 
included in the master pulse circuit, of the 
884 type. The r. m. s. value of voltage impressed 
on the control electrode 32 of the latter device, 
type 884, from the transformer 32 ranged from 
0.2 volt to 2.5 volts. The spark gaps 14 and 15 
were approximately five-eighths inch in length at 
the 65 kilovolts across the gaps, and an air pres- 
sure of from one to two pounds per square inch 
(gauge) in the supply line sufficed to remove lon- 
ization products and to reestablish control after 
the occurrence of the spark.

In the above described practical application 
of the pulse generating system illustrated in Fig. 1, 
the charging voltage was limited as above men- 
tioned to a value of 65 kilovolts. It is to be un- 
derstood that such limiting of the voltage was 
not caused by the spark gap switching arrange- 
ment provided in accordance with my present 
invention but primarily by the characteristics of 
the high voltage transformer 2 and secondarily 
by the danger of spark-over to frame elements 
or other low voltage elements with increase of 
charging voltage. It will be understood that by 
the employing of a suitable higher voltage trans- 
former or like means connected to the storage 
element I and by proper precautions in design 
to preclude the occurrence of a spark, still 
higher instantaneous power at an increased 
charging voltage may be obtained from the sys-

Referring to Fig. 4, in the embodiment of my 
invention illustrated therein a direct current 
source instead of an alternating current source is 
employed as a power supply. The switching 
means comprising spark gap or electrode mem- 
bers 11 to 13 of Fig. 4 may be identical with that 
described in connection with Fig. 1, the trigger- 
ning being accomplished, as in Fig. 1, by reducing 
to a substantial degree the potential of the inter-
mediate member 12 through a space discharge 
device whose control electrode is pulsed positive 
by an inductance 24 in the anode circuit of a sec-
ond space discharge device 26 the energizing of 
the control electrode 38 of which is provided by 
the multivibrator 31. The energizing pulse from 
the multivibrator can in turn be released by a 
negative pulse impressed, from any suitable or 
usual primary or initial timing system (not 
shown), upon the terminal 33. As a result the 
power pulse is generated at a time subsequent to 
the primary pulse by an interval which is the order of one microsecond, but for successive 
pulses this interval is the same within less than 
10⁻⁷ seconds. Other known means may be em-
ployed for energizing the discharge device 19 at 
time intervals which may be varied, in a usual or 
known manner, through wide limits.

As in Fig. 1, in Fig. 4 a capacitive storage ele-
ment 54 is provided adapted to be charged from 
the power source, and to be discharged periodi-

cally, by triggering the spark gap switching 
means, through a load such as resistance 6. The 
capacitive storage element 54 may be the same 
as that designated by the numeral I in Fig. 1, or, 
instead, a capacitive element 55 in series with a 
transmission line 56 having a plurality of induc-
tance capacity sections, at least six in number, 
may be employed. The direct current source is 
adapted to be connected by a switch 57 through 
an inductance 58 and a rectifier 59 to the capaci-
tive storage element 54, and through a switch 57a 
interconnected with switch 57 to the space dis-
charge device 26 to supply anode current thereto. 
The interconnected switch means including 
switches 57 and 57a is so arranged that in initiat-
ing the supply of current to the storage element 
54 and to the space discharge device 26, the 
switch 57 closes first and the switch 57a closes 
a few milliseconds later. The closing of switch 
57 initiates an oscillation involving the induc-
tance 58 and capacity 55, the period of this 
oscillation being determined by the respective 
inductance and capacitance values of these 
elements. During the first half period of the 
oscillation the current flow is in one direction 
only, rising to a maximum and falling to zero. 
Meanwhile the charge on the capacity 55 is ris-
ing continuously until at the instant of zero 
current the capacity is charged to twice the 
direct current voltage of the source, and from 
this instant on the capacity retains the charge 
because the rectifier 59 prevents reversal of the 
current and a continuation of the oscillation. 
At a subsequent time, as assured by the later clos-
ing of switch 57a, the gap fires, the capacity 55 
discharges through the gap and the recharging 
automatically takes place. As long as the re-
charging time, represented by the half period of the oscillation, is less than the pulse interval, the above described action continues automatically. This type of charging may be called half sine wave charging, referring to the shape of the capacity voltage wave during the charging time.

Another type of charging than the half sine wave charging, described above, may be employed in the method of powering from a direct current source shown in Fig. 4. In this other type of charging, the series connection comprising the inductance 58 and the capacity 55 has a natural period whose half value is greater instead of less than the pulse interval. In this latter type of charging, when the switch 57 is closed transient conditions obtain in the circuit for a short time, but a steady state is reached in which the current through inductance 58 never falls to zero and consists of a constant current upon which are superimposed humps consisting of portions (less than half) of sine waves. Corresponding here-to the voltage wave on the condenser 55 approximates to a sawtooth with a linear rise and an abrupt fall, the linear rise being modified in accordance with the variations of the charging current. The larger the value of the inductance 58 the smaller are the variations in current and the more nearly linear is the rise of voltage across the capacity 55. With this method the rectifier 53 is not necessary and, as shown in Fig. 4a, is absent from the system which is otherwise as shown in Fig. 4. This latter type of charging may be called straight line charging.

In a practical application of the invention constructed essentially as described in connection with Fig. 4 except that, instead of the storage element 54 of Fig. 4, the storage element 1 of Fig. 1 was employed, the charging voltage applied to the storage element was approximately 65 kilovolts and the pulse voltage applied to the load resistor 6 approximately 32 kilovolts. In this system a pulse rate up to a rate of 3000 per second was obtained with an accuracy of firing relative to the multivibrator pulse, and hence to the timing signal from any master or primary signal system connected to terminal 53 to control the multivibrator, of better than 10⁻⁷ second accuracy.

Referring to Fig. 5 the modification of my invention illustrated therein may comprise a capacitive storage element 1 adapted to be charged from a suitable source of power, for example a direct current source, and to be discharged through a load resistor 6, connected to a magnetron 7, for example, as in Figs. 1 and 4, by a switching means having spark gap members 11, 12 and 13 providing spark gaps 60 and 61 corresponding to the spark gaps 14 and 15 of the embodiment of my invention illustrated in Figs. 1 and 4. So far as the switching operation is concerned, the load resistor 6 may be grounded at either end, the nature of the output circuit connected thereto determining the proper grounding point. Gap 61 is made longer than gap 60 preferably substantially twice the length thereof and across one of the gaps 60 is connected a resistor 62.

As in the embodiment shown in Figs. 1 and 4, in the modification illustrated in Fig. 5 the spark gap switching means is triggered by changing or disturbing the appportionment of the voltages applied across the spark gaps.

In Fig. 5, however, instead of reducing the potential on the intermediate spark gap member 12 to a substantial degree or close to zero, a pulse of relatively high voltage is impressed upon the member 12 to accomplish the triggering action. For this purpose, preferably at least three device discharge devices 63, corresponding to device 28 of Figs. 1 and 4, arranged in parallel and of the G1613 type for example, are adapted to provide the required energization of an inductance 64, corresponding to inductance 57 of Figs. 1 and 4. The anode circuit of the devices 63 is supplied from the direct current source, and the energizing of the control electrodes of the paralleled devices 63 is produced by a suitable timing means which preferably includes a multivibrator and a primary-terminal timing system associated therewith as in Fig. 4.

In the operation of the pulse generating system shown in Fig. 5 the initiation of the spark discharge from the capacitive storage element 1 is accomplished by suddenly exceeding the breakdown voltage across the gaps 60 and 61 by means of the self-induction pulse from the inductance 64 in the anode circuit of the space discharge devices 63. Reliability of firing across the gap 60 and 61 is increased, if desired, by irradiating the gaps with a continuous light, represented conventionally by the rectangle 65, such as a quartz mercury lamp or a spark in air, during a phase interval which includes at least the firing instant. An air blast across the gaps is necessary to clear the space of all ions before a succeeding firing instant.

My invention has been described herein in particular embodiments for purposes of illustration. It is to be understood, however, that the invention is susceptible of various changes and modifications and that by the appended claims I intend to cover any such modifications as fall within the true spirit and scope of my invention.

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

1. In combination, a capacitive device adapted to store electric energy in electrostatic condition and to produce a discharge voltage of the pulse approximating rectangular wave form, an electrical power source, means to connect said source to said capacitive device to store a charge therein, a load, three spark gap members providing two spark gaps in series with said capacitive device and said load, and means to initiate discharge of said device through said load including an electron discharge device having an electrode connected to at least one of said spark gap members abruptly to change the potential of one of said members and thereby to change the initial apportionment of voltage across said gaps.

2. In apparatus for generating rapidly repeated electric pulses, a capacitive element adapted to store electric energy in electrostatic condition and to produce power pulses, an electrical power source, means to connect said source to said capacitive device to store a succession of charges therein, a load, three spark gap members providing two spark gaps in series with said capacitive device and said load, and means to initiate discharge of said device in succession from said capacitive element of said pulses through said load, said last named means including an electron discharge device having an electrode connected to the intermediate of said spark gap members and arranged by its discharge abruptly to change the potential of said intermediate member thereby to change the initial apportionment of voltage across said gaps.

3. A pulse generating apparatus comprising a capacitive storage element, a load device, means
for periodically charging said storage element, at least three sparking electrodes spaced apart to provide at least two spark gaps in series between said storage element and said load device, and means for initiating periodic discharge of said storage element across said gaps and through said load device, said electron discharge device electrically connected between two of said sparking electrodes across one of said gaps and timing means for periodically rendering said discharge device conductive.

4. In a system for discharging a charged device, one or more conducting elements providing two spark gaps in series with said device, the conducting element having one extreme of potential and the intermediate conducting element each having a duct formed therein and each having an electrode mounted within and projecting from the corresponding duct, each of said electrodes being conductively connected to the corresponding conducting element, said ducts being adapted to be traversed by a gas to remove ionization products from said spark gaps subsequent to said spark discharge.

5. In a system for discharging a charged device, a plurality of conducting elements providing two spark gaps in series with said device, one of said elements at each gap having a duct formed therein and an electrode of refractory material conductively connected thereto mounted within said duct and projecting therefrom into the gap, the other of said elements at each gap having attached thereto a member formed of conductive refractory material to receive the spark discharge from the electrode of the corresponding other element, said ducts being adapted to be traversed by a gas to remove ionization products from said gaps.

6. In combination, a capacitive device, an alternating current source, means including a rectifier to connect said source to said device to store a charge therein, a load, three spark gap members providing two spark gaps in series with said device and said load, a space discharge device having its anode connected to the intermediate one of said spark gap members, means connected to the control grid of said space discharge device to cause said space discharge device to become conducting periodically thereby to reduce substantially the potential of said intermediate member, and means to initiate said pulses from said capacitive element through said load comprising timing means operatively associated with one of said gap members to change periodically at said rated voltage impressed across said gaps from the initial voltage apportionment between said gaps.

7. In combination, a capacitive device, a source of direct current, a load, means comprising an inductance and a rectifier to connect said source to said capacitive device to store a charge therein, three spark gap members providing two spark gaps in series with said capacitive device and said load, a space discharge device having its anode connected to the intermediate one of said spark gap members, and timing means connected to the control grid of said space discharge device to cause said space discharge device to become conducting periodically thereby to reduce substantially the potential of said intermediate member.

8. In combination, a capacitive device, a source of direct current, a load, means comprising an inductance to connect said source to said capacitive device to store a charge therein, three spark gap members providing two spark gaps in series with said capacitive device and said load, and means to change the potential of the intermediate one of said members from the initial potential there-