April 12, 1966 M. R. CLELAND 3,246,230

VOLTAGE MULTIPLICATION APPARATUS

Filed March 5, 1962 7 Sheets-Sheet 1

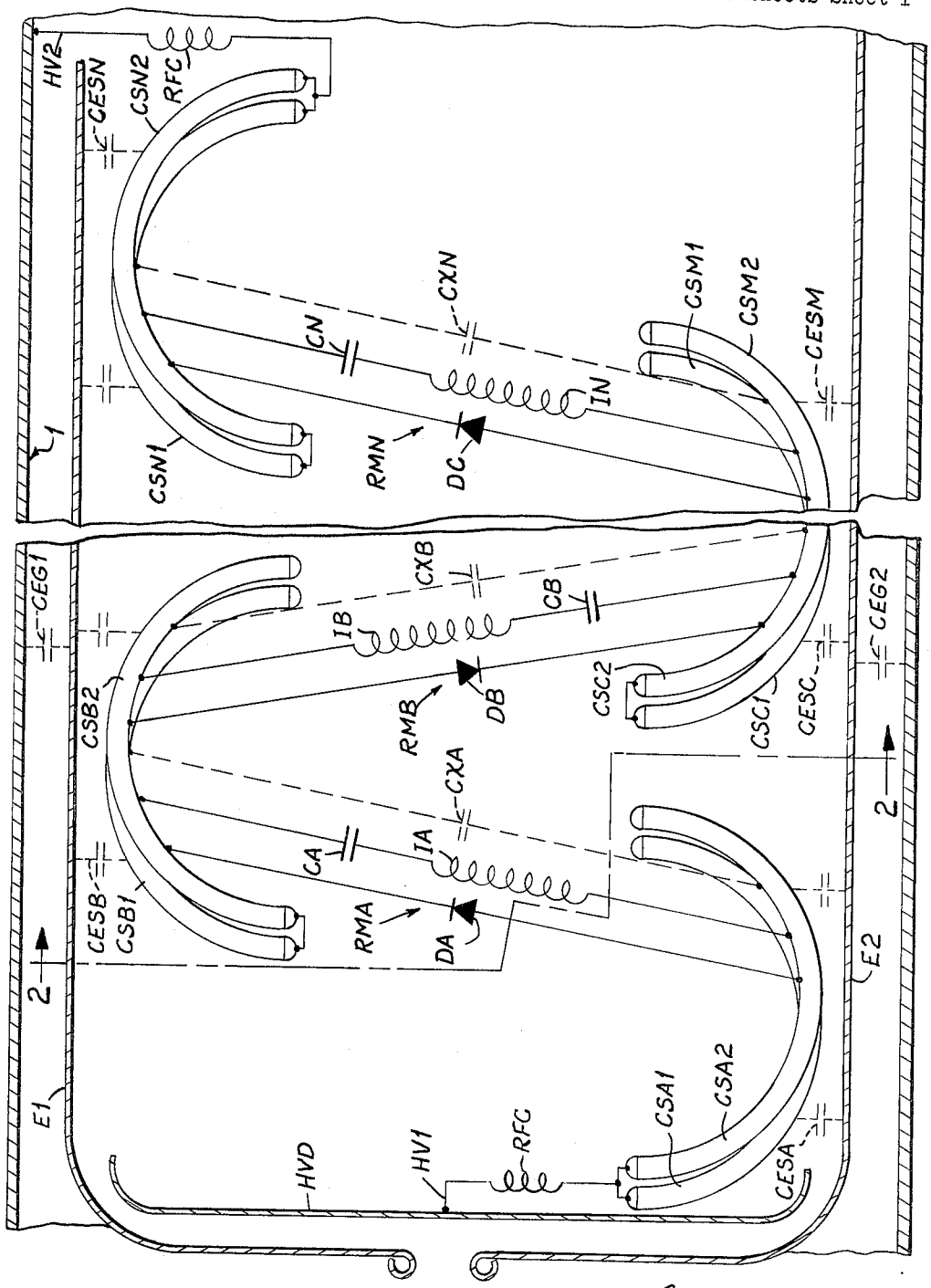

FIG. 1.

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Inventor.
Koenig, Pope, Senniger and Powers,
Attorneys.

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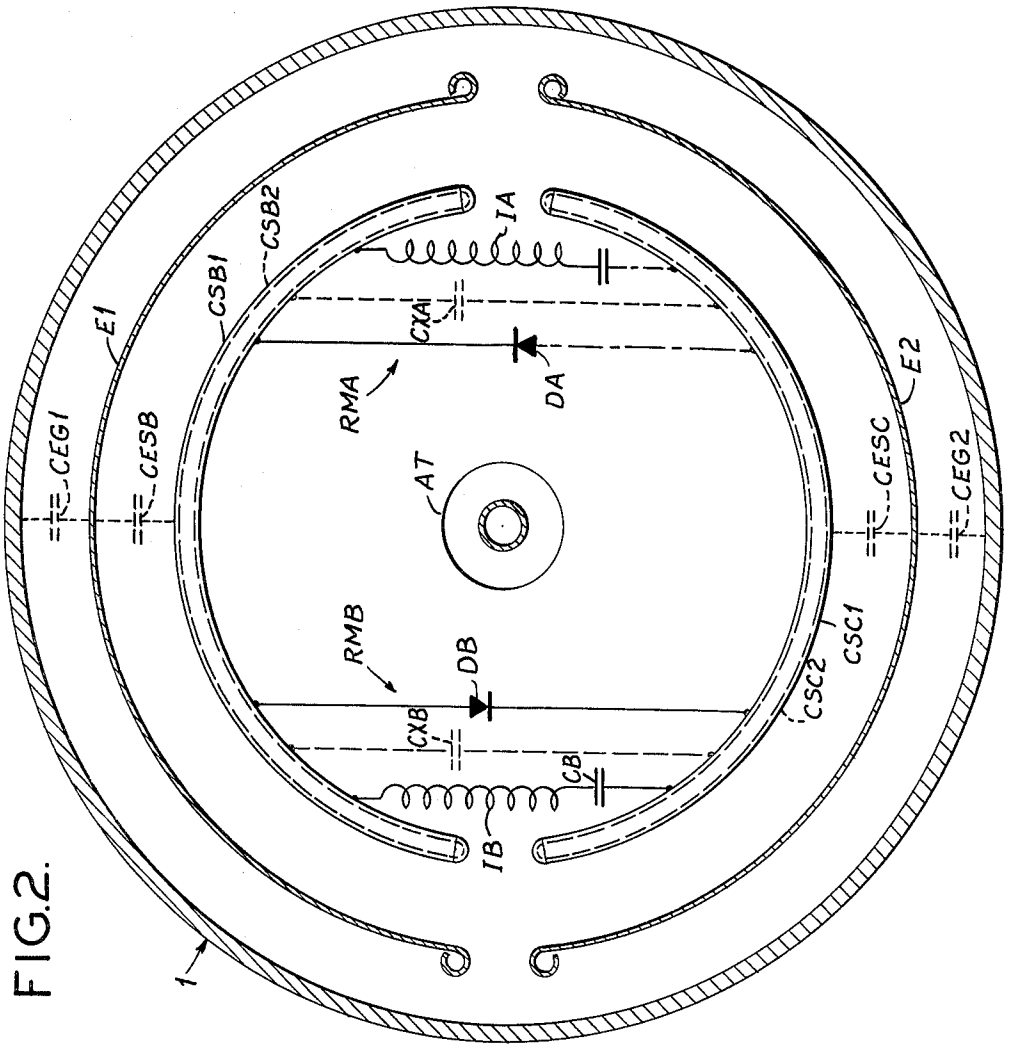

FIG.2.

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FIG. 8.

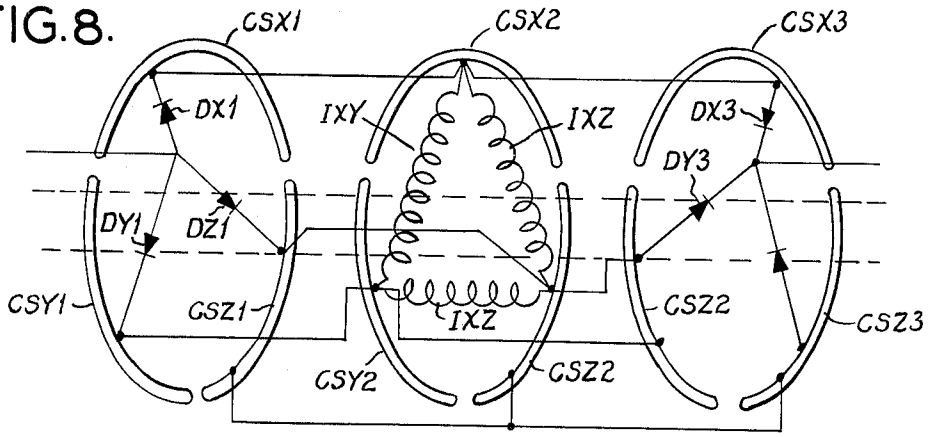
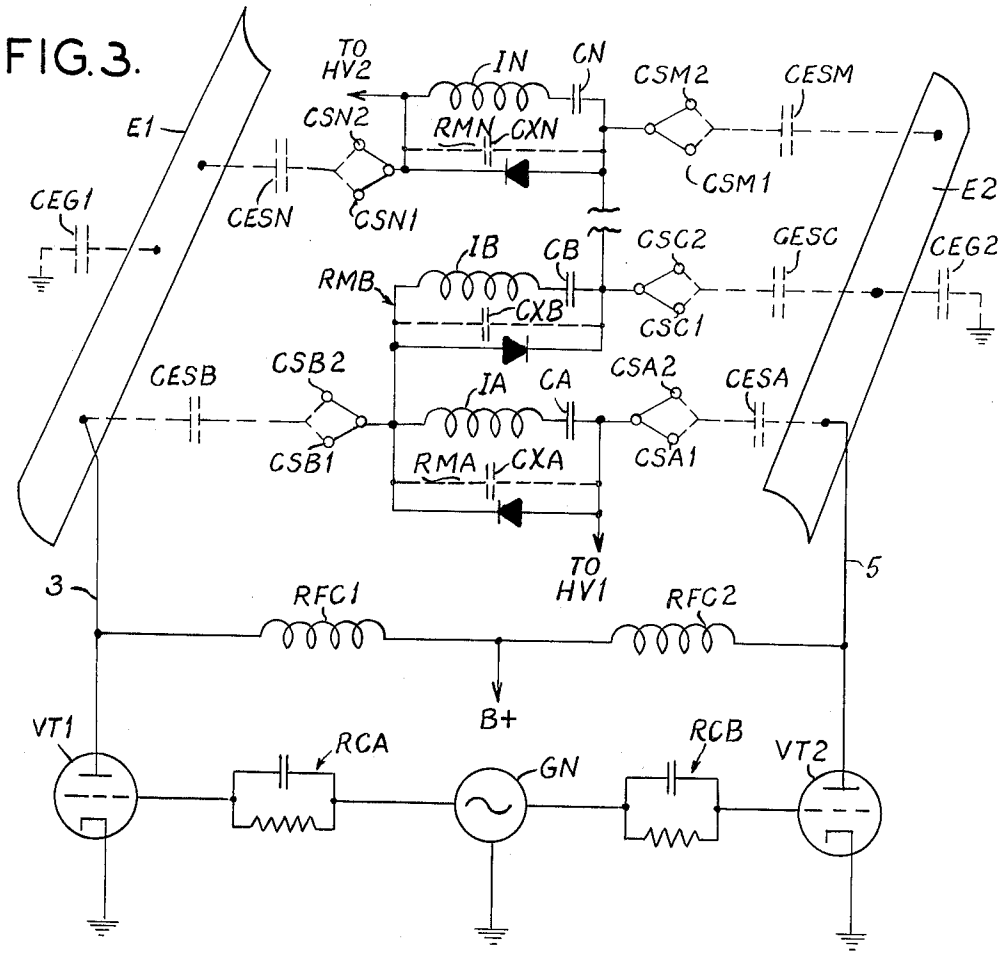


FIG. 3.



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VOLTAGE MULTIPLICATION APPARATUS

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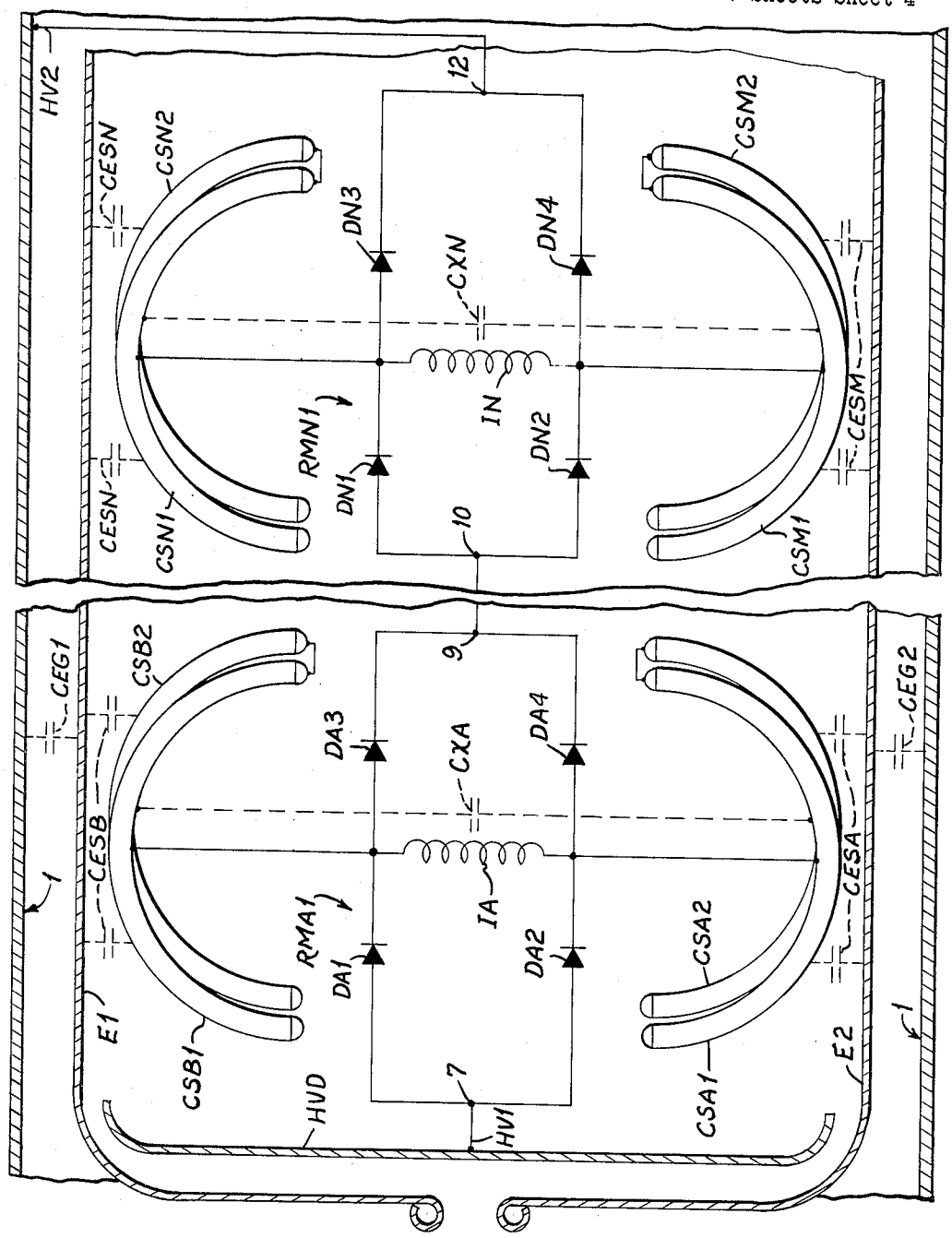

FIG.4.

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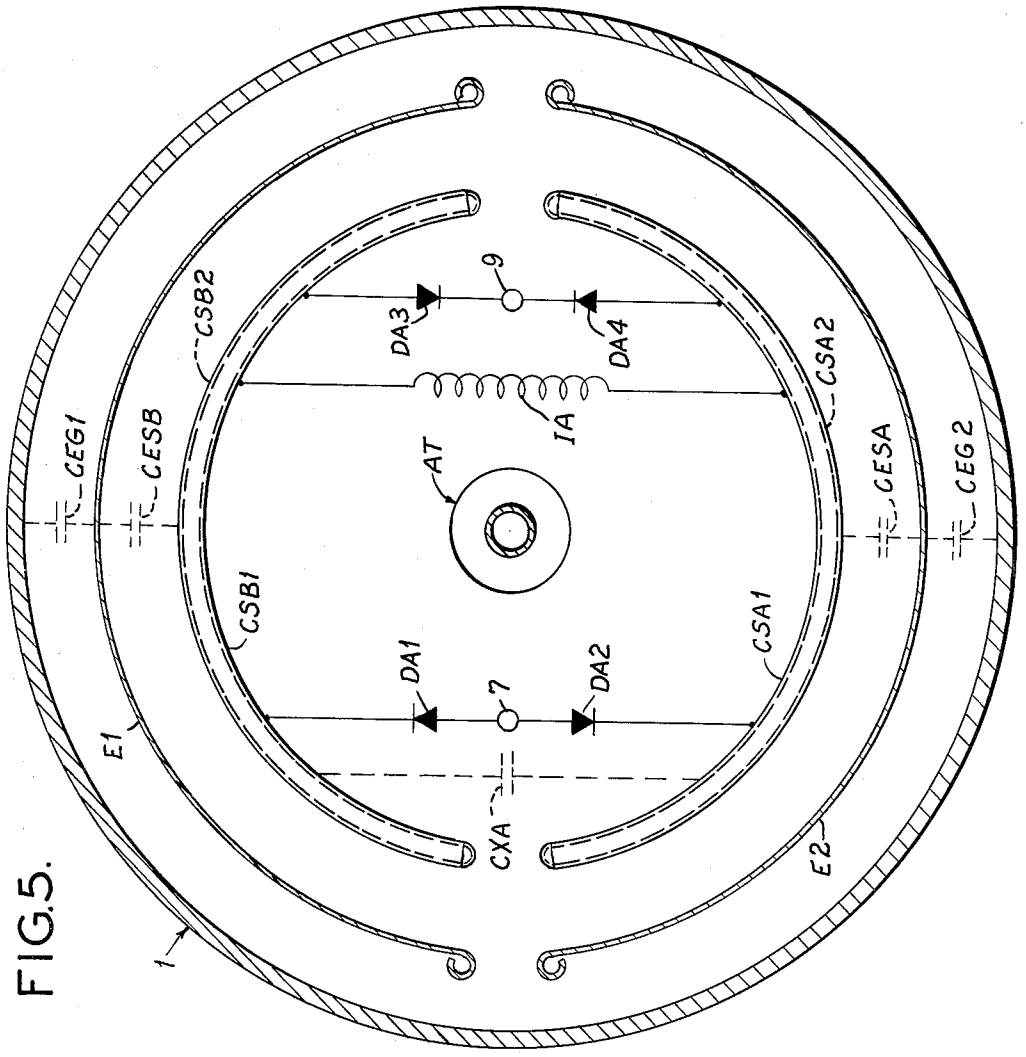

FIG.5.

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FIG.7.

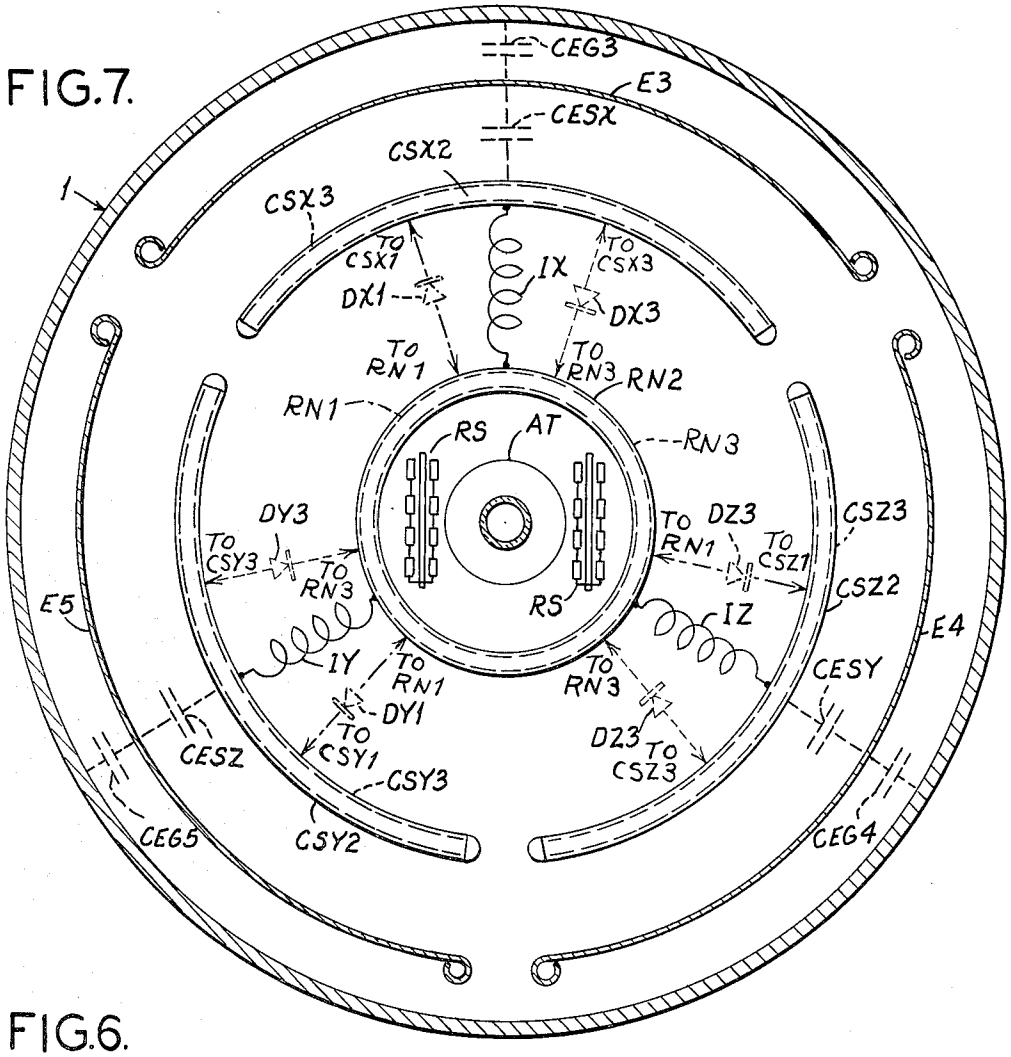

FIG.6.

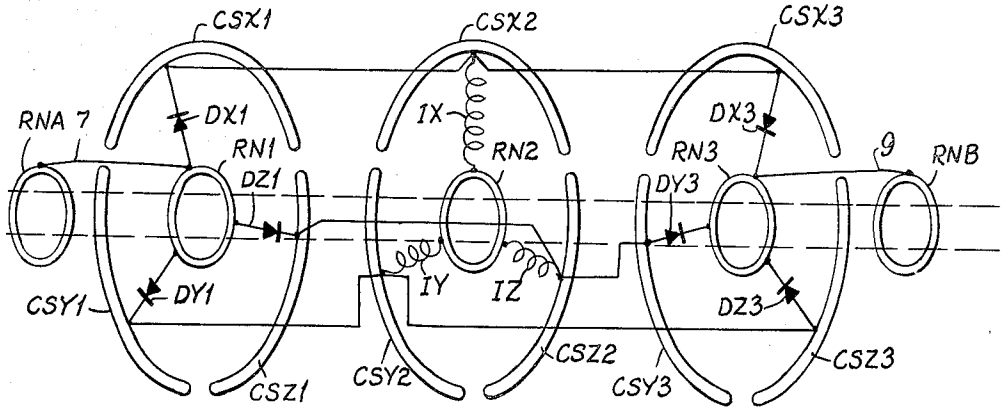

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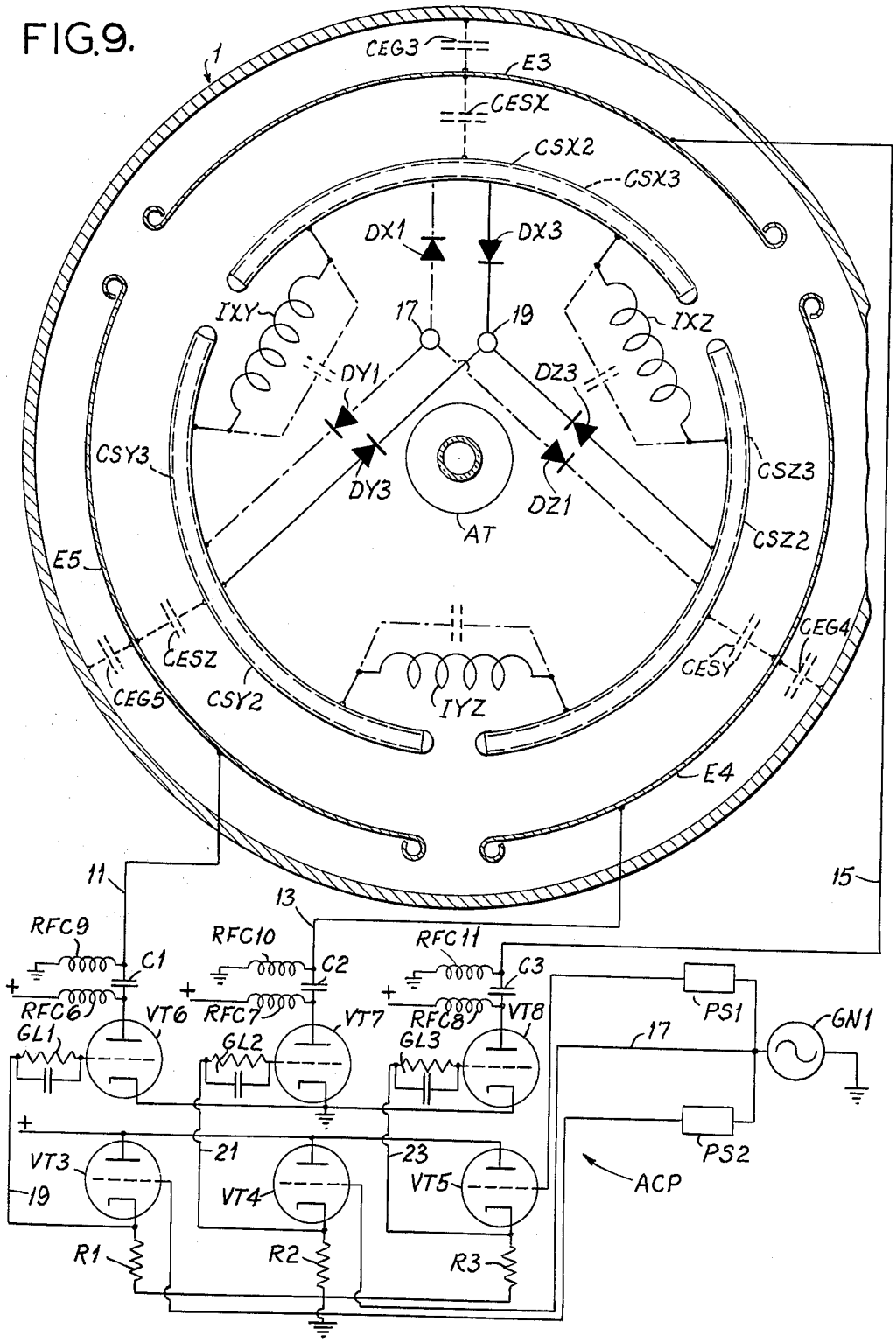
FIG.9.



United States Patent Office 3,246,230 Patented Apr. 12, 1966

3,246,230

VOLTAGE MULTIPLICATION APPARATUS

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Filed Mar. 5, 1962, Ser. No. 177,660
18 Claims. (Cl. 321—15)

This invention relates to voltage multiplication apparatus, and more particularly to voltage multiplication apparatus which provides a high voltage D.C. output potential.

Among the several objects of this invention may be noted the provision of voltage multiplication apparatus which operates with increased efficiency to convert relatively low voltage A.C. power to a high voltage D.C. output potential at improved D.C. output current levels and reduced voltage ripple; the provision of such apparatus which is compact and has reduced insulation requirements; the provision of apparatus of the class described which has decreased cooling requirements and can utilize polyphase A.C. power sources which operate at relatively low frequencies; the provision of voltage multiplication apparatus which may employ an A.C. power source of lower potential and has reduced power dissipation; the provision of apparatus of the class described which more efficiently utilizes rectifiers of decreased ratings; the provision of such apparatus which may conveniently incorporate an accelerator tube for the production of high energy ion or electron beams; and the provision of voltage multiplication apparatus which is reliable in operation and economical in cost. Other objects and features will be in part apparent and in part pointed out hereinafter.

The invention accordingly comprises the constructions hereinafter described, the scope of the invention being indicated in the following claims.

In the accompanying drawings, in which several of various possible embodiments of the invention are illustrated,

FIG. 1 is an exploded side oblique view, partially diagrammatic, of a portion of one embodiment of voltage multiplication apparatus of my invention;

FIG. 2 is a cross section taken on line 2—2 of FIG. 1;

FIG. 3 is a schematic circuit diagram illustrating certain principles of the present invention;

FIGS. 4 and 5 are views respectively similar to those of FIGS. 1 and 2, but of a second embodiment of my invention;

FIGS. 6 and 7 are views respectively similar to those of FIGS. 1 and 2 of another embodiment of this invention but with the grounded container and the intermediate electrodes omitted in FIG. 6; and

FIGS. 8 and 9 are views respectively similar to those of FIGS. 1 and 2 of still another embodiment of my invention, but with the grounded container and intermediate electrodes omitted in FIG. 8.

Corresponding reference characters indicate corresponding parts throughout the several views of the drawings.

Several types of apparatus are now utilized in generating high voltage D.C. potentials in the order of a million and more volts. One of these types of apparatus, which is particularly advantageous in suplying these high D.C. voltages, especially at relatively high current levels in the order or 1 to 10 or more milliamperes, is the cascaded rectifier, such as is disclosed in my coassigned U.S. Patent 2,875,394. In this type of voltage multiplication apparatus, a number of rectifier units are serially connected so that the sum of their respective D.C. output potentials is supplied at high voltage D.C. terminals, and all rectifier

units are energized or driven from a single relatively low voltage A.C. power source. For example, the A.C. power source may constitute a single large inductor which is connected to a pair of spaced-apart metallic shell-shaped electrodes. The inductor may be excited either from an A.C. generator such as an oscillator or a power amplifier, or the inductor itself may be part of the tank circuit of an R.-F. oscillator or amplifier, the capacitance of the shell electrodes and associated components providing at least a portion of the capacitance parameter of an LC circuit resonant at the frequency of the A.C. power source. One of the difficulties encountered with voltage multiplication apparatus of this and many other types is the minimizing of power losses and generally increasing the efficiency of operation.

In accordance with the present invention, voltage multiplication apparatus is provided which greatly improves the operational efficiency, minimizes power losses, permits the use of lower voltage A.C. power sources and more compact structural dimensions, as well as markedly reducing the insulation requirements. In essence my invention comprises a plurality of rectifying modules, each having a rectifier connected between a positive and a negative terminal. These module terminals are series-connected between a pair of high-voltage D.C. terminals, and each module further includes at least two corona shields with an inductor connected therebetween. A source of A.C. power is connected to at least two metallic electrodes to establish an A.C. electric field therebetween. The corona shields and the rectifying modules are positioned in this A.C. field so that electrical energy is capacitively coupled to said corona shields to establish substantially equal A.C. potentials across each of the inductors and each inductor is connected to energize its respective rectifier unit. Preferably, each of the rectifying modules constitutes a portion of a series LC circuit including the interelectrode capacitances between the metallic electrodes and the respective corona shields. By maintaining the frequency of the A.C. power source at approximately the natural resonant frequency of these LC circuits, the magnitude of the A.C. voltage developed across each of the inductors will substantially exceed that of the A.C. power source.

Referring now more particularly to FIGS. 1 and 2, an electrically grounded, heavy steel, cylindric, gas-tight, pressure container is indicated at numeral 1. Enclosed within this container are a number of identical rectifying modules, each indicated generally by reference characters RMA, RMB and RMN. Each of these rectfier units includes an inductor, such as indicated at IA, IB and IN, respectively connected between two pairs of commonly connected arcuate metallic corona shields CSA1, CSA2; CSB1, CSB2; CSC1, CSC2; CSM1, CSM2; and CSN1, CSN2. It will be understood that single or common corona shields may be used instead of pairs of shields. Reference characters CXA, CXB, and CXN indicate the interelectrode capacitances between the opposed pairs of corona shields. Each of these rectifying modules RMA, RMB and RMN further includes a rectifier, such as a diode, DA, DB and DN connected in shunt with its respective inductor IA–IN and the interelectrode capacitances CXA–CXN. As each pair of corona shields CSA1, CSA2–CSN1, CSN2 is respectively commonly connected to opposite electrodes of the rectifier units DA–DN, successive pairs of corona shields constitute opposite polarity terminals of the respective rectifying modules. For example, the negative terminal of rectifying module RMA is CSA1, CSA2, while the positive terminal thereof is CSB1, CSB2. As the CSB1, CSB2 shields constitute the negative terminal of the rectifying module RMB and CSC1, CSC2 are the positive terminal thereof, these ter-

minals of the rectifying modules are seen to be connected in series or cascade between a pair of high voltage D.C. terminals HV1 and HV2. The latter terminal is electrically connected to the grounded container 1, while the former high voltage terminal HV1 is electrically connected to a dome-shaped metallic electrode HVD. Preferably R.-F. chokes RFC are series-connected in the high voltage D.C. circuit to inhibit the flow of R.F. in any electrical load to be energized by connection to terminals HV1 and HV2. A D.C. blocking capacitor, as indicated at CA, CB and CN, is also included in each of the rectifying modules RMA–RMN of this embodiment of FIGS. 1 and 2, each of which is serially connected with the respective module inductor IA–IN. The A.C. impedance of each of these capacitors CA, CB–CN is much lower than that of the respective inductors IA, IB–IN so that their parameters can be ignored in the A.C. analysis.

The assembly of the cascaded rectifying modules is positioned between a pair of spaced-apart metallic shell electrodes E1 and E2. The electrodes are connected to a source of A.C. power, such as for example an R.-F. oscillator or power amplifier capable of supplying potential of about 10,000 volts or more at a frequency range in the order of 20 to 200 kc. to electrodes E1 and E2. The electric field thus established between electrodes E1 and E2 is utilized to drive or energize the rectifying modules RMA–RMN by applying substantially the same A.C. potential across opposed pairs of corona shields CSA1, CSA2; CSB1, CSB2; CSC1, CSC2; etc., via respective interelectrode capacitances CESA, CESB, CESC, CESM, and CESN. Thus A.C. power is coupled capacitively from electrode E2 to corona shields CSA1, CSA2 via the capacitance CESA therebetween. Similarly A.C. power is coupled capacitively from electrode E1 via interelectrode capacitance CESB to CSB1, CSB2. The capacitances between the electrodes E1 and E2 and the grounded container 1 are indicated at CEG1 and CEG2. It will be noted that the corona shields and the shell electrodes are arranged symmetrically along the longitudinal axis of container 1, thus permitting the mounting along the central axis of an elongate accelerator tube AT (shown only in FIG. 2 so as to avoid obscuring circuit details in FIG. 1) across which the high voltage D.C. potential produced by the voltage multiplication apparatus of this invention may be applied. Tube AT constitutes an exemplary load adapted to be connected across the high voltage terminals HV1 and HV2.

The circuit of FIGS. 1 and 2 is shown schematically in FIG. 3, together with an exemplary source of A.C. or R.-F. power constituted by a pair of triode vacuum tubes VT1 and VT2 connected in a push-pull amplifier circuit and excited by a generator GN, which may be any conventional R.-F. signal generator, such as an oscillator. The usual D.C. plate voltage for the anode-cathode circuits of VT1 and VT2 is supplied through the R.-F. chokes RFC1 and RFC2, as indicated at B+, the negative terminal of the plate voltage supply being grounded as is customary. The control grids are connected to respective terminals of generator GN through two similar parallel RC circuits or grid-leak networks RCA and RCB which develop grid bias so as to achieve the high tube efficiency of class C operation. The anodes of VT1 and VT2 are connected by conductors 3 and 5 to the shelf electrodes E1, E2; these electrodes, the corona shields and rectifying modules constituting an LC tank circuit for this push-pull power amplifier. It will be noted that although only two rectifying modules RMA and RMB are illustrated with their associated corona shields in FIG. 3, the others are all effectively connected in parallel therewith relative to the A.C. drive as described above.

Operation of the apparatus of this embodiment is as follows: Assuming that the output A.C. potential impressed across E1, E2 via conductors 3 and 5 is 10,000 volts, A.C. power is coupled to RMA–RMN via the interelectrode capacitances CESA–CESN. For maximum effectiveness in producing the maximum D.C. potential at HV1, HV2, the maximum A.C. voltage should be applied across each rectifying module. This is accomplished in accordance with the present invention inasmuch as each rectifying module constitutes a portion of a series LC circuit which includes the inductance of the inductor, such as IA, and the two interelectrode capacitances CESA, CESB. The interelectrode capacitance CXA between the opposed pairs of corona shields CSA1, CSA2 and CSB1, CSB2 and the inherent capacitance between the electrodes of the rectifying unit DA are effectively in parallel with the inductor IA. The inductive and capacitive parameters of these circuit components and the frequency of the A.C. power source are chosen so that the later approximates the resonant frequency of these series LC circuits, each including a rectifying module and its respective associated capacitances. As the capacitors CA, CB–CN function simply to block D.C. they will have a very low impedance at the frequency of operation of this voltage multiplication apparatus.

By applying an A.C. voltage of, say, 10,000 volts across electrodes E1 and E2 by means of the power amplifier including VT1 and VT2, a voltage of 50,000 volts or more is developed across each of the inductors IA, IB–IN. This amount of voltage gain between the applied across E1, E2 and that developed across IA, IB–IN is a function of the Q of the series resonant LC circuits described above. If there is an effective Q of 5, for example, under usual circuit loading conditions, there will be a voltage developed across each of the inductors of the respective rectifying modules that is five times that of the voltage applied across E1 and E2. Similarly, with an applied voltage of 10 kv. across E1 and E2 and a Q of 10, a voltage of about 100 kv. will be developed across each of the inductors.

It will be noted that although a push-pull configuration vacuum tube power amplifier is illustrated as a source of A.C. power, other equivalent power sources such as semiconductor transducer units and mechanical generators may be employed. Also, as described and illustrated in my coassigned copending application Serial No. 49,773, field August 15, 1960, the source of A.C. power may be a self-excited single-ended or push-pull oscillator in which instance the grids, or equivalent electrodes of transistor or semiconductor transducers, are excited by a signal or signals fed back in proper phase relationship (by means of probes, etc., such as shown in the aforesaid patent application, but preferably positioned adjacent respective corona shields, e.g., CSM1, and CSN1, rather than electrodes E1 and E2 inasmuch as the R.-F. potential across any opposed set of corona shields is greater than across E1, E2). Further, it will be understood that instead of utilizing the L and C of the assembly of the electrodes E1 and E2 and the rectifying modules as the tank circuit of the amplifier or oscillator, this assembly can be driven or excited from a separate tank circuit or other A.C. generator. It is preferred that the A.C. power source be a relatively low impedance source. The capacitances CEG1 and CEG2 can be conveniently adjusted by varying the spacing between the grounded container 1 and the electrodes E1, E2 to adjust the impedance matching, or additional separate capacitors could be utilized between ground and the anodes of VT1 and VT2 for this purpose.

As the voltage differential between the grounded container and electrodes E1, E2 is quite low, the spacing between these elements may be small and the insulation requirements reduced. Also, as circulation of extremely high R.-F. currents and power losses are minimized, the heat generated by the voltage multiplication apparatus of my invention is lessened and this simplifies the design and construction of this apparatus, and decreases the cost of cooling accessories, etc. Thus, a physically quite compact generator with a minimum of expensive cooling

equipment can be constructed that will develop extremely high voltages, e.g., on the order of 5 or 6 mv. or higher, at substantial current levels in the order of several milliamperes and more.

The second embodiment of voltage multiplication apparatus of this invention is illustrated in FIGS. 4 and 5 and is quite similar to that of FIGS. 1 and 2. The principal difference between the two embodiments is that a full-wave rectifier configuration is utilized in each rectifying module (RMA1 and RMN1 in FIGS. 4 and 5), rather than the half-wave rectifier arrangment employed in FIGS. 1 and 2. Thus in FIGS. 4 and 5 an exemplary rectifying module RMA1 includes inductor IA connected between the two pairs of corona shields CSA1, CSA2 and CSB1, CSB2, the former spaced adjacent metallic electrode E2 while the latter is positioned close to electrode E1. The full-wave rectifier includes rectifying units DA1, DA2, DA3 and DA4 connected in a bridge configuration with the input junctions connected across IA and the output junctions constituting the terminals of the rectifying modules as indicated at 7 and 9. Another identical rectifying module RMN1, analogously referenced, is also shown in FIG. 4 having its output terminals 10 and 12 serially connected in the D.C. high voltage circuit.

The operation of the voltage multiplication apparatus of this embodiment is essentially the same as that described above in regard to FIGS. 1 and 2 with only minor differences. For example, as the full-wave rectification reduces the ripple amplitude of the rectified D.C., the R.-F. chokes RFC of FIG. 1 are not needed in this embodiment. The D.C. blocking capacitors CA, CB and CN are also unnecessary in this embodiment and accordingly are omitted. Also, as indicated above, the corona shields are not utilized as the terminals of the rectifying modules in this second embodiment, although these corona shields in both embodiments do serve the dual functions of providing corona protection as well as constituting one electrode of the capacitance which serves to couple A.C. power from the shells E1 and E2 to the rectifying modules.

The third embodiment of this invention, illustrated in FIGS. 6 and 7, is again quite similar to those described above. One essential and important distinction is that a three-phase A.C. power source is utilized to drive or energize three symmetrically disposed metallic electrodes E3, E4 and E5, each connected to one phase of the three-phase power supply. Positioned adjacent and respectively equidistantly spaced from these three electrodes are sets of three arcuate corona shields CSX1, CSY1, CSZ1; CSX2, CSY2, CSZ2; and CSX3, CSY3, CSZ3. These sets of three corona rings, three inductors IX, IY and IZ, and six rectifier units DX1, DX2, DY1, DY2, and DZ1 and DZ2 comprise an individaul rectifying module of this embodiment, there being any desired number of such modules aligned along the longitudinal axis of tank 1 and concentrically relative to the axis accelerator tube AT. The terminals of each of these rectifying modules are serially connected to provide a high D.C. potential (which is the sum of each of the rectified output potentials of each of the modules) at the D.C. high voltage terminals of the voltage multiplication apparatus.

The inductors, IX, IY and IZ are commonly connected at a metallic ring RN2, the other terminals of these three inductors being respectively connected to corona shields CSX2, CSY2 and CSZ2. The three rectifier units DX1, DY1 and DZ1 are respectively interconnected between corona shields CSX1, CSY1 and CSZ1 and a common connection to another concentric metallic ring RN1. Identical interconnections are made between CSX3, CSY3 and CSZ3 with the remaining three rectifier units DX3, DY3 and DZ3 and between these rectifier units and a third ring RN3. It will be noted that each of the two sets of three rectifiers (DX1, DY1, DZ1 and DX3, DY3, DZ3) and the three inductors (IX, IY, IZ) are each interconnected in a Y configuration. The three corona shields CSX1, CSX2 and CSX3 are commonly electrically connected and could be constituted by a single arcuate section if desired. Shields CSY1, CSY2 and CSY3, as well as CSZ1, CSZ2 and CSZ3, are respectively similarly electrically commonly interconnected. Ring RN1 constitutes the negative terminal of this exemplary rectifying module, while ring RN3 constitutes the positive polarity terminal thereof. Ring RN1 is connected by a wire 7 to a similar ring RNA which is the positive terminal of an identical rectifying module to the left of the one illustrated. Ring RN3 is likewise connected by a conductor 9 to an identical ring RNB which is the negative terminal of an identical rectifying module to the right of the one illustrated.

It is preferred that the inductors IX, IY and IZ be of the solenoidal type with their axes radially positioned relative to the central longitudinal axes of the rectifying modules so as to be parallel to the R.-F. electric field established between the arcuate corona shields and the central ring RN2 which thereby insures uniform voltage distribution along the full length of the inductors and rectifiers. The use of the rings RN1, RN2 and RN3 is optional but preferred inasmuch as they serve to prevent R.-F. heating of resistor strings RS interconnected between grading rings of accelerator tube AT. These rings RN1, RN2, RN3 are also especially useful in the three-phase embodiment, inasmuch as it provides some capacitive loading of the junction points of the floating bridge circuits.

The operation of the embodiment of FIGS. 6 and 7 is again similar to that described above, except that the rectification of 120° out-of-phase voltages developed across IX, IY and IZ is accomplished by a three-phase bridge. Again the A.C. potentials developed across these inductors is substantially greater than that applied to electrodes E1, E2 and E3 because of the series LC circuit relationship described above. The use of a three-phase configuration, as illustrated in this embodiment and in the succeeding one, provides a more efficient use of rectifiers wherein smaller rating rectifiers may be utilized and also permits operation at lower frequencies of the A.C. power supply.

Still another embodiment of my invention is illustrated in FIGS. 8 and 9. As in the preceeding embodiment, a three-phase A.C. power source is employed to drive the three elongate, arcuate-in-cross-section, metallic electrodes E3, E4 and E5. A typical three-phase A.C. power supply is indicated generally at ACP interconnected by leads 11, 13 and 15 to these three electrodes. The only significant differences between this and the preceding embodiment are the delta configuration of the three interconnected inductors IXY, IXZ and IYZ, and the elimination of the inner shielding rings RN1, RN2, and RN3. The Y-connected rectifiers DX1, DY1 and DZ1 have a common junction as indicated at 17, while the Y-connected rectifiers DX3, DY3 and DZ3 have a common junction at 19, which junctions 17 and 19 respectively constitute the negative and positive terminals of this exemplary rectifying module. These terminals of this one module are serially connected to the terminals of adjacent identical rectifying modules.

The illustrative three-phase power source ACP includes any customary A.C. or R.-F. generator GN1 having two phase-shifter networks PS1 and PS2 (to effect a +120° and a −120° phase shift relative to the time base of the drive signal present on conductor 17) respectively interconnected to the control grids of vacuum tubes VT5 and VT3. Conductor 17 is connected to the grid of a third amplifier tube VT4, the cathodes of these three tubes being connected via resistors R1, R2 and R3 to ground, and by means of wires 19, 21 and 23, and the usual grid-leak networks GL1, GL2 and GL3, to the control grids of a three-phase power amplifier stage in-

cluding vacuum tubes VT6, VT7 and VT8. The anodes of VT3–VT5 are commonly connected to the positive terminals of a D.C. plate supply, the negative terminal of which is grounded. These three tubes VT3–VT5 and their associated components constitute a cathode-follower driver for the final stage amplifier VT6–VT8, the cathodes of which are commonly grounded. The anodes of these tubes VT6, VT7 and VT8 are interconnected by D.C. blocking capacitors C1, C2 and C3 to conductors 11, 13 and 15 to supply excitation power to the driving electrodes E3, E4 and E5. The anodes of VT6–VT8 are connected by means of three additional R.–F. chokes RFC6–RFC8 to a D.C. plate voltage supply, the negative terminal of which is grounded. Three high impedance isolation chokes RFC9–RFC11 are connected from conductors 11, 13 and 15 respectively to ground to prevent build-up of D.C. potentials on these conductors due to occasional electrical discharges from the corona shields.

The operation of this FIGS. 8 and 9 embodiment is similar to that described above with regard to the other three-phase voltage multiplication apparatus.

It will be understood that although half-, full- and three-phase configuration rectifying modules and apparatus have been specifically disclosed, other polyphase rectifier configurations may be utilized, if desired. Also, it will be noted that any of the conventional types of rectifiers (e.g., vacuum, gas, semiconductor, dry type, etc.) may be used and that several units thereof may be interconnected to constitute a rectifier unit of this invention. Further, these rectifiers may be reversed in their sockets or interconnection to reverse the polarity of the high voltage D.C. terminals, if desired. Any voltage regulator circuitry may also be utilized in conjunction with the A.C. power sources employed to further enhance the voltage versus load curve or characteristics of this apparatus.

In view of the above, it will be seen that the several objects of the invention are achieved and other advantageous results attained.

As various changes could be made in the above constructions without departing from the scope of the invention, it is intended that all matter contained in the above description or shown in the accompanying drawings shall be interpreted as illustrative and not in a limiting sense.

What is claimed is:

1. Voltage multiplication apparatus comprising a plurality of rectifying modules each having a rectifier unit connected between a positive and a negative terminal, the terminals of said modules being series-connected between a pair of high voltage D.C. terminals, each module further including at least two corona shields with an inductor connected therebetween, at least two metallic electrodes, a source of A.C. power connected to said electrodes to establish an A.C. electric field therebetween, said corona shields being positioned in said A.C. field whereby electrical energy is capacitively coupled to said corona shields to establish substantially equal A.C. potentials across each of said inductors and each inductor is connected to energize its respective rectifier unit.

2. Voltage multiplication apparatus as set forth in claim 1 in which each of the rectifying modules constitutes a portion of a series LC circuit including the interelectrode capacitances between the metallic electrodes and the respective corona shields and the frequency of said A.C. power source approximates the natural resonant frequency of said LC circuits, whereby the magnitude of the A.C. voltage developed across each of said inductors substantially exceeds that of the A.C. power source.

3. Voltage multiplication apparatus as set forth in claim 1 in which each of said rectifier units comprises a half-wave rectifier, and each of said inductors is respectively parallel-connected therewith.

4. Voltage multiplication apparatus as set forth in claim 3 in which each rectifying module further includes a D.C. blocking capacitor interconnected in a loop circuit between the inductor and the rectifier unit.

5. Voltage multiplication apparatus as set forth in claim 1 in which each of said rectifying units is a full-wave rectifier.

6. Voltage multiplication as set forth in claim 5 in which each of said full wave rectifiers is connected in a bridge rectifier configuration having input terminals and output terminals, said inductor being connected across said bridge input terminals and said bridge output terminals constitute said positive and negative terminals of said module.

7. Voltage multiplication apparatus as set forth in claim 1 in which said A.C. power source is a three phase A.C. power source and there are three metallic electrodes, one connected to each of said phases, and at least three corona shields, each module including three inductors and two sets of three rectifier units.

8. Voltage multiplication apparatus as set forth in claim 7 in which each of said sets of three rectifier units is Y-connected.

9. Voltage multiplication apparatus as set forth in claim 8 in which said three inductors are Y-connected.

10. Voltage multiplication apparatus as set forth in claim 8 in which said three inductors are delta-connected.

11. Voltage multiplication apparatus comprising at least two opposed metallic shells having their respective edges spaced apart, a plurality of rectifying modules each having a rectifier unit connected between a positive and a negative terminal, the terminals of said modules being series-connected between a pair of high voltage D.C. terminals, said modules being generally symmetrically positioned within the space enclosed by said metallic shells and about a central longitudinal axis of said opposed metallic shells, each module further including at least two corona shields with an inductor connected therebetween, said corona shields of each module being positioned in a plane generally transverse to said longitudinal axis, and a source of A.C. power connected to said metallic shells to establish a radial A.C. electric field therebetween transverse to said axis whereby electrical energy is capacitively coupled to said corona shields to establish substantially equal A.C. potentials across each of said inductors and each inductor is connected to energize its respective rectifier unit.

12. Voltage multiplication apparatus as set forth in claim 11 in which each of the rectifying modules constitutes a portion of a series LC circuit including the interelectrode capacitances between the metallic electrodes and the respective corona shields and the frequency of said A.C. power source approximates the natural resonant frequency of said LC circuits, whereby the magnitude of the A.C. voltage developed across each of said inductors substantially exceeds that of the A.C. power source.

13. Voltage multiplication apparatus as set forth in claim 11 in which each of said inductors is a solenoidal coil having its longitudinal axis aligned radially relative to the axis of said metallic shells.

14. Voltage multiplication apparatus as set forth in claim 11 in which said positive and negative terminals comprise a plurality of parallel spaced apart metallic rings concentrically aligned along said longitudinal axis.

15. Voltage multiplication apparatus as set forth in claim 14 in which said A.C. power sources is a three phase A.C. power source and there are three metallic shells symmetrically positioned about said longitudinal axis, one connected to each of said phases, and at least three corona shields, each module including three inductors and two sets of three rectifier units.

16. Voltage multiplication apparatus as set forth in claim 15 in which each of said sets of three rectifier units is Y-connected.

17. Voltage multiplication apparatus as set forth in claim 15 in which said three inductors in each module

are Y-connected, and the common inter-connection thereof comprises a metallic ring concentrically aligned along said longitudinal axis.

18. Voltage multiplication apparatus as set forth in claim **16** in which said three rectifying units are Y-connected and the common interconnection thereof comprises a metallic ring concentrically aligned along said longitudinal axis.

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