SPARK GAPS

Filed Dec. 30, 1964 3 Sheets-Sheet 1

FIG. 1.

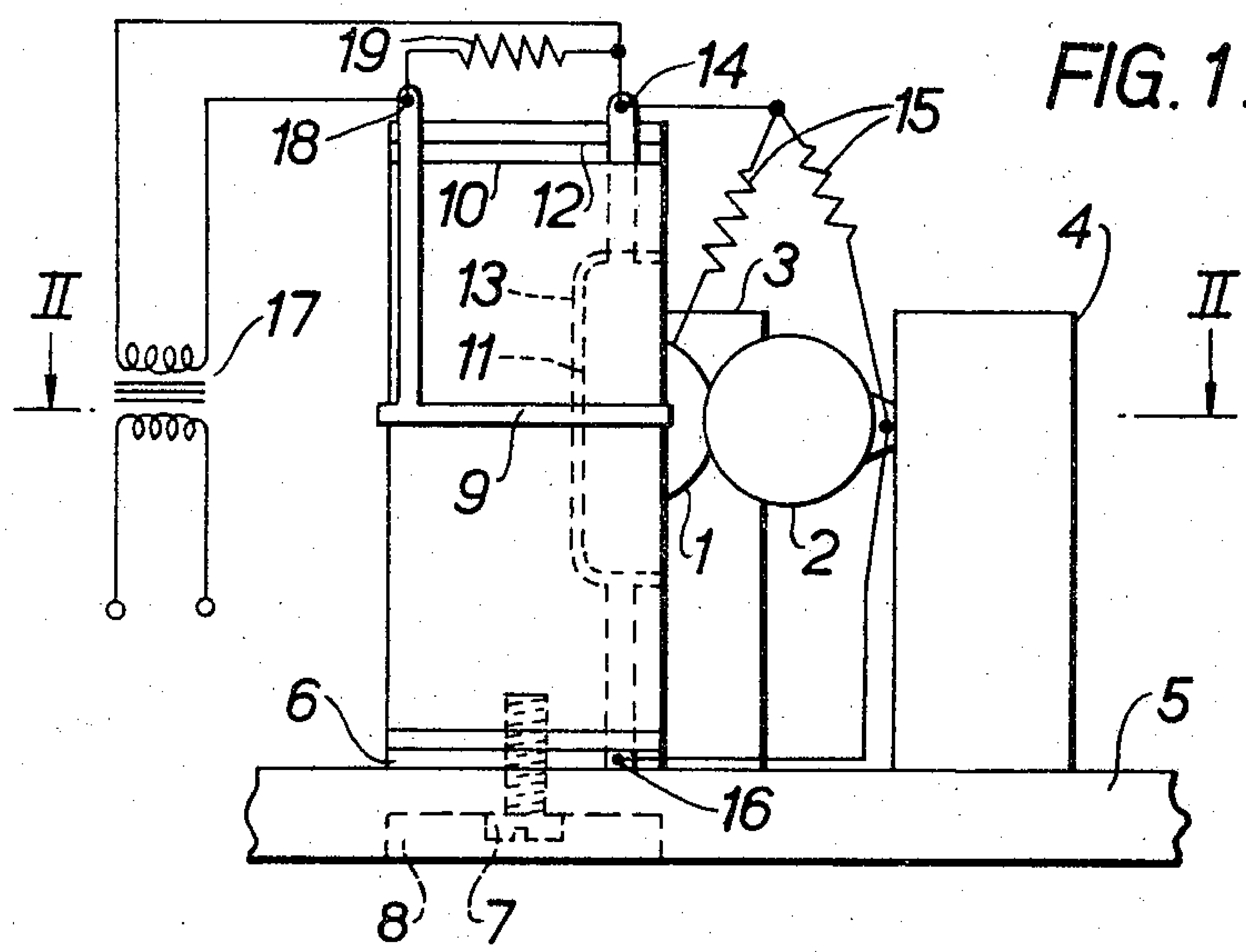


FIG. 2.

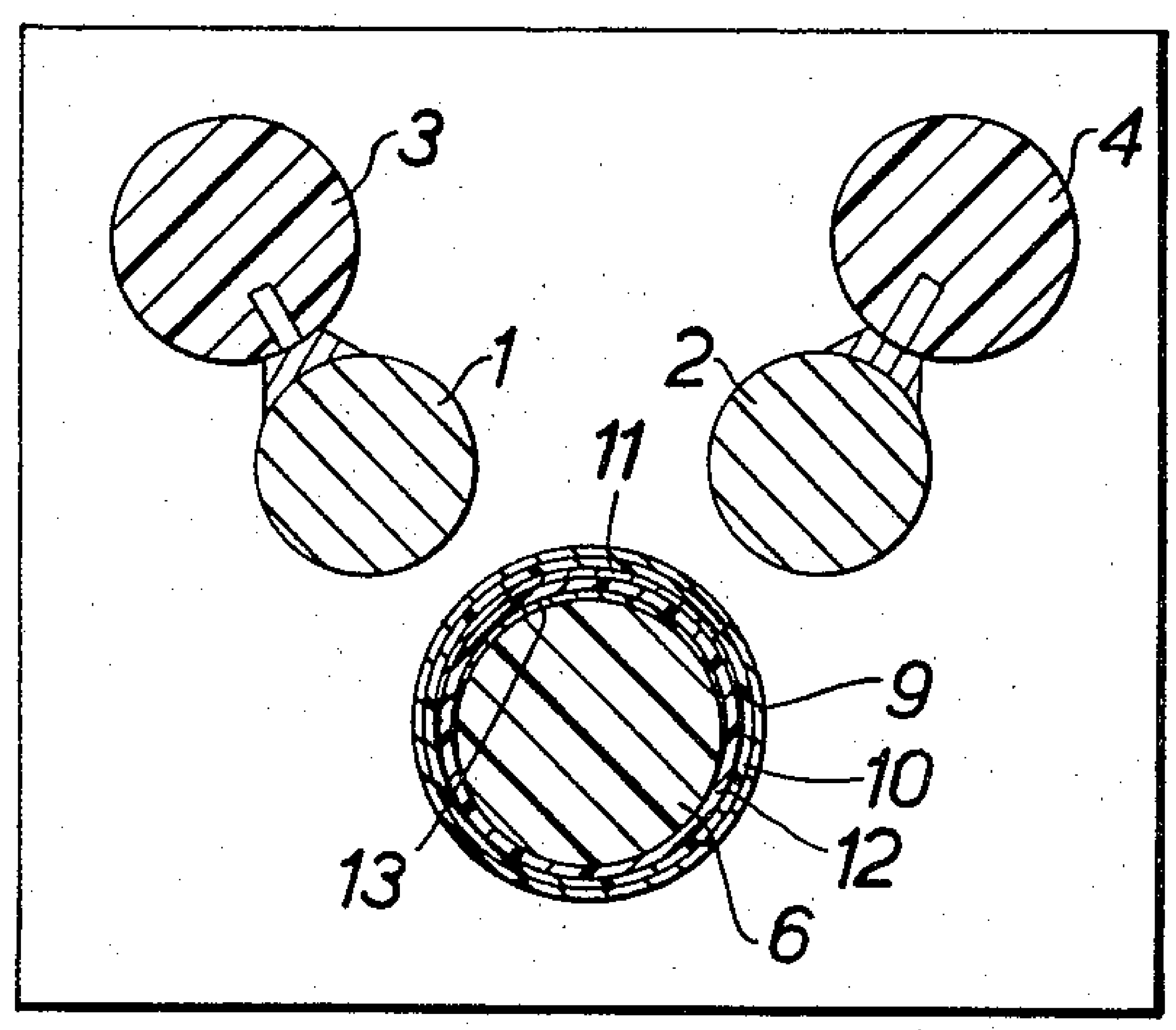
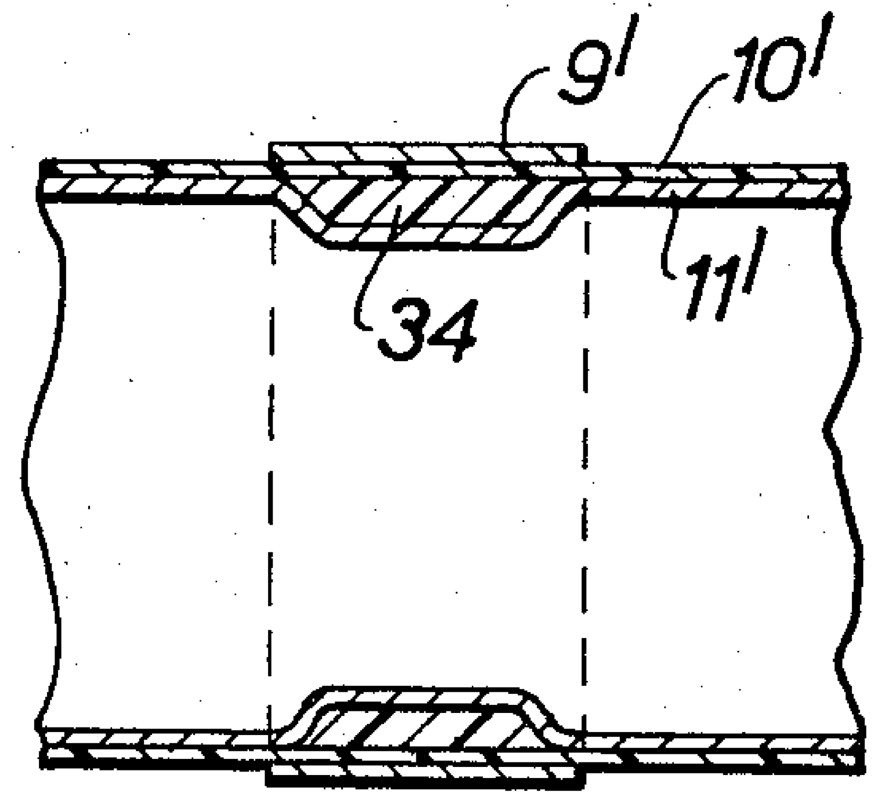


FIG. 4.



Oct. 10, 1967 J. C. MARTIN 3,346,762

SPARK GAPS

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FIG. 3.

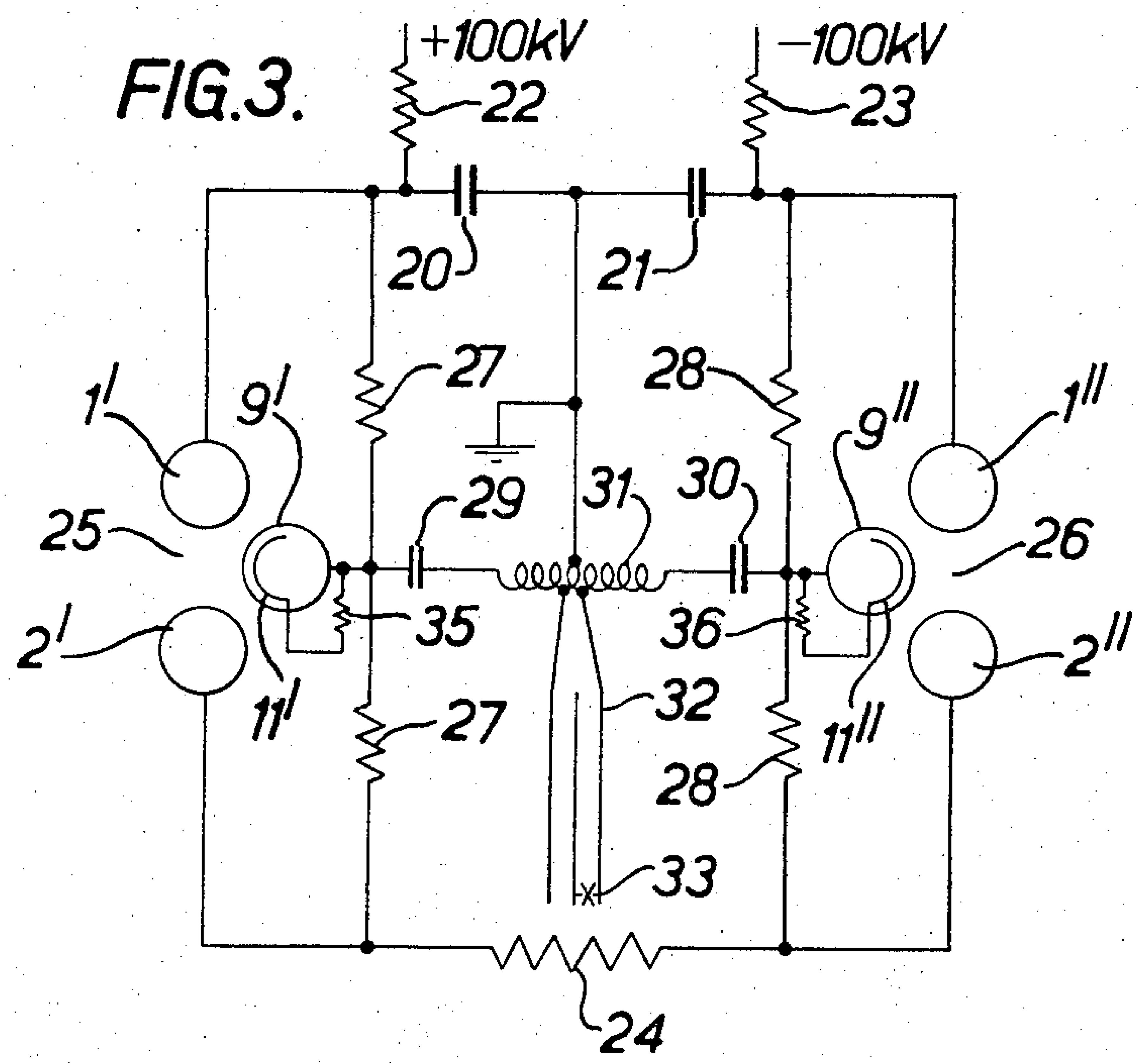


FIG. 5.

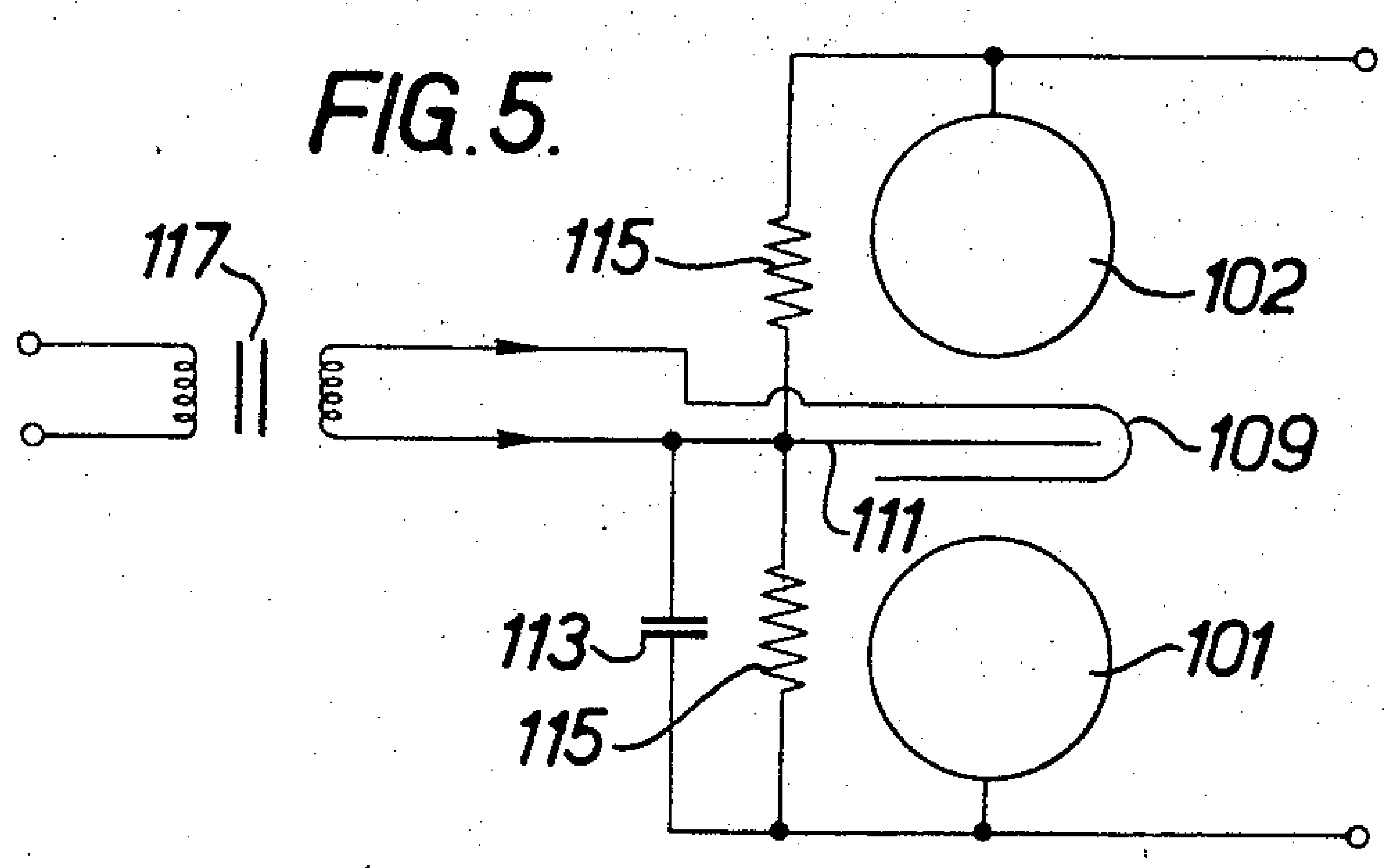


FIG. 6.

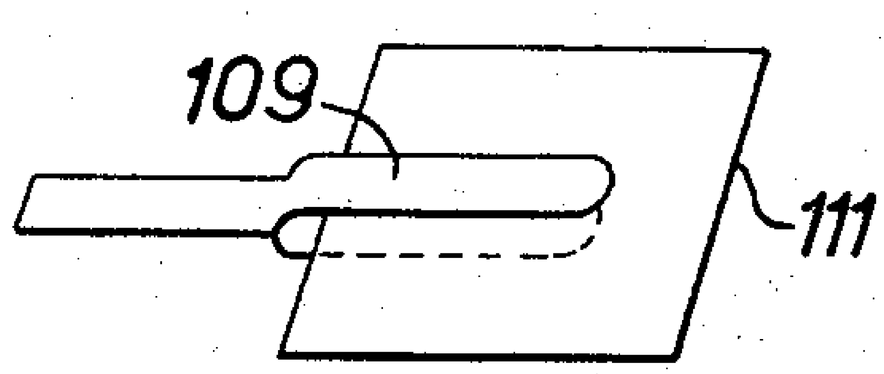


FIG. 7.

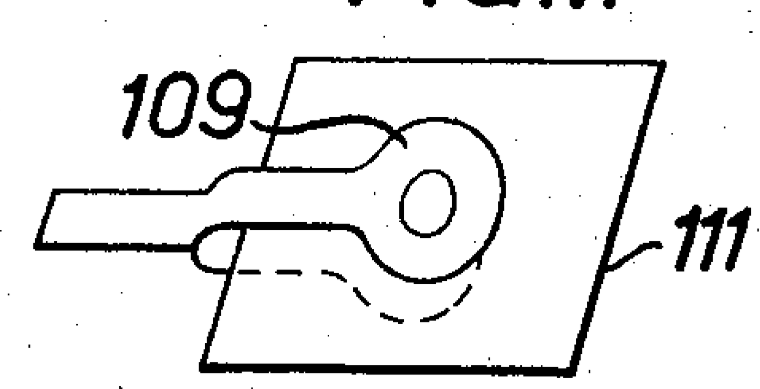


FIG. 8.

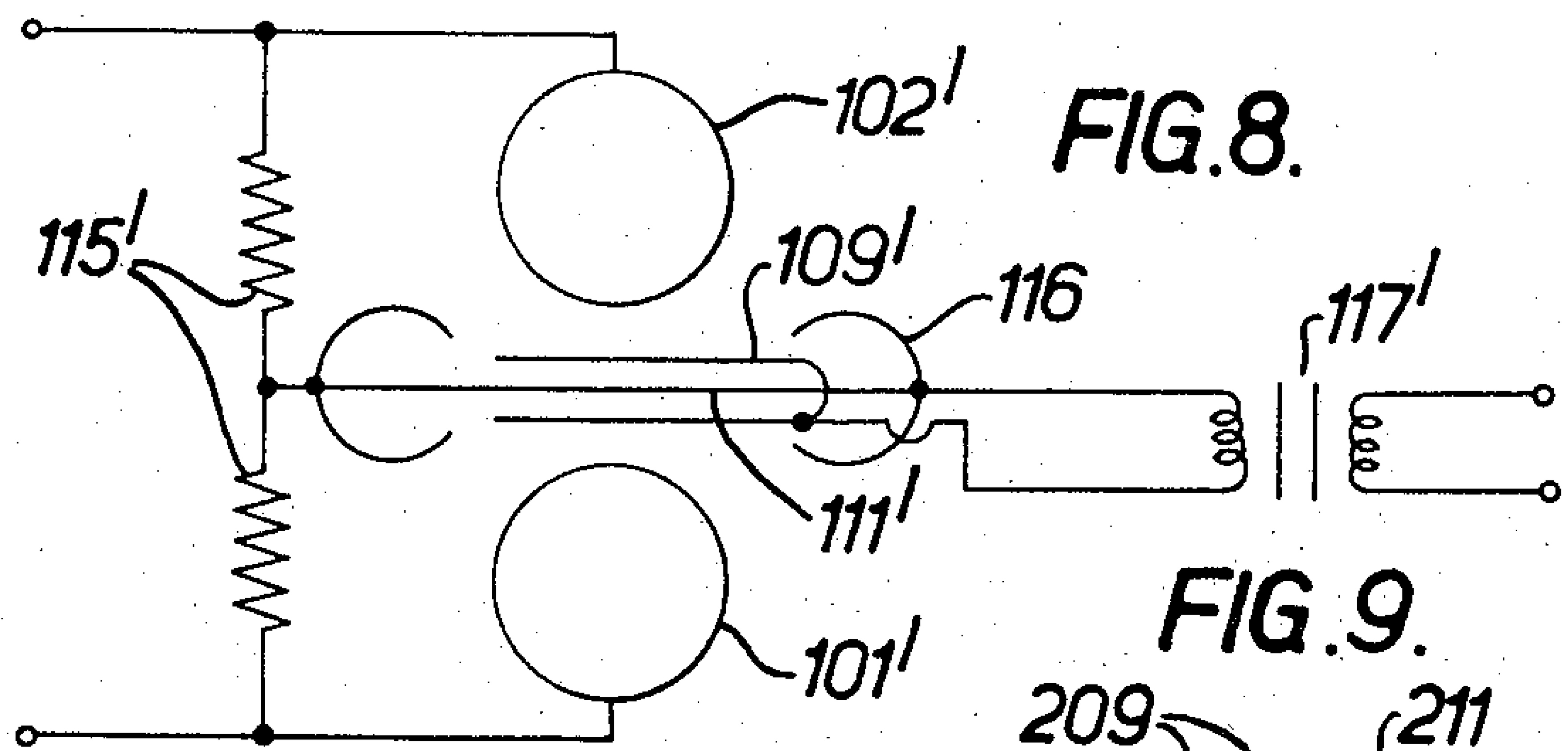


FIG. 9.

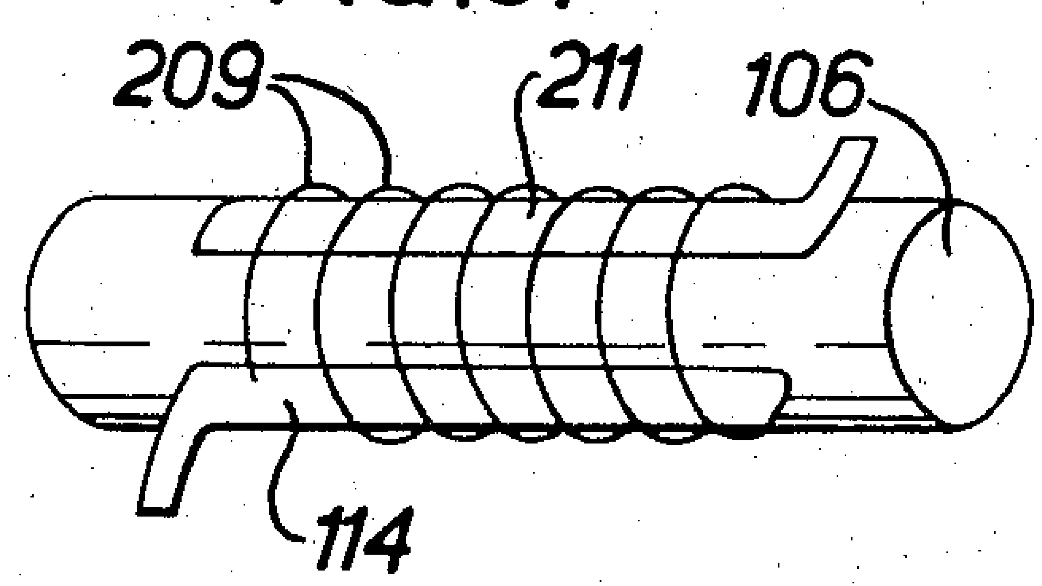
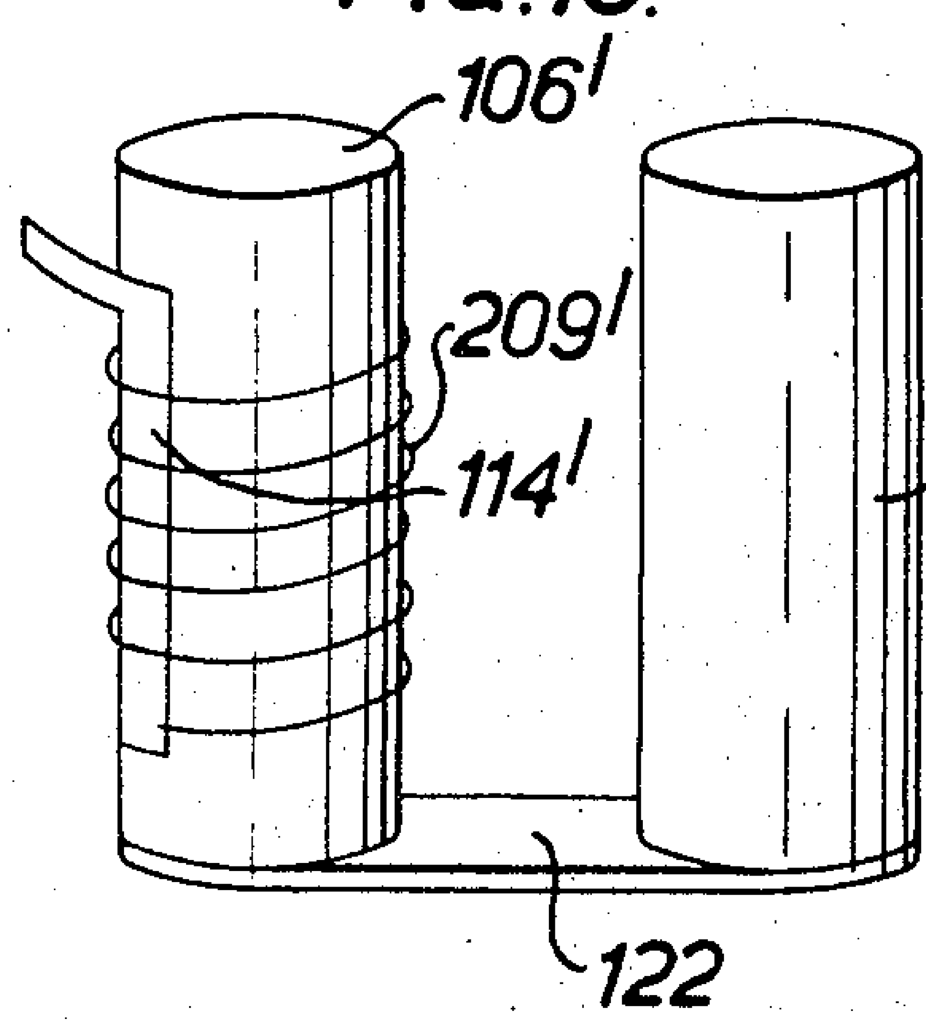


FIG. 10.



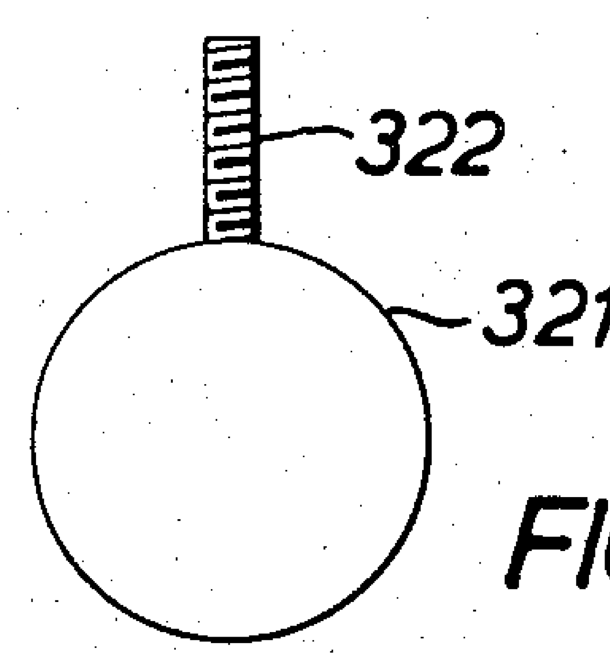


FIG. 12.

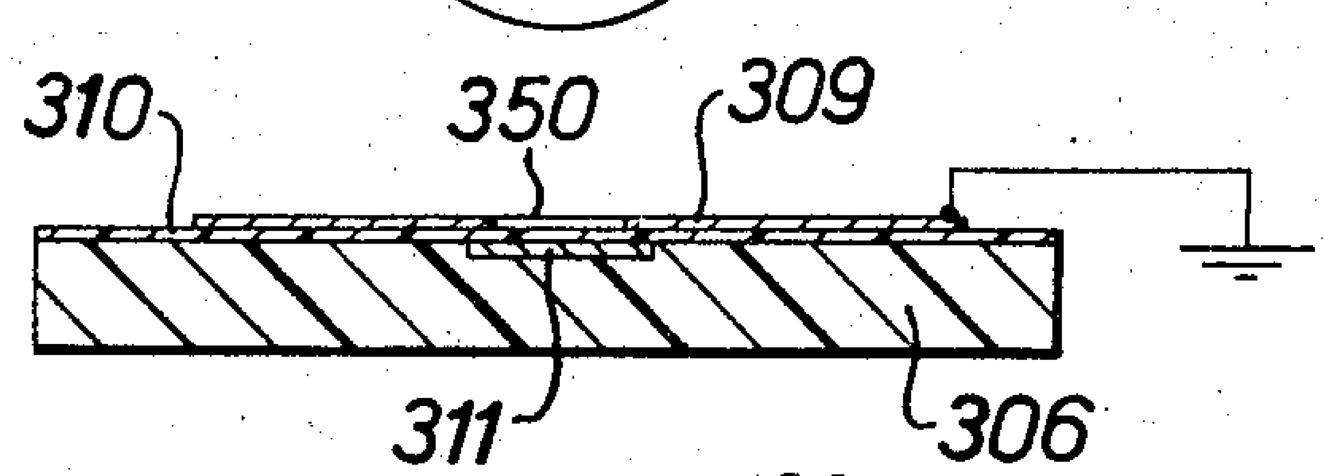
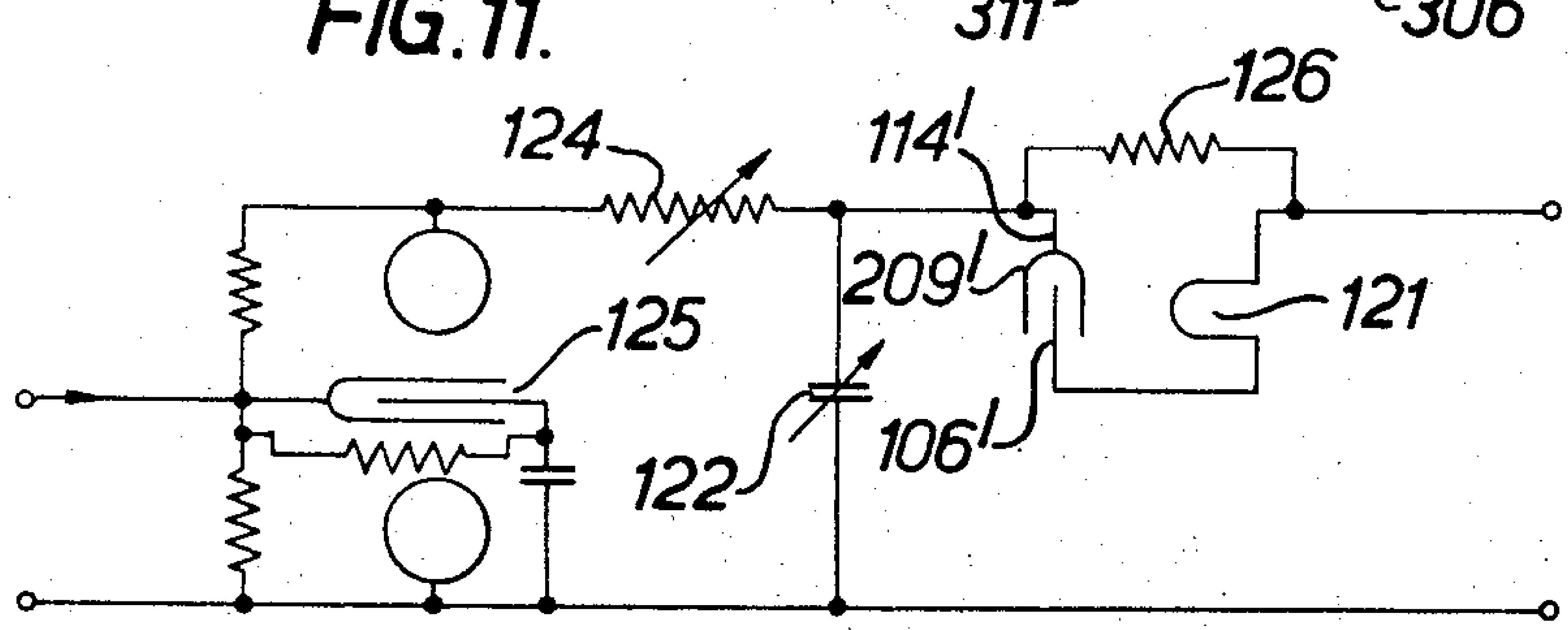


FIG. 11.



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SPARK GAPS

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Claims priority, application Great Britain, Jan. 3, 1964, 430/64
15 Claims. (Cl. 313—306)

ABSTRACT OF THE DISCLOSURE

A spark-gap is provided with a trigger assembly comprising a trigger electrode having a sharp edge exposed to the gap, the sharp edge being separated by a thin insulating layer from a field-forming electrode. In operation the triggering voltage is applied between the trigger electrode and the field-forming electrode, the small separation producing an intense electric field at the sharp edge and thereby causing the production of corona at the sharp edge to initiate breakdown of the main gap, without breakdown occurring between the trigger and field-forming electrodes.

This invention relates to electrical spark-gaps of the type in which the discharge passes through a gaseous medium such as air.

Up to now the timing precision of switches of the gas gap type has been difficult to control. It has been the practice to use a large trigger pulse of high energy in order to achieve some precision. In some such switches the trigger pulse is applied to a trigger electrode to cause electrical breakdown between the trigger electrode and one of the switch electrodes as a consequence of corona initiation. This breakdown throws the full voltage on to the gap between the trigger electrode and the other switch electrode and the main gas discharge is initiated.

The present invention provides a spark-gap in which corona is initiated more readily, giving improved timing precision of breakdown whilst permitting the use of smaller trigger pulses and allowing a greater safety margin between the working voltage and the breakdown voltage.

According to the present invention a spark-gap includes a trigger assembly arranged in spaced relationship with a main electrode of the gap, said assembly comprising a trigger electrode having a sharp edge, a thin layer of solid dielectric material in contact with the sharp edge, and a field-forming electrode separated from said sharp edge by said thin layer.

Said assembly may comprise a member presenting a surface to said main electrode and adapted to be electrically conducting over at least a portion of said surface, said portion constituting said field-forming electrode, and a sharp-edged conductor overlying said portion but insulated therefrom by said dielectric layer to constitute said trigger electrode. Said member may be made of insulating material, said portion being a thin conducting sheet applied to said member. Said surface may be convex, and the sharp-edged conductor may be thin wire or preferably a thin conducting band on said dielectric layer.

One preferred form of the present spark-gap comprises two main electrodes presenting substantially spherical surfaces to said trigger assembly, the sharp-edge conductor being a thin conducting band located substantially in and normal to a common diametral plane of the spherical surfaces. In a modified form the thin conducting sheet below a non-peripheral region of said band is recessed into said member to reduce the capacitance between band and sheet. A further thin conducting sheet may be insulatedly located between said thin conducting sheet and said member to form a capacitor therewith.

Another form of the invention comprises a pair of main spherical electrodes presenting substantially spherical surfaces to said trigger assembly wherein a laminar conducting member constituting said field-forming electrode is located between said spherical surfaces substantially normal to a line joining their centres, said sharp-edged conductor embracing both sides of said laminar member but being insulated therefrom by dielectric layers.

In a self-triggering spark-gap embodying the present invention said field-forming electrode may be electrically connected to said main electrode. The main electrode and said member may present cylindrical surfaces towards one another in spaced parallel relationship. The member may be electrically conducting to constitute said field-forming electrode, and the sharp-edged conductor may be thin wire.

In a preferred form of self-triggered spark-gap said trigger electrode is a thin conducting sheet having a sharp-edged hole therein, said field-forming electrode is a thin conducting sheet overlapping a peripheral region of said hole, and said main electrode faces said hole in capacitive relationship with said field-forming electrode. Preferably the hole and field-forming electrode are circular and the main electrode presents a substantially spherical surface to said field-forming electrode substantially concentric with the hole.

To enable the nature of the present invention to be more readily understood, attention is directed, by way of example, to the accompanying drawings wherein

FIGURE 1 is a partially diagrammatic elevation of a spark-gap embodying the present invention.

FIGURE 2 is a cross-section on the line II—II of FIGURE 1.

FIGURE 3 is a diagram of a circuit using a pair of the present spark-gaps.

FIGURE 4 is a diagrammatic longitudinal section of a modified form of trigger assembly.

FIGURE 5 is a diagrammatic elevation of another type of externally triggered spark-gap embodying the invention.

FIGURES 6 and 7 are perspective views of trigger electrode assemblies used in the spark-gap of FIGURE 5.

FIGURE 8 is a modification of the spark-gap of FIGURE 5.

FIGURE 9 is a perspective view of an alternative form of trigger electrode assembly.

FIGURE 10 is a perspective view of a self-triggered spark-gap incorporating the assembly of FIGURE 9.

FIGURE 11 is a circuit diagram of a delay circuit incorporating the spark-gap shown in FIGURE 10.

FIGURE 12 is a diagrammatic sectional elevation of preferred form of self-triggered spark-gap.

FIGURES 1 and 2 show a spark-gap suitable for use at a working voltage of 40 kv. The main electrodes are a pair of steel spheres **1** and **2** approximately 0.7 in. in diameter mounted on methylmethacrylate (Perspex) pillars **3** and **4** which stand on a base **5**. Equispaced from pillars **3** and **4** and parallel thereto is a similar pillar **6** whose spacing from the spheres is adjustable by means of a screw **7** running in a slot **8** in the base.

Pillar **6**, which is 1 inch in diameter, forms part of the trigger assembly and supports the following layered structure. The outermost layer is a trigger electrode **9** formed as a copper band 0.003 in. thick and 0.15 inch wide fastened tightly round the convex surface of the pillar to prevent it lifting from the adjacent layer in use. Band **9** is insulated by a 0.003 inch thick sheet **10** of polyethylene terephthalate (Mylar) from a rectangular copper field-forming electrode **11**, of similar thickness, which extends about halfway round pillar **6**. Electrode **11** is insulated by a sheet **12**, similar to sheet **10**, from a further copper sheet **13** of similar dimensions which is in contact with the pillar itself. It will be seen that band **9** lies in a common diametral plane of the spheres, with its surface normal to that plane.

In use the field-forming electrode **11** is connected via a tab **14** to the mid-point of a potentiometer chain comprising resistors **15** connected between spheres **1** and **2**. Sheet **13** is connected via tab **16** to sphere **2**. A trigger pulse is applied via an 8:1 step-up transformer **17** between electrodes **9** and **11**, the former of which is provided with a tab **18**. A resistor **19** is connected between tabs **14** and **18**.

In the static condition, prior to the application of a trigger pulse, sphere **1** is at 40 kv. (positive or negative) and sphere **2** is earthed. The trigger electrode **9** is therefore at 20 kv. relative to each sphere and the spacing is such that this is insufficient to break down the gap between electrode **9** and either sphere.

On the application of a trigger pulse between electrodes **9** and **11**, an intense electric field is created at the edges of band **9** where it lies over electrode **11**, because the separation between them is so small. As a result of this field, corona is rapidly formed in copious quantities at these edges. The polarity of the trigger pulse is chosen to supplement the standing voltage between electrode **9** and sphere **2**, and in the presence of the corona the gap between band **9** and sphere **2** becomes overvolted and breaks down. The function of sheet **13** is to rpovide a capacitance between electrode **11** and sphere **2**, thereby stabilising the potential of electrode **11** during the pulse. Resistor **19** acts to damp out any overswing of the trigger pulse.

The breakdown of the gap between electrode **9** and sphere **2** causes the gap between electrode **9** and sphere **1** to become overvolted (no having 40 kv. across it) and hence to break down.

When the above-described spark-gap was fired by an 8 kv. trigger pulse (a 1 kv. input pulse to transformer **17**) having a rise-time of 30–40 nanosecs, the breakdown was delayed by only about 70 nanosecs from the start of the trigger pulse. The jitter (i.e. the variation about this figure) was only 5 nanosecs. By using a 12 kv. trigger pulse, the jitter could be reduced to about 1 nanosec. The rise-time of the current in a 50 ohm cable constituting an external load was 7–8 nanosec. The input capacity between electrodes **9** and **11** is only about 30 p.f.s., and hence the energy required in the trigger pulse is very small as compared with other gas switches (ignitrons, thyratrons etc.) of comparable performance.

Spark-gaps of similar configuration but increased dimensions have been used at 100 kv. In this case, however, it is impracticable to use sheet **13** to stabilise the potential of electrode **11** during the trigger pulse, or to use a separate capacitor for the purpose as in other forms of the invention to be described, because with such arrangements a damagingly high voltage can appear across the insulation between electrodes **9** and **11** when the spark-gap breaks down, owing to this capacitance remaining charged. It is possible, however, to use as this capacitance the stray capacitance which exists between electrode **11** and sphere **2** across the gap, which is automatically discharged by breakdown of the gap, and FIGURE 3 shows a circuit operating in this way.

This circuit comprises two storage capacitors **20** and **21** charged to +100 kv. and −100 kv. respectively via resistors **22** and **23**, which are to be discharged into a load **24**. The circuit is symmetrical about earth and employs two spark gaps **25** and **26** having spheres **1′**, **1″**, **2′** and **2″**, and electrodes **9′**, **9″**, **11′** and **11″** respectively. Electrodes **11′** and **11″** are held at +50 kv. and −50 kv. respectively by potentiometer resistors **27** and **28**.

The electrodes **9′** and **9″** are connected by capacitors **29** and **30** to opposite ends of the winding of a 5:1 step-up air-cored auto-transformer **31** having an earthed centre-

tap. The central turns of this transformer are fed from a parallel-strip transmission-line pulse-generator **32** of the kind described in copending U.S. application Ser. No. 249,873 filed Jan. 7, 1963, now Patent No. 3,225,223, triggered by a swtich **33**, which delivers a 15 kv. output pulse. Trigger pulses of 75 kv. amplitude and opposite polarities are therefore applied to electrodes **9′** and **9″**.

Because the stray capacitance between electrodes **11′** and **11″** and the spheres is so small, the form of trigger assembly shown in FIGURE 1 is unsuitable, since only a relatively small fraction of the applied pulse would appear across the relatively large capacitance between electrodes **9** and **11**. To reduce the latter capacitance, the construction shown in FIGURE 4 is used, in which the portion of electrode **11′** directly below electrode **9′** lies in a recess, the 1/16 inch deep space between electrode **11′** and the 0.005 inch Mylar sheet **10′** being filled with polyethylene **34**. The periphery of electrode **9′**, which is of 0.012 inch beryllium-copper about 0.8 inch wide, overlaps the edges of the recess by only about 0.05 inch. This form of construction reduces the inter-electrode capacitance to a low value, while continuing to provide the intense field at the edges of electrode **9′** to produce corona. (Alternatively sheet **11′** may be divided circumferentially into two halves, the inner edge of each lying just under band **9′**; however this construction is less desirable because of effects arising at the sharp inner edges.) The high-value resistors **35** and **36** maintain the potential of electrodes **11′** and **11″** at 50 kv. prior to triggering the gaps. Four-inch diameter spheres are used spaced about 1 inch from electrodes **9′** and **9″**. The delay between the production of the transformer pulses and the breakdown of the gap was about 200 nanosecs, with a jitter of about 10 nanosecs.

In FIGURE 5 the spheres **101** and **102** are located on opposite sides of the trigger assembly. The latter comprises a thin copper trigger electrode **109** which embraces a laminar field-forming electrode **111** but as before is separated from it by thin sheet Mylar. Typical forms of electrodes **109** and **111** are shown in FIGURES 6 and 7, in which the 0.002 inch Mylar sheet is omitted for clarity. The electrode **111** is maintained at a suitable potential between those of electrodes **101** and **102** by means of resistors **115**. As before, when a trigger pulse is applied between electrodes **109** and **111**, e.g. via a transformer **117** as shown, a corona discharge occurs at the edges of electrode **109** as a result of the intense field produced thereat, causing the gap between it and sphere **101** to break down, which in turn breaks down the other half of the main gap. A separate capacitor **113** stabilises the potential of electrode **111** during the trigger pulse in the manner already described.

For a 10 kv. gap of this kind working at 80% of its breakdown voltage (a safe working voltage) it is found that for minimum trigger voltage and fast working (approx. 50 nanosecs delay), the two halves of the gap should not be equally spaced nor have equal voltages on them. The ratio of the gap breakdown voltages and of the applied voltages is made 2:1, and care is taken that the trigger pulse is of the correct polarity to overvolt the gap having the lower breakdown voltage. Under these conditions the triggering pulse should be greater than 1/7 of the total gap voltage to give fast, reproducible breakdown.

The reason for this unsymmetricity may be explained as follows.

Suppose the breakdown voltage on the gap between electrodes **102** and **101** to be unity and that the gap is to break down at 0.85 of the breakdown voltage as a result of corona initiation. Suppose also that the ratio of the voltages on the gap between electrodes **101** and **109** (termed gap A) and on the gap (termed gap B) between electrodes **102** and **109** to be f:1 respectively.

The volts units on gap A are

$$0.85\frac{f}{f+1}\text{ units}$$

and the volts units on gap B are

$$0.85\frac{1}{1+f}\text{ units}$$

The breakdown voltage of gap A is $f/f+1$ units and of gap B is $1/1+f$ units

When gap A breaks down 0.85 volt units is applied to gap B.

Gap B will break down if

$$0.85>\frac{1}{1+f}$$

and will break down quickly (3×10^{-8} sec.) as discovered empirically, if

$$0.85=1.15\times\frac{1}{1+f}$$

i.e. $f=0.35$

The minimum trigger pulse required for gap A can be calculated as follows:

Volt units on gap is

$$0.85\frac{f}{f+1}$$

Total minimum volt units required to cause fast breakdown is

$$1.15\frac{f}{f+1}$$

∴ volt units required to be supplied by trigger pulse is

$$0.3\frac{f}{f+1}$$

Since $f=0.35$,

Minimum trigger volts=.078 volt units.

This is about 1/10 of the total gap volt units (0.8) and, since there are always losses in the system, this figure is in practice raised to 1/7 of the total gap voltage.

FIGURE 8 shows a somewhat similar gap for use at 100 kv. The spheres **101'** and **102'** are made larger than for the 10 kv. gap of FIGURE 5 and the breakdown voltages of the two halves of the gap are in the ratio 3:4. The electrode **111'** is attached to a toroidal guard-ring **116**, whose stray capacity to the spheres stabilises the potential of electrode **111'** during the trigger pulse as in the circuit of FIGURE 3. Electrodes **111'** and **109'** are separated by 0.020 inch Mylar and a 20 kv. trigger pulse is used for fast, reliable operation.

Although the descriptions of FIGURES 5 and 8 refer to the use of unequal voltages on the two halves of the gap, this is not, of itself, a novel arrangement, and it will be recalled from the descriptions of FIGURES 1–4 (in which equal voltages are applied to the two halves) that it is by no means an essential feature of the invention.

The cylindrical trigger assembly shown in FIGURE 9 is a modified form of those shown in FIGURES 1–4. The Perspex cylinder **106** has a segment of its surface covered with a strip of copper sheet **211** and the whole is wrapped in 0.001 inch Mylar sheet (not shown). On top of the Mylar is wound 0.005 inch dia. copper wire **209**, securing to the Mylar, and in electrical contact with, a strip of copper sheet **114**. The trigger voltage is applied between strips **211** and **114**, giving rise to corona discharge from these portions of the wire **209** which lie above the strip **211**.

A trigger assembly of the type shown in FIGURE 9 has been used in a 3 kv. gap of the kind shown in FIGURES 5 and 8. Another application is the self-triggered gap shown in FIGURE 10. In this example the cylinder **106'** is of metal wrapped with Mylar (not shown), thus dispensing with the need for strip **211** in FIGURE 9.

Spaced from cylinder **106'** but mechanically and electrically connected to it by strip **122**, is a metal cylinder **121**. The gap is defined between wires **209'** and cylinder **121**. Where used in the delay circuit of FIGURE 11, the portions of the spark-gap of FIGURE 9 are shown diagrammatically but with the same reference numbers.

Referring to FIGURE 11, initially the capacitor **122** is charged via resistor **126** from a 3 kv. source. The circuit is triggered by firing the fast gap **125**, which is of the type shown in FIGURES 5 and 8, whereupon capacitor **122** discharges through resistor **124** at a controllable rate. As the voltage on capacitor **122** falls, the voltage between wires **209'** and cylinder **121** of the self-triggered gap increases until corona takes place at the surface of the wires and the gap breaks down, at say, 1.5 kv. The standard error in delay achieved is 3–4% for delays up to 10 μsec and 6–7% up to 1000 μsec.

Another form of self-triggered gap is shown in FIGURE 12. It comprises a thin copper sheet **309** having a circular hole **350**. A circular electrode **311**, also made of thin copper sheet, is separated from sheet **309** by a thin sheet of Mylar **310**, the whole lying on an insulating block **306**. The diameter of electrode **311** slightly exceeds that of hole **350** so that there is a peripheral overlap of 0.05–0.1 inch. Opposite the centre of the hole is mounted a sphere **321** whose distance from the hole can be adjusted by a screw **322**.

In operation the potential of sheet **309** is held steady e.g. at earth, and an increasing potential is applied to sphere **321**. As the potential of the sphere rises, the capacitance between it and sheet **311**, which is electrically floating, raises the potential of the latter relative to sheet **309** causing corona to be produced at the sharp-edged circumference of the hole **350**. Eventually the gap between sphere **321** and sheet **309** becomes overvolted in the presence of the corona and breakdown takes place between the sphere and the edge of the hole. For a gap intended to break down at 25 kv., sphere **322** was about 1 inch in diameter, sheets **309**, **310** and **311** 0.003 inch thick and hole **350** about 1/4 inch in diameter. The spacing between the sphere and the sheets was about 0.4 inch. The stability of this gap is similar to that of FIGURE 10.

Instead of relying on the capacitative potential divider formed by the capacitances between sphere **321** and sheet **311** and between sheet **311** and sheet **309** to determine the potential of sheet **311**, a resistive potential divider can be connected between the supply to sphere **321** and earth to do so. Such an arrangement is particularly useful for gaps working at the lower voltages.

I claim:

1. A spark-gap including a trigger assembly arranged in spaced relationship with a main electrode in the gap, said assembly comprising a trigger electrode having a sharp edge exposed to the gap and a field-forming electrode separated from said exposed sharp edge by a thin layer of dielectric material to produce a corona-producing electric field at said sharp edge by application of a triggering voltage between said trigger electrode and said field-forming electrode, said dielectric material extending beyond said sharp edge to prevent the formation of a further gap extending from a conducting surface of said trigger electrode to a conducting surface of said field-forming electrode and thereby prevent electrical breakdown occurring between said trigger and field-forming electrodes on application of said triggering voltage.

2. A spark-gap as claimed in claim **1** wherein said assembly comprises a member presenting a surface to said main electrode and being electrically conducting over at least a portion of said surface, said portion constituting said field-forming electrode, and a sharp-edged conductor overlying said portion but insulated therefrom by said dielectric layer to constitute said trigger electrode.

3. A spark-gap as claimed in claim **2** wherein said member is made of insulating material, and said portion is a thin conducting sheet applied to said member.

4. A spark-gap as claimed in claim **2** wherein said surface is convex.

5. A spark-gap as claimed in claim **4** wherein the sharp-edged conductor is thin wire.

6. A spark-gap as claimed in claim **4** wherein the sharp-edged conductor is a thin conducting band.

7. A spark-gap as claimed in claim **4** comprising two main electrodes presenting substantially spherical surfaces to said trigger assembly, wherein the sharp-edged conductor is a thin conducting band located substantially in and normal to a common diametral plane of the spherical surfaces.

8. A spark-gap as claimed in claim **7** wherein the thin conducting sheet below a non-peripheral region of said band is recessed into said member to reduce the capacitance between band and sheet.

9. A spark-gap as claimed in claim **7** wherein a further thin conducting sheet is insulatedly located between said thin conducting sheet and said member to form a capacitor therewith.

10. A spark-gap as claimed in claim **2** comprising a pair of main electrodes presenting substantially spherical surfaces to said trigger assembly, wherein a laminar conducting member constituting said field-forming electrode is located between said spherical surfaces substantially normal to a line joining their centres, said sharp-edged conductor embracing both sides of said laminar member but being insulated therefrom by dielectric layers.

11. A self-triggering spark-gap comprising a spark-gap as claimed in claim **2** wherein said field-forming electrode is electrically connected to said main electrode.

12. A spark-gap as claimed in claim **11** wherein said main electrode and said member present convex surfaces towards one another in spaced parallel relationship.

13. A spark-gap as claimed in claim **12** wherein the member is electrically conducting to constitute said field-forming electrode, and the sharp-edged conductor is thin wire.

14. A self-triggered spark-gap comprising a spark-gap as claimed in claim **1** wherein said trigger electrode is a thin conducting sheet having a sharp-edged hole therein, said field-forming electrode is a thin conducting sheet overlapping a peripheral region of said hole, and said main electrode faces said hole in capacitative relationship with said field-forming electrode.

15. A self-triggered spark-gap as claimed in claim **14** wherein the hole and field-forming electrode are circular and the main electrode presents a substantially spherical surface to said field-forming electrode substantially concentric with the centre of the hole.

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