

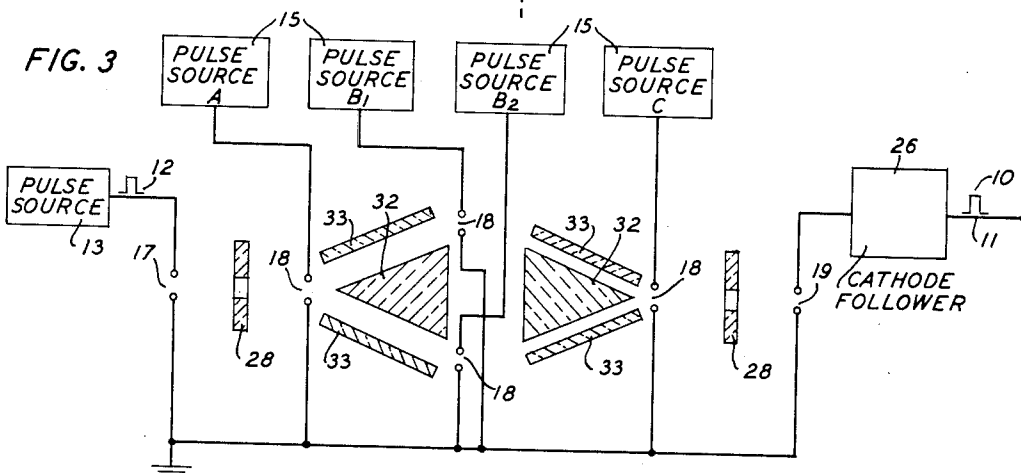
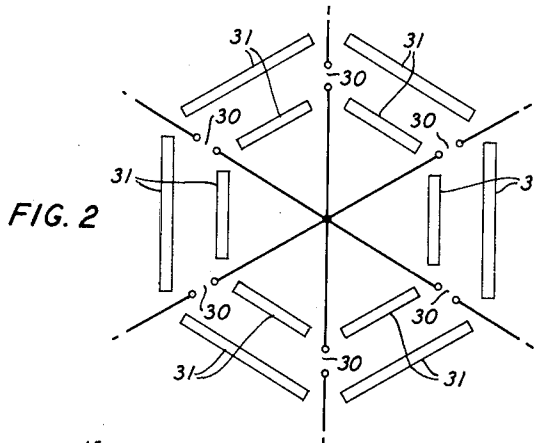
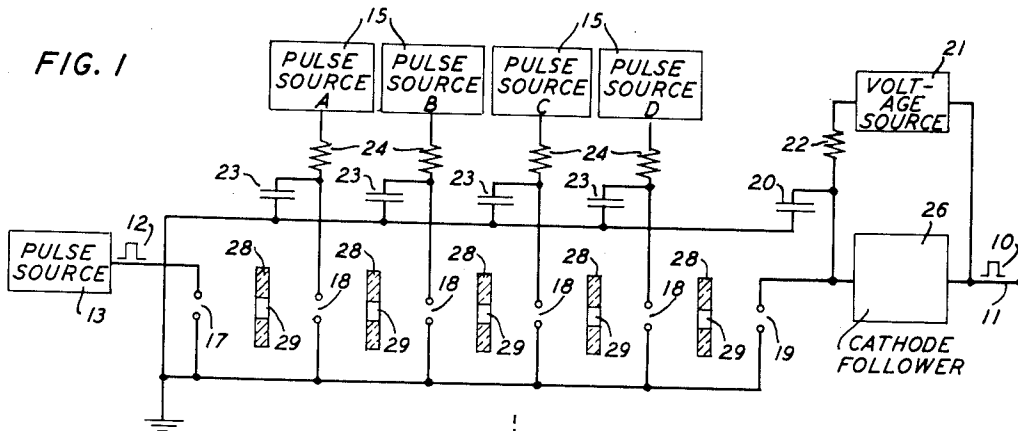
Jan. 3, 1956

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2,729,753

ELECTRICAL CIRCUITS EMPLOYING SPARK GAPS

Filed Sept. 16, 1954



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ELECTRICAL CIRCUITS EMPLOYING SPARK GAPS

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Application September 16, 1954, Serial No. 456,594

10 Claims. (Cl. 307—88)

This invention relates to electrical circuits and more particularly to such circuits particularly utilizable in the attainment of logical functions.

Various logic circuits have become well known and are of considerable importance in the design and operation of electrical systems. One such circuit utilized to provide an output pulse on the occurrence of a particular number of inputs has become known as an AND circuit; another to provide an output on the occurrence of any one of a number of inputs, an OR circuit. Other logic circuits include various combinations of these basic two, and inhibition or the appearance of an output on occurrence of an input unless one or more particular events have occurred.

Priorly these logic circuits have generally been attained by the employment of diodes of the semiconductor type, such as varistors. They have also been attained employing magnetic cores, vacuum tubes, or gas discharge tubes.

It is a general object of this invention to provide a new type of logic circuit.

It is another object of this invention to provide improved logic circuits having a high speed of operation and which are substantially lossless.

Logic circuits in accordance with this invention utilize a plurality of spark gaps and the propagation or transfer of successive shock waves due to spark discharges. In an AND logic circuit, in accordance with one embodiment of this invention, a series of spark gaps are arranged in succession to be electrically isolated from each other but are coupled by an appropriate acoustic coupling structure so that firing of one spark gap can produce a shock wave which is transmitted to another spark gap to effect firing of that gap. In this embodiment, the electrodes of the spark gaps are so spaced that the presence of the shock wave from a prior gap will not fire the gap unless it has received or been primed by an appropriate voltage.

When two spark gaps are associated so as to be acoustically coupled, the shock wave generated by the spark discharge at the first gap reduces the breakdown voltage required to produce a spark at the other gap. This is apparently due to a change in pressure of the gas between the electrodes of the spark gap as the shock wave passes through the succeeding gap. The breakdown of the succeeding spark gap will also be affected by the ions carried along by the gas or atmosphere which follows closely behind the shock front. These ions are effective in reducing the statistical time lag required for breakdown of the succeeding spark gap when an appropriate voltage is applied and will also tend to reduce the effective separation between the electrodes and thus act in the same sense as the decreasing density distribution due to the shock wave itself.

Accordingly, in one embodiment of this invention, a number of spark gaps are arranged in succession to be fired on the occurrence of a shock wave from a spark discharge at the prior gap. Each of these gaps may

be primed by a voltage which is insufficient, for the actual pressure-distance, or pd , characteristic of the gap to effect a spark discharge across the gap. However, on occurrence of a spark discharge at the immediately prior spark gap, the shock wave will reduce both the pressure at the succeeding gap and the effective distance; the pressure-distance characteristic $p'd'$ as the shock wave passes between the electrodes is such that the priming voltage can effect breakdown of the gap. When this gap breaks down a new shock wave is generated and transmitted to the next spark gap in the row of such gaps.

Advantageously, the successive gaps in the row are acoustically shielded from each other so that the shock wave from a spark discharge at one gap is effective in altering the pressure-distance characteristic only of the next adjacent gap to allow it to be broken down on the pressure of the priming voltage. This acoustic shielding may be due to the interposition of a shielding member between adjacent gaps, the shielding member having an aperture therein aligned with the next gap to let only sufficient of the shock wave through the aperture to vary the characteristics of the next adjacent gap; or it may be attained by spatially positioning the gaps. Thus the gaps may be so positioned that only adjacent ones are in a straight line; in such a structure acoustic wave guiding or shielding elements may be employed to prevent the shock wave from spreading radially.

The priming voltage will be present at a particular gap only if the event associated with that gap has occurred or is occurring. In a simple case, let us suppose that a logic circuit in accordance with this invention is to apply an output pulse Y on occurrence of an input pulse X only if conditions A, B, and C have occurred; or, in Boolean algebra notation

$$Y = X + A + B + C \quad (1)$$

If the circuit logic requirements are such that the output Y is to be present if A, B, and C have occurred, regardless of whether they may be now occurring, a condenser may be placed in shunt with the spark gaps and the priming voltage stored on the condenser which is charged on the occurrence of the condition A, B, or C. If the output Y is to occur only if conditions A, B, and C are present concurrent with the input pulse X, the priming voltage is applied directly to the spark gaps from pulse or voltage sources associated with conditions A, B, and C.

Let us now consider the logic involved in the expression

$$Y = X + A + (B_1 B_2) + C \quad (2)$$

This states that an output pulse Y is to be present on the occurrence of an input pulse X if A, C, and B_1 or B_2 have occurred or are occurring. For such a circuit, alternate spark gaps for conditions B and B' would be provided, equally acoustically coupled to the gaps for conditions A and C and electrically isolated from the other gaps.

In the above-described embodiments it has been assumed that the pressure-distance characteristic $p'd'$ of the spark gap on occurrence of the shock wave front from the prior gap is such that the gap will not break down unless a priming voltage is present. In accordance with another embodiment of this invention, the pressure characteristic $p'd'$ of the gap may be such that the gap will break down unless an inhibiting voltage is present. Thus let us consider the expression

$$Y = X + A' + B' + C' \quad (3)$$

In this case, an output pulse Y is to be present on occurrence of an input pulse X only if A, B, and C are not present, or, in another case, have not occurred

priorly. In such embodiments, the normal voltage conditions across the spark gaps would be such as to allow breakdown of the gaps associated with A, B, and C when a shock wave is generated at the prior gap. Breakdown at a particular gap is inhibited or prevented by applying a negative or inhibiting voltage to the gap when the condition occurs. This embodiment accordingly may be considered a multiple inhibiting circuit.

The successive breakdown of the spark gaps and generation of the shock wave fronts occur very rapidly so that circuits in accordance with this invention have high speeds of operation, as of the order of a few microseconds or less, making them compatible with high speed digital electrical circuits and devices. Additionally, whereas conventional diode logic structures introduce loss and attenuate the pulses being passed so that amplification is required, spark gap logic circuits in accordance with this invention are substantially lossless. Therefore, logic stages may be cascaded almost indefinitely without attenuation of the signal pulses.

It is a feature of this invention that a logic circuit comprise a plurality of spark gaps so arranged and constructed that a spark discharge at one gap may be initiated by the shock wave from a spark discharge of another gap.

It is another feature of this invention that a plurality of such gaps be arranged in an array and be electrically isolated but acoustically coupled to each other. Further in accordance with a feature of this invention, the gaps are so arranged as to be effectively acoustically shielded from all but adjacent gaps, so that shock waves generated by the presence of spark discharges at more remote gaps will not affect the breakdown characteristics of the gaps.

It is a further feature of this invention that voltages be applied to one electrode of the spark gaps to determine the logic of the circuit. Thus it is a feature of certain embodiments of the invention that positive priming voltages be applied to one electrode of the spark gaps when a predetermined condition is occurring or has occurred so that successive spark shock wave fronts are generated at successive gaps only on the occurrence of these conditions. And it is a feature of certain other embodiments of this invention that negative inhibiting voltages be applied to one electrode of the spark gaps when a predetermined condition is occurring or has occurred so that successive spark shock waves are generated at successive gaps only if these conditions have not occurred.

It is still another feature of certain embodiments of this invention that the logic involved be determined by the occurrence of prior conditions. In accordance with this feature of the invention, a condenser is connected in shunt across the spark gap and the priming or inhibiting voltage applied to the condenser on occurrence of the prior condition.

It is a still further feature of certain embodiments of this invention that acoustic shielding or absorbent elements be positioned between adjacent spark gaps to prevent the shock wave from one spark gap being effective at other than the next adjacent gap.

A complete understanding of this invention and of these and other features thereof may be gained from consideration of the following detailed description and the accompanying drawing, in which:

Fig. 1 is a schematic representation of one specific illustrative embodiment of this invention;

Fig. 2 is a schematic representation of one alignment of spark gaps employable in specific embodiments of the invention; and

Fig. 3 is a schematic representation of another specific embodiment of this invention.

Fig. 1 is a schematic representation of one specific illustrative embodiment of this invention comprising a logic circuit for recognizing the prior occurrence of a

distinct number of events A, B, C, and D. In this embodiment an output pulse 10 is to appear on an output lead 11 on the occurrence of an input pulse 12 from a pulse source 13 if and only if a distinct number of prior events have occurred. Each of these events A, B, C, and D is recognized by appropriate circuitry which may be considered, schematically, to comprise a pulse source 15.

In accordance with an aspect of this invention, a plurality of spark gaps are aligned with at least adjacent gaps in a row, the gaps including an initiating gap 17, intermediate gaps 18, and an output gap 19, though the last of the intermediate gaps 18 may also serve as the output gap. The input pulse 12 is of sufficient voltage to initiate a spark at the first gap 17; each of the other spark gaps, however, is primed. The output gap 19 is primed by a voltage charge built up on a condenser 20 from a voltage source 21 to which it is connected by a charging resistor 22. Voltage source 21 is arranged, as by a connection back to it from the output lead 11, to keep condenser 20 charged so that the output gap 19 is always primed. Each of the intermediate gaps 18 is primed, if the prior event has occurred, by a pulse from the source 15 which charges the condenser 23 connected in shunt across the gap 18. A charging resistor 24 is connected between condenser 23 and the source 15. Thus if the prior event has occurred, the intermediate gap 18 is primed by the voltage charge on the condenser 23.

The gaps 17, 18, and 19 are electrically isolated from each other but acoustically coupled. When a pulse 12 occurs, the initiating gap 17 breaks down. The spark so generated creates a shock wave which moves rapidly into the vicinity of the first intermediate gap 18. The shock wave serves to reduce the breakdown voltage required to produce the spark at this first gap; the full process by which a shock wave generated by a spark discharge at one position can reduce the breakdown voltage required to produce a spark at another spacial position is not known but certainly involves the variation in gas pressure at the second position due to the shock wave and probably an influx of ions carried along the shock wave. This theory of the spark gap shock wave is further discussed in application Serial No. 444,457, filed July 20, 1954, of W. S. Boyle.

If pulse source 15 had priorly applied a charging pulse to the condenser 23 of the first intermediate gap so that a positive voltage V was present at the gap, the gap 18 will fire. The voltage V is not high enough to fire the gap 18 in the absence of the shock wave due to the spark at gap 17; however, in this embodiment, the gap 18 will not fire unless the voltage V is present when the prior gap fires.

When the first intermediate gap 18 fires and a spark discharge occurs, this spark discharge itself transmits a shock wave to the next intermediate spark gap 18, and the process is repeated, each intermediate gap firing only on the presence of the voltage V stored on its condenser 23 by prior action of its pulse source 15. When the last gap 18 fires its spark discharge generates a shock wave which fires the output gap 19 causing an output pulse 10 to be applied, through a cathode follower 26, to the output lead 11.

In order that each spark gap only be fired by a shock wave from the immediately preceding gap, each gap is acoustically isolated from all but the preceding and succeeding gaps. This may be attained, in the embodiment of Fig. 1, by positioning between adjacent gaps acoustic shields 28 which may comprise acoustic absorbent material, such as a ceramic having a porous, roughened or irregular surface, having a central aperture 29 therein and positioned with respect to the adjacent gaps so that sufficient acoustic pressure from the shock wave at the immediately prior gap is transmitted through the aperture 29 to fire the succeeding gap, if it is primed, but

insufficient pressure is transmitted from other prior gaps, which are removed from this gap by more than one such shield 28, to fire this gap. This acoustic shielding may also be attained by locating the gaps sufficient distances apart; this may readily be attained in the embodiment of Fig. 2, by locating the gaps 30 so that only adjacent of the gaps 30 are in a straight line. Acoustic shielding elements 31 may then comprise cylinders, serving as acoustic wave guide structures, between adjacent gaps, or may be merely two flat pieces of acoustic absorbent material.

The shock wave from each spark discharge explodes, of course, in all directions, and thus is transmitted from a given gap both to the preceding and the succeeding gaps. However, the preceding gap condensers 23 will, of course, have discharged and therefore these gaps will not be primed. In this manner the spark discharge is transferred only in one direction. As the spark is maintained at each gap by a condenser discharge, it is self-extinguishing.

This circuit in accordance with my invention thus is an AND logic circuit which may be represented, in Boolean algebra notation, by the expression

$$Y=X+A+B+C+D \quad (4)$$

Where Y is the output pulse 10, X the input pulse 12, and A, B, C, and D represent the prior occurrences of the conditions or events A, B, C, and D.

In the above embodiment it has been assumed that the pulse sources 15 each charge up its associated priming condenser 23 to a positive voltage V to enable transfer of the spark, or more accurately, regeneration of the spark gap shock wave, along the row of gaps. In this manner, a type of logical AND circuit is attained in which an output occurs only on the prior occurrence of all of a plurality of events. It is apparent, however, that various other embodiments in accordance with the principles of this invention could attain other circuit logic. Thus the gaps 18 may be arranged and spaced so a spark normally occurs when a shock wave from a prior spark arrives at the gap unless a negative voltage has been stored on the condensers 23 by the pulse sources 15. In this manner the circuit may operate as a logical inhibitor, an output pulse 10 occurring in response to an input pulse 12 unless one or more inhibiting signals or pulses have been applied to a condenser 23 to prevent breakdown of a spark at its associated gap.

Similarly in the above embodiment the logic has been concerned with the prior occurrences of certain events. A simpler AND circuit may be attained, without priming condensers 23, if the various events occur simultaneously so that the pulses or voltages from the pulse sources 15 themselves serve to prime the spark gaps. OR logic circuits, in which a spark appearing at any one of a number of gaps generates a shock wave causing an output gap to break down, and combinations of such logic circuits may also be attained in other embodiments of this invention. In the embodiment depicted in Fig. 3 the logical expression

$$Y=X+A+(B_1B_2)+C \quad (5)$$

is attained by the provision of an OR circuit at one intermediate stage in the row of spark gaps 18. Thus alternate spark gaps are provided for conditions B₁ and B₂, the alternate gaps being acoustically coupled to only the adjacent next stage gaps 18 by an acoustic wave guide structure comprising a pair of conical or wedge shaped members 32 and outer members 33. The logic defined by Equation 5 is attained when each of the gaps 18 is arranged so as not to break down on appearance of the shock wave thereat from a prior gap unless a positive priming voltage is concurrently being applied from a pulse source 15. The structure depicted in Fig. 3 may also attain the logic

$$Y=X+A'+(B_1+B_2)'+C' \quad (6)$$

if the gaps 18 are arranged to normally break down on the appearance thereat of the shock wave front due to a spark discharge at the immediately prior gap unless a negative pulse is applied concurrently from the pulse sources 15 and therefore unless condition A, C or both B₁ and B₂ are occurring.

The spark gaps may advantageously be enclosed in an envelope having a gaseous medium therein, such as neon or argon at atmospheric pressure or may be in air at atmospheric pressure. The electrodes of the gap may be of a refractory metal, such as molybdenum, tungsten, etc., or of other material known in the art for spark gap electrodes. To minimize corrosion of the electrode metal due to repeated striking of the gap mercury may be employed to wet the contacts, as by being absorbed in a sponge-like metallic electrode.

The spacing between the electrodes of the gap will depend on the priming voltages available and the spacing between successive gaps. With a priming voltage of 4000 to 5000 volts and a spacing between the gaps of 0.10 inch, the spacing between the electrodes may be of the order of 0.05 inch, depending also on the size of the apertures 29 in the shielding members 28 and the location of the shielding members themselves.

Reference is made to application Serial No. 456,571, filed September 16, 1954, of W. S. Boyle and R. W. Ketchledge, wherein a closely related invention is disclosed and claimed.

It is to be understood that the above-described arrangements are illustrative of the application of the principles of the invention. Numerous other arrangements may be devised by those skilled in the art without departing from the spirit and scope of the invention.

What is claimed is:

1. A logic circuit comprising a plurality of spark gaps arranged in succession, means applying a pulse to a first of said gaps to initiate a discharge thereat, means for preventing the shock wave from a discharge at one gap appearing at any but an adjacent gap with sufficient energy to trigger the gap, means connected to certain of said gaps for determining whether said gaps will break down on occurrence of a discharge at a prior gap, and output means connected to a last of said gaps for receiving an output pulse on the successive breakdown of each of said gaps between said first and last gaps.

2. A logic circuit in accordance with claim 1 wherein said preventing means comprises acoustic shielding elements positioned between adjacent gaps.

3. A logic circuit in accordance with claim 1 wherein said preventing means comprises means positioning only adjacent of said gaps in a straight line and acoustic absorption elements positioned between adjacent gaps.

4. A logic circuit in accordance with claim 1 wherein said means connected to certain of said gaps comprises condensers connected to said certain gaps and means for charging said condensers to prime said certain gaps prior to the application of said pulse to said first gap.

5. A logic circuit in accordance with claim 4 wherein said charging means comprise pulse sources connected to each of said condensers, whereby an output is present on said output means only on the application of a pulse from each of said pulse sources to said condensers.

6. A logic circuit comprising a pair of alternate spark gaps, another spark gap adjacent said pair of gaps, means for effecting a spark discharge at one of said alternate gaps, and means acoustically coupling each of said alternate gaps to said another gap whereby the shock wave on initiation of a discharge at one of said alternate gaps can effect breakdown of said another gap.

7. A logic circuit comprising a plurality of spark gaps arranged in succession and including a pair of alternate spark gaps, means applying a pulse to a first of said gaps to initiate a discharge thereat, means for preventing the shock wave from a discharge at one gap appearing at any but an adjacent gap with sufficient energy

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to trigger that gap, and output means connected to a last of said gaps for receiving an output pulse on the successive breakdown of said gaps between said first and last gaps including at least one of said alternate gaps.

8. A logic circuit comprising a plurality of spark gaps arranged in succession, means applying a pulse to a first of said gaps to initiate a discharge thereat, means for preventing the shock wave from a discharge at one gap appearing at any but an adjacent gap with sufficient energy to trigger the gap, said gaps being arranged so that spark breakdown does not occur at a gap solely due to the appearance thereat of a shock wave front from a discharge at an immediately prior gap, means for applying priming voltages to said gaps, said voltages alone being insufficient to effect breakdown of said gaps but being sufficient to effect breakdown on occurrence of a shock wave from an immediately prior gap, and output means connected to a last of said gaps for receiving an output pulse on the successive breakdown of each of said gaps between said first and last gaps.

9. A logic circuit comprising a plurality of spark gaps arranged in succession, means applying a pulse to a first

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of said gaps to initiate a discharge thereat, means for preventing the shock wave from a discharge at one gap appearing at any but an adjacent gap with sufficient energy to trigger the gap, said gaps being arranged so that spark breakdown occurs at a gap on appearance thereat of a shock wave from an immediately prior spark gap, means for applying voltages to said spark gaps of sufficient magnitude to prevent breakdown of said gaps on appearance thereat of said shock wave, and output means connected to a last of said gaps for receiving an output pulse on the successive breakdown of each of said gaps between said first and last gaps.

10. A logic circuit comprising a plurality of spark gaps aligned in an ordered array, means for initiating a discharge at a first of said spark gaps, means for initiating discharges at successive ones of said gaps on occurrence of a spark discharge at an immediately prior gap in said array and in accordance with the logical requirements of the circuit, and output means connected to a last of said gaps for receiving an output pulse only on the successive breakdown of said gaps in said array.

No references cited.