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PULSE MODULATOR

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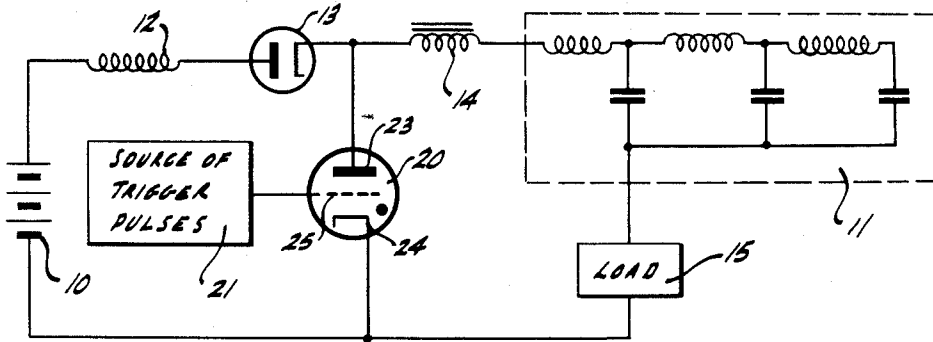


FIG. 1.

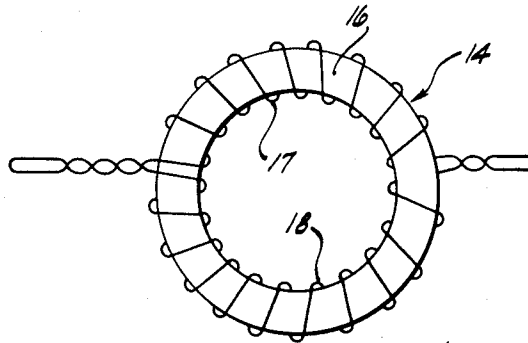


FIG. 2.

FIG. 3(a)

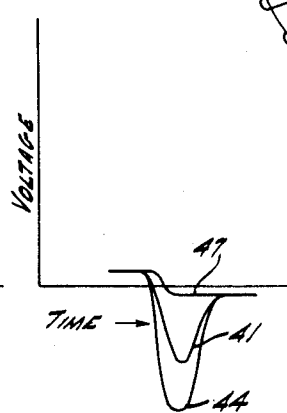
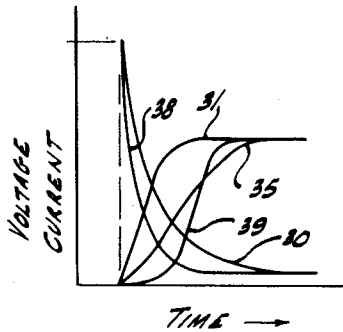


FIG. 3(b)

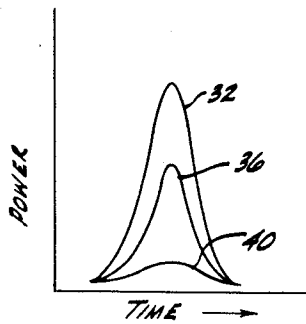


FIG. 4(a)

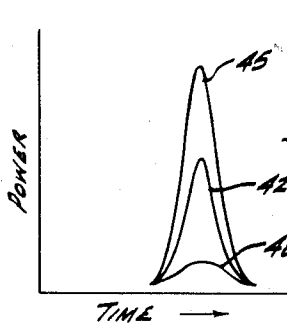


FIG. 4(b)

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PULSE MODULATOR

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This invention relates to control devices for gas discharge devices, and more particularly to means for reducing the ionization and de-ionization power loss in gas-filled tubes.

It is customary in radar systems to employ a pulse modulator supplying pulses to the magnetron, which modulator may comprise, for example, some form of pulse forming network employing a direct-current power supply in series with a charging inductance, together with a hydrogen-filled gaseous discharge switch device, known commercially as a "Thyratron," for causing the network to discharge. Large power losses occur in the gaseous discharge device during the period of ionization because the voltage across the tube cannot decrease to zero instantaneously, so during the ionization period there will be a decreasing voltage across the tube and an increase in the flow of load current through the tube. Under an intermediate condition, a unit current results in a higher power, i.e. the power loss in the gaseous discharge device during ionization is substantially more than after ionization is complete. Moreover, during the de-ionization period, the energy stored in the magnetic and electric fields of the circuit elements, principally from the pulse forming network, causes an inverse spike voltage to appear across the gaseous discharge device. Under this set of conditions, the gaseous discharge device must be capable of dissipating additional power during de-ionization.

In portable and airborne radar, the general trend has been to increase the pulse repetition frequency to get more "looks" at today's faster moving targets, and decrease the size and weight of the circuit components. However, to increase the pulse repetition frequency it is necessary that the gaseous discharge device dissipate proportionately greater power losses in that the power loss occurs during the ionization prior to each pulse. To handle this greatly increased power loss without reducing the pulse power output, it is conventional practice to employ larger and heavier gaseous discharge devices, which is contrary to a basic design requirement for portable and airborne units.

An alternative solution to the problem would be to decrease the ionization power loss. Heretofore, to decrease ionization power loss, an air-core inductor was serially connected between the plate of the thyratron and the pulse forming network to decrease the rate of rise of plate current during ionization until the voltage across the gaseous discharge device had decreased to a low value. One disadvantage of this technique resides in the fact that the time between zero and full current flow in the gaseous discharge device was increased; and a second disadvantage resides in the fact that the magnetic field built up in the inductor contributed to the energy stored in the aforementioned magnetic and electric fields of the circuit elements, and thus increased the amplitude of the inverse spike voltage appearing across the gaseous discharge device during de-ionization.

The present invention provides means whereby the

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ionization and de-ionization power losses are effectively reduced to values unobtainable with prior art devices thereby making possible the use of pulse modulators which provide the desired pulse power output at an increased pulse repetition frequency and, yet, employ smaller and lighter gaseous discharge devices. This is achieved by serially connecting a saturable core reactor between the plate of the gaseous discharge device and the pulse forming network. The reactor is designed such that its impedance during the initial portion of the ionization period remains high, thereby effectively retarding the rate of current rise until the voltage across the gaseous discharge device has decreased to a preselected value. When this value has been reached, the reactor saturates to permit the gaseous discharge device to proceed to full conduction. When the gaseous discharge device starts to de-ionize, the resultant reverse current through the gaseous discharge device is sufficient to drive the reactor out of saturation and into a condition of high impedance. Hence most of the inverse spike voltage will appear across the reactor rather than the gaseous discharge device. The core is ultimately reset by the charging current from the direct-current source to the pulse forming network.

Accordingly, it is an object of this invention to provide a gas discharge circuit employing a saturable core device which makes possible the use of smaller and lighter gas discharge devices.

It is another object of this invention to provide a gas discharge circuit including a saturable core device which makes possible a pulse modulator having a higher pulse repetition frequency without a reduction in pulse power output.

It is another object of this invention to provide in combination with a gas discharge device a saturable core device for delaying the rise of current flow through the gas discharge device during ionization.

It is another object of this invention to provide in combination with the gas discharge device a saturable core device which delays the rise of current through the gas discharge device or gaseous discharge device during ionization until the voltage across the gaseous discharge device has decreased to a preselected value.

It is another object of this invention to provide a saturable core reactor which cooperates with a gaseous discharge device in a pulse modulator circuit in a manner to reduce power loss in the gaseous discharge devices.

It is another object of this invention to provide in combination with a gaseous discharge device an improved saturable core reactor.

The novel features which are believed to be characteristic of the invention, both as to its organization and method of operation, together with further objects and advantages thereof, will be better understood from the following description considered in connection with the accompanying drawing in which an embodiment of the invention is illustrated by way of example. It is to be expressly understood, however, that the drawing is for the purpose of illustration and description only, and is not intended as a definition of the limits of the invention.

Fig. 1 is a circuit schematic diagram of a pulse modulator embodiment of the invention;

Fig. 2 is a view of one embodiment of the saturable core reactor utilized in the circuit shown in Fig. 1; and

Figs. 3(a), 3(b), 4(a) and 4(b) are curves representing certain operating characteristics of a portion of the circuit shown in Fig. 1.

Referring now to the drawing, a schematic circuit diagram of an illustrative embodiment incorporating the device of the present invention is shown in Fig. 1. The embodiment comprises a battery 10, the negative terminal

of which is referenced to a conductor maintained at a substantially fixed potential such as, for example, ground and the positive terminal of which is connected through a charging inductor 12, a charging diode 13 and a saturable core reactor 14 to a pulse forming network 11. A connection from the pulse forming network 11 is returned through a load 15 to the conductor maintained at ground potential. The embodiment further includes a gaseous discharge device 20 including a plate 23 connected to the junction between diode 13 and saturable core reactor 14, a cathode 24 connected to the conductor maintained at ground potential and a control grid 25 which is coupled to a source of trigger pulses 21.

The charging path for a pulse forming network of the pulse modulator shown in Fig. 1 includes the charging inductance 12, the charging diode 13, the saturable core reactor 14, and the load 15. The pulse forming network is a conventional lumped constant transmission line, such as shown and discussed on page 375, et seq. of volume 1 of the M.I.T. Radiation Laboratories Series, published by McGraw Hill Book Co., Inc. of New York. The construction of the reactor 14, shown in more detail in Fig. 2, comprises a toroidal core 16 of magnetic material, about which a pair of windings 17 and 18 are wound about opposite halves of the toroidal core 16 in a manner to provide additive magnetic fields. The type of material used for core 16 is not critical, the main requirement being that it have low loss characteristics, such as cores composed of ferrites, and that it saturate at a predetermined value of working current. Tests on various designs of the reactor 14 have shown that ferrites with a high volume resistance make the best material for the core 16. A ferrite of this type is available commercially under the trade name, "Ferramic G." On the other hand, material known commercially as "Delta Max" or "Permalloy" may be used for core 16 if the laminations are sufficiently thin to limit the flow of eddy currents. This would require laminations of the order of 0.05 mil. thick. Further, the fact that the hysteresis loop of the ferrites is not rectangular is not considered detrimental to their use in the device of the present invention.

Windings 17 and 18 are connected in parallel to provide means for conducting the heavier current flow normally associated with pulse modulators. The input and output connections of windings 17 and 18 are disposed at diametrically opposite points along toroidal core 16 thereby to minimize cross-capacitance and allow the reactor to withstand a higher voltage across the windings.

The discharge path for pulse forming network 11 in the illustrated embodiment includes gaseous discharge device 20, load 15, and saturable core reactor 14.

In operation, pulse forming network 11 is charged from battery 10 through charging inductance 12, diode 13, saturable core reactor 14, and load 15. It is discharged when a trigger pulse from source 21 is impressed on the grid 25 of gaseous discharge device 20 to initiate ionization of the gas, generally hydrogen, therein.

Fig. 3(a) illustrates the voltage-current-time and Fig. 4(a) the power-time relationship of the gaseous discharge device during ionization. During ionization the voltage decreases from a maximum to minimum, whereas the current increases from substantially zero to maximum current flow. Curves 30 and 31, shown in Fig. 3(a), illustrate the voltage-current time relationship, respectively, without any current retarding device connected to the gaseous discharge device, and curve 32, shown in Fig. 4(a), indicates the power loss which occurs therein under this condition. Curves 30 and 35 illustrate the comparative voltage-current time relationship when an air-core inductor is coupled to the gaseous discharge device, and curve 36 indicates the comparative power loss which occurs therein under this condition. Curves 38 and 39 illustrate the comparative voltage-current time relationship when saturable core reactor 14 of the present invention is coupled to the gaseous discharge device, and curve

40 indicates the comparative power dissipated in the gaseous discharge device under this condition.

Figs. 3(b) and 4(b) illustrate the voltage-time and power-time relationship in the gaseous discharge device during de-ionization. Curve 41 indicates the amplitude of inverse spike voltage when no voltage supporting device is connected to the gaseous discharge device, and curve 42 is representative of the power loss occurring therein under this condition. Curve 44 indicates the amplitude of the inverse spike voltage and curve 45 represents the power loss therein when an air-core transformer is associated with the gaseous discharge device. Curve 47 indicates the amplitude of the inverse spike voltage and curve 48 represents the power dissipated when a saturable core reactor is connected to a gaseous discharge device.

It can be readily seen from Figs. 3(a) and 4(a) that without some sort of a current retarding device, large power losses occur in the gaseous discharge device during ionization because the current has risen to a relatively high value before the voltage has had time to decrease to a relatively low value. The insertion of an air-core inductor, while decreasing the ionization loss, has increased ionization time and also increased the amplitude of the inverse spike voltage appearing across the gaseous discharge device during de-ionization, which increases the de-ionization power loss. The insertion of a saturable core reactor 14 not only substantially decreases the ionization power loss, but further causes a decrease in de-ionization power loss. Ionization time is also reduced in comparison to when the air-core inductor was employed.

Saturable core reactor 14 reduces ionization power loss by delaying the current rise through the gaseous discharge device for a preselected time after ionization begins, and thereafter saturates, thereby causing the impedance of windings 17 and 18 to drop to substantially zero, which enables the discharge current to rapidly increase to its maximum value. As shown by curves 38 and 39, this delay allows the voltage to decrease to a low amplitude prior to maximum current flow, resulting in a substantial reduction in ionization power loss due to load current, as shown by curve 40.

After the pulse forming network has discharged through the load, gaseous discharge device 20 commences to de-ionize which causes current to flow through windings 17 and 18 in the opposite direction than when gaseous discharge device 20 was ionizing. Core 16 is now being driven out of saturation which causes windings 17 and 18 to appear as a high impedance in the circuit. Since the reactor impedance is very much higher than the impedance of the gaseous discharge device, most of the inverse spike voltage will appear across the reactor rather than the gaseous discharge device during de-ionization, as shown by curve 47, thereby substantially reducing de-ionization power loss in the gaseous discharge device, as shown by curve 48. After de-ionization has been completed, core 16 continues to be reset by the flow of charging current from battery 10 to the pulse forming network 11.

What is claimed is:

1. Apparatus comprising a pulse forming network having first and second terminals; a load device connected between said first terminal of said pulse forming network and a conductor maintained at a substantially fixed potential; means coupled to said second terminal of said pulse forming network for charging said network to a predetermined potential with respect to said substantially fixed potential; a discharge device containing an ionizable gas connected between said second terminal of said pulse forming network and said conductor whereby said predetermined potential is applied thereacross; means coupled to said discharge device for ionizing said gas, thereby rendering said discharge device conductive whereby said predetermined potential across said discharge device progressively decreases to substantially zero and current

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flow therethrough from said pulse forming network progressively increases to a predetermined maximum value; and a reactor interposed between said discharge device and said pulse forming network, said reactor having a saturable core adapted to saturate when the current flow through said reactor is still less than said predetermined maximum value.

2. The apparatus as defined in claim 1 wherein said saturable core is composed of a ferrite material.

3. The apparatus as defined in claim 1 wherein said reactor comprises a saturable toroidal core element, first and second windings wound over substantially opposite halves of said core element, adjacent extremities of said first and second windings being connected together to provide an input terminal and an output terminal for said reactor with minimum capacitance therebetween, said first and second windings also being disposed around said toroidal core to produce magnetomotive forces of the same direction therearound.

4. Apparatus comprising a pulse forming network having first and second terminals; a load device connected between said first terminal of said pulse forming network and a conductor maintained at a reference potential; charging means coupled to said second terminal of said pulse forming network and including a source of potential referenced to said conductor, a charging inductor and

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a diode for charging said pulse forming network to a predetermined potential relative to said reference potential; a gaseous discharge device connected from said second terminal of said pulse forming network to said conductor whereby said predetermined potential appears thereacross; means coupled to said gaseous discharge device for periodically rendering said discharge device conductive whereby said predetermined potential thereacross progressively decreases to substantially zero and current flow therethrough from said pulse forming network progressively increases to a predetermined maximum value; a reactor interposed serially between said second terminal of said pulse forming network and both said charging means and said gaseous discharge device, said reactor having a saturable core adapted to saturate when the current flow through said reactor is still less than said predetermined maximum value.

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