Feb. 13, 1962 W. S. MACDONALD ETAL 3,020,843

HIGH GAIN SIGNAL AMPLIFYING DEVICE ADAPTED FOR USE WITH A MARINE MINE

Filed June 4, 1942 5 Sheets-Sheet 1

FIG. 1.

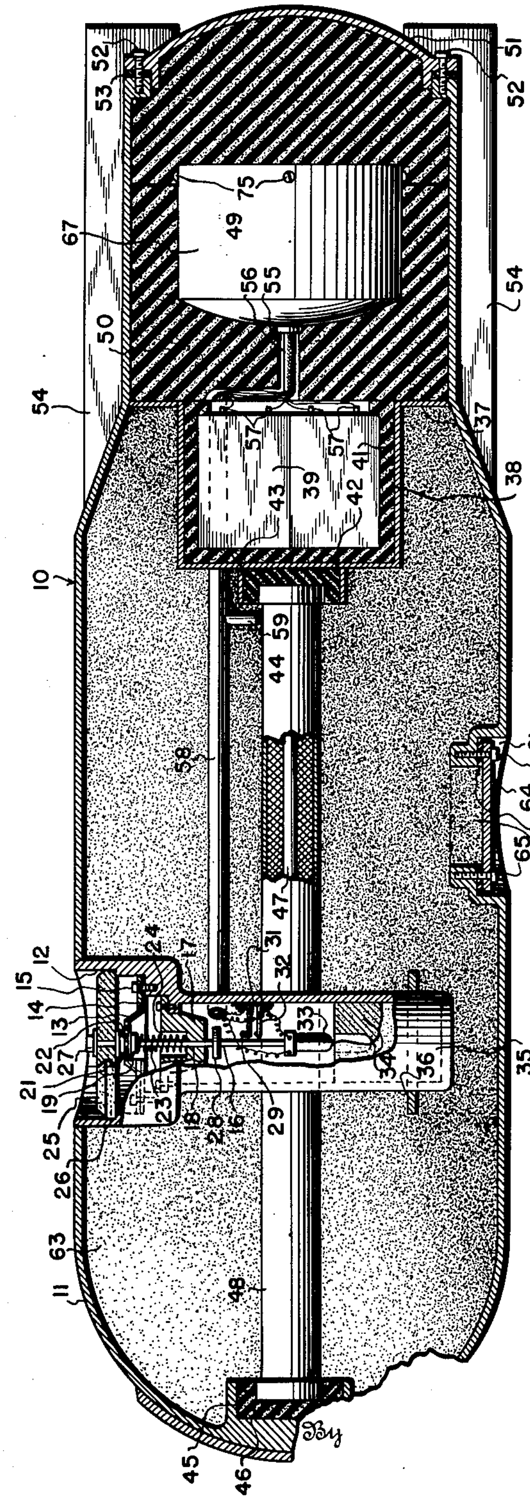

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FIG. 2.

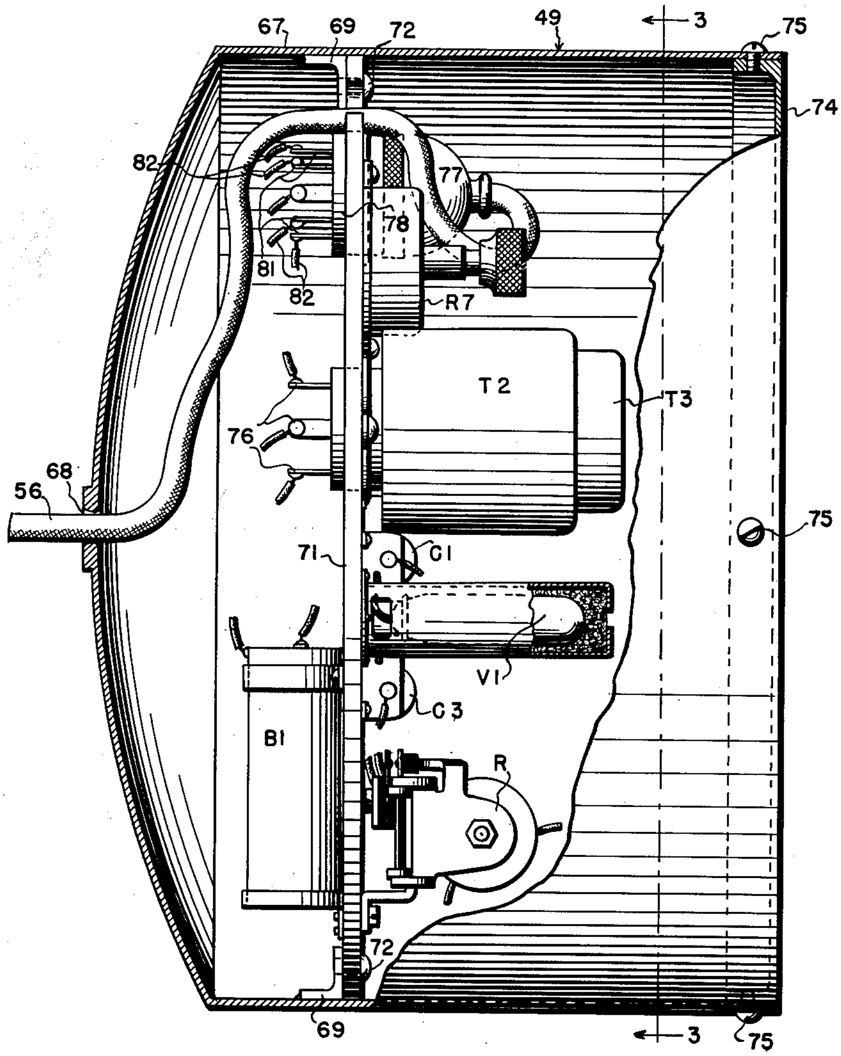

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FIG. 3.

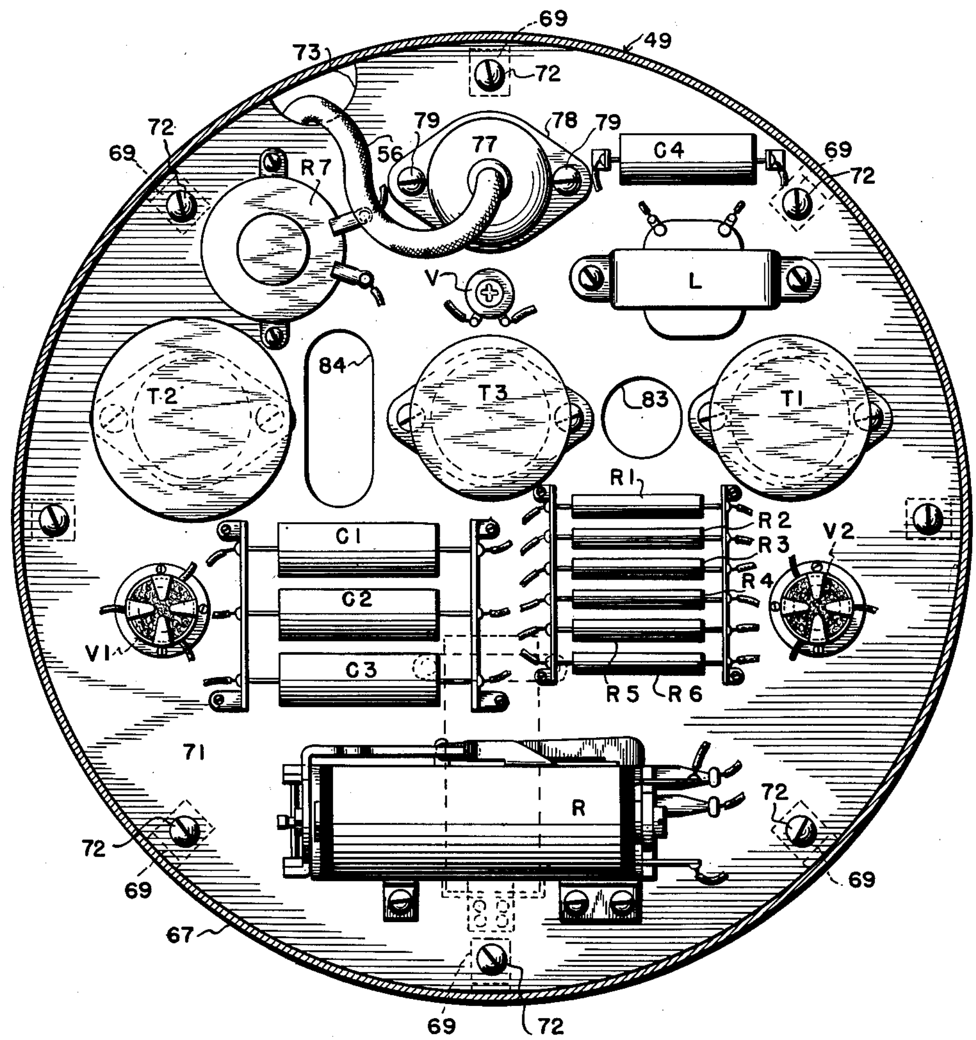

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FIG. 4.

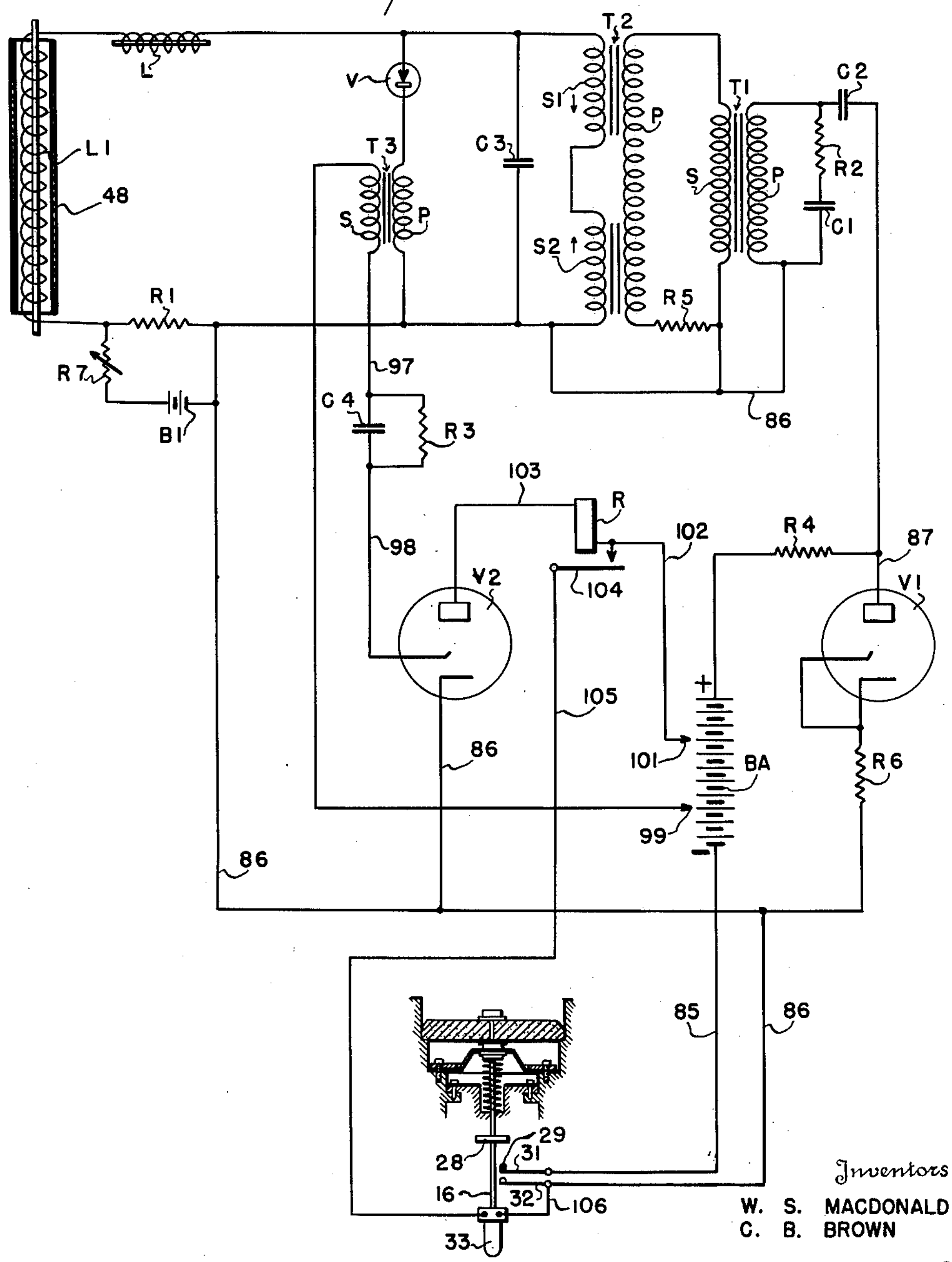

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Fig. 6.

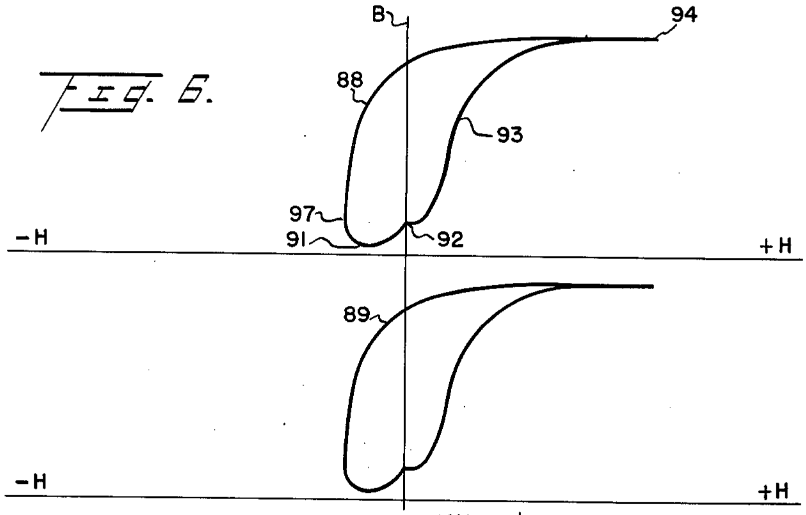


Fig. 7.

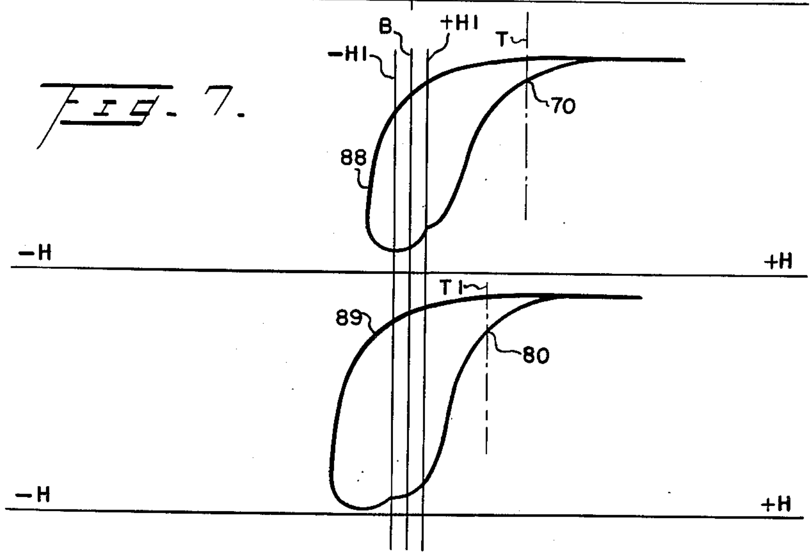
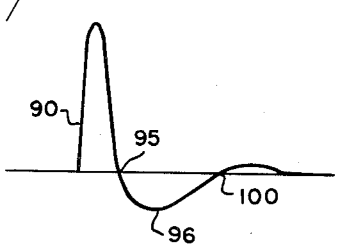


Fig. 8.



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3,020,843
HIGH GAIN SIGNAL AMPLIFYING DEVICE ADAPTED FOR USE WITH A MARINE MINE

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16 Claims. (Cl. 102—18)
(Granted under Title 35, U.S. Code (1952), sec. 266)

This invention relates to firing control devices for submarine mines in which low frequency changes and electrical currents generated by a detecting device are amplified into relatively large voltage changes which are employed to control a voltage sensitive device and fire the mine. More specifically, the invention relates to a new and improved high gain signal amplifying device adapted to respond to a relatively weak input signal of low frequency applied thereto in which the input signal is amplified to cause a relatively large change in the output signal of the amplifier sufficient to fire a grid controlled gaseous discharge tube and thereby operate a firing relay, the operation of the firing relay causing an electro-responsive detonating device to operate and fire the mine.

In devices heretofore proposed for firing a submarine mine in response to a change in the electro-magnetic field adjacent thereto, the signal employed for detecting the presence of a vessel by a change in the earth's magnetic field brought about by the approach of the vessel within the vicinity of the device, is applied to a conventional or well known form of signal amplifier and the amplified signal is employed to operate a relay and fire the mine in response to a predetermined change in the input signal to the amplifier received from the signal detecting device. Such devices are not altogether satisfactory in service for the reason that the change in the earth's magnetic field caused by the movement of a vessel within the vicinity of the device may be relatively small as the result of certain demagnetizing operations which have been performed on the vessel to offset the magnetic influence thereof on the magnetic field of the earth, this demagnetizing process being hereinafter referred to as degaussing, and for this reason the weak electrical signal generated by the detecting device may be insufficient to cause the mine to explode. Furthermore, certain types of mines are adapted to be laid on the bed of a body of water and in cases where the water is particularly deep, the mines are necessarily disposed at a considerable distance from the vessel at all times including the time of passage of the vessel above the mine. In the event that the vessel should be degaussed, the passage of such a vessel above a mine planted at a considerable depth within the water, with the types of mine firing control devices heretofore proposed, would fail to cause the mine to fire and the vessel would, therefore, pass safely through a field of such mines by reason of the relatively weak signals received from the vessel.

In the system of the present invention, a new and improved high gain signal amplifying device is employed in which relatively weak signals received from a vessel are amplified sufficiently to cause the mine to fire by reason of the novel arrangement of circuits and instrumentalities employed in the signal amplifying mechanism.

The signal amplifying device of the present invention comprises a relaxation circuit in which a cold cathode tube hereinafter referred to as a relaxation oscillator tube is alternately lighted and extinguished at a relatively low frequency such, for example, as one cycle of operation a second. The plate circuit of the relaxation oscillator tube is in operative connection with the primary winding of a transformer having the secondary winding thereof connected to a saturation transformer. The saturation transformer is preferably provided with a single primary winding arranged about a pair of magnetically balanced toroidal cores composed of magnetic material suitable for the purpose such, for example, as a material known in the art as 4–79 Molly Permalloy having a composition of 4% molybdenum, 79% nickel and 17% iron. The secondary windings of the saturation transformer are electrically balanced and disposed about each of the magnetic cores thereof respectively, the windings being opposedly connected in series to the terminals of a pickup induction coil or pair of magnetometer coils, as the case may be. As the cores of these transformers are balanced and magnetically saturated during each cycle of operations of the aforesaid relaxation circuit, the combined output voltage of the two secondary windings of the saturation transformer is low with respect to the voltage generated by either of the secondary windings when no change in the external magnetic field is detected by the pickup coil.

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When the external magnetic field is changed sufficiently to cause an electromagnetic signal to be received from the pickup coil, the phase and magnitude of the voltages generated by each of the secondary windings of the saturation transformer is shifted relative to the voltage generated by the other of the secondary windings sufficiently to cause a flow of current in the primary winding of a coupling transformer operatively connected to the secondary windings of the saturation transformer. A voltage is thereby generated in the secondary winding of the coupling transformer sufficient to fire a cold cathode tube having a relay in the plate circuit thereof. When this occurs the relay operates thereby closing a circuit from a source of potential to an electroresponsive detonator and causing the detonator to fire an explosive charge and explode the mine. The specific manner in which this is accomplished will be more clearly apparent as the description proceeds.

One of the objects of the present invention is the provision of a new and improved high gain amplifier for firing a mine in response to relatively weak signals of low frequency applied to the input thereof.

Another of the objects is the provision of a mine firing control mechanism having a saturation type transformer periodically saturated at a predetermined frequency in which signals received from a detecting device are caused to shift the phase relation of the secondary currents generated by the transformer sufficiently to operate a voltage sensitive device and thereby explode the mine in response to relatively weak signals received by the signal detecting device.

Another object is to provide a new and improved high gain amplifier for firing a mine in which the input thereof is continuously employed to detect small changes in the magnetic field adjacent thereto and in which the amplifier is maintanied continuously active with a minute consumption of electrical power.

A further object is the provision of a sensitive mine firing control mechanism adapted to fire the mine in response to relatively weak signals received from a vessel which is economical to manufacture, reliable in operation and which possesses all of the advantages of ruggedness, reliability and economy in the consumption of electrical power.

Still other objects, advantages and improvements will become apparent from the following description taken in connection with the accompanying drawings of which:

FIG. 1 is a view in section partly broken away of a submarine mine in accordance with the present invention;

FIG. 2 is a greatly enlarged view partly in section and partly broken away of the signal amplifying device employed for controlling the firing of the mine of FIG. 1;

FIG. 3 is a view of the signal amplifying control device taken substantially along the line 3—3 of FIG. 2;

FIG. 4 illustrates in diagrammatic form the complete system in accordance with a preferred embodiment of the invention;

FIG. 5 shows in diagrammatic form the exciting current flowing in the primary winding of the saturation transformer;

FIG. 6 shows in diagrammatic form the hysteretic loops of the cores of the saturation transformer when no signal is received from the pickup device connected to the secondary windings thereof; and,

FIG. 7 shows in diagrammatic form the variation in the hysteretic loops of the cores of the saturation transformer in response to a relatively weak signal received from the pickup device.

Referring now to the drawings in which like numerals of reference are employed to designate like parts throughout the several views and more particularly to FIG. 1 thereof, there is shown thereon a submarine mine indicated generally by the numeral **10** comprising a casing **11** having a recessed portion **12** therein within which is arranged a flexible diaphragm **13** secured thereto as by the retaining ring **14** and bolts **15**. The flexible diaphragm is connected at the central portion thereof to a shaft or plunger **16** slideably supported by the guide member **17** as at **18**, the shaft **16** being provided with a shoulder **19** and washer **21** to which the flexible diaphragm is secured as by the nut **22**. The shaft **16** is urged outward by a helical spring **23** arranged within a recessed portion **24** of the guide member **17** in abutting relation with the shoulder **19**. There is also provided a soluble washer **25** in engagement with a shoulder **26** within the recessed portion **12** and secured to the shaft **16** by the nut **27** threaded thereon, a pair of suitable washers being disposed preferably between the soluble washer **25** and the nuts **22** and **27** respectively thereby to prevent movement of the shaft **16** inwardly until the soluble washer has dissolved. The soluble washer is composed of any material suitable for the purpose such, for example, as a composition of salt, glycerine, glue and the like in which the washer is adapted to be softened and dissolved when a predetermined period of time has elapsed after the washer has been brought into contact with the surrounding water. The shaft **16** is also provided with a collar **28** secured thereto and adapted to engage an insulating member **29** and move the contact spring **31** into engagement with the contact spring **32**, the contact springs **31** and **32** being preferably insulated from the casing of the mine. The shaft **16** also supports a detonating device **33** and causes the detonating device to be moved as the hydrostat operates into operative engagement with a booster charge **34** arranged within the lower portion of the well **35**, the well **35** being preferably braced to the mine casing as by the support **36**.

There is also provided within the mine case a partition **37** to which is secured a chamber **38** having a plurality of batteries **39** therein for supplying the electrical energy required for the operation of the mine firing control mechanism. The batteries **39** are preferably disposed within a suitable pad or cushion **41** of yieldable material such, for example, as rubber, felt or the like thereby to prevent injury to the batteries or mine casing as the mine is launched. The chamber **38** has secured thereto a well **42** within which is arranged a yieldable cup-like member **43** adapted to support one end of the induction pickup coil **44**, the other end of the pickup coil being yieldably supported within the well **45** of the mine casing as by the resilient bushing **46**, the members **43** and **46** being preferably of rubber or a synthetic variety thereof. The pickup coil **44** is enclosed within a metallic sleeve **48** and comprises a large number of turns of wire wound about a magnetic core or rod of iron or other material known in the art as Permalloy having a composition of substantially 78½ percent nickel and 21½ percent iron.

The mine firing mechanism comprises a signal amplifying device indicated generally by the numeral **49** arranged preferably within a suitable resilient cushion or pad **50** fitted within the mine case in abutting relation with the partition **37** and sealed therein by the cap **51** and bolts **52**, a gasket **53** preferably being arranged between the cap and the mine casing to insure a water-tight joint therebetween. A plurality of fins **54** secured to the mine casing **11** in any suitable manner are employed to direct and steer the mine during the launching thereof within a body of water. The pad **50** is preferably composed of rubber or any synthetic variety thereof and provided with an aperture **55** therein within which is arranged the electrical cable **56** for establishing an external electrical connection to the amplifying device **49**. Certain of the conductors within the cable **56** are connected to the terminals **57** of the battery **39** and others of the conductors within the cable are continued by way of the tube or cable duct **58** to the detonator **33** and contact springs **31** and **32** of the hydrostat switch mechanism, still others of the cable conductors are connected to the pickup coil **44** by way of the branch **59** of the cable duct **58**.

Whereas on FIG. 1 there is shown an amplifying device **49** encased within a mass of yieldable material such as the cushion or pad **50**, it will be understood that, if desired, the yieldable pad **50** may be omitted and the amplifying device may be directly connected to the casing **11** of the mine in any well known manner as by suitable brackets or the like secured thereto for the reason that the amplifying device is sufficiently rugged to withstand the shock or impact of the mine against the water as the mine is planted or any shocks which may be received as a result of manufacture, handling and transportation of the mine prior to the launching thereof. Also, the battery **39** may, if desired, be clamped or fitted within the chamber **38** without employing a pad or cushion **41** therebetween. There is also provided within the casing **11** a recessed portion **61** having an aperture **62** therein by means of which an explosive charge **63** is introduced within the casing of the mine. The aperture **62** is adapted to be sealed by a cover **64** secured thereto by the bolts **65**, a suitable gasket **66** being provided between the cover and the casing of the mine to prevent the seepage or leakage of water therebetween.

The amplifying device employed with the present invention may conveniently comprise a casing **67**, FIG. 2, having an aperture **68** therein within which is disposed the cable **56**, the casing being provided with a plurality of brackets **69** secured thereto in any well known manner as by brazing the parts together. The brackets **69** are adapted to support a base plate **71** secured thereto as by the screws **72**, the base plate being of suitable shape to fit within the casing **67** and having a recessed portion **73** therein within which the cable **56** is arranged. There is also provided a cover **74** secured to the casing **67** as by the screws **75** thereby to enclose the amplifying mechanism and prevent injury or damage to the same.

On the base plate **71** are arranged a plurality of transformers designated T1, T2 and T3, the transformers being provided with a plurality of terminals **76** for establishing a circuit connection thereto. There is also provided a pair of cold cathode tubes V1 and V2 of which the tube V1 is employed to excite the transformers T1 and T2 periodically at a predetermined frequency and the tube V2 is employed to operate the firing relay R when the voltage generated by the transformer T3 in response to a change in the voltage generated by the secondary windings of the transformer T2 has reached a predetermined value. The amplifying structure also comprises a plurality of resistance units R1, R2, R3, R4, R5 and R6. There are also provided a plurality of condensers C1, C2, C3 and C4, and an inductance or choke coil L, a variable resistor R7, a varistor V of any suitable type such, for example, as a copper oxide rectifier, and a source of electrical energy, such as the battery B1. The cable **56** has a plurality of electrical conductors therein terminating on a multi-prong plug **77** adapted to be inserted within a jack **78** secured to the base plate **71** as by the screws **79**, the jack being provided with a plurality of terminals **81** for establishing an electrical connection between the cable conductors and the various electrical devices comprising the high gain amplifying mechanism as by the conductors **82** secured thereto.

The plate **71** is provided with a plurality of apertures **83** and **84** within which the various conductors required for establishing a circuit connection between the electrical terminals of the various amplifying and control devices arranged on opposite sides of the plate **71** are disposed thereby providing an arrangement in which the electrical conductors required for establishing a circuit connection between the various amplifying and control units are arranged within the confines of the plate **71** thereby to facilitate the assembly of the plate and the devices secured thereto within the casing **67** without the possibility of any of the conductors coming into contact with the casing. The base plate **71** is composed of any material suitable for the purpose such, for example, as brass or a phenolplastic material, each of the apertures within the plate having the corners thereof preferably rounded to prevent damage to the conductors arranged therein.

Referring now to FIG. 4 of the drawings on which is shown in diagrammatic form the entire system, the induction pickup coil L1, it will be noted, is connected in series with an inductance or choke coil L, the secondary windings S1 and S2 of the saturation transformer T2 in series opposition, and the resistance R1. In parallel with the windings S1 and S2 of transformer T2 is connected a condenser C3 and in parallel with the condenser C3 is connected the varistor V and primary of the transformer T3 in series. The transformer T2 is energized by excitation of a common primary winding P thereof connected to the secondary winding S of the transformer T1, the circuit including a resistance R5. The primary of the transformer T1 is connected in parallel with a condenser C1, and resistance R2 in series and has applied thereto from the condenser C2 a pulsating current from the relaxation circuit including the cold cathode tube V1.

The resistance R1 is shunted by the battery B1 and variable resistor R7 in series. The secondary winding S of transformer T3 is connected at one end thereof to a source of positive potential at battery BA and at the other end thereof by way of condenser C4 and resistance R3 in parallel to the grid of the cold cathode tube V2. The plate of the tube V2 is connected in series with the winding of the firing relay R and thence to a source of positive potential at the battery BA. From the foregoing it will be noted that the battery BA is employed to supply the bias voltage for the tube V2 in series with the secondary winding of transformer T3, the plate voltage for the tube V2 in series with the winding of relay R, and the voltage required for the successive operation of the tube V1, the circuit therefor including resistance R4.

From the foregoing it will be noted that the relaxation circuit supplies pulsating current periodically to the primary of transformer T1 in which the induced alternating current in the secondary winding S thereof is employed for energizing the primary winding P of the transformer T2. The wave shape of the alternating current of the transformer T2 is such that the transformer T2 is operated on one side of the BH curve of the cores thereof, FIGS. 6 and 7, the degree of magnetization being preferably such that the transformer cores are driven into the saturation region of the BH curve during each cycle of operation of the relaxation oscillator.

The secondary windings S1 and S2 of transformer T2, it will be recalled, are connected in series opposition, the transformer being balanced both electrically and magnetically to a high degree of coincidence within the limits of commercial manufacture and for this reason the instantaneous voltage generated by each of the windings S1 and S2 is substantially equal and opposite in character and therefore the combined voltage generated by these two secondary windings is low at all times with respect to the voltage generated by either of the secondary windings when no current is generated by the induction pickup coil L1 as the result of changing conditions in the magnetic field adjacent thereto.

This condition may best be understood by reference to FIG. 6 of the drawings on which is shown in diagrammatic form by the curves **88** and **89** respectively the hysteretic loops of the pair of cores of the transformer T2 respectively during successive cycles of operations of the relaxation circuit as the tube VI is fired and extinguished in succession. The magnetizing force B applied to the cores of the transformer T2 by the primary winding P thereof is predominantly of one polarity for the reason that the voltage applied thereto by the transformer T1 is of a considerably greater order of magnitude on that half of the alternating current wave form corresponding to the discharge of condenser C2 by the firing of the relaxation oscillator tube VI than during the succeeding half cycle of the wave form when the condenser C2 is charged to the firing potential of the tube VI during the time that the tube VI is extinguished. This may be readily understood by consideration of the limitation in the charging current of the condenser C2 by reason of the high resistance of the resistor R4 in contradistinction to the relatively rapid discharge of the condenser C2 when the tube V1 fires. For this reason the hysteretic loops **88** and **89** of the cores associated with the secondary windings S1 and S2 respectively of the transformer T2 are disposed entirely above the horizontal line H according to different values of magnetizing force applied thereto. The curve **88**, it will be noted, is nearest to the line H at **91** when the magnetizing force is at a substantial negative value. The current induced in the secondary winding S1 of the transformer T2 corresponding to the discharge of the condenser C2 causes the magnetization of the associated core of the transformer T2 to be increased, the magnetization curve crossing the vertical line B at the point **92** thereof and thereafter increasing along the curved portion **93** of the hysteretic loop **88** until the point **94** thereof is reached, at which time the core is magnetically saturated. The discharge current from the condenser C2 in the relaxation circuit is decreased to zero along the curve **90** illustrated in FIG. 5, of which the numeral 95 is employed to designate the time when the condenser C2 is at the end of its discharge cycle and for the reason that this discharge current is caused to flow through the primary winding P of transformer T1 and the associated networks comprising resistance R2, condenser C1 and the resistance R4, the current through the primary winding P of the transformer T2 is reduced to zero and thereafter increased to a predetermined negative value at the point **96** of the curve **90**. This changes the magnetization of the hysteretic loop **88**, FIG. 6, at the point **97** thereof corresponding to the point **100** of the curve **90** whereupon this discharge current subsides until the point **92** of the curve **88** is reached at which point the magnetization of the core remains substantially unchanged during the succeeding charging operation of the condenser C2. As the relaxation oscillator tube V1 is extinguished, the condenser C2 is again charged to a positive potential by current from the battery BA over a circuit including the high resistance R4.

The curve **89** corresponding to the core of the transformer T2 associated with the secondary winding S2 thereof is substantially identical with the curve **88** when no current is induced in the induction pickup coil L1 by a change in the magnetic field adjacent thereto, the instantaneous magnetic values of the pair of magnetically balanced cores of the transformer T2 being in phase at all times and the instantaneous voltages generated in the secondary windings S1 and S2 of the transformer T2 being substantially equal and opposite in character.

The operation of the system will now be described. Let it be assumed, by way of example, that the mine of FIG. 1 has been launched within a body of water of considerable depth for a period of time sufficiently to dissolve the soluble washer **25** and cause the hydrostat to be operated by the pressure of the water against the flexible diaphragm **13** thereof. As the shaft **16** moves inward, the detonator **33** secured thereto is moved into operative relation with respect to the booster charge **34** and the collar **28** thereon engages the insulating member **29** and causes the contact spring **31** to be moved into electrical contact with the contact spring **32**. When this occurs the negative potential of battery BA is applied to the grid and cathode of the cold cathode discharge tube V1 over the following circuit; negative terminal of battery BA, conductor **85**, contacts **31** and **32** of the hydrostat switch, conductor **86**, resistance R6 and thence to the cathode and grid of the tube V1, the circuit being continued by way of the plate of tube V1, conductor **87**, and resistance R4 to the positive terminal of battery BA. The closure of the hydrostat switch also applies negative battery by way of conductor **86** to the primary winding P of transformer T1 and condenser C1 connected in parallel thereto in a circuit including resistance R2 in series with condenser C2, the other plate of the condenser C2 being connected by way of conductor **87** and resistance R4 to the positive terminal of battery BA thereby causing the condenser C2 to be charged to a potential sufficient to fire the tube V1.

As the cold cathode tube V1 fires, the potential of the conductor **87** is greatly reduced thereby extinguishing the tube V1, the discharge circuit including resistance R6, conductor **86**, primary winding P of transformer T1 in parallel with condenser C1 and resistance R2. The resistance R4, it will be noted, is preferably high, a resistance of the order of 10 megohms having been found to be satisfactory for this purpose, thereby to prevent the accumulation of a charge on condenser C2 sufficient to raise the potential of the plate of the tube V1 to the firing point until a predetermined period of time has elapsed whereby the tube V1 is alternately fired and extinguished at a relatively low frequency of substantially one cycle of operation each second. The potential of the battery BA is preferably of the order of magnitude of 220 volts and the capacity of condenser C2 may be .1 microfarad. It will be understood, however, that various other values of voltage, resistance and capacity may be employed in combination to control the frequency of operation of the tube V1. From the foregoing it will be apparent that the tube V1 is alternately lighted and extinguished at a low frequency. It will also be understood that by employing a cold cathode type of tube and using a resistance R4 of high order of magnitude, the current drain on the battery BA required for the operation of the relaxation oscillator is negligible and the life of the battery BA is, therefore, substantially the same as the shelf life of the battery.

The resistance R1 in series with the windings S1 and S2 of the transformer T2 having the battery B1 and variable resistance R7 connected thereacross is employed to apply a weak current to the secondary windings S1 and S2 of the transformer T2 whereby the hysteretic loops corresponding to the cores of the secondary windings S1 and S2 respectively may be brought into time phase coincidence with each other in the manner illustrated on FIG. 6 when no signal is received from the pickup coil L1. An arrangement is thus provided in which the voltage generated by the secondary windings S1 and S2 of the transformer T2 may be adjusted to matched relationship thereby to compensate for small irregularities in the construction of the transformer T2. Stated somewhat differently, the employment of a source of small direct current in series with the secondary windings S1 and S2 of transformer T2 effectively counteracts any small tendency of the transformer toward residual

unbalance when no signal is received from the induction coil L1.

The pickup coil L1, it will be recalled, is arranged within a metal tube or sleeve **48**, this metal sleeve acting as a short-circuited secondary winding on the induction coil thereby reducing the impedance of the coil to substantially the resistance of the primary winding thereof. The induction or choke coil L is provided with a core of suitable magnetic material and arranged in series with the winding of the pickup coil L1 thereby to provide a high impedance circuit sufficient to prevent a substantial short-circuit of the voltage generated by the secondary windings S1 and S2 of the transformer T2 in response to an unbalance of the transformer T2 caused by current received from the pickup coil L1. The condenser C3 is employed to shift the phase of the unbalanced output voltage slightly when current is being generated by the pickup coil L1 whereby the unbalanced induced current flowing through the secondary windings S1 and S2 of the transformer T2 is more nearly in phase with the impulse current in the primary winding P thereof.

The varistor V and the primary winding P of the transformer T3 connected in series across the secondary windings S1 and S2 of transformer T2 also change the phase of the output current of the transformer T2 such that the circulating current set up in the secondary windings S1 and S2 thereof is additionally increased. The ohmic resistance of the choke coil L, it will be understood, is preferably low with respect to the inductance of the choke coil and should preferably be as low or lower than the remainder of the circuit with which it is in series to prevent the absorption of the power generated by the induction pickup coil L1 in response to a variation in the flux linkages of the pickup coil with the magnetic field adjacent thereto.

When the magnetic field adjacent the pickup coil L1 is changed, as by the approach of a vessel within the vicinity of the mine, an electromotive force is set up by the pickup coil thereby causing a circulating current to flow through the secondary windings S1 and S2 of the transformer T2 sufficient to shift the hysteretic loops of the cores thereof in opposite directions such that the voltages generated by the secondary windings S1 and S2 are out of phase with respect to each other. This condition is illustrated on FIG. 7 in which the curve **88** thereof corresponding to the hysteretic loop of the core associated with the secondary winding S2 is shifted to the right by the amount +H1 due to the current flowing through the secondary winding S1 generated by the induction pickup coil L1, and the curve **89** is shifted to the left by an amount −H1 as a result of the aforesaid current flowing in the secondary winding S2 generated by the coil L1. The extent of the displacement of the curves **88** and **89** is proportional to the strength of current generated by the pickup coil L1 and at a time T, FIG. 7, the instantaneous permeabilities in the two cores of the transformer T2 are furthest apart due to the electromagnetic field generated by the aforementioned current flowing in the secondary windings S1 and S2. The output voltage generated by the transformer T2 is increased in proportion to the strength of current generated by the induction coil L1 and the rate of change of the magnetizing pulse generated by the relaxation oscillator.

On FIG. 7 the vertical lines T and T1 are employed to indicate generally the portions of the BH curves **88** and **89** in which the maximum rate of change of permeability occurs, this being indicated on the curve **88** at the point **70** thereof and on the curve **89** by the numeral **80**. The slope at the point **80** of the curve **89**, it will be noted, is greater than the slope at the point **70** on the curve **88** and therefore a higher voltage is generated by the secondary winding S2 when this portion of the curve **89** is traversed at the time T than is generated by the secondary winding S1 at the corresponding time T1, and for this reason the voltage generated at this time by the winding

S2 is only partially balanced by the voltage generated by the winding S1 and a resultant difference of potential appears across the terminals of condenser C3. During the remaining portion of the magnetization cycle the instantaneous permeabilities of the cores of the saturation transformer T2 are more nearly equal and therefore the unbalanced voltage generated across the terminals of condenser C3 is relatively small with respect to the voltage generated at the portion of the curve traversed at time T at the portions **70** and **80**. By operating the transformer T2 over approximately one-half only of the hysteretic loops of the cores, it is possible to obtain a high degree of secondary voltage balance during the time that no signal is generated by the induction coil L1. This enables the amplifier to be used to amplify weaker signals than when a greater unbalanced condition exists as fluctuations in the residual unbalanced voltage of the transformer T2 generated in the relaxation oscillator have been found to override the signal, thus as the degree of balance between the two hysteretic curves **88** and **89** is increased, the amplifier is adapted to amplify weaker signals received from the pickup coil L1. This out of phase condition causes a current to flow in the primary winding P of the transformer T3 in series with the varistor V thereby causing an induced voltage to be generated by the secondary winding S thereof of greatly increased magnitude by reason of the fact that the transformer T3 is preferably of the type known in the art as a step-up transformer in which the secondary winding S comprises a large number of turns of wire greatly in excess of the number of turns of wire composing the primary winding P thereof. This induced voltage appearing at the secondary winding S of transformer T3 is applied by way of conductor **97**, resistance R3 and condenser C4 in parallel, and conductor **98** to the grid of the cold cathode tube V2 thereby increasing the voltage applied to the grid of the tube by the battery BA at point **99** thereof. When the potential of the grid of the tube V2 has increased to a predetermined value, the tube V2 is fired thereby closing a circuit from positive potential at point **101** of battery BA, conductor **102**, winding of relay R, conductor **103** to the plate of the tube V2 from whence the circuit is continued by way of the cathode thereof, conductor **86**, contact springs **32** and **31** of the hydrostat switch, conductor **85** and thence to the negative pole of battery BA, thereby causing relay R to operate.

As armature **104** of relay R moves into engagement with its make contact a circuit is closed from positive terminal **101** of battery BA, conductor **102**, make contact and armature **104** of relay R, conductor **105**, detonator **33**, conductor **106**, contact springs **32** and **31** of the hydrostat switch, conductor **85** and thence to the negative pole of battery BA thereby causing the detonator to operate and fire the mine.

The condenser C4 and bridging resistance R3 are employed for operating the tube V2 above the normal sustaining voltage of the grid to the cathode arc thereof. This circuit, it will be readily understood, forms a small relaxation oscillator adapted to extinguish the grid cathode arc within the tube V2 in the event that the arc had been started thereby providing an arrangement in which the multiple operation of the tube V2 and relay R occurs within a region which might otherwise be unstable and in which the firing of the tube V2 is accomplished by less voltage than would otherwise be required.

The degree of unbalance of the magnetization curves of the cores associated with the secondary windings S1 and S2 respectively of transformer T2 is proportional to the current generated by the induction pickup coil L1 and the induced currents within each of the windings S1 and S2 which, as will be recalled, are connected in series opposition, are displaced in time phase relationship with respect to each other such that the resultant alternating output voltage generated by the secondary windings S1 and S2 is proportional to the current received from the pickup coil L1. The balancing circuit comprising the battery B1 and variable resistor R7 in parallel with the resistance R1 is adjusted by varying the resistance R7 until a minimum of unbalanced voltage occurs in the secondary circuit of transformer T2. This unbalanced voltage may be measured by connecting a cathode ray oscilloscope across the terminals of condenser C3 or, if desired, across the secondary winding S of the transformer T3.

Briefly stated in summary, this invention contemplates the provision of new and improved signal amplifying mechanism suitable for use in controlling the firing of a submarine mine in response to relatively small changes in the magnetic field adjacent thereto in which the balance of a saturation type transformer having electrical impulses periodically applied thereto is shifted variably in accordance with the signals received from a magnetic field detection device thereby to cause a normally inactive gaseous discharge tube to be activated and operate an electro-responsive device by means of which the mine is caused to fire. Whereas in the illustrated embodiment of the invention, the system has been described with reference to a mine firing control mechanism, it is obviously suitable for other and varied uses such, for example, as the control of the firing of depth charges within a body of water and for use in systems for directing the control of traffic and for the measurement and control of temperatures and for use in other systems where it is desired to measure or control small electrical currents.

While the invention has been described with particularity with respect to a specific example thereof which gives satisfactory results, it will be understood by those skilled in the art, after understanding the invention, that various changes and modifications may be made without departing from the invention, and it is our intention, therefore, in the appended claims to cover all such changes and modifications.

The invention herein described and claimed may be manufactured and used by or for the Government of the United States of America for governmental purposes without the payment of any royalties thereon or therefor.

What is claimed as new and described to be secured by Letters Patent of the United States is:

1. In a submarine mine adapted to be arranged on the bed of a body of water adjacent the path of travel of a vessel, the combination of detecting means for generating an electrical signal variably in accordance with changes in the magnetic field adjacent the mine, a saturable transformer having a pair of opposedly connected secondary windings in circuit with said detecting means, a pair of balanced magnetic cores respectively associated with said secondary windings, means including a cold cathode tube for magnetically saturating said cores at regular predetermined intervals of time, a connecting transformer having the primary winding thereof operatively connected to said opposedly connected secondary windings, a gaseous discharge tube having the grid element thereof operatively connected to the secondary winding of said connecting transformer, and means including an electro-responsive device operatively connected to the plate of said gaseous discharge tube for firing the mine selectively in accordance with a predetermined voltage applied to said grid element by the secondary winding of said connecting transformer.

2. A magnetic signal amplifier comprising a magnetic field detecting coil, a saturable transformer having a pair of opposedly connected secondary windings in series with the coil, a pair of balanced toroidal magnetic cores respectively arranged within said secondary windings, means for producing an asymmetrical cyclic pulse including a primary winding arranged about each of said cores and for magnetically saturating the cores periodically at predetermined intervals of time whereby the hysteresis loops generated in said cores lie substantially to one side

of the point of zero magnetic induction, means controlled by an electrical signal generated by said coil in response to a variation in the magnetic field detected thereby for shifting the phase relation in the magnetic hysteretic curves of said magnetic cores, and means for increasing the shift in said phase relation during successive magnetization cycles of the hysteretic curves while said electrical signal is being generated.

3. A signal amplifying device of the character disclosed comprising a saturable transformer having a primary winding, a pair of opposedly connected secondary windings, and a pair of balanced toroidal magnetic cores respectively arranged within said windings, a damped relaxation circuit for magnetically saturating said cores periodically at predetermined intervals of time whereby the hysteresis loops generated in said cores lie substantially to one side of the point of zero magnetic induction and including a damping oscillatory circuit operatively connected to said primary winding, voltage magnitude discriminating means operable in successive cycles connected to said damping circuit, and a condenser connected between the damping circuit and said discriminating means, detecting means adapted to generate an electrical signal variably in accordance with changes in the magnetic field adjacent thereto, means for operatively connecting said detecting means to said pair of secondary windings, means controlled by said signal detecting means for causing a relatively large phase displacement in the magnetic hysteretic curves of said magnetic cores in response to small changes in the magnetic field detected by said detecting means, and means for controlling the circulating currents in said pair of secondary windings whereby the relative displacement of said magnetic hysteretic curves is increased while said electrical signal is being generated by said detecting means.

4. In a signal amplifying device of the character disclosed, the combination of a saturable transformer having a pair of opposedly connected secondary windings, a pair of toroidal magnetic cores respectively arranged within each of said secondary windings, means for periodically saturating said cores at predetermined intervals of time whereby the hysteresis loops generated lie substantially entirely to one side of the line of zero magnetic induction, said means comprising a vacuum tube oscillator for generating cyclic pulses and a damping circuit including a condenser and resistance connected across the transformer and connecting said oscillator to said transformer for asymmetrically shaping the wave of the pulse for a gradual rise in magnitude and a rapid decay in magnitude, and means settable at will for adjusting to phase coincidence the magnetic hysteretic loops of each of said cores, said last named means comprising a source of potential and a circuit including a variable resistor connecting said potential source with said secondary windings.

5. A firing control mechanism for a marine mine arranged within a body of water adjacent the path of travel of a vessel having an explosive charge therein, means for generating an electrical signal variably in accordance with changes in the magnetic field adjacent thereto, a saturable transformer having a pair of opposedly connected secondary windings operatively connected to said signal generating means and adapted to be controlled thereby, a pair of balanced magnetic cores respectively arranged within said secondary windings, a primary winding disposed about said magnetic cores, a relaxation oscillator including a cold cathode tube for applying current impulses periodically to said primary winding sufficient to saturate said cores, a wave shaping network for controlling the output impulses from said relaxation oscillator thereby to apply to said primary winding current impulses of predetermined character, a connecting transformer operatively connected to said pair of secondary windings adapted to generate amplified signals variably in accordance with the phase displacement of the voltages generated by each of said secondary windings in response to a shift in the phase of the magnetic hysteretic curves of said cores as signals are received from said electrical signal generating means, and means including an electro-responsive device operatively connected to said connecting transformer for exploding said explosive charge when the signal received from said signal generating device has reached a predetermined degree of strength.

6. In a signal amplifier of the character disclosed, the combination of a saturable transformer having a pair of balanced toroidal magnetic cores therein, a pair of secondary windings respectively arranged about said cores and connected to one another in series opposition, signal detecting means operatively connected to said pair of secondary windings and adapted to generate an electrical current variably in accordance with the signal detected thereby, a primary winding arranged about said pair of magnetic cores, means including a damped oscillatory circuit for said primary winding and a relaxation oscillator connected thereto and adapted to operate in unit cycles for applying current impulses of predetermined character to said primary winding sufficient to saturate said magnetic cores periodically whereby the hysteresis loops generated in said cores lie substantially to one side of the point of zero magnetic induction, said damped circuit periodically reversing the direction of the current in said primary winding by a predetermined amount thereby to cause an additional portion of the magnetization curves of the magnetic cores to be traversed during each cycle of operation of said relaxation oscillator.

7. A high gain signal amplifying device of the character disclosed comprising a saturable transformer, a pair of balanced magnetic cores within said transformer, means for periodically saturating said magnetic cores, a pair of opposedly connected secondary windings respectively arranged about said magnetic cores, a circuit having means therein for applying an electrical bias to said secondary windings sufficient to adjust the magnetization of said pair of magnetic cores to substantial coincidence with each other, a coupling transformer having a variable resistance device in the primary circuit thereof connected to said secondary windings, a gaseous discharge tube having the grid element thereof operatively connected to one end of the secondary winding of said coupling transformer, means for applying a fixed bias potential to the opposite end of the secondary winding of said coupling transformer, and means for causing said gaseous discharge tube to fire when a predetermined voltage has been induced in the secondary winding of said coupling transformer in response to a predetermined current set up in the primary winding of the coupling transformer by said pair of secondary windings.

8. In a high gain signal amplifier having a pair of balanced magnetically saturable devices therein, means including a cold cathode tube for periodically saturating said devices, an output circuit comprising a pair of opposedly connected balanced windings respectively disposed about said magnetic devices, a gaseous discharge tube operatively connected to said output circuit, an input circuit operatively connected to said pair of balanced windings, a device having a winding operatively connected to said input circuit for causing a signal current to flow through said balanced windings thereby to unbalance said pair of magnetic devices variably in accordance with changes in the magnetic field adjacent thereto, and means for firing said gaseous discharge tube when said magnetic devices have been unbalanced to a predetermined degree.

9. In a mine firing mechanism of the character disclosed, the combination of a source of electrical power, a relaxation circuit comprising a cold cathode tube connected to said source of electrical power adapted to operate in unit cycles, said relaxation circuit including a condenser, a coupling transformer having the primary

winding thereof operatively connected to said condenser, a saturable transformer having the primary winding thereof in operative connection with the secondary winding of said coupling transformer, a pair of balanced magnetic cores within said saturable transformer adapted to be saturated by current impulses received from the secondary winding of said coupling transformer as the condenser discharges during each cycle of operation of said relaxation circuit, a pair of opposedly connected secondary windings respectively arranged about said magnetic cores, a pickup device operatively connected to said pair of secondary windings and adapted to apply a signal current thereto sufficient to unbalance the magnetic cores variably in accordance with changes in the magnetic field detected by said pickup device, a step-up transformer having the primary winding thereof in circuit with said pair of secondary windings, said last named circuit including a variable resistance device, an output circuit connected to the secondary winding of said step-up transformer, said output circuit including a source of fixed potential, a gaseous discharge tube having the grid element thereof operatively connected to said output circuit, and a firing relay adapted to be operated by said gaseous discharge tube when a predetermined potential is applied to the grid element thereof by said secondary winding of the step-up transformer in response to a predetermined degree of unbalance of said pair of magnetic cores.

10. In a submarine mine adapted to be arranged on the bed of a body of water adjacent the path of travel of a vessel, the combination of a pick-up coil for generating an electrical signal variably in accordance with changes in the magnetic field adjacent the mine, a saturable transformer having a pair of opposedly connected secondary windings in circuit with said pick-up coil, a pair of balanced magnetic cores respectively associated with said secondary windings, a relaxation oscillator including a cold cathode tube connected to the primary of said saturable transformer for magnetically saturating said cores at regular predetermined intervals of time, a connecting transformer, a non-linear resistance, a circuit connecting the primary of said connecting transformer and said non-linear resistance in series across said opposedly connected secondary windings, a gaseous discharge tube having the grid element thereof operatively connected to the secondary winding of said connecting transformer, a relay connected in the plate circuit of said gaseous discharge tube and adapted to be energized when a predetermined voltage is applied to said grid element by the secondary winding of said connecting transformer, a detonator, a source of potential, and a circuit connecting said detonator and said source of potential to the contacts of said relay whereby said detonator is fired when the relay is energized.

11. A firing control mechanism for a marine mine arranged within a body of water adjacent the path of travel of a vessel having an explosive charge therein, means including a pick-up coil having a core of magnetizable material for generating an electrical signal variably in accordance with changes in the magnetic field adjacent thereto, a saturable transformer having a pair of opposedly connected secondary windings operatively connected to said signal generating means and adapted to be controlled thereby, a pair of balanced magnetic cores respectively arranged within said secondary windings, a primary winding disposed about said magnetic cores, a relaxation oscillator including a cold cathode tube for applying current impulses periodically to said primary winding sufficient to saturate said cores, means including an R–C network for shaping the output impulses from said relaxation oscillator to secure a wave form having a gradual rise in amplitude and a rapid decay in amplitude, a connecting transformer, a non-linear resistance, means connecting the primary of said connecting transformer and said non-linear resistance in series across said pair of secondary windings, said connecting transformer being adapted to generate amplified signals variably in accordance with the phase displacement of the voltages generated by said secondary windings in response to a change in the magnetic hysteretic curves of said cores as signals are received from said electrical signal generating means, and means including a gaseous discharge tube and a relay operatively connected to the secondary of said connecting transformer for exploding said explosive charge when the signal received from said signal generating device has reached a predetermined value.

12. A high gain signal amplifying device comprising; a saturable transformer having a primary winding, a pair of balanced magnetic cores, and a pair of matched secondary windings connected in series opposing relationship; a second transformer having the output thereof connected to the primary of said saturable transformer; a relaxation oscillator; means connecting said relaxation oscillator to the primary of said second transformer whereby the cores of said saturable transformer are saturated periodically at the frequency of said relaxation oscillator; a coil having a magnetizable core; means connecting said coil in series with the secondary windings of said saturable transformer; a third transformer; a non-linear resistance; means connecting the primary of said third transformer and said non-linear resistance in series across the secondary windings of said saturable transformer; a vacuum tube having a cathode, grid, and anode; means connecting the secondary of said third transformer to the grid and cathode of said vacuum tube; and an output circuit connected to the anode of said vacuum tube, variations of predetermined magnitude in the magnetic field ambient to the core of said coil causing energization of the output circuit of said vacuum tube.

13. In a high gain signal amplifier having a pair of balanced magnetically saturable devices therein, means including a cold cathode tube for periodically saturating said devices; a circuit comprising a pair of opposedly connected balanced windings respectively disposed about said magnetic devices; a pick-up coil having a core of magnetic material operatively connected to said circuit for causing a signal current to flow through said balanced windings thereby to unbalance said pair of magnetic devices variably in accordance with changes in the magnetic field adjacent to said coil; a gaseous discharge tube operatively connected to said circuit; and means for firing said gaseous discharge tube when said magnetic devices have been unbalanced to a predetermined degree, said last named means including a transformer having a primary and a secondary winding, a non-linear resistance, a second circuit connecting said primary and said non-linear resistance in series across said balanced windings, and a third circuit including a source of biasing potential connecting the secondary of said transformer to said gaseous discharge tube.

14. In a high gain signal amplifier having a pair of balanced magnetically saturable devices therein, means including a relaxation oscillator for periodically saturating said devices, an output circuit comprising a pair of opposedly connected balanced windings respectively disposed about said magnetic devices, a gaseous discharge tube operatively connected to said output circuit, a second circuit including a first resistance operatively connected to said pair of balanced windings, a source of potential, means including a variable resistance connecting said source of potential to said first resistance, a pick-up coil operatively connected to said output circuit for causing a signal current to flow through said balanced windings thereby to unbalance said pair of magnetic devices variably in accordance with changes in the magnetic field adjacent to said coil, and means for firing said gaseous discharge tube when said magnetic devices have been unbalanced to a predetermined degree.

15. In a submarine mine adapted to be arranged on the bed of a body of water adjacent the path of travel of a vessel, the combination of detecting means for generat-

ing an electrical signal variably in accordance with changes in the magnetic field adjacent the mine, transformer means having a pair of secondary windings connected in series in circuit with said detecting means, a pair of magnetic cores respectively associated with said secondary windings, means for periodically saturating said cores and producing voltages of opposing polarity in said secondary windings whereby the sum of voltages is zero when no voltage is generated by said detecting means and is not zero when said detecting means is generating an electrical signal, a connecting transformer, a non-linear resistance, means connecting the primary of said connecting transformer and said non-linear resistance in series across said secondary windings, a gaseous discharge tube having the grid element thereof operatively connected to the secondary winding of said connecting transformer, and means including an electro-responsive device operatively connected to the plate of said gaseous discharge tube for firing the mine selectively in accordance with a predetermined voltage applied to said grid element by the secondary winding of said connecting transformer.

16. A firing control mechanism for a marine mine arranged within a body of water adjacent the path of travel of a moving vessel having a magnetic field, a magnetic field detecting circuit including a voltage generator for generating a voltage proportional to the rate of change of said magnetic field adjacent said detecting circuit, transformer means having a pair of secondary windings connected in series opposing relation with one another and in circuit with said detecting means, a pair of toroidal magnetic cores respectively arranged within said secondary windings, means for periodically saturating said cores and producing equal voltages of opposing polarity in said secondary windings whereby the sum of voltages is normally zero, said last named means including a cold cathode relaxation oscillator tube and a damped oscillatory circuit connected to said tube for producing and applying asymmetrical current impulses periodically to said transformer means sufficient to saturate the cores, said detecting circuit including a condenser and a non-linear resistance connected in parallel with the secondary windings for additively producing a resultant voltage across said secondary windings while said detecting means is generating a voltage, a connecting transformer operatively connected to said pair of secondary windings and adapted to generate amplified signals variably in accordance with the resultant voltage across said secondary windings, and means including an electro-responsive device operatively connected to said connecting transformer for exploding an explosive charge within the mine when the signal received from said voltage generating device has reached a predetermined value.

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