Jan. 31, 1961 F. W. HILL 2,970,247

AMPLIFIER CIRCUITS

Filed July 23, 1958

Fig. 1

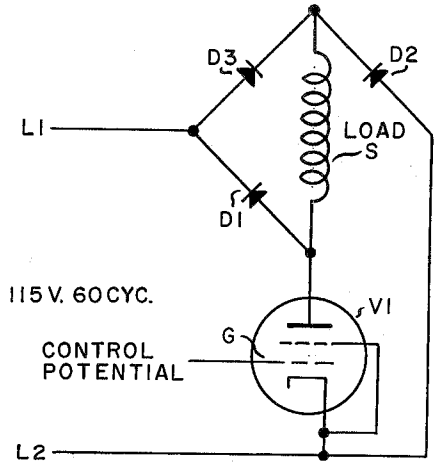
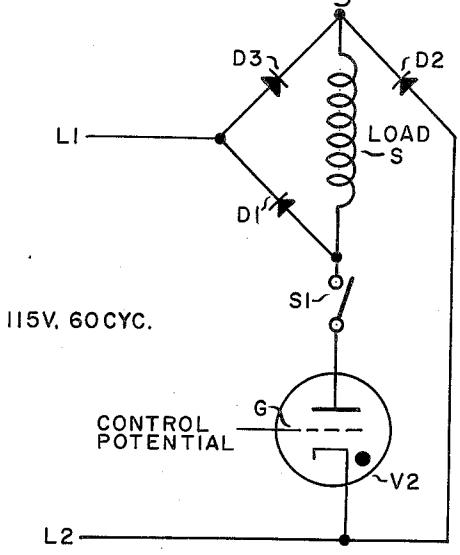


Fig. 2



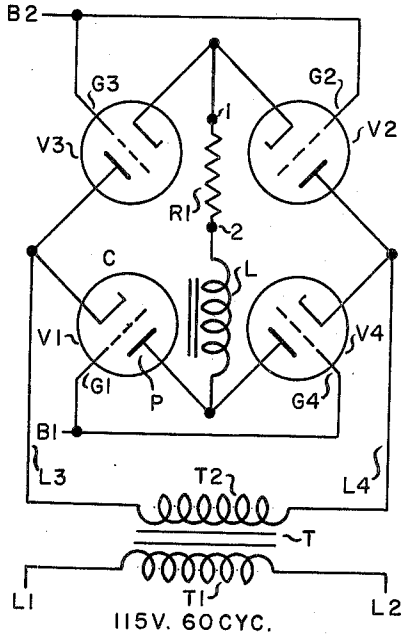


Fig. 4

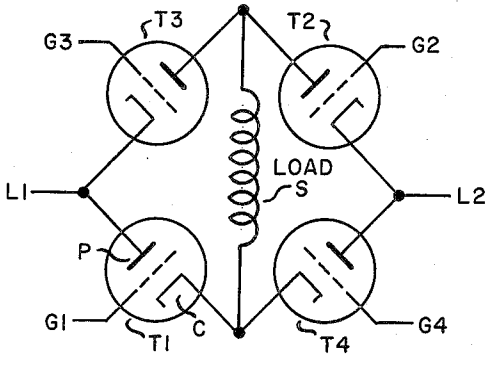


Fig. 3

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AMPLIFIER CIRCUITS

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This invention relates to improvements in electrical amplifier circuits and means for controlling the operation of a device which may draw a relatively heavy current in response to changes in a relatively weak current or voltage. The device requiring a relatively heavy current may be, for example, a motor or solenoid driven device. There are various well known ways of accomplishing this result, a common means being to pass the relatively weak current through a relay coil designed for the available current which operates contacts having sufficient current carrying capacity to control the heavy current consuming device. Another common means is to amplify the weak current through amplification circuits utilizing electron tubes.

The various means of amplification used heretofore have their limitations in one form or another. Some lack the load capacity, some lack the life range desirable, and others are excessively bulky or expensive. It is common in practice to have situations where the relay or solenoid must operate in excess of 5,000,000 operations a year.

A particular amplification problem will be used as an example but the invention is by no means limited to this one problem. Similar problems of amplification arise in many arts and fields of science and industry. The invention may be applied in many similar applications.

The application chosen as an example is the energization of a relatively heavy solenoid which steps a step switch device in a traffic signal controller. The use of a step switch has been found to be very efficient and practical during its many years of application. Its service life is in the order of 20,000,000 to 50,000,000 operations. The difficulty has been in controlling the power to the operating solenoid for this large number of operations.

A solenoid is inherently a highly inductive load which causes considerable arcing and wear on controlling contacts. Attempting to compensate for this excessive contact wear introduces mechanical difficulties in the relay. It is well recognized by those skilled in the art that a relay is the weakest member in a system called upon to make several million operations a year. My invention eliminates the relay. The parts substituted require no periodic adjustment or attention, are compact, inexpensive, and greatly increase the efficiency and reliability of the system.

In the application chosen as an example of a method in use today, the signal current or impulse to be amplified is received from a timing capacitor whose charge and potential decreases with time. The potential is applied to the grid of an electron tube. When the grid potential is reduced sufficiently, it permits the tube to conduct and energize a relay in its plate circuit. The relay in turn applies 115 volts to the load solenoid permitting it to mechanically actuate the step switch.

It is also common practice to use a current supplied by an electron tube to operate a relay with relatively heavy duty contacts which in turn operate a solenoid, a motor,

or other power unit to open and close load contacts in various combinations as desired.

In the usual application of the invention the load exceeds the capacity of the electron tube. Any suitable load may be applied to the circuit without departing from the spirit of the invention.

As noted above, a plate circuit relay has been required to switch line voltage to the solenoid load. The highly inductive nature of the solenoid load causes blackening and burning of the relay contacts after a few thousand operations and makes replacement necessary after a few years of operation. The invention eliminates the relay and permits the solenoid to be operated directly by the electron tube in conjunction with a rectifier circuit.

The novel feature of the invention is the continuous, partial energization of a load device from a low powered rectifier-amplifier circuit with full energization occurring upon signal from a control device.

Another novel feature of the invention is the energization of the load device by rectified A.C. power. A rectifier in the A.C. circuit places the rectified first half cycle of current on the load device at all times. The amount of current rectified is such that the first half cycle of current is insufficient to operate the device. When the control signal is applied the rectified second half cycle of current is applied to the load. This added half cycle of current is sufficient to actuate the device.

The full wave rectifier circuit also includes the electron tube whose grid is connected to the control circuit. This tube serves as a valve.

Although the relay is eliminated, three rectifiers are required in the present embodiment of the invention. Three silicon diodes have been chosen for this embodiment but any type of rectifier could be used. The rectifiers are much more stable, trouble-free, and economical than the relay they replace.

Tests and experience demonstrate that the circuit is a distinct improvement over prior art.

Another feature of the invention is that where the control potential varies in intensity with some phenomenon, such as a temperature to be controlled, the rectifier of the second half cycle will not operate until the control potential reaches a particular value.

Another function of the invention is to permit conversion of power from an alternating current source to direct current power for more efficient utilization. Heretofore, in the application chosen as an example, a vacuum tube supplied to the positive half cycle of an alternating current to a relay coil, and the relay in turn energized a solenoid coil with alternating line potential. In the present invention, the bridge rectifier circuit provides a rectified half cycle of current to the solenoid at all times. When the vacuum tube is allowed to conduct, it provides a path for the other half of the wave of current, causing the solenoid to fully energize. Much more force and work is available from the solenoid when it is energized with direct current than with alternating current.

In another form of the invention a second electron tube may replace one of the diodes. This permits additional control of the circuit. In like manner all of the diodes could be replaced by electron tubes yielding maximum control of the bridge rectification circuit from a plurality of control sources. The four control circuits would have to be in agreement at one time to permit the load to be fully energized.

In this description the term electron tube will be used to describe both a vacuum tube or a gas filled, thyratron type tube.

In this description, explanation of the circuits will be

made in terms of electron flow, which is opposite in direction to conventional current flow.

The principal object of this invention is to actuate a load device in response to a weak control signal wherein current insufficient to actuate said load device is continuously applied and the control signal causes additional current to be supplied from a rectifier and an amplifier.

Another object of the invention is to energize a load device from a rectified alternating current in response to a weak signal received in a rectifier-amplifier control circuit.

Another object is to actuate a solenoid with the rectified two half cycles of an alternating current using a control potential to determine when the second half cycle of the alternating current is to be rectified.

Another object is to actuate a load switch by the rectified two half cycles of alternating current using an electronic tube whose plate circuit forms part of the rectifying circuit for the second half cycle of alternating current.

Another object is to energize an electric load partially from a bridge rectification circuit and partially from an electron tube.

Another object is to partially energize an electric load continuously from one source and intermittently from a controlled source.

Another object is to provide a plurality of current control means utilizing electron tubes in more than one leg of a bridge rectification circuit.

Four forms of the invention will be described with the aid of the following figures in which like symbols identify like parts:

Figure 1 is a diagram of the rectifier-amplifier circuit using a vacuum tube in one leg of the bridge circuit.

Figure 2 is a diagram of the amplifier circuit using a gas filled tube in one leg of the bridge circuit.

Figure 3 is a diagram of a rectifier-amplifier circuit employing four electron tubes, one in each side of the bridge circuit.

Figure 4 is a diagram of an amplifier bridge circuit employing four electron tubes, two with a fixed bias and two with a variable bias.

Description

Figure 1 shows one form of the invention. Diodes D1, D2, D3 are half-wave rectifiers of any of a variety of types. Silicon diodes, number IN1084, of the type manufactured by the Sarkes Tarzian Company and having a current rating of 500 milliamperes have proven satisfactory. They are easy to mount and easy to replace. Tube V1 is a triode or tetrode vacuum tube of a very common type. A ruggedized 6005 tube manufactured by General Electric Company may be used, for example. The load S is in this embodiment a solenoid coil having a highly inductive impedance. Lines L1 and L2 have impressed on them 115 volts, 60 cycle, alternating current, but any standard or non-standard alternating potential may be used. Care should be taken not to use an input voltage higher than that for which the various components are designed. The grid G of tube V1 may have applied to it control potentials suitable to render tube V1 conductive at one time and non-conductive at another time.

The operation of the invention will be described under two conditions:

(*a*) Potential applied to grid G sufficiently negative to prevent conduction through the tube.

(*b*) Potential applied to grid G made less negative to permit conduction through the tube.

Condition (*a*). During the half cycle that negative potential is applied to line L1, the path of electron flow is through diode D1, through load S, through diode D2 to line L2. During the half cycle that negative potential is applied to line L2, electron flow is stopped because the tube V1 is not conducting. The load S is "floating" on half cycle current which is not sufficient to completely energize the coil and cause it to mechanically actuate the solenoid.

Condition (*b*). During the half cycle that negative potential is impressed on line L1, the path of electron flow is through diode D1, through load S, through diode D2 to line L2. This is the same as in condition (*a*). During the half cycle that negative potential is impressed on line L2, the path of electron flow is through tube V1, through load S, through diode D3, to line L1. The load is now fully energized and the solenoid coil is able to mechanically actuate its load. Current will flow during both halves of the alternating potential sine wave applied to lines L1, L2 and the load will remain energized as long as the control grid permits. As soon as the potential applied to the control grid G is made sufficiently negative to cause conduction to stop, the solenoid energizing current will be reduced to the point where the solenoid S drops its mechanical load.

If a thyratron type tube is used the line potential to the plate of the tube must also be removed or reduced to cause the tube to stop conducting. This case is illustrated in Figure 2.

Figure 2 shows the circuit elements arranged as in Figure 1 with the exception that a gas filled tube is used in place of a vacuum tube. A ruggedized 5727 tube manufactured by General Electric Company may be used, for example. The operation of the invention will be described under the two conditions referred to above.

Condition (*a*). With switch S1 closed and during the half cycle that negative potential is applied to line L1, the path of electron flow is through diode D1, through load S, through diode D2 to line L2. During the half cycle that negative potential is applied to line L2, current cannot flow because tube V2 is not conducting. The load S is "floating" on half cycle current which is not sufficient to completely energize the coil and cause it to pull in the armature.

Condition (*b*). During the half cycle that negative potential is impressed on line L1, the path of electron flow is through diode D1, through load S, through diode D2 to line L2. This is the same as in condition (*a*). During the half cycle that negative potential is impressed on line L2, the path of electron flow is through tube V2, through closed switch S1, through load S, through diode D3 to line L1, because tube V2 has been made conducting under condition *b*. The load is now fully energized and the solenoid coil is able to mechanically actuate its load. Current will flow during both halves of the A.C. sine wave applied to lines L1, L2 and the load will remain energized as long as the thyratron permits.

Thyratron tube V2 is made conducting by a combination of two potentials: a less negative control potential and a positive plate potential. Conversely, tube conduction can be stopped effectively by an adjustment of these two potentials. The positive potential must be removed from the plate circuit by opening switch S1 therein. The grid potential must be made sufficiently negative that closure of switch S1 will not cause the tube to refire. As soon as the plate circuit is broken the tube V2 stops conducting and the load current is reduced to the point where solenoid S drops its mechanical load. The solenoid is still partially energized by the half cycle of current flowing from L1, diode D1, load S, diode D2 to line L2.

Another form of the invention discloses that more than one of the rectifiers could be replaced by a vacuum tube or a thyratron tube each equipped with a control grid. In this manner additional control of the circuit could be gained. For instance, control from two or more sources could be required to make the circuit sufficiently conducting to fully energize the load. With four tubes replacing the four rectifiers in a standard bridge circuit, four control elements could be obtained. That is, the

four control circuits would have to be in agreement at one time to permit the load to be fully energized.

Referring to Figure 3, four electron tubes T1 to T4 are shown, one in each side of a bridge circuit. Line potential is applied at diametrically opposite junctions of the circuit. Load S is connected across other opposite junctions of the circuit. Each tube may consist of a plate P, cathode C, and grid G. A control circuit is supplied externally to control one or more grids G1 to G4. The operation of the circuit will be described under conditions (*a*), (*b*), and (*c*) noted below.

Condition (*a*). Potential applied to all grids G1 to G4 sufficiently negative to prevent conduction of tubes T1 to T4. Since none of the tubes is conducting, no current flows through the load S.

Condition (*b*). Potential applied to grids G1 and G2 sufficiently positive to permit conduction, other grids negative. During the half cycle that line L1 is negative, current cannot flow through tube T1 because the polarity is reversed from that required for conduction. Current cannot flow through tube T3 because the grid being negative prevents conduction.

During the half cycle the line L2 is negative, the path of electron flow is through tube T2 because the grid permits conduction, through load S, through tube T1, to line L1. The load S is only half energized and will not mechanically actuate its load.

Condition (*c*). Potential applied to grids G1 to G4 sufficiently positive to permit conduction. During the half cycle that line L1 is negative, the path of electron flow is from line L1, through tube T3, through load S, through tube T4, to line L2. During the half cycle that line L2 is negative, the path of electron flow is from line L2 through tube T2, through load S, through tube T1, to line L1. The load S is fully energized and mechanically actuates its load until one or more control grids is made sufficiently negative to stop or reduce conduction.

Referring to Figure 4, four electron tubes V1 to V4 are shown, one in each side of a bridge circuit. Line potential L1, L2 is applied to the primiary winding T1 of transformer T. The secondary winding T2 of transformer T is applied to diametrically opposite junctions of the bridge circuit over lines L3, L4. Choke L is connected in series with two output terminals 1, 2 across which load R1 is connected. This series combination is connected across the remaining opposite junctions of the bridge circuit.

Each tube may consist of a plate P, cathode C, and grid G. Two control circuits may be supplied externally each to control a pair of grids. A substantially constant bias potential B1 is applied to grid G1 of tube V1 and grid G4 of tube V4. A variable bias potential B2 is applied to grid G2 of tube V2 and grid G3 of tube V3. The operation of the circuit will be described under conditions (*a*), (*b*), (*c*) noted below.

Condition (*a*). B1 bias potential sufficiently negative to prevent tubes V1 and V4 from conducting. No current can flow through a load connected between output terminals 1, 2 because during each half of the cycle the path is blocked by a non-conducting tube, regardless of the bias potential B2.

Condition (*b*). B1 bias potential sufficiently positive to permit tubes V1 and V4 to conduct. With bias B2 potential sufficiently negative to prevent tubes V2, V3 from conducting no load current can flow during either half of the cycle.

Condition (*c*). B1 bias sufficiently positive to permit tubes V1 and V4 to conduct. With bias B2 sufficiently positive to permit tubes V2 and V3 to conduct, load current will flow during each half of the cycle. Load current is dependent on the conduction rate of tubes V2, V3 which is dependent on bias potential B2. Thus, current through the load is proportional to control potential B2.

During the half cycle that line L3 is negative, the path of electron flow is through tube V1, choke L, load terminal 2, load R1, terminal 1, tube V2, to line L4. During the half cycle that line L4 is negative, the path of electron flow is from line L4 through tube V4, choke L, load R1, tube V3, to line L3. The load R1 is as fully energized as the bias control B2 permits. Load R1 is energized until bias B2 is made sufficiently negative to prevent conduction.

It is understood that the load to be applied to the control circuits shown herein must be of the type which will not be damaged when supplied with half its normal voltage and half its normal operating current. A solenoid, for example, can "float" safely on half voltage. The load must also be of the type which will drop out or cease to function after full voltage is reduced to half voltage. If it held in at half voltage the control would not be effective.

Having described four embodiments of the invention it is understood that a number of different embodiments could be made without departing from the spirit of the invention.

I claim:

1. An amplifier circuit for a control current which indirectly controls the functioning of a load circuit energized from an alternating current source, comprising, a load circuit responsive only to the rectified two half waves of alternating current, a half wave rectifying circuit containing two diode rectifiers supplying a half wave of current from the A.C. source to said load circuit at all times during the positive half cycles of the A.C. source, a second rectifying circuit containing a triode vacuum tube and a diode rectifier supplying alternate half waves of current from the A.C. source to said load circuit at controlled times during the negative half cycles of the A.C. source, a control circuit affixed to the grid of said triode vacuum tube to cause the rectified alternate half waves of current to be supplied to said load circuit.

2. An amplifier circuit adapted to supply current to a load device from an A.C. source, a first rectifier circuit adapted to supply alternate half waves of pulsating D.C., a second rectifier circuit adapted to supply intermediate alternate half waves of pulsating D.C., a load device connected to each of said rectifier circuits and adapted to be energized therethrough, said load device designed to be inoperative when energized with said alternate half waves of pulsating D.C. power and to be operative when fully energized with both said alternate and said intermediate alternate half waves of pulsating D.C. power, said first rectifier circuit consisting of two half wave rectifying diodes connected in series, and said second rectifying circuit consisting of one half wave rectifying diode and one half wave rectifying triode connected in series, said triode having a control grid adapted to control the conduction of said second rectifying circuit.

3. An electric circuit including in combination, a full wave rectifier circuit comprised of three non-controllable diode rectifiers and one controllable rectifier consisting of a thyratron tube having at least a cathode and a control grid and a plate, a power supply circuit connected across opposite junctions of said rectifier circuit, a load circuit connected across other opposite junctions of said rectifier circuit, a control circuit connected to said control grid, an electric load connected in said load circuit, said rectifier circuit adapted when said control circuit is in one condition and said power supply circuit is energized to partially energize said load with half wave A.C. and when said control circuit is in a second condition such that said tube conducts to fully energize said load with full wave A.C., and switch means in circuit with said plate of said tube operable when open to cause said tube to stop conducting.

4. In an electronic amplifier and switching circuit, including in combination, a vacuum tube having at least a cathode and a plate and a control grid, a full wave rectifier circuit, said tube forming one leg of said rectifier circuit, a plurality of solid state diode rectifiers, at least one

of said diode rectifiers in each of the remaining legs of said rectifier circuit, a source of alternating potential connected across diametrically opposite junctions of said rectifier circuit, a load circuit connected across remaining diametrically opposite junctions of said rectifier circuit, and an external control circuit connected to said grid, the portion of the rectifier circuit including said tube thereby controlled by said external control circuit to render said portion ineffective to energize said load under one condition of said control circuit and to be effective to energize said load under another condition of said control circuit.

5. In an electric control device, a bridge circuit including half wave rectifiers in each side of said bridge circuit, each of said rectifiers having an anode and a cathode, one of said half wave rectifiers having also a control grid and controllable thereby as to conduction, a source of alternating potential applied across two opposite junctions of said bridge circuit, a load circuit applied across two remaining opposite junctions of said bridge circuit, a control circuit connected to said control grid for said controllable rectifier, a direct current control potential applied to said control circuit, said control circuit adapted when energized to permit its said rectifier to conduct and to provide full energization of said load circuit, and when deenergized to prevent its said rectifier from conducting and to permit partial energization of said load circuit.

6. A full wave rectifier-amplifier circuit adapted to switch a load from half power to full power and back to half power, including in combination, a source of alternating potential including line L1 and line L2, a load device inoperative when half wave potential is applied and operative when full wave potential is applied, a first circuit including said load device and a thyratron and a diode, said thyratron having at least a cathode, an anode and a control grid, said cathode connected to line L2, said anode connected to said load, a source of control potential connected to said control grid, said diode having a cathode connected to said load and having an anode connected to line L1; and a second circuit including said load device and second and third diodes, said second diode having a cathode connected to said cathode of said first diode and having an anode connected to line L2, said third diode having an anode connected to said anode of said thyratron and having a cathode connected to line L1, and switch means in circuit with said thyratron.

7. In combination with an electric load inoperable and undamageable by application of rectified half wave potential for an extended time, a rectifier circuit including a two conductor source of alternating potential, first and second diodes, said first diode connected between one end of said load and one source conductor, said second diode connected between the other end of said load and the other source conductor, to admit continuous half wave power therethrough, a third diode and a thyratron tube, said thyratron tube connected between said one end of said load and said one source conductor, said third diode connected between said other end of said load and said other source conductor to admit controlled half wave power therethrough, said thyratron tube having at least one control element, and a source of control potential applied to said control element.

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